



# **The Ion Complex Upgrade (ICU) Proposal and Impact on the LHC High-Energy Ion Program**

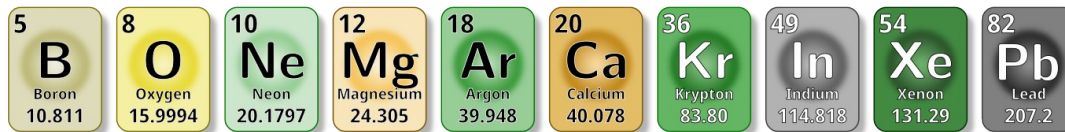
Maciej Slupecki

*Nuclear Shape and BSM Searches at Colliders, 13 January 2025*

# Contents

- Overview of ion physics users and future beam requests
- Selection of present capabilities of the ion injectors
- Ion complex
  - Limitations
  - Upgrade proposal
- Personal view on the possible long-term schedule
- Neon test

# Ion physics users - identified synergies



- NA61++ requested specific ions for Run4
- NA60+ is interested in Pb
- LHC experiments prefer an ion that maximizes nucleon-nucleon luminosity
- Much interest in Ne
- Most challenging request for EA: ion switching in 15' from menu of 4 species
- Proof of principle in preparation in SPS



# Projects' status and challenges

## Experimental physics projects

Tests to assess feasibility in Run3

- NA61++ / SHINE
  - **Completed the first beam test with Mg up to flat-top energy in PS**
- NA60+
  - Ongoing beam tests with Pb  
→ SPS extraction towards experimental area
- LHC experiments / ALICE3
  - Beam tests with Kr up to Linac3 done in 2023
  - One ion species to be selected to maximize luminosity
  - Need inputs from **source tests** with new ions and development of simulations
- Nuclear physics at LHC
  - Collecting feedback at workshops and conferences

## Facilities

- HEARTS\* – most demanding request
  - Provide: O, Ar, Kr, Pb
  - Every operational day, with switching times between species of max 15'
  - The experiment decides the order in which the species are delivered
  - Switch between ions at will
  - **Impossible with present injectors:**
    - Switching between ions takes days/weeks (gas/solid)
- Gamma Factory
  - Proof of principle in the SPS is being prepared

\* Heavy ion irradiation of electronics in the PS East Area, supported by EU and ESA, and formally known as CHIMERA

# Present capabilities of the ion injectors

## Single ion source

- Delivers 2 ions per year
- Ion switching time: weeks
  - can be faster only for selected ion combinations
- Uses O(300) mg material per week

## Mixed proton and ion operation

- Possible in most primary-beam areas
  - Different cycles (seconds) can be set to propagate different species
- Not possible for some experimental transfer lines

## Common beam instrumentation for ions and protons in PS → LHC

- Beam intensity difference
  - $I_p \gg I_{ion}$
  - Ions operate the at low end of the dynamic range
    - low sensitivity
- Important to reach sufficient for the PS ion beam intensities
  - $I_{ion} \gtrsim 10^{10}$  charges per bunch
    - $2 \cdot 10^8$  Pb ions per bunch
    - $14 \cdot 10^8$  Mg ions per bunch

# Current limitations of the ion complex

## Concurrent feasibility studies within a LHC and NA physics year is challenging

- One ion source for development and operation
  - Limited time for studies → small number of issues can be addressed experimentally
  - New ions at the source can potentially contaminate the source → Pb may be compromised
  - Limited beam instrumentation → trial and error → time consuming

## If NA61++ Run 4 program approved (O, Mg, B)

- Ion complex fully committed to operation
- No development for post-LS4 LHC ions possible
- No light ions for LHC in Run 4

## LHC luminosity could be improved by further increasing intensity

- Push boundaries for space charge and IBS in injectors, explore shorter bunch spacing than 50 ns

## Current ion complex cannot fulfil HEARTS++ request

- 15' switching time between 4 different species

# Ion Complex Upgrade (ICU) proposal

More ion species

## ICU DELIVERABLE 1

### New Linac3 source and BI out of both sources

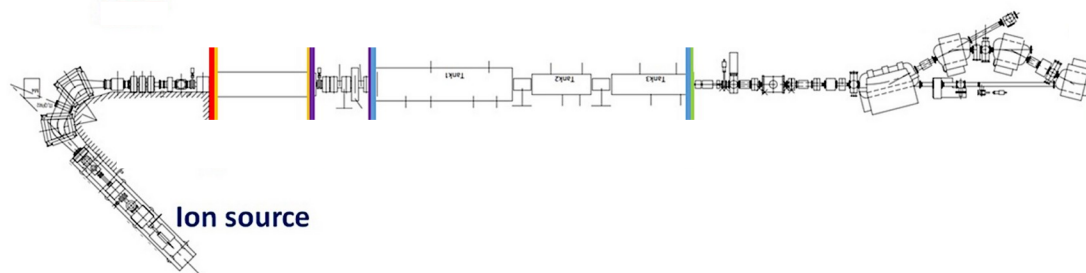
- Operate up to 4 ions per year
- Parallel commissioning of new ion beams for LHC, NA61++ and HEARTS++

## ICU DELIVERABLE 2

### Connection of ion sources and BI downstream

- Fast (15') switching between ions for HEARTS++
- Parallel commissioning of new ion beams for LHC, NA61++ and HEARTS++

## Linac3



# Ion Complex Upgrade (ICU) proposal

More ion species

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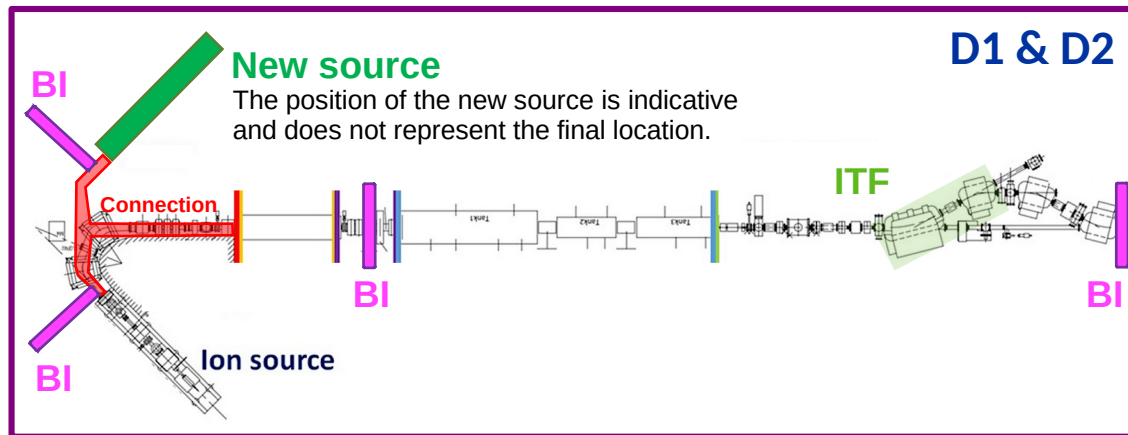
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# Ion Complex Upgrade (ICU) proposal

More ion species

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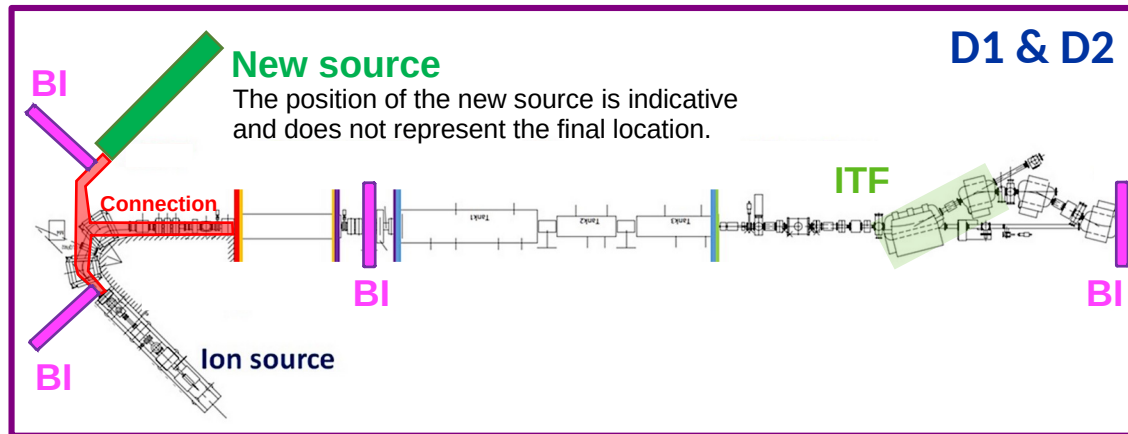
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- Fast (15') switching between ions for HEARTS++
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Higher beam intensity & lumi

## ICU DELIVERABLE 3

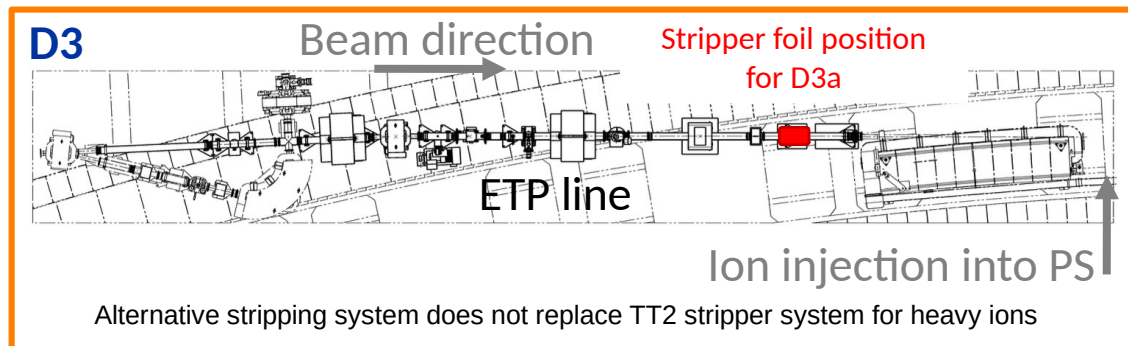
### Alternative stripping scenario

- Increase LHC brightness by reducing space-charge and IBS effects in SPS

## ICU DELIVERABLE 4

### 25 ns bunch spacing at LHC

- Increase LHC luminosity by 40-80% thanks to increased number of bunches

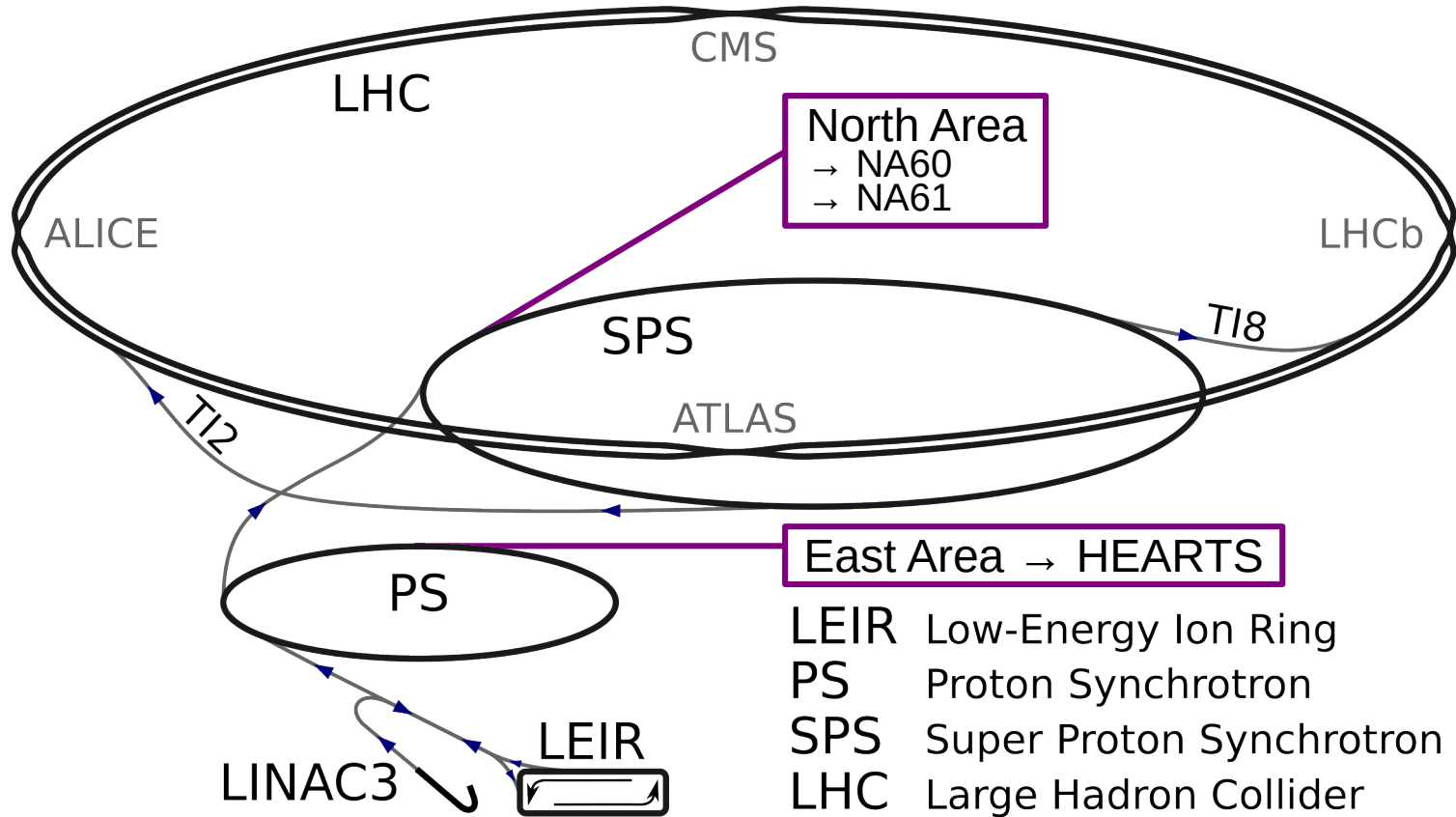


## ICU DELIVERABLE 5

### Consolidation

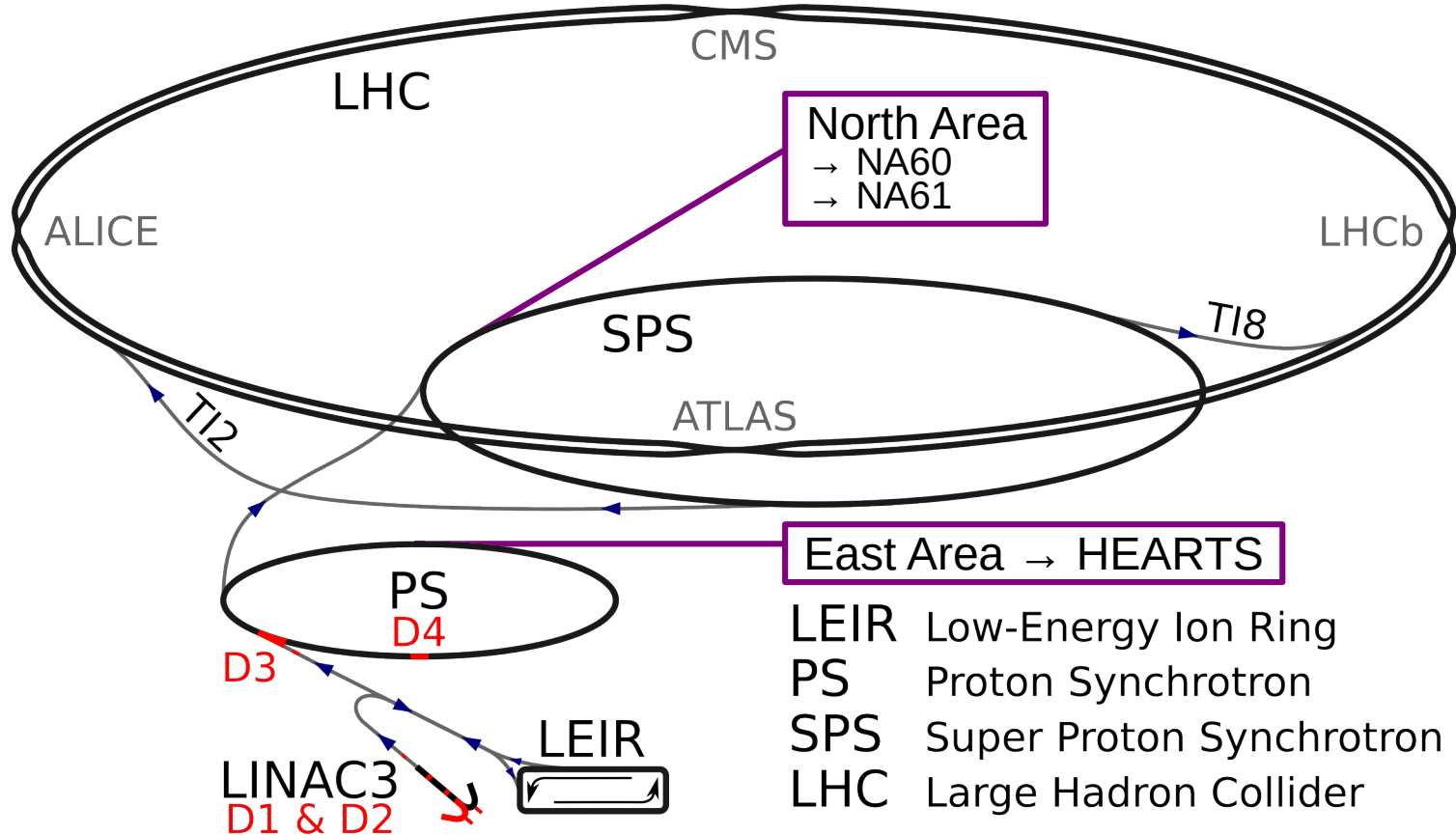
Stripping scenario	$p_{inj}^{SPS}$ (proton-equiv.) [GeV/c]
Pb <sup>54+</sup> → Pb <sup>80+</sup>	17.1 → 25.4
Kr <sup>22+</sup> → Kr <sup>36+</sup>	16 → 26

# Ion Complex at CERN - presently

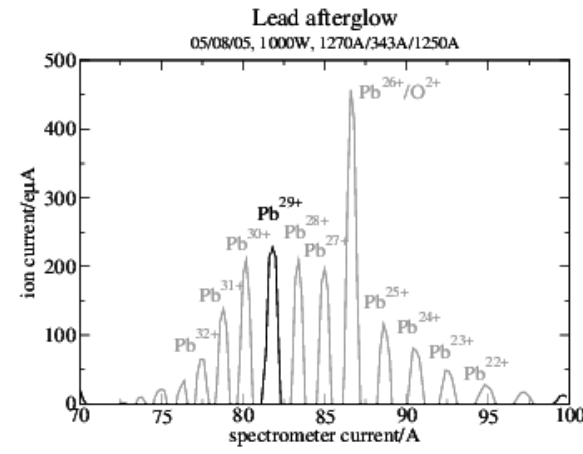


# Ion Complex at CERN

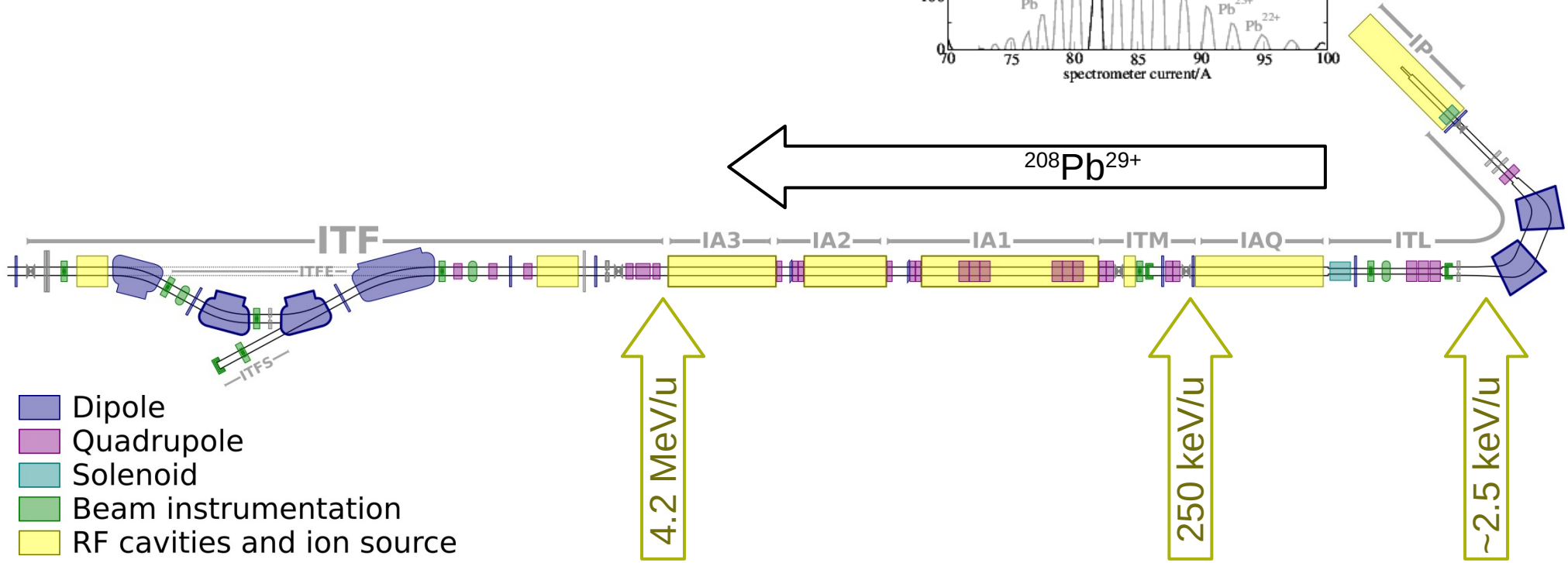
## with ICU Deliverables



# ICU D1 & D2 Linac3 today



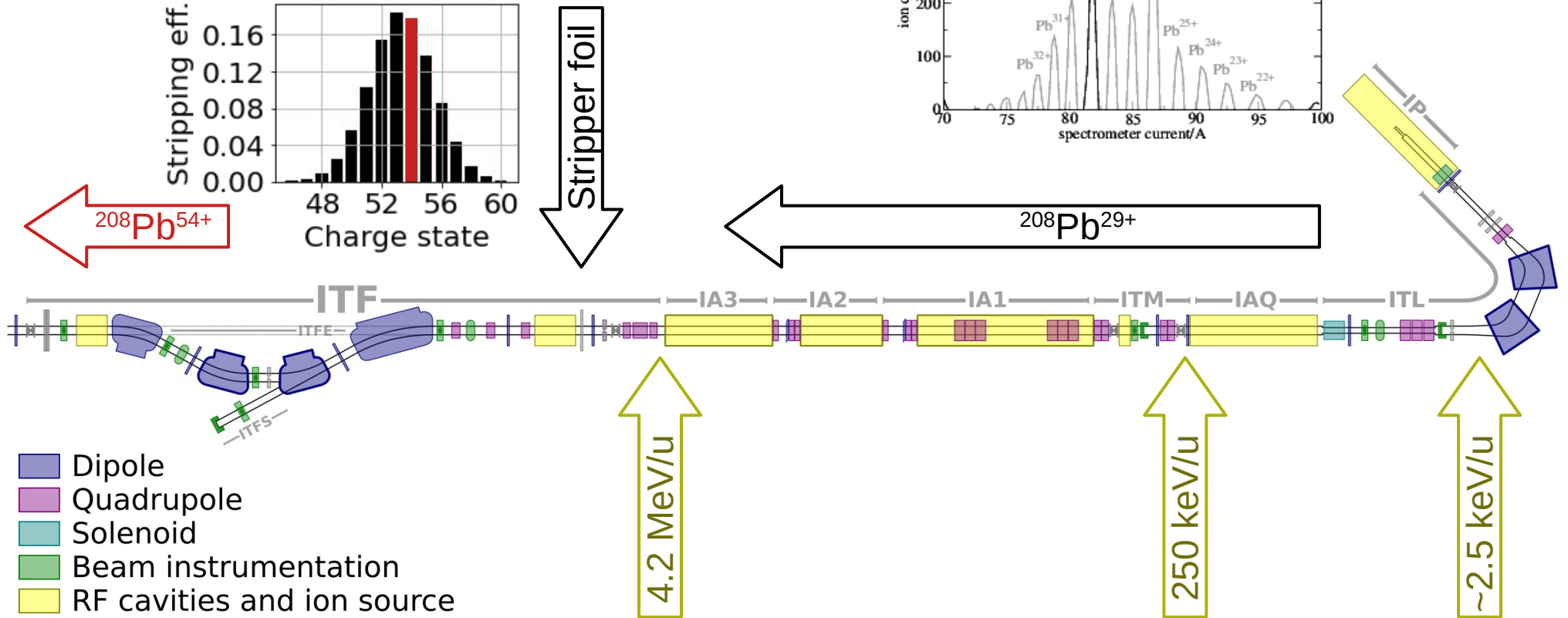
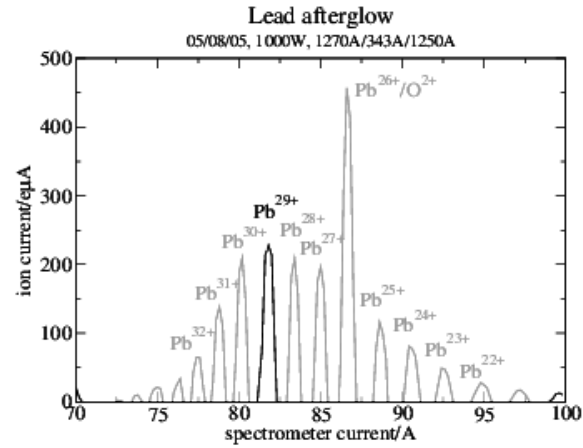
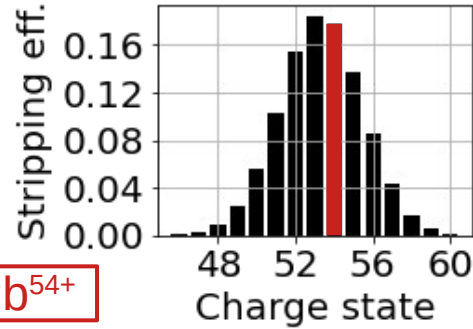
← 208Pb<sup>29+</sup>



- Dipole
- Quadrupole
- Solenoid
- Beam instrumentation
- RF cavities and ion source

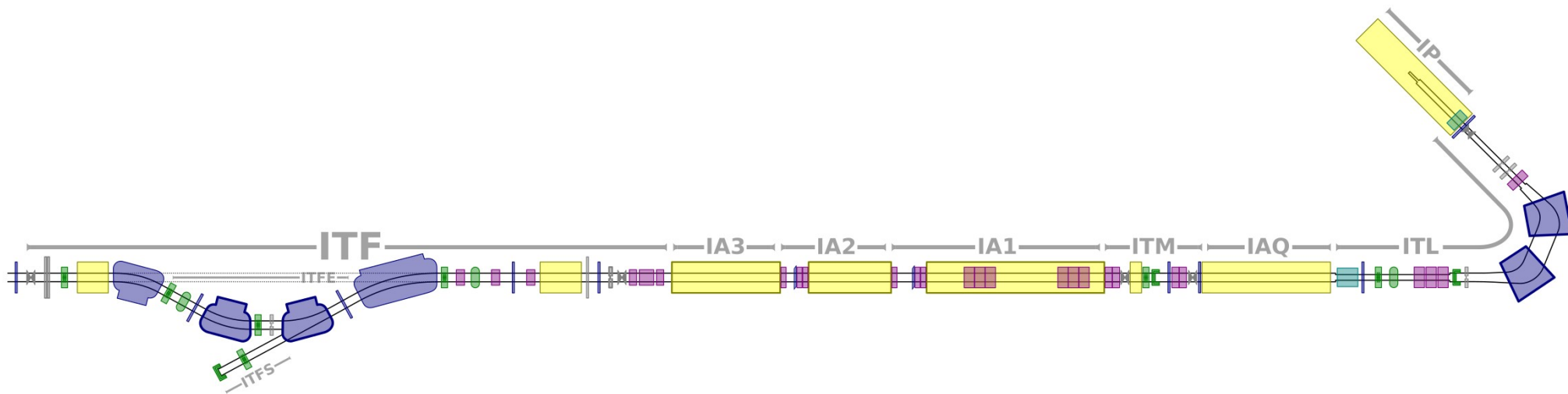
# ICU D1 & D2

## Linac3 today



# ICU D1 & D2

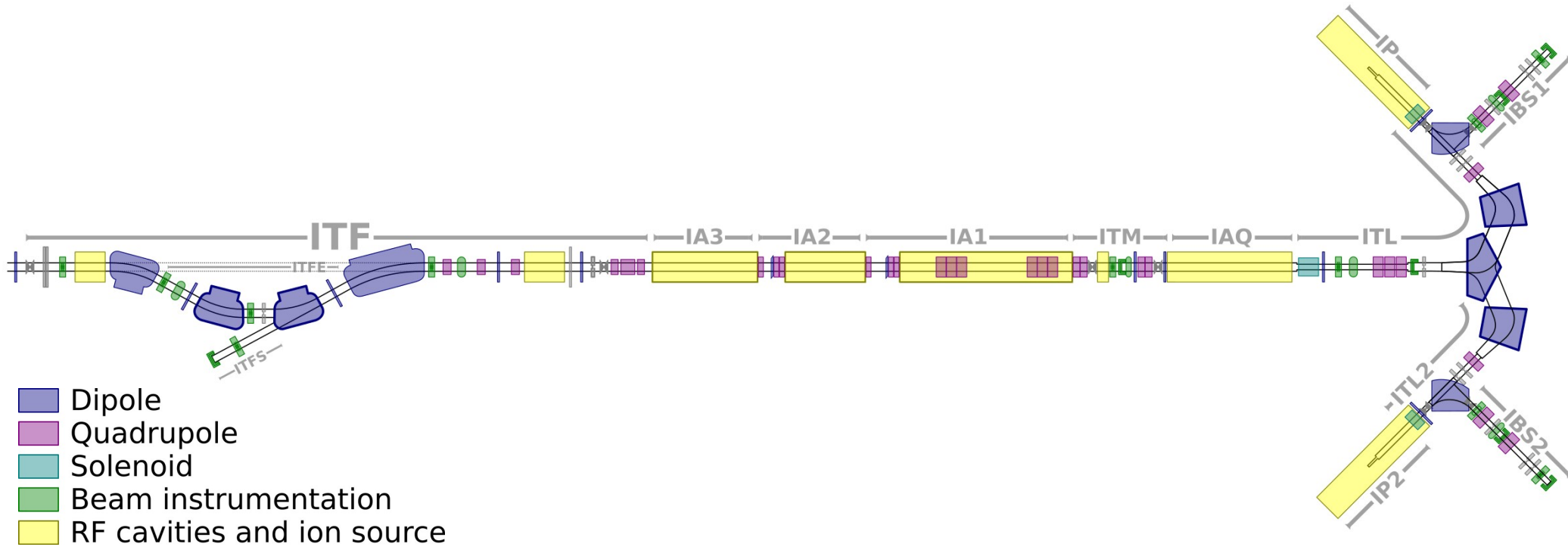
## Linac3 today



- Dipole
- Quadrupole
- Solenoid
- Beam instrumentation
- RF cavities and ion source

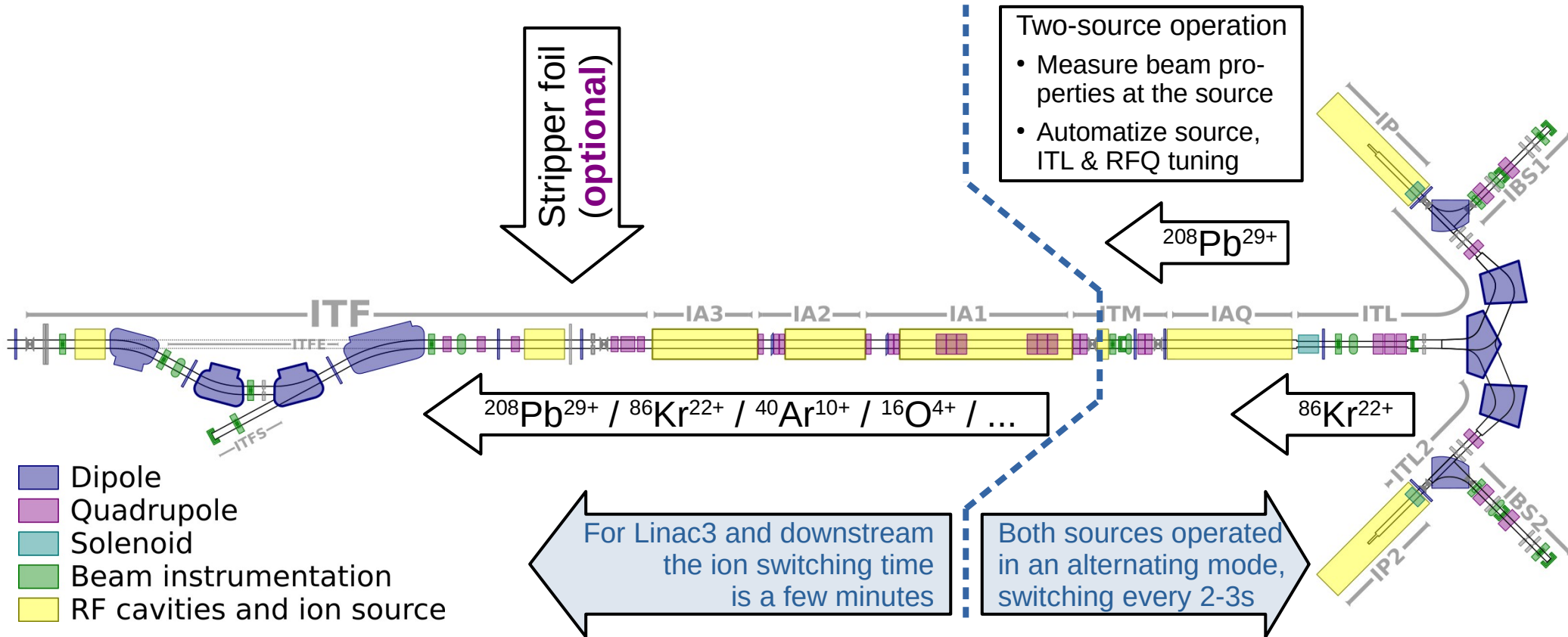
# ICU D1 & D2

## New Linac3 source and beam diagnostic lines



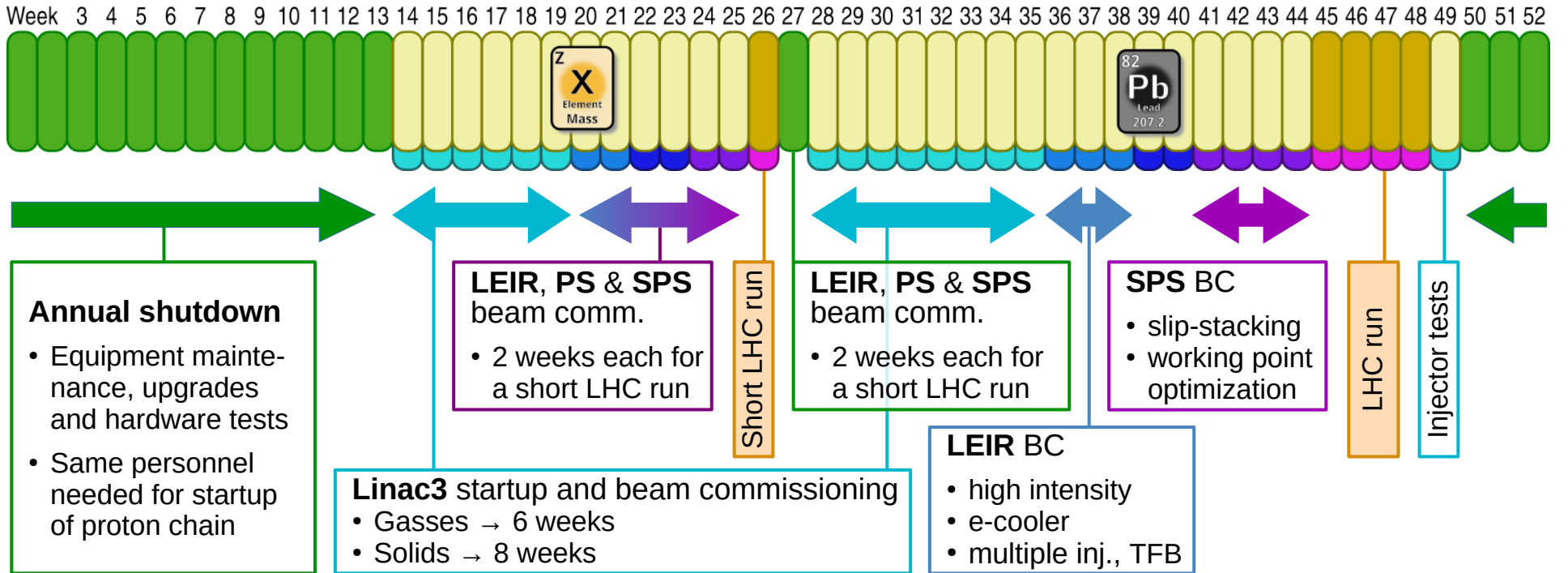
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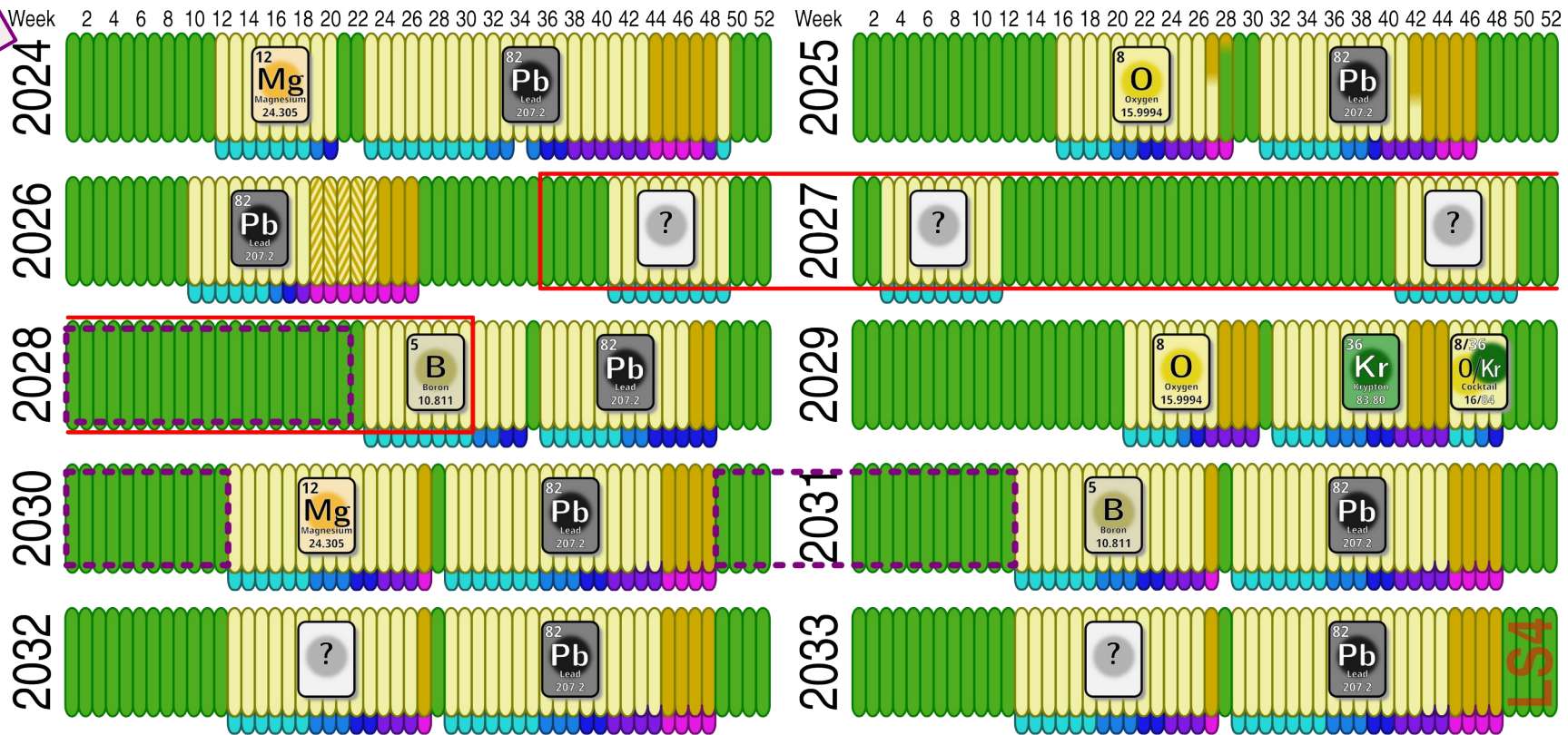


# Typical yearly ion schedule



Unofficial personal view

# Example of the possible long-term LHC schedule Assuming single ion source

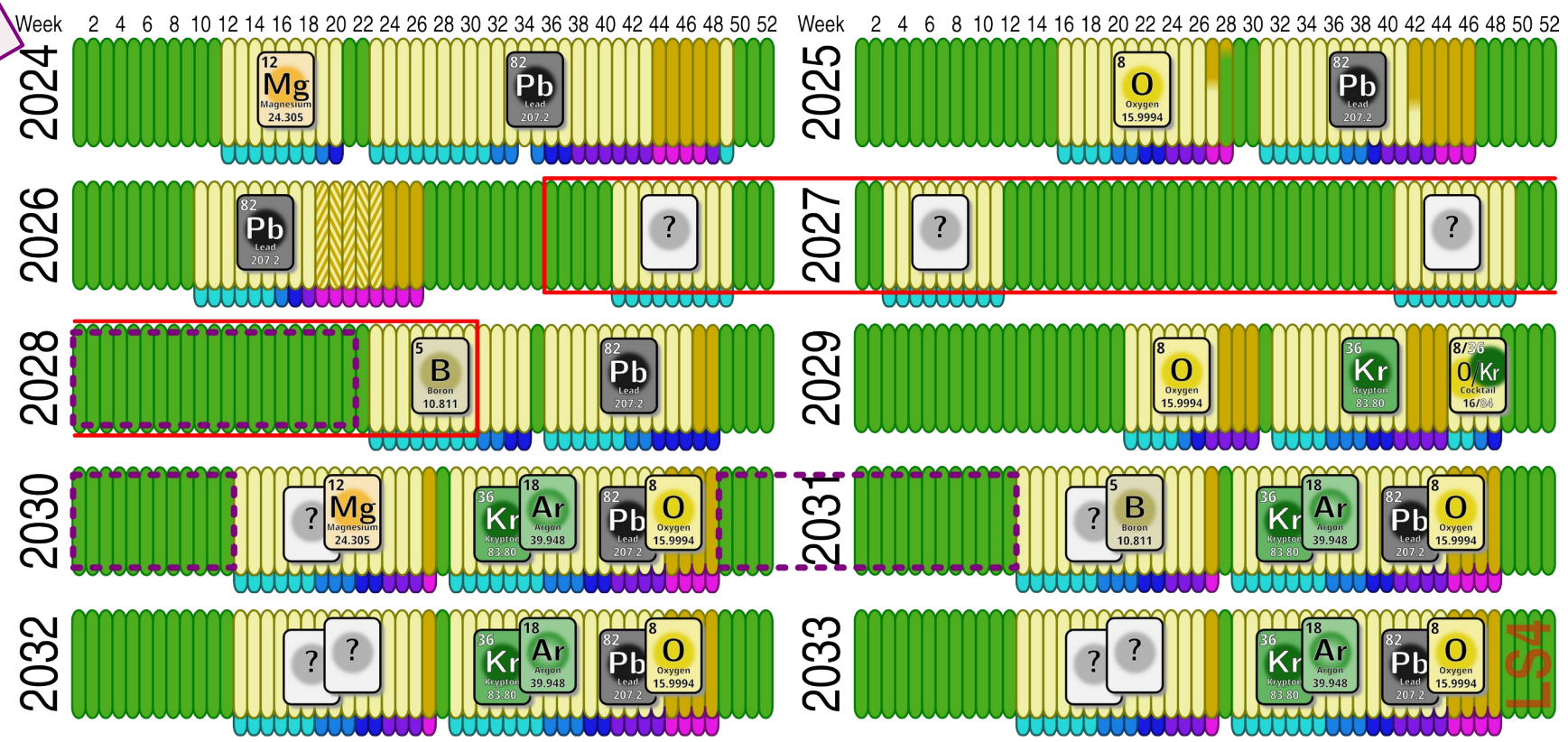


- Annual closure, LS, TS, IST, HWC
- Ion beam commissioning, tests. PS physics
- Ion physics at SPS & LHC
- LS3 in PS complex (LS3 committee < 22.10.2024)
- Slots for ICU installation (approval in Q2 2025)

- Ion beam at Linac3 source
- Ion beam to LEIR
- Ion beam to PS
- Ion beam to SPS
- Ion beam to LHC

Unofficial personal view

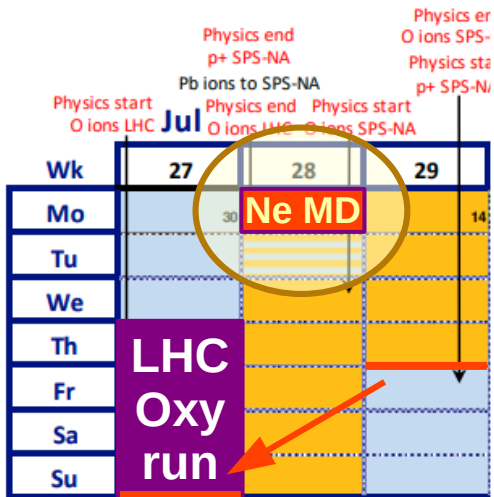
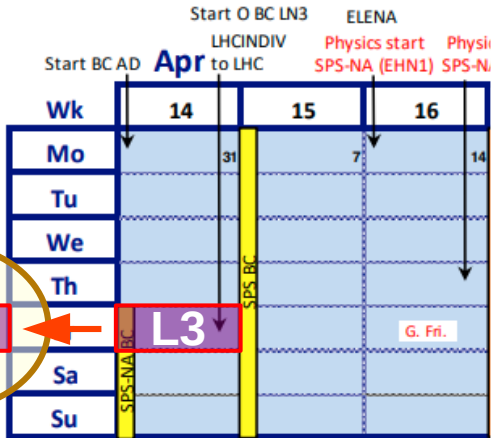
Example of the **optimistic** long-term LHC schedule  
Assuming two ion sources



- Annual closure, LS, TS, IST, HWC
- Ion beam commissioning, tests. PS physics
- Ion physics at SPS & LHC
- LS3 in PS complex (LS3 committee < 22.10.2024)
- Slots for ICU installation (approval in Q2 2025)
- Ion beam at Linac3 source
- Ion beam to LEIR
- Ion beam to PS
- Ion beam to SPS
- Ion beam to LHC

# Future Ions WG proposal → Neon test in 2025

Slide presented at JAP24 workshop



## Motivation:

If Ion Complex Upgrade delayed & no 2<sup>nd</sup> source available after LS3

- Mitigation: deliver two different ions with the same A/Q (beam rigidity) across the complex in a short time
  - Species:  $^{16}\text{O}^{8+} \rightarrow ^{20}\text{Ne}^{10+}$  → Same A/Q and motivated **physics case**

## Goals of the test:

- Assess switching time of ~hours:  $\text{O} \rightarrow \text{Ne}$
- Assess oxygen source contamination & purging speed
- Confirm same settings across the complex are transparent for both ions
- Beam dynamics limitation studies across the complex with a new ion → Ion Injector Model benchmark
- Eventually, send the beam to LHC for **Ne-Ne** collisions

## Timeline:

- To check 1 & 2 → start the source 1 week in advance (as proposed by the LN3 team)
- After the LHC oxygen run, perform a 24 hours test to bring the beams up to SPS
  - Best-effort beam to LHC directly after oxygen run, with collisions if the experiments are interested

<https://arxiv.org/pdf/2402.05995>  
<https://arxiv.org/pdf/2405.20210>

# Summary and outlook

## **Ion Complex Upgrade proposal is being prepared**

- Aiming at first-stage approval in June 2025
- Will allow for much greater versatility of ion species (if approved)
- Upgrade schedule is not fixed yet

## **Possible neon test after the oxygen run**

- Idea presented at JAP24 workshop → triggered quite some discussion
- Neon test proposed at the Linac3 at the beginning of oxygen commissioning to:
  - Ensure the source can switch from O → Ne quickly enough, and
  - Measure the level of oxygen contamination in the neon beam
- Waiting for statement of interest from the experiments (end of Jan)
  - Besides experiments, there is some interest to perform LHC MD on collimation with the neon beam
- Regardless of the LHC decision, Ne beam will be proposed up to SPS for a series of Mds to:
  - Validate ion injector model simulation



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