Running Scenario for Run3

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Thanks to S. Fartoukh, N. Karastathis and the LCR3 Working Group

Aim of this presentation

- Running scenario(s) Run III: what is different?
- Where does this affect Machine Protection?
- Special Concerns?

- Most of the material presented is based on the work done at the the **LHC Run III Configuration Working Group**: https://indico.cern.ch/category/10387/
- More details can be found at
  - S. Fartoukh @ LMC 6 March 2019
  - N. Karastathis @ 9th LHC Operations Workshop Evian 2019

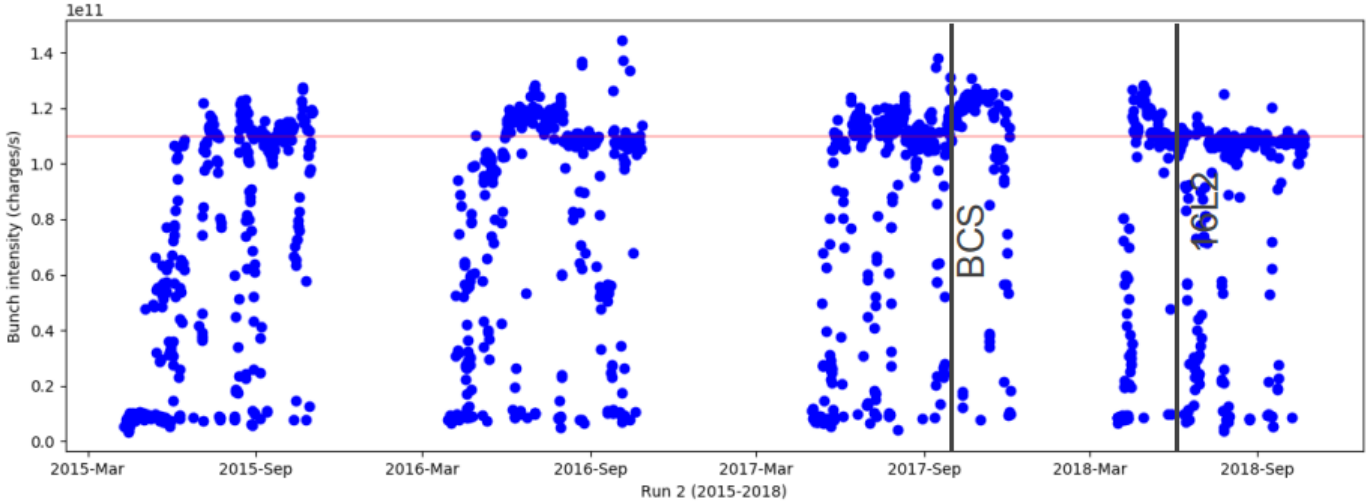
Injectors, Beam Intensity delivered to LHC

LIU forecast at SPS extraction (G. Rumolo & H. Bartosik):

	2021	2022	2023	2024*)	Comments
Bunch charge [10^{11}]	**0 → 1.3-1.4**	**1.4 → 1.8**	**1.8 → 2.1**	**2.1 → 2.3**	**Max intensity reached at the end of each year**
Normalized emittance [μm]					**Intensity ramp up at constant emittance in 2021/2022**
(i) *BCMS or 8b4e*	1.30	1.30	1.30 → 1.55	1.30 → 1.70	
(ii) *Standard 25 ns*	1.65	1.65	1.65 → 1.90	1.90 → 2.10	

If all goes well, the injectors would be able to provide
> 2.1 x 10^{11} p^+/b during Run III

Compared to average value of 1.1 x 10^{11} p^+/b during Run II



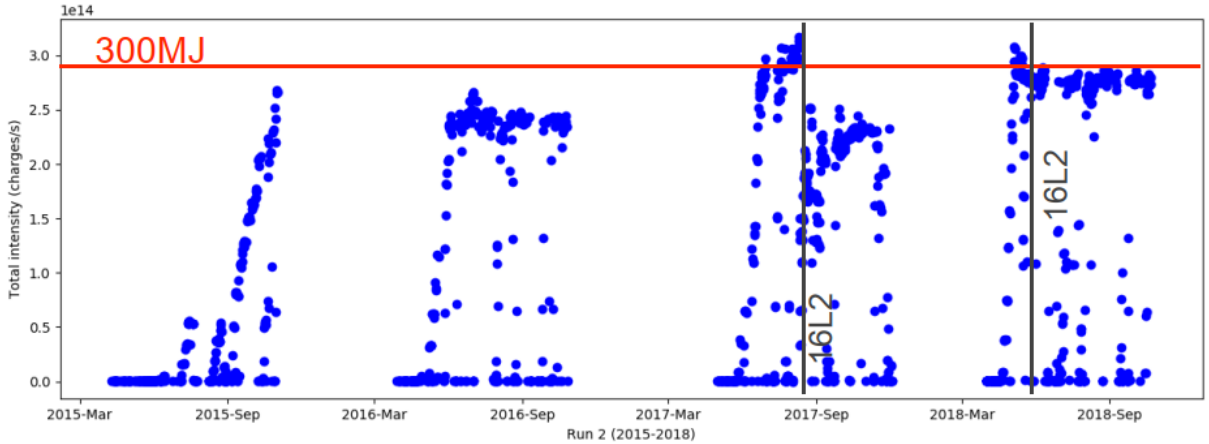
B. Salvachua @ Evian

LHC Beam Intensity limits and Stored Energy

LHC limitations for Run 3 < LIU forecast

System	Limitation	Limit
RF-System	Klystron power at injection and emittance control in ramp	**1.8 x 10^{11} p^+/b**
TCDS	Plastic deformation	1.7 – 1.8 10^{11} p^+/b
TCDQ	Damage in case of erratic type II	1.8 x 10^{11} p^+/b
Collimation	Worries in case of asynchronous beam dump	> 1.8 x 10^{11} p^+/b
Upstream dump window	Worries of damage above **1.3 x 10^{11} p^+/b** for 2 MKBH failing **Change window in 2021 – 2022 EYETS ?**	**Under study** – optics, change window
TDE core	Limits in case of MKBH failures – new materials	> 1.8 x 10^{11} p^+/b, under study

Overall conclusion: In Run III the LHC can aim for bunch intensities up to **1.8 x 10^{11} p^+/b**, as of the end of 2022. Compared to typical bunch intensity in 2018 of 1.1 x 10^{11} p^+/b. Folding in possible operation at 7 TeV, **the typical stored beam energy could be increased from 300 MJ during Run II to 500 MJ, already in 2022 !**



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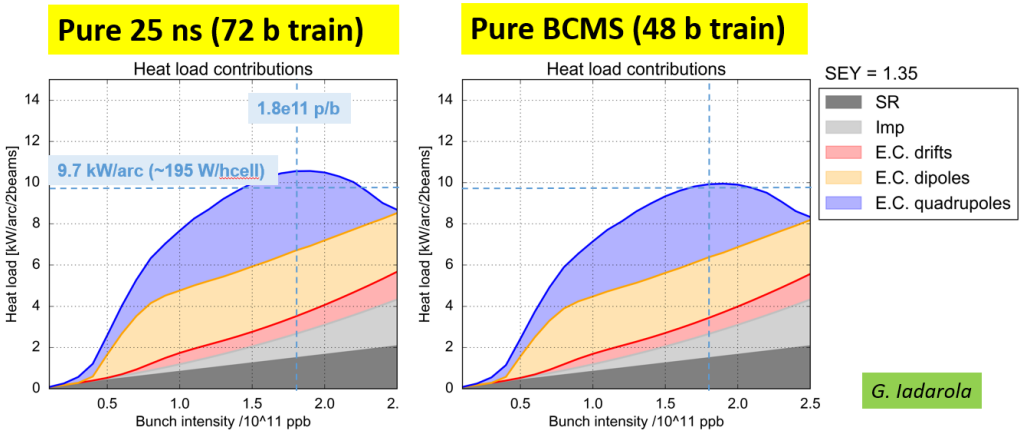
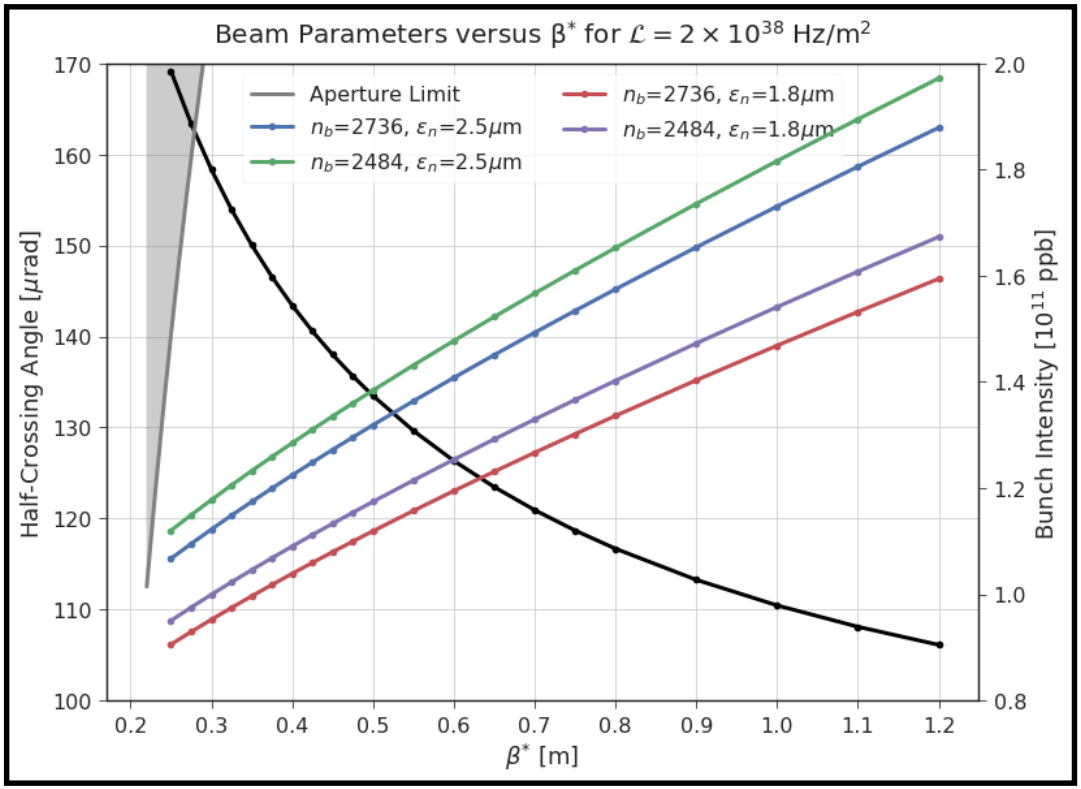
E-cloud and scrubbing

- Following a Long Shutdown and aiming for higher bunch intensities → scrubbing to reduce SEY will be required
- Strategy:
  - Scrub at injection energy with BCMS beams
  - If needed, run with mixed scheme of BCMS and some 8b4e
  - Option to run with standard 25 ns beam for additional collisions
  - **Do not expect to scrub with doublets**
- Doublets have an effect on Beam Instrumentation and BPMs in particular
  - Standard orbit BPMs and Interlocked BPMS affected
  - Upgrades foreseen during Run III, but for the moment exclude doublets

1.8 x 10^{11} p^+/b is about worst case for cryogenics heat load



ATS optics for Run III: Scenario of changing beta* and half-crossing angles during a fill



Change in beta* up to factor 4 – 5 during fill, compared to 20 % in 2018

All of this will need coherent changes of the collimation system

Move TCT centres and operate at constant gap in mm?

Move Roman Pots in physics to stay in shadow of TCTs?

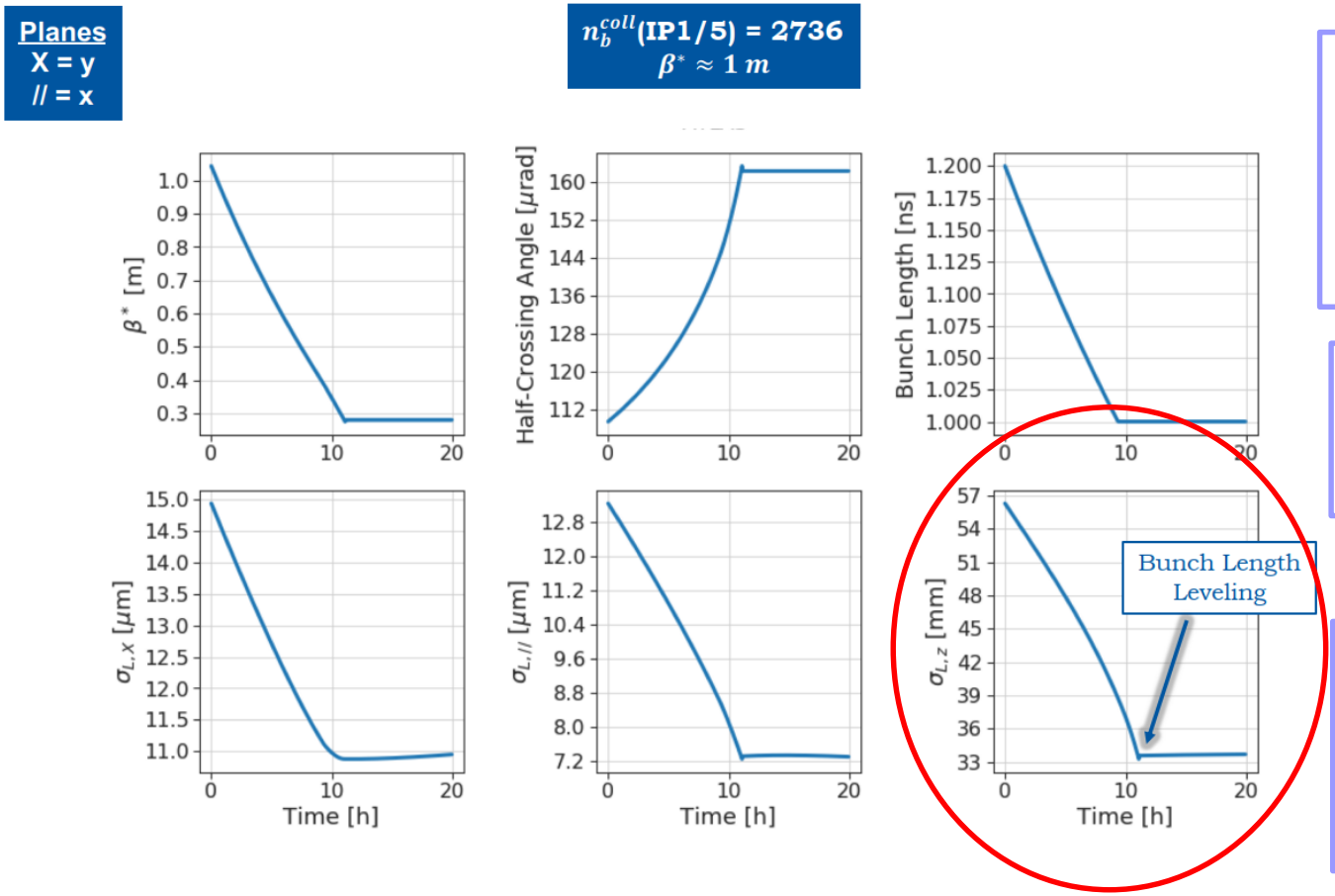
ATS Optics & Co.

- Proposals by LCR3 working group concerning Machine Protection

Plan	Risks
Beta* levelling at IP1/5 to limit lumi at 2e34 with parametric crossing angle variation - Beta* levelling from 1.5 m to 0.24 m - Same time: Crossing angle increase from about 100 µrad to 160 µrad	How is this automated: - Manual or automatic on bunch intensity? How to guarantee coherent parameters: - Movement of collimator centres and/or opening, same RP, hardware limits ….
No Squeeze Break Point: Collide and Squeeze at the end of the Energy Ramp	How to organise loss maps and collimator settings
Round optics and flat optics are possible 2021: 22/28 cm beta* 2023: 50/15 cm beta*, crossing bump rotation at the end of energy ramp, move from round to flat optics at 50 cm.	Lots of gymnastics which has been tested for a large part in MDs in 2017/2018. More complicated than what has been done so far in standard operation and over a larger range
Offset levelling in LHCb with lumi of 2e33 and beta* of 1.5 m (in Run 2 had 3 m)	Vertical crossing angle gymnastics requested, needing further studies
Alice kept with beta* of 10 m, lumi up to 1.4e31	Still rather low lumi
Larger beta's in the arcs	Optics corrections seem fine with tele index < 3

Variation of Parameters

- Beside beta* variation, crossing angle variation and separation levelling in IP2/8 foresee as well **Bunch Length Levelling** between 1.2 ns and 1.0 ns



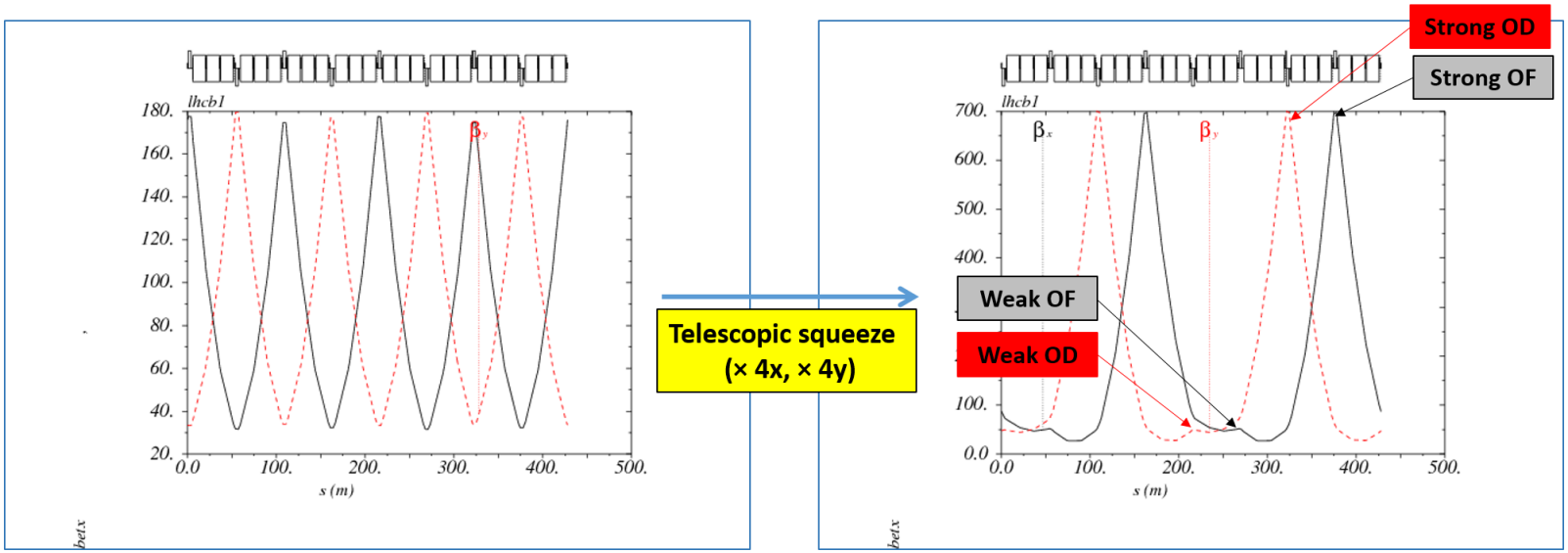
Long Fills ! Integrated lumi IP1/5 ≈ 100 fb^{-1} per year

@ 1.0 ns and long fills: watch heating of MKI et al.

Significant changes of luminous region by almost a factor of 2.

OK-ed by experiments

Telescopic Optics



- Larger beta's in the arc
  - To obtain the small beta* at IP1/5 (telescope)
  - Increase effective strength of octupoles for Landau damping
  - Preferred by Forward Physics experiments
- So-called "anti-telescopic" optics during the energy ramp is needed to cover the full beta* range
  - Combined Ramp and Anti-Telescopic Squeeze (CRATS)
  - Followed by Collide and Telescopic Squeeze to reach lumi
- Will enter a new stability regime of chromaticity and octupole settings
- Optics correction seem OK for telescope < factor 3

MKD – TCDQ – TCT

- Phase advances between MKD and TCDQ and between MKD and TCTs are vital for protection in case of an asynchronous beam dump
- With the present BETS the TCDQ can not be moved at fixed energy (only within BETS limits, small margin); also mechanical concerns in case of small movements
- New optics design made with constant beta at TCDQ and MKD – TCT phase in tolerance (+/- 30 degrees)
- If confirmed for the whole beta* range, no so-called “TCDQ levelling” is required
  - Phases to be checked over the complete cycle
- In case of problems: consider inwards TCDQ movement < 0.5 mm for extended (asymmetric) BETS limit before TCDQ levelling

- TCDQ & TDE upstream window damage limit gives a limit in **bunch intensity**
- For the TDE upstream window this also depends on the **optics**
- Machine protection depends on changing optics and bunch intensity

Conclusions

- If all goes (very) well we might increase the stored beam energy from 300 MJ to **500 MJ** beams in Run III
  - Bunch intensity limit for Run III of **1.8 x 10^{11} p^+/b**, from LHC, to be confirmed
- At the same time, manipulations with significant changes of beta*
  - 2018: beta* change of 20 % vs. **Run III beta* change up to 500 %** (plan A)
  - Follow with crossing angles and bunch length adjustment, all in Stable Beams
- Requiring dynamic collimation & RP adjustments / changes of limits
  - Loss maps, verification of different optics (about 10) and cycles
  - **Configuration driven by bunch intensity,** no redundant measurement
  - **MDs with limited total beam intensity but some high intensity bunches …**
  - Tools needed to guarantee that collimation is safe. Hardware versus Software
  - Protection of Forward Physics Experiments, move RP in physics?
  - TCDQ – MKD – TCT phase advances through the complete cycle?
- Plan B is to reduce telescope and use (partly) off-set levelling
- **Increased complexity, configuration intensity dependent, eating away some safety margins, Stable Beams ≠ Stable Configuration**
- Justification of this complexity
- Are we ready with the Machine Protection systems for this?