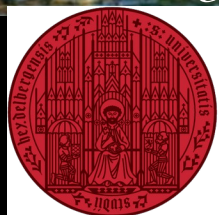


One Year of Light-Ion Collisions: What Have We Learned? or Five Years Later: What We Didn't Know Then

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September 25th
2026



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Timeline of light-ion runs

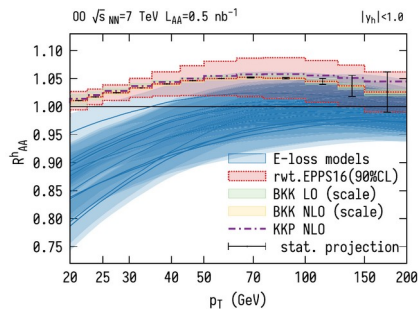
2018 CERN Yellow report
establishing a science case

OO at RHIC

ExtreMe Matter Institute EMMI
EMMI Rapid Reaction Task Force
Nuclear Physics Confronts
Relativistic Collisions of Isobars
Heidelberg University, Germany, May 30 – June 3 & October 12 – 14, 2022

pO, OO and
NeNe at LHC
July 1-9

OO at RHIC



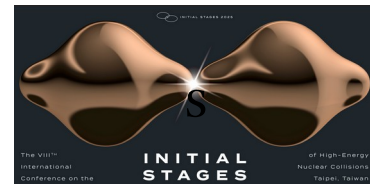
Predictions for energy loss in OO
Huss et al., PRL, 2007.13754



Virtual OO and pO workshop
2103.01939



Light-ions at LHC workshop
→ Ne possible at LHC



First results
in September!

Light-ion runs were a **community** effort
theory+machine+experiment

cern.ch/OppOatLHC



Workshop Summary Discussion

Jasmine Brewer, Aleksas Mazeliauskas and Wilke van der Schee

workshop summary document: [arXiv:2103.01939](https://arxiv.org/abs/2103.01939)

All talks were recorded – a wayback machine!

Questions from 5 years ago

Optimal center-of-mass energy for pO / OO

Maximum energy	Same $\sqrt{s_{NN}}$ as PbPb / pPb
7 TeV OO / 9.9 TeV pO	5.52 TeV OO / 8.79 TeV pO
1.5 higher luminosity	2-3 extra days tuning / system
pp reference?	Re-use pp reference from PbPb, pPb

Van der Meer scan: 2 hr/exp (1.5-3% accuracy)

Can pp reference be reliably interpolated? Which observables?

Quark-gluon plasma in OO?

- OO “sweet spot” between pPb and PbPb (but hotter and smaller than PbPb at same multiplicity).
- Extensive hydro model predictions – going beyond?
- Accurate flow measurements (up to $v_2\{12\}$, $N_{ch} < 100$).
- Change of sign in v_2 - p_T correlation in peripheral OO?
- Geometry control in OO:
 - Any sensitivity to alpha clustering?
 - Subnucleonic fluctuations (> than PbPb, < pPb).

What can be ruled out with OO data?

Energy loss in OO?

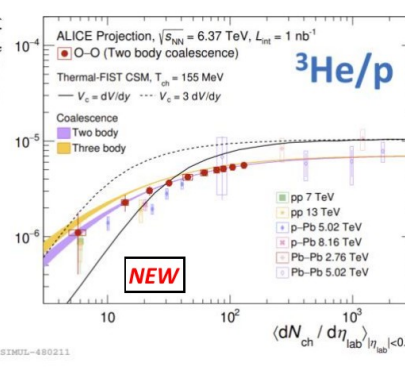
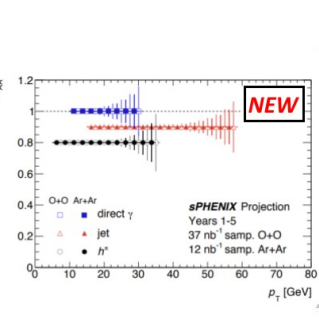
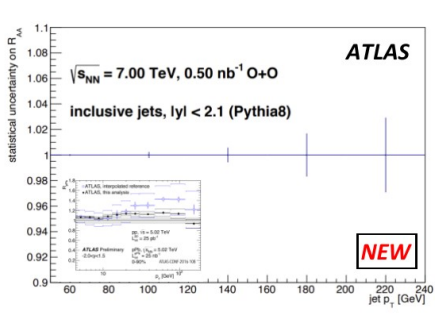
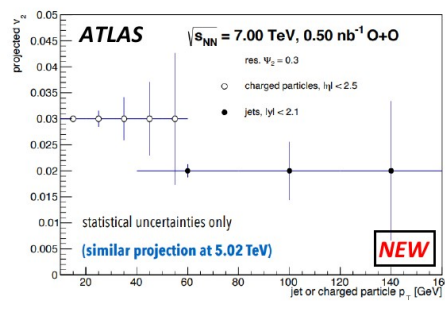
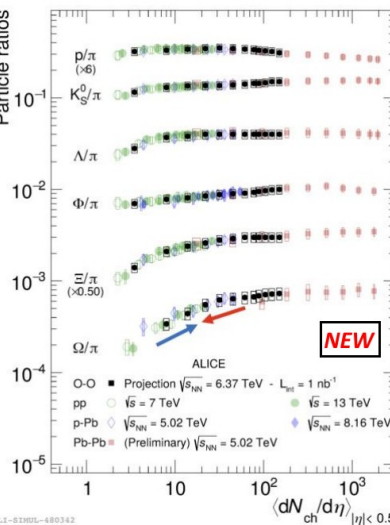
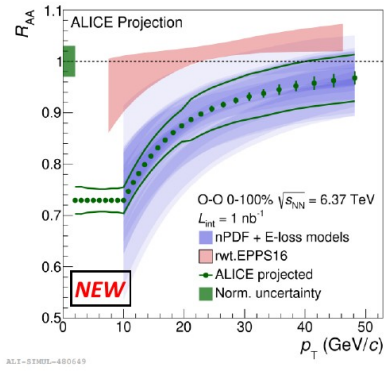
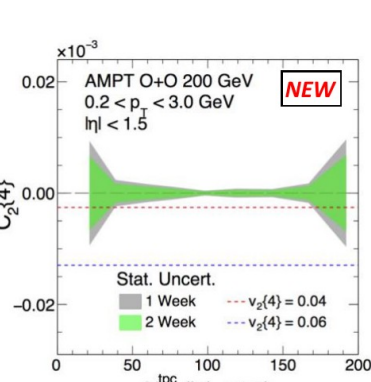
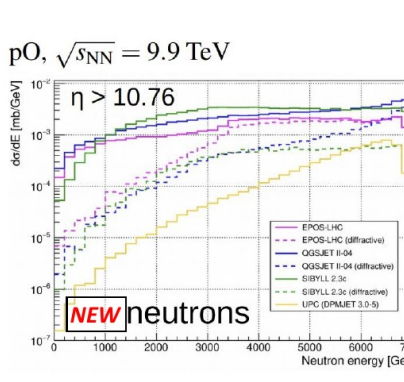
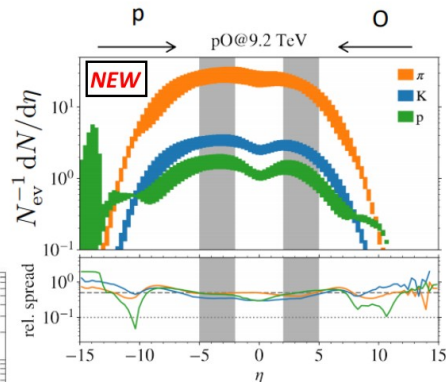
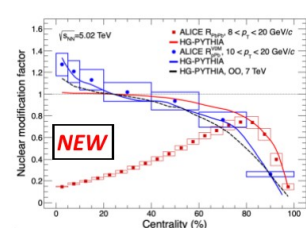
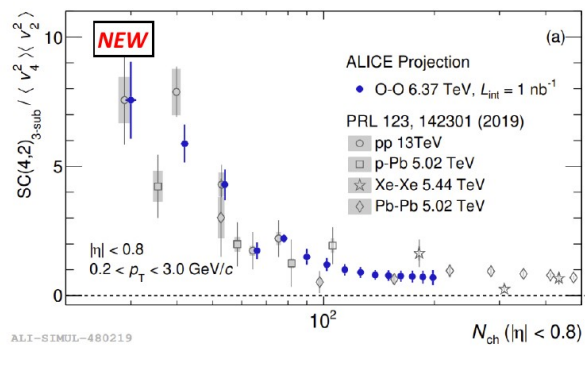
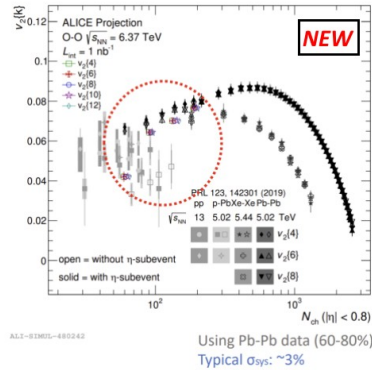
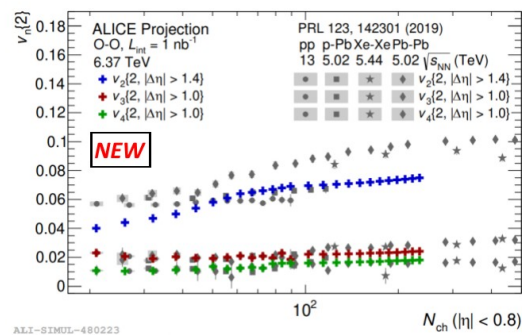
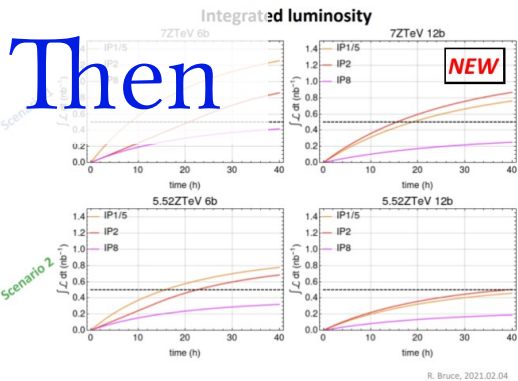
- Small signal expected: uncertainties of theory baseline (nPDFs) is crucial.
- No oxygen data in nPDF fits. Constraints from dijet R_{FB} , and R_{pO} in pO without reference?
- Experimental projections for hard probes (R_{AA} , high- p_T v_2 , h-jet).
- Need for theory developments on integrated soft and hard modelling.

What energy loss signal can be detected (without pp reference) and with which observables (MB / centrality, inclusive, semi-inclusive)?

pO and cosmic rays

- LHCb and LHCf probe relevant forward regions for cosmic rays and Pierre Auger.
- Significant luminosity for fixed target with various systems in SMOG2 (OO, PbO and many more).
- Unique opportunity window (LHCf can only take data in Run 3).

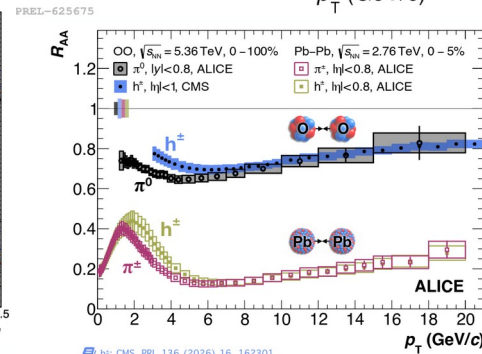
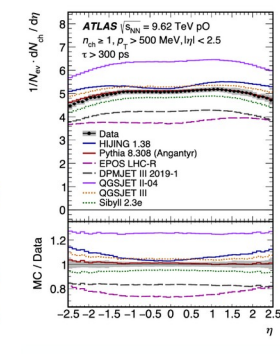
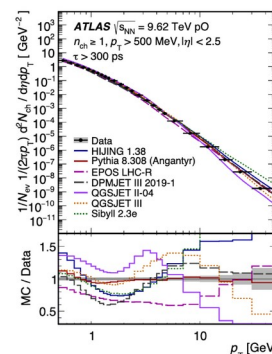
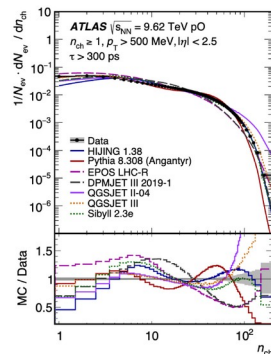
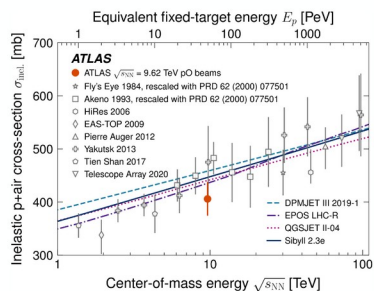
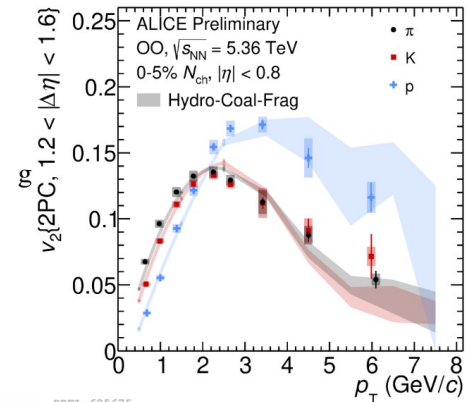
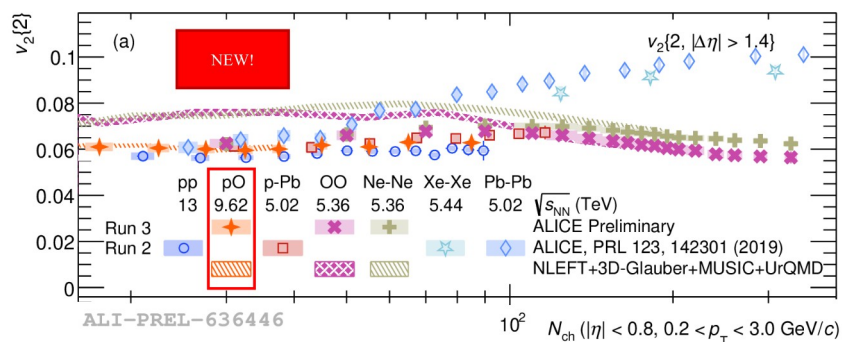
What impact will pO have on CR shower interpretation?



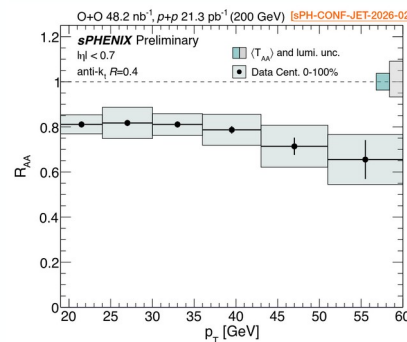
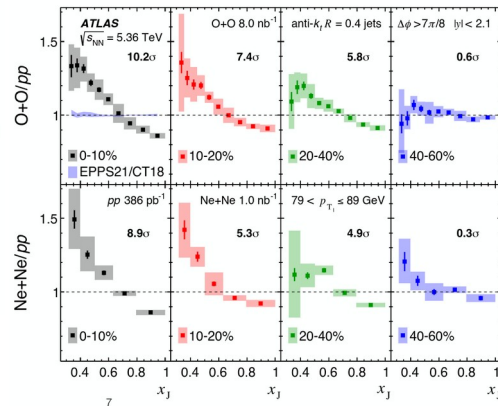
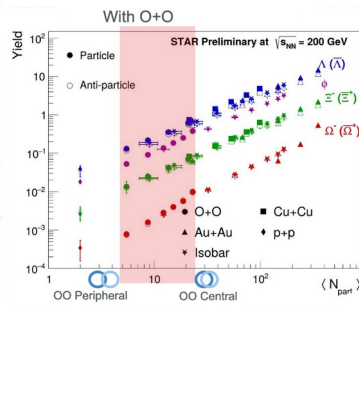
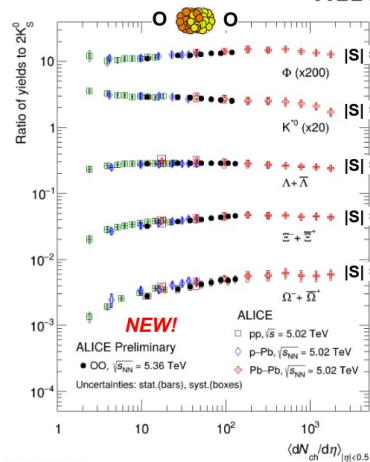
Now

Oxygen-Oxygen Luminosities

	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



ALICE



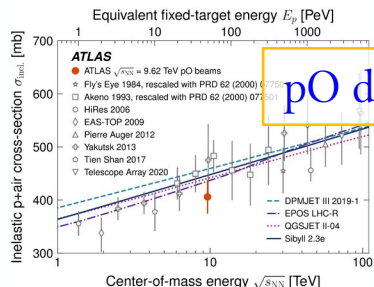
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Oxygen-Oxygen Luminosities

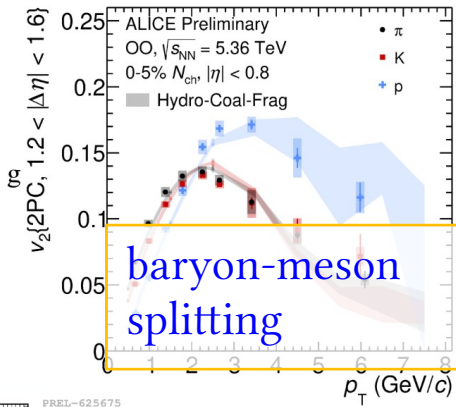
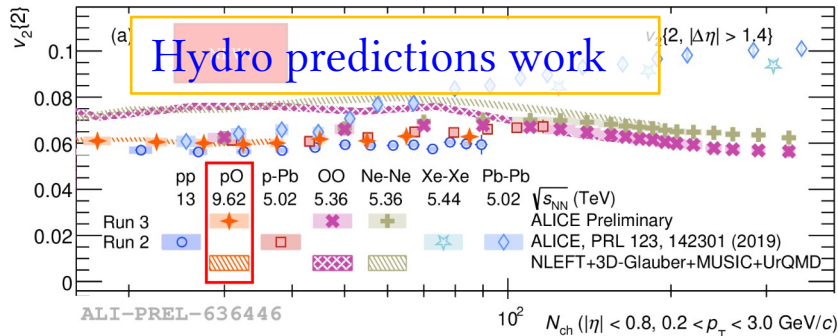
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OO at LHC and RHIC

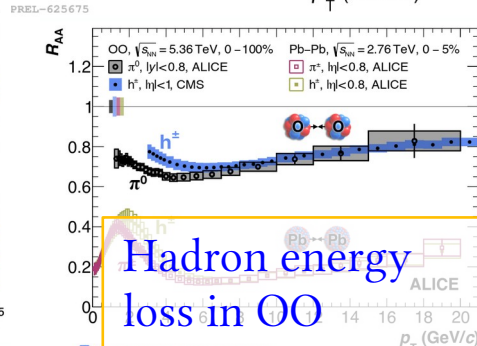
centrality bias?



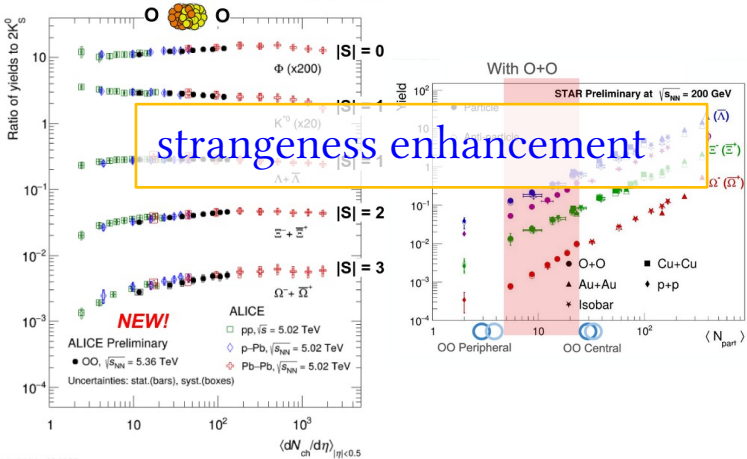
pO data for cosmic rays



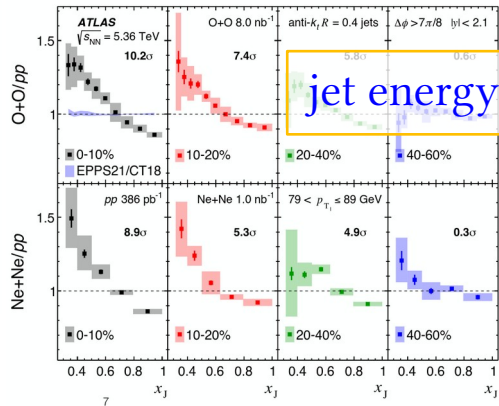
baryon-meson splitting



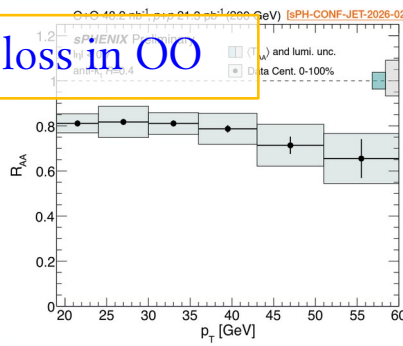
Hadron energy loss in OO



strangeness enhancement

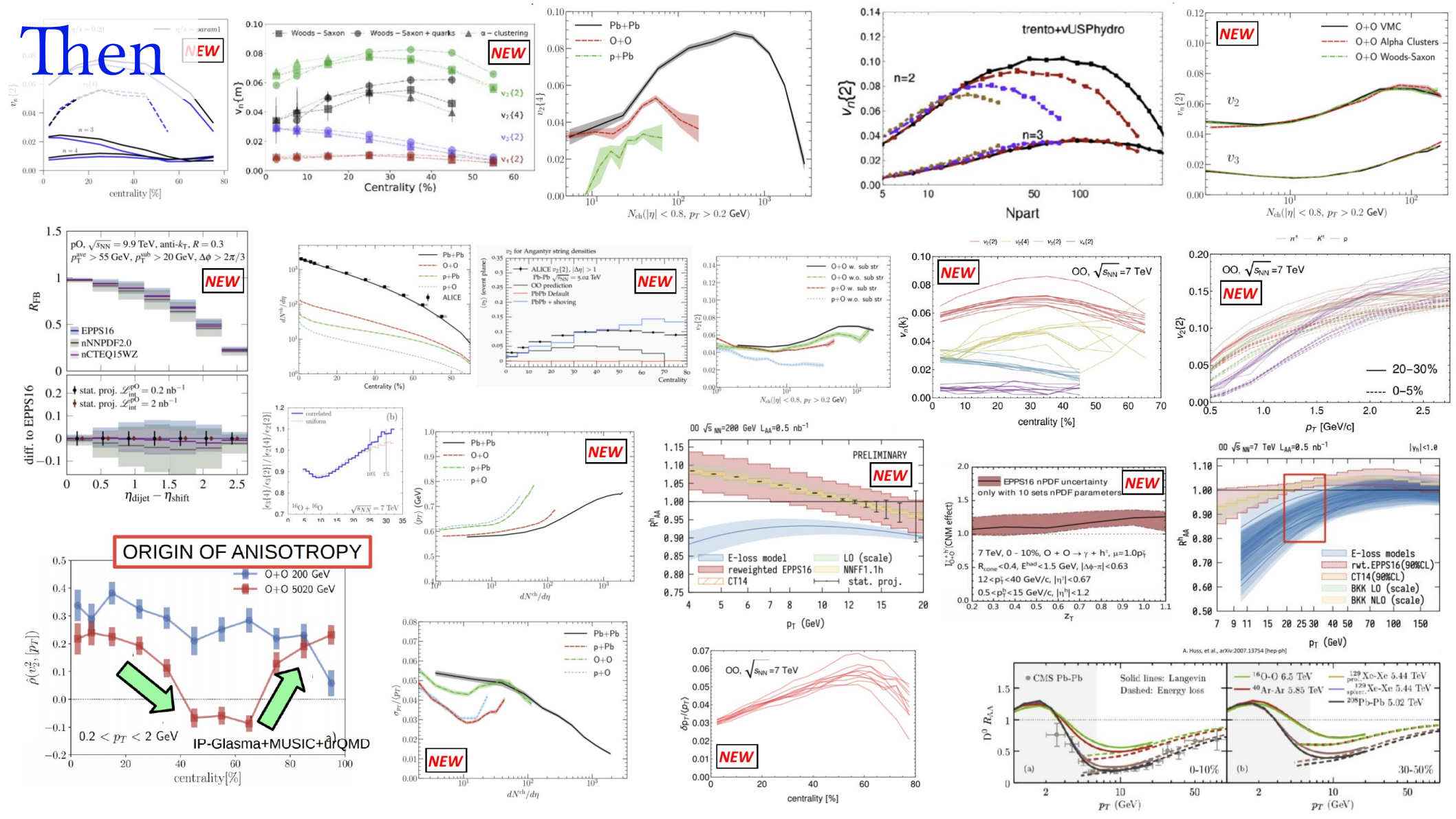


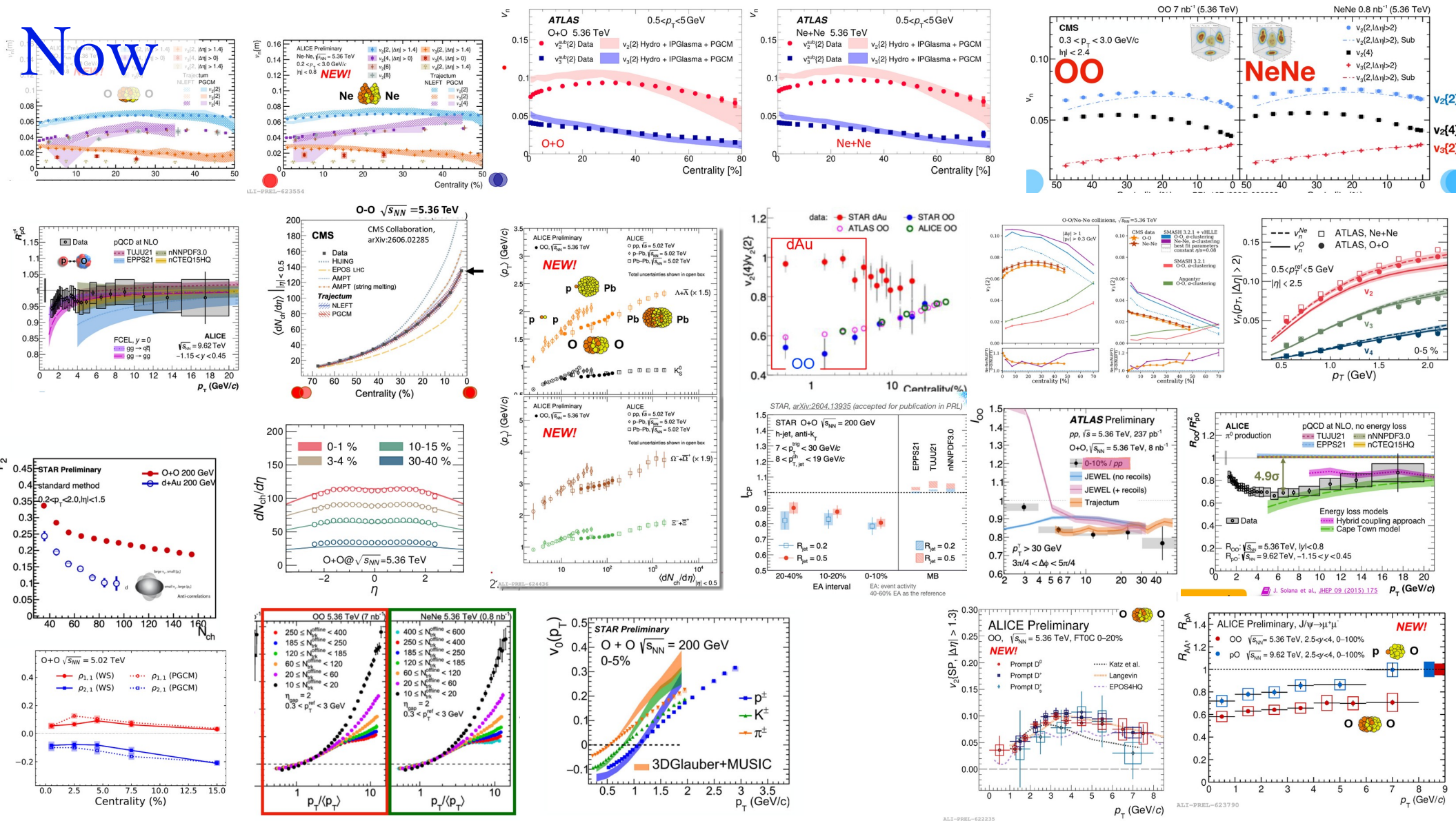
jet energy loss in OO

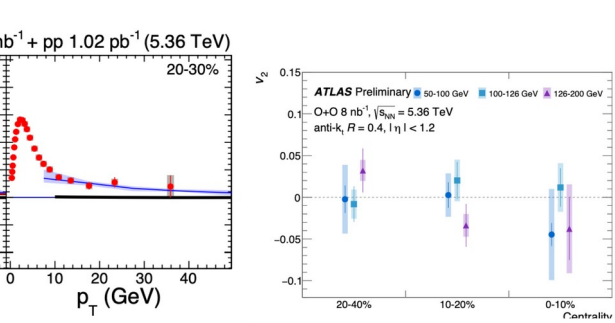
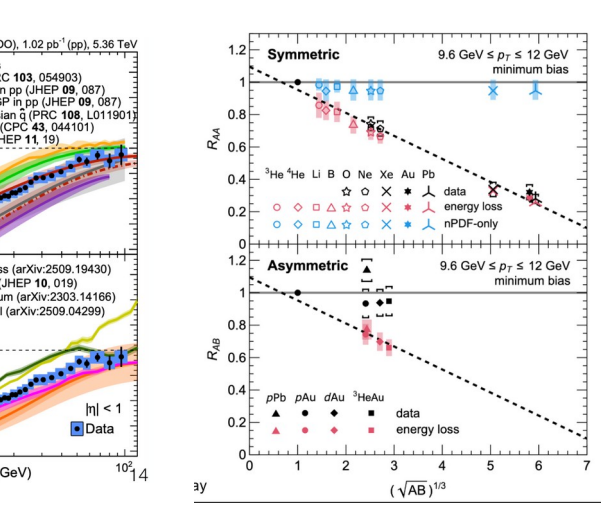
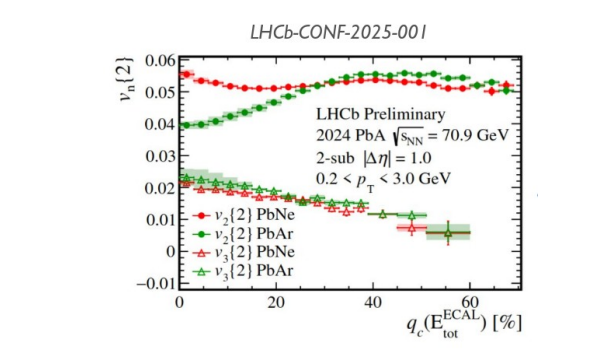
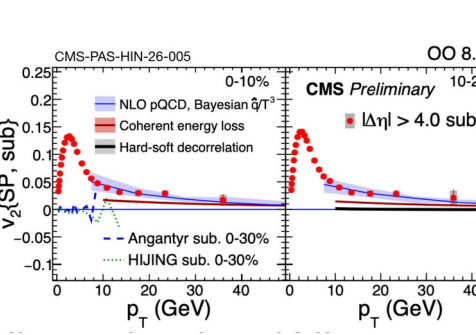
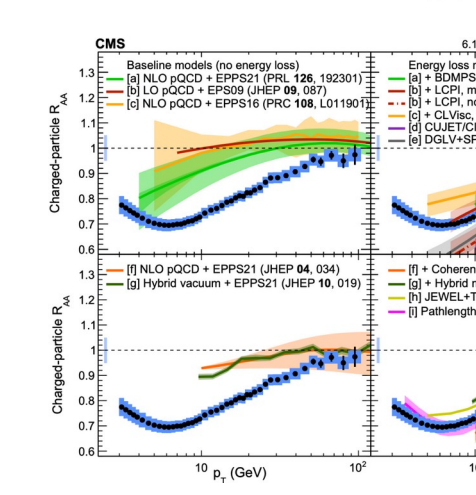
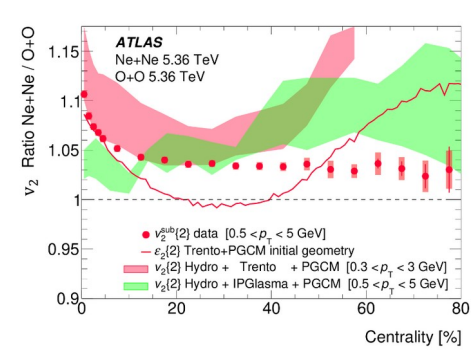
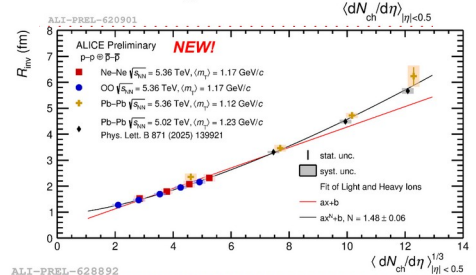
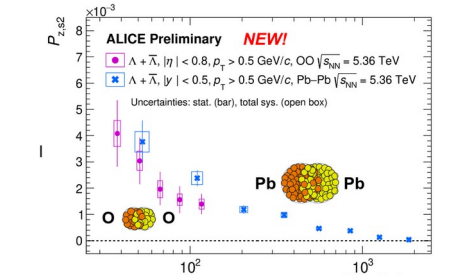
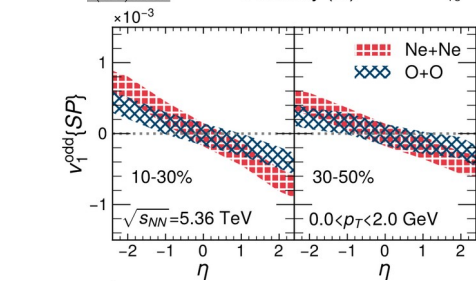
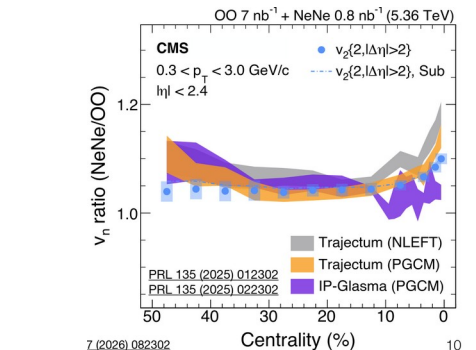
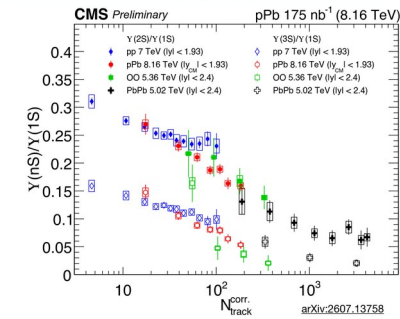
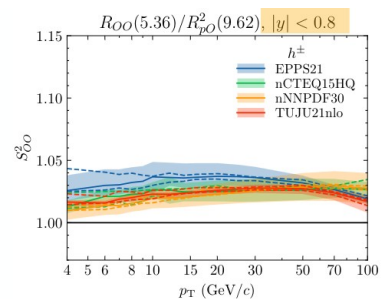
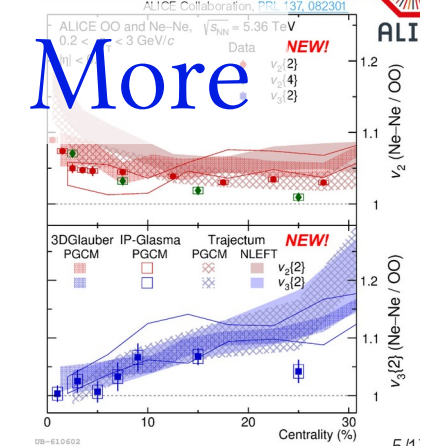


Light-nuclei production?

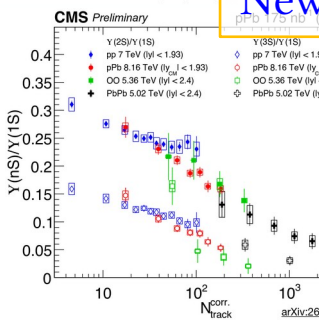
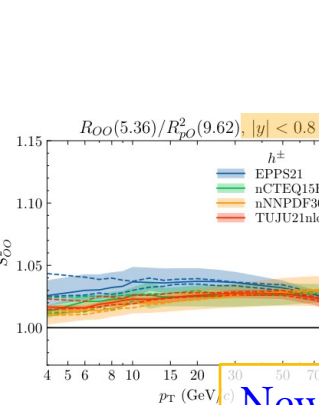
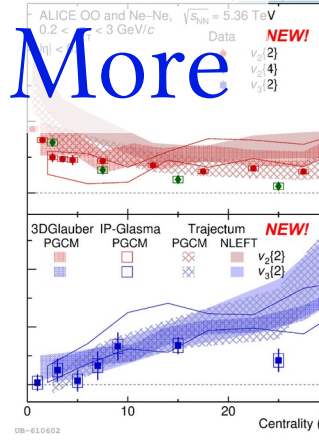
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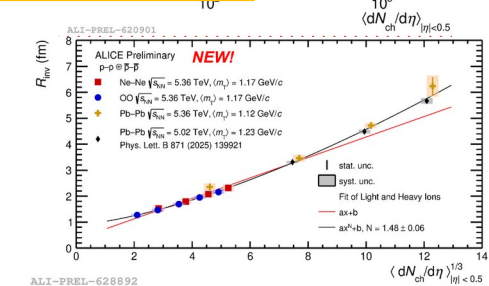
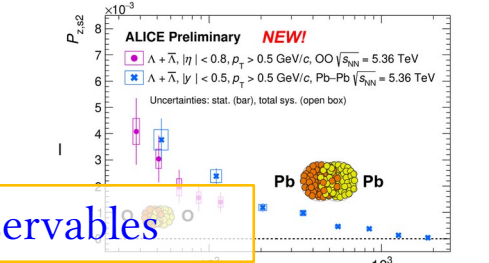
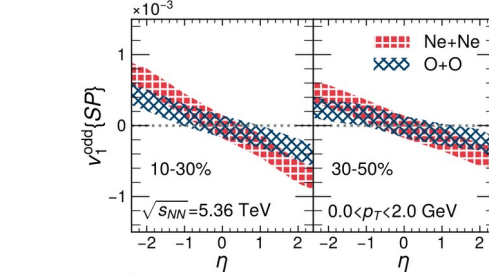
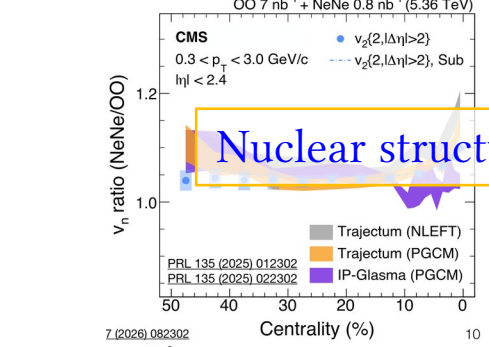




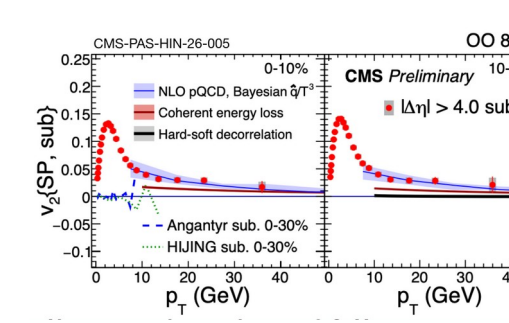
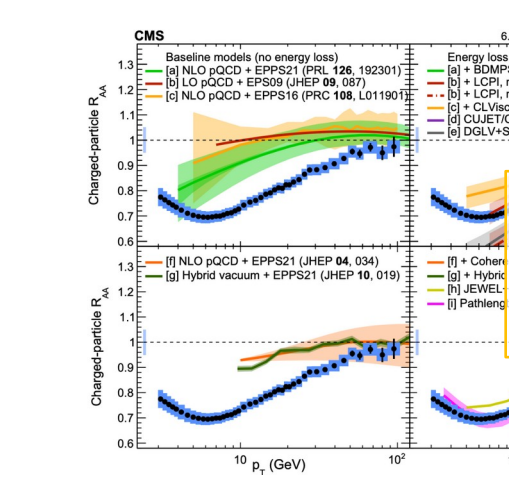
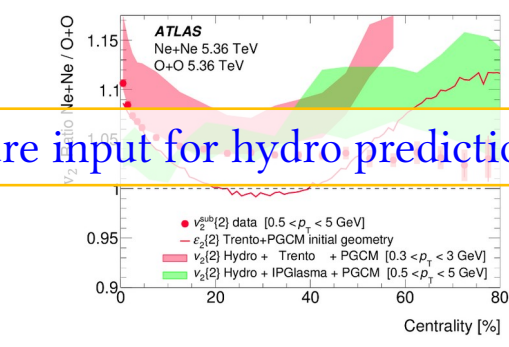
More



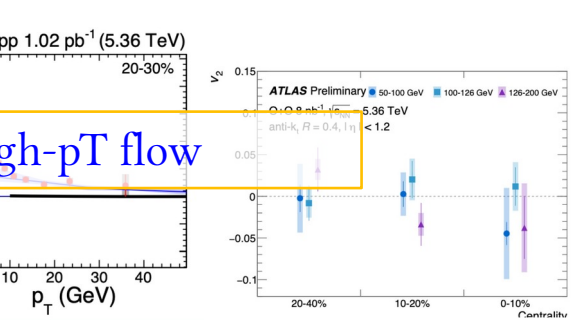
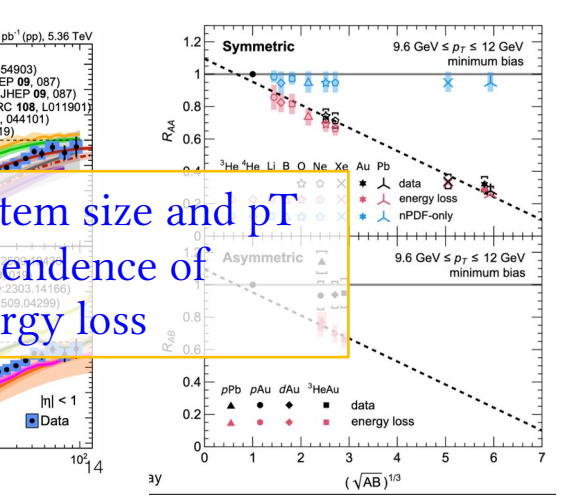
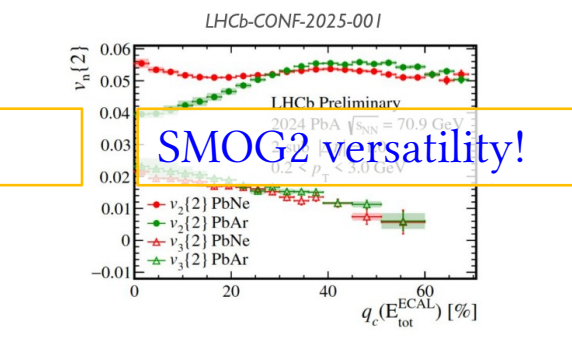
ALI



Nuclear structure input for hydro predictions

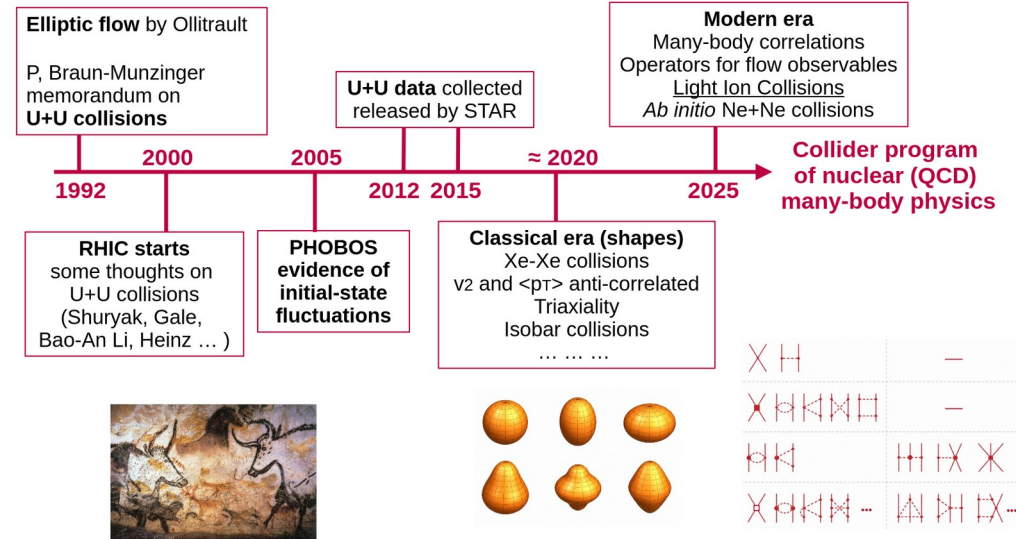
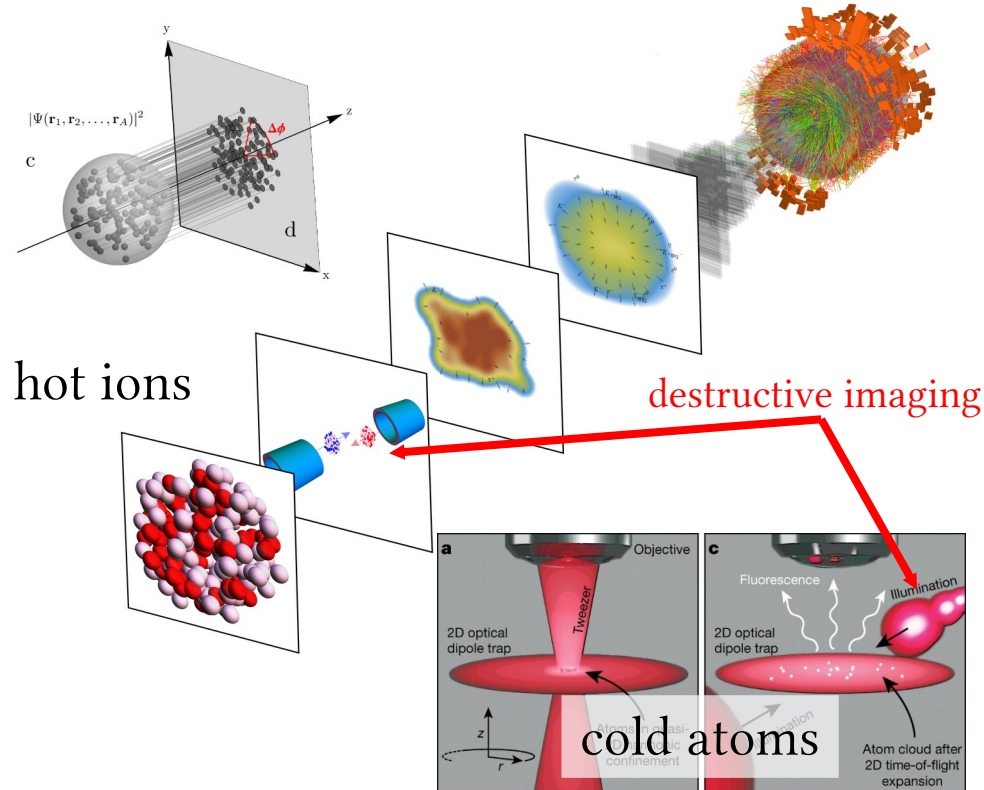


System size and pT dependence of energy loss



High-pT flow

Synergies with nuclear structure physics



Credit: Giacalone

Ion collisions take snapshots of nucleus wave-functions

Impact of light-ion data (survey)

21

valid responses

18

answered Q1

17

answered Q2

SURVEY QUESTIONS

Q1 What did you learn from the light-ion collision data that you did not know, or believed differently, **before?** Please name the specific observables or measurements involved, and state how your understanding changed.

Q2 What would you still like to learn from light-ion collisions? For each item, please indicate what would be required to learn it: new analyses of existing data, theory or modelling developments, or new ion runs.

Thank you for your input!

What have we learned?

- **Light-ion collisions behave much like heavy-ion collisions**
 - Hydrodynamic models describe flow in light-ion systems
 - Energy loss is consistent with extrapolation from larger systems
 - Heavy-flavour observables evolve smoothly with system size
- **Light-ion collisions probe nuclear structure and chiral EFT parameters**
 - Sensitive to nuclear shapes and neutron skins
 - Need precise quantum-mechanical definitions of observables
- **The LHC is a versatile ion machine**
 - Demonstrated fast switching between ion species
 - Close cross-community collaboration is key to turning new ideas into runs

Results are still coming → the light-ion data impact is evolving

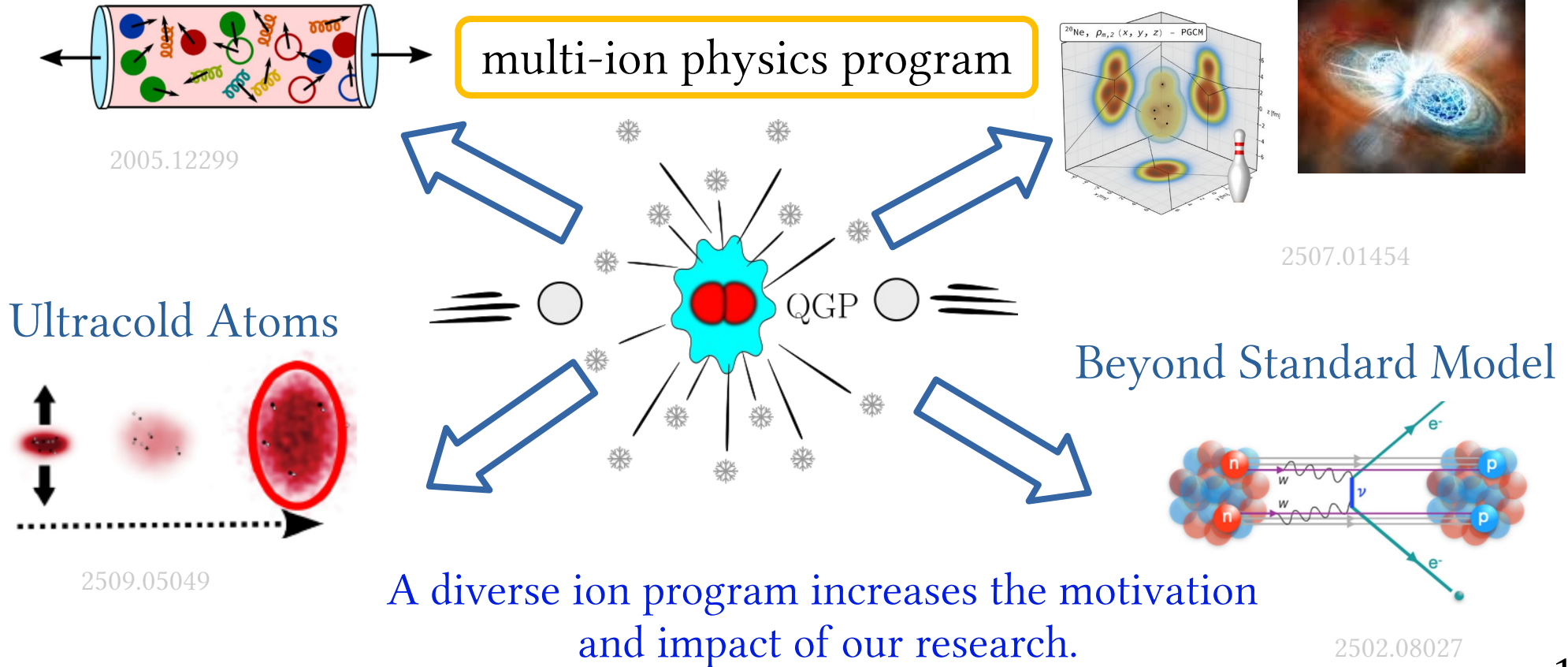
What do we still want to learn?

- **Where do collective effects turn off?**
 - Precise system size dependence of hydrodynamics and jet quenching
 - Signatures of pre-equilibrium and non-hydrodynamic dynamics
 - Consistency of extracted QGP and initial-state parameters with large systems
- **What is the centrality and rapidity dependence of light-ions?**
- **What is the origin of high-pT elliptic flow?**
- **How precisely can we image nuclei?**
 - Quantified theory uncertainties and links to low-energy observables
 - Nuclear-structure imprints in new probes: heavy-flavour flow, spin polarization
- **Which ions should we run next?**
 - Lighter, intermediate-mass, or more O-O?
 - What are our physics priorities?
 - What injector upgrades are needed to make these runs possible

Physics reach of diverse ion program

Hot and Dense QCD

Low energy nuclear physics





Thank you for your participation!