A novel spin-light polarimeter for the Electron Ion Collider

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A Novel Spin-Light Polarimeter
for the
Electron Ion Collider

PRAJWAL MOHANMURTHY

Honors Undergraduate Thesis
Nov 25, 2012
1. Reviewer: Dr. Dipangkar Dutta

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Day of the defense: Dec 04, 2012

Prajwal Mohanmurthy, A Novel Spin-Light Polarimeter for the Electron Ion Collider, Honors Undergraduate Thesis, © Nov 25, 2012
To,
*Amma* and *Appa,*
for their dedication and admirable way of life.
With Jefferson National Accelerator Facility’s (JLAB) 12GeV program in construction phase with a comprehensive set of experiments already planned for the next decade, it is time to think of newer facilities that will further push the boundaries and continue the mission of a premier nuclear physics laboratory to explore the frontiers of fundamental symmetries and nature of nuclear matter. Building of an Electron Ion Collider (EIC) seems to be a natural future step. JLAB is a fixed target laboratory, but at the EIC, the target will also be accelerated thereby providing access to precision physics of quarks and gluons at much higher energies (than 12GeV). JLAB mainly consists of the Continuous Electron Beam Accelerator and 3 halls where the fixed target experiments are performed. Brookhaven mainly consists of the Relativistic Heavy Ion Collider with a number of main collision points on the beam line. There have been two leading proposals for the EIC, i.e.

- **eRHIC**: Electron - Relativistic Electron Collider @ Brookhaven National Laboratory, Upton, NY [i]
Brookhaven already has an ion accelerator and the eRHIC would need addition of an electron accelerator, whereas JLAB already has the electron accelerator and the ELIC would need addition of an ion accelerator.

At JLAB, polarization of the electron beam has played a vital role a number of experiments such as the PVDIS (Parity Violating Deep Inelastic Scattering) and the QWeak (which measured the weak charge of proton). To measure the polarization of the electron beam, JLAB has commissioned Compton and Møller polarimeters which have met the precision demands of JLAB, but the Møller Polarimeter generates a large background as it uses $ee$ scattering to measure the polarization. The future demands greater precision in the measurement of polarization of the beam and so at the EIC, it would be convenient to have a second non-invasive polarimeter, besides a Compton Polarimeter, for systematics comparison.
ABSTRACT

A novel precision polarimeter will go a long way in satisfying the requirements of the precision experiments being planned for a future facility such as the Electron Ion Collider. A polarimeter based on the asymmetry in the spacial distribution of the spin light component of synchrotron radiation will make for a fine addition to the existing conventional Möller and Compton polarimeters. The spin light polarimeter consists of a set of wriggler magnet along the beam that generate synchrotron radiation. The spacial distribution of synchrotron radiation will be measured by an ionization chamber after being collimated. The up-down spacial asymmetry in the transverse plane is used to quantify the polarization of the beam. As a part of the design process, firstly, a rough calculation was drawn out to establish the validity of such an idea. Secondly, the fringe fields of the wriggler magnet was simulated using a 2-D magnetic field simulation toolkit called Poisson Superfish, which is maintained by Los Alamos National Laboratory. This was used to account for beam motion effects and the corresponding correlations were show to be negligible. Lastly, a full fledged GEANT-4 simulation was built to study the response time of the ionization chamber. Currently, this GEANT-4 simulation is being analyzed for variety of effects that may hinder precision polarimetry.
ACKNOWLEDGEMENTS

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Part I

GROUND WORK

Initial work at proposal time is discussed here. Also included are some glimpses into the theory that motivates this work. This section enumerates the work borrowed from previous work done in this field notably at Novosibirsk, Russia. Also presented are some recent developments in Ionization Chamber Technology.
1.1 CLASSICAL SR-POWER LAW

The total radiative power due to circularly accelerated particles is given by Larmor formula which is 
\[ P_{\text{clas}} = \frac{2e^2\gamma^4c}{3R^2} \] (i.e. \( P \) is proportional to \( E^4 \)) [here \( P_{\text{clas}} \) is the classical total radiative power, \( e \) is the electron charge, \( \gamma = \frac{E}{m_ec^2} \): the Lorentz boost, \( c \) is the speed of light, and \( R \) is the radius of trajectory of the electrons]. The angular dependence of radiative power can also be computed via classical electromagnetism.

\[ \frac{dP_{\text{clas}}}{d\Omega} = \frac{e^2\gamma^4c}{4\pi R^2} \left( \frac{1 - \beta \cos \theta)^2 - (1 - \beta^2) \sin^2 \theta \cos^2 \phi}{(1 - \beta \cos \theta)^5} \right) \] (1)

In classical electrodynamics the angular distribution of radiative power from synchrotron (SR) light can be calculated, as indicated in the above eq.(1) [where \( d\Omega = d\theta d\phi \), and \( \beta = \frac{\text{speed of particle}}{\text{speed of light}} \)]. The SR light-cone is spread over a well defined cone with the angular spread - \( \theta \) in retarded time \( \Delta t' \approx \frac{\Delta \theta}{\omega_o} \) [where \( \omega_o \) is the angular frequency of the photon]. There is no reason to believe that the SR spectrum is mono-energetic. The spectral width of SR radiation can be formulated: \( \Delta \omega \approx \frac{1}{\Delta t' |1 - \beta|} = \frac{1}{2\gamma^2 \omega_o} \). A critical acceleration can be envisioned at which the SR may consist of just 1 photon by

Figure 1: Angular distribution of synchrotron radiation shown for the bottom half of the electron’s orbital plane. The left figure is for slow electrons, \( \beta \sim 0 \) and the right figure is for highly relativistic electrons, \( \beta \sim 1 \). \[1\]

\[2\] D. D. Ivanenko, I. Pomeranchuk, Ya Zh. Eksp. Teor. Fiz. 16, 370 (1946); J. Schwinger, Phys. Rev. 75, 1912 (1947)

\[3\] I. M. Ternov and V. A. Bordovitsyn, Vestn. Mosk. Univ. Ser. Fiz. Astr. 24, 69 (1983); V. A. Bordovitsyn and V. V. Telushkin, Nucl. Inst. and Meth. B266, 3708 (2008)
solving the equation $\gamma m_e c^2 = \hbar \omega_C$. To achieve this acceleration, a critical uniform magnetic field can be applied on an electron which is $B_c = \frac{m_e c}{\hbar}$ [here $m_e$ refers to the rest mass of an electron]. The energy of the electron at these accelerations can be called the critical energy, $E_C = m_e c^2 \sqrt{\frac{m_e R_c}{\hbar}} \approx 10^3 \text{TeV}$ for $R_c$ of about $10^m$. It is important to note that even though accelerated electron is under consideration, the equations above don’t have acceleration terms. This is because a conventional circular motion is used to calculate the parameters and only the speed is important as the acceleration is a function of speed.

1.2 QUANTUM CORRECTIONS

In the classical theory, the spin does not explicitly appear in the equation. But, in QED, the angular dependence of synchrotron (SR) light can be calculated to a great degree of precision and the spin of the electron involved in SR emission appears explicitly in the power law \[ \text{(3)} \]. The quantum power law for SR was worked out by Sokolov, Ternov and Klepikov as a solution to the Dirac equation \[ \text{(4)} \] and includes the effects introduced by electrons undergoing $j \rightarrow j'$ (spin dependence) transitions besides also elaborating on the fluctuations to the electron orbit ($n \rightarrow n'$ transitions - linear correction to orbit and $s \rightarrow s'$ transitions - quadratic correction to orbit). The power law when integrated over all polarizations and (spacial) angular dependencies, can be written as \[ \text{(5)} \];

\[
P = P_{\text{clas}} \frac{9 \sqrt{3}}{16\pi} \sum_s \int_0^{\infty} \frac{y dy}{(1 + \xi y)^4} I_{s,s'}^2(x) F(y) \]

\[
F(y) = \frac{1 + jj'}{2} \left[ 2(1 + \xi y) \int_y^{\infty} K_{\frac{3}{2}}(x) dx + \frac{1}{2} \xi^2 y^2 K_{\frac{5}{2}}(y) - j(2 + \xi y) \xi y K_{\frac{3}{2}}(y) \right]
+ \frac{1 - jj'}{2} \xi^2 y^2 \left[ K_{\frac{3}{2}}(y) + 1K_{\frac{1}{2}}(y) \right]
\]

(Where $\xi = \frac{3B_c}{2B_c} \gamma$, $j'$ is the spin of the electron, $y = \frac{\omega_C}{\omega_c}$, $x = \frac{3}{4} \frac{\xi^2 y^2}{1 + \xi y}$, $I_{s,s'}(x)$ are Lagueree functions, and $K_{n}(x)$ are modified Bessel functions).

If $\xi \ll 1$ (given $B_c \approx 4.41 \times 10^9$ Tesla) then Eq. (3) can be Taylor expanded in terms of powers of $\xi$, as follows;

\[
P = P_{\text{clas}} \left[ \left( 1 - \frac{55\sqrt{3}}{24} \xi + \frac{64}{3} \xi^2 \right) - \left( \frac{1 + jj'}{2} \frac{1}{2} j \xi + \frac{5}{9} \xi^2 + \frac{245\sqrt{3}}{48} j \xi^2 \right) \right]
+ \left( \frac{1 - jj'}{2} \frac{4}{3} \xi^2 + \frac{315\sqrt{3}}{432} j \xi^2 \right) + ...
\]

(4)

Eq. (3) and (4) include the a number of effects;
• Classical SR
• Thomas Precession
• Larmor Precession
• Interference between Larmor and Thomas Precession
• Radiation from intrinsic magnetic moment (including anomalous magnetic moment)

Eq. (4) can be re-expressed as a difference between power from unpolarized and polarized electron beam.

\[ P_{\text{Spin}} = P_{\text{Pol.}} - P_{\text{UnPol.}} = -j\xi P_{\text{Clas}} \int_0^\infty \frac{9\sqrt{3}}{8\pi} y^2 K_1(y) dy \]  

Eq. (5) is essentially the spin light that this project is based on which opens up the possibility of using SR part to measure the polarization of the beam.

The power law in eq. (5), that was derived using QED, has been extensively tested and verified at the Novosibirsk Storage ring over a large range of wavelengths (of SR). For this, the Novosibirsk group used a "snake" shaped wiggler magnet to produce the SR from a relatively low energy electron beam of about 0.5GeV\@100\mu A.

![Figure 1. The field vs the current in the 'snake'. A schematic of the 'snake' and the field distribution along its axis are shown below.](image)

Figure 2: Magnetic snake used at the VEPP-4 as a source of SR to test the spin dependence of SR. [6]

Figure 3, clearly demonstrated the power dependence of the SR on beam-electron polarization. It remains to be shows as to how the SR spectra could be measured.

The spin flip probability has a special significance in modern day electron storage rings and is given by the relation [4];

\[ W_{\uparrow \downarrow} = \frac{1}{\tau} (1 + j \frac{8\sqrt{3}}{15}) \]  

[where \( j = +1 \) is spin along the magnetic field (and \( j = -1 \) is spin against magnetic field), and \( \tau \) is the time involved in the process].

As a result of the probability of spin aligning with the magnetic field direction would become very high over long periods of time. A circulating electron beam, such as ones in storage rings self polarize,
theory

Figure 3: Results from the experiment showing the increase in intensity of SR as the polarization builds up and then suddenly drops to zero when an RF field is used to depolarize the beam. \(^{(6)}\)

and this has been studied in great detail at many storage rings such as ones at DESY, PSI and CESR though it was first observed at the Orsay storage ring \(^{(7)}\).

1.3 Spin - Light

In the Spin-Light polarimeter, the spin-flip term in the power law does not play an important role. The integral power law without the spin-flip term can be written as \(^{(4)}\):

\[
P_{\gamma} = \frac{9\eta_{e}c\gamma^{5}}{16\pi^{3}R^{2}} \int_{0}^{\infty} \frac{y^{2}dy}{(1 + \xi y)^{5}} \int d\Omega (1 + \alpha^{2})^{2} \times \left[ K_{\frac{1}{2}}^{2}(z) + \frac{\alpha^{2}}{1 + \alpha^{2}} K_{\frac{1}{2}}^{2}(z) + j\xi y \frac{\alpha}{\sqrt{1 + \alpha^{2}}} K_{\frac{1}{2}}^{2}(z) K_{\frac{1}{2}}^{2}(z) \right] 
\]

where \(z = \frac{\omega}{2\omega_{c}}(1 + \alpha^{2})^{\frac{1}{2}}\) and \(\alpha = \gamma\psi\) where \(\psi\) is the vertical angle \(i.e.\) above and below the orbit of the electron. Notice that the last term with a \(j\) disappears from the integral over all angles \((-\frac{\pi}{2} \leq \psi \leq \frac{\pi}{2})\). But for an electron that is polarized, the power below \(i.e.\) \((-\frac{\pi}{2} \leq \psi \leq 0\)) and above \((i.e.\) \(-\frac{\pi}{2} \leq \psi \leq \frac{\pi}{2}\)) are spin dependent. More importantly the difference between the power radiated above and power radiated below is directly spin dependent, which can be directly obtained from Eq. (7) in differential form for circular arcs in the circular cross-section the SR-light cone at an angle \(\theta\).

\[
\frac{\Delta P_{\gamma}(j)}{\Delta \theta} = \frac{3}{2} \frac{\hbar c \gamma^{3} y}{R} \times \frac{3}{\pi} \frac{1}{137} e j\xi \gamma \int_{y_{1}}^{y_{2}} y^{2}dy \int_{0}^{\alpha} \alpha(1 + \alpha^{2})^{\frac{1}{2}} K_{\frac{1}{2}}^{2}(z) K_{\frac{1}{2}}^{2}(z) d\alpha \quad (8)
\]
INITIAL DESIGN

It is obvious now that our setup will have a wiggler magnet which shall be the source of SR and an ionization chamber to measure the power spectra of the SR emitted at the wiggler magnet by the polarized electrons.

2.1 WIGGLER MAGNET

In order to create a fan of SR light (as illustrated in Figure 5), the electron beam could be made to bend in presence of a magnet. An arrangement that would lead to the production of the SR-Cone must look similar to the "snake" magnets that were used by VEPP-4 as described in Chapter 1.

Figure 4: A 3-pole wiggler with central dipole twice the length of end dipoles.

A set of 3 dipoles (3-pole dipole), each with constant uniform magnetic field would be ideal for this purpose. The central dipole would have twice the pole length as compared to the ones on either side of the central dipole, but with a magnetic field an opposite polarity like in Figure 4. This design will give rise to 4 fans, 2 towards either side of the beam (left and right). Each of the fan will have spacial asymmetry as a function of spin - polarization of the electrons in the vertical plane (up - down the electron beam’s orbit which is perpendicular to the plane which contains the 4 fans). The 4 fans help characterize the systematics better since this configuration will flip the sign of the
spin-dependent term in Eq. (8) twice essentially returning the sign to the original status.

With this geometry in mind, one could then simulate and calculate the requisite pole strengths and pole lengths appropriate to energies at Electron Ion Collider (EIC). Of course, one would also have to consider time scales at which the statistics would be sufficient to achieve the design requirement (<1%) of precision. A number of techniques were employed to tackle the above issues. Including issues such as optimizing the distance between each pole were solved through a full fledged GEANT-4 simulation.

2.2 Collimator

The 4 fans of SR-Light need not be separated from each other. They may in fact overlap and extracting the power-asymmetry information from complicated overlappings would require extensive modeling. This might also introduce new sources of uncertainties. Therefore to uniquely sample each fan at the ionization chamber, collimators would need to be placed on each face of the dipoles to direct and separate the fans of SR. The position of the collimators will be calculated using optimized values of pole-strengths, pole-lengths and relative position of each of the dipoles.

2.3 Ionization Chambers

The Ionization Chambers (IC), one on each side (2 fans per IC) of the beam, could be used for measuring the spacial asymmetry in the SR-fans to be used to compute the polarization of the electrons in the beam. One would not expect a large asymmetry in the Spin-Light component (of the order of about $10^{-4}$), therefore a high resolution, low noise IC is demanded. The IC will be very close to the
beam line and the spin-independent background may be as high as $10^{12}$ photons/s, therefore the ICs have to be radiation hard. The geometry of the magnets could be changed to deal with SR Spectra with characteristic energy peak in the ranges of about $500\text{keV} - 2.5\text{MeV}$. An IC with Xenon as ionization media operated in the current mode \cite{8}. It might be important to note that the Spin-Light asymmetry is spread over the entire spectra of the SR. Sampling radiation over large energy spectrum becomes important. Since Xenon has the lowest ionization energy of about $21.9\text{eV}$, among non-radioactive noble gases, it seems to be an ideal candidate. ICs with Xenon under high pressures have already been developed and well tested to perform well in the energy ranges of $50\text{keV} - 2.0\text{MeV}$ \cite{9}. Pressures involved in HPXe ICs exceed $50\text{atm}@0.55\text{g/cc}$ but they work well at room temperature \cite{10,11,12}. One of the bottlenecks was the precision of purity of the Xenon gas in its pristine form. But owing to advances in gas purification techniques \cite{13}, a best energy resolution of 2.4% at about $0.662\text{MeV}$ has been shown to be possible when current signals from the shower is used in presence of prompt Xenon scintillation \cite{14}. The results from this attempt has been fairly promising (Figure 6). ICs with 3% – 4% energy resolution are even being sold commercially by Proportional Technologies Inc. \cite{15}.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure6.png}
\caption{Cs$^{137}$: $E_i = 1.7\text{kV/cm}$, pulse height spectrum in 57atm at 295K of xenon, $E_i = 1.7\text{kV/cm}$ \cite{14}.}
\end{figure}

\begin{itemize}
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\item \cite{9} T. Doke, Portugal Phys. 12, 9 (1981).
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\item \cite{14} G. Tepper and J. Losee, Nucl. Inst. and Meth. A368, 862 (1996).
\item \cite{15} Proportional Technologies Inc., www.proportionaltech.com.
\end{itemize}
Part II

PROJECT WORK

In this section, the work is presented with additional studies resulting from discussion with experts. It includes establishing the idea with a "back of the envelop calculation" backed by a full fledged GEANT-4 simulation. Also, related effects such as beam motion were studied and their effects that impact the polarimeter negatively were shown to be minimal. Even though the GEANT-4 simulation is still in the making, a skeletal code is briefly explained here.
3 DESIGN CONSIDERATIONS

3.1 SPIN-LIGHT CHARACTERISTICS

Figure 7: A. Plot of difference between the number of SR and spin light photons that go above and below the orbit of the electron ($\Delta P_{\gamma}$) vs. their energy
B. Plot of total number of SR, spin light photons $P_{\gamma}$ vs. their energy
C. Plot of the Asymmetry vs. the photon energies
D. Plot of time required to achieve 1% statistics by sampling one wavelength of the spin-light spectra vs. the energy of the photons.

The spin-dependence of the SR can be studied by examining Eq. (6-8) in Chapter 1. Using $I_{e} = 100\mu$A and $E_{e} = 11$GeV, Eq. (6-8) were numerically integrated (Appendix B.1) between $-1 < \alpha < 1$ and $\Delta \theta = 10\text{mrad}$, for a uniform magnetic field of $B = 4T$ assuming 100% longitudinal polarization.

In Figure 7, the total number of SR and spin light ($P_{\gamma}$) photons radiated is plotted. Also in Figure 7, is a plot the difference between the power of spin light spectra above and below the orbit of the electron
(ΔPγ). An asymmetry term is defined to be \( \Lambda = \frac{\Delta P}{P_U} \), which was used to nail down the range of energies of the photons which must be measured. Lastly, a plot of sampling time required (\( T_s = \frac{\Delta \Lambda}{\Lambda} = \frac{1}{\Lambda \sqrt{2P_{e_r}}} \)) to achieve the design precision goals.

It immediately becomes clear that the ionization chamber, which is envisioned to measure the asymmetry (that in turn will be used to compute the electron polarization), will have to be operational at wavelengths corresponding to hard-XRays. Furthermore, the asymmetry plot, Figure 7.D, demands that the sampling be done at the higher energies (and not close to 0.5MeV) since at higher energies the asymmetry is not rapidly changing, thus making it an ideal high-energy polarimetry technique. It might be important to note that the asymmetry is fairly low but since the integrated power of spin-light is very high, the time required for achieving 1% polarimetry is only of the order of a few seconds. Also, one could plot the asymmetry and SR spectra for different energies to study the trends with change in beam energy. This indicates that there are no suppression effects at higher energies that might hinder effective polarimetry.

![Figure 8](image.png)

Figure 8: (Left) A. Plot of spin light spectra over photon energies for various electron beam energies ranging from 4GeV – 12GeV; (Right) B. Plot of asymmetry over photon energies for various electron beam energies ranging from 4GeV – 12GeV

3.2 WIGGLER MAGNET

In order to establish the dimensions of the dipoles, the same graphs as in Section 3.1 Figure 8 were plotted for various pole lengths and magnetic fields. First, the asymmetry increases very slowly with field strength as shown in Figure 9, and the figure of merit (time for 1% statistics) improves very slowly with magnetic fields above 3T as shown in Figure 10B, therefore \( B = 4T \) was chosen since 4T wiggler magnets are easily available at light sources around the world. Secondly, an appropriate pole length of \( L_p = 10\text{cm} \) was selected by
looking at Figure 10 and selecting out the pole length for the pole strength of 4 Tesla. It is noteworthy to see that the plot of pole length as a function of pole strength was done keeping in mind an SR fan - angular spread of about 10 mrad. The plot in Figure 10.B also reassures the reasonable time requirement to achieve the design precision goal of 1%. The last parameter in the wiggler to be fixed is the distance between each dipole.

Figure 10: (Left - Right)
A. Pole length required for a 10 mrad angular spread of SR light fans with $B = 4T$
B. Dependence of time required to achieve 1% statistics by sampling one wavelength of the spin-light spectra with pole strengths.
3.2.1 Effects of wiggler on the beam

A polarimeter must be non-invasive and therefore answering the question of what would be the effects of putting such as polarimeter on a beam line is very important. But the effect of a high energy electron beam emitting SR has been well studied \cite{16}. The number of photons (N) emitted by an electron when it is deviated by a radian, from its initial linear trajectory, when acted upon by a magnetic field is distributed as per the conventional Poisson distribution \cite{17} about a mean value of $\bar{n}$;

$$N(n) = \frac{n^N e^{-n}}{N!}$$  \hspace{1cm} (9)

$$n(E_e) = \frac{5}{2\sqrt{3}} 137 = 20.6E_e$$  \hspace{1cm} (10)

The average energy of the SR photons can also be written down as (where $E_e$ is the electron energy);

$$\bar{E}_e = \hbar\omega = \frac{3}{2} \frac{h\gamma^3}{R} = \frac{3}{2} \frac{\hbar\gamma^3}{Rm_e^2c^5}$$  \hspace{1cm} (11)

In the case of a spin-light polarimeter, the beam energy is about 11GeV and we choose pole strength to be about 4T in Section 3.2. An angular bend of about 10mrad of the beam is sufficient for such a polarimeter. Using the values of average number of photons emitted and their average energy, the average energy fluctuation ($\Delta\bar{E}_e$) of the beam can be computed.

$$n = 20.62 \times 11_{\text{GeV}} \times .01_{\text{rad}} = 2.06$$  \hspace{1cm} (12)

$$\bar{E}_e = \frac{3}{2} \frac{h(11_{\text{GeV}})^3}{10_{\text{m}} m_e c^5} = .199\text{MeV}$$  \hspace{1cm} (13)

$$\frac{\Delta\bar{E}_e}{E_e} = \sqrt{\frac{n\bar{E}_e}{E_e}} \approx 2.5 \times 10^{-5}$$  \hspace{1cm} (14)

The energy fluctuations are smaller than the typical precision with which the energy can be measured at an electron accelerator.

Another parameter which needs to be checked before proceeding, is the transverse kicks ($\Delta\theta_e$) received by the electrons when emitting SR photons in the magnets. The transverse kicks can be calculated in terms of angles knowing that the SR power spectrum usually peaks at an angle $\theta_\gamma = \frac{1}{\gamma}$ \cite{17} (where $E_\gamma$ is the SR - photon energy);

$$\Delta\theta_e = \frac{E_\gamma \sin(\theta_\gamma)}{E_e} \approx 11.3 \times 10^{-9} \frac{E_e (GeV)}{R(m)}$$  \hspace{1cm} (15)
\[ \theta_e \approx \sqrt{n} \Delta \theta_e \approx 1.5 \times 10^{-8} \text{(rad)} \]  

(16)

It can be clearly seen from Eq. (14) and Eq. (16) that both energy fluctuation and angular kicks shall be negligible. This can be seen for all practical purposes in the GEANT-4 simulation that this work demands. This polarimetry method remains a non-invasive procedure.

3.2.2 Effects of realistic dipole magnetic field with fringes

In Section 3.2, while plotting the power spectra and the asymmetry generated by the code in Appendix B.1 a uniform field was used. But the code can also take a field map. A field map can be generated by solving Maxwell’s equations with appropriate boundary conditions. This is essential since field in the transverse plane (perpendicular to the motion of electrons) might distort the SR spectrum and thereby change the asymmetry. In fact there is a custom built suite of programs written by Los Alamos National Laboratory to precisely do this called LANL Poisson SuperFish \cite{18}.

In LANL SuperFish, the magnet geometry can be easily defined as is done in Appendix B.2. The field map of the magnet can then be plotted. Here, the field map at the edge where the electron beam enters the magnet and at the center of the dipole is presented. In Figures 11 & 13, note that the beam pipe is going at the center below the magnet pole. In Figure 13, the physical taper of the cores can be

\cite{18} Poisson SuperFish 2D EM Solver, laacg1.lanl.gov/laacg/services/sfu_04_04_03.phtml, 2007.
18 design considerations

Figure 13: Plot of both the x and y components of the magnetic field on the transverse plane at the center of the dipole (Beam pipe is centered around 15 cm mark along the ‘x’ axis).

Figure 14: Field map of the dipole face at the edge of the dipole.

notices, since it is at the edge of the magnet face. This taper of the poles is absent in Figure 11, since it is at the center. In Figures 11 & 13, the singularities seen are the areas where the current cuts the plane. Also, it is important to note that the entire ‘C’ magnet is not visible in the field-map, only the top half of the C magnet is shown in the field map.

X - Axis is to the right and left of the beam and Y - Axis is to the above and below the beam. Also the XY plane is perpendicular to the direction of motion of electron. In Figure 13, it might be important to note that there is no component of the magnetic field. This is because it is at the center of the dipole and there is no fringing of the field. But in Figure 15, there is a non-zero X component to the magnetic field.
3.3 Collimation and Spin-Light Fan Size

Even though the distance between the 3 dipoles should in theory not affect the physics involved, it is nevertheless an essential design parameter. A reasonable value of about 1m distance between each dipole was used to start with but this value will be definitely fixed with a full fledged GEANT-4 simulation. A fan with 10mrad spread would then give rise to a spot which is 10cm big in the horizontal plane, 10cm from the wiggler where the ionization chambers will be placed. A more important dimension of the SR-spot at the ionization chamber is its height in the vertical direction. An angular spread of

Figure 15: Plot of both the x and y components of the magnetic field on the transverse plane at the the edge of the dipole (Beam pipe is centered around 15cm mark along the ‘x’ axis).
20 Design Considerations

\[ \Delta \theta = \frac{1}{\gamma} = 100 \mu \text{rad} \]

would then give rise to a spot which is 1 mm big in the horizontal plane, 10 m from the wiggler, where the ionization chambers will be placed.

Figure 18 shows the origin of 4 different fans of SR Light (which contain the spin-light component) that are being created at the wiggler magnet. Corresponding fans of SR light create 4 spots at the ionization chamber which is located 10 m from the wiggler magnet system. The spots at the ionization chamber as shown in Figure 19, merge with each other and may destroy the spacial asymmetry that contains the polarization information. Therefore collimators may be employed at the face of every dipole to select out a small section of the bigger SR fan as illustrated in Figure 20. After collimation the spots are all uniquely separated and 4 distinct spots can be observed at the ionization chamber (as in Figure 21).

3.4 Ionization Chambers

The Spin Light polarimeter detector would consist of a position sensitive ionization chamber to measure the up-down asymmetry in the SR - Light. Such a position sensitive detector that could characterize...
X-Ray spectrum has already been developed at the Advanced Light Source, Argonne National Laboratory and at Sprin-8 Light Source. This uses a split-plane which essentially divides the ionization chamber into 2 separate chambers but with a common electrode. These have been demonstrated to have a resolution of about 5µm \cite{19}. Subtracting the currents from the top chamber from the bottom chamber will then give a measure of the asymmetry in the SR-Light. A schematic diagram of the prototype is presented in Figure 23.

Using such an ionization chamber, one could easily carry out relative polarimetry. A more challenging but possible option would be to have an absolute polarimeter.

3.4.1 Relative Polarimetry

A Xenon media split plate would be an ideal differential ionization chamber. Using Ti windows of sufficient size could in principle cut down on low energy X-Rays (< 50KeV) and Ti has been shown to have a high transparency for hard X-Ray \cite{20}. A schematic diagram of the ionization chambers for the Spin-Light polarimeter is presented in Figure 23. The Spin-Light Polarimeter Ionization chamber shall have 2 compartments into which the 2 collimated fans of SR-Light will enter. On each side of the electron beam is one split-plane ionization chamber and therefore all 4 fans of SR-Light, produced at the wiggler magnet, are measured at the 2 ionization chambers. Notice for

\cite{20} G. Tepper and J. Losee, Nucl. Inst. and Meth. A356, 339 (1995).
Figure 18: A schematic diagram showing the 4 fans of SR that originate at the wiggler magnet system.

Figure 19: A schematic diagram showing the Spin-Light profile at the Ionization Chamber

polarimetry, just one ionization chamber is required. The 2 separate ICs will provide abundant statistics in a short time.
Figure 20: A schematic diagram showing the 4 fans of SR that originate at the wiggler magnet system with collimators.

Figure 21: A schematic diagram showing the Spin-Light profile at the Ionization Chamber with collimators.

Figure 22: A schematic diagram of a prototype split plate Ionization Chamber.

The signal which will give us a measure of the spacial asymmetry could be measured by subtracting the currents from the UP and DOWN parts of the chamber after being amplified as shown in Figure 24. The spin - light asymmetry shall be of opposite signs on the
Figure 23: A schematic diagram of the Spin - Light Polarimeter Ionization Chamber.

Figure 24: A schematic diagram of signal collection configuration.

LEFT and RIGHT parts of the chamber, since SR fans from adjacent wiggler dipole (which have opposite polarity) enter one on each side of the chamber (L-R). Beam motion effects are nullified as any motion will have trend (same sign) on both the LEFT and RIGHT sides of the chambers. Each half (T-B) of the split plane collector measures a current proportional to the difference of photon flux between the 2 sides and therefore any vertical beam motion effects cancel out to the first order. The two signals indicated in Figure 24 can be quantified. This definitely shows that the vertical beam motion effects will be canceled out to first order.

\[
S_1 = N_{SR}^l + N_{spin}^l + \Delta N_z^l - (N_{SR}^r - N_{spin}^r + \Delta N_z^r) = 2N_{spin} \quad (17)
\]

\[
S_2 = N_{SR}^l - N_{spin}^l - \Delta N_z^l - (N_{SR}^r + N_{spin}^r - \Delta N_z^r) = -2N_{spin} \quad (18)
\]

[21] G. Tepper and J. Losee, Nucl. Inst. and Meth. A356, 339 (1995).
Hence \( S_1 - S_2 = 4N_{\text{spin}} \) is a measure of longitudinal polarization and \( S_1 + S_2 \) will give a measure of transverse polarization. The ability to measure both transverse and longitudinal polarization makes this a powerful polarimetry technique. The number of photons absorbed in the ionization chamber can be computed by multiplying the SR Power equation Eq. (8) with the absorption function (where \( \mu \) is the absorption coefficient which is material specific and \( t \) is the length of the chamber) \( A(\lambda, t) = 1 - e^{-\mu(\lambda)\cdot t} \). With the help of values of \( \mu \) obtained from NIST database \(^{21}\), a plot of photons absorbed in a ionization chamber that is 50 cm in length and held at 1 atm pressure is shown in Figure 25. The spectra of number of photons absorbed was used to then calculate the detector response which in this case is asymmetry weighted against absorption.

![Figure 25: NIST plot of dependence of absorption coefficient of Xenon on the photon energy.](image)

3.4.2 Absolute Polarimetry

A relative polarimeter could be turned into an absolute polarimeter by making a few modifications to the ionization chamber. For absolute polarimeter, a high resolution ionization chamber is required and so the natural choice would be a high pressure Xenon IC. A cylindrical chamber capable of withstanding 50 atm of pressure could house the IC setup whereas the rest of the structure would remain unchanged from the relative IC with a few additions. The electrodes could be held in place with thin walled BeO ceramic material which would provide uniform electric field and reduce acoustic noise while being transparent to hard XRays \(^{21}\). This design eliminates the need for

\(^{22}\)S. Kubota, M. Suzuki and J. Ruan, *Phys. Rev. B* 21, 2652 (1980).
Figure 26: Plot of photons absorption spectra for the ionization chamber.

Figure 27: Schematic diagram of the entire Differential Spin Light Polarimeter (The only visible difference between the absolute and relative polarimeters in the schematics is the difference in collector plate bias).

field guide rings which require additional feed throughs and internal voltage dividers. In order to shield against space charge build-up, a wire mesh grid should be placed near the anode which carries a voltage that is intermediate in value to the drift potential (potential between the anode and the cathode). The ratio of the grid field to drift field can be adjusted to maximize the shielding efficiency. The cathodes and the intermediate grids would be built from stainless steel wire mesh to allow the compressed xenon UV scintillation light to be collected by the UV sensitive photomultiplier tubes (PMT). The scintillation signal has a fast component with a decay time of 2.2 ns and slow component with a decay time of 27 ns \(^{22}\). The scintillation light can be used during calibration, to provide a time zero reference for ionization position determination and can also be used for background suppression using pulse shape discrimination and for anti-coincidence Compton suppression. This will help improve the energy resolution and hence aid the determination of the sensitive en-
ergy range of the chamber (during calibration, when the chamber is operated in charge mode). Similar HPXe chamber (without the split anode) have been successfully operated \cite{21} for over a decade now and are also commercially available. A schematic for such an IC is shown in Figure 29. The readout electronics chain would consist of a pre-amplifier and shaping amplifier unlike the current amplifiers used in the current mode ICs. In addition, one would also have to establish the linearity of such an IC given the high flux of photons making the calibration of the IC very challenging. The vertical beam motion effects in an absolute IC shall be cancelled to the first order just like in the differential IC. The current signal from each chamber is an integral over the sensitive energy range of the chamber. This energy range convoluted with the detector response function, can be determined by calibrating the chamber at low electron beam currents ($\sim 1\text{nA}$), where the photon flux is low enough to operate the chambers in charge mode. The pulse height spectrum from these calibra-
tion runs can be used to determine the sensitive energy range and the detector response function. The uncertainty in determining the absolute value of the range of energies integrated (specially the lower bound) is the other major source of uncertainty.

In the case of an absolute IC, 4 different signals involving each part (TOP/BOTTOM parts of split plane) and (LEFT/RIGHT) parts of the chamber can be tapped for analysis as shown below.

\[ S_1 = I_{SR} + I_{spin} + \Delta I_z \quad (19) \]

\[ S_2 = I_{SR} - I_{spin} + \Delta I_z \quad (20) \]

\[ S_3 = I_{SR} - I_{spin} - \Delta I_z \quad (21) \]

\[ S_4 = I_{SR} + I_{spin} - \Delta I_z \quad (22) \]

[Where \( I_{SR} \) is the current due to all SR Photons and \( I_{spin} \) is the current due to just the spin-light photons].

The signal \((S_1 + S_2) - (S_3 + S_4)\) should always be zero ideally. The longitudinal asymmetry in terms of these 4 signals is given by;

\[ A^\text{long} = \frac{I^\text{long}_{spin}}{I^\text{long}_{SR}} = \frac{(S_1 - S_2) - (S_3 + S_4)}{(S_1 + S_2) + (S_3 + S_4)} \quad (23) \]

and the transverse asymmetry in terms of these 4 signals is given by;

\[ A^\text{trans} = \frac{I^\text{trans}_{spin}}{I^\text{trans}_{SR}} = \frac{(S_1 + S_3) - (S_2 + S_4)}{(S_1 + S_3) + (S_2 + S_4)} \quad (24) \]

One could in theory come up with many more electrode arrangements.

### 3.4.3 Effects of Extended Beam Size

In Section 3.2, the numerical code used a point beam. Therefore the effects of having extended beam size of about 100µm must be studied. To do this the code located in Appendix B.3 was used. This code essentially superimposes the SR-Power spectra generated by each of a \(10^6\) such point-cross section beams. The million point-cross section beams together would give a circular beam and each of them was weighted with a Gaussian profile in order to make the extended beam a perfect Gaussian beam. The cumulative spectra can be plotted
and one can guess that it should have the same structure as the original spectra for the point - cross section beam. This is so because the size of the beam \( R_{\text{beam}} = 100 \text{mum} \) is small compared to the size of the collimated SR - Light spot which is about 1mm big. For the beam with a point cross section, the SR - profile is rather ‘box’ like at the IC. When an extended beam, that is Gaussian profile, is introduced, the SR - profile gets a taper which is Gaussian in nature too. The graphs in Figure 30 and 31 show the exact 3D profile correct with position information.
3.4.4 \textit{Current and Future Work: GEANT 4 Simulation}

Figure 32: GEANT4 visualization of Spin - Light Polarimeter Setup. The electron beam is red in color and the SR Fans are yellow in color.

Figure 33: GEANT4 visualization of Wiggler Magnet Setup.

This work demands a GEANT 4 simulation in order to optimize the distance between the dipoles and to optimize the positioning of the collimators. Figure 32 is a GEANT4 visualization of the entire setup. It is important to note that the 2 fans are clearly visible on either side of the beam in the center. The dipoles are the blue blocks on one end
Figure 34: GEANT4 visualization of the 2 Ionization Chamber Setups (One on either side of the beam).

and the ICs are the green blocks on the other end. Work on this part is in progress and will be complete by 2013 May.

The GEANT-4 simulation includes processes such as EM suite including ionization and synchrotron radiation. Primitives are being used to count the number of ionization particles in the IC and the SR spectra produced by the wiggler setup. Further more, histograms are being written into the code to study the recovery time of the IC. Given that the present motion in EIC design is to use a Gatlin gun\textsuperscript{[23]}, the recovery time will need to be less than a second if every bunch of electron beam needs to be measured for polarization. This is not an issue since polarimetry can be done as an averaging measurement over many bunches.

\textsuperscript{[23]} V. N. Litvinenko, Gatling Gun: High Average Polarized Current Injector for eRHIC, EIC BNL Whitepapers (2012)
4.1 SYSTEMATICS

If the ionization chambers are used in differential mode and have split anodes, the false asymmetries will cancel to first order. Moreover, since the signal used is a differential signal the size of the background must be small compared to the signal. A full simulation is needed to study the background and the asymmetry associated with the background. In the experiment the background can be determined by monitoring the difference in the signal from the chambers with the wriggler magnets turned on and off. The other major source of systematic uncertainty is the lower bound of the integration window used to generate the IC signals. The absolute value of the spin light asymmetry depends on the absolute value of the energy window over which the IC signals are integrated. It is especially sensitive to the lower bound because of the steep fall of the SR intensity with energy. However given the excellent energy resolution that has been demonstrated for HPXe ionization chambers, one should be able to calibrate the chamber and determine the response function and the lower bound of the chamber to better than 2%. A preliminary table of estimated systematic uncertainties is shown in table below.

| Source                      | Uncertainty                      | $\delta A/A$   |
|-----------------------------|----------------------------------|----------------|
| Dark Current                | pA                               | $< 0.01\%$     |
| Intensity Fluctuations      | $\Delta N \times 10^{-3}$        | $< 0.10\%$     |
| Beam Energy                 | $1.0 \times$                     | $< 0.05\%$     |
| Density of gas in IC        | Relative uncertainties           | $< 0.05\%$     |
| Length of Chamber           | Can be corrected                 | -              |
| Band - width of X - Rays    | 2% (for only absolute polarimetry)| 1.20%          |
| Background related Dilutions| To be determined if known to 0.5% | $< 0.50\%$     |
| Other dilutions             | Cancel to First Order            | $< 0.50\%$     |
| Total                       | Relative Polarimetry             | $< 0.68\%$     |
|                             | Absolute Polarimetry             | $< 1.88\%$     |

Table 1: Systematic uncertainties
4.2 CONCLUSION

Spin light based polarimetry was demonstrated over 30 years ago, but has been ignored since then. The figure of merit for such a polarimeter increases with electron beam energy and the strength of magnetic field used. The 11GeV beam at JLab is well suited for testing a spin light polarimetry and such a polarimeter would help achieve the $<0.5\%$ polarimetry desired by experiments envisioned for the EIC era. A 3 pole wriggler with a field strength of 4T and a pole length of 10cm would be adequate for such a polarimeter. A dual position sensitive ionization chambers with split anode plates is ideally suited as the X-ray detector for such a polarimeter. The differential detector design would help reduce systematic uncertainties. Locating a reasonable piece of beam-line real estate is however very challenging.
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This program is distributed in the hope that it will be useful, but without any warranty; without even the implied warranty of merchantability or fitness for a particular purpose. See the GNU General Public License for more details.
B.1 NUMERICAL INTEGRATION OF THE SR - POWER LAW

PROGRAM Ngamma.f (WRITTEN BY D. Dutta 1/7/2010)

C and

C Ngamma spectra.f by Prajwal Mohanmurthy (Sept 2011),
C prajwal@jlab.org, Mississippi State University

C To include effects from the Real Magnetic field
C with non-zero gradient taper.

C This program calculates the total number (and
C difference in number above and below the orbital
C plane) of Synchrotron photons emitted by longitudinally
C polarized electrons over a horizontal angular range of
dTheta and vertical angular range of
C +/-alpha = +/-gamma*Psi

C where gamma is the Lorentz boost, i.e.;
C +/-alpha approx = +/-1
C when traversing a 3 pole wriggler magnet with a field
C strength of Bwg tesla and a pole length of Lwg.

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

IMPLICIT REAL*8(A-H,O-Z)

EXTERNAL fn01
EXTERNAL fn02
EXTERNAL gno1
EXTERNAL gno2
REAL*8 xheeng(48), xhemu(48), couB(15)
REAL*8 couxn, coudn

PARAMETER (xMe=0.5109998902) ! electron mass in MeV/c^2
PARAMETER (GeV2MeV=1000.0)
PARAMETER (hbarc=197.3269602) ! MeV*fm
PARAMETER (xmuB=5.788381749E-11) ! Bohr magnetron MeV/T
PARAMETER (c=299792458) ! m/s
PARAMETER (pi=3.141592654)
PARAMETER (qe=1.602176462E-19) ! coulomb
PARAMETER (n1=10) ! number of times the integration alg
is compounded
PARAMETER (n2=10)

Common gamma,y

C write(6,*) 'Enter Ebeam (GeV) and current (micro A)'
C read(5,*) Ebeam, xIe
C write(6,*) 'Wriggler B-field (T) and Pole length (m)'
C read(5,*) Bwg, xLwg
do i = 1,15
   couB(i)=4.55
enddo

51
couB(1)=4.11
couB(2)=4.38
couB(14)=4.38
couB(15)=4.11
open(unit=10,file="spinlight_gydep4.dat",status="unknown")
open(unit=11,file="xenon.dat",status="old")

56
doi =1,48
   read(11,*)xheeng(i),xhenu(i)
enddo

close(11)
ymin = 0.01 ! min fractional photon freq (W/Wc)

61
cymax=0.02 ! initialize
Ebeam=4.0+(i-1)*1.0 ! e–beam energy GeV
Ebeam=11.0 ! e–beam energy GeV
xle=100.0 ! e–beam current micro A
do i =1,1000
   do j =1,15
      couxn=0.0
      coudn=0.0
      Bwg=couB(j) ! B–field in T
      Bwg=1.0+(i-1)*1.0
      xLwg=0.066 ! pole length in m
      write(6,*) 'Ebeam =',Ebeam, 'GeV'
      gamma = Ebeam+GeV2MeV/xMe ! Lorentz boost = E/(Me*c^2)
      R_bend = gamma*hbarc*1.0E-15/(2.*xmuB*Bwg) ! bending radius in m
      Omega_o = c/R_bend ! betatron freq.
      Omega_c = 1.5*gamma**3*Omega_o ! central photon frequency
      E_cent=(Omega_c*hbarc*1.0E-15/c)*1000. ! central photon energy in keV
      xlambda_c=2.*pi*c/Omega_c
      ymax = 0.02+(i-1)*0.01 ! max fractional photon freq (W/Wc)
      y_cent= (ymin+ymax)/2.
      E_min = (ymin+Omega_c*hbarc*1.0E-15/c)*1000. ! min photon energy in keV
      E_max = (ymax+Omega_c*hbarc*1.0E-15/c)*1000. ! max photon energy in keV
      E_cent = (y_cent+Omega_c*hbarc*1.0E-15/c) ! photon energy in MeV
      xLwg = 0.0135 ! pole length in m
      dTheta = xLwg/R_bend ! horizontal angular range
   71
   ij =2
   ik=1
   if not (

   81
   endif
   if (E_cent.lt.xheeng(ii).and.ifft.eq.1) then
      ij=ii
      ik=ii-1
      iftt=iftt+1
      endif
enddo
xrayab=xhemu(ik)+

  (((E_cent-xheeng(ik))/(xheeng(ij)-xheeng(ik))))
> (xhemu(ij)-xhemu(ik))

absconst=0.023*(2./4.)*(2.*xlambda_c*1.0E+10/y_cent)**2.78
if (absconst.1t.0.1) absconst=0.1
write(6,*)xrayabs
absconst=xrayabs*(5.9/1000.)
Amut=(1.0-exp(-absconst**0.5))
write(6,*)'Wriggler B-field and pole lengths =',Bwg,
xLwg
c write(6,*)'boost, central freq and bend radius=',gamma,
Omega_c,
1 R_bend
c write(6,*)'vertical ang. range, min and max photon
ergy =','
1 dTheta, E_min, E_max,xlambda_c,absconst,y_cent,Amut,E_cent
c Psi_min = -asin(1./gamma) ! min vertical angle
c Psi_max = asin(1./gamma) ! max vertical angle
c alpha_min = gamma*Psi_min ! boosted min vertical angle
c alpha_max = gamma*Psi_max ! boosted max vertical angle
c z_min = (ymin/2.)*(1.+alpha_min**2.)**1.5 ! z=(y/2)
*(1+alpha)**1.5
c z_max = (ymax/2.)*(1.+alpha_max**2.)**1.5
c write(6,*)alpha_min, alpha_max,z_min,z_max

xNe=xle+1.0E-06/qe ! # of electrons
xi=1.5*gamma**2*hbarc+1.0E-15/xMe/R_bend ! crit
parameter
xHbyHo=gamma*hbarc+1.0E-15/xMe/R_bend
tau=(8.*sqrt(3./15.))*(hbarc+1.0E-15/xMe/c) ! use
hbarc/qe^2 =137
1 *(1./xHbyHo)**3*(1./gamma**2.)*137.0
sflip=hbarc*(xLwg/c)*(1.+8.*sqrt(3./15.)*0.5+1./tau)
c write(6,*)'sflip probability',sflip
const1=3.*xNe*gamma*dTheta/(4.*pi**2.*137.)
const2=4.*const1*xi
call p3pgs(ymin,ymax,n1,fn01,gno1,vint1) !
integrations for N
call p3pgs(ymin,ymax,n2,fn02,gno2,vint2) ! integraton
for Delta N
xn=const1*vint1
dn=const2*vint2
xa=(dn/xn)*sqrt(2.*xn)
xpow=xn*E_cent+1.6E-19+1.0E+6! power released in W
dpow1=dn*E_cent+1.6E-19+1.0E+10 ! power of spin light
in W
c write(6,*)'edep',xdpow !Ebeam, gamma, dTheta, gamma=
dTheta, const1, vint1
c write(6,*)'photon energy, #of photons, up/dn diff, asym,
c 1 analyzing pwr, photons abs'
c write(6,15) (E_min+E_max)/2000.,xn,dn,dn/xn,xa,xpow,
Amut*xn
y_cent = E/E_max (do not add), E_cent: bi central
energy (do not add), xn: tot. num. events (add),dn:Events
from Spin light (add), \( \text{dn}/\text{xn} = \text{ratio} \), \( \text{xa}= \) events above – events below / sum, \( \text{xpow} \): integrated per bin, \( \text{Amut} \times \text{xn} \): signal size

\[
\text{counx} = \text{counx} + \text{xn}
\]
\[
\text{coudn} = \text{coudn} + \text{dn}
\]
\[
\text{ndo} = \text{coudn}
\]
\[
\text{xn} = \text{counx}
\]
\[
\text{write(10,15) y \_ cent, E \_ cent, xn, dn, dn/xn, xa, xpow, Amut \times xn}
\]
\[
\text{ymin} = \text{ymax}
\]
\[
\text{enddo}
\]
\[
\text{END}
\]

SUBROUTINE IKV (V, X, VM, BI, DI, BK, DK)

C
C ==========

C Purpose: Compute modified Bessel functions \( \text{I}_v(x) \) and \( \text{K}_v(x) \), and their derivatives

C Input: \( x \) — Argument (\( x > 0 \))
C \( v \) — Order of \( \text{I}_v(x) \) and \( \text{K}_v(x) \)
C (\( v = n+v_0, n = 0,1,2,\ldots, 0 < v_0 < 1 \))

C Output: \( \text{BI}(n) = \text{In}+v_0(x) \)
C \( \text{DI}(n) = \text{In}+v_0'(x) \)
C \( \text{BK}(n) = \text{Kn}+v_0(x) \)
C \( \text{DK}(n) = \text{Kn}+v_0'(x) \)
C \( \text{VM} \) — Highest order computed

C Routines called:
C (1) \text{GAMMA} for computing the gamma function
C (2) \text{MSTA} \text{1} and \text{MSTA} \text{2} to compute the starting point for backward recurrence

C ==========

C IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION BI(0:*),DI(0:*),BK(0:*),DK(0:*)
P1=3.141592653589793D0
X2=X*X
N=INT(V)
V0=V-N
IF (N.EQ.0) N=1
IF (X.LT.1.0D-100) THEN
DO 10 K=0,N
BI(K)=0.0D0
DI(K)=0.0D0
BK(K)=-1.0D+300
DK(K)=1.0D+300
10 IF (V.EQ.0.0) THEN
BI(0)=1.0D0
DI(1)=0.5D0
ENDIF
VM=V
RETURN
ENDIF
PIV=PI+V0
VT=4.0Do+V0+V0
IF (V0.EQ.0.0Do) THEN
   A1=1.0Do
ELSE
   VoP=1.0Do+V0
   CALL GAMMA(VoP,GAP)
   A1=(0.5Do*X)**V0/GAP
ENDIF
K0=14
IF (X.GE.35.0) K0=10
IF (X.GE.50.0) K0=8
IF (X.LE.18.0) THEN
B10=1.0Do
R=1.0Do
DO 15 K=1,30
   R=0.25Do*R*X2/(K*(K+V0))
   B10=B10+R
15
CONTINUE
IF (DABS(R/B10).LT.1.0Do) GO TO 20
B10=B10+A1
ELSE
CA=DEXP(X)/DSQRT(2.0Do+PI*X)
SUM=1.0Do
R=1.0Do
DO 25 K=1,K0
   R=-0.125Do*R+(VT-(2.0Do*K-1.0Do)**2.0)/(K*X)
   SUM=SUM+R
25
B10=CA*SUM
ENDIF
M=MSTA1(X,200)
IF (M.LT.N) THEN
   N=M
ELSE
   M=MSTA2(X,N,15)
ENDIF
F2=0.0Do
F1=1.0Do-100
DO 30 K=M0,-1
   F=2.0Do*(V0+K+1.0Do)/X+F1+F2
   IF (K.LE.N) BI(K)=F
   F2=F1
30
F1=F
CS=B10/F
DO 35 K=0,N
   BI(K)=CS+BI(K)
   DI(0)=V0/X*BI(0)+BI(1)
35
DO 40 K=1,N
   DI(K)=-(K*V0)/X*BI(K)+BI(K-1)
IF (X.LE.9.0Do) THEN
   IF (V0.EQ.0.0Do) THEN
      CT=DLLOG(0.5Do*X)-0.5772156649015329Do
      CS=0.0Do
      W0=0.0Do
      R=1.0Do
      DO 45 K=1,50
   ELSE
   ENDIF
ENDIF
ENDIF
42 numerical integration code

45

IF (DABS((WA*WW)/WA) .LT. 1.0D-15) GO TO 50

50

BK0=CT+CS

ELSE

VoN=1.0D0-V0

CALL GAMMA(VoN,GAN)

A2=(0.5D0+X)**V0/GAP

SUM=A2-A1

R1=1.0D0

R2=1.0D0

DO 55 K=1,120

R1=0.25D0*R1*X2/(K*(K-V0))

R2=0.25D0*R2*X2/(K*(K+V0))

SUM=SUM+A2-R1-A1+R2

WA=DABS(SUM)

IF (DABS((WA*WW)/WA) .LT. 1.0D-15) GO TO 60

55

BK0=SUM

ENDIF

ELSE

CB=DEXP(-X)*DSQRT(0.5D0*PI/X)

SUM=1.0D0

R=1.0D0

DO 65 K=1,K0

R=0.125D0*R*(V0-K-1.0D0)**2.0)/(K*X)

65

SUM=SUM+R

BK0=CB*SUM

ENDIF

BK1=(1.0D0/X-BI(1)*BK0)/BI(0)

BK(0)=BK0

BK(1)=BK1

DO 70 K=2,N

BK2=2.0D0*(V0+K-1.0D0)/X*BK1+BK0

BK(K)=BK2

BK0=BK1

70

BK1=BK2

DK(0)=V0/X*BK(0)-BK(1)

DO 80 K=1,N

DK(K)=-(K+V0)/X*BK(K)-BK(K-1)

VM=NV0

RETURN

80

END

SUBROUTINE GAMMA(X,GAM)

C

C ==================================================

C Purpose : Compute gamma function a(x)

C Input : x —— Argument of a(x)

C ( x is not equal to 0,-1,-2,uuu)

C Output: GAM —— a(x)

C ==================================================

SUBROUTINE GAMMA(X,GAM)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION G(26)
PI=3.141592653589793D0
IF (X.EQ.INT(X)) THEN
   IF (X.GT.0.0D0) THEN
      GA=1.0D0
      M1=X-1
      DO 10 K=2,M1
      GA=GA+K
   ELSE
      GA=1.0D+300
   ENDIF
ELSE
   IF (DABS(X).GT.1.0D0) THEN
      Z=DABS(X)
      M=INT(Z)
      R=1.0D0
      DO 15 K=1,M
      R=R*(Z-K)
      Z=Z-M
   ELSE
      Z=X
   ENDIF
ENDIF
306
307
DATA G/1.0D0,0.5772156649015329D0,
&      -0.6558780715202538D0, -0.420026350340952D-1,
&      0.1665386113822915D0, -0.42197734555443D-1,
&      -0.65219715278770D-2, 0.72189432466630D-2,
&      -0.11651675918591D-2, -0.2152416741149D-3,
&      0.1280502823882D-3, -0.201348547807D-4,
&      -0.12504934821D-5, -0.11330272320D-5,
&      -0.2056338417D-6, -0.61160950D-8,
&      0.50020075D-8, -0.11812746D-8,
&      0.1043427D-9, -0.77823D-11,
&      -0.36968D-11, -0.51D-12,
&      -0.206D-13, -0.54D-14, -0.14D-14, -0.1D-15/
316
GR=G(26)
DO 20 K=25,1,-1
   GR=GR+Zi(G(K))
   GA=1.0D0/(GR+Z)
   IF (DABS(X).GT.1.0D0) THEN
      GA=GA*R
   ELSE
      IF (X.LT.0.0D0) GA=-PI/(X*GA+DSIN(PI*X))
   ENDIF
ENDIF
20
341
346
INTEGER FUNCTION MSTA1(X,MP)

=====================================================================

Purpose: Determine the starting point for backward recurrence such that the magnitude of Jn(x) at that point is about 10^(-MP)

Input: x — Argument of Jn(x)
MP — Value of magnitude

END
Output: MSTA1 — Starting point
============================================================================

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
A0=DABS(X)
No=INT(1.1*A0)+1
Fo=ENVJ(No,A0)-MP
Ni=No+5
F1=ENVJ(N1,A0)-MP
DO 10 IT = 1,20
   NN=Ni-(Ni-No)/(1.0D0-F0/F1)
   F=ENVJ(NN,A0)-MP
   IF (ABS(NN-N1).LT.1) GO TO 20
   No=Ni
   F0=F1
   Ni=NN
10 F1=F
20 MSTA1=NN
RETURN
END

INTEGER FUNCTION MSTA2(X,N,MP)
============================================================================

Purpose: Determine the starting point for backward recurrence such that all Jn(x) has MP significant digits
Input: x — Argument of Jn(x)
n — Order of Jn(x)
MP — Significant digit
Output: MSTA2 — Starting point
============================================================================

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
A0=DABS(X)
HMP=0.5D0+MP
EJN=ENVJ(N,A0)
IF (EJN.LE.HMP) THEN
   OBJ=MP
   No=INT(1.1*A0)
ELSE
   OBJ=HMP+EJN
   No=N
ENDIF
ENDIF
Fo=ENVJ(No,A0)-OBJ
Ni=No+5
F1=ENVJ(N1,A0)-OBJ
DO 10 IT = 1,20
   NN=Ni-(Ni-No)/(1.0D0-F0/F1)
   F=ENVJ(NN,A0)-OBJ
   IF (ABS(NN-N1).LT.1) GO TO 20
   No=Ni
   F0=F1
   Ni=NN
10 F1=F
20 MSTA2=NN+10
B.1 numerical integration of the sr - power law

RETURN
END

REAL,\ast{} 8 FUNCTION ENVJ(N, X)
DOUBLE PRECISION X
ENVJ=0.5D0*DLOG10(6.28D0+N)-DLOG10(1.36D0*X/N)
RETURN
END

SUBROUTINE P3PGS ( A, B, N, FN, GN, VINT )

******************************************************************************

C THIS SUBROUTINE USES THE PRODUCT TYPE THREE-POINT GAUSS-
C LEGENDRE-SIMPSON RULE COMPOUNDED N TIMES TO APPROXIMATE
C THE INTEGRAL FROM A TO B OF THE FUNCTION FN(X) * GN(X).
C FN AND GN ARE FUNCTION SUBPROGRAMS WHICH MUST BE SUPPLIED
C BY THE USER. THE RESULT IS STORED IN VINT.
C
DOUBLE PRECISION A, AG, AM(2,3), B, F(2), FN, G(3),
& GN, H, VINT, X(2), Y(2), DBLE

DATA AM(1,1), AM(2,3) / 2 * 1.718245836551854D0 /,
& AM(1,2), AM(2,2) / 2 * 1.0D0 /, AM(1,3), AM(2,1)
& / 2 * -.2182458365518542D0 /

H = ( B - A ) / DBLE ( FLOAT ( N ) )
X(1) = A + .1127016653792583D0 * H
X(2) = A + .8872983346207417D0 * H
Y(1) = A + H / 2.0D0
Y(2) = A + H
VINT = 0.0D0
G(3) = GN ( A )
DO 3 I = 1, N
AG = FN ( Y(1) )
G(1) = G(3)
DO 1 J = 1, 2
F(J) = FN ( X(J) )
G(J+1) = GN ( Y(J) )
1 X(J) = X(J) + H
Y(J) = Y(J) + H
VINT = VINT + AG * 4.0D0 * G(2)
DO 3 J = 1, 2
AG = 0.0D0
DO 2 K = 1, 3
AG = AG + AM(J,K) * G(K)
2 VINT = VINT + F(J) * AG
3 VINT = H * VINT / 9.0D0

RETURN
END
function fn01(x)
  implicit none

  integer n

  double precision fn01
  double precision x

  fn01 = x

  return
end

function fn02(x)
  implicit none

  integer n

  double precision fn02
  double precision x

  fn02 = x**2.

  return
end

function gn01(x)
  implicit real*8(A-H,O-Z)

c  real*8  Psi_min, Psi_max, alpha_min, alpha_max, y, vint3

c  real*8  gamma

c  integer n

  external fn03
  external gn03

c  double precision gn01
  c  double precision x

  parameter (n=20)

  common gamma, y

  Psi_min = -asin(1./gamma) ! min vertical angle
  Psi_max = asin(1./gamma) ! max vertical angle
  alpha_min = 2.*gamma*Psi_min ! boosted min vertical angle
  alpha_max = 2.*gamma*Psi_max ! boosted max vertical angle
  alpha_cutoffm = -0.16
  alpha_cutoffp = 0.16
  y=x

  call p3pgs(alpha_min, alpha_max, n, fn03, gn03, vint31)

c  call p3pgs(alpha_min, alpha_cutoffm, n, fn03, gn03, vint31)

c  call p3pgs(alpha_cutoffp, alpha_max, n, fn03, gn03, vint32)

gn01 = vint31 !+vint32
return
end

function gno2(x)
    implicit none
    real*8 Psi_min, Psi_max, alpha_min, alpha_max, y, vint4
    real*8 gamma

    integer n
    external fn04
    external gno4

    double precision gno2
    double precision x
    parameter (n=20)
    common gamma, y

    Psi_min = -asin(1./gamma) ! min vertical angle
    Psi_max = asin(1./gamma) ! max vertical angle
    alpha_min = 0. !16 !for the diff the int is from alpha_cut
    alpha_max = 2.*gamma*Psi_max ! boosted max vertical angle
    y=x
call p3pgs(alpha_min, alpha_max, n, fn04, gno4, vint4)
gno2 = vint4

return
end

function fn03(x)
    implicit none

    integer n
    double precision fn03
    double precision x

    fn03 = (1+x**2.)*2.

return
end

function fn04(x)
    implicit none

    integer n
    double precision fn04
    double precision x

    fn04 = x*(1+x**2.)*1.5
function gn03(x)

implicit real*8 (A-H,O-Z)

c real*8 z,v,k23,k13, gamma, y, vm

c dimension BI(o:*), DI(o:*), BK(o:*), DK(o:*)

c integer n

double precision gn03

double precision x

common gamma, y

COMMON BI(o:250), DI(o:250), BK(o:250), DK(o:250)

xk23=0.
xk13=0.
z=(y/2.)*((1+x**2)**1.5 ! z= (omega/omega_c)*(1+alpha^2)^3/2

v=2./3.
call IKV (V, z, VM, BI, DI, BK, DK)
xk23=BK(0)

v=1./3.
call IKV (V, z, VM, BI, DI, BK, DK)
xk13=BK(0)

c write (6,*) 'gn03 gamma, y, x, z', gamma, y, x, z

return

double precision gn04(x)

implicit real*8 (A-H,O-Z)

c real*8 z,v,k23,k13, gamma, y, vm

Dimension BI(o:*), DI(o:*), BK(o:*), DK(o:*)

integer n

double precision gn04

double precision x

Common gamma, y

COMMON BI(o:250), DI(o:250), BK(o:250), DK(o:250)

z=(y/2.)*((1+x**2)**1.5

v=2./3.
call IKV (V, z, VM, BI, DI, BK, DK)
xk23=BK(0)

v=1./3.
call IKV (V, z, VM, BI, DI, BK, DK)
xk13=BK(0)
B.2 LANL POISSON SUPEFISH GEOMETRY DESCRIPTION

Listing 1: LANL Poisson SupeFish Geometry Description

Dipole Magnet Problem
DIPOLE 6 Simulation of Spin Light Chicane Magnet

; Copyright 1987, by the University of California.
; Unauthorized commercial use is prohibited.
; Author: Prajwal Mohanmurthy; Dec, 2011; (prajwal@jlab.org)

&reg kprob=0, ! Poisson or Pandira problem
mode=0, ! Some materials have variable permeability
nbsup=0, ! added by gb
nbslf=0,
rhogam=0.001 !try this gb
xreg1=14.0,kreg1=82, ! Physical and logical coordinates of x
xreg2=25.0,kreg2=98,
xreg3=48.0,kreg3=150,
yreg1=14.0,lreg1=65, ! Y line regions
yreg2=18.0,lreg2=70,
yreg3=21.0,lreg3=74,
lmax=80 &

&po x=−30.0000,y=0.0000 &
&po x=60.0000,y=0.0000 &
&po x=60.0000,y=30.0000 &
&po x=−30.0000,y=30.0000 &
&po x=−30.0000,y=0.0000 &

&reg mat=1,cur=−104000.0 &
&po x=30.5000,y=6.0000 &
&po x=40.0000,y=6.0000 &
&po x=40.0000,y=12.0000 &
&po x=30.5000,y=12.0000 &
&po x=30.5000,y=6.0000 &

&reg mat=1,cur=104000.0 &
&po x=−10.0000,y=6.0000 &
&po x=−0.5000,y=6.0000 &
&po x=−0.5000,y=12.0000 &
&po x=−10.0000,y=12.0000 &
&po x=−10.0000,y=6.0000 &

&reg mat=3,mtid=−2, mshape=0 &
&po x=0.00,y=5.62 &
&po x=1.50,y=2.62 &
&po x=3.50,y=1.27 &
&po x=26.50, y= 1.27 &
&po x=28.50, y= 2.65 &
&po x=30.00, y= 5.62 &
&po x=30.00, y= 12.50 &
&po x=40.50, y= 12.60 &
&po x=40.50, y= 0.00 &
&po x=60.00, y= 0.00 &
&po x=60.00, y= 30.00 &
&po x= 0.00, y= 30.00 &
&po x= 0.00, y= 5.62 &

&mt mtid=1
bgam=0.0000  0.0017513135

900  0.001747079
950  0.001741742
1000  0.001735498
1050  0.001728309
1100  0.00172014

1150  0.001710963
1200  0.001700753
1250  0.001689494
1300  0.001677174
1350  0.001663786

2800  0.001080694
2850  0.001068051
2900  0.001056142
2950  0.001044912
3000  0.001034309

3050  0.001024289
3100  0.001014809
3150  0.001005028
3200  0.000997312
3250  0.000989226

3300  0.000981539
3350  0.000974222
3400  0.000967988
4500  0.000856798
5000  0.000818493

5500  0.000788085
6000  0.000764202
6500  0.000745863
7000  0.000723261
7500  0.000696056

8000  0.000671820
8500  0.000647105
9000  0.000620758
9500  0.000592611
10000  0.000563723

10500  0.000535294
10578  0.000507625
11319  0.000480510
11940  0.000453752
12451  0.000427403

12912  0.000402368
13313  0.000379671
13654  0.000358225
13935  0.000337923
B.3 RECURSIVE SR SPECTRA ADDING CODE

Listing 2: LANL Poisson SupeFish Geometry Description

```mathematica
(*Recursive SR - Spectra Adding Code*)
(*Author: Prajwal Mohanmurthy, Dec 2011 (prajwal@jlab.org)*)
(* Mathematica 7 File*)

up = 30;
down = 25;
asym = 5;
sigup = up/E;
sigdown = down/E;
width = 200; (*100+100*)
mid = width / 2;
motion = 10;
scale = 0;
If[up - asym != down, Print["Check Var : asym, down, up"]]
sr = Table[Table[0, {k, 1, width + (2 motion)}], {kk, 1, 21}]; (*Set ‘X’
width = 21*)

(*Print["--- --- --- --- --- --- --- --- --- ------"]*)
For[xx = 1, xx <= 21, xx++,
count = 0;
```
count2 = 0;
x = xx - 1;
For[y = 0, If[x <= 10, y <= x, y <= 10 - Abs[10 - x]], y++,
count2++;
(* Print[x, ": x | y = ", y]; *)
For[k = motion + 1 + y, k <= motion + mid + y, k++,
    sr[[xx]][[k]] += Floor[(down*E^(-(((x - 10)^2 + (y)^2)/sigdown)))];
    scale += E^(-(((x - 10)^2 + (y)^2)/sigdown));
    (* Print["Adding ", Floor[(down*E^(-(((x - 10)^2 + (y)^2)/sigdown)))]
     to ", k]; *)
];
(* Print["----------------"] ; *)
For[y = 0, If[x <= 10, y <= x, y <= 10 - Abs[10 - x]], y++,
count2++;
(* Print[x, ": x | y = ", - (y + 1)]; *)
For[k = motion + 1 + (y + 1), k <= motion + mid - (y + 1), k++,
    sr[[xx]][[k]] += Floor[(up*E^(-(((x - 10)^2 + (y + 1)^2)/sigup)))];
    scale += E^(-(((x - 10)^2 + (y + 1)^2)/sigup));
    (* Print["Adding ", Floor[(up*E^(-(((x - 10)^2 + (y + 1)^2)/sigup)))]
     to ", k]; *)
];
(* Print["----------------"] ; *)
50
(* Print["count = ", count, " | count2 = ", count2]; *)
(* Print["----------------"] ; *)
N[scale]
(* ListPlot3D[sr, PlotRange -> Full] *)
400.023
nsizesize = 520;
mw = size - (2*motion);
Dimensions[sr];
sr2 = Table[Table[0, {k, 1, 220}], {k, 1, nsize}];
Dimensions[sr2];
For[i2 = 1, i2 <= 21, i2++,
    For[j2 = 1, j2 <= 220, j2++,
        For[k2 = i2, k2 <= mw + i2, k2++,
            sr2[[k2]][[j2]] += sr[[i2]][[j2]]];
    ];
];
}
Export["3dcontour_manypt.png", ListPlot3D[Transpose[sr2],
   ColorFunction->"BlueGreenYellow", AxesLabel->{"x","y","N"},
   PlotRange->Full]]

For[i2=11, i2<=110, i2++,
 For[j2=11, j2<=nw+motion, j2++,
   sr3[[j2]][[i2]]=sr2[[nsize/4]][[50]];
 ];
 ];
 For[i2=111, i2<=210, i2++,
 For[j2=11, j2<=nw+motion, j2++,
   sr3[[j2]][[i2]]=Max[sr2];
 ];
 ];
 Export["3dcontour_onept2.png", ListPlot3D[Transpose[sr3],
   AxesLabel-->{"x","y","N"}, ColorFunction->"BlueGreenYellow",
   PlotRange-->Full]]

Clear[write2]
write2=OpenWrite["srXYdisc1.dat"]
WriteString[write2,"# x (micro m) " , "|" , "y (micro m) " , "|" , "N",
   "|\n"];
 For[i=1, i<=220, i++,
 For[j=1, j<=nsize, j++,
   WriteString[write2,Floor[20 j] , "|t" , Floor[5 i] , "|t" , Floor[sr2[[j]][[i]]] , "|\n"];
 ];
 Close[write2]

OutputStream[ srXYdisc1.dat , 36]
srXYdisc1.dat

Clear[write1]
write1=OpenWrite["srXYdisccone1.dat"]
WriteString[write1,"# x (micro m) " , "|" , "y (micro m) " , "|" , "N",
   "|\n"];
 For[i=1, i<=220, i++,
 For[j=1, j<=nsize, j++,
   WriteString[write1,Floor[20 j] , "|t" , Floor[5 i] , "|t" , Floor[sr3[[j]][[i]]] , "|\n"];
 ];
 Close[write1]
OutputStream[ srXYdisccone1.dat , 37]
srXYdisccone1.dat

For the complete program, refer to mohanmurthy.com/a/SpinIC.gz.tar
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#include "Em10DetectorConstruction.hh"
#include "Em10DetectorMessenger.hh"
#include "Em10CalorimeterSD.hh"
#include "Em10Materials.hh"

#include "G4Material.hh"
#include "G4Box.hh"
#include "G4LogicalVolume.hh"
#include "G4PVPlacement.hh"
#include "G4UniformMagField.hh"
#include "G4FieldManager.hh"
#include "G4PropagatorInField.hh"
#include "G4TransportationManager.hh"
#include "G4SDManager.hh"
#include "G4GeometryManager.hh"
#include "G4RunManager.hh"
#include "G4UserLimits.hh"
#include "G4MagneticField.hh"
#include "G4Mag_UsualEqRhs.hh"
#include "G4ChordFinder.hh"
#include "G4ClassicalIRK4.hh"
#include "G4RKG3_Stepper.hh"
#include "G4VisAttributes.hh"
#include "G4Region.hh"
#include "G4RegionStore.hh"
#include "G4PhysicalVolumeStore.hh"
#include "G4LogicalVolumeStore.hh"
#include "G4SolidStore.hh"
#include "G4ProductionCuts.hh"
#include "G4VisAttributes.hh"
#include "G4Colour.hh"
#include "G4UnitsTable.hh"
#include "G4ios.hh"
#include "G4Element.hh"

///////////
// Vacuum
G4double density = universe_mean_density;
    // from PhysicalConstants.h
G4double pressure = 1.e-19*pascal;
G4double temperature = 0.1*kelvin;
G4double a = 1.01*g/mole;
G4double z = 1.;
G4Material* vacuum = new G4Material("vacuum", z, a, density, kStateGas, temperature, pressure);

///////////
// Magnets Description

void Em10DetectorConstruction::magnets()
{
    // Magnets Generic variables
    G4Material* iFe = fMat->GetMaterial("Iron");
    G4bool propagateToDaughters = true;
G4double fMinStep = 0.001*mm; // minimal step of 1 mm is default
G4double stdfield = 1.0*tesla;
G4VisAttributes* colorends = new G4VisAttributes(G4Colour(0.0, 0.0, 1., 0.5));
G4VisAttributes* colormid = new G4VisAttributes(G4Colour(1.0, 1.0, 0.3));
colorends->SetForceSolid(true);
colormid->SetForceSolid(true);

\/\/######## 1st magnet###################
G4Box* fmagnetonetop;
G4LogicalVolume* fLogicmagnetonetop;
G4PVPhysicalVolume* fPhysicsmagnetonetop;
G4Box* fmagnetonebot;
G4LogicalVolume* fLogicmagnetonebot;
G4PVPhysicalVolume* fPhysicsmagnetonebot;
G4Box* fmagnetonemid;
G4LogicalVolume* fLogicmagnetonemid;
G4PVPhysicalVolume* fPhysicsmagnetonemid;
G4UniformMagField* magFieldone;
G4FieldManager* fieldMgrone;
G4Mag_UsualEqRhs* fLocalEquationone;
G4MagIntegratorStepper* fLocalStepperone;
G4ChordFinder* fLocalChordFinderone(0);

// top end plates
fmagnetonetop = new G4Box("magnet1t", 5.0*cm, 2.5*cm, 5.0*cm);

fLogicmagnetonetop = new G4LogicalVolume(fmagnetonetop, fFe, "magnet1t");

fPhysicsmagnetonetop = new G4PVPlacement(0, G4ThreeVector(0, 7.5*cm, -5.80*mm), "magnet1t", fLogicmagnetonetop,
fPhysicsWorld, false, 0);

// bottom end plates
fmagnetonebot = new G4Box("magnet1b", 5.0*cm, 2.5*cm, 5.0*cm);

fLogicmagnetonebot = new G4LogicalVolume(fmagnetonebot, fFe, "magnet1b");

fPhysicsmagnetonebot = new G4PVPlacement(0, G4ThreeVector(0, -7.5*cm, -5.80*mm), "magnet1b", fLogicmagnetonebot,
fPhysicsWorld, false, 0);

// Middle field area geometry
fmagnetonemid = new G4Box("magnet1m", 5.0*cm, 5.0*cm, 5.0*cm);
fLogicmagnetonemid = new G4LogicalVolume(fmagnetonemid, vacuum, "magnet1m");

fPhysicsmagnetonemid = new G4PVPlacement(o, G4ThreeVector(0,0,-5.80*m), "magnet1m", fLogicmagnetonemid, fPhysicsWorld, false, o);

//Middle-local field manager
magFieldone = new G4UniformMagField(G4ThreeVector(0, stdfield, 0));
fieldMgrone = new G4FieldManager();
fieldMgrone->SetDetectorField(magFieldone);

fLogicmagnetonemid->SetFieldManager(fieldMgrone, propagateToDaughters);

fLocalEquationone = new G4Mag_UsualEqRhs(magFieldone);

fLocalStepperone = new G4ClassicalRK4(fLocalEquationone);
if (fLocalChordFinderone) delete fLocalChordFinderone;
fLocalChordFinderone = new G4ChordFinder(magFieldone, fMinStep, fLocalStepperone);

fieldMgrone->SetChordFinder(fLocalChordFinderone);

//Colors
fLogicmagnetonemid->SetVisAttributes(colormid);
fLogicmagnetonetop->SetVisAttributes(colorends);
fLogicmagnetonebot->SetVisAttributes(colorends);

//######## 2nd magnet####################

G4Box* fmagnettwotop;
G4LogicalVolume* fLogicmagnettwotop;
G4VPhysicalVolume* fPhysicsmagnettwotop;

G4Box* fmagnettwobot;
G4LogicalVolume* fLogicmagnettwobot;
G4VPhysicalVolume* fPhysicsmagnettwobot;

G4Box* fmagnettwomid;
G4LogicalVolume* fLogicmagnettwomid;
G4VPhysicalVolume* fPhysicsmagnettwomid;

G4UniformMagField* magFieldtwo;
G4FieldManager* fieldMgrtwo;
G4Mag_UsualEqRhs* fLocalEquationtwo;
G4MagIntegratorStepper* fLocalSteppertwo;

G4ChordFinder* fLocalChordFindertwo(o);

// top end plates

fmagnettwotop = new G4Box("magnet2t", 5.0*cm, 2.5*cm, 10.0*cm);
fLogicmagnettwotop = new G4LogicalVolume(fmagnettwotop, fFe, "magnet2t");

fPhysicsmagnettwotop = new G4PVPlacement(0, G4ThreeVector(0, 7.5*cm, -5.3*cm), "magnet2t", fLogicmagnettwotop, fPhysicsWorld, false, 0);

// bottom end plates
fmagnettwobot = new G4Box("magnetzb", 5.0*cm, 2.5*cm, 10.0*cm);

fLogicmagnettwobot = new G4LogicalVolume(fmagnettwobot, fFe, "magnetzb");

fPhysicsmagnettwobot = new G4PVPlacement(0, G4ThreeVector(0, -7.5*cm, -5.3*cm), "magnetzb", fLogicmagnettwobot, fPhysicsWorld, false, 0);

//Middle field area geometry
fmagnettwomid = new G4Box("magnetzm", 5.0*cm, 5.0*cm, 10.0*cm);

fLogicmagnettwomid = new G4LogicalVolume(fmagnettwomid, vacuum, "magnetzm");

fPhysicsmagnettwomid = new G4PVPlacement(0, G4ThreeVector(0, 0*cm, -5.3*cm), "magnetzm", fLogicmagnettwomid, fPhysicsWorld, false, 0);

//Middle-local field manager
magFieldtwo = new G4UniformMagField(G4ThreeVector(0., -stdfield, 0.));

fieldMgrtwo = new G4FieldManager();

fieldMgrtwo->SetDetectorField(magFieldtwo);

fLogicmagnettwomid->SetFieldManager(fieldMgrtwo, propagateToDaughters);

fLocalEquationtwo = new G4Mag_UsualEqRhs(magFieldtwo);

fLocalSteppertwo = new G4 ClassicalRK4(fLocalEquationtwo);

if (fLocalChordFindertwo) delete fLocalChordFindertwo;

fLocalChordFindertwo = new G4ChordFinder(magFieldtwo, fMinStep, fLocalSteppertwo);

fieldMgrtwo->SetChordFinder(fLocalChordFindertwo);

//Colors
fLogicmagnettwomid->SetVisAttributes(colormid);

fLogicmagnettwotop->SetVisAttributes(colorends);

fLogicmagnettwobot->SetVisAttributes(colorends);

//####### 3rd magnet####################################

G4Box* fmagnetthreetop;
G4LogicalVolume* fLogicmagnetthreetop;
G4VPhysicalVolume* fPhysicsmagnetthreetop;
G4Box*fmagnetthreetop;
G4LogicalVolume*fLogicmagnetthreetop;
G4VPhysicalVolume*fPhysicsmagnetthreetop;

G4Box*fmagnetthreemid;
G4LogicalVolume*fLogicmagnetthreemid;
G4VPhysicalVolume*fPhysicsmagnetthreemid;

G4UniformMagField* magFieldthree;
G4FieldManager* fieldMgrthree;
G4Mag_UsualEqRhs* fLocalEquationthree;
G4MagIntegratorStepper* fLocalStepperthree;
G4ChordFinder* fLocalChordFinderthree();

// top end plates
fmagnetthreetop = new G4Box("magnet2t", 5.0*cm, 2.5*cm, 5.0*cm);

fLogicmagnetthreetop = new G4LogicalVolume(fmagnetthreetop,
fFe, "magnet2t");

fPhysicsmagnetthreetop = new G4PVPlacement(0, G4ThreeVector (0, 7.5*cm, -4.8*cm), "magnet2t", fLogicmagnetthreetop, fPhysicsWorld, false, 0);

// bottom end plates

fmagnetthreebot = new G4Box("magnet2b", 5.0*cm, 2.5*cm, 5.0*cm);

fLogicmagnetthreebot = new G4LogicalVolume(fmagnetthreebot, fFe, "magnet2b");

fPhysicsmagnetthreebot = new G4PVPlacement(0, G4ThreeVector (0, -7.5*cm, -4.8*cm), "magnet2b", fLogicmagnetthreebot, fPhysicsWorld, false, 0);

// Middle field area geometry
fmagnetthreemid = new G4Box("magnet2m", 5.0*cm, 5.0*cm, 5.0*cm);

fLogicmagnetthreemid = new G4LogicalVolume(fmagnetthreemid, vacuum, "magnet2m");

fPhysicsmagnetthreemid = new G4PVPlacement(0, G4ThreeVector (0, 0*cm, -4.8*cm), "magnet2m", fLogicmagnetthreemid, fPhysicsWorld, false, 0);

// Middle—local field manager

magFieldthree = new G4UniformMagField(G4ThreeVector(0., stdfield, 0.));

fieldMgrthree = new G4FieldManager();
fieldMgrthree->SetDetectorField (magFieldthree);

fLogicmagnetthreemid->SetFieldManager(fieldMgrthree, propagateToDaughters);

fLocalEquationthree = new G4Mag_UsualEqRhs(magFieldthree);
fLocalStepperthree = new G4ClassicalRK4(fLocalEquationthree);
if (fLocalChordFinderthree) delete fLocalChordFinderthree;

fLocalChordFinderthree = new G4ChordFinder(magFieldthree, fMinStep, fLocalStepperthree);
fieldMgrthree->SetChordFinder(fLocalChordFinderthree);

//Colors
fLogicmagnetthreemid->SetVisAttributes(colormid);
fLogicmagnetthreetop->SetVisAttributes(colorends);
fLogicmagnetthreebot->SetVisAttributes(colorends);

////////////////////////////////
// Ionization Chamber Description

void Em10DetectorConstruction::ic () {
    //IC Generic Variables
    G4Material* fAr = fMat->GetMaterial("Argon");
    G4Material* fAl = fMat->GetMaterial("Al");
    G4VisAttributes* coloricout = new G4VisAttributes(G4Colour(1.0, 1.0, 0.0, 0.5));
    G4VisAttributes* coloricin = new G4VisAttributes(G4Colour(0.0, 1.0, 0.0, 0.2));
    coloricout->SetForceSolid(true);
    coloricin->SetForceSolid(true);

    //IC1 Geometry Variables
    G4Box* ficoutone;
    G4LogicalVolume* fLogicicoutone;
    G4VPhysicalVolume* fPhysicscicoutone;
    G4Box* ficinone;
    G4LogicalVolume* fLogicicinone;
    G4VPhysicalVolume* fPhysicscicinone;

    //IC1 Geometry
    ficoutone = new G4Box("icout1", 5.1*cm, 5.1*cm, 50.0*cm);
    fLogicicoutone = new G4LogicalVolume(ficoutone, fAl, "icout1");
    fPhysicscicoutone = new G4PVPlacement(0, G4ThreeVector(5.2*cm, 0.5, 20*cm), "icout1", fLogicicoutone, fPhysicsWorld, false, 0);
    ficinone = new G4Box("icin", 5.0*cm, 5.0*cm, 50.0*cm);
    fLogicicinone = new G4LogicalVolume(ficinone, fAr, "icin1");
fPhysicsicinone = new G4PVPlacement(0, G4ThreeVector(5.2*cm, 0, 5.20*cm), "icin1", fLogiccinone, fPhysicsWorld, false, 0);

//IC2 Geometry Variables
G4Box* ficouttwo;
G4LogicalVolume* fLogicicouttwo;
G4VPhysicalVolume* fPhysicscicouttwo;

G4Box* ficintwo;
G4LogicalVolume* fLogicicintwo;
G4VPhysicalVolume* fPhysicscicintwo;

//IC2 Geometry
ficouttwo = new G4Box("icout1", 5.1*cm, 5.1*cm, 50.0*cm);
fLogicicouttwo = new G4LogicalVolume(ficouttwo, fAl, "icout1");
fPhysicscicouttwo = new G4PVPlacement(0, G4ThreeVector(-5.2*cm, 0, 5.20*cm), "icout1", fLogicicouttwo, fPhysicsWorld, false, 0);

ficintwo = new G4Box("icin", 5.0*cm, 5.0*cm, 50.0*cm);
fLogicicintwo = new G4LogicalVolume(ficintwo, fAr, "icin1");
fPhysicscicintwo = new G4PVPlacement(0, G4ThreeVector(-5.2*cm, 0, 5.20*cm), "icin1", fLogicicintwo, fPhysicsWorld, false, 0);

//IC Colors
fLogicicoutone->SetVisAttributes(coloricout);
fLogiccinone->SetVisAttributes(coloricin);
fLogicicouttwo->SetVisAttributes(coloricout);
fLogicicintwo->SetVisAttributes(coloricin);

if ( fRegGasDet != 0 ) delete fRegGasDet;
if ( fRegGasDet == 0 ) fRegGasDet = new G4Region("XTRdEdxDetector");

fRegGasDet->
  AddRootLogicalVolume( fLogicicintwo );
fRegGasDet->
  AddRootLogicalVolume( fLogiccinone );

}



// Collimator Description

void Em10DetectorConstruction::collimators()
{

//G4Material* fPb = fMat->GetMaterial("Lead");
Em10DetectorConstruction::Em10DetectorConstruction() : fSetUp("simpleprajwal")
{
    fDetectorMessenger = new Em10DetectorMessenger(this);
    fMat = new Em10Materials();
    //userLimits = new G4UserLimits();
}

Em10DetectorConstruction::~Em10DetectorConstruction()
{
    delete fDetectorMessenger;
    delete fMat;
}

G4VPhysicalVolume* Em10DetectorConstruction::Construct()
{
    return ConstructDetectorXTR();
}

G4VPhysicalVolume* Em10DetectorConstruction::
    ConstructDetectorXTR()
{
    // Cleanup old geometry

    G4GeometryManager::GetInstance() -> OpenGeometry();
    G4PhysicalVolumeStore::GetInstance() -> Clean();
    G4LogicalVolumeStore::GetInstance() ->Clean();
    G4SolidStore::GetInstance() ->Clean();

    if (fSetUp == "simpleprajwal")
    {
        return SetUpprajwal();
    }
    else
    {
        G4cout << "Experimental setup is unsupported. Check /XTRdetector/setup " << G4endl;
    }
G4cout<"Run default: prajwal"<G4endl;
  return SetUpprajwal();

  // return 0;
}
}

void Em10DetectorConstruction::SetMagField(G4double fieldValue)
{
  // apply a global uniform magnetic field along Z axis
  G4FieldManager* fieldMgr
  = G4TransportationManager::GetTransportationManager()->GetFieldManager();

  if (magField) delete magField;     // delete the existing
      mag field
  if (fieldValue!=0.)  // create a new one if non null
  {
    magField = new G4UniformMagField(G4ThreeVector(0.,0.,fieldValue));
    fieldMgr->SetDetectorField(magField);
    fieldMgr->CreateChordFinder(magField);
  }
  else
  {
    magField = 0;
    fieldMgr->SetDetectorField(magField);
  }
}

void Em10DetectorConstruction::SetMaxStepLength(G4double val)
{
  // set the maximum length of tracking step
  //
  if (val <= DBL_MIN)
  {
    G4cout << "\n --- warning from SetMaxStepLength: maxStep "
    << val << " out of range. Command refused" << G4endl;
    return;
  }
  G4TransportationManager* tmanager = G4TransportationManager::GetTransportationManager();
  tmanager->GetPropagatorInField()->SetLargestAcceptableStep(val);
}

// Simplified setup for SpinLight Polarimeter (~2012).
// Runs by: TestEm10 SpinIC.mac
// Author: Prajwal Mohanmurthy (prajwal@mohanmurthy.com)
// Adopted from GEANT-4 example suite example TestEm10
// available under folder '~/examples/extended/electromagnetic'
G4VPhysicalVolume* Em10DetectorConstruction::SetUpprajal() {
    fWorldSizeZ = 12.0*m;
    fWorldSizeR = 50.0*cm;

    // Radiator and detector parameters
    fRadThickness = 0.020*mm;
    fGasGap = 0.250*mm;
    foilGasRatio = fRadThickness / (fRadThickness + fGasGap);
    fFoilNumber = 220;

    fAbsorberThickness = 38.3*mm;
    fAbsorberRadius = 100.0*mm;
    fAbsorberZ = 136.0*cm;
    fWindowThick = 51.0*micrometer;
    fElectrodeThick = 10.0*micrometer;
    fGapThick = 10.0*cm;
    fDetThickness = 40.0*mm;
    fDetLength = 200.0*cm;
    fDetGap = 0.01*mm;
    fStartR = 40*cm;
    fStartZ = 100.0*mm;
    fModuleNumber = 1;

    // Preparation of mixed radiator material
    G4Material* Mylar = fMat->GetMaterial("Mylar");
    G4Material* Al = fMat->GetMaterial("Al");

    G4double foilDensity = 1.39*g/cm3; // Mylar
    G4double gasDensity = 1.2928*mg/cm3; // Air
    G4double totDensity = foilDensity*foilGasRatio + gasDensity*(1.0-foilGasRatio);

    G4double fractionFoil = foilDensity*foilGasRatio/totDensity;
    G4double fractionGas = gasDensity*(1.0-foilGasRatio)/totDensity;

    G4Material* radiatorMat = new G4Material("radiatorMat", totDensity, 2);
    radiatorMat->AddMaterial(Mylar, fractionFoil);
    radiatorMat->AddMaterial(vacuum, fractionFoil);
    radiatorMat->AddMaterial(vacuum, fractionGas);
// default materials of the detector and TR radiator
fRadiatorMat = radiatorMat;
fFoilMat = Mylar; // CH2; // Kapton; // Mylar; // Li;
// CH2;
fGasMat = vacuum; // CO2; // He; //
fWindowMat = Mylar;
fElectrodeMat = Al;

fAbsorberMaterial = fMat->GetMaterial("Xe15CO2");

fGapMat = fAbsorberMaterial;

fWorldMaterial = vacuum; // CO2;

fSolidWorld = new G4Box("World", fWorldSizeR, fWorldSizeR, fWorldSizeZ/2.);

fLogicWorld = new G4LogicalVolume(fSolidWorld, fWorldMaterial, "World");

fPhysicsWorld = new G4PVPlacement(0, G4ThreeVector(), "World", fLogicWorld, 0, false, 0);

// % % % % % % % MAGNETS % % % % % % % % % % % % % % % % % % % % % %
magnets();

// % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % %
// % % % % % % %Collimators% % % % % % % % % % % % % % % % % % % % % % % % %
collimators();

// % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % %
// % % % % % % %I o n i z a t i o n c h a m b e r% % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % %
ic();

// % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % % %
// TR radiator envelope
fRadThick = fFoilNumber*(fRadThickness + fGasGap) - fGasGap + fDetGap;

fRadZ = fStartZ + 0.5*fRadThick;

// fSolidRadiator = new G4Box("Radiator",1.1*fAbsorberRadius, 1.1*fAbsorberRadius, 0.5*fRadThick);
// fLogicRadiator = new G4LogicalVolume(fSolidRadiator, fRadiatorMat, "Radiator");
// fPhysicsRadiator = new G4PVPlacement (0, G4ThreeVector (0,0,0), "Radiator", fLogicRadiator, fPhysicsWorld, false, 0);

// create region for window inside windowR for
if ( fRadRegion != 0 ) delete fRadRegion;
if ( fRadRegion == 0 ) fRadRegion = new G4Region("XTRradiator");
    //fRadRegion->
    AddRootLogicalVolume(fLogicRadiator);

fWindowZ = fStartZ + fRadThick + fWindowThick/2. + 15.0*mm ;

fAbsorberZ = fElectrodeZ + fAbsorbeThickness/2. + 0.01*mm;

fPhysicsAbsorber = new G4PVPlacement (0, G4ThreeVector (0,0,0), fAbsorberZ, "Absorber", fLogicAbsorber, fPhysicsWorld, false, 0);

if ( !fCalorimeterSD )
    fCalorimeterSD = new Em10CalorimeterSD("CalorSD",this);

 SDman->AddNewDetector( fCalorimeterSD );

// if ( fLogicAbsorber ) fLogicAbsorber->SetSensitiveDetector( fCalorimeterSD );
PrintGeometryParameters();

//Uniform Magnetic field for all of world volume is defined here
G4double fieldValue = 0.0*tesla;
G4UniformMagField* magField = new G4UniformMagField(
    G4ThreeVector(0., fieldValue, 0.));

G4FieldManager* fieldMgr = G4TransportationManager::
    GetTransportationManager()->GetFieldManager();
fieldMgr->SetDetectorField(magField);

return fPhysicsWorld;
}

void Em10DetectorConstruction::PrintGeometryParameters()
{
    G4cout << "\n The WORLD is made of " << fWorldSizeZ/mm << " mm of " << fWorldMaterial->GetName() << G4endl;
    G4cout << ", the transverse size (R) of the world is " << fWorldSizeR/mm << " mm. " << G4endl;
    G4cout << " The ABSORBER is made of " << fAbsorberThickness/mm << " mm of " << fAbsorberMaterial->GetName() << G4endl;
    G4cout << ", the transverse size (R) is " << fAbsorberRadius/mm << " mm. " << G4endl;
    G4cout << " Z position of the (middle of the) absorber " << fAbsorberZ/mm << " mm. " << G4endl;
    G4cout << fRadZ = " << fRadZ/mm << " mm" << G4endl;
    G4cout << fStartZ = " << fStartZ/mm << " mm" << G4endl;
    G4cout << fRadThick = " << fRadThick/mm << " mm" << G4endl;
    G4cout << fFoilNumber = " << fFoilNumber << G4endl;
    G4cout << fRadiatorMat = " << fRadiatorMat->GetName() << G4endl;
    // G4cout<<"fAbsorberZ = " << fAbsorberZ/mm<<" mm"<<G4endl;
    G4cout << WorldMaterial = " << fWorldMaterial->GetName() << G4endl;
//   G4cout<<"fAbsorberZ = " << fAbsorberZ/mm<<" mm"<<G4endl;
}

}
```cpp
void Em10DetectorConstruction::SetAbsorberMaterial(G4String materialChoice)
{
    // get the pointer to the material table
    const G4MaterialTable* theMaterialTable = G4Material::GetMaterialTable();

    // search the material by its name
    G4Material* pttoMaterial;
    for (size_t J = 0; J < theMaterialTable->size(); J++)
    {
        pttoMaterial = (*theMaterialTable)[J];
        if (pttoMaterial->GetName() == materialChoice)
        {
            fAbsorberMaterial = pttoMaterial;
            fLogicAbsorber->SetMaterial(pttoMaterial);
            // PrintCalorParameters();
        }
    }
} // //

void Em10DetectorConstruction::SetRadiatorMaterial(G4String materialChoice)
{
    // get the pointer to the material table
    const G4MaterialTable* theMaterialTable = G4Material::GetMaterialTable();

    // search the material by its name
    G4Material* pttoMaterial;
    for (size_t J = 0; J < theMaterialTable->size(); J++)
    {
        pttoMaterial = (*theMaterialTable)[J];
        if (pttoMaterial->GetName() == materialChoice)
        {
            fRadiatorMat = pttoMaterial;
            fLogicRadSlice->SetMaterial(pttoMaterial);
            // PrintCalorParameters();
        }
    }
} // //

void Em10DetectorConstruction::SetWorldMaterial(G4String materialChoice)
{
    // get the pointer to the material table
    const G4MaterialTable* theMaterialTable = G4Material::GetMaterialTable();

    // search the material by its name
    G4Material* pttoMaterial;
    for (size_t J = 0; J < theMaterialTable->size(); J++)
    {
        pttoMaterial = (*theMaterialTable)[J];
        if (pttoMaterial->GetName() == materialChoice)
        {
            fWorldMat = pttoMaterial;
            fLogicWorld->SetMaterial(pttoMaterial);
            // PrintCalorParameters();
        }
    }
} // //
```
// get the pointer to the material table
const G4MaterialTable* theMaterialTable = G4Material::GetMaterialTable();

// search the material by its name
G4Material* pttoMaterial;

for (size_t J = 0; J < theMaterialTable->size(); J++)
{
    pttoMaterial = (*theMaterialTable)[J];

    if (pttoMaterial->GetName() == materialChoice)
    {
        fWorldMaterial = pttoMaterial;
    fLogicWorld->SetMaterial(pttoMaterial);
        // PrintCalorParameters();
    }
}

////////////////////////////////////////
//
//

void Em10DetectorConstruction::SetAbsorberThickness(G4double val)
{
    // change Absorber thickness and recompute the calorimeter parameters
    fAbsorberThickness = val;
    // ComputeCalorParameters();
}

////////////////////////////////////////
//
//

void Em10DetectorConstruction::SetRadiatorThickness(G4double val)
{
    // change XTR radiator thickness and recompute the calorimeter parameters
    fRadThickness = val;
    // ComputeCalorParameters();
}

////////////////////////////////////////
//
//

void Em10DetectorConstruction::SetGasGapThickness(G4double val)
{
    // change XTR gas gap thickness and recompute the calorimeter parameters
    fGasGap = val;
    // ComputeCalorParameters();
}
70 numerical integration code

}  

//////////////////////////////////////////
//
//
void Em10DetectorConstruction::SetAbsorberRadius(G4double val)
{
    // change the transverse size and recompute the calorimeter parameters
    fAbsorberRadius = val;
    // ComputeCalorParameters();
}

//////////////////////////////////////////
//
//
void Em10DetectorConstruction::SetWorldSizeZ(G4double val)
{
    fWorldChanged=true;
    fWorldSizeZ = val;
    // ComputeCalorParameters();
}

//////////////////////////////////////////
//
//
void Em10DetectorConstruction::SetWorldSizeR(G4double val)
{
    fWorldChanged=true;
    fWorldSizeR = val;
    // ComputeCalorParameters();
}

//////////////////////////////////////////
//
//
void Em10DetectorConstruction::SetAbsorberZpos(G4double val)
{
    fAbsorberZ = val;
    // ComputeCalorParameters();
}

//////////////////////////////////////////
//
//
void Em10DetectorConstruction::UpdateGeometry()
{
    G4RunManager::GetRunManager()->DefineWorldVolume(ConstructDetectorXTR());
}

}
