LHC Collimation and Loss Locations

BLM Audit

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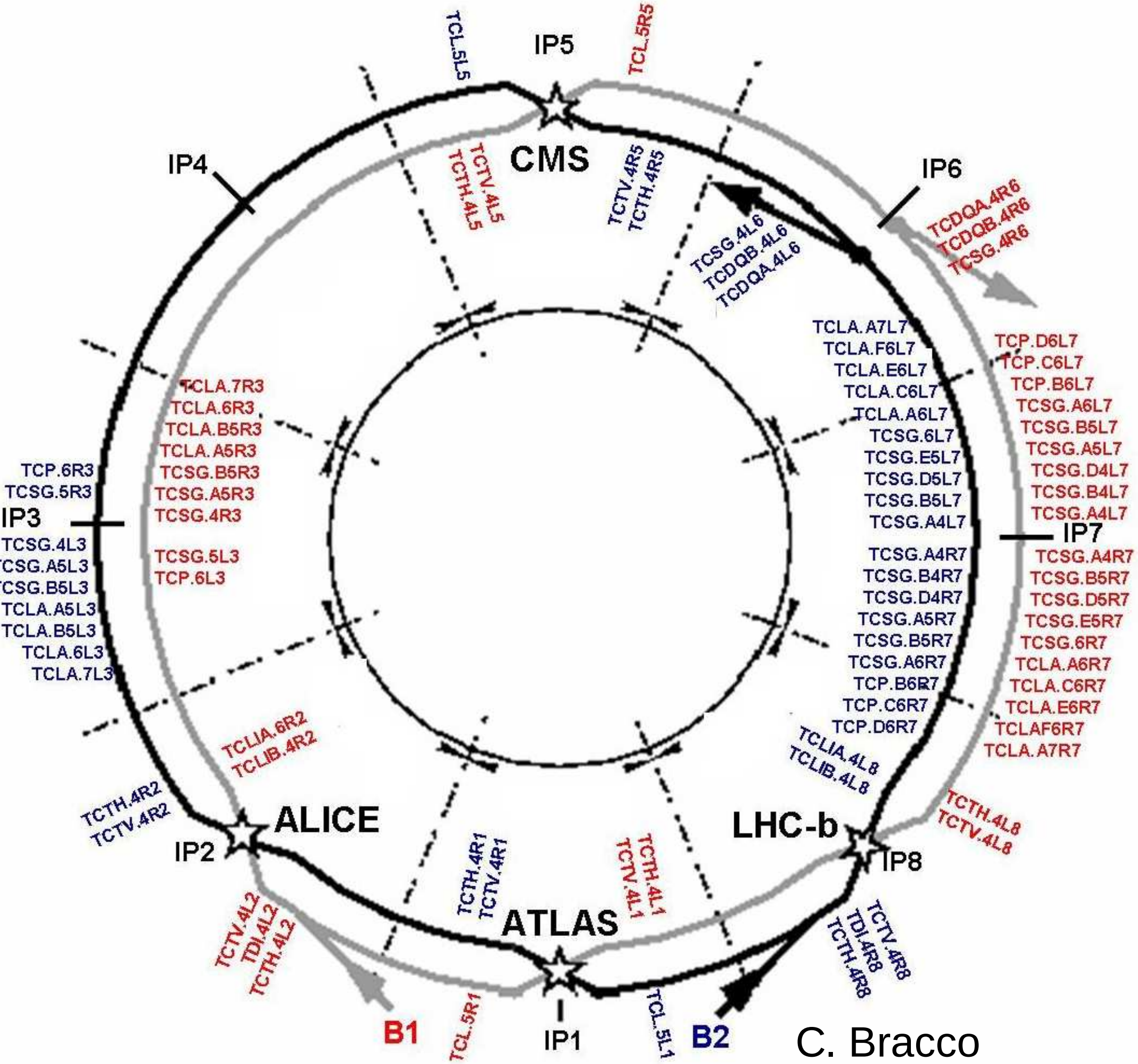
Outline

- Introduction / Motivation
  - LHC Layout
  - The LHC Challenge
  - Collimation Principle / Multi Stage Cleaning
- Loss Rates
- Intensity and Cleaning Inefficiency
- Simulations: SixTrack and Beam Loss Pattern
- Loss location around the ring (injection and top energy)
- Summary

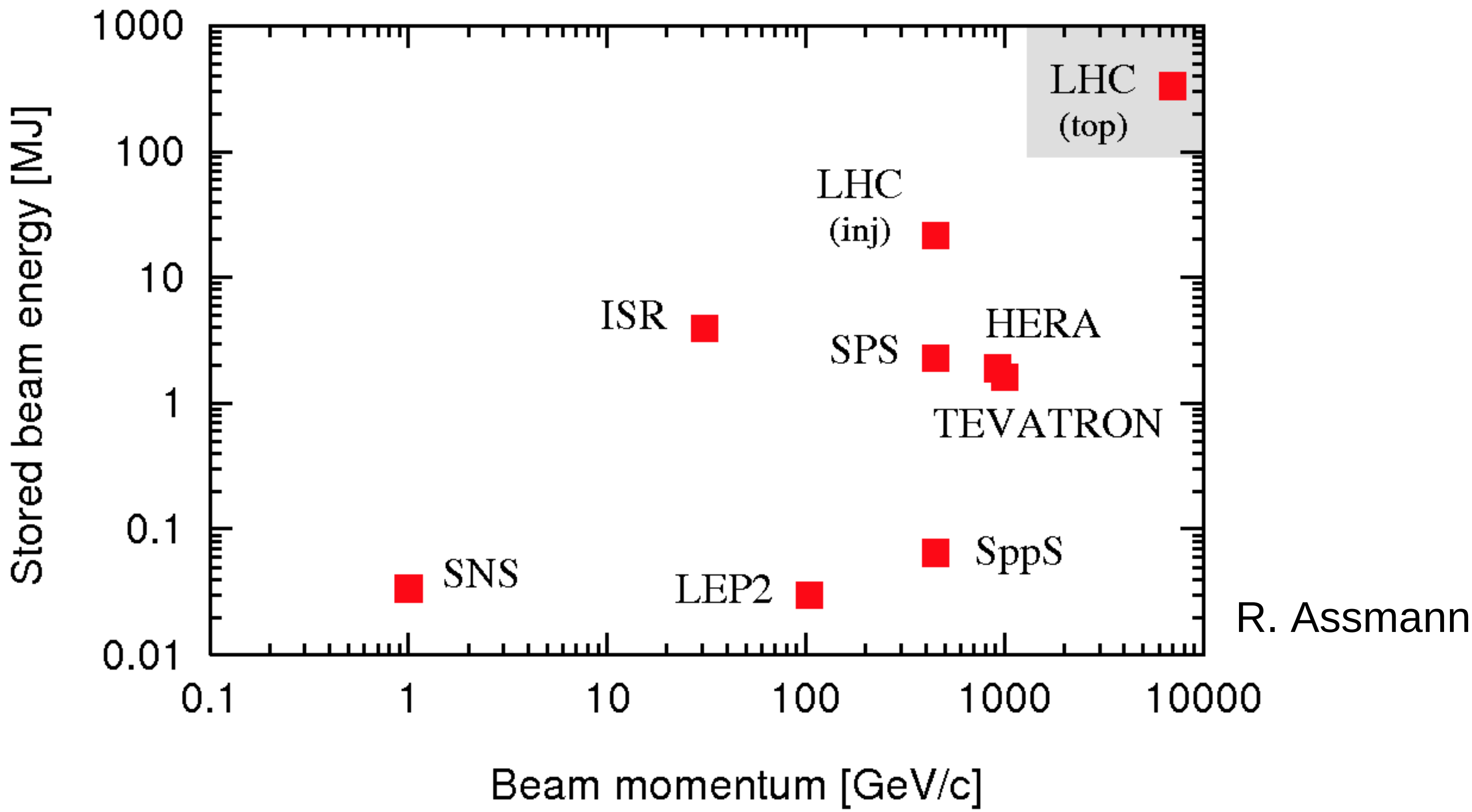
Layout of the LHC Ring



C. Bracco

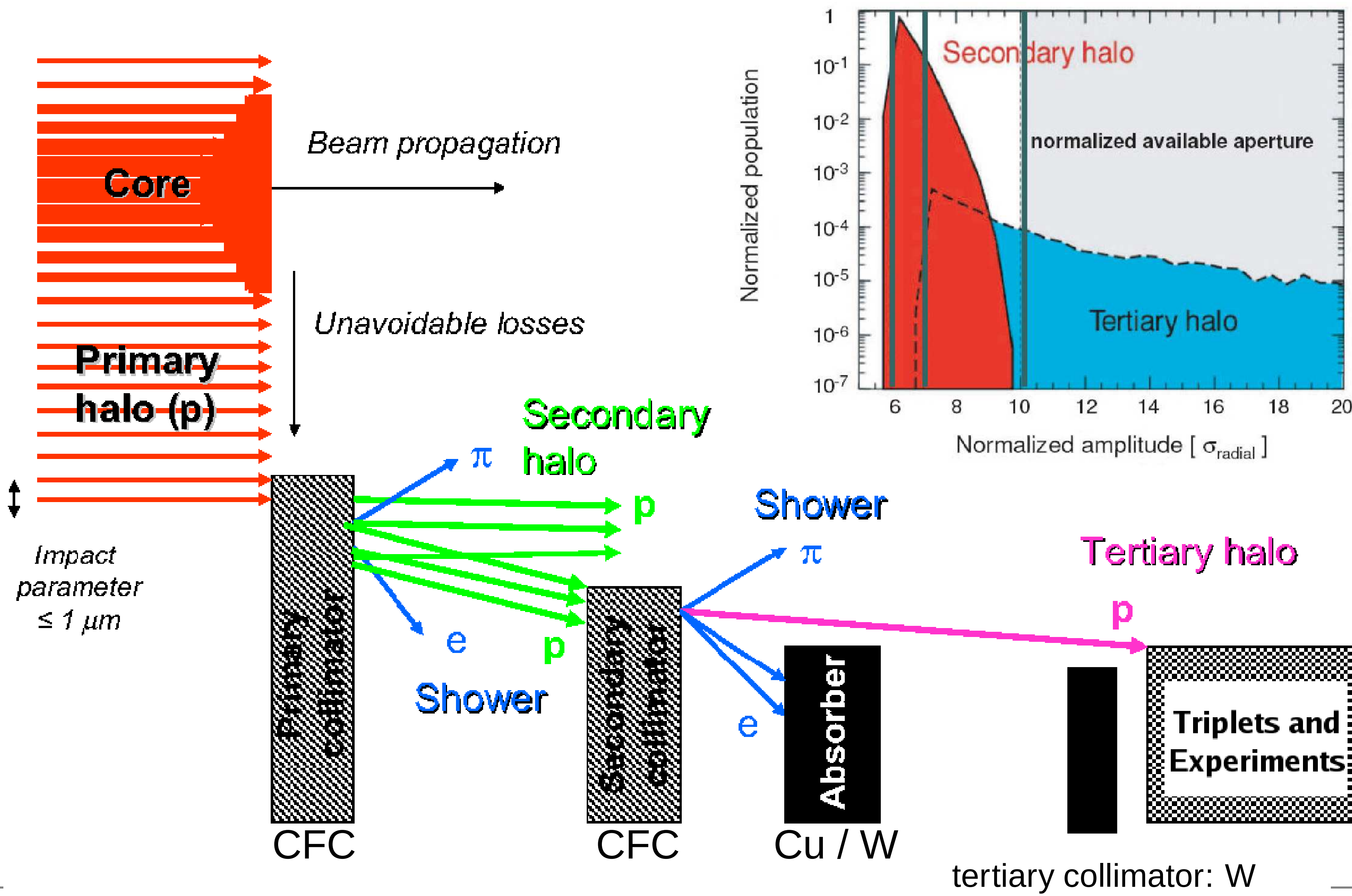
- 7 TeV protons for collision
- super-conduction magnets to bend and focus beam
- four experimental insertions
- two dedicated cleaning insertions in region with normal conducting magnets
- dump protection (in case of kicker failure)

The LHC Challenge

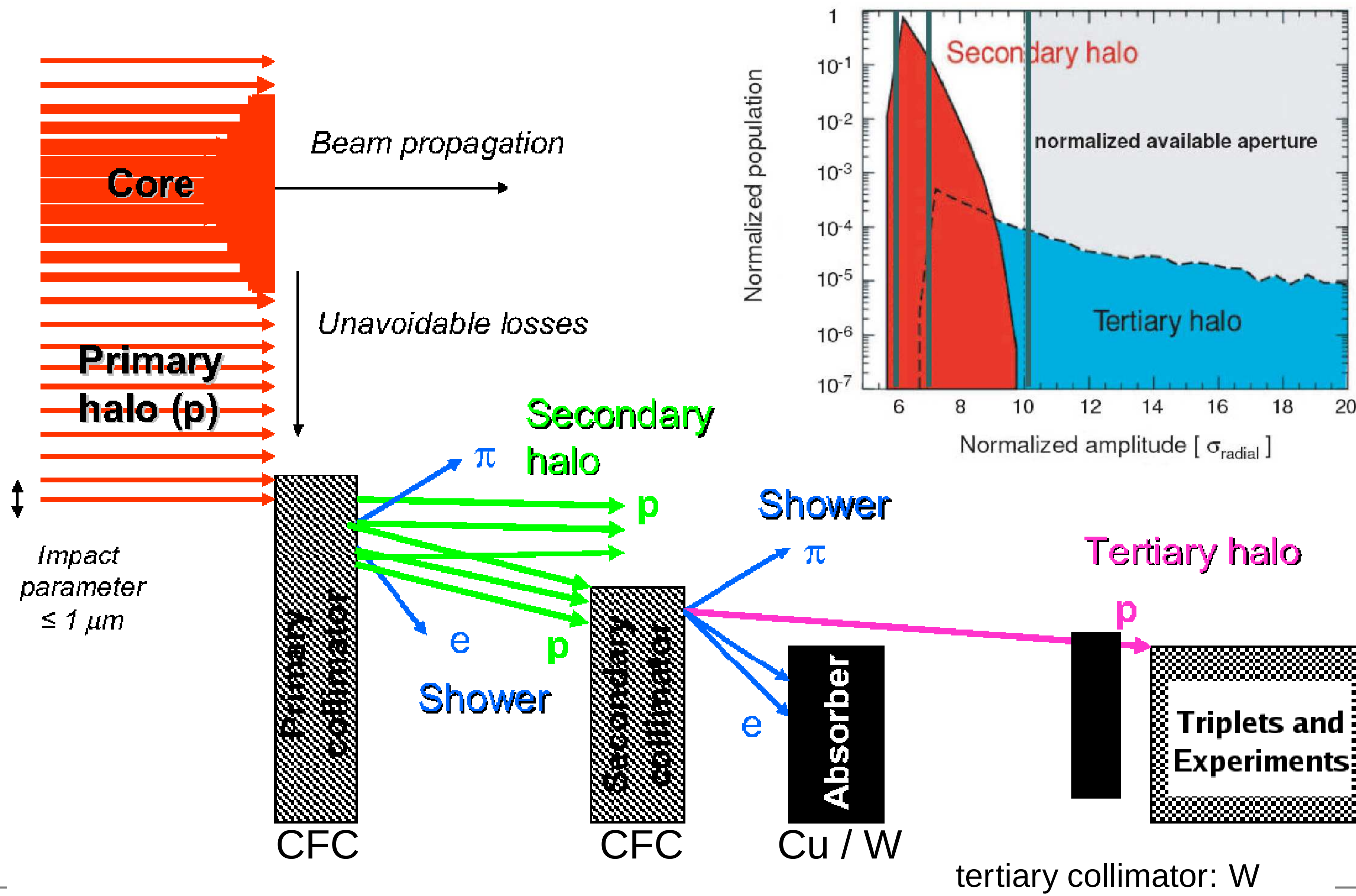


- Stored beam energy $360\,$MJ, ≈ 200 times larger than any other existing proton machine, enough energy to melt $500\,$kg of copper.
- For quenching a superconducting magnet one needs $\approx 10\,$mJ cm^{-3}

Multi-Stage Cleaning



Multi-Stage Cleaning



Loss Rates (slow)

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

Mode	T [s]	τ [h]	R_{loss} [p/ s]	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}	1098
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 7 TeV the beam lifetime is 20 h

Loss Rates (fast)

For an asynchronous dump (dump kicker pre-fire) it is assumed that 6 bunches can be lost into the collimation system. Similar scenario as for injection kicker failure.

- collimators (prim. and sec. type) can sustain shock beam impacts of 6.4 MJ mm^{-2} in 200 ns (7 TeV)
- TCT collimator may be hit by one bunch in case of misalignment of the dump protection by about 2σ, otherwise the TCT is in the shadow of the dump protection and primary/secondary collimators. The intensity of one bunch is sufficient to damage the collimator (tertiary are made of tungsten).

Intensity and Cleaning Inefficiency

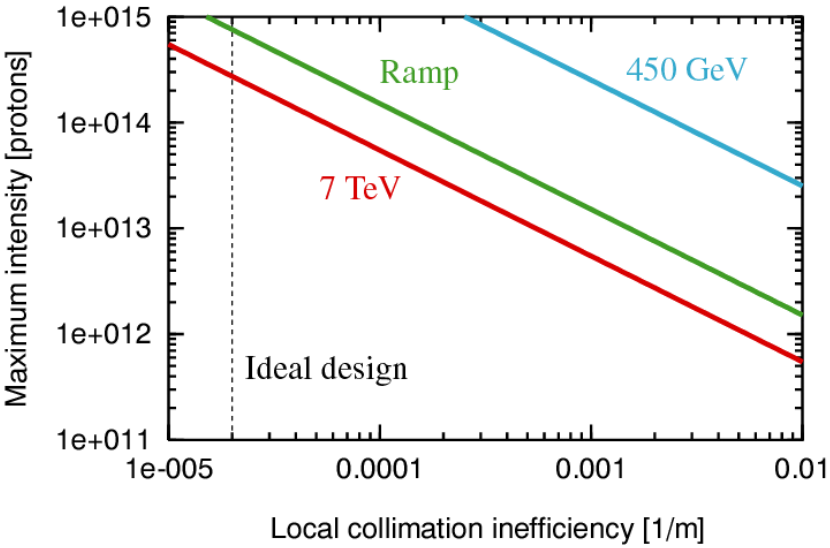
quench threshold
7.8×10^6 p/m/s at 7 TeV
7.0×10^8 p/m/s at 450 GeV

beam lifetime
e.g. 0.22h

allowed
intensity

dilution length
50 m (simplified)

$$N_p^{max} \approx \frac{\tau \cdot R_q \cdot L_{dil}}{\eta_c}$$



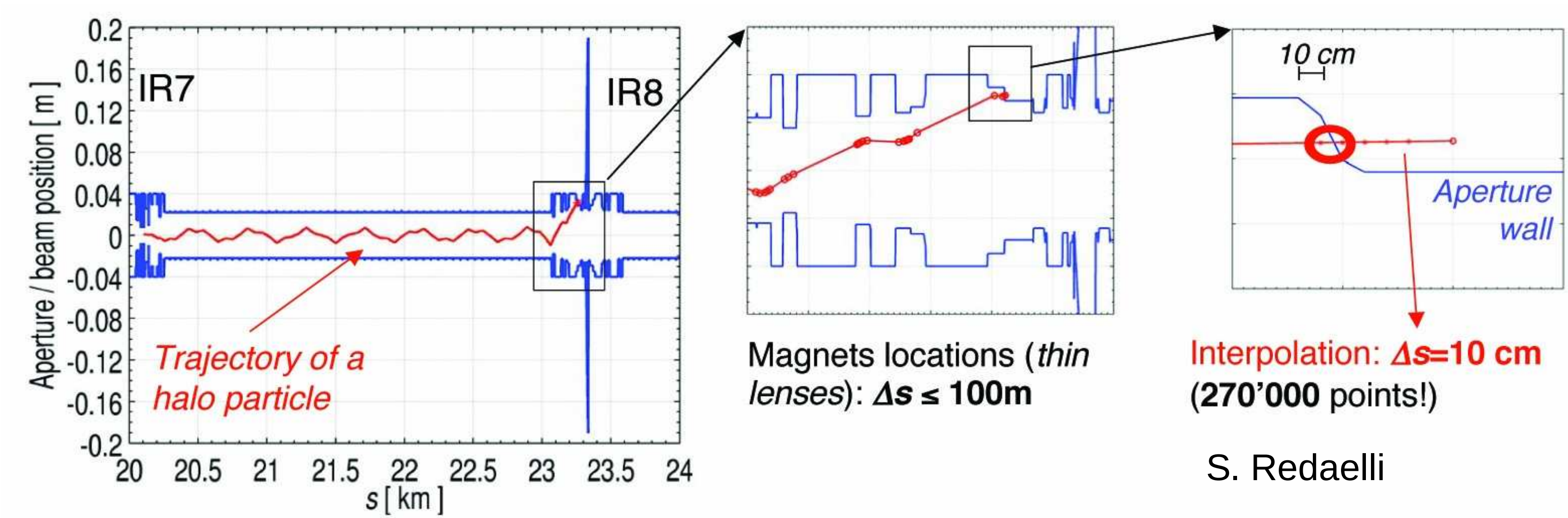
cleaning inefficiency
(for $L_{dil} = 1$ m)
$\eta_c = 2 \times 10^{-5}$ m^{-1} at 7 TeV
$\eta_c = 1 \times 10^{-3}$ m^{-1} at 450 GeV

Simulation Tools: SixTrack

- For the collimation studies we use an extended version of SixTrack (full 6d treatment) including a scattering routine for simulating the interaction of the primary protons in the collimator (Colltrack routines). The field maps are generated using MADX (using official LHC optics).
- To reduce computing time only the beam halo, which hits the primary collimator (6σ half-gap), is considered in the simulations. A typical simulation tracks around 5 million particles over 200 turns. Reminder: aim is a cleaning inefficiency of $2 \times 10^{-5}\,\mathrm{m}^{-1}$
- In general the simulation treats only the beam halo particle, beam gas interactions are not included. But it is possible load an external distribution for tracking studies (e.g. for kicker failure or for p-p interactions)

Simulation Tools: Beam Loss Pattern

The tracking information received by SixTrack is afterwards analysed using the beam loss pattern program. It compares the particle tracks with an detailed aperture model and returns the loss locations (particles touching the aperture before being absorbed in a collimator) with an 10 cm resolution.



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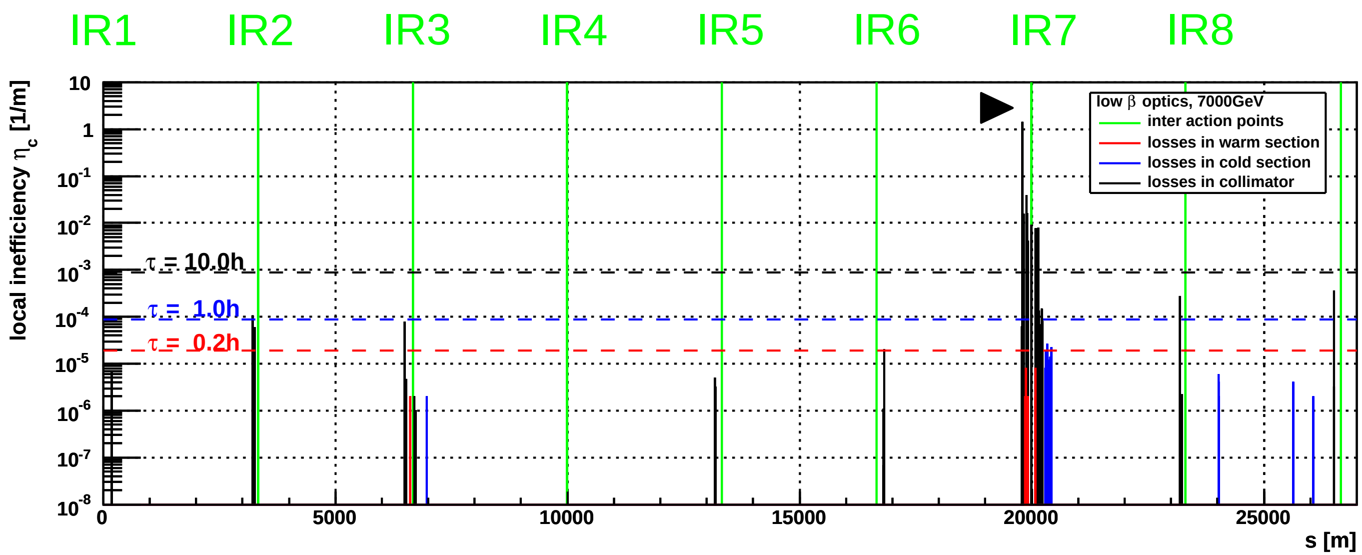
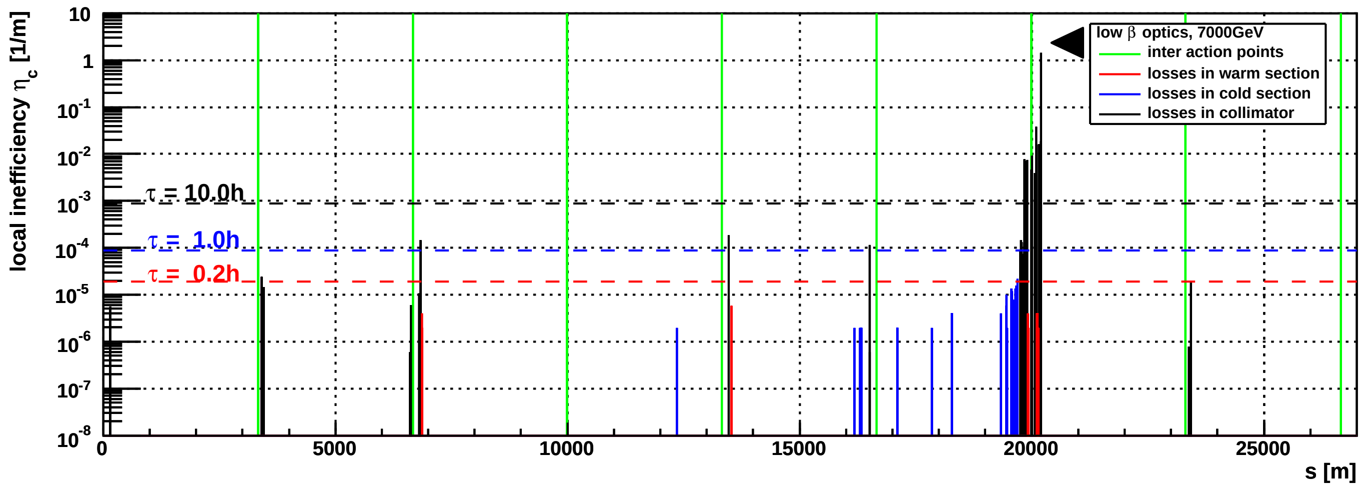
System Performance at 7TeV (Phase1)



beam 1

- 7 TeV
- horizontal betatron halo
- standard settings
- ideal machine



beam 2

- 7 TeV
- horizontal betatron halo
- standard settings
- ideal machine

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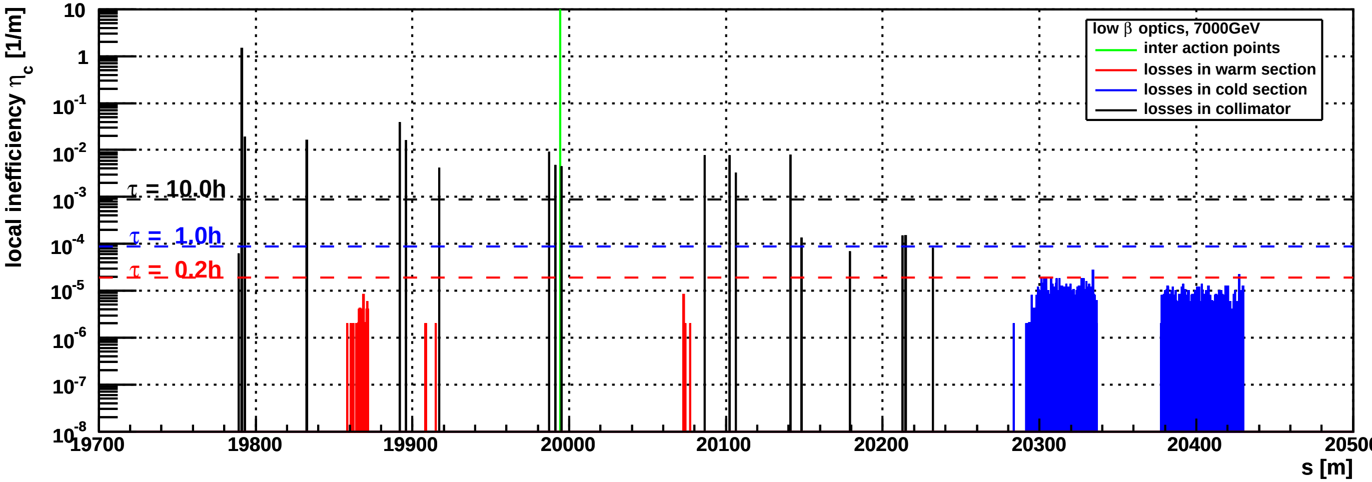
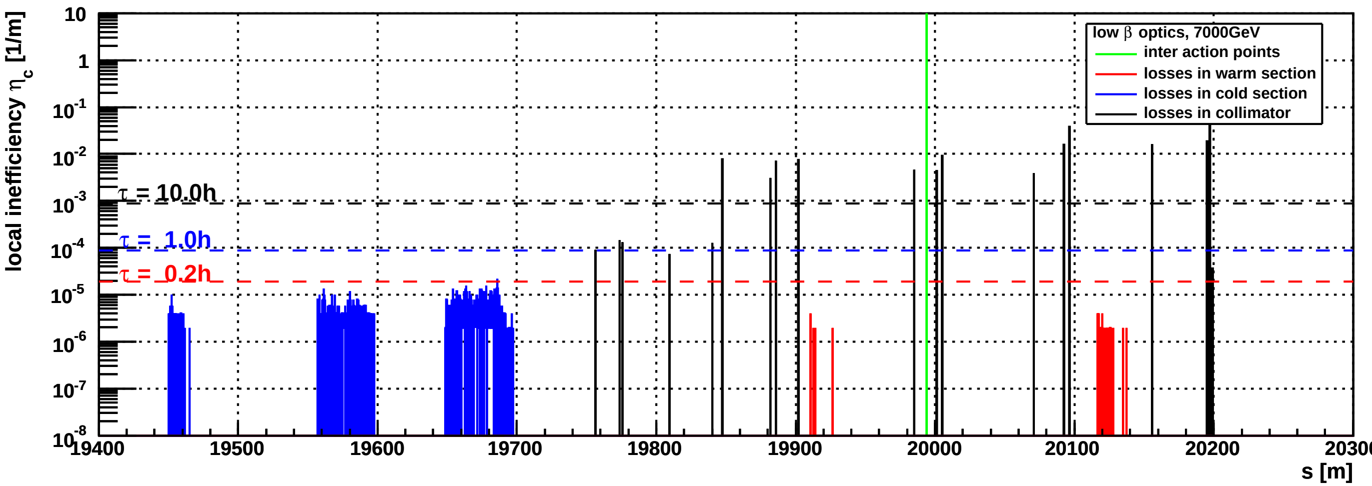
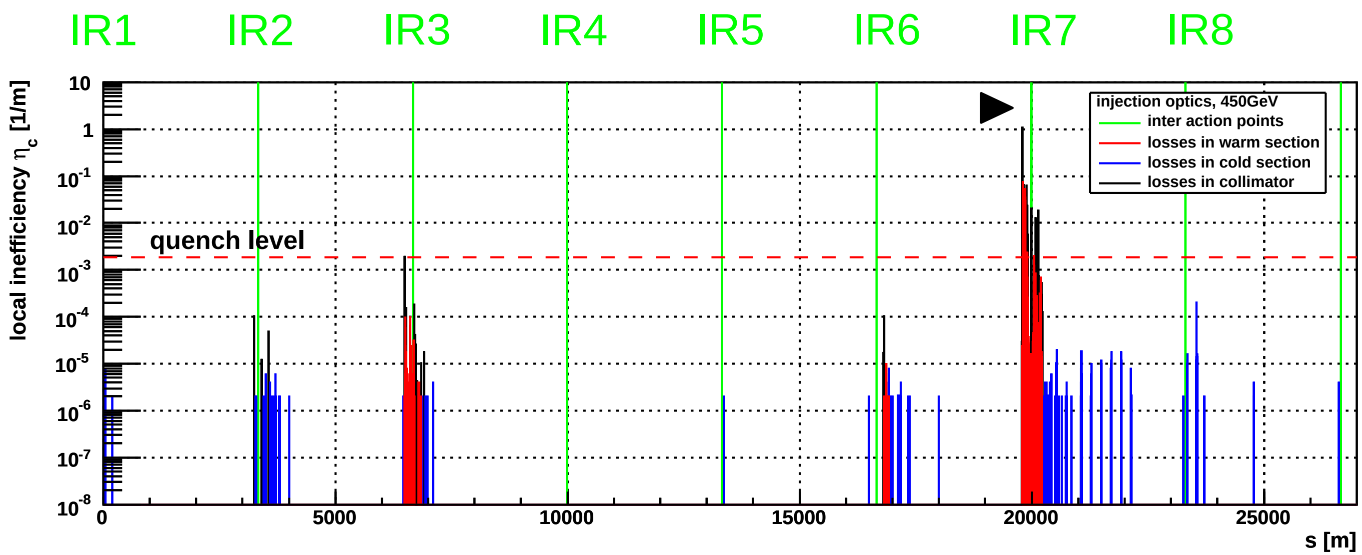
Cleaning Insertion in IR7



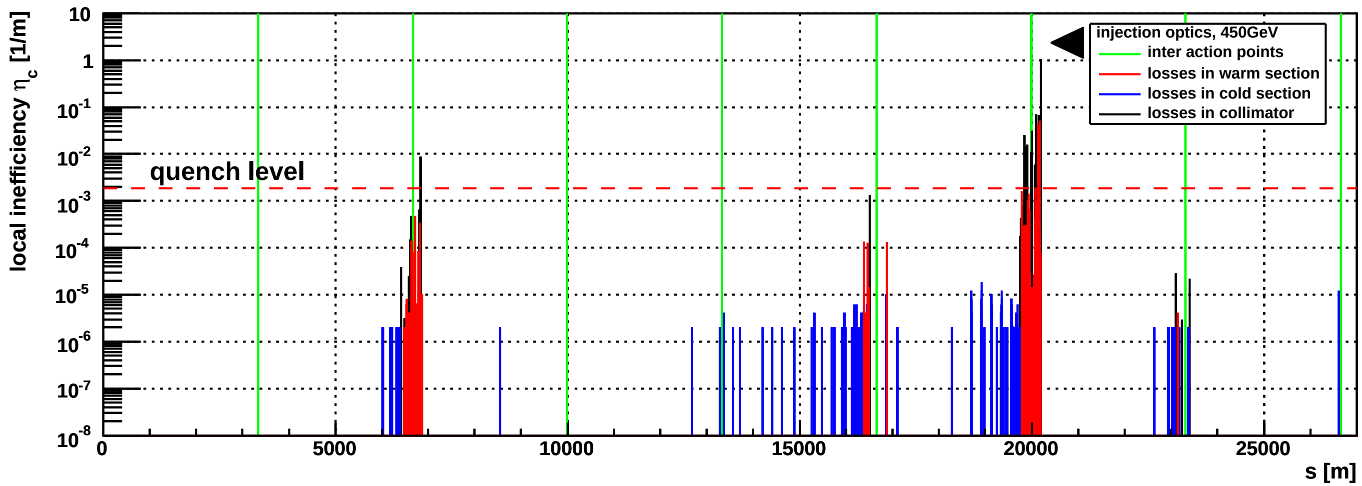


System Performance at Injection



beam 1

- 450 GeV
- horizontal betatron halo
- standard settings
- ideal machine

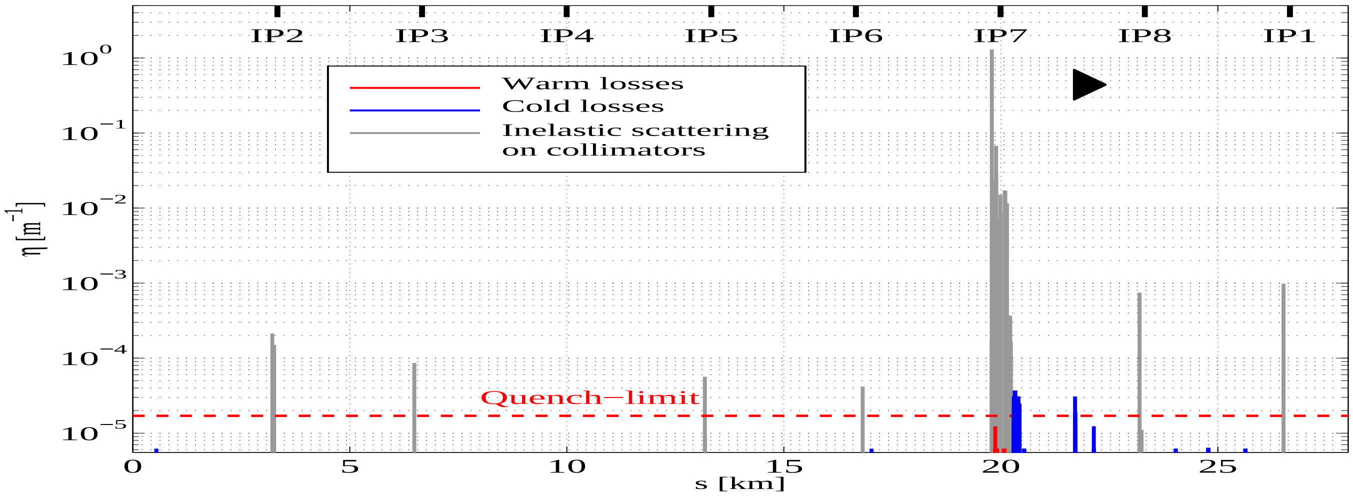


beam 2

- 450 GeV
- horizontal betatron halo
- standard settings
- ideal machine

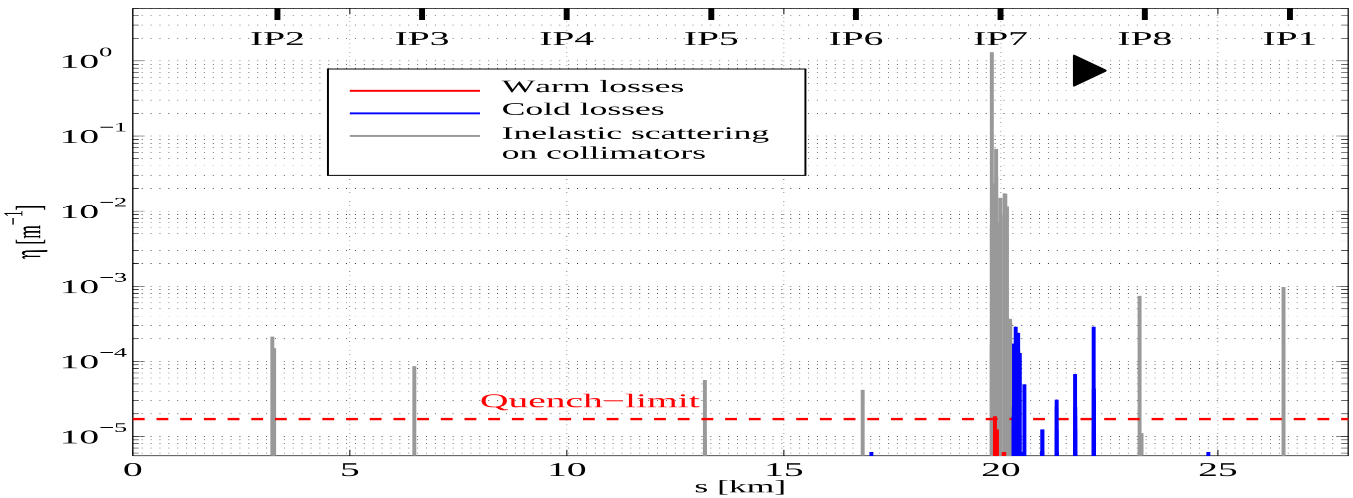
System Performance at 7TeV (Phase1)

(with closed orbit, alignment error, jaw flatness error)



beam 1

- horizontal betatron halo
- collimator misalignment
- closed orbit



- horizontal betatron halo
- collimator misalignment
- closed orbit
- aperture misalignment

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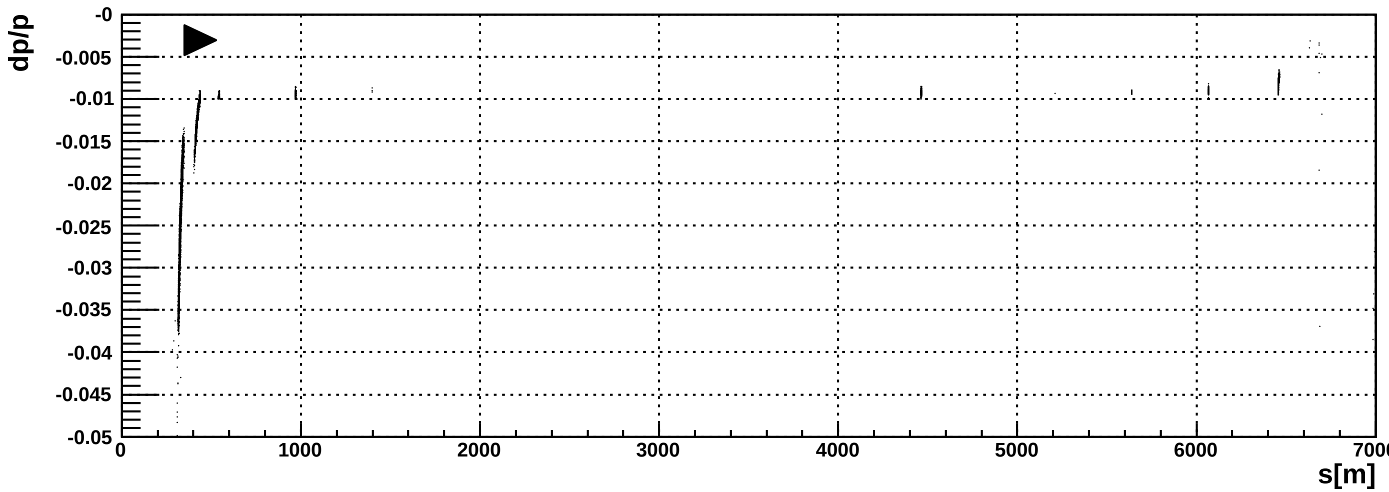
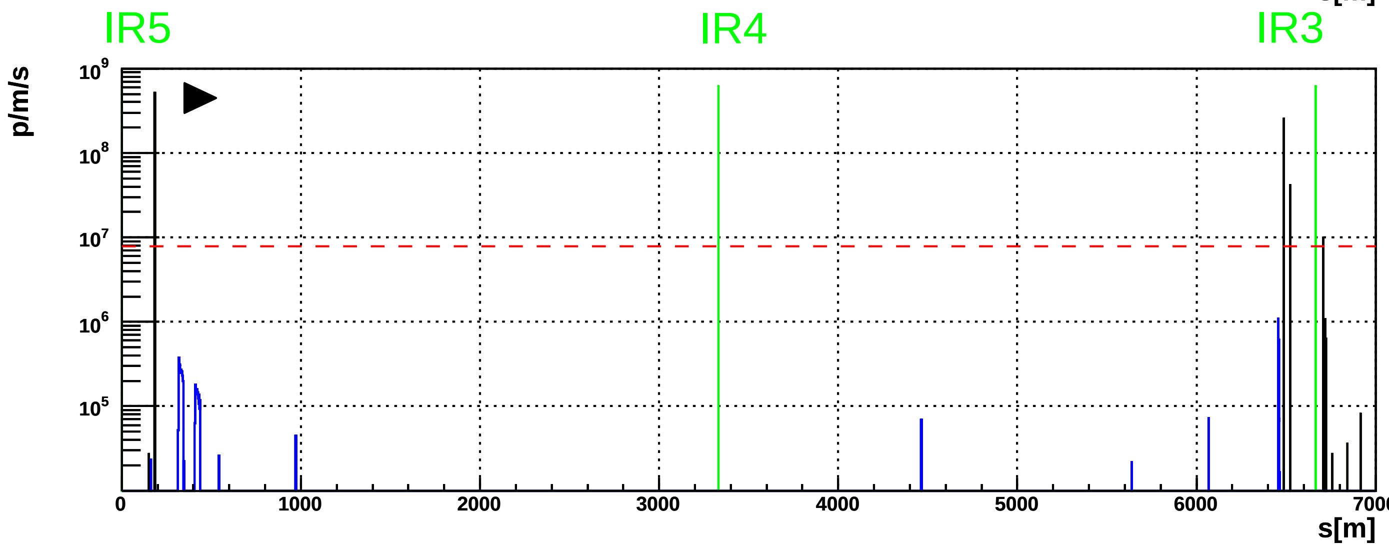
p-p Interactions (DPE)

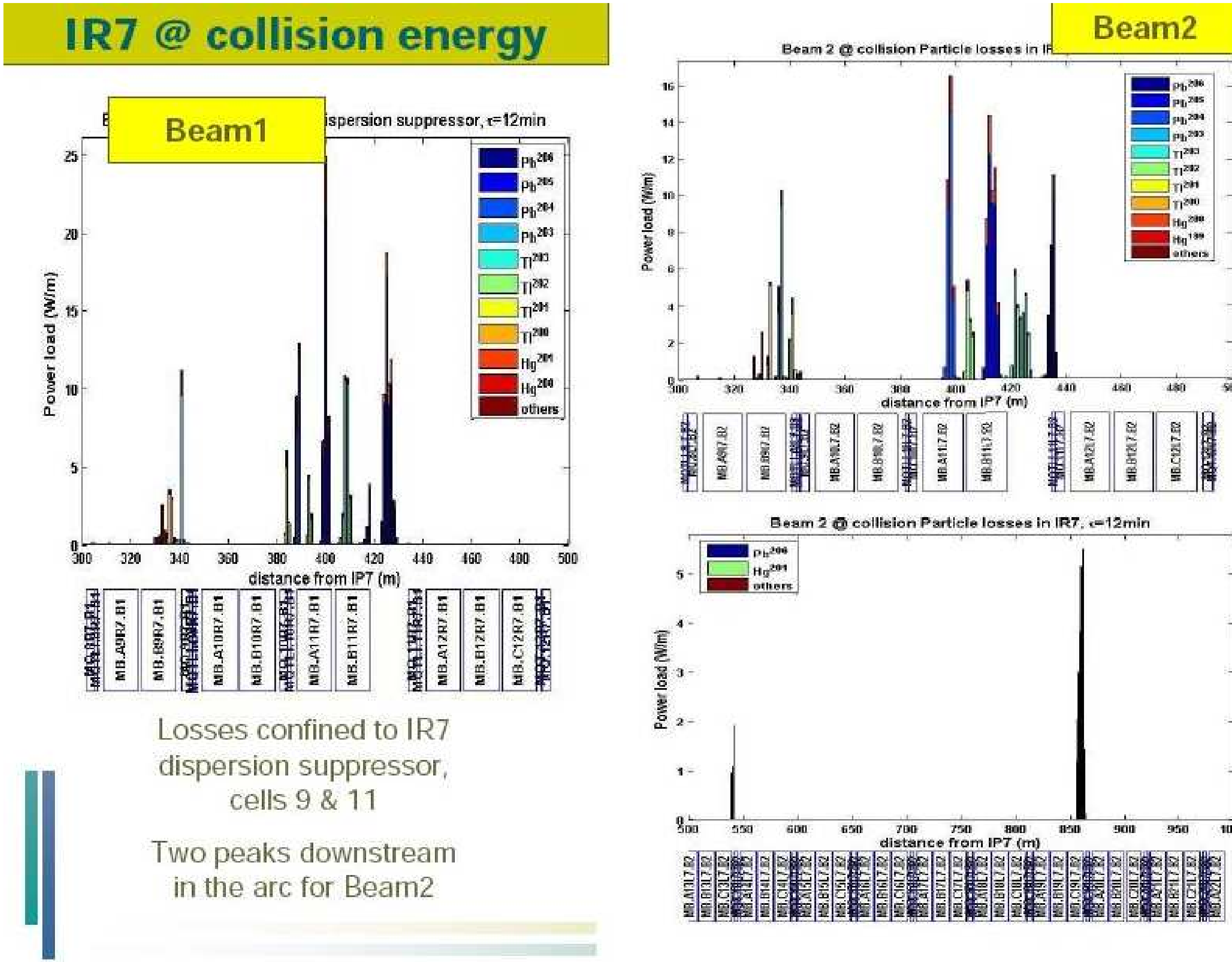


Loss loactions according to momentum loss for DPE



Expected loss rate for DPE and SD events at peak luminosity 10^{34} cm^{-2} s^{-1}

Losses for Ions



G. Bellodi LHC CWG meeting Nov.2006

Simulation Results available

Overview of available simulated cases.

- standard optics (injection, early collision, all IRs squeezed, IR1 and IR5 squeezed), ideal machine
- start-up configuration (early collision optics with reduced number of TCS collimators in IR7)
- commissioning scenarios
- energy ramp
- error scenarios
  - collimator misalignment (tilt, gap, offset)
  - closed orbit
  - aperture misalignment
- losses from p-p interactions in the IRs (only IR5 so far)

Loss Locations

injection energy						collision energy			
beam 1		beam 2				beam 1		beam 2	
Q11.R3	Q27.R7	Q28.R3	MB20.L6	Q31.L7	MB11.L7	Q6L3	Q21.R7	Q11.R6	Q9.L7
DFBA.R6	Q31.R7	Q18.L4	MB16.L6	Q27.L7	MB9.L7	Q8.R7	MB34.L8	MB12.R6	MB9.L7
MB9.R7	Q33.L8	Q10.L4	MB14.L6	Q23.L7	Q8.L7	MB9.R7	Q33.L8	Q25.R6	Q8.L7
MB11.R7	Q29.L8	Q22.R5	MB12.L6	Q19.L7	MB8.L7	Q9.R7	Q25.L8	Q33.R6	MB8.L7
Q11.R7	Q25.L8	Q28.L6	MB9.L6	MB19.L7		Q10.R7	Q17.L8	Q19.L7	
MB13.R7	Q2.R8	MB28.L6	MB8.L6	Q15.L7		MB11.R7	Q16.R8	Q13.L7	
Q13.R7	Q6.R8	Q25.L6	Q4.L6	MB15.L7		Q11.R7	Q30.R8	MB13.L7	
Q23.R7		Q20.L6	Q11.R6	Q11.L7		Q13.R7	Q22.L1	Q11.L7	
						MB21.R7		MB11.L7	

(see thesis G. Robert-Demolaize)

p-p interactions for beam 2 from IR5									
MB.A9L5	MB.B9L5	Q9.L5	MB.B11L5	MS.11L5	Q11.L5	MB.C13L5	MS.13L5	Q13.L5	MS.21L5
Q21.L5	MS.24L4	Q24.L4	MS.22R3	Q22.R3	MS.14R3	Q14.R3	BPM.6R3		

Summary

- Full set of simulation tool available to simulate the cleaning inefficiency of the collimation system and generate beam loss maps along the ring.
- Loss location for different optics, running scenarios and mechanical alignment errors available.
- Standard run considers around 5 million particles, due to the required low cleaning inefficiency only a few hundred particles are lost to the aperture.
- Main loss locations (see also previous slide):
  - dispersion suppressor after the cleaning insertions
  - dispersion suppressor in experimental insertion (for p-p interaction)
  - Q6 in IR3

Spare Slides

Estimated Damage Interlock Limits

Device	Location	Energy	Condition 1	Condition 2	Condition 3
TCP	IR3	450 GeV	dN/dt > 1.2e12 p/s for T > 10 s (87 kW)	dN/dt > 6e12 p/s for 1 s < T < 10 s (430 kW)	dN/dt > 1.5e13 p/s for T < 1 s (1.1 MW)
TCP	IR7	450 GeV	dN/dt > 1.2e12 p/s for T > 10 s (87 kW)	dN/dt > 6e12 p/s for T < 10 s (430 kW)	
TCP	IR3, IR7	7 TeV	dN/dt > 0.8e11 p/s for T > 10 s (90 kW)	dN/dt > 4e11 p/s for T < 10 s (449 kW)	
TCSG	IR3	450 GeV	dN/dt > 1.2e11 p/s for T > 10 s (9 kW)	dN/dt > 6e11 p/s for 1 s < T < 10 s (43 kW)	dN/dt > 1.5e12 p/s for T < 1 s (110 kW)
TCSG	IR7	450 GeV	dN/dt > 1.2e11 p/s for T > 10 s (9 kW)	dN/dt > 6e11 p/s for T < 10 s (43 kW)	
TCSG	IR3, IR7	7 TeV	dN/dt > 0.8e10 p/s for T > 10 s (9 kW)	dN/dt > 4e10 p/s for T < 10 s (45 kW)	
TCLA	IR3	450 GeV	dN/dt > 6e8 p/s for T > 10 s (45 W)	dN/dt > 3e9 p/s for 1 s < T < 10 s (215 W)	dN/dt > 7.5e9 p/s for T < 1 s (550 W)
TCLA	IR7	450 GeV	dN/dt > 6e8 p/s for T > 10 s (45 W)	dN/dt > 3e9 p/s for T < 10 s (215 W)	
TCLA	IR3, IR7	7 TeV	dN/dt > 4e7 p/s for T > 10 s (45 W)	dN/dt > 2e8 p/s for T < 10 s (225 W)	

R. Assmann: Damage Limits for LHC Collimators (note in preparation)

Estimated Damage Interlock Limits

Device	Location	Energy	Condition 1	Condition 2	Condition 3
TCTH, TCTVA, TCTVB	IR1, IR2, IR5, IR8	450 GeV	dN/dt > 6e8 p/s for T > 10 s (45 W)	dN/dt > 3e9 p/s for T < 10 s (215 W)	
TCTH, TCTVA, TCTVB	IR1, IR2, IR5, IR8	7 TeV	dN/dt > 4e7 p/s for T > 10 s (45 W)	dN/dt > 2e8 p/s for T < 10 s (225 W)	
TCL, TCLP	IR1, IR5	450 GeV	dN/dt > 6e9 p/s for T > 10 s (450 W)	dN/dt > 3e10 p/s for T < 10 s (2.2 kW)	
TCL, TCLP	IR1, IR5	7 TeV	dN/dt > 4e8 p/s for T > 10 s (450 W)	dN/dt > 2e9 p/s for T < 10 s (2.2 kW)	
TCLIA, TCLIB, TCSG	IR2, IR6, IR8	450 GeV	dN/dt > 1.2e11 p/s for T > 10 s (9 kW)	dN/dt > 6e11 p/s for T < 10 s (43 kW)	
TCLIA, TCLIB, TCSG	IR2, IR6, IR8	7 TeV	dN/dt > 0.8e10 p/s for T > 10 s (9 kW)	dN/dt > 4e10 p/s for T < 10 s (45 kW)	

R. Assmann Damage Limits for LHC Collimators (note in preparation)