SEARCH FOR NEW PHYSICS VIA BARYON EDM AT LHC

ANDREA MERLI

Università degli Studi di Milano & INFN

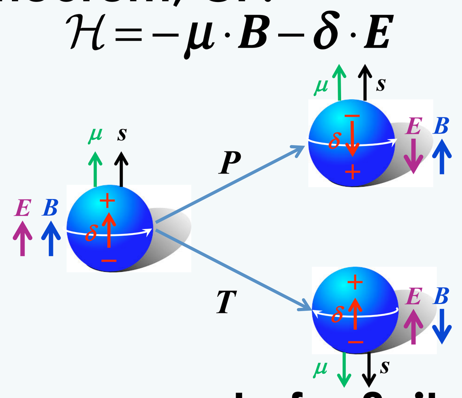
WHERE'S ANTI-MATTER?

- The Standard Model (SM) of particle physics cannot account for the observed matter-antimatter imbalance in the Universe. Physics beyond the SM (BSM) must bring new sources of CP violation (CPV) that need to be tested experimentally.

EDM: A GOLDEN OBSERVABLE

- The Electric Dipole Moment (EDM) of a particle violates P and T and, relying on the CPT theorem, CP.

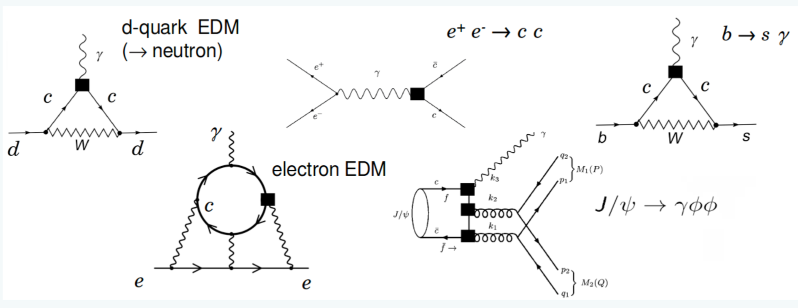
$$\mathcal{H} = -\mu \cdot B - \delta \cdot E$$



- Any measurement of a finite EDM would be a clear sign of BSM
- We propose to [1]:
  - measure for the first time the EDM of charmed baryons
  - improve the limits on the strange baryons EDM by 2 orders of magnitude
  - test CPT with measurements of baryons and anti-baryons magnetic dipole moment (MDM)

INDIRECT LIMITS

- The dipole couplings of the charm quark are bounded indirectly by different observables, using some model assumptions. These bounds, at the level of $<10^{-15}$-10^{-17} *ecm*, can be challenged with this proposal



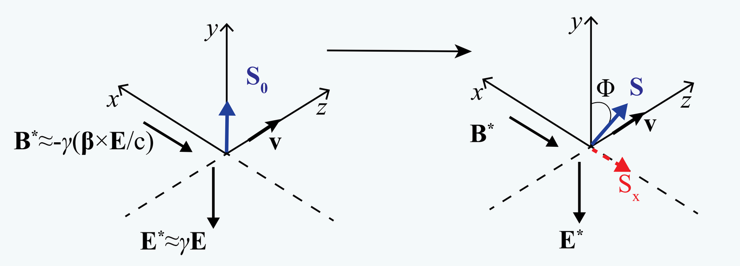
- The indirect limits on the s-baryons from the neutron EDM, $<10^{-23}$ *ecm*, are beyond the reach of this proposal.

SPIN PRECESSION

- In the presence of an electromagnetic field, the electric and magnetic moment of a particle induces a rotation of the spin-polarization vector (T-BMT equation). The MDM drives the main precession, around B*, while the EDM shifts the spin in the perpendicular direction, around E*.
- For short-lived charmed baryons, huge EM fields (~10^3 T) are needed. These are only achievable in the channeling process through a bent crystal. Any component $s_x \neq 0$ signals the presence of an EDM ($d \neq 0$),

$$s = s_0\left(\frac{d}{g-2}(\cos\Phi - 1), \cos\Phi, \sin\Phi\right)$$

$$\Phi \approx \frac{g-2}{2}\gamma\theta_c \qquad \theta_c \approx 10 \text{ mrad}$$



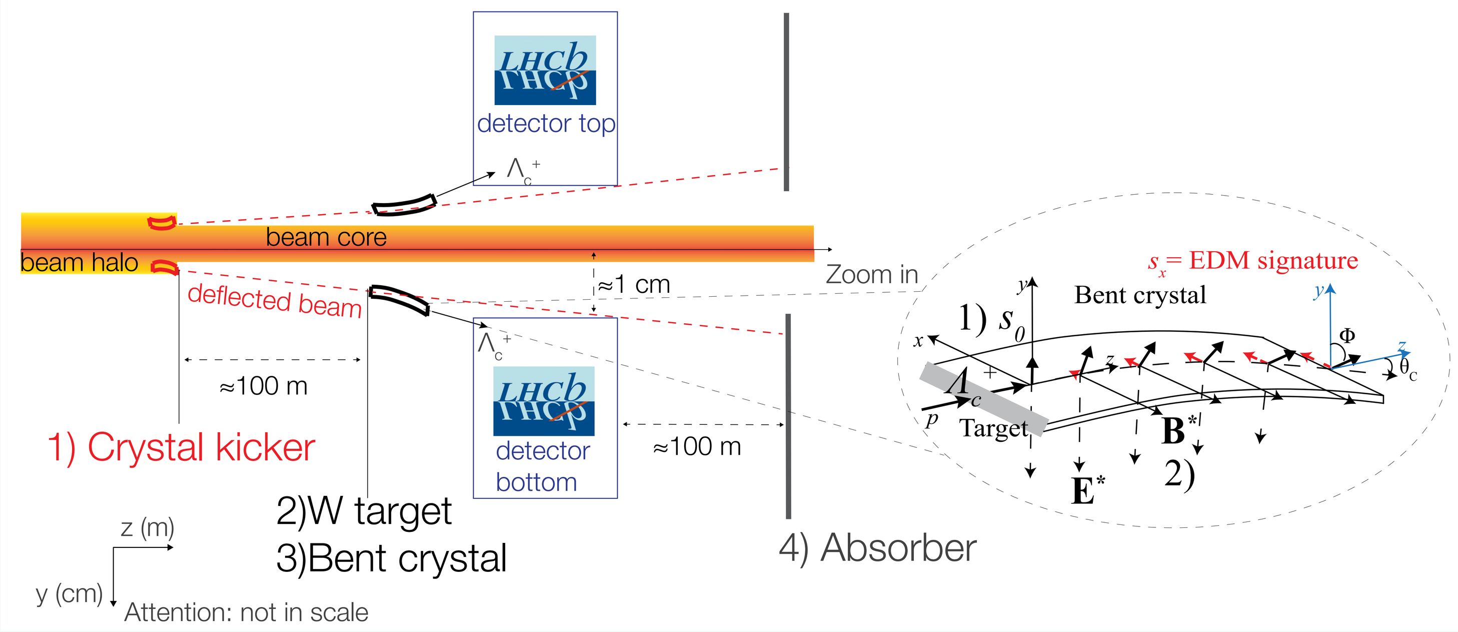
- In the case of strange baryons, the spin s precesses around the LHCb magnetic field (y-axis). A build-up of an s_y component is the EDM signature. For $s_0 = s_0\hat{z}$ and $B = B_y\hat{y}$,

$$s = s_0\left(-\sin\Phi, -\frac{d\beta}{g}\sin\Phi, \cos\Phi\right)$$

where $\Phi \approx \dfrac{gD_y e}{2\beta mc^2}$ $\quad D_y = \int_0^l B_y dl' \approx 4 \text{ T m}$

POSSIBLE REALIZATION AT LHCb

- **CHARM CASE**

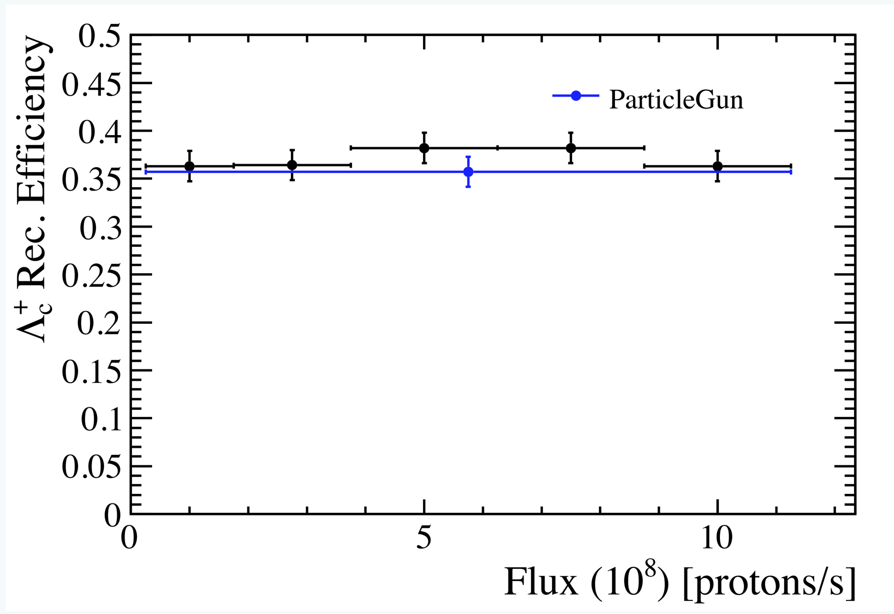


- A first bent crystal extracts protons from the LHC beam halo, which arrive on a fixed target
- Charmed baryons are produced with an initial polarization s_0~50% from strong interaction
- The spin-polarization vector precesses in the intense EM field between atomic planes of a second bent crystal (Si or Ge)
- The final polarization is measured in the LHCb detector through the angular distributions of the e.g. $\Lambda_c^+ \to pK^-\pi^+$ decay products

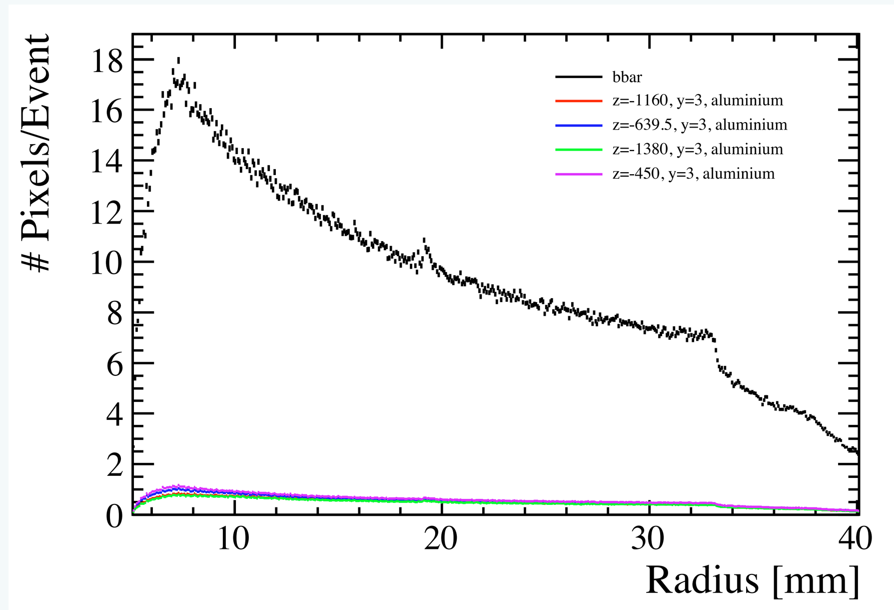
- **STRANGE CASE**
- Strange baryons are selected from charm-baryon decays, produced in pp collisions
- Large longitudinal polarization is induced in weak decays, s_0~90%
- The spin-polarization vector precesses in the magnetic field of the LHCb tracking system
- Challenging reconstruction of long-lived Λ particles through $\Lambda \to p\pi^-$

SIMULATION AT LHCb

RECONSTRUCTION EFFICIENCY



DETECTOR OCCUPANCY



- Dedicated run:
  - Reconstruction efficiency vs proton flux ~ constant
  - Higher flux to compensate less time of data taking.
  - Flux limited by the LHC beam dynamics: ~5x10⁸ p/s per target, ~10⁹ p/s in total
- Synergetic run with pp collision:
  - Occupancies under control with a flux of 10^7 p/s
  - Possibility to run in synergetic mode with pp collisions.
  - Flux is limited to avoid interference with $b\bar{b}$ events

SENSITIVITY: STRANGE

- Huge $c\bar{c}$ cross section at LHC yields, Λ selected from charm decays, $>10^{11}$ Λ per fb^{-1}

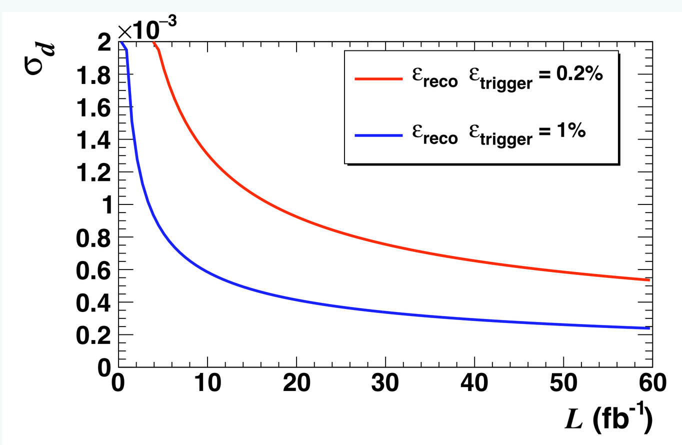
$$N_\Lambda = 2\mathcal{L}\sigma_{q\bar{q}} f(q \to H)\mathcal{B}(H \to \Lambda X')$$
$$\mathcal{B}(\Lambda \to p\pi^-)\mathcal{B}(X' \to \text{charged})$$

- Obtaining the geometrical efficiency from simulations and estimating reconstruction and trigger efficiencies,

$$\varepsilon_{det} = \varepsilon_{geo}\varepsilon_{reco}\varepsilon_{trigger} \approx 1.6 \times 10^{-3}$$

- At the end of Run3 (50 fb^{-1}), the Λ EDM upper limit will be improved by two orders of magnitude with respect to the current limit, reaching

$$\sigma_\delta \approx 1.3 \times 10^{-18} \text{ ecm}$$



- Measurement of the magnetic moment for Λ and $\bar{\Lambda}$ will allow the first CPT test via g-2 for an unstable baryon, at 10^{-3} level.

SENSITIVITY: CHARM

- The EDM uncertainty is dominated by statistics

$$\sigma_d \approx \frac{g-2}{\alpha s_0(\cos\Phi - 1)}\frac{1}{\sqrt{N^{reco}_{\Lambda_c^+}}}$$

- $N^{reco}_{\Lambda_c^+}$ is the number of Λ_c^+ baryons produced in the target, channeled in the crystal, reaching its end (without decaying inside), and reconstructed by the detector,

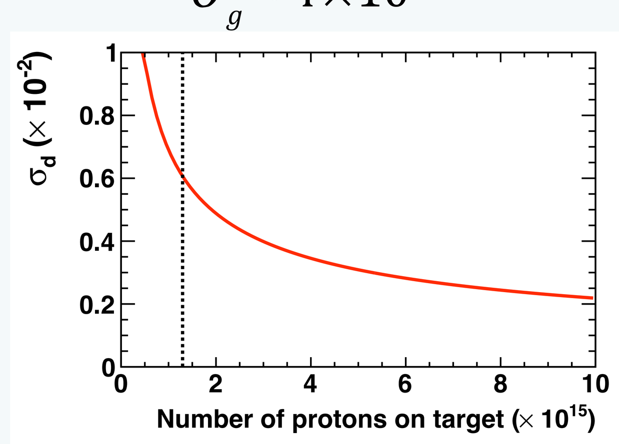
$$\frac{dN^{reco}_{\Lambda_c^+}}{dt} = \frac{dN_{\Lambda_c^+}}{dt}\mathcal{B}(\Lambda_c^+ \to \Delta^{++}K^-)\varepsilon_{chan}\varepsilon_{decay}\varepsilon_{det} \approx 21.2 \text{ h}^{-1}$$

- With ~ one month of data taking at flux 5x10⁸ Hz (~10^{15} protons on target) the EDM sensitivity would be

$$\sigma_\delta \approx 1.3 \times 10^{-17} \text{ ecm}$$

- The Λ_c^+ magnetic moment can be measured, for the first time, with

$$\sigma_g \approx 4 \times 10^{-3}$$



CONCLUSIONS AND PROSPECTS

- First EDM search and MDM measurement of charmed baryons. Can open new research opportunities to probe BSM physics.
- Extends the LHC physics program including direct spin precession measurements
- Can be extended to positive anti-hyperons and eventually to b-baryons

BIBLIOGRAPHY

[1] F. J. Botella, L. M. Garcia Martin, D. Marangotto, F. Martinez Vidal, A. Merli, N. Neri, A. Oyanguren and J. Ruis Vidal. *On the search for the electric dipole moment of strange and charm baryons at LHC* Eur. Phys. J., C77(3):181,2017

Andrea.Merli@mi.infn.it