Cleaning and Collimator Operation Outlook

B. Salvachua

for the Collimation Team

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Many thanks to

OP, ADT, Injection and Dump Protection, BLM and STI teams

Evian 2012

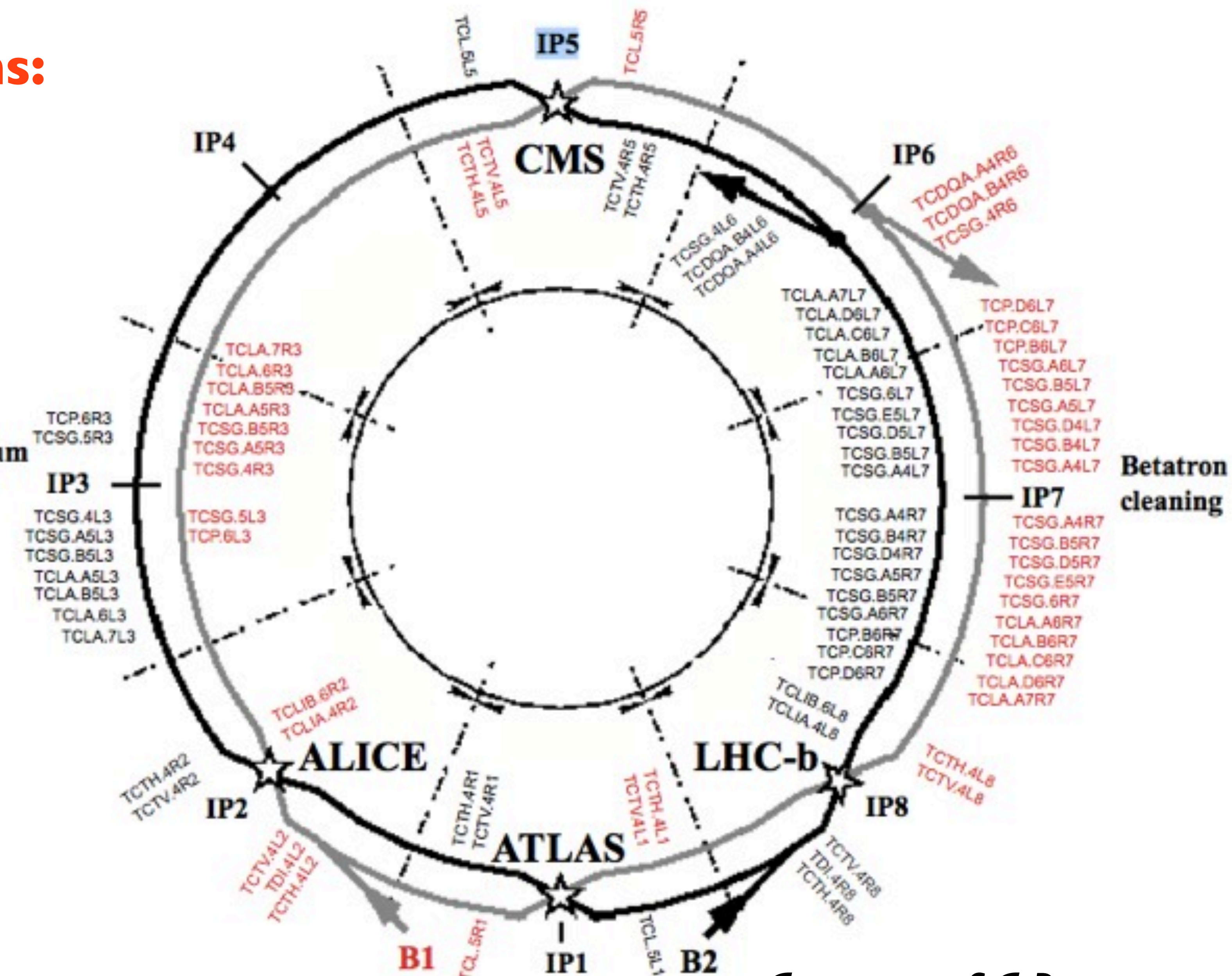
Outline

- Collimation system 2010-2012
  - Tight collimator settings
  - System performance
    - Collimation Setup
    - Loss maps and Cleaning
    - Physics Debris Cleaning
  - Lifetime thought the cycle
- Studies towards LS1
  - Collimators with BPMs buttons
  - Proposal of collimator settings
  - β* reach after LS1
- Summary

Collimation Performance 2010-2012

LHC Collimation Layout

- **Two warm cleaning insertions:**
  - IR3: momentum cleaning
    - 1 Primary (H)
    - 4 Secondaries (H/S)
    - 4 Shower Abs. (H/V)
  - IR7: betatron cleaning
    - 3 Primaries (H/V/S)
    - 11 Secondaries (H/V/S)
    - 5 Shower Abs. (H/V)
- **Local cleaning at triplets**
  - 8 tertiaries: 2 per IP per Beam
- **Physics debris absorption**
  - 2 TCL (1 per beam IP1/IP5)



Courtesy of C.Bracco

8 passive absorbers for warm magnets in IP3/IP7

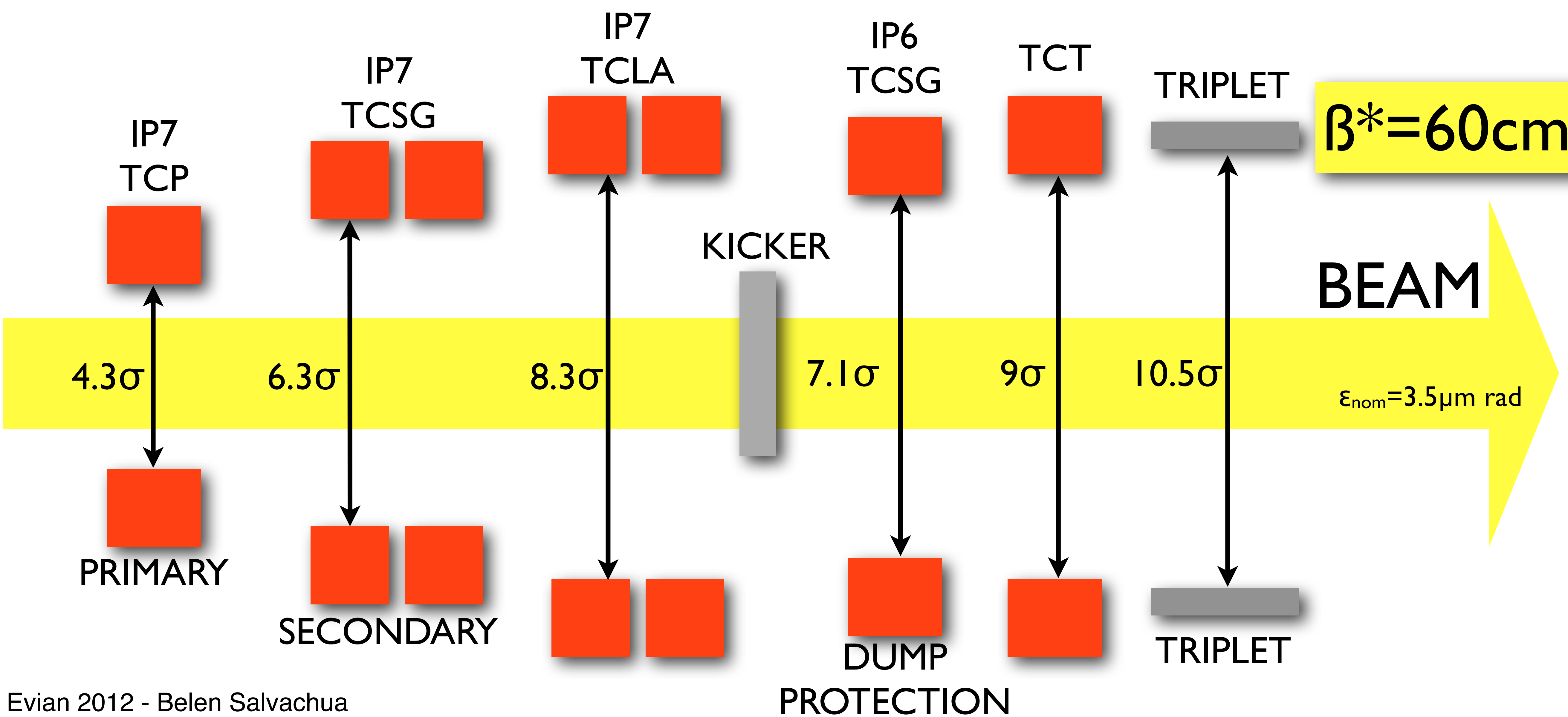
Transfer lines (13 collimators)

Injection and dump protection (10 collimators)

Total of 108 collimators
(100 movable)

4 TeV Tight Settings

- Multi-stage collimation system
- Hierarchy between cleaning stages must be preserved to assure the needed cleaning protection and functionalities.
- Up to date, no quench with circulating beam, with store energies up to 140 MJ



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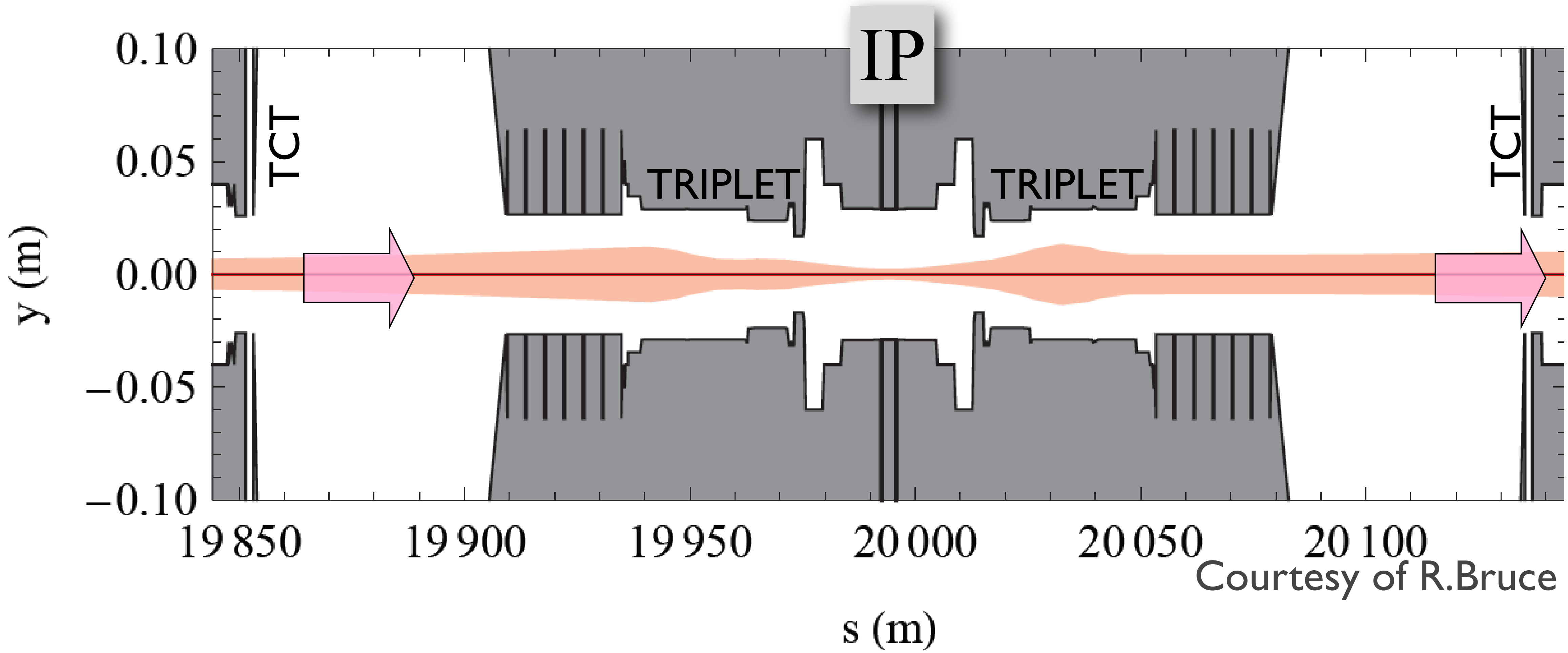
Collimators ⇔ β*

- **Normalized Triplet aperture decreases when reducing β***
- **Triplet** aperture MUST be **protected by** the tertiary collimators (**TCTs**)
- At the same time, **TCTs** must **be shadowed** by the **dump protection**
- Dump protection must be outside the primary and secondary collimators
- Hierarchy must be maintained despite orbit and optics drifts after setup
  - Margin needed between collimator families and triplet



Courtesy of R.Bruce

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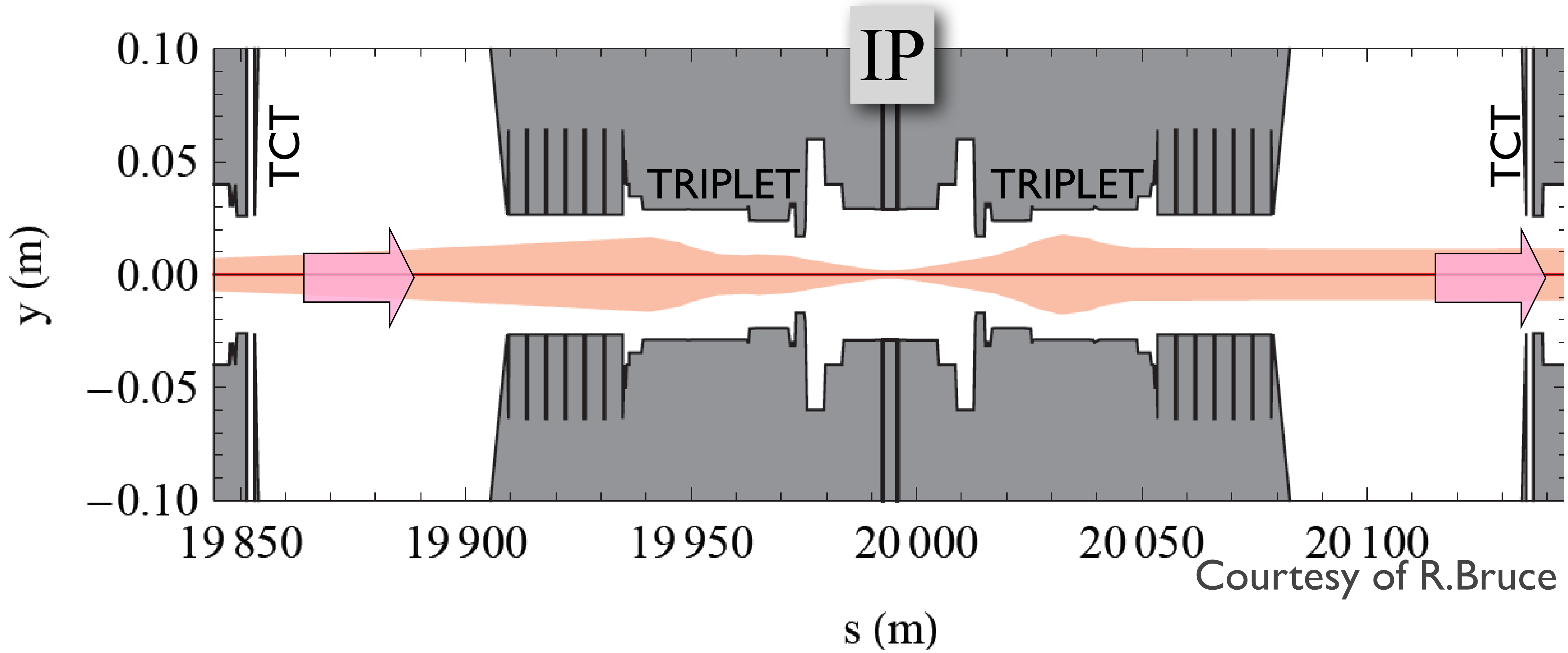

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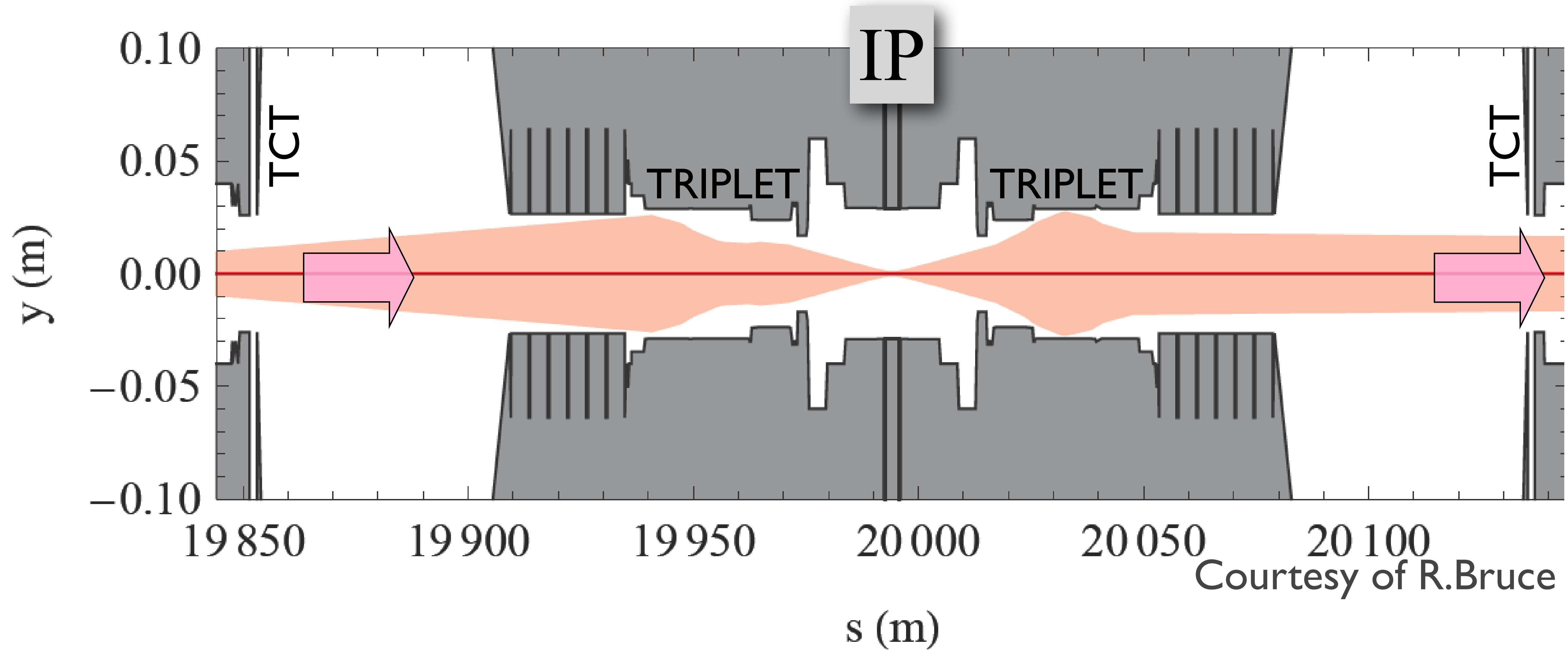
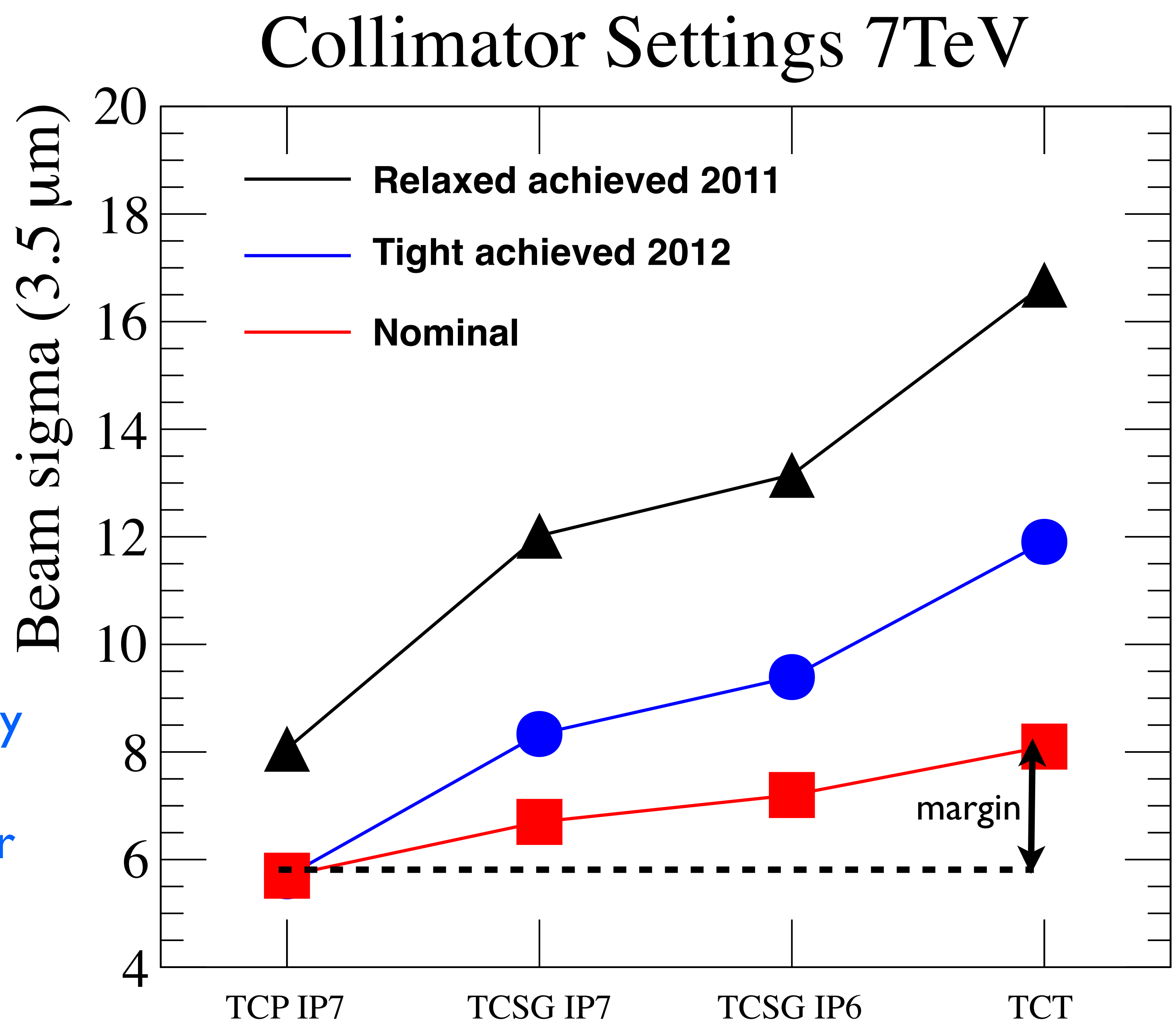


Courtesy of R.Bruce

Settings Evolution

Expressed in σ at 7TeV	Relaxed 2011	Tight 2012	Nominal
TCP IP7	8.1	5.7	5.7
TCSG IP7	12.0	8.3	6.7
TCSG IP6	13.2	9.4	7.2
TCT	16.7	11.9	8.1

- The cleaning hierarchy must be respected in order to guarantee the required cleaning.
- Reduce margins in collimation hierarchy allow smaller aperture margins at the MQX for smaller β^* but impose tighter tolerances (might require frequent alignments).
- Collimator gaps are smaller than 3mm, this can be only achieved if collimators are precisely aligned around the correct orbit.

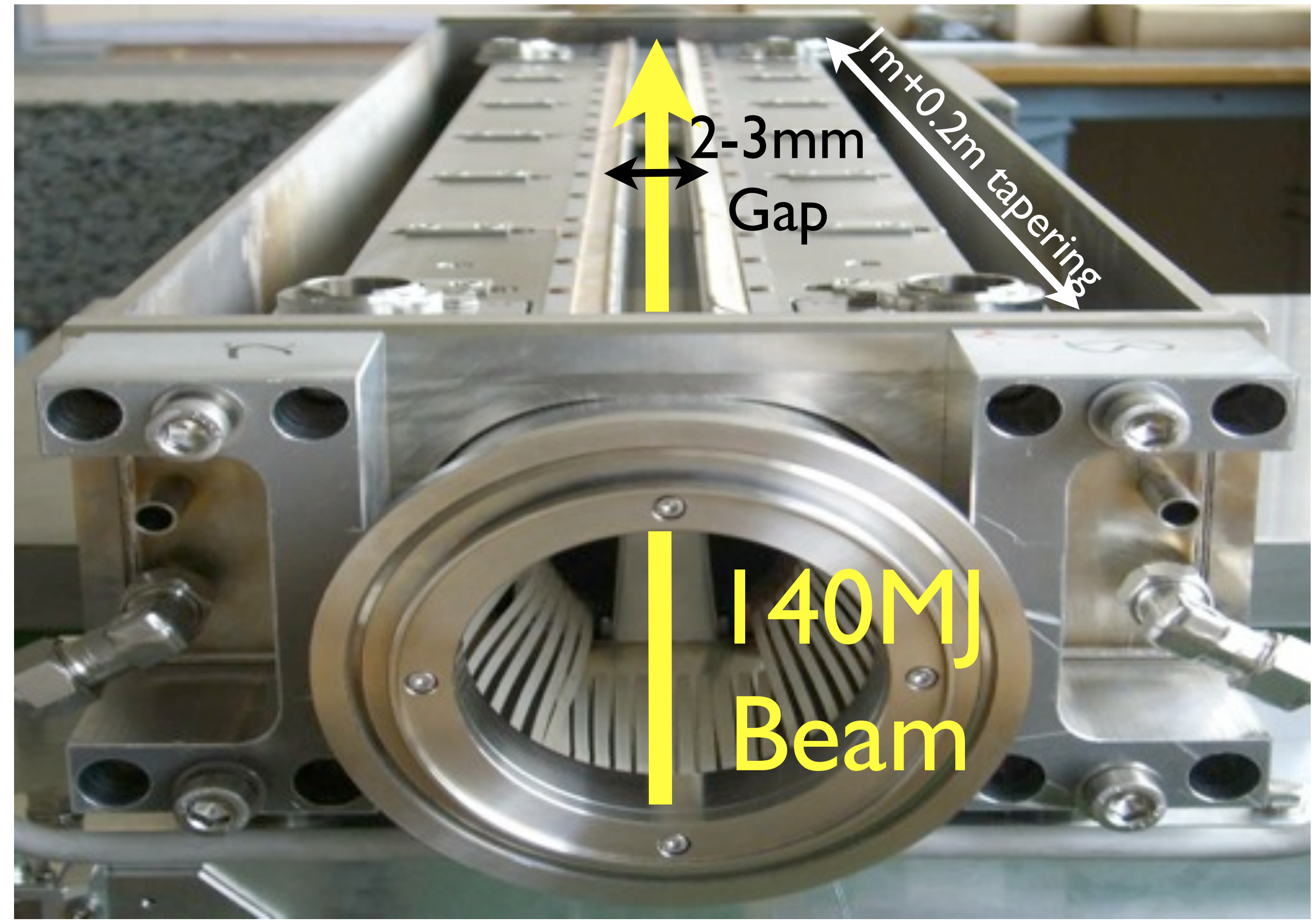


Many MD studies were needed to achieve the Tight 2012 settings.

Expect similar evolution at 7TeV.

Alignment Strategy

- All collimators are setup symmetrically around the beam.
- Different centers and gaps for each machine configuration: injection, flattop,squeeze,collisions
- With gaps as small as 2 mm.
- Both jaws are aligned independently.
- The alignment is based on the BLM spike observed when moving the collimator IN until it touches the beam.
- In dedicated LOW INTENSITY fills

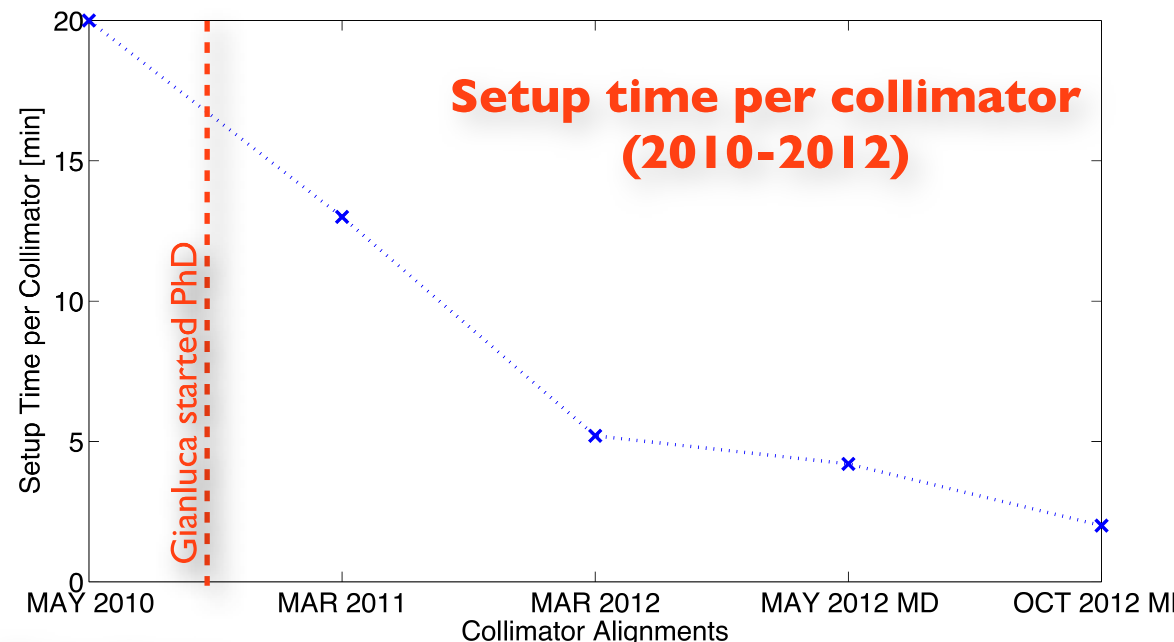


Operational Strategy:

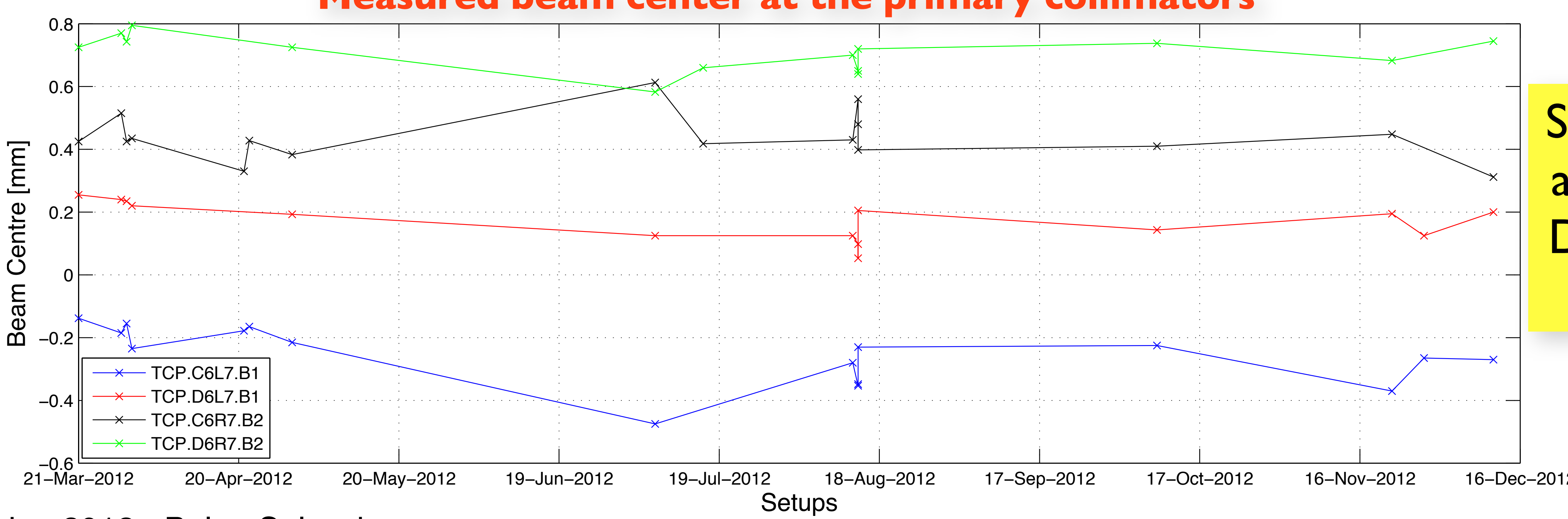
- **2011-2012**: only **ONE full alignment** in IR3/IR7.
- Monitoring of cleaning: **loss maps** taken **regularly** minimum after every TS or 8 weeks to validate cleaning and hierarchy to evaluate if a new alignment is needed.
- Alignment of the TCTs (16 collimators) repeated for new physics configurations.

Alignment Performance

- Alignment time reduced from 2010 up to now:
  - From 20min to 3 min per collimator → lower-bound time limit reached!
  - From 30 hours to about 5 hours for 80 collimators
  - From 3 fills to 1 fill per alignment
- Now, ONLY 1 fill needed for new physics alignments.
- Now, all IR7 collimators re-aligned in 50min!
- Beam center at the primary collimators is monitored regularly.
  - Around 200um variation along the year, compatible with orbit accuracy.



Measured beam center at the primary collimators



Since semi-automatic alignment, NO more DUMPs during setup at top energy!

G.Valentino

Collimation Setup Tools

Improvements on the setup application towards a faster and more reproducible alignment.

Begin 2011:
Manually selection of the alignment parameters (BLM thresholds, step size, etc.)
Sequential collimator alignment

- **12.5 Hz beam loss** data available from the start of the 2012 run of all LHC BLMs.

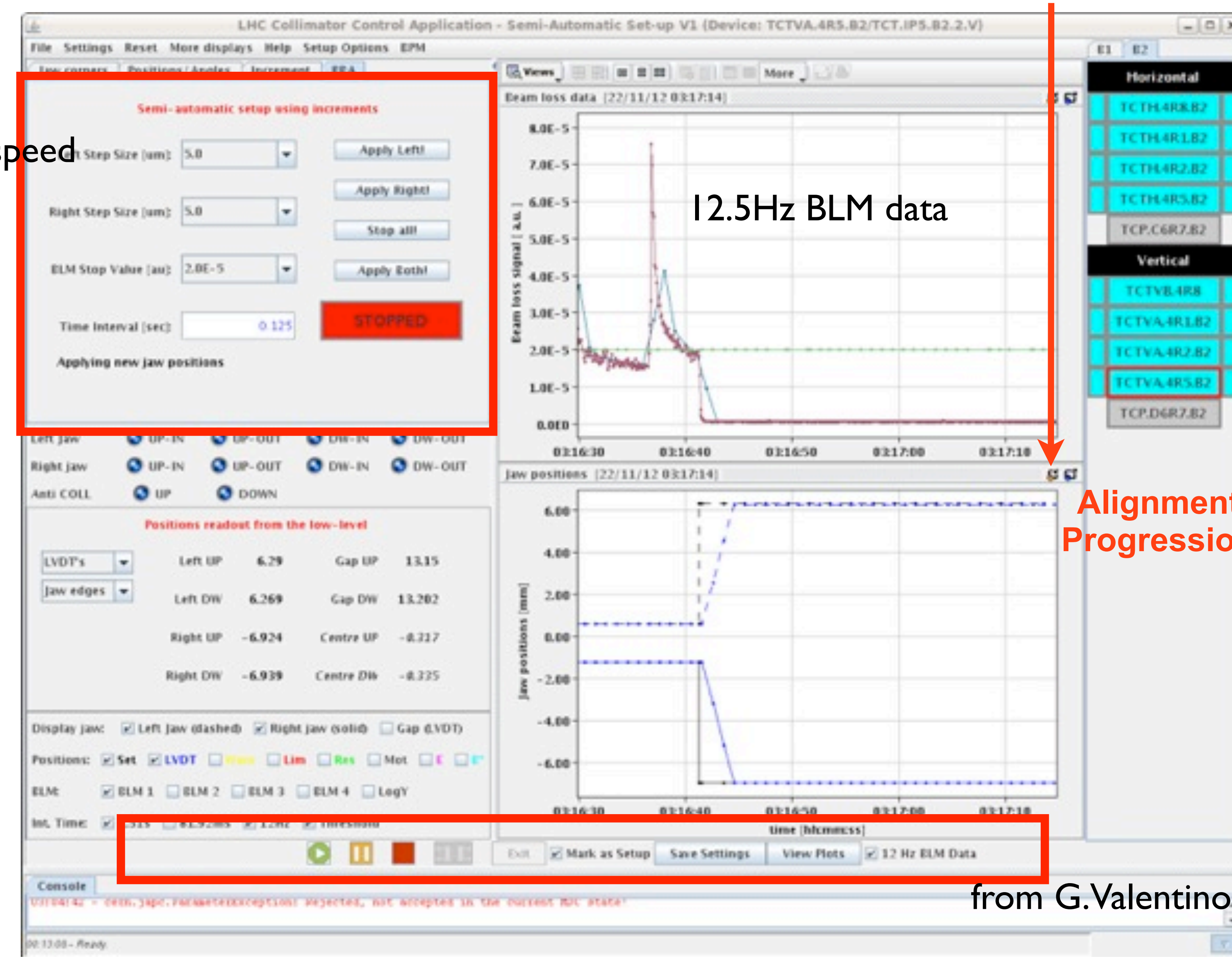
Main improvement on alignment speed

- This allows to use the **maximum collimator movement rate of 8 Hz** (before limited to 1Hz)
- **Parallel alignment.**
- **Automatic loss spike identification**
- **Automatic generation of beam centers tables** used for setting generation.
- **New tools to compare settings against the values found in the alignment.**

End 2012:
Full parallel alignment sequence: automatic selection of alignment parameters for all collimators

12.5 Hz BLM data acquisition thanks to:
A.Bland, V.Baggiolini, B.Dehning, S.Jackson, C.Zamantzas!!

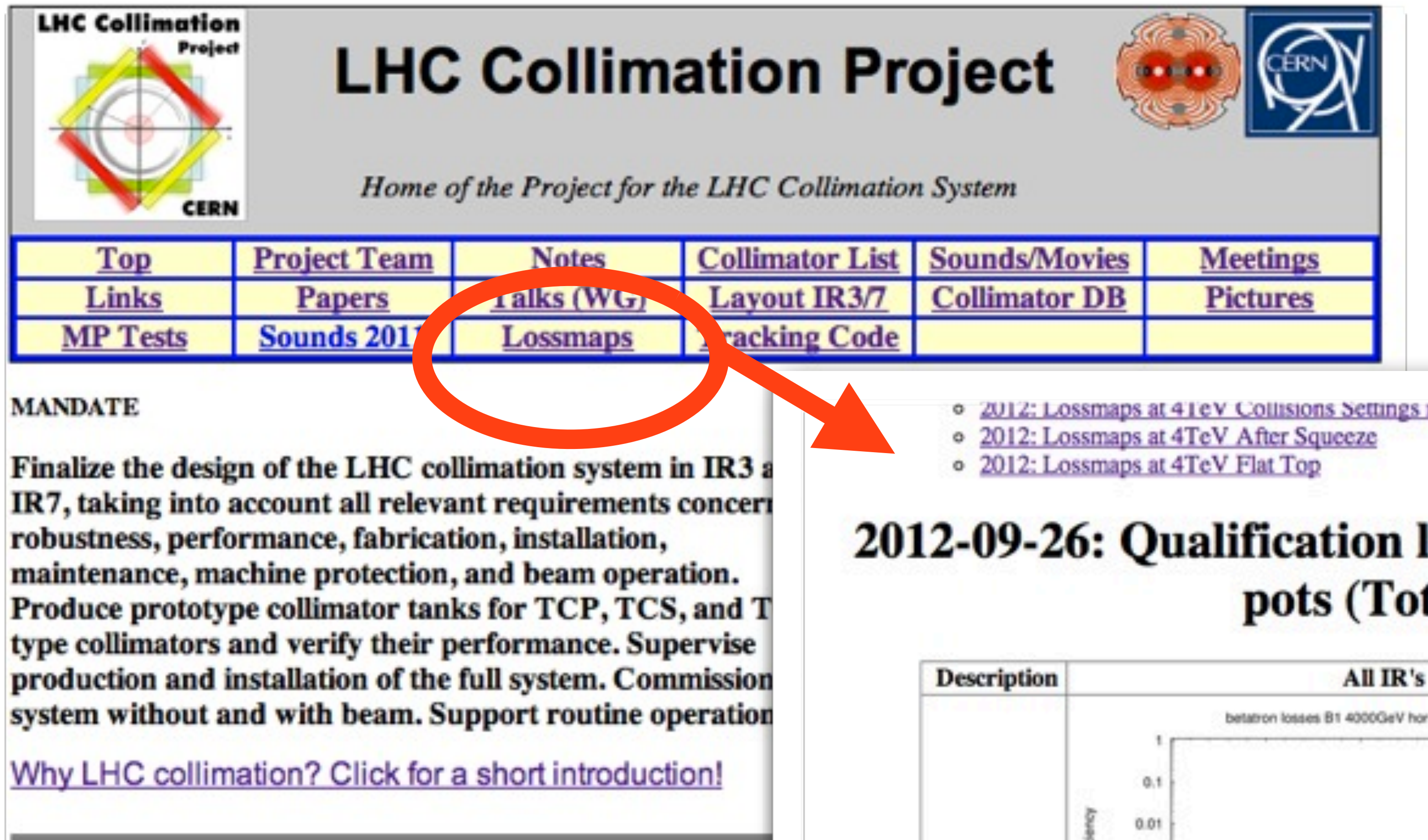
8Hz collimator movement thanks to A.Masi & STI team



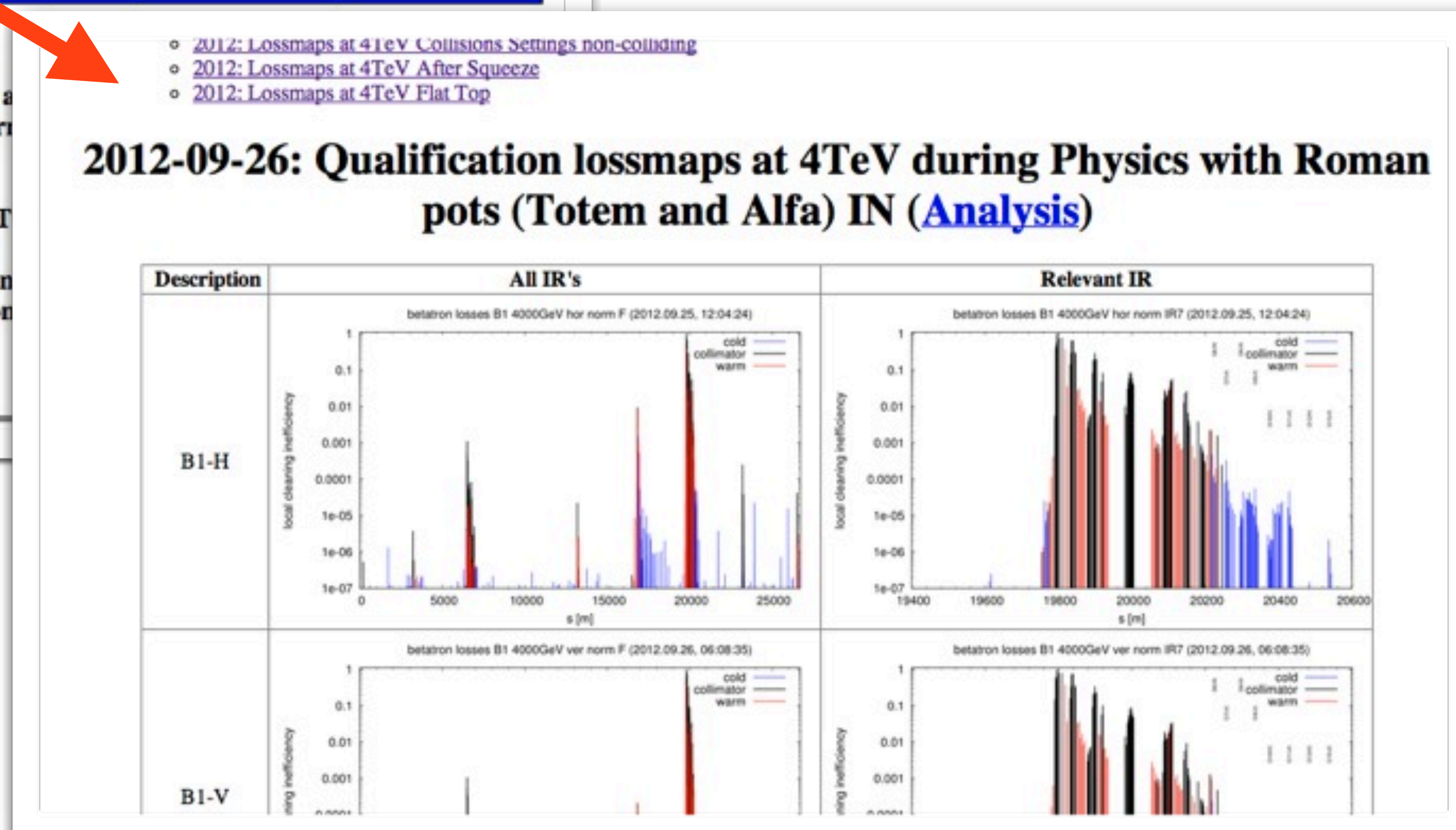
from G.Valentino

Loss Maps Documentation

http://lhc-collimation-project.web.cern.ch/lhc-collimation-project/



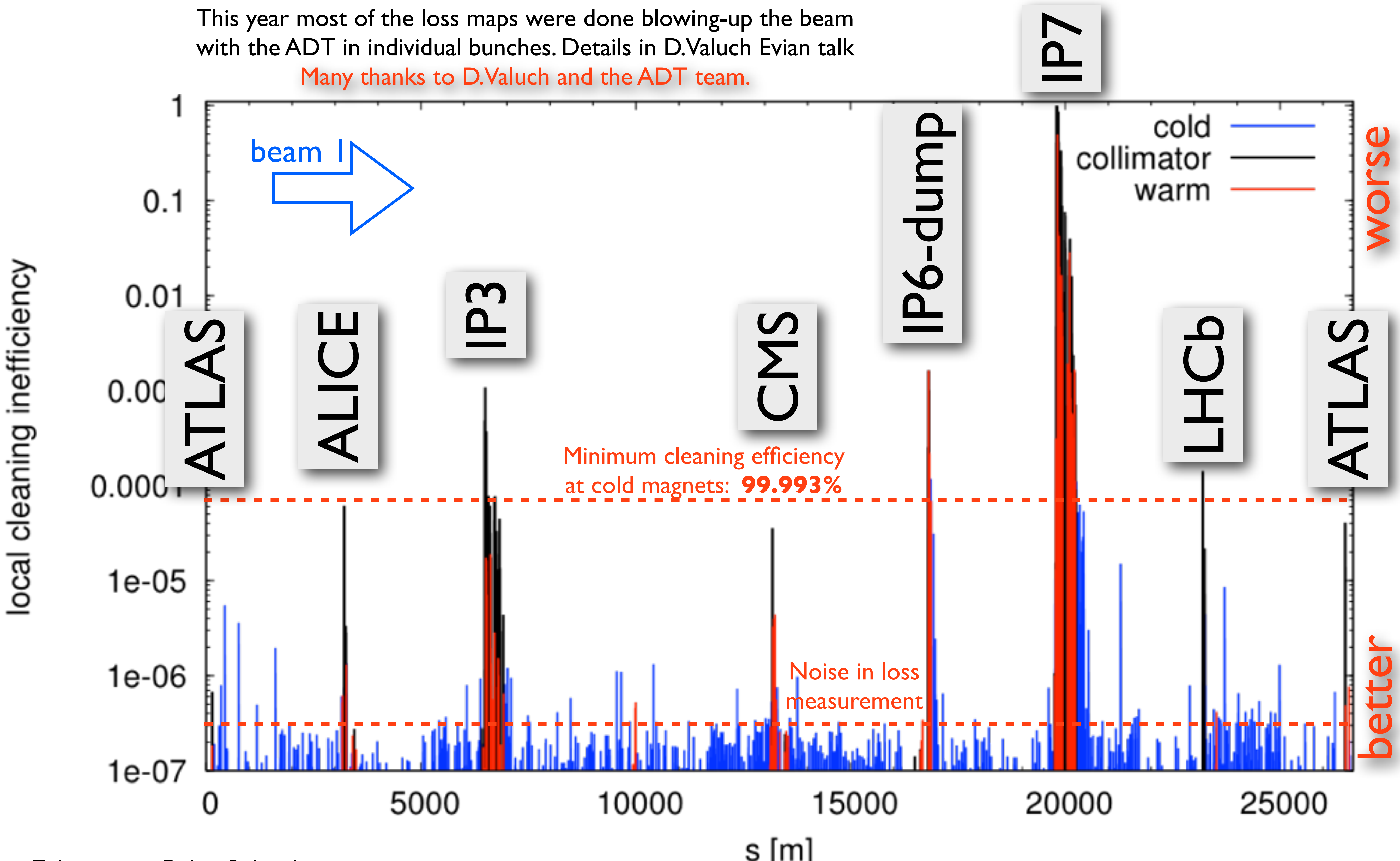
Qualification loss maps of 2012



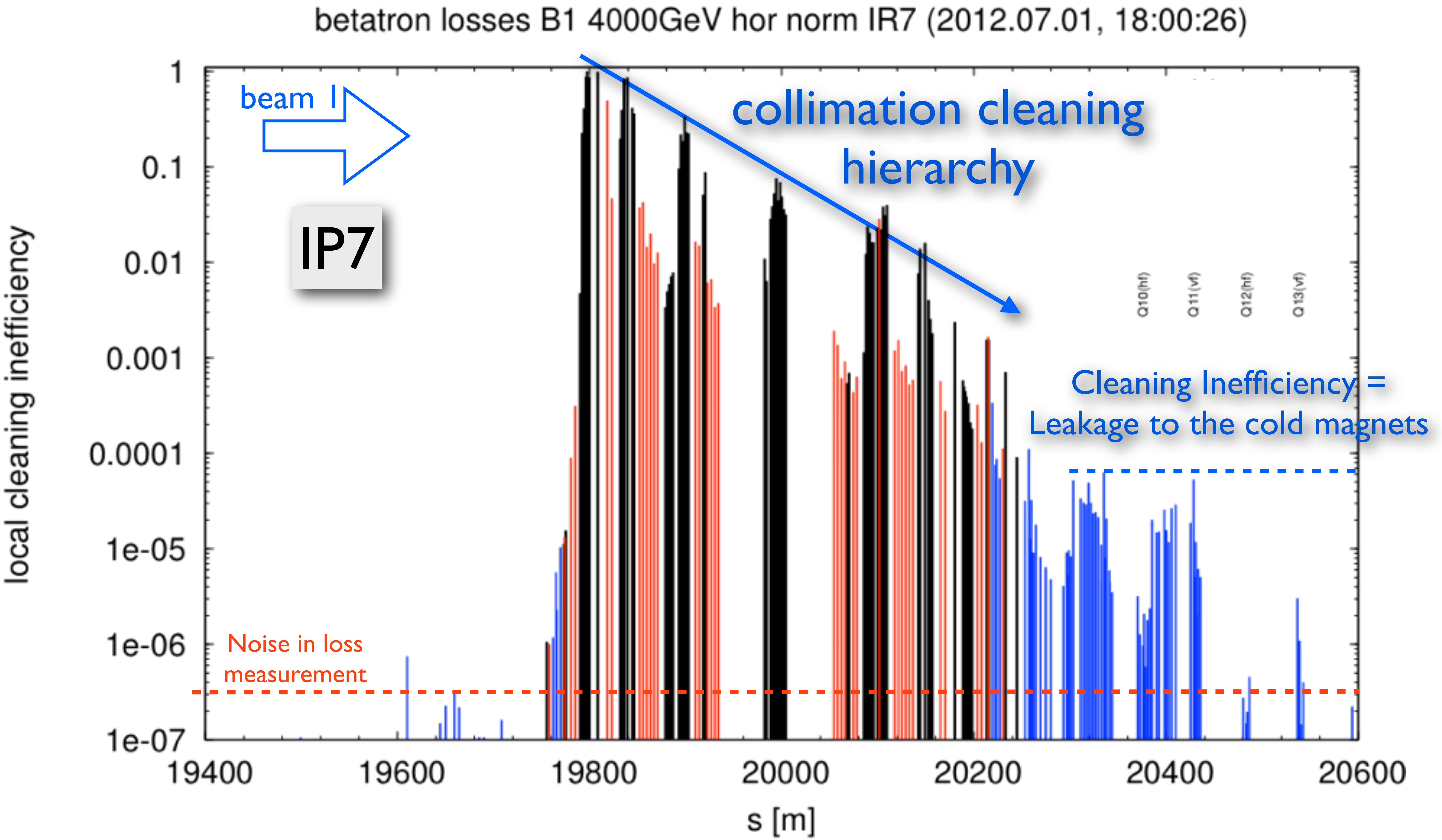
Cleaning Inefficiency

This year most of the loss maps were done blowing-up the beam with the ADT in individual bunches. Details in D.Valuch Evian talk

Many thanks to D.Valuch and the ADT team.

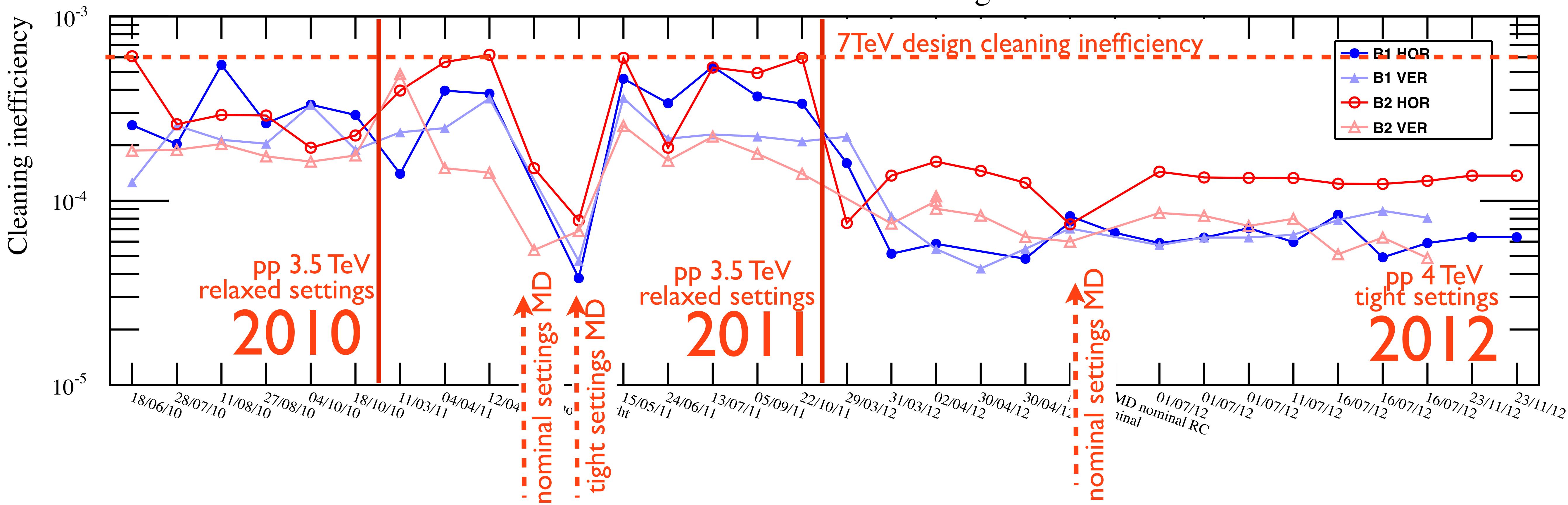


Cleaning in IR7



Cleaning Inefficiency

2010-2012 Collimation Cleaning Performance



Thanks to the OP team for all the support during loss maps and validation campaigns!

Excellent stability of cleaning performance observed

Achieved with only one alignment campaign per year (March 2012) IR3/IR7 (30collimators)
In 2012 with tight settings the **cleaning improved from 99.97% to 99.993%**

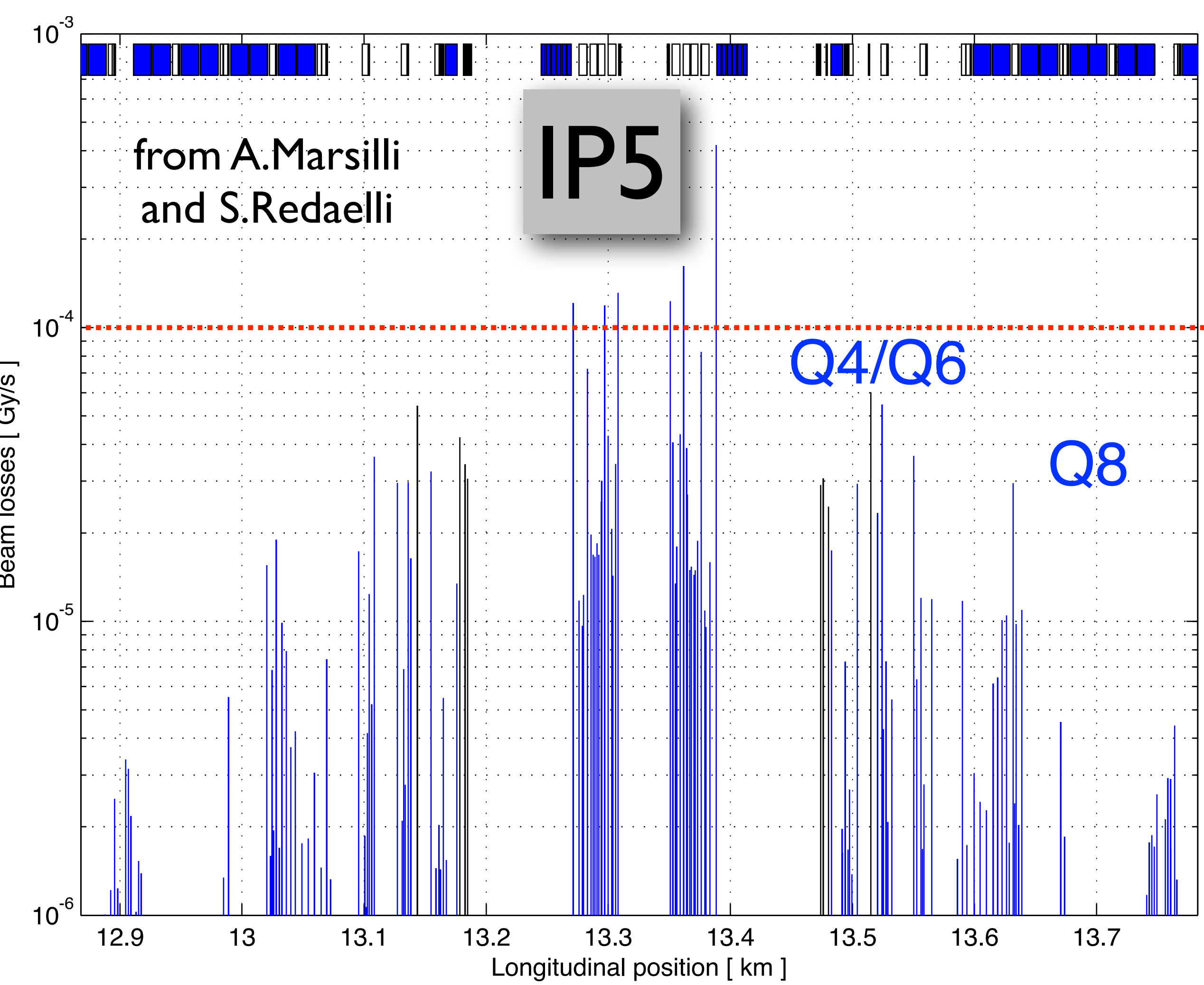
Cleaning in IR7 is similar for all 4TeV cycles → IR7 cleaning not much affected by changes in the IRs

Losses from luminosity debris

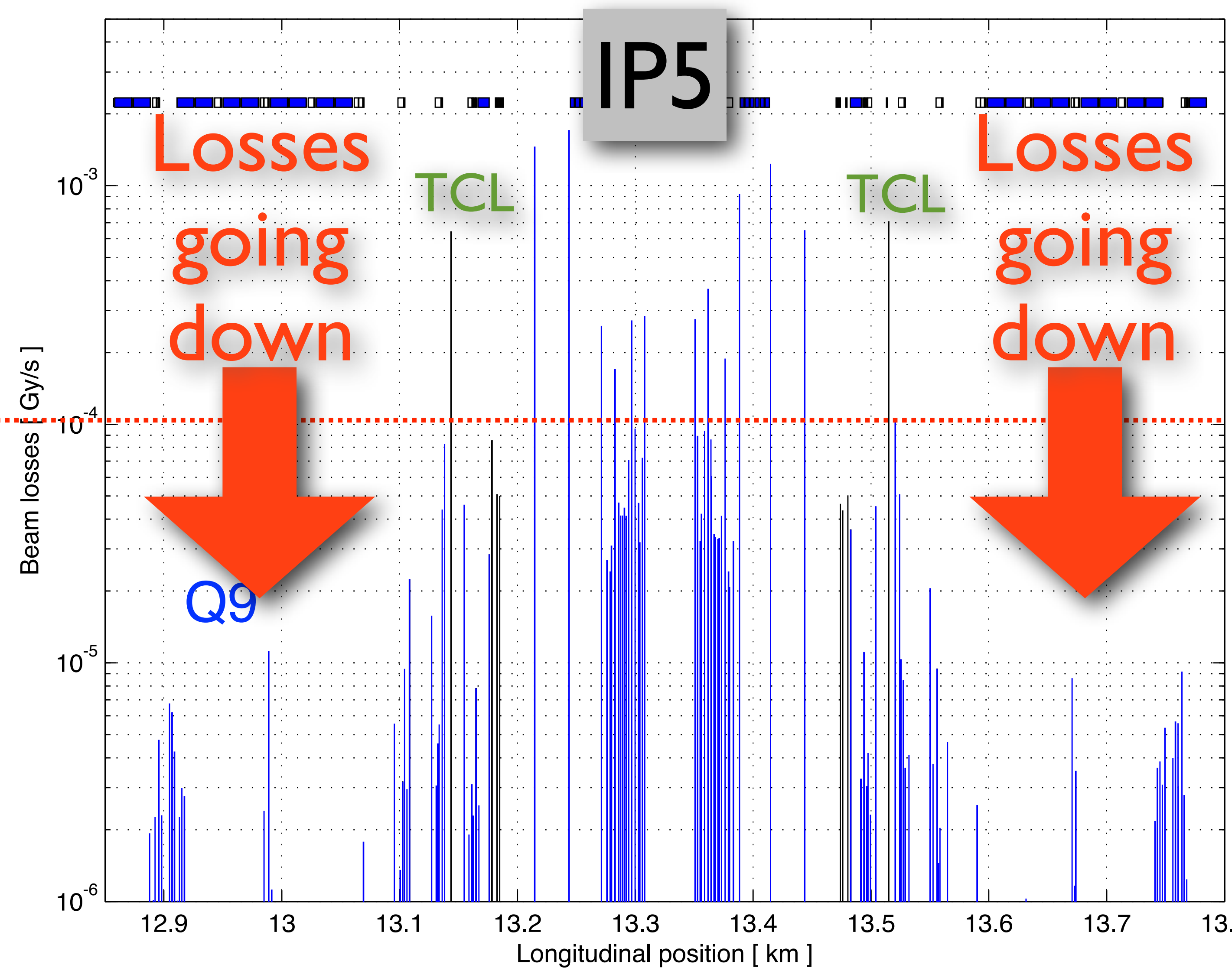
- In 2012, we have started using the TCL collimators in IP1 and IP5 that catch physics debris.
- Set to 10σ since the start of the run.
- We have performed TCLs scans to understand the impact on reducing the losses and the load to the magnets. At 10σ measured losses at Q8 reduced by a factor of 50!
- Benchmark simulations.

See G. Spiezia's talk on R2E
Significant improvement of SEU's in IR1 and IR5

Proton operation in 2011



Proton operation in 2012



Intensity reach

- How much charges can be injected without quenching the magnets:

$$N_p^{max} = \tau_{beam} \times \frac{dN_p}{dt} \approx \tau_{beam} \times R_{loss}^{tcp} = \tau_{beam} \times \frac{\tilde{R}_q}{\tilde{\eta}_c}$$

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cleaning inefficiency

➡ The cleaning hierarchy very stable over the year, it depends on the collimation settings and the energy.

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quench limit

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Min. Beam Lifetime

cleaning inefficiency

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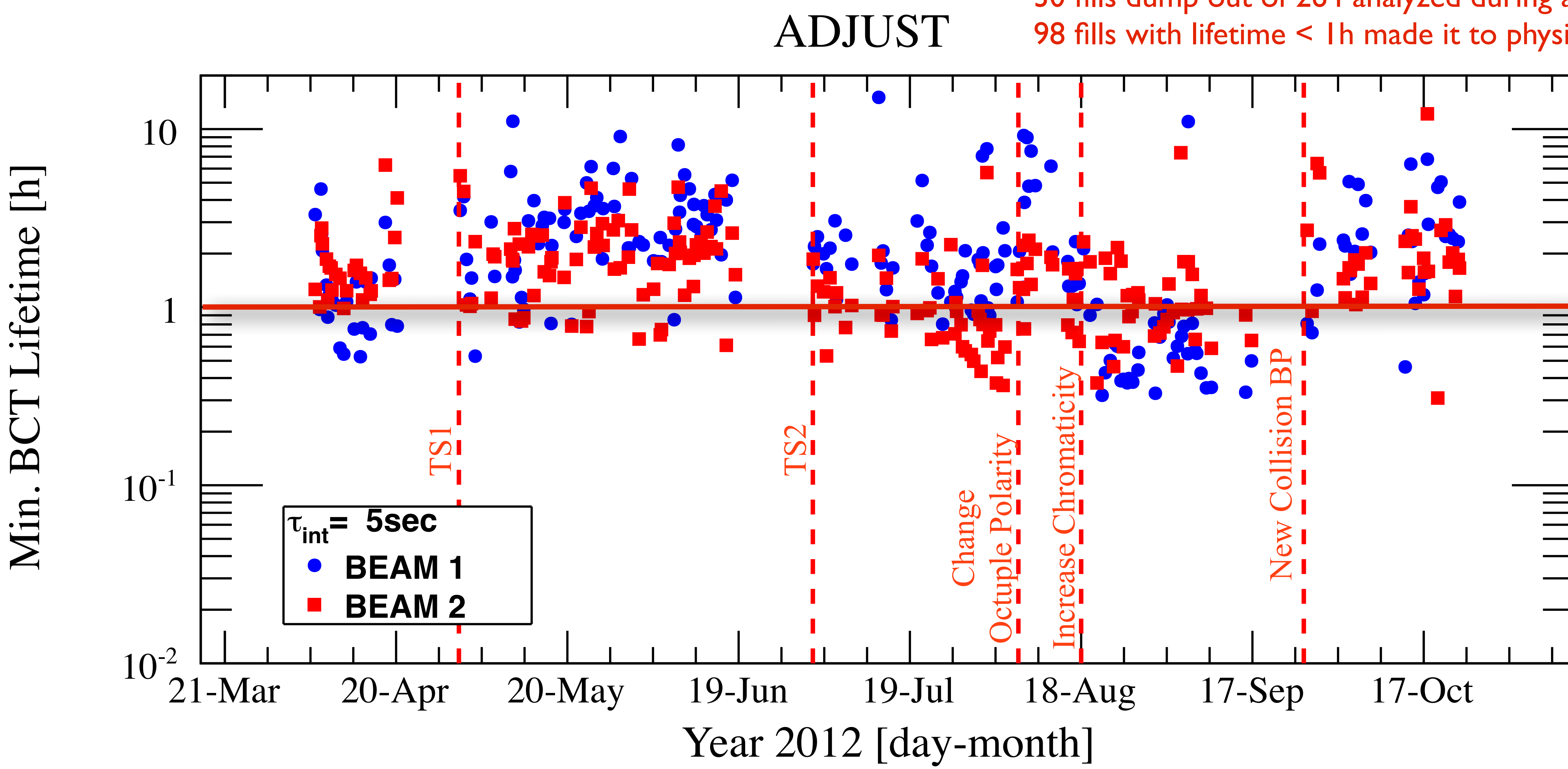
➡ The quench limit, not reached in 2011 quench test, we will know more in few months from now, after the new quench test.

➡ For a given quench limit the lifetime defines the performance reach.

Lifetime: ADJUST

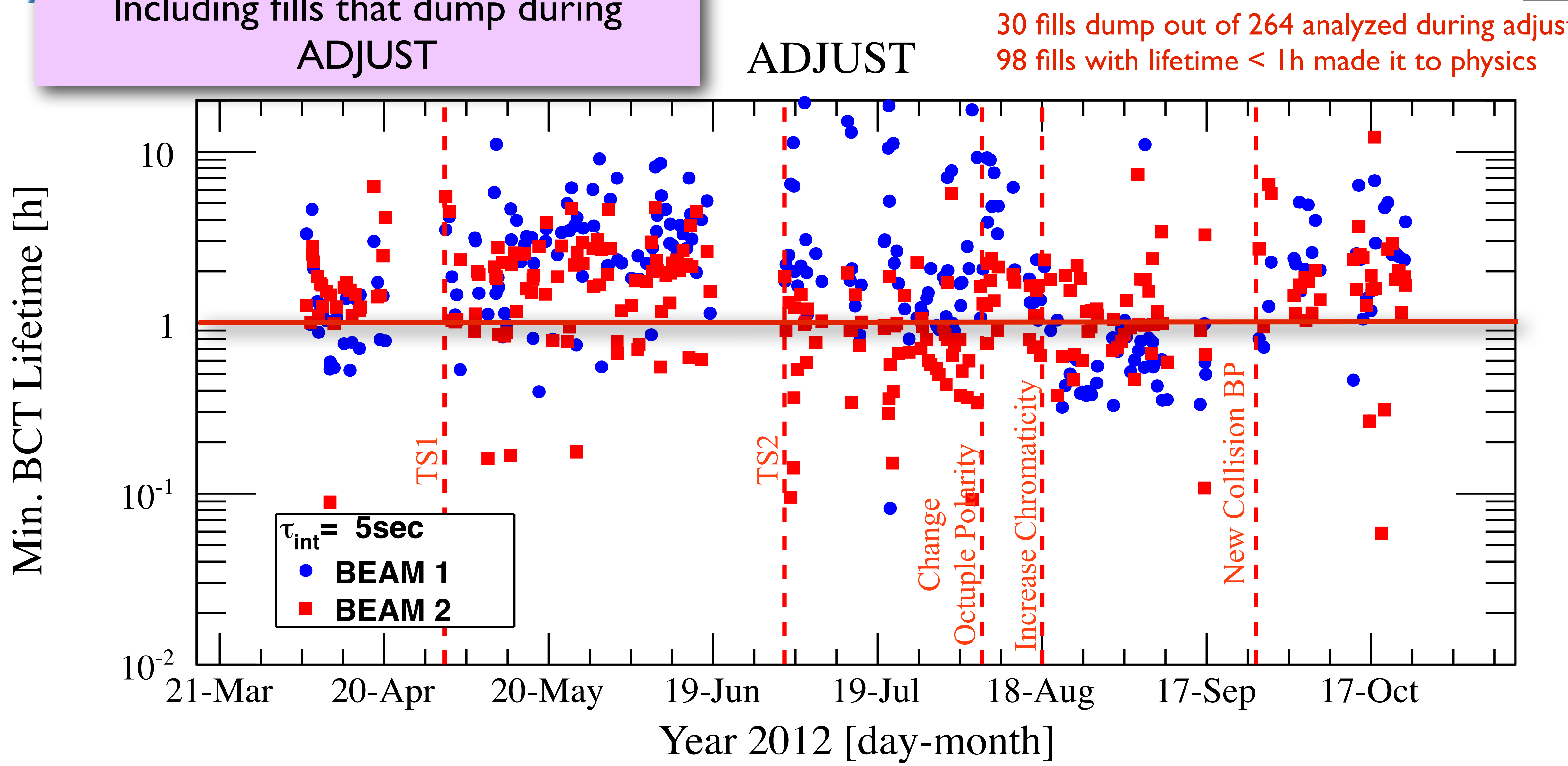
30 fills dump out of 264 analyzed during adjust
98 fills with lifetime < 1h made it to physics



- Average MINIMUM lifetime per fill along the year is between 0.3-10 hours worse than RAMP and SQUEEZE.
- Limitations in the DS can only be addressed with major hardware changes that have been postponed until LS2. Improvements during LS1 will focus on the operational limitations.
- Detailed performance reach estimate must wait until execution of quench test in 2013 [preparing collimation project review in spring]

Lifetime: ADJUST

Including fills that dump during ADJUST



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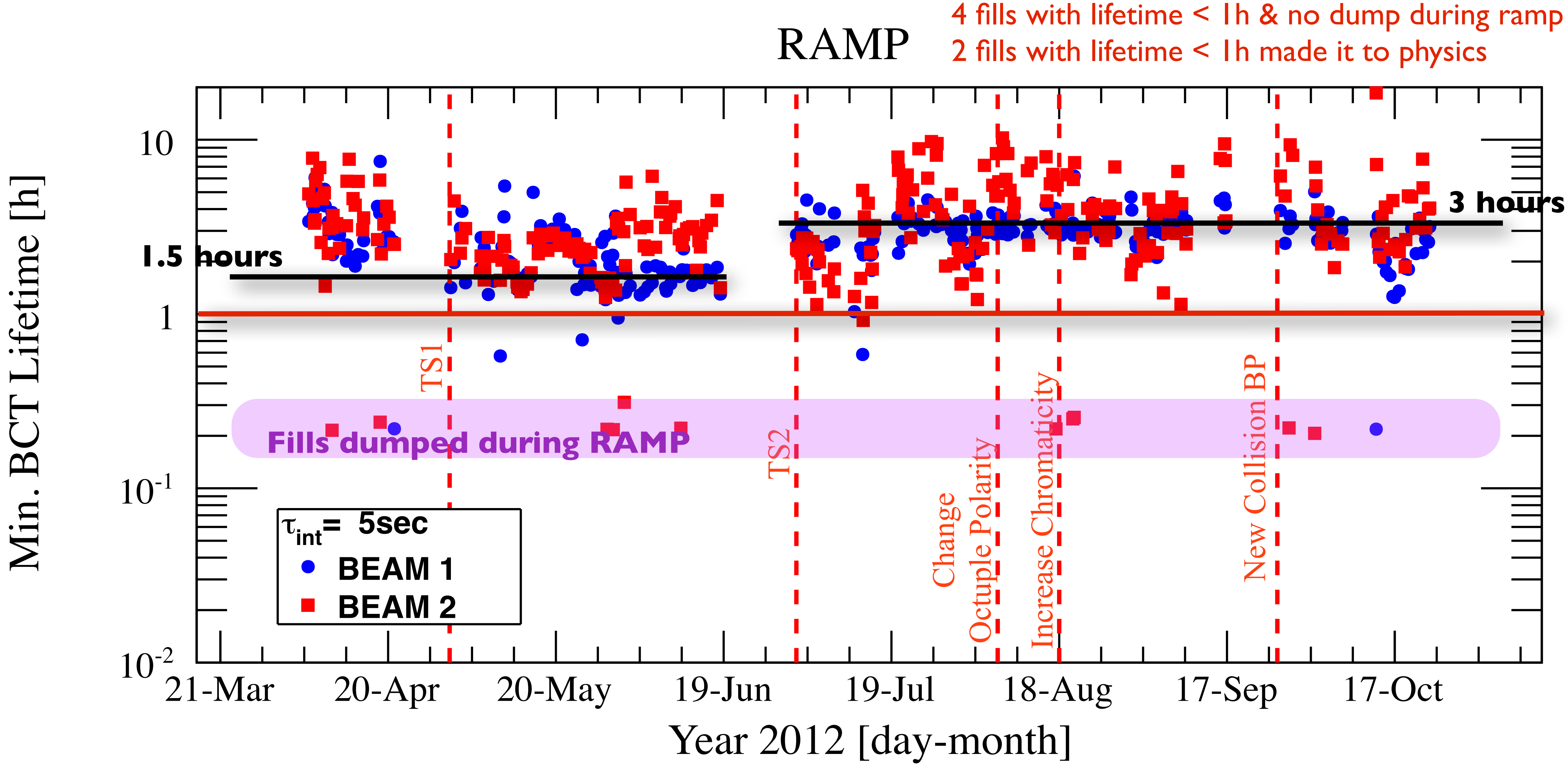
Lifetime: RAMP

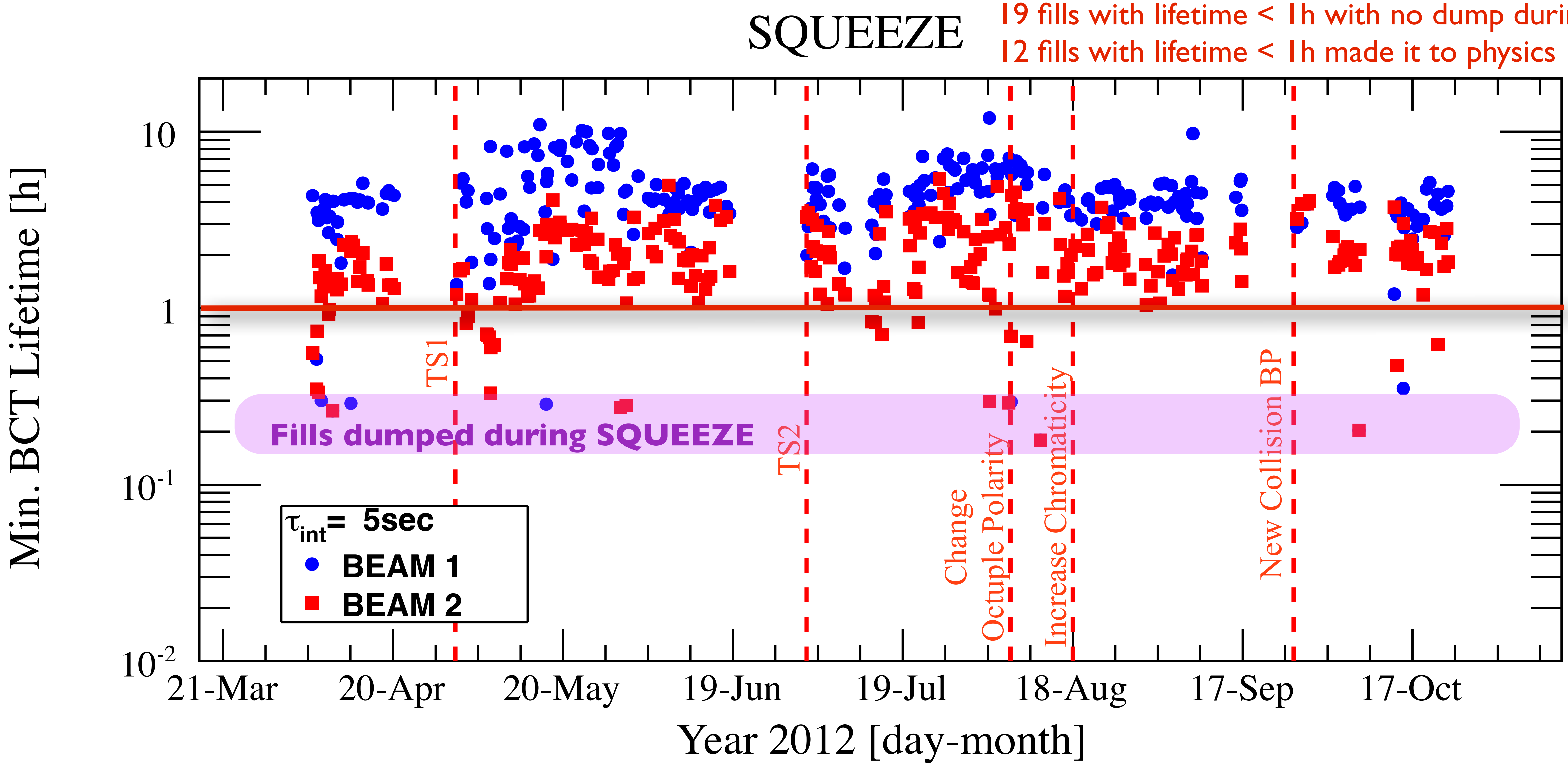
14 fills dump out of 313 analyzed during ramp
4 fills with lifetime < 1h & no dump during ramp
2 fills with lifetime < 1h made it to physics



- ➡ Average MINIMUM lifetime per fill along the year is between 2-10 hours
- ➡ Improvement in beam lifetime after TS2 from about 2 hours → 4 hours

Lifetime: SQUEEZE

16 fills dump out of 283 analyzed during squeeze
19 fills with lifetime < 1h with no dump during squeeze
12 fills with lifetime < 1h made it to physics

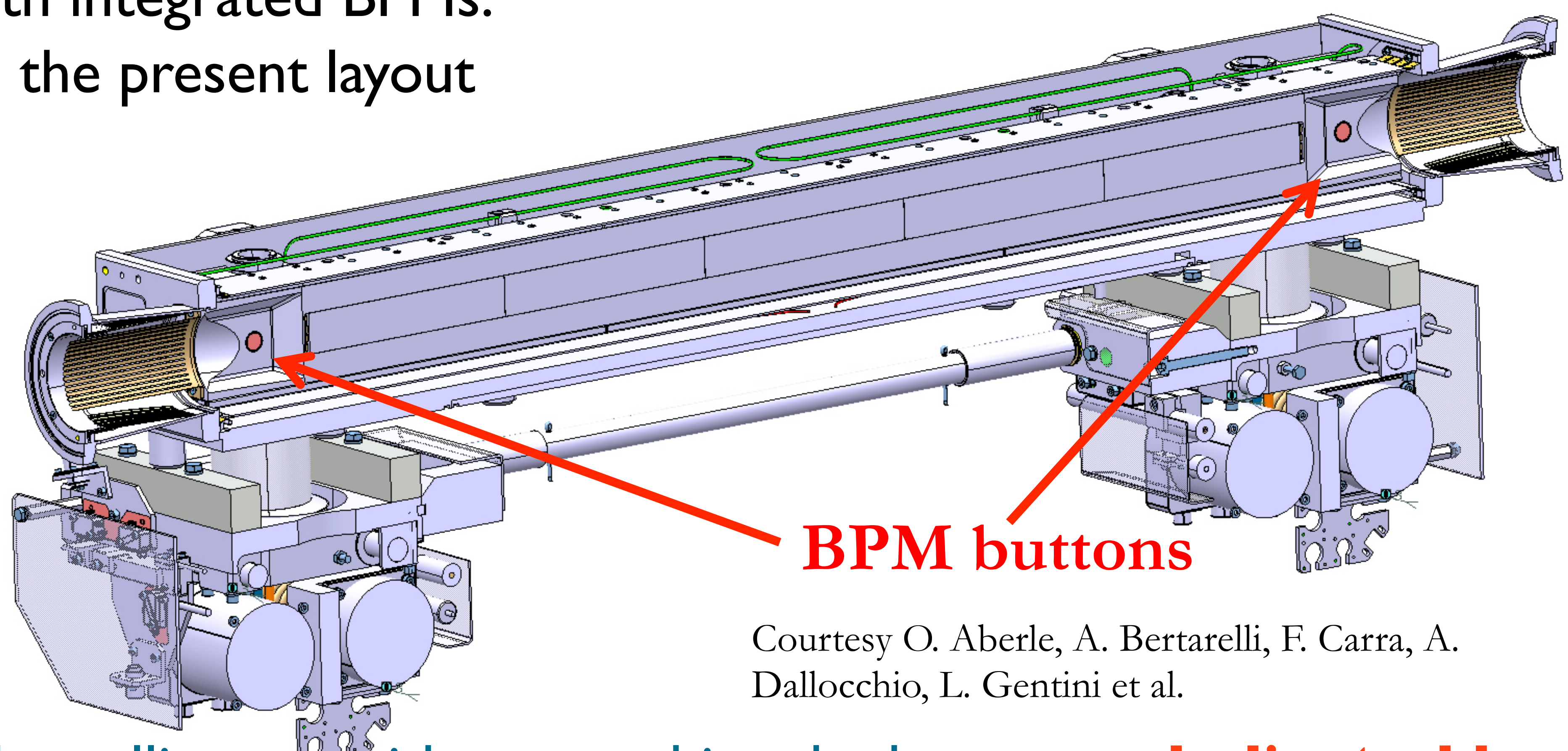


- ➡ Average MINIMUM lifetime per fill along the year is between 2-10 hours same as RAMP
- ➡ Periods with significant decrease of lifetime

Collimation after LS1

Collimators with BPMs

- 16 Tungsten TCTs in all IRs and 2 Carbon TCSGs in IR6 will be replaced by new collimators with integrated BPMs.
- No changes in the present layout



Courtesy O. Aberle, A. Bertarelli, F. Carra, A. Dallocchio, L. Gentini et al.

- Gain:
  - Can align the collimator without touching the beam, **no dedicated beam intensity fills.** Improved operational flexibility for IR configurations.
  - Reduce orbit margins → **more room to squeeze, $\beta^* \geq$ 35cm** (R.Bruce)
- Solid experimental validation of this concept in SPS beam tests 2010-2012
  - **Achieved 10sec alignment with accuracy of about 10μm**
- Other changes on collimation system not discussed here: passive absorbers, new TCL layouts in IR1 and IR5, etc.

Limitation when going to smaller β*

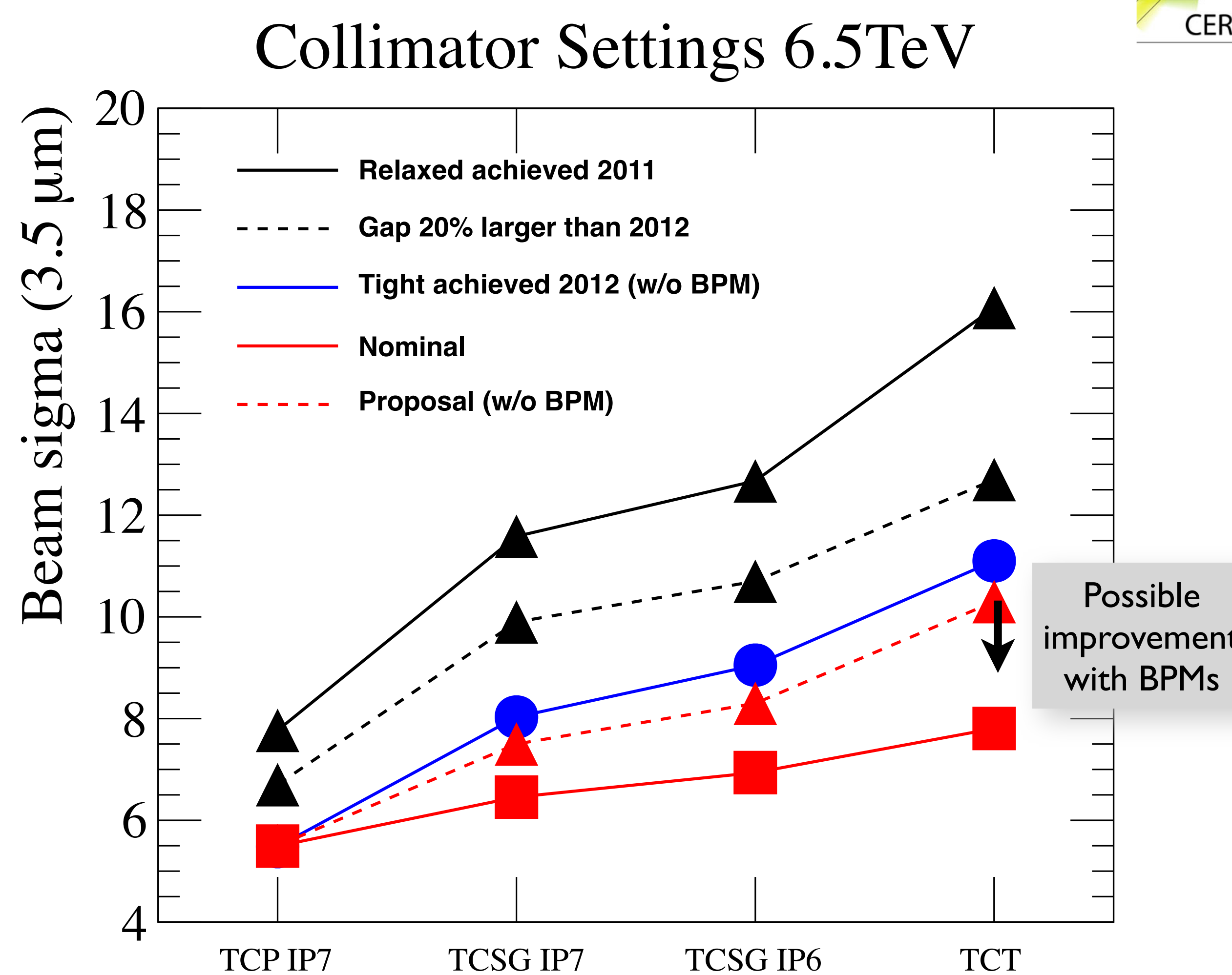
- Magnetic limit: max gradient in quadrupoles and chromaticity.
- Beam-beam limit.

Geometrical part that I will discuss here

- Aperture limit: decreasing margins in triplet when decreasing β*.
- Assumptions for calculating collimator settings and aperture after LS1:
  - Same excellent apertures, orbit, beta-beat as today
  - TCP at same position in mm.
  - BPM button collimators: assume 50μm precision of orbit at TCT and TCSG6 (pessimistic case), before 0.5-1mm.
    - allowing significantly reduced orbit margins

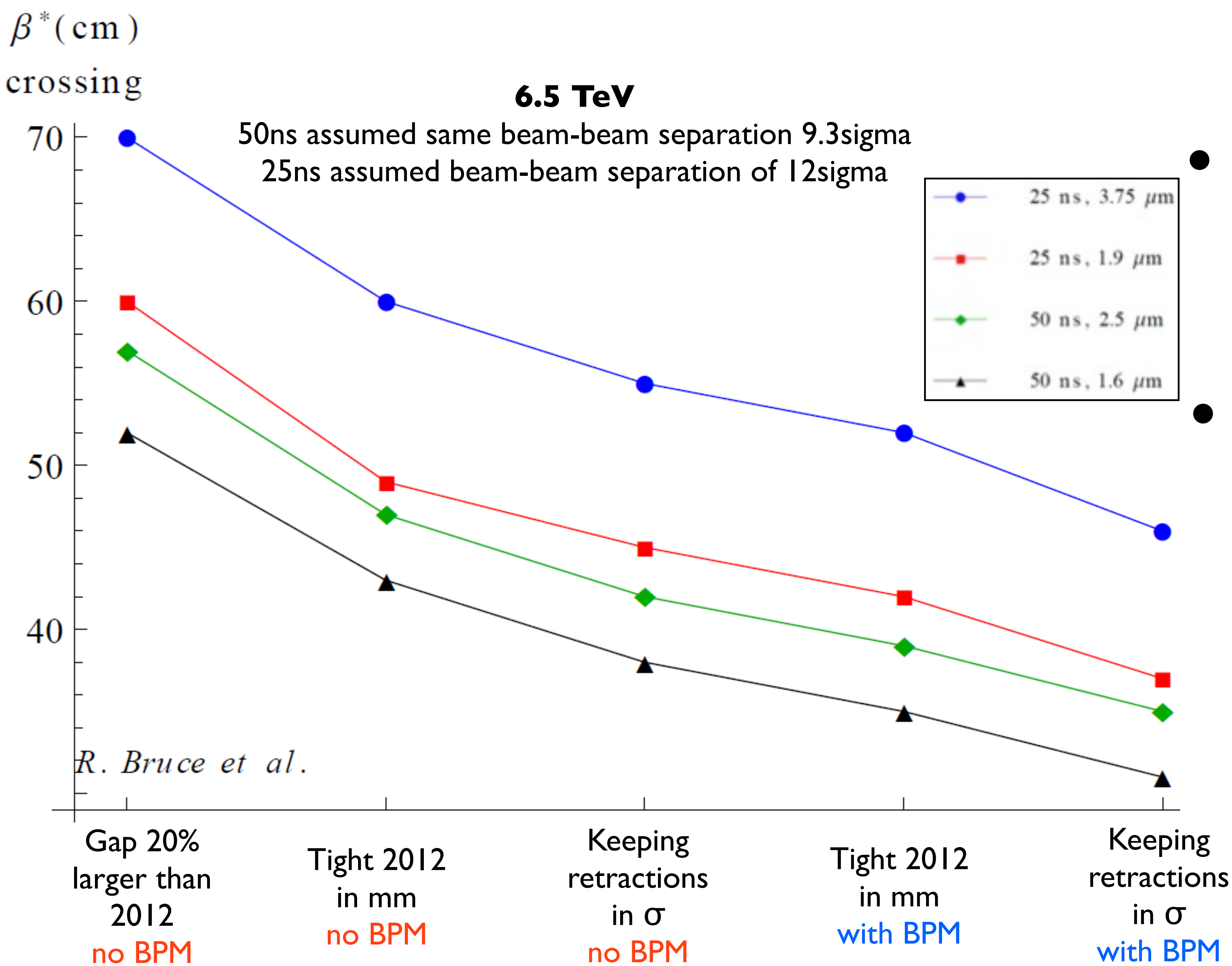
Possible settings for 6.5TeV

Expressed in beam σ at 6.5TeV (ε=3.5μm)					
	Gap 20% larger than 2012	**Tight 2012 in mm**		**Keeping retractions in σ**	
TCP 7	6.7	5.5		5.5	
TCSG 7	9.9	8.0		7.5	
TCLA 7	12.5	10.6		9.5	
TCSG 6	10.7	9.1		8.3	
TCDQ 6	11.2	9.6		8.8	
	w/o BPM	w/o BPM	with BPM	w/o BPM	with BPM
TCT	12.7	11.1	10.0	10.3	9.1
Aperture	14.3	12.6	11.2	11.7	10.3



- See Roderik's talk LBOC 11th Dec 2012
- Assuming that we are not limited by instabilities from collimator impedance:
  - See Nicolas' talk in Evian 2012
- New iterations with needed margins will be done when HiRadMat test on TCT damage limit is fully analyzed.
- Start without exploiting the full potential of Collimator with BPMs and then after some experience possibility to tighten the TCT settings.

β* reach at 6.5 TeV



- Pessimistic scenario:
  - ➡ β* = 70cm at 25ns
  - ➡ β* = 57cm at 50ns
- Optimistic scenario:
  - ➡ β* = 37cm at 25ns
  - ➡ β* = 30cm at 50ns

Other options: Move collimators during SQUEEZE

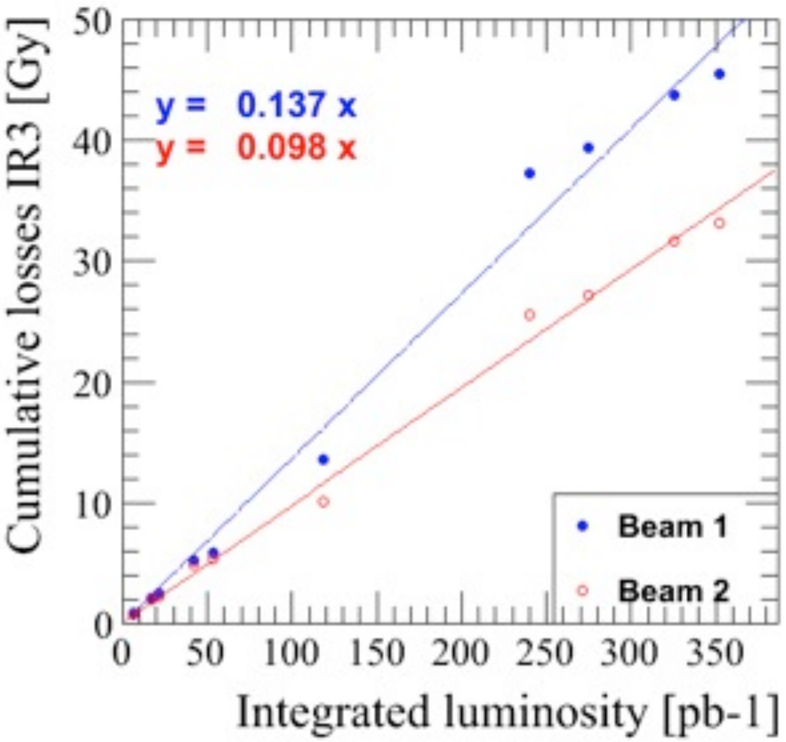
- Now IR3/IR7 collimators go to tight settings during RAMP.
- However after LS1 there might not be enough octupole current to damp the instabilities at flat top
- A new scenario could be:
  - Closing collimators only when "really" needed to achieve the minimum ß*, i.e. in the last part of the squeeze.
  - However this can only be done for the secondary collimators (and so on), because the TCP will cause high losses while cutting into the beam tails.
- Possibility:
  - Moving the TCSGs to the final position in the region below ß* = 2-3m
  - This will degrade the cleaning until they arrive to the final position, but we need to evaluate if it is acceptable.
- Interesting if it is combined with beams in collisions: see Xavier's talk Evian 2012

Summary

- Performance of the collimator system:
  - Cleaning inefficiency in a few limiting locations in DS of IR7 is 10^{-4}. Most of the cold magnets are between 10^{-6} and 10^{-5}, achieved with ONE alignment per year.
  - Improvements on the semi-automatic alignment tools deployed and extensively used over the year.
  - Tighter collimator settings allowed a ß*=60cm (we are now at 77% of 7TeV design luminosity).
- Collimator system upgrades taking place during LS1 were presented:
  - TCT and TCSG with BPM buttons in IPs and IR6:
    - Alignment without touching the beam in 10sec achieved in SPS MD.
    - Better ß* reach.
- Show preliminary proposals on start up settings after LS1
  - Assuming same conditions as end 2012 (orbit stability, aperture, etc.) and adding expected performance of BPM buttons, we can go below nominal ß* (ß*≥35cm).
  - Start more relaxed at the beginning of the year, then envisage a check point in the middle of the run for a possible reduction of ß*. As was done in 2011 to go to ß* =1m.
  - Impedance limitations need to be considered for the strategy on how to arrive to the required collimator settings

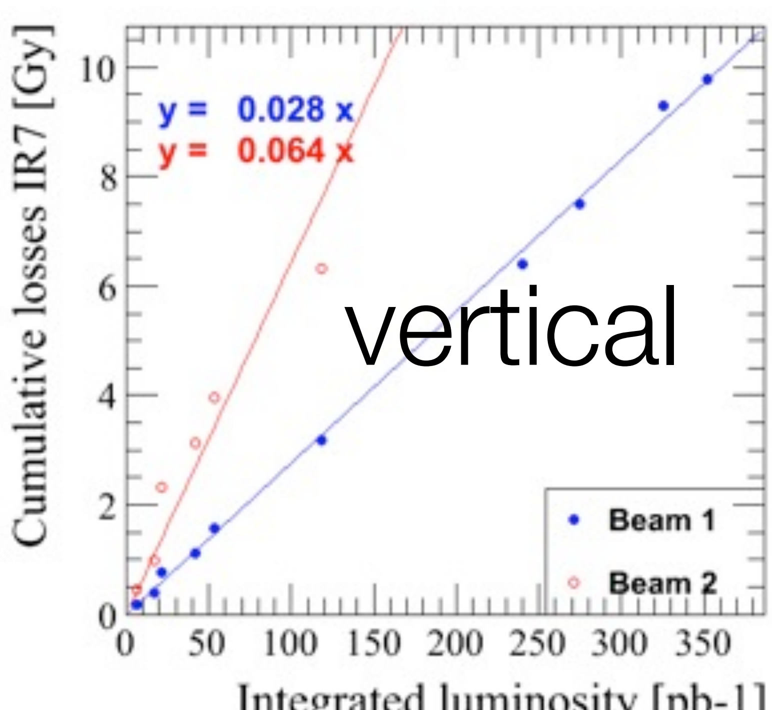
Thanks for your attention

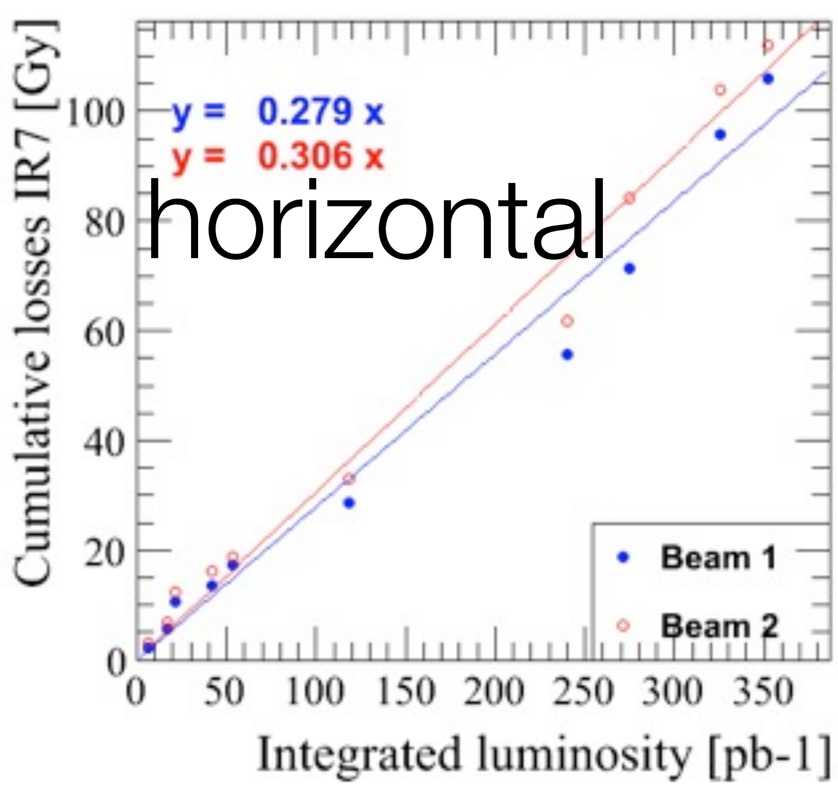
Losses vs int. luminosity 2011

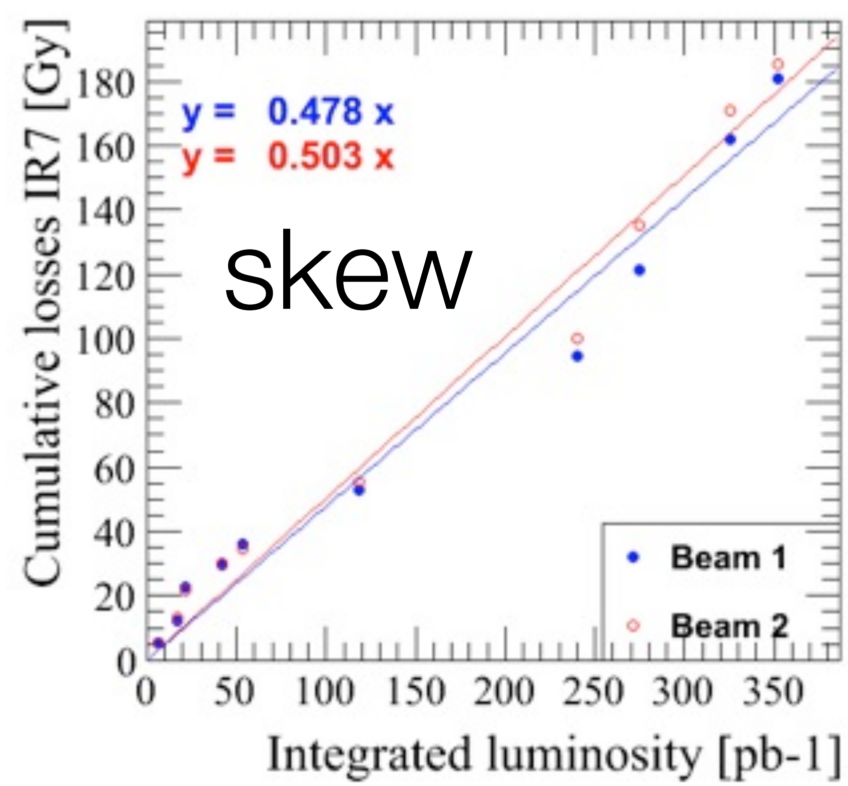


2011 losses in IR3 increase faster with luminosity than this year (2012), while losses in IR7 increase at the same rate or slower. Remember we were using RELAXED collimator settings.

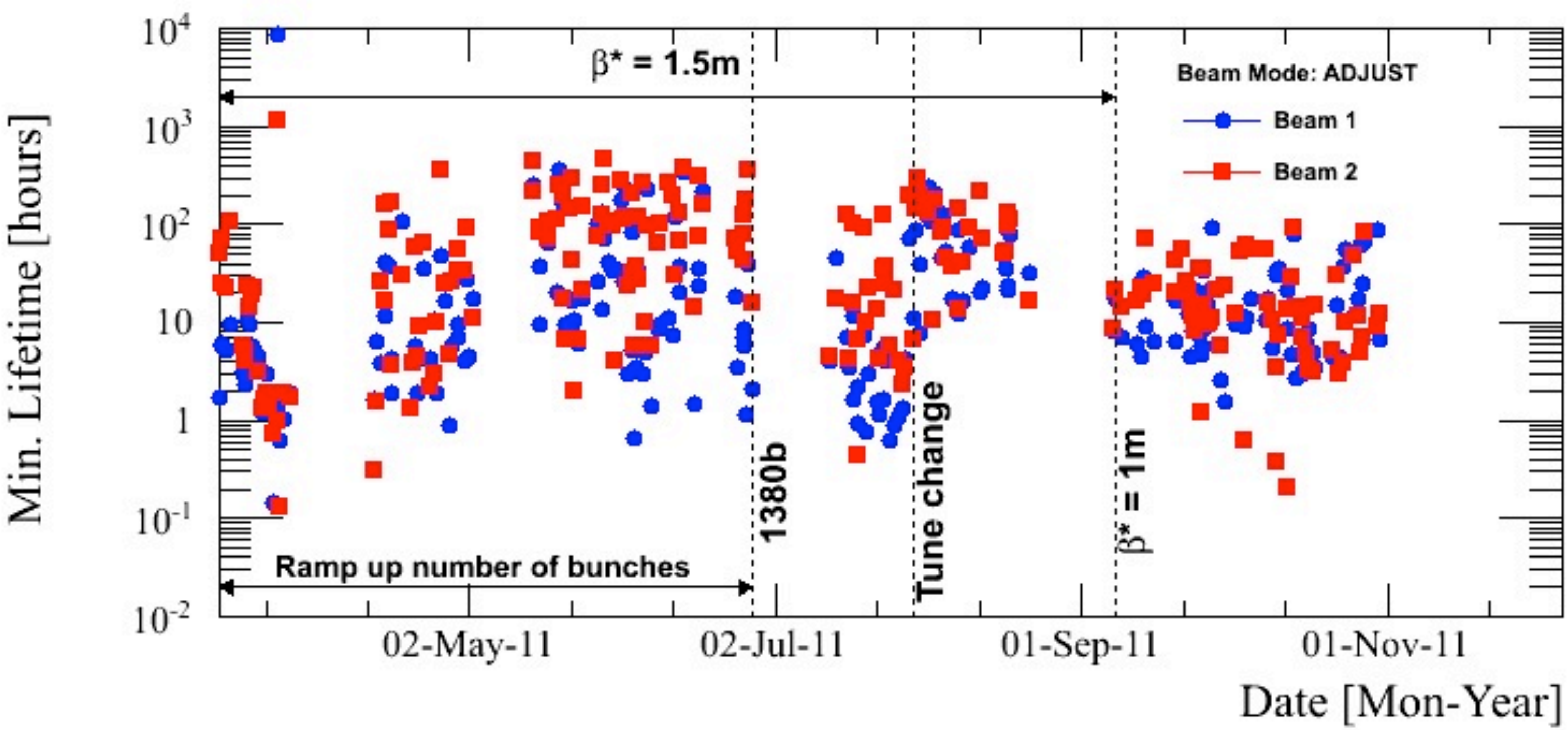
Ratio IR3/ IR7	IR7 vertical	IR7 horizontal	IR7 skew
Beam 1	408%	40%	22%
Beam 2	153%	29%	16%







2011 - ADJUST



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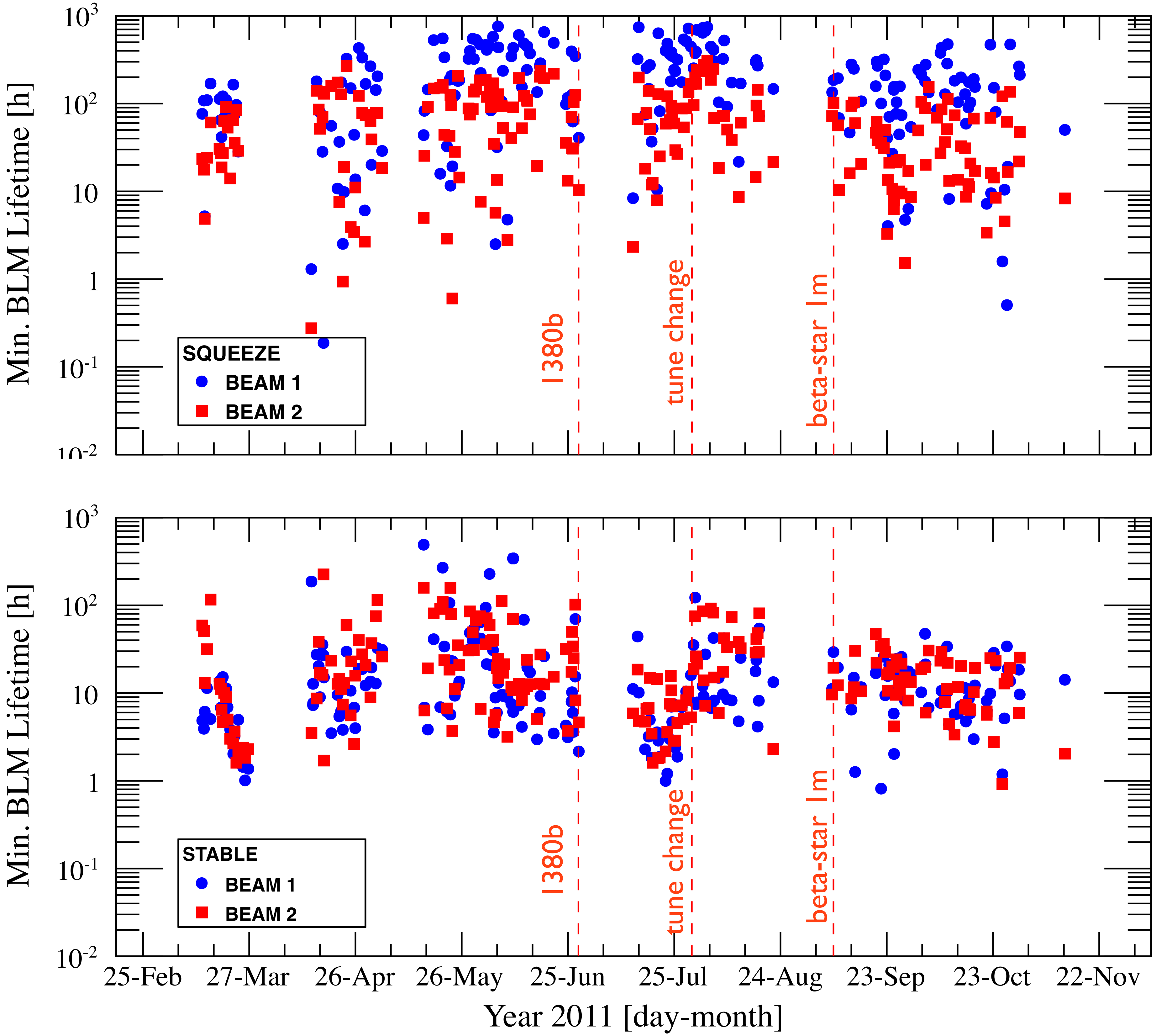
BLM lifetime 2011



SQUEEZE

STABLE

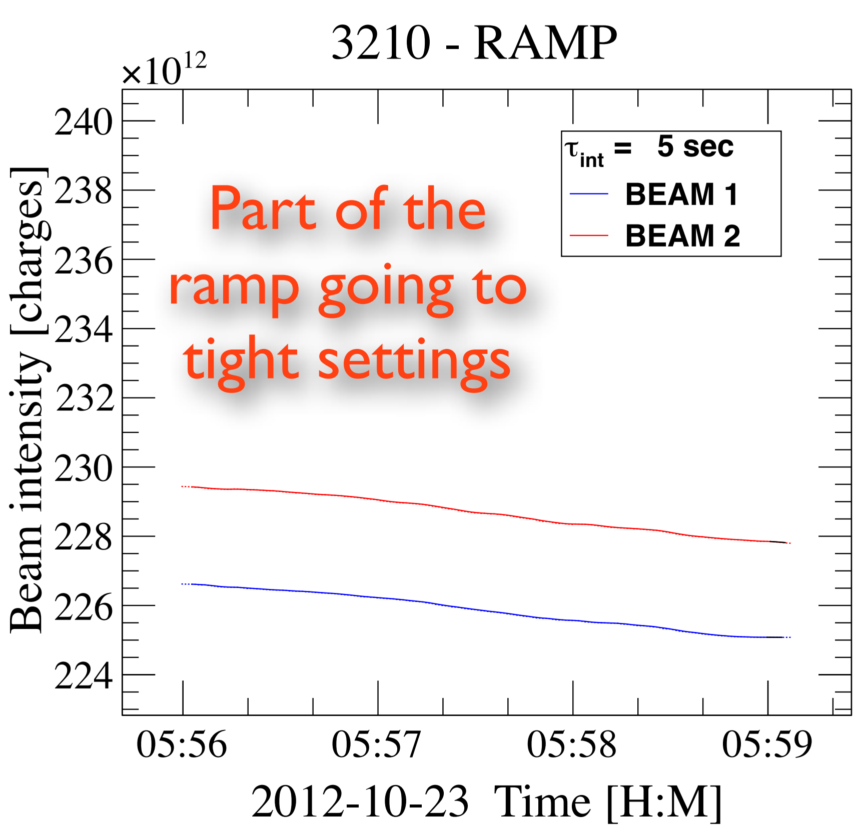
Beam lifetime

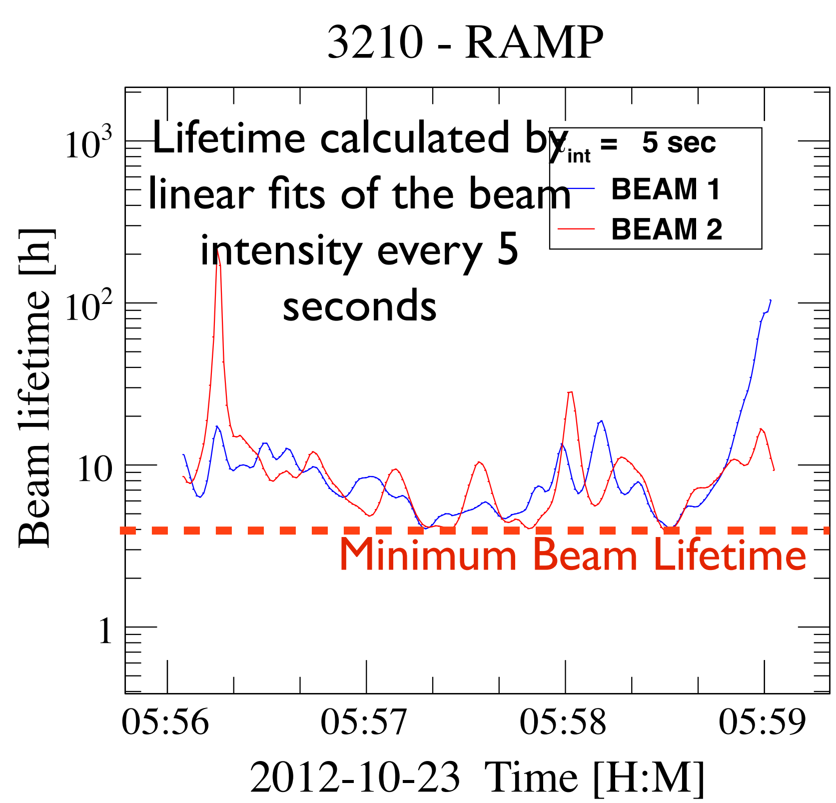
- **Beam lifetime ⇔ decay time of the beam**.
- Before collisions the beam is lost only at collimators:
  - Beam lifetime defines the performance of the machine and the collimation system.
- We are interested on fast losses that will limit the intensity reach.

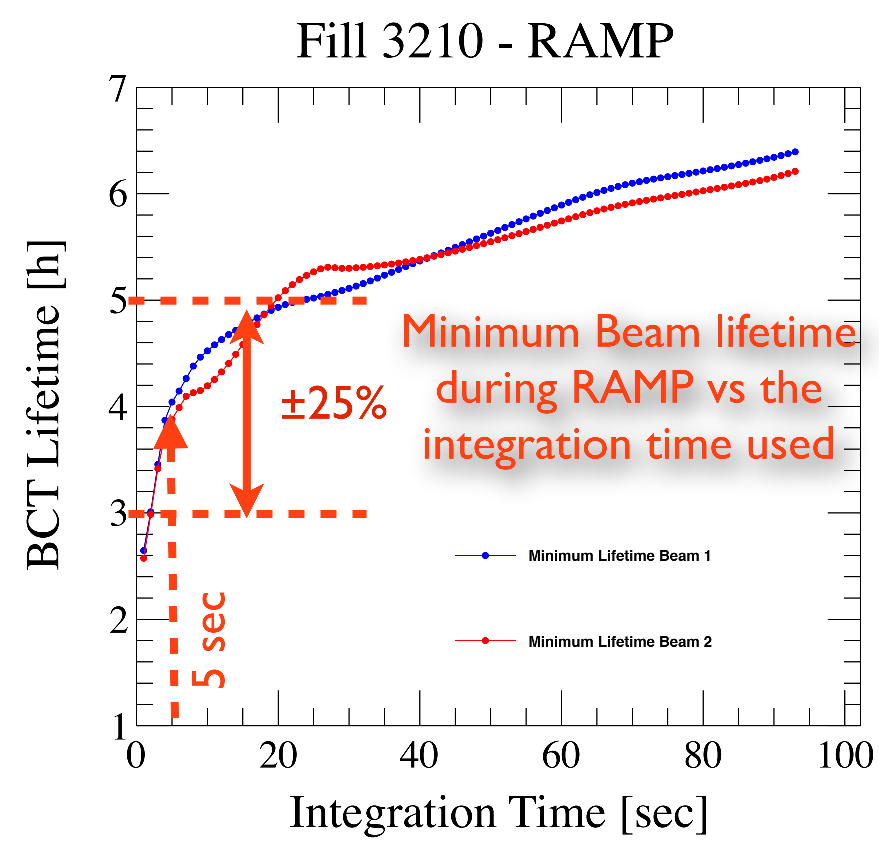
Beam Intensity

$$I = I_0 e^{-t/\tau}$$

BEAM INTENSITY	BEAM LIFETIME	Integration Time used







step 1: smooth signal by 5sec

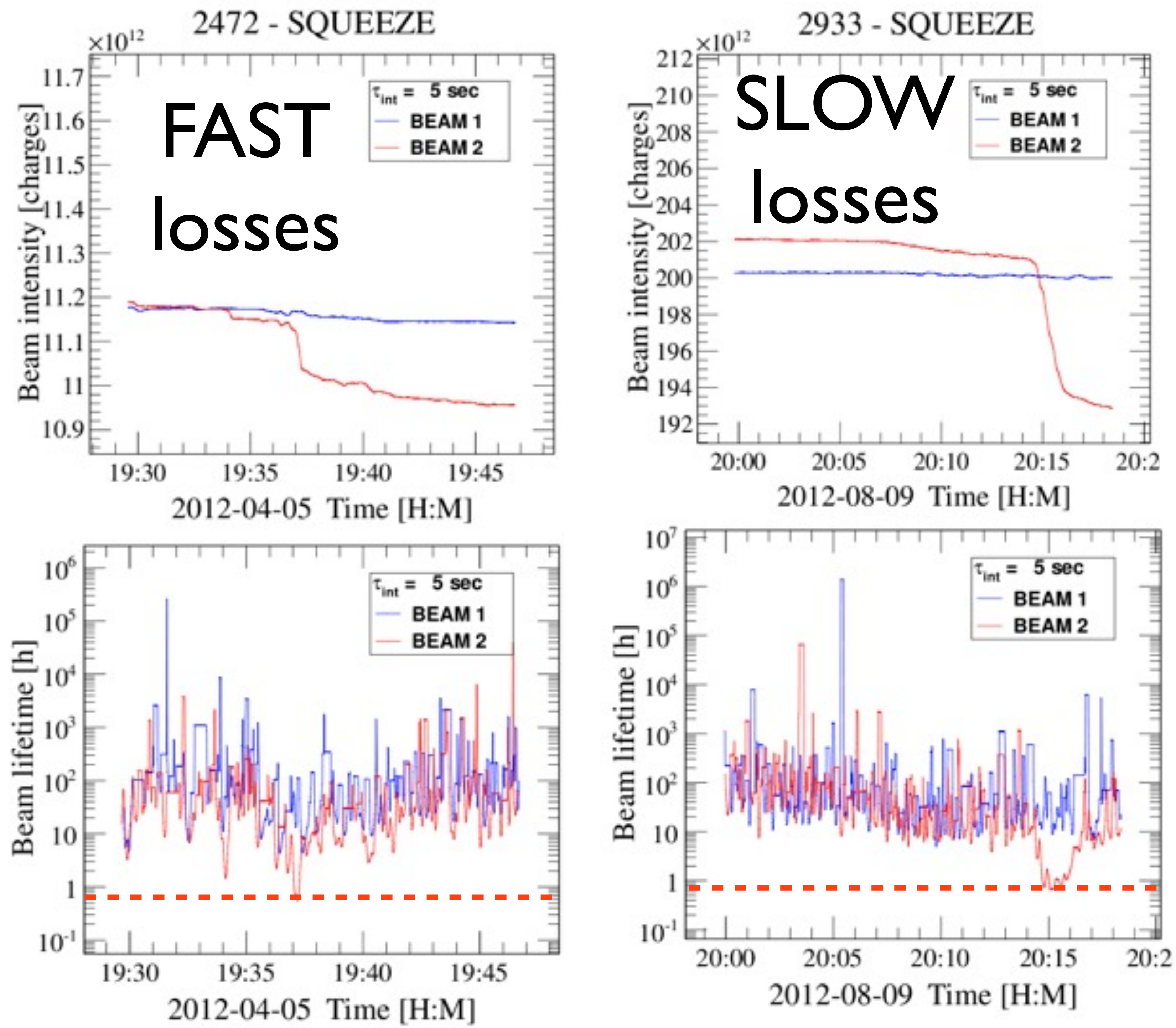
step 2: linear fit every 5 sec

Lifetime: SQUEEZE

2 types of losses:

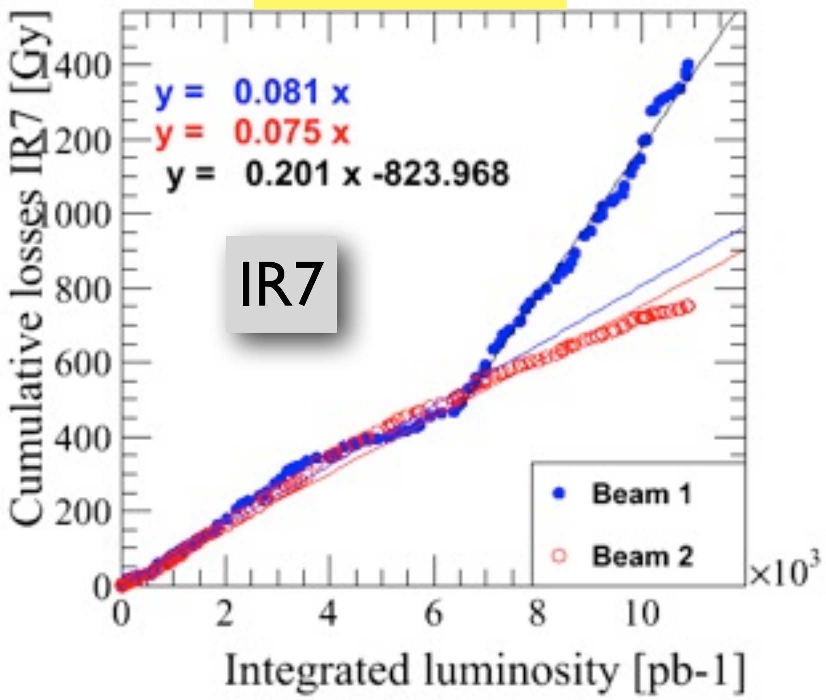
➡ Ver fast losses 1-2 seconds

➡ Slow losses towards the end of squeeze 1min, some fills Aug 2012

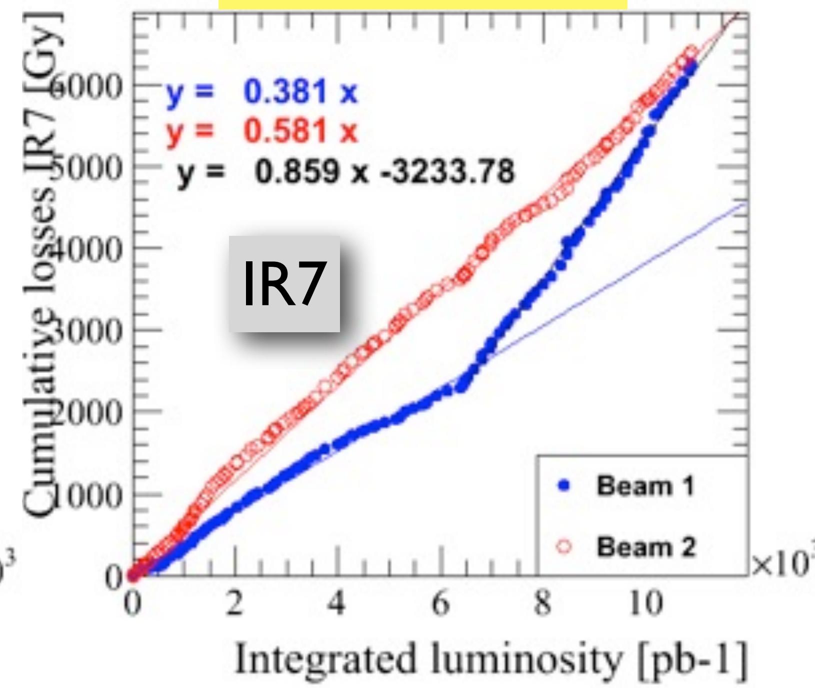


Loss share IR3/IR7

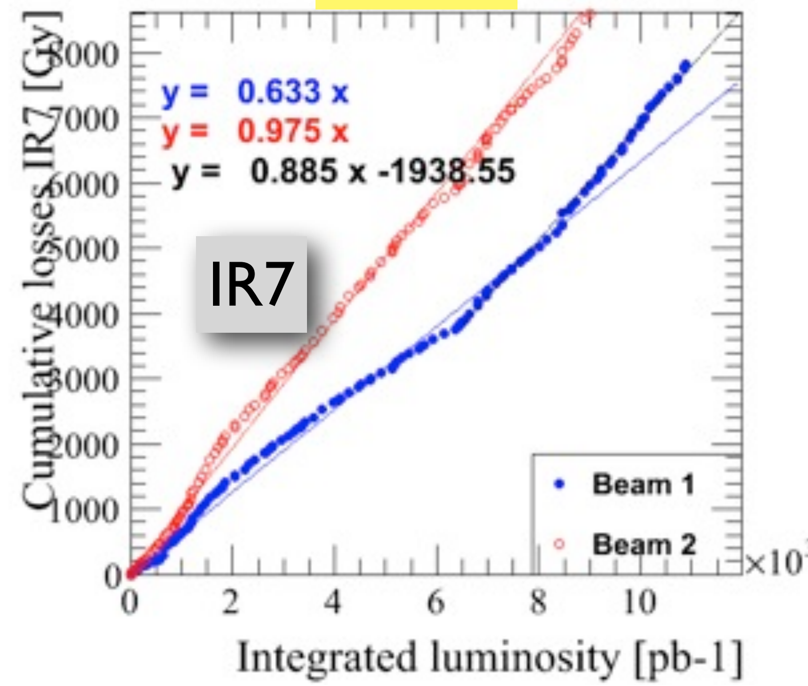
VERTICAL

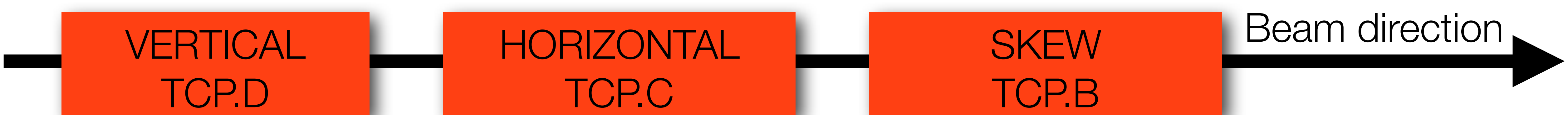


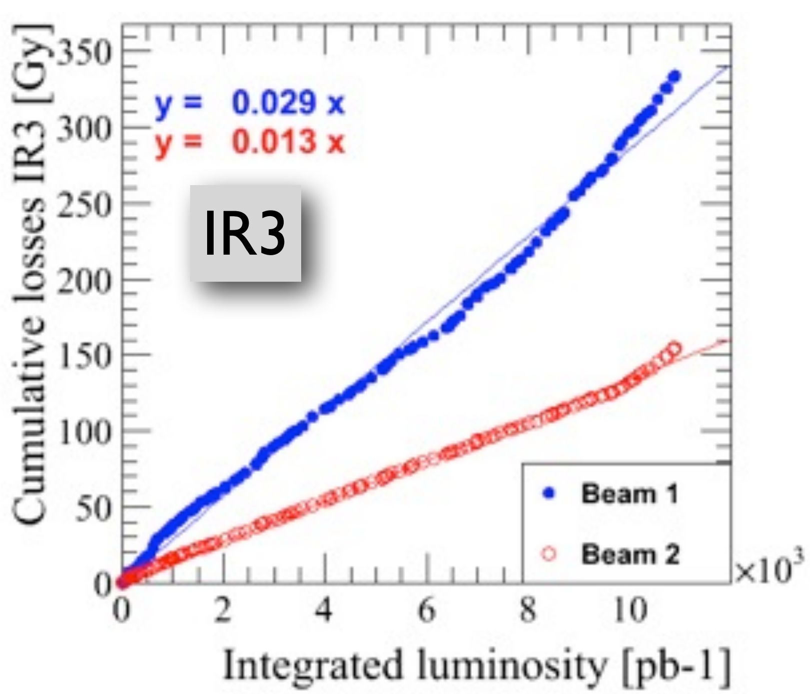
HORIZONTAL



SKEW







TCP	Beam 1 [Gy/ pb^{-1}] bf TS2	Beam 1 [Gy/ pb^{-1}] af TS2	Beam 2 [Gy/ pb^{-1}]	Ratio IR3/IR7 [%] bf TS2	Ratio IR3/IR7 [%] af TS2	Ratio IR3/IR7 [%]
IR3	0.029	0.029	0.013		- - -	
IR7 vertical	0.081	0.201	0.075	35.8	14.4	**17.3**
IR7 horizontal	0.381	0.859	0.581	7.6	3.4	**2.2**
IR7 skew	0.633	0.885	0.975	4.6	3.3	**1.3**

Expected dose IR3/IR7

Table from Julia B. Trummer

Dosimeter reading

	IR 3 left	right	IR7 left	right
TCP	8.6 kGy	3.1 kGy	302.1 kGy	> 500 kGy

Dosimeters in IR3 and IR7 were read out during TS2

$$\left\{\left(\frac{6.5\ \mathrm{TeV}}{4.0\ \mathrm{TeV}}\right)\cdot\left[\int\mathcal{L}dt\right]\cdot\left[\frac{\mathrm{Gy}}{\mathrm{pb}^{-1}}\right]\right\}\cdot\left[\frac{\text{Dosimeter reading}}{\text{BLM signal}}\right]$$

Linear extrapolation with energy

Luminosity assumed 40fb^{-1}/year

BLM signal per pb^{-1}

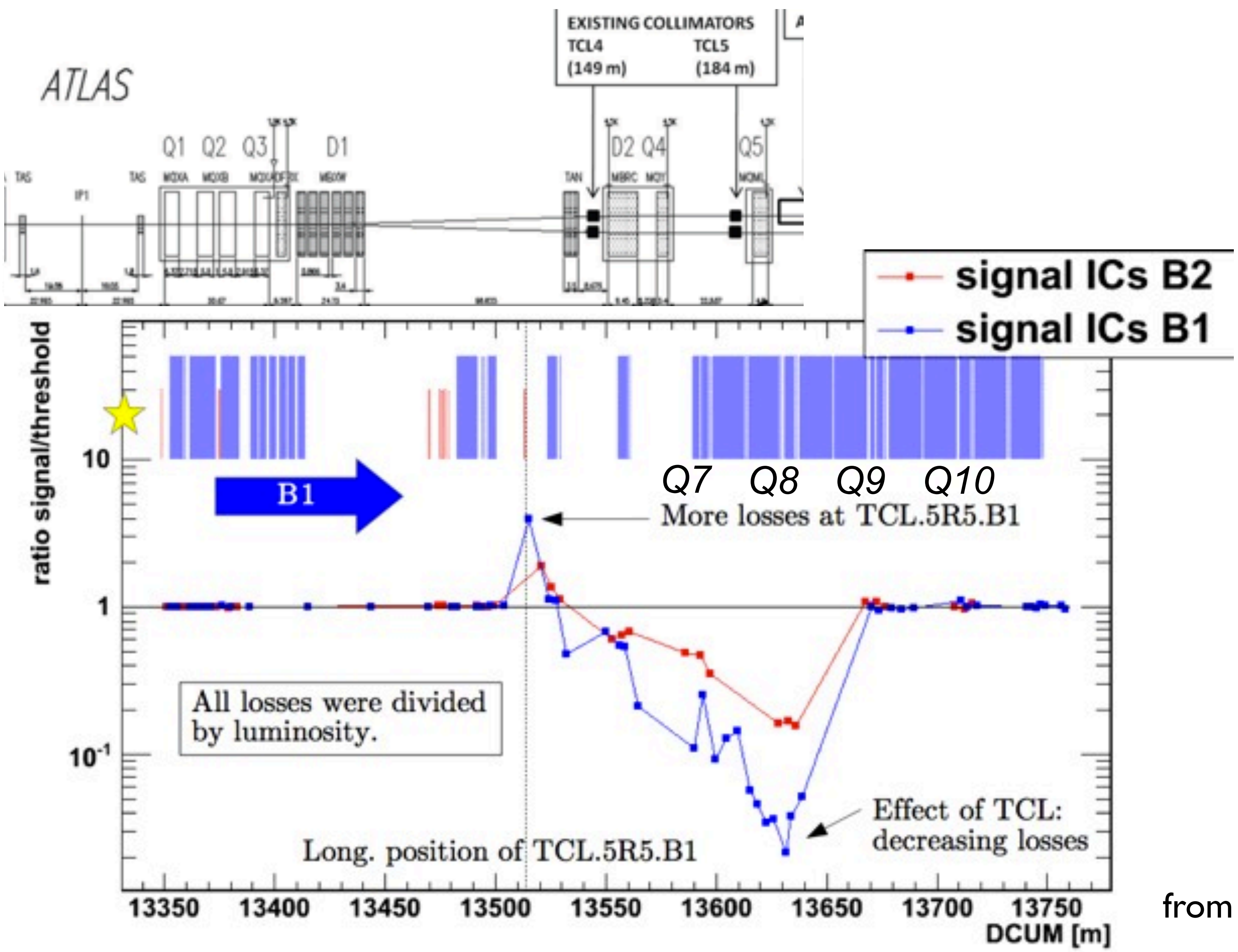
Calibration from BLM to real dose

dose [kGy] / year	IR3	IR7 skew
B1 trend before TS2	95.4	3,271.0
B1 trend after TS2	95.4	4,573.2
B2	30.8	5,281.3

- ✓ IR3 losses will increase if relaxing the settings in IR7.
- ✓ In 2011 losses in IR3 where a factor of 20 higher due to the use of relaxed settings.
- ✓ Installation of passive absorbers in IR3 is therefore recommended so operation settings are not limited.

Role of the present TCL-5

- During 2012, we have performed TCLs scans to understand the impact on reducing the losses from physics debris and the load to the magnets.

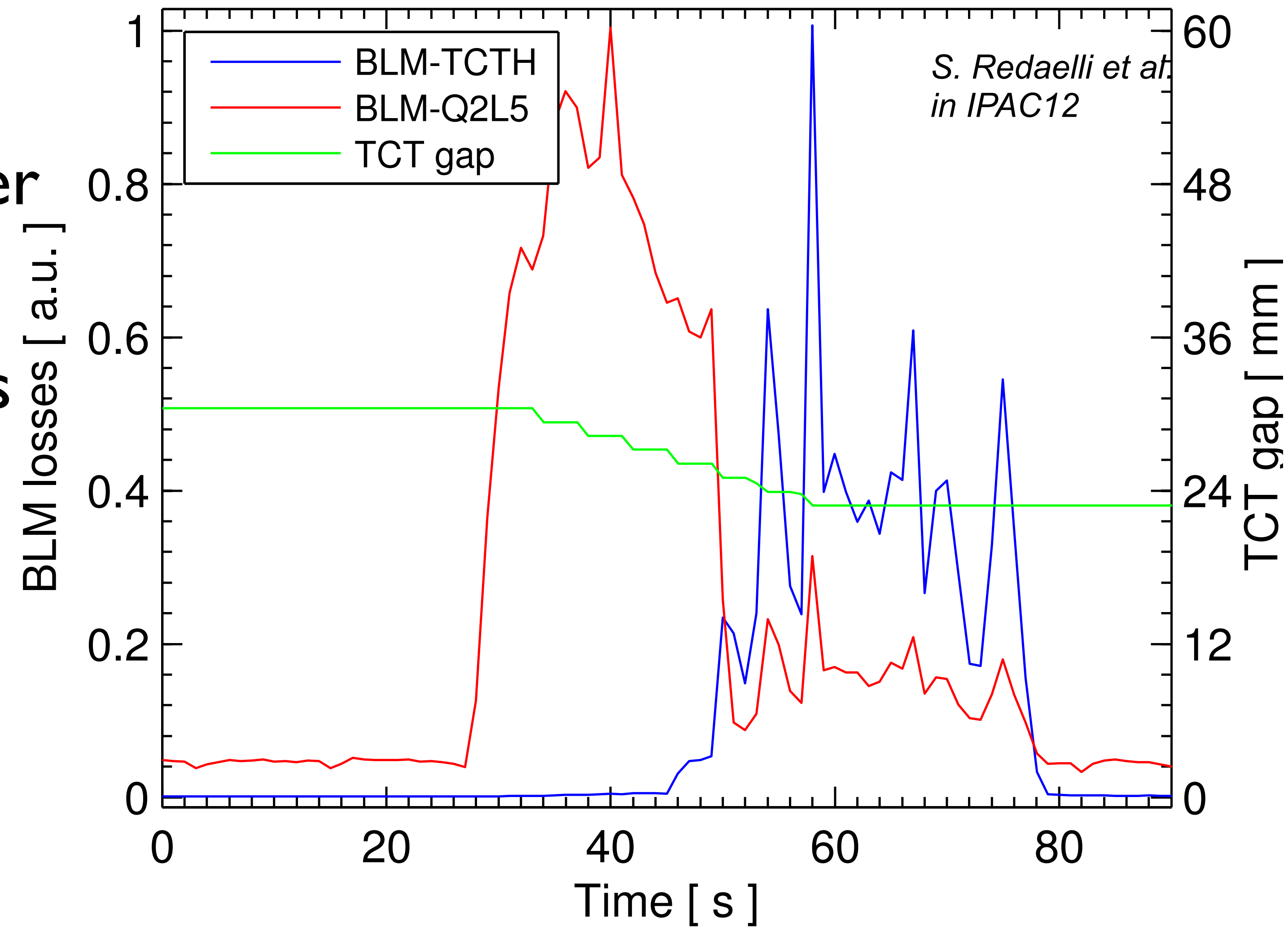


- Measured losses at Q8 reduced by a factor of 50!
- These observations motivated a recent analysis of energy deposition for different TCL layouts on-going

from A.Marsilli and S.Redaelli

Measured aperture 2012

- Aperture measured using a collimator scan and losses provoked by the transverse damper
- Collimator move in steps while provoking losses. Monitoring BLMs at collimator and aperture bottleneck.
- Significant improvement in measured speed since last year!
- Result:
  - Triplet apertured measured to 11-12 sigmas depending on IP and plane
  - Predicted > 10.8 sigma



Good agreement with calculations

We use this model to extrapolate β* at higher energies