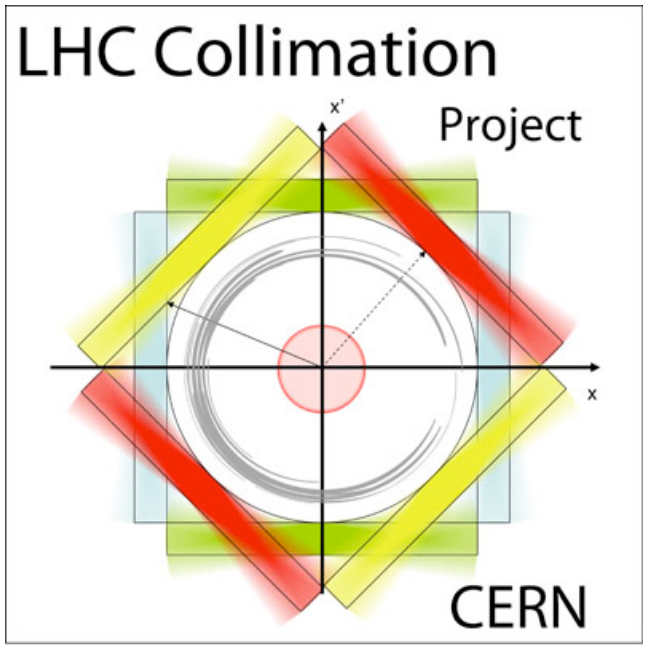
First Cleaning with LHC Collimators



D. Wollmann, CERN/BE

25.05.2010

IPAC10, Kyoto, Japan

May 23-28 2010

On behalf of the LHC Collimation Team

at CERN:

O. Aberle, G. Arnau-Izquiedo, R. Assmann, J.-P. Bacher, V. Baglin, G. Bellodi, A. Bertarelli, A. Bouzoud, C. Bracco, R. Bruce, M. Brugger, S. Calatroni, F. Caspers, F. Cerruti, R. Chamizo, A. Cherif, E. Chiaveri, P. Chiggiato, A. Dallochio, B. Dehning, M. Donze, A. Ferrari, R. Folch, P. Francon, P. Gander, J.-M. Geisser, A. Grudiev, E.B. Holzer, D. Jacquet, J.B. Jeanneret, J.M. Jimenez, M. Jonker, J. Jowett, K. Kershaw, L. Lari, J. Lendaro, F. Loprete, R. Losito, M. Magistris, M. Malabaila, M. Mayer, A. Marsili, A. Masi, S. Mathot, E. Métral, C. Mitifiot, N. Mounet, R. de Morais Amaral, A. Nordt, R. Perret, S. Perrollaz, C. Rathjen, S. Redaelli, G. Robert-Demolaize ,S. Roesler, A. Rossi, B. Salvant, M. Santana, I. Sexton, P. Sievers, T. Tardy, M. Timmins, K. Tsoulou, E. Veyrunes, H. Vincke, V. Vlachoudis, V. Vuillemin T. Weiler, F. Zimmermann

and Abroad:

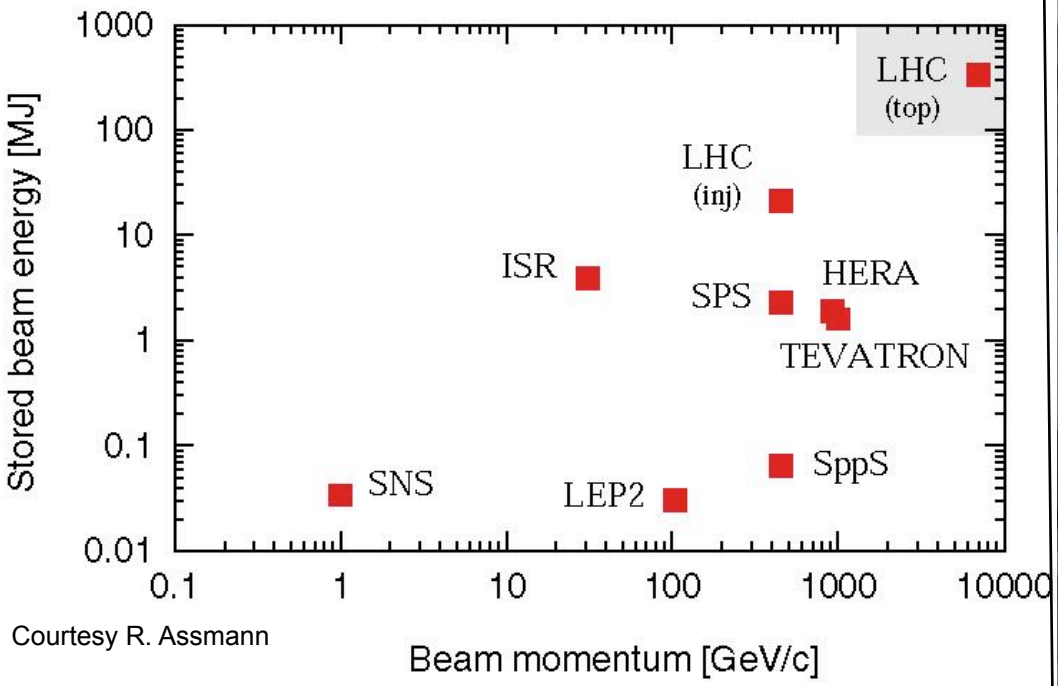
TRIUMF (D. Kaltchev), IHEP (I. Baishev & team), SLAC (T. Markiewicz & team), FNAL (N. Mokhov & team), BNL (N. Simos, A. Drees & team).

Finishing of Collimation phase-I (06.2009)

Outline

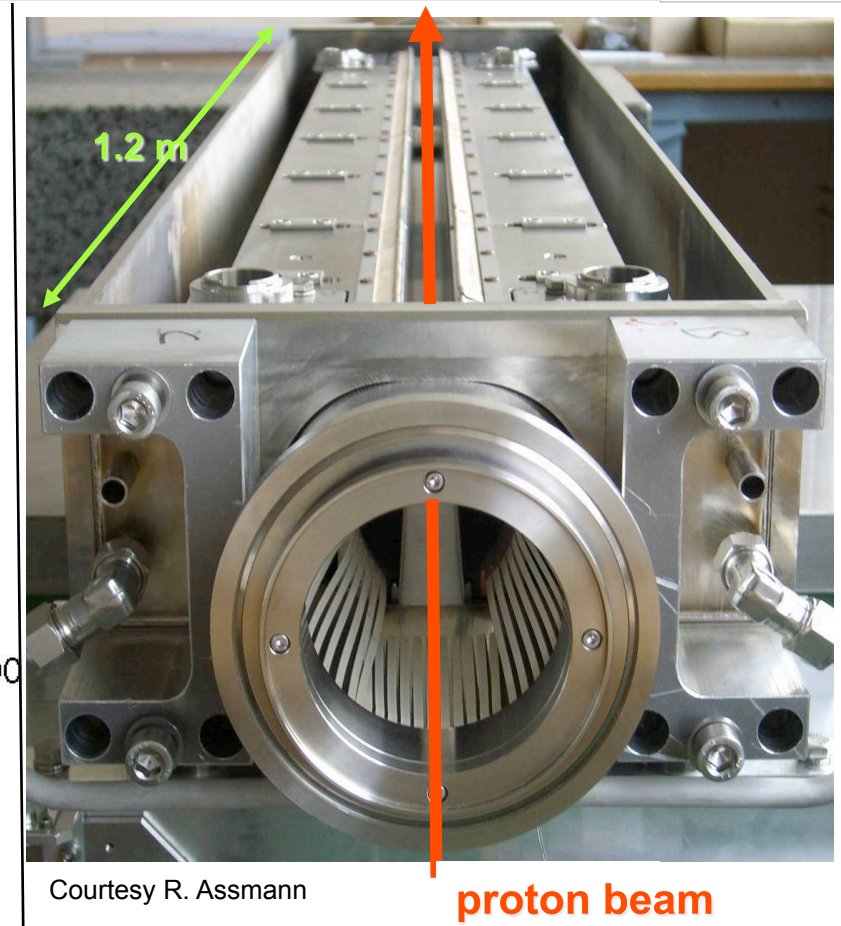
- Introduction
  - Challenges for LHC collimation
  - 4-stage cleaning system
- Beam based setups at 450GeV
  - Goals
  - Methods
- Results of loss experiments
  - B1 horizontal losses
  - Achieved cleaning inefficiencies
  - First results for 3.5TeV
- Summary

Challenges for LHC collimation



Courtesy R. Assmann

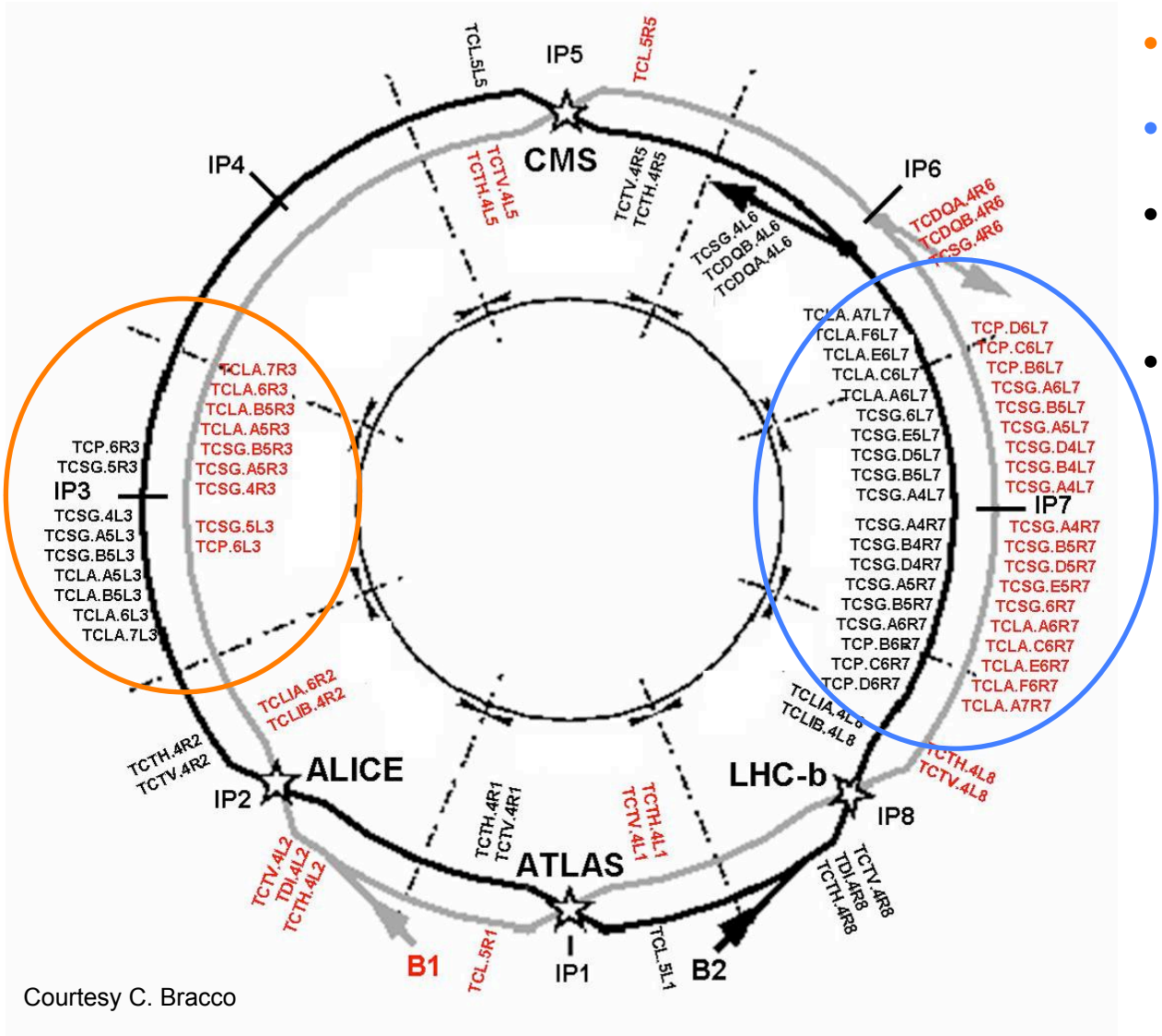
- 362MJ stored energy per beam at 7TeV with 3e14 protons
- Quench limit (7TeV): 7.6e6 $ps^{-1}m^{-1}$



Courtesy R. Assmann

- Phase-I collimator

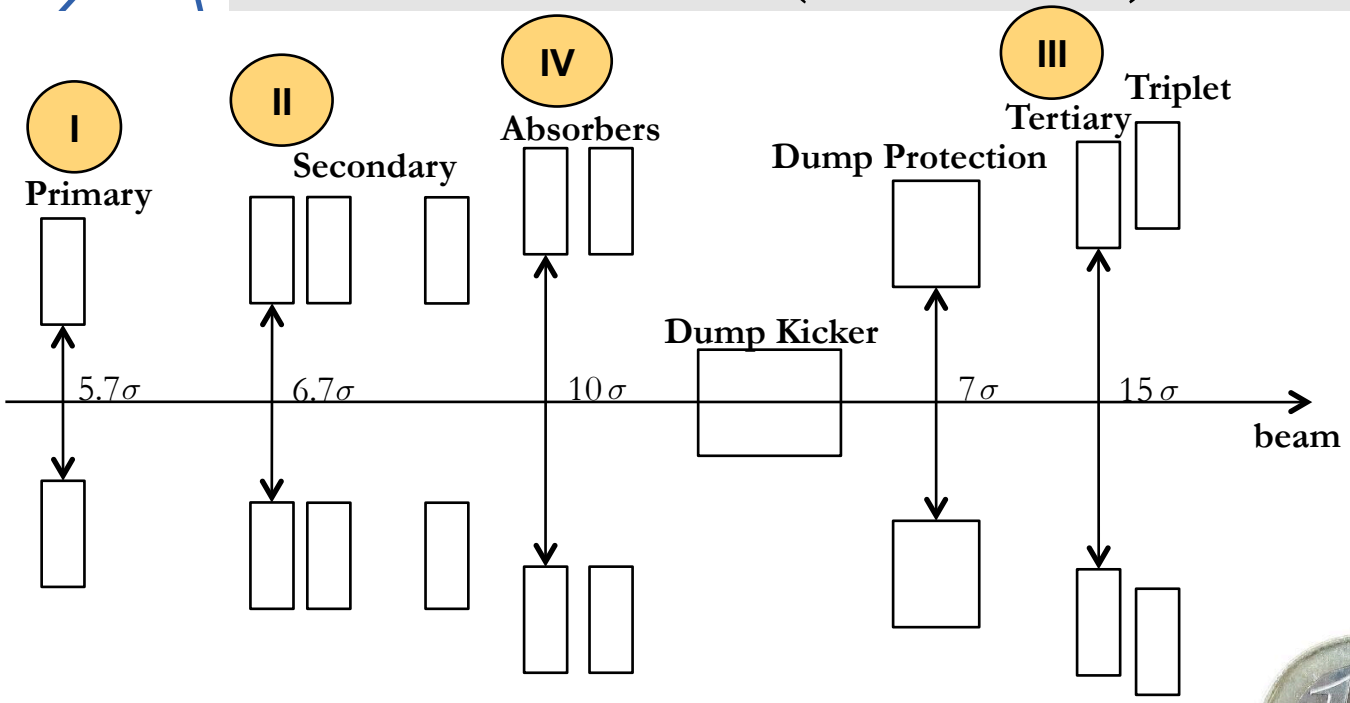
Installed Phase-I Collimation System



Courtesy C. Bracco

- IR3 momentum cleaning
- IR7 betatron cleaning
- Injection and Dump protection
- Protection of Experimental insertions and triplets

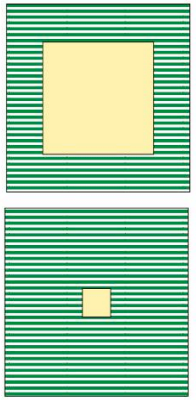
4-stage cleaning with collimators (schematic)



1 σ (450GeV) ≈ 1mm

Collimator type	N_i	Collimator type	N_i
TCP IR3	8 σ	TCDQ IR6	8 σ
TCSG IR3	9.3 σ	TCSG IR6	7 σ
TCLA IR3	10 σ	TCLI IR2/IR8	6.8 σ
TCP IR7	5.7 σ	TCT IR2/IR8	25 σ
TCSG IR7	6.7σ	TCT IR1/IR5	15 σ
TCLA IR7	10 σ	TCL IR1	20 σ

10 mm

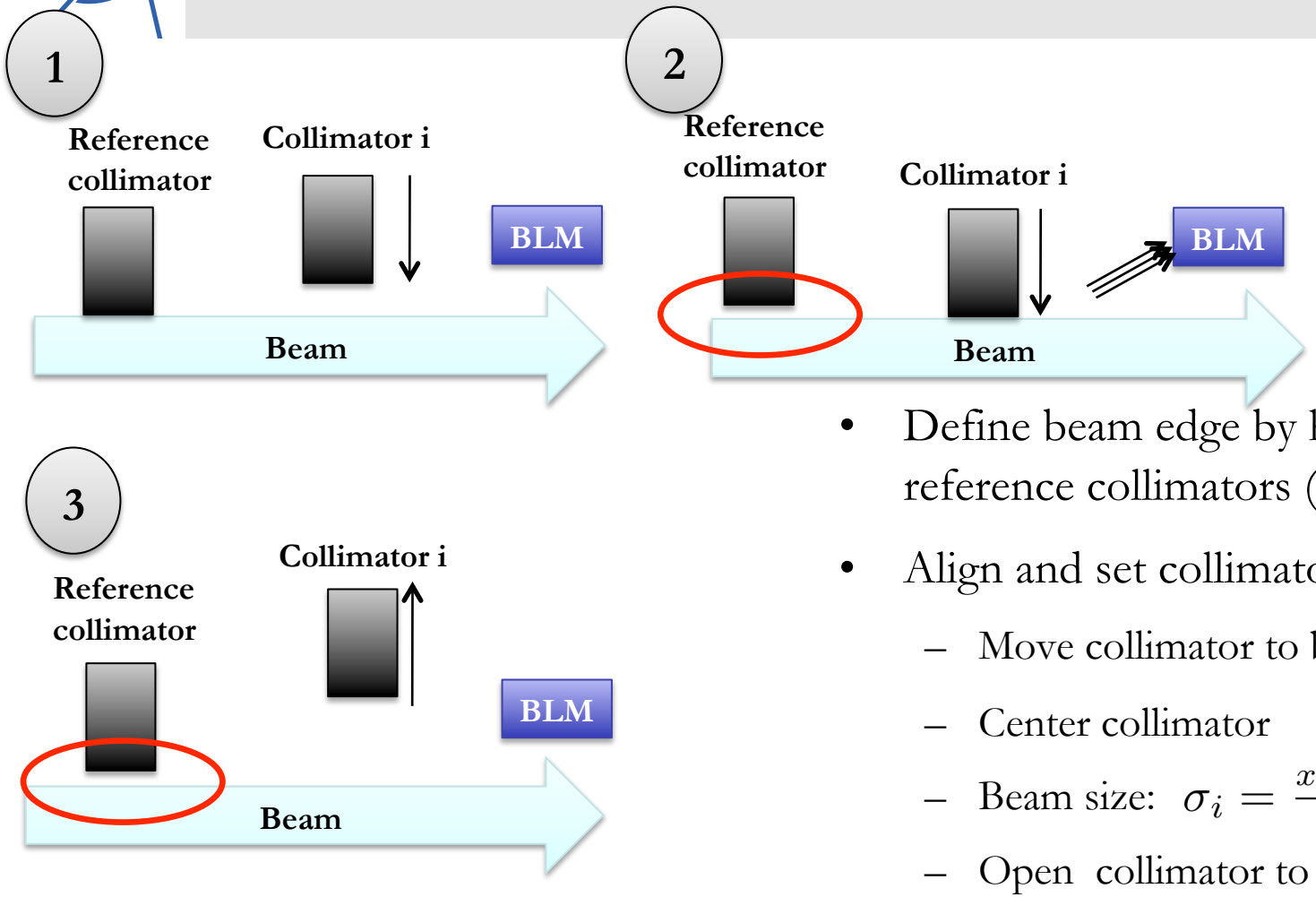


Courtesy R. Assmann

Beam based setup

- Goals of beam based alignment:
  - Center collimator jaws around beam
  - Determine local beam size at collimators
  - Achieve setup of collimation system with desired hierarchy
- Performed setups:
  - 2 setups
  - 42 collimators per beam
  - B1 and B2 in parallel
  - Beam intensity: 1) 5e9 p; 2) 1e11 p
  - Steps size of collimator jaw movement: 1) 100 μm; 2) 40 μm

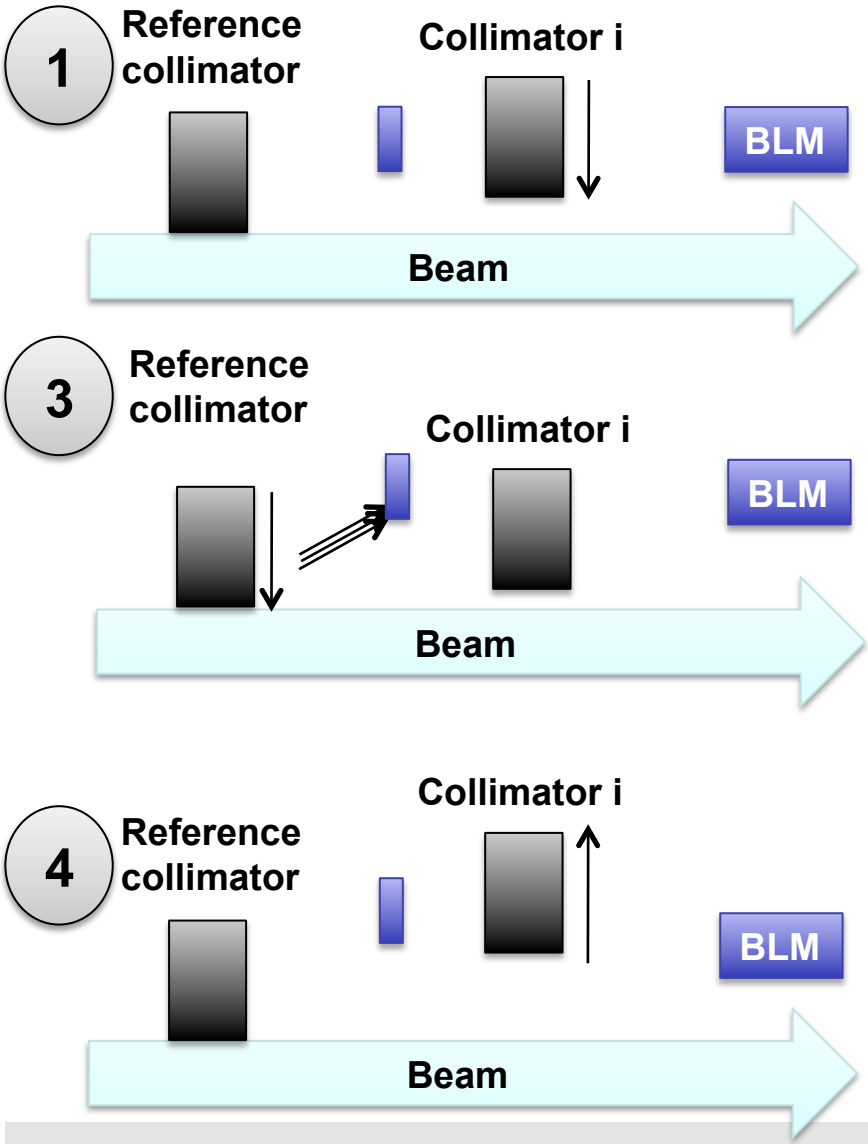
Procedure Setup-I



- Define beam edge by hor and ver reference collimators (half gap: $N_0 \cdot \sigma_n$)
- Align and set collimators one by one:
  - Move collimator to beam edge
  - Center collimator
  - Beam size: $\sigma_i = \frac{x_i^{L,m} - x_i^{R,m}}{N_0}$
  - Open collimator to $N_i \cdot \sigma_i$

Problem: Each collimators cuts deeper into the halo, so that the reference collimator does no longer define the beam edge. ⟶ Need to improve algorithm.

Procedure Setup-II

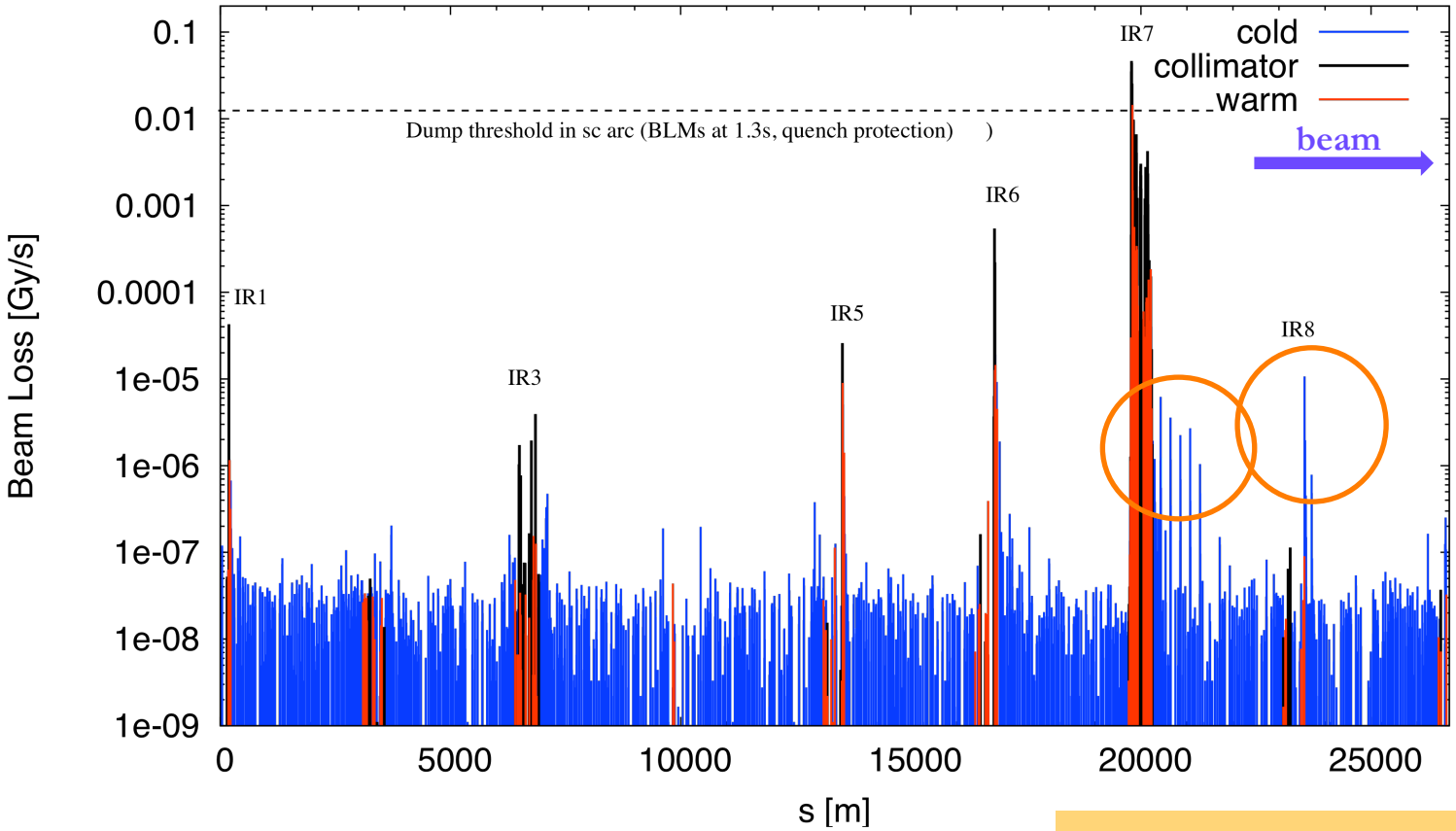


- Define beam edge by hor, ver or skew reference collimator
- Center collimator i
- Re-center reference collimator
- Beam size: $\sigma_i = \frac{x_i^{L,m} - x_i^{R,m}}{(N_0^{k-1} + N_0^{k+1})/2}$
- Open collimator to $N_i \cdot \sigma_i$

Result: found good agreement between measured and expected beam sizes

450GeV Loss Measurements for Settings found by Setup-II (B1, hor betatron losses)

Goal: Minimize blue spikes (leakage to SC magnets)



Measurement:

- 5e10p lost
- BLM signals in Gy/s
- Local cleaning inefficiency:

$$\eta_j = \frac{L_j}{L_{tcp}}$$

- Highest loss at TCP in IR7: 5.5e-2 Gy/s
- Highest loss in cold aperture: 1e-5 Gy/s

- $\eta_j = 1.8\text{e-}4$
- **Cleaning efficiency > 99.982%**

Results 450GeV Loss Measurements

Comparison of maximal local cleaning inefficiencies (simulations versus measurements):

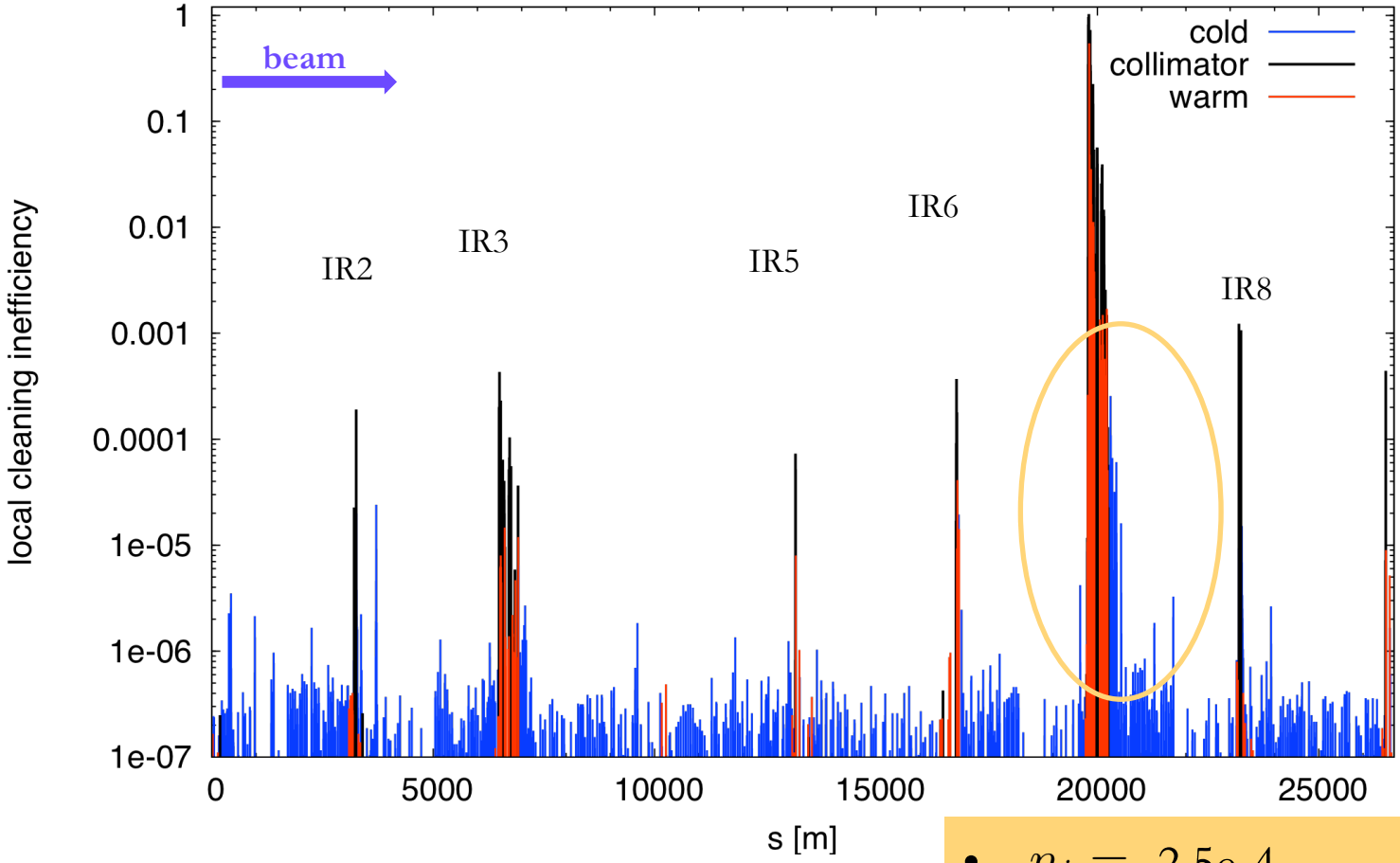
η_j	sim [1/m]	setup-I	setup-II
B1 hor	2e-4	2e-4	1.8e-4
B1 ver	5e-5	2.5e-3	3.2e-5
B2 hor	1e-4	2e-4	1.8e-4
B2 ver	2e-5	2.5e-3	1.4e-5

Cleaning efficiency:

- Simulations: >99.98%
- Setup-I: > 99.75%
- Setup-II: > 99.982%

3.5TeV Loss Measurements for Reduces Setup (B1, hor betatron losses)

Goal: Minimize blue spikes (leakage to SC magnets)



Measurement:

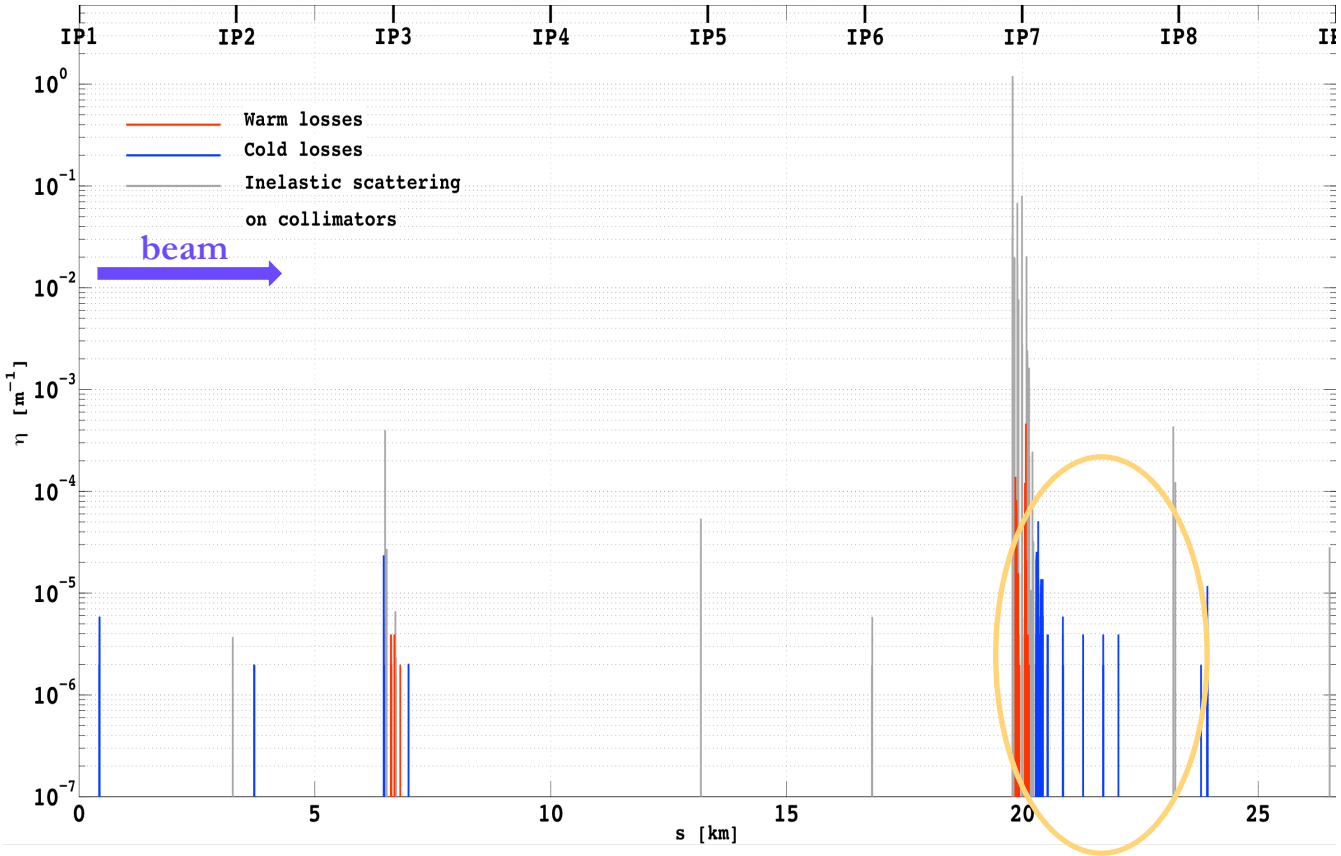
- 2e10 protons
- normalized to highest losses
- Local cleaning inefficiency:

$$\eta_j = \frac{L_j}{L_{tcp}}$$

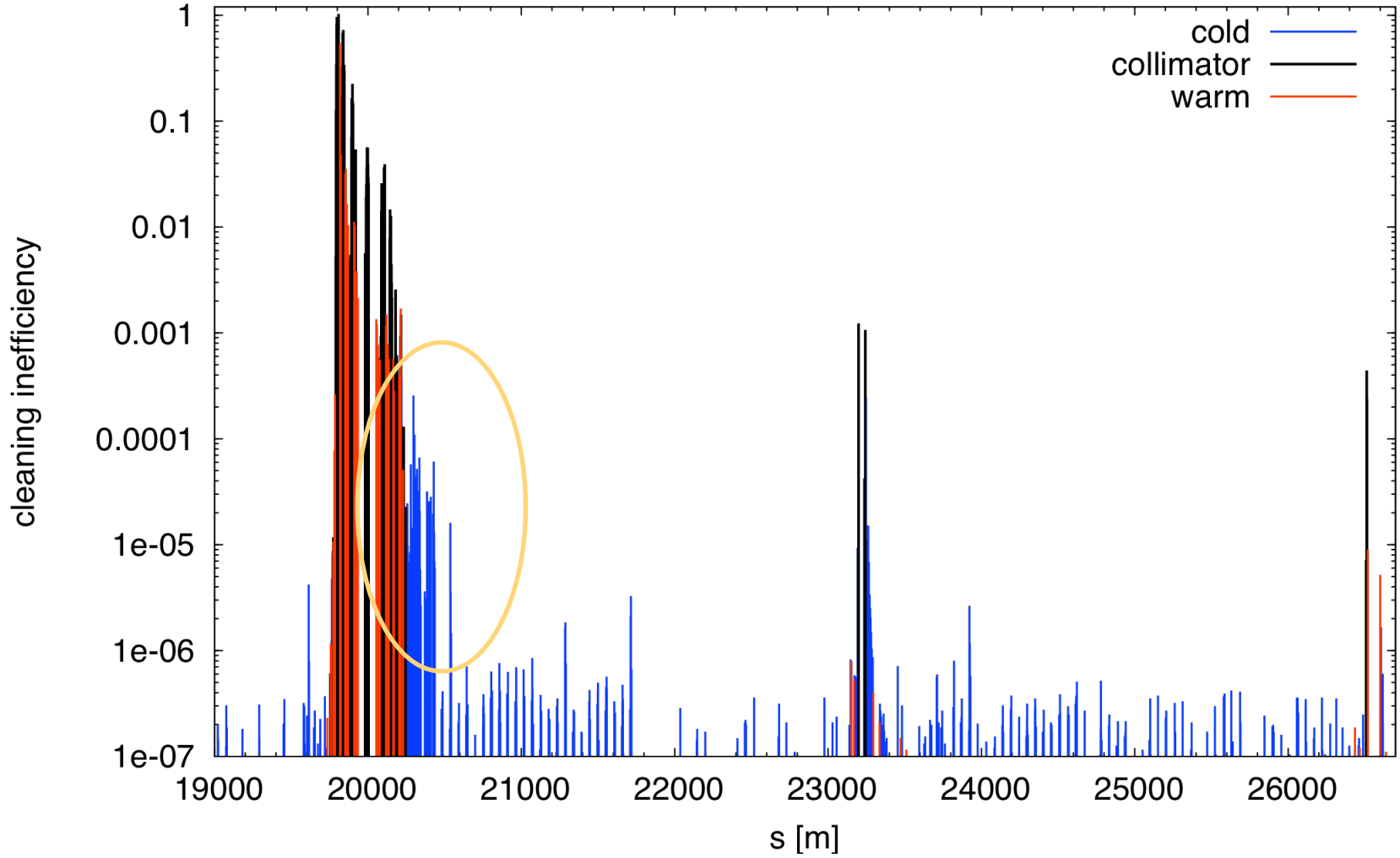
- η_j = 2.5e-4
- **Cleaning efficiency > 99.975%**

3.5TeV Simulated Cleaning (B1, hor beam loss)

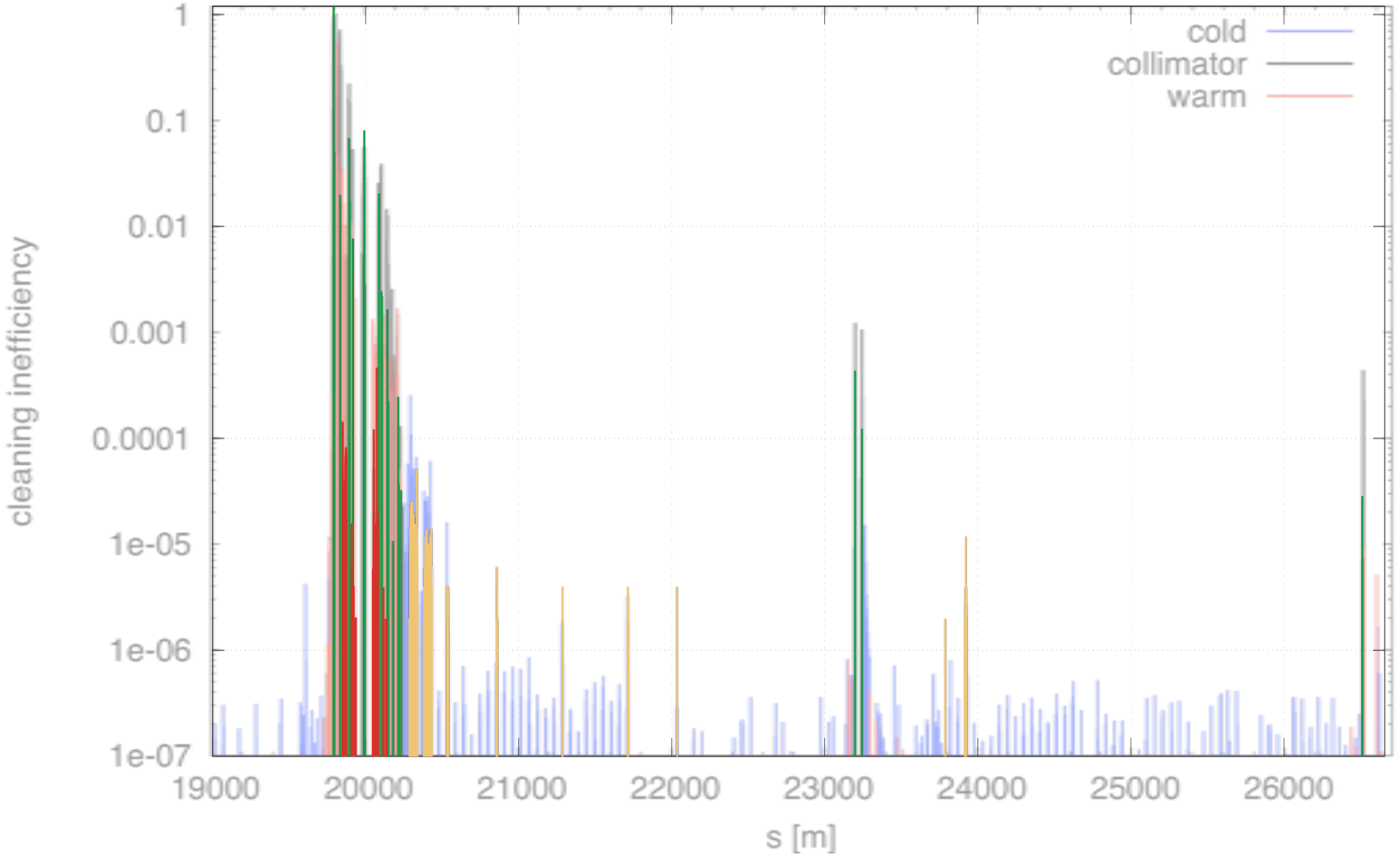
- Simulated cleaning inefficiency



Measurements versus Simulation at 3.5 TeV (B1, hor, intermediate)



Measurements versus Simulation at 3.5 TeV (B1, hor, intermediate)

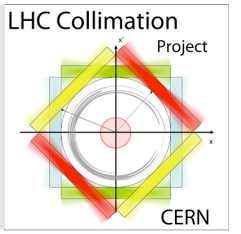


Conclusion

- Full phase-I LHC collimation system in operation
- Two complete setups performed at 450GeV
- One setup of a reduced system for 3.5TeV
- Setup procedure was refined and is still being improved
- Setup-I at 450GeV: cleaning efficiencies > 99.75% were achieved in both beams
- Setup-II at 450GeV: cleaning efficiencies > 99.982% were achieved for both beams
- Reduced setup at 3.5TeV: cleaning efficiency > 99.975%
- Measurements at 450GeV in good agreement with simulation results (at factor 2 level)
- Phase-I very satisfactory, work for designing and building phase-II has already started: expect a factor 15-90 improvement in efficiency (LHC nominal, ultimate and upgrade performance)

END

A1: Intensity limits by collimation phase-I



Intensity limits due to phase-I collimation system (assuming a loss rate of 0.002/s, factor 2 higher than the design loss rate of 0.001/s, simulated cleaning inefficiency):

- 3.5TeV :
  - Intermediate settings: 7e13 p, i.e. 23% of nominal
  - Tight settings: 1.5e14 p, i.e. 50% of nominal
- 7 TeV :
  - Intermediate settings: 6e12 p, i.e. 2% of nominal
  - Tight settings: 1.8e13 p, i.e. 6% of nominal