Collimator settings during the energy ramp

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Outline

- Introduction
  - Definition of beam intensity limitation
  - Overview on the maximum allowed beam intensity I_{max} for the nominal cases

- Collimator settings at different operational stages

  layout during the energy ramp has to be defined, analysis of several cases at different energies

- Quench limit at different energies

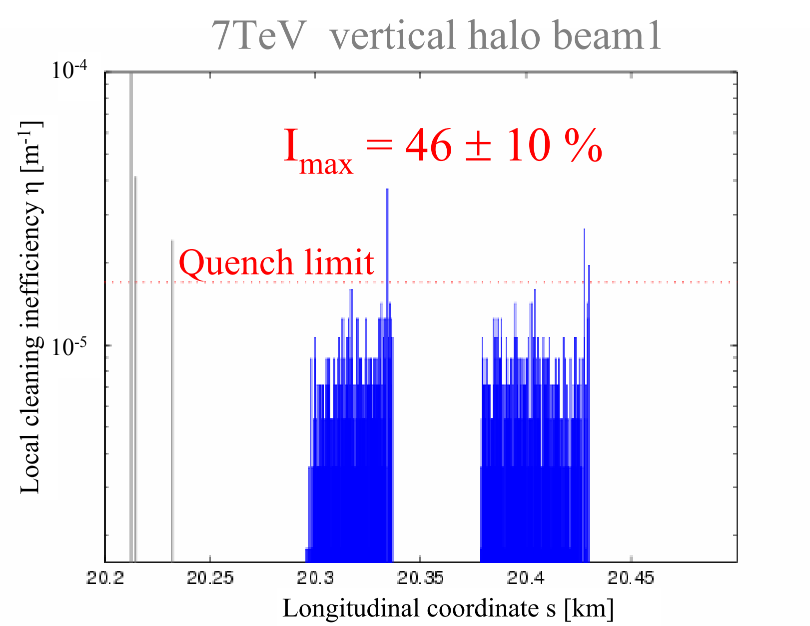
- Conclusions

Intensity limitation

Main contributions to possible intensity limitations from collimation for the LHC beam:

1) Collimator-induced impedance (small gaps, high resistivity CFC) ~ 40% nominal intensity

2) Losses above the quench limit in the sc-magnets
most critical are the magnets in the dispersion suppressor



For **nominal** setting of collimators at 7TeV after the squeeze:

*	B1	B2
Hor.halo	54±13%	65±17%
Ver.halo	46±10%	65±17%

No limitation at 450GeV injection!

* Perfect machine

How to evaluate the maximum allowed beam intensity

The maximum allowed beam intensity is given by:

Beam lifetime τ
0.1h @ 450GeV
0.2h @ 7TeV

$$I_{max} = \frac{\tau \cdot R_q}{\eta}$$

Quench threshold for continuous losses
7×10^8 p/(m · s) @ 450GeV
7.8×10^6 p/(m · s) @ 7TeV

Local cleaning inefficiency
(in unit of m^{-1})

$I_n = 3.23 \times 10^{14}$ protons ➔ $\eta_{quench} = 7.8 \times 10^{-4}$ m^{-1} @ 450GeV
$\eta_{quench} = 1.7 \times 10^{-5}$ m^{-1} @ 7TeV

η_{max} : maximum cold peak from loss maps ➔

$$I_{max} = \frac{\eta_{quench}}{\eta_{max}} I_n$$

$$\text{Error} = \frac{\eta_{quench}}{\eta_{max}^2} \sigma_{\eta_{max}}$$

Statistical fluctuations

Real machine

Systematic errors and imperfections can be more important than statistical ones.

Errors in:

- Quench limit
- Cross sections
- Non-zero closed orbit (~30% I_n) [G. Robert-Demolaize]
- Beta beating (~25% I_n) [R.Assmann]
- Aperture imperfections (~25% I_n)[S. Redaelli]
- Setup errors (~10% I_n) [T.Weiler, C.Bracco]

Can reduce the estimated beam intensity up to a factor 5 or more.

Collimation setting at different operational stages

Injection

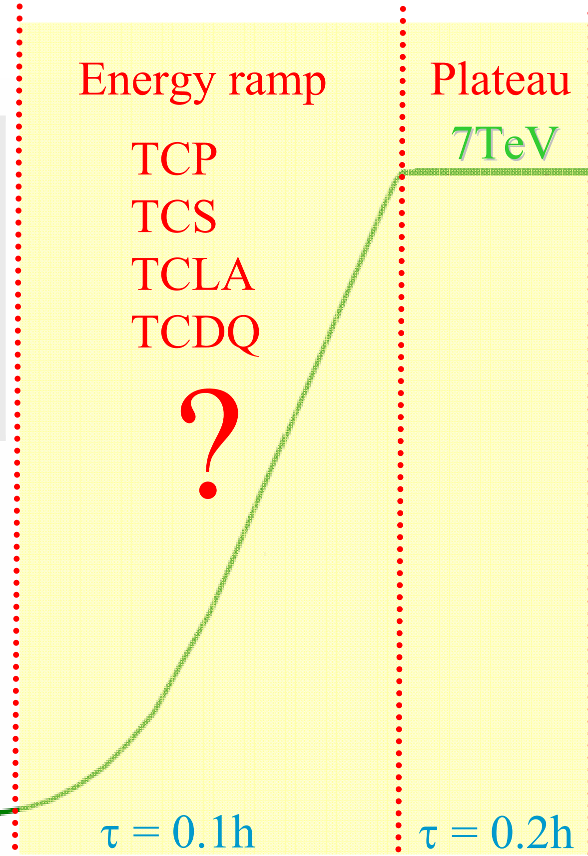
*	TCP	TCS	TCLA
IR3	8	9.3	10
IR7	5.7	6.7	10
	TCDQ	TCS	
IR6	8	7	

+

*	TCLI	TDI
IR2/8	6.8	6.8

Injection protection

450GeV



Squeeze and Collision

*	TCP	TCS	TCLA
IR3	15	18	20
IR7	6	7	10
	TCDQ	TCS	
IR6	8	7.5	

+

*	TCLP
IR1/5	10
	TCT
IR1/2/5/8	8.3

Physics debris

Triplets protection

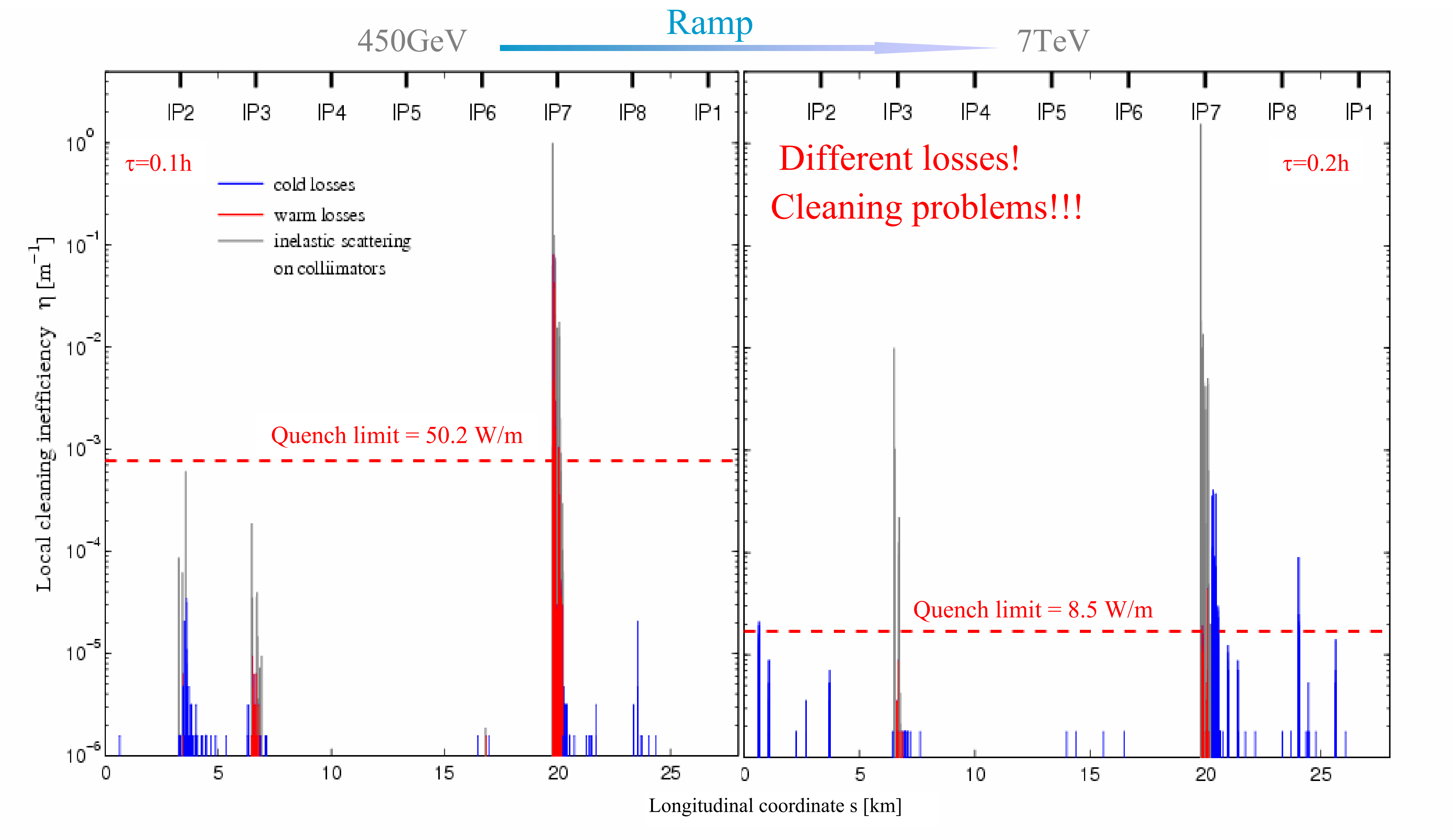
Constant optics and LHC available aperture during the energy ramp before the squeeze + smaller beam

↓

Constant collimator settings as at injection? [R.Assmann Chamonix 2005]

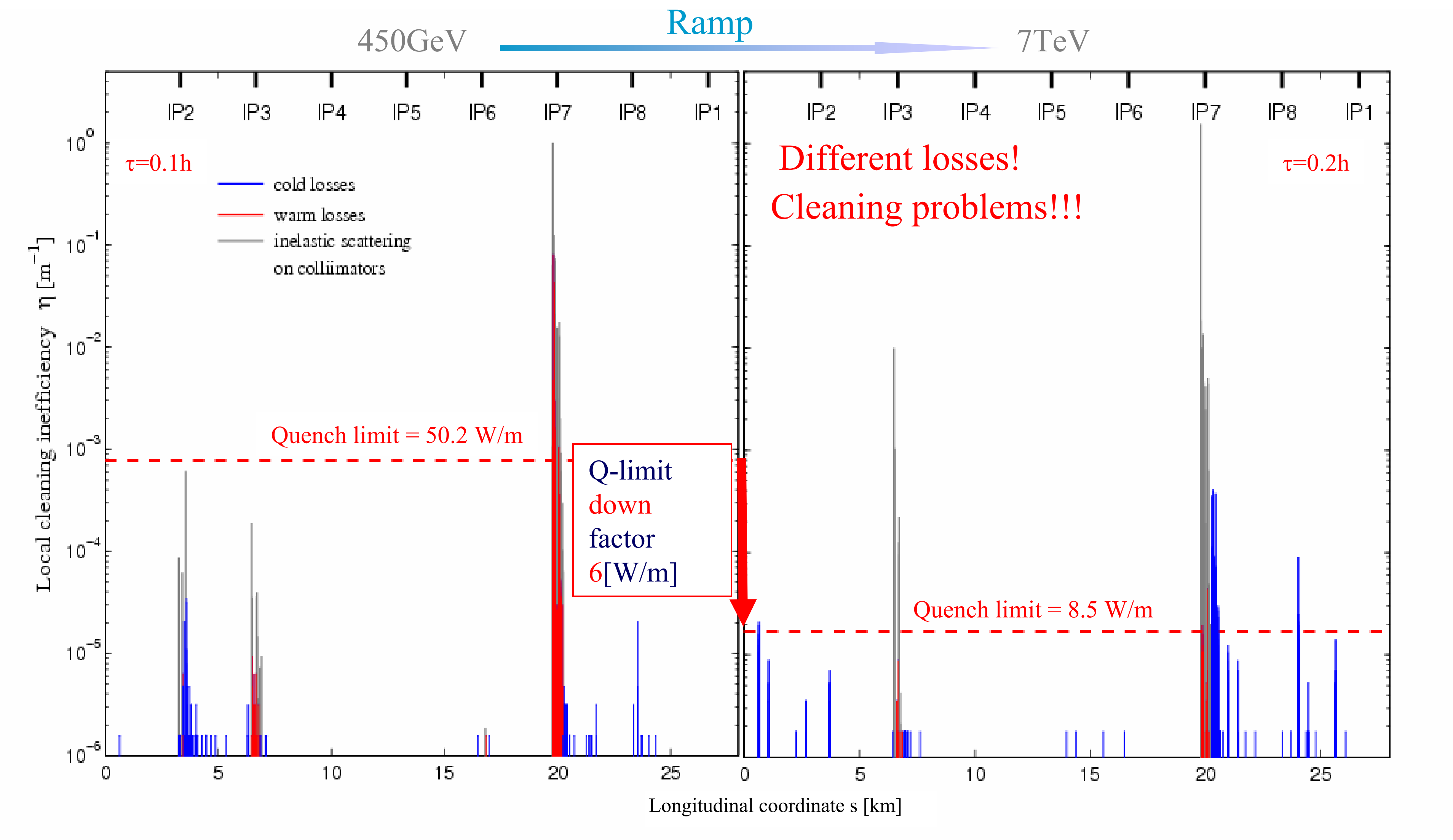
* Collimator apertures in unit of σ

Injection settings



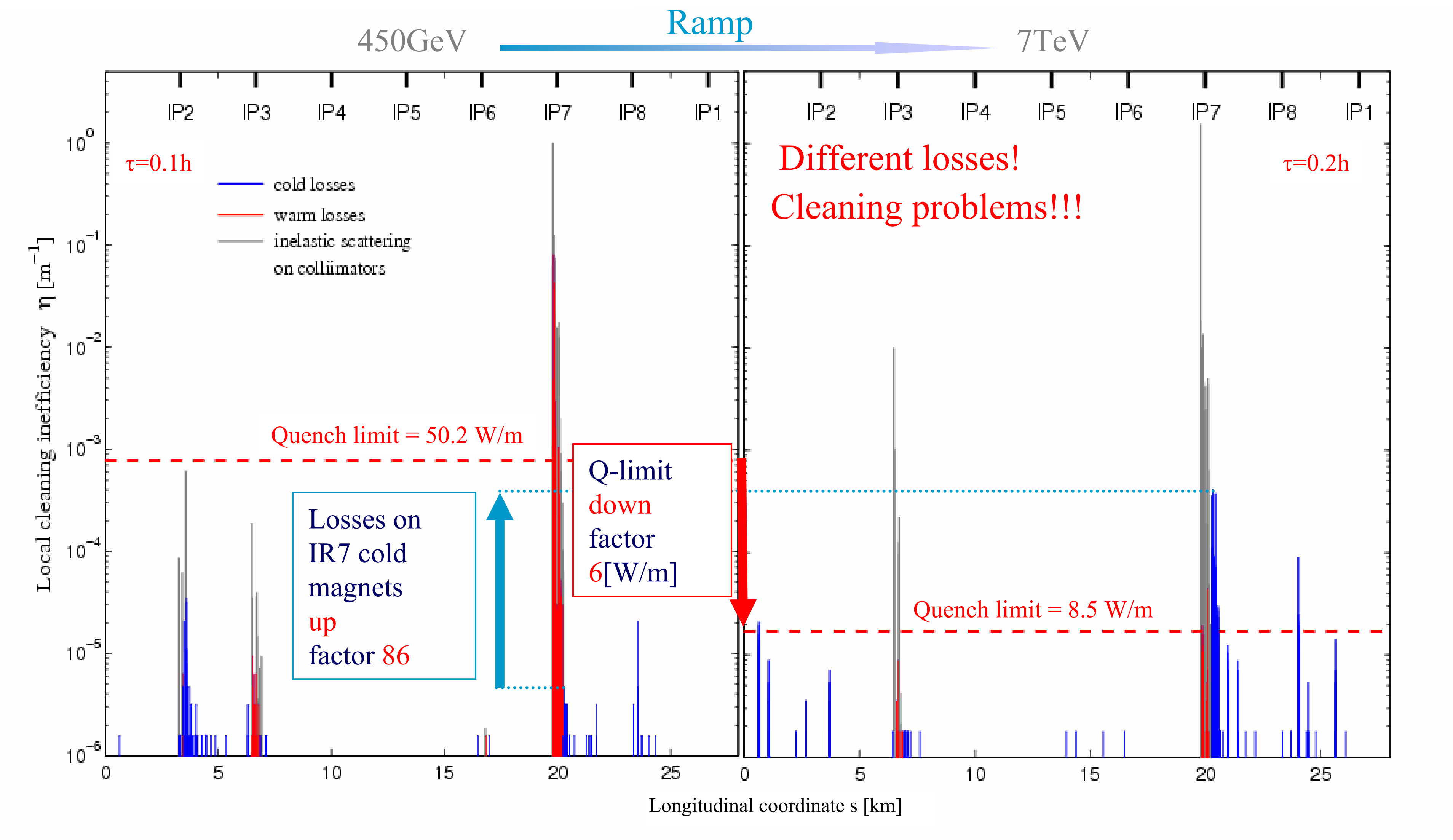
* Most critical case: vertical halo Beam1

Injection settings



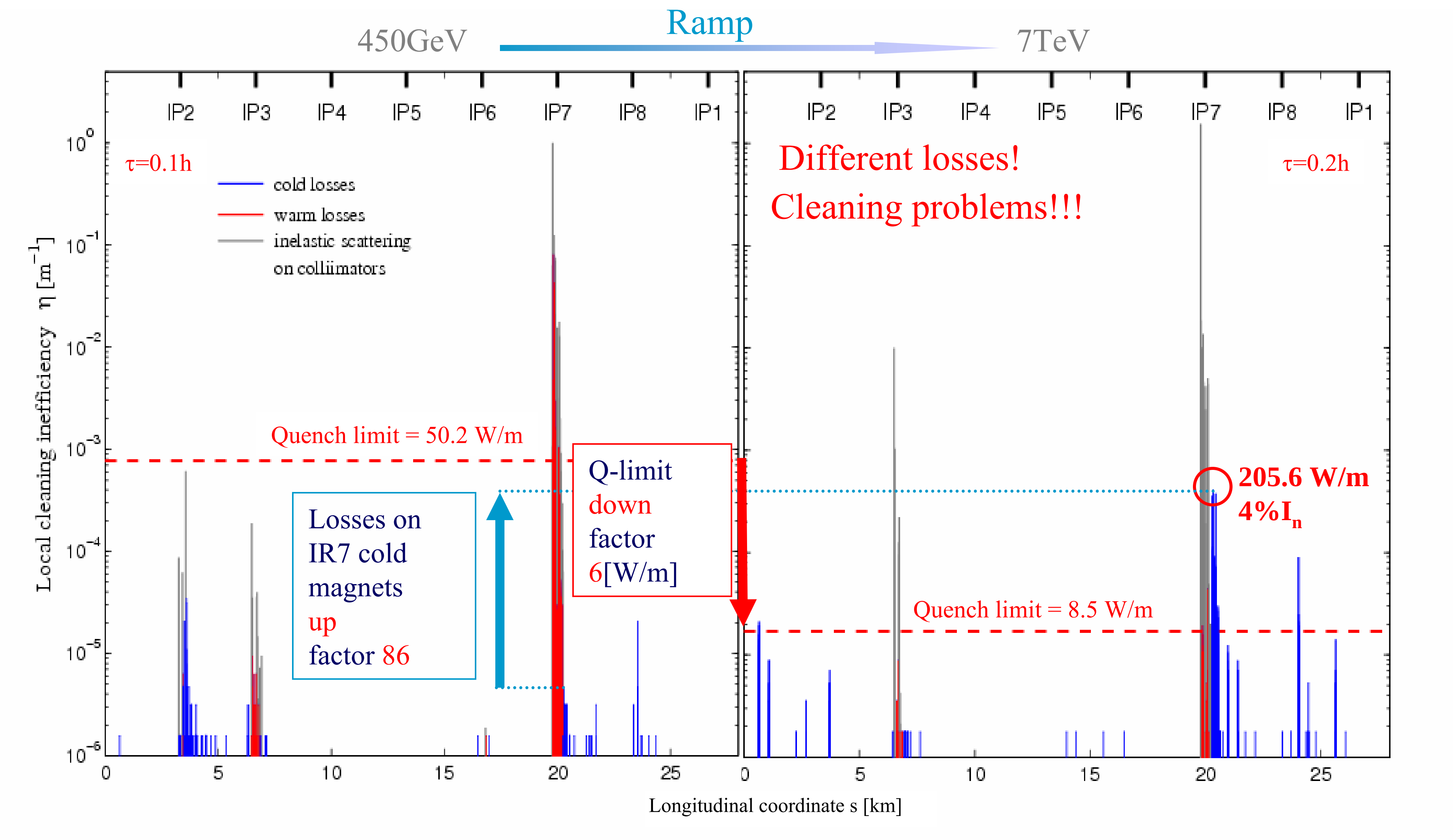
* Most critical case: vertical halo Beam1

Injection settings



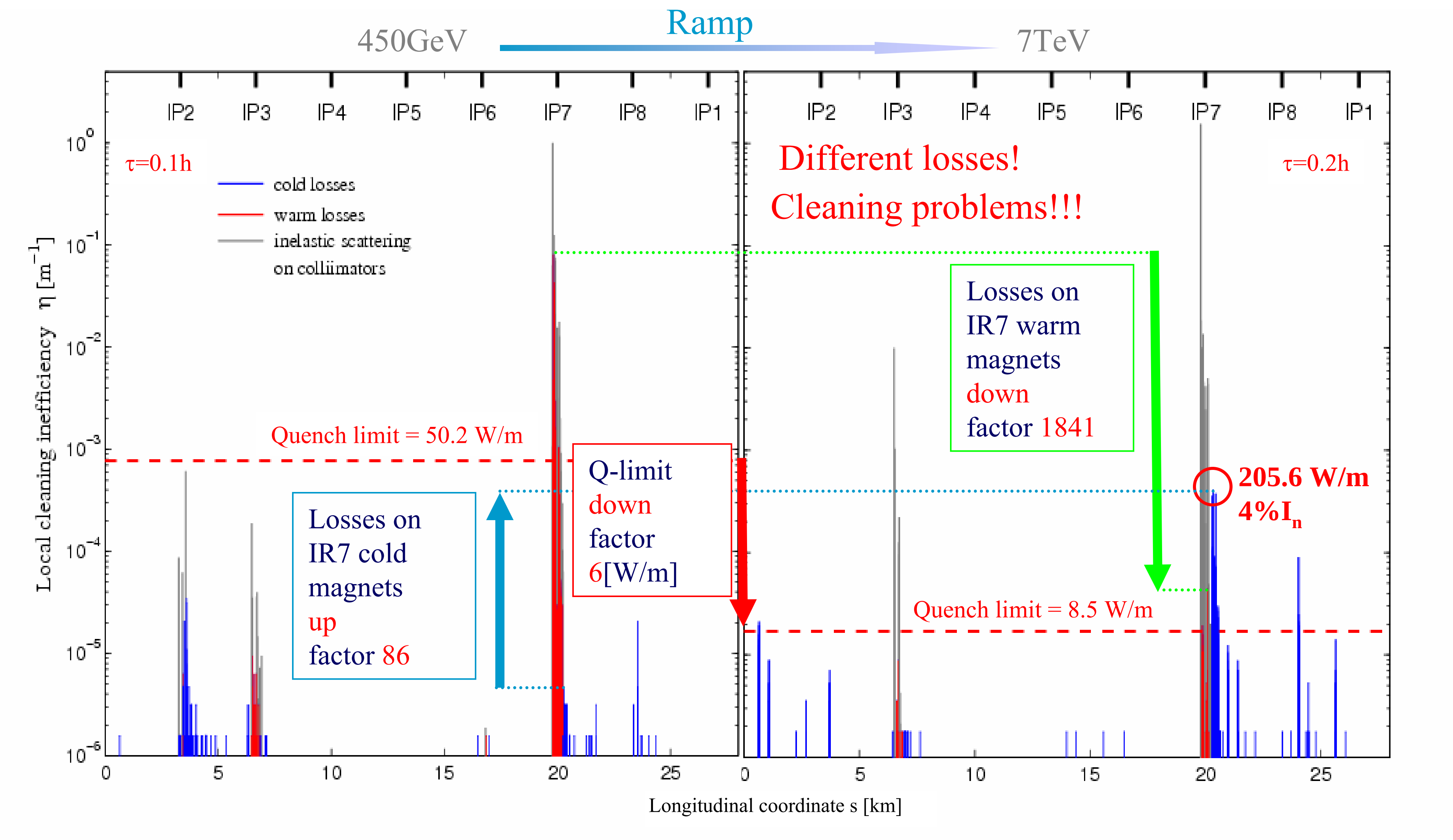
* Most critical case: vertical halo Beam1

Injection settings



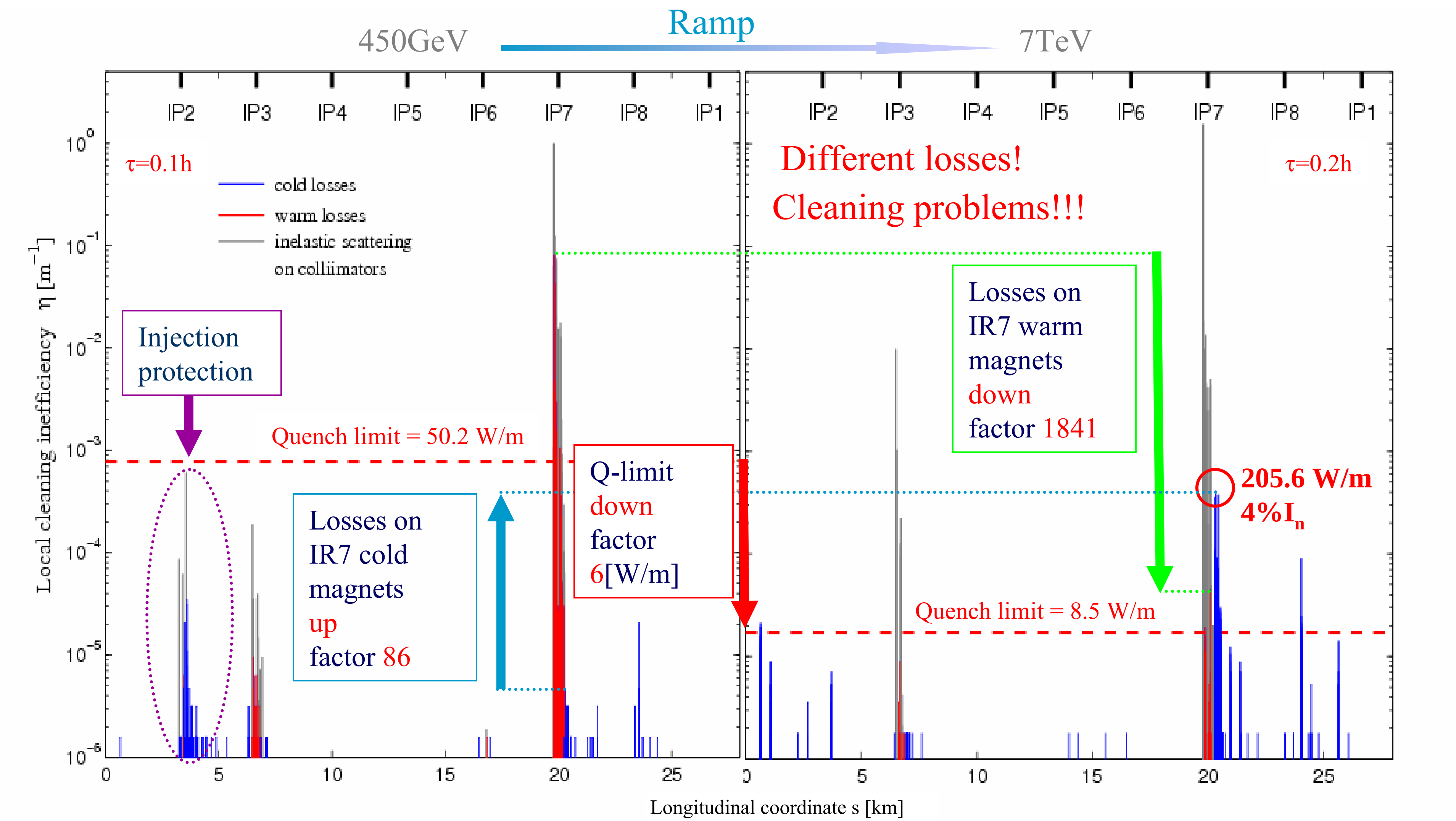
* Most critical case: vertical halo Beam1

Injection settings



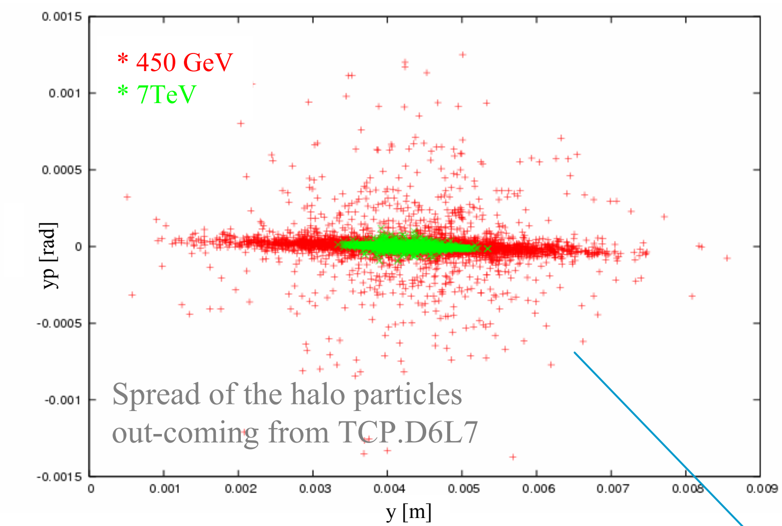
* Most critical case: vertical halo Beam1

Injection settings



* Most critical case: vertical halo Beam1

Why different losses?

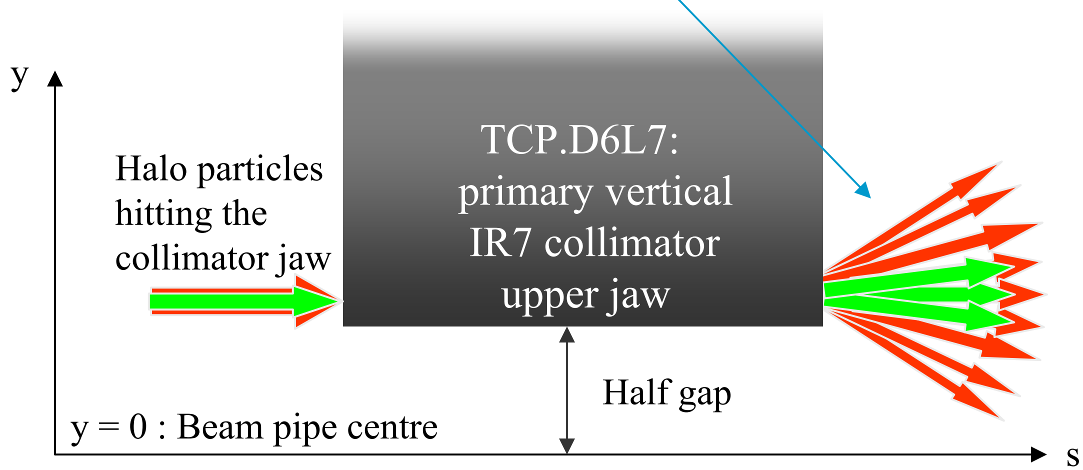


Moliere's Theory: kick angle

$$\theta(s) = \frac{13.6\text{MeV}}{vp} z \sqrt{\frac{s}{X_0}} \left[1 + 0.038 \ln\left(\frac{s}{X_0} \right) \right]$$

s = thickness
X_0 = radiation length
} of the scattering medium

p = momentum
v = velocity
z = charge number
} of the incident particle

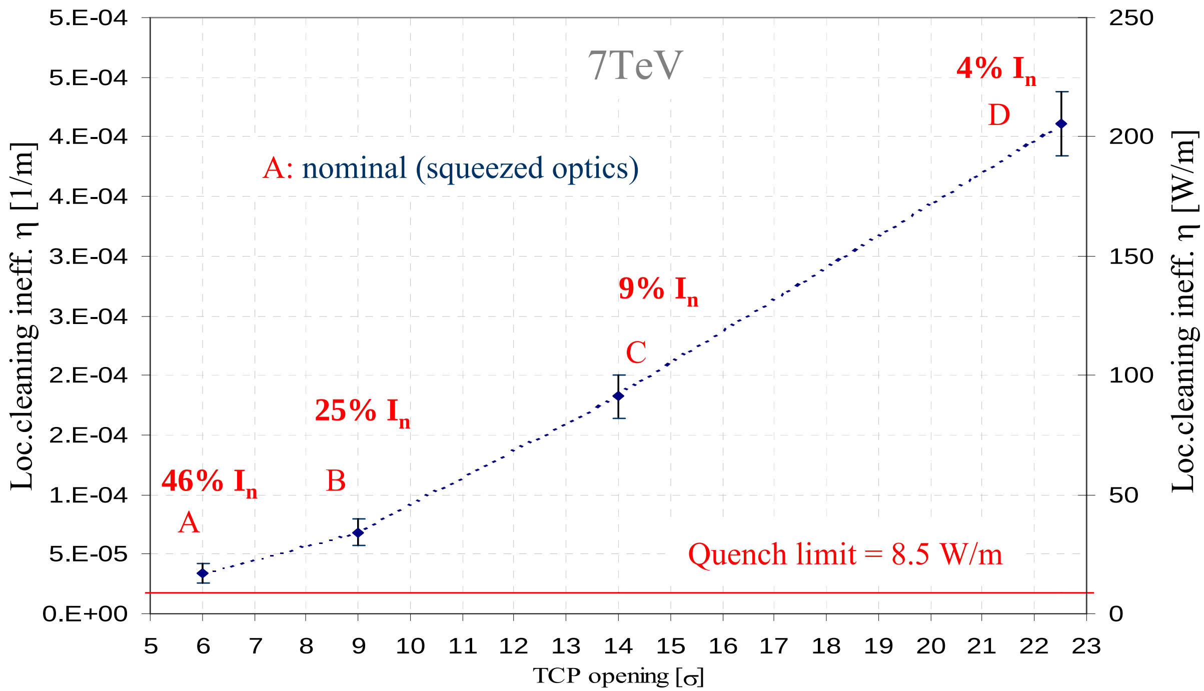


Efficiency versus collimator settings

The cleaning inefficiency is dominated by losses on the sc-magnets of the dispersion suppressor in IR7. These losses do not depend on the optics or on the β*, but only on the energy and on the collimation setting.
At high energy, the closer the collimators are to the cold aperture the higher are losses in the dispersion suppressor

↓

Worse efficiency



Collimator settings*:

* Collimator apertures in unit of σ

Squeezed optics TCTs @11.3σ → B

Un-squeezed optics → C, D

*	IR3			IR6		IR7		
	TCP	TCS	TCLA	TCDQ	TCS	TCP	TCS	TCDQ
B	18	21	23	11	10.5	9	10	13
C	23	27	30	19	17	14	19	24
D	32	36.7	39.4	31.6	27.6	22.5	26.5	39.4

Tolerances

During the energy ramp and the first part of the plateau we don't want to have the collimators at their nominal "7TeV" aperture because the beam can be unstable and tolerances are extremely tight :

Tolerance budget: $T_{coll} = n2 - n1 - 0.4\sigma$

[R.Assmann Chamonix 2006]

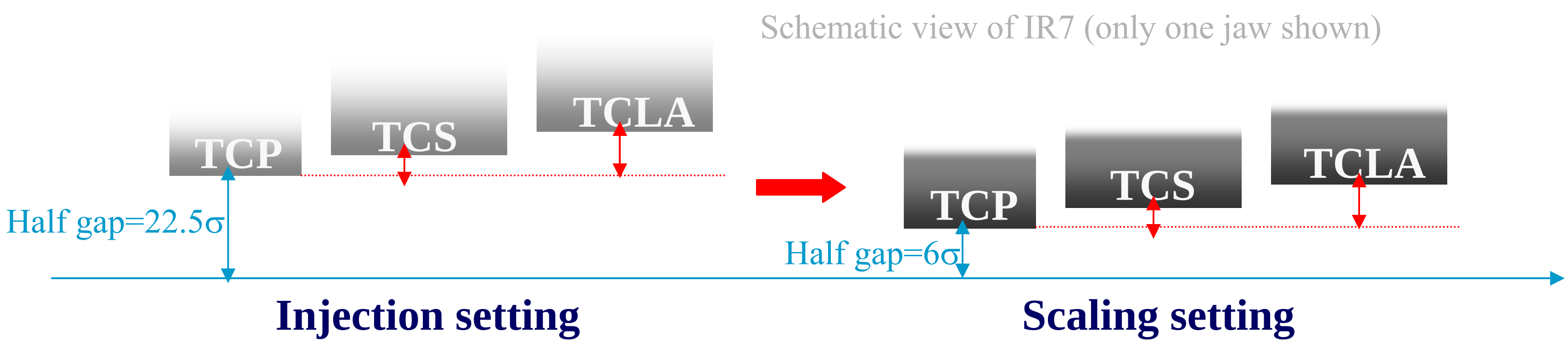
n1: TCP aperture [σ]
n2: TCS aperture [σ]
0.4σ: minimum tolerance

a) Nominal settings (IR7)
450GeV: TCP @ 5.7σ, TCS @ 6.7σ ➔ $T_{coll} = 0.6\sigma \cong 0.6$ mm
7TeV: TCP @ 6σ, TCS @ 7σ ➔ $T_{coll} = 0.6\sigma \cong 0.15$ mm

b) Injection setting (IR7)
7TeV: TCP @ 22.5σ, TCS @ 26.5σ ➔ $T_{coll} = 3.6\sigma \cong 0.9$ mm

Define a collimator setting at 7TeV with the same tolerance budget as the injection one (0.9mm) but with an improved cleaning efficiency!!

TCP.IR7 @ 6σ

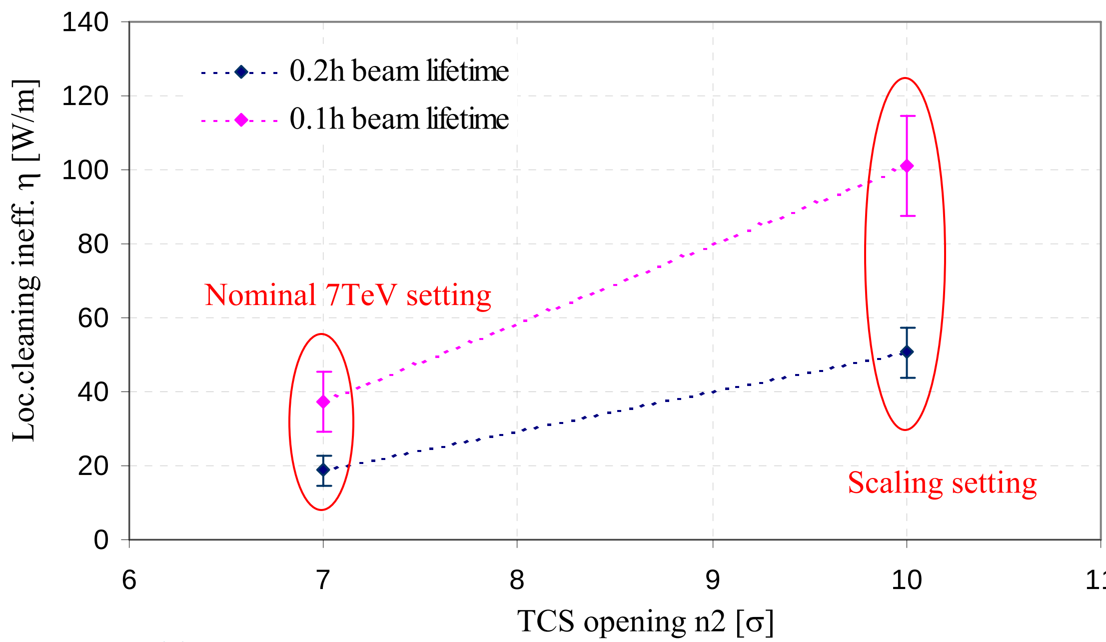


Scaling setting: the collimator system is closed "rigidly" driving the TCP down to 6σ. The offset between the TCP and all the other collimators (red arrows) is kept unchanged as it is at the injection setting:

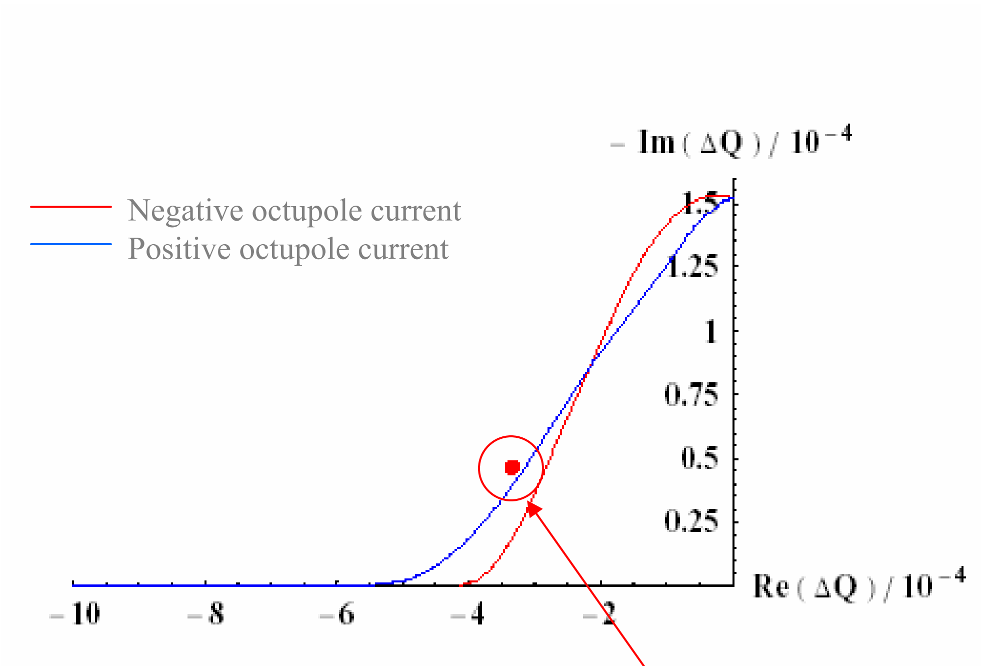
	TCP	TCS	TCLA
IR3	15.2	20.4	23.2
IR7	6.0	10	23.2
	TCDQ	TCS	
IR6	15.2	11.2	

$T_{coll} = 3.6\sigma \cong 0.9$ mm

Efficiency: factor 4 improved respect to injection setting (205 W/m)!



Impedance



[E. Metral]

Stability diagram for:

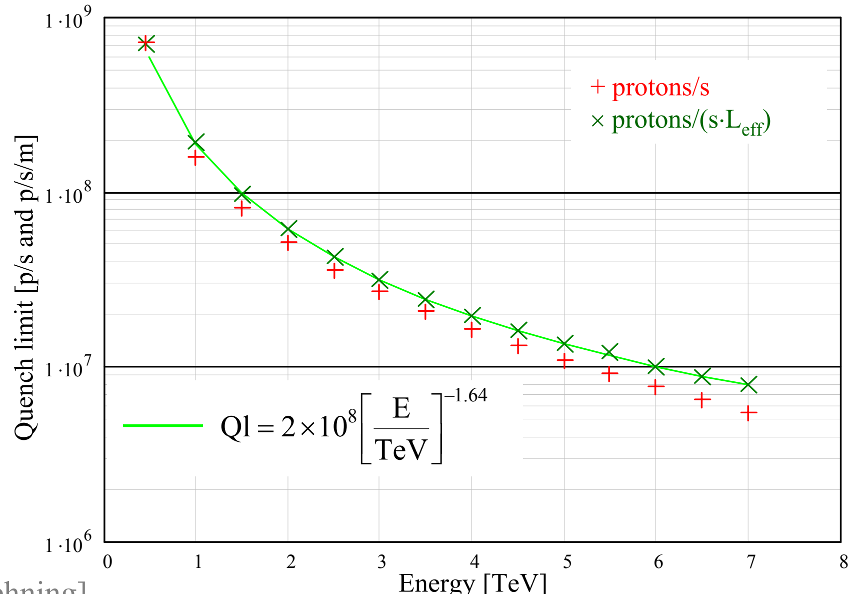
- 7TeV plateau optics
- scaling collimator setting
- nominal beam intensity
- vertical coherent tune shift
- mode m = 0
- zero chromaticity

Almost STABLE BEAM!!!

No further limitations to the beam intensity, coming from the collimator-induced impedance, for the scaling setting.

Quench limit at different energies

The definition of I_{max} during the energy ramp requires the knowledge of the quench limit Ql at the different energies E.



[B. Dehning]

Local cleaning inefficiency

Energy[TeV]	Quench limit [1/m]
0.45	7.8×10^{-4}
1	2.3×10^{-4}
1.5	1.2×10^{-4}
2	7.3×10^{-5}
2.5	5.1×10^{-5}
3	3.8×10^{-5}
3.5	2.9×10^{-5}
4	2.3×10^{-5}
4.5	2.0×10^{-5}
5	1.6×10^{-5}
5.5	1.4×10^{-5}
6	1.2×10^{-5}
6.5	1.1×10^{-5}
7	8.5×10^{-6}

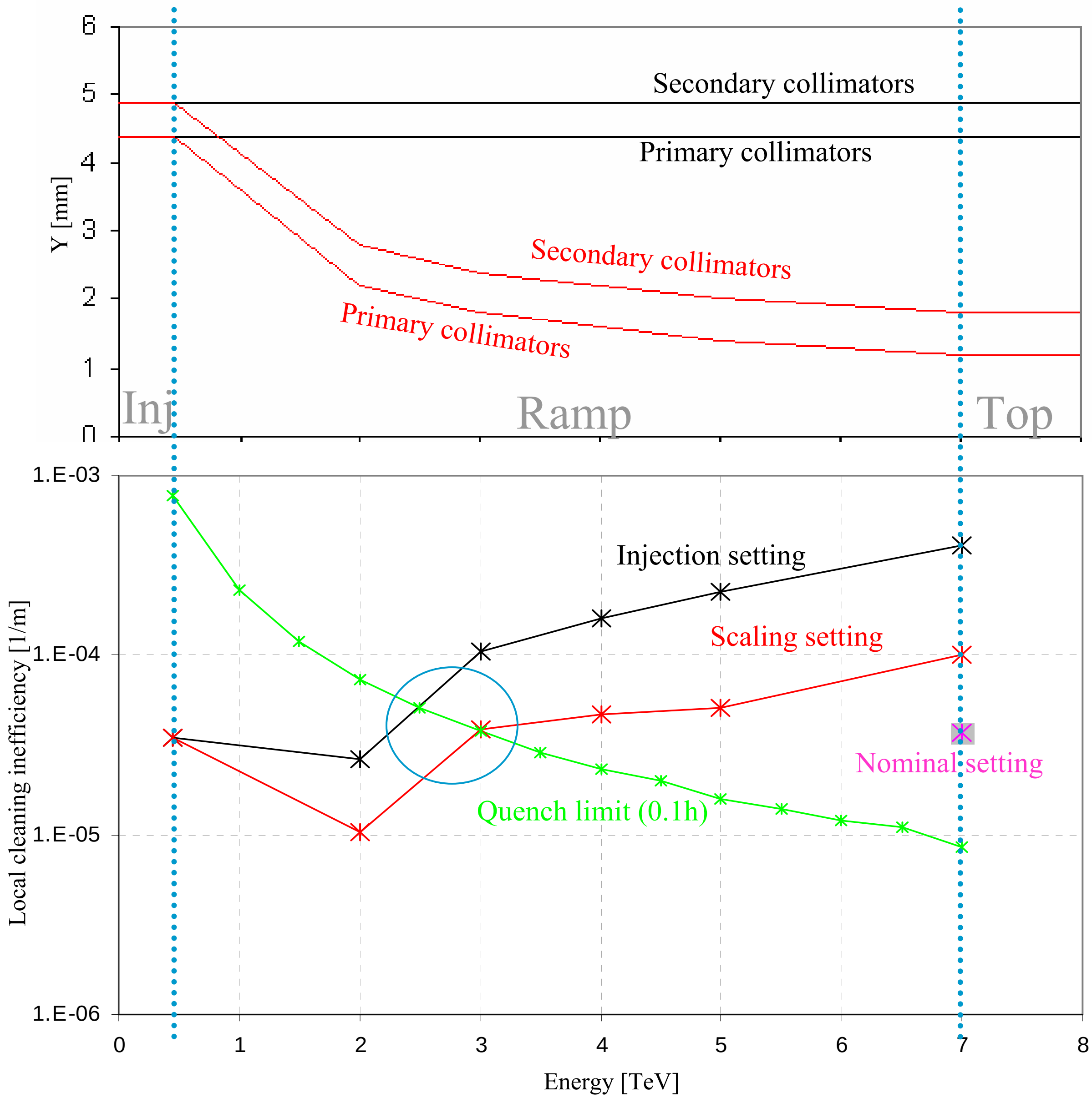
$\tau = 0.1h$

Effective showers length L_{eff} : 1m @ 450GeV
0.7m @ 7TeV

[J.B. Jeanneret]

General behavior of Ql [p/m/s] vs E : $Ql = a\left[\frac{E}{TeV}\right]^{-r}$ with $r \cong 3/2$

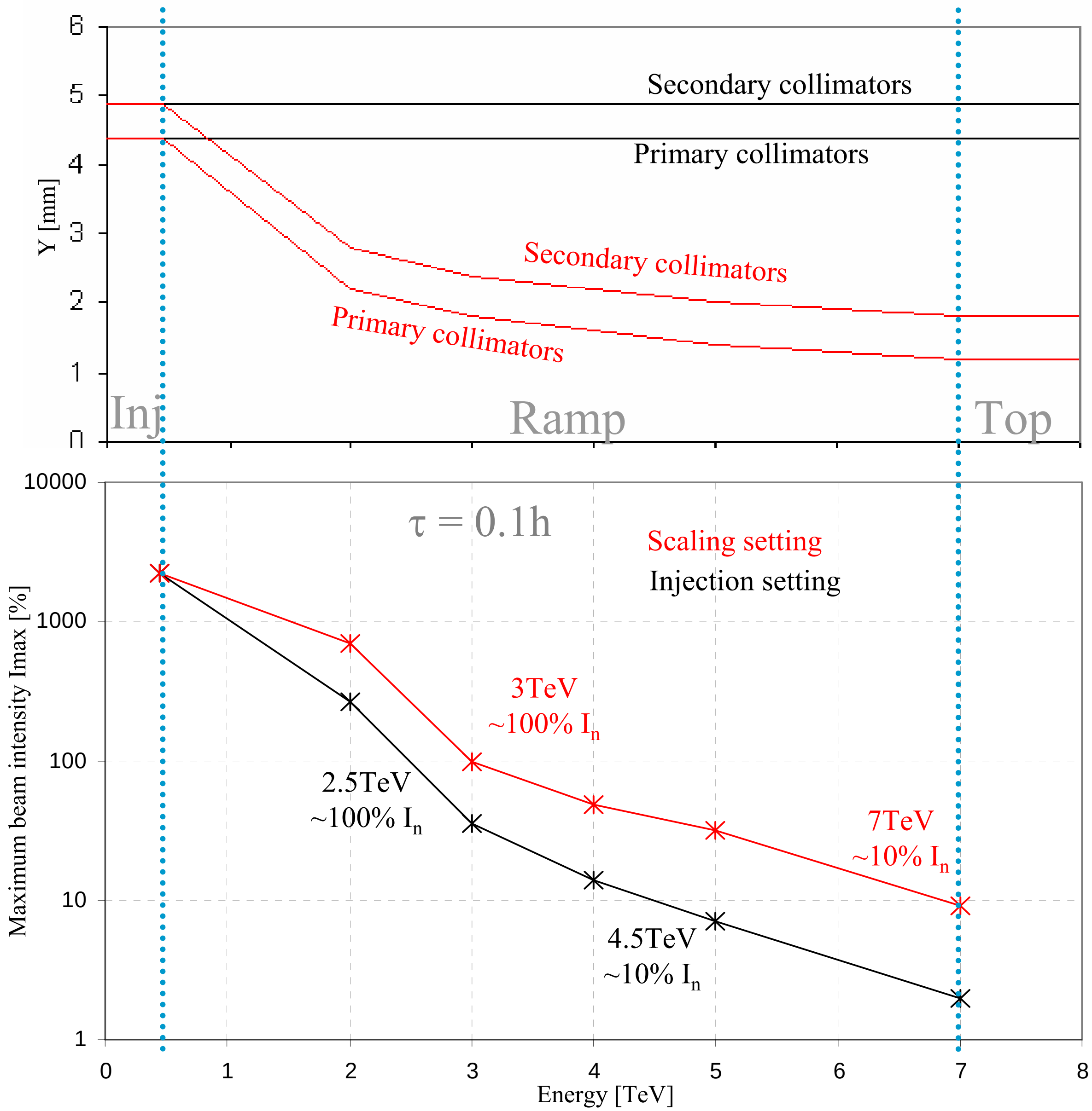
Cleaning inefficiency during the ramp



Always worse efficiency respect to the nominal 7TeV setting!

With the scaling setting: average gain ≅ factor 4 in cleaning efficiency respect to injection setting!

Imax during the ramp



Converting the cleaning inefficiency in terms of maximum allowed beam intensity

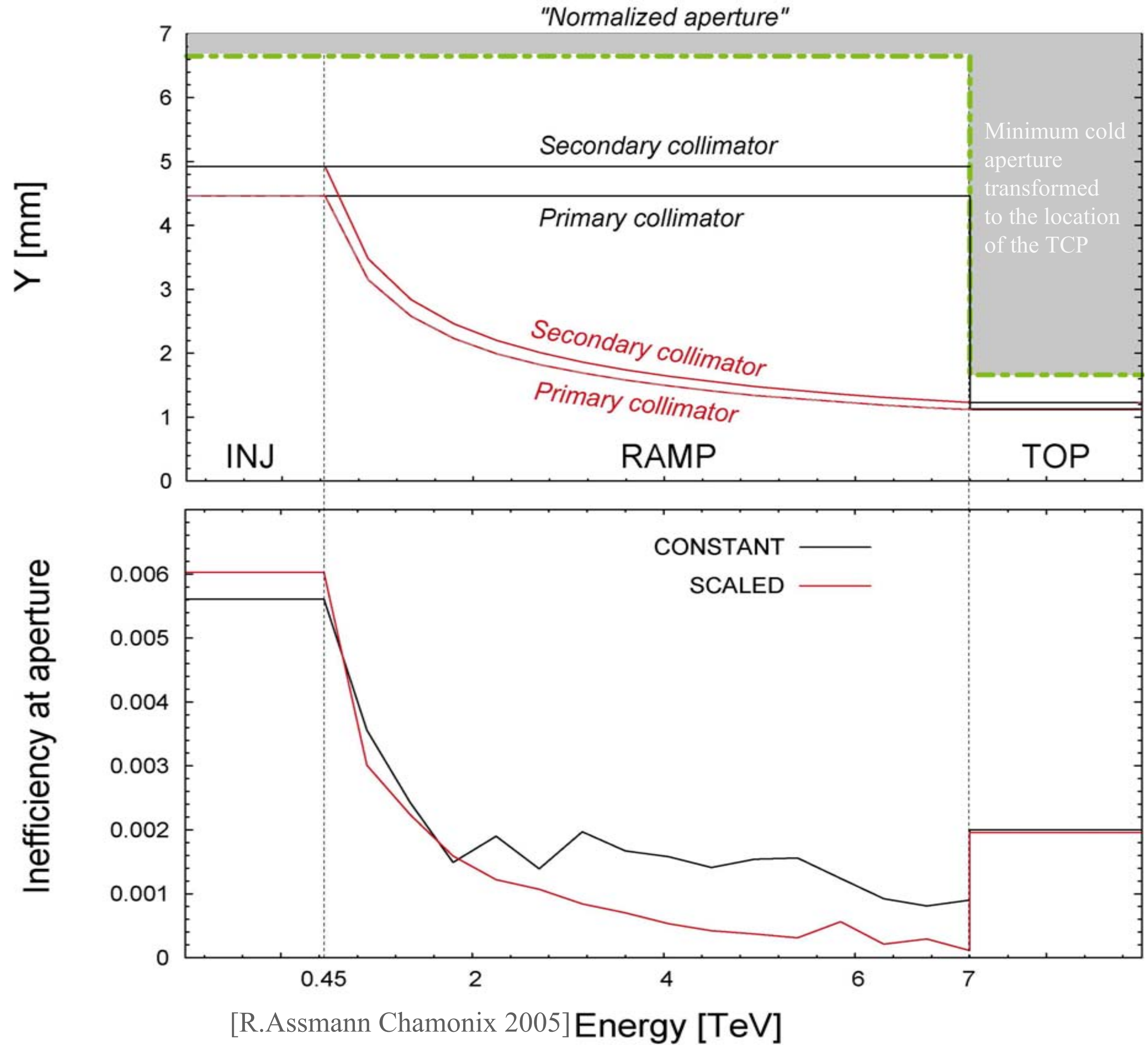
Old studies

Preliminary studies on the global cleaning efficiency showed completely different results!!

Now available tools allow to map losses along the ring with 10cm resolution.

↓

The efficiency of the collimation system is limited by local losses.



[R.Assmann Chamonix 2005]

Conclusions

- Maximum allowed beam intensity depends strongly on the local losses on the superconducting magnets.

- Keeping the optics of the machine and the opening of the collimators unchanged, the behavior of the losses along the ring changes during the energy ramp ➔ losses above the quench limit in the dispersion suppressor for E > 2.5TeV.

- Closing the TCP @ 6σ and keeping the offset of the other collimators as it is at injection ➔ gain about a factor 4 in I_{max} with relaxed tolerances.

- During the energy ramp it should be possible to operate safely the machine with the maximum achievable beam intensity, without closing the collimators, up to 2.5TeV.
  The collimation system should be then rigidly closed, driving the TCP at 6σ, in order to reach 7TeV with at least 10% of I_n ➔ Nominal setting.