Collimators and Beam Cleaning: First Results and Future Plans

Chiara Bracco

with Ralph Assmann, Stefano Redaelli, Adriana Rossi, Daniel Wollmann

Acknowledgements to:

B.Goddard and team for collaborative studies on injection & dump protection devices

B.Dehning and BLM tem for beam loss studies

A. Masi and CO team, O. Aberle and HW commissioning team

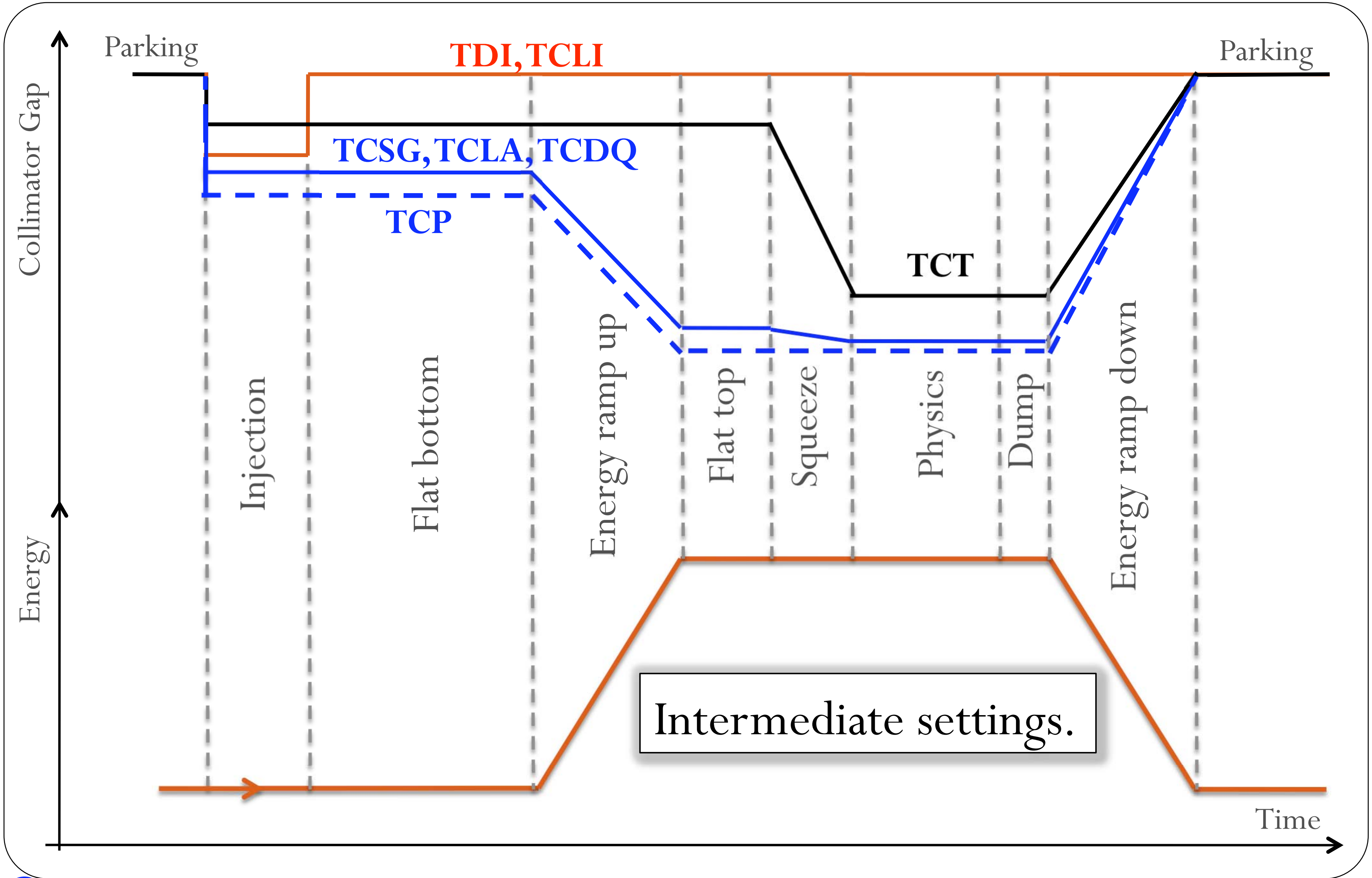
Outlines

- Principle of operation with collimators (settings, thresholds…)
- Hardware commissioning tests
- Beam based alignment procedure, beam experience and first results
- Interlock threshold setup
- Analysis of collimation induced interlocks
- Beam loss studies
- Lessons and future plans

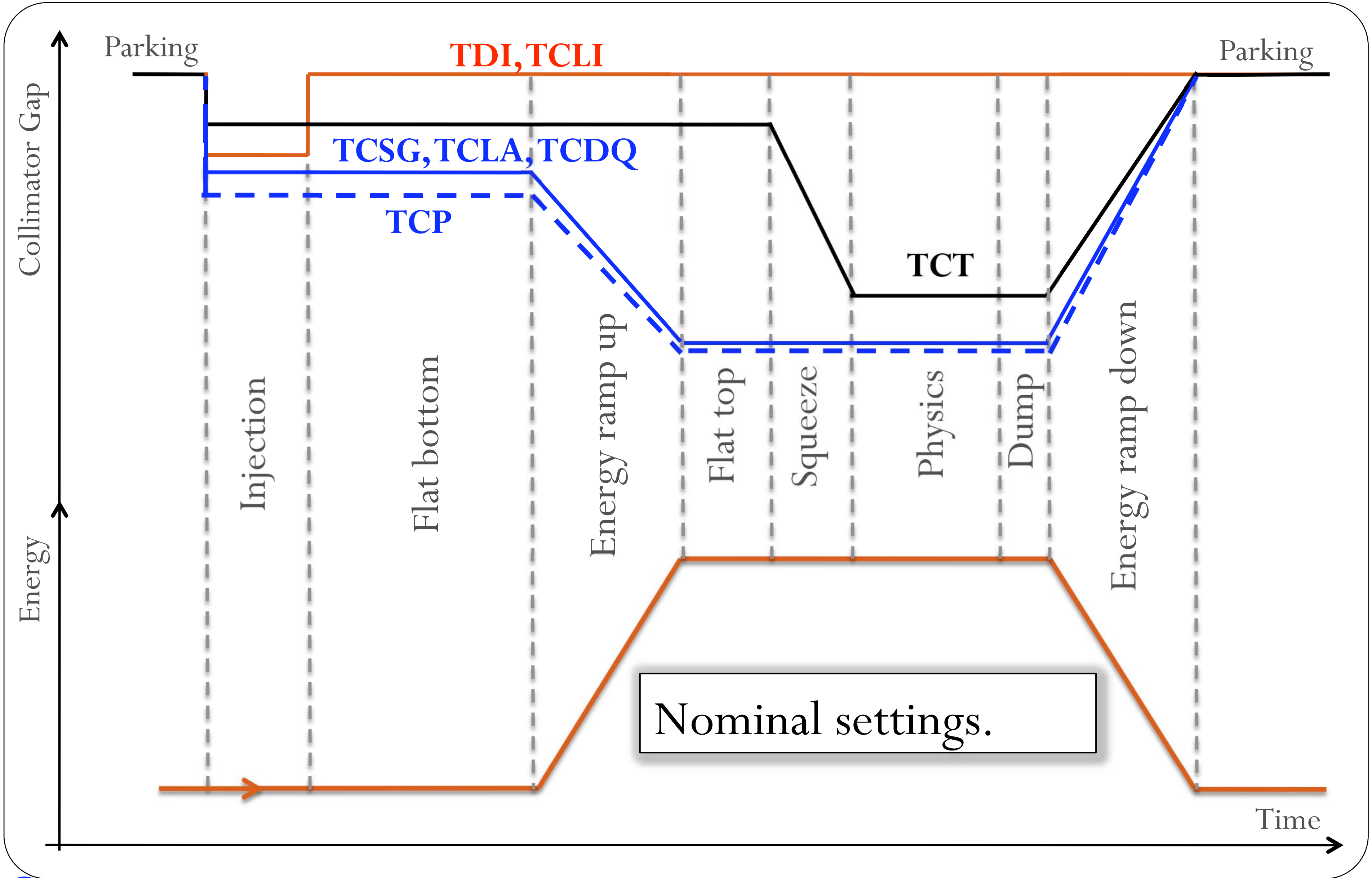
Logic of the LHC Collimation System Operation

- LHC collimators are needed during the full cycle of machine operations
- Collimators must be set up implementing a well defined hierarchy
- Alignment requirements and positioning tolerances become more demanding when increasing beam intensity and energy
- A new beam based alignment must be performed any time beam and machine optics change, orbit drift, …
- LHC collimation is a dynamic system!

Nominal Cycle



Nominal Cycle



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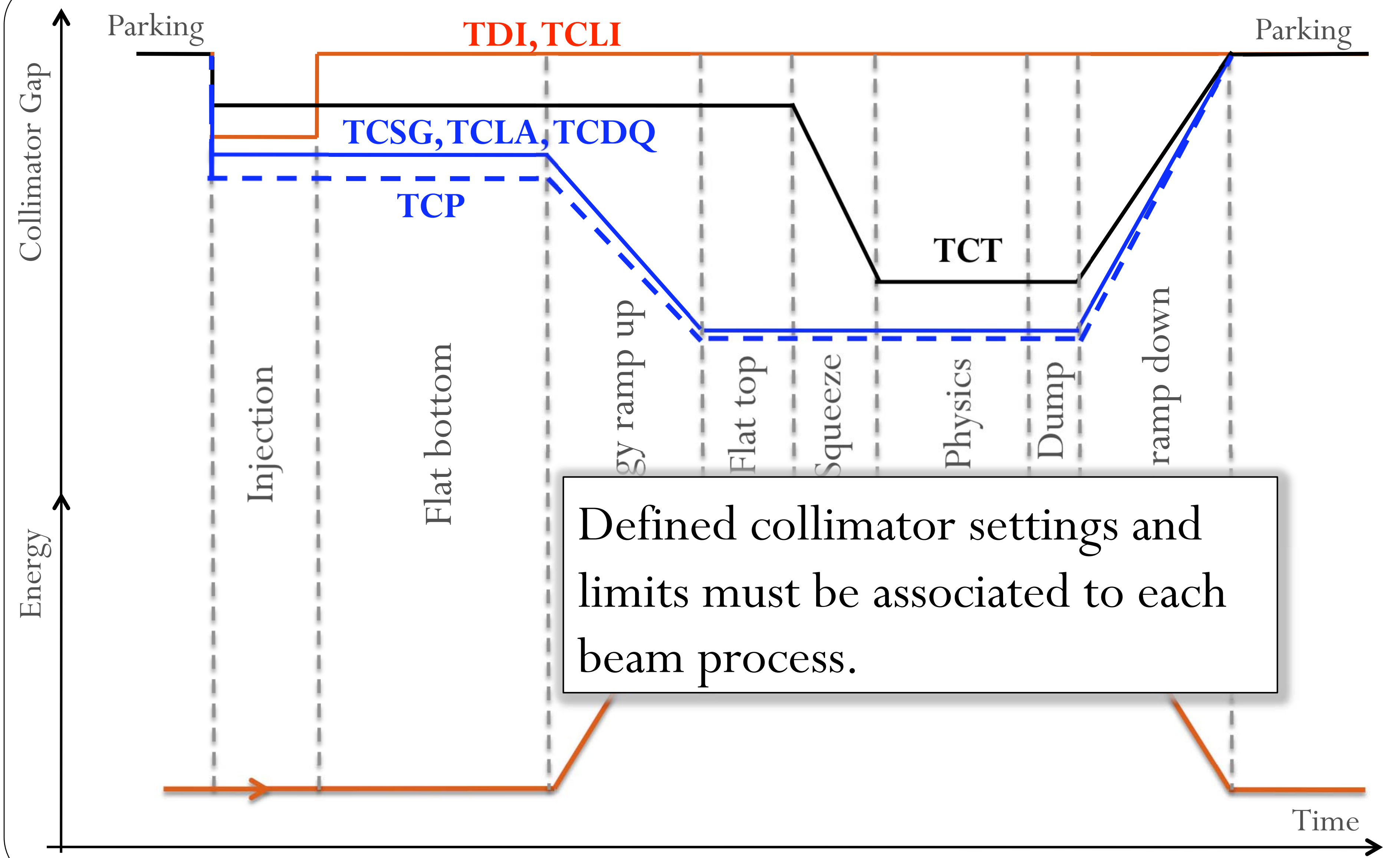
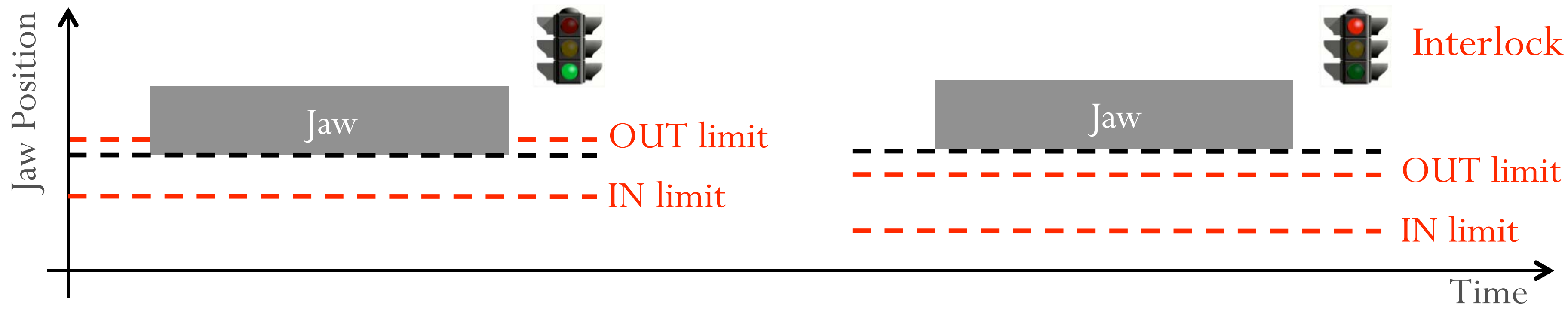


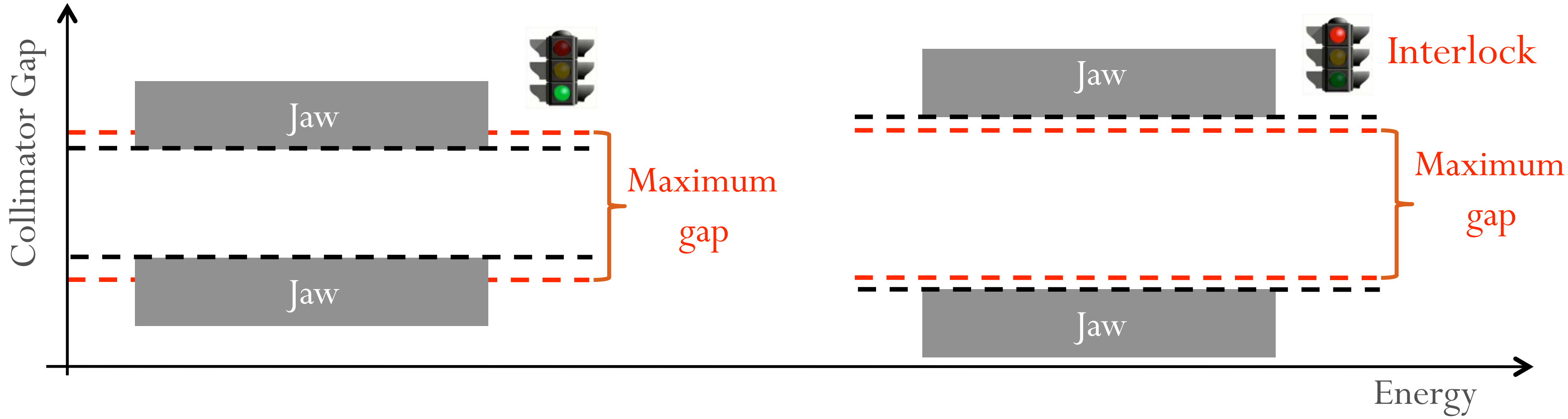
Defined collimator settings and limits must be associated to each beam process.

Thresholds and Interlocks

- Position time dependent interlocks.



- Energy dependent interlocks.



- Temperature dependent interlocks.

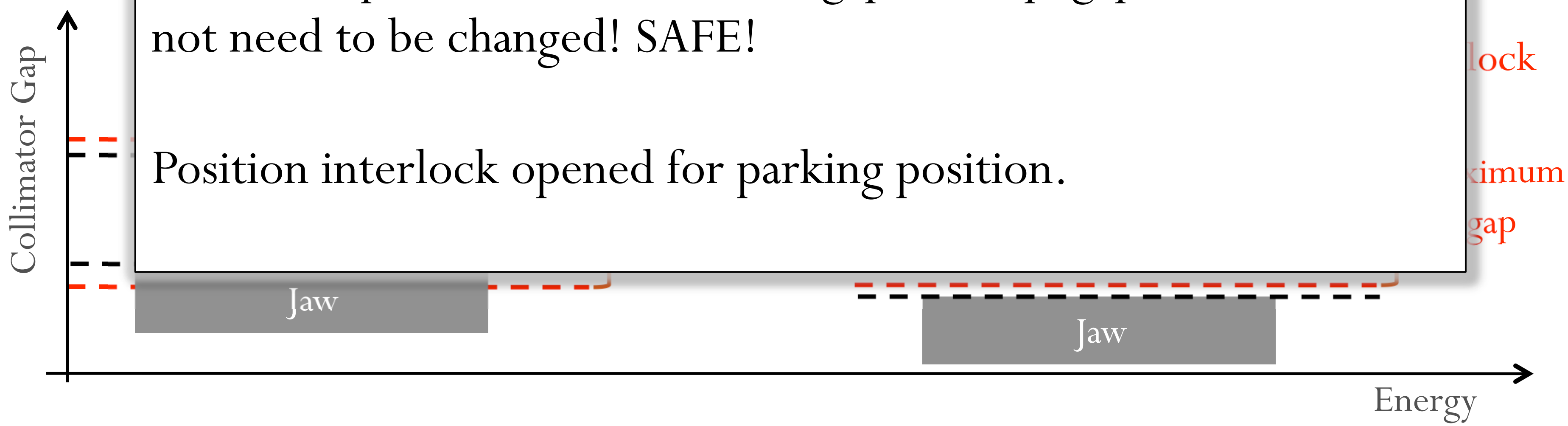
Thresholds and Interlocks

- Position time dependent interlocks.

- Ene

E-dep. gap interlock not opened for parking position ➔ jaws can move but beam is inhibited.
Without squeeze or with nominal gaps: E-dep. gap interlock does not need to be changed! SAFE!

Position interlock opened for parking position.



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Hardware commissioning

All 100 collimators have been tested in preparation for operations with beam:

- Hardware tests: minimum and maximum gap, maximum tilt, switches, mechanical play. These tests included also TDI and TCDQ (E. Carlier, C. Boucly).

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	A	B
1	Collimator	MPP test resutls: EDMS Doc. No.
2		
3	TCDIH-29012	https://edms.cern.ch/document/1052530/1
4	TCDIH-29050	https://edms.cern.ch/document/1052525/1
5	TCDIH-29205	https://edms.cern.ch/document/1052526/1
6	TCDIH-29465	https://edms.cern.ch/document/1052522/1
7	TCDIH-87441	https://edms.cern.ch/document/1052527/1
8	TCDIH-87904	https://edms.cern.ch/document/1052528/1
9	TCDIH-88121	https://edms.cern.ch/document/1052529/1
10	TCDIV-29012	https://edms.cern.ch/document/1052675/1
11	TCDIV-29234	https://edms.cern.ch/document/1052531/1
12	TCDIV-29509	https://edms.cern.ch/document/1052532/1
13	TCDIV-87645	https://edms.cern.ch/document/1052533/1
14	TCDIV-87804	https://edms.cern.ch/document/1052535/1
15	TCDIV-88123	https://edms.cern.ch/document/1052536/1
16	TCL-5L1-B2	https://edms.cern.ch/document/1052537/1
17	TCL-5L5-B2	https://edms.cern.ch/document/1052539/1
18	TCL-5R1-B1	https://edms.cern.ch/document/1052540/1
19	TCL-5R5-B1	https://edms.cern.ch/document/1052541/1
20	TCLA-6L3-B2	https://edms.cern.ch/document/1052542/1
21	TCLA-6R3-B1	https://edms.cern.ch/document/1052543/1
22	TCLA-7L3-B2	https://edms.cern.ch/document/1052544/1
23	TCLA-7R3-B1	https://edms.cern.ch/document/1052546/1
24	TCLA-A5L3-B2	https://edms.cern.ch/document/1052547/1
25	TCLA-A5R3-B1	https://edms.cern.ch/document/1052548/1
26	TCLA-A6L7-B2	https://edms.cern.ch/document/1052549/1
27	TCLA-A6R7-B1	https://edms.cern.ch/document/1052550/1
28	TCLA-A7L7-B2	https://edms.cern.ch/document/1052551/1
29	TCLA-A7R7-B1	https://edms.cern.ch/document/1052552/1
30	TCLA-B5L3-B2	https://edms.cern.ch/document/1052554/1
31	TCLA-B5R3-B1	https://edms.cern.ch/document/1052555/1
32	TCLA-B6L7-B2	https://edms.cern.ch/document/1052556/1
33	TCLA-B6R7-B1	https://edms.cern.ch/document/1052557/1
34	TCLA-C6L7-B2	https://edms.cern.ch/document/1052558/1
35	TCLA-C6R7-B1	https://edms.cern.ch/document/1052559/1
36	TCLA-D6L7-B2	https://edms.cern.ch/document/1052560/1
37	TCLA-D6R7-B1	https://edms.cern.ch/document/1052561/1
38	TCLIA-4L8	https://edms.cern.ch/document/1052562/1
39	TCLIA-4R2	https://edms.cern.ch/document/1052563/1
40	TCLIB-6L8-B2	https://edms.cern.ch/document/1052564/1

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All 100 collima

- Hardware te ... cal play. These t
- Machine pro ... dependent l ... https://wir ... x/ Projects/Co ... x

Summary | Sub-Documents | Approval & Comments | Used in | Access Rights | Versions & other info

Actions:

Description, External Reference and Keywords

Description	Machine Protections tests on LHC Collimators
External Reference	
Keywords	

Files of the Document

MPP_TCDIV-87804_CIB-SR8-INJ2-1_2009-11-16-17-34 png (23 Kb)

Sub-Documents

Associated URL (CDD Drawing Folder, Library...)

Context

What's next ?	Change Status action expected from the originator, once all the files have been uploaded.
Context	EDMS-USERS: EDMS documents visible to all EDMS users
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File(s)	MPP_TCDIV-87804_CIB-SR8-INJ2-1_2009-11-16-17-34.png	https://edms.cern.ch/file/1052535/1/MPP_TCDIV-87804_CIB-SR8-INJ2-1_2009-11-16-17-34.png

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External Reference	

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TCDIV-87804_CIB-

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Status of TCLA.C6L7.B2

File

Collimator MP sequence for	TCLA.C6L7.B2 / TCLA.IP7.B2.3.V
Information on monitoring	TCLA.C6L7.B2/CollimatorStatus#prsErrors
	CIB.TZ76.U7.B2/ COLLPOS input (CH8)
Sequence start time :	29/10/2009 11:43:11

Sensor – Limit violated	BIC fault	BIC time	PRS fault	PRS time	Delay [ms]	Result
GAP DOWNSTREAM – ENERGY MAX	Ok	11:48:09:057	Ok	11:48:09:098	-41	Ok
GAP UPSTREAM – ENERGY MAX	Ok	11:47:50:897	Ok	11:47:50:918	-21	Ok
GAP DOWNSTREAM – IN	Ok	11:47:25:447	Ok	11:47:25:667	-220	Ok
GAP DOWNSTREAM – OUT	Ok	11:47:05:637	Ok	11:47:06:476	-839	Ok
GAP UPSTREAM – IN	Ok	11:46:42:687	Ok	11:46:43:246	-559	Ok
GAP UPSTREAM – OUT	Ok	11:46:24:132	Ok	11:46:23:045	1087	Ok
RIGHT DOWNSTREAM – IN	Ok	11:46:00:027	Ok	11:46:00:824	-797	Ok
RIGHT DOWNSTREAM – OUT	Ok	11:45:40:036	Ok	11:45:40:624	-588	Ok
RIGHT UPSTREAM – IN	Ok	11:45:17:156	Ok	11:45:17:393	-237	Ok
RIGHT UPSTREAM – OUT	Ok	11:44:57:236	Ok	11:44:58:202	-966	Ok
LEFT DOWNSTREAM – IN	Ok	11:44:34:356	Ok	11:44:34:972	-616	Ok
LEFT DOWNSTREAM – OUT	Ok	11:44:14:466	Ok	11:44:14:771	-305	Ok
LEFT UPSTREAM – IN	Ok	11:43:51:496	Ok	11:43:51:540	-44	Ok
LEFT UPSTREAM – OUT	Ok	11:43:31:556	Ok	11:43:32:350	-794	Ok

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- Automatic sequences to drive collimators through nominal OP cycles.

Hardware commissioning

All 100 collimat

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- Machine prot
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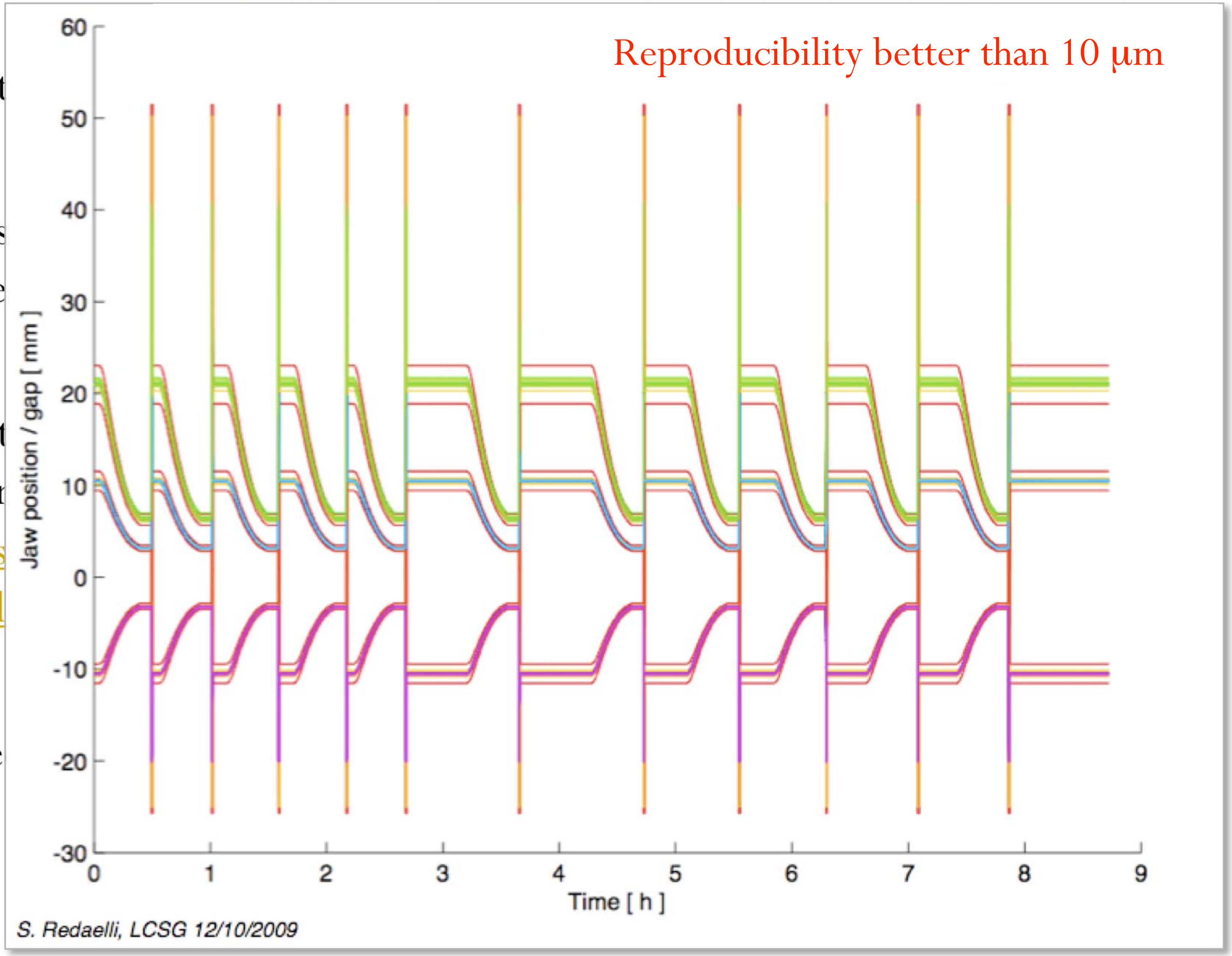
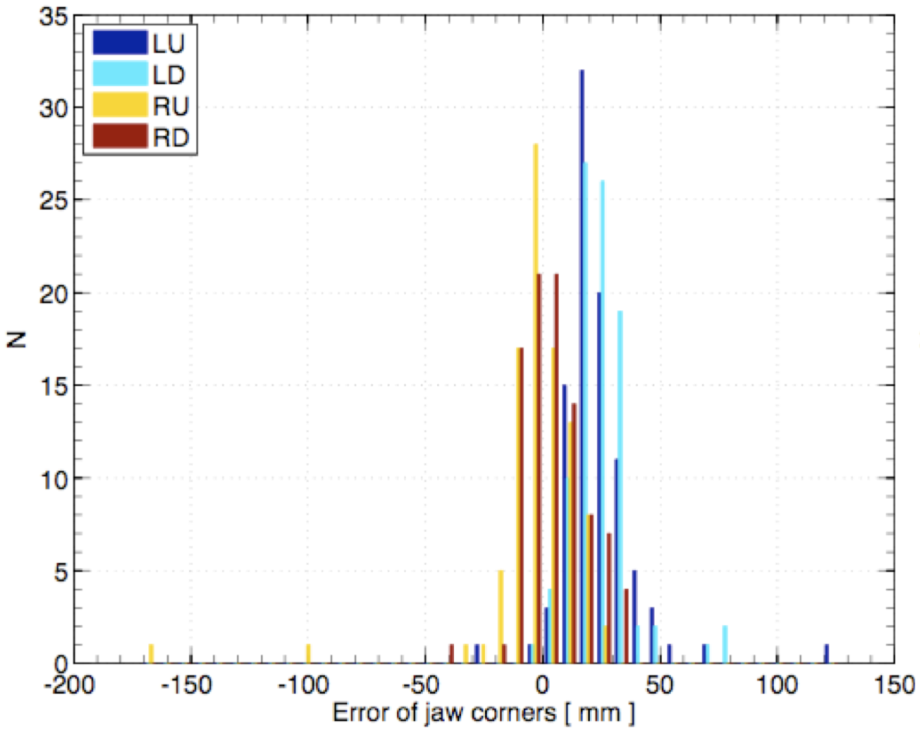
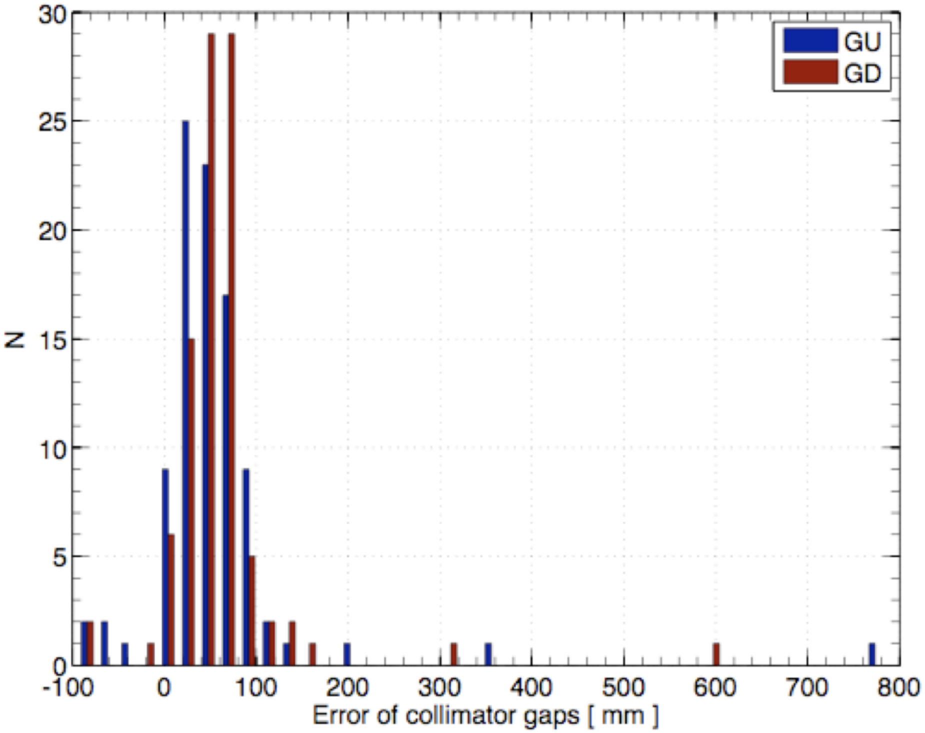
- Automatic se



Ramp Tests: Errors w.r.t. Settings





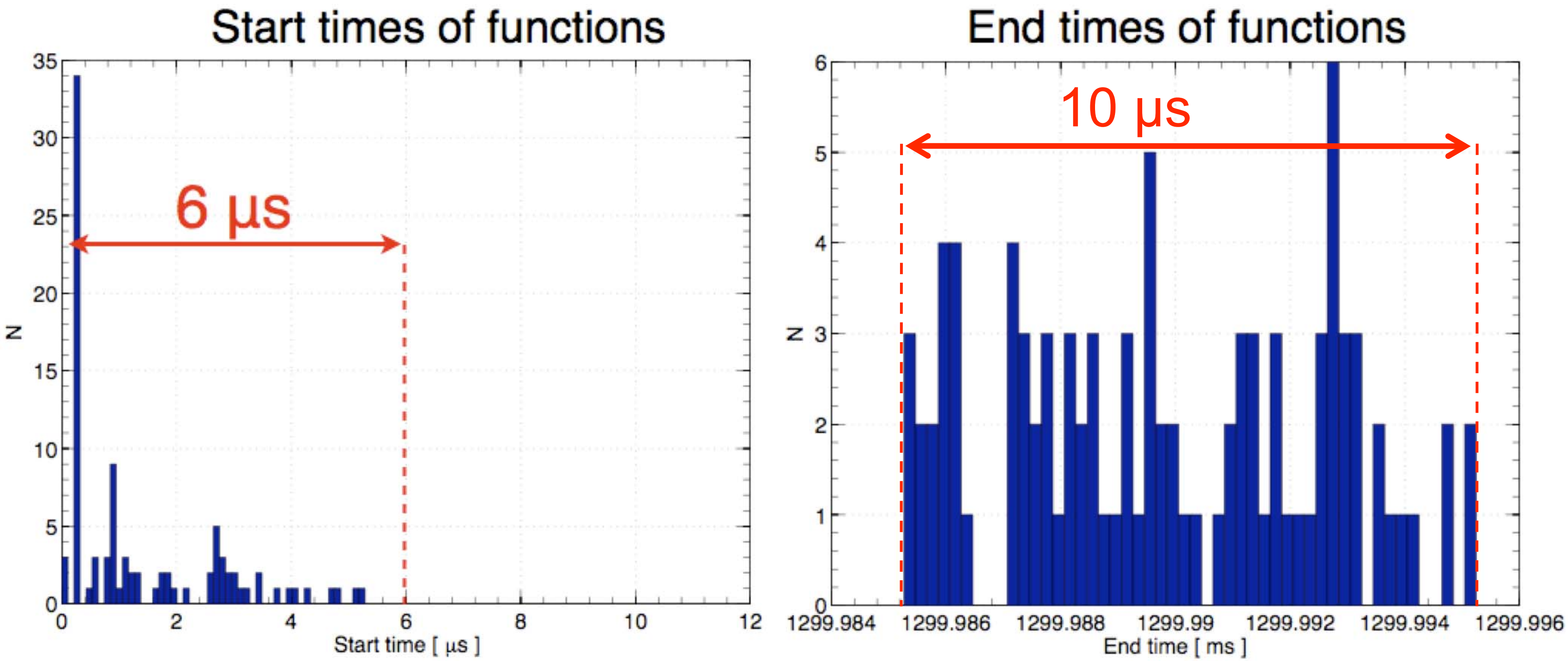
Corner position:
Errors < 50 µm

Collimator gaps:
Errors up to 200 µm

Impact on settings?

Courtesy of S. Redaelli LCSG 12/10/2009

Ramp Tests: Synchronization



Ramp up to 5 TeV (1300 s):

Collimators in different locations start together within 6 μs.

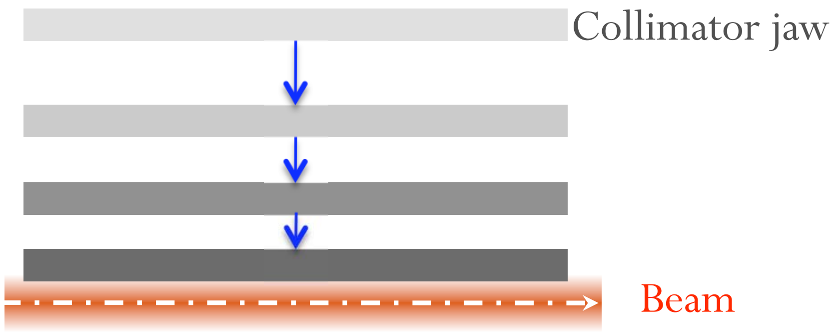
End times of profiles within 10 μs.

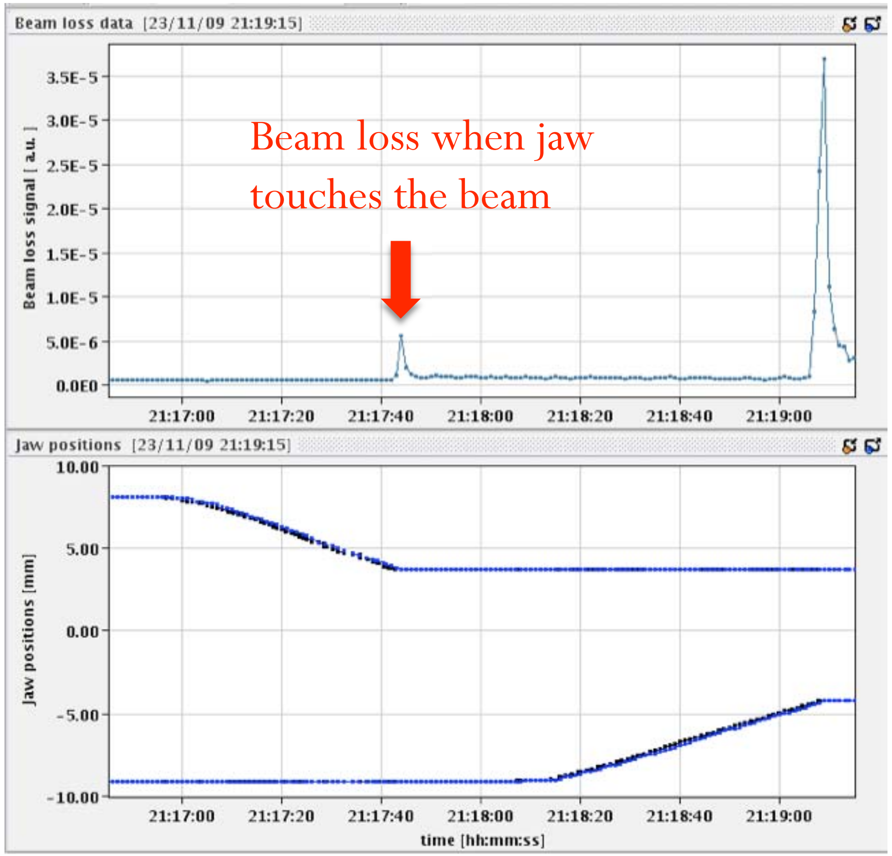
Courtesy of S. Redaelli LCSG 12/10/2009

Beam Based Alignment

The LHC collimation system has been used for beam cleaning and passive machine protection this year for the first time.

Beam based alignment:





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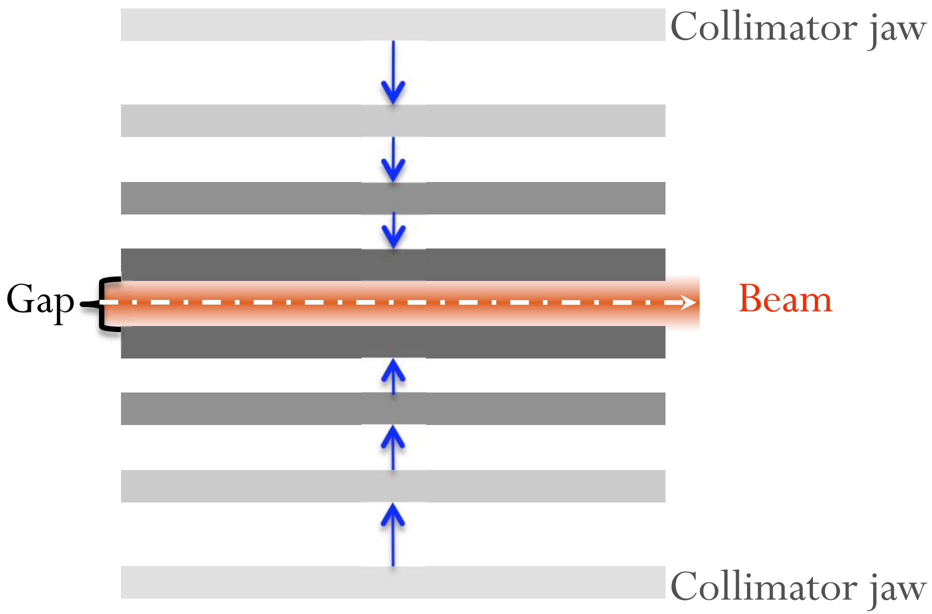
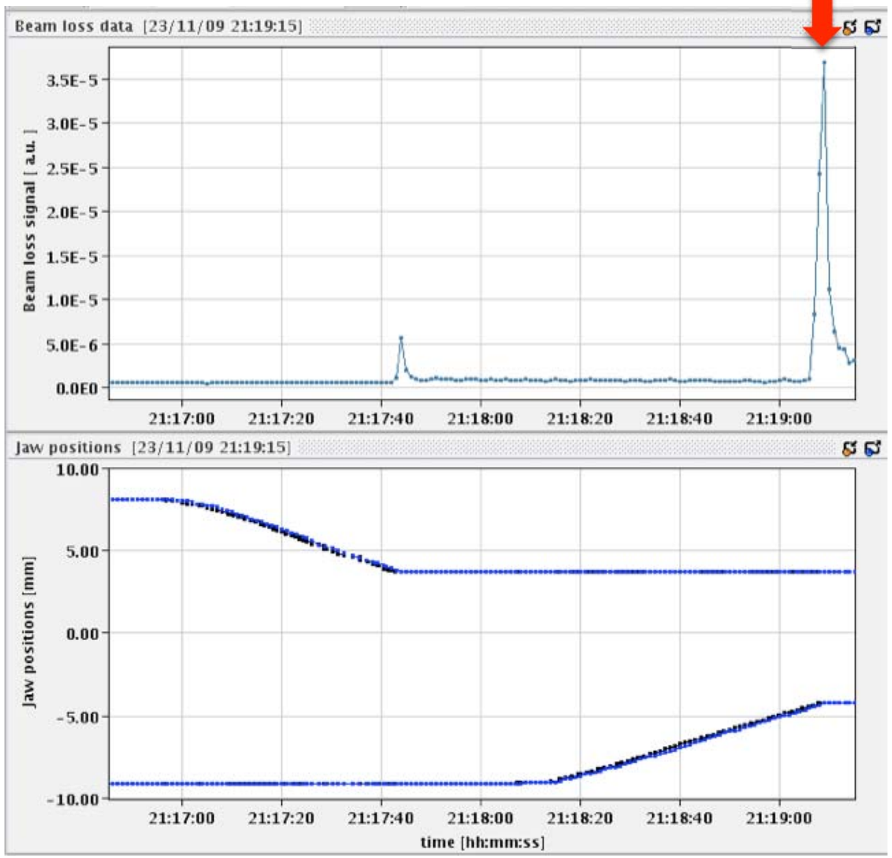


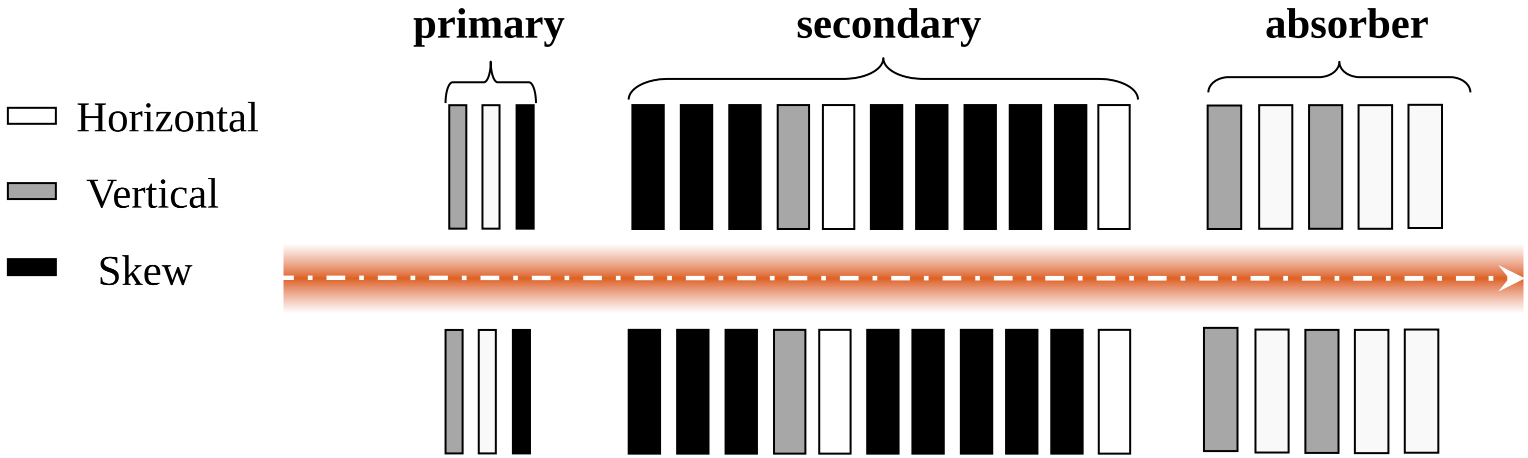
Gap => Beam centre

Beam size => Nominal settings

Beam loss when jaw touches the beam

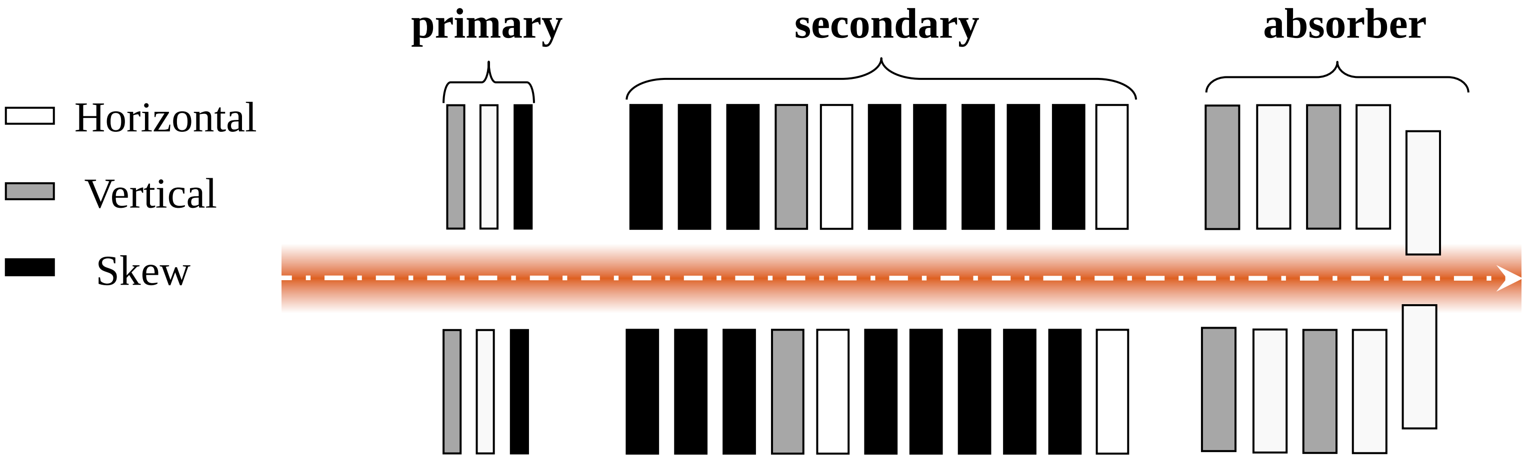


Setup Procedure



Schematic view of IR7

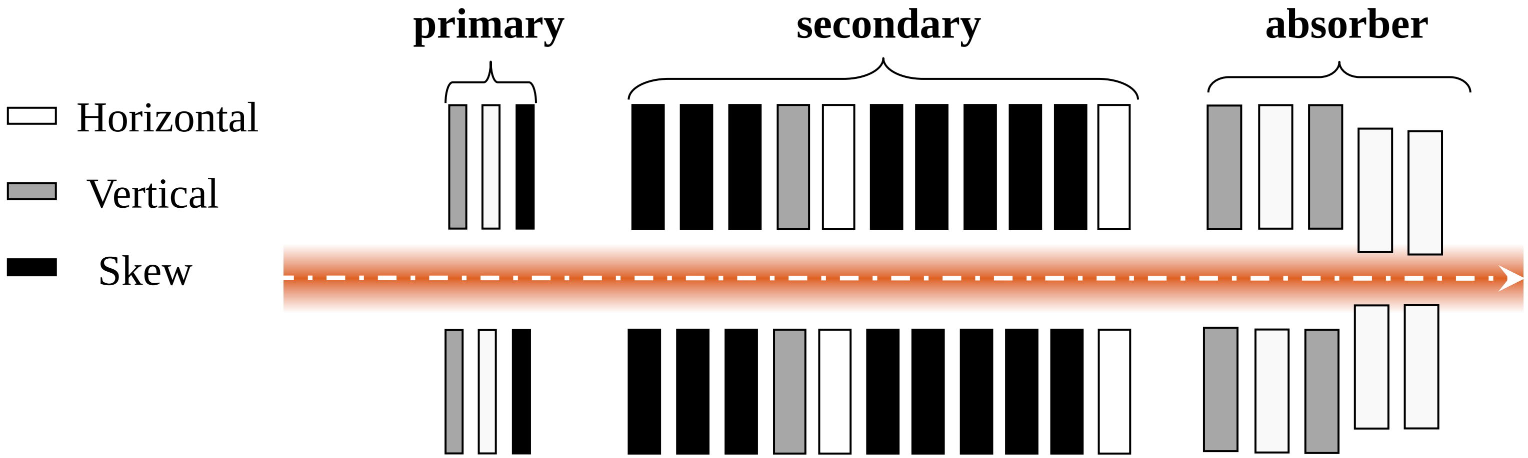
Setup Procedure



Schematic view of IR7

- Start aligning last horizontal collimator by setting it at 5.7σ (nominal injection) => reference "beam edge"

Setup Procedure



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- Start aligning last horizontal collimator by setting it at 5.7σ (nominal injection) => reference "beam edge"
- Close each remaining horizontal collimator going backwards w.r.t the beam (clean BLM signal) until touching the beam (5.7σ) and then retract to nominal position (i.e. IR7: TCSG at 6.7σ, TCLA at 10σ).

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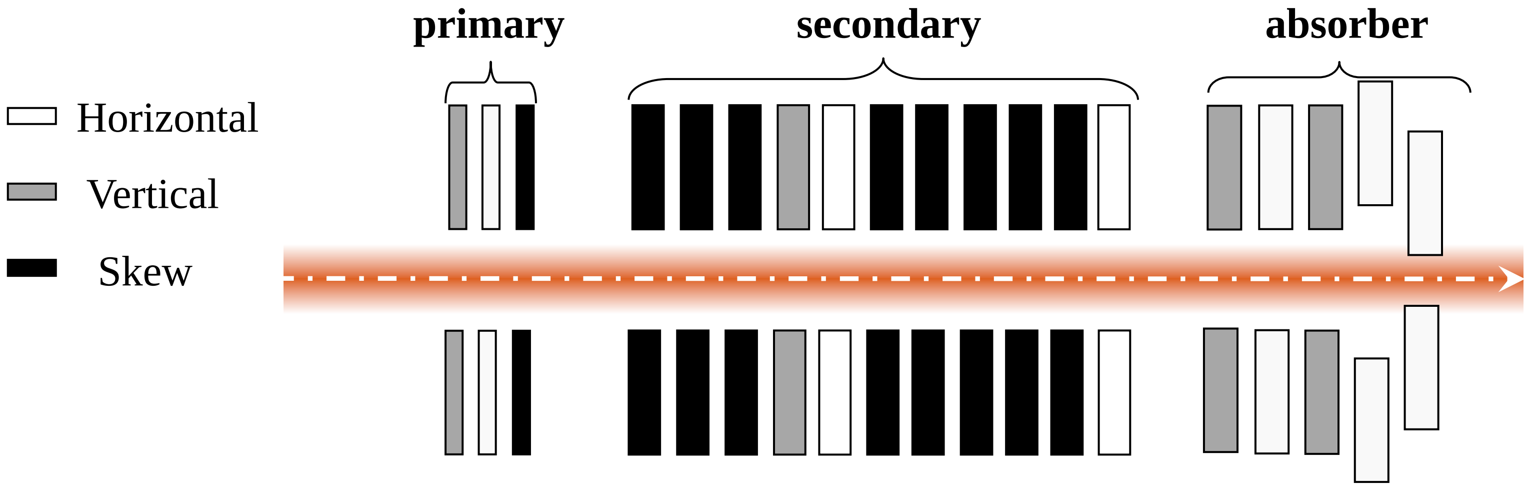

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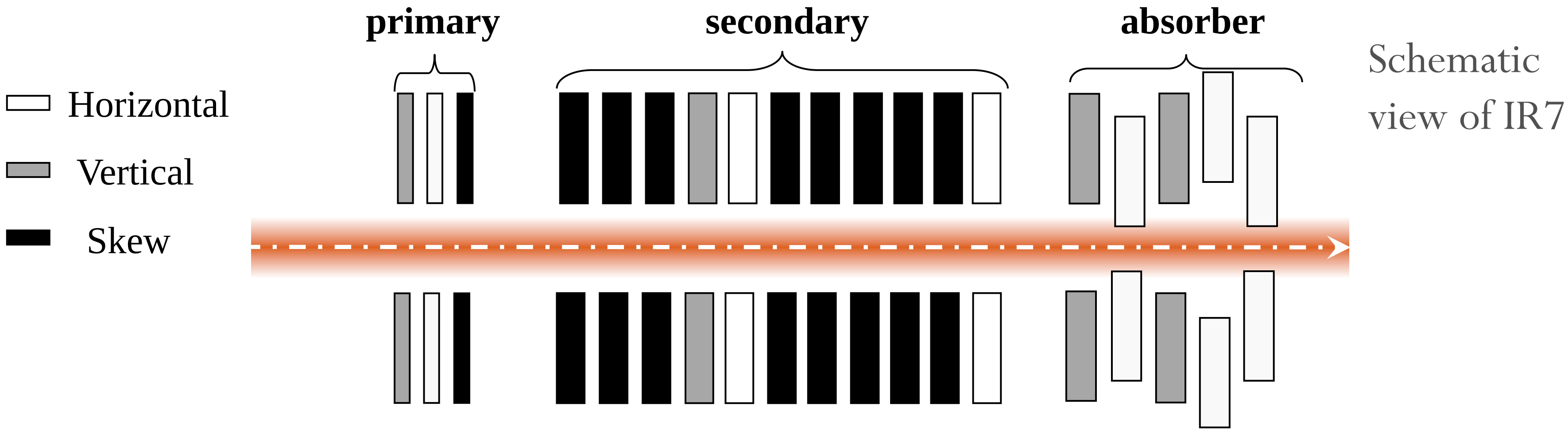

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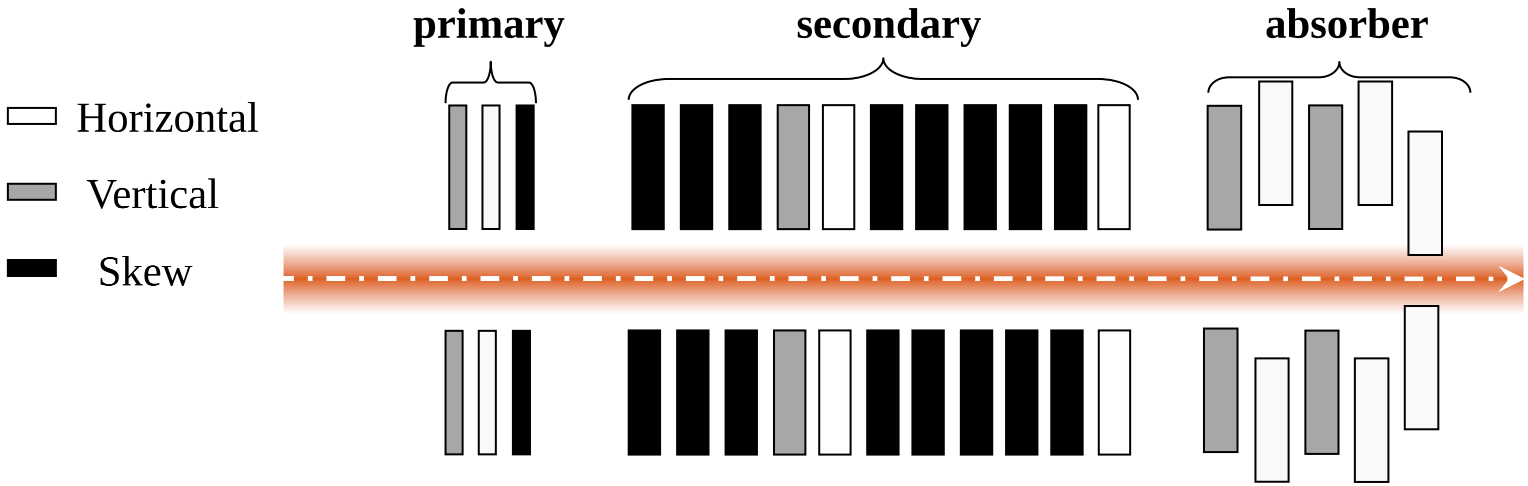

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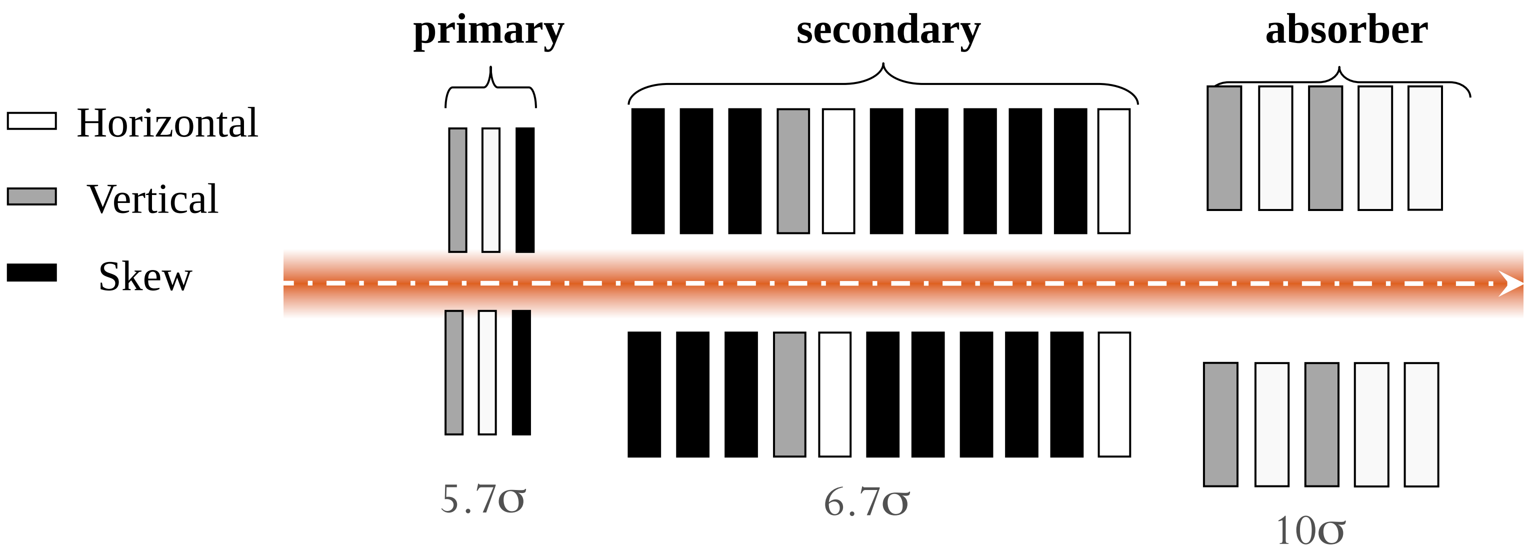

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- Repeat for vertical and skew planes => Collimator hierarchy established!

November 23rd: First LHC Collimator Setup

Collimators set up in parallel for the two beams. No disturbing crosstalk in losses between beams.

Beam 1:

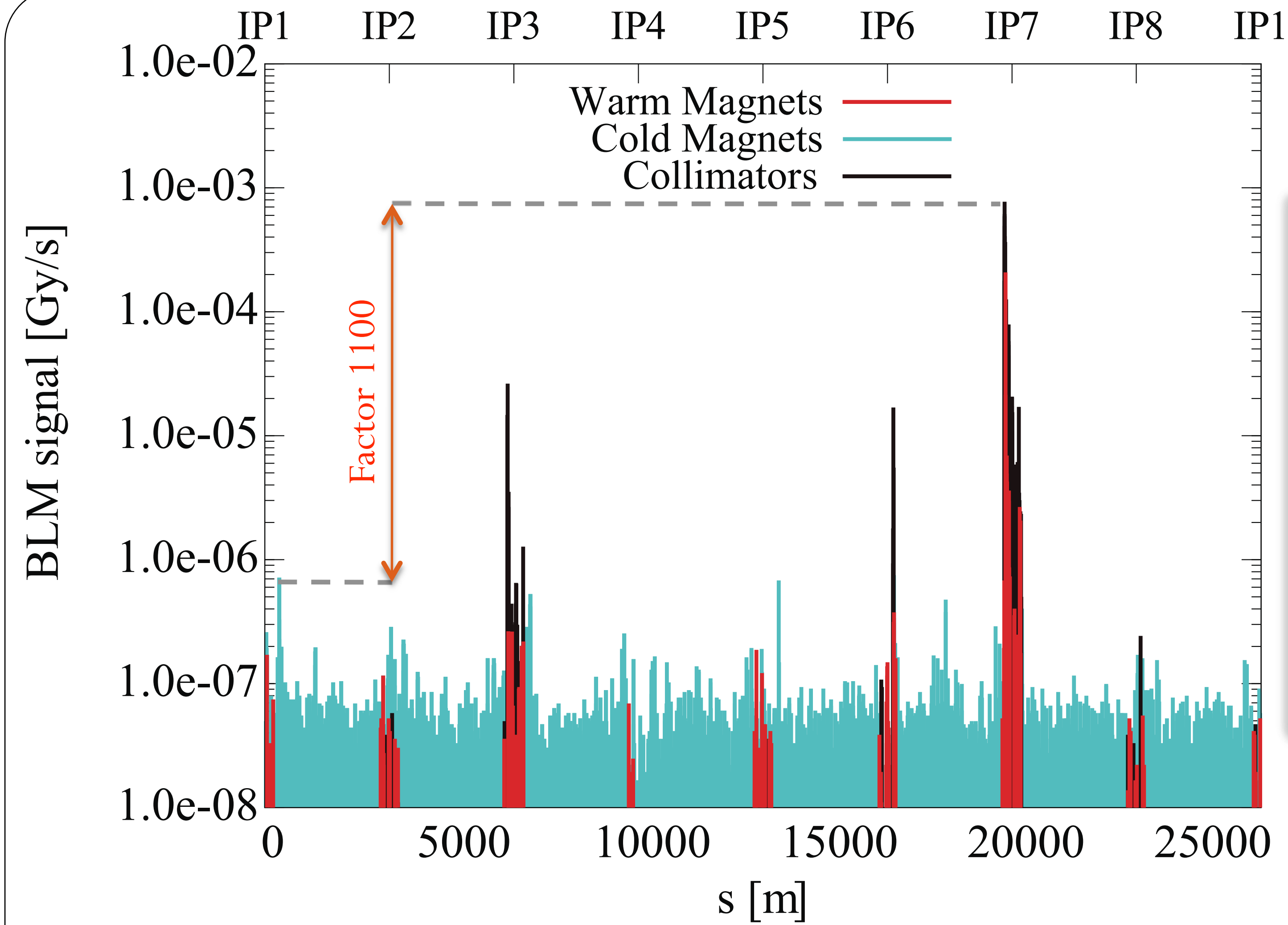
- IR7: Set up horizontal and vertical primary collimators plus all absorbers. Secondary collimators left at coarse position (around 10σ, not enough time for detailed setup).
- IR6: Tried setup of TCDQ and associated secondary collimator. Puzzling beam response. Left devices at assumed nominal positions.
- IR3: Set up primary collimator (8σ) and 1 TCLA (10σ). Other tungsten collimators (TCLA) and secondary collimators left at coarse position (nominal + 3σ).

Beam 2:

-IR3: All collimators set up at nominal settings (TCP at 8σ, TCSG at 9.3σ, TCLA at 10σ).

20 Collimators set up in about 3 hours, ~200 μm accuracy. Accuracy from step size used.

Loss Map Beam 1 Injection for Partial Setup



Highest losses in the collimation insertions at the primary collimators!

99.9% cleaning efficiency.

All tertiary collimators: half gap =15mm (~15-20 σ)

Offset without beam (background) subtracted.

November 29^{th}: Second LHC Collimator Setup

New alignment after defining a reference "golden orbit": Santa Klaus.
- IR3, IR6 and IR7: all collimators set up at nominal settings.
- IR1: horizontal and vertical tertiary collimator positions crosschecked and set at 15mm. Remaining TCT not touched and kept at 15mm.

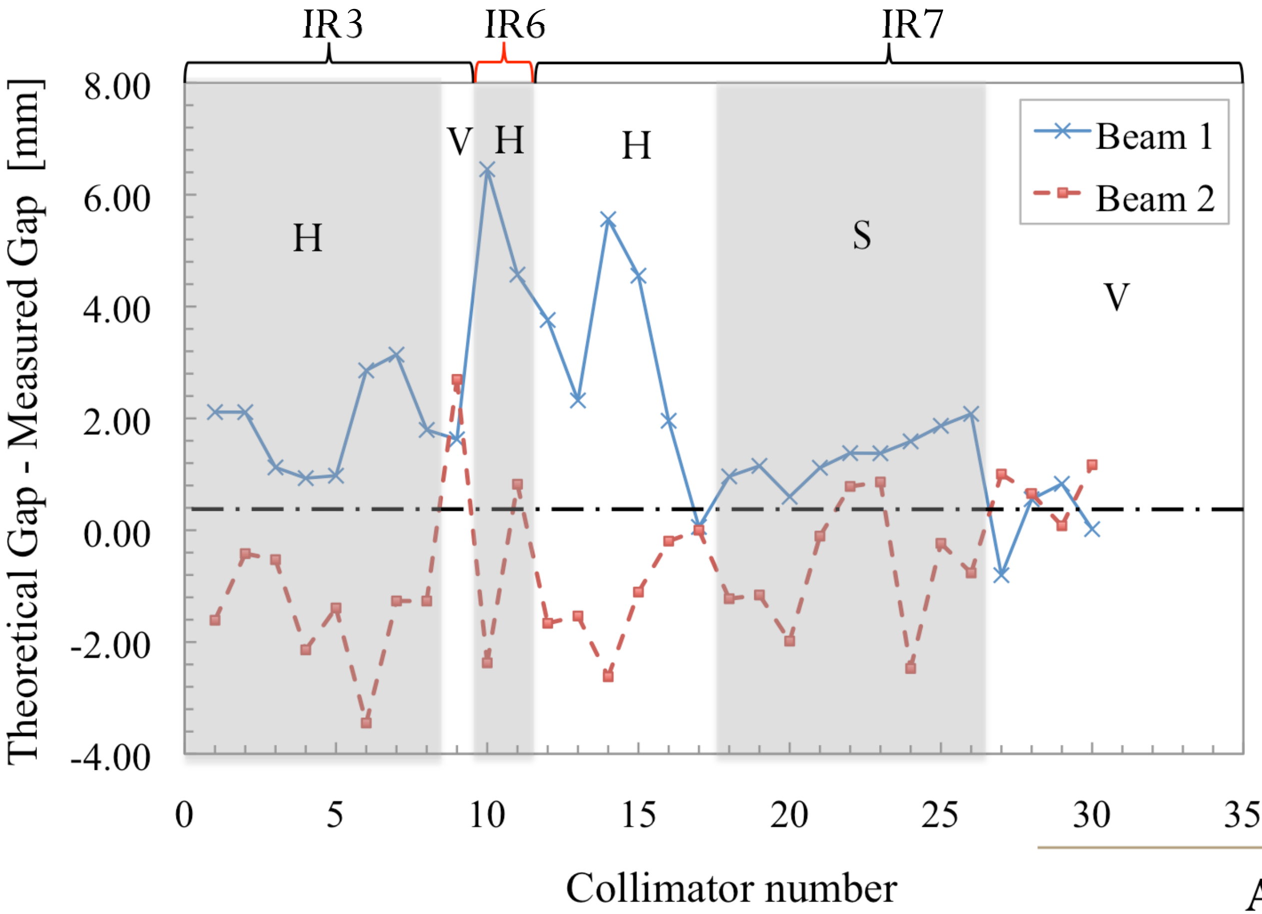
Beam 2:

- IR3, IR6 and IR7: All collimators set up at nominal settings.
- All TCT untouched and kept at 15mm.

First full multi-stage collimation set up! We implemented directly 4 stage cleaning: primary ➔ secondary ➔ tertiary ➔ active absorbers

62 Collimators set up in about 7 hours, ~50-100 μm accuracy. Accuracy given by step size used during collimator setup (larger steps to speed up process).

Difference Theoretical – Measured Collimation Gaps



H: horizontal collimators
V: vertical collimators
S: skew collimators

Theoretical gaps calculated for:
Emittance = 3.5 μm rad

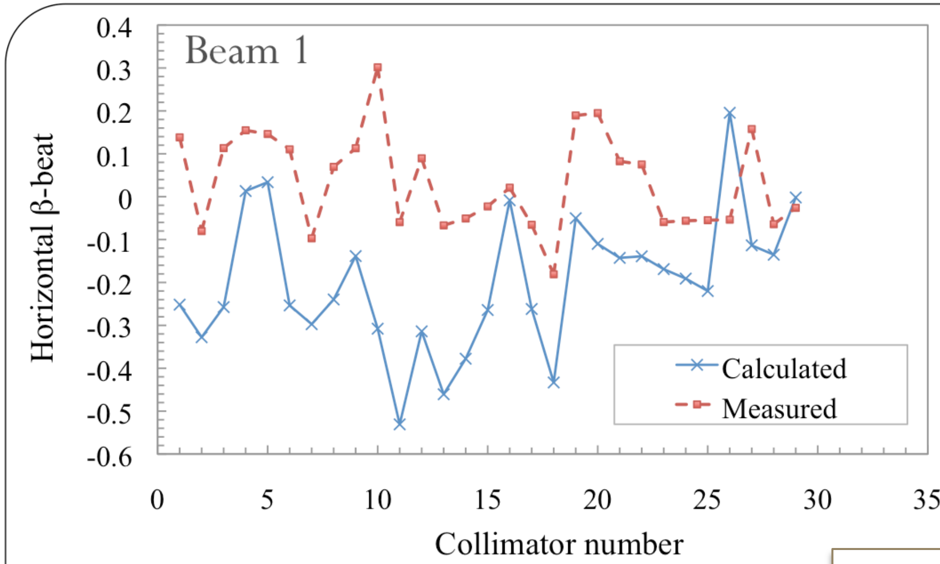
Beam 1 differences:
IR6 – TCDQ set-up accuracy
IR7 – Large initial difference

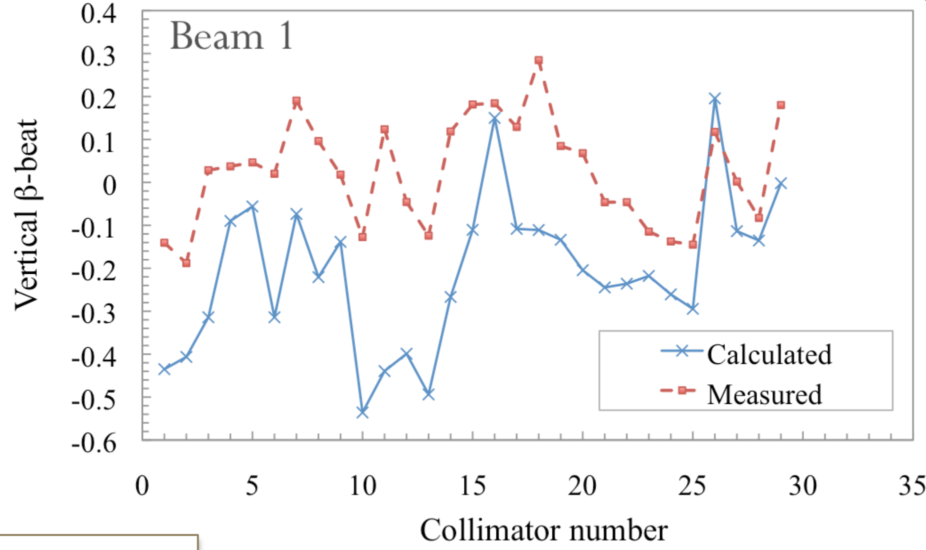
β-beat problem beam1 in IR7?

Average difference [mm]

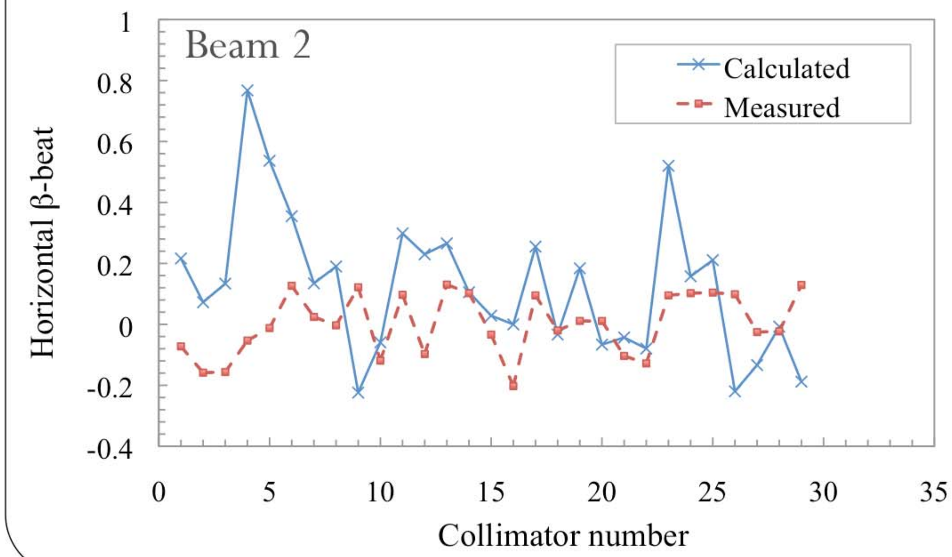
	H	V	S
Beam 1	+2.77	+0.45	+1.35
Beam 2	-1.30	+1.12	-0.70

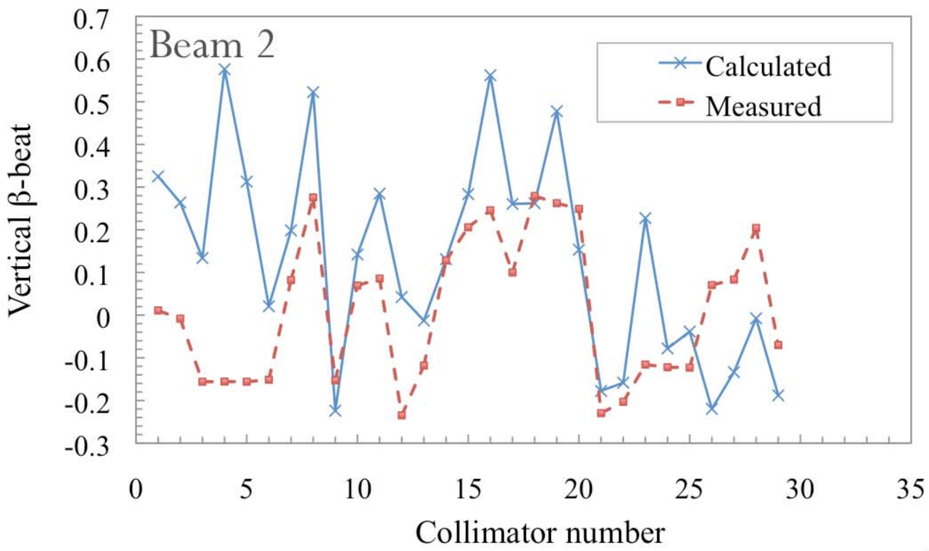
Comparison β-Beat From Collimation and Measurement.





β-beat: Δβ/β0

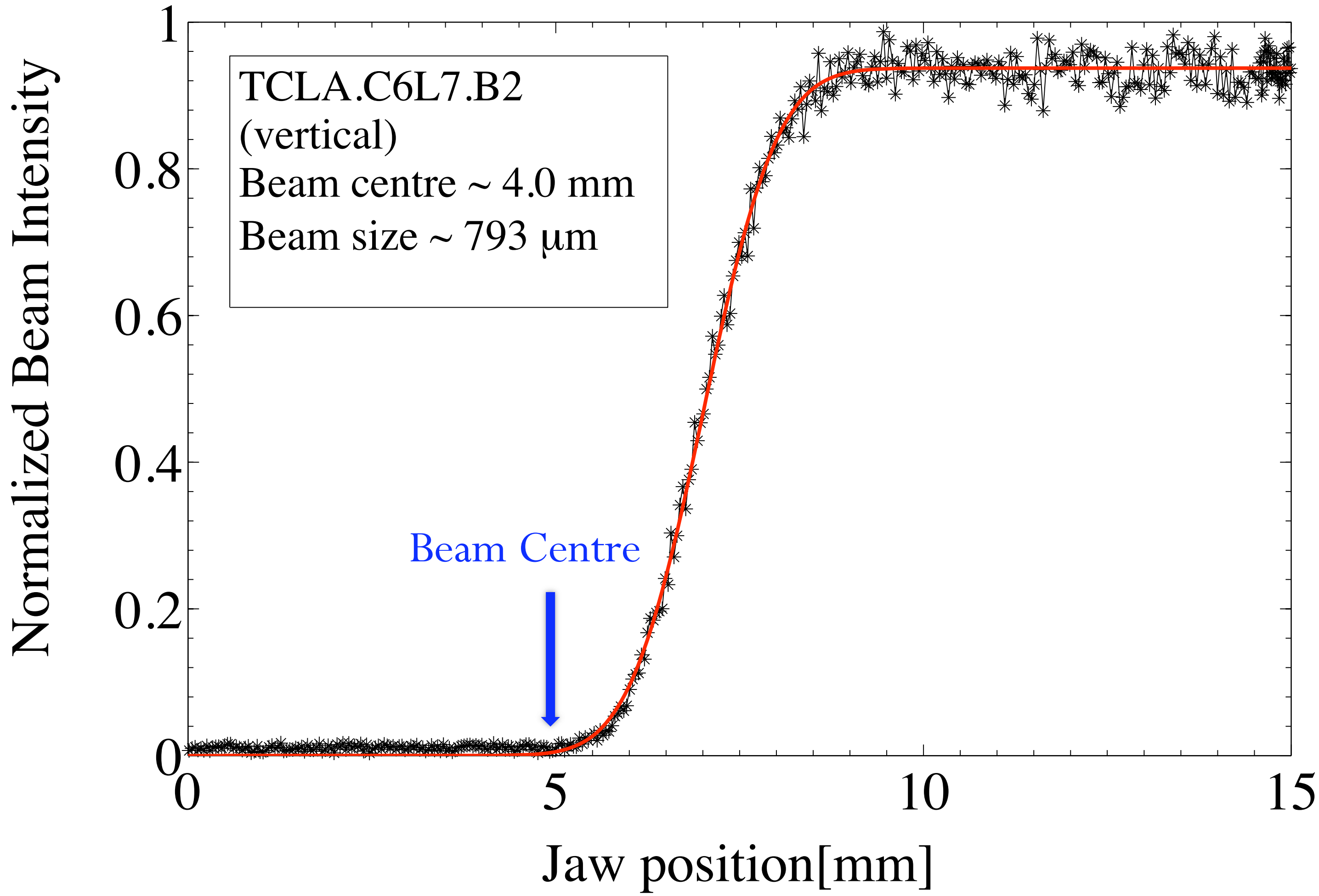




*Data for β-beat courtesy of Glenn Vanbavinckhove

Full Beam Scraping

Cross check of beam size and beam centre at the collimators used as a reference for beam based alignment (IR7, TCLA).



Comparison of the Results

Full beam scraping:

	Beam 1		Beam 2	
TCLA	Beam Centre [mm]	Beam Size [μm]	Beam Centre [mm]	Beam Size [μm]
Hor.	0.4	736	N.A.	N.A.
Vert.	2.2	920	4.0	**793**

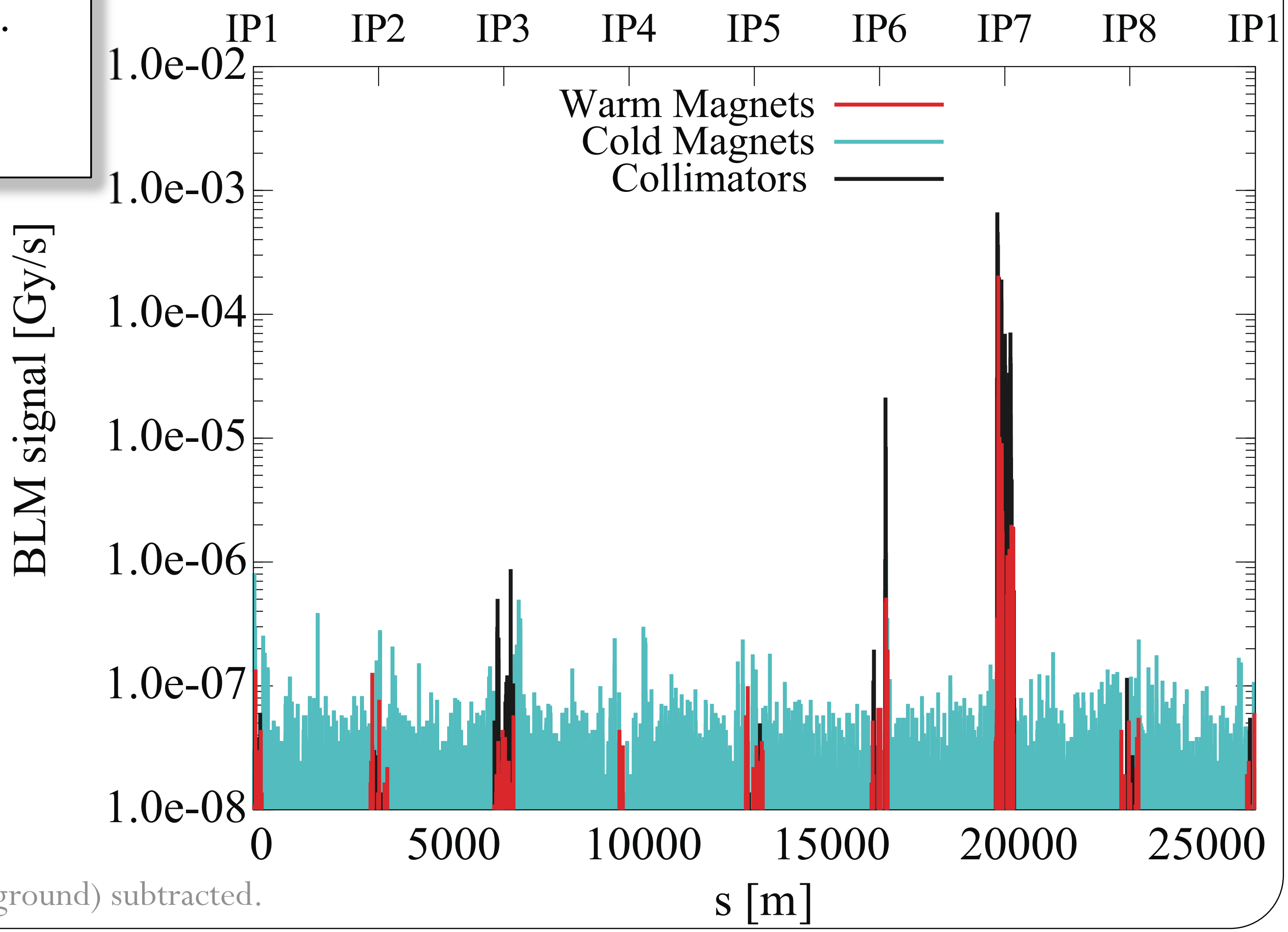
Beam based alignment:

	Beam 1		Beam 2	
TCLA	Beam Centre [mm]	Beam Size [μm]	Beam Centre [mm]	Beam Size [μm]
Hor.	0.2	683	0.2	693
Vert.	1.2	1051	1.4	**1048**

➔ Reasonable agreement, except beam2 vertical: how to explain 0.25mm difference in beam size?
➔ Indication of inaccurate collimator beam-based alignment (see also shift in centre) or drift?

Loss Map Beam 1 Injection for Full Setup

Same loss pattern as previous alignment.
Factor of 30 lower losses in IR3.

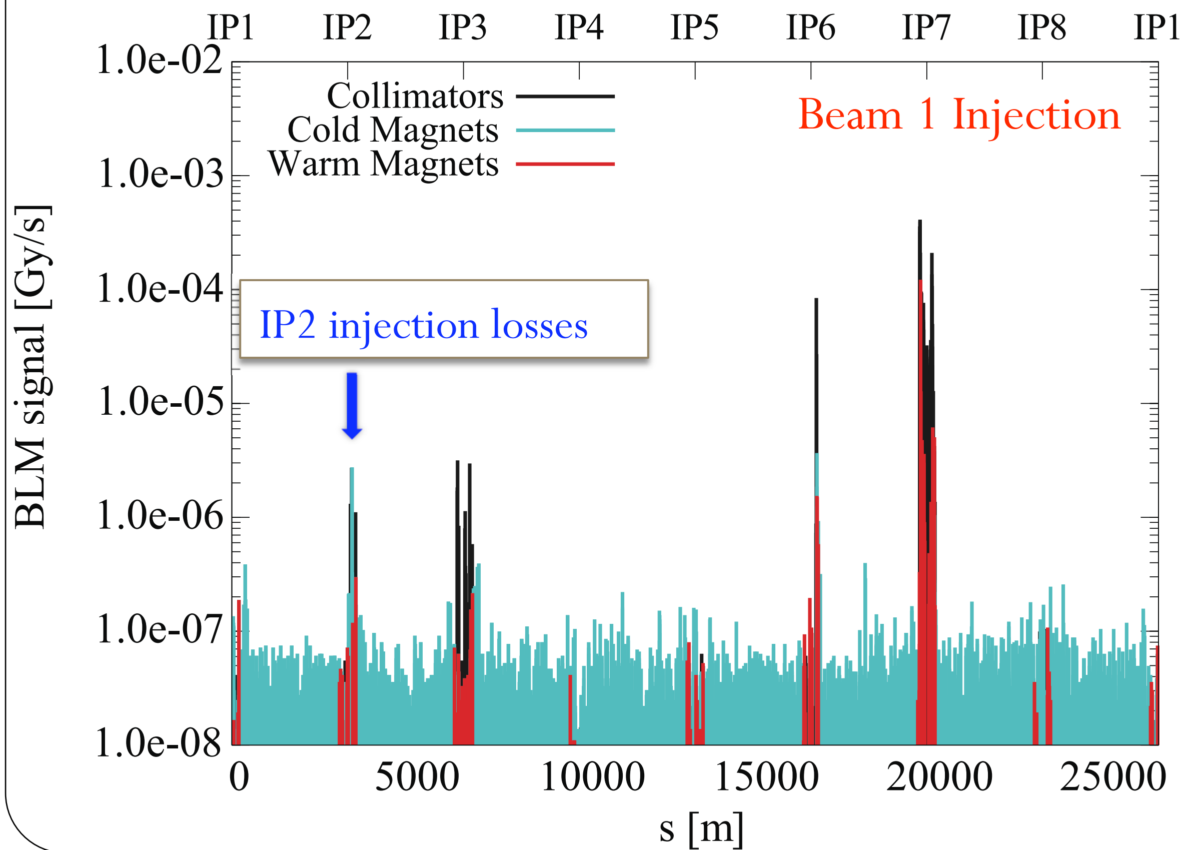


Offset without beam (background) subtracted.

December 5th : Third Collimator Setup

Re-setup collimation after power cut.

- Golden orbit re-established
- Collimators set at the settings defined on November 29th. No retuning was performed but we relied on machine and optics reproducibility.



Both beams injected with ~30% intensity loss.

Collimator setup still valid after 6 days! Not as good as before but hierarchy OK! TDI too tight (see Wolfgang's talk)

Reference settings in the sequencer!

Offset without beam (background) subtracted.

Thresholds Setup During 2009 First LHC Beam

Low beam intensity allowed to keep the collimators with static settings during all the phases of the machine cycle.

Position dependent thresholds set up ➔ interlocks if outside of limits:

a) All IR3 and IR7 collimators: limits at ±0.5mm around defined position

b) All tertiary collimators: limits at ±1mm around defined position

Also set position dependent thresholds for injection protection collimators (TDI) which have to be moved IN during injection and OUT for stable beam.

Energy dependent thresholds active but relaxed: maximum gap = 60 mm.

All Interlocks Generated by collimators (during beam commissioning)

Date & Time	Beam	Activity	Collimator	Remarks
23.11.09, 10:14	B2 Interlocked	Collimators in IR7 set to coarse settings	TCLA.A7L7.B2 TCLA.D6L7.B2	Position out of limits, interlock active
01.12.09, 04:32	B1 dumped	Open TCTH in IR1 to ±15mm due to losses	TCTH.4L1.B1	Position out of limits, interlock active
02.12.09, 23:11	B1 dumped	B1 collimators set to coarse settings	TCTH.4L1.B1 TCTVA.4L1.B1	Position out of limits, interlock active
05.12.09, 14:11	B1 dumped	Start of collimator studies (no entry in logbook)	TCTVA.4L1.B1 TCTVA.4L5.B1 TCTH.4L1.B1 TCTH.4L2.B1 TCTH.4L5.B1 TCTH.4L8.B1	Position out of limits, interlock active
07.12.09	B2 Interlocked	Spontaneous problem.	TCLA.6L3.B2	600μm drift of LVDT-RD without movement
14.12.09, 00:53	B1 Interlocked	B1 collimators moved out of sequence to parking position	TCLIB.6R2.B1 TCLIA.4R2	Position out of limits, interlock active

Courtesy of D Wollmann

All Interlocks Generated by collimators (during beam commissioning)

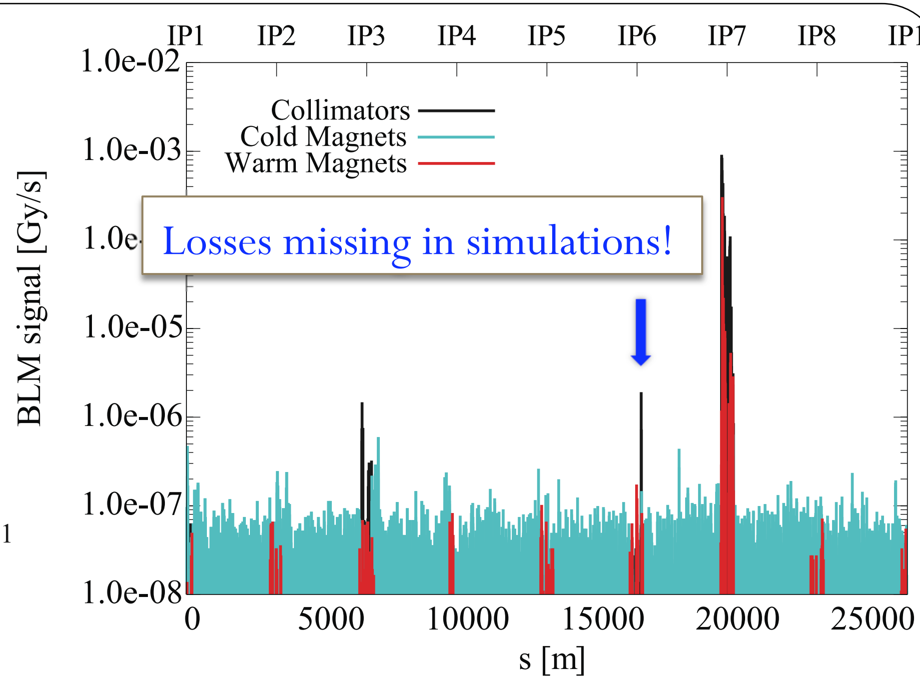
Date & Time	Beam	Activity	Collimator	Remarks
23.11.09, 10:14	B2 Interlocked	Collimators in IR7 set to coarse settings	TCLA.A7L7.B2 TCLA.D6L7.B2	Position out of limits, interlock active
01.12.09, 04:32	B1 dun	Open TCTH in IR1 to	TCTH.4L1.B1	Position out of limits, interlock active
02.12.09, 23:11	B dun		H.4L1.B1 A.4L1.B1	Position out of limits, interlock active
05.12.09, 14:11	B dun		A.4L1.B1 A.4L5.B1 H.4L1.B1 TCTH.4L2.B1 TCTH.4L5.B1 TCTH.4L8.B1	Position out of limits, interlock active
07.12.09	B2 Interlocked	Spontaneous problem.	TCLA.6L3.B2	600μm drift of LVDT RD without movement
14.12.09, 00:53	B1 Interlocked	B1 collimators moved out of sequence to parking position	TCLIB.6R2.B1 TCLIA.4R2	Position out of limits, interlock active

Only hardware problem caused interlock from the collimation system.
All other cases generated by inappropriate user requests: violating interlock limits!

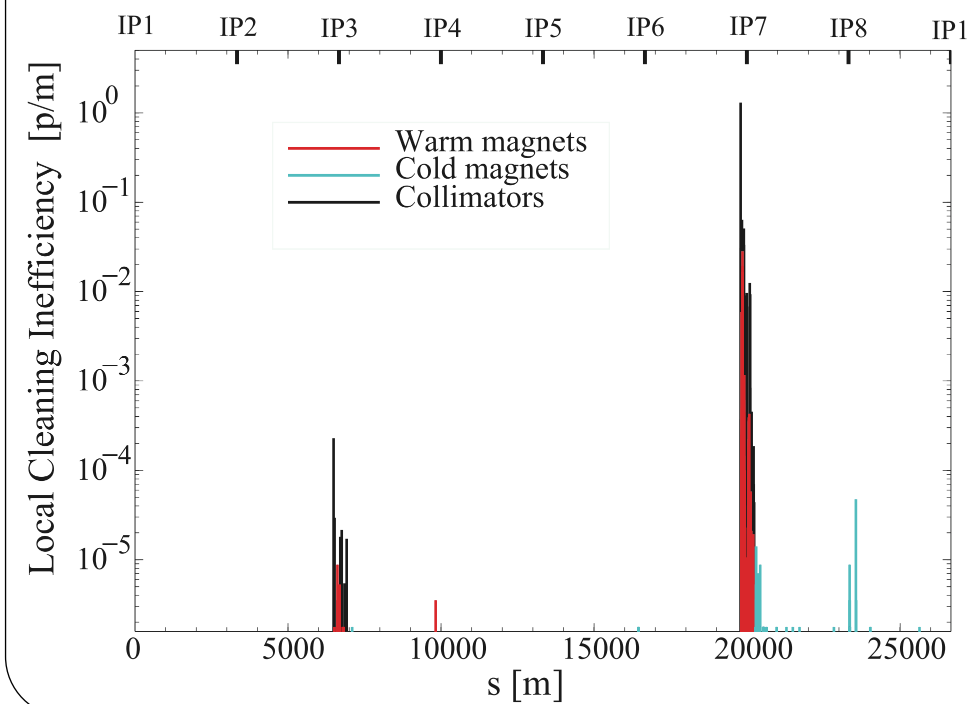
Courtesy of D Wollmann

Loss Map at Top Energy (Beam 1)

Measured loss map at 1.18TeV for Beam 1 (ramp of December 8th)



Offset without beam (background) subtracted.

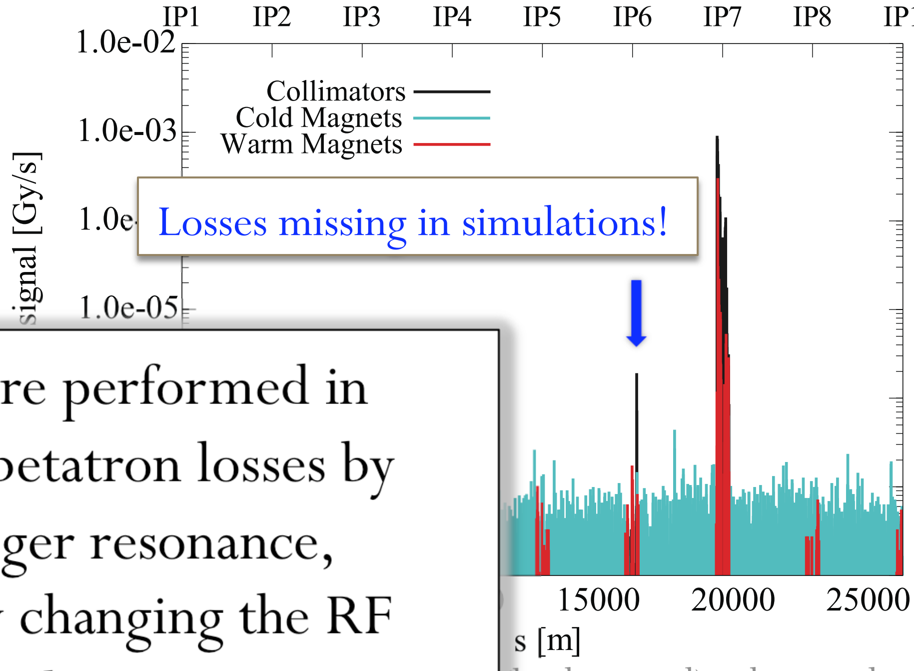


Simulated proton loss map at 1TeV for Beam 1

*note that shower development is not included, only primary proton losses.

Loss Map at Top Energy (Beam 1)

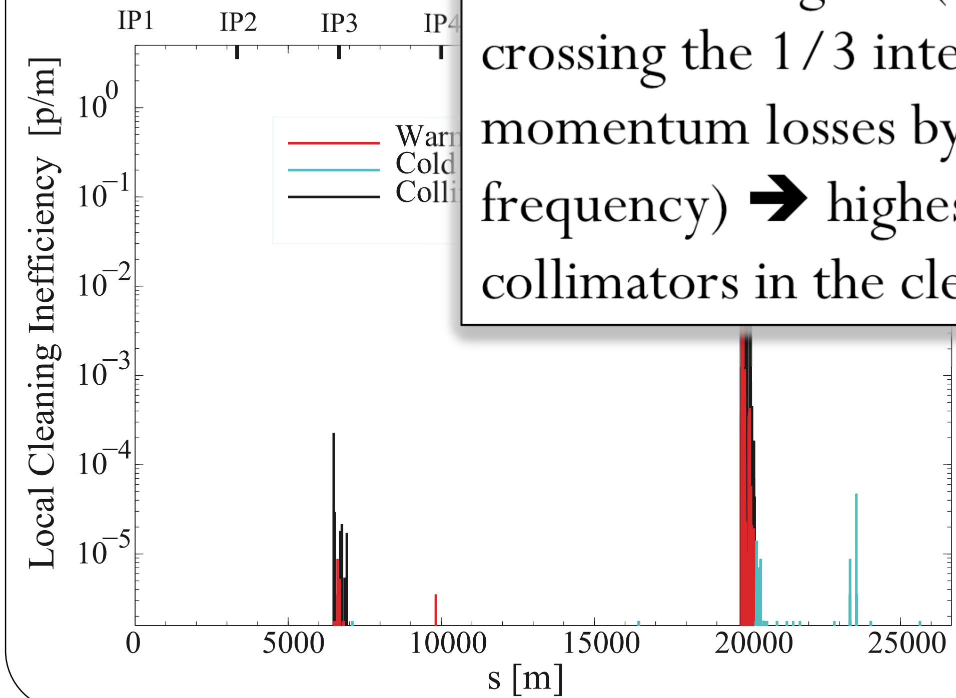
Measured loss map at 1.18TeV for Beam 1 (ramp of December 8th)



Losses missing in simulations!

(background) subtracted.

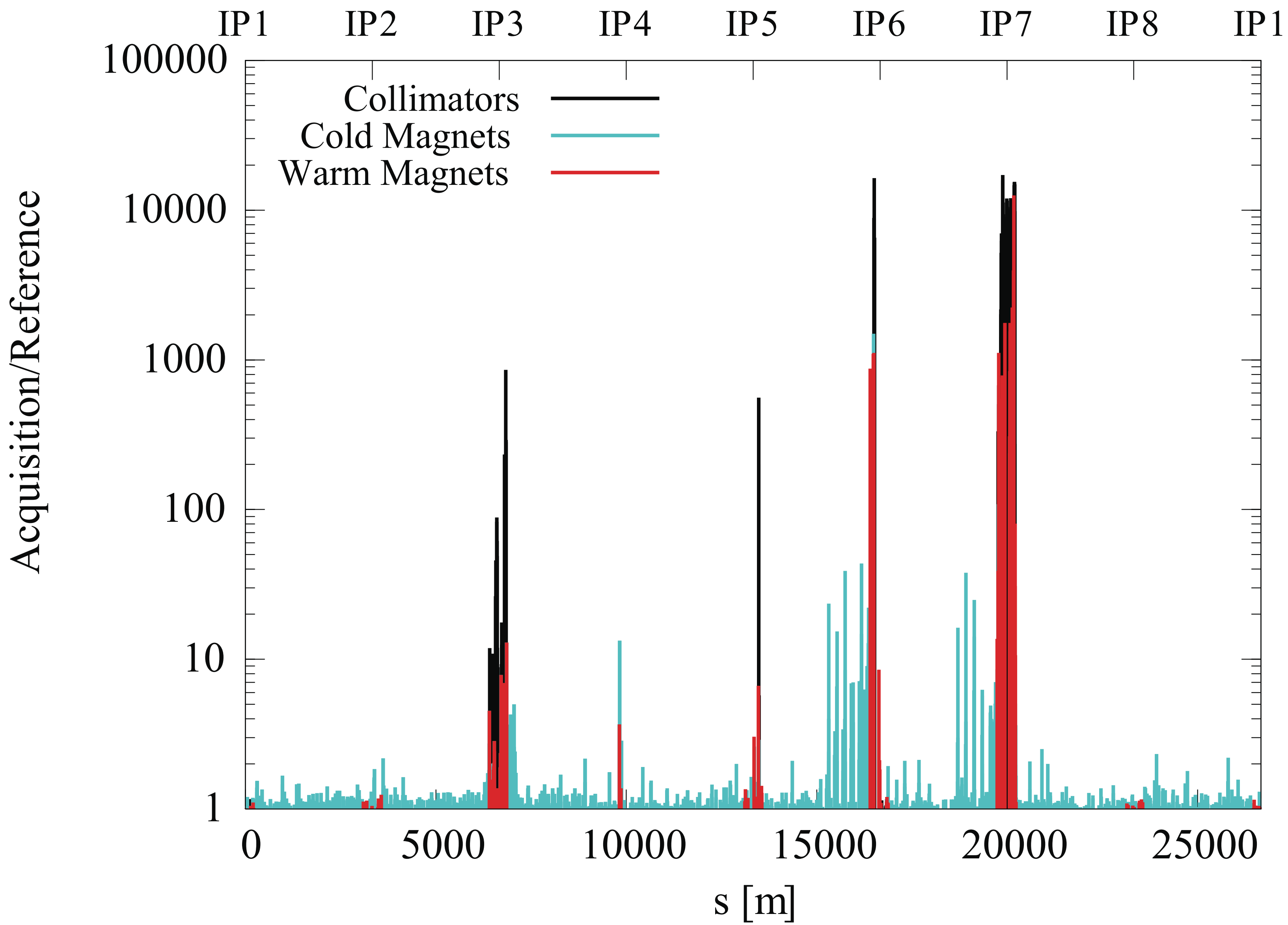
Beam loss studies were performed in several loss regime (betatron losses by crossing the 1/3 integer resonance, momentum losses by changing the RF frequency) ➔ highest losses at primary collimators in the cleaning insertions.



Simulated proton loss map at 1TeV for Beam 1

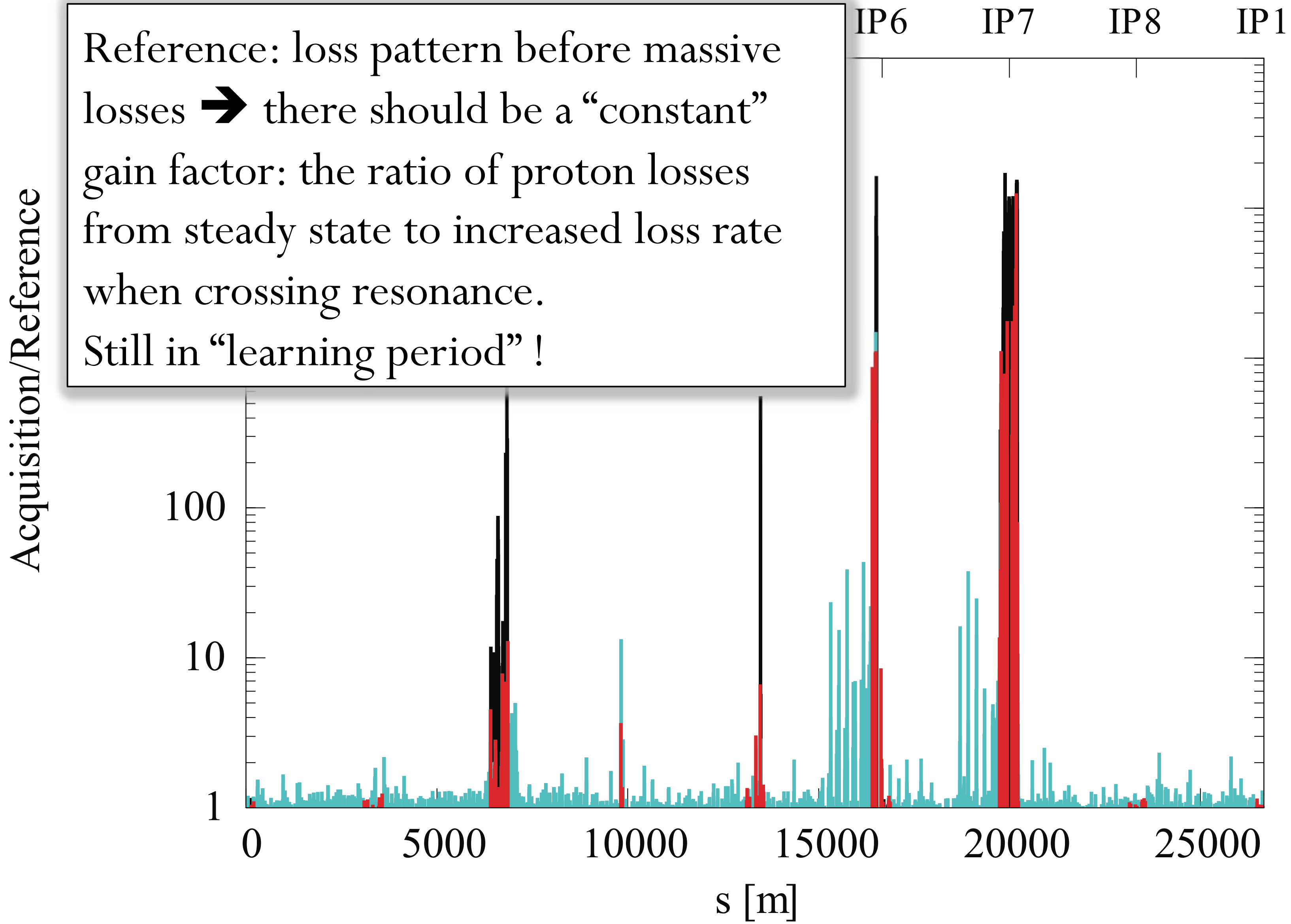
note that shower development is not included, only primary proton losses.

Loss Map Ratio Beam 2 Crossing 1/3 Integer Resonance (Qy)

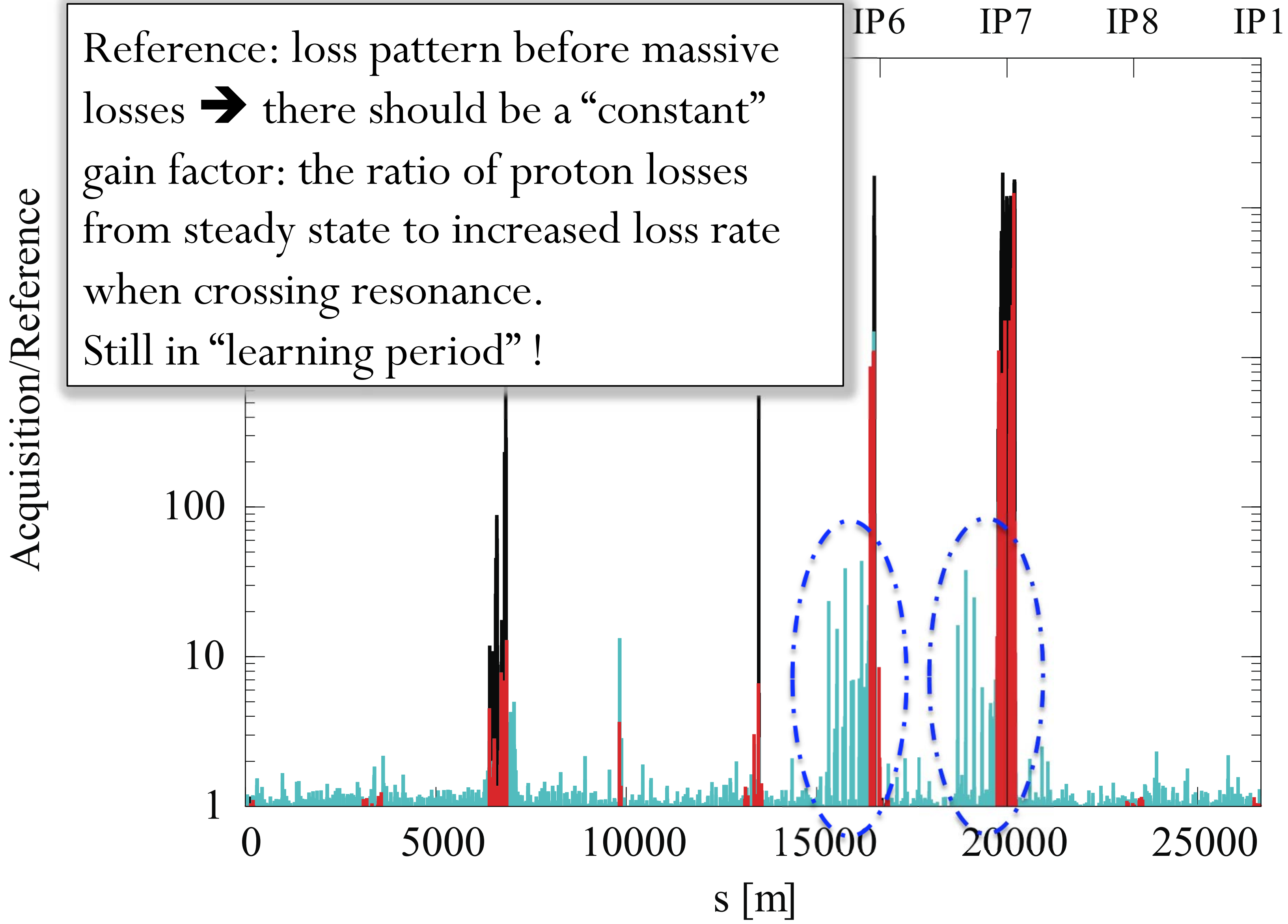


Loss Map Ratio Beam 2 Crossing 1/3 Integer Resonance (Qy)

Reference: loss pattern before massive losses ➔ there should be a "constant" gain factor: the ratio of proton losses from steady state to increased loss rate when crossing resonance.
Still in "learning period" !

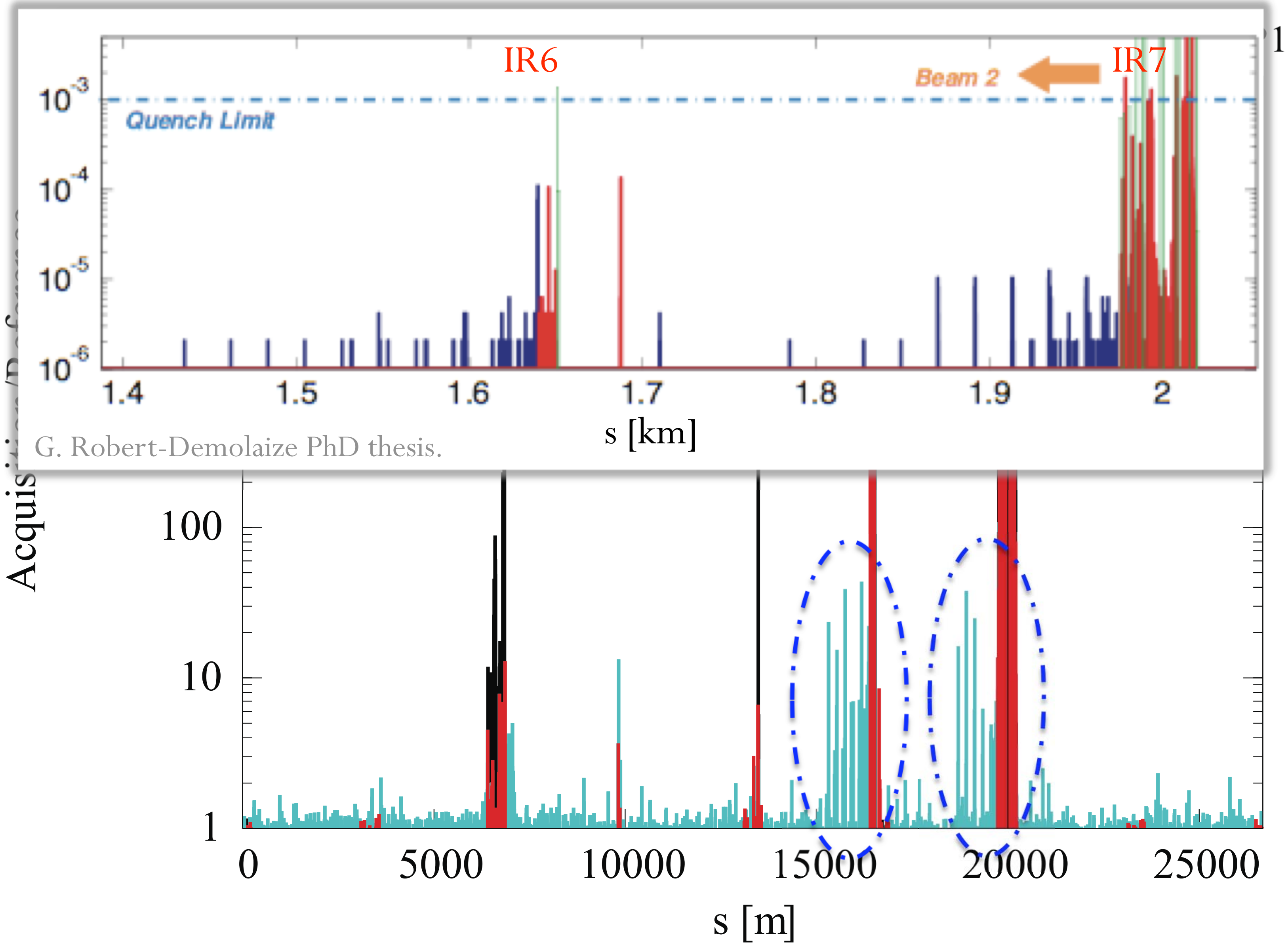


Loss Map Ratio Beam 2 Crossing 1/3 Integer Resonance (Qy)

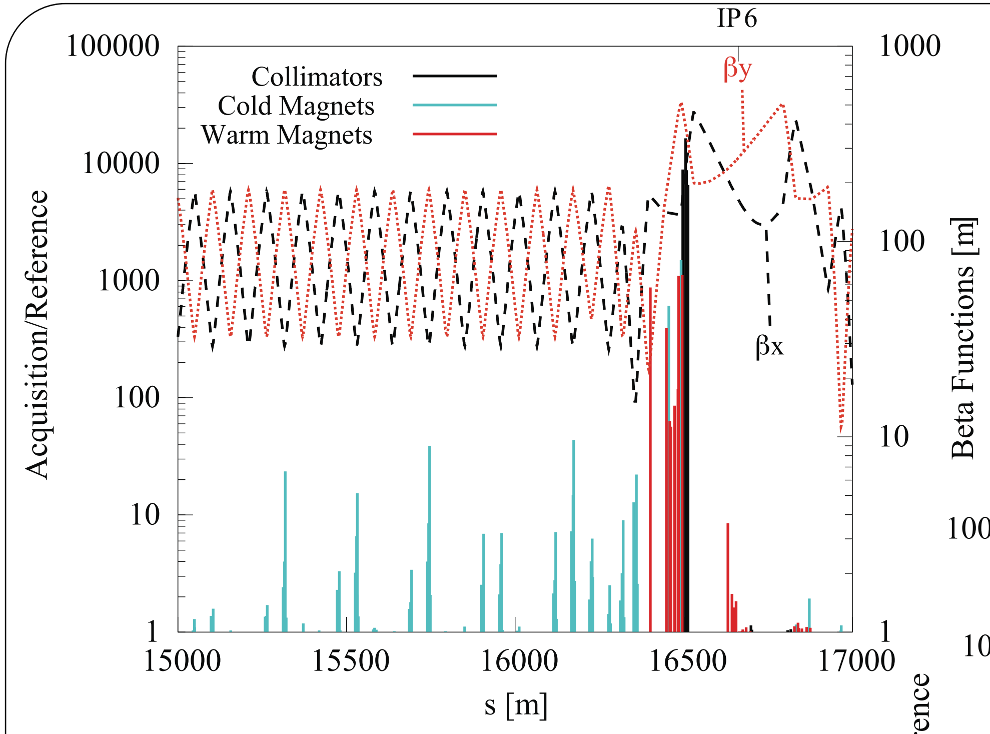


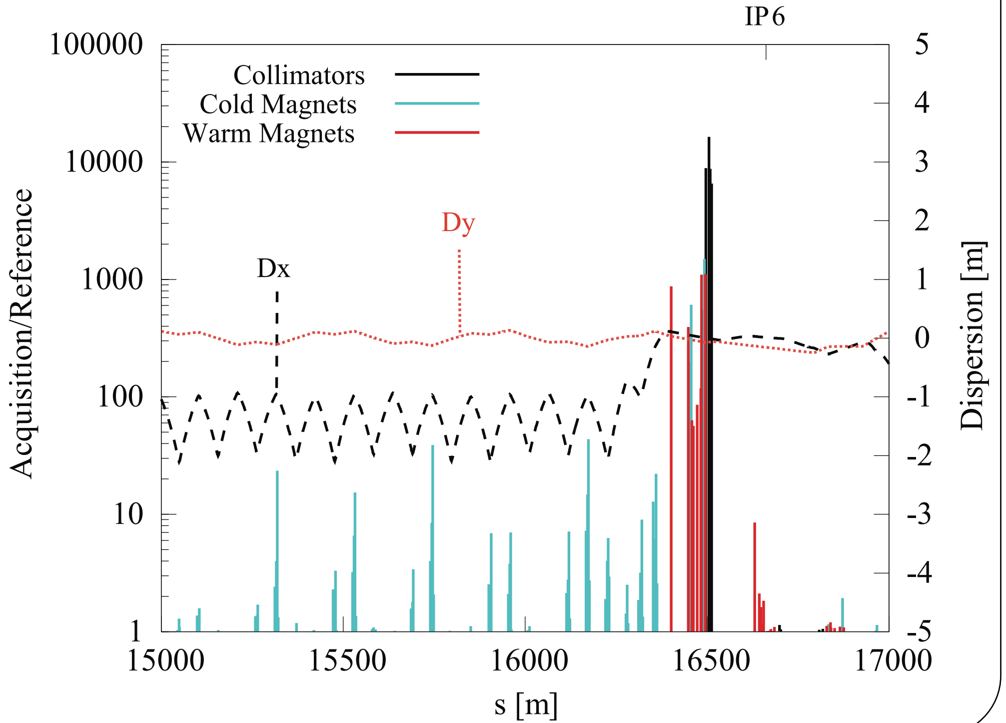
Reference: loss pattern before massive losses ➔ there should be a "constant" gain factor: the ratio of proton losses from steady state to increased loss rate when crossing resonance.
Still in "learning period" !

Loss Map Ratio Beam 2 Crossing 1/3 Integer Resonance (Qy)

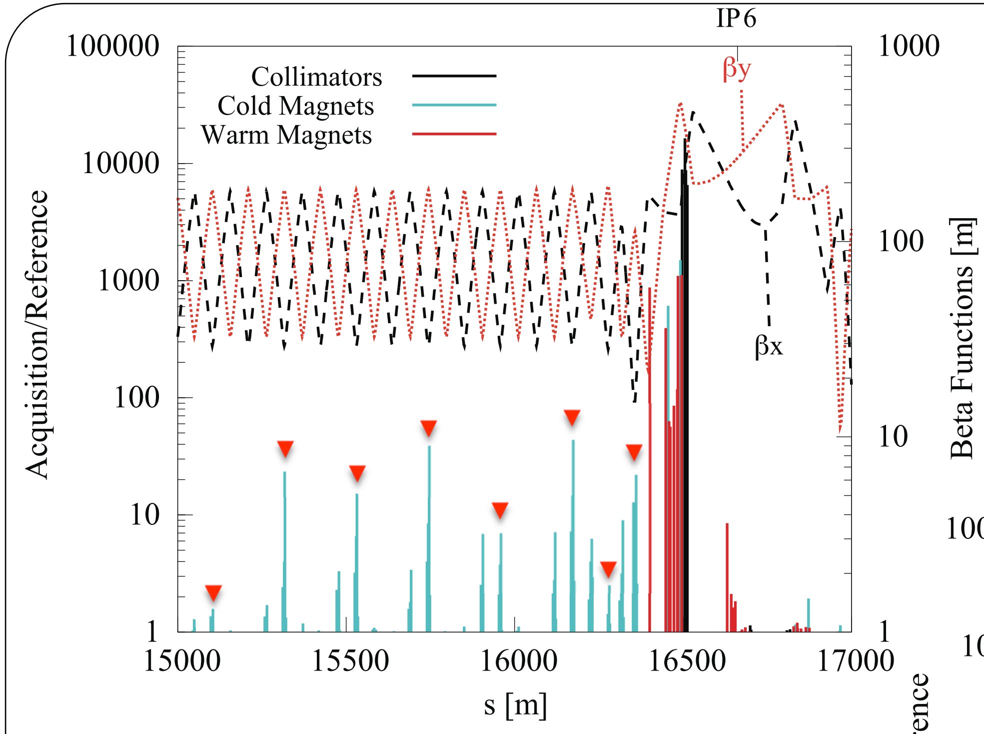


Loss Ratios Downstream of IR6 (Beam 2)



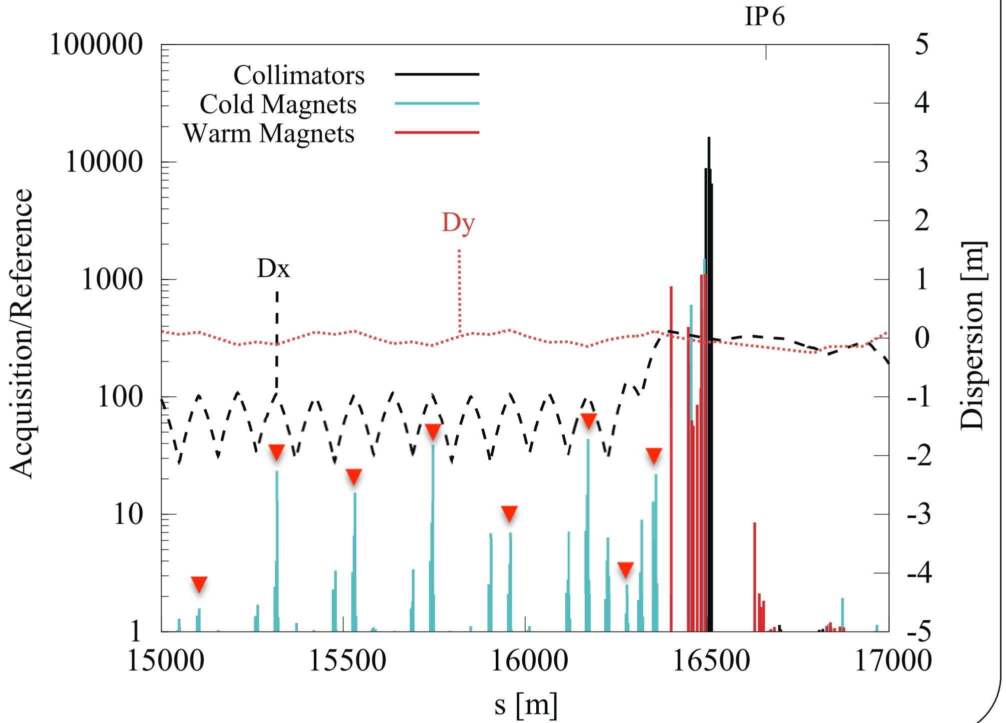


Loss Ratios Downstream of IR6 (Beam 2)

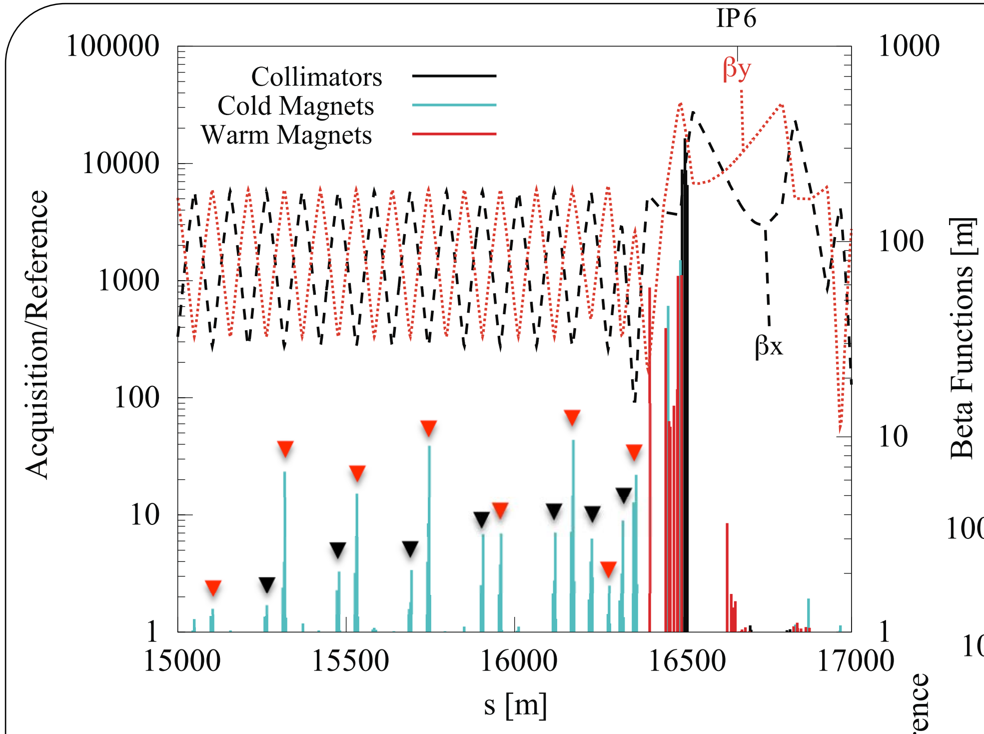


Red arrows:

Maximum βy

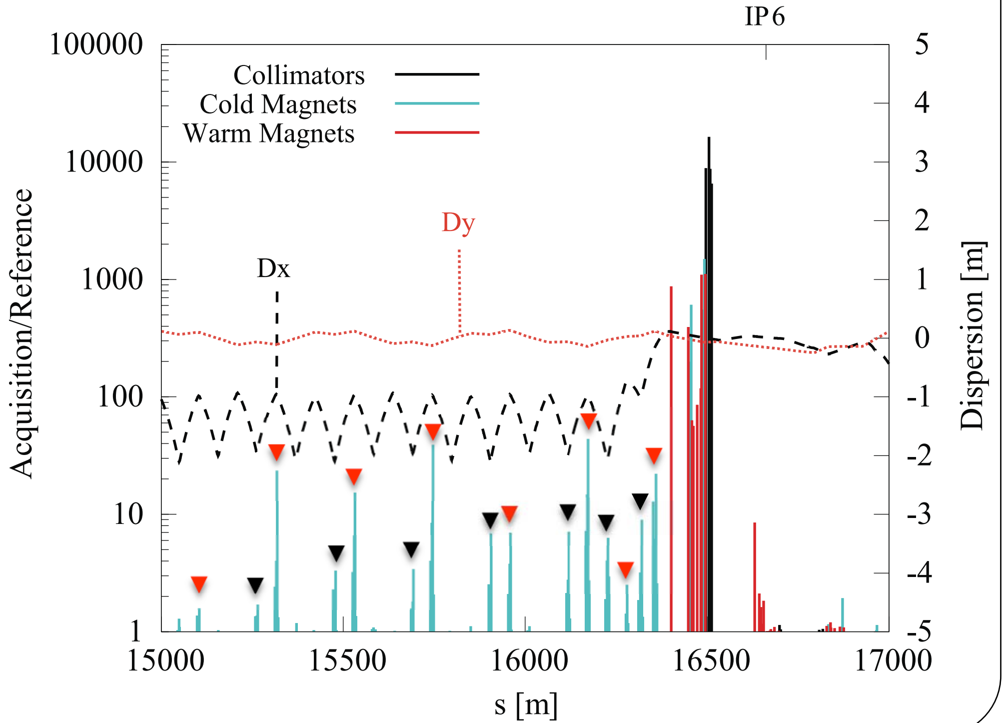


Loss Ratios Downstream of IR6 (Beam 2)



Red arrows:

Maximum βy

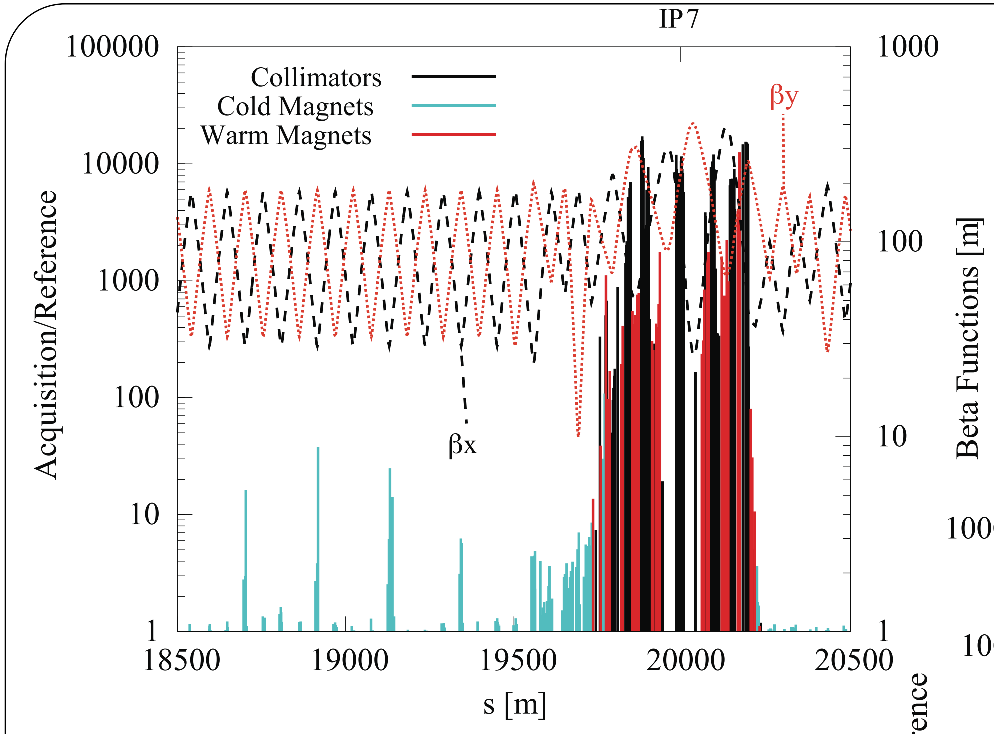


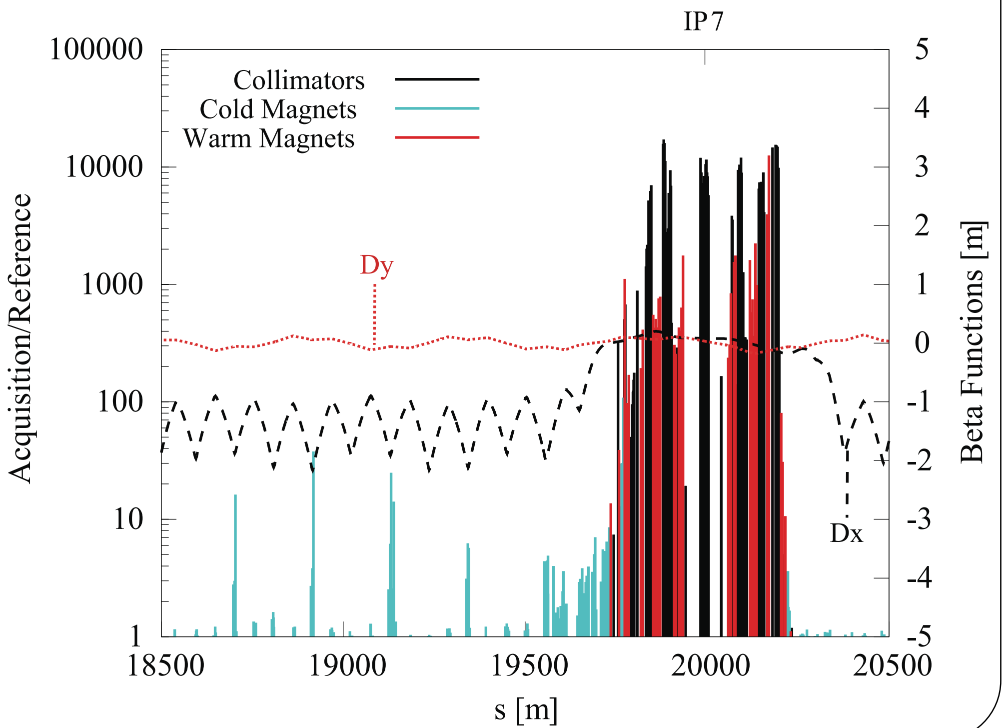
Black arrows:

Maximum βx

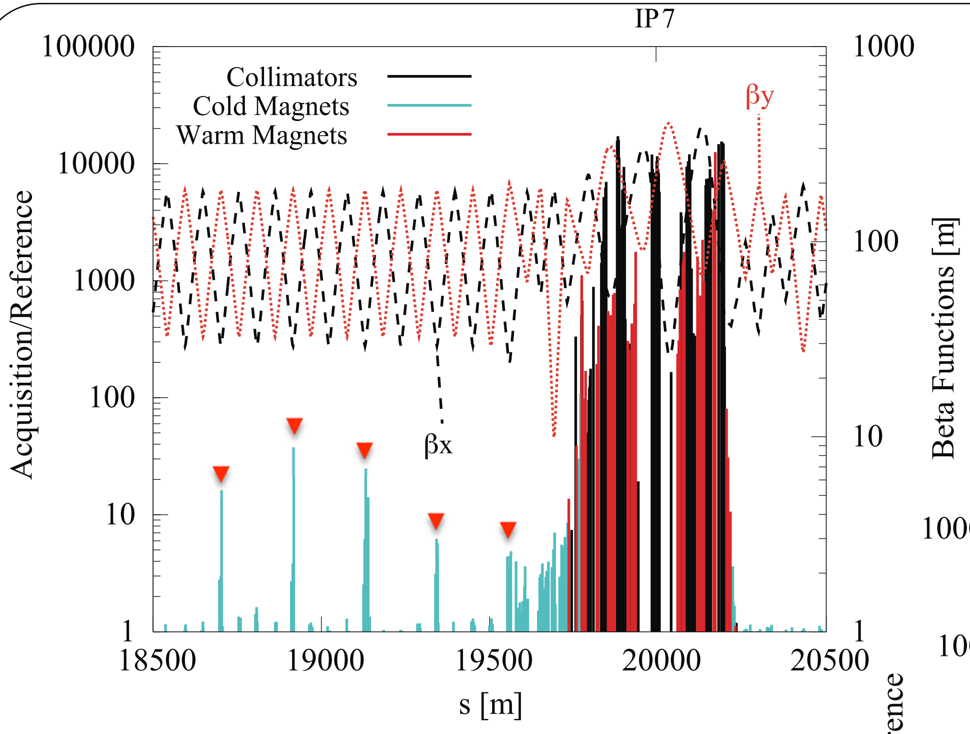
Maximum Dx

Loss Ratios Downstream of IR7 (Beam 2)



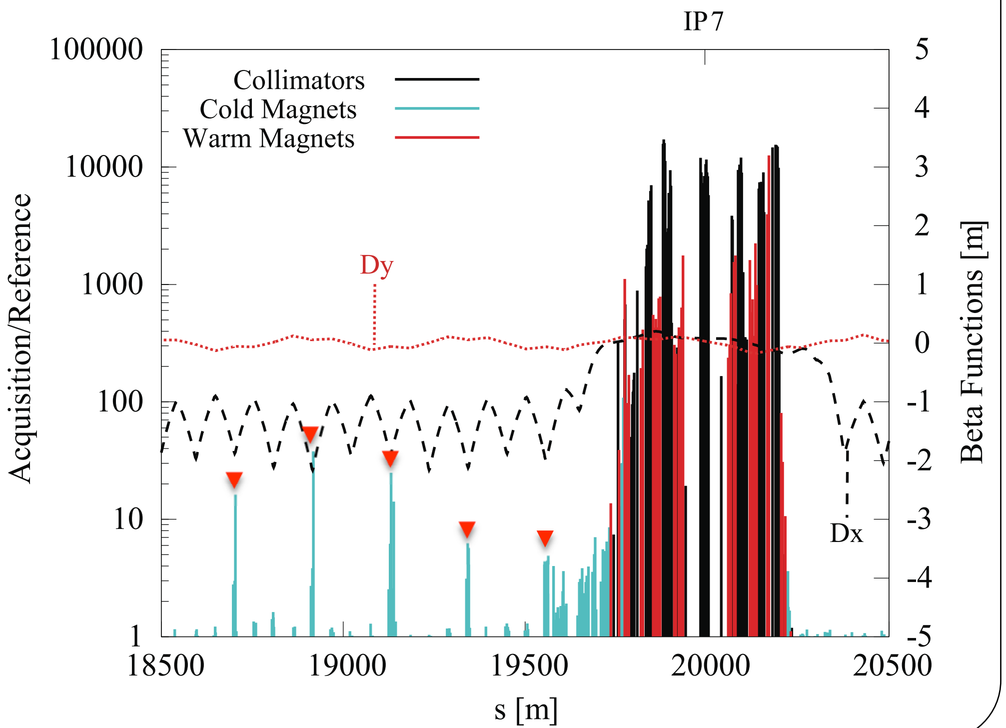


Loss Ratios Downstream of IR7 (Beam 2)

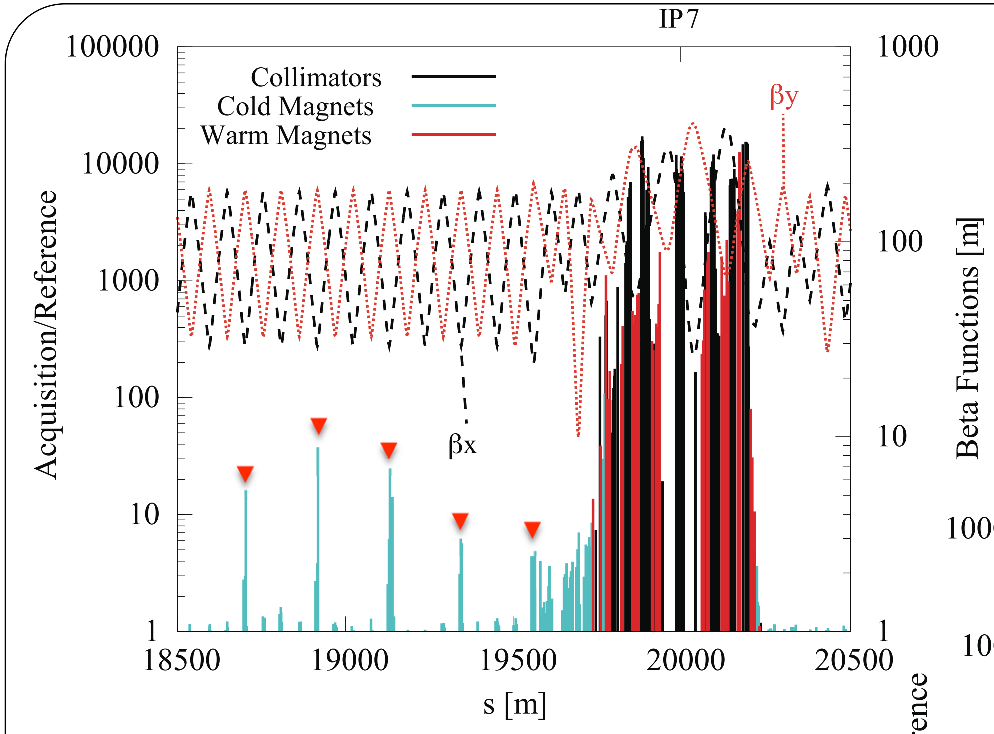


Red arrows:

Maximum βy

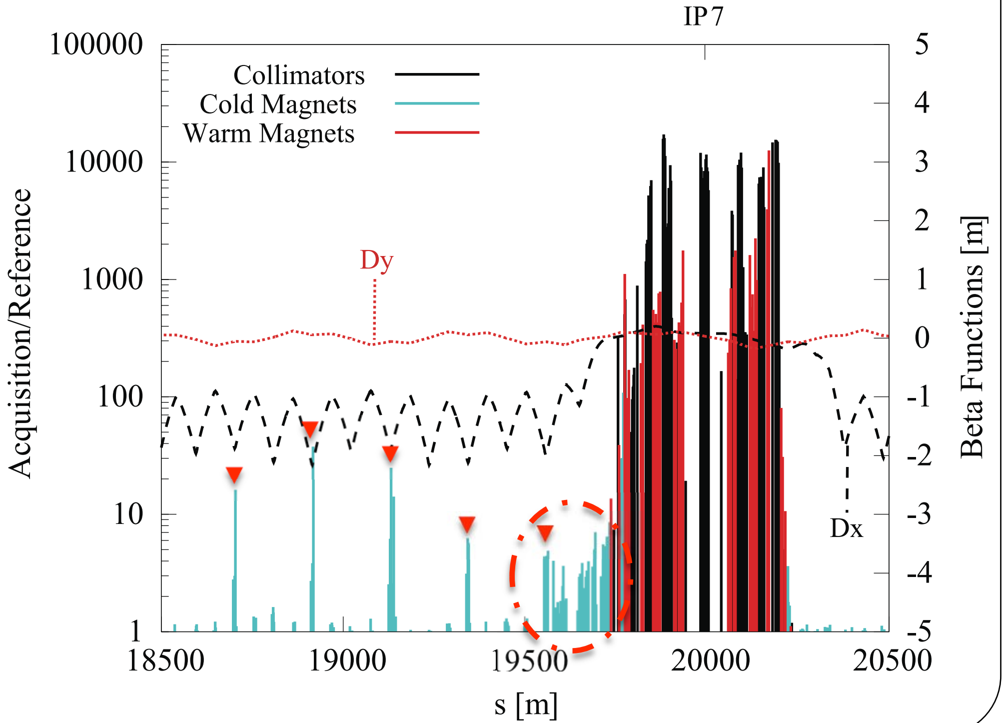


Loss Ratios Downstream of IR7 (Beam 2)



Red arrows:

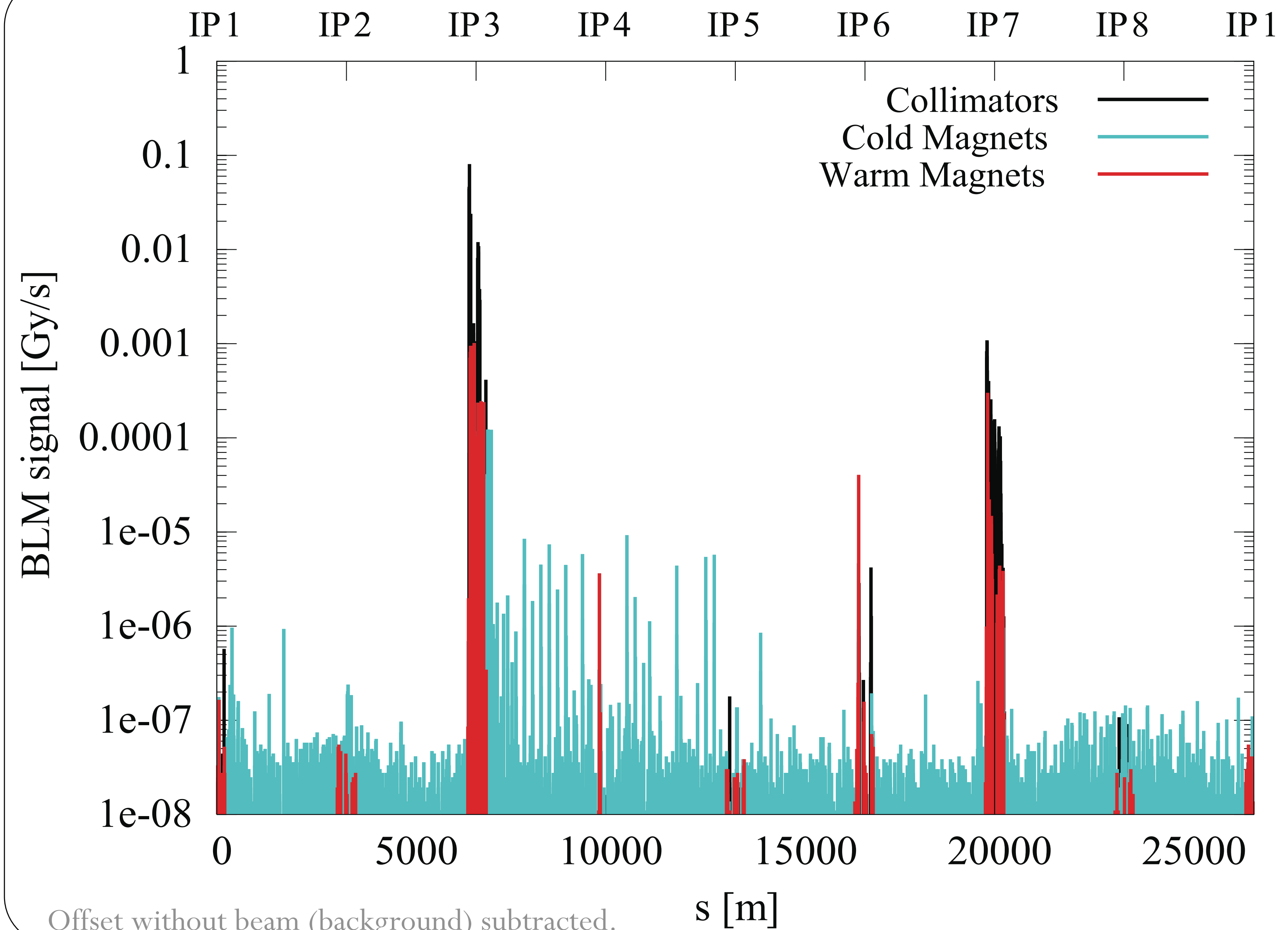
Maximum βy



Red circle:

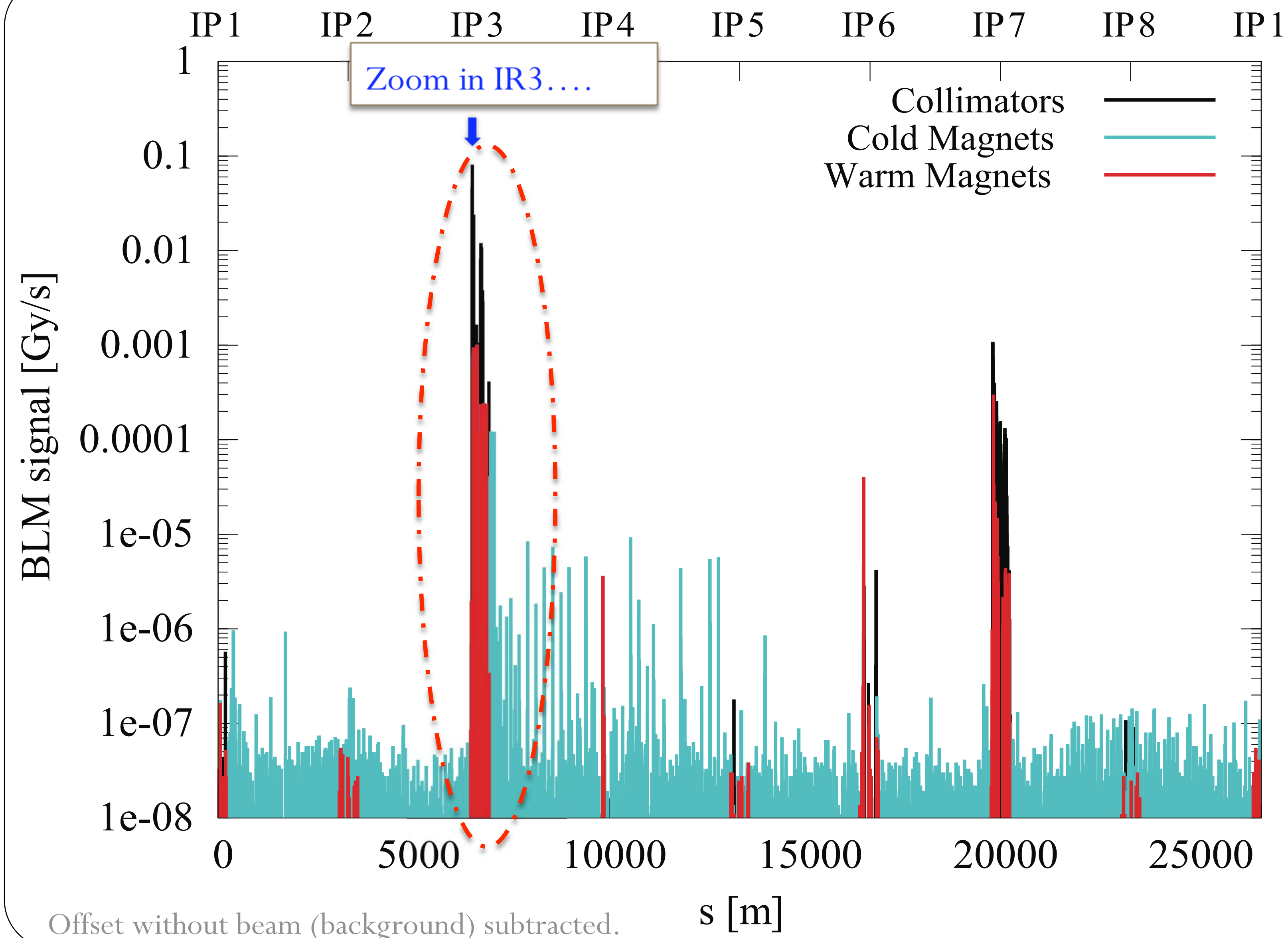
Dispersion suppressor

Loss Map Beam 1 Changing RF frequency



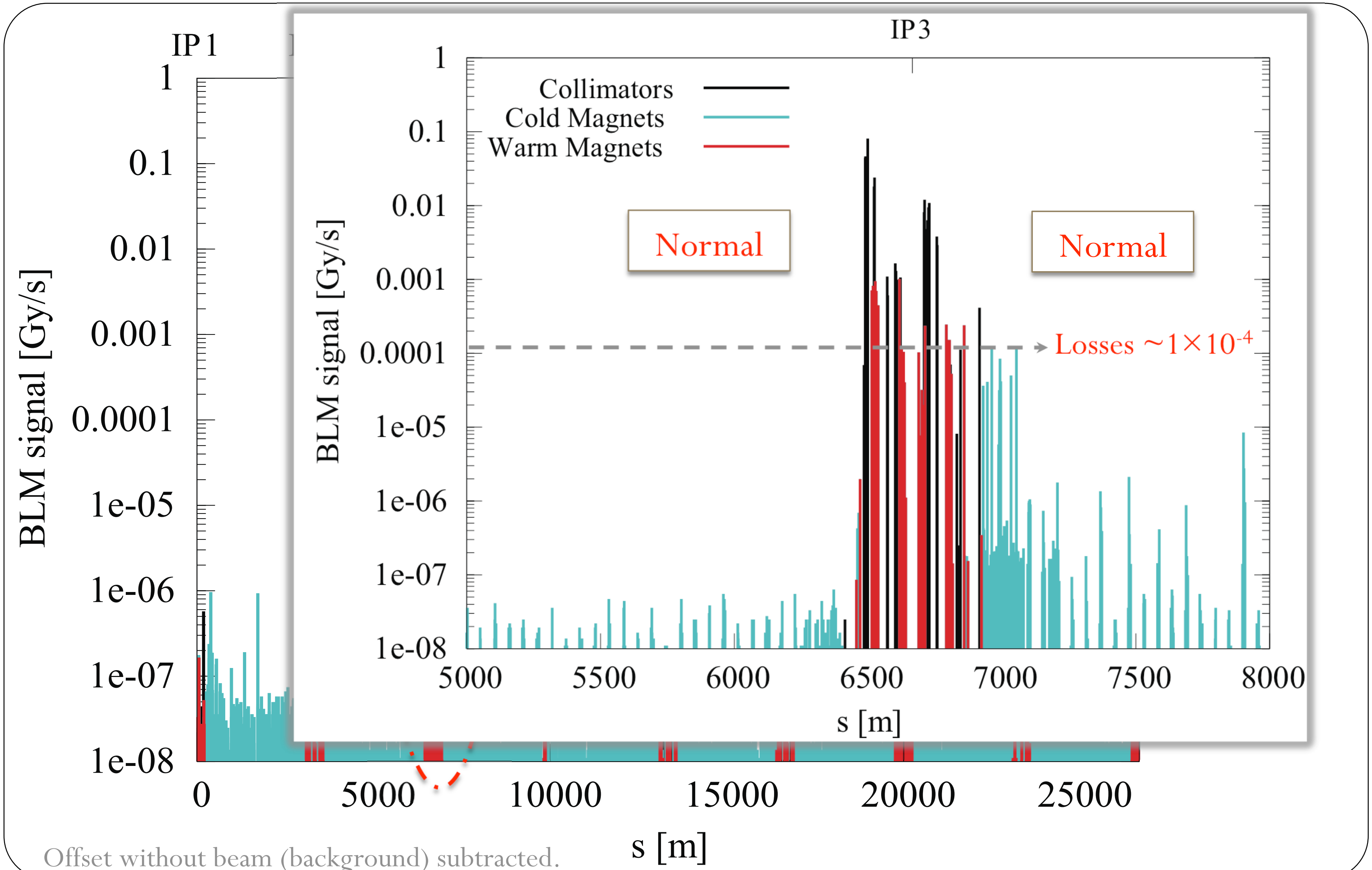
Offset without beam (background) subtracted.

Loss Map Beam 1 Changing RF frequency



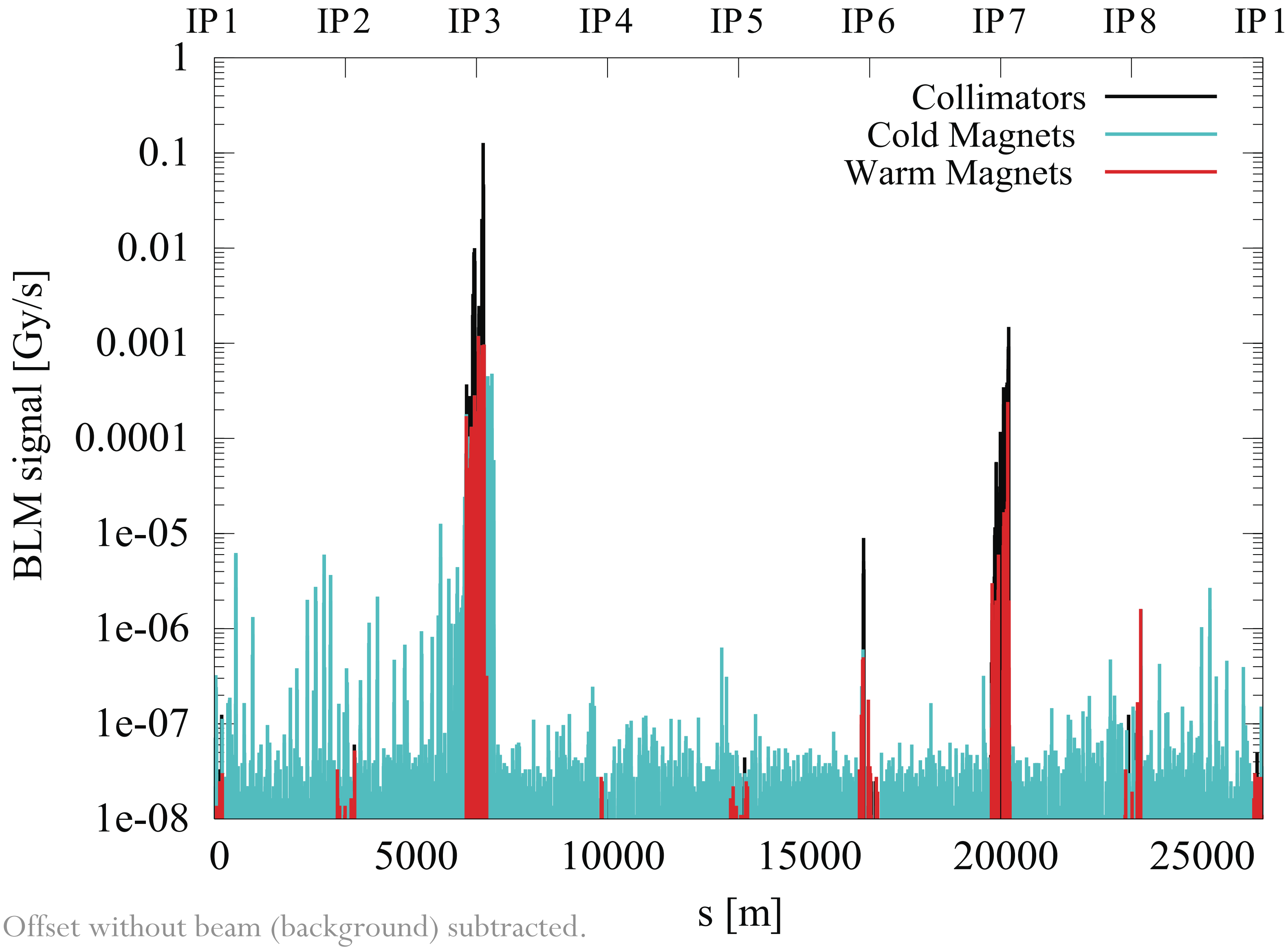
Offset without beam (background) subtracted.

Loss Map Beam 1 Changing RF frequency



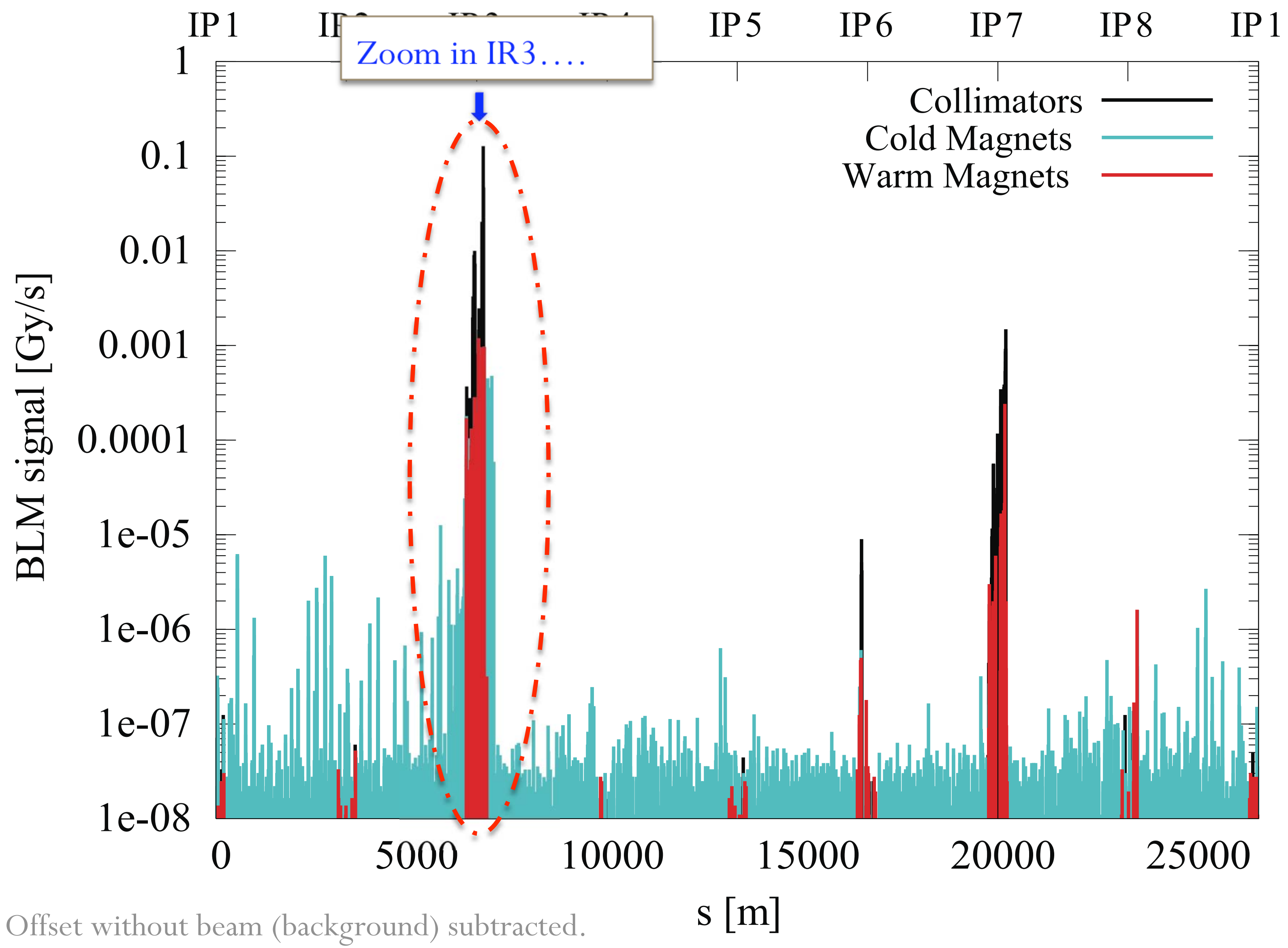
Offset without beam (background) subtracted.

Loss Map Beam 2 Changing RF frequency



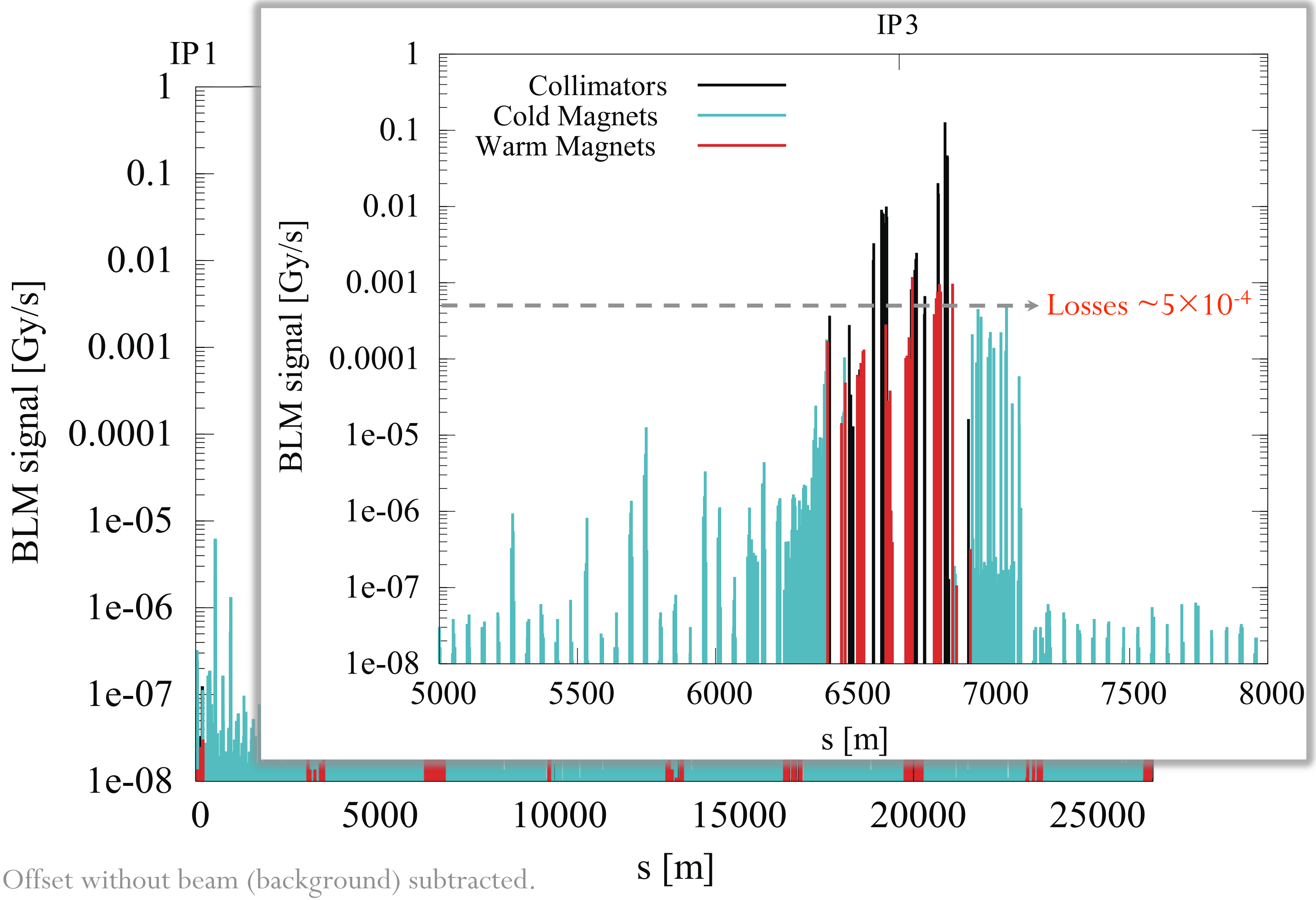
Offset without beam (background) subtracted.

Loss Map Beam 2 Changing RF frequency



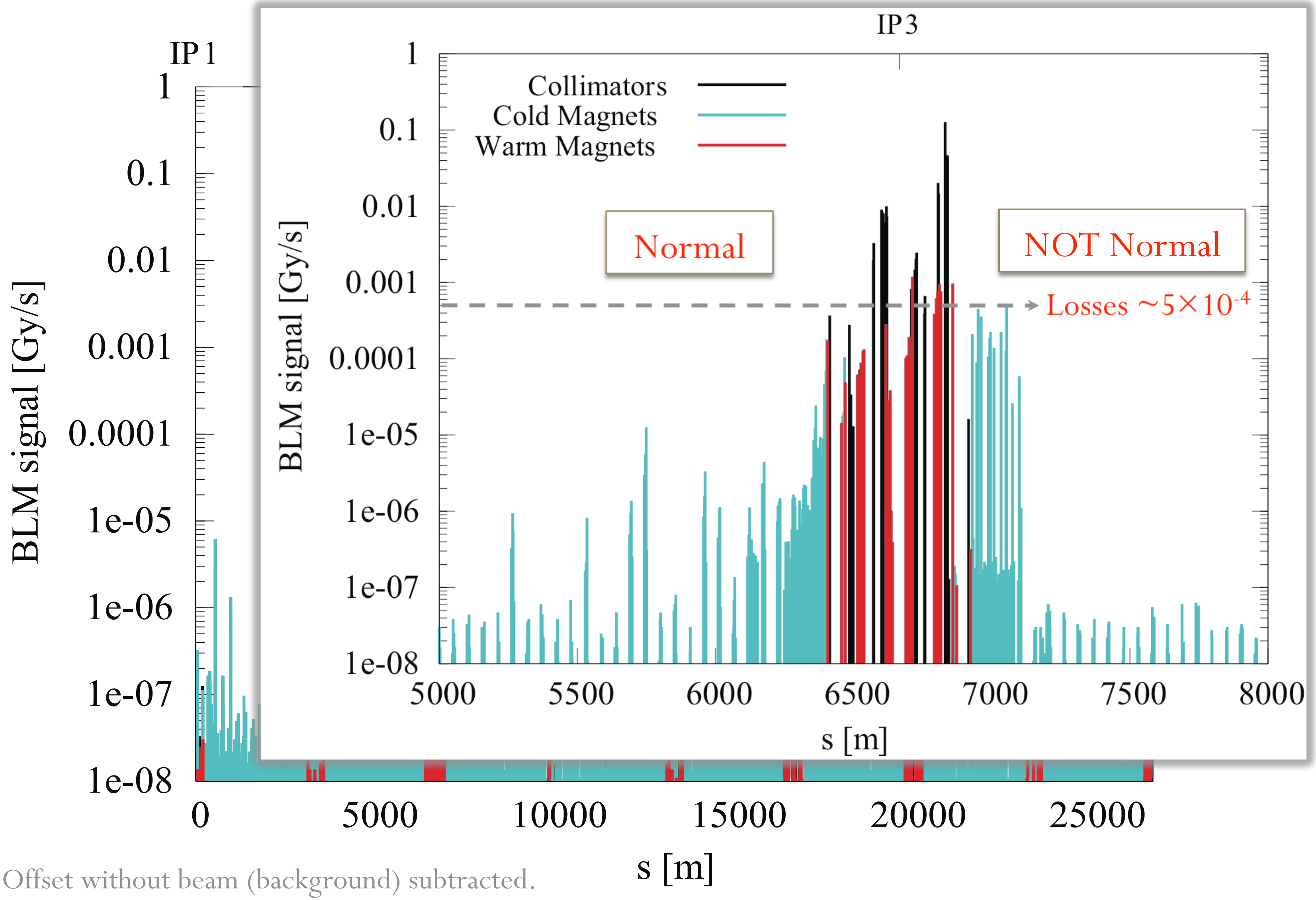
Offset without beam (background) subtracted.

Loss Map Beam 2 Changing RF frequency



Offset without beam (background) subtracted.

Loss Map Beam 2 Changing RF frequency



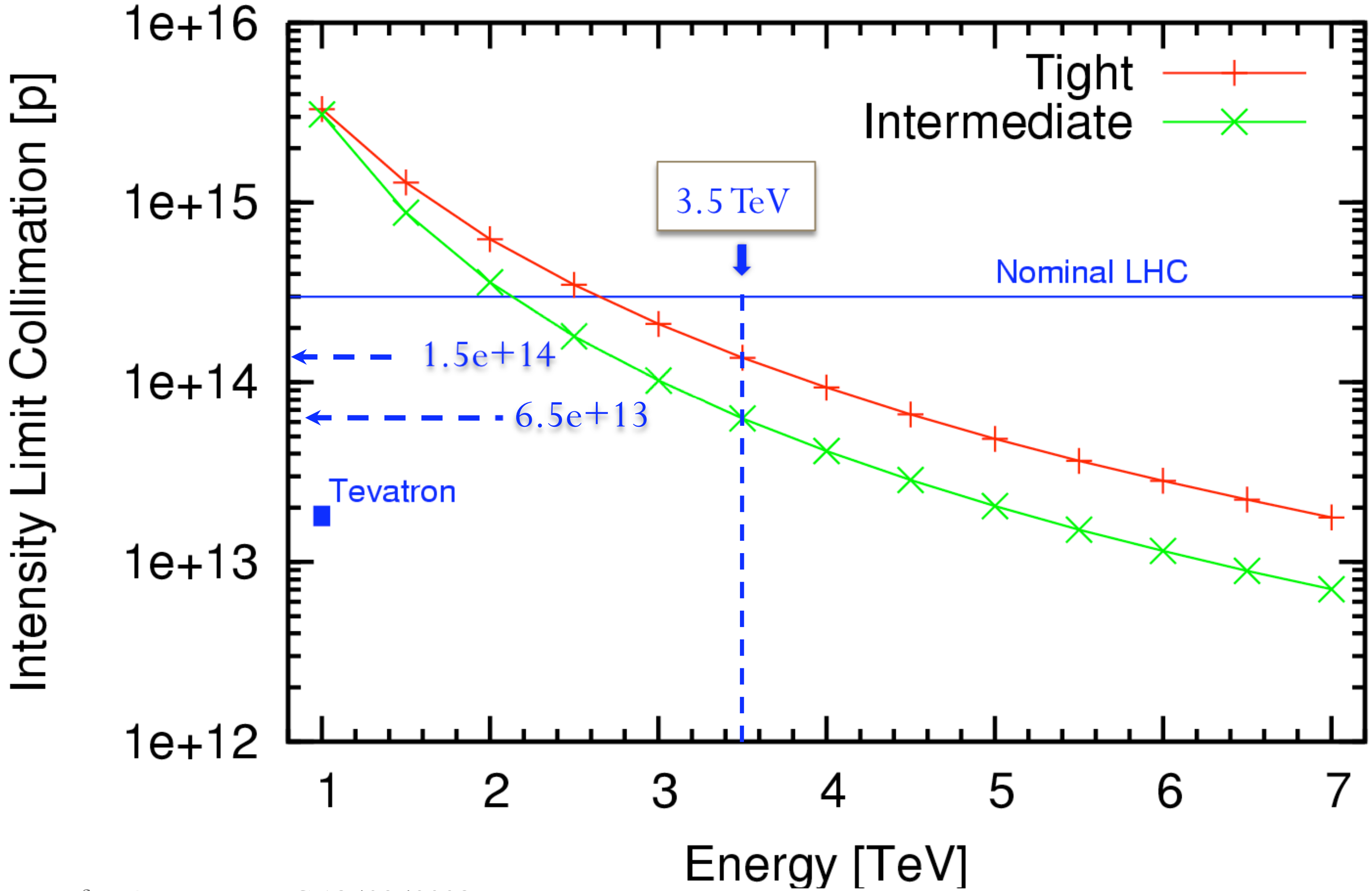
Offset without beam (background) subtracted.

Lessons learnt, including the unexpected…

- System works as designed. Nice start of beam commissioning for LHC collimation. Expected cleaning and leakage processes seen.
- Possible to verify passive protection: losses at primary collimators.
- Beam-based settings different from theoretical: why? Need to understand in more detail. More beam time.
- Drift LVDT: tracked to problem of backplane connection in one rack.
- Wrong sequence ➔ collimators parking ➔ interlocks. Safe but not nice. Follow logical & debugged sequence is essential. Cannot set up by hand.
- Abnormal losses in right dispersion suppressor of IR3: why? Leftover alignment error from 3-4 incident? Needs to be understood.
- Power cut: all collimators could be reset by STI piquet quite fast (~2h). This is a feature, as controls is on UPS, not the high power drivers.
- Need faster analysis for loss maps, collimator movements, interlocks, …

Expected Intensity Reach (no reason to doubt our simulations, so far)

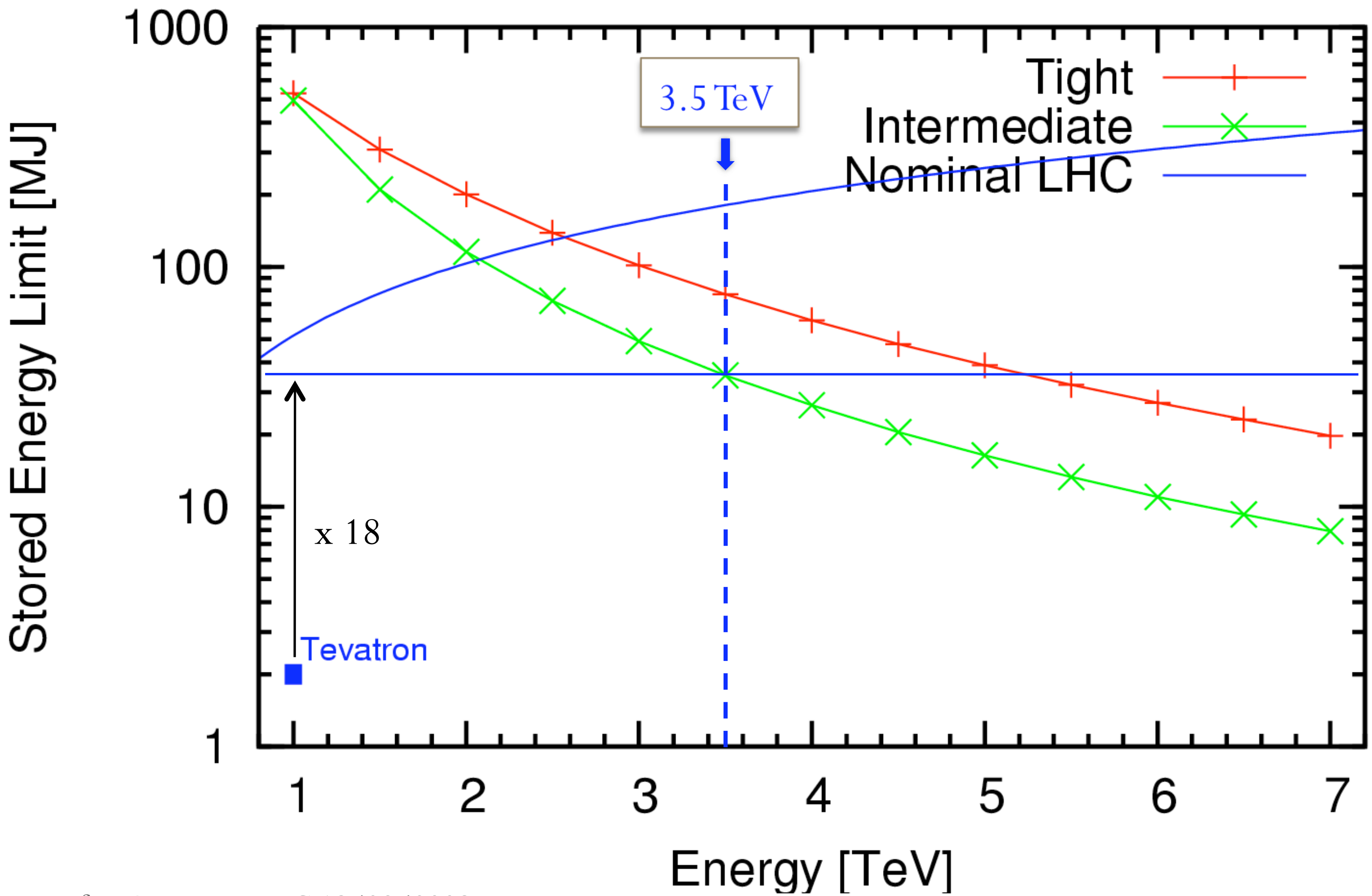
Peak beam loss rate: 0.2 %/s



Courtesy of R. Assmann, LMC 19/03/2009

Expected Reach Stored Energy (no reason to doubt our simulations, so far)

Peak beam loss rate: 0.2 %/s



Courtesy of R. Assmann, LMC 19/03/2009

Future Plans

- Further understanding of loss locations and collimation leakage (qualitatively looks as expected on first analysis).
- Assure BLM thresholds at factor of 3 below quench limit (together with BLM team).
- Commission variable collimator settings during ramp with beam (first with tolerance optimized settings then nominal settings).
- Change of collimator settings during squeeze to be commissioned with beam.
- Automatic procedure for MP temperature interlock verification (as exists for rest).
- Beam-based alignment at higher beam energy.
- Better accuracy alignment for higher intensity and energy.
- Performance commissioning with higher loss rates (up to 5 kW tested, goal is 500 kW to 1,000 kW).