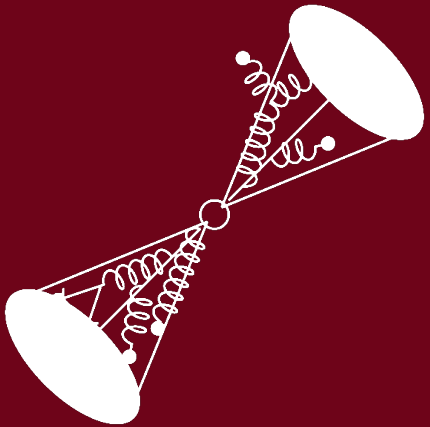
Recent Measurements in Small Systems at the LHC and RHIC

Chris McGinn

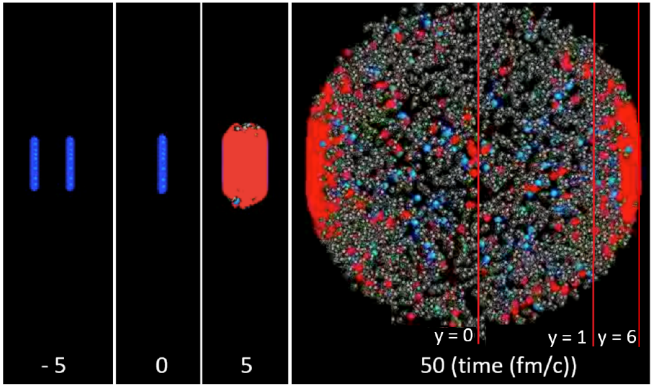
RHIC/AGS Annual Users' Meeting

11 May 2026



MITHIG's work is supported by US DOE-NP

Schematic of Heavy Ion Collisions

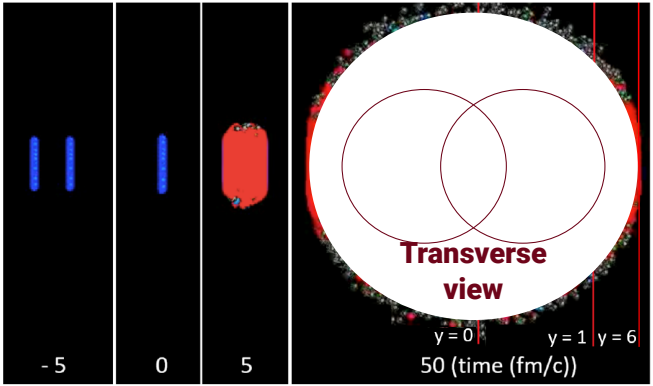


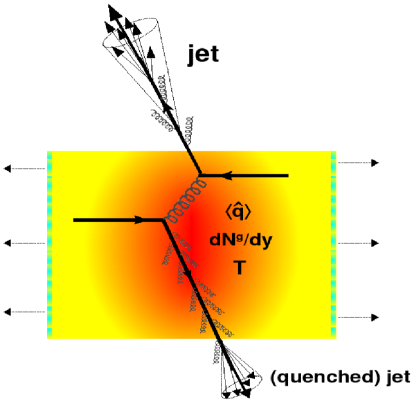
Still via Ann.Rev.Nucl.68 (2018)

Full video via Yen-jie Lee, Wit Busza, and Andre Yoon

1. Lorentz-contracted nuclei inbound
2. Initial collision
3. After some formation time, Quark Gluon Plasma (QGP) - hydrodynamics takes over
4. After some longer time, freezeout and hadronization

Probing the Quark Gluon Plasma with Jets

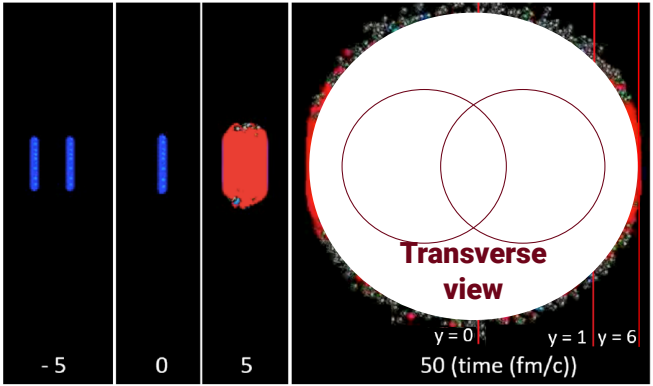


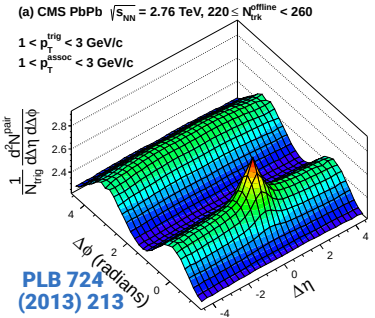


Via D. d'Enterria

- Hard-scattered partons act as QGP probe
  - Energy loss observed in jets taken as possible sign of QGP formation

Geometry to Momentum Space Correlations





Initial state geometry in AA → long range correlations via hydro.

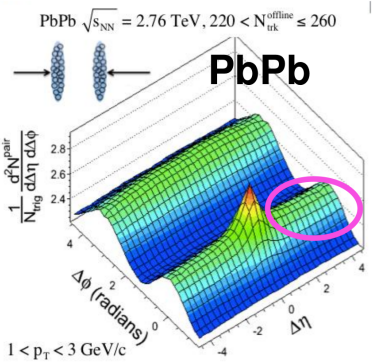
$\sim 1 + 2\,\Sigma_n v_n^2 \cos(n\Delta\phi)$

v_2 → **ellipticity**

- **Long-range correlations taken as possible sign of QGP formation**

A Droplet of Plasma in Small Systems?

PLB 724 (2013) 213



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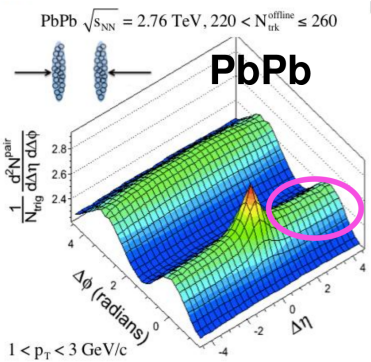
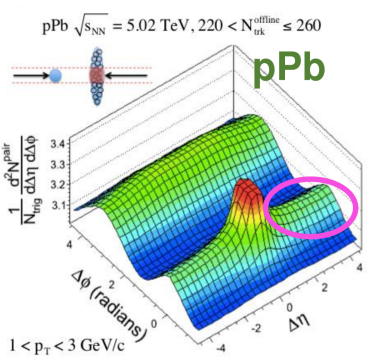
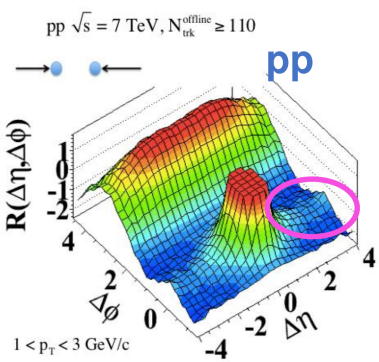
PLB 724 (2013) 213



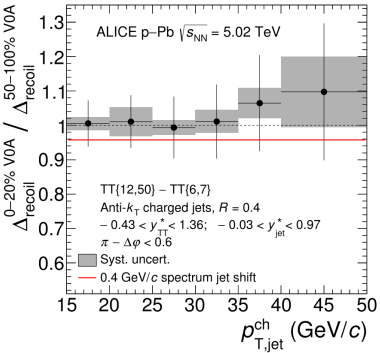


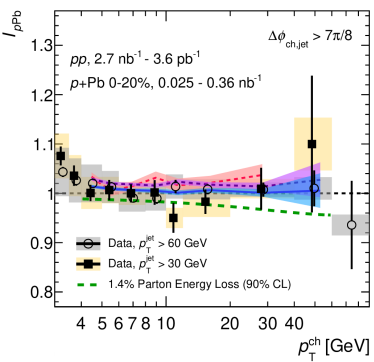
PLB 765 (2017) 193

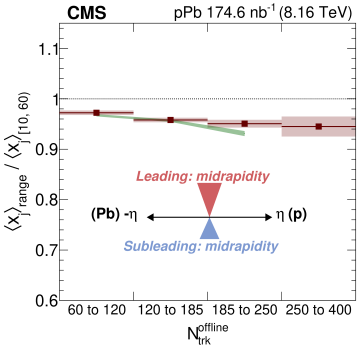


- **Observable phenomena in collision systems of all sizes!**
- **Possible signature of QGP droplet formation in small systems?**

Where Is Quenching in Small Systems?







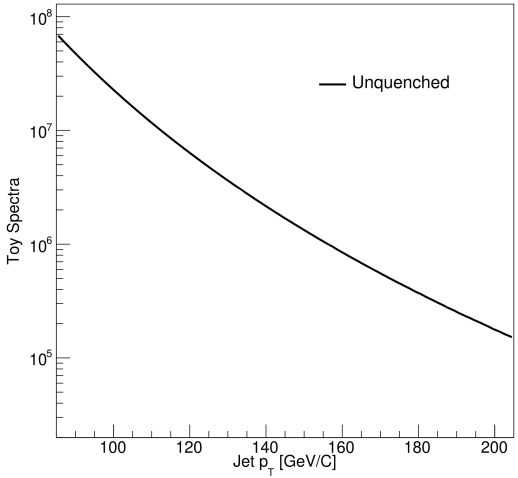
PLB 783 (2018) 95

PRL 131 (2023) 072301

JHEP 07 (2025) 118

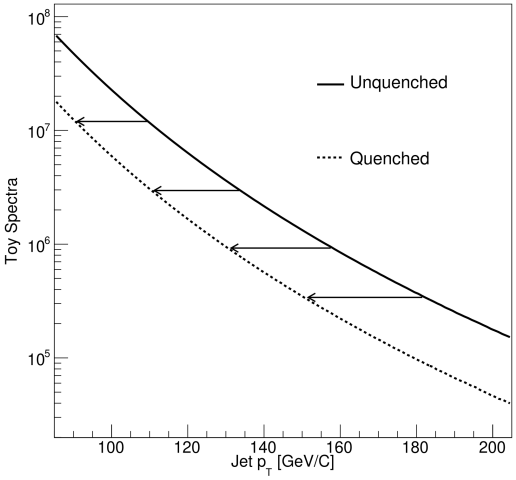
- Many independent searches for quenching in pPb have returned no indications
- ALICE, ATLAS, and CMS have all set stringent limits w/ dijet x_J, jet-hadron correlations

Energy Loss and Spectra



$$R_{AA}\ (R_{pA}) = \frac{\text{Spectra in AA (pA)}}{\text{Spectra in pp, scaled by \# of nucleon-nucleon collisions}}$$

Energy Loss and Spectra



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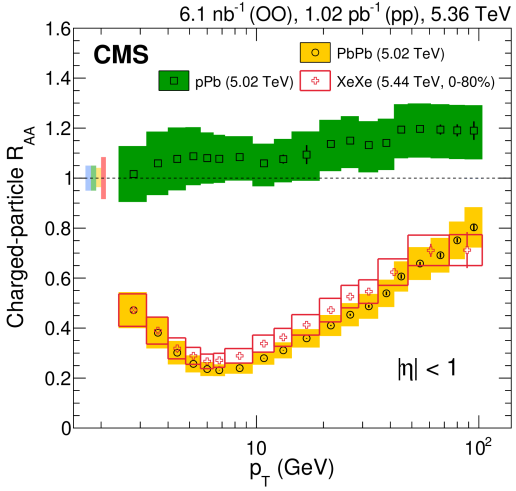
Quenching shifts spectra left $\rightarrow$ R_{AA} (R_{pA}) suppressed!

Energy Loss and Spectra



R_{AA} (R_{pA}) = **Spectra in AA (pA) / Spectra in pp, scaled by # of nucleon-nucleon collisions**

Quenching shifts spectra left → R_{AA} (R_{pA}) suppressed!

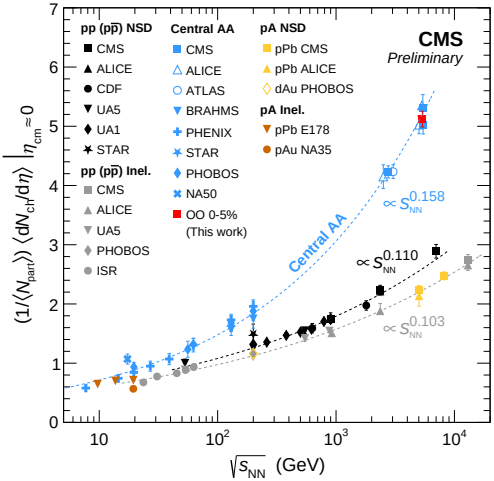
No such shift observed in R_{pA}

Adapted from PRL 136 (2026) 162301

The Case for Light Ion Collisions

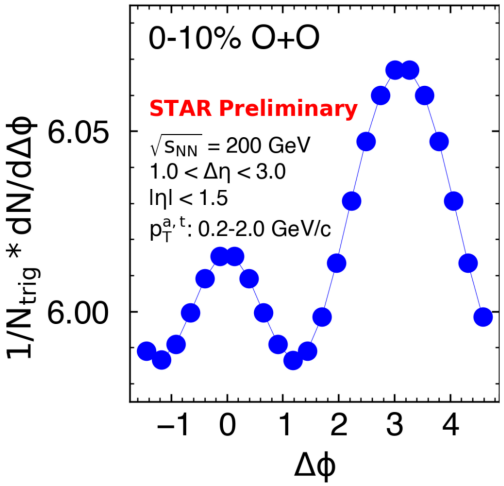
Light ions to bridge the gap

- N_{part} **comparable with pA**
- **No longitudinal asymmetry**
- **Greater transverse area of collision**
- **Reduced bias in centrality selections**



CMS-PAS-HIN-25-010

Flow Measurements in OO with STAR

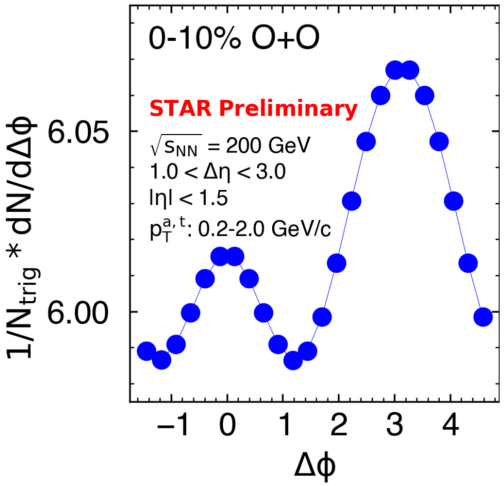


Sijie Zhang, QM2025

STAR took OO collisions in 2021

- **Clear long-range correlation signature!**

Flow Measurements in OO with STAR



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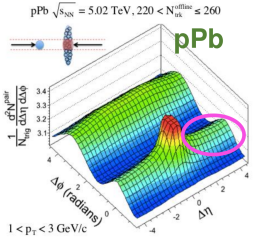

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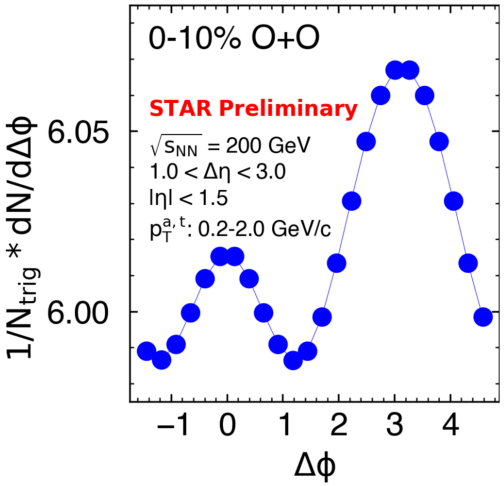

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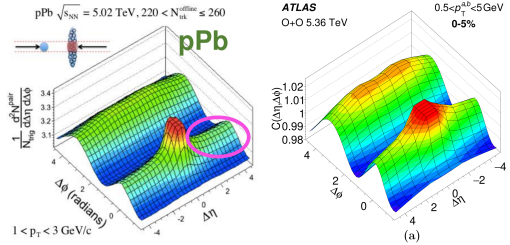
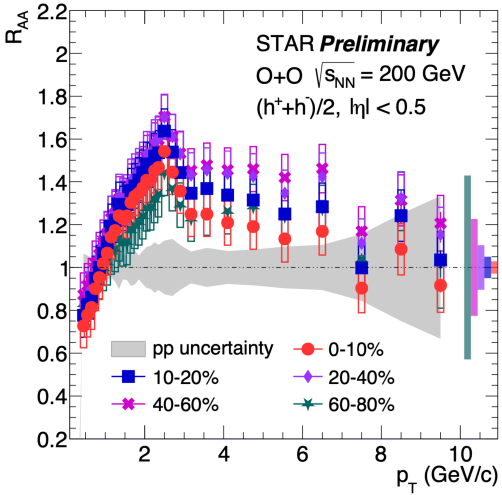


- **Also seen w/ later LHC datataking**
- **What about quenching signatures?**

Quenching Search in OO from STAR

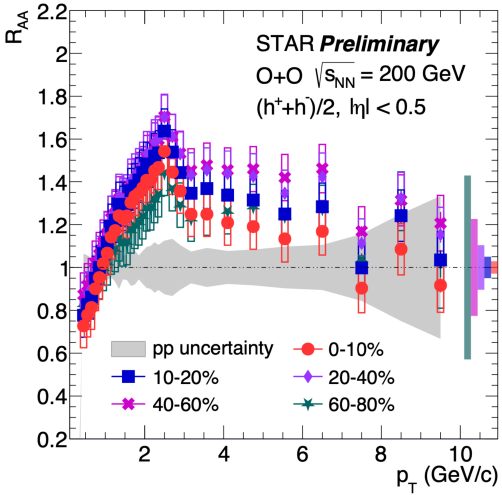


Sijie Zhang, QM2025

Initial quenching search inconclusive

- **Significant normalization uncertainties**

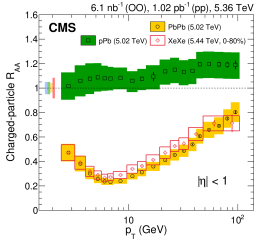
Quenching Search in OO from STAR



Sijie Zhang, QM2025

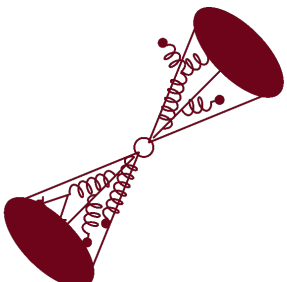
Initial quenching search inconclusive

- **Significant normalization uncertainties**
- **Compare w/ pA hadron R_{pA}**



- **Other initial studies (hadron-triggered I_{CP}) also inconclusive**

New Light Ions Data at the LHC

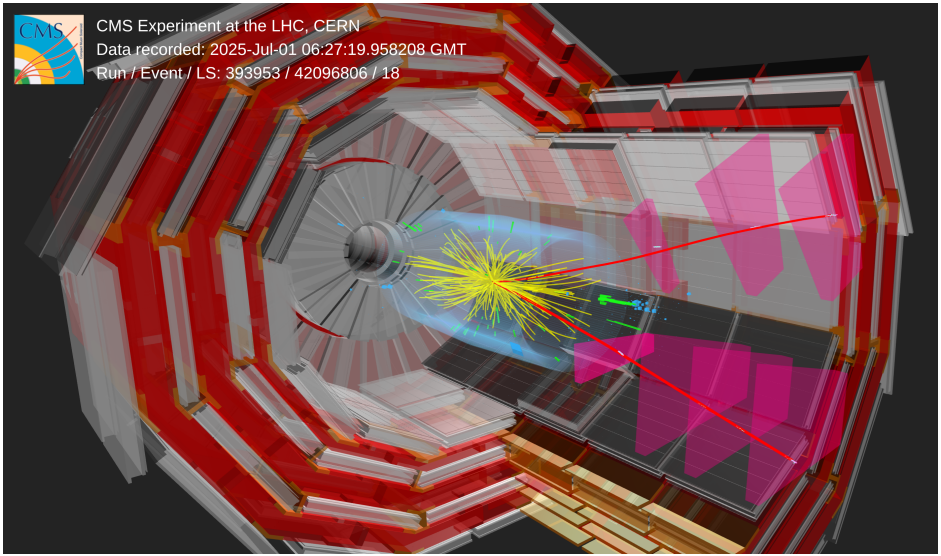


New Light Ions at the LHC

	Jul		Aug						Sep				
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	30	7	14	21	28	4	11	18	25	1	8	15	22
Tu	O ion setting up	Ne-Ne run								MD 2			
We		ZDCs out											
Th	MD 1b	VdM program									Jeune G.		
Fr													
Sa	O-O & p-O Ions run												
Su													

3 short runs in July 2025 →

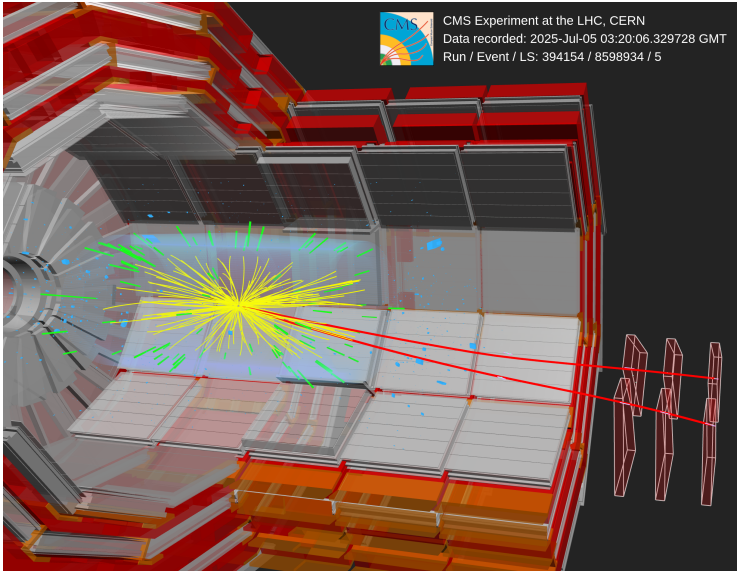
LHC Datataking for pO,



Data taken July 1st-3rd

pO event displays via CDS

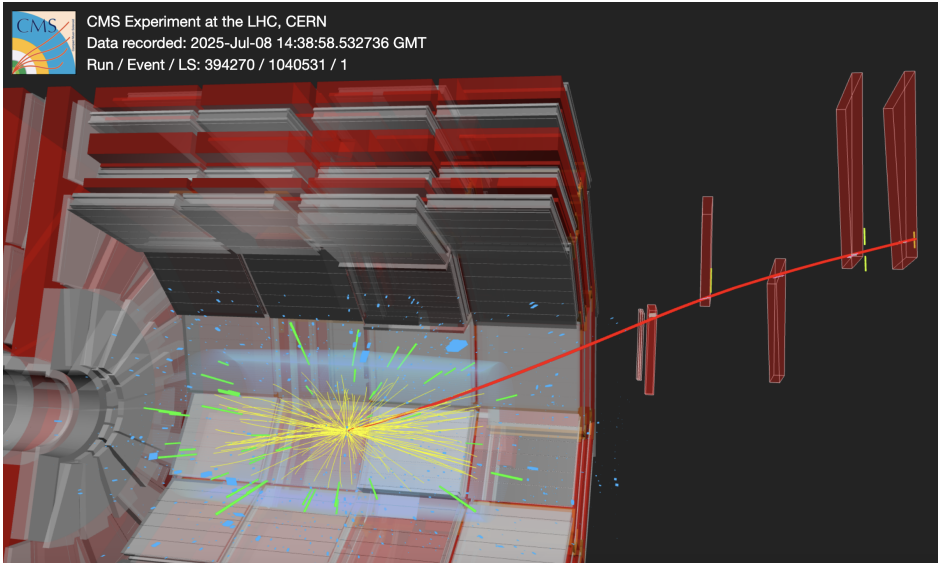
LHC Datataking for pO, OO,



Data taken July 5th-7th

OO event displays via CDS

LHC Datataking for pO, OO, and NeNe!



Data taken July 8th-9th

NeNe event displays via CDS

Luminosity Delivered in Light Ions at the LHC

	Jul		Aug							Sep			
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
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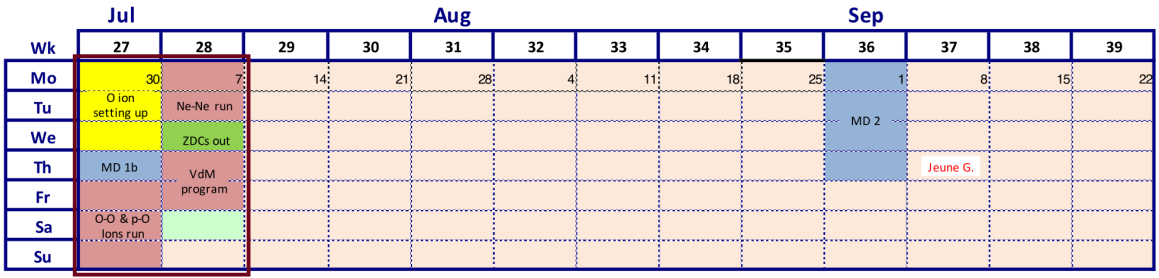

OO

(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

NeNe

(nb^{-1})	target	delivered	F
ATLAS	0.1	1.0	10
ALICE	0.1	0.91	9.1
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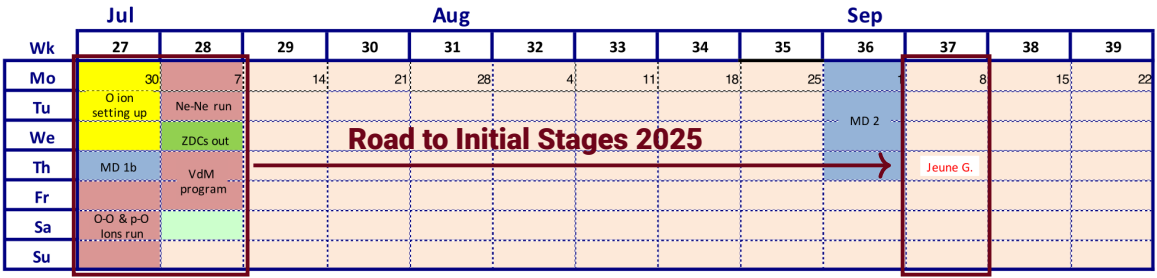
LHCb	0.1	0.61	6.1

Via LHC report at Sept. Jamboree

Luminosity Delivered in Light Ions at the LHC



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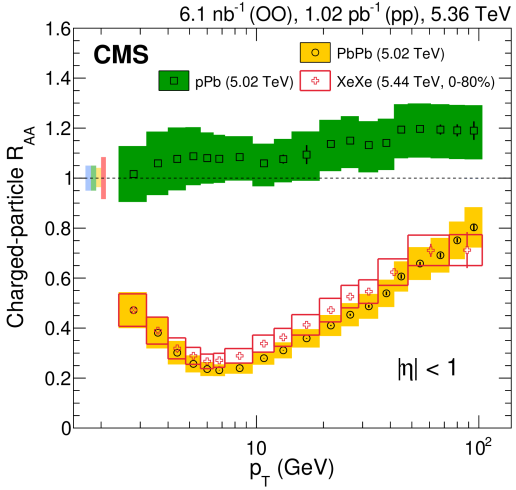
Will we see the onset of quenching?

Via LHC report at Sept. Jamboree

CMS Charged-Particle R_{AA} in OO



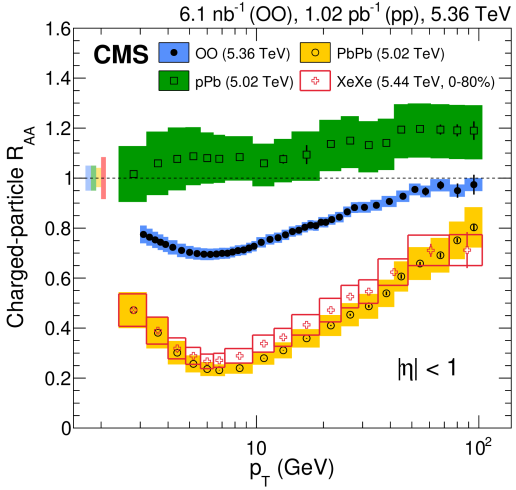
CMS charged-particle spectra

- **Measure inclusive in centrality → avoid Glauber modeling**
- **Take R_{AA} definition as:**

$$R_{AA} = \frac{1}{A^2} \frac{d\sigma_{OO}/dp_T}{d\sigma_{pp}/dp_T}$$

Adapted from PRL 136 (2026) 162301

CMS Charged-Particle R_{AA} in OO



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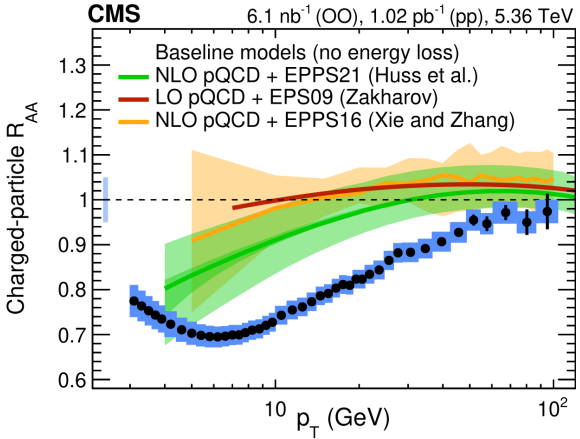
- **Take R_{AA} definition as:**

$$R_{AA} = \frac{1}{A^2} \frac{d\sigma_{OO}/dp_T}{d\sigma_{pp}/dp_T}$$

- **Suppression, $\sim 7\sigma$ significance**
- **$\sim$0.69 at 6 GeV**

Adapted from PRL 136 (2026) 162301

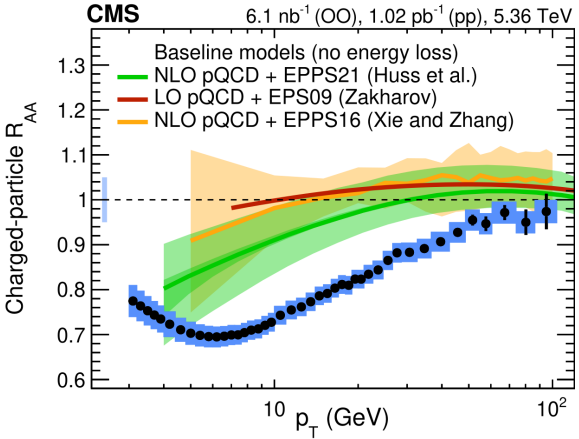
Comparison to Baseline without Quenching

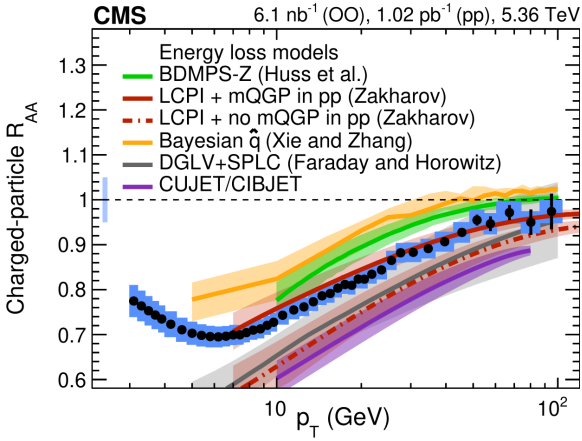


Adapted from PRL 136 (2026) 162301

- **nPDF effects can explain some fraction of observed suppression**
- **This measurement alone insufficient for quenching observation**
- **EPPS21 approximately 2σ from data**
  - **pO data will prove crucial for constraining nPDFs!**
  - **First results from ATLAS!**

Comparisons To Quenching Models

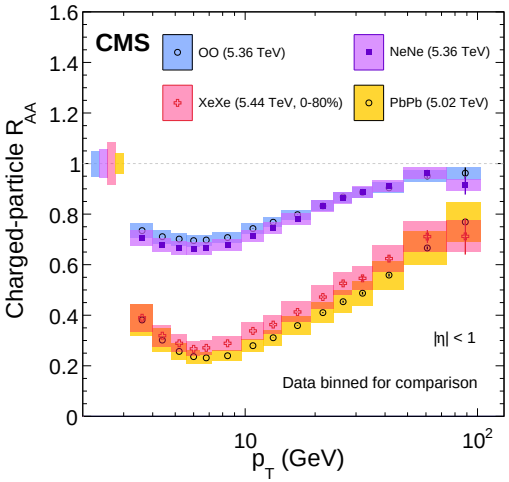




Adapted from PRL 136 (2026) 162301

- **However, data is clearly best described with quenching models!**

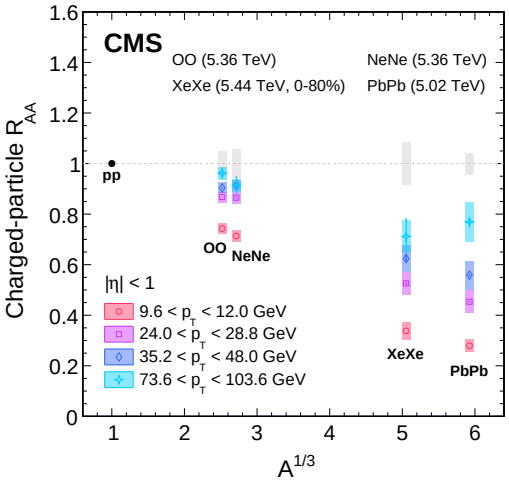
Measurement of R_{AA} in NeNe Collisions



Submitted PLB

- Measured charged-particle R_{AA} in NeNe collisions!
- Slight increase in observed suppression
  - O: 16 nucleons
  - Ne: 20 nucleons
- Need to take normalization uncertainties seriously!

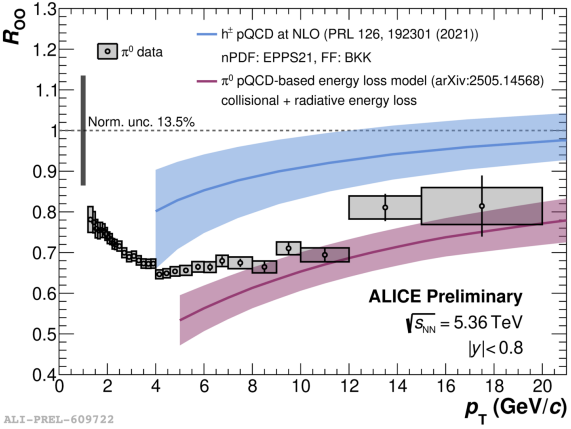
Dependence of R_{AA} vs. $A^{1/3}$



Submitted PLB

- LHC AA quenching data now spans many systems!
- We can now consider ordering in A^n
- Plot vs. $A^{1/3}$ as a path-length proxy
  - Qualitative linearity on inspection
- Important follow-ups:
  - pO data for nPDF constraints
    - (ATLAS first look!)
  - Centrality-differential R_{AA}

ALICE π^0 R_{AA} in OO

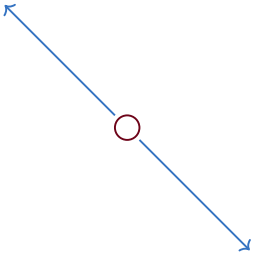


ALICE Preliminary

- **Significant suppression observed in independent measurement!**
- **Comparison w/ CMS must come with caveats**
  - **π^0 vs. all charged-particles**
  - **Different acceptance in η**
- **Qualitative agreement in overall suppression**
- **Shared limitations of luminosity uncertainty and nPDF effects**

Dijet Balance as a Quenching Probe

Consider a qq hard-scattering:



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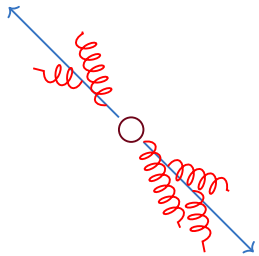

- **Parton will fragment+hadronize**

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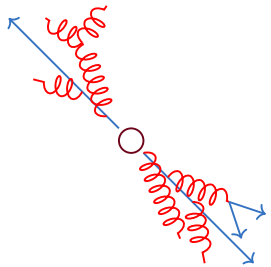

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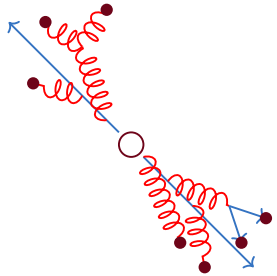
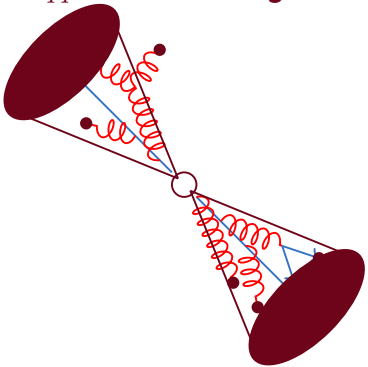


- **Parton will fragment+hadronize**
- **We have focused on hadrons**

Dijet Balance as a Quenching Probe

Consider a qq hard-scattering:



- **Parton will fragment+hadronize**
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- **What about at the jet level?**

Dijet Balance as a Quenching Probe

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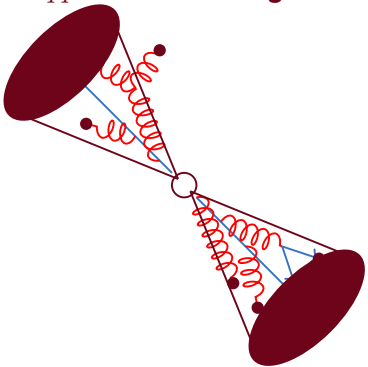
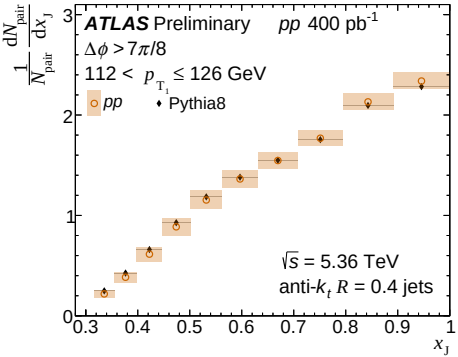


- **Parton will fragment+hadronize**
- **We have focused on hadrons**
- **What about at the jet level?**

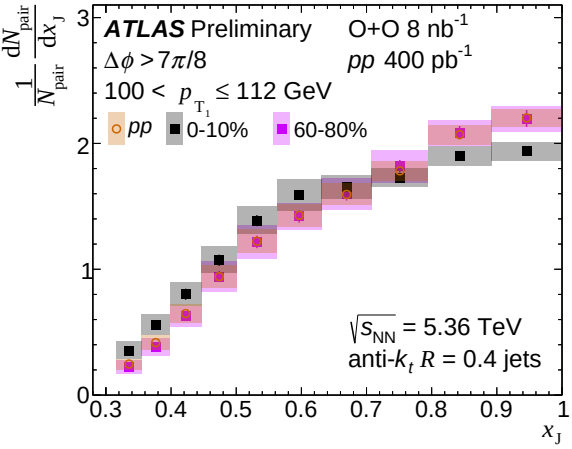
Consider x_J = $p_{T,SubleadingJet}$ / $p_{T,LeadingJet}$

Via ATLAS-CONF-2025-010



- **Well-modeled by PYTHIA in pp**

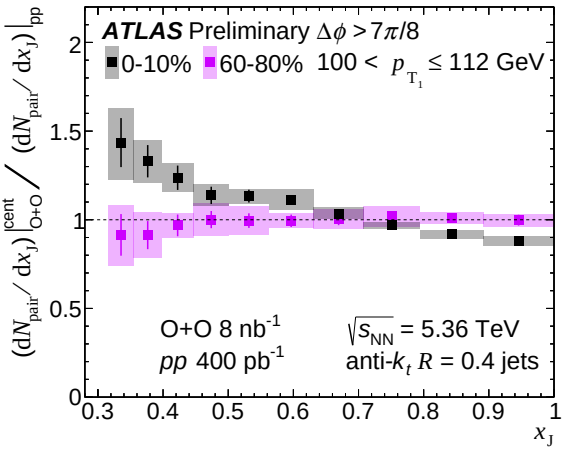
Dijet Balance in OO with ATLAS



ATLAS-CONF-2025-010

- **Jet measurements have reduced sensitivity to nPDFs**
- **Differential in centrality → stronger quenching potential**

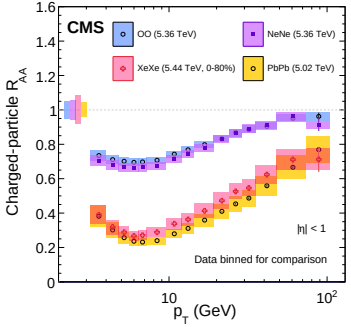
Dijet Balance in OO with ATLAS

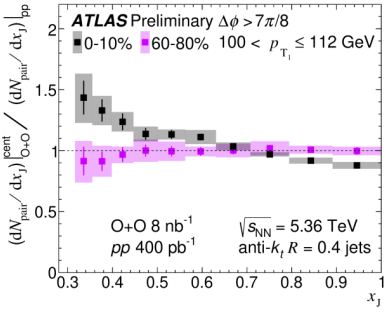


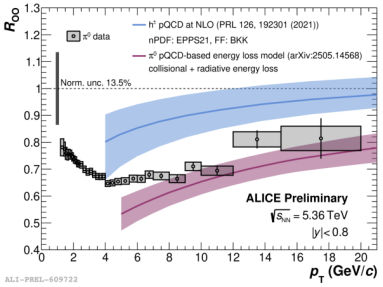
ATLAS-CONF-2025-010

- **Jet measurements have reduced sensitivity to nPDFs**
- **Differential in centrality → stronger quenching potential**
- **Uncertainties highly correlated → cancel in ratio**
- **Centrality-dependent enhancement of asymmetric x_J!**

Big Picture: Quenching Models Preferred

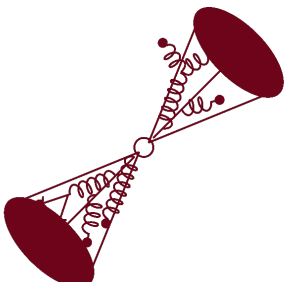






- **Each experiment's results come with caveats regarding significance of quenching**
- **Considered together, a strong case for the formation of a QGP**

Light Ions Results in 2026

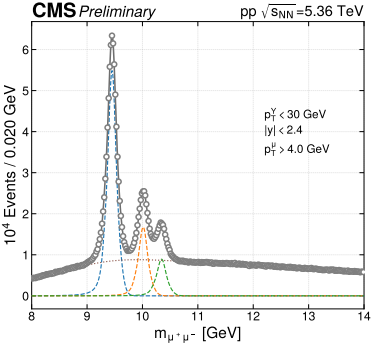


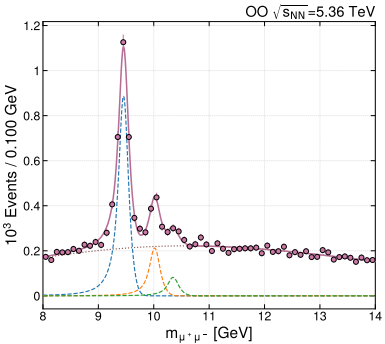
Explosion of Results from Light Ions

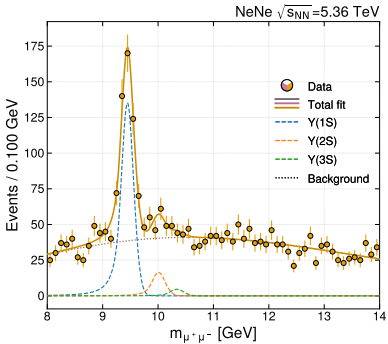
An incomplete selection:

- **dN/dη from ATLAS, CMS, and ALICE**
- **Flow results from ATLAS, CMS, ALICE, and LHCb**
- **HF production from LHCb and flow results from ALICE**
- **Many new results in strangeness at SQM 2026**
- **Highlighting two new entries from 2026: CMS Upsilon and STAR Quenching Evidence**

Upsilon 1s, 2s, and 3s with CMS



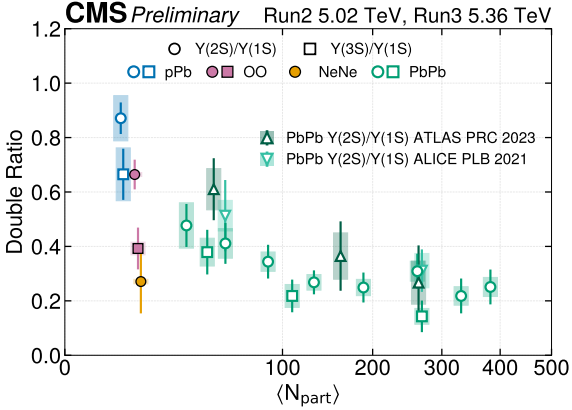




CMS-PAS-HIN-25-015

- **Sequential quarkonia suppression → different mechanism than quenching**
- **Offered here as parallel evidence of miniature QGP formation**

Upsilon Suppression in OO and NeNe with CMS

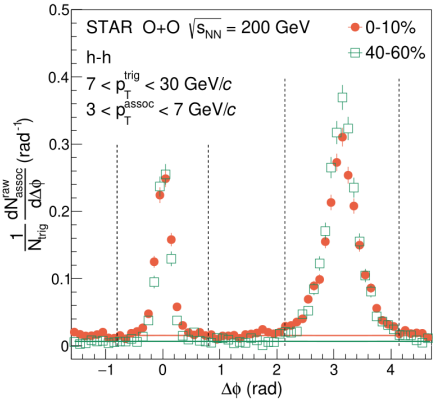


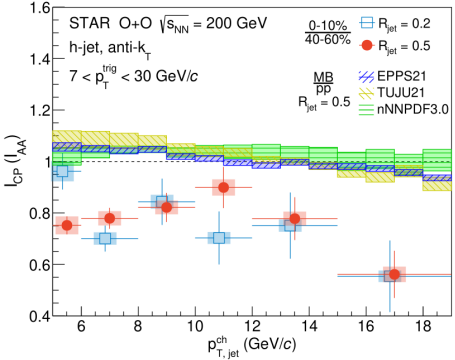
CMS-PAS-HIN-25-015

- **Significant suppression for 2s/1s and 3s/1s in OO**
  - **2s/1s suppression observed in NeNe**
- **Suppression appears intermediate between pPb and PbPb**
- **All probes of QGP formation being pursued in light ions!**

New STAR Measurement Submitted to PRL

Submitted PRL

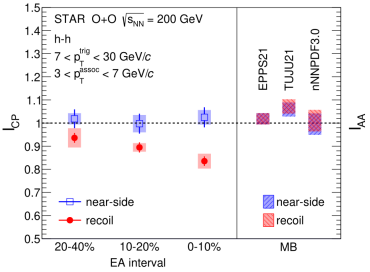




- **Re-analysis of hadron-hadron and hadron-jet correlations in 2021 OO data**
- **Study w/ I_{CP}, using 40-60% centrality as a reference**
  - **Similar to R_{AA}, except per trigger hadron and no pp reference**

New STAR Evidence of Quenching

Submitted PRL



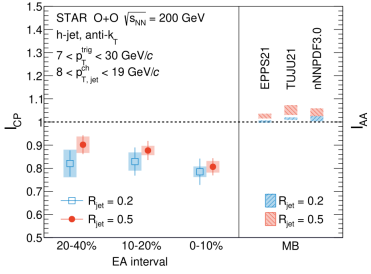
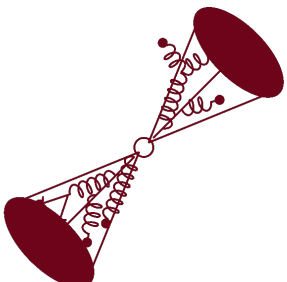


TABLE I. Significance of recoil yield suppression in h-h and h-jet correlations in the 0-10% EA population, compared to several different choices of no–quenching baseline. See text for details.

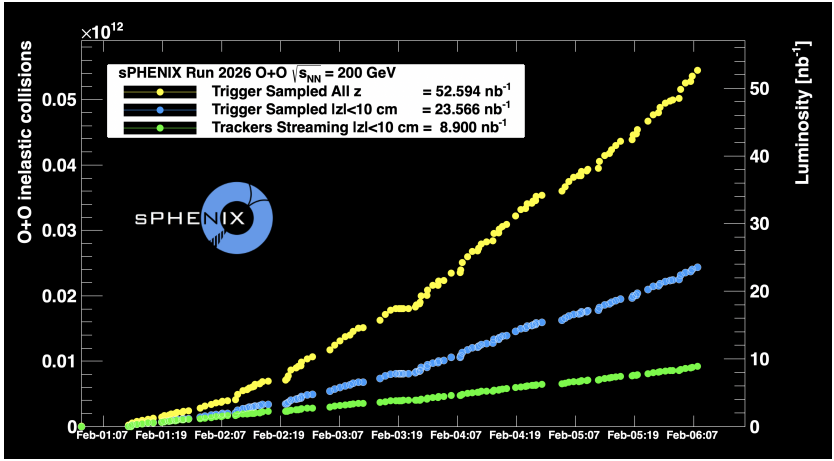
Baseline	h-h recoil	h-jet, $R = 0.5$	h-jet, $R = 0.2$
Unity	4.3σ	4.3σ	3.5σ
h-h near side	3.3σ	N/A	N/A
EPPS21	4.0σ	4.8σ	3.5σ
TUJU21	5.2σ	4.9σ	3.7σ
nNNPDF3.0	2.7σ	5.0σ	3.7σ

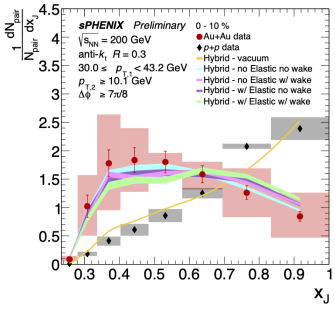
- **Left: Hadron-hadron I_{CP}, integrated over p_T. Right: hadron-jet I_{CP}, integrated over p_T**
- **nPDF effects accounted for w/ I_{AA} on right-hand side of figures**
- **Global significance greatest for R=0.5 hadron-jet correlations**
- **Emergent light-ions quenching picture shared between RHIC and the LHC!**

Future Directions



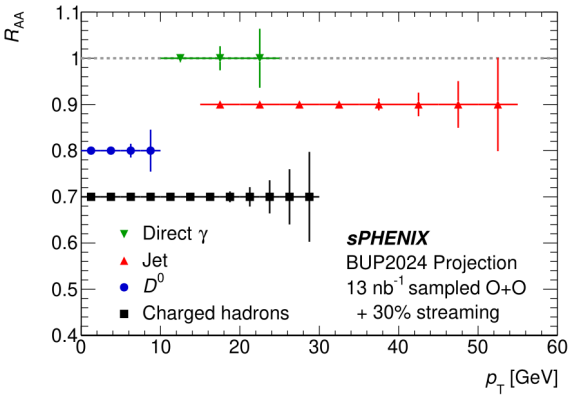
New OO Datataking with sPHENIX

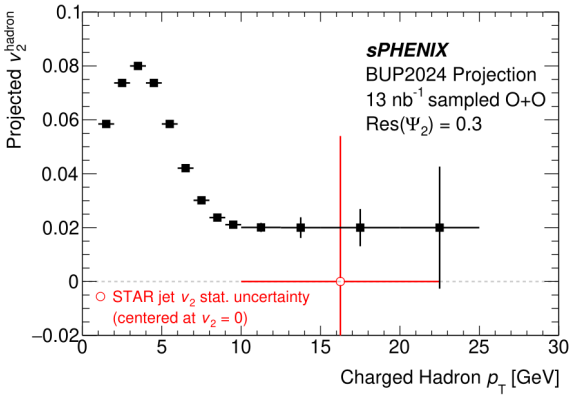




- **Large new OO sample collected by sPHENIX to end RHIC program**
- **sPHENIX preliminaries already available for x_J in pp and AA!**

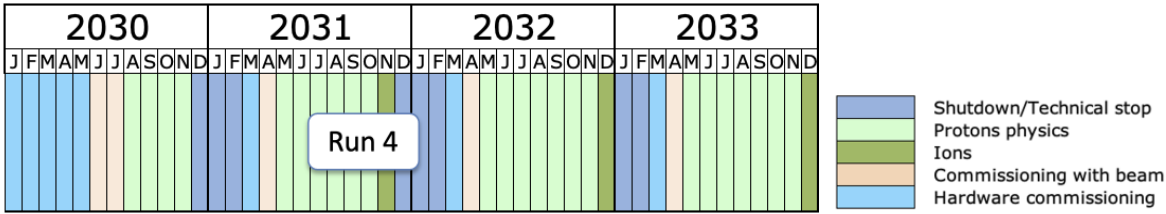
Projections for OO with sPHENIX





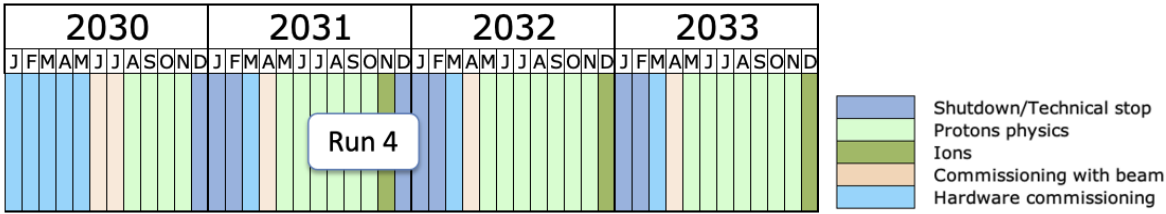
- **Projections for sPHENIX measurements in OO should be sensitive to quenching**
  - **Sensitivity to high-p_T v_2 $\rightarrow$ understanding signal in pA (see next slides)**

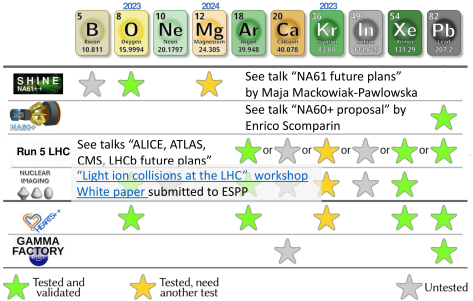
Future Prospects for Light Ions at the LHC



Next light ions opportunity at the LHC in Run 4
Balancing beamtime with PbPb, pPb running

Future Prospects for Light Ions at the LHC

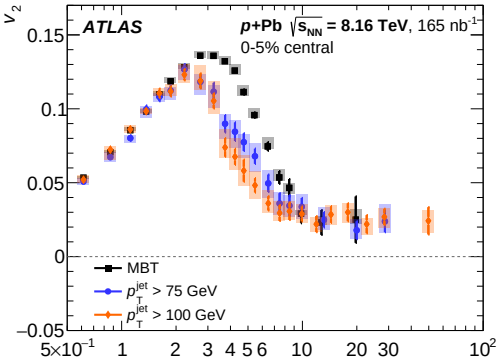




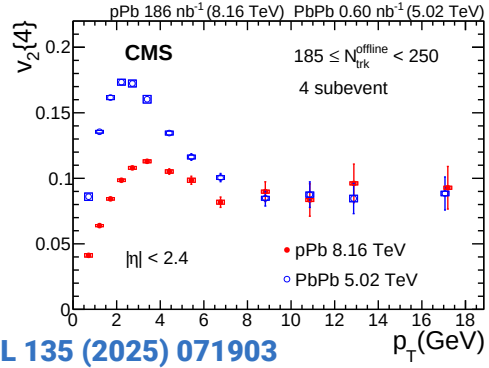
Next light ions opportunity at the LHC in Run 4
Balancing beamtime with PbPb, pPb running

New species being considered (α collisions?)
Via Town Hall contribution from R.A. Fernandez

Open Question: High-p_T v_2 in pPb



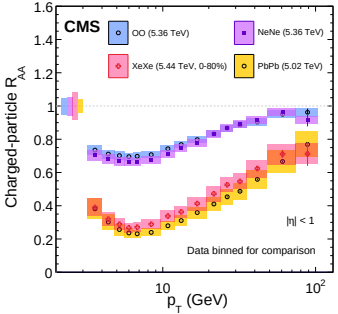
EPJC 80 (2020) 73

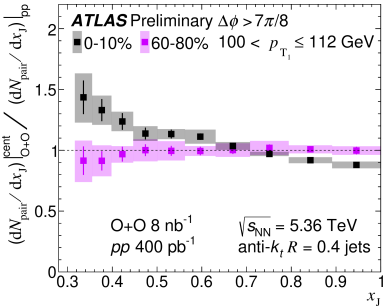


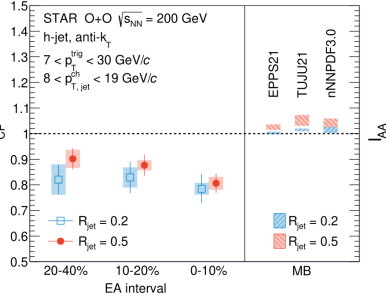
PRL 135 (2025) 071903

- **CMS and ATLAS see a consistent high-p_T v_2 in pPb**
- **High-p_T v_2 in PbPb was explained by models with path-length dependent energy loss**
  - **But no jet energy loss in pPb is detected**
  - **What does high-p_T v_2 look like in OO? (sPHENIX projections!)**

Conclusion

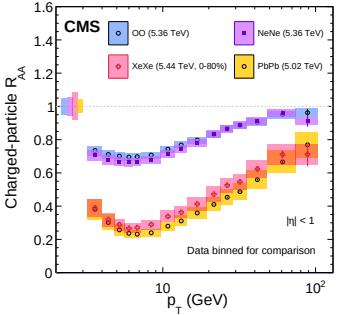


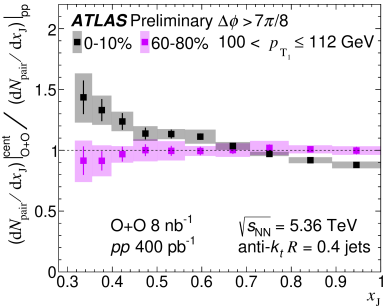


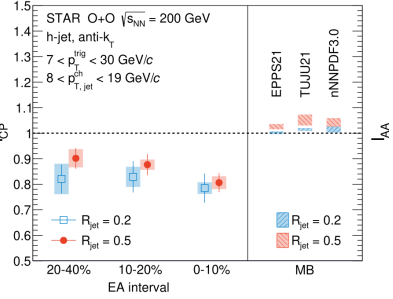


- **Consistent picture at RHIC and LHC: light ions data favors quenching**
- **First claims of evidence threshold; next steps confirmation + observation**
- **More exciting opportunities w/ new RHIC data at sPHENIX, future runs at the LHC!**

Conclusion







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Thank You!

Special thanks to Hannah Bossi, Cristian Baldenegro, Jing Wang, Virginia Bailey, Yeonju Go, Isaac Mooney, Sijie Zhang, Rongrong Ma, and Peter Jacobs for helpful discussions