2016 machine configuration: can we get to β*=40 cm?

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Outline

- Recap of 2015 considerations and configuration
- Ways to push performance (luminosity) in 2016
- Ways to push β* in 2016
  - Focus on collimation hierarchy
- Possible configurations in 2016
- Conclusions

Chamonix 2014: strategy for 2015

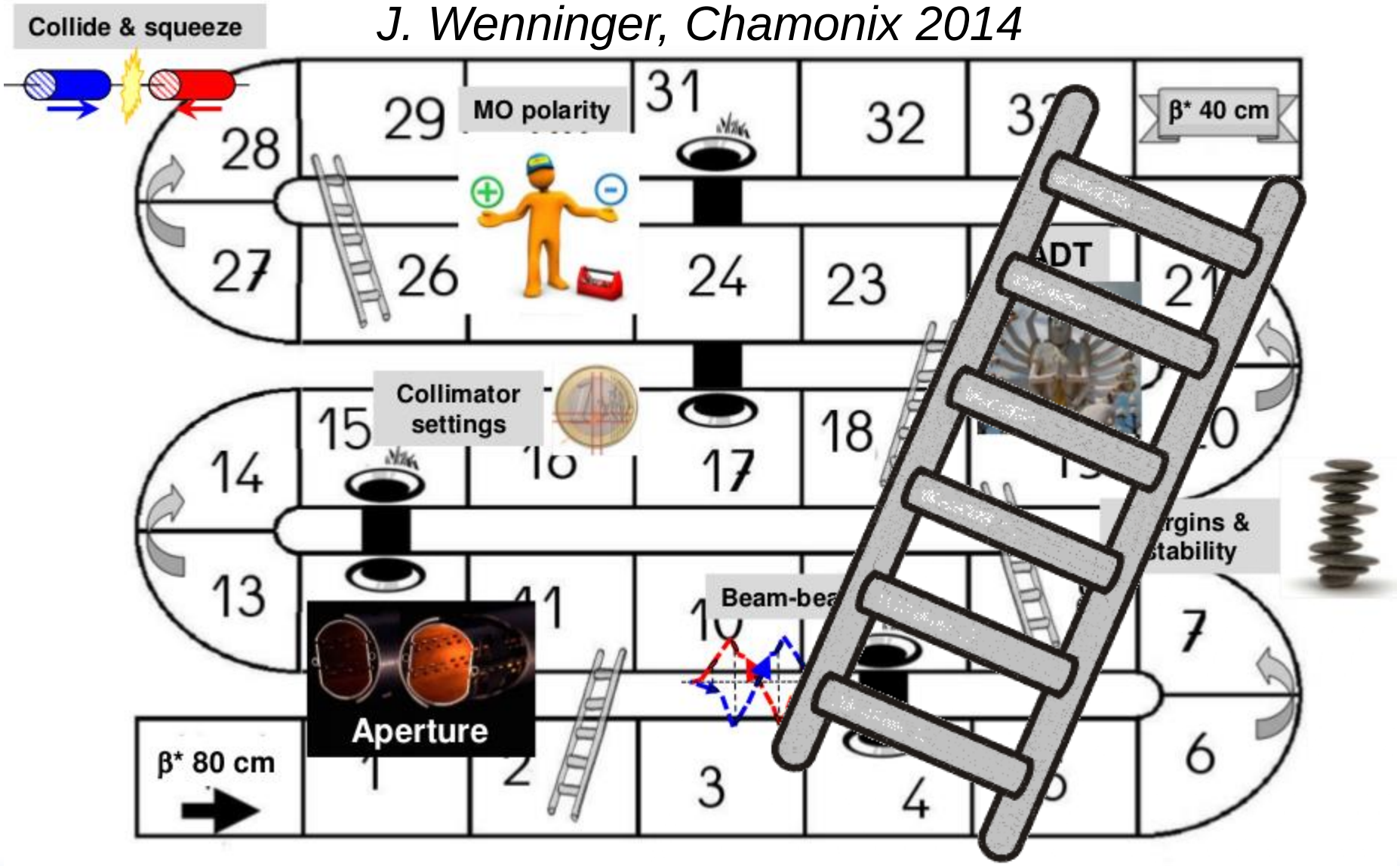
- **Startup:**
  - Put focus on feasibility, stability and ease of commissioning. Allow comfortable margins for operation and avoid introducing too many untested features at once
  - Main priority: Get LHC running 25 ns at 6.5 TeV
  - Where possible, calculate parameters based on what we know can be 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 scenario

- With focus on feasibility and ease of commissioning, and due to uncertainties on assumptions, it was decided to:
  - Start relaxed at $\beta^*=80$ cm
  - Keep 2012 collimator settings in mm
  - 11 σ beam-beam separation
  - Standard 25 ns filling scheme
- When we have sufficient OP experience at 6.5 TeV and 25 ns, push performance
  - Are we there now? Yes!

Reaching 40cm

J. Wenninger, Chamonix 2014



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Pushing luminosity

Increase bunch intensity

Increase number of bunches

$$\mathcal{L} = \frac{N_1 N_2 f_{\mathrm{rev}} k_B}{4\pi\beta^* \epsilon_{xy}} F$$

Increase F: shorter bunches, smaller crossing angle

$$\frac{1}{\sqrt{1+\left(\frac{\sigma_s}{\sigma_x}\frac{\phi}{2}\right)^2}}$$

Smaller β*

Smaller emittance

Parameters for increased luminosity

- Number of bunches: Through scrubbing, good hope to finalize intensity rampup to 2748 bunches (see talk G. Iadarola)
- Bunch population, emittance: given by parameters at injection, from SPS

	Standard 25 ns		BCMS	
	2015	2016?	2015	2016?
Bunch population	**1.2e11**	1.3e11	1.1e11	1.3e11
Transv. emittance	**2.6 µm**	2.7 µm	1.6 µm	1.9 µm

G. Rumolo, H. Bartosik

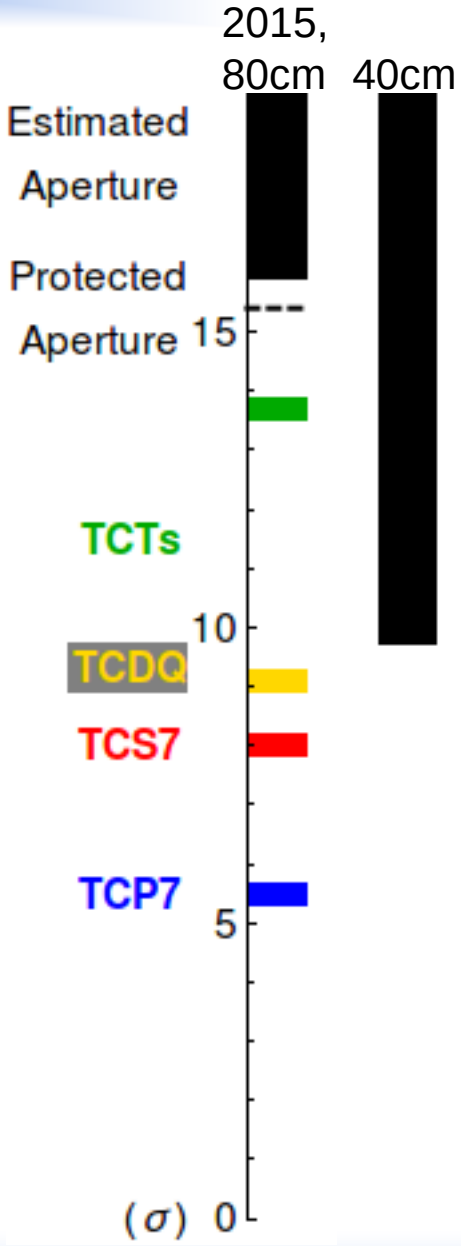
- BCMS interesting option, but could cause stability issues (see talks K. Li, G. Iadarola, L. Carver)
- Should finish intensity rampup with standard 25 ns, could then move to BCMS with blown-up emittances, then decrease emittance gradually
- BCMS emittances can be improved, but work is required. Need to know this early on

Parameters for increased luminosity

- Bunch length: At least for the start, keep 10 cm bunch length to control heat load in the ramp. Once rampup is finished, consider gradually decreasing bunch length
- Crossing angle: MDs have demonstrated possibility to reduce beam-beam separation from 11 σ to 10 σ for 3.75 μm emittance (talk T. Pieloni)
- β^*: several ways to reduce.
  - Profit of better than expected aperture (done in run 1, but now aperture gold mine is probably depleted)
  - Reduce beam-beam separation (gains aperture)
  - Reduce collimation hierarchy - main topic for rest of this talk

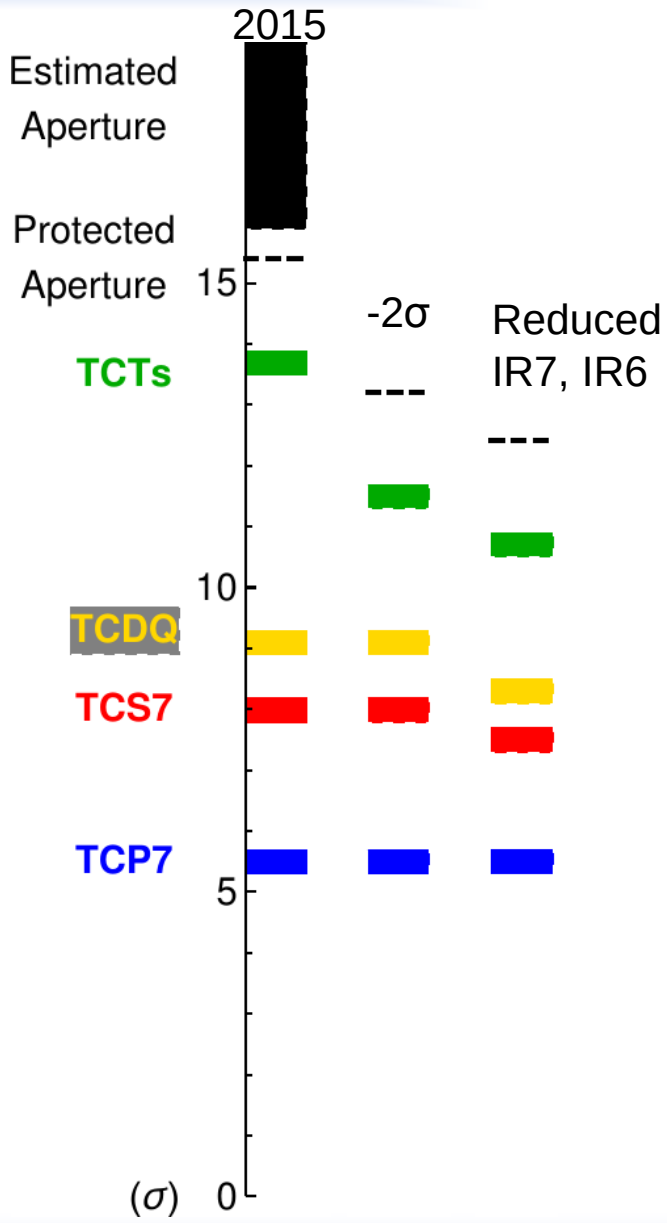
Collimation hierarchy and aperture

- Collimators ordered in hierarchy, must protect aperture
- Normalized aperture becomes smaller when β* is decreased
- Need to significantly reduce collimation margins to accommodate small β*
- Series of MDs carried out:
  - MD 307: 40 cm aperture measured in excellent agreement with predictions.
    - But aperture measurements with ions worse!
  - MD 310: Are tighter collimator settings possible without jeopardizing cleaning and protection?



Reducing collimation margins

- Could remove 2 σ added when stepping back to 80 cm
- Reduce IR7 and IR6 margins for cleaning
  - Secondary collimators have high impedance contribution. MDs: Can reduce to 2 sig retraction (talk L. Carver)
  - MD 314: Hierarchy with 2012 margins in σ OK for long term cleaning stability (Talk G. Valentino)
- Reduce machine protection margins
  - Margins in place to protect sensitive elements (TCTs and triplets) against asynchronous beam dumps



Asynchronous beam dump

- Standard dump: extraction kickers fire when no beam passes

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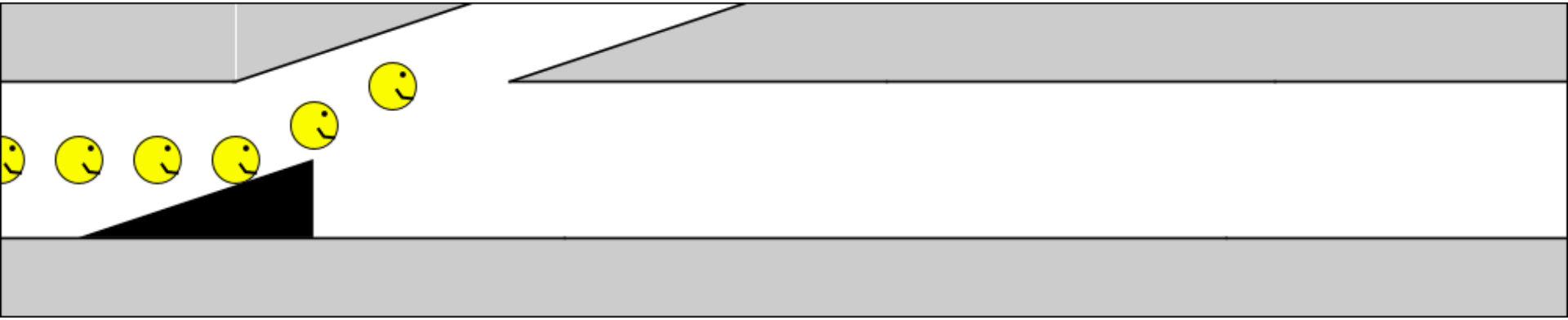

- Asynchronous dump: kicker(s) fire when beam passes – kicked beam damage could TCTs/triplets. TCDQ should protect

Asynchronous beam dump

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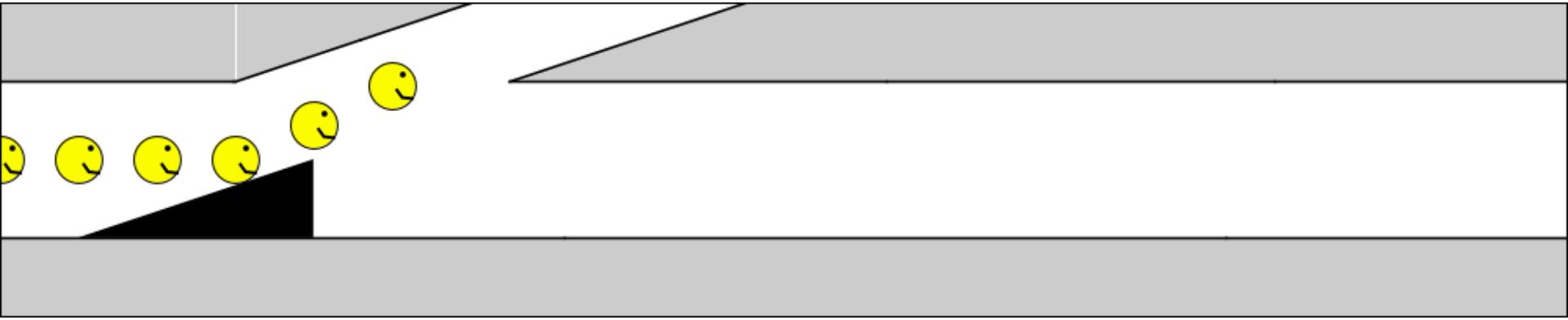

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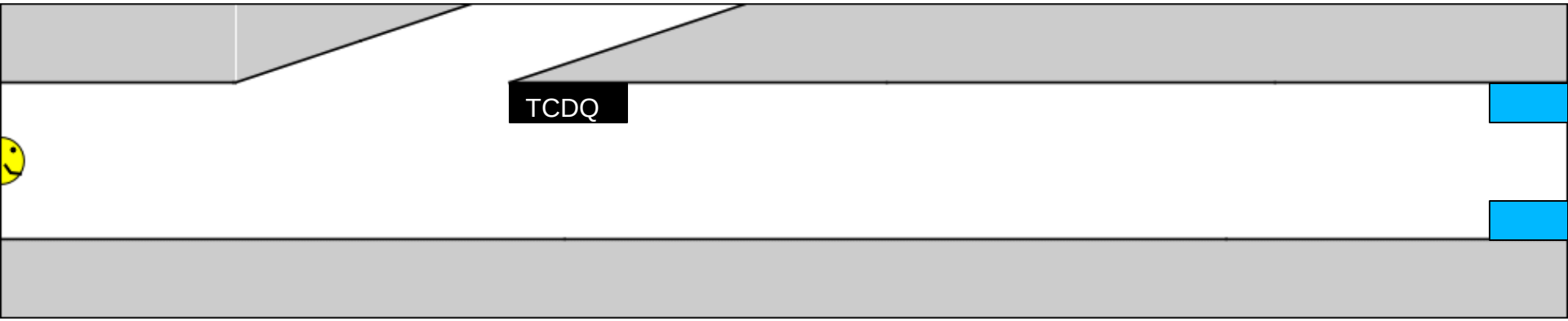
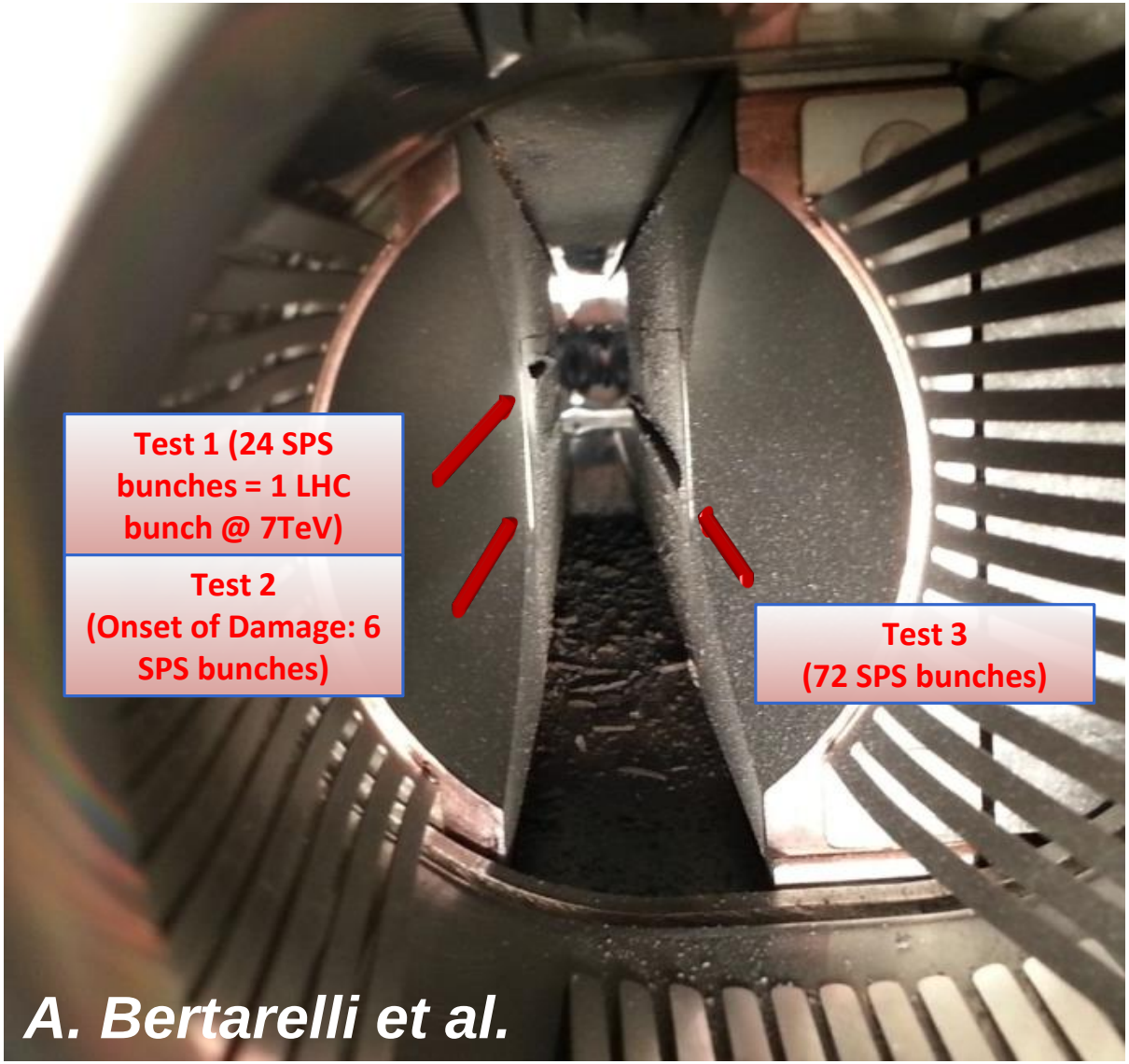


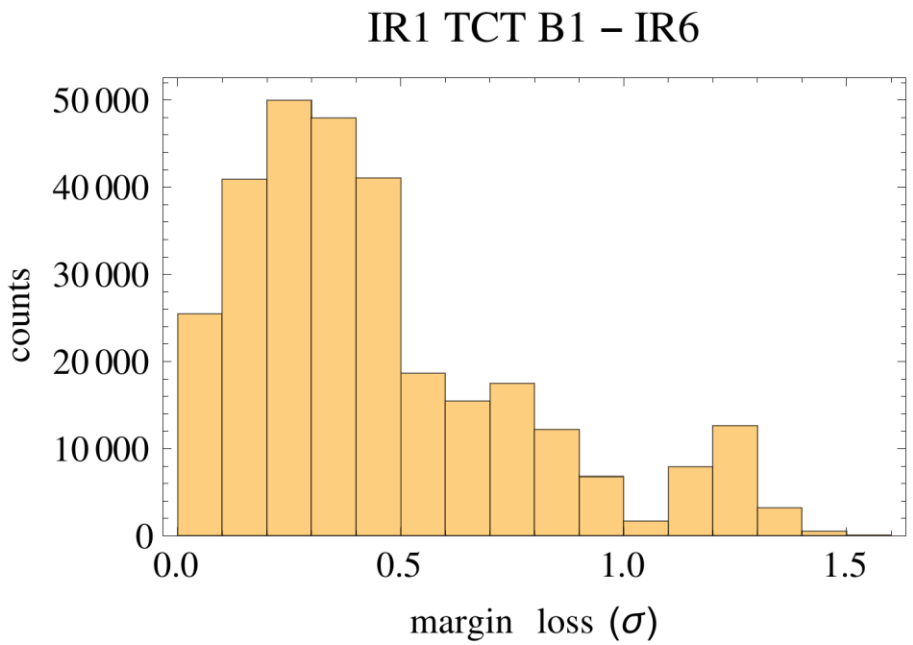
What can happen if a TCT is hit?

- Impacts studied in HiRadMat
- Significant damage observed



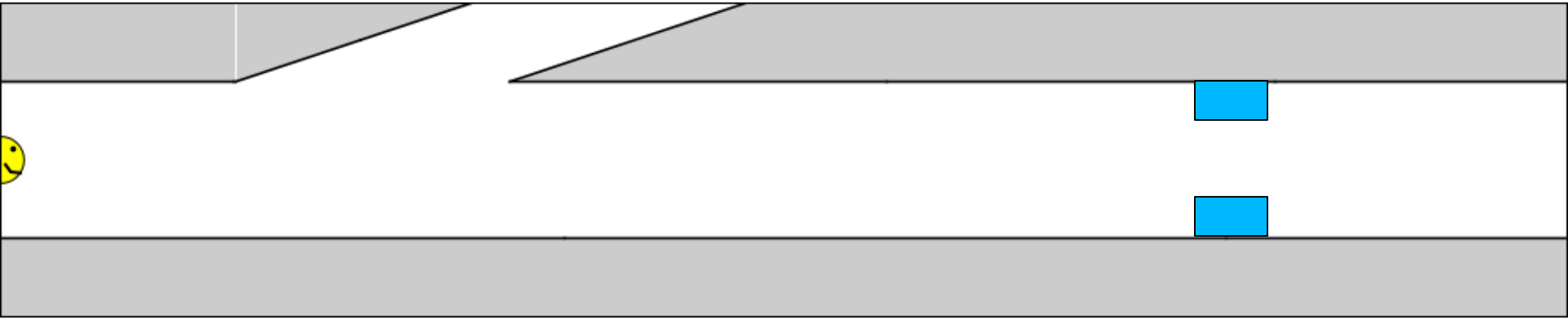
Margin TCT-dump protection

- Margins ensure that TCTs/triplets are not damaged, accounting for orbit/optics imperfections
- Use better orbit stability in 2015 than in 2012 (2011!)
  - However, assumed 1 asynch dump per year (Evian 2014) – now assume 3
  - When accounting for more dumps but better orbit, still some gain
  - Need 1.4 σ TCDQ-TCT (instead of 1.7) and
  - 1.1 σ TCT- triplet (was 1.1)



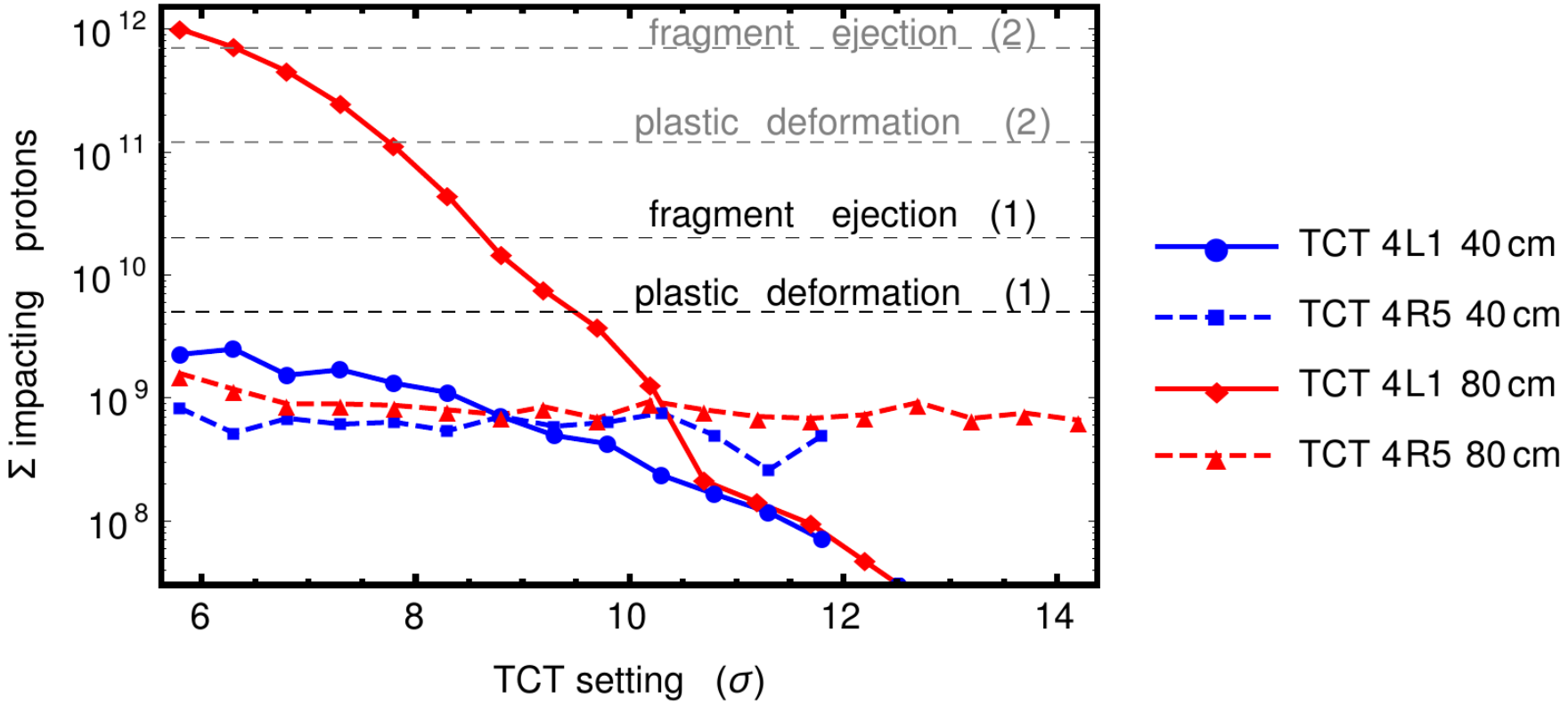
Reducing margin from dump protection

- Interlocks on collimator BPMs (see talk G. Valentino)
  - Dump beam before we get into a dangerous zone
  - If too tight, we get spurious dumps
- Adjust betatron phase from dump kicker to TCTs/triplets
  - In the past, assumed 90 deg phase advance, but this is often pessimistic
  - New optics underway with < 20 deg (R. de Maria et al.)



Expected TCT losses, asynch dump

- Expect secondary (outscattered) losses also at good phase (simulated with SixTrack), but they have factor ~20 higher damage level
- Example: IR5, B2, had ~180 deg phase advance already in 2015. Saw very similar losses at 13.7 σ, 80 cm, and 7.8 σ, 40 cm

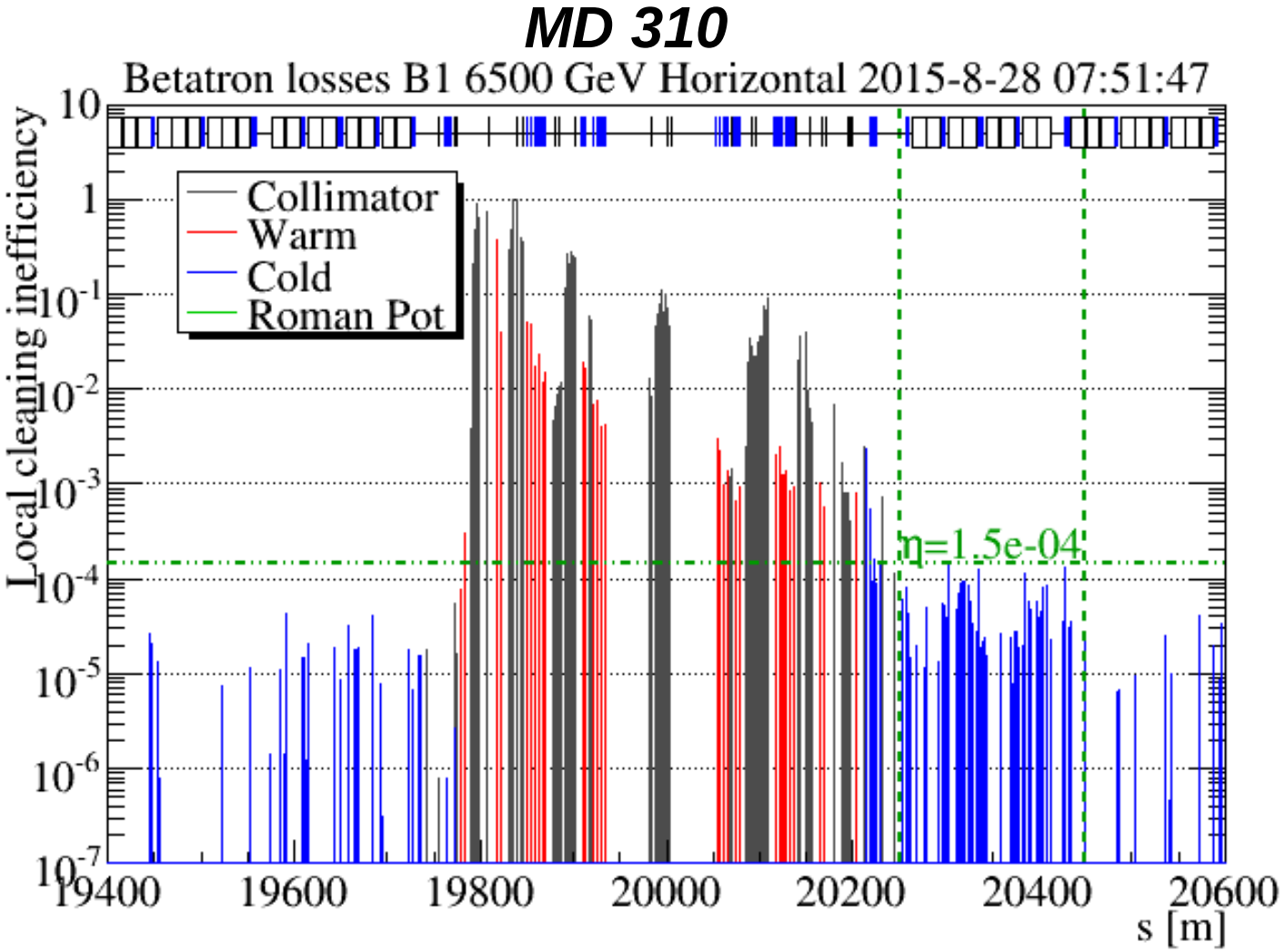


Other limitations for moving in TCTs

- At phase advance close to zero, no primary losses from asynch dump expected on TCTs / triplets
- Other constraints limit the innermost TCT setting
  - Cleaning hierarchy: we don't want secondary halo on TCTs
  - Experimental background
- MD 310 carried out to assess these points
  - ATLAS and CMS monitored backgrounds. Increase observed at 40 cm, but probably not a showstopper
  - Cleaning: Satisfactory performance with the proposed settings.

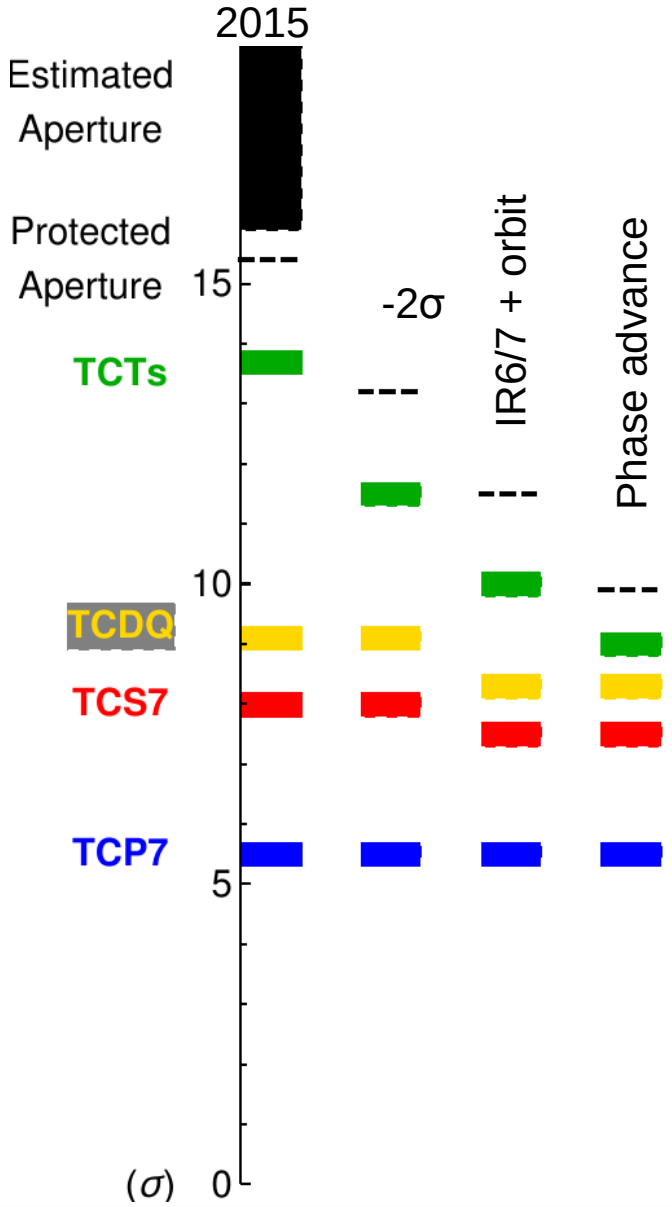
Loss map at β*=40 cm

- Cleaning even better (factor ~2) with tighter hierarchy.



Possible collimator settings

- Ultimate limit of TCTs from cleaning believed to be around the level of the TCDQ (~8.3 σ)
- Propose to start a bit more relaxed: TCTs at 9 σ, aperture >9.9 σ. Potential to push this limit further (35 cm?)



Possible actions to ensure safety

- 20 deg and TCTs at 9σ: about as much margin as in 2015 between TCT setting and damage level! At 0 deg, more margin
- At startup, qualify two TCT settings with asynch dump test
  - one at proposed settings, one with large loss in margin TCDQ-TCT
  - Use collimator BPM interlock to dump before we get outside the qualified interval
  - Add in XPOC more detailed analysis of standard dumps?
- Interlock on phase (quadrupole currents) under study (M. Zerlauth, K. Fuchsberger et al.)
- With these measures, should be as safe as in 2015

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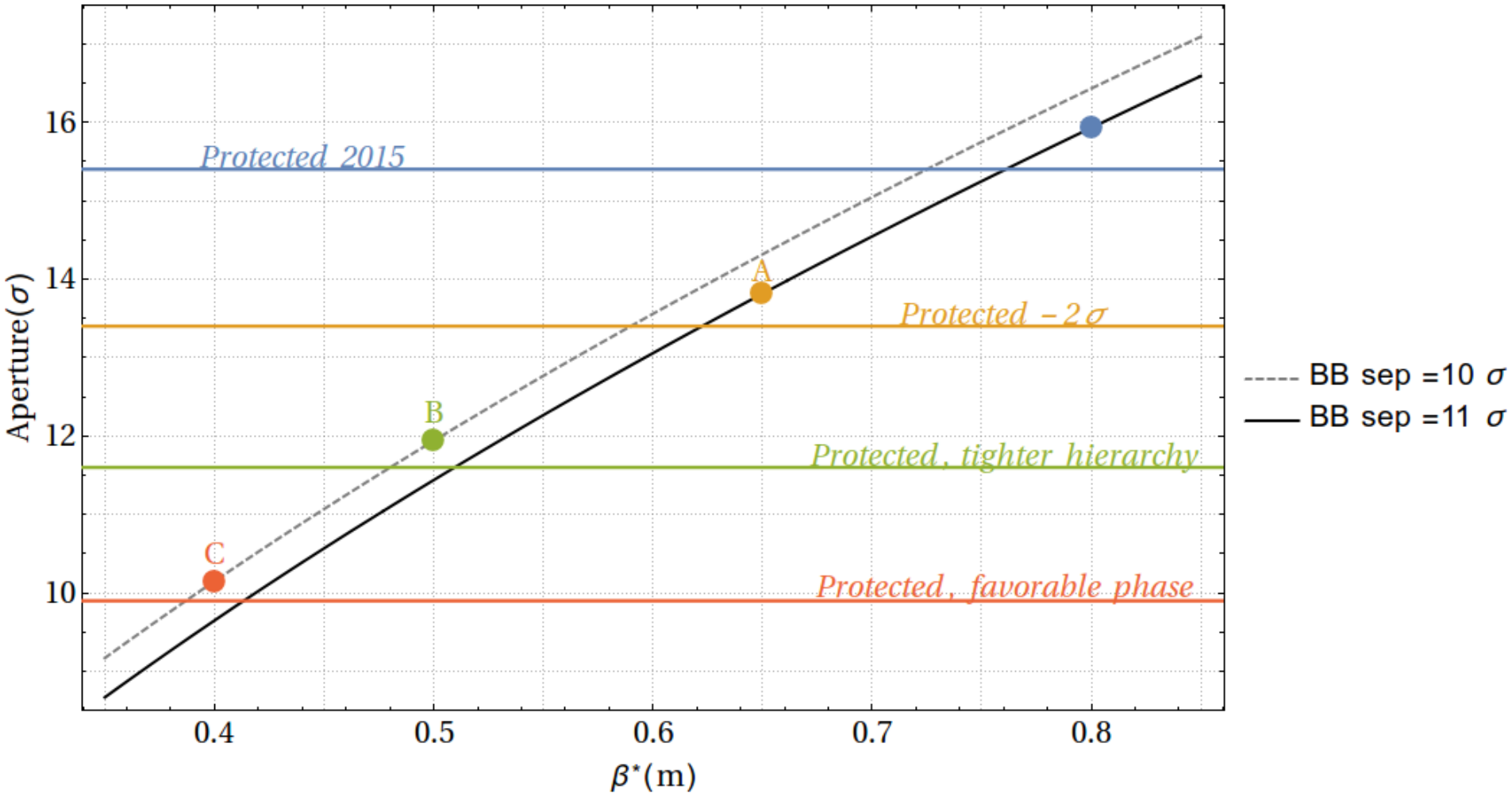
β*-reach 2016



- With tighter hierarhcy in IR7/6, 10σ BB separation, optics with re-matched phase, and assuming aperture does not deteriorate => β*=40 cm possible

Scenarios for 2016

A: β=65 cm*

- 160 µrad half Xing (11 σ BB)
- Remove 2 σ additional margin from 80cm

Collimator	Setting
TCP IR7	5.5
TCSG IR7	8.0
TCSG IR6	9.1
TCDQ IR6	9.6
TCT IR1/5	11.5
P. Aperture	13.4
C. Aperture	13.8

B: β=50 cm*

- Use tighter IR7/6 hierarchy, 10 σ BB (165 µrad), better orbit in 2015

Collimator	Setting
TCP IR7	5.5
TCSG IR7	7.5
TCSG IR6	8.3
TCDQ IR6	8.3
TCT IR1/5	10.0
P. Aperture	11.5
C. Aperture	11.9

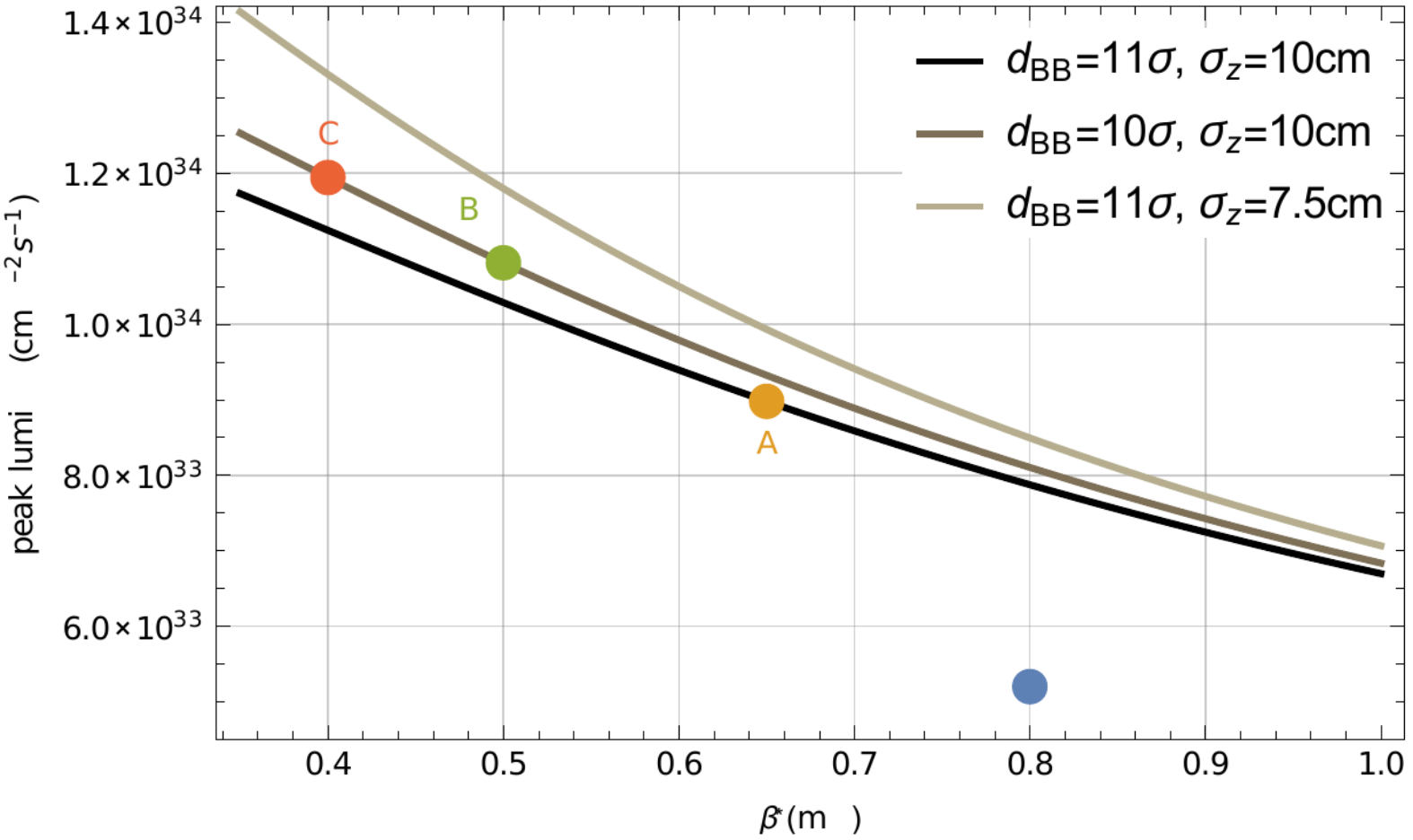
C: β= 40 cm*

- In addition to 50 cm, rely on phase
- 185 µrad half Xing (10 σ BB)

Collimator	Setting
TCP IR7	5.5
TCSG IR7	7.5
TCSG IR6	8.3
TCDQ IR6	8.3
TCT IR1/5	9.0
P. Aperture	9.9
C. Aperture	10.2

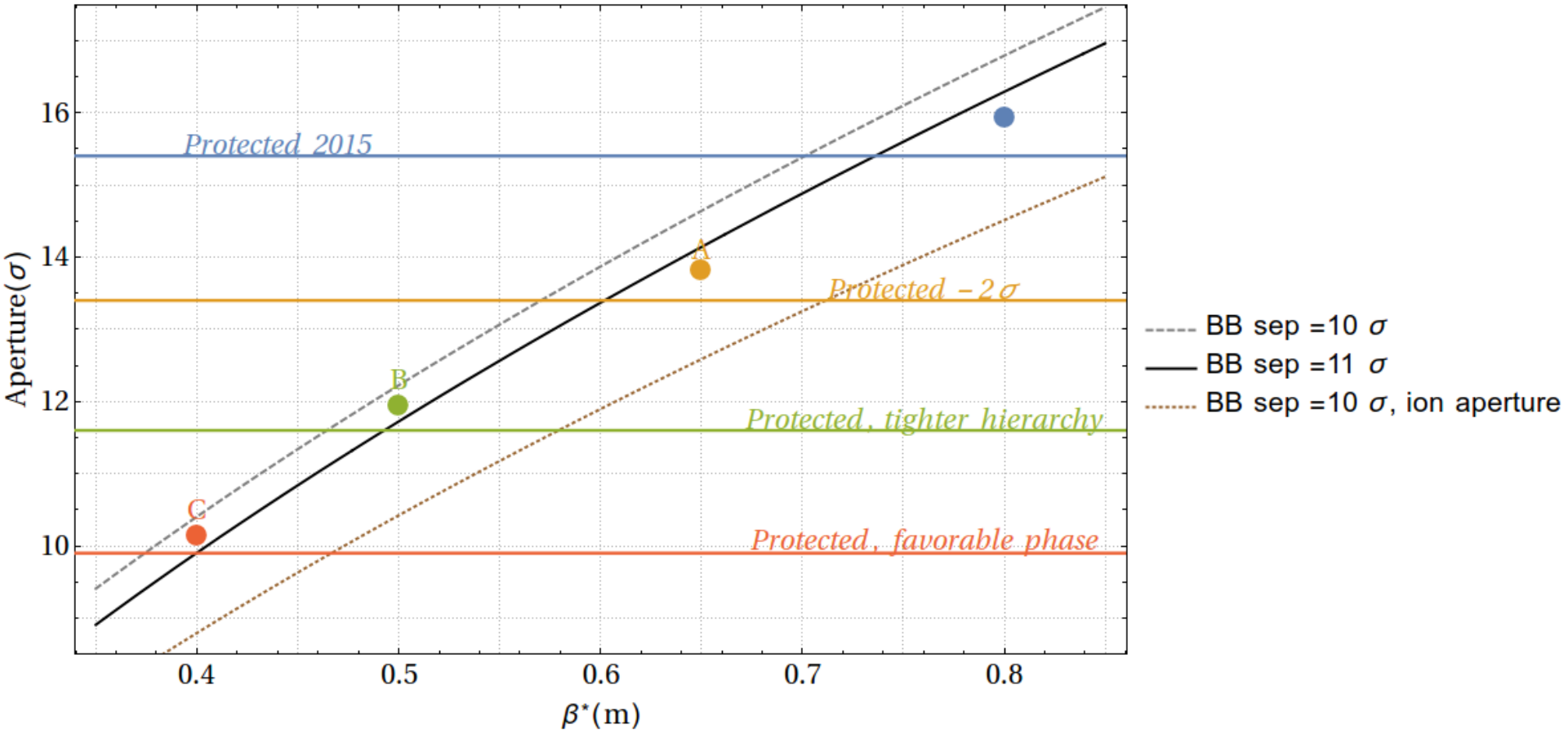
Peak luminosity

- Example: assume 1.3e11 p/bunch, 2736 bunches, ε=3.75μm



In case of worse aperture

- Calculating the aperture by scaling the *first* heavy-ion measurement, we lose 5-10 cm in β*



Strategy for 2016: for discussion

- Regardless of final choice of β*, decision in optics team to have optics with improved phase advance
- Should choose best performance without jeopardizing safety
- It is essential to re-measure the aperture very early on - do we get back the good proton aperture?
- Try early on 2 asynch dump tests at 40 cm with new optics, to verify expected behaviour and set interlock
  - Should see secondary TCT losses: weak dependence on settings
- If these tests turn out as expected/hoped, go for 40 cm
- If not, step back to 50 cm

Summary

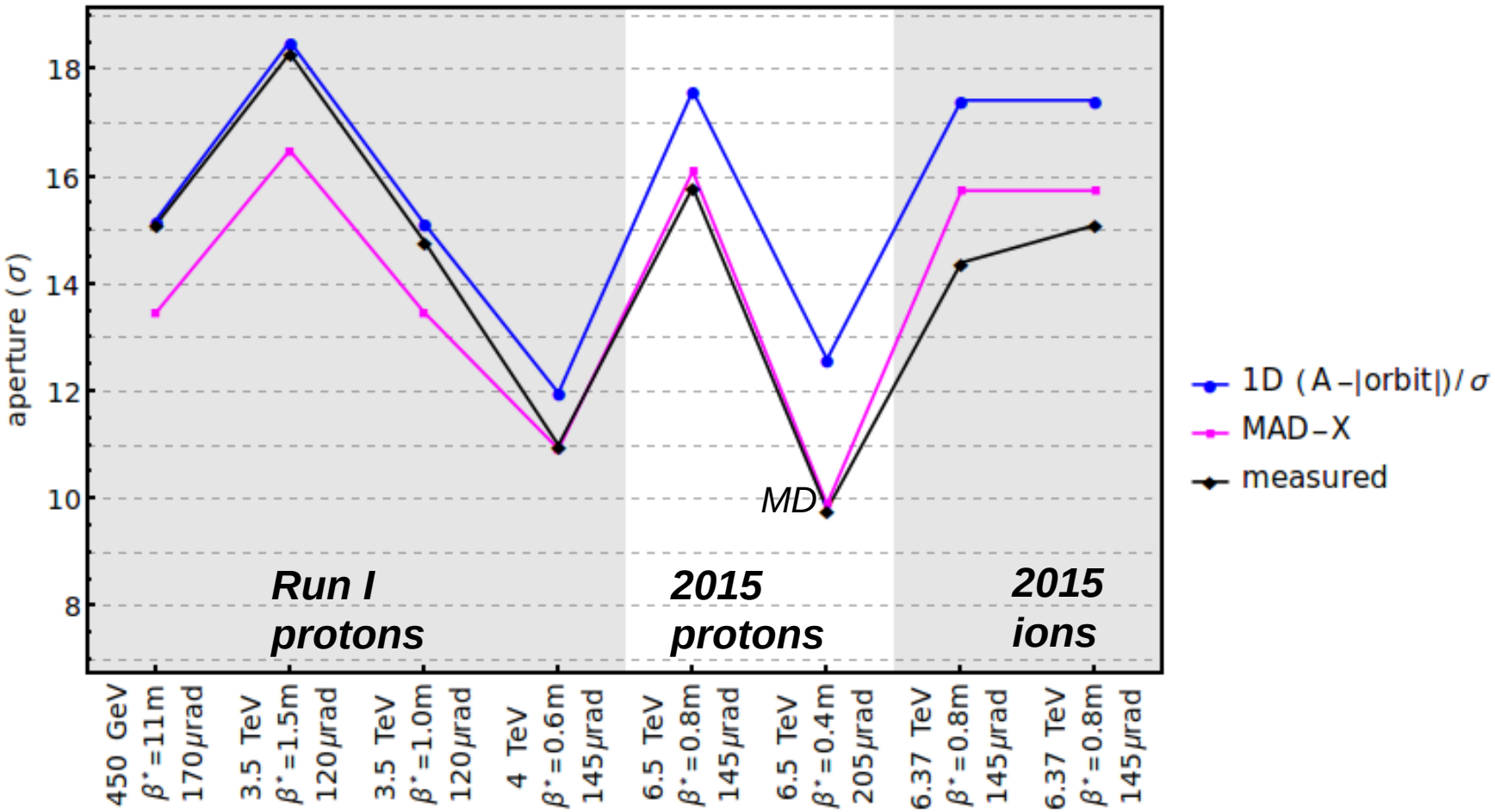
- 2015 : commissioning year, 2016: production year
- 2016 goal: increase performance as much as possible within limits of machine safety
  - Try to maximize number of bunches and bunch intensity. Reduce emittance, bunch length, crossing angle, β*
- Several MDs carried out to study ways to increase performance
- Based on MDs and OP experience, presented scenarios for 65 cm, 50 cm and 40 cm.
- We could reach $\beta^*=40$ cm
  - Use tighter collimation hierarchy, optics with re-matched phase advance dump kicker-TCT, 10 σ beam-beam separation
  - Assuming proton aperture is reproducible. If aperture is worse as in ion run, be prepared to step back to $\beta^*=50$ cm

Can we get to β*=40 cm?

*Provided aperture stays good

Backup

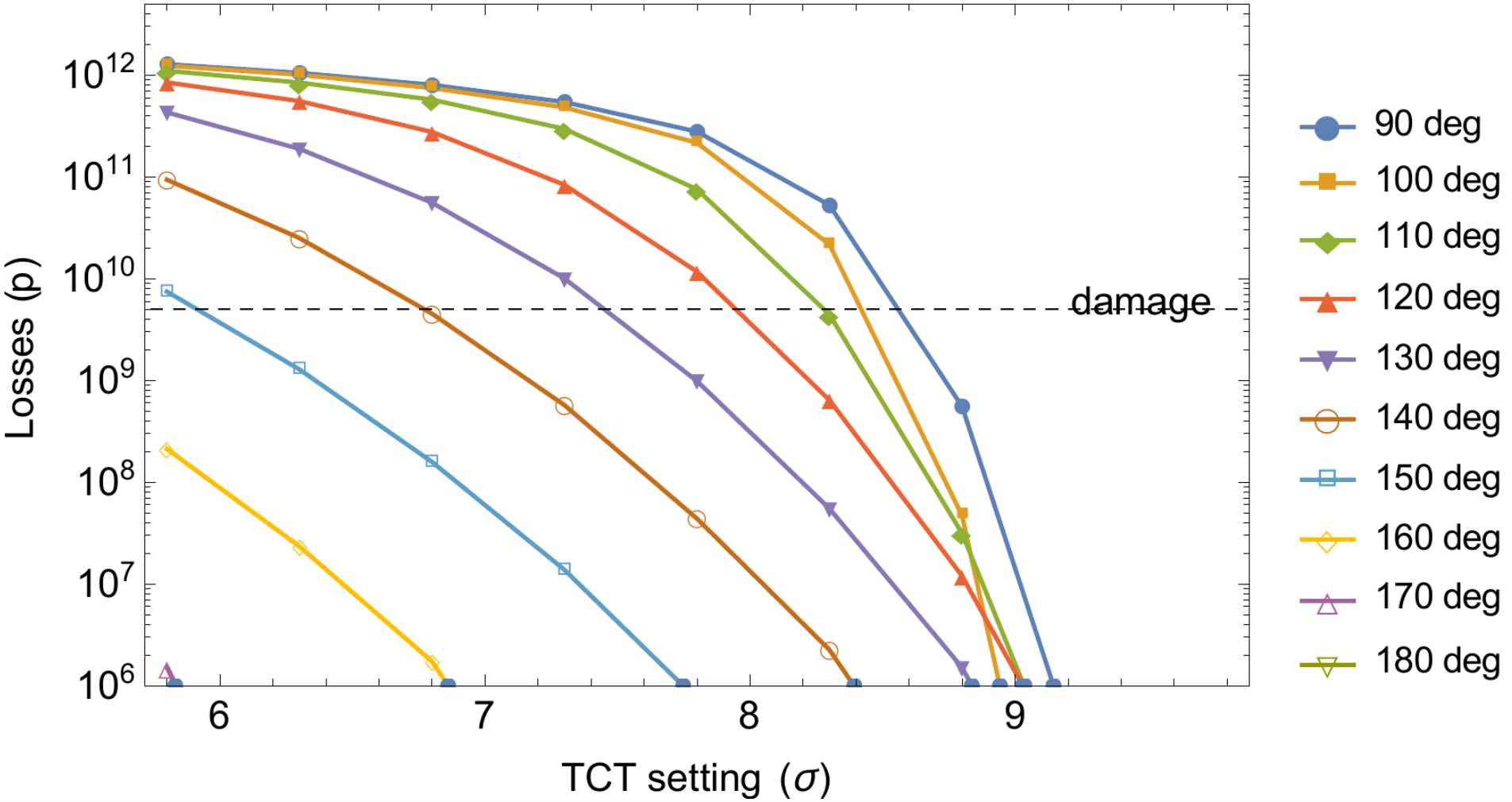
IR1/5 triplet aperture measurements



- *Normalized* aperture in σ, not in mm, reflects the orbit, optics etc
- 2015 proton measurements (80cm and 40cm) in excellent agreement with 2012 extrapolation. Smaller aperture with ions!

Expected TCT losses, asynch dump

- Simulated *primary* impacts on TCT as function of setting and phase



Damage level vs phase

- Setting where TCT is damaged as function of phase advance (TCDQ @ 8.3σ)