Crystal experiments and recent measurements at CERN

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12 June 2024

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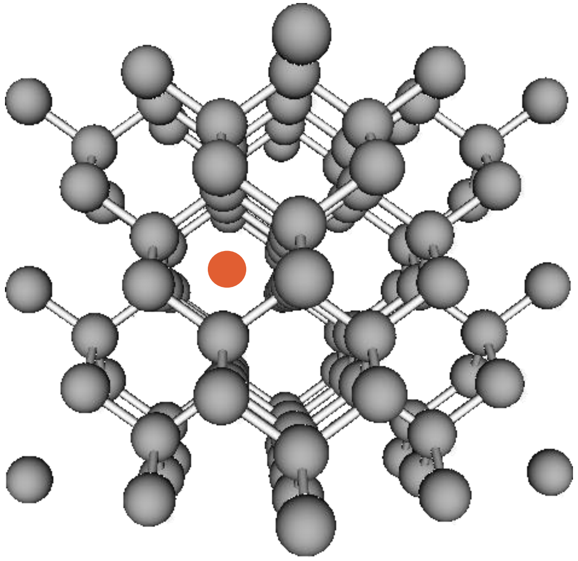
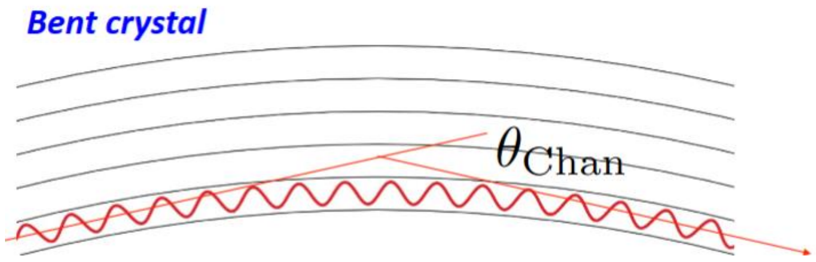
Why use bent crystals?

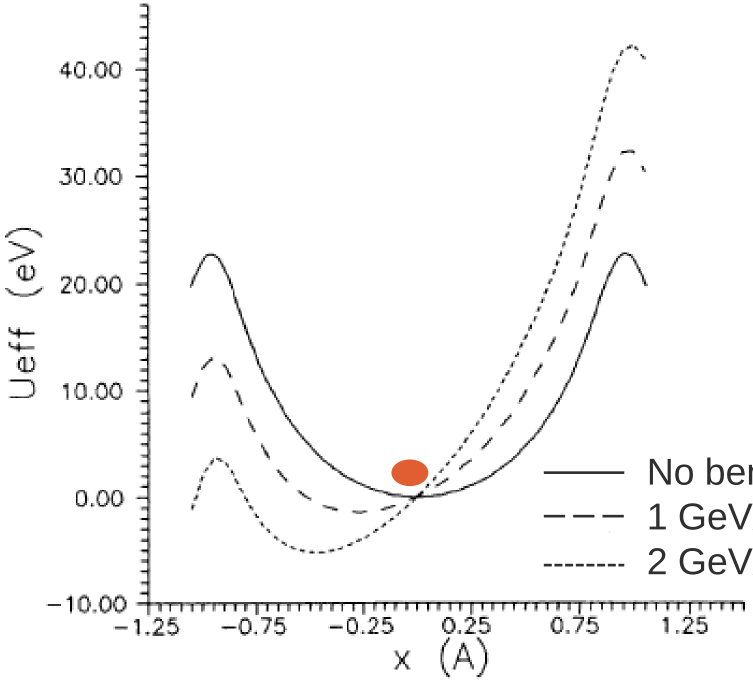
Charged particles follow the lattice structure of the silicon crystal. Holders clamp the silicon crystal sheet into a bent position. With bent crystals, particle trajectories can be bent in a short distance.

Crystal lattice





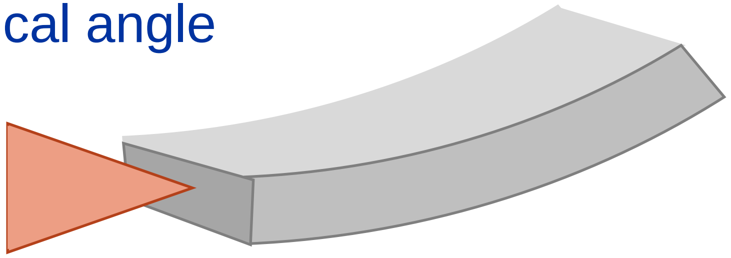
Channel particles

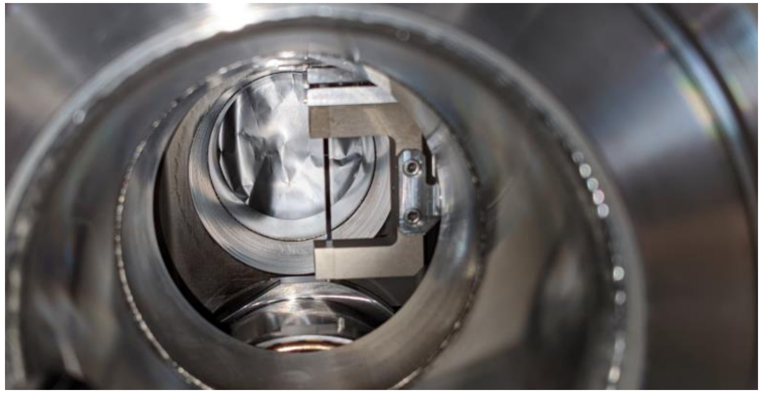


V. M. Biryukov et al., 1997
doi: 10.1007/978-3-662-03407-1.

Bend trajectory

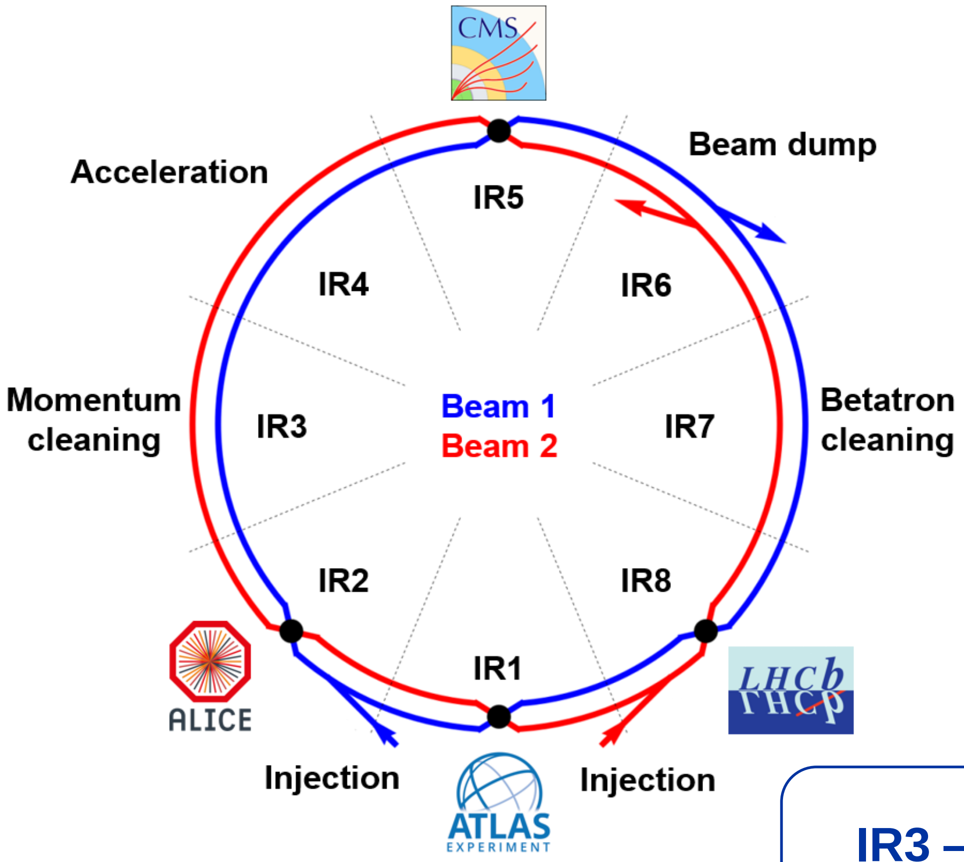
Critical angle



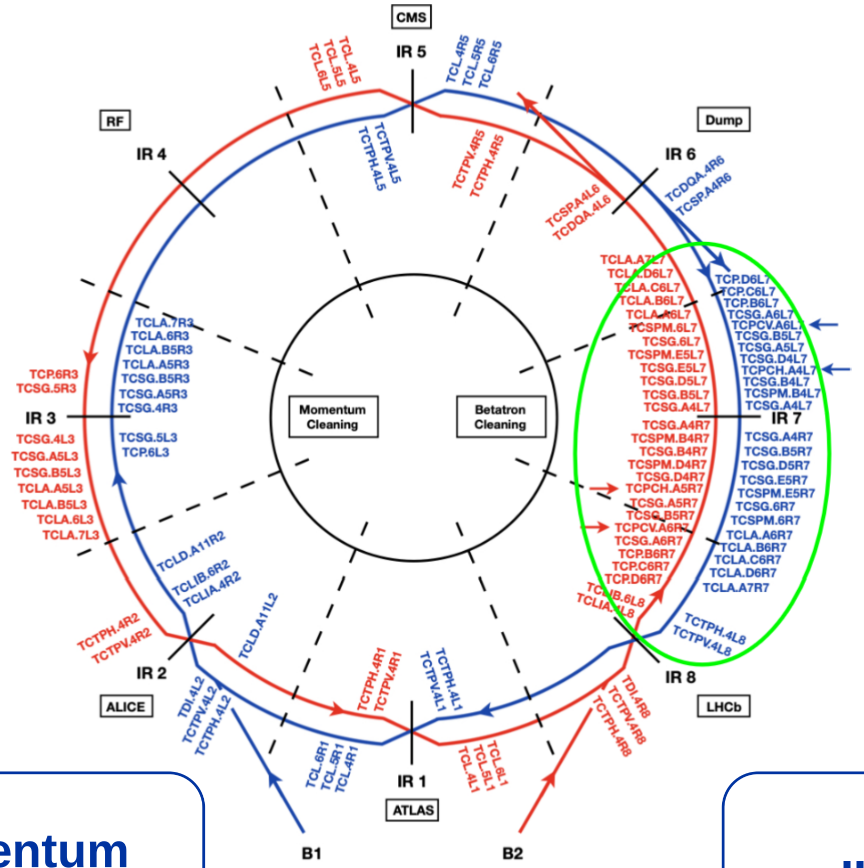


Crystals for collimation

LHC



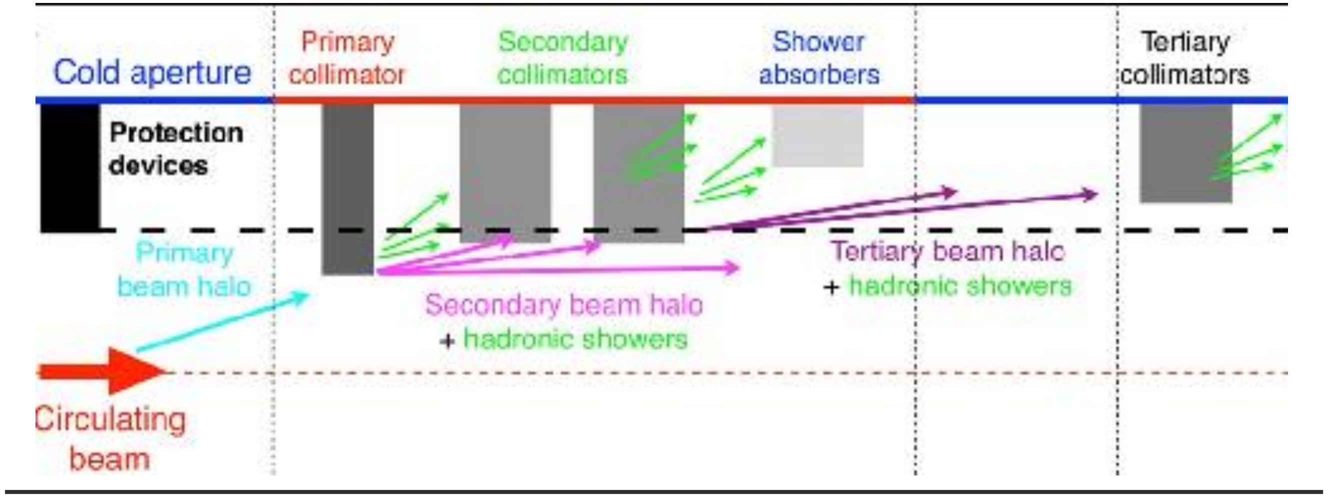
Collimators

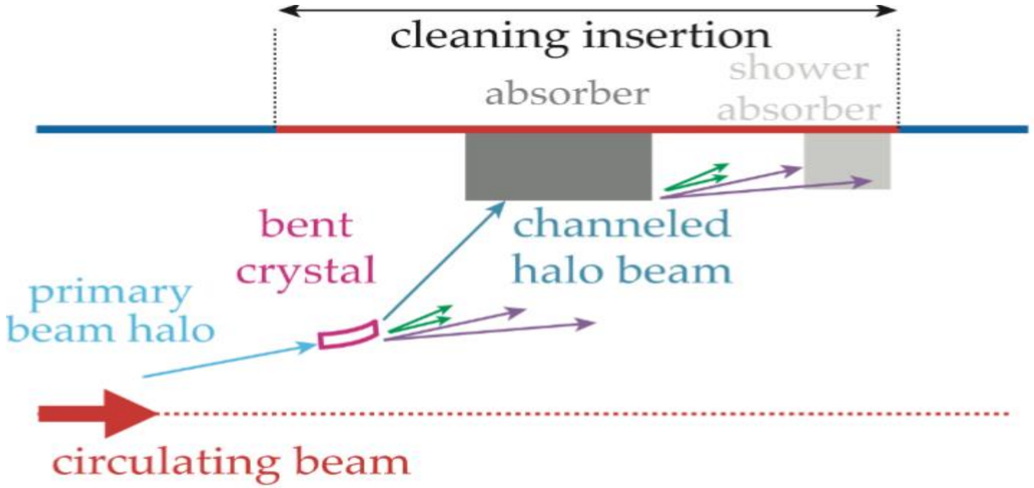


IR3 – momentum cleaning

IR7 – main collimation region (betatron cleaning)

Crystals for collimation



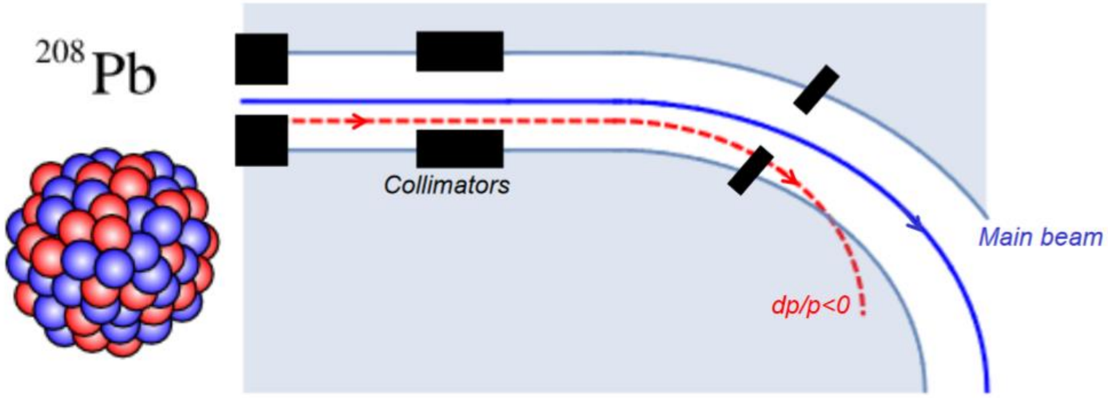


A hierarchy of collimators scatter, and eventually absorb particles from the beam halo. Works for the LHC!

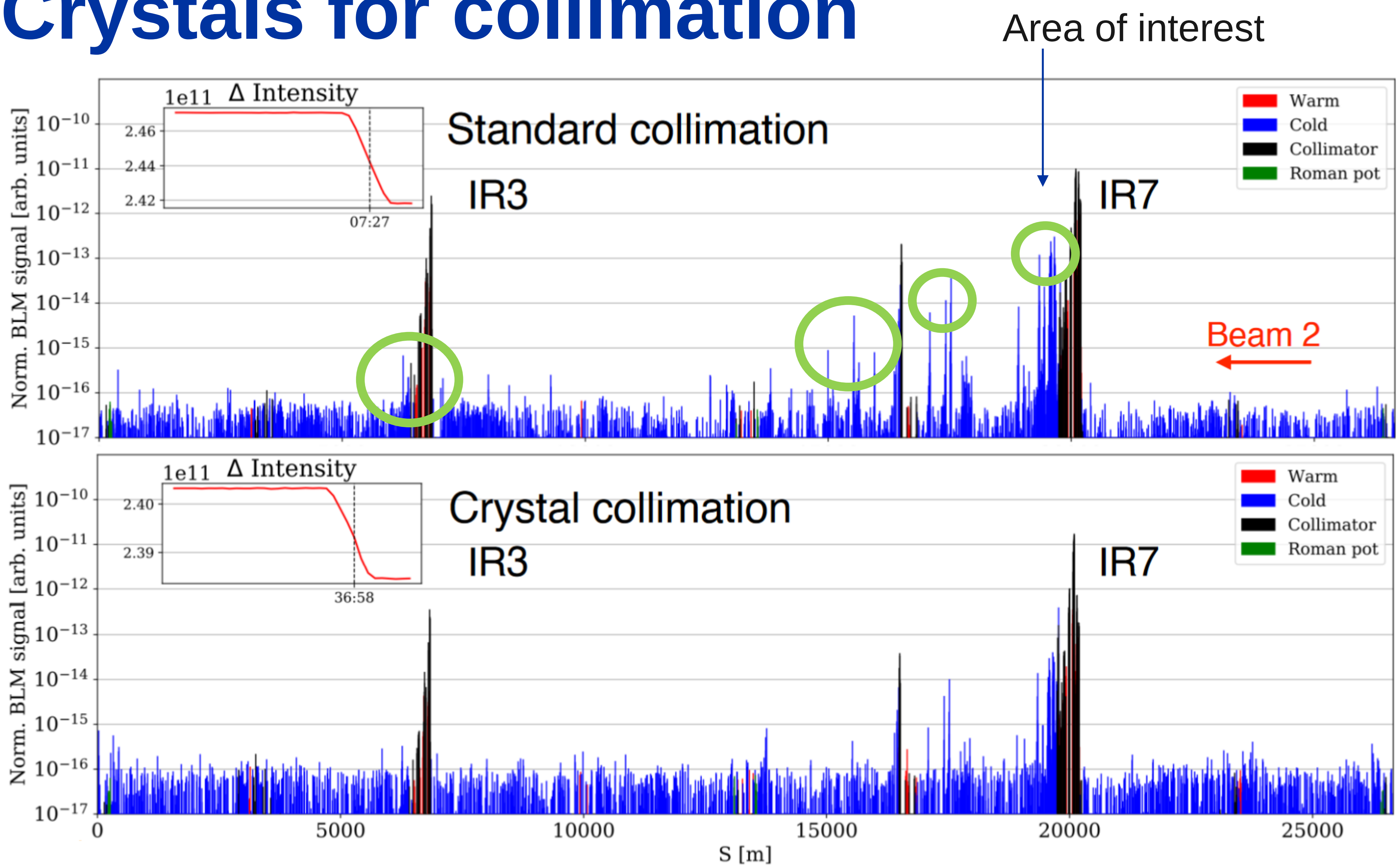
Projected collimation performance at the HL-LHC:

OK for proton beams!

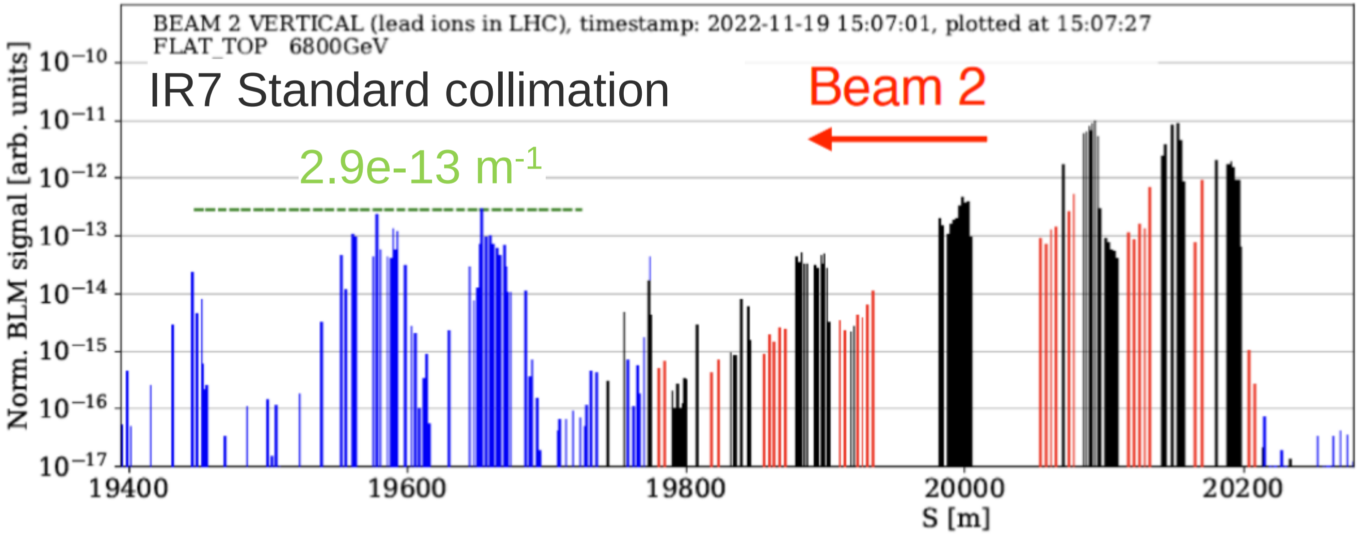
Not OK for lead ion beams ☹

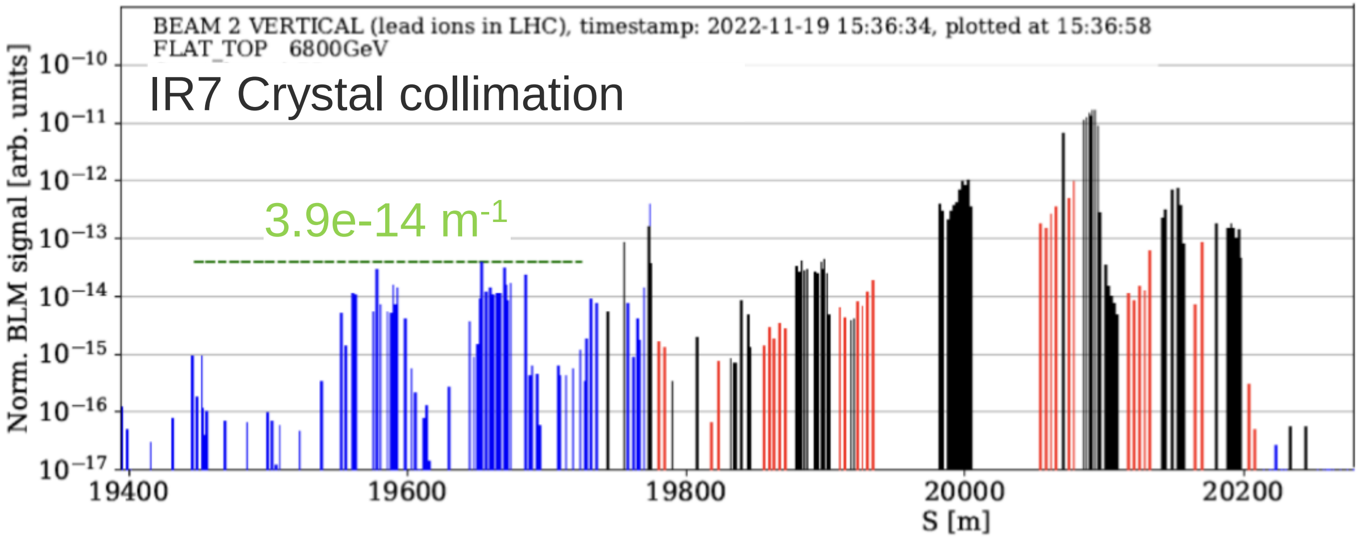


Crystals for collimation



Crystals for collimation





The first comparisons of cleaning the LHC 6.8 Z TeV lead ion beams with crystal collimation was carried out in 2022/2023.

The crystal collimators are located in IR7.

Cleaning efficiency was improved in every case. Empirical comparisons indicate gains with a factor >5 for the best crystals!

Find out more, read the paper:

D’Andrea et al., Operational performance of crystal collimation with 6.37 Z TeV Pb ion beams at the LHC, Jan 2024
https://doi.org/10.1103/PhysRevAccelBeams.27.011002

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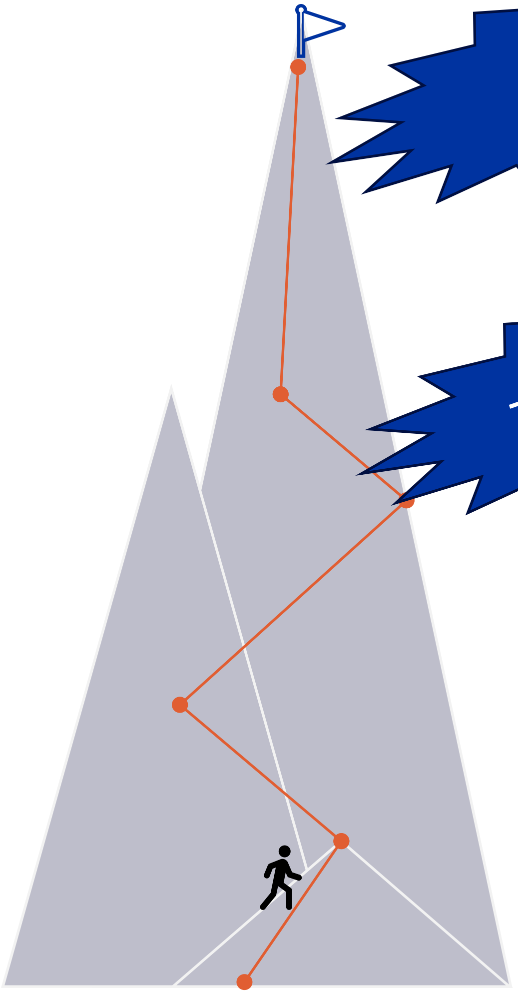
1. Why use bent crystals?
2. Crystals for collimation of the lead ion beam
3. **The TWOCRYST experiment**
4. Channelling efficiency measurements
5. Summary

Physics Beyond Colliders: IR3 experiment

ALADDIN: An Lhc Apparatus for Direct Dipole-moments INvestigation



Final PBC double-crystal experiment
Aim: To measure the magnetic and electric dipole moments of rare baryons (Λ_c).

Run 4
HL-LHC
2029 +

TWOCRYST

Proof-of-principle (PoP) test stand
Aims: To gain operational and technical experience.
To characterise the IR3 crystals.
To measure crystal channelling efficiency at TeV energies.

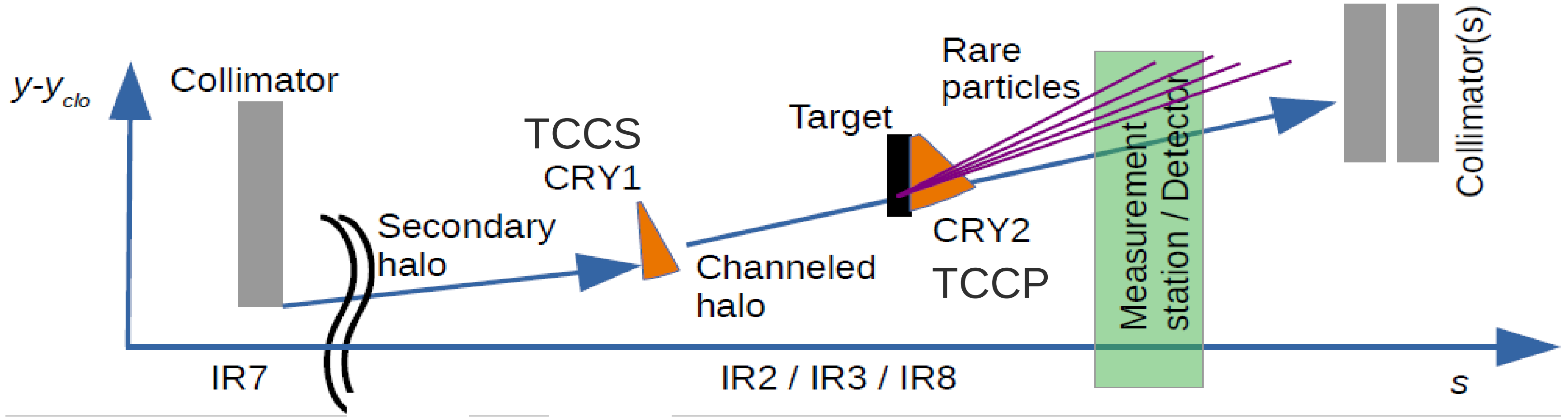
Run 3
LHC
2025 +

Crystals in the LHC
Collimation crystals are already installed in IR7.
Crystal prototypes for IR3 are being manufactured and tested.

Run 3
LHC
2023 (today)

The final PBC experiment: ALADDIN

double-crystal setup – high intensity operation



Protons impact the collimator (TCP in IR7) – **some particles form a secondary halo**

Intercept halo particles with a first **bent crystal** (CRY1) directing them **towards a fixed target**

Fixed target at safe distance from beam Proton interactions produce rare baryons

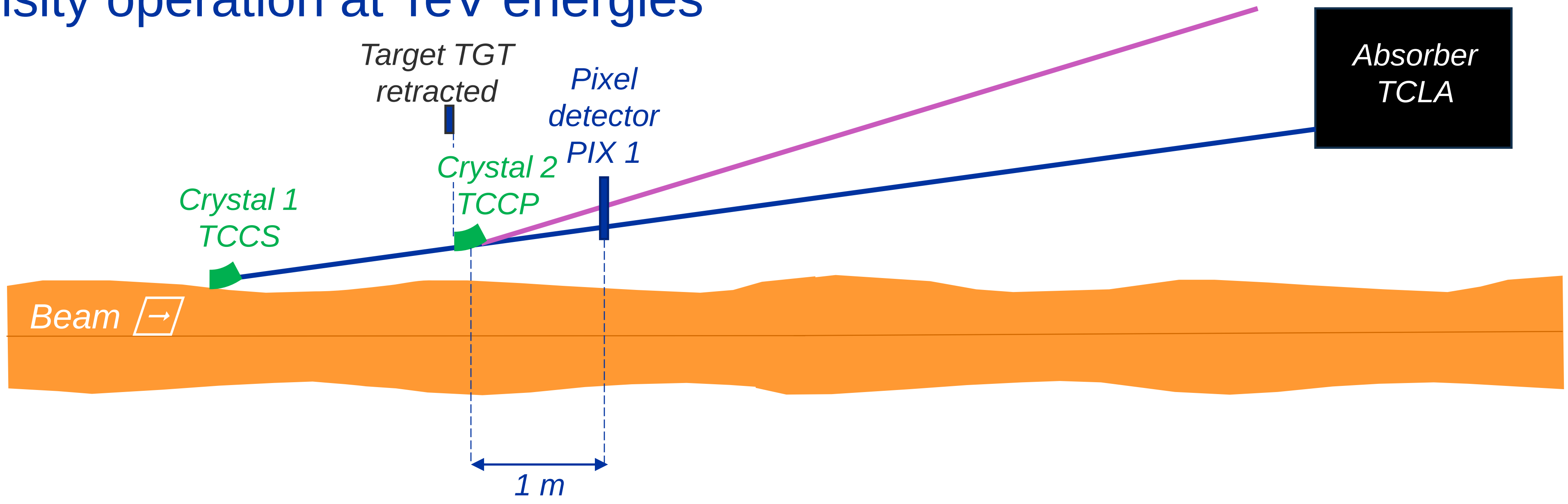
A second **bent crystal enforces precession** of the rare baryons

Detector including spectrometer: measure precession + decay products

Collimators: safely absorb residuals of the channelled halo

A Proof of Principle experiment: TWOCRYST

low intensity operation at TeV energies



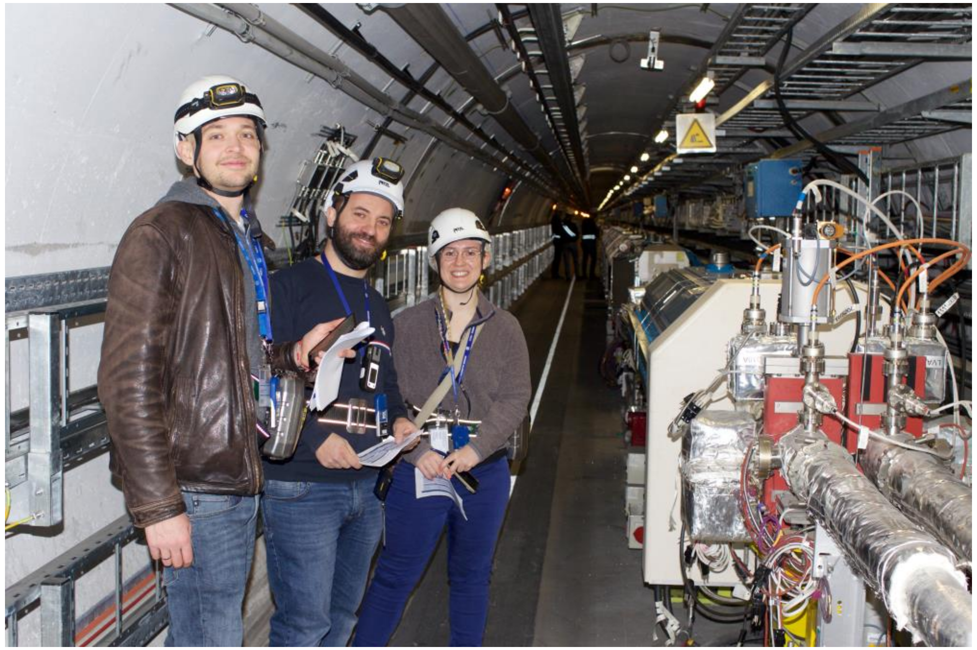
One goal on the journey: find the channelling efficiency of crystal 2 (TCCP)

Align CRY1 with the edge of the main beam (~5σ) to produce channeling – one spot on pixel detector
Align CRY2 (linear and angular position) to produce double-channelling – second spot on pixel detector
Measure intensity of double-channelled halo spot on the detector, to **find the channelling efficiency** of CRY2.
For a prediction from simulations see IPAC paper doi: 10.18429/JACoW-IPAC2024-TUPC64.

TWOCRYST to be installed this year

Visit to IR3 in February 2023 to check component positions and space requirements.
Components will be installed in the Year-End-Technical-Stop (YETS) of 2024/2025.
Measurements will take place in 2025.

Crystal 1 at 6775 m
Space available



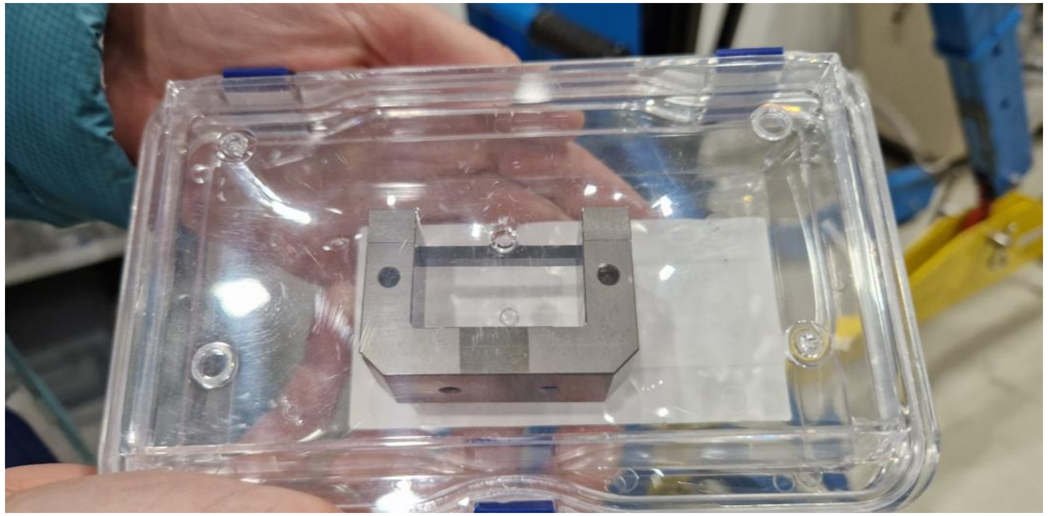
Crystal 2 at 6655 - 6675 m
Plenty of space available

Contents

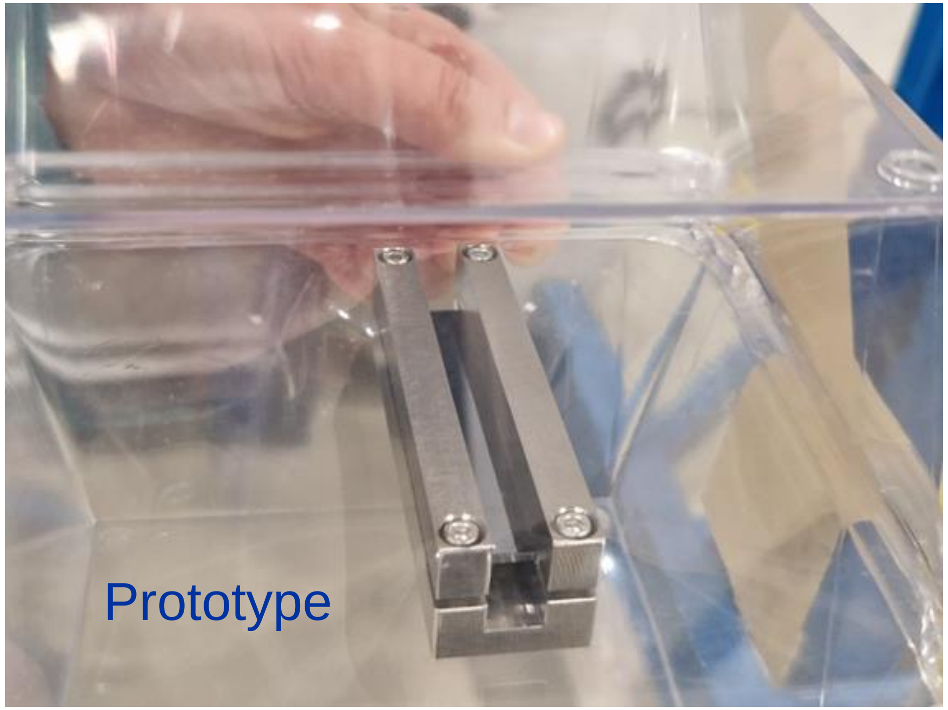
The TWOCRYST crystals: TCCS and TCCP

The TCCS and TCCP were delivered to CERN in summer 2023. Single-pass experiments were carried out to measure the single-pass channelling efficiency.

TCCS (crystal 1)

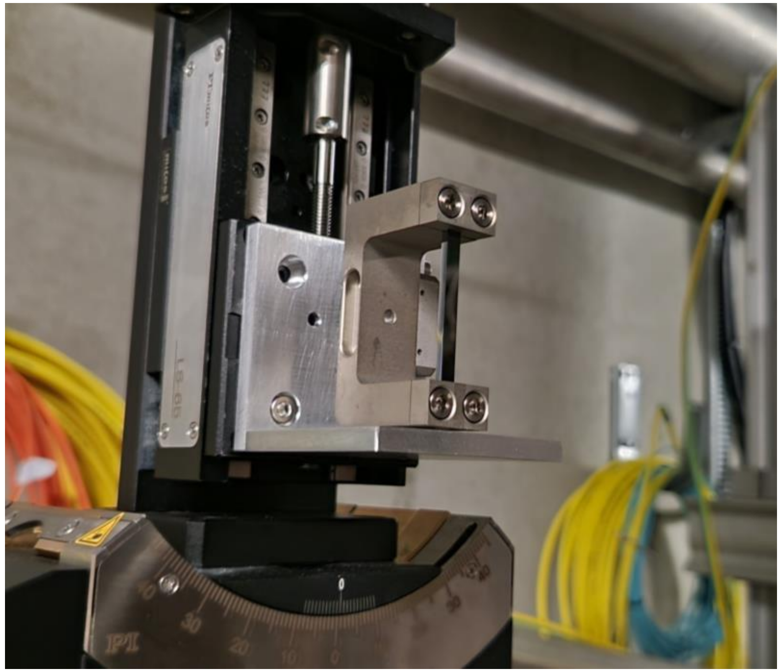


TCCP (crystal 2)



3. The TWOCRYST crystals

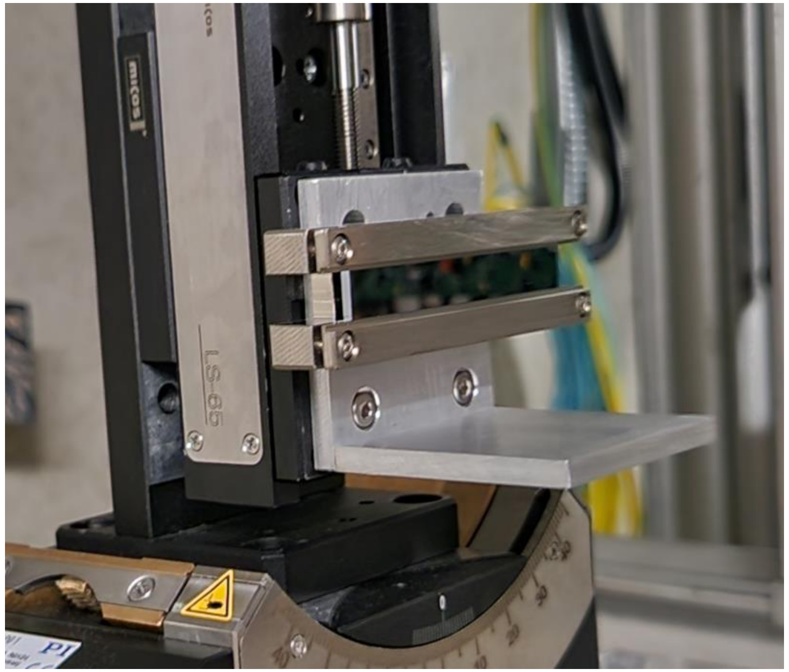
Crystal 1 (short)



Crystal properties:

Length	4 mm
Material	Silicon
Bend radius	80.0 m
X dimension	2 mm
Y dimension	35 mm

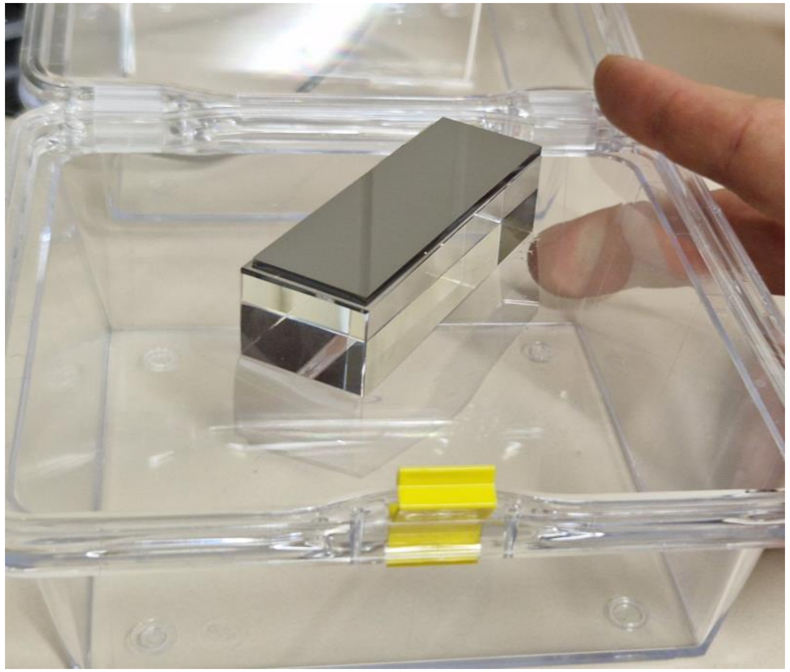
Crystal 2 (long)



Crystal properties:

Length	70 mm
Material	Silicon
Bend radius	10.0 m
X dimension	2 mm
Y dimension	8 mm

Anodic-bonded crystal



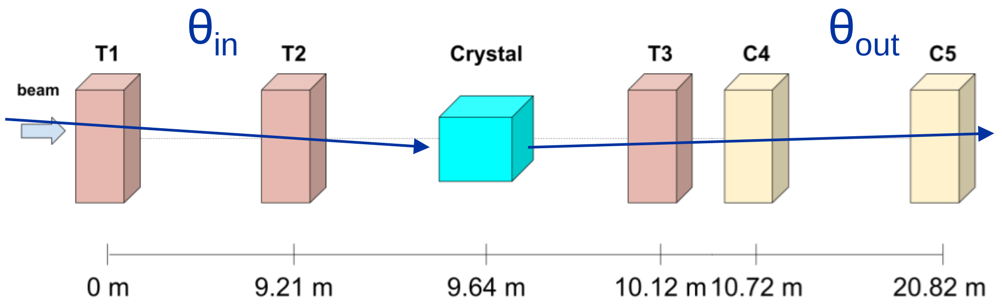
Crystal properties:

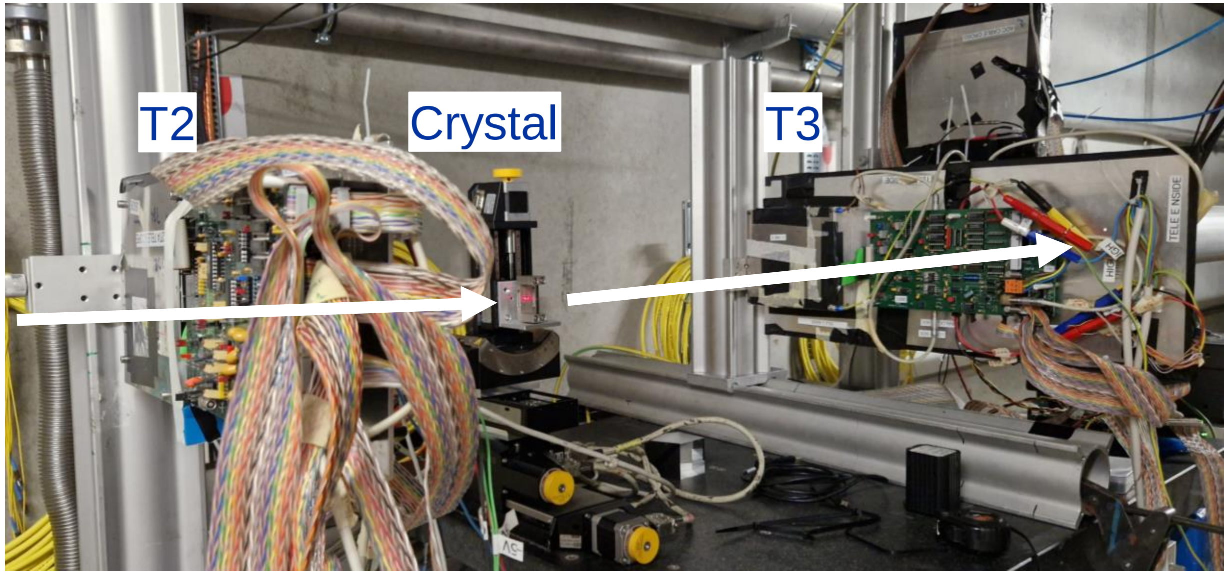
Length	70.5 mm
Material	Silicon
Bend radius	5.3 m
X dimension	2 mm
Y dimension	22.5 mm

The TWOCRYST crystals: TCCS and TCCP

Single-pass experiments were carried out in Aug 2023 in the CERN North Area (beamline H8) to measure the single-pass channelling efficiency. Results soon to be published.

H8 experiment





Preliminary results:
cut at *half* of the critical angle

Crystal and data cut point	Ch. Eff. expected from simulation	Whole crystal Ch. Eff. H8 data	Central 2.5 mm Ch. Eff. H8 data	Bend angle H8 data
Crystal 1 (TCCS) (+/- 7.7 μrad)	~77 %	59.7 %	63.4 %	48 μrad (aim 50)
Crystal 2 (TCCP) (+/- 7.3 μrad)	~36 %	8.0 %	13.0 %	6915 μrad (aim 7000)
Anodic-bonded crystal (+/- 7.0 μrad)	~ 30 %	10.0 %	12.4%	13280 μrad (expected 13302)

Summary

1. Why use bent crystals?
   - For collimation: the bend angle does not vary with the mass-to-charge ratio.
   - For spin-precession: short-lived particles can traverse a short (cm-length) crystal before they decay.

2. Crystals for collimation of the lead ion beam
   - Have been show to improve the cleaning efficiency

3. The TWOCRYST experiment
   - Components will be installed in the upcoming YETS
   - Measurements in the LHC will take place in 2025
   - Single-pass channelling efficiency measurements have been carried out in the North Area

Thank you.

Read the IPAC 2024 papers:

https://doi.org/10.18429/JACoW-IPAC2024-TUPC64

https://doi.org/10.18429/JACoW-IPAC2024-TUPC65

https://www.jacow.org/ipac2024/doi/jacow-ipac2024-frxn3/index.html