Measuring magnetic moments with bended crystal

Achille Stocchi (LAL Orsay – Paris Sud/IN2P3)

Many people contribute to this presentation (discussions/ideas/work)

The magnetic moment of the long living baryons has been measured by looking at the precessing of the spin along a intense magnetic field (change in the polarisation). It was done for long living particle such as the strange baryons (example: \( c\tau(\Sigma^+)=2.4\text{cm} \))

No measurement of magnetic moments of charm or beauty baryons has been performed so far. A reason of the non-availability of experimental information is because the lifetimes of charm/beauty baryons are too short to measure the magnetic moment by standard techniques.\*\*\* \( \)Short living particles i.e. \( c\tau \approx 100\text{microns} \rightarrow \text{with boost} \approx 100-200 \rightarrow L=2-3\text{cm} \)

Crystals \( \equiv \) Thousands Tesla over cm length

The proposal is to use the bended crystals for measuring the magnetic moment of the charmed charged hadrons starting from \( \Lambda c^+ \) ( \( c\tau(\Lambda c^+) \approx 60\mu\text{m} \) )

Eventually the technique could be also used to measure the lepton \( \tau \) magnetic moment

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Introduction

The magnetic moment of the long living baryons has been measured by looking at the precessing of the spin along a intense magnetic field (change in the polarisation). It was done for long living particle such as the strange baryons (example: \( c\tau(\Sigma^+)=2.4\text{cm} \))

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**References:**

- D. Chen et al. (E761 Coll.) PRL Vol. 69, NUMBER 23 7 December 1992.
- S. Paul “Measurement of Magnetic Moments of Charmed Baryons” presented at “CERN workshop New Opportunities 2008”. 

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The reason of measuring magnetic moments?

Historically, the prediction of baryon magnetic moments was one of the striking successes of the quark model. The importance of the measurement of heavy quark magnetic moment is to test the possibility that the charmed and/or beauty quarks has an anomalous magnetic moment, arising if those quarks are composite object. Obviously measurements on magnetic moments of heavy quarks introduce new dimensions and should be accounted for by any comprehensive hadronic theory.

\[ \mu = \frac{1}{2} g \frac{q \hbar}{2mc} \]

\[ \mu_N = \frac{e \hbar}{2m_p c} \]

<table>
<thead>
<tr>
<th>Particle</th>
<th>Predicted ( \mu )</th>
<th>Predicted in ( \mu_N )</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p )</td>
<td>( \frac{4}{3} \mu_u - \frac{1}{3} \mu_d )</td>
<td>+2.79</td>
<td>+2.793</td>
</tr>
<tr>
<td>( n )</td>
<td>( \frac{4}{3} \mu_d - \frac{1}{3} \mu_u )</td>
<td>-1.86</td>
<td>-1.913</td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>( \mu_s )</td>
<td>-0.61</td>
<td>-0.613 ± 0.004</td>
</tr>
<tr>
<td>( \Sigma^- )</td>
<td>( \frac{4}{3} \mu_d - \frac{1}{3} \mu_s )</td>
<td>-1.04</td>
<td>-1.160 ± 0.025</td>
</tr>
<tr>
<td>( \Sigma^0 )</td>
<td>( \frac{2}{3} (\mu_d + \mu_u) - \frac{1}{3} \mu_s )</td>
<td>+0.82</td>
<td>Lifetime too short</td>
</tr>
<tr>
<td>( \Sigma^+ )</td>
<td>( \frac{4}{3} \mu_u - \frac{1}{3} \mu_s )</td>
<td>+2.69</td>
<td>+2.458 ± 0.010</td>
</tr>
<tr>
<td>( \Xi^- )</td>
<td>( \frac{4}{3} \mu_s - \frac{1}{3} \mu_d )</td>
<td>-0.51</td>
<td>-0.651 ± 0.003</td>
</tr>
<tr>
<td>( \Xi^0 )</td>
<td>( \frac{4}{3} \mu_s - \frac{1}{3} \mu_u )</td>
<td>-1.44</td>
<td>-1.250 ± 0.014</td>
</tr>
<tr>
<td>( \Omega^- )</td>
<td>3( \mu_s )</td>
<td>-1.83</td>
<td>-2.20 ± 0.05</td>
</tr>
</tbody>
</table>

\[ R^D_{\gamma} = \frac{\Gamma_\gamma^0}{\Gamma_\gamma^+} = \frac{\Gamma(D^{0} \rightarrow D^0 \gamma)}{\Gamma(D^{+} \rightarrow D^+ \gamma)} = \left( \frac{E_\gamma^0}{E_\gamma^+} \right)^3 \left( \frac{\mu_u + \mu_c}{\mu_d + \mu_c} \right)^2 \]

\( \mu_c \) enter in other determinations, like in radiative D decays

Some tension in the past. Now seems to be ok.
The case of heavy charged charm baryons: \( \bar{\mu}_Q = \frac{\vec{S} \cdot \vec{q} \cdot e}{2m_Q} \)

\[ \mu_X = \frac{1}{2} g \mu_N \left( \frac{m_p}{m_X} \right) \]

Predictions: \( \mu_{\Lambda_c} = 0.3 - 0.4 \mu_N \)

Predictions also for \( \Xi_c \)

If \( g = 2 \rightarrow \mu_{\Lambda_c} = \frac{1}{2} g \mu_N \left( \frac{m_p}{m_{\Lambda_c}} \right) \sim 0.4 \mu_N \)

\( \Lambda_c \) is behaving like a elementary particle (c quark dominating)

General comment: very little theoretical activity on this subject.
The basic principle and formula of the measurement - 1

The precession angle is proportional to the bending angle through the boost and the magnetic moment \((g-2)\)

For large \(\gamma\)

\[
\Delta\phi \approx \frac{(g-2)}{2} \gamma \Delta\theta
\]

The interest is

- As **large** as possible **boost** \(\gamma\) clear advance to be at LHC vs SPS
- As **large** as possible **bending angle** \(\Delta\theta\) crystal developments in the last years (UA9)

For « experts » in crystals when energy of particle increases to avoid dechanneling you need **longer crystal**.

1 message: to be at **LHC** and use **long bended crystals**
The basic principle and formula of the measurement - 2

$\Lambda_c$ have to be polarised.

Polarization of baryon $\Lambda_c$ is a consequence of the parity conservation in strong interactions and would arise due to spin-orbital interaction.

*Simple example* $p + N \rightarrow \Lambda_c + N'$, the polarization vector $P_{\text{in}}$ is perpendicular to the plane spanned by momenta of the proton and baryon $\Lambda_c$, i.e. it $P_{\text{in}} \sim P(\Lambda_c) \times P(\text{beam})$.

For getting $g$ from

$$\Delta \phi \approx \left( \frac{g - 2}{2} \right) \gamma \Delta \theta$$

1. **Measurement of the $P_{\text{in}}, P_{\text{out}}$ to get $\Delta \phi$**
   with the angular distribution of the decay product

   *Because the baryon decay violates parity, the polarization (helicity) can be measured by its decay angular distribution. There is an extra parameter called weak asymmetry parameter (often noted $\alpha$) which is decay dependent.*

2. **Measurement of the angle $\Delta \theta$ and of the energy of the $\Lambda_c$ for getting the boost**
   i. Using the decay products

2 message: fixed target experiment and angular analysis of heavy baryon decays (need « good » detector)
First Observation of Magnetic Moment Precession of Channeled Particles in Bent Crystals

Proton (800 GeV/c) + Cu \rightarrow \Sigma^+ n \text{ particles}

\[ \Sigma^+ \rightarrow p \pi^0 \]

As illustrated in Fig. 1, a vertically polarized $\Sigma^+$ beam [14] was produced by directing the Fermilab Proton Center extracted 800-GeV/c proton beam onto a Cu target (T). The resulting $\Sigma^+$ were produced alternately at a $+3.7$- or $-3.7$-mrad horizontal targeting angle relative to the incident proton beam direction. This allowed the polarization direction to be periodically reversed. The mean

The two bending crystals. Each crystal precess the channelled particle’s spin in opposite direction

The deflection of the channeled particles was measured to be $\omega = 1.649 \pm 0.043$ and $-1.649 \pm 0.030$ mrad for the up- and down-bending crystals, respectively. For 375-GeV/c $\Sigma^+$ this corresponds to an effective magnetic field of $B_x \approx 45$ T in the crystals. The magnetic moment [6] of the $\Sigma^+$ should precess by $\varphi \approx 1$ rad in such a field.
\[
\frac{dN_i}{N_0 \, d\cos \theta_i} = \frac{1}{2} \left(1 + \alpha P_i \cos \theta_i \right)
\]

\[
\frac{N^+ - N^-}{N^+ + N^-} = \alpha P_i \cos \theta_i
\]

Using non-channeled \( S \) +

Using channeled \( S \) +

\( \mu = (2.40 \pm 0.46) \mu_N \)
The polarisation $P$ of $\Lambda_c$ has not been yet measured precisely. There are some old experiments and the indicative values are $P(\Lambda_c) \sim [0.4 \text{-} 0.6]$ ($P(\Lambda_c) = 0.6$ (e.g. Bis-2))

The parameter $\alpha$ is decay dependent

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\text{Br}$</th>
<th>$\alpha$</th>
<th>$\alpha$ input parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(\Lambda_c \rightarrow \Lambda \pi)$ $\times$ Br($\Lambda \rightarrow p \pi$)</td>
<td>1.07% x 64% $\sim$ 0.007</td>
<td>$\sim 1$</td>
<td>0.59</td>
</tr>
<tr>
<td>$(\Lambda_c \rightarrow \Lambda \pi)$ $\times$ Br($\Lambda \rightarrow n \pi^0$)</td>
<td>1.07% x 35.8% $\sim$ 0.004</td>
<td>$\sim 0.6$</td>
<td>0.59</td>
</tr>
<tr>
<td>$(\Lambda_c \rightarrow \Sigma^+ \pi^0)$ $\times$ Br($\Sigma^+ \rightarrow p \pi^0$)</td>
<td>1.00% x 51.5% $\sim$ 0.005</td>
<td>$\sim 0.7$</td>
<td>0.44</td>
</tr>
<tr>
<td>$(\Lambda_c \rightarrow \Sigma^+ \pi^0)$ $\times$ Br($\Sigma^+ \rightarrow n \pi^+$)</td>
<td>1.00% x 48.3% $\sim$ 0.005</td>
<td>$\sim 0.6$</td>
<td>$\sim 0$ For the numerical study we use $P(\Lambda_c) \times \alpha \sim 0.6 \times 0.59 \sim 0.35$</td>
</tr>
<tr>
<td>$(\Lambda_c \rightarrow \Lambda \text{ev})$ $\times$ Br($\Lambda \rightarrow p \pi$)</td>
<td>2.00% x 64% $\sim$ 0.0128</td>
<td>$\sim 1.8$</td>
<td>0.60</td>
</tr>
<tr>
<td>$(\Lambda_c \rightarrow \Lambda \mu \nu)$ $\times$ Br($\Lambda \rightarrow p \pi$)</td>
<td>2.00% x 64% $\sim$ 0.0128</td>
<td>$\sim 1.8$</td>
<td>0.60</td>
</tr>
<tr>
<td>$(\Lambda_c \rightarrow p K^- \pi^+)$</td>
<td>5.00% $\sim$ 0.05</td>
<td>$\sim 12.5$ not known</td>
<td></td>
</tr>
</tbody>
</table>

Two observations:
1) Consider that the sensitivity of the analysis goes as $(P \times \alpha)^2$
2) More decay channels can be used. In particular if the $\alpha$ parameter of $\Lambda_c \rightarrow p K^- \pi^+$ decay mode is measured and happened to be large, it would allow to give access to much larger statistics. Possible at LHCb!
We had a preliminary look at the feasibility at LHC.

Important to have an extraction scheme with high flux and with the possibility of entering in the acceptance of a detector.

→ Example at LHC scheme with LHCb zone/detector:
   see talks of yesterday from W. Scandale and S. Redaelli

All devices placed in available slots in IR8

Crystal 1  Target & Crystal 2  1m CFC absorber

Work by D. Mirarchi
- Full **LHCb** detector simulation
- Generate 15000 $\Lambda_c \to p K \pi$ at the crystal position
  
  \[(x=0.945\text{mm}, y=4\text{mm}, z=-2379\text{mm})\]
- $p(\Lambda_c) = 100$ GeV

![Graphs](Image)

- Mass resolution: 14 MeV
- $z$ decay position resolution: 18mm
- Efficiency: 1.5%!

The particles selected after the crystal are
- -2.5m from the interaction point in $z$
- at extremely large momentum

**Not ideal for resolution and efficiency!**
Very preliminary simulations

\[ N(\Lambda_c) = F \times \frac{N_A \rho T \sigma(\Lambda_c)}{A_t} \times \text{Br}(\Lambda_c \rightarrow \Lambda \pi) \times \text{Br}(\Lambda \rightarrow p \pi) \times \varepsilon_{\text{TOT}} \]

\begin{align*}
F &= \text{Flux} \quad [\text{Number of proton/sec}] \\
N_A &= \text{Avogadro number} \quad [\text{mol}^{-1}] \\
\rho &= \text{Target density} \quad [\text{gr/cm}^3] \\
T &= \text{Target thickness} \quad [\text{cm}] \\
A_t &= \text{atomic mass} \quad [\text{gr/mol}] \\
\sigma(\Lambda_c) &= \text{cross section} \quad [\text{cm}^2]
\end{align*}

First simulations done using Tungsten (\(\rho = 19.25 \text{ gr/cm}^3\)) target of T = 0.5 cm

\begin{align*}
\text{Br}(\Lambda_c \rightarrow \Lambda \pi) &= \text{Branching fraction} \\
\text{Br}(\Lambda \rightarrow p \pi) &= \text{Branching fraction} \quad 1.07\% \times 64\% \sim 0.007 \\
\mathcal{P} &= \text{Polarization} \\
\alpha &= \text{Asymmetry Weak parameter} \quad 0.59 \\
\varepsilon &= \text{efficiency}
\end{align*}

\begin{itemize}
  \item Crystal channeling acceptance \(\varepsilon_{\text{channeled}}\)
  \item Decay flight \(\varepsilon_{\text{Decay flight}}\)
  \item Efficiency of reconstruction \(\varepsilon_{\text{Reconstruction}}\)
\end{itemize}

The number of the effective number of \(N_{\text{eff}}(\Lambda_c)\) useful for the angular analysis is

\[ N_{\text{eff}}(\Lambda_c) = N(\Lambda_c) \times \mathcal{P}^2 \times \alpha^2 \]
Example. To have a precision on $g \pm 0.1$

With a single channel ($\Lambda_c \rightarrow \Lambda \pi$) $\times \text{Br}(\Lambda \rightarrow p \pi)$

Example
with quite high flux of $5 \times 10^8$ protons/sec
With $\varepsilon(\text{det}) = 2\%$

STONG DEPENDENCE
upon choices of crystal characteristics
 crystal length (~cm); radius; bending (~mrad); type

From Leonid Burmistrov
Conclusions

The measurement of magnetic moment of charmed barions (in particular $\Lambda_c$) seems to be possible now using bending crystal techniques

1. At the LHC energies
2. With a vigorous program on crystals (long and with large bending angles)
3. Having a performant detector

→ To implement beam splitting scenario with two crystals in LHC
→ It would imply to perform « fixed target » experiment in LHC, in front of an existing detector and/or equipping a dumping zone (run in parasitic mode)

+ Polarization measurements as a by product.

+ Possibility of using more $\Lambda_c^+$ decay modes. An experimental effort for that is needed

+ Possibility to extent from $\Lambda_c^+$ to $\Xi_c^+$ and $\Xi_{cb}^+$

+ Could open a way to go for $\tau$ magnetic moment with the same techniques...? (Some faisability study on going, probably need more complex detector setup)
BACKUP
Polarization of the baryons is baryon dependent and could depend on some kinematical variable.

Example $\mathcal{P}(\Sigma^+) \sim 0.1$

The polarisation of $\Lambda_c$ has not been yet measured precisely. There are some old experiment and the indicative values are $\mathcal{P}(\Lambda_c) \sim [0.4-0.6]$ ($\mathcal{P}(\Lambda_c) = 0.6$ (e.g. Bis-2)

The value of the $\mathcal{P}(\Lambda_c)$ is a crucial parameter for the determination of its magnetic moment. If it is too small, a huge statistics would be needed. On the other hands the $\mathcal{P}(\Lambda_c)$ could be measured by the proposed experiment.
It is very Important to distinguish between channeled and non channeled baryons.

1) It is possible by using an instrumented crystal as in the E791 Fermilab experiment?

If you can measure the energy loss of the particles traversing the crystal it helps in distinguishing channelled particle, which have less energy loss wrt non-channeled ones.

2) kinematical cuts?

Other possibility: non-channelled events = events without crystal.

(a) Energy loss distribution for triggered events in the down-bending crystal. The peak at lower energy loss values is due to channeled particles. The solid line through the nonchanneled portion is a theoretical Landau distribution.
**Results on cross section of charmed hadrons at energy up to HERA-B**

| Table 9. Ratios of cross sections. The first error is statistical and the second systematic. |
|:--:|:--:|:--:|:--:|
| $D^0/D^+$ | 0.41±0.06±0.04 | 0.44±0.11±0.05 |
| $D^0/(D^++D^0)$ | 0.27±0.09±0.05 | 1.07±0.26±0.14 |

**6 Summary**

With the HERA-B detector we have measured the total and single differential cross sections $\sigma$, $d\sigma/dy$, and $d\sigma/dx$, the atomic mass number dependence of the cross sections, and the leading to non-leading particle asymmetries for the production of $D^0$, $D^+$, $D_s^-$ and $D_s^+$ mesons in $pA$ collisions at the proton energy of 920 GeV. Extrapolating to the full phase space, the total cross sections per nucleon (in mb) are: $48.7 \pm 4.7 \pm 6.6$, $20.2 \pm 2.2 \pm 3.0$, $18.5 \pm 6.4 \pm 4.1$ and $21.6 \pm 4.7 \pm 3.6$ for the $D^0$, $D^+$, $D_s^-$ and $D_s^+$, respectively. In the range $-0.15 < x_F < 0.05$ the measured cross sections are: $26.8 \pm 2.6 \pm 2.7$, $11.1 \pm 1.2 \pm 1.3$, $10.2 \pm 3.5 \pm 2.0$ and $11.9 \pm 2.6 \pm 1.7$ for the $D^0$, $D^+$, $D_s^-$ and $D_s^+$, respectively.

The cross section per nucleon for $c\bar{c}$ production is $\sigma(c\bar{c}) = (40.1 \pm 4.6 \pm 7.4) \mu$b.

We have measured the cross section ratios $\sigma(D^+)/\sigma(D^0) = 0.41 \pm 0.07 \pm 0.04$ and $\sigma(D^{**})/\sigma(D^0) = 0.44 \pm 0.11 \pm 0.05$, as well as the vector to scalar meson production ratio, $F_V = 0.61 \pm 0.09 \pm 0.06$. Our result for the ratio $\sigma(D_{s+}^-)/(\sigma(D^{**}) + \sigma(D^+)) = 0.27 \pm 0.09 \pm 0.06$ is the first measurement of this quantity in $pA$ reactions.

From the measured atomic mass number dependence of the production cross section, the parameter $\alpha = 0.98 \pm 0.04 \pm 0.01$ is extracted. This value is in agreement with the assumption of a linear dependence of cross sections, $\alpha=1$. The measured leading to non-leading particle asymmetries in the $x_F$ range $-0.15 < x_F < 0.05$ are consistent with existing measurements for different $x_F$ regions.

The results of our studies are in good agreement with previous measurements of open charm production in $pA$ interactions and provide, in the majority of cases, an improvement in accuracy.
$\Lambda_c$ production in p + Target collision at SPS energy. Cross Section - 2

Results on cross section of charmed hadrons at energy at LHCb

Table 2: Open charm production cross-sections in the kinematic range $0 < p_T < 8 \text{ GeV}/c$ and $2.0 < y < 4.5$. The computation of the extrapolation factors is described in the text. The first uncertainty is statistical, the second is systematic, and the third is the contribution from the extrapolation factor.

<table>
<thead>
<tr>
<th></th>
<th>Extrapolation factor</th>
<th>Cross-section (µb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^+$</td>
<td>1.003 ± 0.001</td>
<td>1661 ± 16 ± 125 ± 2</td>
</tr>
<tr>
<td>$D^+$</td>
<td>1.007 ± 0.013</td>
<td>645 ± 11 ± 72 ± 8</td>
</tr>
<tr>
<td>$D^{**}$</td>
<td>1.340 ± 0.037</td>
<td>677 ± 26 ± 77 ± 19</td>
</tr>
<tr>
<td>$D^+_s$</td>
<td>1.330 ± 0.056</td>
<td>197 ± 14 ± 26 ± 8</td>
</tr>
<tr>
<td>$\Lambda^+_c$</td>
<td>1.311 ± 0.077</td>
<td>233 ± 26 ± 71 ± 14</td>
</tr>
</tbody>
</table>

Table 4: Cross-section ratios for open charm production in the kinematic range $0 < p_T < 8 \text{ GeV}/c$ and $2.0 < y < 4.5$. The numbers in the table are the ratios of the respective row/column.

<table>
<thead>
<tr>
<th></th>
<th>$\sigma(D^+)$</th>
<th>$\sigma(D^0)$</th>
<th>$\sigma(D^{**})$</th>
<th>$\sigma(D_s^+) $</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(D^0)$</td>
<td>0.389 ± 0.029</td>
<td>1.049 ± 0.092</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma(D^{**})$</td>
<td>0.407 ± 0.033</td>
<td>1.049 ± 0.092</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma(D_s^+)$</td>
<td>0.119 ± 0.016</td>
<td>0.305 ± 0.042</td>
<td>0.291 ± 0.041</td>
<td></td>
</tr>
<tr>
<td>$\sigma(D_s^0)$</td>
<td>0.140 ± 0.045</td>
<td>0.361 ± 0.116</td>
<td>0.304 ± 0.111</td>
<td>1.183 ± 0.402</td>
</tr>
</tbody>
</table>

$\sigma(\Lambda_c)/\sigma(D_s) \sim 1.2 \quad \sqrt{s} \sim 14 \text{ TeV}$

$\sigma(D_s) \sim 8 \mu b \ (30\% \ error) \quad \sqrt{s} \sim 28 \text{ GeV} \ [\text{SPS (400 GeV)}]$

$\Rightarrow \sigma(\Lambda_c) \sim 10 \mu b \ (30\% \ error)$

Pythia gives us $\Rightarrow \sigma(\Lambda_c) \sim 2 \mu b$ ??

From the simulation I use 3µb for SPS

12µb for LHC
A word on the background...

At SPS. There 5000 zones which can be filled separated by 5nsec (called bucket). In each bucket there is a bunch (2nsec)
A particle makes 44000 tours/sec
→ we have 5000 bucket x 44000/sec = 2.2x10^8 bucket/sec

Suppose a flux of 2.2x10^8 proton/sec, it means that we extract in average a proton at each bucket, thus the protons are separated by 5nsec....
In fact since we have 5 particles/proton, in a detector put after the target we would have
1 particle every nsec.

But what’s matter is how many particles in a detector which is put after the bended crystal.
The typical channeling efficiency is order around 10^{-3}, thus:
1 particle every μsec.

\[ N_{\text{ND}} = 27 \text{mbarn} \quad \text{(from Phythia)} \]

N(non diff) = \( N_A \times \rho \times T \times \sigma_{\text{ND}} \times \text{mult.} \)
~1.7 \times 10^{-2} \times 300
\[ N_{\text{ND}} = \sim 5 \text{ptc/proton} \]

See talk of Giovanni Calderini
The basis of the experiment is to measure the changes in the polarisation due to the spin precession around the magnetic field. Let’s suppose that the particle enter in the crystal with an initial polarisation such that \( P = P_y \). Namely perpendicular to the channelling plane and to its moving direction. Due to the spin precession one should observe a longitudinal polarisation along \( z \) (direction of the the \( \Lambda_c \) such that \( |P_z| = |P| \sin(\Delta \phi) \)

For instance if we consider that for \( \Lambda_c \) we have \( g/2 \sim 0.5 \) and suppose \( \gamma \sim 100 \rightarrow \Delta \phi \sim 0.5 \times 100 \times 1.0 \times 10^{-3} \sim 0.05 \) rad

\[
\text{With } P = 0.6 \rightarrow |P_z| \sim 0.03
\]

For having 3 sigma we should measure it with \( \Delta P_z = 0.01 \)

Which imply \( \Delta P_z / |P| \sim 0.01/0.6 \sim 2\% \) precision!
\[ \Delta \theta = \frac{\theta_0}{P} - \theta_{\infty} \]

\[ 1 + \left( \frac{E}{E_0} \right)^P \]

**Effective Channeling Angle**

- \( R = 40 \text{ m} \):
  - 1 cm: 0.25 mrad
  - 4 cm: 1.0 mrad
- \( R = 20 \text{ m} \):
  - 1 cm: 0.5 mrad
  - 4 cm: 2.0 mrad
- \( R = 10 \text{ m} \):
  - 1 cm: 1.0 mrad
  - 4 cm: 4.0 mrad

**\( \Lambda_c^+ \) Decay with Lenth**

**\( \Lambda_c^+ \) Energy Distribution with Lenth**

<table>
<thead>
<tr>
<th>R</th>
<th>T</th>
<th>Ψ</th>
<th>( \theta_0 )</th>
<th>( E_0 )</th>
<th>P</th>
<th>( \theta_{\infty} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>4</td>
<td>1</td>
<td>42.7</td>
<td>150</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>2</td>
<td>16.7</td>
<td>770</td>
<td>1.36</td>
<td>0.75</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>4</td>
<td>8.88</td>
<td>970</td>
<td>3</td>
<td>0.02</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1</td>
<td>11.1</td>
<td>950</td>
<td>2.65</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Effective Deflection of Short-Living Charged Particle by a Bent Crystal

O.Fomin, A.Stocchi. Workshop LIA IDEATE, October 15-16, 2015, LAL Orsay
O.Fomin, L.Burmistrov, A.Stocchi. Workshop MACUMBA, February 2nd, 2015, LAL Orsay

Top-left figure represents the effective capture angle. It is a critical channeling angle, that takes into account the dechanneling process for a specific conditions:

Crystal – Si (110),
Crystal Thickness = 1 cm,
Bending Radius = 2 m.

The fitted function for energies (50GeV < E < 500GeV) is:

$$\Delta \theta = \frac{46.3 \mu rad}{E} - 6.1 \mu rad$$

$$1 + \frac{E}{100 \text{ GeV}}$$
The Efficiency of $\Lambda_c$ Planar Channeling in a Bent Crystal for its Magnetic Moment Measuring at SPS CERN

O. Fomin, L. Burmistrov, A. Stocchi. Workshop MACUMBA, February 2nd, 2015, LAL Orsay

- Simulation of $\Lambda_c$ and $\Sigma^+$ production on W target using Phythia code
- Simulation of $\Lambda_c$ and $\Sigma^+$ passage though a bent Si crystal (Binary-Collision Model)
- Calculation of channeled (thin curves) and over-barrier (thick curves) fraction of $\Lambda_c$ and $\Sigma^+$ particles deflected by a bent crystal as a function of the angle between initial proton beam and crystallographic plane for different crystal curvature angles (5, 10 mrad) and thicknesses (10, 15 mm)