Improved Proton Collimation Efficiency

Conceptual Design Review LHC Phase II Collimation

Th. Weiler, R. Assmann, E. Metral, J. Jowett

Beams Department, CERN

Institut für Experimentelle Kernphysik, Universität Karlsruhe (TH)

Overview

- Beam Lifetime/Loss Rates and Definition of Cleaning inefficiency
- Limitations Phase I and Phase II (only TCSM) with respect to cleaning inefficiency, imperfections and impedance
- Proposed solution: dispersion suppressor layout
- Cleaning inefficiency of proposed solution
- Impact of gap size on cleaning inefficiency and impedance
- Distribution of single diffractive protons at location of cryogenic collimators
- Loss rates at the tertiary collimators
- Summary/Outlook

Reminder: Beam Lifetimes / Loss Rates

The table summarises the specified maximum loss rates for a safe operation of the LHC machine and its collimation system.

Mode	T $[s]$	τ $[h]$	$\mathbf{R_{loss}}$ $[p/s]$	$\mathbf{P_{loss}}$ $[kW]$
Injection	cont.	1.0	0.8×10^{11}	6
	10	0.1	8.6×10^{11}	63
Ramp	≈ 1	0.006	1.5×10^{13}	1200
Collision	cont.	1.0	0.8×10^{11}	97
	10	0.2	4.3×10^{11}	487

- Keep in mind, that for nominal LHC operation at 7TeV the beam lifetime is 20h.

Intensity and Cleaning Inefficiency

cleaning inefficiency:

$$\eta(s) = \frac{n_{abs}(s)}{n_{total}}$$

intensity:

$$N_p^{max} = \frac{\tau \cdot R_q}{\eta_c}$$

Rate of continuous losses of protons per meter which induce a quench:

7.0×10^8/p/m/s at 450 GeV

7.8×10^6/p/m/s at 7 TeV

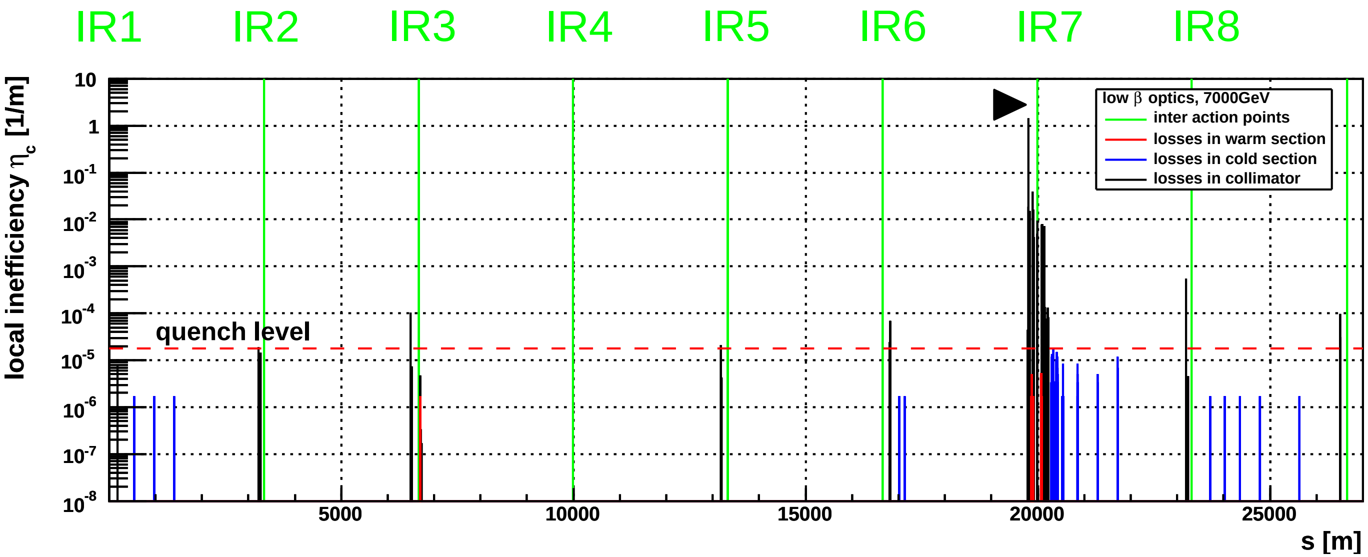
(LHC-Project-Report-44)

Required cleaning inefficiency:

$\eta_c = 7.8 \times 10^{-4}$/m at 450 GeV (for $0.1h$ and 3.2×10^{14} p)

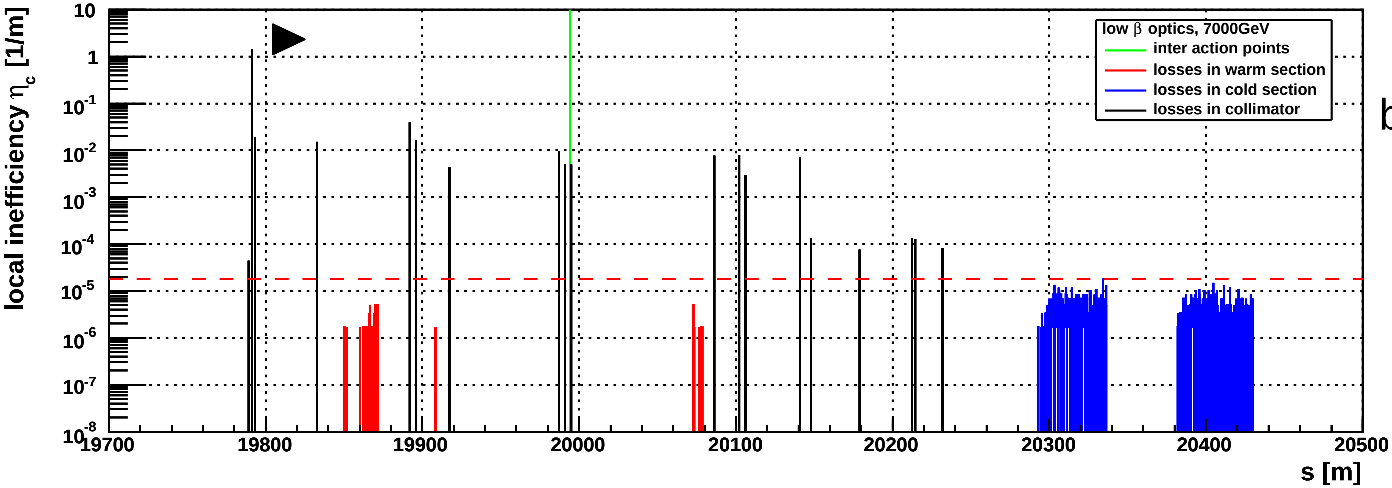
$\eta_c = 1.74 \times 10^{-5}$/m at 7 TeV (for $0.1h$ and 3.2×10^{14} p)

Performance Phase1 System



beam 1

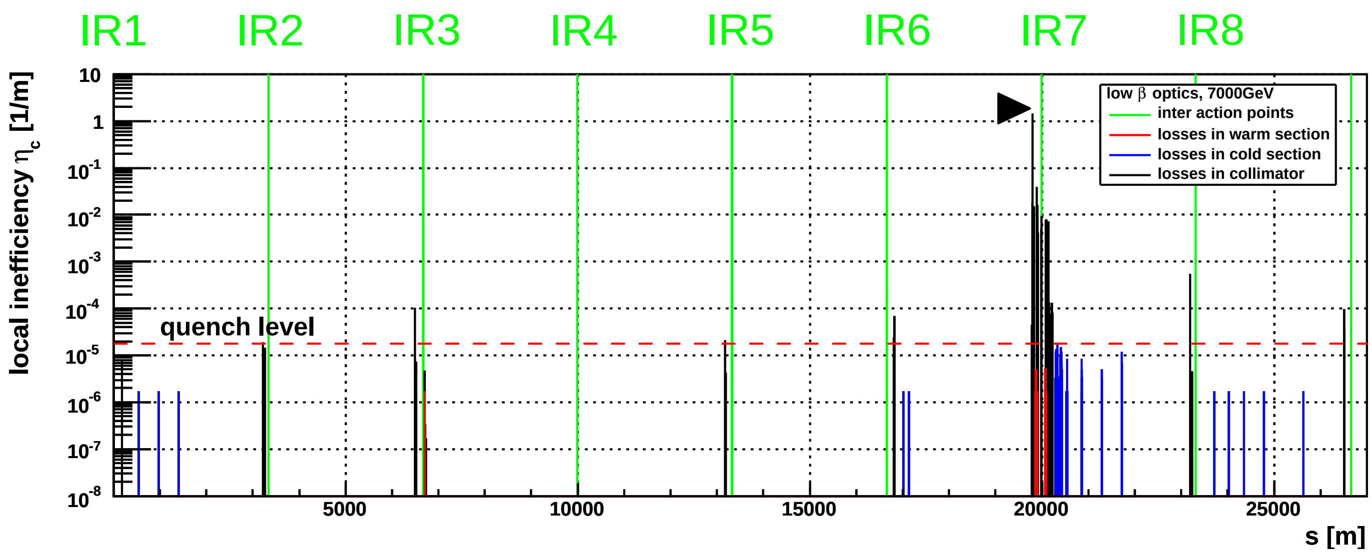
- V6.503 / 7 TeV
- horizontal betatron halo
- standard settings
- ideal machine



beam 1

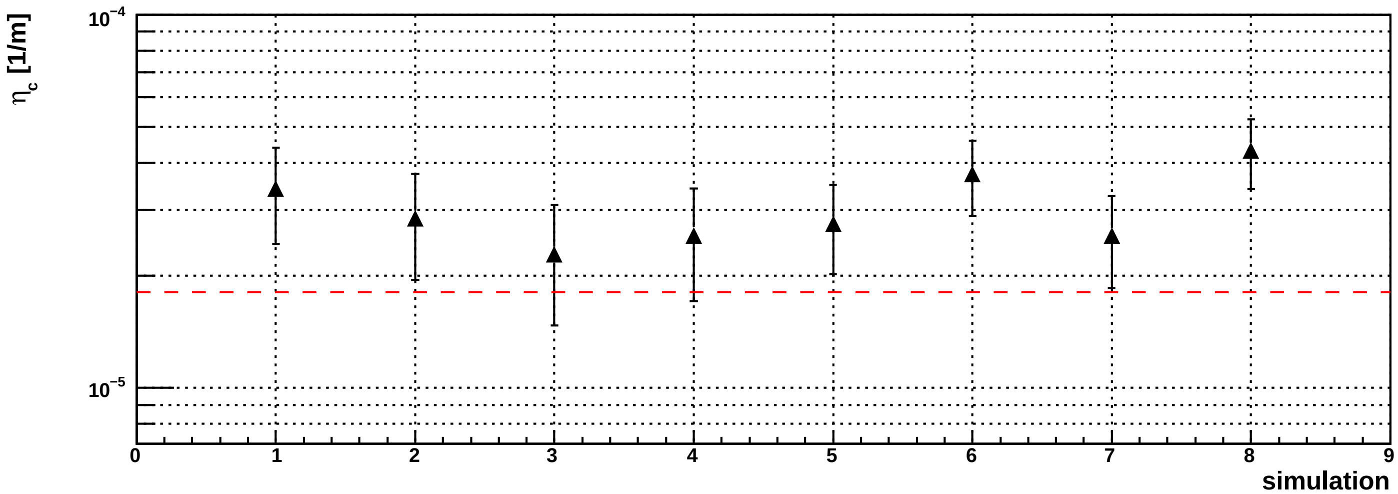
- V6.503 / 7 TeV
- zoom in IR7

Performance Phase1 System



beam 1

- V6.503 / 7 TeV
- horizontal betatron halo
- standard settings
- ideal machine

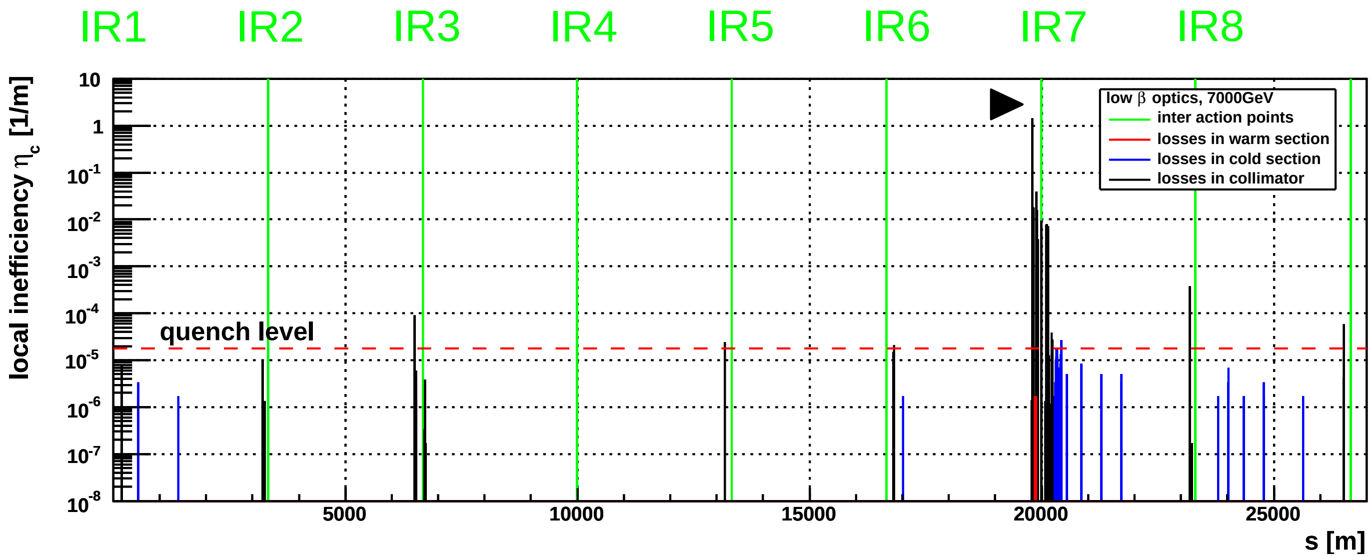


η_c for different simulations horizontal and vertical halo

vertical halo horizontal halo

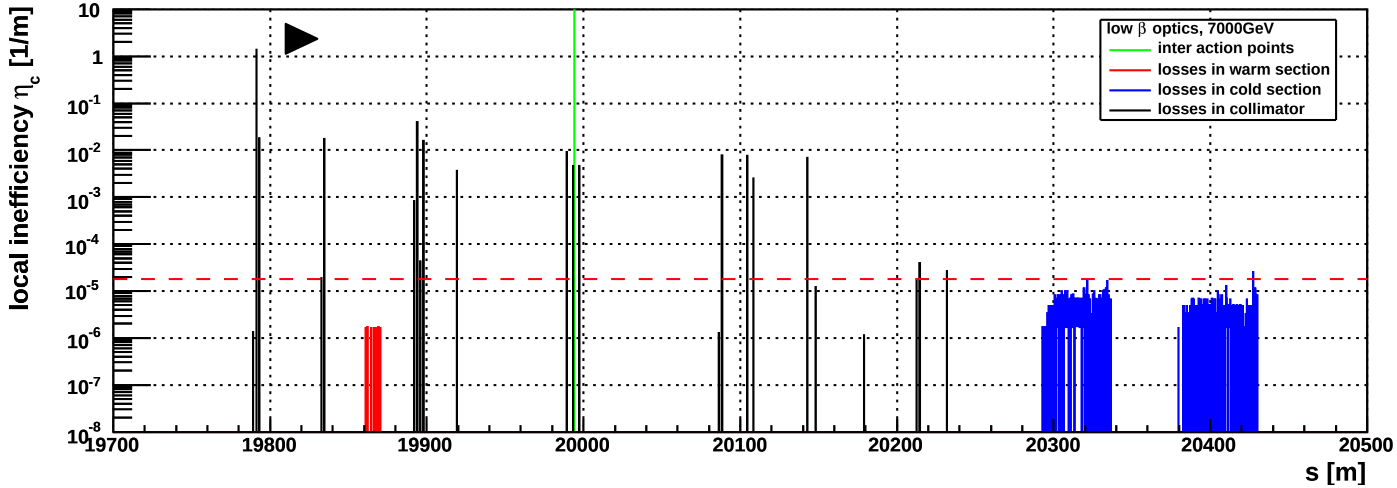
Performance Phase2 System

(metallic secondaries)



beam 1

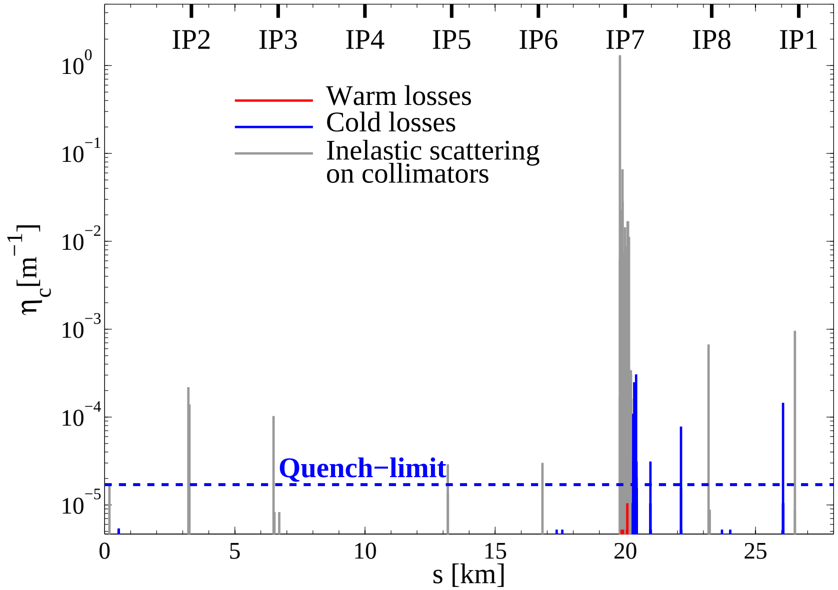
- V6.503 / 7 TeV
- horizontal betatron halo
- standard settings
- ideal machine



beam 1

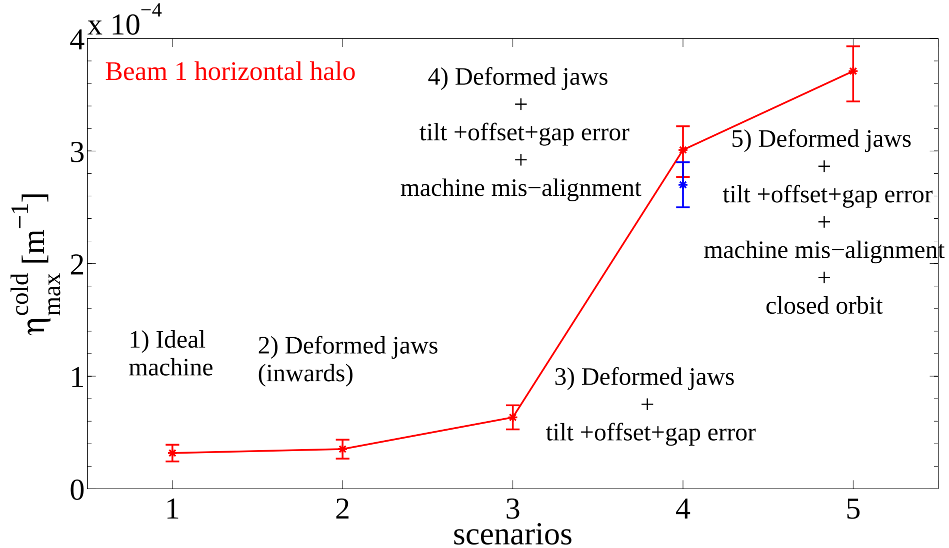
- V6.503 / 7 TeV
- zoom in IR7

Impact of Imperfections



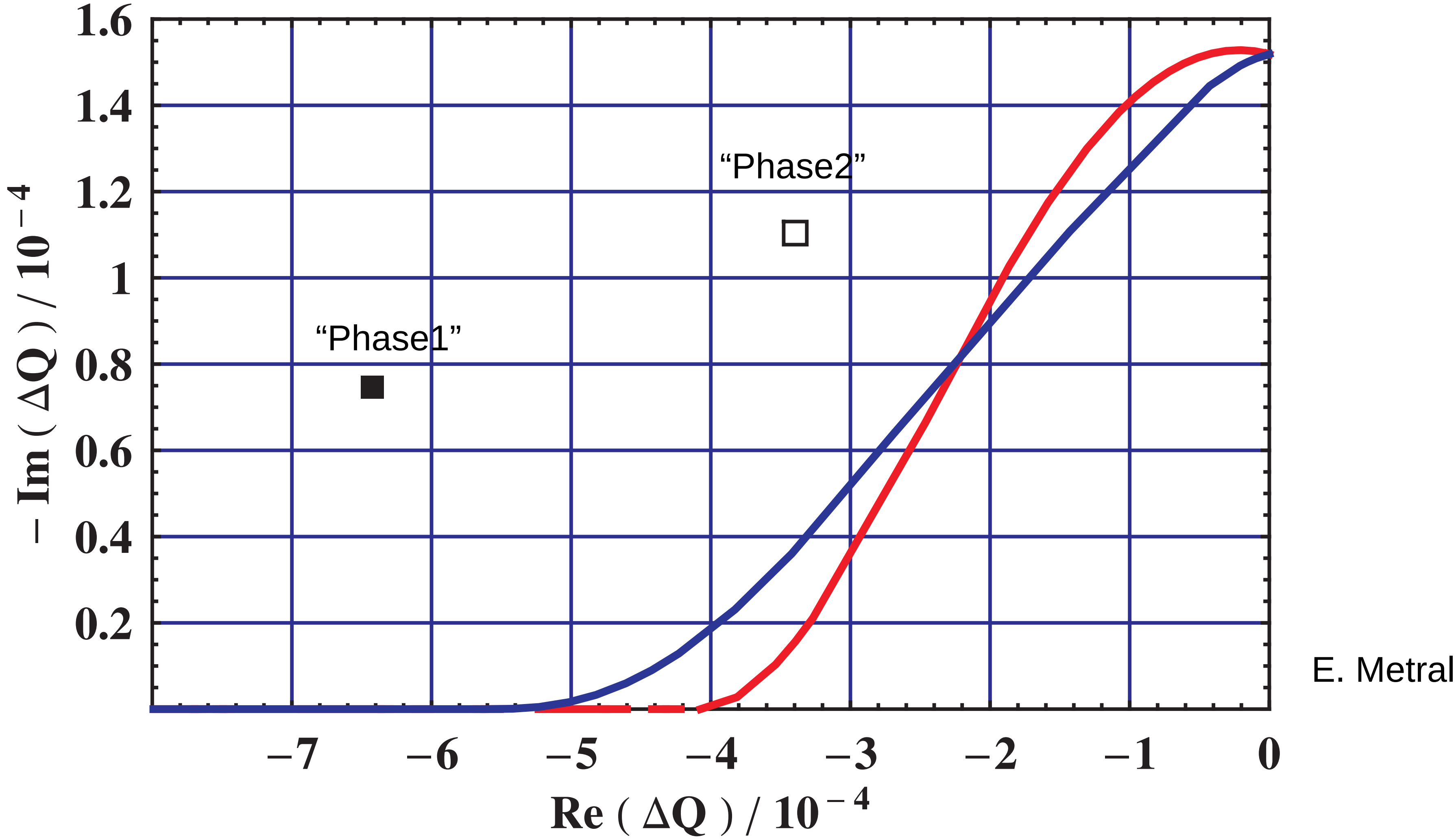
Loss map including jaw flatness error, collimation setup errors (tilt, offset and gap-size) and machine alignment errors.

Local cleaning inefficiency for various error scenarios, Intensity could be limited to less than 5% on nominal considering scenario 5



C. Bracco, Commissioning Scenarios and Tests for the LHC Collimation system, PhD Thesis, 2008.

Impedance

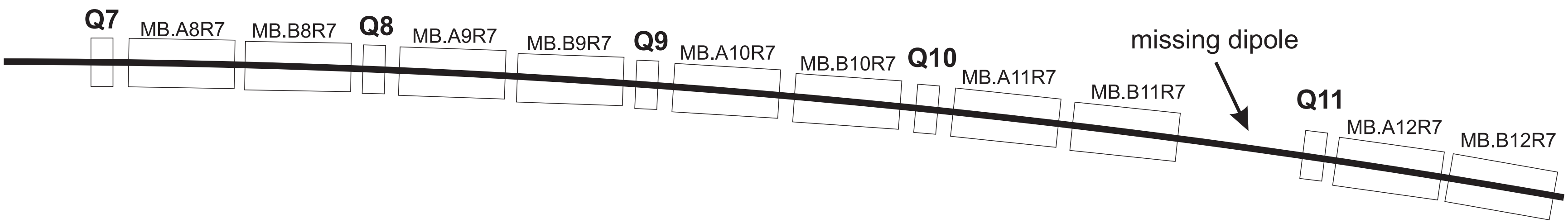


Phase 1 and Phase 2 system are both outside the stability region (provided by Landau octupoles)

Proposal for Phase2 Efficiency Improvement

Problem from the cleaning efficiency side of view of Phase1 and Phase2 system are the losses in the dispersion suppressor after the cleaning insertions.

Idea for a possible Phase2 system is to add additional collimators in the dispersion suppressor at the location of the loss peaks seen.

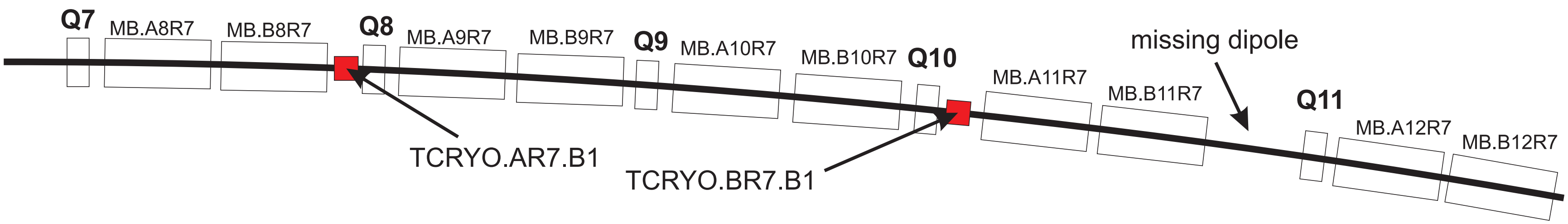


$\Rightarrow$ make use of space from missing dipole

Proposal for Phase2 Efficiency Improvement

Problem from the cleaning efficiency side of view of Phase1 and Phase2 system are the losses in the dispersion suppressor after the cleaning insertions.

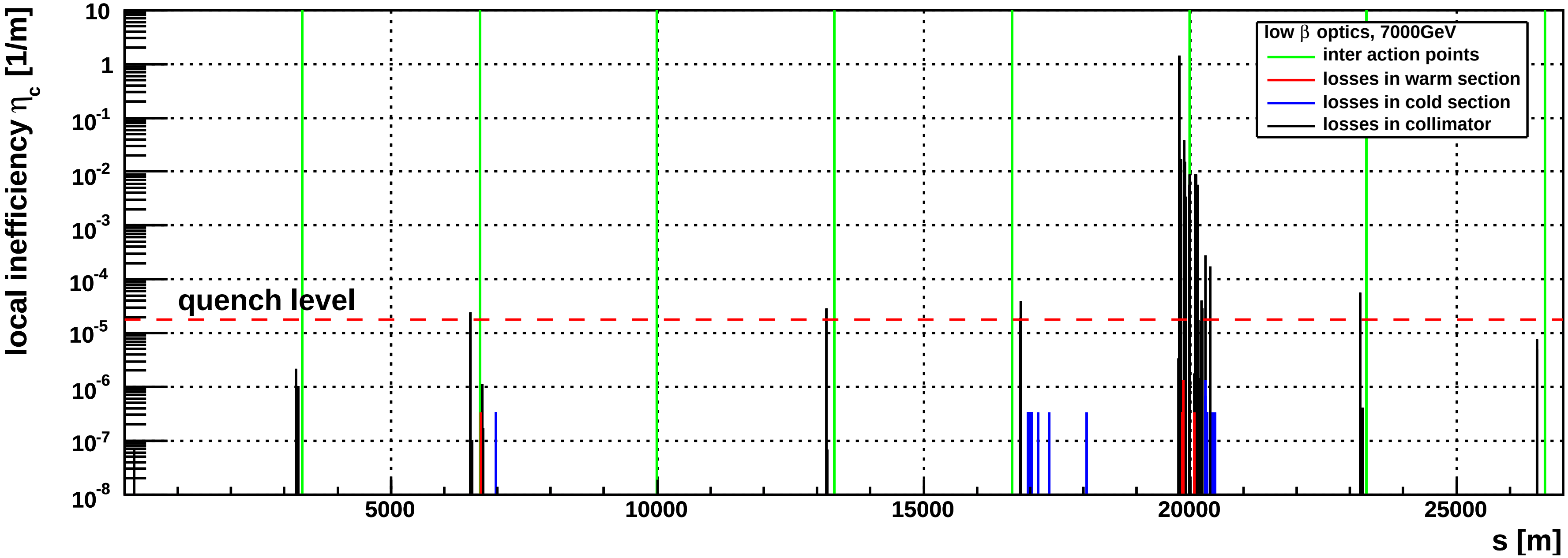
Idea for a possible Phase2 system is to add additional collimators in the dispersion suppressor at the location of the loss peaks seen.



symmetric shift of two dipoles at the beginning and end of the dispersion suppressor by 3 m.

Upgrade Performance (Optics V6.503)

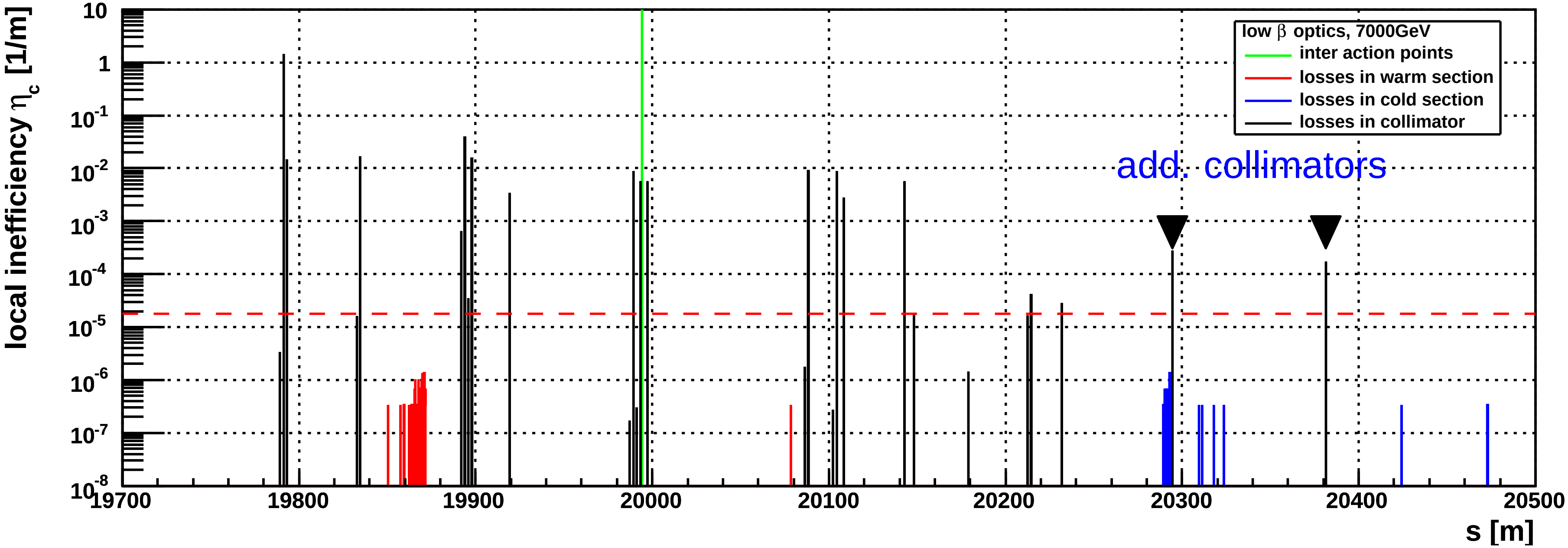
Loss-map around LHC for beam 1 (for 29.0M particles)



Copper secondaries set to nominal settings, carbon secondaries set to relaxed opening (26.5σ), cryogenic collimators (material copper, length 1 m) placed at 298.89 m and 388.44 m from IR7 at 15σ.

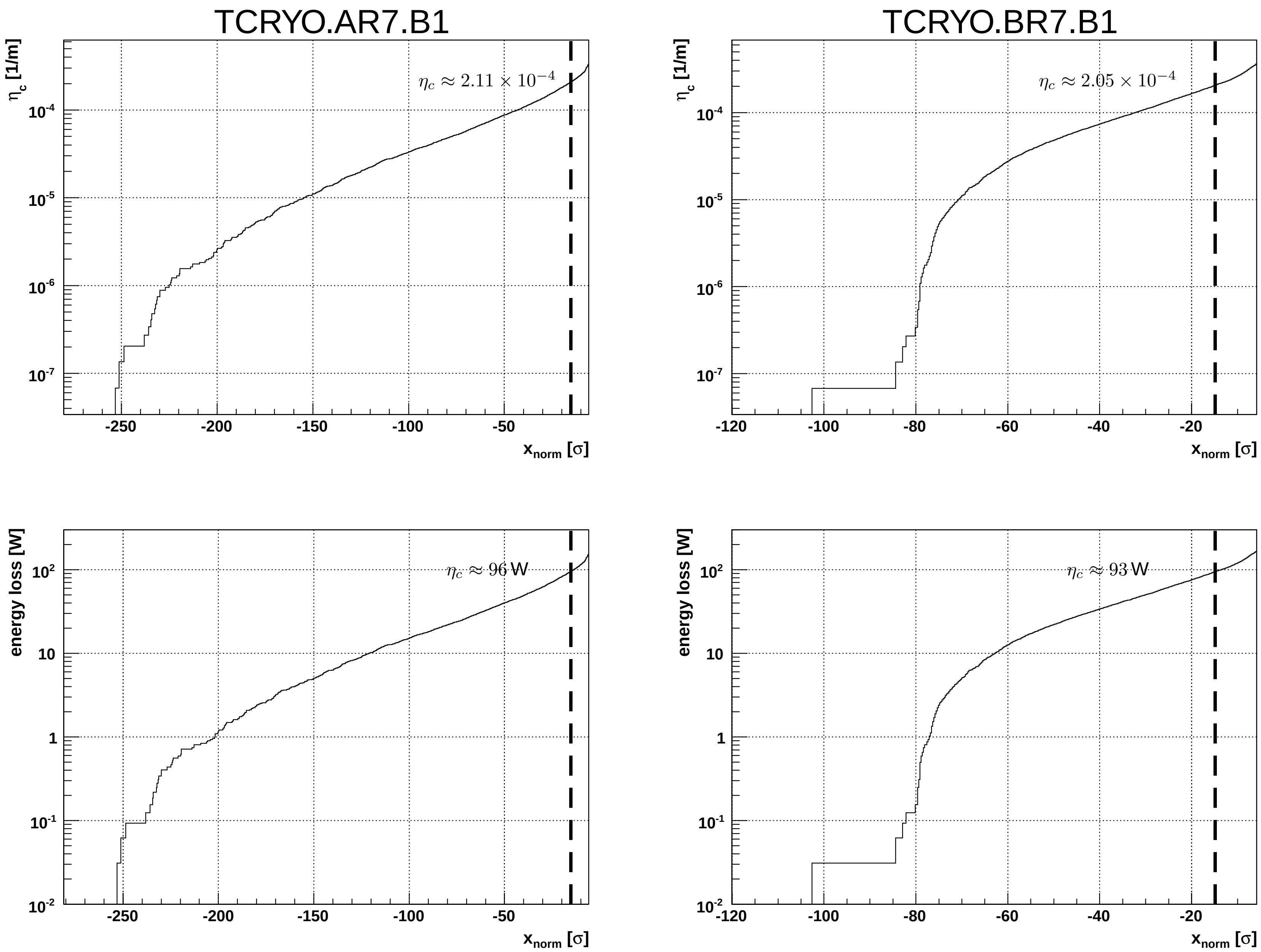
Upgrade Performance (Optics V6.503)

Zoom in IR7 and dispersion suppressor



Copper secondaries set to nominal settings, carbon secondaries set to relaxed opening (26.5σ), cryogenic collimators (material copper, length 1 m) placed at 298.89 m and 388.44 m from IR7 at 15σ.

Single Diffractive Particles



Further Studies

- cleaning inefficiency for increased gap size
- impedance for increased gap size (⇒ E. Metral)

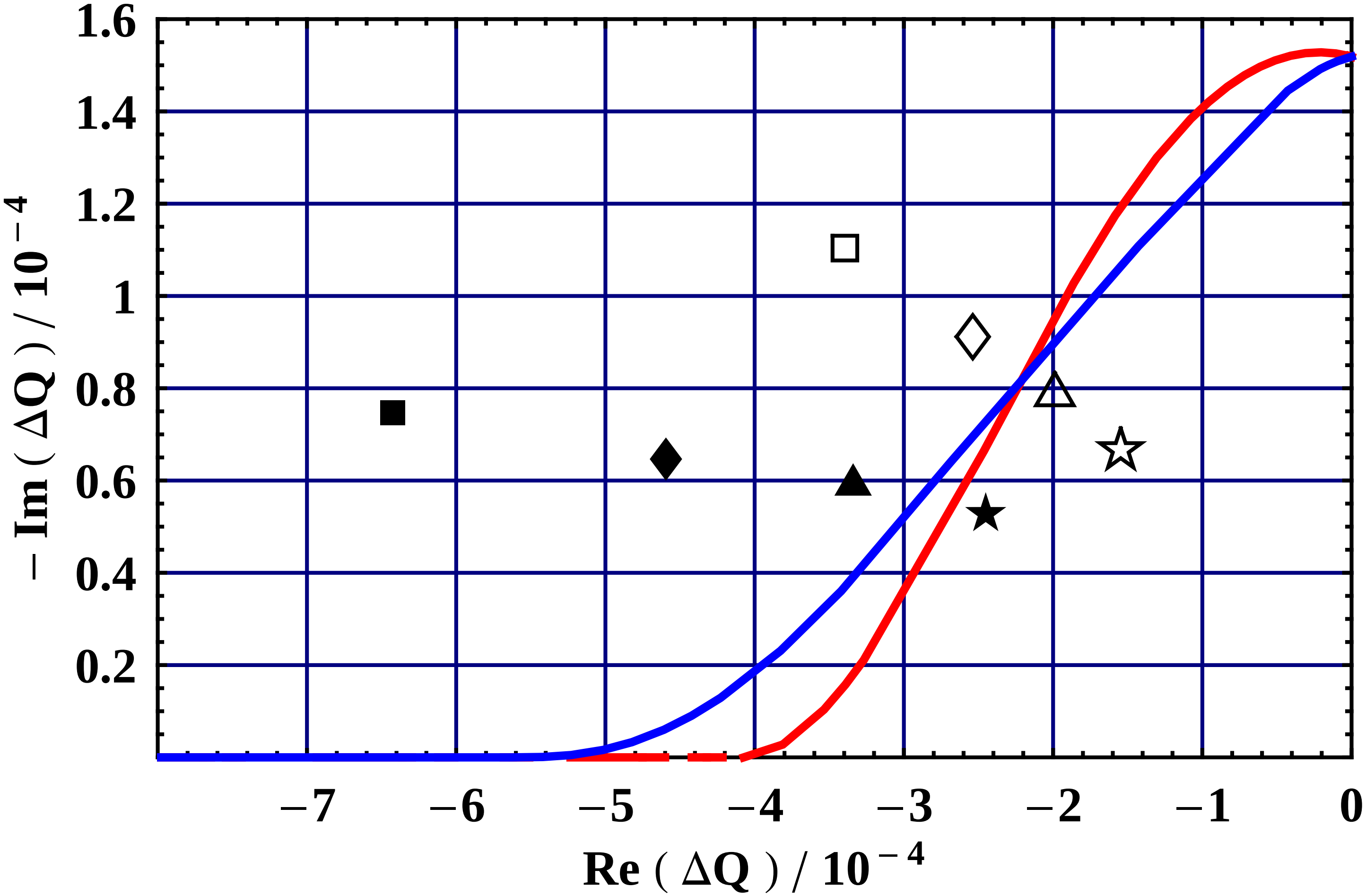
⇒ find settings within stable region and below quench limit

Collimator group	**nominal** $[\sigma]$	**step1** ($\approx \times 1.2$) $[\sigma]$	**step2** ($\approx \times 1.5$) $[\sigma]$	**step3** ($\approx \times 2.0$) $[\sigma]$
TCP IR7	6.0	7.2	9.0	12.0
TCS IR7	7.0	8.4	10.5	14.0
TCLA IR7	10.0	12.0	13.0	16.0
TCLP	10.0	12.0	13.0	16.0
TCT	8.3	10.0	12.5	16.6
TCDQ IR6	8.0	9.6	12.0	16.0
TCSG IR6	7.5	9.0	11.25	15.0
TCRYO	15.0	15.0	15.0	17.0

⇒ IR3 collimators kept at nominal settings.

⇒ step1 to step3 academic case for present triplet design.

Impedance

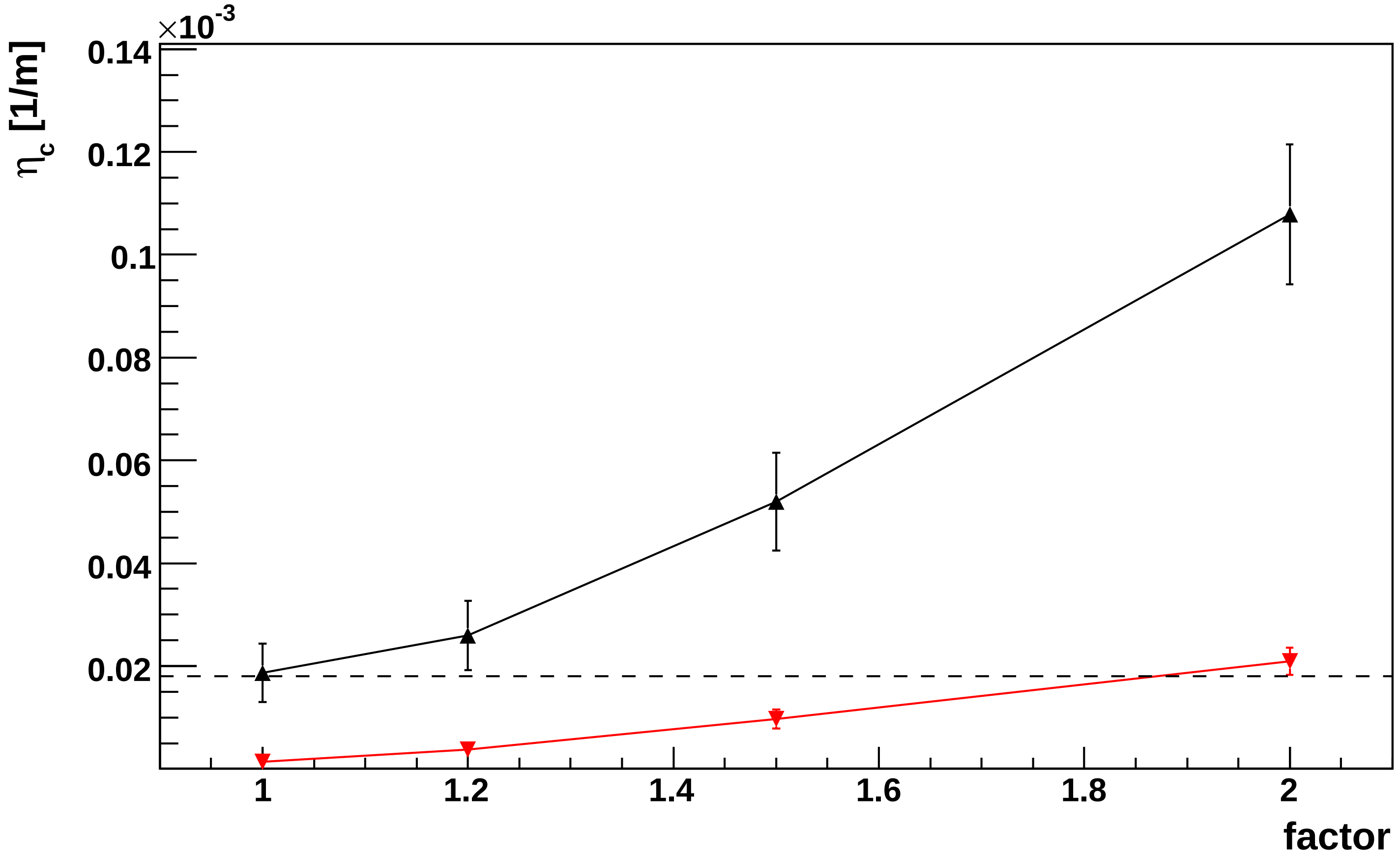


E. Metral

Filled symbol phase 1, empty symbols phase 2 with cryogenic collimators.

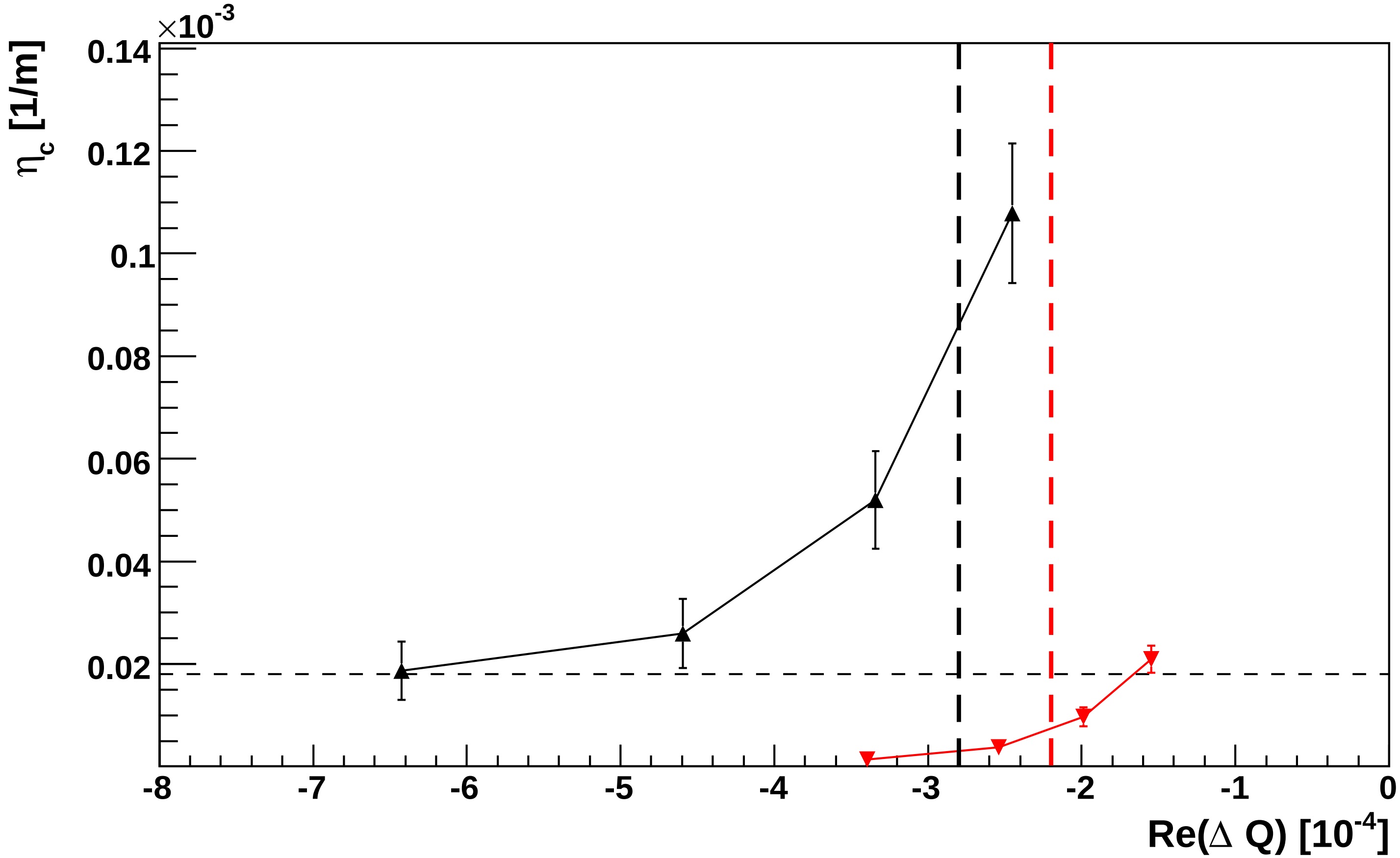
$\square = \text{nominal}, \diamond \approx 1.2, \triangle \approx 1.5, \ldots$ (see table on previous slide)

Gap Size and η_c



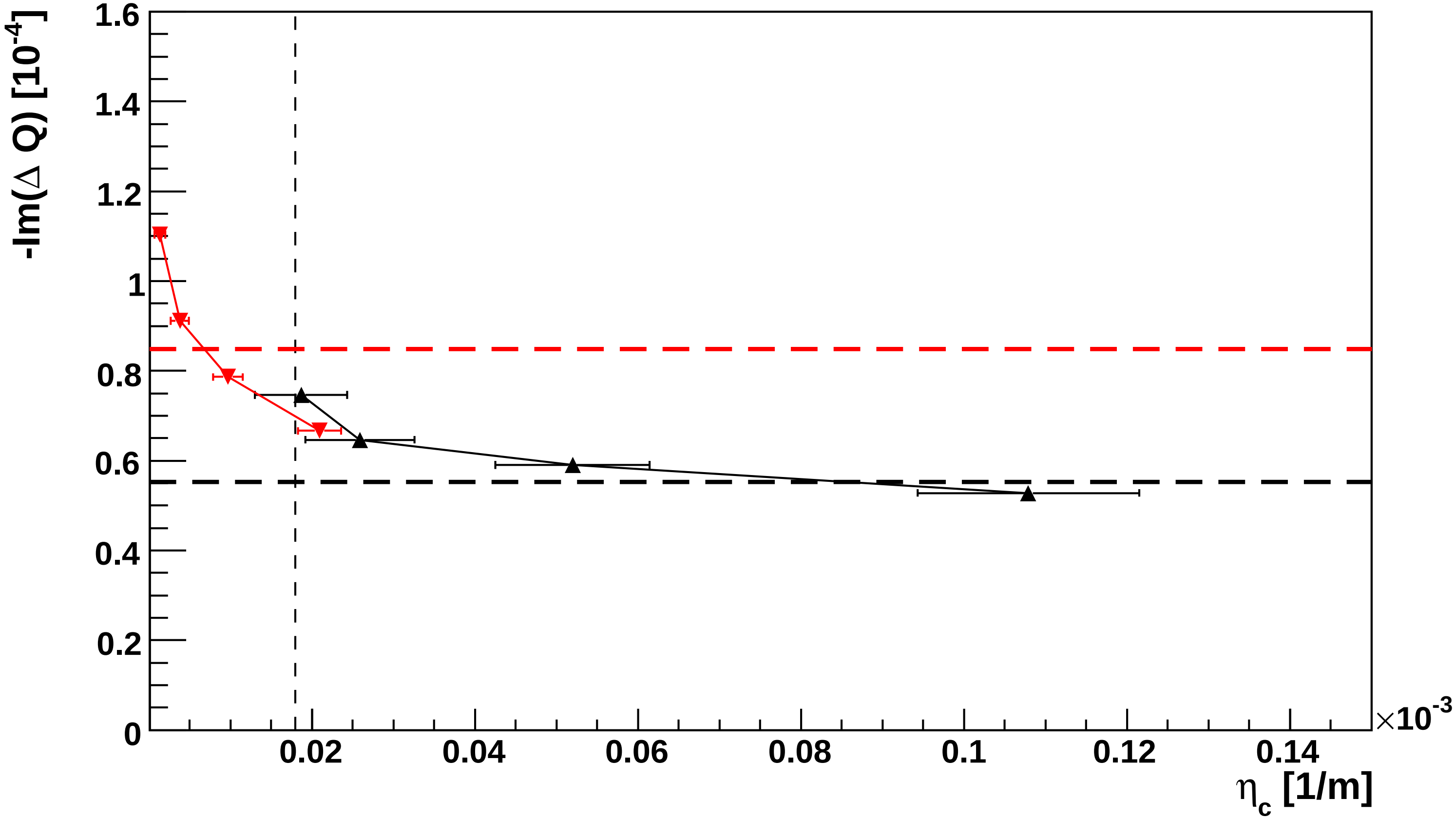
Reminder: multiplication “factor” is only true for TCP and TCS collimators. For phase 2 and ideal machine, opening the gaps up-to a “factor” 1.5 possible. $\Rightarrow$ increased triplet aperture needed or β^* has to be adapted.

Re Impedance and η_c

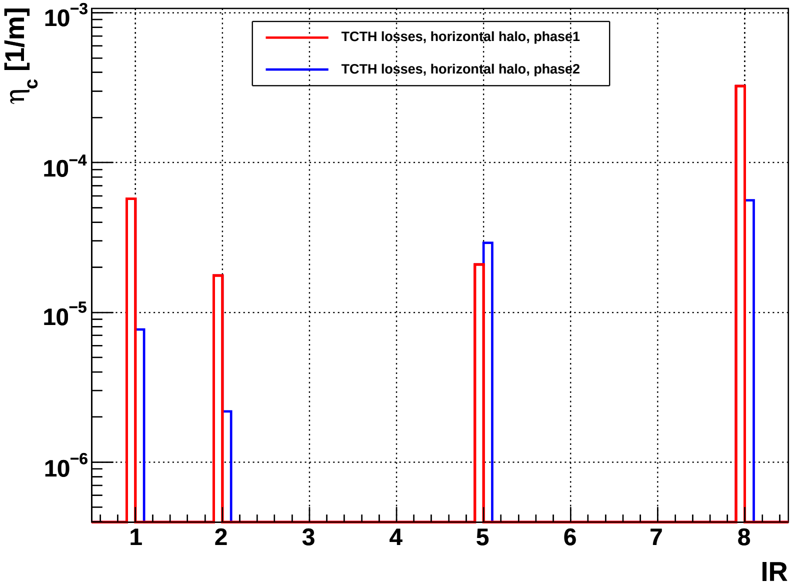


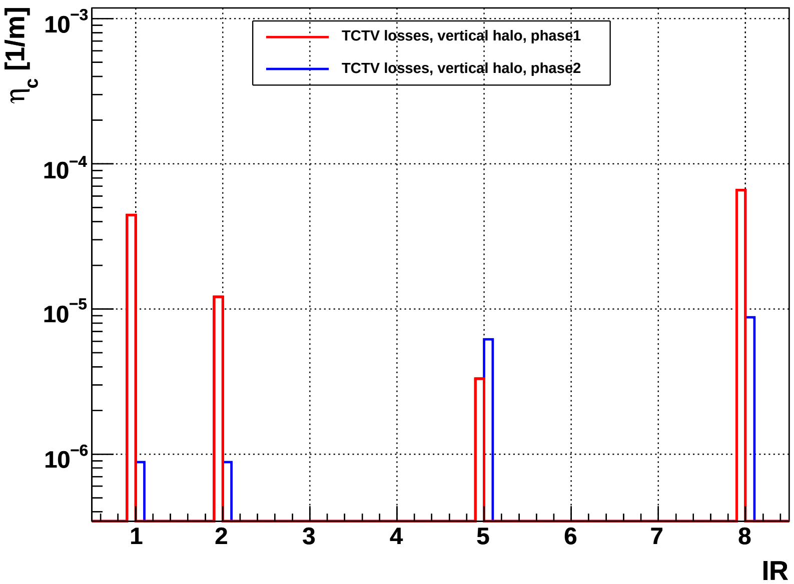
Only for phase 2 with cryogenic collimators one finds settings to stay below the required η_c and withing the stable region.

Im Impedance and η_c



Losses at the tertiary collimators



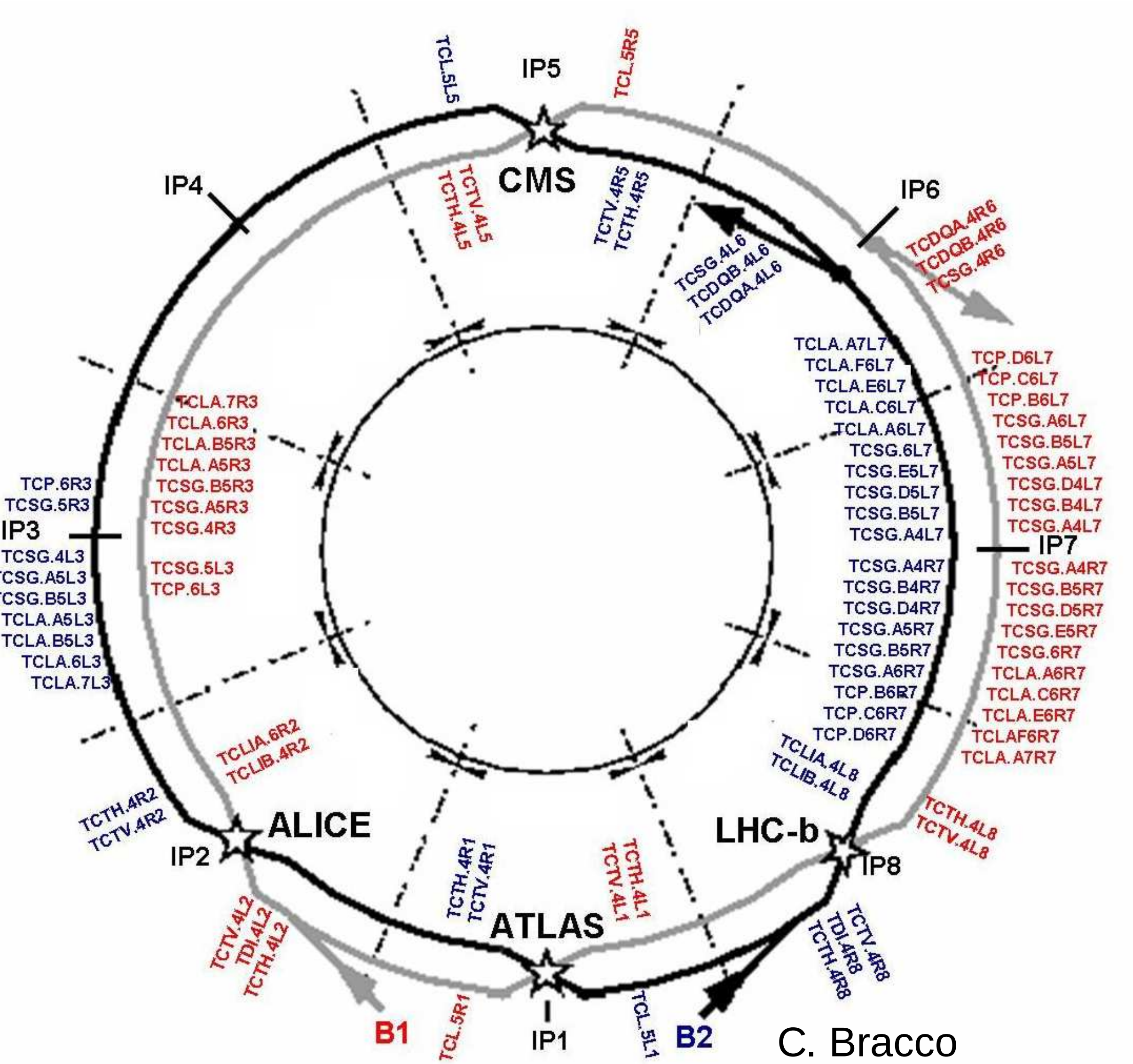


The proposed upgrade solution also reduces load on the tertiary collimators (background) in front of the experimental insertions.
No change in losses on tertiary collimators in IR5 due to missing cryogenic collimators in dispersion suppressor in IR3.

Summary

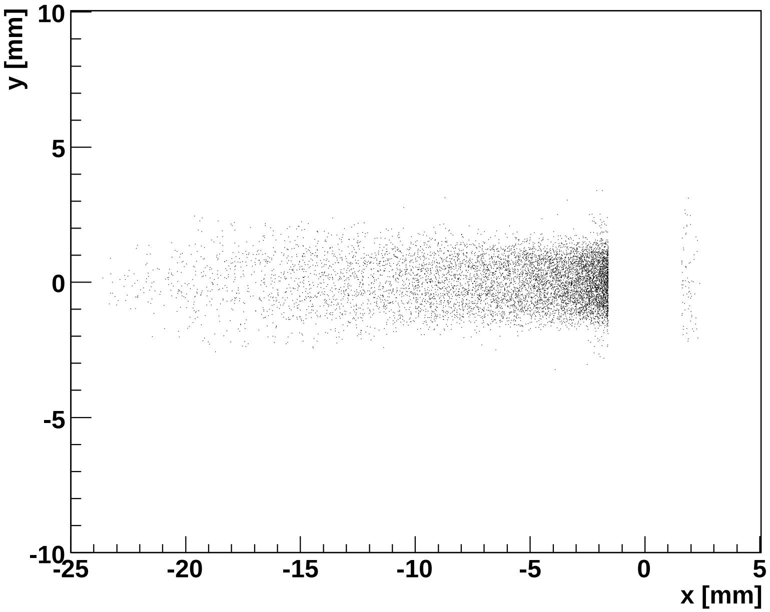
- Present collimation layout limits beam intensity due to cleaning efficiency and impedance (about 40% to 5% of nominal intensity).
- The presented upgrade solution improves the cleaning efficiency by one order of magnitude.
- The gain in cleaning efficiency allows to increase the gap size of collimators, reducing the impedance to values within the stable region.
- Halo load on the tertiary collimators in front of the experimental insertions is reduced up to two orders of magnitude.

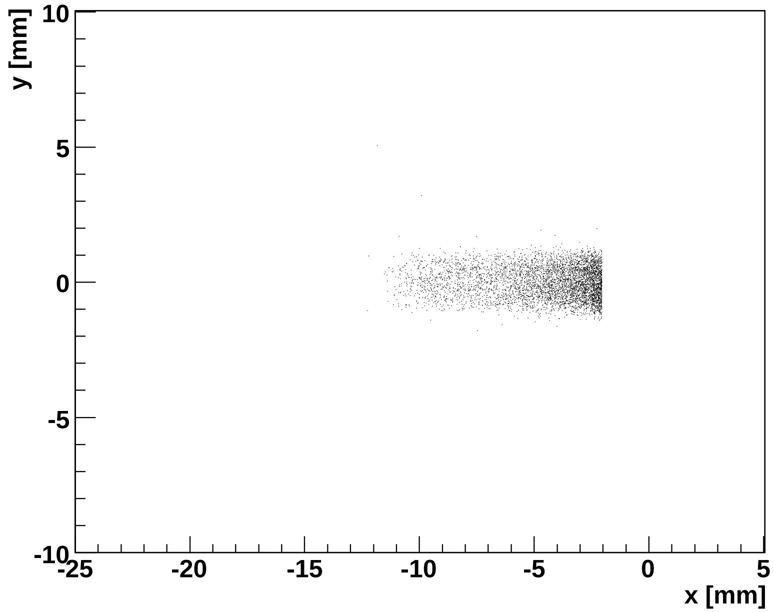
Layout of the LHC Ring



- 7 TeV protons for collision
- super-conduction magnets to bend and focus beam
- four experimental insertions
- two dedicated cleaning insertions in region with normal conducting magnets
- dump protection (in case of kicker failure)

Impact Distribution





TCRYO.AR7.B1
at 300m from IR7
opening 15σ
≈ 2.0 mm

TCRYO.BR7.B1
at 387m from IR7
opening 15σ
≈ 1.8 mm