Proposal for beam splitting in LHC IR2

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Outline

- Motivation
- Channeling
- Collimation
- UA9 and collimation
- Proposal for ALICE
- Conclusion and Outlook

Motivation

Fixed Target (FT) Experiments in the MultiTeV energy range have been dreamt of since a long time.

+ The expertise gained by the UA9 collaboration and the LHC collimation team in the last few years in the manipulation of beams by means of bent crystals
+ The successful experimentation with crystals in LHC

might make that dream easier to realize.

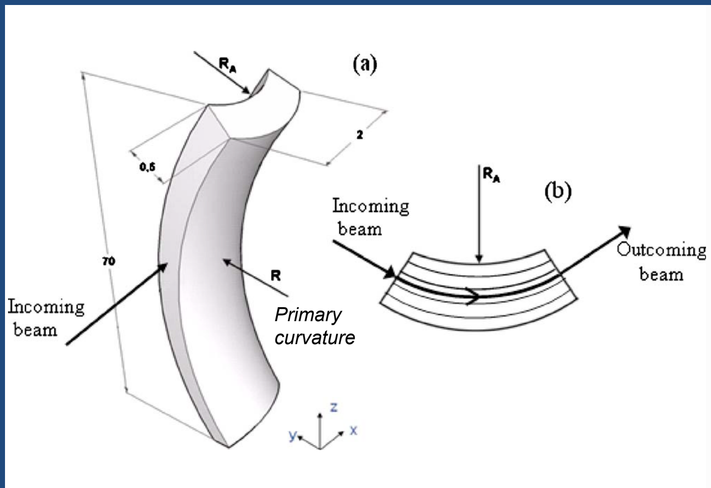
At LHC energy in-beam FT seems now a more viable option than FT from extraction lines.

FT experiments were one of the interesting topics of Physics Beyond Colliders.

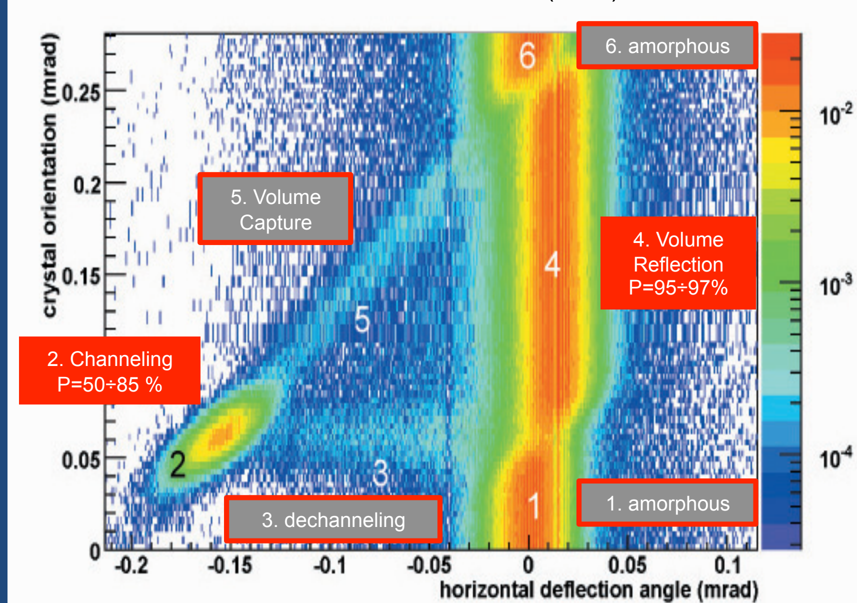
Some colleagues from the ALICE collaboration asked our help to investigate an in-beam FT scenario from a crystal-split beam before the Alice detector.

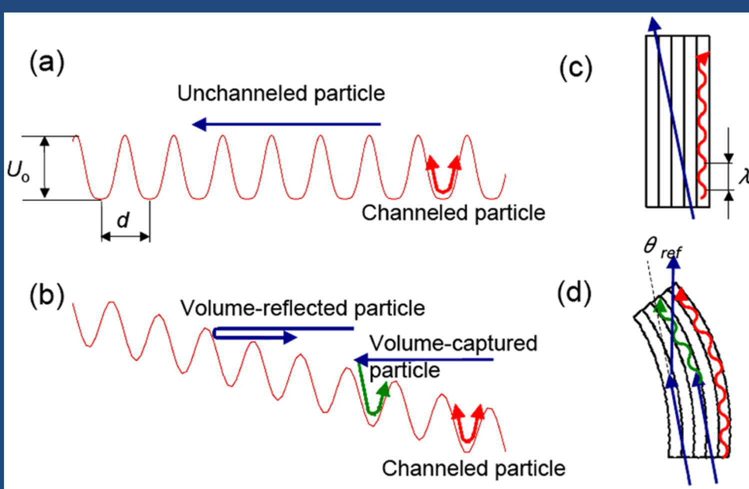
Coherent interaction beam/crystal

Anticlastic curvature of a strip crystal



W. Scandale et al, PRL 98, 154801 (2007)





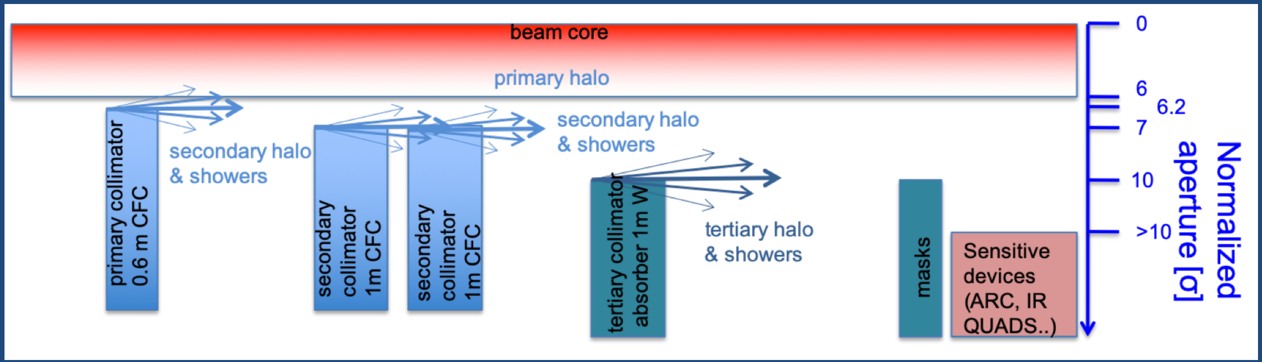
$$\theta_c = (2U_o/\mathrm{pc})^{1/2}$$

$$\theta_c^b = \theta_c\left(1 - \frac{R_c}{R}\right)$$

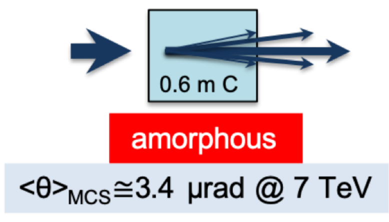
Si Case	Energy [GeV]	θ_c [μrad]	$\lambda[\mu m]$	R_c [m]
SPS coast	120	18.3	33.0	0.3
SPS coast	270	12.2	49.6	0.6
H8	400	10	60.3	1.0
LHC inj.	450	9.4	64.0	1.1
LHC top	6500	2.5	243.2	15.6
LHC top	7000	2.4	252.3	16.8

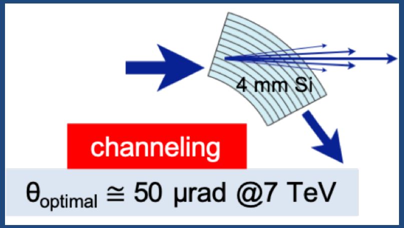
Crystal Application: Collimation

- Standard: The halo particles are removed by a cascade of amorphous targets:

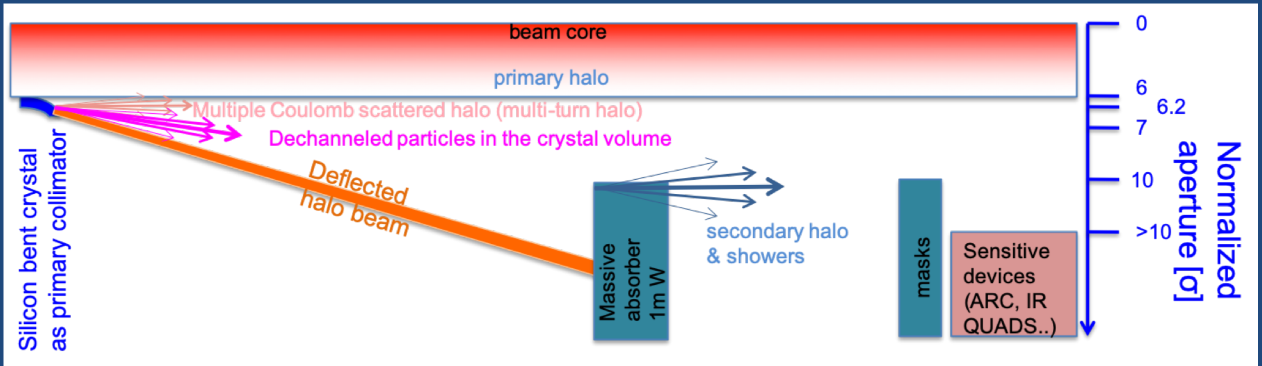


1. Primary and secondary collimators intercept the diffusive *primary halo*.
2. Particles are repeatedly deflected by Multiple Coulomb Scattering also producing hadronic showers that is the *secondary halo.*
3. Particles are finally stopped in the absorber.
4. Masks protect the sensitive devices from *tertiary halo.*





- Crystal-assisted: Channeling in the particle-crystal interaction imparts large deflection to the *primary halo:*



1. The escaping particle rate is minimized.
2. The collimation efficiency is improved.

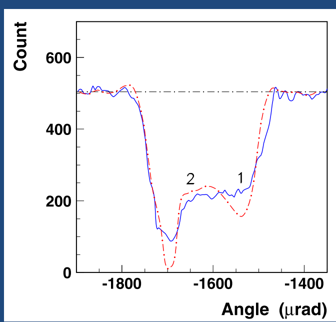
UA9 – Collimation in SPS

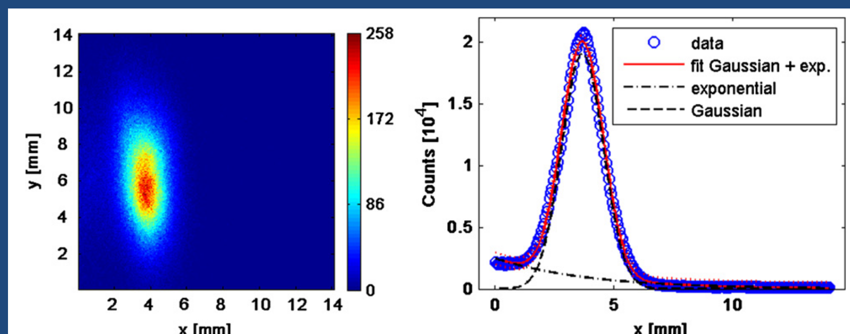
First and main objective:

Demonstration of the feasibility of crystal-aided beam halo collimation in high energy particle colliders such as the LHC.

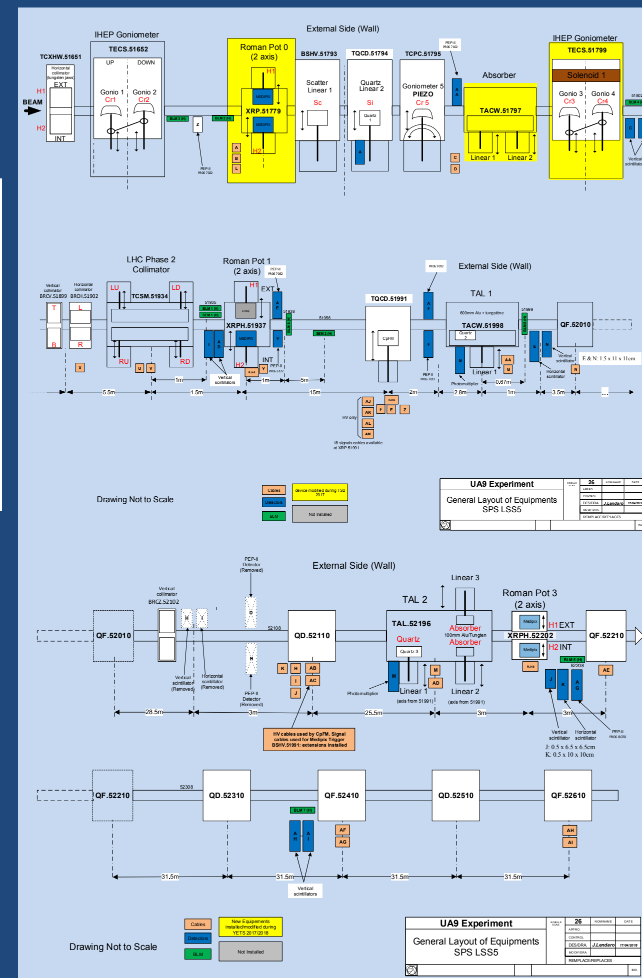
2009-2012

- Collimation demonstration in SPS Long Straight Section 5 (LLS5)





W. Scandale et al., Phys. Lett. B 692 (2010) 78-82



→ Approval for installation of crystals in LHC

2015 on

- Investigation of beam interaction with crystals in circular machines
- Understanding crystal collimation features from LHC runs
- Other crystal-assisted beam manipulations: extraction, etc…

UA9 – Collimation in LHC

LS1 2013-2014
Installation of 2 goniometers (horizontal and vertical) in LHC-Beam1 IR7

2015
Successful test of halo collimation in LHC at 450 GeV and 6.5 TeV

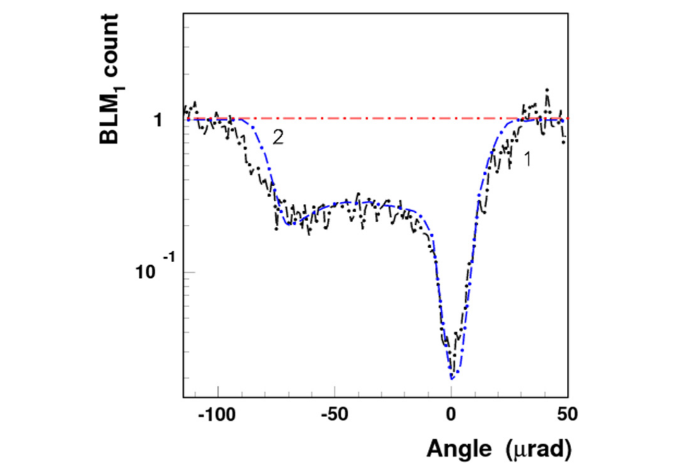


Fig. 2. (Color online.) The dependence of the beam losses observed with the BLM_1 downstream of the crystal (curve 1) for the injection case with 450 GeV/c protons. Curve 2 shows the dependence of the number of inelastic nuclear interactions of protons in the crystal on its orientation angle obtained by simulation.

W. Scandale et al., Phys. Lett. B 758 (2016) 129-133

YETS 2017-2018

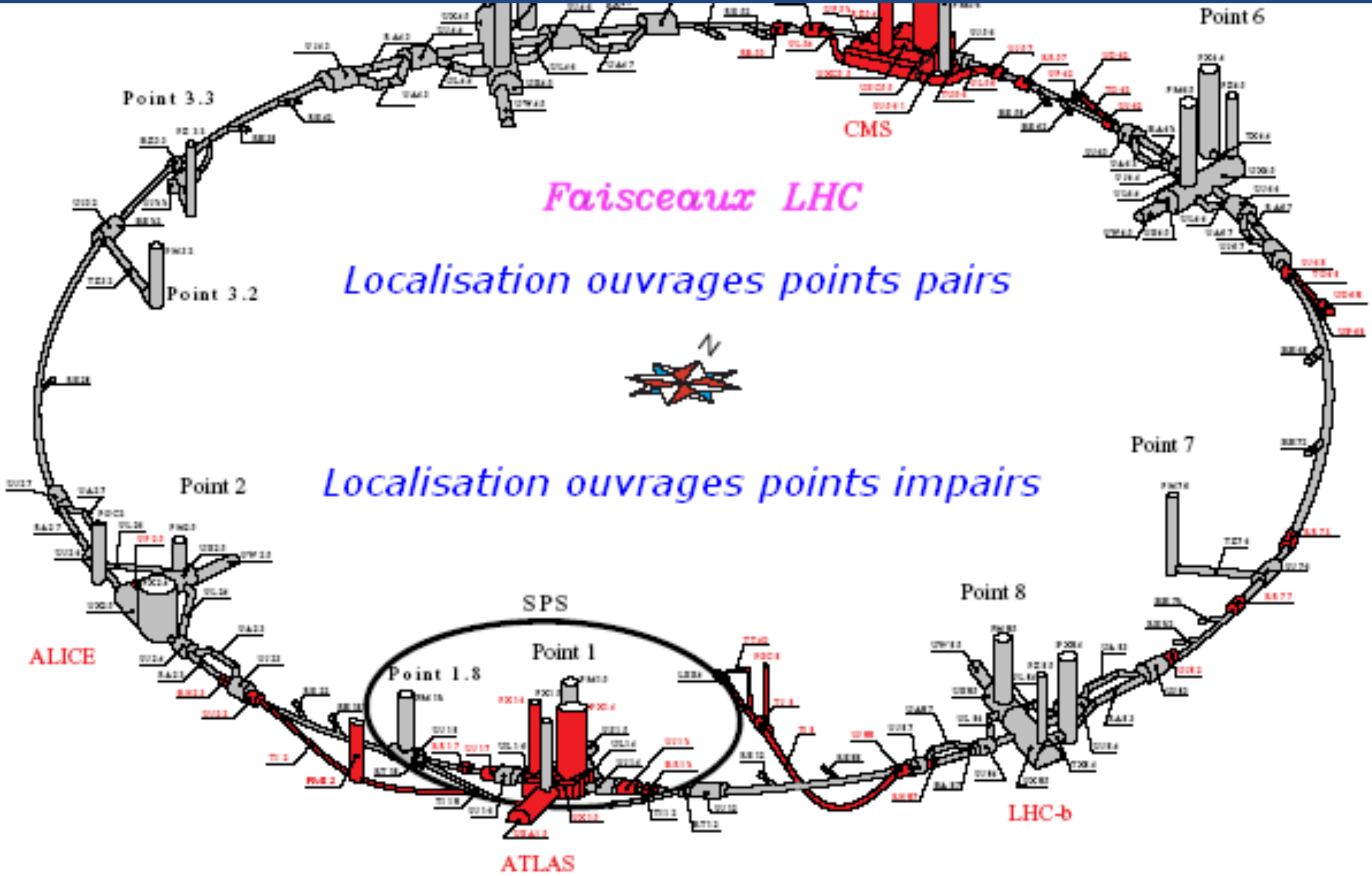
2 goniometers installed to equip LHC-Beam2.

In 4 year Machine Developement channeling and cleaning performance assessment for

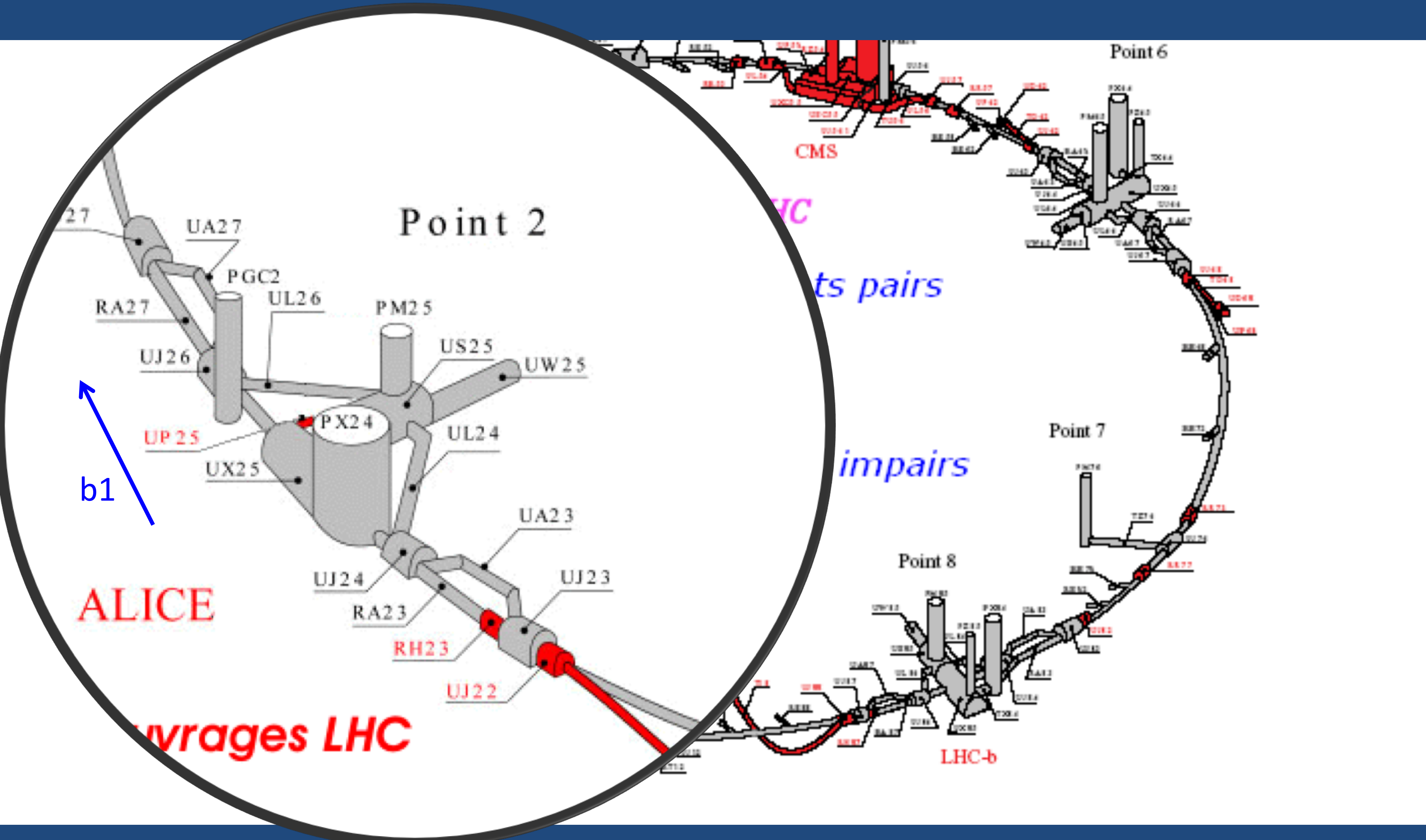
- protons, Pb Ions and Xe Ions,
- at injection and at collision energies,
- during energy ramp and beam squeeze,
- and in collision.

First successful operational use during TOTEM and ALPHA physics run in 2018

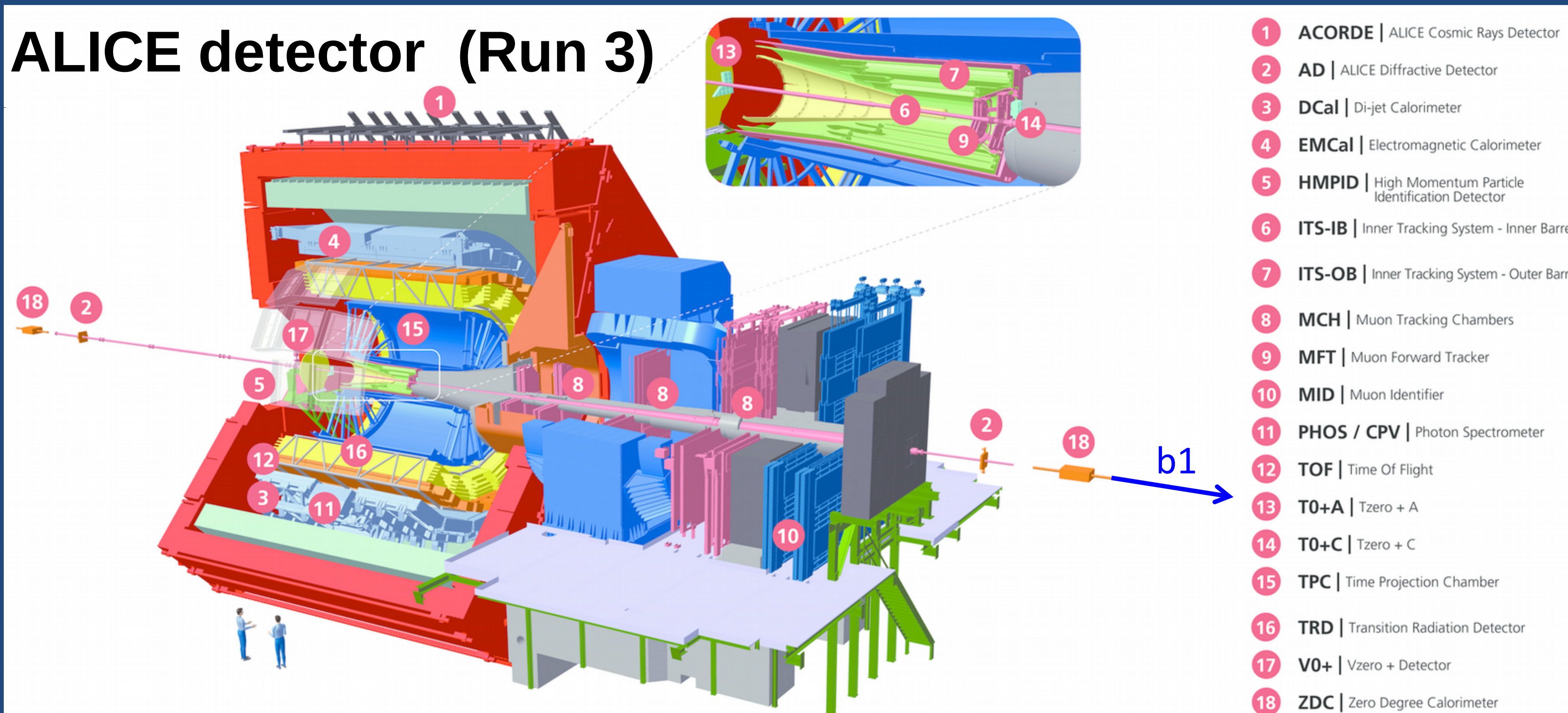
LHC installations



LHC installations



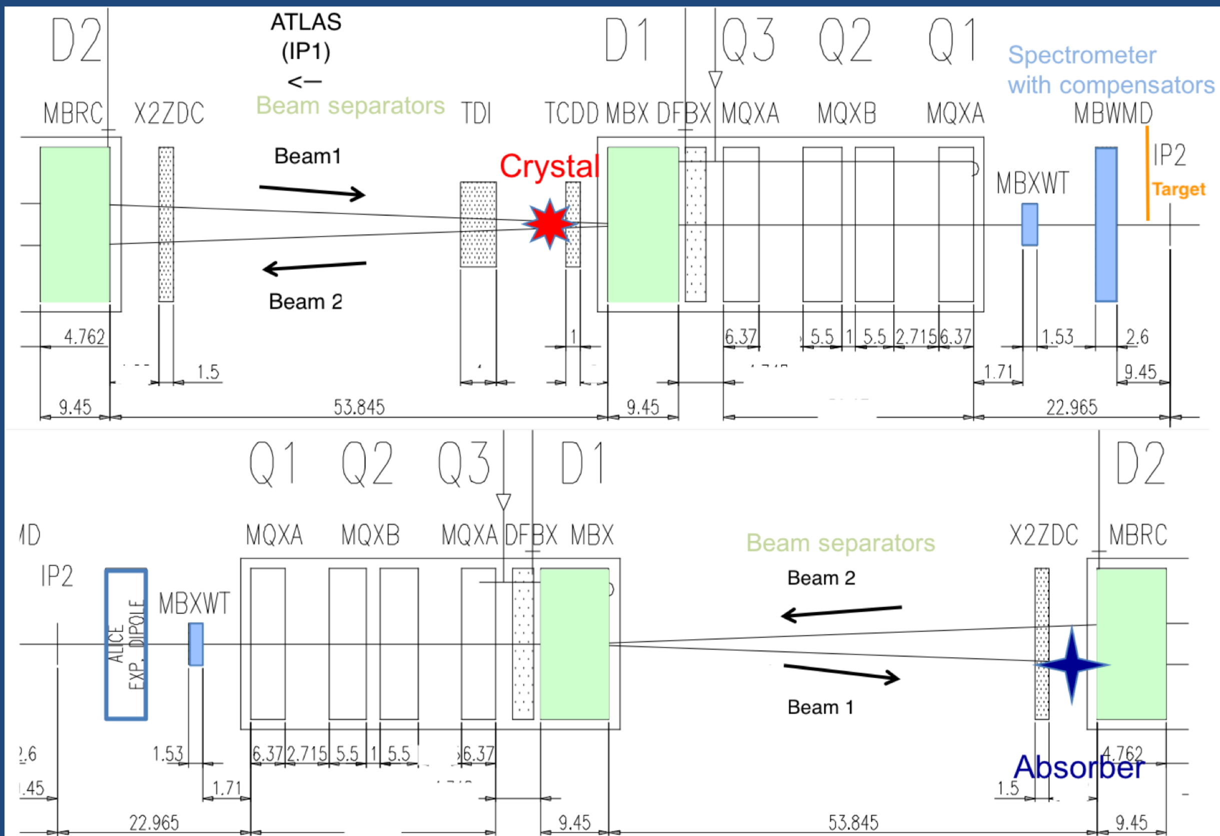
ALICE detector



View from inside LHC

ALICE IP Region – A possible layout

Conceptual scenario developed in the framework of PBC-FT working group.



Beam 1

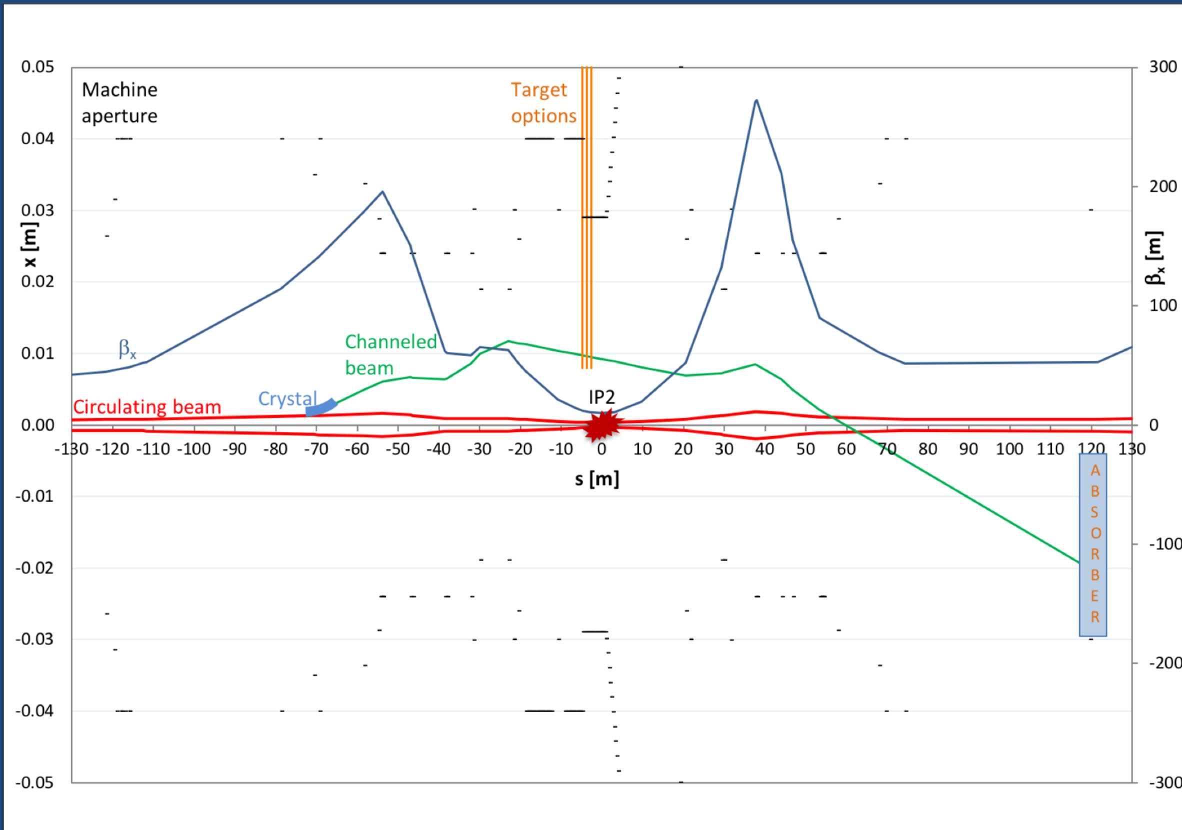
Target positions according space availability in ALICE detector @ ~5 m before IP2

Several positions for a crystal analyzed
Crystal @ 72 m before IP2

Absorber @ ~120 m after IP2

A bent crystal deflects the beam halo onto an internal solid target located near IP2.
An absorber downstream captures the non-interacting particles.

ALICE IP Region – Beam trajectories



Constraints:

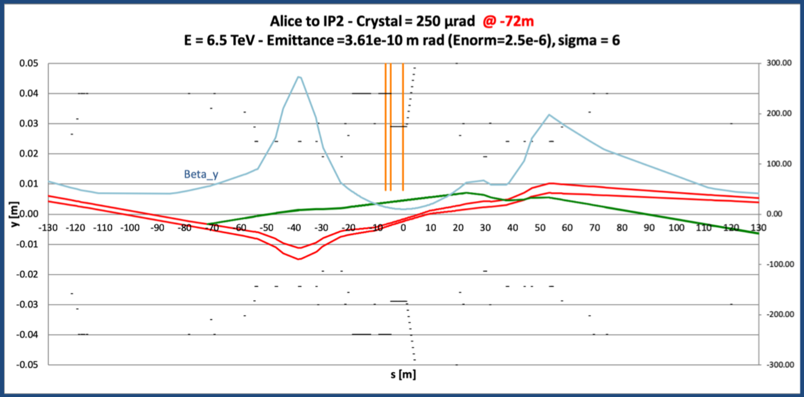
Bending angle = 250 µrad

Target @ 8 mm max from pipe center

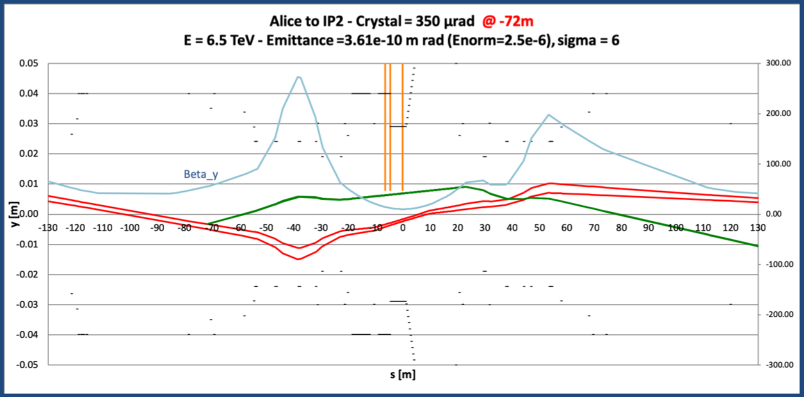
Phase advance cry/target = 70÷90 deg

Particle trajectories for an internal fixed-target experiment:
A bent crystal splits and deflects the halo from the circulating beam, and sends it on an internal target placed in front of the ALICE detectors; the non-interacting channeled particles are caught by an absorber downstream; a safe distance is maintained between the channeled beam and the machine aperture.

Vertical split with tight constraints

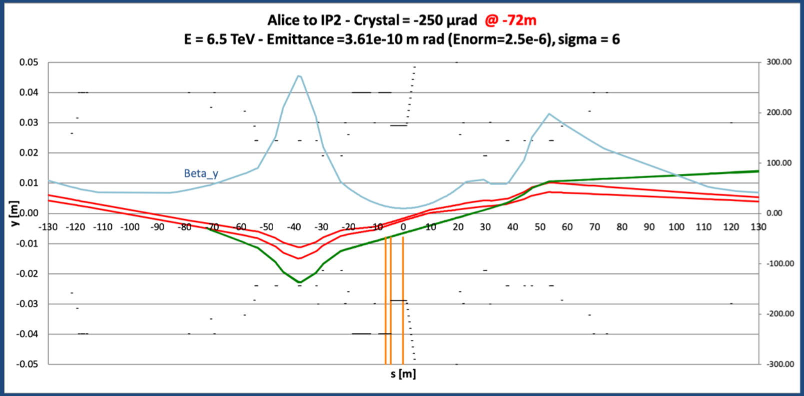


θ = 250 µrad -Target not reached

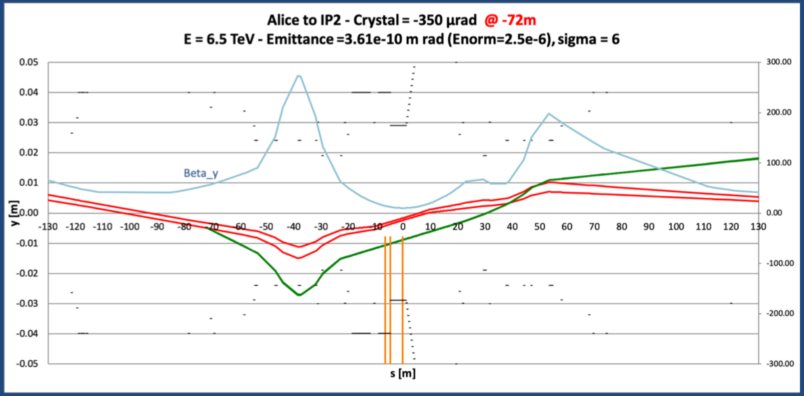


θ = 350 µrad - Target not reached

Target @ 8 mm



θ = -250 µrad - Target not reached



θ = -350 µrad - Aperture too small

From Conceptual to Operational

Layout optimization

- Acceptable distance of target from circulating beam (4 mm in IR3 studies)
- Acceptable crystal angle
  - → Vertical plane might become accessible to avoid asynchronous dump risk
  - → Full local collimation system might be needed
- Availability of beam line slots to be checked: preliminary integration study

Simulation studies

a. Compatibility with machine protection and collimation system
b. Comprehensive simulation of the system with beam loss assessment
c. Compatibility with parasitic run

d. Background control
e. PoT fluxes simulations

Experimental preliminary studies

The recent experience with LHC collimation teaches us that a solid demonstrator in less constraining conditions is desirable before migrating the concept to LHC.

UA9 has an efficiently equipped set-up available in SPS where some useful measurements, like target background estimate, can already be performed in view of an internal FT experiment (see R.Rossi's talk).

UA9 set-up has a suitable target tank downstream crystals for an à-la ALICE scenario, and it is already in the collaboration plans to test it.

The choice of the target (material and size) should be made soon, because the beam line reinstallation is imminent.

Some collaboration with ALICE-FT study group would be mostly welcome.

Possible topics:

1. target choice
2. simulation of interaction of target with particles emerging from the crystal
3. simulation of background

a. test of pneumatic insertion target
b. implementation of extra detectors downstream target

Conclusion and Outlook

We have just set a starting point for a lot more work to come.

From experience of crystal collimation in LHC:
→ accurate feasibility tests in an easier environment are preferable if not mandatory.

UA9 has now moved beyond collimation and it is ready to share its expertise for other challenging studies like those aimed to an internal Fix Target Experiment in LHC.

We hope that
- there can be an interest from the ALICE experiment
- adequate resources and support can be found

in order to start a fruitful experimental collaboration soon.

THANK YOU
for
YOUR ATTENTION

Expected luminosities

Achievable luminosities considering ALICE detector rate limitations

Target			ALICE proton beam ($\sqrt{s_{NN}}$ = 115 GeV) $\mathcal{L}$ [cm^{-2} s^{-1}]	σ_{inel}	Inel rate [kHz]	$\int \mathcal{L}$	Pb beam ($\sqrt{s_{NN}}$ = 72 GeV) $\mathcal{L}$ [cm^{-2} s^{-1}]	σ_{inel}	Inel rate [kHz]	$\int \mathcal{L}$
Internal gas target	Gas-Jet	$H^{\uparrow}$	4.3×10^{30}	39 mb	168	43 pb^{-1}	5.6×10^{26}	1.8 b	1	0.56 nb^{-1}
		H_2	2.6×10^{31}	39 mb	1000	0.26 fb^{-1}	2.8×10^{28}	1.8 b	50	28 nb^{-1}
		$D^{\uparrow}$	4.3×10^{30}	72 mb	309	43 pb^{-1}	5.6×10^{26}	2.2 b	1.2	0.56 nb^{-1}
		$^3He^{\uparrow}$	8.5×10^{30}	117 mb	1000	85 pb^{-1}	2.0×10^{28}	2.5 b	50	20 nb^{-1}
		Xe	7.7×10^{29}	1.3 b	1000	7.7 pb^{-1}	8.1×10^{27}	6.2 b	50	8.1 nb^{-1}
Beam splitting	Unpolarised solid target	C (658 μm)	3.7×10^{30}	271 mb	1000	37 pb^{-1}	–	–	–	–
		C (5 mm)	–	–	–	–	5.6×10^{27}	3.3 b	18	5.6 nb^{-1}
		Ti (515 μm)	1.4×10^{30}	694 mb	1000	14 pb^{-1}	–	–	–	–
		Ti (5 mm)	–	–	–	–	2.8×10^{27}	4.7 b	13	2.8 nb^{-1}
		W (184 μm)	5.9×10^{29}	1.7b	1000	5.9 pb^{-1}	–	–	-	–
		W (5 mm)	–	–	–	–	3.1×10^{27}	6.9 b	21	3.1 nb^{-1}

Assumptions:

	proton beam	lead beam
Number of bunches in the LHC	2808	592
Number of particles per bunch	1.15×10^{11}	7×10^{7}
LHC Revolution frequency [Hz]		11245
Particle flux in the LHC [s^{-1}]	3.63×10^{18}	4.66×10^{14}
LHC yearly running time [s]	10^7	10^6
Nominal energy of the beam [TeV]	7	2.76
Fill duration considered [h]	10	5
Usable particle flux in the halo (when relevant) [s^{-1}]	5×10^{8}	10^5

- ❑ ALICE runs the full year in fixed target mode
- ❑ Maximum readout rate considered 1MHz in pp/pA collisions and 50kHz in PbA
- → higher rate could be envisoned in fixed-target mode depending on detector occupancy (factor ~2 Pb/Xe, factor ~10 pH)

Proton flux to be (re)considered from recent studies: 10^6 p/s (could potentially be increased to 10^7 p/s) CERN-PBC-REPORT-2019-001

Decrease of the flux can be compensated by increasing the target thickness

eg: pC ($\Phi = 10^6$ p/s, length = 1cm, L_{int} = 1.1pb^{-1})

Extraction of Pb beam with bent crystal needs further studies (crystal location (primary/secondary/tertiary halo), composition in terms of species of the channelled ion beam…)

Phys. Lett. B703 (2011) 547–551 (UA9 studies with Pb beam)

ALICE Fixed-Target - L. Massacrier

PBC WG meeting, 5-6 Nov.2019, CERN

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