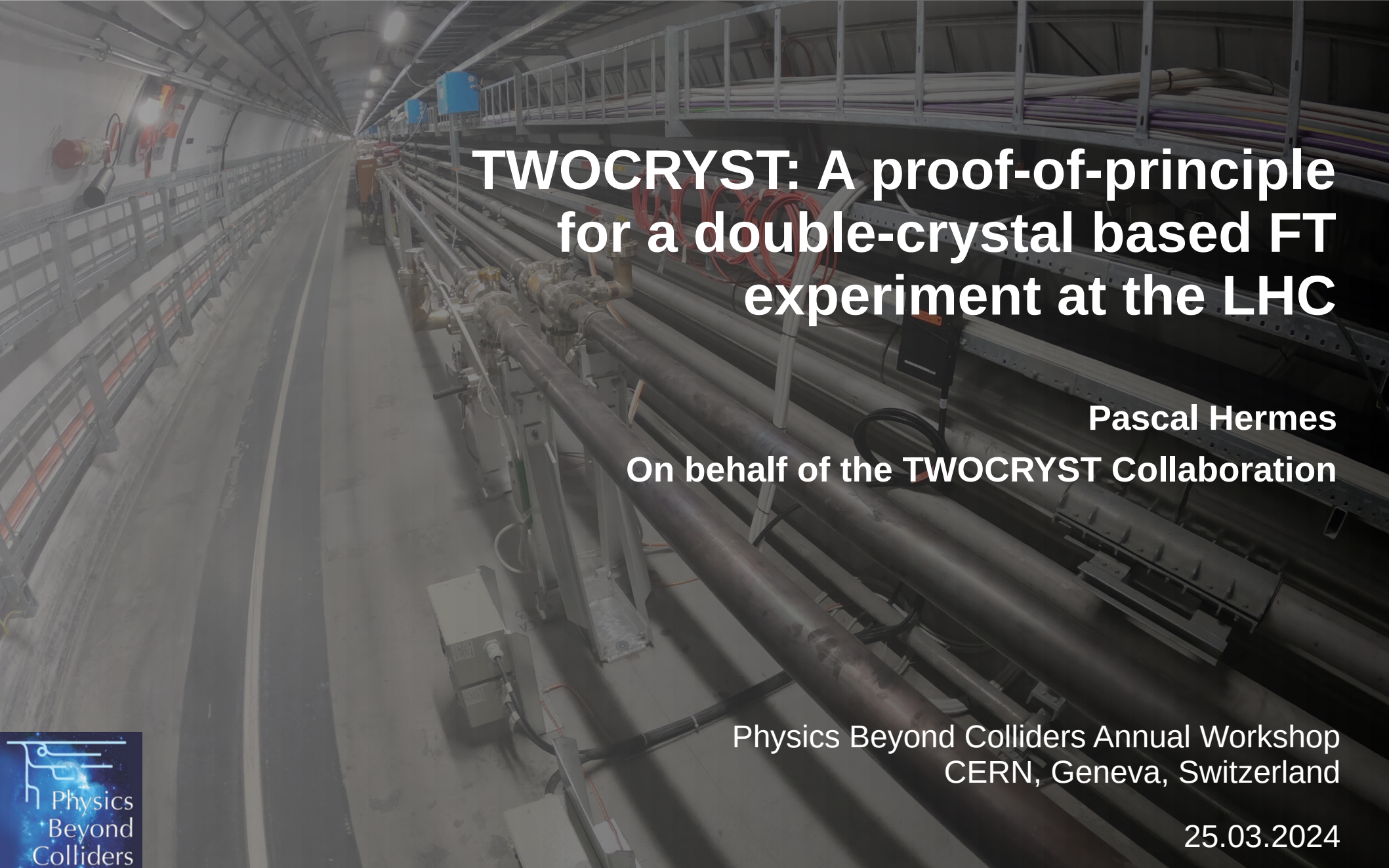

TWOCRYST: A proof-of-principle for a double-crystal based FT experiment at the LHC

Pascal Hermes

On behalf of the TWOCRYST Collaboration

Physics Beyond Colliders Annual Workshop
CERN, Geneva, Switzerland

25.03.2024

Physics Beyond Colliders

TWOCRYST contributor list

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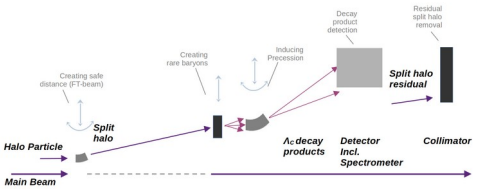
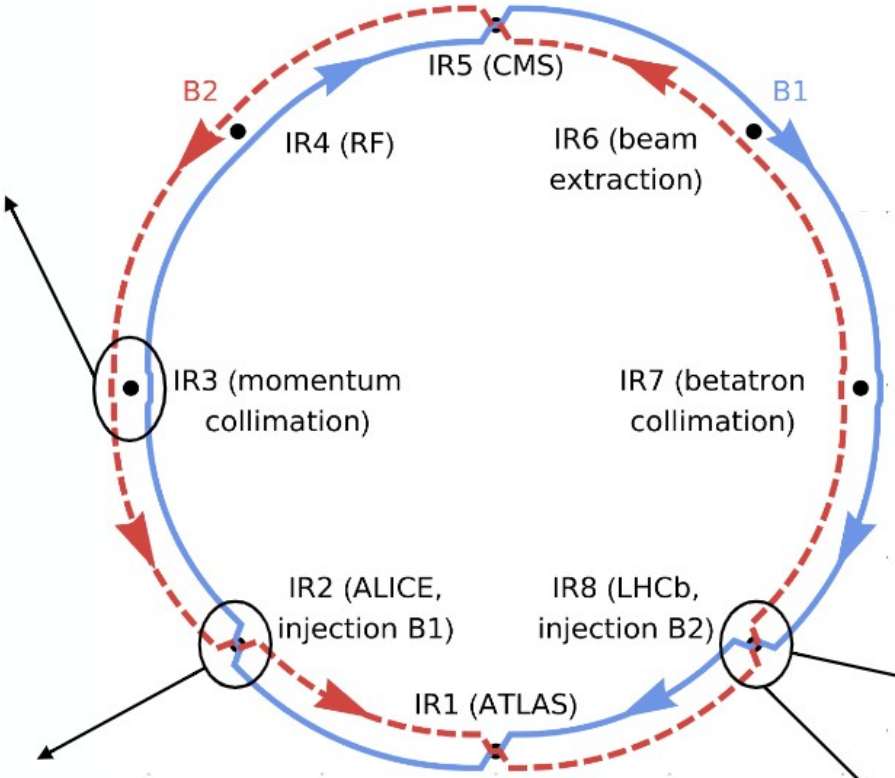
Table of Content

PBC LHC FT Studies

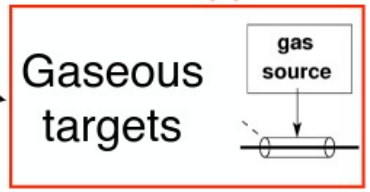
*After **2016***
PBC kick-off



IR3 Double-Crystal Setup



SMOG2

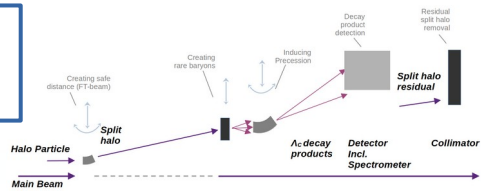


Installed in LS2

Halted

Single-crystal setup

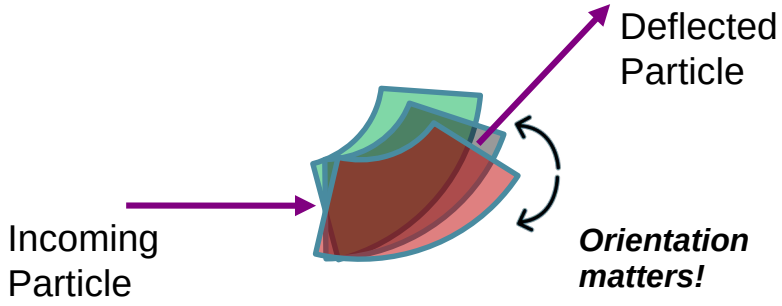
IR8 Double-Crystal Setup



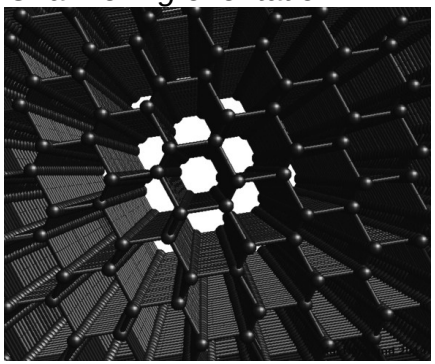
S. Redaelli, PBC General WG, 02/12/2021

Particle channelling and deflection in bent crystals

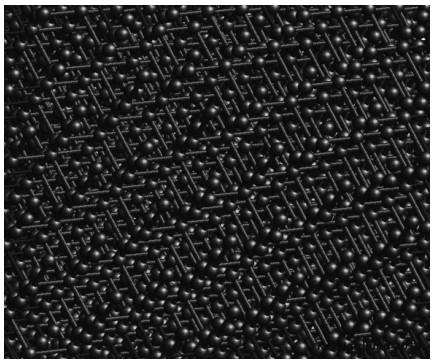
Particle channelling induces deflection



Channelling orientation

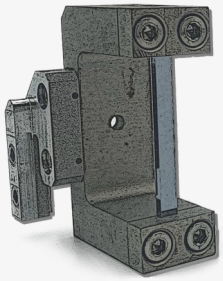


Random orientation



Knordlun, CC BY-SA 3.0 via Wikimedia Commons

Bent Silicon crystal for LHC Collimation



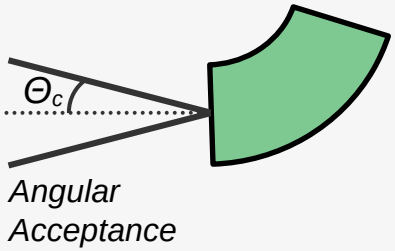
50µrad / 4mm

Equivalent deflection to ~300Tm magnet!

A. Mazzolari

Critical angle Θ_c

Precise angular alignment needed

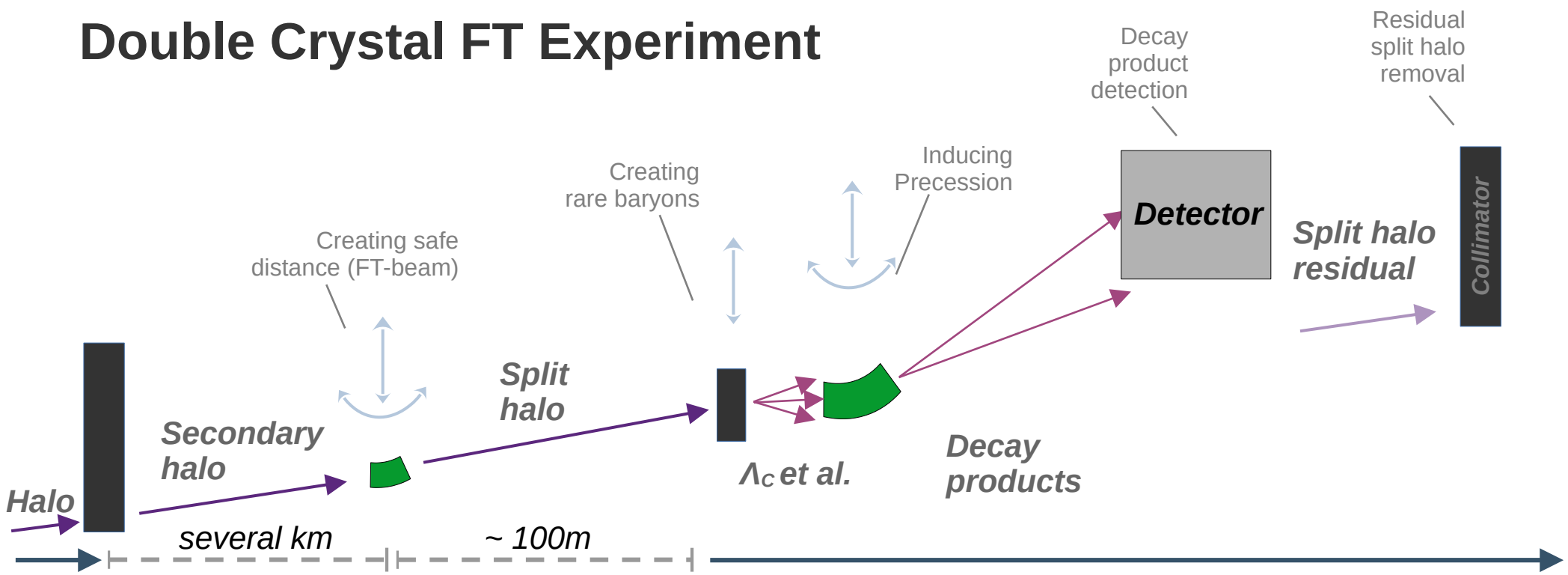


Angular Acceptance

Energy [GeV]	Θ_c [µrad]
180	18
450	9.4
7000	2.4

Silicon

Double Crystal FT Experiment



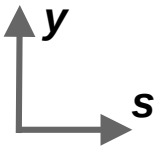
TCP
Primary Collimator (IR7)

TCCS *50-150µrad*
Splitting Crystal

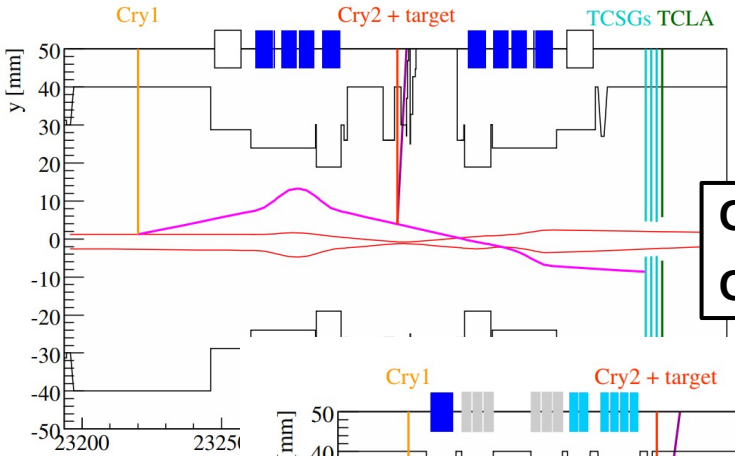
Target

TCCP *7-14mrad*
Precession Crystal

Detector Incl. Spectrometer

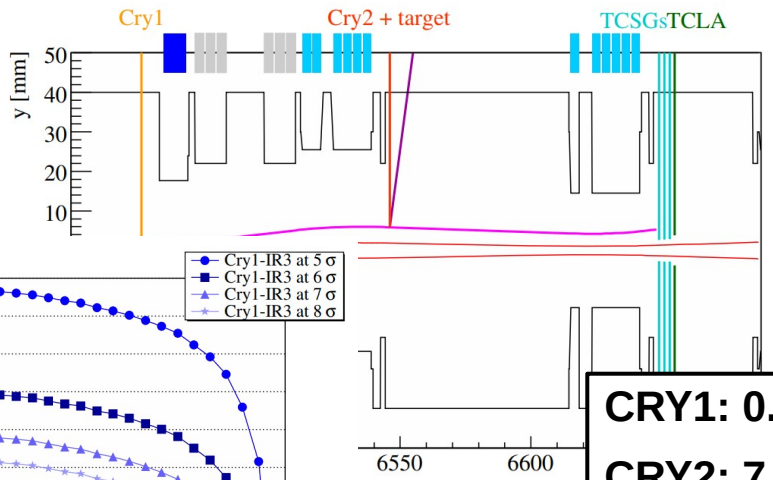


LHC Options for Double-Crystal FT Experiments



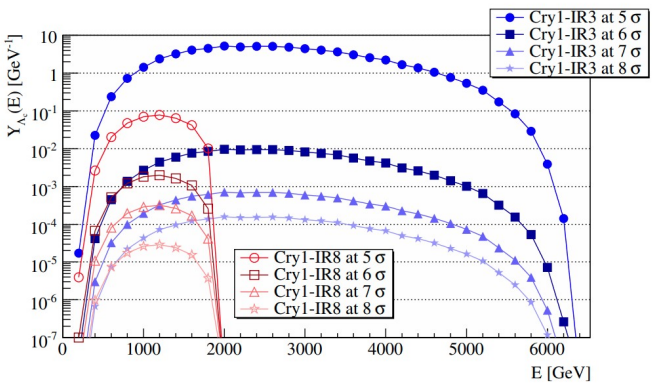
CRY1: 0.15 mrad

CRY2: 14 mrad

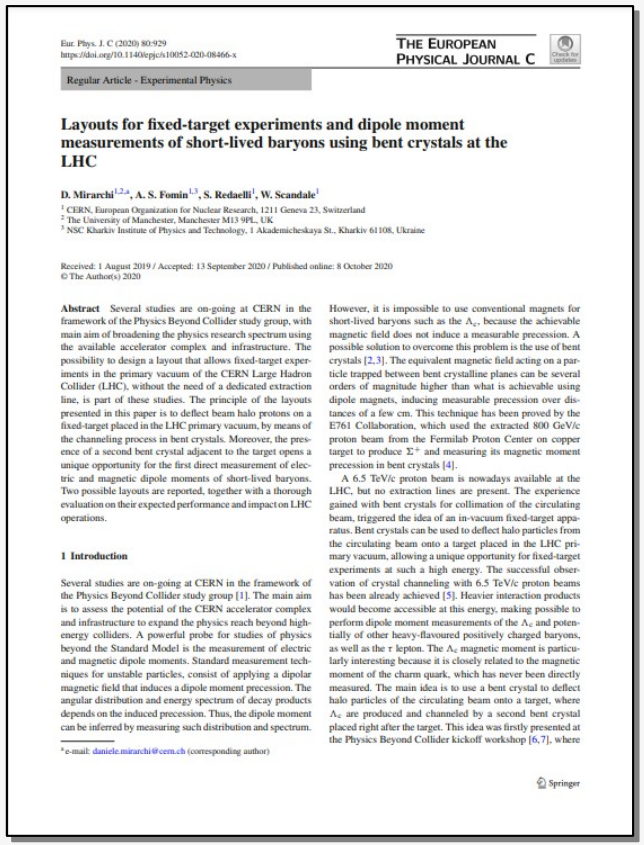


CRY1: 0.05 mrad

CRY2: 7 mrad



Possible LHC B1 layouts and achievable PoT studied by D. Mirarchi et al. (2020)



Eur. Phys. J. C (2020) 80:929
https://doi.org/10.1140/epjc/s10052-020-08466-x

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Layouts for fixed-target experiments and dipole moment measurements of short-lived baryons using bent crystals at the LHC

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Received: 1 August 2019 / Accepted: 13 September 2020 / Published online: 8 October 2020

Abstract Several studies are on-going at CERN in the framework of the Physics Beyond Collider study group, with main aim of broadening the physics research spectrum using the available accelerator complex and infrastructure. The possibility to design a layout that allows fixed-target experiments in the primary vacuum of the CERN Large Hadron Collider (LHC), without the need of a dedicated extraction line, is part of these studies. The principle of the layouts presented in this paper is to deflect beam halo protons on a fixed-target placed in the LHC primary vacuum, by means of the channeling process in bent crystals. Moreover, the presence of a second bent crystal adjacent to the target opens a unique opportunity for the first direct measurement of electric and magnetic dipole moments of short-lived baryons. Two possible layouts are reported, together with a thorough evaluation on their expected performance and impact on LHC operations.

1 Introduction

Several studies are on-going at CERN in the framework of the Physics Beyond Collider study group [1]. The main aim is to assess the potential of the CERN accelerator complex and infrastructure to expand the physics reach beyond high-energy colliders. A powerful probe for studies of physics beyond the Standard Model is the measurement of electric and magnetic dipole moments. Standard measurement techniques for unstable particles, consist of applying a dipolar magnetic field that induces a dipole moment precession. The angular distribution and energy spectrum of decay products depends on the induced precession. Thus, the dipole moment can be inferred by measuring such distribution and spectrum. However, it is impossible to use conventional magnets for short-lived baryons such as the Λ_c, because the achievable magnetic field does not induce a measurable precession. A possible solution to overcome this problem is the use of bent crystals [2,3]. The equivalent magnetic field acting on a particle trapped between bent crystalline planes can be several orders of magnitude higher than what is achievable using dipole magnets, inducing measurable precession over distances of a few cm. This technique has been proved by the E761 Collaboration, which used the extracted 800 GeV/c proton beam from the Fermilab Proton Center on copper target to produce Σ^+ and measuring its magnetic moment precession in bent crystals [4].

A 6.5 TeV/c proton beam is nowadays available at the LHC, but no extraction lines are present. The experience gained with bent crystals for collimation of the circulating beam, triggered the idea of an in-vacuum fixed-target apparatus. Bent crystals can be used to deflect halo particles from the circulating beam onto a target placed in the LHC primary vacuum, allowing a unique opportunity for fixed-target experiments at such a high energy. The successful observation of crystal channeling with 6.5 TeV/c proton beams has been already achieved [5]. Heavier interaction products would become accessible at this energy, making possible to perform dipole moment measurements of the Λ_c and potentially of other heavy-flavoured positively charged baryons, as well as the τ lepton. The Λ_c magnetic moment is particularly interesting because it is closely related to the magnetic moment of the charm quark, which has never been directly measured. The main idea is to use a bent crystal to deflect halo particles of the circulating beam onto a target, where Λ_c are produced and channeled by a second bent crystal placed right after the target. This idea was firstly presented at the Physics Beyond Collider kickoff workshop [6,7], where

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Springer

D. Mirarchi, Eur. Phys. J. C (2020) 80 :929

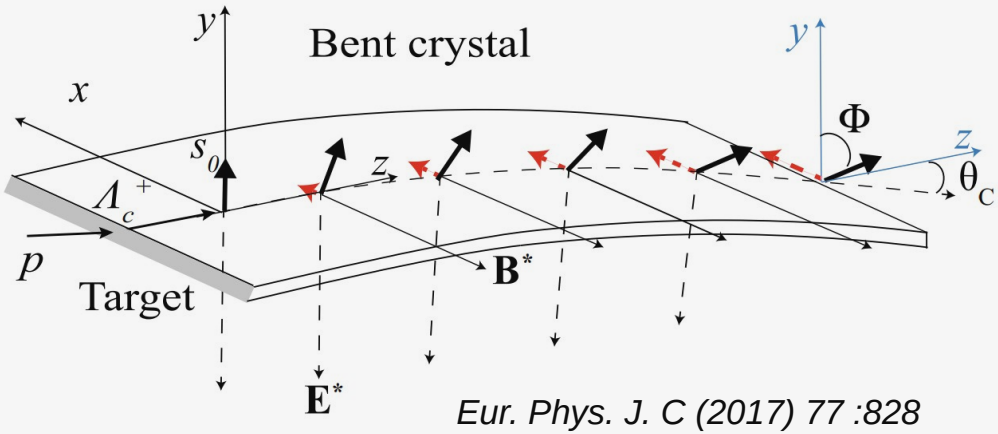
Motivations for a Proof-of-Principle

Bent crystals for spin precession (TCCP)

Long precession crystals were so far tested with SPS beams but **never probed in TeV range**

7mrad / 7cm

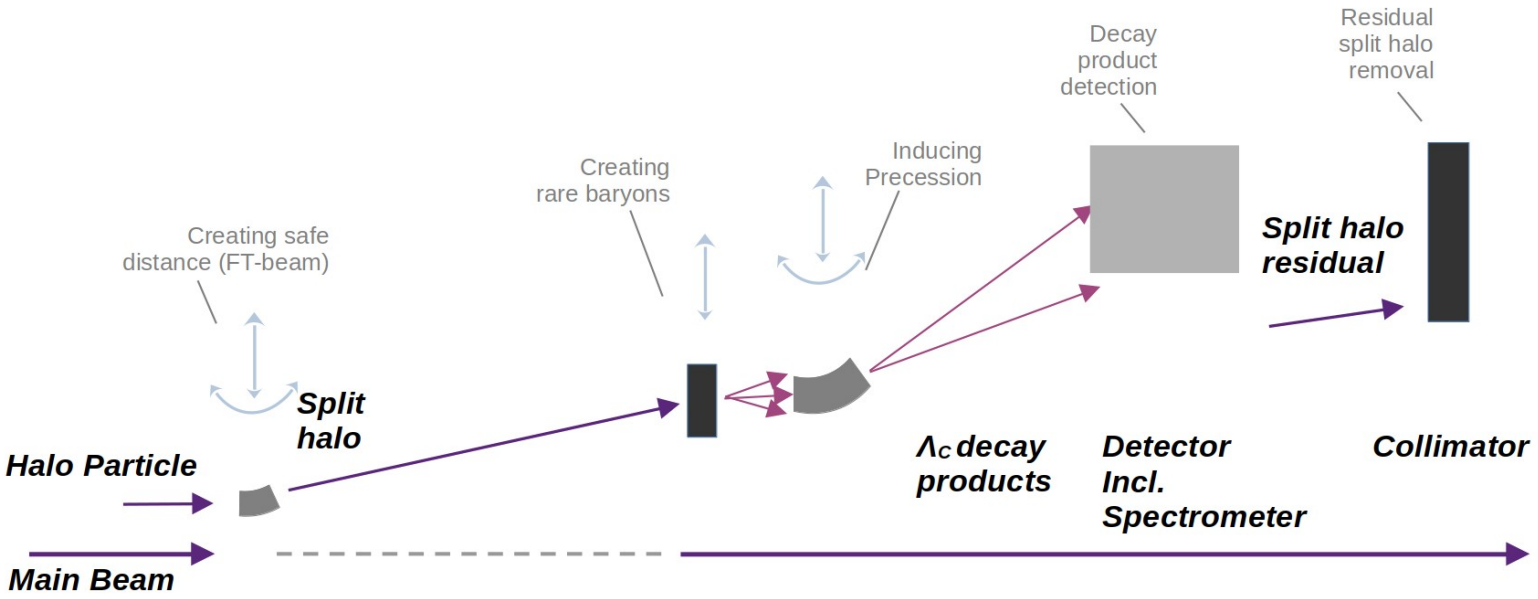
Figure: courtesy of A. Mazzolari



Eur. Phys. J. C (2017) 77 :828

What are the crystal properties in energy range of interest (~TeV) ?

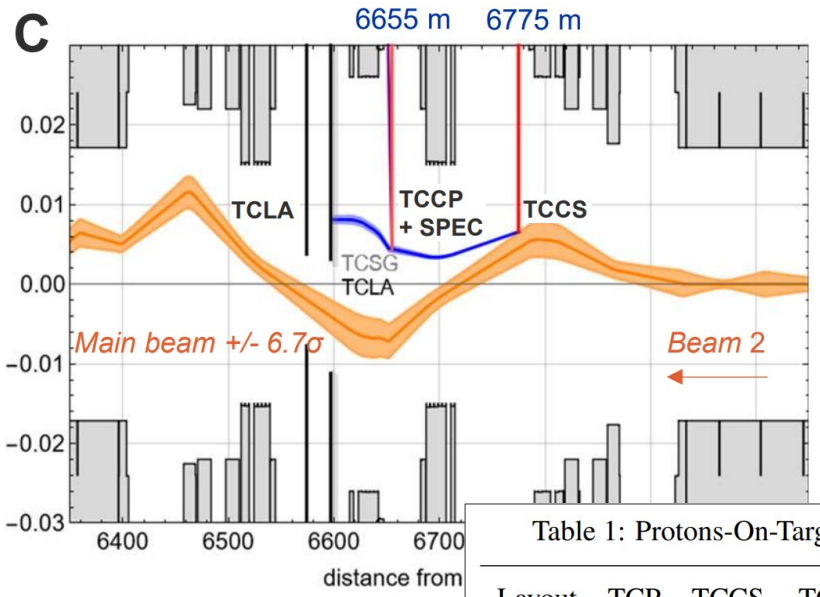
Double Crystal Setup in Operation



- Integration in collimation hierarchy
- High angular precision needed for 2 devices
- Operationally challenging

Can a double-crystal setup be reliably operated in the LHC?

Performance estimates



- **Performance estimates based on complex** combination of particle-matter interaction **simulations** and symplectic particle tracking
- Relies on tools **designed for other applications**
- **Experimental validation of** achievable **PoT** would **strengthen physics case**!

Table 1: Protons-On-Target (PoT) for each Layout

Layout (Beam)	TCP y[σ]	TCCS s[m]	TCCP s[m]	Proportion channelled	PoT (10h) [$\times 10^{10}$]
A (1)	8.5	6430	6674.5	0.17	0.11
B (1)	8.5	6554.5	6674.5	0.35	1.40
C (2)	8.5	6775	6655	0.58	1.19
A (1)	6.7	6430	6674.5	0.39	0.52
B (1)	6.7	6554.5	6674.5	0.30	1.55
C (2)	6.7	6775	6655	0.57	1.26

K. Dewhurst

What statistics can be reached with the double crystal setup in the LHC?

2025 Proof of Principle - TWOCRYST

Validate crystal properties

Long TCCP crystal: challenging to manufacture with required accuracy

Hadron beam test (NA + SPS): promising results but need data in TeV range

Scaling to TeV to be addressed experimentally

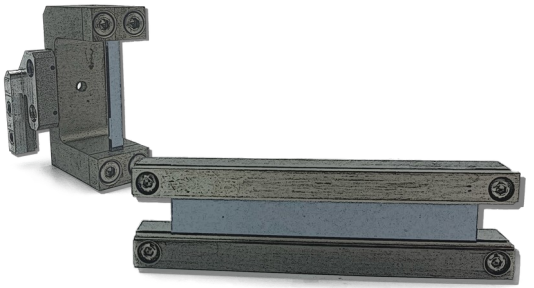
- All uncertainties could be alleviated by a proof-of-principle setup in IR3
- TWOCRYST: A proof-of-principle setup in LHC IR3 for MDs in 2025

Prepare Device Operation

Need to demonstrate operational feasibility + gain experience

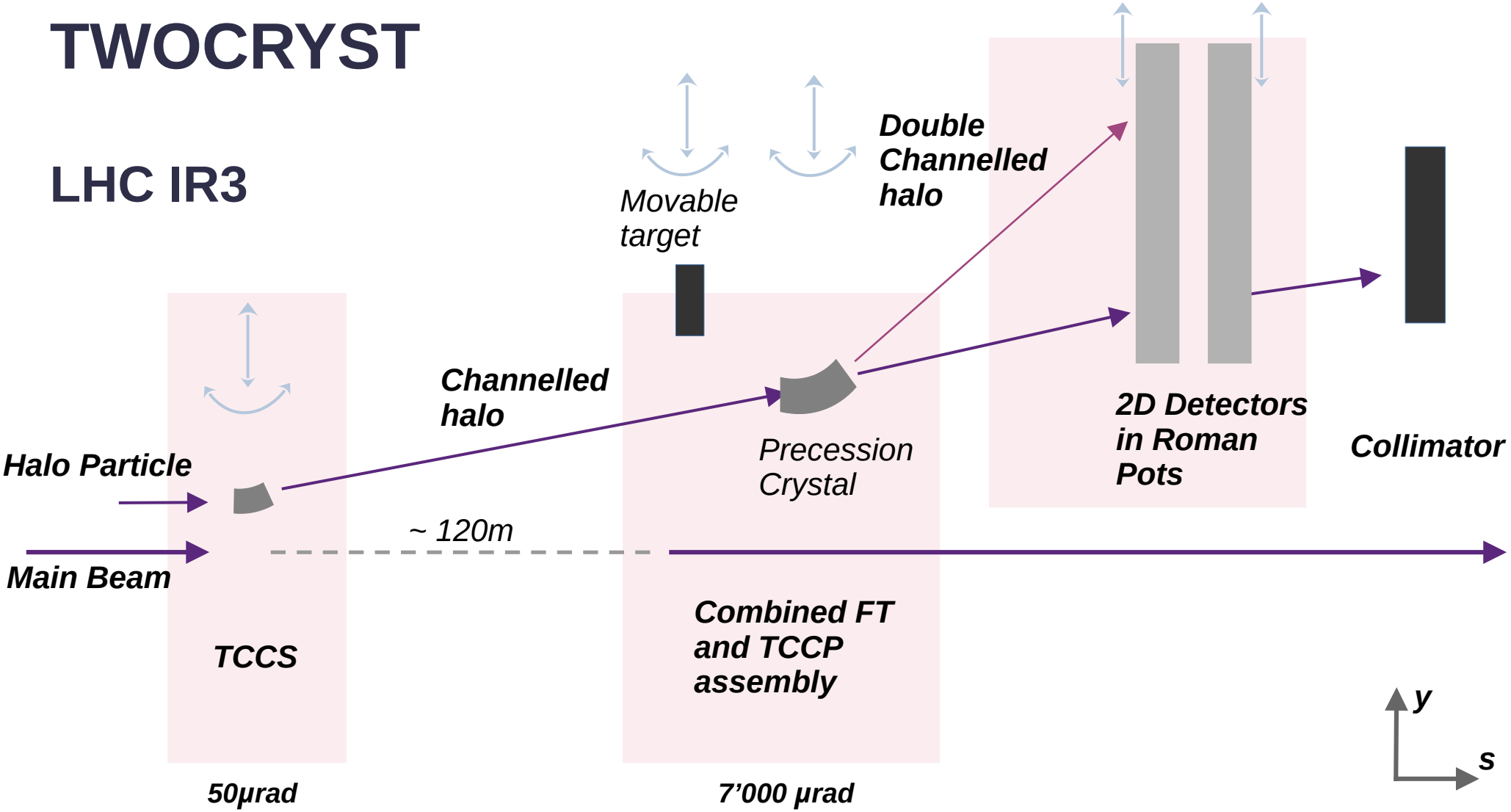
Prepare input for experiment design

Experimental validation of simulation based performance estimates



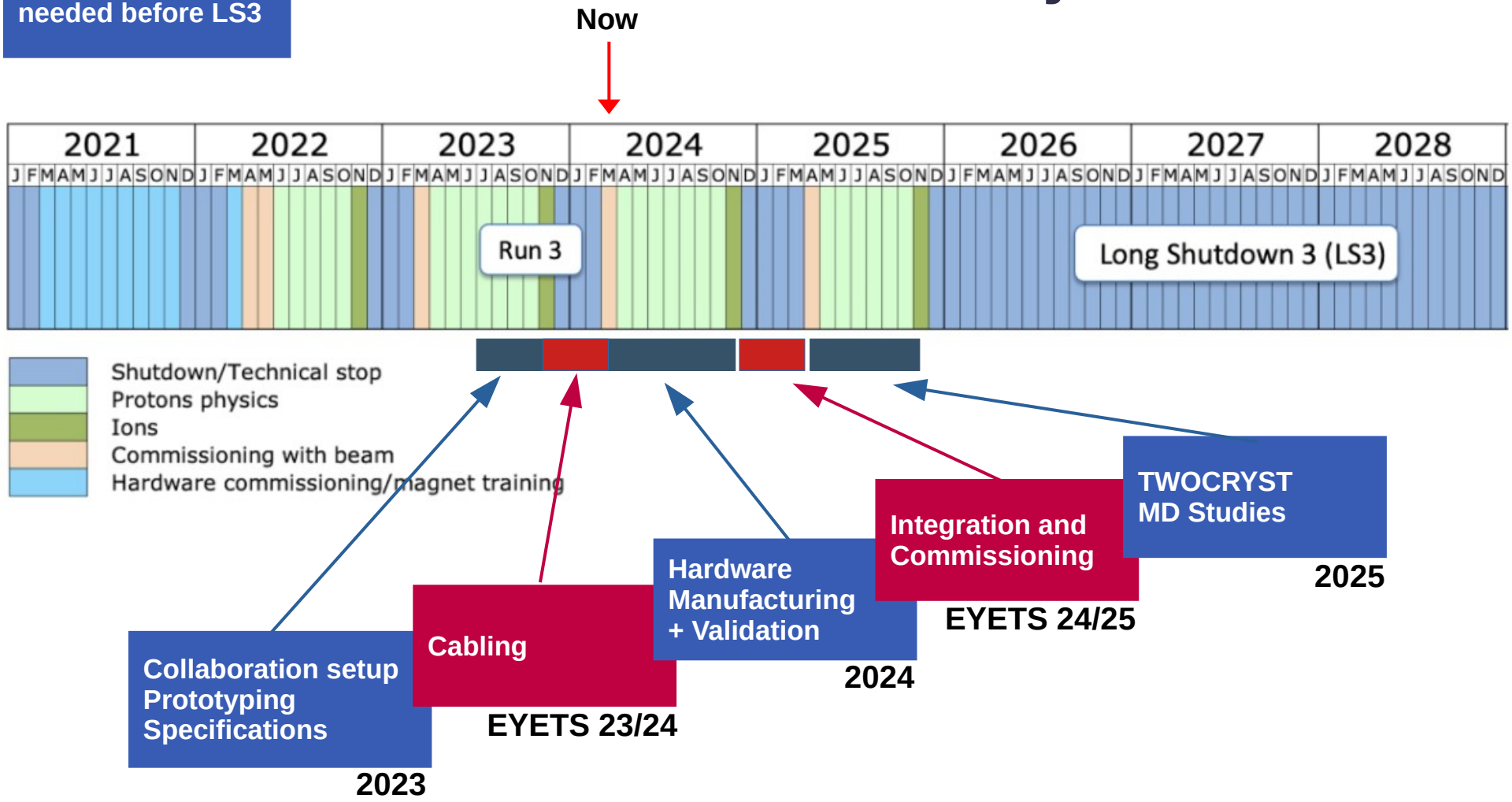
TWOCRYST

LHC IR3



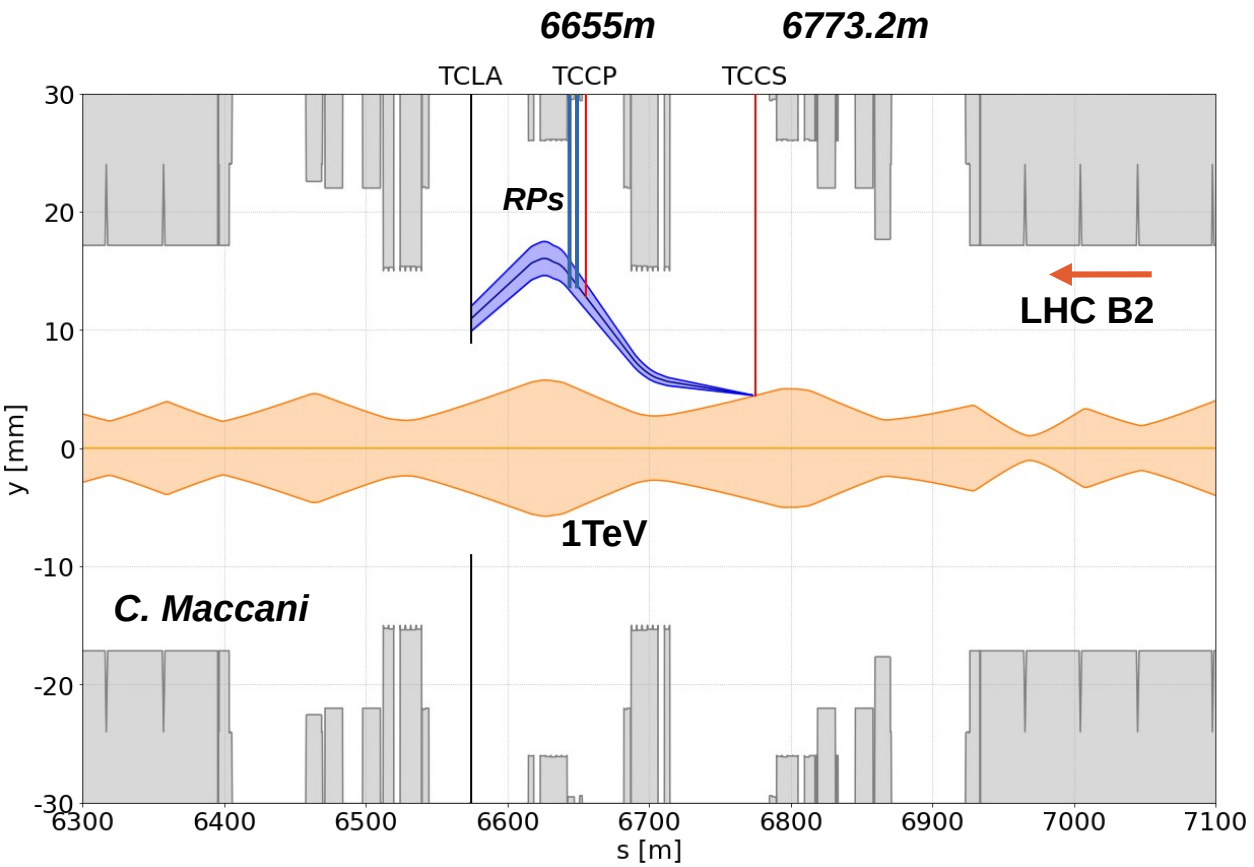
Project Schedule

TWOCRYST inputs needed before LS3

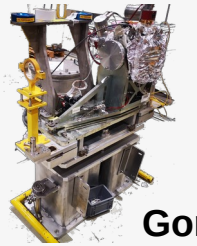


Layout and Devices

Layout



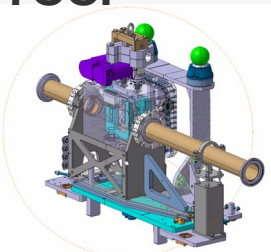
TCCS



50 µrad

Recovered Goniometer from IR7

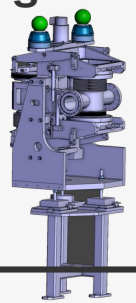
TCCP



7 mrad

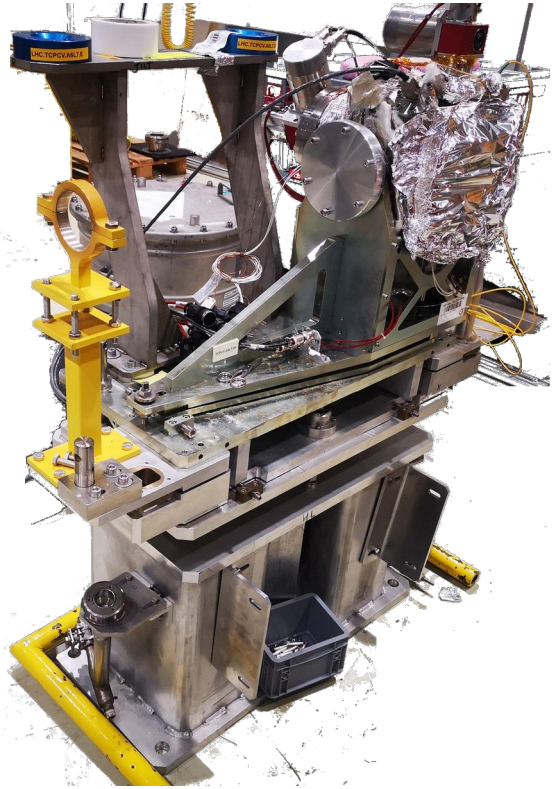
New Target/Crystal Goniometer (STI)

RPs



Recovered Roman Pot Stations from ATLAS-ALFA

TCCS assembly



TCPC - STI device in collaboration with CEM

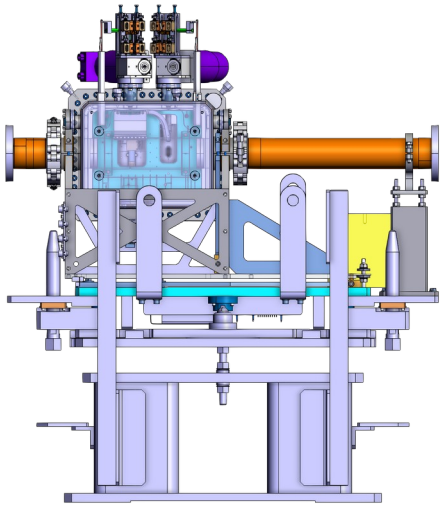
TCCS goniometer recovered from LHC IR7

Refurbishment currently ongoing
(experts from STI & CEM)

Crystal installation imminent

Cables for motion control installed in YETS23/24

TCCP Assembly (Combined Target and Long Crystal)



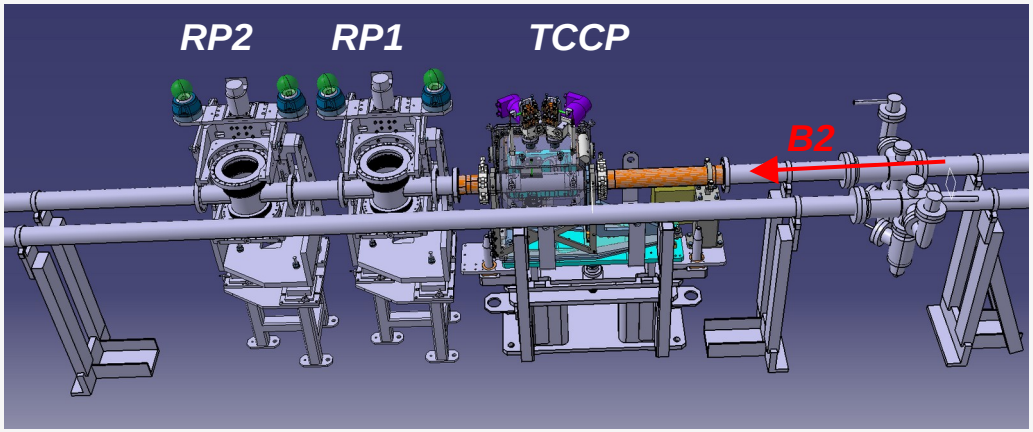
R. Seidenbinder

TCCP goniometer designed for TWOCRYST (CERN SY-STI)

Independent motion of target and TCCP crystal

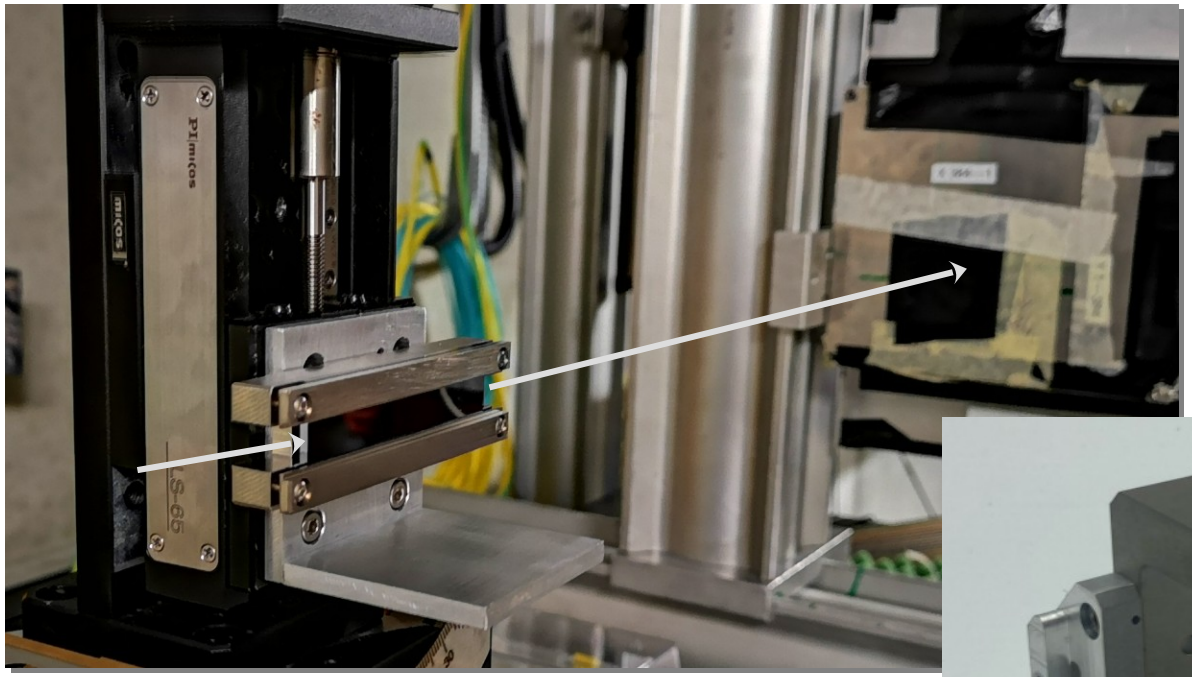
Currently procuring raw material for construction

Cables for motion control installed in YETS23/24



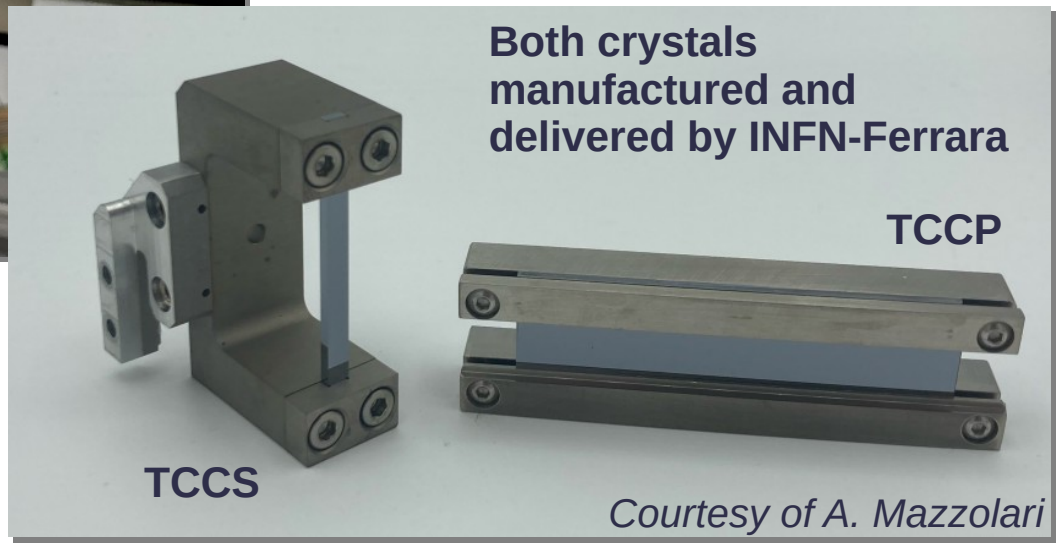
J.-P. Corso

Crystals



TCCP crystal mounted for H8 beam test

Successfully tested in CERN NA at H8 beam line (180GeV Pions)

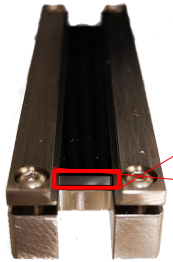


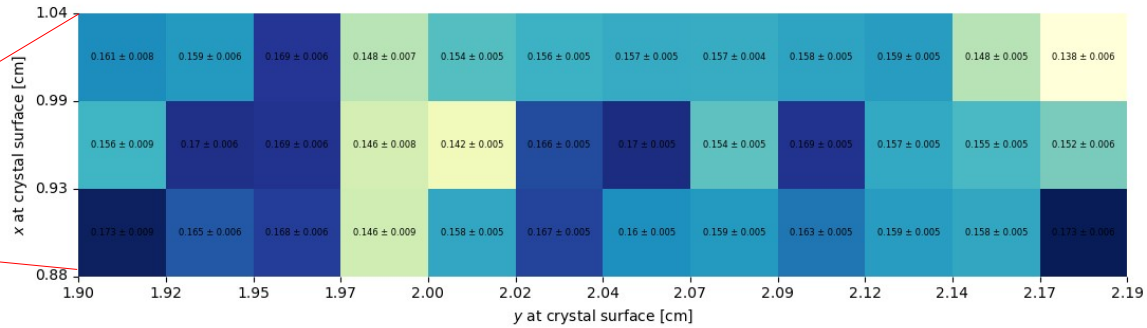
TCCP crystal also under development by CERN SY/STI team

H8 Beam Test Results

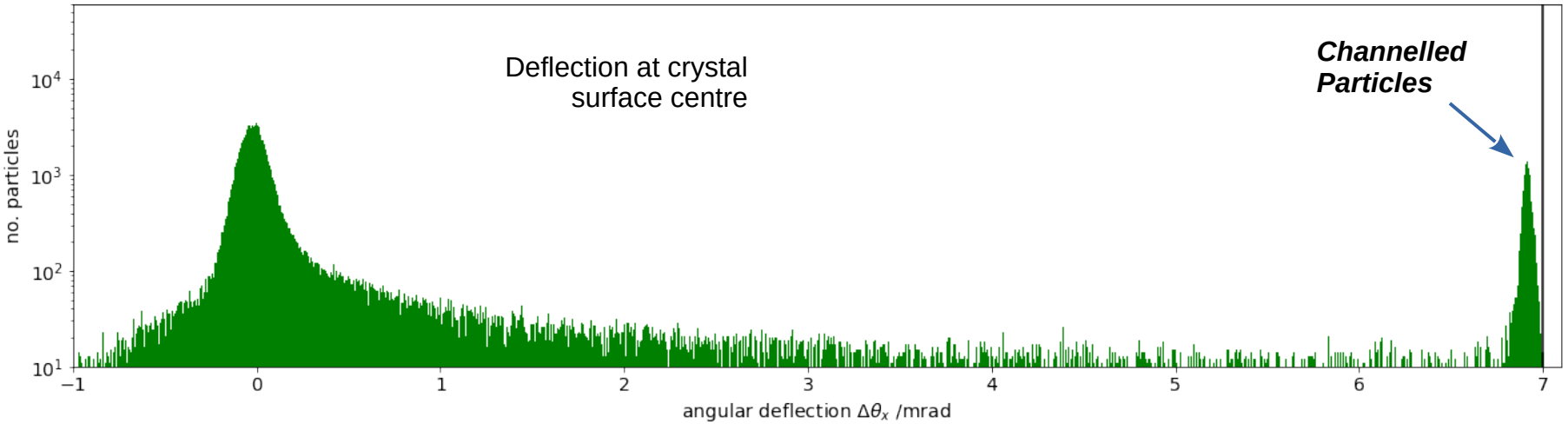
S. Cesare

Channelling Efficiency
vs. Position



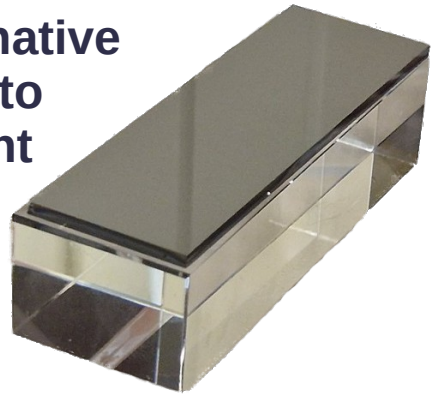


K. Dewhurst



Anodic Bonding Crystal

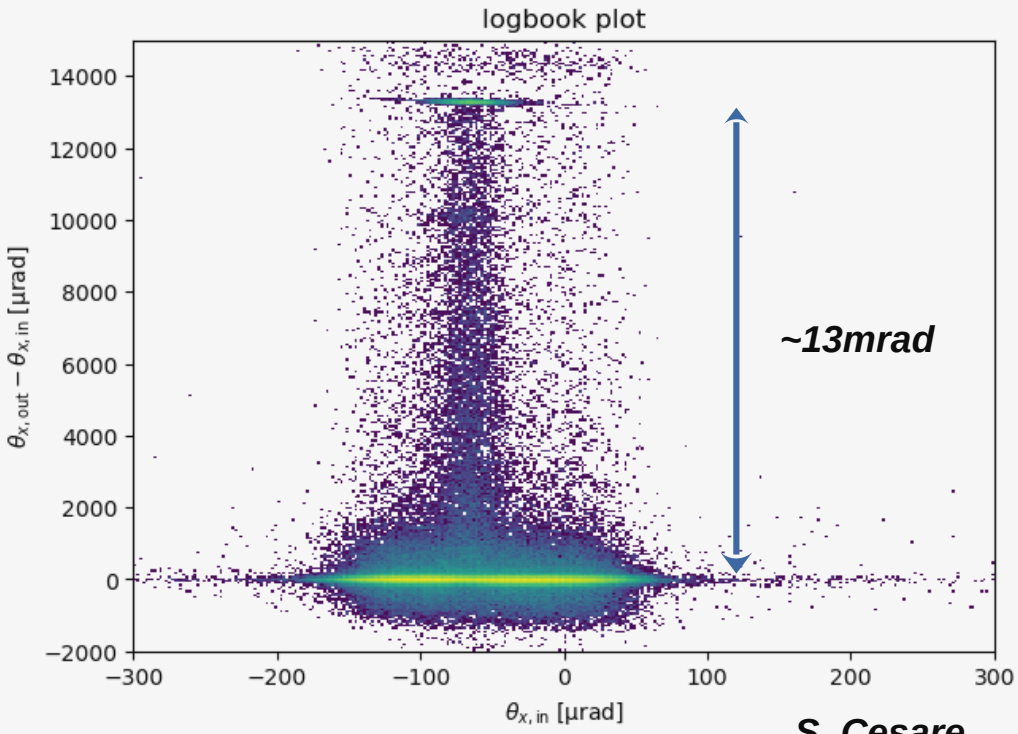
R&D : Alternative technology to produce bent crystals



Under discussion: production of 7mrad crystal?

New technology: Potential LHC installation would require multiple validation studies

First hadron channelling through anodically bonded crystal measured in TWOCRYST hadron beam test

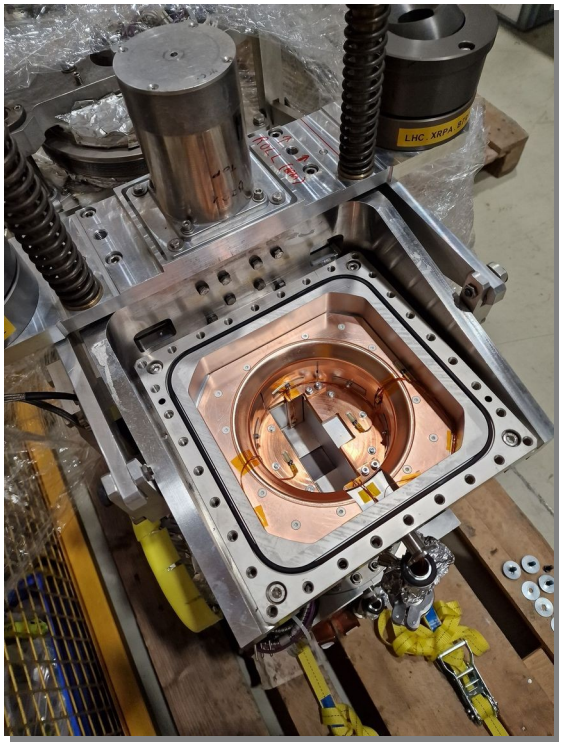


S. Cesare

Devices: Roman Pots

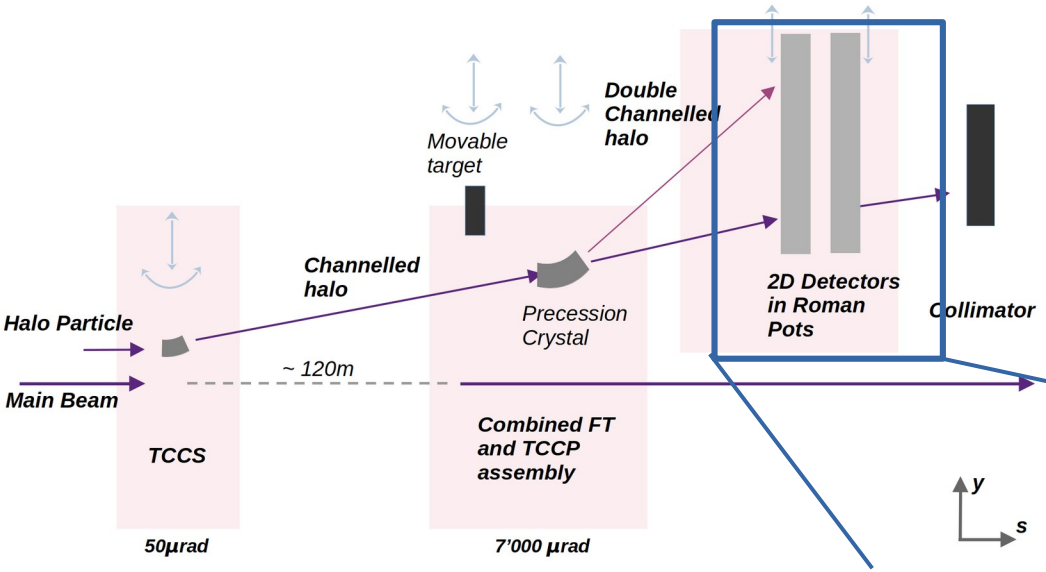
Removal of two ATLAS-ALFA Roman Pot stations after high-β run 2023

ALFA detectors removed → refurbishment ongoing

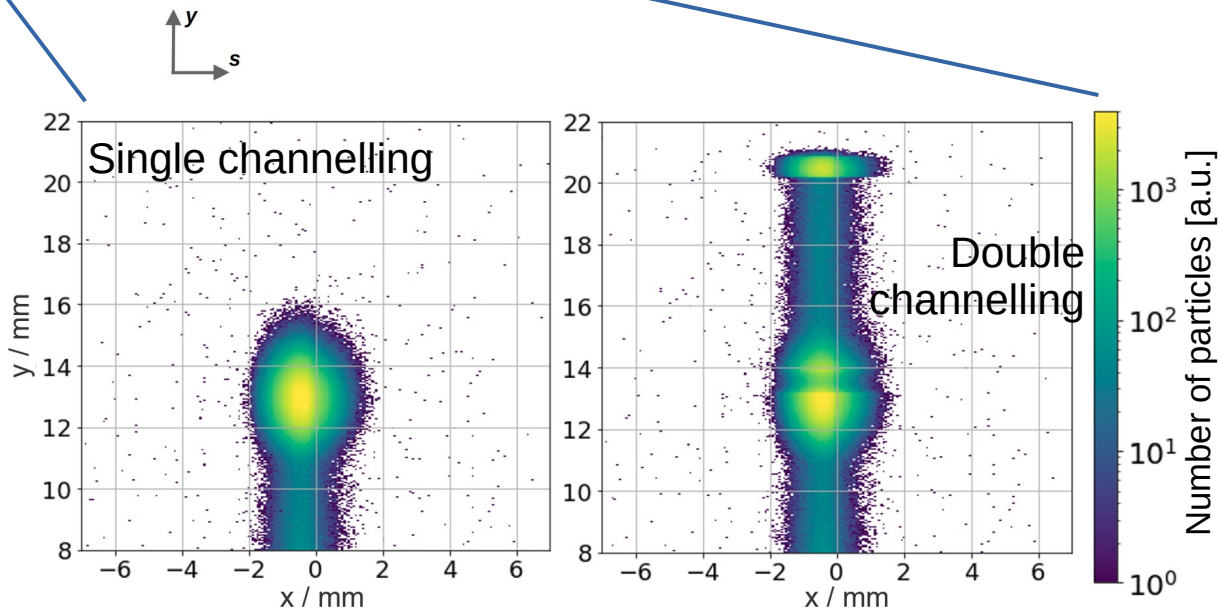


S. Jakobsen

Detectors



2D detector/s needed: observe double channelling and estimate efficiency

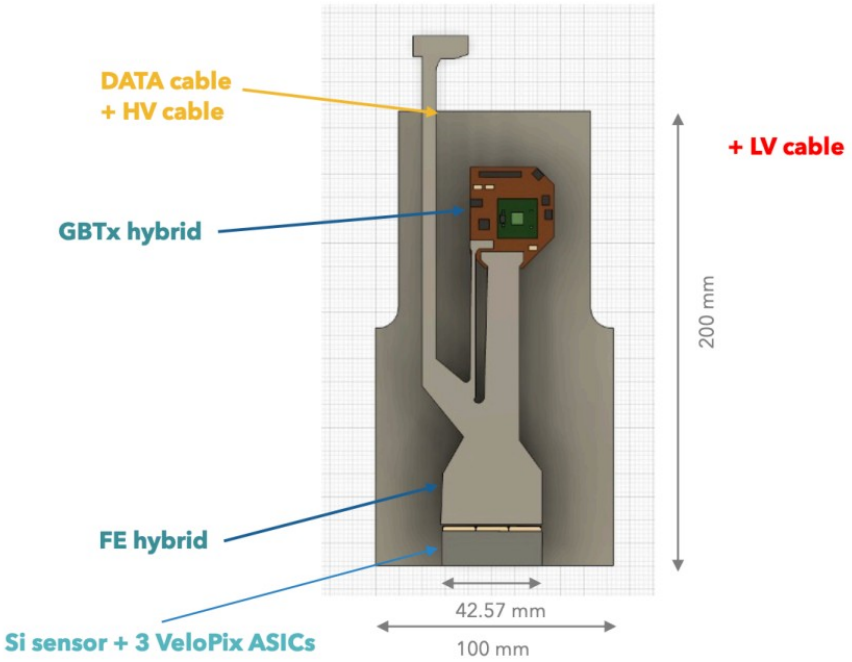


K. Dewhurst

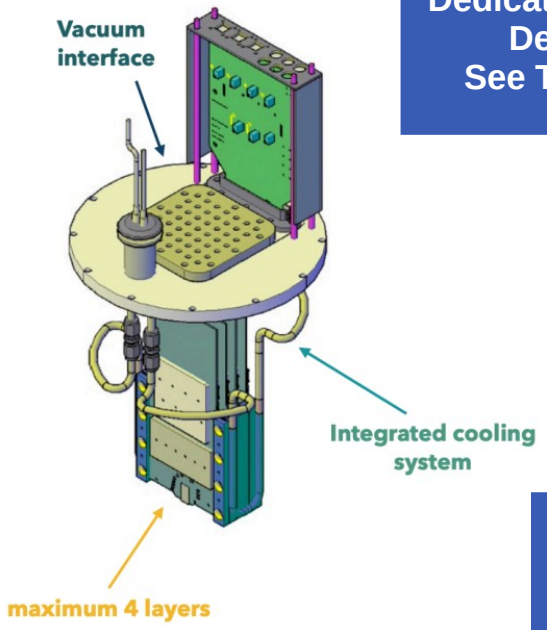
Pixel sensor module

** dedicated experiment solution shown here*

- Based on VELO sensors and CMS-Totem mechanics/cooling



Acknowledgements: J. Buytaert, V. Coco, E. Lemos from LHCb VELO group



Acknowledgments: N. Turini from CMS-Totem

Dedicated TWOCRYST Detector WG
See Talk by N. Neri

Discussions ongoing to define second 2D - detector

Milestones for 2024

Milestones 2024

- **2024 will be the last year of preparation**
- Crystal x-ray validation & thermal cycle checks at CERN
- Beam test with hadrons >180GeV: possibly during NA commissioning
- Finalize preparation and validation of TCCS assembly and RPs
- Complete detector design and procurement of acessories
- Construction, validation of TCCP assembly
- Installation of TWOCRYST devices in YETS24/25: challenging timeline!

MD Program

MD Program

All MDs with setup beam flag

Possible in present machine

2024

1 shift: Establish optimized energy ramp in steps to 1 TeV and 3 TeV	***Preparation***
1 shift [Optional]: Identify secondary halo channelling (IR3 TCP & IR7 crystal)	***PoT***

Proposed with new hardware

2025

2 shifts: Commissioning detector & TCCP crystal characterization at 450GeV	***Preparation***
1 shift: TCCP crystal characterization at 1 TeV and 3TeV	***TCCP***
1 shift: Measurements of double-channelling without/with target	***OP***
1 shift: Identify secondary halo channelling with IR7 TCP / IR3 TCCS	***PoT***
1 shift [Optional]: Full operational configuration test	***PoT***

Collaboration

Collaboration

CERN with 7 involved teams

INFN, Italy

IJCLab, France

IFIC, University of Valencia-CSIC, Spain

University of Malta, Malta

Warsaw University of Technology, Poland

MoUs signed - Contributions defined at the TWICB (Addenda need to be finished)

One institute expressed interest in joining TWOCRYST

University of Chinese Academy of Sciences (J. Fu)

Acknowledgments for financial support

European Research Council
Established by the European Commission

Physics Beyond Colliders

SELDOM
project G.A. 771642

Conclusions

Conclusions

- TWOCRYST project : a proof-of-principle for a double-crystal based FT experiment in the LHC
- Project is well on track but on a very challenging timeline
- Thanks a lot to all contributors!