Proton beam performance with and without IR3 upgrade

A Rossi on behalf of the collimation team

Collimation Upgrade Review 2011

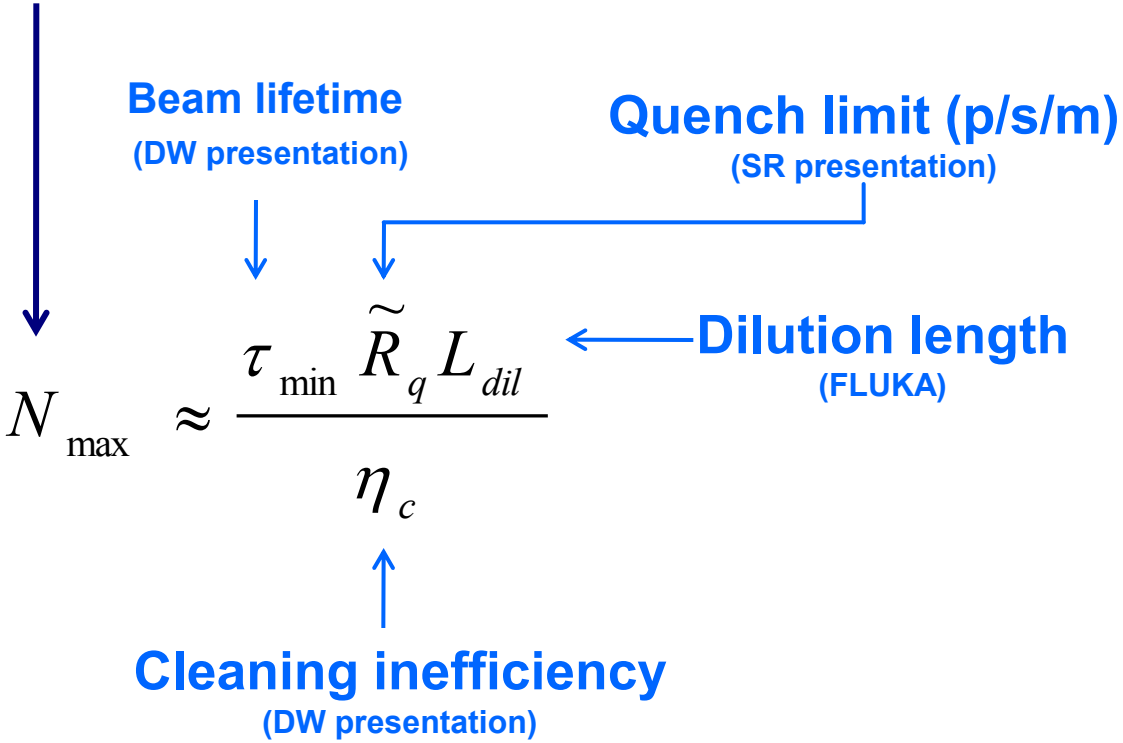
June 14th, 2011

Outline

- Performance reach from collimation
- Highlights of recent MDs :
  - Nominal collimator settings and DS quench test
- Performance reach predictions
- Description of IR3 upgrade
- Comparison between simulations and measurements
- Simulation results for IR3 combined cleaning
  - With and without DS collimators
  - With machine alignment imperfections
- Summary and conclusions

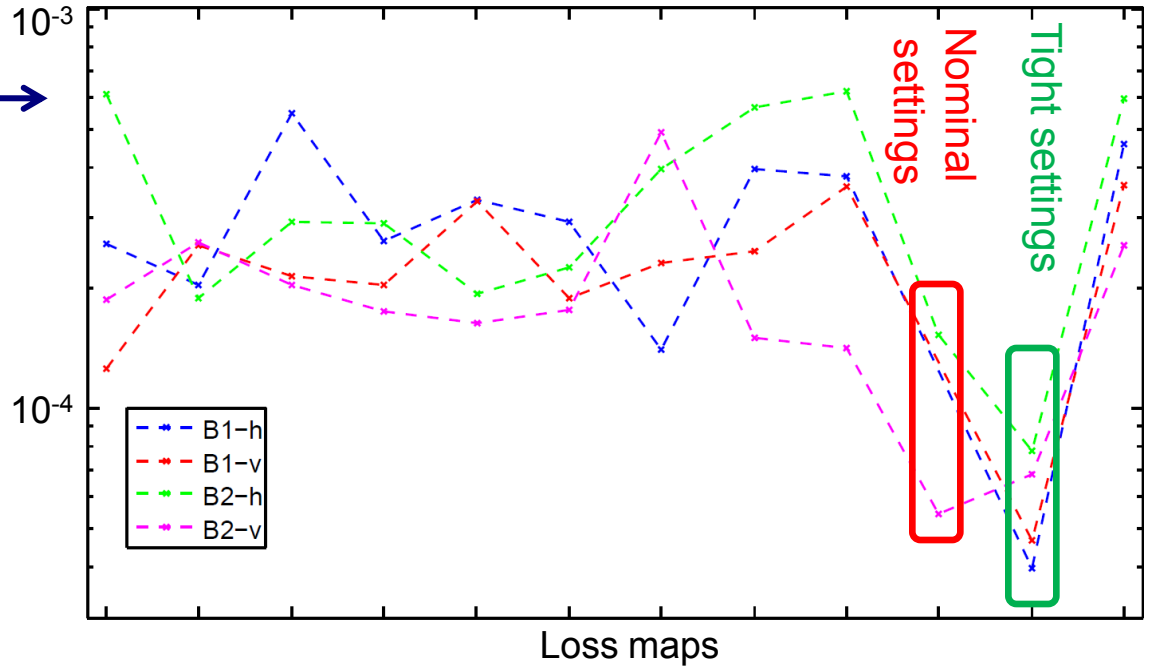
Performance reach from collimation

Maximum allowed beam intensity :



Highlights of MD on nominal collimator settings

- Local cleaning inefficiency in Q8 downstream of IR7 improved by 3 to 10 with tight settings
- New tight settings with larger retraction between primary and secondary invented on the spot to keep hierarchy



- Higher cleaning efficiency => higher intensity can be tolerated
- Smaller gaps in the whole hierarchy => a smaller aperture can be protected, and thus a smaller β* can be used

Highlights of MD on nominal collimator settings

- Local cleaning
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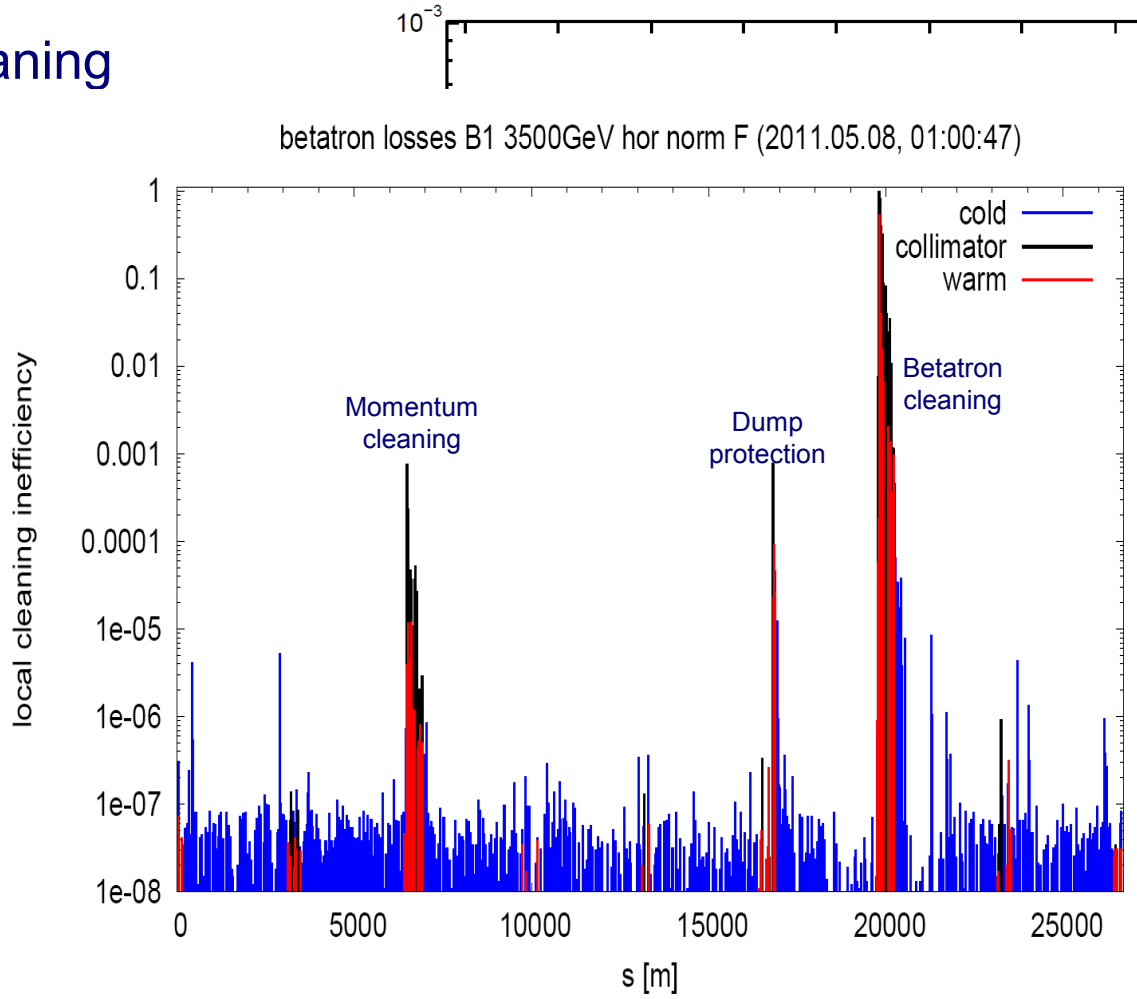

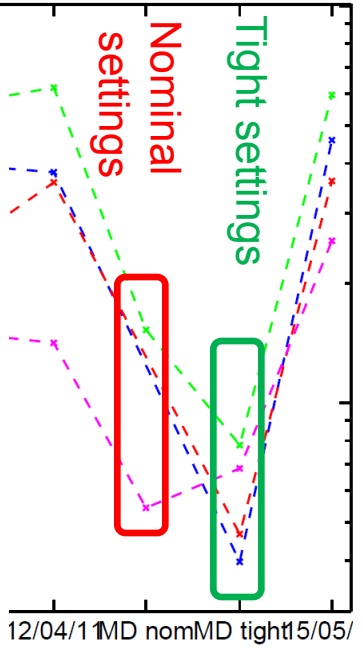

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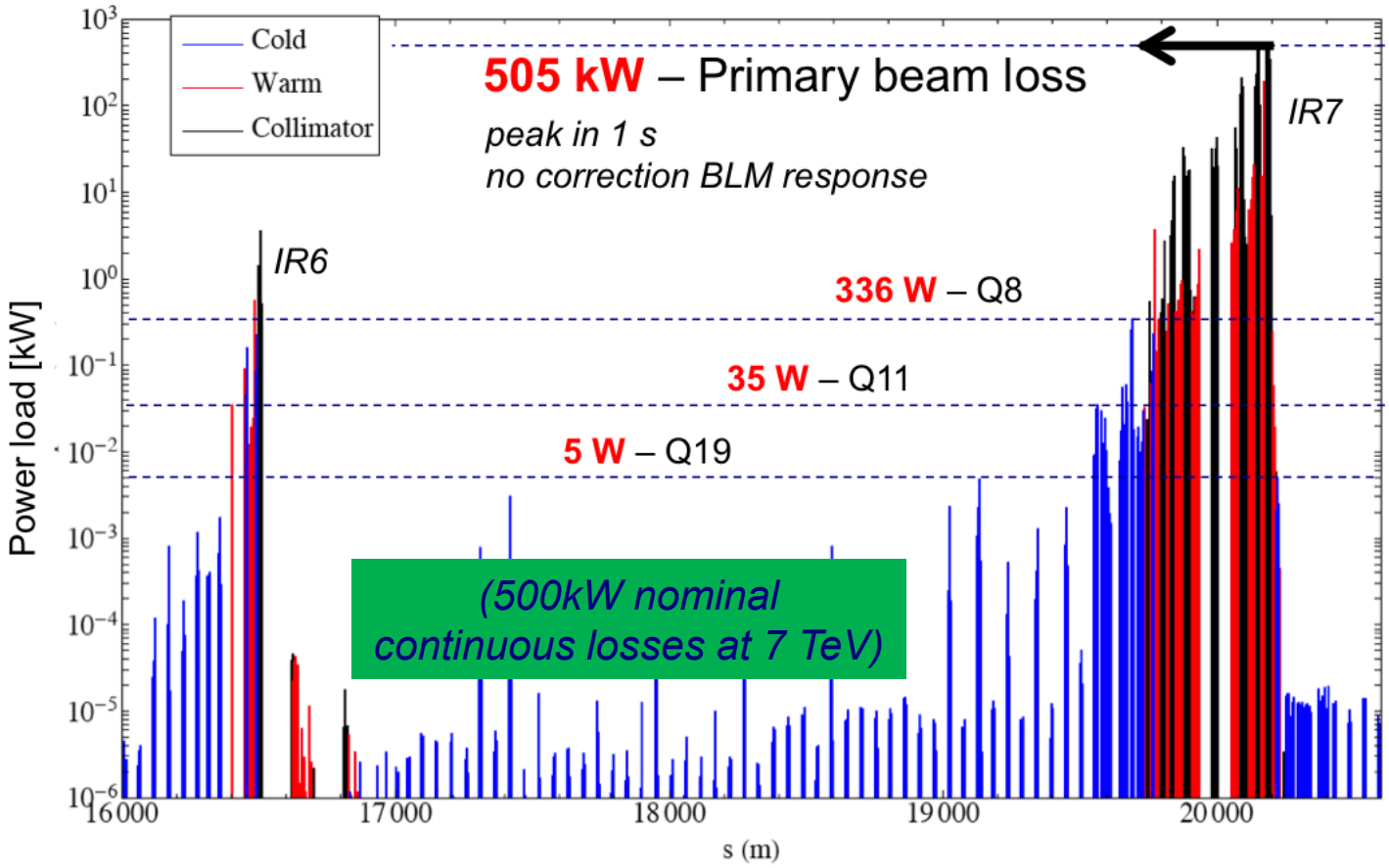
Highlights of MD on DS quench test



- 3.5 TeV operational collimator settings (not best possible)
- No magnet quenched => Either quench limit higher than expected or losses more diluted

Performance reach : predictions

Maximum allowed beam intensity

$$N_{max} \approx \frac{\tau_{min} \, \tilde{R}_q \, L_{dil}}{\eta_c}$$

- τ_{min}: **Minimum beam lifetime** (DW presentation)
- $\tilde{R}_q$: **Quench limit (p/s/m)** (SR presentation)
- L_{dil}: **Dilution length** (FLUKA)
- η_c: **Cleaning inefficiency** (DW presentation)

	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%
MD	1.56E-04	99.98%	1.22E+09	1.0	2.8E+16	0.94E+16	2900%

Cleaning efficiency: Gain factor 3.3 (MD on collimation settings)

Quench limit times dilution length: Gain factor 14.5 (MD on DS quench)

Min. lifetime: Gain factor 1.7 (2011 operation)

Performance reach : predictions

Maximum allowed beam intensity

Beam lifetime (DW presentation)

Quench limit (p/s/m) (SR presentation)

$$N_{max} \approx \frac{\tau_{min}\,\tilde{R}_q\,L_{dil}}{\eta_c}$$

Dilution length (FLUKA)

Cleaning inefficiency (DW presentation)

	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}
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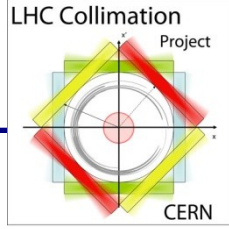
	Extrapolation to 7 TeV						
	η_{ineff}	Efficiency	$R_q\,L_{dil}$ [p/s]	τ_{min} [h]	N_{max} [p]	N_{lim} @BLM [p]	N_{lim}/N_{nom}
2010	1.30E-03	99.87%	2.71E+07	0.6	4.8E+13	1.6E+13	5%
MD							

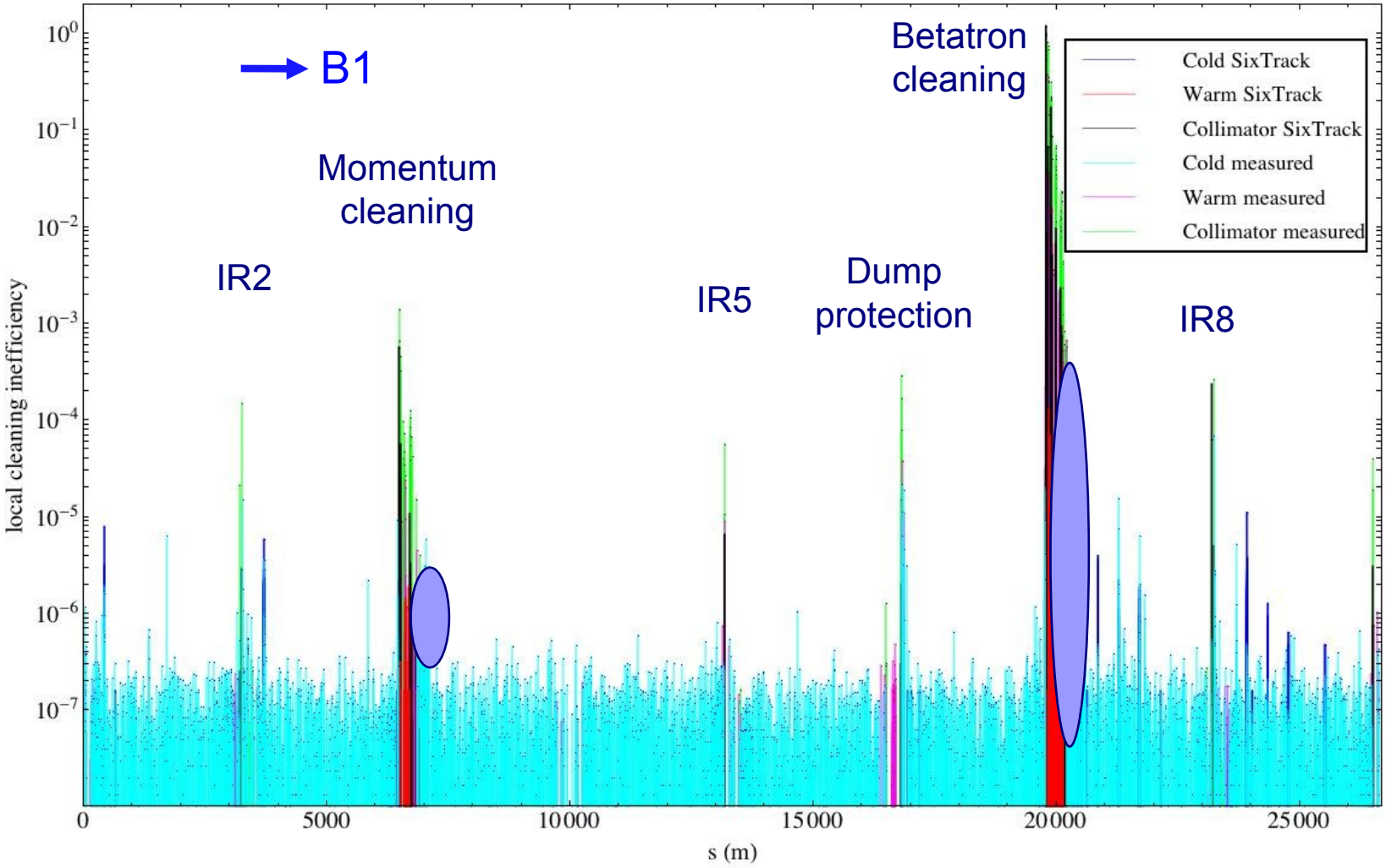
Assumptions for 7TeV extrapolation



- 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 magnets at 3.5 TeV and 7 TeV.
- Peak MD performance 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, ions, …).

Comparison simulations versus measurements

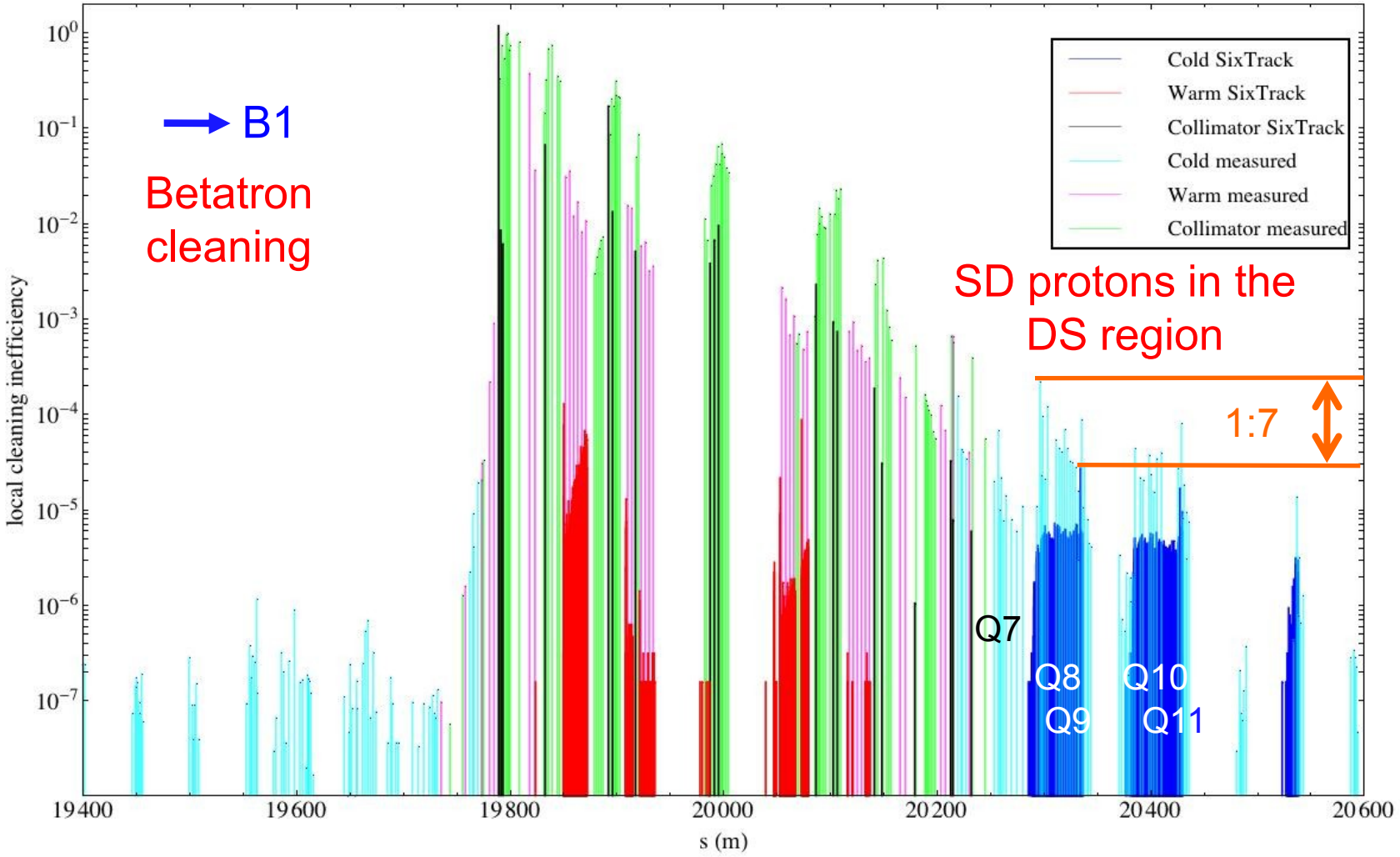
Simulations: perfect machine, B1 vertical, 3.5TeV, β*=3.5m



Comparison simulations versus measurements

Simulations: perfect machine, B1 vertical, 3.5TeV, IR7

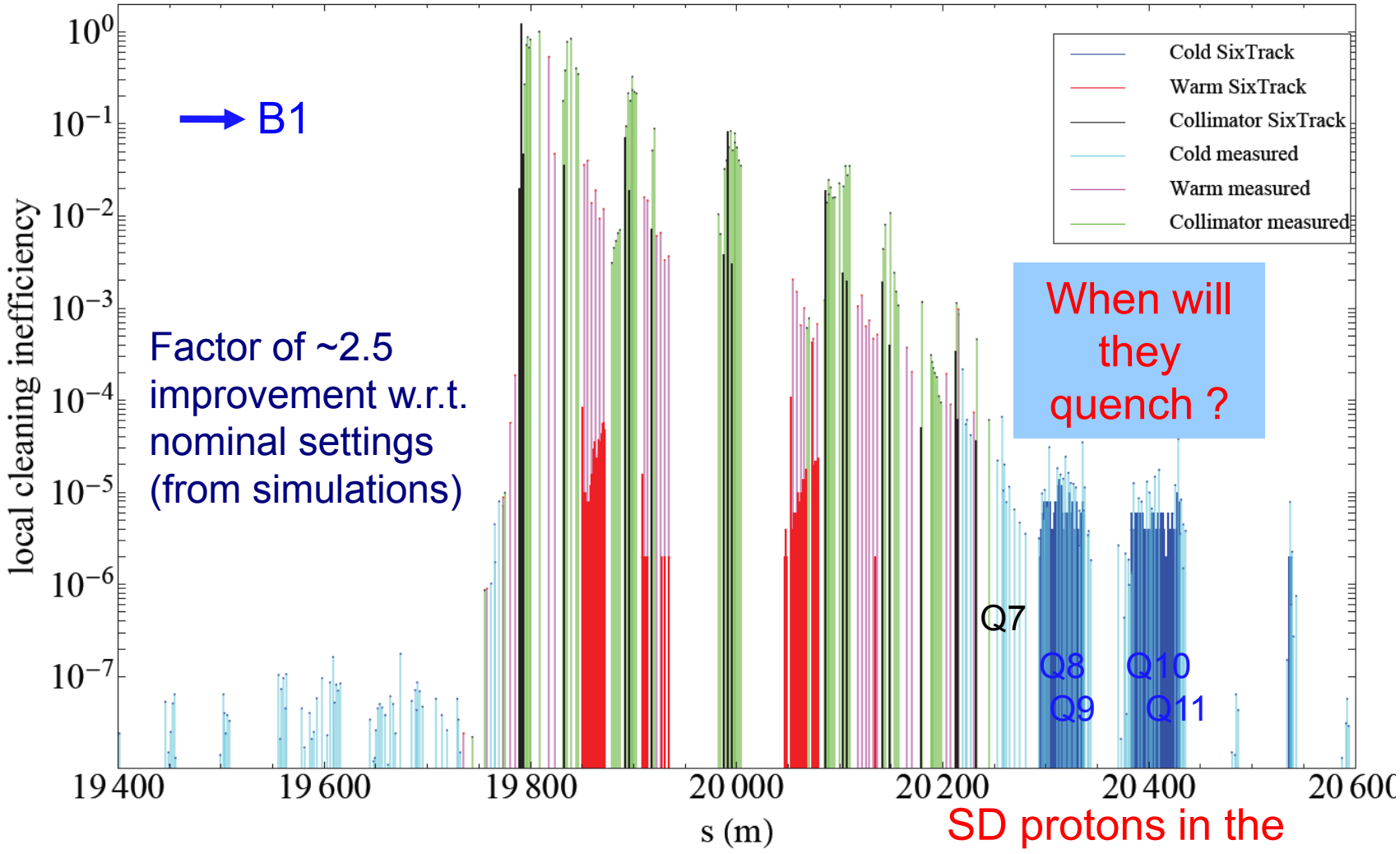
Intermediate settings



Comparison simulations versus measurements

Simulations: perfect machine, B1 vertical, 3.5TeV, IR7

Tight settings



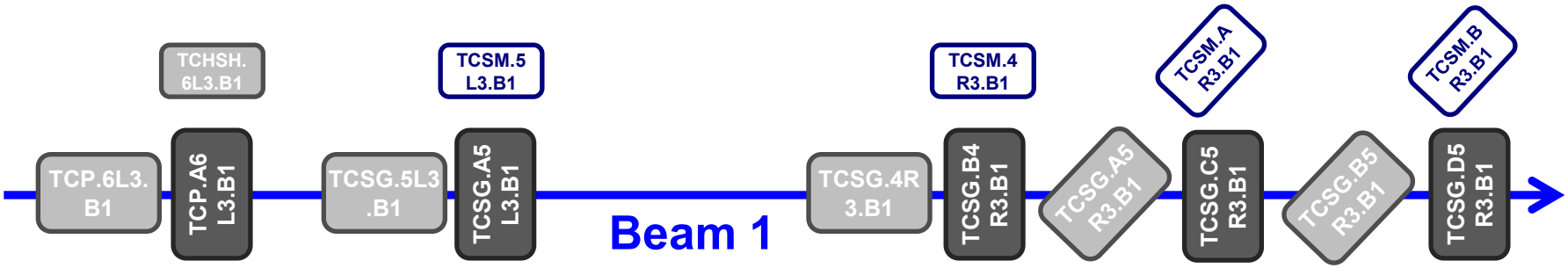
Factor of ~2.5 improvement w.r.t. nominal settings (from simulations)

When will they quench ?

SD protons in the DS region

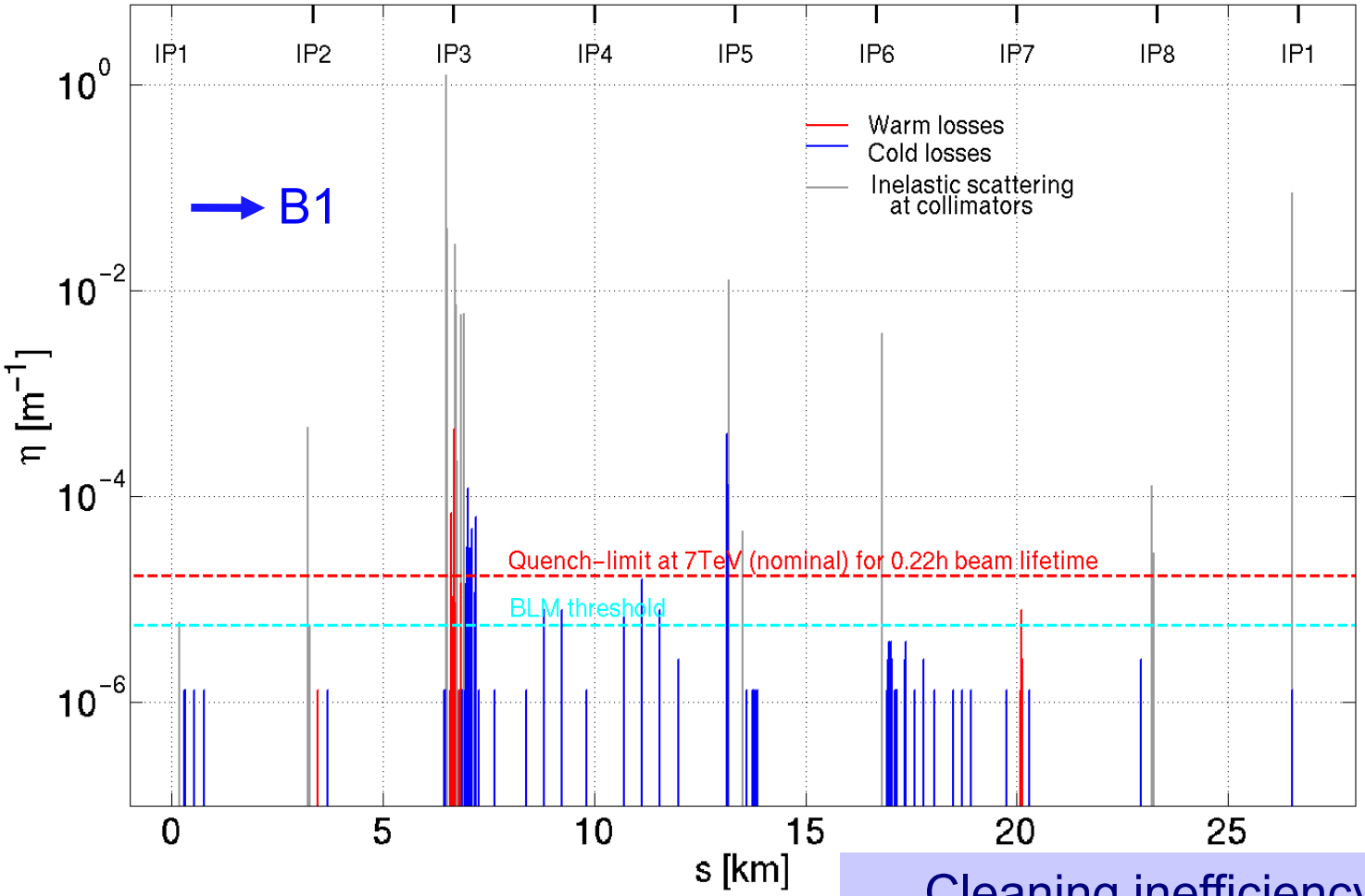
IR3 upgrade

- IR3 combined betatron / momentum cleaning



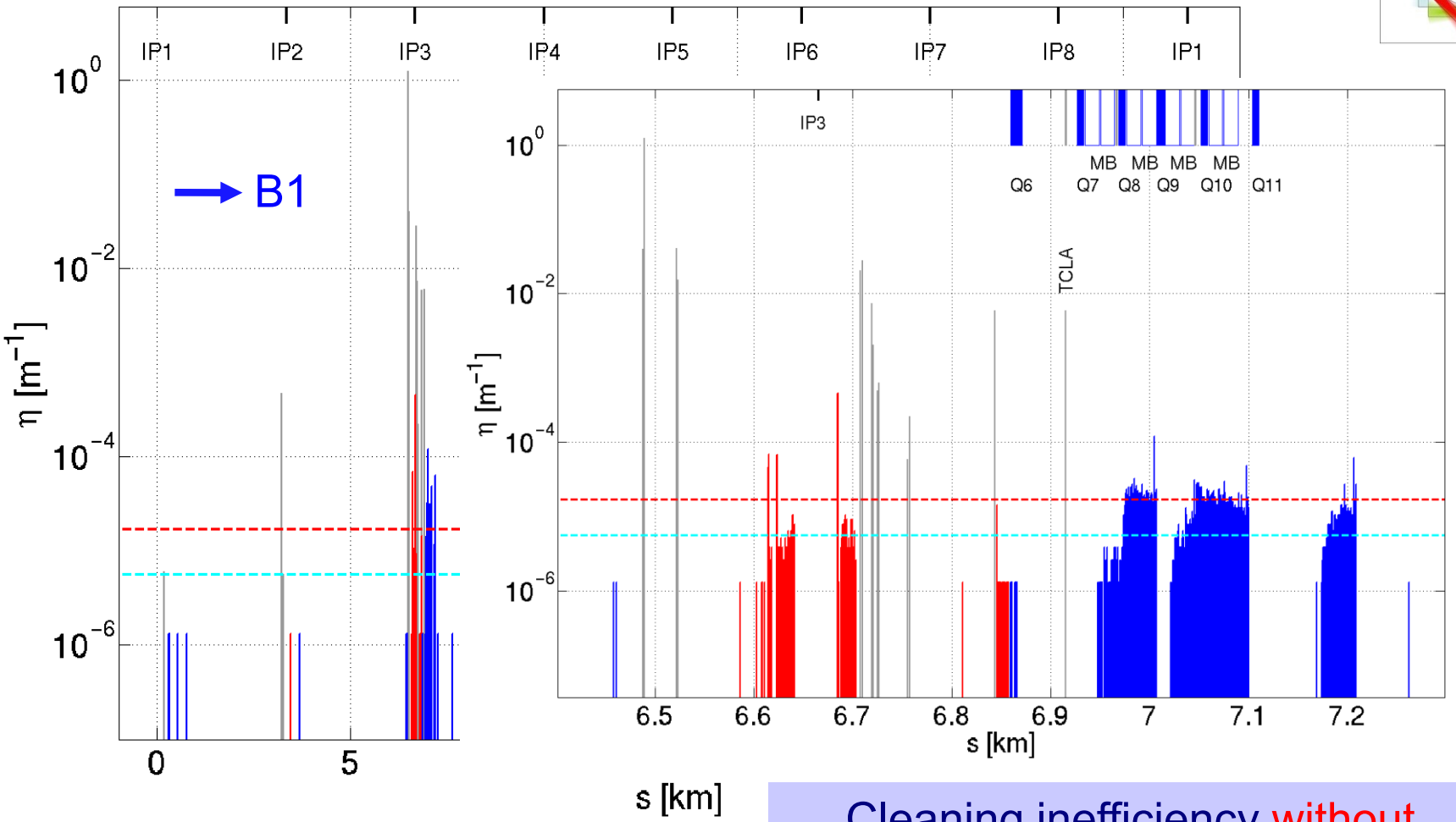
- Graphite collimators replacing TCHSH and phase 2.
- R2E:
  - Super Conducting link cables in IR3 OK for 500 kW losses at primary collimators (nominal). Maybe require additional passive absorbers.
  - Limitations with Single Event Upset in IR7 are avoided as losses are relocated to IR3 (100 times less radiation to electronics for same beam loss in IR3).
- Operations:
  - LHC collimation with 28 collimators less than now ➔ faster setup and lower impedance (20 TCP/TCS instead of 38 TCP/TCS)
  - System in IR7 would be kept operational ➔ larger flexibility to react to limitations + spares

Simulation results for IR3 combined cleaning, vertical



Cleaning inefficiency without DS collimator. Simulation at 7TeV, vertical sheet beam 1

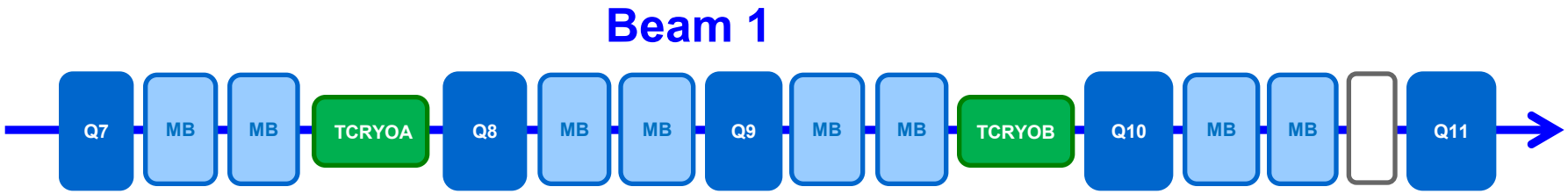
Simulation results for IR3 combined cleaning, vertical



Cleaning inefficiency without DS collimator. Simulation at 7TeV, vertical sheet beam 1

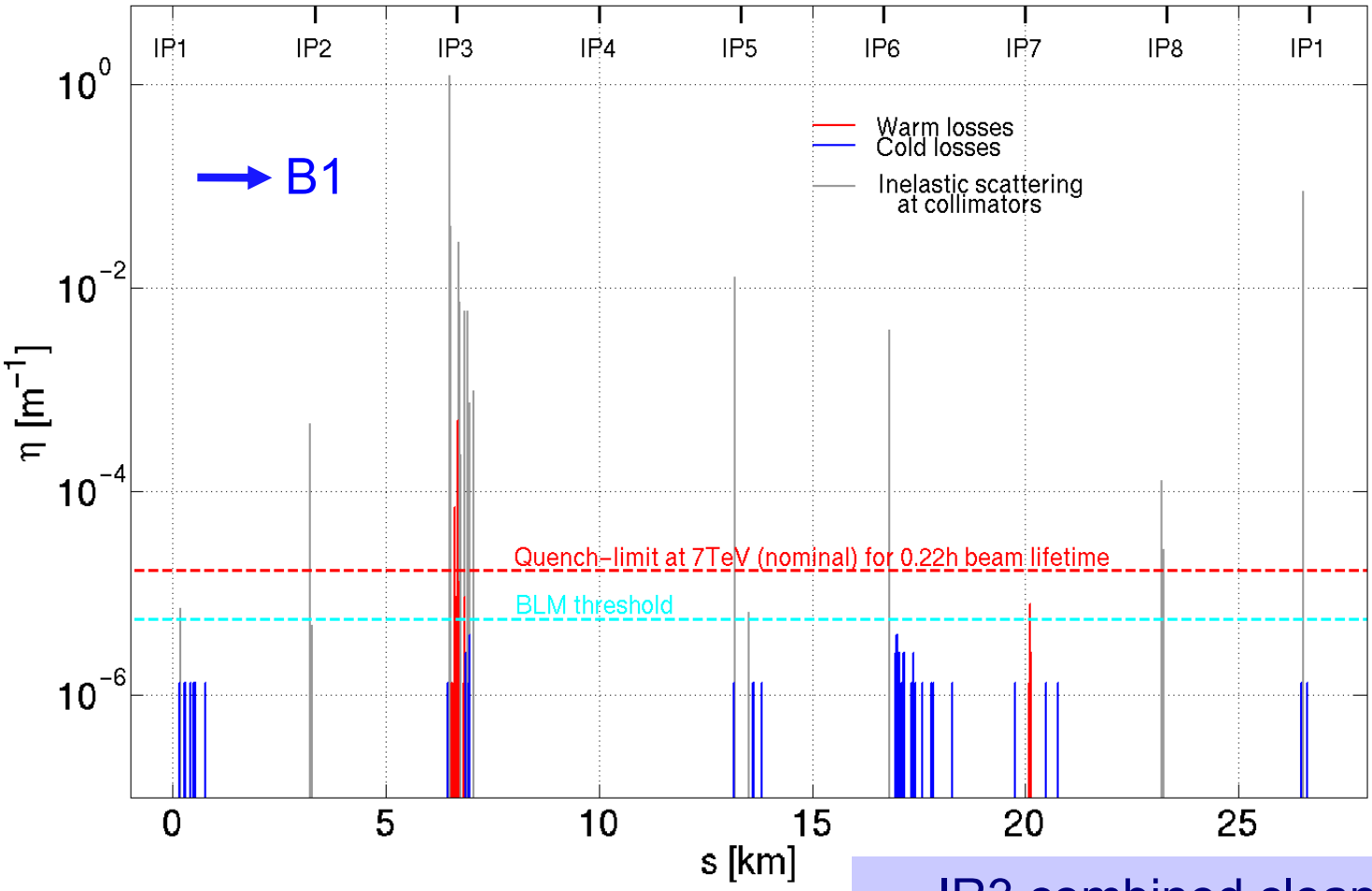
IR3 upgrade

- DS3 collimators (present solution at RT)



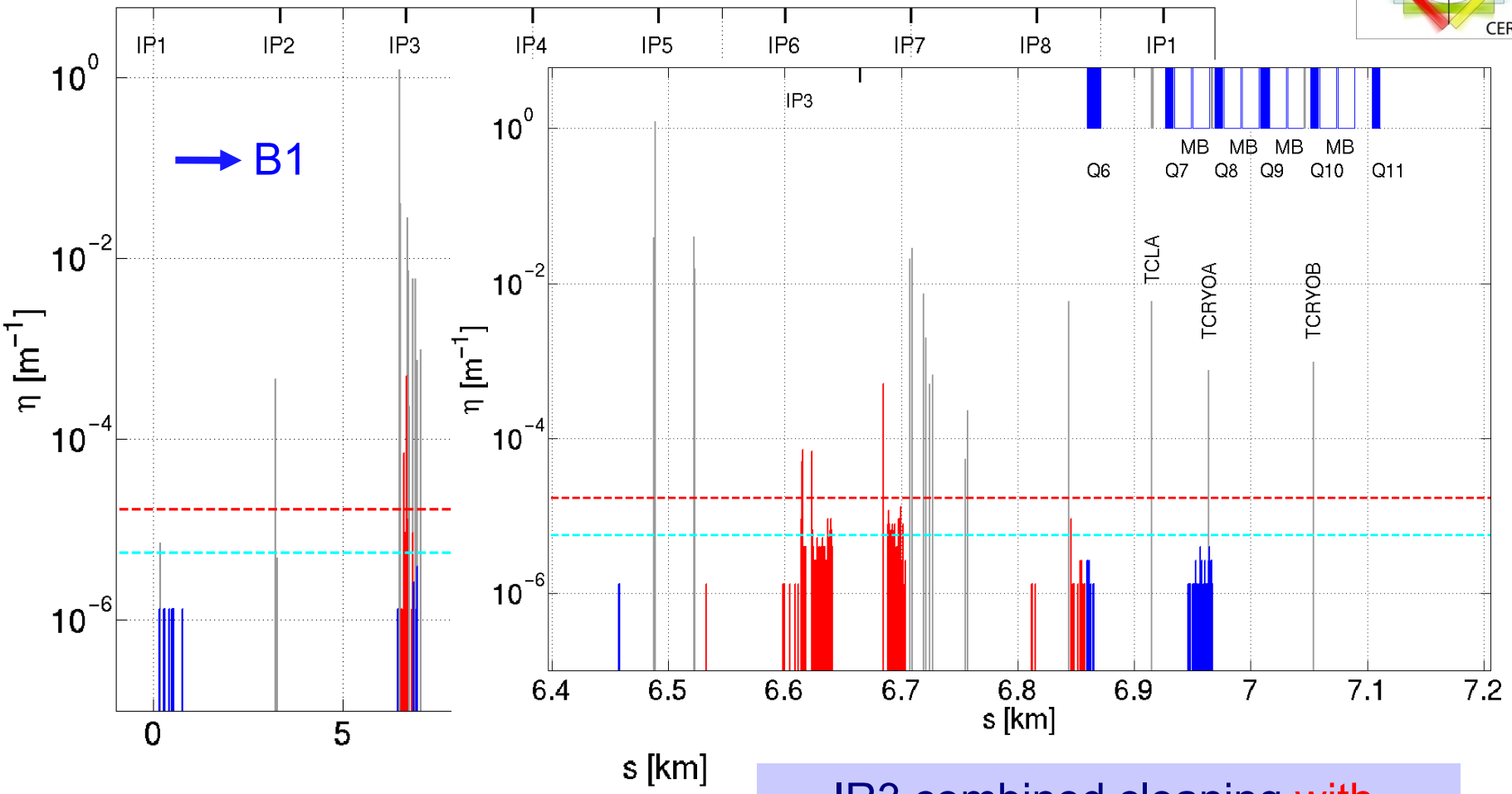
  - Tungsten collimators in front of Q8 and Q10 to catch off momentum particles (from Single Diffractive scattering at collimators, from collisions …) at high dispersion regions

Cleaning inefficiency with DS collimators



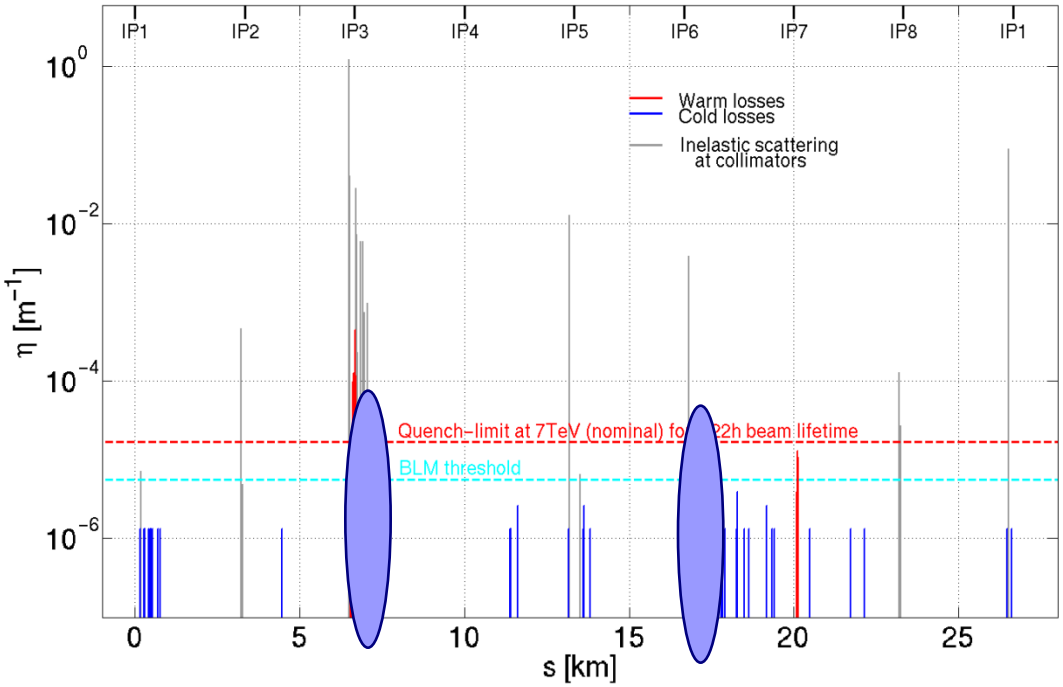
IR3 combined cleaning with DS collimator at 15 σ.
7TeV, vertical sheet beam 1

Cleaning inefficiency with DS collimators



IR3 combined cleaning with DS collimator at 15 σ.
7TeV, vertical sheet beam 1

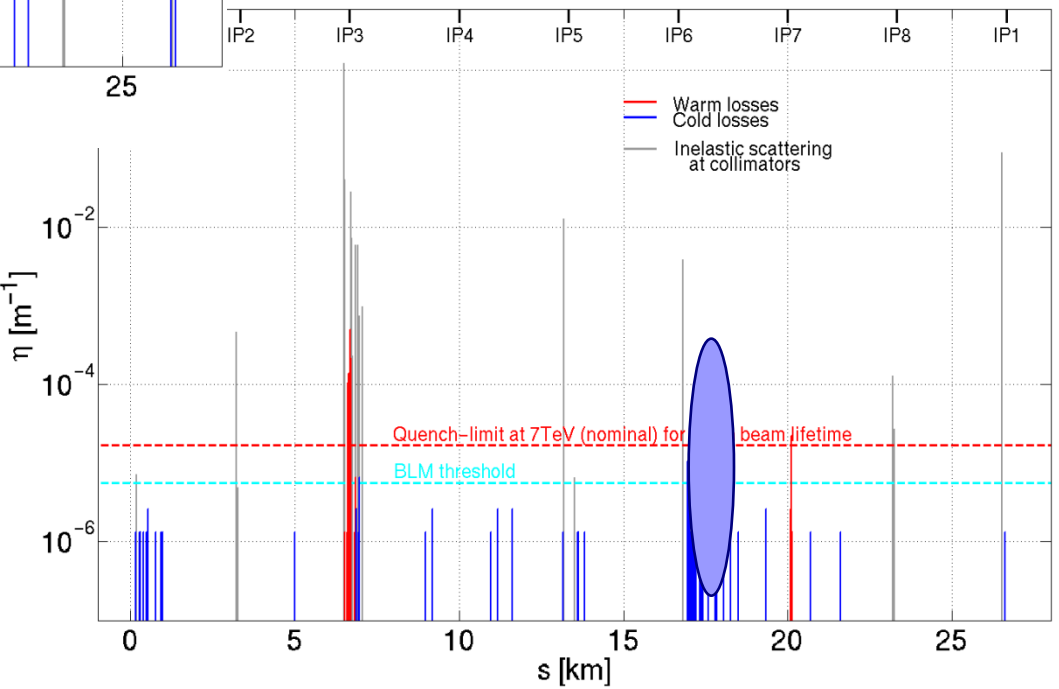
Cleaning inefficiency with machine alignment imperfections



RMS offsets (measured) in the horizontal and vertical planes defined for families of elements.

10 cases studies

DS collimator at 15 σ.
7TeV, vertical sheet beam 1,
Studies with aperture imperfections



H plane (DS collimators) : no impact of imperfections.

V plane (no DS collimators): lose a factor of 7 to 8 in inefficiency as before.

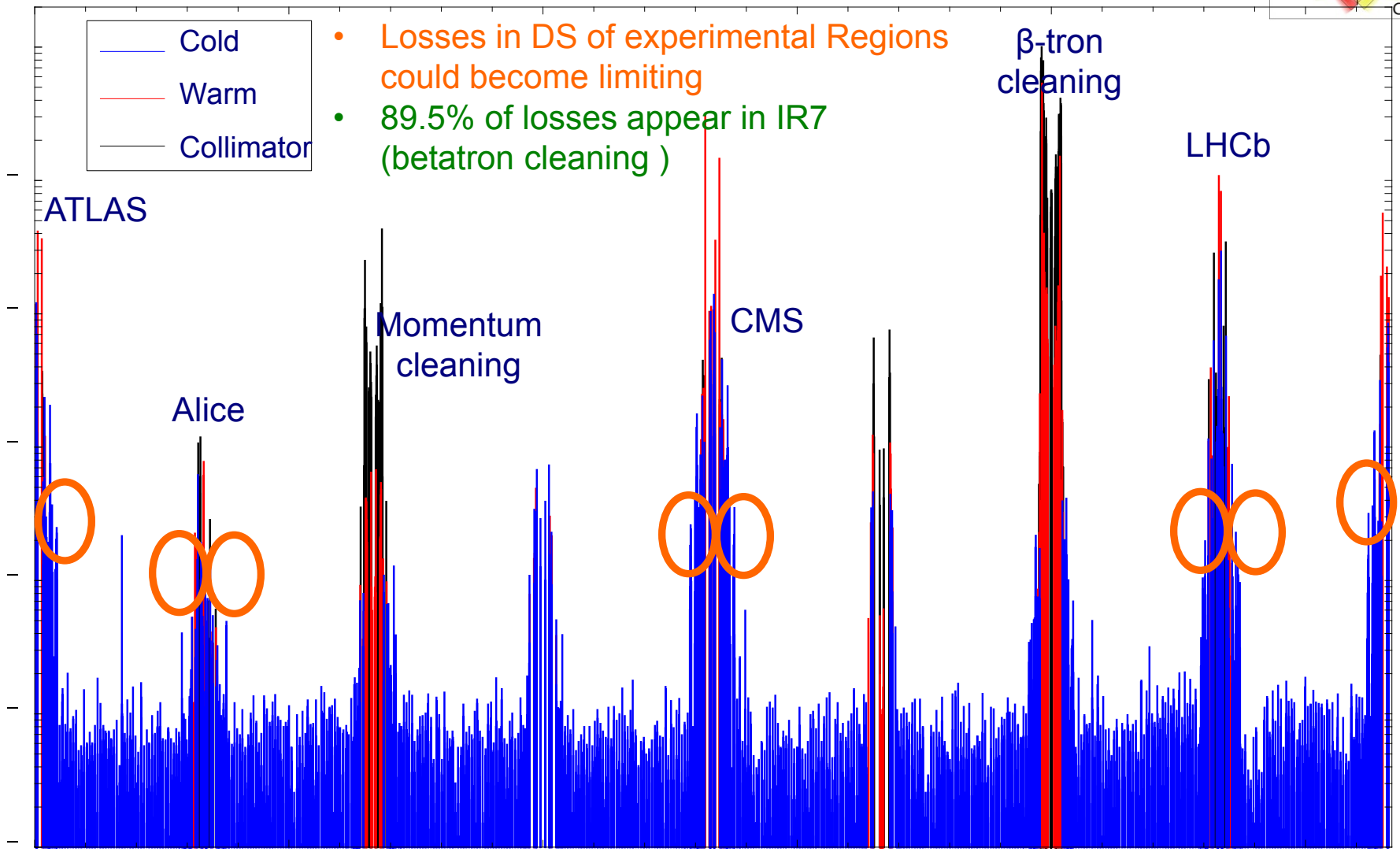
Preliminary results

Summary and conclusions

- Present system (IR7) : ~4 times nominal intensity if extrapolation correct.
- IR3 combined cleaning (without DS collimators)
  - Improves R2E, reduces setup time, increases flexibility (IR7 still operational).
  - Performance ~5 times worse than present: 80% nominal if IR7 limited by R2E.
  - MD measurements yet to be carried out.
  - Higher leakage predicted in the experimental regions.
- IR3 combined cleaning (with DS collimators):
  - Gain factor > 10 → factor ~ 8 margin for nominal intensity in 2014.
  - Efficiency becomes independent of imperfections (in the H plane). The V plane is sensitive to imperfections (no DS collimator).
- BUT work close to limit:
  - No efficiency margin.
  - No operational margin.
  - No margin to open for impedance.
- Can we assume the same performance of the LHC at 7 TeV (lifetimes, loss locations and dilution, scaling of inefficiency and quench limit, …)?

BACKUP slides

Measured losses during stable beams 1092 b



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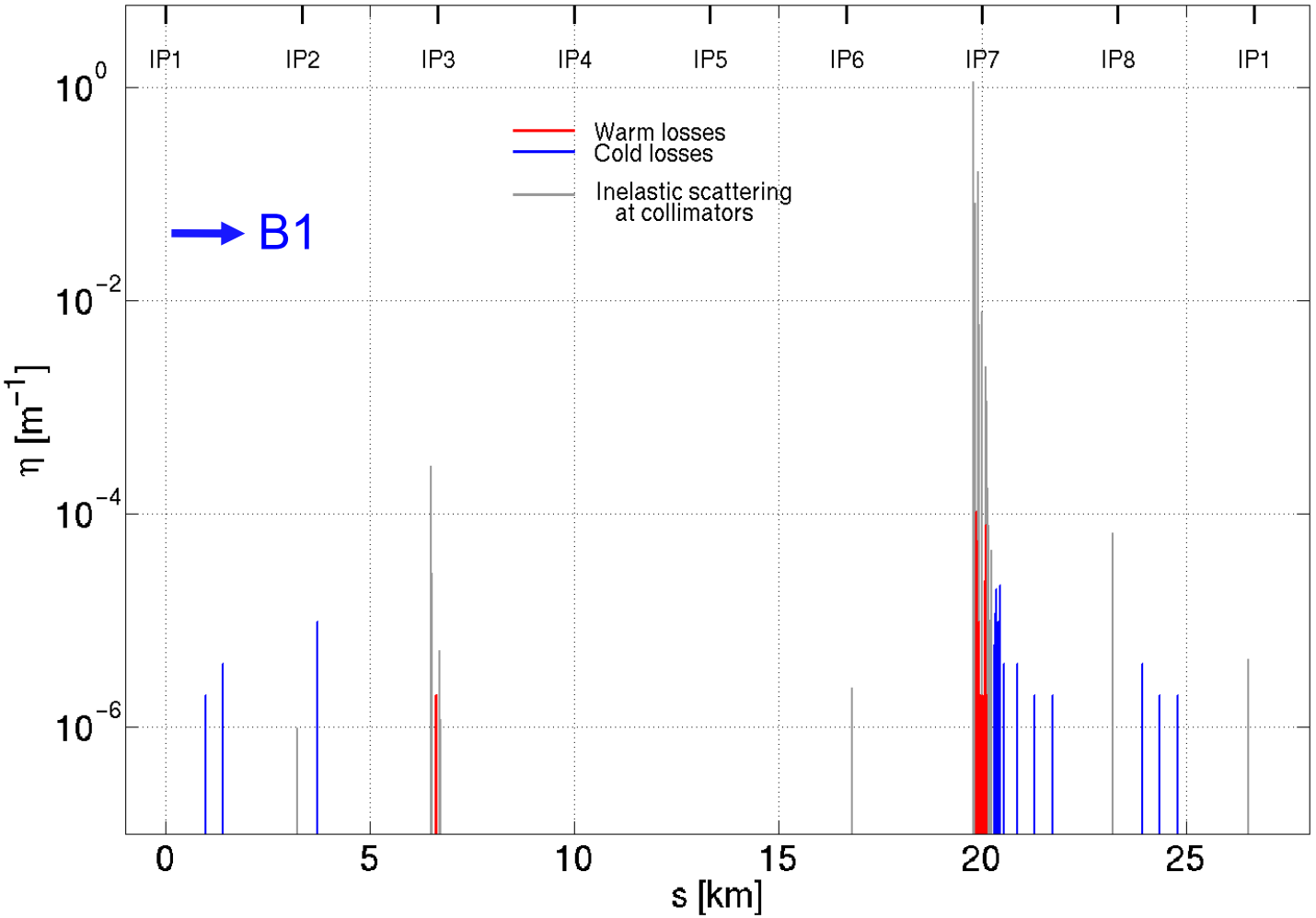
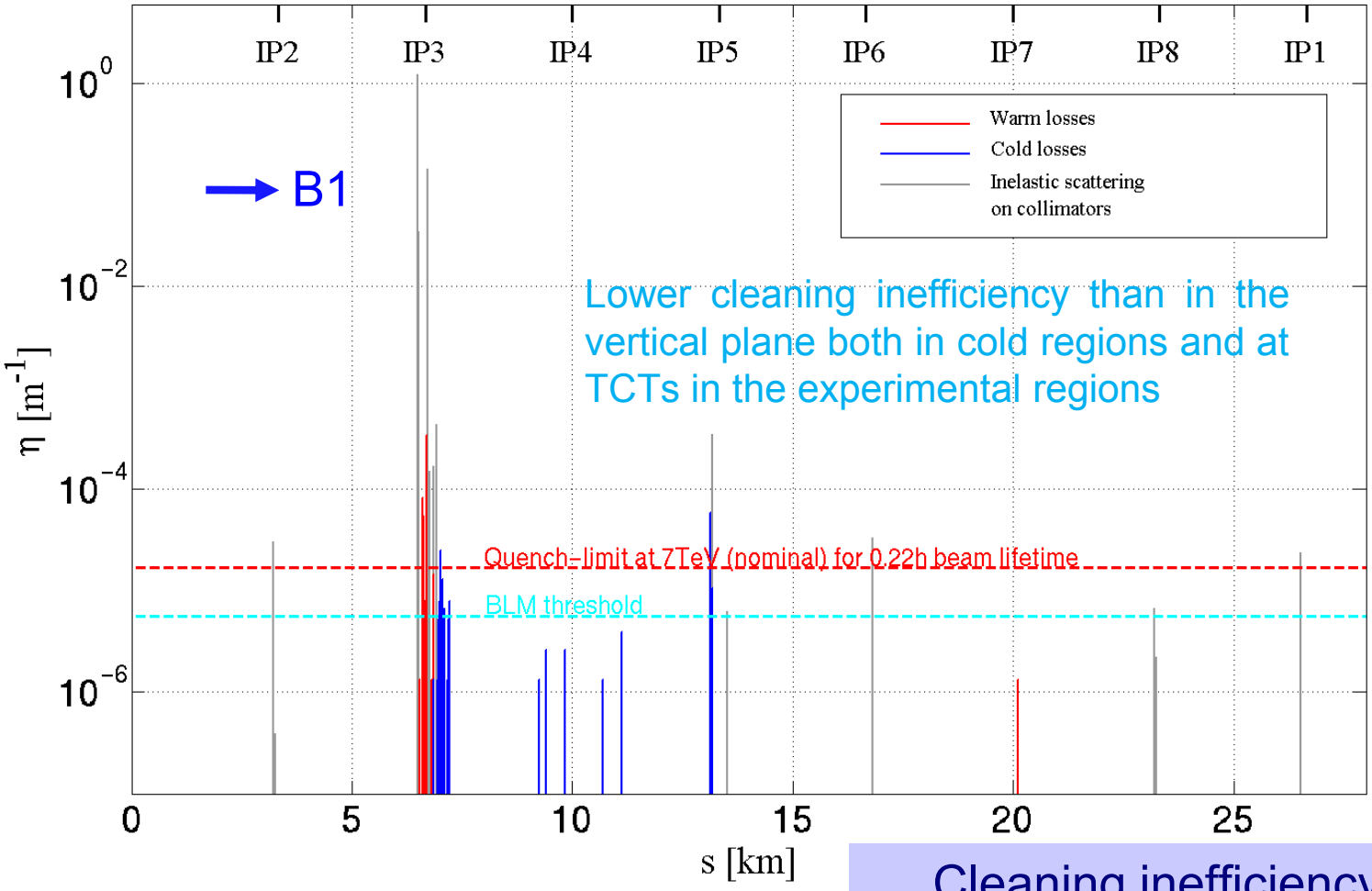
Present machine, tight settings, vertical (TCT 26sigma)

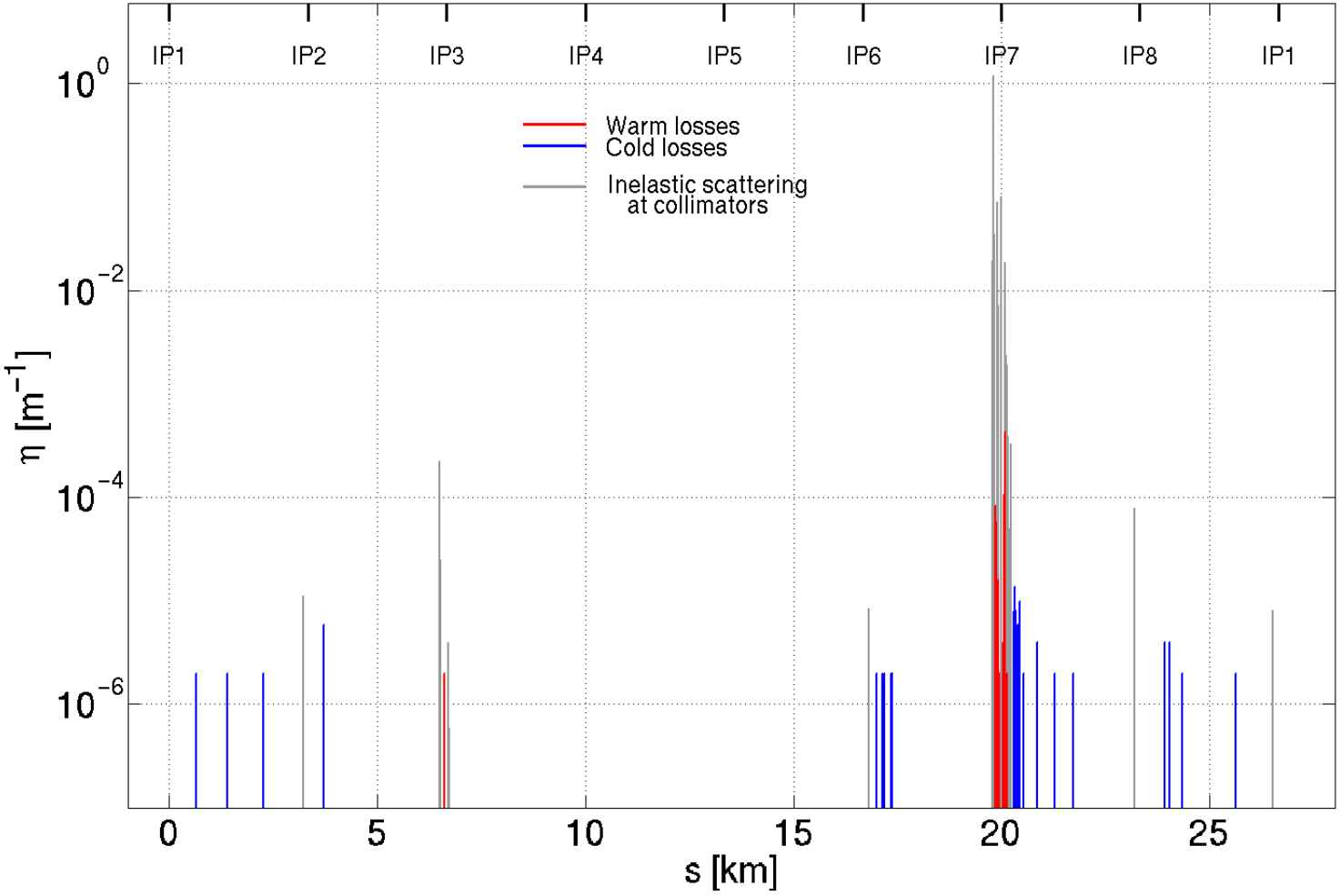


Simulation results for IR3 combined cleaning, horizontal

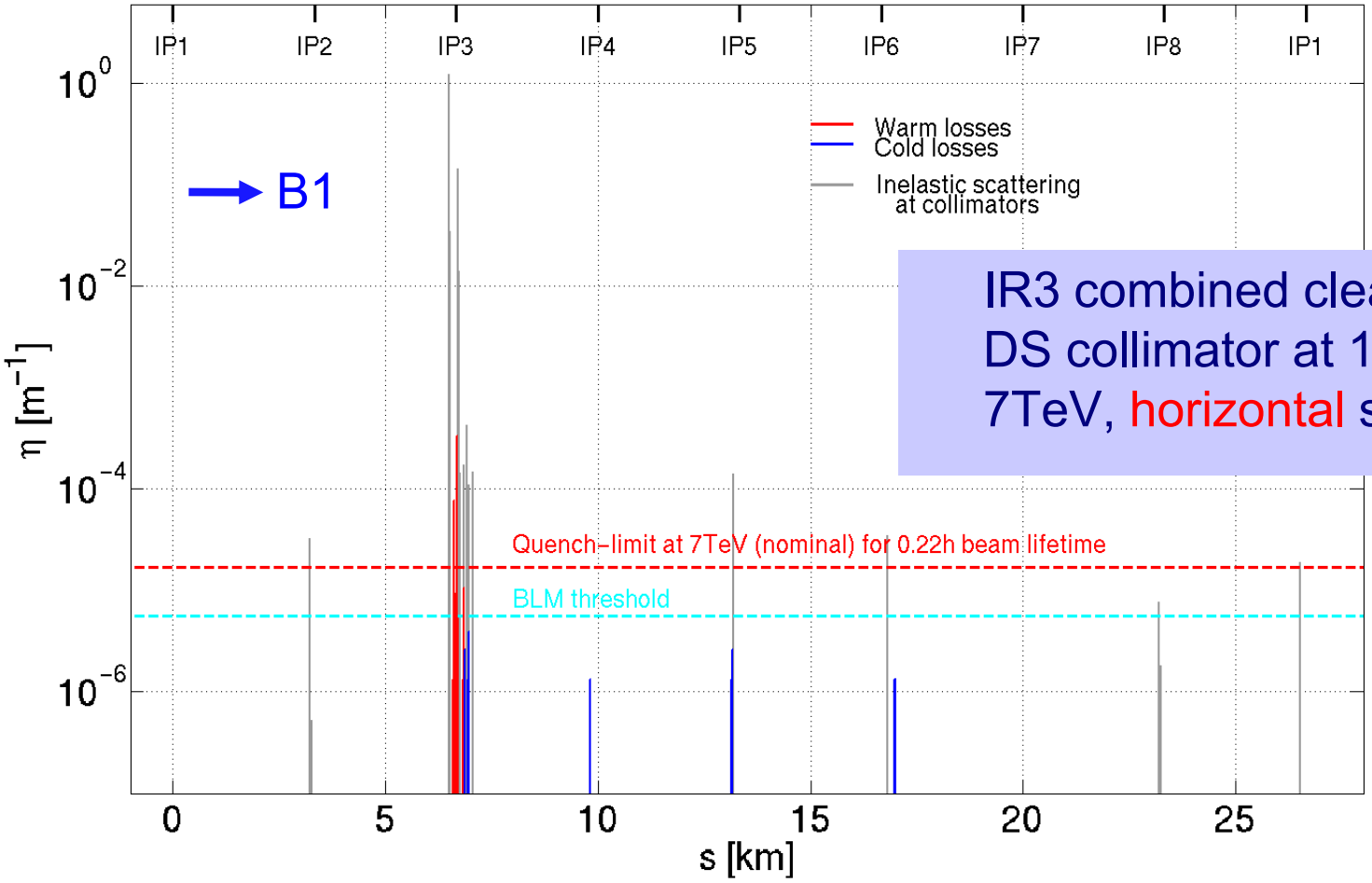


Cleaning inefficiency without DS collimator. Simulation at 7TeV, horizontal sheet beam 1

Present machine, tight settings, horizontal



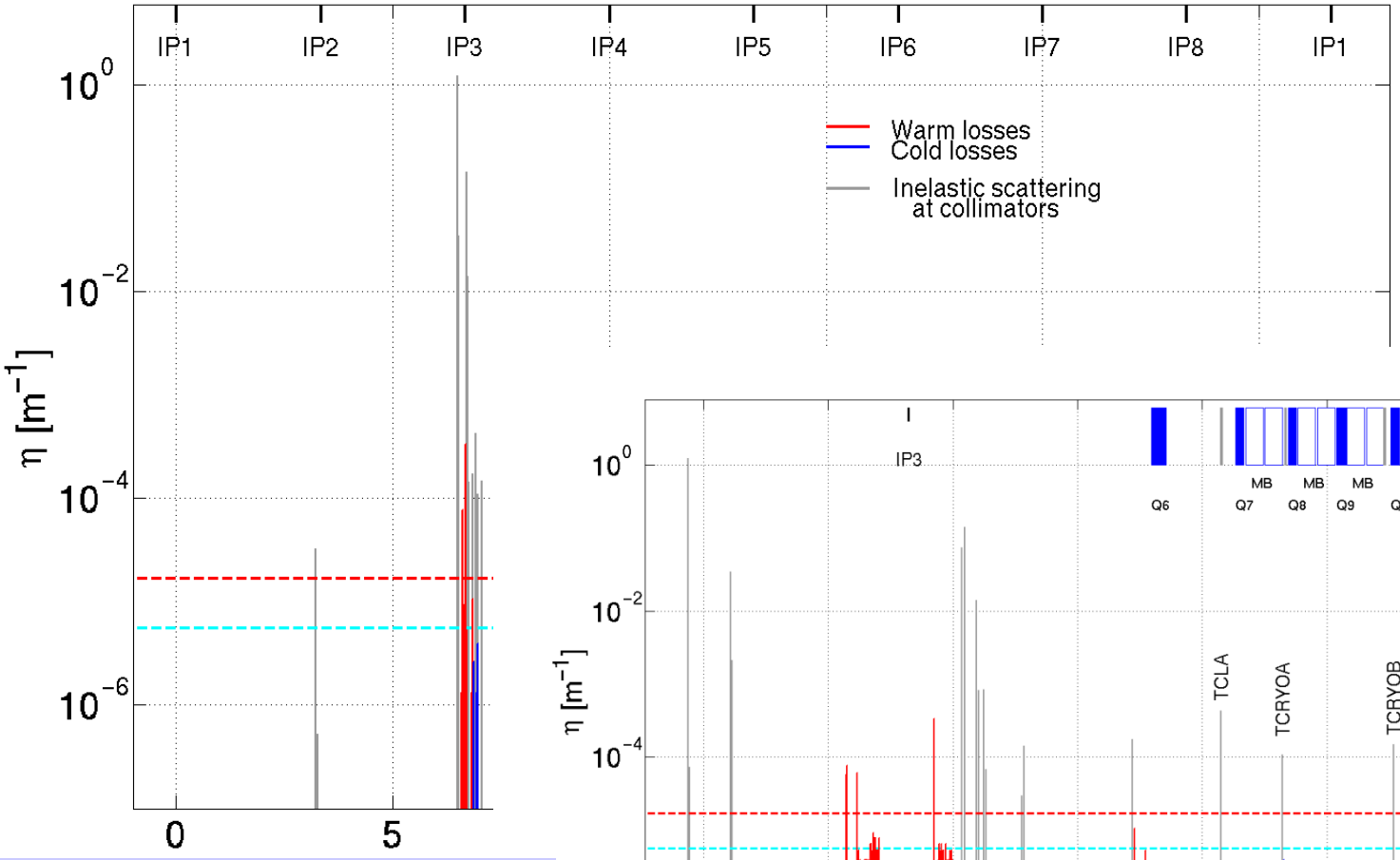
Cleaning inefficiency with DS collimators



IR3 combined cleaning with DS collimator at 15 σ.
7TeV, horizontal sheet beam 1

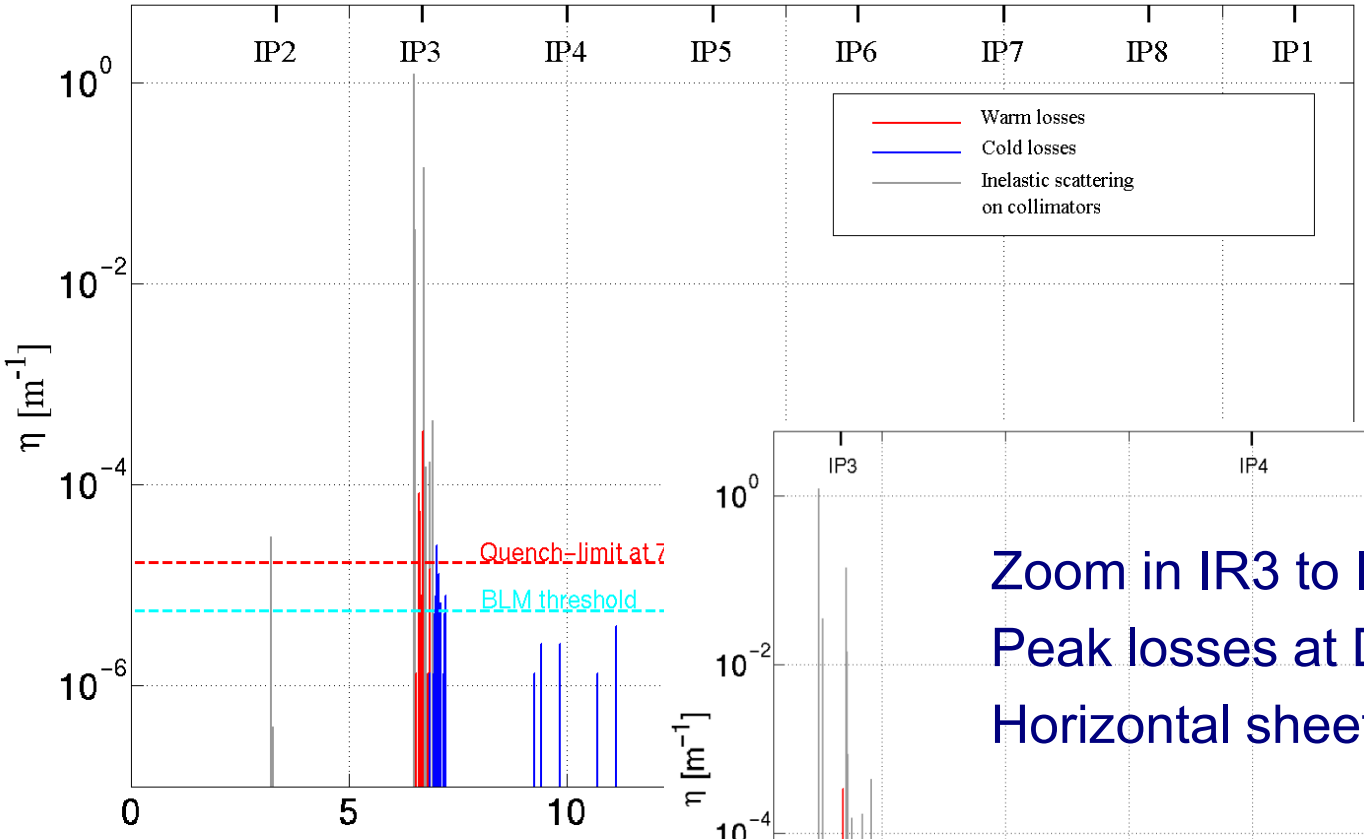
Machine alignment imperfections worsen performance by max. a factor of ~ 2
(over 10 cases studied)

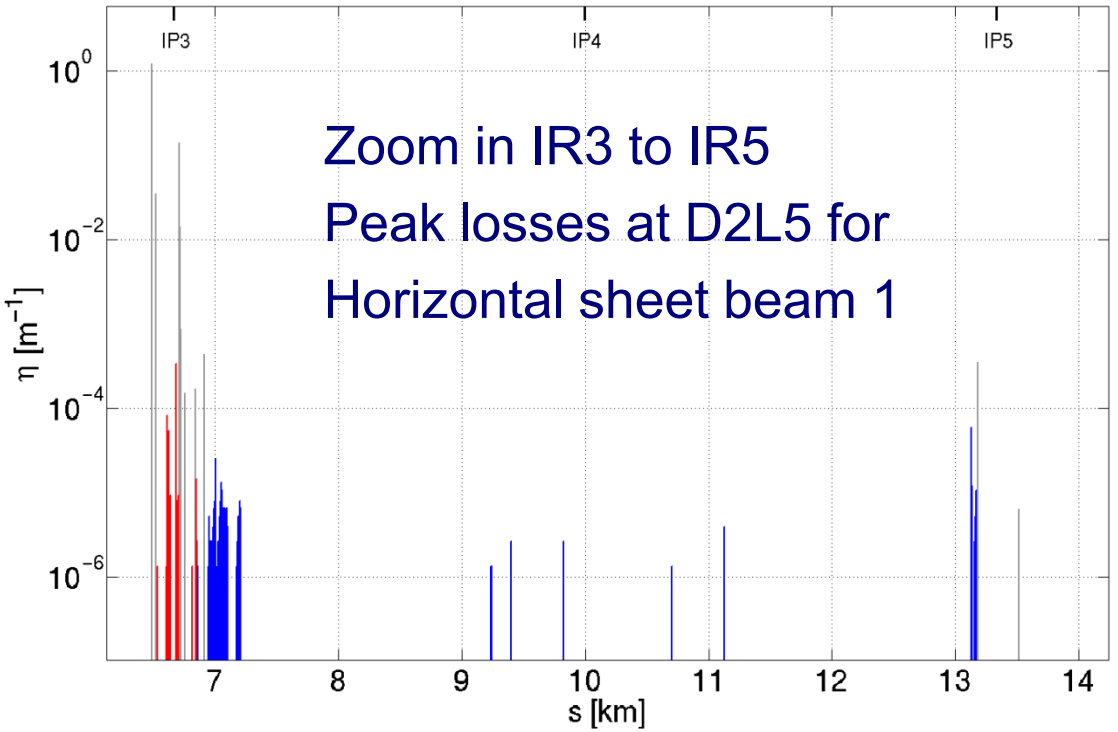
Cleaning inefficiency with and without DS collimators



Zoom in IR3
7TeV, horizontal
sheet beam 1

Cleaning inefficiency with and without DS collimators





Zoom in IR3 to IR5

Peak losses at D2L5 for Horizontal sheet beam 1

Intermediate settings at 3.5 TeV, beam1

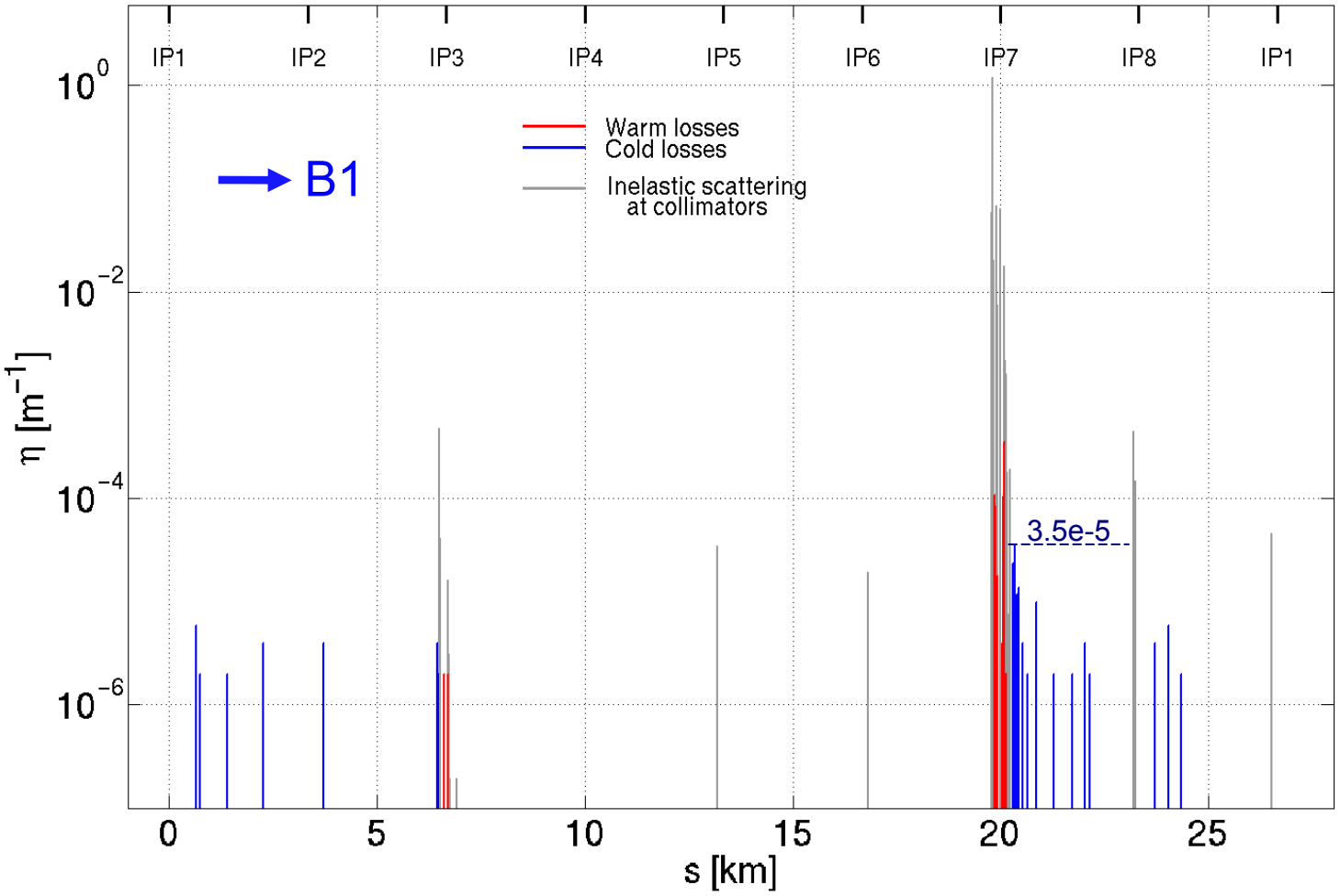
name		Material	Length[m]	nsig	halfgap[mm]	betax[m]	betay[m]
TCL.5R1.B1	hor	CU	1.00	-	open	73.525	360.65
TCTH.4L2.B1	hor	W	1.00	26.00	7.28	77.917	90.428
TDI.4L2.B1	ver	CU	4.00	-	open	138.58	87.798
TCTVB.4L2	ver	W	1.00	26.00	7.86	155.16	91.013
TCLIA.4R2	ver	C	1.00	-	open	89.858	149.7
TCLIB.6R2.B1	ver	C	1.00	-	open	176.59	74.453
TCP.6L3.B1	hor	C	0.60	12.00	4.36	131.52	144.7
TCSG.5L3.B1	hor	C	1.00	15.60	3.66	54.607	298.63
TCSG.4R3.B1	hor	C	1.00	15.60	2.53	26.211	395.17
TCSG.A5R3.B1	skw	C	1.00	15.60	3.27	35.868	344.08
TCSG.B5R3.B1	skw	C	1.00	15.60	3.70	45.538	312.65
TCLA.A5R3.B1	ver	W	1.00	17.60	7.40	142.52	176
TCLA.B5R3.B1	hor	W	1.00	17.60	6.87	151.61	168.67
TCLA.6R3.B1	hor	W	1.00	17.60	6.35	129.42	168.7
TCLA.7R3.B1	hor	W	1.00	17.60	4.54	66.234	96.901
TCTH.4L5.B1	hor	W	1.00	11.80	9.04	584.21	225.66
TCTVA.4L5.B1	ver	W	1.00	11.80	5.77	586.15	237.79
TCL.5R5.B1	hor	CU	1.00	-	open	73.654	361.76
TCDQA.A4R6.B	hor	C	3.00	9.80	6.90	493.7	167.94
TCDQA.B4R6.B	hor	C	3.00	9.80	6.98	504.79	172.21
TCSG.4R6.B1	hor	C	1.00	9.30	6.71	517.2	177.14
TCP.D6L7.B1	ver	C	0.60	5.70	1.60	158.87	78.263
TCP.C6L7.B1	hor	C	0.60	5.70	2.22	150.53	82.763
TCP.B6L7.B1	skw	C	0.60	5.70	1.87	142.46	87.488
TCSG.A6L7.B1	skw	C	1.00	8.80	2.97	39.872	226.93
TCSG.B5L7.B1	skw	C	1.00	8.80	3.55	159.98	166.51
TCSG.A5L7.B1	skw	C	1.00	8.80	3.63	185.96	145.93
TCSG.D4L7.B1	ver	C	1.00	8.80	2.32	332.92	68.864
TCSG.B4L7.B1	hor	C	1.00	8.80	3.30	139.75	130.98
TCSG.A4L7.B1	skw	C	1.00	8.80	3.24	128.66	141.28
TCSG.A4R7.B1	skw	C	1.00	8.80	3.25	118.28	152.21
TCSG.B5R7.B1	skw	C	1.00	8.80	3.73	121.85	267.55
TCSG.D5R7.B1	skw	C	1.00	8.80	3.74	213.87	158.53
TCSG.E5R7.B1	skw	C	1.00	8.80	3.75	241.4	136.1
TCSG.6R7.B1	skw	C	1.00	8.80	5.11	335.75	47.359
TCLA.A6R7.B1	ver	W	1.00	17.70	3.89	297.06	48.158
TCLA.B6R7.B1	hor	W	1.00	17.70	7.09	159.49	76.391
TCLA.C6R7.B1	ver	W	1.00	17.70	6.92	68.608	151.89
TCLA.D6R7.B1	hor	W	1.00	17.70	4.53	65.041	157.92
TCLA.A7R7.B1	hor	W	1.00	17.70	4.50	64.255	147.41
TCTH.4L8.B1	hor	W	1.00	11.80	5.81	241.35	302.67
TCTVB.4L8	ver	W	1.00	11.80	6.85	536.73	335.57
TCTH.4L1.B1	hor	W	1.00	11.80	9.04	584.21	225.66
TCTVA.4L1.B1	ver	W	1.00	11.80	5.77	586.15	237.79

Tight settings at 3.5 TeV MD, beam 1

name		Material	Length[m]	nsig	halfgap[mm]		betax[m]	betay[m]
TCL.5R1.B1	hor	CU		1.00	999.00	open	7.35E+01	3.61E+02
TCTH.4L2.B1	hor	W		1.00	26.00	7.28	7.79E+01	9.04E+01
TDI.4L2.B1	ver	CU		4.00	999.00	open	1.39E+02	8.78E+01
TCTVB.4L2	ver	W		1.00	26.00	7.86	1.55E+02	9.10E+01
TCLIA.4R2	ver	C		1.00	999.00	open	8.99E+01	1.50E+02
TCLIB.6R2.B1	ver	C		1.00	999.00	open	1.77E+02	7.45E+01
TCP.6L3.B1	hor	C		0.60	12.00	4.36	1.32E+02	1.45E+02
TCSG.5L3.B1	hor	C		1.00	15.60	3.66	5.46E+01	2.99E+02
TCSG.4R3.B1	hor	C		1.00	15.60	2.53	2.62E+01	3.95E+02
TCSG.A5R3.B1	skw	C		1.00	15.60	3.27	3.59E+01	3.44E+02
TCSG.B5R3.B1	skw	C		1.00	15.60	3.70	4.55E+01	3.13E+02
TCLA.A5R3.B1	ver	W		1.00	17.60	7.40	1.43E+02	1.76E+02
TCLA.B5R3.B1	hor	W		1.00	17.60	6.87	1.52E+02	1.69E+02
TCLA.6R3.B1	hor	W		1.00	17.60	6.35	1.29E+02	1.69E+02
TCLA.7R3.B1	hor	W		1.00	17.60	4.54	6.62E+01	9.69E+01
TCTH.4L5.B1	hor	W		1.00	26.00	19.93	5.84E+02	2.26E+02
TCTVA.4L5.B1	ver	W		1.00	26.00	12.71	5.86E+02	2.38E+02
TCL.5R5.B1	hor	CU		1.00	999.00	open	7.37E+01	3.62E+02
TCDQA.A4R6.B	hor	C		3.00	**7.50**	5.28	4.94E+02	1.68E+02
TCDQA.B4R6.B	hor	C		3.00	**7.50**	5.34	5.05E+02	1.72E+02
TCSG.4R6.B1	hor	C		1.00	**7.00**	5.05	5.17E+02	1.77E+02
TCP.D6L7.B1	ver	C		0.60	**4.00**	1.12	1.59E+02	7.83E+01
TCP.C6L7.B1	hor	C		0.60	**4.00**	1.56	1.51E+02	8.28E+01
TCP.B6L7.B1	skw	C		0.60	**4.00**	1.31	1.42E+02	8.75E+01
TCSG.A6L7.B1	skw	C		1.00	**6.00**	2.03	3.99E+01	2.27E+02
TCSG.B5L7.B1	skw	C		1.00	**6.00**	2.42	1.60E+02	1.67E+02
TCSG.A5L7.B1	skw	C		1.00	**6.00**	2.47	1.86E+02	1.46E+02
TCSG.D4L7.B1	ver	C		1.00	**6.00**	1.58	3.33E+02	6.89E+01
TCSG.B4L7.B1	hor	C		1.00	**6.00**	2.25	1.40E+02	1.31E+02
TCSG.A4L7.B1	skw	C		1.00	**6.00**	2.21	1.29E+02	1.41E+02
TCSG.A4R7.B1	skw	C		1.00	**6.00**	2.22	1.18E+02	1.52E+02
TCSG.B5R7.B1	skw	C		1.00	**6.00**	2.54	1.22E+02	2.68E+02
TCSG.D5R7.B1	skw	C		1.00	**6.00**	2.55	2.14E+02	1.59E+02
TCSG.E5R7.B1	skw	C		1.00	**6.00**	2.56	2.41E+02	1.36E+02
TCSG.6R7.B1	skw	C		1.00	**6.00**	3.49	3.36E+02	4.74E+01
TCLA.A6R7.B1	ver	W		1.00	**8.00**	1.76	2.97E+02	4.82E+01
TCLA.B6R7.B1	hor	W		1.00	**8.00**	3.20	1.59E+02	7.64E+01
TCLA.C6R7.B1	ver	W		1.00	**8.00**	3.13	6.86E+01	1.52E+02
TCLA.D6R7.B1	hor	W		1.00	**8.00**	2.05	6.50E+01	1.58E+02
TCLA.A7R7.B1	hor	W		1.00	**8.00**	2.03	6.43E+01	1.47E+02
TCTH.4L8.B1	hor	W		1.00	26.00	12.81	2.41E+02	3.03E+02
TCTVB.4L8	ver	W		1.00	26.00	15.10	5.37E+02	3.36E+02
TCTH.4L1.B1	hor	W		1.00	26.00	19.93	5.84E+02	2.26E+02
TCTVA.4L1.B1	ver	W		1.00	26.00	12.71	5.86E+02	2.38E+02

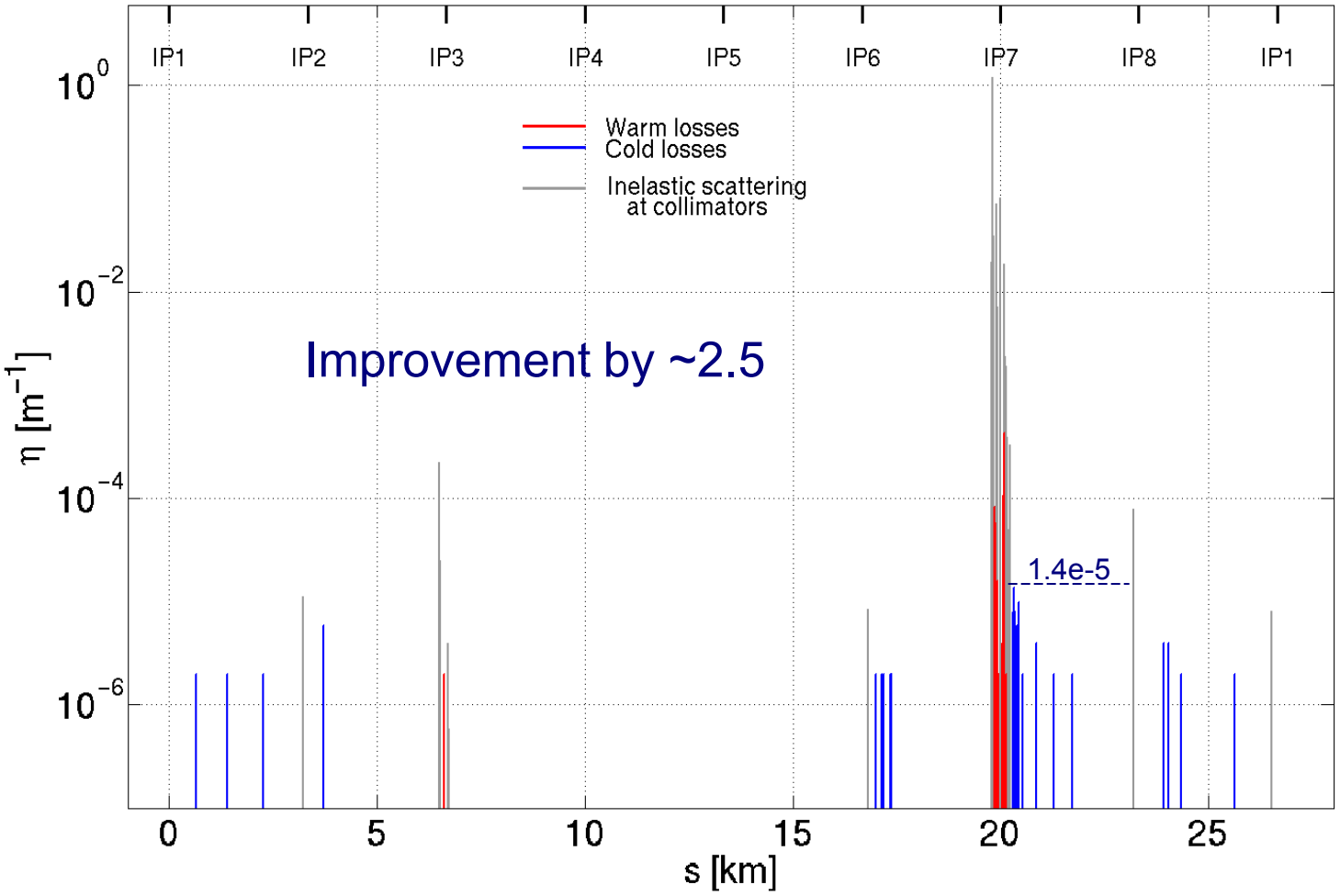
Simulation results the present machine

Simulation at 3.5TeV,
horizontal sheet beam 1



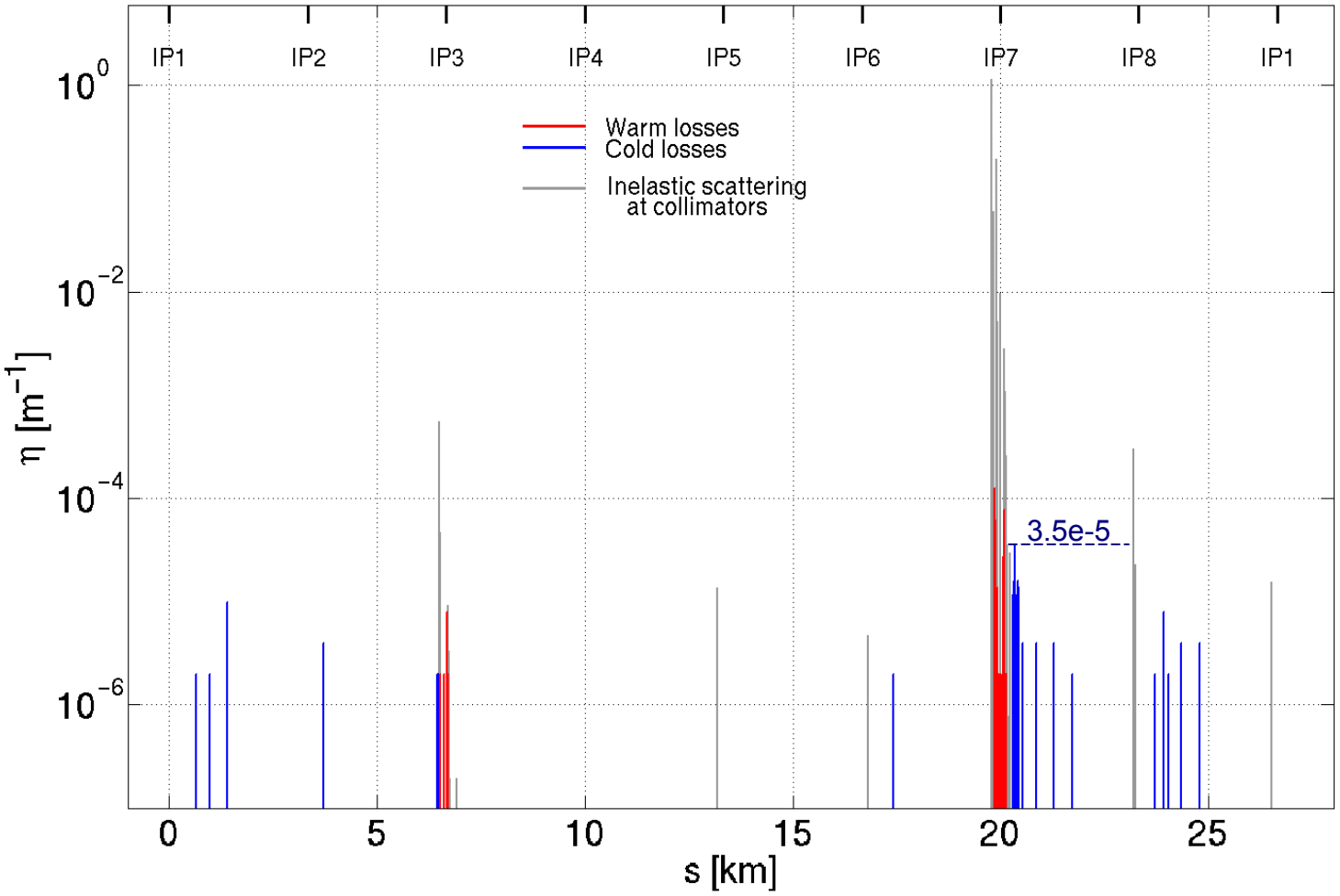
Simulation results with MD tight settings

Simulation at 3.5TeV,
horizontal sheet beam 1



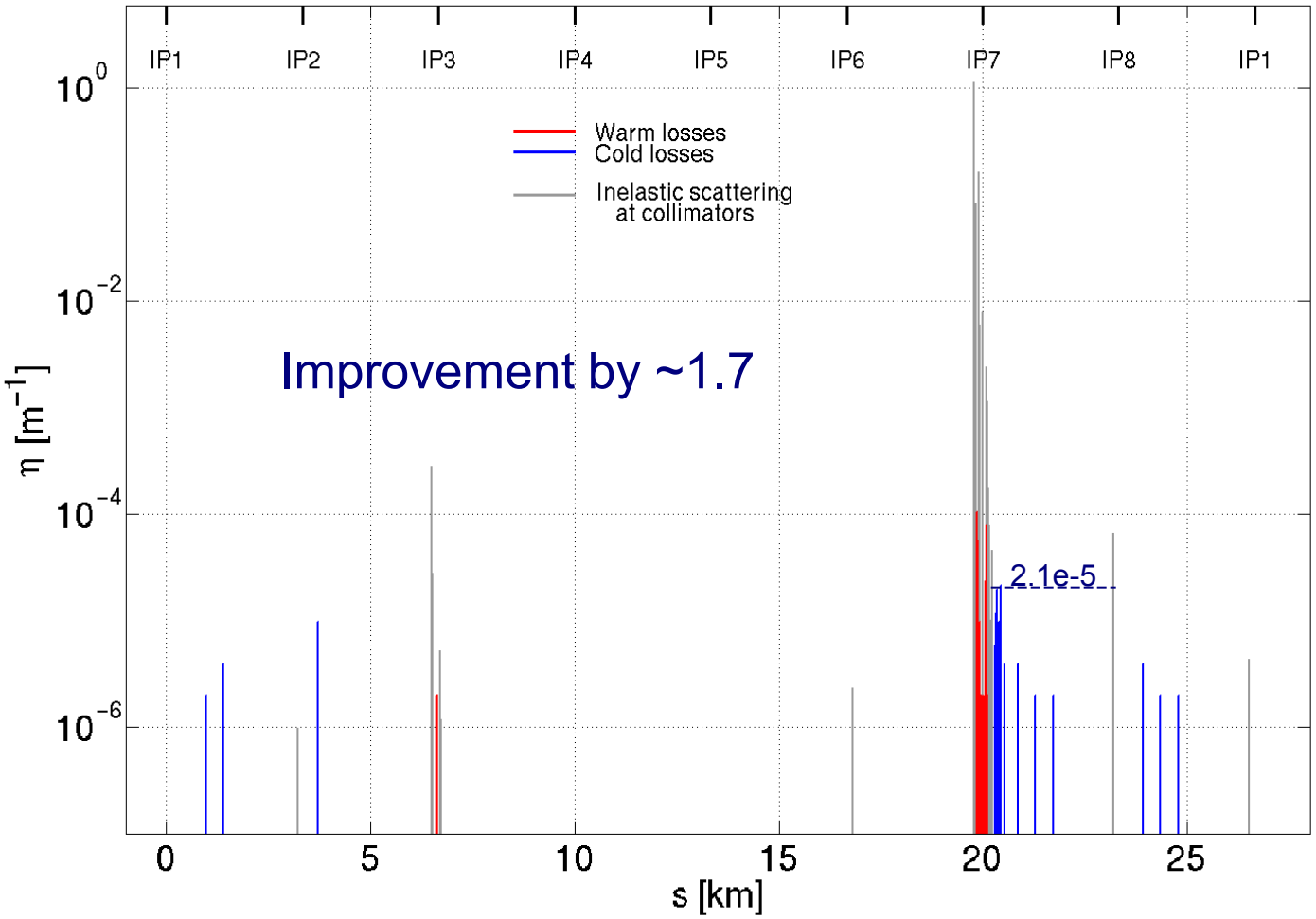
Simulation results the present machine

Simulation at 3.5TeV,
vertical sheet beam 1



Simulation results with MD tight settings

Simulation at 3.5TeV,
vertical sheet beam 1



Machine alignment imperfections

- Alignment errors applied randomly (1.5σ cut) starting from measured values

	RMS_x (mm)	RMS_y (mm)
MB.	2.4	1.56
MQ.	2.0	1.2
MQX	1.0	1.0
MQWA	2.0	1.2
MQWB	2.0	1.2
MBW.	1.5	1.5
BPM	0.5	0.5