The ALADDIN experiment at the LHC

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On behalf of the ALADDIN collaboration

4th Italian Workshop on the Physics at High Intensity Bari 12/11/2025

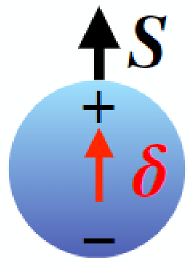
Outline

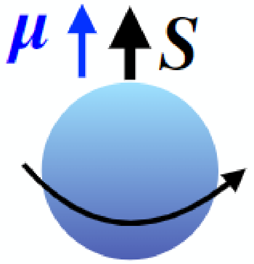
- Introduction and physics motivation
- Proposed experiment at LHC
- Detector layout and integration
- Summary

Electromagnetic dipole moments

- For spin $\frac{1}{2}$ particles we define:

EDM $\boldsymbol{\delta} = \frac{1}{2} d\mu_B \boldsymbol{P}$ MDM $\boldsymbol{\mu} = \frac{1}{2} g\mu_B \boldsymbol{P}$





with $\boldsymbol{P} = 2 < \boldsymbol{S} > /\hbar, \quad \mu_B = \frac{q\hbar}{2m}$

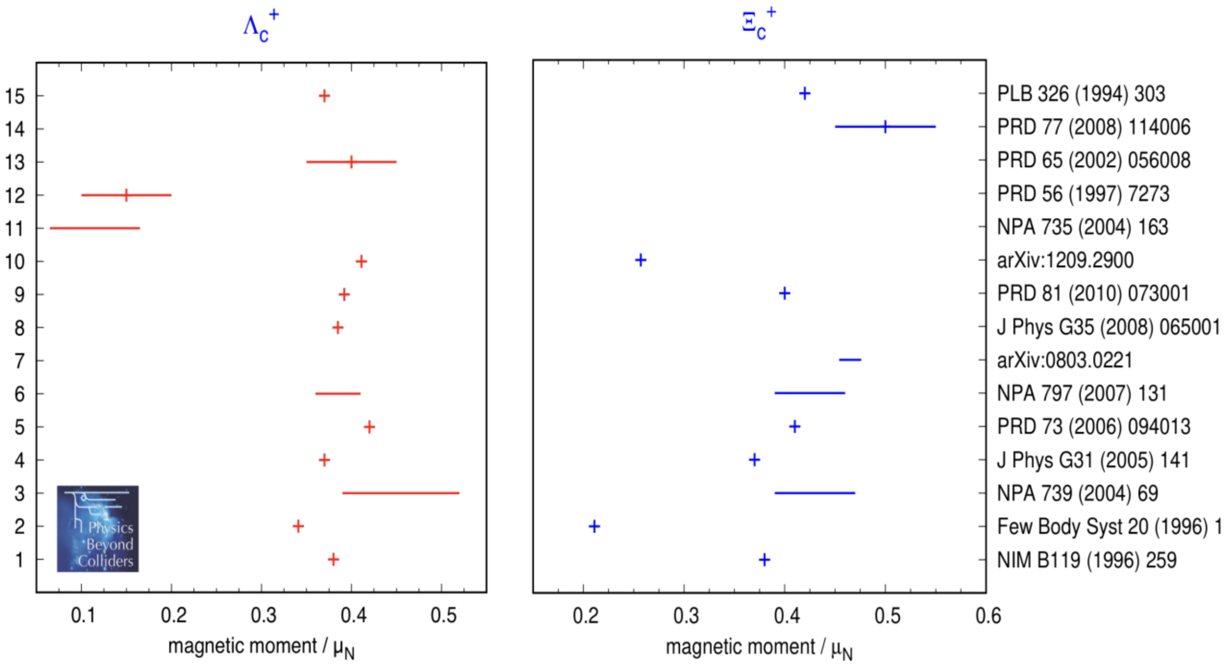
- Hamiltonian: $H = -\boldsymbol{\mu} \cdot \boldsymbol{B} - \boldsymbol{\delta} \cdot \boldsymbol{E} \xrightarrow{\text{P, T}} H = -\boldsymbol{\mu} \cdot \boldsymbol{B} + \boldsymbol{\delta} \cdot \boldsymbol{E}$

- The EDMs violate P,T $\longrightarrow$ **CP violation beyond the Standard Model (BSM)**
  - Not yet measured for ***charm*** and ***beauty*** baryons and ***tau*** leptons

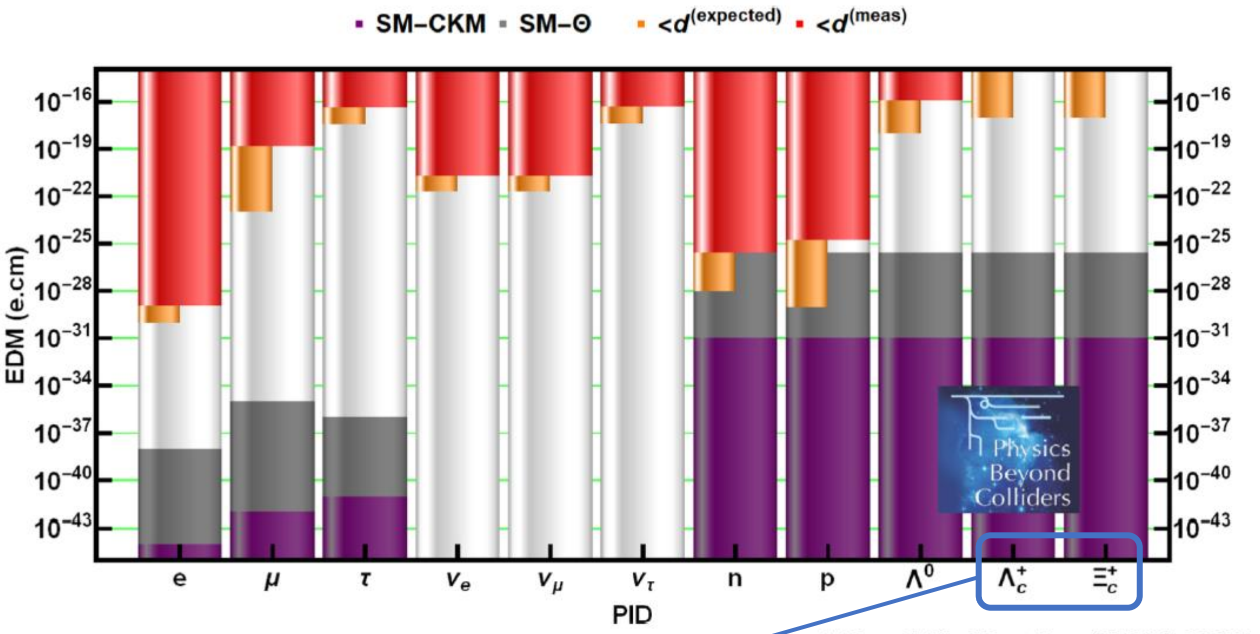
- The MDMs provide important information to QCD calculations

Dipole moments of charm baryons

MDM



EDM



J. Phys. G: Nucl. Part. Phys. **47** (2020) 010501

$\tau \sim 10^{-13}$ **s**

- No direct measurements of dipoles for charmed baryons due to their short lifetime.
- **Need experimental measurements to verify theoretical predictions**

CERN-PBC-REPORT-2018-008

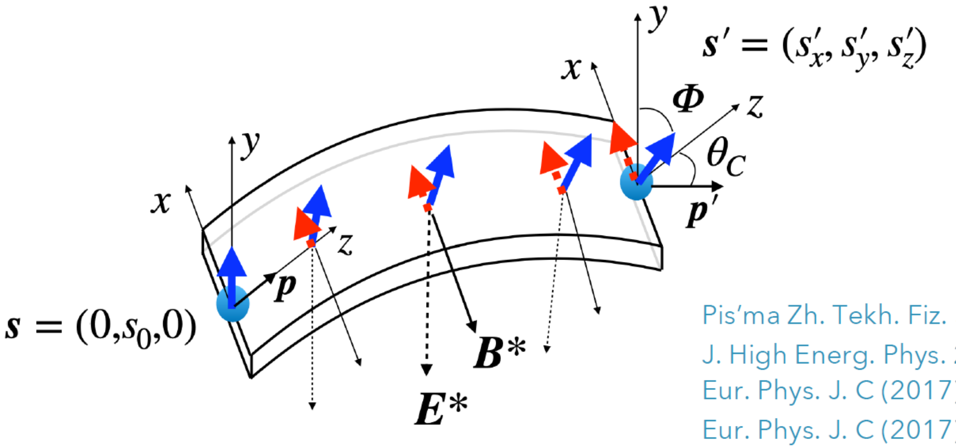
Measurement with bent crystals

- For short-lived particles ($\gamma c\tau \approx 5\mathrm{cm}$), intense EM fields are needed to induce spin precession before the decay, not possible with magnets


Developed by INFN Ferrara (A. Mazzolari et al.)

- Exploit **channeling** in **bent crystals**:
  - Effective fields between atomic planes $E \approx 1\mathrm{GV/cm}$, $B \approx 500\mathrm{T}$
  - Steer the trajectory of particles
  - Induce **spin precession**

$$\Phi \approx \frac{g-2}{2}\gamma\theta_c \qquad s'_x \approx s_0 \frac{d}{g-2}$$



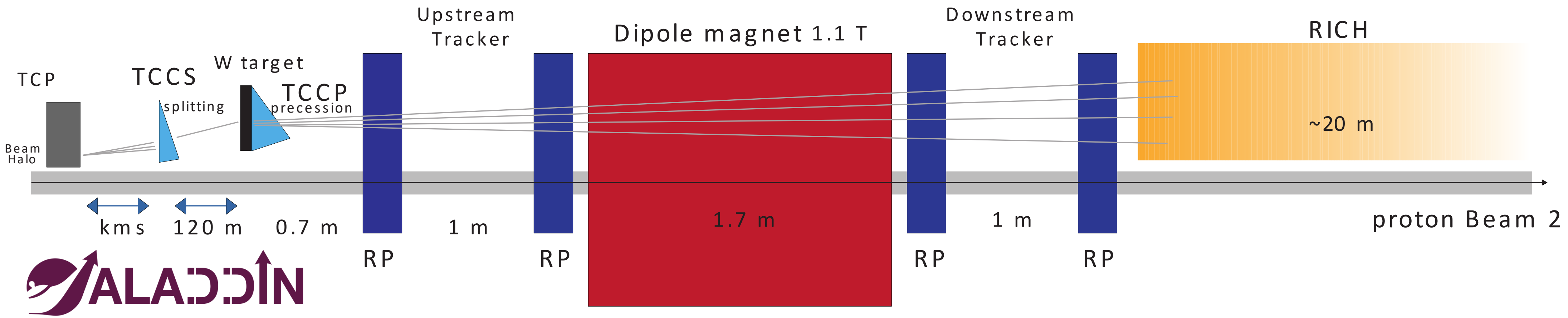
Pis'ma Zh. Tekh. Fiz. 5 (1979) 182
J. High Energ. Phys. 2017 (2017) 120
Eur. Phys. J. C (2017) 77:181
Eur. Phys. J. C (2017) 77:828

- Dipole moments measured with precession angles reconstruction

The ALADDIN experiment

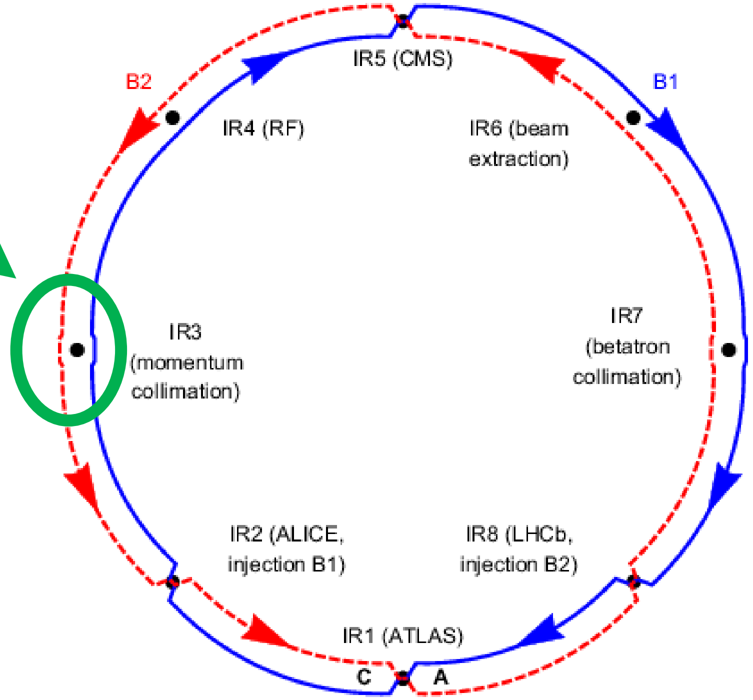
***A** **L**hc **A**pparatus for **D**irect **D**ipole moments **IN**vestigation*

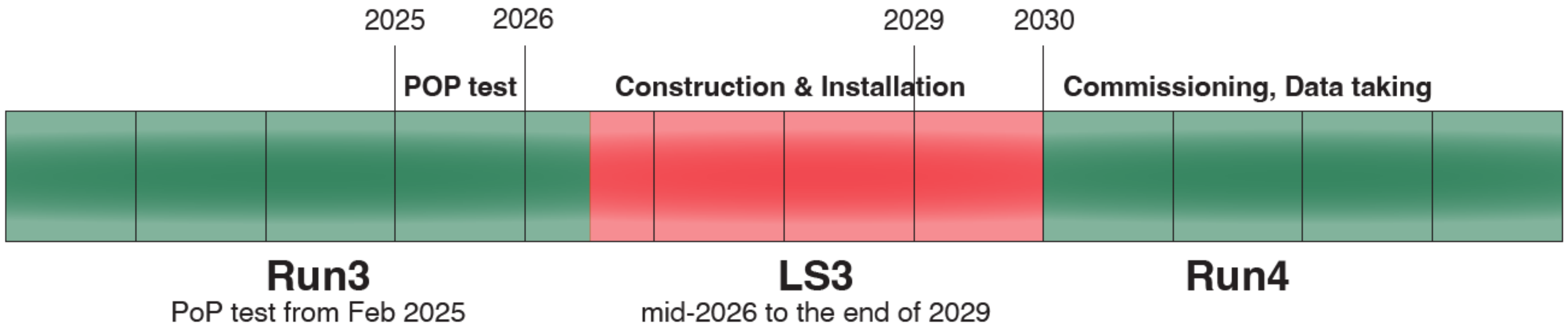
- Fixed-target experiment at LHC for EDM/MDM measurement of **charm baryons**
- Very forward region $5 < \eta < 9$ (additional measurements in *D* and *J/ψ* production)
- 10^{13} Protons on Target (PoT) in 2 years of data taking (10^6p/s) to reach:
  - **EDM** sensitivity up to 10^{-16}e cm
  - **MDM** precision of 10%



The ALADDIN experiment

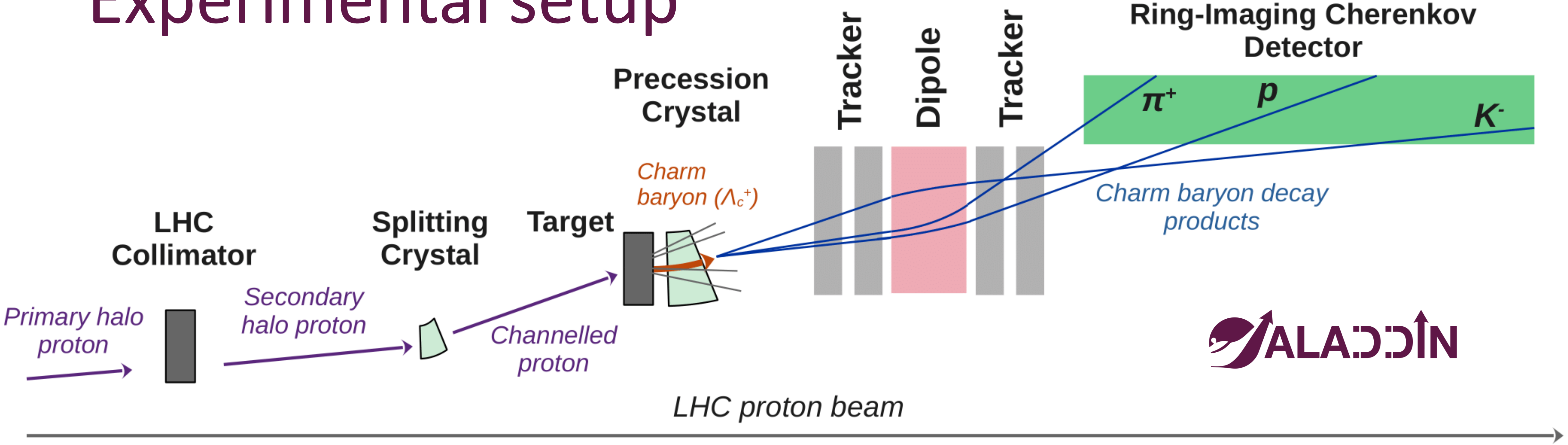
- Proposed location in Insertion Region 3 (**IR3**) of LHC
- Proof of Principle (PoP) **TWOCRYST** ongoing to prove the feasibility of the experimental technique
- A **Letter of Intent** (LoI) was submitted to the LHCC and received positive feedback [CERN LHCC-I-041]
- Technical proposal under preparation





aladdin.web.cern.ch

Experimental setup



Credits: Pascal Hermes

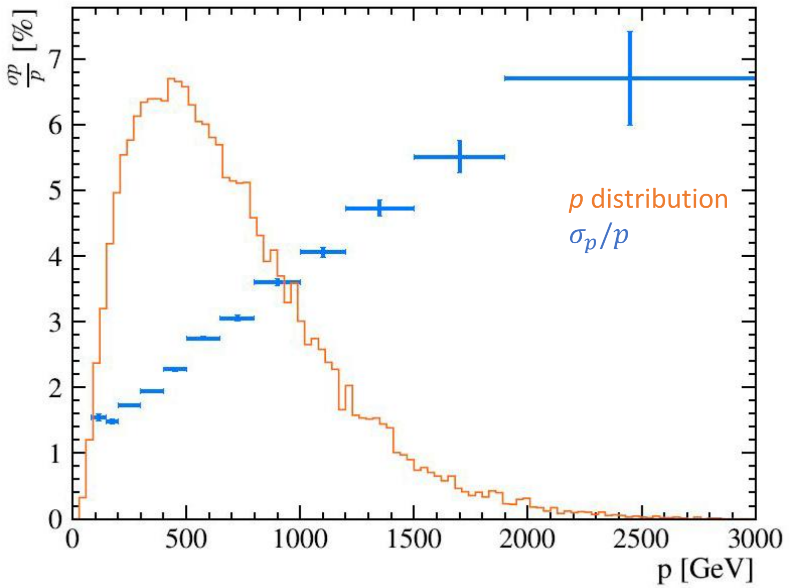
- Splitting crystal (**TCCS,** 4mm long): proton extraction from LHC halo
- Tungsten **target**: charm baryons production (Λ_c^+, Ξ_c^+)
- Precession crystal (**TCCP,** 7cm long): spin precession of charm baryons
- Magnetic spectrometer + RICH: event reconstruction

Spectrometer

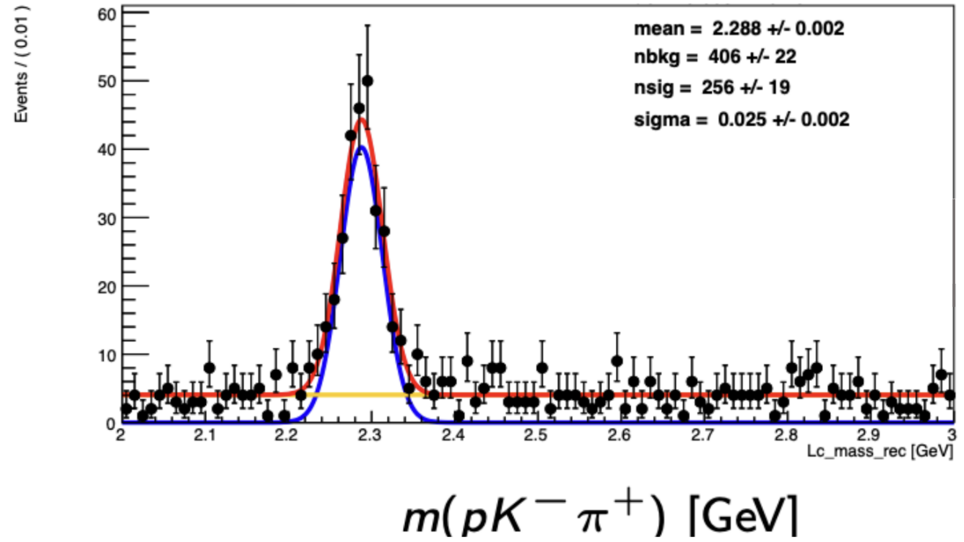
- Baryons produced in **very forward region**, with momentum distribution up to **1 TeV**
- Detector layout optimized to maximize acceptance of:

$$\Lambda_c^+ \rightarrow p\, K^-\, \pi^+$$

- Invariant mass resolution < **25 MeV**, to discriminate *D* mesons background:
  - $D^+ \rightarrow K^-\pi^+\pi^+$ one π^+ misidentified as p
  - $D_s^+ \rightarrow K^+K^-\pi^+$ with K^+ misidentified as p
- **Mass resolution** = 18 (27) MeV for 6 (2) tracking layers
- Momentum resolution $\frac{\sigma_p}{p} \approx 3.51\, \sigma_x\, p$
- Acceptance $\approx 60\%$

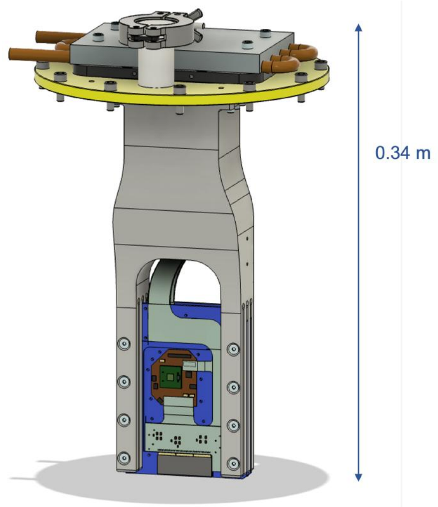


Invariant mass distribution



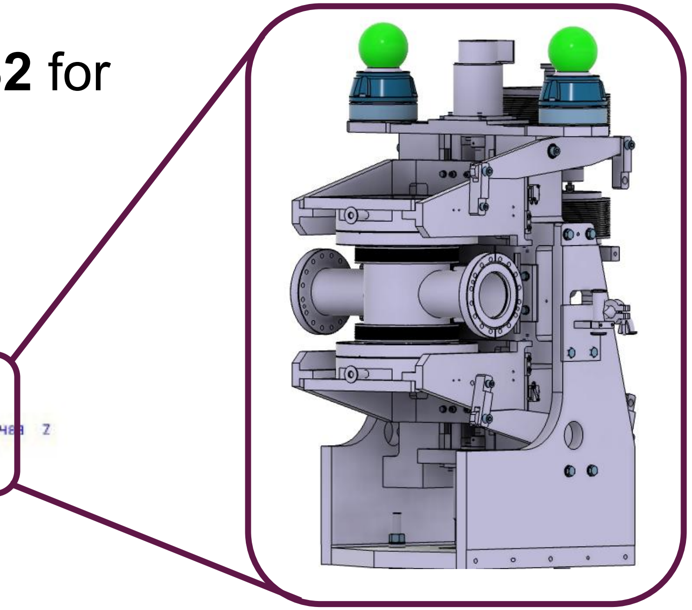
Spectrometer

- Dipole **magnet** (1.1T, 1.7m) available in situ
- 2 tracking stations upstream the magnet and 2 (1) downstream
- Each station is equipped with 6 -12 layers of **silicon pixel sensors**
- Detector housed in **Roman Pots** to approach the beam (1cm)
- Strong **synergy** with LHCb **VELO** Upgrade2 and CMS **PPS2** for sensor/DAQ R&D and mechanics/cooling respectively



TWOCRYST
pixel tracker

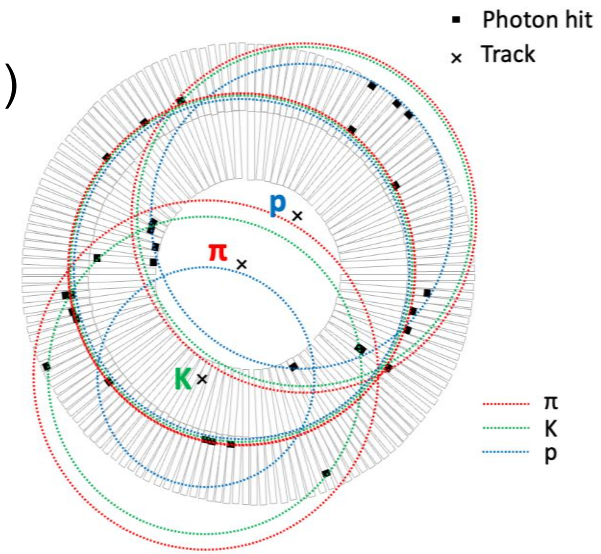
Dipole magnet

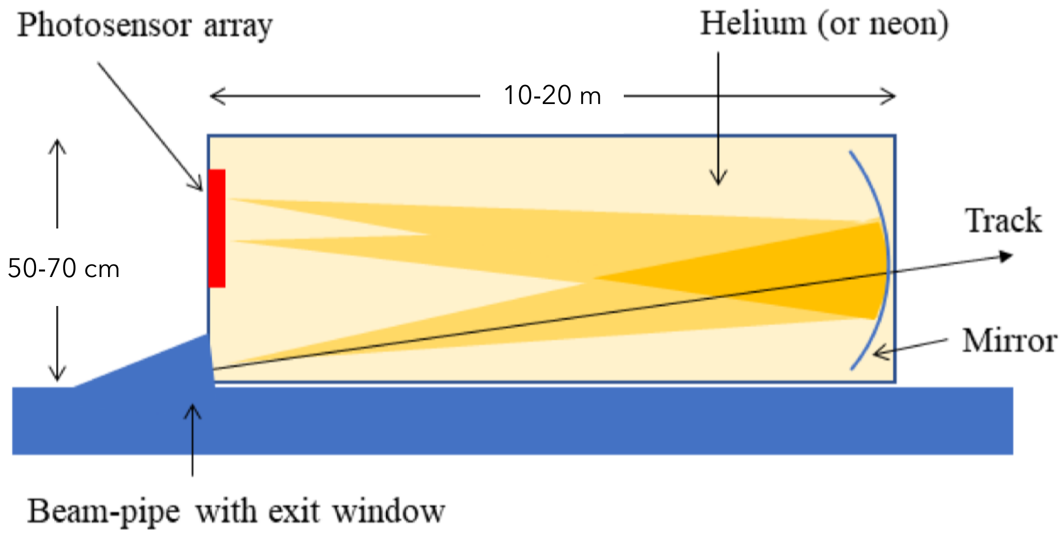


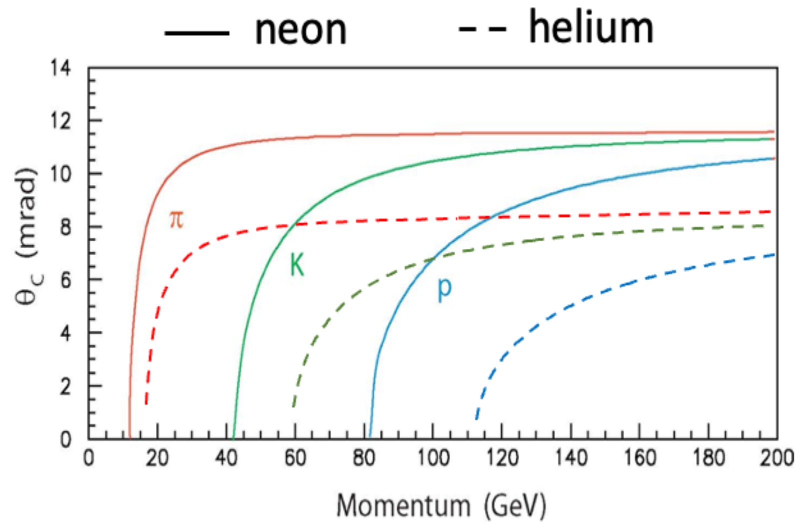
ALFA Roman Pot

Particle Identification

- **RICH** detector needed to separate signal events and suppress background (D^+, D_s^+)
- Challenging high momenta, up to ~ **1 TeV** → excellent resolution required
- Aim for scaled-down RICH, using highly pixelated photosensors (e.g. SiPM or MCP-PMT) to compensate for reduced size
- Spherical mirror at the end of the radiator volume
- Gas: He/Ne
- Pixel size: $2 \times 2\ mm^2$
- Angular resolution: ~50 μrad/detected photon

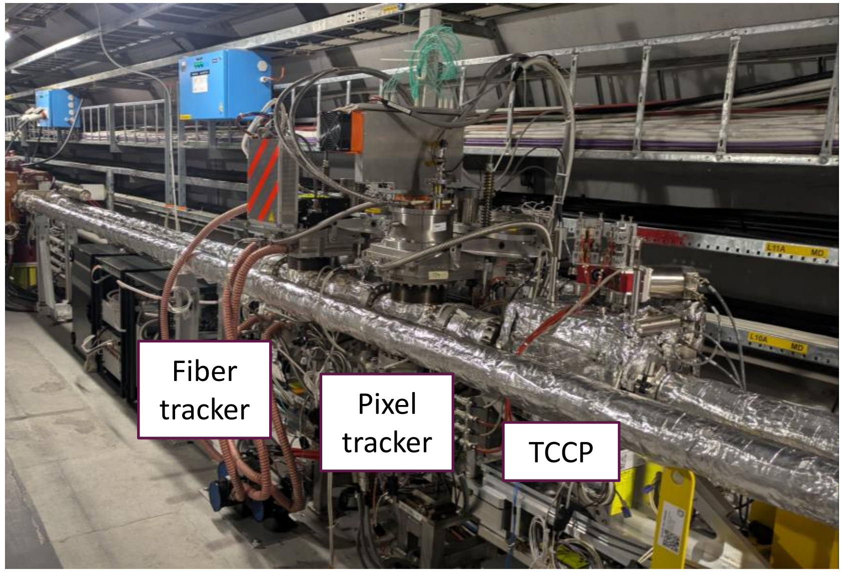


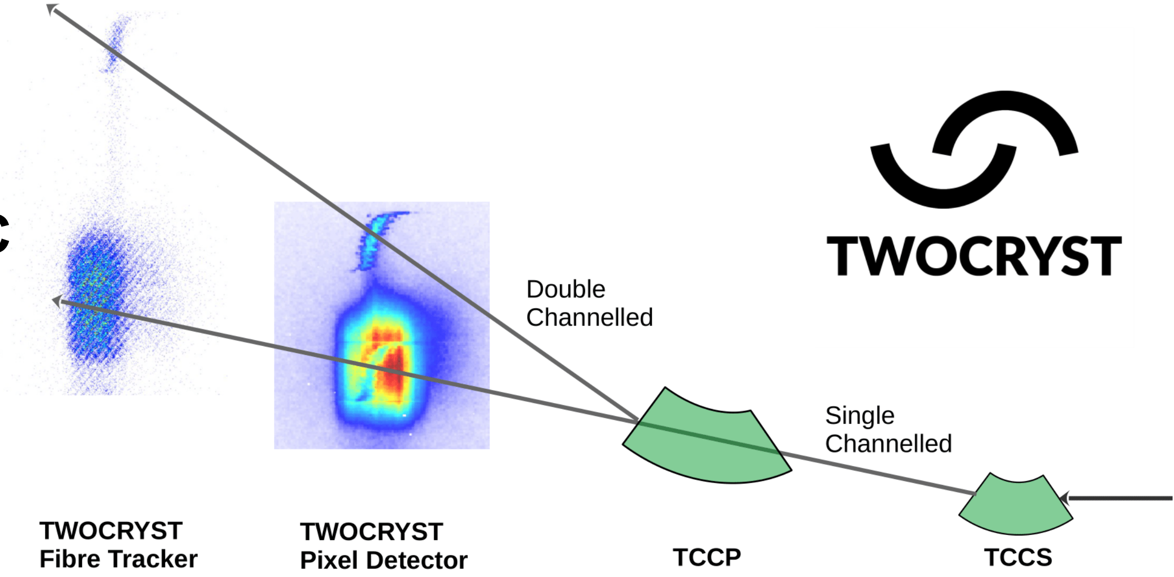




TWOCRYST Proof of Principle

- **Goals** of TWOCRYST:
  1. Demonstrate the operational feasibility of the double crystal setup
  2. Confirm the estimated achievable rates of protons on target
  3. Measure channeling efficiency of long crystals at TeV energies
  4. Perform background studies
- Succesful installation in LHC IR3 in YETS 2025
- Succesfully completed 4 MD blocks of data taking
- **First observation of double channeling at the LHC**
- Ongoing measurement of channeling efficiencies
- Planned upgrade of the pixel tracker in 2026





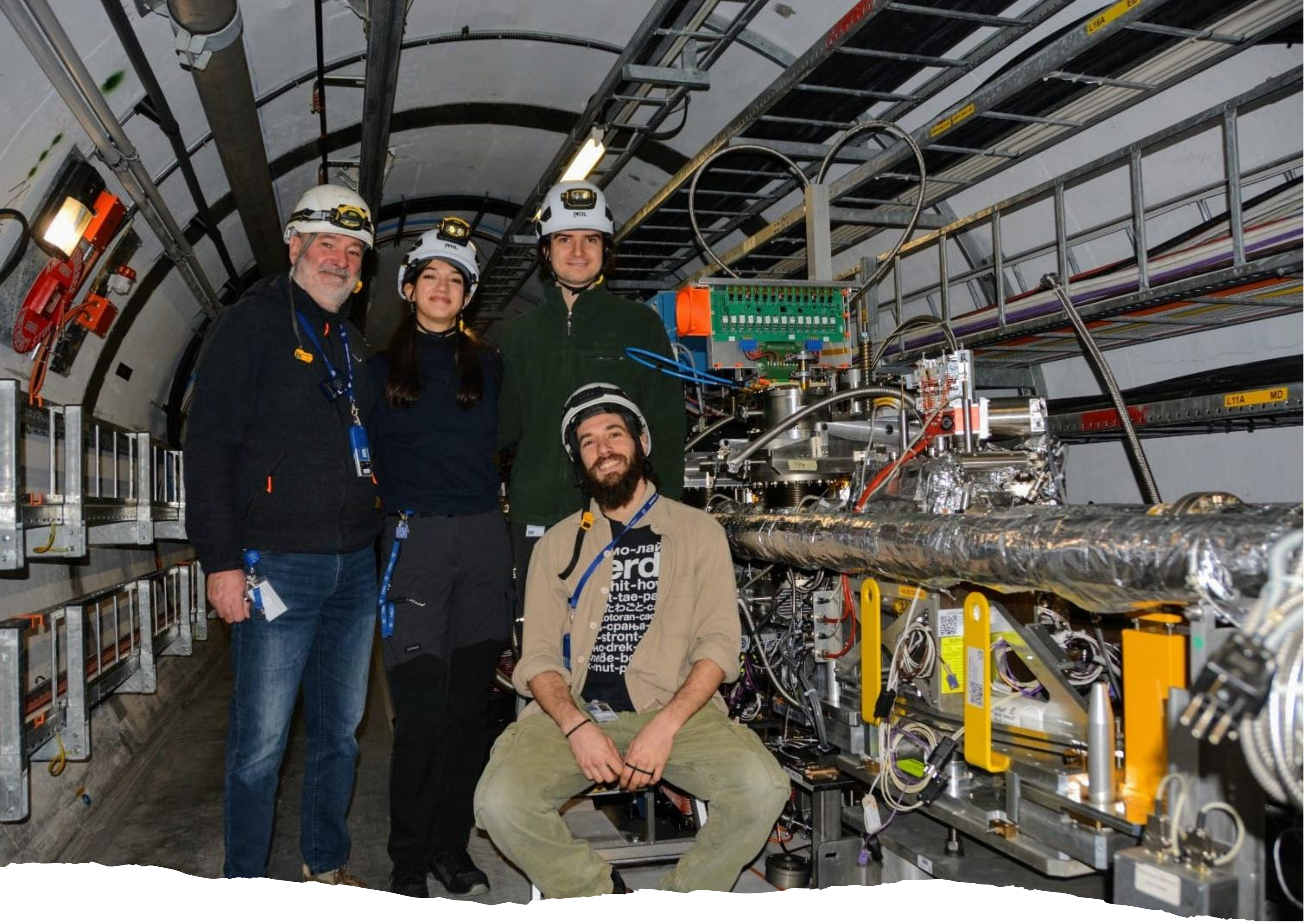
TWOCRYST

CERN news

Credits: Pascal Hermes

Conclusions

- ALADDIN is a fixed-target experiment proposed at LHC for **EDM/MDM** measurement of charmed baryons.
- Expected sensitivity for MDM of $2 \times 10^{-2}\ \mu_N$ and EDM of $3 \times 10^{-16}\ e\ cm$ with 10^{13} PoT
- Successful Proof-of-principle **TWOCRYST** took place in June 2025
- **Letter of Intent** was submitted in June 2024
- Very positive response from the LHCC committee
- A **technical proposal** will be submitted by the end of 2025 to consider approval of the experiment and installation during LS3



Thanks for the attention!

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- **PRIN 2022**, Italian Ministry of University and Research (MUR), 202277EWLW
- **Physics Beyond Colliders** study group
- **ATLAS ALFA experiment**

Backup

TWOCRYST contributor list

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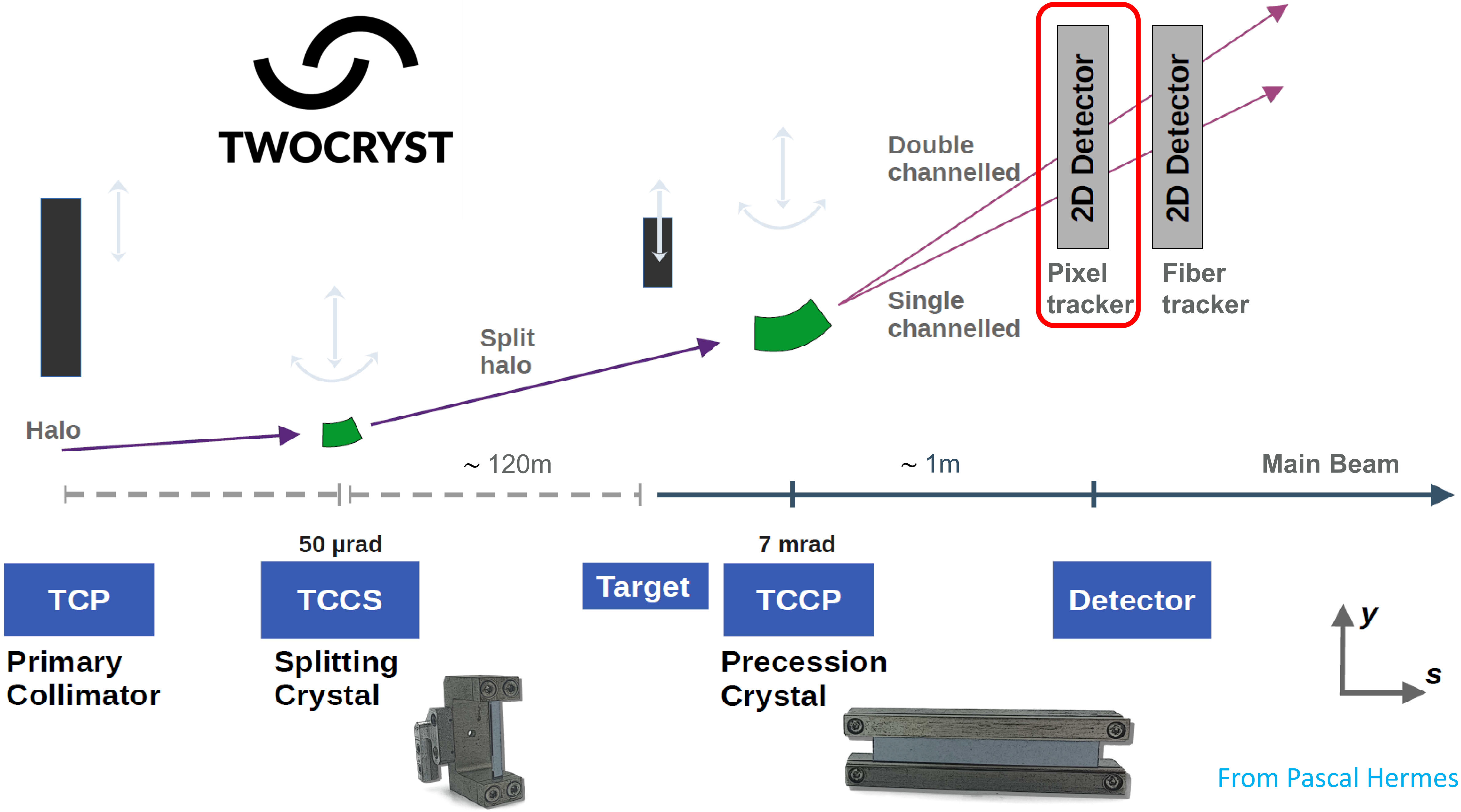
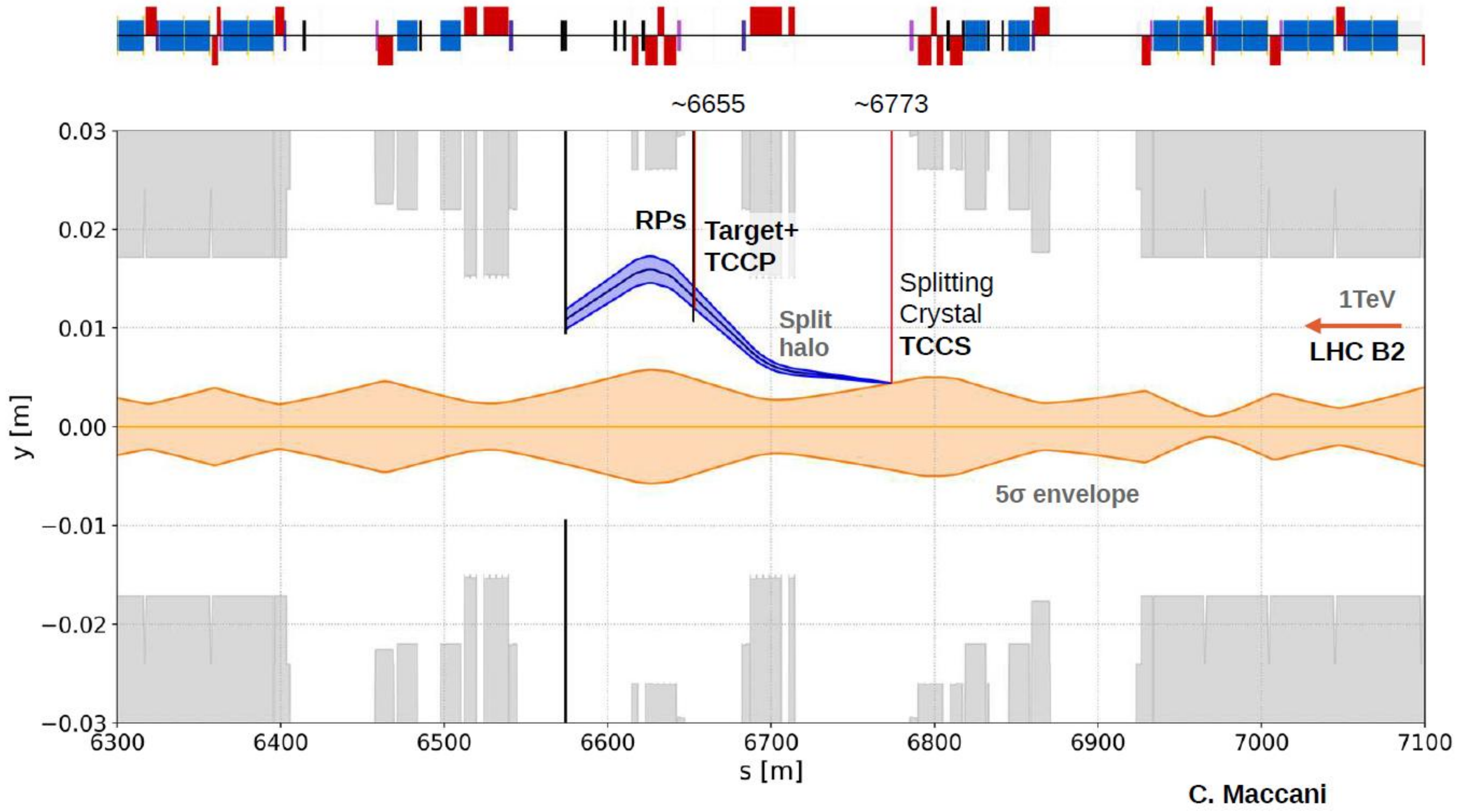
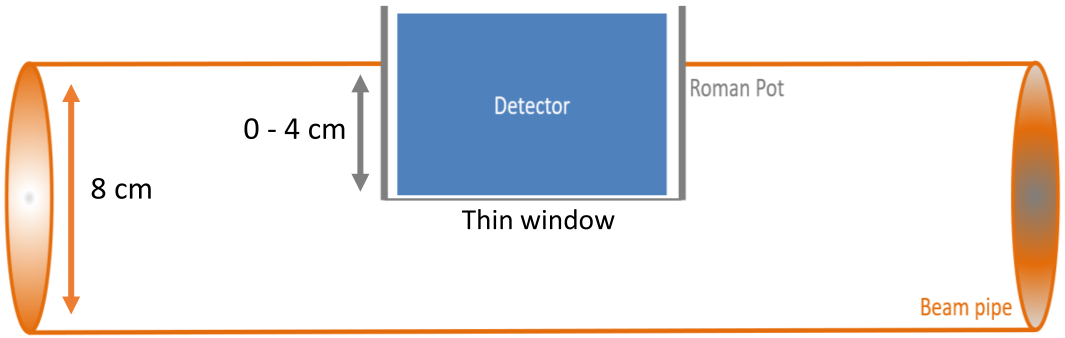

TWOCRYST
Double channelled
Single channelled
2D Detector
2D Detector
Pixel tracker
Fiber tracker
Split halo
Halo
~ 120m
~ 1m
Main Beam
50 μrad
7 mrad
TCP
TCCS
Target
TCCP
Detector
Primary Collimator
Splitting Crystal
Precession Crystal
y
s
From Pascal Hermes

TWOCRYST layout

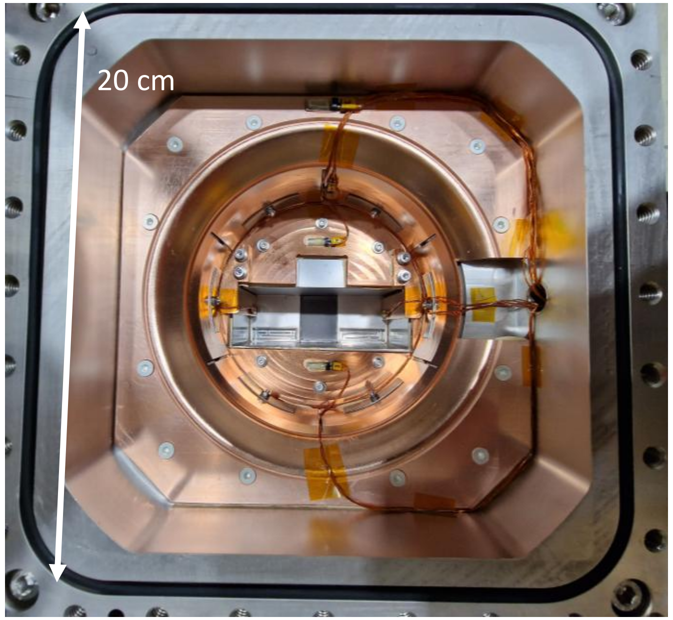


Roman Pot station

- Radial distance between beam and target < 1cm → detector must be **inside** the beam pipe
- Solution: **Roman Pot** station from ATLAS-ALFA
- To avoid bulging the *thin window* (200μm), the detector is kept under secondary **vacuum** (2mbar)

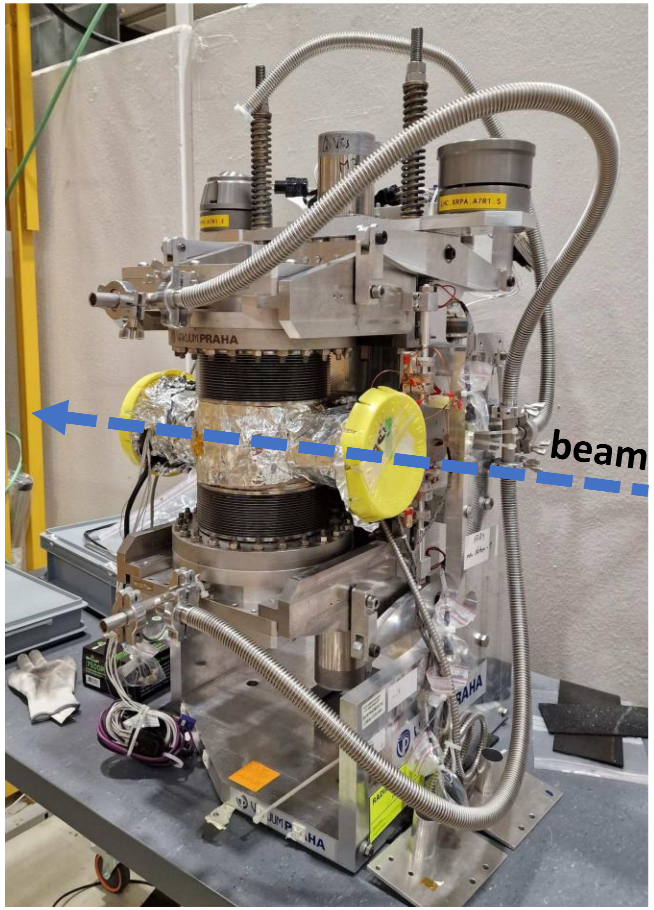


Need to re-adapt the VELO module to the Roman Pot geometry



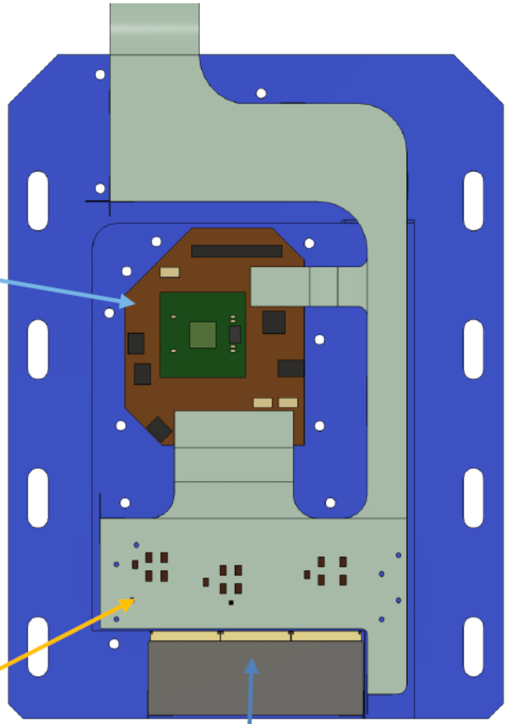
Top view of the Roman Pot

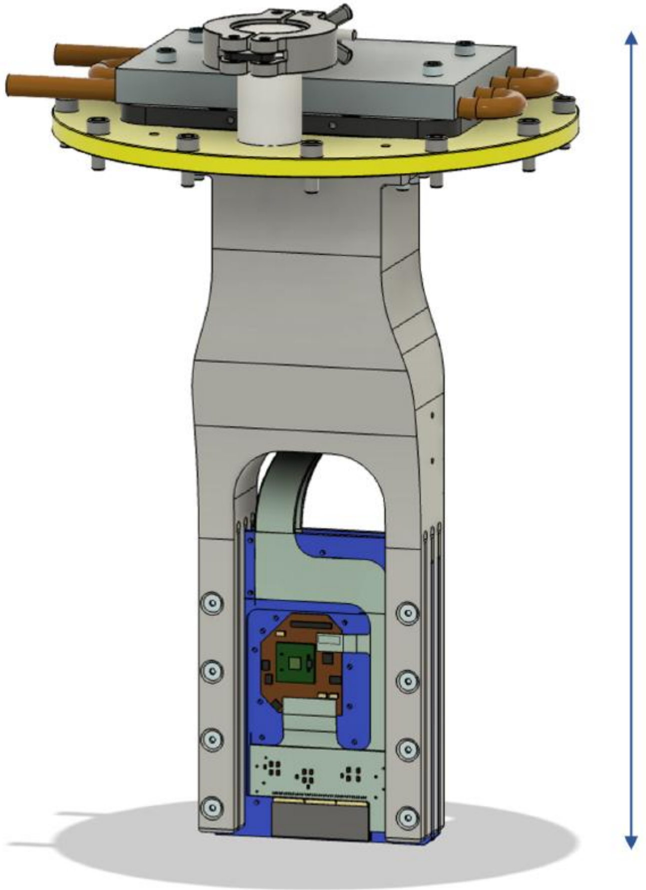
Credits: Sune Jakobsen

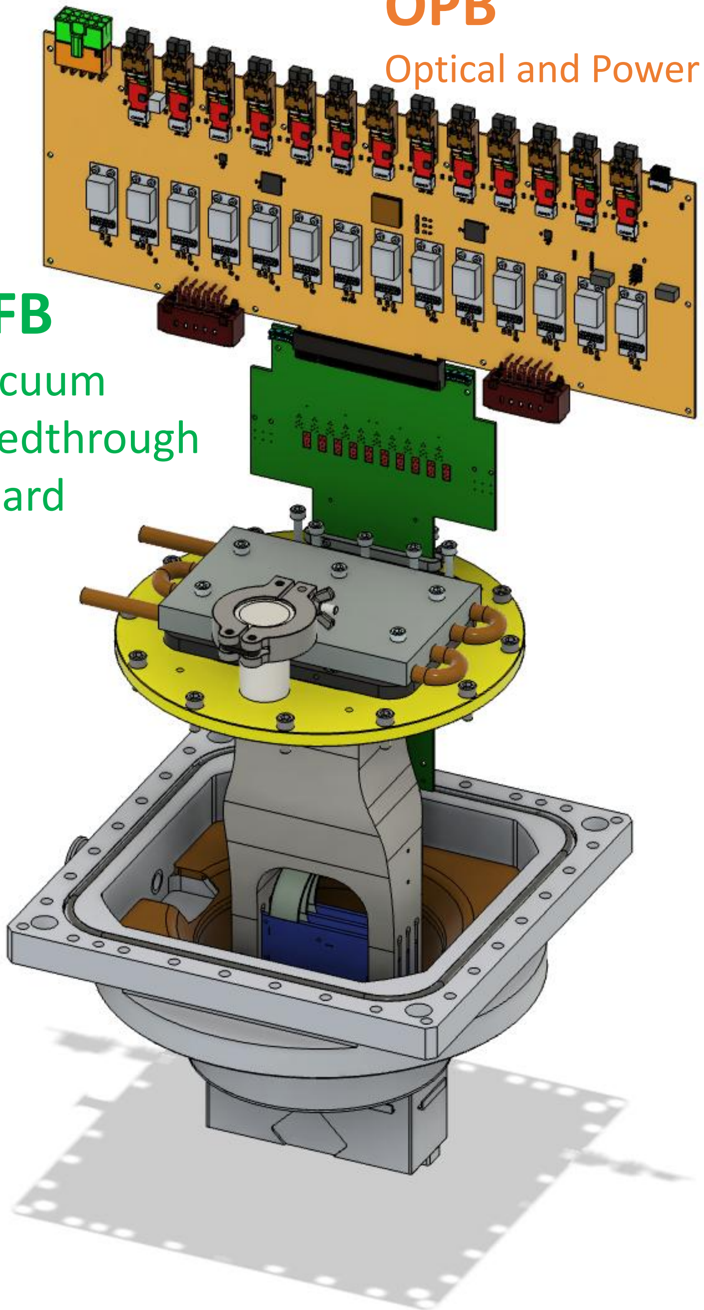


Roman pot station from ATLAS-ALFA

TWOCRYST pixel tracker







Credits: Massimo Benettoni, Nicola Turini

Detector electronics

New flex cables:

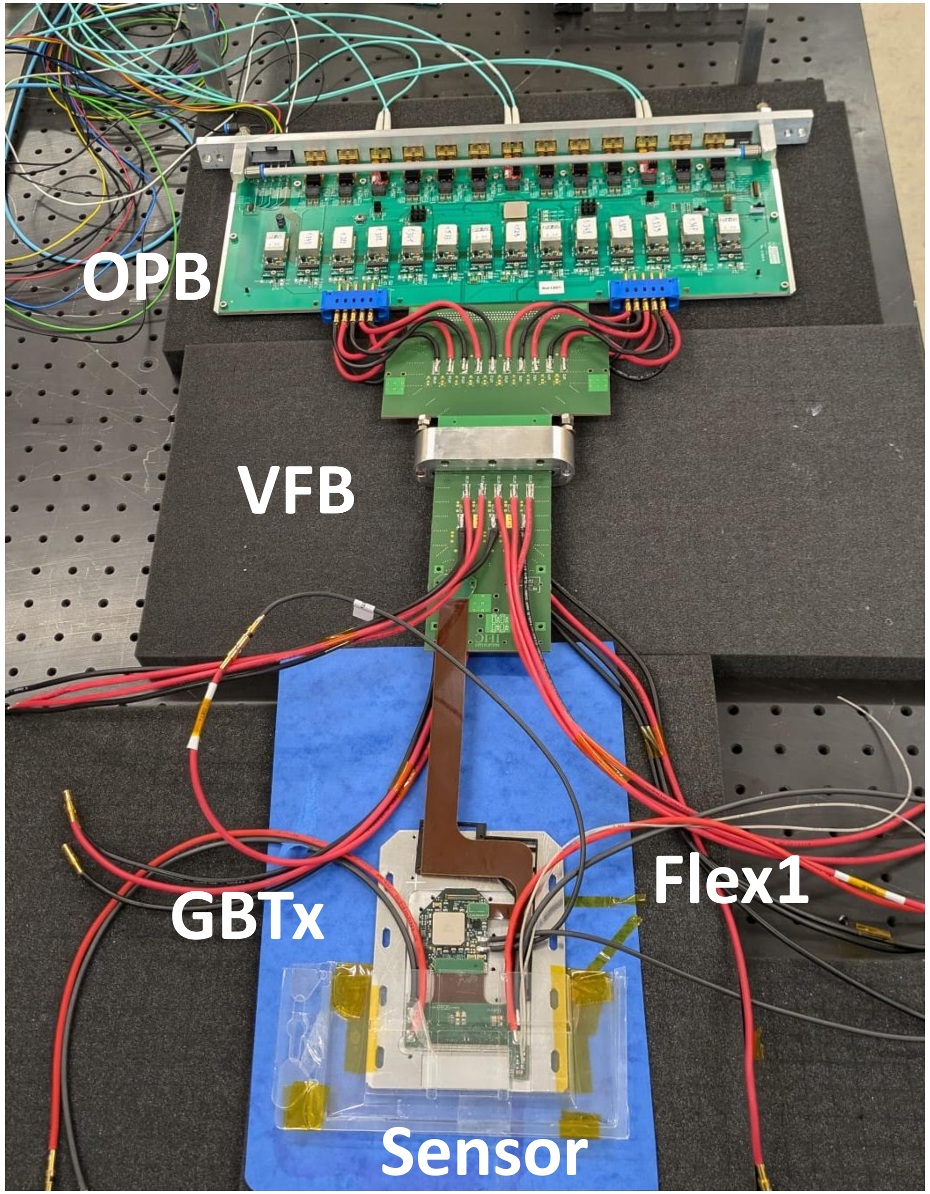
- Single circuit to integrate data and control signals and power
- Wire-bonded to the ASICs

Vacuum feedthrough board (VFB):

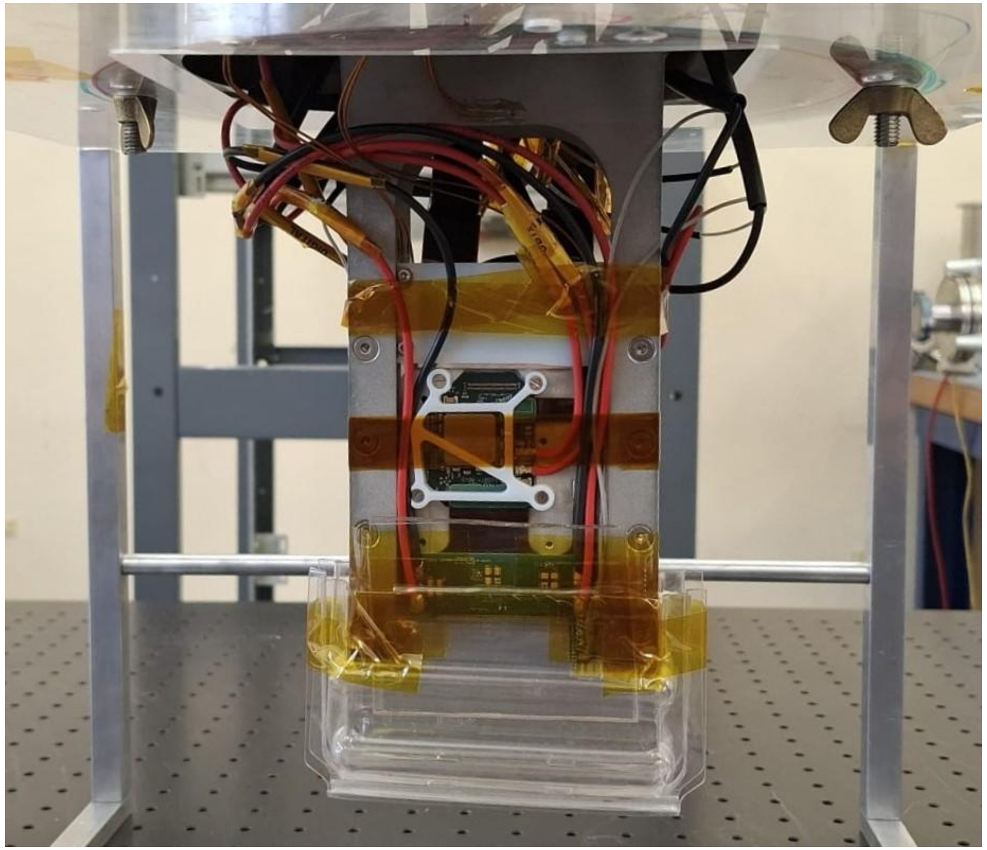
- Passage of data, controls, LV and HV from air to vacuum
- Adapted design from VELO to fit in the vacuum flange

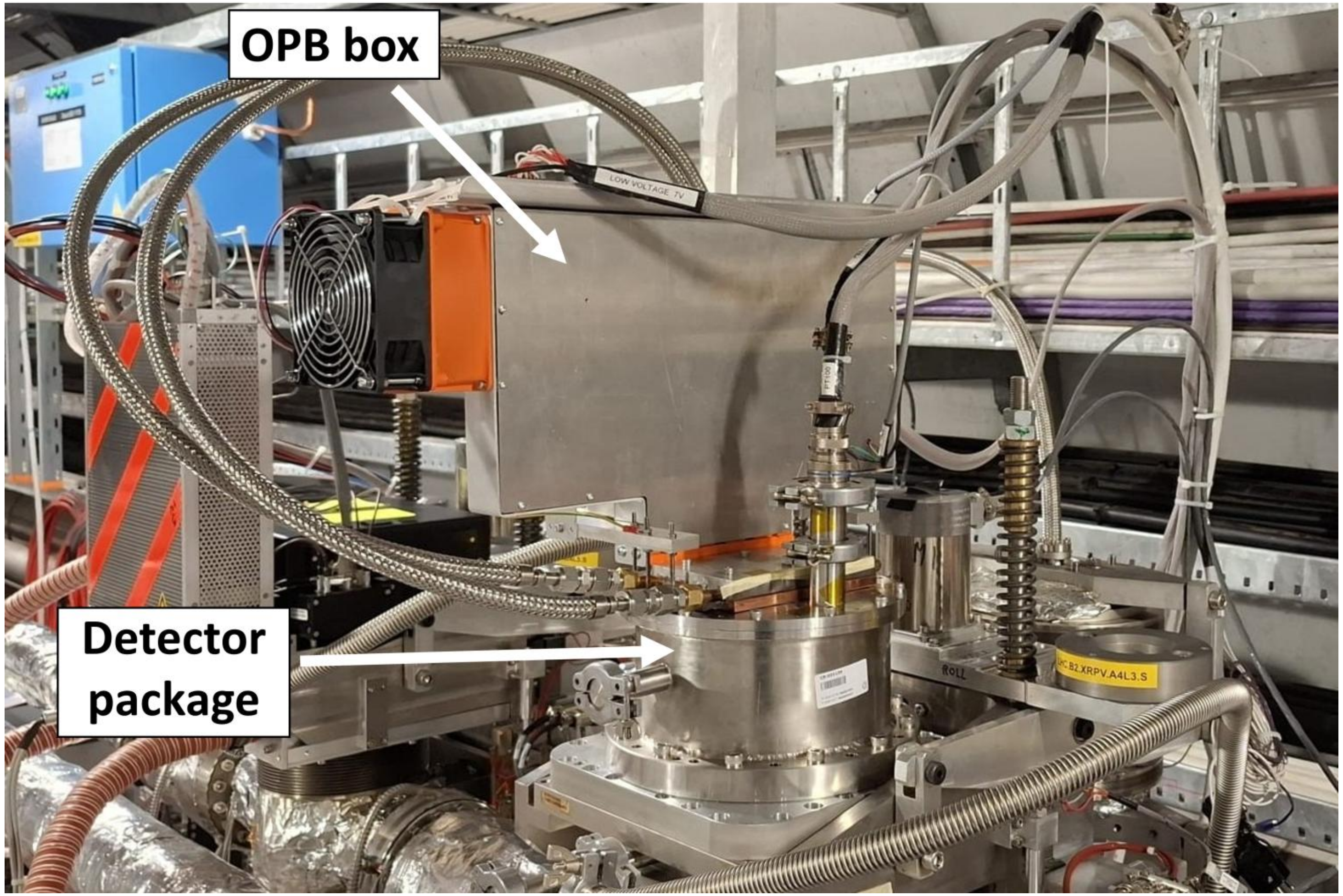
Optical and Power board (OPB): [CERN-LHCb-PUB-2021-012]

- DC/DC converters to manage LV power
- Optical data links (VTTx) and control links (VTRx)



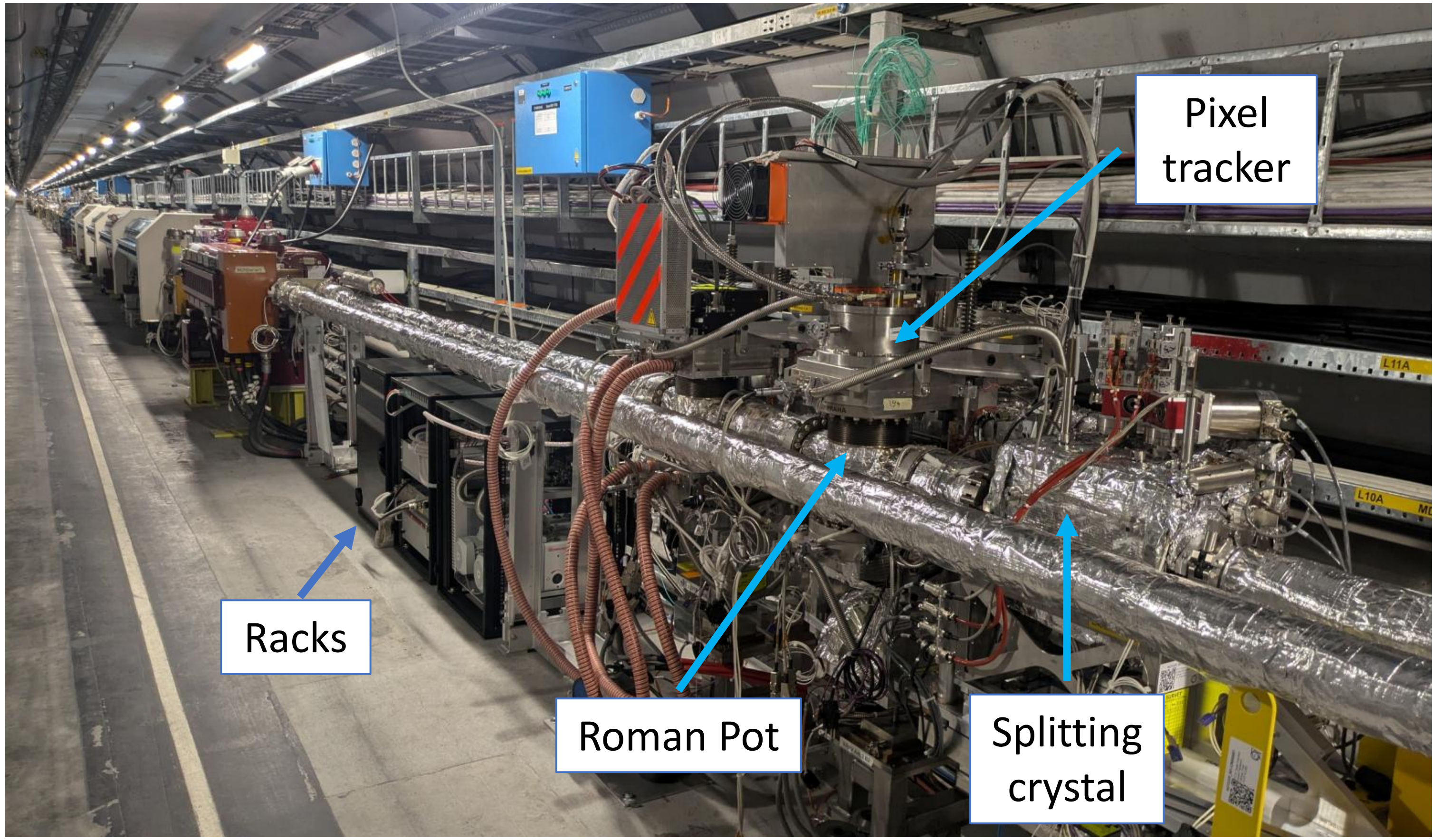
Installation in the LHC





Installation in the LHC

- ✓ Installation of the detector inside the Roman Pot
- ✓ Installation of the electronics in the racks
- ✓ Connection of the cables
- ✓ Vacuum tightness
- ✓ Monitoring and interlocks tests
- ✓ Cooling test ($T_{detector} = 3°C$)
- ✓ Power up and configuration of the detector
- ✓ Noise measurements
- ✓ Roman Pot movement test



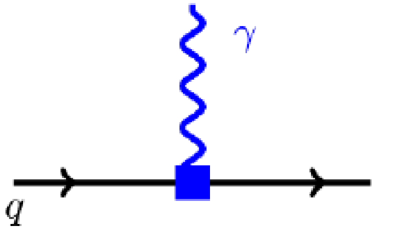
LHC tunnel at IR3

Electric dipole moments of charm baryons

From Sara Cesare

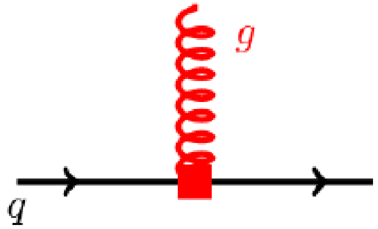
charm EDM

$d_q\,\bar{q} i \sigma^{\mu\nu} \gamma_5 q\, F_{\mu\nu}$



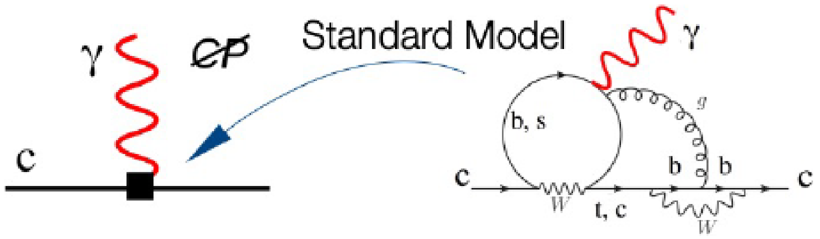
charm chromo-EDM

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



Charm EDM in SM-CKM ~10^{-32} e cm

Khriplovich, Lamoreaux (1997)



Charm EDM with new physics ~$5 \cdot 10^{-17}$ e cm

EPJC 77 (2017), 102