Towards an LHC test stand for crystal assisted fixed-target experiments

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Acknowledgments

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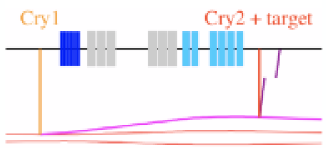
LHC fixed target proposals

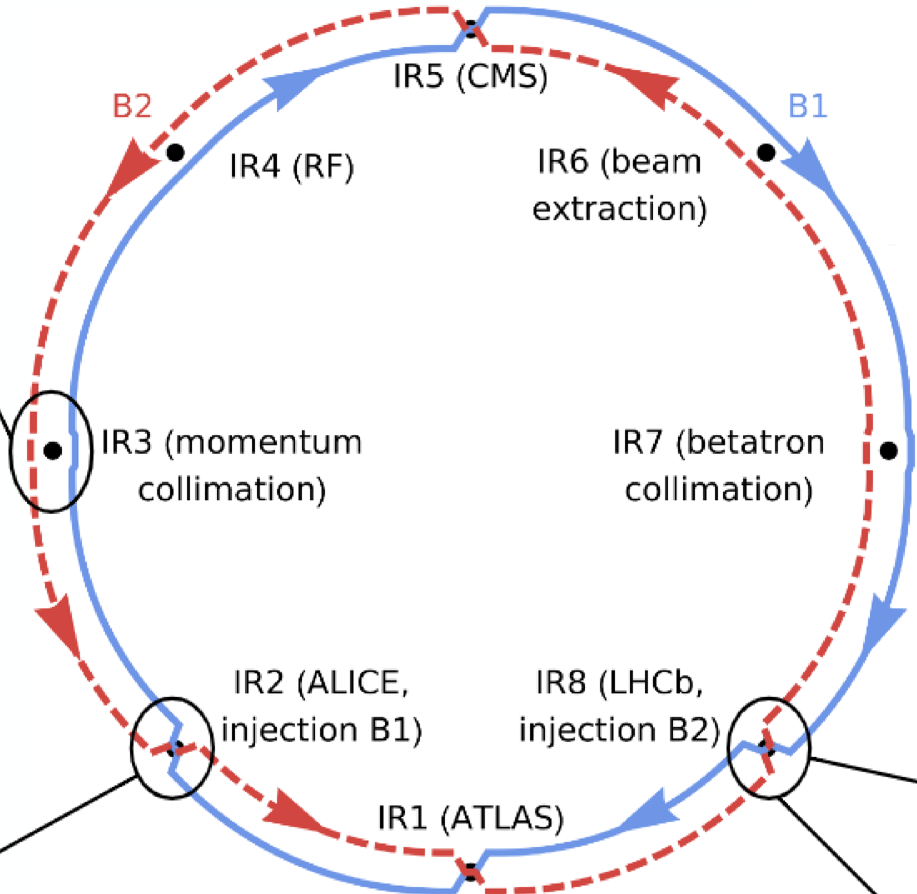
See also talks by
D. Kikoła
L. Libero Pappalardo

Double-crystal setup



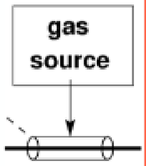
CRY1: 50μrad
CRY2: ~7000μrad

Timeline: LS3



SMOG-2: Installed

Gaseous targets



Single-crystal setup

CRY1: 100-175μrad

Double-crystal setup

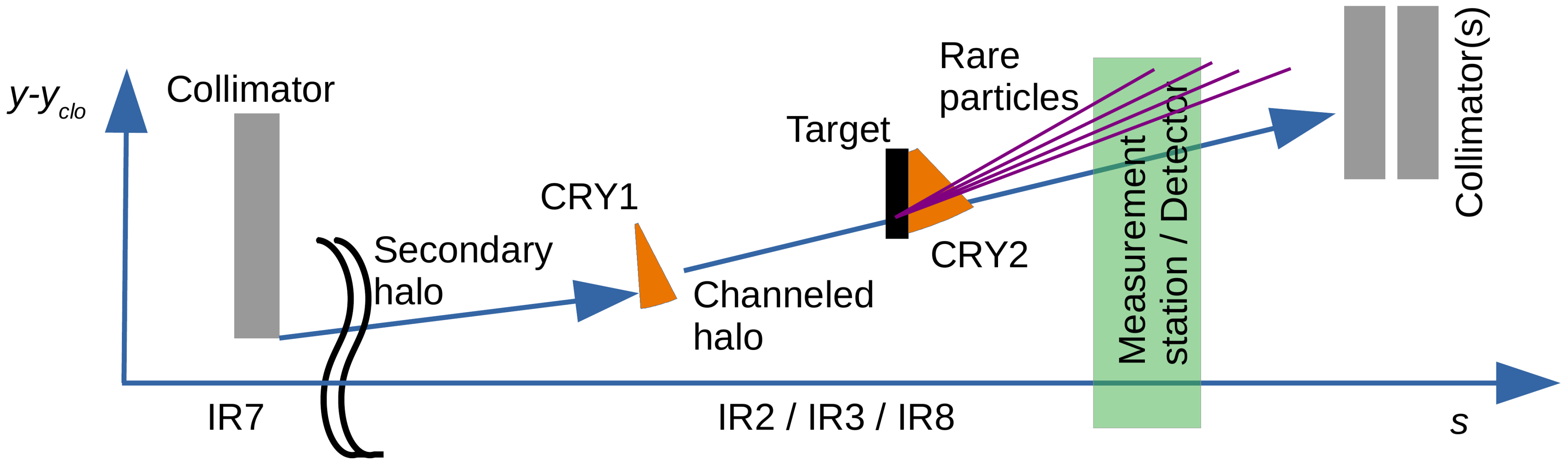
CRY1: 150μrad
CRY2: ~14000μrad

Timeline: LS3

S. Redaelli, PBC General WG, 02/12/2021 8

Double crystal setup

High intensity operation



Particles impact the IR7 TCP – **some particles form a secondary halo**

Intercept secondary halo originating at IR7 TCP **with bent crystal**

Fixed target at safe distance from beam – produce rare baryons

Crystal enforcing precession

Detector including spectrometer: measure precession

Collimators: safely absorb residuals of channelled halo

See also:
S. Redaelli, PBC Kick-off workshop 2016
W. Scandale, PBC Kick-off workshop 2016

Physics motivation:
See talk by N. Neri, this workshop

Proof of Principle (PoP)

- **Double-crystal FT experiment: unprecedented experimental setup** challenging combination of high precision devices
- Attempt for **simplified** (yet compatible with final experiment) **IR3** double-crystal **setup during LHC Run 3**

Main Goals

- **Measure achievable protons on target:** so far only simulation based
- **Assess performance of CRY2** in TeV range (only available at LHC)
- **Gain experience / develop solutions** for expected operational challenges: crystal alignment, establishing double channelling, etc.
- Performance and background environment for IR3 detector studies

Operational Scope

	Proof of Principle	*Final Experiment*
	Machine Development	**Nominal operations**
Aim	**Dedicated beam time** for proof of principle	Physics **production**
Beams	**Setup beams** (up to 3×10^{11} p)	**Full machine** ($>3 \times 10^{14}$ p)
Machine Protection	**Possible to mask** some interlocks	**All protections active**
Operations	Flexibility for **expert handling**	**Fully automated** handling

Courtesy of D. Mirarchi

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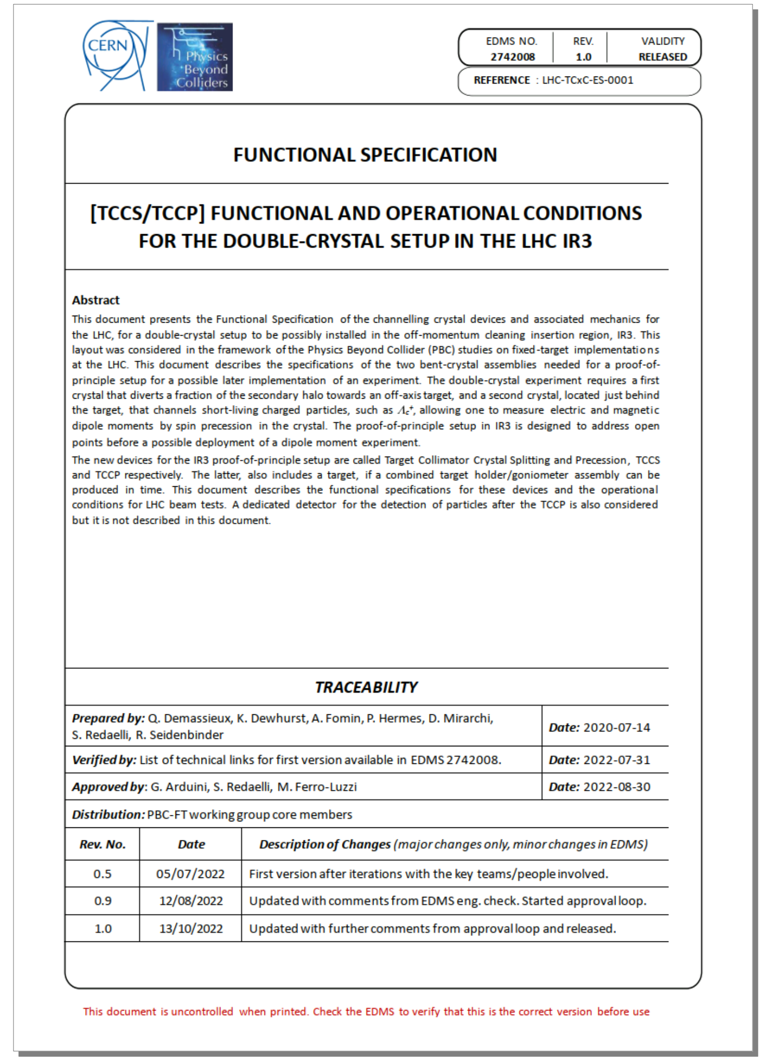
Status

- **Gain experience in operation and demonstrate concept feasibility** in LHC Run 3 → **proof of principle (PoP)** setup
- 2022 - PoP functional specification document approved (**EDMS 2742008**)
- **Memorandum of Understanding** – available for signature by collaborators
- **Work Breakdown Structure under finalization** with groups and external collaborators



EDMS NO.	REV.	VALIDITY
2742008	1.0	RELEASED

REFERENCE : LHC-TCxC-ES-0001

FUNCTIONAL SPECIFICATION

[TCCS/TCCP] FUNCTIONAL AND OPERATIONAL CONDITIONS FOR THE DOUBLE-CRYSTAL SETUP IN THE LHC IR3

Abstract

This document presents the Functional Specification of the channelling crystal devices and associated mechanics for the LHC, for a double-crystal setup to be possibly installed in the off-momentum cleaning insertion region, IR3. This layout was considered in the framework of the Physics Beyond Collider (PBC) studies on fixed-target implementations at the LHC. This document describes the specifications of the two bent-crystal assemblies needed for a proof-of-principle setup for a possible later implementation of an experiment. The double-crystal experiment requires a first crystal that diverts a fraction of the secondary halo towards an off-axis target, and a second crystal, located just behind the target, that channels short-living charged particles, such as Λ_c^+, allowing one to measure electric and magnetic dipole moments by spin precession in the crystal. The proof-of-principle setup in IR3 is designed to address open points before a possible deployment of a dipole moment experiment.

The new devices for the IR3 proof-of-principle setup are called Target Collimator Crystal Splitting and Precession, TCCS and TCCP respectively. The latter, also includes a target, if a combined target holder/goniometer assembly can be produced in time. This document describes the functional specifications for these devices and the operational conditions for LHC beam tests. A dedicated detector for the detection of particles after the TCCP is also considered but it is not described in this document.

TRACEABILITY

Prepared by: Q. Demassieux, K. Dewhurst, A. Fomin, P. Hermes, D. Mirarchi, S. Redaelli, R. Seidenbinder	***Date:*** 2020-07-14
Verified by: List of technical links for first version available in EDMS 2742008.	***Date:*** 2022-07-31
Approved by: G. Arduini, S. Redaelli, M. Ferro-Luzzi	***Date:*** 2022-08-30

Distribution: PBC-FT working group core members

Rev. No.	***Date***	***Description of Changes*** *(major changes only, minor changes in EDMS)*
0.5	05/07/2022	First version after iterations with the key teams/people involved.
0.9	12/08/2022	Updated with comments from EDMS eng. check. Started approval loop.
1.0	13/10/2022	Updated with further comments from approval loop and released.

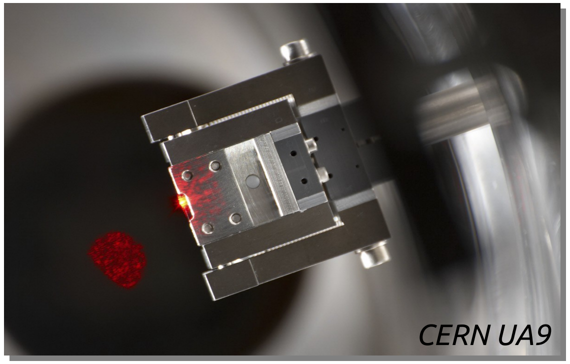
This document is uncontrolled when printed. Check the EDMS to verify that this is the correct version before use

IR3 crystal design layout parameters

Property	Specification	
Device	**TCCS (CRY1)**	**TCCP (CRY2)**
Material	Si	Si
Bending angle (μrad)	50	7000
Length (mm)	4	70
Bending radius (m)	80	10

TCCS: identical to crystals **already used in LHC collimation**

TCCP: new challenging crystal parameters **- exp. characterization in TeV range needed**



Layout and key devices

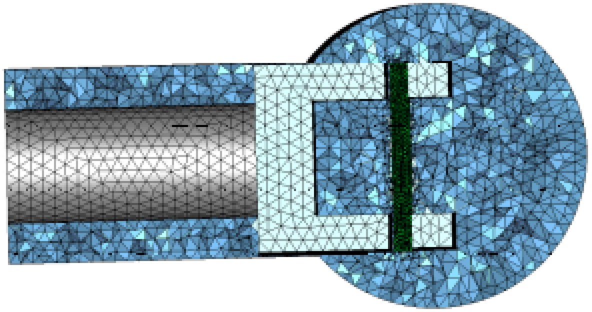
Name	*s* from IP1 [m]	Bending [μrad]	Bending radius	Bending planes	Length [cm]	Material	Max field [T m]
TCCS crystal	6430	50	80	110	0.4	Si	
Target	6674.5				0.5	W†	
TCCP crystal	6674.5	7000	10	110	7.0	Si††	
MCBWV.4R3.B1	6674.9				170		1.87
TCLA.A5R3.B1	6755.7				100	W	

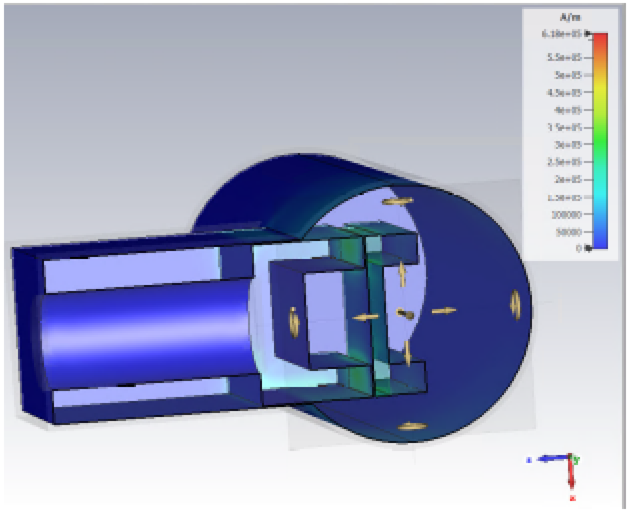
Existing (MCBWV.4R3.B1, TCLA.A5R3.B1)

More details later in the talk

Technological challenges

- **Example – goniometer with new constraints** compared to existing TCPC assembly (selection):
  - Accommodate **heavier CRY2**
  - Impedance: **HL-LHC proton intensity compatibility**
  - Ongoing effort for new technological solutions (combined effort of STI and CEM)





Courtesy of Chiara Antuono, BE/ABP

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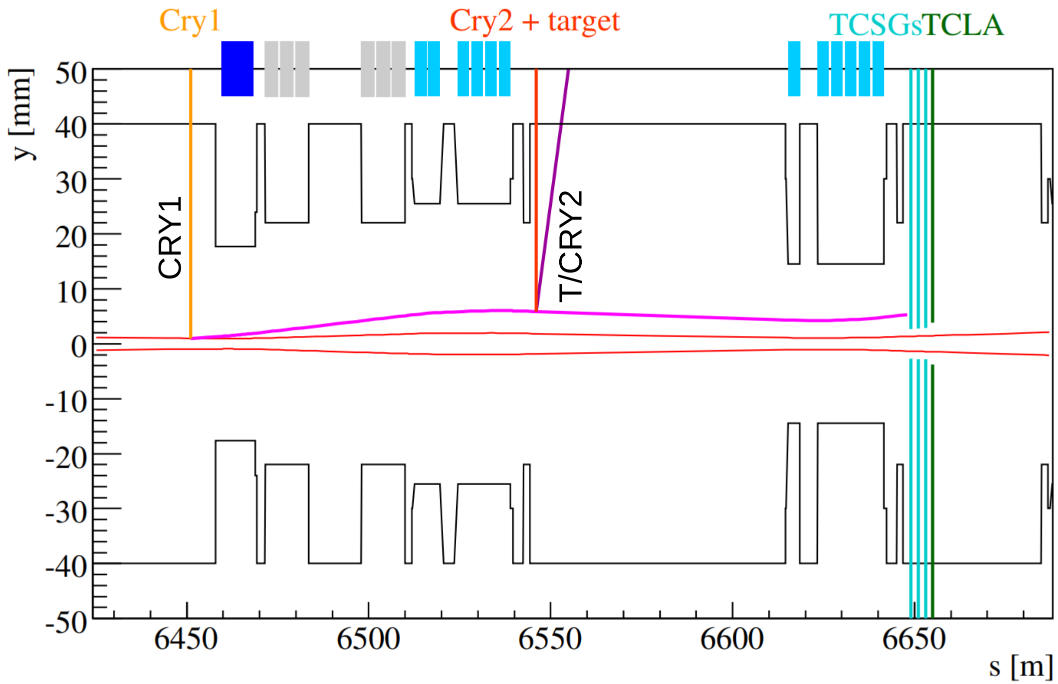
Initial IR3 Layout

- IR3 layout defined in 2019 for final experiment
- Visit of LHC tunnel early 2022 with colleagues from STI → received feedback on integration aspects

6451m 6546m



2019 layout for final experiment

Courtesy of D. Mirarchi

Updated Layout

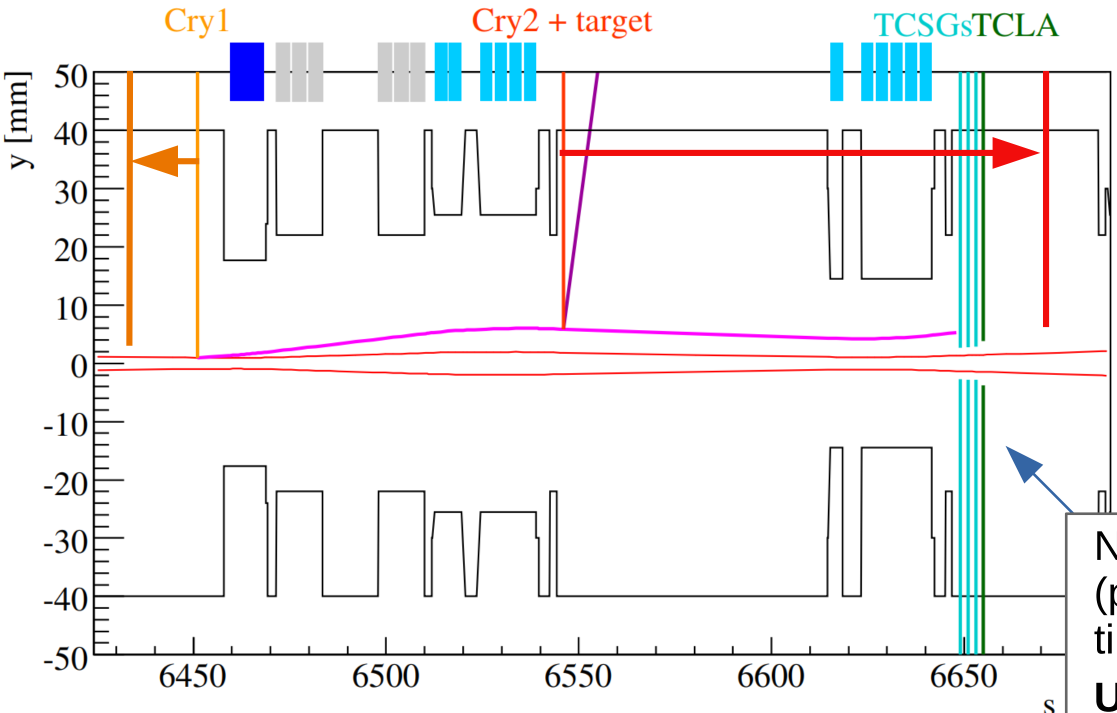
CRY1 re-located (integration aspects)

CRY2 re-located to be close to MCBWV (prelim. spectrometer)

CRY1 -21m

CRY2 +128.5m

6430m ~~6451m~~ ~~6546m~~ 6674.5m

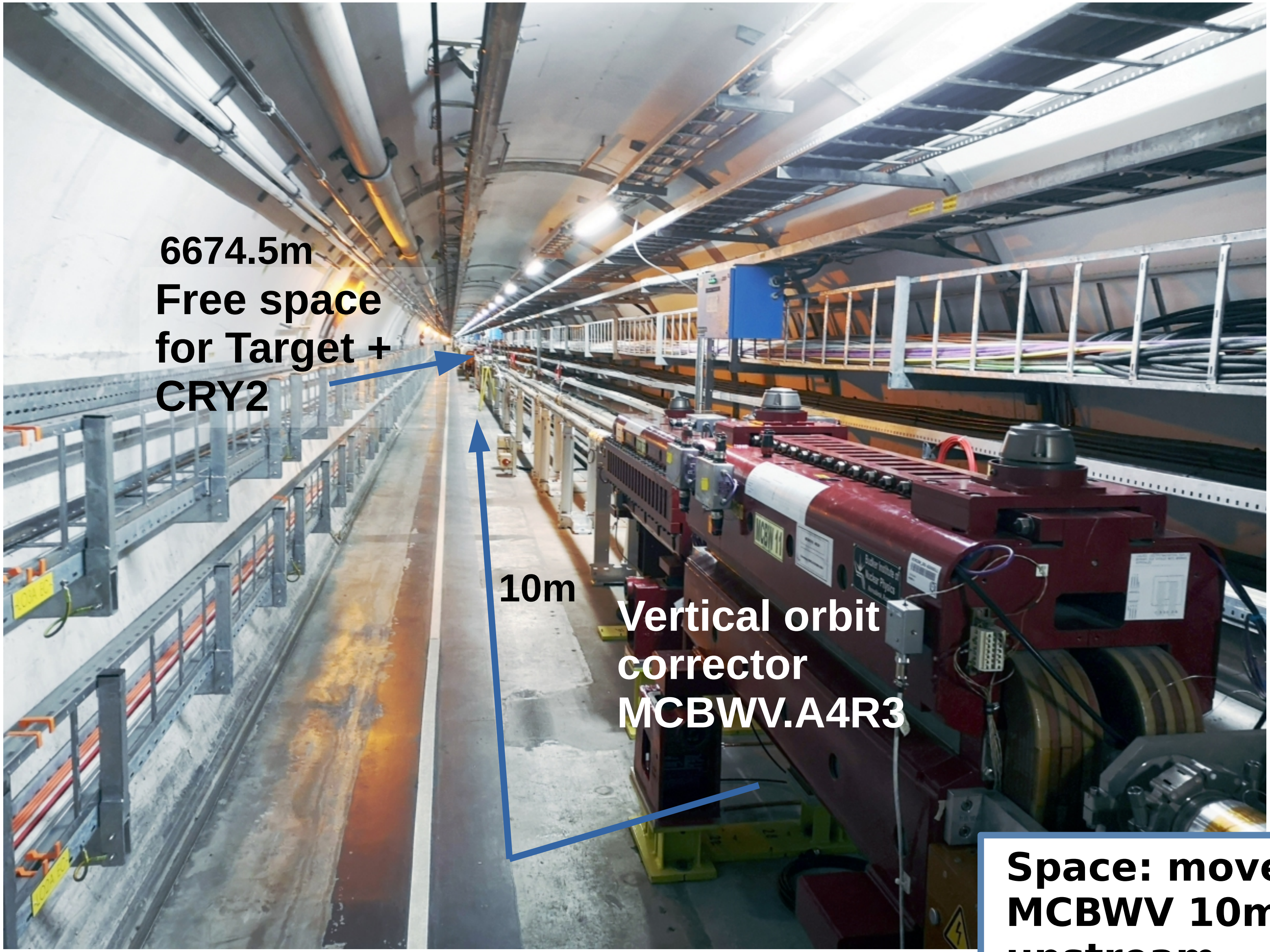


Courtesy of D. Mirarchi

No new collimators (positions obsolete + timeline constraints)

Use existing vertical TCLA for PoP

New proposed CRY2 location



Space: move MCBWV 10m upstream

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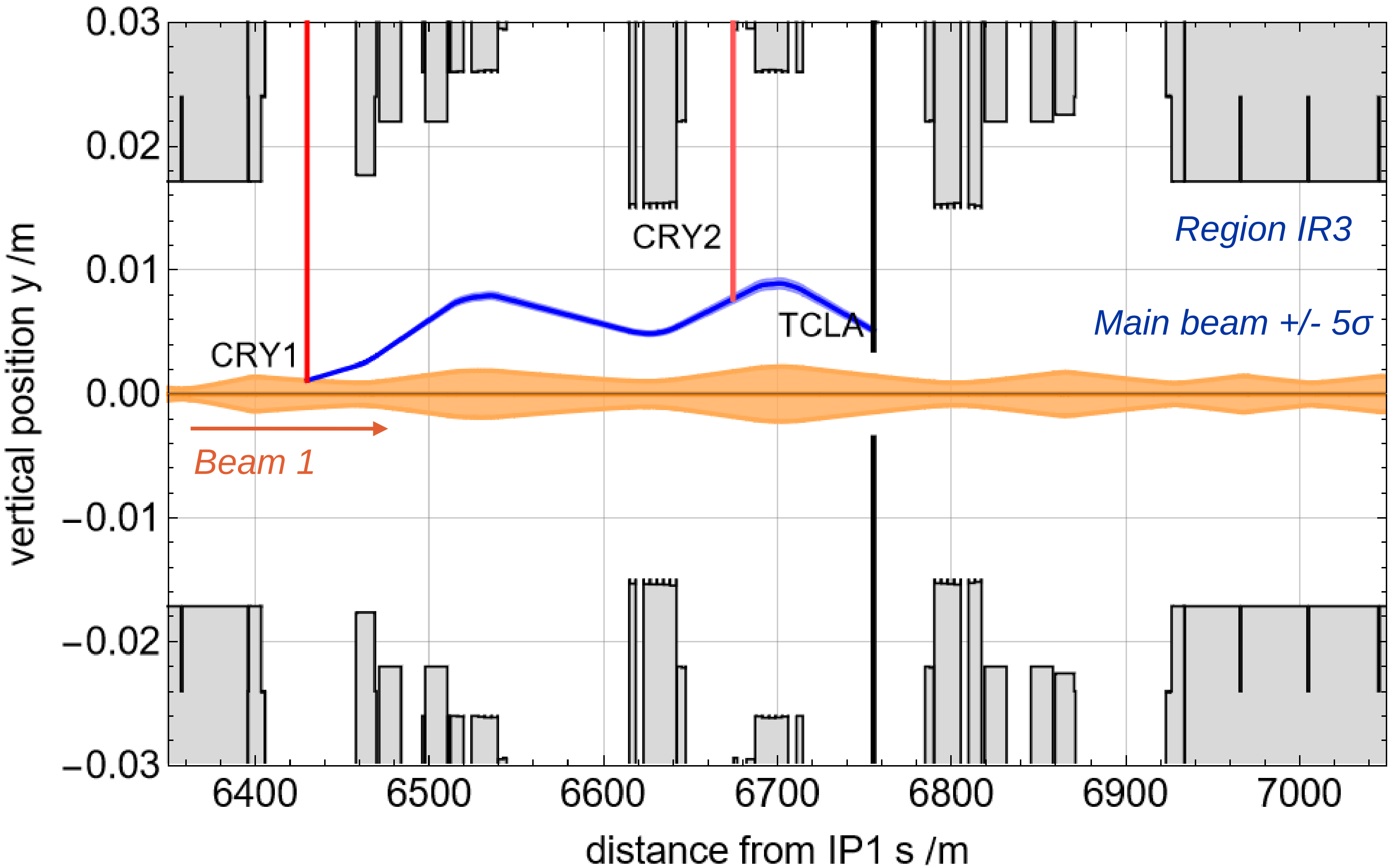
Goal of beam dynamics simulations

- **Beam orbit** simulations:
  - Verify safe separation between main beam and channelled halo
  - Verify that residual of channelled halo is safely removed
- Simulate performance measurements of **CRY2 in TeV range**
- Probe possible solutions for expected **operational challenges**: crystal alignment, establishing double channelling, etc.
- Simulate expected **efficiency** (not discussed here)

Beam orbit simulations 6.8 TeV

Courtesy of K. Dewhurst



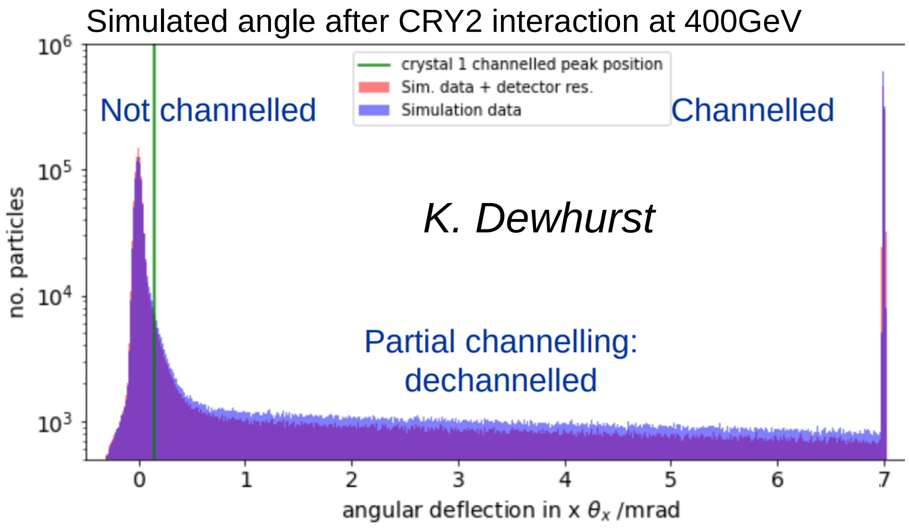
Optimized for top energy → compatible with final experiment

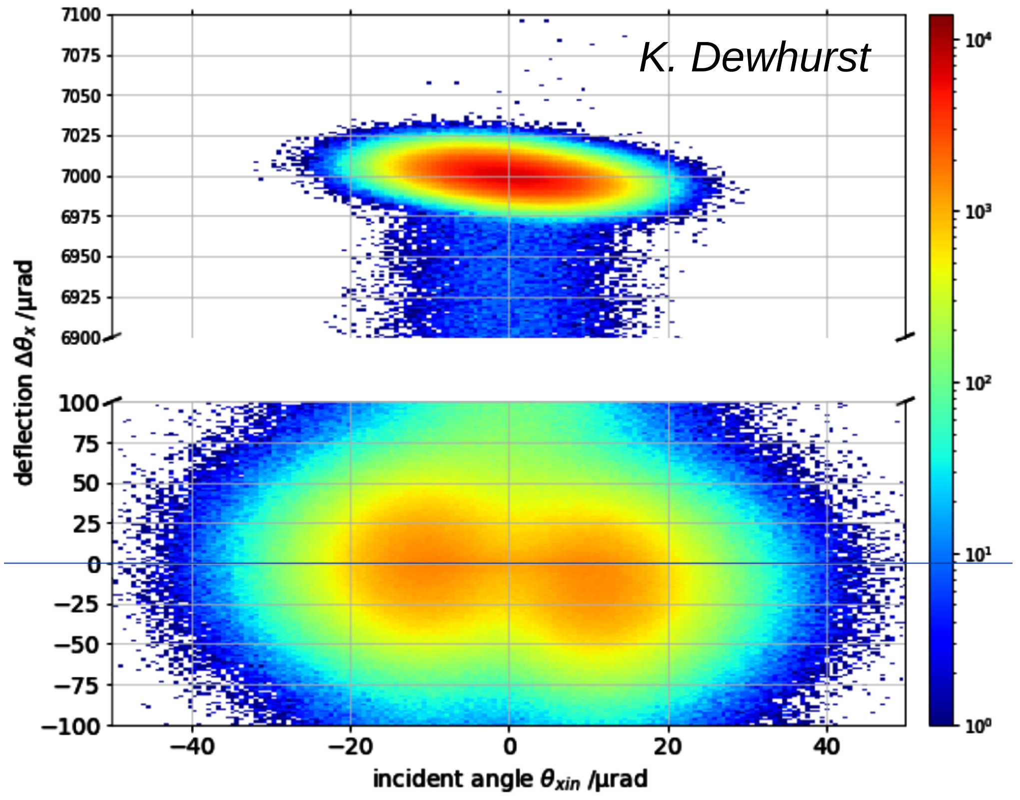
Conclusions

- **Good separation @ CRY2**
- **TCLA can intercept the channelled halo**

CRY 2 channelling efficiency

- Assessment of (long) CRY2 channelling efficiency crucial for experiment
- CRY2 channelling efficiency **at 400GeV can be measured at H8** using SPS beams
- Functional specifications – based on SixTrack simulations
- Expected efficiency ~ 42% for ideal crystal





CRY 2 channelling efficiency at 1TeV

- Measure **channelling efficiency at ~1TeV to 3TeV**: region of interest for Λ_c produced at interaction of 7TeV protons with target
  - Pixel detector **after CRY2** with channelled halo
  - Identify when double channelling is established
  - Measure intensity of double-channelled halo

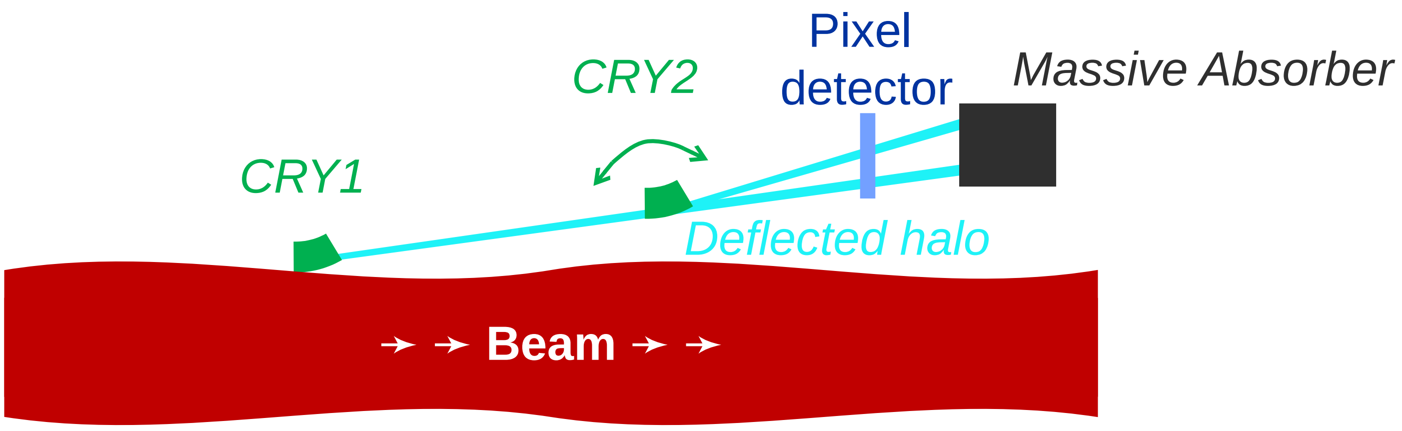
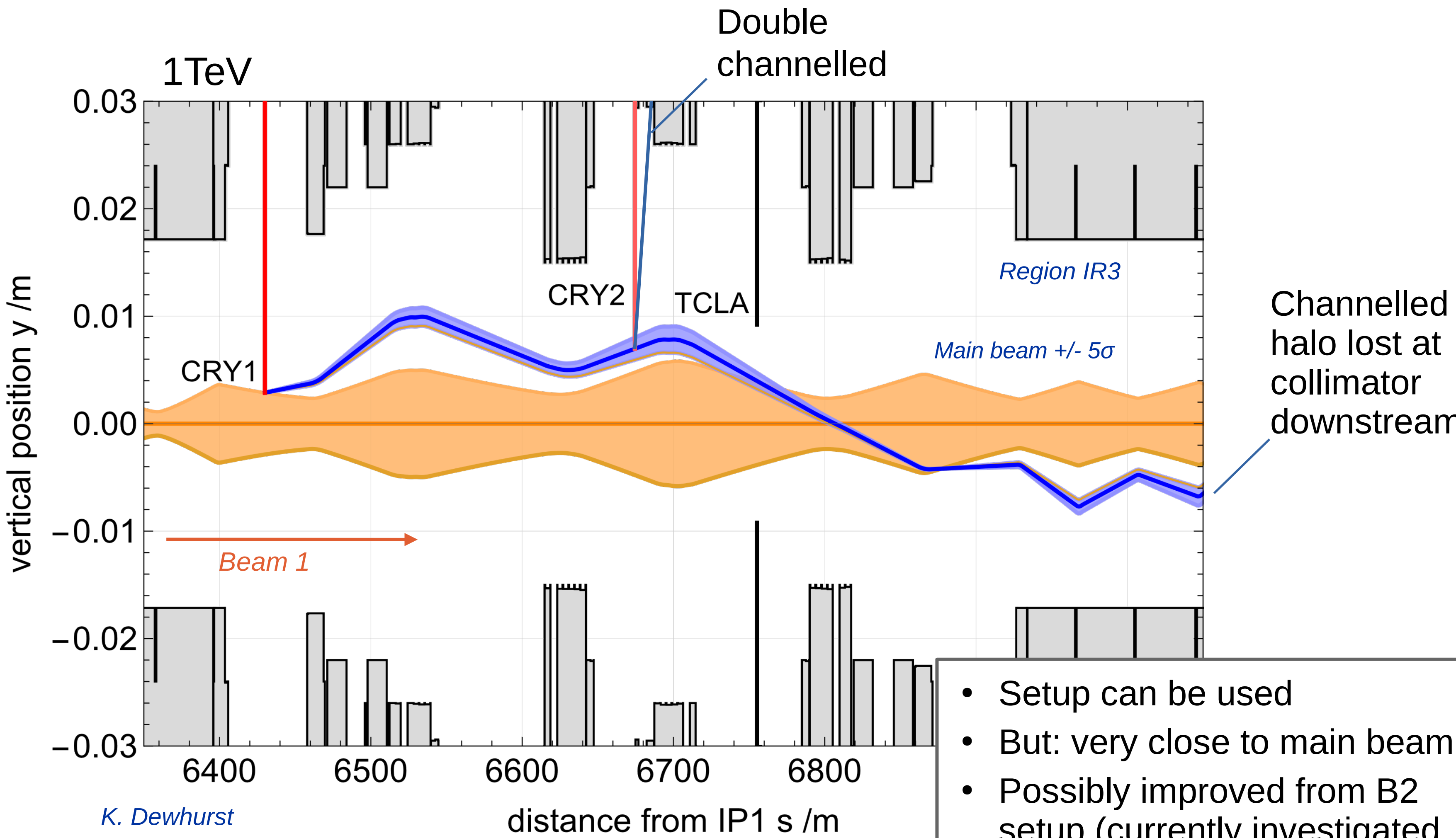


Illustration by D. Mirarchi

CRY 2 channelling efficiency at 1TeV



- Setup can be used
- But: very close to main beam
- Possibly improved from B2 setup (currently investigated for same CRY2 specs)

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Outlook

Possible pre-PoP machine studies (selection):

- Use collimator in IR3 in existing crystals in IR7 to **demonstrate principle of capturing secondary beam halo** (inverse setup)
- **Studies with optimized phase advance Collimator-CRY** → can statistics be improved by changing LHC magnet configuration?
- **Confirm proposed orbit setup with bump (from spectrometer)** – should not disturb nominal operation

Conclusions

- **IR3 double crystal setup installation in LHC Run 3 for test purposes**
  - Demonstrate concept validity
  - Gain experience with operational challenges
- **Considerable progress** on the way towards the Run 3 test stand:
  - Functional specifications approved
  - First simulation campaigns with promising results
  - Key hardware under construction or design (SY)
  - Concept for operation in preparation (OP)

References

Presentations

Layout and simulated performance of a LHC fixed-target test stand,
2nd MDM/EDM Workshop, Gargnano **-** 27.09.2022

Revised layout for fixed target experiments in IR3, PBC-FT WG – 11.03.2022

Possible crystal and magnet layout for FT experiments in IR3, PBC-FT WG – 28.10.2021

Fixed target layouts inspection, PBC-FT WG – 28.10.2021

Beam orbit with spectrometer for FT experiments in IR3, PBC-FT WG – 02.07.2021

Update on publication of IP3 and IP8 double-crystal layouts, PBC-FT WG – 20.11.2020

Publications

D. Mirarchi et al., ***Eur. Phys. J. C 80, 929 (2020)***

M. Patecki et al., ***JACoW IPAC2022 (2022) 108-111, MOPOST024***

P. Hermes et al. ***JACoW IPAC2022 (2022) 2134-2137, WEPOTK033***