WP2: Collimation

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Outline

- Introduction
- Goal and plans of FCC collimation studies
- Role of collimation tasks within the EuroCirCol - WP2
- Where we are now
- Conclusions

Introduction

Several roles of the collimation system. The driving ones in a hadron collider are:

- **Halo cleaning** versus quench limits (for SC machines)
- Passive **machine protection** - first line of defense in case of accidental failures

Driving constraint for LHC and FCC-hh!

Collimation challenges for FCC

	LHC (Design)	HL-LHC	FCC-hh (Baseline)
Beam energy	7 TeV	7 TeV	50 TeV
Beam intensity	3 x 10^{14}	6 x 10^{14}	10 x 10^{14}
Stored energy	360 MJ	690 MJ	8500 MJ
Power load (τ=0.2h)	~500 kW	~960 kW	~11800 kW
Energy density	~1 GJ/mm^2	~1.5 GJ/mm^2	~200 GJ/mm^2

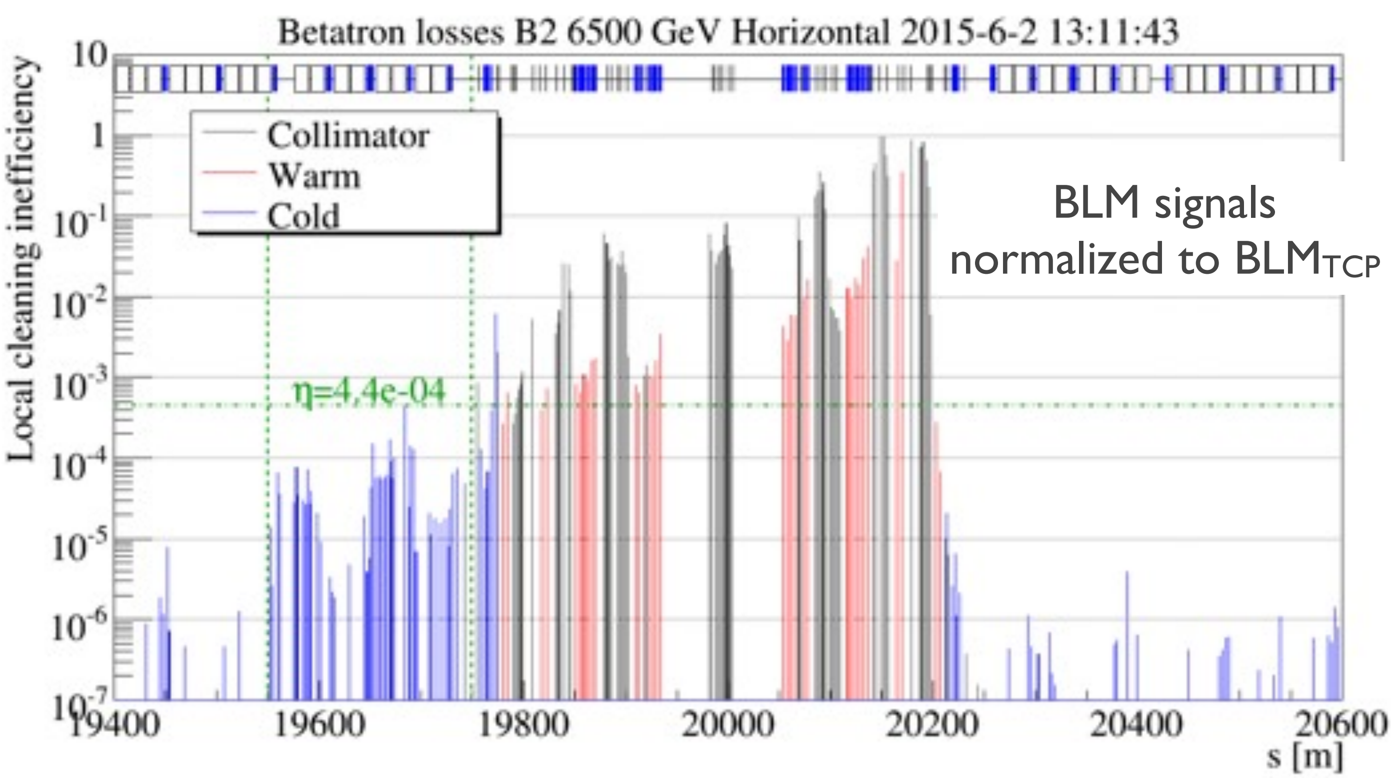
Factor 20 x LHC: stringent requirements on **cleaning inefficiency** to avoid quenches

2 orders of magnitude above the LHC: outstanding challenges for collimator materials

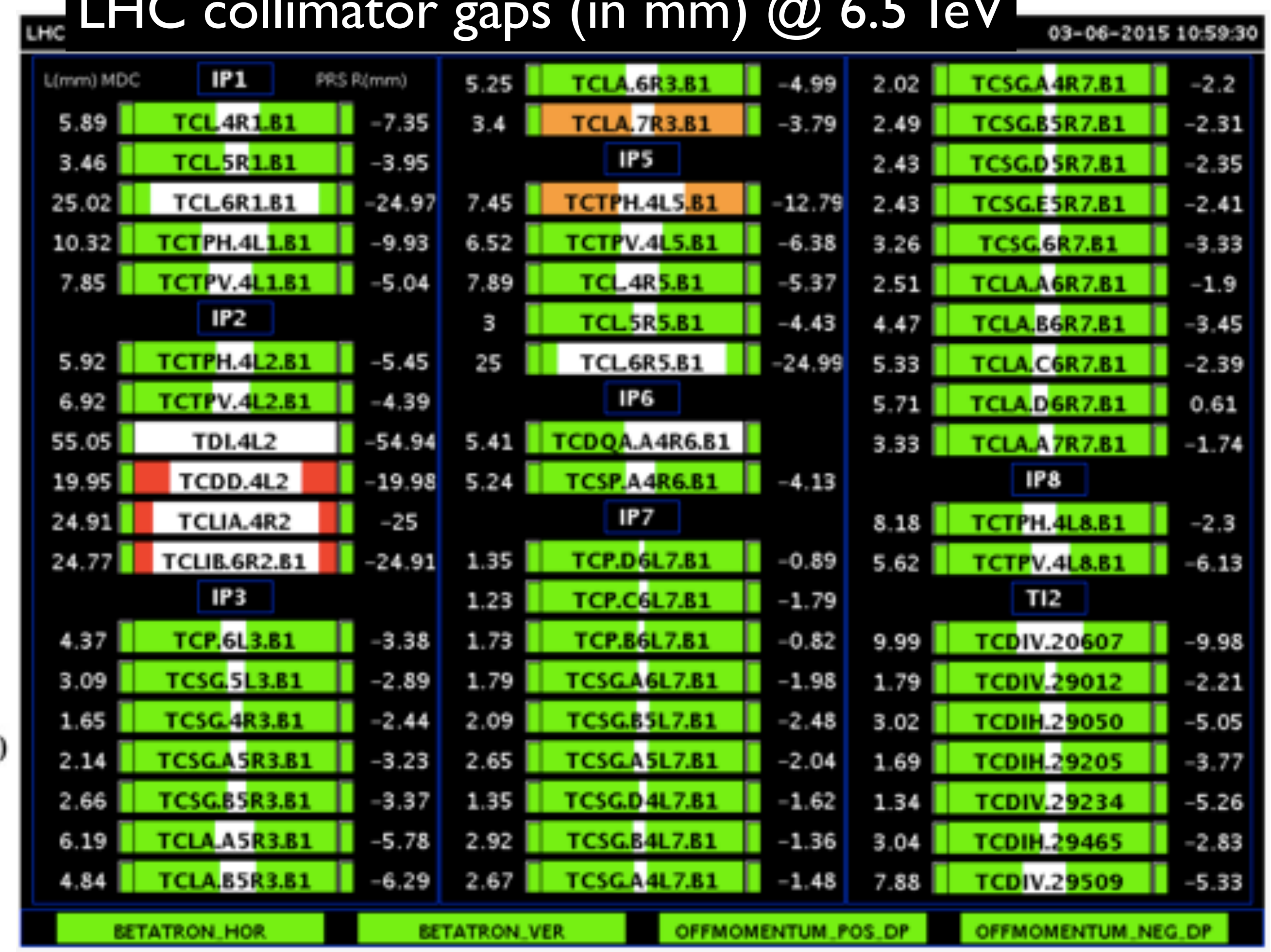
Goals of FCC collimation studies (I)

Target: early 2016 (MS12 and FCC week)

- First baseline for a collimation system design
  - based on a scaled-up version of the present LHC system
    → results should tell us how far we can go with current state-of the art
    - very good performance of the present system so far (validated up to 6.5 TeV)
    - feasible given the tight timescale and available man-power
- List of alternative options for further studies



LHC collimation cleaning at 6.5 TeV
in IR7 (betatron cleaning)



LHC collimator gaps (in mm) @ 6.5 TeV

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➡ Detailed scope for first baseline:

- dedicated insertions for betatron and momentum cleaning
- IR collimation: incoming beam ("tertiary collimators")
- IR collimation: physics debris cleaning

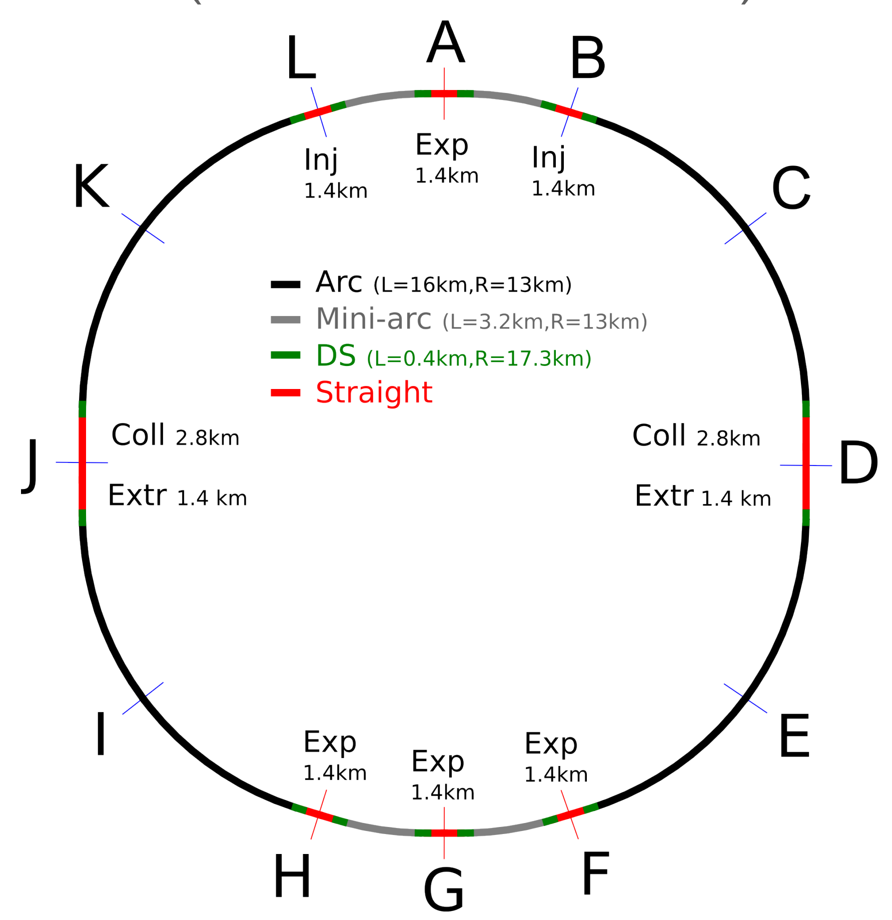
Goals of FCC collimation studies (II)

Requirements to achieve first baseline:

- Define ring layout (FCC collimation WG + FCC dump WG)
- Validation of the cleaning performance with tracking simulations (complete loss maps)
- Calculation of FCC aperture and definition of baseline for collimator settings
- First evaluation on contribution to impedance

➡ All this will serve as input for the collimation hardware design

FCC preliminary ring layout
(still under discussion)



Organization:

• FCC collimation working group meetings - interface between different teams to cover several aspects (optics, performance, energy deposition studies, hardware design, etc.)

• First two meetings before FCC week. For the future plan to meet ~once per month.

Collimation task in EuroCirCol - WP2

Plan to achieve first baseline:

- Development of an aperture model and define baseline collimator settings - Oct. 2015
- Define specifications for momentum cleaning - soon (July 2015 ?)
- Decision on lattice layout - Sept. 2015
- Optics for momentum cleaning - Sept. 2015 EU
- Design of dispersion suppressor regions including TCLD collimators - Sept. 2015 EU
- Performance evaluation with full set of loss maps and optimization of collimation settings - end of 2015

➡ input for impedance evaluation and HW design

EU **EuroCirCol WP2 contribution:** optics design for collimation

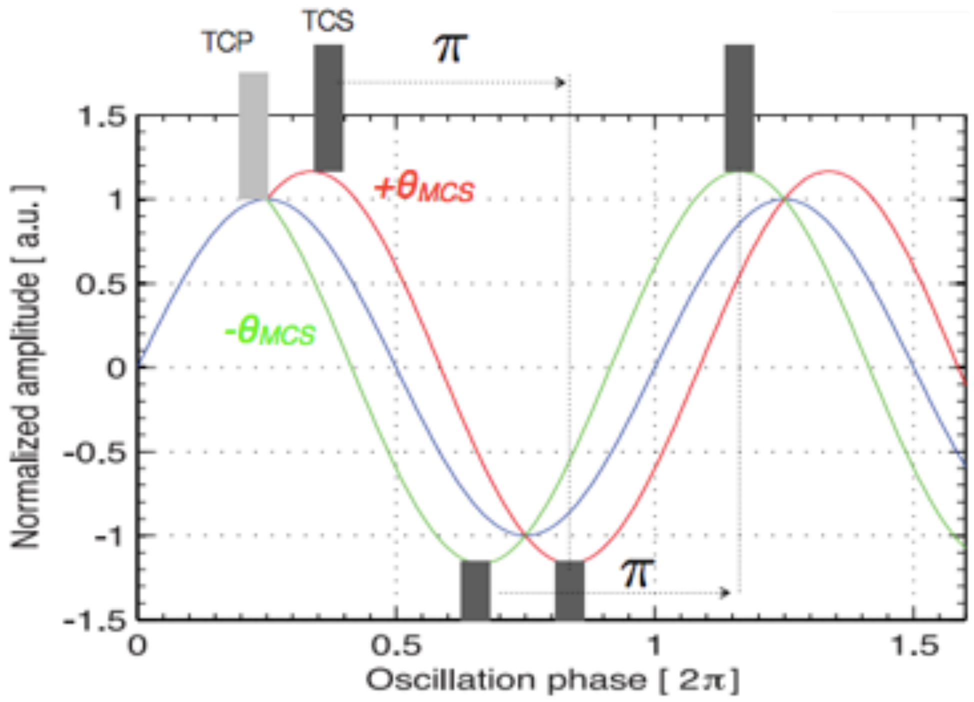
Where we are

Baseline available for a first FCC betatron collimation layout, based on a scaled-up version of the present system

- Standard optics for multi-stage cleaning
- Beta functions scaled to have similar collimator gaps as in the LHC
  → push until later technological developments beyond present state-of-the-art
- Initially, keep current collimation system layout (same number of collimators, positioned at same phase advance, based on C-reinforced-C material for primary and secondary stages)
  → to be optimized later (more collimators for secondary and tertiary stages, new materials...)

Secondary collimators must be placed at optimum phase locations to catch secondary halo

see *Phys. Rev. Spec. Top. Accel. Beams 1 (1998) 081001*

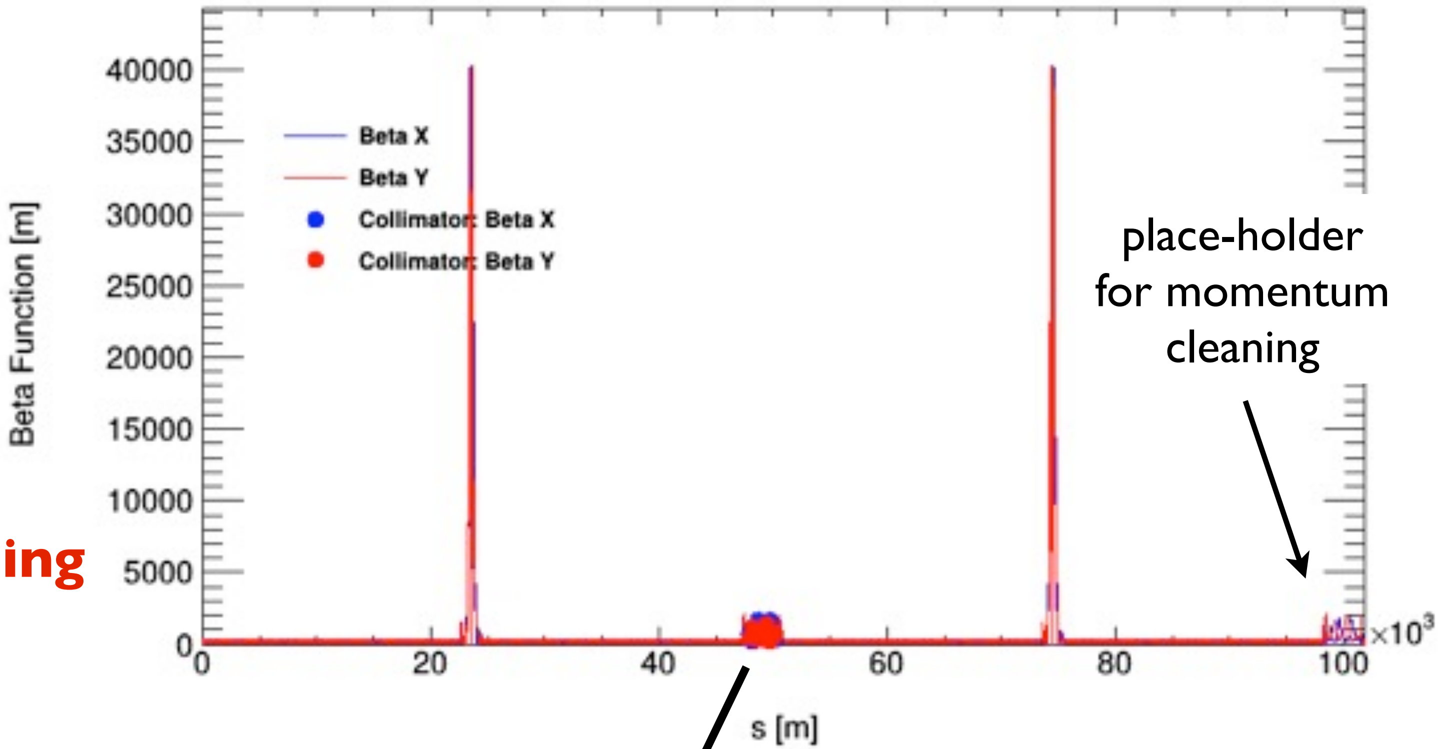


- Dedicated insertion for off-momentum cleaning (yet to be implemented)

Tracking simulation setup

We performed tracking simulations using a lattice with:

- 2 low-beta insertions
- 2 cleaning insertions

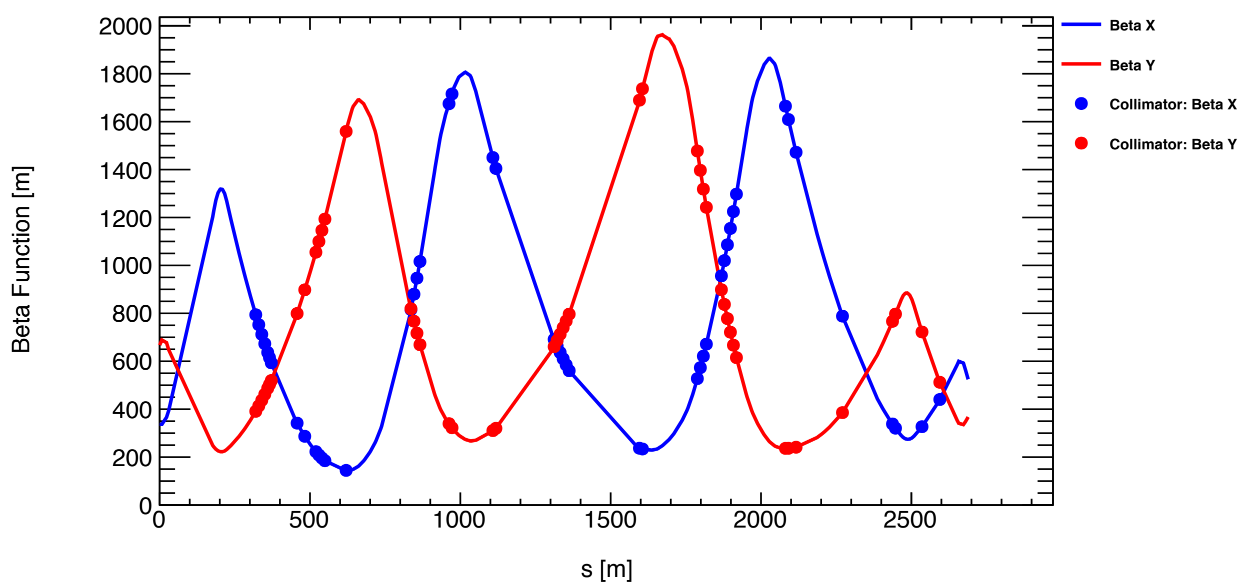


➡ Implemented a **three-stage betatron cleaning** with 19 collimators

Zoom in IR2 (betatron cleaning)

LHC optics and insertion lengths scaled up by a factor 5

- insertion length ~ 2.7 km
- collimator gaps (in mm): 0.84 x LHC gaps



Collimator Settings

3 primaries	TCP	7.6 σ
11 secondaries	TCSG	8.8 σ
5 absorbers	TCLA	12.6 σ

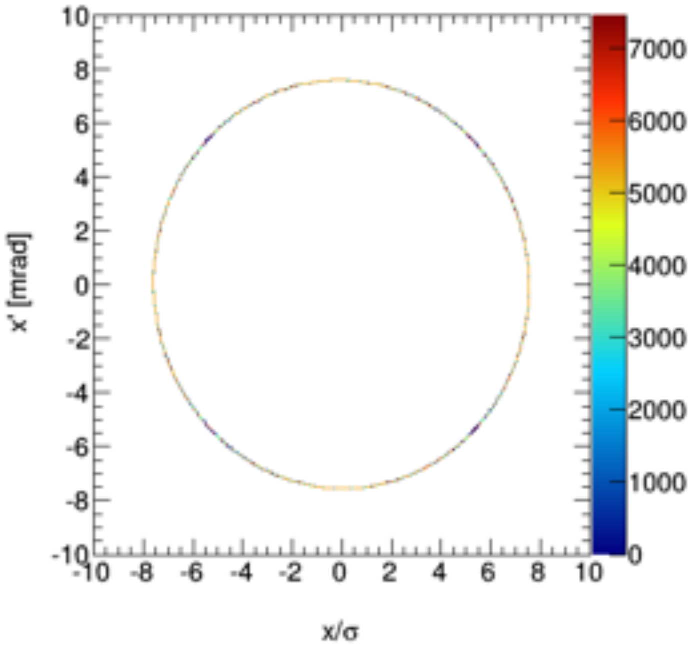
* same settings as for LHC nominal (6/7/10 σ) expressed in σ units for the FCC-hh emittance of 2.2 μm

➡ No momentum cleaning, nor collimation in dump. Implemented also collimation in experimental insertions (two TCTs per IR).

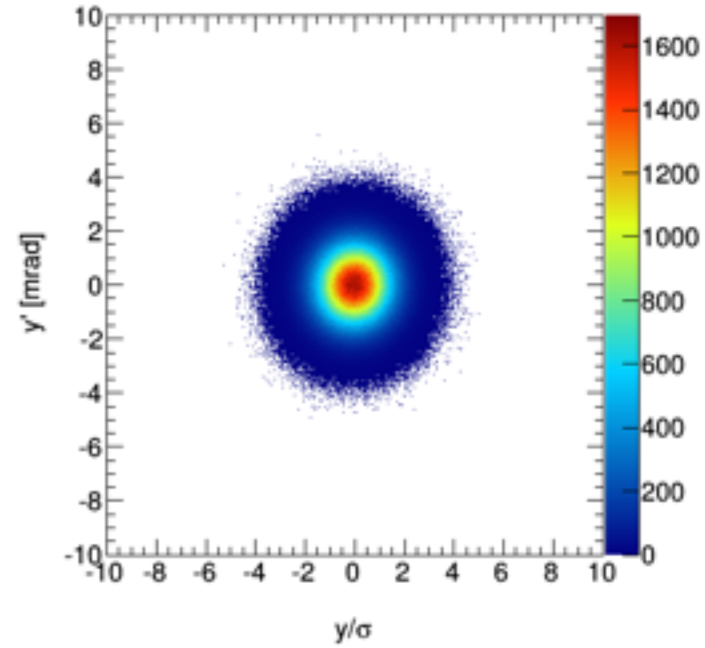
Tracking simulation results

Annular halo setup with predefined impact on primary collimators

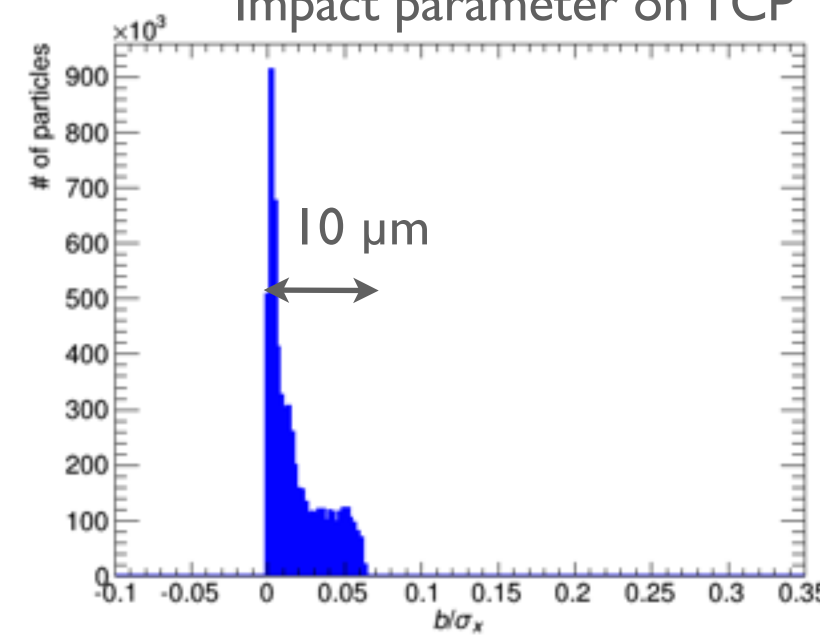
Horizontal halo at 7.6 σ



Gaussian distribution in y-plane

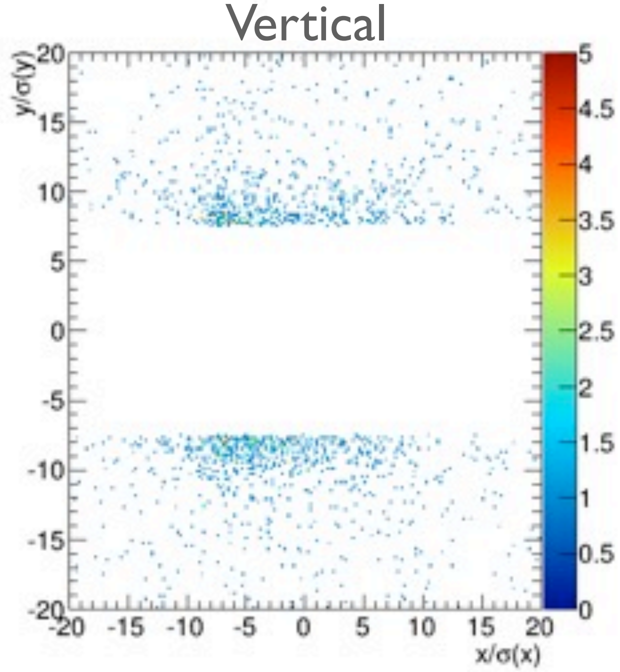


Impact parameter on TCP

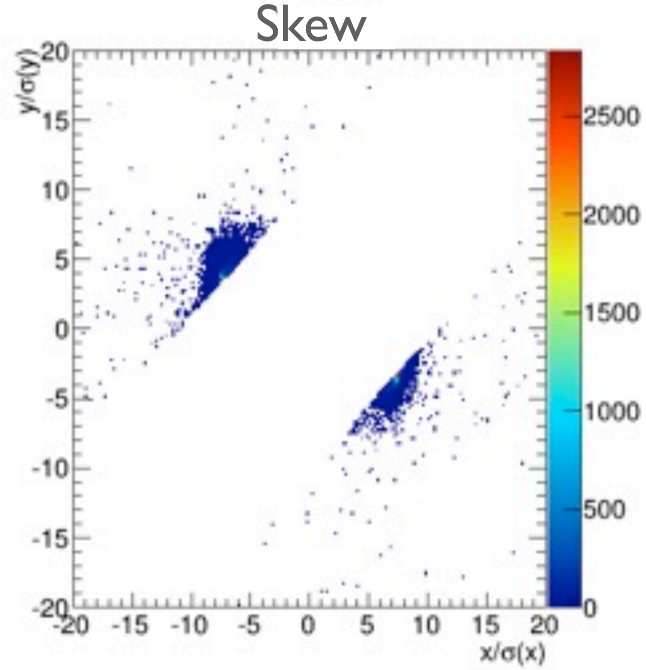


Distribution of inelastic impacts on the primary collimators

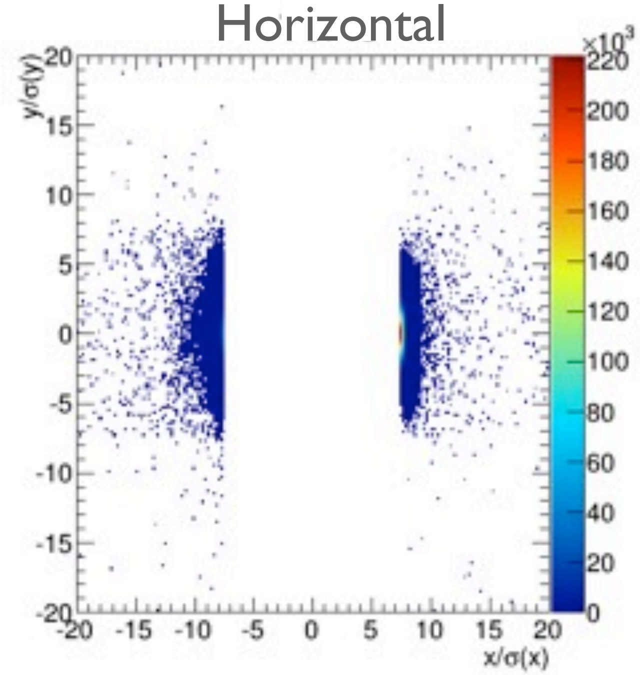
Vertical



Skew



Horizontal



FCC cleaning inefficiency

Performance of the system characterized by a global cleaning inefficiency

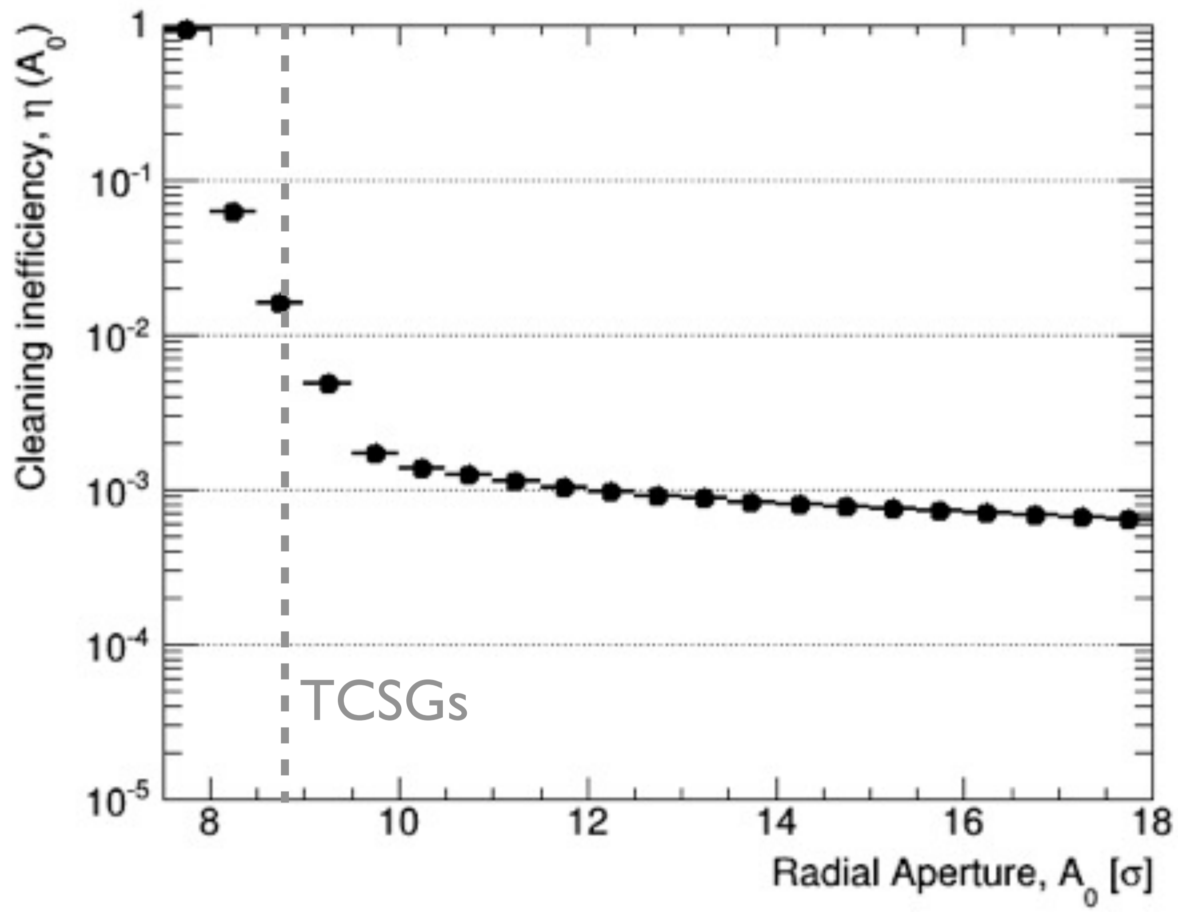
- depends on collimator settings
- no need for machine aperture model

Cleaning inefficiency vs. radial amplitude

$$\eta_c(A_i) = \frac{N_p(A > A_i)}{N_{abs}}$$

→ number of particles above amplitude A_i

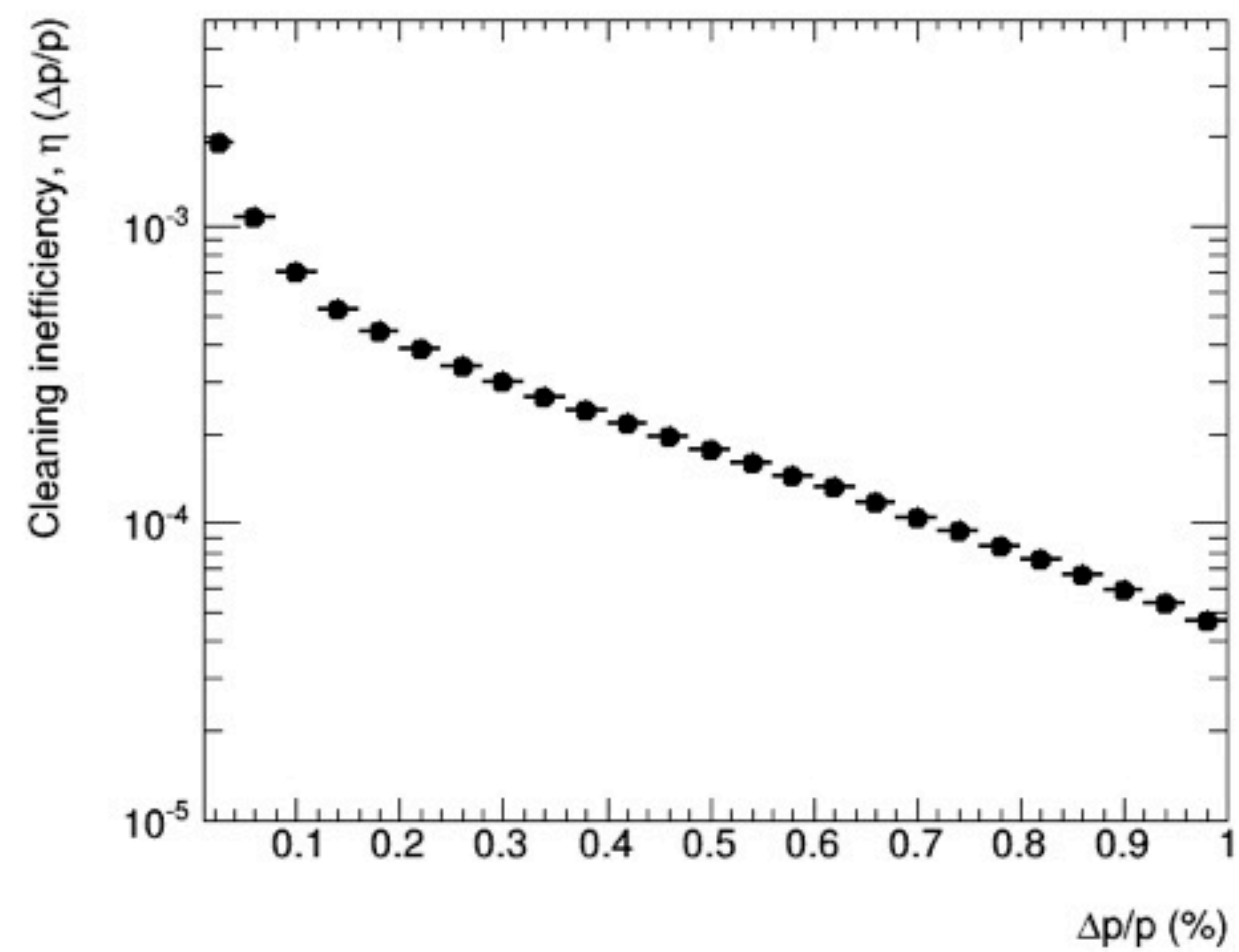
→ number of particles absorbed in coll. system



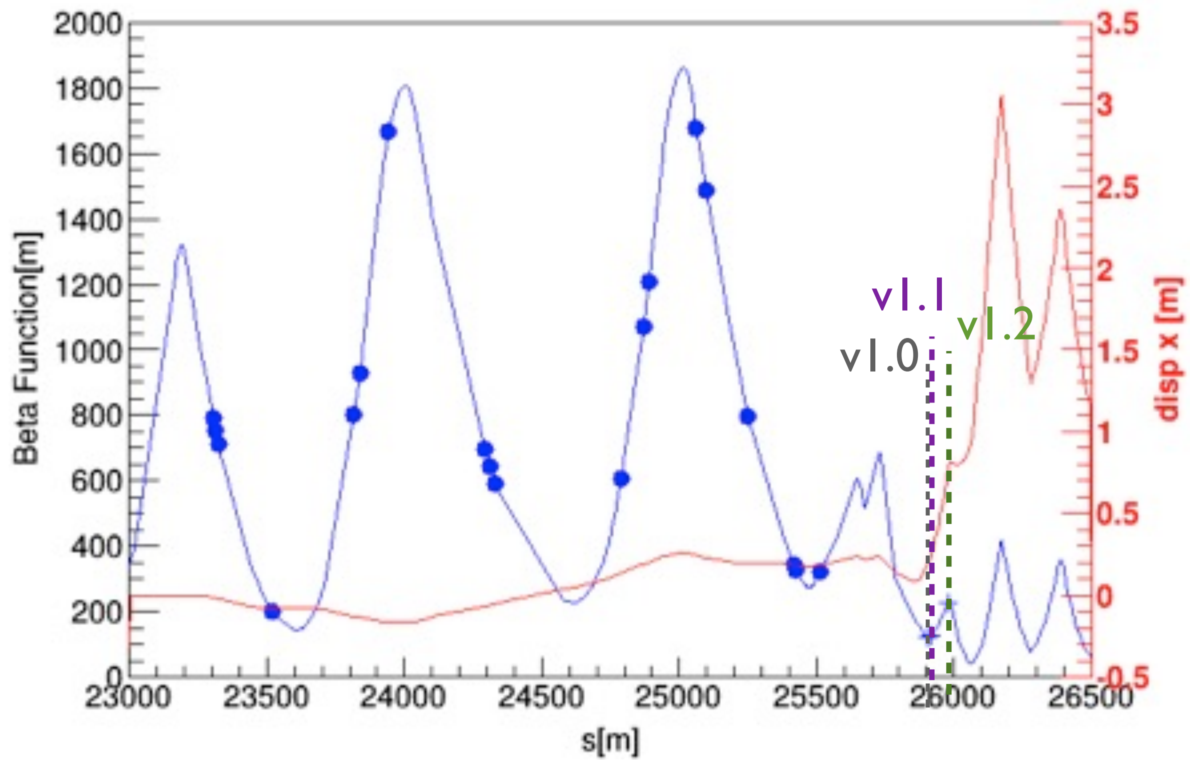
Cleaning inefficiency vs. Δp / p

(off-momentum halo population)

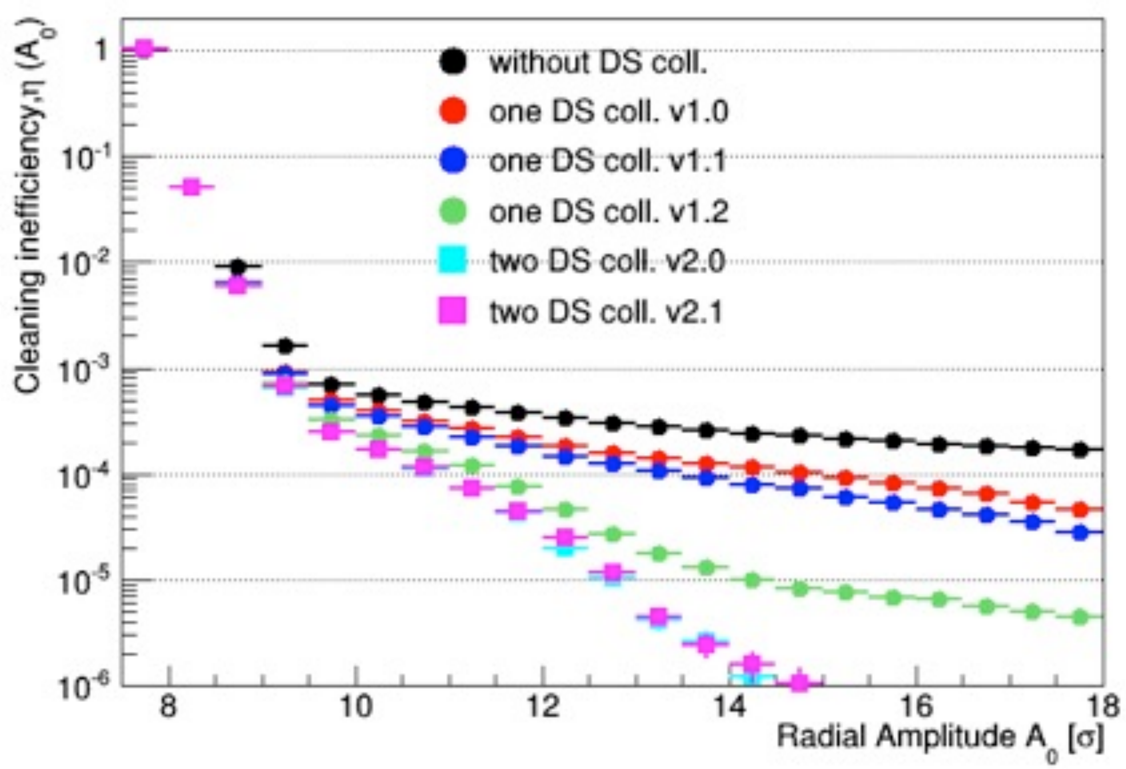
Δp/p: relative momentum loss of protons after interaction in the collimators

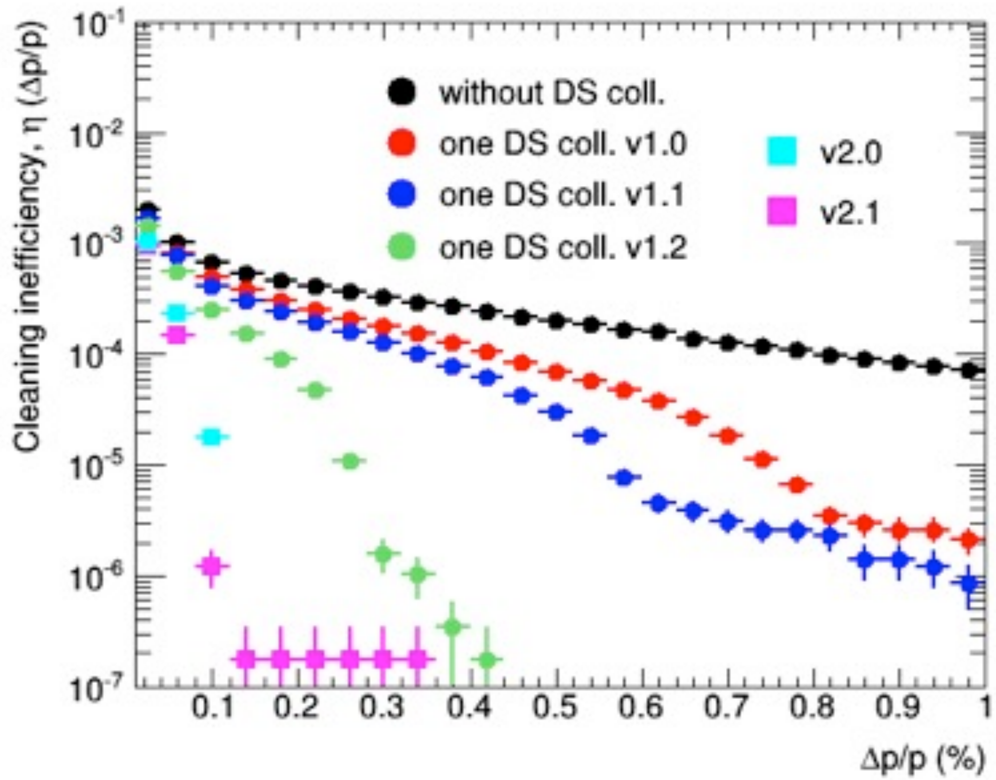


DS collimators in FCC



- **Main cleaning limitation** of current system: critical losses in the DS after the betatron cleaning
- Present system: make space for two room temperature collimators close to first dipole where dispersion starts growing (one15m long dipole replaced with two 5.5m long 11T dipoles)
- We run simulations with one or two DS collimators in FCC layout in cells 8(9), 10(11)
- Two DS collimators provide good cleaning of off-momentum particles





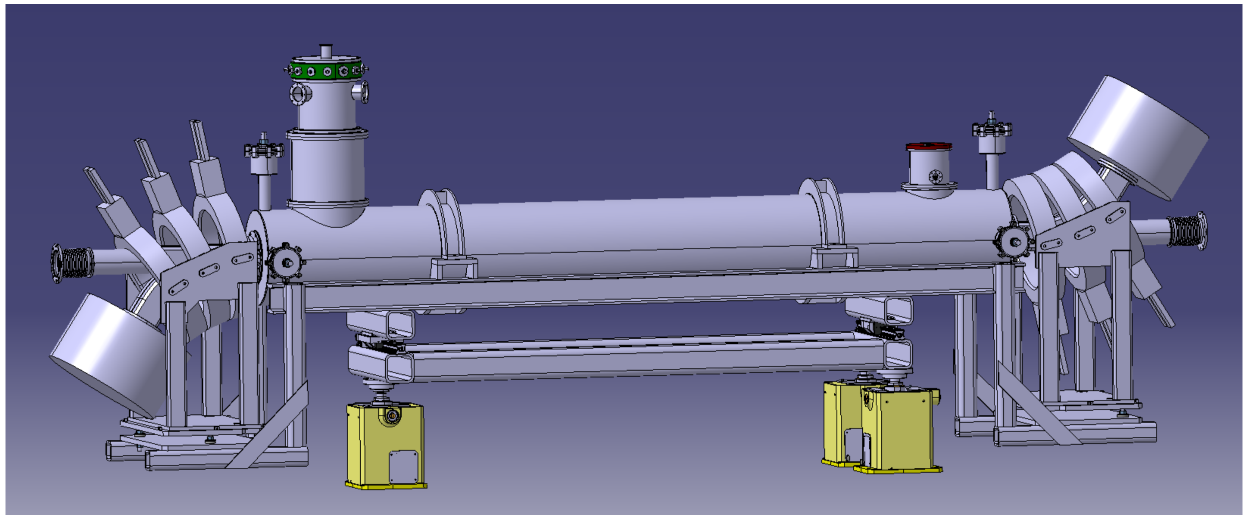
Conclusions

- We have defined the goals and plans to achieve **MS 12 in early 2016**
- EuroCirCol can give an important contribution to the collimation task providing the needed optics support
- We already have in hand the tools to assess and optimize the system performance (tracking simulations, simplified cleaning analysis)
- Soon to be integrated by a full loss maps analysis (currently working on the aperture model) → will then be able to fully and quickly validate the system once the input lattice is available
- First baseline for the FCC collimation layout:
  - "conservative approach": first conceptual design based on a scaled-up version of the present system
  - results should tell us how far we can go with current state-of-art
- In the future, studies of alternative designs and advanced collimation concepts (hollow e-lens and crystal collimation - now part of baseline R&D for the LHC and HL-LHC) and of collimator materials are also foreseen.

Advanced collimation concepts

Hollow e-lens

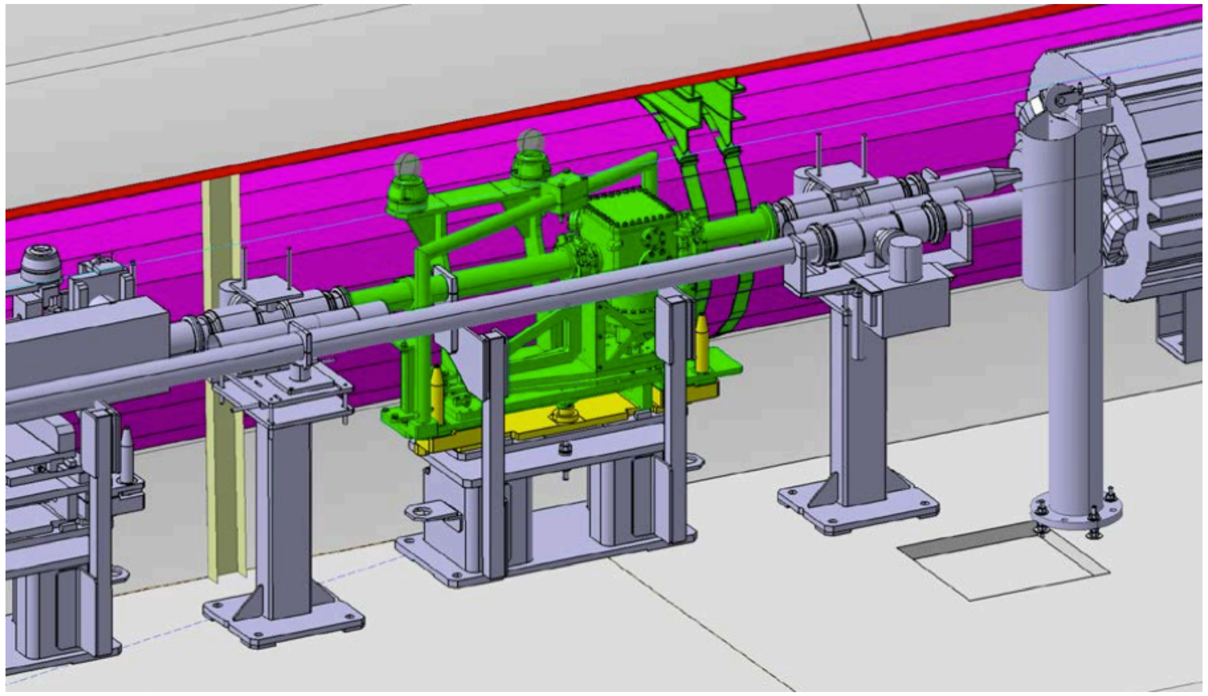
- Hollow electron beam parallel to the p-beam:
  - halo particles see field dependent on (Ax, Ay) plane, while core is unaffected
  - adjusting e-beam parameters can be used as halo scraper



- Expect to be a key asset to control loss rates on collimators
- Working on a design for implementation in LHC in LS2. Decided to build test bench at CERN → also crucial for FCC

Crystal collimation

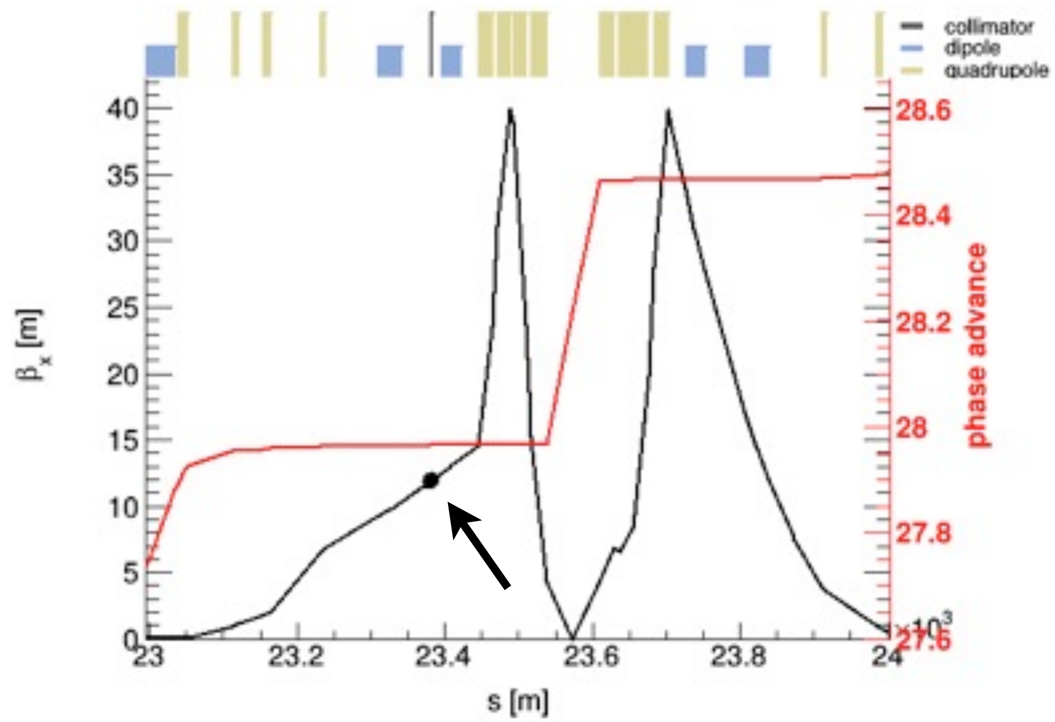
- Bent crystal can be used for channeling and extracting the beam halo in a controlled way
  - can improve cleaning efficiency
  - reduce impedance: less secondary collimators, larger gaps



- Low intensity beam tests at the LHC in 2015
- Promising for the FCC, but large uncertainties on extrapolations to high energies and several operational challenges.

EXTRAS

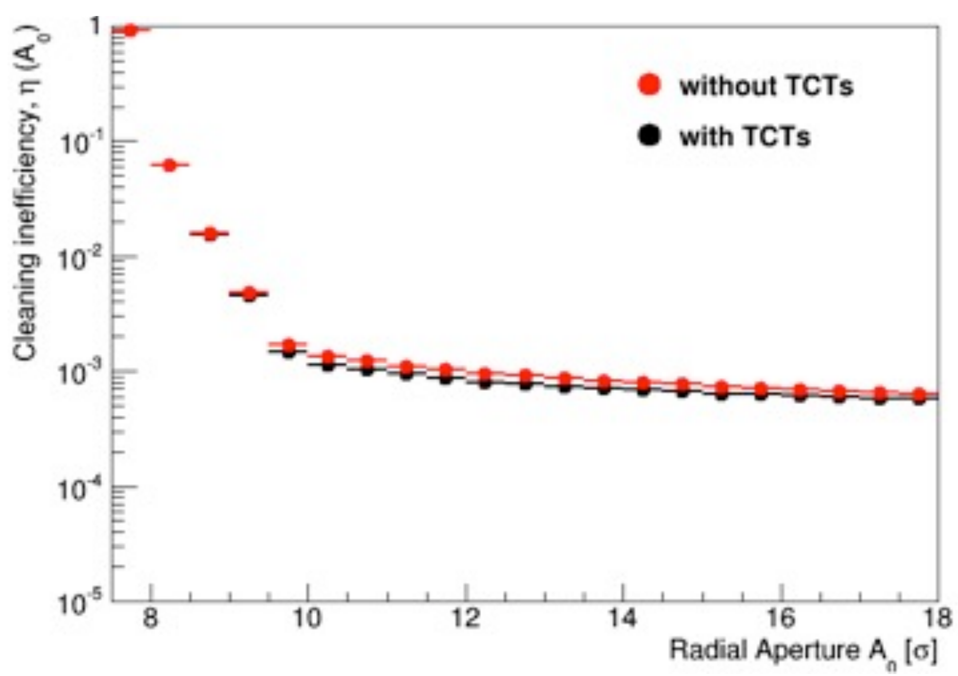
IR collimation: simulation results

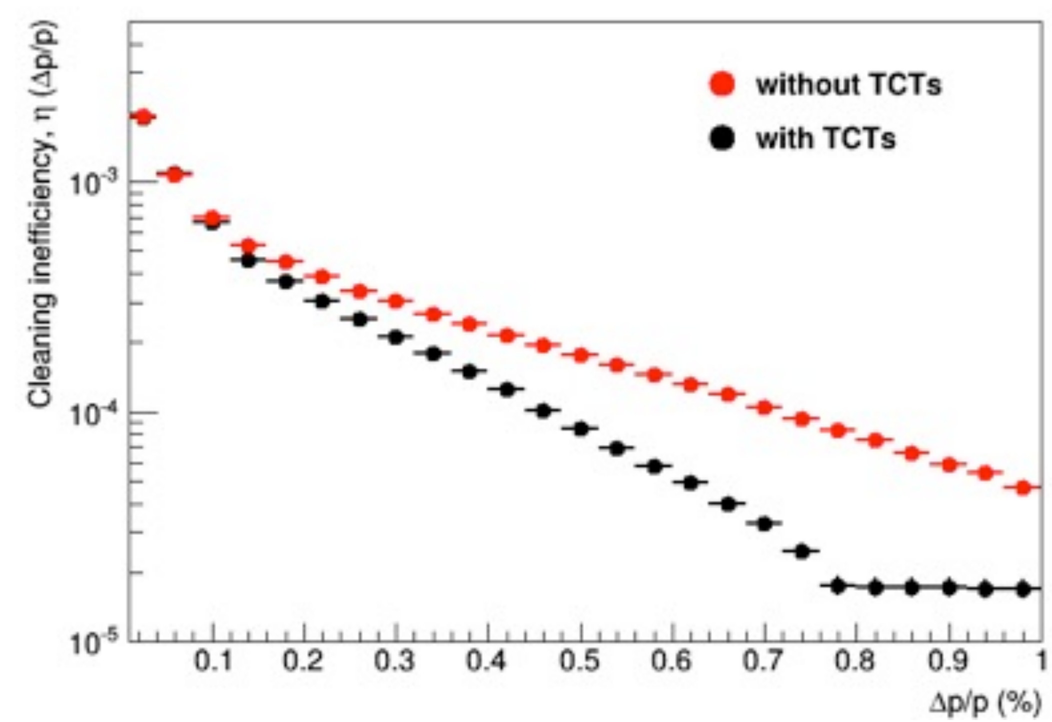


Implemented 2 TCTs (one horizontal, one vertical) in experimental insertions

Collimator settings: LHC nominal settings

TCP	7.6 σ
TCSG	8.8 σ
TCLA	12.6 σ
TCT	10.5 σ



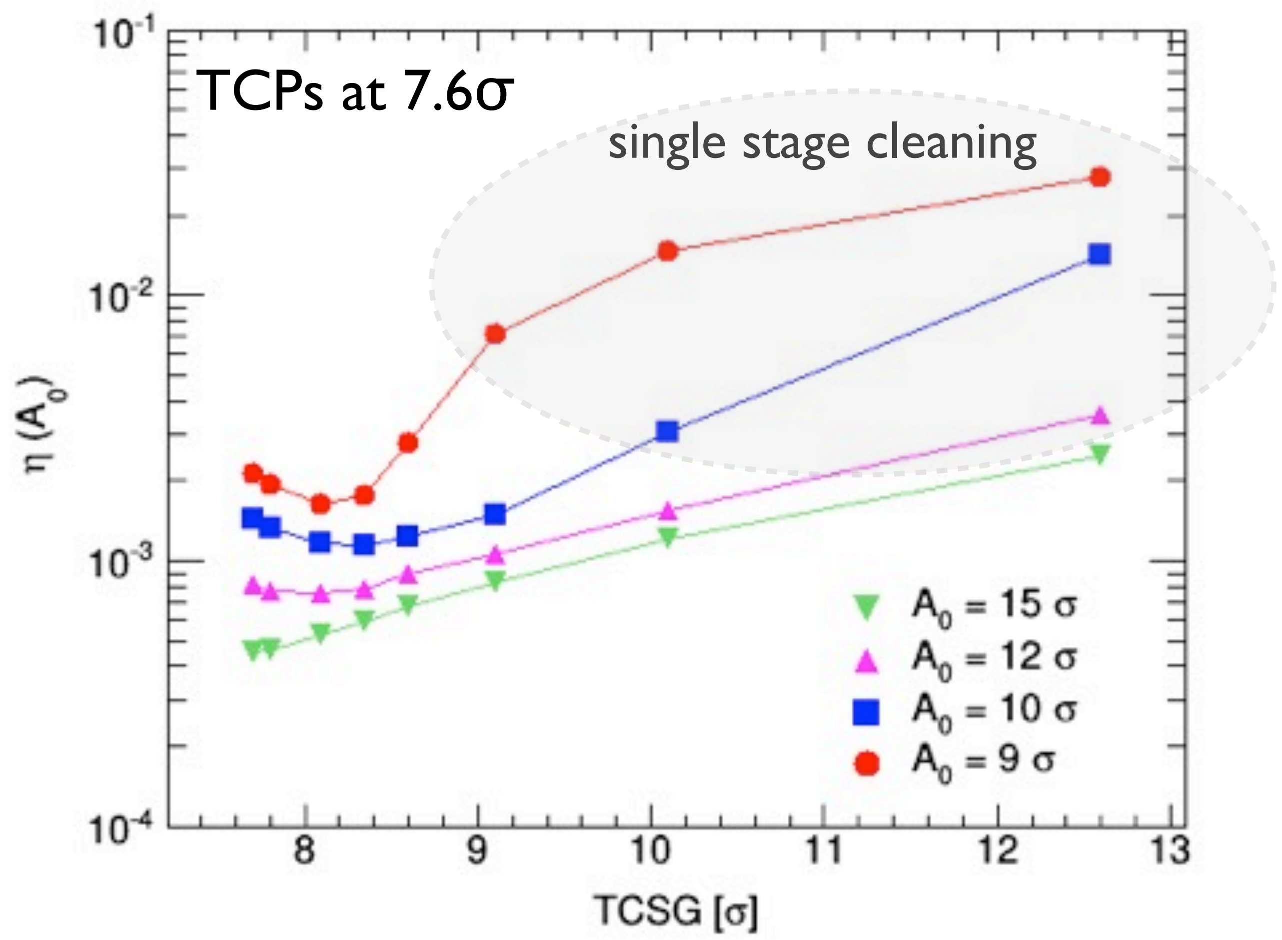


Note: betatron cleaning only (without DS collimators)!
Similar behaviour observed for LHC with IR7 only, while effect of TCTs is negligible with momentum cleaning in IR3.

Cleaning inefficiency vs. settings

Performed a scan of simulation varying the retraction between primary and secondary collimators

Cleaning inefficiency vs. setting of secondaries

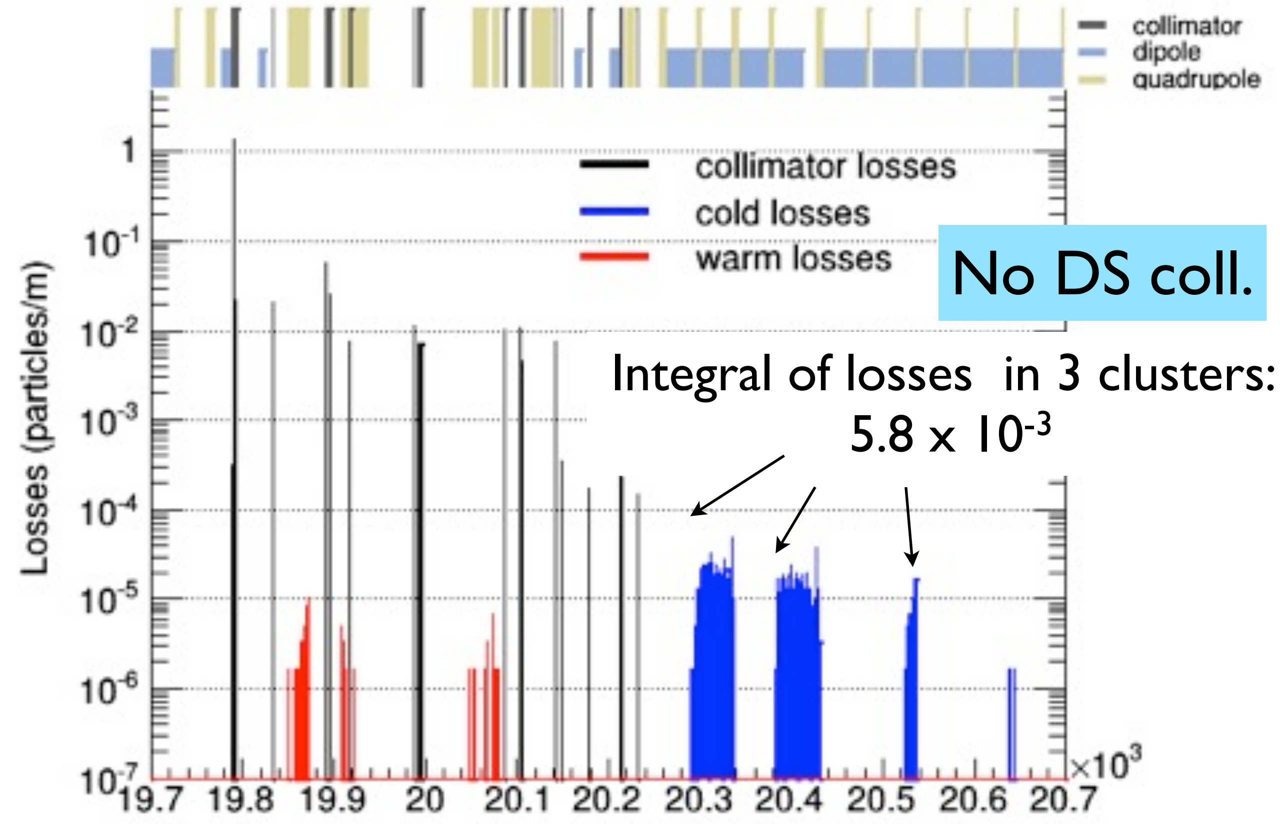


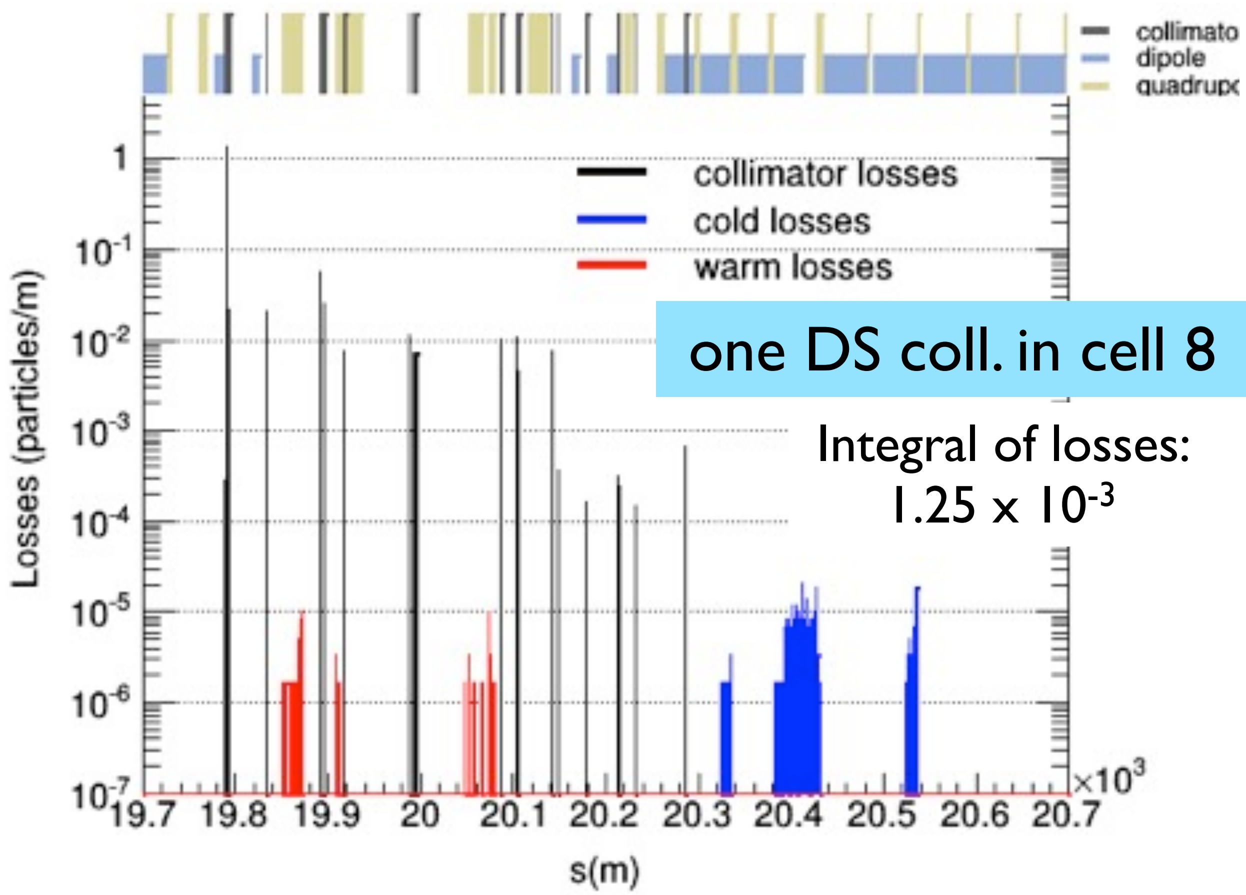
→ will re-optimize phases and optics if needed, once aperture well defined

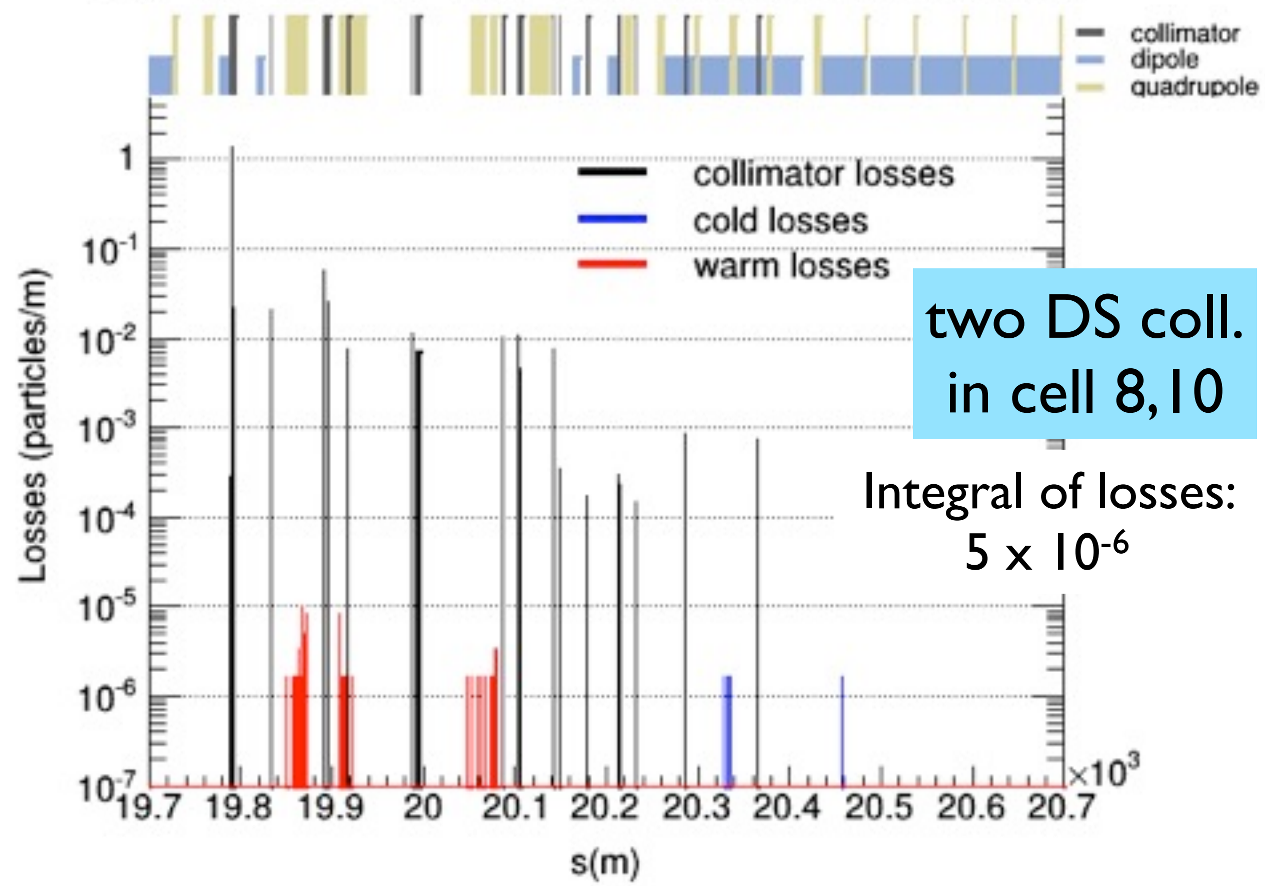
DS collimators in HL-LHC (v1.0)

Layout:
only betatron cleaning
+ 0/1/2 DS collimators

Settings: 6/7/10 σ

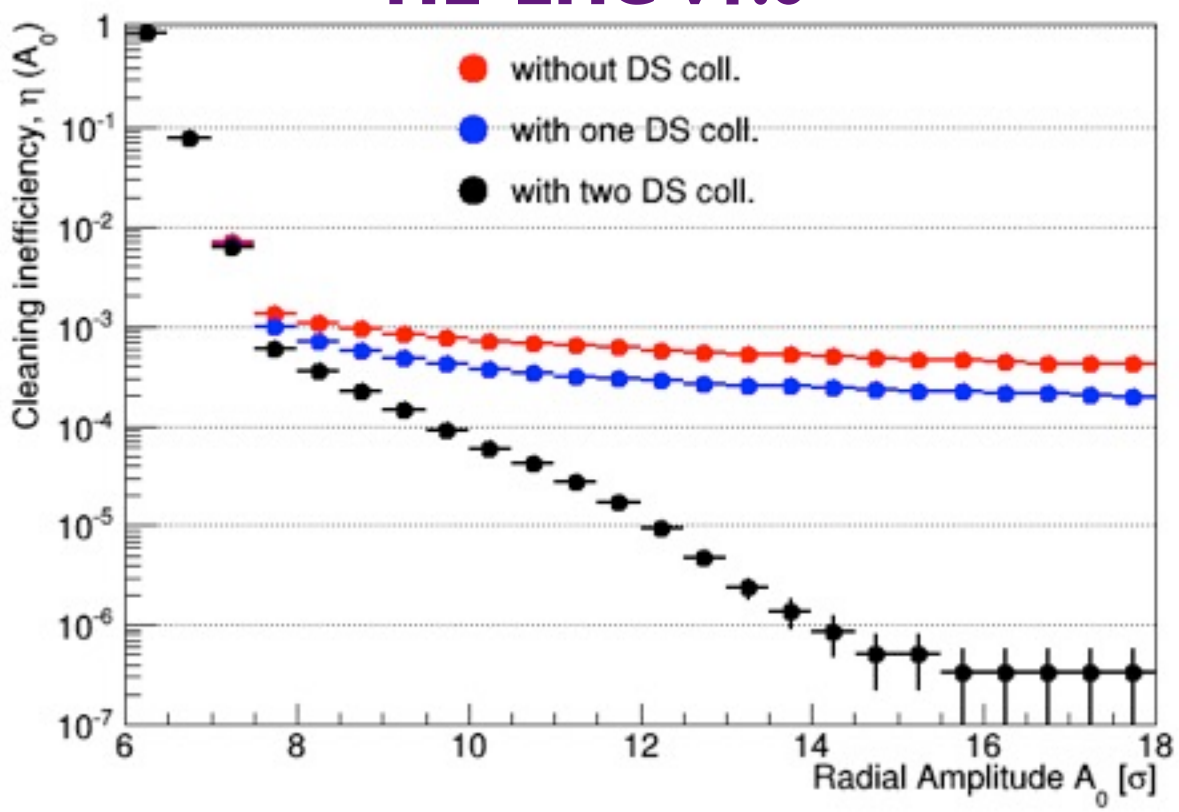


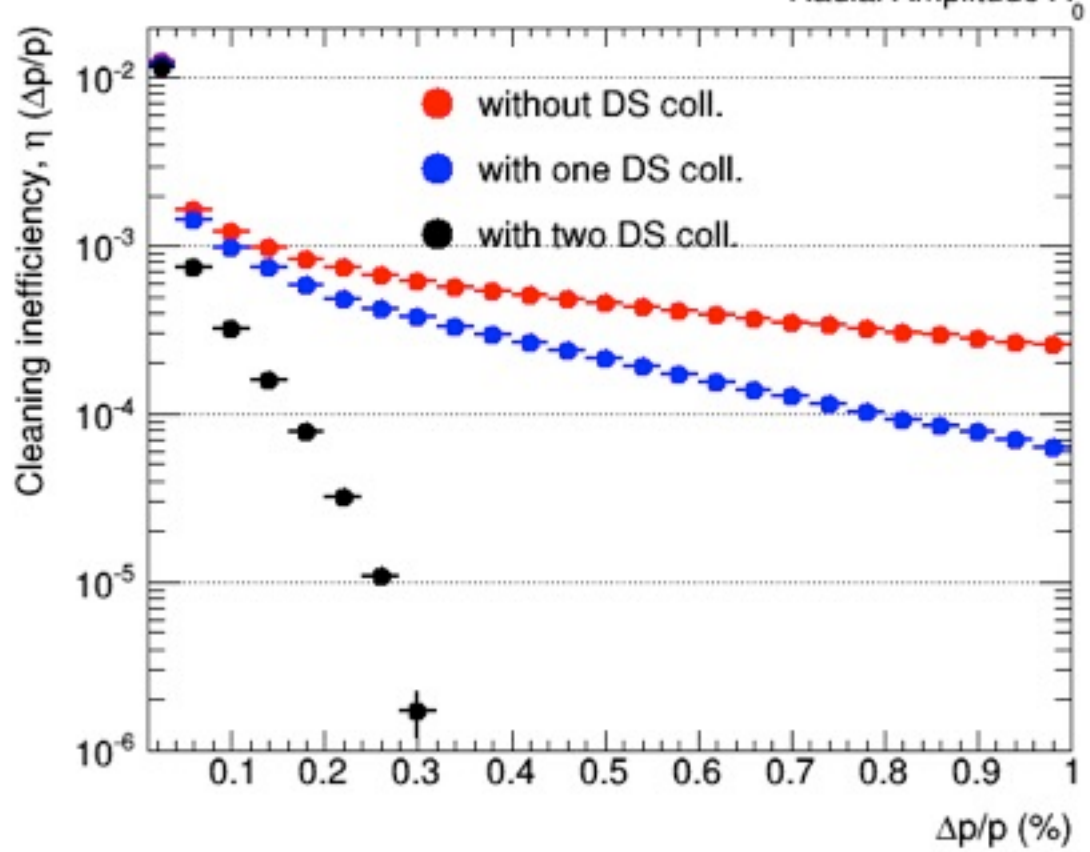




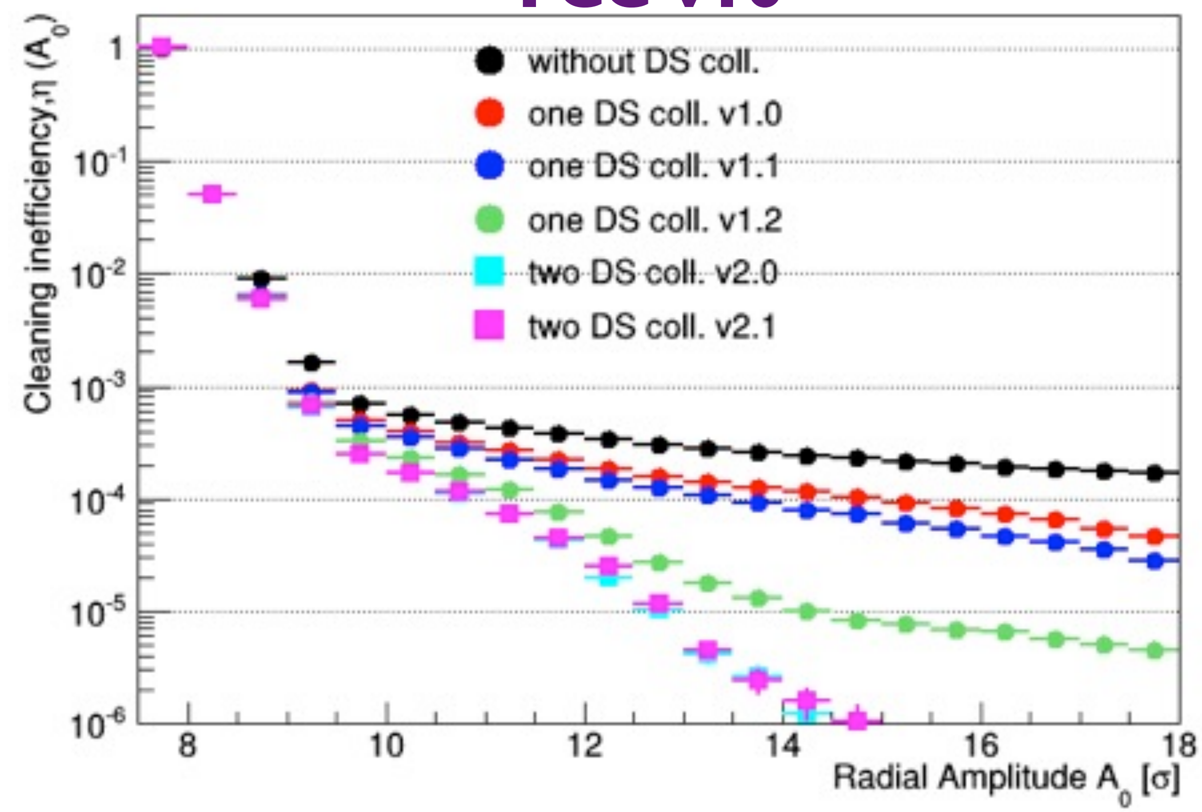
DS collimators: HL-LHC vs FCC

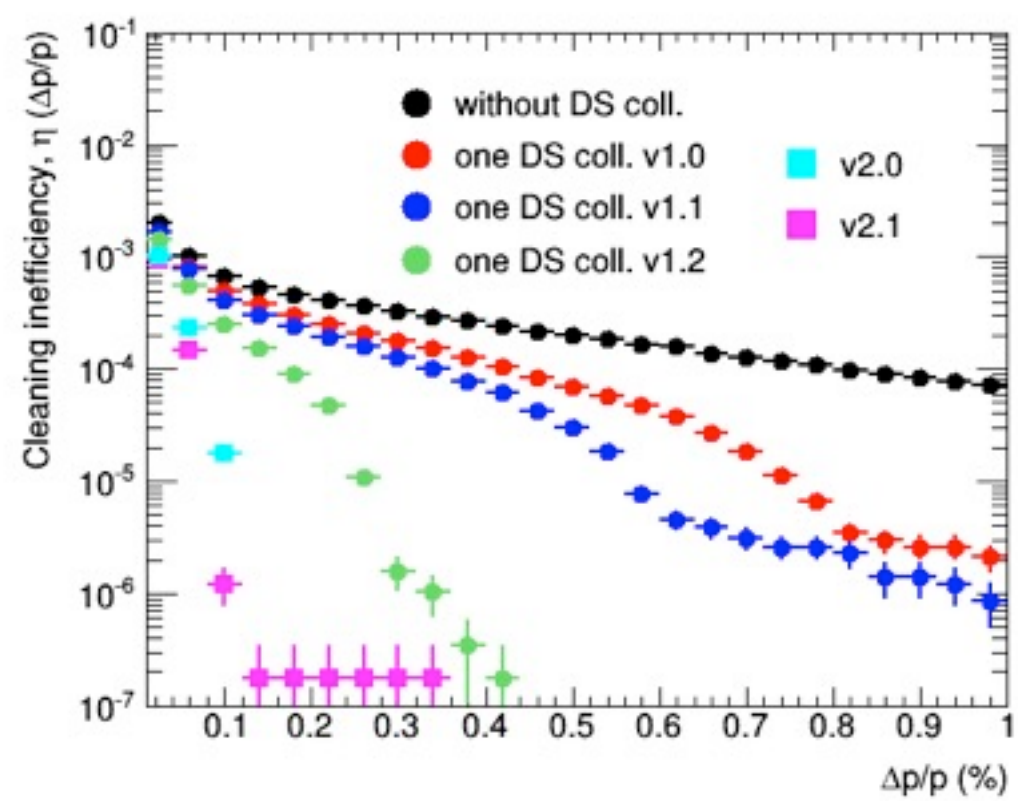
HL-LHC v1.0





FCC v10





LHC operational experience

✓ **Very good performance** of the collimation system so far

- Compatible with HL-LHC parameters at 7 TeV - pending verification with operational experience in 2015

✓ **Validation of simulation** tools over 7 orders of magnitude

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✓ **Validation of simulation** tools over 7 orders of magnitude

➡ **Main cleaning limitation:** critical losses in the dispersion suppressor after the betatron cleaning

➡ The **β^* reach** is determined by collimation constraints: respect collimator hierarchy - retraction between the dump and horizontal tertiary collimators which are not robust

➡ Collimators determine the **LHC impedance**: research of new materials

➡ Collimator handling in **radiation environment** is challenging

Preliminary FCC layout

- Two high-luminosity experiments (A,G)
- Two other experiments (F, H)
- Two collimation lines
- Two injection and two extraction lines