Lead ions throughout the complex: Fixed Target and LHC beams

S.Albright, R.Alemany Fernandez, T.Argyropoulos, P.Baudrenghien, G.Bellodi, N.Biancacci, D.Bodart, R.Bruce, F.Carlier, M.Bozzolan, H.Damerau, P.Deep Meruga, M.Dolenc, A.Frassier, D.Gamba, G.Hagmann, A.Huschauer, S.Jensen, I.Karpov, D.Kuchler, A.Lasheen, G.Le Godec, E.Mahner, N.Madysa, O.Marqversen, C.Mutin, G.Papotti, G.Piccinini, R.Scrivens, A.Spierer, D.Quartullo, F.Velotti, E.Waagaard, R.Wegner, C.Wetton, PS, SPS and LHC OP teams.

Joint Accelerator Performance Workshop
7-12-2022

Outline

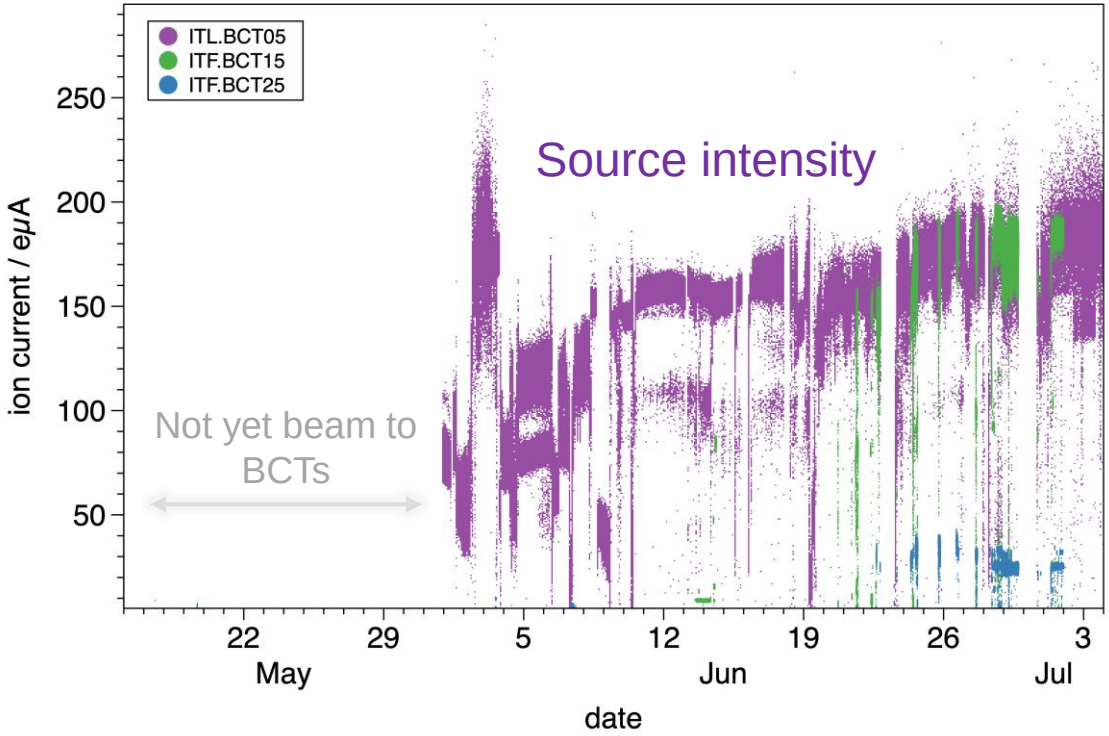
- Pb ions beam commissioning and performance from source to SPS.
- Transmission between machines.
- FT/LHC beams.
- Summary and outlook.

Source commissioning

- Maintenance:
  - Change of extraction gap by +10 mm (following last year's experience).
  - Commissioning of the new source interlock system.
  - Upgrade of the source solenoid cooling.
  - Optimization tool for the LEBT developed based on the CERN optimization framework.
- Source start 16.05.2022, beam to LEIR 04.07.2022.
- The long time is needed to condition the source to reach the required beam intensity and stability.
- 6 oven refills, average of 29±7 days between refills.
- Stable operation with beam of 33±3 μA out of the linac.

Source commissioning

Ramp up of intensity shows ~6 weeks is needed for intensity and stability.

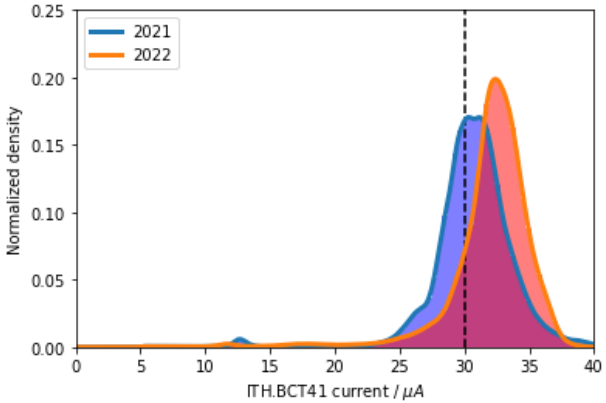


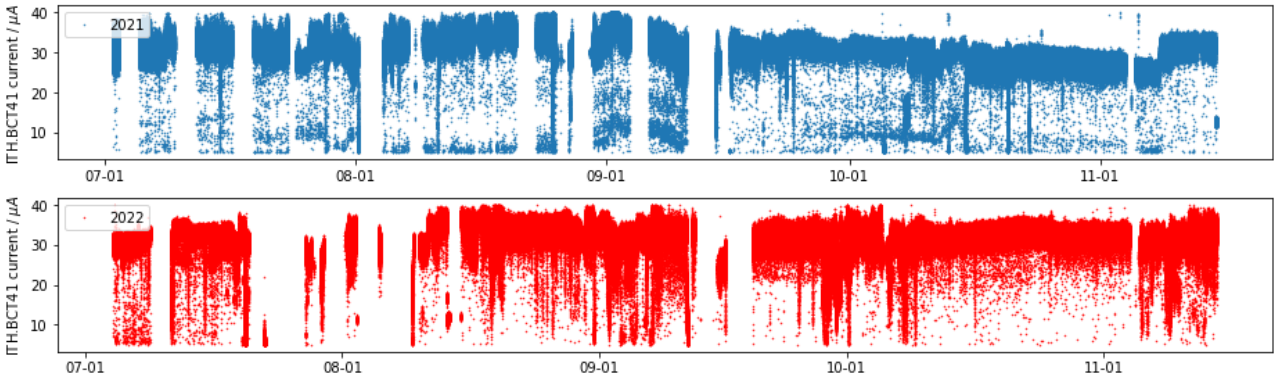
Linac 3 commissioning

- Commissioning duration in the shadow of source commissioning.
- Source requires RFQ beam available after 1 week.
- As each RF system is HWC, we follow with the BC.
- In 2022 restart, buncher cavity was available 2.5 weeks later than planned → BC had to be compacted with many systematic measurements not performed (e.g. no systematic RF setting up, no emittance measurements).
- An oven refill was made near to the delivery of beam to LEIR.

Linac 3 performance

Performance further improved with ~33 uA delivered on average (KPI at 30 uA).

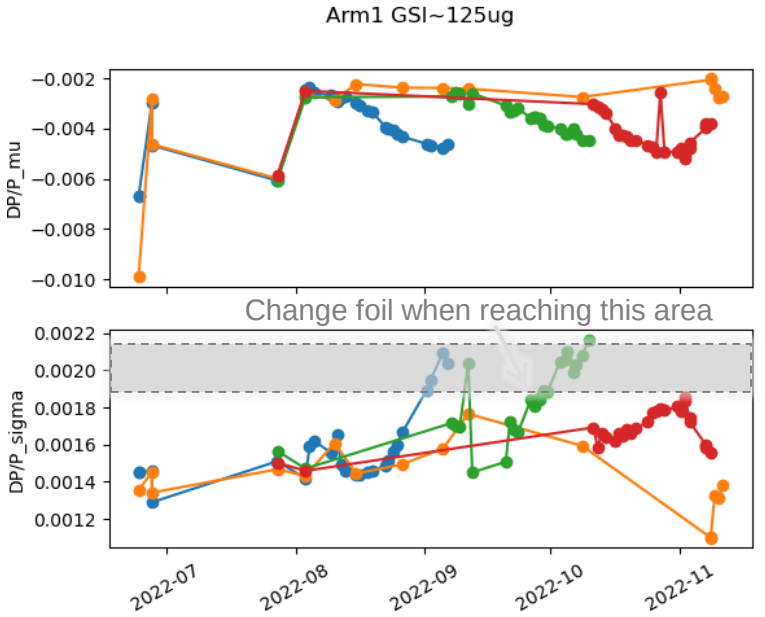


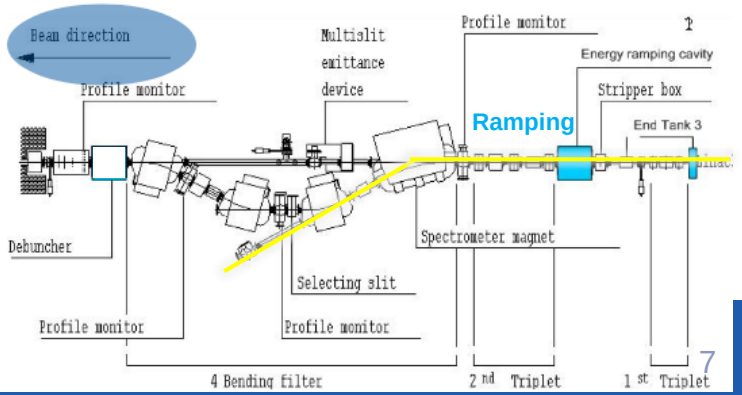


- Shot to shot variations sometimes important → *define a KPI for 2023?*
- Mitigated by Linac3 team with adequate source tuning but not always possible w/o stopping beam (e.g. during LHC run)

Stripper Foils

- 4 GSI foils per arm, 4 arms installed.
- Collision of 1 arm with the tank, required realignment of the system (21/07/2022).
- Performed daily measurement of momentum distribution, in ITFS (after Ramping cavity).
- Observe rms dpp ~2.1×10^{-3} is a limit for EOL.





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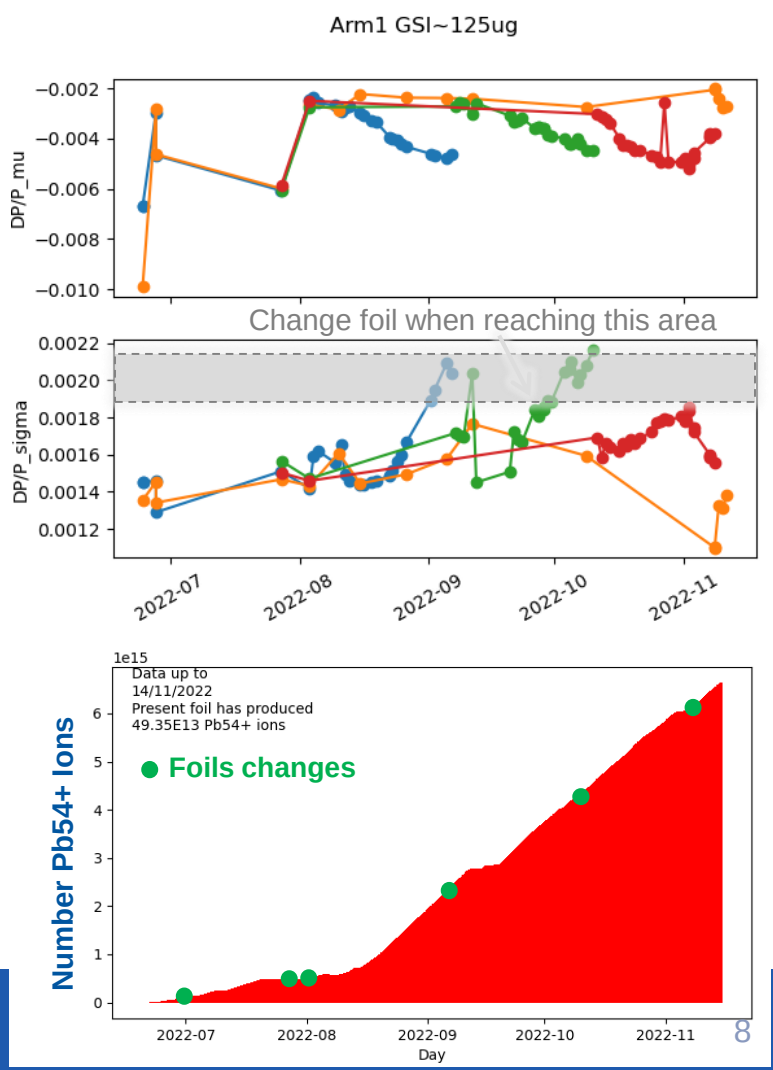
- Observe rms dpp ~2.1×10^{-3} is a limit for EOL.
- EOL occurs at ~200E13 Pb54+ ions produced (Approx 4 weeks).
- Reproducible behaviour (huge improvement wrt old pre-LS2 foils).



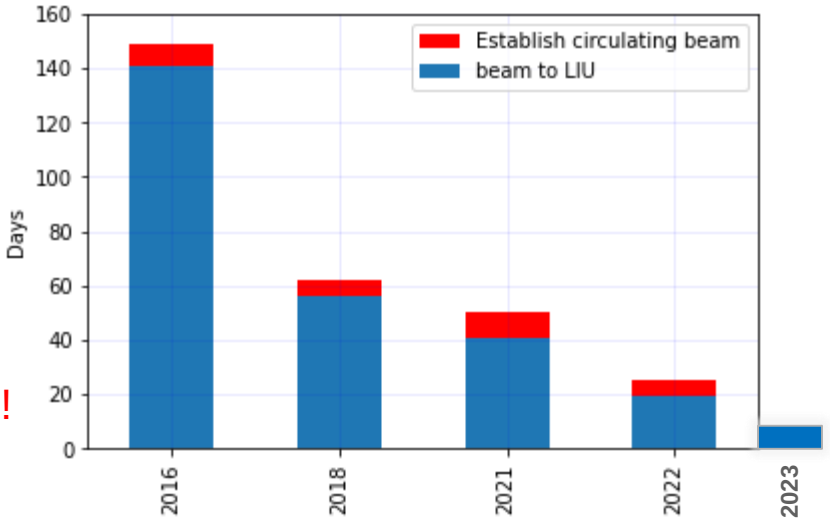
LEIR commissioning

- Beam arrived into LEIR transfer lines on 28/06 and 1/07.
- First beam in LEIR only on 6/07 (energy mismatch with Linac3 by 0.5%).
- Commissioning went slow due to holiday season.
- Eventually stopped on 28/7 due to **no manpower** → ion chain held on very few pillars…
- Restarted on 10/08, NOMINAL at spec in 2d (thanks to previous EARLY commissioning).

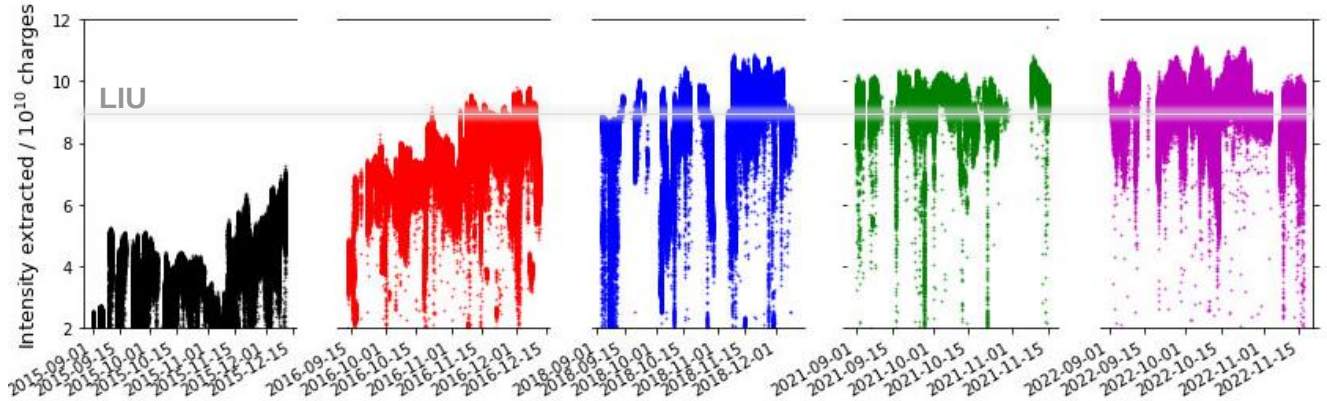
Continuous improvement on machine physics and operation → faster NOMINAL BC time every year.

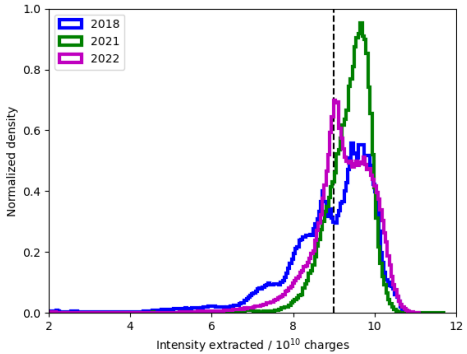
But 1w to circulate EARLY beam → 1st turn measurement could speed this up.

In 2023, 1w for BC with less manpower → challenging!



LEIR performance

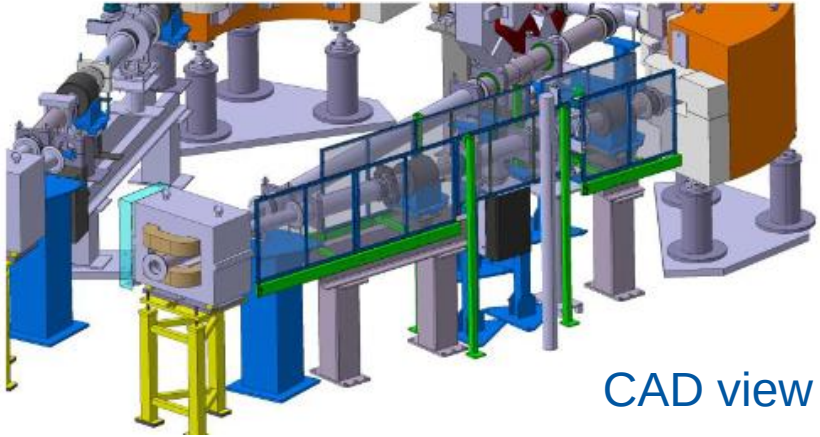




- Progress inline with global LEIR machine improvements over last years.
- At/Above LIU target most of the time.
- Sources of performance change identified and followed-up:
  1. Stray fields from PS.
  2. Stripper foils evolution.

Stray fields

This year: shielded part of the ITE line by EN/MPC (294th IEFC).



CAD view

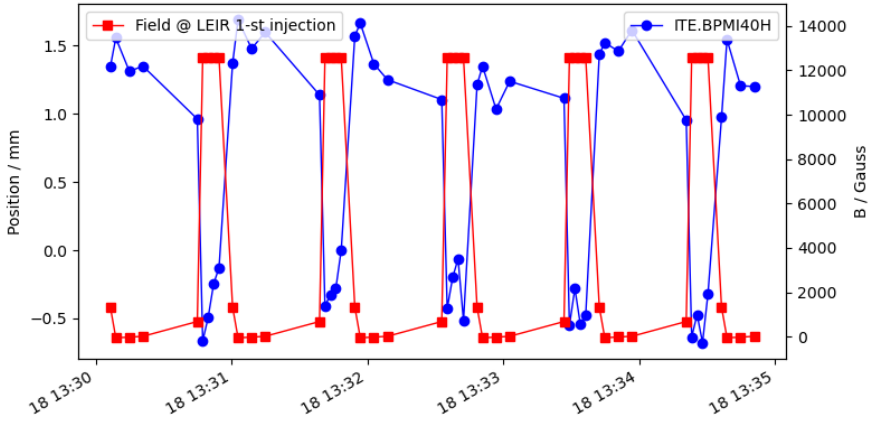
As installed

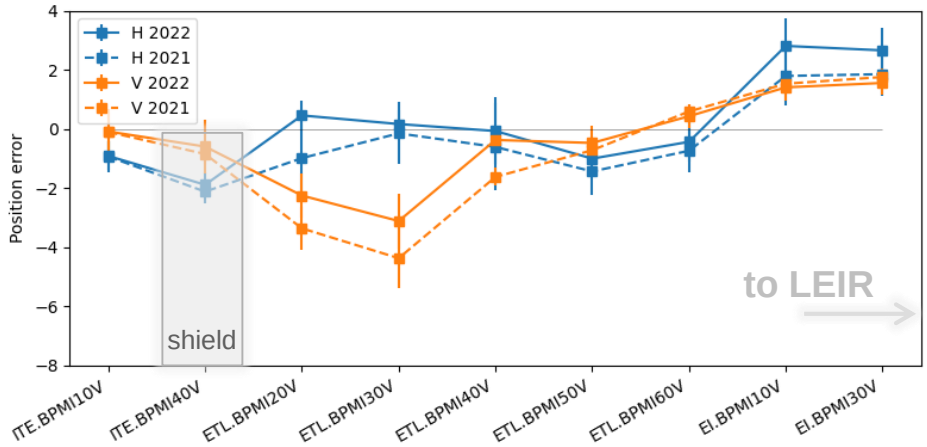
D.Bodart

Beam measurements done to quantify the stray field reduction.

Stray fields

Effect correlated to the PS magnetic field.





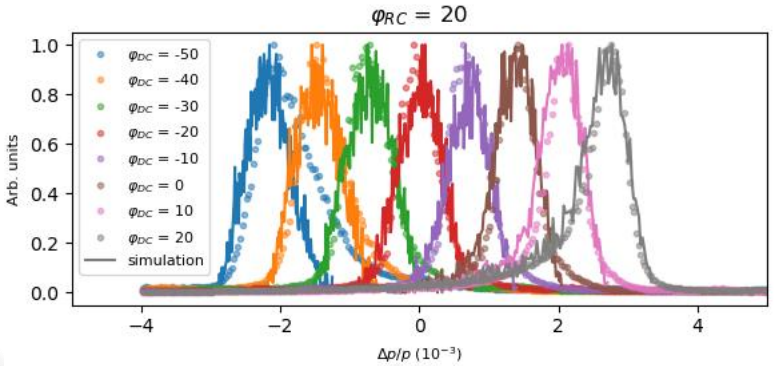
- Effect on shielded area visible → x2 kick reduction in V as expected (Ions-MPC 8/3 and 6/9).
- Still large error: probably combined effect of full ITE loop + magnets roll angles.

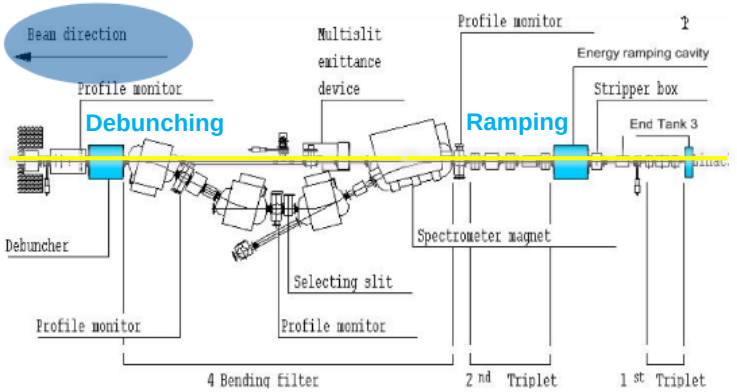
→ *next steps to being planned (improved/additional shields, automatic corrections...)*

Stripper foils

Tracking tool developed to compute the machine injection efficiency with different energy distributions Linac3.

Simulated/measured energy distribution from Schottky





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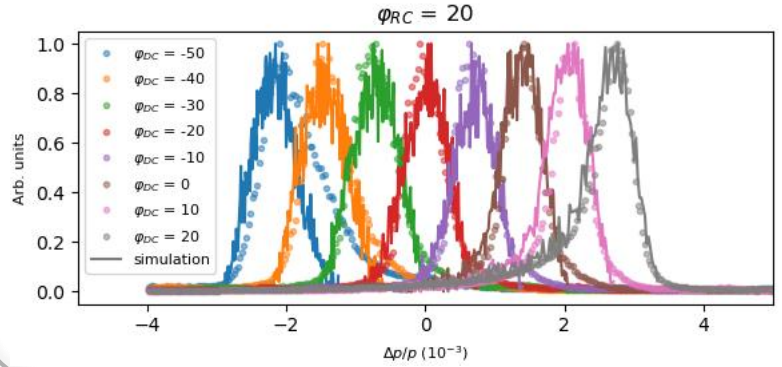
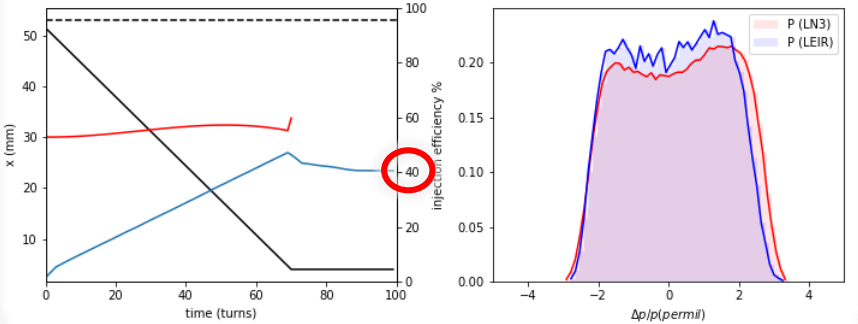


Simulated injection efficiency

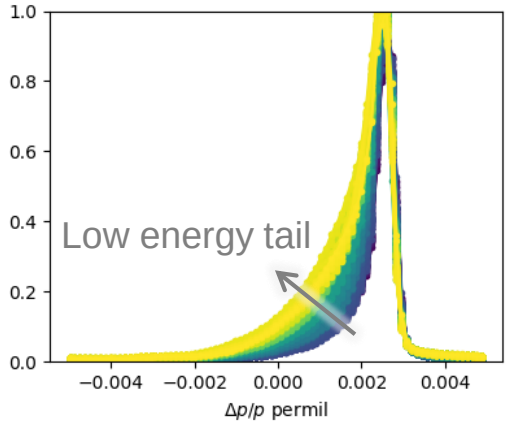


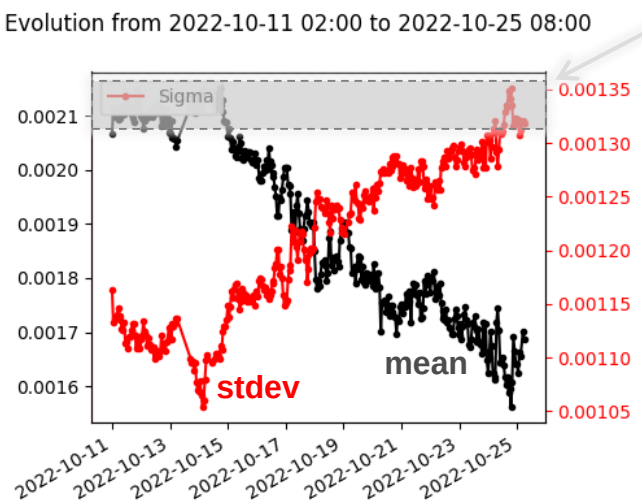
- Injection efficiency depends on energy distribution.
- Foils tends to develop tails at low energy (see Linac3 report at FOM #33).

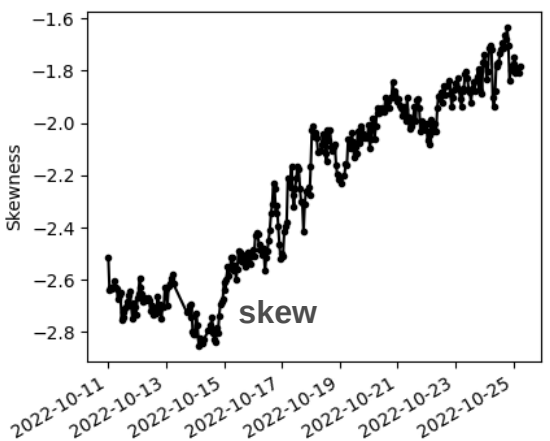
→ LEIR/Linac3 worked to identified maximum tails extent.

Stripper foils

A dedicated cycle monitors continuously the Linac3 energy distribution.







- Observed low energy tail developing with time.
- Reproducible threshold identified → foil exchange + setting revert = back to performance!
- Observable is compatible with Linac3 ITFS measurements (detailed comparison ongoing)

Machine development activities

- Autopilot development for machine automatic control and recovery (*R.Alemany*)
- Joint Linac3-LEIR MDs on energy matching (*P.Meruga, L3 team*)
- Transfer line optics characterization (*F.Velotti*)

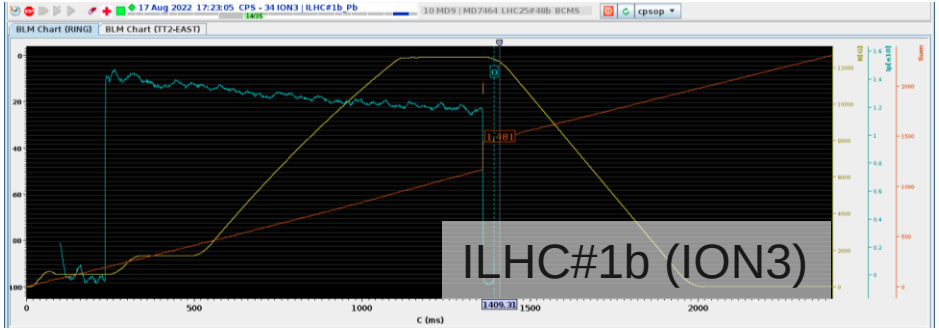
- First turn measurements (*O.Marqversen, S.Jensen*)
- Turn by turn optics measurements at injection (*F.Carlier*)

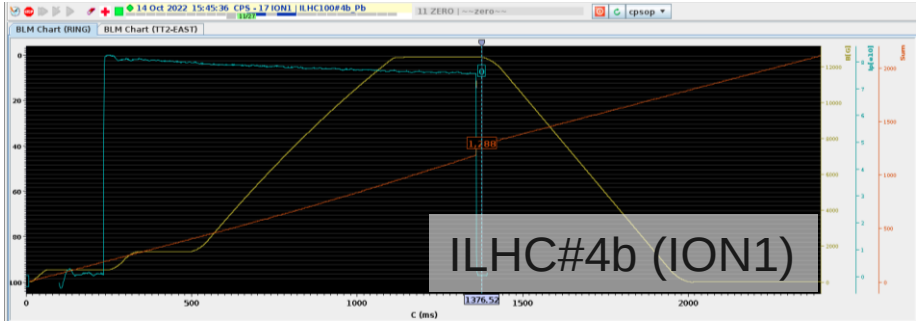
- ML studies for Schottky image recognition (*N.Madysa*)
- Schottky deformation with space charge (*N.Biancacci*)

- Electron beam trajectory measurements (*A.Frassier, D.Gamba, O.Maeqversen*)
- Improvement in regulation (ITE.BHN40) (*C.Mutin, EPC team*)
- Baseline correction on injection line BCTs (ETL.BCT20) (*M.Dolenc*)

PS

- Both EARLY and NOMINAL sent in W33 (ahead of planned W35 and W36).
- Smooth commissioning from injection to extraction of ILHC#1b and ILHC#4b.
- New cavity controller for the 80MHz cavity commissioned.
- PS-SPS synchronization and energy matching required a few iterations and adjustments on the PS side.
- Beam transmission as in 2021 but slightly lower than in 2018 → 2023.

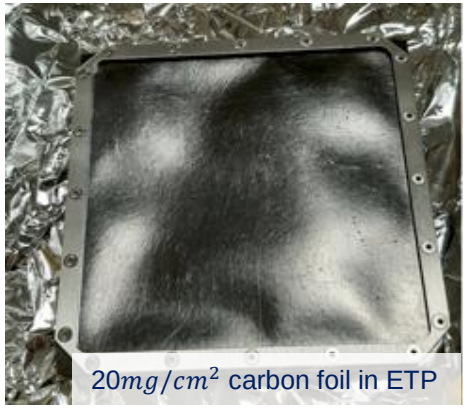


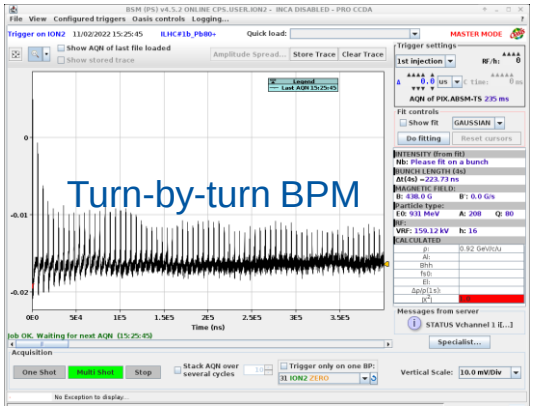


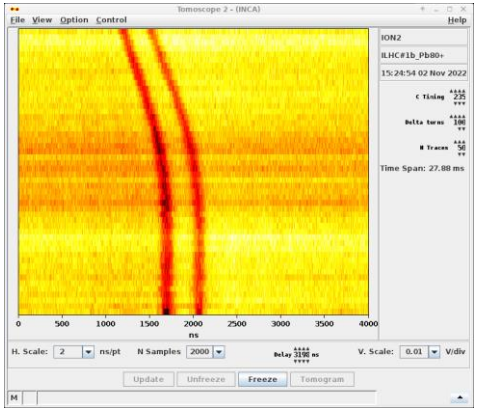
Intense MD activity (*see also R.Bruce in Session 8*), → here Pb80+ test.

Special MDs in PS: Pb80+

Within scope of future light ions operation, tested stripping Pb54+ → Pb80+ in ETP.



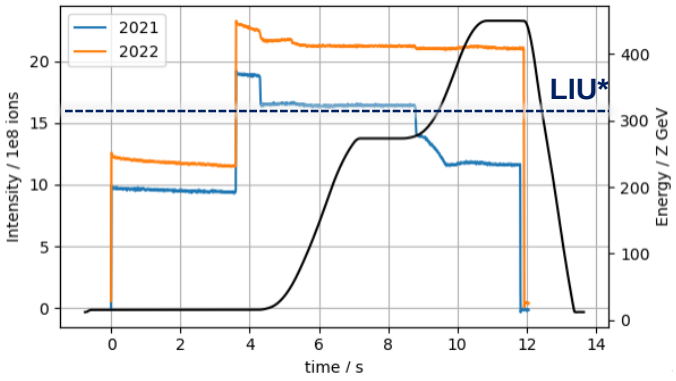


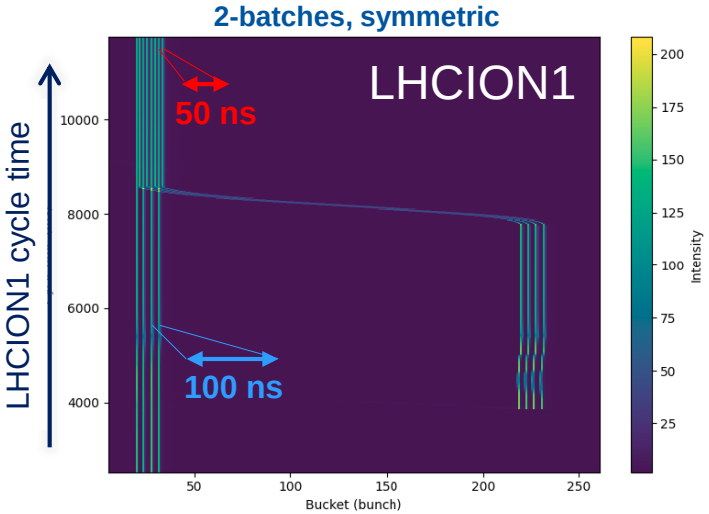


- ~5% beam injected, probably too large beam blow-up / energy spread after foil.
- ~5% loss in mean momentum from stripping in ETP, in agreement to simulations done by GSI.
- Sync. LEIR-PS transfer impossible with present LLRF → Pb80+ captured and accelerated “a’ la main”.

→ next, new stripper foil position in ETL/ETP optimized w.r.t. emittance growth (if new tests needed/planned).

SPS



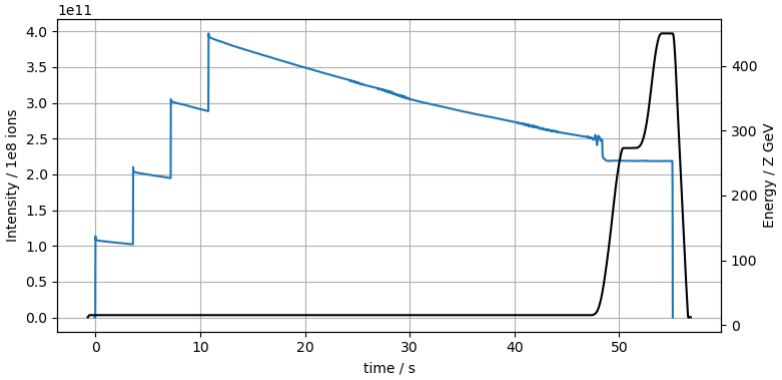


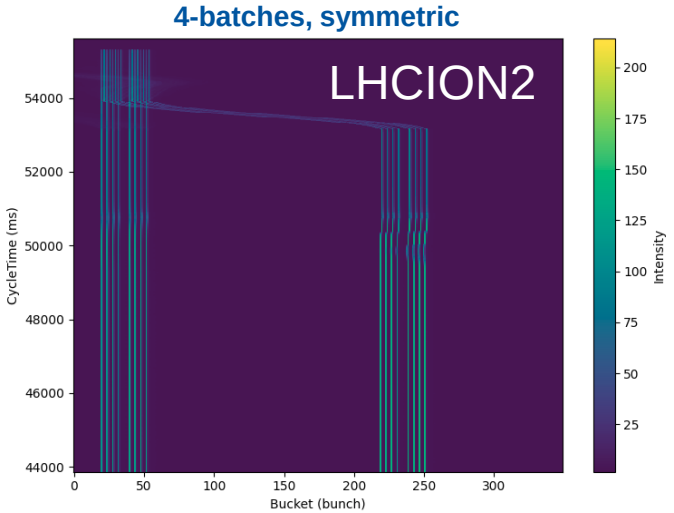
Continued commissioning of slip stacking cycle for 50 ns beam with 2 batches (LHCION1).

- Intensity above LIU* target (1.9e8 ions/bunch).
- Smooth transition crossing thanks to the operation with the 800MHz RF system.
- Bunch length: 1.6ns ± 20% ok for extraction without bunch rotation (available if needed).

(*) LIU target refers to 14 injections.

SPS





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- Bunch length: 1.6ns ± 20% ok for extraction without bunch rotation (available if needed).

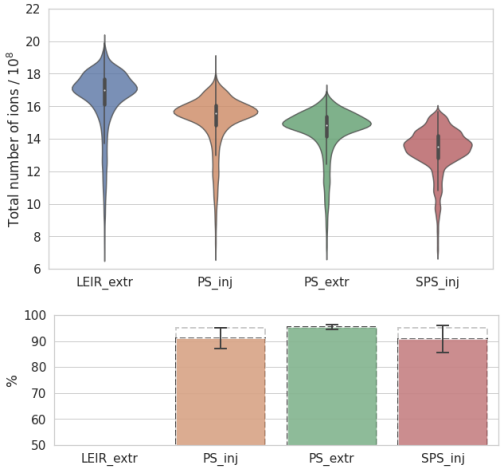
Operation with 14 injections (LHCION2) → not enough time, taken up to 4/14 injections, *to be continued in 2023*.

Smooth operation with 3 EARLY cycles (LHCION3).

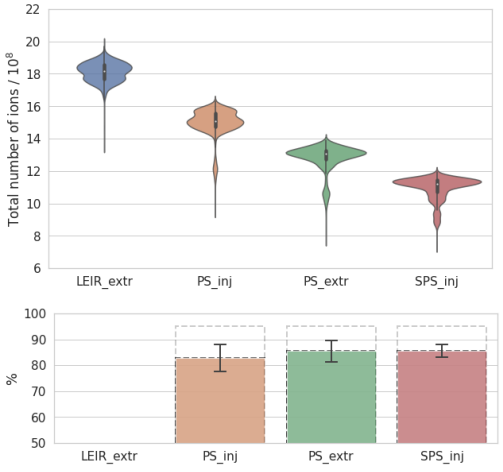
(*) LIU target refers to 14 injections.

Transmission to SPS (LHCION1)

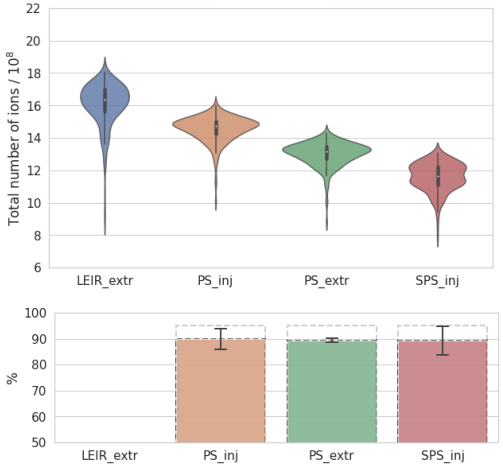
2018



2021



2022



- 90% injection efficiency LEIR → PS (as in 2018).
- 90% injection efficiency PS → SPS (as in 2018).
- Lower transmission in PS: preliminary studies done, *to be continued in 2023.*

LHC/Experiments

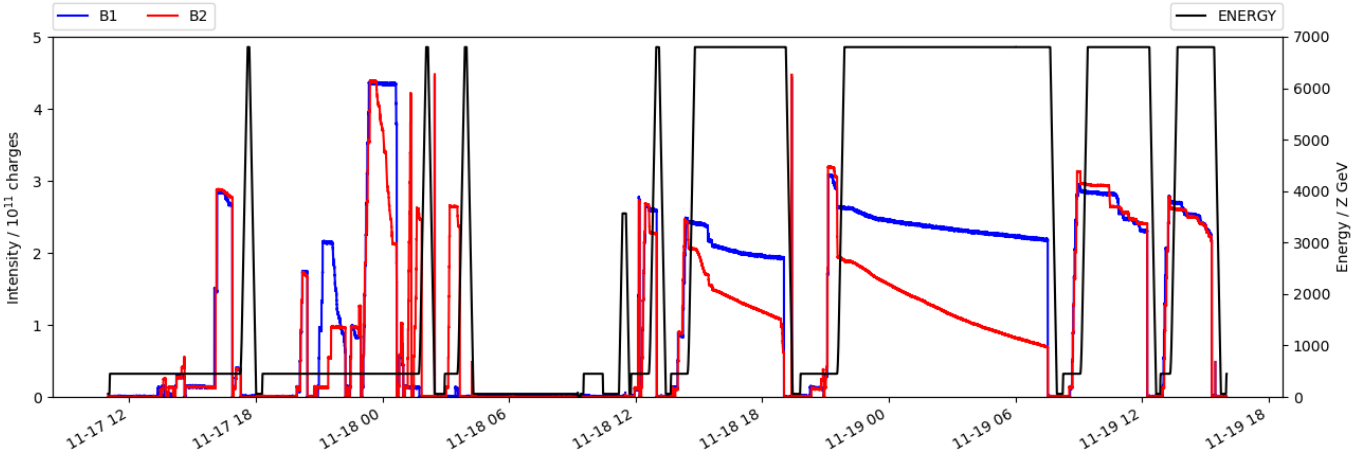
Beam available on time and delivered for Fixed Target experiments (Chimera/Charm, NA60/61) and to LHC short run.

→ *Details on FT experiments and beam production in K.Li, D.Banerjee and M.Delrieux presentations in Session 2.*

Here, LHC beam production:

- Ion run overview.
- Intensity/Emittance evolution from injectors to LHC.

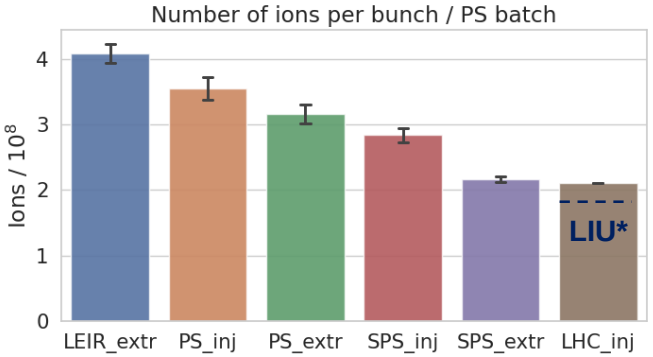
LHC ions run overview

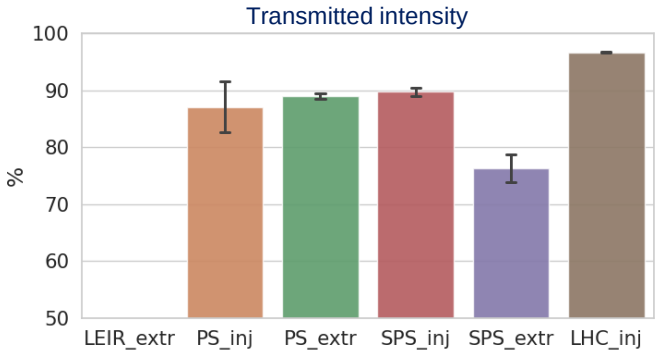


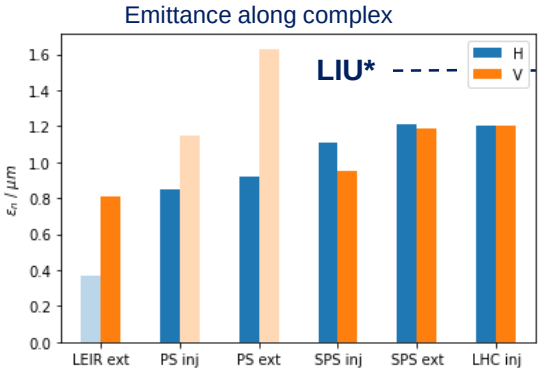
Short test-run with ions on 17-19/11/2022 with dense and successful program:

- Machine commissioning with ions.
- Injected, ramped and collided 50 ns 8-bunch Pb trains for the first time.
- First Pb-Pb collisions to experiments at record energy of 6.8 Z TeV.
- Crystal collimation and dispersion suppressor collimation test in IR2.

Intensity/Emittance evolution







Intensity

- Intensity above 14-injections LIU target (1.9 10^8 ions/bunch).
- Transmission will reduce with 14 injections → to be tested/measured in 2023.
- Can get more margin optimizing transfer in downstream machines → 2023.

Emittance

- Emittance below LIU target (1.5 μm)
- Growth in V mainly in SPS, in H distributed from PS-SPS → input for machine models.
- No yet reliable data for LEIR H, and PS V from BGI's → *check/improve in 2023*.

(*) LIU target refers to 14 injections.

Summary and outlook

Ions through the complex:

- Smooth commissioning for **source** and **Linac3**: current stable and above target.
- **LEIR** commissioning delayed by manpower unavailability but recovered afterwards thanks to yearly speed-up → *1w BC in 2023 is a challenge.*
- **PS** received beam ahead of schedule, smooth commissioning → *transmission to be improved in 2023.*
- **SPS** continued commissioning of slip-stacked beam up to 4 injections but not enough time for 14 injections → *to be continued in 2023.*

Performance during ion run:

- LHC beam at/above spec (intensity/emittance).
- Performed systematic intensity/emittance evolution through complex → input to refine our models.

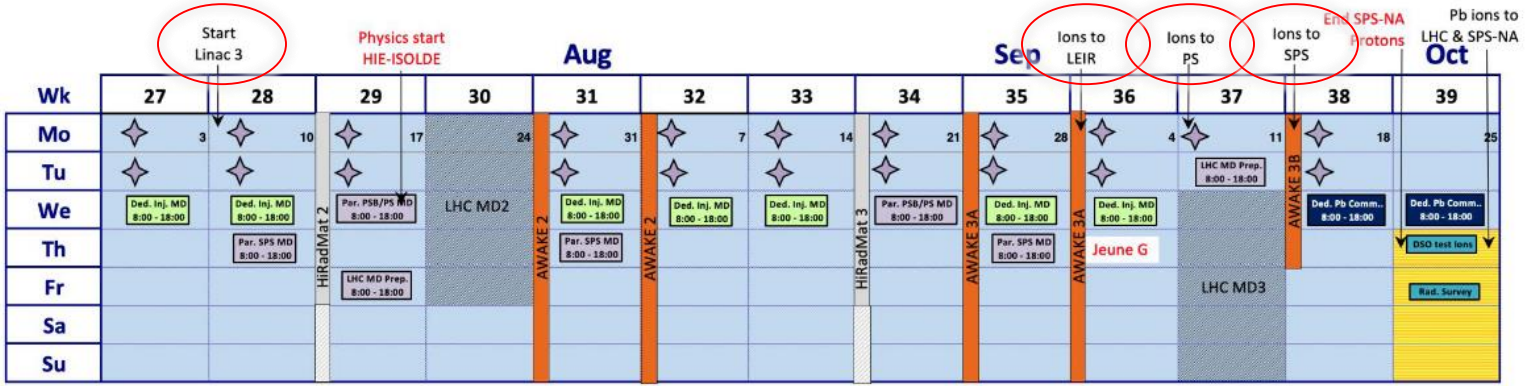
Improvements/MDs:

- Several improvements on long term performance monitoring in Linac3 and LEIR (energy matching, injection efficiency, stray fields).
- Pb80+ injected and accelerated in PS, lifetime studies performed.

Thanks for your attention!

Backup

2023 ion schedule

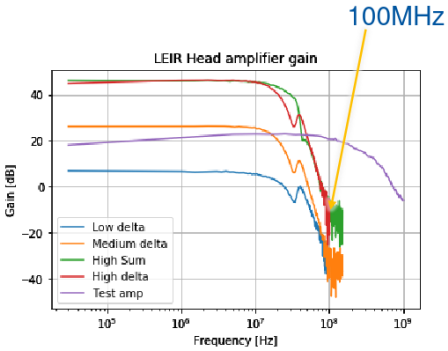


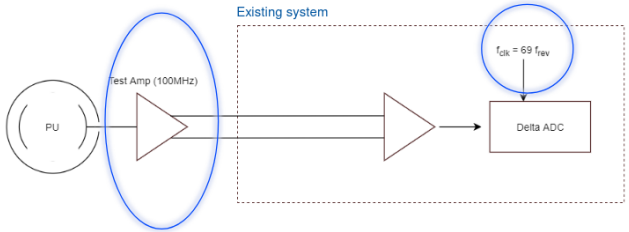
319th IEFC meeting

First turn measurements

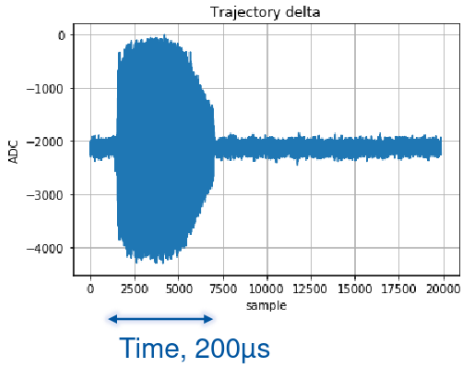
Test setup (HW):

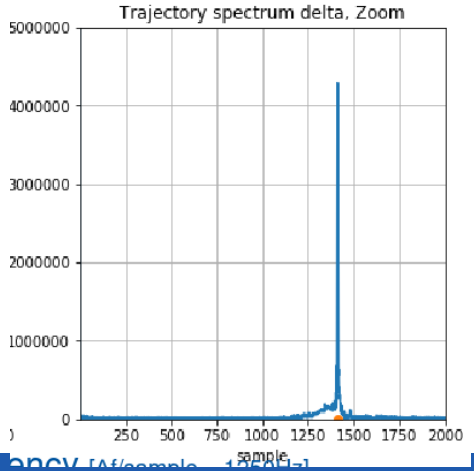
- New orbit head amplifier (prototype) … installed in H14 -> only one plate i.e. “sum” signal





O.Marqversen





First turn measurements

Resolution

SNR Estimated to be ~30dB

PU sensitivity / SNR ->

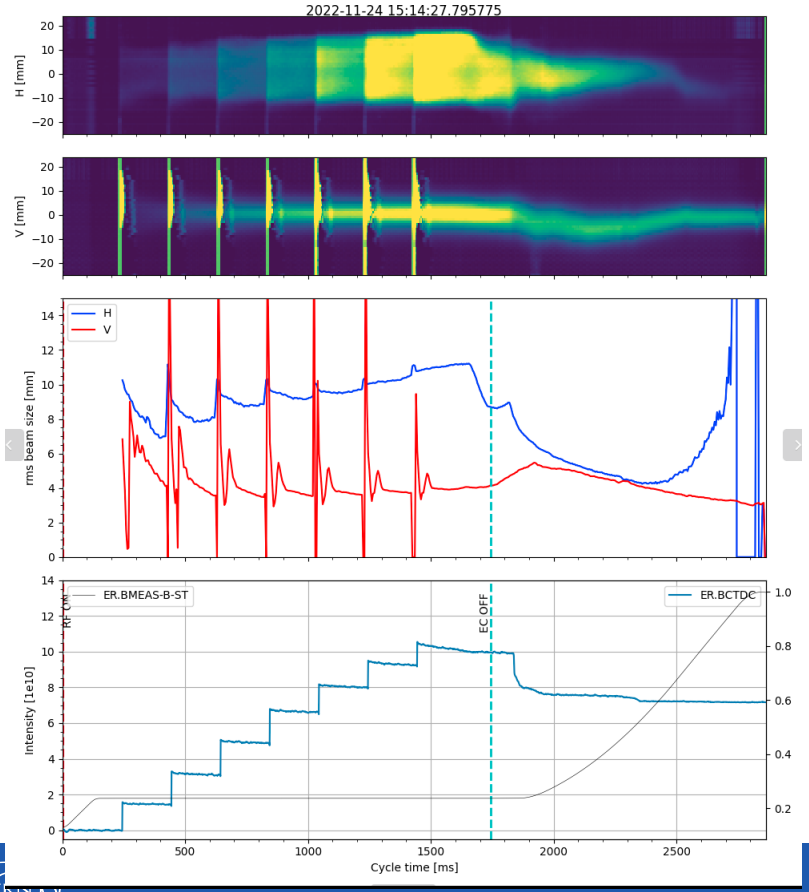
PU	Ch nb	Offset	LG a1	MGa1	HG a1	Resolution [mm]
UEH11	1	-2.7	103.8	108.8	108.8	3.4
UEH12	2	-0.4	105.6	110.3	110.3	3.5
UEH13	3	0.0	111.4	117.8	117.8	3.7
UEH14	4	0.0	111.4	116.5	116.5	3.7
UEH21	5	1.6	79.6	82.7	82.7	2.6
UEH22	6	-1.1	79.0	82.6	82.6	2.6
UEH23	7	0.0	111.2	116.4	116.4	3.7
UEH24	8	0.0	112.2	117.4	117.4	3.7
UEH31	9	-3.1	101.3	106.0	106.0	3.4
UEH32	10	-0.9	102.4	107.3	107.3	3.4
UEH33	11	0.0	107.9	116.5	116.5	3.7
UEH34	12	0.0	112.1	116.8	116.8	3.7
UEH41	13	3.2	103.3	108.4	108.4	3.4
UEH42	14	-2.5	105.4	110.1	110.1	3.5
…	…	…	…	…	…	…

Outlook:

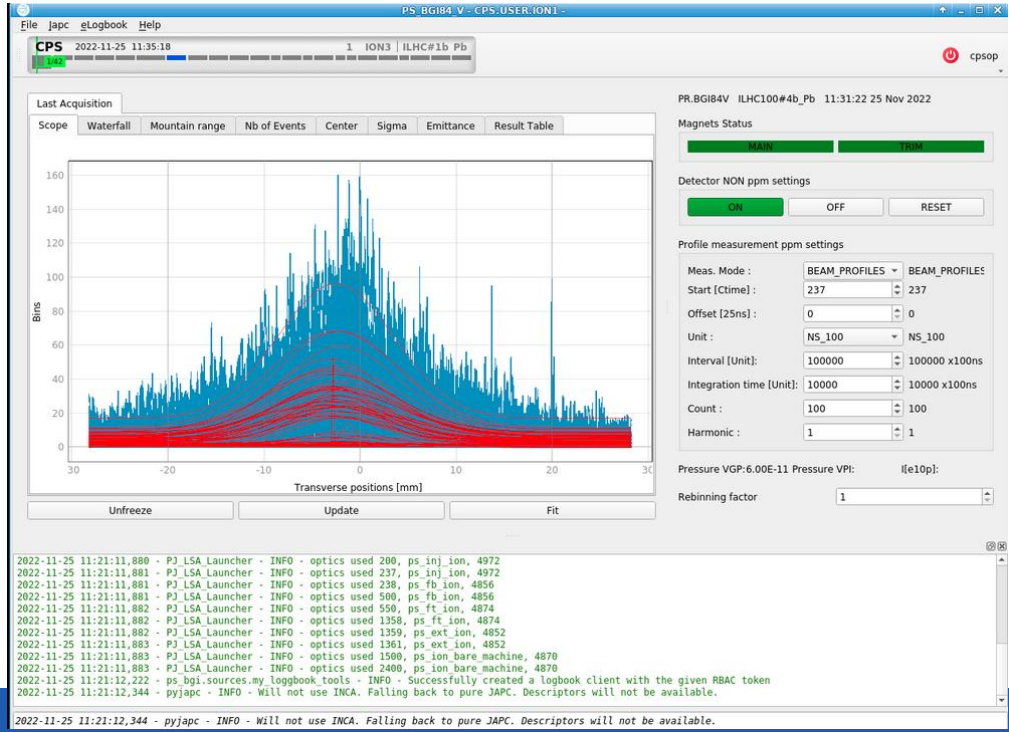
- Proto type (with sum and delta) developed, *is* in the design office for finalization….
- Proto type produced / tested — Spring 2023 (possible test with beam !?)
- Update design / Production of amplifiers series — Fall 2023
- Installation — YEST 2023/2024
- ….

O.Marqversen

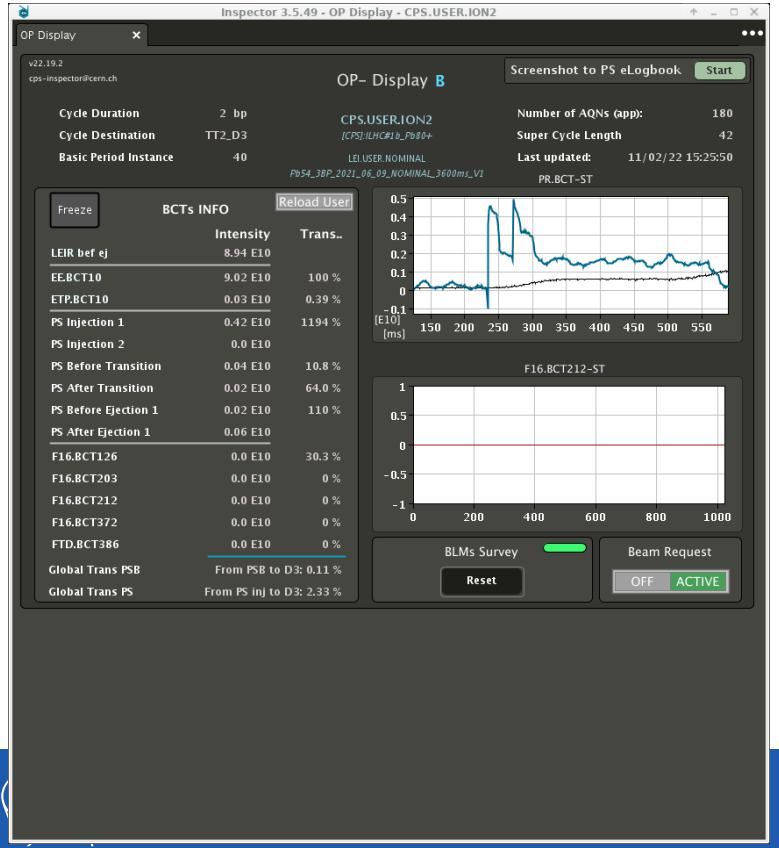
LEIR BGI-H

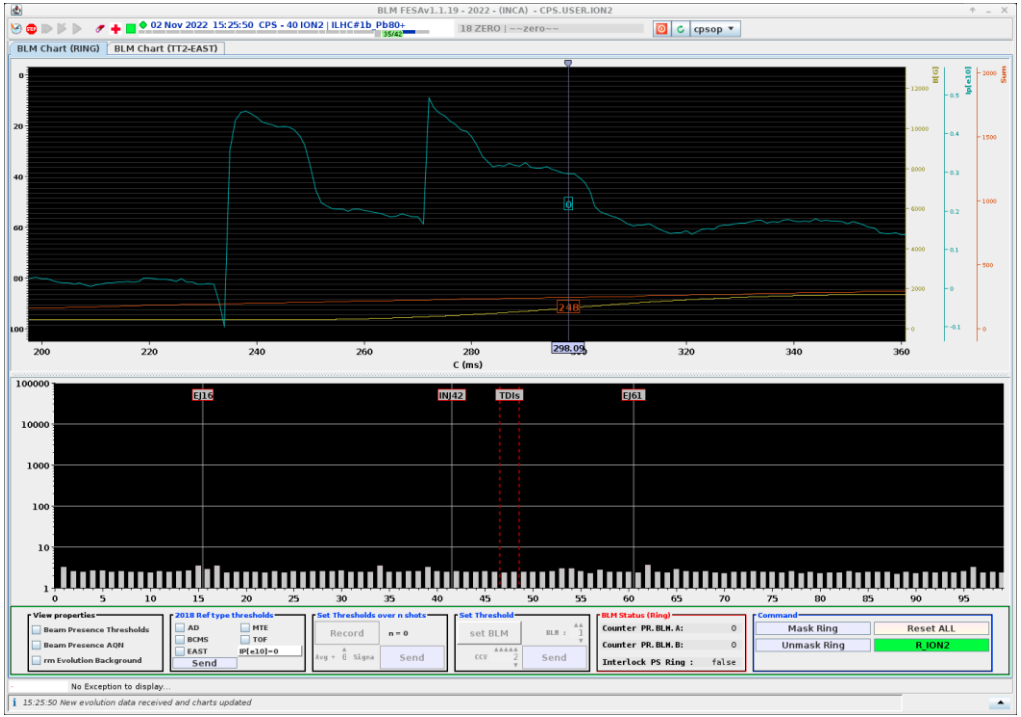


PS BGI-V

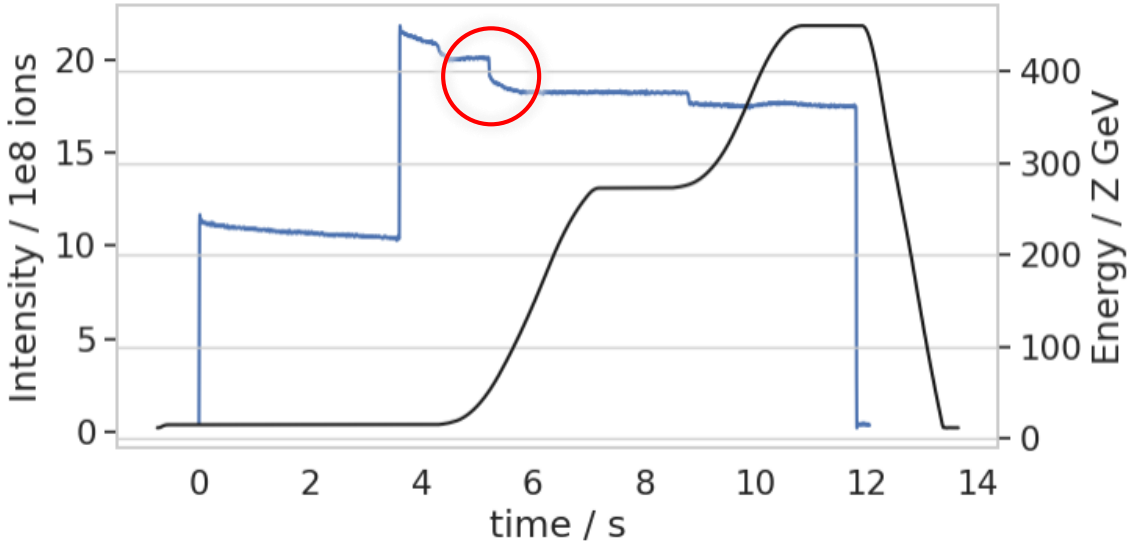


Pb80+, injected intensity





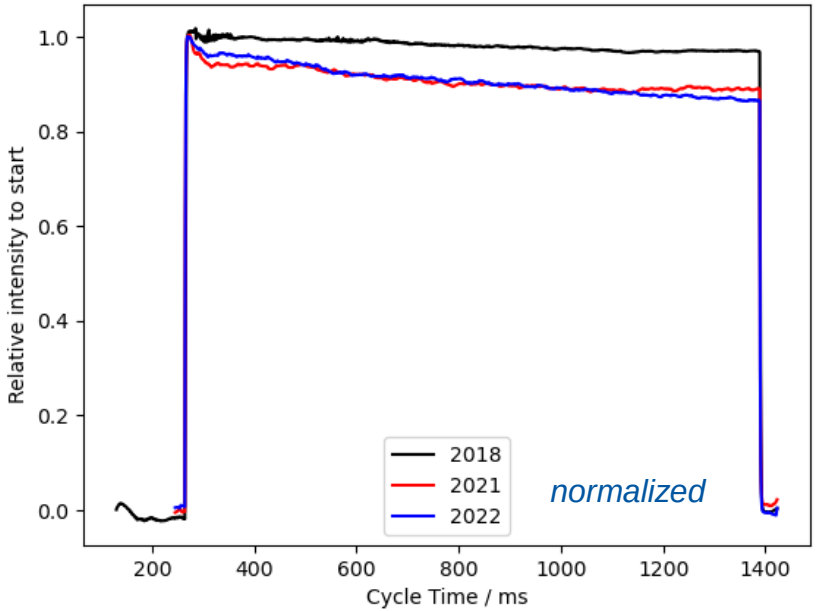
SPS ION3 during LHC run

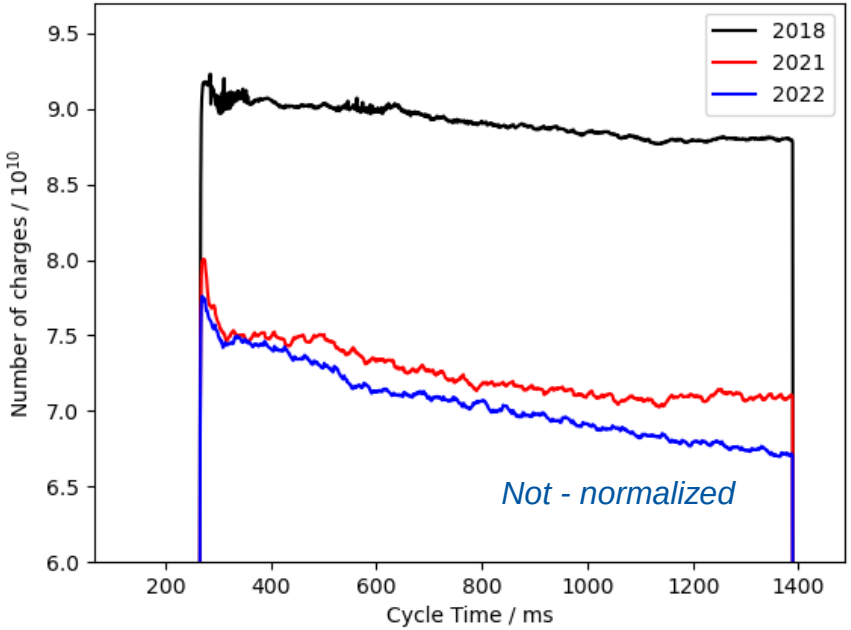


Larger losses at capture: reason to be checked.

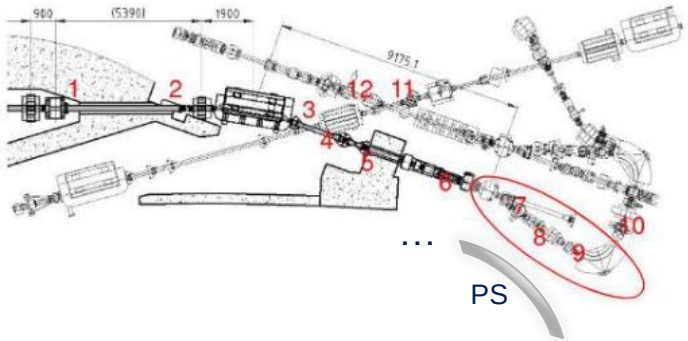
PS transmission (2018 to 2022)

ILHC100#4b_Pb





Stray fields measurements



Assumed 0.3mT from ITE.BHN03

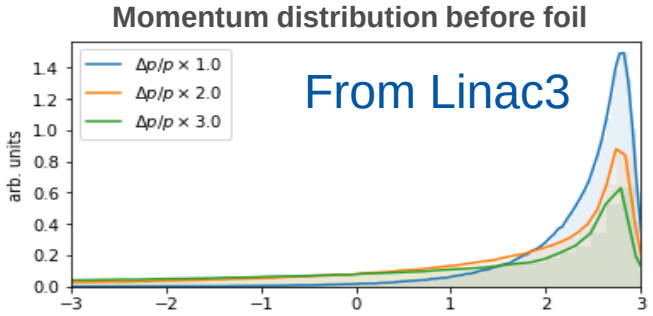
Location	Vertical B max [mT]	Horiozontal B max [mT]	Magnetic shield around the chamber [yes/no]
1	N/A	N/A	No
2	0.059	0.032	No
3	0.046	0.004	No
4	0.239	0.226	Yes
5	0.022	0.021	Yes
6	0.09	0.380	No
7	0.292	0.137	No
8	0.298	0.078	No
9	0.225	0.005	No
10	0.029	0.074	No
11	0.055	0.030	No
12	0.030	0.010	No

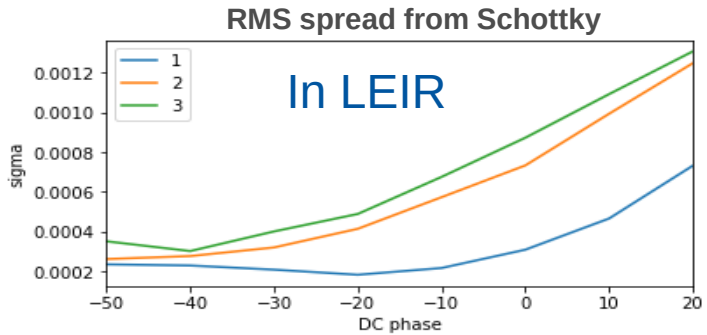
Dominique Bodart

D.Bodart in Ions-MPC meeting, https://indico.cern.ch/event/1034144/

Used foil, simulated effect of tail

Simulated increasing $\Delta p/p$ before RC, tracked to LEIR and injected.

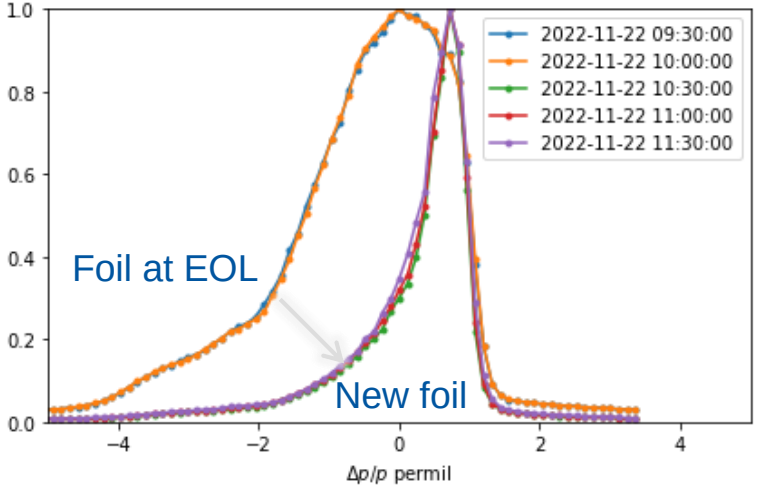


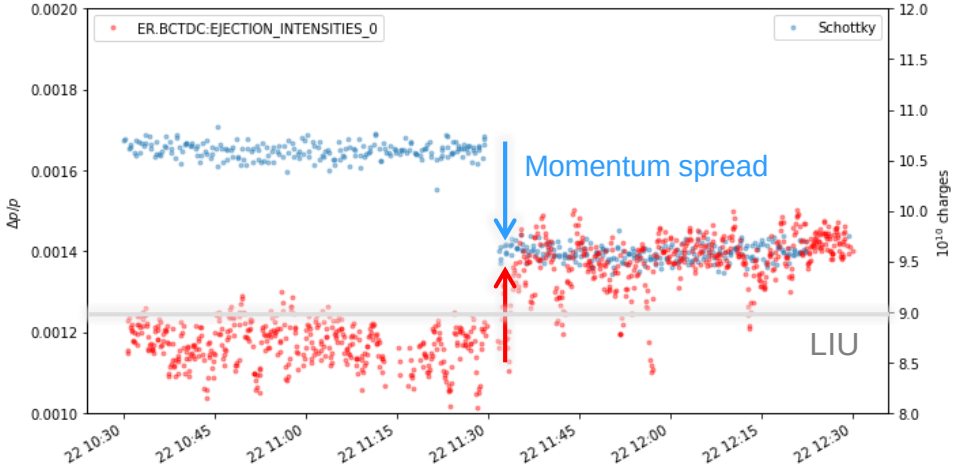


- The foil tail development translates in larger spread measured at each DC phase in LEIR.
- Maximum spread at ~1.3e-3 in LEIR as in measurements (= KPI).

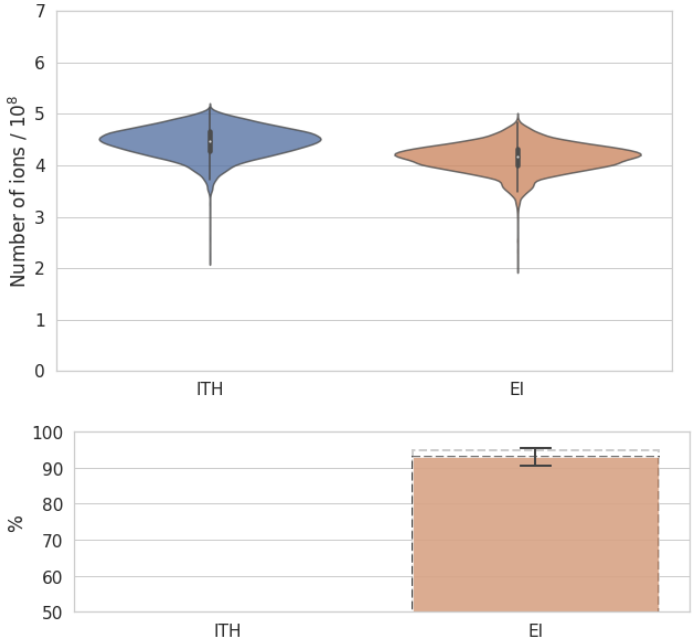
→ LEIR monitors DC phase = 20 to probe foil tails evolution.

Effect of stripper foil change





Linac3 to LEIR transmission



95%