LHC experiments feedback on 2023 run & wishes for 2024

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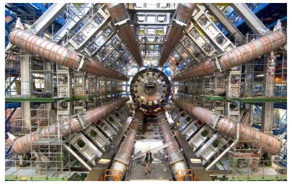
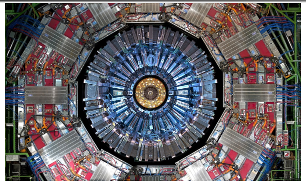
LPC

Motivation: LHC physics

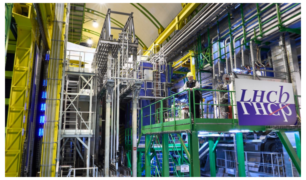
ATLAS

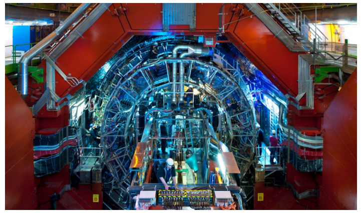




CMS

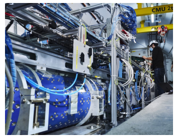
LHCb





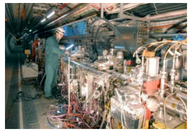
ALICE

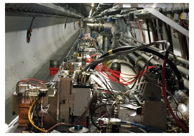
FASER



SND@LHC

TOTEM





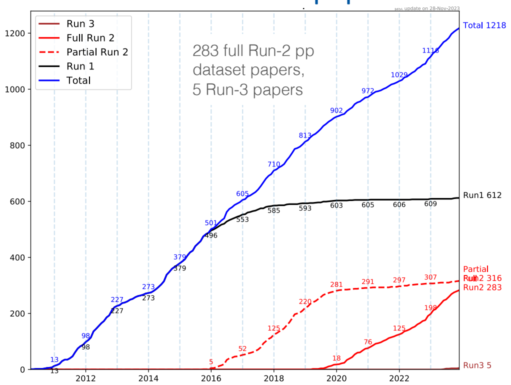
LHCf

Moedal

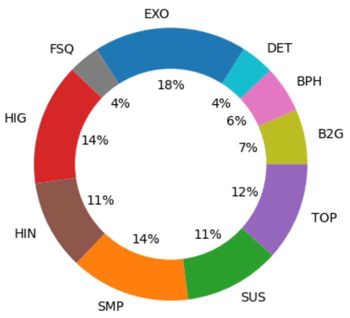
Direct searches for new physics (Dark Matter, new resonances, superpartners, Dark Photons, Heavy Neutral Leptons, Axion-Like Particles, milli-charged particles, magnetic monopoles, …)

Higgs physics
Top physics
Z physics
W physics
Photon physics
QCD
Diffractive physics
b-physics
c-physics
Neutrino physics
High density QCD (heavy ion)
…

ATLAS submitted papers



CMS publications per topic



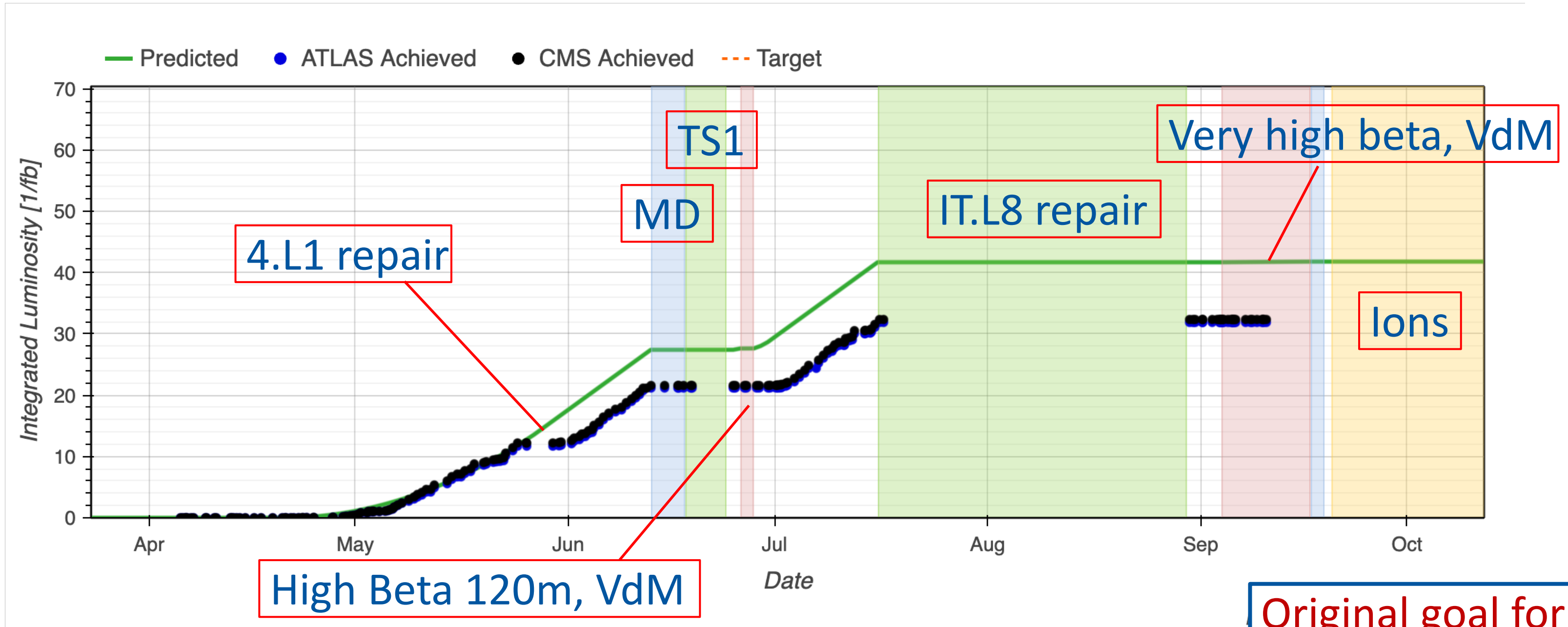
ATLAS: > 6000 members
CMS: > 6000 members
ALICE: > 2000 members
LHCb: > 1600 members

LHC collaborations published > 3500 papers so far on all these topics

2023 LHC run

To carry out all this programme … need statistics!

2023 was a very challenging year:

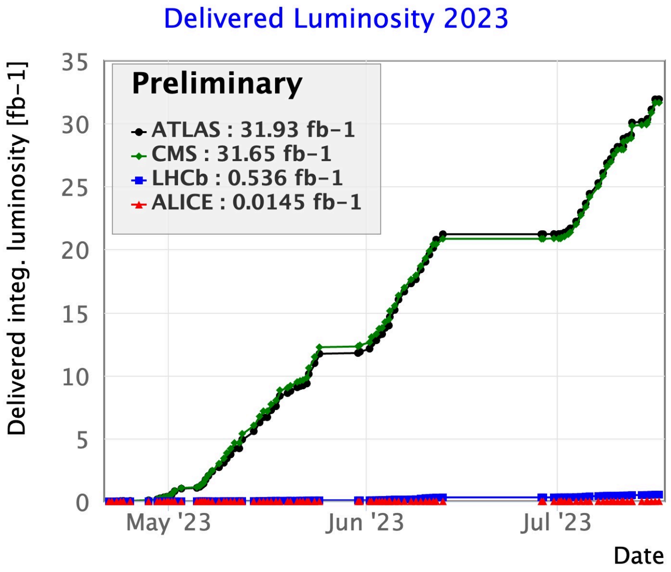


Original goal for 2023: 75 fb^{-1}

After 4.L1 incident, slope limited by intensity < 1.6×10^{11} ppb

After the IT.L8 repair: no more high intensity proton operation in 2023 → total 2023 proton dataset for ATLAS/CMS is 32 fb^{-1}

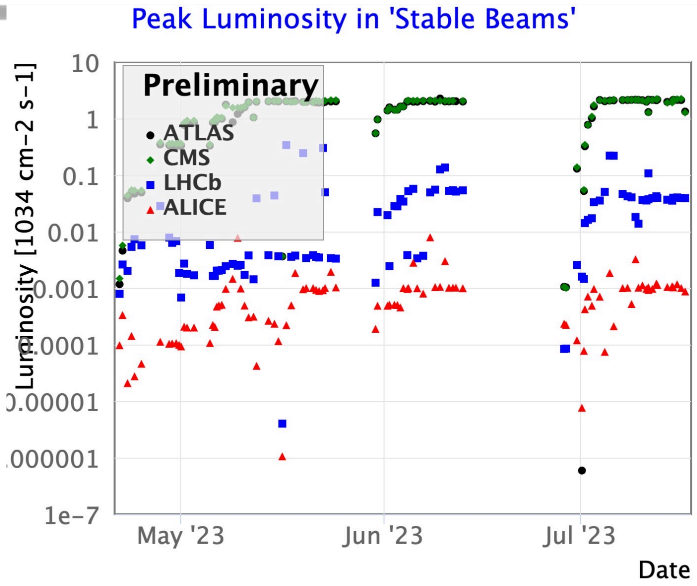
LHC performance 2023



32 fb^{-1} ATLAS/CMS

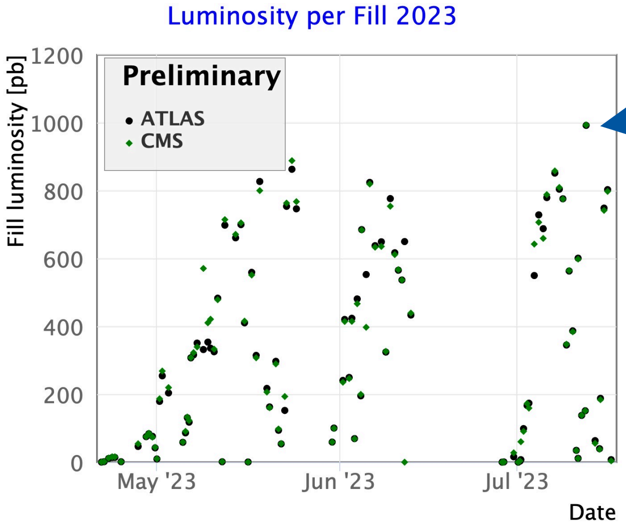
0.5 fb^{-1} LHCb

15 pb^{-1} ALICE



max 2.2 x 10^{34} $cm^{-1}s^{-1}$ in IP1/5

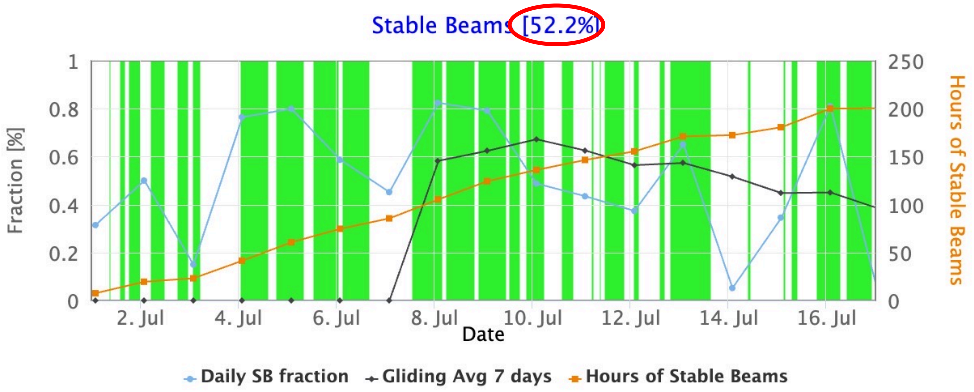
LHCb increasing over the year (target nominal lumi not yet reached)



max 0.99 fb^{-1}/fill

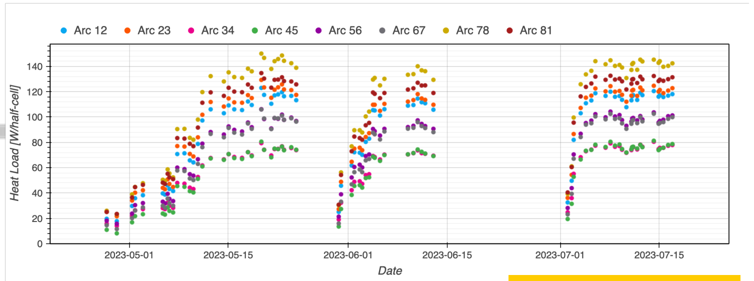
Record bunch intensity in SB:
1.61 x 10^{11} ppb

Record luminosity in 24h:
1.2 fb^{-1} in 24h



LHC performance in first 2 weeks of July
(= period without downtime due to incidents)

Proton beam in 2023

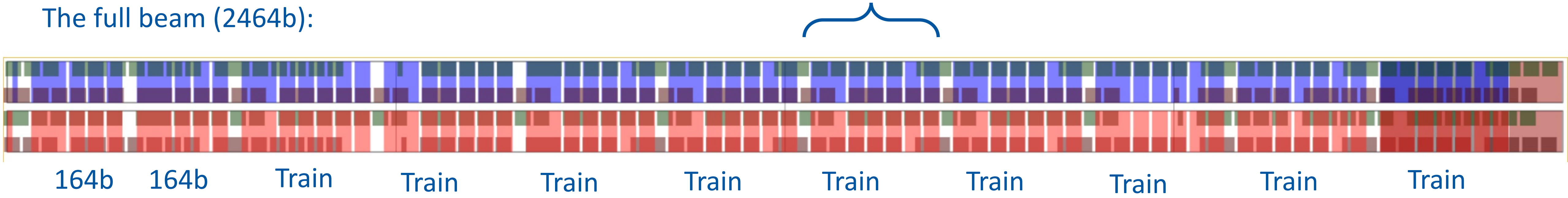


Heat load in 2023

Hybrid scheme used in 2023: 7 x 8b4e + 5 x 36 b

The long train (236b):

The full beam (2464b):



Reduced trains in the beginning (to aid steering)

Beam Info	
Bunches B1/B2	2464 / 2464
Injections B1/B2	12 / 12

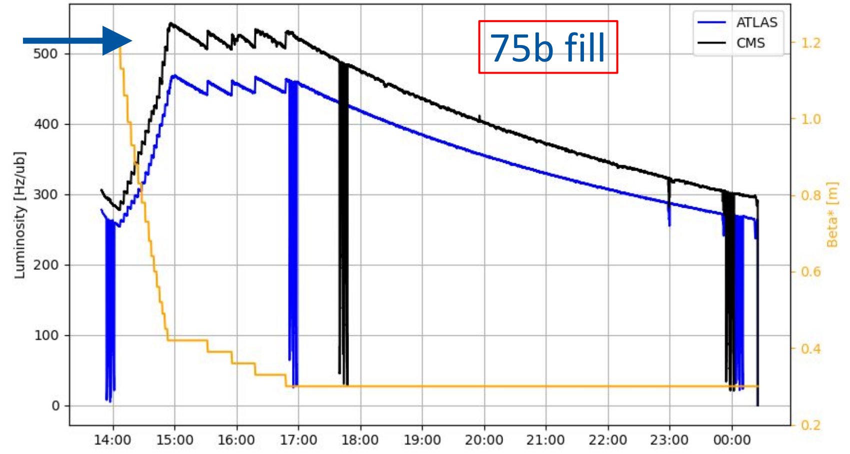
Collisions	
ATLAS/CMS	2452
ALICE	1842 (75.1%)
LHCb	1821 (74.3%)
Non Colliding B1	0
Non Colliding B2	0

LHC experiments were happy with beam quality from injectors.
For hybrid beam, LHC experiments prefer same bunch properties in 8b4e and in 40b bunches.

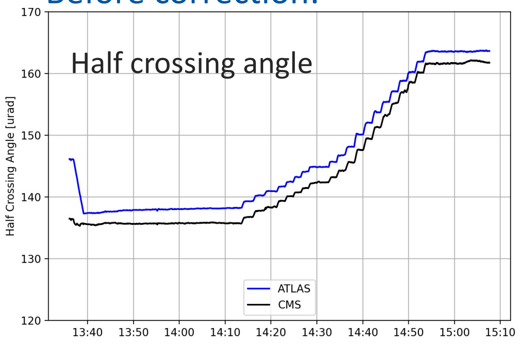
Lumi difference between IP1/5

Luminosity difference between ATLAS/CMS during early ramp up fills around 13%

PU = 60

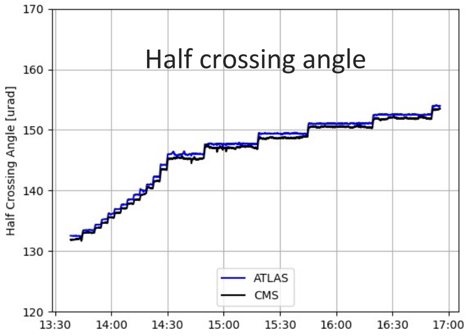


Before correction:



DOROS

After correction:



DOROS

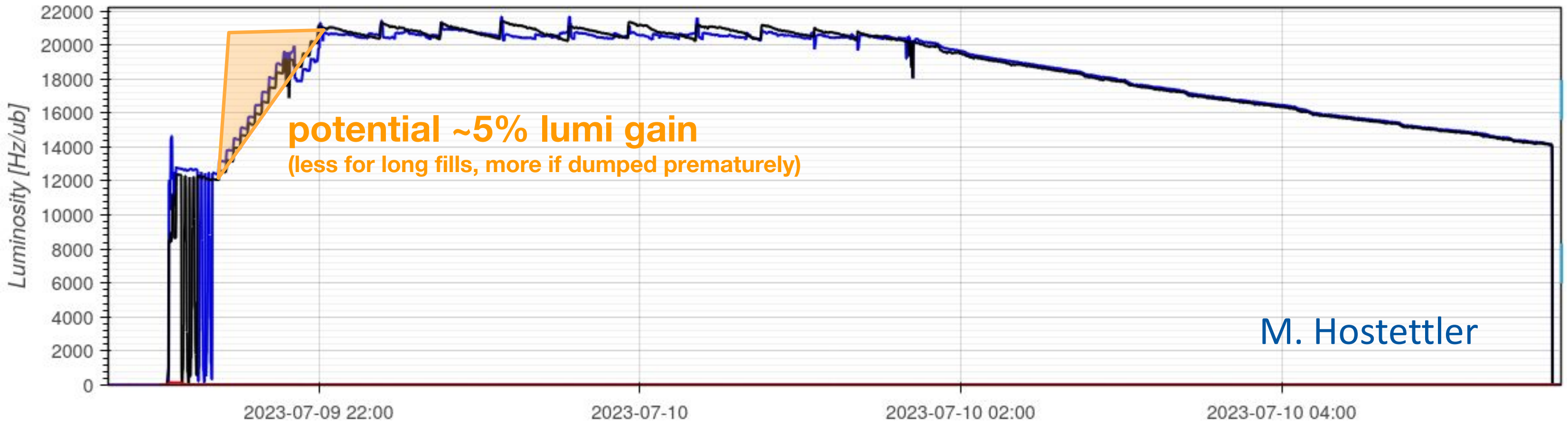
Decided to adjust crossing angle (reduced in IP1 by 10 murad). Validated by loss maps and repeat of 400b/900b ramp up fills.

Remaining lumi difference after correction?

- Remaining difference could be caused by beam effects, e.g. difference between H and V emittance, or expt. luminosity calibration
- finetuning of crossing angle by up to ~5 urad accepted by Machine Protection after TS1
- End-of-year difference between IP1/5 < 1% (but final expt. calibrations not yet ready)
- Need to pay attention to crossing angle during 2024 commissioning

Faster beta* steps between 120 and 60 cm

- The 2023 squeeze ends at beta*= 120cm, then leveling from 120cm till 30cm
  → this was optimized with a bunch intensity of 1.8 x 10^{11} ppb in mind
- Since we were not exceeding 1.6 x 10^{11} ppb, it takes 45min of beta* steps to reach the target luminosity
- This could be reduced to < 10min if steps are "skipped" and longer segments could be used
  - But segmented collimation limits do not allow skipping steps
  - Proposal for cumulative limit functions developed
  - Has been tested in cycle with setup beam and MPP accepted to go ahead after dry test, starting with small jumps, increase each fill
  - Propose to maintain this in 2024



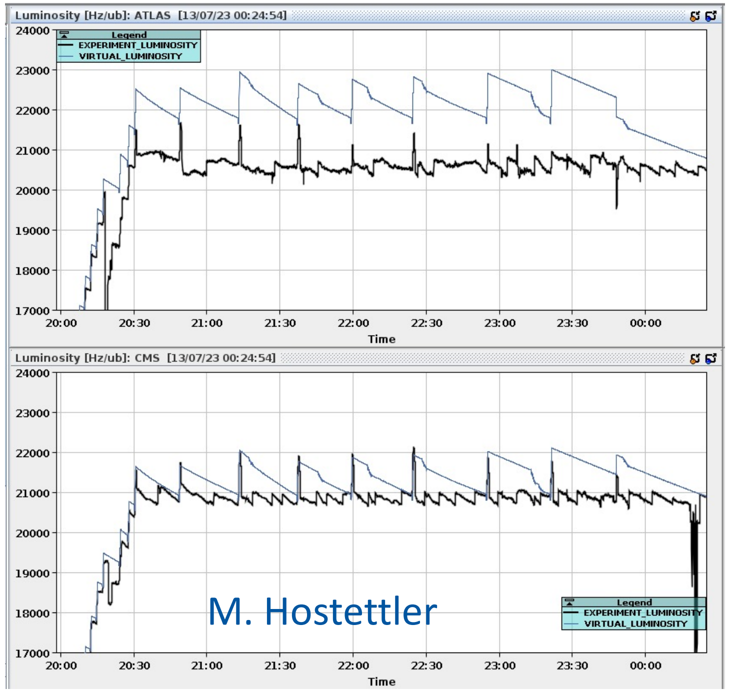
M. Hostettler

Leveling on virtual lumi

- Beta* leveling implies steps of +/- 2.5% in lumi (“saw tooth”)
- Offset leveling is smoother and is preferred by ATLAS/CMS, since running at limit of their PU capabilities
- Pretend there is a virtual experiment that is beta* leveled at mu=65; then offset level both ATLAS and CMS wrt. this
- Beam stability shown not to be a problem
- Keep this option available for 2024

Expect that ATLAS and CMS will want to level between mu=60 and 65 in 2024

Fill 9063



Virtual lumi: beta* leveling @ mu = 65

ATLAS offset leveled at mu = 60 +/- 1.5%

CMS offset levelled @ mu = 61 +/- 1.5%

VdM beams

ATLAS

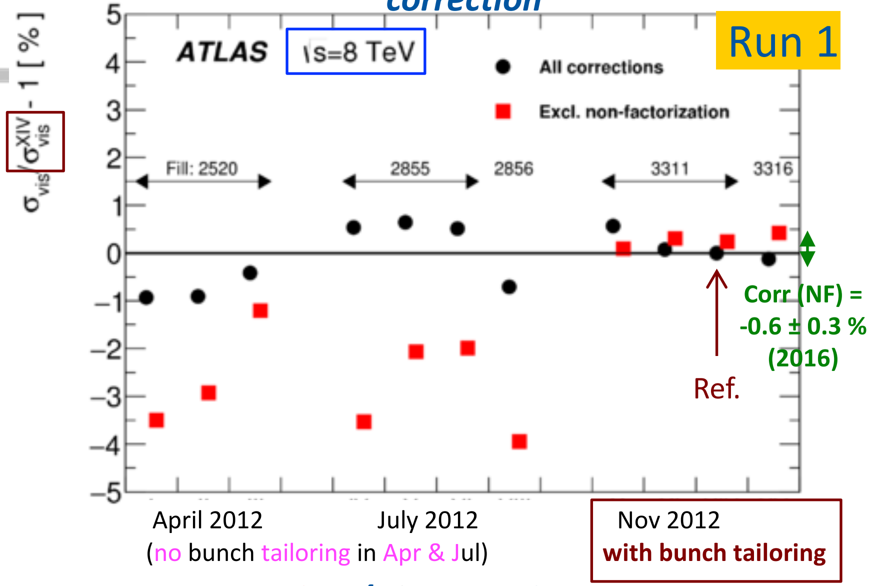
Luminosity precision goal for Run 3: < 1% !

VdM beam requirements for IP1/5:

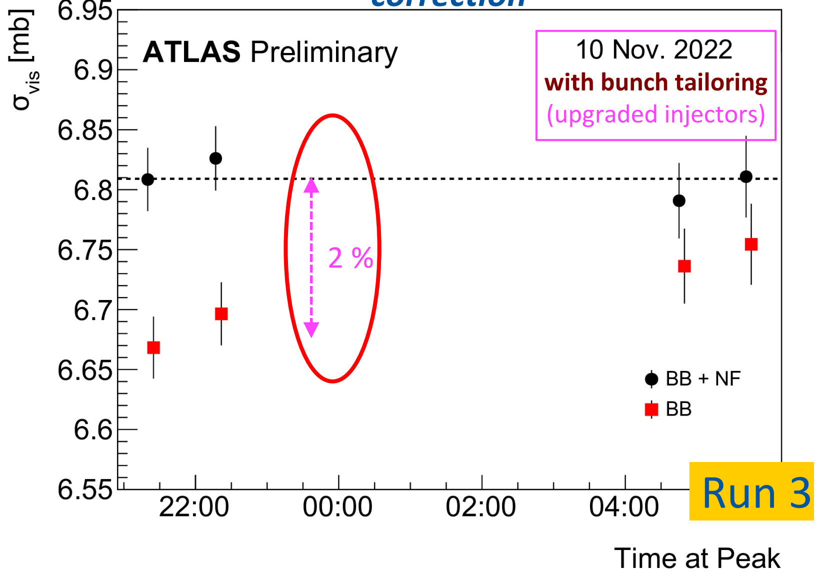
β^* = 19 m, Zero crossing angle
Filling scheme: ~ 140 colliding + 2 non-colliding bunches per beam

- Bunch intensity: ~ 0.8 10^{11} p/bunch
  achieved in 2018 + 2023, a bit too high in 2022
- ε_N ~ 3.0 (2.8) μm.rad early in (averaged over) STABLE BEAMS
  reasonably achieved in 2018 + 2023, a bit too low in 2022
- Pile-up parameter μ ~ 0.5 [derived quantity]
  just right in 2018, too high in 2022, about right in 2023
- Non-factorization (NF) biases < 0.5%
  achieved at the end of Run 1 (Nov 2012) and most of Run 2, thanks to bunch tailoring
  2022: NF biases ~ 1-2 %, seemingly time-dependent
  → one of the largest uncertainties - and probably the one most difficult to control
  2023 looks similar to 2022

Before/after non-factorization correction



Before/after non-factorization correction



Why the non-factorization biases are so much larger in Run 3 than in Run 2?

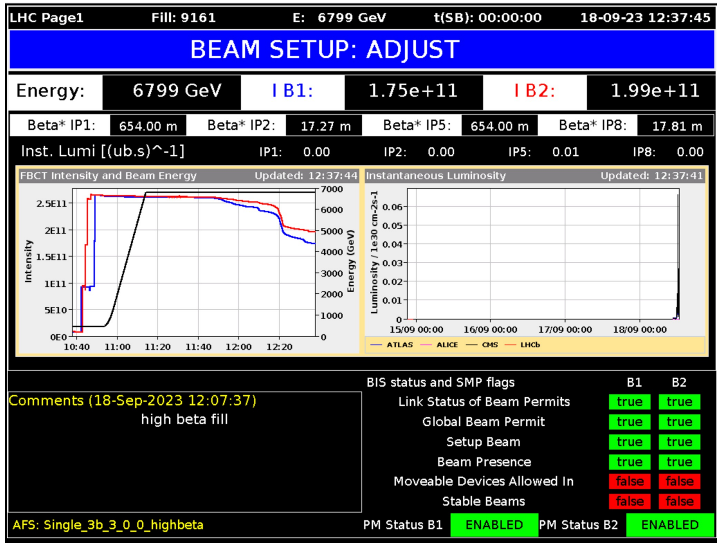
- Is it conceivable that the injector upgrade be responsible, at least in part? Could this be studied in a **dedicated injector MD?**
- The bunch-tailoring procedure fundamentally relies on making the **beams as Gaussian as possible**. However, a key diagnostic, the **SPS wire scanners**, were unavailable during the 2023 scans. Will they be **more robust in 2024**?

Special runs in 2023: high beta runs

120m run for TOTEM T2:

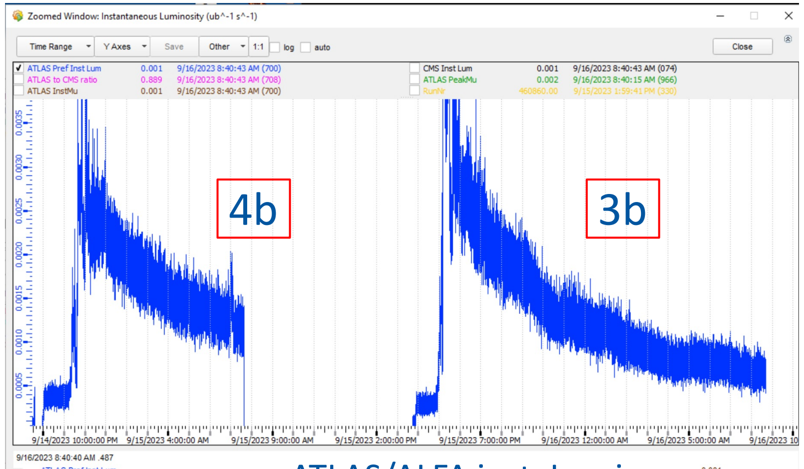
- Single 12h fill, ADJUST, 3/4 bunches
- Emittance and bunch intensities as requested

L = 3x10^{28} cm^{-2}s^{-1}
mu = 0.08



Very high beta run for ALFA and TOTEM:

- De-squeeze to β_x = 3km, β_y = 6km, 3 or 4 single bunches + pilot, safe beam
- Setup started on Sept 4th , very challenging (crystal collimation, orbit drift, …)
- A lot of machine availability issues, ATLAS magnet trip, water leaks …
- Huge efforts of collimation team (crystal collimation) and experimental teams
- In total 9 fills, 70h of stable collisions



ATLAS/ALFA inst. Lumi

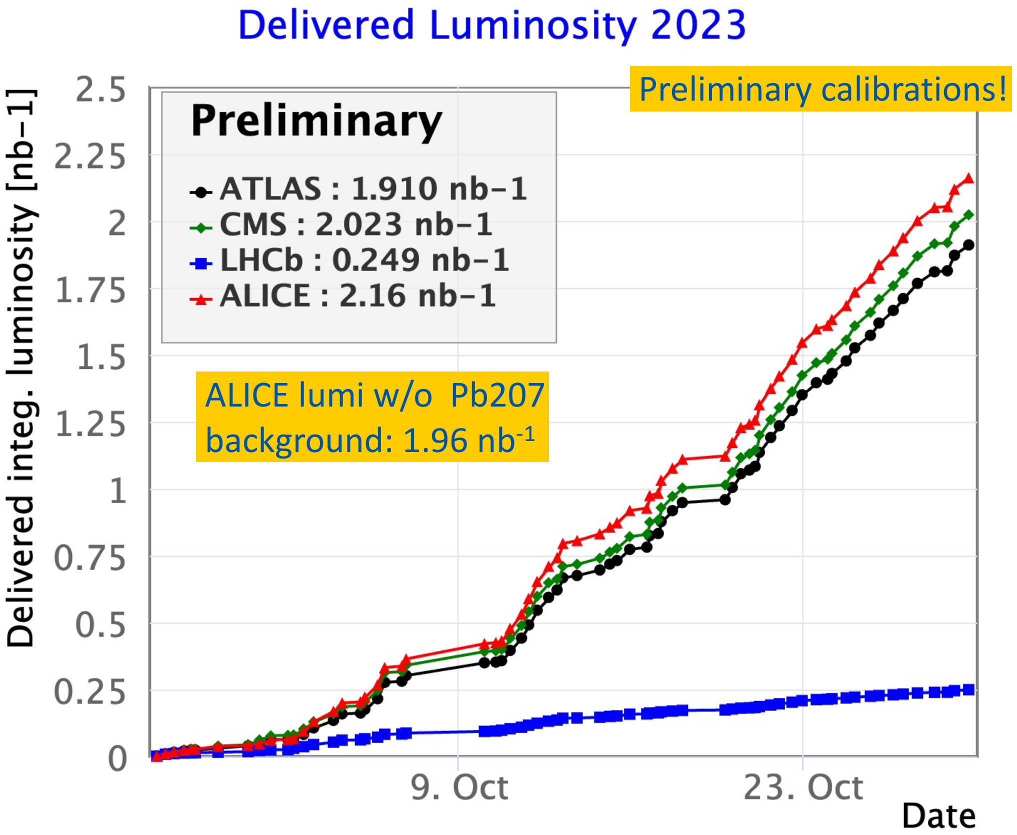
Total luminosity high beta run:
ALFA: 329 μb^{-1} (10% more than goal!)
TOTEM: ~300 μb^{-1}

Successful end of the high beta programme at the LHC

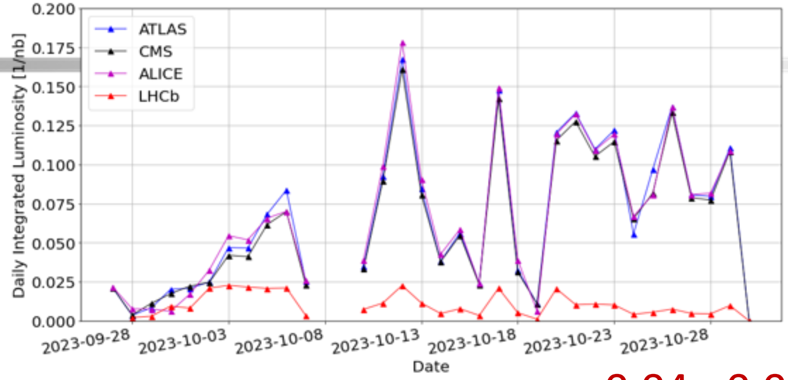
- 1 side of ALFA detector removed, location goes to TWOCRYST
- Roman Pots of TOTEM go to CMS/PPS

Many thanks to all involved over the years!

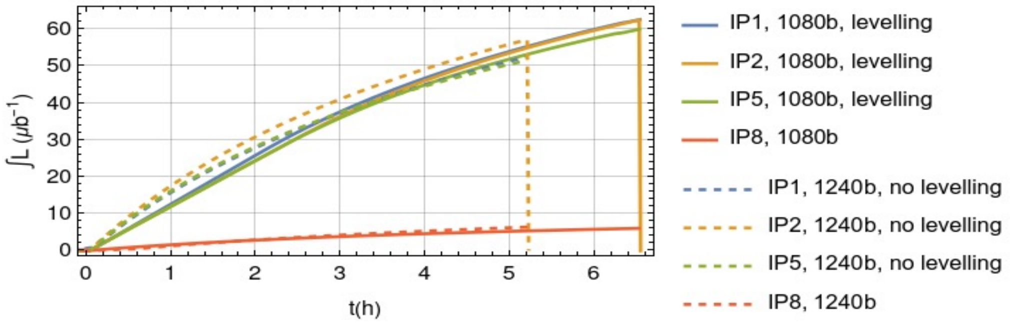
Ion luminosity 2023

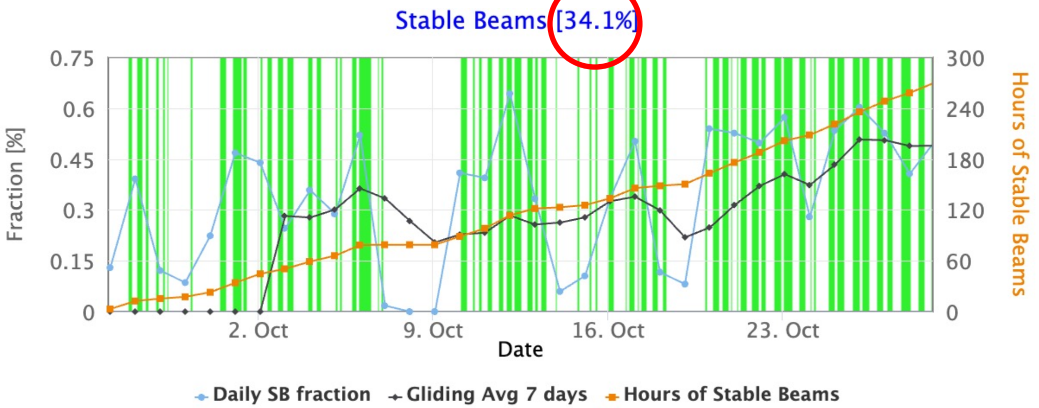


Best lumi/day: 0.175 nb^{-1}



0.04 - 0.06 nb^{-1} per fill





Original luminosity goals for PbPb run in 2023 were

- ALICE: 3.25 nb^{-1}
- ATLAS/CMS: ~3 nb^{-1}
- LHCb: 0.4 nb^{-1}

Reached only ~2/3 of initial goal
Most expts got more data than in 2018
ALICE MB dataset 40x larger than Run 2

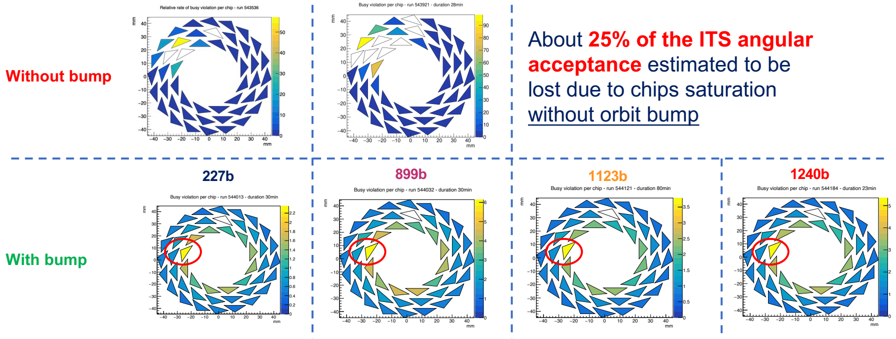
Ion run

2023 ion run very challenging: a lot of new concepts (slip stacking, crystal collimation, new IP2 TCLD, …)

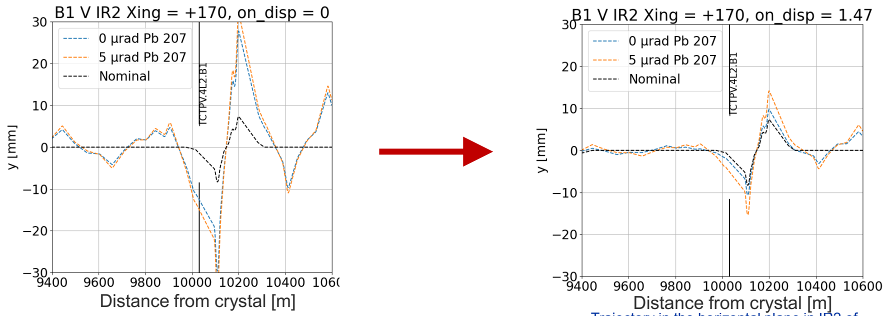
These new concepts actually worked very well, but we encountered a lot of other hickups:

- Losses in the ramp: would it be useful to move the squeeze out of the ramp? Or is it sufficient to run with the final BLM thresholds?

- ALICE background: further reduction of background possible? (Impact of background on ITS3 and ALICE3?)



Residual beam background only slightly increasing with # of bunches
Local increase of BUSY violation rate still affecting the tracking efficiency



Trajectory in the vertical plane in IR2 of Pb207 exiting from vertical crystal

Trajectory in the horizontal plane in IR2 of Pb207 exiting from vertical crystal

- SEU in QPS electronics boards: migation possible during ongoing EYETS?

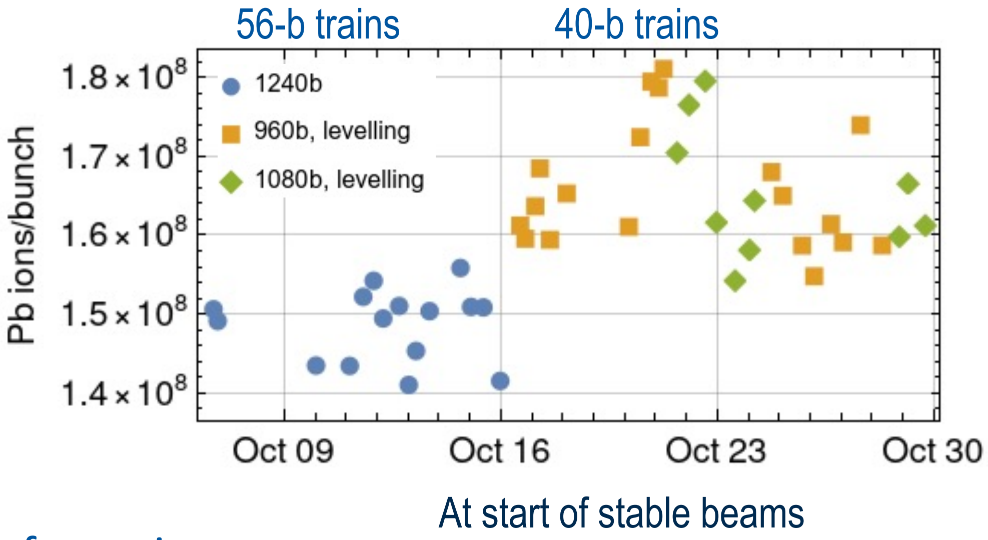
- Any ideas to reduce 10Hz dumps?

Ion run (2)

- Beam quality at start of Stable Beam worse than expected
  - Both emittance and bunch intensity
  - 1.8 x 10^{11} ppb reached during a few days for 40b trains, then deterioration

Goal:

	LHC design	2018	Run 3
Beam energy (Z TeV)	7	6.37	6.8
Bunch spacing (ns)	100	75	50
Total n.o. bunches	592	733	1240
Bunch intensity (10^7 Pb ions)	7	21	18
Normalized transverse emittance (μm)	1.5	2.3	1.65



- Need to come up with improved performance estimates for future ion runs:
  - Can we reach and maintain 1.8 x 10^8 ions/b also with 56b slip-stacked trains?
  - If not, can we maintain 1.8 x 10^8 ionspb with 40b slip-stacked trains?
  - If not, should we go back to 75ns beam (non slip-stacked) where we could reach 2.1 x 10^8 ionpb in 2018? (bonus: less out-of-time PU)
  - Can the emittance be improved? (we got ~2um instead of the expected 1.65um)
  - Can the injection time (1h) be shortened?

Roadmap improved ion performance to be defined

Outlook for 2024 and 2025

- 2024 (2025) schedules have 2 (4) weeks more physics time than 2023
  (reduction of Run 3 due to electricity crisis was 6 weeks in 2023, 4 weeks in 2024 and 2 weeks in 2025)

- Current beam limitations (TDIS, springs, …) likely fixed after 23/24 EYETS:
  - Mitigation strategy to replace TDIS (link) and warm vacuum modules in coming EYETS (link)
  - Expect no more limitations to #bunches and intensity from these hardware issues
  - **At the moment**, no showstopper to go up to $1.8x10^{11}$ ppb as originally foreseen in 2023
  (define roadmap how to reach this?)

- Overall Run3 planning needs adjustment after major loss of physics time due to IT.L8 incident this summer (49 physics days lost, 50.5% of 2023 pp time, ~ 12% of total Run 3 pp time)
  - Loss to be shared *pro rata* by proton physics, ion physics and MD.

- Options for LHC schedule for 2024 and 2025 presented in the next slides
  - input from both machine and experimental communities

Ion physics time in 2024/2025

- Balancing the loss of physics time due to the Triplet (ITL8) leak this year leads to the reduction of ion physics time in 2024+2025 to ~6.5 weeks
- From this, we need to subtract the 2024 pp reference run (1 week)
- This leaves ~5.5 weeks PbPb physics to be
  - Either distributed between 2024 and 2025, i.e. 2.5 weeks each + a 0.5w pp reference run in 2025 (option 1)
  - Or all to happen in one year, e.g. 2025 (option 2)
- A short pPb run instead of PbPb in either 2024 or 2025 still a possibility, but none of the experiments are asking for this at the moment.
- Additionally (i.e. special run, not ion time) there will be a 1-week oxygen run (4 days setup + 3 days p-O + 1 day O-O) at top energy (6.8 Z TeV). There will not be time for a dedicated pp reference run at these energies.

Option 1

PbPb run at end of both 2024 and 2025

- Have a short PbPb run (2.5-3 week of physics data taking) at the end of both 2024 and 2025
- This is less efficient (twice setup, twice ramp up), but also distributes the risk over two periods
- The oxygen run is scheduled after TS1 in 2024, no special run in 2025
- The 2024 pp reference run is tentatively scheduled after TS1 (can also be attached to ion period)

Total 2024:
- 115 days of proton physics
- 4 days of oxygen physics (OO + pO)
- 23 PbPb + ppref days
- 20 MD days

Total 2025:
- 145 days of proton physics
- 20 PbPb + ppref days
- 20 MD days

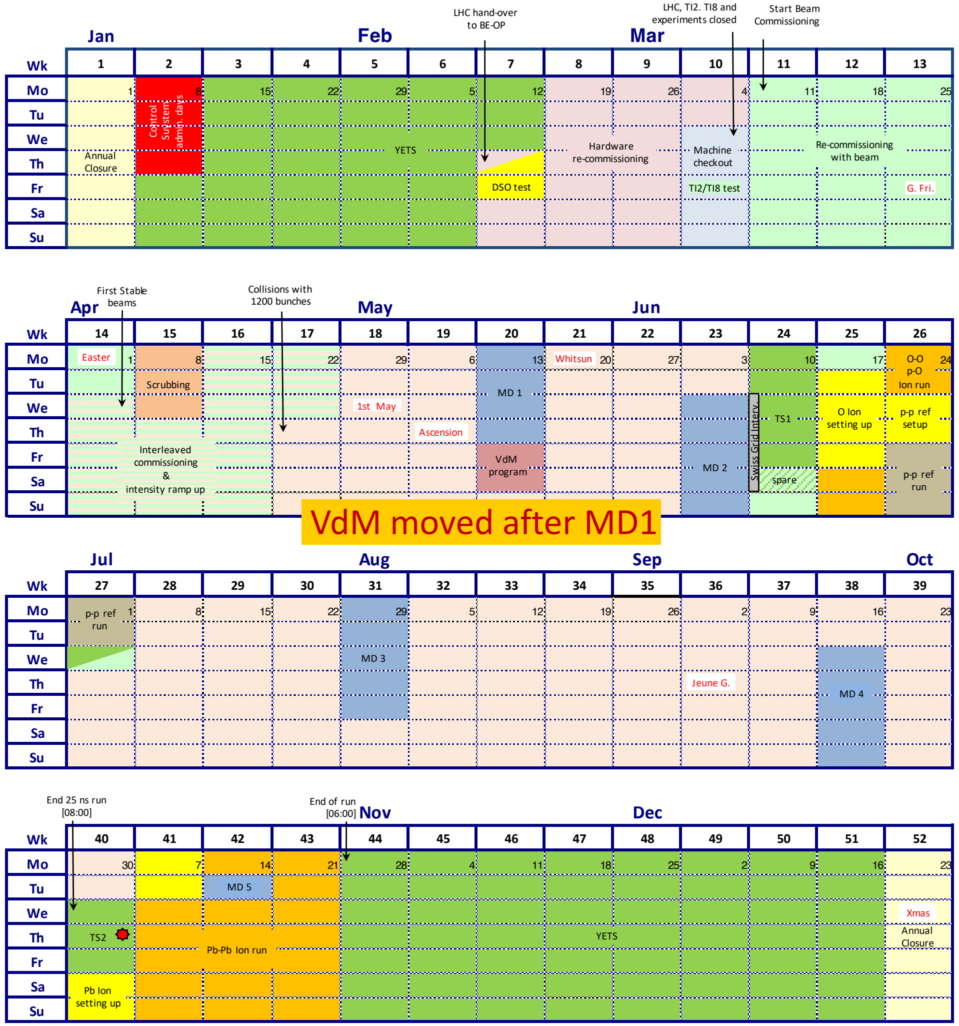
Option 1: schedule 2024 and 2025

RS

DRAFT LHC Schedule 2024 PROPOSAL
Energy cost optimised

November 20, 2023
ver. 0.7 Option 1

Version 22.11.2023

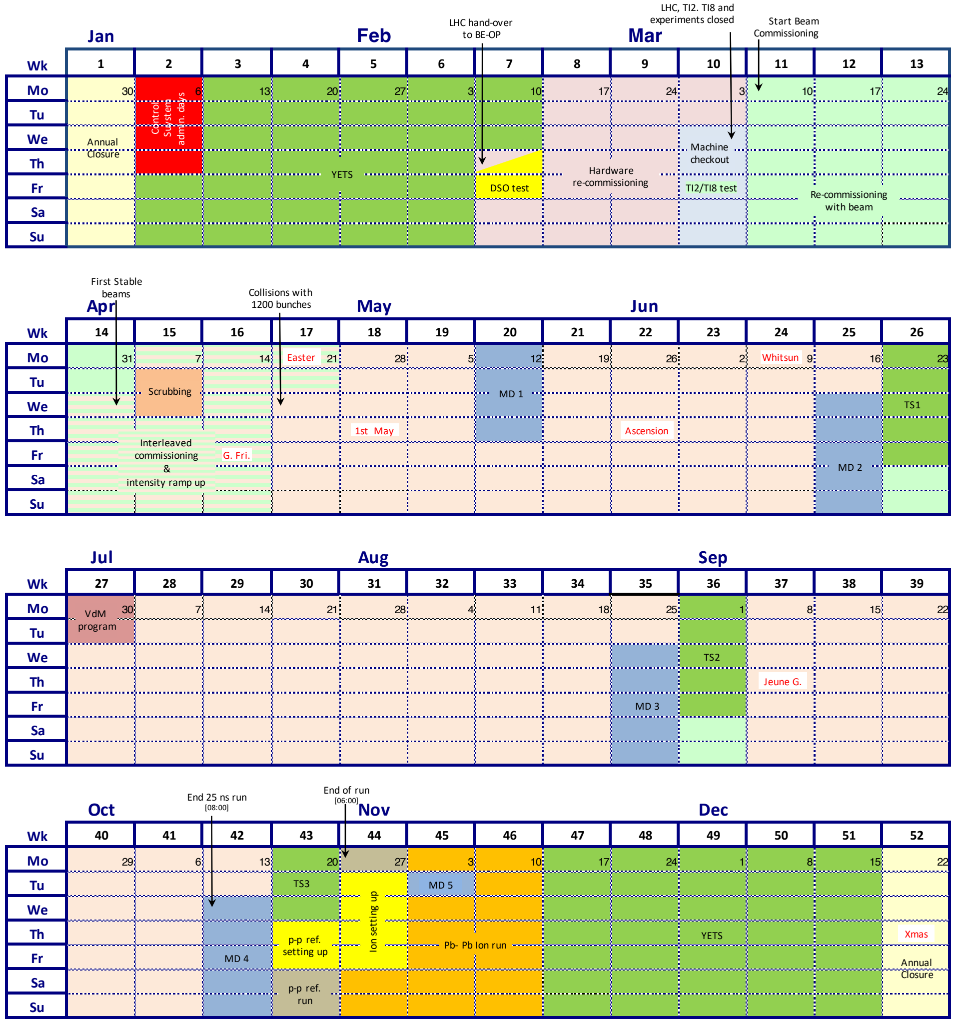


RS

DRAFT LHC Schedule 2025 PROPOSAL
Energy cost optimised with baseline LS3 start

November 20, 2023
ver. 0.3 Option 1

Version 22.11.2023



Option 2

Long PbPb run at end of 2025

- Single, long PbPb run (5.5 weeks of physics data taking) at the end of 2025
- This provides maximal radiation cooldown before the start of LS3
- This is more efficient from the lumi production point of view (single setup and ramp up)
- The oxygen run is currently scheduled after TS1 (injector community request)
  → but oxygen run at end of year would allow more cooldown before EYETS24/25 (CMS request)
- The 2024 pp reference run is scheduled after TS1

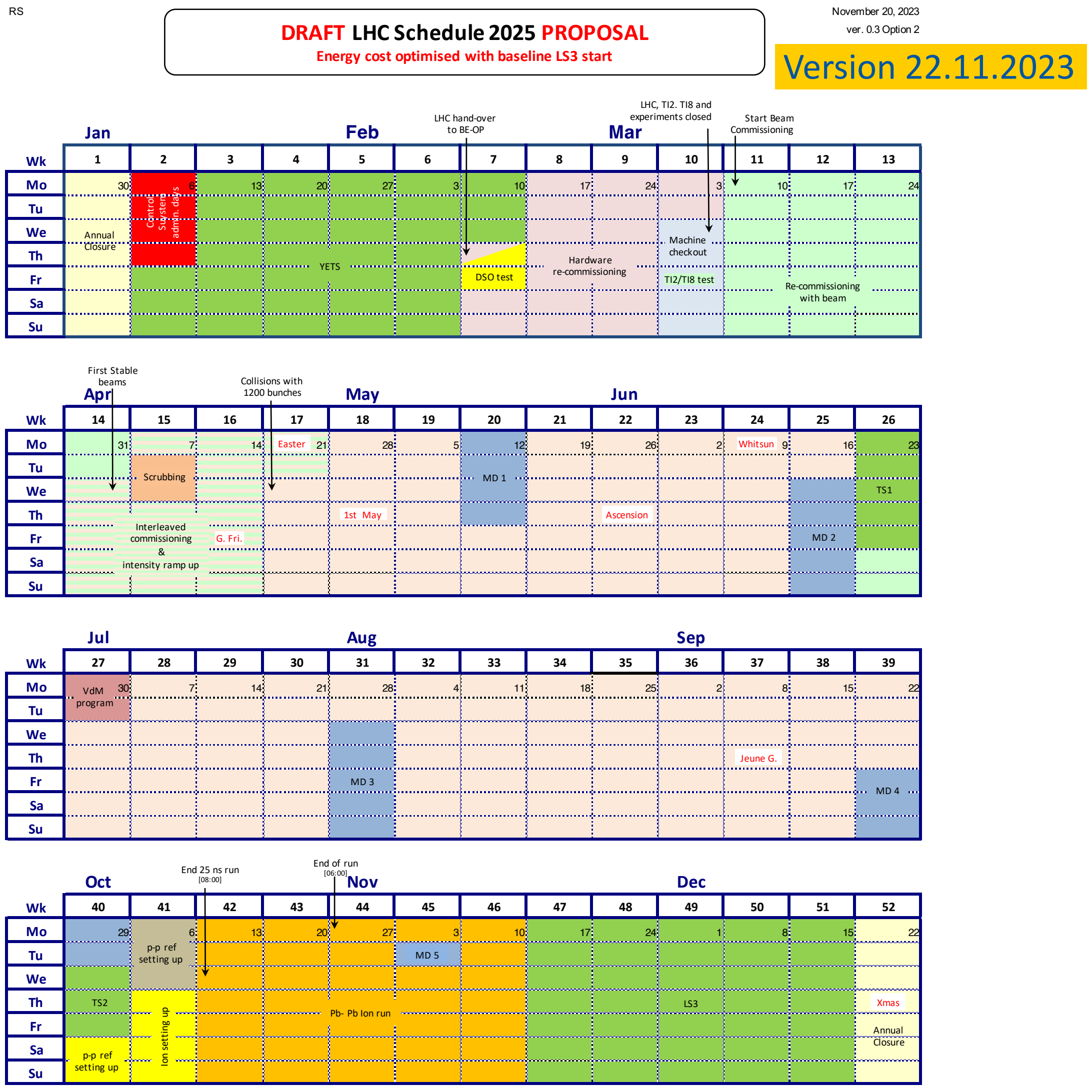
Total 2024:

- 135 days of proton physics
- 4 days of oxygen physics (OO + pO)
- 5 ppref days
- 20 MD days

Total 2025:

- 132 days of proton physics
- 39 PbPb + ppref days
- 21 MD days

Option 2: schedule for 2024 and 2025



oxygen run moved after TS1, no cooldown for EYETS

Luminosity comparisons 2024/2025

Option 1:

2024:	pp (115d):	83 fb^{-1}
	ion (18d):	1.9 nb^{-1}
2025:	pp (145d):	107 fb^{-1}
	ion (15d):	1.45 nb^{-1}
Total 24+25:	pp (260d):	190 fb^{-1}
	ion (33d):	3.35 nb^{-1}
[2022+2023:	pp (119d):	72 fb^{-1}]
	ion (32d):	2 nb^{-1}]
Total Run 3:	pp (379d) :	262 fb^{-1}
	ion (65d):	5.35 nb^{-1}

Option 2:

2024:	pp (135d):	99 fb^{-1}
	ion (--):	--
2025:	pp (132d):	96.6 fb^{-1}
	ion (34d):	4.3 nb^{-1}
Total 24+25:	pp (267d):	195.6 fb^{-1}
	ion (34d):	4.3 nb^{-1}
[2022+2023:	pp (119d):	72 fb^{-1}]
	ion (32d):	2 nb^{-1}]
Total Run 3:	pp (386d) :	267.6 fb^{-1}
	ion (66d):	6.3 nb^{-1}

Luminosity comparisons 2024/2025 (2)

pp reference runs: 2024 (5d) : 3 pb^{-1} (ALICE), 250-350 pb^{-1}(ATLAS/CMS), >>25 pb^{-1}(LHCb)
(targets) 2025 (3d, tbc) : goals tbc

oxygen run: O-O (1d) : 0.5 nb^{-1} (ALICE, ATLAS, CMS, LHCb?)
(targets) p-O (3d): 2 nb^{-1} (LHCb), 1.5 nb^{-1} (LHCf)

Assumptions:

pp: **average** daily integrated luminosity in June/July 2023 (excluding special runs, MDs, etc.): 0.7 fb^{-1}/day
assumption of ~1.8 x 10^{11} ppb and PU=65 in 2024/2025 → multiply by 1.15 → 0.8 fb^{-1}/day
ramp up: 0.3 fb^{-1}/day during 18 days

ion: **best** daily integrated luminosity in October 2023: 0.15 nb^{-1}/day (**optimistic!**).
assumption that future improvements can make this number the average for 2024/2025 (?)
ramp up: 0.05 nb^{-1}/day during 8 days

To be understood in the coming weeks if this is realistic .

PbPb is assumed during all ion periods in Run 3

No contingency for potential incidents is included!

Other options

Option 1 prime:

- Oxygen run after TS1 in 2025, instead of in 2024
- Same total luminosity as option 1 (8 pp days, or 6.4 fb^{-1}, shift from 2025 to 2024)

Option 2 prime:

- Long PbPb run at end of 2024, no PbPb in 2025
- Oxygen run at end of 2025
- Only 1 pp reference run in 2024, gain ~3 days (setup+ramp-up)
- Much less benefit of cooldown before LS3 (needed for e.g. taking out the TAS from IP1/5 at the start of LS3)

Preferences on schedule options

- Preferences expressed by LHC experiments:
  - ATLAS: option 2
  - CMS: option 2
  - LHCb: option 2
  - ALICE: option 1

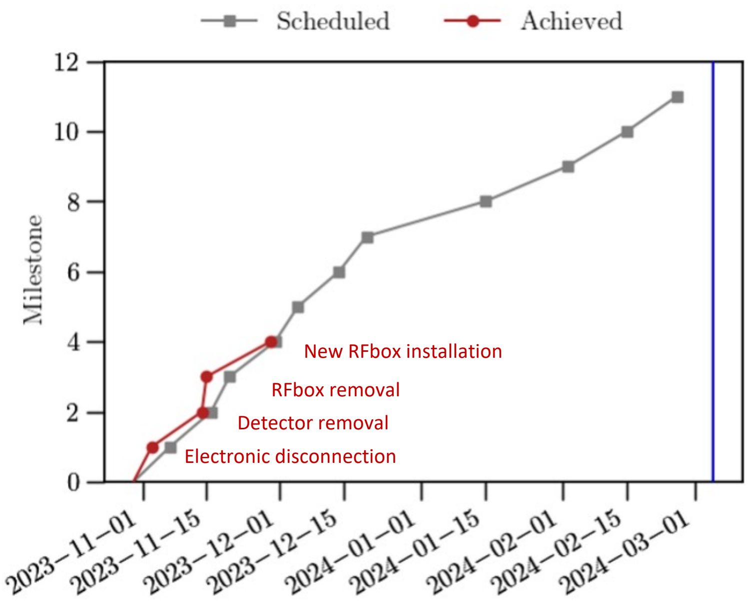
  - LHCf: fine with both options (provided oxygen after TS1)
  - FASER: slight preference for option 1

- Recommendation from LHCC
  - Currently being drafted

LHCb status

LHC detectors unchanged except for LHCb VELO

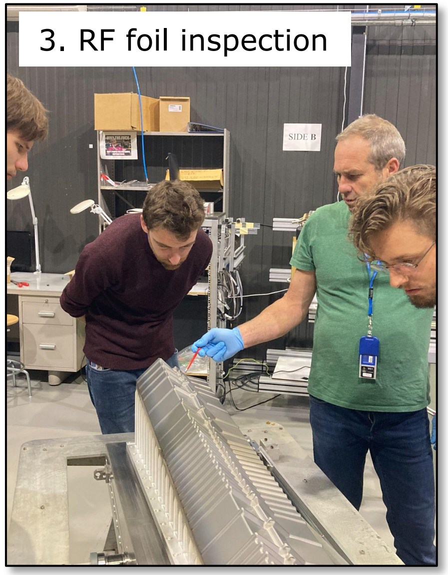
- VELO RFbox replacement currently on schedule
  - new RFbox installed; motion system tested
  - Leak tests in December
  - Bake-out planned to start on 4 January
  - Detector installation planned first half of February
- In 2024, plan to close VELO to nominal position
  - In 2023, gap was 49mm, i.e. moved out horizontally by +/- 24.5 mm
- LHCb aims to go to nominal mu early in the year (steps being defined) to reach 7 fb^{-1} in 2024.



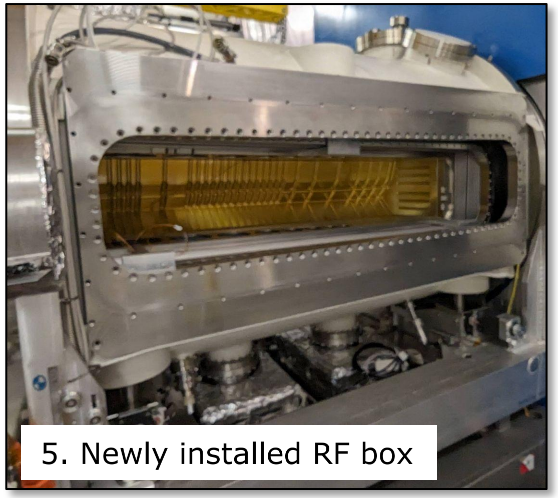
LHC VELO status

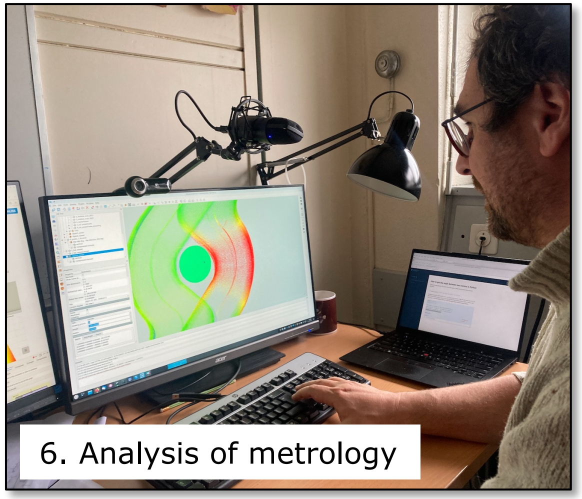

1. Detector removal


2. RF foil inspection


3. RF foil inspection


4. WF suppressor inspection


5. Newly installed RF box


6. Analysis of metrology

First metrology results indicate VELO back to 2022 conditions

Final Remarks for 2024

- Large proton dataset main priority for 2024
- Hope for smooth proton running in 2024 with conditions as originally foreseen in 2023
- Looking forward to proposals to improve the ion running conditions for the rest of Run 3
- For VdM, request to injectors to produce beams that minimize non-factorization, as was achieved in Run 2, to allow us to reach the 1% target on the luminosity precision
- Expect a decision on the baseline schedule for 2024 soon (Research Board tomorrow?)
- Finally, please always keep in mind that the LHC experiments are very large collaborations. Any change in plans should be clearly communcated, well in advance if possible, to make sure that the experiments can react appropriately.