Baseline Machine Parameters and Configuration for 2015

R. Bruce, G. Arduini, S. Fartoukh,
M. Giovannozzi, M. Lamont, E. Metral,
T. Pieloni, S. Redaelli, J. Wenninger

Thanks for essential input from many colleagues:
H. Bartosik, X. Buffat, E. Chapochnikova, R. de Maria, G. Iadarola, V. Kain, E. Meschi, N. Mounet, Y. Papaphilippou, G. Papotti, G. Rumolo, B. Salvachua, B. Salvant, M. Solfaroli, R. Tomas, G. Valentino, D. Valuch, M. Zerlauth

Outline

- Challenges and strategy for 2015
- Startup scenario
  - Focus on collimation / aperture, crossing angle, β*
- How can we push the performance?
- Summary

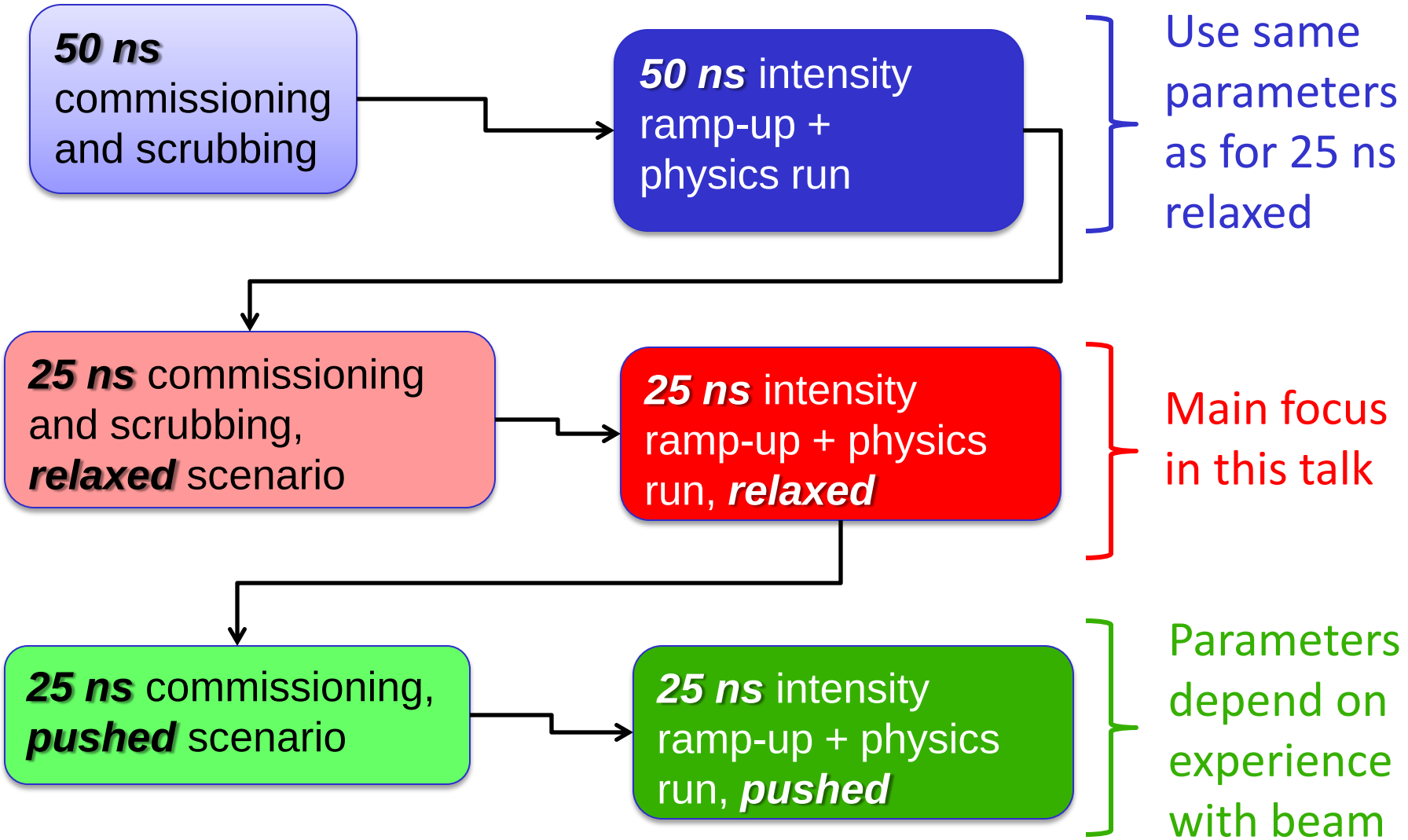
Run 1 → Run 2

- Fast Re-commissioning in 2012 : quickly back at high luminosity
- Run 2 pre-requisites: **Run at increased energy (≤6.5 TeV) and 25 ns bunch spacing**
- Apart from higher energy and more bunches, many things changing :
  - LS1 activities and upgrades…
  - At higher energy: more dangerous beams, lower quench limit, higher risk for asynchronous dumps
  - Uncertainties in scaling of 2012 issues with loss spikes and instabilities to higher energy
- Many unknowns! Has to be proven with beam that LHC works as well as in Run 1.
- **Start carefully…**

Strategy for 2015

- **Startup:**
  - Put focus on feasibility, stability and ease of commissioning. Allow comfortable margins for operation and avoid introducing too many untested features at once
  - Main priority: Get LHC running 25 ns at 6.5 TeV
  - 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 through OP experience and MDs, we can push the performance

2015 proton run outline



2015 scenario

- Main goal of parameters in this talk: usability with 25 ns
  - Focus on the relaxed startup configuration
  - At 50 ns: use *same* settings as for 25 ns to save commissioning time
- For simplicity at startup (do not add too many new things!):
  - *No combined collide and squeeze* (initially)
  - *No combined ramp and squeeze* (initially)
  - *No β* levelling* (initially)

  } For discussion
- More details on 2015 strategy: talk J. Wenninger

Overview of machine parameters

- **Key parameters influencing luminosity, beam stability and machine protection** – should be addressed at injection and in physics

– Energy	M. Solfaroli
– Bunch spacing	E. Meschi
– Bunch characteristics: intensity, emittance, bunch length	Y. Papaphilippou, A. Butterworth
– Optics	M. Giovannozzi
– Collimator settings	*This talk*
– Crossing angle, separation	*This talk*
– β*	*This talk*

Energy and bunch spacing

- **Beam energy: Baseline target = 6.5 TeV**
  - Not really any news since Evian…
  - Further details: talk M. Solfaroli
- **Bunch spacing: 25 ns**
  - Strong request from experiments – lower pileup than 50 ns. The LHC was designed for this!
  - Some complications: e-cloud (talk G. Iadarola), stronger long-range beam-beam …

Bunch characteristics

- **Beam injected in LHC:** could optimistically hope for (talk Y. Papaphilippou):
  - Standard: **1.3e11** p/bunch, ε_n= **2.4** µm, 2748 bunches (**2736** colliding at IP1/5).
  - BCMS: **1.3e11** p/bunch, ε_n= **1.3** µm, <2604 bunches(<**2592** colliding at IP1/5).
- **In LHC:**
  - Beam stability poses limits on brightness (E. Metral, LMC 3/9/14) – BCMS could be problematic
  - If 95% transmission of intensity => ~1.2e11 p/bunch in collision
  - 5-20% emittance increase expected from IBS (M. Kuhn in Evian14) and potentially more from e-cloud if scrubbing not successful (talk G. Iadarola)
- **Longitudinal parameters** (talk A. Butterworth):
  - Injection: 6 MV RF voltage and 1.2 ns bunch length
  - Top energy: 12 MV RF voltage and 1.25 ns bunch length

Optics

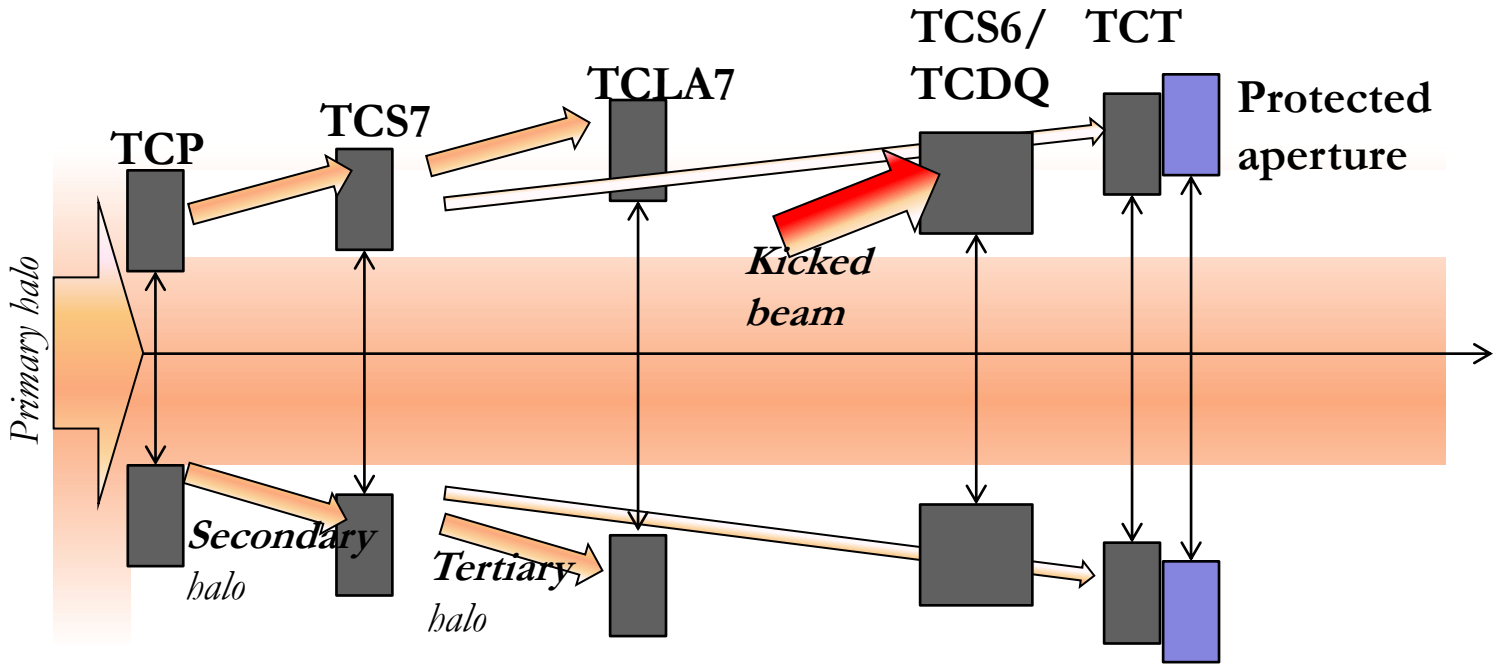
- **Baseline: nominal optics**, possibly modified to match new requirements

- ATS optics: promising option, but still some points to be studied

- Further details: talk M. Giovannozzi

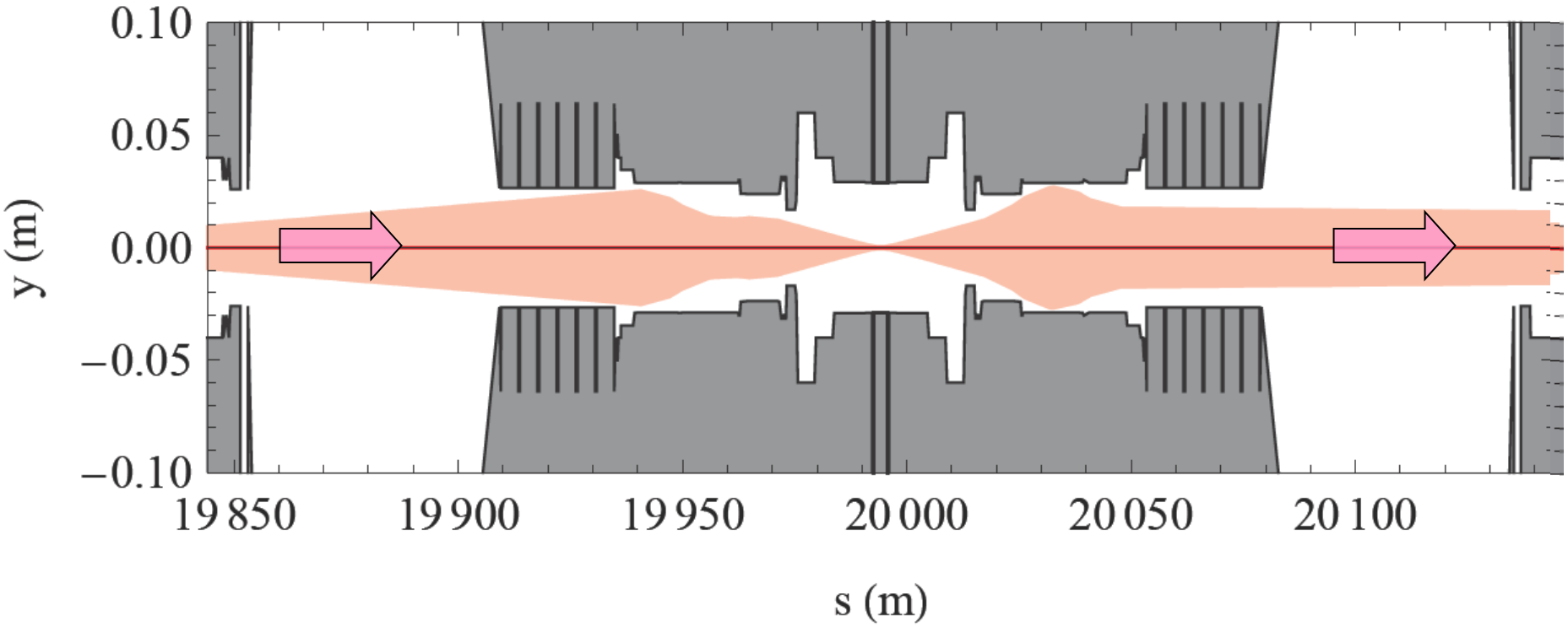
Collimation

- Collimator settings influence performance
  - Cleaning efficiency. Together with lifetime, sets limit for max intensity
  - Impedance. Sets limit for beam stability
  - Aperture: sets limit for β*. Main β* limit in Run 1



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*



Collimator settings at startup

- Evian proposal: **2012 collimator settings in mm** (inj. + 6.5TeV)
- Well proven long-term stability of hierarchy and cleaning in 2012
  - MDs: Confident more performing settings could work (2 sigma retraction), but not justified to increase impedance at startup
- **Cleaning** – verification with final optics pending. A priori no issues, unless very bad surprises in lifetime or quench limit
- **Protection:**
  - Margins adequate with underlying assumption that **orbit and optics correction are not worse than 2012**
  - Asynchronous beam dumps more likely at higher energy. Should be prepared!
  - For more relaxed margins at startup: **consider adding 1σ to TCT setting**

Collimator settings in physics

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

Startup

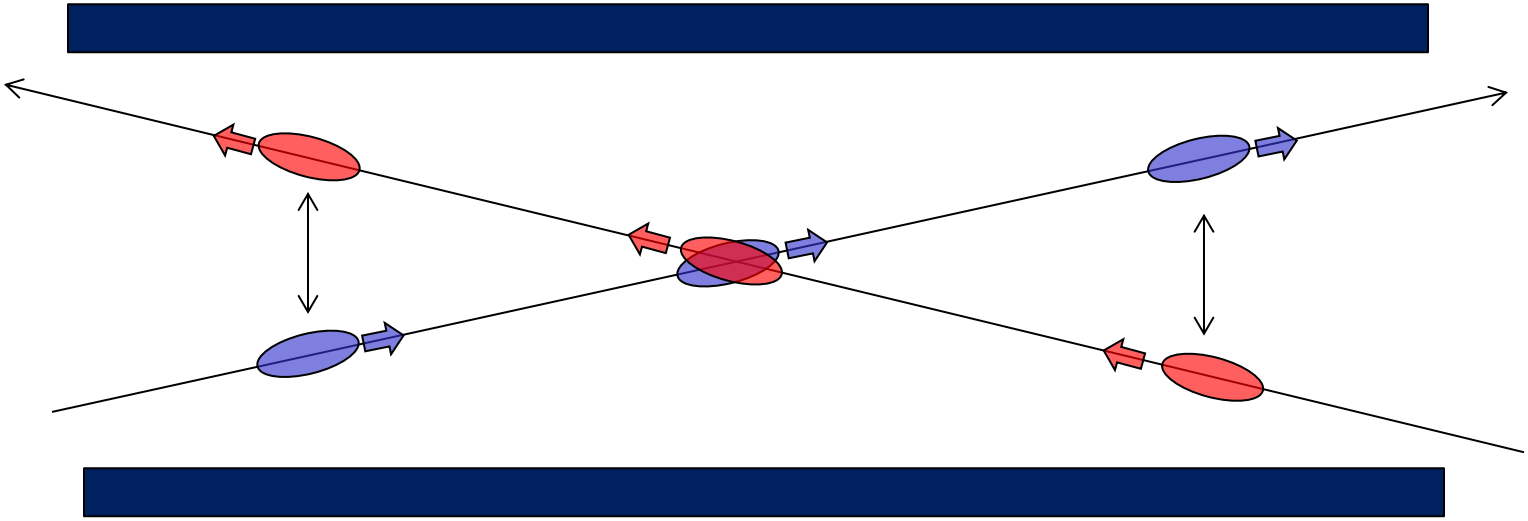
MP margins to be checked if operating at β significantly different from 2012*

Aperture at 2015 startup

- Need to estimate aperture for calculation of β*
- 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
  - If bad surprises: re-evaluate reach in β*

Beam-beam separation

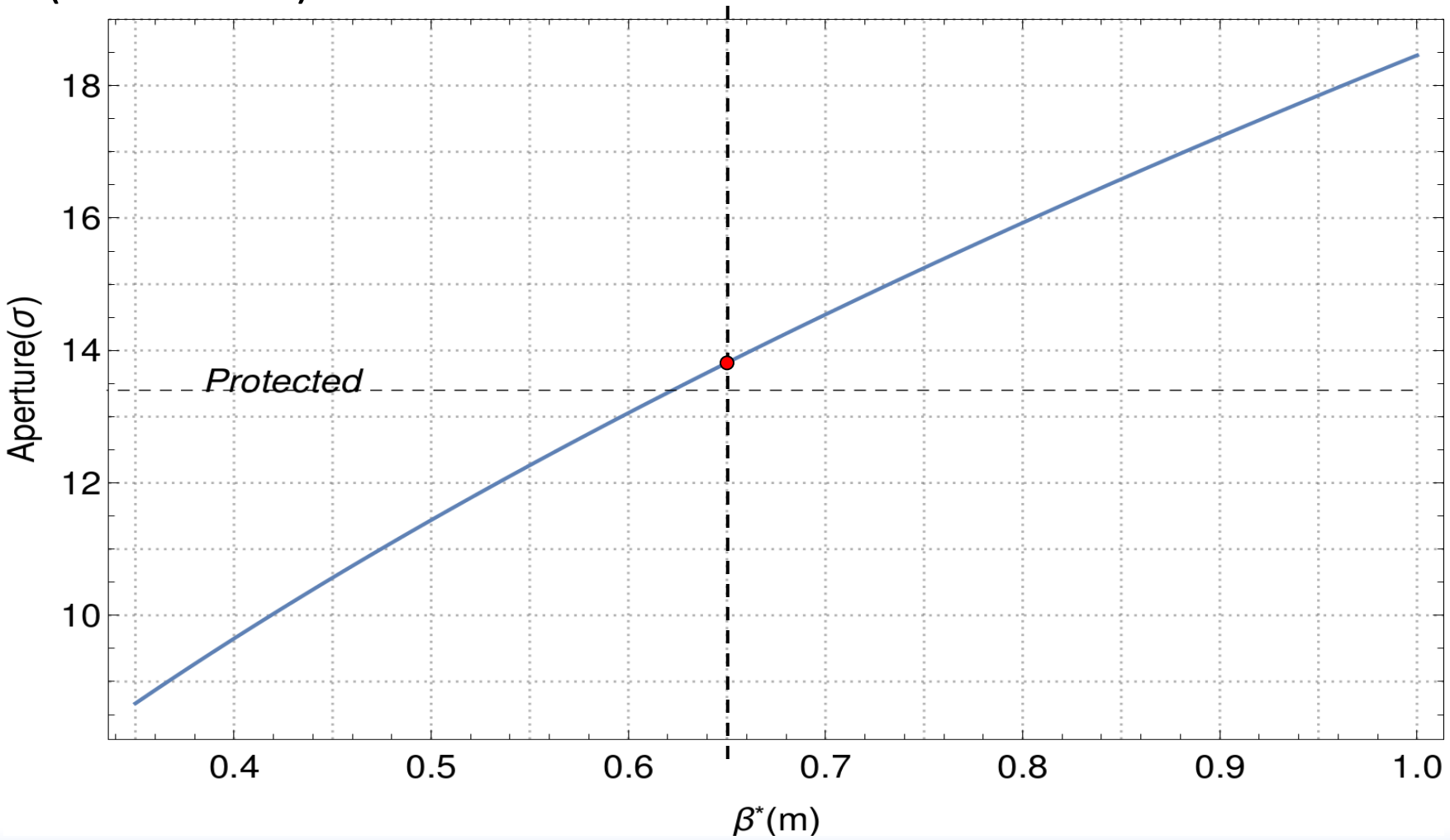
- Crossing angle needed to calculate aperture at given β*.
- Need sufficient crossing angle to minimize detrimental effect of parasitic encounters (small dynamic aperture → beam losses)



- Talk T. Pieloni in Evian: Baseline of 11 σ beam-beam separation for nominal beam (ε=3.75 μm) – driven by intensity of 1.3e11. Gives sufficient angle in μrad also for smaller ε.
- Parallel separation: Scaling 2012 value to 6.5 TeV gives 0.55 mm at 6.5 TeV

Aperture vs β*

- With the given assumptions, the limit is at **β*=65 cm**, 160 µrad (Evian 2014)

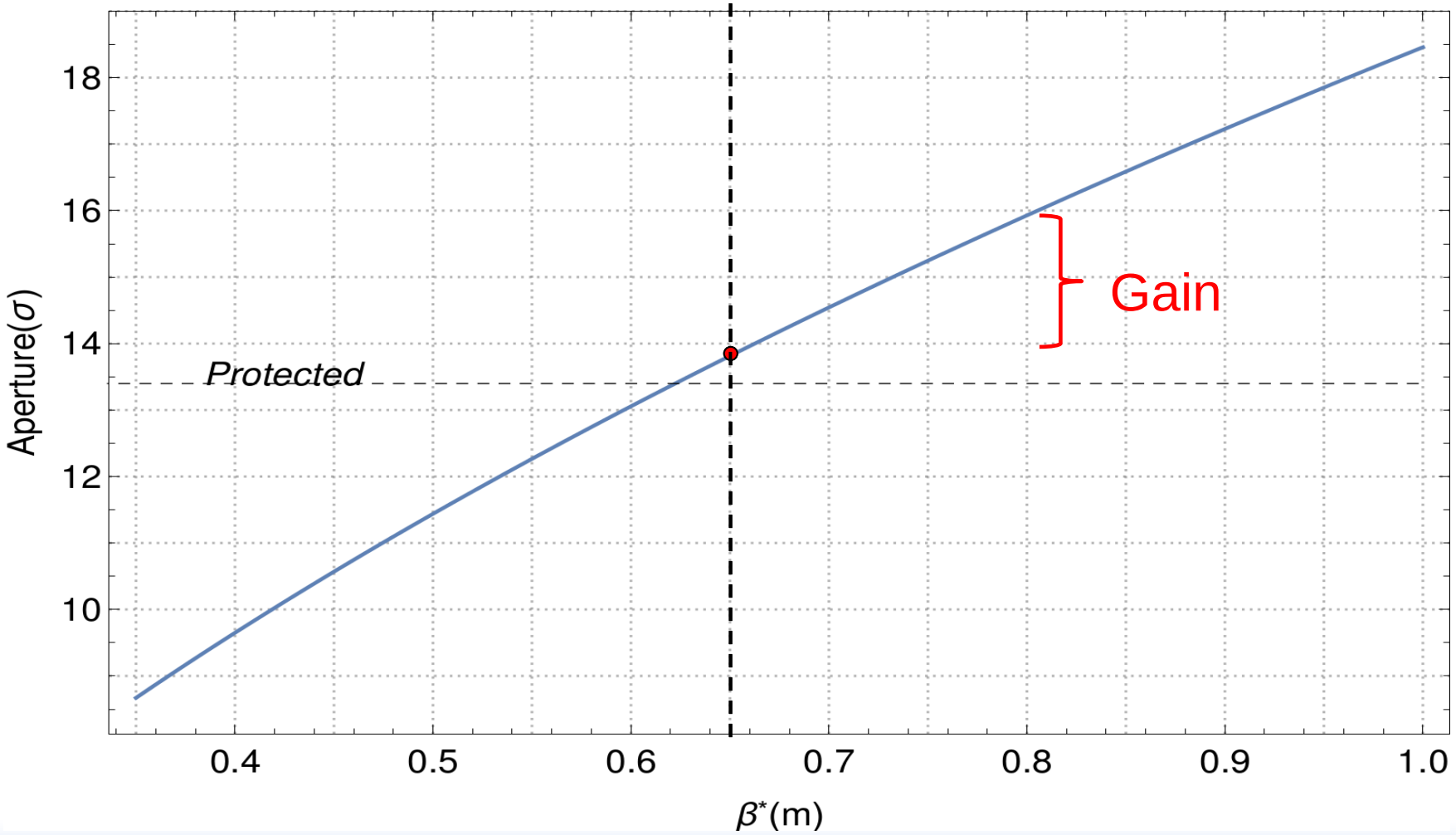


Additional margins

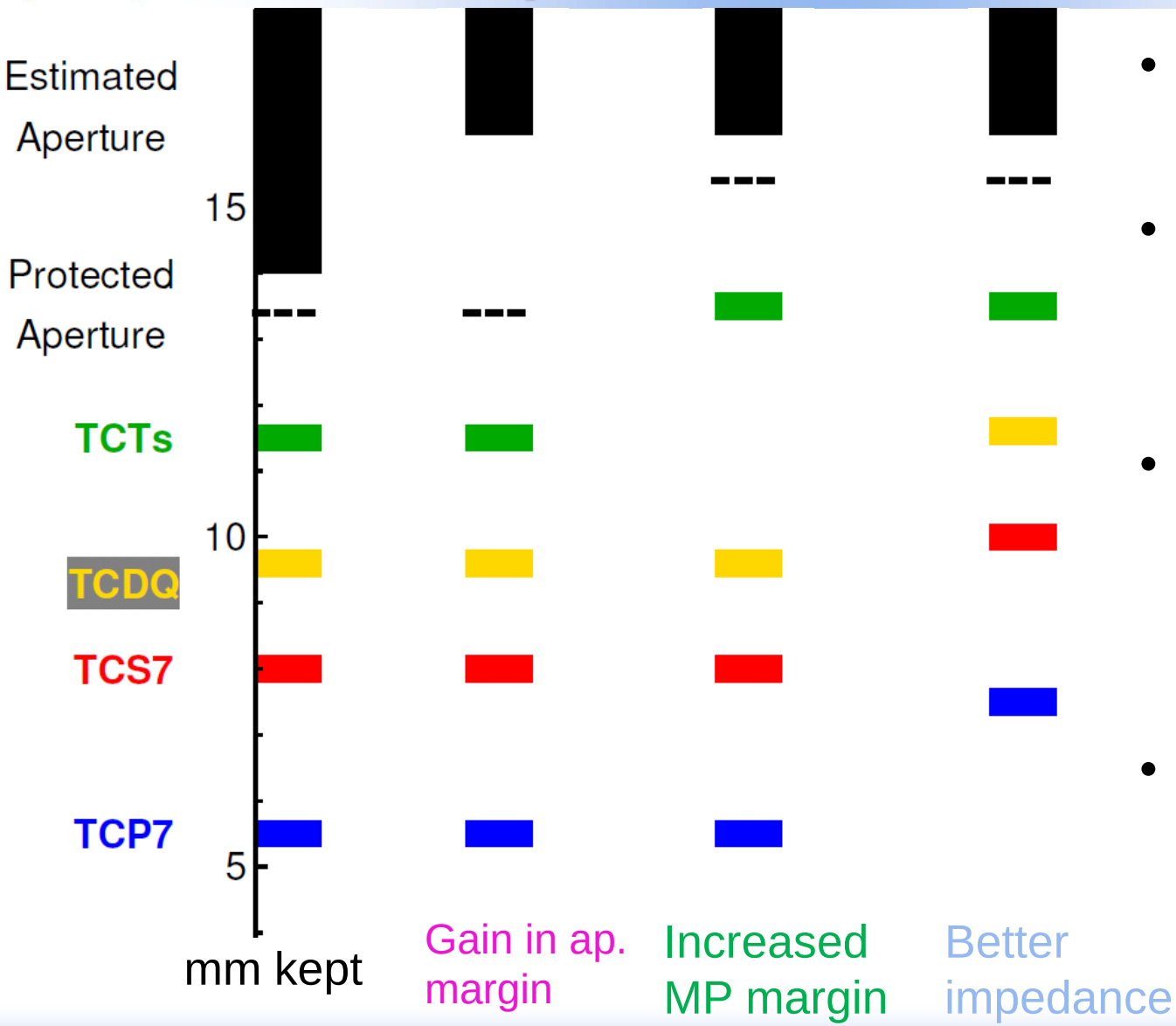
- Some uncertainties in the underlying assumptions, e.g.
  - Will orbit and β-beat be as good as in 2012 (assumption for collimation hierarchy)?
  - How do the instabilities / lifetime drops observed in 2012 scale to higher energy and 25 ns?
- With the philosophy that focus at the startup is on feasibility and ease of commissioning, and that we can push performance at a later stage: **wise to take some extra margins**
- LMC 3/9/2014 : **Decision to start at β*=80 cm**

Margins at β*=80 cm

- Going to **β*=80 cm, 145µrad** buys us ~2σ margin



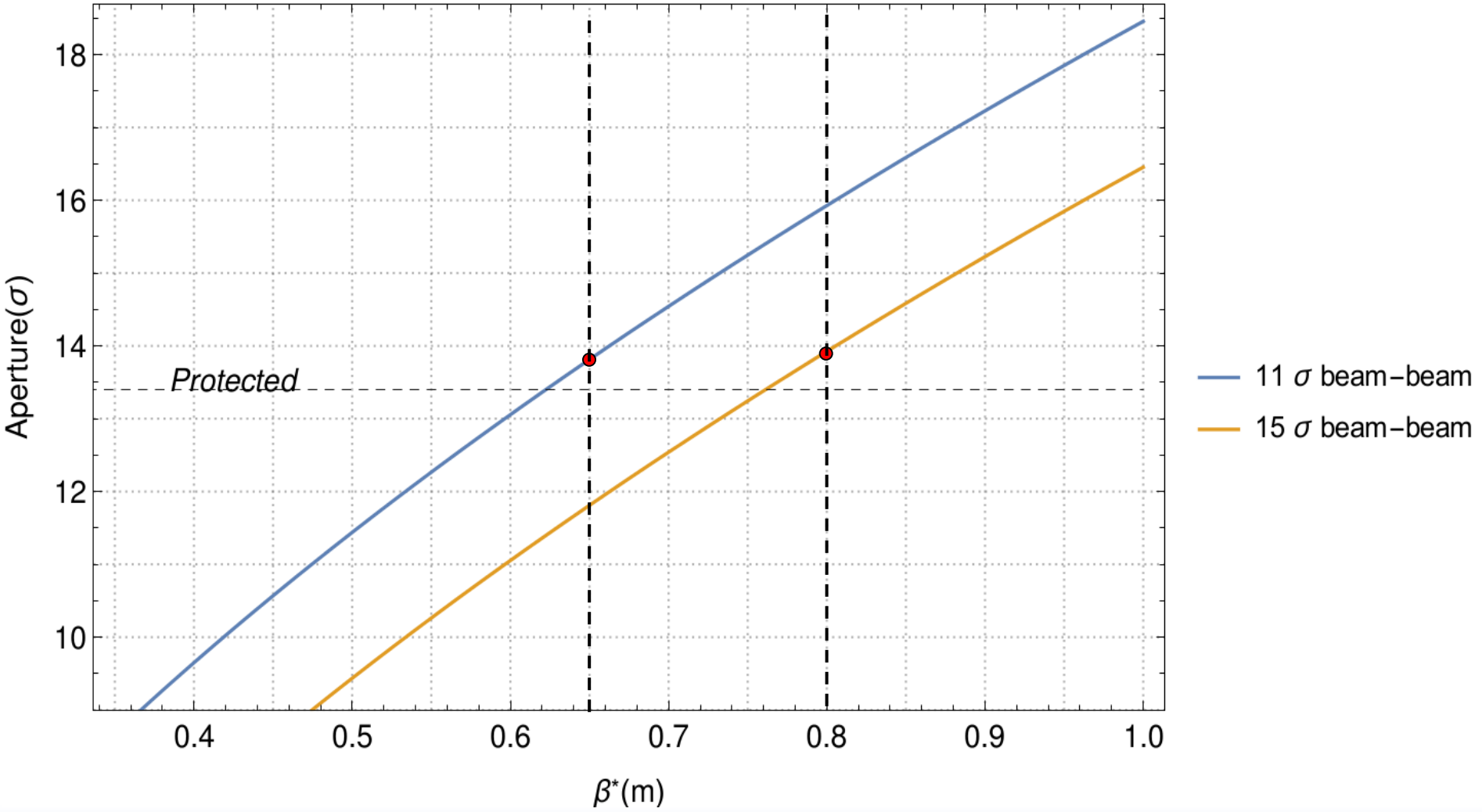
How can the gain in aperture be used?



- Gain in aperture margin
- Gain in MP margin – move out TCTs
- Gain in impedance – move out all collimators
- OR: increase crossing angle and β* – plot doesn't change

Increased beam-beam separation

- If all margin for beam-beam separation: 15σ possible at β*=80 cm



Use of additional margins

- Not decided yet how the additional 2 σ gain will be used
  - Pending LMC action
- Example 1: maintain beam "challenges" with increased protection.
  - Put all margin on machine protection
- Example 2: splitting 1 σ machine protection + 1 σ beam-beam
  - 1 σ more aperture allows about 2 σ larger beam-beam separation
- Could even be decided/changed during commissioning, when we see where it is most needed

Outline

- Challenges and strategy for the 2015 startup
- Startup scenario
  - Focus on collimation / aperture, crossing angle, β*
- How can we push the performance?
- Summary

How to push performance

- Later, with beam experience, push performance. What to change:
  - **Smaller emittance:** Better lumi both through beam size and possibility of smaller crossing angle → β*.
  - **Increase bunch intensity**: most beneficial parameter for luminosity.
  - **Tighter collimation hierarchy**: makes smaller β* possible. Tighter cleaning margins (IR7) or tighter MP margins, e.g. through BPM buttons. Limitations: impedance, machine stability, TCT damage limit.
  - **Smaller beam-beam separation**: gains aperture and hence allows smaller β*. Possible limitations: Beam stability
  - **Aperture:** should already be close to the limit. Probably not much to gain
  - **Squeeze separation plane β*** more than crossing plane (more aperture)
  - **Shorter bunch length:** impacts lumi through reduction factor, but higher pileup

Pushed β* - how low can we go?

- **β*=65 cm** should be within reach even with rather conservative assumptions (see Evian 2014)
- **β*=55 cm** likely to be within reach. E.g.:
  - Tighter collimator settings (2σ retraction on the aperture limit), or
  - 10 σ beam-beam separation and 2.5 µm emittance
- **β*=40 cm** possible with optimistic assumptions (Evian 2014) – maybe not for 2015, and not given that we can go there
  - Still commission optics down to 40 cm to be prepared
  - Oval optics, e.g. 40cm/50cm might be easier to reach for aperture and could give slightly better luminosity than 40cm/40cm (depends on bunch length and BB sep.).
- Caveat: Pushed scenario might introduce additional OP complexity, e.g. collide and squeeze
- Final limit can only be determined based on beam studies in 2015

Summary

- **Run 2:** Many things have changed - baseline: 6.5 TeV and 25 ns
  - Start carefully and push performance later.
- For initial 50 ns run, use same settings as for 25 ns
- **Beams** from injectors: Choice between standard and BCMS
- **Collimator settings:** 2012 settings in mm
  - Possibility to increase margins for machine protection or impedance
- **11 σ** beam-beam separation
- **β*=80cm** at startup to allow relaxed margins
  - Push performance later when limits are better known
  - Commission optics down to β*=40 cm

2015 baseline parameters (startup)

Parameter	Value @ injection	Value @ collision
Energy [TeV]	0.45	6.5
β* (1/2/5/8) [m]	11 / 10 / 11 / 10	0.8 / 10 / 0.8 / 3
Half X-angle (1/2/5/8) [μrad]	-170 / 170 / 170 /170	-145* / 120 / 145* / -250
Tunes (H/V)	64.28 / 59.31	64.31 / 59.32
Separation (1/2/5/8) [mm]	2 / 2 / 2 / 3.5	0.55 / 0.55 / 0.55 / 0.55
Emittance (BCMS/standard) [μm]	≥ 1.3 / ≥ 2.4	≥ 1.7 / ≥ 2.7**
Bunch intensity [p]	≤ 1.3e11	≤ 1.2e11***
4 σ bunch length [ns]	1.2	1.25
Collimator settings	2012 mm kept	2012 mm kept****

* Corresponding to 11 σ beam-beam separation. Room for increased angle if needed

** Assuming blowup from IBS only (M. Kuhn, Evian14). Much worse if scrubbing not successful (talk G. Iadarola)

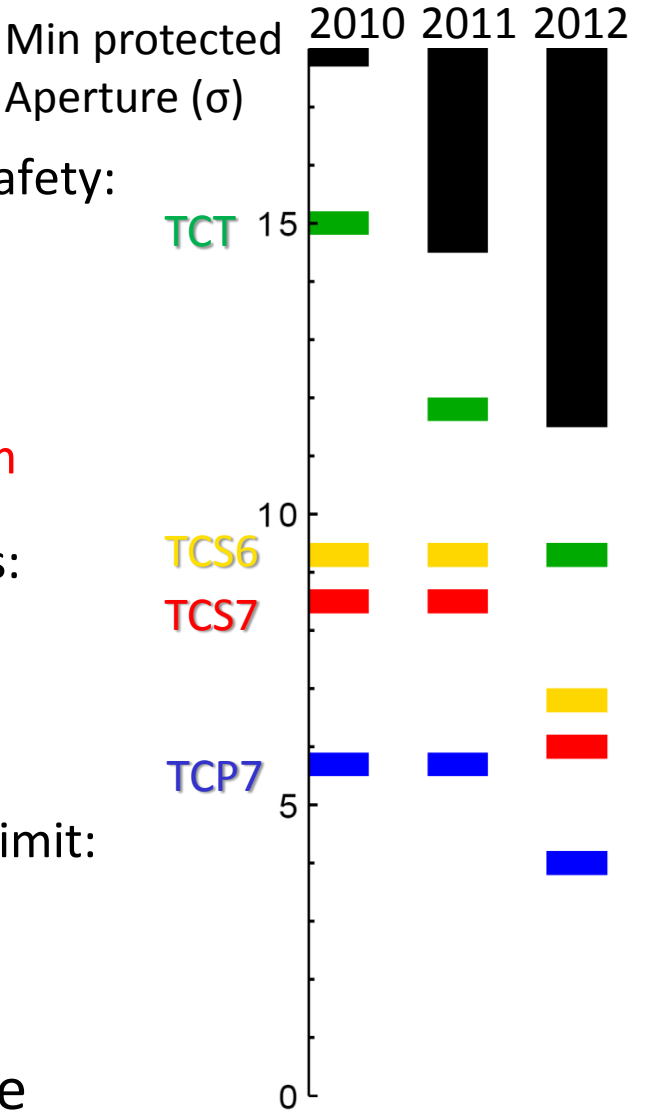
*** Assuming 95% transmission

**** Room for increased margins for machine protection and impedance if needed

Backup

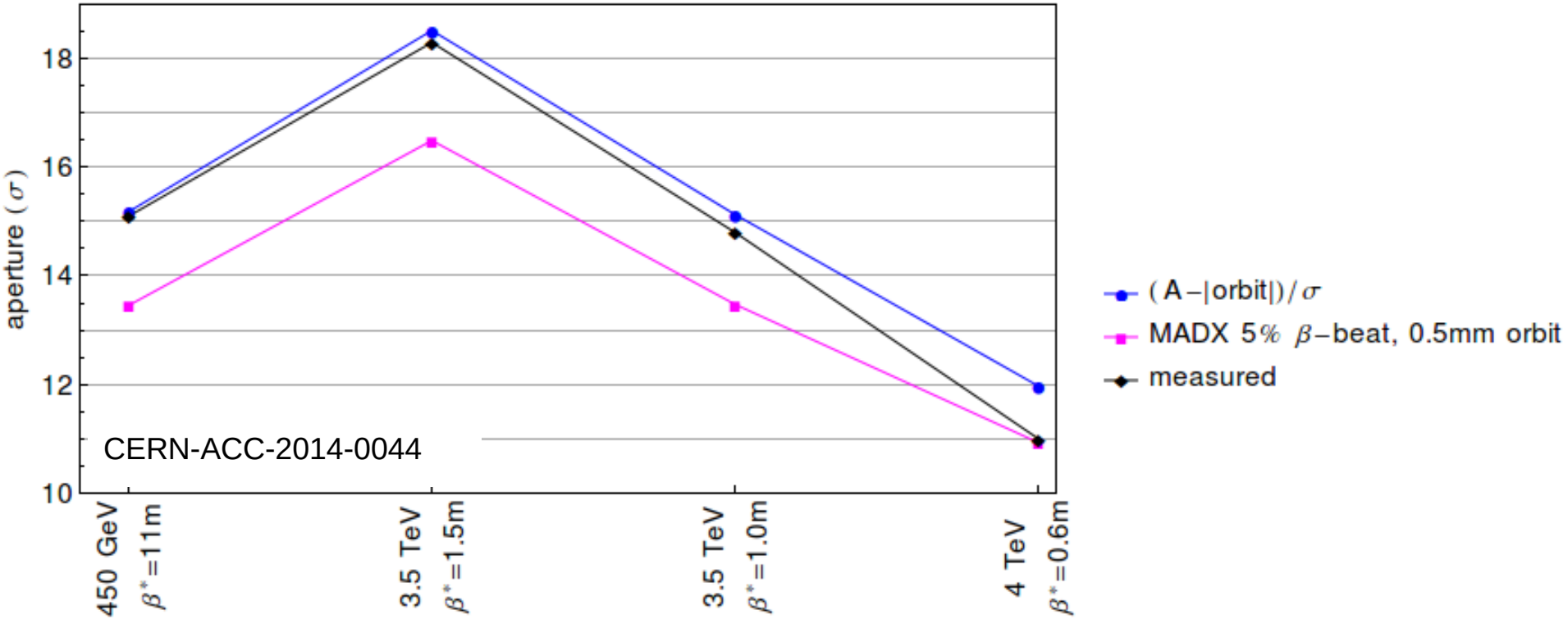
Collimation and β* in Run 1

- 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



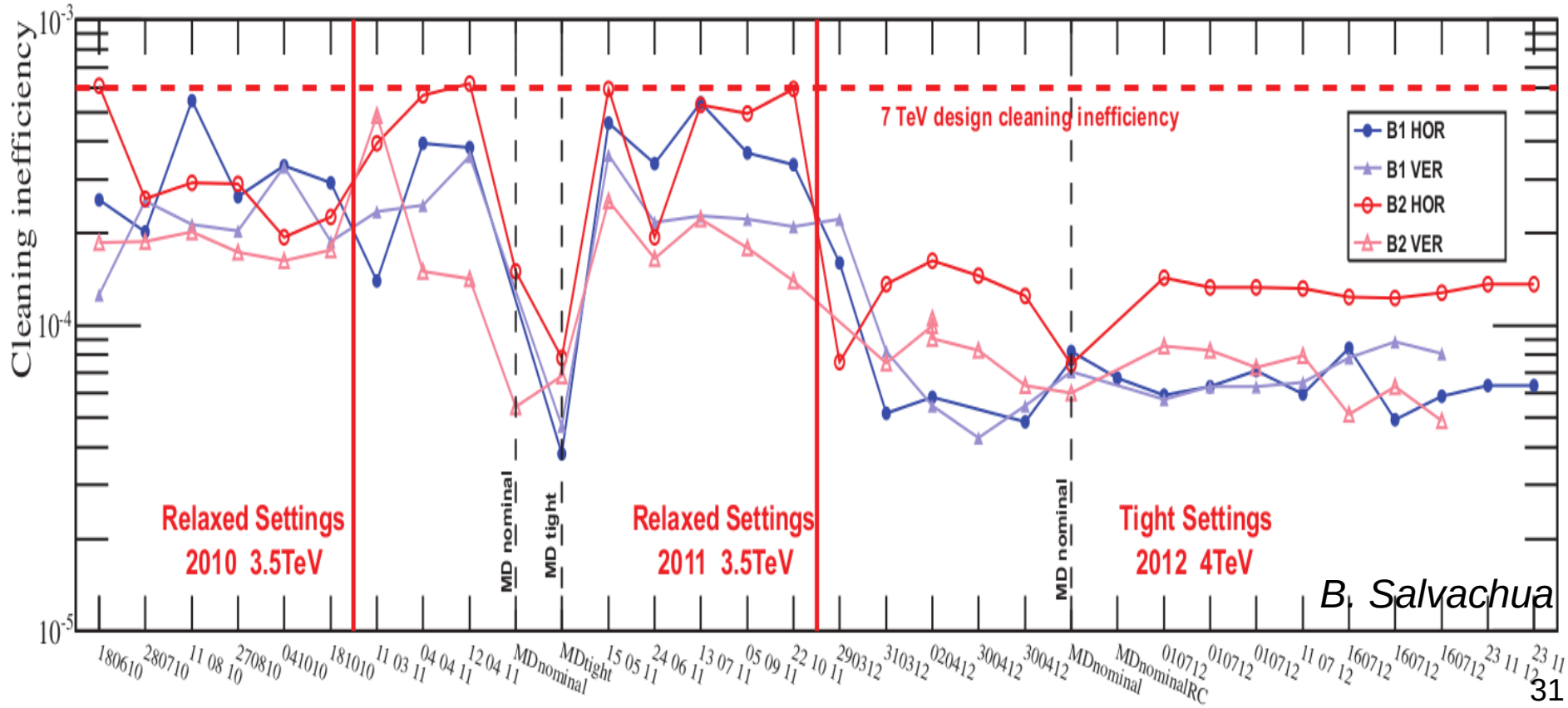
Aperture in Run 1

- 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



2015 scenario

- Main goal of parameters in this talk: usability with 25 ns
  - Focus on the relaxed startup configuration
  - At 50 ns: use *same* settings as for 25 ns to save commissioning time
- For simplicity at startup (do not add too many new things!):
  - *No combined collide and squeeze* (initially)
  - *No combined ramp and squeeze* (initially)
- More details on 2015 strategy: talk J. Wenninger