Status of the Accelerator

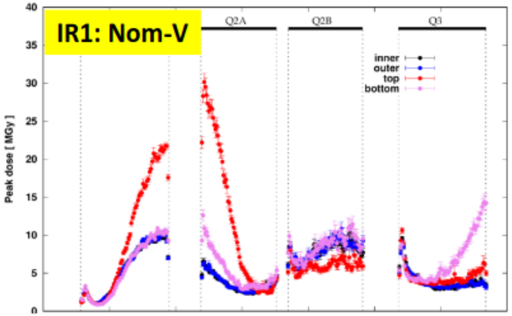
Michi Hostettler
on behalf of the LHC team

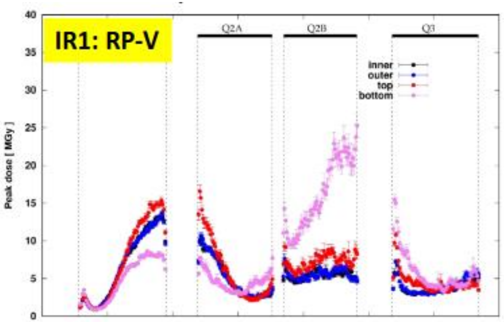
"reverse polarity" optics

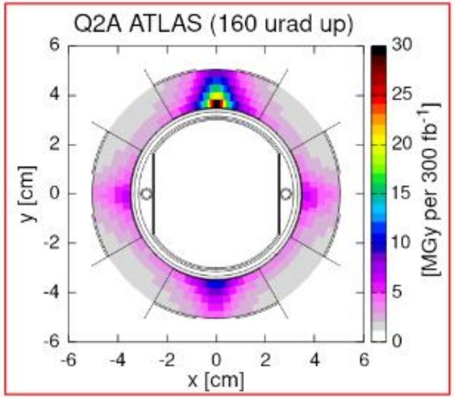
- **inner triplet magnets next to the high-lumi interaction points reaching their "life expectancy" of integrated radiation**

- **invert polarity of triplet quadrupoles (local optics change)**
  - ➜ re-distribute the radiation to less irradiated parts
  - ➜ reduce the risk of failure until HL-LHC (IP1/5 triplets will be replaced)

- **2024: implemented in IR 1 (ATLAS) - most critical**
  - ○ options for 2025 and beyond being studied



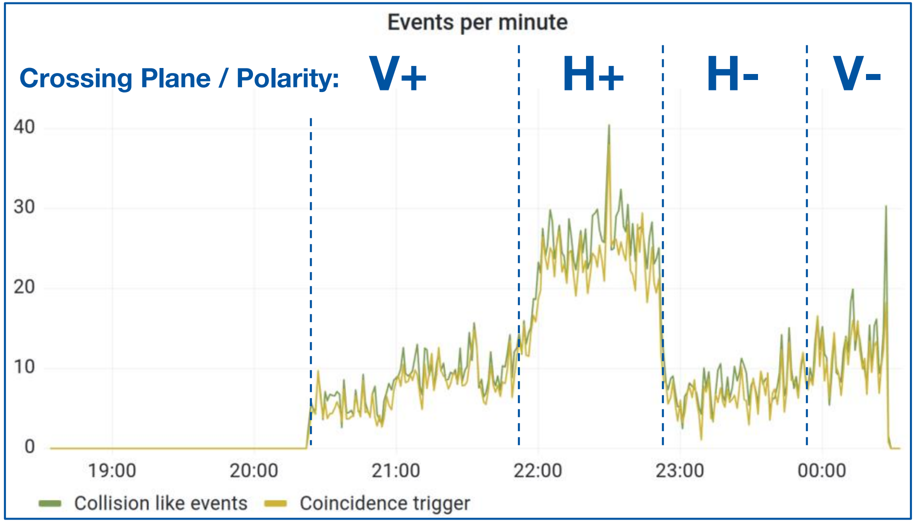




LHC triplet task force and S. Fartoukh

FASER / SND background

- **consequence of RP optics: increased background in FASER and SND**
  - factor of ~2 w.r.t. 2023
  - **TeV muons from the IP**
- **requires more frequent emulsion exchanges (if available)**
- **accelerator side mitigations being studied for 2025**
  - not straightforward to intercept with collimation system
  - deflection might be possible (crossing angle, bump, …)



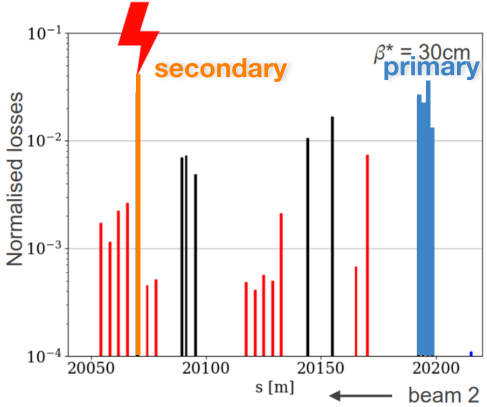
B. Lindstrom, J. Wenninger, J. Boyd, collimation team & FASER collaboration

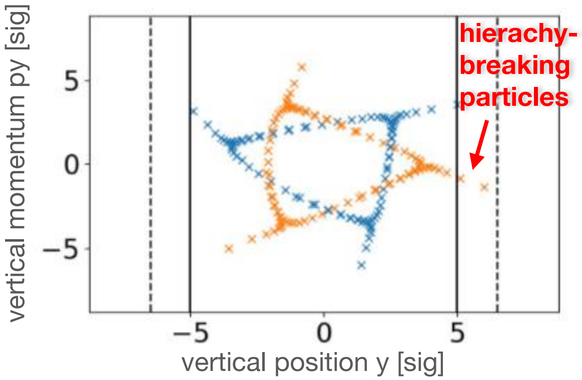
collimation hierarchy breakage at β* = 30cm

- **"broken hierarchy" observed at β* = 30cm**
  - losses on one secondary collimator > primary
    - possible machine protection issue
  - not observed during validation with single bunches
    - a beam-beam driven effect

- **off-momentum particles lost in the secondary collimators: combination of contributions**
  - beam-beam long range orbit effect
  - spurious vertical dispersion
  - beam-beam driven 3rd order resonance
  - → mitigation: dispersion correction, lower chromaticity

→ β* levelling to 30cm restored!

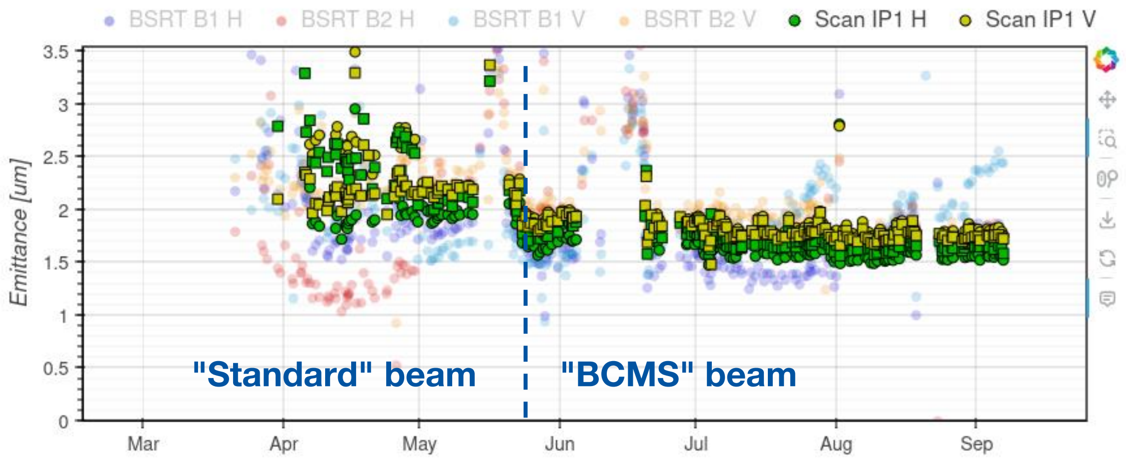


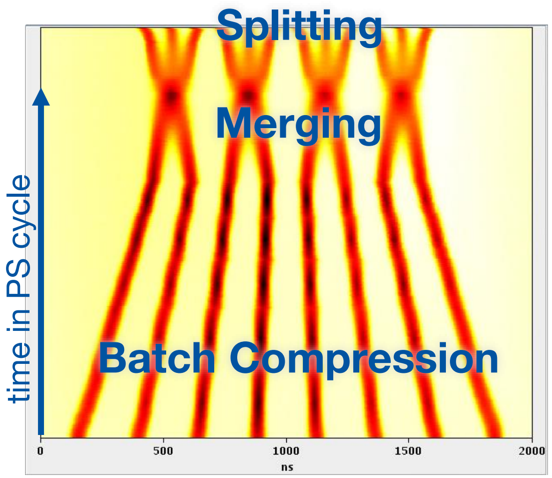


F. Van der Veken, D. Mirarchi, X. Buffat, K. Papastergiou et al.

beams from injectors: BCMS

- **Batch Compression, Merging, Splitting ("BCMS") beam production scheme used since June**
  - use 8 instead of 6 bunches from PSB → PS
- **~10% improvement in beam brightness**
  → gains ~1-2h of time levelled at peak lumi





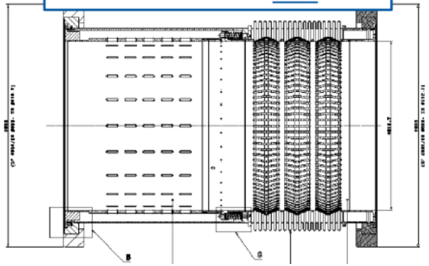
A. Lasheen, H. Damerau and the PS OP team

vacuum modules: intensity limitation

- **2023: RF fingers of warm vacuum interconnect module in cell 4L1 lost contact - sparking**
  - post mortem inspection showed plastification of spring due to localized heating > 500° C
  - ➜ replacement needed, ~5 days lost
- **heating due to high-intensity, short bunches**
- **consolidation ongoing**
  - 47 modules replaced in EYETS 23/24
  - 24 still to be replaced in YETS 24/25

➜ **bunch intensity limitation to ~1.6 10^{11} ppb**
  - better bunch length control further limits the risk

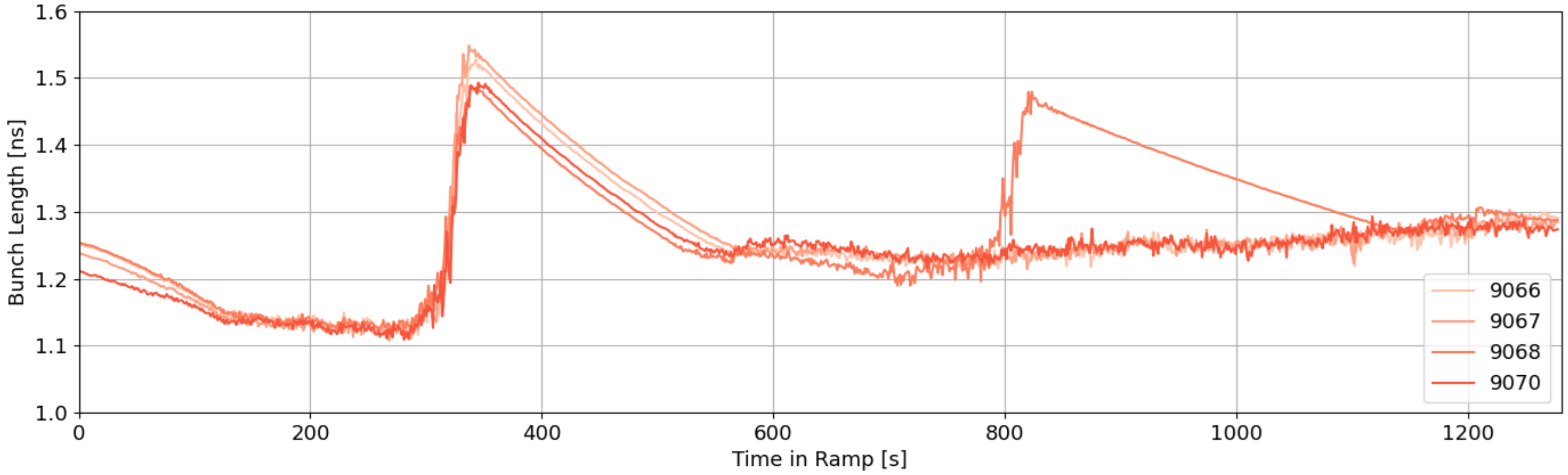

Example of damaged RF finger of A4L1 warm module

New DRF LHCVM___0098


G. Bergliozzi, P. Krkotic, C.Antuono, C. Zannini et al.

improved bunch length control

- **adiabatic shrinking of bunch length during the ramp (1/√γ - factor 4)**
  - counteracted by controlled longitudinal blow-up
  - feedback control optimized in 2024 Machine Development



H. Timko, A. Butterworth, N. Gallou, M. Jaussi, RF & LHC-OP teams

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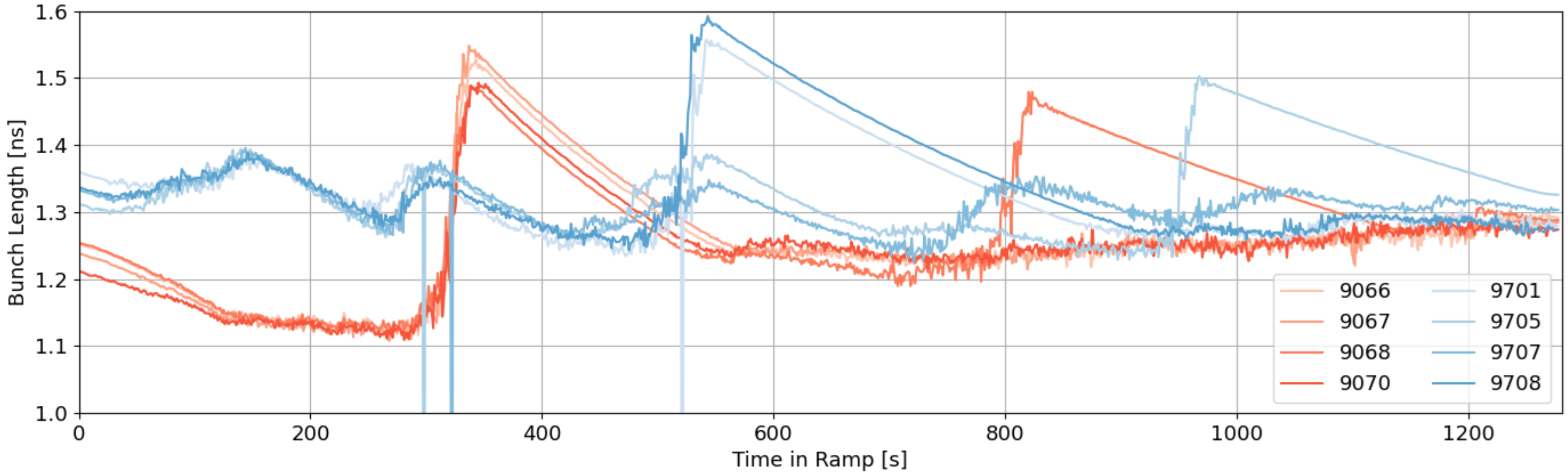
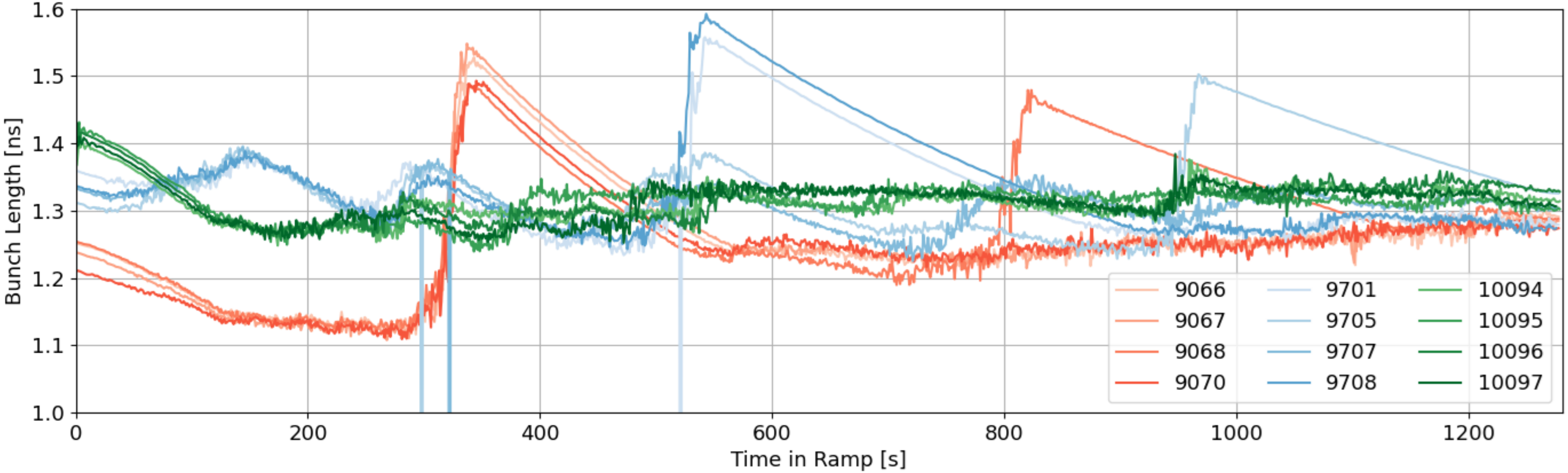


H. Timko, A. Butterworth, N. Gallou, M. Jaussi, RF & LHC-OP teams

improved bunch length control

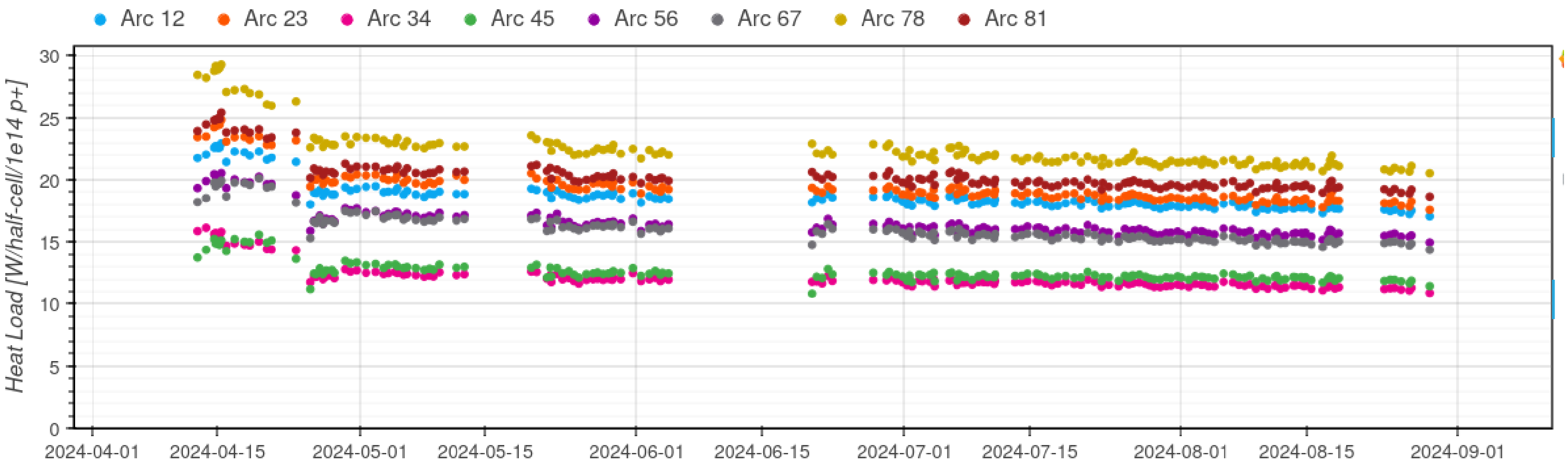
- **adiabatic shrinking of bunch length during the ramp (1/√γ - factor 4)**
  - counteracted by controlled longitudinal blow-up
  - feedback control optimized in 2024 Machine Development

→ **over-/undershoots significantly reduced**



H. Timko, A. Butterworth, N. Gallou, M. Jaussi, RF & LHC-OP teams

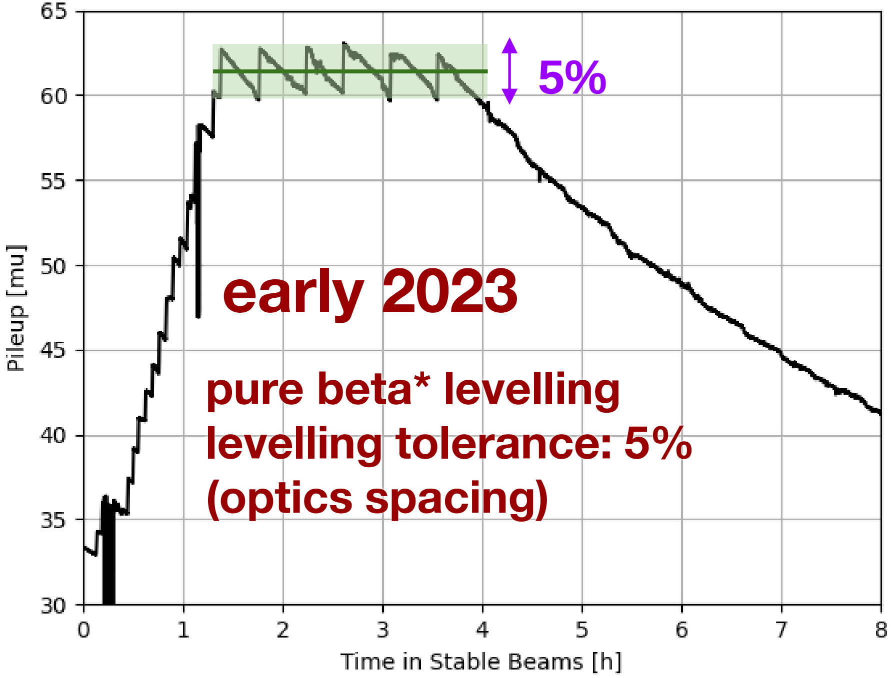
electron cloud and heat load

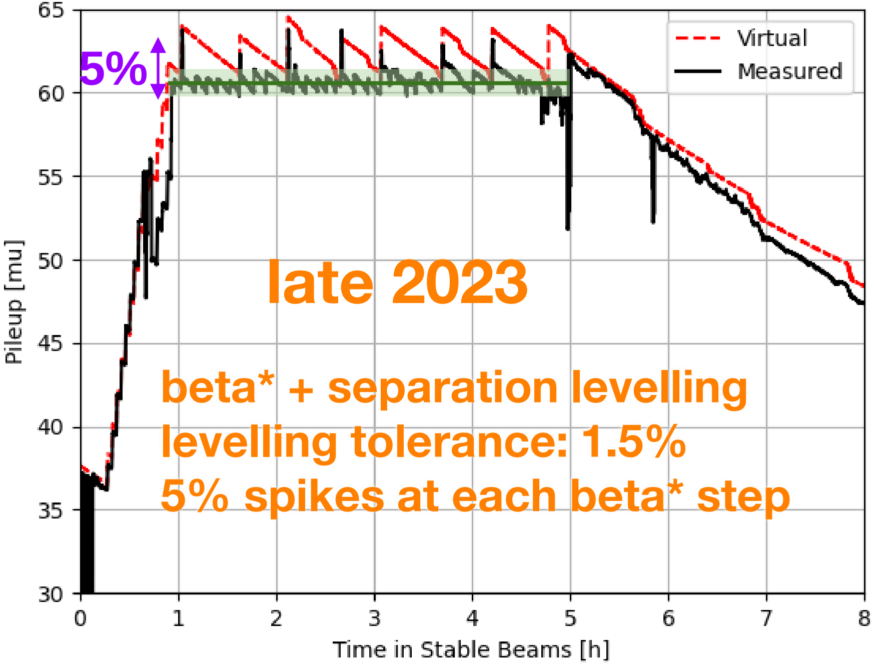


- **electron cloud induced heat-load: sector 7-8 limiting**
  - limits the train length and total number of bunches
  - 2024: 3x36b trains, 2352b total

→ conditioning over 2024 gained ~5-10% margin

luminosity levelling: beta* and separation

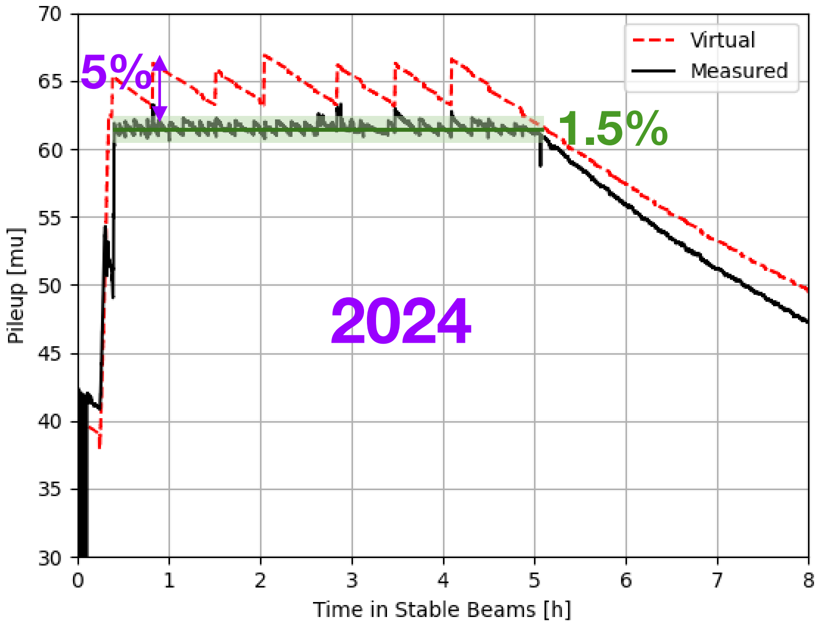


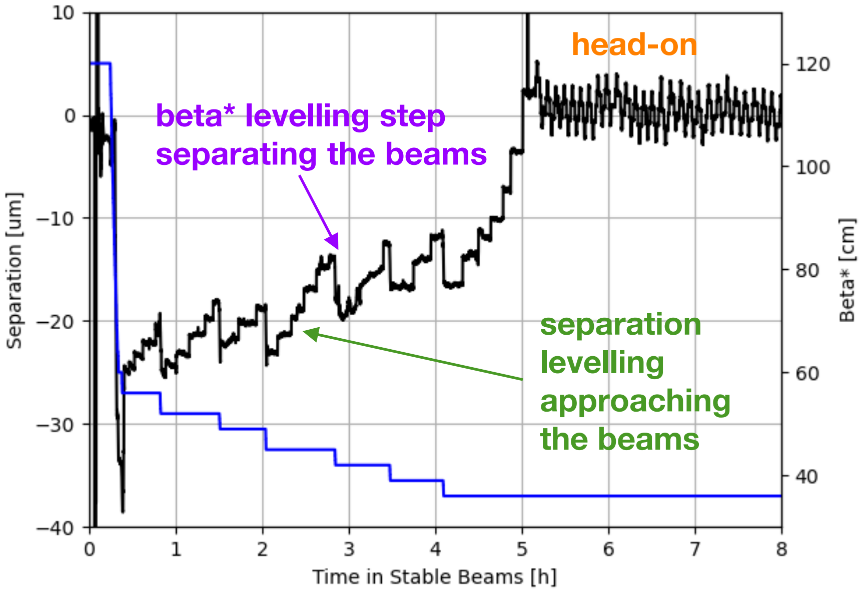


luminosity levelling: beta* and separation

- **5% spikes flattened by increasing separation in parallel to beta* steps**

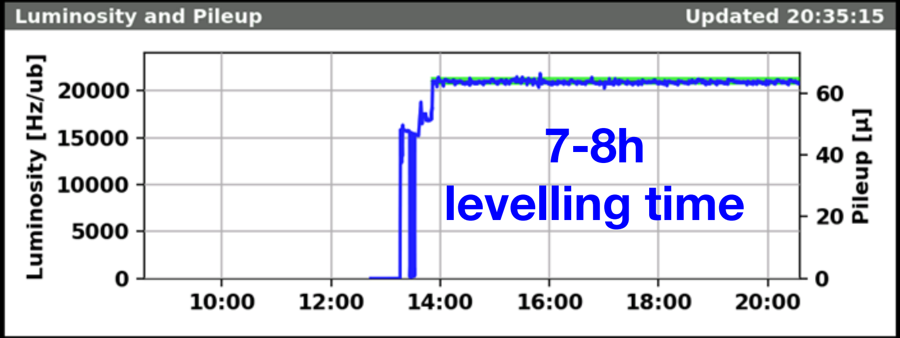
→ **experiments can approach pile-up limit – no trigger issues due to spikes**





IP1: ATLAS

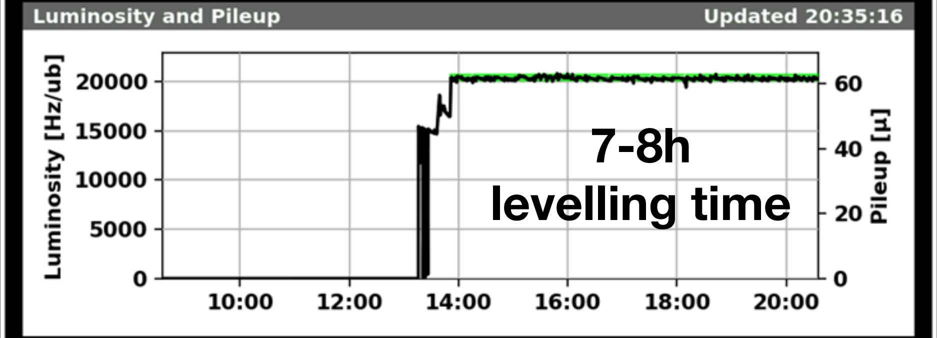
Lumi [Hz/ub]: 20830 **# Coll:** 2340 **μ:** 63.3 ± 3.0



Levelling: Beta* + Separation **Target:** μ = 64.0 ± 1.5 %

IP5: CMS

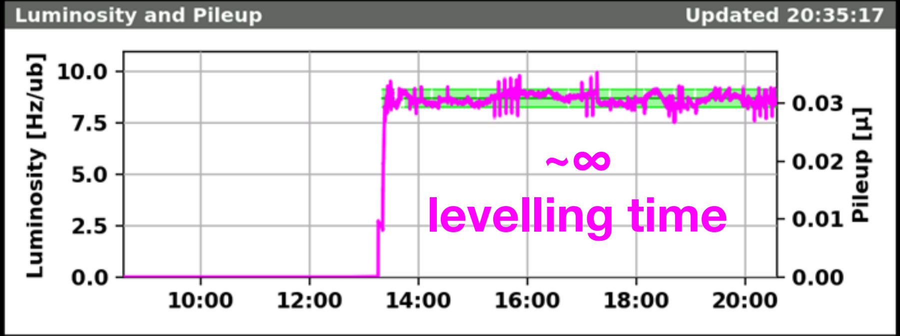
Lumi [Hz/ub]: 20205 **# Coll:** 2340 **μ:** 61.4 ± 3.5



Levelling: Beta* + Separation **Target:** μ = 62.0 ± 1.5 %

IP2: ALICE

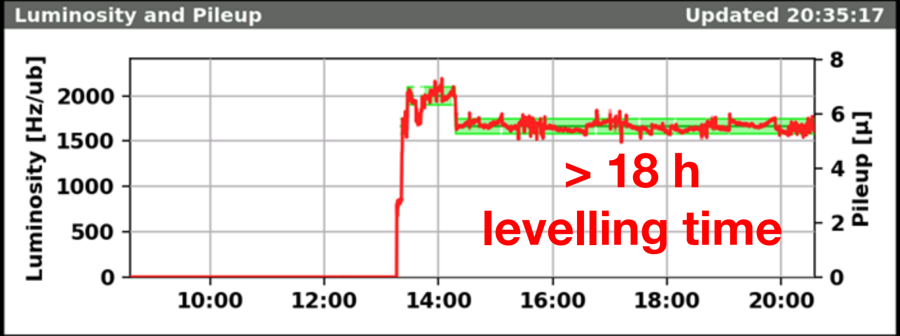
Lumi [Hz/ub]: 8.62 **# Coll:** 2004 **μ:** 0.031



Levelling: Separation **Target:** L = 8.70 Hz/ub ± 5.0 %

IP8: LHCb

Lumi [Hz/ub]: 1611 **# Coll:** 2133 **μ:** 5.37

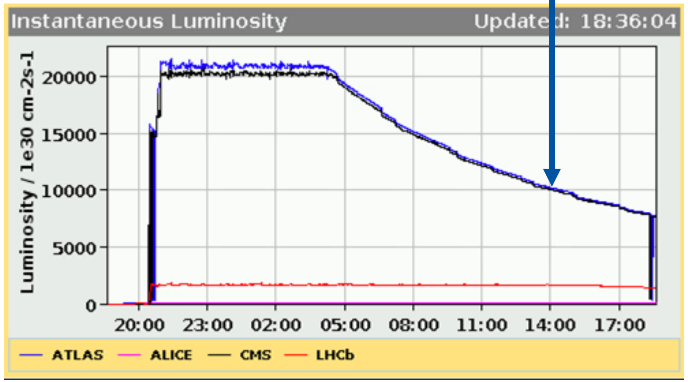


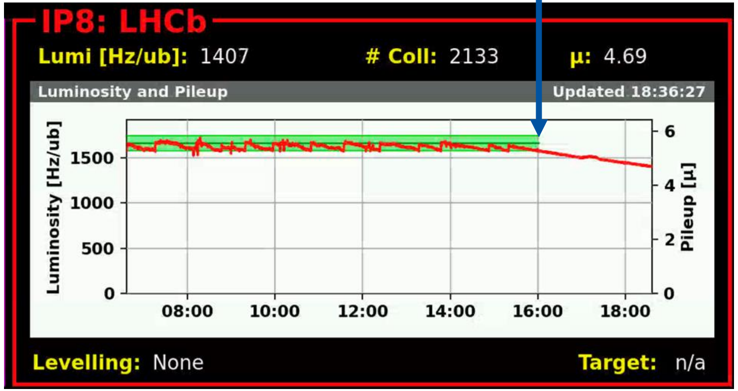
Levelling: Separation **Target:** L = 1665 Hz/ub ± 5.0 %

what if … we keep a fill longer?

LHC design luminosity
10^{34} cm^{-2} s^{-1}
reached after ~17h

LHCb out of levelling after ~19h

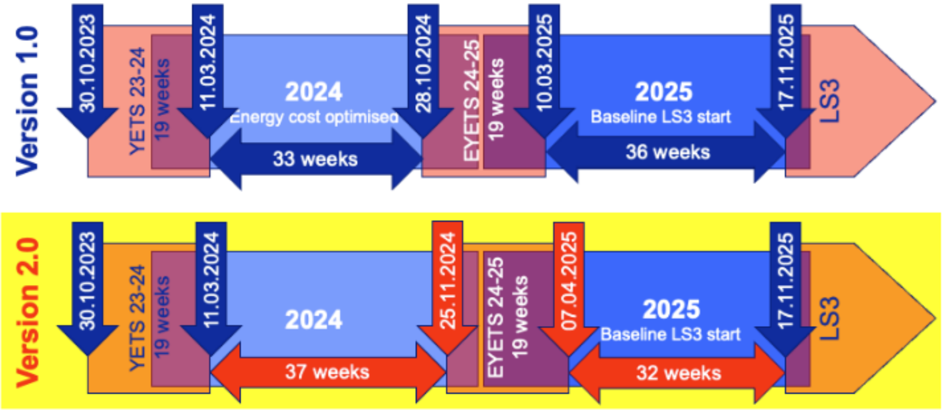




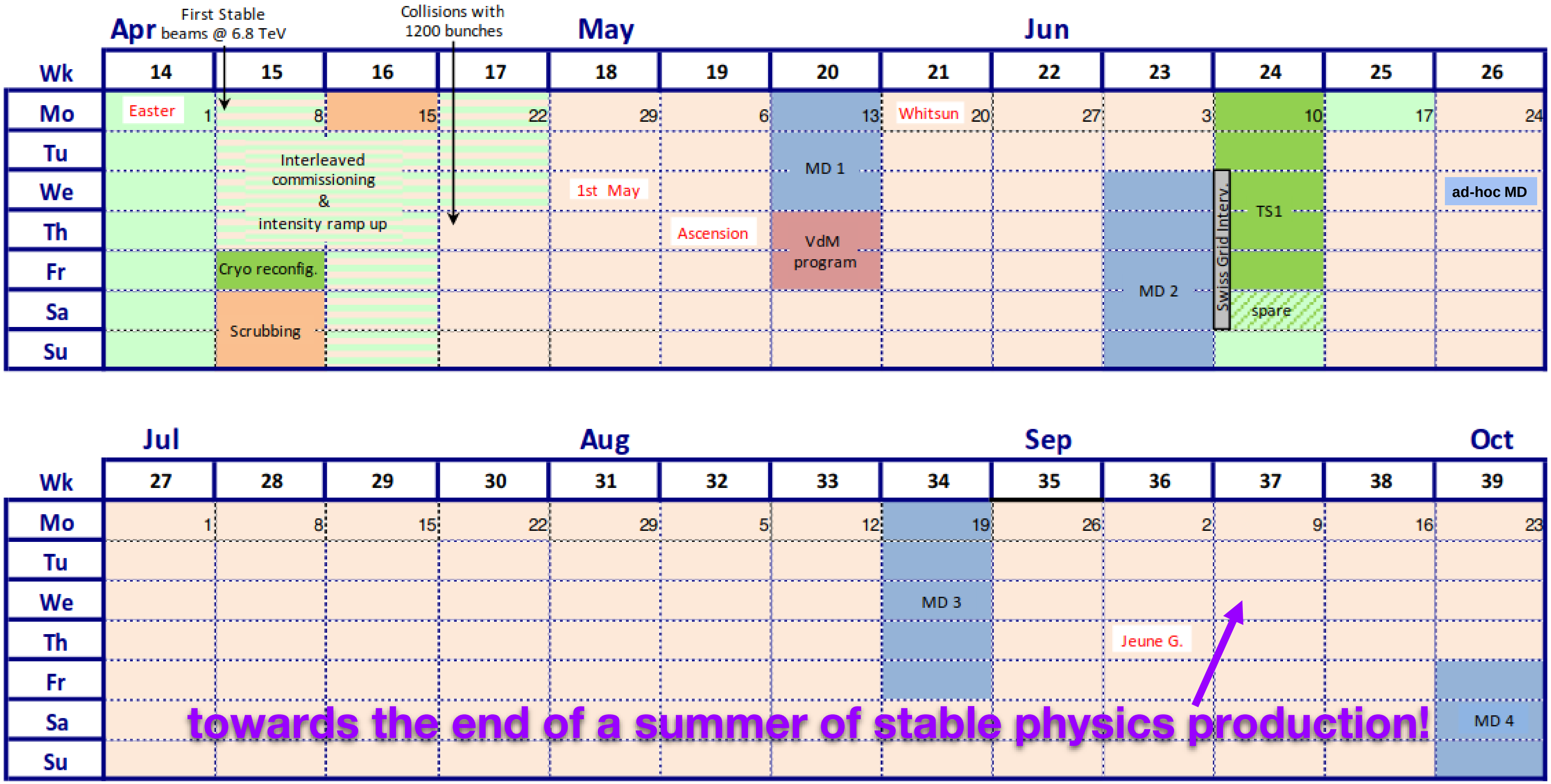
fill 10084 kept for ~22h due to SPS injection kicker issue

2024 schedule 2.0

- **injector YETS shifted by 5 weeks & reduced by 3 weeks**
- **LHC YETS 24/25 shifted by 4 weeks**
  - 2024: 4 weeks longer
  - 2025: 4 weeks shorter
    1 technical stop removed
- **extra time in 2024 for proton physics**
  - integrated lumi target for ATLAS & CMS: 90 fb^{-1} → 110 fb^{-1}
- **2024 + 2025: total 5.5 days gained for proton physics**



2024 schedule - where we stand?



steadily cruising ...

14:59:00

SHIFT SUMMARY:

Stable beams all shift.

17-08-2024 06:59:00

SHIFT SUMMARY:

Arrived during the ramp, squeezed, brought to stable beams, and stayed there.

13-07-2024 22:59:00

SHIFT SUMMARY:

Arrived in stable beams, left in stable beams!

24-08-2024 14:59:00

***** SHIFT SUMMARY *****

Stable Beams, programmed dump, ~1h49 turnaround, Stable Beams.

15-08-2024 22:59:00

SHIFT SUMMARY:

Quiet shift: filled machine, ramped, squeezed and brought to stable beams.

06-08-2024 06:59:00

SHIFT SUMMARY:

Stable beams!

14-07-2024 22:59:00

SHIFT SUMMARY:

Arrived in stable beams, program dumped, refilled, ramped, squeezed and left the machine in stable beams.

30-05-2024 22:59:00

SHIFT SUMMARY:

Quiet shift in stable beams.

24-08-2024 06:59:00

SHIFT SUMMARY:

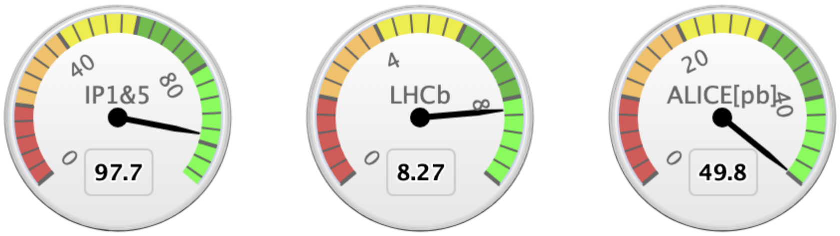
Quiet Stable Beams shift
All IPs on Target

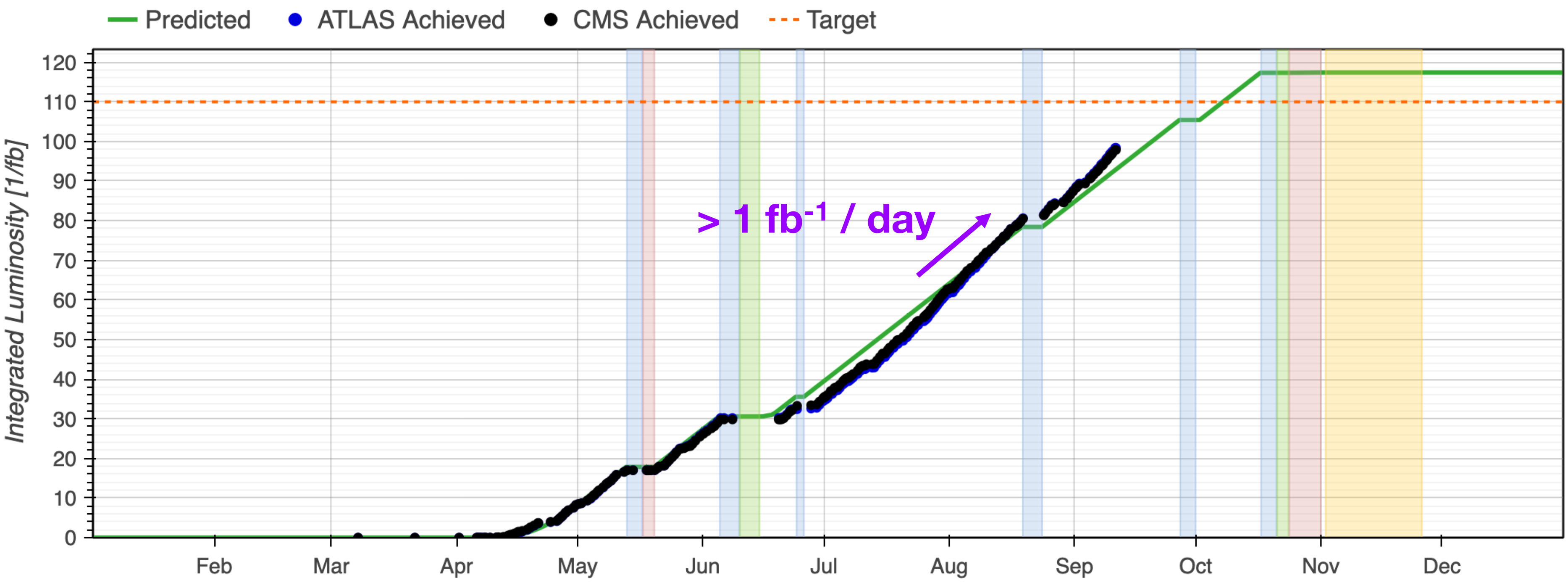
27-07-2024 22:59:00

***** SHIFT SUMMARY *****

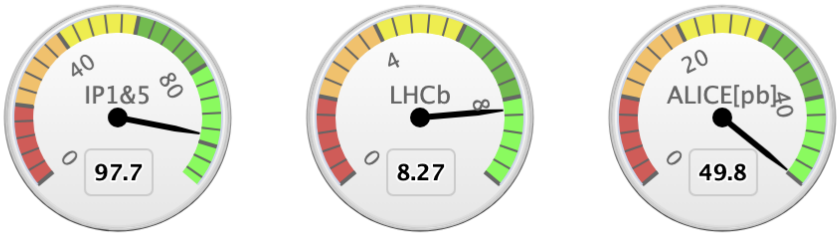
An easy and productive shift of Stable Beams.

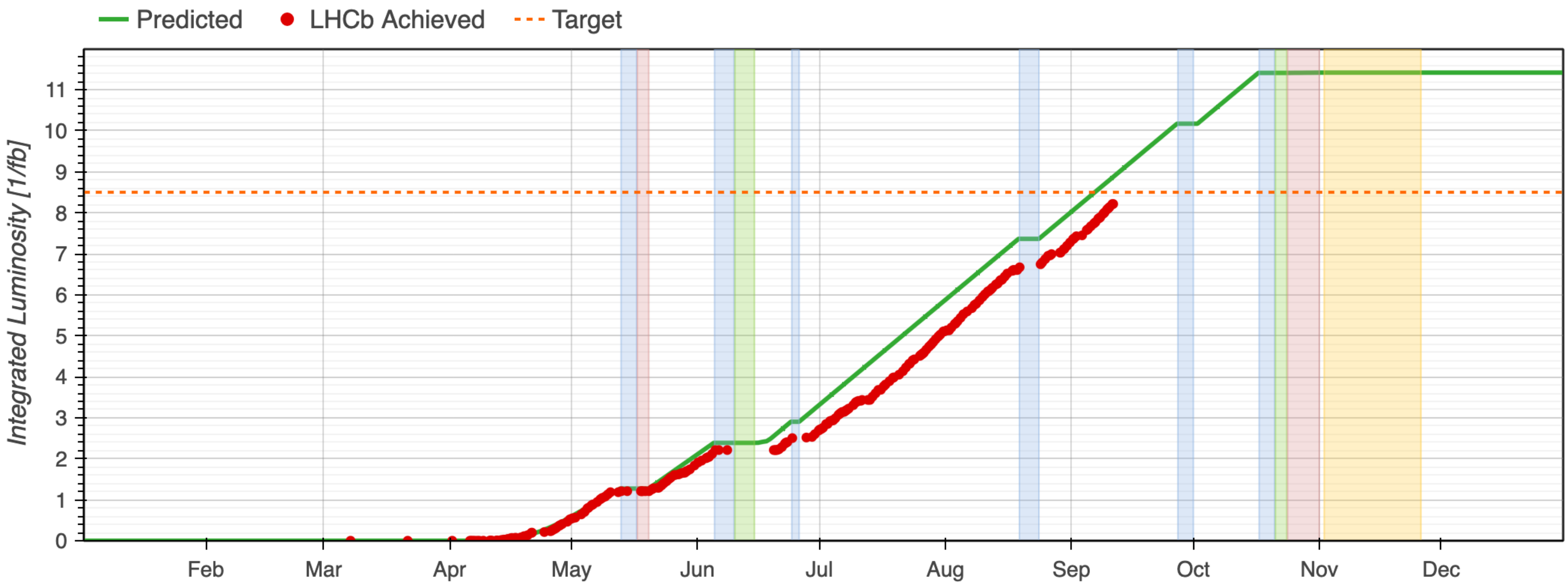
… on track to 110 fb^{-1} …



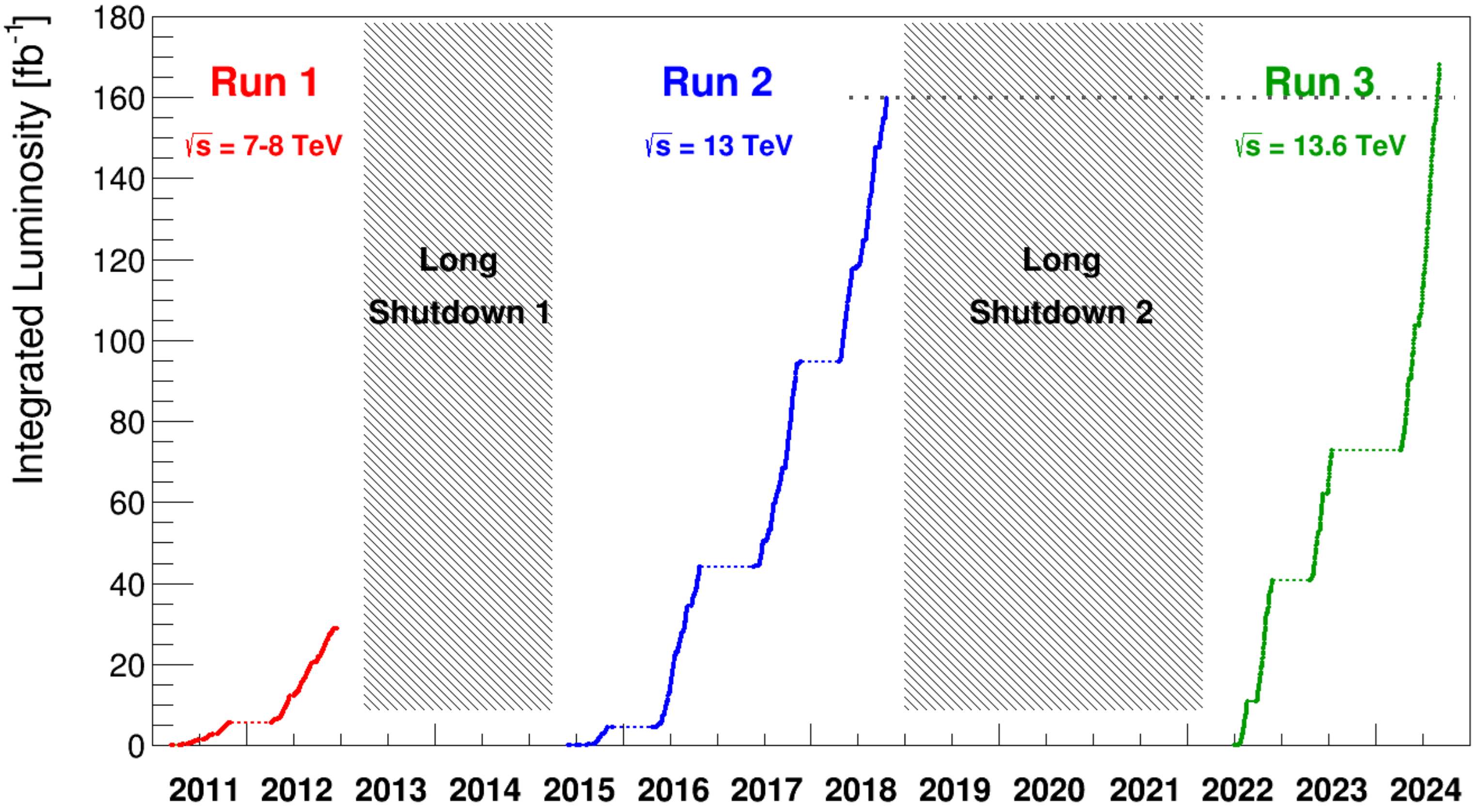


… to 8.5 fb^{-1} in LHCb …



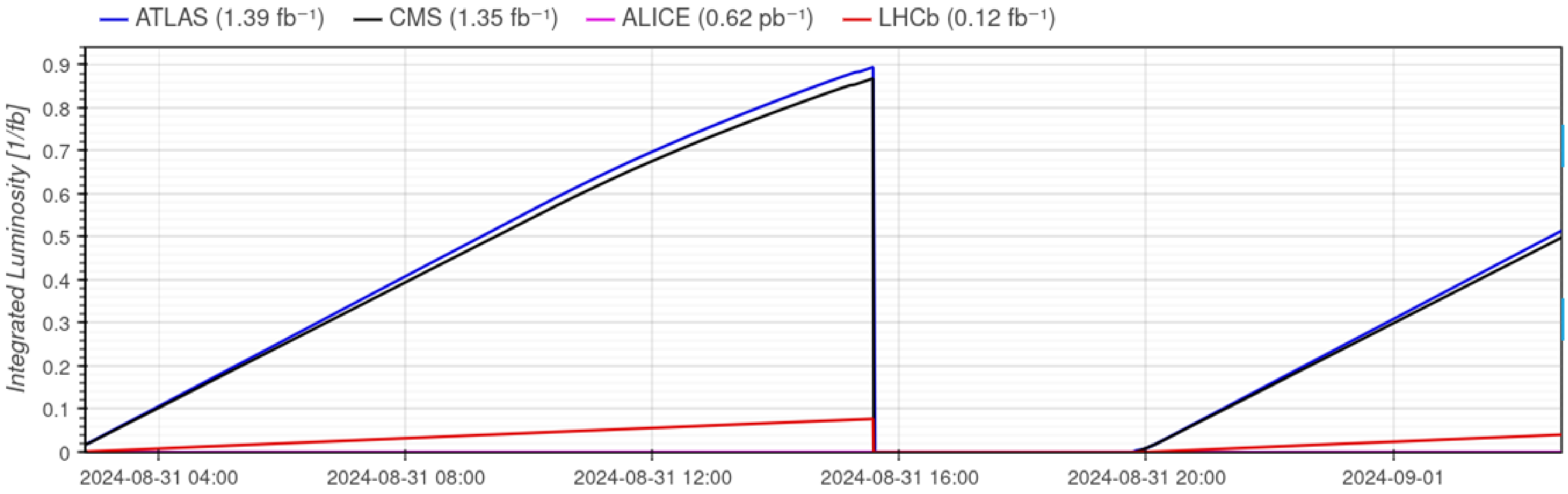


… and exceeding run 2.



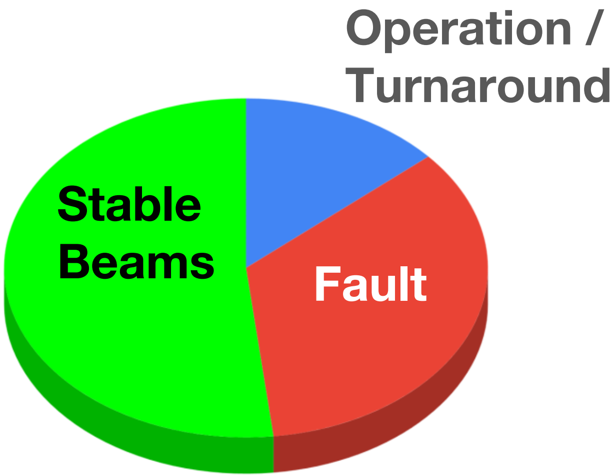
performance reach

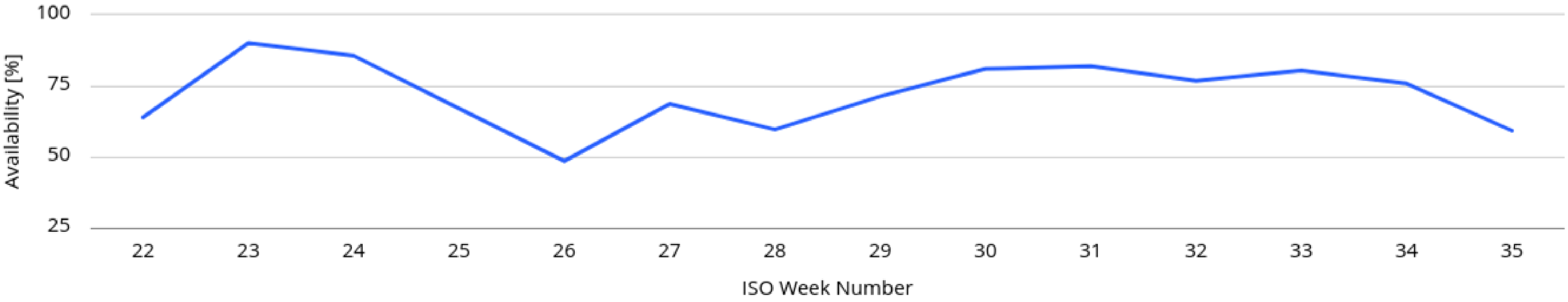
- **~1.4 fb^{-1} / 24h in ATLAS / CMS possible with good availability**
- **~7.5 fb^{-1} / week achieved on average in "good" weeks**



availability

- **availability is key for performance!**
- **2022 & 2023 dominated by long faults**
    - 2022: RF burst disks
    - 2023: vacuum modules & triplet L8
- **2024: "good" weeks availability > 75%, stable beams > 60%**

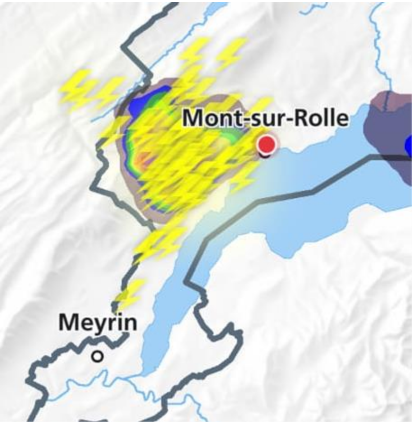


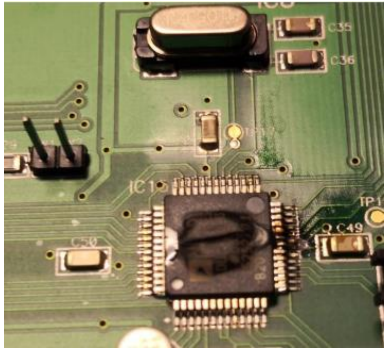


unplanned dumps: main causes

- **electrical perturbations & thunderstorms (~20%)**
  - summer is the thunderstorm season
  - power grid perturbations early in the morning
  - typically trips RF power converters,
    exp. spectrometers, QPS of some quadrupoles
- **Quench Protection System: R2E (~10%)**
  - typically SEU / SEL on boards close to IP1 and IP5
    - running for hours with > 2x LHC design luminosity!
  - consolidation in progress
- **spurious trips (~25%)**
  - e.g. instrumentation glitches on PC or RF

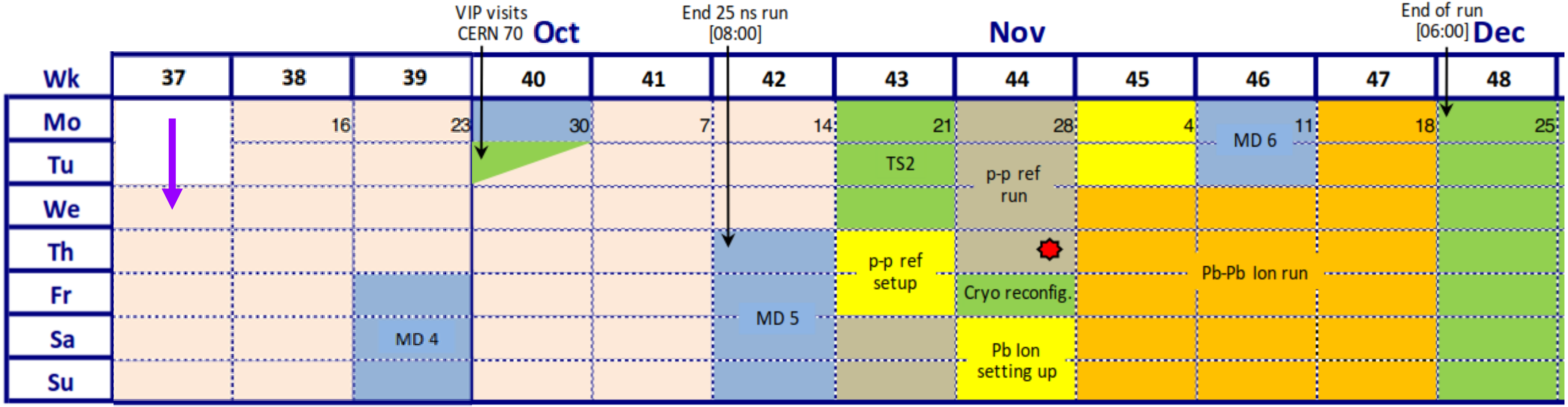
→ **short faults, recovery typically < 4h**





J. Steckert, R. Denz & QPS team

outlook



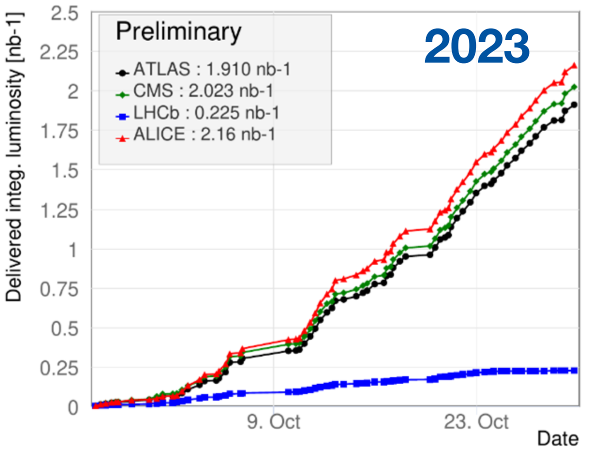
30.5 days remaining of proton run

6 days of 2x2.68 TeV p-p reference run

17 days of Pb-Pb ion run

2024 heavy-ion run

- **6 days of proton-proton "reference run"**
  - 2.68 TeV per beam, equivalent of 6.8 Z TeV Pb-Pb
  - luminosity targets:
    - ATLAS / CMS: ~300 pb^{-1}
    - ALICE: 4.5 pb^{-1}
    - LHCb: 100 pb^{-1}
- **17 days of Pb-Pb heavy ion run**
  - 6.8 Z TeV per beam - same configuration for run 3
  - luminosity target:
    - 5.3 nb^{-1} in all run 3 (2 nb^{-1} collected in 2023)
    - ~1.5 nb^{-1} in 2024
  - LHCb: full heavy-ions program
  - mitigations in place for 2023 issues (“10 Hz” losses, QPS)



→ challenging targets - challenge accepted!

R. Alemany, R. Bruce, F. Alessio, C. Young et al.

conclusions & outlook

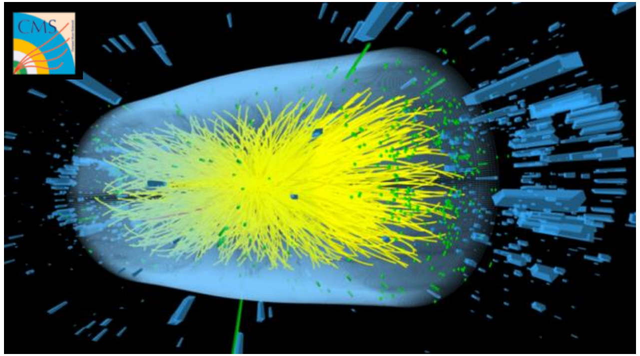
- **the LHC is steadily cruising in physics!**
  - > 1 fb^{-1} produced per 24h if all goes well
  - ~60% of time in Stable Beams
  - faults: mostly short glitches
- **until the end of the year:**
  - protons: **well on track to 110 fb^{-1} in ATLAS / CMS**
  - ions: a challenging run ahead!
- **next year (and beyond):**
  - "Reverse Polarity" optics - full, half, or none?
  - protons: gentle increase of bunch intensity beyond 1.6 10^{11} ppb?
  - ions: oxygen in LHC (and another Pb ion run)
  - **limit changes - continue cruise production!**

thanks for your attention

instantaneous luminosity: levelling IP1 & IP5

- **ATLAS and CMS pile-up**
  - processing power for event reconstruction
  - data taking efficiency & dead-time
  - limit on the average pile-up

    ➜ single-bunch instantaneous luminosity limit



- **IR1 & 5 inner triplet cooling**
  - heating due to luminosity debris
  - cooling capacity different per triplet-side
    - risk of losing cryo conditions (helium overflow)
    - slow processes: ~15 minutes "inertia"
  - limit on the total triplet heat load

    ➜ total instantaneous luminosity limit