Collimation Setup and Performance

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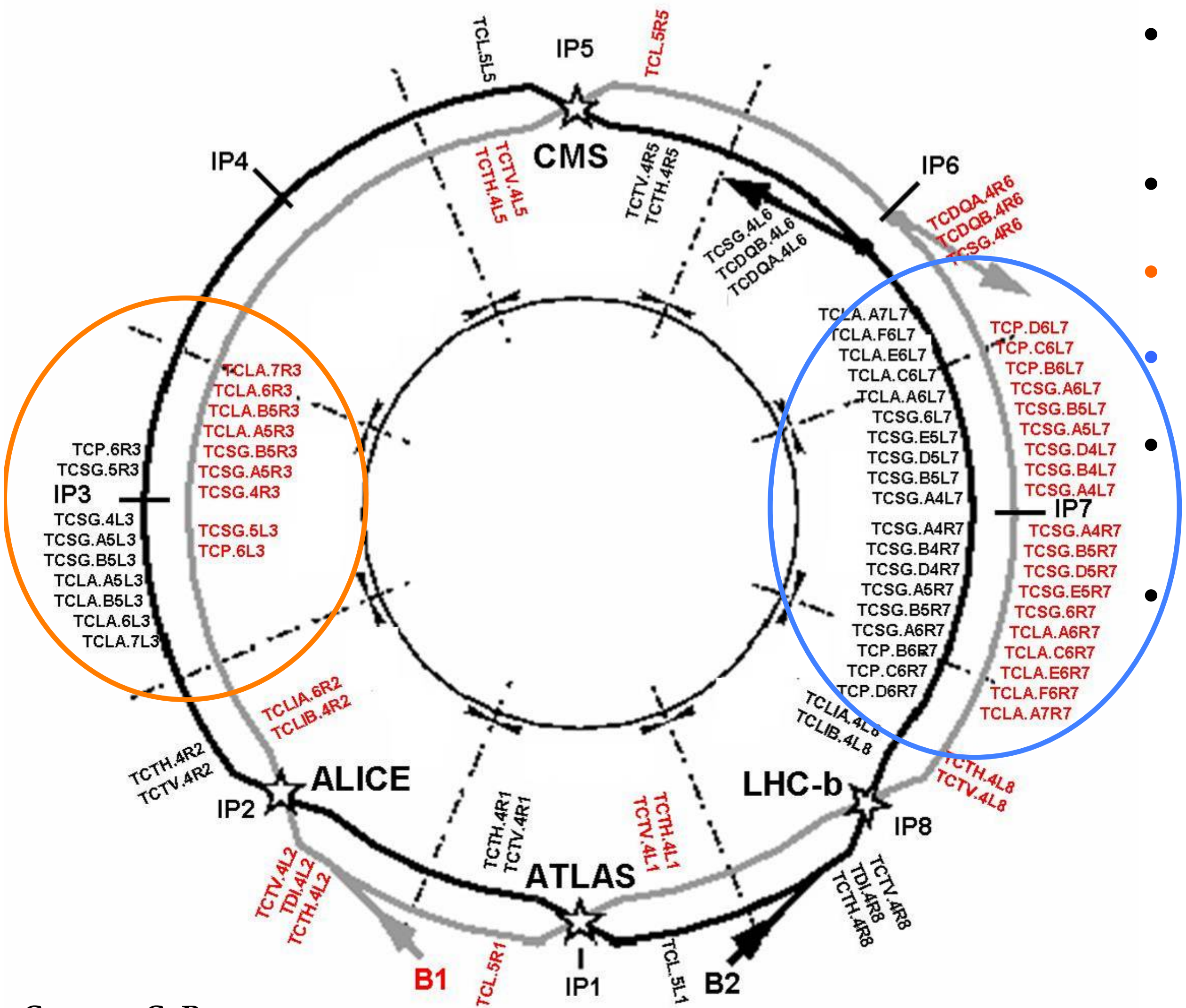
Outline

- Introduction:
  - LHC collimation system: settings, setup and qualification
- Performance of Collimation System
  - Inefficiency measurements compared to simulations
  - Performance stability
  - Inefficiency for ions
- Performance reach estimations for 3.5 TeV and 7 TeV
  - Instantaneous lifetime, quench limit, achievable inefficiency
- Conclusion

Phase-I Collimation System



Courtesy C. Bracco

- 44/43 collimators per beam installed in the LHC ring
- 4 stage cleaning
- IR3 momentum cleaning
- IR7 betatron cleaning
- Injection and Dump protection
- Protection of Experimental insertions and triplets

Beam based setup and qualification of collimation system

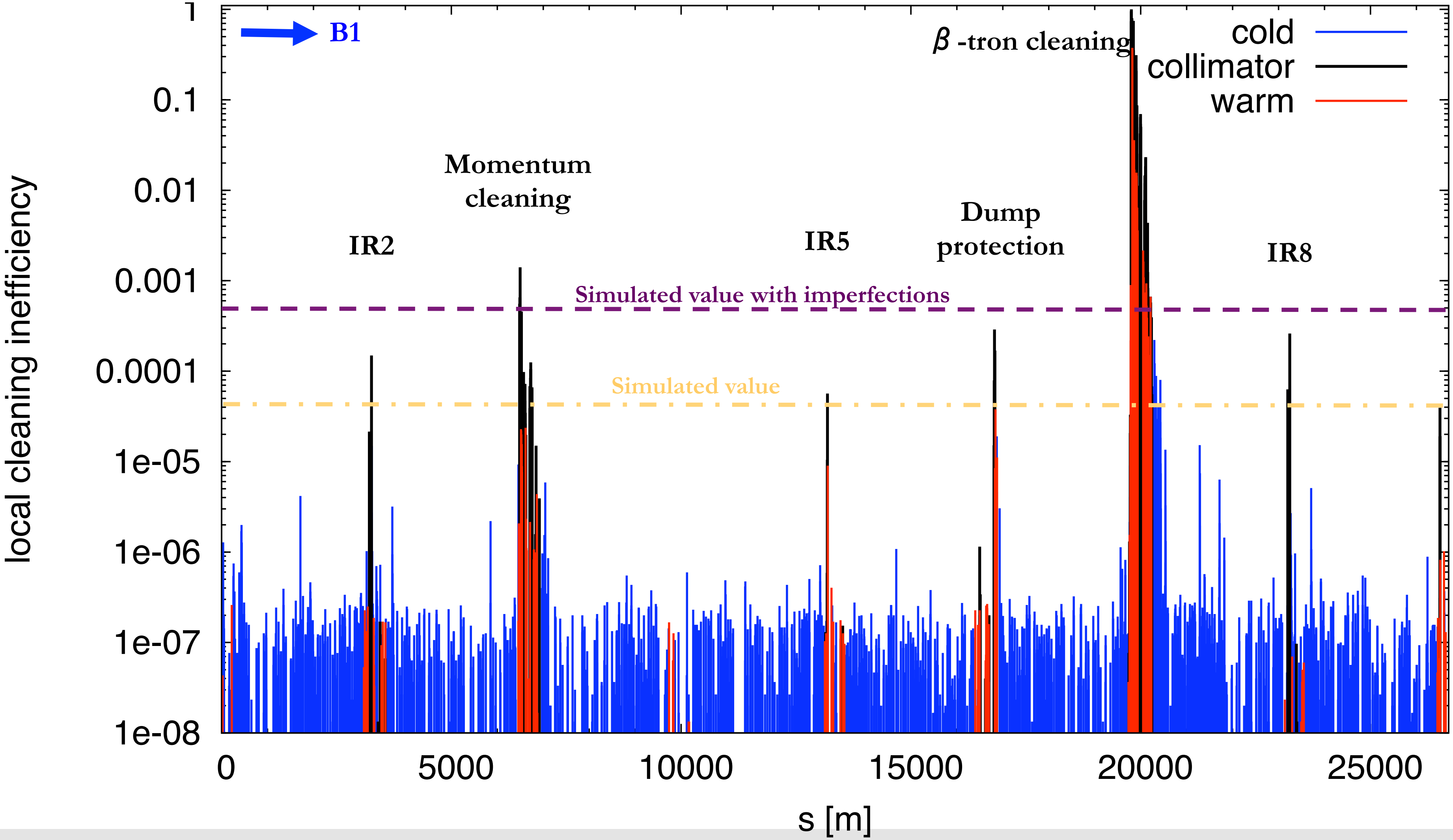
- Centre collimator jaws around beam (by touching the beam halo).
- Determine local beam size at collimators.
- Set up system with agreed collimator settings.

➔~15mins per collimator & machine state (two beams in parallel, semi-automatic application).

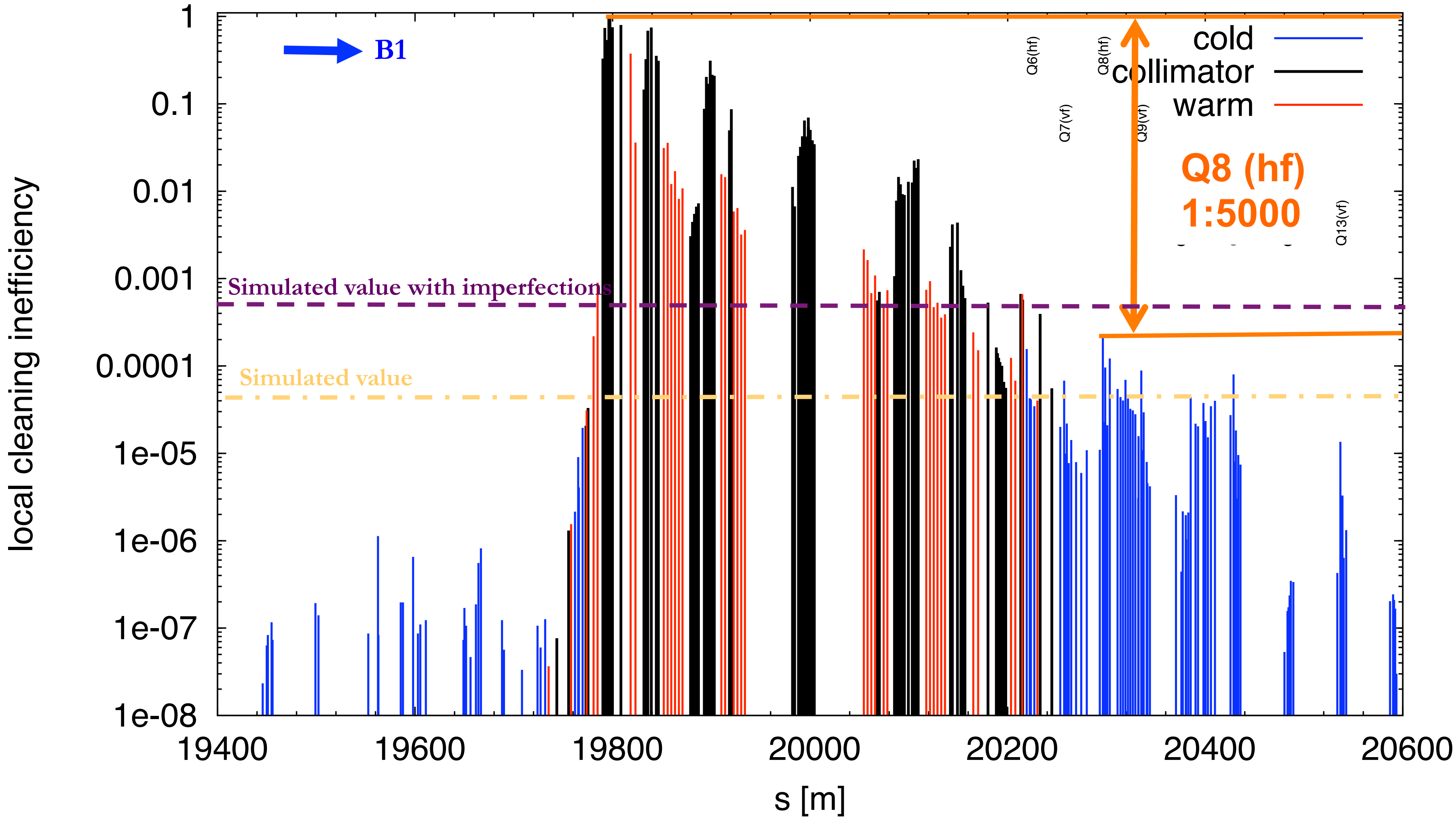
- Qualify system by measuring the cleaning efficiency
  - β-tron losses by crossing a third integer tune resonance (B1-h, B1-v, B2-h, B2-v).
  - Momentum losses by changing the RF frequency (± 1000 Hz, B1+B2). 1000Hz to make sure that full beam is lost with off-momentum error. Could use smaller.

Measured: β -tron losses, B1v, 3.5TeV, $\beta^*=3.5$m

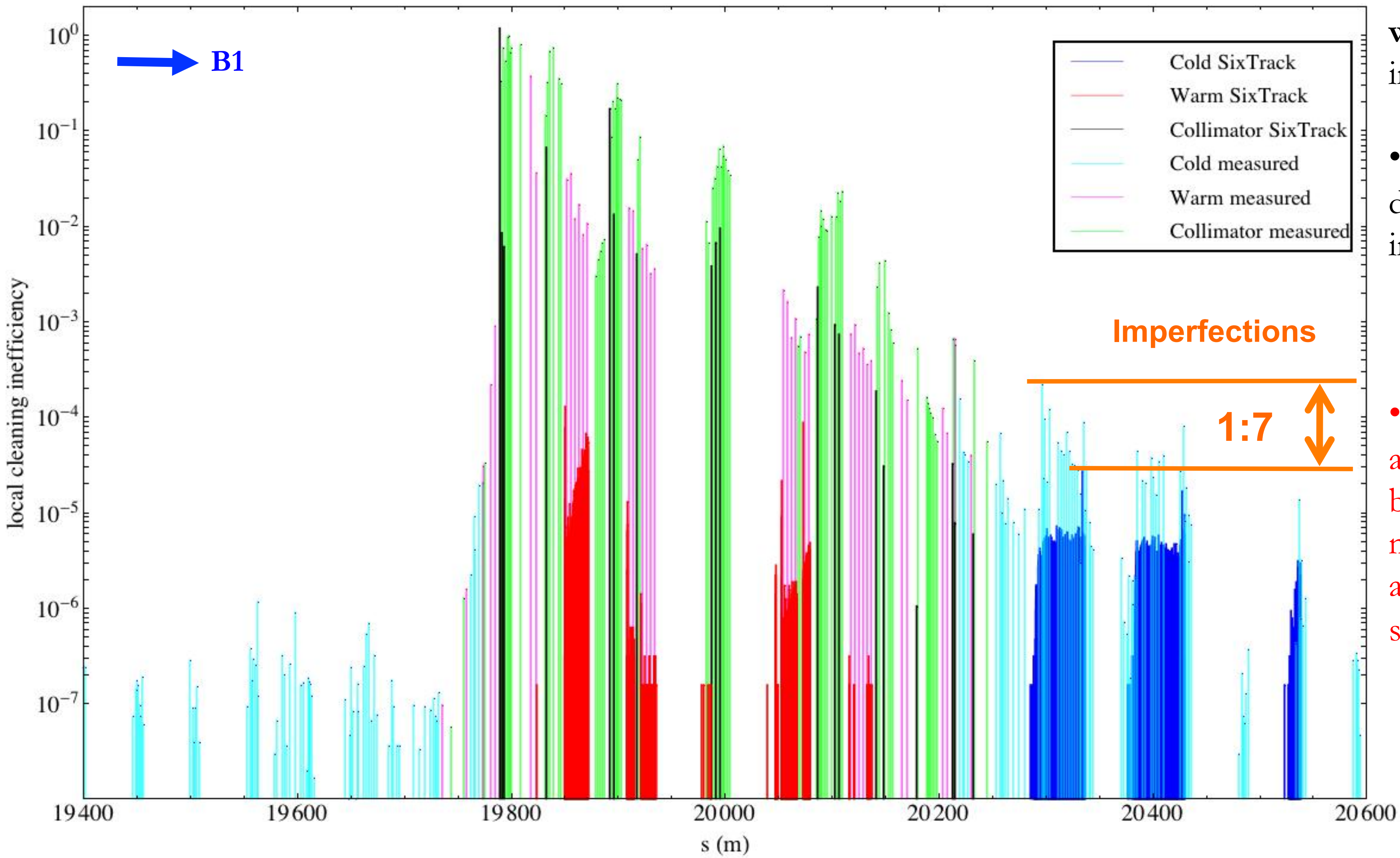
Goal: minimize blue spikes (losses to sc. Magnets)



Measured: β -tron losses, B1v, 3.5TeV, β^*=3.5m, IR7



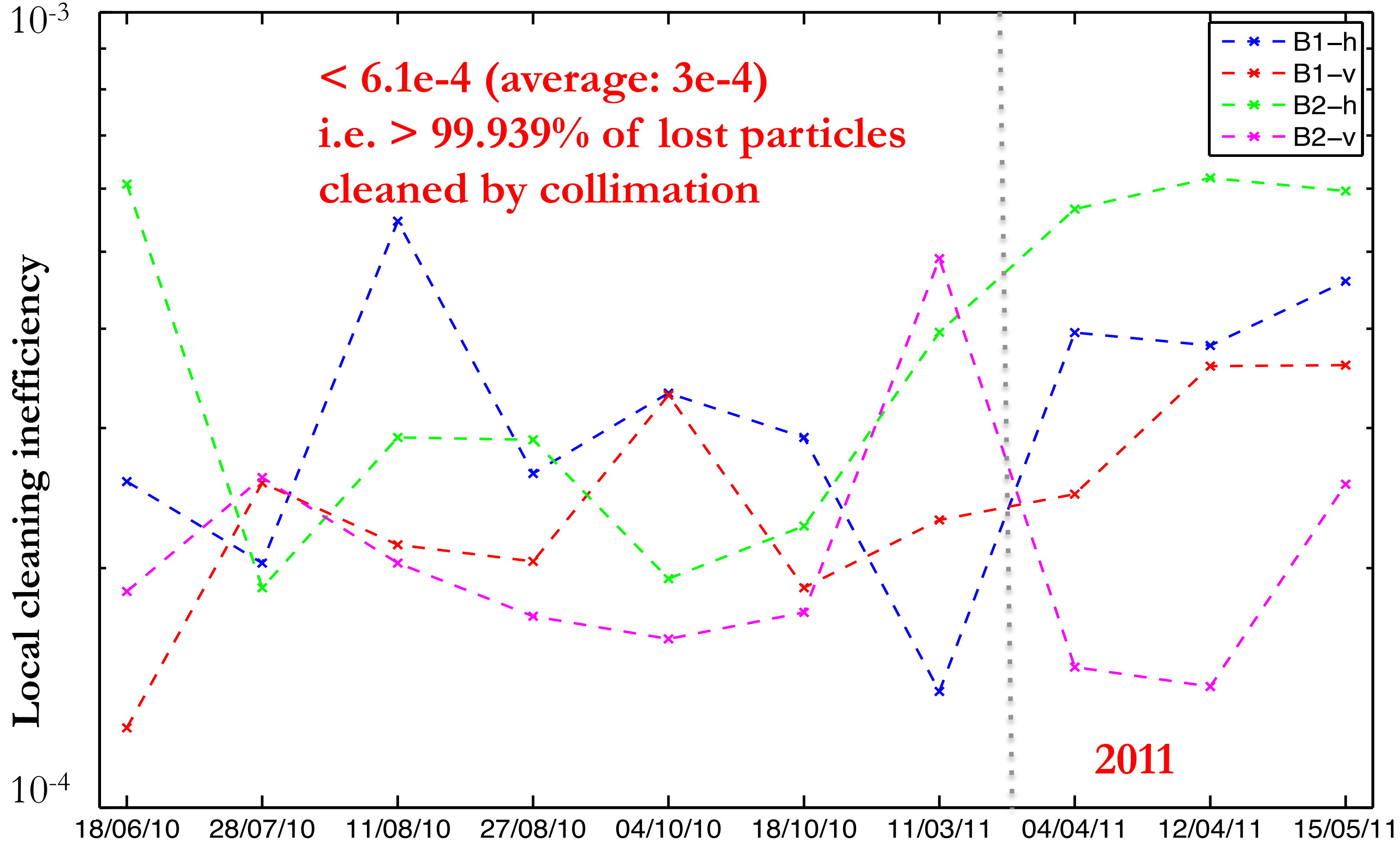
Comparison
Simulations versus Measurement
B1v, 3.5TeV, β*=3.5m, IR7



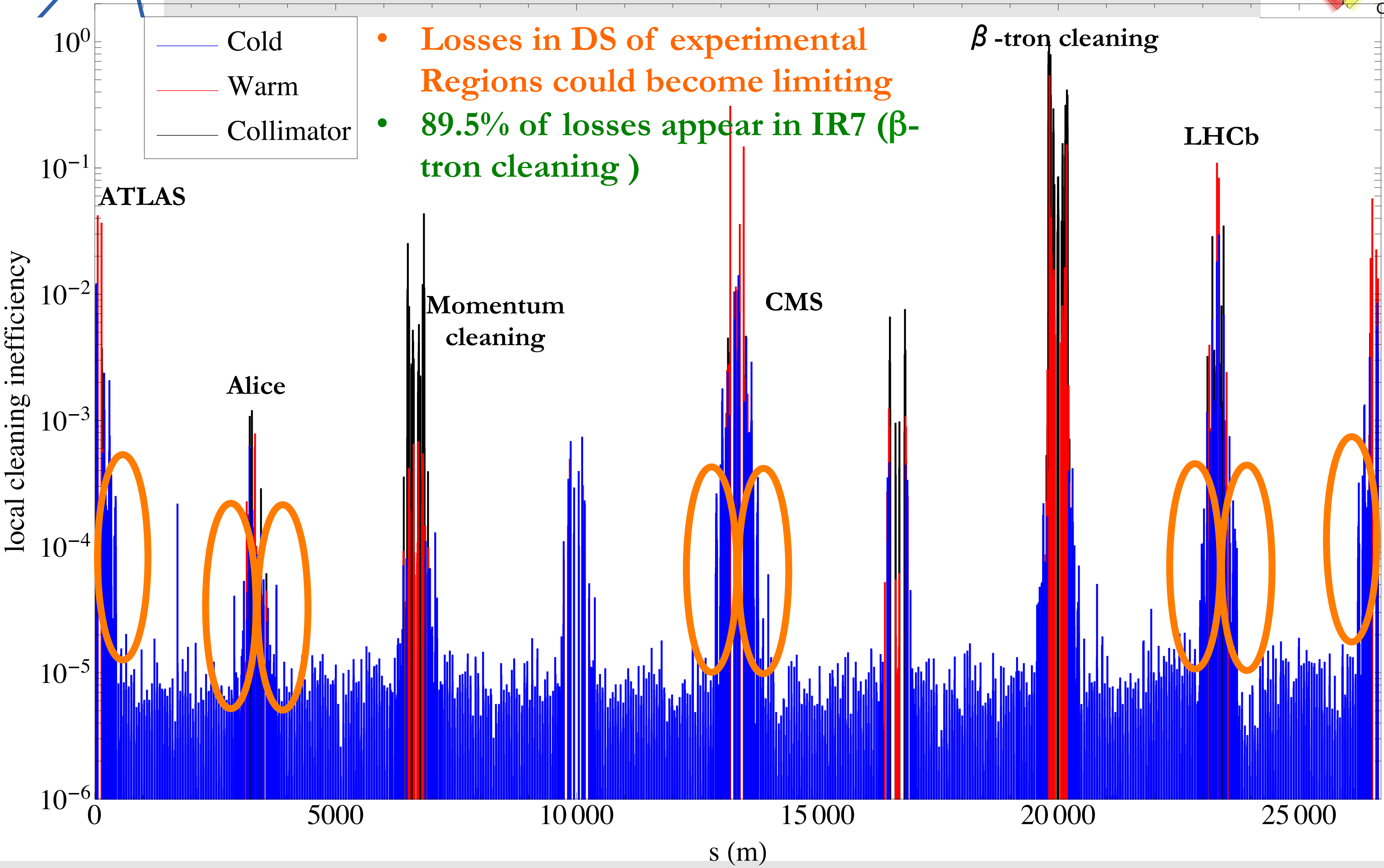
- Simulations **without** imperfections
- Measured data **with** imperfections
- good agreement between measurements and simulations!

Cleaning inefficiency at Collision since June 2010

Leakage during betatron losses into Q8 of IR7 DS



Measured losses during stable beams 1092 b

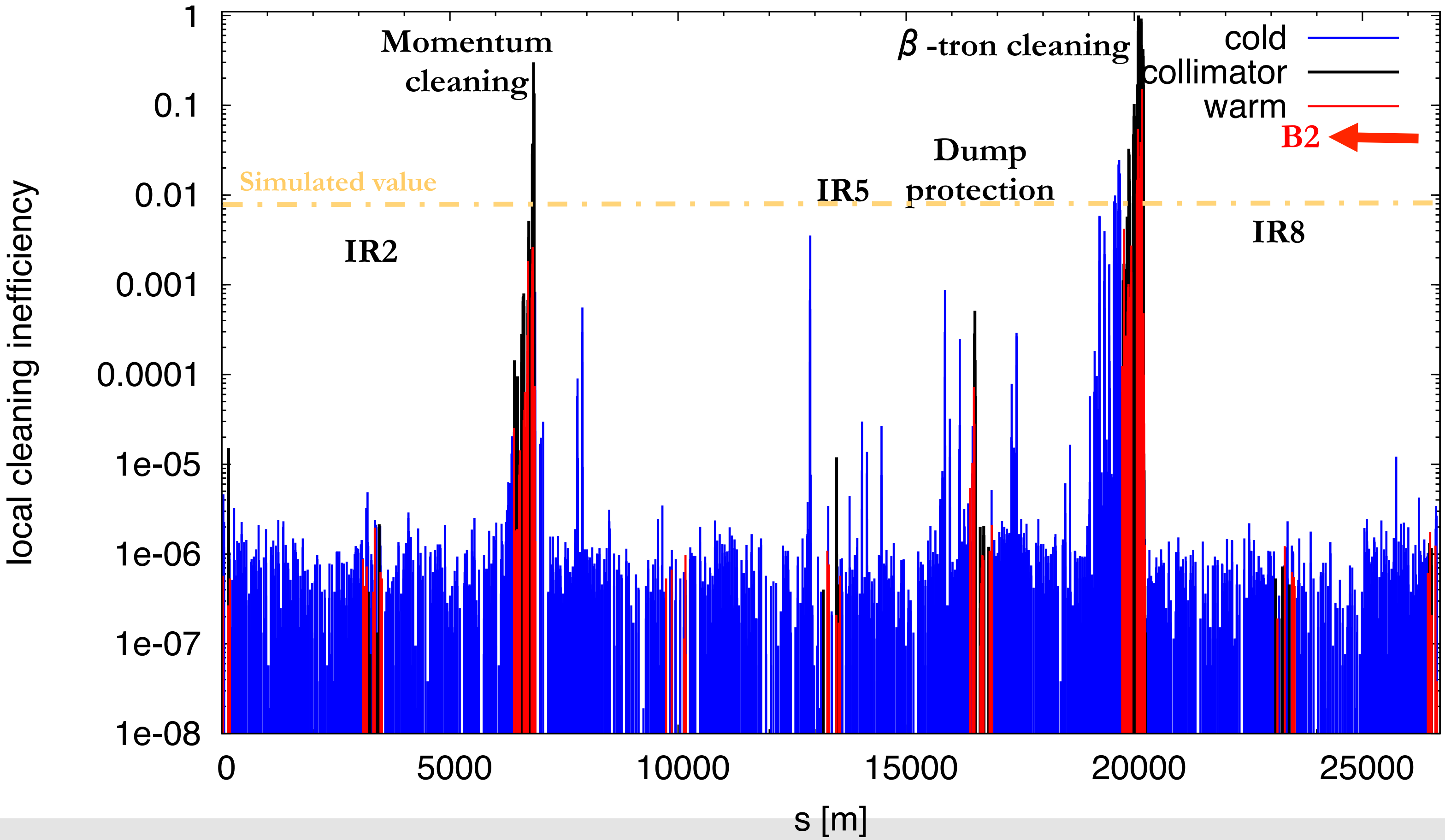


- Losses in DS of experimental Regions could become limiting
- 89.5% of losses appear in IR7 (β-tron cleaning)

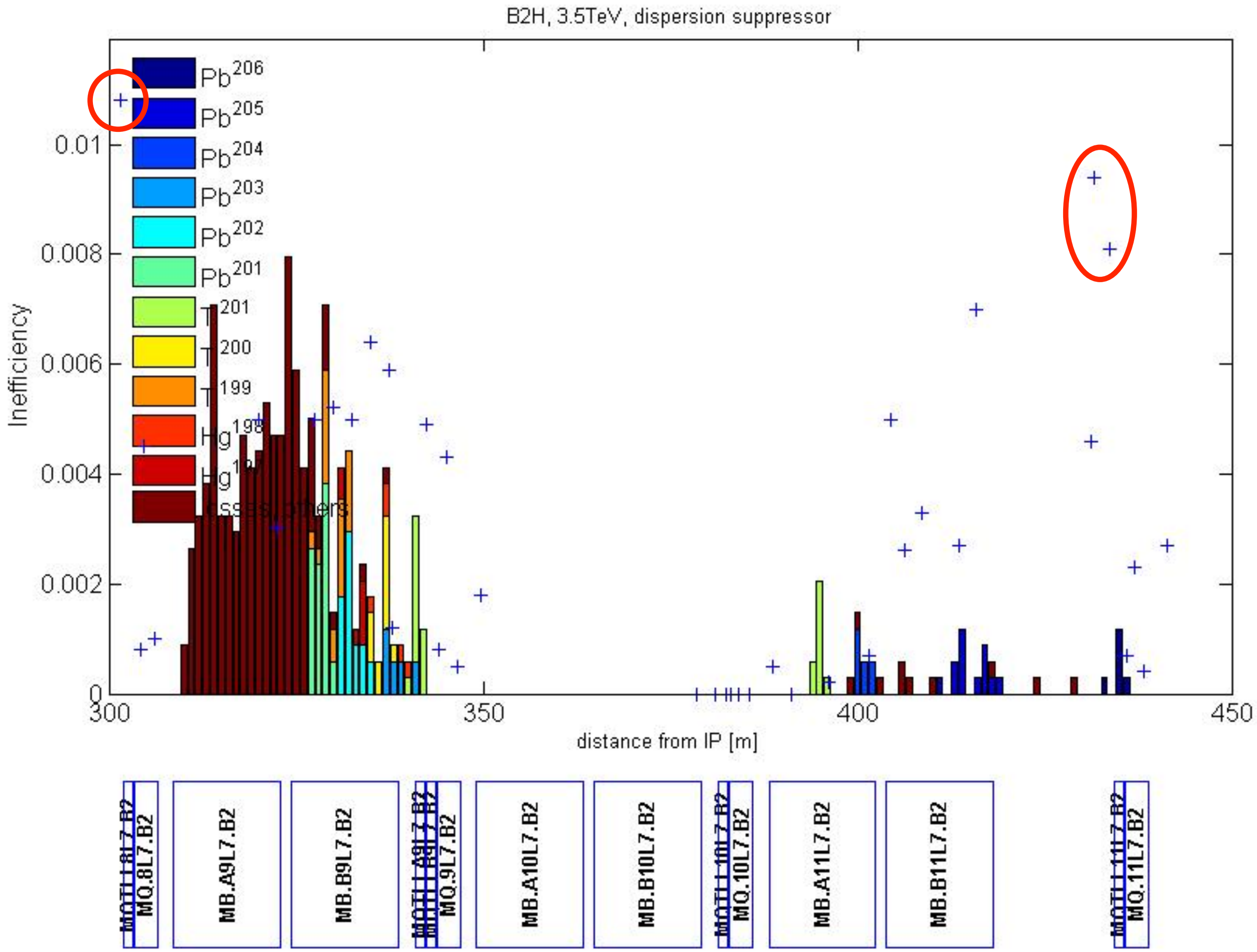
Ions: Beam2 Leakage from IR7 Collimation Much Worse (as expected)

Betatron losses B2 v, 3.5 *Z TeV , physics conditions

• Leakage to IR7 DS higher in B2 (compared to B1) due to asymmetry of hor dispersion function between B1 and B2



Comparison
Simulations versus Measurement
B2h, 3.5TeV *Z, β *=3.5m, DS IR7



Courtesy G. Bellodi

- Simulation performed with perfect machine
- Uncertainties in cross sections for hadronic fragmentation and electrom. dissociation with Pb nuclei on carbon/tungsten (although using state of the art simulations)
- Positions of loss peaks in the dispersion suppressor can be reproduced in simulations.
- Leakage higher in measurements than in simulations
- To be understood further

Cleaning inefficiency with Ions factor 50 to 100 worse compared to protons:

Leakage for ions into specific regions (ratio to losses at highest primary collimator)

	DS	COLD	TCT
B1h	0.02	0.006	1.0e-4
B1v	0.027	0.005	0.001
B2h	0.03	0.011	8e-5
B2v	0.025	0.006	1.4e-4
B1+B2 pos. off momentum	**0.045**	8e-4	0.06
B1+B2 neg. off momentum	0.007	2e-4	0.005

- As expected cleaning with ions much worse (only one stage cleaning).
- Leakage in the order of percent into DS and TCTs.
- Losses very localized.

Performance Reach Ingredients

Maximum Beam intensity (due to collimation)

Beam lifetime

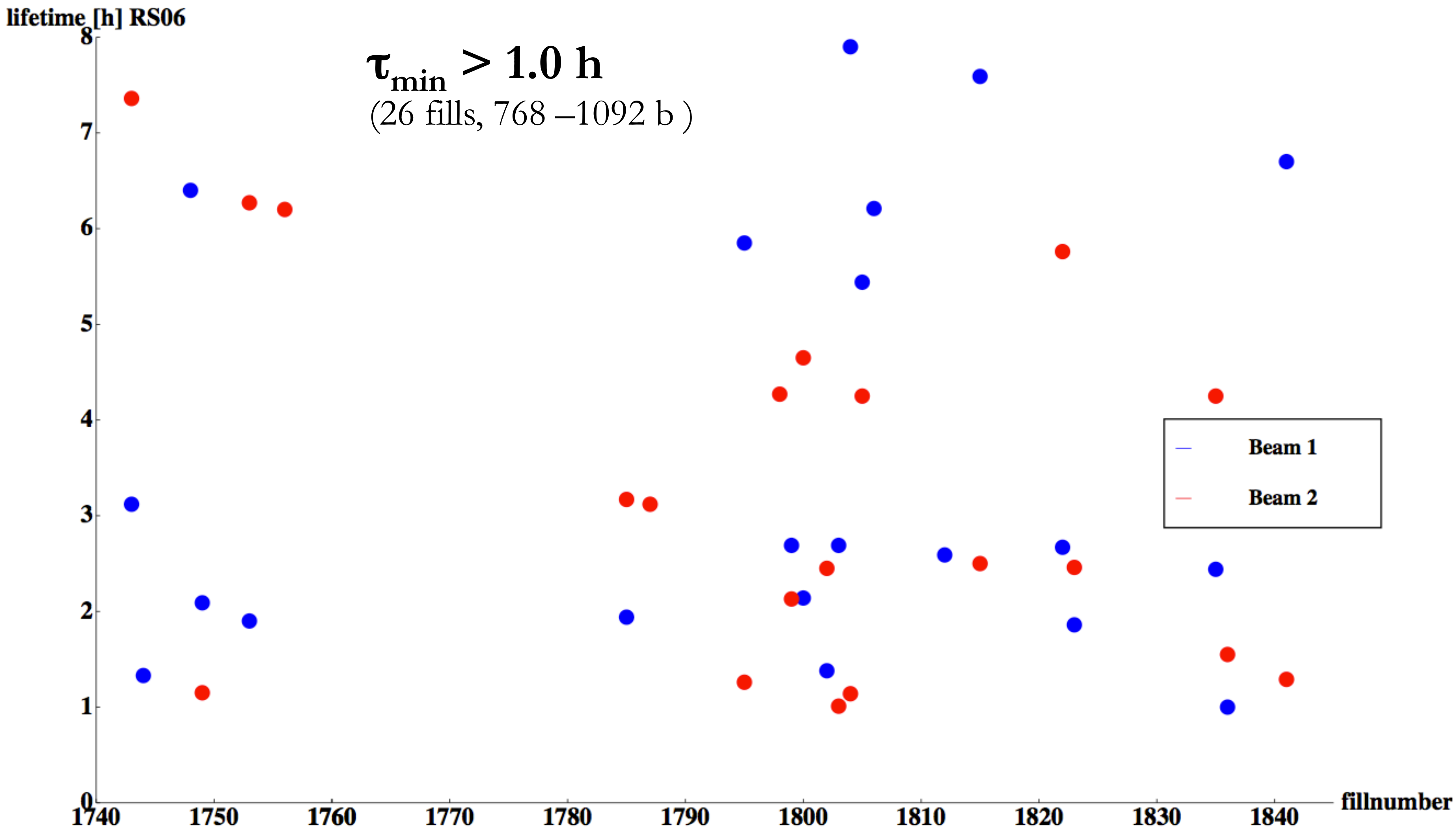
Product of: Quench limit (p/s/m) and Dilution length (m)

$$N_{i,max} = \frac{\tau_{min} R_q L_{dil}}{\tilde{\eta}_c} \cdot c_{blm}$$

Cleaning inefficiency (including BLM response factor c_{resp})

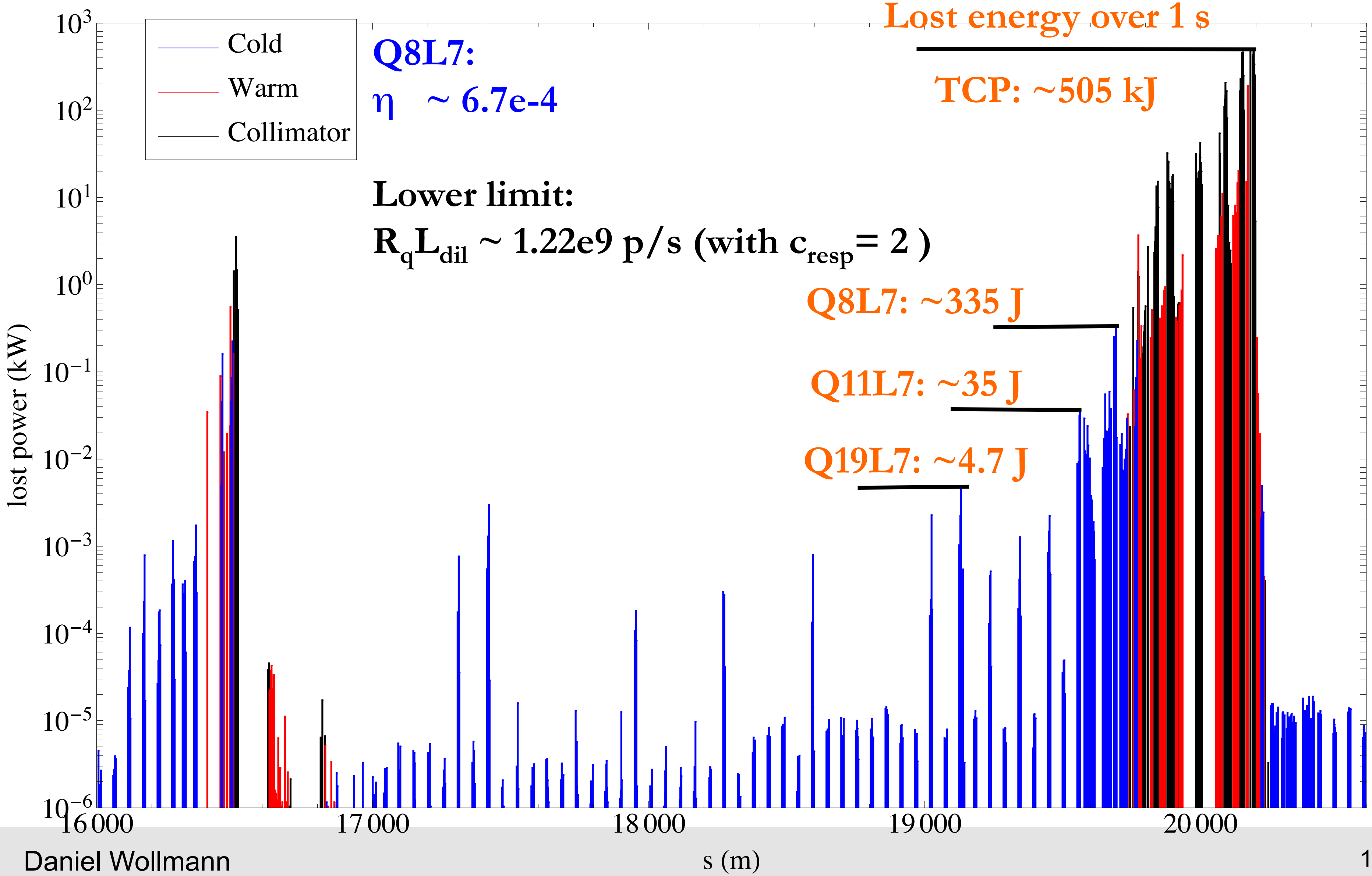
BLM threshold factor (1/3)

Measured minimum instantaneous life time during physics operation



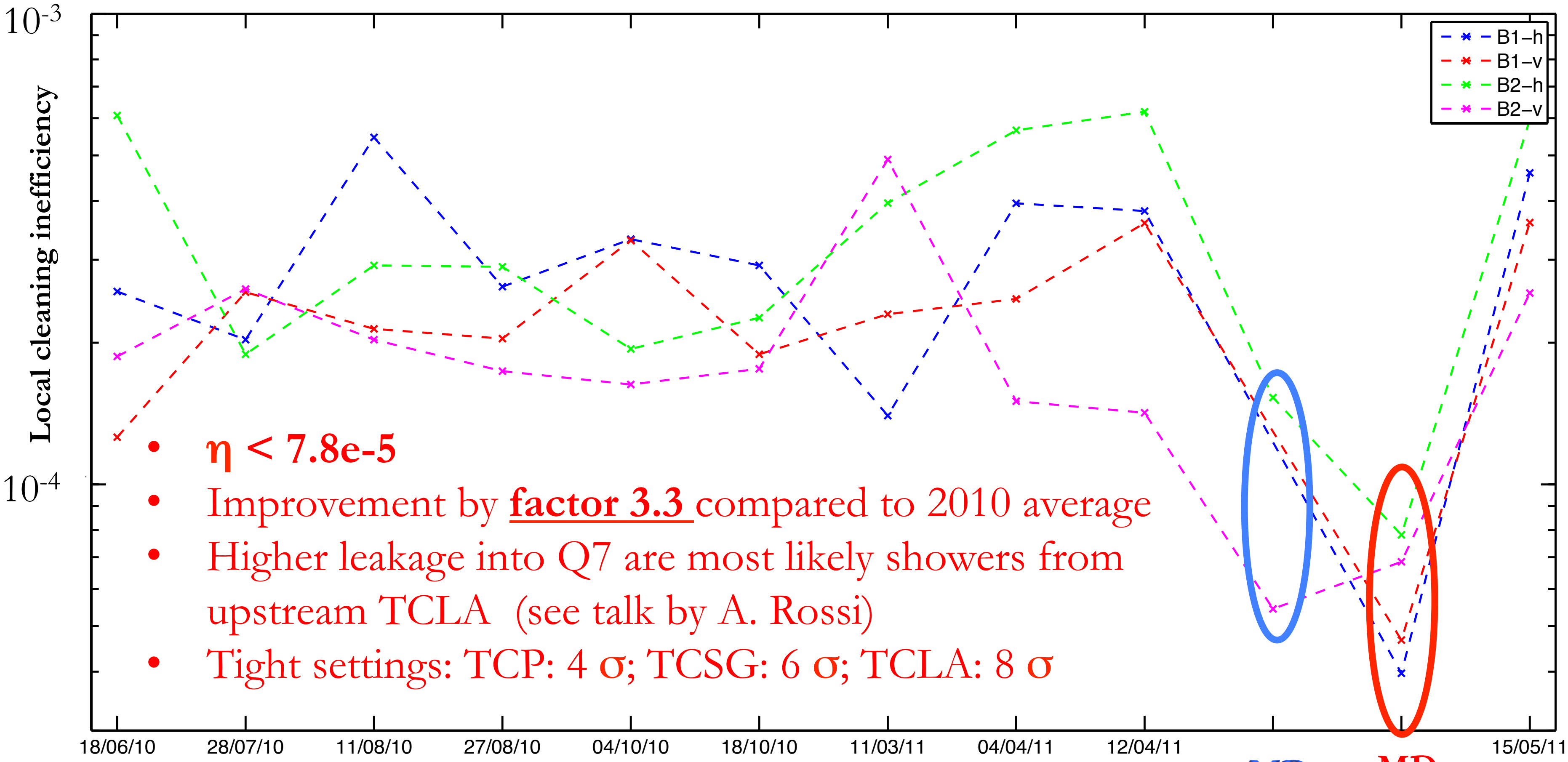
Courtesy F. Burkart

Measurement: 500kJ losses at primary collimators (loss rate: 9.1e11 p/s) – IR7



Measurement: Cleaning with nominal and tight collimator settings

Leakage during betatron losses into Q8 of IR7 DS



- **$\eta < 7.8e\text{-}5$**
- Improvement by **factor 3.3** compared to 2010 average
- Higher leakage into Q7 are most likely showers from upstream TCLA (see talk by A. Rossi)
- Tight settings: TCP: 4 σ; TCSG: 6 σ; TCLA: 8 σ

- **Nominal settings: TCP: 5.7 σ; TCSG: 6.7 σ; TCLA: 9.7 σ**

Performance Reach Ingredients

Maximum Beam intensity (due to collimation)

Beam lifetime

Product of: Quench limit (p/s/m) and Dilution length (m)

$$N_{i,max} = \frac{\tau_{min} R_q L_{dil}}{\tilde{\eta}_c} \cdot c_{blm}$$

Cleaning inefficiency (including BLM response factor c_{resp})

BLM threshold factor (1/3)

Performance Reach: 3.5 TeV

	3.5 TeV						
	η_{ineff}	Efficiency	$R_q L_{dil}$ [p/s]	τ_{min} [h]	N_{max} [p]	N_{lim} @BLM [p]	N_{lim}/N_{nom}
2010	5.20E-04	99.95%	8.40E+07	0.6	3.7E+14	1.2E+14	41%
2011	1.56E-04	99.98%	1.22E+09	1.0	2.8E+16	0.94E+16	2900%
BLM						4.0E+16	12400%

Cleaning efficiency: Gain factor 3.3 (MD result)

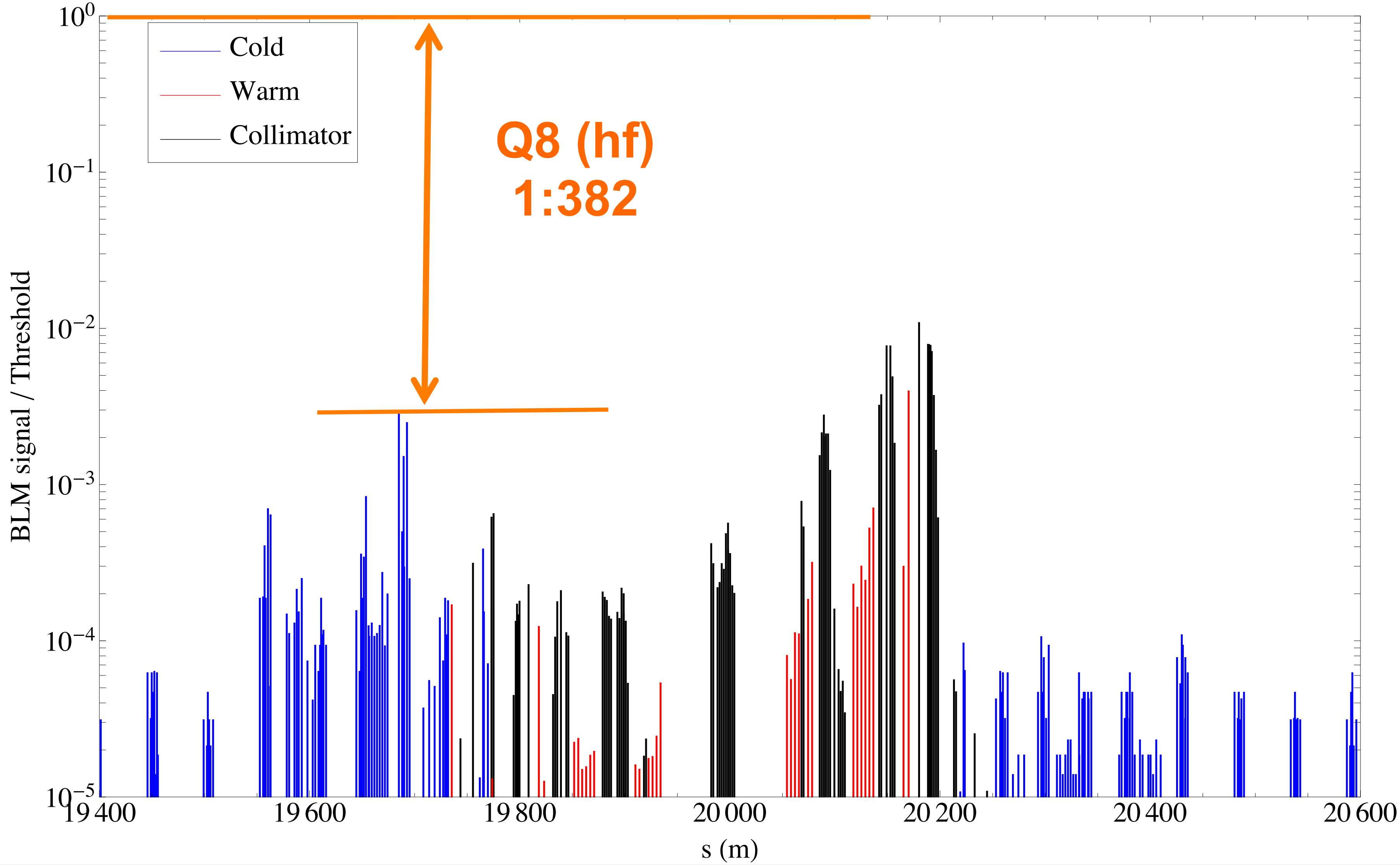
Quench limit times dilution length: Gain factor 14.5 (MD result)

Min. lifetime: Gain factor 1.7 (2011 operation)

Scaling highest BLM signal in cold region to dump threshold

Performance reach with ions see talk of G. Bellodi

Measured: Ratio of BLM signal to dump threshold (912b, B2, τ_{min} = 1h)



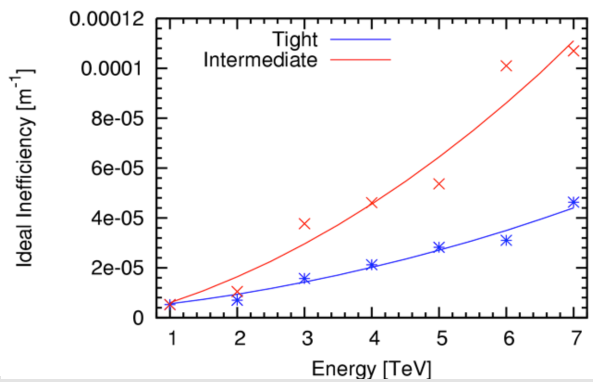
Performance Reach: 7 TeV

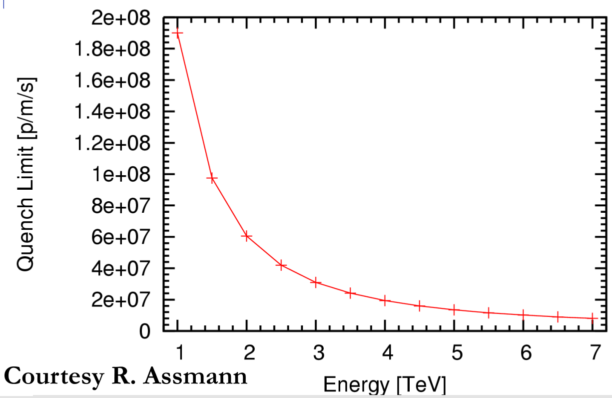
	Extrapolation to 7 TeV						
	η_{ineff}	Efficiency	R_q L_{dil} [p/s]	τ_{min} [h]	N_{max} [p]	N_{lim} @BLM [p]	N_{lim}/N_{nom}
2010	1.30E-03	99.87%	2.71E+07	0.6	4.8E+13	1.6E+13	5%
06.2011	3.90E-04	99.97%	3.96E+08	1.0	3.65E+15	1.22E+15	377%

Cleaning Inefficiency:
Gain factor 3.3
(MD result)
Scaled to 7 TeV (x2.5)

Quench limit times dilution length:
Gain factor 14.5
(MD result)
Scaled to 7 TeV (x3)

Min. lifetime:
Gain factor 1.7
(2011 operation)





Courtesy R. Assmann

Performance reach with ions see talk of G. Bellodi

Assumptions

- Same **minimum beam lifetime** at 3.5 TeV and 7 TeV.
- Minimum beam lifetime independent from intensity.
- No disturbing effect from much **larger impedance**.
- Theoretical **scaling** of **cleaning efficiency** and **quench limit**.
- Same **spatial distribution** of losses in SC magets at 3.5 TeV and 7 TeV:
- Tight collimator **settings achievable** in routine operation and at 7 TeV.
- No disturbing effect from **smaller impact** parameters at 7 TeV.
- Both beams behave the same.
- Same **locations for peak loss** into SC magnets.
- No other performance limits included (IR1/5, …)

Conclusion

- Phase-I LHC collimation system delivers **expected collimation efficiency**.
- **Setup procedure** has been refined, optimized and performed in a **semi-automatic** way (15-20mins per collimator needed)
- Validity of collimation setup **~5-6 months**, i.e. two setups for a 10 months running period expected.
- Instantaneous **lifetime** about **factor 7 higher** than specified.
- **Cleaning inefficiency** can be **reduced by a factor > 3.3** with tight settings (MD result).
- Product of **quench limit times dilution factor** was measured to be a factor **14.5 higher** than expected (MD result - lower limit).
- With this we should be **good for nominal intensity at 3.5 and 7.0 TeV** (in terms of cleaning efficiency – other issues like R2E not considered here). Scaling losses to **BLM threshold** gives **consistent result**.
- But: Long list of **assumptions raise uncertainties** in performance expectations.
- Can we **assume the same performance** of the LHC at 7 TeV (lifetimes, loss locations and dilution, scaling of inefficiency and quench limit, …)**?**
- Cleaning with **ions** much **less efficient** than for protons (as expected): Leakage in orders of **percents into DS magnets** and TCTs, very localized losses.

END

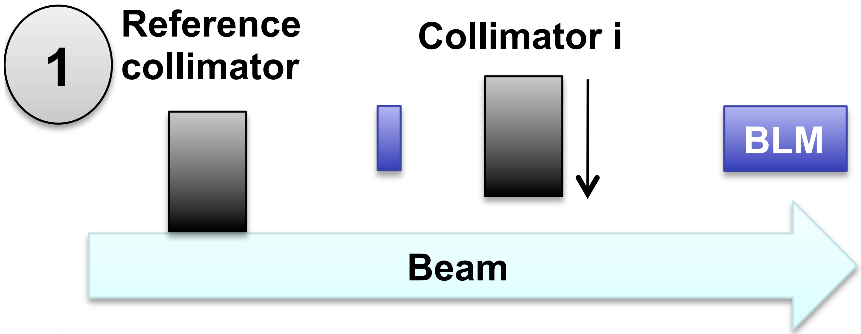
Backup Slides

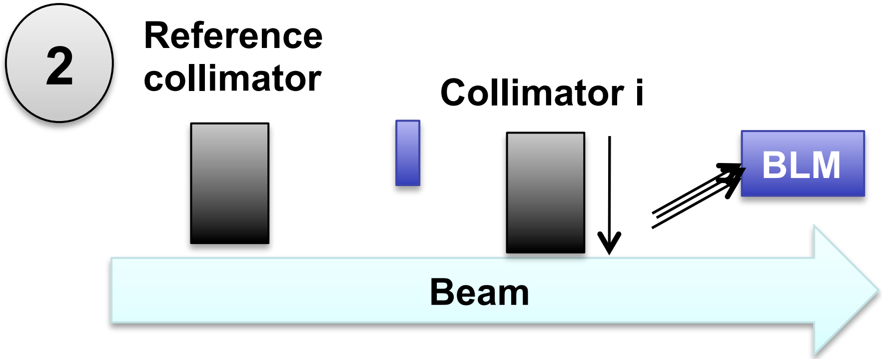
Collimator Settings

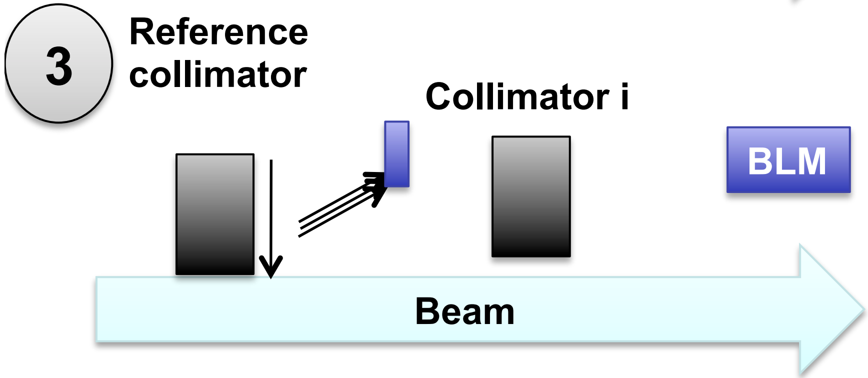
	Injection optics	Injection optics	Squeezed optics
Energy [GeV]	450	3500	3500
Primary cut IR7 (H, V, S) [σ]	5.7	5.7	5.7
Secondary cut IR7 (H, V, S) [σ]	6.7	8.8	8.8
Quaternary cut IR7 (H, V) [σ]	10.0	17.7	17.7
Primary cut IR3 (H) [σ]	8.0	12	12
Secondary cut IR3 (H) [σ]	9.3	15.6	15.6
Quaternary cut IR3 (H, V) [σ]	10.0	17.6	17.6
Tertiary cut exp. (H, V) [σ]	13	26	11.8/26/11.8/11.8
TCSG/TCDQ IR6 (H) [σ]	7/8	9.3/9.8	9.3/9.8

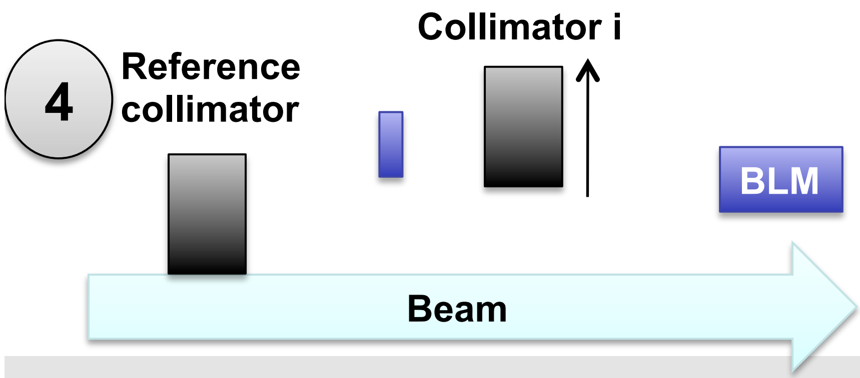
- Collimators are **driven by functions** during the ramp, squeeze and collapsing the separation bumps.
- Beam based setups performed 26.-28.02.2011 (Injection) and 06.-11.03.2011 (3.5 TeV).

Beam based setup procedure for LHC collimators



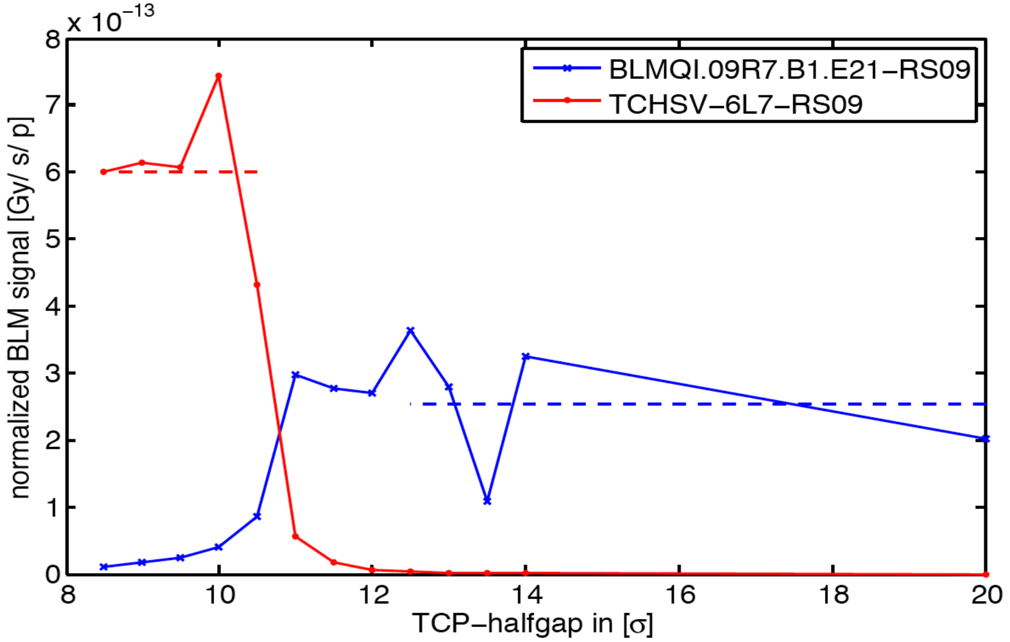


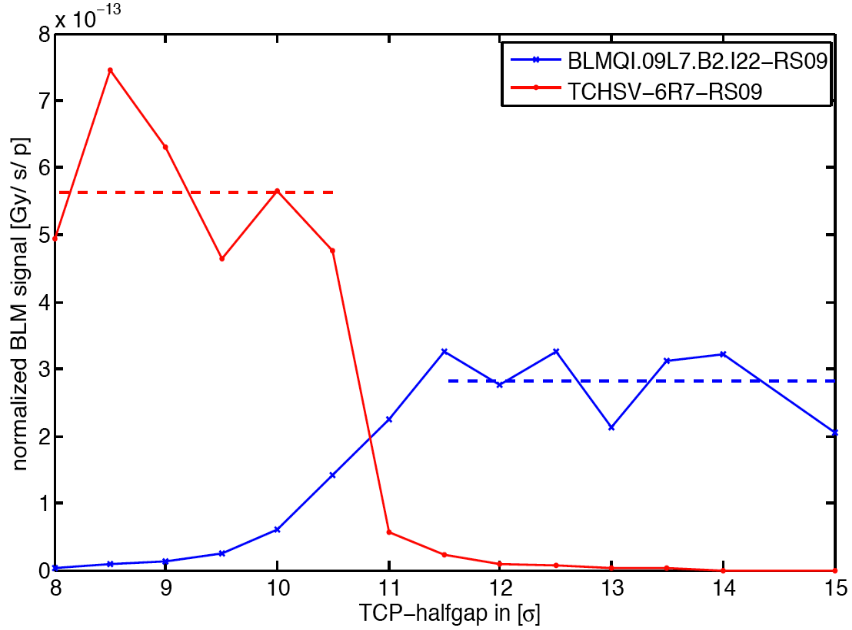




- Define beam edge by hor, ver or skew reference collimator
- Center collimator i
- Re-center reference collimator
- Beam size: $\sigma_i = \frac{x_i^{L,m} - x_i^{R,m}}{(N_0^{k-1} + N_0^{k+1})/2}$
- Open collimator to $N_i \cdot \sigma_i$

Measured BLM response between losses on TCP and DS magnets

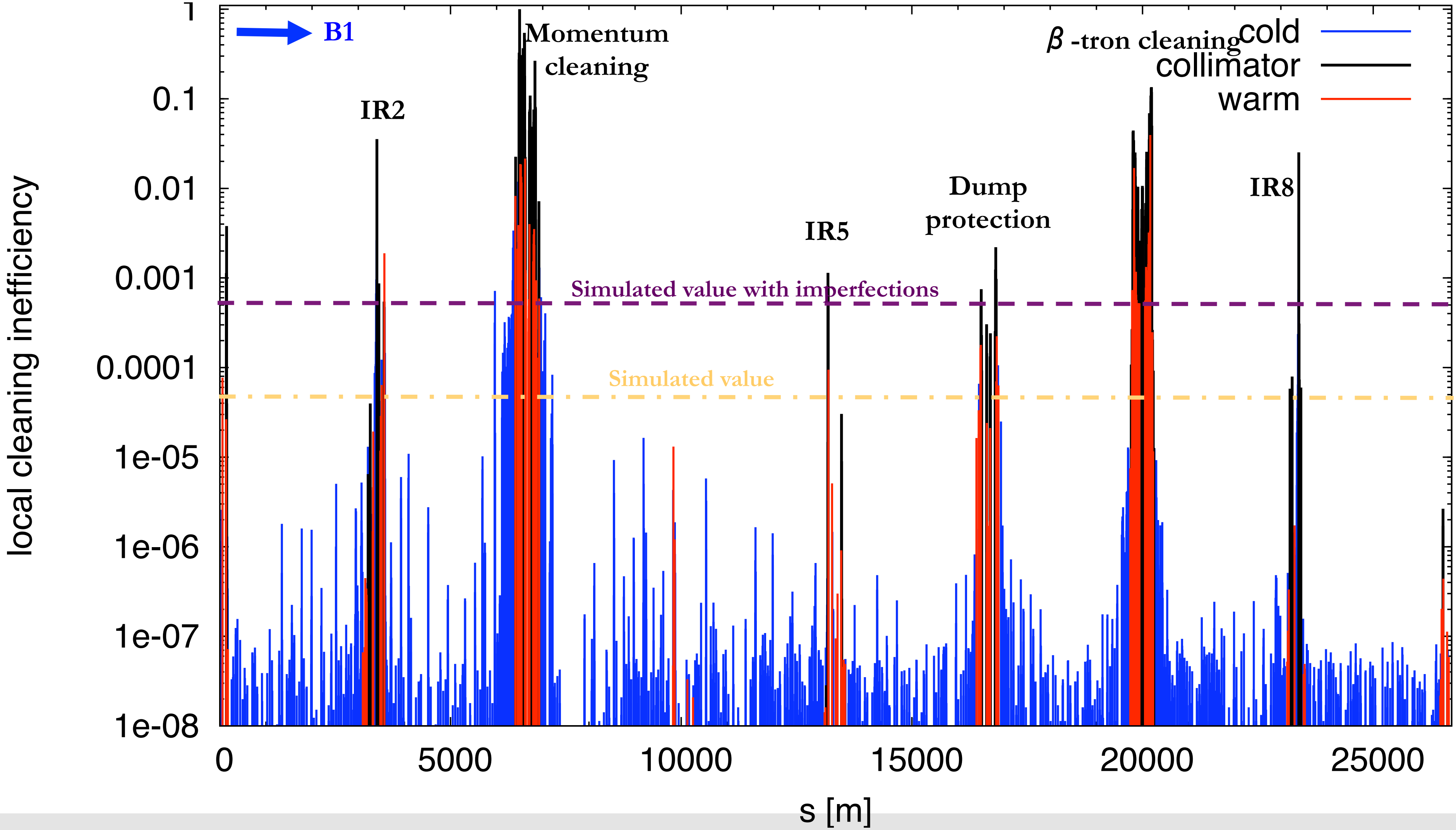




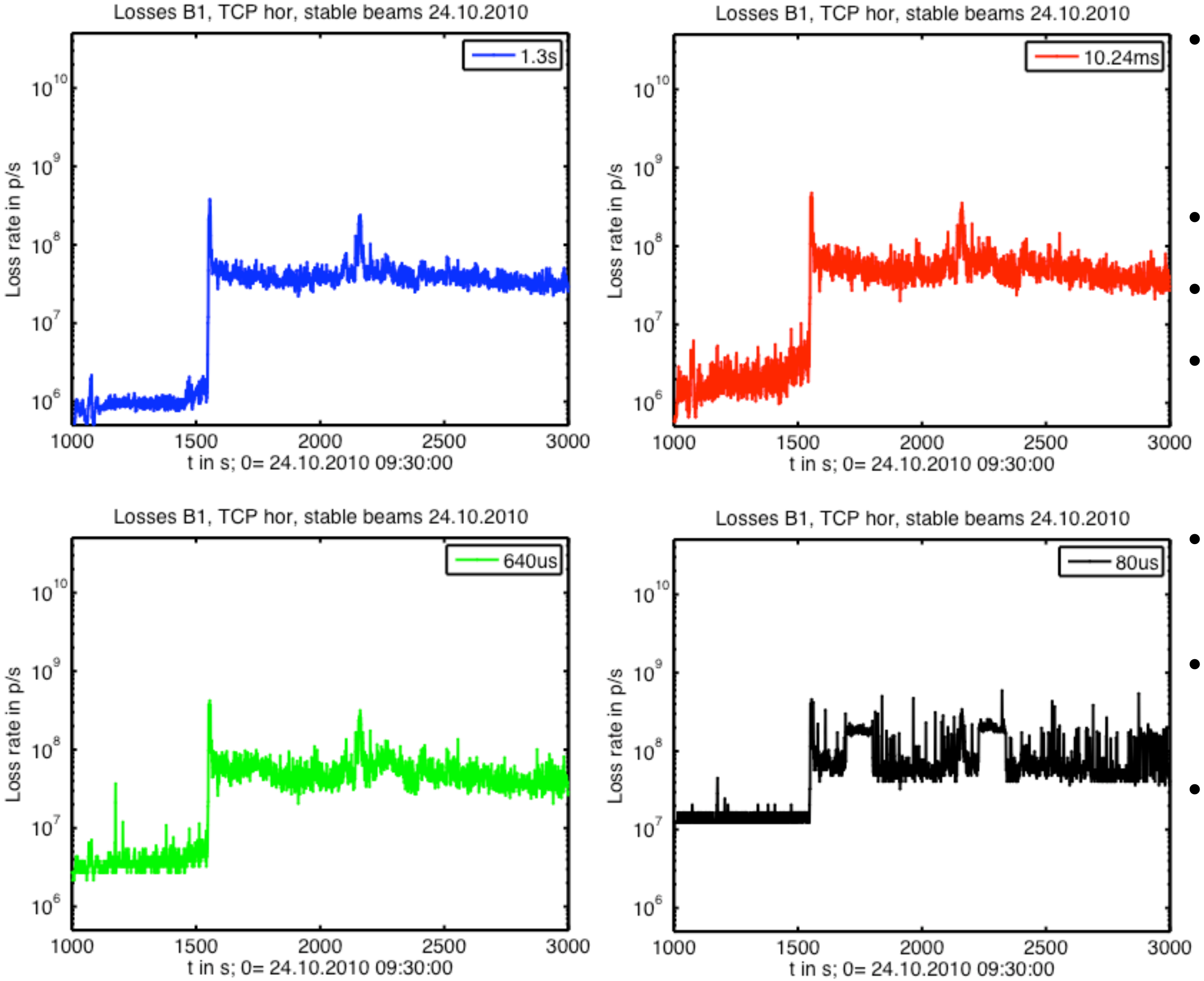
$$c_{resp} \approx 2$$

Positive momentum offset, B1+B2, 3.5TeV, β*=3.5m

Goal: minimize blue spikes (losses to sc. Magnets)



Loss rate at hor. TCP in IR7 during high luminosity run, 150ns, 312b (24.10.2010)



- **First 1500s in collision for different integration times**
- 150ns bunch spacing
- 312 bunches
- Significant **increase in losses** when going into collisions
- Loss spike during the whole run
- **Loss pattern** seen in all integration times
- 80us signal with lots of **loss spikes**