β*-dependence on collimation

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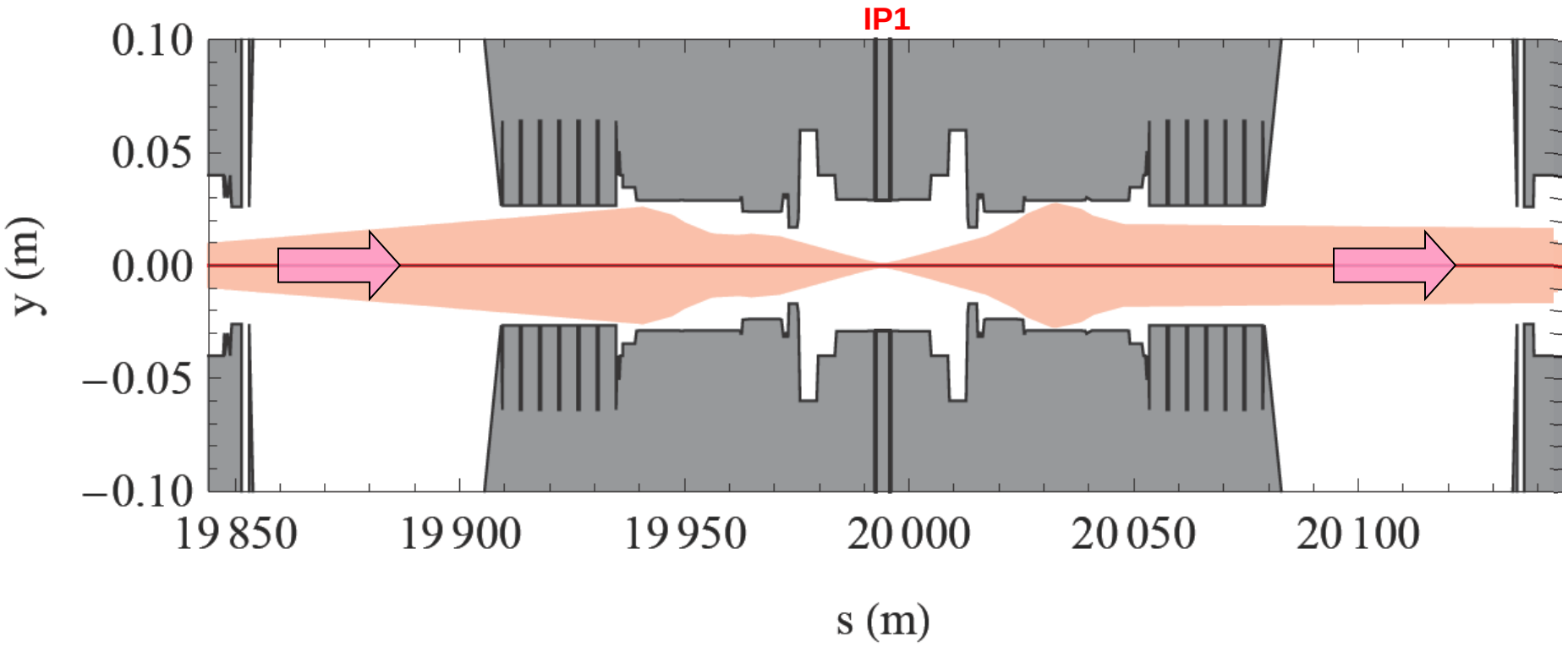
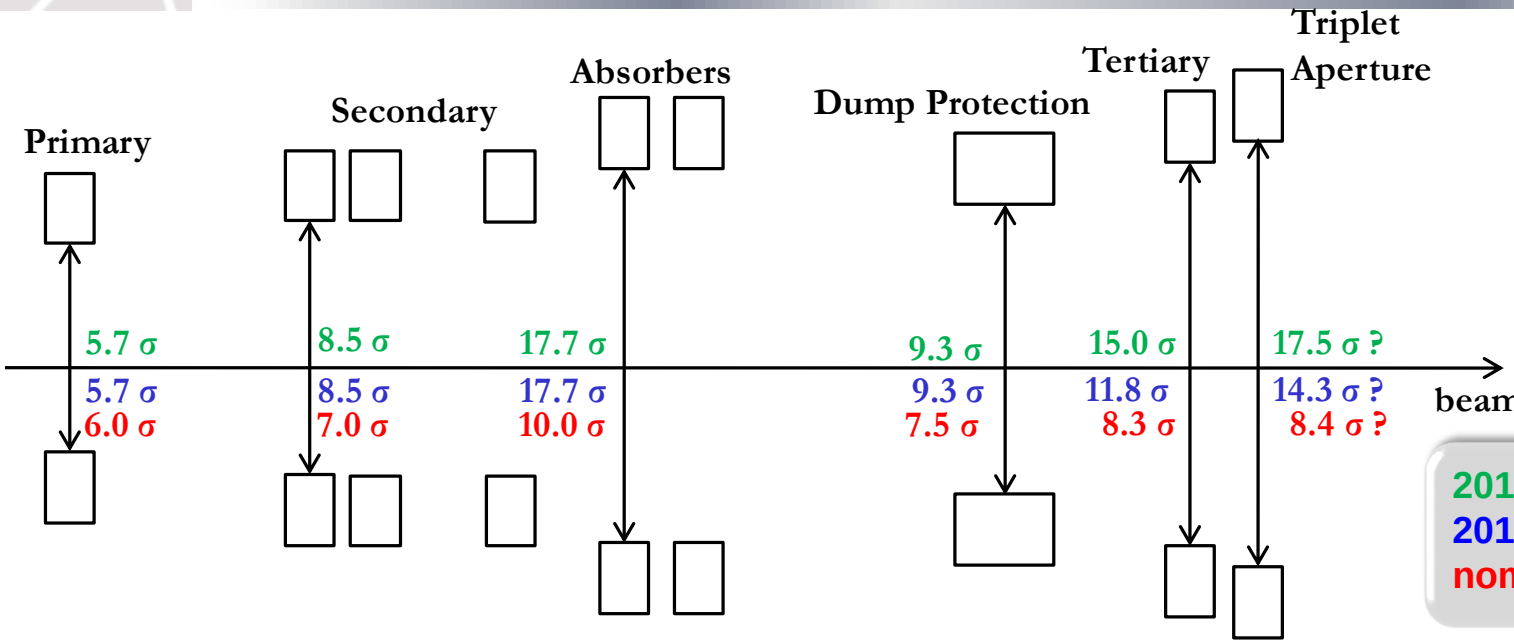
Introduction

- Main limitations when going to smaller β*
  - Magnetic limits: max gradient in quadrupoles and chromaticity
  - Beam-beam limit …
  - Aperture limit: decreasing margins in triplet when decreasing β*. Present LHC limit!



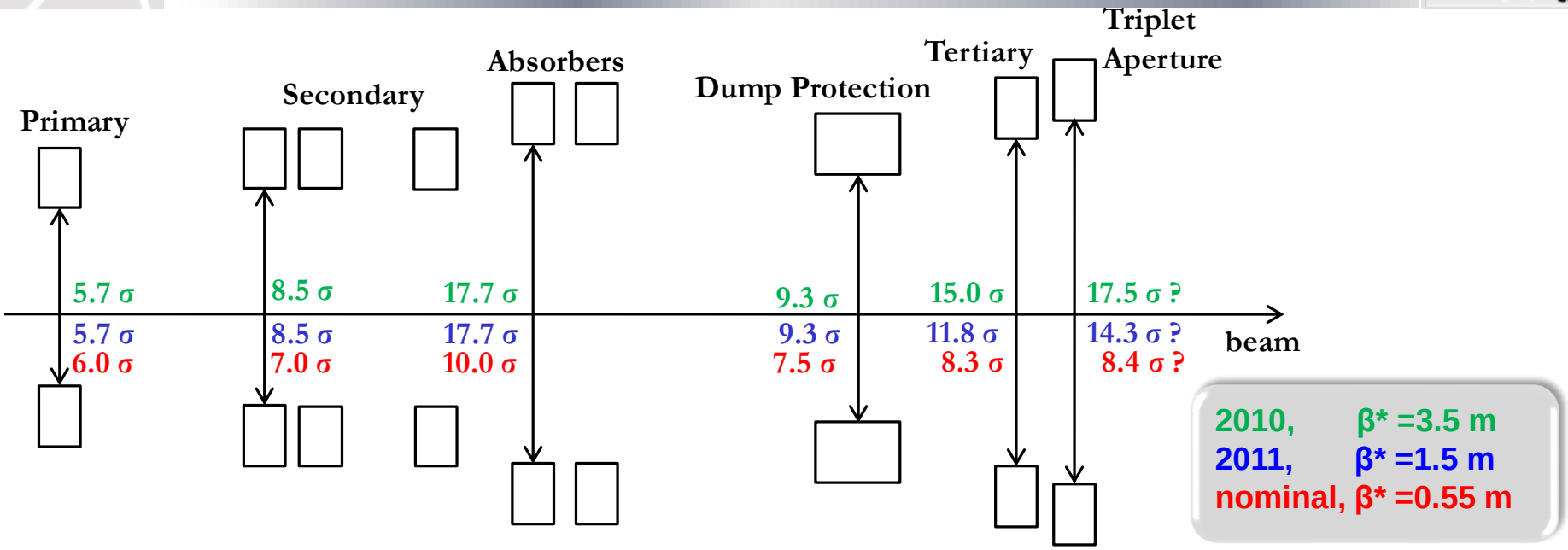
Importance of collimation for β*



2010, β* =3.5 m
2011, β* =1.5 m
nominal, β* =0.55 m

- Triplet aperture must be protected by tertiary collimators (TCTs)
- TCTs must be shadowed by dump protection
- Dump protection must be outside primary and secondary collimators
- Hierarchy must be satisfied even if orbit and optics drift after setup $\Longrightarrow$ margins needed between collimators

Importance of collimation for β*



2010, β* =3.5 m
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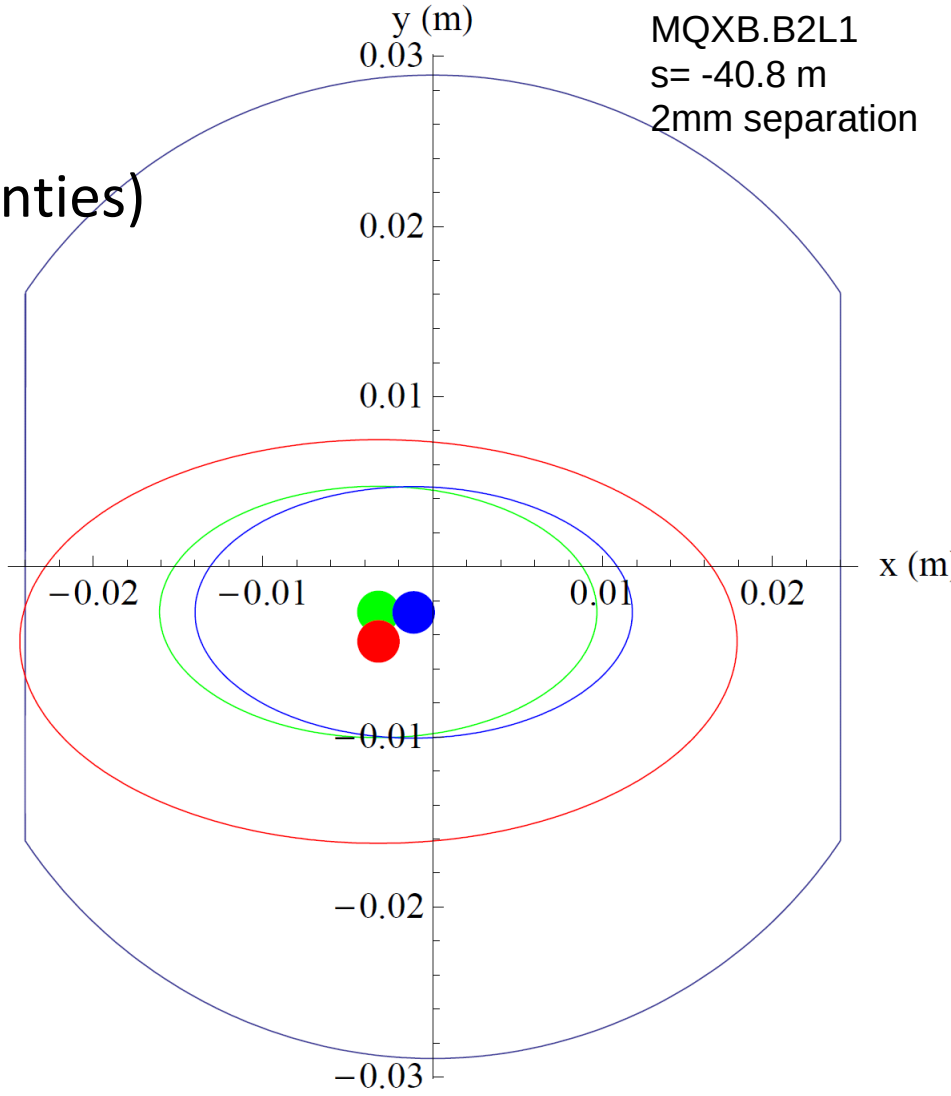
- Collimation system with margins defines min. aperture that can be protected
- Possible values of β* depend on the settings of all collimators and therefore on machine stability and frequency of collimation setups!
- To optimize β*, we have to review
  - Triplet aperture
  - Machine stability and necessary margins in collimation hierarchy

Aperture calculations

Using 2 methods:

- n1 (theory based, adding uncertainties)
- Measured aperture
  - 2010: measurements at injection.
  - Scale beam size to pre-collision (larger β_x and γ), add orbit offsets in relevant plane
  - Solve for top energy aperture
  - 2011: new local triplet aperture measurements at top energy

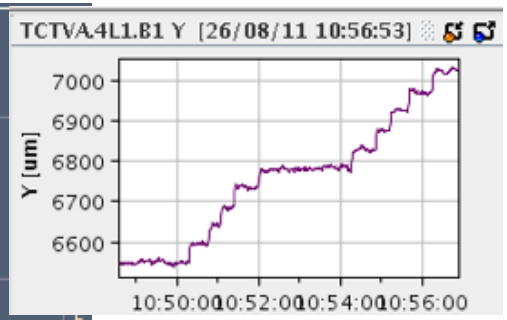


Example of 3.5 TeV measurement

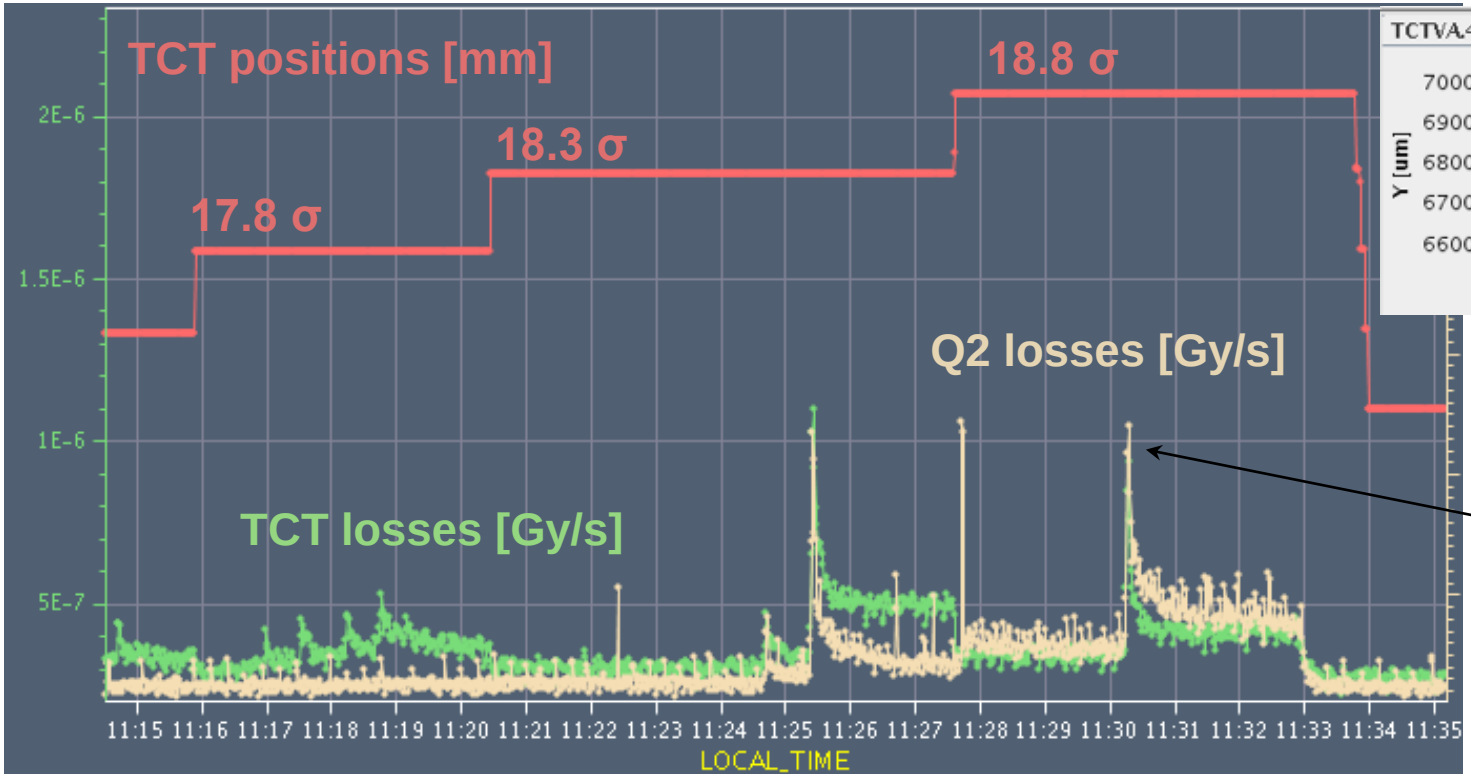
Procedure for “gentle” measurements:

1. Open TCT by 0.5 sigma (250-320µm in H-V)
2. Increase local bump in IR in steps of 0.25 sigma until losses seen
3. Check relative height of BLM spikes: TCT vs MQX (Q2). Go back to 1.

Start from initial settings: TCTs at 11.8 sigmas.



Orbit at TCT and Q2



Loss spikes while the orbit is increased, touching TCT or MQX

Courtesy S. Redaelli

Aperture results

Example: IR5 horizontal plane

			Model	BPM (CO_{Xing} + ΔCO_{bump})
3.5 TeV	*IP5-H (crossing)*	CO_{Xing}	= 5.8 mm	
	(120 µrad)	ΔCO_{bump}	= 17.7 mm	24.4 mm
		$n_\sigma \times \sigma$	= 4.8 mm	4.8 mm
(n_σ = 4)		A_{mm}	= 28.3 mm	29.2 mm

Mechanical aperture: 28.9 mm (30 mm without tolerance)

- Found aperture is very close to the ideal mechanical aperture
- During design phase, pessimistically added margins for different tolerances
- Measured aperture thus better than expected

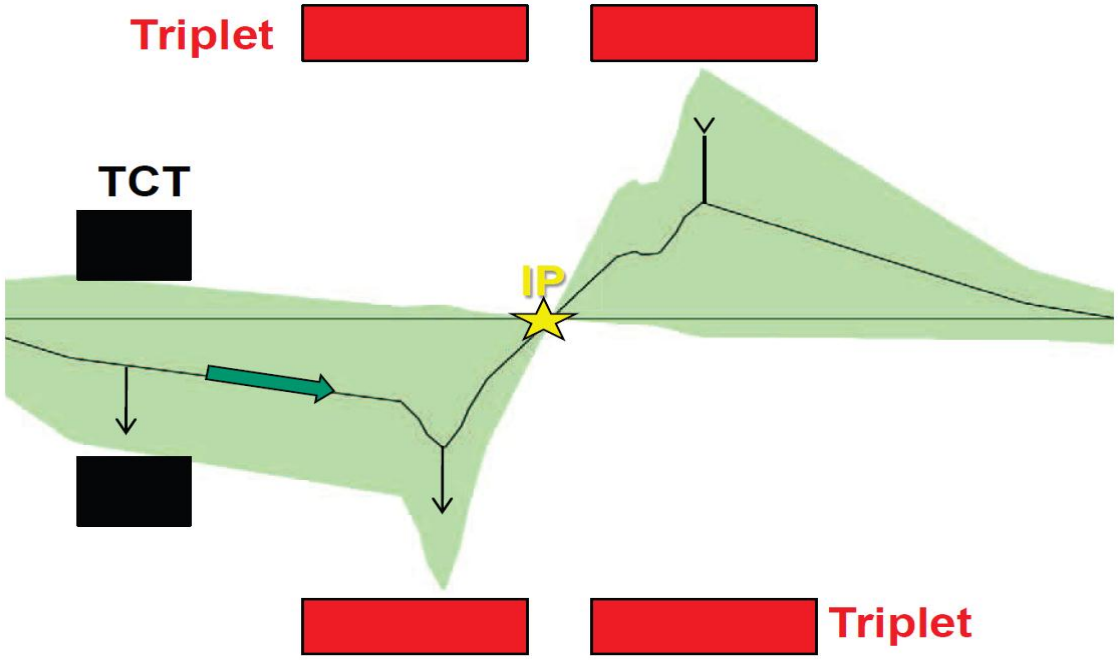
Reference: MD note in preparation
Presentations by S. Redaelli and M. Giovannozzi in LMC and LSWG

Margins in cleaning hierarchy

- Orbit: separate analysis on following slides
- 10% β-beating. Bias in correction at TCT-triplet wanted
- Positioning error (small!)
- Setup error (small!)
- Small lumi scans can be included in the margin

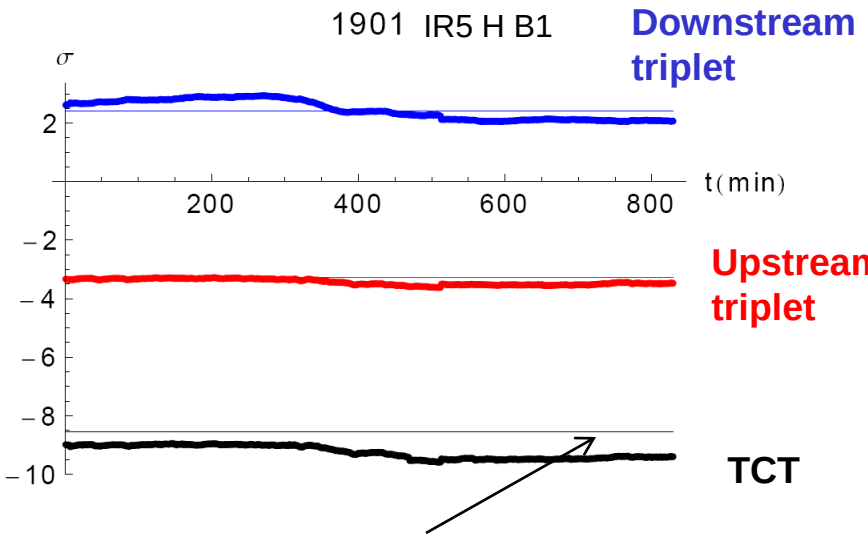
Orbit stability

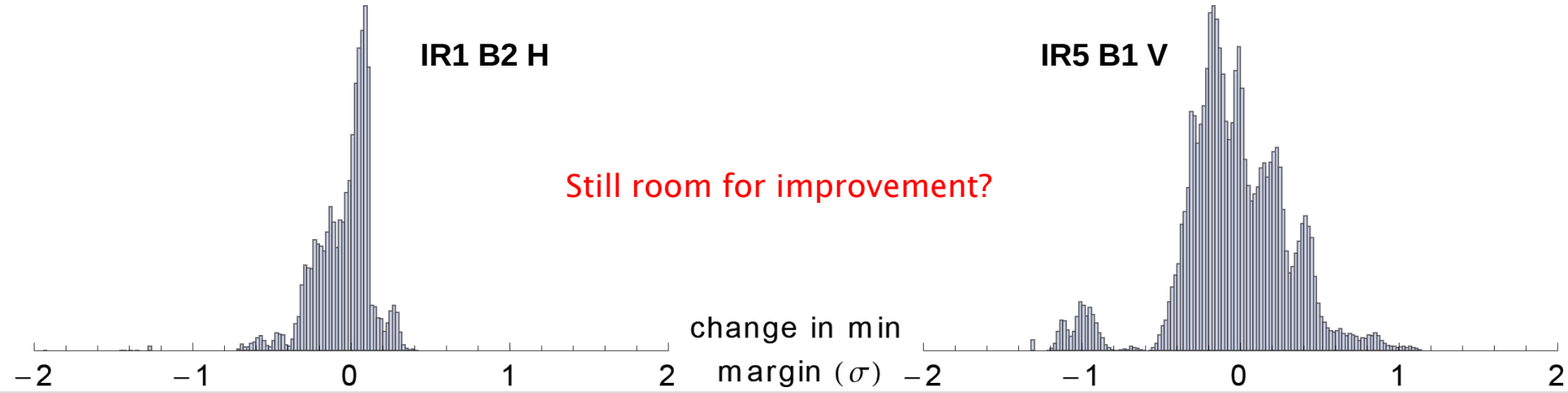
- Check *reduction* in margin during all fills with stable beams
  - Relative change needed between both devices (collimators or aperture)
  - Consider change w.r.t. *reference orbit* used during setup
- For margin TCT-aperture, take phase advance into account (only one jaw relevant)



Orbit stability triplets/TCTs

- First half of 2011 in many cases better than 2010
- Very good stability within fills
- change in minimum margin TCT-triplets during all 2011 stable beams
- 1.1 σ margin needed for 99% coverage (gain 0.5 σ).





Margins between collimators

- Analysis shows
  - 99% of the time in stable beams, the triplets in IR1 and IR5 are shadowed by the TCTs with a 1.1 σ margin in first part of 2011 run
  - 99% of the time in stable beams, all horizontal TCTs are shadowed by the dump protection with a 1.1σ margin in first part of 2011 run
  - We should not reduce the margin between IR7 and dump protection

Damage risks

- What does a 99% coverage mean in terms of damage risks?
  - Assume 1 asynchronous dump per year
  - Assume 1% of the time the margin dump-TCT is violated (uncorrelated to async. dump)
  - Assume 1/3 of the time spent in stable beams
    => 1 event in 300 years could be dangerous for the TCTs
  - Assume 1% of the time the margin TCT-triplet is violated
    => 1 event in 30000 years could be dangerous for the triplets
  - This considers only orbit. Simultaneously all other errors have to add up pessimistically at both locations.
    => **The real risk is much lower!**
  - In case of the TCT being hit by a bunch there is no catastrophic damage, most likely it will be scratched and we can use a spare surface (see talk A. Bertarelli in Chamonix 2011)

Operational margins and settings

Summing *linearly* we get the margins

	2010		2011	
	(σ)	(mm)	(σ)	(mm)
triplet–TCT	2.5	0.9–2.1	2.3	1.1–2.7
TCT–TCSG IR6	5.7	3.5–4.4	2.5	1.3–1.8
TCSG IR7–TCP	2.8	0.6–1.6	2.8	0.5–1.5

and the settings

TCP IR7	TCS IR7	TCS IR6	TCT	aperture
5.70	8.50	9.30	11.80	14.10

The year 2011 started with β*=1.5m, but refined aperture measurements in September showed that β*=1.0m can be obtained with the same settings

Future improvements

- If machine stability improves, smaller margins in hierarchy possible
- Moving in primary collimators closer to beam (smaller than nominal emittance!) and the rest of the system gains aperture
  - Probably only possible at 3.5 TeV – at 7 TeV impedance becomes problematic
  - Tested tight collimator settings in MDs in 2011 (primary collimators at 4 $\sigma \cong$ nominal gaps in mm at 7 TeV).
  - Excellent cleaning performance obtained, but improved orbit stability during squeeze needed (work underway - S. Redaelli)
- Refined analysis for present machine underway

Possibilities for HiLumi LHC

- Upgraded collimators with built-in BPM buttons allow collimators to be quickly re-centered without touching beam, which makes smaller margins possible.

- We can probably not go below nominal gaps (in mm) of the primary collimators due to impedance at 7 TeV

- To go to very small β*, we thus need larger aperture as in upgrade scenario (see S. Fartoukh et al.)

Conclusions

- β* is dependent on margins in collimation system. Present limitation on β* in the LHC. Choice of β* should maximize performance without risking safety
- A review of both aperture and all margins allowed β* to be reduced from 3.5m in 2010 to 1.5m in beginning of 2011 and later to 1.0m
- Presently the aperture tolerances are better than expected but we run with larger margins in the collimation hierarchy. Main cause: long-term orbit stability
- Future improvements from collimation possible
- Larger aperture needed for HiLumi-LHC parameters