Overview of present collimation performance

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With material from N. Fuster Martinez, A. Mereghetti, D. Mirarchi

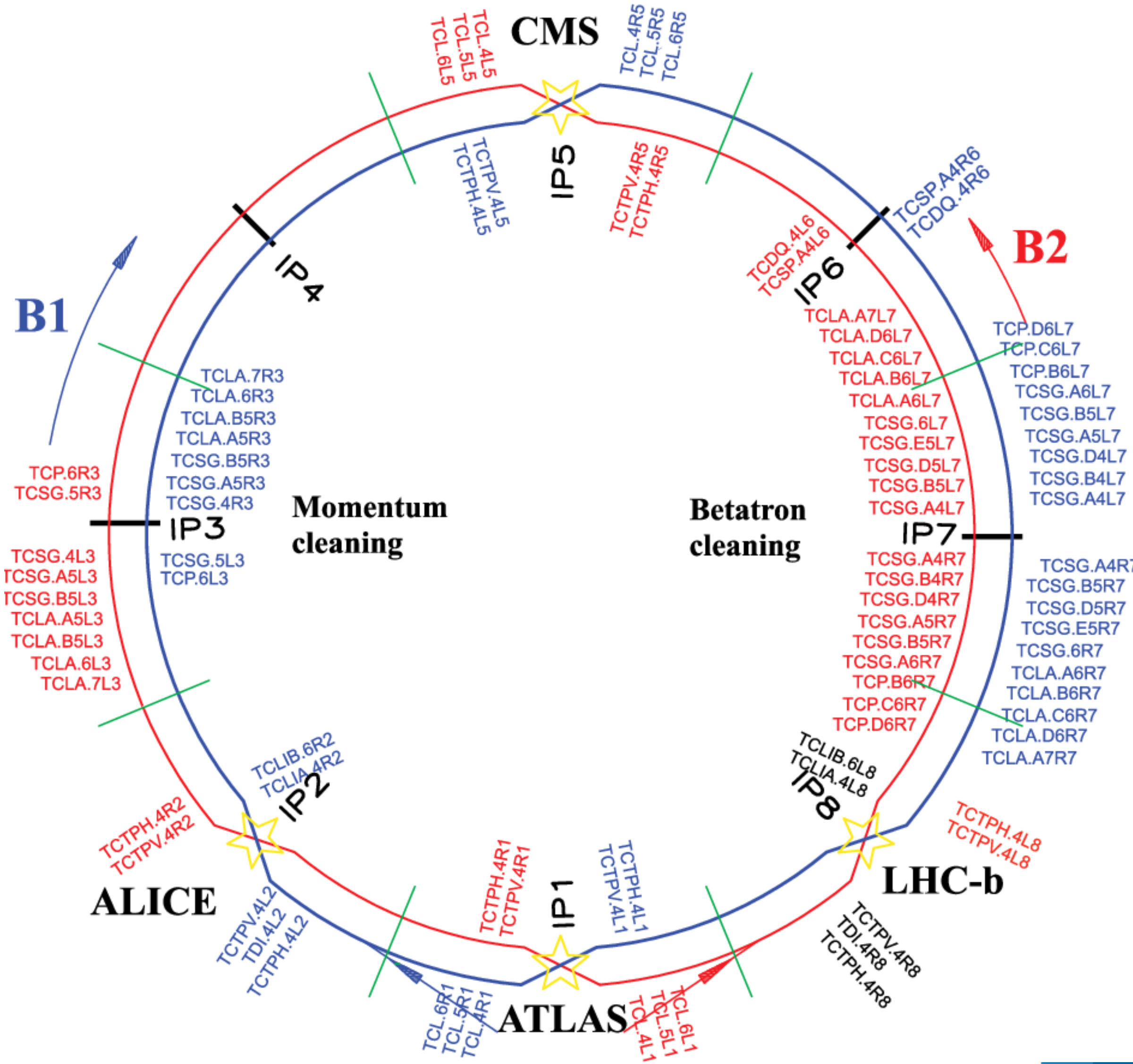
HL-LHC collimation review, CERN, 11/2/2019

Outline

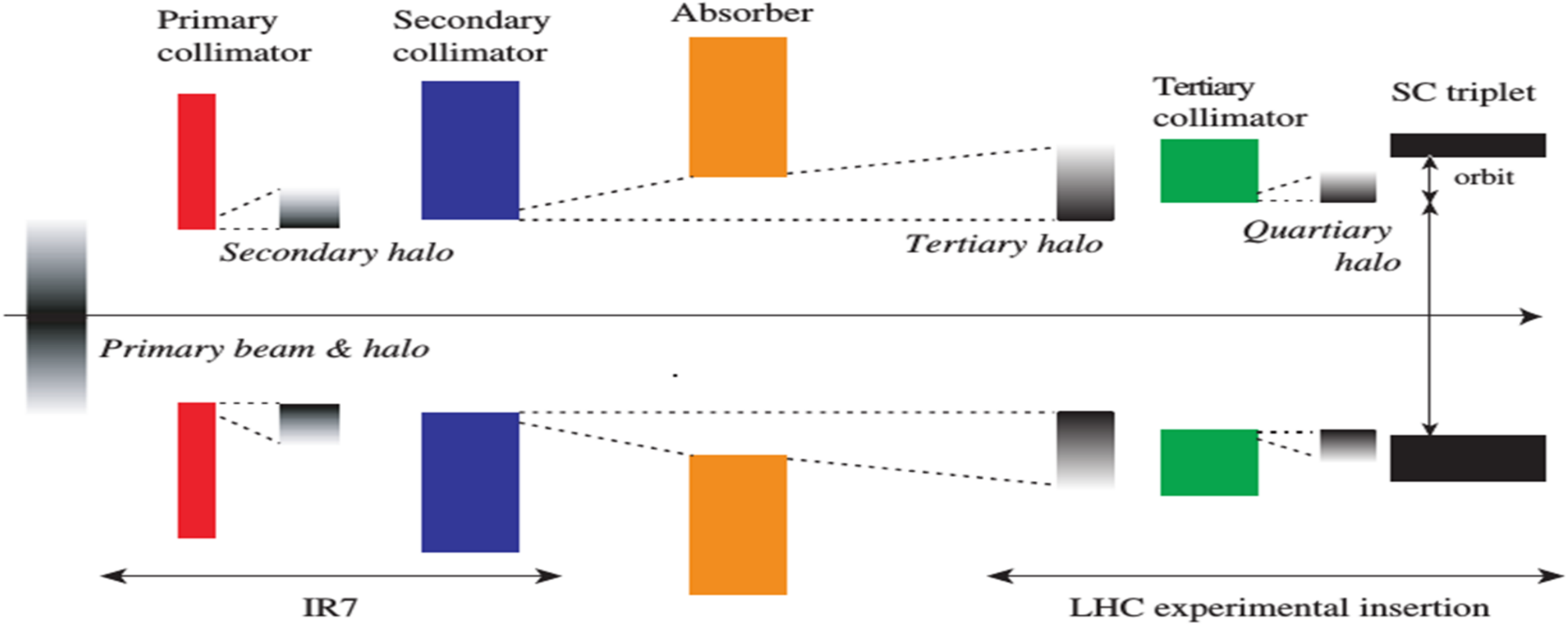
- Present LHC collimation system
- Cleaning performance in the LHC
  - Performance of IR cleaning (incoming and outgoing)
- LHC performance increase with tighter collimators
- LHC collimation system reliability
- HL-LHC beam loss scenarios and aperture to protect

LHC collimation system design

- Main collimation insertions
  - IR7 – betatron cleaning
  - IR3 – momentum cleaning
- Additional collimators in experimental and dump insertions



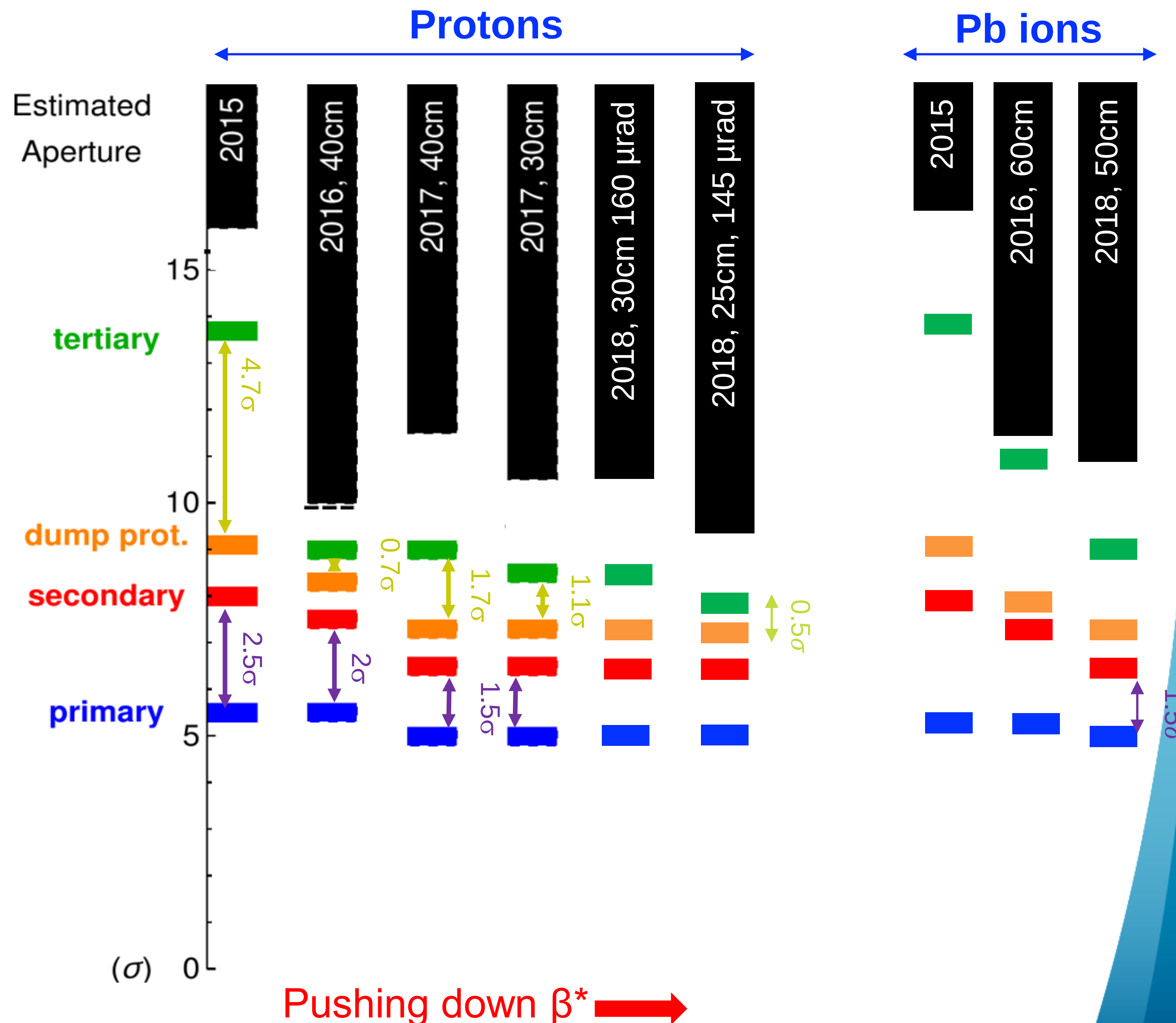
Collimation hierarchy



- Multi-stage system
- Collimation hierarchy sets lower limit for protected aperture
- Beam size increases in triplet when β* is squeezed – more challenging for protection
- Need tighter collimators to protect aperture at smaller β*

Evolution of collimator settings

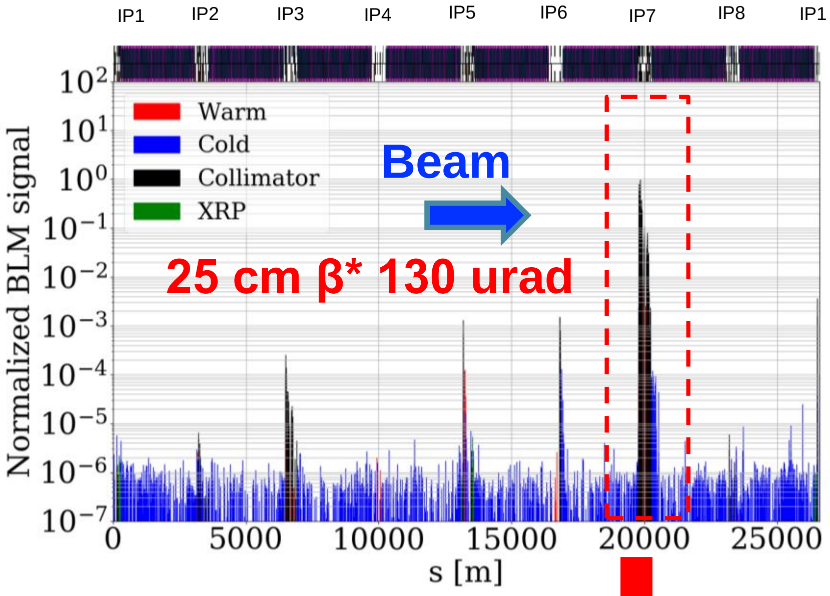
- Collimators tightened over the years
- Driven by desire to achieve smaller β* for higher luminosity
- Used machine development to ensure feasibility of tighter settings

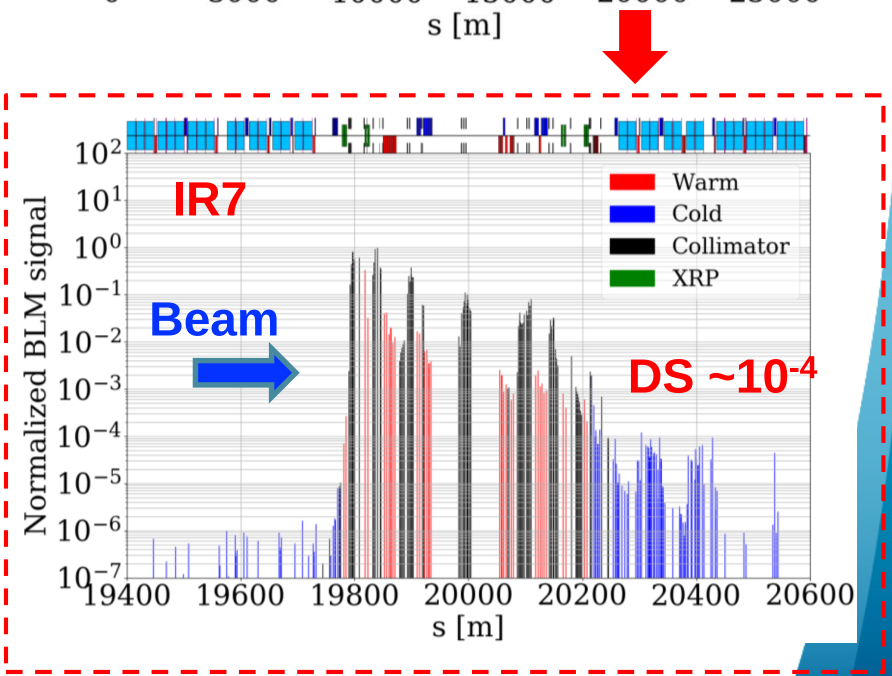


Cleaning performance

N. Fuster Martinez

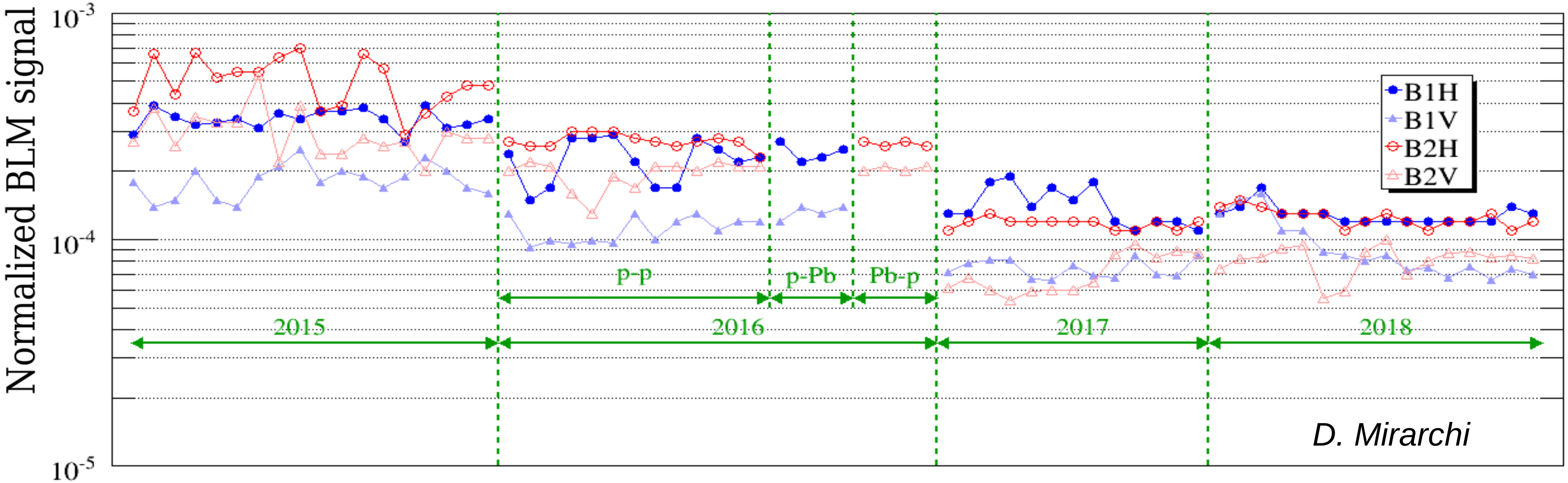
- Performance of collimation system tested through loss maps
  - Controlled blow-up of low-intensity beam
- Bottleneck: dispersion suppressor of IR7
- Cleaning assessed throughout all parts of cycle
  - Collimators moved dynamically; increasing operational complexity - see talk B. Salvachua





Cleaning performance over the years

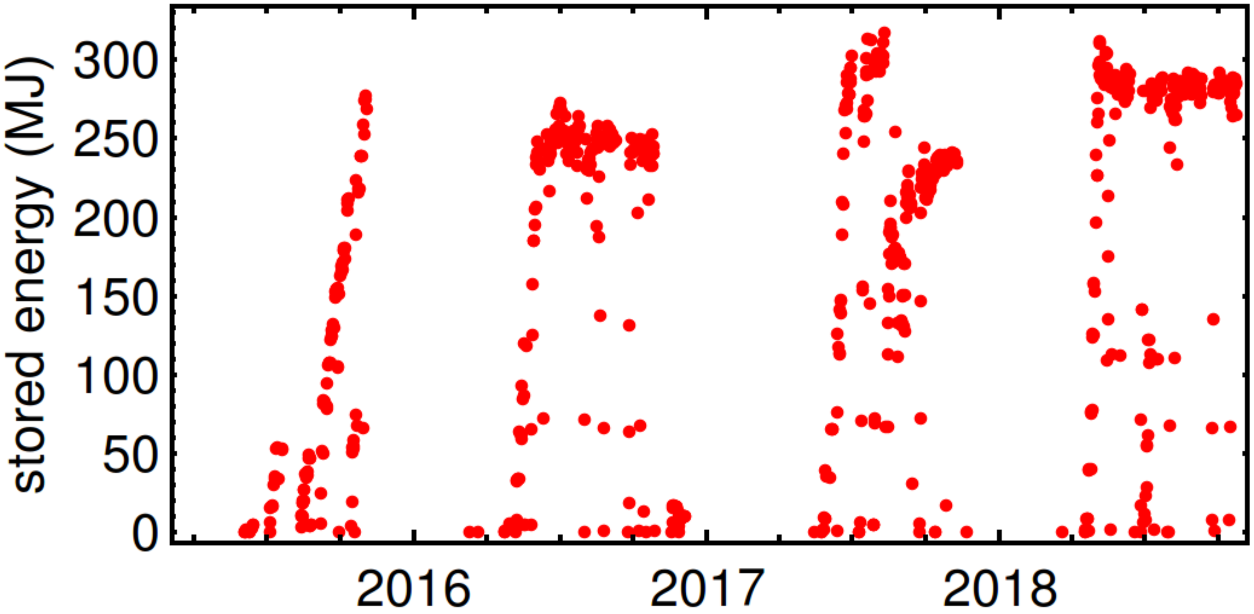
- Monitoring leakage to DS over the years – looking at highest monitor



- Excellent and stable cleaning performance over the years
- Improvements in 2016 and 2017 with tighter TCSGs and TCLAs

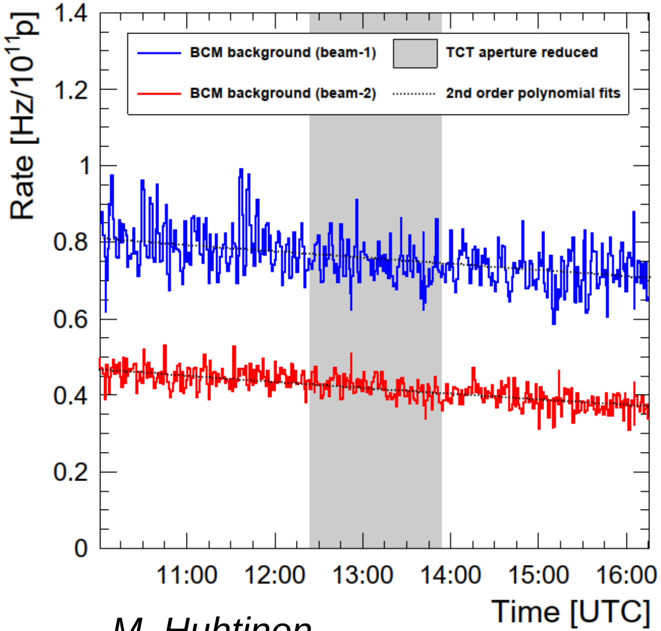
Stored energy over the years

- No quenches or damage with circulating beam
  - Regularly stored 300 MJ!



Performance of IR cleaning – incoming beam

- One pair (H+V) of TCTs installed in front of each experiment
- Protects well the triplet
  - No triplet losses seen in loss maps and asynch dump tests
- TCTs are not a major contributor to beam-induced background
  - Studies with ATLAS showed that halo cleaning is on the percent level of total background, dominated by beam-gas



M. Huhtinen

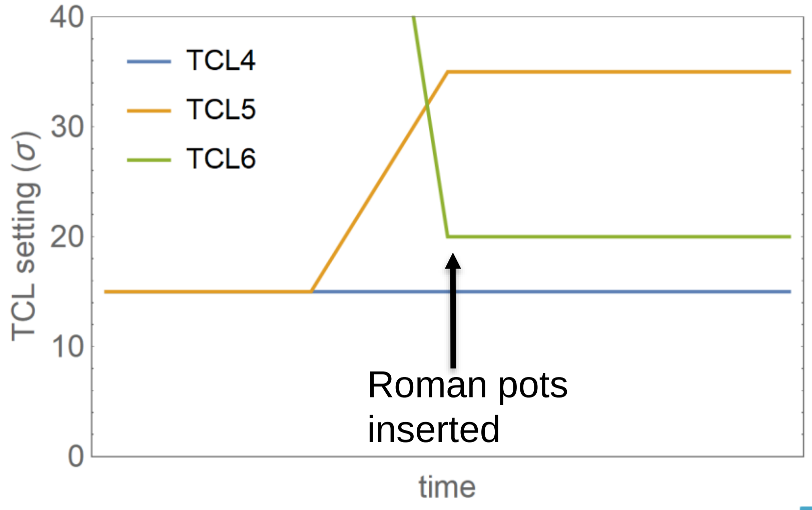
No effect seen on background when closing TCTs

For HL-LHC: see talk H. Garcia

Performance of IR cleaning – outgoing beam

- Three physics debris absorbers (TCL4,TCL5,TCL6) protect the elements downstream of ATLAS / CMS
  - Installed TCL6 in LS1
  - Gave increased flexibility for protection schemes
- Dynamically changed TCL configuration in stable beams to accommodate roman pots

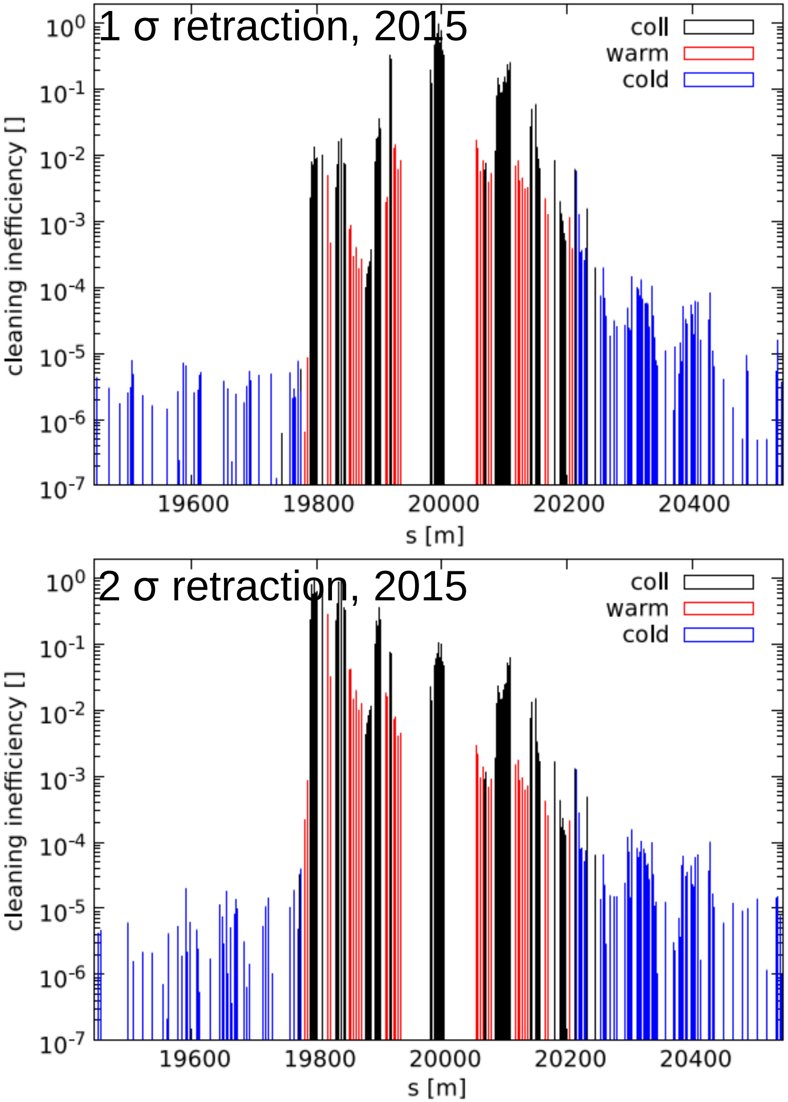
- Present luminosity limitation: heat load on triplet.
  - Losses related to TCLs in the shadow
  - Only notable effect: some dumps related to R2E – TCL6 setting tradeoff between losses in cell 8/9 and in RR



For HL-LHC: see talk F. Cerutti

Machine studies for tighter IR7 collimators

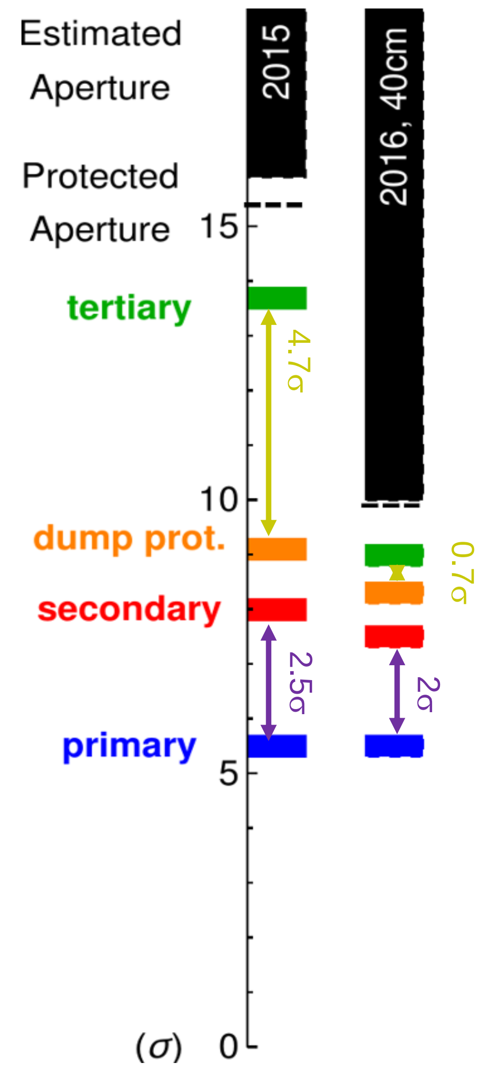
- Tighter retraction between TCPs and TCSGs OK for impedance and cleaning hierarchy
- Hierarchy breakage understood
  - compensated by tilt in 2018 operation with 1.5 σ retraction
- Tighter TCP setting qualified – did not show significant increase of losses



A. Mereghetti et al.

Reduction of margin to TCT

- Large margin between TCTs and triplet at start of Run 2
- Driven by fear of damage during asynchronous beam dump
- Significant reduction in 2016



Asynchronous beam dump

- Standard dump: extraction kickers fire when no beam passes

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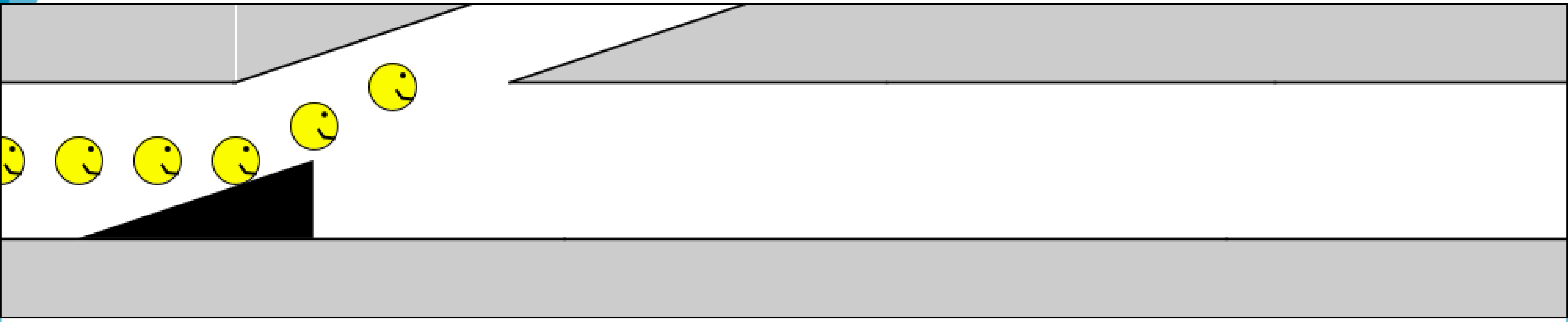

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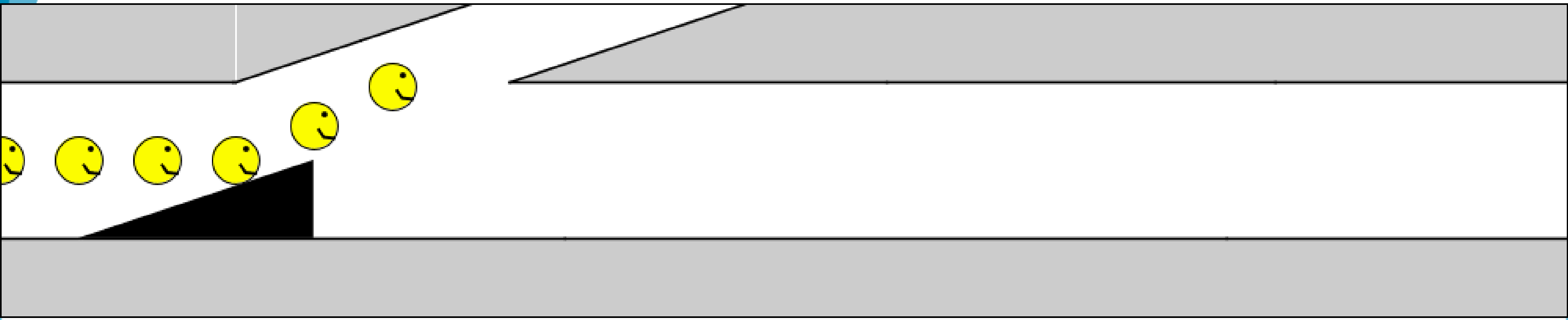

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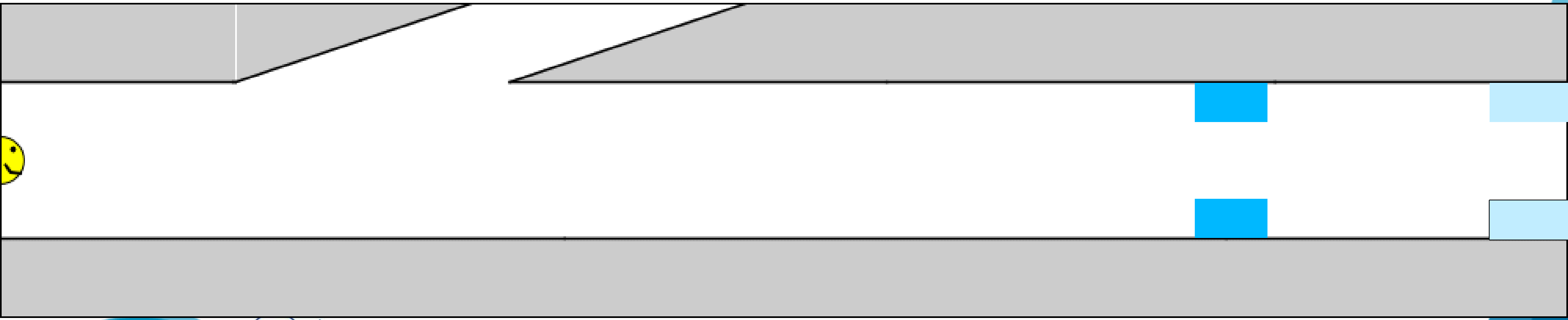
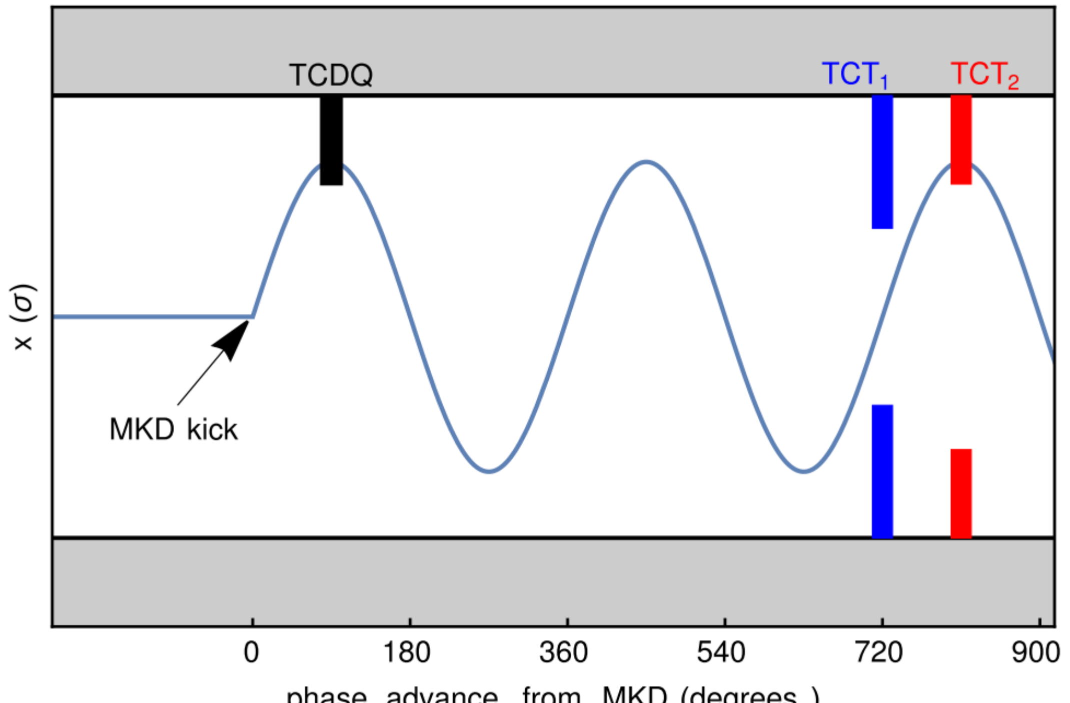


New optics for smaller β*

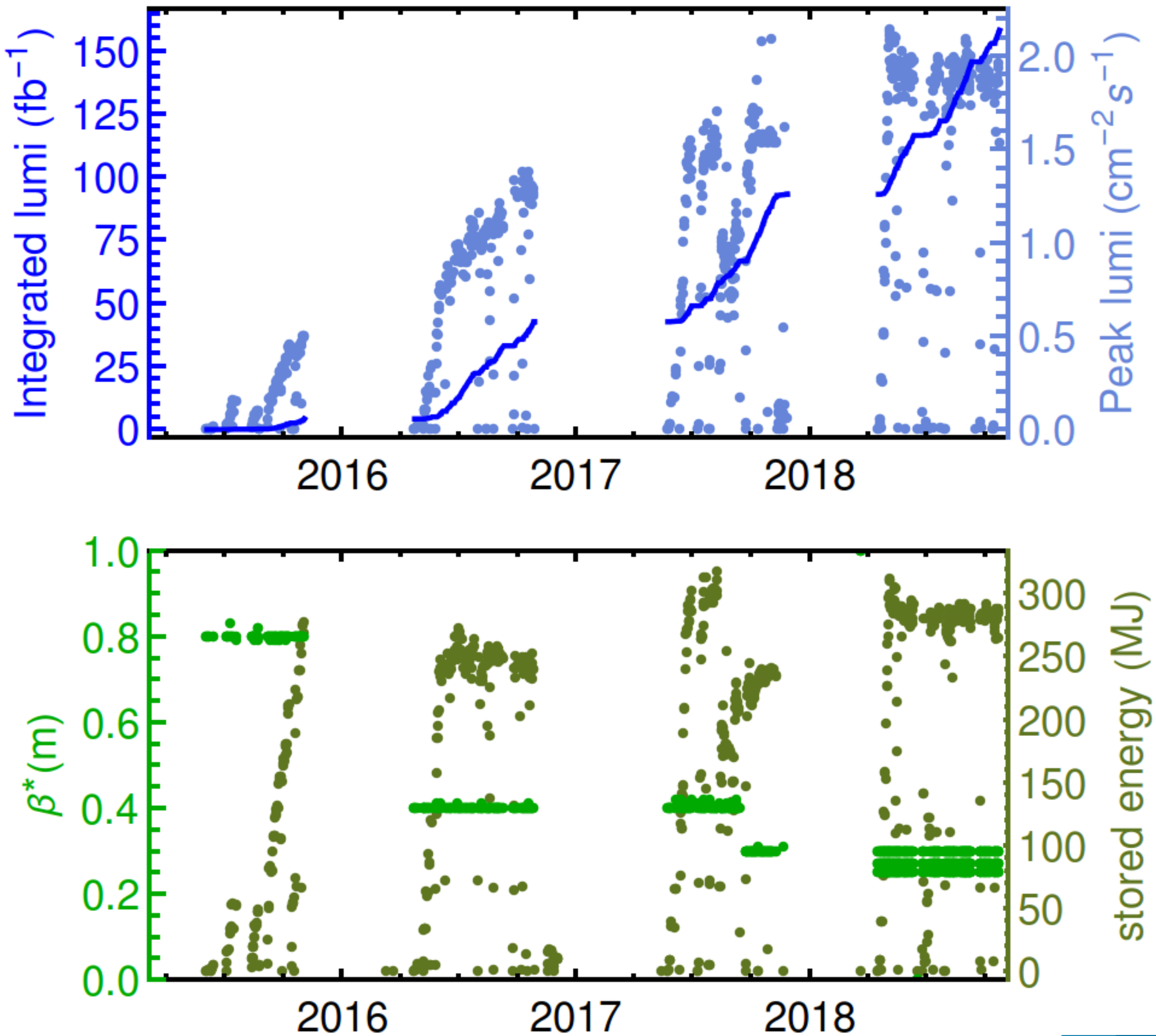
- Possible to reduce margin by demanding that TCTs / triplets should be close to the minimum of the oscillating miskicked beam
  - Triggered design of new optics for 2016 (R. de Maria et al.), demanding MKD-TCT phase stays below 30 deg
- Key to reducing β* from 80 cm to 40 cm in 2016



Luminosity and β* over the years

- Steady increase of peak performance over the years
  - Tighter collimators was a key!
- Large decrease of β*, stored energy about constant since 2015

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



Achieved LHC parameters

- Keys to good peak performance:
  - Small emittance
  - Small β* at collision point
- Very important for β* with matched phase advance and reduced collimator settings to gain aperture

Parameter	2018	LHC Design
Energy [TeV]	6.5	7.0
No. of bunches	2556	2808
Max. stored energy per beam (MJ)	312	362
β* IR1/5 [cm]	**30→25**	**55**
Half crossing angle IR1/5 [μrad]	160→130	142.5
Normalized beam-beam separation	10.6→7.9	9.4
p/bunch (typical value) [10^{11}]	1.1	1.15
Typical normalized emittance [μm]	**~1.9**	**3.75**
Peak luminosity [10^{34} $cm^{-2}s^{-1}$]	**2.1**	**1.0**

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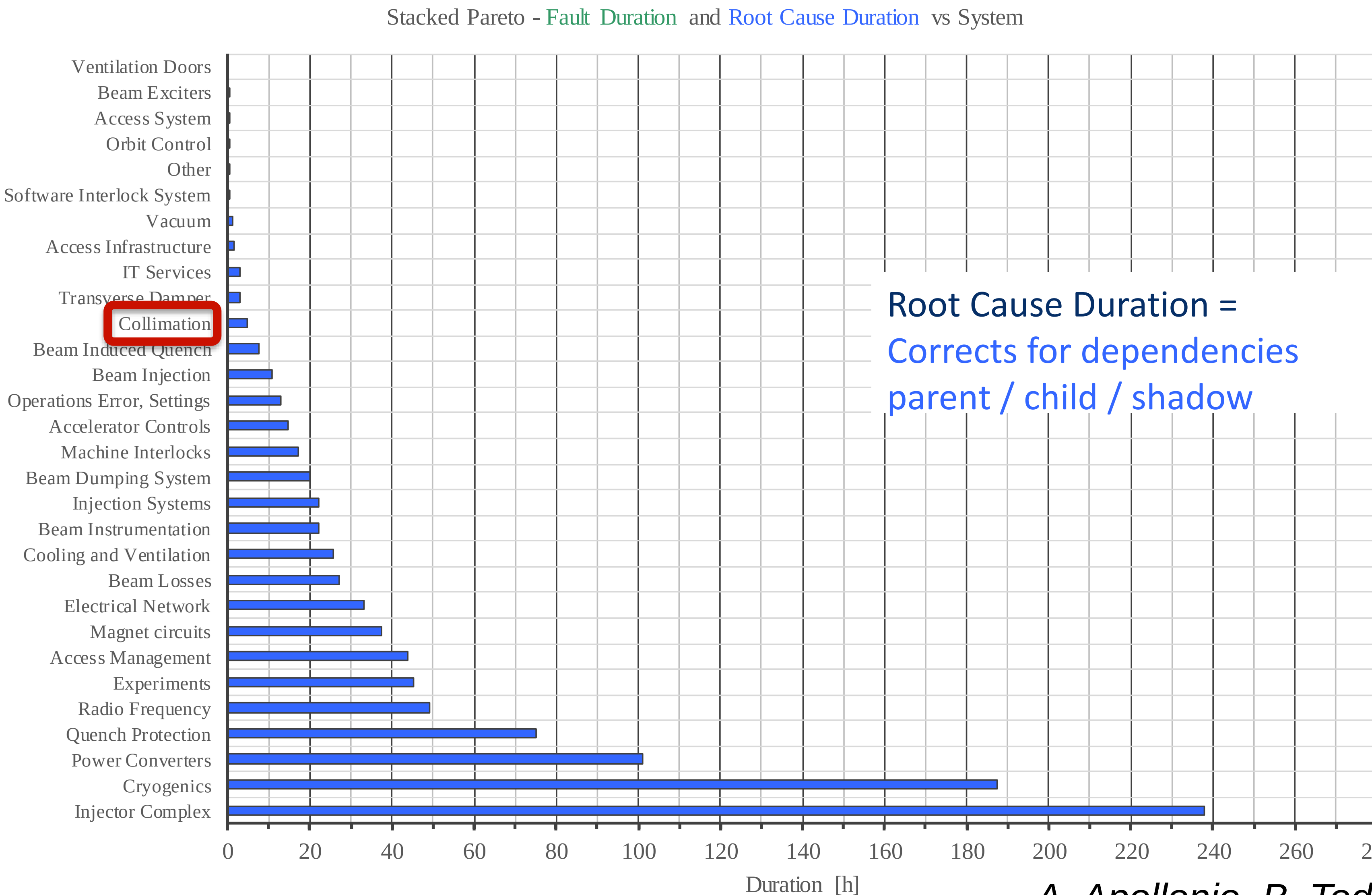
Availability

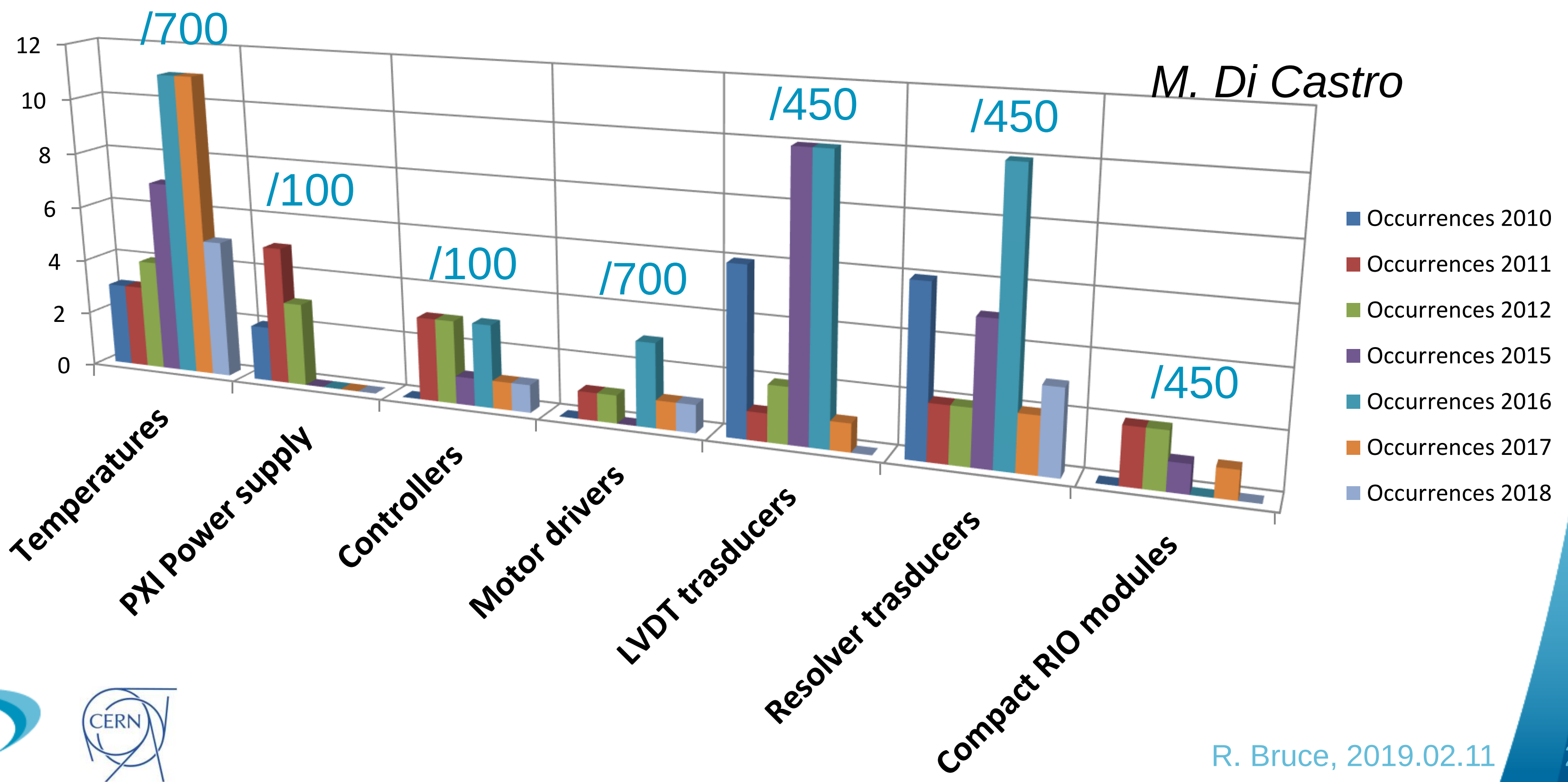
- Collimators among the most available LHC systems



A. Apollonio, B. Todd

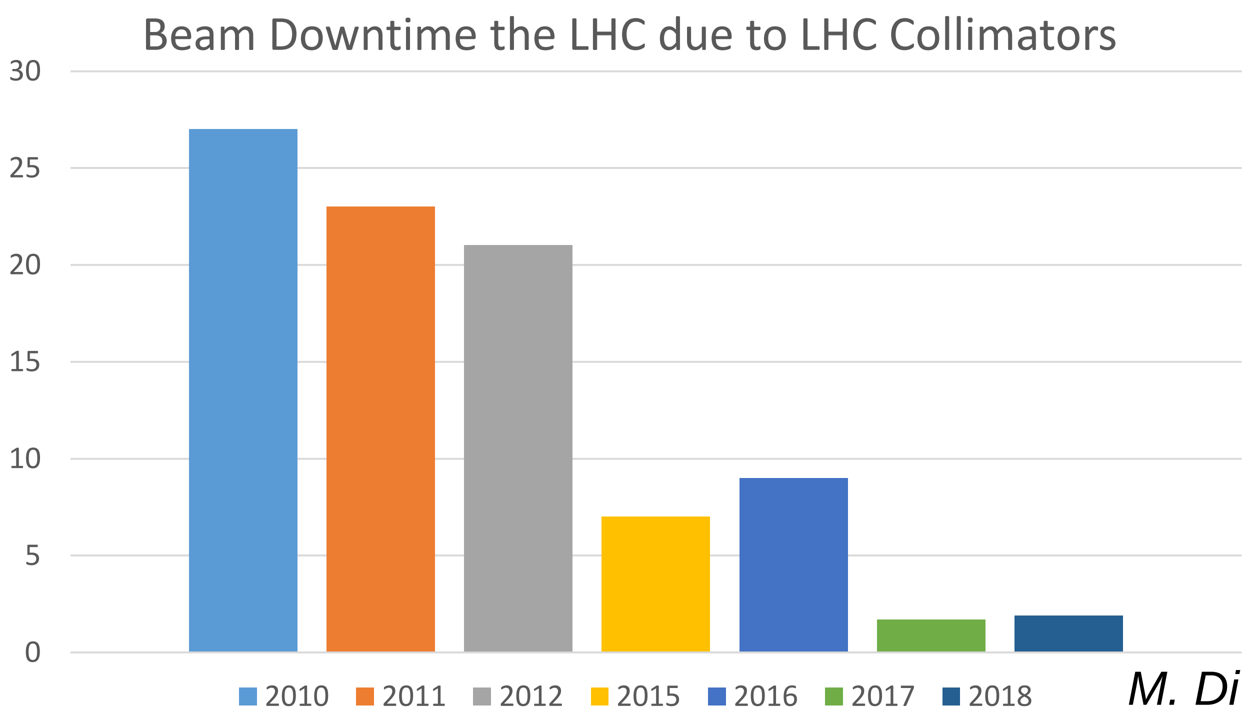
System reliability

- Hardware failures have been very rare
- Temperature sensors main source of faults – plans for mitigation in Run 3 (see talk A. Masi)



Downtime due to collimators

- Steady decrease in beam downtime due to collimator downtime over the years
  - Could increase in the future with ageing system if nothing is changed



M. Di Castro

Looking forward

- Collimation has worked very well in Run 1 – Run 2
- More demanding beam loss conditions expected for HL-LHC
- Ageing system

HL-LHC design loss scenarios

- Collimation system to be designed for a number of scenarios with HL-LHC beams:
  - Betatron cleaning:
    - withstand 12 minute lifetime drops over 10 s and 1 h lifetime "infinitely" without dumping or quenching
  - Injection failure
    - TCSGs to withstand 288 bunches
  - Asynchronous beam dump at top energy (7 TeV):
    - IR7 TCPs and TCSGs: Impact of 8 bunches
    - TCTs:
      - 1 single bunch → still needed if MKD-TCT phase implemented, as in HL-LHC v1.3 ?
      - realistic impacts from tracking
    - Showers (and direct beam?) on the TCSPs in IP6 that are not planned for upgrades in HL

Pessimistic!

Experience on beam losses

- Achieved beam lifetime → See talk B. Salvachua
- No injection failure with large impacts on TCPs or TCSGs so far
- No asynchronous beam dump with full machine so far
  - One asynchronous dump in 2015: only 4 bunches in the machine → clean extraction
  - Possibly more critical at 7 TeV
- New failure scenarios identified during Run 2
  - More critical variant of asynchronous beam dump with slower kicker rise
- Significant work ongoing in LBDS team to improve reliability (see talk C. Bracco in Evian 2019)
- Keeping design scenarios → conservative assumption

HL-LHC protected aperture

- HL-LHC v1.2: Collimation system should protect triplet aperture protection of 14.6 σ at top energy

- From HL-LHC optics version 1.3, including matched MKD-TCT phase advance
  - Can allow smaller triplet aperture of 11.8 σ
  - Key to recovering β*=15 cm after 2016 rebaselineing

Conclusions

- LHC collimation has shown excellent performance and reliability so far
- No quenches from collimation losses with circulating beam
- Progressive tightening of collimator gaps over the years was a key to decreasing β* and pushing the LHC performance
- More challenging beam losses expected in the future, and equipment is ageing

Backup

IR layout in HL v1.3