Search for EDM of heavy and strange baryons at the LHC

E. Bagli, L. Bandiera, S. Barsuk, O.A. Bezshyyko, L. Burmistrov, G. Cavoto, M. Ferro-Luzzi, A.S. Fomin, S.P. Fomin, F. Galluccio, M. Garattini, V. Guidi, A.Yu. Korchin, I.V. Kirillin, L. Henry, Y. Ivanov, L. Massacrier, D. Marangotto, F. Martinez Vidal, A. Mazzolari, A. Merli, D. Mirarchi, S. Montesano, A. Natochii, N. Neri, S. Redaelli, P. Robbe, J. Ruiz Vidal, W. Scandale, N.F. Shul'ga, A. Stocchi

Physics Beyond Colliders Annual Workshop,

CERN, 21-22 November 2017

Based upon

- V. G. Baryshevsky, *The possibility to measure the magnetic moments of short-lived particles (charm and beauty baryons) at LHC and FCC energies using the phenomenon of spin rotation in crystals*, Phys. Lett. B**757** (2016) 426.
- L. Burmistrov, G. Calderini, Yu Ivanov, L. Massacrier, P. Robbe, W. Scandale, A. Stocchi, *Measurement of short living baryon magnetic moment using bent crystals at SPS and LHC*, CERN-SPSC-2016-030 ; SPSC-EOI-012.
- F. J. Botella, L. M. Garcia Martin, D. Marangoto, F. Martinez Vidal, A. Merli, N. Neri, A. Oyanguren, J. Ruiz Vidal, *On the search for the electric dipole moment of strange and charm baryons at LHC,* Eur. Phys. J. C **77** (2017) 181.
- A.S. Fomin , A.Yu. Korchin, A. Stocchi, O.A. Bezshyyko, L. Burmistrov, S.P. Fomin, I.V. Kirillin , L. Massacrier , A. Natochii, P. Robbe, W. Scandale, N.F. Shul'ga, *Feasibility of measuring the magnetic dipole moments of the charm baryons at the LHC using bent crystals*, JHEP **1708** (2017) 120.
- E. Bagli, L. Bandiera, G. Cavoto, V. Guidi, L. Henry, D. Marangotto, F. Martinez Vidal, A. Mazzolari, A. Merli, N. Neri, J. Ruiz Vidal, *Electromagnetic dipole moments of charged baryons with bent crystals at the LHC,* arXiv:1708.08483 (2017), accepted by EPJC.
- V. G. Baryshevsky, *On the search for the electric dipole moment of strange and charm baryons at LHC and parity violating (P) and time reversal (T) invariance violating spin rotation and dichroism in crystal,* arXiv:1708.09799 (2017).
- L. Henry, D. Marangotto, F. Martinez Vidal, A. Merli, N. Neri, P. Robbe, J. Ruiz Vidal, CERN-LHCb-INT-2017-011, *Proposal to search for baryon EDMs with bent crystals at LHCb* (internal).

Outline

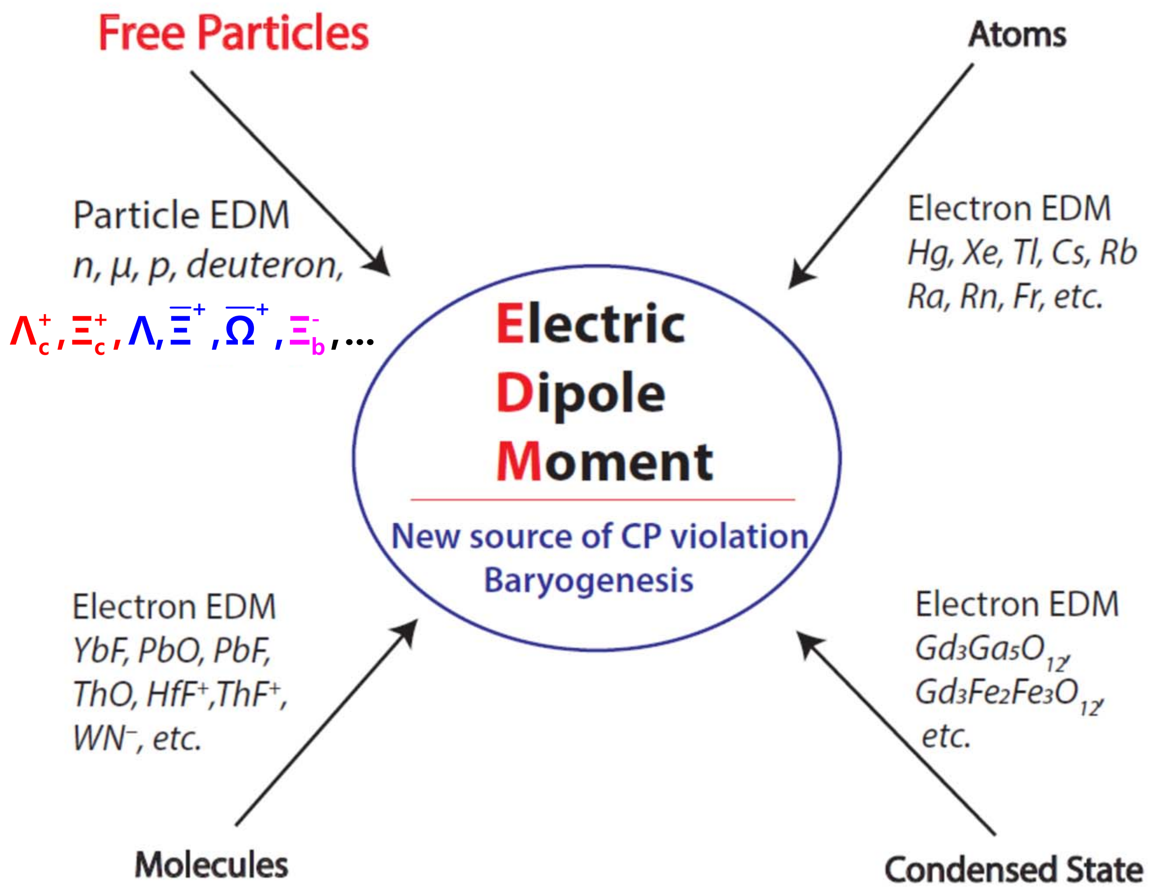
- This talk focuses on **new physics opportunities via EDM** along with **feasibility** & **sensitivity** studies with **bent crystal experiments** at the LHC under **realistic experimental conditions**
  - ✓ **MDM** and **EDM** of **heavy** and **strange baryons**
  - ✓ Experimental layout based on **LHCb detector**

- Most **technical aspects** of the proposal covered in other talks:
  - ✓ A. Stocchi, *Crystal based experiments* (Session 2, QCD)
  - ✓ M. Ferro-Luzzi, *LHC fixed target* (Session 3, Accelerator)

EDM as a portal to new physics

- CKM mechanism cannot account for the observed baryon-antibaryon asymmetry, by a factor ~10^8
- **Baryogenesis** calls for BSM physics and must bring new CPV sources
- EDMs can access these new sources from **flavour-diagonal CPV**
- **‘Background-free’ search** for new physics
- **BSM contributions** can largely enhance EDMs

Worldwide, long standing program

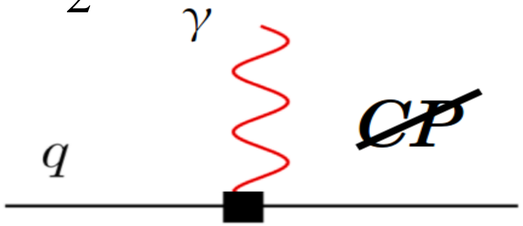


Baryon EDM: complementarity

- **EDM searches** in different systems are **complementary** to disentangle the underlying source of CPV
- A measurement of a heavy baryon EDM is **directly sensitive** to:

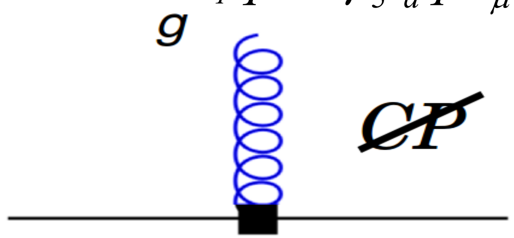
***q*EDM**

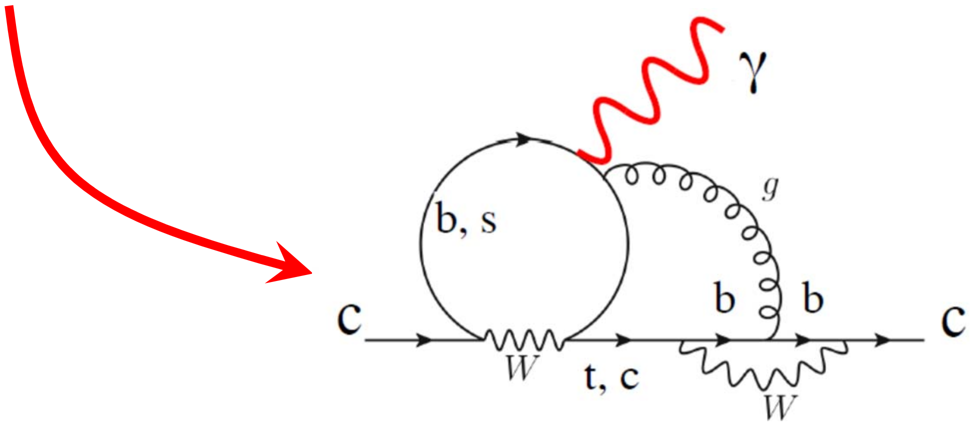
$$-\frac{i}{2}\delta_q \bar{q}\sigma^{\mu\nu}\gamma_5 q F_{\mu\nu}$$



***q*CEDM**

$$i\tilde{\delta}_q \bar{q}\sigma^{\mu\nu}\gamma_5 t_a q G^a_{\mu\nu}$$





LACK OF THEORETICAL ACTIVITY !

$\delta_c \sim 10^{-32}$ e cm, negligible (SM, 3-loop level)

EPJC **77** (2017) 102

Some BSM theories reach $\delta_c \sim 10^{-17}$ e cm, e.g. some versions of SUSY

Baryon EDM: complementarity

- **EDM searches** in different systems are **complementary** to disentangle the underlying source of CPV
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qEDM

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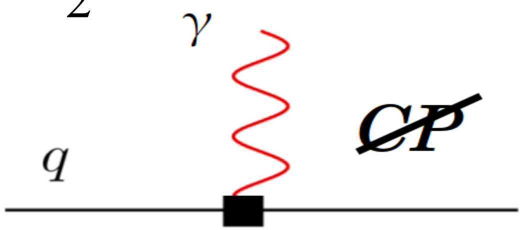
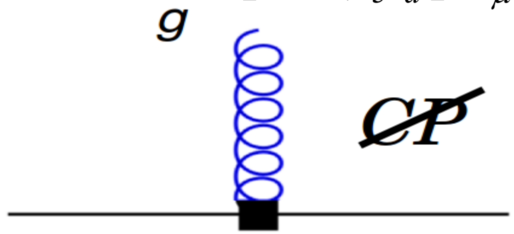


qCEDM

$$i\tilde{\delta}_q \bar{q}\sigma^{\mu\nu}\gamma_5 t_a q G^a_{\mu\nu}$$

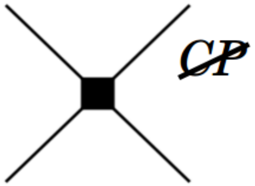


- All other contributions are **suppressed**

Higher dimension op. and *n*EDM constraints

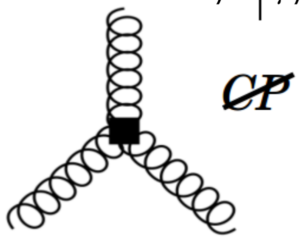
4 quark op.

$$C_{ijkl}\bar{q}_i\Gamma q_j \bar{q}_k \Gamma' q_l$$



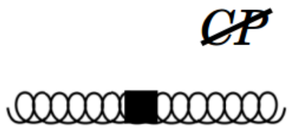
Weinberg op.

$$\frac{d_W}{6} f_{abc}\varepsilon^{\mu\nu\alpha\beta}G^a_{\alpha\beta}G^b_{\mu\rho}G^{c\rho}_{\nu}$$



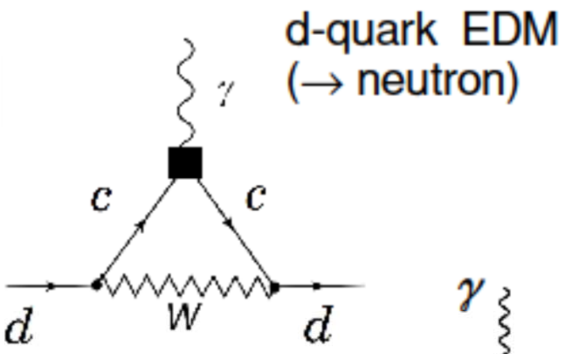
θ-QCD

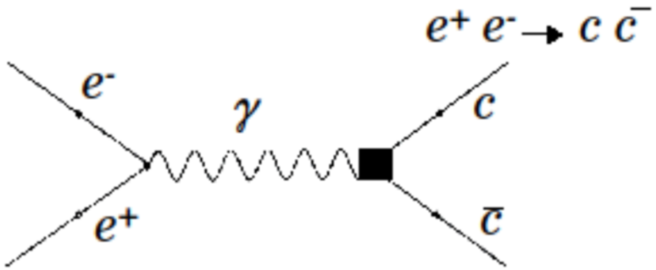
$$-\bar{\theta}\frac{g^2}{64\pi^2}\varepsilon^{\mu\nu\alpha\beta}G^a_{\mu\nu}G^a_{\alpha\beta}$$

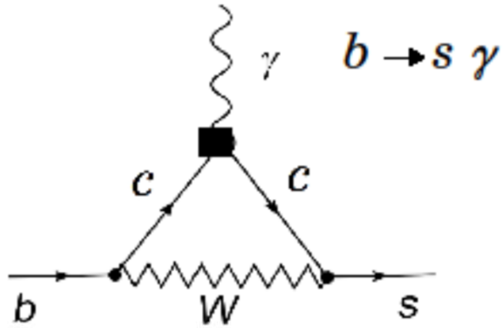


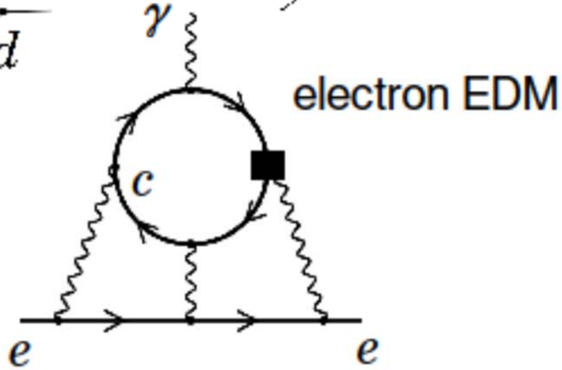
Indirect baryon EDM limits

- **The valence heavy quark dominates,** $\delta_B \approx \delta_q$ e.g. PRD **56** (1997) 7273
- Indirect bounds can be extracted from observables containing ***q*EDM** and ***q*CEDM** couplings (with some model assumptions)









$|\delta_c| < 10^{-17} - 10^{-15}\ e\ \mathrm{cm}$

$|\delta_b| < 10^{-17} - 10^{-12}\ e\ \mathrm{cm}$

LACK OF THEORETICAL ACTIVITY !

Sala, JHEP **03** (2014) 061
Zhao et al, EPJC **77** (2017) 102
Gozin et al., NPB **821** (2009) 285
Escribano, Masso, NPB **429** (1994) 19
Blinov, Rudenko, NP PS **189** (2009) 257
Cordero et al, JPG **35** (2008) 025004

- Direct EDM measurements sensitive to the **static EDM** (q^2=0), eliminates strong model dependences in low energy hadronic calculation

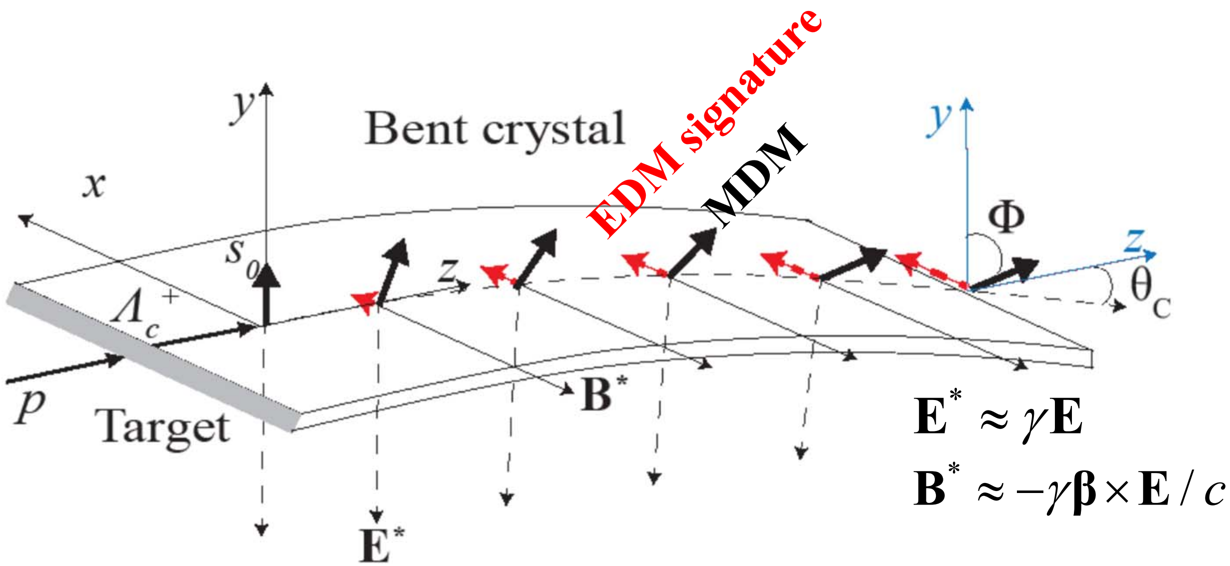
Spin precession

- **Heavy baryons** are short-lived, $\tau \sim 10^{-13} - 10^{-12}$ s

  $\Rightarrow$ **Need large boost** and **≈ 10^3 T** over ~ cm $\Rightarrow$ **E field in bent crystal** (~ GV/cm)

- **Spin evolution** derived from **T-BMT equation** EPJC **77** (2017) 181

- After channeling along the bent crystal with deflection angle θ_C :



$$\Phi \approx \frac{g-2}{2} \gamma \theta_C \sim \pi$$

$$\mathbf{s} = \begin{cases} s_x \approx s_0 \dfrac{d}{g-2} (\cos\Phi - 1) \\ s_y \approx s_0 \cos\Phi \\ s_z \approx s_0 \cos\Phi \end{cases}$$

✓ Main (MDM) precession in the *yz* plane

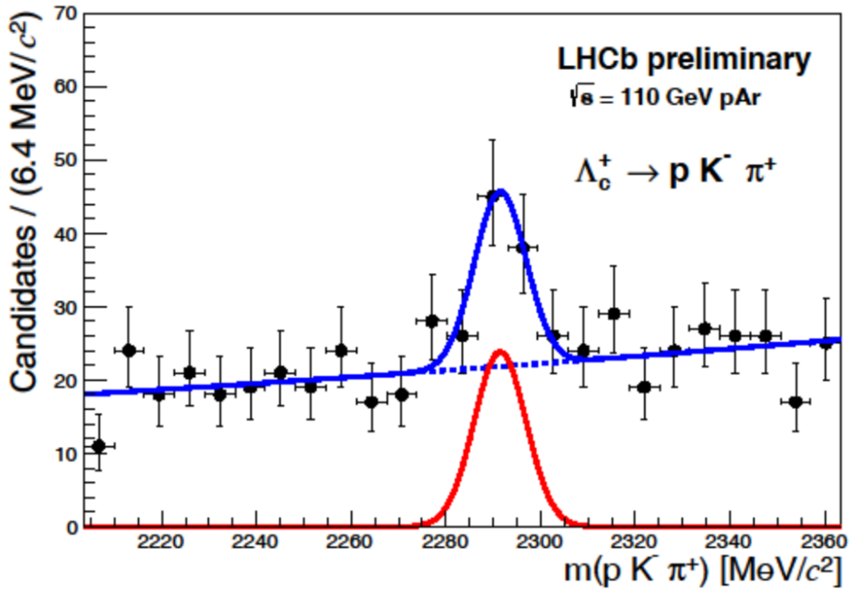
✓ **EDM induces a s_x component** otherwise not present

✓ Spin precession $\propto \gamma\theta_C \Rightarrow$ needs **high momentum** and **large θ_C**

Ongoing measurements at LHCb

- **Polarization can be measured** using **p-gas SMOG data** @ $\sqrt{s}\approx$115 GeV

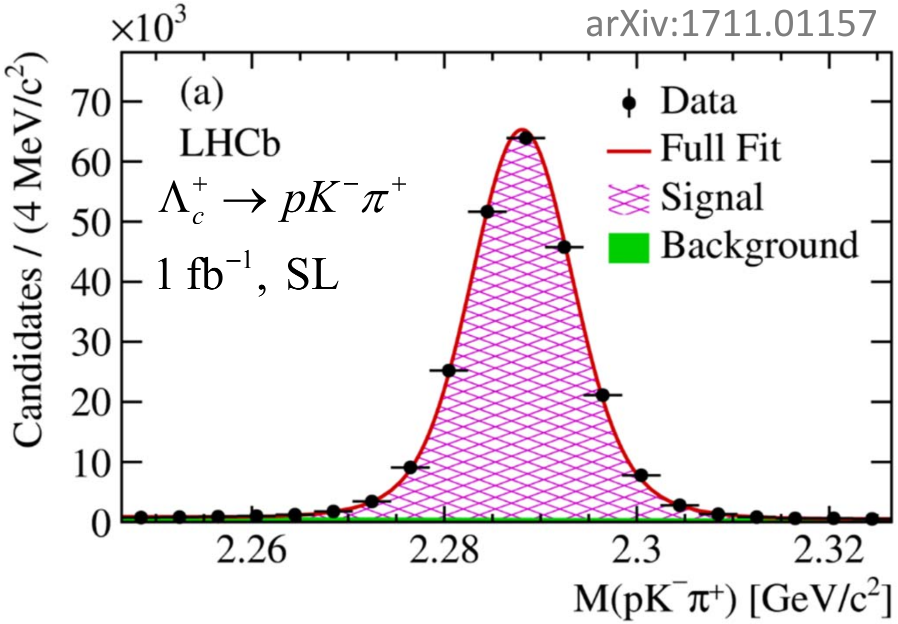
LHCb-CONF-2017-001



- ✓ pAr run of 2015 with 6.5 TeV beam (one day): 51±14 candidates
- ✓ First high-intensity SMOG run currently ongoing: expect ×10-100. G. Graziani's talk, *LHCb as a fixed-target experiment*

- Parity-violating parameters α **can be measured** with high precision using **pp collision data** @ 14 TeV

arXiv:1711.01157



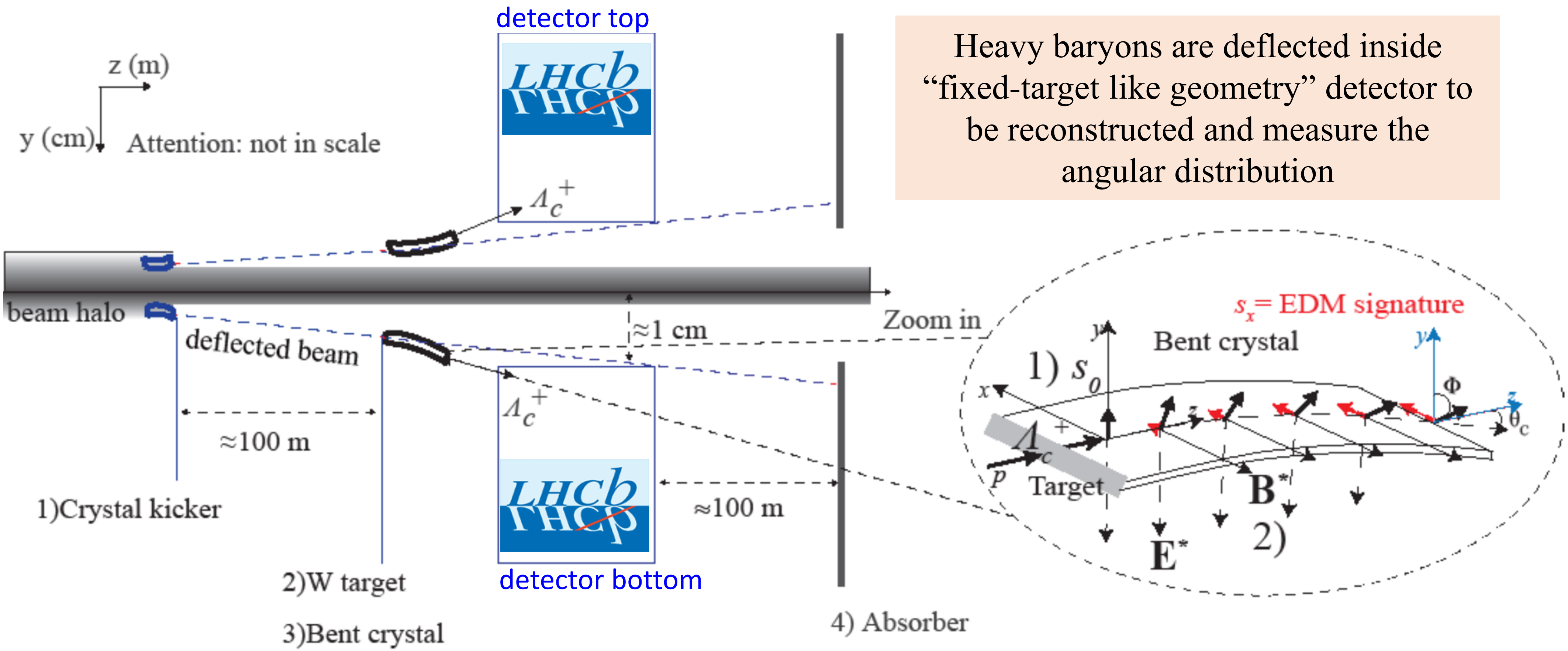
PLB **471** (2000) 449

- ✓ e.g. $\Lambda_c^+ \to pK^-\pi^+$ E791 analysis performed with $\approx 10^3$ events
- ✓ $\approx$ few $\times 10^6$ from prompt and SL Λ_b^0 decays, Run I+II

Proposed experimental layout at IP8

Extracted p beam is directed on W target attached to a 2nd bent crystal for spin precession

Heavy baryons are deflected inside "fixed-target like geometry" detector to be reconstructed and measure the angular distribution



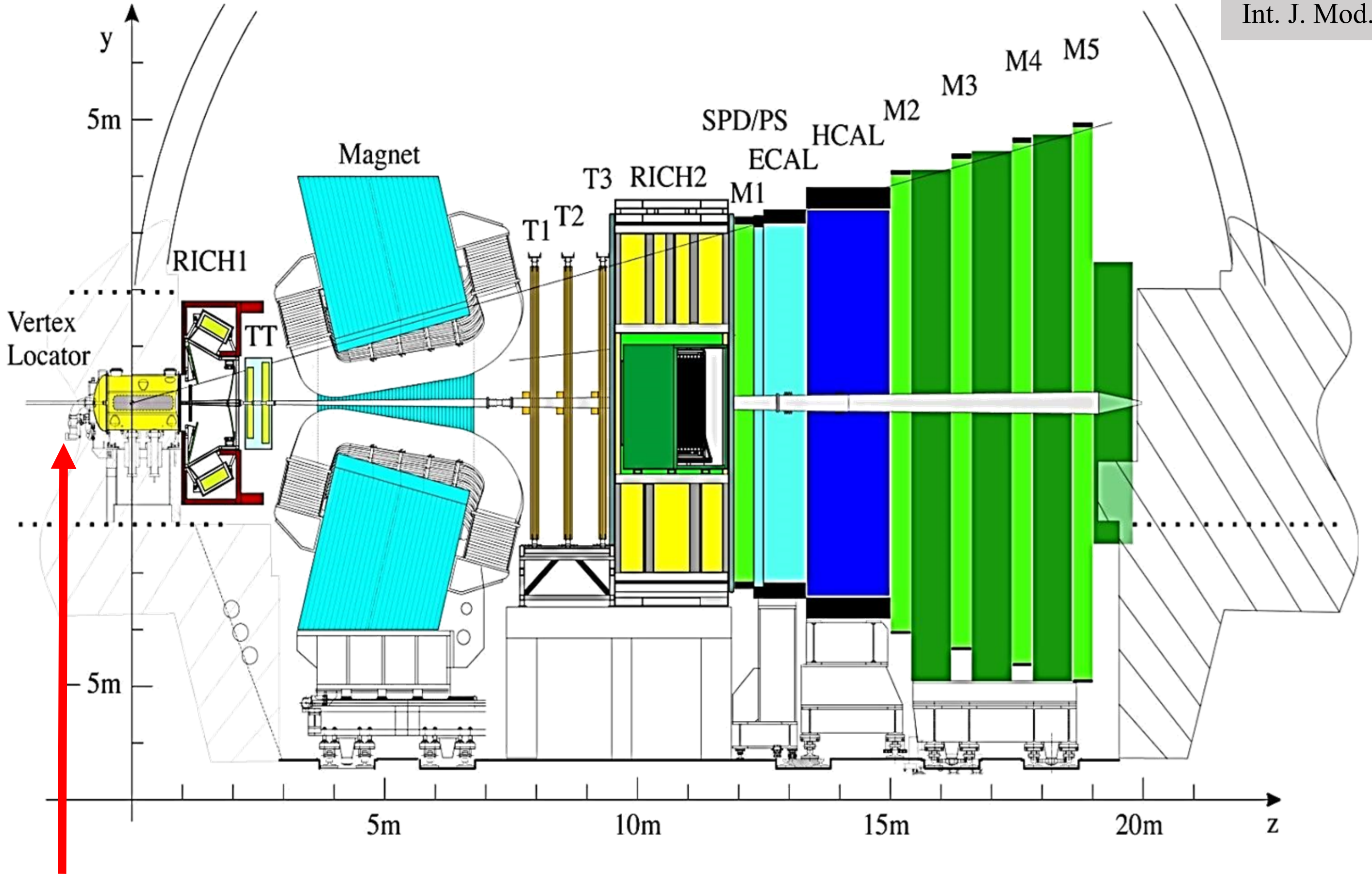
A first bent crystal extracts 7 TeV protons from LHC beam halo (kicker)

Non-interacting protons, non-channeling particles from hard pW interactions, and most of secondary interactions follow the beam pipe to be absorbed downstream the detector

LHCb apparatus: fixed target location

- Experimental layout based on LHCb

JINST 3 (2008) S08005
Int. J. Mod. Phys. A30 (2015) 1530022



✓ Close to VELO for optimal vertex resolution, but outside vacuum tank: ≈116 cm upstream nominal pp collision point, ≈87 cm upstream VELO

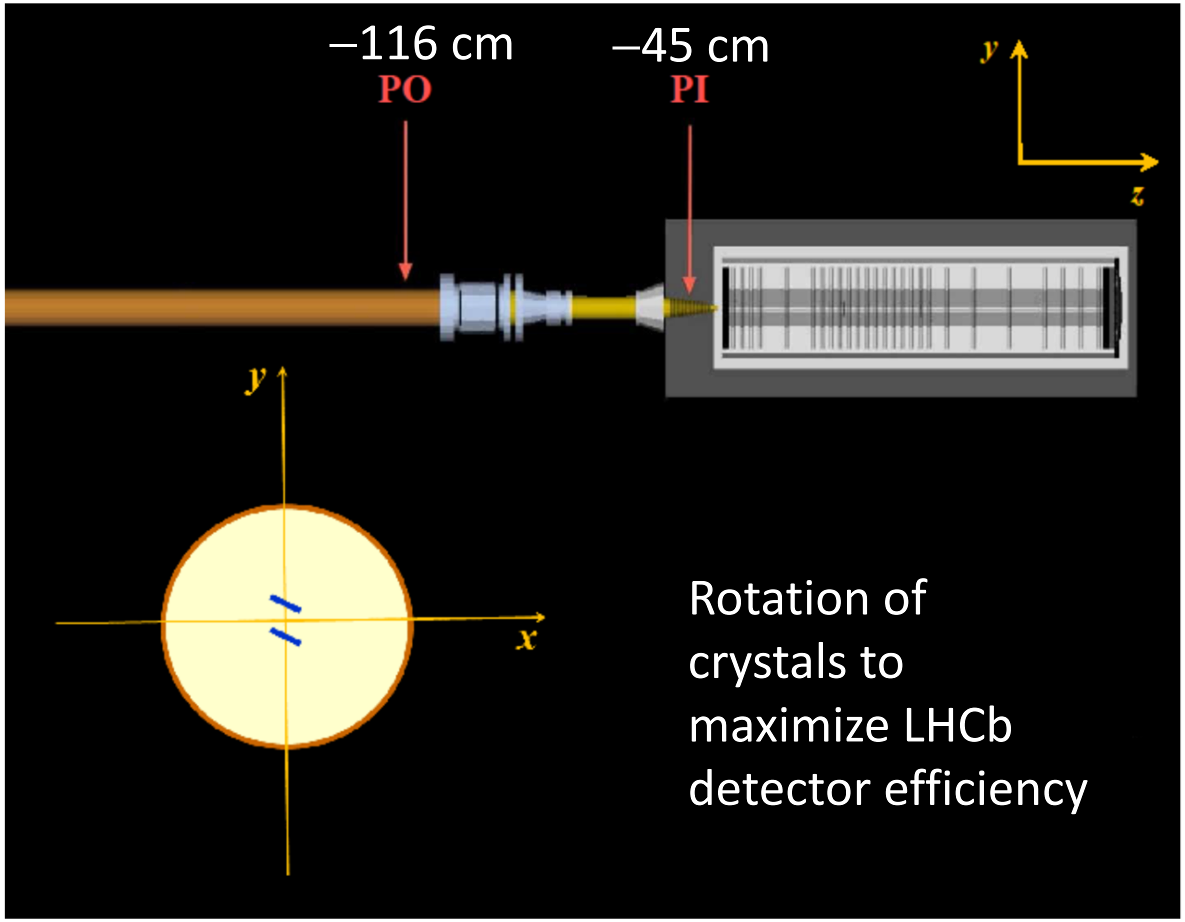
- A Fixed Target Panel (FITPAN) review at LHCb under way

Fixed target & crystal specifications

- W target positioned at (0, 0.4, –116) cm
- W target attached to long bent crystal
- Target thickness 0.5 cm, not yet optimized, depends on proton flux (pW int. prob. 5% for 0.5 cm, 18% for 2 cm)
- Long bent crystals optimized for maximum EDM/MDM sensitivity

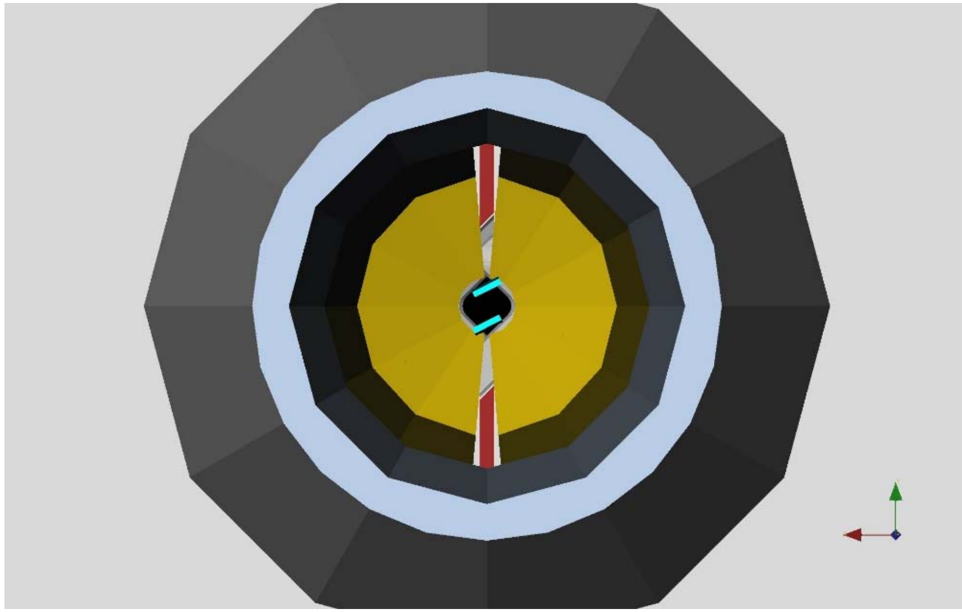
	Ge	Si
L(cm)	≈5	≈7
θ_C (mrad)	≈15	≈14

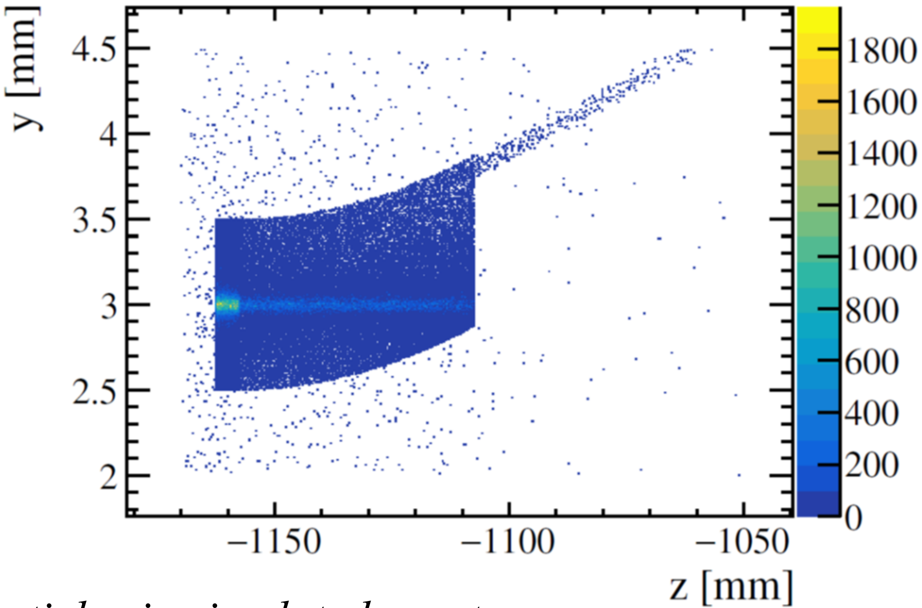
- **Bending angle > 10 mrad determined by LHCb acceptance**



Simulation studies

- GEANT4 for W target & crystal geometry
- EPOS for fixed target minimum bias events
- PYTHIA8 for baryons produced in pW hard collisions
- Full LHCb simulation to reconstruct signal events and study backgrounds

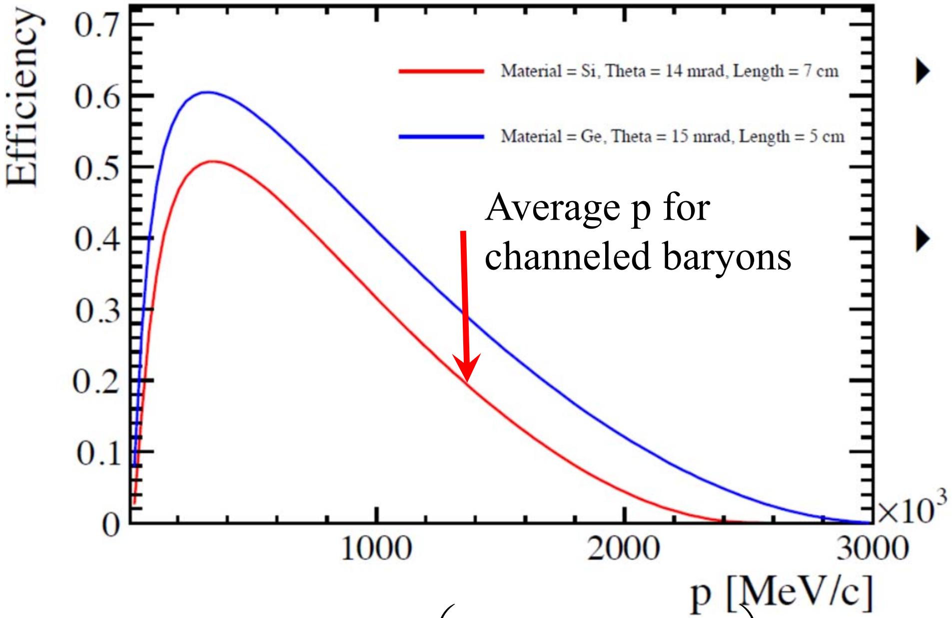




Distribution of origin vertex of stable charged particles in simulated events, including hadronic interactions, pair production, bremsstrahlung, Compton, δ rays

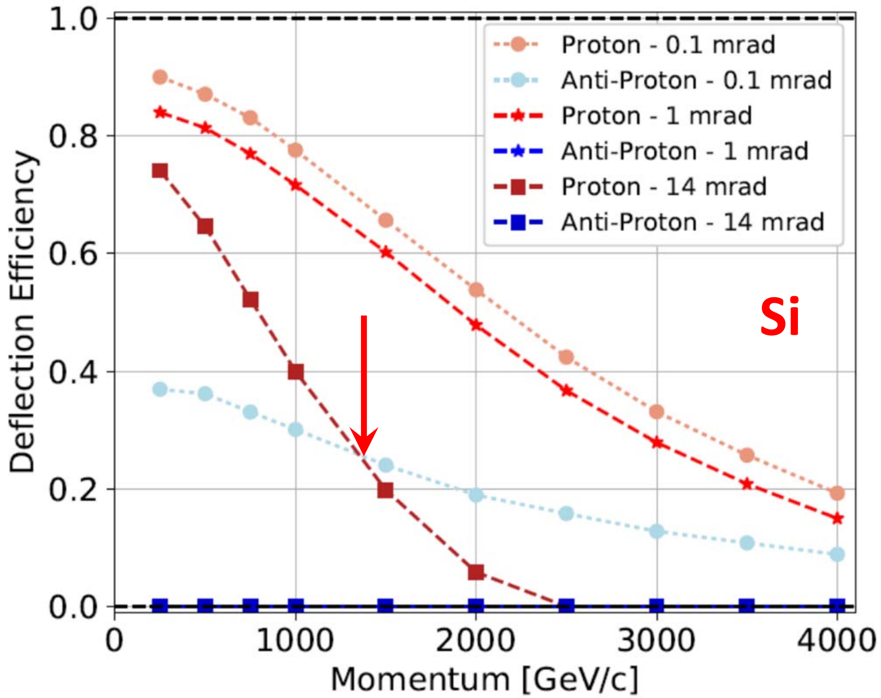
Channeling efficiency

- Channeling efficiency for Λ_c^+ particles within Lindhard angle



$$w(\theta_C, R) = (1-\eta_c)^2 \exp\left(-\frac{\theta_C}{\theta_D \eta_c (1-\eta_c)^2}\right), \quad \eta_c = \frac{R_c}{R}$$

Parameterisation from Biryukov et al., *Crystal Channeling and Its Application at High-Energy Accelerators*, Springer (1997)



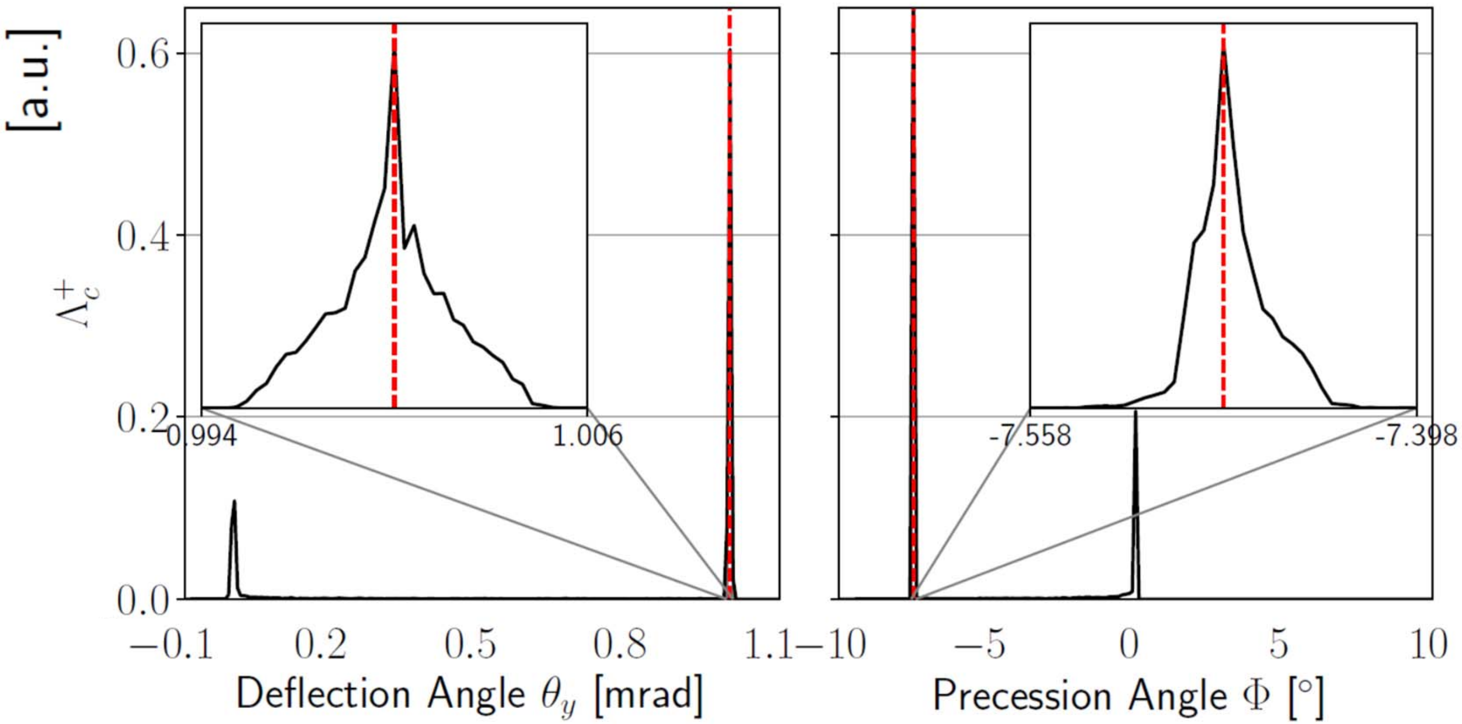
DYNECHARM++ and ECHARM within GEANT4 arXiv:1708.08483

- Total channeling efficiency, including trapping (Lindhard angle), dechanneling and Λ_c^+ decay flight: 1.2×10^{-5} (Si), 4.6×10^{-5} (Ge)

Spin rotation in GEANT4

A major step forward

- Spin rotation induced by MDM and EDM in crystals implemented in GEANT4
  - ✓ Validated against analytical expectations for several *c*, *b*, *s* baryons
  - ✓ E.g. Λ_c^+, for $(g-2)/2 = -0.3$ and $d = 5\times10^{-2}$



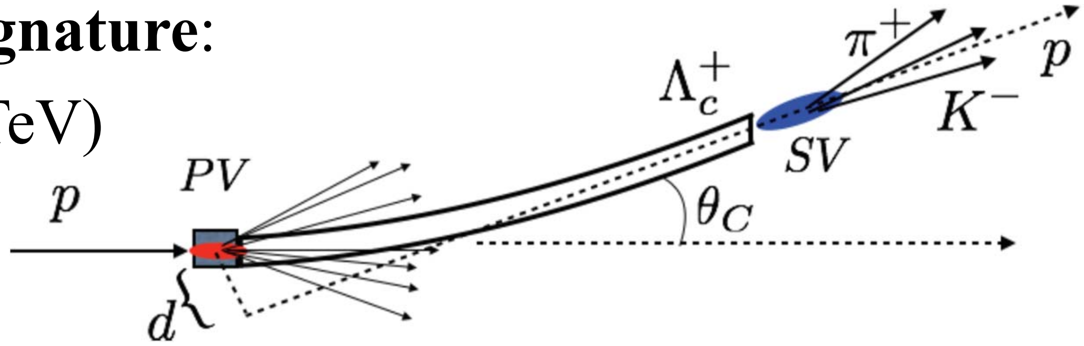
Si, 1 mrad

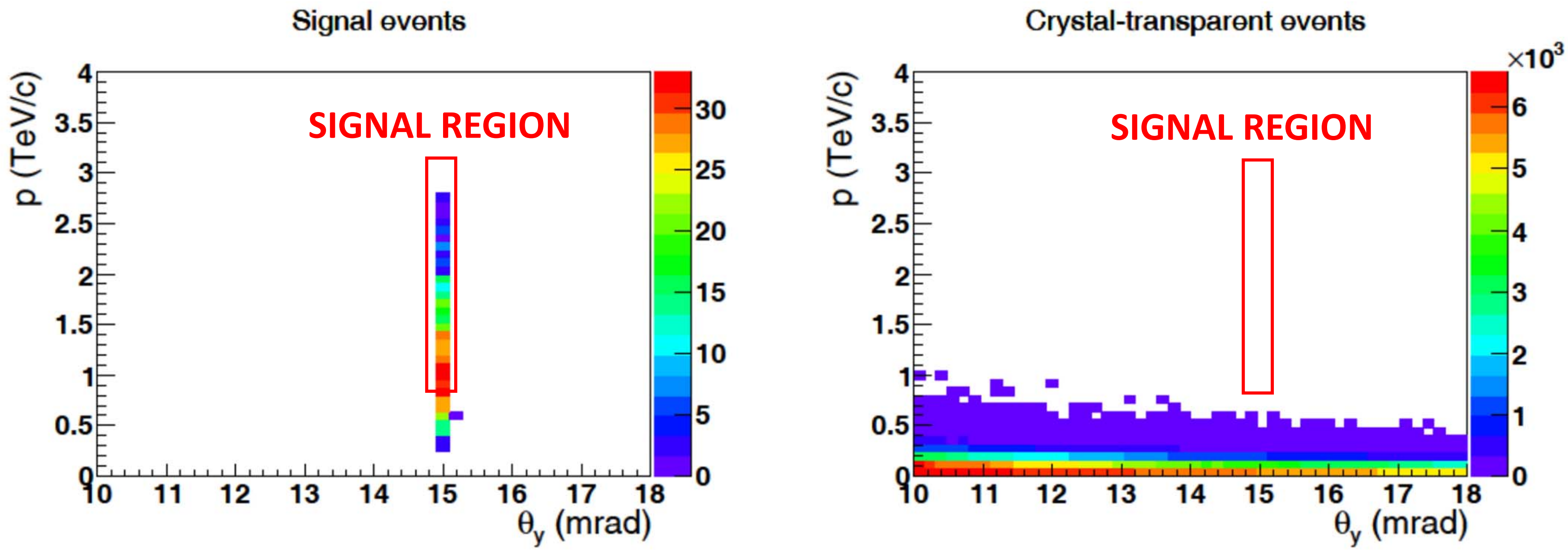
arXiv:1708.08483

Φ_{exp} [°]	Φ_{sim} [°]	$s_{x,\text{exp}}$	$s_{x,\text{sim}}$	ε_c [%]
-7.518	-7.474 ± 0.015	7.17×10^{-4}	$(7.19 \pm 0.03) \times 10^{-4}$	71.0 ± 0.08

Signal identification and bkg rejection

- Signal events have a **distinct signature**:
  - ✓**High momentum** (>≈ 0.8 TeV)
  - ✓**Polar angle**, defined by θ_C
  - ✓**Invariant mass**

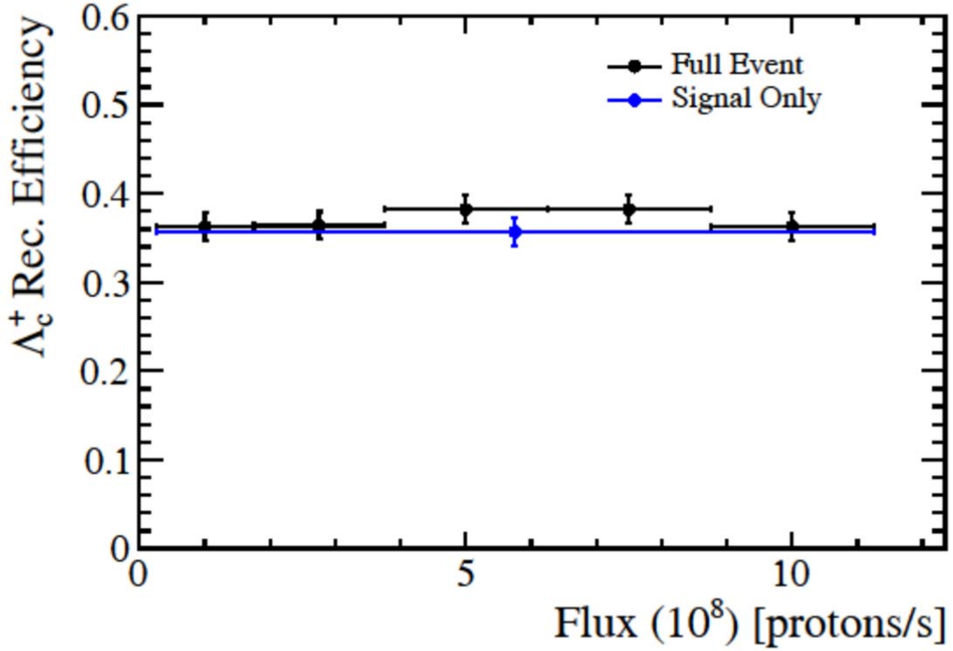




- Bkg rejection at 10^{-7} level and efficiency ~80%
- Vertex reconstruction and PID based on momentum hierarchy help

Main simulation results

- **Detector occupancies with 2×10⁸ p/s** on target 0.5 cm thick W target
  - ✓ ν=0.36 for W, ν≈1.4 (1.6) with Si (Ge)
  - ✓ ≈ generic $b\bar{b}$ events, for ν=7.6 pp collisions (LHCb upgrade conditions)
- **Reconstruction efficiency ≈ 35%**, for $\Lambda_c^+ \to pK^-\pi^+$
- **Resolutions**, for $\Lambda_c^+ \to pK^-\pi^+$
  - ✓ Angular (θ_y, θ_x) ≈ 25 μrad
  - ✓ invariant mass ≈ 15 MeV
  - ✓ *z* (*xy*) vertex 8 mm (50 μm)
- Efficiency and resolutions are **stable up to 10^9 p/s**
- Room to tune **proton flux**, **W thickness** and **operation mode**



*Synergetic means here not affecting the other LHC experiments except the host one.

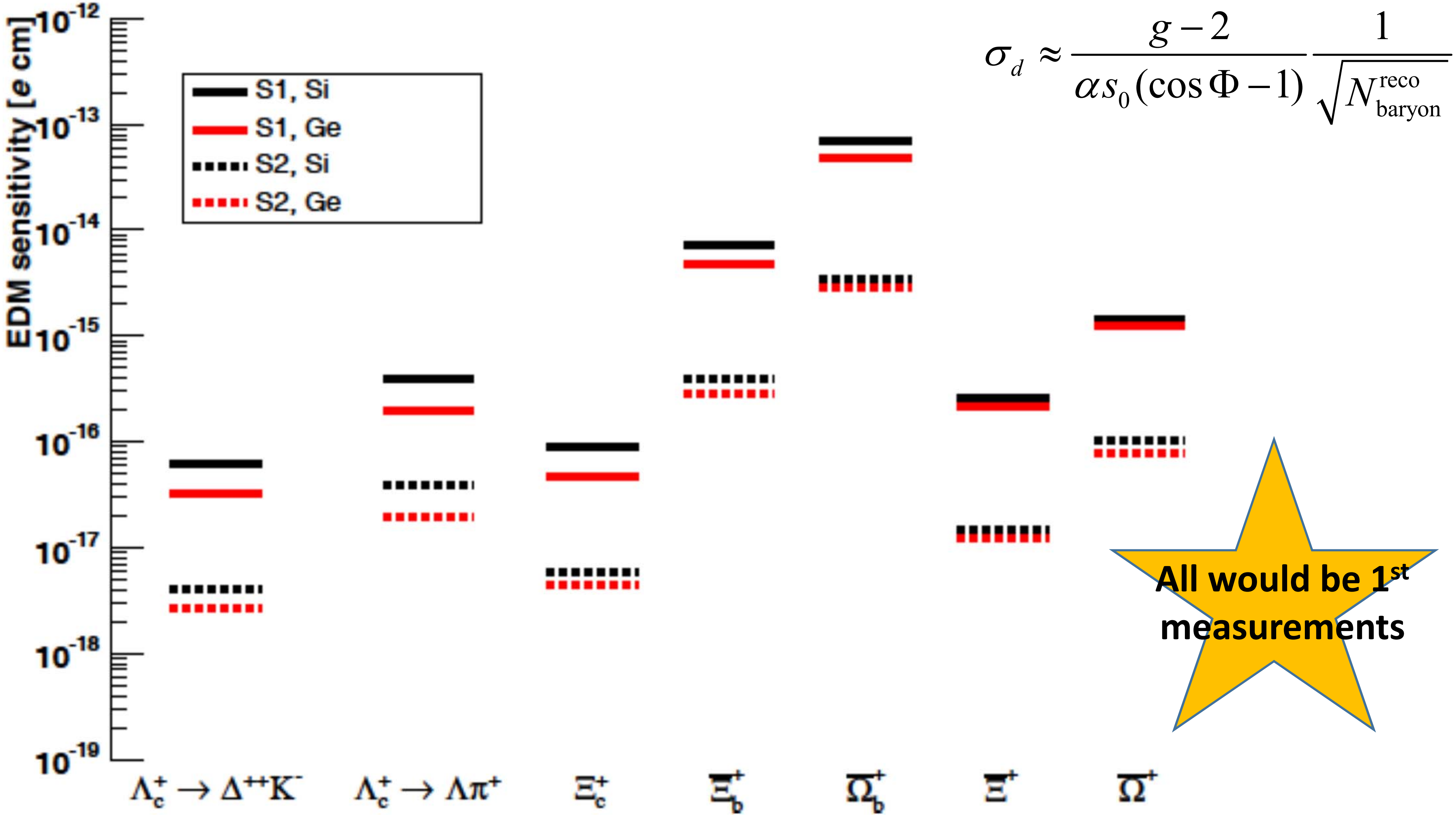
Sensitivity reach

- Cross-sections from measurements at other energies rescaled @ $\sqrt{s} \approx 115$ GeV
- Fragmentation fractions and BFs from measurements
- g–2, α, and s_0 @ $\sqrt{s} \approx 115$ GeV for heavy baryons poorly known, estimates from combination of lower energy data, models and theoretical estimates
- **Two scenarios**:

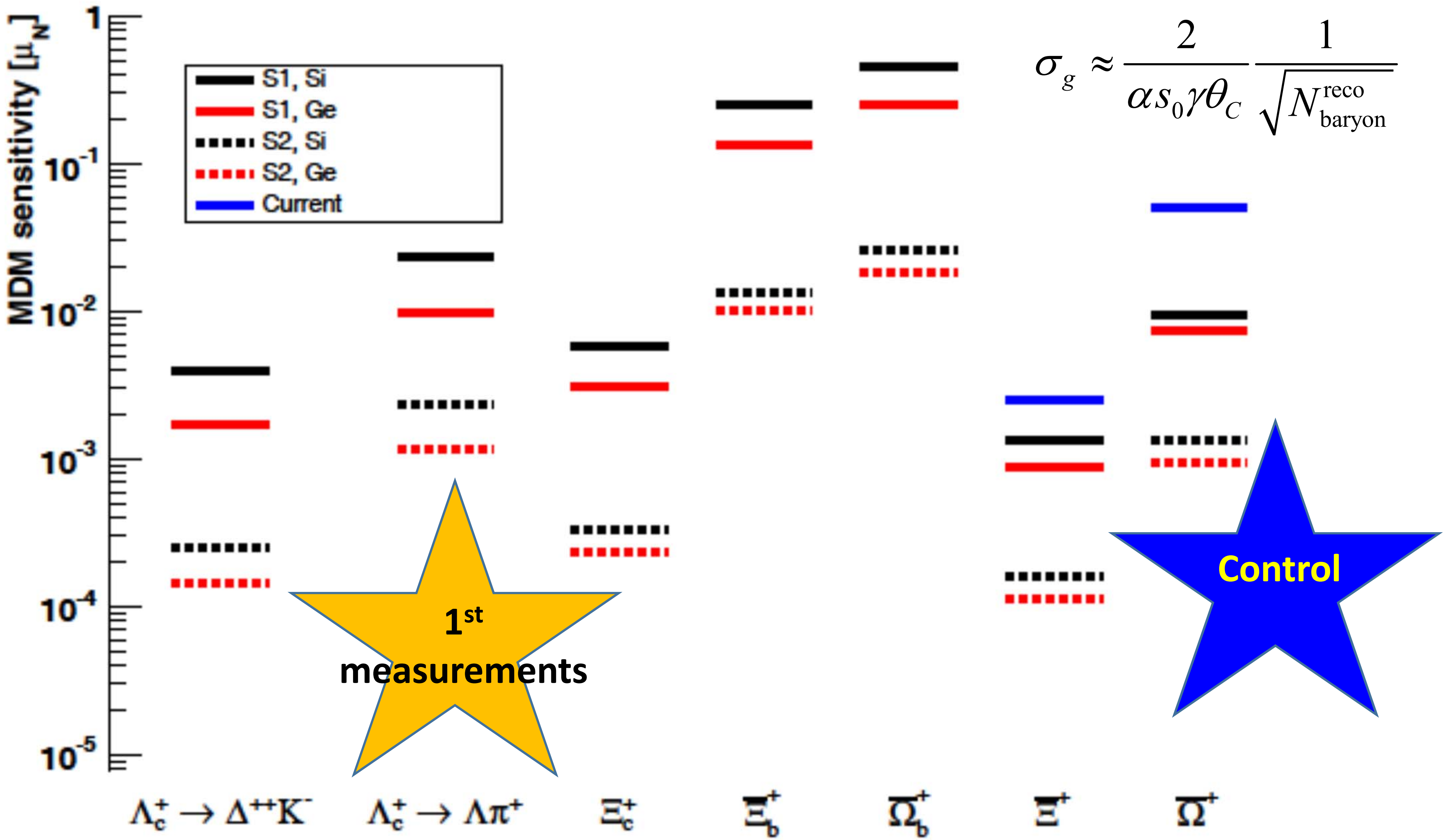
S1	S2
IR8 and LHCb	**Dedicated location**
	(see M. Ferrro-Luzzi talk)
10^{15} p on **0.5 cm W target** (5×10^{13} pW interactions) or **2.8×10^{14} p** on **2 cm W target**	Working assumptions: longer data taking, dedicated detector closer to target, capable to deal with higher occupancies, extended η coverage
	Bending angle > 5-6 mrad to separate channeled vs unchanneled baryons
	~10^{17} p on **0.5 cm W target**

Sensitivity reach: EDM

$$\sigma_d \approx \frac{g-2}{\alpha s_0 (\cos\Phi - 1)} \frac{1}{\sqrt{N_{\text{baryon}}^{\text{reco}}}}$$



Sensitivity reach: MDM



$$\sigma_g \approx \frac{2}{\alpha s_0 \gamma \theta_C} \frac{1}{\sqrt{N_{\text{baryon}}^{\text{reco}}}}$$

Summary

- A **bent crystal based experiment** is unique to access **heavy and strange baryon MDM and EDM**, extending the LHC physics potential
- **LHCb apparatus compatible** with the required setup:
  - ✓ Proton flux 10^8-10^9 p/s on 0.5 cm W target, to be tuned
  - ✓ Target position at (0, 0.4, –116) cm, azimuthal angle 65°
  - ✓ Up- and down-bending crystals, ≈6 cm long and ≈15 mrad bending, required for systematic cancellations
- **Ge crystals** provide significantly enhanced sensitivity
- With **10^{15} p** on **0.5 cm W target**,

	$\delta\,(e\text{ cm})$	$\mu\,(\mu_N)$
c	$\approx 10^{-17}$	$\approx 10^{-3}$
b	$\approx 10^{-14}$	$\approx 10^{-1}$
s	$\approx 10^{-15}$	$\approx 10^{-2}$

pp collision data @ 14 TeV and p-gas SMOG data @ 115 GeV will provide soon important measurements to refine these projections

NEED TO ASSESS THE PHYSICS IMPACT OF EDM/MDM SENSITIVITIES

NEED INPUT FROM THEORISTS !

Backup

Baryon MDMs

- Experimental anchor point for test of low-energy QCD models, related to **non-perturbative QCD** dynamics

Neetika et al, PRD**81**, 073001 (2010)

[nuclear magnetons]

Baryon	Data [3]	NRQM [4]	Lattice QCD [43]	QCDSR [12] QSSR [13]	LCQSR [14]	Valence	Sea	Orbital	Total
$\mu(\Lambda_c^+)$	$\cdots$	0.39	$\cdots$	0.15 ± 0.05	0.40 ± 0.05	0.409	-0.019	0.002	0.392
$\mu(\Xi_c^+)$	$\cdots$	0.39	$\cdots$	$\cdots$	0.50 ± 0.05	0.41	-0.02	0.01	0.40
$\mu(\Lambda)$	-0.613 ± 0.004	-0.65	-0.50 ± 0.07	-0.56 ± 0.15	-0.7 ± 0.2	-0.59	0.02	-0.01	-0.58
$\mu(\Xi^-)$	-0.651 ± 0.003	-0.53	-0.51 ± 0.07	-0.64 ± 0.06	-0.7 ± 0.2	-0.59	0.03	0.06	-0.50

Baryon	Data [3]	NRQM [4]	Lattice QCD [43]	QCDSR [12]	LCQSR [15]	Valence	Sea	Orbital	Total
$\mu(\Omega^-)$	-2.02 ± 0.06	-1.94	-1.40 ± 0.10	-1.49 ± 0.45	-1.65 ± 0.35	-1.76	0.08	-0.03	-1.71

Rohit, Kim, Verma, PRD**88**, 094002 (2013)

[nuclear magnetons]

Baryons	Effective Quark Mass	Screened Quark Charge	[39]	[12,39]	[38]	[36]	[30]	[17]
Ξ_b^-	-0.062	-0.066	-0.063	-0.050	$\cdots$	-0.06	$\cdots$	$\cdots$
Ω_b^-	-0.741	-0.863	-0.545	-0.79	-0.960	-0.82	$\cdots$	-0.714

✓ Discriminate among proposed models, which predict different MDM values

- **Test of quark structure**: an anomalous *g*–2 would be a sign of charm/beauty/strange quark substructure

Indirect baryon EDM limits: charm

Bound	Ref.	Measurement	Method
$\|d_c\| < 4.4 \times 10^{-17}$ ecm	Sala:2013osa	neutron EDM	Considers threshold contributions of d_c into d_d. Neglects all other contributions to the d_n.
$\|d_c\| < 3.4 \times 10^{-16}$ ecm	Sala:2013osa	BR($B \to X_s \gamma$)	Considers contributions from d_c to the Wilson coefficient C_7.
$\|d_c\| < 3 \times 10^{-16}$ ecm	Grozin:2009jq	electron EDM	Extracted from d_c threshold contribution to d_e through light-by-light scattering diagrams.
$\|d_c\| < 1 \times 10^{-15}$ ecm	Grozin:2009jq	neutron EDM	Similar approach than ref. Sala:2013osa. Evaluates contributions in two steps: c-quark → d-quark → neutron.
$\|d_c\| < 5 \times 10^{-17}$ ecm	Blinov:2008mu	$e^+e^- \to c\bar{c}$	The total cross section (LEP) might be enhanced by the charm qEDM vertex $c\bar{c}\gamma$.
$\|d_c\| < 8.9 \times 10^{-17}$ ecm	Escribano:1993xr	$\Gamma(Z \to c\bar{c})$	Measurement at the Z peak (LEP). Uses model dependent relationships to weight contributions from d_b and d_b^w.
		charm chromo-EDM	
$\|\tilde{d}_c\| < 1.0 \times 10^{-22}$ ecm	Sala:2013osa	neutron EDM	Considers threshold contributions of d_c into the light quark EDMs $d_{u,d}$ and the Weinberg operator w
$\|\tilde{d}_c\| < 3 \times 10^{-14}$ ecm	Kuang:2012wp	$\psi' \to J/\psi \pi^+ \pi^-$	The $\tilde{d}_c$ contributes to the static potential betwen c and $\bar{c}$ both in ψ' and J/ψ. It also affects the dynamical transition amplitudes

$$|\delta_c| < 10^{-17} - 10^{-15} \; e \text{ cm}$$

LACK OF THEORETICAL ACTIVITY !

Indirect baryon EDM limits: beauty

Bound	Ref.	Measurement	Method
$\|d_b\| < 7 \times 10^{-15}$ ecm	Grozin:2009jq	electron EDM d_e	From the b-quark EDM threshold contribution to d_e through light-by-light scattering diagrams
$\|d_b\| < 2 \times 10^{-12}$ ecm	Grozin:2009jq	neutron EDM d_n	Similar estimation but evaluating contributions in two steps: b-quark $\to$ up-quark $\to$ neutron
$\|d_b\| < 2 \times 10^{-17}$ ecm	Blinov:2008mu	$e^+e^- \to b\bar{b}$	The total cross section (LEP) might be enhanced by the charm qEDM vertex $b\bar{b}\gamma$.
$\|d_b\| < 1.22 \times 10^{-13}$ ecm	CorderoCid:2007uc	neutron EDM d_n	Similar estimation than Grozin:2009jq. But neglects longitudinal component in the W propagator, thus missing emerging divergences.
$\|d_b\| < 8.9 \times 10^{-17}$ ecm	Escribano:1993xr	$\Gamma(Z \to b\bar{b})$	Measurement at the Z peak (LEP). Uses model dependent relationships to weight contributions from d_b and d_b^W.
bottom chromo-EDM			
$\|\tilde{d}_b\| \lesssim 1.1 \times 10^{-21}$ cm	Konig:2014iqa using Chang:1990jv		

$$|\delta_b| < 10^{-17} - 10^{-12}\ e\ \text{cm}$$

LACK OF THEORETICAL ACTIVITY !

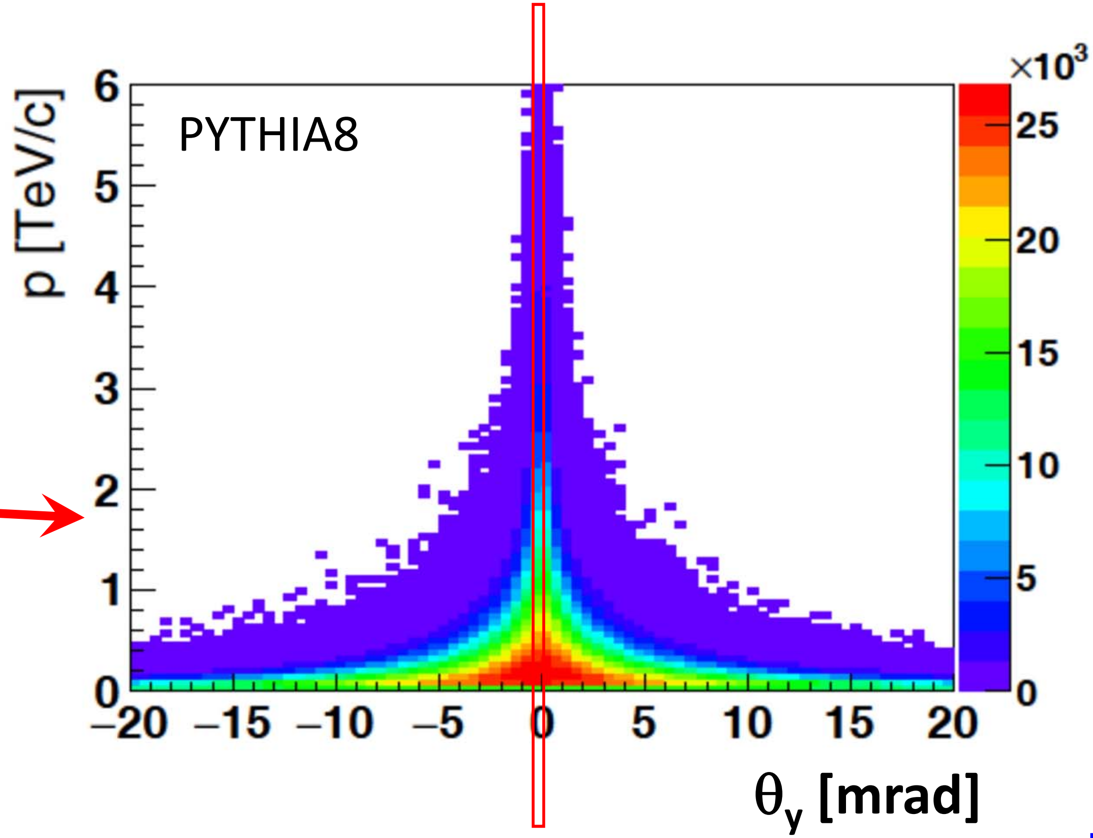
Baryon production

- For reaching channeling regime at TeV energies, baryon incident angle wrt crystallographic planes must be within ≈ few μrad
- Short-lived baryons and alignment with crystal impose the need for a **fixed-target experiment** with **high energy impinging beam**

✓ Angular divergence $\sim 1/\gamma$

✓ For 7 TeV LHC protons, *p*-N collisions at $\sqrt{s} \approx 115$ GeV/*c*

✓ Trapping efficiency $\sim 10^{-3}$ dominates channeling efficiency



Signal events (within ≈ 6-7 μrad)

Initial polarization

- Parity conserving production, **polarization transverse** to the proton-baryon production plane
- Unknown for p-N at $\sqrt{s}\approx$115 GeV/c
- $s_0 = -0.65\pm0.20$ from 230 GeV/c π^- on copper target, p_T>1.1 GeV/c

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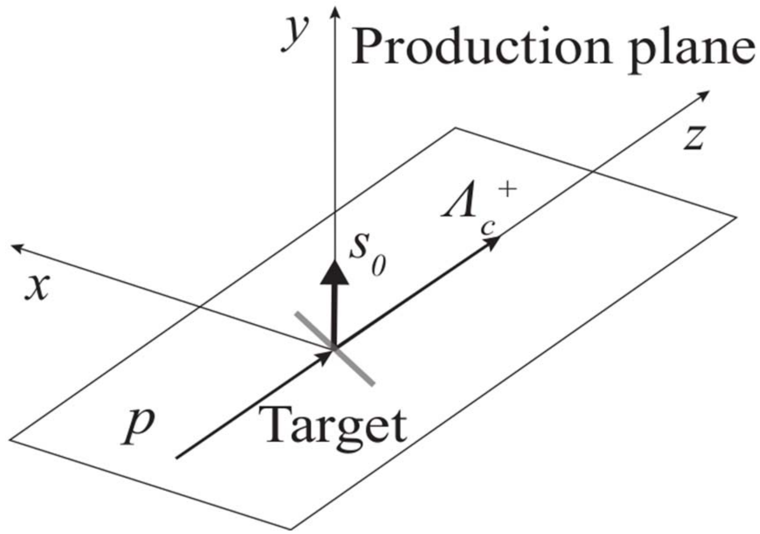
- Between ≈ 0.2 and –0.7 vs p_T from 500 GeV/c π^- on platinum and diamond thin target foils (E791)

PLB **471** (2000) 449



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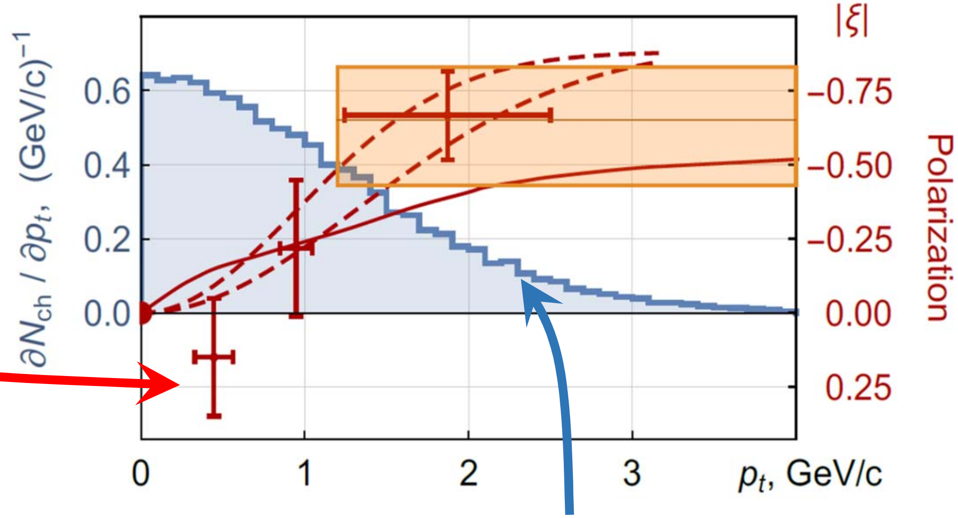

Channeled Λ_c^+
≈–0.4 average polarization

Spin rotation measurement

- Extract spin-polarization vector of channeled baryons from (quasi) two-body **angular analysis**, e.g. $\Lambda_c^+ \to \Delta^{++}K^-, p\overline{K}^{*0}, \Lambda\pi^+$

Very poorly known

$$\frac{dN}{d\Omega} \propto 1 + \alpha \mathbf{s} \cdot \mathbf{k}$$

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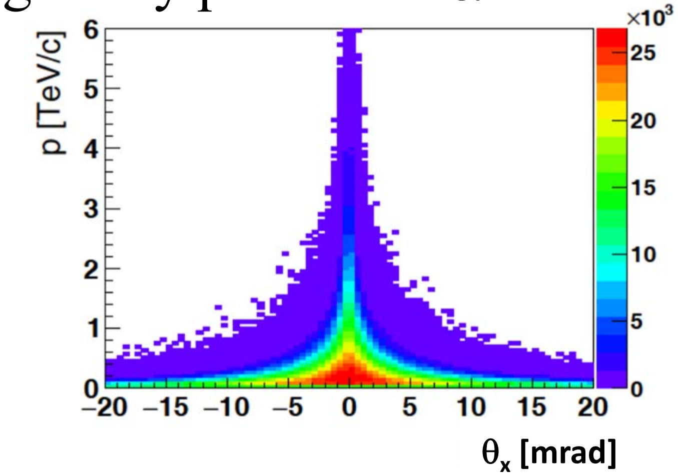
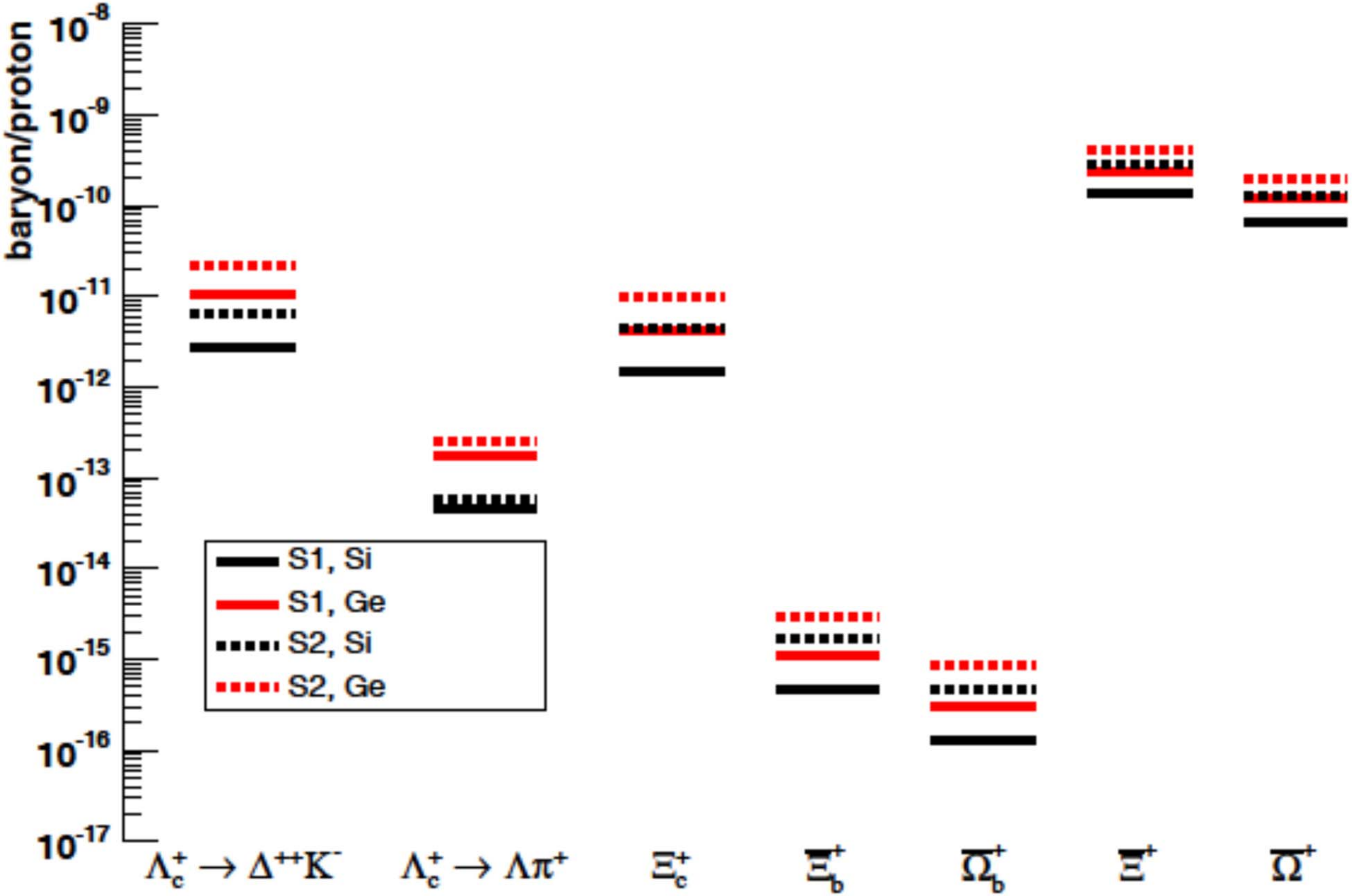
Decay		BF (%)	α
$\Lambda_c^+ \to pK^-\pi^+$	$\Delta^{++}(p\pi^+)K^-$	1.09 ± 0.25	-0.67 ± 0.30
	$\overline{K}^{*0}(K^-\pi^+)p$	1.98 ± 0.28	-0.54 ± 0.35
	$\Lambda(1520)(pK^-)\pi^+$	2.2 ± 0.5	-0.11 ± 0.60
	$pK^-\pi^+$ non res.	3.5 ± 0.4	?
$\Lambda_c^+ \to \Lambda\pi^+$		1.3	-0.91 ± 0.15

  - ✓ Holds for 1/2 → 1/2 + 0, 1/2 → 1/2 + 1, 1/2 → 3/2 + 0 decays
  - ✓ Requires precise knowledge of parity-violating decay parameter α
  - ✓ Ultimate sensitivity from amplitude analysis
- Can be done as a function of:
  - ✓ Boost, γ
  - ✓ Exit angle wrt x axis, θ_x



Baryon production rates



Sensitivity reach: inputs

- Cross-sections from measurements at other energies rescaled @ $\sqrt{s}$ ≈115 GeV
- Fragmentation fractions and BFs from measurements
- g–2, α, and s_0 @ $\sqrt{s}$ ≈115 GeV for heavy baryons poorly known, estimates from combination of lower energy data, models and theoretical estimates

Particle	Λ_c^+		Ξ_c^+	Ξ_b^+	$\overline{\Omega}_b^+$	$\overline{\Xi}^+$	$\overline{\Omega}^+$
Decay channel	$\Delta^{++}K^-$	$\Lambda\pi^+$	$\Delta^{++}K^-$	$\overline{\Xi}^+ J/\psi$ $\overline{\Xi}_c^0\pi^+$	$\overline{\Omega}^+ J/\psi$ $\overline{\Omega}_c^0\pi^+$	$\overline{\Lambda}\pi^+$	$\overline{\Lambda}K^+$
Cross section, σ [mb]	0.0182		0.0129	4.67×10^{-3}	4.67×10^{-3}	3.4	1.03
$\lvert s_0\rvert$	0.6		0.6	0.6	0.6	0.5	0.2
g'	−0.3		−0.3	1.4	5.8	1.9	2.2
$\mathcal{B}$	1.09%	0.83%	0.31%	2.9×10^{-6}	8.3×10^{-7}	63.83%	43.32%
α_f	−0.67	−0.91	−0.67	0.91	0.91	0.458	−0.642
R_{pT}				≈ 1			
$R_{\overline{q}/q}$	1		1	0.5	0.5	0.8	0.9

arXiv:1708.08483