Measurement of Magnetic Moments of Charmed Baryons

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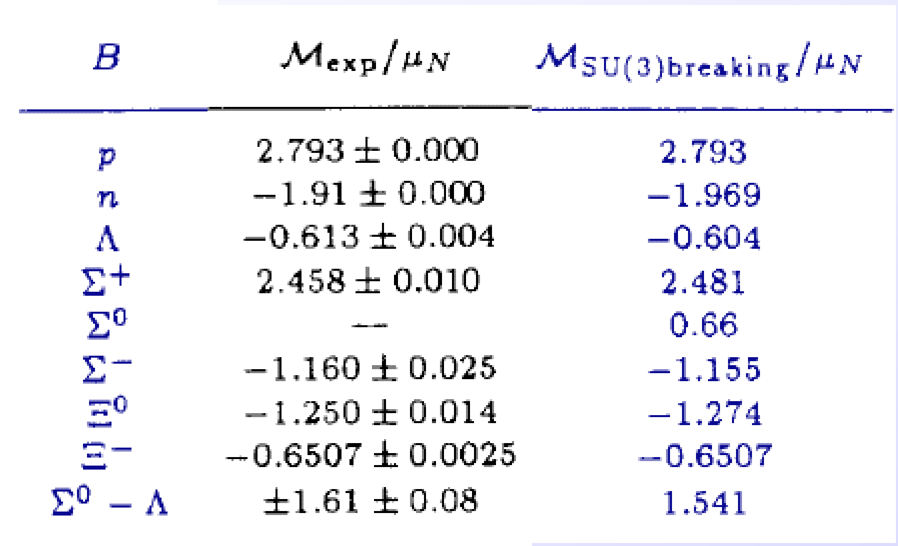
Overview

- Magnetic moments and measurements
- Challenges for charmed baryons
- Experimental approach
  - Crystal channeling
  - Requirements
- Count rate estimates

Status and Predictions of Magnetic Moments

- Basic quantity characterising fermion
- The case of strange baryons



B	$\mathcal{M}_{\rm exp}/\mu_N$	$\mathcal{M}_{\rm SU(3)breaking}/\mu_N$
p	2.793 ± 0.000	2.793
n	-1.91 ± 0.000	-1.969
Λ	-0.613 ± 0.004	-0.604
Σ^+	2.458 ± 0.010	2.481
Σ^0	—	0.66
Σ^-	-1.160 ± 0.025	-1.155
Ξ^0	-1.250 ± 0.014	-1.274
Ξ^-	-0.6507 ± 0.0025	-0.6507
$\Sigma^0 - \Lambda$	$\pm 1.61 \pm 0.08$	1.541

Good description possible
but problems with XPT (loops)

- The case of heavy baryons:
  - Predictions: $\mu_{\Lambda c}$=0.3-0.5 μ_N
    $\mu_{\Xi c}$=0.3-0.8 μ_N
  - Mostly :$\mu_{\Lambda c}$ ~ 0.37 μ_N and $\mu_{\Lambda c}$ ~ 0.42 μ_N

$$\vec{\mu}_Q = \vec{S}\,\frac{q \cdot e}{2m_Q}$$

Measurement Technique

- ‘Standard’ method for short lived particles (hyperons)
  - – Produce polarized hyperons with high energy proton beams
    - High x_F and high p_T required
    - Polarization observed transverse to production plane
    - Mechanism theoretically not understood but many models
  - – Hyperon extraction via magnetic channel
    - Spin precession in guiding B-field
  - – Spin analysis
    - Use parity violating decays (interference of S- and P-waves in decay amplitudes)
    - Use decays with high analyzing power
      - – $\Lambda \rightarrow p \pi^-$ ($\alpha = 0.642$)
      - – $\Sigma^+ \rightarrow p \pi^0$ ($\alpha = -0.980$)
  - – Vary B-field to vary spin precession angle

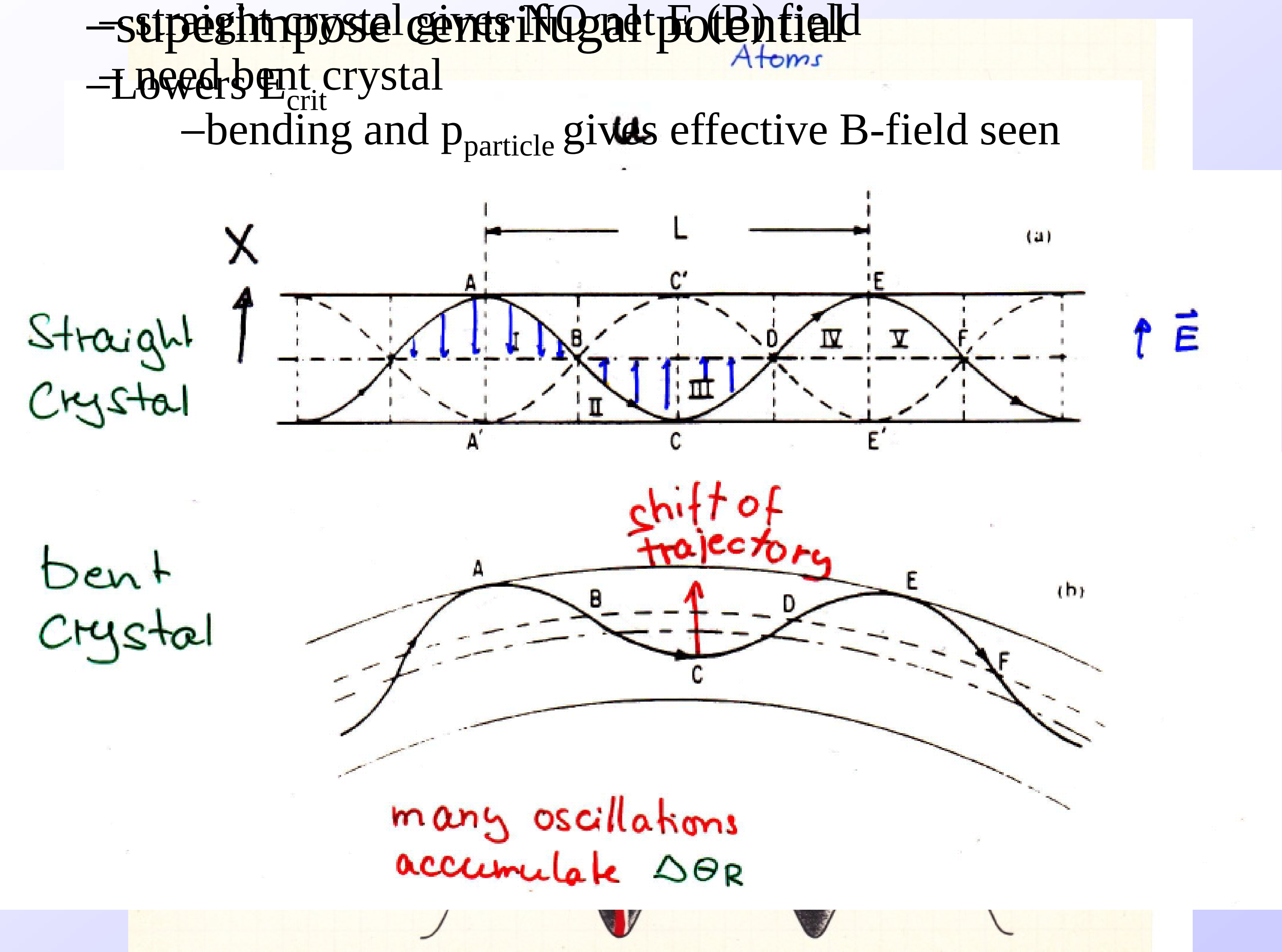
Challenge for Charmed Particles

- Lifetime of charmed baryons small (200-400fs)
  - Flight path (cτγβ) of Λ^+_c ~ 0.8cm @300 GeV; 8cm @3 TeV
  - Flight path (cτγβ) of Ξ^+_c ~ 1.6cm @300 GeV; 16cm @3 TeV
- Production cross section very small
  - $\sigma(\Lambda_c)$ ~40 μb/nucleon ($10^{-3}\ \sigma_{tot}$) at 300 GeV
  - $\sigma(\Lambda_c)$ ~400 μb/nucleon ($10^{-2}\ \sigma_{tot}$) at 8 TeV) crude extrapolation
- Polarisation unknown (except for R608 experiment)
- Branching ratio for individual decays small
  - BR $\Lambda_c \rightarrow \Lambda\pi^+$ ~ 1±0.3%
  - Analyzing power large ($\alpha_{\Lambda\pi} = -0.91\pm0.15$)
  - BR $\Lambda_c \rightarrow \Lambda\ l^+\nu$ ~ 2±0.6%
  - Analyzing power large ($\alpha_{\Lambda\ l+\nu} = -0.86\pm0.04$)
  - BR $\Lambda_c \rightarrow \Sigma^+\pi^0$ ~ 1±0.34%
  - Analyzing power large ($\alpha_{\Sigma\pi} = -0.45\pm0.31$)
- Effect expected to be small : μ_c~ 0.4 μ_N ~ $\mu_{\Lambda c}$

Experimental realization I

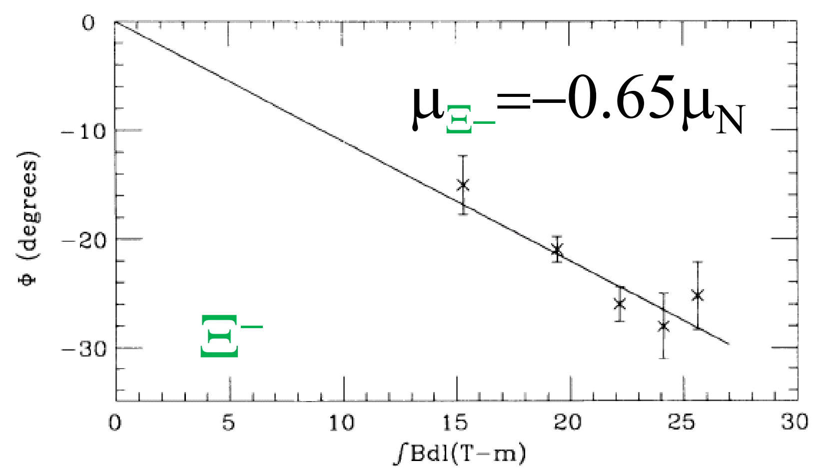
- Channeling for particles with $E_\perp < E_{crit}$
- Channeling in bent crystal:
  - –superimpose centrifugal potential
  - –Lowers E_{crit}

- Use channeling to produce high magnetic fields
  - – need positively charged particle (scattering off nuclei for -)
  - –straight crystal gives NO net E (B) field
  - – need bent crystal
    - –bending and $p_{particle}$ gives effective B-field seen



Spin Rotation for Channeling Particles

- Measurement for charged particles in a static B-field
  - Sensitivity to g-2
  - $\Delta\omega = \omega_{Lamor} - \omega_{cyclotron}$
  - Typical B-fields : $\int B \cdot dl = 15\ Tm$

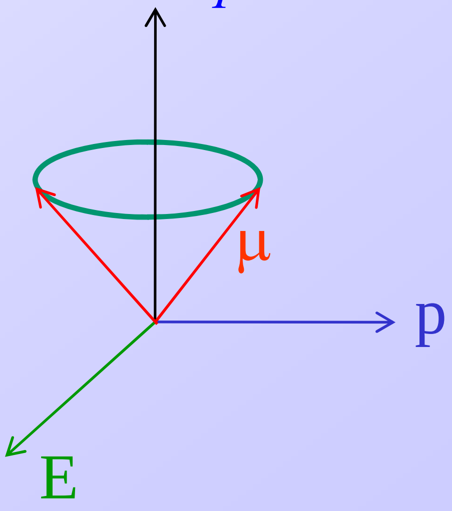


- For channeling in crystal:
  - E-fields: 10^{10}V/cm, B-fields 10^{3}T
  - $\int B \cdot dl = 10\ Tm$ for l ~ 1cm

$$\Delta\phi_{Spin} = \frac{1}{2}(g-2)\cdot\gamma\cdot\Delta\varphi_{Bending}$$

$$\Delta\phi = [1 - \mu_{\Lambda_c^+}\frac{m_{\Lambda_c^+}}{m_p}]\cdot\gamma\cdot\Delta\varphi$$

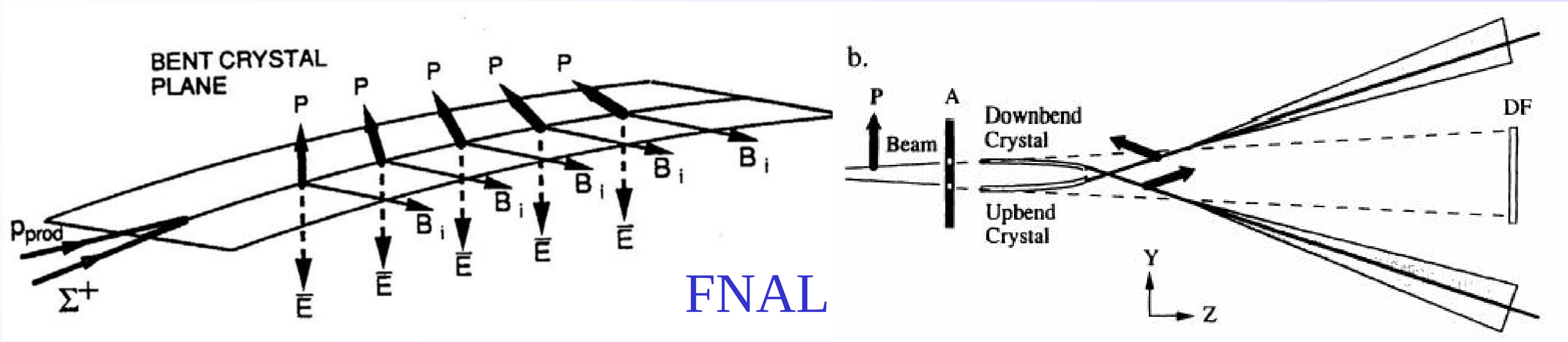
$\Delta\phi_{Spin}$ is □ (*trajectory*, *spin*)



$$\vec{B} = \vec{E} \times \vec{p}$$

Experimental Realization

- Assume FNAL realization (Σ^+): $\Delta\phi_{trajectory} = 1.6$ mr



FNAL

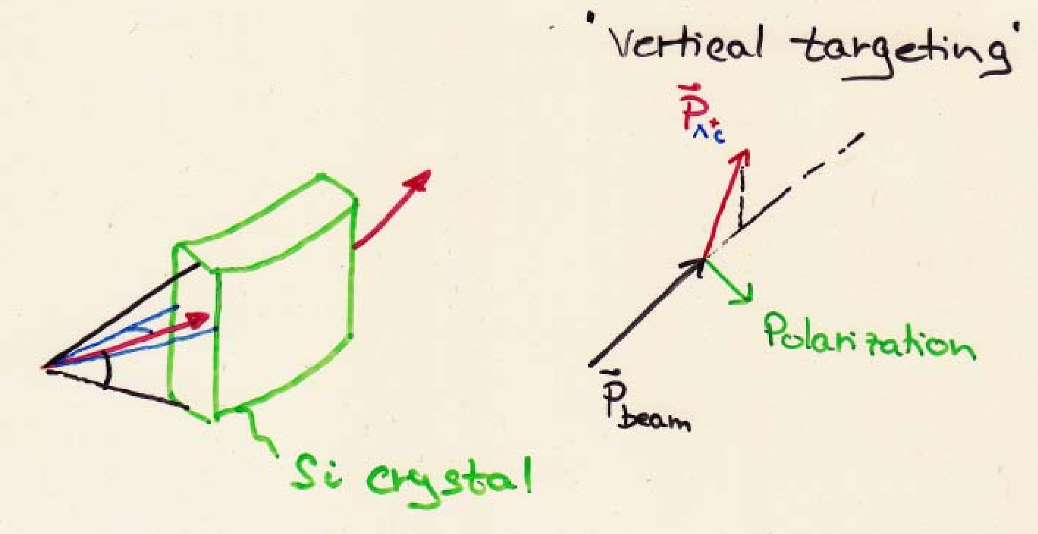
μ_c	0.2	0.3	0.4	0.6	[μ_N]
4 TeV $\Delta\Phi_{\Lambda c}$	-1500	-784	-73	1350	[mr]
6 TeV $\Delta\Phi_{\Lambda c}$	-2240	-1176	-110	2020	[mr]

$$d\Delta\phi_{spin} = \gamma\Delta\varphi_{trajectory}\frac{m_{\Lambda_c}}{m_N}\cdot d\mu_{\Lambda_c} = 10.6\cdot d\mu_{\Lambda_c} \quad @\ 6\ \text{TeV}$$

- 5% measurement on $\mu_{\Lambda c}$ → 200mrad in $\Delta\Phi_{spin}$
- Wide range of momenta accepted

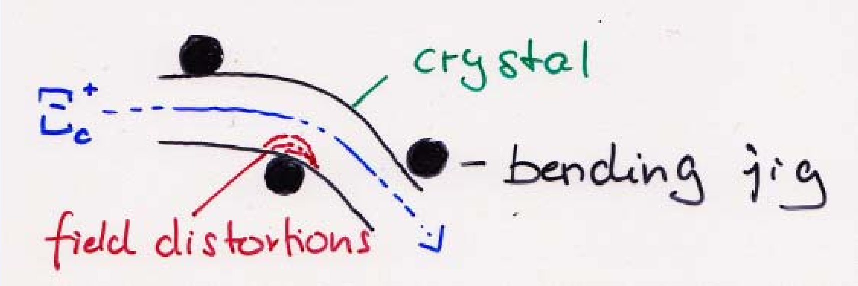
Count Rates Estimates I

- Assume
  - 8TeV (ô s ~ 120 GeV)
  - $\sigma(\Lambda_c)$ ~400 μb/nucleon
  - $x_F > 0.4$ and $p_T > 0.6$ GeV/c (as in hyperon polarization)
  - 10^8 p/s (100 days)
  - assume R608 cross section and p spectrum
  - $N_{\Lambda c} = 4\ \Lambda_c$/s / %$\lambda_I$ (→Λπ) ÿ10^7 s
  - assume L = 8cm for silicon and crystal (decay losses 63%)
  - Channeling efficiency:
    - Crystal height: 1cm
    - Crystal length 4-5cm
    - Crystal width 1mm
    - θ_{vert}: no limits
    - θ_{hori}: $\theta < \theta_{cri\ t}$~ 10μrad
    - $\varepsilon_{channeling}$ ~ 0.01



Count Rates Estimates II

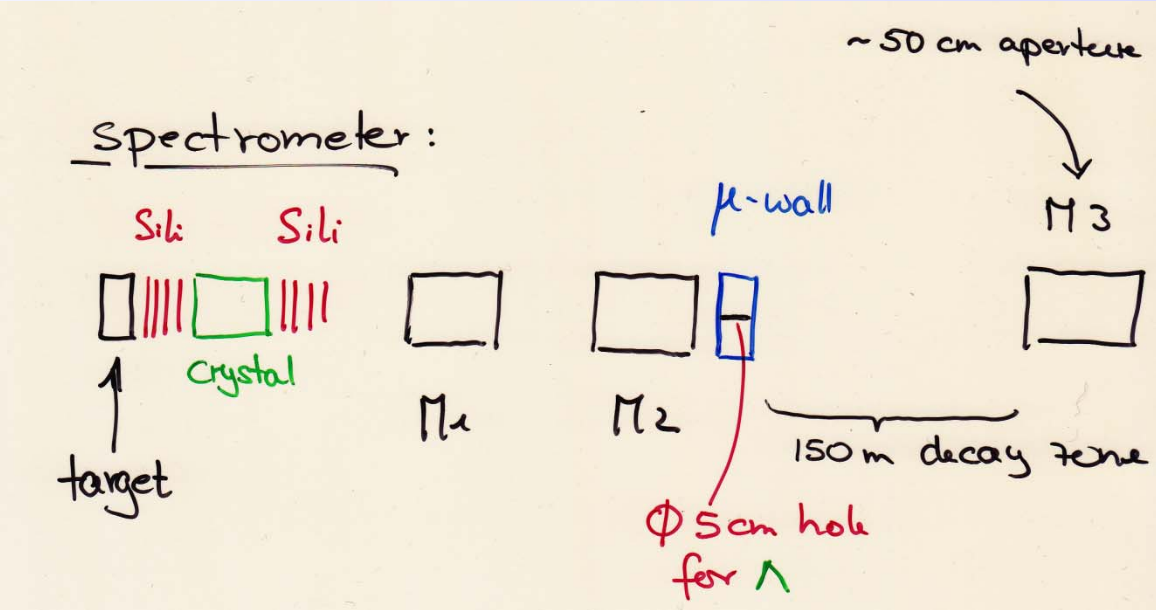
- Dechanneling (interactions with e^-) : no problem
- Bending dechanneling (distortions due to jig)
  - R_{curv} = 30m with p ~6 TeV: $f_{dechannel}$ ~ 0.5



- S_{acc} : Surface acceptance: (channeling/total area: 0.5)
- Total acceptance: ΔΩ ÿ $f_{dechannel}$ ÿ S_{acc} ~ 2.5 ÿ 10^{-3} (~ 5 ÿ 10^{-4})
  - B = 45 Tm (2.5cm length, Δm_{beam} = 1.6mr) at FNAL
  - B ~ 300 Tm (mechanically tried → Δm_{beam} = 12mr) at FNAL
- Δx = 3-5% λ_I
- N_{total} ~ 50000 Λ_c ($\rightarrow \Lambda\pi$)

Set-up and 'But's:

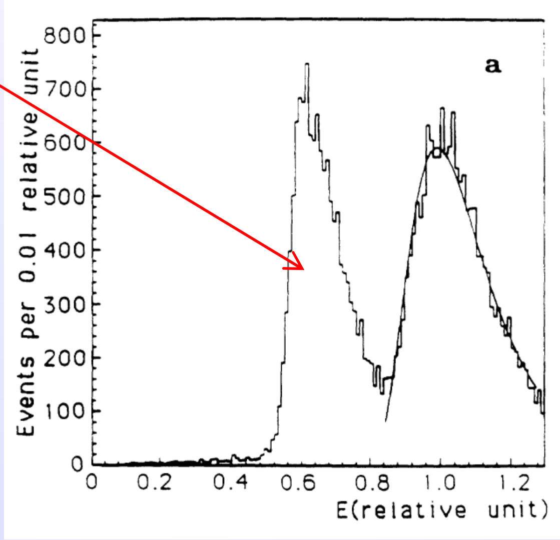
- What is the polarization of Λ_c ?
- Which final state to take ?
  - $\Lambda_c \rightarrow \Lambda \pi^+$: flight path of Λ ($c\tau$ = 7.8cm) ~ 160m (low detection efficiency)
  - $\Lambda_c \rightarrow \Sigma^+ \pi^0$: flight path of Σ ($c\tau$ = 2.4cm) ~ 45m
  - $\Lambda_c \rightarrow p\, K^- \pi^+$: *unknown* analyzing power (but good sec. vertex)
  - ……



  - Reconstruction efficiency (typical) 5-10%

Measurement

- How to identify channeled particles
  - Deflection angle (short silicon telescope ΔL = 2-3cm)
  - Specific (reduced) energy loss in crystal (instrumented silicon crystal)



- Effective number of events: $N^{\Lambda_c}_{eff} = N^{\Lambda_c}_{tot} P^2 \alpha^2$
  - P(Λ_c) = 0.6 (e.g. Bis-2)
  - $\alpha_{\Lambda c}$ ÿα_{Λ} = 0.9ÿ0.64 = 0.57
  - σ for $\Delta\Phi_{Spin}$ = 200mr → ΔP/P = 20% ($\mu_{\Lambda c} = 0.4\mu_N$) → $N^{\Lambda_c}_{tot}(\Lambda\pi) \sim 350$

Conclusion

- Charged weakly decaying members of charm/beauty baryons can be measured via crystal channeling
  - Charm: Λ_c^+ Ξ_c^+
  - Beauty $\cancel{\Xi_b^-}$ Ξ_{cb}^+
- Effect: Δθ: [-500,500]mr
- Events needed: few hundred
- Need: very high energy beam (TeV)
  - Short lifetime
  - High effective field (spin precession)
- Cross section and polarization uncertain
- Analyzing power of most interesting channel unknown
- Seems feasible based on present knowledge
- Helps to understand heavy baryons

Estimates of μ_c from radiative D*-decays

- What do we know about μ_c ?
- Lets look at radiative decays

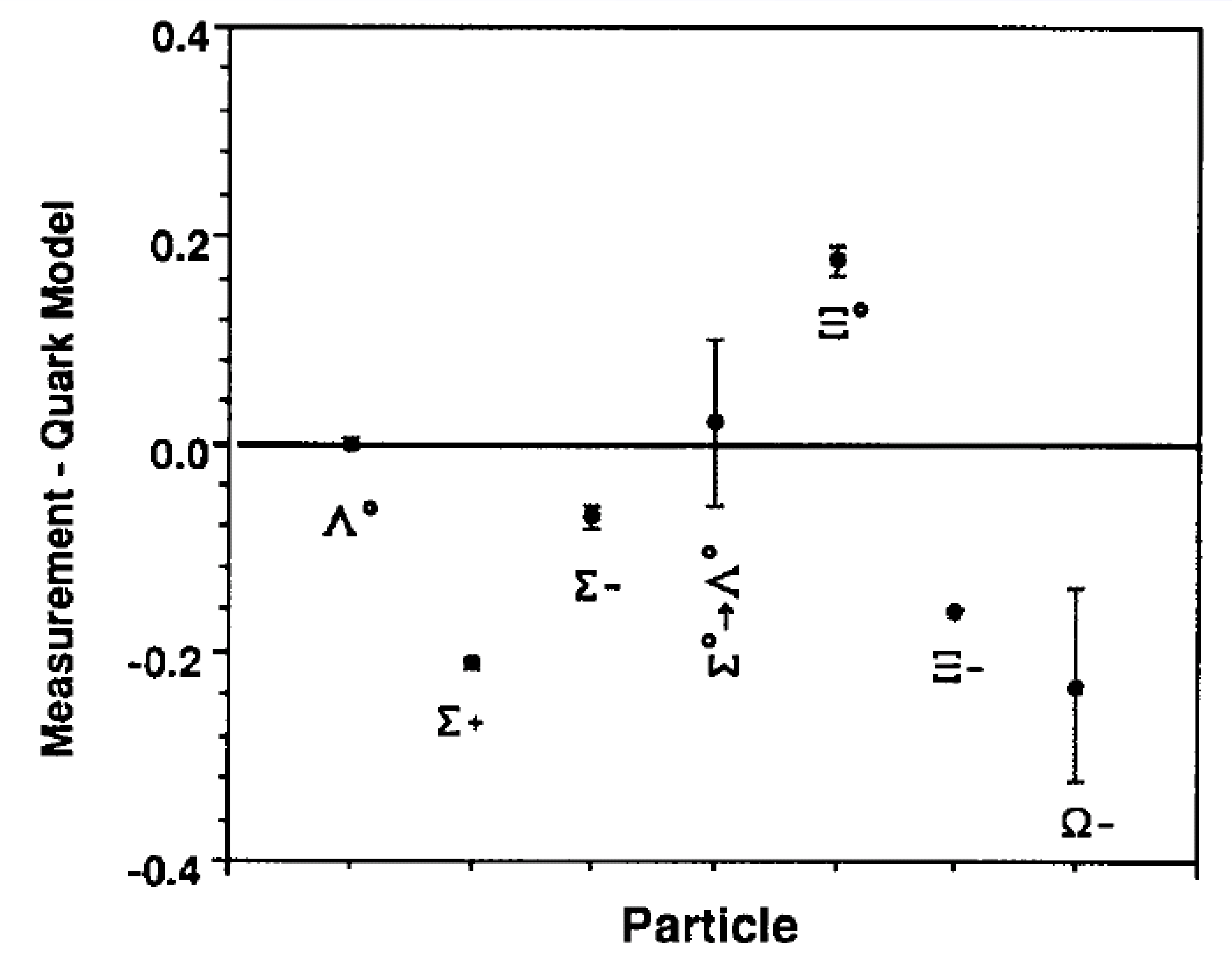
$$R_\Gamma^D = \frac{\Gamma_\gamma^0}{\Gamma_\gamma^+} = \frac{\Gamma(D^{*0} \to D^0\gamma)}{\Gamma(D^{*+} \to D^+\gamma)} = \left(\frac{E_\gamma^0}{E_\gamma^+}\right)^3 \left[\frac{\mu_u + \mu_c}{\mu_d + \mu_c}\right]^2$$

  - Experiment: $R_\Gamma^D > 6$
  - Predictions: $R_\Gamma^D \sim 12 - 92$ (see e.g. Lepage et al.)

- Agreement: but large uncertainties

References

- S. Paul (1993)
  Talk given at an LHB meeting (spokesperson G. Carboni)
- V.M. Samsonov NIM B119 (1996)


0.4
0.2
0.0
-0.2
-0.4
Measurement - Quark Model
Particle
Λ°
Σ+
Σ−
Σ°→Λ°
Ξ°
Ξ−
Ω−