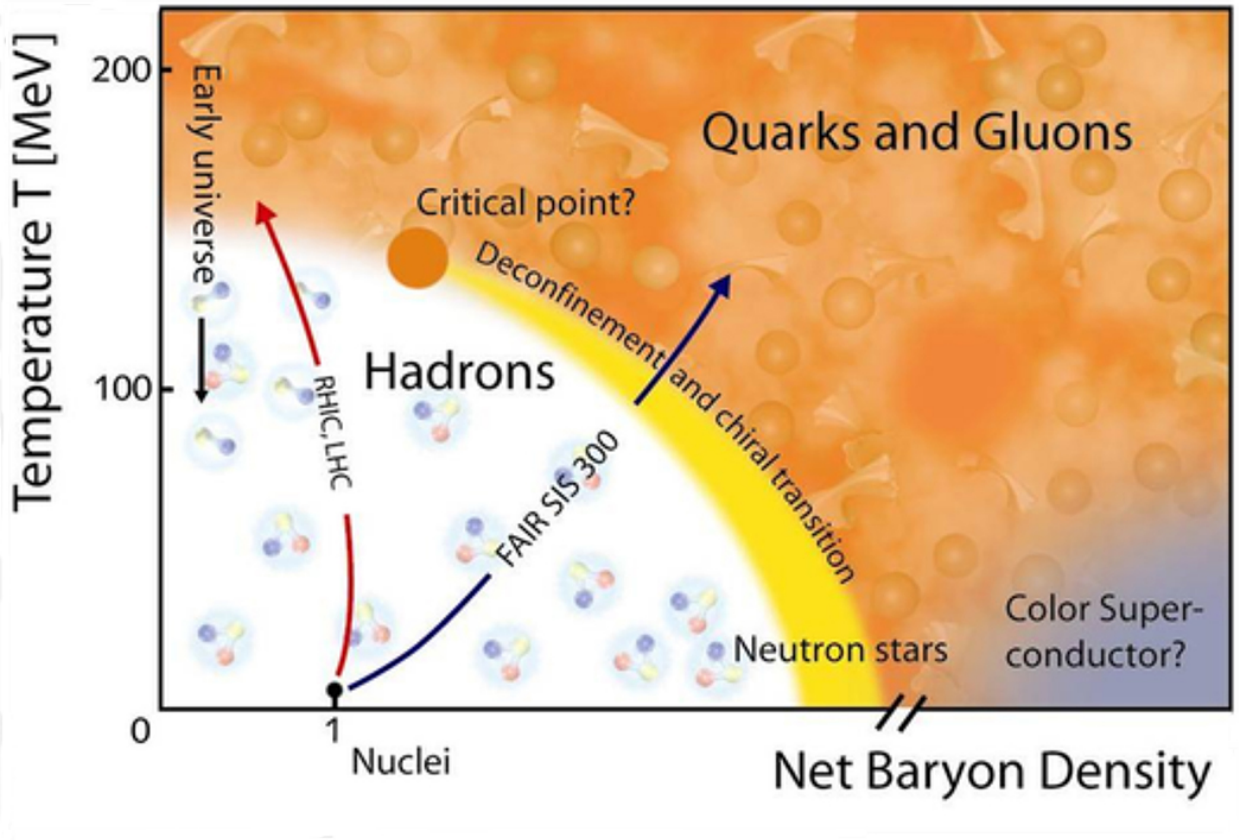
A journey from the LHC to an EIC with a *short stop* at RHIC and HERA

Kong Tu

BNL

CFNS Inauguration Symposium

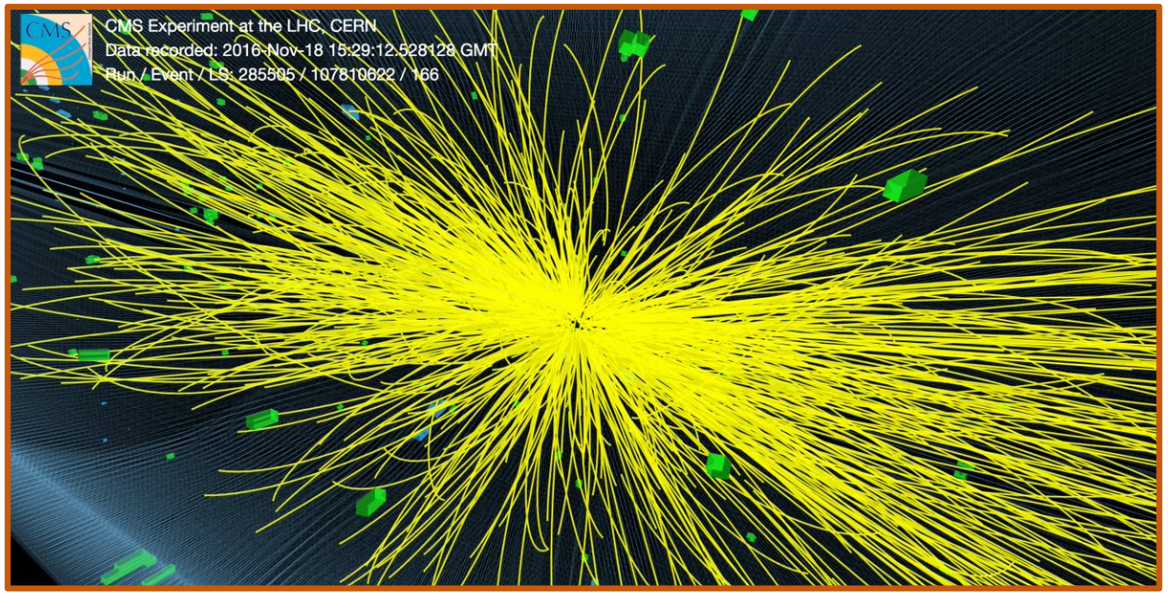
Emergence of Quantum Matter



Big question:

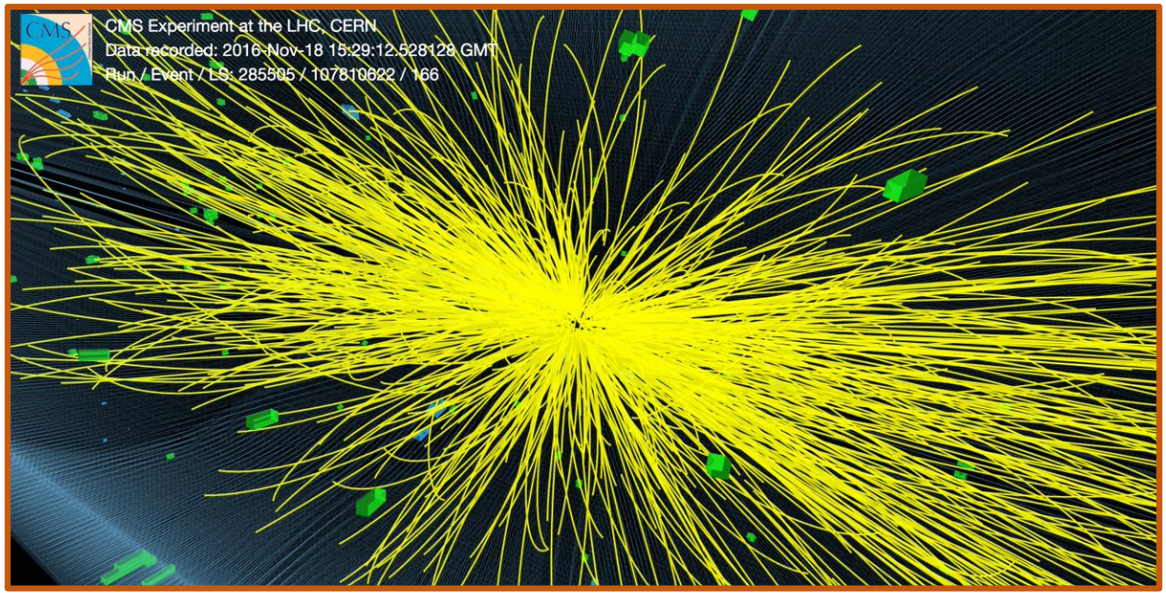
- Detail properties of this emergent QCD matter, .e.g.,
  Chiral symmetry restoration in Quark-Gluon-Plasma?

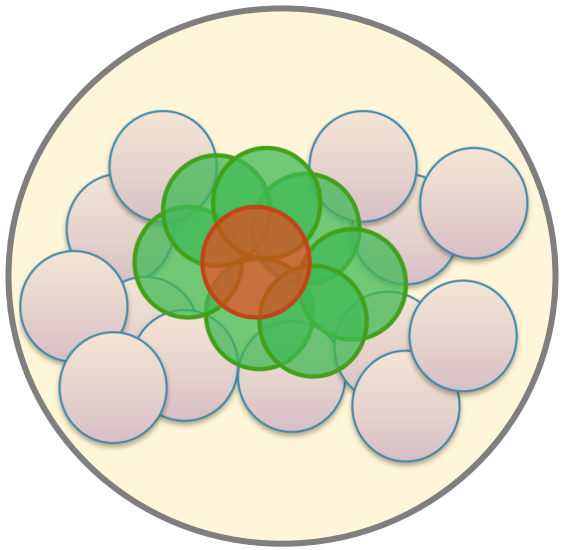
LHC, where “*violent events*” happen



LHC, where "*violent events*" happen

High-multiplicity pA collisions

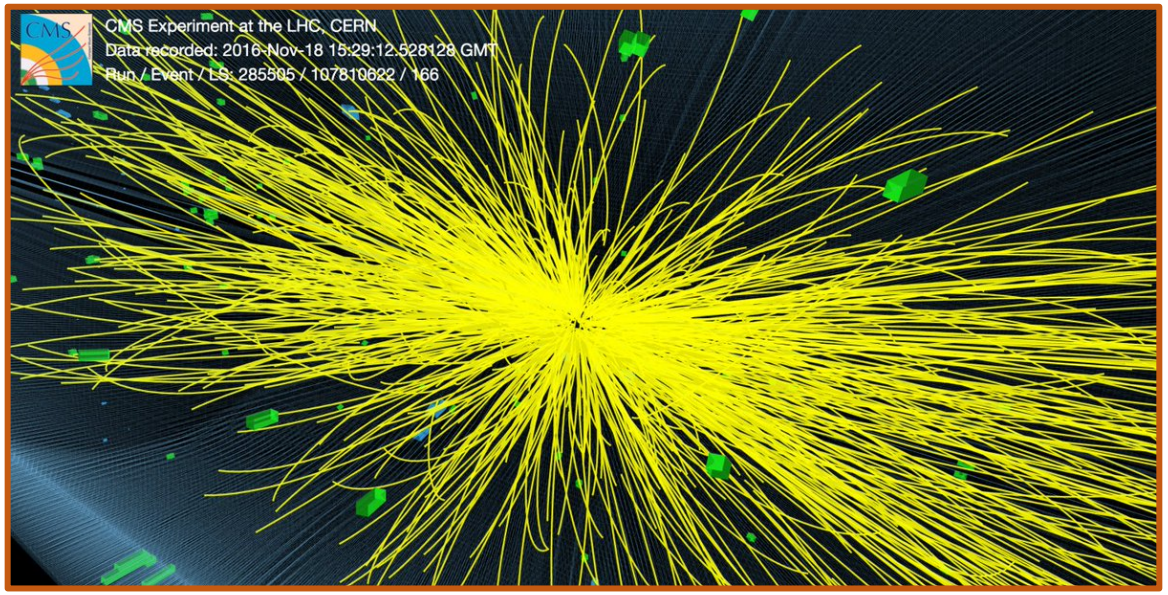


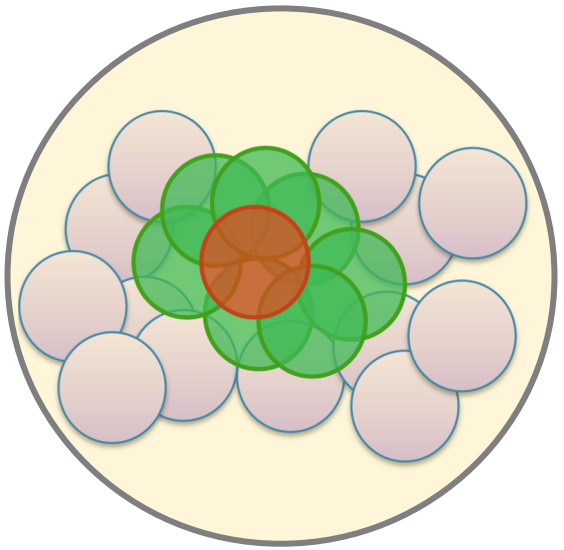


Rare events, ~1 in 10M minimum-bias collisions

LHC, where "*violent events*" happen

High-multiplicity pA collisions





Rare events, ~1 in 10M minimum-bias collisions

Why do such thing?

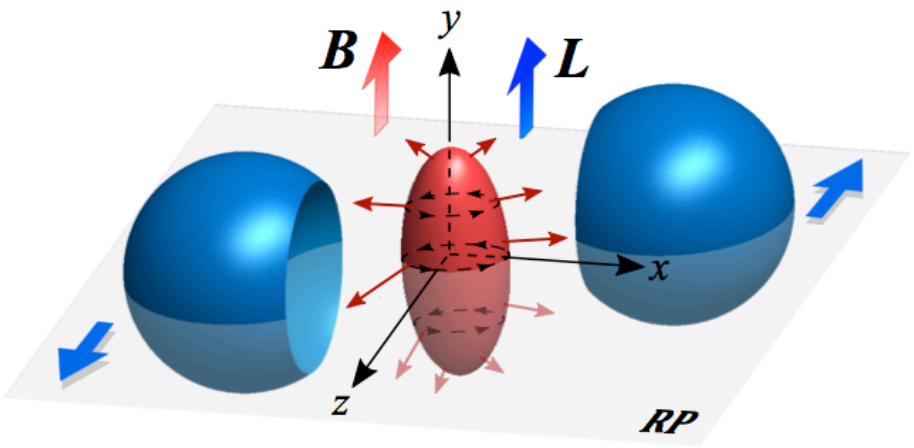
- Shown *some* properties of the hot QGP medium, e.g., long-range particle correlation

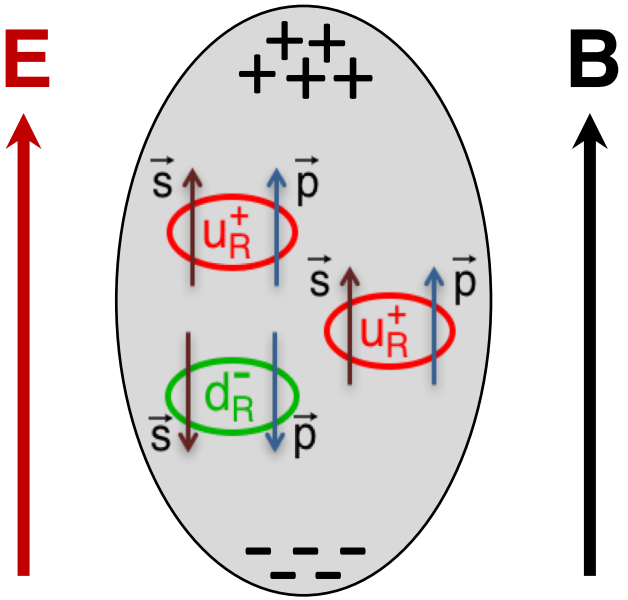
provides a baseline for (not) finding exotic physics

Chiral Magnetic Effect

Three birds, one stone

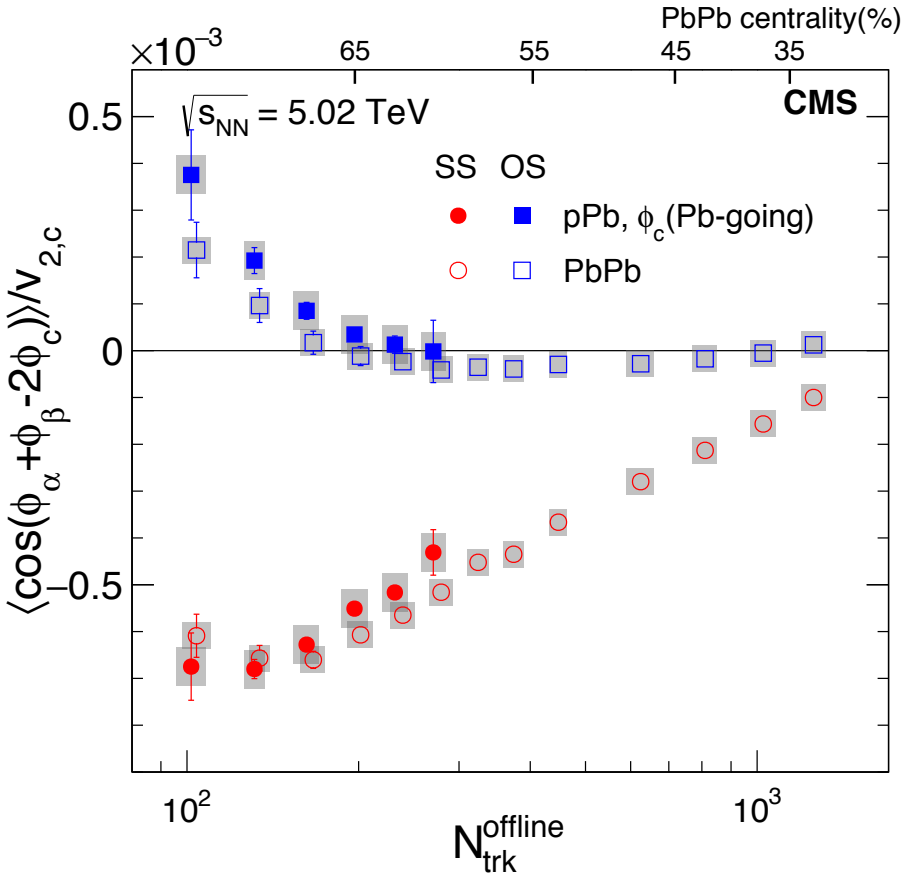
- Local *strong P* and *CP* violation
- Chiral symmetry restoration
- Initial strong magnetic field





CME: charge separation w.r.t event plane

Chiral Magnetic Effect



This CME observable

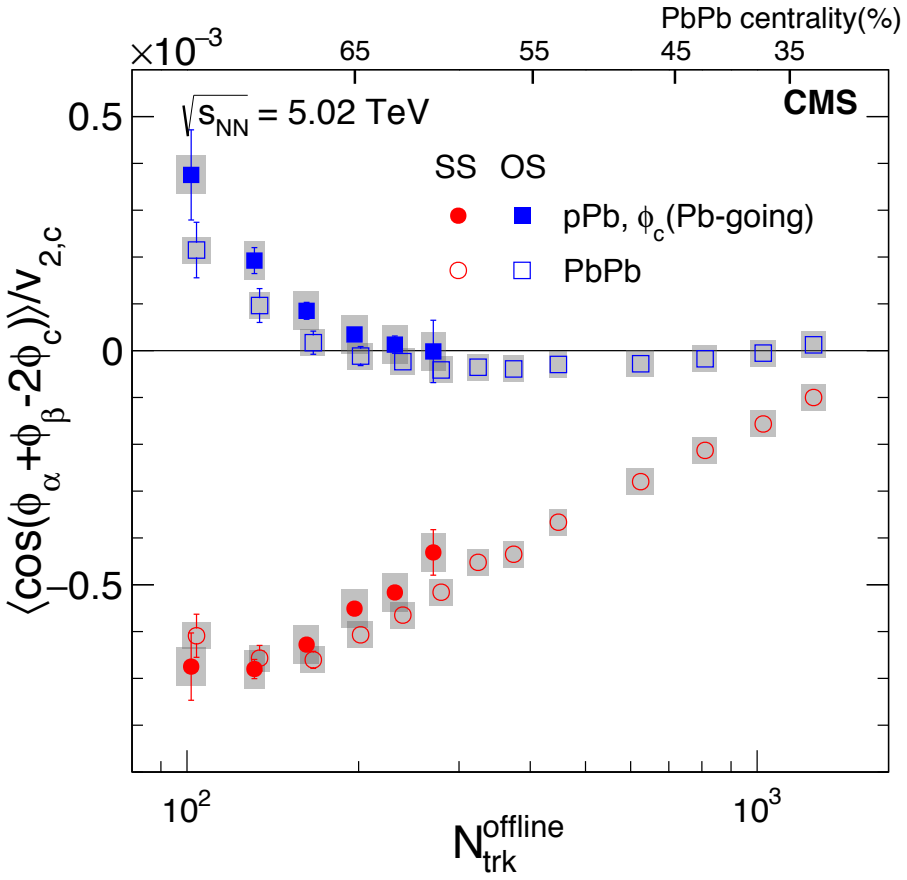
pPb collisions:

- No CME is expected, but share similar medium properties of AA collisions

PbPb collisions:

- CME and/or other effects

Chiral Magnetic Effect



This CME observable

pPb collisions:

- No CME is expected, but share similar medium properties of AA collisions

PbPb collisions:

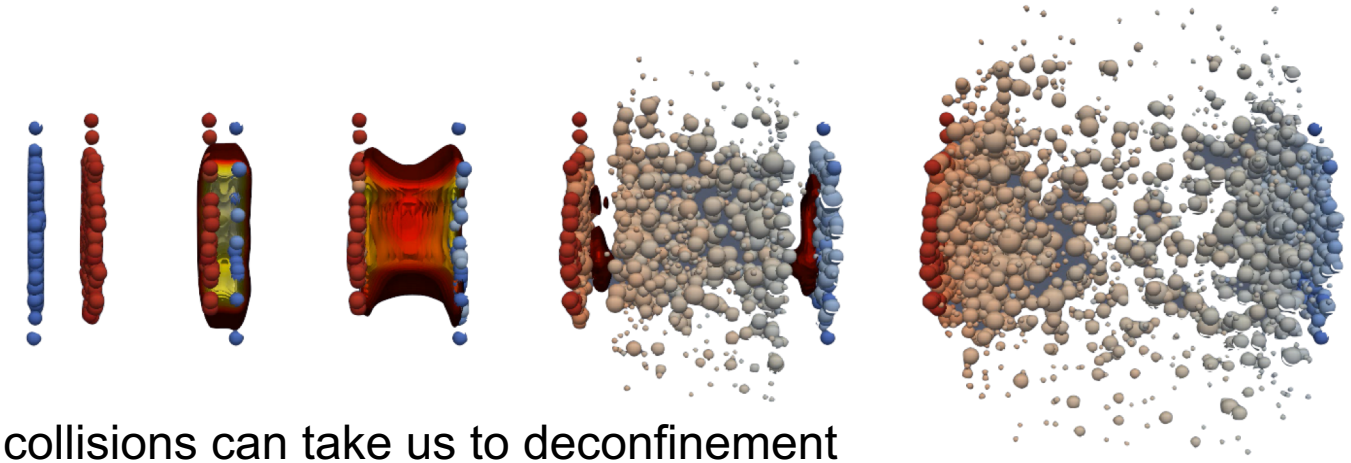
- CME and/or other effects

(~ 90-100%)

Unambiguous prove of presence of background in data!

New insights and baseline for CME searches at RHIC

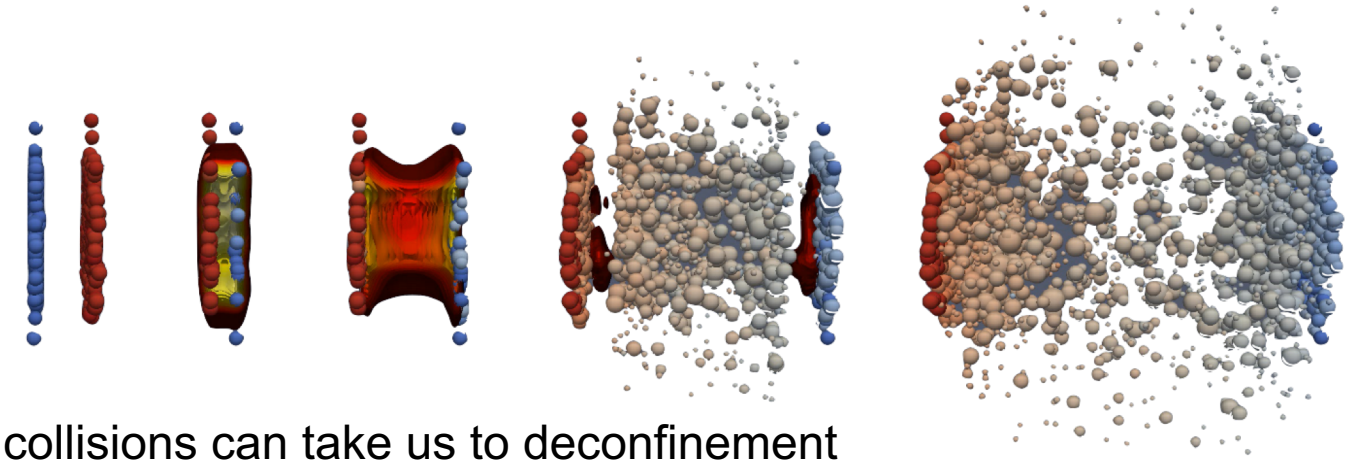
Confinement



Heavy ion collisions can take us to deconfinement

But, what is the origin of confinement?

Confinement



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One proposal is to use ***entanglement entropy as a probe of confinement***

R. Klebanov, D. Kutasov and A. Murugan (2007)

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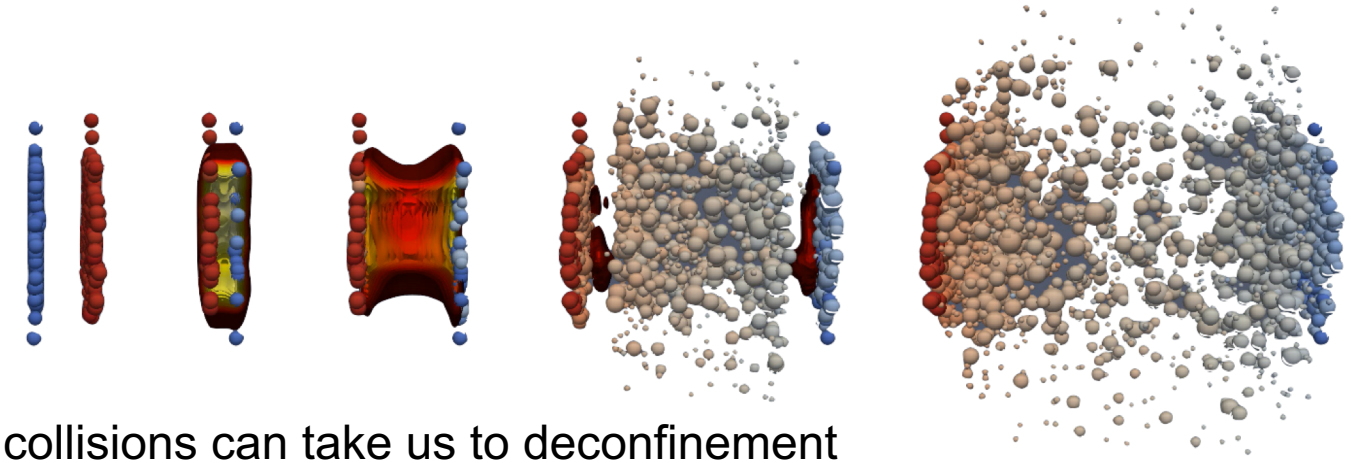

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Wiki:

Von Neumann entanglement entropy [edit]

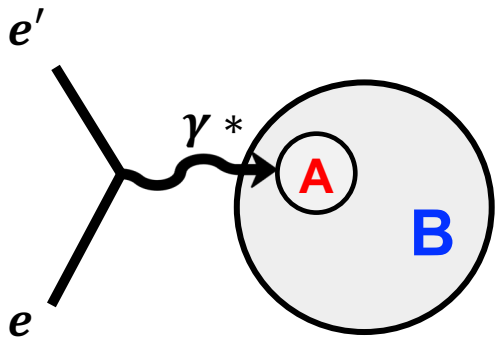
The bipartite Von Neumann entanglement entropy S is defined as the Von Neumann entropy of either of its reduced states; the result is independent of which one we pick. That is, for a pure state $\rho_{AB} = |\Psi\rangle\langle\Psi|_{AB}$, it is given by:

$$\mathcal{S}(\rho_A) = -\operatorname{Tr}[\rho_A \log \rho_A] = -\operatorname{Tr}[\rho_B \log \rho_B] = \mathcal{S}(\rho_B)$$

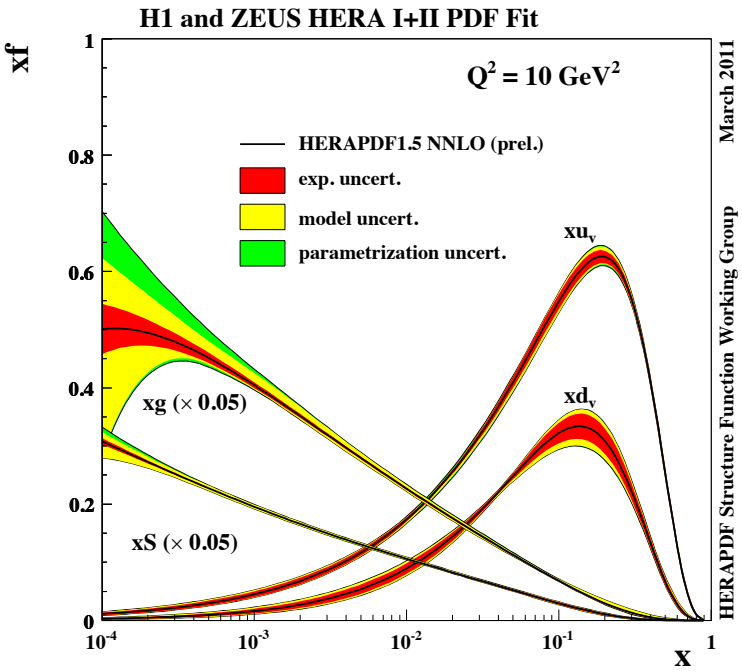
where $\rho_A = \operatorname{Tr}_B(\rho_{AB})$ and $\rho_B = \operatorname{Tr}_A(\rho_{AB})$ are the reduced density matrices for each partition.

Entanglement entropy inside of a proton?

Phys. Rev. D 95, 114008 (2017)



reduced states A and B



If region A and B are **entangled**,

$$\ln\{xG(x)\} \sim \sum_n \rho_n \ln\{\rho_n\}$$

ρ_n is the probability of finding n parton

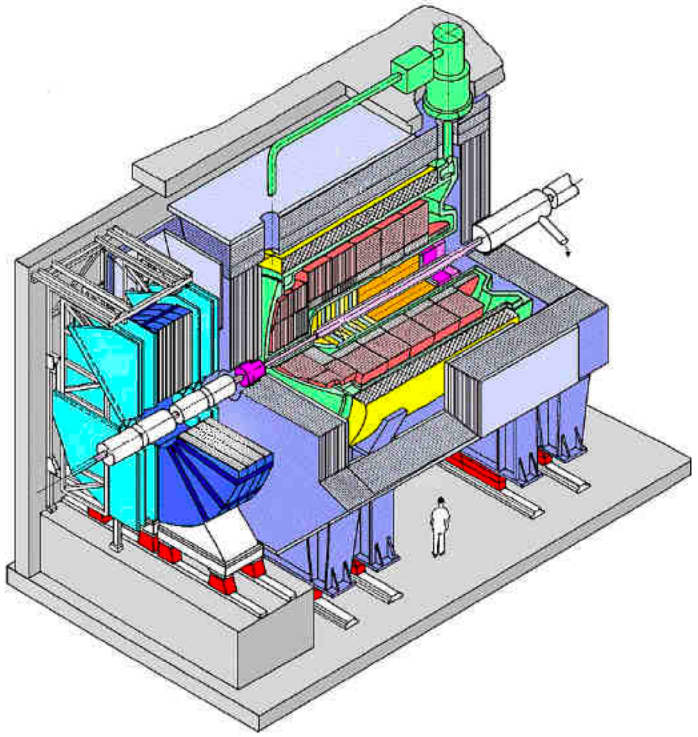
Measurement of final-state hadron P_n can provide the entanglement entropy

("local parton-hadron duality")

Entanglement Entropy at HERA and at an EIC

Measurement:

- Event by event charged-particle multiplicity distribution in DIS at low-x for the target fragmentation region



H1 experiment at HERA

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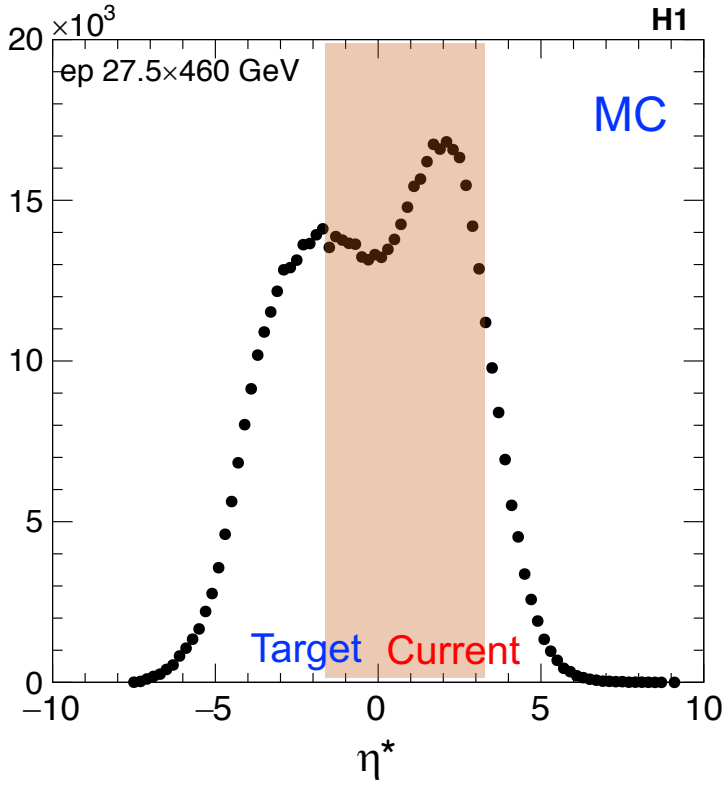

Limited in acceptance

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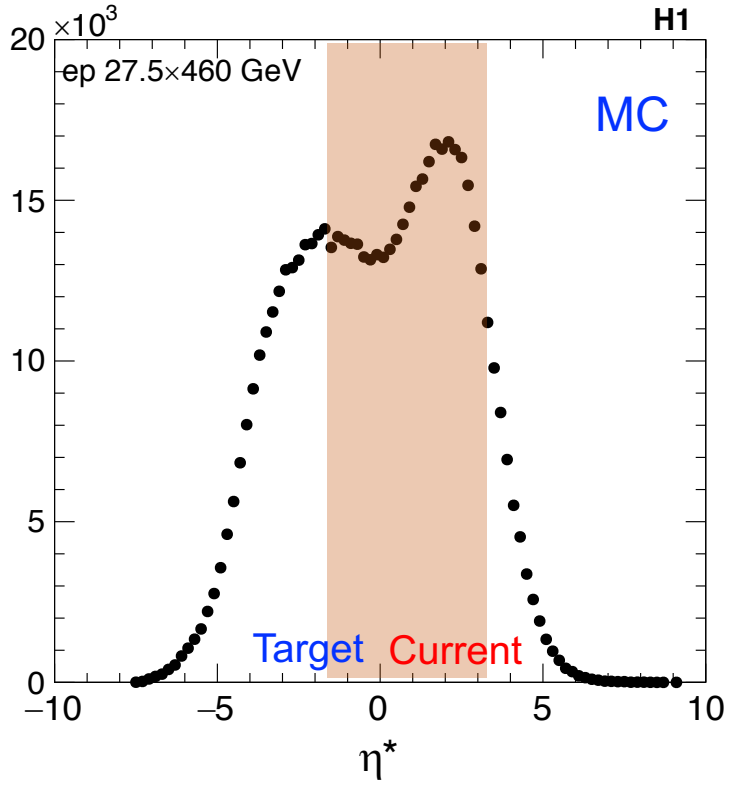

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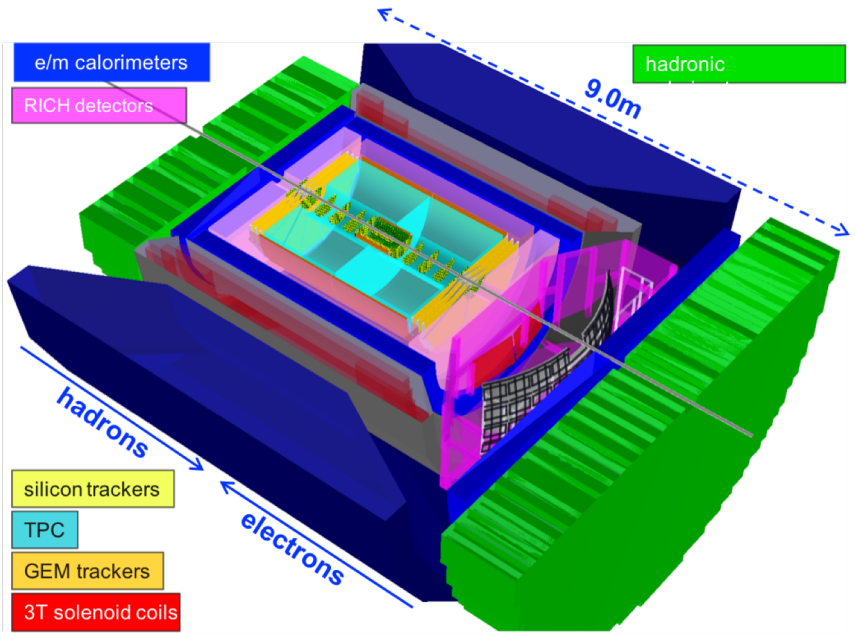


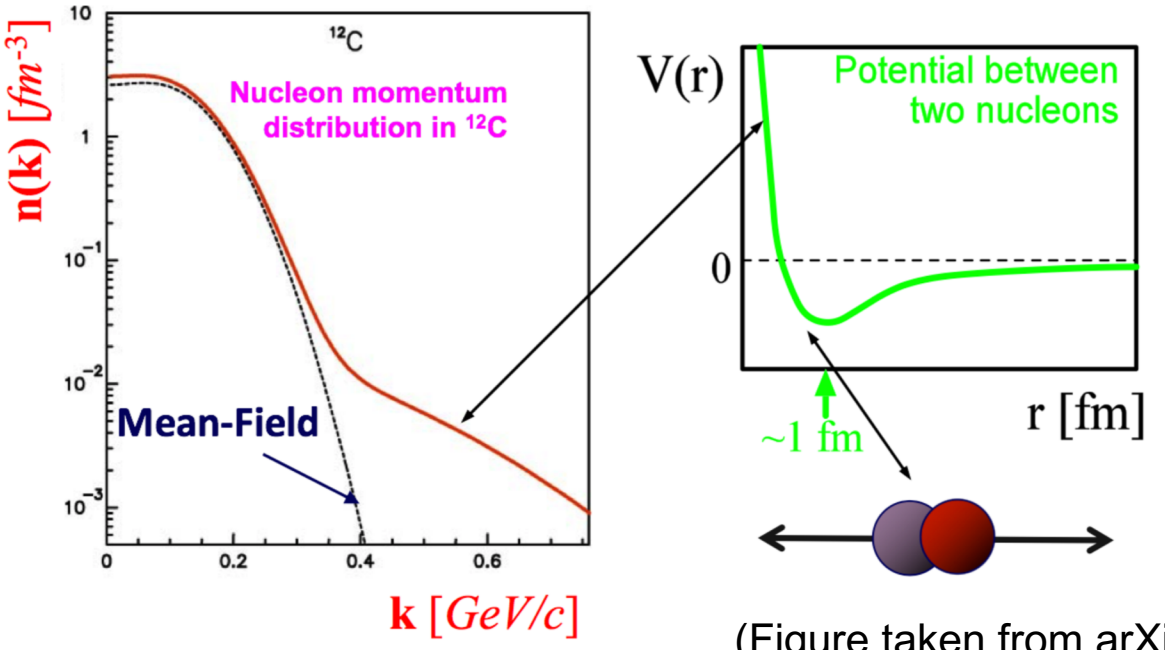
Large rapidity coverage with less asymmetric beams at an EIC will be a game changer

Short-range nuclear correlations

- How do nucleons bound together to form a nuclei?
- What is the dynamics of nucleon-nucleon interactions at short distance?

Short-range nuclear correlations

- How do nucleons bound together to form a nuclei?
- What is the dynamics of nucleon-nucleon interactions at short distance?



(Figure taken from arXiv:1810.03667)

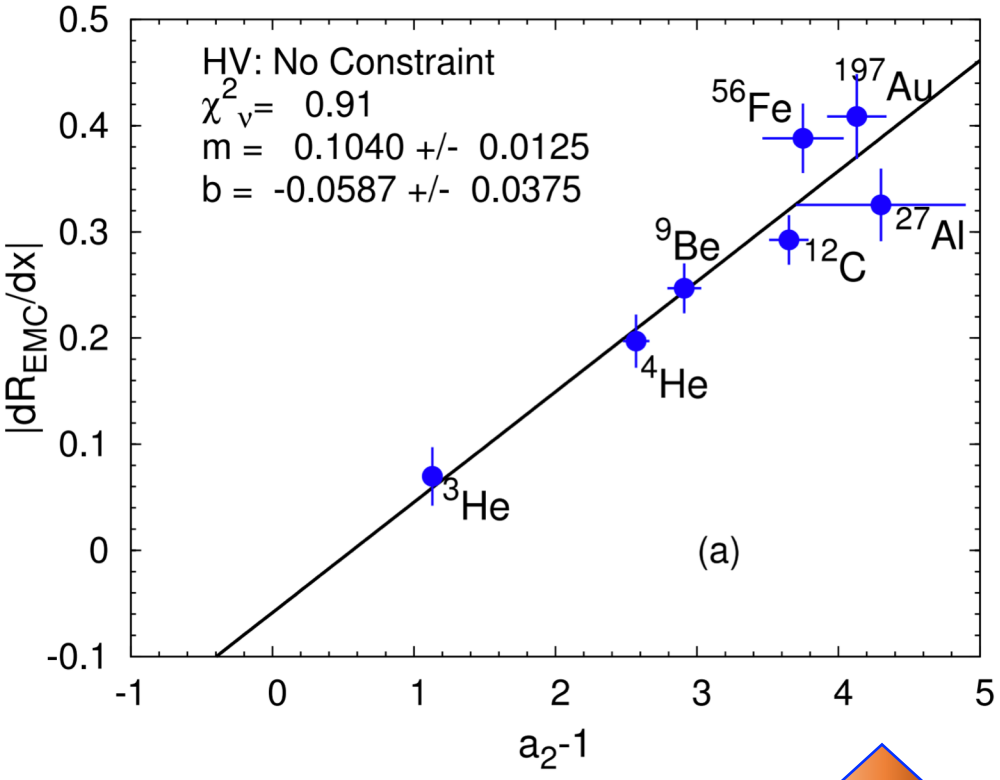
- Nucleons, protons and neutrons, interacts weakly at large distance (> 2fm), and strongly at short distance (~1fm), inside of nuclei

- Two distinct regions: $k < k_F$ and $k < k_F$ corresponds to:
  Mean-field theory, e.g., Shell model, vs Short-Range Correlations (SRCs)

A puzzle of nuclear physics

- *EMC* effect vs *SRCs*

How much nucleon PDF gets modified



Effect of nuclear density?

How strong the SRCs

A puzzle of nuclear physics

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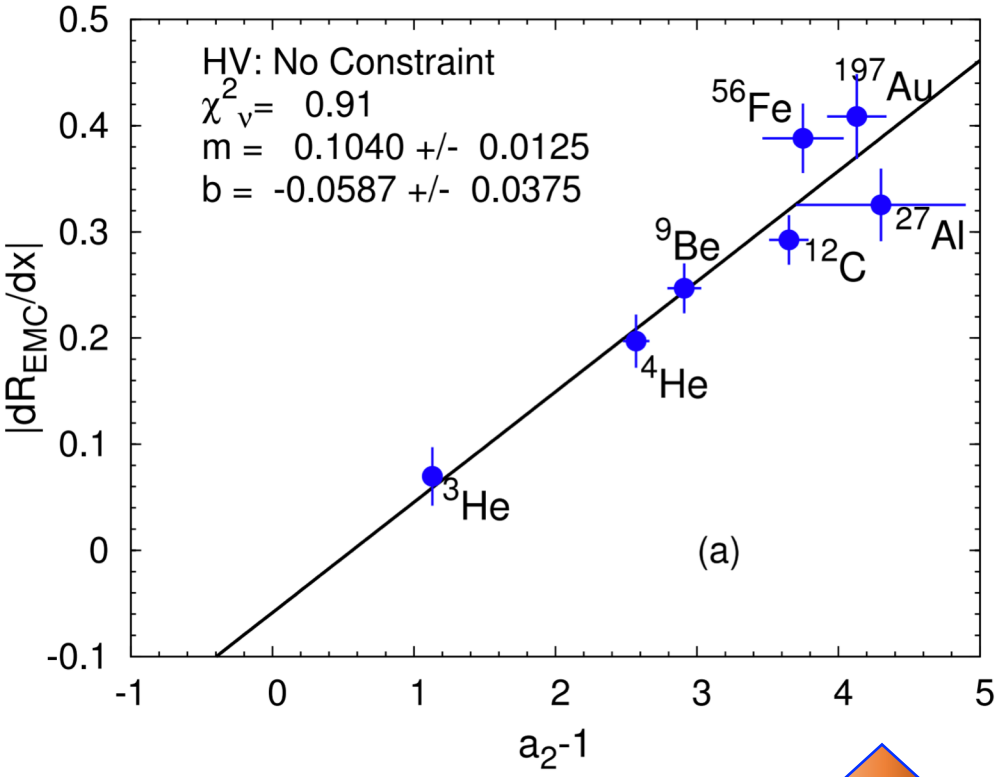
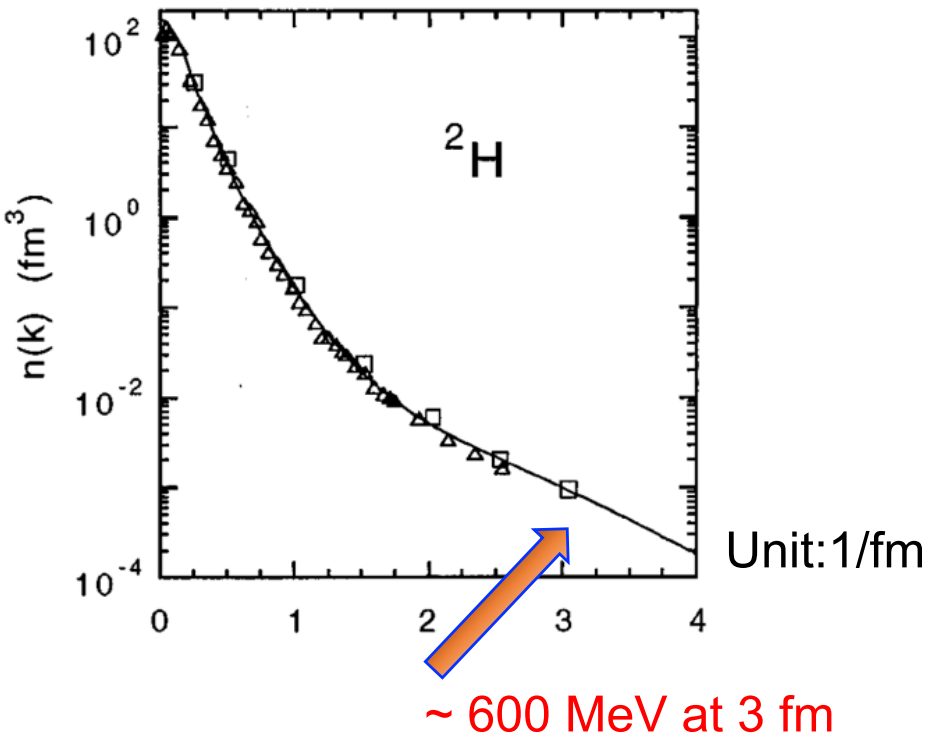


Effect of nuclear density?

How strong the SRCs

Can we study the SRCs in the simplest nuclei?

Probing *pn* configuration in deuteron at an EIC



- SRCs can be accessed by the *high pT component*

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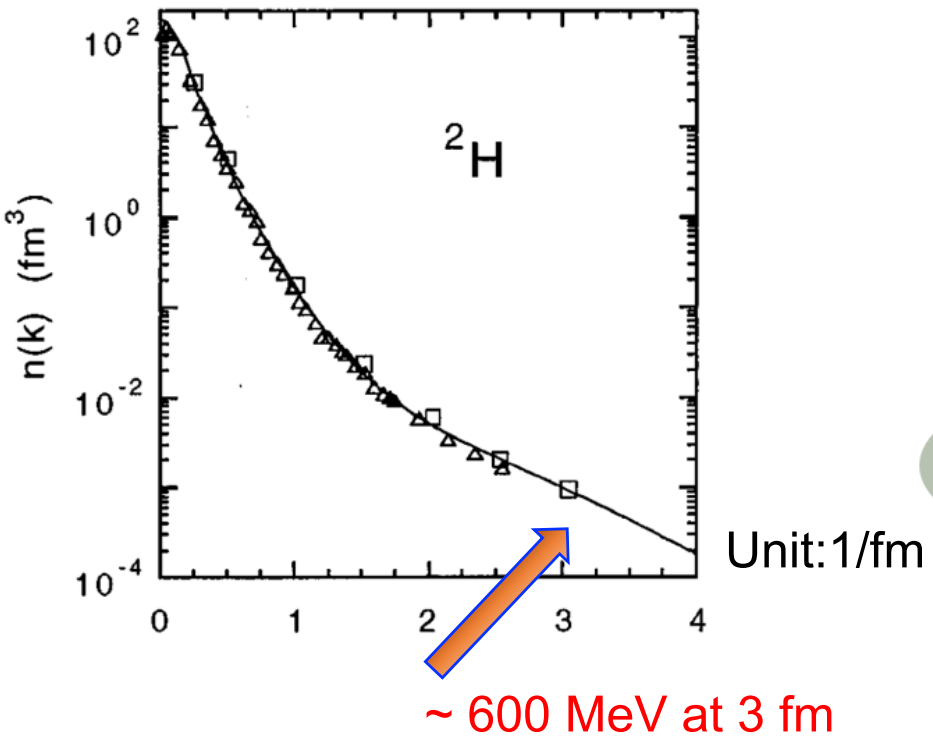
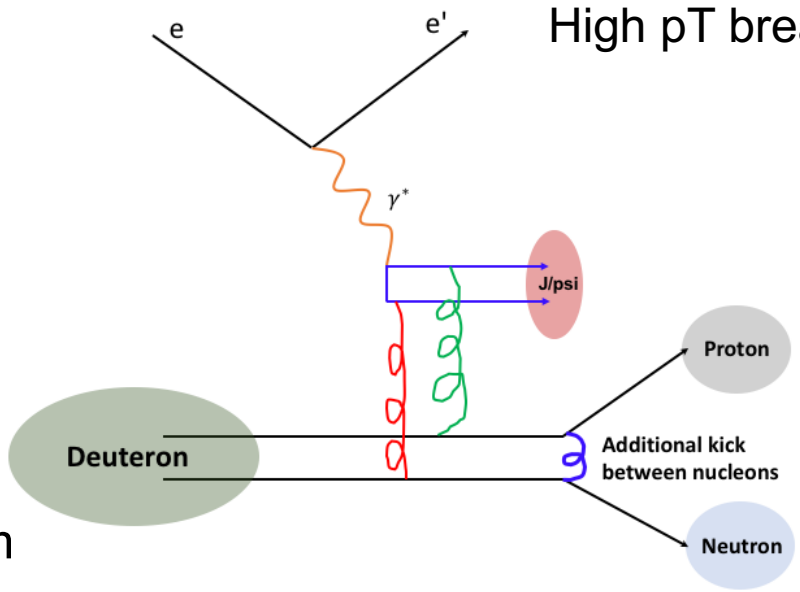


High pT breakup



Miller, Sievert, Venugopalan (2016)

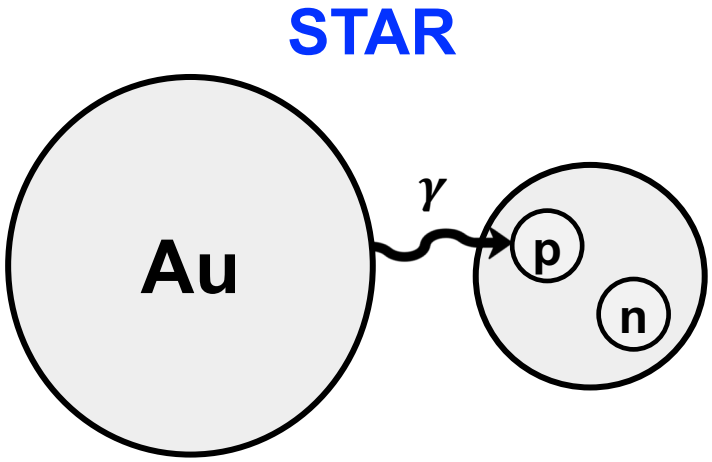
- SRCs can be accessed by the *high pT component*
- Sensitive to deuteron GPD
- Constrains SRCs models

Will be a challenging measurement at an EIC

Opportunities at RHIC via ultra-peripheral collisions

- Current dAu UPCs data:
  1. ***J/psi photoproduction off deuterons***

  2. Baseline estimates of ***pn*** configuration in deuteron by tagging a neutron? direct connection to ***SRCs***



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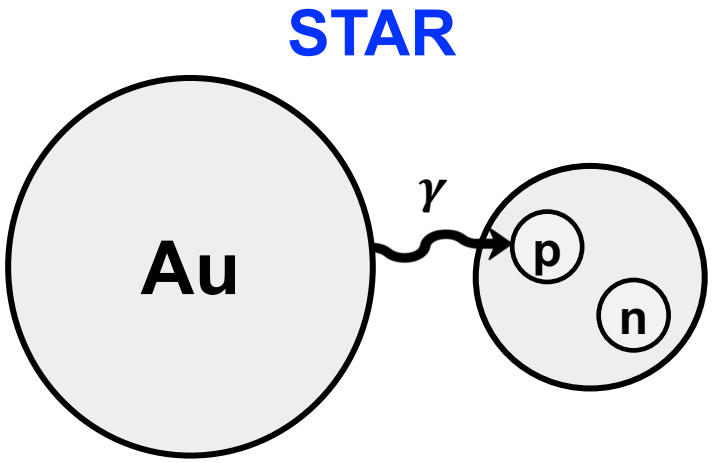

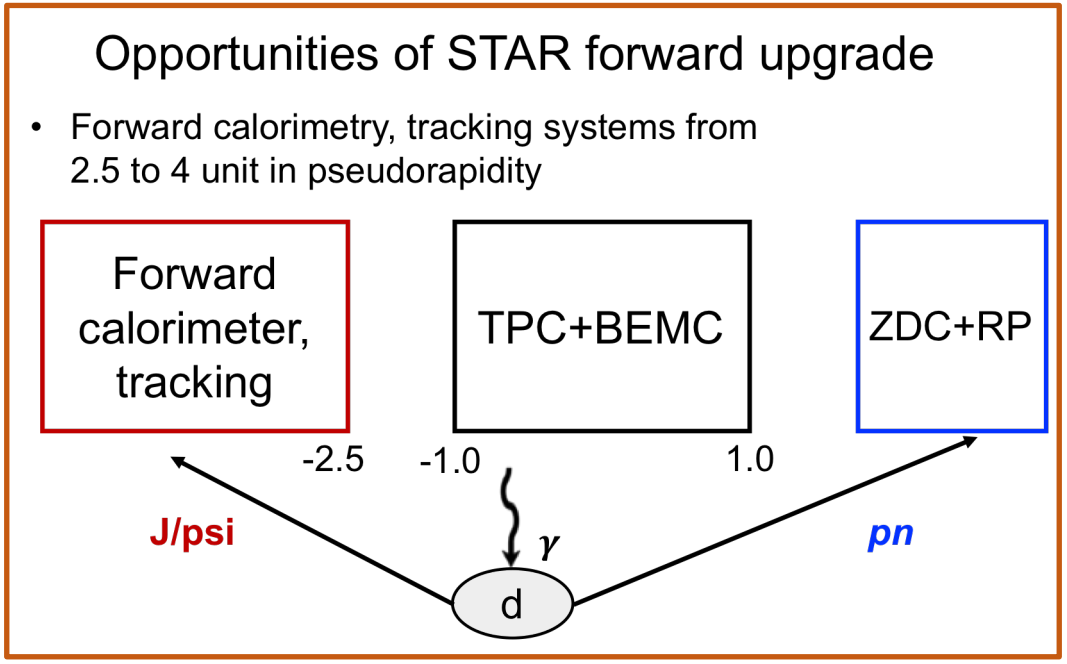

Maybe we can get a taste of the EIC physics before a decade later?

“If I ever get a career in physics, (I hope) it will be in an EIC”

Thank you!