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

K. Dewhurst, P. Hermes, M. Ferro-Luzzi, D. Mirachi, S. Redaelli

Fixed target experiments at LHC
Strong-2020 workshop
06/01/2023

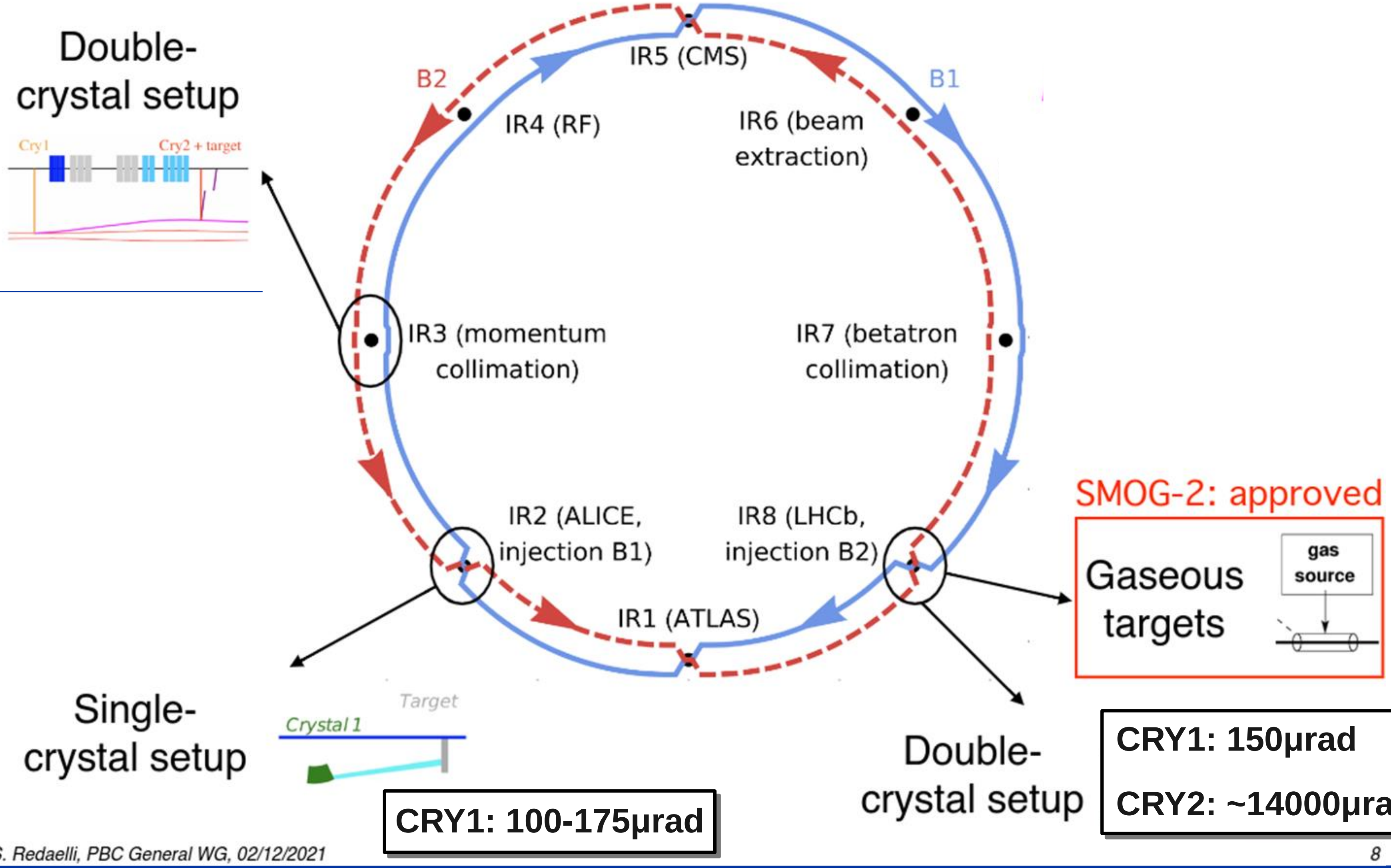
Contents

Location of double-crystal experiment

CRY1: 50μrad

CRY2: 7000μrad

Timeline: LS3



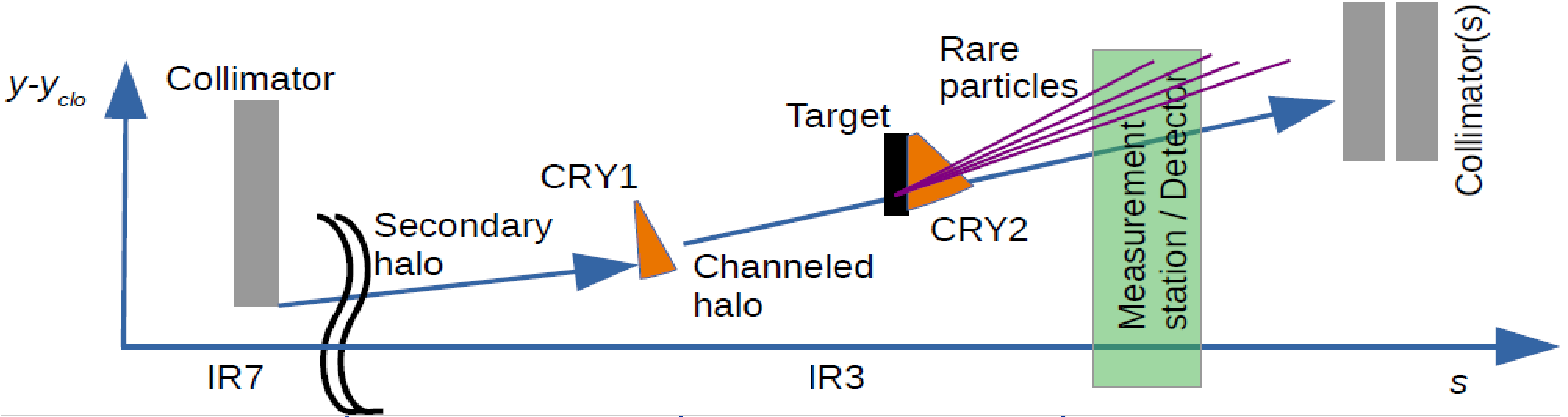
CRY1: 100-175μrad

CRY1: 150μrad

CRY2: ~14000μrad

Double-crystal setup

Final experiment – high intensity operation



Protons impact the 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	**Collimators:** safely absorb residuals of the channelled halo

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

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 the LHC)
- Gain experience / develop solutions for expected operational challenges: crystal alignment, establishing double channelling, etc.
- Possibly study background environment for IR3 detector

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

Contents

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 finalisation** 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.

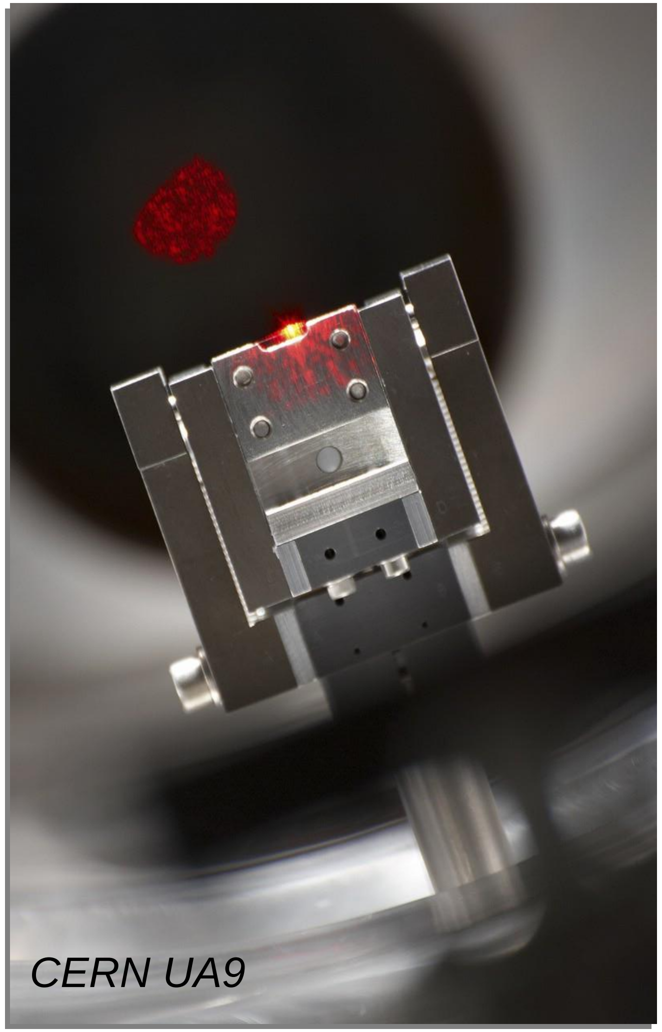
IR3 crystal design parameters

Functional Specification

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 **needs exp. characterisation in TeV range**



Layout and key devices

Functional Specification

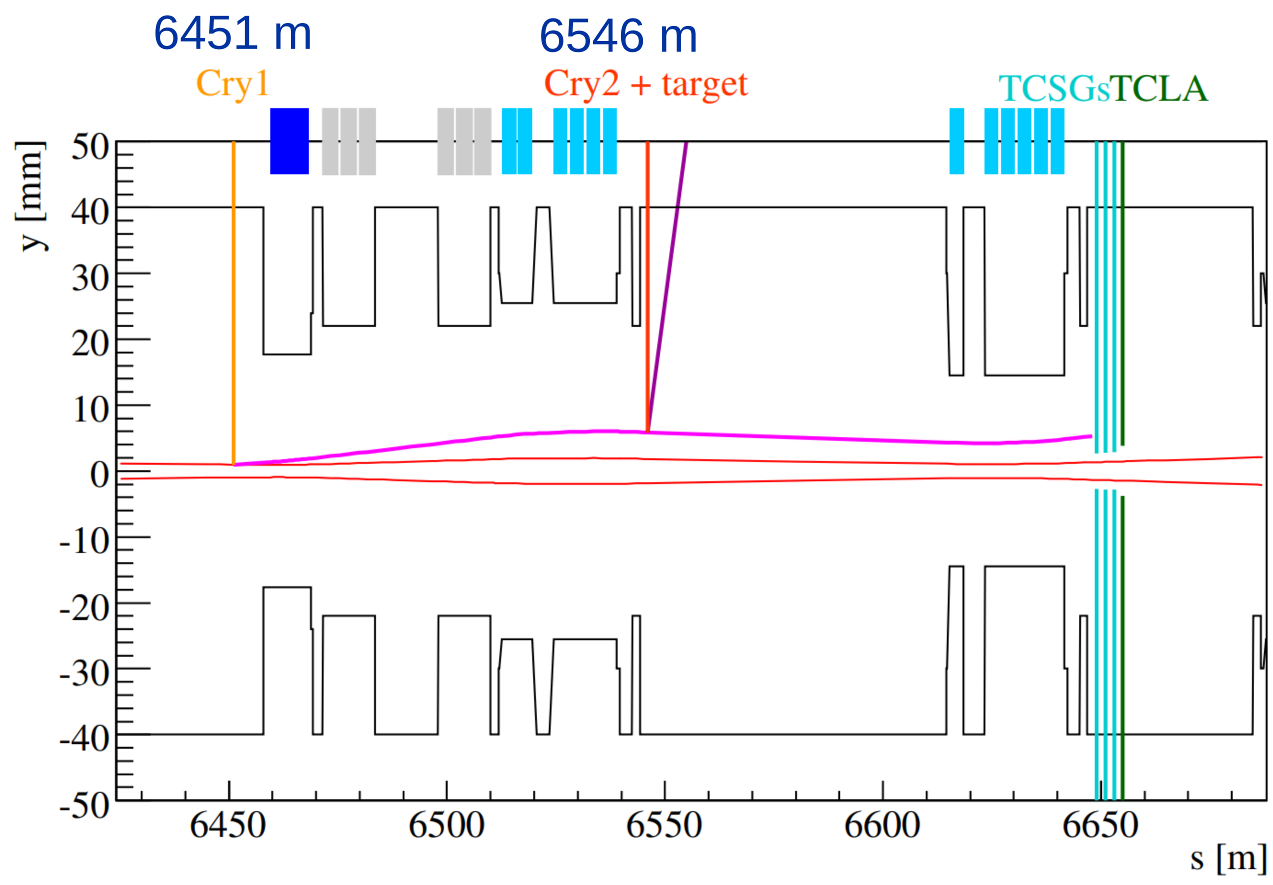
Name	*s* from IP1 [m]	Bending [µrad]	Bending radius	Bending planes	Length [cm]	Material	Max field [T m]
TCCS crystal	6430	50	80	110	0.4	Si	
Target	6674.5				0.5	W†	
TCCP crystal	6674.5	7000	10	110	7.0	Si††	
MCBWV.4R3.B1	6674.9				170		1.87
TCLA.A5R3.B1	6755.7				100	W	

Existing

Contents

Initial IR3 Layout

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



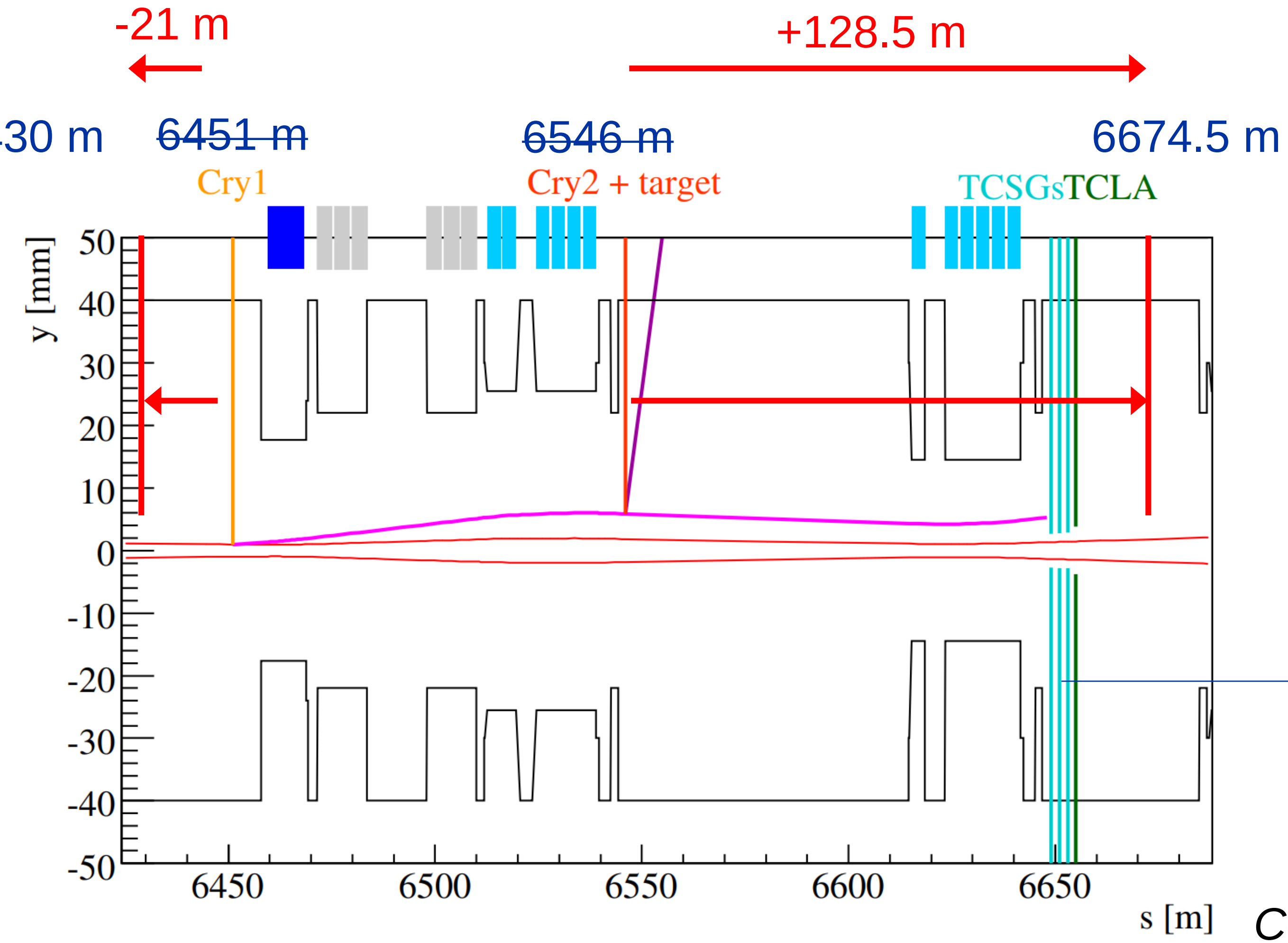
2019 layout for final experiment

Courtesy of D. Mirarchi

Updated IR3 Layout

- IR3 layout updated for integration into LHC tunnel

CRY1 re-located (tunnel integration)



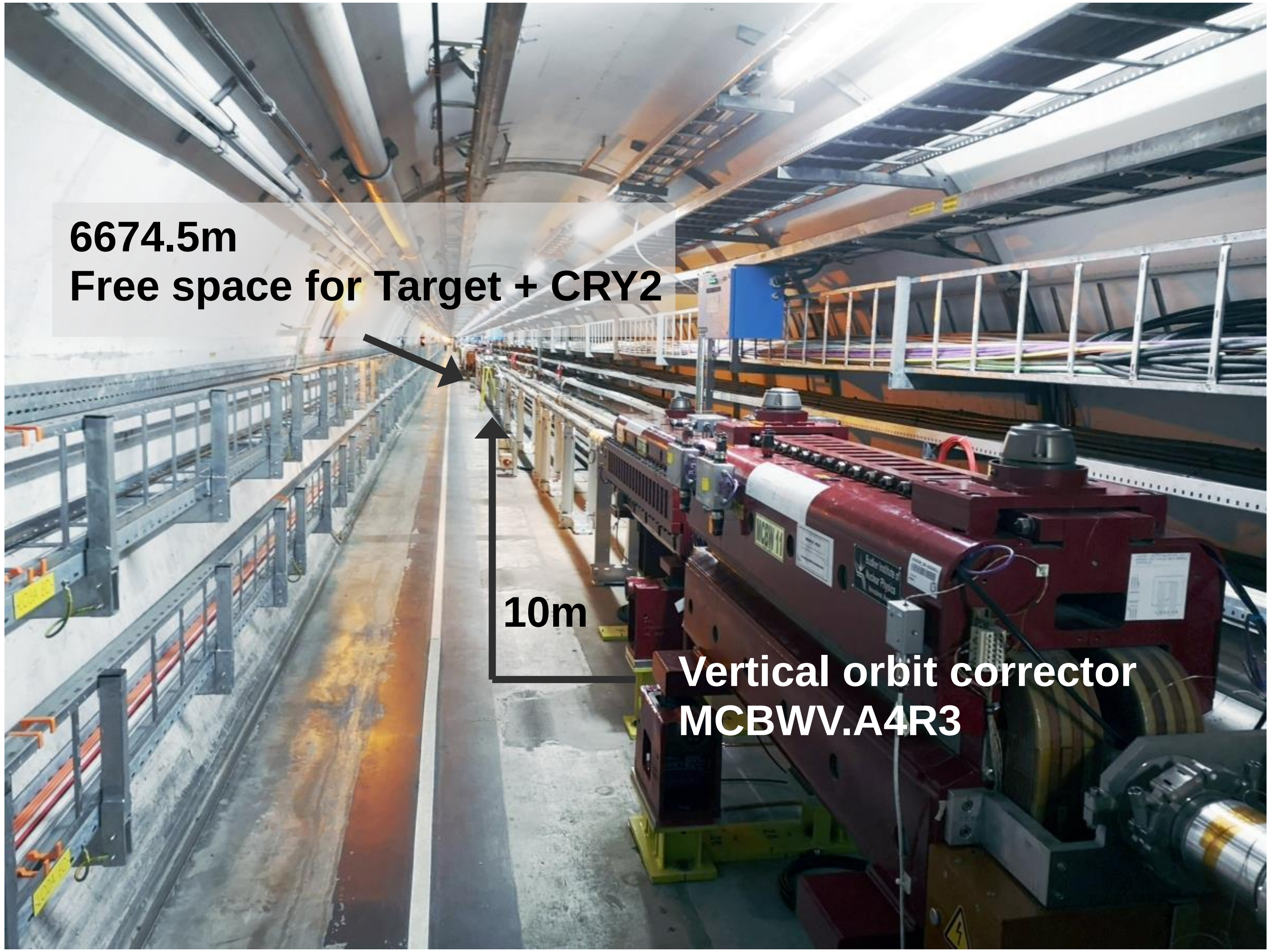
CRY2 re-located to be close to MCBWV (prelim. spectrometer)

No new collimators (positions obsolete)

Use existing vertical TCLA for PoP

Courtesy of D. Mirarchi

New proposed CRY2 location



Space: Move MCBWV
10m upstream

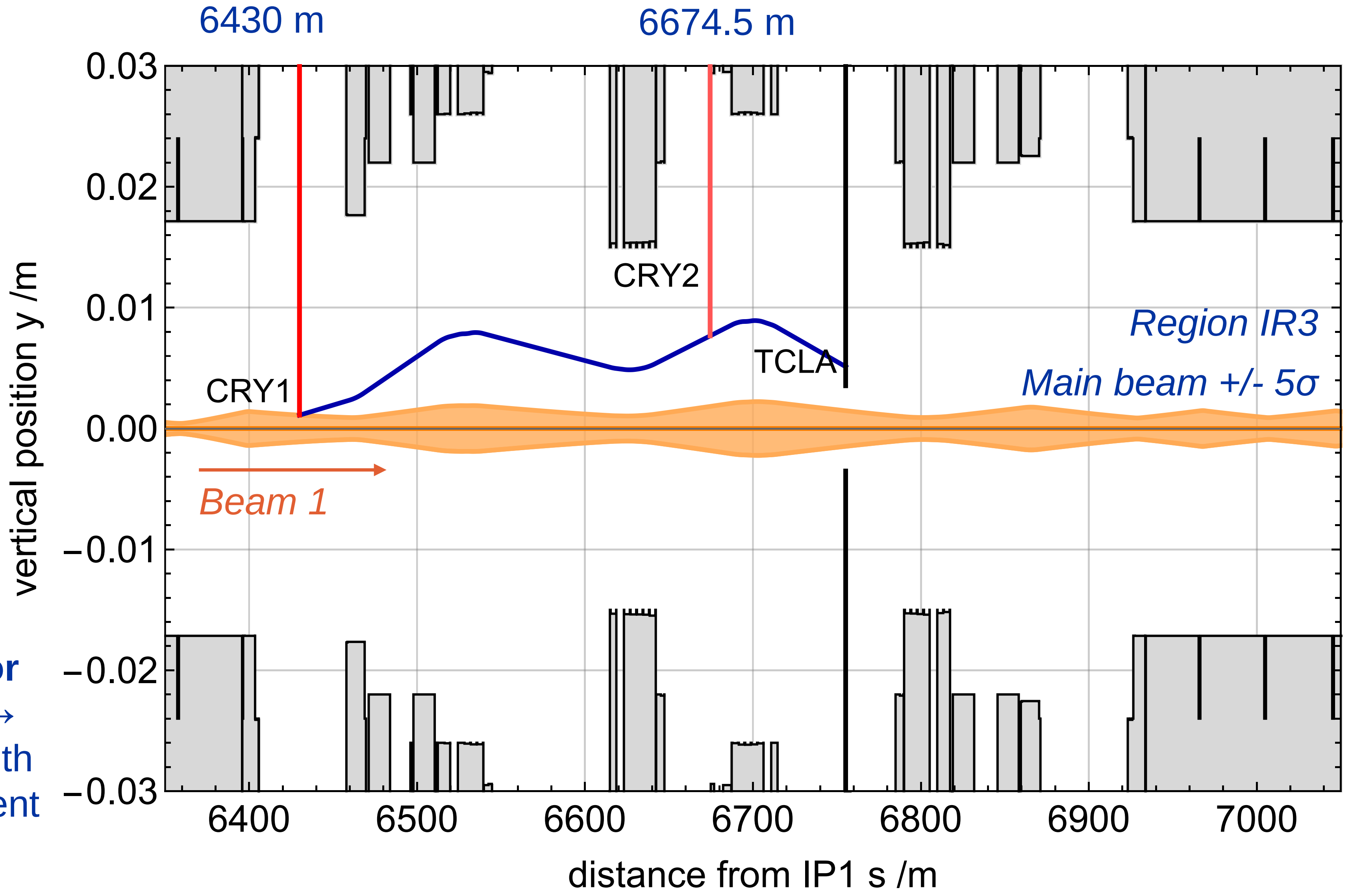
Contents

Beam dynamics simulations

Main Goals

- Verify safe separation between main beam and channelled halo
- Verify that residuals from the channelled halo can be 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**

Beam orbit simulations at 6.8 TeV



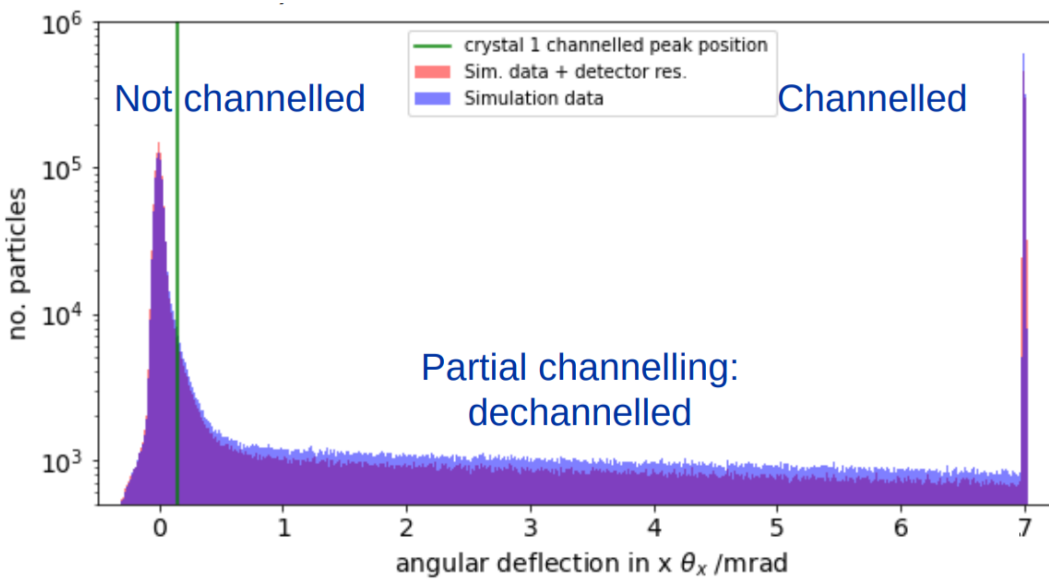
Optimised for top energy → compatible with final experiment

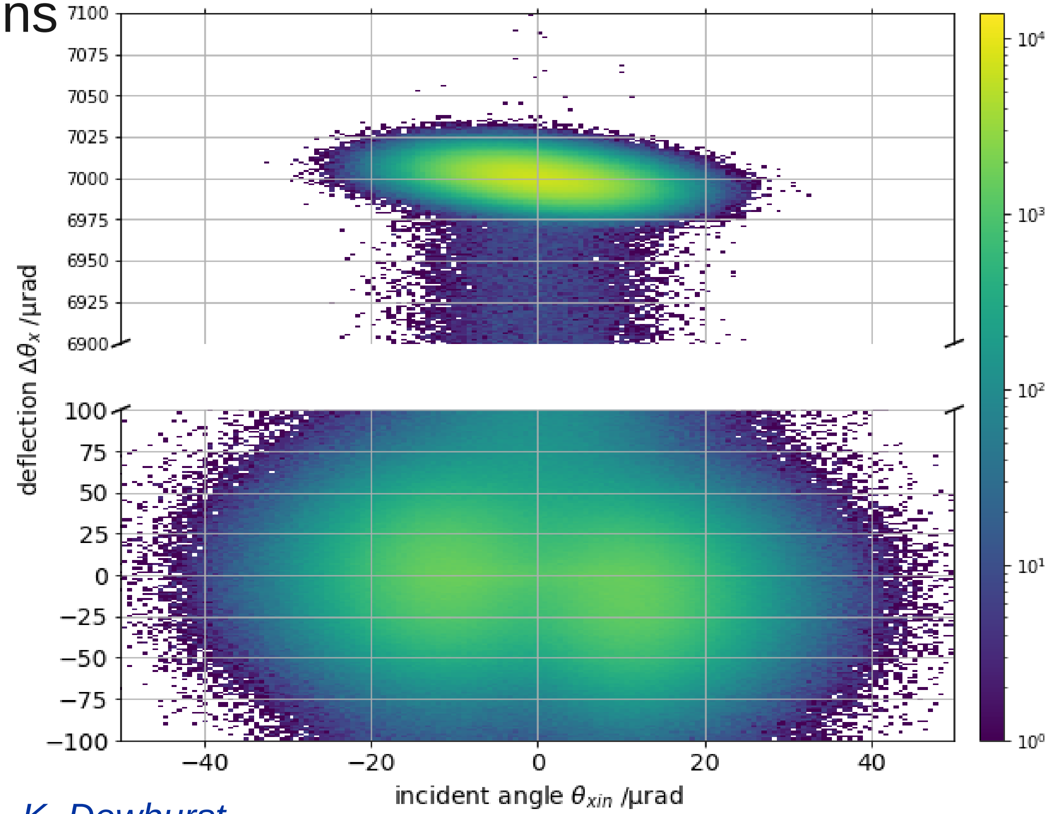
Conclusions
Good separation at CRY2
TCLA can intercept the channelled halo

CRY2 channelling efficiency

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

Simulated angle after CRY2 interaction at 400 GeV

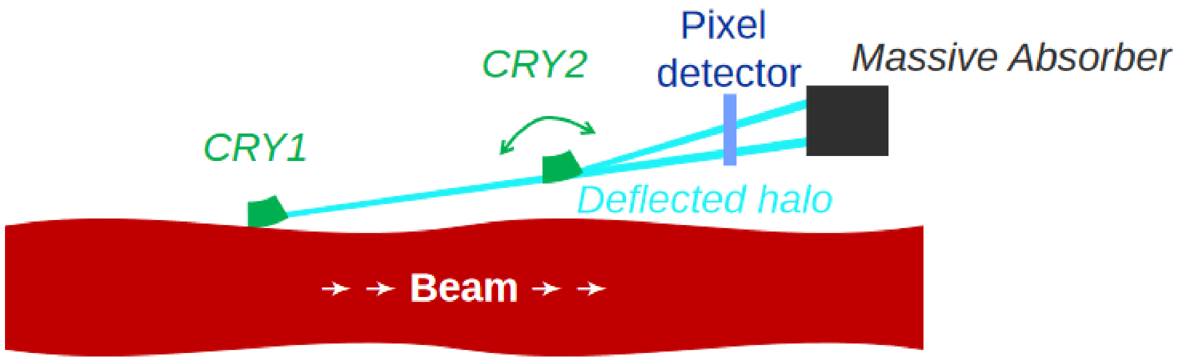




K. Dewhurst

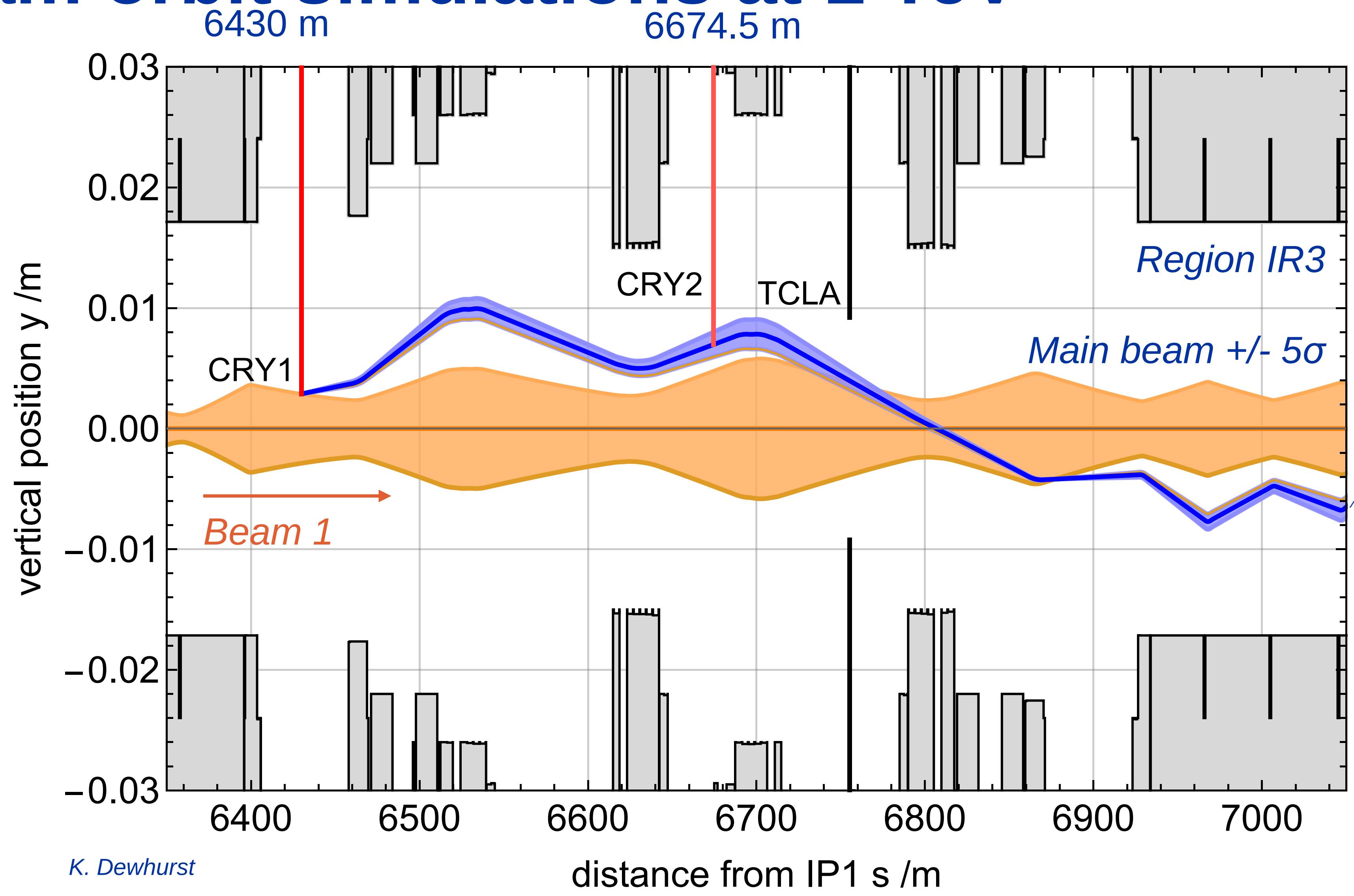
CRY2 channelling efficiency at 1TeV

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



Courtesy of D. Mirarchi

Beam orbit simulations at 1 TeV



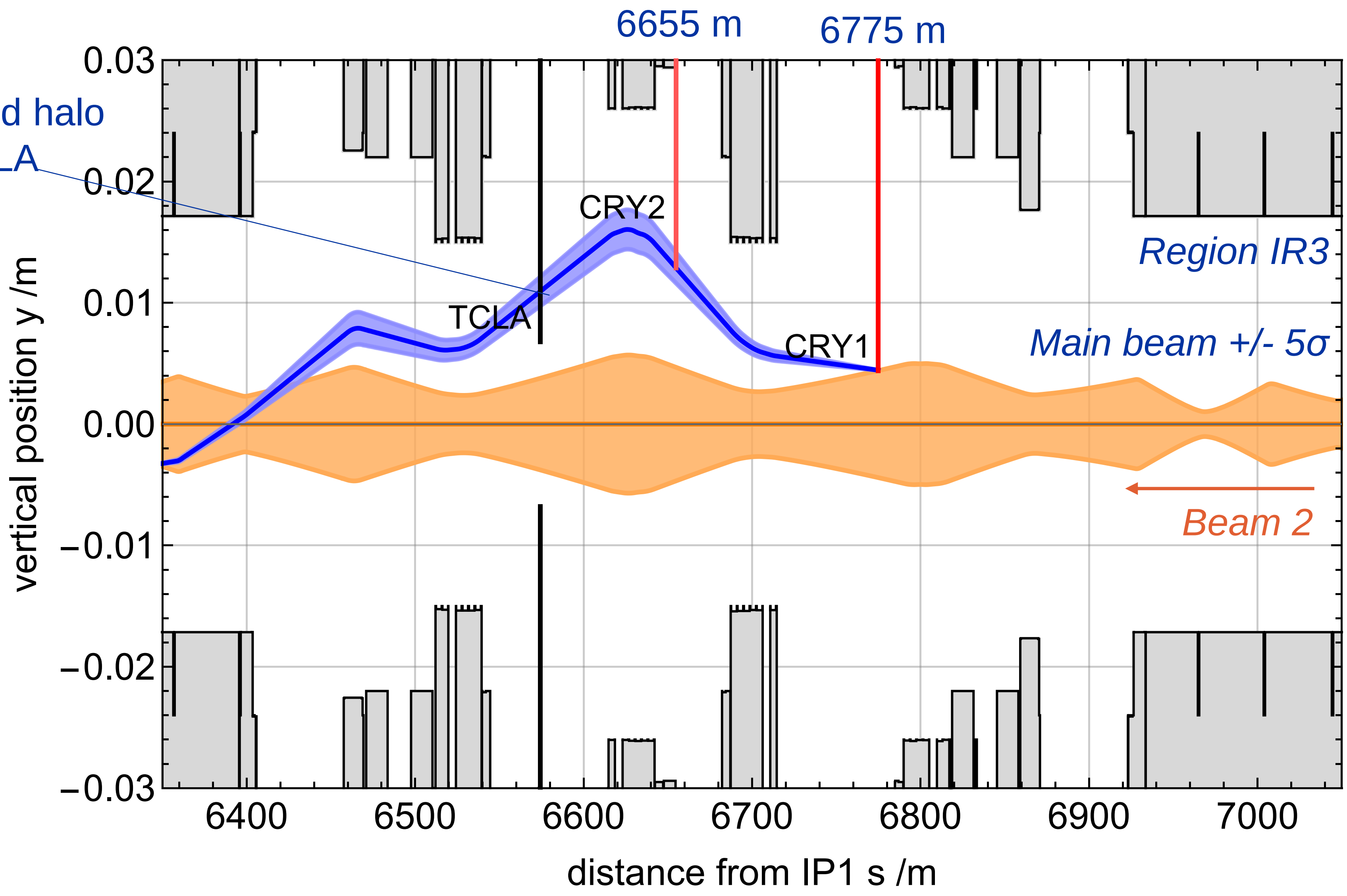
K. Dewhurst

Channelled halo lost at downstream TCT collimator

Conclusions
Setup can be used
But: very close to main beam
Possibly improved from B2 setup (under investigation)

Beam 2 orbit simulations at 1 TeV

Channelled halo lost at TCLA collimator



Conclusions

More gap with main beam

Needs checks for compatibility with final setup

Contents

Outlook

Possible pre-PoP machine studies (selection)

- Use collimator in IR3 with existing crystals in IR7 to **demonstrate principle of capturing secondary beam halo** (inverse setup)
- **Studies with optimised 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 towards the Run 3 test stand:

- Functional specifications approved
- First simulation campaigns with promising results
- Key hardware under construction or design
- Concept for operation in preparation

References

Presentations

Towards a double-crystal test stand in the LHC, *PBC Annual Workshop* **-** 08.11.2022

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***