

Magnetic and electric dipole moments of charm baryons

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2026-03-04 8:00 AM

EDMs2026: WE-Heraeus Workshop, Les Houches

05.03.2026



Outline

- Why charm baryon dipole moments?
- Experimental technique
- Preparatory LHCb measurements
- The ALADDIN experiment
- The TWOCRIST proof-of-principle
- Summary

Why charm baryon dipole moments?

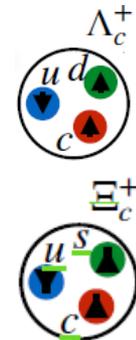
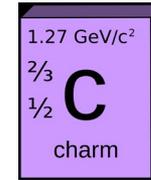
- First direct measurements of Λ_c^+ , Ξ_c^+ magnetic (MDM, μ) and electric (EDM, δ) dipole moments

✓ To date, out of experimental reach

- Dipole moments are sensitive to **baryon substructure**. Arise from electric charge and current distributions inside baryons

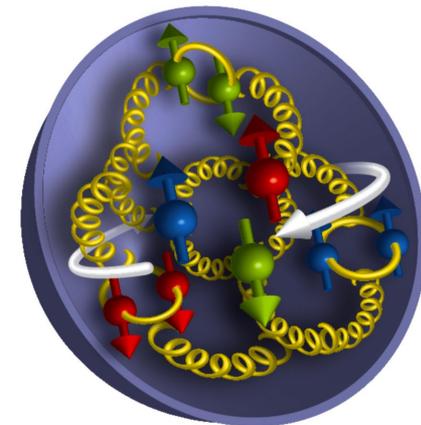
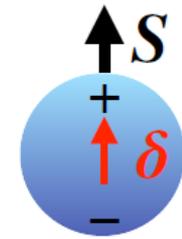
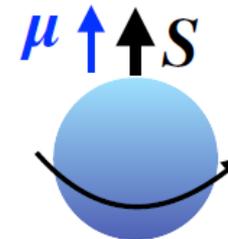
- MDMs can test **QCD theory**

- EDMs are sensitive to **new physics**



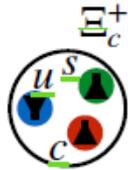
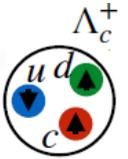
$$\mu = g \frac{q}{2m} S$$

$$\delta = d \frac{q}{2m}$$



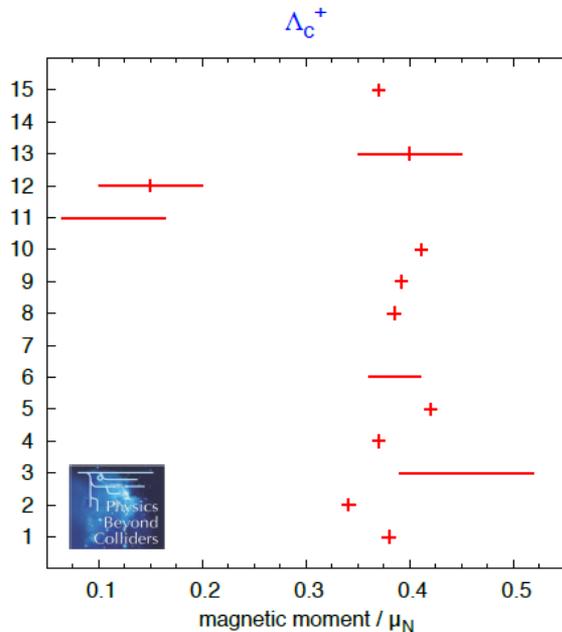
Why charm baryon dipole moments?

- In the naïve quark model $\Lambda_c^+ = [ud]c$, $\Xi_c^+ = [us]c$: $\mu_{\Lambda_c^+ (\Xi_c^+)} = \mu_c$
- Theory predictions $g_{\Lambda_c^+ (\Xi_c^+)} \approx 0.9 g_c$

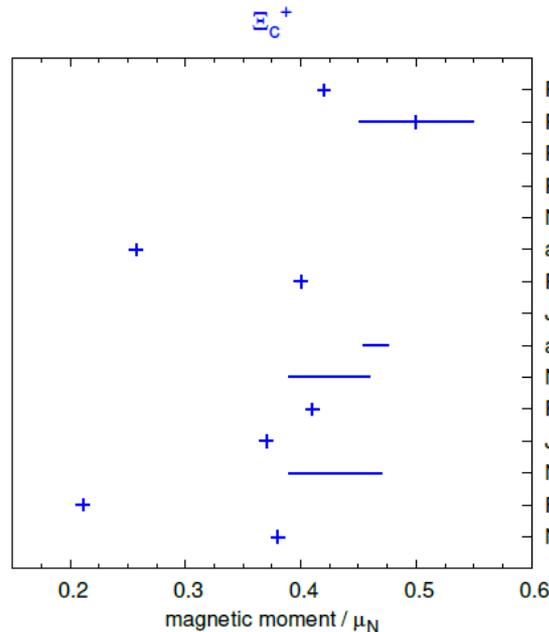


1.27 GeV/c²
 $\frac{2}{3}$
 $\frac{1}{2}$ C
 charm

CERN-PBC-REPORT-2018-008



$\mu \approx 0.1\mu_N$	$\mu \approx 0.4\mu_N$
$g \approx 0.49$	$g \approx 1.95$
$a \approx -0.76$	$a \approx -0.03$



$\mu \approx 0.2\mu_N$	$\mu \approx 0.4\mu_N$
$g \approx 1.05$	$g \approx 2.10$
$a \approx -0.47$	$a \approx 0.05$

PLB 326 (1994) 303
 PRD 77 (2008) 114006
 PRD 65 (2002) 056008
 PRD 56 (1997) 7273
 NPA 735 (2004) 163
 arXiv:1209.2900
 PRD 81 (2010) 073001
 J Phys G35 (2008) 065001
 arXiv:0803.0221
 NPA 797 (2007) 131
 PRD 73 (2006) 094013
 J Phys G31 (2005) 141
 NPA 739 (2004) 69
 Few Body Syst 20 (1996) 1
 NIM B119 (1996) 259

$$\mu = gS \frac{m_p}{m} \mu_N$$

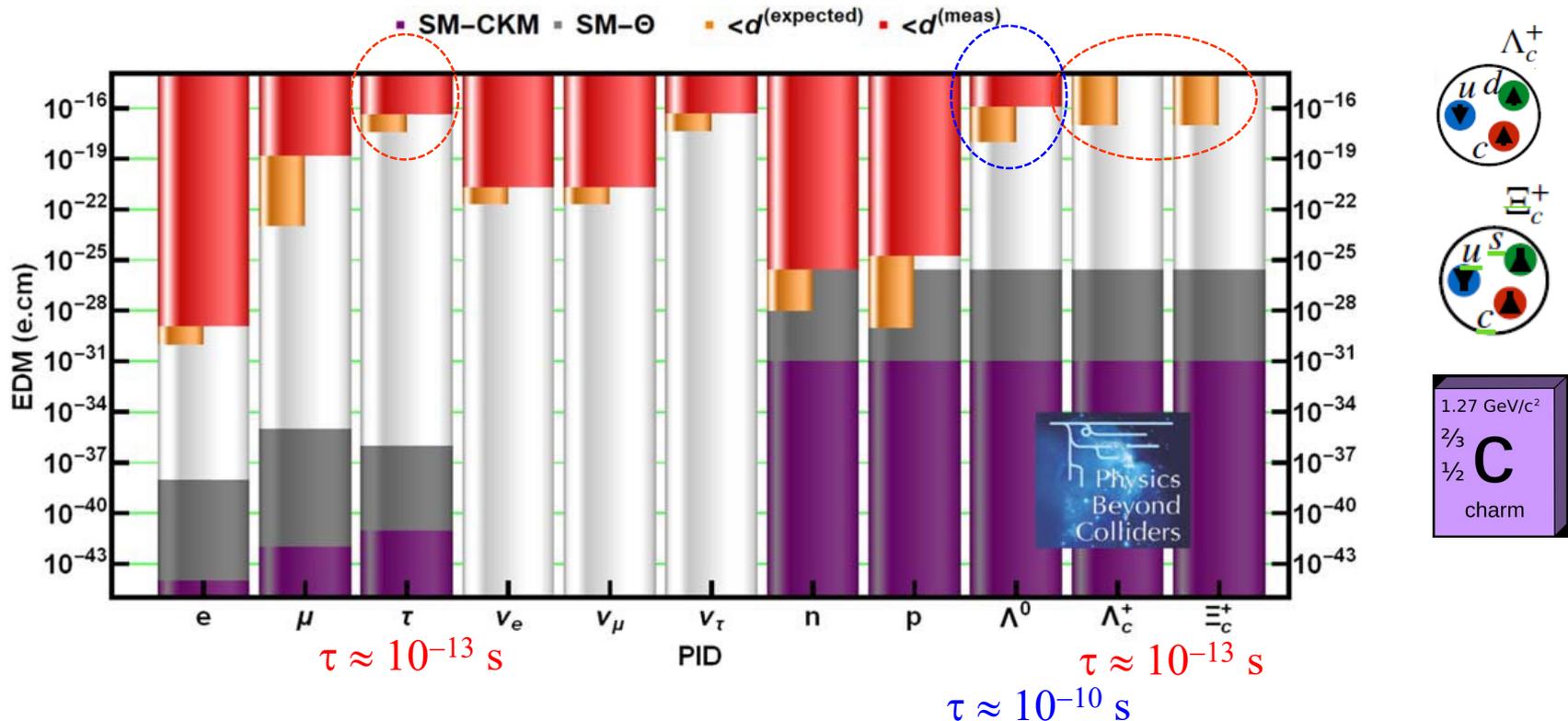
$$a = \frac{g-2}{2}$$

- A measurement of $\mu_{\Lambda_c^+}$ and $\mu_{\Xi_c^+}$ at 10% precision would be useful to confront with theory predictions

Why charm baryon dipole moments?

- Search for **charm EDM**, probe for BSM physics
- Fill gaps of **world-wide effort**: charm quark might have special BSM couplings

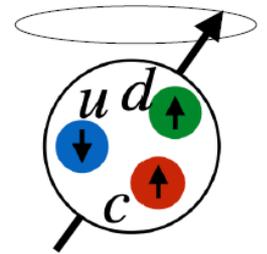
[J. Phys. G: Nucl. Part. Phys. 47 \(2020\) 010501](#)



- Coherent effort with **strange baryons** (G. Tonani's talk) and dreaming the **τ lepton...**

Experimental technique

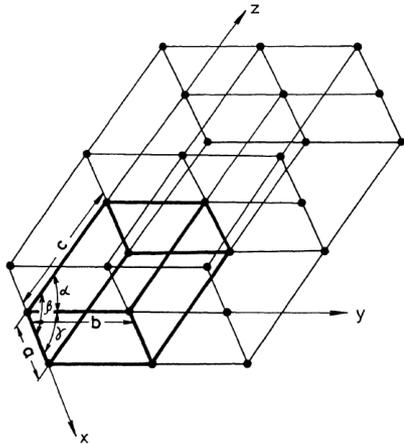
- **MDM** and **EDM** accessed through spin precession in EM field
- Requirements & challenges:
 - ✓ Charm baryon lifetimes are very short, $\tau \approx 2-4 \times 10^{-13}$ s
 - ⇒ large enough **flight length** $\approx 7-10$ cm ⇒ **ultrarelativistic baryons**, $\gamma \approx 1000$
 - ⇒ very **strong EM field**, $B_{\text{eff}} \approx 500$ T
 - ✓ **High intensity beam of polarised** charm baryons
 - ✓ **Forward spectrometer** for signal reconstruction, background rejection and angular analysis (analysing power)
- Charm baryons from fixed target-target **pW collisions** at the LHC, $\sqrt{s} \approx 115$ GeV (7 TeV proton beam)
- And the EM field?



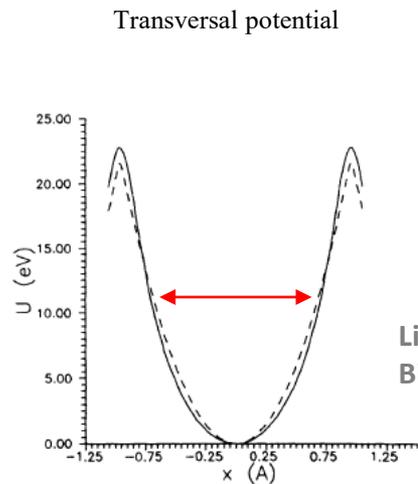
Channeling in bent crystals

- Potential well between crystal planes
- Incident positive charge particle can be trapped if parallel to crystal plane (within few μrad)
- Well understood phenomenon (Lindhard 1965)
- **Bent crystals** used to:
 - ✓ Steer high-energy particle beams
 - ✓ Induce **spin precession**

From Biryukov, Chesnokov, Kotov, "Crystal channeling and its applications at high-energy accelerators" (Springer)



The structure of the crystal lattice and its primitive cell



Lindhard (1965)
Biryukov (1997)

Si 110



Spin precession in bent crystals

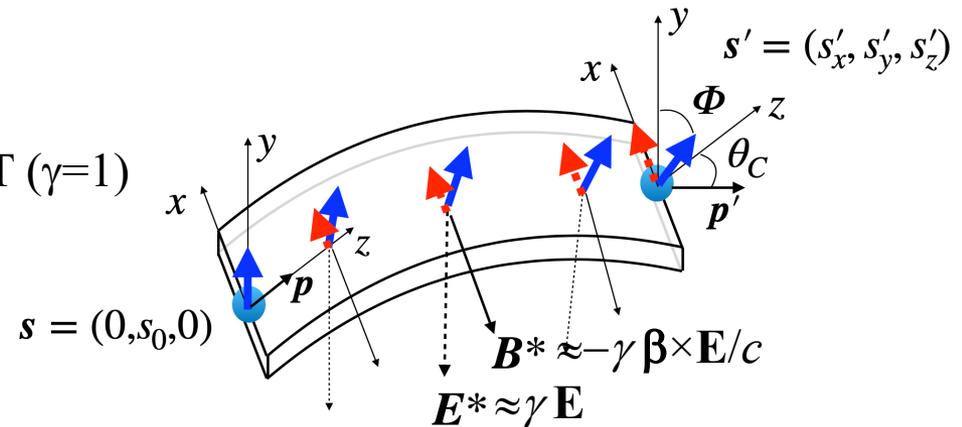
- First predicted by Baryshevsky (1979)

$$\frac{d\mathbf{S}}{dt} = \boldsymbol{\mu} \times \mathbf{B}^* + \boldsymbol{\delta} \times \mathbf{E}^*$$

- In bent crystals we have:

- ✓ Electric field $E \approx 2 \text{ GV/cm}$
- ✓ Effective magnetic field $B_{\text{eff}} \approx 500 \text{ T}$ ($\gamma=1$)

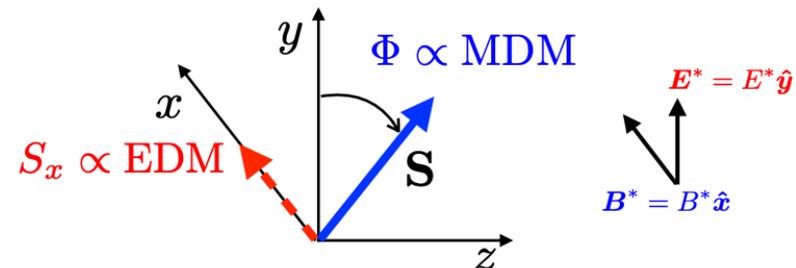
[Pis'ma Zh. Tekh. Fiz. 5 \(1979\) 182](#)
[Phys. Rev. Lett. 69, 3286 \(1992\)](#)
[JHEP 1708 \(2017\) 120](#)
[Eur. Phys. J. C \(2017\) 77:181](#)
[Eur. Phys. J. C \(2017\) 77:828](#)
[Phys. Rev. D 103, 072003 \(2021\)](#)



- Induce **spin precession** of the particles in a short distance

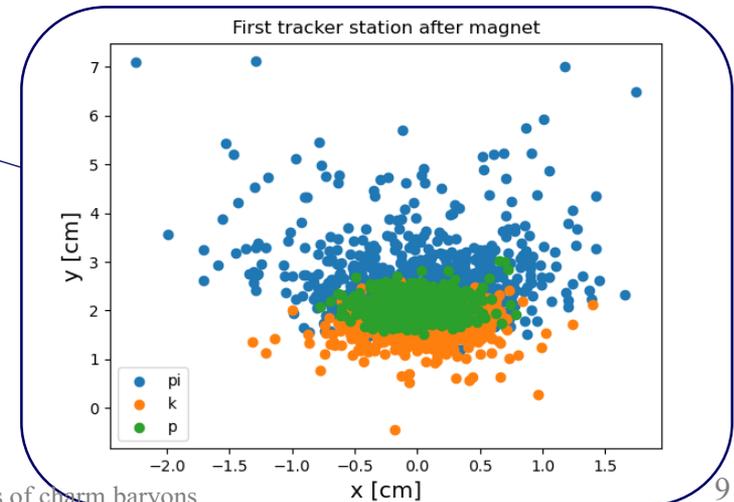
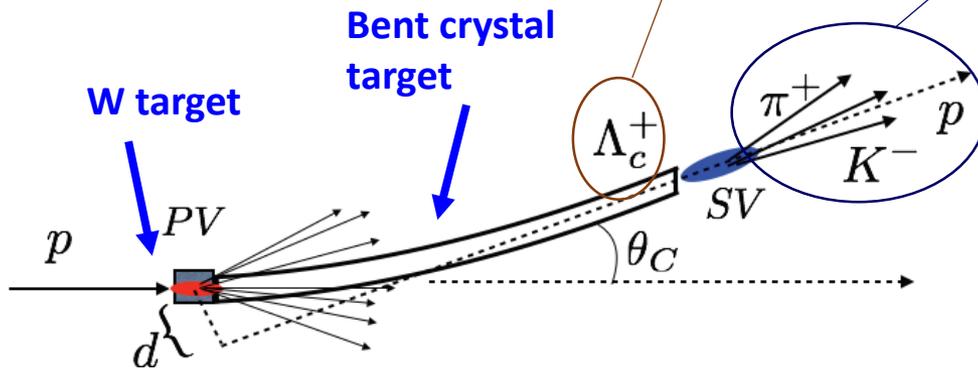
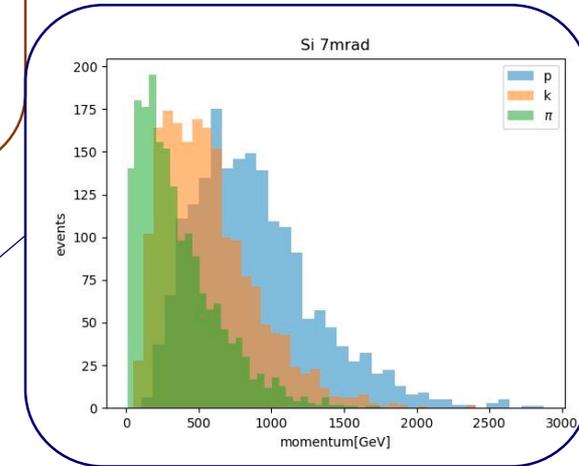
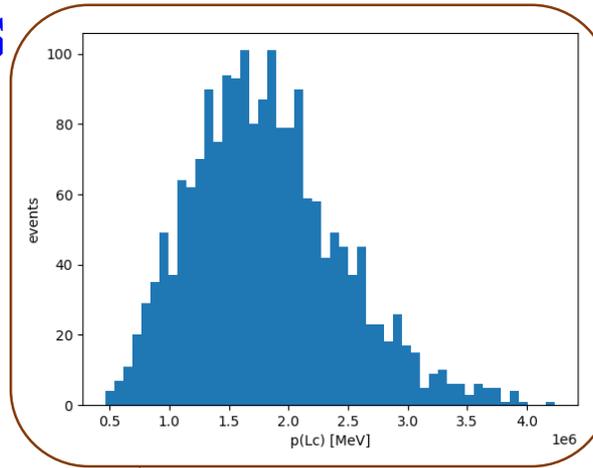
$$\Phi \approx \frac{g-2}{2} \gamma \theta_c$$

$$s_x \approx s_0 \frac{d}{g-2} (\cos \Phi - 1)$$



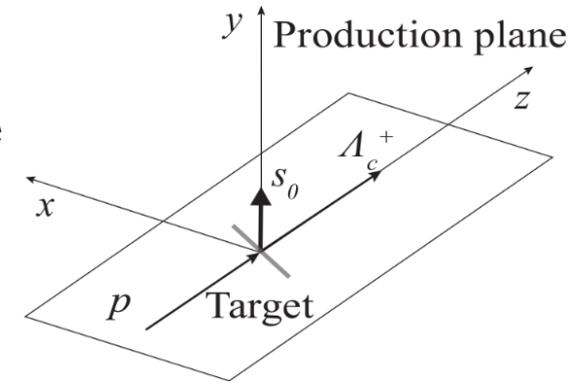
Signal kinematics

- With 7 TeV LHC protons and 7 mrad bent crystal
 - Charm baryons produced in a **very forward** direction
 - Very high momentum, higher than **1 TeV**

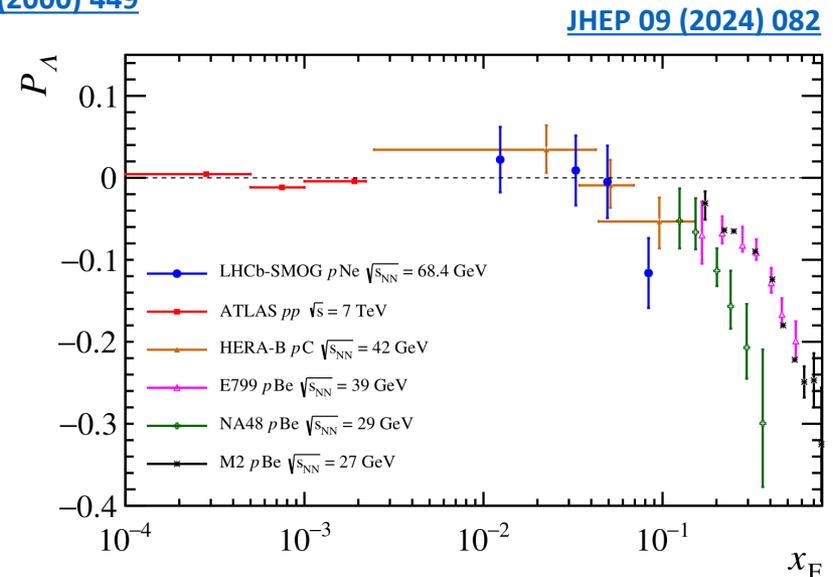
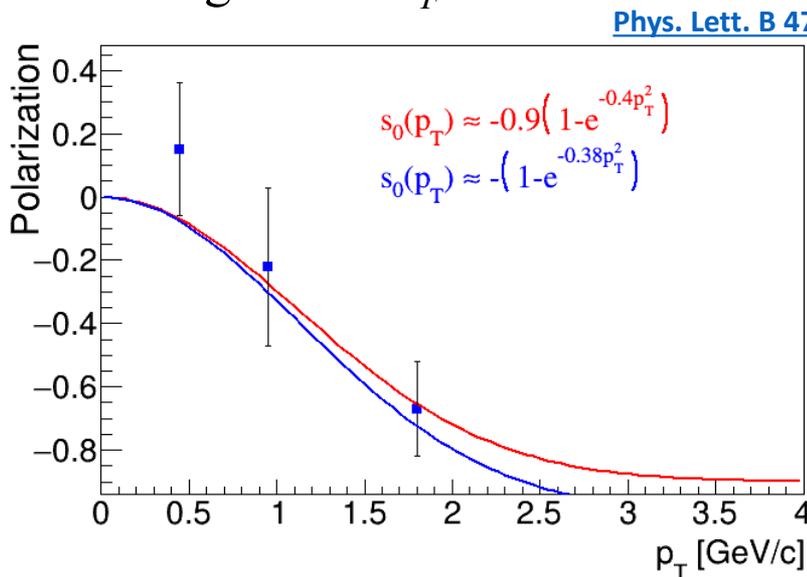


Polarisation

- Parity-conserving production, **polarization transverse** to the $p\text{-}\Lambda_c^+$ production plane, unknown for $p\text{-}N$ at $\sqrt{s} \approx 115$ GeV
- Until the past week, only existing Λ_c^+ polarization data was from E791 with 500 GeV/c π^- beam, covering $-0.1 < x_F < 0.4$



- Indications from Λ baryon



x_F in $p\text{-}W$ at $\sqrt{s} \approx 115$ GeV and \approx zero angle ≈ 0.1 and $0.5 \Rightarrow$ expected $\approx 30\%$

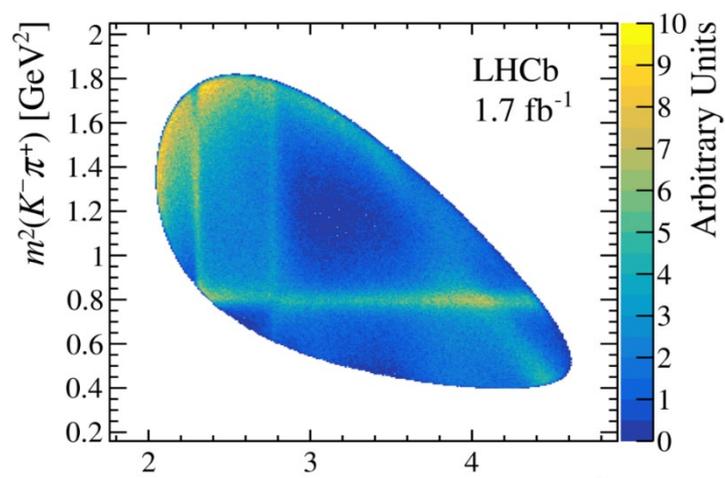
LHCb measurements and MEDMs

- Dominant Λ_c^+ , Ξ_c^+ final states are **3-body** with protons and hyperons, e.g.

$$\Lambda_c^+ \rightarrow pK^- \pi^+ \qquad \Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+, pK^- \pi^+ \text{ (CS)}$$

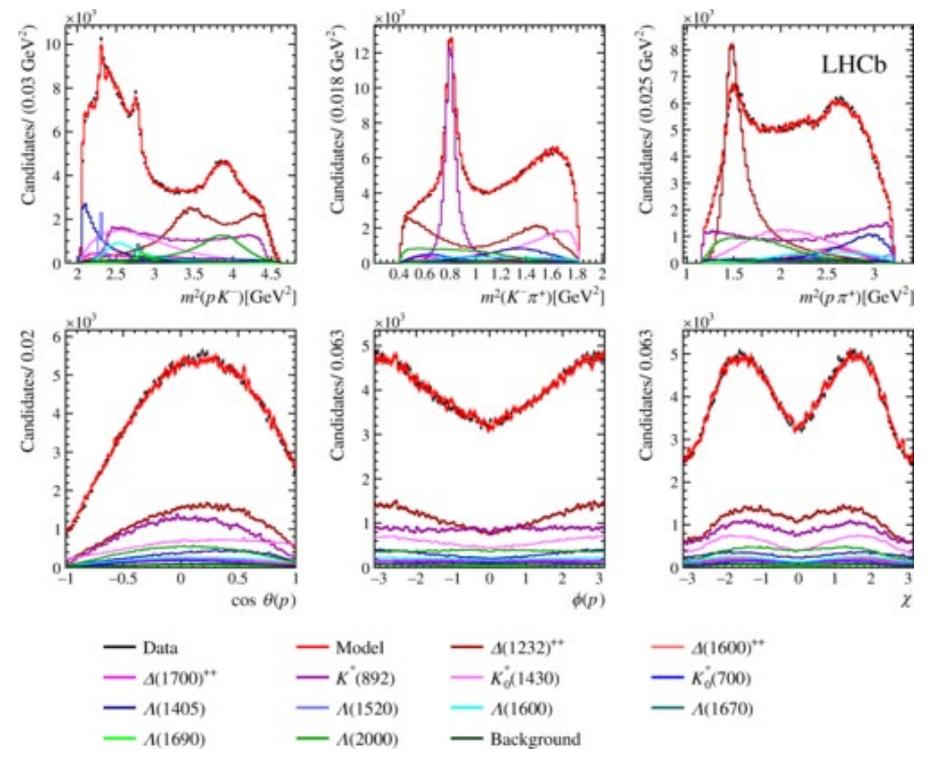
⇒ **amplitude analyses** from pp collision data at **LHCb** performed/ongoing

- 400k $\Lambda_c^+ \rightarrow pK^- \pi^+$ signal events from beauty hadron decays to determine the amplitude model and Λ_c^+ polarisation



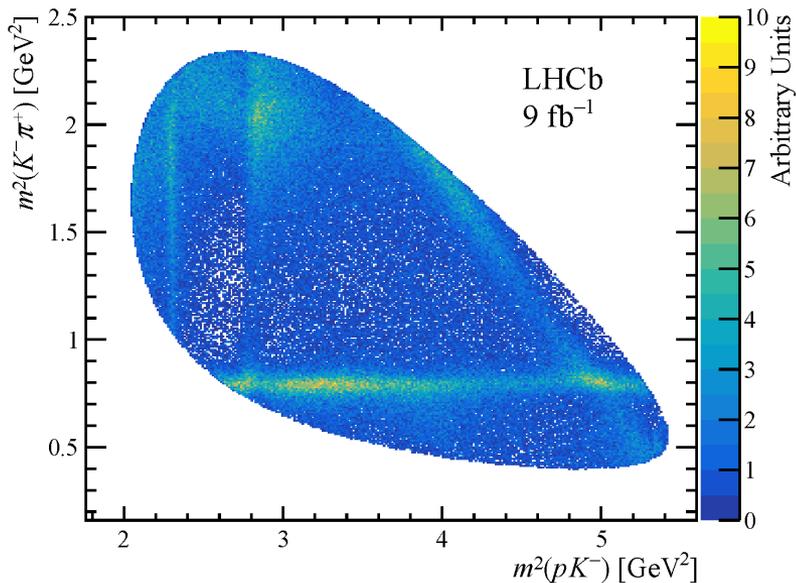
[Phys. Rev. D108, 012023 \(2023\)](#)

- Large sensitivity to polarisation (**analysing power**): $|\alpha_{\text{eff}}| \approx 66\%$



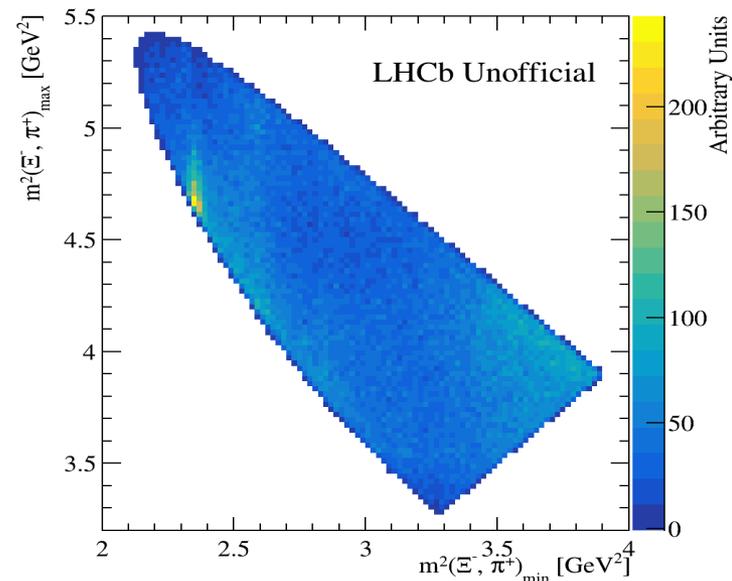
LHCb measurements and MEDMs

- $\approx 190\text{k } \Xi_c^+ \rightarrow pK^- \pi^+$ signal events from beauty hadron decays to determine amplitude model and Ξ_c^+ polarisation



[Phys. Rev. D112, 092003 \(2025\)](#)

- $\approx 200\text{k } \Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+, \Xi^- \rightarrow \Lambda \pi^-, \Lambda \rightarrow p \pi^-$ signal cascade decays from beauty decays and prompt production to determine amplitude and Ξ_c^+ polarisations (model agnostic)



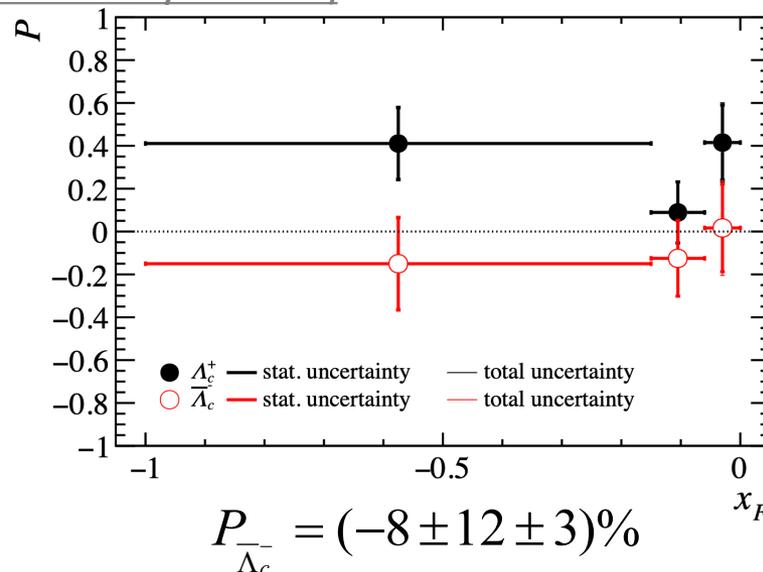
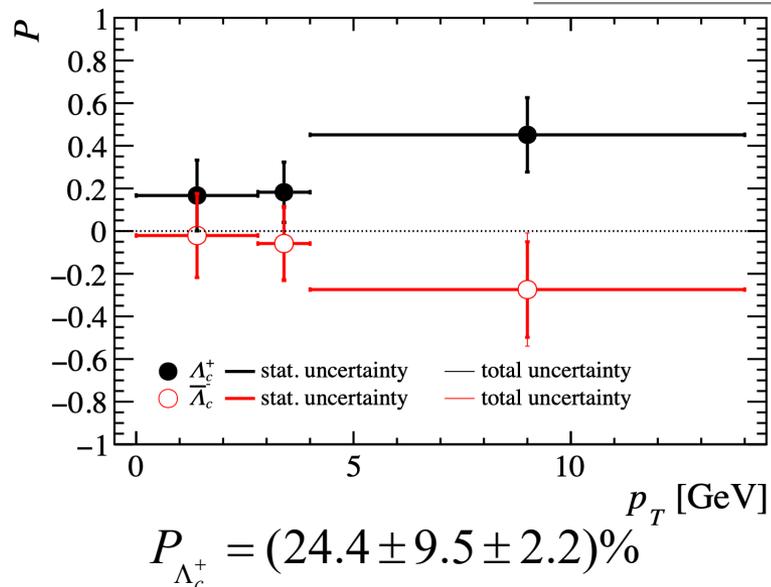
- Large analysing power: $|\alpha_{\text{eff}}| \approx 69\%$

- Analysing power?

LHCb SMOG measurements and MEDMs

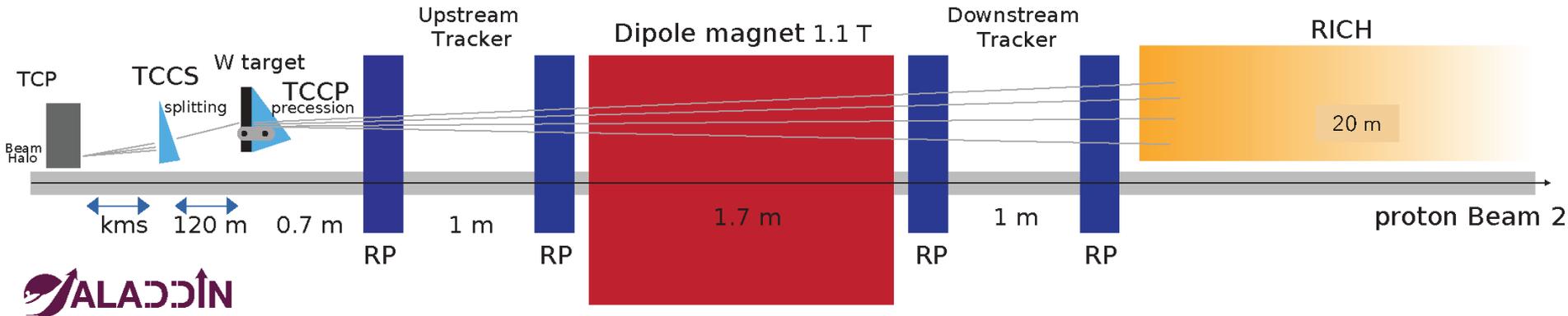
- Λ_c^+ polarisation in pW collisions at $\sqrt{s} \approx 115$ GeV is unknown
- Measure Λ_c^+ polarisation in LHCb SMOG p-Ne collisions at $\sqrt{s} \approx 68.6$ GeV, with $\approx 2k$ $\Lambda_c^+ \rightarrow pK^-\pi^+$ and $\bar{\Lambda}_c^- \rightarrow \bar{p}K^+\pi^-$ signal decays
- **First differential measurement** of Λ_c^+ and $\bar{\Lambda}_c^-$ polarisation as a function of p_T and x_F . Interesting per se to understand polarisation mechanism in QCD

arXiv:2602.17184 (submitted to Phys. Rev. Lett.)



- Larger yields ($> \times 10$) with different gasses (Ar, D, He, H₂, Ne) already recorded with SMOG2

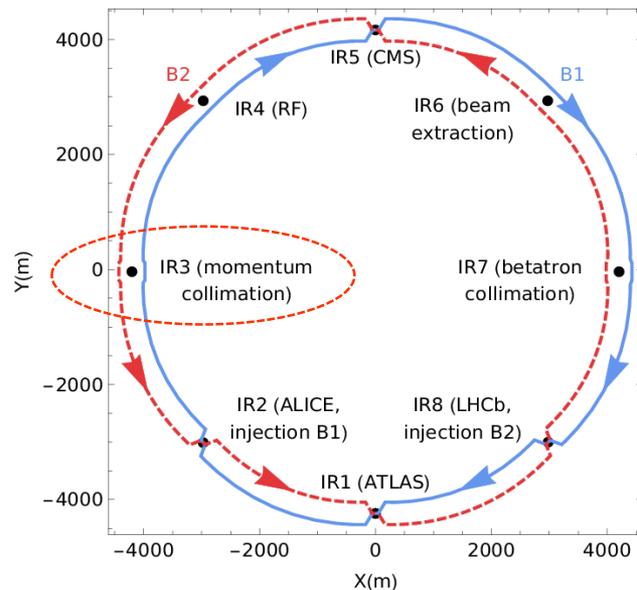
The ALADDIN experiment



ALADDIN is a fixed-target experiment proposed at LHC for **MDM/EDM** measurements of charm baryons

Experimental apparatus

- **Crystal 1 (TCCS)**: sec. halo extraction from LHC beam
- **W target** ~ 2 cm
- **Crystal 2 (TCCP)**: spin precession of charm baryons
- **Spectrometer**: baryon reconstruction with a 1.9 Tm magnet
- Particle identification detector - **RICH**



Spectrometer specifications

- Pseudorapidity acceptance $5 < \eta < 9$
- Excellent **angular resolution** $\approx 15 \mu\text{rad}$
- Good momentum & **mass resolution** $< 25 \text{ MeV}$ to separate the signal from misidentified background, eg.

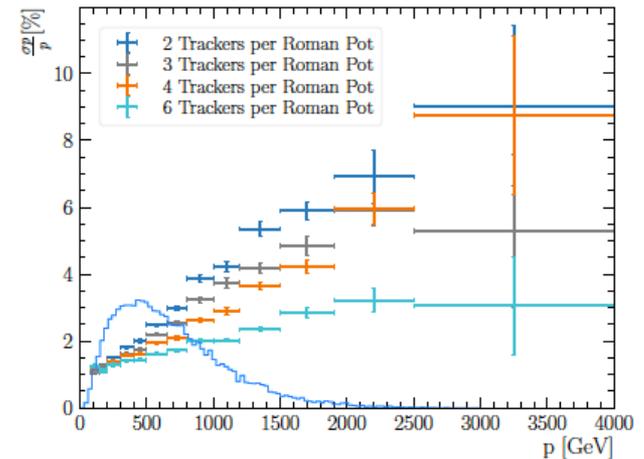
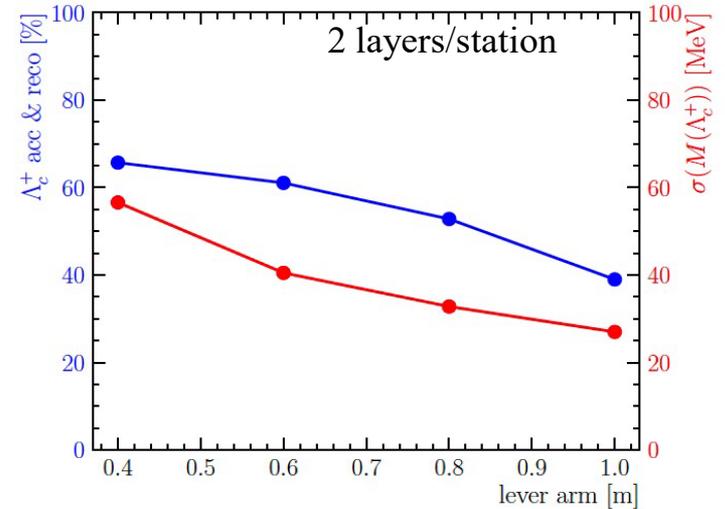
$D^+ \rightarrow K^- \pi^+ \pi^+$ with one π^+ misidentified as p

$D_s^+ \rightarrow K^+ K^- \pi^+$ with K^+ misidentified as p

have similar cross section, channeling efficiency, and lifetime as Λ_c^+

- Tracker requirements:

\Rightarrow 1 m lever arm, at least 6 layers/station, 3-4 stations

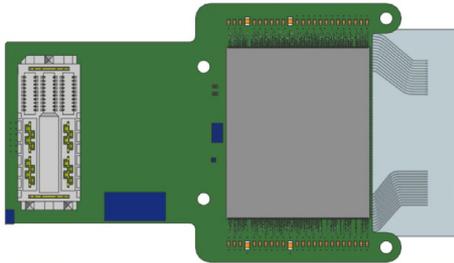


	pitch (μm)	hit rate (MHz/cm ²)	fluence (n _{eq} /cm ²)	area (cm ²)	tech. solution
Upstream	55	250	3.5×10^{15}	10	Si pixel
Downstream	100	30	9.0×10^{13}	30	Si pixel/strip

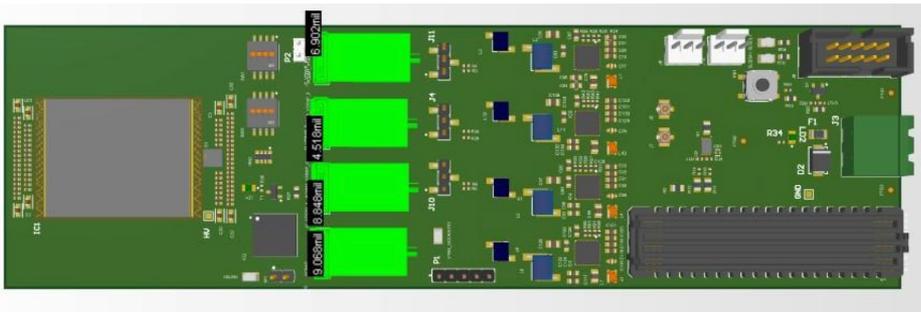
Pixel detector for the tracker

- Layout based on the **LHCb VELO U2**
 - ✓ 3D Si sensors – 45 mm pitch
 - ✓ Readout ASIC: 28 nm IGNITE & LA-PicoPix
 - ✓ VeloPix2 Control Electronics & DAQ: VTRX+ (baseline) or Silicon Photonics (SiPh)
- **Detector package mechanics** based on the **PPS2 (CMS)** development
 - ✓ Modules in secondary vacuum (S1 & S2) and possibly air (S3 & S4)
 - ✓ Cooling based on Peltier cells
 - ✓ Can use both VTRX+ and SiPh

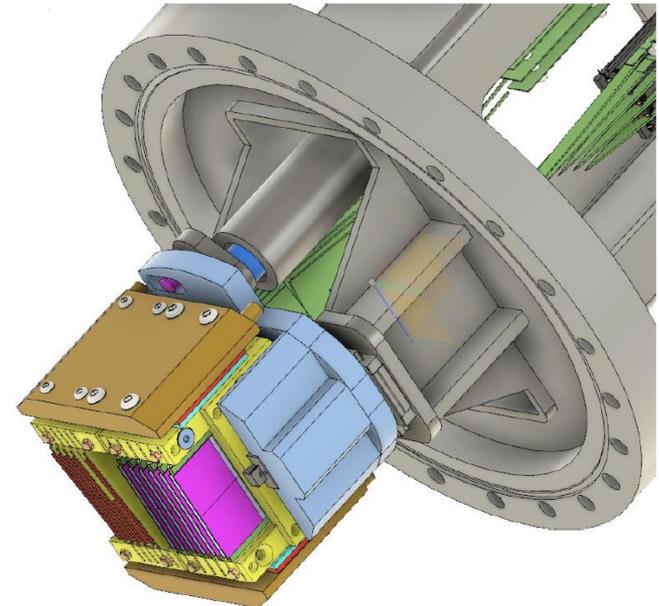
LHCb upgrade 2 pixel detector prototype



LHCb upgrade 2 pixel readout board prototype

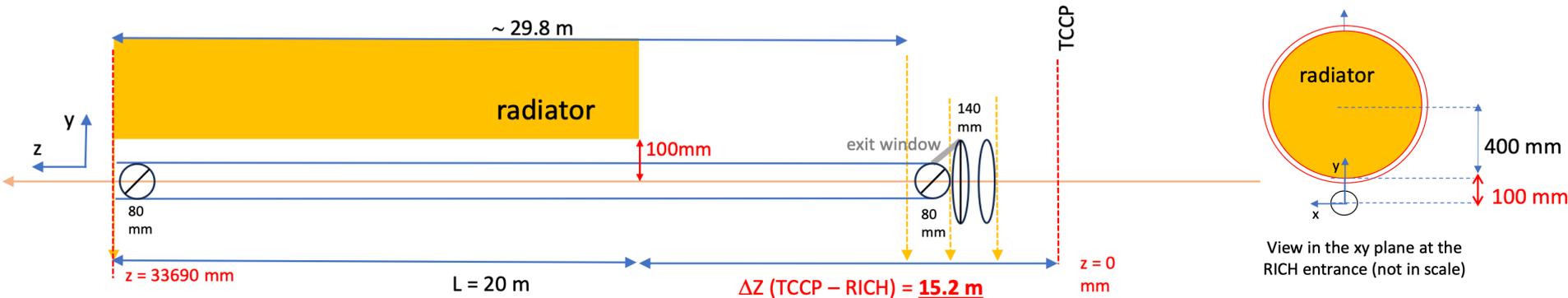


PPS upgrade mechanics/cooling



RICH detector

- Need a RICH for charged particle identification **up to 1 TeV** to suppress background from misidentification and random combinations
- Design choice for baseline: **20 m long vessel**, 80 cm diameter, filled with Ne (980 mbar, 25 °C, $\lambda=309$ nm), **single reflection** configuration

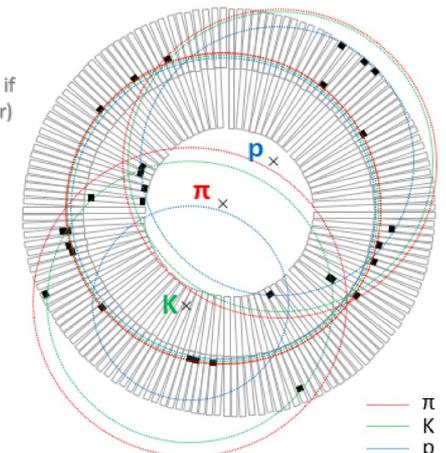


I. Panichi (Firenze)

- Uses highly pixelated (100 cm², 0.5×0.5 mm² pixel) & efficient photosensors (SiPM or MCP-PMT)
- Using the track and the position of the detected photon, the Cherenkov angle at emission can be reconstructed

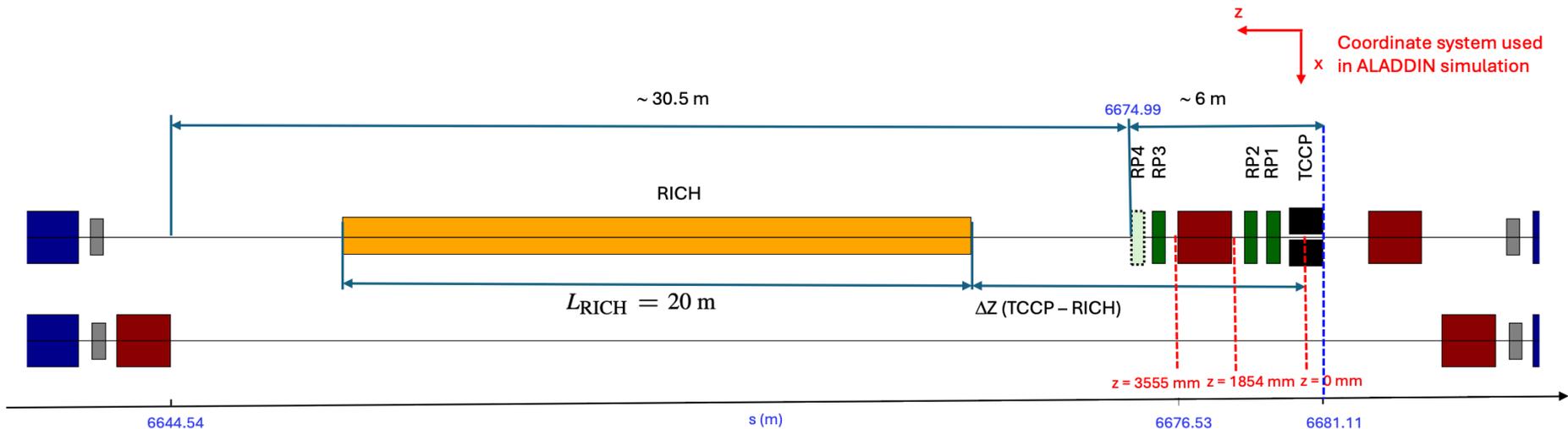
$$\sigma_{\theta} \approx 50 \mu\text{rad} \text{ per photon}$$

- Photon hit
- Track (impact point on detector plane as if reflected in mirror)



Machine-detector layout

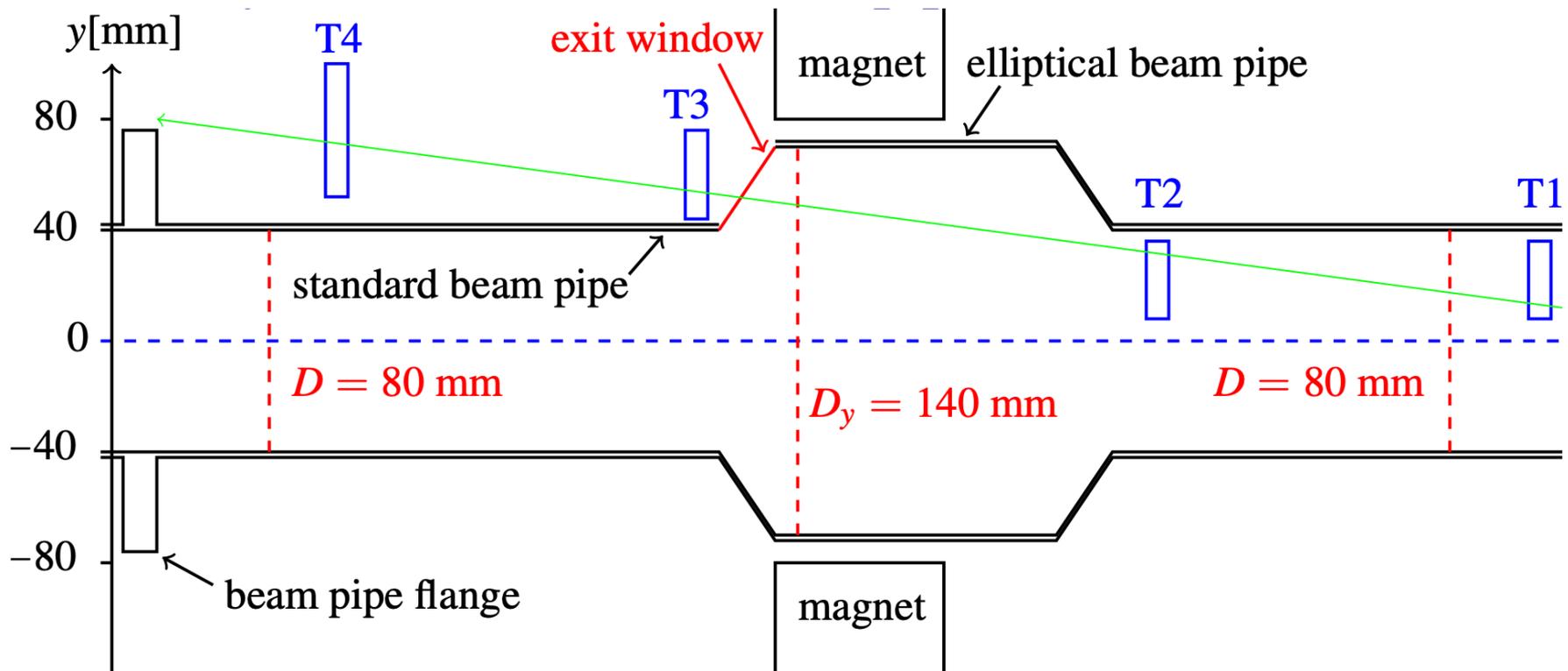
- Main goal: **integrate spectrometer and RICH in IR3** while minimizing technical challenges (beam pipe modifications)
- Full **simulation studies** and analysis of technical aspects ongoing to define an optimal and realistic layout
- **Machine impedance** and **beam dynamics studies** from the machine for HL-LHC conditions are required to validate the layout



P. Hermes (CERN), C. Maccani (CERN-Padova)

Machine-detector layout: simplified concept

- Try to **minimise** the impact on the (Cu) **beam pipe modifications**. Below, the downstream tracking stations are positioned outside the vacuum



F. Bertinelli (CERN), F. Bizzeti (Firenze), N. Turini (Siena)

Sensitivities to charm dipole moments

First measurements of charm baryon MDM and EDM

- ✓ 2-year data taking
- ✓ 10^6 p/s
(1.37×10^{13} PoT)
- ✓ $P \approx 30\%$

$$\sigma_g \approx \frac{2}{S \langle s_y \rangle \langle \gamma \rangle \theta_C} \frac{1}{\sqrt{N_{\text{rec}}}}$$

$$\sigma_d \approx \frac{g-2}{S} \frac{1}{\sqrt{\langle s_y \rangle^2 \eta^2 + 2 \langle s_x \rangle^2 \eta}} \frac{1}{\sqrt{N_{\text{rec}}}}$$

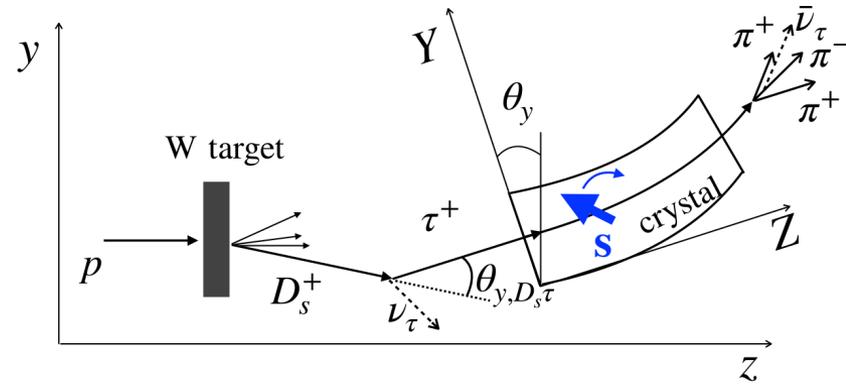
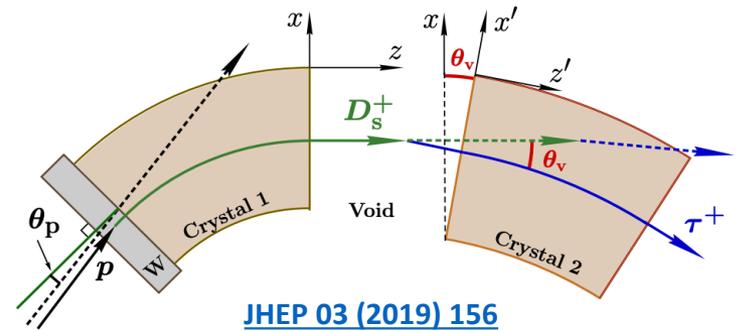
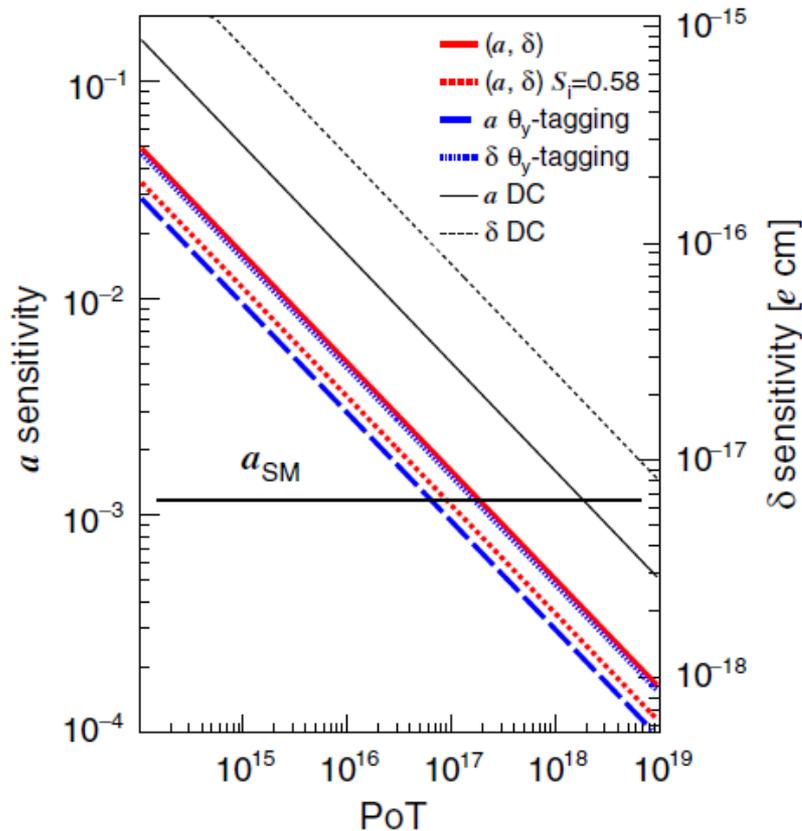
$$\eta = 1 - \cos \langle \Phi \rangle$$

[Phys. Rev. D103, 072003 \(2021\)](#)

	Si		Ge
Deflection angle [mrad]	7	5	7
Length [cm]	7	7	7
Λ_c^+ baryon			
a	$\approx -0.03[-0.76]$		
N_{tot} deflected per 10^{10} PoT	86	162	120
$\langle \gamma \rangle$	945	1036	886
$\langle p_T \rangle$ (GeV/c)	0.84	0.88	0.81
$\langle s_x \rangle$	0.20	0.23	0.20
$\langle s_y \rangle$	0.24	0.24	0.24
N_{rec} $pK^-\pi^+$ only	1474	2773	2066
N_{rec} all charged	2836	5409	3940
σ_μ ($\times 10^{-2} \mu_N$) all charged	1.2	1.1	1.1
σ_δ ($\times 10^{-16} e \text{ cm}$) all charged	1.5 [4.6]	1.2 [3.1]	1.4 [3.8]
Ξ_c^+ baryon			
a	$\approx 0.05[-0.47]$		
N_{tot} deflected per 10^{10} PoT	135	215	98
$\langle \gamma \rangle$	596	641	602
$\langle p_T \rangle$ (GeV/c)	0.74	0.77	0.74
$\langle s_x \rangle$	0.16	0.17	0.14
$\langle s_y \rangle$	0.27	0.28	0.26
N_{rec} $\Xi^-\pi^+\pi^+$ only	735	1202	1096
N_{rec} all charged	1939	3198	2898
σ_μ ($\times 10^{-2} \mu_N$) all charged	1.8	1.8	1.5
σ_δ ($\times 10^{-16} e \text{ cm}$) all charged	3.1 [3.0]	3.0 [2.5]	2.9 [2.3]

Other opportunities

- Opportunity for **other measurements** in the **very forward region**, $5 < \eta < 9$, i.e. cross section of charm hadron production, QCD polarisation, J/ψ photoproduction
- Explore measurement of τ $g-2$ and EDM**
 - Requires much larger #PoT and further R&D



Schedule and synergies with LHCb U2

- [Letter of Intent \(LoI\)](#) submitted in June 2024
- Very positive review by the LHC Committee (LHCC), ongoing
- ALADDIN collaboration created and organized
- Technical Proposal to be presented to the LHCC by Summer 2026. Dedicated workshop in [La Biodola, Isola d'Elba \(May 17-21, 2026\)](#)
- Data taking during LHC Run 4. Installation during LS3 & a Run 4 YETS

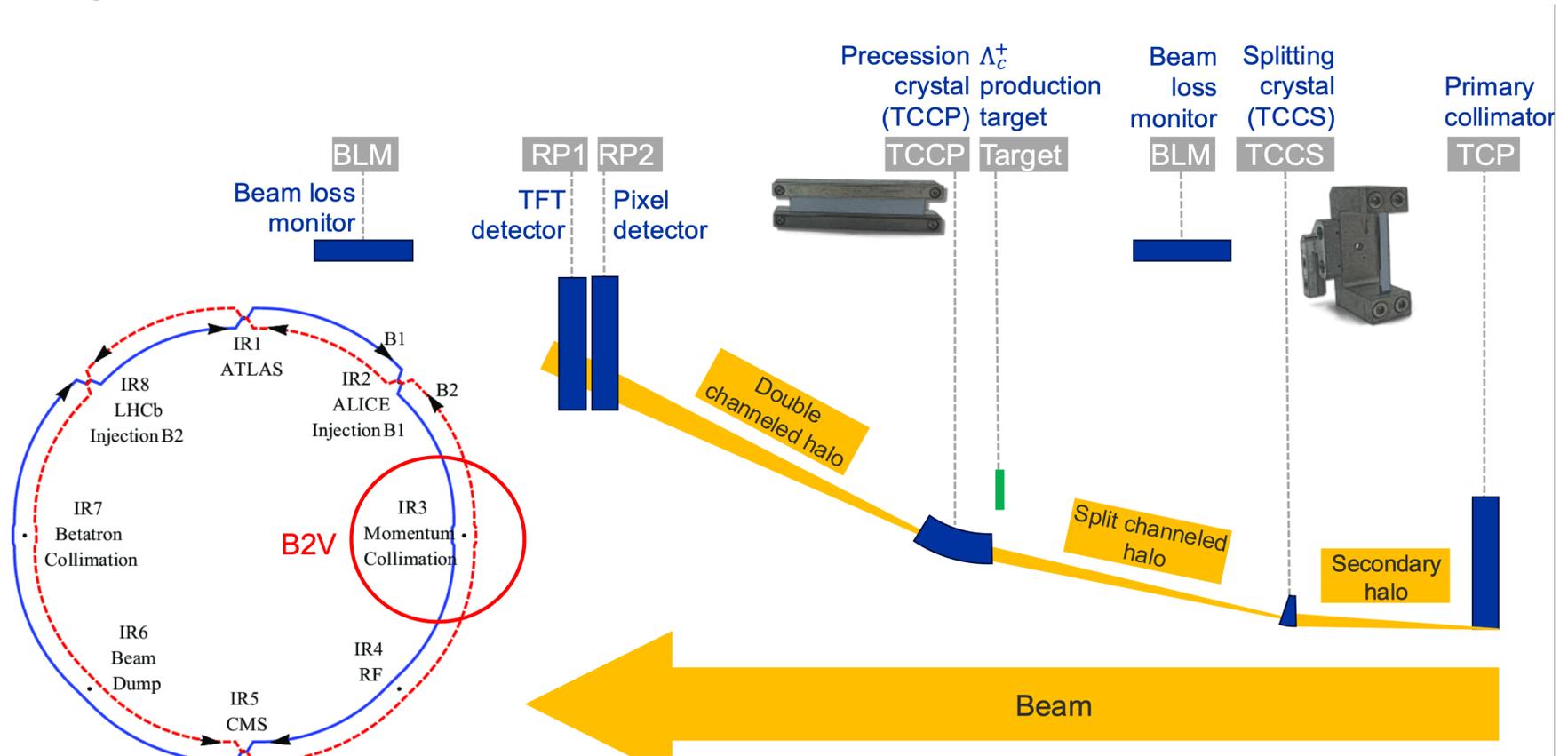


- Strong synergy with LHCb U2 for tracker, DAQ & trigger



Proof-of-principle: TWOCRIST

- The TWOCRIST PoP was installed in 2025 at IR3, one of the two collimation regions of the LHC, where ALADDIN will be housed



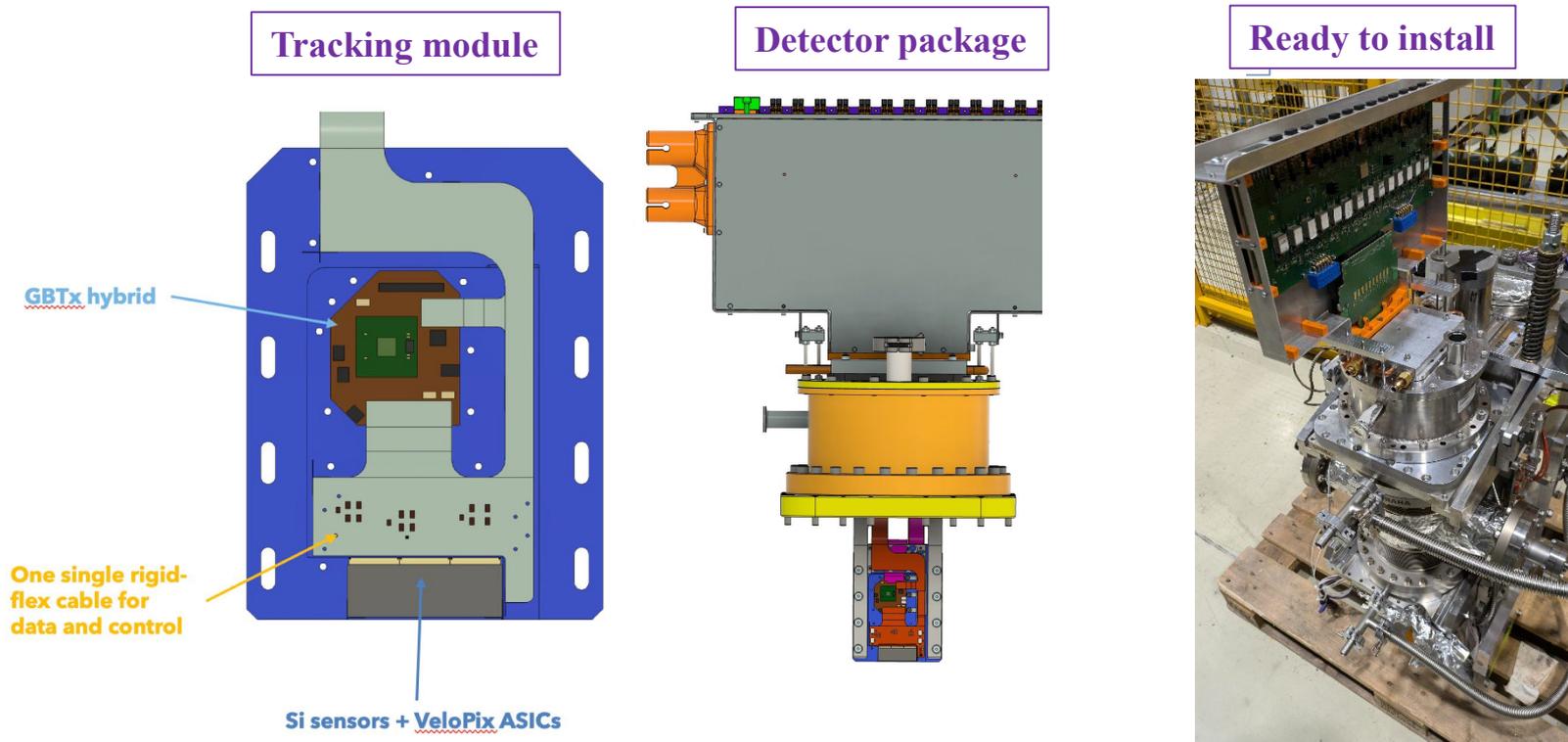
Goals of the PoP

- Demonstration of operational feasibility.
- Measurement of channeling efficiency for long crystals at TeV energies.
- Study of proton beam intensity on target and study of criticalities.

From [R. Cai at EPS2025](#)

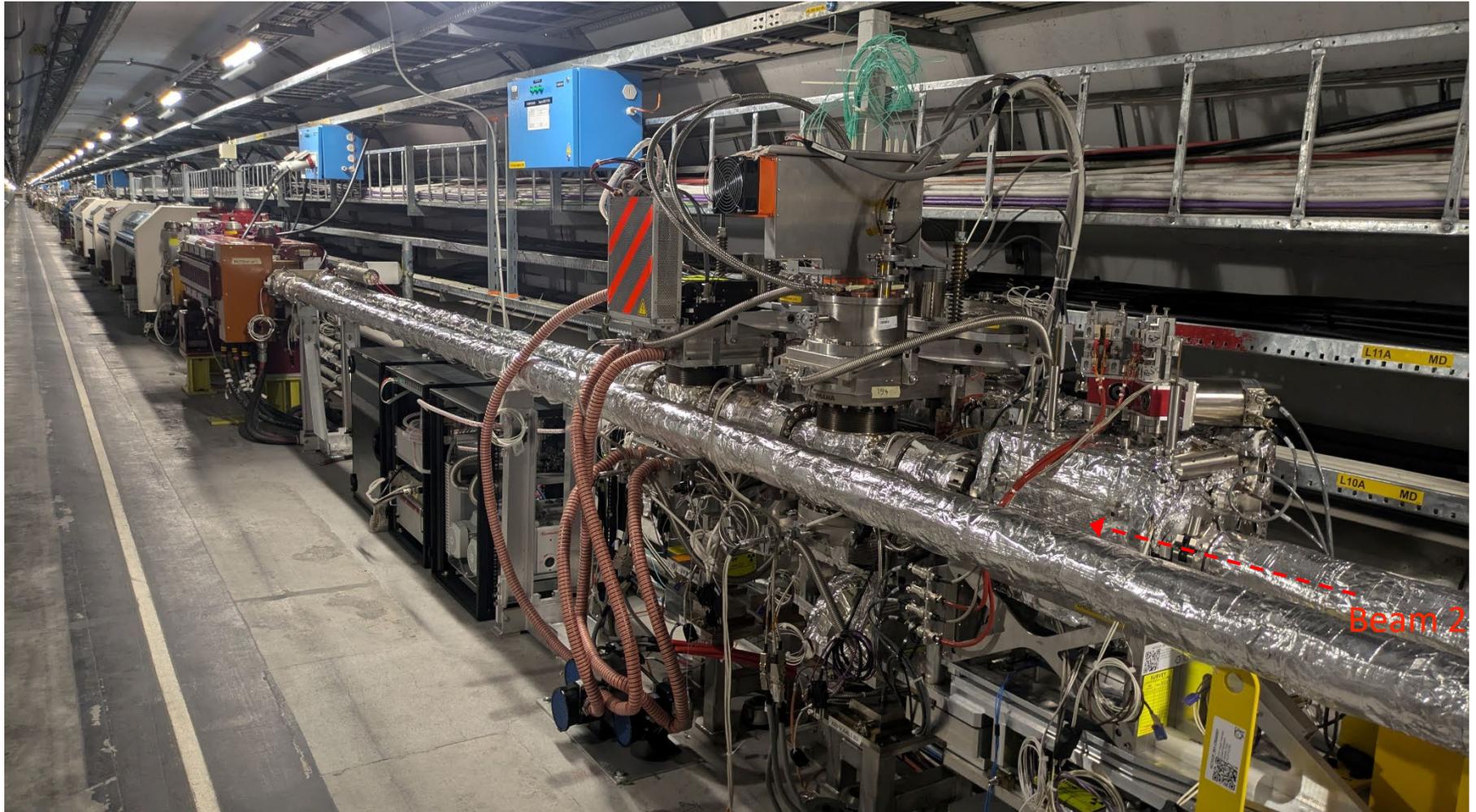
Pixel detector

- Based on **LHCb VELO pixel sensors** and **VeloPix ASIC** (2 layers)
- New design of **vacuum feed-through board** and **data flex** to accommodate control and data lines inside RP, water & **Peltier cooling**
- Housed in **ATLAS-ALFA RP** (width 128× height 60× thickness 46 mm³) extracted from LHC tunnel, with CMS-TOTEM based design for detector package in the RP



Installation in the LHC tunnel

- Successfully installed & commissioned in March 2025



Successful operation & preliminary results

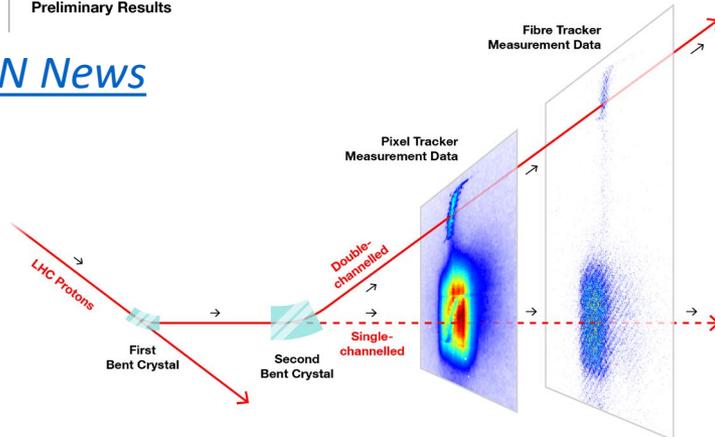
- 4 dedicated MD runs in 2025, experimental technique established: successful machine studies conducted during MDs, double channeling achieved at LHC

First observation of the double channeling at the LHC

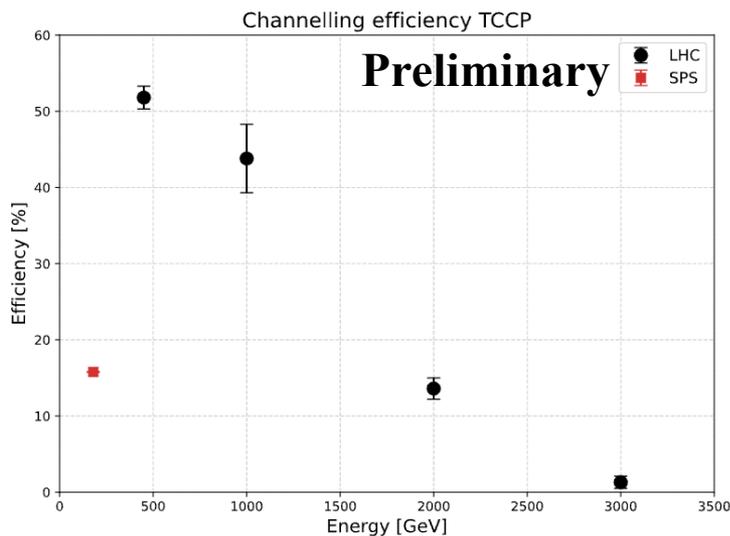


Preliminary Results

[CERN News](#)



TWOCRIST members in the CCC



“shelf of fame” in the CCC

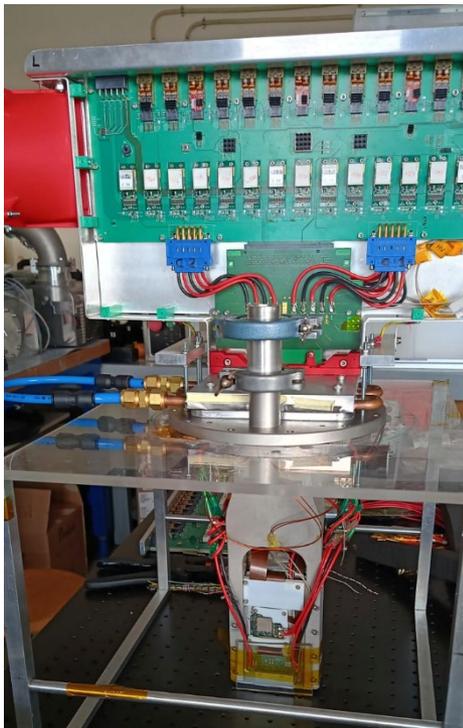


[S. Cesare PhD Thesis \(Milano\)](#)

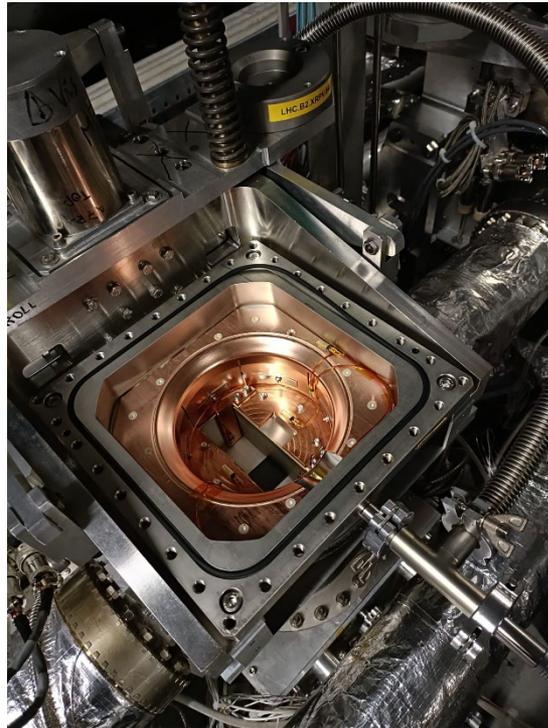
2nd pixel detector for 2026

- In Jan 2026 replaced the TFT with a 3 layers pixel station:
 - ✓ tracking of double-channeled particles & vertex reconstruction
 - ✓ proton flux
 - ✓ channeling at additional energies & backgrounds

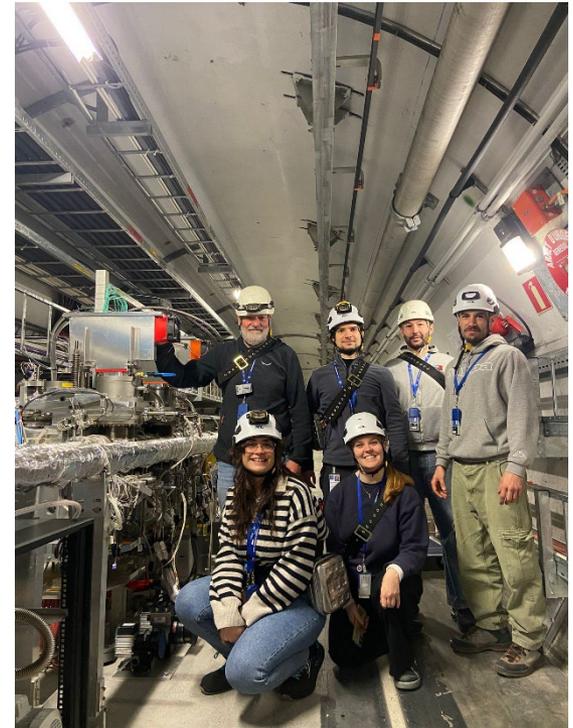
The 2nd tracker ready to install



The RP before insertion



The installation crew: N. Turini (Siena), C. Vinotto (Pisa), J. Mazorra, V. Svintozelskyi (Valencia), G. Tonani (Milano), F. Zangari (CERN)



Summary



- **ALADDIN** is a proposed fixed-target experiment for the LHC Run 4 with the goal to **first measure charm baryon MDMs** with sensitivity of $2 \times 10^{-2} \mu_N$, and explore **EDMs** at $10^{-16} e \cdot \text{cm}$ level with 10^{13} PoT
 - ✓ Opportunity for major **synergies** with LHCb U2 & CERN R&D projects



- **TWOCRIST** is a successful proof-of-principle: demonstration of operational feasibility and channeling of secondary beam halo with efficiency at TeV energies according to expectations



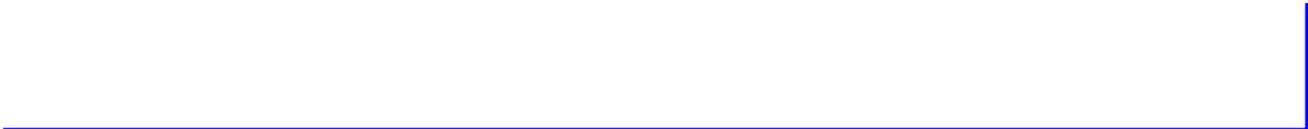
- **Preparatory measurements** for ALADDIN delivered and ongoing at LHCb

Next stop: TP & La Biodola, Isola d'Elba

- 17-21 May. See [indico](#) page of the workshop with the details for registration
- Main goal discuss **theory, machine, detector** aspects for ALADDIN Technical Proposal

Anyone is welcome to join!





Backup

ALADDIN collaboration



<https://aladdin.web.cern.ch/>

Authors as 22/07/2025

61 proponents from 25 institutions

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[Constitution of the collaboration](#)

Machine people at CERN

In particular, we would like to acknowledge the help of P. Hermes, K. Dewhurst, R. Cai, C. Maccani, D. Mirarchi, S. Redaelli and G. Arduini

Organization

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CB Chair: Roberta Cardinale (Padova)

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Pixel WG coordinators: Sara Cesare, Nicola Turini

RICH WG coordinators: Francesca Bucci, Tonino Sergi

DAQ & Trigger WG coordinators: Marco Sozzi, Federico Alessio



Acknowledgments



We would like to thank our colleagues in the CERN accelerator department for their help and fruitful collaboration in the definition of the machine running conditions.

We acknowledge support from CERN and from the national agencies: INFN (Italy) and MICIU, AEI and GVA (Spain), and the Fundamental Research Funds for the Central Universities (China).

We acknowledge financial support:

- National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, Call for tender No. 1409 published on 14.9.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU - Project Title 202277EWLW
- The ERC Consolidator Grants SELDOM G. A. 771642
- The NRRP - NextGeneration EU in the Valencian Community GVANEXT Project Reference ASFAE/2022/030

TWOCRIST collaboration



TWOCRIST

<https://twocryst.web.cern.ch>

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Acknowledgments



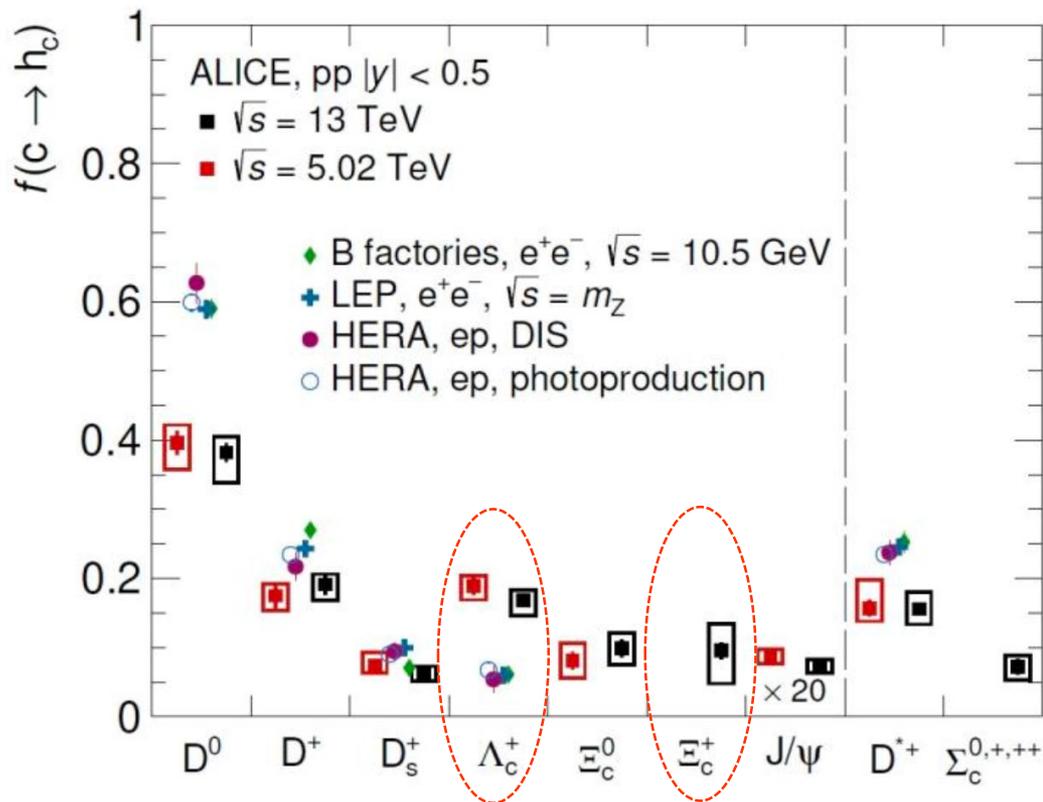
TWOCRIST is carried out under the Physics Beyond Colliders (PBC) Fixed-Target Working Group and is a collaboration of the institutes CERN, INFN (Italy), IFIC (University of Valencia-CSIC, Spain), IJCLab (France), the University of Malta, the Institute of Nuclear Physics of the Polish Academy of Sciences, Warsaw University of Technology (Poland), and UCAS (China).

The project acknowledges support from the PBC project; the HL-LHC project; the ATLAS-ALFA collaboration; the ERC SELDOM Grant No. 771642; the INFN CSN5 project OREO; the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU under Project Title PRIN 202277EWLW; contributions from the AICRYSCON project funded by Xjenza Malta through the FUSION: R&I Research Excellence Programme; support from MICIU, AEI, and GVA (Spain) under projects PID2022-139842NB-C22, CIPROM/2022/36, ASFAE/2022/030, and NextGenerationEU; and funding from the National Science Centre, Poland (project No. 2021/43/D/ST2/02761).

The project acknowledges the work of A. Mazzolari (UNIFE & INFN Ferrara) for the design and realization of TCCS and TCCP and A. Sytov (INFN Ferrara) for MC studies on channeling efficiency.

LHCb SMOG measurements and EMDMs

- Charm fragmentation fractions recently measured by ALICE are not in agreement with previous measurements from e^+e^- , e^-p , pp data

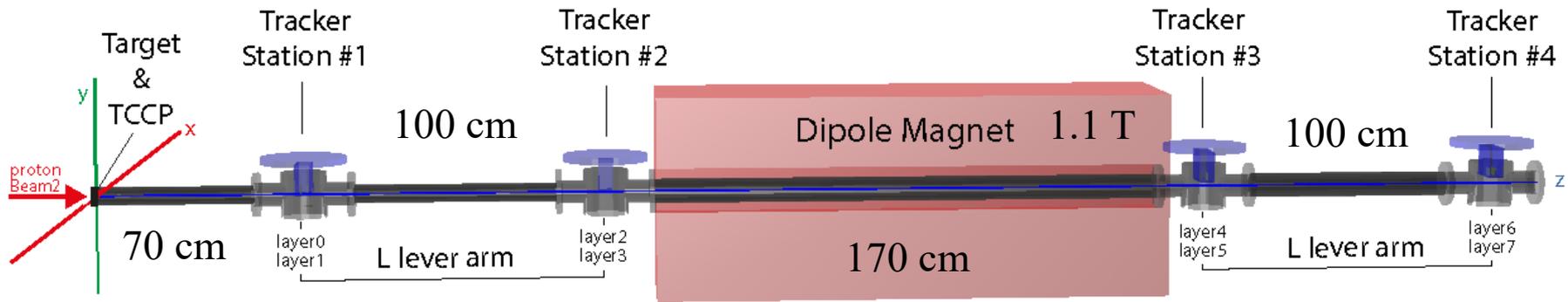


PRD 105 (2022) L011103
 JHEP 12 (2023) 086
 arXiv:2405.14571

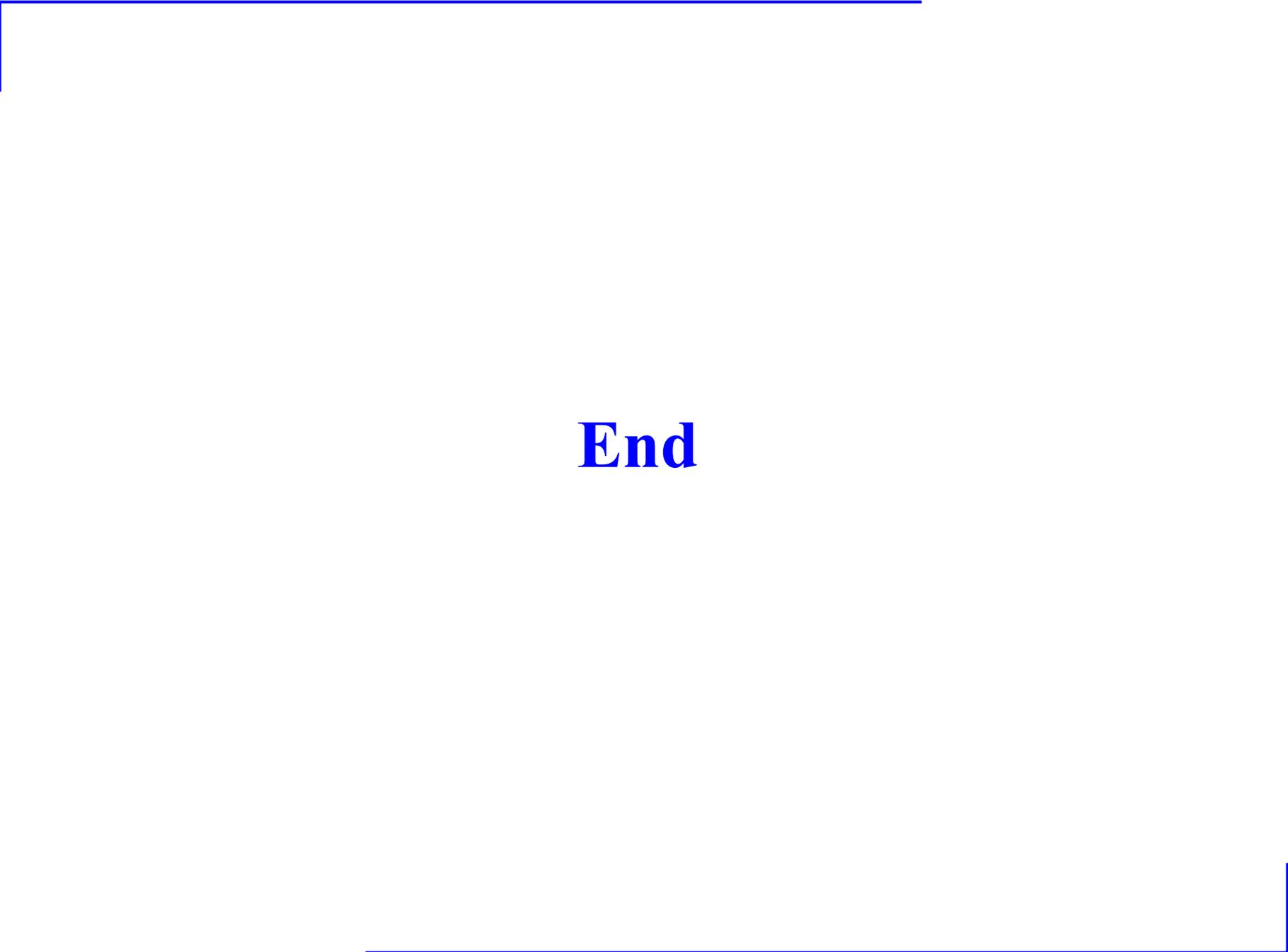
- ✓ Points to an increase of charm baryon fragmentation fractions with lower p_T
- New measurements ongoing with LHCb SMOG(2) at similar \sqrt{s} and low p_T

(Very) forward spectrometer

- Pseudorapidity acceptance $5 < \eta < 9$
- **4 tracking stations:** 2 upstream housed in Roman Pots (RPs) + 2 downstream (w/ or w/o RPs)
- A local corrector **dipole magnet** MCBWV (1.1 T, 1.7 m) available in situ



- **Momentum resolution:** $\frac{\sigma_p}{p} \approx \frac{2p}{0.3BLD} \sigma_x \approx 2\%$, with $p = 500 \text{ GeV}/c$, $BL = 1.9 \text{ Tm}$, $D = 1 \text{ m}$, $\sigma_x \approx 10 \mu\text{m}$
- **Track angle resolution:** $\sigma_\theta \approx \sqrt{2} \sigma_x / D \approx 14 \mu\text{rad}$
- **Impact parameter resolution:** $\sigma_{x,y} \approx 20 \mu\text{m}$



End