# Fixed target experiments at the EIC:

## Another heavy ion perspective

**Christine Nattrass (UTK)**

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# Attribution: Many ideas drawn from this workshop

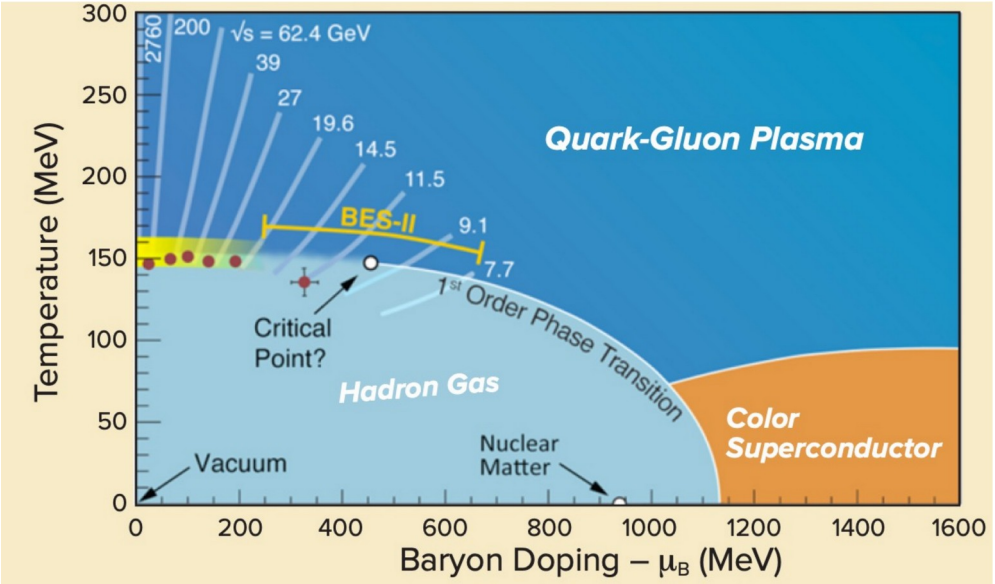
Advancing Nuclear Physics: New Horizons with Fixed-Target Proton-Nucleus Experiments at Intermediate Energies


As well as conversations with: Niseem Magdy, Giorgio Torrieri

But I take full blame for anything you don't like!

# What would a fixed target program at the EIC have which is new?

- Polarized beams
- $e^{(\uparrow)}+A^{(\uparrow)}$ and $p^{(\uparrow)}+A^{(\uparrow)}$ measurements in same experiment
- Better insight!  Better data management!

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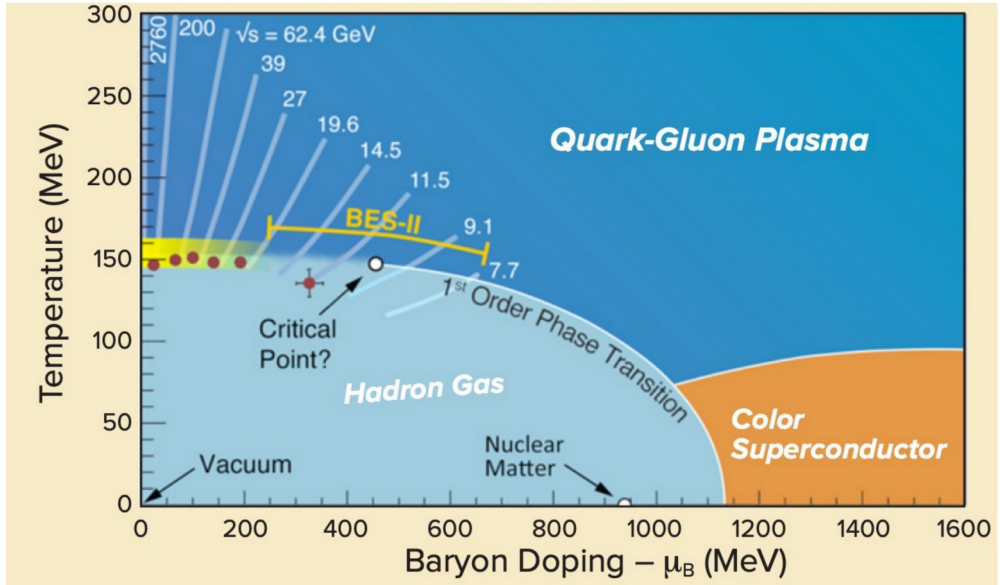


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# Some thoughts

- Fixed target→ higher luminosity, better for rare probes (could be an advantage)
- RHIC BES fixed target did not us p+A.  Also might be nice to reproduce some p+A, A+A for consistency, systematic uncertainties
- Rare probes which we're better at measuring with current detectors: high $p_T$ photons! Lambdas!
- RHIC's strength has always been its versatility.  Would be really nice to have system scan, look for collective motion.

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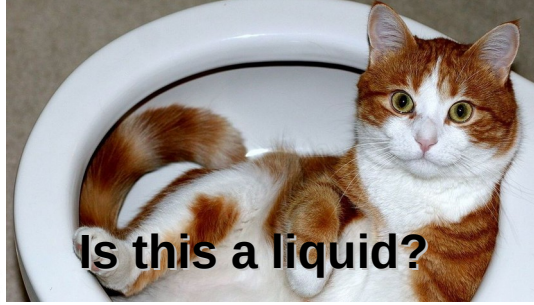
https://www.catster.com/cat-breeds/most-common-cat-colors/

# Origin of hydrodynamic response

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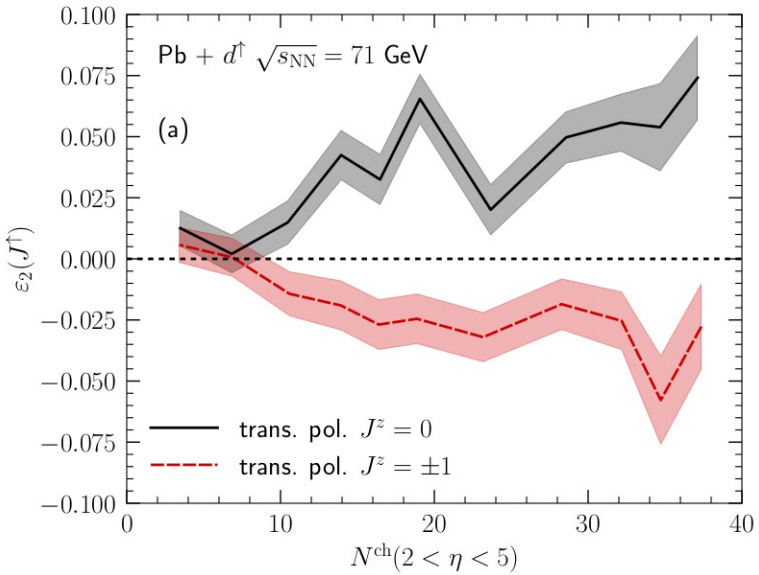
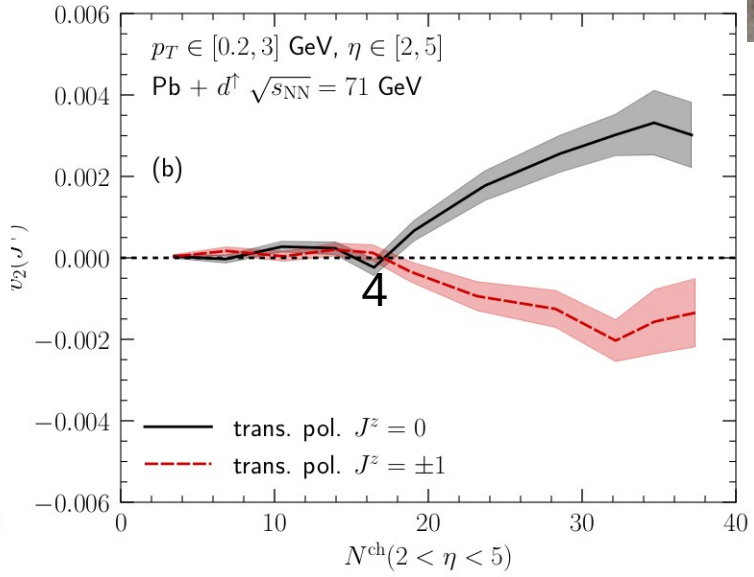


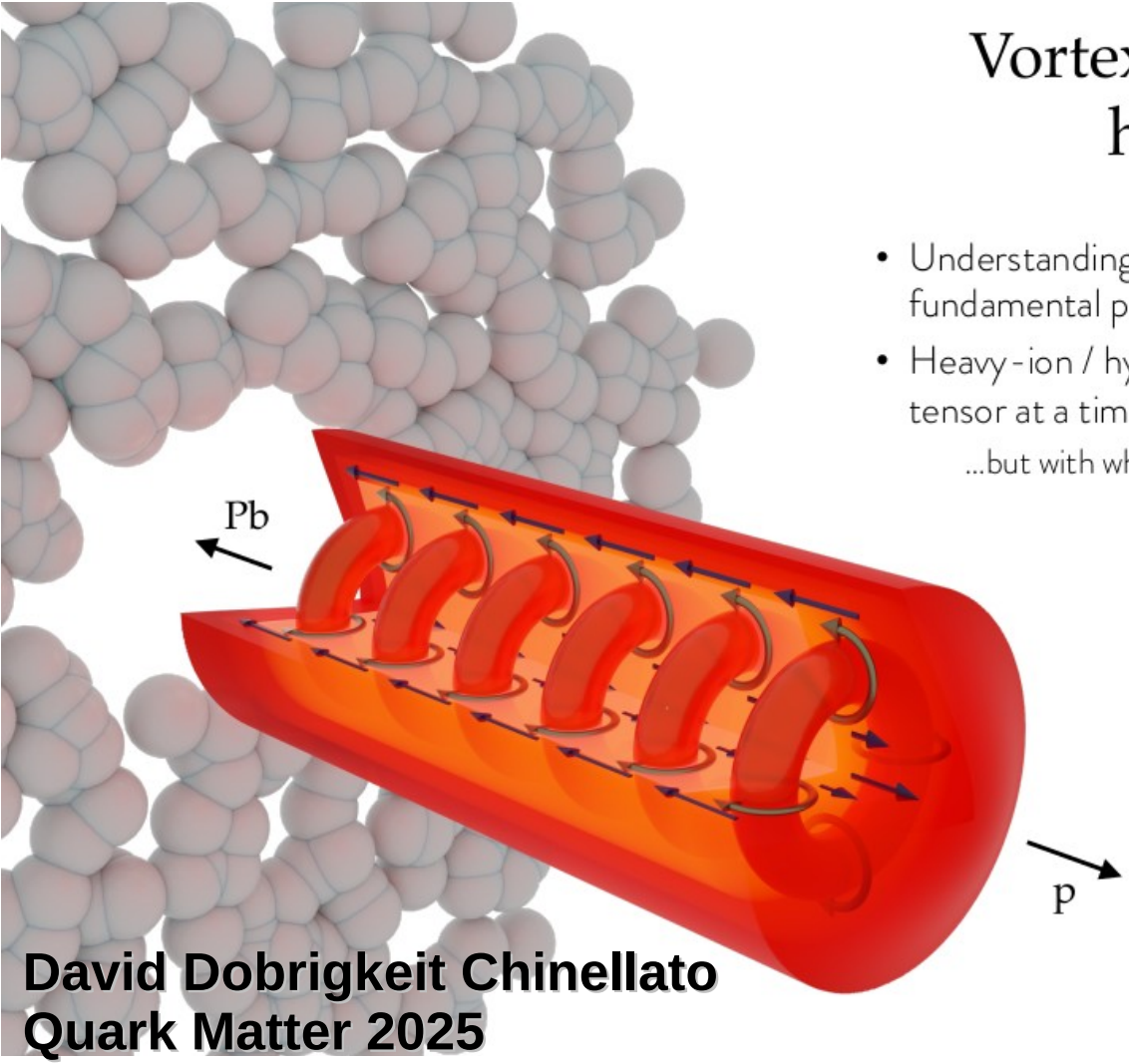

Heikki Mäntysaari, Björn Schenke, Chun Shen, Wenbin Zhao

arXiv:2509.00511

Heikki Mäntysaari, Quark Matter 2025

“Hydrodynamic response to initial-state geometry predicts a distinct sign of v2 correlated with the deuteron's polarization states, providing a clean test case for elucidating the collective origin in small collision systems.”
PYTHIA predicts opposite signs

# Vortex rings from asymmetric heavy-ion collisions




- Understanding the **initial stages of a proton-nucleus interaction** is a fundamental problem of the field
- Heavy-ion / hydrodynamic treatment: initialize energy-momentum tensor at a time $\tau_0$ in which the system is sufficiently thermalized

  ...but with which conditions?

Assuming no initial transverse flow, two cases act as limits for the longitudinal flow:

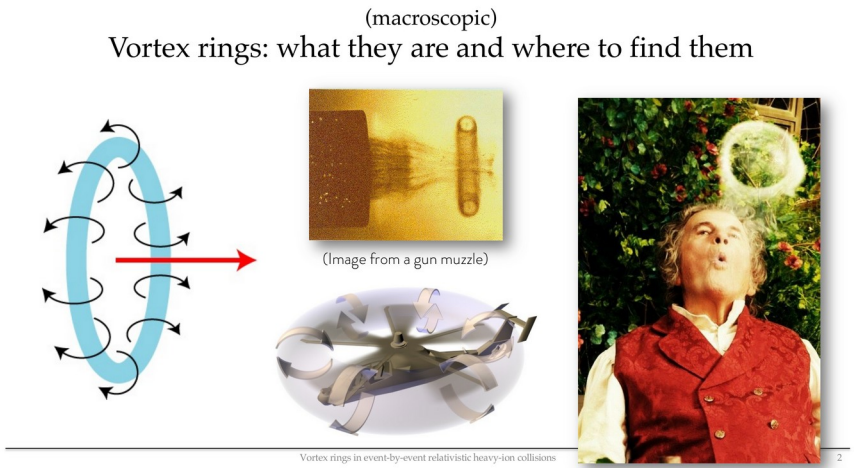
- **Bjorken flow**: $v \propto z$, initial longitudinal flow does not depend on transverse position
- **Matter (overlap)-dependent flow**: at each transverse position, $v$ tracks the matter imbalance going in each direction: flow depends on transverse position

Vortices laid out with cylindrical symmetry: "**vortex rings**"
→ search for angular momentum carried to final state

**David Dobrigkeit Chinellato**
**Quark Matter 2025**
https://arxiv.org/abs/2509.00512

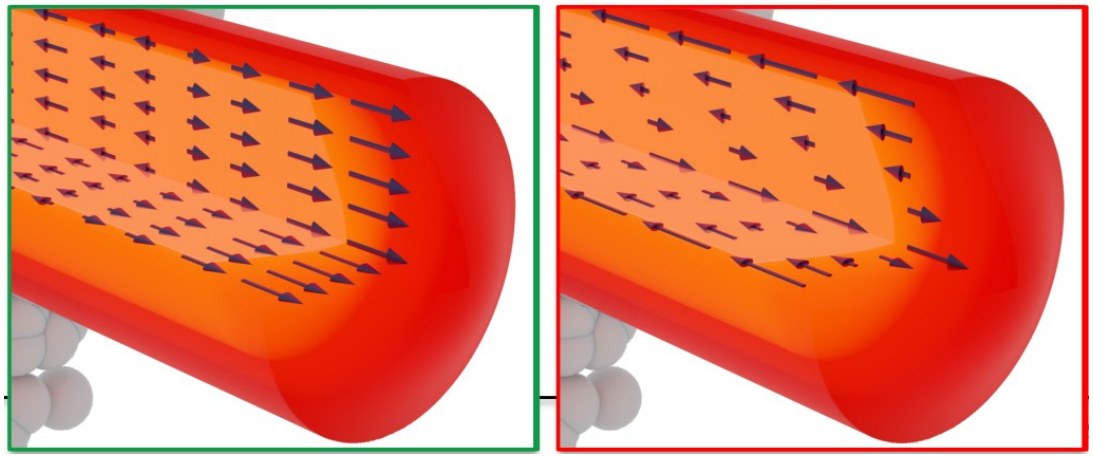
# Vortex Rings

- Measure with Λ
- Work did not include polarized beam




$f = 0$: bjorken flow

$f = 1$:'matter overlap'



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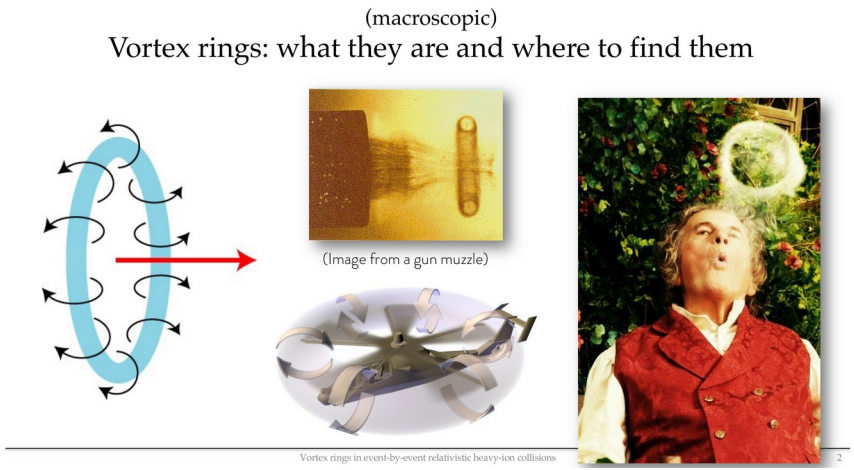
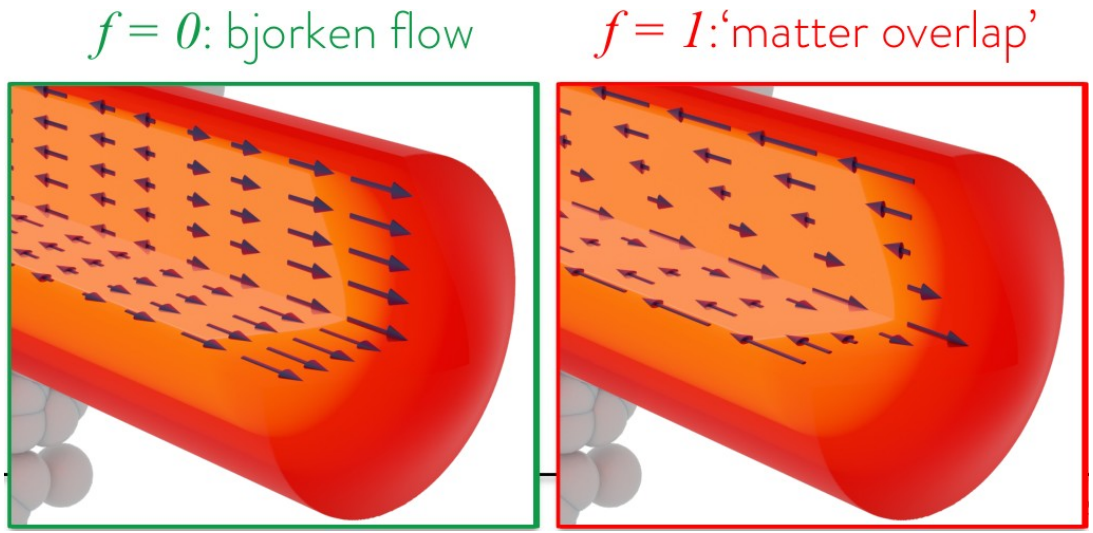
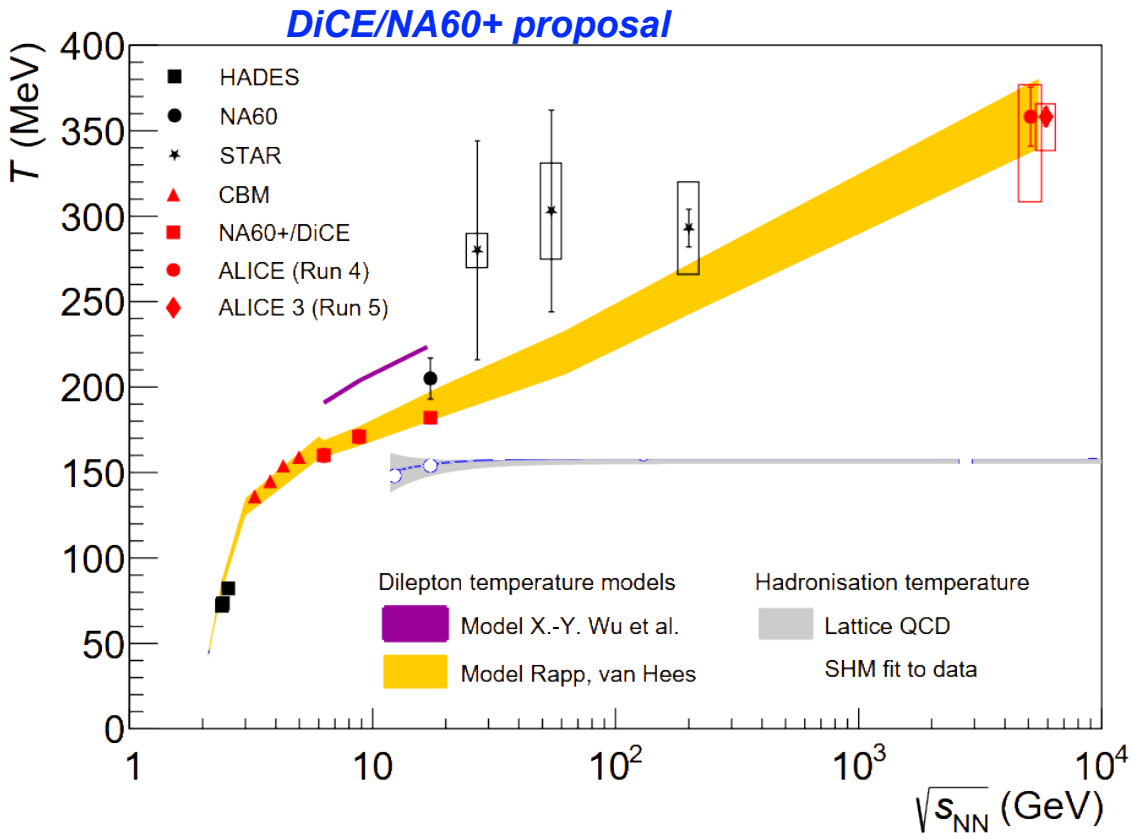



# Thermal Radiation Performance Studies

## Pb-Pb at for 2, 1, 1 month data taking

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**Axel Drees**

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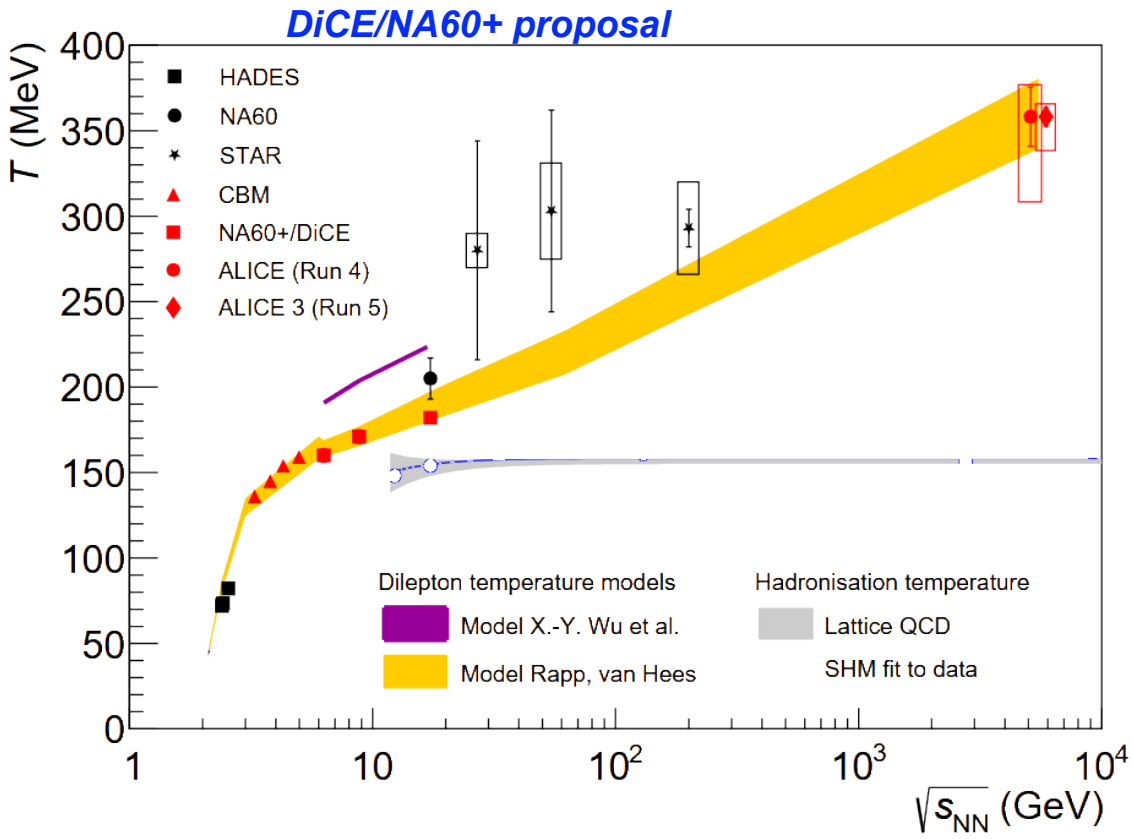


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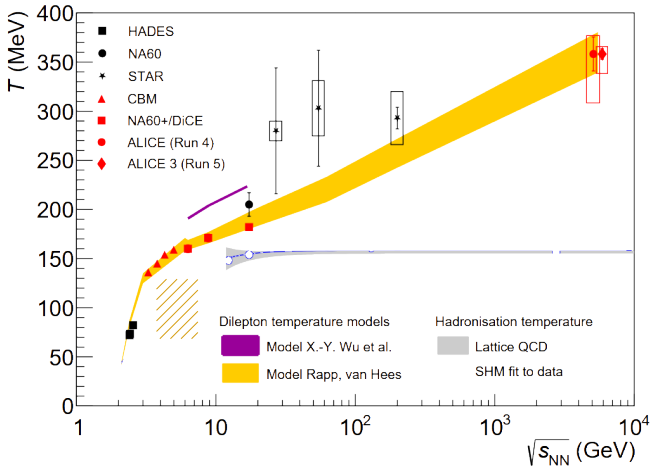
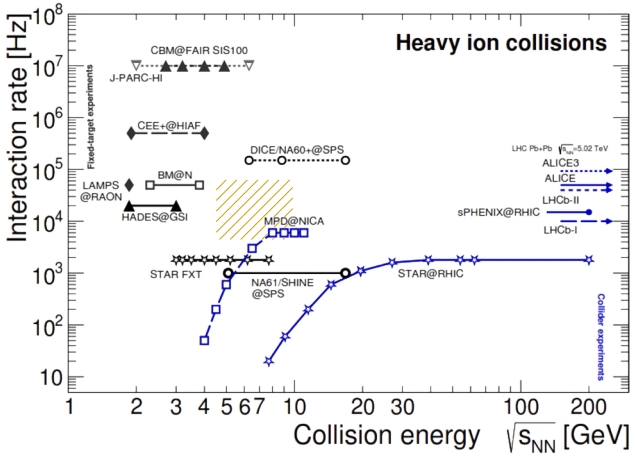
# Heavy Ion Physics in this region




- **Initial system near**
  - Initial partonic state
  - Immediate hadronization

**Ideally suited to study hadronization?**

- **Competitive environment with state-of-the-art experimen**
  - @FAIR CBM multipurpose and dilepton detector
  - @SPS DiCE dimuon & charm & some hadronic obs

**Absence of photon measurements!**

**Possible opportunity: low $p_T$ direct photons from hadronization**

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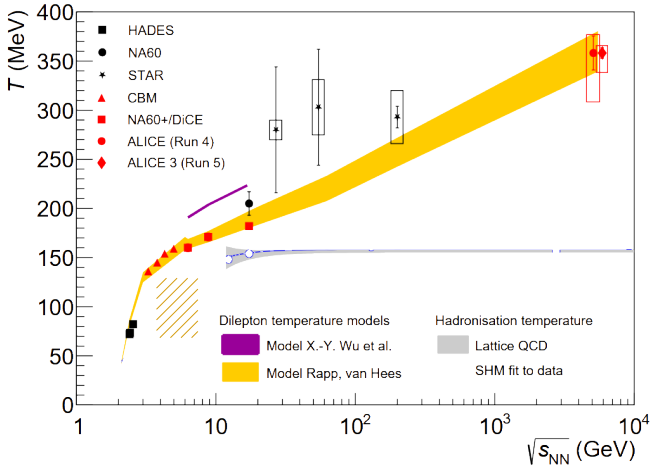


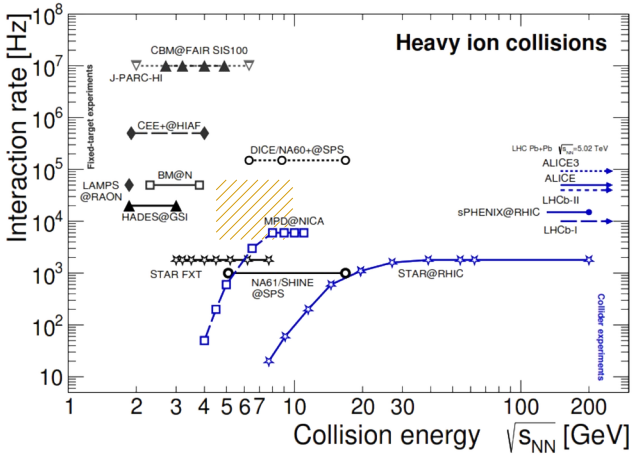


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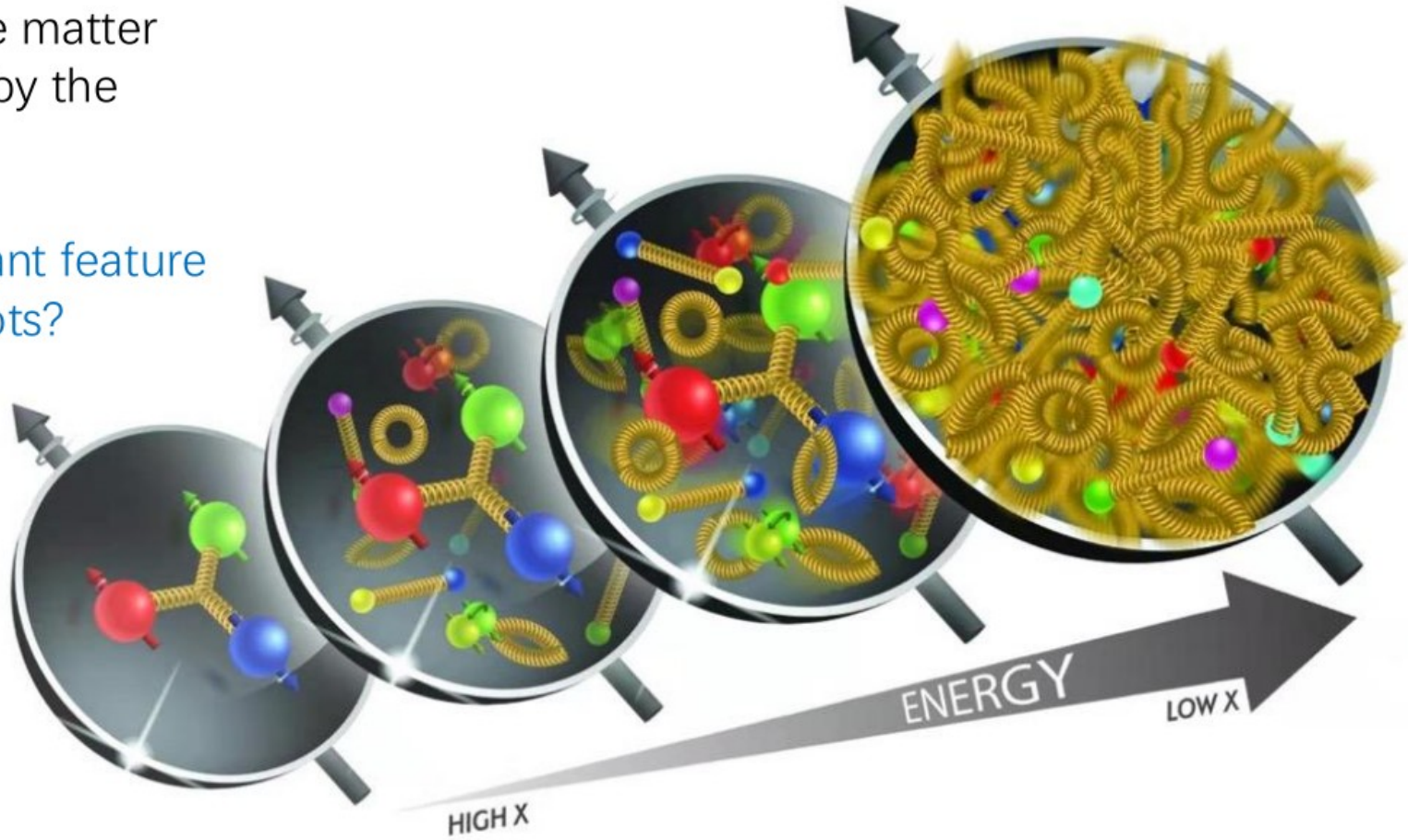
# Search for baryon junctions

In nuclei, 99% of the matter mass is generated by the strong interaction

What is the dominant feature in all these snapshots?

**Zhangbu Xu**



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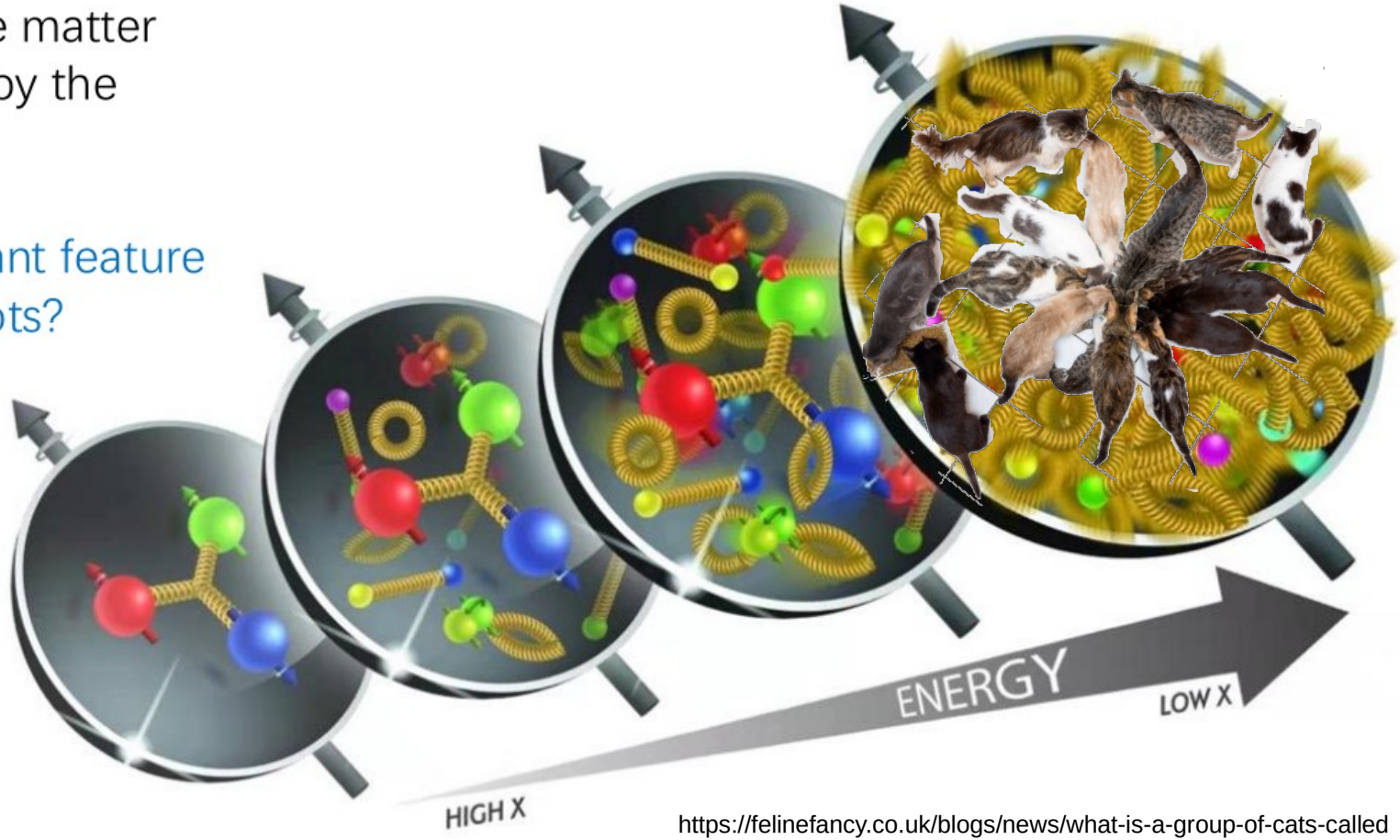
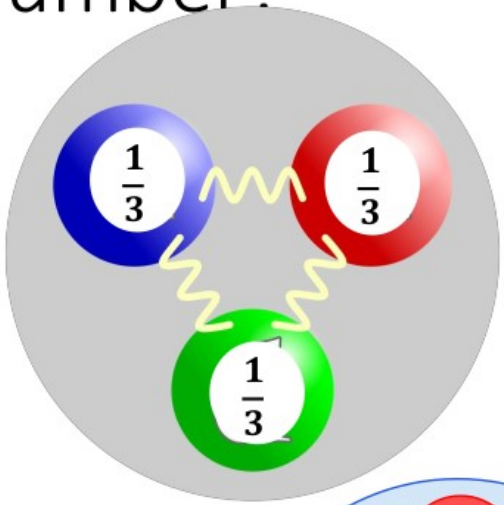
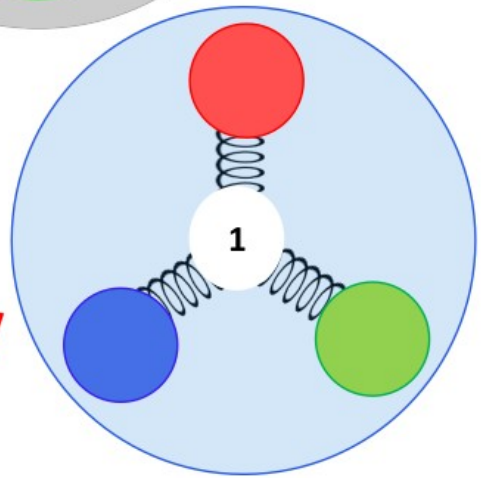



https://felinefancy.co.uk/blogs/news/what-is-a-group-of-cats-called

# Measurements of quark baryon number?

- Textbook picture of a proton
  - Lightest baryon with strictly conserved baryon number
  - Each valence quark carries 1/3 of baryon number
  - Proton lifetime >$10^{34}$ years
  - Quarks are connected by gluons
- Alternative picture of a proton
  - Proposed at the Dawn of QCD in 1970s
  - A Y-shaped gluon junction topology carries baryon number (B=1)
  - The topology number is the strictly conserved number
  - Quarks do not carry baryon number
  - Valence quarks are connected to the end of the junction always
- **Neither of these postulations has been verified experimentally**

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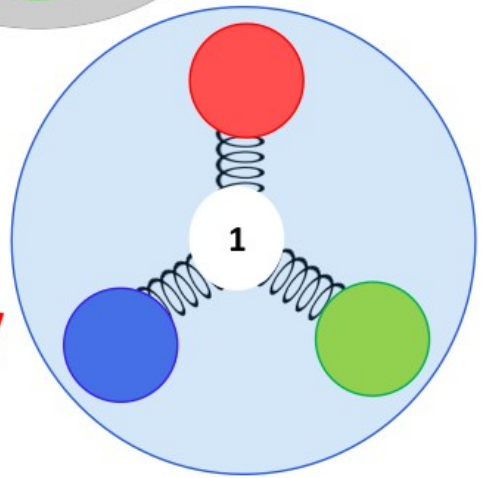


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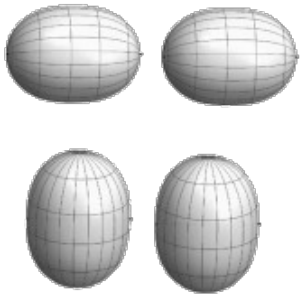
https://www.reddit.com/r/cat/comments/nsdtma/how_my_brothers_three_cats_were_found_asleep_this/

# System scan at low energy?

Perturb the initial condition and observe the final-state responses, potentially with a large lever arm to probe the dynamics at similar volume. AGS is a unique facility for this

Stopping and expansion dynamics depend on orientation



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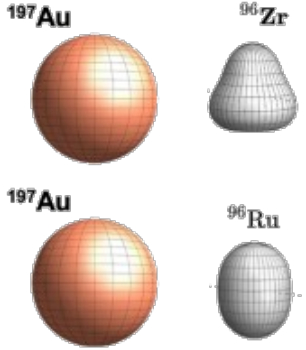


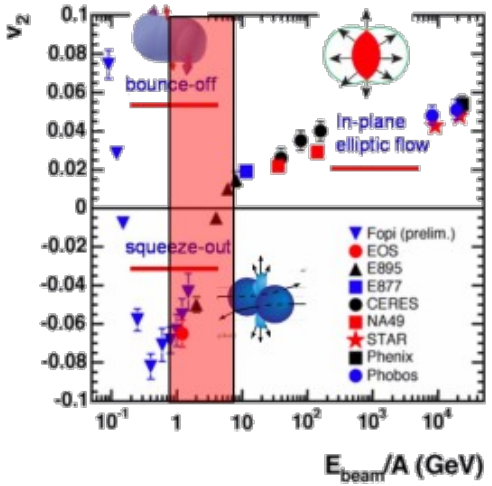


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|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | Ar, S | 80 | Se, Kr | 106 | Pd, Cd | 124 | Sn, Te, Xe | 148 | Nd, Sm | 174 | Yb, Hf |
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| 46 | Ca, Ti | 86 | Kr, Sr | 110 | Pd, Cd | 128 | Te, Xe | 152 | Sm, Gd | 180 | Hf, W |
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| 64 | Ni, Zn | 96 | Zr, Mo, Ru | 115 | In, Sn | 136 | Xe, Ba, Ce | 160 | Gd,Dy | 190 | Os, Pt |
| 70 | Zn, Ge | 98 | Mo, Ru | 116 | Cd, Sn | 138 | Ba, La, Ce | 162 | Dy,Er | 192 | Os, Pt |
| 74 | Ge, Se | 100 | Mo, Ru | 120 | Sn, Te | 142 | Ce, Nd | 164 | Dy,Er | 196 | Pt, Hg |
| 76 | Ge, Se | 102 | Ru, Pd | 122 | Sn, Te | 144 | Nd, Sm | 168 | Er,Yb | 198 | Pt, Hg |
| 78 | Se, Kr | 104 | Ru, Pd | 123 | Sb, Te | 146 | Nd, Sm | 170 | Er,Yb | 204 | Hg, Pb |

$$R_{\mathcal{O}} \equiv \frac{\mathcal{O}_{\mathrm{X+X}}}{\mathcal{O}_{\mathrm{Y+Y}}} \approx 1 + c_1\Delta\beta_2^2 + c_2\Delta\beta_3^2 + c_3\Delta R_0 + c_4\Delta a$$

Dynamics is a strong function of $\sqrt{s}$ , need collisions of the same isobar pairs at a few $\sqrt{s}$

AGS covers the range where the dynamics change the most

**Jiangyong Jia**

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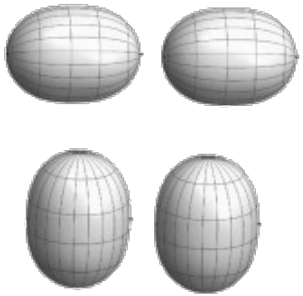

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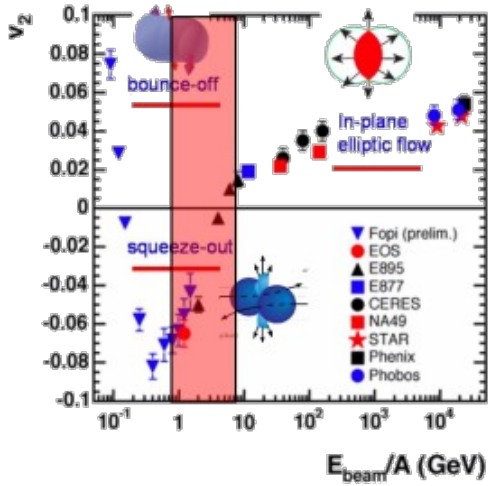


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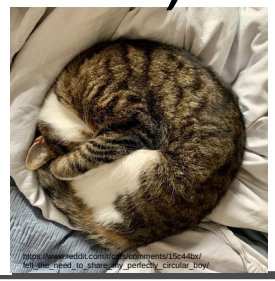
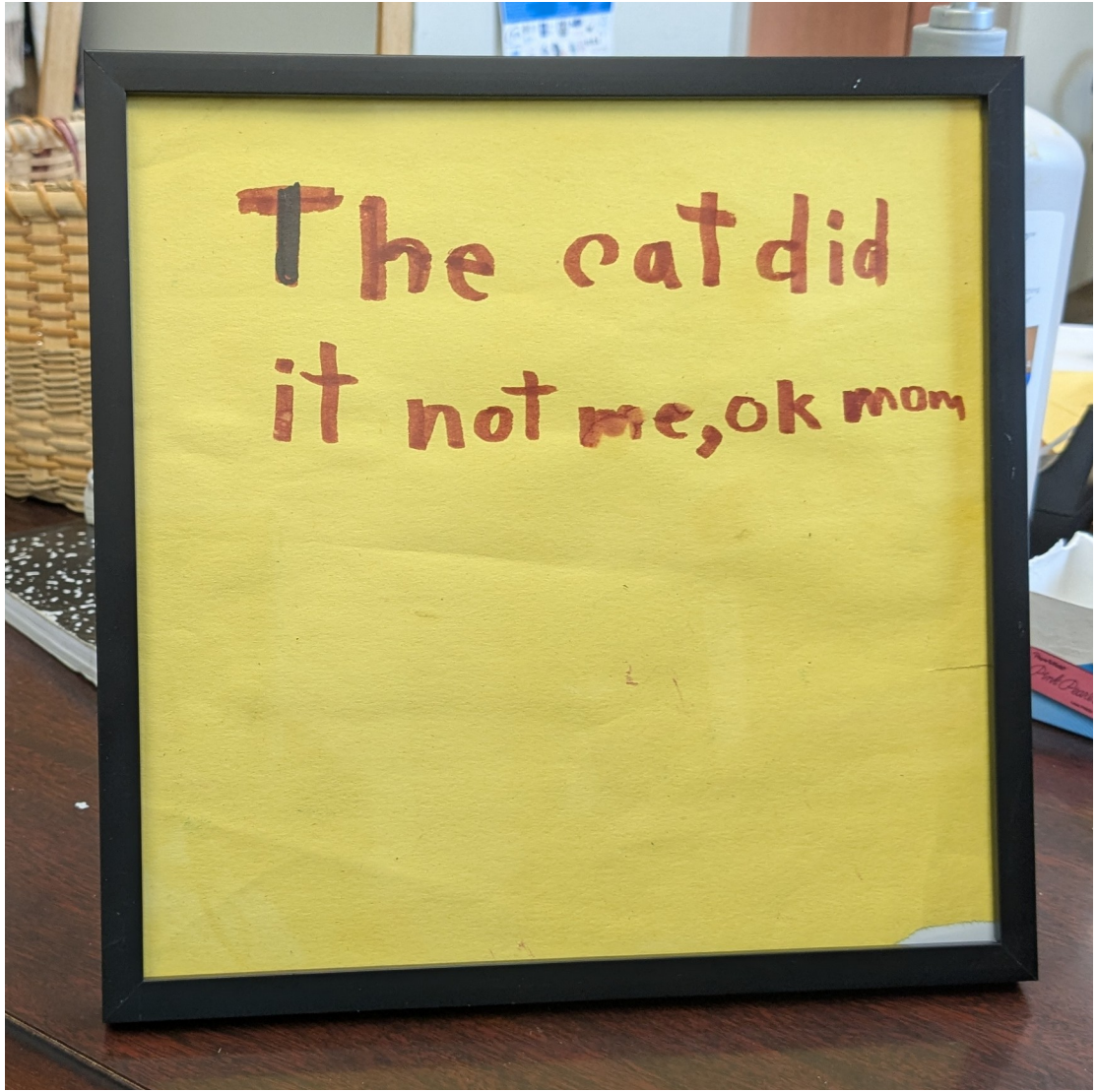
# Summary of Ideas

- (Polarization-dependent) hydrodynamics (p+A)
- Vortex rings (p+A)
- Thermal radiation (p+A, A+A)
- Baryon junctions (p+A, A+A)
- System scan (p+A, A+A)



The cat did
it not me, ok mom

# Backup

| $e$-beam energy (GeV) | $p$-beam energy (GeV) | |
|---|---|---|
| 18 | 275 | |
| 10 | 275 | |
| 10 | 100 | |
| 5 | 100 | |
| 5 | 41 | |

- EIC fixed target energies per nucleon pair: 8.87, 13.77, 22.75 GeV
- AGS: 2.72-6.67 GeV AGS pA $\sqrt{s_{NN}}$: 2.72-6.67 GeV