Experiment Requests and Constraints for Run-3

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24 November 2021
10th LHC Operations Workshop

Introduction

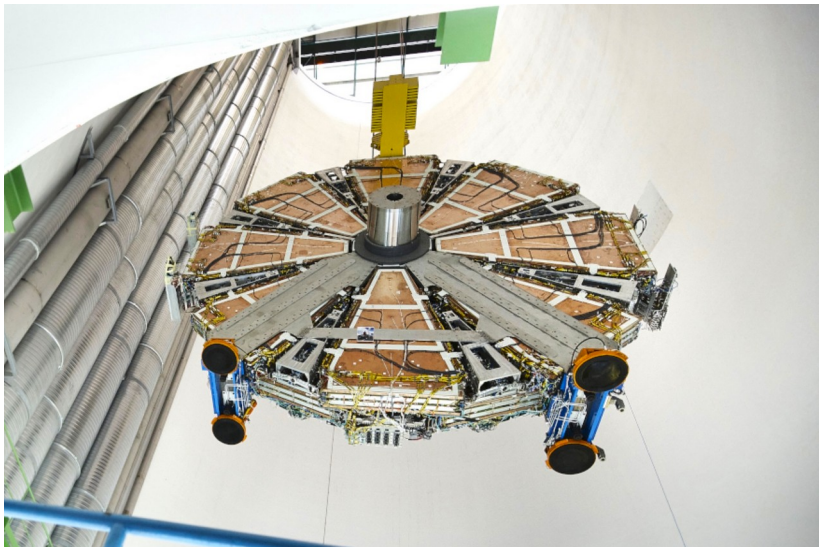
- Major detector upgrades carried out during LS2
  - Many detectors will also be commissioning in 2022
- Improved detector capabilities enables some major changes to their normal running conditions

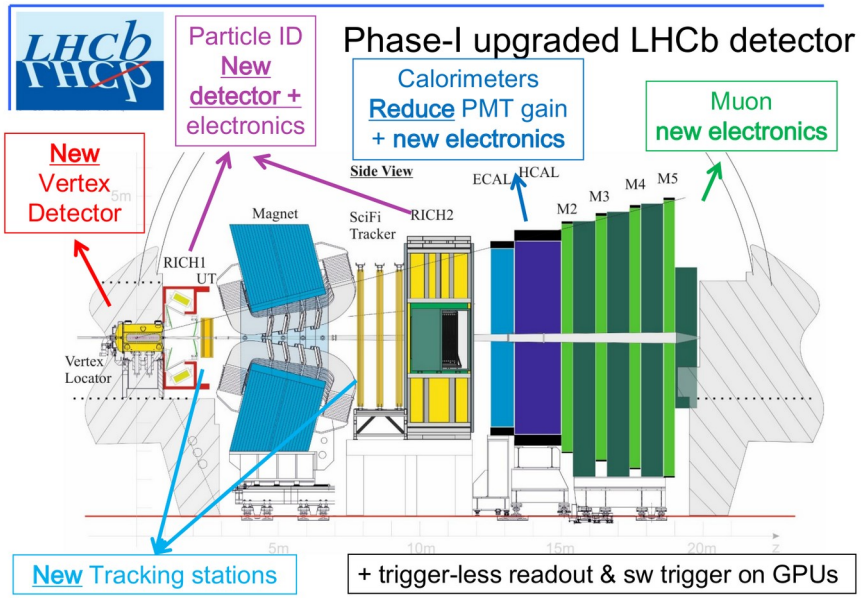
- Outline of talk:
  - Operation requests for p-p running
  - Operation requests for heavy ion running
  - Special run requests

Experiment Upgrades for Run 3

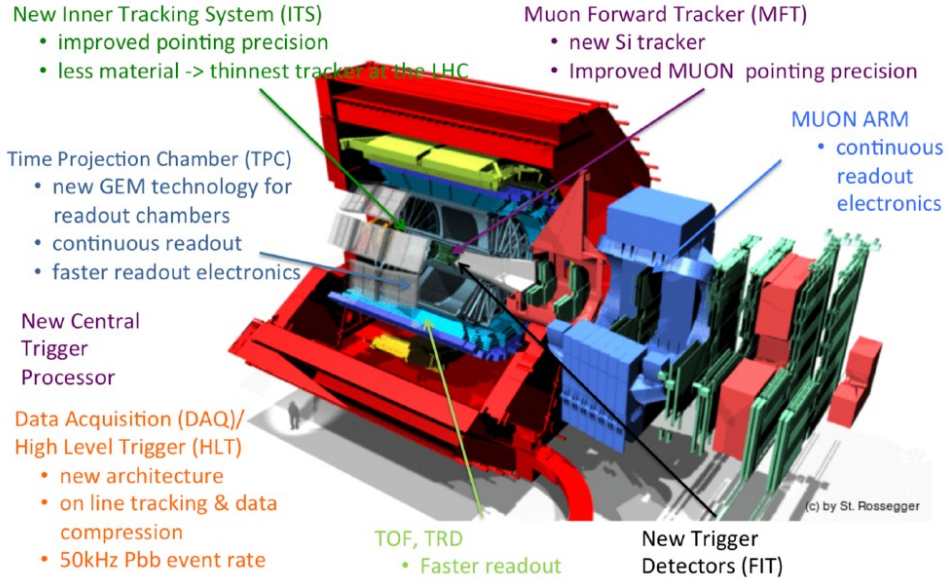
- All experiments carried out major upgrades and consolidations during LS2
- For LHCb and ALICE enables them to run at higher luminosity
- Most upgrades on track for Run 3
  - LHCb upstream tracker will not be complete in time
    - LHCb requests extended TS

ATLAS NSW





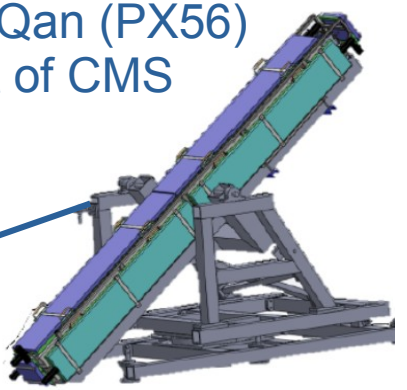
ALICE upgrades during LS2

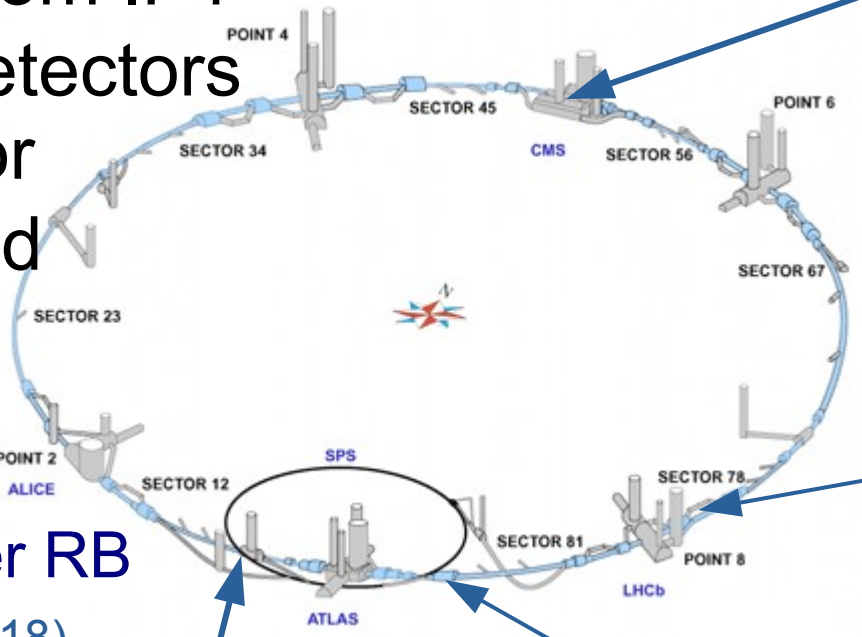


New LHC Experiments

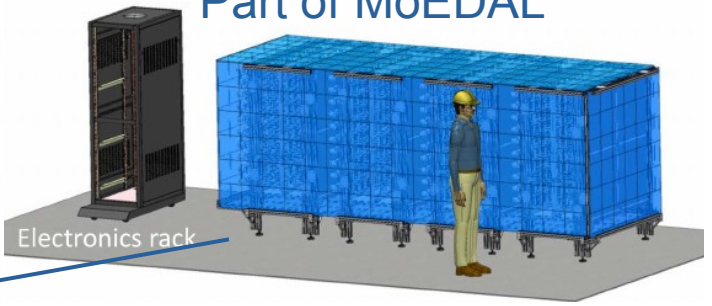
- Two new LHC experiments for neutrinos measurements and long-lived particles searches at ±480m from IP1
- Two new detectors to search for milli-charged particle
  - To be approved in December RB

milliQan (PX56)
Part of CMS

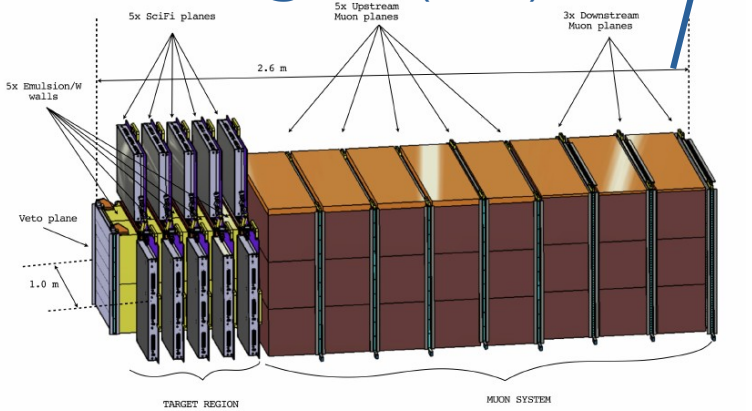




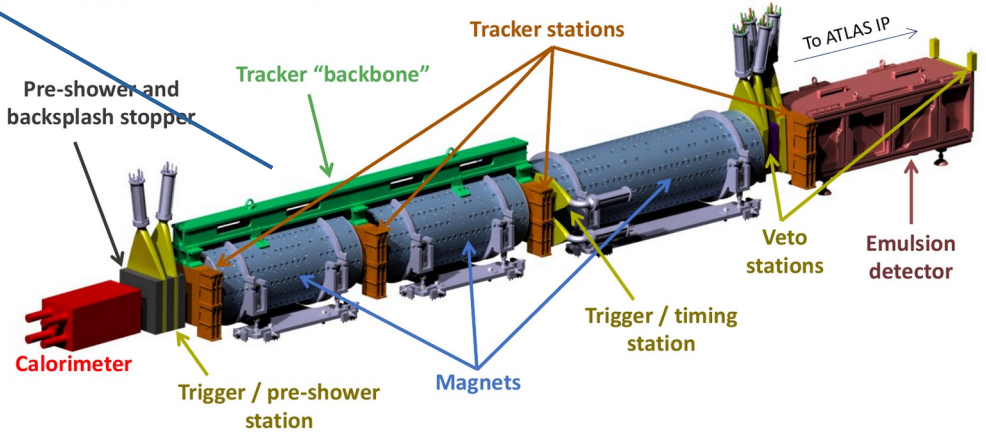
MAPP (UA83)
Part of MoEDAL



SND@LHC (TI18)



FASER (TI12)

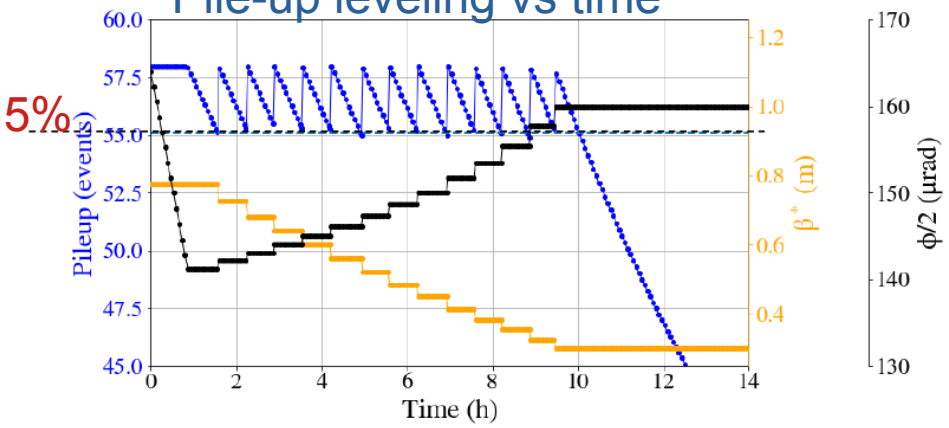


p-p Running

ATLAS and CMS

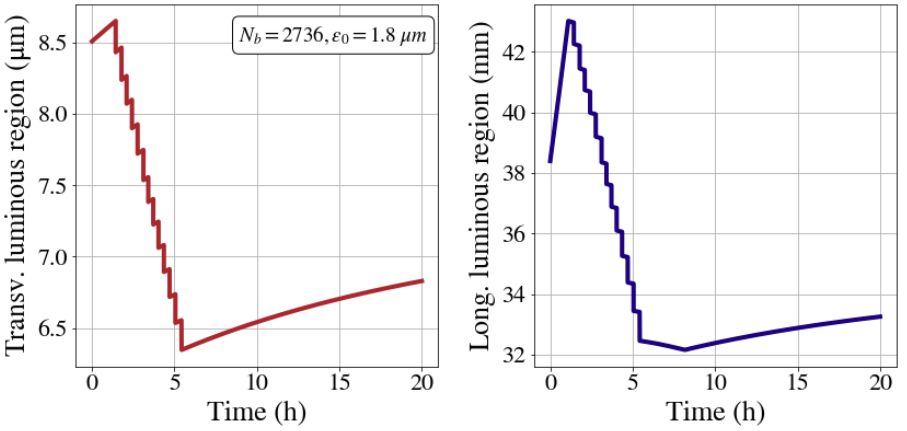
- Luminosity and pile-up limitations
  - Both experiments limited to pile-up less than ~60
    - Full BCMS scheme preferred
    - If needed, can handle some trains of 8b4e, but should bring integrated luminosity gain
  - Luminosity jumps during leveling should be below ~5%
    - Optimal use of trigger bandwidth
    - Allows to use data recorded during β* change without any issue

Pile-up leveling vs time



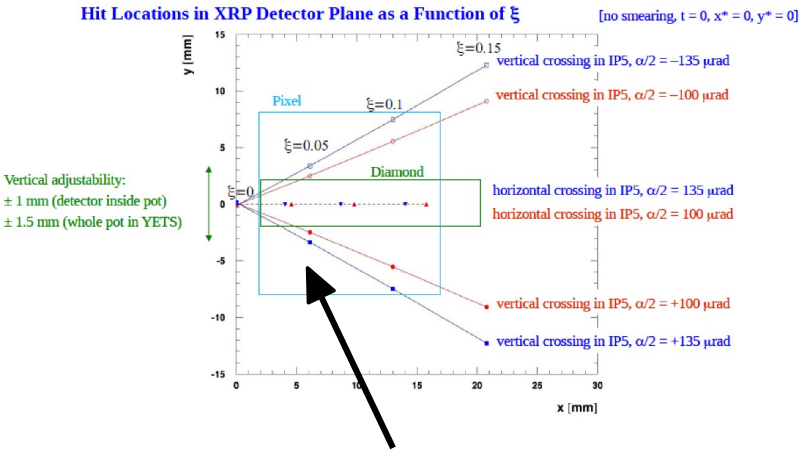
- Luminous region limitations
  - Luminosity leveling with β* means the luminous region size changes significantly during a fill
  - No issue with transverse size
  - Longer longitudinal size helps reduce pile-up density
  - For σ_z>50mm CMS lose a few % of 3-pixel track (triplets) efficiency
    - Little overall effect on physics

Lumi-region size vs time



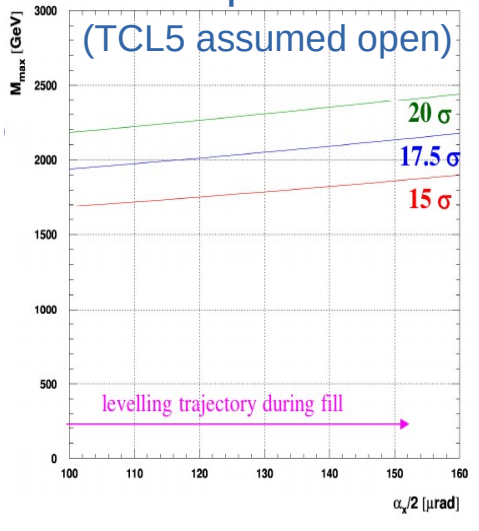
ATLAS and CMS – Roman Pots

- 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 ξ 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



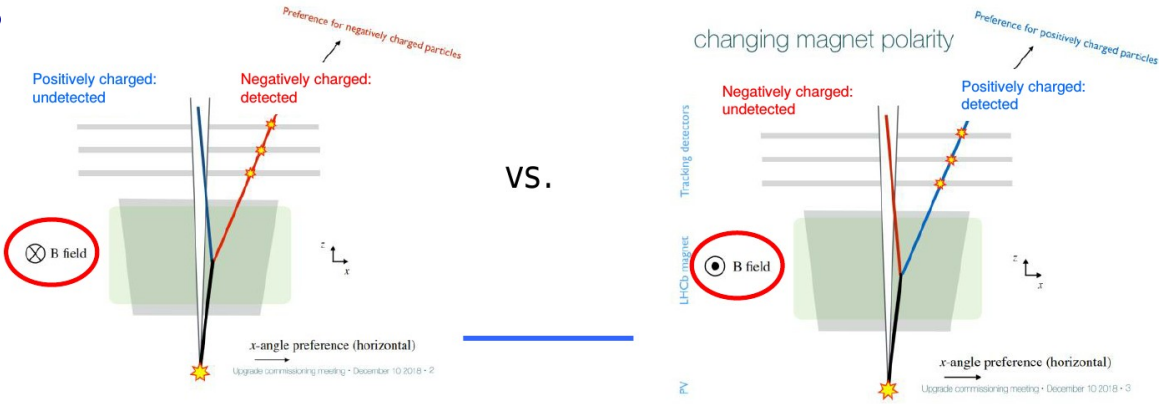
- Collimators also affect acceptance
  - Request to keep TCL4 as open as possible
    - Drives upper mass acceptance
    - CWG agreed to same mm setting as 2018 (17σ)
  - To keep RP close to beam, TCTs will need to move during β* leveling (from 2023)
    - Allows most RPs to stay at ~1.5mm from beam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

Mass acceptance vs TCL4



LHCb

- After upgrade expect to run at $L=2x10^{33}cm^{-2}s^{-1}$
  - Wants to run at constant pile-up level from 2023 onward
    - Both during each fill (i.e. no drop-off at end) and over time
  - 2022 will be commissioning and early physics year for LHCb
    - Expect to take data at different pile-up levels for testing etc.
- Request to switch to vertical crossing angle at flat top
  - Horizontal crossing angle introduces difference between the two magnet polarities
    - Beam size
    - Acceptance
  - With high statistics in Run 3, could be significant systematic for some measurements



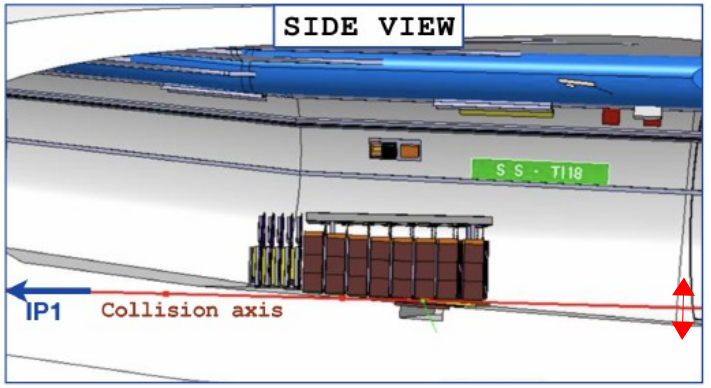
- It is fine to only deploy vertical crossing from 2023 onward
  - Assume it will be tested during MDs in 2022

ALICE

- Remains leveled during p-p running
  - Expected to level at 0.6 to 1.3x$10^{31}$$cm^{-2}s^{-1}$ (0.5-1 MHz rate)
- During 2018 had small issue with luminosity transients during β* leveling steps in IP1/5
  - TPC distortion corrections depend on luminosity
  - Expect this to be less of an issue in Run 3 as correction is applied with finer time granularity
- ALICE requests to have at least 3 months of p-p data before the first PbPb run to fully commission and validate the upgraded detector
  - Not required to be at full luminosity throughout period
  - Latest schedule has 5 week ramp-up and 11 weeks of physics

FASER and SND

- Detector acceptance depends on crossing angle in IP1
  - 150μrad crossing angle moves collision axis by 72mm



- For SND:
  - +18% more neutrinos for upward crossing angle
  - -22% for downwards with respect to zero crossing angle
- For FASER:
  - Designed to move with crossing angle polarity (in a YETS)
  - Can not fully move on line-of-sight for downward polarity
- Preference for upward crossing angle, *but inner triplet lifetime has priority*
  - Still, ideally minimize the number of polarity flips
- Both experiments needs to exchange emulsion in TS
  - Preference for regularly spaced TS (i.e. every 25-30/fb)
  - Should also be possible to exchange in a long (scheduled) access

Heavy Ion running

Luminosity Limits and Sharing

- All four main experiments participate in HI program
- ATLAS, CMS and LHCb: no limit for PbPb luminosity
- ALICE will likely need to leveled to $6 \times 10^{27} cm^{-2} s^{-1}$

- With 50ns bunch spacing cannot maximize colliding bunches in all experiments at same time
  - Have to share between experiments

Integrated luminosity for 24 days of physics at 50% eff:

From R. Bruce

Filling scheme	$\mathcal{L}_{tot}$ IP1/5	$\mathcal{L}_{tot}$ IP2	$\mathcal{L}_{tot}$ IP8
1240b_1240_1200_0	2.5 [2.6]	2.7 [2.8]	0 [0]
1240b_1144_1144_239	2.4 [2.5]	2.7 [2.8]	0.18 [0.21]
1240b_1088_1088_398	2.4 [2.4]	2.6 [2.7]	0.30 [0.34]
1240b_1032_1032_557	2.3 [2.3]	2.5 [2.6]	0.39 [0.44]
1240b_976_976_716	2.2 [2.2]	2.5 [2.6]	0.46 [0.50]
75ns: 733b_733_702_468	1.7 [1.8]	1.9 [1.9]	0.35 [0.36]

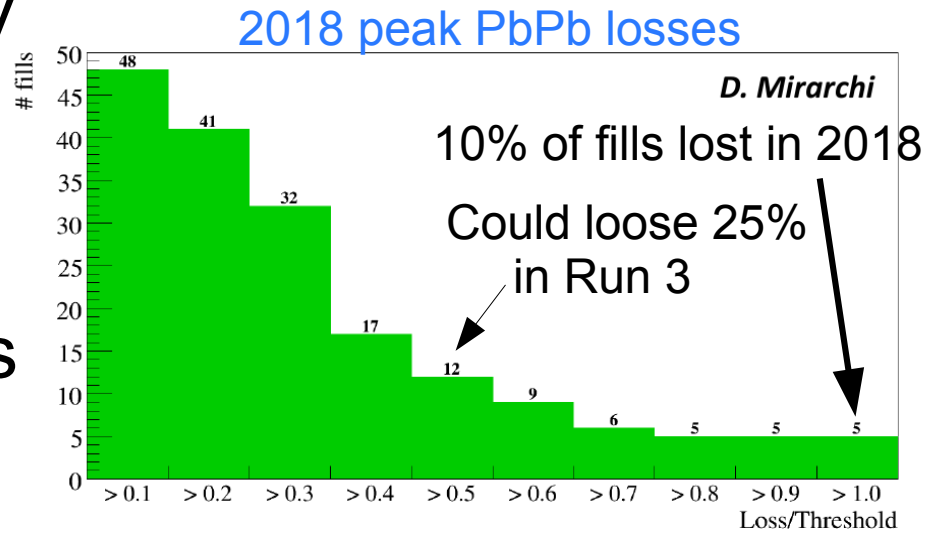
In nb^{-1}

[] is from alternate calculation

- 50ns bunch spacing still provides best option for all
  - <10% loss for IP1/2/5 to give good luminosity for IP8

Collision Energy for PbPb?

- Run-2 PbPb run at E=6.37Z·TeV and 733 bunches
- Run 3 could be at E=6.8Z·TeV and 1240 bunches
- Since there is no collimators due to missing 11T dipoles this could lead to more dumps
  - At E=7Z·TeV estimated factor ~2.1 higher sensitivity



- Expect this can be mitigated through use of crystal collimators during PbPb running
- If not, could lower risk by staying at E=6.37Z·TeV
  - Not a large loss to physics and easier to combine with Run 2
- Decision should be taken by summer 2022
  - Before large MC simulation campaigns are started

pp Reference Runs for HI

- Requests for p-p reference data in 2022
  - ALICE: 3/pb at 0.5T field running at full readout rate (1MHz)
  - ATLAS: 350/pb (for 2/nb PbPb) - roughly x4 the PbPb NN-lumi
  - CMS: 150/pb (for 2.3/nb PbPb) - ~x1.5 the PbPb NN-lumi
  - LHCb: >25/pb
- ATLAS and CMS requests can be optimized by increasing pile-up for faster accumulation
- ALICE limited by readout rate, so sets length of p-p ref. run
  - Expect to need 5 days of p-p running plus 2 days for setup
  - Other experiments can optimize pile-up vs integrated luminosity
- More p-p reference data will be needed for future runs
- Optimal scheduling of p-p ref. run still to be determined

HI Running in Run 3

- Current plan for HI running in Run 3:
  - 1 month of PbPb in 2022 (including p-p reference run)
    1 month of pPb in 2023 (including p-p reference run)
    2 months of PbPb in 2024 (including p-p reference run)
- The extended run in 2024 was added when 2021 run was canceled
  - It also helps with machine “cool-down” (how much is needed?)
- With 23/24 EYETS and O-O/p-O run in 2024 this leaves rather little time for p-p running in 2024
- If extra year added, some options for re-balancing:
  - Only O-O/p-O in 2024 and 2 month PbPb in 2025
    - If EYETS still needed, might move start of YETS earlier?
  - 1 month of PbPb in both 2024 and 2025
    - Depends if cool-down is needed for LHC LS3 work
    - Could also move pPb to later part of Run 3
- *Expect this to be discussed in Chamonix workshop*

Special Run Requests

LHCf Low-μ Run Request

- Requests a high statistics low-μ run with upgraded DAQ
  - "Combined" data-taking with ATLAS, if possible
  - Detectors not rad-hard – needs to be installed/removed in TAN (~1 shift)
- Beam and run parameters requested:

Beam parameters for the LHCf run with $p+p$ collisions at $\sqrt{s}$ =14 TeV

Parameter	*Value*
Colliding bunches	~ 500
Minimum bunch spacing	200 ns
Luminosity ($cm^{-2}s^{-1}$)	$\lesssim 10^{30}$
Inelastic cross section (mb)	80
μ (average n. of collisions per BC)	0.~~04~~ <0.02
Beam crossing	vertical, downward
Beam crossing angle (μrad)	best: 290 (total)
β^* (m)	best: ~ 10 ($\gtrsim 1$)

Run parameters for the LHCf minimum physics program with $p+p$ collisions at $\sqrt{s}$ =14 TeV ($L = 10^{30}\,cm^{-2}s^{-1}$)

Parameter	*Value*
Number of $p+p$ collisions per detector position	$\sim 3 \times 10^9$
Delivered integrated luminosity per detector position (nb^{-1})	~ 40
Recorded integrated luminosity per detector position (nb^{-1})	~ 20
Collision rate at IP1 (kHz)	80
Arm1/Arm2 acceptance	~ 0.12
Hit rate on Arm1/Arm2 (kHz)	~ 10
Typical DAQ rate (kHz, including dead time)	~ 1.0
Net operation time at max rate (h)	~ 24
Net operation time at 600 Hz with ATLAS (h)	~ 48
Total number of collected type I and II π^0 events	$\sim (2 \div 3) \times 10^6$
Total number of collected η events	$\sim 6 \times 10^4$

Req. 2 positions

- LPC run proposal to minimize overall impact:
  - Install detector in 2022 TS and do run with vdM optics (β*=19m)
    - Use offset leveling to run at desired μ value
  - Filling scheme with 152 bunches at μ~0.02 would need ~4 days at 50% eff.
  - Large synergy with vdM scan if done in same period
    - Also useful for having optimal luminosity precision for the run

CMS Low Pile-up Run

- Expect CMS to request “low” pile-up run (μ~2-3)
  - Primarily for precision EW measurements
    - W and Z cross sections
    - W mass measurement
  - Similar to run taken for ATLAS in 2018
- Integrated luminosity target of ~0.5/fb
  - Would take around two weeks in normal running conditions
  - Expect it could be done with offset leveling with other experiments running normally apart with longer fills
    - Can this be done with β* leveling in IP1?
- Optimal schedule is early 2023
  - Fully commissioned and optimized detector
  - Radiation damage degradation minimal
  - Ideally close to vdM scan for optimal luminosity precision

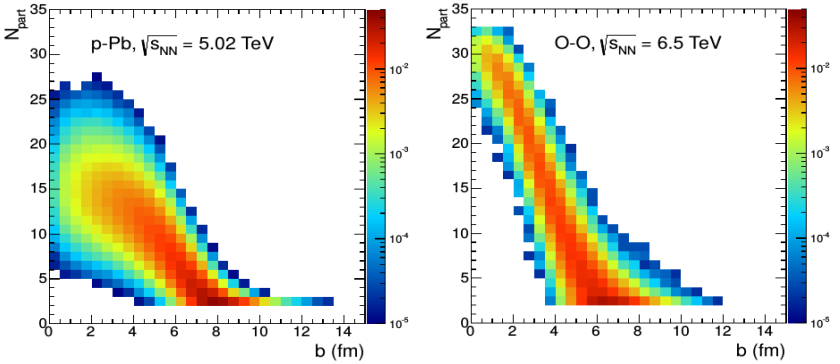
Two High β* Runs

- β*=90m for TOTEM inelastic xsection with new T2 det.
  - T2 must be installed in TS before HI period as it is not rad-hard and cannot be removed/installed without ramping down CMS solenoid
  - Request for μ=0.04-0.1 for ~6 hours (~1/nb, no stable beam)
  - Will need few days of beam preparation before TS,
    - Expect this to also be useful for very high β* run (part of the same de-squeeze)

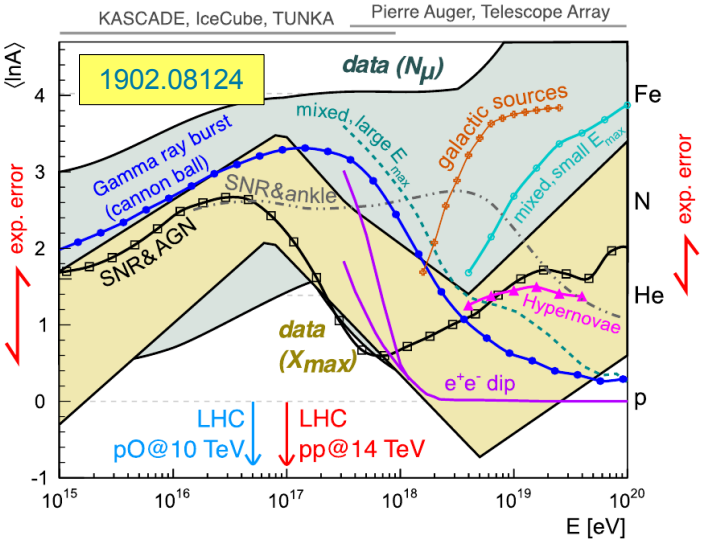
- β*=(3,6) km for elastic scattering in CNI region
  - For ATLAS (ALFA) and TOTEM
    - ATLAS requests early run due to radiation damage to ALFA
  - Used to measure rho parameter at highest possible energy
  - Very low physics rate: ~65 Hz for elastic signal only
    - Requires special collimation scheme (possibly crystals?)
  - 4-5 days of physics to record 350-400/pb at 50% eff (~Run 2)

O-O and p-O Runs

- Plan a short (1-week) run of O-O and p-O collisions
- Oxygen-Oxygen collisions can be used to study emergence of collective effect in small systems
  - O-O has similar multiplicity to pPb, but geometry is better defined



- Study bulk-particle production, such as flow harmonics and charged-particle energy loss
- Proton-Oxygen collisions long-standing request from cosmic-ray community
  - Will improve modeling of high energy air-showers
  - Air-shower models critical in extracting mass of cosmic ray (lnA), which helps identify the source
  - Could also help resolve discrepancy between muon density and shower maximum observations in cosmic rays



Luminosity and Energy for O-O/p-O

- For O-O around 0.5/nb is sufficient for a comprehensive soft physics measurement programme
  - Expect it can be recorded in ~1 day with just a few bunches
    - Most time consuming is likely the setup
- For p-O request is for up to 2/nb (LHCb)
  - LHCf would like 1.5/nb at μ=0.02 and 2μs bunch spacing
    - Would take around 24 hours with 36 bunches
    - LHCf again requires downward polarity

- To minimize setup time, plan is to reuse PbPb optics
  - Means β*=0.5m in IP1/2/5 and 2m in IP8
  - Collision energy per nucleon is 6.8 TeV, higher than PbPb
- There is request to have same energy in O-O as PbPb to reuse p-p reference run from PbPb without extrapolation
  - Would add additional setup time to commission new energy
  - Until determined otherwise assume running at maximum energy
    - Also the preferred solution for p-O from LHCf/LHCb

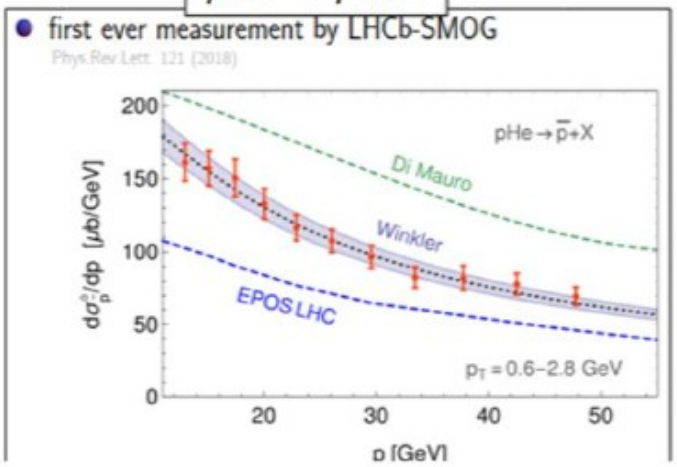
- Would like to keep the total time to no more than 1 week
- Experiments would like run in 2023 while machine prefers 2024

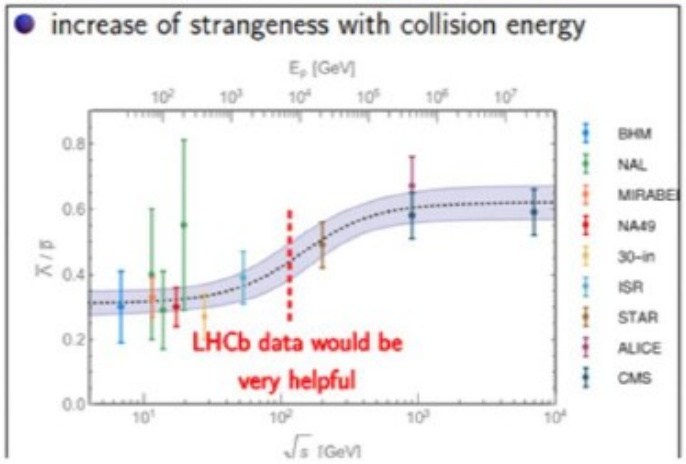
p-He Collisions at Injection Energy

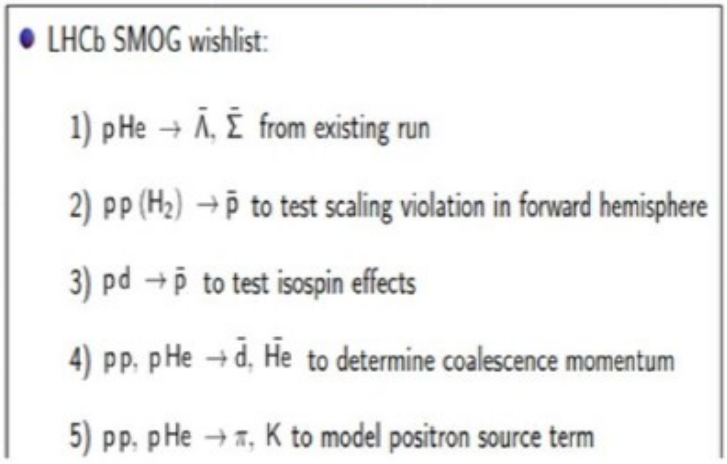
- LHCb request for p-He (SMOG) at injection energy
  - Measure anti-proton production to help understanding of cosmic anti-proton flux excess
  - Additionally some nuclear medium measurements

$pHe \rightarrow \bar{p}+X$

From M. Winkler, Sep 2019, https://agenda.infn.it/event/18734







- LHCb need VELO in closed position for measurement
  - Not compatible with nominal beam size at injection energy
  - Will require accelerator work on having smaller beams
    - Possibly a squeeze to β*=7m at injection energy?
  - Actual physics data taking is three hours with 50-100 bunches
  - Run not before 2023 as detector and SMOG2 to be commissioned

Baseline for Special Runs in Run 3

- Have made proposal for Run 3 special run schedule
  - Comes out at roughly one week per year
  - Should fit in with accelerator wishes (mainly on O-O)

Special run type	Experiment	Duration	When
VdM scans etc.	All	2-3 days	Every year after TS
Low-μ (<0.02) p-p	LHCf	~4 days	2022 after TS
β*=90m	TOTEM	~3 days	2022 after last TS
β*=(3,6) km	ATLAS,TOTEM	4-5 days	Early 2023
Low-μ (2-3) p-p	CMS	(2 weeks)*	Early 2023
p-He at 900 GeV	LHCb	2 days	2023
O-O and p-O	All	7-8 days	2024 after TS

* CMS low μ run not expected to affect others or machine much

- Will most likely evolve as Run 3 goes on
  - Will revisit scheduling if one more year added

Summary

Run 3 Luminosity Targets

- Proton-proton production (not incl. HI reference runs)

Experiment	Run 3	Run 3+Run 4
ATLAS, CMS	160/fb	-
LHCb	25/fb	50/fb
ALICE	200/pb	-

- PbPb production

Experiment	Run 3	Run 3+Run 4
ALICE, ATLAS, CMS	6/nb	13/nb
LHCb	1/nb	2/nb

- pPb production

Experiment	Run 3	Run 3+Run 4
ATLAS, CMS	0.5/pb	1/pb
ALICE	0.25/pb	0.5/pb
LHCb	0.1/pb	0.2/pb

- These are minimum targets
  - Experiments can happily take more integrated luminosity

Summary

- Requests and constraints from experiments presented
  - Largely in line with what is expected at last Evian workshop
  - Have to large extent already be incorporated into planning
- ATLAS and CMS desiderata very similar to Run 2
  - Will need to gain further experience with β* leveling
  - Most limits/wishes come from forward detectors
    - To be balanced against lumi-production and machine needs
- ALICE and LHCb can now handle much higher lumi
  - Some additional requests from LHCb, but only from 2023
- List of special runs presented – ~1 week per year
  - Some will require significant preparations from machine side

All experiments look forward to Run 3 starting