Collimation and β*-reach

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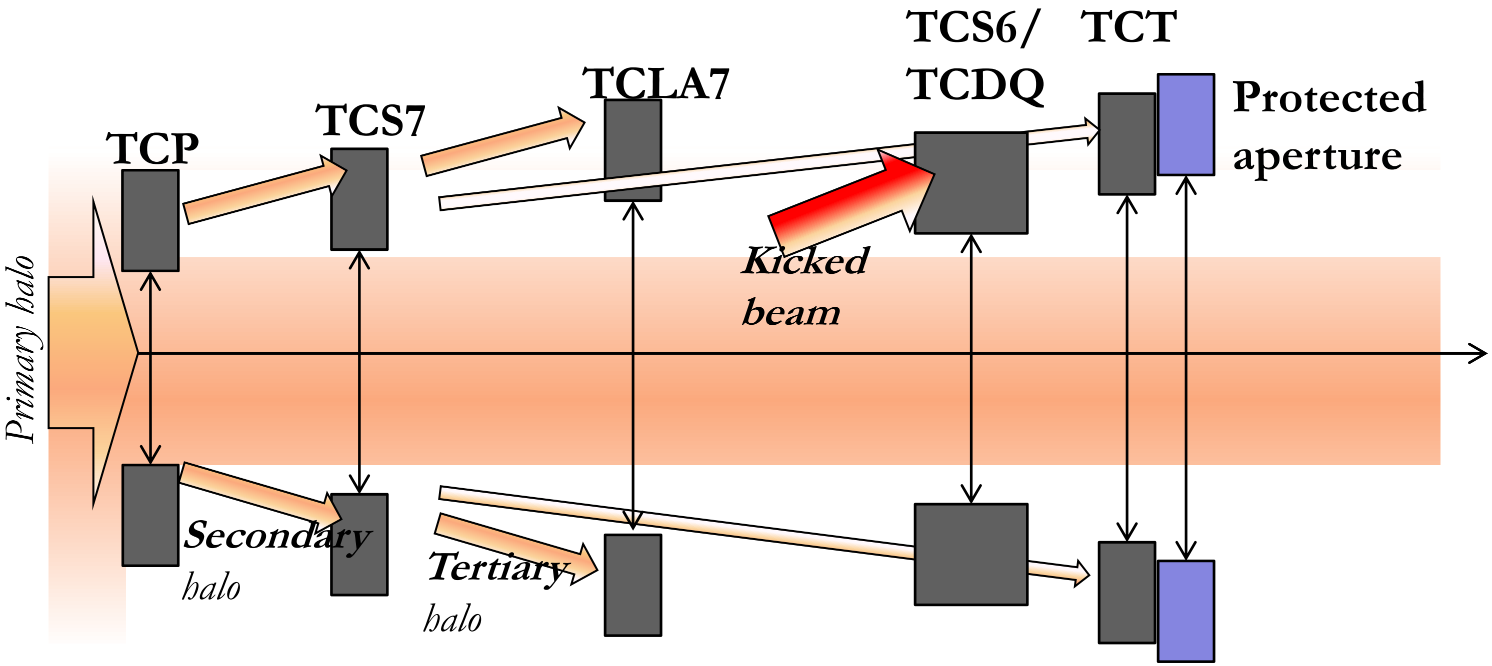
Outline

- Introduction
  - Importance of collimation for machine performance
  - Brief recap of Run 1
- Outlook for Run 2
  - Startup scenario
  - How can we push the performance?
  - “Ultimate” scenario
- Summary

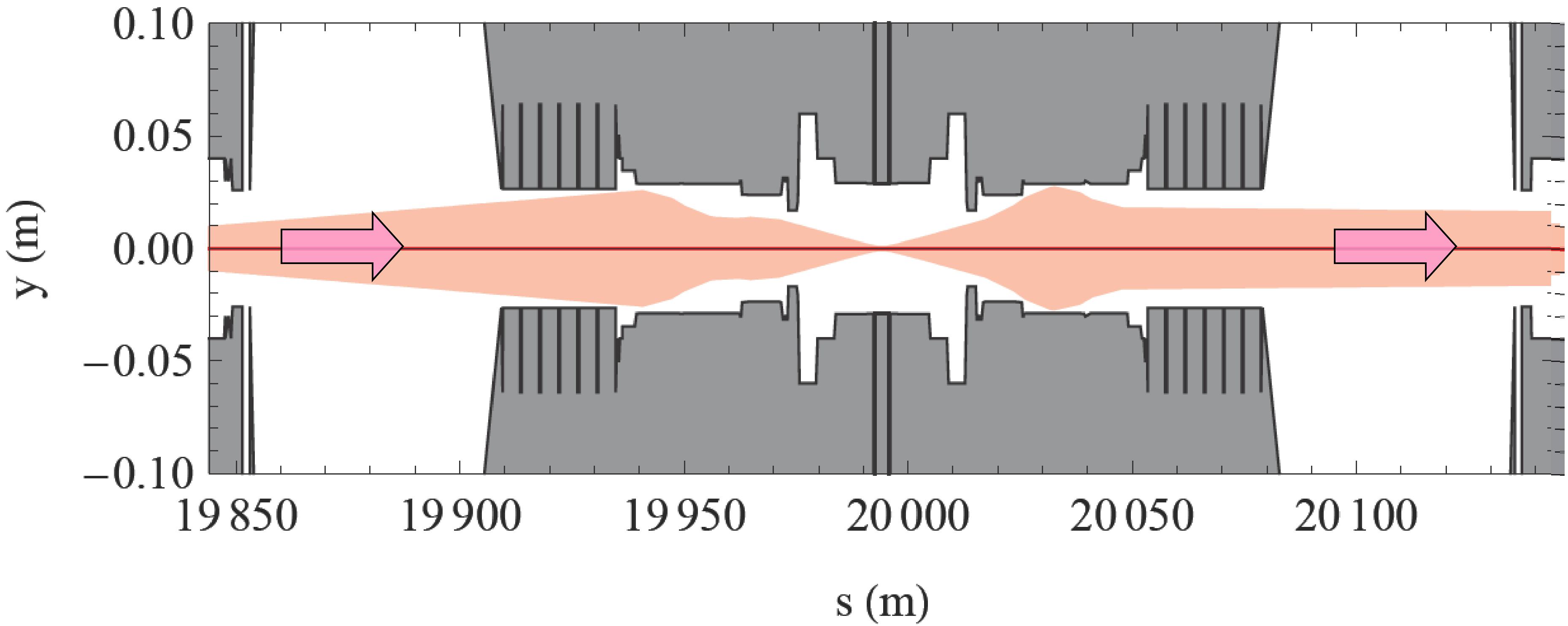
Influence of collimation on machine performance

- Collimation influences important parameters
  - Aperture: sets limit for β*. Main β* limit in Run 1
  - Cleaning efficiency. Together with lifetime, sets limit for max intensity



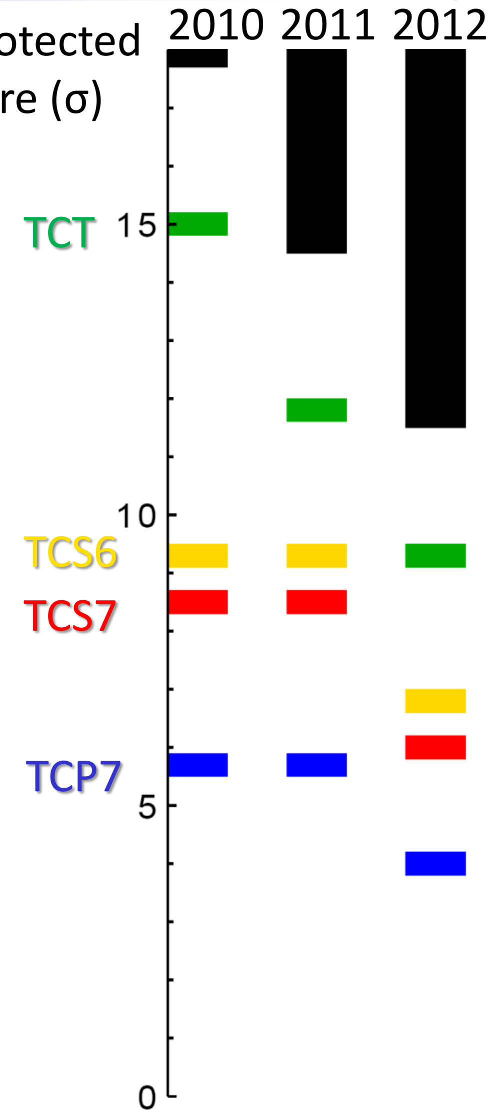
Aperture limit on β*

- Collimation hierarchy determines minimum protected aperture
- As β* is squeezed to achieve a smaller beam size at IP, and higher lumi, beam size increases in triplet => Aperture margin decreases => Limitation on β*



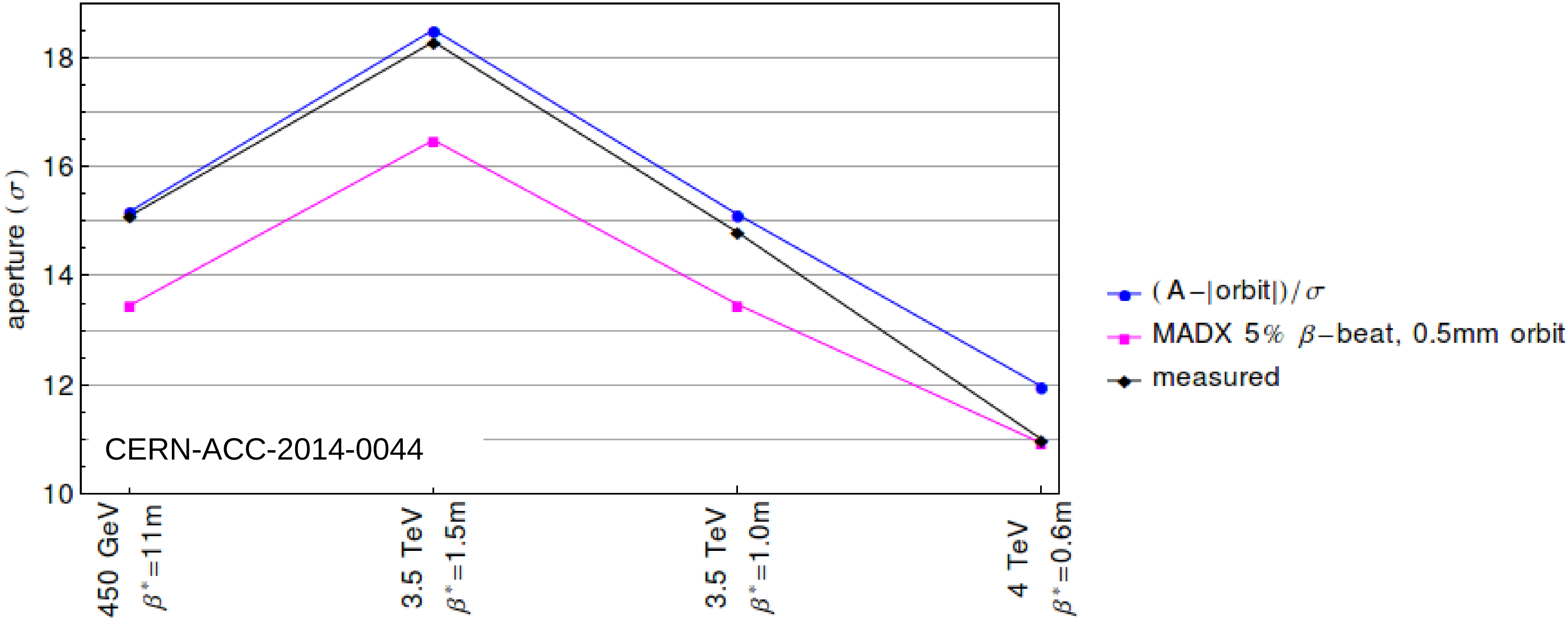
Collimation and β* in Run 1

- 2010:
  - Relaxed start with large margins for maximum safety: Relaxed collimator settings, β*=3.5m
- 2011 *(Evian 2010)*:
  - New calculation of collimation margins: β*=1.5m
  - IR aperture measurements with squeezed optics: β*=1.0 m
- 2012 *(Evian 2011, Chamonix 2012)*:
  - tight collimator settings, aperture very close to limit: push to β*=60 cm
- Performance evolving with collimation hierarchy and better knowledge of aperture



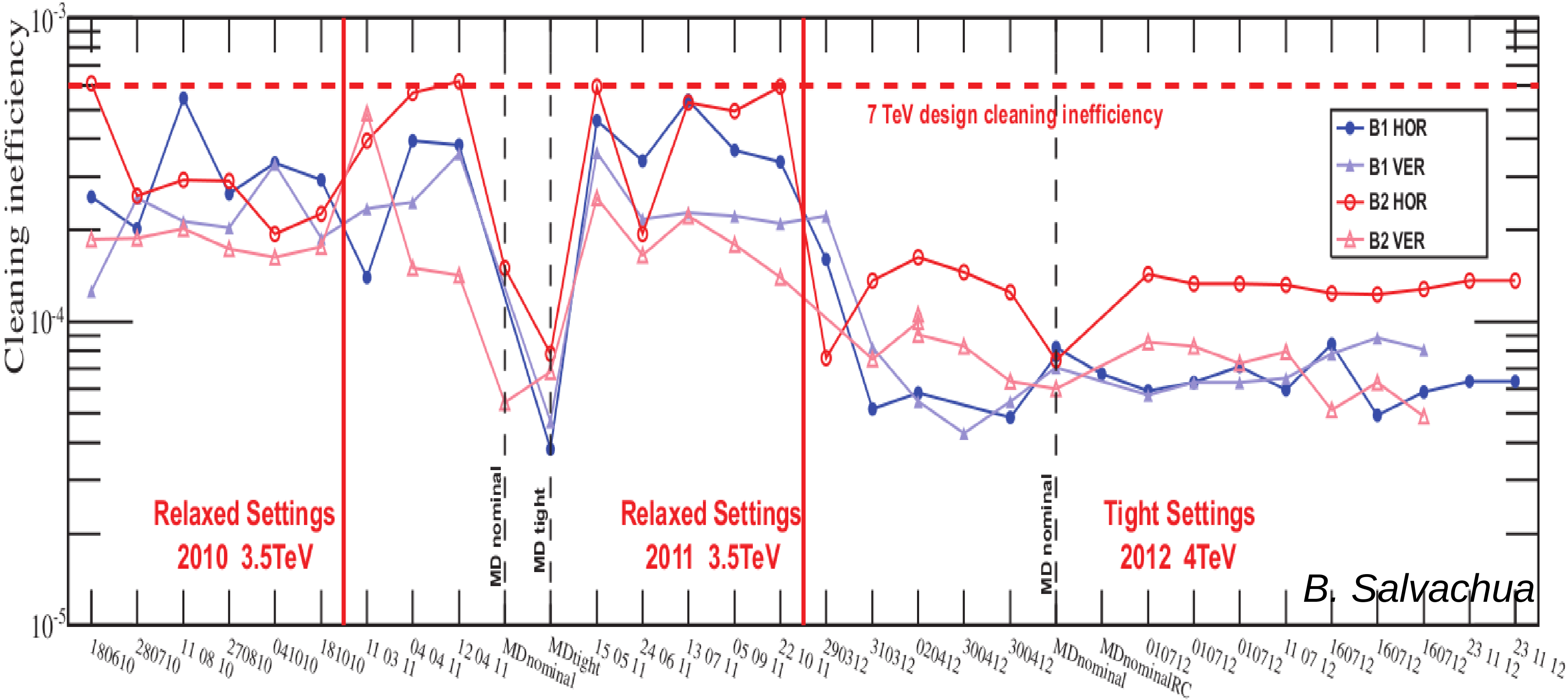
Aperture in Run 1

- Run 1: IR triplet apertures measured with beam on several occasions – close to ideal design value!



Cleaning in Run 1

- Cleaning working very well and good quench performance
  - Collimation was not limiting factor for intensity in Run 1
  - Very stable settings – only 1 full alignment per year



Run 1 → Run 2

- Many things changing for Run 2: energy, 25 ns, LS1 activities…
  - See e.g. talk G. Valentino for collimator hardware changes
- Has to be proven with beam that LHC works as well as in Run 1
  - Known: more dangerous beams, lower quench limit
  - Uncertainties: Loss spikes, instabilities,…
- **Start carefully…**

Philosophy for Run 2

- **Startup:**
  - Put focus on feasibility, stability and ease of commissioning. Allow comfortable margins for operation and avoid introducing too many untested features at once
  - Where possible, calculate parameters based on what we know can be achieved from Run 1 experience
  - Performance should not be main focus, but we should also not be overly pessimistic
- **Later in the run**
  - When we know better how the machine behaves at 6.5 TeV thorugh OP experience and MDs, we can push the performance

Beam assumptions for startup

- 6.5 TeV
- Standard 25 ns beam from the injectors. Tolerate/encourage large emittance up to 3.75 um in collision (as in design report)
  - Most beneficial for single-beam stability among available options (see talk N. Mounet)
  - Well-tested in injectors
  - Intensity: up to 1.3e11 p/bunch at injection
  - See later talk H. Bartosik

Collimator settings at 6.5 TeV

Startup

[σ with ε=3.5μm]	Relaxed settings	2012 mm kept	2 σ retraction
TCP IR7	6.7	5.5	5.5
TCSG IR7	9.9	8.0	7.5
TCSG IR6	10.7	9.1	8.3
TCDQ IR6	11.2	9.6	8.8
TCT IR1/5	13.1	11.5	10.7
aperture	14.6	13.4	12.3

Collimator settings at startup

- Proposal: Keep the **2012 collimator settings in mm**
- With large emittance, single beam should be stable with both octupole polarities (impedance covered in talk N. Mounet).
  - If using LOF>0, we could maybe live without collide and squeeze. Maybe even with LOF<0? Octupole strategy: see talk T. Pieloni
- Well proven long-term stability and cleaning in 2012
  - 2012 MDs: Confident we can have same stability for more performing settings (2 sigma retraction), but not justified to increase impedance at startup
- Cleaning predicted to be satisfactory at 6.5 TeV (simulations)
  - Unless very bad surprises with the quench limit, cleaning should not be the limiting factor for intensity in Run 2

Protection of TCTs/aperture

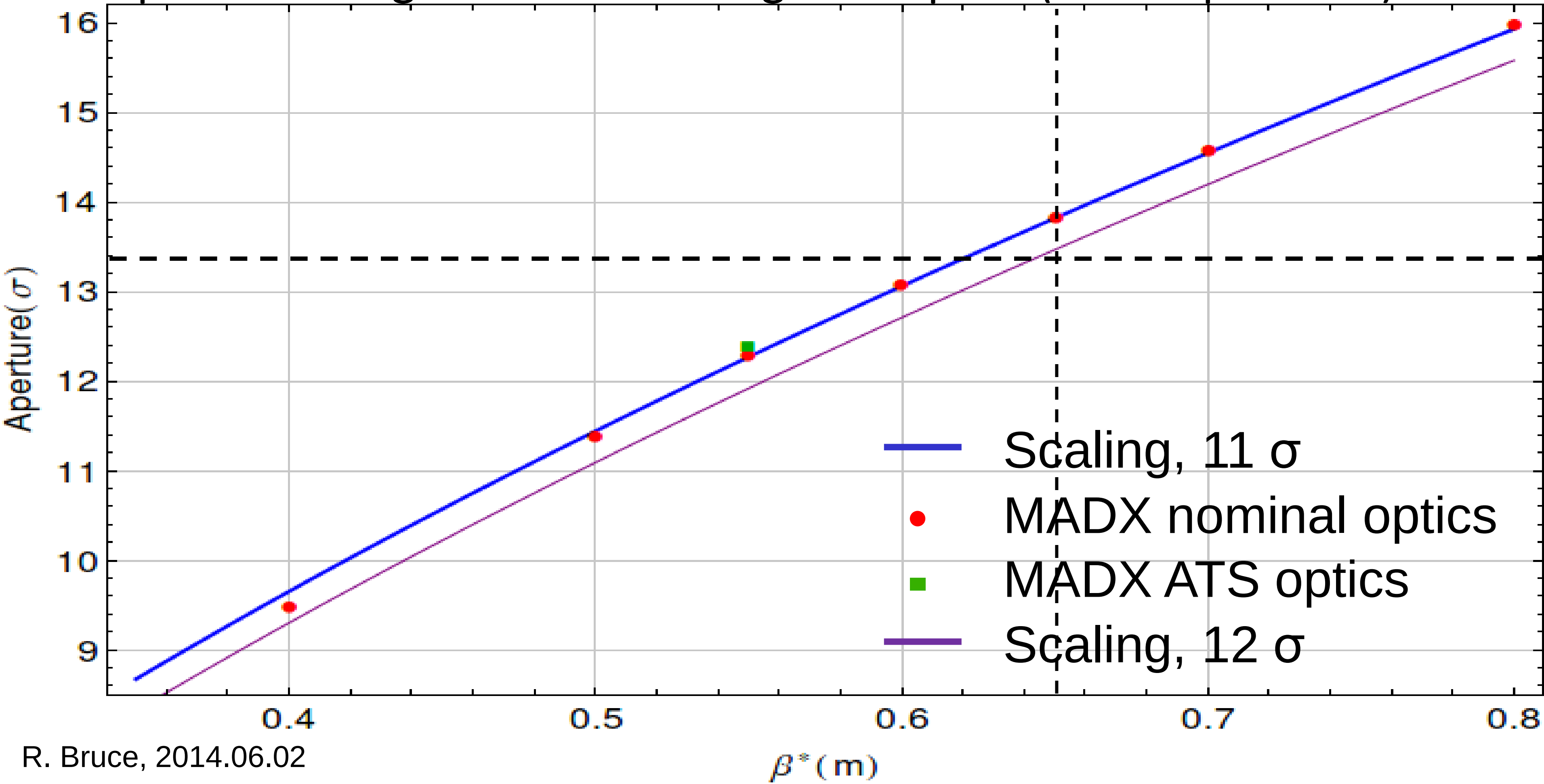
- No beam dump failure in Run 1 with full physics beam.
- Asyncrounous dumps / single module pre-fire more likely at higher energy. Should be prepared!
- With ATS optics, phase advance dump kicker→IR5 TCT close to 90 degrees
  - Ongoing study to quantify expected impacts on TCTs during accident using new simulation tools. Verify if proposed margins are enough!
  - Asynchrounous dump tests are essential part of commissioning
- Note: Underlying assumption that **orbit and optics correction are not worse than 2012** for sufficient margins! Check during commissioning

Aperture at 2015 startup

- Machine realigned - aperture (hopefully) not worse than 2012
- Use **same method for aperture calculation as in 2012**
  - Estimated aperture very close to allowed limit as in 2012. No hidden margin!
- **Important to measure aperture early on** in commissioning, as in 2012, or even earlier (injection). See talk S. Redaelli
- Need crossing angle to calculate aperture at given β^*. Assume 11 σ beam-beam separation for nominal beam (see talk T. Pieloni)
  - Corresponds to 170 μrad half angle at β^*=55cm
  - If possible, even larger margins could be beneficial for long-range

Aperture vs β*

- Possible configuration: **β*=65 cm**, 160 µrad, L=0.7e34 $cm^{-2}s^{-1}$
- If more margin needed for long-range/squeeze: could use up aperture margin to increase angle: 170µrad (12 σ separation)



R. Bruce, 2014.06.02

Collimator settings at 6.5 TeV

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aperture	14.6	13.4	12.3
β* (m)	**0.75**	**0.65**	**0.55 - 0.6**

Assumtion: 11 σ beam-beam separation for 3.75 μm emittance
Should give angle in μrad compatible also with smaller emittance

Caveats

- In case of **worse aperture, optics correction or orbit** than in 2012, be prepared to **step back in β***
  - If settling for 170μrad, this is more likely to happen
- If **stepping back to 70cm** : gain 0.8 sigma in aperture but lose about 6% in peak lumi (if stepping back in crossing angle, lose less)
  - If we are concerned about aperture, optics correction or orbit stability, we **could consider more relaxed start** at 70 cm

How to push performance

- With beam experience, push performance. What can we change:
  - **Bunch intensity**: roughly independently of β*. No limit expected from cleaning
  - Shorter **bunch length** (see later talks) – independently of β*
  - **Collimation hierarchy**: smaller margins make smaller β*possible
    - MDs, impedance measurements, BPM studies. OK long-term stability
  - **Crossing angle**: With smaller emittance, and/or smaller beam-beam separation, smaller crossing angle possible, allows smaller β*
    - Emittance: Smaller beam from injectors. Study stability, possibly MDs.
    - Beam-beam separation: MDs to study limitations
  - **Aperture:** should already be close to the limit. Probably not much to gain

Example: how to reach 55 cm

Psychologically important to reach design parameters. Seems likely to be within reach as intermediate scenario. Some examples on how to get there:

- **2 σ retraction collimator settings**
  - β*=55cm, 170 μrad fits exactly with aperture – measure to tell if possible…
  - Have to study effect of impedance increase, but calculated single-beam stability should still be OK for large emittance (see talk N. Mounet). Collide and squeeze? Octupoles?
- **Reducing crossing angle** (smaller beam-beam separation and/or emittance)
  - β*=55cm, 130 μrad fits exactly within the 13.4 σ aperture with collimator 2012 settings
  - Possibly compatible with 6 σ DA but needs beam-beam MDs to study feasibility (see talk T. Pieloni, compare DA)

Ultimate scenario

- Assume that **all considered parameters can be pushed to optimistic values**. Probably not for 2015…
  - Collimators: 2 σ retraction and assuming max theoretical gain from BPM buttons.
  - Assume (rather aggressively) 10 σ beam-beam separation and an emittance of not more than 2.5 um.
  - Count on significant re-commissioning time. Leveling?
- If all these assumptions come true: **β*=40cm,** 155 μrad
  - Alternative: flat beams, e.g. 40/50 cm
  - Not given that we can go so low. Could commission optics to 40cm and beam experience will tell real limit – could be also e.g. 45 cm or 50 cm.

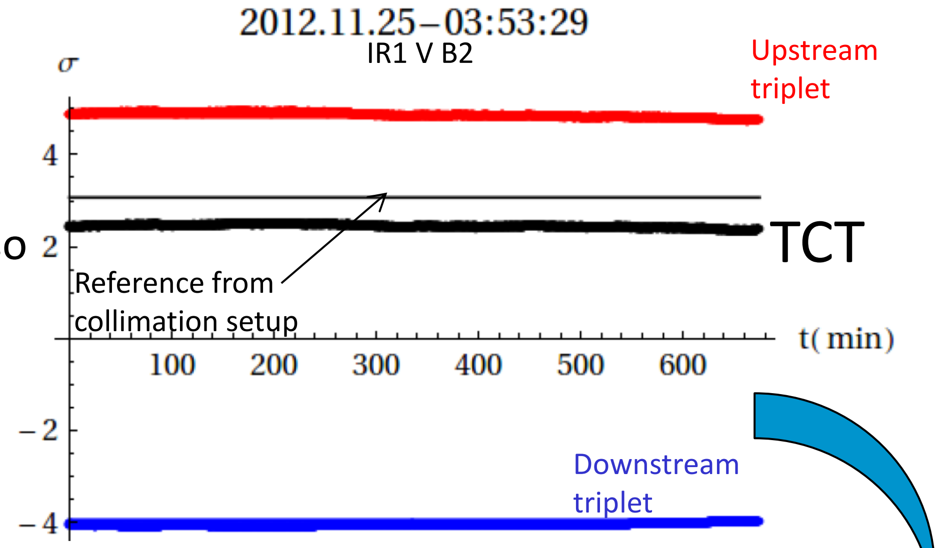
Summary

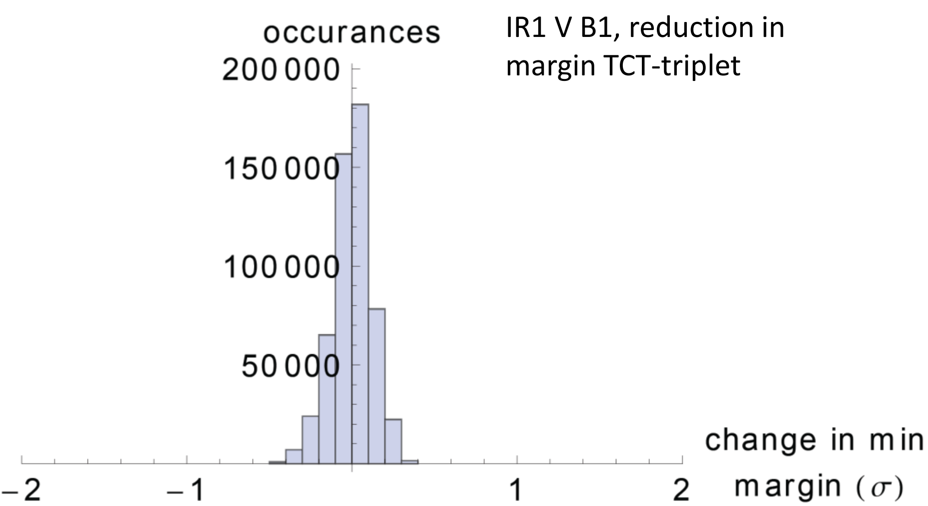
- Collimation influences machine performance: β* and intensity reach
- **Run 1:** β* successfully pushed down in steps. Collimation was not limiting intensity
- **Run 2:** Many things have changed. Start carefully and push performance later.
  - Cleaning not expected to limit intensity
  - Start-up: **β*=65 cm,** assuming 2012 collimator settings, aperture, correction
  - Intermediate step to **β*=55 cm** hopefully within reach
  - "Ultimate" scenario: **β*=40 cm**. Not likely that we will go lower, but not given that we can get there. The machine will tell us the real limit!

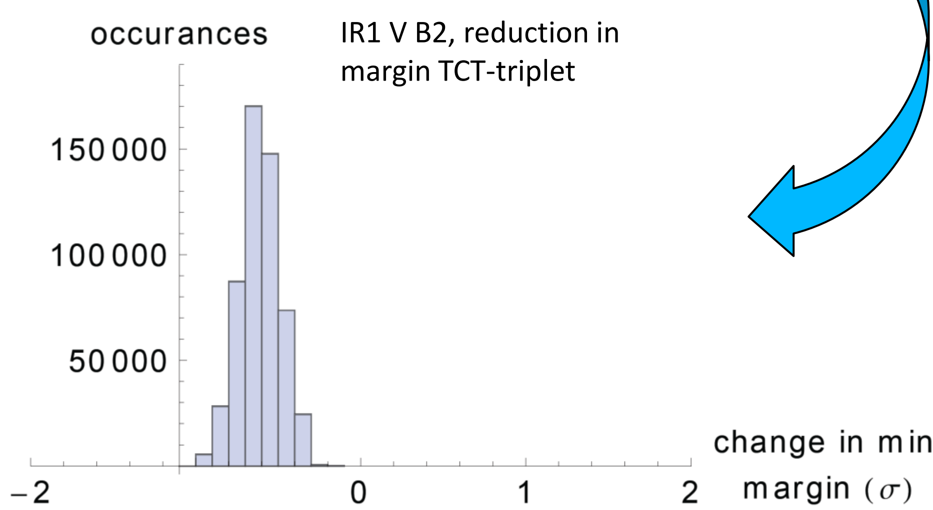
Backup

Margins for orbit – 2012 example

- Calculating reduction in margin (in σ) due to orbit drifts compared to orbit during collimation setup
- Considering all periods with stable beams – so far, sampled every 15 seconds – 1 minute.
- Statistical approach – calculating the needed margin to protect against 99% of observed drifts. Artifacts from temperature effects?





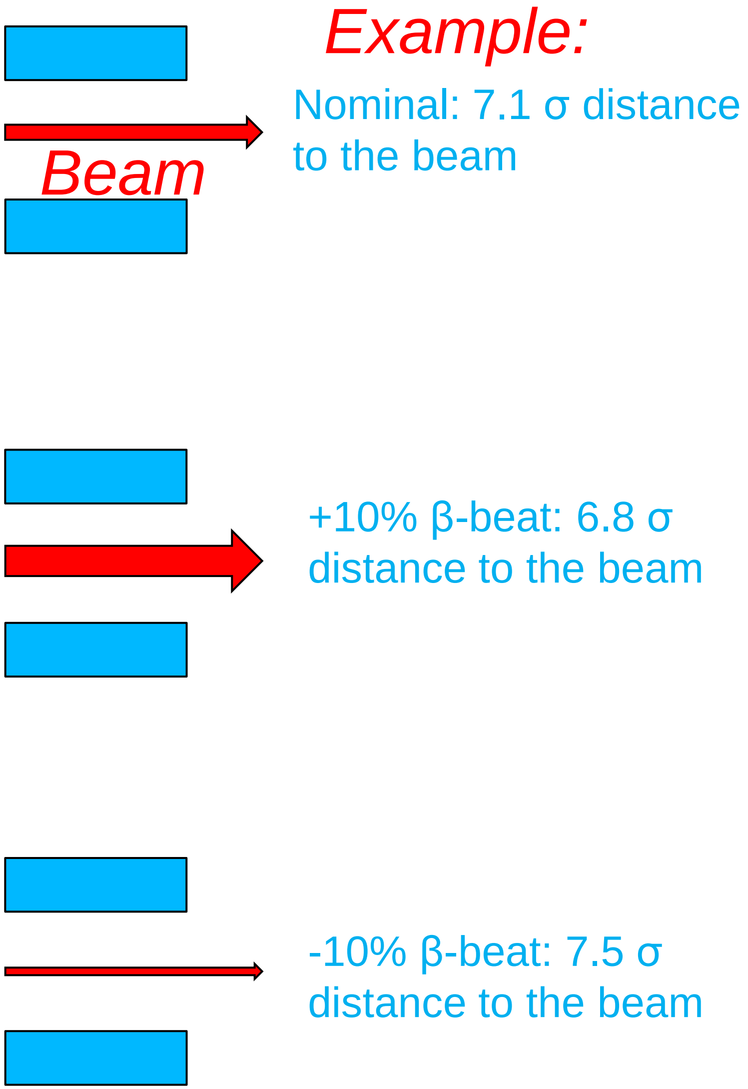


Margins for optics errors

- So far: assume most pessimistic β-beat and calculate needed margin
  - Assuming now +10% at location to protect, -10% at protection device (very pessimistic!)
  - Change in margin (in σ) of an aperture is given by

$$M_\beta = n\left(\sqrt{\frac{\beta_n}{\beta_r}} - 1\right)$$

  - Implicit pessimistic assumption: aperture bottlenecks always at 90 deg from kick
- More detailed model: account for full phase space motion
- First study on leakage to ring collimators during abnormal dumps, including the actual phase advance with imperfections, done in PhD thesis by T. Kramer (2011) for beam 1 at 7 TeV, nominal machine



Collimation in Run 1

- Some sources of concern:
  - Instabilities and impedance appearing with tighter settings
  - Loss spikes around cycle with low lifetime. What is the scaling to 6.5 TeV?
  - Time spent in setup when changing Irs
  - Significant time spent before reaching high performance, driven by machine protection aspects