Tracking for Collimation Workshop
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First loss maps and halo population simulations for FCC-hh

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Outline

- Introduction
- Initial layouts for FCC collimation
- Cleaning and halo populations
- First FCC-hh proton loss maps
- Conclusions

Work presented on behalf of M. Fiascaris.

High Luminosity LHC

Introduction

- Design studies for an ambitious post-LHC accelerator program triggered by the European Strategy for Particle Physics in 2013 and the US P5 recommendation in 2014
- Future Circular Collider studies include FCC-hh (long term goal), FCC-ee (potential intermediate step) and FCC-eh.
- Goal: conceptual design report by the end of 2018

FCC-hh key parameters	LHC (Design)	HL-LHC	FCC-hh (Baseline)	FCC-hh (Ultimate)
Beam energy [TeV]	7		50	
Circumference [km]	26.7		100 (83)	
Dipole Field [T]	8.33		16 (20)	
Luminosity [10^{34} cm^{-2} s^{-1}]	1	5	5	20
Bunch spacing [ns]	25		25	5
Bunch population [10^{11}]	1.15	2.2	1	0.2
Norm. emitt. [μm]	3.75	2.5	2.2	0.44
IP beta function [m]	0.55	0.15	1.1	0.3

Stored energy challenge

	LHC (Design)	HL-LHC	FCC-hh (Baseline)
Beam energy	7 TeV	7 TeV	50 TeV
Beam intensity	3×10^{14}	6×10^{14}	10×10^{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

2 order of magnitudes above the LHC:

↓

outstanding challenges for collimator materials

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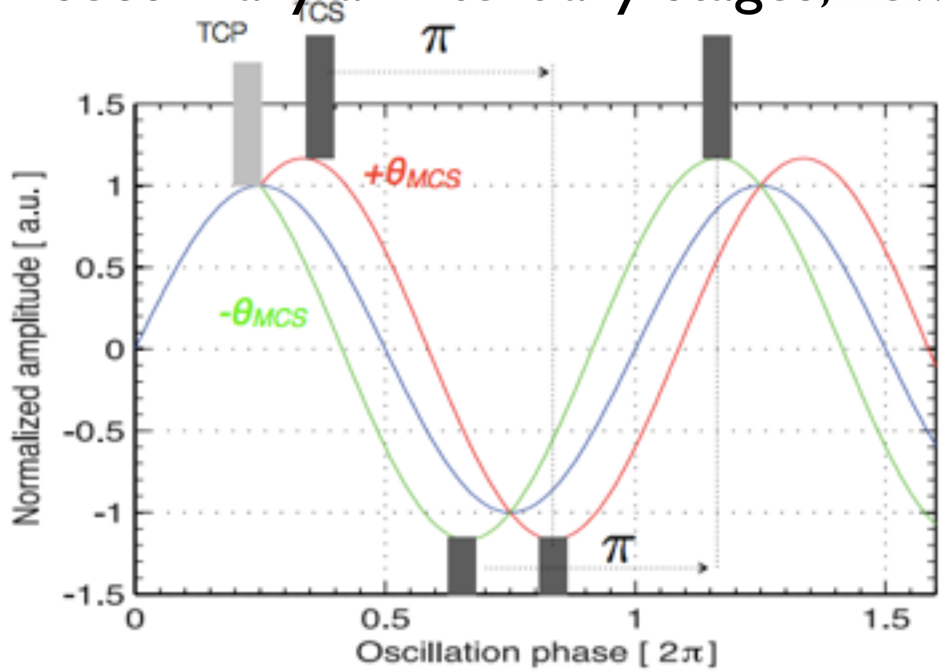
FCC collimation: our initial approach

- Present LHC collimation solution fully validated: **natural and solid solution** to start with!
- First conceptual solution for the betatron collimation at the FCC:
  scaled-up system derived from the present one
  - 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

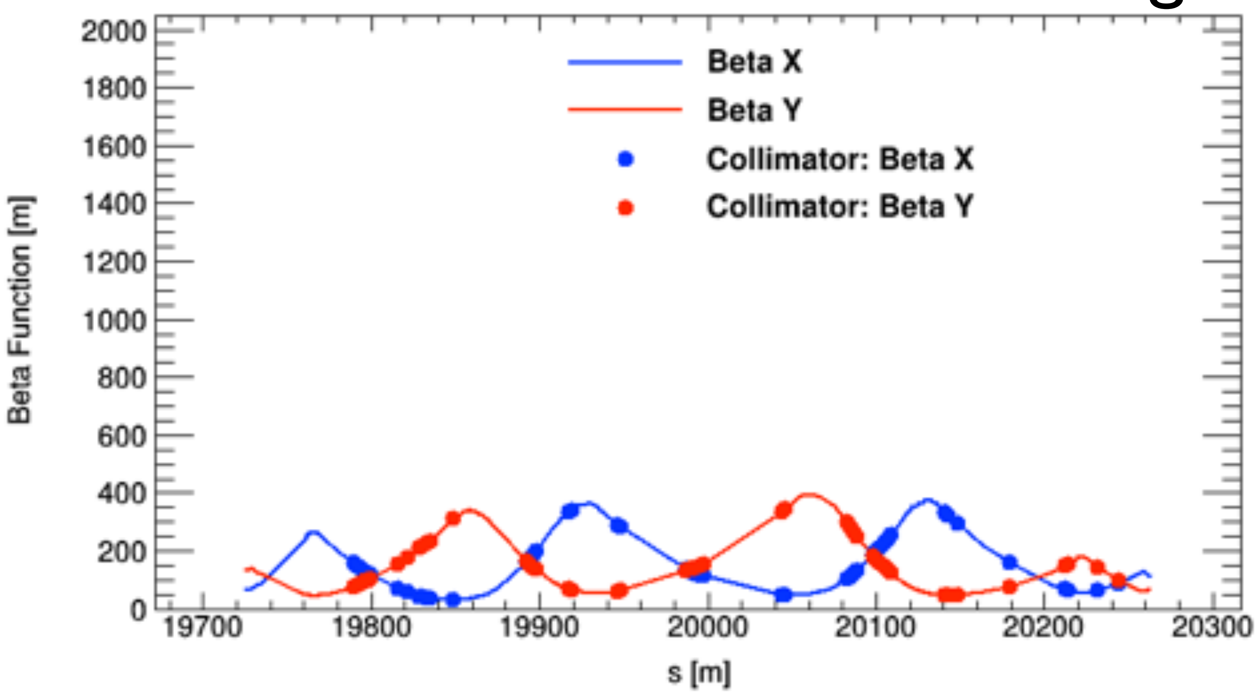
see *Phys. Rev. Spec. Top. Accel. Beams 1 (1998) 081001*



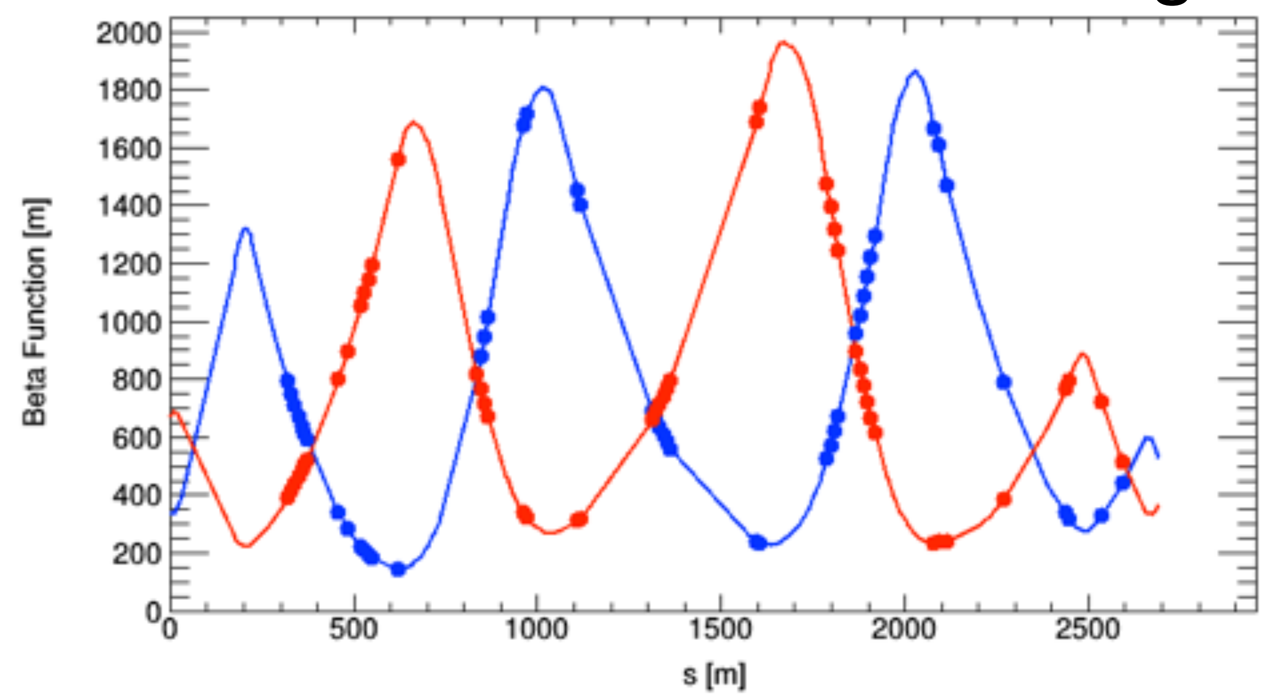
- Dedicated insertion for off-momentum cleaning; early on implement DS collimation.

FCC collimation: our initial approach

- Present LHC collimation solution fully validated: **natural and solid solution** to start with!
- LHC IR7 - betatron cleaning



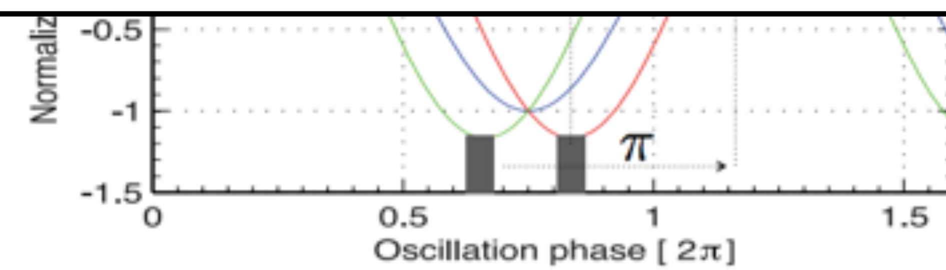
FCC IR2 - betatron cleaning



Optics and insertion lengths scaled up by a factor 5

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

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



- Dedicated insertion for off-momentum cleaning; early on implement DS collimation.

High Luminosity LHC

Lattice for first collimation studies

Tracking simulations using a lattice with:

- 2 low-beta insertions
- 2 cleaning insertions

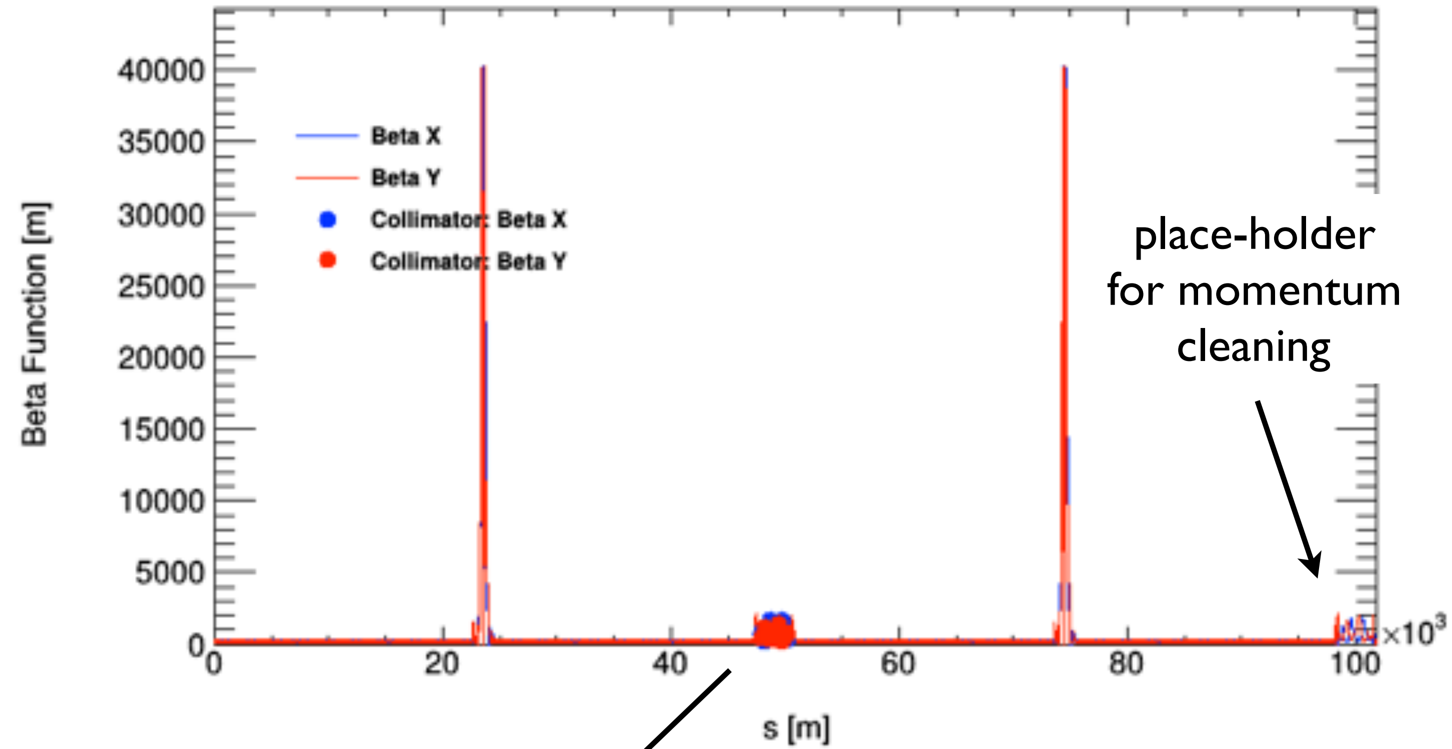
➡ Implemented a **three-stage betatron cleaning** with 19 collimators

Collimator Settings

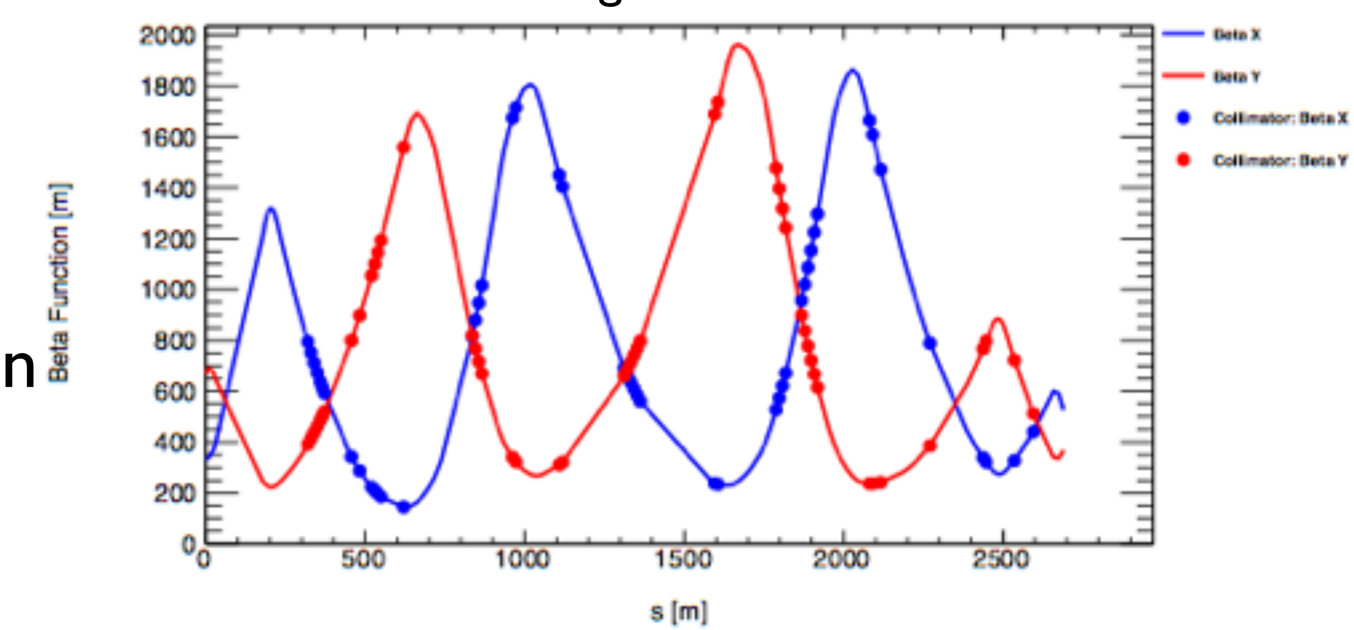
3 primaries	TCP	7.6 σ
11 secondaries	TCSG	8.8 σ
5 absorbers	TCLA	12.6 σ

* 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. For IR collimation see later.



Zoom
IR2: betatron cleaning



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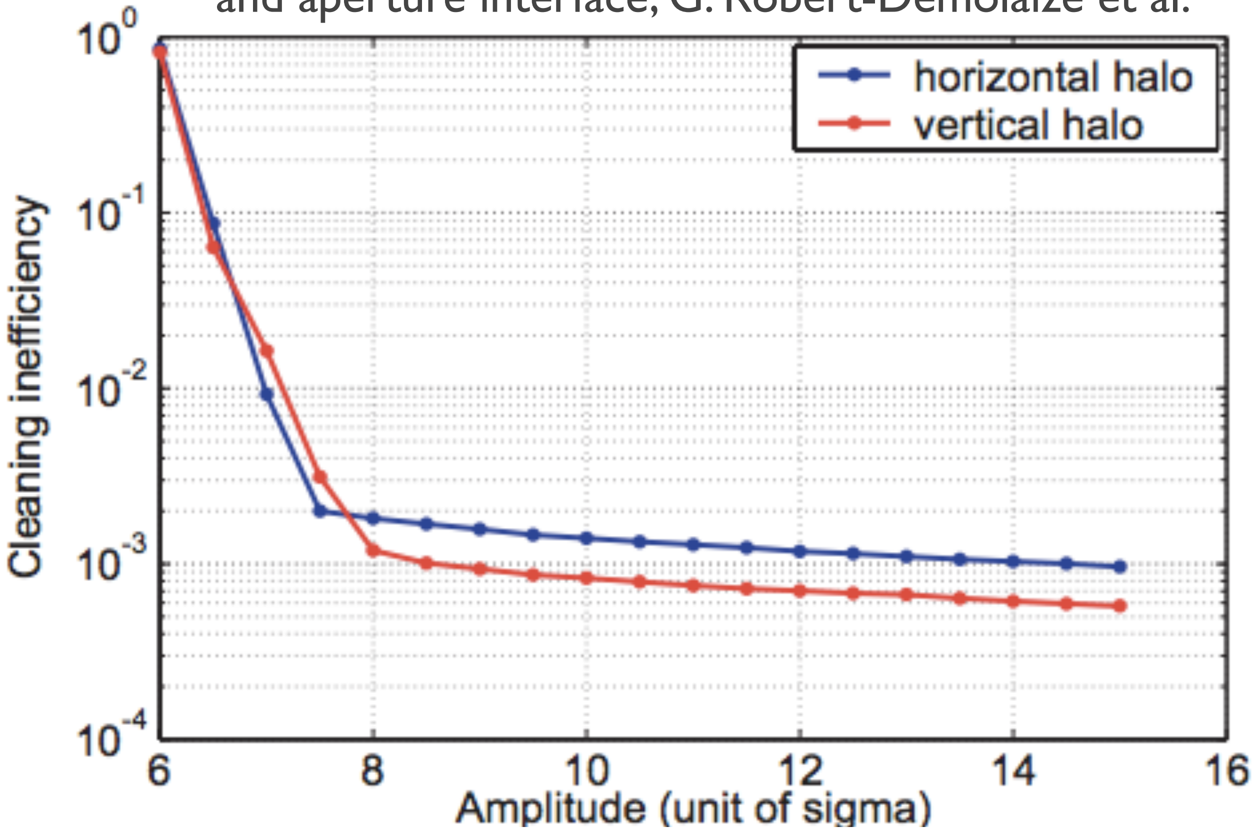
Loss analysis through halo population

- High level of accuracy in LHC loss maps is the result of years of experience and operations.
- In view of FCC studies we need to go one step backward, reviving the performance studies done at the time of the LHC system design

PAC 2005, A new version of SixTrack with collimation and aperture interface, G. Robert-Demolaize et al.



Cleaning inefficiency

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

$N_p(A > A_i)$ → number of particles above amplitude A_i

N_{abs} → number of particles absorbed in coll. system

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

→ Included **new performance plots: off-momentum halo population now in SixTrack (M. Fiascaris)**

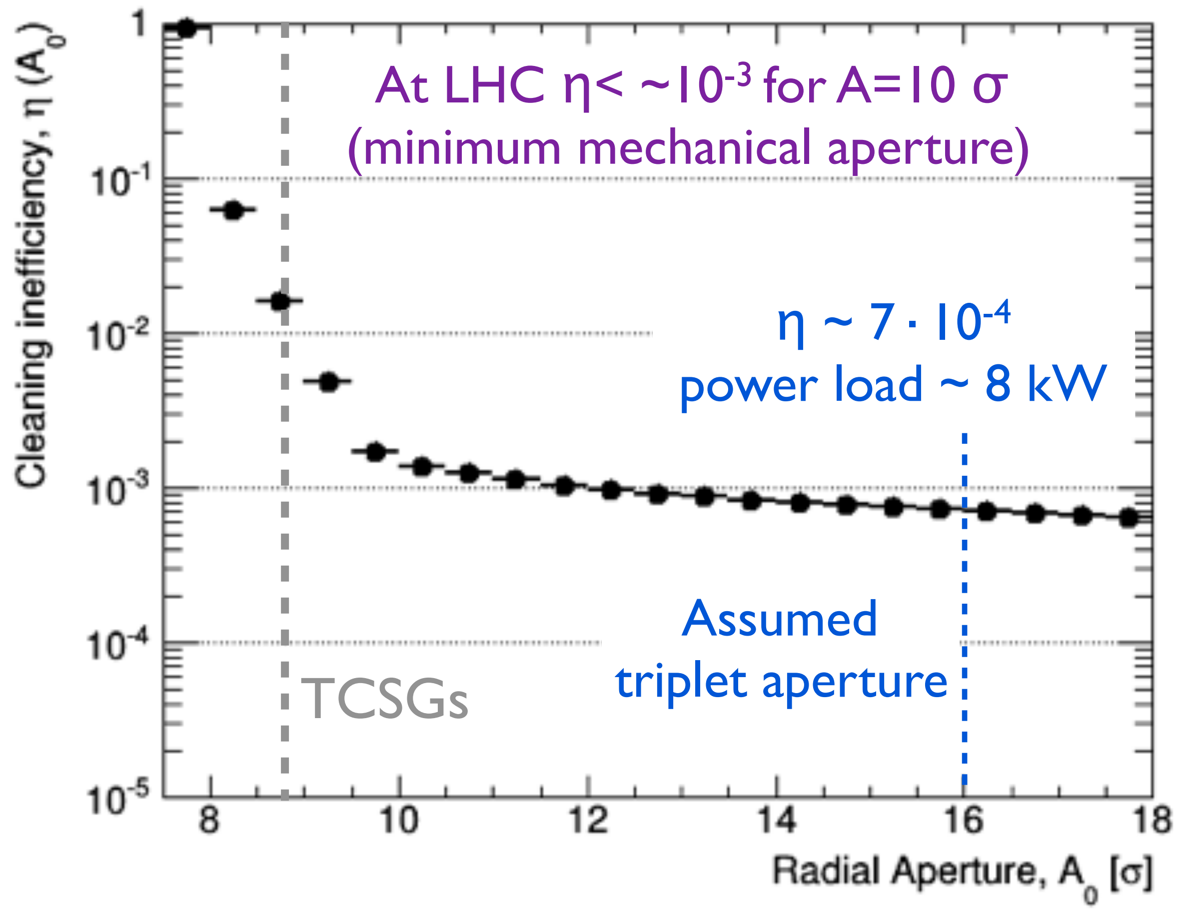
Halo population and cleaning at FCC

Cleaning inefficiency vs. radial amplitude

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

→ number of particles above amplitude A_i

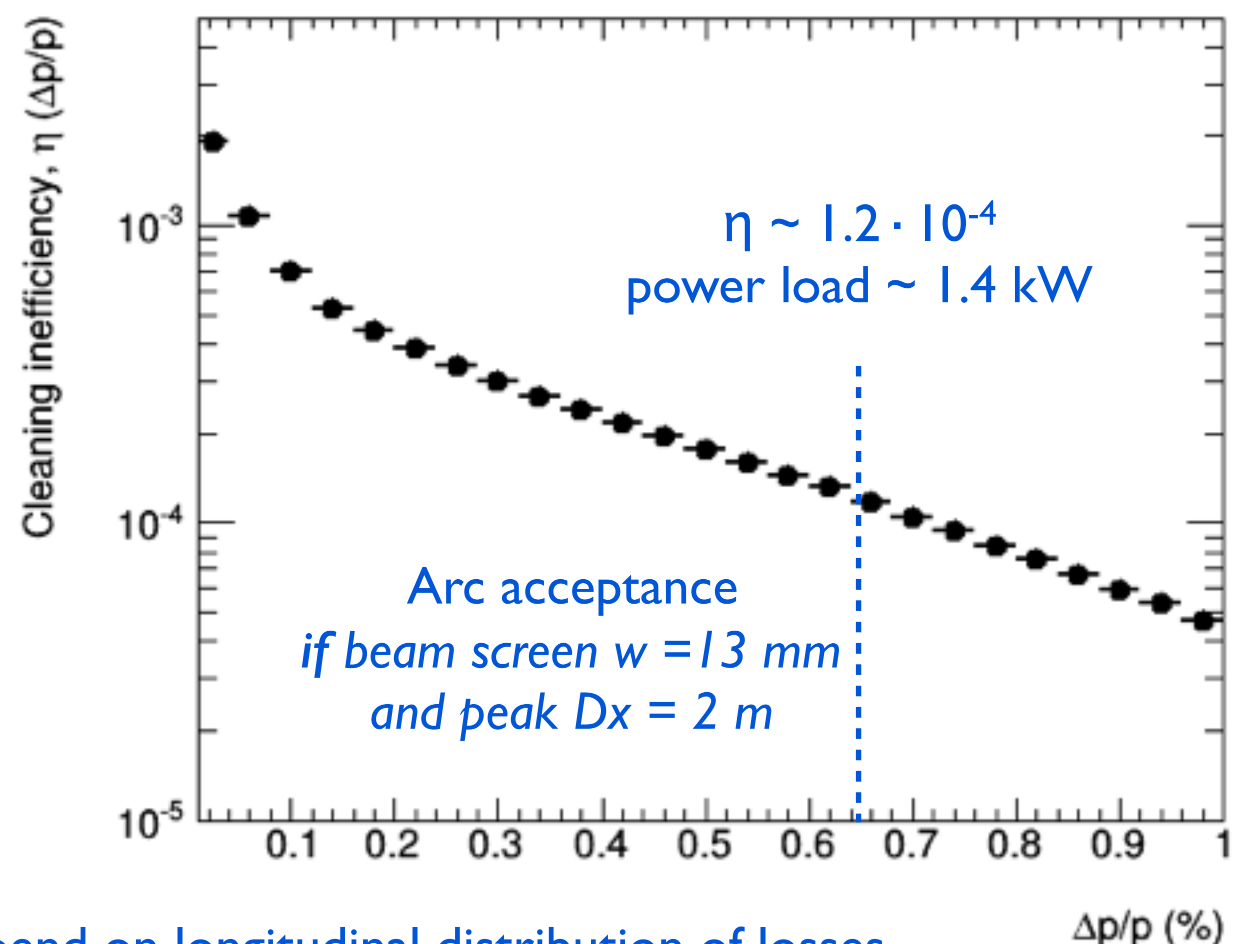
→ number of particles absorbed in coll. system



Cleaning inefficiency vs. Δp / p

(off-momentum halo population)

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

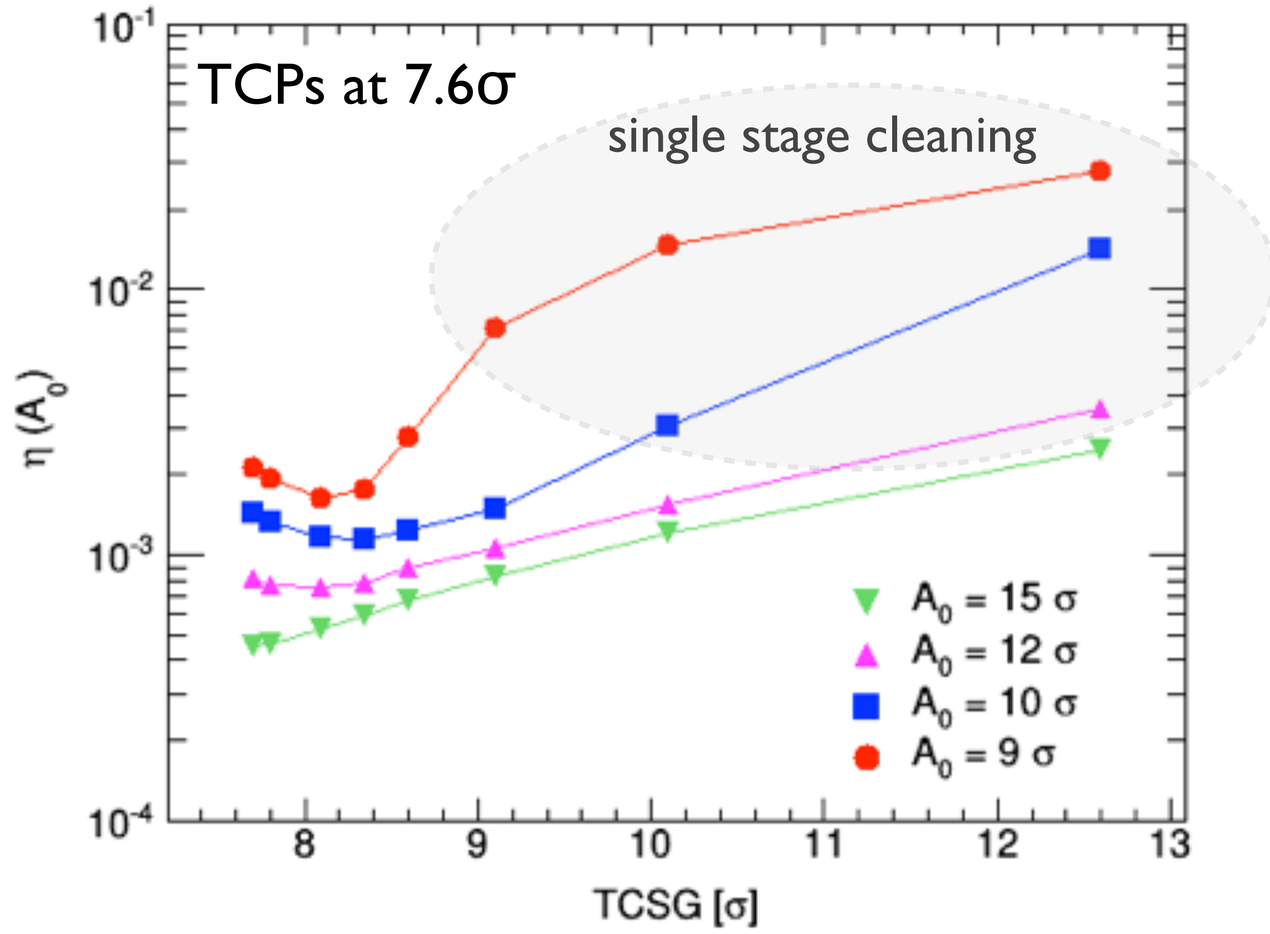


Power loads on cold elements will depend on longitudinal distribution of losses

Optimum cleaning vs TCSG settings

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

Cleaning inefficiency vs. setting of secondaries

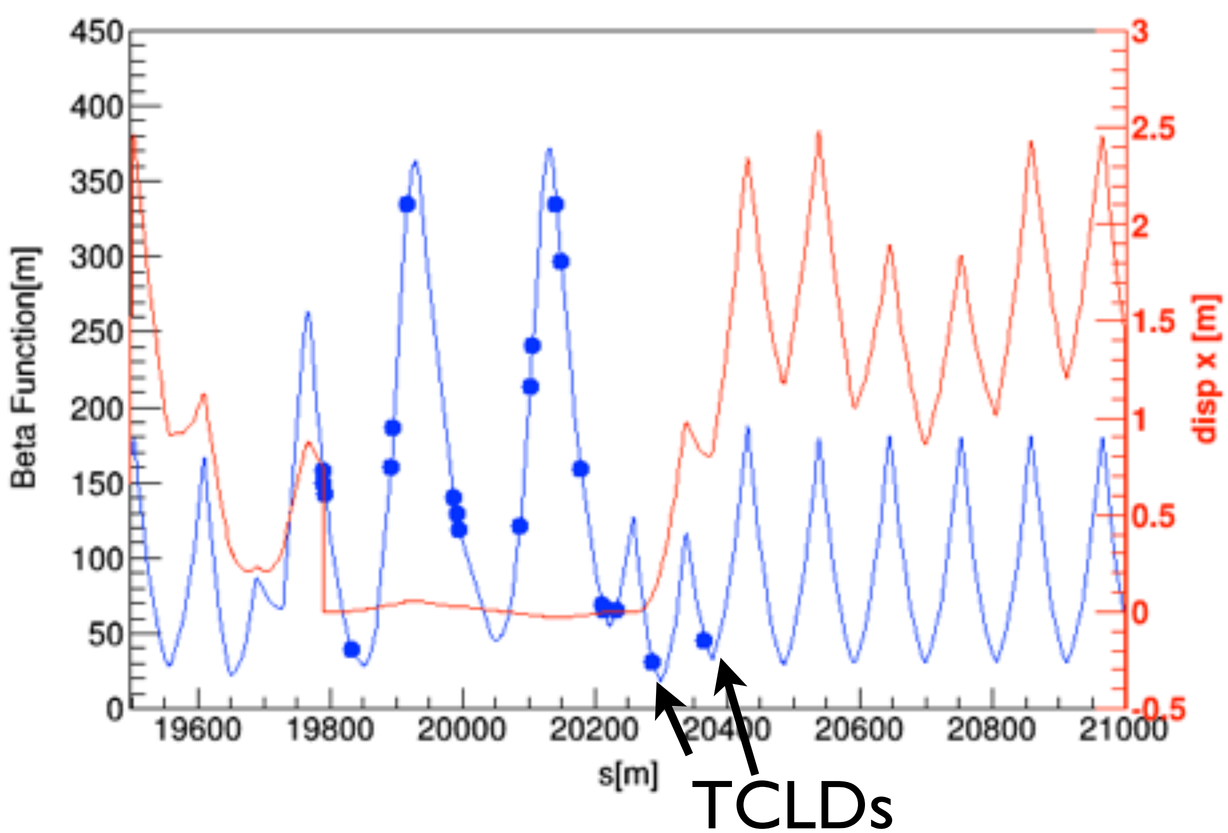


→ will re-optimize phases and optics if needed, once aperture well defined

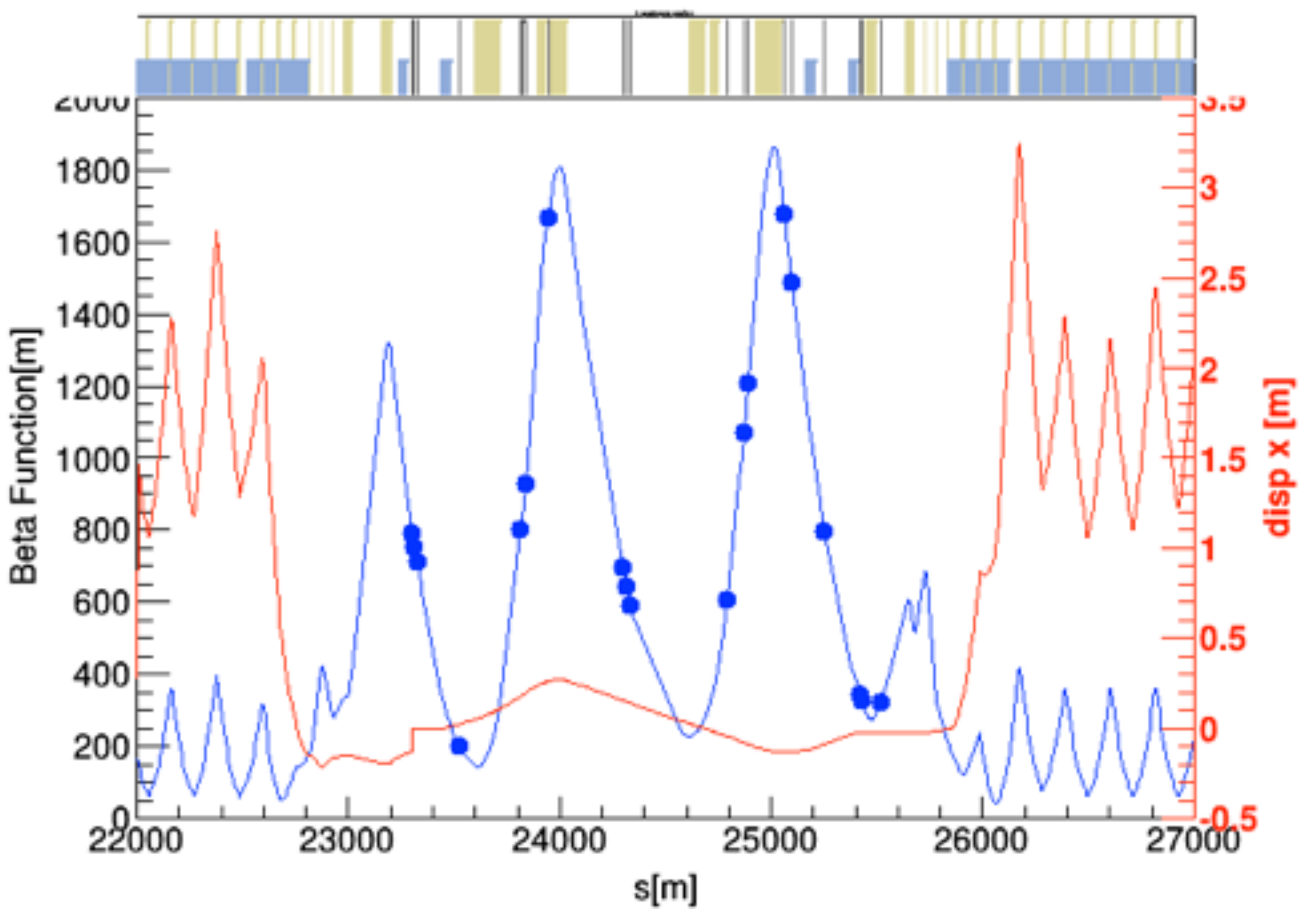
Dispersion suppressor collimation

- Main cleaning limitation of current system: critical losses in the dispersion suppressor 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)
- Appropriate solutions must be foreseen early on into the FCC lattice design!

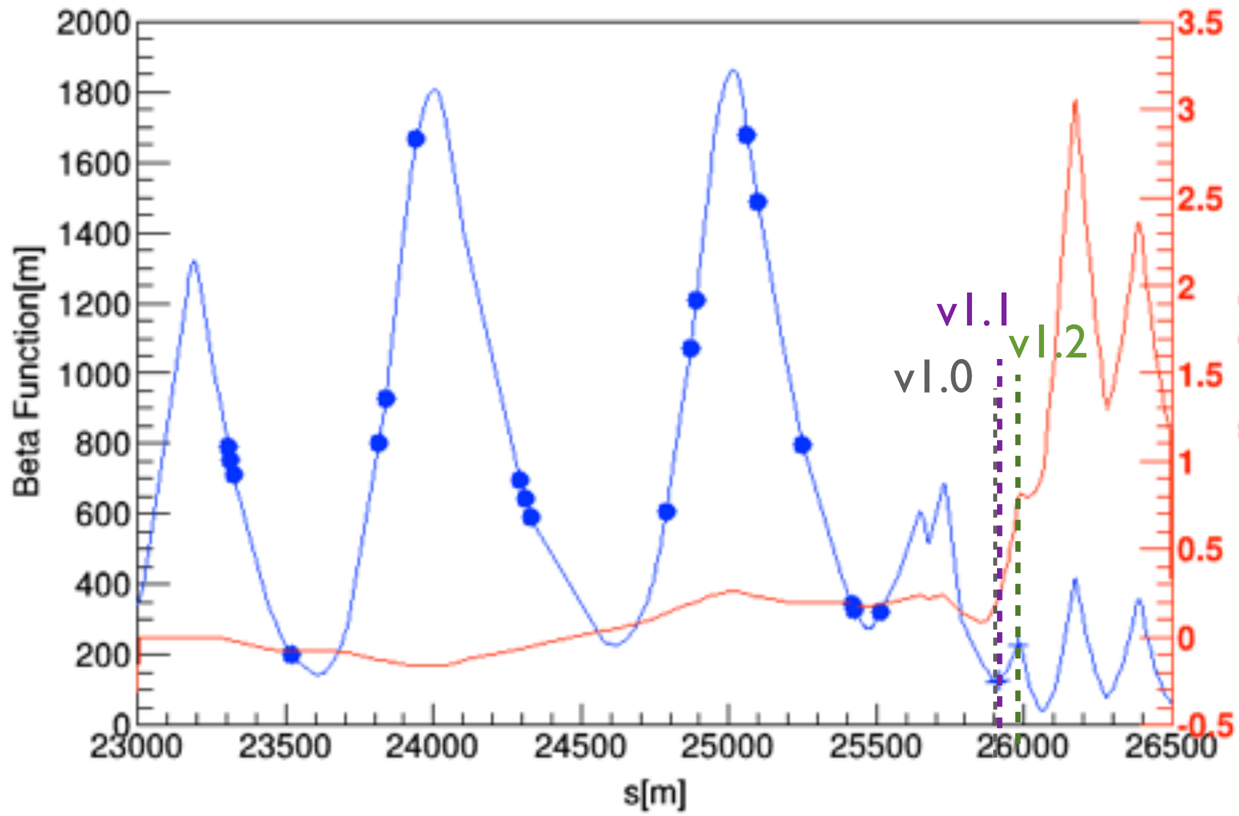
HL-LHC v1.0



FCC v10

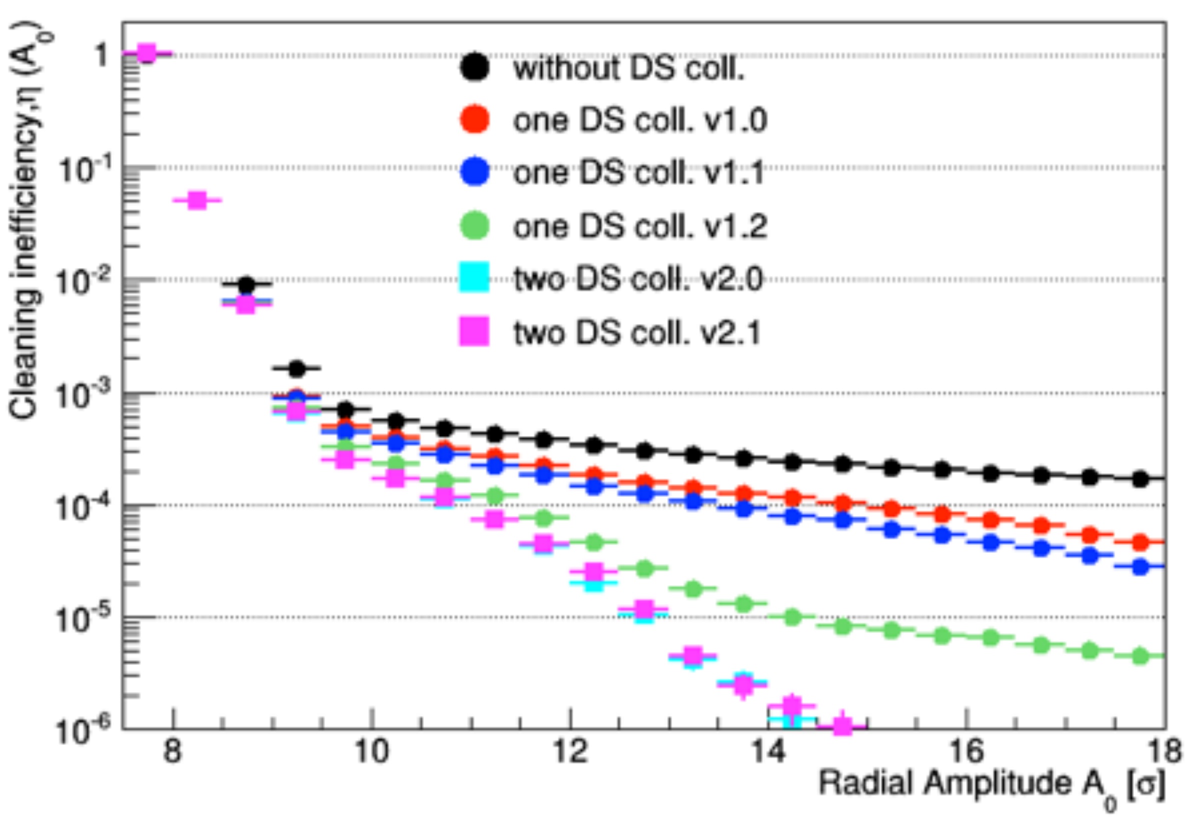


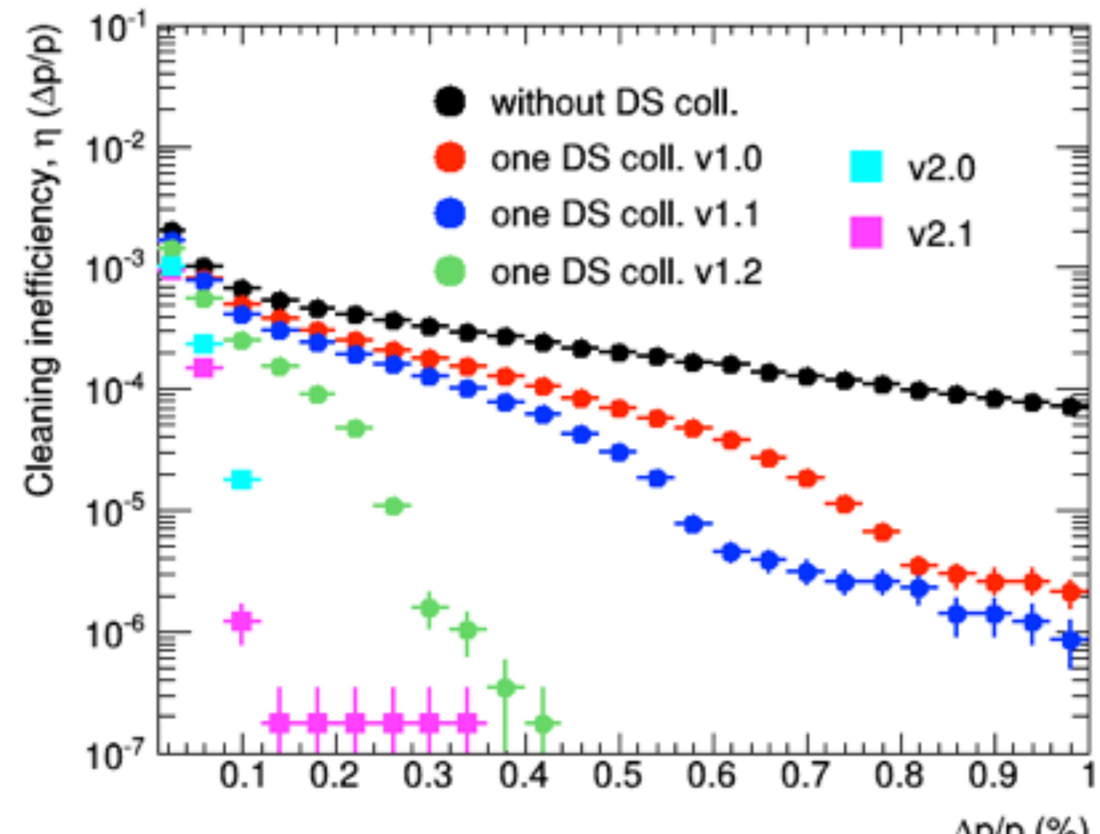
Effect of "TCLD" on halo distributions



Effect of adding one or two DS collimators on cleaning inefficiency curves:

- v1.0: TCRYO in cell 8 (Δp/p cut = 0.0048)
- v1.1: TCRYO in cell 9 (Δp/p cut = 0.0036)
- v1.2: TCRYO in cell 9 (Δp/p cut = 0.0016)
- v2.0:TCRYO in cells 8,10
- v2.1:TCRYO in cells 9,11





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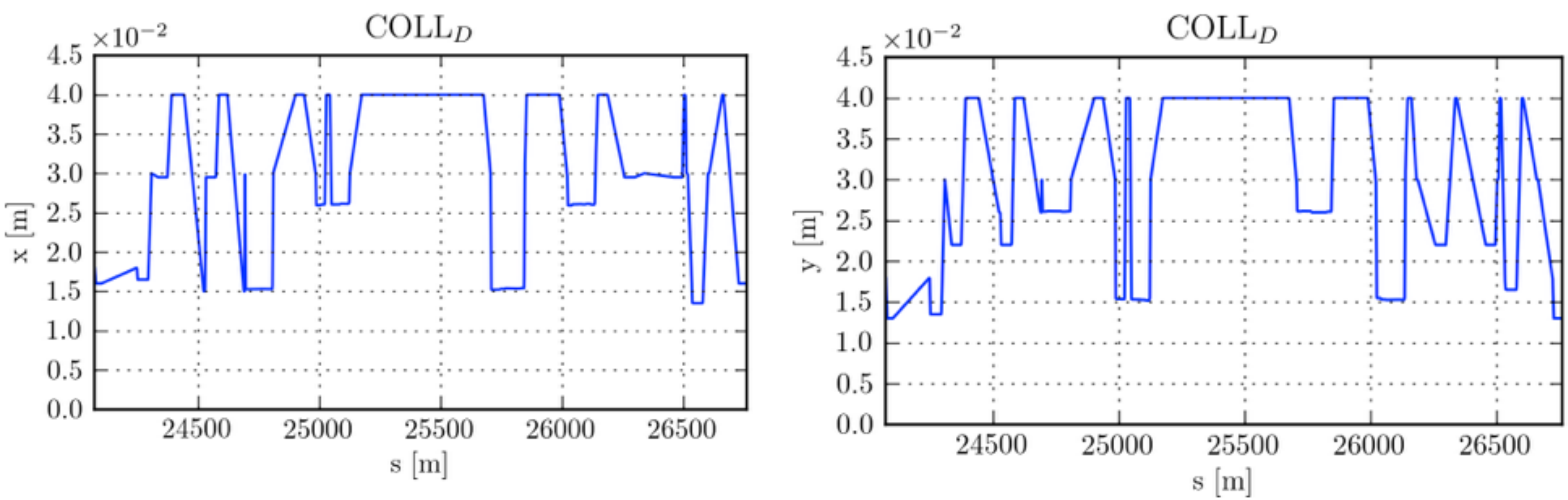
Preliminary aperture model - i

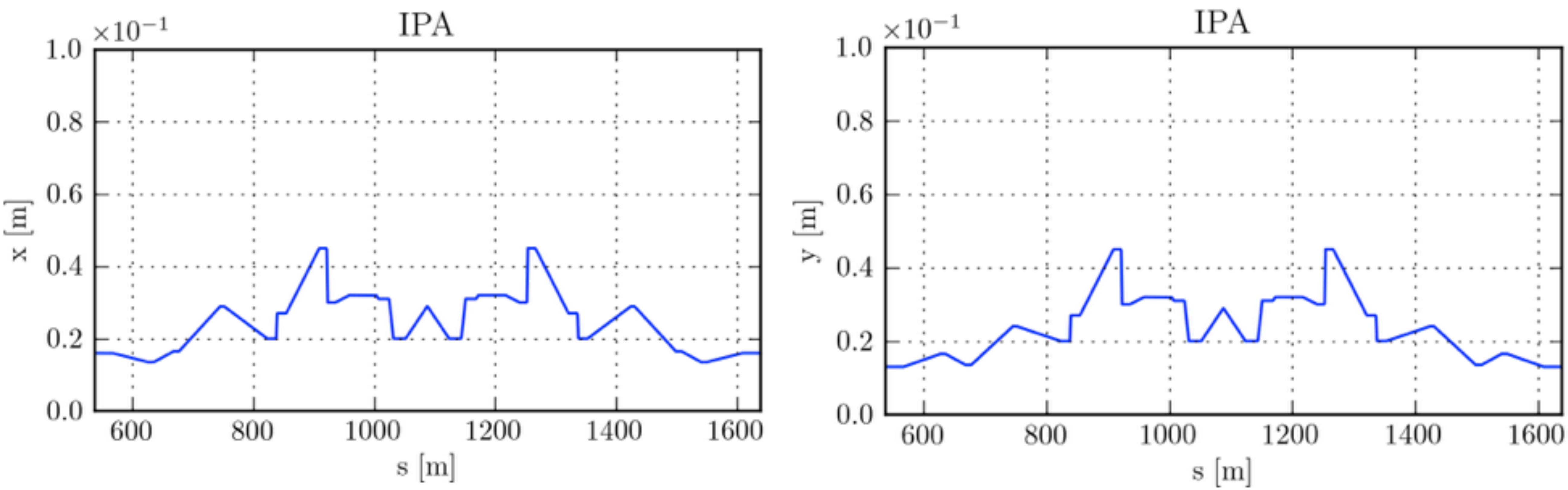
- beamscreen dimensions 16 x 13 mm
- cleaning insertions and experimental insertions LHC-like



cleaning insertion

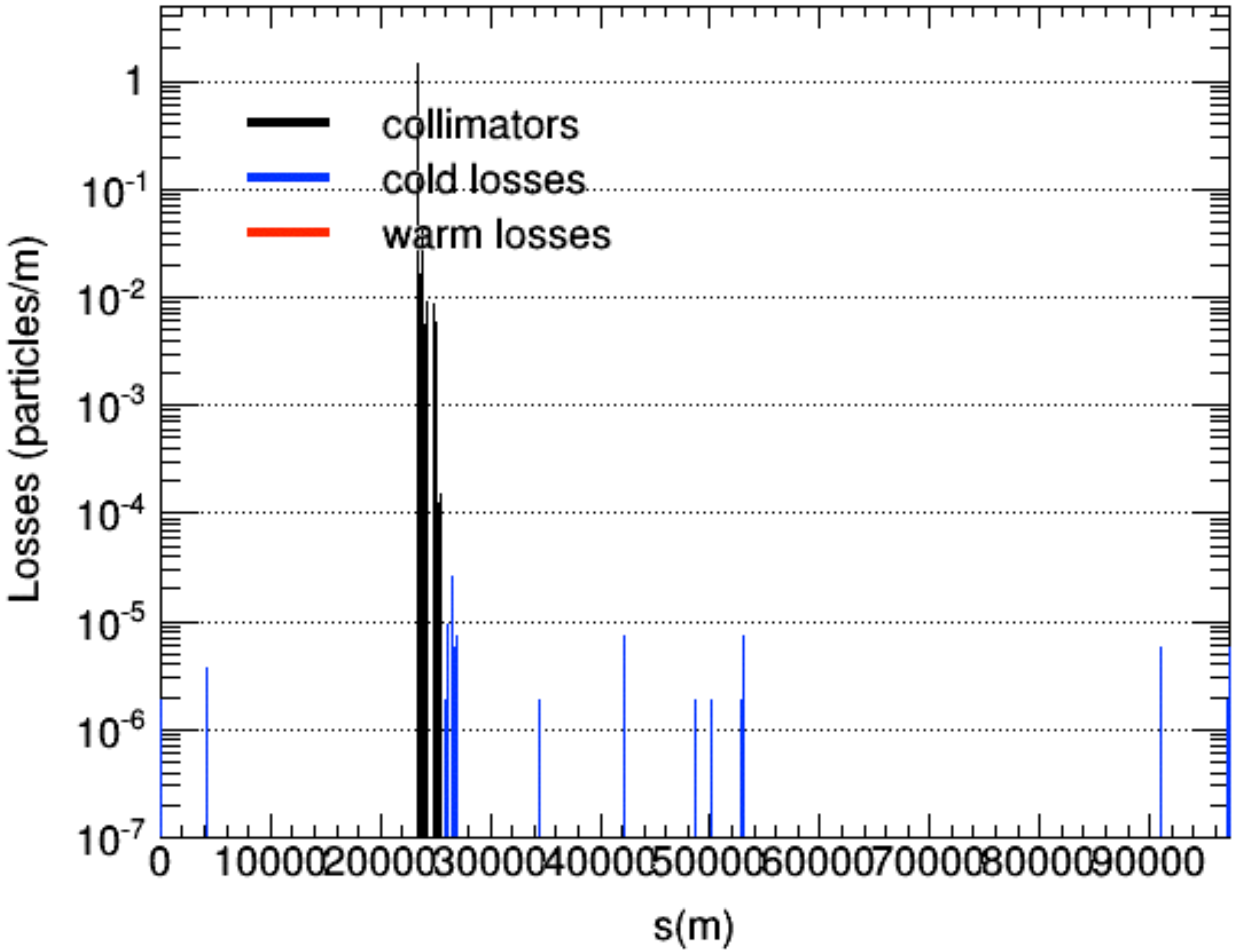
Preliminary aperture model - ii

- beamscreen dimensions 16 x 13 mm
- cleaning insertions and experimental insertions LHC-like

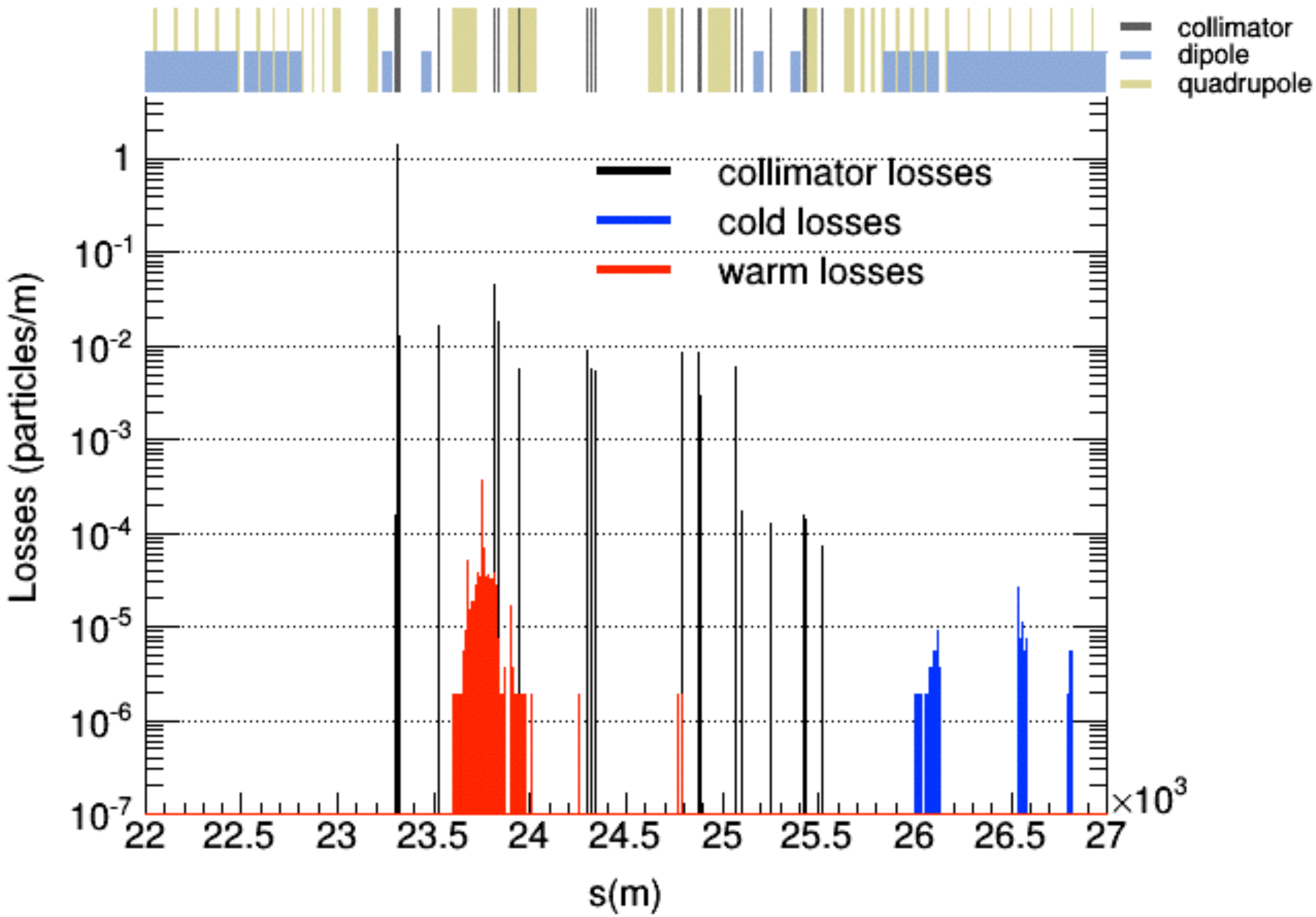


experimental insertion

First FCC-hh proton loss maps - i



First FCC-hh proton loss maps



Conclusions

- Reported results of first studies of FCC-hh collimation, done with the version of SixTrack for collimation studies.
- Tools we have in hand already allow us to improve the system performance by optimizing the cleaning inefficiency
  Crucial in this design phase
- First complete loss maps are now also simulated !
- More inputs required to assess if the performance of the collimation system is sufficient to achieve at the design parameters (maximum intensity, β* reach):.
  Wish to see soon in place a FCC collimation team addressing the
- Advanced collimation: hollow lenses, crystals: natural synergy!

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