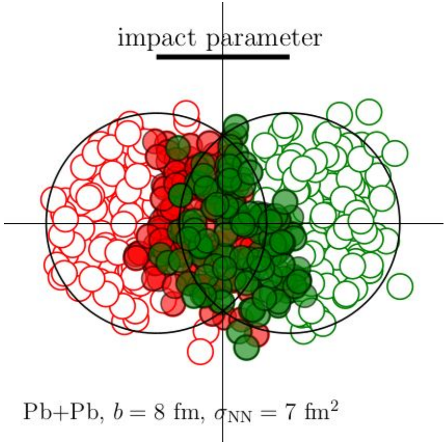
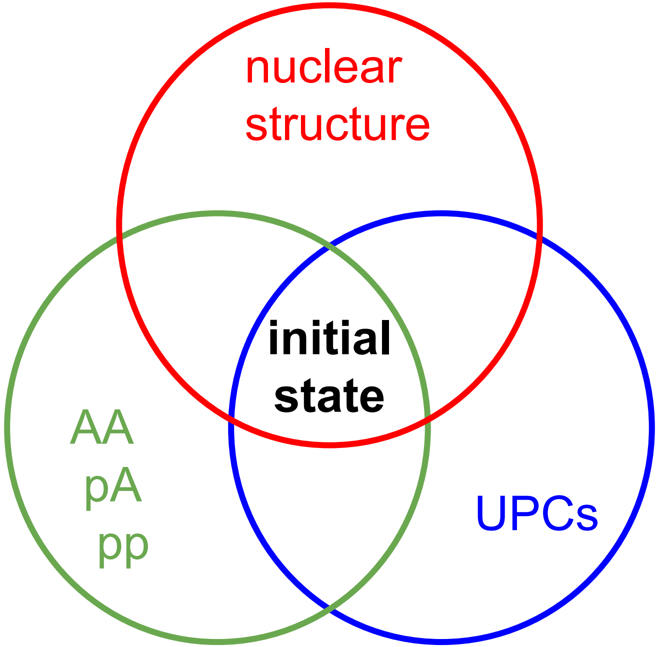
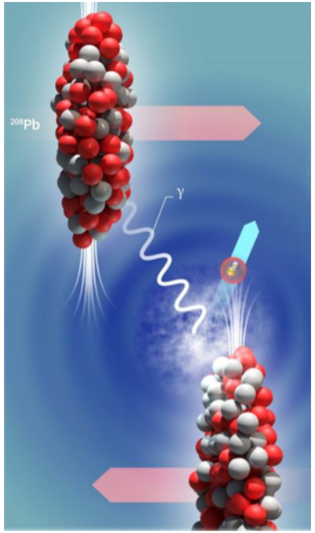
Initial state and UPC







Giuliano Giacalone and Michael Winn

06.09.2024

Motivation from a hadron-hadron collision perspective

Initial conditions

- Precision in large system
- *To be or not to be a QGP* in small systems

Unification goal

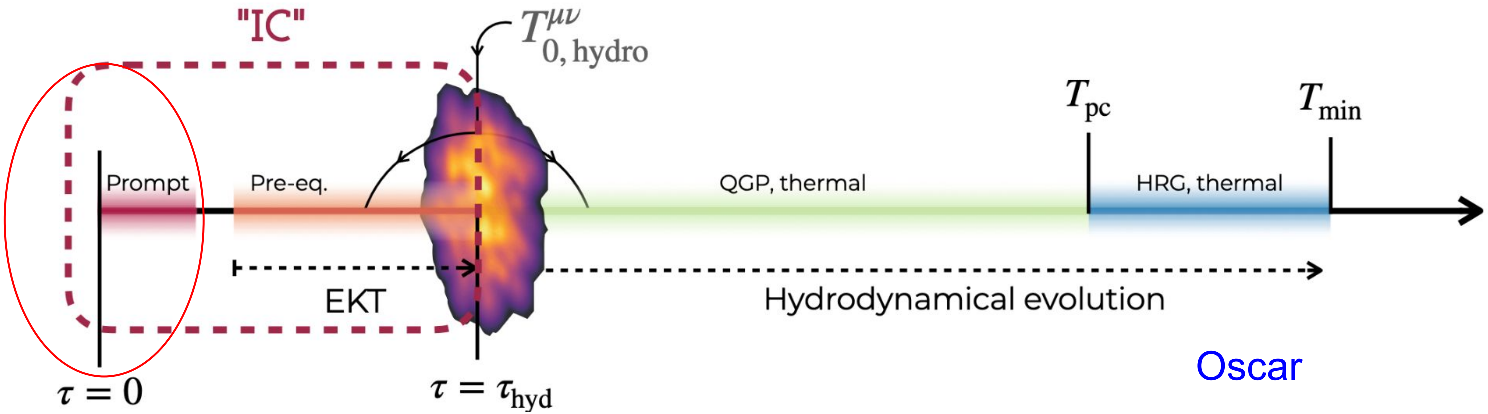
Oscar

- Map *hadron structure measurements* to initial conditions for bulk QGP

Challenges if connection to be made generic:

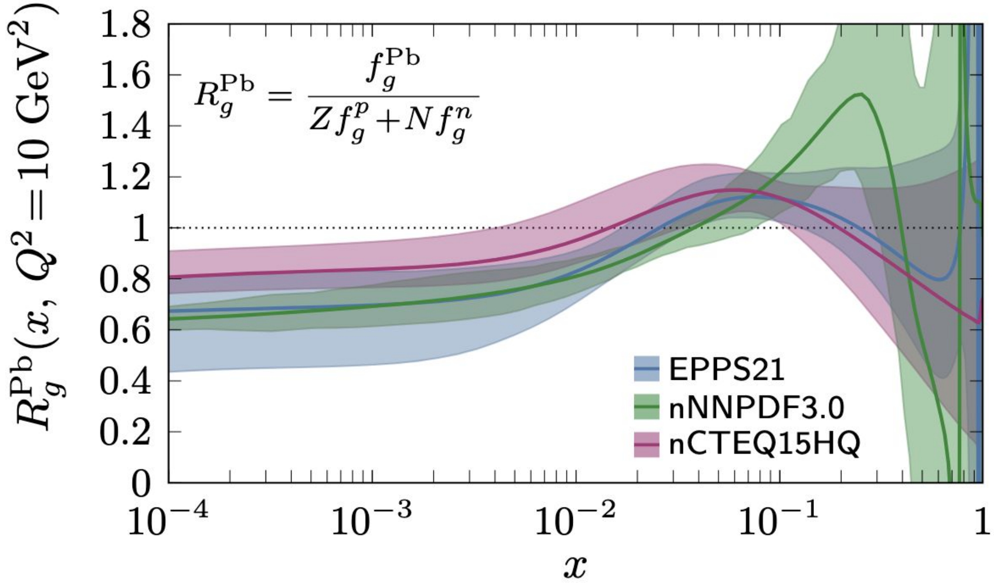
- Collinear perturbative QCD or color glass condensate paradigm requires hard scale
- Hadron-hadron collisions initial state given by multiple interactions per nucleon-nucleon scattering

Initial state and initial stages



- Focus on initial state rather than initial stages
  - A few comments on pre equilibrium at the end

Overview of nuclear parton distribution functions

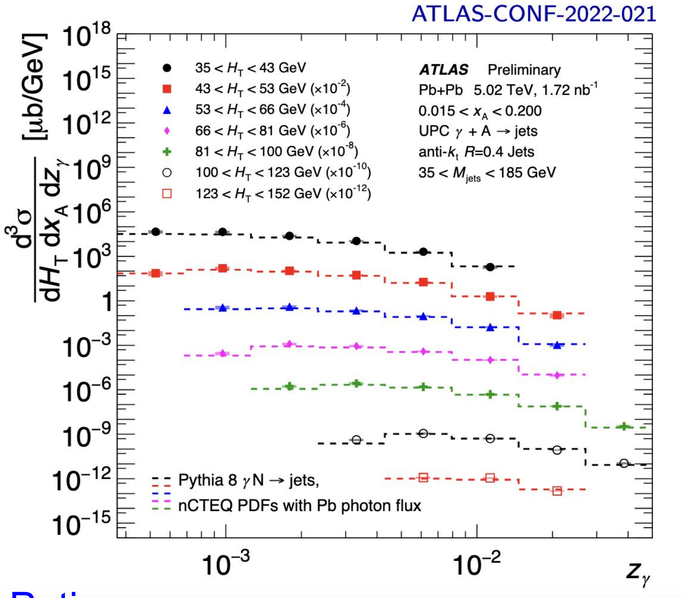


Petja

- independent nuclear PDF fits with different methodology and data selection
    - Strong impact of LHC data, review: Klasen&Paukkunen https://arxiv.org/abs/2311.00450
    - LHC impact limited by uncertainties related to: missing higher order corrections, higher twist (coh. energy loss) & hadronisation, indirect relation between exclusive observables and PDFs
        - Non-used exclusive observables indicate a similar nuclear suppression at low-x

Inclusive UPC: closest you can get to DIS in UPC

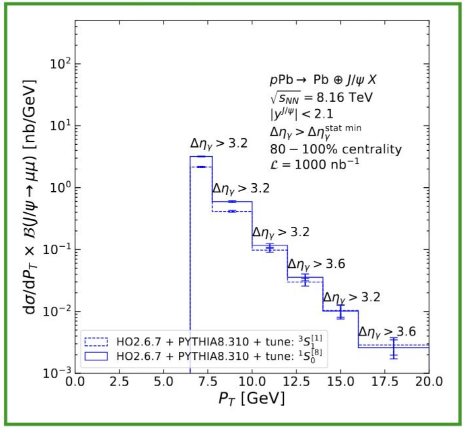
Dijet ATLAS data eagerly awaited as a first of its kind



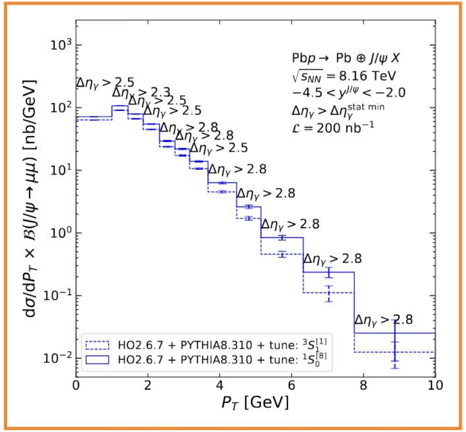
Petja

First feasibility on charmonium production: encouraging

General purpose detector [ATLAS, CMS]



Forward muon arm [ALICE, LHCb]



Lansberg et al. https://arxiv.org/abs/2409.01756

Kate

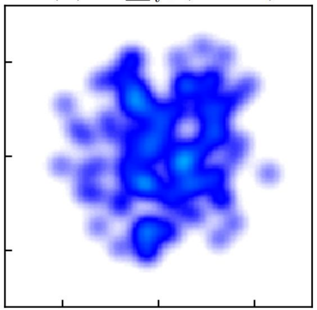
Paradigms of high-energy nuclear reactions

- HEAVY ION COLLISIONS

DENSE-DENSE SCALING

$$\epsilon(\mathbf{x}, \tau = 0^+) = t(\mathbf{x})t'(\mathbf{x})$$

$$t(\mathbf{x}) = \sum_i^{A} g(\mathbf{x} - \mathbf{x}_i)$$

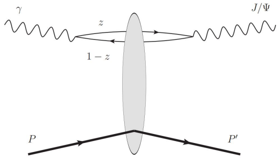


$$g(\mathbf{x} - \mathbf{x}_i) = \frac{1}{2\pi w^2} \exp\left(-\frac{(\mathbf{x} - \mathbf{x}_i)^2}{2w^2}\right)$$

- ULTRA-PERIPHERAL COLLISIONS

e.g. VECTOR MESON PRODUCTION

$$\mathcal{A}^{\gamma^* A \to VA} \propto \int_{\mathbf{b}} e^{-i\mathbf{b}\cdot\mathbf{\Delta}} N(\mathbf{r}, \mathbf{b}, x)$$



weak-field IP-SAT limit:

$$N(\mathbf{r}, \mathbf{b}, x) \propto t(\mathbf{b})$$

PHENOMENOLOGY:

energy-density correlations

nuclear structure (1-body) — nucleon structure — nuclear structure (2-body)

$$\langle \epsilon(\mathbf{x})\epsilon(\mathbf{y})\rangle_{\rm ev} = \left(A \int_{\xi_i} P_{1\perp}(\xi_i) g(\mathbf{x} - \xi_i) g(\mathbf{y} - \xi_i) + (A^2 - A) \int_{\xi_i \neq \xi_j} P_{2\perp}(\xi_i, \xi_j) g(\mathbf{x} - \xi_i) g(\mathbf{y} - \xi_j) \right)^2$$

incoherent production

$$\frac{d\sigma^{\gamma^* A \to VA}}{d|t|} \propto \langle |\mathcal{A}|^2 \rangle - |\langle \mathcal{A} \rangle|^2 \propto \int_{\mathbf{b_1}, \mathbf{b_2}} e^{-i\mathbf{\Delta}\cdot(\mathbf{b_1} - \mathbf{b_2})} \left[\langle t(\mathbf{b_1}) t(\mathbf{b_2}) \rangle - \langle t(\mathbf{b_1}) \rangle \langle t(\mathbf{b_2}) \rangle \right]$$

Great progress in matching low-energy theory to high-energy processes

Modern nuclear theory: EFT of low-energy QCD

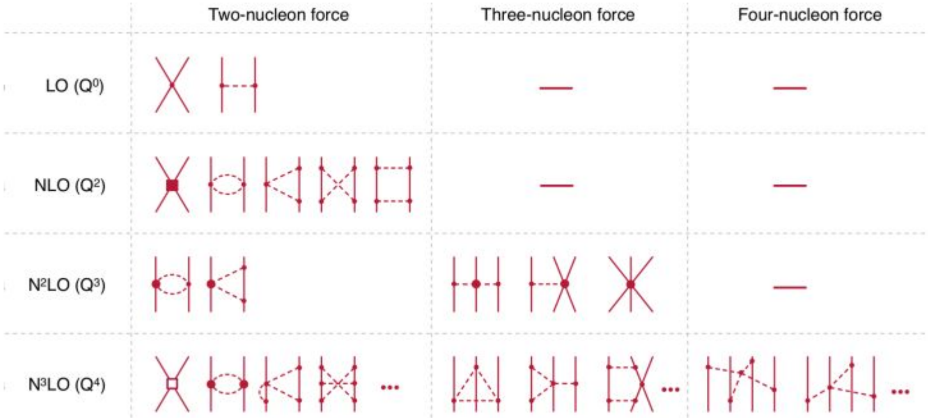
$(Q/\Lambda)^n$ (power counting)

Weinberg *et al.*, Phys. Lett. B 251, 288 (1990)

$$\mathcal{H} = \sum_i \mathcal{T}_i + \sum_{i<j} V_{ij} + \sum_{i<j<k} V_{ijk} + \cdots$$

$$\rightarrow H|\Psi_k^A\rangle = E_k^A|\Psi_k^A\rangle$$

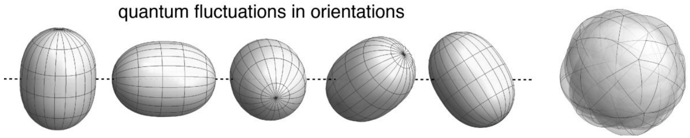
Benjamin



Projected Generator Coordinate Method (PGCM) – superposition of intrinsic states:

$$|\Psi\rangle = \sum_q f(q)|\Phi(q)\rangle$$

q=shape params.



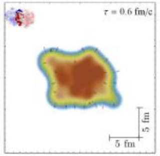
Density for high-energy simulations:
($\bar{q}$ = average shape)

$$\rho_m(x,y,z) = \sum_{st} \frac{\langle\Phi(\bar{q})|a^+_{xyzst}\, a_{xyzst} P^Z P^N|\Phi(\bar{q})\rangle}{\langle\Phi(\bar{q})|P^Z P^N|\Phi(\bar{q})\rangle}$$

EFT → **Nuclear structure** → **Relativistic hydrodynamic** → **Hadron transport** → **Nucl-th**

χEFT
N3LO

TAURUS



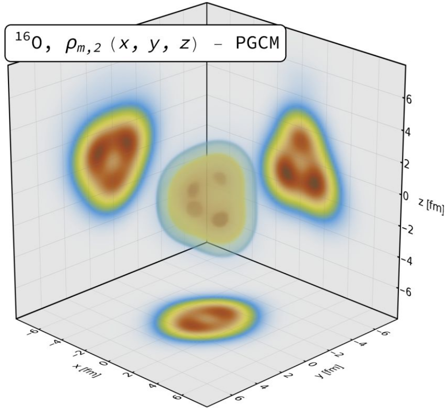
Trajectum

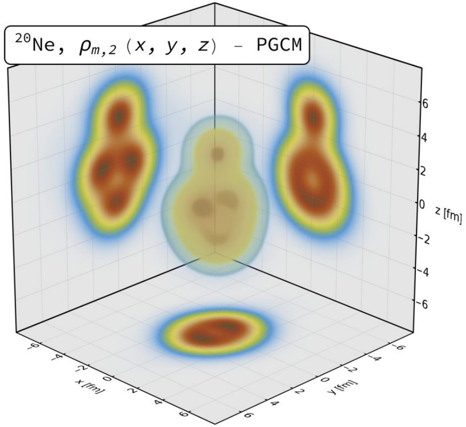
smash

arXiv:2402.05995

Benjamin

https://arxiv.org/pdf/2402.05995
https://arxiv.org/pdf/2405.20210



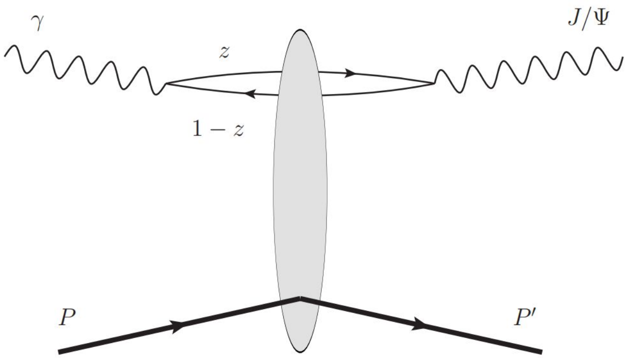


First attempt to generalize nPDFs to include short-range correlations:

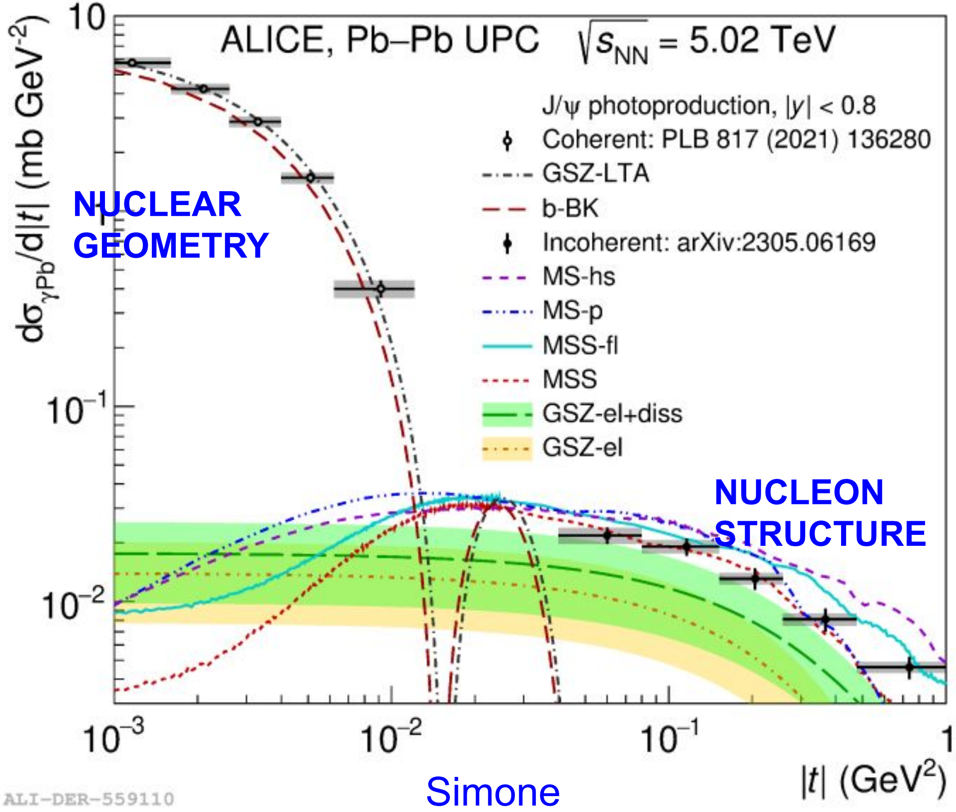
NCTEQ15 https://arxiv.org/pdf/2312.16293

$$f_i^A(x,Q) = \frac{Z}{A}\left[(1-C_p^A)\times f_i^p(x,Q) + C_p^A \times f_i^{\mathrm{SRC}\,p}(x,Q)\right] + \frac{N}{A}\left[(1-C_n^A)\times f_i^n(x,Q) + C_n^A \times f_i^{\mathrm{SRC}\,n}(x,Q)\right]$$

Coherent and incoherent data from ALICE



Inferring parameters for ^{208}Pb and nucleon shape/fluctuations within nucleus?



Simone

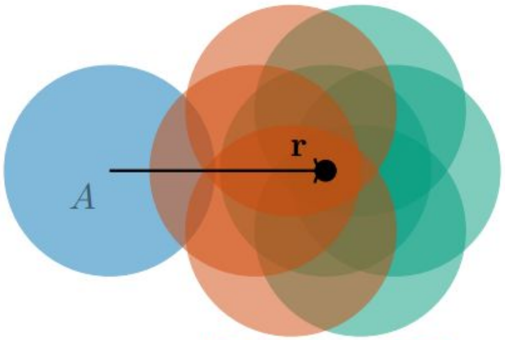
Independent information on initial condition modeling of pp, pA, AA collisions

Incoherent data: https://arxiv.org/abs/2305.06169, coherent https://arxiv.org/abs/2101.04623

back to inclusive di-jet

$$d\sigma^{AB\to A+\text{dijet}+X} = \sum_{i,j,X'} f^{\text{eff}}_{\gamma/A}(y) \otimes f_{i/\gamma}(x_\gamma, Q^2) \otimes f_{j/B}(x, Q^2) \otimes d\hat{\sigma}^{ij\to\text{dijet}+X'}$$

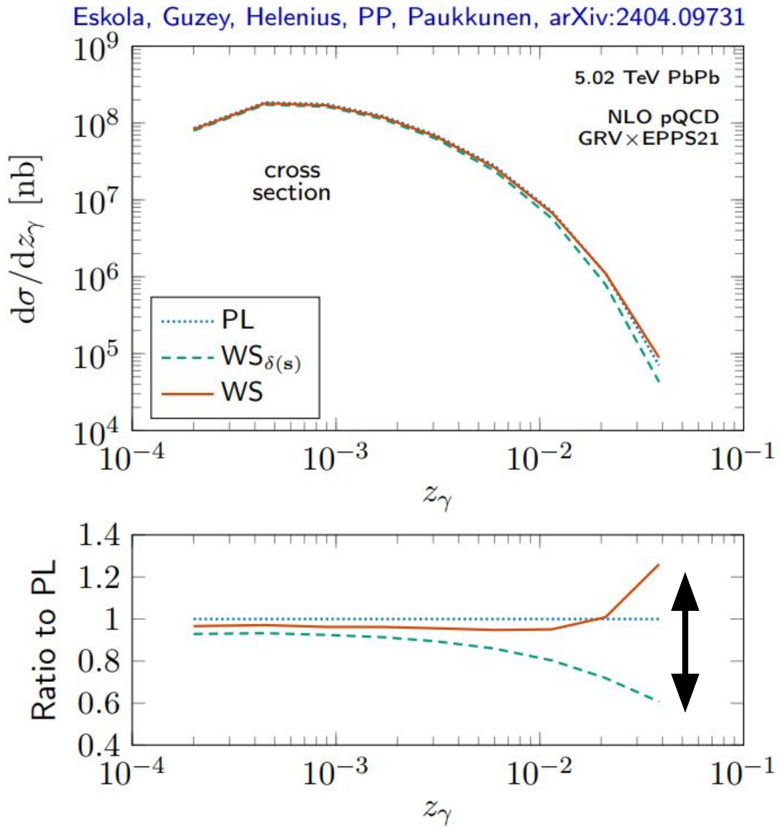
events at high z_γ probe geometry of overlap!



Petja

$$f^{\text{eff}}_{\gamma/A}(y) = \frac{1}{B}\int d^2\mathbf{r}\int d^2\mathbf{s}\, f_{\gamma/A}(y,\mathbf{r})\, T_B(\mathbf{s})\, \Gamma_{AB}(\mathbf{r}-\mathbf{s})$$

$$f_{j/B}(x, Q^2, \mathbf{s}) = \frac{1}{B} T_B(\mathbf{s}) \cdot f_{j/B}(x, Q^2)$$



Initial state: interesting on its own

- A key motivation: search for saturation
  - Would need more different view points for a representative discussion

Short discussion of best observable to probe saturation, mentioned cases:

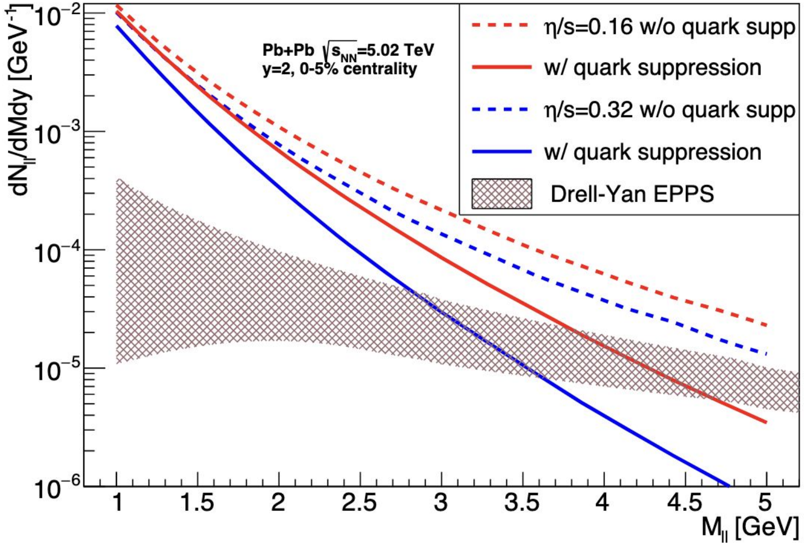
- Intuition fluctuations vs. average extreme kinematics: dissociative J/psi production in gamma-p
  - Experimental feasibility demonstrated in https://arxiv.org/abs/2304.12403
  - See model https://arxiv.org/abs/1608.07559
- Intuition fluctuations vs. average, nuclear case: Incoherent J/psi production in UPC at high-t
  - See model calculation: https://arxiv.org/abs/2312.11320
- Precision: longitudinal structure function in DIS, e.g. EIC
  - See quantitative comparison between collinear and saturation in https://arxiv.org/abs/2203.05846
- Extreme kinematics and cleaner than hadron production: Forward photon production at the LHC in pp vs pA: Focal/LHCb

Inter-track discussion on preequilibrium

- Current set of observables in global fits (e.g. Trajectum) poorly sensitive to preequilibrium physics
  - Conceptually a key question how to ‘thermalize/hydrodynamise’
  - Better understanding of small systems

- Dileptons at high masses proposed as a handle on this stage

  - high mass: early emission



Coquet et al. https://arxiv.org/abs/2104.07622 (yield),

https://arxiv.org/pdf/2112.13876 (mt-scaling),

https://arxiv.org/pdf/2309.00555 (polarisation)

Garcia-Montero et al. (full kinetic theory):

https://arxiv.org/pdf/2403.04846

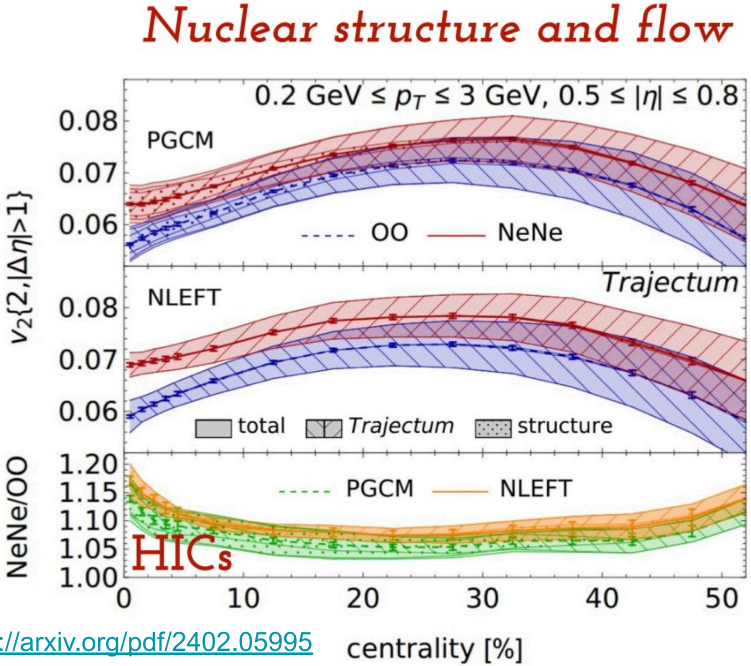
- Key motivation for future measurements at ALICE2/3 & LHCb U1 and U2

Inter-track discussion on small systems

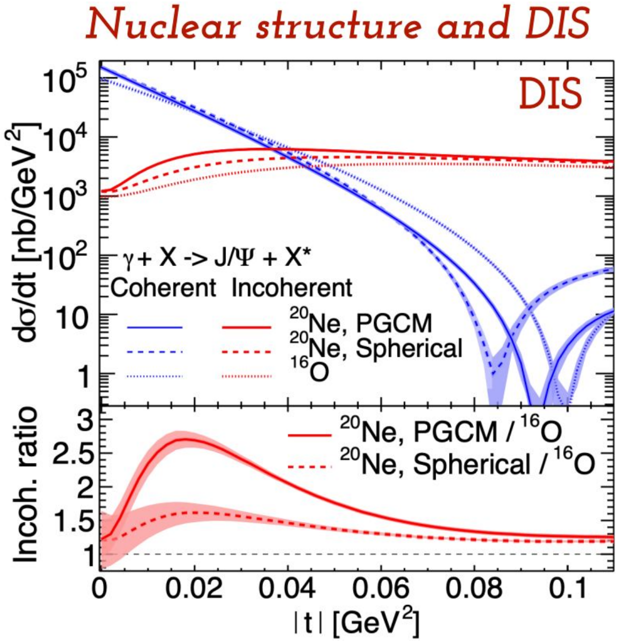
Understanding “small system flow”: initial state is big bottleneck in p-A and p-p

Exploiting light nuclei: improved theoretical systematics. Combine with UPCs!

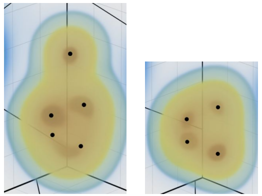
https://arxiv.org/pdf/2303.04866



https://arxiv.org/pdf/2402.05995



Oscar




Light ion collisions at the LHC
Location: CERN
Date: Nov. 11-15, 2024
Website: cern.ch/lightions
Topics covered:
3D initial conditions and small systems
Cosmic rays and the LHC
Experimental highlights
Experimental projections for light ion collisions
Heavy flavour in small systems
Hydrodynamics in small systems
Initial conditions and small systems
Jets in small systems
Nuclear geometry and ultraperipheral collisions
Nuclear parton distribution functions
Machine development
Nuclear structure and the LHC
Organisers:
Reyes Alemany Fernandez
Giuliano Giacalone
Qipeng Hu
Govert Hugo Nijs
Saverio Mariani
Wilke van der Schee
Huichao Song
Jing Wang
Urs Wiedemann
You Zhou

Question: use of JLab data for geometry constraints

Reply:

- Caveats:
  1) Access to fluctuations needed for heavy-ion collision observable description:

     provided by HERA and UPC data incoherent/dissociative jpsi production, standard form factors/DVCS only sensitive to average sizes/distribution

     not aware of any equivalent data from JLAB on ‘incoherent production’, fluctuation picture of incoherent/dissociative production relies on Good-Walker picture (difficult to imagine to make it work at low energy)

  2) Collision energy difference

  3) LHC heavy-ion collisions sensitive to gluonic content:

     provided by J/psi data at HEA/LHC

     gluon sensitive measurements at JLAB very rare and/or typically close to threshold (e.g. Jpsi production), requires formalism adapted for threshold production

  4) If perturbative QCD used to transfer information: requires sufficiently large Q2, at the edge for large fraction of JLab data, see e.g. PDF fits