Collimation margins and β^*

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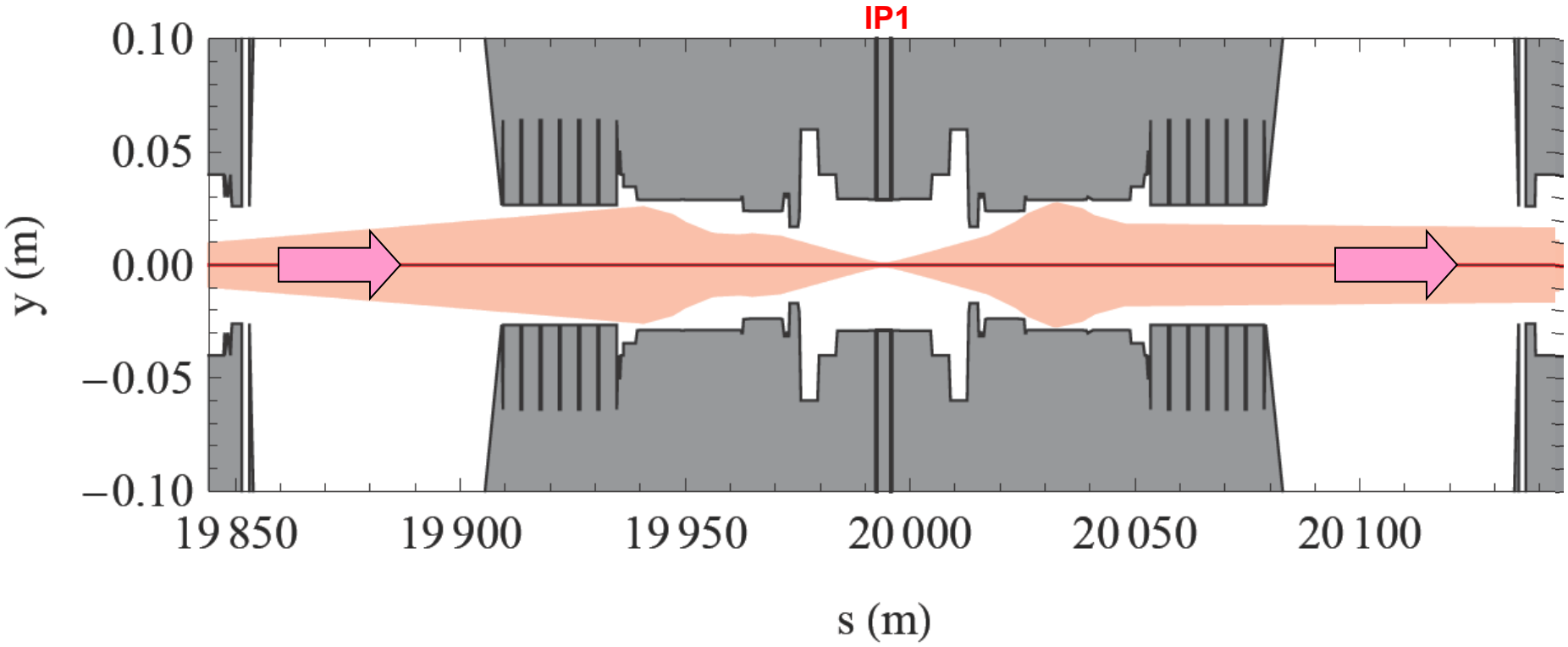
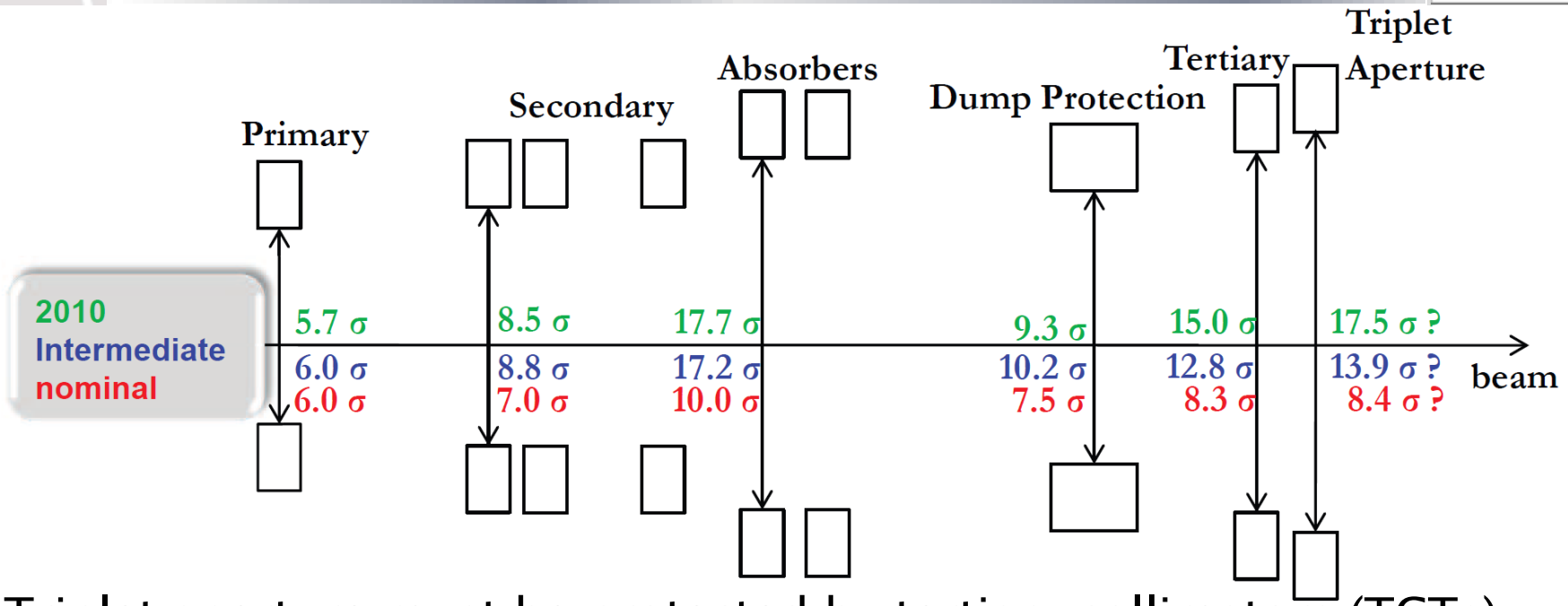
Introduction

- 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! New regime compared to other machines

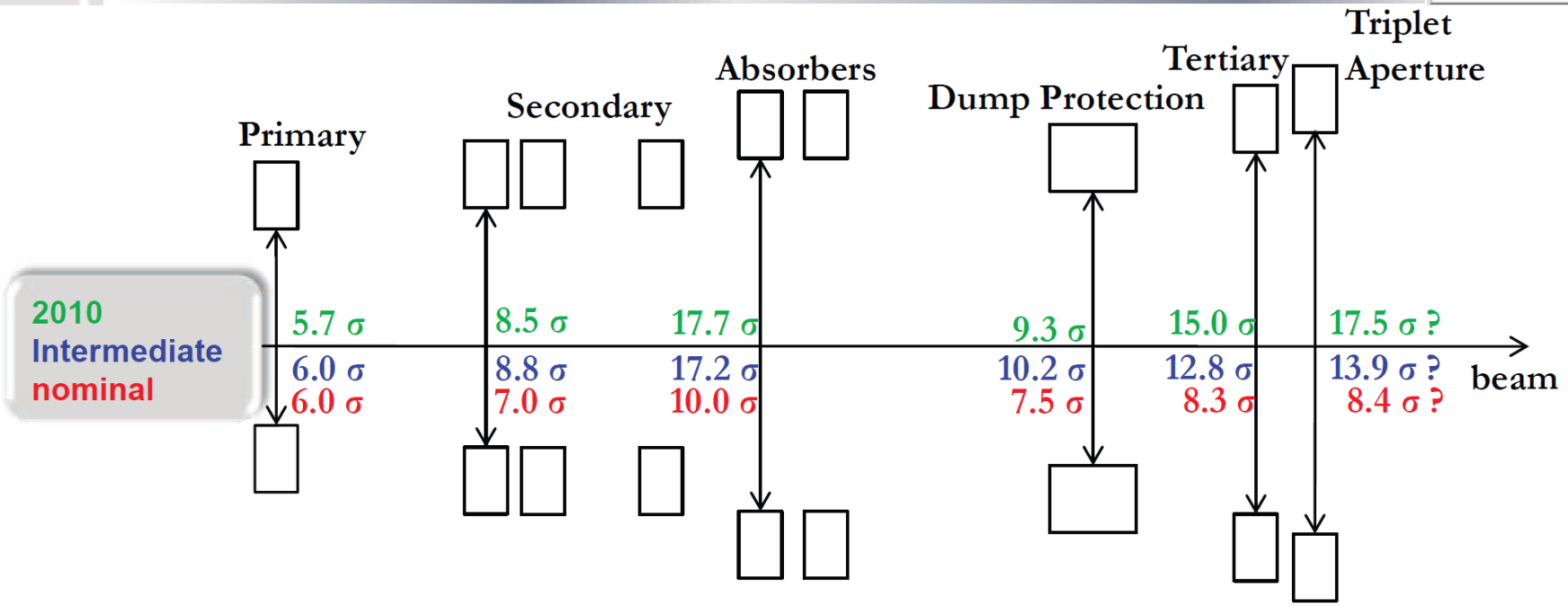


Importance of collimation for β^*



- 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

Influence of collimation



- 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

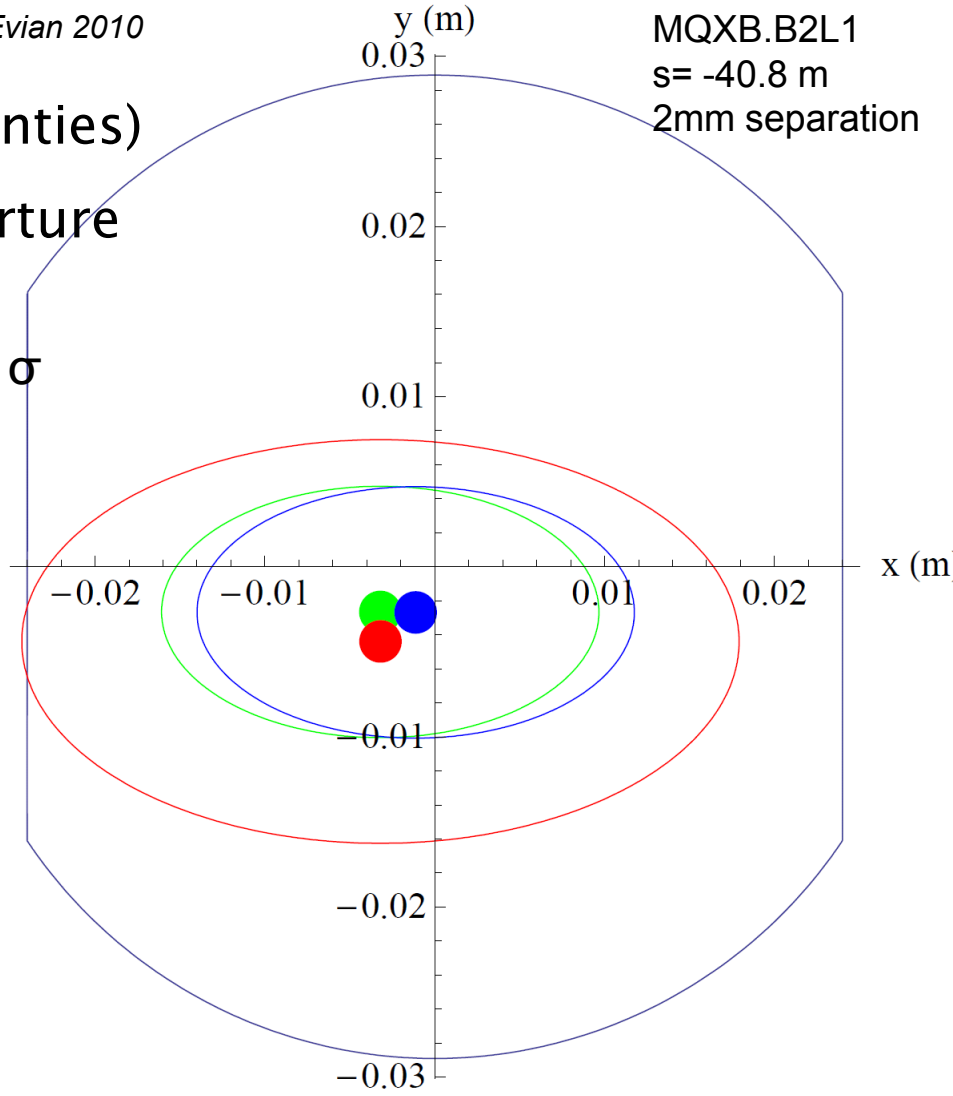
Aperture calculations

Using 2 methods: *reference R.Bruce,R.Assmann, Evian 2010*

- n1 (theory based, adding uncertainties)
- scaling of measured injection aperture
  - Assume *pessimistically* injection aperture=global limit+2 σ
  - Only one plane matters with good approximation – reduce to 1D
  - Scale beam size to pre-collision

$$|u_i| + n_i\sigma_i = |u_p| + n_p\sigma_p$$

  - Solve for top energy aperture
- 2011: new local triplet aperture measurements. Ongoing work to refine calculations

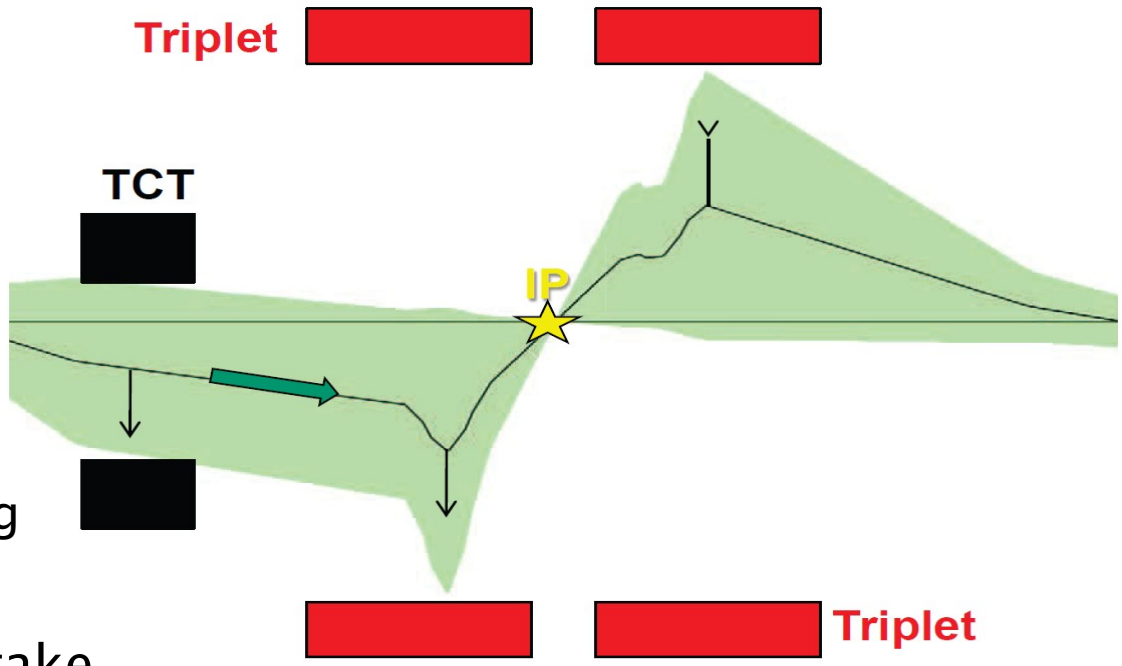


Margins in cleaning hierarchy

- 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 in 2010

- 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)



Margins between collimators

- Analysis shows
  - 99% of the time in stable beams, all triplets except IR2 are shadowed by the TCTs with a 1.6 σ margin
  - 99% of the time in stable beams, all horizontal TCTs are shadowed by the dump protection with a 1.1σ margin
  - We should not reduce the margin between IR7 and dump protection
  - We should not reduce the margin between primary and secondary collimators in IR7 (possible loss in cleaning efficiency)

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)

Proposed 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

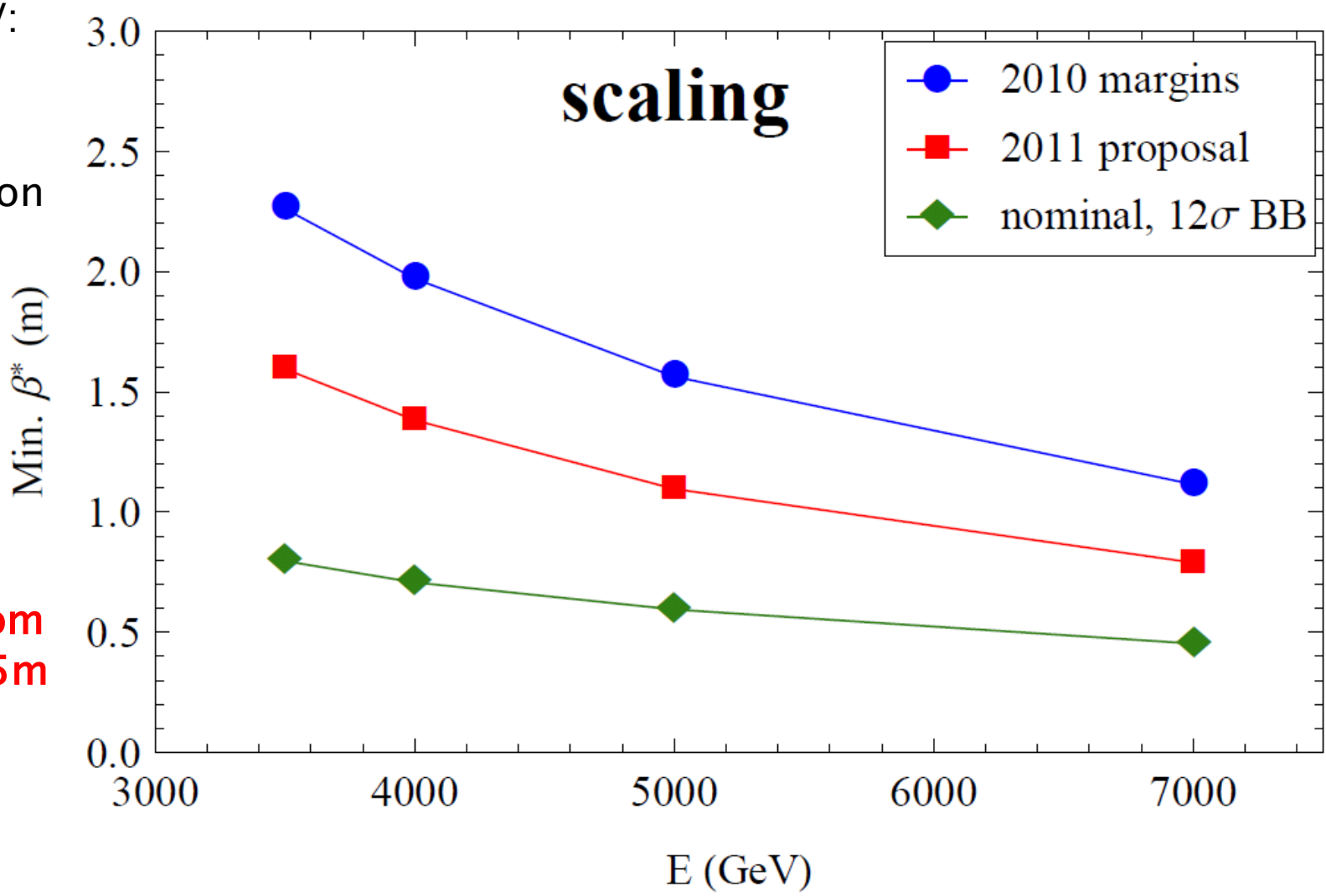
and the settings

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

Assuming IP2 remains at larger margins. Proposed settings very similar to what was used in 2010 run with $\beta^*=2.0$m

β^* reach with aperture scaling

- For 3.5 TeV: $\beta^*=1.6$m
- Reducing BB separation to nominal 9.5σ (real emittance smaller!) allows $\beta^*=1.5$m
- 2011: β^* reduced from 3.5m to 1.5m
- Factor 2.3 gain in luminosity



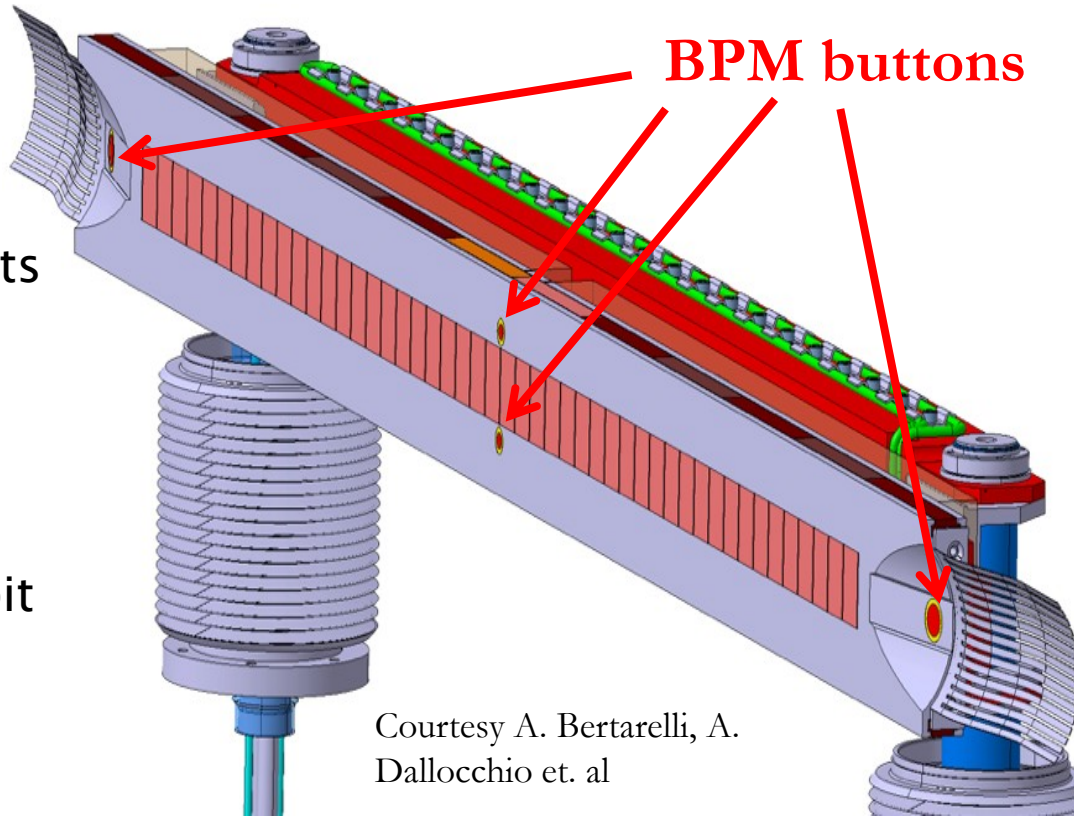
Can we go even lower?

Can we go even lower?

- 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
  - Recently qualified tight settings in MD (primary collimators at 4 nominal σ) with one bunch
  - Possible to operate with these settings in physics? Impedance? Lifetime?
- Refined analysis underway including more recent aperture measurements and MD results
- In upgrade scenario, new optics and magnets allow much smaller β^* (S. Fartoukh et al)
- Upgraded collimators with built-in BPM buttons allow collimators to be quickly re-centered without touching beam
  - Prototype installed in the SPS

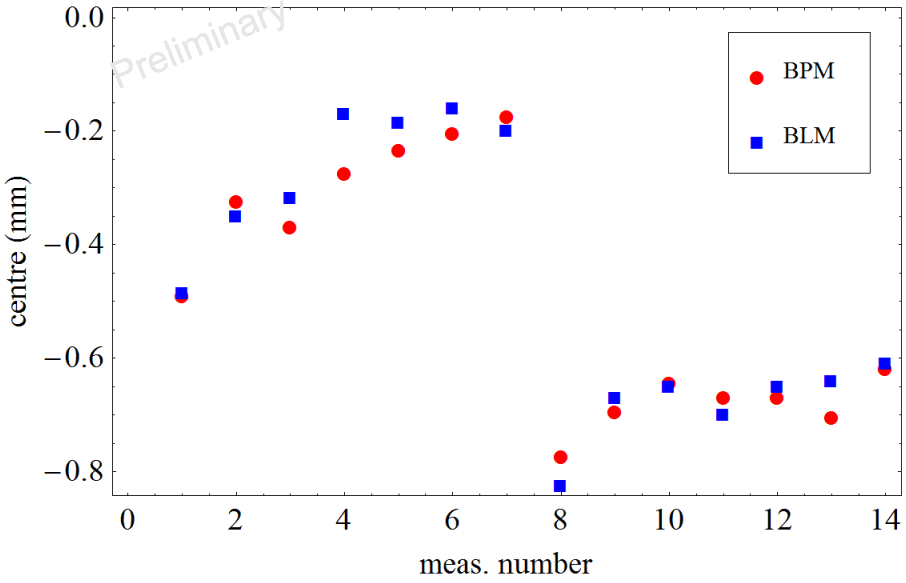
Collimators with built-in BPMs

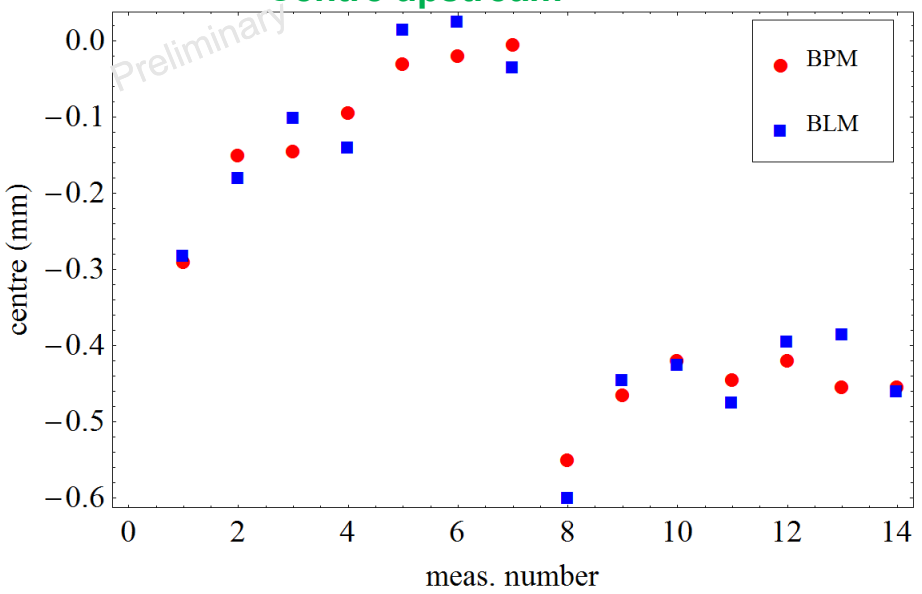
- Factor 1000 reduction of setup time – more frequent setups possible
- Less strict requirements on long-term orbit stability.
- More flexibility for local IR orbits (crossing angle, separation for luminosity leveling, etc.).
- Allows reduction of margins between collimator families, as collimators can follow slow orbit drifts
  - tighter collimator settings possible with better cleaning
  - Smaller β^*– Maybe only way to allow nominal margins!
  - To have full benefit, BPMs must be implemented in all collimators!



Courtesy A. Bertarelli, A. Dallocchio et. al

Recent MD with prototype in SPS





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- Excellent agreement between different alignment methods (BLM and BPM).
- Discrepancy ($< 70\ \mu$m) dominated by step size (50 μm).
- No effect of showers seen on BPMs so far
- Very promising concept, although not main focus of review

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 estimates and all margins allowed β^* to be reduced from 3.5m in 2010 to 1.5m in 2011
- Future improvements from collimation possible
  - With present machine (ongoing work)
  - With upgraded collimators with BPM buttons