DEVELOPMENT OF GASEOUS PARTICLE DETECTORS BASED ON SEMI-CONDUCTIVE PLATE ELECTRODES

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 RPC EVOLUTION
(Avalanche regime)

Standard Bakelite Electrode + Phase0 FE
- $\rho \approx 10^{10} \Omega \cdot cm$
- $d = 1.8mm$
- $\varepsilon_r \approx 5 - 8$
- Gap = 2mm
- FE Noise $\approx 10000$ $e^-$

Thin Bakelite Electrode + new FE
- $\rho \approx 10^{10} \Omega \cdot cm$
- $d = 1.2mm$
- $\varepsilon_r \approx 5 - 8$
- Gap = 1mm
- FE Noise $\approx 1000$ $e^-$

Semi-Insulating Electrode SI-GaAs + new FE
- $\rho \approx 6.4 \times 10^7 \Omega \cdot cm$
- $d = 0.4mm$
- $\varepsilon_r \approx 12$
- Gap = 1mm
- FE Noise $\approx 1000$ $e^-$

Timeline
- 2010
- 2018
- ?

Intrinsic Rate Capability
- 1kHz/cm²
- 10kHz/cm²
- MHz/cm²?

PRC EVOLUTION
(Avalanche regime)
LUMPED ELEMENT MODEL

- $C_G = \text{Gas capacitance}$
- $C = \text{Electrode capacitance}$
- $R_L = \text{Electrode longitudinal resistance}$
- $R_L = \text{Electrode transversal resistance}$
- $R_G = \text{Graphite resistance}$

Unit Cell

Discharge

$V_{Drop} = 2 \rho d < Q > \phi_{eff}$

Recharge

$\tau \cong \rho \varepsilon_0 \left( \varepsilon_r + 2 \frac{d}{g} \right)$

$R_T = \rho \cdot \frac{d}{l^2}$

$R_L = \rho \cdot \frac{d}{d \cdot l}$

- Lowering $\rho \rightarrow \text{decrease } V_{Drop}$ and $\tau$
- Lowering $d \rightarrow R_L \gg R_T \rightarrow \text{reduced Unit Cell}$

(Increased Rate Capability)
Prototype 1

- **HV Electrode**: SI-GaAs
  \((\rho = 7 \cdot 10^7 \Omega \cdot \text{cm}; 400\mu\text{m})\)
- **Ground Electrode**: SI-GaAs
  \((\rho = 7 \cdot 10^7 \Omega \cdot \text{cm}; 400\mu\text{m})\)
- **Gas-gap**: 1mm
- **Gas**: 95%TFE/4.5%iC\(_4\)H\(_{10}\)/0.5%SF6

Prototype 2

- **HV Electrode**: SI-GaAs
  \((\rho = 6.4 \cdot 10^7 \Omega \cdot \text{cm}; 400\mu\text{m})\)
- **Ground Electrode**: Silicon
  \((\rho = 10^4 \Omega \cdot \text{cm}; 400\mu\text{m})\)
- **Gas-gap**: 1.5mm
- **Gas**: 40%iC\(_4\)H\(_{10}\)/60%Ar

Prototype 3

- **HV Electrode**: SI-GaAs
  \((\rho = 5.7 \cdot 10^7 \Omega \cdot \text{cm}; 400\mu\text{m})\)
- **Ground Electrode**: SI-GaAs
  \((\rho = 5.7 \cdot 10^7 \Omega \cdot \text{cm}; 400\mu\text{m})\)
- **Gas-gap**: 1.3mm
- **Gas**: 95%TFE/4.5%iC\(_4\)H\(_{10}\)/0.5%SF6
PROTOTYPE 1
(Semi-Insulating GaAs)

Gas: 95%TFE/4.5%iC₄H₁₀/0.5%SF₆

Prototype 1 shows instability during tests

Prototype 1 Pulses

1kΩ  50Ω
Experimental Set-Up
(BTF-LNF[1])

Beam specs:
Energy = 450 MeV;
Bunch Rate = 50Hz;
MeanMultiplicity = 0.3;

FE features:
Low Voltage = 4V;
Sensitivity = 2-4 mV/fC;
Bandwidth = 10-100MHz
Input impedance = 100-50Ω
1000 noise electrons

[1]http://www.lnf.infn.it/acceleratori/btf/
[2]BENOIT M. ET AL., *Jinst*, 10.1088/1748-0221/11/03/P03011 (IOP for SISSA Medialab) 9/2016.
RESULTS
EFFICIENCY – TIME RESOLUTION

- 1mm gas gap
- Efficiency = triple/double
- Threshold=5*RMS background (~7mV)
- 2% Random count probability in 30ns time window

- HV=5627V
- Time walk correction

$$\sigma_{\text{trig}} = 180\text{ps}$$
$$\sigma_{\text{RPC}}^2 = \sigma^2 - \sigma_{\text{trig}}^2$$

$$\sigma_{\text{RPC}} = 590\text{ps}$$

100kHz/cm² Random Counting Rate!

Counts

| htemp     | Entries  | Mean   | Std Dev | $\chi^2$ / ndf | Constant | Mean ± Sigma |
|-----------|----------|--------|---------|----------------|----------|--------------|
|           | 120      | 0.007229 | 1.68    | 26.76 / 28     | 12.09 ± 1.76 | 0.2882 ± 0.0677 | 0.6242 ± 0.0694 |
PROTOTYPE 2
(Semi-Insulating GaAs/Silicon)

Prototype 2 shows stability only with Argon/Isobutane mixture.

Graphite

Copper

FOAM

Si-GaAs

Si

Current

Prompt signal

Gas IN

PET

Gas Out

40%CH₄/60%Ar

HV

1MΩ

50Ω

Current

Prompt signal
**Experimental Set-Up**

**INFN ROMA2**

Prototype 2 characterization was carried out exploiting atmospheric muons.

Two scintillators have been used as trigger reference.

Time resolution has been measured with TOF technique, with respect to a scintillator.

The trigger time resolution has been measured during the test resulting in 456ps.

**Scope Features:**
- Bandwidth 3GHz
- Sampling rate 10GS/s

**Gas Mixture:**
40% $\text{iC}_4\text{H}_{10}/60\% \text{Ar}$

**Prototype 2 characterization was carried out exploiting atmospheric muons.**

**Two scintillators have been used as trigger reference.**

**Time resolution has been measured with TOF technique, with respect to a scintillator.**

**The trigger time resolution has been measured during the test resulting in 456ps.**
RESULTS

EFFICIENCY – TIME RESOLUTION

- 1.5mm gas gap
- Efficiency=triple/double
- Threshold=5*RMS background (~7mV)

- HV = 6190V
- Time walk correction

\[
\sigma_{RPC}^2 = \sigma^2 - \sigma_{scint}^2
\]

\[
\sigma_{scint} = 456\,\text{ps}
\]

\[
\sigma_{RPC} = 1.1\,\text{ns}
\]

More than 30kHz/cm² Random Counting Rate

Counts

| Entries | 211 |
|---------|-----|
| Mean    | -0.004041 |
| Std Dev | 2.616 |
| \(\chi^2/\text{ndf}\) | 19.65/20 |
| Constant | 36.09 ± 3.22 |
| Mean    | 0.4375 ± 0.0852 |
| Sigma   | 1.168 ± 0.062 |

Time (ns)
Random counting rate has been measured acquiring waveforms in a 10μs time window and discriminating signals over the same threshold used in efficiency measure.
Prototype 3 shows impressive stability with standard mixture.
Experimental Set-Up (INFN ROMA2)

Prototype 3 characterization was carried out exploiting atmospheric muons.

Two scintillators and one RPC have been used as trigger reference.

Time resolution has been measured with TOF technique, with respect to a scintillator.

The scintillators time resolution has been measured during the test resulting in 267ps.

Scope Features:
- Bandwidth 2.5GHz
- Sampling rate 20GS/s

Gas Mixture:
95%TFE/4.5%\(\text{C}_4\text{H}_{10}\)/0.5%SF6

RPC
Prompt
Ionic

Prototype 3

Gas Mixture:

IN
Discriminator

OUT

CAEN Mod. SY2527

CAEN Mod. N470

HV

WaveRunner 625Zi

CH1 50Ω
CH2 1MΩ
CH3 1MΩ
CH4 50Ω

AND

CAEN Mod. 81A

RPC
Scintillator 1
Scintillator 2

Prompt

RESULTS

EFFICIENCY – TIME RESOLUTION

- 1.3mm gas gap
- Efficiency=quadruple/triple
- Threshold=5*RMS background (~25mV)

- HV = 6130V
- Time walk correction

\[ \sigma_{RPC}^2 = \sigma^2 - \sigma_{scint}^2 \]

\[ \sigma_{RPC} = 736\text{ps} \]

\[ \sigma_{scint} = 267\text{ps} \]
RESULTS
RANDOM COUNTING RATE

Random Counting Rate has been measured discriminating signals with 30mV threshold

4cm² Surface
Prompt and Ionic signals

Ionic signals
200μs waveforms without random pulses

Prompt signals (Charge amplifier shaping)
Conclusions

All prototypes give good results in term of efficiency knee and time resolution.

Prototype 1 test, on electron beam, proves that detector can reach at least 90% efficiency despite 100kHz/cm² random counting rate (lower limit for Rate Capability)

Prototype 2 test prove that similar results can be reached substituting ground electrode with one of lower resistivity

Prototype 3 test prove that random counting rate can be drastically reduced improving build quality

Stability and low noise reached in prototype 3 allow to conduct careful studies on ionic/prompt ratio in addition to process dynamics and Rate Capability