# LPC Report

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LPC

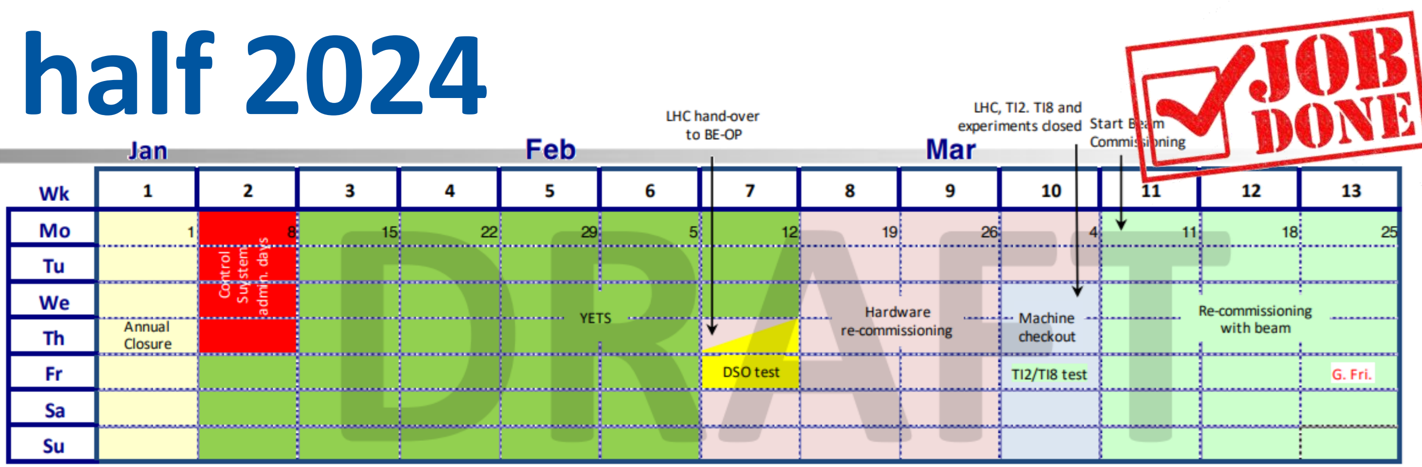
# Topics for today

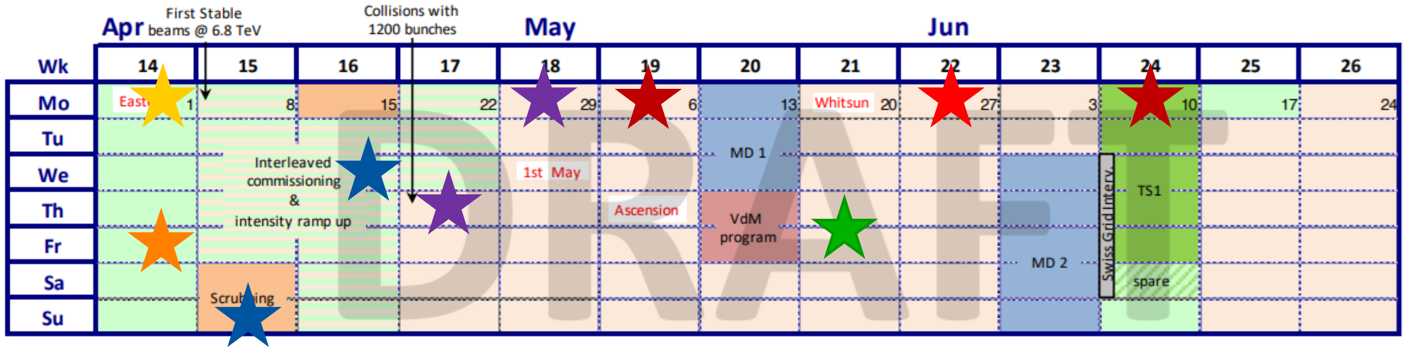
- 2024 realized schedule
- Yearly physics productions
- Physics driven feedback/messages
- Running conditions feedback
- FASER/SND background studies
- On the optics choice for 2025
- Approved schedule for 2025
  - 2026 for info
- Conclusions

# Realized schedule 1st half 2024

Important dates 1st half of 2024:

- ✓ Annual LHC-Experiment Handshake test on Tuesday 05/03, 4 pm
- ✓ Machine and exp closed 06/03
- ✓ First recirculating beams 08/03
- ✓ Few fills of SB @ 450 GeV in ~March 2024
- ✓ First SB @ 6.8 TeV on 05/04
- ✓ Reached full machine at 3x36bpi on 29/04
- ✓ VIP access on Monday 06/05
  - Emulsion removal FASER/SND – 13 $fb^{-1}$
- ✓ VdM after first MD1 block, Thur-Fri week 20
  - Shift earlier by 1 day due to holiday week
  - Emulsion removal SND – 11 $fb^{-1}$
- ✓ TS1 on June 10th



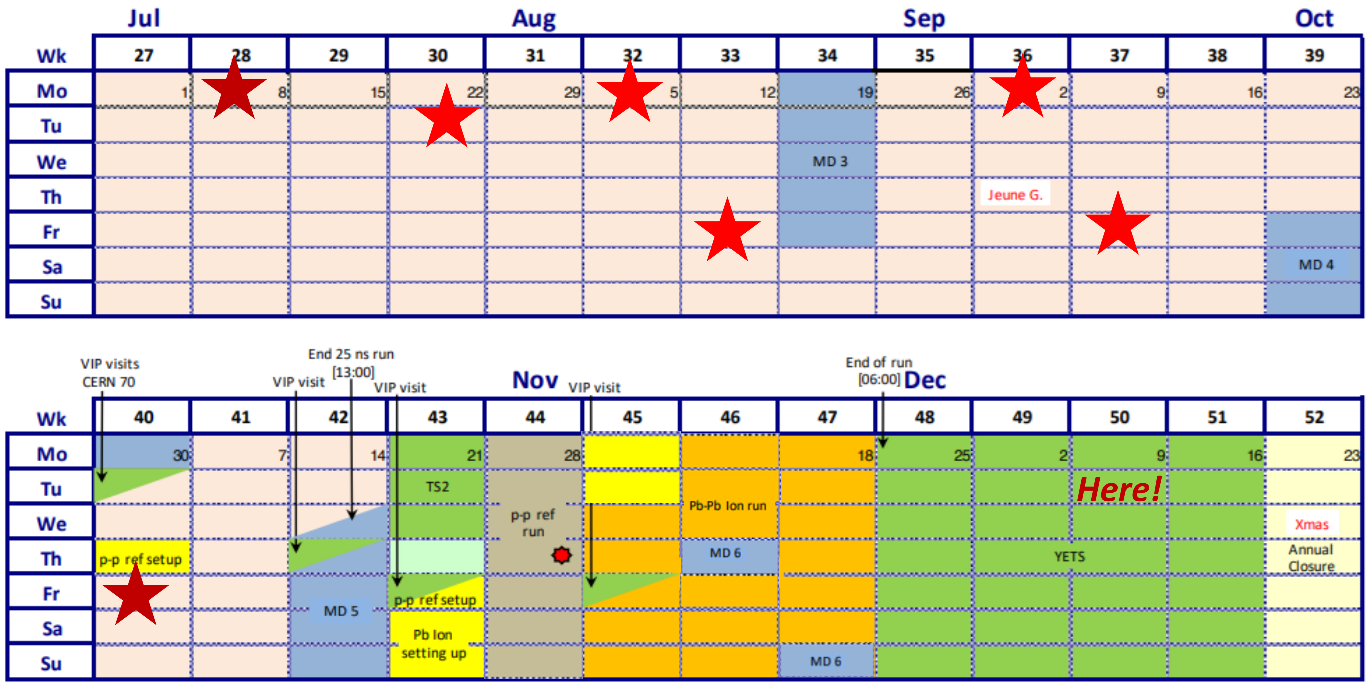

- 450 GeV Stable Beams fills
- Start of 6.8 TeV Stable Beams fills
- 1200b / 1800b in collisions with 3x48bpi
- 1950b / 2352b (full machine) in collisions with 3x36bpi
- 2352b (full machine) with BCMS beams
- FASER/SND emulsion de-/installation
- SND only installation

# Realized schedule 2nd half 2024


Important dates 2nd half of 2024:

- ✓ FASER/SND post-TS1 emulsions exchange on 08/07 (~10 $fb^{-1}$ collected)
- ✓ MD3 on 19/08
- ✓ MD4 on 27/09
- ✓ CERN's 70th birthday + VIP access on 01/10
  - VIP accesses on 17/10, 25/10 and 08/11
- ✓ MD5 on 17/10 @ 12am + TS2 on 21/10 @ 6am
- ✓ final pp reference setup (<=1 day left)
- ✓ Pb setup (2.5 days) before pp reference run
- ✓ pp reference run 28/10 to 04/11 (7 days
- ✓ final Pb set up (4 shifts)
- ✓ PbPb ion run 05/11 to 24/11 (6am)

→ YETS starting on 24/11 for 19 weeks




★ FASER/SND emulsion de-/installation on 4th October

★ SND emulsion exchange in an unplanned access

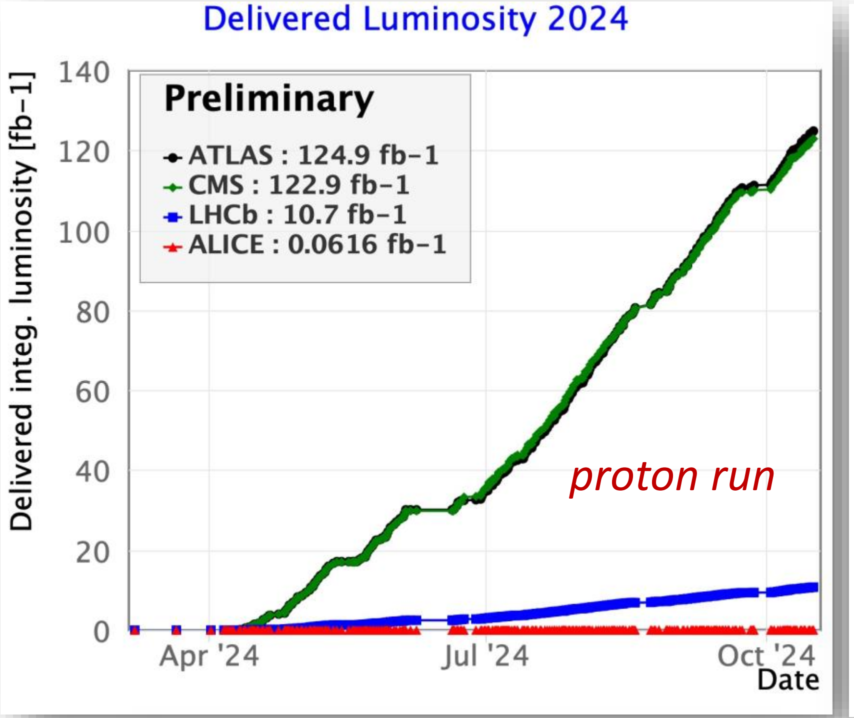
- 24/07 @ 13.3 $fb^{-1}$, 05/08 @ 12.7 $fb^{-1}$, 16/08 @ 11.5 $fb^{-1}$, 02/09 @ 10.8 $fb^{-1}$ , 13/09 @ 11.1 $fb^{-1}$ , 21/09 @ 11.8 $fb^{-1}$

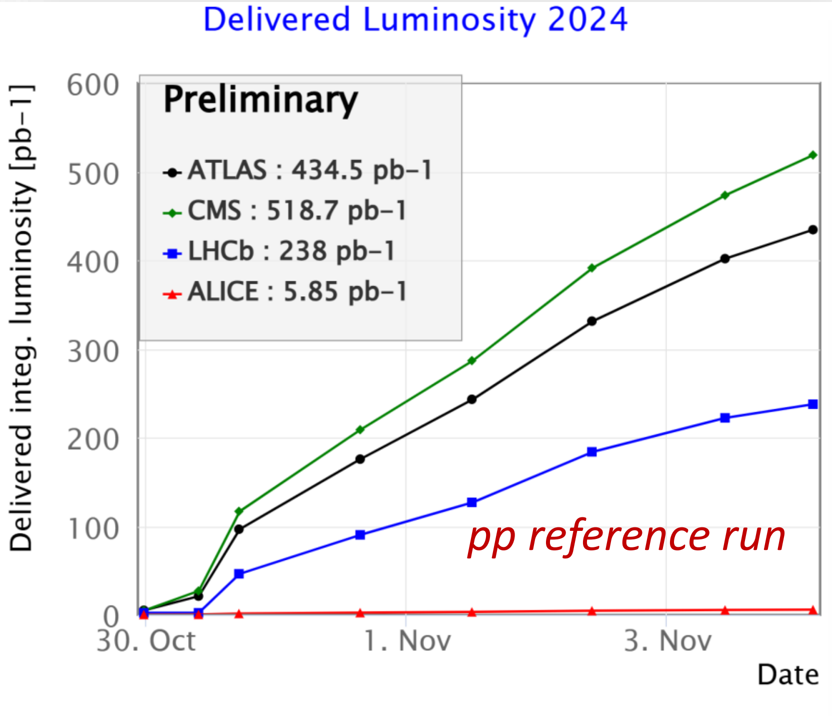
# Wrap-up physics production

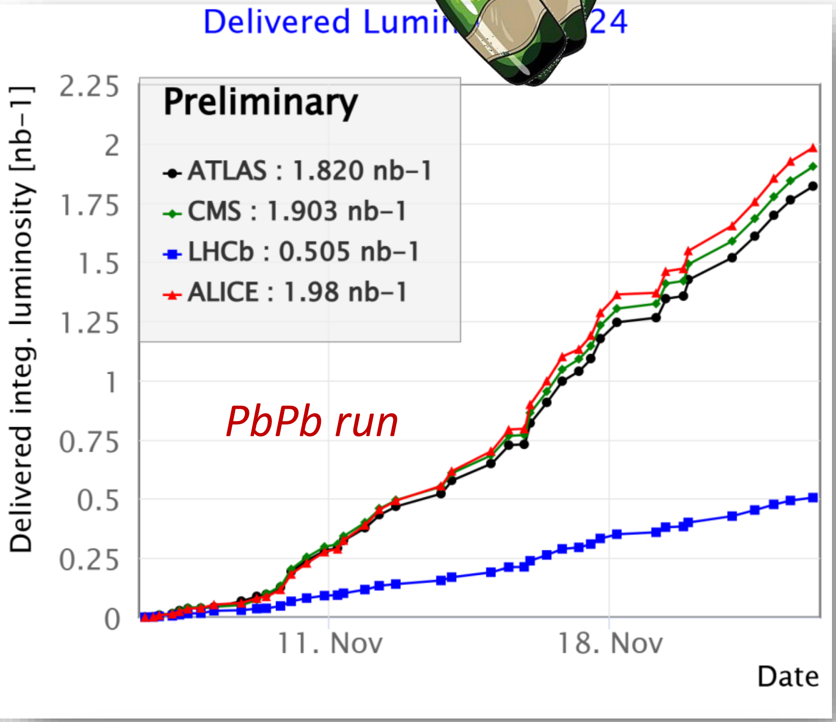
Impressive amount of integrated luminosity delivered to the experiments!

→ All targets and goals were reached and often surpassed!

→ Amazing performance and incredible achievements!




| Availability | Stable beams (SB) |
|---|---|
| 72.8% | 48.5% |

| Availability | Stable beams (SB) |
|---|---|
| 91.8% | 75.5% |

| Availability | Stable beams (SB) |
|---|---|
| 75.2% | 42.3% |

# Physics feedback – protons

***ATLAS + CMS:*** Run3 dataset is of fundamental importance for the physics and publications program.

→ Need a substantial increase of integrated luminosity relative to Run2 to keep ATLAS+CMS physics impact of publications high.

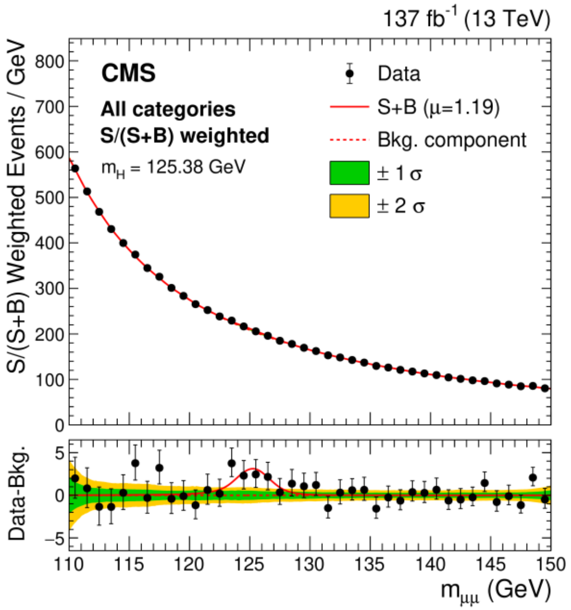
- Run3 large pp dataset will be used to probe unexplored territories in searches for New Physics (dark matter, new resonances), exploiting a very diverse physics program.
- Every extra $fb^{-1}$ recorded allows us to reach higher masses.

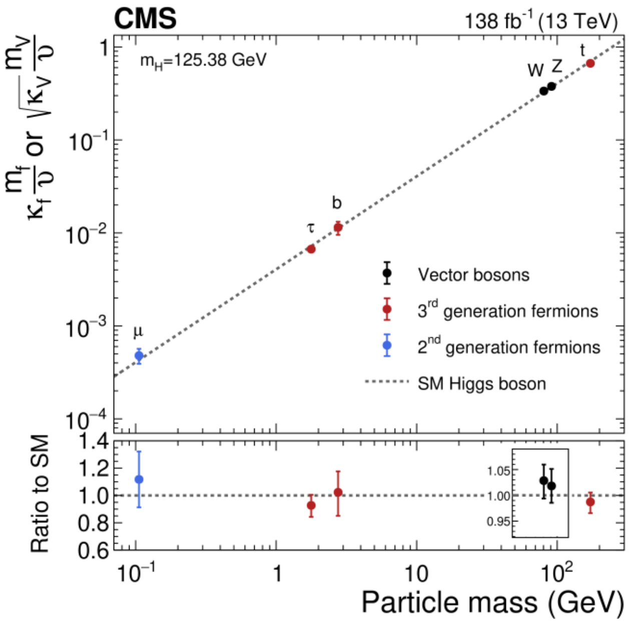
→ A few benchmark measurements that will rely on the ~400 $fb^{-1}$ of Run 3 and that are strongly statistically limited are:

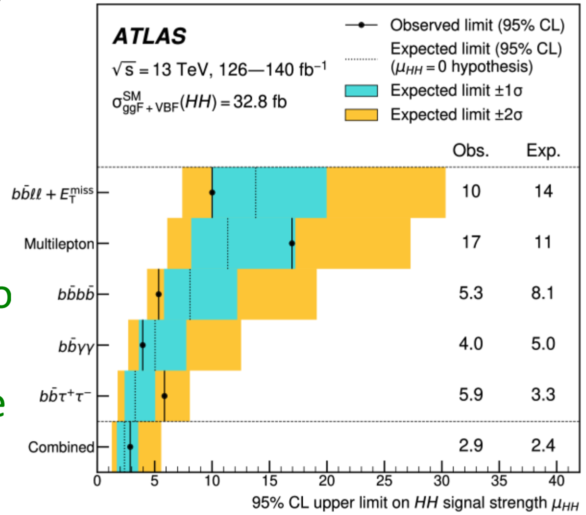
- searches for HH production – testing Higgs self-coupling!
- rare processes like H->μμ (2 sigma achieved in Run 2, may reach 5 sigma observation combined with CMS)
- H->Zγ (3 sigma achieved in Run 2 combined with CMS).

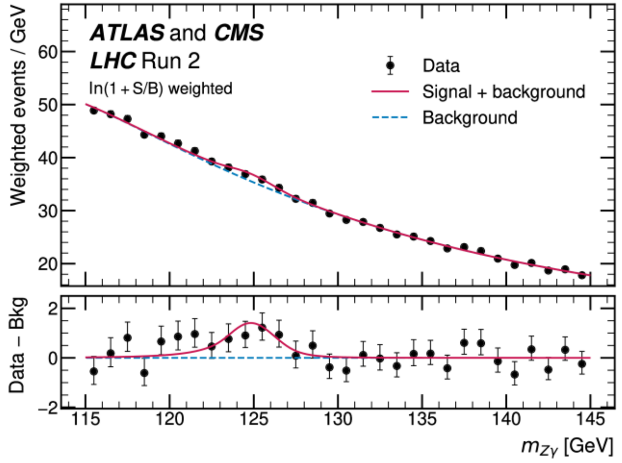
→ Data are used for a broad spectrum of precision studies in properties of H, W, Z, bosons, top and other quark, neutrinos, …

This will be (combined with Run 2) ATLAS+CMS baseline data set to produce high-impact publications and keep the community engaged until a sizeable (doubling Run 2 + Run3) luminosity will be collected at the HL-LHC, through the (long) LS3 period .



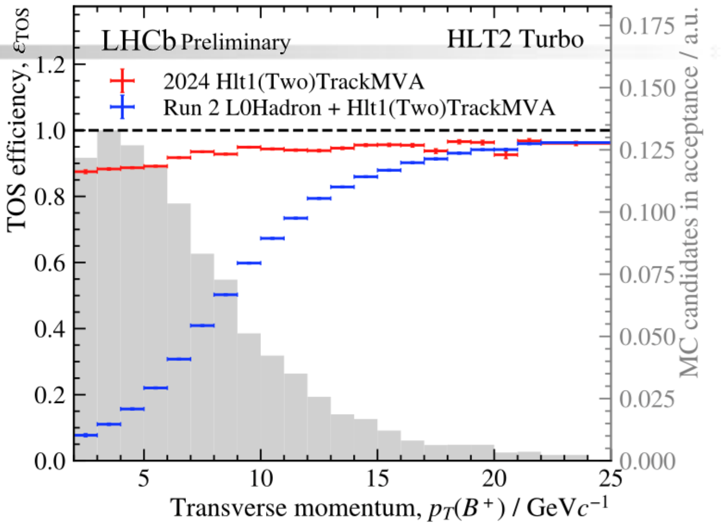



# Physics feedback - protons

***LHCb:*** has recorded 9.56 $fb^{-1}$, which is more than the Run1+2 dataset, and the new software trigger allowed to collect hadronic beauty and charm hadronic channel decays with a factor 2–3 higher efficiency

→ the overall precision of most measurements of the LHCb physics programme with 2024 data will be equal or better than that based on the entire Run1+2 dataset

- The software trigger also allows to study channels that were previously strongly affected by the hw level-0 trigger (e.g. trigger on K_S–>ππ)
- The full Run3 dataset (25 $fb^{-1}$ recorded) will typically allow to reduce the statistical uncertainty of some previous measurements by >> a factor of 2

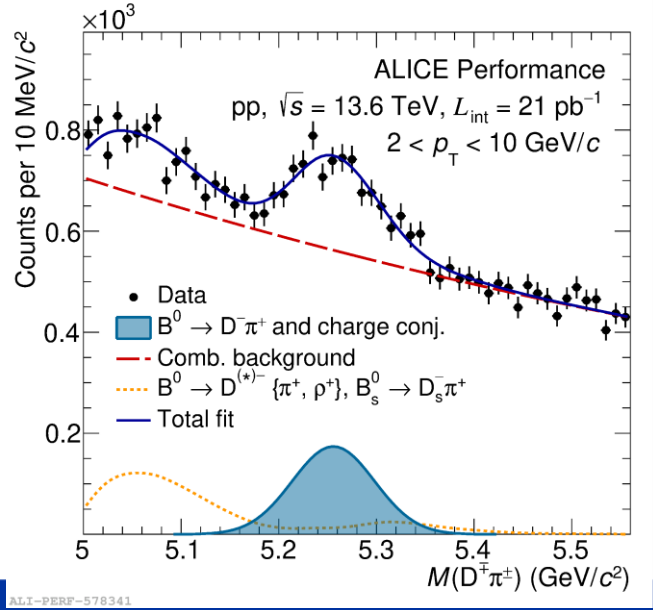



(a) TOS efficiencies in $B^+ \to \overline{D}^0 (K^+\pi^-)\pi^+$.

***ALICE:*** recorded >50 $pb^{-1}$ , aiming at getting >150 $pb^{-1}$ for the full Run3, which would increase by 2500 times the Run 1+2 minimum-bias data set.

→ the larger Run 3 data set will allow to significantly refine the statistical precision of existing measurements, and extend them to include more rare processes, particularly in the charm and beauty sectors.

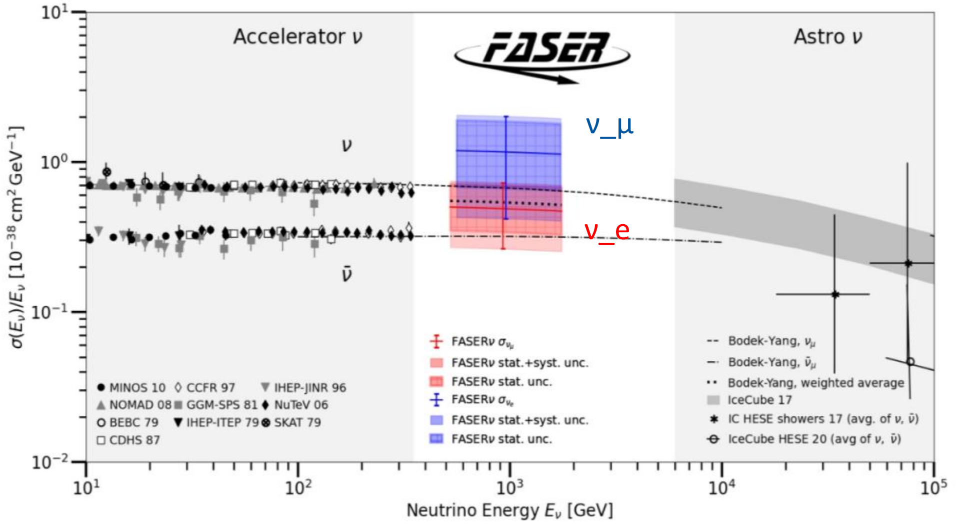
- As an example, the full reconstruction of B mesons is possible for the first time in ALICE with the Run 3 pp data, thanks to the analysis-level trigger selection
- Extends similar measurement of CMS and ATALS to lower $p_T$ at midrapidity access momenta similar to the mass of the beauty hadrons

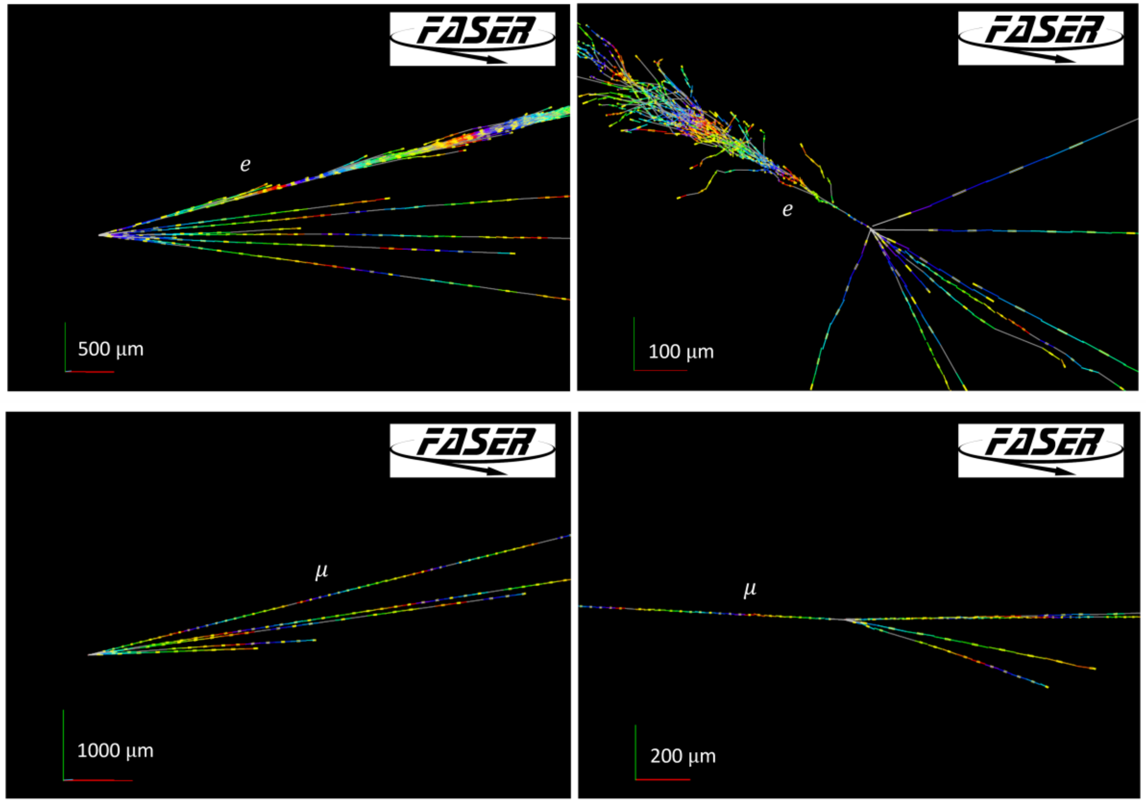


# Physics feedback - protons

***FASER:*** recorded 34 fb$^{-1}$ (out of 124 fb$^{-1}$) with emulsion program + rest of detector suffered from high background throughout the entire year.

- First cross section neutrino measurements using emulsion data

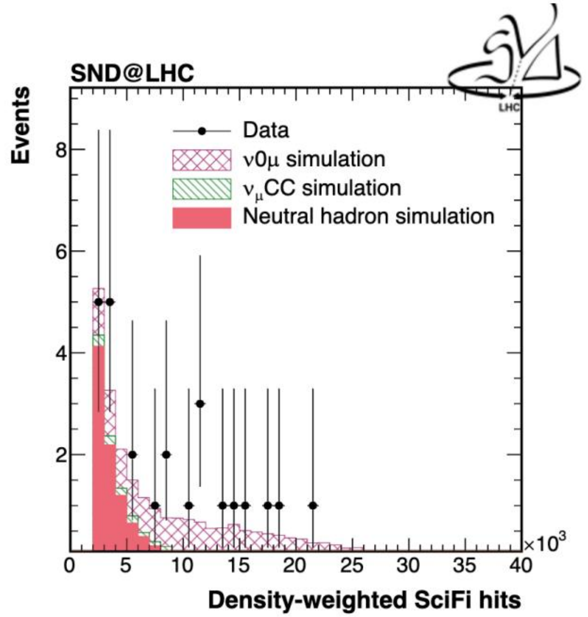



***SND:*** recorded 101 fb$^{-1}$ with mostly half-targets (65% acceptance)

- Now scanning through emulsions targets of 2023 and 2024

→ ν0μ observation with electronics detectors at 6.4σ submitted to PRL



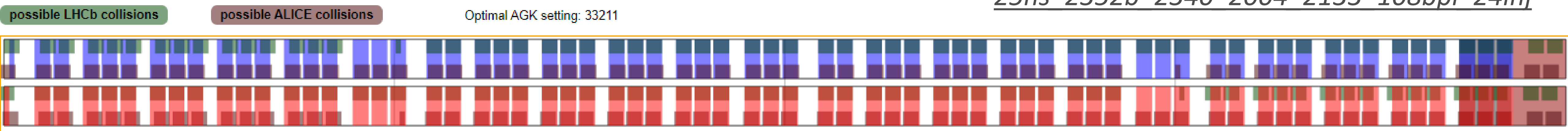

→ Even with worse operational conditions, the experiments managed to produce valuable results → room for more!

# Physics feedback - protons

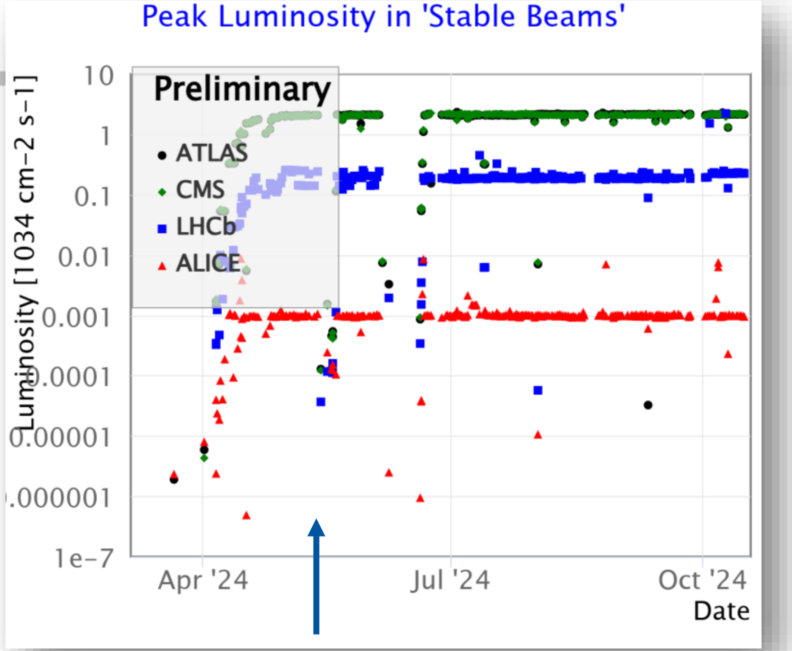

Proton production filling scheme provided 2340b colliding in ATLAS/CMS, 2133b in LHCb

- Choice of injection scheme and filling scheme critical in exploring availability of accelerator complex
  - Hybrid schemes provide operational overhead at all levels
    → also disfavoured by experiments due to different “families of bunches”
  - All experiments request to maximize the number of colliding bunches
    → direct impact on the <pileup> and ultimately integrated luminosity (if <pileup> too high to deal with)
    → support investigations if 4x36bpi scheme possible within cryo margins
    - If increase of number of colliding bunches with 25ns / BCMS beams is not possible, preference is to keep the filling scheme from 2024.
  - Long time spent in levelling at <pileup> is considered very important
    → provides operational stability and maximises integrated luminosity

*25ns_2352b_2340_2004_2133_108bpi_24inj*



# Physics feedback - protons



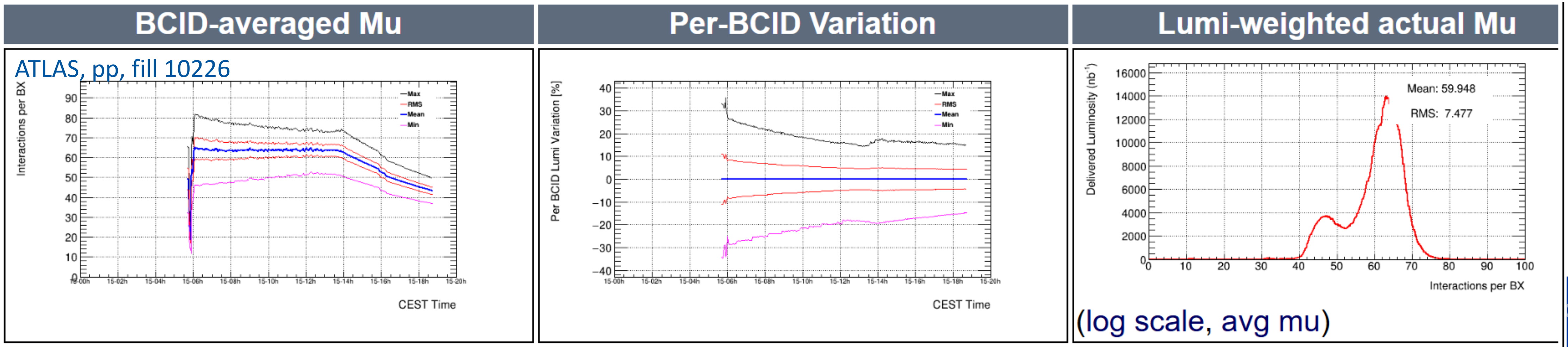

Expect similar situation in 2025

Leveling values:

- CMS & ATLAS plans to level at <pileup> = 65 +/- 2
  - pending further analysis from high-mu / high-rate test
  - depending on the choice of filling scheme
- LHCb plans to level continuously at <L_inst> = 2 x $10^{33}$ $cm^{-2}s^{-1}$
  - reconstruction efficiency strongly depending on <pileup>: critical impact of colliding bunches
- ALICE plans to level continuously at <L_inst> = 8.7 x $10^{30}$ $cm^{-2}s^{-1}$

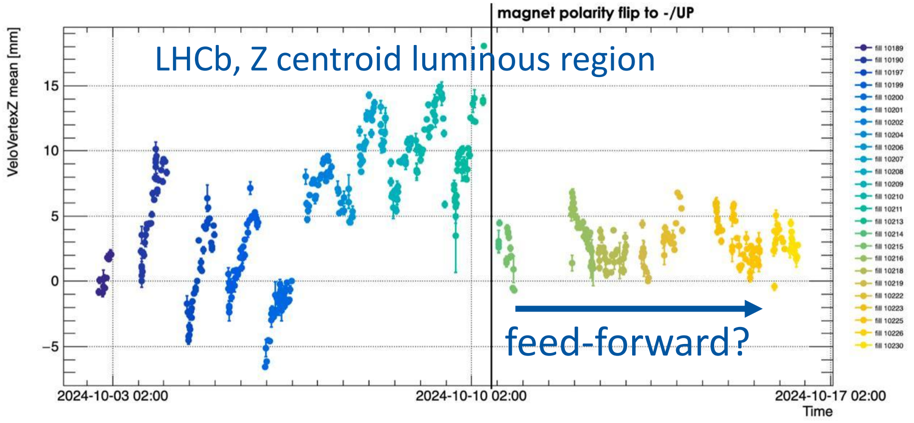
Pileup spread per bunch:

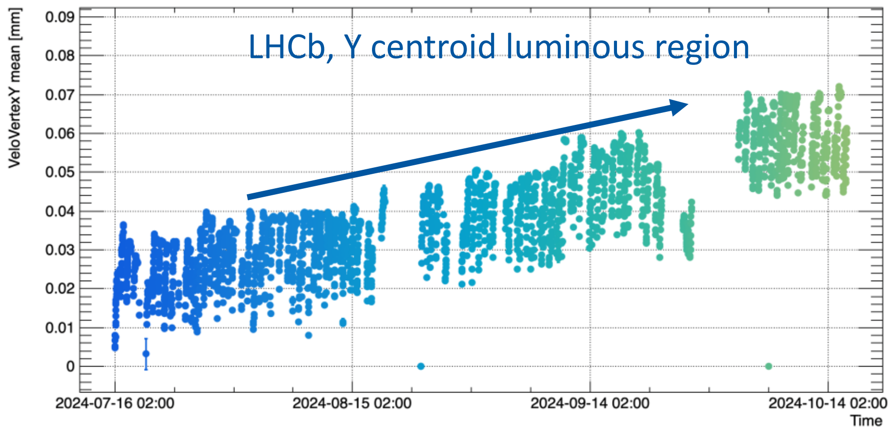
- Observed RMS ~ 8% in pp at start of SB, in line with full Run3
  - Multiple peaks when head-on period (ATLAS/CMS), likely due to larger burn-off of LHCb's bunches



# Physics feedback - protons

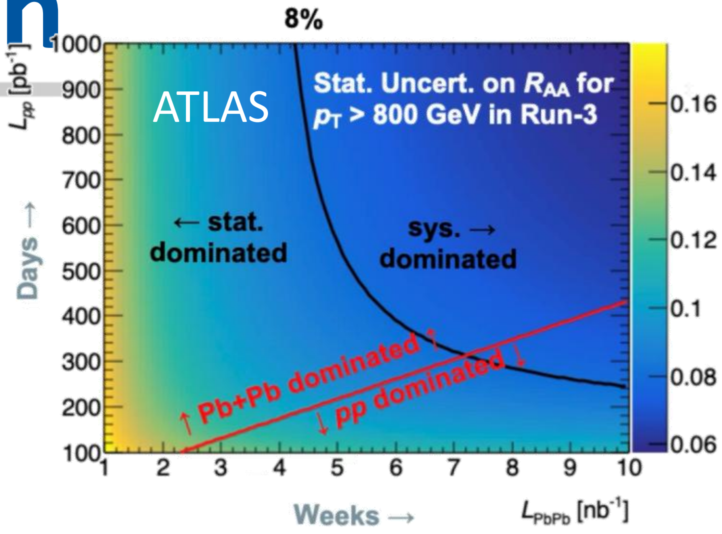
- LHCb/ALICE observed significant movement in luminous region in z depending on the feed forward corrections
    - Thanks to the LHC for the fast iterations this year!
    - It is desirable to limit the movement in z within a fill, in particular (applies to all experiments in fact)
        - limit within +/- 5mm is highly desired
    - generally, if shift is small can be adjusted using RF cogging even if the shift is not fully in agreement among experiments
- LHCb observed a trend in luminous region x,y compatible with the beta* levelling of ATLAS/CMS
    - Not really a problem, unless drift is too large. To be watched.
- LHCb and CMS would like to keep the orbit bumps introduced in 2024 to adjust the beam-spot positions
- LHCb magnet polarity flip: a bit of overhead due to risk of beams going head-on. Possible mitigations to be explored.
- Beam quality of vdM beams: pending further vdM analysis; will be a major topic at the LHC lumi days in March 2025
    - Big thanks to the injector system for their efforts to study and improve the beams delivered



# Physics feedback - pp reference run

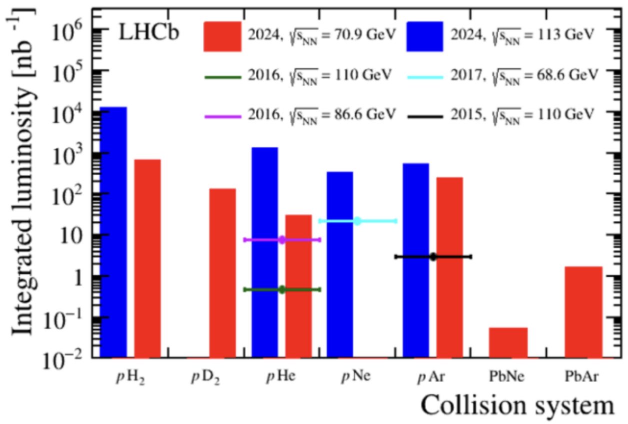
***ATLAS:*** with 400 $pb^{-1}$ of pp-ref and 7 $nb^{-1}$ of PbPb data we ensure the statistical uncertainties at high $p_T$ to be smaller than the systematic uncertainties.




***CMS:*** size of dataset in principle sufficient for >>7 $nb^{-1}$ of PbPb data, however still studying if use of low PU pp data at top energy is sufficient to monitor the various detector changes over time with sufficient precision. Study still ongoing.

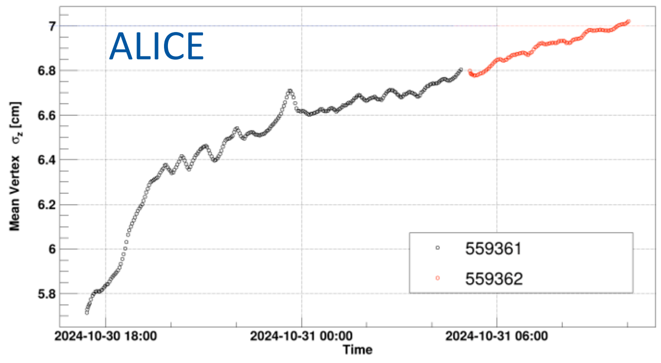
***LHCb:*** integrated luminosity in 2024 more than doubles the requested target (sufficient even taking into account the extension and increased PbPb sample)

- the collected luminosity will allow hard QCD measurements at 2.68GeV (Z, W, dijet, gamma+jet, gamma+c, and direct photon production),
- the new LHCb software trigger allows some of these measurements to be done also in LHCb, contrary to before
- four species of gas injected into the SMOG2 cell, notably deuterium




***ALICE:*** minimal 5.5 $pb^{-1}$ pp reference data requested for 6.5 $nb^{-1}$ of PbPb data

- estimates for needed statistics are based on the $R_{AA}$ measurements of heavy-flavour hadrons
    - The main criterion is that the reference uncertainty becomes subdominant wrt the uncertainty of the PbPb measurement
- wider luminous region in Z in ppRef compared to p-p 6.8 TeV, particularly with the smaller crossing angle

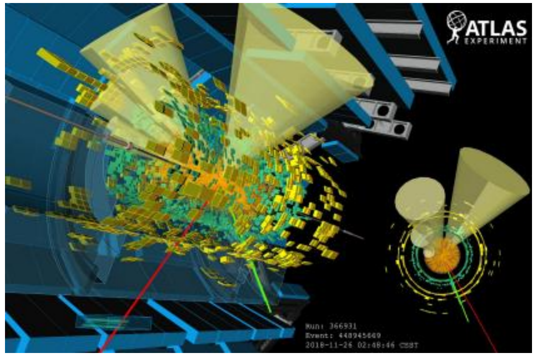


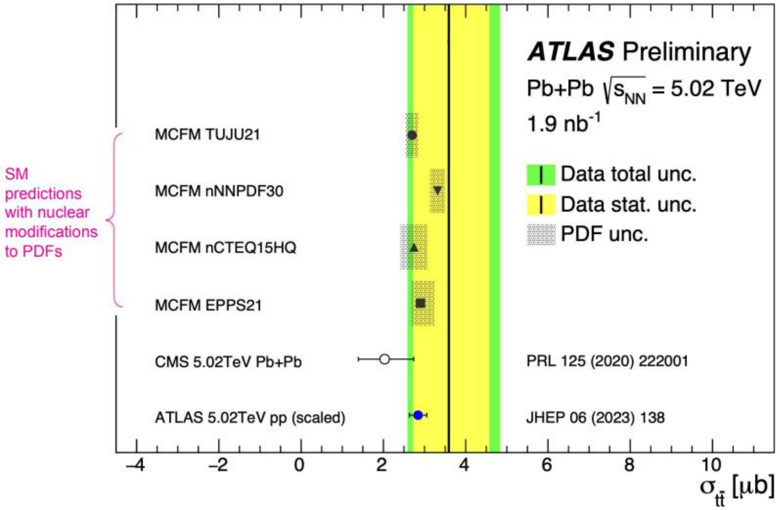
# Physics feedback - PbPb run

ATLAS first observation of ttbar in PbPb collisions

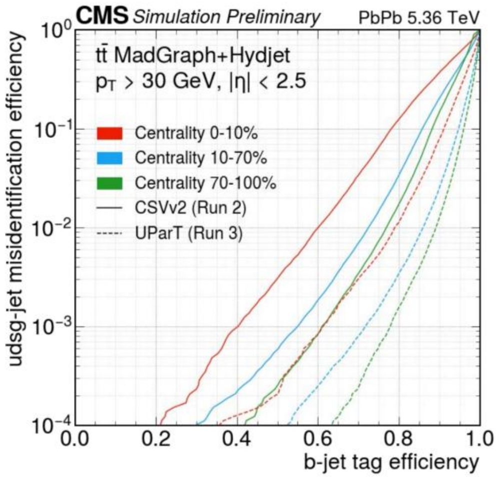
***ATLAS+CMS:*** Potential PbPb measurements include gamma-jet and b-jet substructure and fragmentation, ttbar with proper b-tagging, and X(3872).

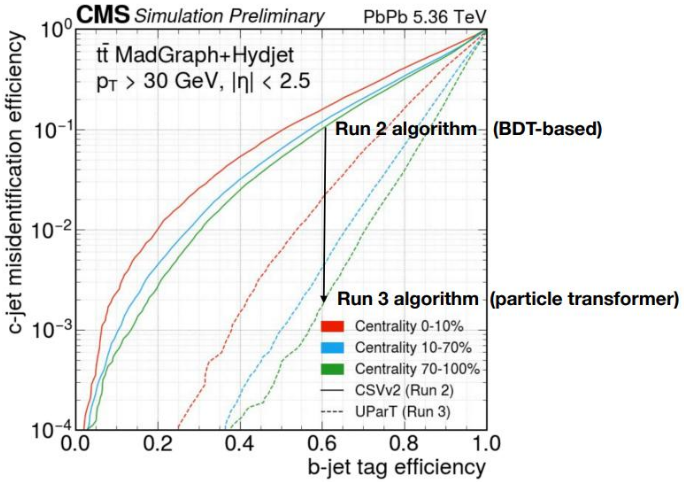
- Both experiments have a preference for at least 7 $nb^{-1}$ of good recorded quality data in Run 3 and to run with PbPb in 2025 and 2026
- ***ATLAS on pPb***: if a decision is made to run with pPb in 2026, then it should be conducted at the same energy as the 2024 pp reference data and with a large enough data set. The statistics must exceed the pPb sample collected in 2016 (184 $nb^{-1}$) and μ must be lower than 0.5 so that the ATLAS FCAL and ZDC can be used.
- ***CMS on pPb***: after the PbPb goal is reached, CMS could be interested in pPb dataset provided it is significantly larger than the Run 2 dataset and provided the pPb cooldown before LS3 is confirmed to be sufficient.




CMS significantly improved b-jet tagging with 2023 PbPb data wrt to Run2



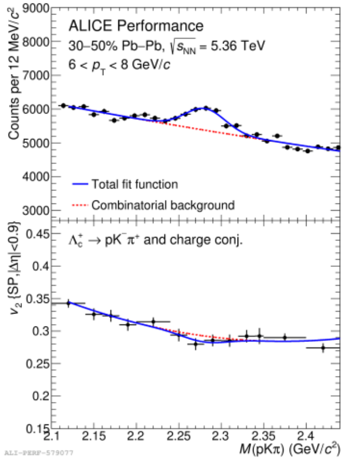
# Physics feedback - PbPb run

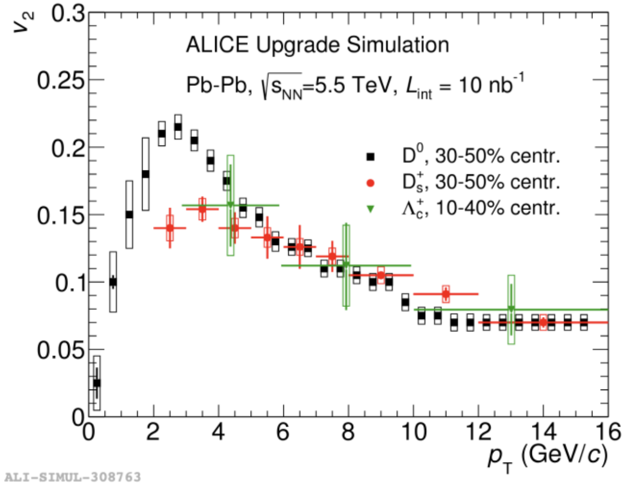
***LHCb:*** 0.46 $nb^{-1}$ of good recorded PbPb data in 2024 will allow to obtain unprecedented results in the forward region, including ultraperipheral collisions, collective flow, quarkonia, open charm and open beauty production the large statistics enables new studies in the beauty production in heavy ion collisions

- Wish to integrate order 2 $nb^{-1}$ of PbPb collisions in the whole Run 3
- Unique opportunities given the concurrent fixed-target data-taking with injection of Ar in the SMOG2 cell
- ***LHCb on pPb***: interested in pPb+Pbp (both!) if statistics is sufficiently large (0.3 $nb^{-1}$ total in Run3)

***ALICE:*** the total statistics of 6.5 nb-1 Pb-Pb collisions expected in Run 3 will significantly extend the ALICE physics reach, in particular from the measurement of $R_{AA}$ and collective flow of charm and beauty hadrons, the reconstruction of thermal photons from low-mass di-leptons, the extension of charmonium measurements to higher mass states, or the study of hyper-nuclei production with the inclusion of more rare states.

- Minimal target for full Run 3 is 6.5 $nb^{-1}$ delivered
- Example: elliptic flow parameter $v_2$ of charm baryons
  - Very well measured for light flavour hadrons and D-mesons, but never measured for charm baryons
  - A first measurement of $\Lambda_c$ $v_2$ would provide important insights for the characterization of the quark-gluon plasma.



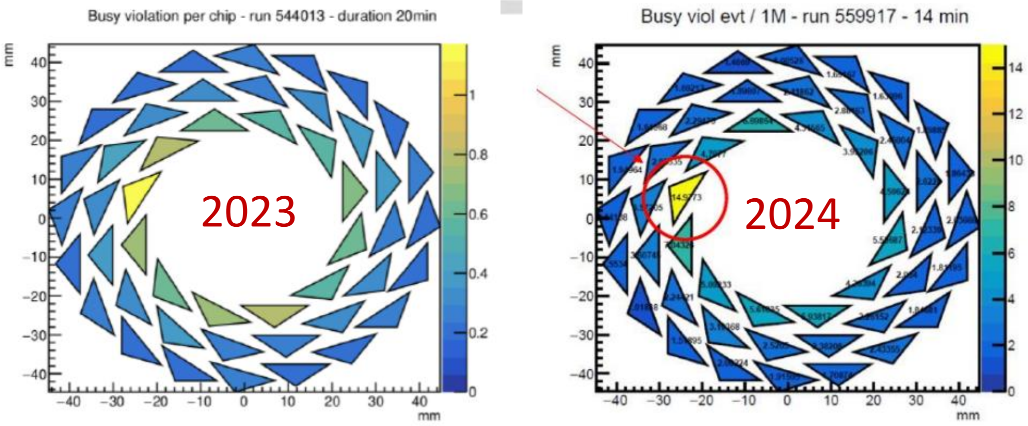




- ***ALICE on pPb***: interested even if it is a short run (>150 $nb^{-1}$), after collecting PbPb targets

# ALICE (and LHCb) background in PbPb

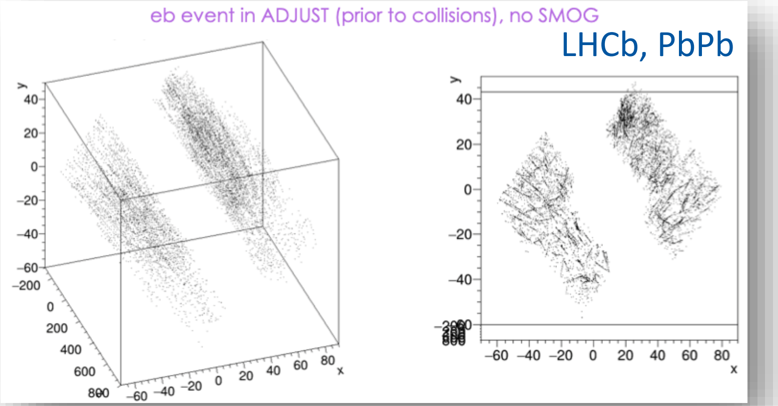
***ALICE:*** Residual Pb beam background from 2024 run being analysed in detail

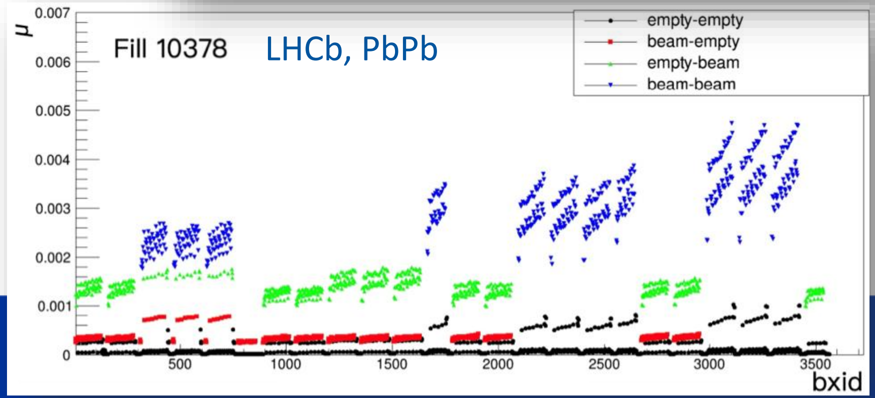
- Source not yet understood, ALICE strongly encourage further efforts to better understand its origins
- Impact on the detector acceptance not completely negligible, we strongly support the study of further mitigation measures
- Pb-Pb VdM (and pp reference VdM) suffered from baseline drifts in the LSC . Mitigations welcome.




***LHCb:*** observed events with very high occupancy already in ADJUST, VELO open and not yet colliding. It should not have an impact on physics, but investigation will follow

- Spread in pileup per bunch at the level of 20-30% , noticeable due to large luminosity background subtraction



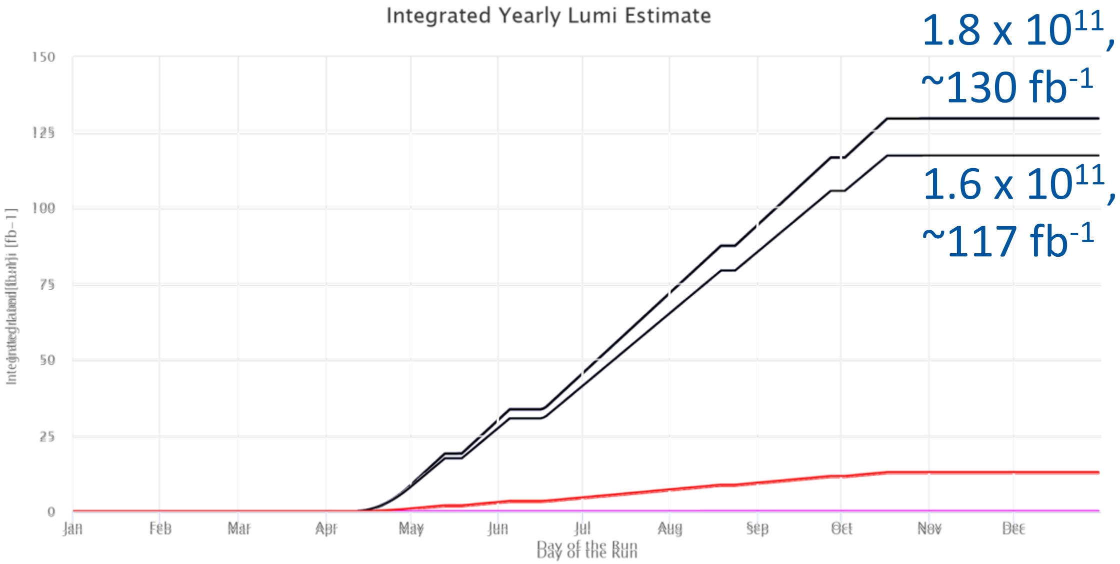
# A word on availability

High availability and high ratio of Stable Beams time is key to high integrated luminosity harvest

- Availability remains the absolute highest priority for 2025/2026 for the experiments
  - → Experiments request that ny foreseeable improvement be evaluated in a conservative fashion with respect to availability
    - It is obviously a difficult exercise to do, and it is made even more difficult by the fact that we have found a high availability (and stable…) point so moving away from it implies – taking a risk. Question is: how big of a risk?

Proton and PbPb production are already at the level needed to reach integrated luminosity targets. Nevertheless, experiments are supportive towards machine improvements for 2025/2026:

- Increasing intensity per bunch is welcome, provided commissioning time and foreseen risks are low and availability is not impacted more than the projected increase in performance, keeping conservative margins and large safety factors
- PbPb improvements are also very welcome (smaller X-angle, smaller β*) to provide larger margins in availability, if they do not imply increased commissioning or decrease of PbPb time availability.
  - Unfortunately, the PbPb MDs that could not be done end of 2024 cannot provide input to the decision.
  - Also, do not forget impacts on detectors: i.e. ATLAS ZDC asks for impact on crossing angles if lower β* chosen in PbPb

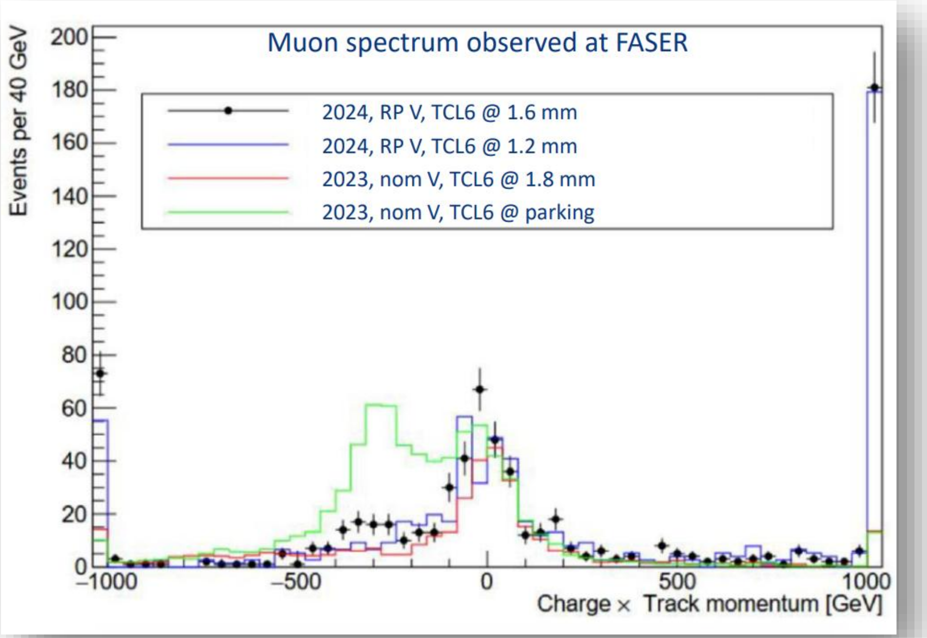



→ Going from $1.6 \times 10^{11}$ to $1.8 \times 10^{11}$ provides ~10% increase in integrated luminosity

# FASER & SND Background Studies

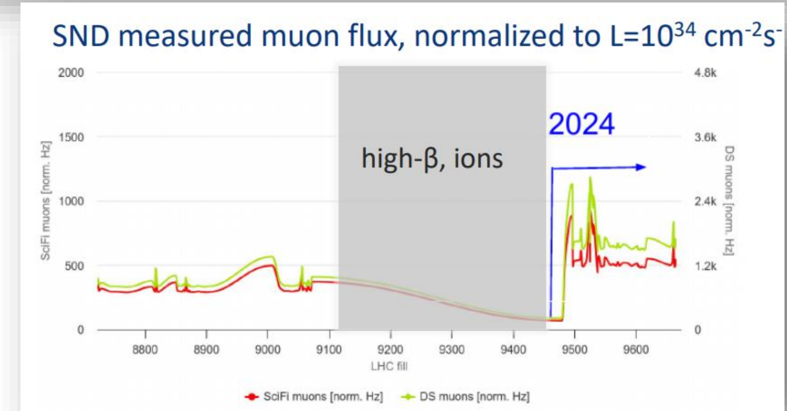
As previously reported FASER & SND suffered from higher backgrounds in 2024 due to the “reverse polarity” optics at IP1.
→ See Roderik Bruce at LMC for more details

- The increase observed was a factor ~2 higher and was also high E muons that leave multiple tracks in the emulsion.
- The electronic parts of both detectors could cope with this increase but further increases could lead to significant dead-time, and additional disk-space was required by both collaborations.




The emulsion detectors can only take a given track occupancy before they need exchanged.

- With the increased background FASER could only take a maximum of ~13 $fb^{-1}$ rather than 30 $fb^{-1}$.
  → FASER therefore only recorded 34 $fb^{-1}$ out of 125 $fb^{-1}$ in 2024 (2 emulsions)
- SND installed emulsions only in the lower sections (65% acceptance) and had 9 emulsions with 8-13 $fb^{-1}$ per emulsion.
  → This meant exchanges more frequently than every 2 weeks by the end of the year, implying quite a load on the experiment operations




→ Further increases in the background will kill both experiments emulsion physics programs as the emulsion replacement will become operationally unfeasible

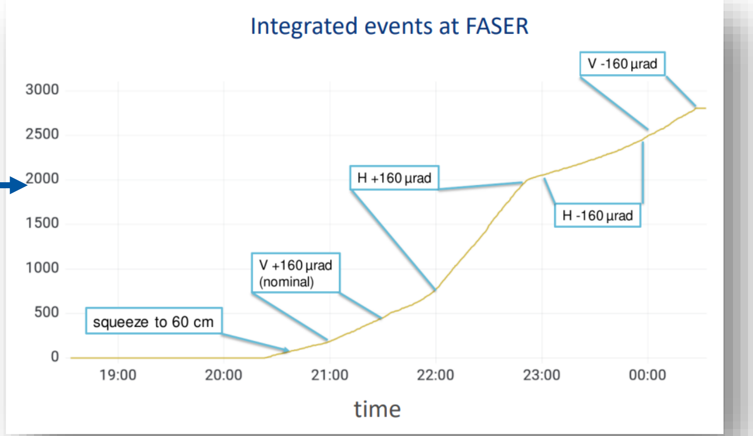
# FASER & SND Background Studies

Major simulation effort set up during 2024 to tackle this problem!

- A huge thank you for the investment in the problem and the commitment to look for a solution
- Unfortunately, no mitigation was found.

Multiple initial tests with beam were done to try different optics at IP1 to see the changes in the background

- RP-V+ (current), RP-V-, RP-H+, RP-H- (although this is not practical) were tested.
- RP-H+ was seen to increase the background by a factor of 2.3 (FASER) / 1.5 (SND).
  - Changing the sign of the vertical crossing angle made little difference.

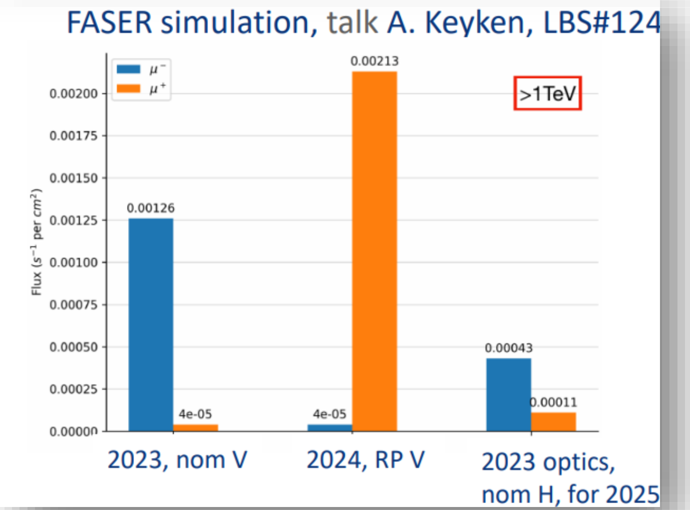



A second set of tests were to try to introduce a bump to reduce the background without changing the configuration.

- The idea was to bump the beam up with one corrector and then down again with a later magnet, while the lower energy muons would get larger bumps and miss the second magnet.
- Only a 10% reduction could be achieved with this method
  → it simply isn't possible to fix the high background configs.

Simulations of the background now could reproduce the trends.

- Simulations of Nominal-H+ show background levels similar or slightly lower than in 2023 (but not possible to test in LHC in 2024).
- Good general confidence this is the best solution possible for FP experiments

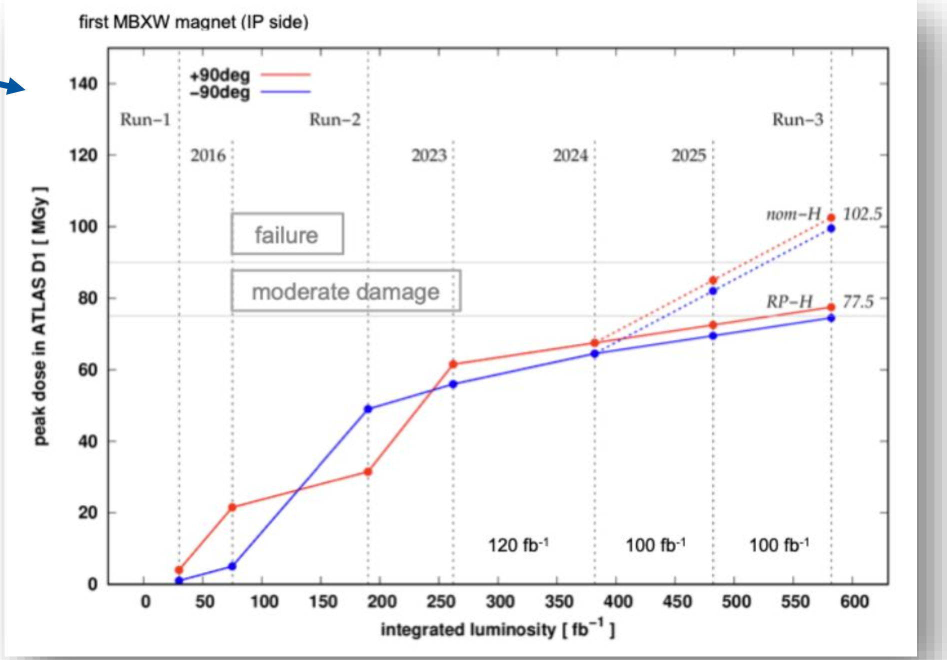


# Experiment feedback on 2025/2026 optics

Optics for 2025/2026 were chosen: Nominal Horizontal in IP1, RP Vertical in IP5.

- This implies that CMS PPS needs to be rotated in IP5 and this is being implemented.
- Latest simulation output shows a dramatic background improvement at the location of FASER/SND/AFP wrt to 2024 and an even better situation wrt to 2023 (Nom-V in IP1)
  - FASER and SND consider such choice the best possible configuration for 2025
  - ATLAS also supports the optics choice (NOM-H) which preserves the ATLAS forward physics program

- Experiments understand and acknowledge that the D1 magnet at IP1 remains at risk in this scenario:
  - Possible replacement was discussed, ATS management post-poned this to YETS25/26.
  - Mitigation in the event of failure of the 1st D1 magnet is possible with the other 5 magnets. This does require using a less reliable power converter and would require new optics corrections, and an intensity ramp-up.
- See Stephane Fartouk's LMC presentation on the optics for 2025 and possible mitigations.
  - Aims at using flat optics with 60.0/18.0 cm, and constant X-angle 160 urad to start with in 2025

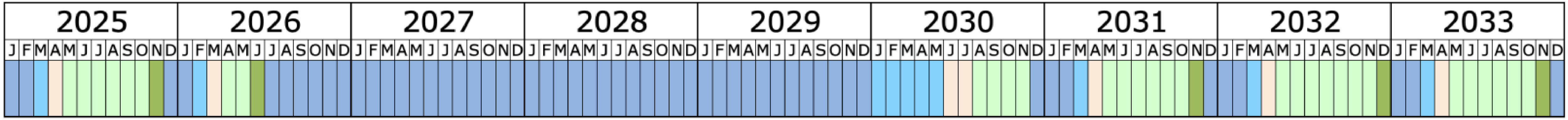


# 2025/2026 schedule

Following Run3/LS3/Run4 schedule change approved at the Research Board on 18th September 2024, LPCs were tasked in preparing an optimized proposal for the LHC schedules 2025 / 2026, with these boundary conditions:

- short YETS 2025/2026
  → LS3C decision taken on 30/10 for a 11-weeks YETS (8th December 2025 @6am to February 23rd 2026 at 6am)

- run LHC until end of June 2026 with Heavy Ion run taking place in June
  → End of Run 3 date on Monday 29th June 2026 @ 6am (LS3C decision)
  → Requirement to have at least one month cooldown period before LS3 (CMS request)



# 2025/2026 schedule

The number of days of proton-proton, heavy ion, machine development and special runs were re-balanced respecting the original ratios from the start of Run 3

- Almost regained all operation days for Run3: initial plan 715 vs actual 696 (-2.6%)
  → Loss of days from incidents in 2022 and 2023 almost matched by additional running in 2026
- Numbers calculated equalizing *relative loss within* pp, PbPb and MD
  - *pp, PbPb and MD same relative ratio of roughly -4% wrt to Run3 initial plan*
  - *Special Runs got +30% (from 2023) and cannot be rebalanced anymore as leftover Special Runs are incompressible*
- Proton program corresponds to 67% of all operation days, total of 204 proton days for 2025/2026
  - All proton operation physics days with machine with >=1200b
- 50 days assigned to HI program in 2025+2026 : this includes setup (4 days) + intensity ramp-up (4 days) and VdM (1day)
  - 2025+2026 corresponds to ~40% of days of entire HI program of Run3 and ~17% of all operation days
  - Main point of discussions:
    - Split HI runs in 25/26 or single HI run in 26?
      - A single HI run provides 7 more days of PbPb physics days.
        → No single HI run in 25 as it cannot provide cooldown
    - Re-include pPb program in baseline scenario?
      - Experiments showed varying interest in having pPb data however keep priority for PbPb data (i.e. reach targets).
        - A pPb run could either be at top energy of 8.54 TeV or to match the PbPb_NN center of mass energy of 5.36 TeV
      - PbPb ATLAS/ALICE/CMS target set at 6.5 $nb^{-1}$ delivered for full Run3, preferred to reach 7 $nb^{-1}$ recorded (ATLAS/CMS)

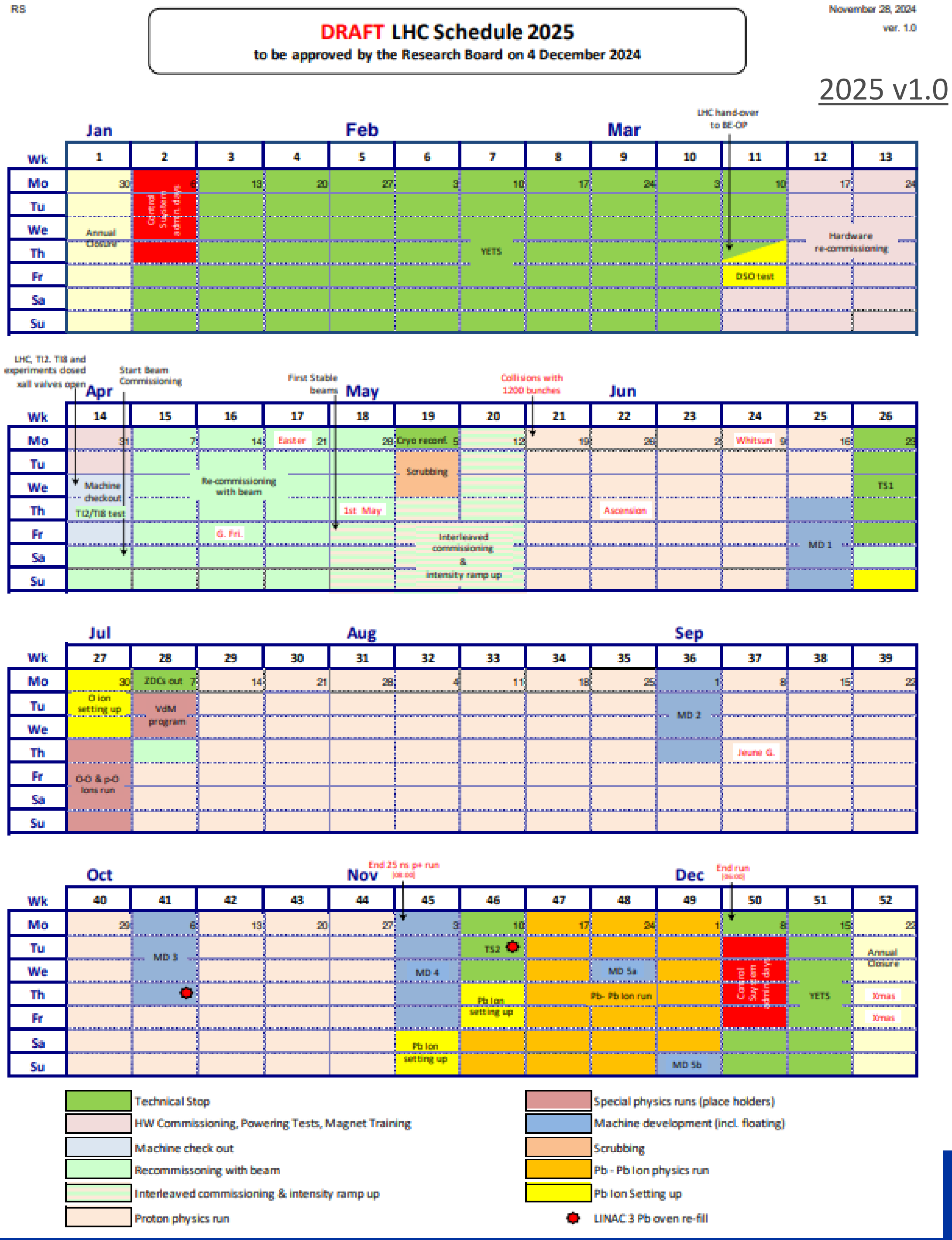
**Research Board directive: any extra activity should not go at the expense of proton physics production...**

# 2025 schedule (approved)

Adopt equal split of ion days between 2025 and 2026

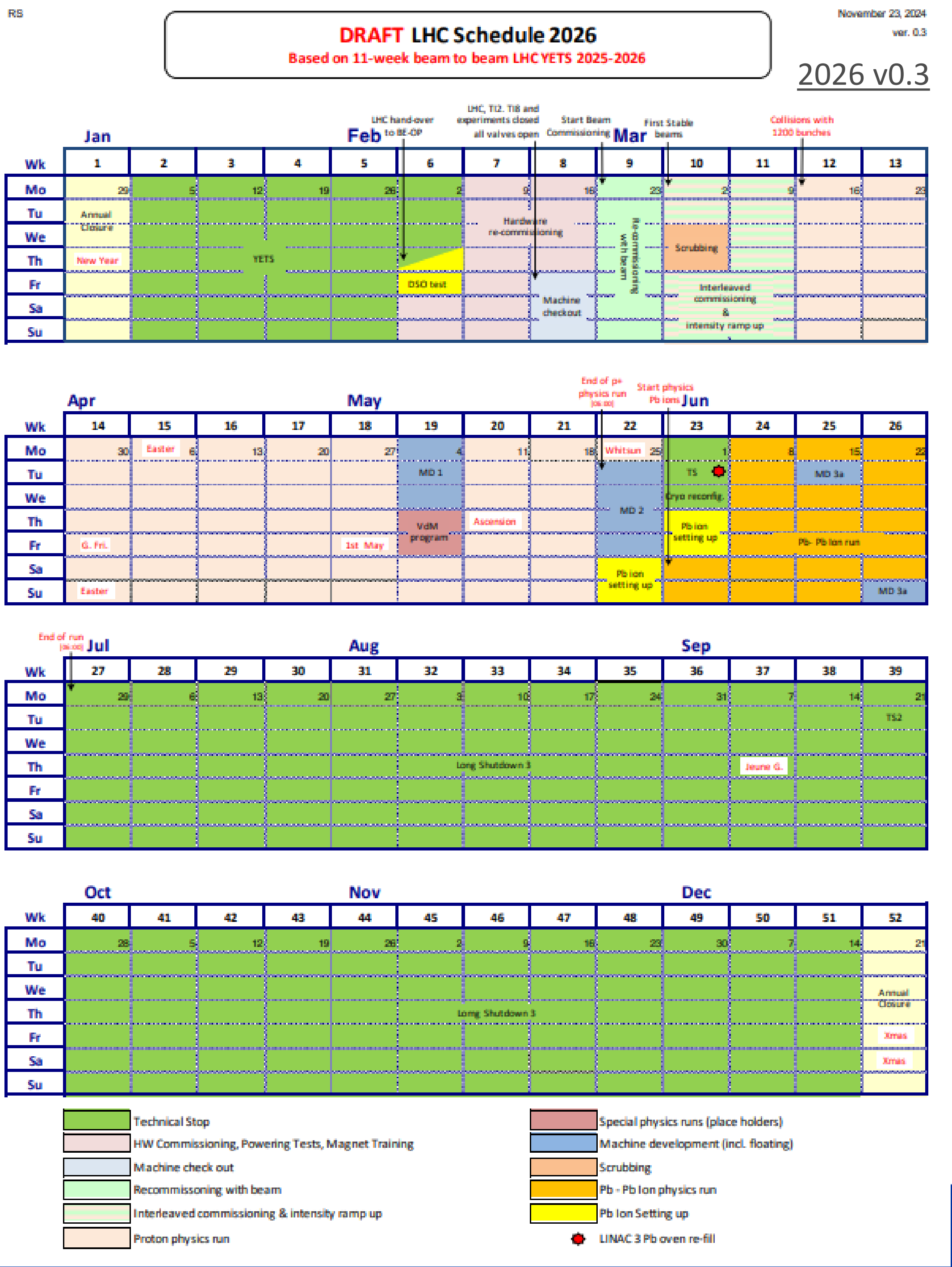
- 138 days proton physics production (>=1200b in machine)
- 2 days pp VdM
- Ion run of 25 days @ end of 2025
  - includes 4 days setup, 4 days intensity ramp-up and 1 day VdM
- no pp reference for PbPb
- Oxygen run after TS1 in 2025, preceded by 4 days of setup
- TS2 needed before ion run
- 2 days of ion setup before TS2
- End of 2025 on 8th December 2025 (6am)

Approved at the RB on December 4th 2024, see R. Steerenberg @ LMC for more info



# 2026 schedule (info)

- 66 days proton physics production (>=1200b in machine)
- 2 days pp VdM
- One week proton recommissioning
  - Supposes no changes in machine configuration (optics)
- Ion run of 25 days @ end of 2026
  - Includes 4 days setup, 4 days intensity ramp-up and 1 day VdM
- no pp reference for PbPb
- TS1 needed before ion run
- 2 days ion setup before TS1
- If 2026 is also PbPb, then knowledge gained in 2025 can be exploited in 2026
- Decision on pPb can be done knowing the outcome of the 2025 PbPb run
  - pPb possible in 2026 as cooldown period
  - if pPb higher energy is chosen, need of a pp reference run of at least 4 days (2 setup)
- End of run 29th June 2026 (6 am)



# 2025/2026 luminosity projections (for info)

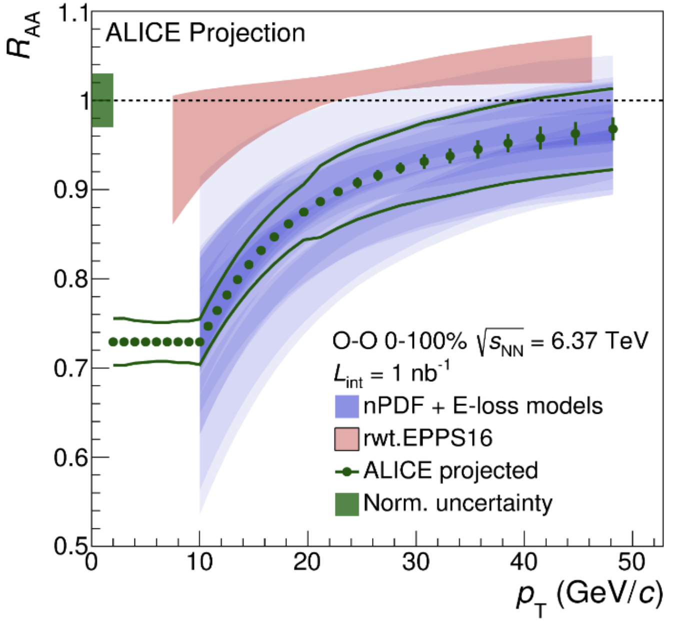
Based on 2024 performance and above scenario, we computed some rough luminosity projections for 2025/2026:

- pp : 180-200 $fb^{-1}$ ATLAS/CMS, 18.3-19.5 $fb^{-1}$ LHCb, 195-200 $pb^{-1}$ ALICE
  - Range between 2024-like performance (0.9 $fb^{-1}$ /day in ATLAS/CMS) and better one (1 $fb^{-1}$ /day in ATLAS/CMS)
    - 2022+2023+2024 ATLAS/CMS = 196 $fb^{-1}$ (>380 $fb^{-1}$ reachable by end of Run3)
    - 2022+2023+2024 LHCb = 12.5 $fb^{-1}$ (>30 $fb^{-1}$ reachable by end of Run3)
    - 2022+2023+2024 ALICE = 117 $pb^{-1}$ (>300 $pb^{-1}$ reachable by end of Run3)
- PbPb : 5.2–6.5 $nb^{-1}$ ATLAS/CMS/ALICE, 1.4–1.7 $nb^{-1}$ LHCb (No pPb run included in these estimations)
  - Range between 2024-like performance (0.15 $nb^{-1}$ /day in ATLAS/CMS/ALICE and 0.04 $nb^{-1}$ /day in LHCb) and better one (0.18 $nb^{-1}$ /day in ATLAS/CMS/ALICE and 0.047 $nb^{-1}$ /day in LHCb)
    - 2023+2024 ATLAS/CMS/ALICE = 3.9 $nb^{-1}$ (6.5-7.1 $nb^{-1}$ delivered by end of 2025)
    - 2023+2024 LHCb = 0.25+0.5 $nb^{-1}$ (1.45-1.6 $nb^{-1}$ delivered by end of 2025)
- pPb : 200-300 $nb^{-1}$ ATLAS/CMS , 65-100 $nb^{-1}$ ALICE/LHCb at sqrt(s) = 8.54 TeV
  - Very optimistic numbers based on simulation assumptions, needs extra commissioning to be clarified
    - If higher energy is chosen, need a pp reference run (ALICE limiting on integrated luminosity)
    - If lower energy chosen, integrated luminosity numbers will reduce but no need for extra pp reference run

  → Schedule allows to postpone decision on pPb to 2025 (or 2026…) after statistics on PbPb collected

# 2025 special runs

Charged particles $R_{AA}$ (nuclear modification factor) in O-O collisions
Assuming $L_{int} = 1\ nb^{-1}$ (ALICE)



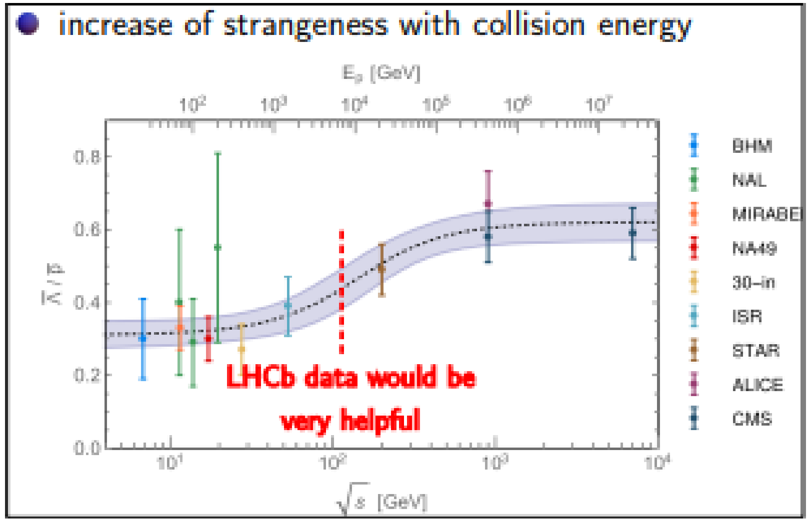

## Oxygen run now scheduled for 2025, after TS1

- Targets:
  - 0.5 $nb^{-1}$ in OO (all exp, 1 day, very challenging for LHCb)
  - 2 $nb^{-1}$ in LHCb and 1.5 $nb^{-1}$ in LHCf in pO (3 days max, p in beam1)
- Re-use PbPb optics for both OO and pO, minimizing commissioning time
  - To follow-up, running conditions (in particular β*) in LHCb and LHC
- Very difficult to add extra time to the run given the priority to pp

## LHCb requests Stable Beams at 450 GeV with VELO fully (or almost, 2mm minimum) closed for fixed target program

- Currently requested for 2025 which allowed for more studies regarding aperture, even though it is in fact a long-standing request since Run2
- Requested one shift data taking, ideally with no extra commissioning required. Inject SMOG2 (He) for anti-proton production studies.

→ currently, aperture does not allow to go down to 2mm keeping safety aperture margins: need LHCb squeeze be done at 450 GeV "for free"… ☺. To be discussed.



# Conclusions


2024 was a hugely successful year, where all targets and goals were achieved!

- Impressive commitment, dedication and competence shown by the accelerator colleagues!
- **A huge thank you on the behalf of the experiments!**

→ Availability has been a key factor throughout the full year amounting to >70% with ~50% of time spent in SB

→ Due to the change of optics a physics penalty for FASER (major) and SND (mitigated) experiments incurred, and high radiation levels at the AFP location near ATLAS generating issues for the AFP detector.

  - Extensive background studies were performed educating the decision on the optics scenarios for 2025/2026

Machine performance and feedback from experiments is very positive, only a few minor issues to be looked at

- Experiments are supportive of machine performance improvements in 2025/2026, provided it does not affect availability and integrated luminosity and request proposals are considered with conservative margins
- Highest priority remains integrate a large sample of data to reach 400 $fb^{-1}$ in Run3 in ATLAS/CMS and >25 $fb^{-1}$ in LHCb.
- PbPb performance also dramatically improved, experiments wish for >6.5-7 $nb^{-1}$ (ATLAS/CMS/ALICE and ~2 $nb^{-1}$ (LHCb) integrated luminosity

A recent LMC decision defined the optics scenario for 2025 to be Nom-H in IP1 and RP-V in IP5

- Such solution is the best compromise between preserving the Forward Physics detectors as well as the machine elements around IP1 and IP5 with the exception of D1 around IP1, which would be at the limit (depending on physics production).
- Wish for 2026 to use same configuration minimizing recommissioning time, but not at the expense of higher risks.

Following the extension of Run3, we worked in defining schedule solutions for 2025/2026

- The scenario where two ion runs, of equal length, are allocated at the end of both 2025 and 2026 was approved at the RB

And let's not forget the slew of VIPs that we happily welcome in the LHC, stopping operations… ☺

*Thank you for all the Champagne I could drink for free!*

# Thank you, my friends, and best of luck!

# First feedback from Chamonix, protons

- Short faults (<1 day) stable at ~16% / year (Run2+Run3)
  - If no major accident, expect good LHC performance
- No limitations from the injectors for LHC Run3 beam parameters
  - BCMS and standard beams to be directly compared in LHC in terms of performance + dedicated MD in injectors
- TDIS replaced with similar (non-conform) modules
  - High temperature readings could occur also in 2024 run. Possible mitigations under study.
    - *If failure occurs, lose ~3 weeks to recover*
- RF fingers and warm module issues failures can occur in 2024 due to degraded contact fingers/transition tube
  - No intensity threshold can be estimated due to the strong dependence on contact quality
    - *If accident repeats, lose ~1 week*
  - Bunch length (1.2ns -> 1.3ns) can play an important factor reducing the risk
- Partial Reversed Polarity considered as the baseline for 2024 operations
  - Optics being prepared, confirmation of baseline at one of following LMC
- E-cloud compatible with pure 5 x 36b filling scheme up to 1.8 x $10^{11}$ ppb after rebalanced cryo
  - Proposal to start with pure 36b trains, after confirmation of cryo margins. If heat load reached, back to hybrid
  - Proposed not to go beyond 2.2x$10^{34}$ cm$^{-2}$ s$^{-1}$ to avoid entering risky zone in cryogenics limits
- Reaching 1.8 x $10^{11}$ ppb (12.5% intensity increase) could provide a +9% in luminosity production
  - → Possible intensity strategy in 2024 (and 2025) to be discussed

# First feedback from Chamonix, ions

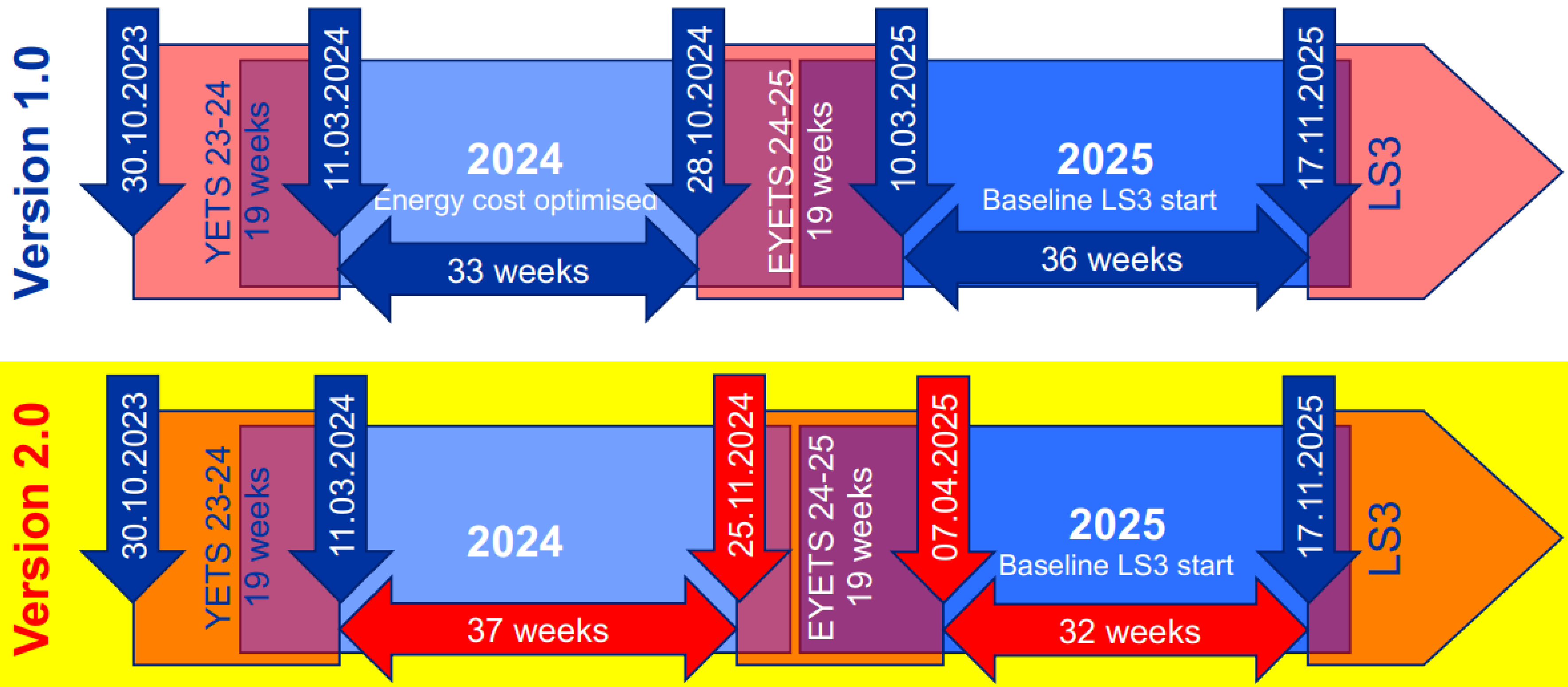
- Many major achievements in 2023
  - 50ns slip-stacked successfully setup. Crystal collimation cleaning performance demonstrated. TCLD collimators + BFPP bump in IR2 increasing ALICE luminosity by factor 6. BFPP bump in IR8 allowing for higher LHCb luminosity
- LHC beam performance saw degradations reducing overall performance
  - 56b-trains with 6 out of 7 injections from LEIR. Degradation of beam quality over time. Radiation effects on quench protection system. Bunch intensity reached target only in a few fills. 10Hz losses. ALICE background.
    - Estimated that ~1.5 $nb^{-1}$ was lost in 2023 due to encountered problems
- Highest priority in 2024 and 2025 is maximize integrated luminosity
  - Action plan being put in place to overcome 2023 performance limits
  - First, mitigate encountered problems : increasing availability is the most critical aspect
    - 2024 possible configuration assumes same β* and crossing configuration as in 2023
    - Estimated production in 2024 (18days - 1 ppref - 1 extra MD day): 1.2-1.6 $nb^{-1}$ in IP1/2/5, 0.16-0.2$nb^{-1}$ in IP8
- Minimize risk of new problems : avoid new untested concepts in 2024, potential performance improvements in 2025
  - Intensity increase could give sizeable boost. Try to push intensity already in 2024, more commissioning in injectors.
  - For 2025: crossing angle reduction in IP1/2/5, reduction of β* in IP1/2/5 (<50cm) and IP8 (β* = 1m, TBC), different injection/filling scheme to give more colliding to LHCb with no penalty at ATLAS/CMS/ALICE.
- Oxygen test in injector successful, targets already reached. Run scheduled in LHC in 2025.
  - Use same optics as PbPb in 2024. OO target difficult to LHCb, pO targets reachable in 2.5 days.

# pp running conditions recap

- Bunch intensities limited to <= 1.6 x $10^{11}$ ppb at Stable Beams
- Cryo margin limited to <= 185 +/- 5 W/hc in S78
  - Initially estimated to be <= 215 +/- 5 W/hc in S78: 10% lower than anticipated
  - Slight conditioning observed, gain a few W/hc
- 3x36b trains allowed at full machine
  - 2340 colliding in ATLAS/CMS, 2133 in LHCb
  - Lower Flat Bottom at SPS allowing for BCMS beams and improved beam brightness
  - Started with 3x48b as they provide shorter SPS FB, but could not fill the machine due to lower-than-expected cryo limits
- Started with standard 25ns beams then switch to BCMS beams in week 21
  - Provide better emittance, roughly 10-15% better
- $\beta^*$ levelling down to 30cm
  - Solution for collimation hierarchy problem after TS1
- TCL6 collimators at 1.6 mm opening to minimize impact on FASER/SND
  - Background increased by factor 2 and high energy muons provoking even more background
  - AFP radiation levels increased, balanced vs possible SEU effects on LHC electronics

# 2024/2025 shift in schedule

Agreed at LHC Machine Committee 10/04/2024 on linear shift of 4 weeks with respect to previous schedule



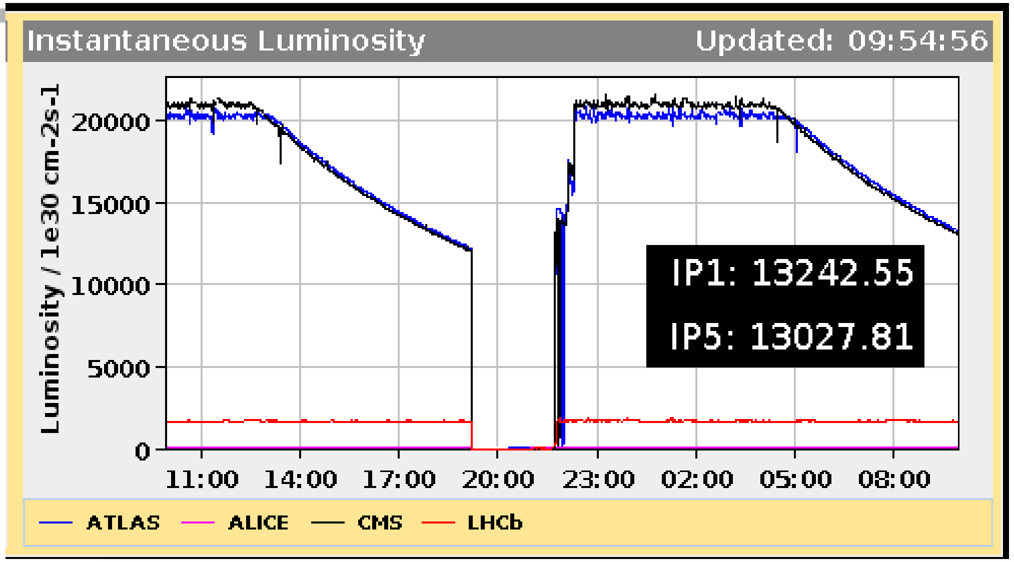

- LHC: 4-week YETS shift, 19 weeks length maintained
- Injectors: 5-week YETS shift, reduction by 3 weeks

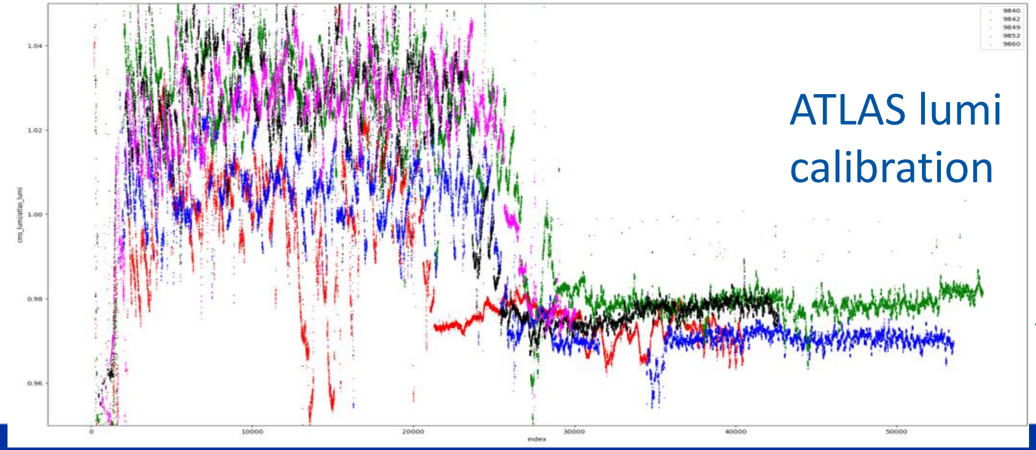
# ATLAS/CMS luminosity imbalance (head-on)

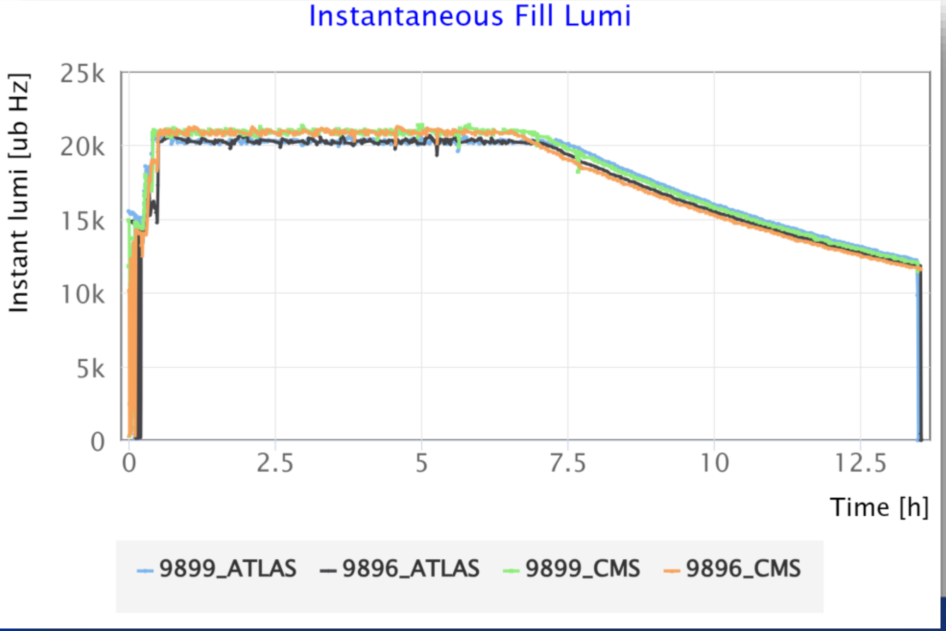
Latest changes/considerations:

- CMS luminosity calibration -4.4% post-2024 VdM.
  - However, this is not the full analysis, so it may bear a larger uncertainty (2%)
- CMS luminosity calibration regular updates +1% due to radiation effects
- ATLAS luminosity calibration update to -1.5%
- No differences between BCMS beams
- Evidence of similar emittance evolution H vs V (V always slightly worse)
- Currently sitting at -1.5% difference in favour of ATLAS when head-on

→ Difference is currently within uncertainty, no correction is anticipated

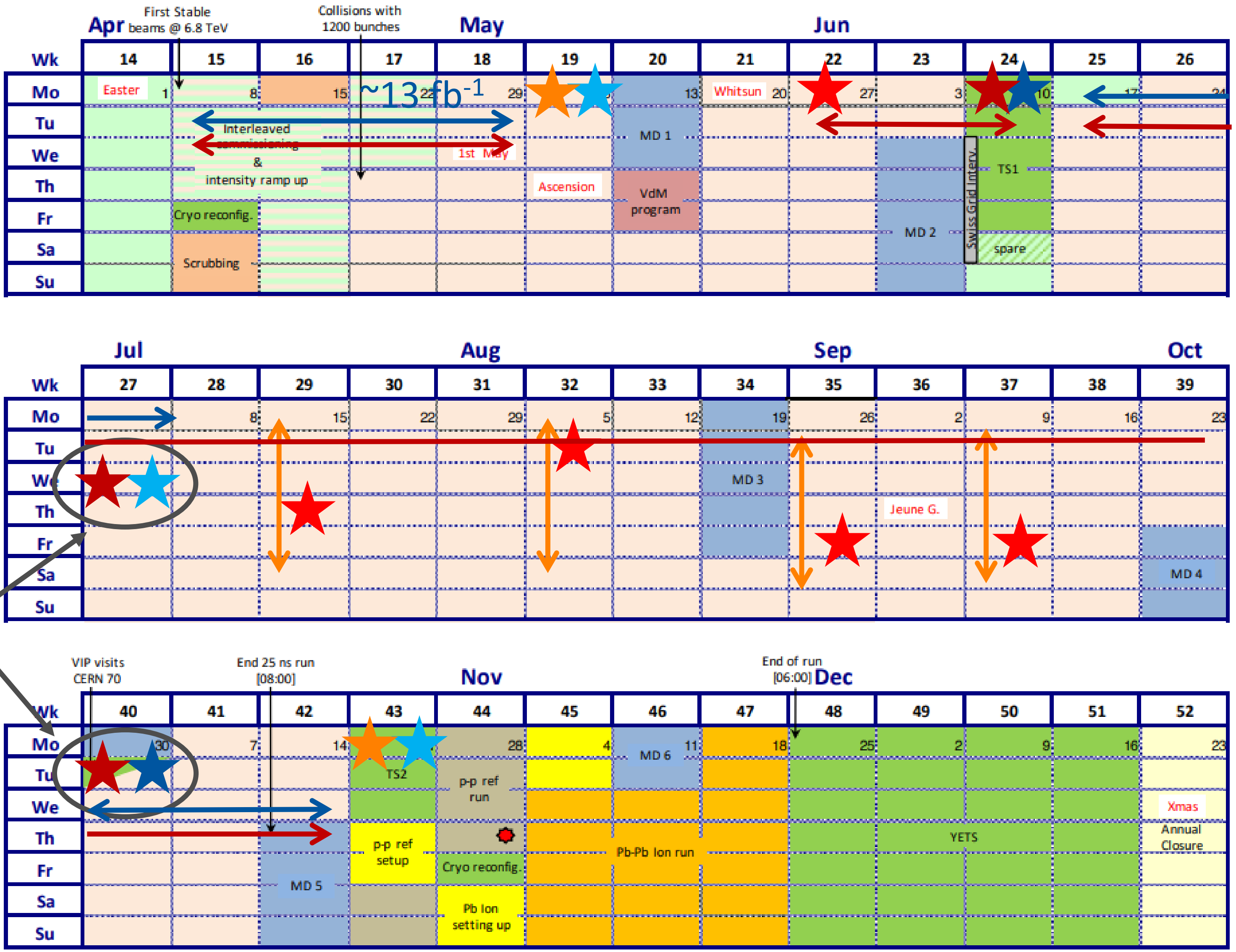


# FASER/SND emulsion exchanges schedule – plan

1st installation in March (SND full target)




Already planned accesses

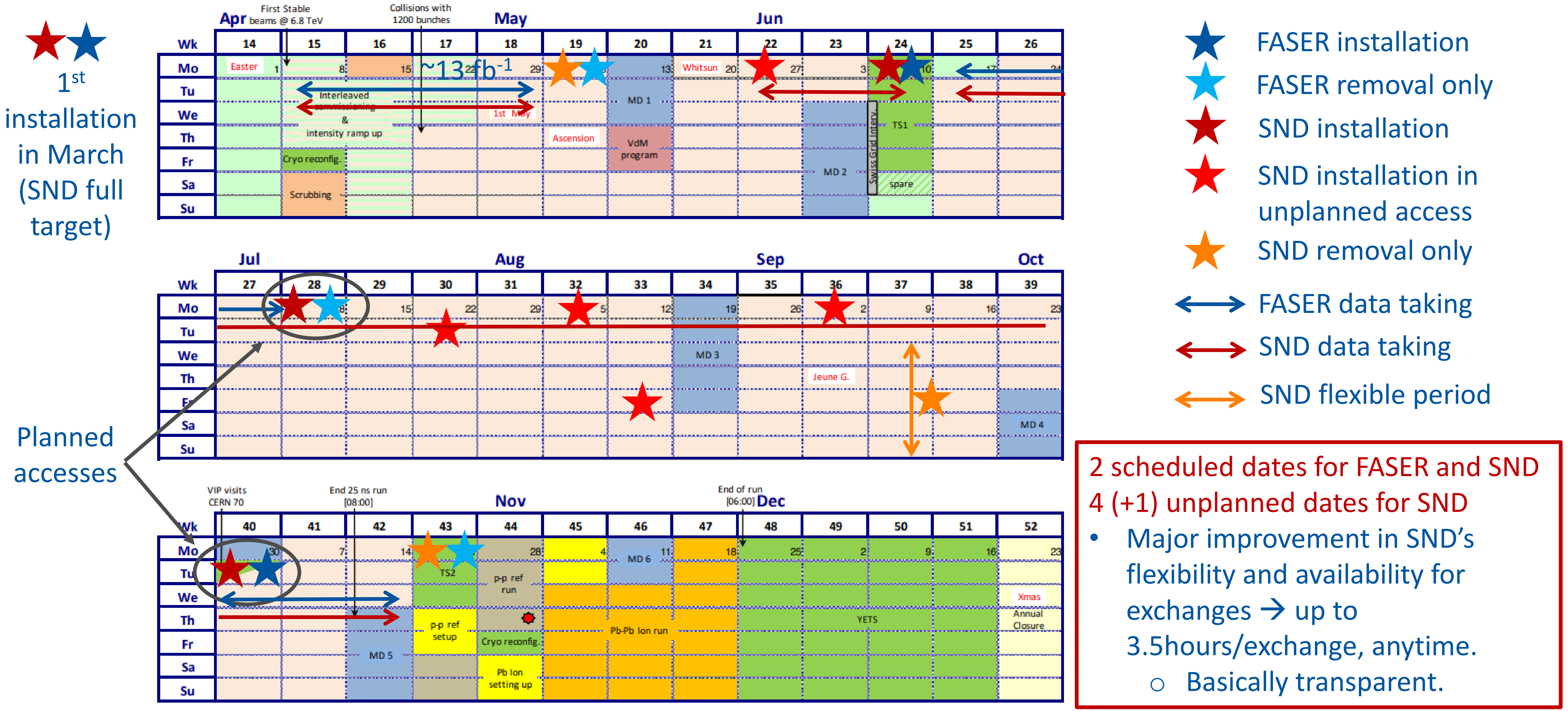
- FASER installation
- FASER removal only
- SND installation
- SND installation in unplanned access
- SND removal only
- FASER data taking
- SND data taking
- SND flexible period

2 scheduled dates for FASER and SND

- 1 to be planned independently of any other access
- 1 in shadow of CERN's 70th bday stop

4 (+1) unplanned dates for SND

# FASER/SND emulsion exchanges schedule – realized




2 scheduled dates for FASER and SND
4 (+1) unplanned dates for SND

- Major improvement in SND's flexibility and availability for exchanges → up to 3.5hours/exchange, anytime.
  - Basically transparent.

# FASER/SND emulsion exchanges

Lower limits on emulsion exchanges due to background produces strain on scheduling

→ With an average of 5-6 $fb^{-1}$ / week at the LHC, an emulsion box can only stay in for ~2 weeks

→ On the positive side, FASER/SND are now synchronized with their limits

Status of boxes to be installed in 2024:

- FASER has now two emulsion boxes left: 1 target has taken ~13 $fb^{-1}$ of data
- SND has decided to install half emulsion boxes (see backup slide) and they purchased an extra one
  → left with 7 emulsion half-boxes: 1 full target has taken ~13 $fb^{-1}$ and one half-target is currently taking data

Proposal and policy agreed with FASER/SND:

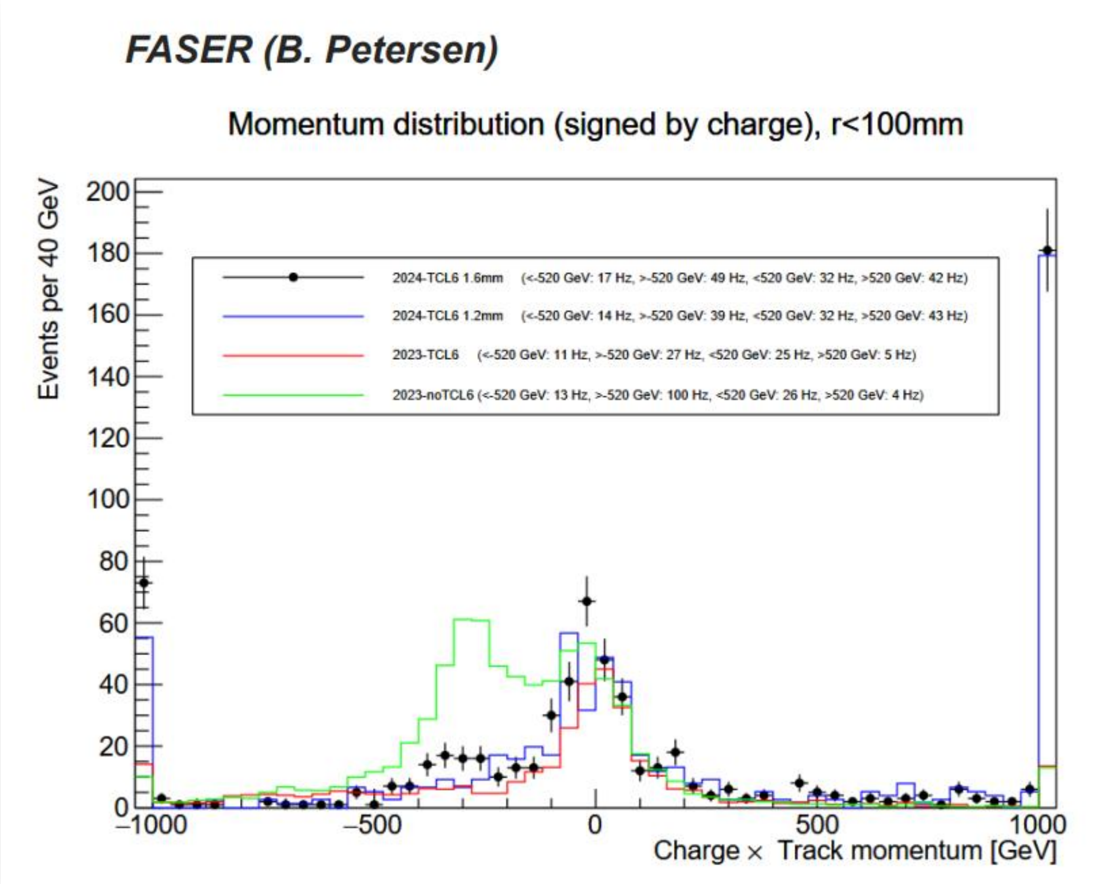
- SND installed another half-target on 27/05/2024 in // to a cryo stop in S12
- FASER and SND to install another box/half-box respectively in TS1
- Schedule an access two weeks later for FASER/SND independently of any other request (but experiments can still profit from it): FASER removes box and does NOT install another one, SND installs another half-target box
- FASER and SND to install another box /half-box in CERN's $70^{th}$ birthday stop (01/09/2024)
- SND to install other half-boxes in unscheduled accesses (4 remaining). Requires extra flexibility:
  - In the case of a planned access, be ready within the previous 48 hours
    - Flexibility in fact really depends on CERN transport EN-HE → require "ready to go" teams
  - In the case of an unplanned access, quick access to remove targets if urgent, then deal with transport later. Train SND people to do the transport themselves. Store boxes in HL-LHC gallery.

# FASER/SND background and TCL6 settings

Reminder: the background rate at FASER/SND increased by more than a factor 2 following the introduction of the new optics for the Partial Reversed Polarity

Background tests for FASER over Easter for different TCL6 settings, with complementary tests for TCL4 and TCL5

- TCLs have little impact on the FASER and SND background rates
- The background increase is driven by TeV scale muons, originating from IP region before Q4
- In agreement with FLUKA simulations which indicate an origin before TCL4
- Main culprit is still unknown. Initially thought to be Q4 being OFF that does not sweep anymore muons away from FASER/SND, however, recent studies seems to point to a source in between IP and TAN
- TCL6 setting at 1.6mm, balancing R2E effects




Since last LHCC , multiple experts and studies tackled this issue

# FASER/SND background simulations

Dedicated MD (MD12844) to specifically cross check simulation (see LBS122) vs observations

- Make sure the simulation is sufficiently reliable for future studies and to drive decisions
- Tested various configuration to look for possible mitigations to be implemented in 2025++
    - Note: even if found, not possible to implement in 2024 as it would imply a full machine revalidation
    - Currently, no solution was found that can mitigate the situation. FASER/SMD preference is no-RP optics (as in 2023) for 2025.


SND and FASER background measured in different configurations:

- V xing +160 urad (21:00 - 21:48):
  429 / 48 / 5.32 counts / min / (avg. lumi) = 1.68
- H xing +160 urad (22:02 - 22:49):
  1130 / 47 / 6.28 counts / min / (avg. lumi) = 3.83
- H xing -160 urad (22:56 - 23:55):
  403 / 59 / 6.45 counts / min / (avg. lumi) = 1.06
  → Lower background but not operationally feasible and reduces signal to SND
- V xing -160 urad (02:00 - 00:27):
  291 / 25 / 6.11 counts / min / (avg. lumi) = 1.91

Unfortunately, could not complete one final last step/configuration (vertical bump in the orbit)

→ Strong support to complete this final test: half-shift injecting 2 colliding bunches within safe beam limit

Investigations will continue in conjunction with early simulation of dose deposit at limiting elements around IP1 and IP5.

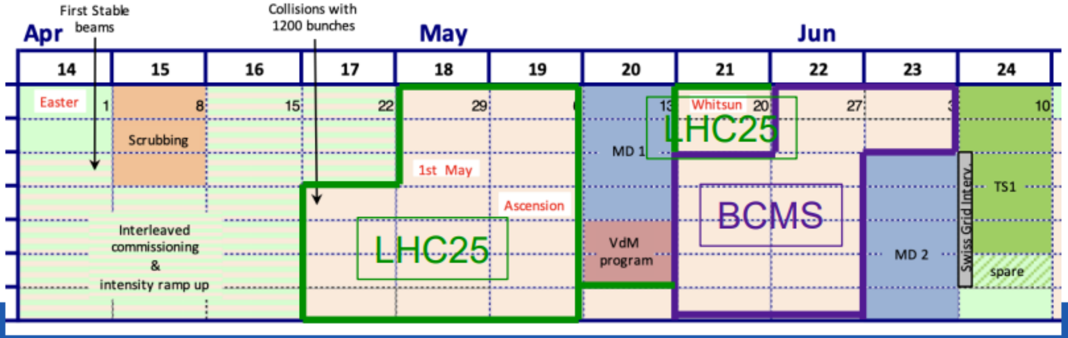
→ Open to testing other suggested configurations that are being worked on by accelerator physicists

# Standard vs BCMS* beams

## Proposal (LHC)

Conform to the proposals made in the JAP and Chamonix workshops

- Use 72b LHC25 standard cycle for LHC scrubbing
- Perform LHC intensity ramp-up following LHC scrubbing with LHC25 standard cycle
- Run 2.5 weeks in stable conditions with LHC25 standard
  - In parallel, profit in the injectors to optimise the BCMS cycle
- After MD1 + VdM week, restart with LHC25 until confirmed stable and then switch to BCMS
- Decision point after ~2 weeks stable LHC running whether it is worth to continuing with the BCMS until the end of the 2024 run
  - **With similar performance keep LHC25 standard as LHC physics beam** to save resources and focus on performance improvements for future HL-LHC operation




LMC 28/02/2024 - B. Mikulec 8

LMC 28/02/2024 approved strategy on standard 25ns vs BCMS beams

→ practically there are no consequences for experiments, but BCMS can provide better reach for further performance improvements

→ to be weighted against availability considerations

*BCMS = Batch Compression (and) Merging (and) Splitting.

→ Type of batch generation done at the level of the PS

# Standard vs BCMS beams

## LHC25 Standard and BCMS facts

LHC injection scheme for 2024: 5 x 36 (48) b (72b for scrubbing)

**Standard:**

- Important effort went into optimisation since LIU upgrades and needs to continue for HL-LHC readiness
- Needed at the start of the 2024 run for SPS and LHC scrubbing
- Progressive scrubbing required throughout the year in SPS to be able to reach LIU intensity target
- Triple harmonic in PSB + dynamic working point optimisation expected to improve performance in 2024
- Produced in **2 BPs** by shorter flat bottom in PS (max. 48 bunches)
- 2023 LHC injection issues seem understood and mitigated

**BCMS:**

- BCMS beam not used operationally since 2022 and needs to be optimised (also in view of brightness preservation along the chain)
- ~10% better brightness measured at SPS end of flat bottom for 4 injections and special working point with higher losses
- Produced in **3 BPs** → 4.8 s longer on SPS flat bottom than standard → how much brightness gain remains?
- Longer LHC injection due to longer SPS filling and reduced time for FT physics

→ Need a back-to-back comparison to compare beam performance in LHC as well as SPS scraping needs and LHC injection efficiency

CERN



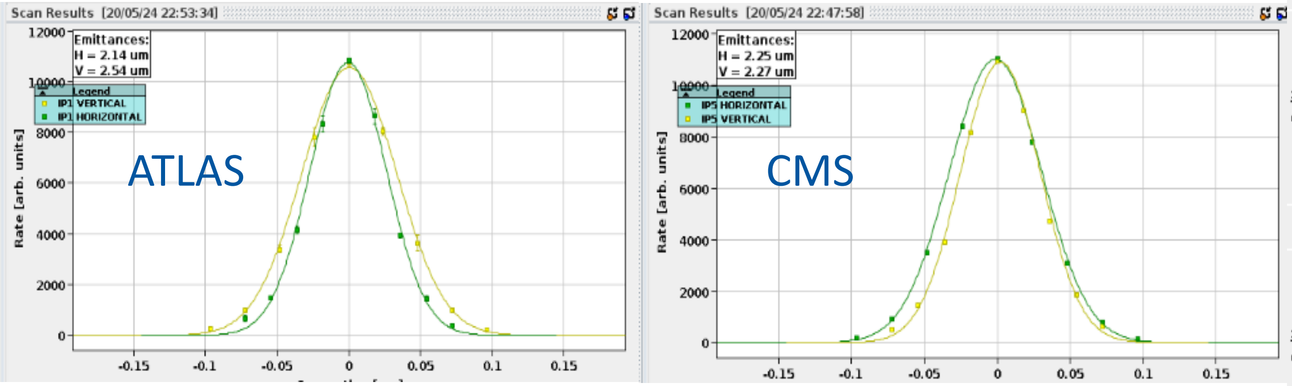
Agreed strategy:

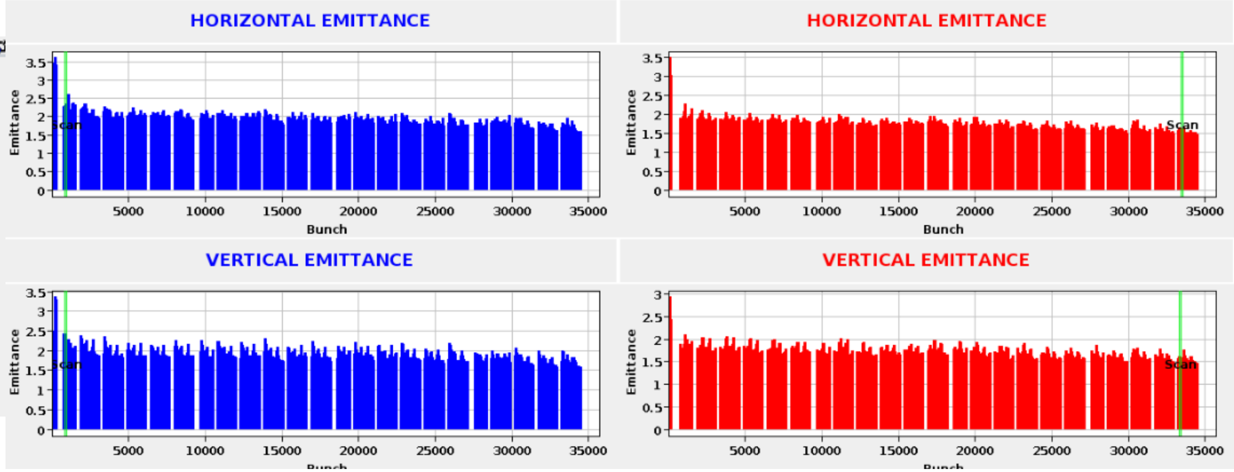
- compare the two beam species at full machine and with full number of colliding bunches for long period of time (10 days)
- allow for work in injectors to tune performance (i.e. try many fills even if initially not better than 25ns standard)

# Standard vs BCMS beams, observations

BCMS injected first in fill 9664 (23/05/2024). After a few fills of tuning, emittance are significantly smaller, < 2um steadily

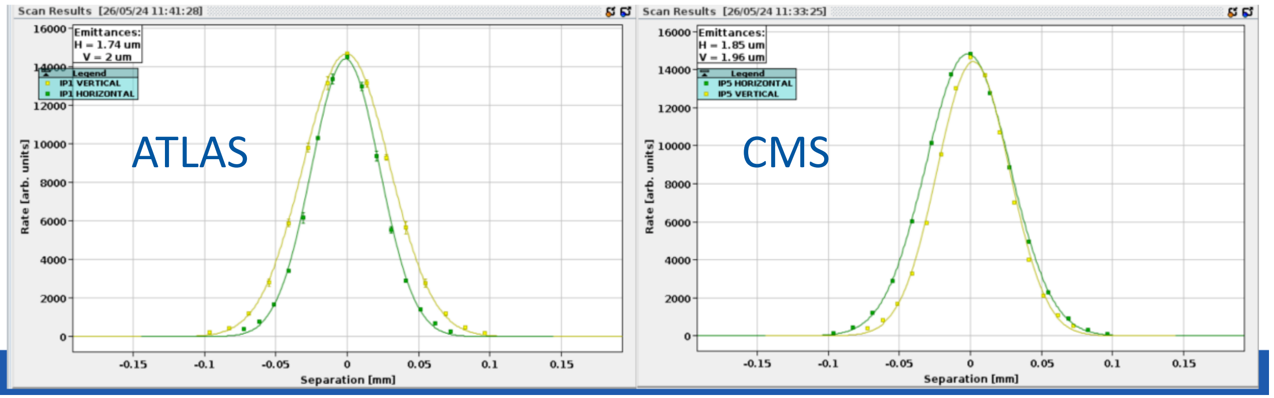
Standard 25ns

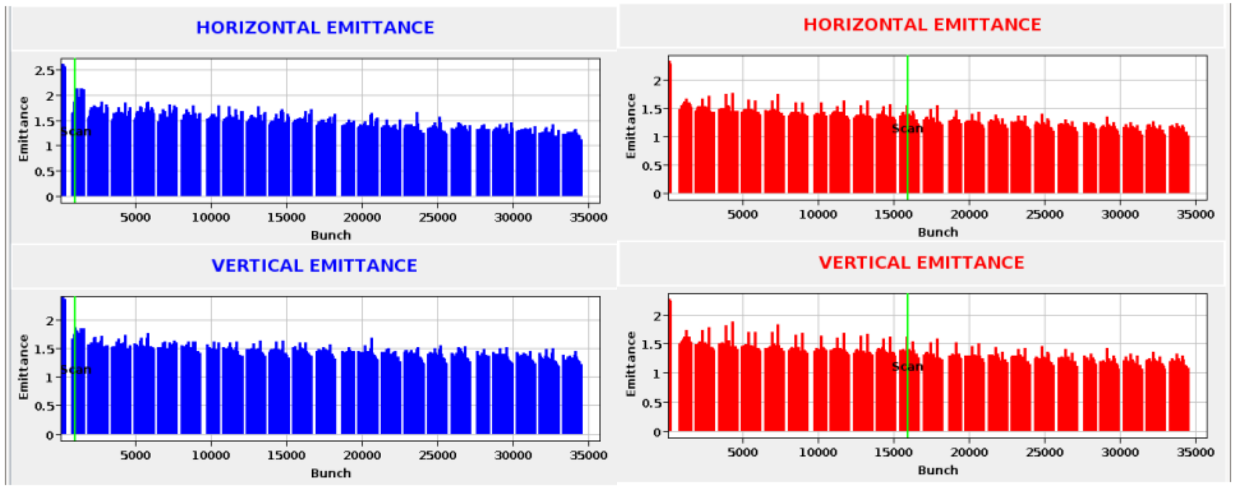



Standard 25ns : 2.1 – 2.5 um, no more improvements expected

BCMS



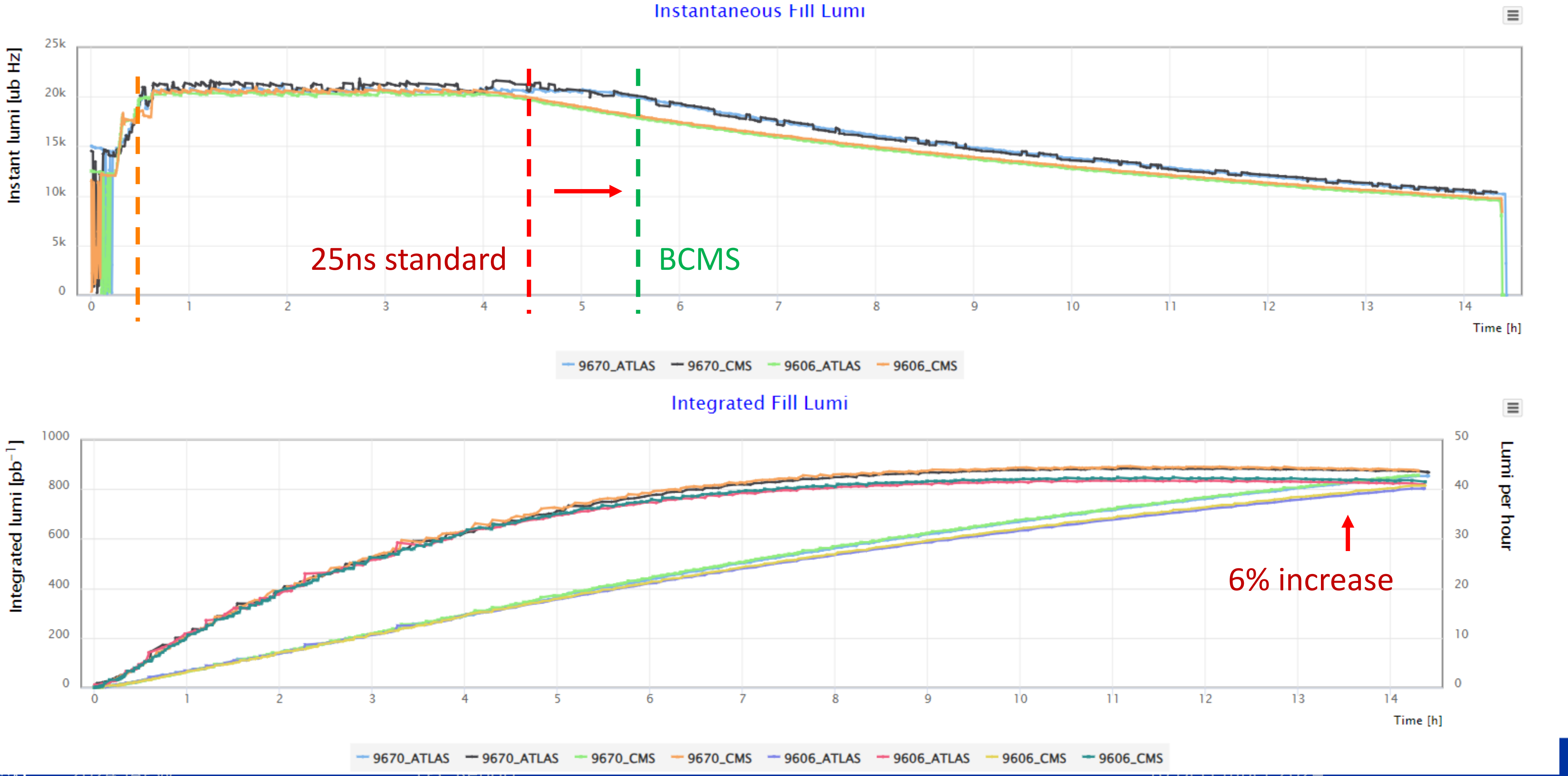




BCMS : 1.7 – 2 um, still improvements expected in spread

# Standard vs BCMS beams, observations

Better brightness in BCMS beams directly translates in higher leveling time: ~25-30% increase

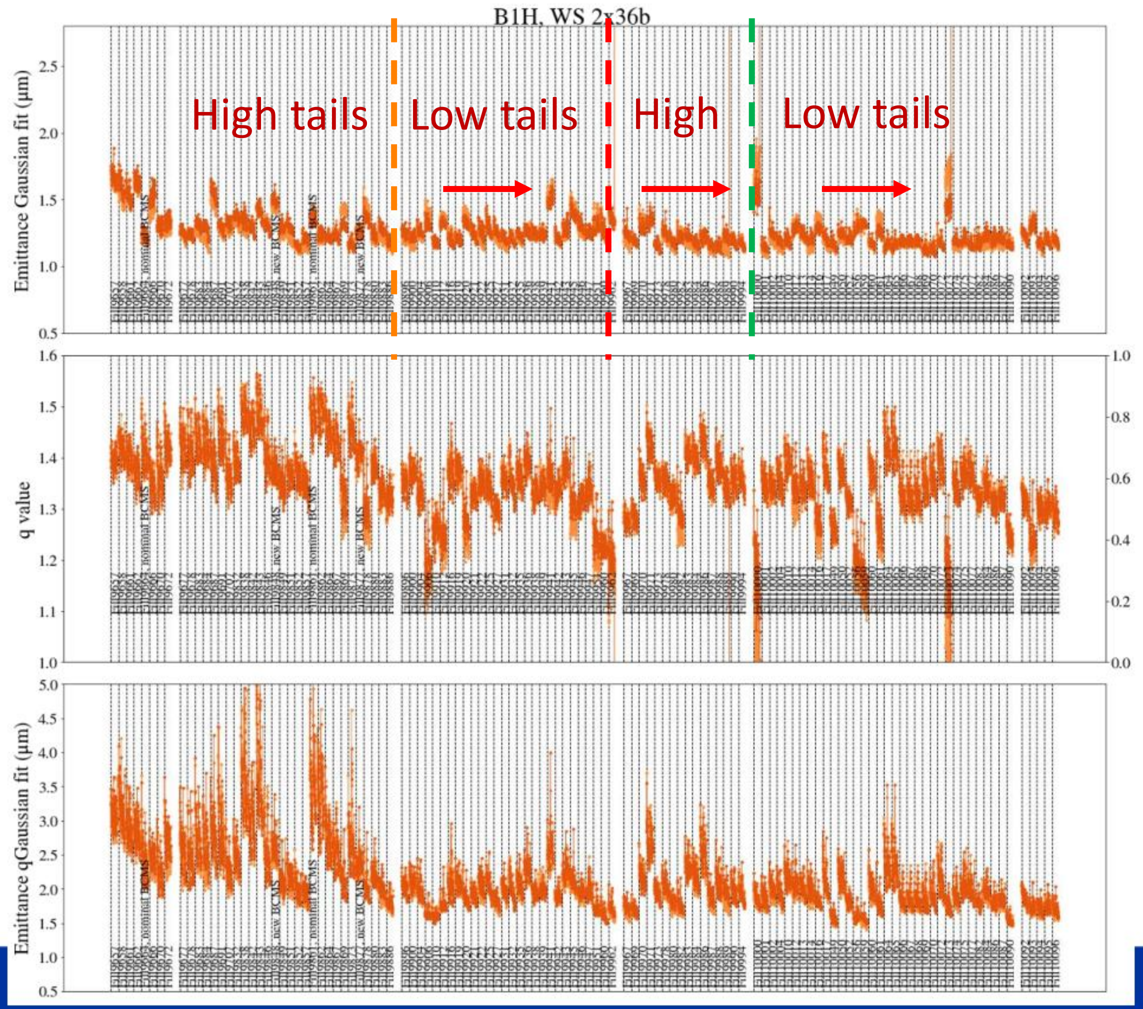
- 6-8% more integrated luminosity → keep BCMS beams in production!

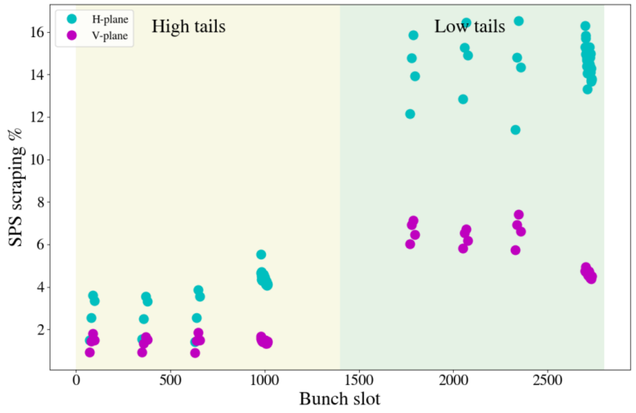


# BCMS vs BCMS-low-tails, observations

Only possible extra improvement foreseen for 2024: inject BCMS type beams with low-tails

- Heavy scraping in the injectors to reduce losses coming from the tails
- No significant difference between BCMS and BCMS-low-tails beams



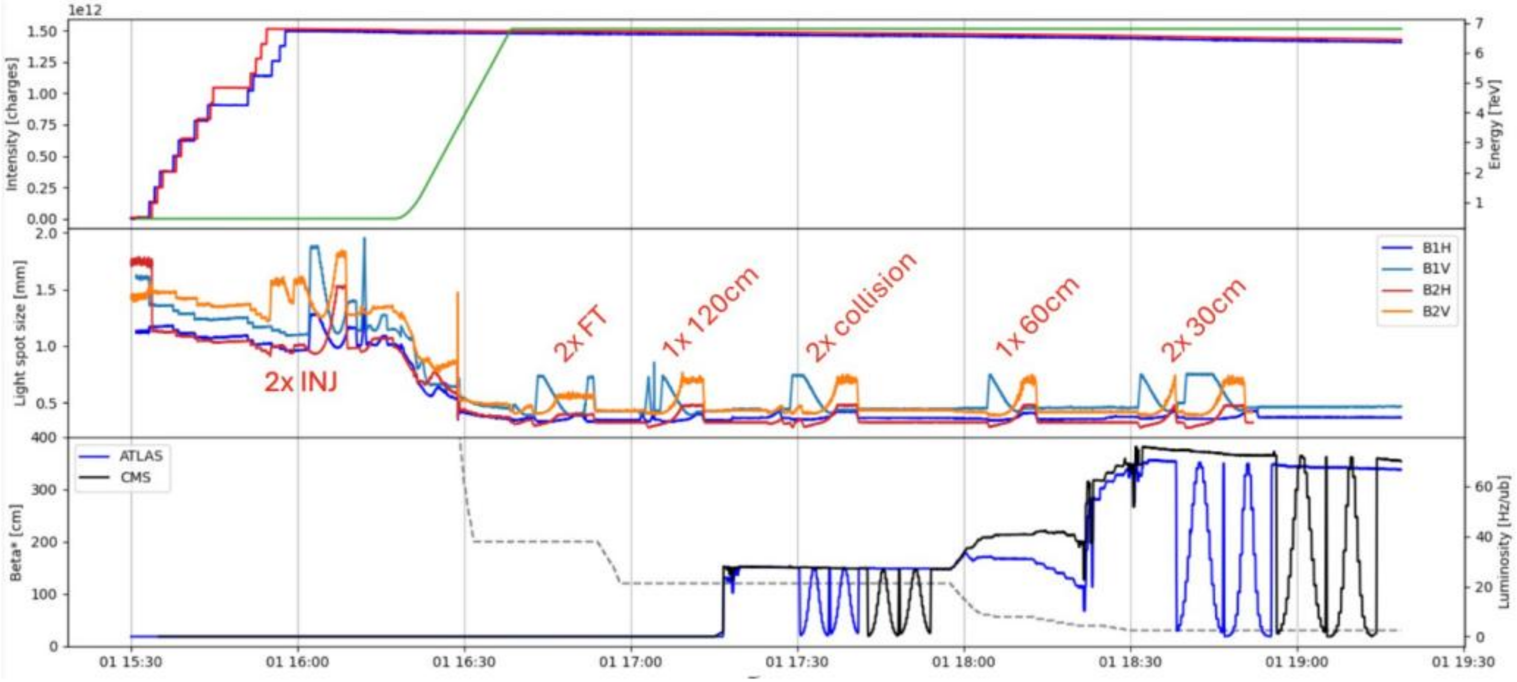




Not a clear reduction of tails when SPS low-tail BCMS beams reach the LHC

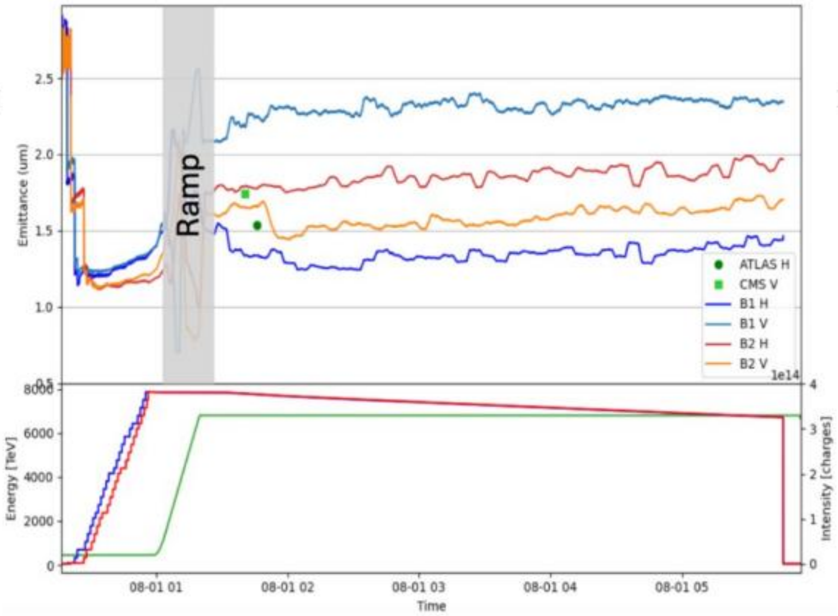
- Emittance growth very similar between the two beams
- Losses at start of collisions dominated by LHCb rather than tails
- Leveling time increase does not depend on tails
- Beams do become more Gaussian: such method is extremely beneficial to VdM program and luminosity calibration precision

# BSRT Calibration Fill

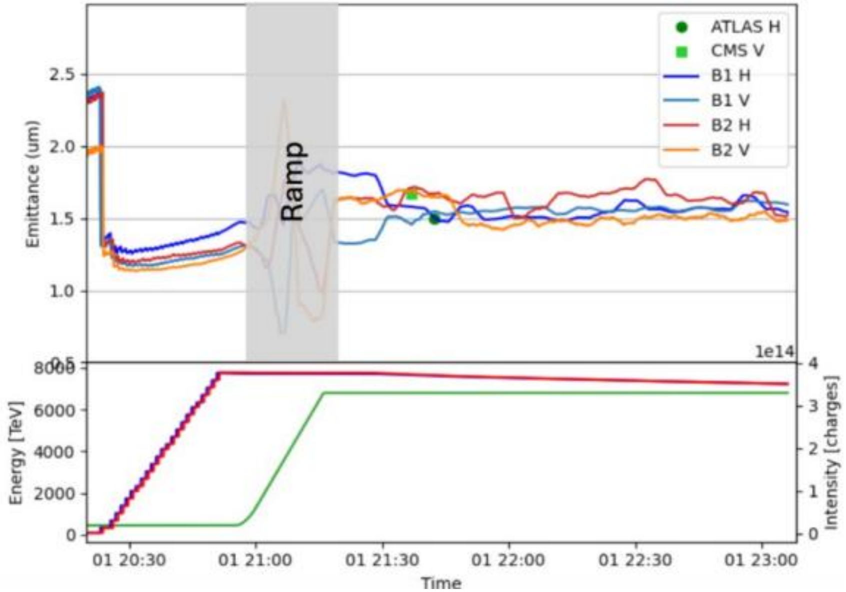
- → An issue followed by an intervention on the BSRT system meant that a calibration was required for the beam 1 BSRT system.
- → OP asked if any experiments were interested in participating and a program of scans for ATLAS and CMS was requested.
- → Fill went very smoothly scanning at 120cm and 30cm in IP1/5.
- → BSRT calibration appears much improved with preliminary results!




Fill 9962 (old calibration)

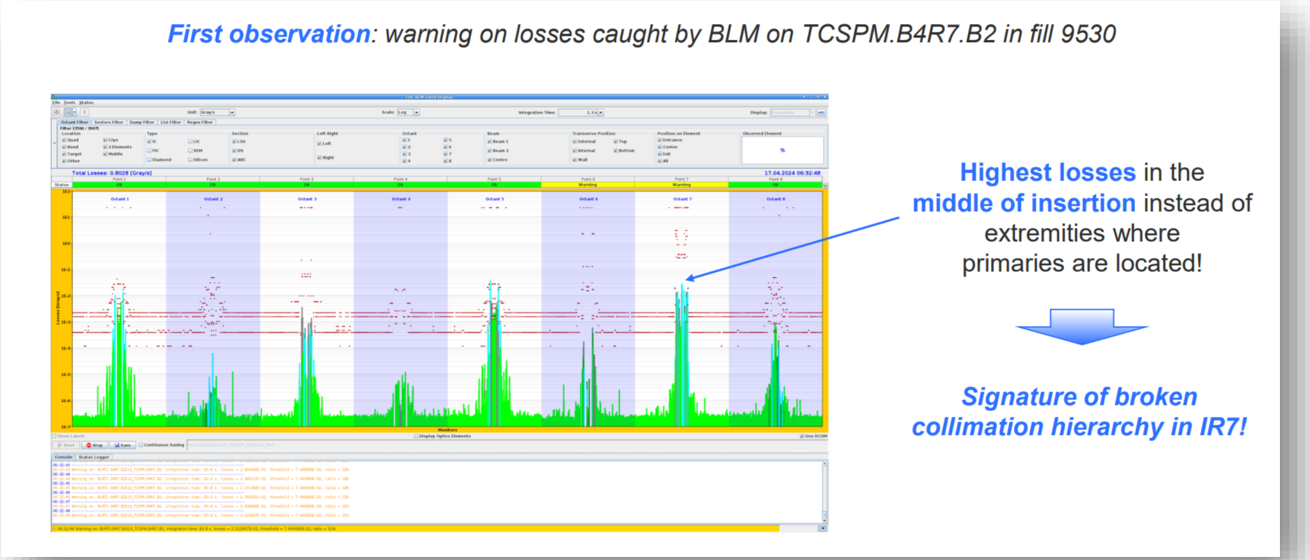



Fill 9967 (new preliminary calibration)



# Collimation hierarchy breaking problem

Observed unexpected losses around IR7 when squeezing to 33/30 cm
→ Decision to NOT allow squeezing past 36cm until TS1




Very complex problem involving all aspects of the machine:

- Collimation, orbits, degraded lifetime at 33, mostly vertical plane
- Beam-beam effects and IP1 crossing angle effect
- Losses from tails on secondary collimators

→ Problem attacked at multiple joint collimation+beam operations+machine protection working group meetings with many experts dedicated to the task

Performed various End-Of-Fill tests to investigate the origin of such hierarchy problem:

- Traced to off momentum halo in the positive direction of the vertical plane that hit the secondary collimators and produces extra losses → asymmetric scraping
  - Mitigated by adding a dispersion value around IP1 in the vertical plane to reduce the production of off momentum particles!
  - **Tested in an EOF test before TS1, machine fully revalidated after TS1 with full set of loss maps → back to squeezing to 30cm in production!**

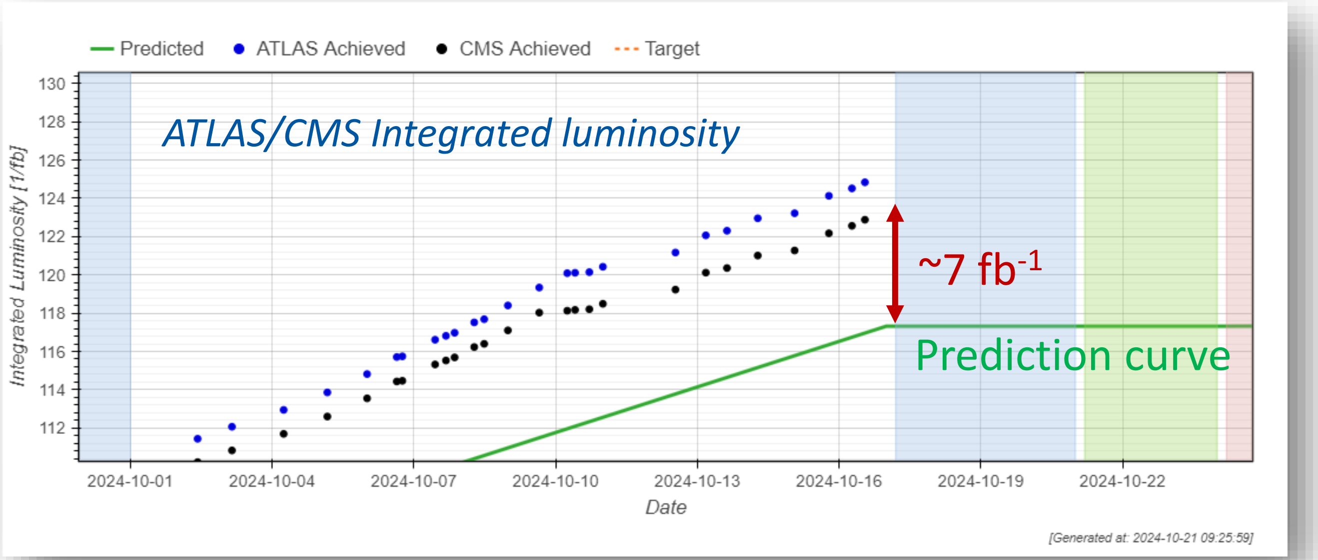
# Notable events related to loss of efficiency

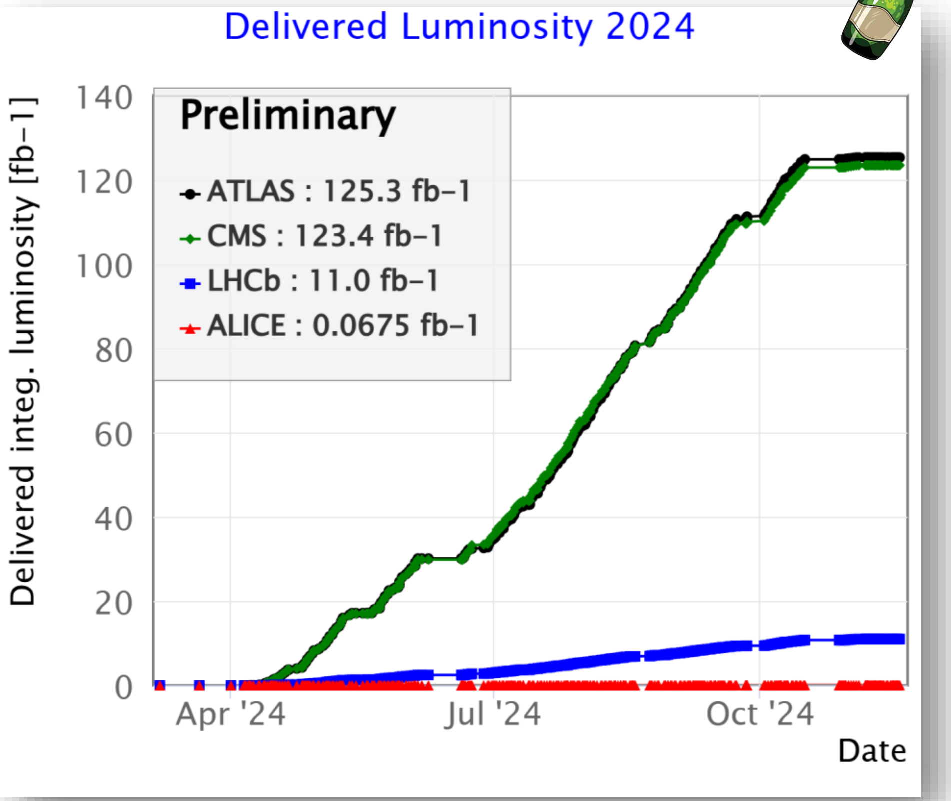
- ATLAS cryo cooling problem following TS1 , filters blocked: toroid and solenoid OFF from 19/06 to 25/06
  - Readjusted schedule to insert floating MDs to minimize loss of physics for ATLAS: lost 3.4 $fb^{-1}$
- VELO Aside belt damaged on 11/07, repaired on 12/07)
  - VELO carriers realigned and revalidated with extra 400b fill . Two fills lost for LHCb, 9885 + 9886, lost 25 $pb^{-1}$
- ALICE magnet cooling failure following a water leak and a thyristor failure on 15/07, then fixed on 16/07
  - Lost ~23h of data. L3 magnet kept ON for longer times to minimize cycles, loss of CHF
- ATLAS Tile FE cooling incident on 18/07 and 20/07: requested urgent access and early dump
- CMS tracker cooling issues on 09/08: frozen pipe and fault in a pump, requested urgent accesses
  - One fill lost, CMS separated to pileup 5
- LHCb multiple magnet trips due to faulty temperature sensor on 16/08: fixed only 18/08 afternoon
  - Three fills lost, LHCb separated due to e-cloud effects
- AUG button cut by mistake triggered loss of cooling water at ATLAS , slow dump of toroid and solenoid
- AUG button cut by mistake (another…) at point 4, triggered loss of cryo in Sector 34 and 45
- Loss of cryo (QURC) at point 8, faulty sensor replacement ~36h downtime
- Outstanding problem with cryogenics compressor at point 6,
  - Risk of 4 days downtime, currently being mitigated with 1 truck / day of 17t of LN2
  - Intervene during TS2, extended stop to 4 days. Compensate pp reference setup day lost in pp period.

# Wrap-up proton physics production

Impressive amount delivered to ATLAS & CMS : ~124 $fb^{-1}$

- >= 110 $fb^{-1}$ recorded in both experiments
  - Finished ~14 $fb^{-1}$ (~11%) ahead of target!
- CMS & ATLAS running at <pileup> 64 steadily in last weeks




Proton physics statistics excluding only MDs and TS1!

| Availability | Stable beams (SB) |
| --- | --- |
| 72.8% | 48.5% |

- LHCb at ~11 $fb^{-1}$ delivered and at ~9.5 $fb^{-1}$ recorded!!
  - LHCb doubled the integrated recorded luminosity of Run 1+2 in a single year !!
  - Ended up running steadily at nominal luminosity of $2x10^{33}$ $cm^{-2}s^{-1}$
- ALICE at >> 60 $pb^{-1}$ delivered and >> 50 $pb^{-1}$ recorded

# Wrap-up pp reference run

Initial required targets reached at all experiments!!

→ Extension by 1 day (exactly 24h) to satisfy extra requirements due to new Run3 extended schedule

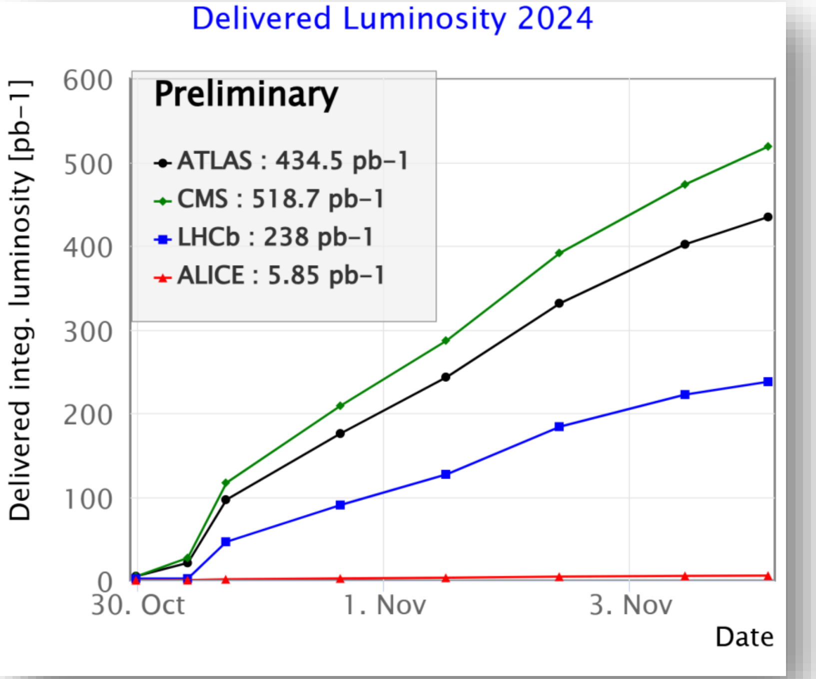
- ALICE (target 5.5 $pb^{-1}$): 5.8 $pb^{-1}$
- ATLAS (target 350 $pb^{-1}$): 435 $pb^{-1}$
- CMS (target 350 $pb^{-1}$): 520 $pb^{-1}$
- LHCb (target > 100 $pb^{-1}$): 240 $pb^{-1}$

+ full VdM program and intensity ramp-up!

<u>Only excellent machine availability and amazing Stable Beams fraction made it possible to achieve such targets</u>

| Availability | Stable beams (SB) |
|---|---|
| 91.8% | 75.5% |

Statistics from Monday 28th October 6am to Monday 4th November 6am




- Baseline is now NOT to do a pp reference run in 2025/2026 → net gain of 3 PbPb days!
  - If PbPb statistics is significantly higher than the current target of 6.5 $nb^{-1}$ for full Run3, then ALICE might request more pp reference data.

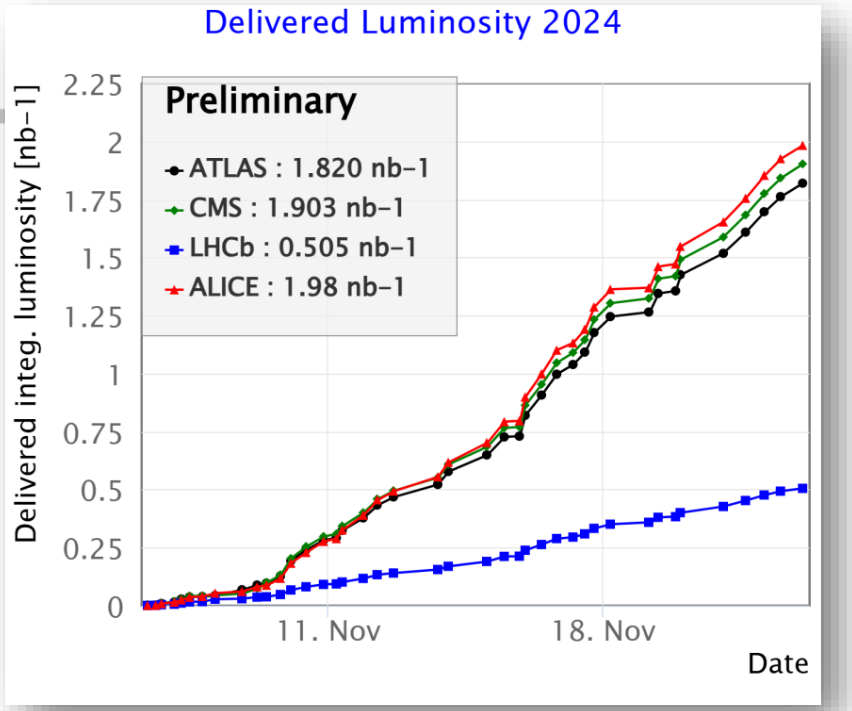
# Wrap-up PbPb run

Intensity ramp-up + VdM from 06/11 at 10am to 18/11 at 12am

- 3.5 days (-0.5 days wrt plan) of intensity ramp-up
  - → Roughly 100 $ub^{-1}$ collecting in intensity ramp-up
- 2 days of PbPb commissioning (+0.5 days wrt plan)
- 1 day VdM (== wrt plan)
- 16 hours MD (+3 hours loss maps) + 24 hours MD not done
- 19 hours for ALICE polarity reversal

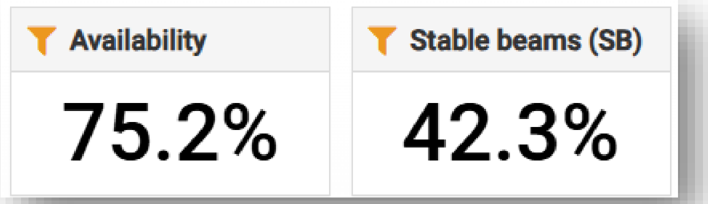
→ ~12.5 days physics with full machine, from 10/11 at 1.30am

- ~1.8 $nb^{-1}$ in ATLAS/CMS/ALICE → 0.144 $nb^{-1}$/day
- ~0.45 $nb^{-1}$ in LHCb → 0.036 $nb^{-1}$/day




Many goals reached! See Roderik Bruce at LMC

- ~reached the target daily production of 0.15 $nb^{-1}$/day (0.04 in LHCb)
- Leveling at 6.4E27 in ALICE/ATLAS/CMS and 1.5E27 in LHCb for >>1h
- Ions per bunch at >2.4E8 at SB
- Filling scheme 50ns_1240b_1032_1032_557_56bpi_PbPb provided +40% collisions to LHCb (-5% to others), using a mixture of 40bpi and 56bpi
- Emittance at 2.5-3 at SB
  - No margins on this, this is coming already from injectors, but beam brightness is >> LIU (thanks to increased ions per bunch)

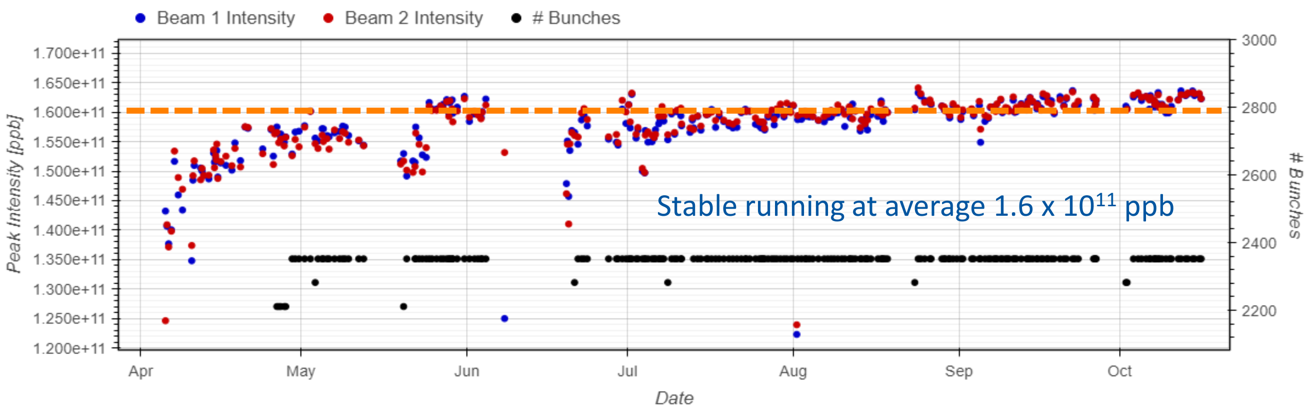


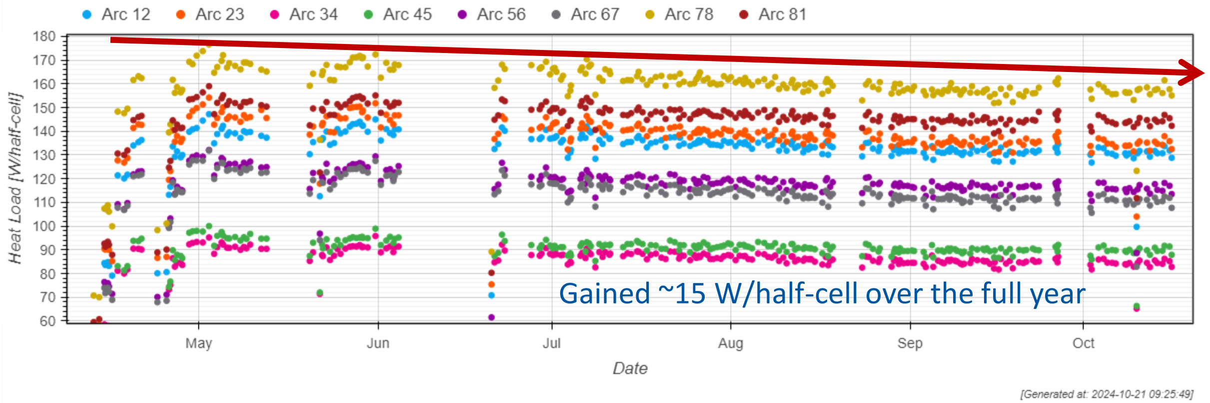

since start of PbPb SB
w/o 16 hour MD

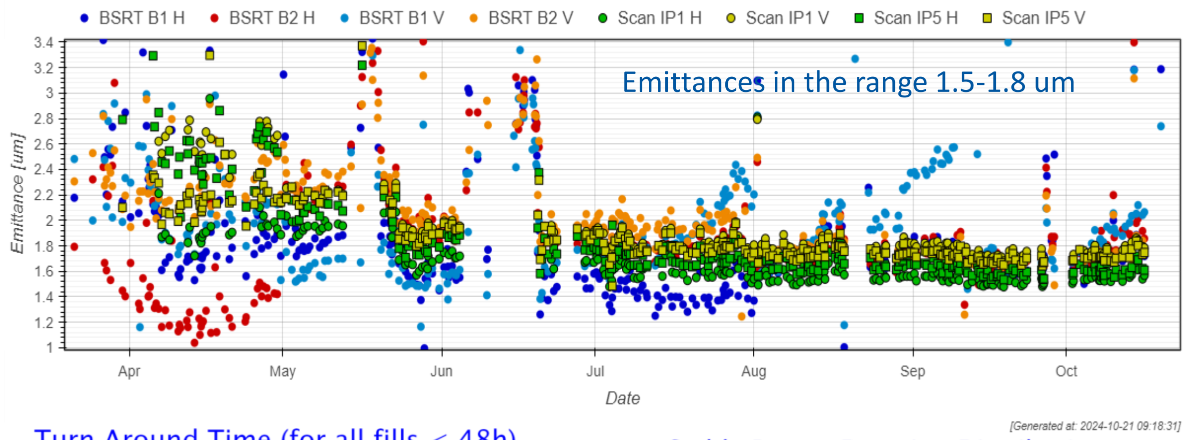
# Wrap-up proton physics production

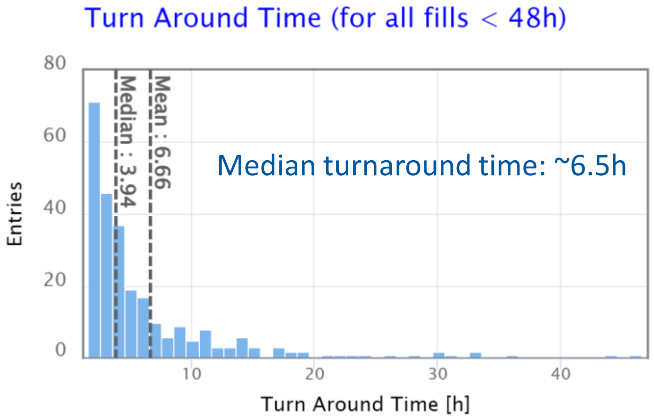
- Beam brightness from injectors at the levels of HL-LHC already (margin to gain still)
- Observed also slight conditioning of cryogenics over time (not initially expected)

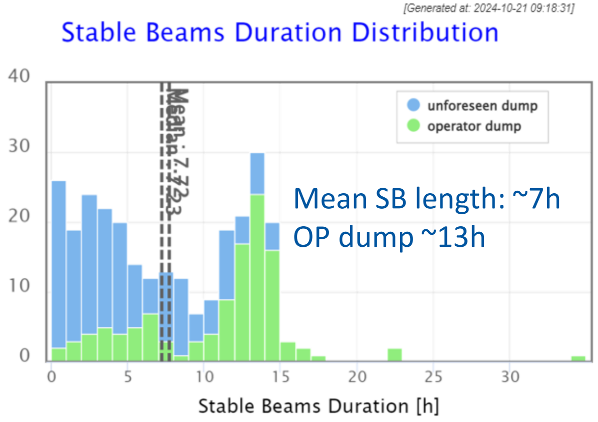
→ Reaching stable and steady LHC conditions before the summer was the highest priority!
→ These are exceptional numbers!




Decided not to change parameters during 2024: intensity per bunch, filling schemes, β* remained the same

- Discuss explorations to be done in 2025 (or 2026?)
- Clear interest from LHC on increasing charges per bunch
  - from $1.6 \times 10^{11}$ up to $1.8 \times 10^{11}$

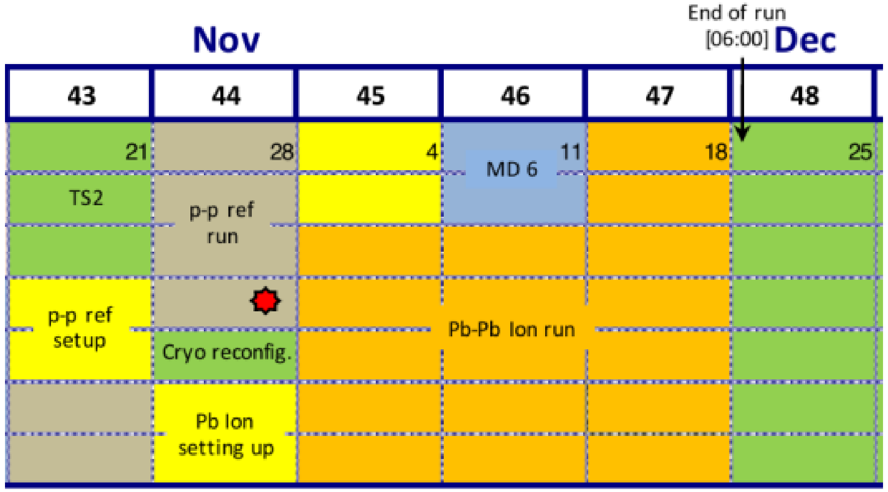
# Early discussions on ion/pp reference run

From LBOC 25/06/2024: https://indico.cern.ch/event/1427737/

- First discussion on plans and preparation for 2024 PbPb ion and pp-reference run

Reminder:

- pp reference run currently set to 6 days +2 days of setup
  - 8 days total between 2024 and 2025, excluding setup
  - very much preferable to not do a pp reference run in 2025, to gain 4 more days in 2025
    - CMS still requesting pp reference run in 2025
    - Also subject to ALICE obtaining 4.5 $pb^{-1}$ in 2024
- 17 days allocated to the ion period (+4 days setup)
  - 4 days of intensity ramp-up
- 1 day of VdM in both ion and pp reference run period
- 2 days of ion MD, one day taken out of the pp MD pool



LHC planning 2024, v2.0

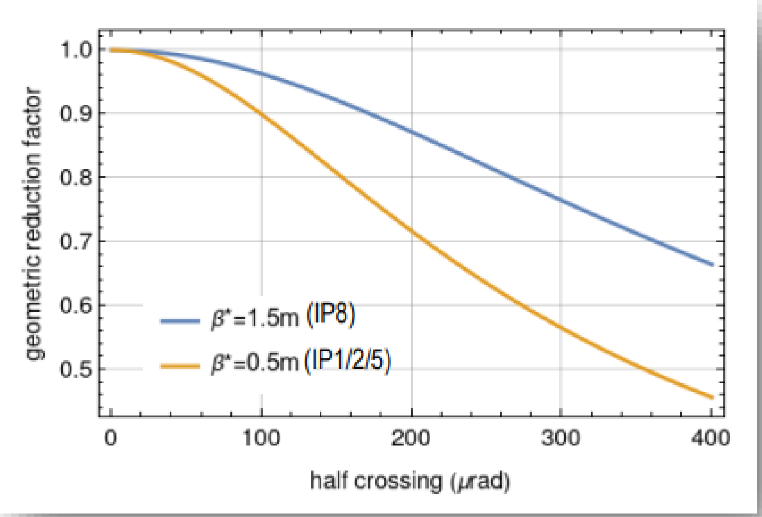
- Strive to gain two (2) more days in 2024.
  - Cryo reconfiguration day proposed to be removed and not run in ECONOMY mode during the ion period
    - To be ratified at an upcoming LMC. Initial expected cost 200-250kCHF and reduces recovery times (~20%)
  - Anticipate pp reference setup to before TS2
    - One day to compensate cryo intervention at pt 6 that extends TS2 + strong wish to complete setup before TS to calculate and prepare settings in time. Very tight if setup must go directly into physics production. To be done before MD4.

# Preparation for ion run

Global strategy for ion run:

- Priority to fix problems and re-establish stable running conditions
  - Overcome 2023 performance limits
  - Minimize risks, avoid new concepts in 2024
  - Push beam intensity, injector set-up
  - Short run in 2024: ~12 days of physics with full machine + 4 days of intensity ramp-up + 1 day VdM (hope to add 2 more days…)
- Same optics as in 2023, but reversed IP1 polarity
  - $\beta^*$ = 0.5m in IP1/2/5, $\beta^*$ = 1.5m in IP8
- Open collimation hierarchy to mitigate various losses
- Possibly decrease crossing angle (“reasonably”)
  - *Detailed values being finalized on beam-beam studies*
  - Reversed LHCb spectrometer polarity to compensate external crossing
- Baseline filling scheme is 50ns_1240b_1032_1032_557_56bpi_PbPb (uses 56b trains)
  - Gives best performance provided injection from LEIR is good and can take all injections
  - +40% colliding to LHCb as agreed among experiments and management
- Re-establish luminosity leveling at 6.4x10$^{27}$ cm$^{-2}$s$^{-1}$

Targets: IP1/2/5 >= 5.3 nb$^{-1}$ in Run3 (2 nb$^{-1}$ in 2023), IP8 >= 2 nb$^{-1}$ (0.25 nb$^{-1}$ in 2023)




| values currently being studied | IP1/5 | IP2 | IP8 |
|---|---|---|---|
| Spectrometer half crossing (μrad) | 0 | ±72 | +139 |
| External half crossing (μrad) | 130-150 | ±130-150 | -235 |
| Net half crossing (μrad) | 130-150 | ±58-78 | -96 |

Absolute ranges ok for ZDCs

LHCb with UP polarity

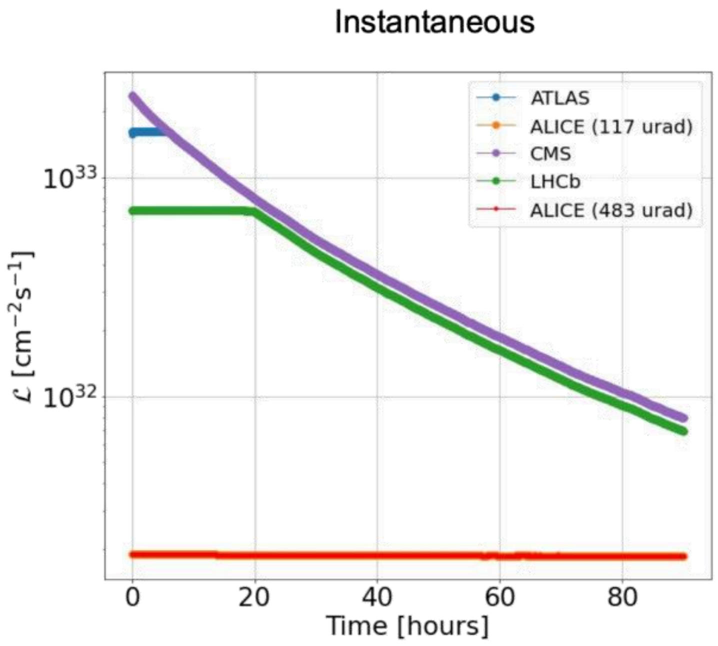
# Preparation for pp reference run

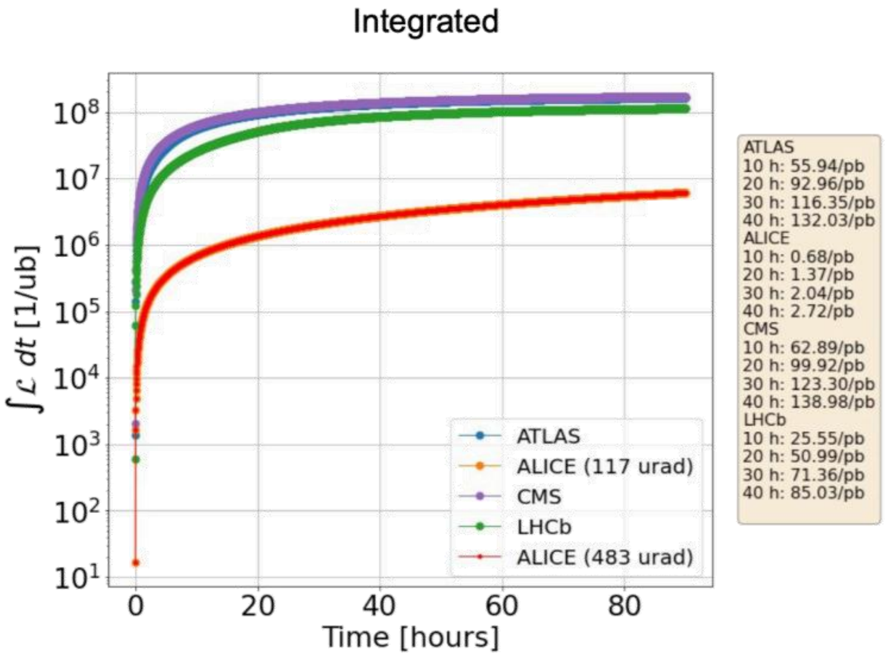
Global strategy for pp reference run:

- Experiments requests:
  - ATLAS/CMS 250-350 $pb^{-1}$
    - ATLAS level at pileup 4
    - CMS head-on. Damaged ZDC ready for TS2
  - LHCb requested >= 100 $pb^{-1}$
    - LHCb levelled at pileup 2
  - ALICE requested <= 4.5 $pb^{-1}$ for 5.3 $nb^{-1}$ collected in ion period
    - ALICE level at 15 Hz/ub
- Combined ramp & squeeze to 3.1m @ 2.68 TeV in IP1/5/8, 10m in IP2
  - Slightly longer ramp-down, as first ramp-up to 3.5 TeV equivalent energy
- Bunch intensity of 1.6 x $10^{11}$ ppb
- Proposed full machine filling scheme in pp reference to favor ALICE: 25ns_2352b_2340_2247_2079_108bpi_24inj_ppRef_ALICE
  - Other experiments targets more easily within reach
- Crossing angles: +170 urad IP1/5, -170 urad IP8, +300* urad IP2
  - *may become +350 urad if beam-beam effects too strong
    - in this case, it would need more machine revalidation → longer setup

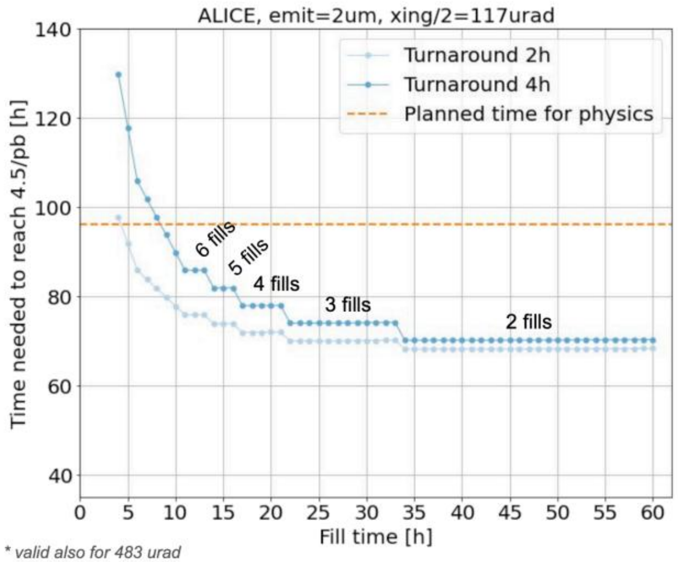
- Intensity ramp-up (TBC)
  - 4b/12b into collisions
  - 75b (>= 2h in SB)
  - 400b (>= 5h in SB, checklist)
  - 1200b (>= 5h in SB)
  - 2400b (checklist after 1st fill)
- VdM requests
  - Expect 3-to-4 hours per experiments
  - Plan in preparation with the experiments
- pp reference setup needs a BLM threshold update (following a subset of lossmaps) before TS2
  - Propose to anticipate some of the pp reference run setup before TS2 (in the pp period) as part of the compensation for the cryogenics at point 6 intervention that happens in the PbPb period and budget for possible extra machine revalidation

# Expectations for for pp reference run




Parameters and allocated days just about right to fulfill experiments requests




Strategy:

- Aim at very long fills, to minimize effect of turnaround time
- Ideally, two long fills are sufficient to fulfill ALICE's request
  - In practice, some adjustments/decisions will be done on the fly
  - ALICE plans to flip magnet polarity half-way thru the pp reference run

# Optics 25/26: Two of the Discussed Choices

Option 1

- Full RP with rotated planes: RP horizontal crossing in IP1, RP vertical crossing in IP5.

Option 2

- Rotated planes, RP in IP5 only: Nominal horizontal crossing in IP1, RP vertical crossing in IP5.
    - (note both options are the same for IP5, only IP1 is different)

- Both options are designed to protect the magnets, in particular the inner triplet.
- The second option preserves the FASER/SND emulsion physics program while the first does not.
- AFP physics also cannot occur with the first option.
- We consider 100 $fb^{-1}$ for each of 2025 and 2026.

- Several other options were also considered including ones with different configurations for 2025 and 2026.

# Magnets we are discussing

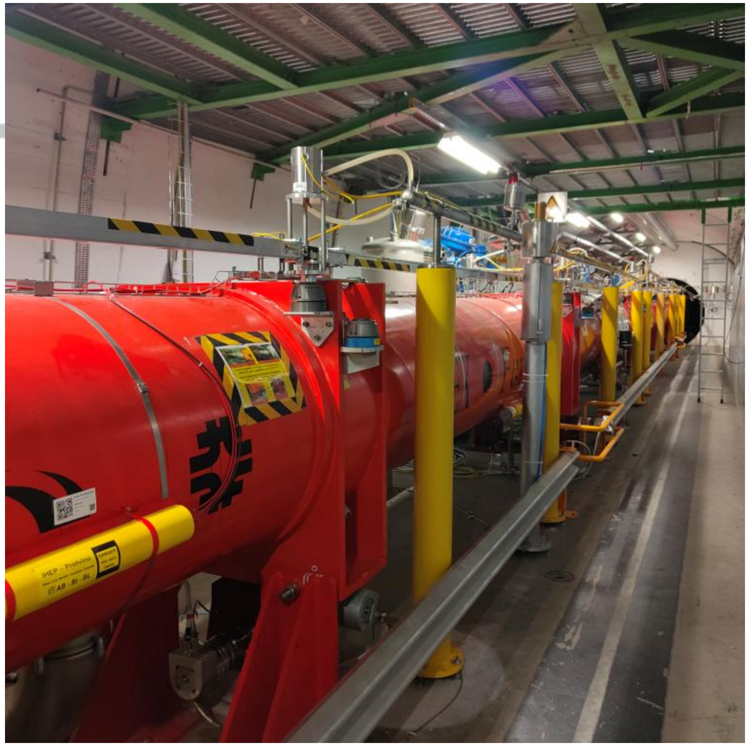
Triplet at IP1 and IP5 (top right)

- Triplet (3) quadrapole magnets either side of the IP
- Used to focus the beams to the interaction point.
- These are superconducting so not easy to fix/replace.

Separation dipole (D1) (bottom right)

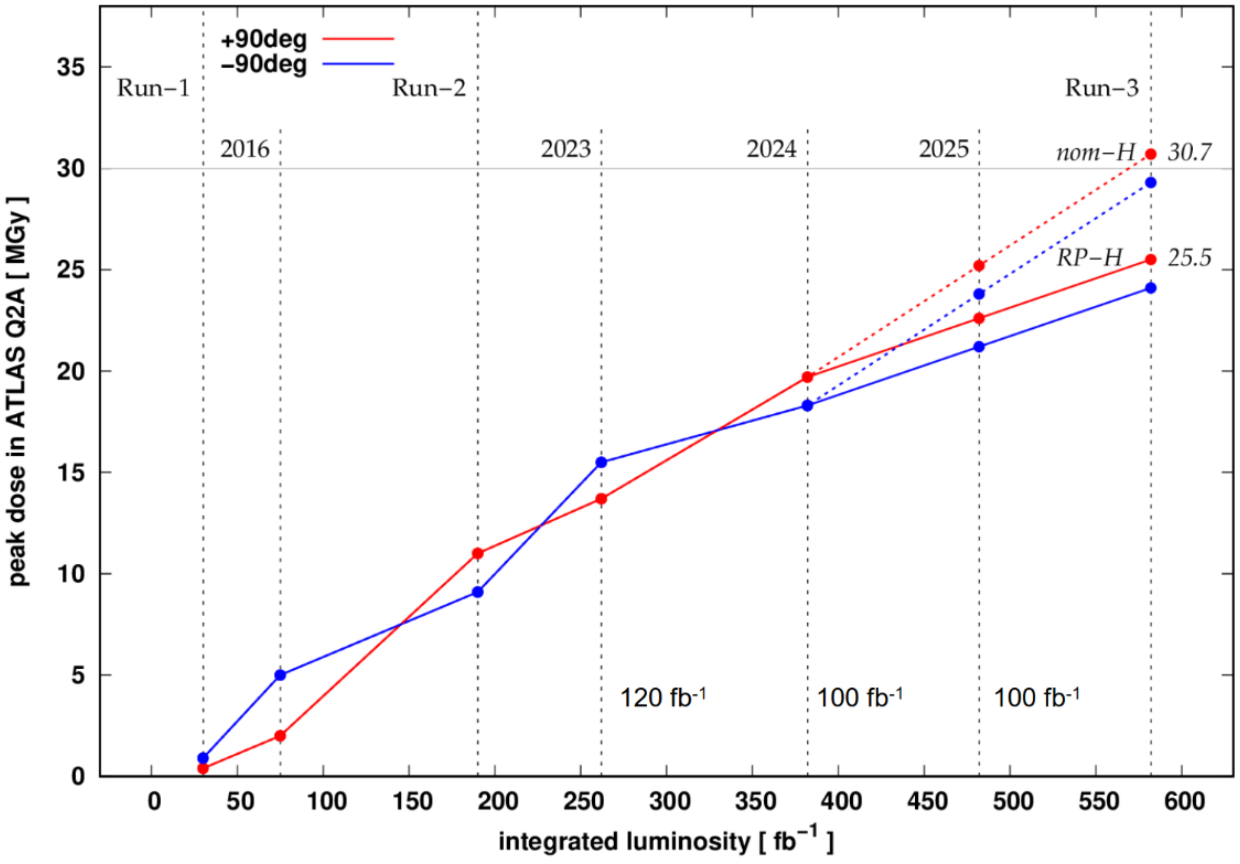
- D1 is a series of several separation dipole magnets that make the beam go into/out-of the two separate beampipes.
- Warm magnets (not superconduting)

There are also other LHC magnets in these regions that get irradiated but they can be corrected for in the case of failure so I don’t discuss them here.

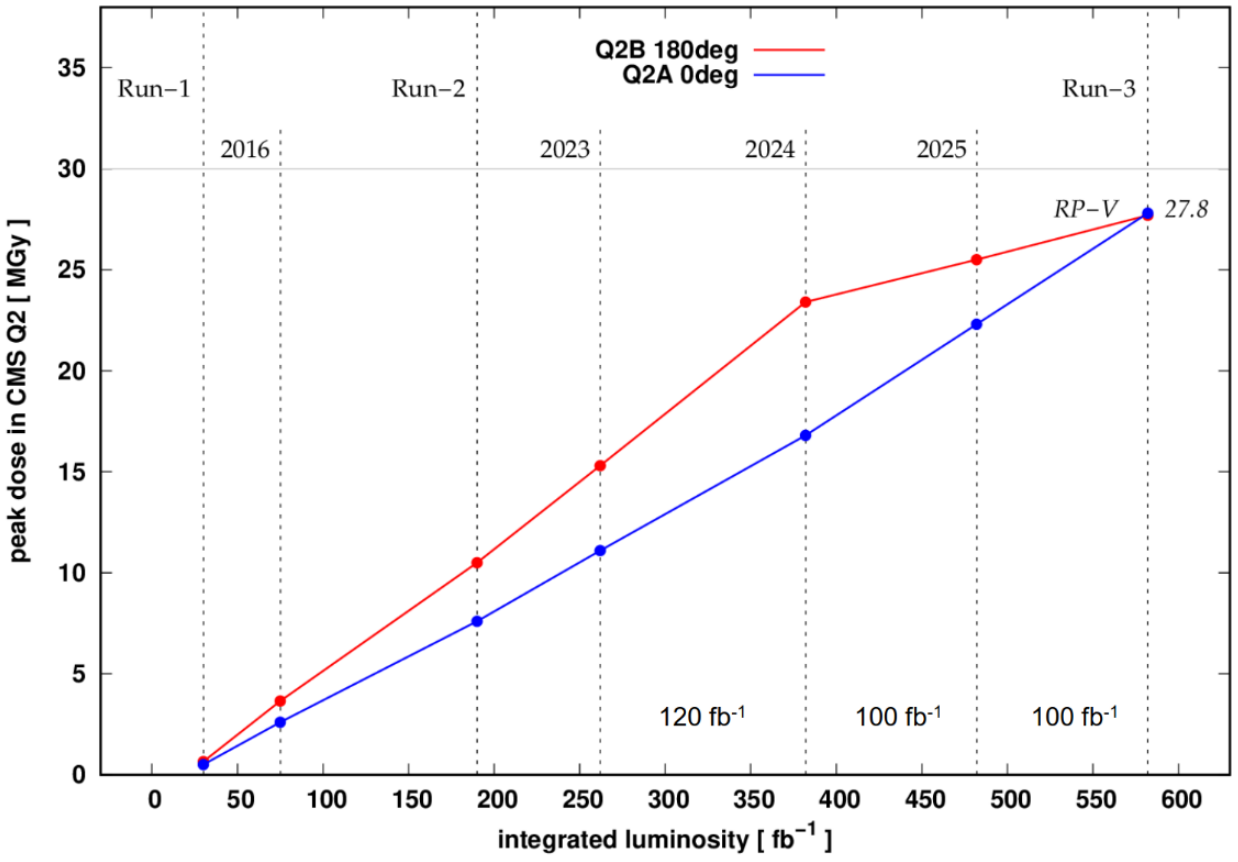


# Inner Triplets

## LIMITING QUADRUPOLE (Q2A) IN IR1

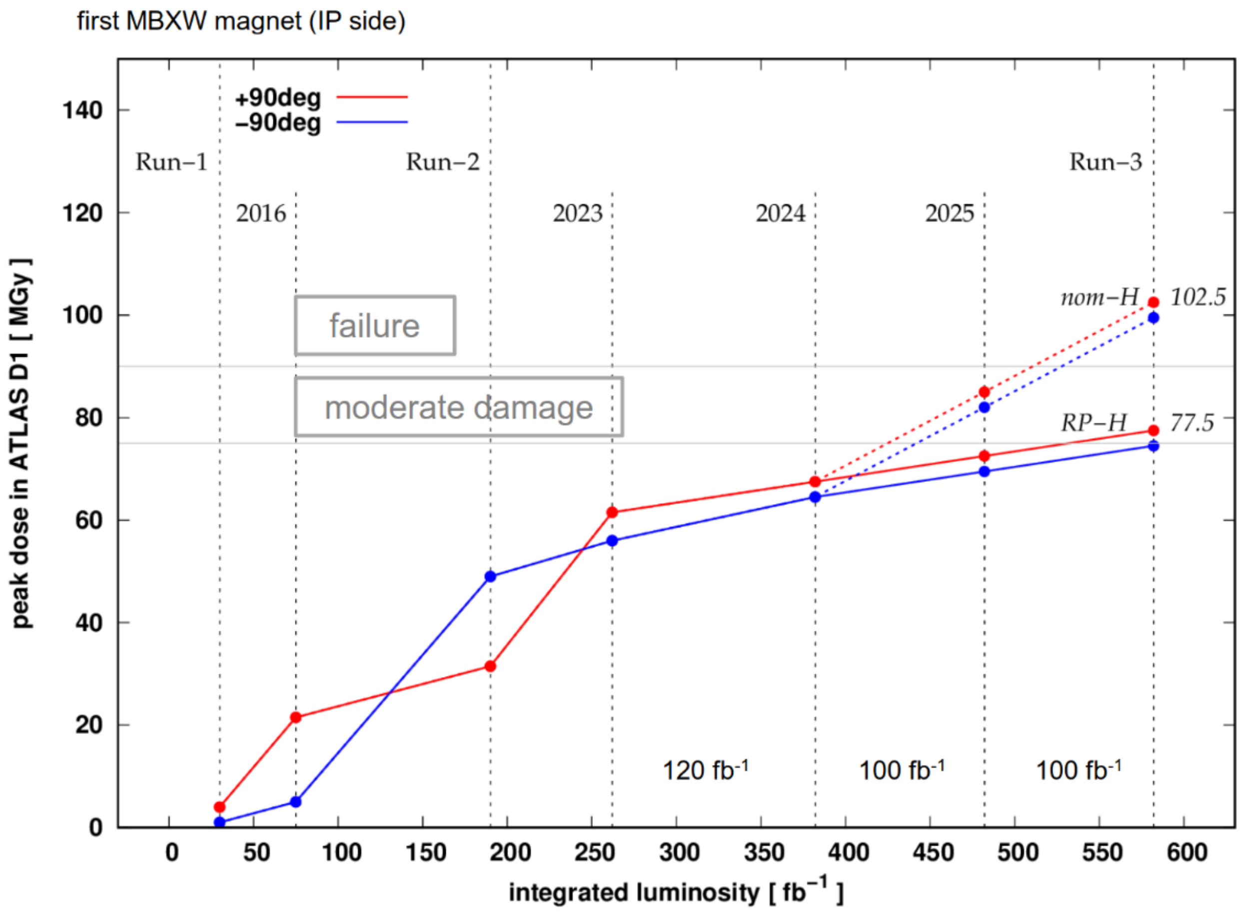


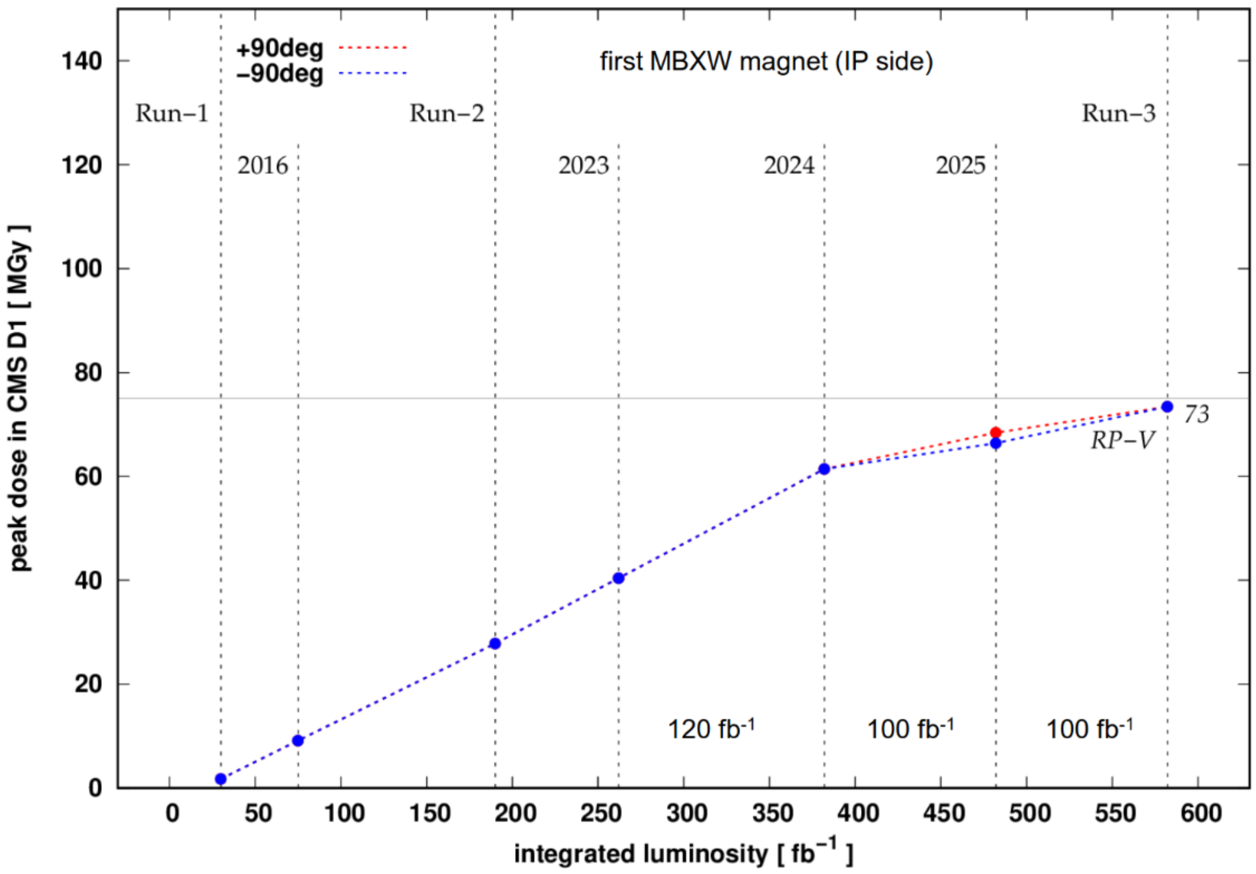

## LIMITING QUADRUPOLES (Q2B→Q2A) IN IR5




→ Just staying near/within the limits in Option 2 in IP1, more protected in Option 1.

# Separation Dipoles (D1)




→ Option 2 results in damage even in 2025 – preventive replacement must be investigated

→ All options get close to moderate damage by end of the run.

# Schedule for 2025/2026

- *Scenario A: all ion run in 2025 (omitted)*
- *Scenario B: split ion run in 2025/2026*
- *Scenario C: all ion run in 2026*

| Table of days and ratios for 2025/2026 for Scenario B | | | | |
|---|---|---|---|---|
| **Year** | **pp** | **PbPb/ppRef (physics days)** | **Special** | **MD** |
| **2022 (v1.3)** | 70 | 2 (2 PbPb) | 10 | 10 |
| **2023 (v1.5)** | 48 | 39 (32 PbPb) | 15 | 7 |
| **2024 (v2.2)** | 145 | 30 (5 ppRef + 15 PbPb) | 2 | 24 |
| **2025** | 138 | 25 (19 PbPb) | 10 | 19 |
| **2026** | 66 | 25 (19 PbPb) | 2 | 10 |
| **Totals (wrt to baseline)** | | | | |
| **697 (-2.6%)** | **467 (-3.9%)** | **121 (-4.0%)** | **39 (+30%)** | **70 (-5.0%)** |
| **Ratio to Total** | **66.95%** | **17.39%** | **5.60%** | 10.06% |
| **Ratio to Physics (pp + PpPb/ppRef + Special)** | 74.44% | 19.33% | 6.23% | **11.18%** |

# 2025/2026 schedule

Possible schedules: 3 Scenarios

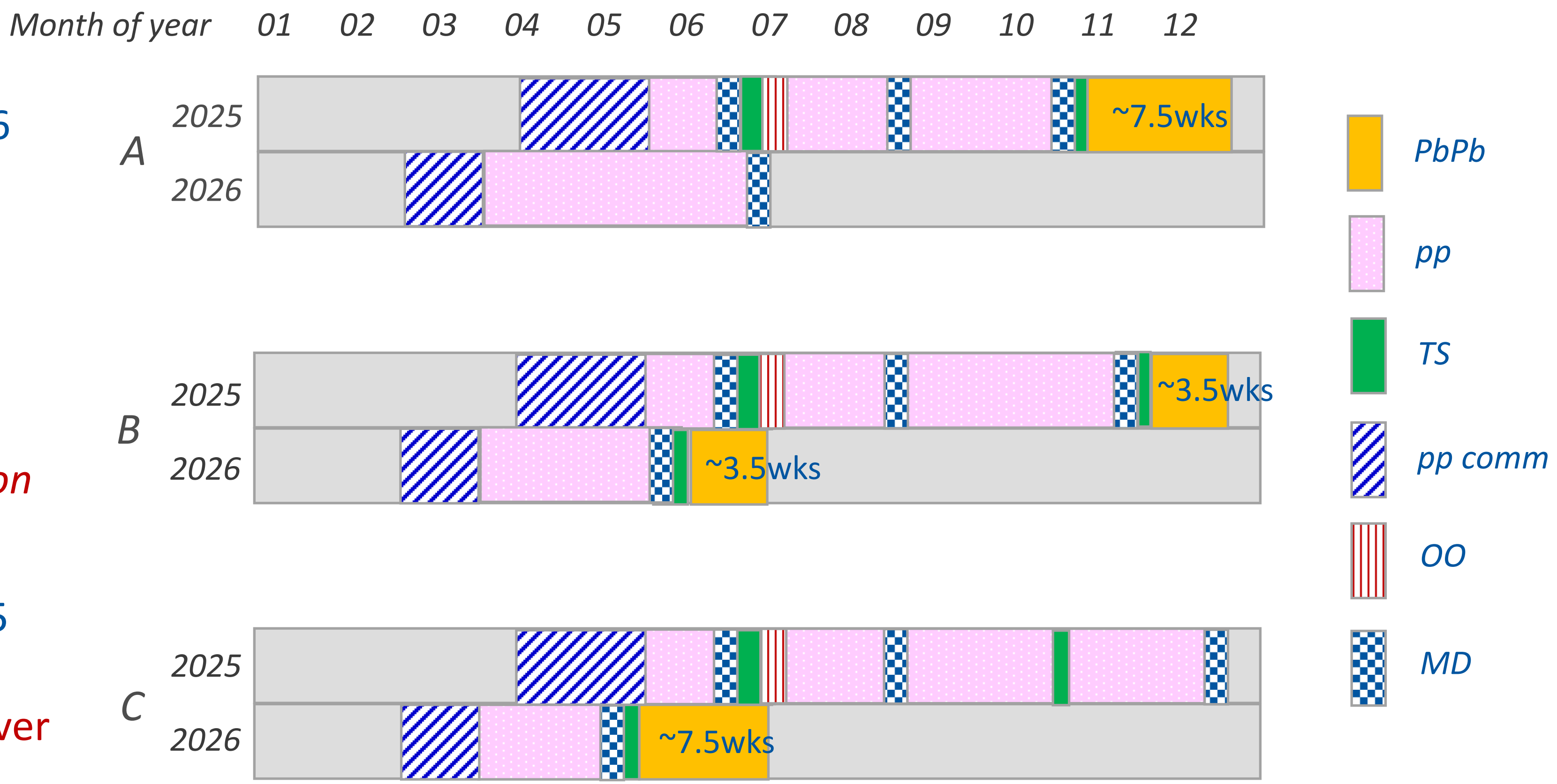
- A = full ion run in 2025; cooldown in 2026 proposed with MD days and low-mu run.

→ VETOed by CMS as does not provide sufficient cooldown before LS3

- B = split ion run in two periods, *currently* roughly equally (25 vs 26 days).
  - *Lose 7 days purely due to doubling ion setup + intensity ramp-up + VdM*

- C = full ion run in 2026; cooldown in 2025 proposed with MD days and low-mu run.

→ VETOed by ALICE as risk of losing all leftover ion physics considered too great




- Number of pp days remains the same (as well as luminosity projections) regardless of the scenario
- OO/pO in July '25, right after TS1, regardless of the scenario chosen

# 2025/2026 schedule

| Expts | Preference | PbPb | pPb | Veto |
|---|---|---|---|---|
| ALICE | NO single ion run in ’26 | Collect Run3 target (6.5 $nb^{-1}$) | • Yes, if/after target for PbPb (Run3) is reached<br>• Preference for sqrt(s) = 5.36 TeV | C |
| ATLAS | Single ion run in ’26 | Collect large amount of data wrt to Run2 (> 7 $nb^{-1}$) | • Lower priority, for Run4<br>• Preference for sqrt(s) = 5.36 TeV, if higher energy, needs new pp reference | None |
| CMS | Single ion run in ’26 | Collect sizeable amount of PbPb data (> 7 $nb^{-1}$) | • Lower priority, for Run4<br>• Energy TBC | A |
| LHCb | NO single ion run in ’26 | 2 /nb in Run3, or at least double instantaneous luminosity wrt to 2023 | • Yes, 300 /nb in pPb/Pbp, lower priority wrt to PbPb<br>• Preference for sqrt(s) = 8.54 TeV, no need for pp reference run, also ok sqrt(s) = 5.36 TeV | None |

- Given that cooldown before LS3 is considered highest priority for (experiment’s) LS3 schedule and personnel,

→ scenario A is now excluded and a cooldown period before LS3 is “guaranteed”

- All experiments have expressed interest in pPb run *only* after PbPb targets (or significant statistics increase) for Run3 are achieved. This implies, doing a pPb run in 2026 only if and after securing a PbPb successful run.

→ using pPb/Pbp as cool-down is confirmed by early analyses and studies

# 2025/2026 schedule

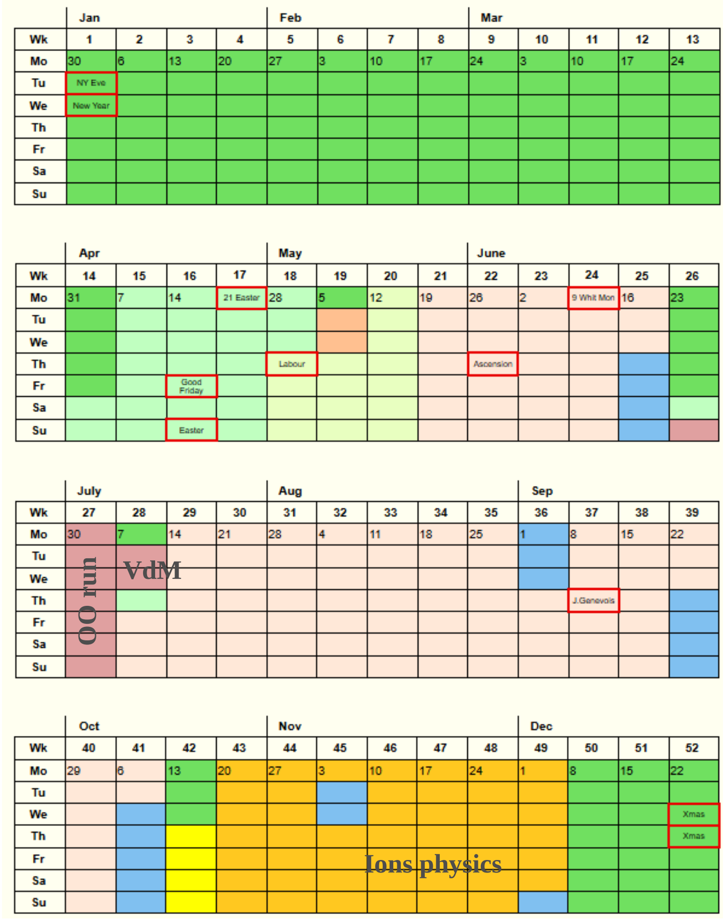
| Scenario | Optimization | Cooldown | Risk to PbPb run | Veto |
|---|---|---|---|---|
| A | Yes | OK ‘25<br>Bad ’26 | Best | CMS |
| B | Bad, lose 7 PbPb physics days | OK | Mitigated<br>(~20% impacted ) | |
| C | Yes | Bad ’25<br>OK ‘26 | Worst (~40% impacted) | ALICE |

Definitions:

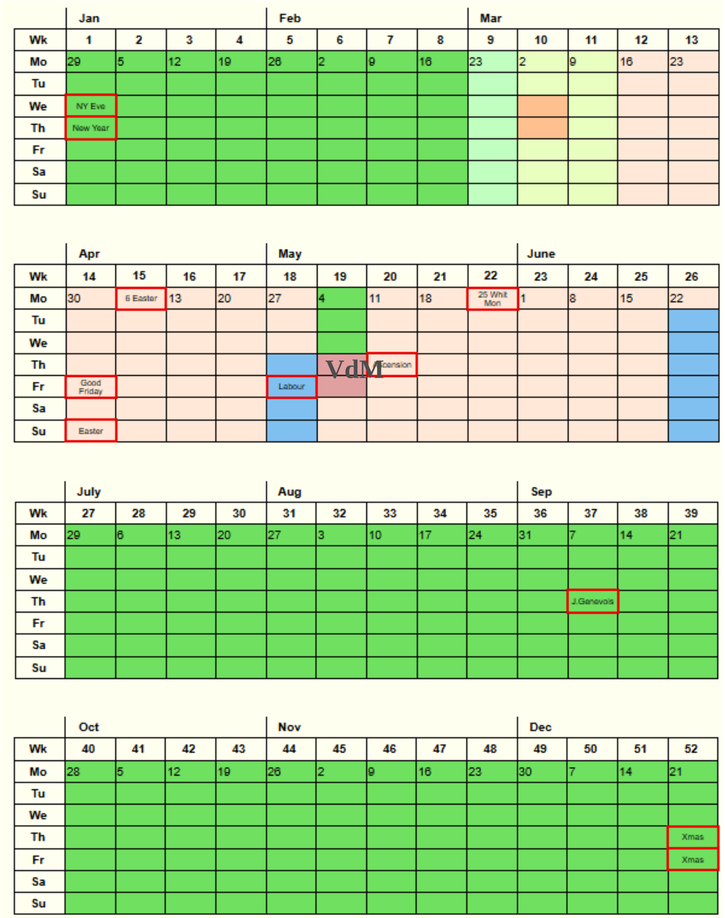
- *Optimization* = optimize number of PbPb days
- *Cooldown* = provide 4 weeks cooldown with low luminosity period
- *Risk to PbPb run* = evaluation of risk for losing sizable amount of PbPb physics
- *Veto* = experiment strongly against scenario

# Proposal for 2025/2026 schedule, Scenario A

2025, DRAFT A




2026, DRAFT A




## Scenario A:

- Single ion run end of 2025
  - *Very long ion run of > 7 weeks*
- MD + low-mu end of 2026 for cooldown before LS3
  - *Not be sufficient for cooldown (CMS)*
- pPb in Run3 ?
  - *breaks the optimization concept of saving up setup days, but minimized days for pPb setup*
- 2 days pp VdM in 2026
- no pp reference in 2025
- Oxygen run after TS1 in 2025
- TS1 in 2026 not strictly needed
  - *May provide a gain of 3 days of pp*

| Physics | Special Run | HI | Ion Setup | TS | Recom. | Interleaved Recom. | Scrubbing | MD |
|---|---|---|---|---|---|---|---|---|

# Proposal for 2025/2026 schedule, Scenario B

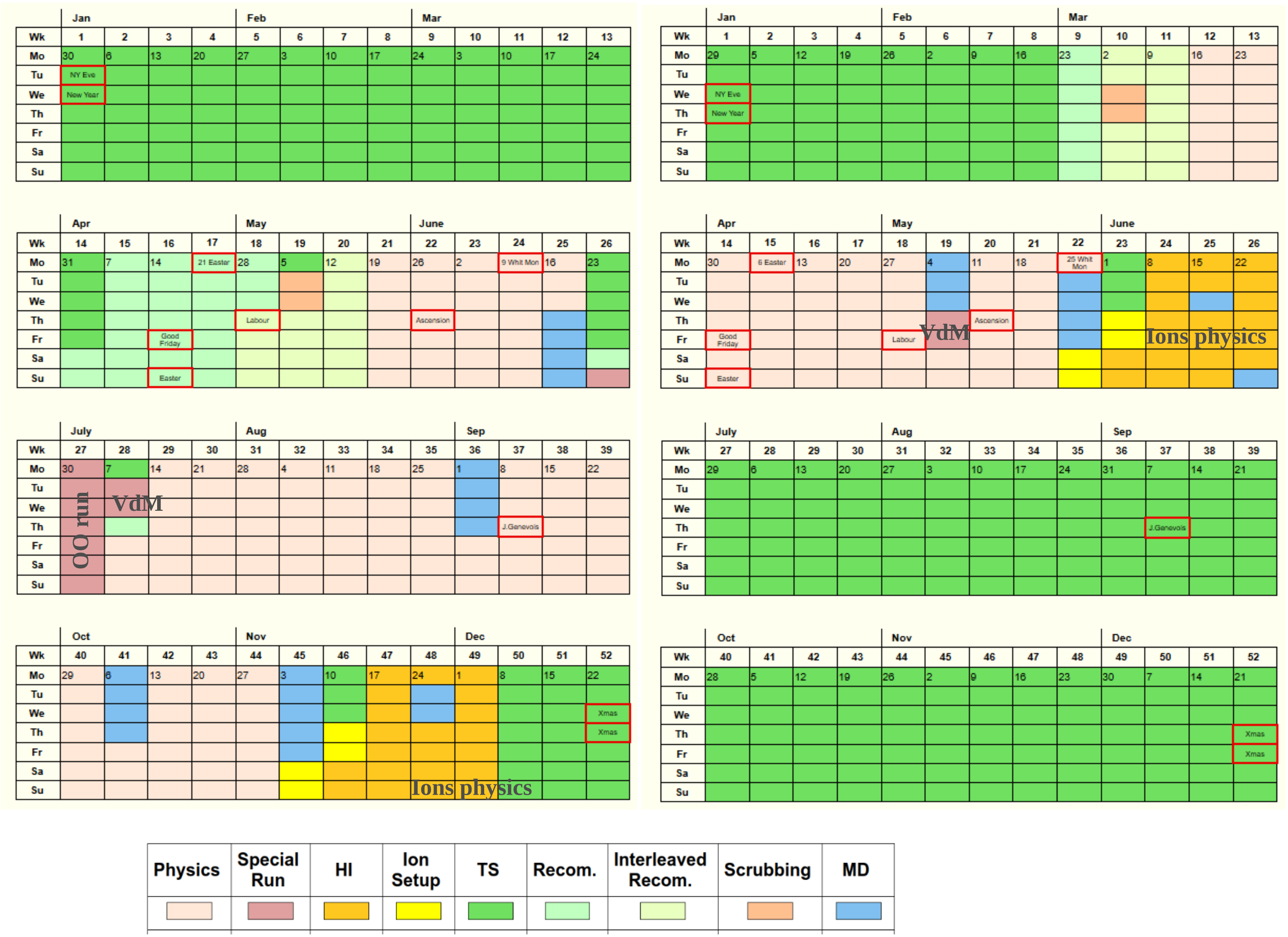
Scenario B:

- Two ion runs both end of 2025 AND 2026
- pPb in 2026 as cooldown period
- 2 days pp VdM in 2026
- no pp reference in 2025/2026 , unless higher energy for pPb is chosen
- Oxygen run after TS1 in 2025
- TS2 in 2025 needed before ion run
- TS1 in 2026 needed before ion run
- MD block before TS1 in 2026 could be put at very end for “special LHC tests”

The exact splitting of days in 2025 and 2026 for ion runs can be modified based on decisions regarding pPb physics run

2025, DRAFT B

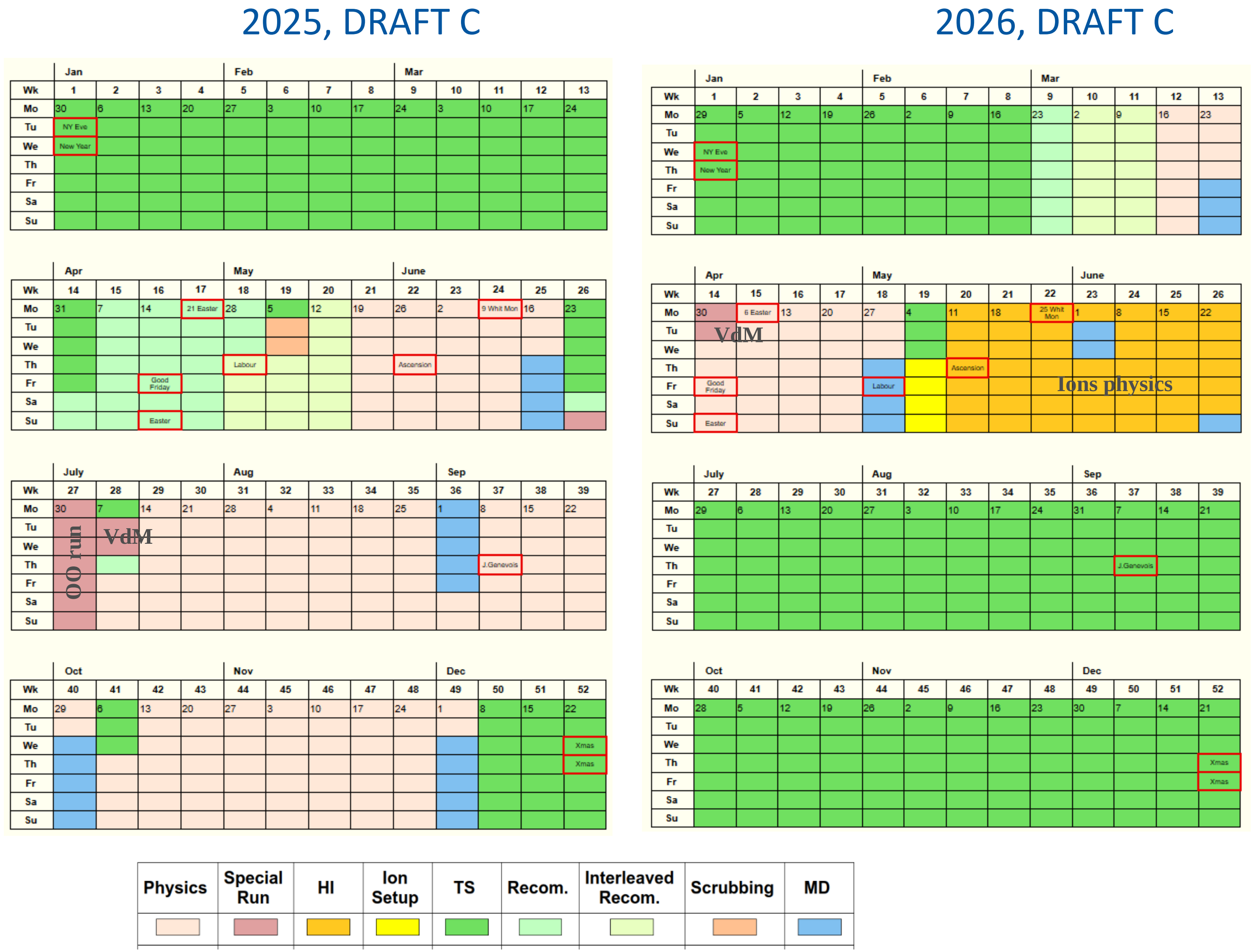
2026, DRAFT B



# Proposal for 2025/2026 schedule, Scenario C

Scenario C:

- Single ion run end of 2025
  - *Very long ion run of > 7 weeks*
- MD + low-mu end of 2025 for cooldown before YETS25/26
  - *Not be needed*
- pPb in Run3 ?
  - *breaks the optimization concept of saving up setup days, but minimized days for pPb setup*
- 2 days pp VdM in 2026
- no pp reference in 2026
- Oxygen run after TS1 in 2025
- TS2 in 2025 probably needed anyway given long year
- TS1 in 2026 needed before ion run
- MD block before TS1 in 2026 could be put at very end for “special LHC tests”



# pp Luminosity Projections, 2025/2026

Based on the above schedules we give two very rough luminosity projections for the pp data-taking based on the LPC tool. Both assume the 2024 filling scheme (BCMS with 3x36bpi, 2352 colliding in ATLAS/CMS and 2133 colliding in LHCb).

**2024-like:**

- 60% availability, 11h fills, default parameters in the tool including:
  - $1.6 \times 10^{11}$ ppb, $\varepsilon_n$ = 2µm

The following parameters are updated;

  - IP1/5 leveled at µ=64, IP8 leveled at 2000 µb/Hz, IP2 at 8.7 µb/Hz.

**Futuristic:**

- includes the $\varepsilon_n$ achieved from BCMS and higher bunch intensity
- 60% availability, 14h fills, with the following parameters updated:
  - $1.8 \times 10^{11}$ ppb, $\varepsilon_n$ = 1.6µm, IP1/5 leveled at µ=64, IP8 leveled at 2000 µb/Hz, IP2 at 10 µb/Hz.

Note that neither take into account other possible improvements (eg. squeeze to 25cm, higher availability, change of filling scheme) but also don't include any accounting for problems or long stops.

Note that the totals are the same for all scenarios → minor differences are rounded!

# pp luminosity projections

2024-like: ~0.9 $fb^{-1}$ /day ATLAS/CMS, ~0.09 $fb^{-1}$ /day LHCb, ~0.41 $pb^{-1}$ /day ALICE

| | Scenario A/{C(flip years)} | | Scenario B | | Total 2025/2026 | Total Run3 (469) |
|---|---|---|---|---|---|---|
| Year (days) | 2025 (113) | 2026 (90) | 2025 (138) | 2026 (66) | (204) | [f(p)$b^{-1}$/day] |
| IP1/5 ($fb^{-1}$) | 102 | 81 | 123 | 60 | **183** | **378** [0.81] |
| IP2 ($pb^{-1}$) | 47 | 37 | 57 | 27 | **84** | **194** [0.41] |
| IP8 ($fb^{-1}$) | 10.2 | 8.1 | 12.3 | 6.0 | **18.3** | **30.6** [0.065] |

Futuristic: ~0.98 $fb^{-1}$ /day ATLAS/CMS, ~0.094 $fb^{-1}$ /day LHCb, ~0.44 $pb^{-1}$ /day ALICE

| | Scenario A/{C(flip years)} | | Scenario B | | Total 2025/2026 | Total Run3 (469) |
|---|---|---|---|---|---|---|
| Year (days) | 2025 (113) | 2026 (90) | 2025 (138) | 2026 (66) | (204) | [f(p)$b^{-1}$/day] |
| IP1/5 ($fb^{-1}$) | 112 | 89 | 136 | 65 | **201** | **394** [0.84] |
| IP2 ($pb^{-1}$) | 50 | 41 | 61 | 30 | **91** | **199** [0.42] |
| IP8 ($fb^{-1}$) | 10.7 | 8.5 | 13.0 | 6.2 | **19.2** | **31.5** [0.067] |

# PbPb Luminosity Projections, 2025/2026

Based on the above schedules we give two very rough luminosity projections for the ion data-taking based on average integrated luminosity per day. The baseline filling scheme is : 1240b_1032_1032_557.

***Baseline, conservative:***

- 0.10 $nb^{-1}$ /day (ATLAS/ALICE/CMS): performance re-gain wrt to 2023, with no additional improvements
- 0.02 $nb^{-1}$ /day (LHCb): smaller crossing angle, more favorable filling scheme

***Futuristic, optimistic:***

- 0.15 $nb^{-1}$/day (ATLAS/ALICE/CMS): 60% LHC availability, 2.4e8 ions per bunch, 2.8 um emittance
- 0.04 $nb^{-1}$ /day (LHCb): $\beta^*$ to 1m instead of 1.5m

Note:

- Only physics days are considered: 4 days of PbPb setup + 50% days (2) of intensity ramp-up + 1 day of VdM are excluded
- Neither take into account MAJOR improvements for 2025 and beyond
  - eg. squeeze to 30cm, even higher availability, higher number of colliding bunches, even smaller x angles.
- 2022 was a Pb ion test, it did not bring any integrated luminosity (2 days are ignored).
- 2024 only uses baseline in both projections as there is no plan to reach “performance increases” in 2024.
- The pp reference run costs 4 days in all scenarios.
- Numbers have a large uncertainty, which can be narrowed down after the PbPb 2024 run.
- Reminder: +2 $nb^{-1}$ for ATLAS/CMS/ALICE and +0.25 $nb^{-1}$ for LHCb from 2023 to totals.

# PbPb luminosity projections

Baseline: 0.10 $nb^{-1}$ /day ATLAS/ALICE/CMS, 0.02 $nb^{-1}$ /day LHCb in 2024/2025/2026

| | | | Scenario A/{C(flip years)} | | Scenario B | | |
|---|---|---|---|---|---|---|---|
| Year (days) | 2023 (32) | 2024 (15) | 2025 (43) | Totals (90) | 2025 (18) | 2026 (18) | Total (83) [-7 wrt A] |
| IP1/2/5 ($nb^{-1}$) | 2 | 1.5 | 4.3 | **7.8** | 1.8 | 1.8 | **7.1** |
| IP8 ($nb^{-1}$) | 0.25 | 0.3 | 0.86 | **1.41** | 0.36 | 0.36 | **1.27** |

Futuristic: 0.15 $nb^{-1}$ /day ATLAS/ALICE/CMS, 0.04 $nb^{-1}$ /day LHCb in 2025/2026

| | | | Scenario A/{C(flip years)} | | Scenario B | | |
|---|---|---|---|---|---|---|---|
| Year (days) | 2023 (32) | 2024 (15) | 2025 (43) | Totals (90) | 2025 (18) | 2026 (18) | Total (83) [-7 wrt A] |
| IP1/2/5 ($nb^{-1}$) | 2 | 1.5 | 6.45 | **9.95** | 2.7 | 2.7 | **8.9** |
| IP8 ($nb^{-1}$) | 0.25 | 0.3 | 1.72 | **2.27** | 0.72 | 0.72 | **1.99** |

Targets Run3 : 6.2-6.5 $nb^{-1}$ ATLAS/ALICE/CMS, 2 $nb^{-1}$ LHCb (increased after 2023, was 1 $nb^{-1}$)
No pPb run is considered, as opposed to baseline for Run3.

# How to split HI days in Scenario B

These 2 slides look at some possible splitting of days between 2025 and 2026 under the assumption that Scenario B is chosen.

- Under Scenario C (or A but it is off the table) the situation is much simpler – all the days are together and any switch to p-Pb can be decided nearer the time (or not at all).
- In all cases I assume that pPb can provide cool-down such that it forms the 2026 run with PbPb in 2025.

Under Scenario B there are several key questions that we need to answer if there is a p-Pb run:

- How should the days be split between PbPb and p-Pb? (ie. how many pPb days do we put in 2026).
- Do we consider both p-Pb and Pb-p, or just one (which one?)
  → this also influences the number of days.
- What energy should we do p-Pb? $\sqrt{s_{NN}}$=5.36 TeV (to match PbPb/ppRef) or $\sqrt{s_{NN}}$=8.54 TeV (maximum)
  → yellow report assumes the maximum but in 2016 we did both.

At the LMC feedback was having 2 days commissioning before the TS is highly advantageous, and no TS on Friday is desirable.

For luminosity projections I assume:

- PbPb: 0.15 $nb^{-1}$/day (IP1/2/5), 0.04 $nb^{-1}$/day (IP8)
- p-Pb: 20 $nb^{-1}$/day (IP1/5), 13 $nb^{-1}$/day (IP2/8) (rough numbers)
  → These are *optimistic* numbers (particularly for IP8)

I assume 3 days are dedicated to vdM and intensity ramp-up each year and 4 days commissioning which is *optimistic.*

2016 schedule

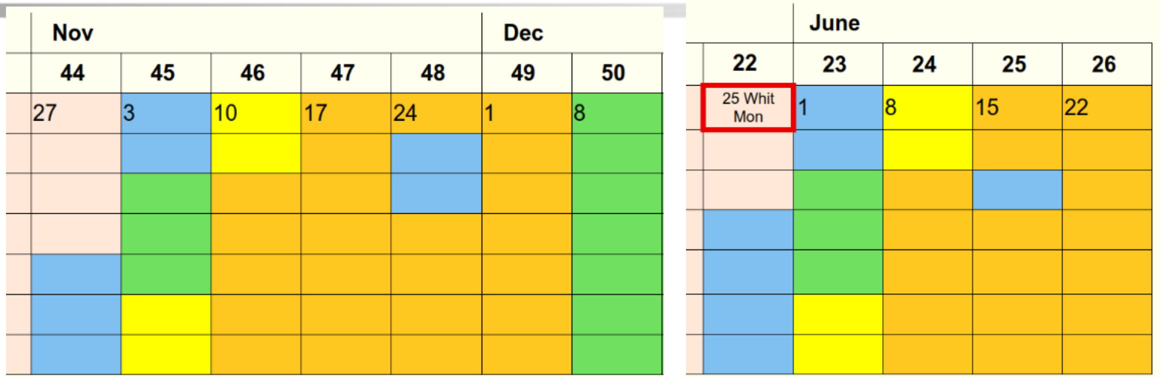
| | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|
| week1 | set up 5 | set up 5 | 5 TeV | 5 TeV | 5 TeV | 5 TeV | 5 TeV |
| week2 | 5 TeV | 5 TeV* **VIP Visit** | set up 8 | set up 8 | set up 8 | 8 TeV | 8 TeV |
| week3 | 8 TeV | 8 TeV | 8 TeV | 8 TeV | LHCf run* | reversal | reversal |
| week4 | MD | 8 TeV | 8 TeV | 8 TeV | 8 TeV | 8 TeV | 8 TeV |

Schedule from 2016 run [1] it took 2 days to do the p-Pb / Pb-p reversal – I assume the cost will be the same and that this includes some short intensity ramp-up. Last time we did a single 200b fill of 2.5h [2].

# Some possible configurations of days

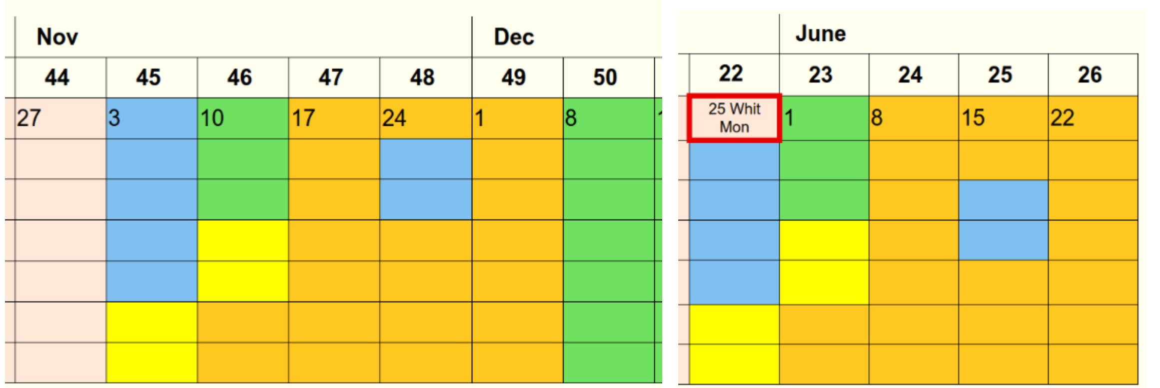
**Current split:** 21 physics days in 2025, 15 physics days in 2026.
- All PbPb: 3.15+2.25=5.4 $nb^{-1}$ (IP1/2/5), 0.84+0.6=1.44 $nb^{-1}$ (IP8)
- With pPb (2026): 300 $nb^{-1}$/ 195 $nb^{-1}$ (IP1/5)/(IP2/8)
- With pPb+Pbp (2026): 2x 130 $nb^{-1}$/ 85 $nb^{-1}$ (IP1/5)/(IP2/8)

With this split we should make the PbPb targets in 2025 for IP1/2/5.



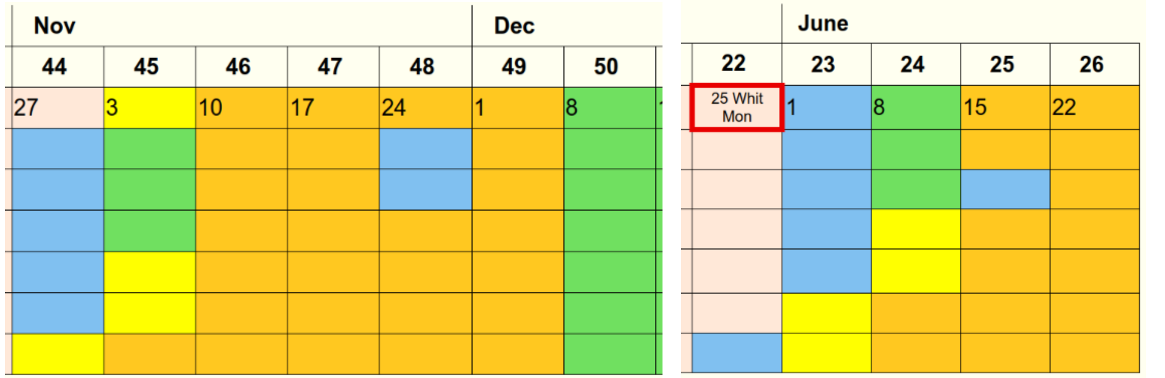

**Even split:** 18 physics days in 2025, 18 physics days in 2026.
- All PbPb: 2.7+2.7=5.4 $nb^{-1}$ (IP1/2/5), 0.72+0.72=1.44 $nb^{-1}$ (IP8)
- With pPb (2026): 360 $nb^{-1}$/ 234 $nb^{-1}$ (IP1/5)/(IP2/8)
- With pPb+Pbp (2026): 2x 160 $nb^{-1}$/ 104 $nb^{-1}$ (IP1/5)/(IP2/8)

With this split we probably struggle to get to PbPb targets in 2025.
Possible option for all PbPb to take advantage of knowledge gained?




**Max 2025:** 24 physics days in 2025, 12 physics days in 2026.
- All PbPb: 3.6+1.8=5.4 $nb^{-1}$ (IP1/2/5), 0.96+0.48=1.44 $nb^{-1}$ (IP8)
- With pPb (2026): 240 $nb^{-1}$/ 156 $nb^{-1}$ (IP1/5)/(IP2/8)
- With pPb+Pbp (2026): 2x 100 $nb^{-1}$/ 65 $nb^{-1}$ (IP1/5)/(IP2/8)

With this split we should exceed PbPb targets in 2025 for IP1/2/5.
pPb+Pbp doesn't seem sensible – little gain over 2016 data?



# 2025 Running Conditions for Computing

Estimates including contingency

| | |
|---|---|
| ATLAS/CMS luminosity: | < 150/fb |
| ATLAS/CMS average pile-up: | 65 (peak PU 67) |
| LHCb luminosity: | < 15/fb |
| ALICE luminosity (pp): | < 100/pb |
| Running time pp: | < 6.5 x $10^6$ seconds |
| Running time ions: | < 1.2 x $10^6$ seconds |

# 2026 Running Conditions for Computing

Estimates including contingency

- ATLAS/CMS luminosity: < 80/fb
- ATLAS/CMS average pile-up: 65 (peak PU 67)
- LHCb luminosity: < 10/fb
- ALICE luminosity (pp): < 70/pb
- Running time pp: < $3.5 \times 10^6$ seconds
- Running time ions: < $1 \times 10^6$ seconds