β*-reach in 2017

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Outline

- Recap of constraints on β*
- Strategy used in 2016
- Possible improvements in 2017
- Scenarios for β* in 2017

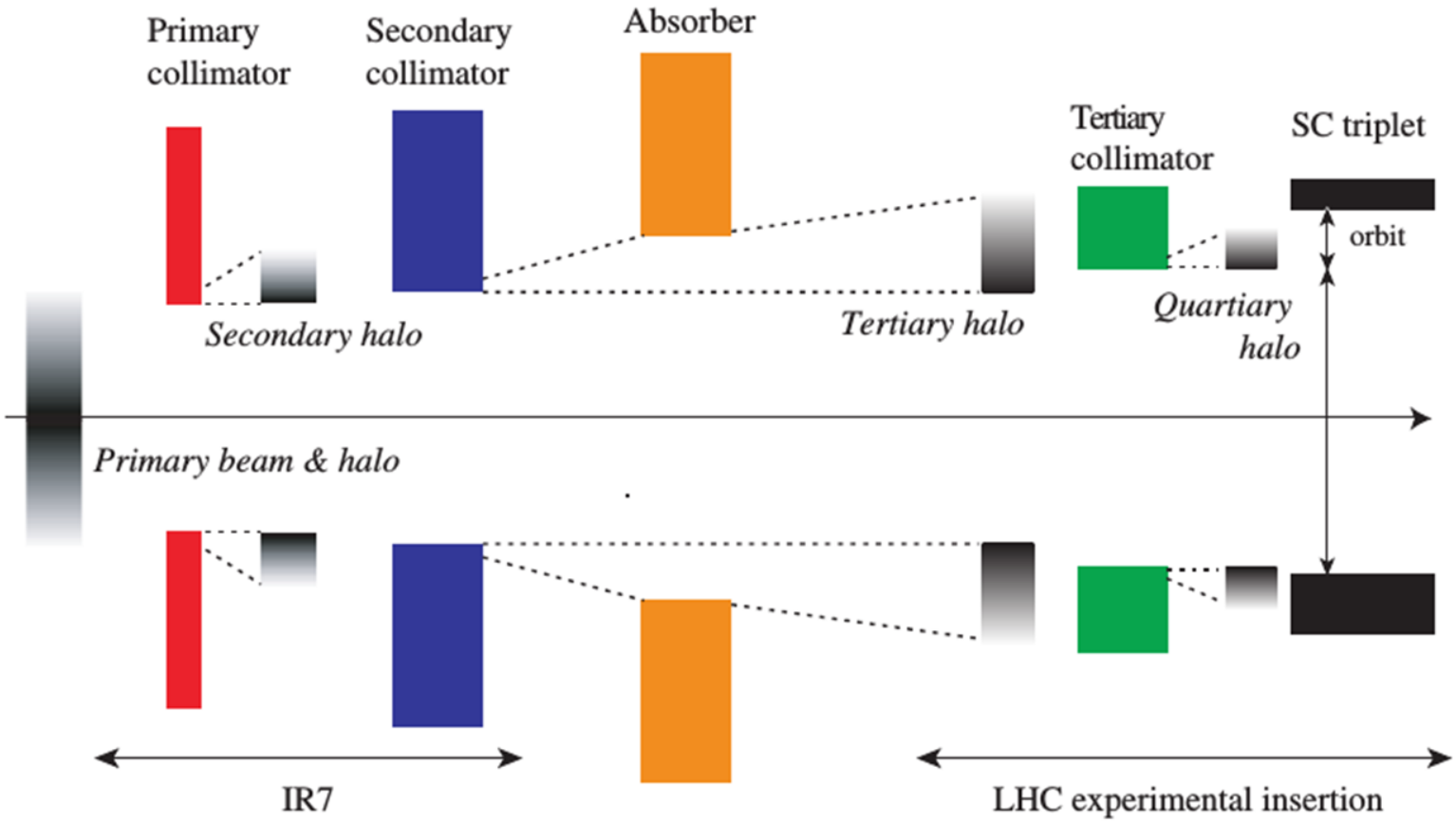
Limitations on β* in the LHC

- Main limitations when squeezing to smaller β*
  - Magnetic strength
    - Was not the driving limitation so far. Still the case – all β*-values considered for 2017 possible with both nominal and ATS optics
  - Protected aperture, determined by collimation hierarchy
    - Has been the main limitation so far

Focus of this talk

Limit on aperture

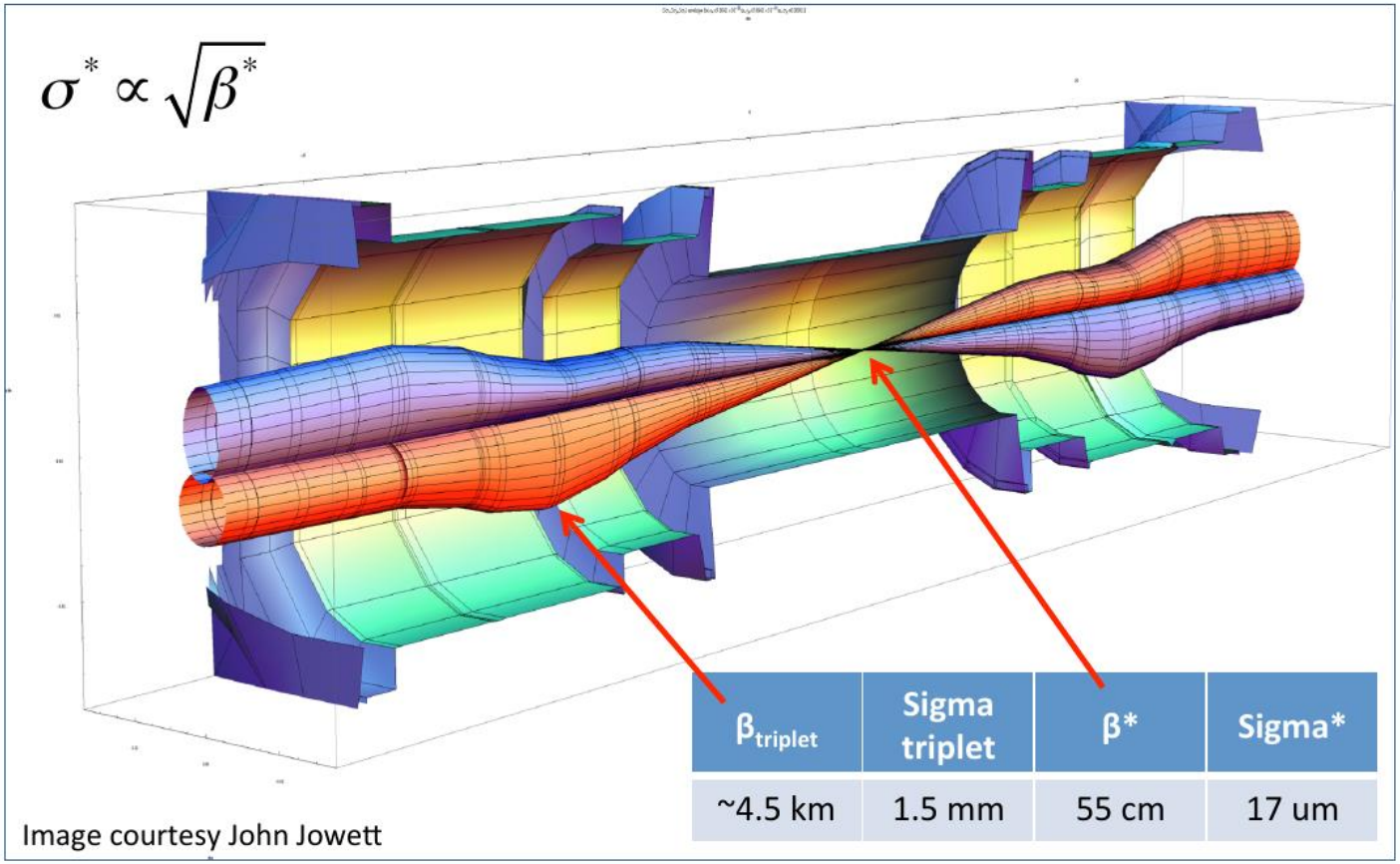
- Collimation hierarchy sets lower limit for protection of aperture
- All elements (e.g. triplet) must have larger apertures (in σ)



Triplet aperture and β*

- Beam size increases in triplet when β* is squeezed
- Smaller β* usually requires larger crossing angle

=> smaller normalized aperture in σ with smaller β*



$\beta_{triplet}$	Sigma triplet	β*	Sigma*
~4.5 km	1.5 mm	55 cm	17 um

Ways to gain aperture

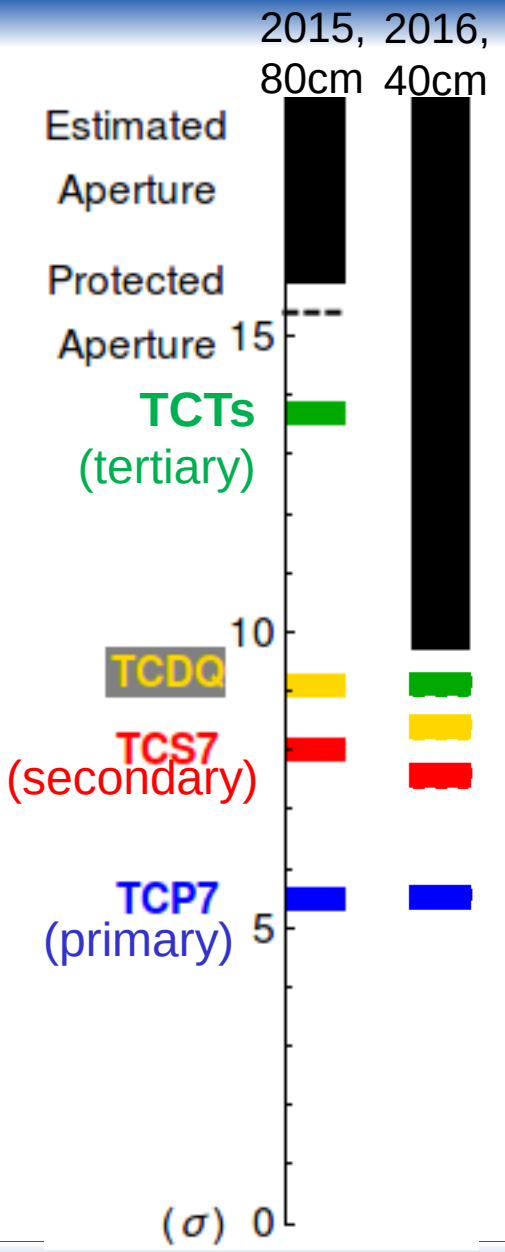
- Tighter collimators => protect smaller normalized aperture
- Smaller normalized beam-beam separation => smaller crossing angle and more aperture at any given β*

Strategy in 2016

- Better knowledge of the aperture allows a smaller margin on the aperture
  - Used to squeeze in Run I

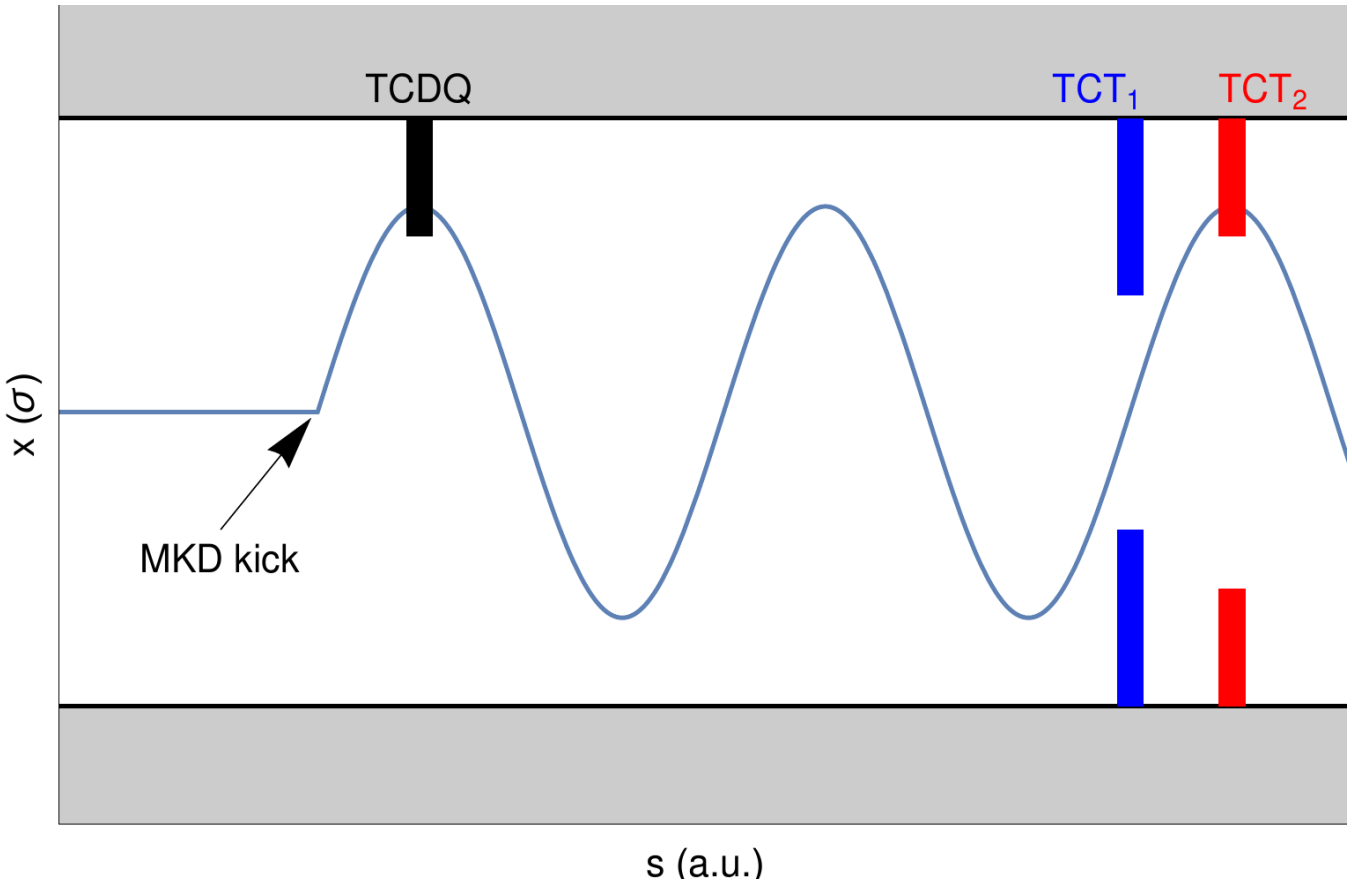
Recap: what did we do in 2016?

- Beam-beam separation
  - see talk X. Buffat
  - Reduced from 11 σ in 2015 to 10 σ in 2016 (for nominal emittance 3.75 µm).
  - Further reduction in September to 9.3 σ for BCMS emittance 2.5 µm but without further reduction in β* Crossing angle reduction from 185 urad to 140 urad
- Much tighter collimation hierarchy
  - Smaller retraction between TCP and TCSG
  - New optics with specially matched phase advance allowed smaller retraction TCDQ - TCT



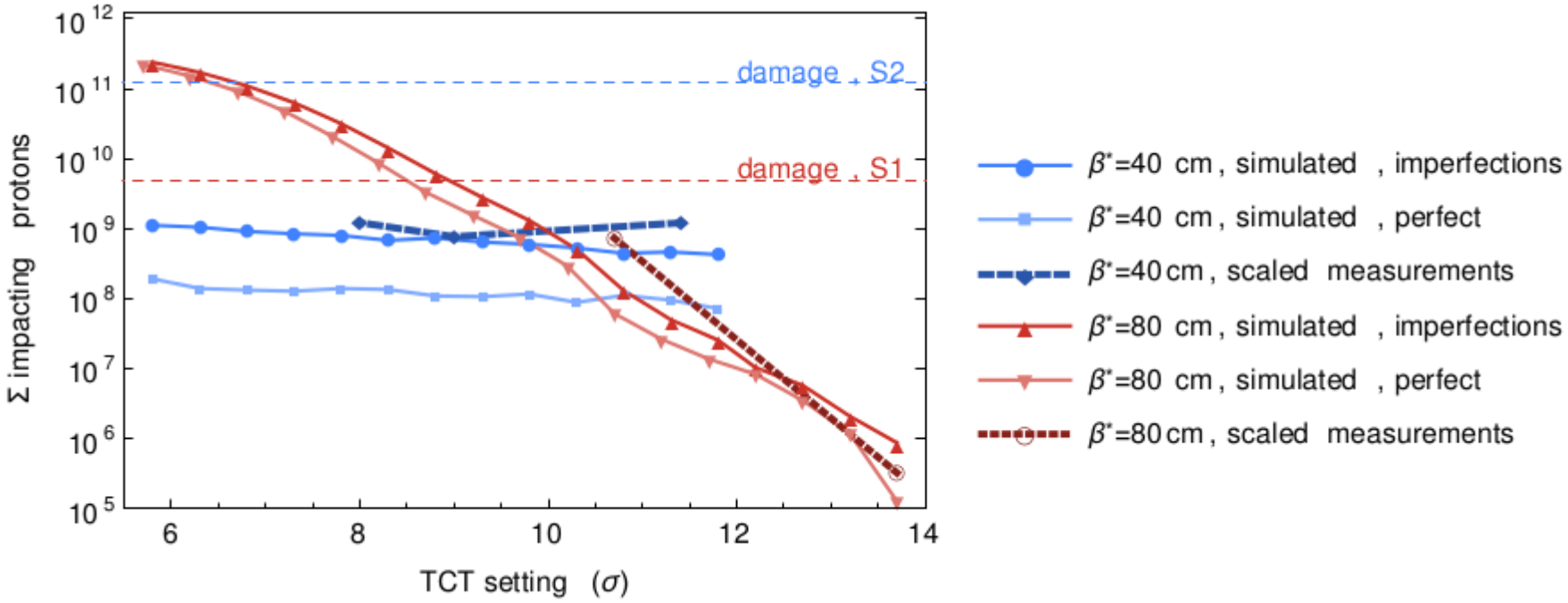
Gain from phase advance

- TCTs at a good phase can be closer to beam without damage risk during asynchronous beam dump



2016 beam tests of asynch dump

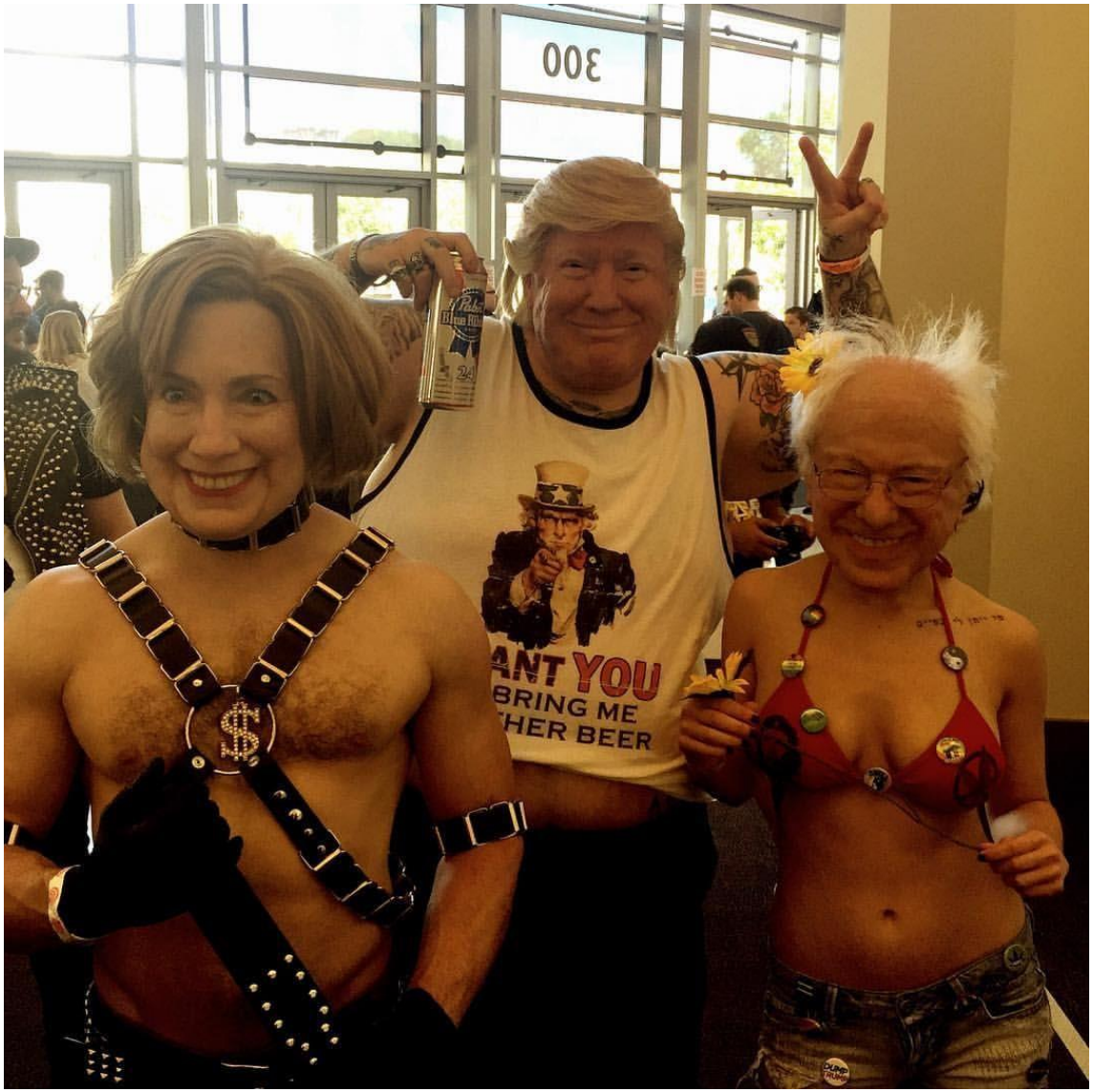
- Verified TCT losses experimentally with several asynchronous dump tests in different optics



- As expected, do not see dependence on TCT setting at 40 cm
- Record-low β*=40 cm successfully used in operation

Conclusion in Evian last year

Can we really do better in 2017 ?

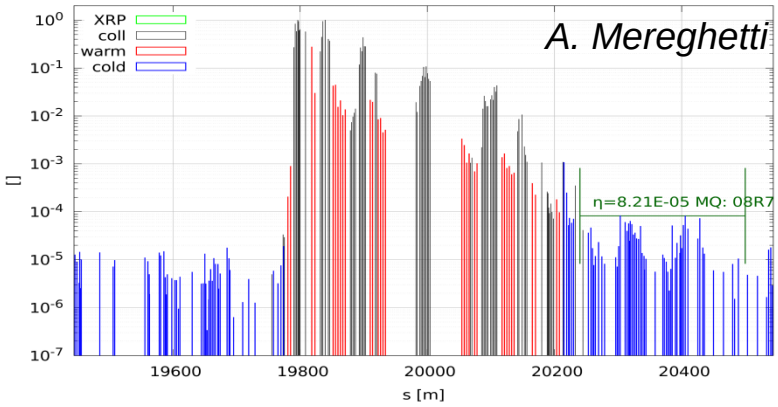


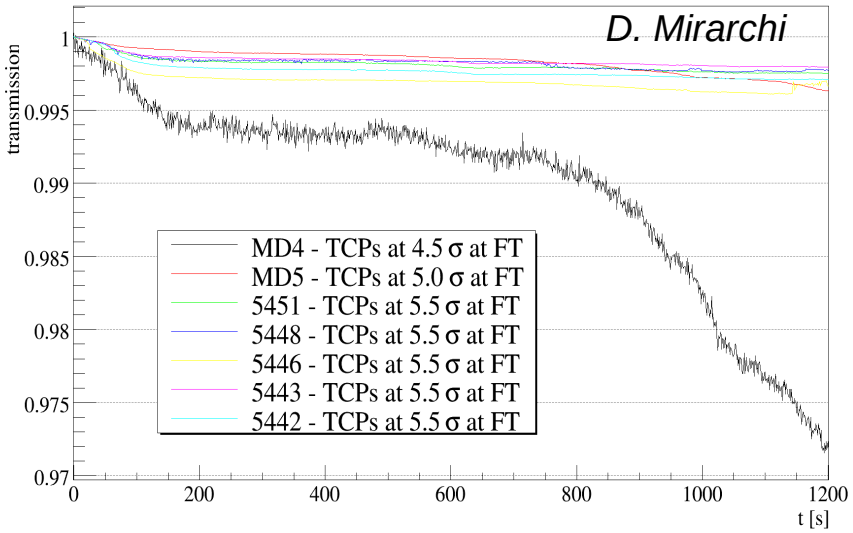
Can we really do better in 2017 ?

- Short answer: Yes we can!
- If we keep the new beam-beam separation from crossing angle reduction, already have some margin
- For 2017, investigate 3 different beam-beam scenarios:
  - Assume that we keep the same normalized separation as in the end of the 2016 run (9 σ for 2.5 µm emittance), or
  - Step back to 10 σ for 2.5 µm to have margin for higher bunch intensities (G. Arduini, Y. Papaphilippou, D. Pellegrino)
  - For nominal beams: keep 9 σ for 3.5 µm emittance
- Collimation hierarchy and aperture: several MDs carried out to improve retractions

MD studies on tighter collimators

- MD1447: IR7 Collimation Hierarchy Limit and Impedance
  - Tighter TCSGs possible for cleaning hierarchy: can correct breakage with tilt (see talk D. Mirarchi)
- MD1878: Operation with primary collimators at tighter settings
  - no detrimental effect on losses through the cycle with TCP 0.5 σ tighter
- End-of-fill: TCT closure test
  - No increase in experimental background seen with 0.5 σ tighter TCTs
- MD 1673: detailed aperture measurements
  - Input to aperture calculations





Proposed 2017 collimator settings

- Collimation working group on 7/11/2016: assess tighter collimator feasibility
- New proposal
  - Reduced TCP-TCSG by 0.5 σ
  - Reduced TCSG-TCT by 0.5 σ
  - Could also push TCP setting in by 0.5 σ
    - Tested in one MD fill
- In total: We gain around 1.0 - 1.5 σ in aperture
- Impedance OK for these settings (see talk L. Carver)

Collimator	2016	2017a	2017b
TCP IR7	5.5	5.5	5.0
TCSG IR7	7.5	7.0	6.5
TCLA IR7	11.0	10.5	10.0
TCP IR3	15.0	15.0	15.0
TCSG IR3	18.0	18.0	18.0
TCLA IR3	20.0	20.0	20.0
TCSG IR6	8.3	7.8	7.3
TCDQ IR6	8.3	7.8	7.3
TCT IR1/5	9.0	8.0	7.5
Aperture 1/5	*9.9*	*9.0*	*8.5*
TCT IR2	37.0	37.0	37.0
TCT IR8	15.0	15.0	15.0

Settings in σ with ε=3.5 μm

Aperture measurements

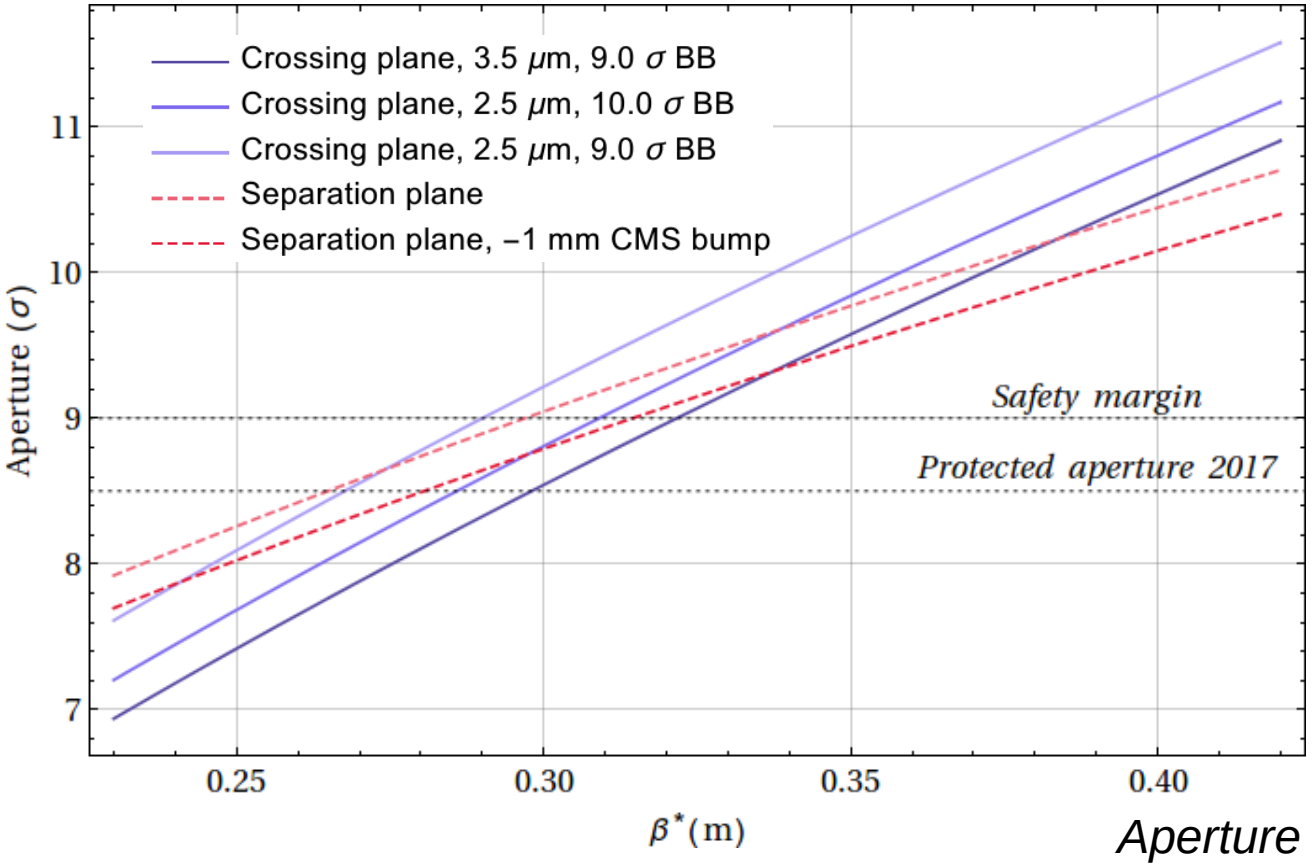
- For reach in β*, need accurate aperture knowledge
- Aperture in 2016 measured much more frequently than before
  - Some fluctuations seen over the year
  - Global bottleneck found (likely) on D1 L1 on incoming beam (IR1, B1V)
  - Measured aperture always with spec, but no margin

Date	Config.	B1H [σ]	B1V [σ]	B2H [σ]	B2V [σ]
10/4	Coll.	11.3 (Q3/D1R5)	**10.0** (D1 L1)	11.6 (D1 R1)	10.7 (D1 R1)
17/4	Coll.	11.0 (D1/TANR5)	**9.9** (D1 L1)	12.1 (D1 R1)	10.4 (D1 R1)
17/4	Inv. IR1 Xing	-	11.8 (D1 L1)	-	10.8 (D1 R1)
18/4	Sep.	11.5 (D1/TANR5)	**9.9** (D1 L1)	11.5 (D1 R1)	11.0 (D1 R1)
10/6	Coll.	>11.1 (Q3/D1R5)	**10.0** (D1 L1)	12.0 (D1 R1)	**10.0** (D1 R1)
5/10	MD5	**10.6** (D1 L1)	**10.0** (D1 L1)	**10.8** (D1 R1)	10.6 (D1 R1)
5/10	MD5, Inv. IR1 Xing	**10.6** (D1 L1)	10.8 (Q2L5/D1R5)	**10.8** (D1 R1)	11.5 (D1 R1)

Aperture calculations

- Conservative approach for aperture calculations
  - Use most pessimistic measured aperture and scale it to new configuration
  - Add 0.5 σ safety margin to account for drifts over the year
    - Not counting on more aperture with other sign on IR1 crossing
    - Good reach in β* even with these precautions
  - Potential improvements in crossing plane studied but not yet ready for operation: MD on detailed IR aperture
- Complication: vertical shift of CMS by -1 mm
  - Bump to be applied – loss in aperture. See e.g. LMC 30/11
  - Difficulty: aperture never measured at predicted bottleneck => calculation contains significant uncertainties
  - Could maybe be compensated by introducing IP shift only when separation is collapsed, or consider to move in further vertical TCTs
- Crucial to re-measure aperture during commissioning

Aperture vs β*



Aperture in σ with ε=3.5 μm

- Depending on separation and CMS bump, limitation can be in the crossing or separation plane

Achievable β*

Without CMS bump

TCP / beam-beam	9.0 σ, 3.5 μm	10.0 σ, 2.5 μm	9.0 σ, 2.5 μm
5.5 σ	35 cm (cross)	34 cm (cross)	33 cm (sep)
5.0 σ	32 cm (cross)	31 cm (cross)	30 cm (sep)

With -1 mm CMS bump*

TCP / beam-beam	9.0 σ, 3.5 μm	10.0 σ, 2.5 μm	9.0 σ, 2.5 μm
5.5 σ	35 cm (cross)	35 cm (sep)	35 cm (sep)
5.0 σ	32 cm (cross)	32 cm (sep)	32 cm (sep)

** significant uncertainty in aperture calculation*

Optics considerations

- β* calculated assuming the phase advance MKD-TCT is such that asynchronous dumps are not limiting
  - Specified max. 30 deg including imperfections
- Nominal 2016 optics: 4 deg
  - Estimated that imperfections (off-momentum + optics correction) could cause a 10 deg slip => max 14 deg
  - Large safety margin
- ATS optics: 26 deg, within specifications but close to limit
  - Could reach 30 deg with imperfections
  - Around 1.5 σ smaller safety margin but still around 2 σ left => sufficient
  - Safety could be improved by introducing collimator BPM interlocks
    - Introduced in LSA in 2016, but not activated. Should not reduce availability
  - No aperture deterioration due to off-momentum beta-beat

Conclusions

- In 2016: β* reduced from 80 cm to 40 cm, with tighter collimators, new optics, tighter beam-beam
  - 40 cm has worked very well and could be used also in 2017
- In 2017: If we want, room for further reductions
  - Gain up to 1.5 σ in collimation hierarchy, tighter beam-beam
- Some options for 2017:
  - **β*=30 cm** with BCMS beams and 9 σ beam-beam sep.
  - **β*=31 cm** with BCMS beams and 10 σ beam-beam sep.
  - **β*=32 cm** with nominal beams and 9 σ beam-beam sep.
  - With BCMS, could lose 1-2 cm with -1 mm CMS bump, not with nominal
  - 3 cm loss in β* if we leave TCP cut at the 2016 setting
- Low β* in reach => maybe consider flat optics for the future?

β* is like toothpaste…