Towards the measurement of electromagnetic dipole moments of strange and charm baryons at LHC

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Electromagnetic dipole moments: what? why?

Static property of particles

In a quantum system, for spin ½ particles:

- Electric dipole moment (**EDM**)

$$\boldsymbol{\delta} = \frac{1}{2} d \mu_B \mathbf{P}$$

- Magnetic dipole moment (**MDM**)

$$\boldsymbol{\mu} = \frac{1}{2} g \mu_B \mathbf{P}$$

with the spin polarization vector:

$$\mathbf{P} = 2 < \mathbf{S} > / \hbar$$

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P, T

$$H = -\delta \cdot E - \mu \cdot B$$

$$H = +\delta \cdot E - \mu \cdot B$$

- **EDM** violates T and P → **CP violation** via CPT theorem
- SM prediction (from neutron EDM): EDM < 10^{-26} e cm [1]→ sensitive to physics **Beyond the Standard Model** at the current experimental sensitivity
- **MDM** measurement of particle and anti-particle → **CPT invariance test**
- **MDM** measurement → experimental test of low-energy **QCD models**, related to non-perturbative QCD dynamics + sensitive to internal baryon dynamics

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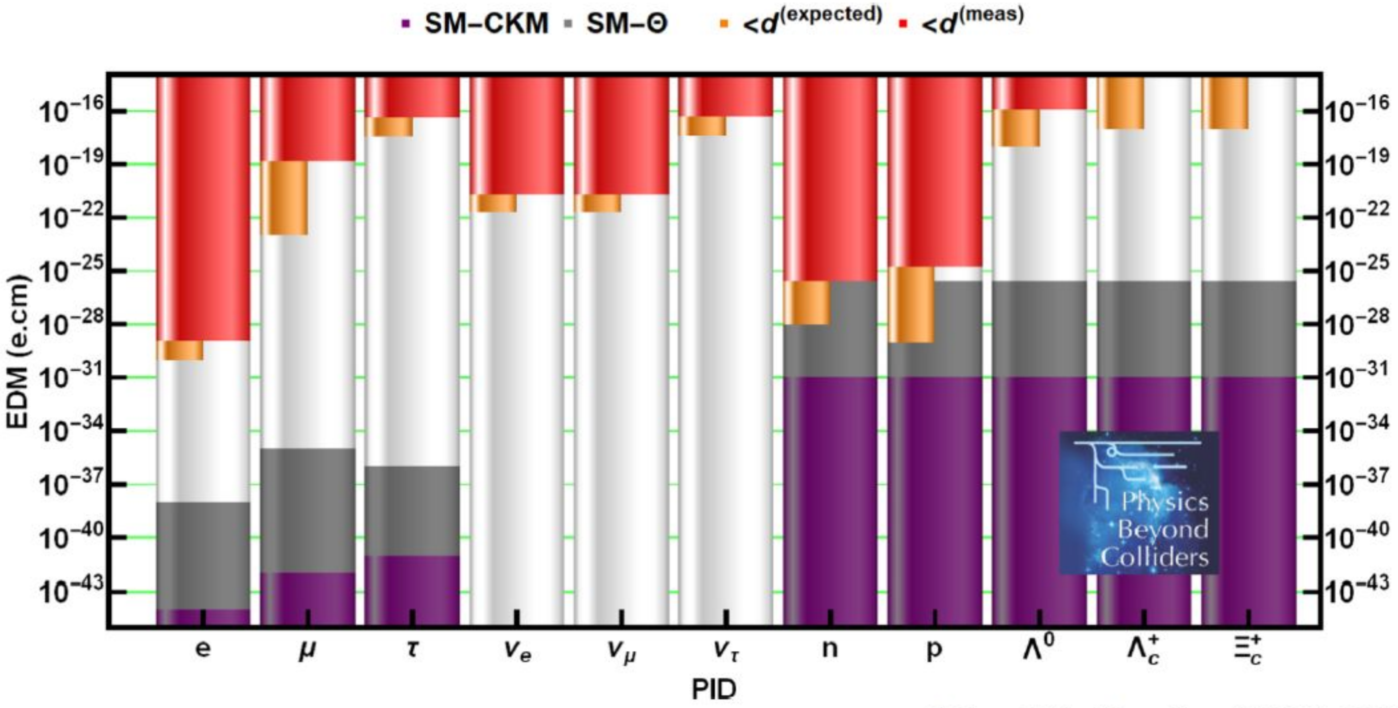
Electromagnetic dipole moments: why?



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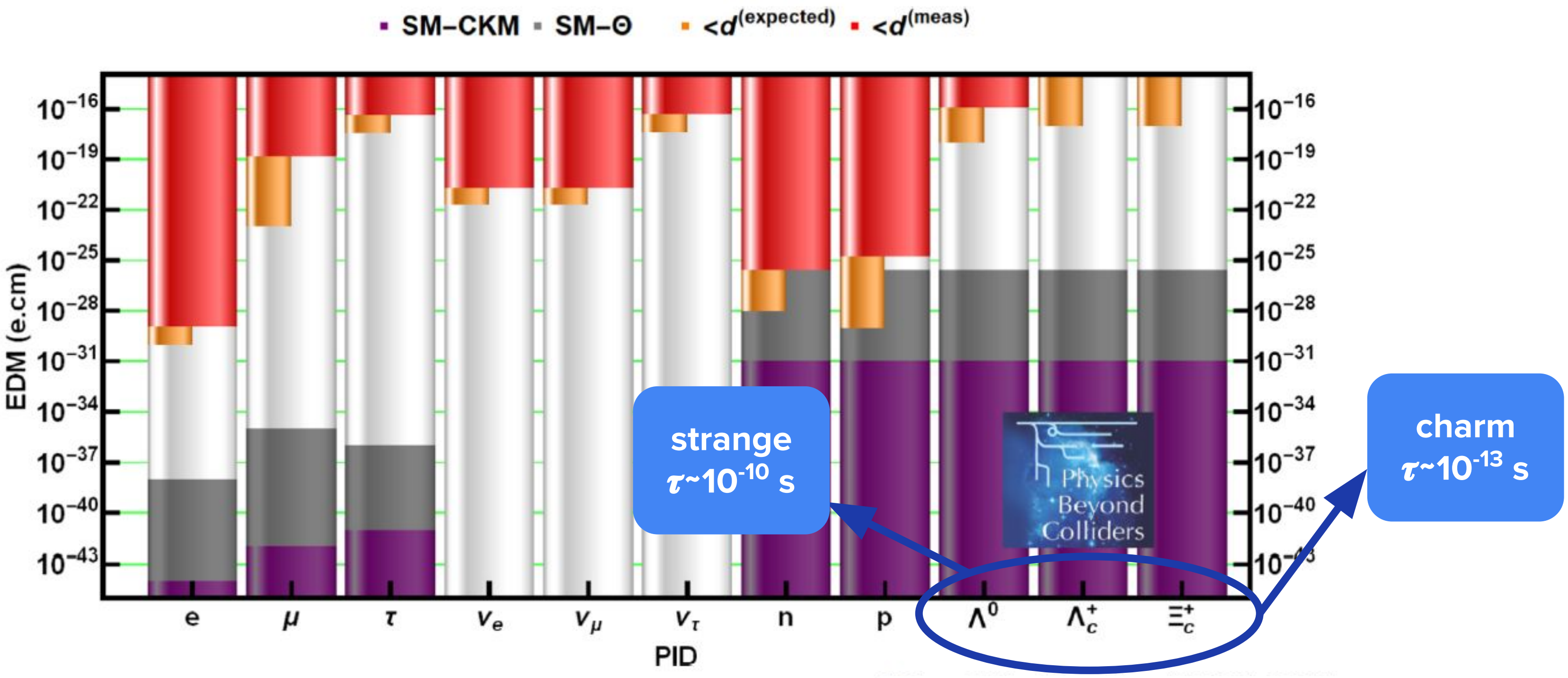

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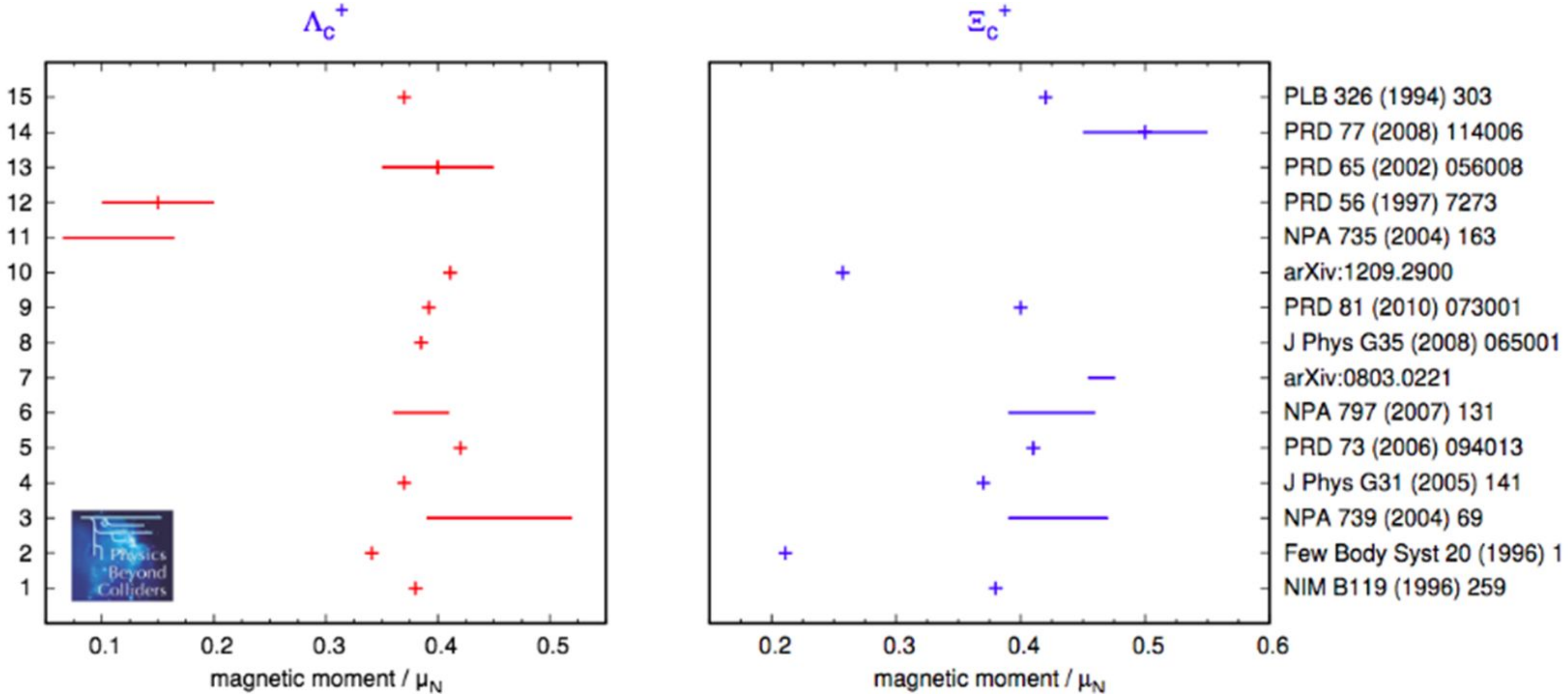

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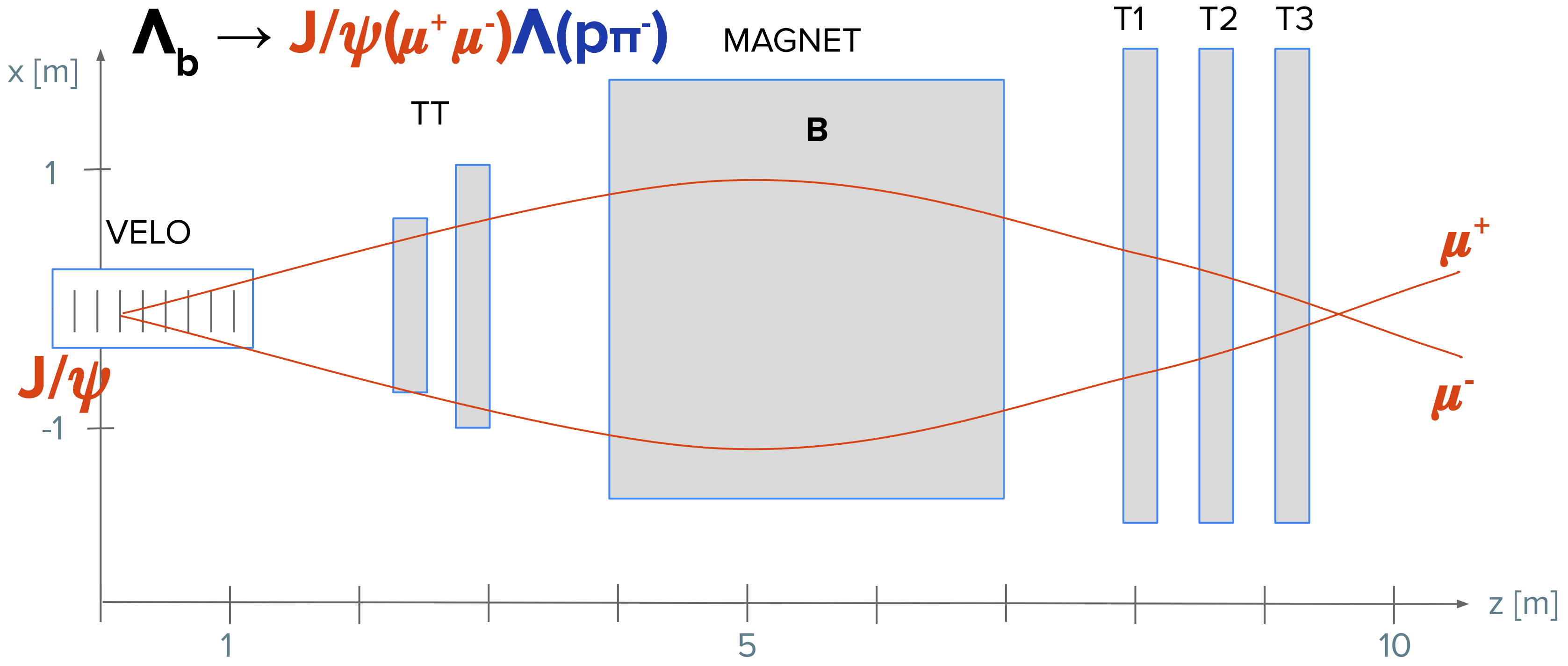
Electromagnetic dipole moments: how?

strange

Polarization precession in electromagnetic field: Λ at LHCb experiment

$\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda(p\pi^-)$



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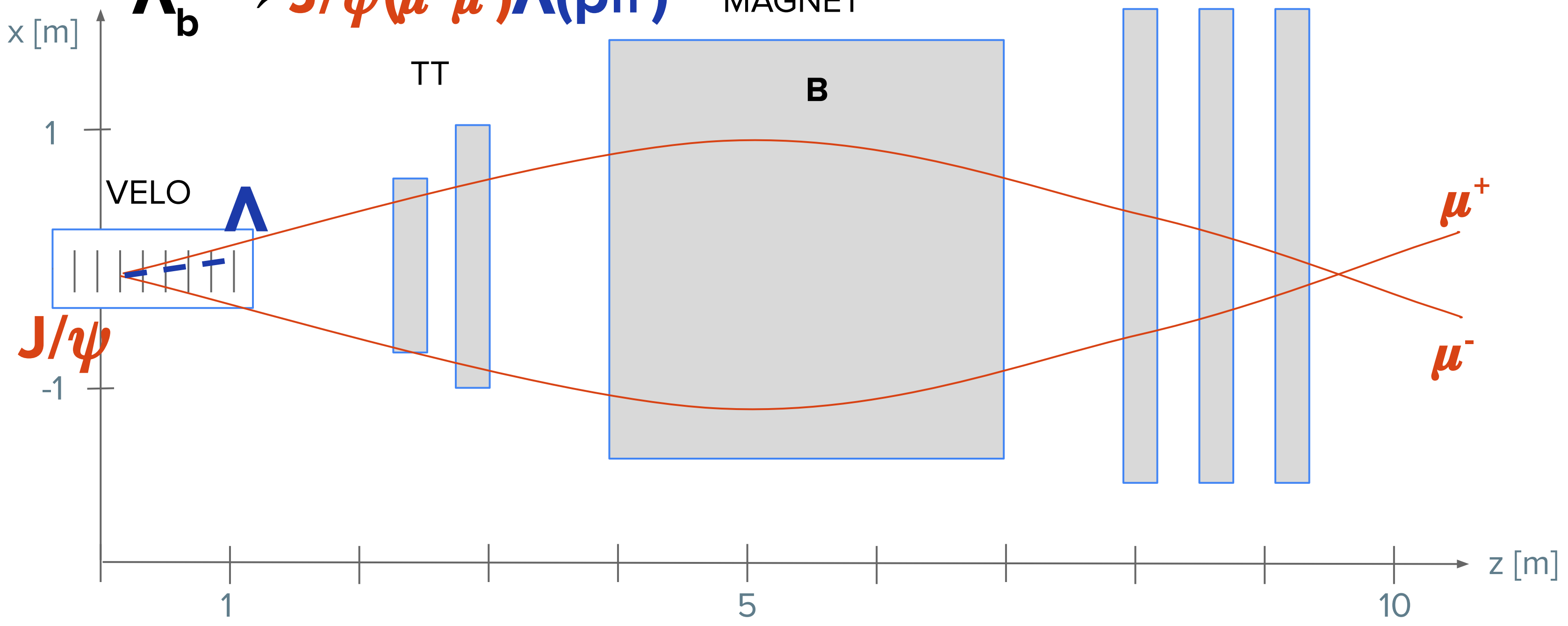

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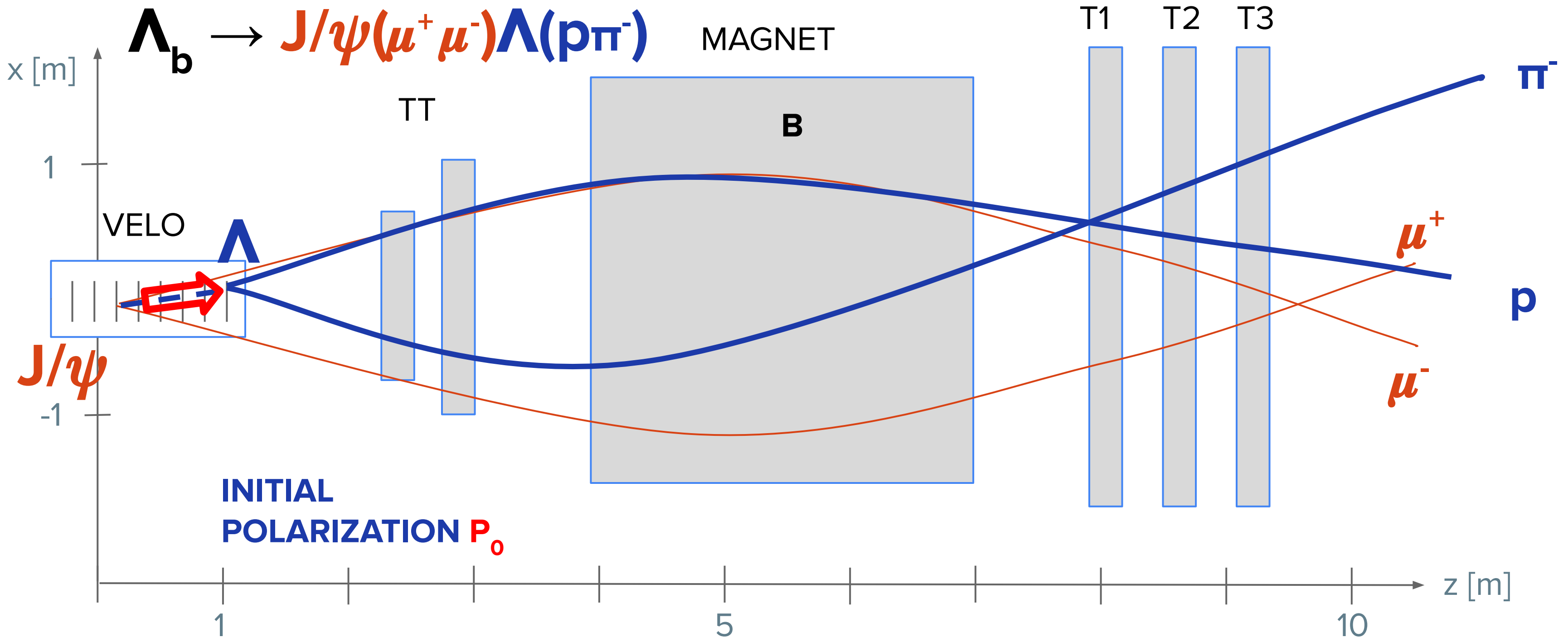

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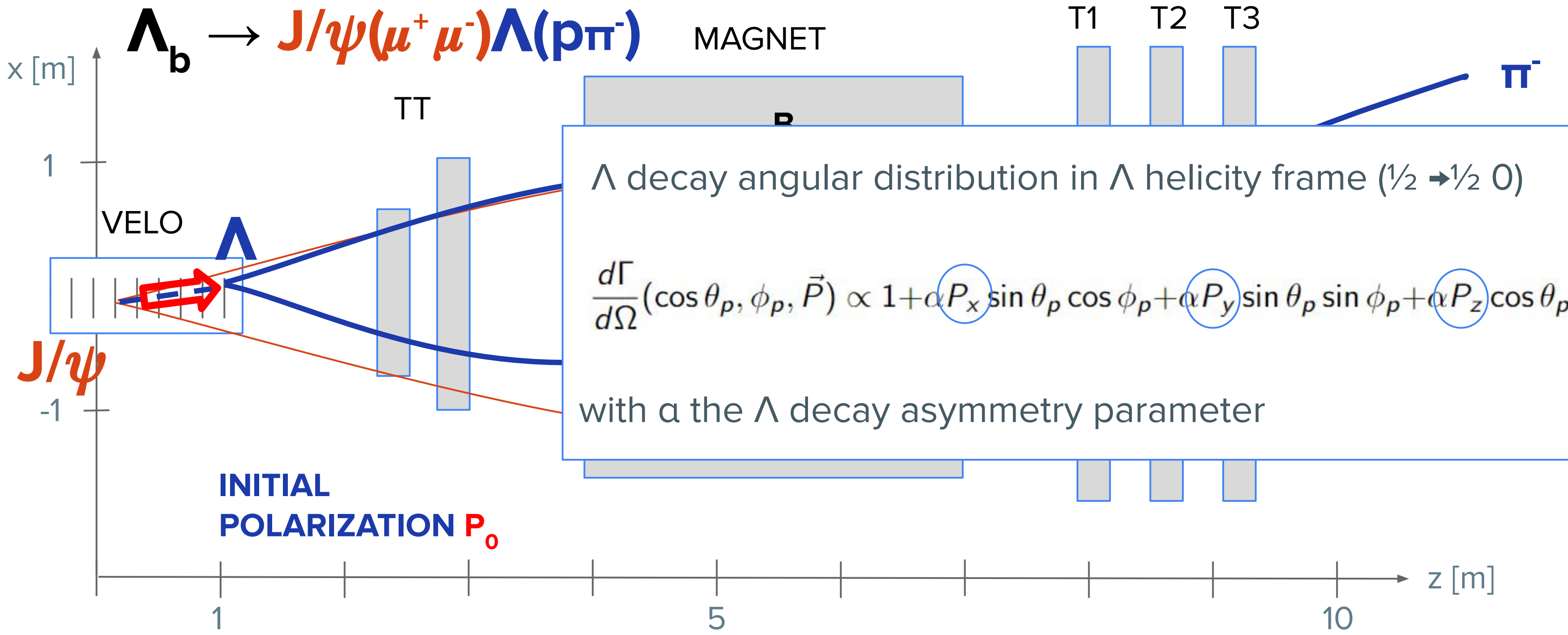

Λ decay angular distribution in Λ helicity frame (½ →½ 0)

$$\frac{d\Gamma}{d\Omega}(\cos\theta_p, \phi_p, \vec{P}) \propto 1+\alpha P_x \sin\theta_p \cos\phi_p + \alpha P_y \sin\theta_p \sin\phi_p + \alpha P_z \cos\theta_p,$$

with α the Λ decay asymmetry parameter

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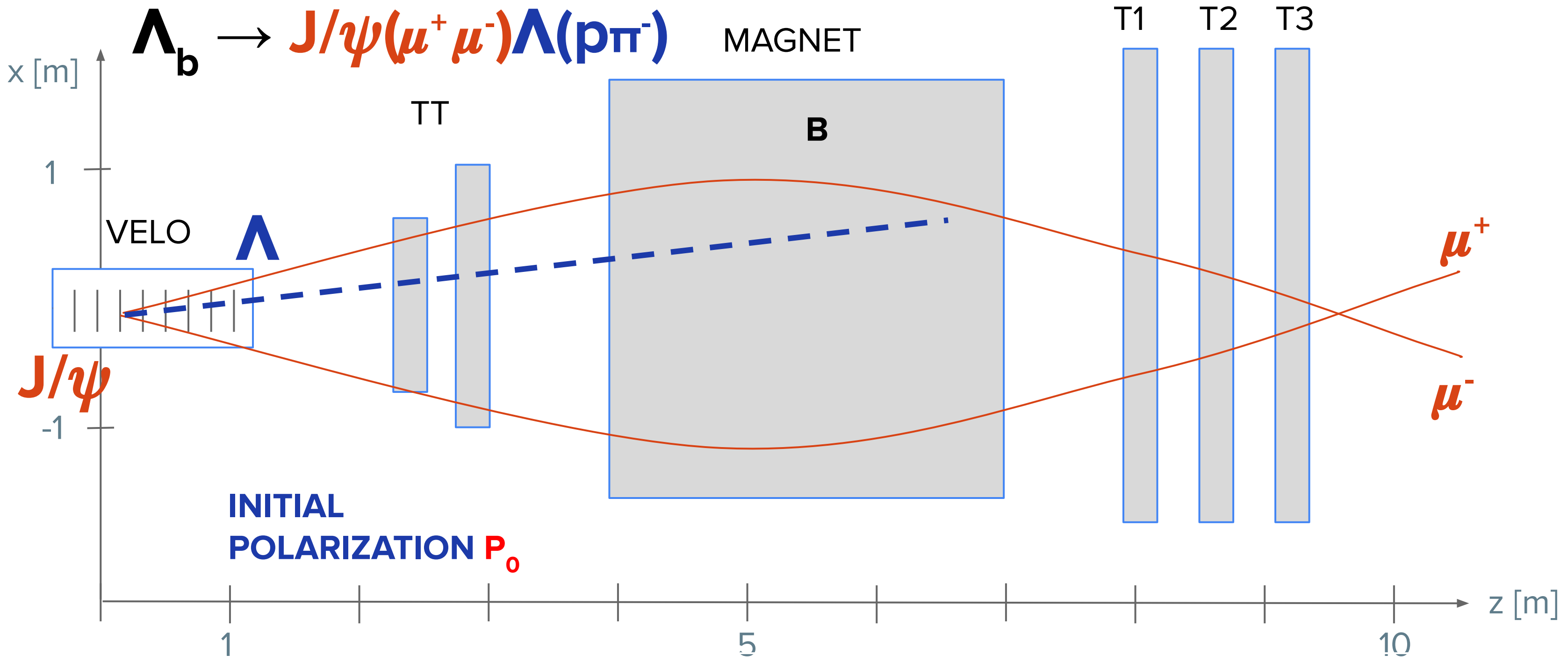

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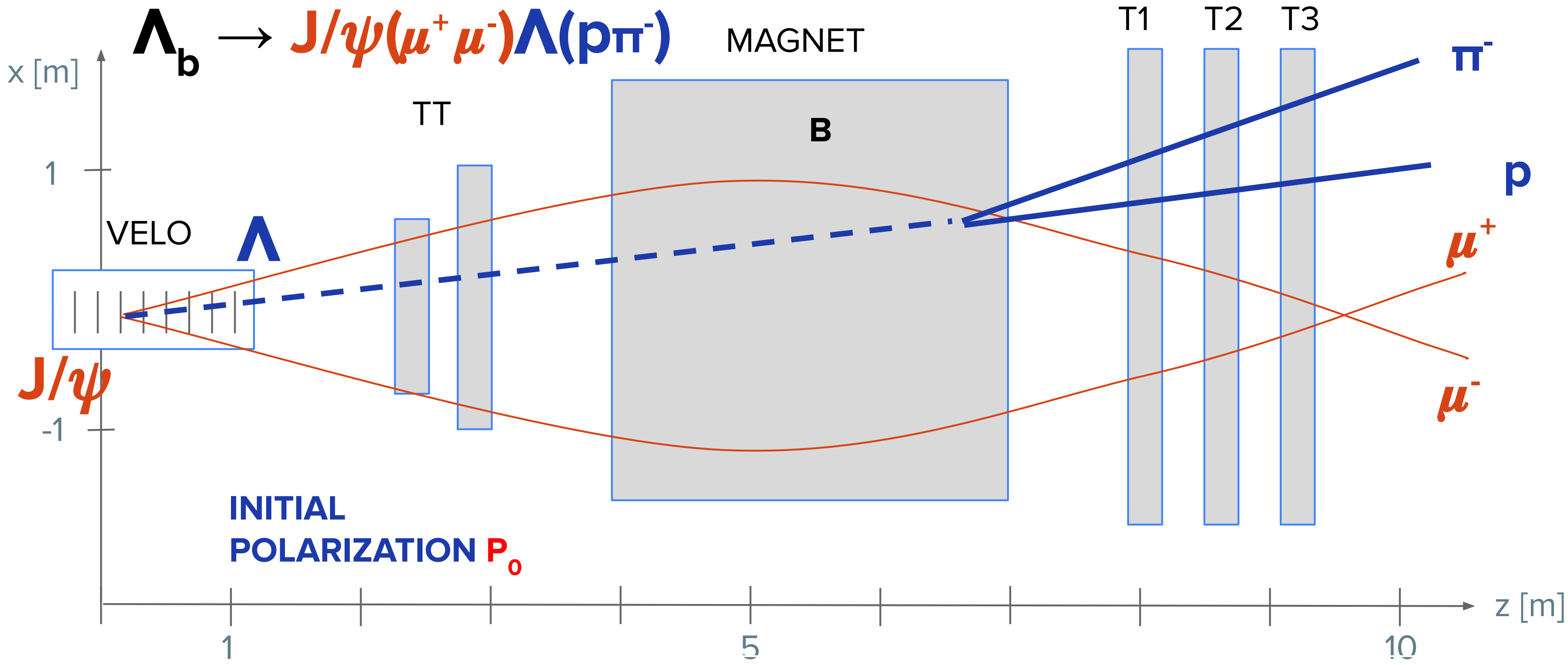

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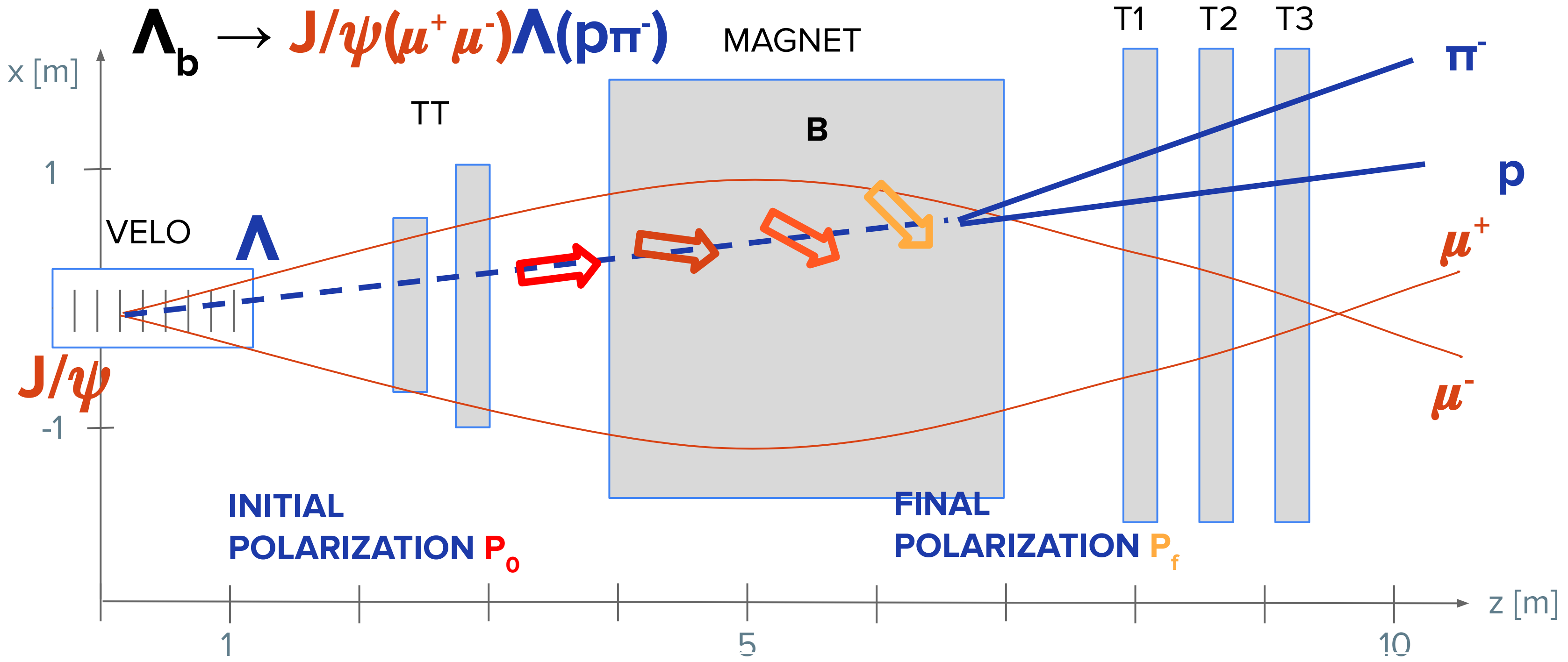

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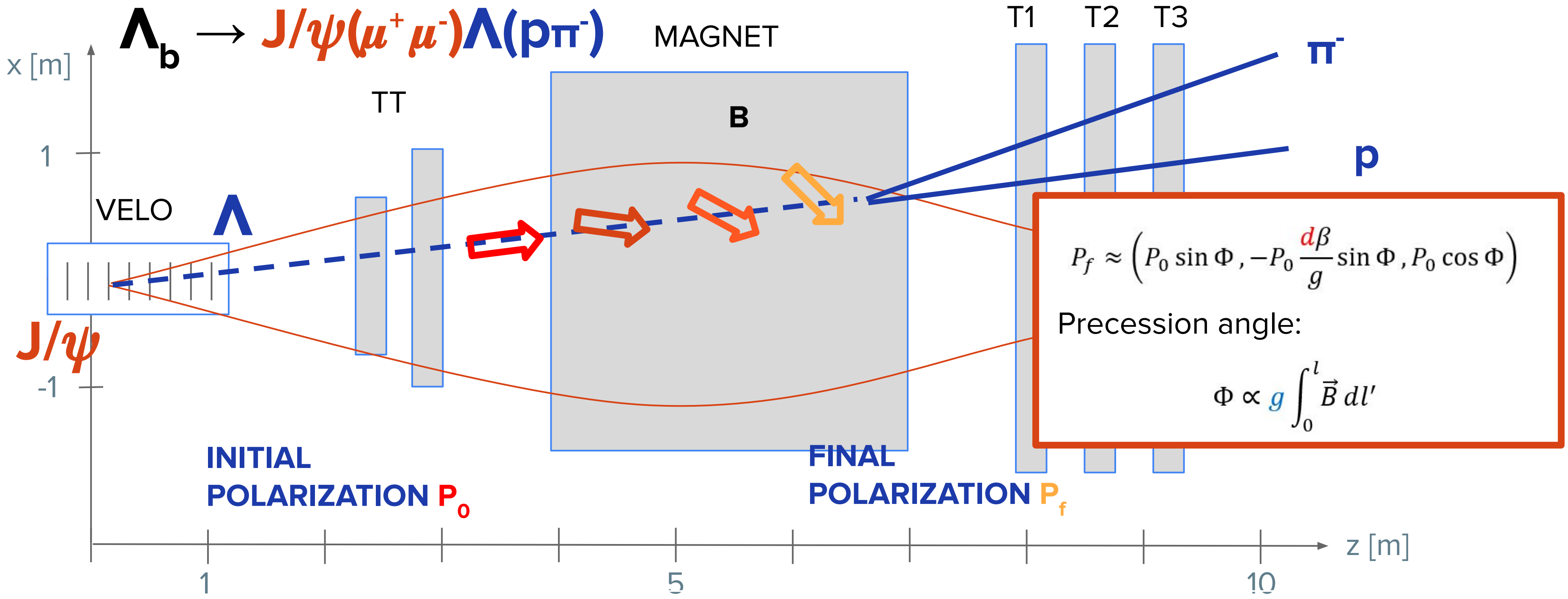

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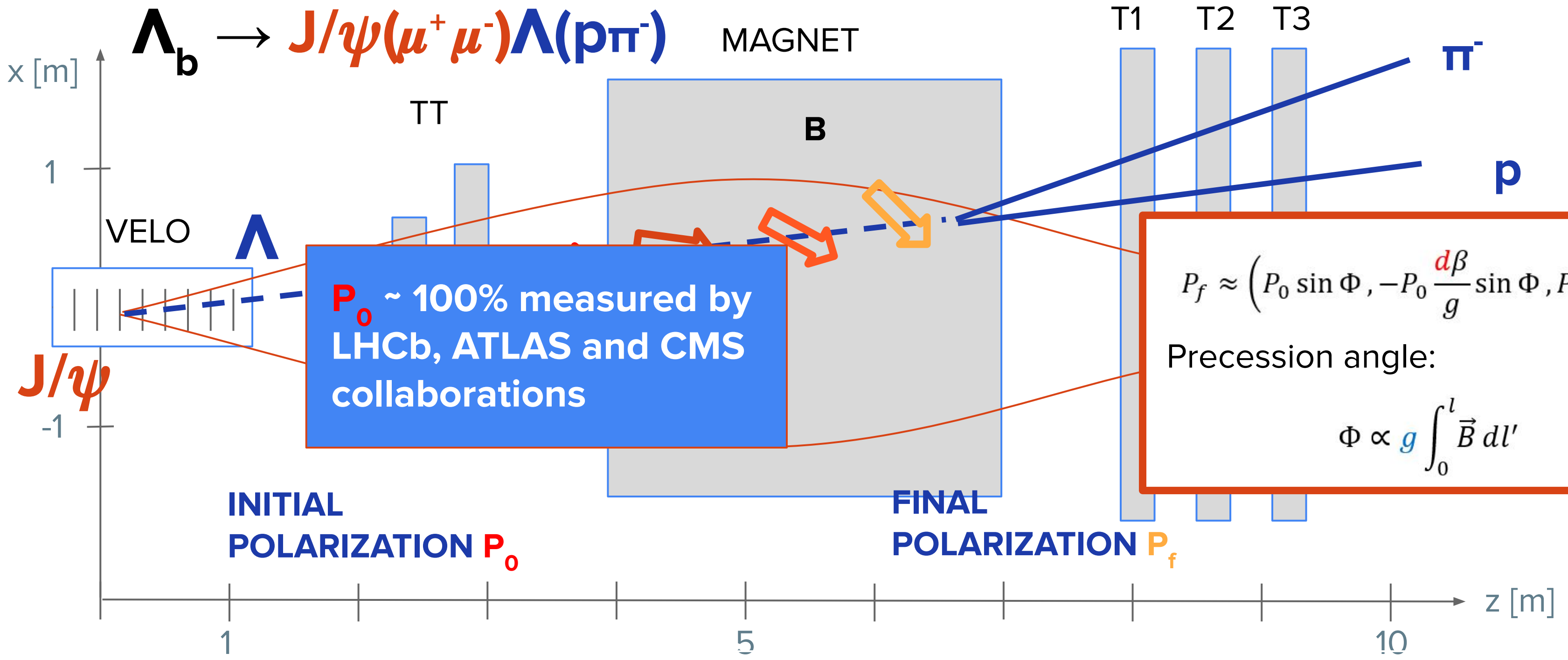

$$P_f \approx \left(P_0 \sin\Phi\,, -P_0 \frac{d\beta}{g} \sin\Phi\,, P_0 \cos\Phi\right)$$

Precession angle:

$$\Phi \propto g \int_0^l \vec{B}\, dl'$$

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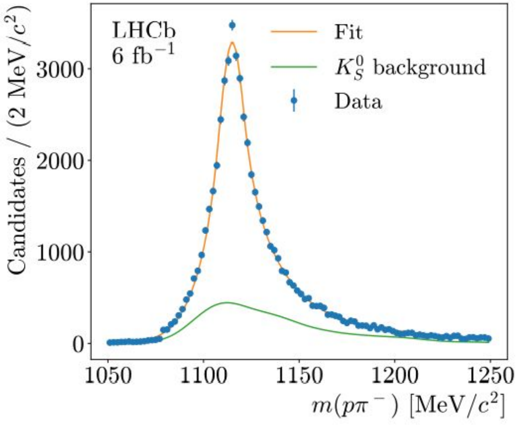
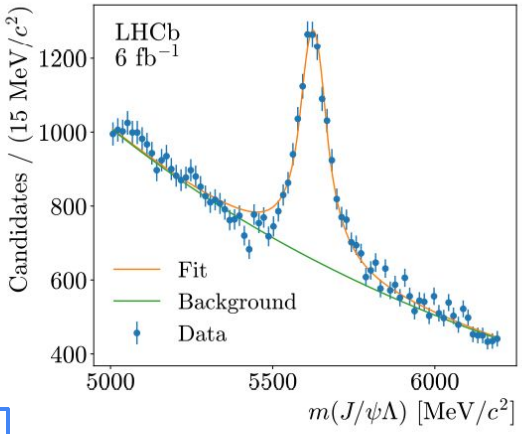
Electromagnetic dipole moments: how? Final polarization P_f

strange

- **Most challenging** part: never performed a physics measurement at LHCb with particles decaying at the end of the magnetic field, between about 6 and 8 m after production (poor resolution)





- **Reconstruction** feasibility **demonstrated** (LHCb-DP-2022-001 paper shortly released by LHCb)

Next step: polarization and first electromagnetic dipole moments **measurements**

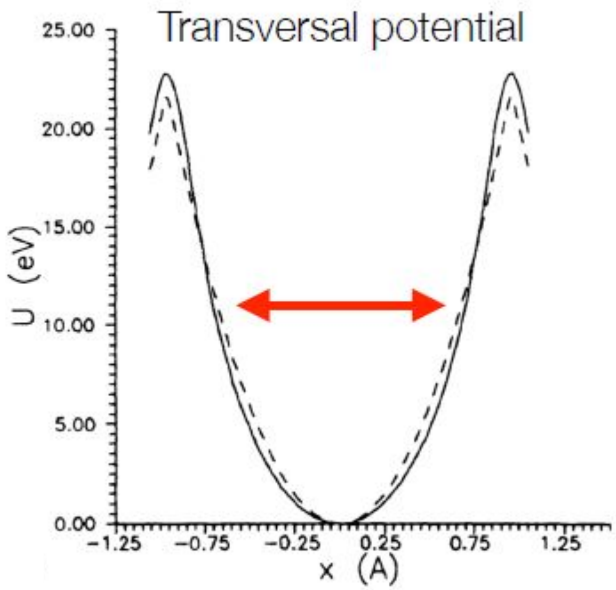
Electromagnetic dipole moments: how?

charm

Very short-lived particles (~ 5 cm) ➔ need large EM field in small space (~ 10^3 T)

Bent crystals:

- Electric field between atomic planes **E ≈ 1 GV/cm**
- Incident positively-charged particles can be **trapped** if their transverse energy is small ⇒ small incident angle w.r.t the crystal planes (few µrad)
- To induce a net EM field, the crystal must be bent ⇒ effective magnetic field of **B≈500 T** ⇒ **spin precession**



[1] Pis’ma Zh. Tekh. Fiz. **5** (1979) 182
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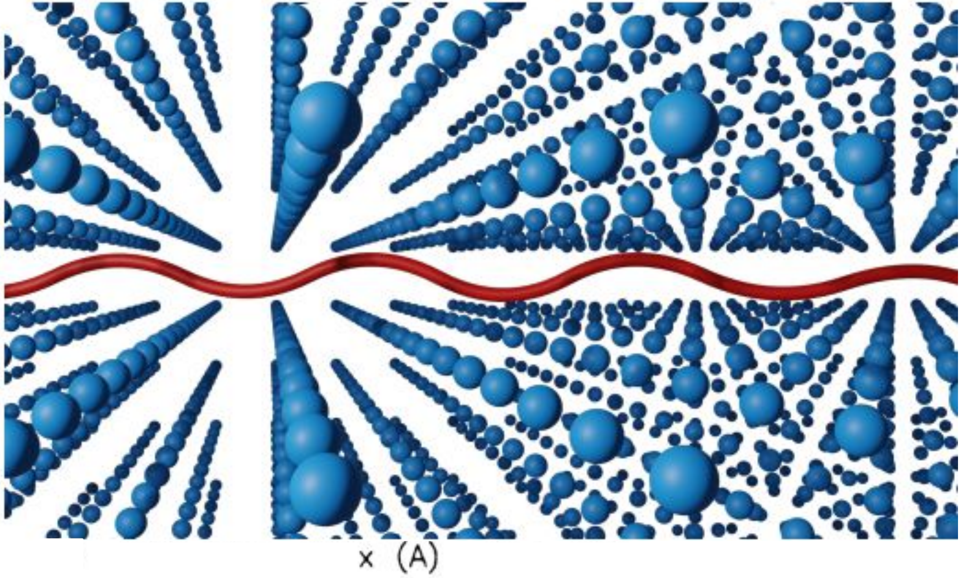

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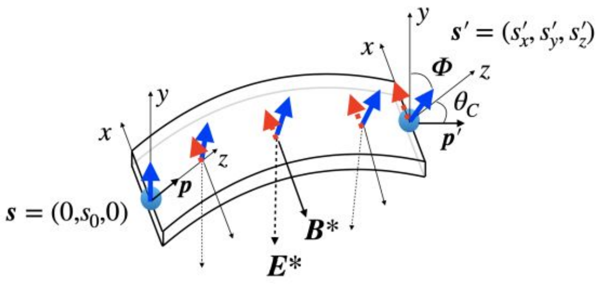
$$\mathbf{s} \approx s_0 \left(\frac{d}{g-2}(\cos\Phi - 1),\ \cos\Phi,\ \sin\Phi \right) \ , \quad \Phi \approx \frac{g-2}{2}\gamma\theta_C \approx \pi$$

Initial polarization (s_0) perpendicular to the production plane



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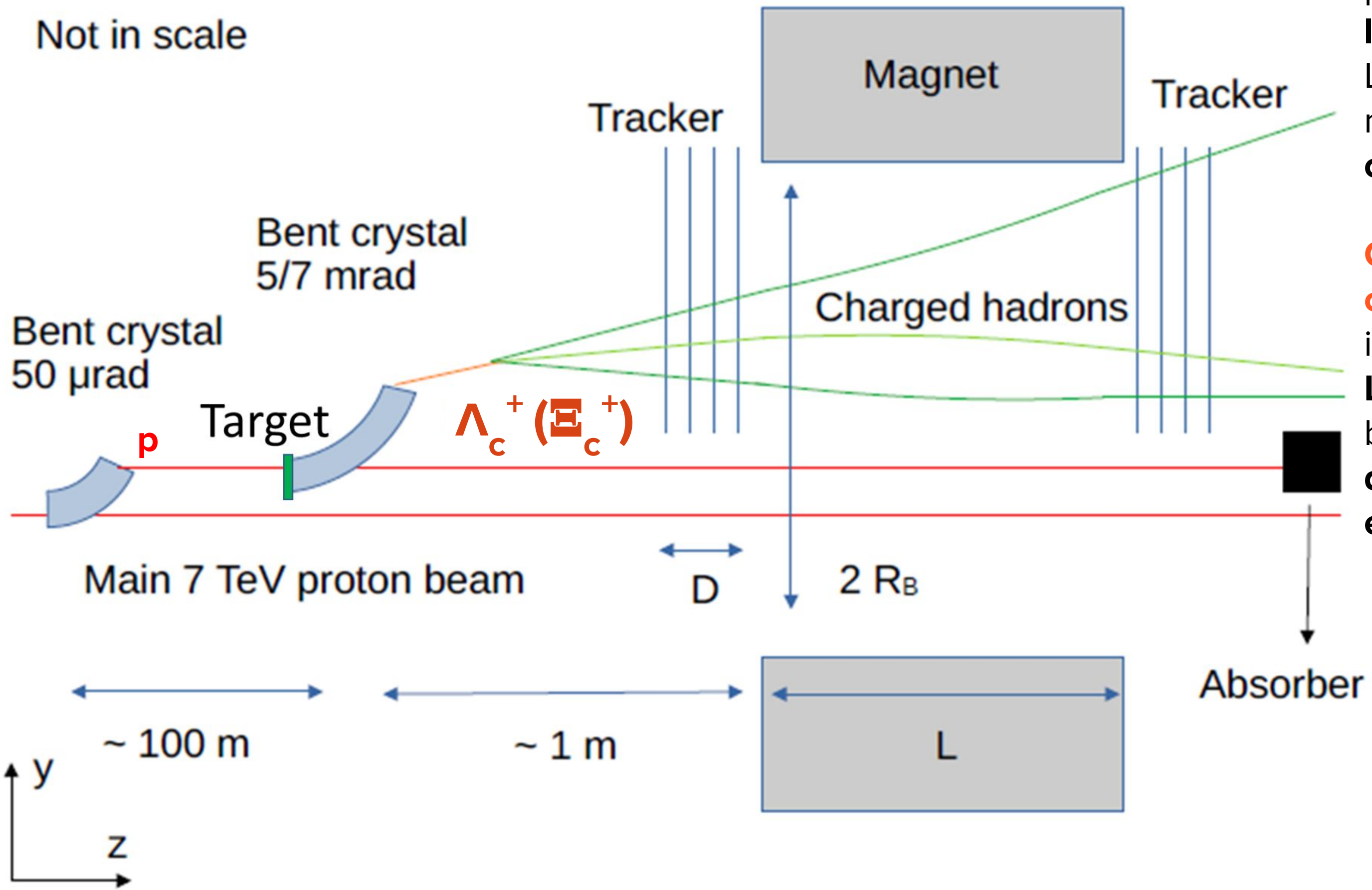
Proof of principle test at LHC



Goal of the test: prove the **layout** at the LHC energy and measure crystal **channeling**

Once completed: install in front of **LHCb** or build a **dedicated experiment**

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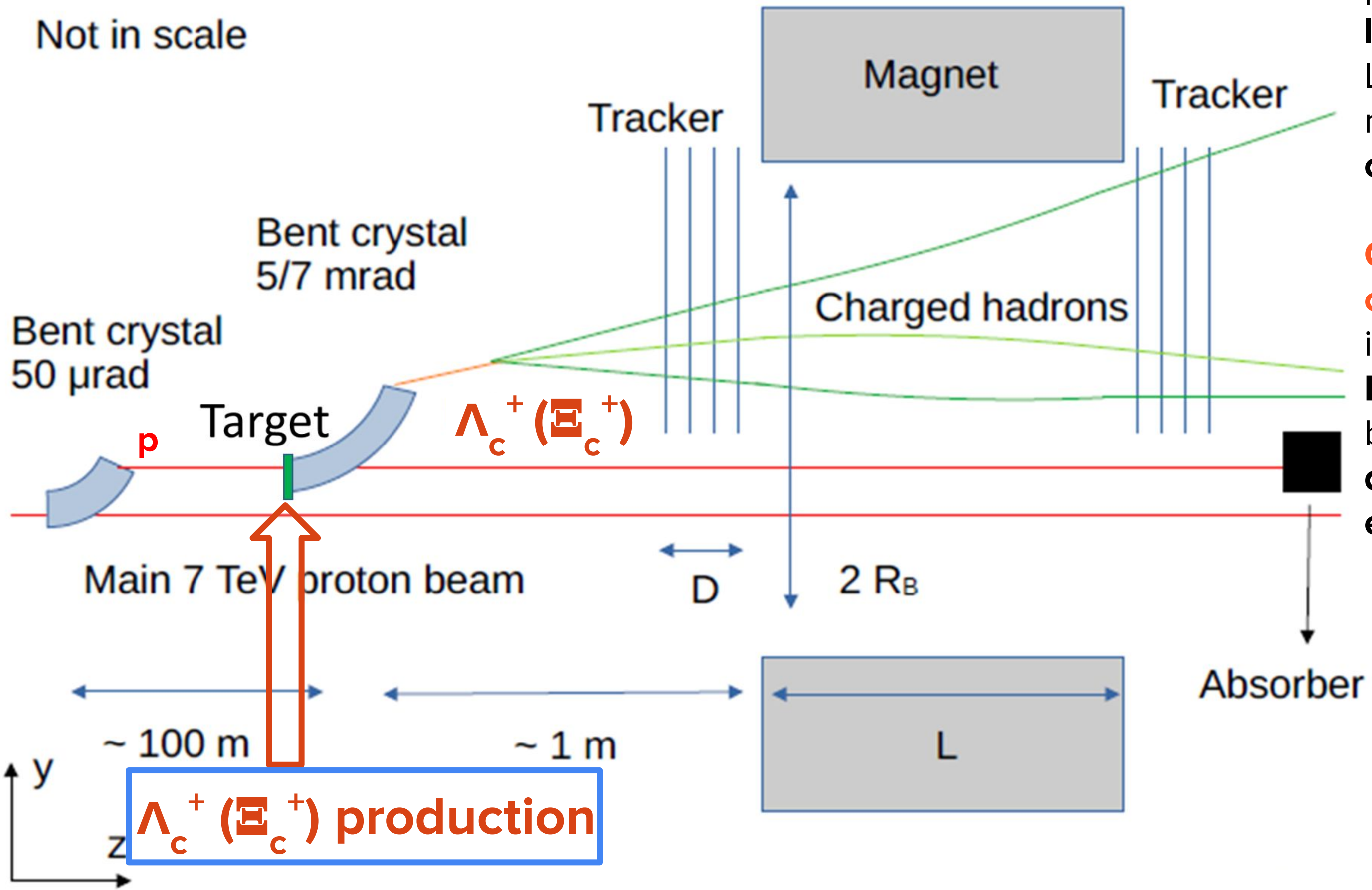

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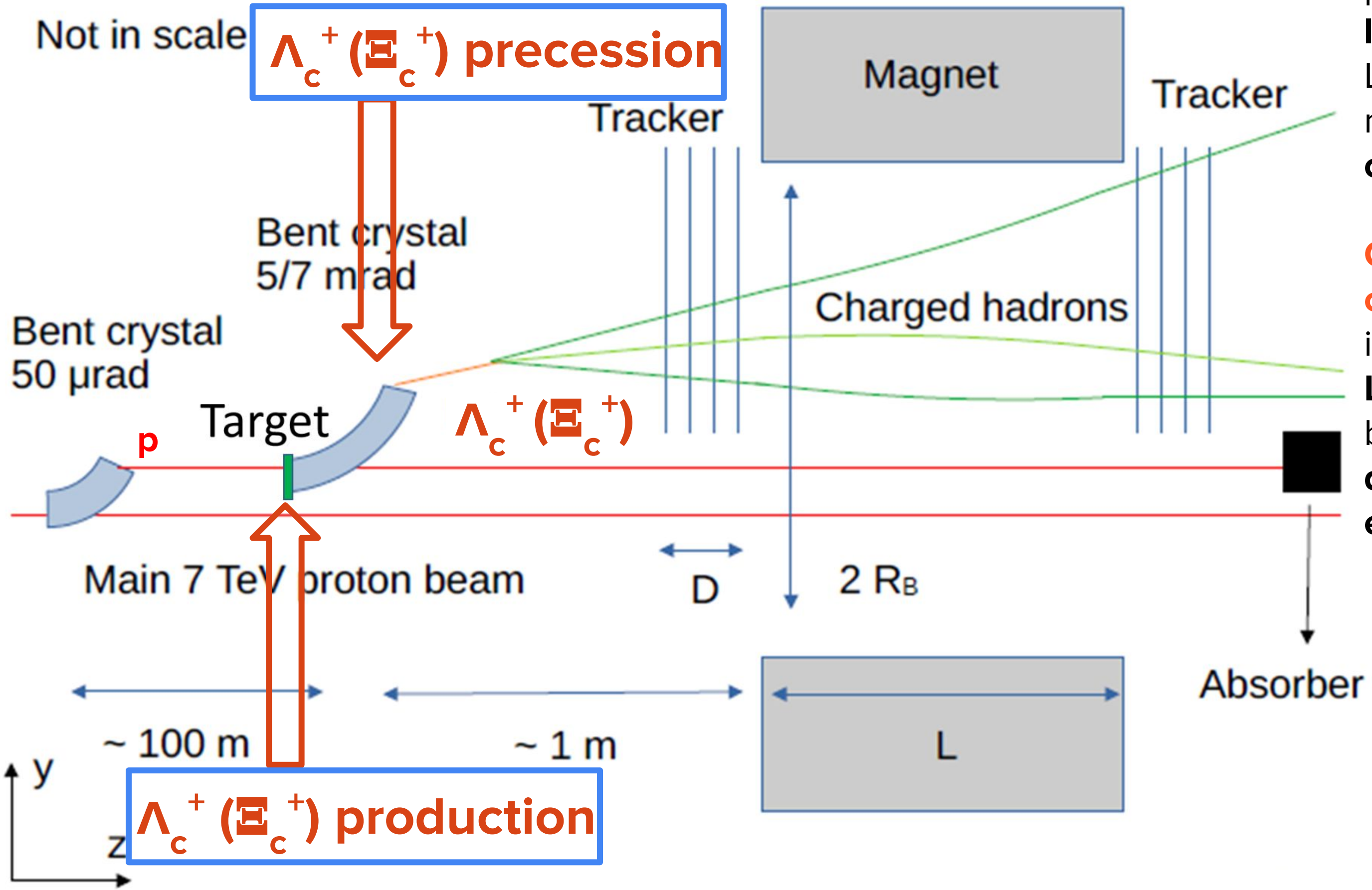

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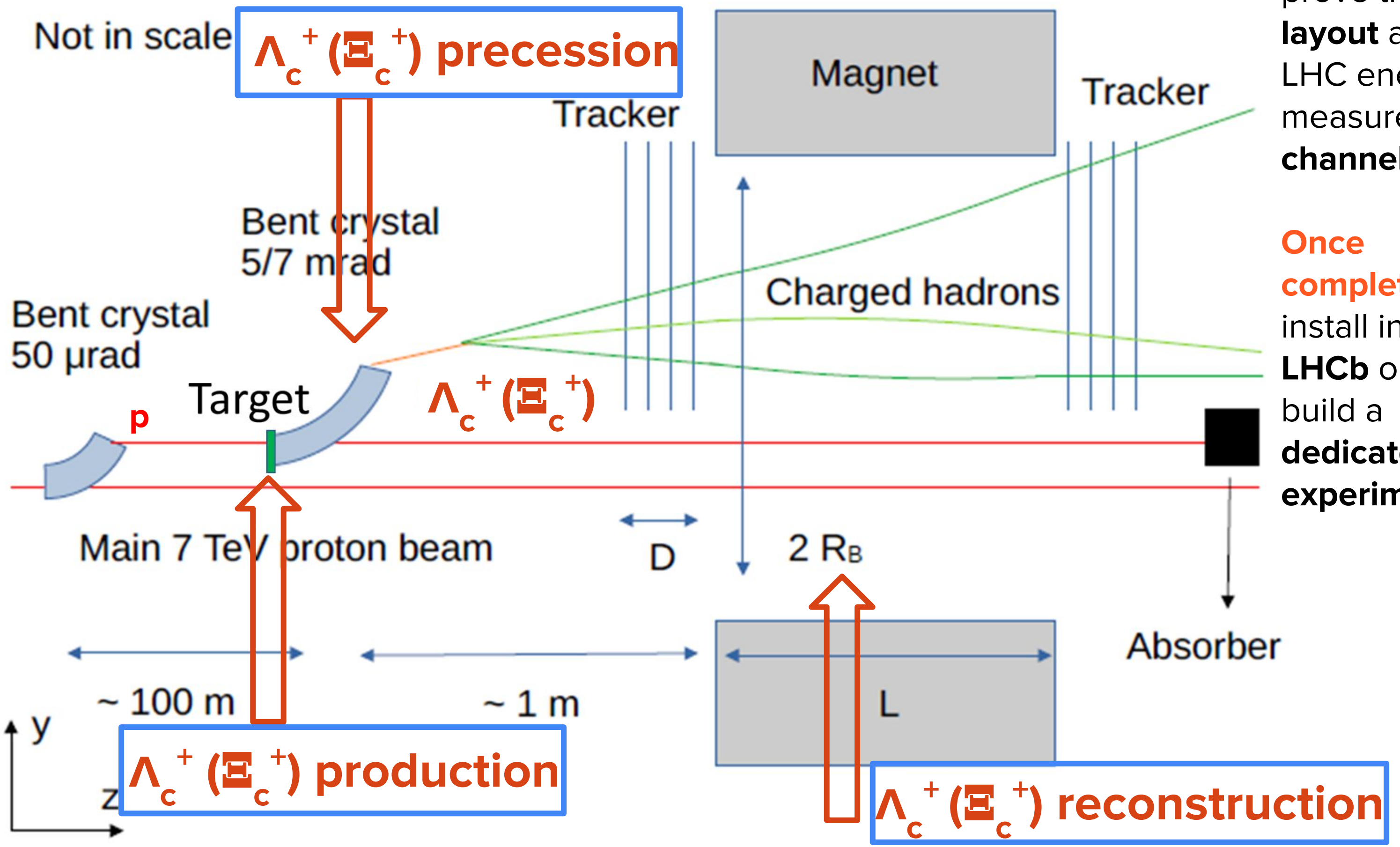

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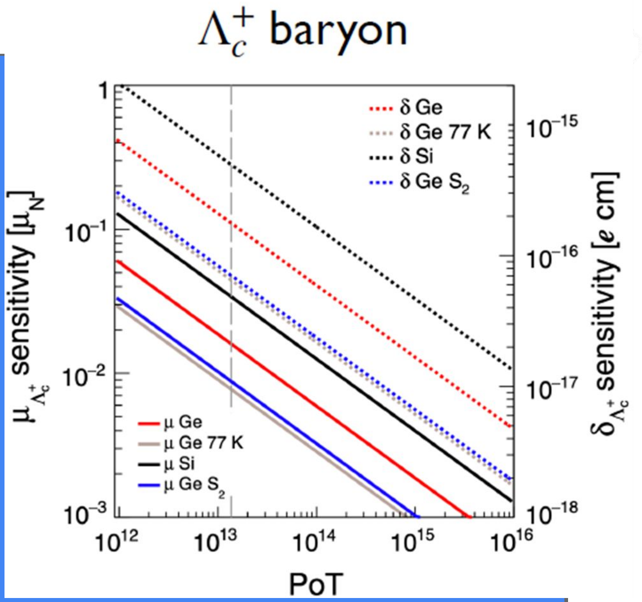
Electromagnetic dipole moments: sensitivity

- Current limit Λ EDM: Fermilab, 1981, fixed target experiment **Λ EDM < 1.5 × 10^{-16} ecm**, with 95% C.L.
- Expected improvement Λ EDM: LHCb project, sensitivity reachable **$\sigma_\delta \approx 1.3\times10^{-18}$ ecm** with 50 fb^{-1} data
- Current measured value Λ MDM: **$\mu = 0.613 \pm 0.004\ \mu_N$**
- Expected improvement Λ MDM: sensitivity reachable **$\sigma_\mu \approx 10^{-4}\mu_N$** with 50 fb^{-1} data ⇒ first **CPT** test at **10^{-4} level** with Λ baryons

With two years of data taking (10^{13} PoT)

- Λ_c^+ (Ξ_c^+) EDM sensitivity: **$\sigma_\delta \approx 4 \cdot 10^{-16}$ecm**



- First measurement of Λ_c^+ (Ξ_c^+) MDM: **$\sigma_{g-2} \approx 2 \times 10^{-2}$**

[1] Phys. Rev. **D** 103 (2021) 072003