Direct measurement of charm baryon dipole moments at LHC

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On behalf of the ALADDIN Collaboration

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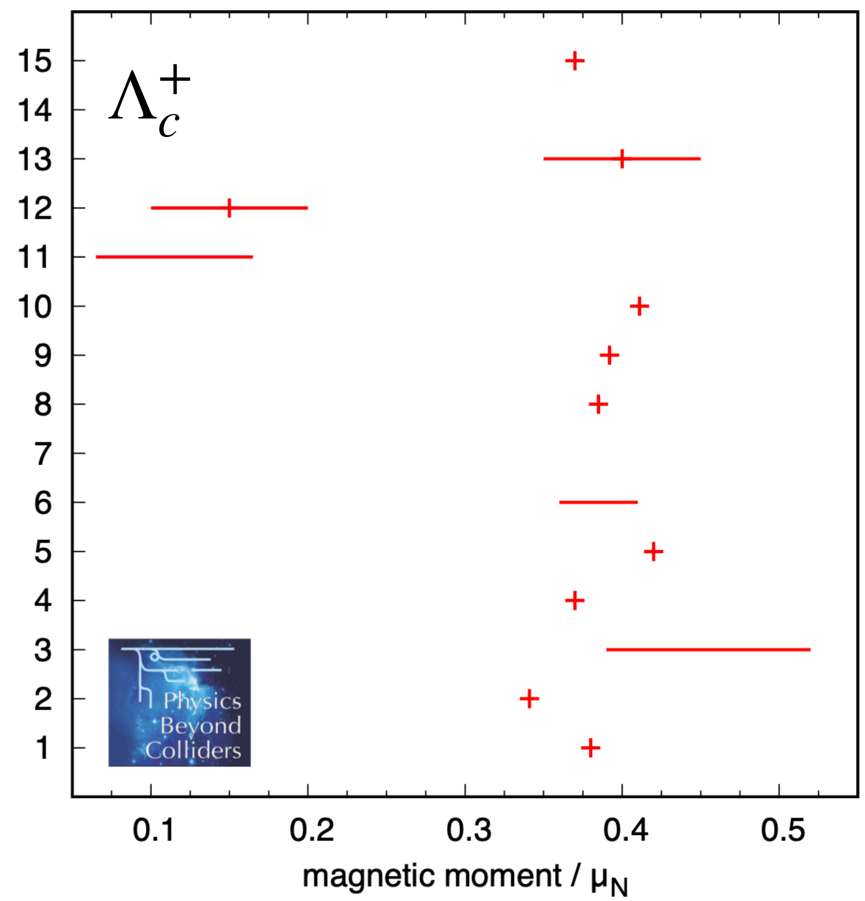
Introduction

First measurement of electromagnetic dipole moments of Λ_c^+ and Ξ_c^+

MDM



PLB 326 (1994) 303
PRD 77 (2008) 114006
PRD 65 (2002) 056008
PRD 56 (1997) 7273
NPA 735 (2004) 163
Lith.J.Phys. 53 (2013) 2
PRD 81 (2010) 073001
J Phys G 35 (2008) 065001
arXiv:0803.0221
NPA 793 (2007) 131
PRD 73 (2006) 094013
J Phys G 31 (2005) 141
NPA 739 (2004) 69
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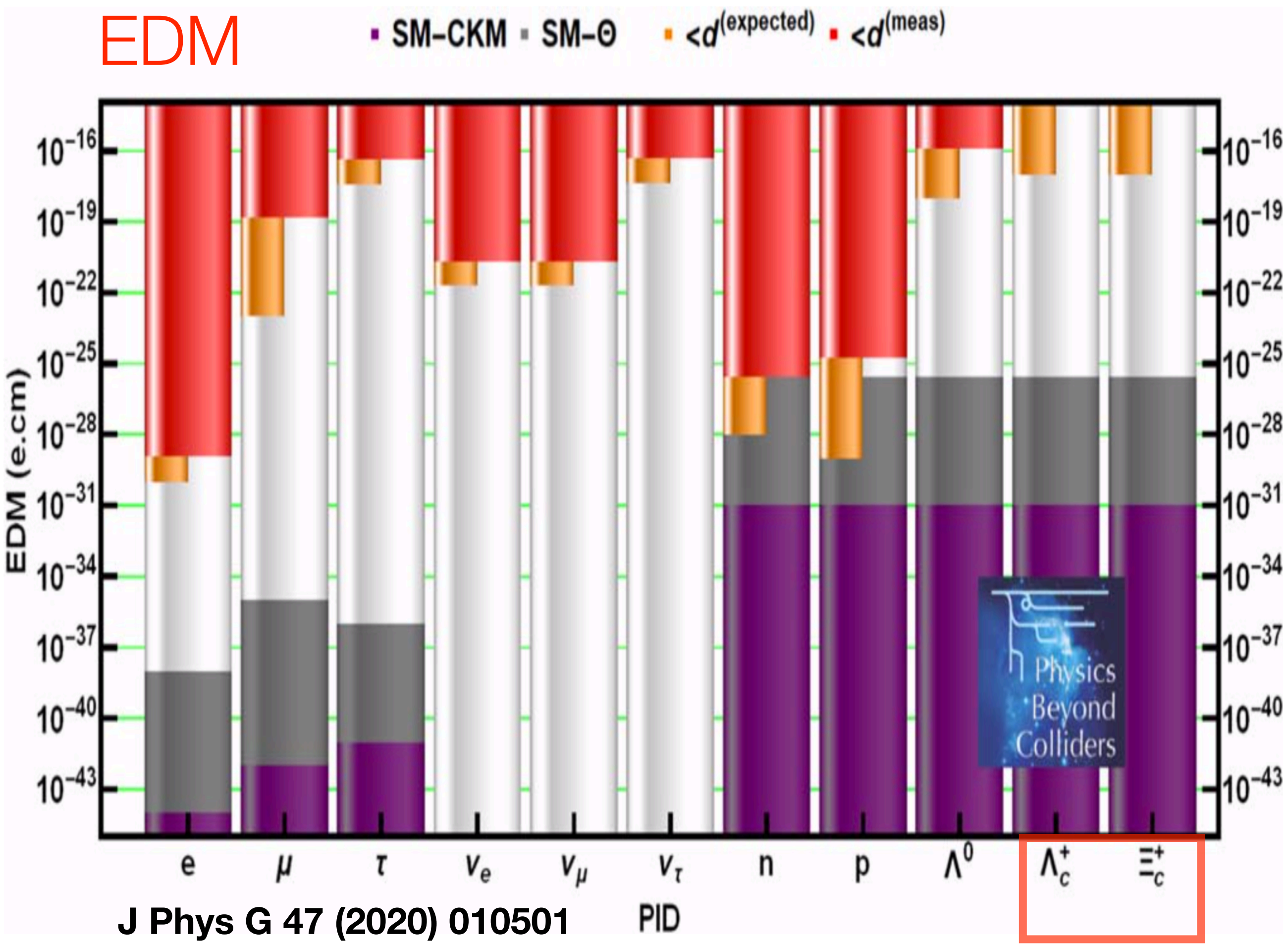
NIM B 119 (1996) 259

CERN-PBC-REPORT-2018-008

EDM



J Phys G 47 (2020) 010501

Quark model: $\mu_{\Lambda_c^+} = \mu_{\Xi_c^+} = \mu_c$

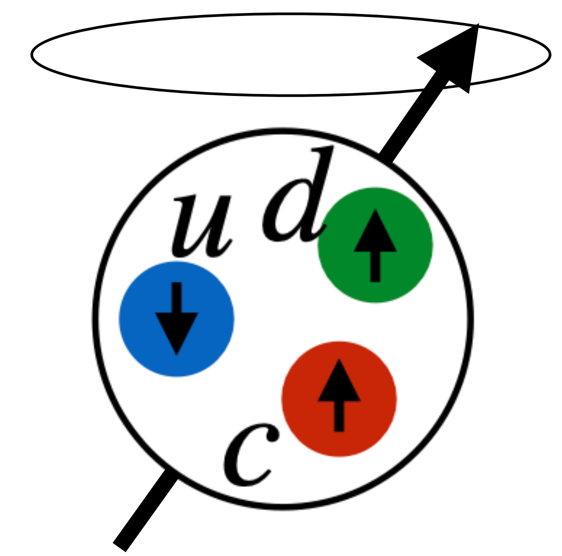
HQFT: require at least 10% precision from experiment

Charm quark might have special coupling with new physics

Global EDM analysis needs experimental input from charm sector

How to access EDM and MDM

- EDM and MDM extracted from spin procession in EM field



$$\frac{d\mathbf{s}}{dt} = \mathbf{s} \times \mathbf{\Omega} \qquad \mathbf{\Omega} = \mathbf{\Omega}_{\mathrm{MDM}} + \mathbf{\Omega}_{\mathrm{EDM}} + \mathbf{\Omega}_{\mathrm{TH}}$$

$$\mathbf{\Omega}_{\mathrm{MDM}} = \frac{g\mu_B}{\hbar}\left(\mathbf{B} - \frac{\gamma}{\gamma+1}(\boldsymbol{\beta}\cdot\mathbf{B})\boldsymbol{\beta} - \boldsymbol{\beta}\times\mathbf{E}\right)$$

$$\Omega_{\mathrm{EDM}} = \frac{d\mu_B}{\hbar}\left(\mathbf{E} - \frac{\gamma}{\gamma+1}(\boldsymbol{\beta}\cdot\mathbf{E})\boldsymbol{\beta} - \boldsymbol{\beta}\times\mathbf{B}\right)$$

- Experimental requirement

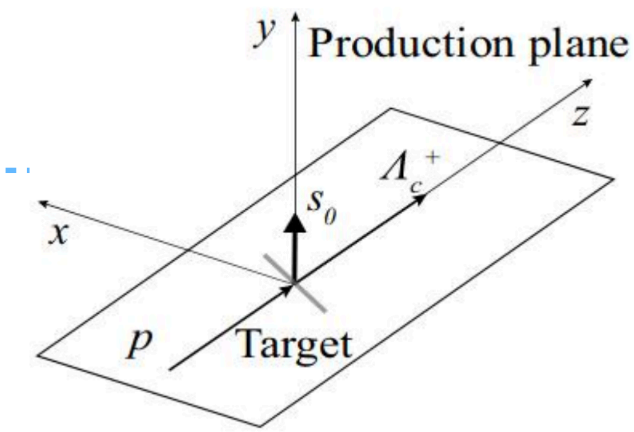
  Sizable polarized Λ_c^+ and Ξ_c^+ sources

  Enough flight length/Strong EM field for spin procession

  Excellent detector for polarization measurement from angular analysis

- Significant challenge for charm baryons: $\tau \sim 10^{-13}$s

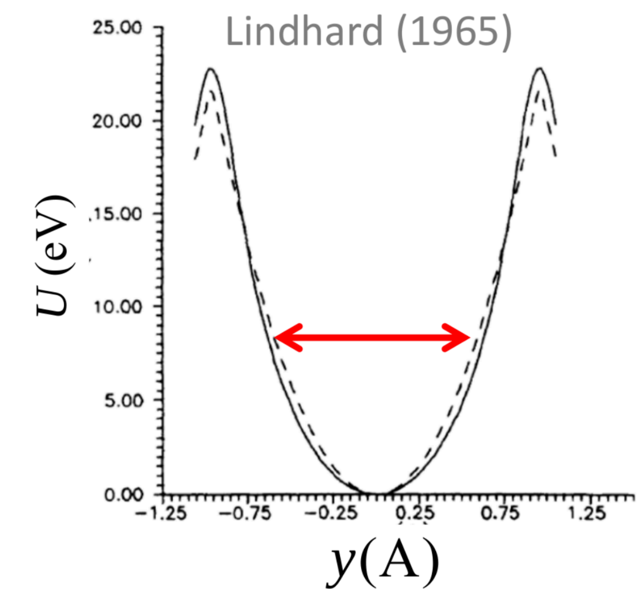
New experiment concept

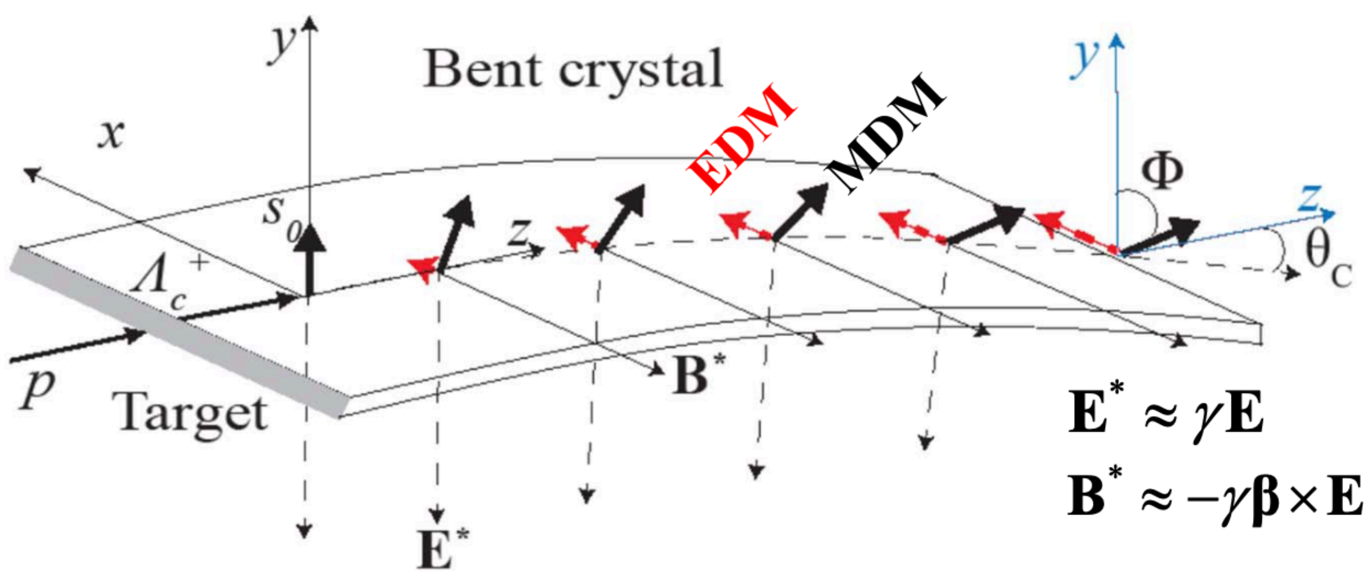


- Polarized Λ_c^+ and Ξ_c^+ sources
  produced from fixed-target pW collisions at
  LHC $\sqrt{s} \approx 110\text{GeV}$
- Flight length:
  high boost $\gamma \approx 600 - 900 \Longrightarrow \beta\gamma\tau c \approx 7 - 10$ cm
- Strong EM field induced from bent crystal
  Spin procession by channeling effect

$E \approx 6$GV/cm

$B^* \approx 10^6$ T





$\mathbf{E}^* \approx \gamma \mathbf{E}$

$\mathbf{B}^* \approx -\gamma \boldsymbol{\beta} \times \mathbf{E} / c$

- Spin-polarization analysis for
  i.e. $\Lambda_c^+ \to p K^- \pi^+$ decays
  $\mathcal{W} \propto 1 + \alpha_{\text{eff}} \boldsymbol{s}' \cdot \hat{\boldsymbol{k}}$,

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

$$s'_x \approx s_0 \frac{d}{g-2} [\cos \Phi - 1]$$

$\boldsymbol{s} = (0, s_0, 0)$

$\boldsymbol{s}' = (s'_x, s'_y, s'_z)$

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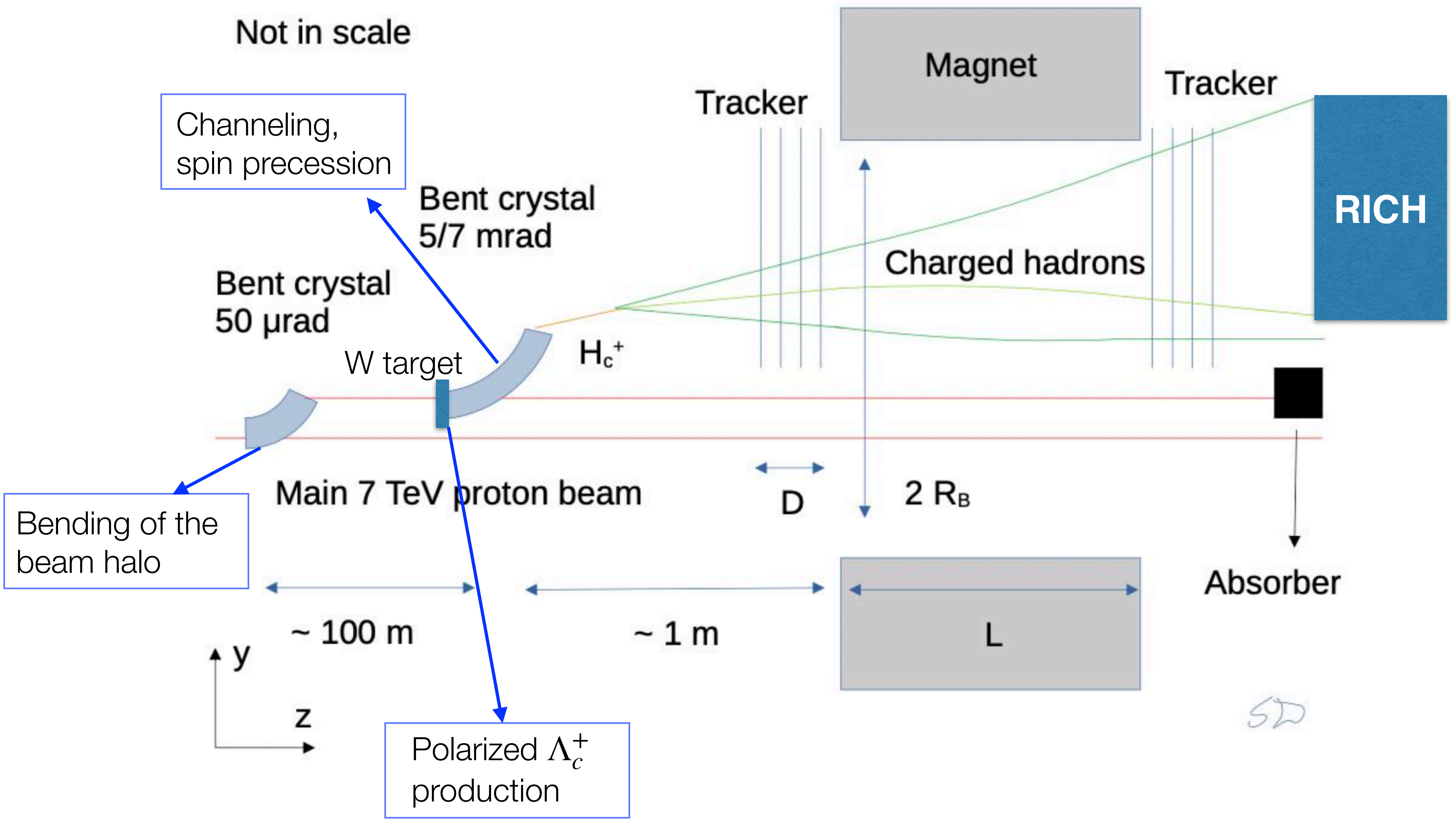
Double-crystal setup for MDM and EDM measurement

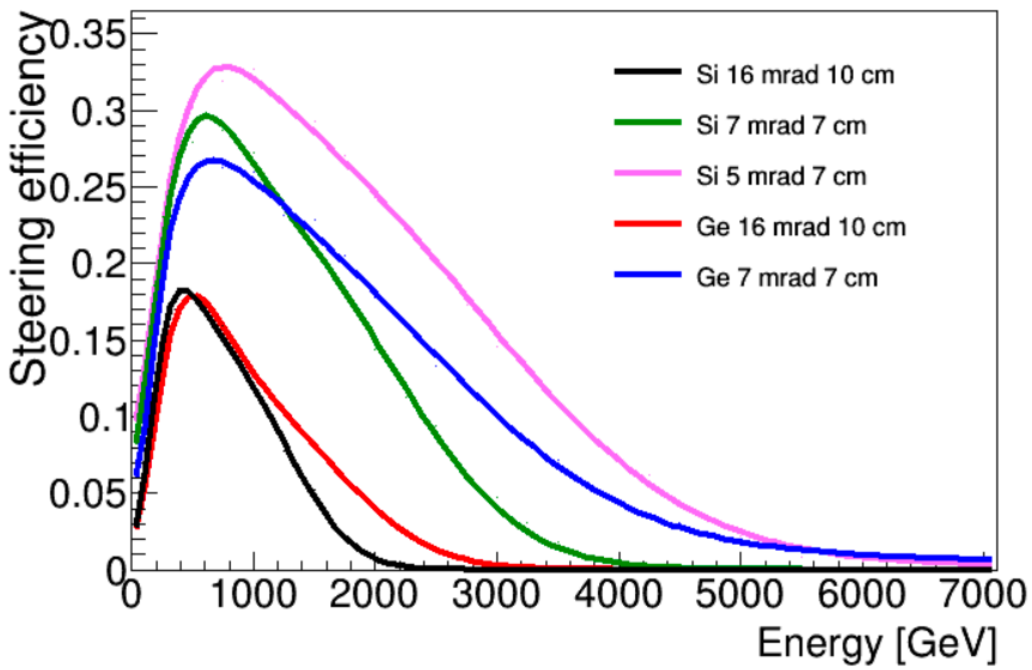


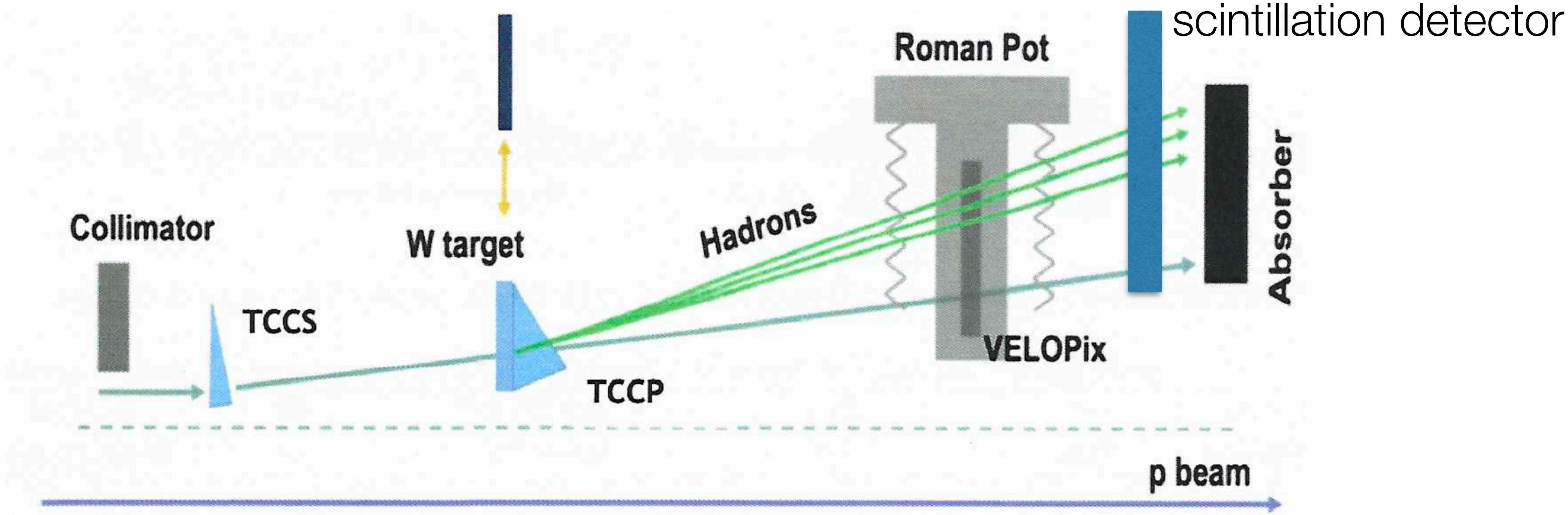
TWOCRYST: proof-of-principle test at LHC

Details in Pascal Hermes slides

- Validate crystal properties, channeling eff. at TeV beam
- Demonstration of operational feasibility
- Validation of achievable PoT
- Background studies for RICH detector

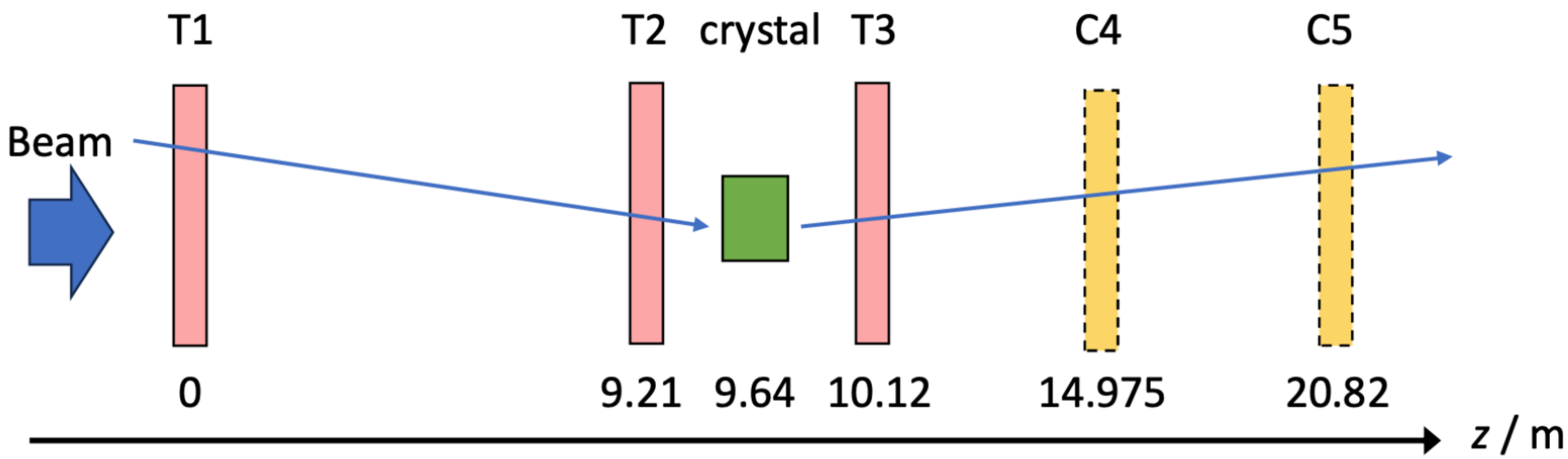
channeling eff. simulation



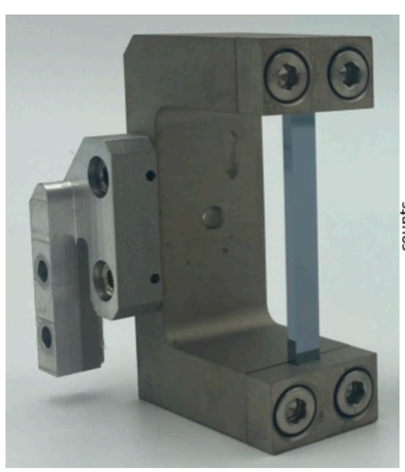


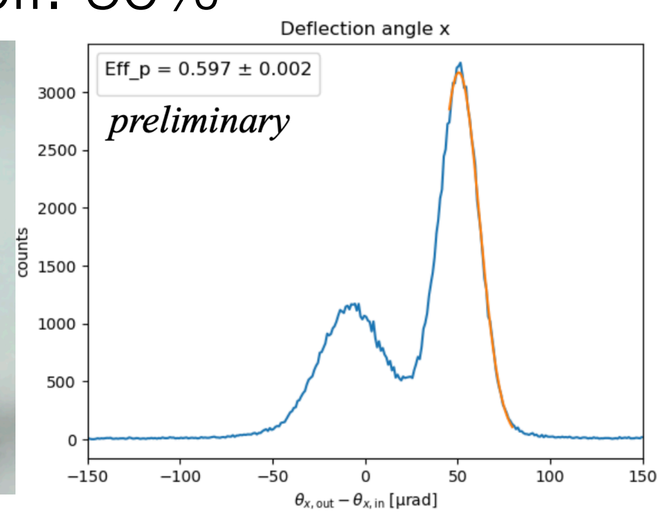
Bent crystal testbeam at CERN SPS

- Two silicon crystals: splitting crystal (TCCS) and precession crystal (TCCP)
- Produced by INFN Ferrara (A. Mazzolari). Tested at SPS H8 with 180GeV/c hadron beam (Aug. 2023)

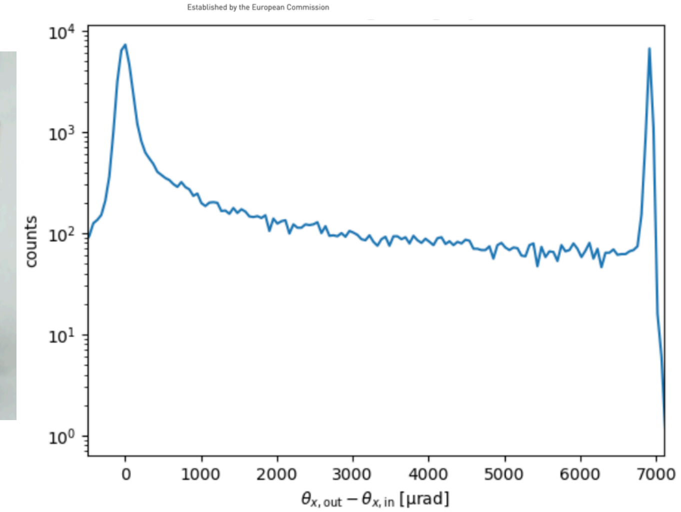


TCCS: 4mm, 50μrad, channeling eff. 60%





TCCP:70mm, 7mrad, channeling eff. 16%

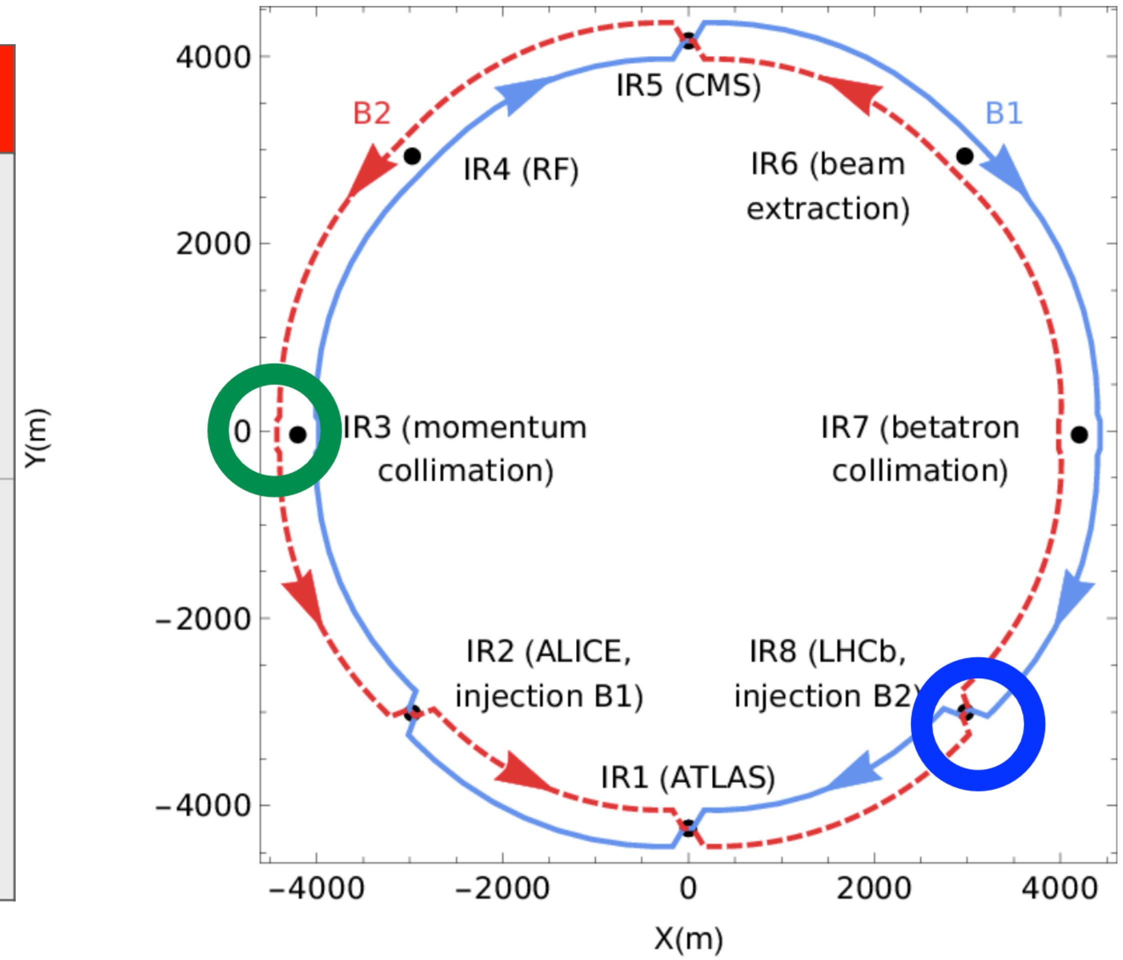


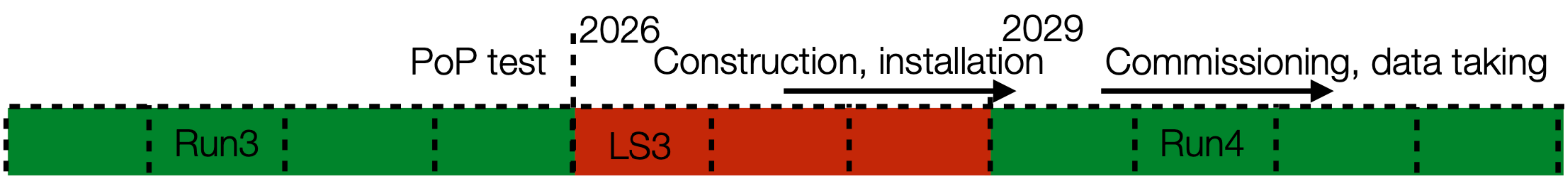
- Will Probe TCCP performance at energies 1-3TeV in TWOCRYST PoP test

Proposed experiment at LHC and timeline

- Two alternative proposals: **i) dedicated experiment at IR3 (baseline)** ii) use LHCb detector at IP8 (fallback option)

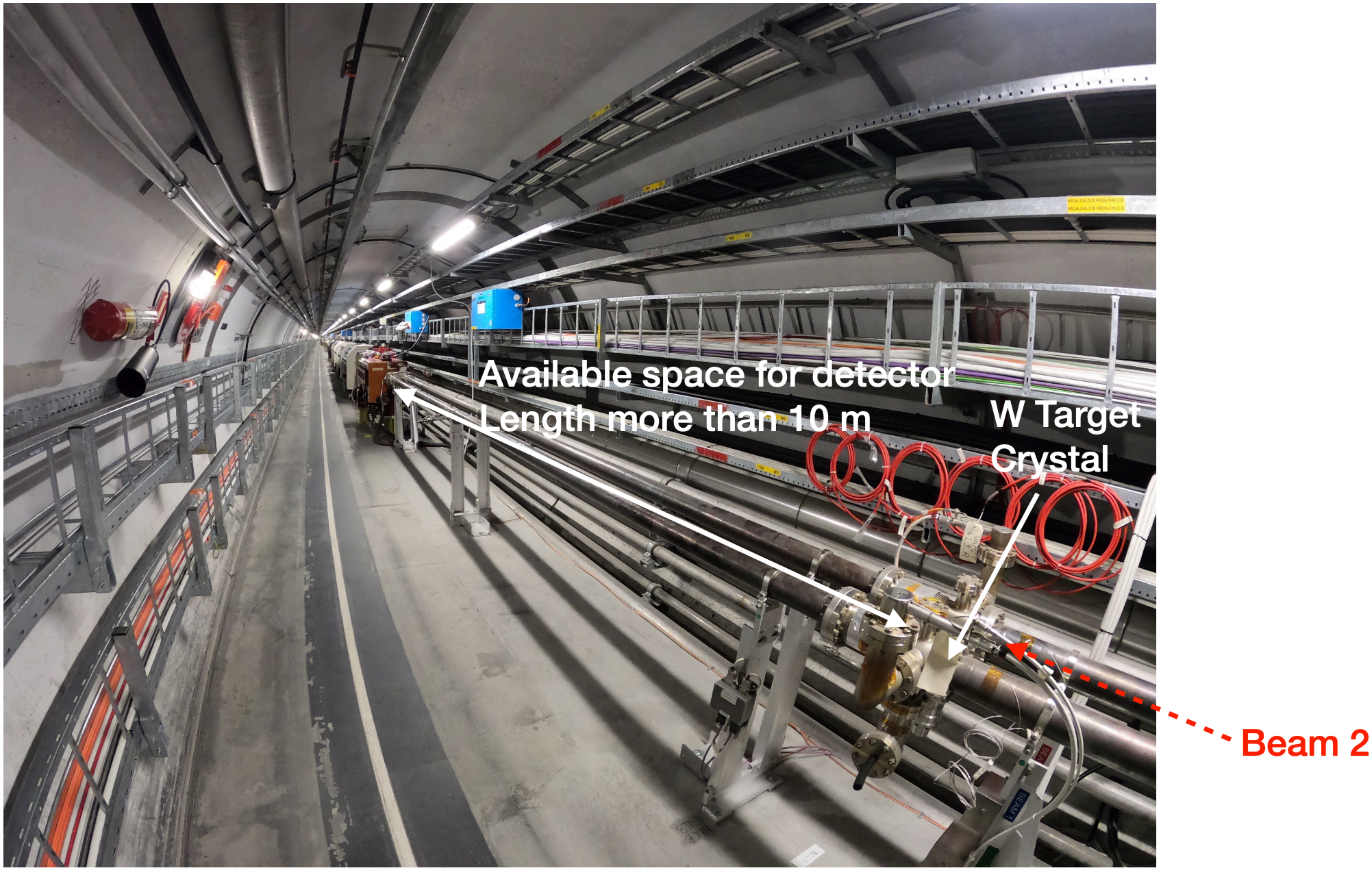
	Pro	Cons
IR3	**Optimal experiment and detector. PID information**	More resources needed. New detector, services (long cables, cooling)
LHCb	Use existing tracking detector and infrastructure. Experimental area	No PID for p>100 GeV. Potential interference with LHCb core program





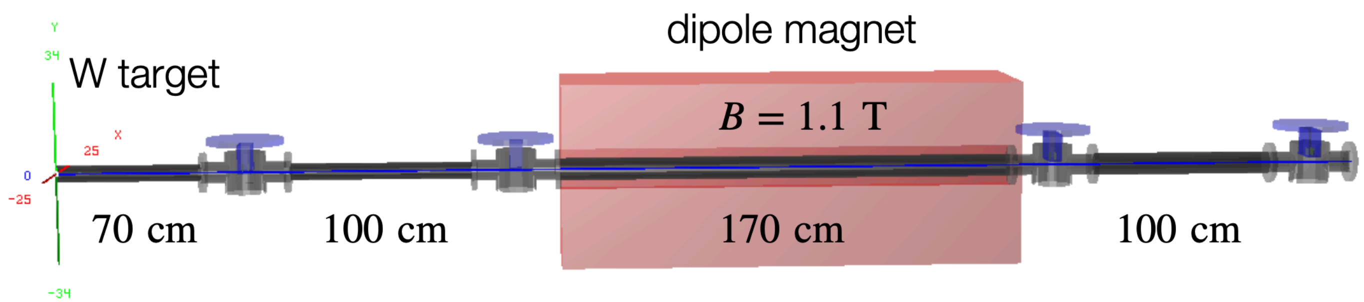
LHC IR3 venue

- IR3 region for experiment

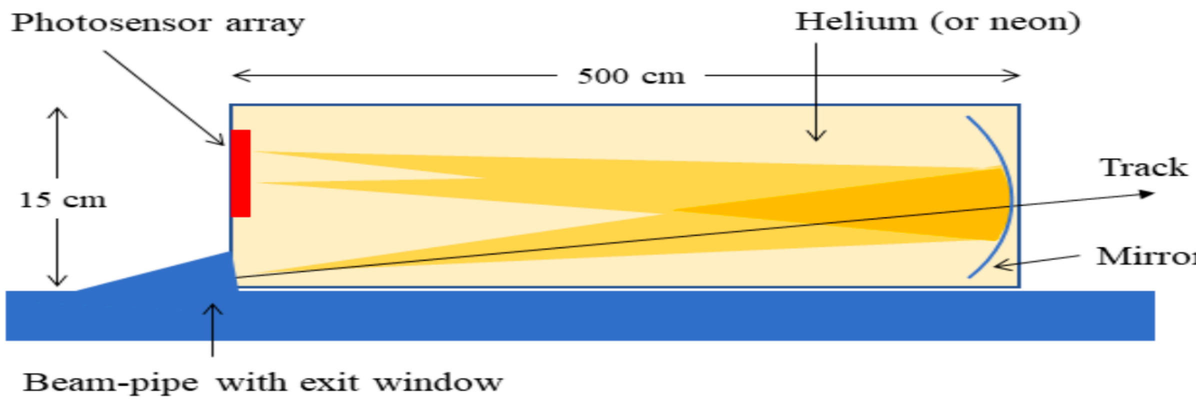


Detector layout

Spectrometer: 440 cm length



RICH: 500 cm length



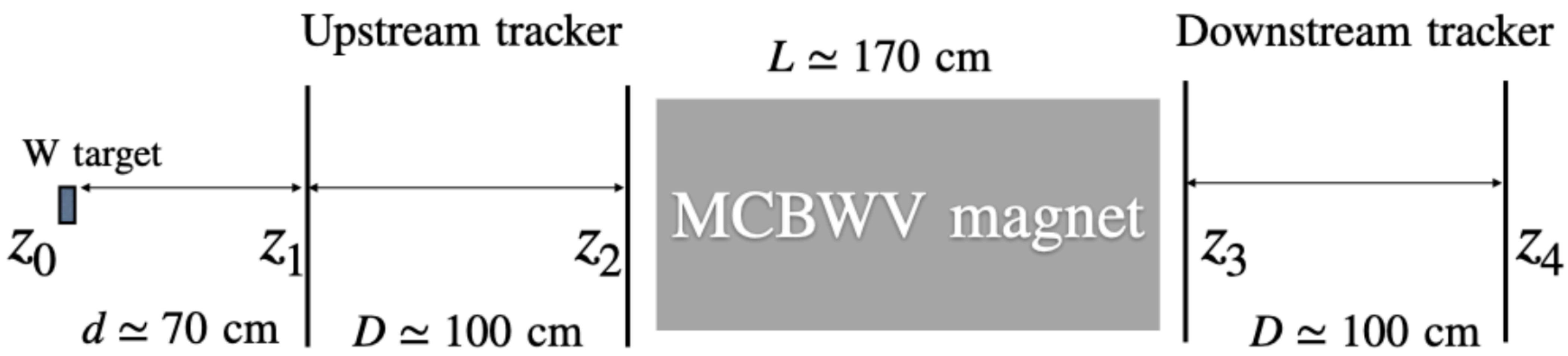
Pixel detectors in 4 Roman Pot stations

Helium radiator gas with SiPM array

Specification required for tracking detectors

	pitch (μm)	hit rate (MHz/cm^2)	fluence (n_{eq}/cm^2)	area (cm^2)	tech. solution
Upstream	55	250	3.5×10^{15}	10	Si pixel
Downstream	100	30	9.0×10^{13}	30	Si pixel/strip

Spectrometer layout

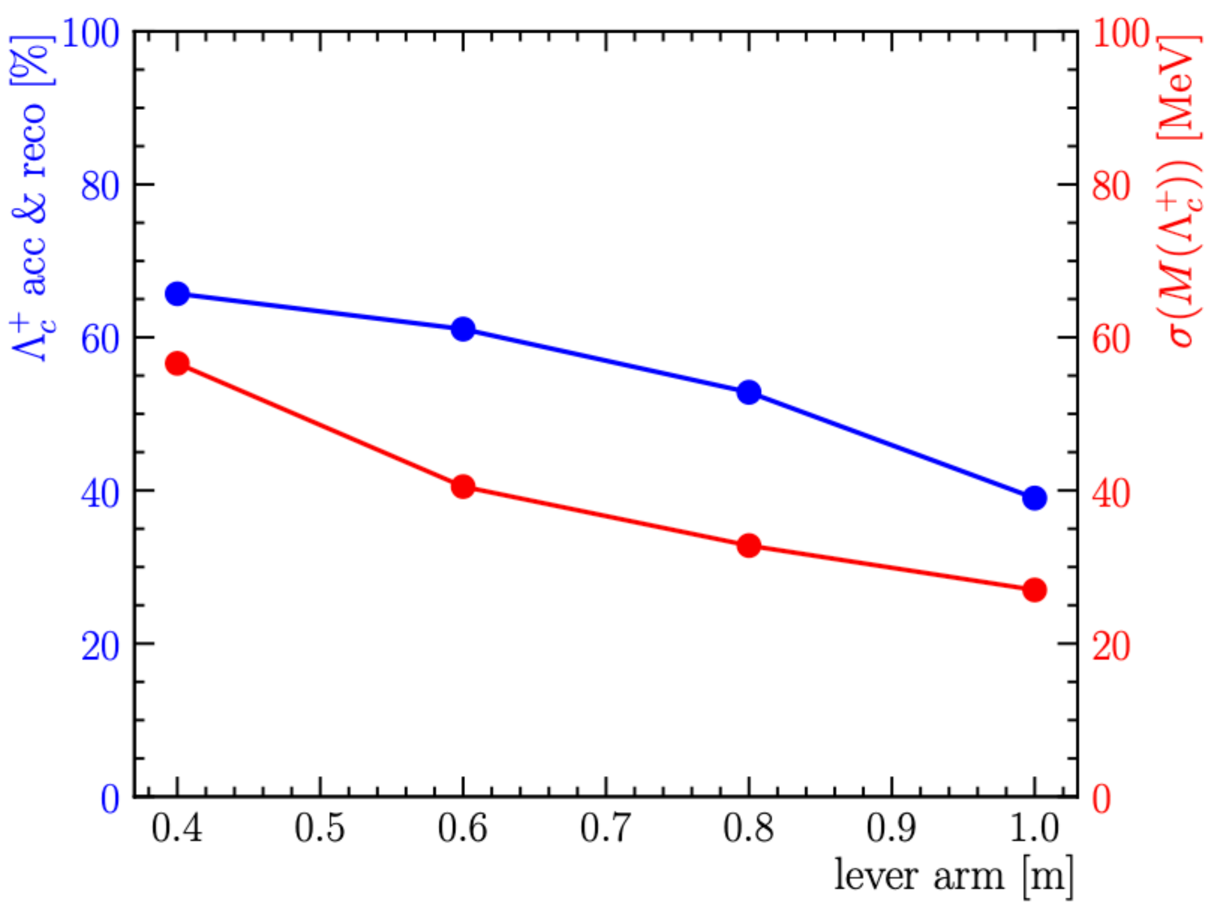


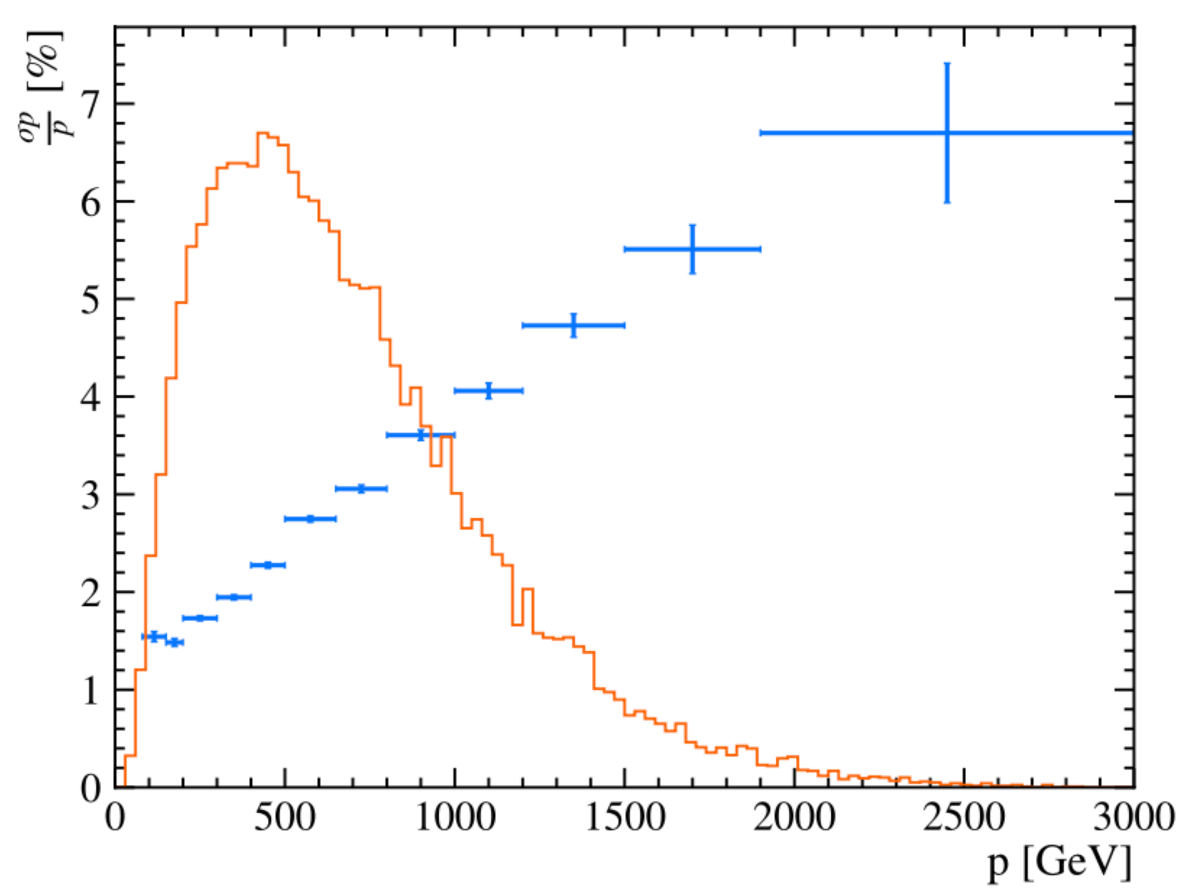
- Cover the pseudorapidity $5 < \eta < 9$
- VELO pixel sensors in four Roman Pots, two layers for each RP
- A dipole magnet MCBWV available in situ, B=1.1T, L=1.7m
- Momentum resolution: $\frac{\sigma_p}{p} \approx \frac{2p}{qBLD}\sigma_x$

p=500GeV, σ_x=10μm $\Longrightarrow \sigma_p/p \approx 2\,\%$

Spectrometer performance from simulation

- Simulated $\Lambda_c^+ \to pK^-\pi^+$ decays
- Good reconstruction efficiency and mass resolution
- Good momentum resolution of daughter particles for channeled Λ_c^+

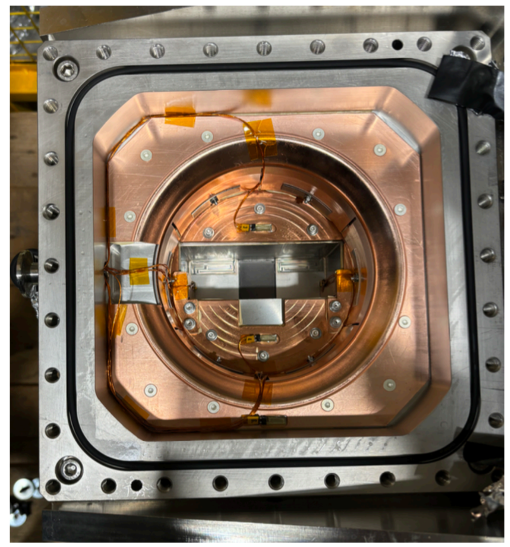




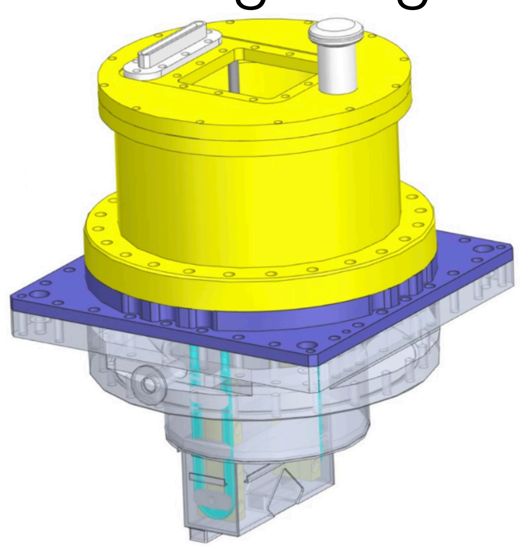
Roman Pot and VELO module

ATLAS-ALFA Roman Pot

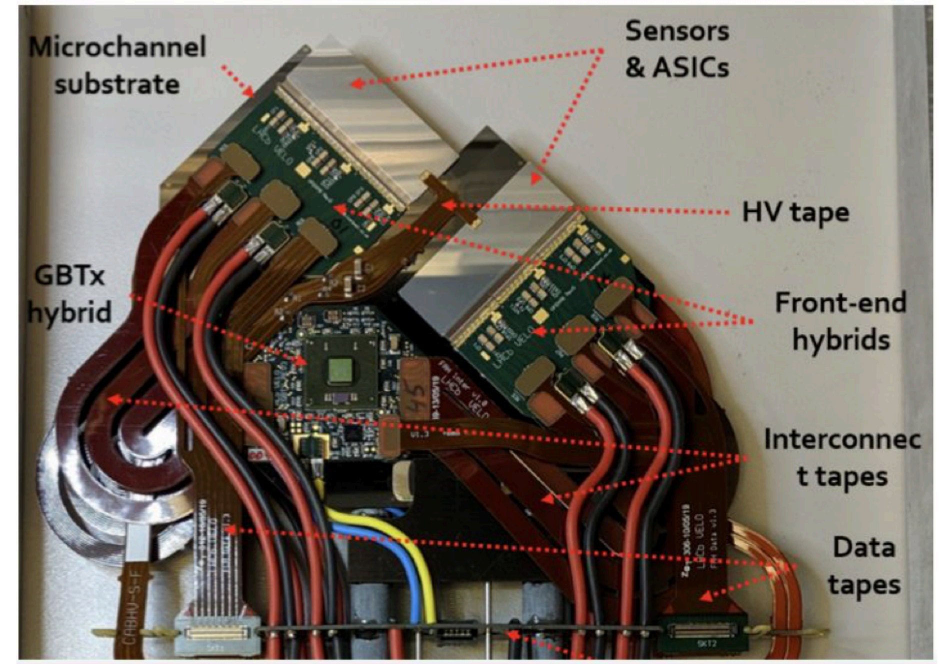
Detector housing



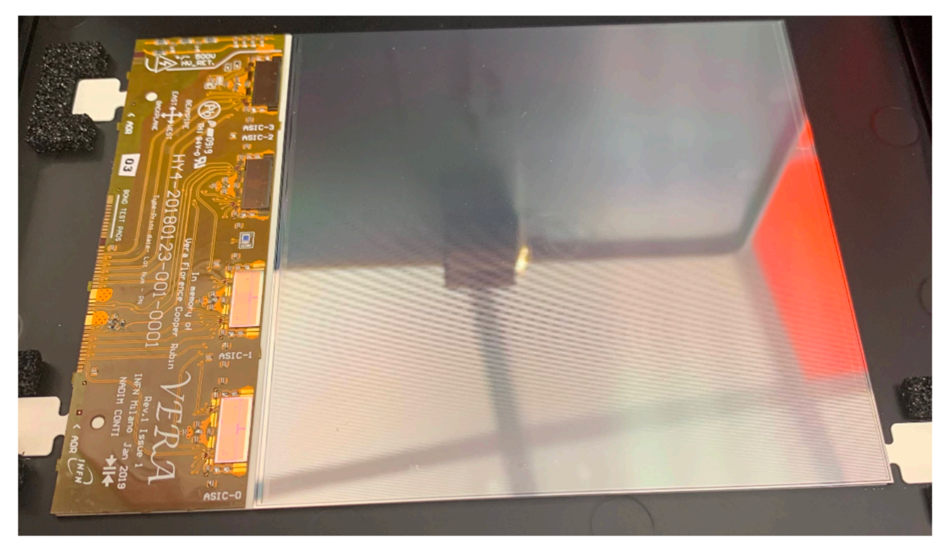
Closing flange



LHCb VELO module assembled

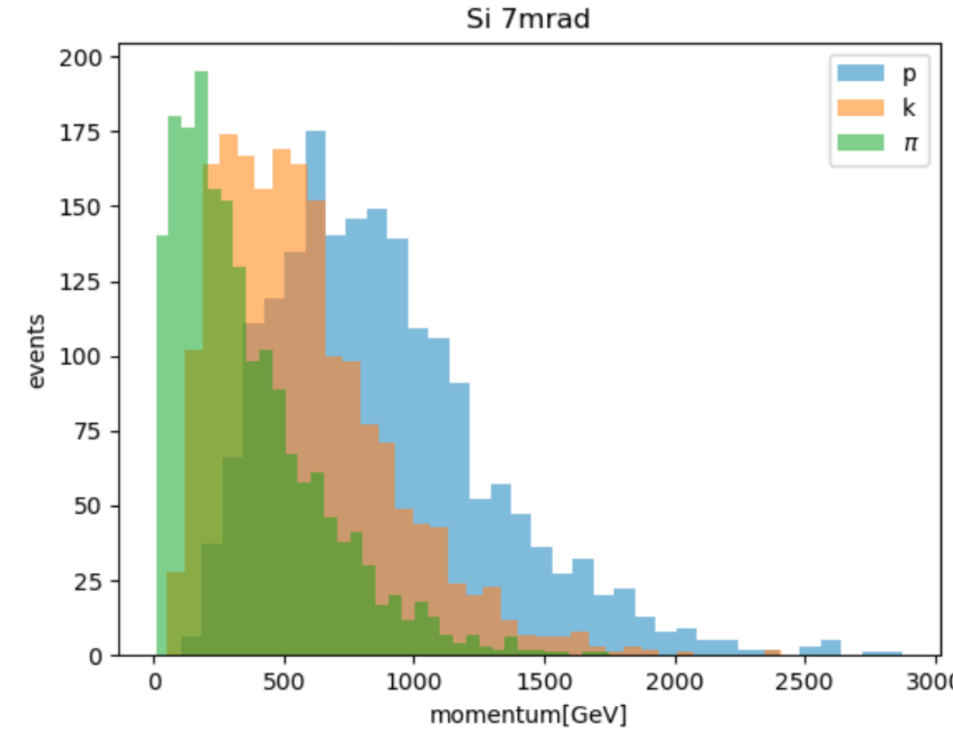


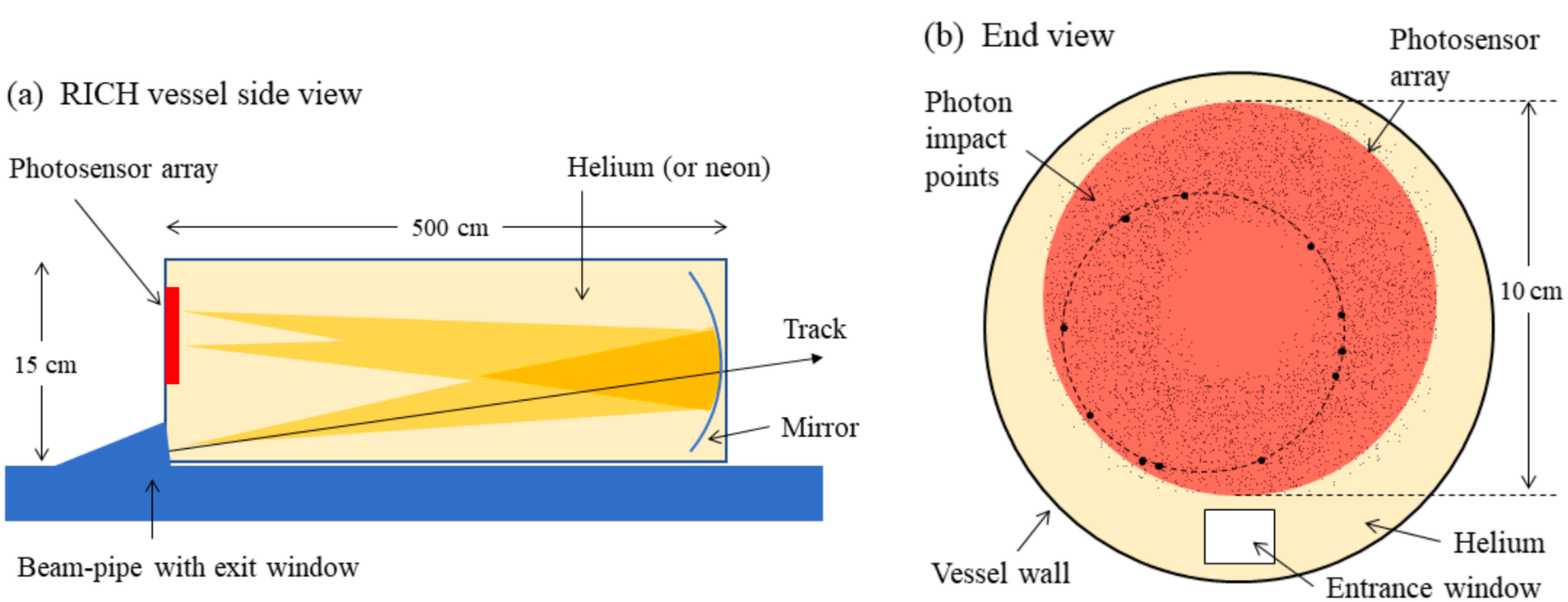
LHCb UT silicon strip sensor and front-end electronics



RICH detector

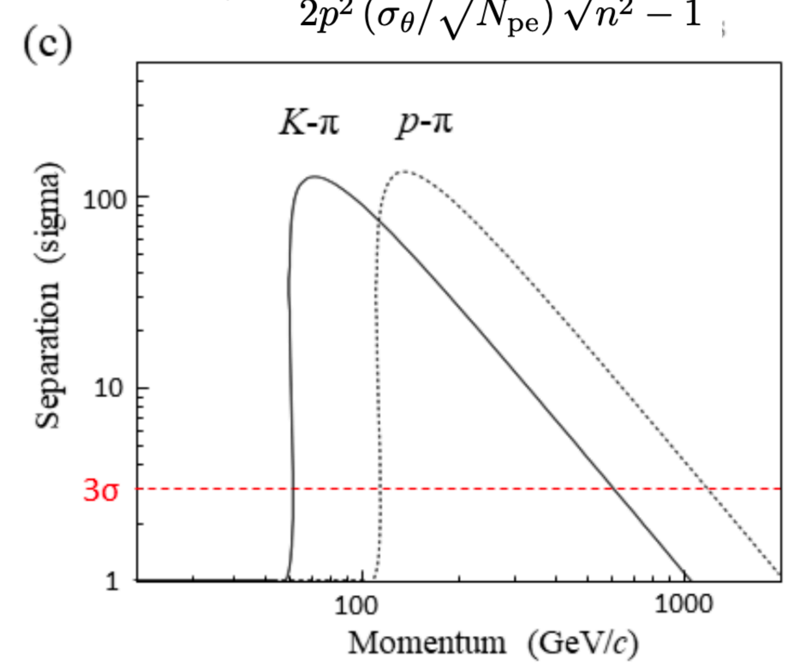
- High-momentum charged particles at 1 TeV/c range
- Helium radiator gas n=1.000035, L=500cm, $N_{pe} \approx 12$, cover relative large momentum range w.r.t. neon gas
- SiPM for photon readout





Separation power

$$N_\sigma = \frac{|m_1^2 - m_2^2|}{2p^2\,(\sigma_\theta/\sqrt{N_{\rm pe}})\,\sqrt{n^2-1}}$$



Physics reach

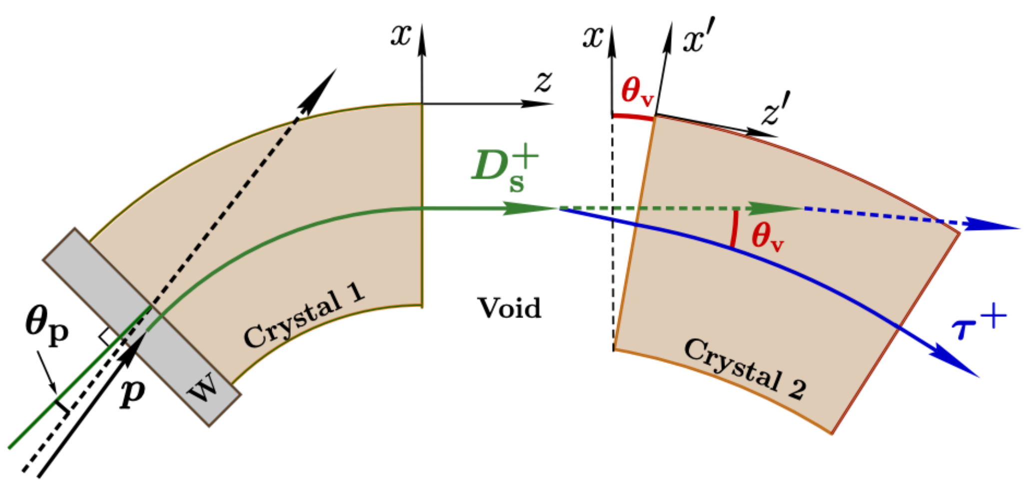
- First measurement of MDM and EDM of Λ_c^+ and Ξ_c^+ in 2 year data taking

  assuming 10^6p/s, 2 cm W target, polarization ~20%

  sensitivity: $2\times10^{-2}\mu_N$ and 3×10^{-16} e cm with 1.4×10^{13} PoT

- Provide opportunity for measurements in the very forward region $5<\eta<9$, i.e. cross-section of charm hadron production, QCD polarization, J/ψ photo production

- Measurement of τ MDM and EDM (further R&D)



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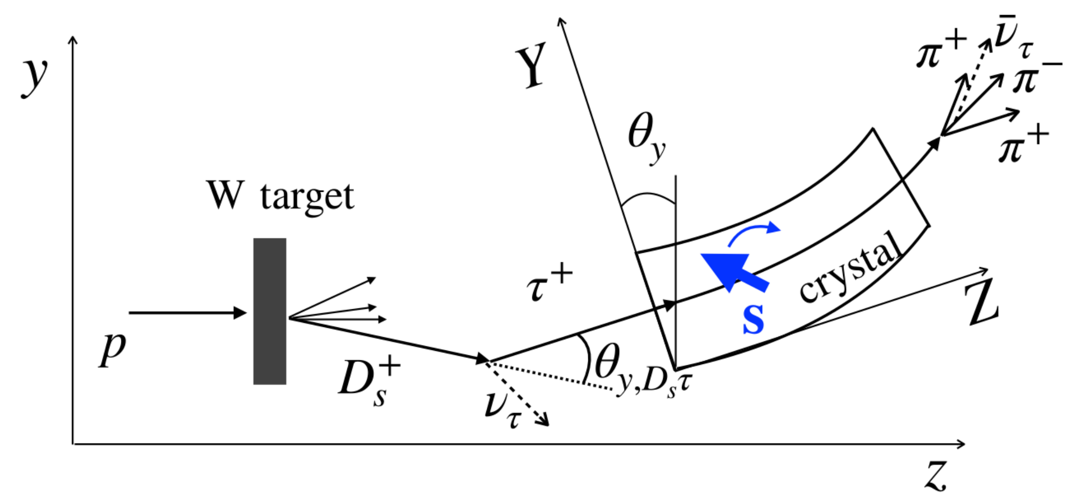

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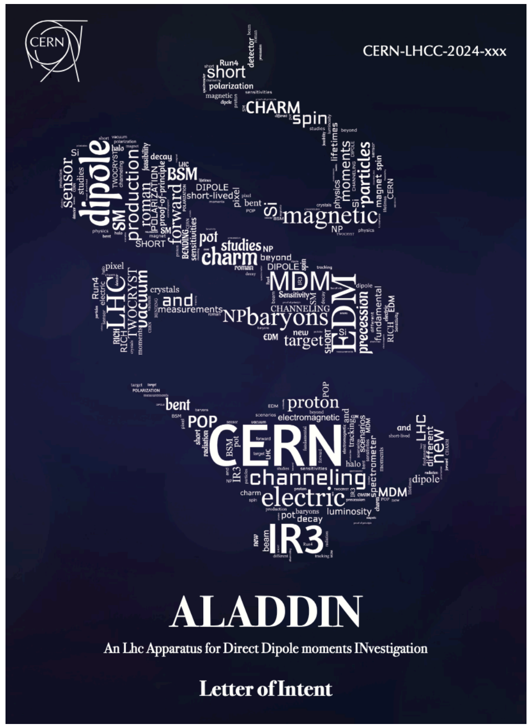
Proponents of ALADDIN LOI and other authors

- A proto-collaboration of the ALADDIN experiment, 58 members, 19 groups from 8 countries



K. Akiba [1], *F. Alessio* [2], *M. Benettoni* [3], *A. Bizzetti* [23,24], *F. Borgato* [3,4], *F. Bucci* [23], *R. Cardinale* [5,6], *S. Cesare* [7,8], *M. Citterio* [8], *V. Coco* [2], *P. Collins* [2], *E. Dall'Occo* [9], *M. Ferro-Luzzi* [2], *A. Fomin* [21], *R. Forty* [2], *J. Fu* [10], *P. Gandini* [8], *M. Giorgi* [11,12], *J. Grabowski* [13], *S. J. Jaimes Elles* [14], *S. Jakobsen* [2], *E. Kou* [21], *G. Lamanna* [11,12], *H. Li* [10,16], *S. Libralon* [14], *C. Maccani* [3,4], *D. Marangotto* [7,8], *F. Martinez Vidal* [14], *J. Mazorra de Cos* [14], *A. Merli* [15], *H. Miao* [10,16], *N. Neri* [7,8], *S. Neubert* [13], *A. Petrolini* [5,6], *A. Pilloni* [17], *J. Pinzino* [12], *M. Prest* [19], *P. Robbe* [21], *L. Rossi* [7,8], *J. Ruiz-Vidal* [14,22], *I. Sanderswood* [14], *A. Sergi* [5,6], *G. Simi* [3,4], *M. Sorbi* [7,8], *M. Sozzi* [11,12], *E. Spadaro Norella* [5,6], *A. Stocchi* [21], *G. Tonani* [7,8], *T. Tork* [7,8], *A. Triossi* [3,4], *N. Turini* [18,12], *E. Vallazza* [19,20], *S. Vico Gil* [14], *Z. Wang* [8], *M. Wang* [8], *T. Xing* [8], *M. Zanetti* [3,4], *F. Zangari* [7,8]

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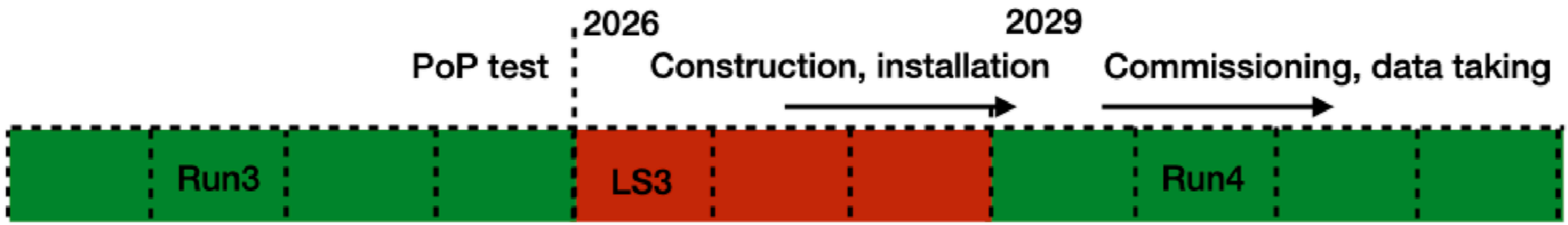
Stefano Redaelli
Marcin Patecki
Daniele Mirachi
Kay Dewhurst
…

Summary

- Proposed a dedicated experiment (ALADDIN) for first measurement of EDM and MDM of charm baryons
- TWOCRYST proof-of-principle test at LHC will be performed in the end of 2025
- ALADDIN experiment at LHC IR3 aims to take data in LHC Run4
- LoI for ALADDIN experiment is in preparation and will be released soon



Thank you!