Layout and simulated Performance of a LHC Fixed-Target Test Stand

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Acknowledgments

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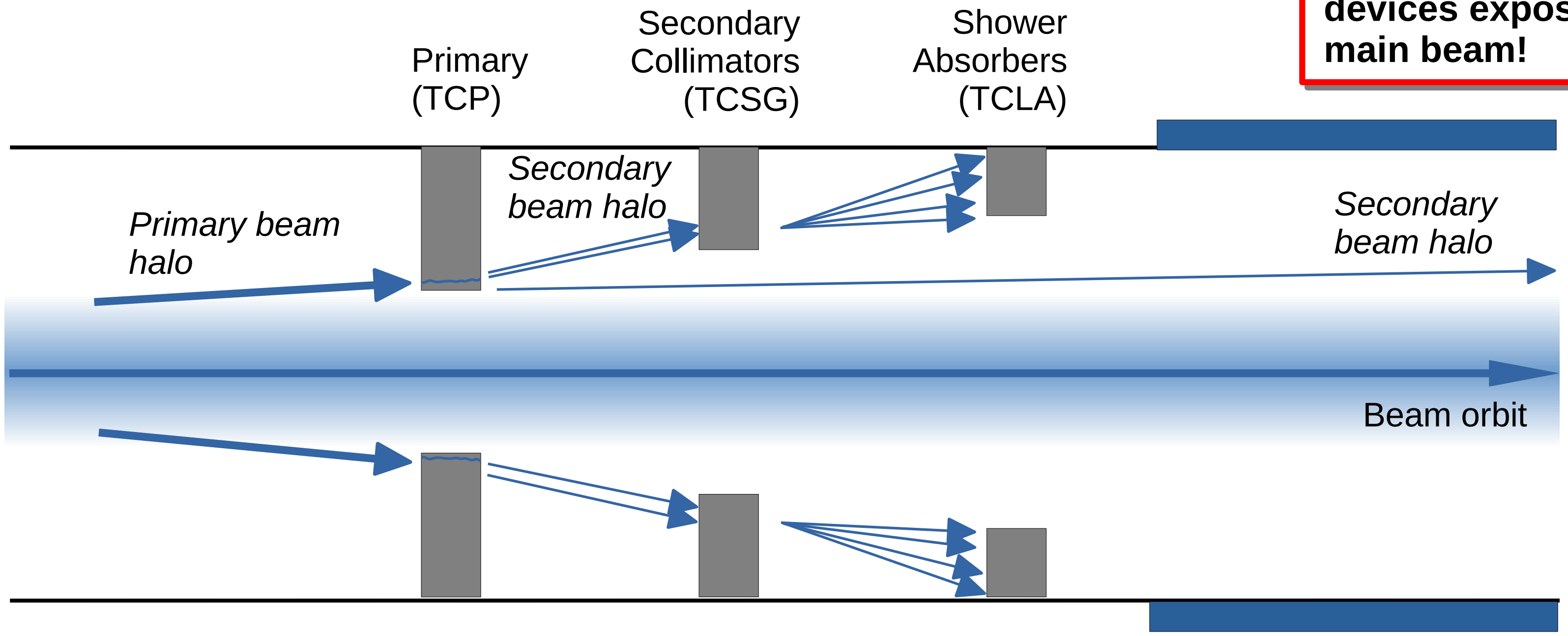
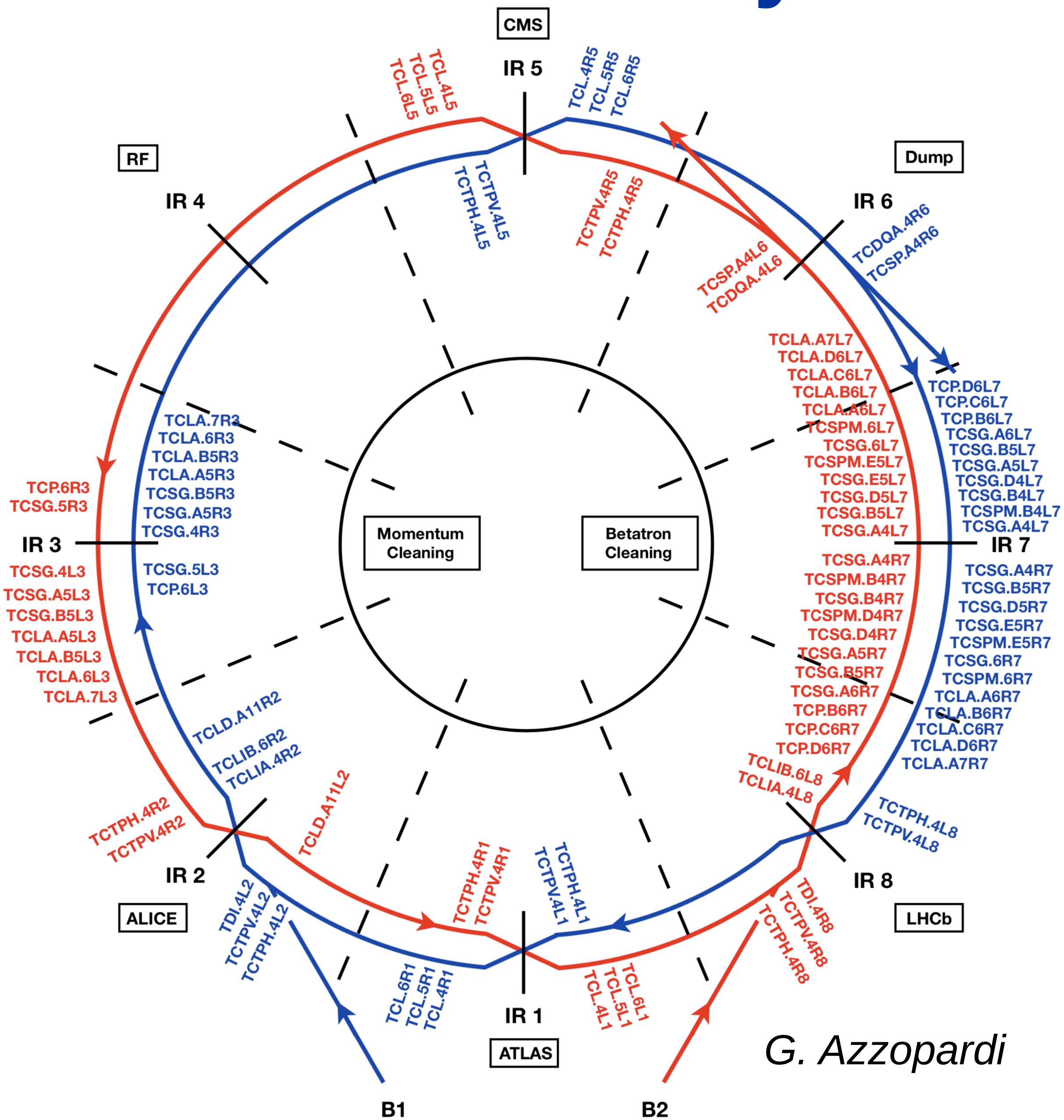
LHC Collimation System

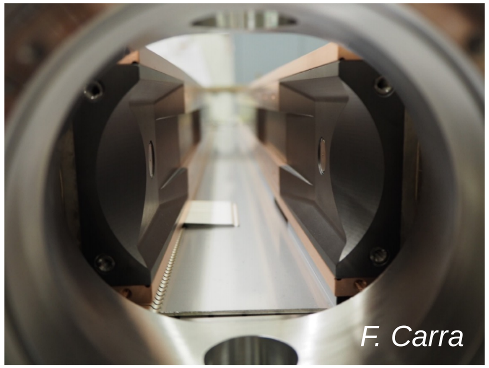
High intensity: TCPs must be the only devices exposed to main beam!



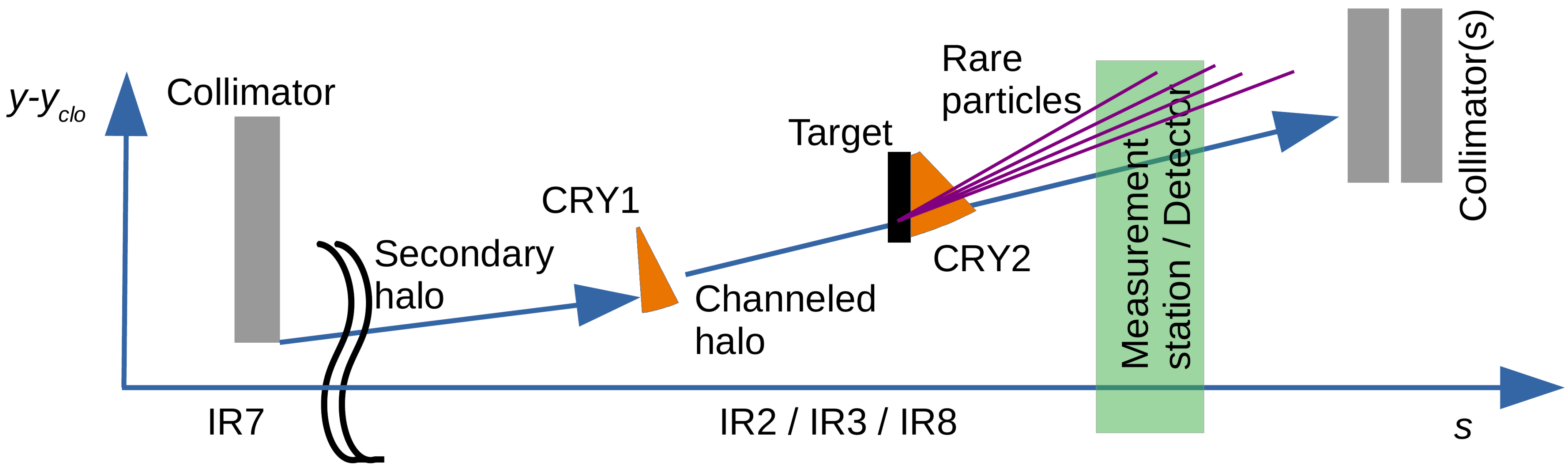
- LHC stored beam energy up to ~500MJ can cause severe damage!
- **Collimation system should safely handle** regular and irregular **particle loss**: >80 massive movable absorbers
- Relies on **scattering from primary into retracted secondary collimators**
- Some particles form secondary beam halo and escape → absorbed later
- Many constraints for high-energy operation (>3x10^{11} particles per beam)

LHC Collimation System





LHC double crystal setup



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

Proof of Principle (PoP) Setup

- **Unprecedented experimental setup** with challenging combination of high precision devices
- Final setup: installation not possible before LS3
- Idea to **probe operation and demonstrate concept feasibility** in LHC Run 3: **proof of principle** setup
- **Efficiency estimates** currently simulation based (uncertainty) → PoP allows for confirmation in measurements
- Preparation of PoP, need to:
  - **Select LHC region for installation**
  - **Find suitable positions for new key devices**
  - **Study efficiency in simulations**
  - Many more items (integration, controls etc.) outside the scope of this talk

Contents

Channelling in bent crystals

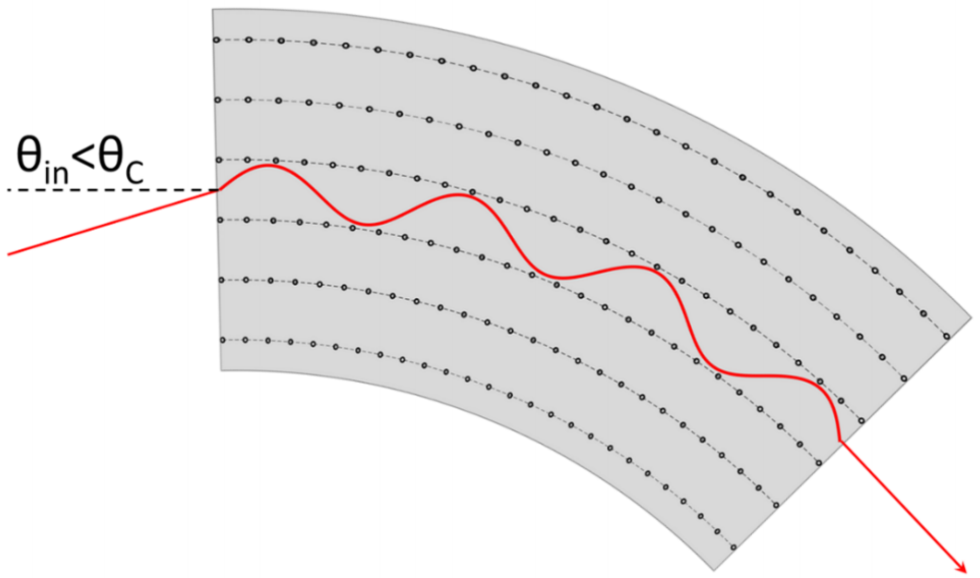
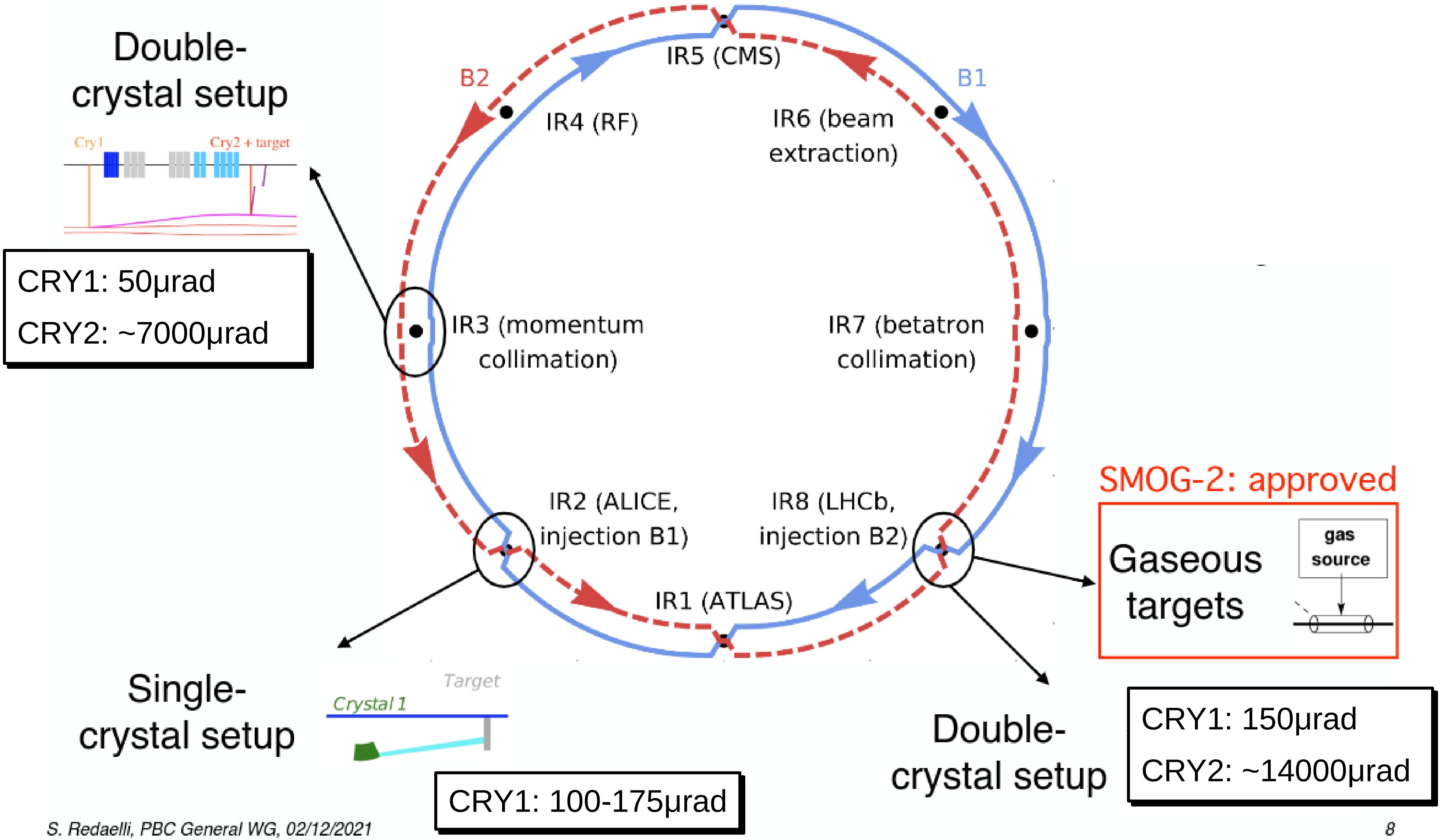


Figure: M. Romagnoni et al., Crystals 2022, 12(9)

LHC FT double crystal setup proposals



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 - experimental characterization needed

Could be produced for installation in Run 3!

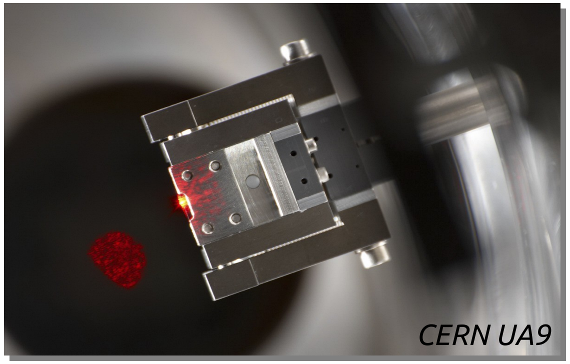


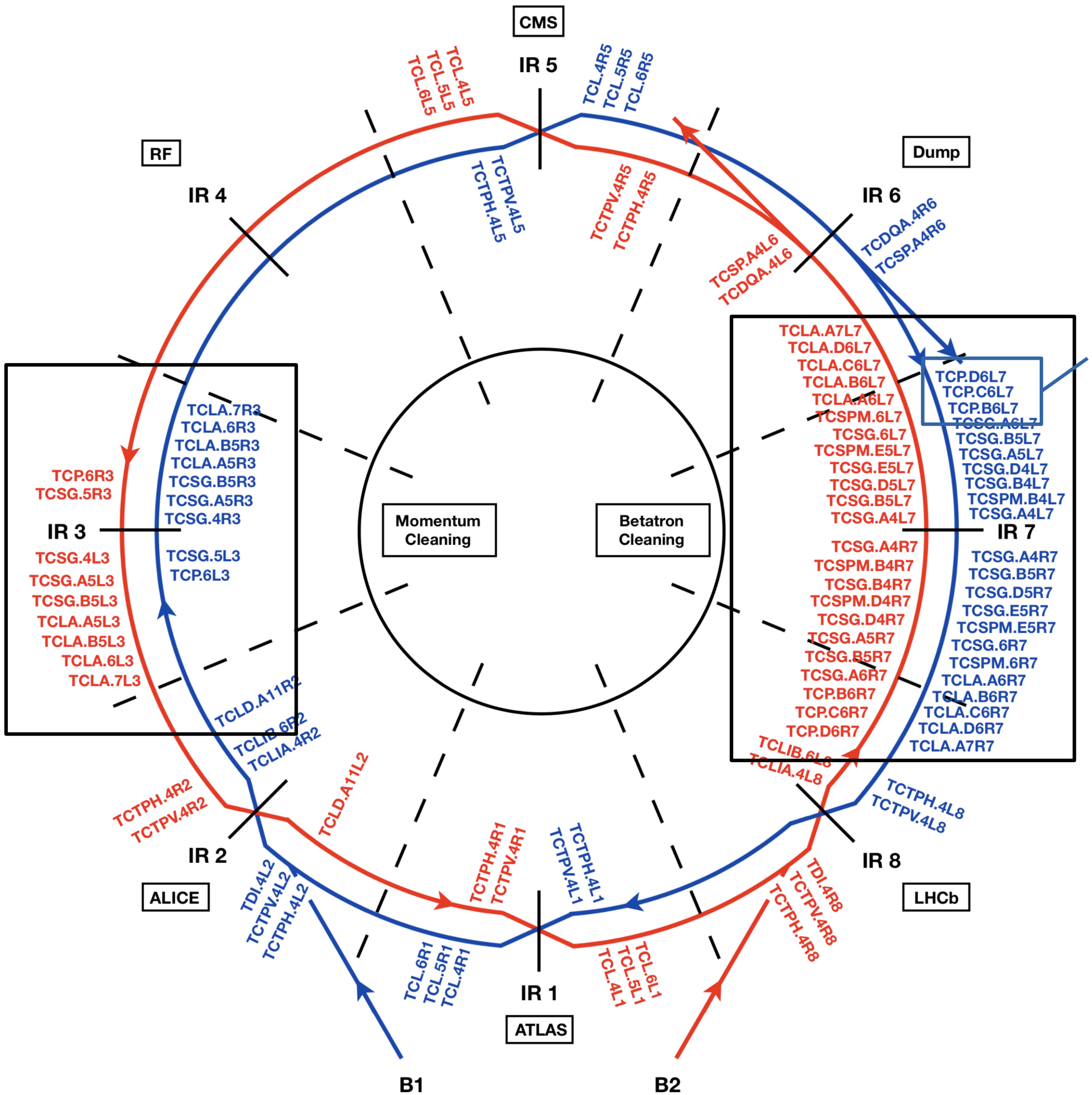
Figure: G. Azzopardi

In the context of collimation

Momentum collimation system in IR3

Capture off momentum particles: less collimators needed

Straight section with free space for devices needed



Betatron collimation system in IR7

Primary collimators (TCP): closest to beam

TCPs must be the **only** devices exposed to main beam particles

Secondary halo to be captured by CRY1 downstream

IR3 Proof of Principle

- Key devices for IR3 setup could already be installed during LHC Run 3 (around 2025) for a proof-of-principle setup
- **Main goals:**
  - **Measure achievable PoT:** currently 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.
  - Possibly even first precession measurements

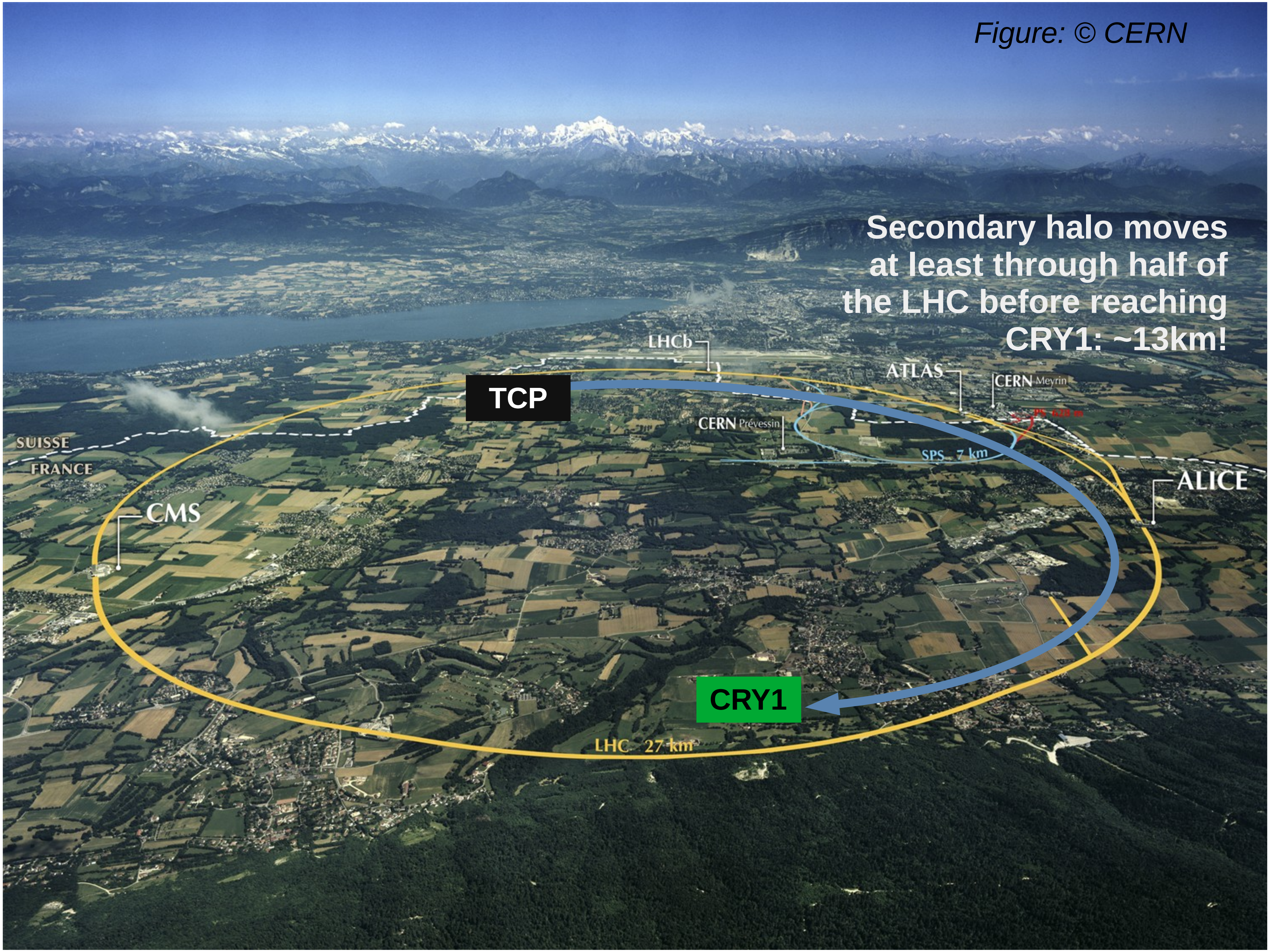
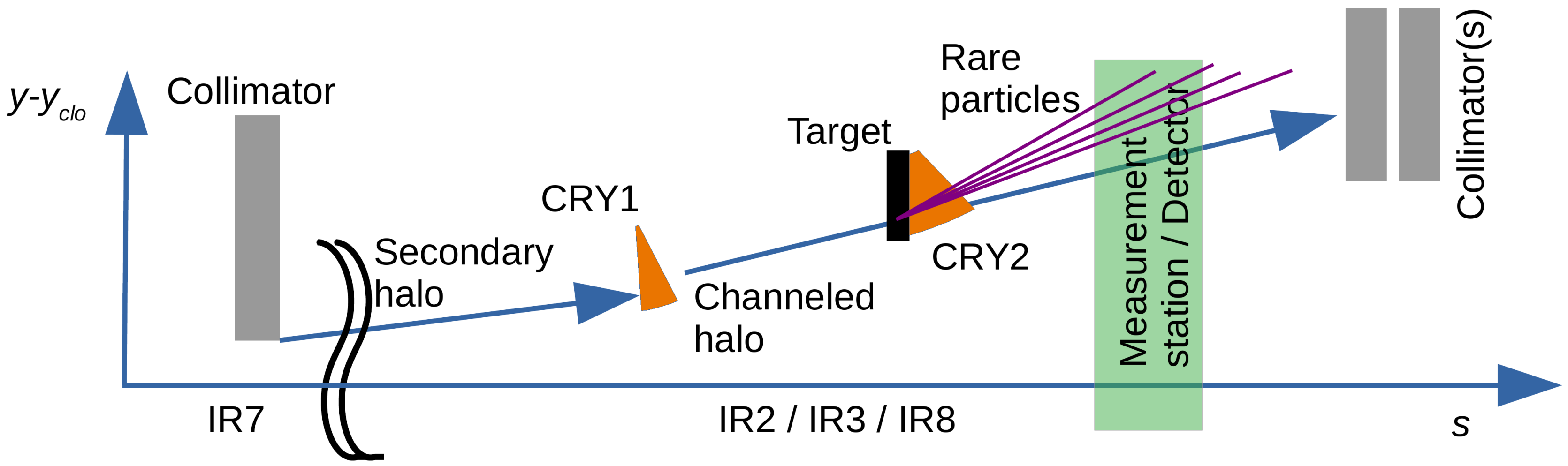


Figure: © CERN
Secondary halo moves at least through half of the LHC before reaching CRY1: ~13km!
LHCb
ATLAS
CERN Meyrin
TCP
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
CRY1
LHC 27 km

IR3 Proof of Principle

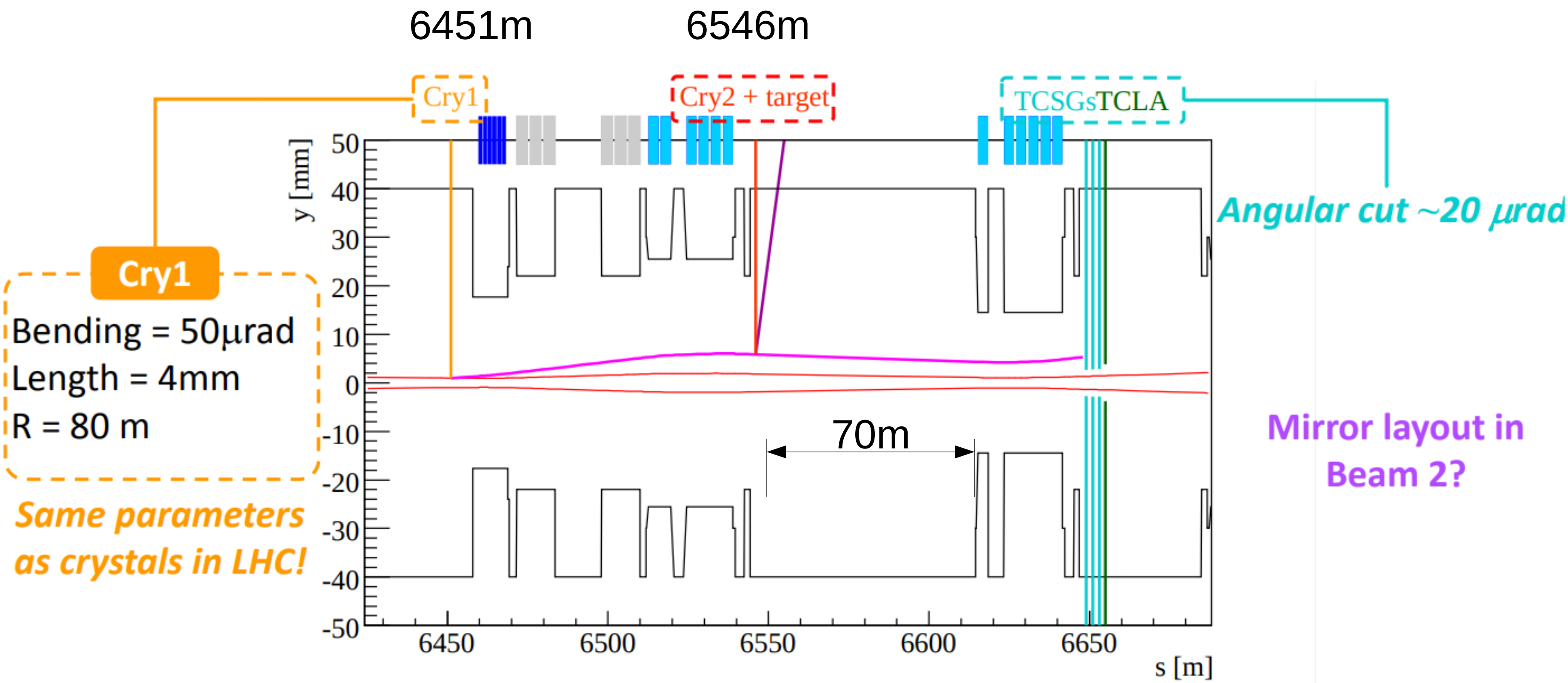


- **Devices needed for the proof of principle setup:**
  - **Crystal 1** in operational goniometer
  - **Target + Crystal 2** in goniometer assembly
  - For first precession measurements: detector incl. **spectrometer dipole**
  - One (for low intensity only) or multiple **absorbing collimators**
- Where possible: create and use **synergies with final HL-LHC setup**

Crystal 1 Location

Crystal 1 Location

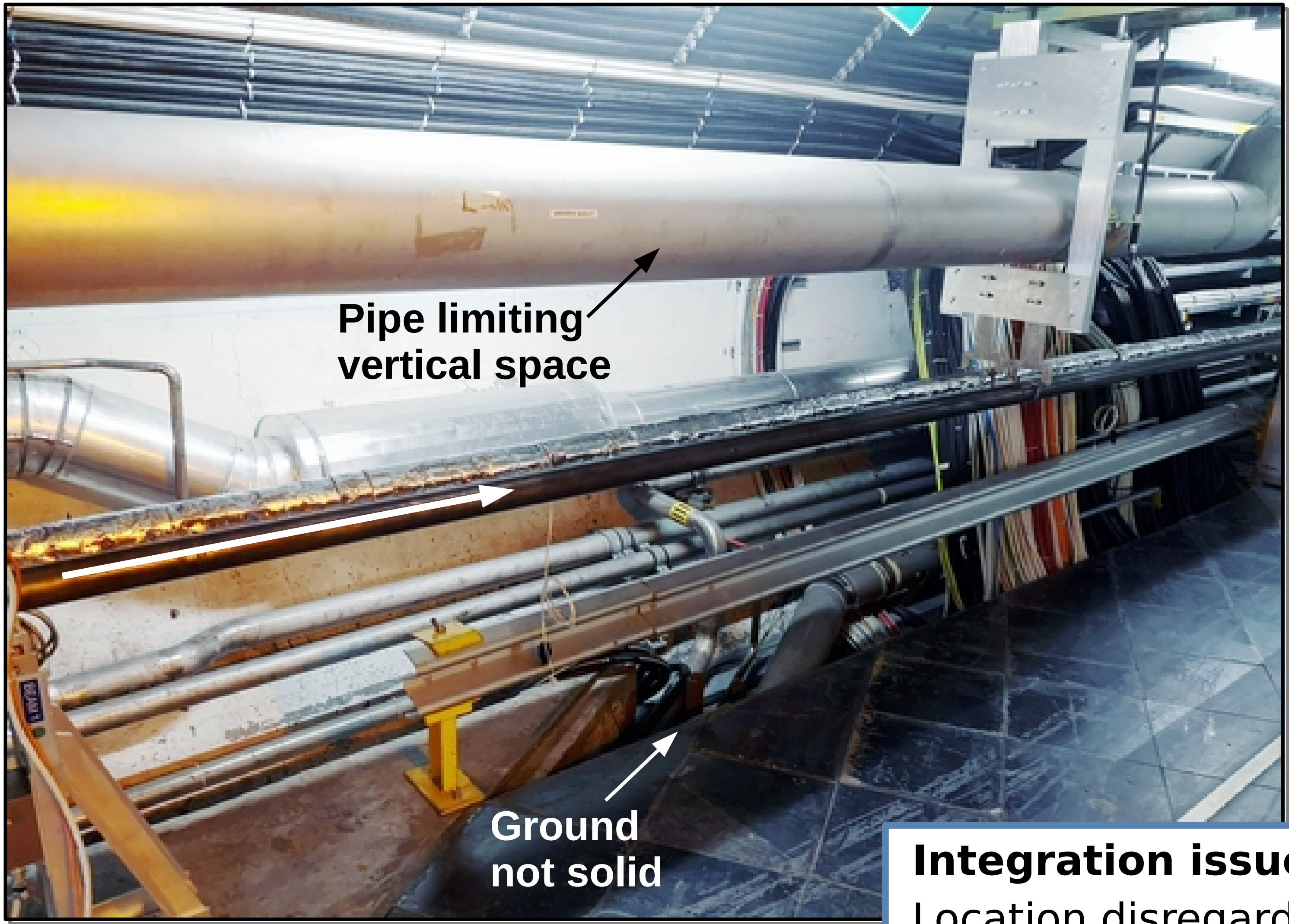
- IR3 layout defined in 2019 for final experiment
- Visit of LHC tunnel early 2022 with colleagues from STI → received feedback on integration aspects



Courtesy of D. Mirarchi

Crystal 1 Location

6451m



Integration issues
Location disregarded

Crystal 1 Location

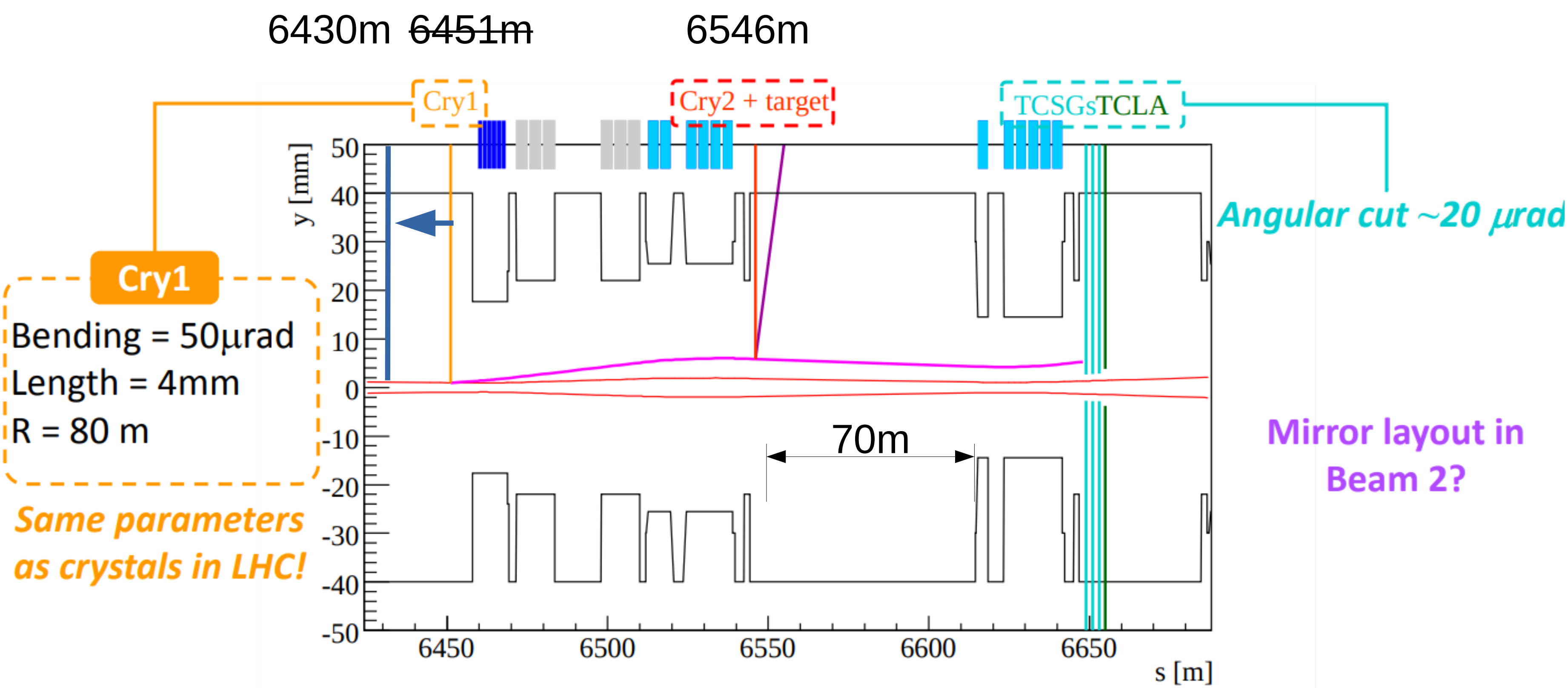
6430m

Suitable CRY1 location

Crystal 2 Location

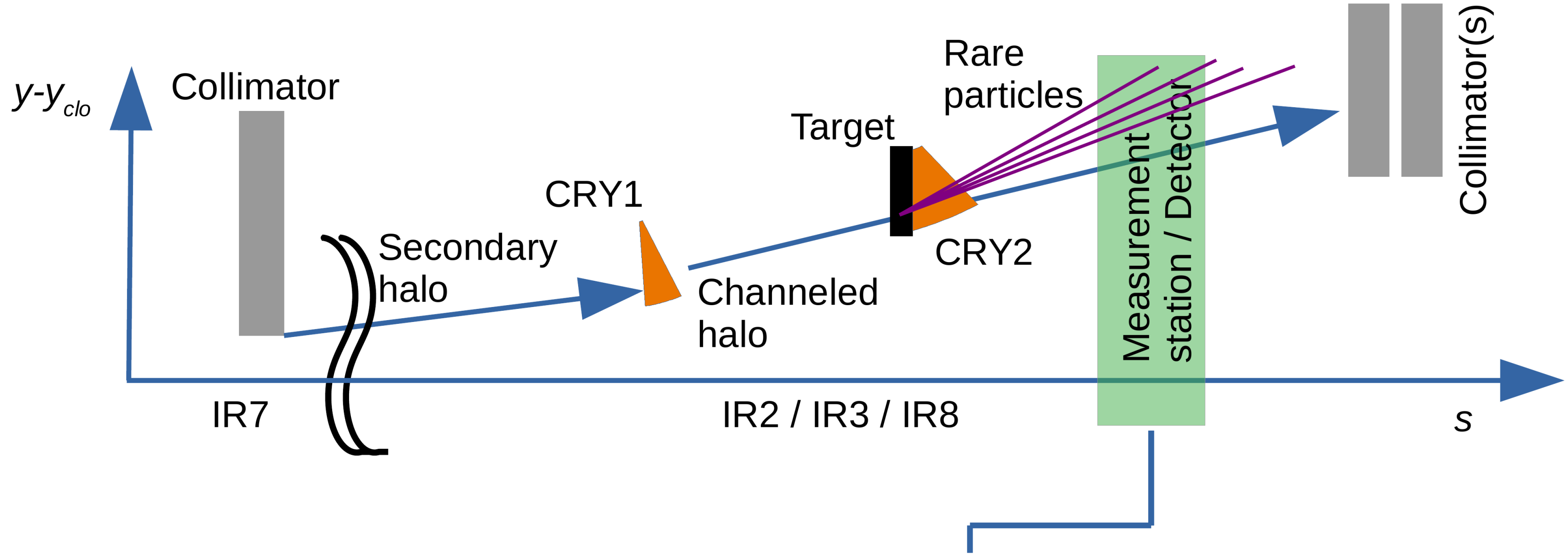
Crystal 2 Location

- IR3 layout defined in 2019 for final experiment
- CRY2 location revised to enable PoP (see next slides)



Courtesy of D. Mirarchi

CRY2 Location in PoP setup



- **Final IR3 setup: install 4Tm spectrometer dipole**
- Not compatible with PoP timeline
- Idea: use existing beam orbit corrector dipole as spectrometer
- **New constraint:**
    - CRY2 must be immediately adjacent to vertical orbit corrector

Initially proposed CRY2 Location

Courtesy of D. Mirarchi

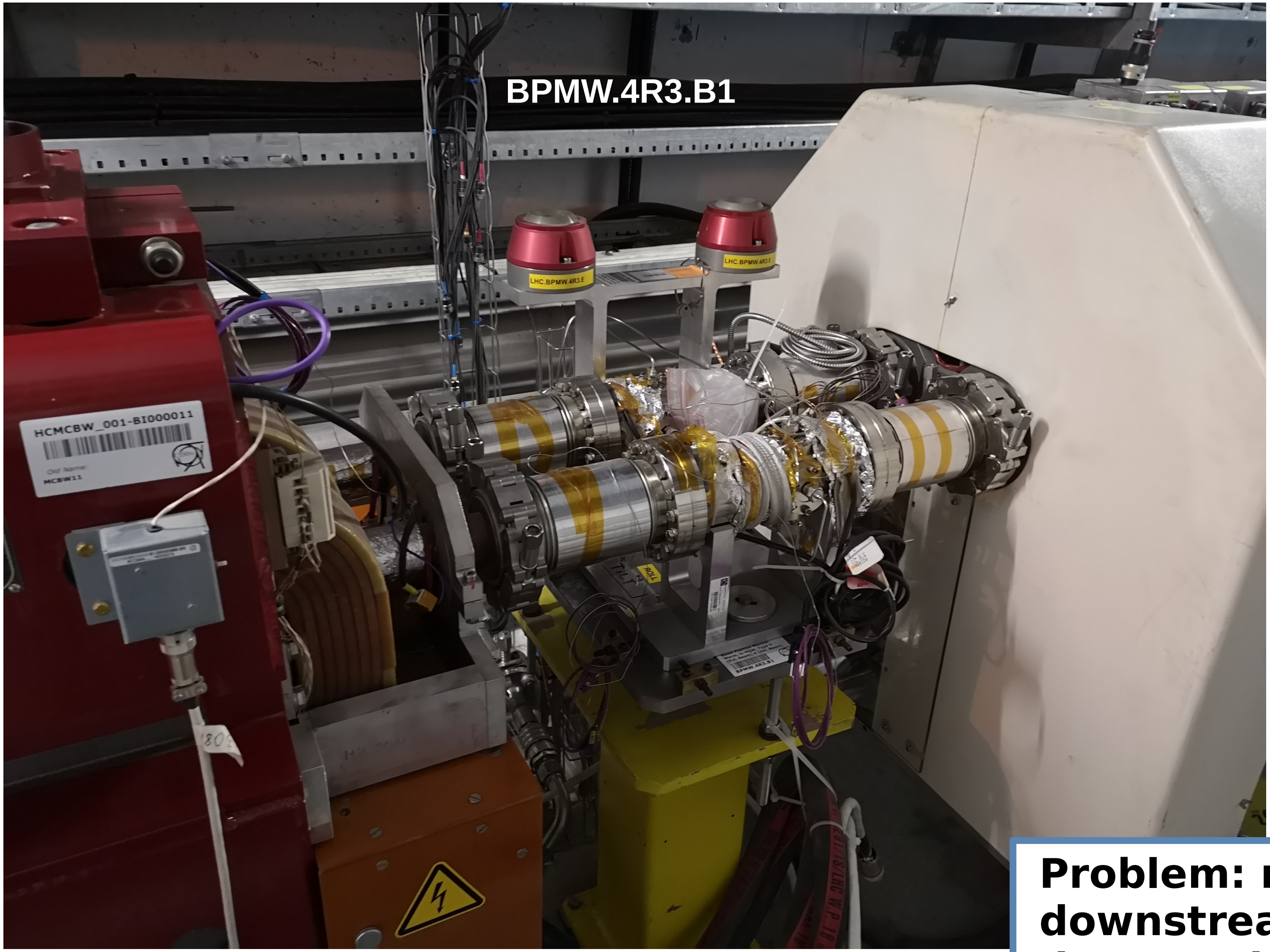
6546m

No orbit corrector dipole available

New proposed CRY2 location

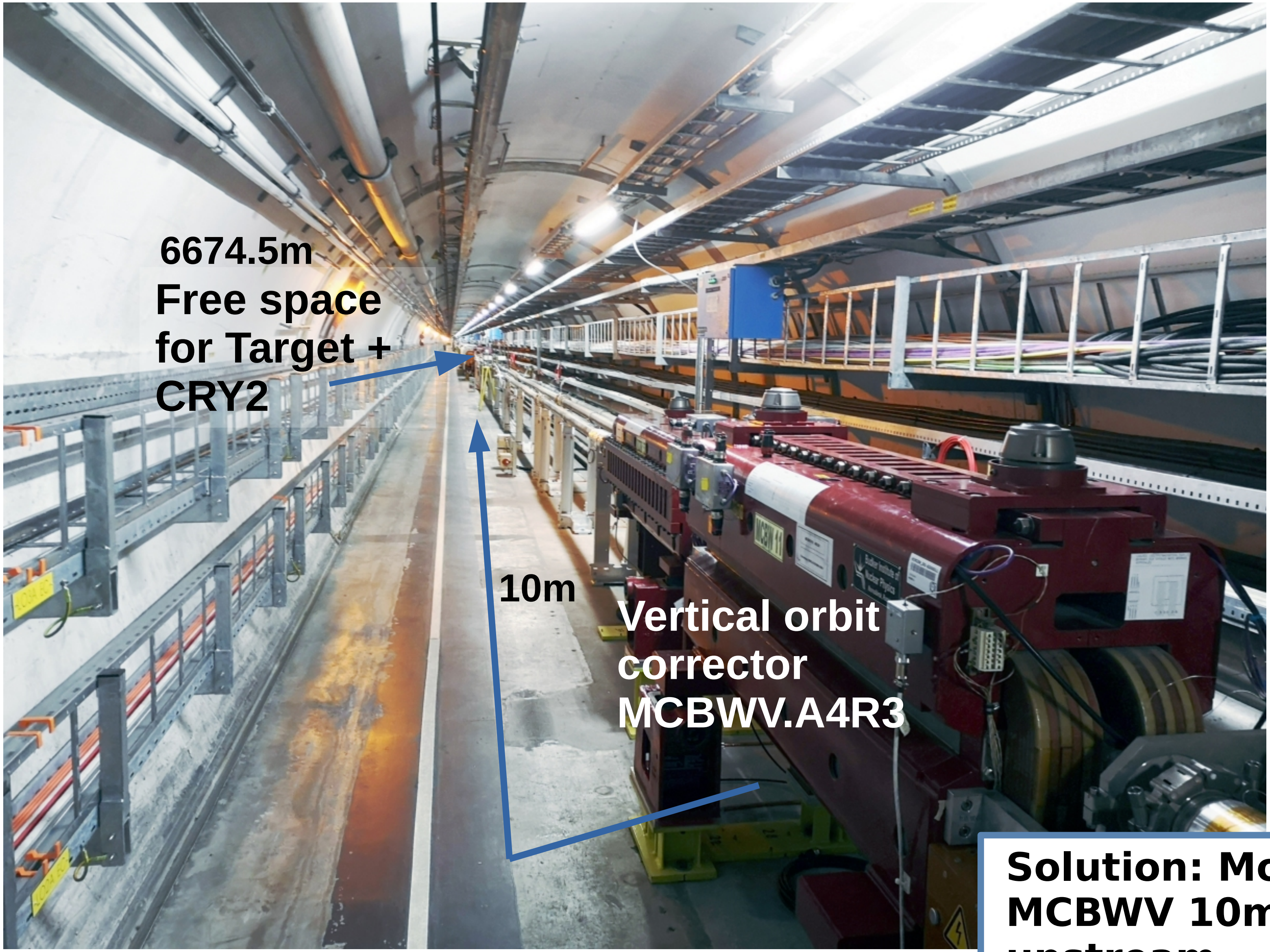
Max. field 1.87Tm

New proposed CRY2 location



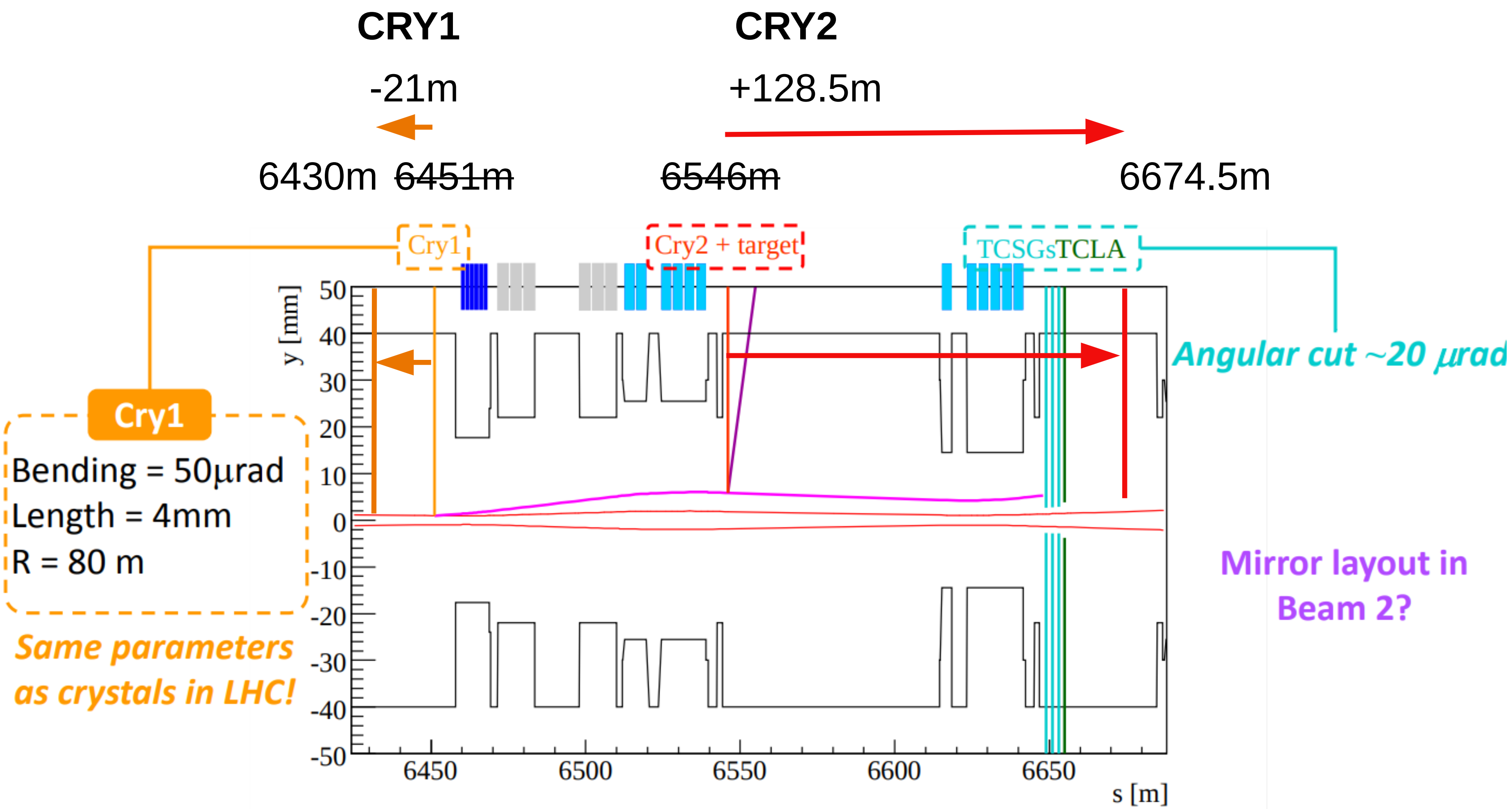
Problem: no space downstream for detector hardware

New proposed CRY2 location



Solution: Move MCBWV 10m upstream

Updated Layout



Courtesy of D. Mirarchi

Absorbing Collimators

Updated Layout

CRY1

-21m

CRY2

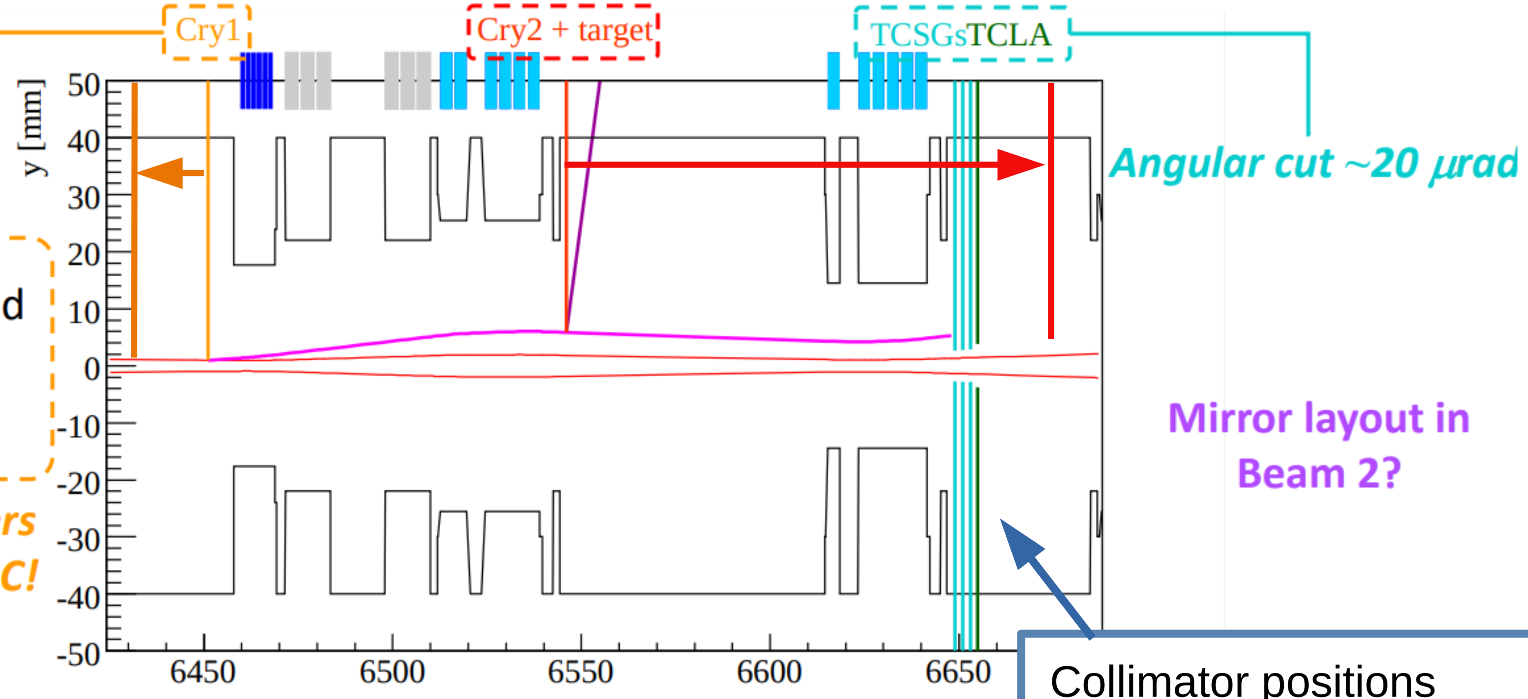
+128.5m

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

Cry1

Bending = 50µrad
Length = 4mm
R = 80 m

Same parameters as crystals in LHC!



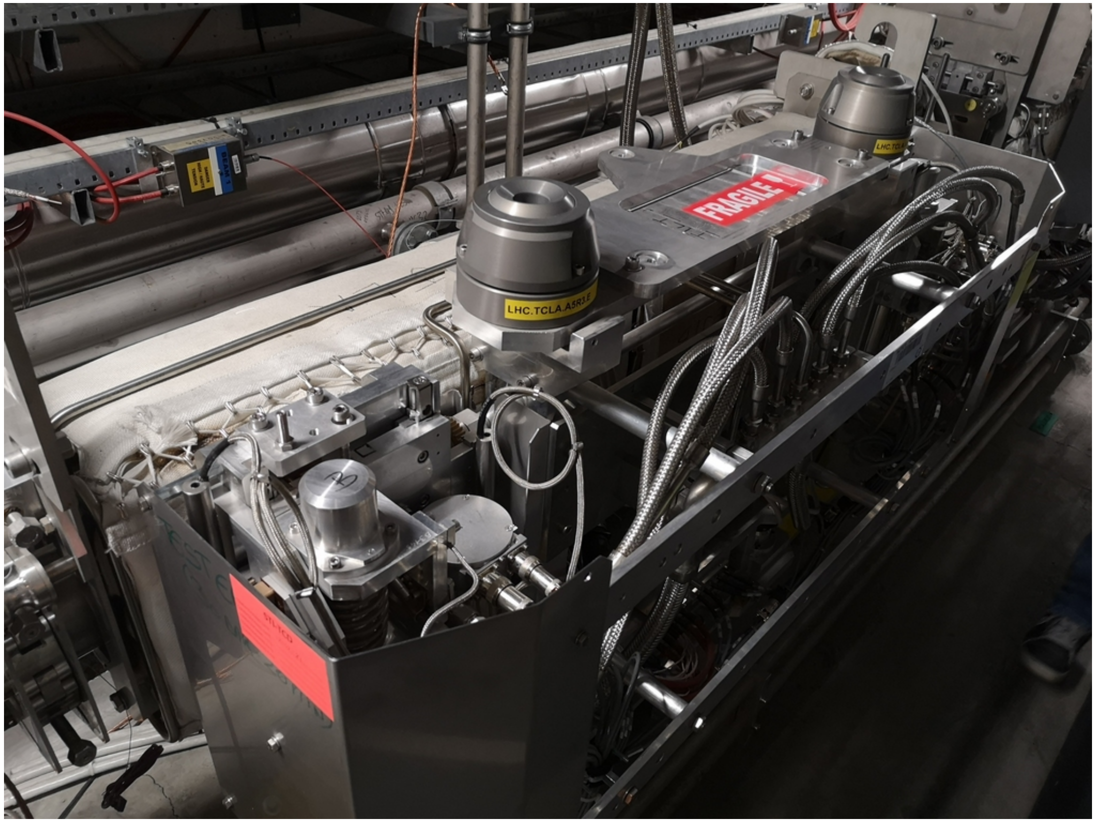
Courtesy of D. Mirarchi

Mirror layout in Beam 2?

Collimator positions obsolete + can't be installed in PoP timeline

Absorbing collimator

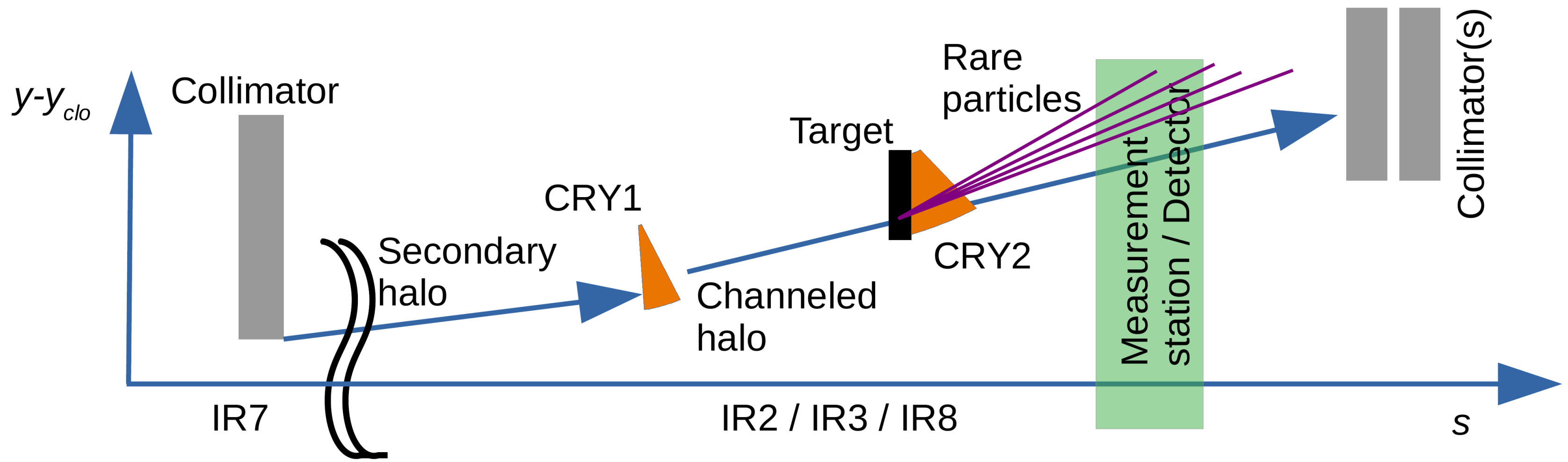
TCLA.A5R3.B1



6755m

- Existing vertical collimator downstream of CRY2
- Compatible with low intensity PoP tests (some few 10^{11} protons)
- IR3: space available for additional collimators downstream of CRY2

Layout goals



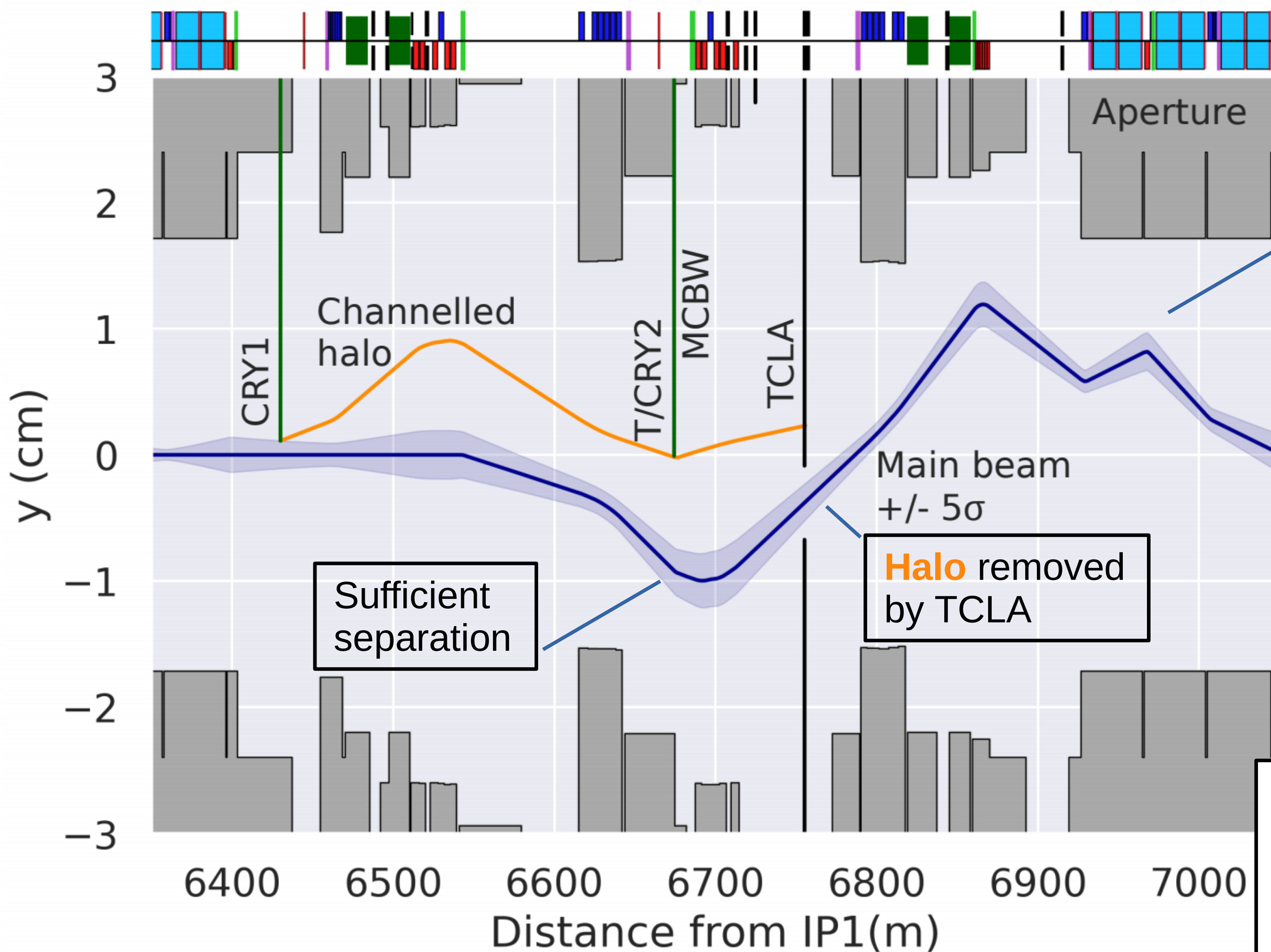
- **Devices needed – positions assigned**
  - ☑ **Crystal 1** in operational goniometer: 6430m
  - ☑ **Target + Crystal 2** in goniometer assembly: 6674.5m
  - ☑ **Spectrometer dipole**: ~6674.9m (move existing MCBWV.4R3.B1)
  - ☑ **Absorbing collimators**: 6755m (existing)

Beam dynamics simulations

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 expected **efficiency** (protons on target)
- Simulate performance measurements of **CRY2 in TeV range**
- Probe possible solutions for expected **operational challenges**:
  crystal alignment, establishing double channelling, etc.

Beam orbit simulations 6.8 TeV



Orbit off-center due to kick from MCBWV: compensating with other dipole correctors

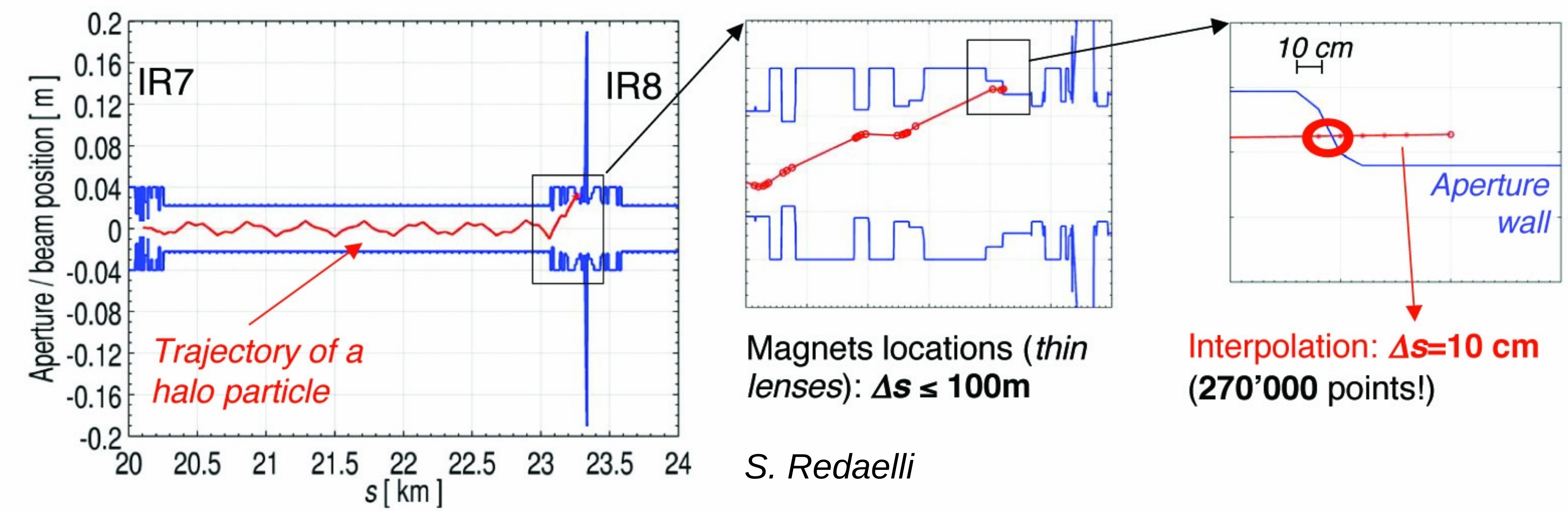
No showstoppers also for HL setup

Test of OP with MCBW kick in LHC envisaged

Simulations in MAD-X

Protons on target

- Combined **particle tracking** and Monte-Carlo **particle-matter interactions**
- Integrated framework in SixTrack, **established tool** with long experience benchmarked with machine data
- Follow trajectory of each particle and compare with machine aperture
- Heavy simulations of 20 Million initial particles on cluster of CPUs



Magnets locations (*thin lenses*): **Δs ≤ 100m**

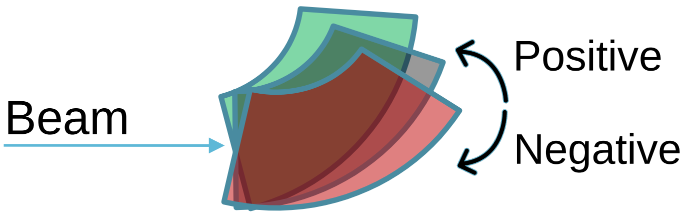
Interpolation: **Δs=10 cm** (**270'000** points!)

S. Redaelli

Protons on target

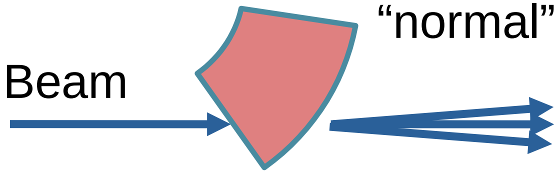
- **Concept:**
  - Simulate particles impacting the TCP (particle-matter interaction) → transverse distribution based on assumptions
  - Follow their trajectory
  - If impact on CRY1: simulate channelling process
  - Count impacts on Target/CRY2
- **First step: CRY1 alignment**

Crystal alignment

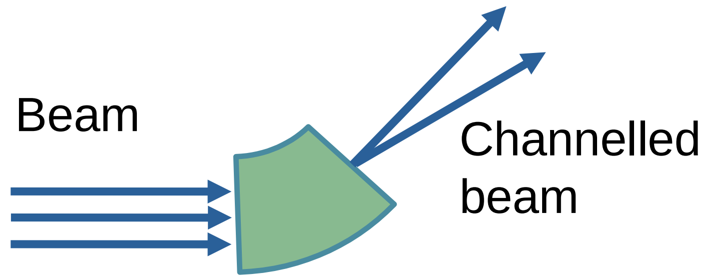


Crystal efficiency: sensitive to angular orientation (at 7 TeV ~µrad) → crystals on rotatable goniometers

No channelling: behaves like "normal" material



Wrong orientation
No channelling possible

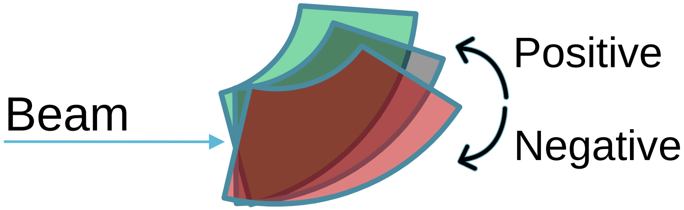


Ideal orientation
Max. channelling efficiency

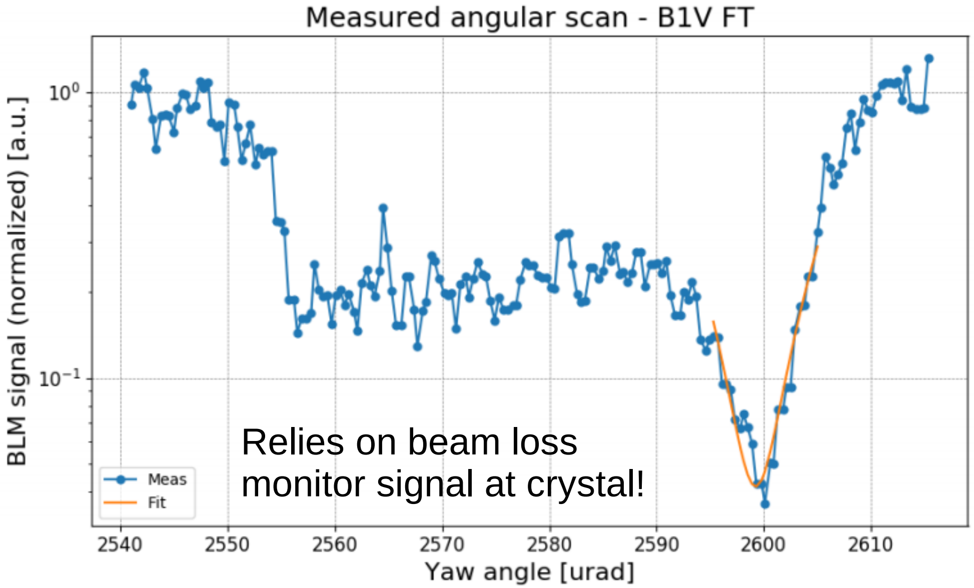
Illustration: Courtesy of R. Cai

See talk by Q. Demassieux

Alignment in operation



Angular scans:
Crucial to gauge crystal orientation in operation!

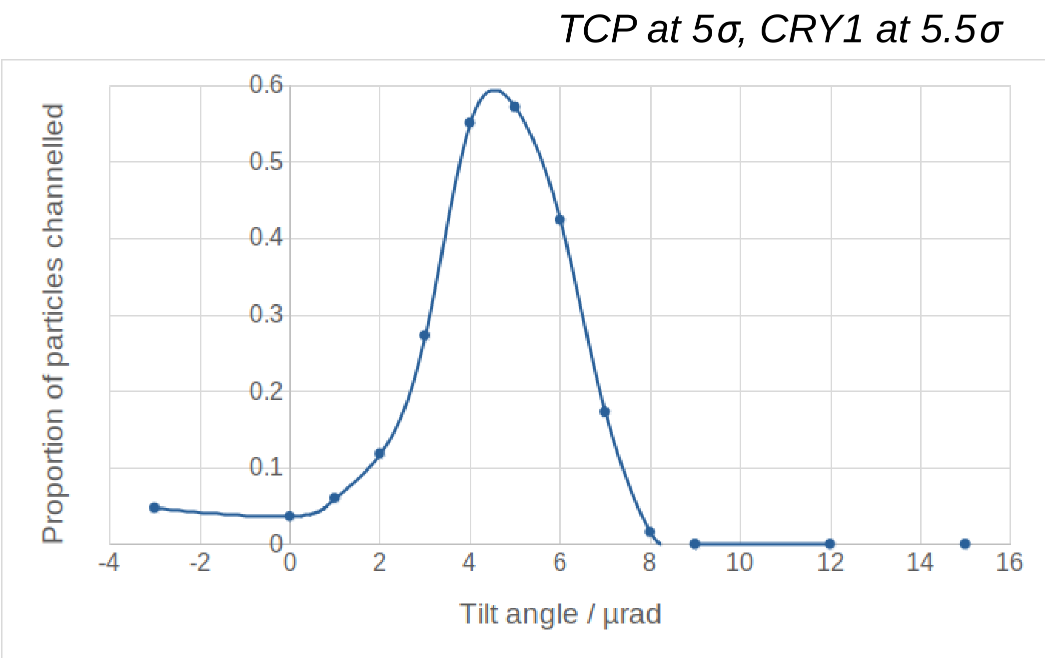


Channelling orientation

Illustrations: Courtesy of R. Cai and M. D'Andrea

See talk by Q. Demassieux

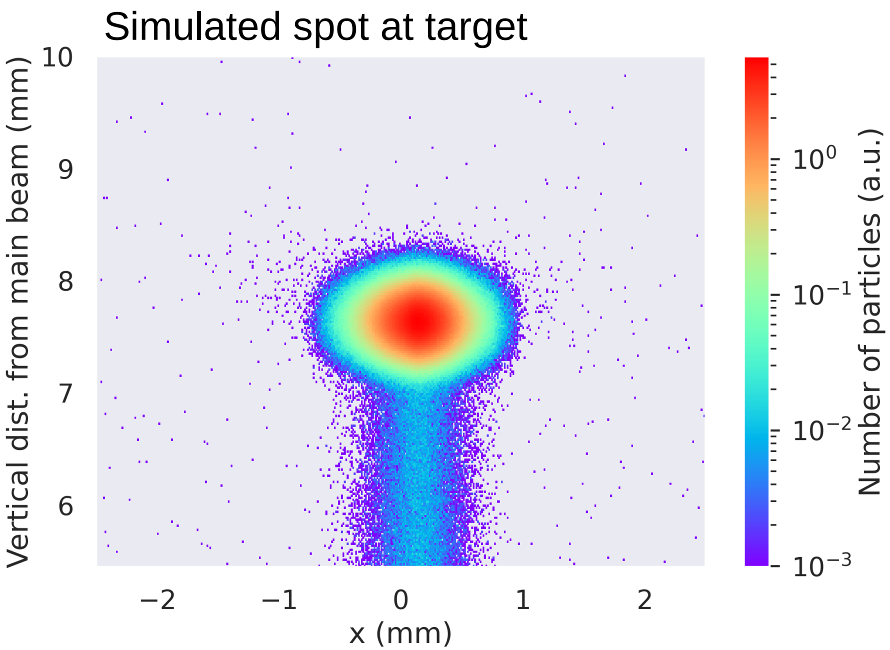
CRY1 alignment in simulations



- Carry out a low statistics (2×10^4 particles) simulation for each angle of the CRY1
- Step size 1µrad
- Identify optimal orientation
- Move on with high statistics for optimal orientation

Figure: Courtesy of K. Dewhurst

Protons on target efficiency



	TCP	CRY1	Target
Particle impacts	100%	18%	13%

- Simulated efficiency for 6.8TeV for CRY1 at same setting (5σ) as TCP (not high intensity compatible)
- Delivers **upper boundary for proton on target efficiency: 13%**
- Each configuration envisaged requires dedicated simulations
- **PoP: validate these simulations!**

Upcoming challenges

Upcoming challenges

For IR3 FT operation

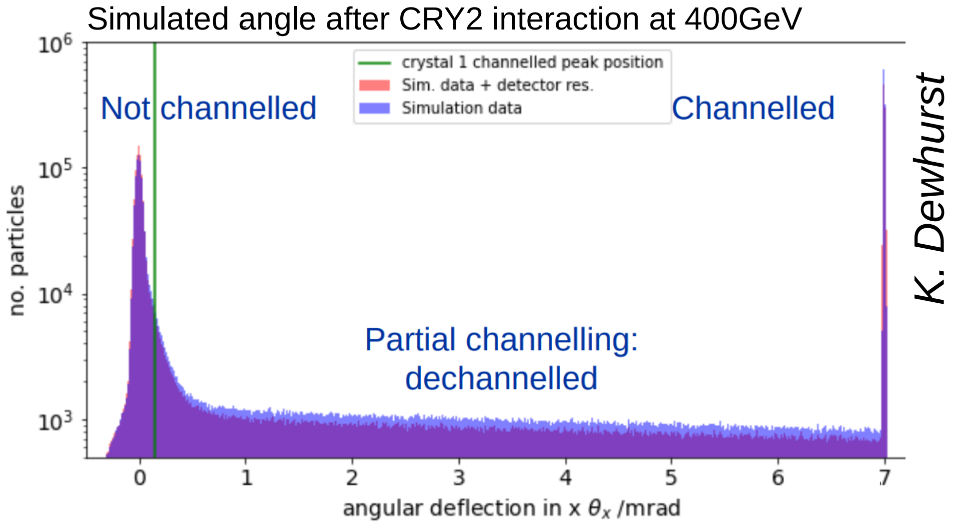
- CRY1 in shadow of the TCP
- CRY2 in shadow of TCP+CRY1
- BLM signals might be too weak to find the channelling

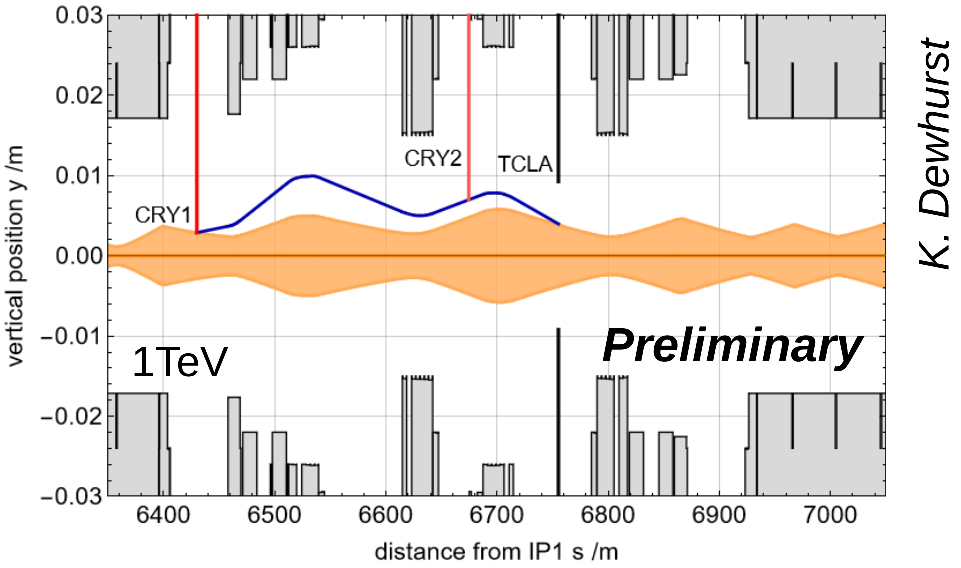
Proof of principle tests

- **CRY1**: can we **align with main beam** and calculate correct angle for retracted settings?
- **CRY2**: channelling of 6.8TeV protons not possible, need to **align using lower energy beams**

Upcoming challenges

- CRY2 channelling efficiency **at 400GeV can be measured at H8** using SPS beams
- **How to measure** channelling efficiency of CRY2 **at ~ 1TeV?**
- Idea: use **MediPix** pixel tracking detector **before and after CRY2** with channelled halo using 1TeV LHC beam
  - Identify when double channelling is established
  - Measure intensity of double-channelled halo
- Larger beam size at 1TeV: preliminary simulations indicate challenges – solutions under investigation





Preparatory beam tests before PoP

- Use existing crystals in LHC IR7 and collimator in IR3 to **demonstrate principle of capturing secondary beam halo** (inverse setup)

- **Confirm proposed orbit setup with bump** – should not disturb nominal OP

- **Studies with optimized phase advance TCP-CRY1** → demonstration that protons on target efficiency can be improved by changing magnet configuration

Conclusions

- Challenging double crystal proposal for EDM/MDM measurements
- Require experimental verification of aspects that impact their performance
- IR3 installation during LHC Run 3 for test purposes
- Gain experience with operational challenges and demonstrate functionality
- Suitable locations for key devices identified
- First simulation campaigns with promising results
- Further simulations ongoing to
  - Design channelling efficiency measurements in TeV range
  - Develop concepts for solving operational challenges
  - Possible detector architecture for IR3 PoP

References

Presentations

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***