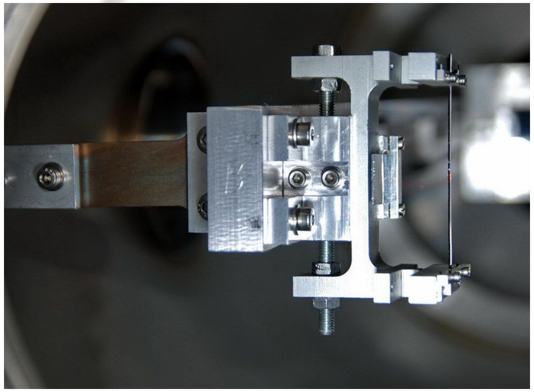
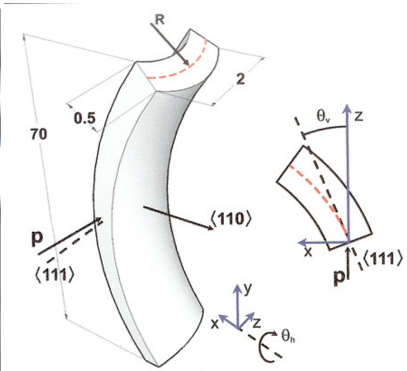
LHC Collimation Project
CERN

Studies for possible Crystal Layout at the LHC





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Outline

- Introduction
- Possible scenarios
- Semi-analytical studies
- Full simulation studies
- Conclusions

Introduction

From 2009 UA9 is taking data in the SPS demonstrating that collimation of proton and lead ion beams can be reliably obtained.

In September 2011, a letter of intents was presented to the LHCC, asking to extend UA9 to the LHC:

✓ new experiment (LUA9) recommended by the LHCC and accepted by the accelerator directorate

Goals:

- demonstrate the extraction of the beam halo in the LHC
- measure the possible improvements with respect to standard collimation

Aim of the studies presented:

Set up appropriate simulation tools (reproduce the past results)

Propose and validate the position for the installation during the LS1

Comparative assessment of different layouts by detailed tracking simulations, in relation with the plans for the first tests wanted to be done

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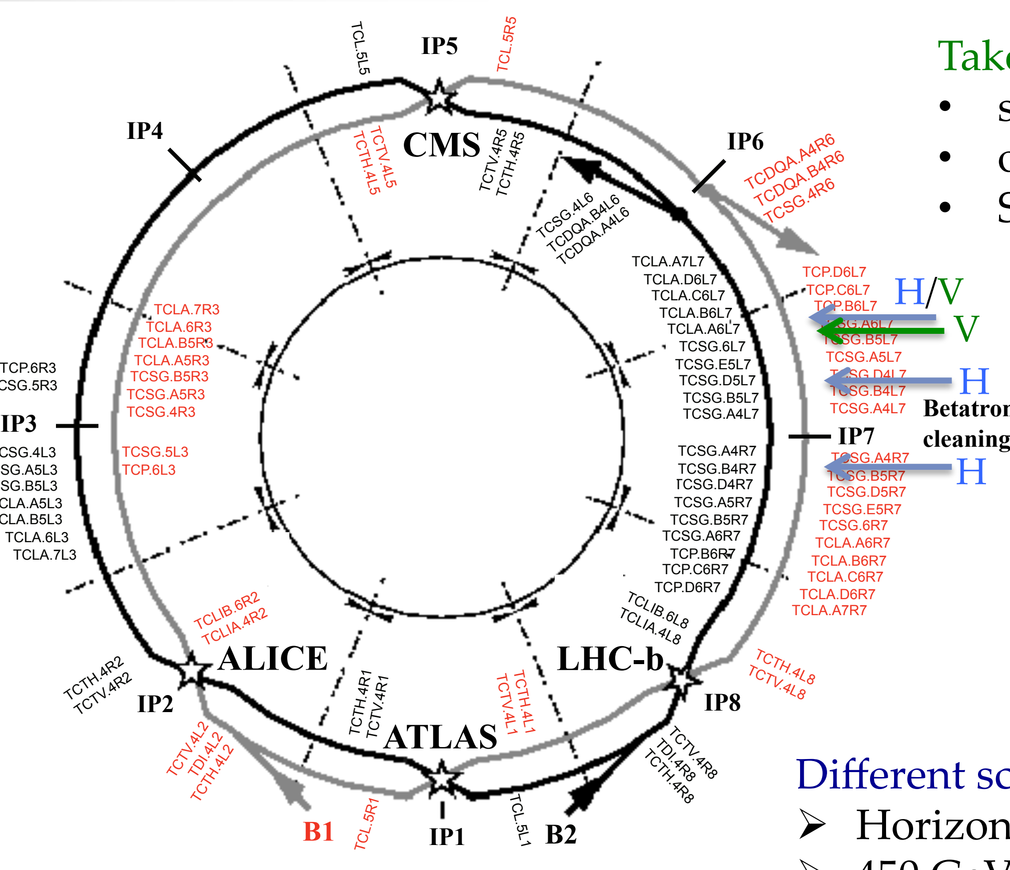
Possible scenarios

Considered possible installation only in the IP7, B1.



Taken into account various positions, based on:

- space availability
- optics considerations
- SixTrack simulations

Possible preliminary tests after LS1:

- low intensity (pilot bunch)
- inj. and top energy
- full collimation chain in place

then…

- higher intensity (still within safe boundaries)
- possibility "to play" with the TCSG settings

Different scenarios are under investigation:

- Horizontal & Vertical planes
- 450 GeV & 7 TeV
- Full collimation chain in place with crystal as primary
- Crystal as primary and only one TCSG

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Tools

Study based on Semi-analytical Models and full SixTrack simulations

Calculated the trajectory of the channeled beam for any available position of the crystals :

$$x_s = \sqrt{\frac{\beta_s}{\beta_{Cr}}} \cos\left(\Delta\phi\right) x_{Cr} + \Theta\sqrt{\beta_s \beta_{Cr}} \sin\left(\Delta\phi\right)$$

Calculate the displacement at every secondary given by a kick of 40μrad at the Crystal and its aperture has been set

First selection of the layouts that give better impact parameters on the secondary collimator at any energy

Then:

Full SixTrack simulations with complete layout and geometry implemented for the choose subset

Simulations based on the SixTrack version modified by Valentina Previtali with the insertion of the crystal routine.

Design concept

Energy [GeV]	θ_c [μrad]
450	9.42
7000	2.39

"Ideal" position:

✓ $\alpha \sim 0$

alignment independent of beam energy!

only linear movement needed during the ramp

✓ D ~ 0

possible reduction of b (imp. par.)

✓ ~90°ΔΦ w.r.t. secondary collimator

Other "constraints" taken into account:

- Crystals close to the "primary's area" (full chain of secondary collimators available downstream)
- Absorption of channeled beam sufficiently upstream from cold magnets
- space availability along the channeled beam path for its detection and measurements, with a possible dedicated detector (feasibility studies are ongoing).

Example of check w.r.t. geometrical apertures:

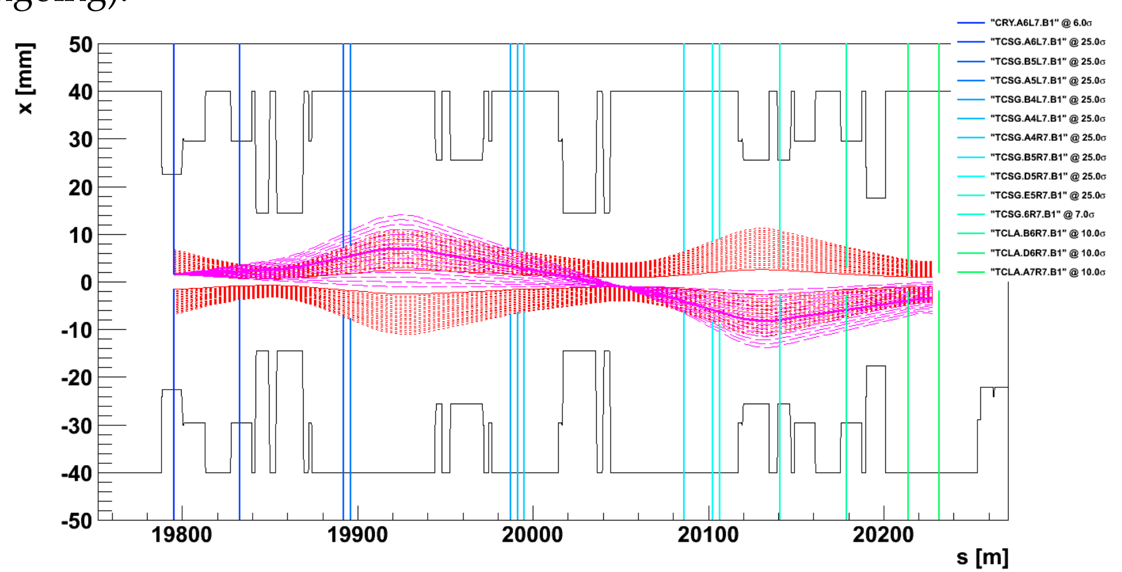
---- beam envelop

– – kicked particle traj.

—— Hor. aperture

Available TCSG & TCLA

(see next slides…)

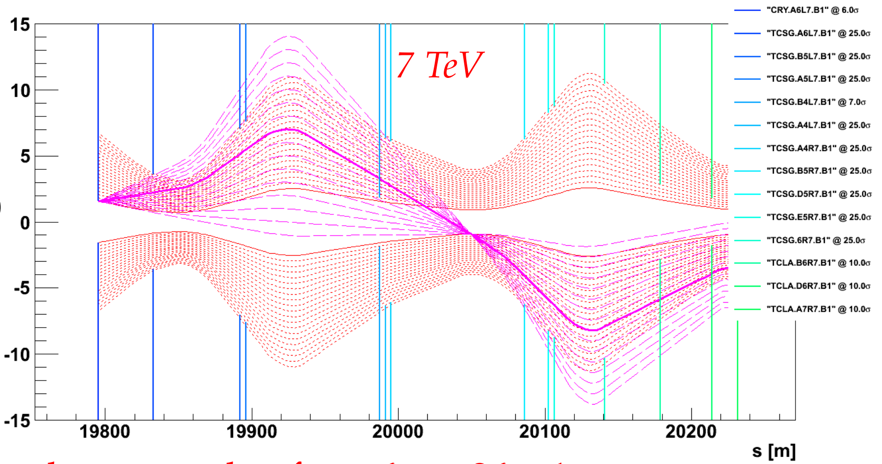


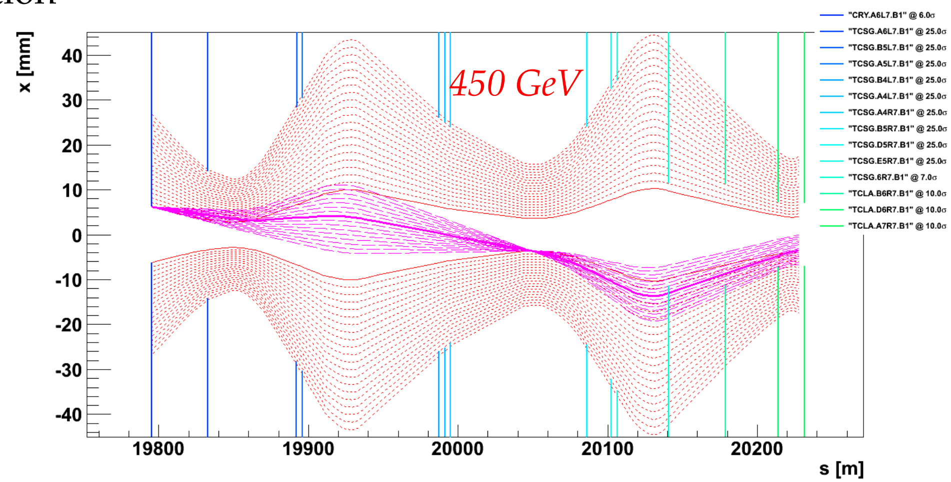
Candidate locations in IR7

Reported the two "more significant" cases (horizontal):

✓ right after the present primaries at TCP.A6L7.B1 location

(1)





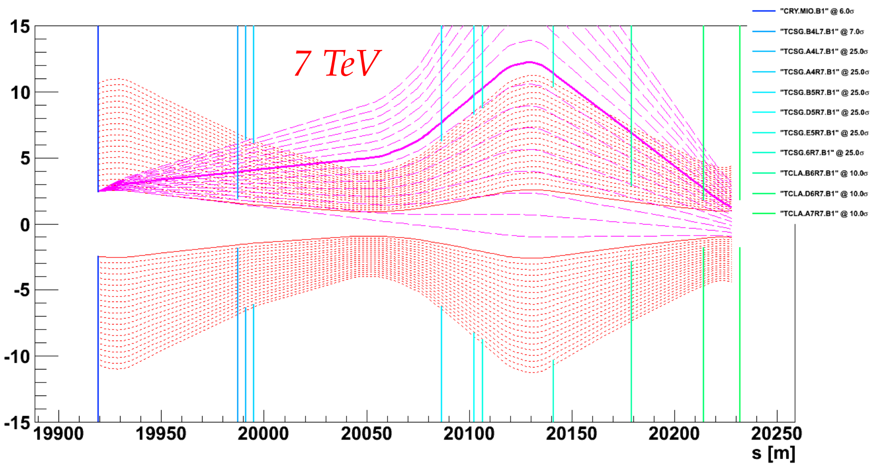
beam envelop from 6σ to 26σ, 1σ steps

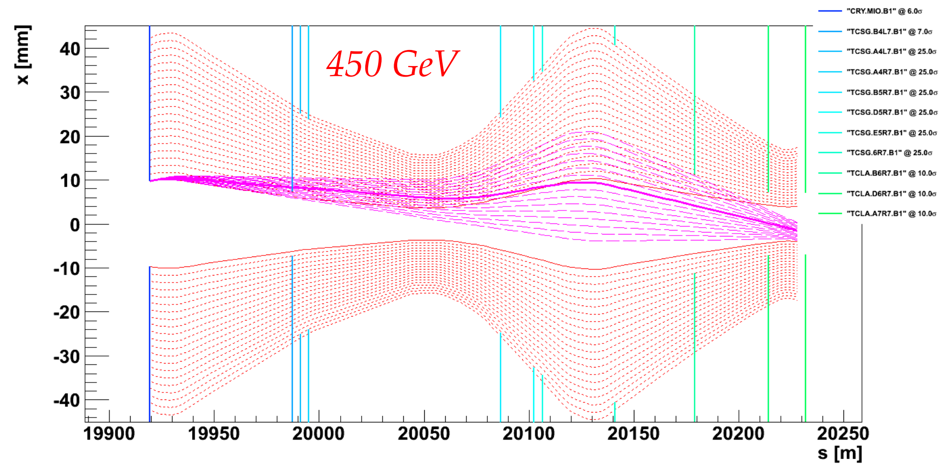
kicked particle traj. from 0μrad to 80μrad, 5μrad steps

x projection of the Available TCSG & TCLA

✓ between the TCSG.D4L7.B1 & TCSG.B4L7.B1

(2)





Main difference: (1) may needed to change TCSG btw inj. and top energy, (2) no change & early abs.

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Simulations

After a first selection choose the following position:

2 for the Horizontal plane ➔ @ TPC.A6L7
@ between TCSG.D4L7 & TCSG.B4L7

2 for the Vertical plane ➔ @ right after TPC.A6L7
@ between TCSG.A6L7 & TCSG.B5L7

Reported result only for the horizontal cases, still some debug needed in case of the vertical

For every position made comparative studies between:

- Standard collimation system
- For crystal in channeling and amorphous conditions:
  - using only one secondary collimator to absorb the channeled beam
  - using the full chain of secondary collimator downstream the crystal in place
- Injection and Top Energy (450GeV and 7TeV respectively)

Crystal simulation set up

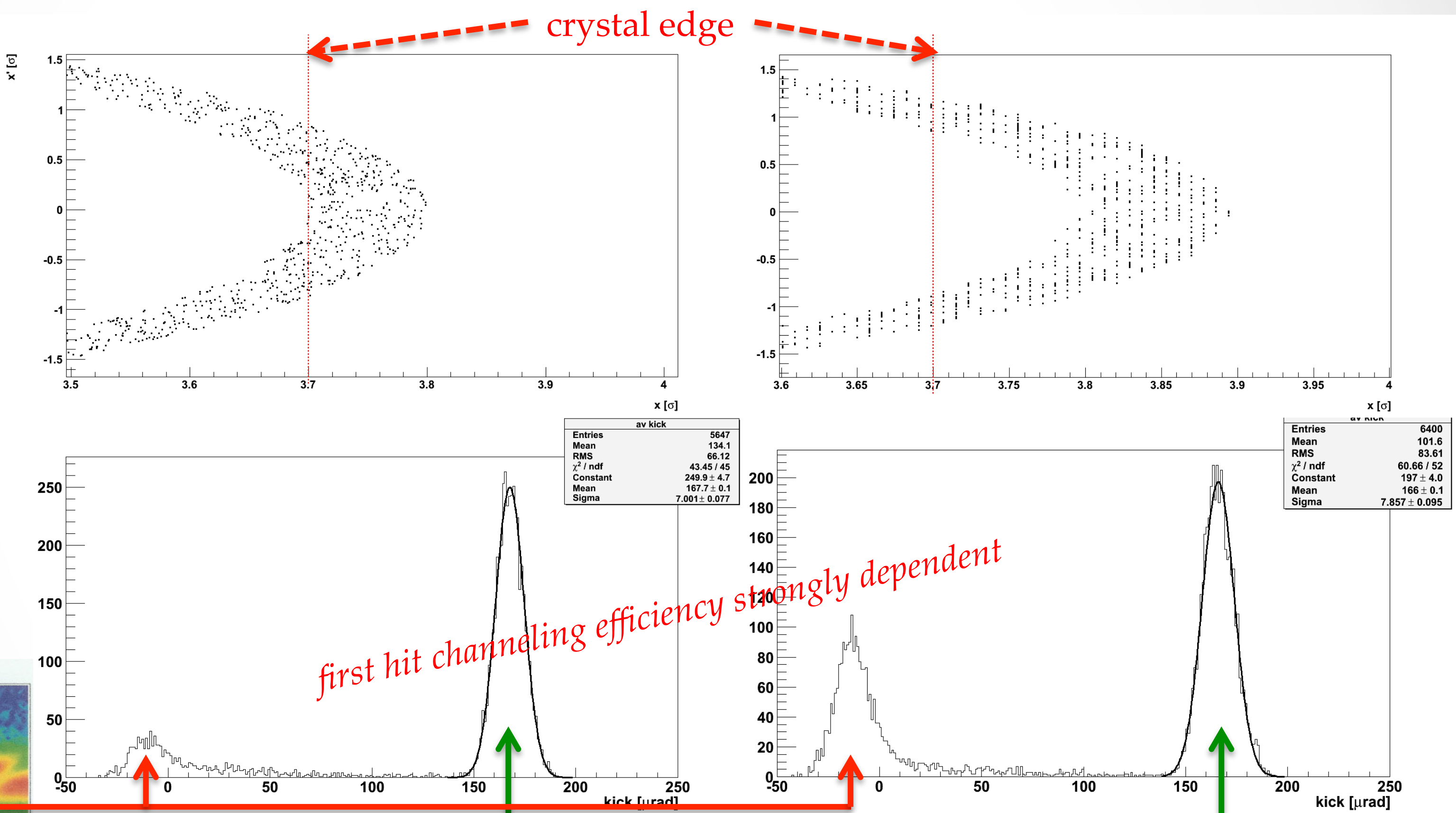
Preliminary checks comparing simulations and experimental data from UA9 in the SPS

Key parameter in case of crystal collimation simulations: **Impact Parameter**

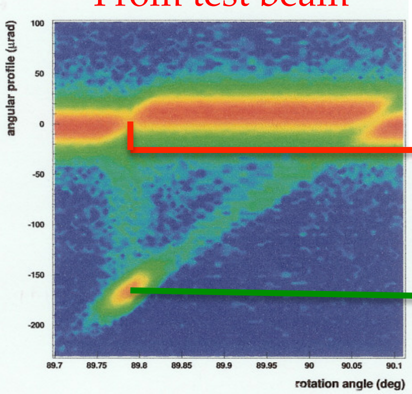
("example of extreme situations")

Generated halo

Kick got at the first hit on crystal



From test beam



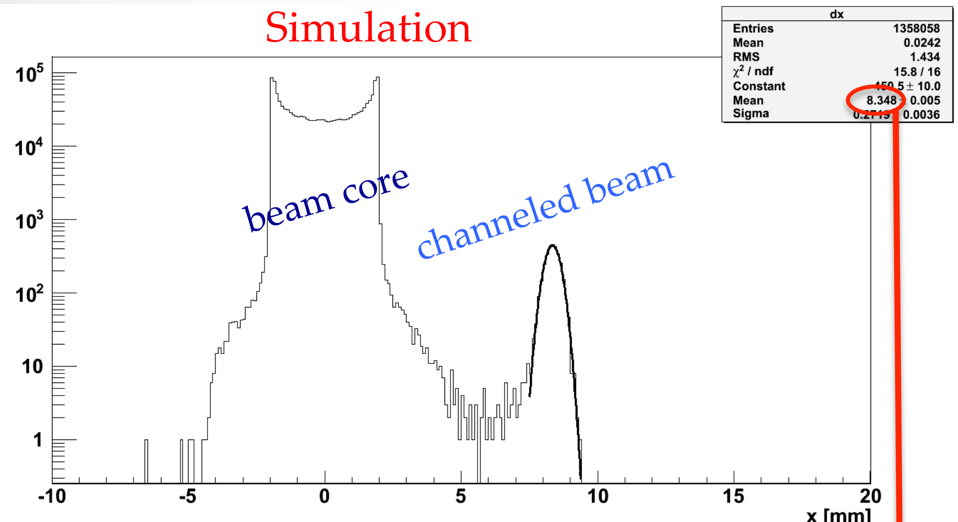
Theoretical deflection expected (for crystal in the SPS at 270 GeV):

- 170.0 ± 7.3 μrad

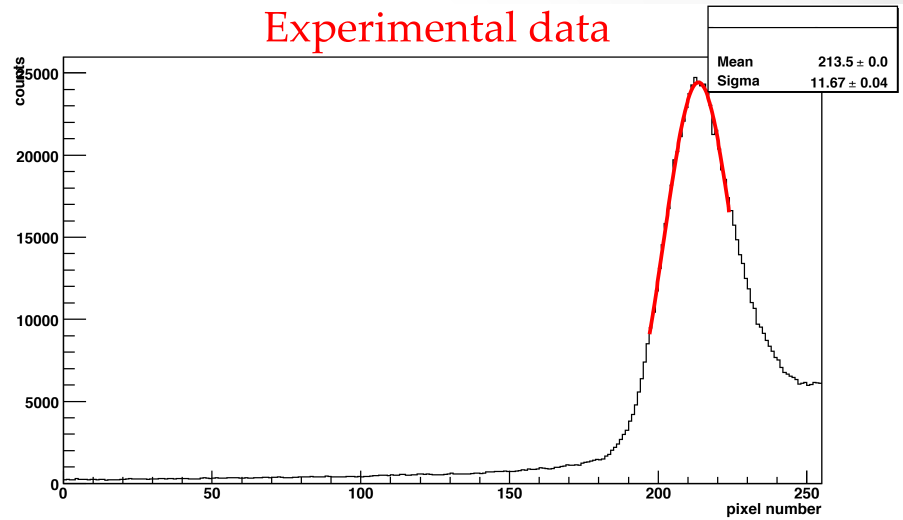
Used the distribution that gives the closer results to experimental data

Preliminary validation with SPS data

<u>Reproduced the spot of the extracted beam on the Medipix (pixel detector in the UA9 layout)</u>



Theoretical position expected of the extracted halo:
- 8.4 mm and full spot width ~700μm



Profile of the extracted halo on the Medipix:
- full spot width ~12 pixel * 55μm ➔ ~600μm

<u>Very good agreement with the simulation!</u>

Tested many initial distributions impacting on the crystal, changing the crystal portion used:
- ➢ spot at Medipix unchanged and always compatible with the width given by the angular spread of the channeled particles (θ_c)

Estimation of the beam spot on the absorber possible using only optic calculations

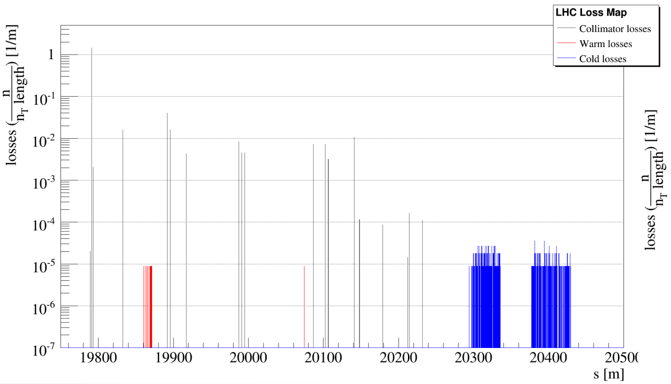
Depending on the position of the primary and the secondary used, full spot width from ~300μm up to ~1.5mm ➔ *<u>Crucial estimation for the absorber robustness</u>*

LHC Simulations

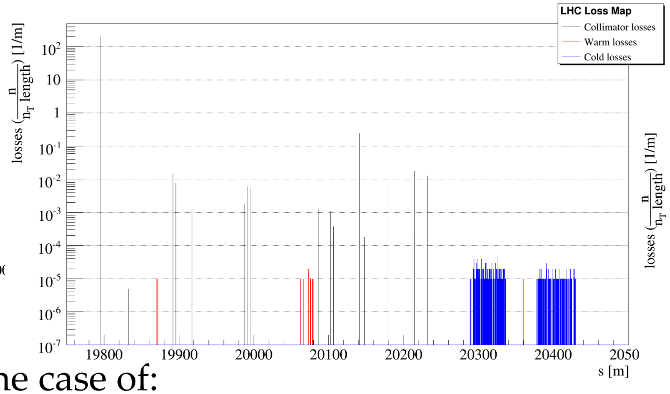
Comparison between full simulations of different collimation processes @ 7TeV

Case of Crystal @ TCP.A6L7.B1

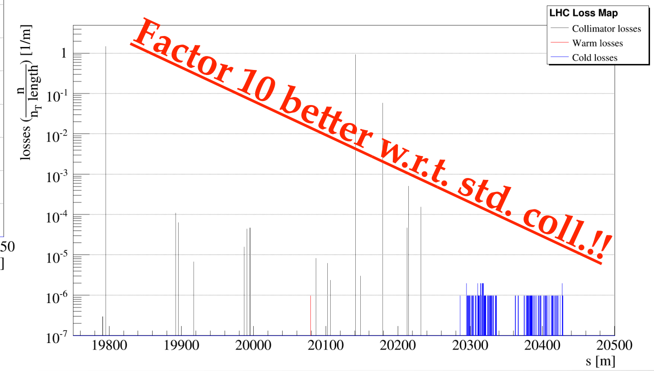
Full collimations system in place:
- ➢ TCP.* @ 6σ
- ➢ TCSG.* @ 7σ
- ➢ TCT* @ 8.3σ
- ➢ TCLA.* @ 10σ



Crystal in amorphous orientation:
- ➢ CRY.A6L7.B1 @ 6σ
- ➢ TCSG.6R7.B1 @ 7σ
- ➢ TCT* @ 8.3σ
- ➢ TCLA.* @ 10σ



Crystal in channeling orientation:
- ➢ CRY.A6L7.B1 @ 6σ
- ➢ TCSG.6R7.B1 @ 7σ
- ➢ TCT* @ 8.3σ
- ➢ TCLA.* @ 10σ



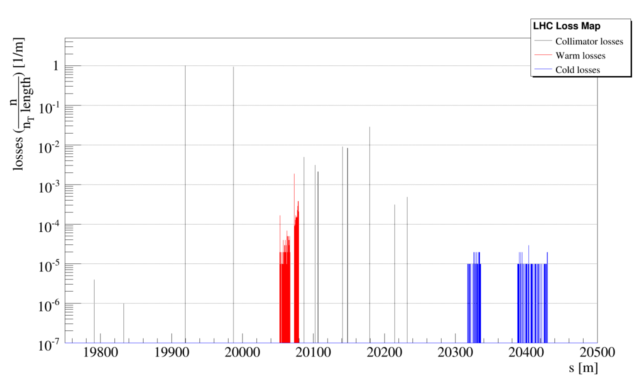
Reported simulations (only IR7) in the case of:
- ✓ 7 TeV (55cm β*)
- ✓ Horizontal plane
- ✓ ~1.3 10^6 particles tracked
- ✓ Number of turns dependent on the system (from 300 for std. coll., up to 5000 for cry. in am.)

LHC Simulations

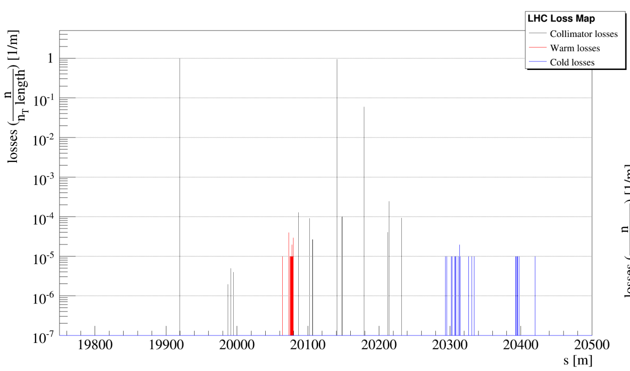
Comparison between full simulations of different collimation processes @ 7TeV

Case of Crystal between the TCSG.D4L7.B1 & TCSG.B4L7.B1
changing the TCSG used to abs. the extracted halo

Crystal in channeling orientation:
- CRY.B1 @ 6σ
- TCSG.B4L7.B1 @ 7σ
- TCT.* @ 8.3σ
- TCLA.* @ 10σ

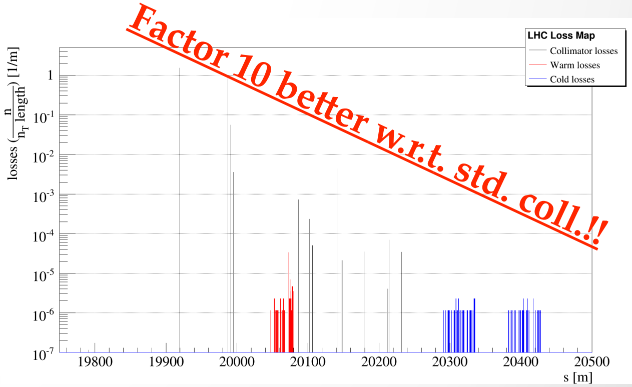


Crystal in channeling orientation:
- CRY.B1 @ 6σ
- TCSG.6R7.B1 @ 7σ
- TCT.* @ 8.3σ
- TCLA.* @ 10σ



Crystal in channeling orientation:
- CRY.B1 @ 6σ
- TCSG.* @ 7σ
- TCT.* @ 8.3σ
- TCLA.* @ 10σ

Factor 10 better w.r.t. std. coll.!!



Same simulations “boundary conditions” as in the previous slide.

Having the previous plots in mind, in this case:
- ✓ same level of losses at the disp. supp. using only 1 TCSG, w.r.t. “standard collimation”
- ✓ achieved also here a factor 10 better in the losses at the disp. supp. using the full TCSG chain closed!

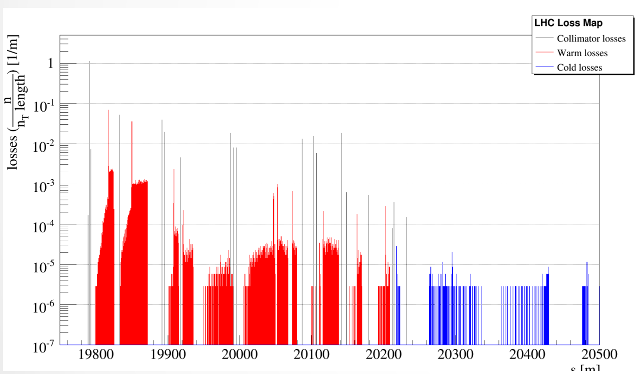
LHC Simulations

Comparison between full simulations of different collimation processes @ 450GeV

Almost same beam losses using different TCSG configurations:
reported only the cases with full chain in place, slightly better for the losses all around the LHC (and not only IP7)

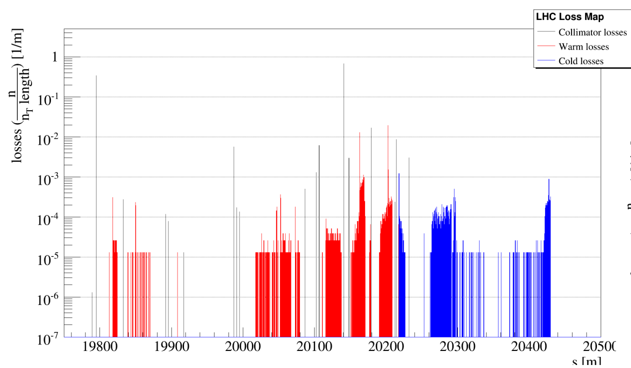
Full collimations system in place:

- ➢ TCP.* @ 6σ
- ➢ TCSG.* @ 7σ
- ➢ TCT.* @ 8.3σ
- ➢ TCLA.* @ 10σ



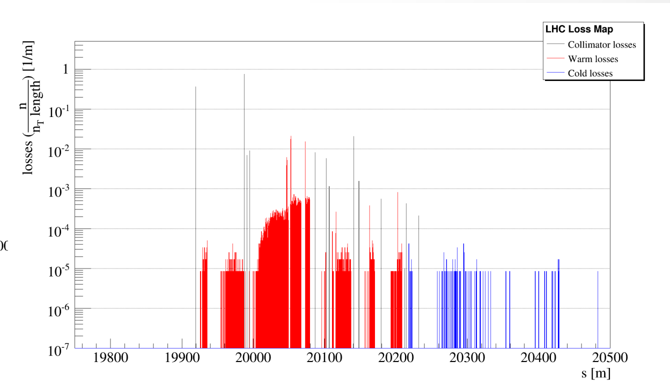
Crystal in channeling orientation:

- ➢ CRY.A6L7.B1 @ 6σ
- ➢ TCSG.* @ 7σ
- ➢ TCT.* @ 8.3σ
- ➢ TCLA.* @ 10σ



Crystal in channeling orientation:

- ➢ CRY.B1 @ 6σ (D4L7<Cry<B4L7)
- ➢ TCSG.* @ 7σ
- ➢ TCT.* @ 8.3σ
- ➢ TCLA.* @ 10σ



Considerations about cleaning inefficiency :

- ✓ worse in case of crystal @ A6L7 w.r.t. standard collimation
- ✓ similar in case of crystal btw D4L7 and B4L7 (maybe needed more statistics)
- ✓ much harder to set the right impact parameter w.r.t. the 7TeV case, maybe possible some improvements

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Conclusions

Shown "the main" theoretical background needed to run simulations for crystal collimation, then checked with the experimental data, and applied to extrapolate key parameters (i.e. b, and beam spot on the absorber)

Reported only results for the horizontal plane, soon results also for the vertical case.

Reasonable scenarios for the first tests after the LS1:

If crystal installed at TCP.A6L7.B1:

- even with perfect crystal channeling, hard to see any improvements at 450GeV for p beams
- instead very good performance at 7TeV:
  - get a factor 10 better in cleaning inefficiency with the crystal and only one secondary in place

huge gain also in impedance, but possible improvements visible only at 7TeV

If crystal installed between TCSG.D4L7 and TCSG.B4L7:

- possible to see improvements also at 450GeV with full TCSG chain closed
- possible to test the system performance and improvements also during the energy ramp (already demonstrated that crystals well follow the beam envelop remaining in "extraction mode")
- to get a factor 10 better in cleaning inefficiency @ 7TeV needed to keep the TCSG chain downstream the crystal closed

impedance unchanged, possible improvements visible at any energy and more safe procedure