Feedback from LHC Experiments and 2023 Outlook

Brian Petersen
On behalf of LHC experiments and LPC

Joint Accelerator Performance Workshop
5 December 2022
Outline

- Brief recap of 2022
  - Programme overview
  - LHC performance
  - Beam quality

- Feedback from experiments
  - Performance/activities in 2022
  - Interactions with LHC operations

- 2023 outlook
  - Overall schedule for 2023 and Run 3
  - Optimizing filling schemes and pile-up level
  - Special runs including ion running
Brief Recap of 2022

Much more in session 4 tomorrow
- First full year of LHC running after LS2
- Short physics year due to delays, extensive machine recommissioning, RF cryo incidents and early stop due to electricity supply crisis
- About two months lost with respect to the plan at start of the year
- Had to cancel ion run for 2022 – longer ion run next year

### Actual 2022 Schedule

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- First Stable beams at 6.8 TeV
- Collisions with 1200 bunches
- Emulsion extraction

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- End of run (Dec)
- Nov
- Dec
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- Tu 41
- We 42
- Th 43
- Fr 44
- Sa 45
- Su 46
- Mo 47
- Tu 48
- We 49
- Th 50
- Fr 51
- Sa 52
- Su 53

- MD 1
- MD 2
- MD 3
- FMD 1
- FMD 2
- FMD 3
- VTX run
- Pb ions test
- Annual
- Kmax
Recommissioning Year

- 2022 also (re-)commissioning year for experiments
- Extensive programme of special tests, access etc.
  - High luminosity/pile-up runs
  - First insertions of LHCb VELO and gas injections in SMOG2
  - Magnet polarity changes and magnet off runs
  - Tests for 2023+ configurations
  - ...

Detailed programme for post-TS1 run:

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<td>Revalidation of low $\beta$</td>
<td>LHCf removal</td>
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<td>Partial VELO ins.</td>
<td>ALICE High rate</td>
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<td>Full VELO insertion</td>
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<td>LHCf run</td>
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Many tests could only be done during working hours due to complexity of coordinating expert team availability.
LHC Integrated Luminosity

- Despite short, complicated run got good physics data
- ATLAS/CMS got about same luminosity as 2016
- ALICE have highest integrated p-p luminosity ever
  - *But no Pb-Pb physics data taking this year*
- LHCb mostly focused on detector commissioning
Rapid Ramp-up in Bunch Intensity

- Performance driven by record bunch intensity and emittance – benefited greatly from LIU

Bunch intensity pushed to $\sim 1.5 \times 10^{11}$ ppb (Limited by heatload)

This was $\sim 1.1 \times 10^{11}$ ppb in 2018 run

Beam emittance typically $\sim 1.8$ um

Was $\sim 2.2$ um in 2018
Beta* Leveling Fully Deployed

- High bunch intensity required extended beta* leveling
  - Could level up to 6 hours at pile-up of ~54 in ATLAS/CMS
  - In a few cases had to use offset-leveling as even starting beta*=60cm gave too high pile-up for experiments

Experiments are happy with ±2.5% variation in luminosity between steps
Concern about bunch-to-bunch pile-up variations did not materialize in 2022
- Current ±10% variation (RMS) is fully acceptable
- Similar variation seen with 48b and hybrid schemes (8b4e+48b trains)

Beam spot length shorter than originally foreseen in IP1/5
- Gives mismatch with MC simulation
- Partially mitigated by bunch blow-up in later fills (to reduce heating)
- Best guess for 2023 size needed
- LHCb need length >35mm

Still have mystery as to why z-width not the same in IP1/5
- 6-8% larger in IP5 for low-β optics
- Luminosity the same (within errors)
Experiment Feedback
Commissioning of new detectors and new electronics in 2022

- Limited by L1 rate and pile-up in August
  - Stable at $\mu=55$ later in the year
- Lower data efficiency at start of the year, but improving with time
  - 92% recording efficiency
  - 89% certification efficiency

Collision point offset by 1.1mm in $x$

- Request to move collision point by 1.1mm (or at least~ 0.6mm)
  - To uniformly irradiate pixel detector
- Commissioning muon detector (NSW) and new L1 trigger systems
- Physics data taking at 93% efficiency.
  - Extra few % dead time from pixel/NSW
    - 97% of this data is good for physics
  - Muon barrel trigger efficiency 5% below 2018
    - Improvements made during run and in YETS
- Limited to $\mu=55$ due to HLT/DAQ bandwidth
  - Should be improved in 2023 from TDAQ hardware replacements
  - Further gains from activating new L1 systems
- ALFA station damaged by water leak
  - Being repaired in YETS to be part of high $\beta^*$ run

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**2022 data taking**

![Cumulative Recording Efficiency Graph]

- ATLAS Preliminary
- 2016 pp $\sqrt{s} = 13$ TeV
- 2017 pp $\sqrt{s} = 13$ TeV
- 2018 pp $\sqrt{s} = 13$ TeV
- 2022 pp $\sqrt{s} = 13.6$ TeV

**Comparison of old/new trigger**

![Efficiency Graph]

- ATLAS Preliminary
- Run 439532
- $\sqrt{s}=13.6$ TeV
- $|\eta| \leq 0.8$
During 2022 commissioned major upgrade of detectors
- Using high rate (4MHz) runs to emulate load of Pb-Pb runs
  - 3.5MHz p-p ~ 50kHz Pb-Pb
- Largest p-p dataset for physics

2 day Pb test used to commission data flow and take first PbPb data with full detector
- Very important step to prepare for 2023 Pb-Pb

Time-of-flight perf. In PbPb collisions
LHCb

- Almost completely new detector
- Major systems commissioned
  - Online and safety systems
  - All detectors included in main run control
  - VELO closure and use in physics
  - SMOG2 gas injections
  - Real-time and alignment trigger on tracks
- Focus on commissioning, but took data for later studies
  - 35/pb of p-p in physics data configuration
  - Scans over pile-up up to $\mu=5$
  - Participated in van-der Meer scans, including ghost-charge measurements for all experiments
  - Ion test with PbPb and PbAr (gas inj.)
- Still some commissioning in 2023
  - Optimizing detector performance
  - New upstream tracker installed in YETS
SND and FASER

- New forward experiments ±480m from IP1 for
  - Neutrino measurements
  - Searches for long-lived particles
- High data-taking efficiency
  - >95% in both experiments
  - Physics analysis starting
- Emulsion exchanges needed every 20-30/fb
  - Keep track density <<10^6 tracks/cm^2
  - Needed access of 4-5 hours
- FASER found background dependence on TCL6
  - Request to keep TCL6 with small opening (<4mm)
    - Cycle was adjusted to close collimator before collisions
LHCf Run in 2022

- LHCf had requested special run of \( \sim 80/nb \) at pile-up \( \sim 0.02 \) to measure forward production of neutral particles
- Managed to almost have full request done in one long fill
  - 57 hours of SB
  - Used by other exp. for vdM-like scans and detector commissioning
    - first ALICE ZDC run
- 7 times more events than in 2015 run
  - 50 times more \( \eta \)'s

Very happy with data!

Next (final) run with LHCf is for p-O collisions in 2024
Scheduling

- Main goal is to have high luminosity stable beam production, but we had very dynamic scheduling throughout the year
  - Plans for tests, special runs, etc. often changed with few days or even few hours of notice to experiments
    - Also often last minute requests from experiment side
  - Particularly hard during periods with low availability or special tests
- Flexibility increases machine efficiency, but difficult to plan
  - Challenging to have multiple activities in parallel or right after each other
- **Time during working hours of high value to exp. and machine**
  - Commissioning and tests require many experts to be available
  - Can be frustrating when planned stable beam fill etc. cancelled/moved
    - Often driven by machine availability, but should strive to find balance
- Had regularly scheduled access (4-8 hours) most weeks in 2022
  - Typically on Wednesdays to overlap with SPS MDs
  - Hope access requests will reduce in 2023, at least towards then end...
- Possible interference with/constraints from other programmes
  - Injector MDs, AWAKE runs, HiRadMat runs
  - Schedule around by keeping fills a bit longer, avoid tests on certain days, etc.
    - In practice was not a major issue for 2022
  - Still, in case of beam loss, LHC normally takes priority
Communication

- Many channels of communication
  - Page1 for current/next activity
  - LHC e-log also followed by experiments
  - Phones for urgent requests/questions
    - Can interrupt EIC at critical times
  - Email between LPC, run coordinators and machine coordinators
  - NEW: mattermost channel
    - For non-urgent questions, info and discussion between coordinators/EICs
    - Still learning optimal way of using it
  - LHC morning and LPC meetings
    - Three LHC meetings/week on zoom
    - LPC meeting in person once per week
  - Google spreadsheet with schedule
    - Provides plan at ½ shift level
- MD planning mostly outside of exp.
- More detail on luminosity requests for MDs would be useful for experiments
  - Absolute/bunch-by-bunch or just relative needed?
2023 Outlook
Overall Run-3 Plan

- Electricity crisis also affecting plans for rest of Run 3
- Outline Run-3 plan prepared in September
  - EYETS every year except this year (only YETS+2 weeks)
  - EYETS to start end of October
- Results in ~20% less physics time for Run 3
  - Split fairly over proton and ion time (and MDs):

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- Plans for later years still not frozen
  - Hope to add back more p-p and ion time later
  - Could have p-Pb instead of Pb-Pb run in 2024 (or 2025)
- Expect more discussion in Chamonix workshop
- 2023 schedule discussed in LMC last week
- Short year, but extended ion run as planned
- Fast ramp-up foreseen for p-p period

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**First beam**

- March 27

**Last beam**

- October 30

**Technical Stop**

- HW Commissioning, Powering Tests, Magnet Training
- Machine check out
- Recommissioning with beam
- Interleaved commissioning & intensity ramp up
- Proton physics run
- Special physics runs (place holders)

**Machine development (incl. floating)**

- Scrubbing
- Pb - Pb ion physics run
- Pb ion or p - p reference setting up
- p - p reference run
- LINAC 3 Pb oven re-fill

**SPS HiRadMat Run & reserve (08:00 - 24:00)**

**2023 Draft Schedule**

**27 days of PbPb**
2023 Experiment Plans (protons)

- Still some commissioning to be done
  - ALICE: regular rate scans (5kHz-4MHz) to prepare for PbPb
  - ATLAS: Switch to upgraded L1 trigger system
  - LHCb: Finish detector commissioning
    Commission upstream tracker in parallel with physics
  - Expect requests for isolated bunch(es), scheduled day-time fills, etc.

- Main goal is to have luminosity production year
  - Push bunch intensity etc., but should maintain efficiency

- Peak/steady-state pile-up targets for 2023:

<table>
<thead>
<tr>
<th>Pile-up</th>
<th>ALICE</th>
<th>ATLAS</th>
<th>CMS</th>
<th>LHCb</th>
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<td>60(TBC)</td>
<td>60</td>
<td>5.5(TBC)</td>
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- CMS request: run at target pile-up from day 1, i.e. in ramp-up
- LHCb request: run at constant pile-up throughout fills/years for physics (outside commissioning periods)
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Last week of 2022 run, LHC demonstrated it could deliver luminosity at \(2.4 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}\) (or higher)

ATLAS/CMS to re-evaluate maximum possible pile-up/lumini...
Different options for 2023

- Pure 8b4e – low heatload, but low #bunches
  25ns_1972b_1967_1178_1886_224bpi_12inj_8b4e

- Hybrid scheme (7x8b4e+4x48b) – likely solution for 2023
  25ns_2452b_2440_1952_2240_248bpi_12inj_mixed

- Trains of 36b as in 2022, but likely limiting bunch intensity
  25ns_2496b_2484_2132_2280_180bpi_16inj_5x36b

- Trains of 48b, fills the ring, but likely to be severely e-cloud limited in 2023 – should aim to reach this in later years
  25ns_2748b_2740_2250_2376_240bpi_13inj_800ns_bs200ns

Optimized for all IPs
No INDIVs included
(removes 1-2 batches)
Fillings Schemes for 2023?

- Different options for 2023
  - Pure 8b4e – low heatload, but low #bunches
    25ns_1972b_1967_1178_1886_224bpi_12inj_8b4e
  - Hybrid scheme (7x8b4e+4x48b) – likely solution for 2023
    25ns_2452b_2440_1952_2240_248bpi_12inj_mixed
    7x8b4e+4x48b might not be possible at $I_b=1.8\times10^{11}$pb
    7x8b4e+5x36b could be alternative but few % less collisions in IP1/5/8
  - Trains of 36b as in 2022, but likely limiting bunch intensity
    25ns_2496b_2484_2132_2280_180bpi_16inj_5x36b
  - Trains of 48b, fills the ring, but likely to be severely e-cloud limited in 2023 – should aim to reach this in later years
    25ns_2748b_2740_2250_2376_240bpi_13inj_800ns_bs200ns

Optimized for all IPs
No INDIVs included
(removes 1-2 batches)

More by Lotta tomorrow
Lumi Comparisons – $l_b=1.5\times10^{11}\text{ppb}$

- Can compare expected luminosity for different schemes
  - Uses simple lumi-modelling, so absolute scale not quite right
  - At current bunch intensity, would stay with 36b scheme
  - Can gain \(~4\%\) in integrated lumi by pushing to pile-up of 60
    - Probably a bit more as not all fills go to the end

### Estimates for $l_b=1.5\times10^{11}\text{ppb}$ (peak reached in 2022)

<table>
<thead>
<tr>
<th>$\mu$</th>
<th>#coll bunches</th>
<th>$L_{\text{peak}}$ [x10^{34}\text{cm}^{-2}\text{s}^{-1}]</th>
<th>$L_{\text{int.,day}}$ [fb^{-1}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>1967</td>
<td>1.5</td>
<td>0.89 (-21%)</td>
</tr>
<tr>
<td></td>
<td>2440</td>
<td>1.86</td>
<td>1.11 (-2%)</td>
</tr>
<tr>
<td></td>
<td>2484</td>
<td>1.89</td>
<td>1.13 (+10%)</td>
</tr>
<tr>
<td></td>
<td>2740</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>1607</td>
<td>1.65</td>
<td>0.93 (-17%)</td>
</tr>
<tr>
<td></td>
<td>2056</td>
<td>2.05</td>
<td>1.16 (+3%)</td>
</tr>
<tr>
<td></td>
<td>2086</td>
<td>2.08</td>
<td>1.18 (+4%)</td>
</tr>
<tr>
<td></td>
<td>2300</td>
<td>2.3</td>
<td>1.30 (+15%)</td>
</tr>
<tr>
<td>65</td>
<td>1925</td>
<td>1.8</td>
<td>0.96 (-14%)</td>
</tr>
<tr>
<td></td>
<td>2235</td>
<td>2.23</td>
<td>1.20 (+6%)</td>
</tr>
<tr>
<td></td>
<td>2275</td>
<td>2.27</td>
<td>1.22 (+8%)</td>
</tr>
<tr>
<td></td>
<td>2480</td>
<td>2.5</td>
<td>1.34 (+19%)</td>
</tr>
</tbody>
</table>

- Only accounts for 4h turn-around, not availability
- Leveling: \(~7h\)
  - Optimal fill: 11.5h
- Leveling: \(~5.5h\)
  - Optimal fill: 10h
- Leveling: \(~4h\)
  - Optimal fill: 9.5h

More by Sofia tomorrow
Lumi Comparisons – $I_b = 1.8 \times 10^{11}$ ppb

- Can gain ~10% in 2023 by switching to hybrid scheme and pushing bunch intensity to the maximum
- Also much longer leveling time, which should push up efficiency
- Can gain another 6-7% by pushing to pile-up of 60
- Once e-cloud conditioned, move towards 48b scheme

### Estimates for $I_b = 1.8 \times 10^{11}$ ppb (target for 2023)

<table>
<thead>
<tr>
<th></th>
<th>8b4e</th>
<th>Hybrid</th>
<th>36b</th>
<th>48b</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>#coll bunches</strong></td>
<td>1967</td>
<td>2440</td>
<td>2484</td>
<td>2740</td>
</tr>
<tr>
<td>$\mu=54$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_{\text{peak}} [x10^{34}\text{cm}^{-2}\text{s}^{-1}]$</td>
<td>1.5</td>
<td>1.86</td>
<td>1.89</td>
<td>2.1</td>
</tr>
<tr>
<td>$L_{\text{int.,day}} [\text{fb}^{-1}]$</td>
<td>1.00</td>
<td>1.25</td>
<td>1.27</td>
<td>1.4</td>
</tr>
<tr>
<td>( -11%)</td>
<td>( +10%)</td>
<td>( +12%)</td>
<td>( +24%)</td>
<td></td>
</tr>
<tr>
<td>$\mu=60$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_{\text{peak}} [x10^{34}\text{cm}^{-2}\text{s}^{-1}]$</td>
<td>1.65</td>
<td>2.05</td>
<td>2.08</td>
<td>2.3</td>
</tr>
<tr>
<td>$L_{\text{int.,day}} [\text{fb}^{-1}]$</td>
<td>1.07</td>
<td>1.32</td>
<td>1.35</td>
<td>1.49</td>
</tr>
<tr>
<td>( -5%)</td>
<td>( +17%)</td>
<td>( +20%)</td>
<td>( +32%)</td>
<td></td>
</tr>
<tr>
<td>$\mu=65$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_{\text{peak}} [x10^{34}\text{cm}^{-2}\text{s}^{-1}]$</td>
<td>1.8</td>
<td>2.23</td>
<td>2.27</td>
<td>2.5</td>
</tr>
<tr>
<td>$L_{\text{int.,day}} [\text{fb}^{-1}]$</td>
<td>1.11</td>
<td>1.39</td>
<td>1.42</td>
<td>1.57</td>
</tr>
<tr>
<td>( -0%)</td>
<td>( +24%)</td>
<td>( +26%)</td>
<td>( +39%)</td>
<td></td>
</tr>
</tbody>
</table>

Leveling: ~10h
Optimal fill: 14h
Leveling: ~9h
Optimal fill: 12.5h

Only accounts for 4h turn-around, not availability

More by Sofia tomorrow
Luminosity Comparisons – $I_b = 1.8 \times 10^{11}$ ppb

- **Can gain ~10% in 2023 by switching to hybrid scheme and pushing bunch intensity to the maximum.**
- **Also much longer leveling time, which should push up efficiency.**
- **Can gain another 6-7% by pushing to pile-up of 60.**
- **Once e-cloud conditioned, move towards 48b scheme.**

### Luminosity estimates for 2023?

Difficult to predict effect on availability from longer fills, high $I_b$, etc.

At 1.32/fb per day for 97 days at 50% efficiency: ~64/fb

*Double counts inefficiency of the 4 hours refilling*

Assuming 50% stable beam time (1150 hours): ~82/fb

*Does not account for ramp-up in bunches and intensity*

*Short run period also increases sensitivity to incidents, etc.*

For LHCb will scale with SB time and #colliding bunches.

For 1150 hours and 2280 bunches expect ~7/fb at $\mu = 5.5$ (*ignoring test fills,...*)

<table>
<thead>
<tr>
<th>$\mu$</th>
<th>$L_{peak} \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$</th>
<th>$L_{int,day} \text{[fb}^{-1}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>1.5</td>
<td>1.25 (+10%)</td>
</tr>
<tr>
<td></td>
<td>1.86</td>
<td>1.89 (+12%)</td>
</tr>
<tr>
<td></td>
<td>2.1</td>
<td>1.4 (+24%)</td>
</tr>
<tr>
<td>60</td>
<td>1.65</td>
<td>1.32 (+17%)</td>
</tr>
<tr>
<td></td>
<td>2.08</td>
<td>1.35 (+20%)</td>
</tr>
<tr>
<td></td>
<td>2.3</td>
<td>1.49 (+32%)</td>
</tr>
<tr>
<td>65</td>
<td>1.8</td>
<td>1.39 (+24%)</td>
</tr>
<tr>
<td></td>
<td>2.27</td>
<td>1.42 (+26%)</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>1.57 (+39%)</td>
</tr>
</tbody>
</table>
SND/FASER Emulsion Exchanges

- FASER and SND emulsions measured track densities of $1.3 \times 10^4 / cm^2 / fb^{-1}$ and $2 \times 10^4 / cm^2 / fb^{-1}$ primarily from muon background.
- Maximum allowed track density for reconstruction is currently $\sim 4 \times 10^5 / cm^2$.
- Emulsion to be replaced after $\sim 20 / fb$ ($30 / fb$) for SND (FASER).
- Will need 2-3 exchanges, but only one TS planned.
- Can be done in 4 hour stop, but needs planning ahead of time.
- Optimal exchange point is not necessarily the same for FASER and SND.
- Also need to plan sharing of dark room between SND, FASER and NA65 at SPS.
Special Run Plans

- Besides usual vdM scans, two special runs foreseen
  - $\beta^*=90\text{m}$ run for inelastic cross-section with new TOTEM T2 detector
    - Needs just one fill, but CMS magnet off to install/remove T2 which is not radiation hard
  - $\beta^*=3/6\text{km}$ run for elastic scattering in CNI region for measuring $\sigma$ and $\rho$
    - For both TOTEM and ATLAS/ALFA
    - 4-5 day of physics running for 350-400/pb
    - Likely needs a few fills before to finalize optics/collimation

- 90m run best done right after after TS1
  - Requires CMS magnet off in TS1 and ramped after run with T2

- 6km run before or after August holiday break?
  - Needs some beam time to validate optics and collimation before

Will complete LHC high $\beta$ programme
Ion Run Planning

- Extended Pb-Pb run at the end of 2023 run
  - 6 weeks when including TS, setup and p-p reference run
    - Start with p-p reference run
    - 4 weeks for Pb-Pb physics running

- Luminosity goals for 2023
  - ALICE: 3.25/nb of PbPb at 50 kHz interaction rate
    - 3/pb of p-p reference at 1MHz interaction rate
      - Takes about 5 days for p-p reference at 50% efficiency
  - ATLAS/CMS: similar PbPb request (no rate limit)
    - >150/pb of p-p reference at higher pile-up
  - LHCb: ~0.4/nb of PbPb
Ion Run Planning

- Recent ion test gives confidence in use of 50ns trains
  - Though still questions on optimal train length
- Crystal cleaning efficiency still waiting for offline analysis
  - Expect it is good enough to reduce risk of running at max $E_{\text{beam}}$
  - Confirm beam energy early next year after analysis completed
    - Unless elevated risk, would go for 6.8Z TeV
- With extended ion period in 2023, should be able to deliver 2.5-3.5/nb of Pb-Pb to ALICE/ATLAS/CMS

Will have ~27 days

Integrated luminosity over 24 days in nb^{-1}

<table>
<thead>
<tr>
<th>Run</th>
<th>IP1/5</th>
<th>IP2</th>
<th>IP8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1240_1200_1240_0</td>
<td>2.5, 3.1</td>
<td>2.7, 3.3</td>
<td>0., 0.</td>
</tr>
<tr>
<td>1144_1144_1144_239</td>
<td>2.4, 3.</td>
<td>2.6, 3.3</td>
<td>0.17, 0.22</td>
</tr>
<tr>
<td>1088_1088_1088_398</td>
<td>2.3, 2.9</td>
<td>2.6, 3.2</td>
<td>0.29, 0.36</td>
</tr>
<tr>
<td>1032_1032_1032_557</td>
<td>2.2, 2.8</td>
<td>2.5, 3.1</td>
<td>0.38, 0.48</td>
</tr>
<tr>
<td>976_976_976_716</td>
<td>2.2, 2.7</td>
<td>2.4, 3.</td>
<td>0.46, 0.57</td>
</tr>
<tr>
<td>733_702_733_468</td>
<td>1.7, 2.1</td>
<td>1.9, 2.3</td>
<td>0.34, 0.42</td>
</tr>
</tbody>
</table>

Green: above target
Red: Below target

Roderik at 2022 Chamonix
Summary
Summary

• 2022 was a short, tough, but very productive year
• Much time was spend on detector commissioning
• Managed to complete large parts of this and take an excellent physics data sample

• 2023 will be a short year with some commissioning and performance optimizations still to be done
  • Aim to be ready for higher pile-up than this year
• Experiments will be ready for a lot physics data

Huge thanks to all LHC and injectors operators, experts, piquets and coordinators

Looking forward to 2023 data taking
Backup
**Run 3 Overview Comparison**

**Original running plan:**
- **2022:** 10w p-p, 1w LHCf+, 4w PbPb
- **2023:** 20w p-p, 1w high β, 4w PbPb
- **2024:** 16w p-p, 1w OO, 4w pPb
- **2025:** 17w p-p, 4w PbPb

**Reduced running plan with PbPb only:**
- **2022:** 9w, 1w high β, 5w PbPb
- **2023:** 13w p-p, 1w high β, 4w PbPb
- **2024:** 16w p-p, 1w OO, 3w pPb
- **2025:** 17w p-p, 4w PbPb

**Alternate reduced running plan with short pPb:**
- **2022:** 13w p-p, 1w high β, 5w PbPb
- **2023:** 16w p-p, 1w OO, 3w pPb
- **2024:** 17w p-p, 1w OO, 5w PbPb
- **2025:** 16w p-p, 1w OO, 5w PbPb

- Does not include ramp-up, TS, MDs etc.
- Includes pp reference
- Extended ion run

*Other variations are also possible*
Run 3 Overview Comparison

Original running plan: ~18% reduction of p-p and ion physics

- 2022: 10w p-p, 1w LHCf, 4w PbPb
- 2023: 20w p-p, 1w high β, 4w PbPb
- 2024: 17w p-p, 1w OO, 3w pPb
- 2025: 17w p-p, 5w PbPb

If run reductions after 2022 are scaled back would add extra week of ions in 2024 and/or 2025

Reduced running plan with PbPb only:

- 2022: <1w LHCf, 4w PbPb
- 2023: 20w p-p, 5w PbPb
- 2024: 20w p-p, 4w PbPb
- 2025: 17w p-p, 4w PbPb

Expect ion running plan for 2024/2025 to be decided after seeing performance in 2023

Alternate reduced running plan with short pPb:

- 2022: <1w LHCf, 9w
- 2023: 13w p-p, 1w high β, 1w pPb
- 2024: 17w p-p, 1w OO, 3w pPb
- 2025: 16w p-p, 5w PbPb

Other variations are also possible

~18% reduction of p-p and ion physics
Ion Test

- No Pb-Pb period, but added ~2 day test of injecting Pb beams into the LHC to better prepare for 2023 Pb-Pb run
  - Machine test of injection/ramp of slip-stacked 50ns beams
  - Machine test of crystal collimation with new crystals
  - Validate new collimator for high-luminosity running in ALICE
  - Experiments to test new detectors and data-processing (mainly ALICE)

- Use p-p optics to minimize setup
  - Similar to special run with Xe in 2017
  - Meant factor 16 worse luminosity in ALICE than ATLAS/CMS
    - Compensated by having all bunches collide in ALICE and leveling ATLAS/CMS down after first hour of beam

- Kept $I_b < 3 \times 10^{11}$ charges
  - Minimized validation time
  - Limited beams to ~20 bunches

- Two stable beam fills for experiments

- Actual schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>17-Nov</th>
<th>18-Nov</th>
<th>19-Nov</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Crystals, injection</td>
<td>Trying ramp</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Access (LBDS, BB wire, ATLAS)</td>
<td>Crystals, top energy</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Commissioning</td>
<td>Stable beams</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Slip-stacking</td>
<td>Trying to ramp</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
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<td></td>
</tr>
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<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ion Test Results

- Managed to complete full programme
  - Took just over 2 days of beam time
    - Though had difficult recovery (2 days lost)
- Slip-stacked beam successfully ramped
  - Two trains of 8 bunches colliding in stable beam
- Crystal collimation demonstrated
  - Factor 2-5 extra cleaning
  - Offline analysis on-going
- 11.5 hours of stable beam
  - Short fill with indiv bunches, longer slip-stacked fill
  - 0.15/ub for ALICE (1M evts)
  - 0.30/ub for ATLAS/CMS
    - Leveled down after first hour
- Very useful preparation for 2023 ion run

Slip-stacking principle:
ATLAS and CMS – Roman Pots

- Roman pot acceptance depends strongly on optics near IP
  - Driver for use of telescopic squeeze
- Flat optics could increase triplet lifetime by rotating crossing plane
  - Would reduce $\xi$ acceptance for AFP/PPS
  - *Almost total loss of acceptance for PPS diamond detectors*
  - Radiation damage compensation in AFP more complicated
    - Still small preference for flat in ATLAS if lumi-region is larger
    - Any deployment of flat optics should be as late as possible

- Collimators also affect acceptance
  - Request to keep TCL4 as open as possible
    - Drives upper mass acceptance
    - CWG agreed to same mm setting as 2018 ($17\sigma$)
  - To keep RP close to beam, TCTs will need to move during $\beta^*$ leveling (from 2023)
    - Allows most RPs to stay at ~1.5mm from beam
    - Still open issue for one AFP RP where moving it during $\beta^*$ leveling would be beneficial

![Hit Locations in XRP Detector Plane as a Function of $\xi$](image1.png)

![Mass acceptance vs TCL4](image2.png)

(TCL5 assumed open)
### Reminder: Two Special Runs

See LPC 14/06/2021:

- Both runs: very special beam conditions and close XRP positions  
  → **no Stable Beams**!
- Different objectives, lengths, operation parameters:

<table>
<thead>
<tr>
<th>( \beta^* = 90 \ pm 120 \ m ):</th>
<th>((\beta_x^<em>, \beta_y^</em>) = (3 \ km, 6 \ km):)</th>
</tr>
</thead>
</table>
| Measurement of \( \sigma_{\text{tot}} \) with lumi-indep. method | Measurement of elastic scattering in CNI region  
  \( \rho \) |
| inelastic cross-section with new T2 detector | normalisation via Coulomb scattering |
| (see TDR: CERN-LHCC-2019-007) | XRPs @ 2.8 – 3 \( \sigma \)  
  \( \rightarrow \) very special collimation scheme |
| \( L \sim 2 - 5 \times 10^{28} \ \text{cm}^{-2} \ \text{s}^{-1}, \ \mu = 0.04 - 0.1 \) | (conditions under discussion with machine experts) |
| Rate: 2.5 – 6.5 kHz (signal only) | very high \( \beta^* \)  \( \rightarrow \) low \( L \sim 2 \times 10^{27} \ \text{cm}^{-2} \ \text{s}^{-1} \) |
| **duration:** \( \sim 6 \text{ hours} \) (same fill as alignment) \( \approx 1 \ \text{nb}^{-1} \) | Rate: \( \sim 65 \ \text{Hz} \) (elastic signal only) |
| | **duration:** \( \sim 4 \text{ days} \ \approx 350 - 400 \ \mu\text{b}^{-1} \) |

- Scheduling:
  new T2 cannot withstand high-lumi operation  
  → install, run, uninstall  
  minimize number of CMS magnet ramps  
  → good slot: after TS1,  
  we could run with magnet still off

- Scheduling:
  flexible,  
  but complex beam commissioning,  
  preferentially after 90 m run with \( \geq 2 \) weeks between

---

**Optics from Ilias:**

**ready**

**far advanced**
LHCb is a complete new detector at the LHC and a huge amount of work was completed in 2022:

- All online components developed and ready from day 1
- All sub-detectors with all devices included in the main Run Control
- Safety systems developed and fully commissioned
- VELO closing achieved and regularly used in Physics fills
- SMOG2 injection and validation of the system
- Real-Time and Alignment (RTA) triggering on tracks in addition to triggering ECAL activity + VELO half alignment applied in real-time during physics fills
- Van der Meer scan for luminosity calibration
- Participation in the Ion run test and taken data in PbPb and PbAr configurations
- Taken data at different values of mu and reached ultimate peak value
- Collected a small sample of data for winter shutdown studies
  - 25 pb-1 in polarity DOWN and 10 pb-1 in polarity UP

LHCb has now reached the point of being able to take data regularly, with the full detector included and the VELO regularly closed.

→ The work to reach a performant detector has just started and will be done in 2023. There is still a lot to do...

LHCb would like to congratulate the LHC colleagues and LPCs in the many milestones achieved and thank them for the valuable, proficuous and daily collaboration and cooperation.
LHCb input to LHC performance workshop

LHCb’s goals for 2023

→ 2023 is to be considered for LHCb partly a commissioning year and partly a production year.
  • Fix and debug issues/problems observed in 2022 and not yet fixed
  • Increase mu and regularly run at higher luminosity
    o in 2022 LHCb stayed at $\mu = 1.1$, goal is $\mu = 5.5$ and $L = 2 \times 10^{33}$ cm$^{-2}$s$^{-1}$ with full machine
  • Regularly and continuously take efficient data
  • Participate and fully profit of the ion run
  • Complete the commissioning of the detector and finalize performance studies
  • Commission the UT detector while continuously take data with the rest of LHCb

LHCb’s required running conditions for 2023 (no new requests, just repeating)

• As many colliding bunches as possible to minimize mu and maximize integrated luminosity
  o LHCb is generally neutral to the type of filling scheme, what we care about is the total # of collisions
• Leveling at $L = 2 \times 10^{33}$ cm$^{-2}$s$^{-1}$ for the full fill length (or alternatively at the value of $L$ for a given $\mu$)
  o A compromise on the optimal fill length will need to be discussed, if needed
• Vertical external crossing angle and leveling in the tilted plane
  o LHCb understands this was tested in an MD and awaits validation, but we consider it unofficially ok
• Regular magnet polarity flips + regular emittance scans + Van der Meer scans
  o Many detectors will run at different working points and new recalibrations will be needed
  o Luminous region in Z not too small ($>35$mm). Studies may be done to see if there is a upper limit

LHCb will provide luminous region, beam shapes and bunch by bunch luminosity in 2023 as soon as the detector is running stably and in physics production mode.
Stable Beam Time and Availability

Full week excluding MDs
SB: 28% (20%) 2 of 17 days

Working days (8:00-18:00) excluding scheduled access days and MDs
42% (48%) 9 of 15 days

Stable Beams [31.9%]

Working days with >5h SB
50% (46%) 16 of 32 days