

Opportunities and synergies with future light ion runs at the LHC

Austin Baty
University of Illinois Chicago

July 8, 2026

EMMI Workshop: Mining for gluon saturation at the LHC
and the future EIC
Darmstadt, Germany

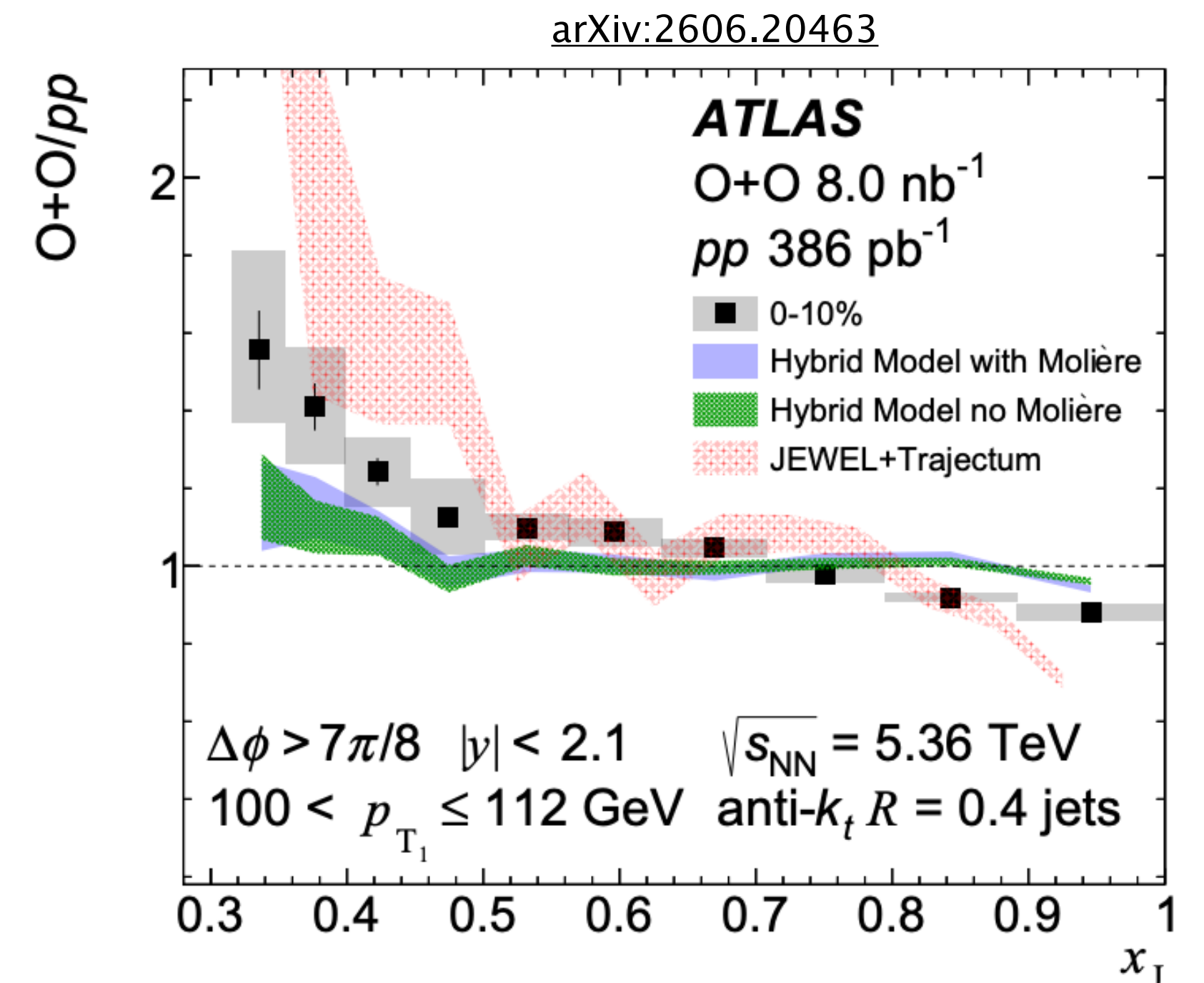
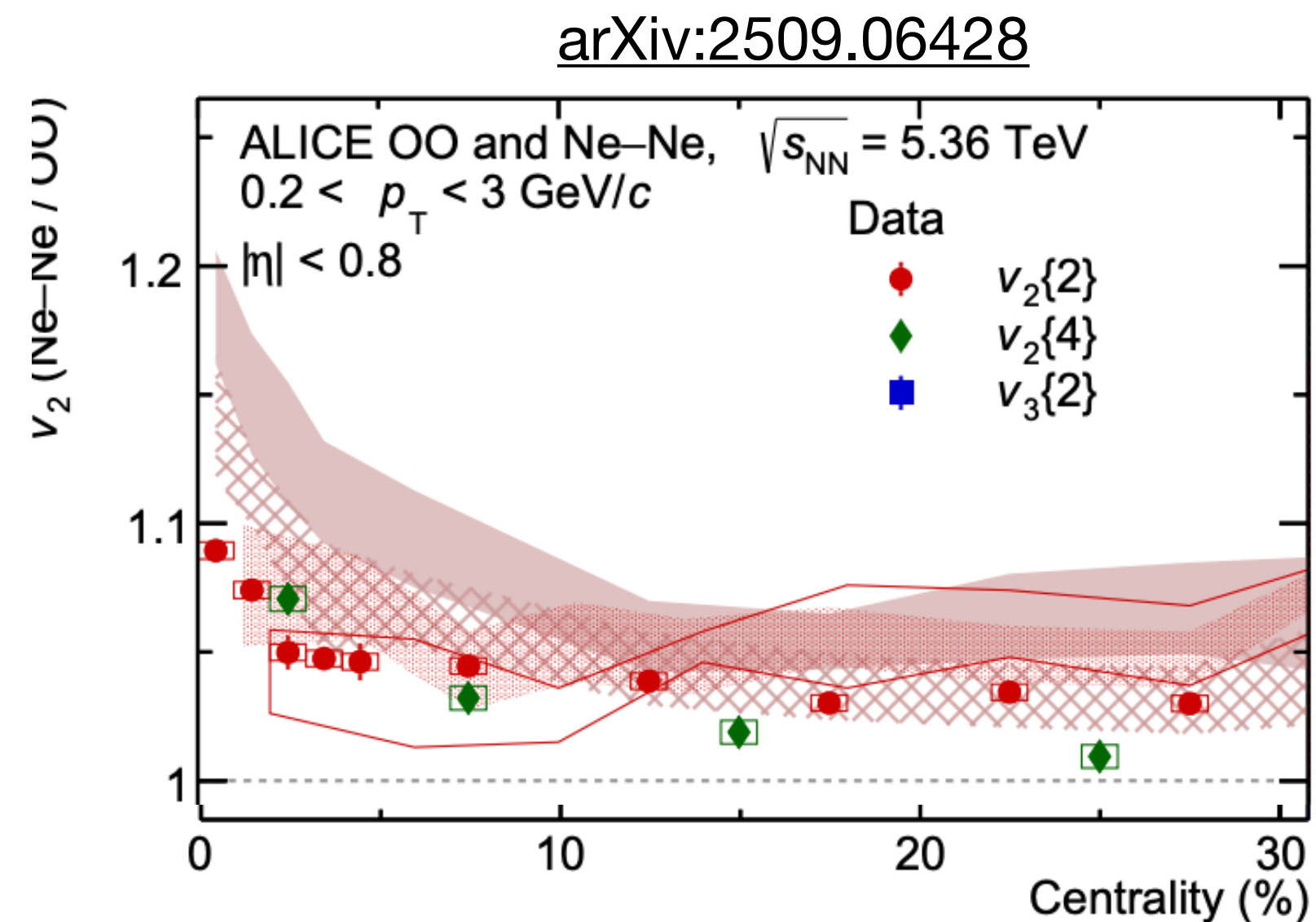
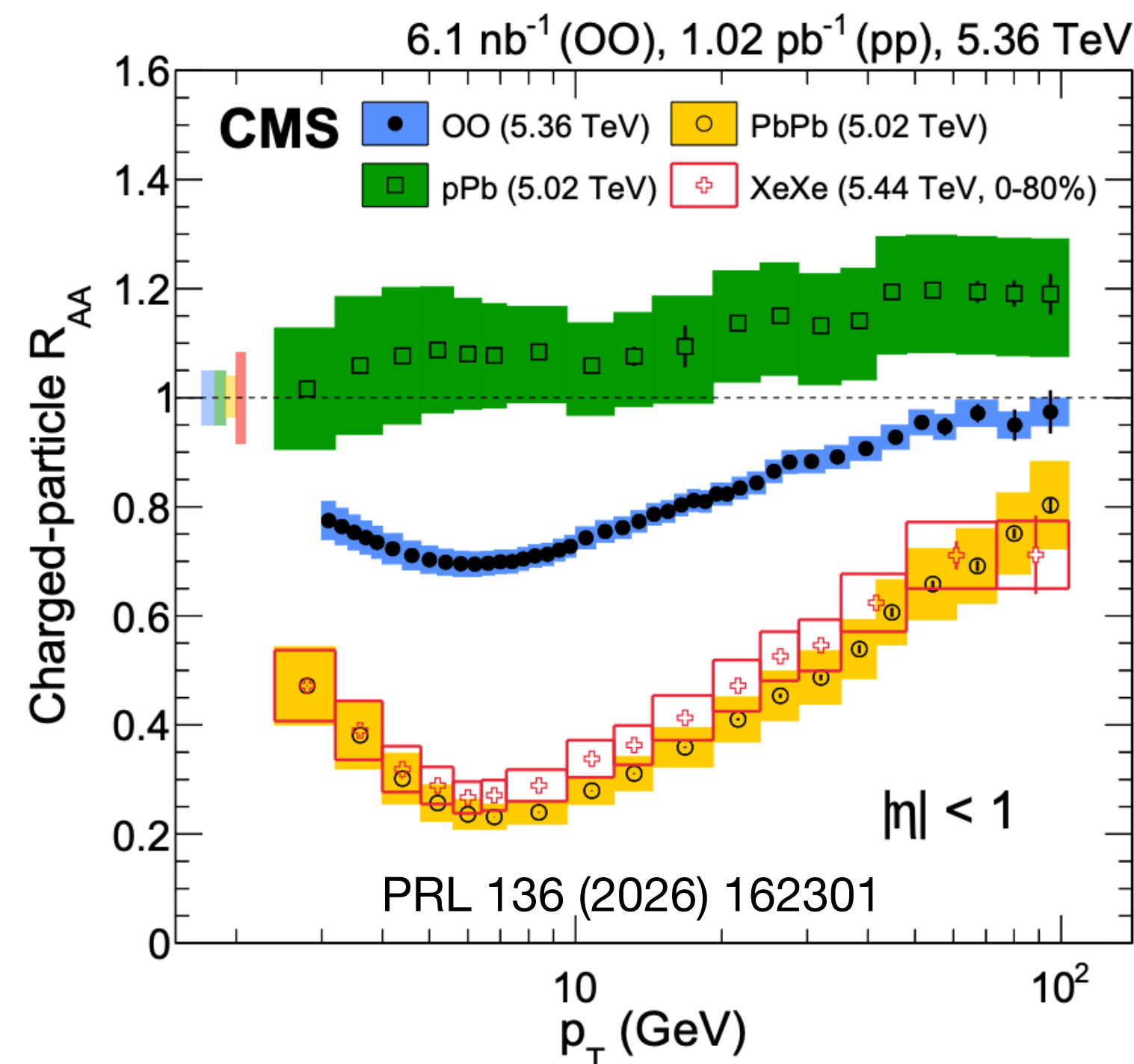


U.S. DEPARTMENT
of **ENERGY**

The UIC group is supported by the DoE Office of Science

Motivation for new ion species

- LHC has shown high scientific productivity with short ‘special’ runs
 - Started with pPb ‘pilot’ run, then XeXe, now Oxygen/Neon
- Have demonstrated the ability to extend beyond ‘traditional’ heavy ion physics
 - Nuclear structure, cosmic ray physics, etc.
- Getting LHC beam time is hard
 - Need to develop strong/diverse physics case to see if new ions viable in future



Case study: the Oxygen and Neon Run



CMS Experiment at the LHC, CERN

Data recorded: 2025-Jul-05 02:50:13.306688 GMT

Run / Event / LS: 394153 / 243679213 / 100

- Recent oxygen/neon run provides guidance about past planning efforts
- Run collected OO, pO, and NeNe data

Oxygen-Oxygen Event Display

2018 CERN Yellow Report



CERN-LPCC-2018-07
February 26, 2019

Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams

Group 5 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

9.10 Potential of O–O Collisions

A promising opportunity to study the emergence of collective phenomena further as well as the presence of possible parton energy loss in small collision systems, are collisions of smaller nuclei. In particular,

11.3 Proton-oxygen collisions for cosmic ray research

In conclusion, collisions of p–O at the LHC are highly desirable to solve the outlined questions. The corresponding measurements would be a crucial input to cosmic ray physics and have the potential to result in significant advances in the century-long ride of the origin of cosmic rays. The luminosity

- **Community-driven effort identified OO and pO as having interesting physics impact**

LHCf request for proton-oxygen

LHCf

Technical Proposal for the LHC Run3

Addressing Cosmic Ray physics
with forward measurements in
proton–proton and proton–light
nuclei collisions at LHC

- **LHC-forward**
- **Designed to measure neutral particles in the forward region**
- **Perfect for cosmic ray physics!**
- **Detector to be removed in 2026:**
 - **Needed proton-oxygen some time from 2022-2026 or opportunity is lost forever.**
- **CERN accelerator department completed positive feasibility study**

2021 workshops and letters

- February workshop to gather Heavy Ion + Cosmic Community
- Letter from cosmic ray community (signed by 125 people) asking CERN for pO
- Pierre Auger Collaboration letter explaining importance of pO data for their physics



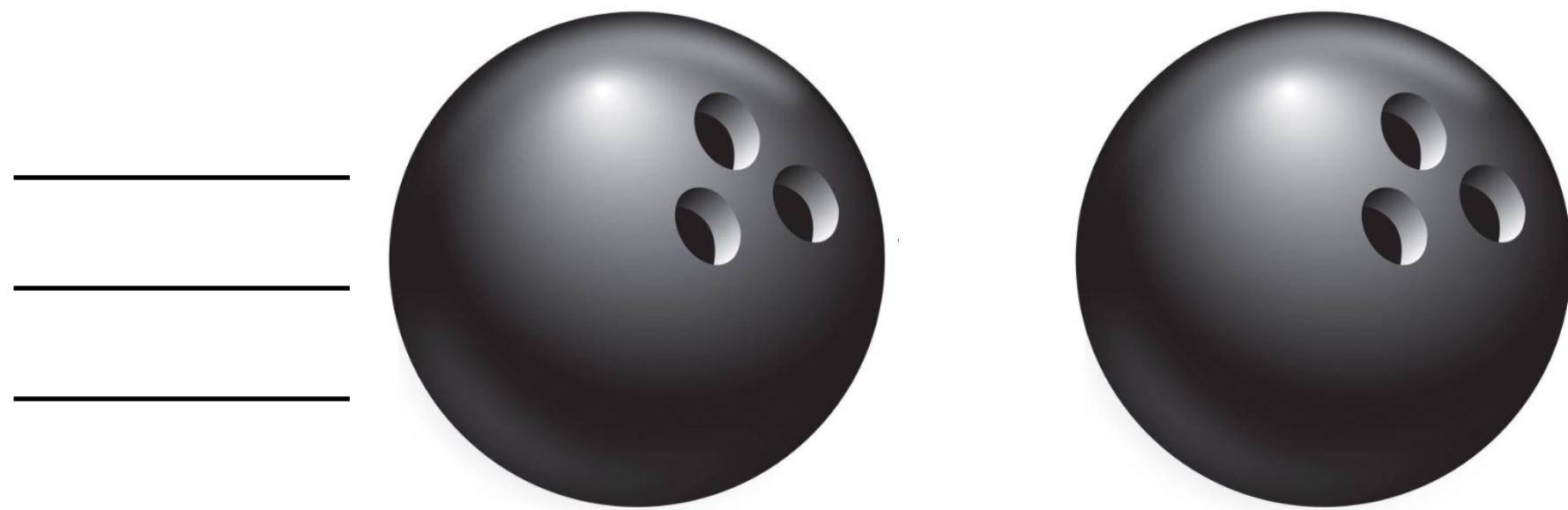
- Relativistic Heavy Ion Collider (RHIC) took oxygen-oxygen data in 2021 as well!
- CERN council approved oxygen run (pO + OO) for 2024 (eventually delayed to 2025)

'24 Proposal to add Neon-Neon

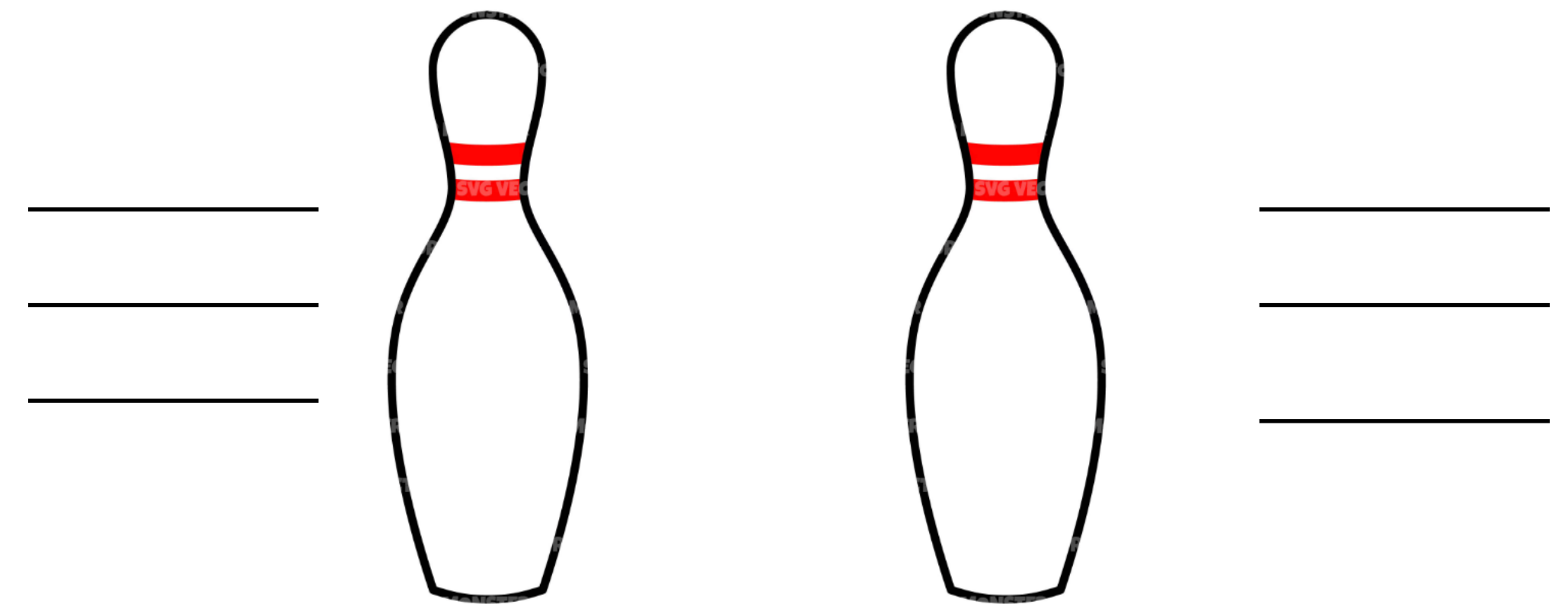
Phys. Rev. Lett. **135**, 012302

The unexpected uses of a bowling pin: exploiting ^{20}Ne isotopes for precision characterizations of collectivity in small systems

Giuliano Giacalone,^{1,*} Benjamin Bally,² Govert Nijs,³ Shihang Shen,⁴
Thomas Duguet,^{5,6} Jean-Paul Ebran,^{7,8} Serdar Elhatisari,^{9,10} Mikael Frosini,¹¹ Timo A. Lähde,^{12,13}
Dean Lee,¹⁴ Bing-Nan Lu,¹⁵ Yuan-Zhuo Ma,¹⁴ Ulf-G. Meißner,^{10,16,17} Jacquelyn Noronha-Hostler,¹⁸
Christopher Plumberg,¹⁹ Tomás R. Rodríguez,²⁰ Robert Roth,^{21,22} Wilke van der Schee,^{3,23,24} and Vittorio Somà⁵



Oxygen-Oxygen



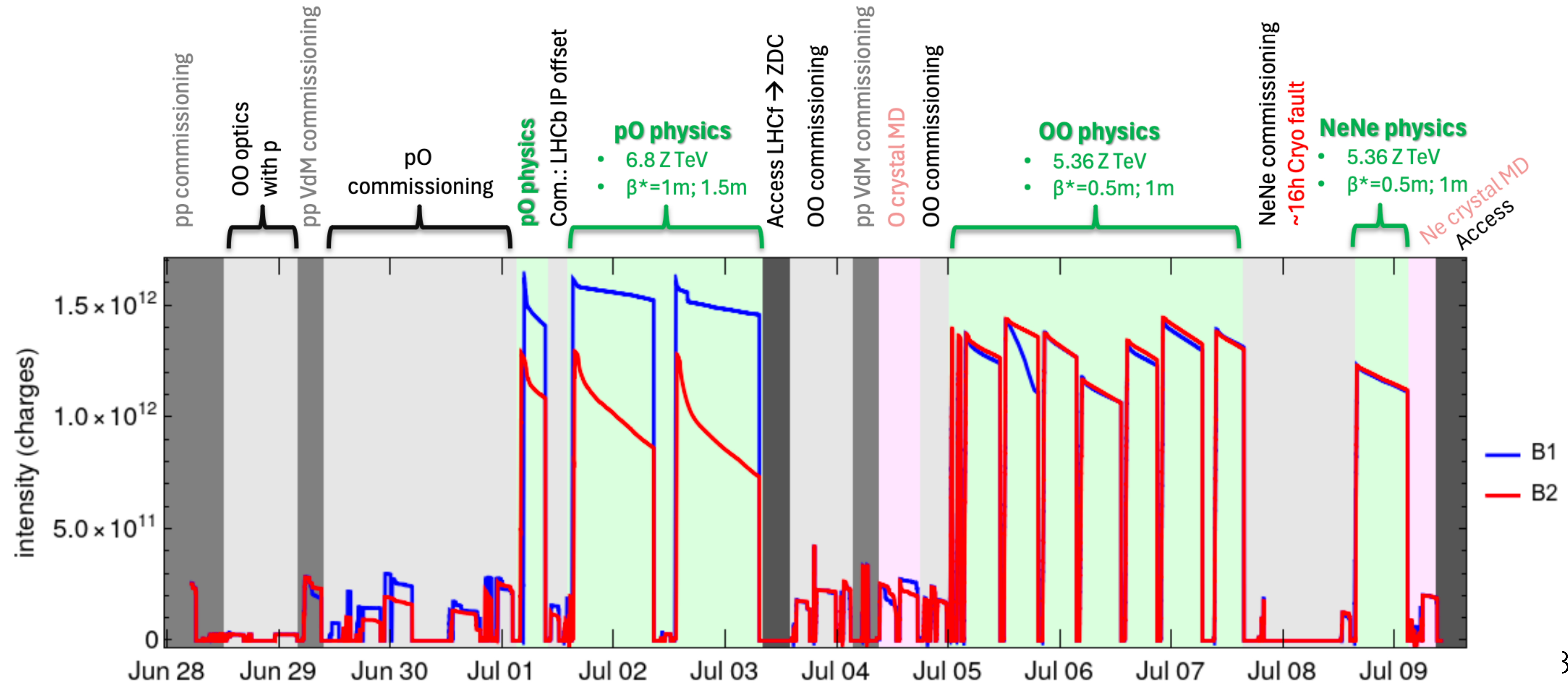
Neon-Neon

- Flow can be used to measure initial geometry: can we learn about Neon deformation?
- Neon and Oxygen have same charge-to-mass ratio - easy for LHC to change!
- NeNe collisions proposed in Nov. 2024 (very 'late!')
- 12-hours allocated in March 2025 after lengthy debate

Run performance

- 8 days of extremely involved scheduling
- Exceptionally good accelerator performance!

Figure from Roderik Bruce



Total Luminosity Collected

Figure from Roderik Bruce

- **Luminosity targets exceeded by an order of magnitude!**
 - **up to 16x for pO**
 - **10-12x for OO**
 - **6-10x for NeNe**
- **Huge success after years of preparation!**

proton-Oxygen

(nb ⁻¹)	target	delivered	Ratio
ATLAS/LHCf	1.5	1.8	1.2
ATLAS	--	6.9	--
ALICE	5	7.85	1.6
CMS	3	48.4	16
LHCb	2	33.1	16.6

Oxygen-Oxygen

(nb ⁻¹)	target	delivered	ratio
ATLAS	0.8	8.2	10.3
ALICE	0.5	5.15	10.3
CMS	0.8	9.4	11.8
LHCb	0.5	5.75	11.5

Neon-Neon

(nb ⁻¹)	target	delivered	F
ATLAS	0.1	1.0	10
ALICE	0.1	0.91	9.1
CMS	0.1	0.91	9.1
LHCb	0.1	0.61	6.1

Lessons to be Learned

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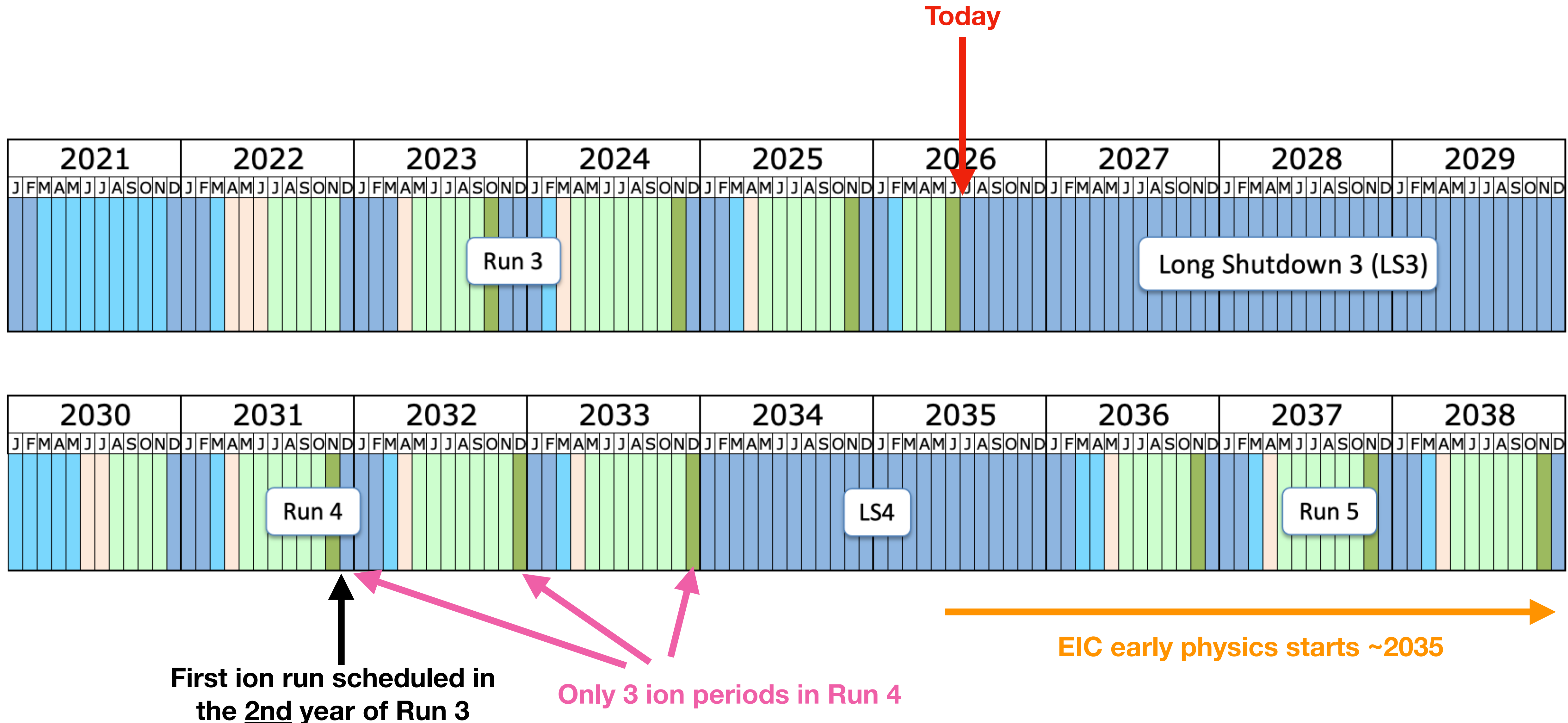
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- **Be willing to adjust - NeNe added late, LHC schedule changed, etc.**
- **The light ion run was made easier by CERN dedicating a ‘special run’ to it**
 - **Current management’s position is that future ion runs will not be ‘special’ and will come out of HIN community beam allocation**
 - **Physics case must be very strong!**

Lessons to be Learned

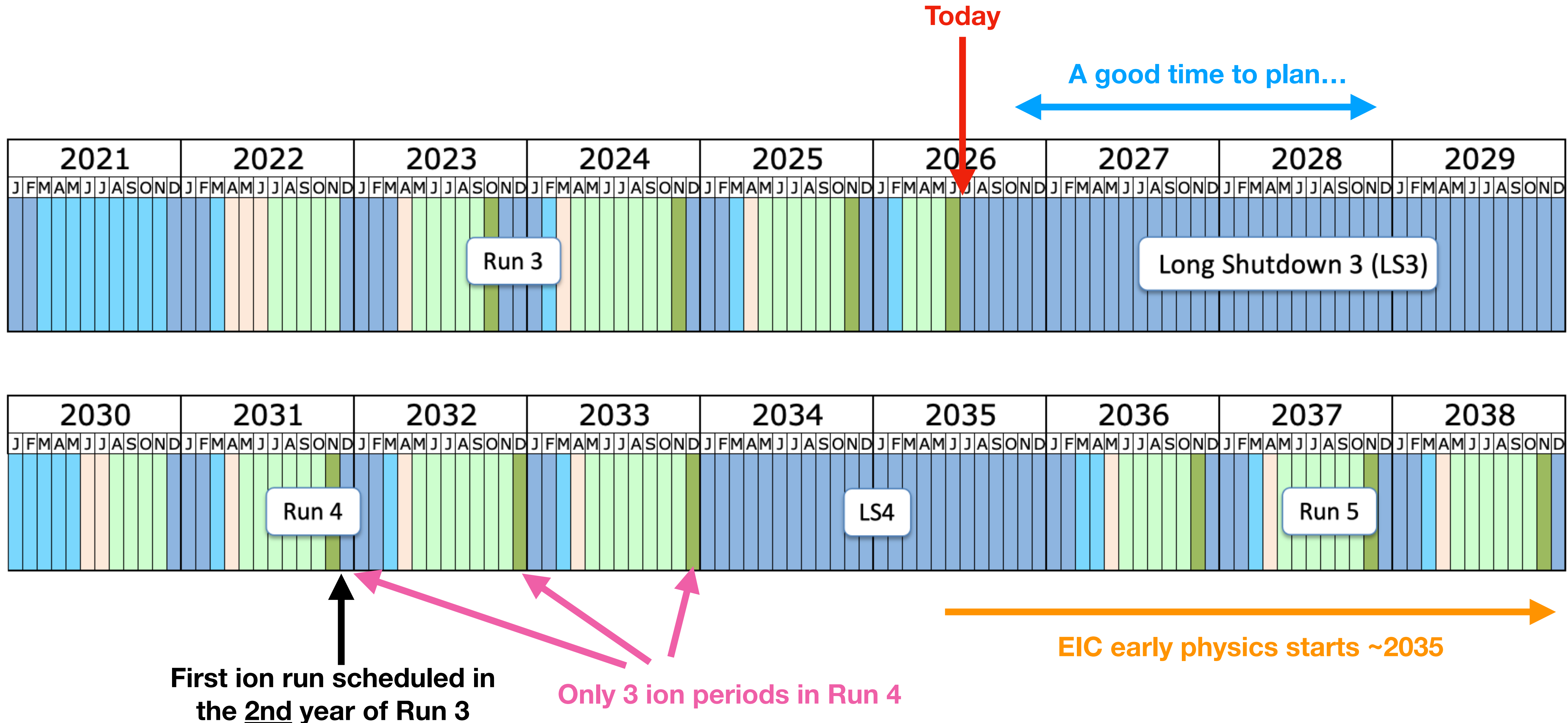
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Efforts already underway to address these three items in the context of LHC Run 4 and beyond

Setting the stage...



Setting the stage...



First workshop after light ion run

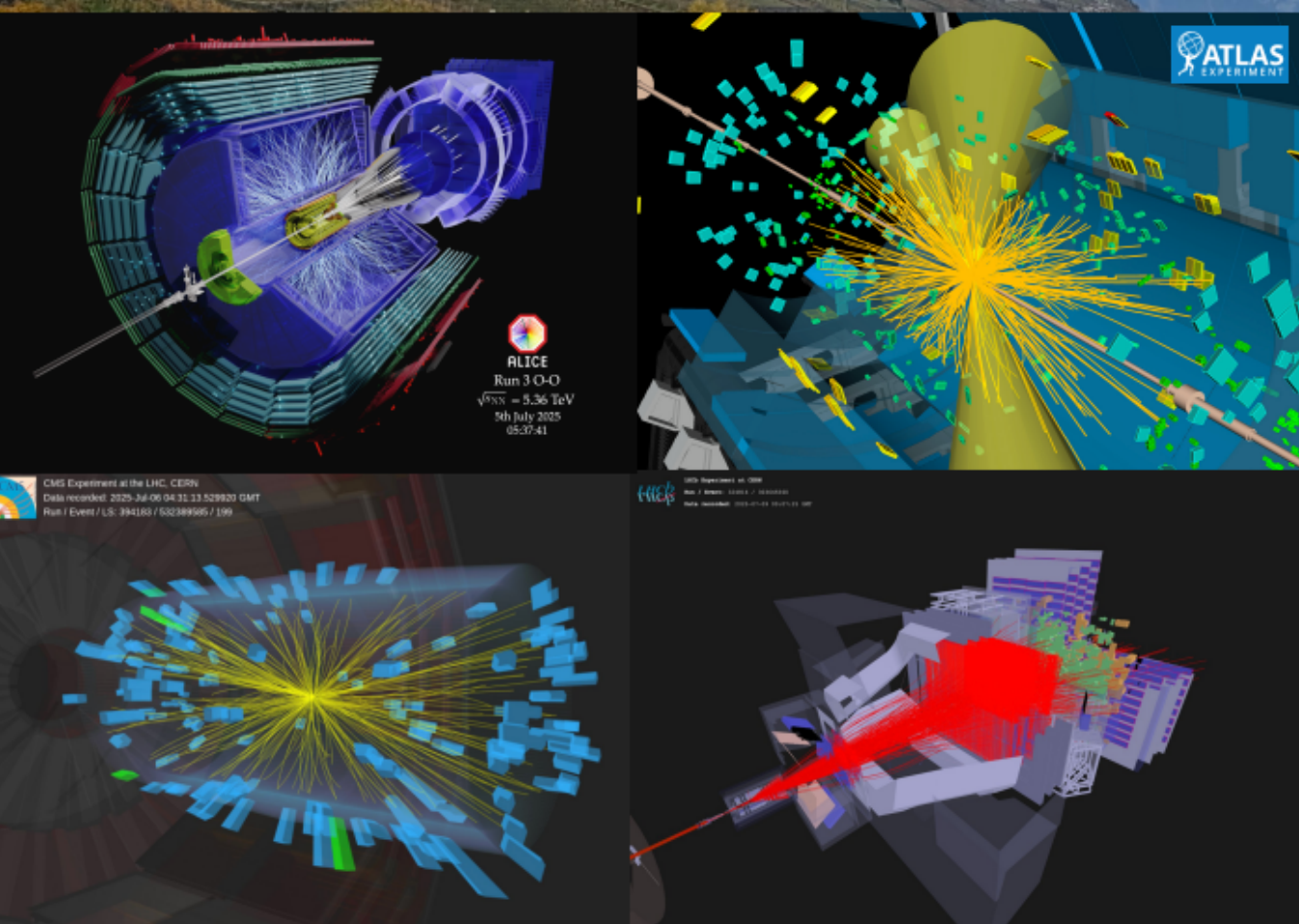
Light Ion Collisions at the LHC 2025

Workshop on light-ion collision results
and future opportunities

Dec 1-3, 2025, CERN
cern.ch/lightions2025



- **Discussing first results and organizing for potential future efforts**



Programme:

Experimental overviews of collectivity and energy loss
Hydrodynamics and non-equilibrium dynamics
Jet quenching in small systems
nPDFs of light ions
Synergies with nuclear structure physics and other areas
Accelerator and experiments perspectives for future light-ion runs

Organizers:

Reyes Alemany Fernandez (CERN)
Giuliano Giacalone (CERN)
Qipeng Hu (USTC Hefei)
Gian Michele Innocenti (MIT)
Georgios Krintiras (University of Kansas)
Saverio Mariani (CERN)

Aleksas Mazeliauskas (ITP Heidelberg)
Dennis Perepelitsa (CU Boulder)
Anthony Timmins (University of Houston)
Wilke van der Schee (CERN)
Urs Wiedemann (CERN)
You Zhou (NBI Copenhagen)

Outcome was ‘New Ions @ LHC’ effort

New Ion Collisions at CERN for Run 4

Monday 19 Jan 2026, 08:00 → 10:00 America/Chicago

08:00 → 08:05	Introduction Speaker: Reyes Alemany Fernandez (CERN)  Kick_off_meeting....  Kick_off_meeting....	🕒 5m
08:05 → 08:45	Experiment proposal Speaker: Giuliano Giacalone  kickoff_Giuliano.p...	🕒 40m
08:45 → 09:15	Experiment proposal Speaker: Jiangyong Jia (Stony Brook University (US))  JiangyongJia_ligh...	🕒 30m
09:15 → 09:45	Experiment proposal Speaker: Dennis Perepelitsa (University of Colorado Boulder)  dvp-ABcollisions-...	🕒 30m

- Kickoff meeting at: <https://indico.cern.ch/event/1634270/>
- CERN e-group mailing list: [lhc-new-ion-collisions-run4](#)

Main goals of the new ions effort

New Ion Collisions at CERN

KICK-OFF MEETING

Giuliano Giacalone
Wilke Van Der Schee
Govert Hugo Nijs
Urs Wiedemann
Reyes Alemany Fernandez

SETTING THE SCENE

- *2nd Light Ion Collisions at the LHC* workshop (December 1–3, 2025)
<https://indico.cern.ch/event/1597414/overview>

- **Coordinated effort across-communities** of theoretical, experimental, and machine physicists → new ion collision experiments in LHC **Run 4** ←

This effort is focused on Run 4, although physics cases will likely also apply to Run 5 and beyond

- Key aspect: enabling a **multi-energy approach** →

ISOLDE	SPS fixed-target experiments
EIC	LHC
- Develop **three to four well-documented proposals** for pilot runs
- **Complementary** program to the main LHC lead runs
- **The final goal is to prepare a paper by 2028 for approval by the relevant CERN committees, increasing the chances of realizing these proposals in Run 4**

LPCC HIN WG gets involved

New Ion Collisions @ LHC Run 4

Monday 16 Mar 2026, 09:00 → 11:00 America/Chicago



call_for_inputs.pdf

video_recording.t...



There are minutes attached to this event. [Show them.](#)

09:00 → 09:20 **Introduction to the LPCC Heavy Ion Working Group (HI-WG)**

⌚ 20m

Speaker: Alice Ohlson (Lund University (SE))

HIWGintro.pdf

09:20 → 10:00 **Introduction to New Ions Collisions @ LHC Run 4 - Scope and timelines**

⌚ 40m

Speaker: Giuliano Giacalone

Newlons_pres.pdf

10:00 → 11:00 **Q&A**

⌚ 1h

Speakers: Giuliano Giacalone, Reyes Alemany Fernandez (CERN)

- LPCC HIN WG was engaged to help discuss within the major LHC experiments
- Public LPCC HIN WG meeting at: <https://indico.cern.ch/event/1655628/>
- Happy to coordinate with the LPCC Forward WG

Roadmap to a white paper

- **Roadmap and timelines**

- **Phase 1** – Collecting ideas for science cases to be pursued

[deadline in two months from now, May 18]

MAY 26

We are here.
(Recommended ion
species to be
announced soon)

- **Phase 2** – Call for abstracts on physics studies related to science cases

List of contributions that will constitute the White Paper

[deadline with Heidelberg workshop Sept 21-25 / but submissions welcome afterward]

SEP 26

→ **[review progress in LPCC workshop Sep 27]**

- **Phase 3** – Completion of scientific studies to appear in White Paper

Publication-style results. They can of course appear in journals and arXiv

[deadline around end of 2028]

SEP 28

→ **[LPCC workshop]**

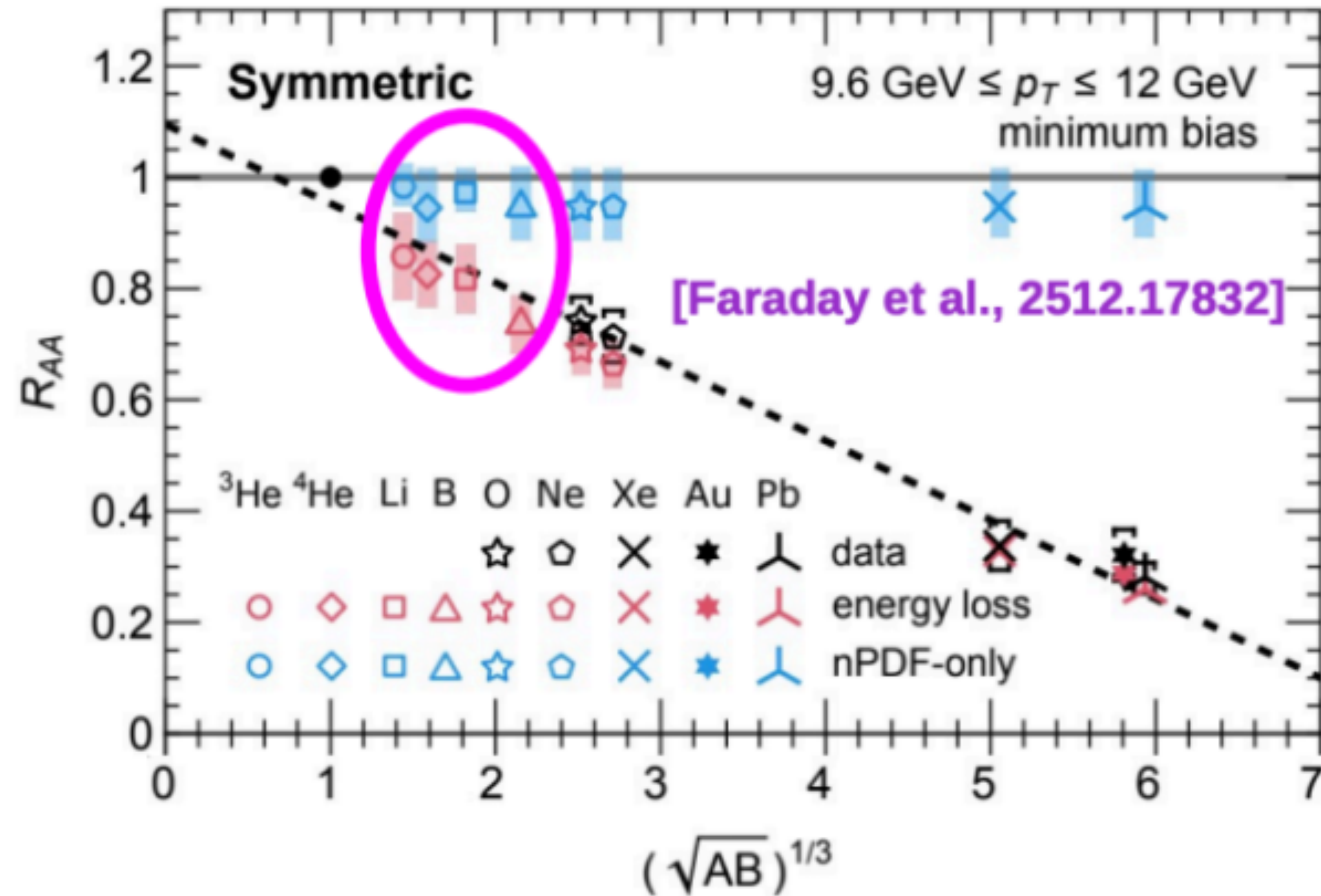
- **Phase 4** – Assembly of the White Paper [deadline in Spring 2029]

- **Submission to experimental collaborations and relevant boards**

MAR 29

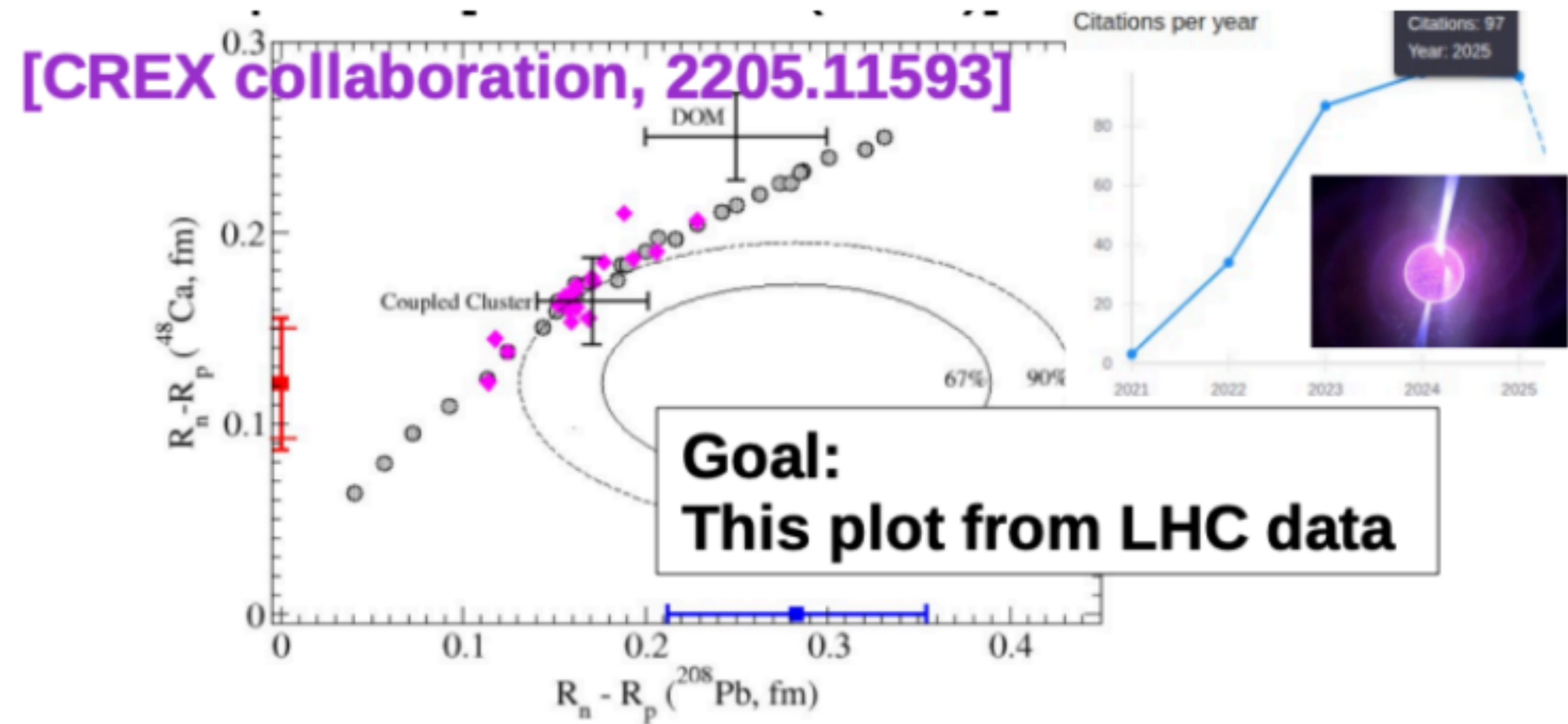
Three 'themes' appearing (1)

- Exploration of more light nuclei
- Small ion nPDFs, onset of QGP effects, alpha clustering...
- He^4 ... C^{12} , O^{16} , Ne^{20} , Mg^{24}



Three 'themes' appearing (2)

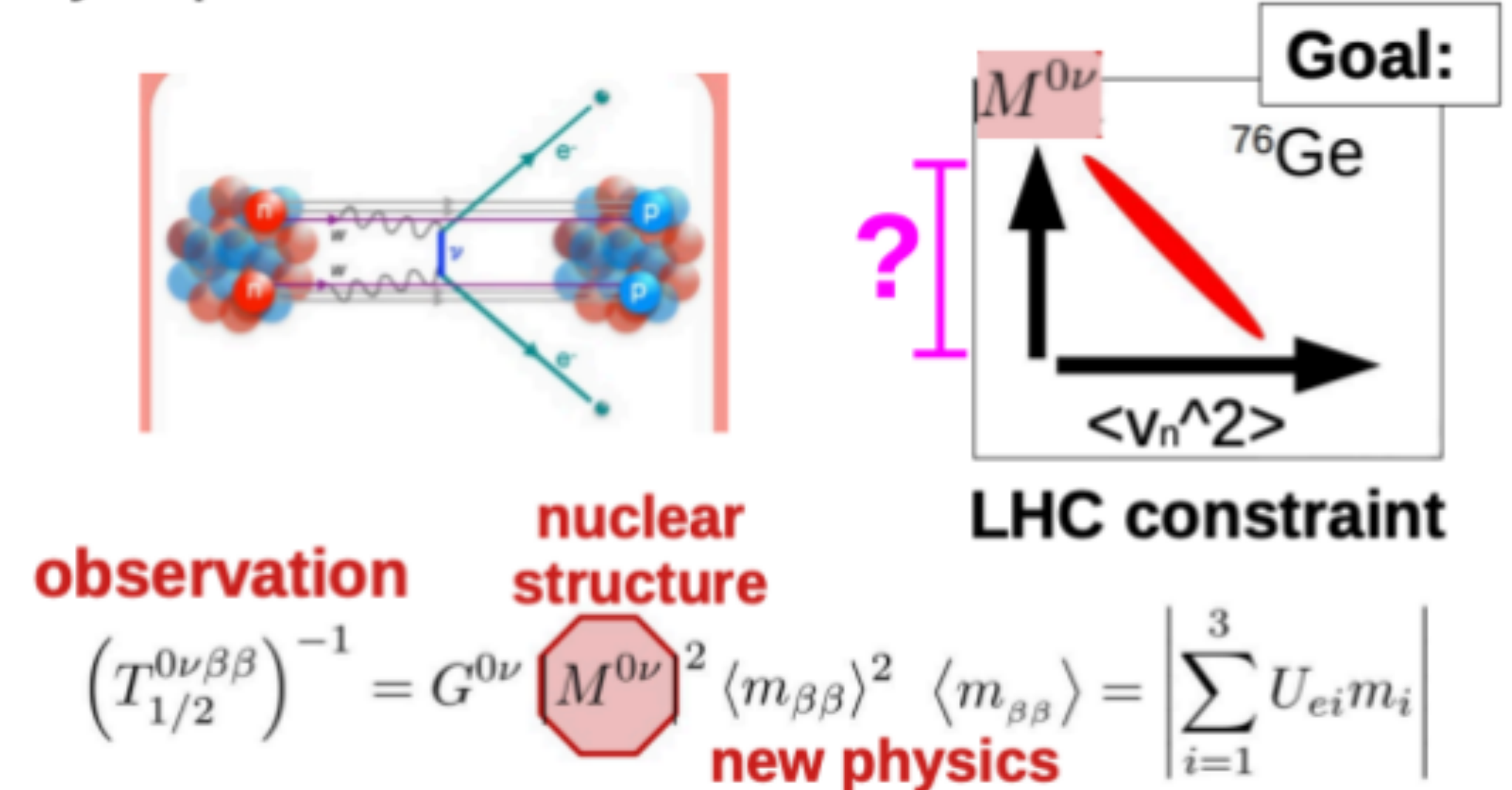
- Nuclei around $A=40$ to 48
- Double-magic Ca isotopes (40,48)
 - Neutron skin studies, neutron start EOS...
- Ar^{40} similar size but a gas



Three 'themes' appearing (3)

- Nuclei around A=80
- Ge⁷⁶, Se⁷⁶, Kr⁷⁸
- Potential to constrain nuclear structure that would have implications for neutrino less double beta decay searches

Money plot: theory uncertainties on NMEs reduced by experimental information from collisions



- Final system recommendations from New Ions @ LHC + LPCC HIN WG coming soon
 - Likely to follow these themes, although details may differ...

Heidelberg Workshop

- Promises to be a major event in the planning timeline
 - Community discussion on proposals up to this point
 - ‘Kick off’ for in-depth physics studies to be placed in a white paper
-
- September 21-25, 2026
 - Abstracts for workshop talks are due **TODAY!**

ExtreMe Matter Institute EMMI

EMMI Workshop

Light-Ion Collisions 2026

September 21-25, 2026
Heidelberg University, Germany



Recent light-ion collision campaigns — proton-oxygen, oxygen-oxygen and neon-neon runs at the LHC, and oxygen-oxygen collisions at RHIC — have opened a transformative window onto the origins of collective behavior in small QCD systems. Simultaneously, high-energy collisions offer a novel probe of nuclear ground-state structure. Driven by these research frontiers, the 2026 EMMI Workshop on Light-Ion Collisions serves as a dedicated forum to synthesize the emerging experimental results, clarify their implications for the field, and discuss scientific cases for ion runs in LHC Run 4 and beyond.

Scientific program:

- Out-of-equilibrium QCD phenomena and onset of collectivity
- Onset of jet quenching in small and intermediate systems
- Collectivity of heavy flavors across system sizes and shapes
- Interdisciplinary connections (nuclear structure, nuclear astrophysics, neutrinoless double-beta decay, cold atoms)
- Prospects for future ion runs at LHC Run 4 and beyond

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Aleksas Mazeliauskas (Heidelberg U.)
Wilke van der Schee (CERN)
Alexander Tichai (TU Darmstadt)

Information:
www.gsi.de/emmi/workshops

Website:
<https://indico.gsi.de/event/25022/>

More about EMMI:
www.gsi.de/emmi



Luminosity estimates

- CERN to detailed luminosity estimates for a few of the selected collision systems
- Note: now know that initial estimates from 2018 were incorrect
- Oxygen will not maximize nucleon-nucleon luminosity - likely Krypton is better for this

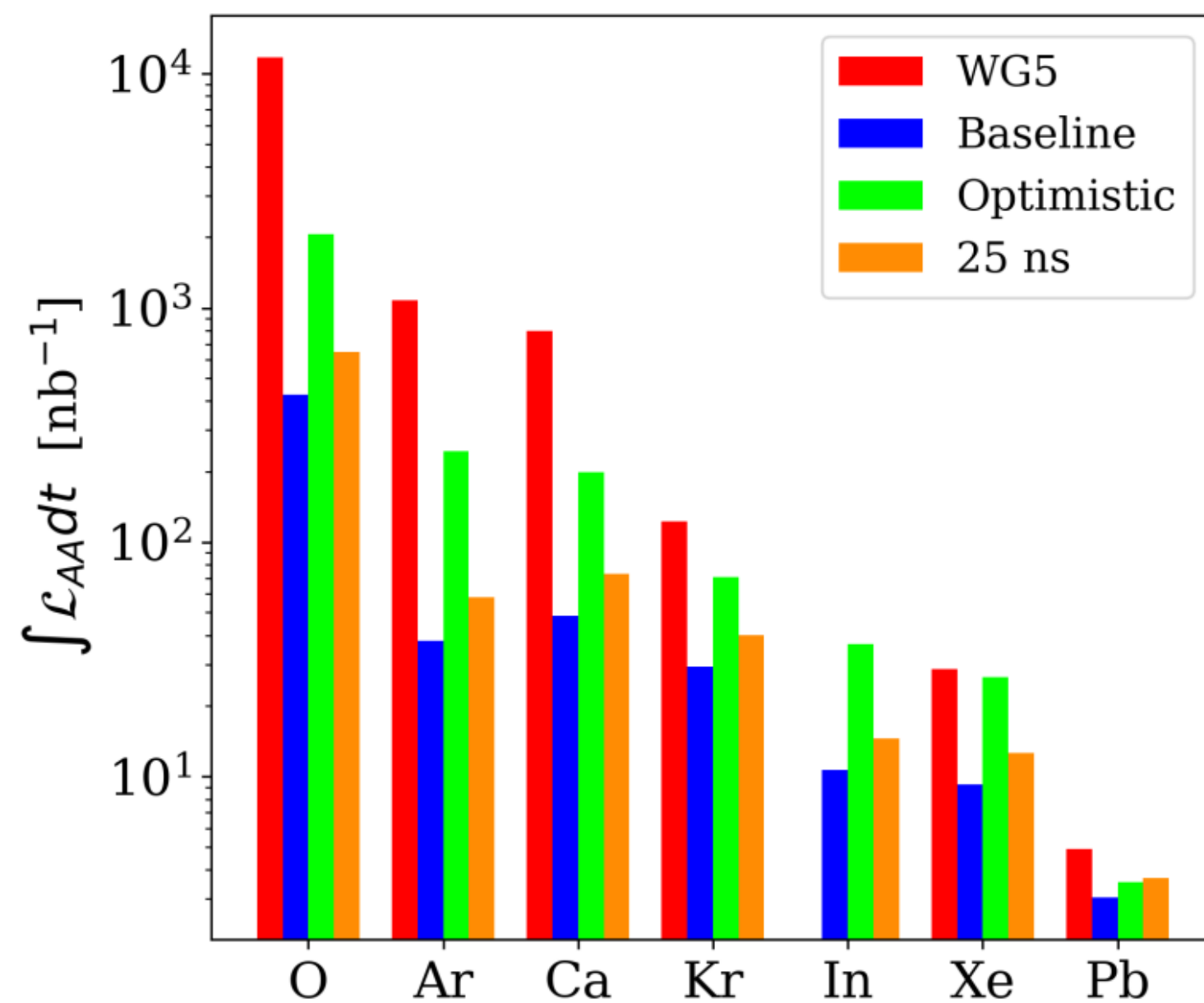


Figure 10: One-month integrated ion-ion luminosity $\int \mathcal{L}_{AA} dt$ in nb^{-1} for the various cases.

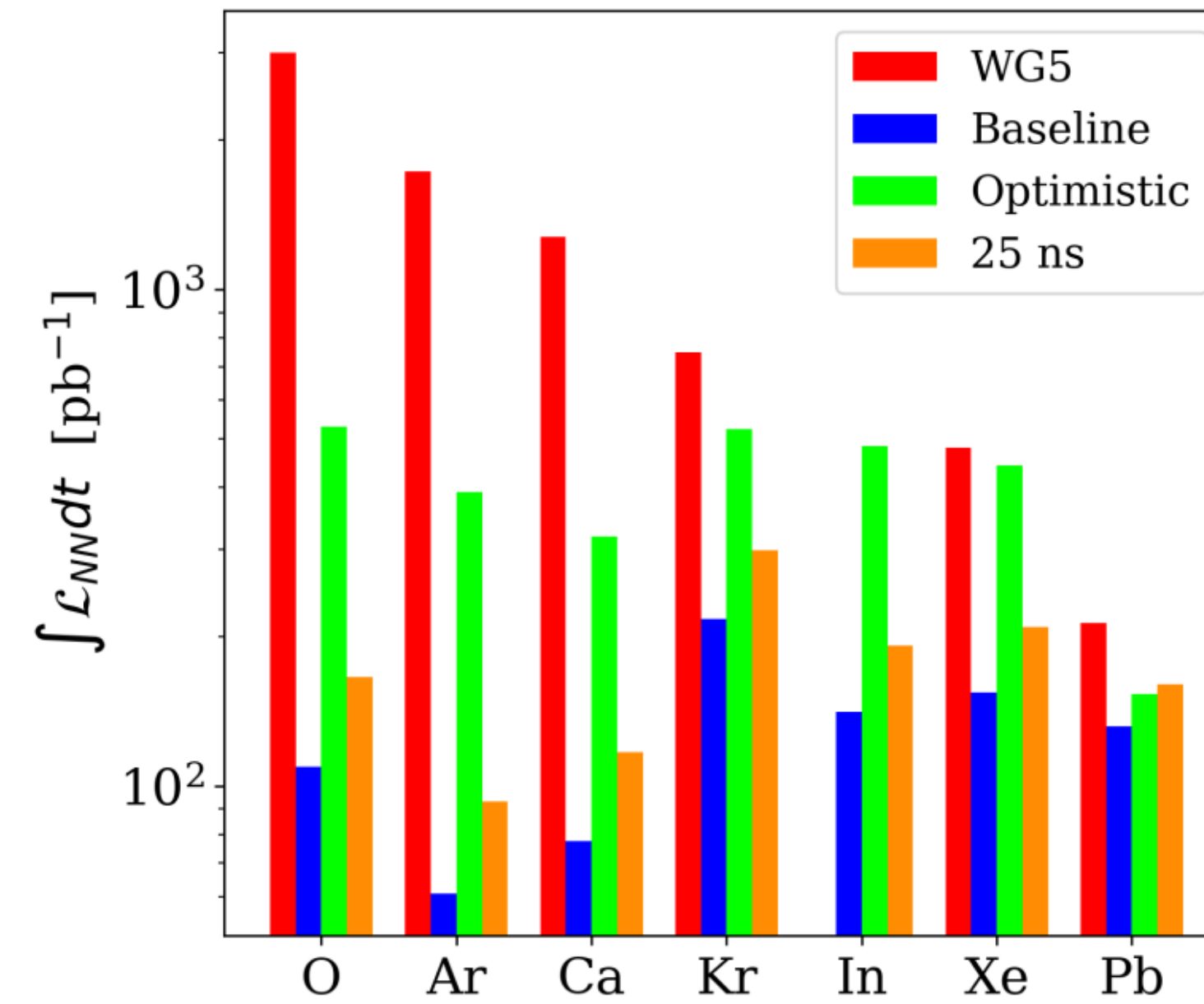
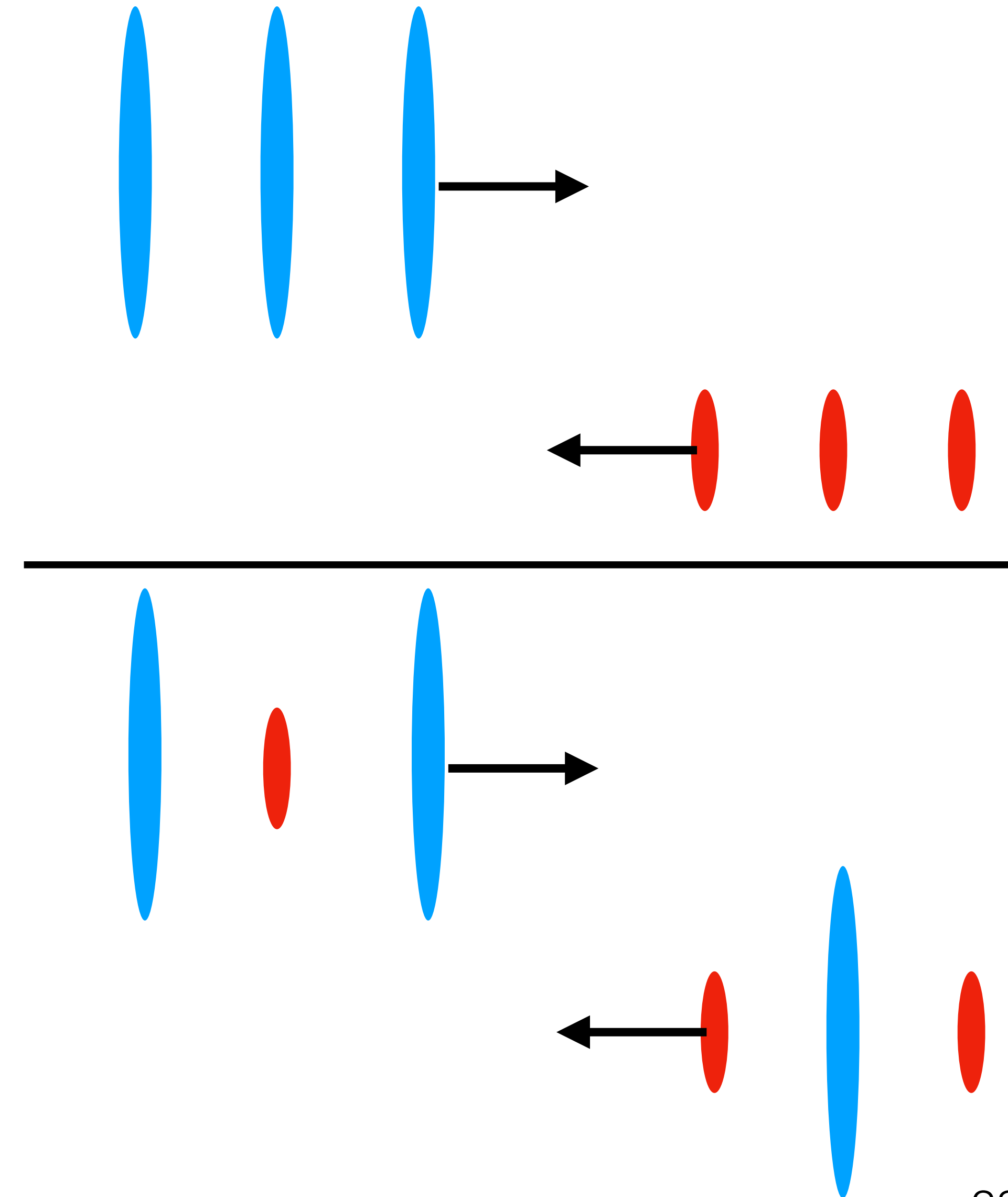


Figure 11: One-month integrated nucleon-nucleon luminosity $\int \mathcal{L}_{NN} dt$ in pb^{-1} for the various cases.

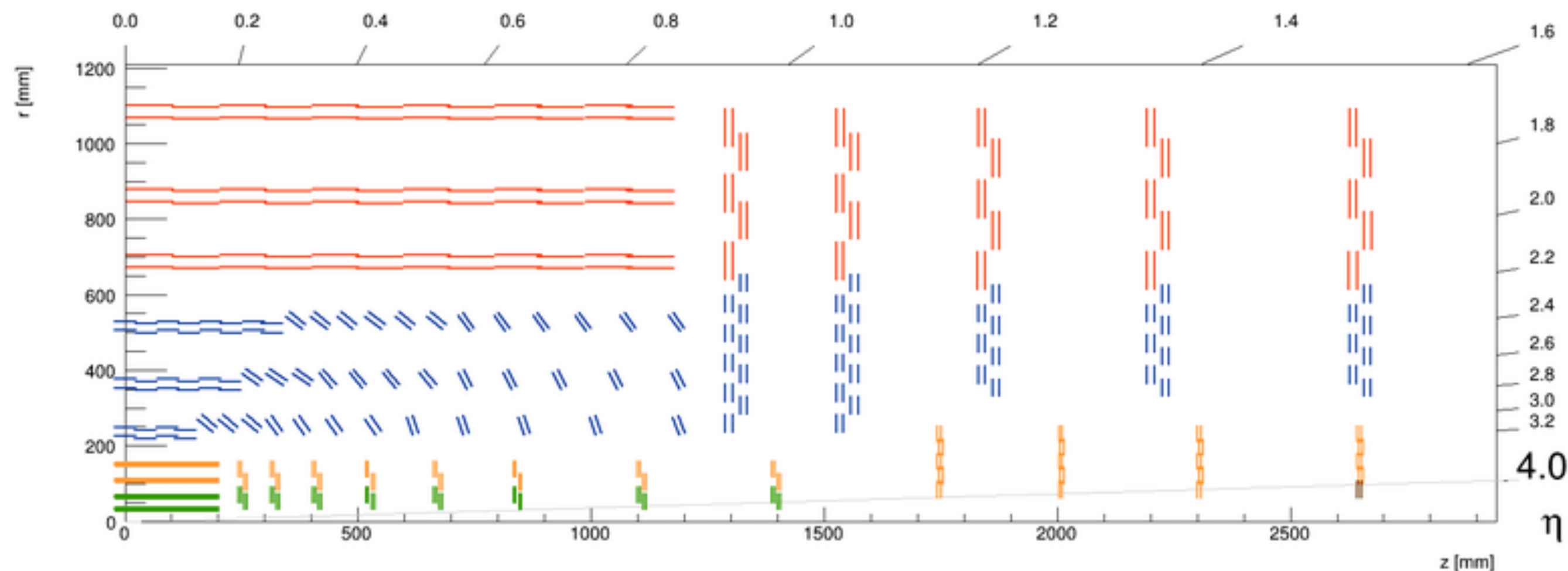
Second ion source

- Currently CERN can only do 1 (solid) ion every few months because the source must be conditioned
- Having a second source would allow:
 - A+B collisions (for example, PbO for UPCs)
 - Potential for simultaneous A+A, B+B, A+B, B+A collisions to cancel uncertainties
 - Fast turn-around for swapping non-gaseous ions
- Source costs O(500 kCHF)
- Must be acquired with long lead time
 - Proposals requiring 2 sources for Run 4 must be known very soon!



Experimental Upgrades

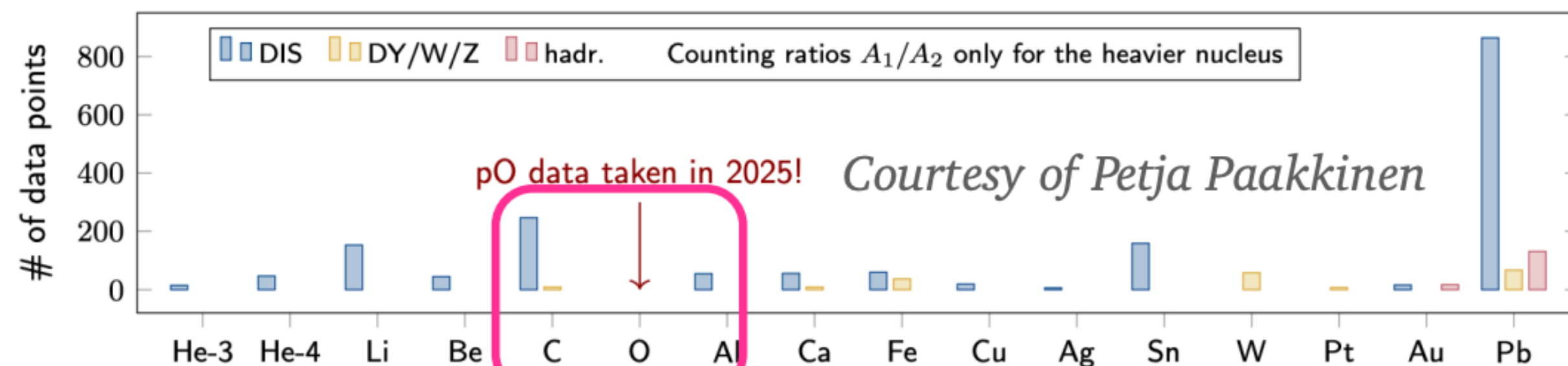
- Run 4 upgrades: better tracking (all experiments)
 - CMS: PID capabilities + High-Granularity Calorimeter + forward (PPS, FSC)
 - CMS+ATLAS: ZDC Upgrades
 - ALICE: FoCAL
 - All experiments: DAQ upgrades/refinements
- Run 5: ALICE 3



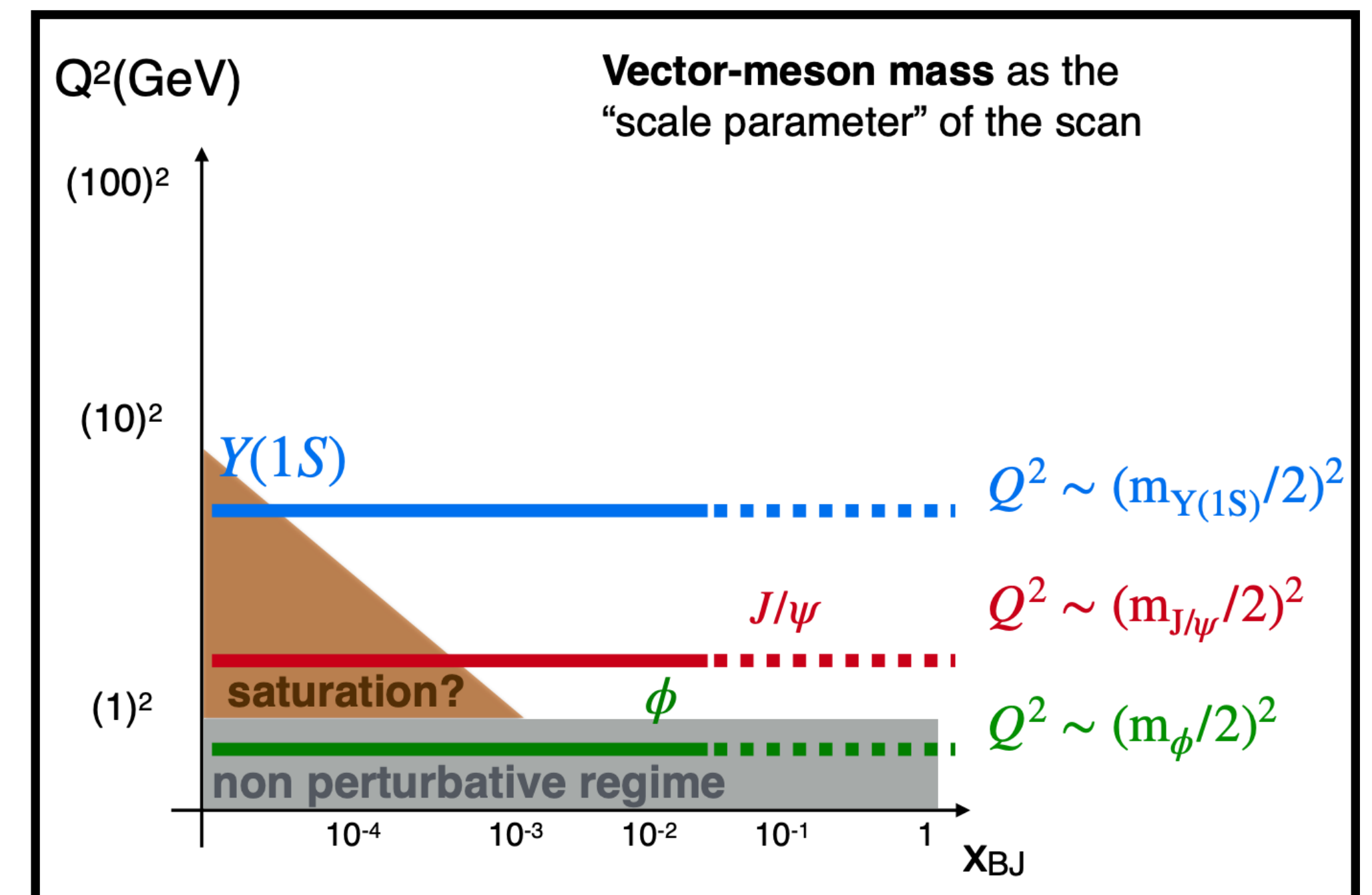
FOCAL detector setup in 2023 testbeam!

Potential synergistic physics

- A few ideas for synergies:
 - Vector meson photoproduction for smaller ions
 - Studies of gluon nPDF smaller ions
 - ...and plenty of room or creative ideas...



A-dependence of gluon nPDF is practically unconstrained!



From Gian Michele Innocenti's IS '25 talk

Summary

- **LHC very productive with short runs of new ion species**
- **History proves that future new ion efforts require:**
 - **Early planning**
 - **Strong and diverse physics case**
- **HIN community coordination for white paper underway**
- **Input to strengthen physics cases welcome!**
- **Hope this workshop helps stimulate new ideas and active discussion of this topic**

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Backup