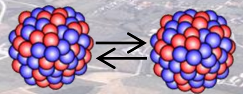
Planning for the 2022 Pb ion test



R. Bruce

With essential inputs from R. Alemany, T. Argyropoulos, H. Bartosik, C. Bracco, A. Butterworth, R. Cai, M. D'Andrea, A. Frasca, P. Hermes, C. Hernalsteens, J. Jowett, S. Kostoglou, D. Mirarchi, F. Moortgat, G. Papotti, B. Petersen, S. Redaelli, M. Solfaroli, G. Sterbini, H. Timko, J. Uythoven, J. Wenninger, D. Wollmann

Outline

- Introduction
  - Goals of test
  - Overview of plannning
- Detailed plan of test
  - Commissioning
  - Crystal collimation test
  - Slip-stacking test
  - Stable beams
- Conclusions

Pb ion test

- Initially planned 2022 Pb-Pb run postponed to 2023
- 2-day LHC Pb ion test slotted in on November 17-18

- General goals of test
  - Give some first Pb-Pb collisions to the experiments, in particular the new ALICE detector
  - Learn as much as possible on the machine side to finalize the energy choice, and for future performance estimates and optimizations

- More specifically
  - Stable beams with Pb-Pb collisions at all IPs → New record-high energy for Pb-Pb collisions!
  - Crystal collimation tests
  - Tests slip-stacked beams in the LHC
    - Ideally test colliding slip-stacked trains at top energy
  - Anything else we can learn parasitically
    - Achieved Pb beam parameters through LHC cycle – be careful with extrapolation though
    - Test of ALICE ZDC acceptance?
    - Beam-beam?
    - Tests of newly installed TCLDs in IR2 for Pb collision products?

- Test to be done at low intensity (< 3E11 charges / beam) using standard proton cycle to minimize time used for commissioning and validation

Overview of planning

- Plan (**Total: 36h**)
  - Commissioning → **6h**
  - Slip-stacking tests at injection → **2h**
  - Crystal collimation test → **12h**
  - Stable beams, 2 fills → **16h**
  - Have 2 days allocated, i.e. we have some contingency in case of unexpected problems, machine downtime etc.

- Advantages of doing things in this order:
  - If beam quality is satisfactory, we can do stable beams with short slip-stacked trains
    - Request from ALICE and ATLAS - can learn more with the new detector conditions closer to standard physics
    - We can study the transmission, beam parameters and luminosity with slip-stacked beams in the LHC throughout the cycle, and hence make better performance estimates for the future
    - We can potentially get experience of long-range beam-beam and lifetime with slip-stacked beams in collision
  - If there are no issues, we can do stable-beam Pb ion operation with crystal collimation (first time ever!)

Outline

- Introduction
  - Goals of test
  - Overview of plannning
- Detailed plan of test
  - Commissioning
  - Crystal collimation test
  - Slip-stacking test
  - Stable beams
- Conclusions

Needed commissioning

- Transfer lines SPS-LHC
  - Need steering of transfer lines (different optics in SPS, Q26)
  - Typically done with protons, but can be done with single-bunch ion injections in this case (low total injected intensity)
  - If we see significant losses or emittance blowup, consider realigning transfer line collimators or re-check transfer line optics

- LHC injection / RF
  - Need different RF frequency for ions
  - Need to commission RF capture, stable phase and RF buckets for ions

- No further commissioning foreseen – will use standard proton cycle

- Total time estimated: Around 6h
  - Could also be faster if things go smoothly

Outline

- Introduction
  - Goals of test
  - Overview of plannning
- Detailed plan of test
  - Commissioning
  - Crystal collimation test
  - Slip-stacking test
  - Stable beams
- Conclusions

Crystal collimation tests

- Reminder:
  - Planned to rely on crystal collimation in all future LHC Pb ion operation
  - Present system: Two new crystals installed in LS2 + two “old” devices remaining since Run 2
  - Plan to exchange also the remaining two in the YETS with the new design
  - Hope to improve availability and minimize “10-Hz” dumps with improved cleaning efficiency
    - Discussions with experiments about possibly making Run 3 physics at 6.37 Z TeV instead of 6.8 Z TeV to increase margins

- Goals of crystal collimation studies in beam test
  - Characterize crystals with Pb beams, in particular the new ones, and demonstrate channeling
    - In particular, investigate skew planes for B1V
  - Study cleaning performance improvement w.r.t. standard collimation system
    - Would give very important inputs for decisions on beam energy
  - Study cleaning performance with a few different settings of crystal-based system

- Conditions for test
  - Will need about 20 non-colliding bunches per ring (staying below 3E11 charges)
    - possibly with batches of 3 individual bunches per SPS cycle as in previous tests to minimize injection time
  - Use standard proton cycle at flat top (β^*=1.3m at IP1/5)
  - With Pb beams, need to switch LHC BPM gain to higher sensitivity – could induce some orbit variation, but expected to be very small

Program for crystal collimation test

- Total estimated: 10.5h
  - Additional time for cycle, ramp-down: count 12h

- Preparations: hardware and controls experts to move in crystals and move out replacement chamber

Duration (hrs)	Task
0.5	Injection
2	Beam based alignment of all four crystals at injection Angular scan at injection to find channeling
0.5	Injection
0.5	Ramp
1	Check offsets on BPM collimators BPM alignment of IR7 and TCTs, move in TCTs BLM alignment if needed of a few key collimators
2	Beam based alignment of all four crystals Angular scans at flat-top to find channeling
1	Linear scans (especially B2V to study skew planes)
1.5	Loss maps in different configurations: 1. Standard system without crystal 2. Crystal at 4.75 sigma 3. Crystal at 4.5 sigma 4. Collimators upstream of crystal open 5. TCLAs to 8 sigma 6. Retracted secondary to test mis-cut and asymmetry 7. Some other TCLA settings to test if we have bunches left
1.5*	OP work, miscellaneous

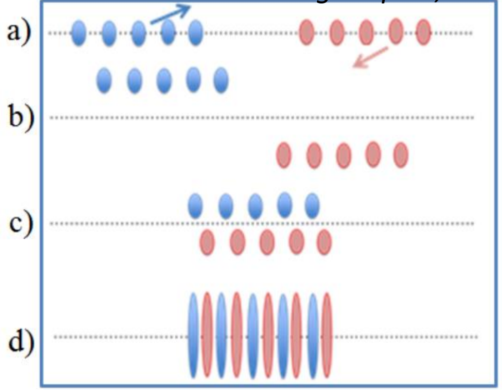
Outline

- Introduction
  - Goals of test
  - Overview of plannning
- Detailed plan of test
  - Commissioning
  - Crystal collimation test
  - Slip-stacking test
  - Stable beams
- Conclusions

Slip-stacking tests

- Reminder: Future LHC Pb ion physics program relies on new slip-stacked beams from the injectors
  - Interleave 100 ns bunch trains in the SPS through RF manipulations to achieve a 50 ns bunch structure
  - Result: 70% more bunches than in 2018 (had 75 ns spacing)
  - Injectors have done great progress on the commissioning of slip-stacked beams in 2022

From LIU technical design report, vol. 2



- Goal of test: set up, inject and study short slip-stacked train of 8 bunches
  - Study beam quality and characteristics on circulating beam at injection - any quick adjustments needed?
  - If test successful, can use slip-stacked beams for stable beams at top energy
  - If SPS can produce longer trains we can try to inject (up to 4*8 to stay below setup beam flag) but not likely
  - (Optional: Could leave beam circulating at injection for some ~20-30 minutes to study blowup and lifetime)

- Estimated time: 2h

Outline

- Introduction
  - Goals of test
  - Overview of plannning
- Detailed plan of test
  - Commissioning
  - Crystal collimation test
  - Slip-stacking test
  - Stable beams
- Conclusions

Stable beams

- All experiments interested in collisions - especially ALICE eager to test new detector
- Plan to do **two stable-beam fills** with different filling schemes – total time about 16 h
  - First fill relying on single bunches as in Xe run – can have four non-colliding bunches for loss maps. Goal to validate on the fly in the same fill – see next slide
  - Second fill with two slip-stacked 8-bunch-trains per ring, combined with a few single bunches
- Use standard pp cycle, go to end of squeeze, β*= [0.6 , 10 , 0.6, 1.5] m
  - Can piggy-back on the proton OP cycle and collision beam process – easiest option for OP
  - No β*-levelling foreseen – stay at 60 cm
- Compared to standard proton cycle, need to change ALICE crossing angle
  - In standard pp operation, use 200 urad external angle, which adds to spectrometer angle (net angle 272 urad)
  - For ZDC acceptance, max net angle is 100 urad → Need to reverse spectrometer polarity so they subtract, decrease external angle of max 172 urad
  - Before trimming crossing angle, need to open IR2 TCTs symmetrically
- If crystal tests are satisfactory, propose to insert crystal as primary collimator in physics fill
  - Nice achievement to have Pb-Pb stable beams with crystal collimation
  - Standard collimation system still to stay in place with standard pp settings

MP validation for stable beams

- Standard proton cycle and collimator settings as used in 2022 for high-intensity proton operation - aperture is fully protected. Only difference is the beam species, intensity, ALICE crossing, possibly the insertion of crystal

- Beam: setup beam of <3E11 charges, about 18-20 bunches with around 1.5E10 charges / bunch – like a “fat pilot” with protons
  - In filling scheme with single injections, cannot hit more than one bunch with an asynch dump
  - In filling scheme with 2*8 bunch-train, more bunches could be affected. Still, 5o ns spacing, about 1.5E10 charges/bunch

- Propose “light” validation given setup beam of <3E11 charges, and that we use nominal proton cycle
  - Do it on the fly in stable-beam fill – need to add 2 non-colliding bunches per beam (take 4 to have contingency)
  - As in 2017 Xe test: betatron loss maps were done just before stable beams, in same fill
  - If first fill will end with OP dump, can do it with an asynch dump

- Validation in crystal fill not optimal - not planned to use collision configuration and changed ALICE crossing angle

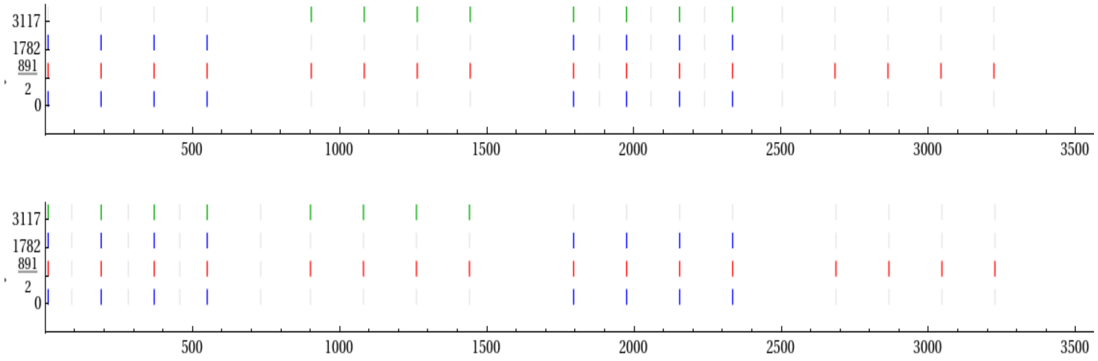
- Proposed procedure:
  - Go to end of squeeze
  - Insert crystal, open IR2 vertical TCTs symmetrically, open TCLIA to max gap 29.5 mm
  - Go in collision (change of ALICE crossing in beam process), optimize
  - Do betatron loss maps, validate on the fly
  - Declare stable beams

- To be worked out: which interlocks need masking?
  - Want to be as safe as possible, but must also avoid dumping on spurious interlocks

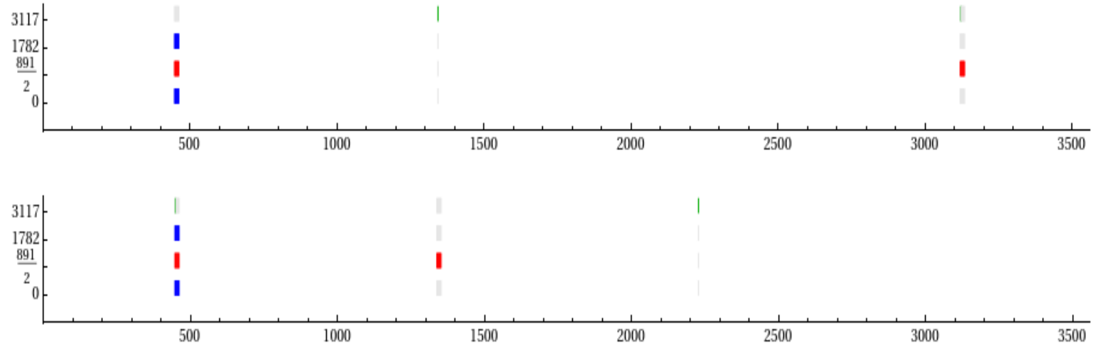
Filling schemes

- ALICE will have much larger β* (factor ~17)
  - to compensate, ALICE should get more colliding bunches in filling scheme
- First stable-beam fill: Propose same scheme as in 2017 Xe test: 20b_8_16_8_8
  - Has four non-colliding bunches for loss maps
- In second stable-beam fill: Propose filling scheme with slip-stacked trains of 8 bunches
  - Option a: 2 trains collide with each other in ALICE, adding single bunches that collide with given bunch in train at ATLAS/CMS and LHCb : Scheme 18b_2_16_2_2
  - Option b: 2 trains collide with each other in ALICE, 1 train colliding at ATLAS/CMS. Adding single bunches that collide at LHCb : Scheme 18b_2_16_2_2
  - Depending on achieved intensity, Further single bunches may be added

20b_8_16_8_8



17b_8_16_8_2

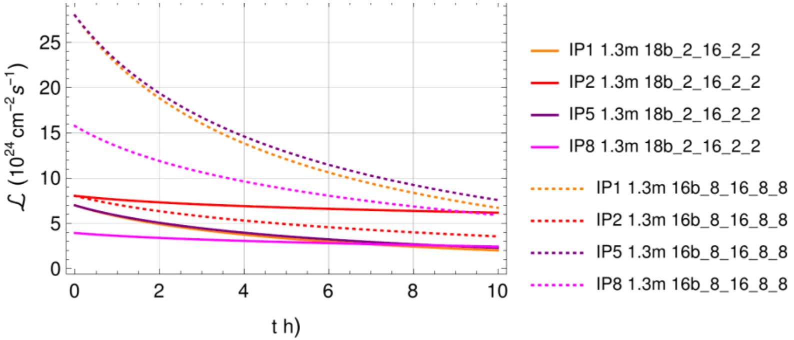


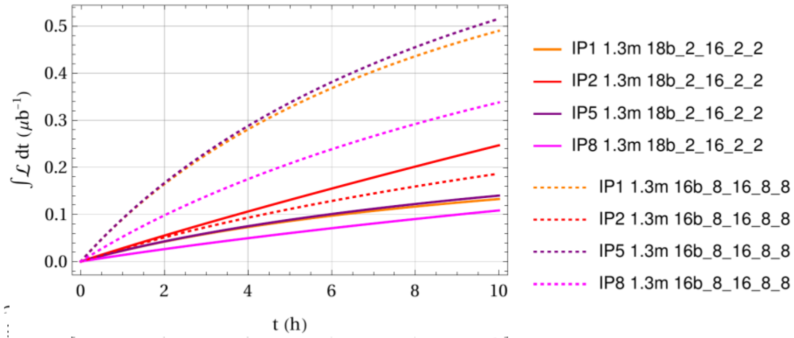
Beam evolution

Instantaneous lumi

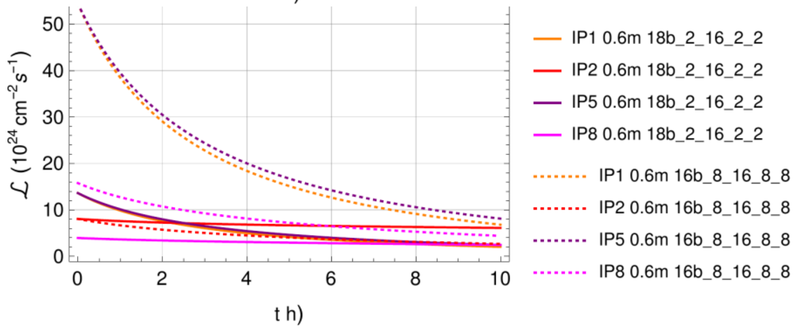
Integrated lumi

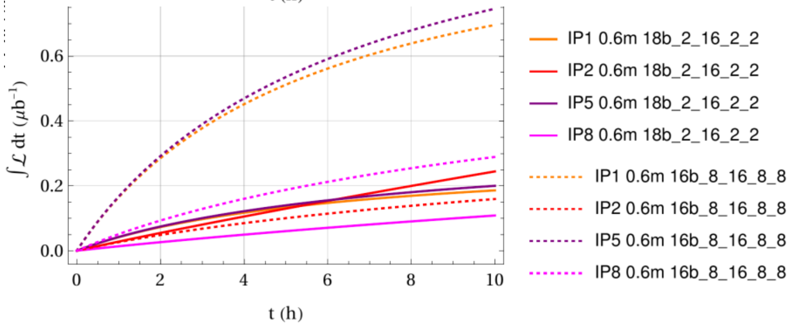
1.3 m





0.6 m





Expected luminosity

- Assume we keep each fill 5h, assign 6h for injections, turnaround etc

- Very rough estimate of integrated luminosity
  - 0.1 μb^{-1} per fill in ALICE, could get 0.4 μb^{-1} at ATLAS/CMS
  - ALICE loses integrated luminosity due to fast beam burnoff at ATLAS/CMS, where β^* is small - consider separation levelling in ATLAS/CMS to give a more balanced sharing

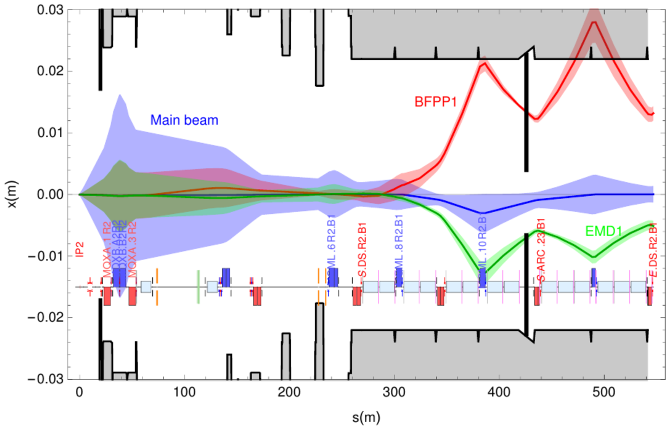
- Very high error bar!
  - Beam parameters still uncertain – estimates to be taken with significant unertainty
  - Very sensitive to actual machine availability

Other activities – optional, under discussion

- Is ALICE ZDC acceptance OK for 100 urad?
  - If accepance would not be OK, very important to know this early on for the 2023 run
  - Could imagine doing some steps down in crossing angle – 100 urad is the limiting case, and with smaller angles we should be fine
  - In touch with ALICE to understand if this is wished
  - Should check with MP if this is OK (but aperture is >40 sigma at 10m, and will only be better for smaller crossing angle)
  - Leave TCT constant at symmetric settings

- If we anyway do crossing angle scan at ALICE, where slip-stacked trains collide, could potentially learn something about the beam-beam limits
  - Important for future ion operation to learn more about the beam-beam limit, in order to work out a machine configuration with maximum performance
  - Weak beam-beam expected with β*=10m, but might still see effects if we go to very small effective beam-beam separations
  - Could maybe still learn something by benchmarking simulations, which can then be used to estimate limit in real physics run
  - Alternative proposal: consider a crossing angle scan in ATLAS/CMS, with β*=0.6m, if fine for experiments. Maybe end of fill?

- IR2 TCLDs installed in LS2 to intercept BFPP ions
  - Could parasitically move them in to verify that they work
  - Possible caveat: BLM signals from BFPP beam will be very low (expect 8E-7Gy/s from approximate scaling)
  - If so, need also to apply BFPP bump in IR2 – some preparation work needed
  - Should ideally be done before loss maps, but could also be done as end-of-fill going back in ADJUST
  - Would need some time to tune the bump and the collimator setting – 30 minutes?
    - Done with collisions on



Outline

- Introduction
  - Goals of test
  - Overview of plannning
- Detailed plan of test
  - Commissioning
  - Crystal collimation test
  - Slip-stacking test
  - Stable beams
- Conclusions

Conclusions

- 2022 heavy-ion physics run postponed, short test scheduled on November 17-18

- Main goals
  - Collisions to experiments
  - Crystal collimation tests
  - Tests of slip-stacked beams
  - Anything else we can learn from the machine side to prepare future ion runs

- Program proposed, using setup beams (<3E11 charges) and the standard pp cycle
  - Minor modifications: ALICE crossing angle, crystal as primary collimator
  - Finish with 16h allocated for two stable-beam fills
  - Machine protection validation on the fly in the first fill
  - Second fill to be done with short slip-stacked trains

- Extra/parasitic activities still under discussion

- Several other talks on this topic foreseen next week

Thanks for the attention!

Update 4/11: ALICE crossing angle

- Proposal from ALICE to have different crossing angles in the two fills
  - First fill: -72(internal) + 172(external) = +100 urad net angle
    - This allows testing the ALICE ZDC acceptance at the max foreseen crossing angle
  - Second fill: -72(internal) + 128(external) = +56 urad
    - Smaller angle, close to what we had in 2018

- Validation will be done only in first fill with 100 urad
  - In second fill, angle is smaller, so we should have more aperture and be safer
  - Similar strategy as for VdM validation

- TCT settings will be constant in mm in both fills
  - From standard pp setting, open the inner TCT jaw symmetrically. Aperture should still be protected on both sides
  - Nominal TCT setting is 37 sigma, aperture with standard 200 urad external angle is above 40 sigma. We expect more aperture in the test, where the angle is smaller

Update 4/11: masking of interlocks

- For the crystal test, same masking needed as for standard collimator alignment

- The following interlocks will be masked in the stable-beam fills:
  - Crystal interlock: Plan to insert crystal as primary collimator in stable beams
  - Collimator movement and energy limit in IR2: Need to open the IR2 TCTs symmetrically to accommodate ALICE crossing change
  - Collimator BPM in IR2 (TCTs will be off-centered)
  - Orbit remains interlocked, but margin in IR2 needs to be adapted to accept change of crossing angle in ALICE
  - PC interlock is automatically masked with SBF=True. Could investigate if there is a way to un-mask

- If we do TCLD test as end-of-fill, we would go back in ADJUST and then mask as for collimation setup (check also orbit from BFPP bump)