Conference Highlight: Initial state and early time dynamics

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HP2024
NAGASAKI

Thanks to Sören, Oscar, Petja, Heikki, Carlota, Giuliano, Yuuka, Jean-Francois, Dennis, Rithya, Jasmine, Isobel and others for useful input

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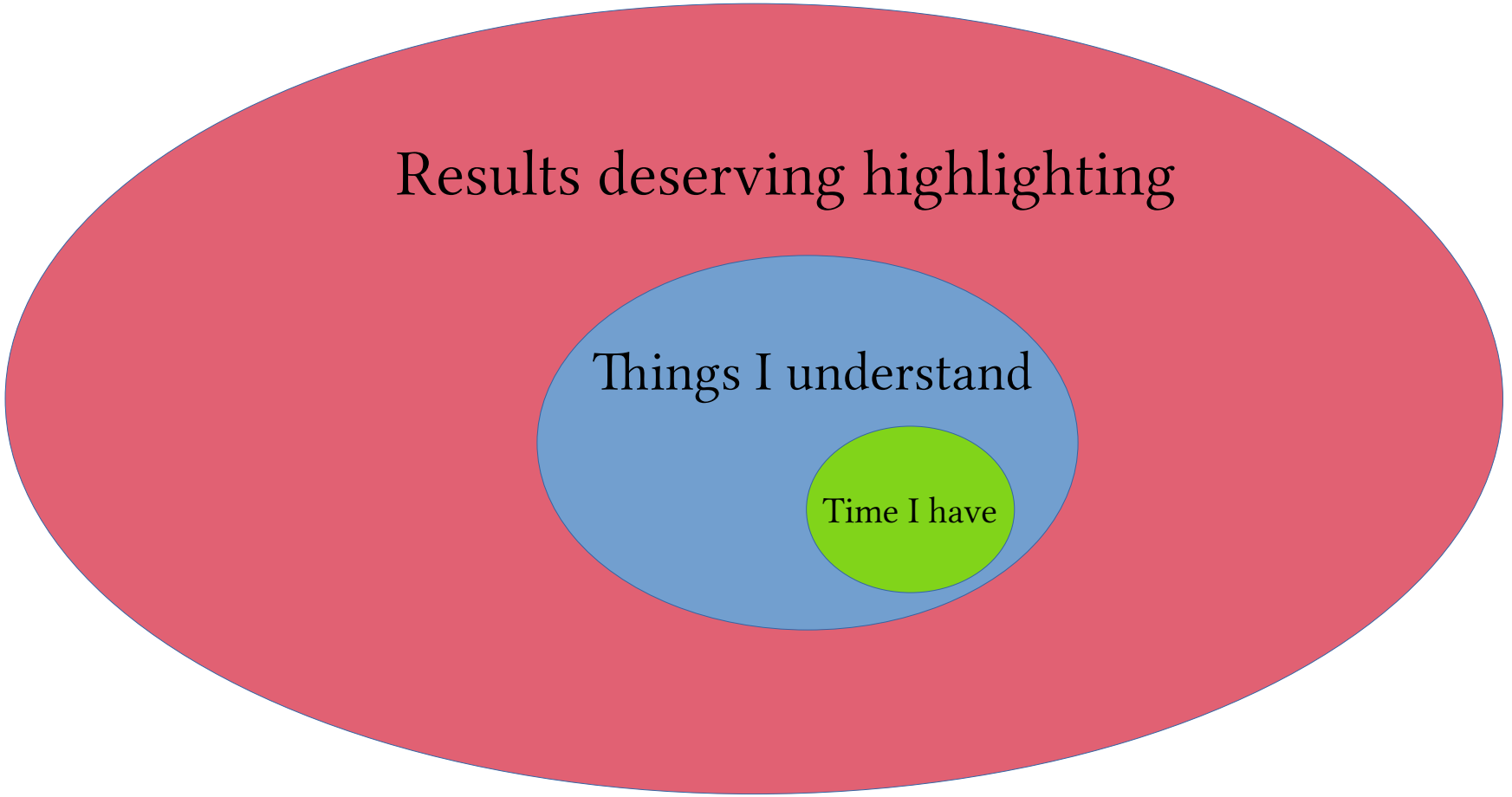
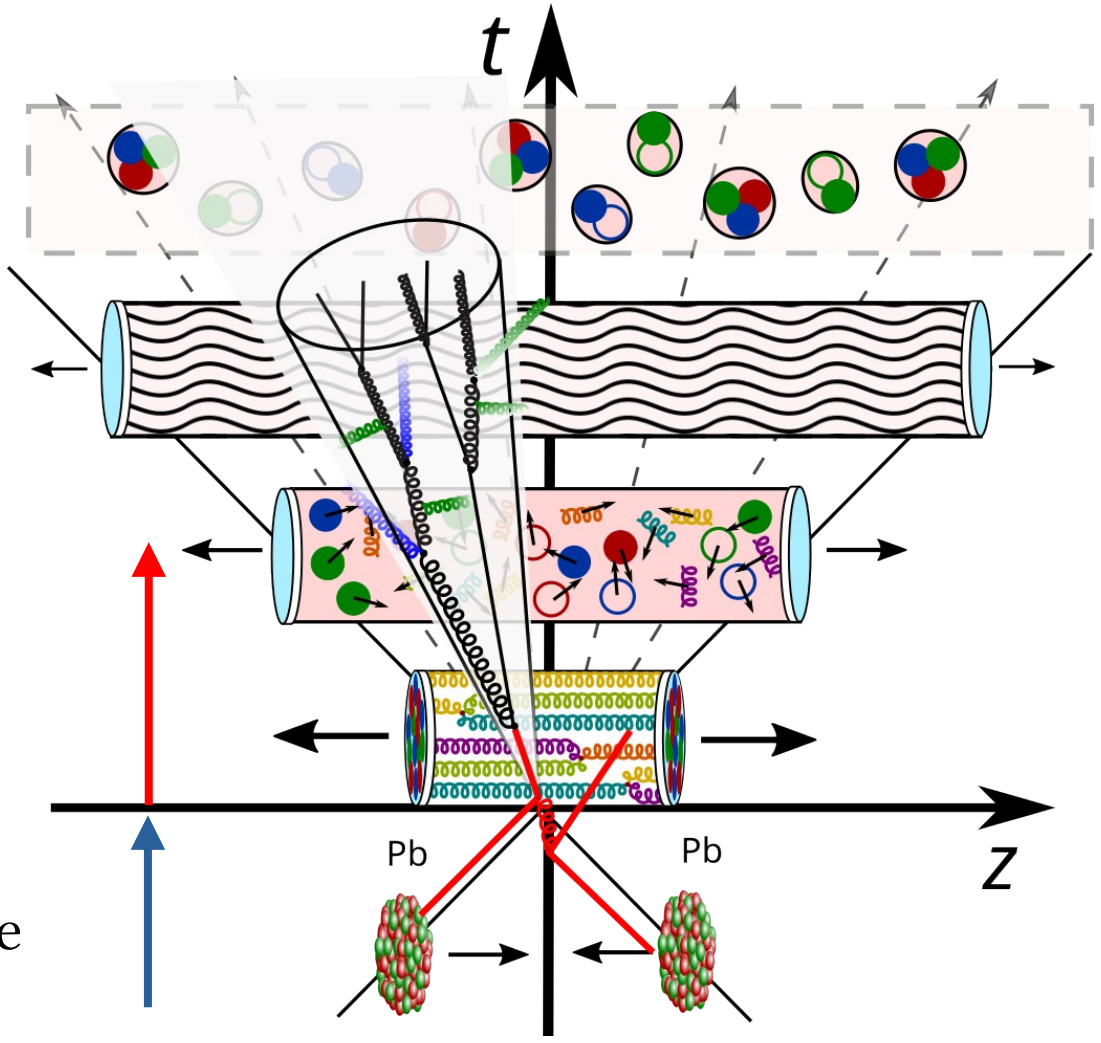
Outline


Results deserving highlighting
Things I understand
Time I have



Early time dynamics

Initial state

hydrodynamics

kinetic theory

glasma

CGC

nPDF

Outline

IS&ETD Hidetoshi Taya, Sun 14:00

nPDFs Petja Paakkinen, Thu 14:50
CGC Farid Salazar, Thu 15:15
UPCs Minjung Kim, Fri 8:45

Initial state physics

- What is the state of nucleus before the collision?
- How is energy deposited in the collision region?
- What are relevant initial state fluctuations?

Early time dynamics

- How does pre-equilibrium affect soft observables?
- How does pre-equilibrium affect hard observables?
- What is happening in small systems?

Jet response Daniel Pablos, Thu 09:00
Hard-Soft Ismail Soudi, Thu 09:25
Finite-size Isobel Kolbe, Thu 09:50
EW T Lipei Du Thu, 14:00
EW E Daiki Skihata, Thu 14:25
EW H Jean-Francois Paquet, Fri 12:15

nPDFs Petja Paakkinen, Thu 14:50
CGC Farid Salazar, Thu 15:15
UPCs Minjung Kim, Fri 8:45

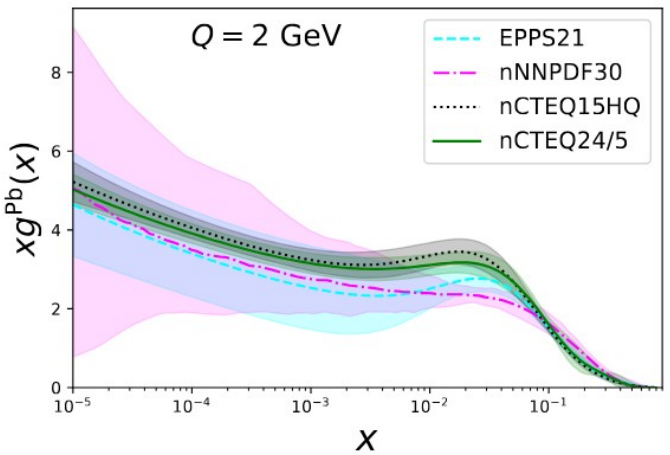
Initial state at short distances

Nuclear parton distribution functions

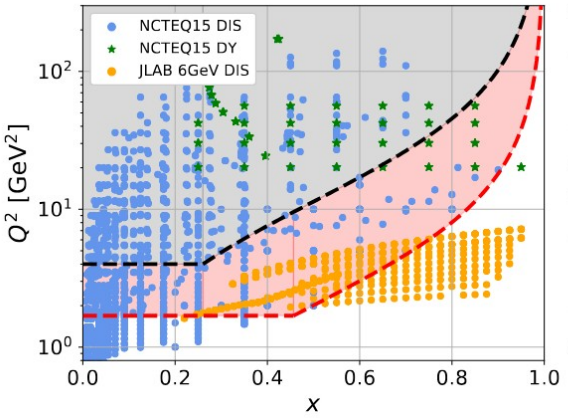
- Important for pQCD (no-medium) baseline computations
- New nCTEQ24/5 fit with more data and new parametrization
- Caution needed for data with possible final state effects

Comparison to other nPDFs

Kusina
Mon 15:00



Extended kinematics



nCTEQ15
$Q > 2$ GeV
$W > 3.5$ GeV
$N_{\text{data}} = 708$

nCTEQ15HIX
$Q > 1.3$ GeV
$W > 1.7$ GeV
$N_{\text{data}} = 1679$

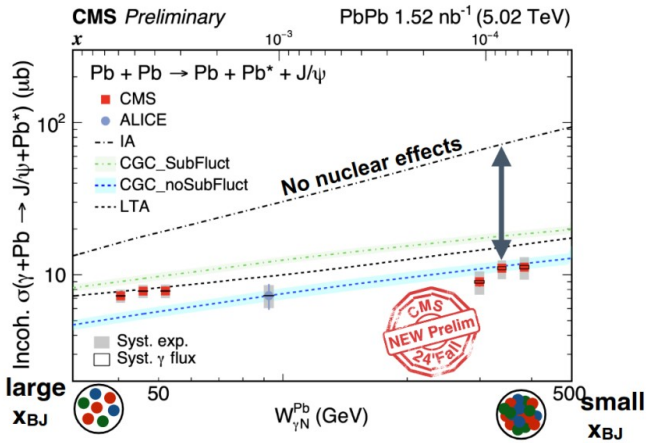
- Important to compare multiple nPDF extractions
- Data missing for light-ions ⟶ uncertainties in A-dependence

New constraints from ultra-peripheral collisions

- Access a wide range of Bjorken x $(10^{-4}<x<10^{-2})$ and Q values

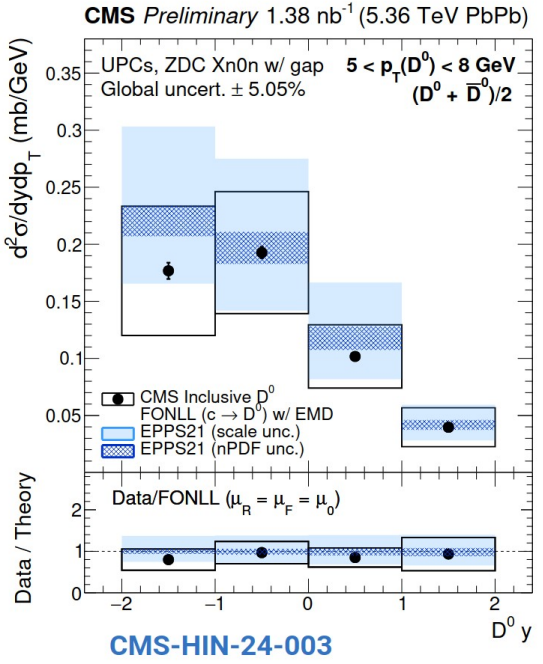
incoherent J/ψ production

Ye, Wed 11:30



D^0 measurement

Mc Ginn
Wed 10:50

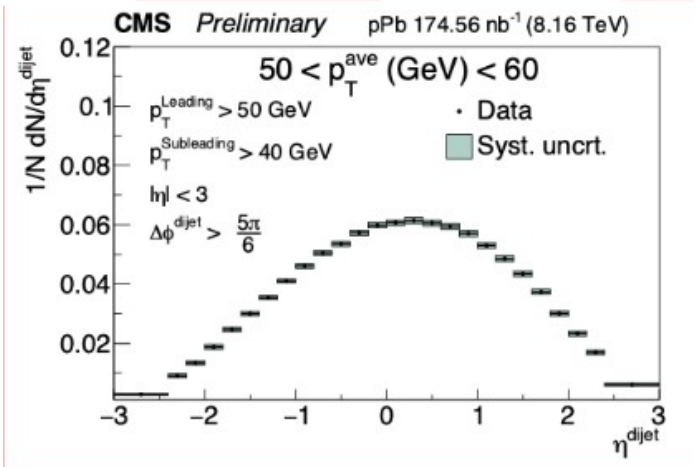


- UPCs should be included in global nPDF fits

New constraints from pPb collisions

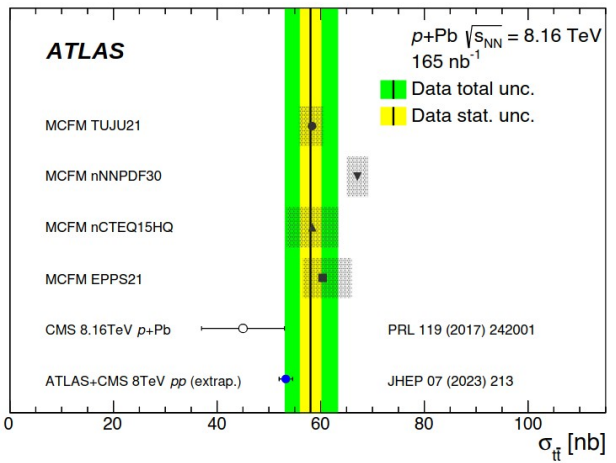
- t-tbar: 9% uncertainty in cross-section
- di-jets: 10^5 entries in uncertainty covariance matrix

di-jets small x



Nigmatkulov
Mon, 14:00

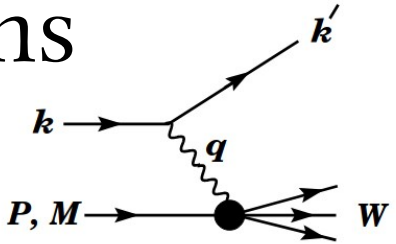
$t\bar{t}$ large x



Potępa
Mon, 14:20

- Absolute di-jet cross-sections would be even better
- More statistics needed for differential t-tbar measurement

Alternative to PDFs: structure functions



- Structure functions measurable in deep-inelastic scattering

$$\frac{d^2\sigma^i}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\,\eta^i \left\{ \left(1 - y - \frac{x^2y^2M^2}{Q^2}\right) F_2^i + y^2 xF_1^i \mp \left(y - \frac{y^2}{2}\right) xF_3^i \right\},$$

- Replace PDFs with structure functions $F_i(x, Q^2) = \sum_j C_{ij}(Q^2, \mu^2) \otimes f_j(\mu^2)$

Tevio
Mon, 15:20

Physical basis evolution

- Renormalization scheme in $\alpha_s(\mu_r^2)$
- Perturbative truncation
  $\longrightarrow$ sum rule not exact
- Parametization of observable quantities

Evolution with PDFs

- Factorization scheme and scale
- Renormalization scheme in $\alpha_s(\mu_r^2)$
- Easy to enforce an exact sum rule
- Parametization of non-observable quantities

- Will benefit from future EIC data
- A lot of work still needed to catch up with PDF precision

Initial state at long distances

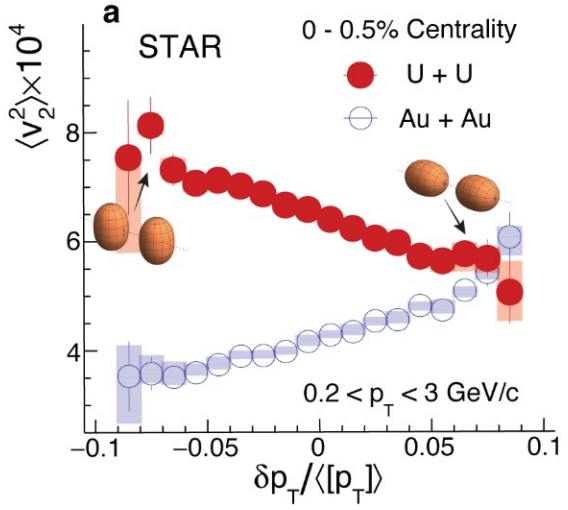
New constraints from ultra-central collisions

- Great success story of theory proposal and experimental measurement
- Precision determination of nuclear structure

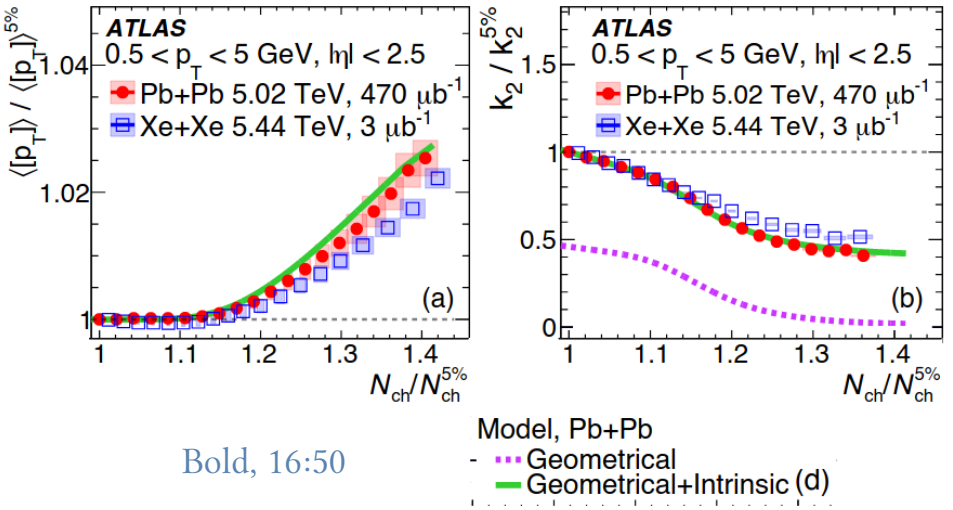
. Gardim, Giacalone, Ollitrault, PLB (2020)

Giacalone, PRL (2020) p_T—v_2 correlations

STAR 2401.06625



p_T fluctuations



Bold, 16:50

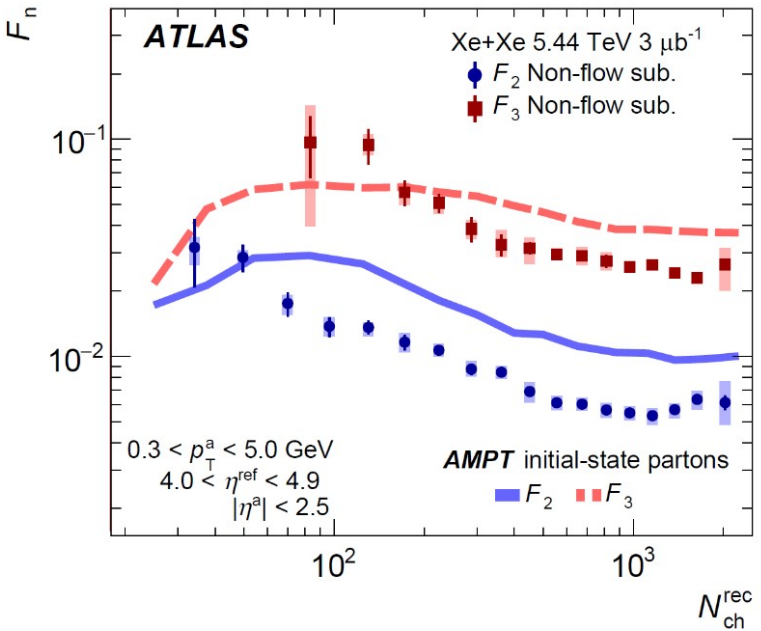
- Validation of heavy-ion modeling and measurement
- Light-ions ⟶ direct comparison to ab-initio computations Giacalone et al. 2402.05995

Puzzling longitudinal phenomena

- Strong rapidity decorrelation of flow coefficients
- Jets and heavy-mesons show large directed flow

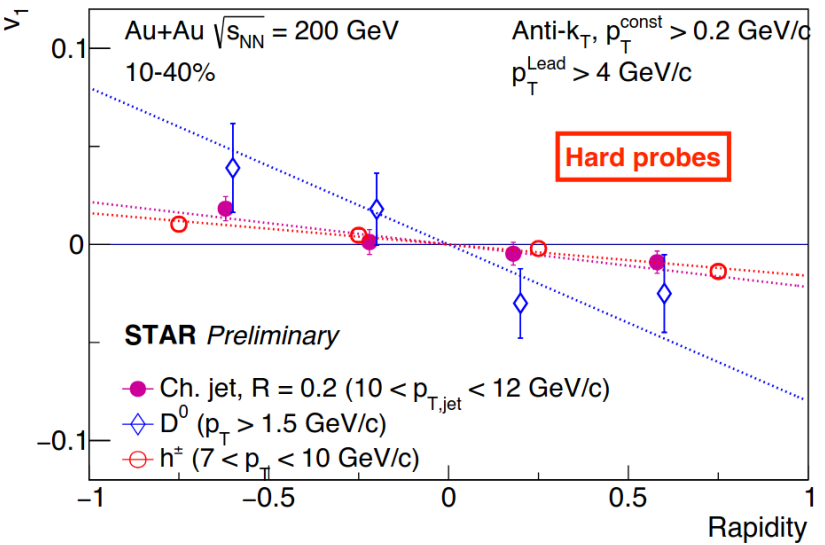
longitudinal flow decorrelation

Seidlitz, Mon 14:20



directed flow of jets

Radhakrishnan, Tue 14:00



Need better description of 3D initial state

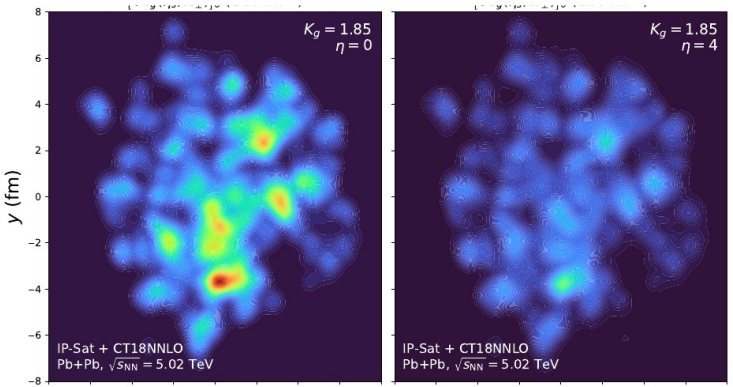
New 3D initial state models

Garcia-Montero, Elfner, Schlichting, 2308.11713

McDipper

- $k_\perp$ factorized CGC + DIS input
- baryon stopping
- systematically improvable

mid-rapidity forward-rapidity

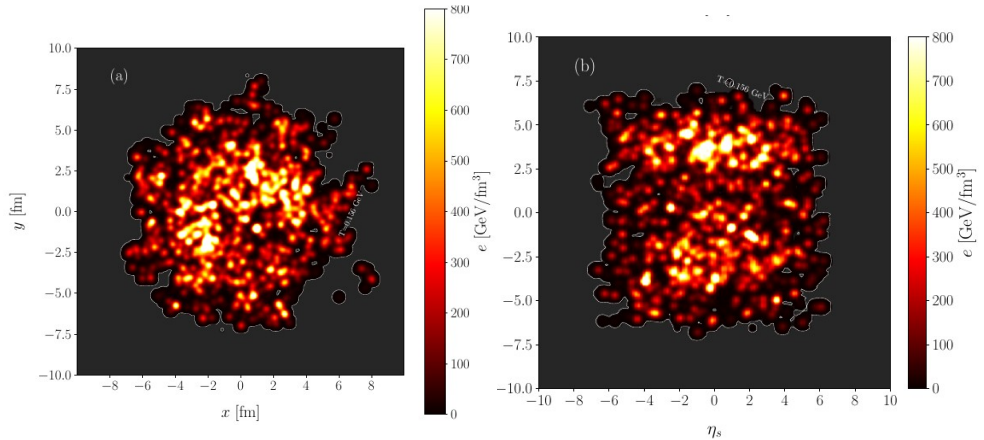


Kuha, Auvinen, Eskola, Hirvonen, Kanakubo, Niemi, 2406.17592

MC-EKRT

- pQCD mini-jet production
- low and high-p_T partons
- impact-parameter dependent nPDFs

transverse longitudinal



Now need integration in heavy-ion simulations

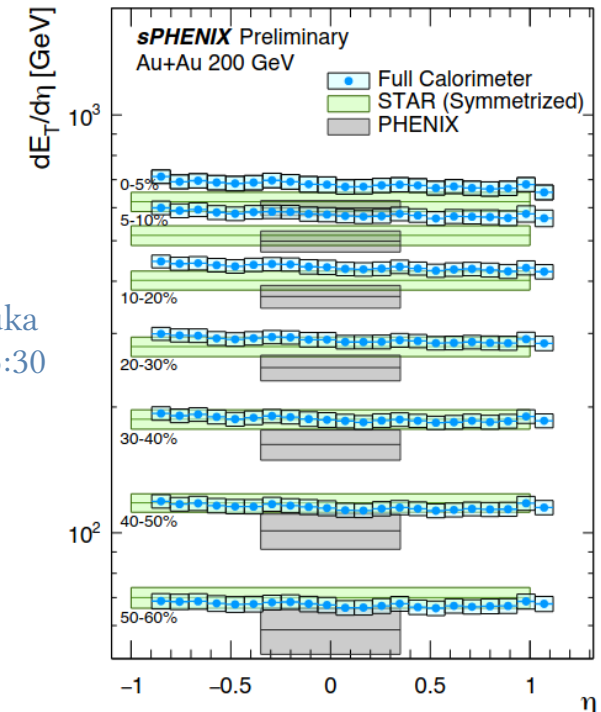
Bulk early time dynamics

Hard-Soft Ismail Soudi, Thu 09:25

Energy and entropy equilibration

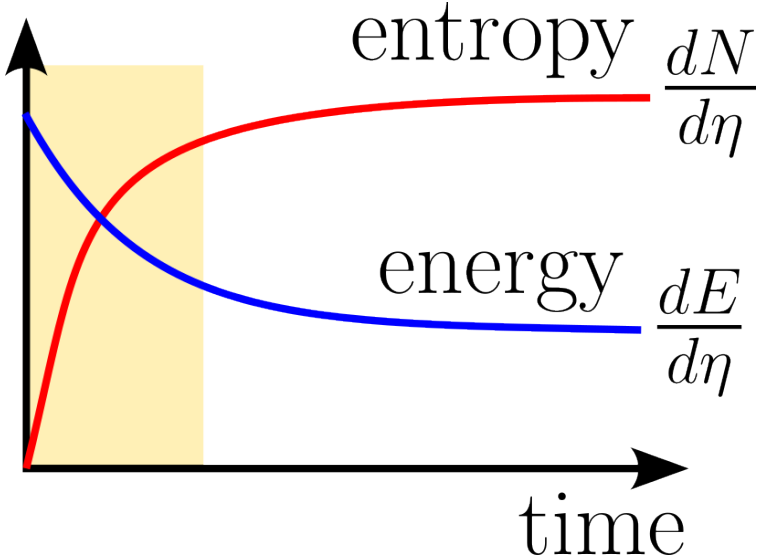
- Energy and multiplicity sensitive to pre-equilibrium

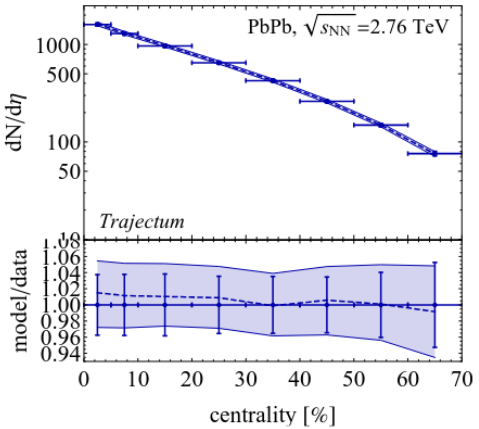
Energy per rapidity

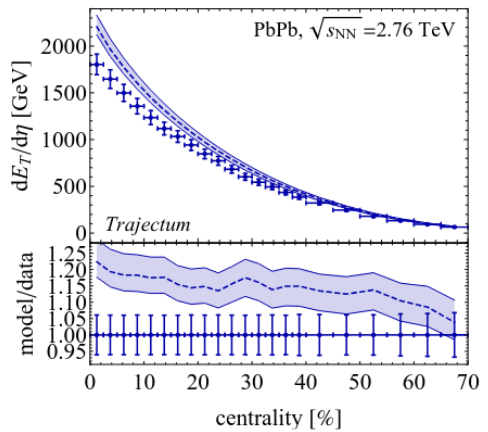


Nukazuka
Mon 16:30

Giacalone, AM, Schlichting, PRL 2019







Nijs van der Schee, PRL (2022)

Energy flow harmonics would help in small systems

Quantifying hydrodynamic behavior

- Flow response sensitive to opacity parameter (interaction rate)

$$v_n = \kappa_{n,n} \cdot \epsilon_n$$

flow/ellipticity

Werthmann
Mon 15:50

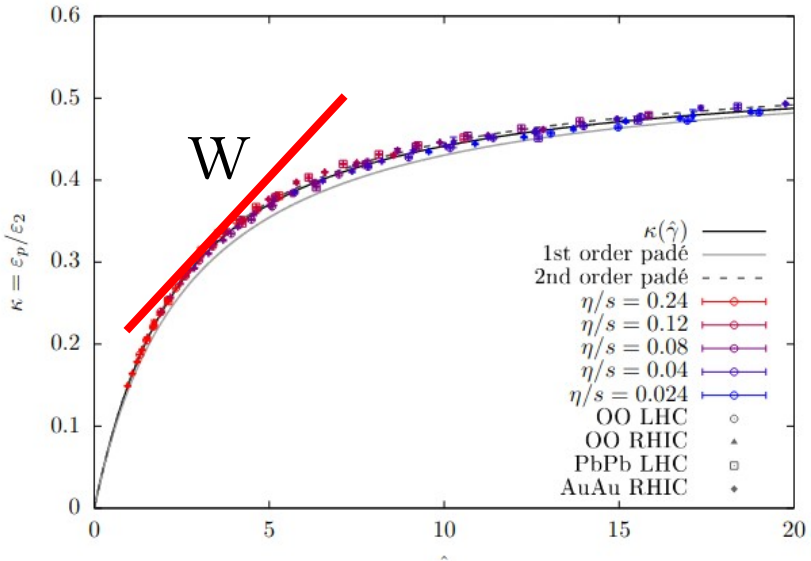
- Extract slope W using log derivative

hydrodynamization observable

$$\mathrm{W} = \frac{2}{k}\frac{\Delta \log(c_2\{2k\})}{\Delta \log(\mathrm{d}E_\perp/\mathrm{d}y)} \approx \frac{\mathrm{d}\log\kappa}{\mathrm{d}\log\hat{\gamma}}$$

previous hydrodynamization criterion

$\hat{\gamma} \sim 3$ corresponds to $\mathrm{W} \sim 0.5$



opacity $\sim (dE/d\eta)^{1/4}$

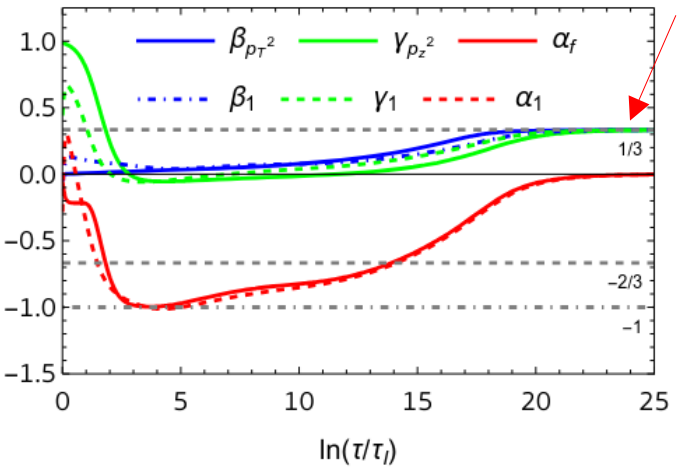
Need same geometry, different energy ⟶ e.g. OO at RHIC and LHC

Adiabatic hydrodynamization at early and late times

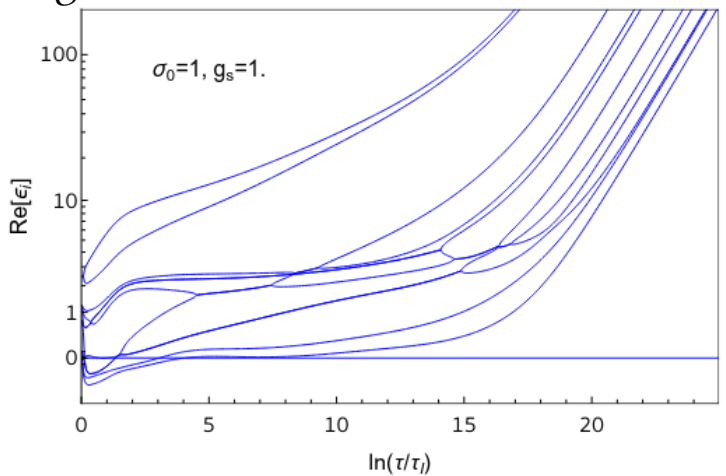
- Parametrize distribution with generalized scaling form
- Find the eigenvalues of kinetic evolution

$$f(p, p_z, y) = A(y) w\left(\frac{p}{D(y)}, \frac{p_z}{p}, r(y), y\right)$$

Scaling exponents



Eigenvalues



Steinhorst
Mon 17:10

thermal state

Convenient to study different stages of bottom-up thermalization in a single framework

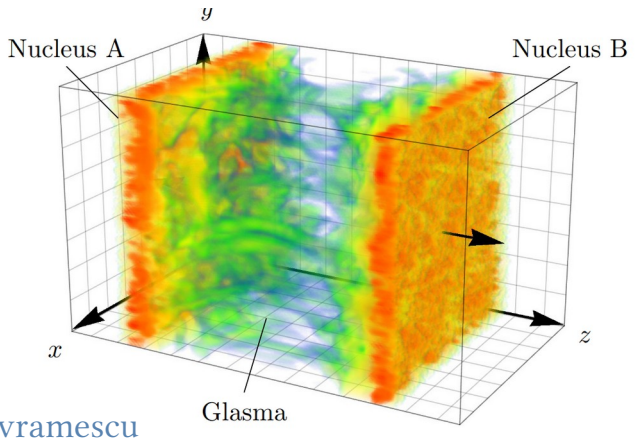
Jets and heavy-quarks in pre-equilibrium

Hard-Soft Ismail Soudi, Thu 09:25

Quark diffusion in glasma phase

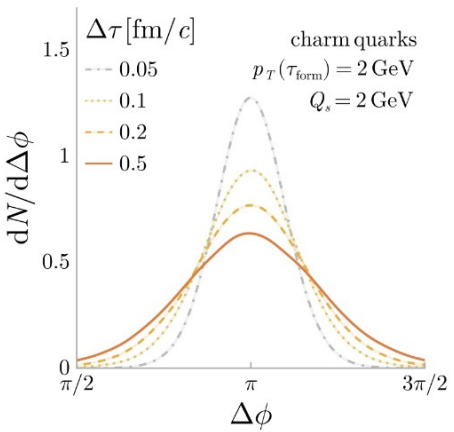
- Initial stages dominated by strong anisotropic glasma fields
- Simulate back-to-back heavy quark diffusion as a classical particle

Glasma fields

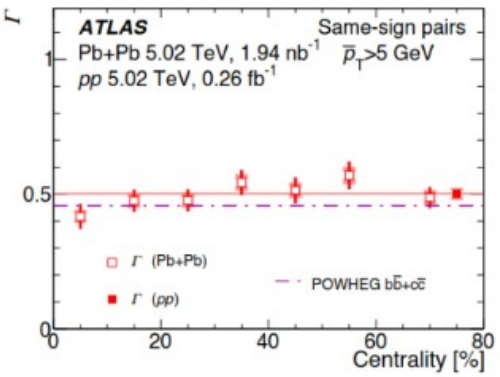


Avramescu
Tue, 14:40

$c\bar{c}$ decorrelation



$\mu\mu$ correlation width from beauty decays



Mohapatra, Tue 14:00

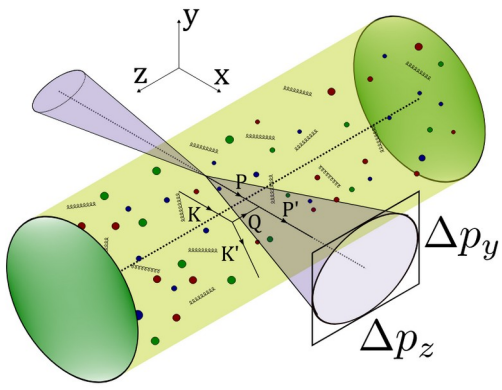
- Predicts large azimuthal decorrelation of $c\bar{c}$ pairs in glasma $\longrightarrow$ $D\bar{D}$
- Later stage diffusion not included; no decorrelation measured for beauty

Anisotropic $\hat{q}$ in early stages

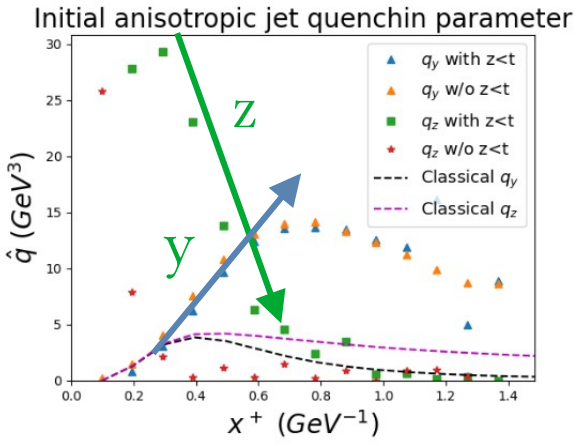
See also Sadofyev, Mon 17:50, Silvia, Wed 11:10

- Light-front Hamiltonian treatment of broadening in glasma — Lamas, Wed 12:10
- QCD kinetic theory computation of broadening in non-equilibrium QGP

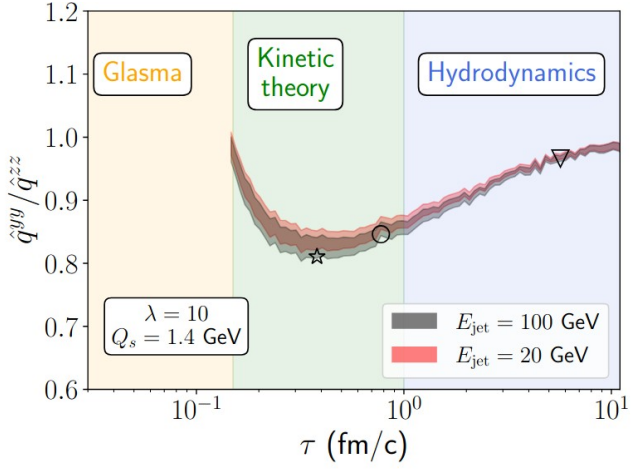
anisotropic broadening



glasma phase



kinetic phase



Lindenbauer, Mon 17:30

- Enhanced broadening along beam axis in early stages

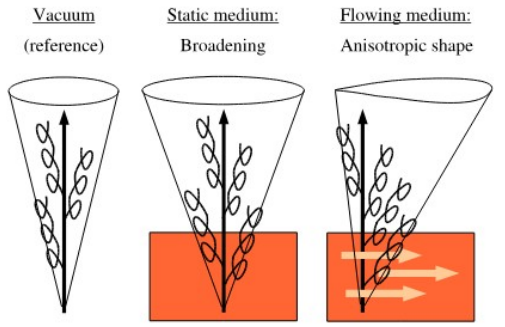
Effect of flow and gradients

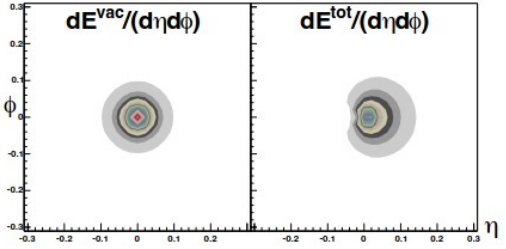
Jet response Daniel Pablos, Thu 09:00

Effect of collective flow and gradients on jets

- Flow/gradients ⟶ anisotropic radiation/quenching
- An idea proposed 20 years ago…

Armesto, Salgado, Wiedemann PRL (2004)





Salgado
Wed 11:30

Why now?

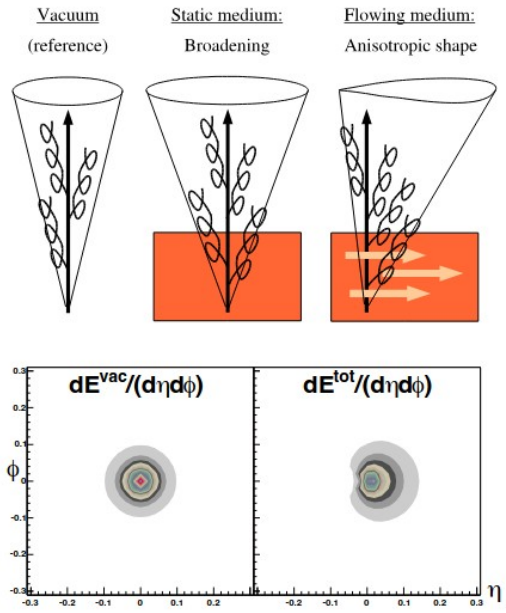
- Theoretical progress in jet quenching formalism
- Experimental progress in measuring
- Could contribute to high-momentum v_2

Effect of collective flow and gradients on jets

- Flow/gradients ⟶ anisotropic radiation/quenching
- An idea proposed 20 years ago…

Armesto, Salgado, Wiedemann PRL (2004)

Old but not obsolete



Salgado
Wed 11:30

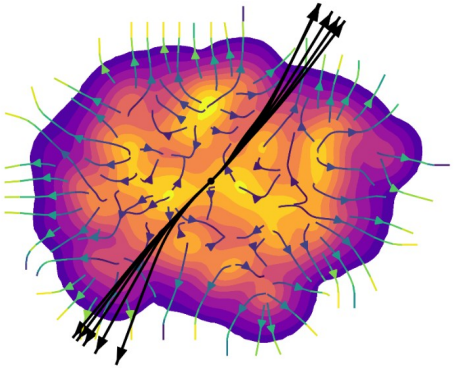
Why now?

- Theoretical progress in jet quenching formalism
- Experimental progress in measuring
- Could contribute to high-momentum v_2

Different model implementations

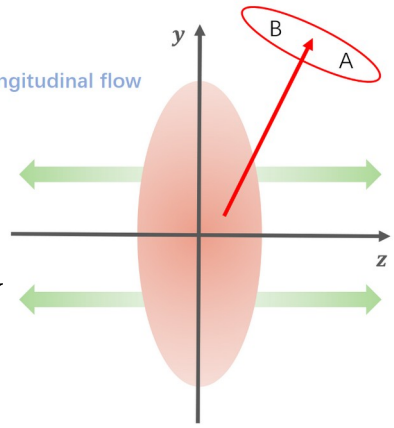
- Realistic hydro
- Parton shower
- Anisotropic parton evolution
- Effect on R_{AA}, v_2…

Bahder, Mon 11:50



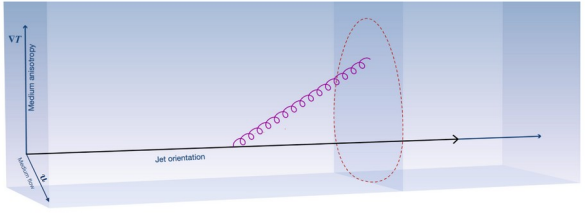
- Realistic hydro
- Parton shower
- Linear Boltzmann Transport
- Intra-jet asymmetry

Luo, Wed 10:00



- BDMPS-Z
- Flow and temperature gradients
- Gluon spectrum

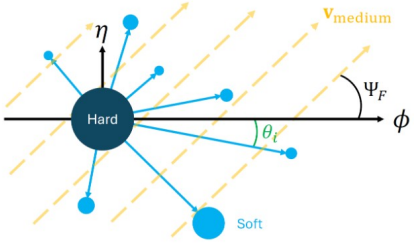
Mayo, Wed 11:10



See also Salgado, Wed 11:30

- JETSCAPE 3.5
- QGP brick
- Harmonic deformation

Fries, Wed 10:50



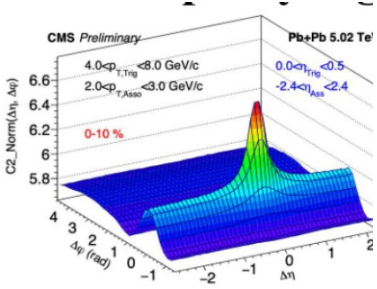
Longitudinal asymmetry of the near-side peak

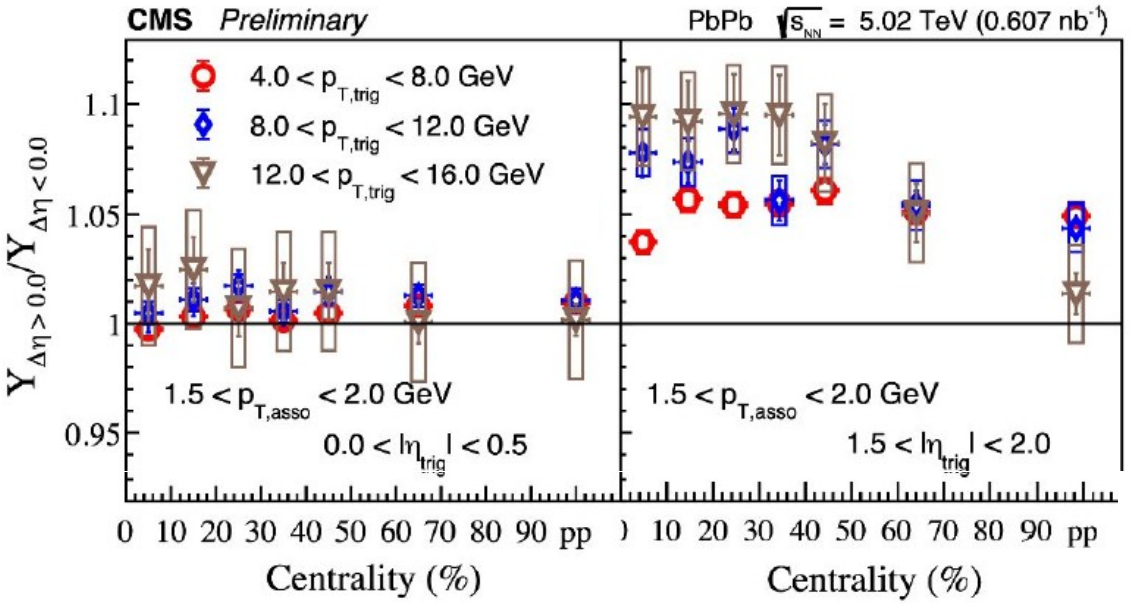
See also ALICE PRL (2017)

di-hadron correlation rapidity asymmetry

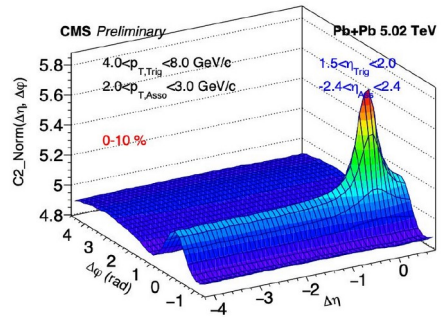
Chatterjee, poster

mid-rapidity





forward-rapidity



- Increasing rapidity with system-size for soft hadrons
- Increasing rapidity asymmetry in forward-rapidity
  → sign of longitudinal flow?

EW T Lipei Du Thu, 14:00
EW E Daiki Skihata, Thu 14:25
EW H Jean-Francois Paquet, Fri 12:15

Electromagnetic probes in pre-equilibrium

See next talk by Jean-Francois Paquet

Garcia-Montero, Tue 09:00

KEY MESSAGE TODAY

The dynamics and evolution of the pre-equilibrium phase of HICs can be accessed based on a phenomenology of the electromagnetic probes.

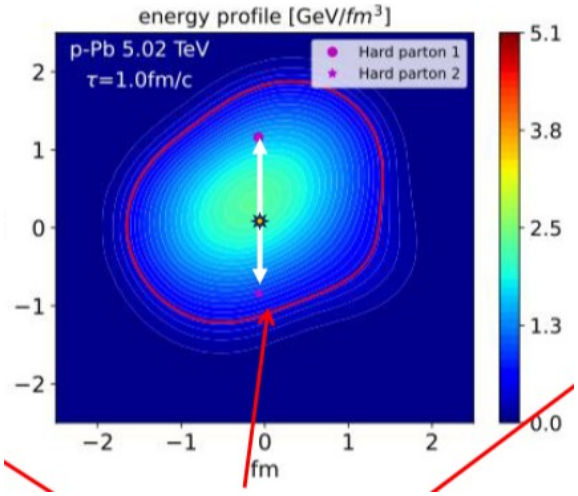
Small systems

Finite-size Isobel Kolbe, Thu 09:50

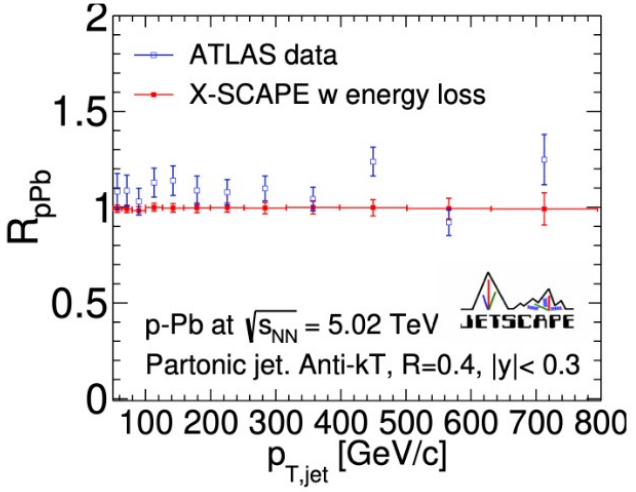
Energy loss in small systems with X-SCAPE

- Concurrent running of hard, hydro and hadronic evolution
- Energy conservation important in small systems

pPb fireball at 1 fm/c



Jet modification factor



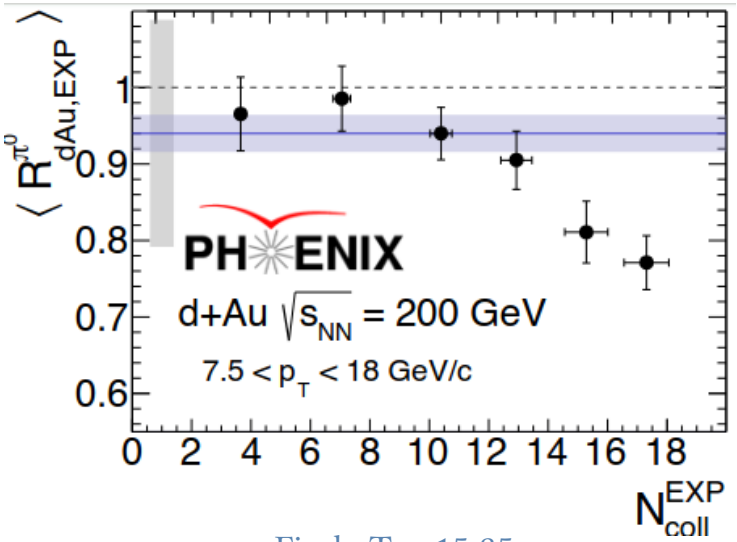
Jeon/Majumder
Wed 16:15

- Good description of pp data ⟶ important baseline
- No significant suppression in jets and leading hadrons in pp, pA

Potential energy loss signal in dAu

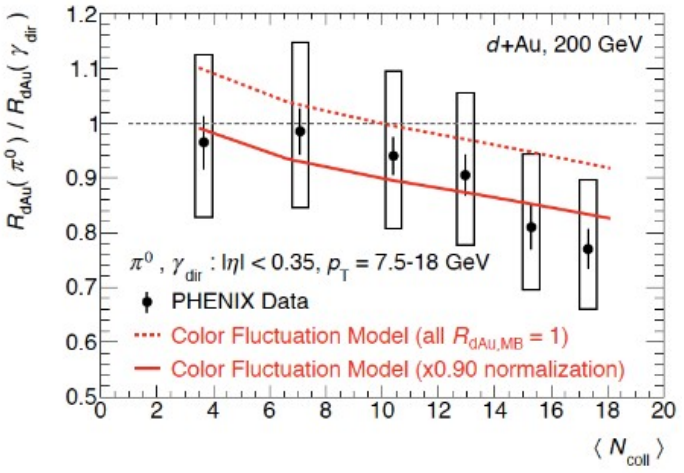
Use direct photons to estimate N_{coll} experimentally

Suppression of high p_T pions



Firak, Tue 15:35

Color Fluctuation Model



Perepelitsa, Mon 14:40

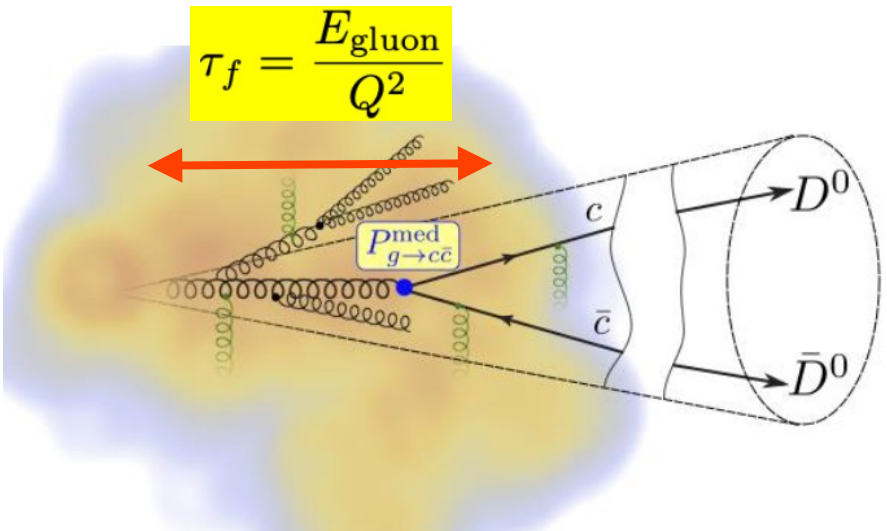
Selection bias to large Bjorken x → possible suppression from initial state effect

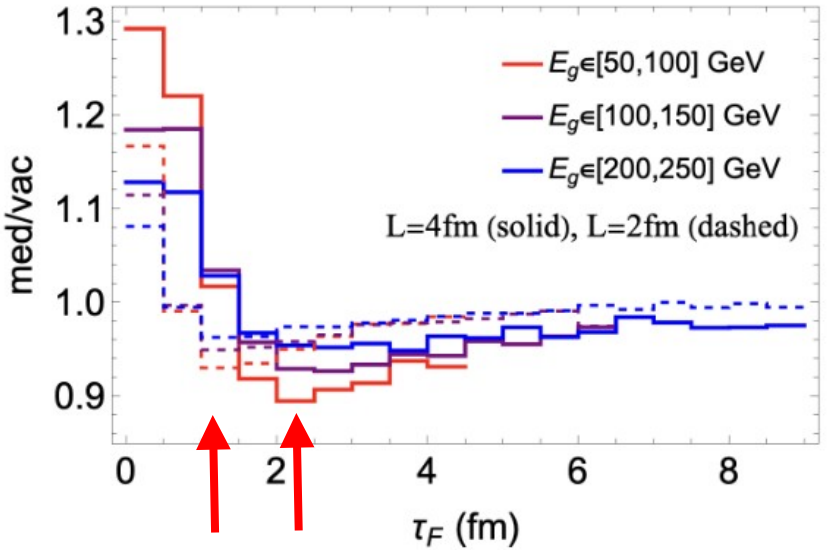
Probing formation time with heavy quarks

- Use heavy quark splittings as a distance-ruler
- Softdrop + Flavorcone to reconstruct splitting time

Wiedemann, Tue 15:55

formation time





location of avg. scattering center ~L/2

Possibility to measure the system size directly

Conclusions

Conclusions

nPDFs Petja Paakkinen, Thu 14:50
CGC Farid Salazar, Thu 15:15
UPCs Minjung Kim, Fri 8:45

Initial state physics

- UPC – new constraints on nPDFs
- UCC – new constraints on nuclear structure and fluctuations
- Longitudinal dynamics still puzzling ⟶ new theory models

Early time dynamics

- Thermalization affects energy and entropy production
- Anisotropic quenching in glasma and kinetic phases
- Jet interplay with QGP flow and temperature gradients
- Importance of electromagnetic probes
- Energy loss in small systems still debatable
  ⟶ opportunity for oxygen-oxygen collisions

Hard-Soft Ismail Soudi, Thu 09:25
EWT Lipei Du Thu, 14:00
EWE Daiki Skihata, Thu 14:25
EWH Jean-Francois Paquet, Fri 12:14