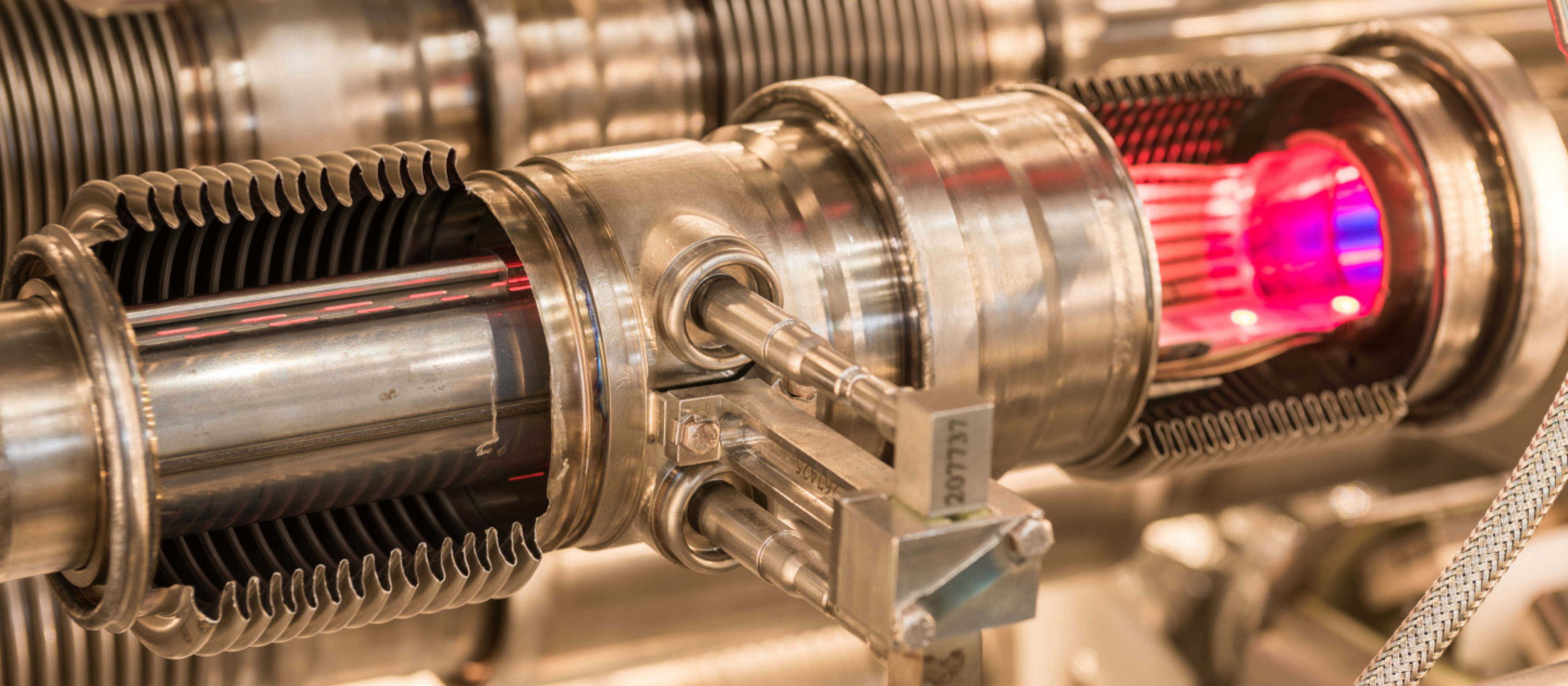
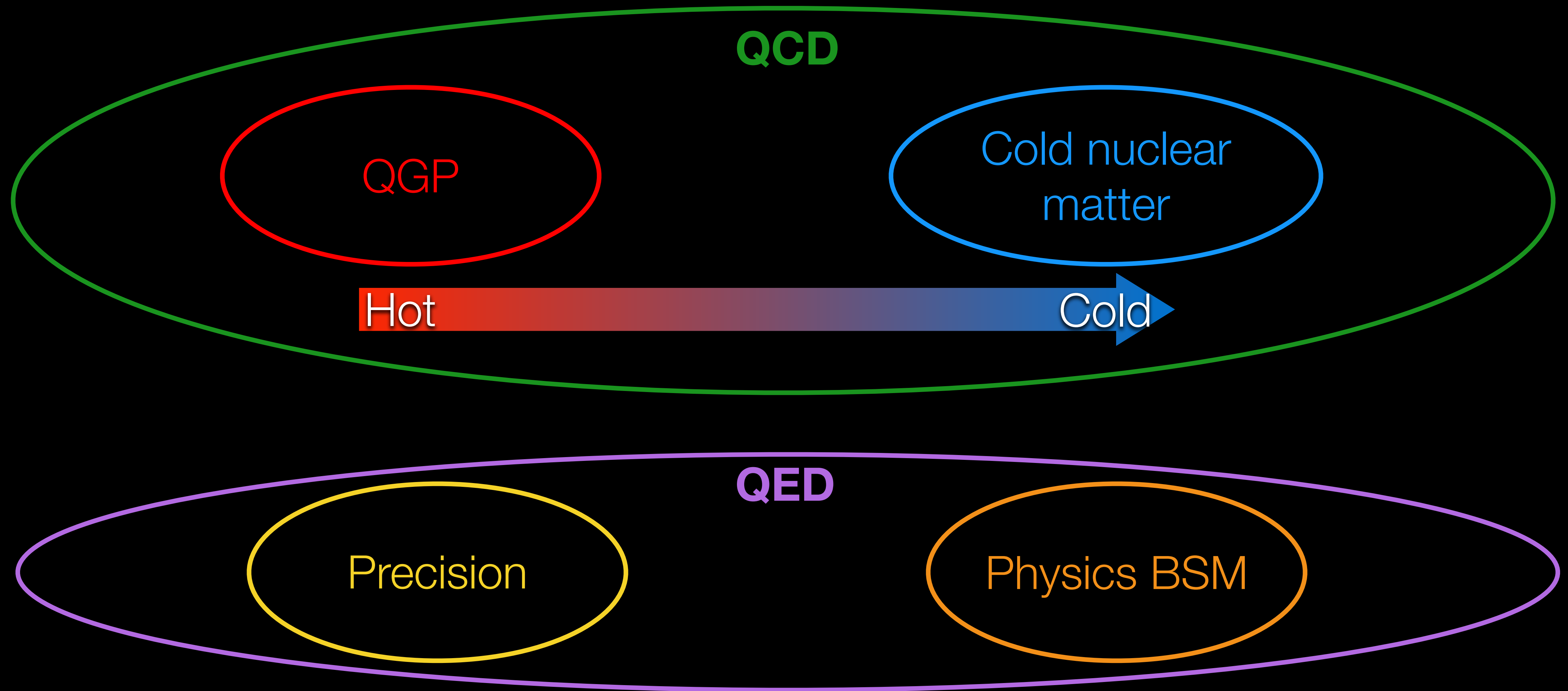




The case for a second ion injector: ATLAS perspective

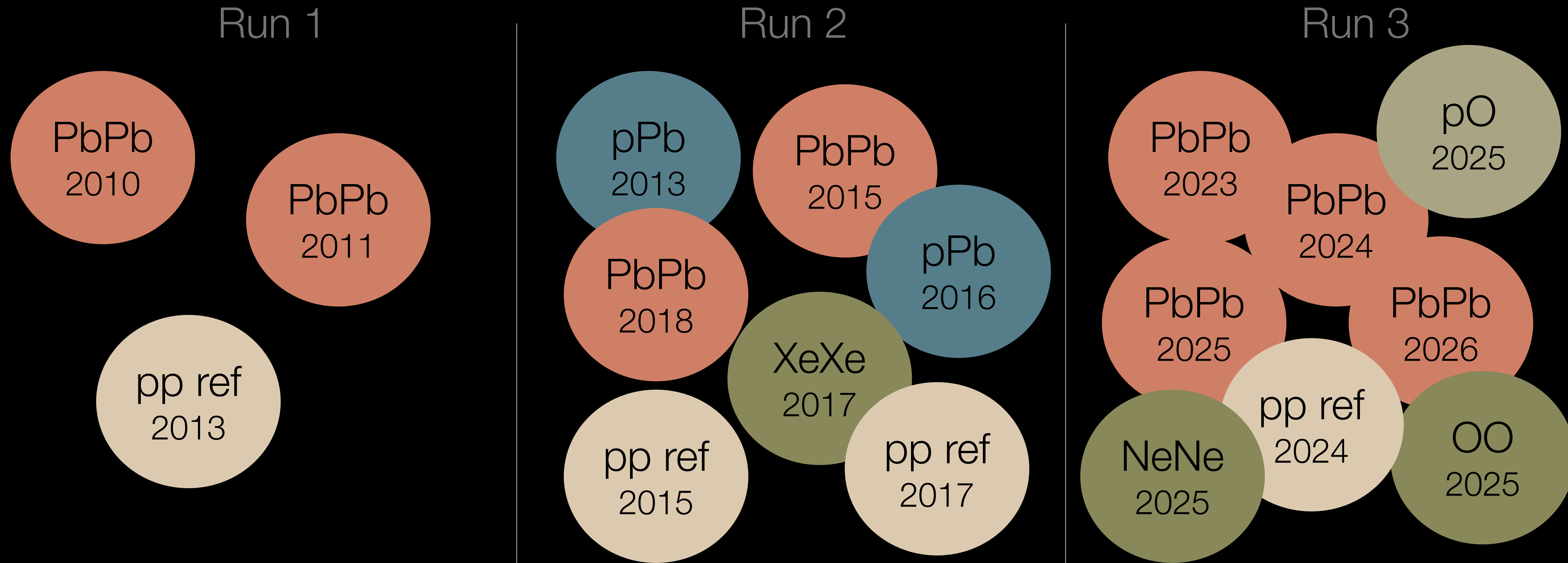
Monica Dunford - Heidelberg University
Special thanks to: R. Alemany Fernandez, R. Bruce, D. Küchler, R. Scrivens, M. Slupecki

The heavy-ion programme is a huge success and has grown substantially



To maximize the physics, the beam time needs to be used as efficiently as possible

Diversity within the HI data-taking has also increased



There are also multiple needs within the HI community

The worse case for all of us is having to choose what physics not to do

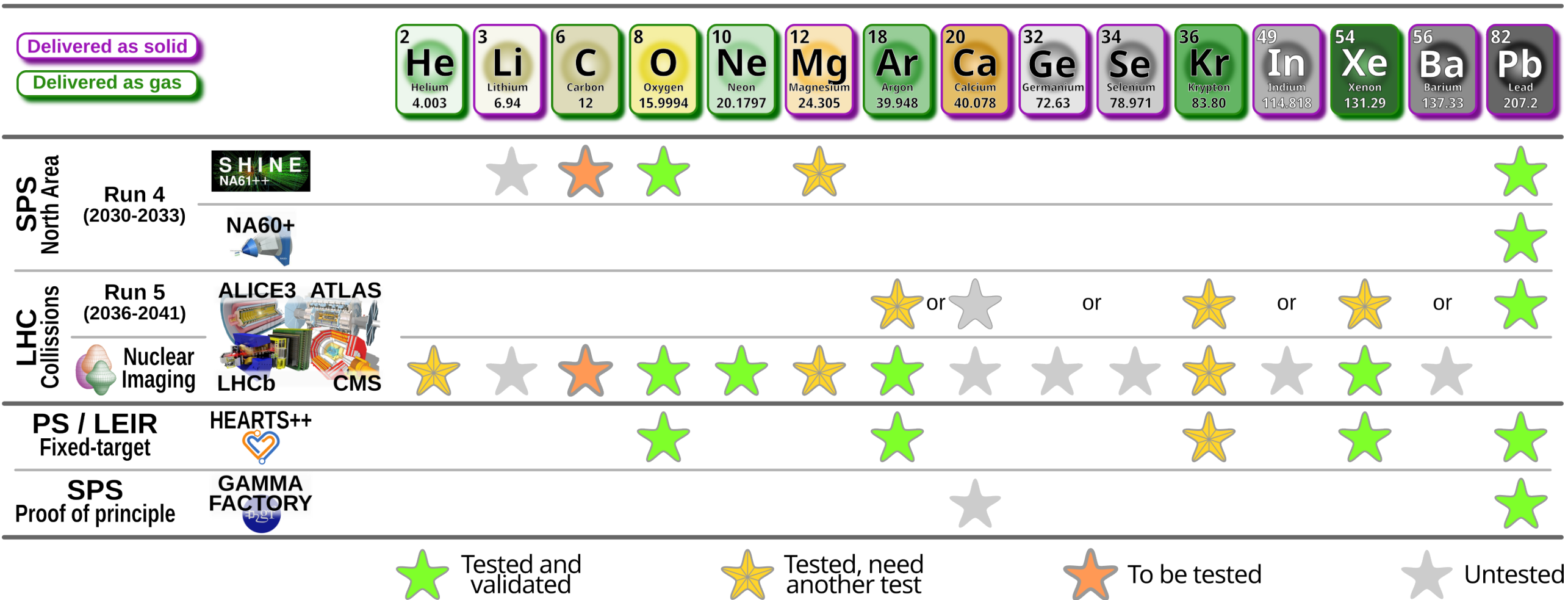
Is there another solution?

Key points on ion running that we (the experiments) should consider

NIM article for many details

Centre-of-mass energy and machine setup

- If the ion programme and desired energies are known sufficiently early, machine preparations can be done transparently
- The injector-chain preparation can largely be done during proton running. Machine simulations, etc. can also be done in advance



Preparation is key. A unified run plan across experiments is the most optimal

Key points on ion running that we (the experiments) should consider

Charge-to-mass ratio: Z/A

- Ion species with the same Z/A can largely use the same injector-chain settings and LHC settings/optics, substantially reducing recommissioning
- A second injector removes any issues of source contamination
- Can this be exploited strategically?

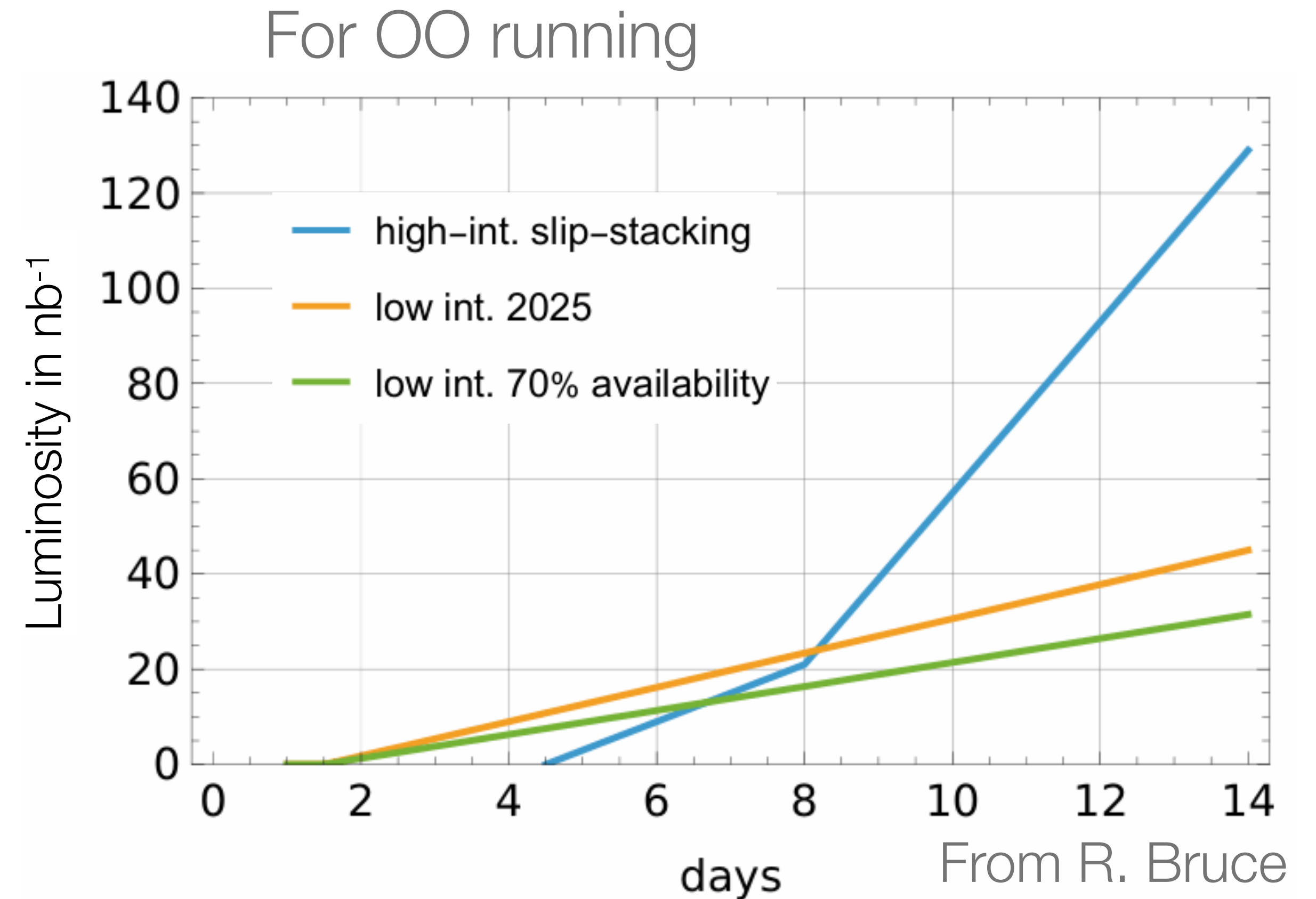
Table of Elements with an $N = Z$ ($Z/A = 1/2$) Stable Isotope and Its Natural Abundance

Element (Z)	Isotope (A)	Symbol	Natural abundance*		
Hydrogen	2	^2H (deuterium)	0.015 % ($\approx$ 156 ppm)		
Helium	4	^4He	$\approx$ 100 % (virtually all helium)		
Boron	10	Oxygen	16	^{16}O	99.76 %
Carbon	12	Neon	20	^{20}Ne	90.48 %
Nitrogen	14	Magnesium	24	^{24}Mg	78.99 %
		Silicon	28	^{28}Si	92.2 %
		Sulfur	32	^{32}S	94.85 %
		Argon	36	^{36}Ar	0.337 %
		Calcium	40	^{40}Ca	96.94 %

Key points on ion running that we (the experiments) should consider

Low intensity vs. full-machine operation

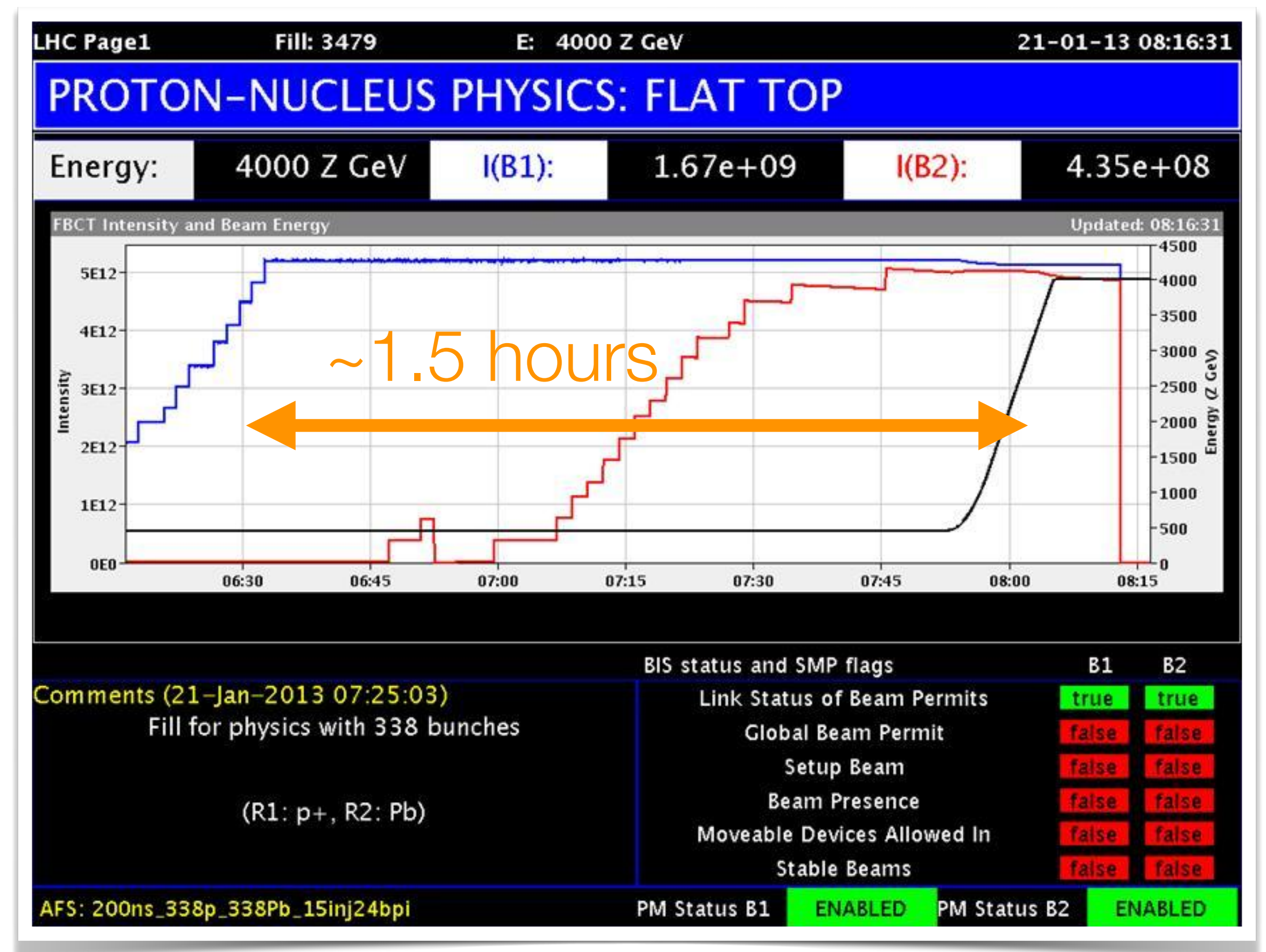
- Main criteria is the total stored beam charge/energy and the corresponding machine-protection requirements
- ~1.5 days for low-intensity operation
- Up to ~4.5 days for high-intensity/slip-stacking operation



Key points on ion running that we (the experiments) should consider

Asymmetric running

- Like p+Pb or ultimately O+Pb, one ion type is injected and circulates in the ring until the second ion type is injected
- Analysis of the 2025 O-O run confirms that in single bunch injection (no slip stacking), there is no significant intensity loss during the flat-bottom waiting time
- For higher intensities, simulations of the beam quality for slip-stacked oxygen beams show acceptable emittance growth



Key points on ion running that we (the experiments) should consider

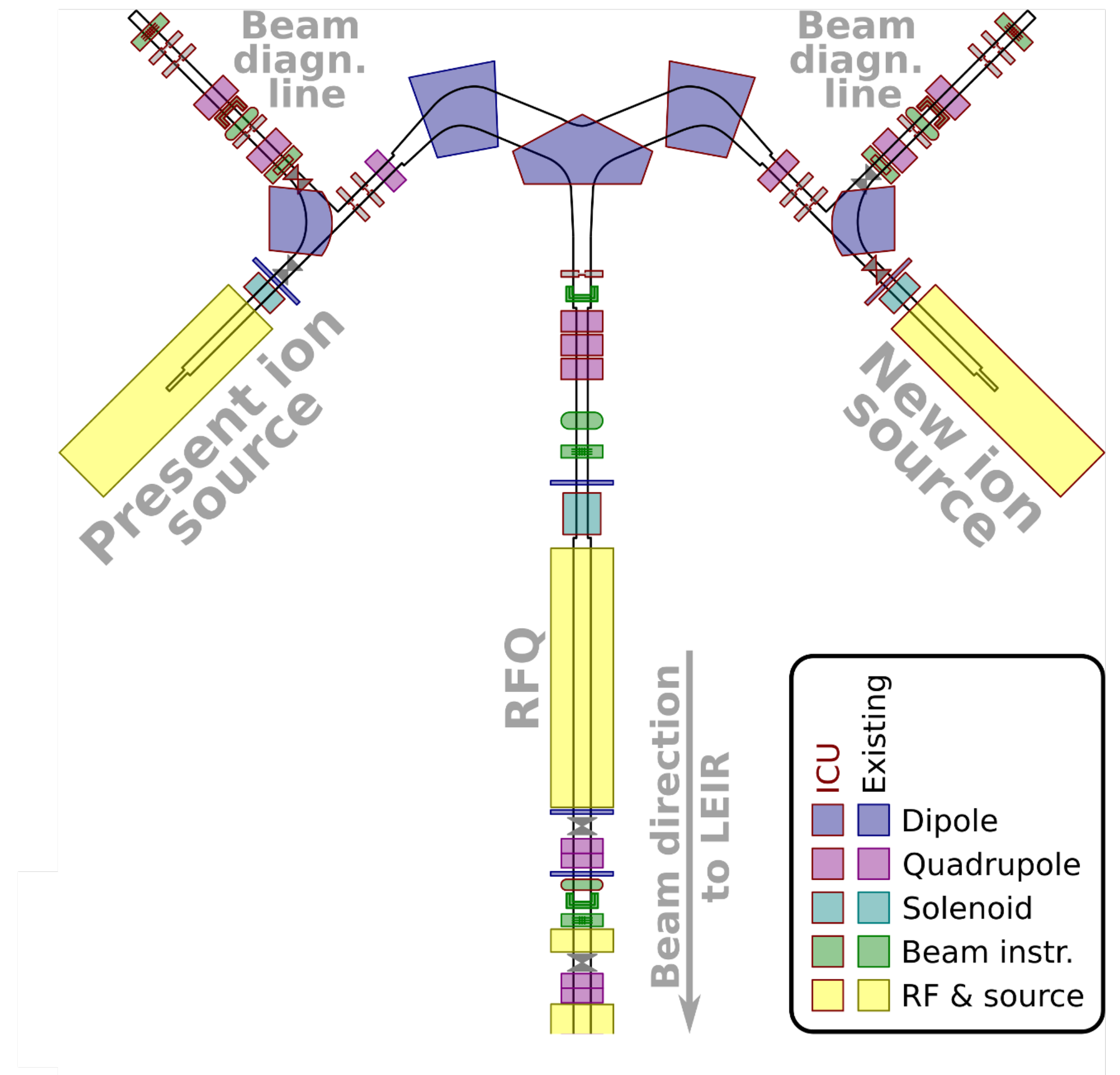
The source and changing ion species

- Changing the source requires both source/injector preparation and LHC commissioning
- All new ion types need "quiet" testing in advance
- i.e. 2 days for set-up is roughly 7–8% of the 4-week HI running. For the OO run, +2 days is 28% more physics time
- A run plan like 3 weeks of Pb followed by 2-3 days each of Ar - Kr - He - C is not possible without a second injector

<i>Switch from</i>	<i>Time Needed</i>
Another ion to Pb	~6 weeks
Another ion to O	~2 weeks ~1-2 for Pb to O
Pb to noble gas	~2 days (with constant tuning)
O to Ne	~ 1 day (with a few % contamination)

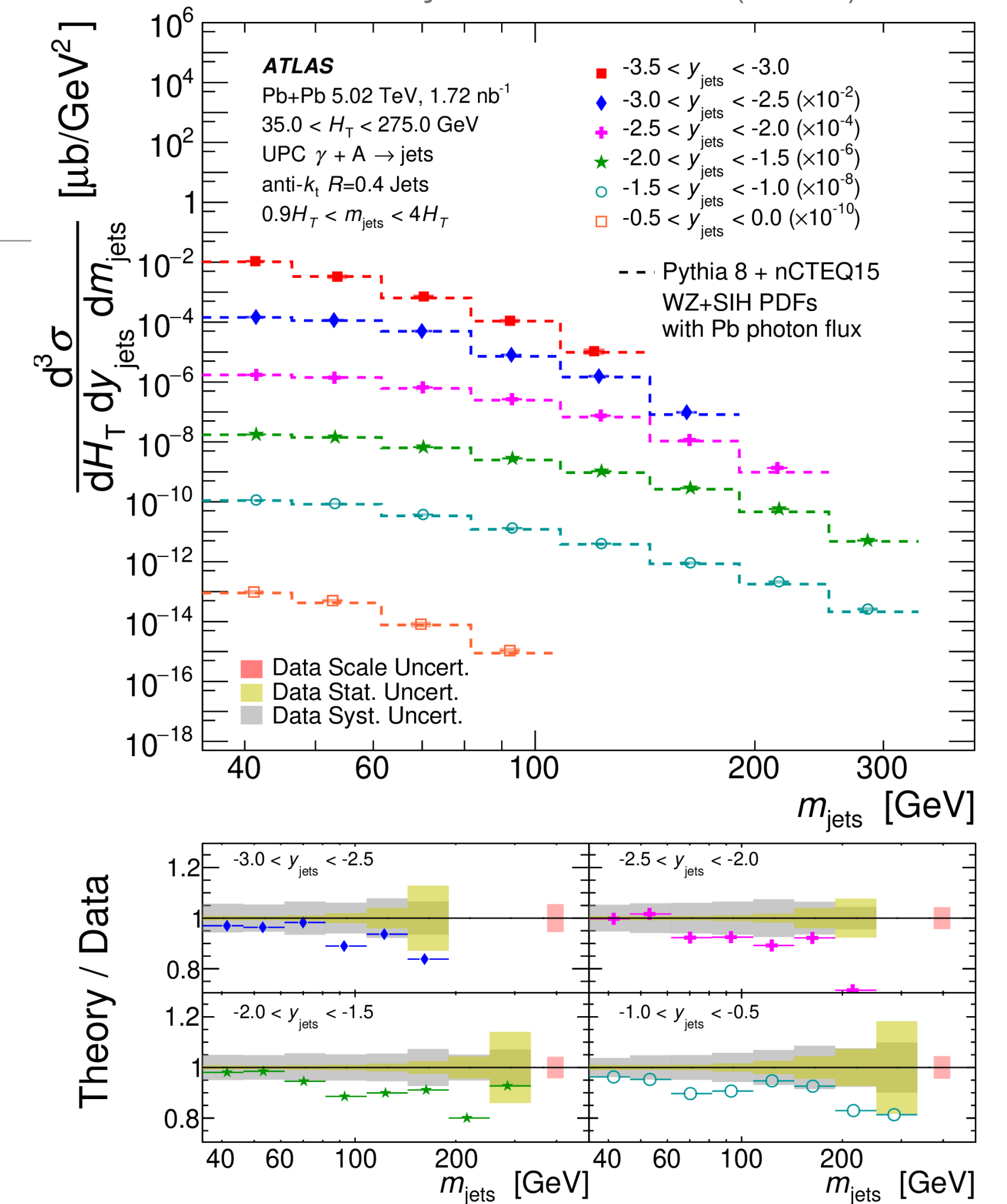
A second injector system

- A second injector helps with species switching and enables asymmetric operation of two ion types
- For asymmetric collisions with different Z/A , operation would still involve sequential injection of the two species and associated waiting time.
- For same- Z/A species, switching could be much more efficient.



The physics potential of asymmetric systems

- *Denser, controlled geometry:* Pb eclipses the light ion $\rightarrow$ $\sim 50\%$ higher energy density at fixed size.
- *System-size scan:* He+Pb / O+Pb probe the onset and evolution of QGP effects.
- *Nuclear structure:* UPCs provide unique sensitivity to nPDFs, separating initial-state effects from energy loss.



Lumi. needed to reach equivalent precision

O+Pb: $\sim 35 \text{ nb}^{-1}$

He+Pb: $\sim 120 \text{ nb}^{-1}$

An ATLAS example - 2025 Running

- ZDC installation: typically 1-2.5 days of commissioning of the detector (w/o and w/ beam). Strict radiation protection requirements determine when it can be installed. Several HI runs during the year is also not sustainable for the small operation teams

- 2025 - actual sequence



- Possible (hypothetical) sequence with second injector



- With two injectors the light ion run could have been adjacent (before or after) the PbPb running, saving ZDC installation time

An ATLAS example - 2025 Running

An optimal, single run set up for ATLAS:

- ZDC installation: typically 1-2.5 days of commissioning of the detector (w/o and w/ beam). Strict radiation protection requirements determine when it can be installed. Several HI runs during the year is not sustainable for the small operation teams
- Before start of HI running period, load injector 1 with Pb and injector 2 with ion X
- Start with pilot runs of X+X (or X+Pb)

• Move to Pb+Pb and in meantime recommission second injector with ion Y

- Finish run with Y+Y or Pb+Y

• Possible (hypothetical) sequence with second injector

Optimizes setup of ZDC, consistent detector conditions and trigger and availability of the small operations team

- Save 1-2.5 days on ZDC installation and source switching between ions

A second injection system: Next possibilities

- A second injector is realistically available only for Run 5.
- The estimated cost is on the order of several M CHF
- HEARTS++ is a key opportunity. A joint interest from the LHC experiment in a second injector will greatly strengthen this
- CERN is proceeding through HEARTS++ toward a possible second-injector TDR, expect starting in 2030 and targeting completion by end of 2031
- European funding maybe be possible to support the TDR and associated equipment/infrastructure studies.
- After the TDR, CERN would still need to approve the project and procure/construct the hardware

More physics from the same LHC

- The ion programme has grown.
A reflection its scientific success
- The programme has diversified.
PbPb, light ions and asymmetric systems all have compelling physics cases
- Serial preparation creates pressure on the HI and overall LHC physics programmes.
We as a community will get the best physics if we can discuss/agree/plan beforehand
- A second injector increases efficiency and flexibility and enables asymmetric running
A modest investment for an irreplaceable dataset over the next decades
Our strongest argument is a compelling physics case

