HYPERON POLARIZATION AND VECTOR MESON PRODUCTION AT 2.85 GeV
(Preliminary Results)

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Surprisingly large polarization in hyperon production by unpolarized proton beam has been known since long time. Huge inclusive hyperon polarization data are available in literature, few data are disponible on spin observables and none on exclusive hyperon measurements. Evidence of relevant violation of the OZI rule in several reactions are also shown in recent measurements. These two items, connected together by the hypothesis of existence of a sizeable $q\bar{q}$ sea in the nucleon, can be studied using the DISTO is a spectrometer installed in the polarized proton beam of the Saturne accelerator in Saclay. The compact experimental set-up is designed to detect four or more charged particles signaling $\Lambda, \Sigma^0, Y^*$ or $\phi$ production in $\vec{p}p$ interaction. An outline of the physical motivations and a brief description of the experimental apparatus is given as well as some preliminary results from the first production running.

1 Introduction

The study of strangeness production in $\vec{p}p$ reactions is the central research project of the DISTO Collaboration [1] at Saturne.

Two major related physical questions: I) the puzzling problem of the hyperon polarization; II) the surprising large violation of the OZI rule in several reactions, constitute the core of the DISTO program.

In this paper, I will briefly describe the present status of this two questions and I will show some very preliminary results from the first production running.

1.1 Hyperon polarization

One of the most puzzling and persistent, since long time, spin effect was observed in inclusive hyperon production in collisions of unpolarized hadron beams. A very significant polarization of the $\Lambda$-hyperon was discovered at Fermilab more than two decades ago [2], in certain kinematical conditions.

The $\Lambda$ weak decay into a proton and $\pi^-$ with a 64.1% branching can be used to extract the normal polarization from the parity-violating asymmetry of the decay proton having the emission angle $\theta^*$ with respect to $\hat{n}_\Lambda$ in the $\Lambda$ rest frame.

$$dN \over d\cos \theta^* = N_0(1 + \alpha P_\Lambda \cdot \cos \theta^*)$$

where $k$ is the momentum of the projectile or the produced $\Lambda$ hyperon.

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$$dN \over d\cos \theta^* = N_0(1 + \alpha P_\Lambda \cdot \cos \theta^*)$$

where $\alpha$ is the measure of mixing of parities in the decay; $\alpha = 0.642 \pm 0.013$.

The behavior of the polarization is usually expressed in terms of three kinematics variables:
total C.M. energy $E^* = \sqrt{s}/2$, Feynman’s variable $x_F = \rho^* / \rho_{\text{max}}^*$, and transverse momentum $p_T = p \sin \phi$.

Based primarily on the huge $\Lambda$ polarization data presently available, which span the largest kinematic region, the polarization was considered consistent with the kinematic behavior summarized below:

- it is roughly independent of C.M. energy between about 10 to 2000 GeV/c;
- it linearly increases with $p_T$ up to about 1 GeV/c. Above 1 GeV/c the polarization is constant;
- it is compatible with 0 when $\bar{\Lambda}$s are produced by a proton beam but is not equal to 0 when they are produced by a $\bar{p}$ beam [3];
- it linearly increases with $x$ up to $p_T = 1$ GeV/c; it is independent of $p_T$ above;
- it is weakly dependent on the target type, and decreases with increasing atomic weight [4];
- it is positive when $\Sigma$ particles are produced but negative for $\Lambda$ particles inclusive production.

A more complete review and the references to the original experiments can be found in Ref. [4].

This behavior was generalized and extended to the polarization of other hyperons and was thought to be a general behavior of polarization phenomenon. However, recent data have cast great doubt on such a hasty conclusion.

The fact that early experiments had shown $\bar{\Lambda}$ to be unpolarized, whereas, in the same kinematical region the $\Lambda$ was polarized, lent credence to the idea that polarization is a leading particle effect. This was supported by measurements [5] showing the $\Omega^-$ to be unpolarized in this kinematical region. Two out of three quarks of the $\Lambda$ are the valence quarks of the incident proton and the quark $s$ is picked-up from the sea. The $\Omega^-$ is composed of three strange valence quarks, it contains none of the valence quarks of the incident proton.

But the recent measurements of the $\Xi^-$ polarization by the E576 experiment at Fermilab [6] which showed that $\Xi^-$ hyperons are produced in high energy collisions with a polarization of the same sign, though roughly half the magnitude of that of $\Sigma^+$. Moreover, for the first time, the $\Sigma^+$ polarization was observed to increase with $p_T$, achieve a maximum near $p_T = 1$ GeV/c and then decrease.

This would indicate that the polarization of anti-hyperons is a common phenomenon, and we should now turn our attention to why the $\bar{\Lambda}$ and the $\Omega^-$ are not produced polarized.

It must be mentioned that the $\Lambda$ polarization data quoted until now have been obtained in inclusive measurements, i.e. in reactions where only one of the reaction products is measured.

The directly produced $\Lambda$’s cannot be distinguished from those coming from the decay of other hyperons like $\Sigma^0$ ($\Sigma^0 \rightarrow \Lambda \gamma$) or $S = -1$ resonances ($Y^*$) or nucleonic resonances ($N^*$) which decayed strongly to the measured final $\Lambda$ particle.

The important role played by the hyperon resonance $\Sigma^*(1385)$ and the mesonic resonance $K^*(892)$ in the $\Lambda$ polarization was pointed out by recent results [7]. They reveal how the new measurements, which are able to disentangle the contribution to the polarization coming from all the possibles sources, are required to clarify the present complexity and richness of the experimental scenario.

To explain these puzzling data, several theoretical attempts have been made during the last decades [11–21].

The proposed models span from the “QCD inspired models” to the “boson-exchange models” with a wide range of different flavors. However, they have had little real exhaustive predictive power and none of them deal, for instance, with the polarization of antihyperons (with the exception of the hydro-dynamical model [17]).

Two new “dynamical QCD models” [20, 21] seem to be more promising when used to predict other polarization observables (see below).

A more exhaustive review can be found in the Kroll [22] or Soffer [3] articles. Although rather old (they do not account for the most recent models) and written before the polarization of the $\Xi^+$ and $\Xi^-$ was discovered, they are, in my knowledge, the best theoretical compilations yet.
1.2 Spin observables in hyperon production

The availability of polarized proton beams allows the study of a new set of spin observables other than polarization $P$, viz., analyzing power $A_N$ and depolarization $D_{NN}$.

\[
A_N = \frac{\sigma(\uparrow) - \sigma(\downarrow)}{\sigma(\uparrow) + \sigma(\downarrow)} \\
D_{NN} = \frac{\sigma(\uparrow\uparrow) + \sigma(\downarrow\downarrow) - \sigma(\uparrow\downarrow) - \sigma(\downarrow\uparrow)}{\sigma(\uparrow\uparrow) + \sigma(\downarrow\downarrow) + \sigma(\uparrow\downarrow) + \sigma(\downarrow\uparrow)}
\]

where $\sigma$ is the pure spin cross section, the first arrow refers to the beam polarization direction and the second one refers to the measured hyperon polarization \[23\].

They are a generalization of the Wolfenstein spin-rotation parameters for proton-proton elastic scattering \[24\] and are theoretically defined as a ratio of cross sections. So all of the normalizations used to calculate cross sections cancel, leaving only the key parameter of the interaction.

Measurements of these parameters, particularly $D_{NN}$ for which the prediction is parameter-free in some models, provide crucial tests of the models and its assumptions that the process can be treated at the quark level.

Due to the lack of good quality polarized beams, the experimental scenario is rather poor compared to the inclusive hyperon polarization data. Only three measurements are available up to now: at 6 GeV/c \[25\], at 13.3 and 18.5 GeV/c \[26\] and 200 GeV/c \[27\].

The common feature of these inclusive experimental data, when compared in the same kinematical range, is a relevant asymmetry and a substantial spin transfer as large as 30% in the beam fragmentation region. No data are available in the target fragmentation region due to the limited acceptance of these experiments.

A recently proposed model \[28\], based on the idea of rotating constituents in polarized proton, in the direction suggested by the results of deep inelastic experiments \[32\], is fairly successful in accounting the observed $A_N$ behavior. The $D_{NN}$ trend is also qualitatively reproduced by this model.

1.3 Intrinsic strangeness content of the nucleon

The idea that strange quarks may reside in the nucleon was pointed out by J. Ellis, E. Gabathuler and M. Karliner \[23\] to provide an explanation for several experimental puzzles.

The first one was the controversial problem of the SU(3) chiral symmetry breaking operator measured through the $\pi-N$ $\sigma$-term \[30\]. This term is a factor 2 higher than the one expected from the Gell-Mann-Okubo mass formula and the assumption $< p|s\bar{s}|p > = 0$. This discrepancy is explained in recent lattice QCD calculations \[31\] assuming a sizeable contents of sea $\bar{s}s$ pairs inside the nucleon.

The second point is the famous result of deep inelastic scattering measurements \[32\], which indicate that $\Delta s = -0.10 \pm 0.03$, where $\Delta s$ is the fraction of spin carried by strange quarks and antiquarks. The minus sign means that the strange $q$ and $\bar{q}$ have a net polarization opposite to the direction of the nucleon spin.

Moreover, the high $KK$ yield in $\bar{p}p$ annihilation at rest, the backward peak in $\bar{p}p \rightarrow K^-K^+$ reaction at $p = 0.5GeV/c$, and the anomalous high cross section $\sigma(\bar{p}p \rightarrow \phi\phi)$ can be easily accommodated in the intrinsic strangeness model of the nucleon \[34\].

The last puzzle is the violation of the Okubo-Zweig-Iizuka (O.Z.I.) rule \[34\] experimentally observed in several reactions.

In the naive quark model, the O.Z.I. rule put limits on the possible schemes of quark rearrangement processes that lead to meson production.

According to this rule, it was predicted \[33\] that the possible values of

\[
R = \frac{\sigma(A + B \rightarrow \phi X)}{\sigma(A + B \rightarrow \omega X)} \quad (2)
\]

are $R = 4.2 \times 10^{-3}$ using the quadratic Gell-Mann-Okubo mass formula or $R = 0.15 \times 10^{-3}$ using the linear mass formula.

The experimental values of $R$, however, stay typically in the range $(10 \div 20) \times 10^{-3}$. From this disagreement between experiment and theory a semi-empirical rule was given that implies \[33\] that the O.Z.I. rule is generally violated at least at the level of 10%. As shown in Fig. 4 a much larger apparent violation was found in $\bar{p}p$ annihilation at rest \[34\].

It was suggested \[21\] \[37\] that this strong violation of the O.Z.I. rule could be explained with the existence of an admixture of a $\bar{s}s$ quark pair in the nucleon even at large distances. In Ref. \[33\] it is shown that the amount of the admixture needed
Figure 1: Ratios $R = \frac{\phi X}{\omega X}$ in different reactions at increasing momenta $p$. The horizontal line is the theoretical prediction from quadratic Gell-Mann-Okubo mass formula $R = 4.2 \cdot 10^{-3}$. See Ref. [33] for data and extensive figure caption.

To accommodate the data is quite small. Moreover, it was shown [38], that the strange quark pairs are polarized in the opposite direction to the nucleon spin.

The study of the $\phi$-meson production is a particularly sensitive test of the validity of the O.Z.I. rule because the $\phi$ is almost a pure $\bar{s}s$ state, containing just a small admixture of $\bar{u}u + \bar{d}d$.

An interesting consequence of this is the possible link between the polarization of the nucleon strange sea and the different yields of the $\phi$-meson production from different spin states of the $NN$ system and from different annihilation channels. Remembering that the intrinsic spin of the $\phi$ meson is $J = 1$, one can expect a maximum enhancement of $\phi$ production in the $^3S_1$ channel where the spins of strange quarks and anti-strange quarks are parallel.

Among the possible checks [33] of this model, the most straightforward one would be to measure the $\phi$ production rate in the reaction $\vec{p}\vec{p} \rightarrow pp\phi$. If the aforesaid assumptions are correct [33], the $\phi$ rate should be maximal when the spin of the beam and the spin of the target are oriented parallel.

Using the polarized beam of Saturne, DISTO could make a first step in that direction, as we will allow to absolute $\phi$ production rate and its dependence on the beam polarization. A comparison with the $\omega$ production rates in the same kinematical range, measured in the same experimental apparatus, can also be made. This will be the first attempt to measure the $\phi$ production at threshold because there are only two measurements at 10 and 24 GeV/$c$ (see Fig. 1) far from the threshold.

2 The DISTO program

The DISTO experiment [1] was specifically designed to study the associated $\Lambda$ and $\Sigma^0$ production

$$\vec{p}\vec{p} \rightarrow pK^+Y \quad (Y = \Lambda, \Sigma^0, Y^*)$$

and the vector meson production

$$\vec{p}\vec{p} \rightarrow ppV_m \quad (V_m = \phi, \omega)$$

at 2.85 GeV, the maximum usable energy of Saturne, and 2.5 GeV for hyperon production.

The experimental set-up (see Fig. 2) is designed to track the four charged products signaling hyperon or vector meson production through a strong magnetic field. The measurements of the angles and momenta of the $\Lambda$ (or $\phi$) decay products, of the primary proton and of the associated kaon (or proton) will allow a complete kinematical reconstruction of the missing mass of the reaction products. Only in this way the contributions to the $\Lambda$ polarization coming from different sources can be disentangled. For the $\Sigma^0$ production, only the photon from the ($100\%$ branch) $\Sigma^0 \rightarrow \Lambda\gamma$ decay is missing. For the $\omega$ production, only the $\pi^0$ from the ($88.8\%$ branch) $\pi^0 \rightarrow \pi^+\pi^-\pi^0$ decay is missing.

Taking advantage of the high quality of the polarized beam produced by Saturne, the DISTO collaboration plans to:

- measure the differential cross-sections $d\sigma/d\Omega$ for $\Lambda, \Sigma^0$, and $Y^*$ productions;
- measure the polarization $P$ of the hyperons produced;
- study the dependence on the beam polarization of these observables getting the analyzing power $A_N$, and the depolarization parameter $D_{NN}$;
- study the relationship between these observables and the $N^*$ and $Y^*$ ($S = -1$) resonances;
• measure the differential cross-section and
  the analyzing power $A_N$ of the reaction $pp \rightarrow pp\phi$ near the production threshold and the
  $\phi/\omega$ ratio (eq. 2).

This experiment is the first attempt to carry out a complete study (including the spin) of the re-
action mechanisms through an exclusive measure-
ment. The measurement of $D_{NN}$, simultaneously
for $\Lambda$ and $\Sigma^0$ production, is expected to provide an
especially strong constraint on various theoretical
models.

3 The DISTO set-up

The experimental setup, shown in Fig. 2, includes
the magnet S170 from CERN which provides a
maximal magnetic field of 14.7 kGauss, an angular
acceptance $\Delta \theta = \pm 120^\circ$ in the horizontal plane
and $\Delta \phi = \pm 20^\circ$ in the vertical plane.

The detector array is designed to cover a dip
angle of $\pm 15.5^\circ$ and a scattering angle of 45° on
both sides of the curved beam trajectory.

The tracking detectors comprise two left-right
pairs of semi-cylindrical scintillating fiber cham-
bers (two stereo layers, $u$-$v$ planes, and one hori-
zontal $y$ plane, of 1 mm square fibers); similarly
two pairs of $x$-$u$-$v$ planar multi-wire proportional
chambers will be mounted at the edge of the mag-
net poles.

Located radially at about 140 cm from the
unpolarized 2-cm thick liquid hydrogen target, a
scintillator hodoscope records particle multipliciti-
ties, allows $p$ vs $K^+$ time-of-flight particle identifi-
cation, and provides a sample of $\vec{p}p$ elastic scatter-
ing events to monitor the beam polarization and
intensity.

Finally, behind the hodoscope, a vertically
segmented Cerenkov counter gives information on
the velocity of crossing particles making easier the
separation between pions, kaons and protons on
the whole spectrum of particles produced.

The trigger selects events with at least four
charged prongs within the detector acceptance, us-
ing the hit multiplicity information given by the
scintillation fiber detectors and by the hodoscope.

Although the trigger rate sustained by data
acquisition system is $\geq 10$ KHz per spill (0.5 s),
it is kept around 3 KHz events per spill by beam
intensity and trigger logic, in order to have a dead-
time of roughly 10%.

4 Preliminary results

The DISTO detector assembly has been completed
during July 1996. The first production running
with a fully operational detectors system, level 1
trigger and data acquisition was done during past
November 1996. During 10 days of beam around
500 · $10^6$ triggers have been recorded.

Some preliminary results of the November ’96
and May ’97 production runs (around 600 runs)
are shown in Fig. 3-10.

Fig. 3 show the $p\pi^-$ invariant mass spectra
left by the standard cuts. Each of the cuts has
been made sufficiently conservative to remove es-
tially no events in the $\Lambda$ peak.

This conservative approach leaves significant
background in these spectra. In what follows, we
often subtract background from subsequent spec-
tra by means of a cut on invariant mass outside
the peak. This background is basically flat and
not resonant (see Fig. 4) so this technique is es-
tially bias free.

Making cuts a bit tighter or adding additional
cuts (Fig. 3 right) would reduce the background
by a large factor, at the expense of 10-20% of the
pKY events.
Figure 3: $p\pi^-$ invariant mass spectra after the standard software cuts. The present conservative approach leaves significant background in these spectra. Left: no cuts on 4-track Missing Mass. The $\Lambda$ and background cuts used in the subsequent analysis are also shown. Right: Improved signal / background ratio with the additional cut: $-0.10 \geq MM(4\text{-track}) \geq 0.08\text{GeV}^2$.

Figure 4: $pK^+$ missing mass spectra for $\Lambda$ (solid line) and background events (dashed line) (see Fig. 3). The background is clearly not resonant.

Figure 5: Background subtracted $pK^+$ missing mass spectra. The prominent peaks are $\Lambda(1115)$, $\Sigma^0(1192)$, and $\Sigma(1385)$. Dashed line: missing $MM(4\text{-track}) \geq \pi^0$ cut; the cut eliminates the $\Lambda$ and $\Sigma(1192)$ peaks.

Figure 6: Background subtracted decay distribution for $\Lambda(1115)$. L and R refer to $\Lambda$ produced to the beam left or right; the arrows refer to the beam polarization direction. A) $P_\Lambda$: integrated ($\hat{k}_{p\Lambda} \cdot \hat{n}$) distribution in the $\Lambda$ rest frame. B) $D_{NN}$: integrated spin difference distribution. C), D), E): polarization, analyzing power and depolarization parameter vs. $X_F$. 

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Fig. 4 shows the missing mass spectra reconstructed from the reaction products identified as the primary proton and kaon, for events within the \( \Lambda \) invariant mass peak and within the background gate.

In the background subtracted spectrum shown in Fig. 5, we see clear peaks for the \( \Lambda(1115) \), the \( \Sigma(1192) \), and the \( \Sigma(1385) \). Also shown is the background subtracted spectrum gated by a cut requiring the overall missing mass to exceed 0.01 GeV, in order to select only events missing a pion, a pion and gamma, two pions etc. This cut essentially eliminates the \( \Lambda \) and \( \Sigma(1192) \) peaks, but leaves \( \Sigma(1385) \), which decays to \( \Lambda \pi \) or \( \Sigma \pi \).

For the analysis of polarization results, we separate \( \Lambda \), \( \Sigma(1192) \) and \( \Sigma(1385) \) events by the purposely narrow cuts shown in Fig. 5.

Some preliminary polarization results are shown in Fig. 6. The histogram (A) shows the decay angle distribution summed for \( \Lambda \)’s left and right and for spin up and down, and summed over \( P_T \) and \( X_F \). The hyperon polarization, given by eq. 1, would show up via a systematic fore-aft asymmetry in this spectrum, which is not seen in this distribution not corrected for geometrical acceptance.

In contrast histogram (B) shows the spin-difference spectrum relevant to the polarization transfer in \( \bar{p}p \to pK^+\bar{\Lambda} \). Here a sizeable fore-aft asymmetry is seen indicating a large value of \( D_{NN} \), even when the yields are summed over the full acceptance, \( P_T \), and \( X_F \). \( D_{NN} \) being a ratio of cross-sections, the geometrical acceptance corrections are not relevant, at least in the first order.

Histograms (C), (D), and (E) show the \( \Lambda \) polarization (P), analyzing power (\( A_N \)) and depolarization parameter (\( D_{NN} \)) as a function of the Feynman scaling variable \( X_F \), summed over \( P_T \).

These preliminary results indicate a substantial polarization, analyzing power and depolarization parameter, as large as 40%, in the beam fragmentation region, i.e for \( X_F \) large and positive.

For the first time it is also possible to study the polarization observables approaching the target fragmentation region. Although the error bars are relevant with the present statistics, clear indication of polarization and analyzing power behavior similar to that observed in the beam fragmentation region can be shown. Viceversa \( D_{NN} \) is compatible with 0 in this region.

Fig. 7-10 show the first preliminary results on

**Figure 7**: pp missing mass spectra. Left: conservative cut; Right: missed \( \pi^0 \) cut

**Figure 8**: KK missing mass spectra. Left: The \( \phi \) peak is clearly shown. cut: 4-track invariant mass = 0 Right: phase-space simulation with the same cuts.

**Figure 9**: kinematical correlation of events in the \( \omega \) missing-mass region. solid line bands: expected distribution from a phase-space Monte Carlo simulations

**Figure 10**: Kinematical distribution of \( K^+K^- \) pair in the mass region \( m_0 \pm 15 \text{ MeV} \). solid line bands: expected distribution from a phase-space Monte Carlo simulations
vector meson production.

Fig. 7 shows the \( pp \) missing mass with two different cuts. Left: \( m_{\pi\pi}^2 \leq 0.41 \text{ GeV}^2 \); right: \( m_{\text{cm}-pp}^2 - m_{\pi\pi}^2 \leq 0.15 \text{ GeV}^2 \).

By fitting a Gaussian function to the signal, the number of events of the type \( pp\omega \) can be estimated. The background is fitted with a third order polynomial function. The signal from \( pp\eta \) is also taken into account by adding an additional Gaussian function in the fit.

Fig. 8 shows the \( K^+K^- \) pair invariant mass, compared to a Monte Carlo simulation with uniform \( m_{KK} \) distribution and a phase space distribution for the system \( p,p,K,K \).

The two kaons are identified using the water Cerenkov pulse height and several geometrical and kinematical boundary conditions, mainly \( m_{\text{cm}-pp}^2 - m_{KK}^2 \approx 0 \).

Fig. 9 and 10 show the kinematical distribution of the \( \omega \) and \( \phi \) mesons as a function of \( P_T \) and rapidity \( Y \).

For comparison the solid line bands show the distribution from a Monte Carlo simulation using 3-body phase space.

Although there is no significant deviation from phase space in \( \phi \) production, the \( \omega \) shows a relevant difference. This means a careful simulation is required for doing accurate acceptance corrections.

5 Conclusions

The good preliminary results shown in the previous section, obtained with only 1/5 of the final statistics foreseen at 2.85 GeV, allow us to say that DISTO experiment could make an essential contribution to clarifying the present puzzle of polarization phenomena and OZI rule and, in turn, the role of the strangeness in the nucleon.

However some “caveat” have to be expressed for a correct interpretation of the results presented: I) the beam polarization was determined on-line by our polarimeter. A more precise determination of the beam polarization is in progress by off-line analysis. II) no acceptance corrections are included as well as no dead-time corrections.

In spite of these reserves very important results are already shown by our data:

1. \( \phi \) and \( \omega \) production is clearly shown in our data. Once more statistics will be available and the acceptance corrections under control, the determination of the relative production rates will be possible and an important contribution to the OZI rule puzzle will be given. The determination of the analyzing power for two vector mesons will also be possible.

2. an important result, still observable even if integrated on the whole acceptance of DISTO set-up, is the large value of the depolarization parameter \( D_{NN} \) for direct \( \Lambda \) production. This indicates a transfer of polarization, during the transition, from the beam to the \( \Lambda \). At the same time \( P \) is small when summed over \( P_T \) and \( X_F \) but increases with \( X_F \) in the beam fragmentation region. This result is in agreement with those obtained in inclusive production at 6 GeV/c [25] and 200 GeV/c [27].

Once the full statistic will be available we can study the dependence of the spin observables on the different kinematical parameters for the \( \Lambda, \Sigma (1192) \), and \( \Sigma (1385) \).

3. the measurement at 2.5 GeV, planned during this year, will allow to understand the reaction mechanism, by comparing the polarization observables in an energy regime where the pion exchange is more favorite than the kaon exchange.

At the end of this year the Satune accelerator will be definitively closed, depriving the physicist community of a high quality and unique tool to study the fundamental interactions.

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