Pythia results and future developments

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Outline:

- PYTHIA for heavy ions: ANGANTYR
- DIPSY for PYTHIA: Mueller dipole formalism
- Conclusion & outlook

Motivation

The questions we all would like to answer:

- Is a QGP formed in heavy ion collisions?
- What are the signals of a QGP?
- Why are (some of) these signals also seen in pp?
- Is a plasma also formed in pp?
- Can the measurements be explained by non-QGP models?

Focus on HI physics. A lot of new updates related to pp neglected from this talk. See e.g. the Update history of the PYTHIA 8 webpage.

Heavy ions

Event generators

Small systems:

- pp event generators (PYTHIA, HERWIG, SHERPA) successfully describe almost all observables
- Primary ingredients in PYTHIA include:
  - Multiple subcollisions using MPI models
  - Possible hard first interaction (e.g. gauge bosons, jets etc)
  - Initial- and final-state evolution of the MPIs
  - Colour reconnections between final-state partons
  - Hadronization of partons
- Also includes elastic and (hard and soft) diffractive processes
- Soon coming: Hadronic rescattering w. URQMD and internally in PYTHIA (See e.g. C. Bierlich @ SQM 2019)

Large systems:

- pA, AA event generators usually take one of two approaches
  - Extrapolation of pp dynamics to pA and AA: HIJING, ANGANTYR
  - Assume quark-gluon plasma (QGP): AMPT, EPOS

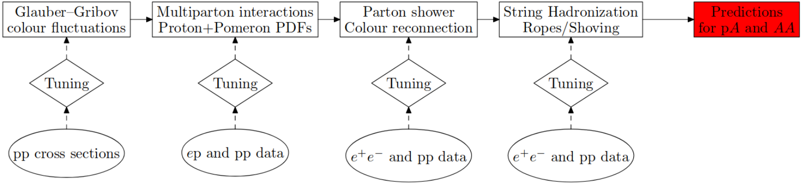
Angantyr for heavy ions

ANGANTYR: new model for HI in PYTHIA 8.

Several steps are taken in ANGANTYR:

- Glauber model for number of collisions.
- Wounded nucleons for particle production.
- Possibility for additional subcollisions in an event (similar to MPIs in pp.)

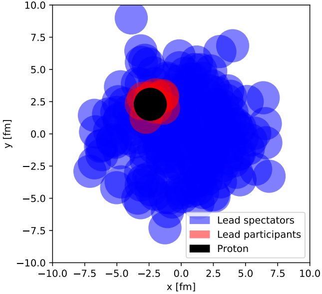
Only tuning to small systems.

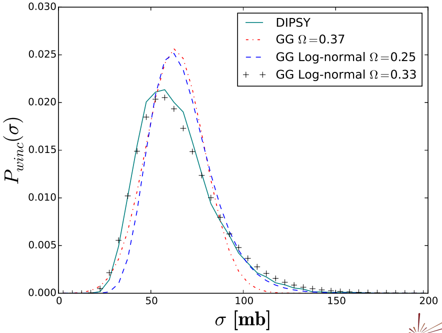


Angantyr for heavy ions

First step:

- Glauber-Gribov method to calculate number of interacting nucleons and binary collisions.
- Event-by-event colour fluctuations parametrized from DIPSY.
- ANGANTYR is first model to include colour fluctuations in *both* target and projectile.

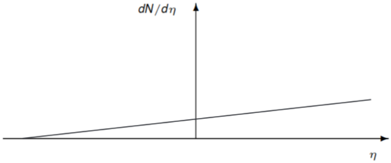




Angantyr for heavy ions

Second step:

- Wounded nucleon model by Białas and Czyz used to create exclusive final states.
- Wounded nucleons contribute equally to multiplicity in η.



$$\frac{dN}{d\eta} = F(\eta)$$ (single wounded nucleon

- Original model $F(\eta)$ fitted to data. ANGANTYR uses own model.
- $F(\eta)$ fitted to reproduce high-energy pp events, but **no** fitting to HI.

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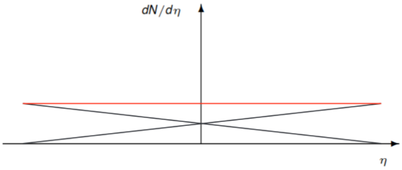

$$\frac{dN}{d\eta} = F(\eta) + F(-\eta) \qquad \text{(pp)}$$

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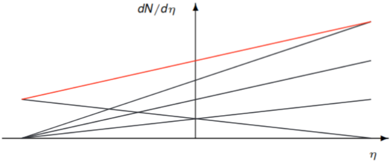

$$\frac{dN}{d\eta} = w_t F(\eta) + \quad F(-\eta) \qquad\qquad (pA)$$

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Angantyr for heavy ions

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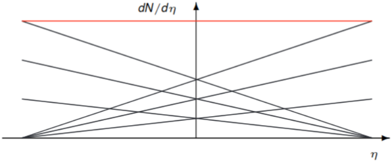


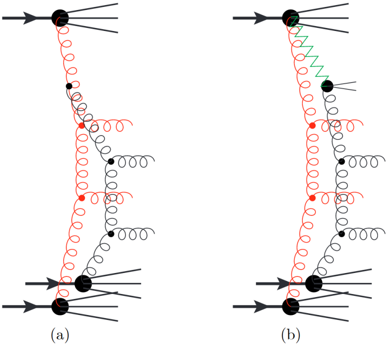
$$\frac{dN}{d\eta} = w_t F(\eta) + w_p F(-\eta) \qquad (AA)$$

- Original model $F(\eta)$ fitted to data. ANGANTYR uses own model.
- $F(\eta)$ fitted to reproduce high-energy pp events, but **no** fitting to HI.

Angantyr for heavy ions

Third step:

- Method to combine nucleon-nucleon events needed as collision can contain scatterings that are hard to describe in large systems.
- Simplest system pD-collision with three wounded nucleons:

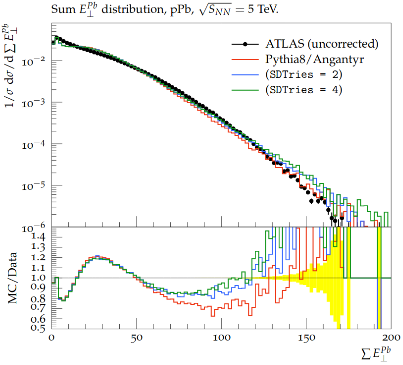


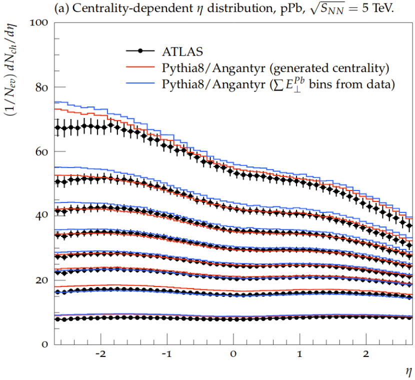
ANGANTYR cheat-sheet:

- First scattering modelled as a normal non-diffractive pp event.
- Second is modelled as a single diffractive event.
- Generalizes to all pA and AA collisions.

Angantyr for heavy ions

Results from pPb:

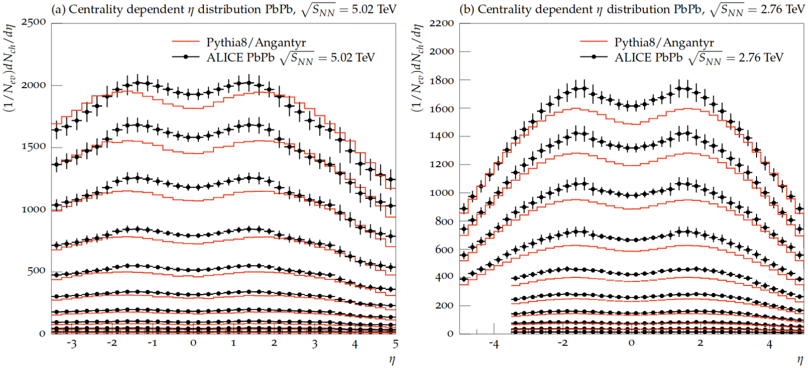




- Centrality often described by binning in $\sum E_\perp$.
- ANGANTYR can use experimental centrality definition or internal centrality measure.
- Centrality and multiplicity well reproduced by ANGANTYR.

Angantyr for heavy ions

Results from PbPb:



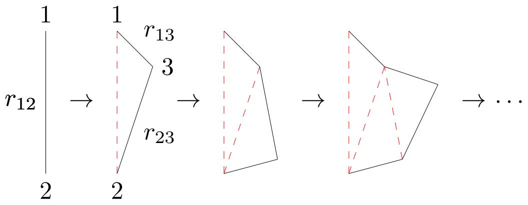
- Multiplicity well described by ANGANTYR.
- Dip around $\eta = 0$ caused by PYTHIA pp not describing $p_\perp < 500$ MeV (ALICE measures to $p_\perp = 0$ MeV).

Dipole formulation

Dipole formulation

- Mueller dipole formalism describes evolution of a single dipole in rapidity.
- Defined by the dipole splitting probability,

$$\frac{\mathrm{d}P}{\mathrm{d}^2\mathbf{r}_3\mathrm{d}y} = \frac{3\alpha_S(Q^2)}{2\pi^2}\frac{r_{12}^2}{r_{13}^2 r_{23}^2},$$

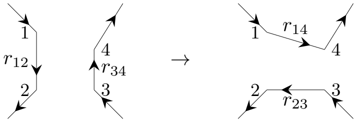


- After evolution the two chains of dipoles are allowed to interact.

Dipole formulation

- Interaction given by dipole-dipole scattering probability,

$$f_{ij} = \frac{\alpha_S^2(Q^2)}{2} \log^2 \left[\frac{r_{14} r_{23}}{r_{24} r_{13}} \right],$$



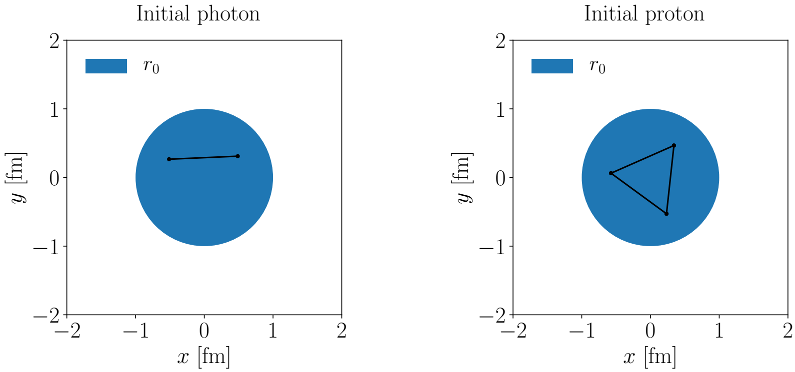
- Measurable quantities obtained from unitarized dipole-dipole scattering amplitude plus Good-Walker formalism,

$$T(\mathbf{b}) = 1 - \exp\left(- \sum_{i=1}^{N_A} \sum_{j=1}^{N_B} f_{ij} \right)$$

$$\sigma_{\mathrm{tot}} = \int \mathrm{d}^2\mathbf{b} 2 \langle T(\mathbf{b}) \rangle, \quad \sigma_{\mathrm{el}} = \int \mathrm{d}^2\mathbf{b} \langle T(\mathbf{b}) \rangle^2$$

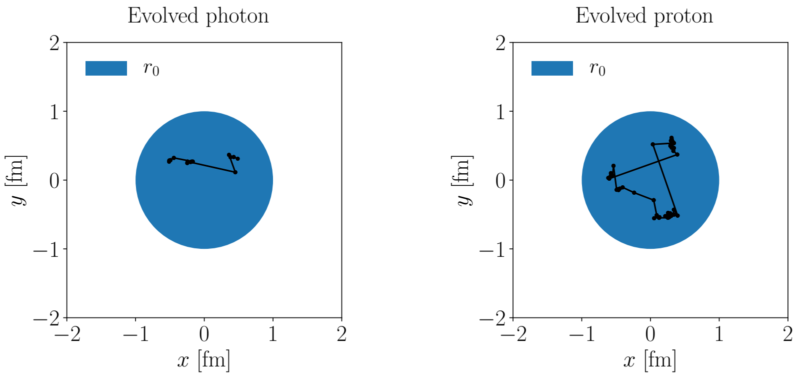
Dipole formulation

Initial state not from first principles:



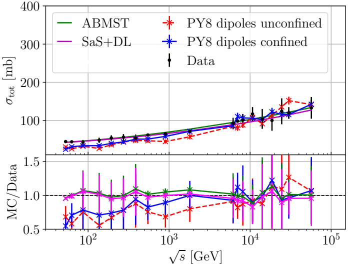
Dipole formulation

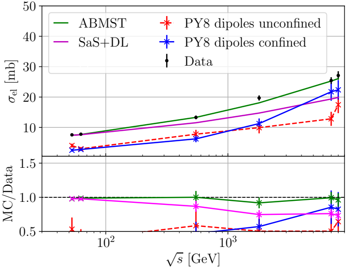
After a full evolution:

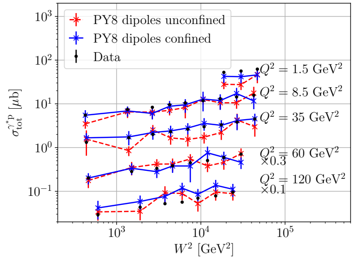


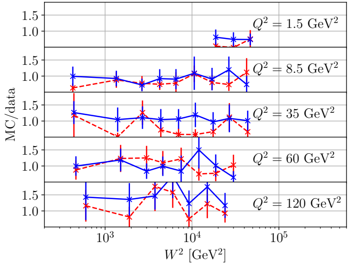
Dipole formulation

Model tuned to γp and pp cross sections.









Dipole formulation

- Study effects of asymmetry in partonic eccentricities ϵ_n and normalised symmetric cumulants in $\mathrm{pp}, \mathrm{pA}, \mathrm{AA}$
- Linear response function often assumed in AA: $v_n = f(\epsilon_n) \approx a\epsilon_n$

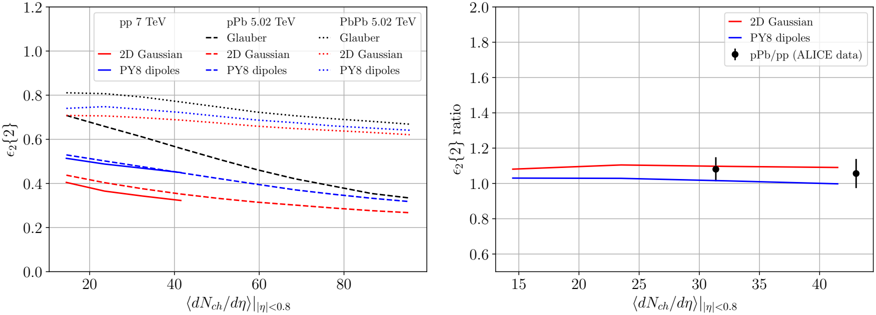
$$\epsilon_n = \frac{\sqrt{\langle r^n \cos(n\phi)\rangle^2 + \langle r^n \sin(n\phi)\rangle^2}}{\langle r^n \rangle}$$

$$NSC(n,m) = \frac{\langle v_n^2 v_m^2\rangle - \langle v_n^2\rangle\langle v_m^2\rangle}{\langle v_n^2\rangle\langle v_m^2\rangle} \approx \frac{\langle \epsilon_n^2 \epsilon_m^2\rangle - \langle \epsilon_n^2\rangle\langle \epsilon_m^2\rangle}{\langle \epsilon_n^2\rangle\langle \epsilon_m^2\rangle}$$

Space-time information used as input for PYTHIA 8 MPI model:

- Glauber: MPIs moved to nucleon position
- Gaussian model: x, y chosen from gaussian with $r_p = 0.7$ and $w_r = 0.1$
- Dipole model: x, y chosen w.r.t. dipole-dipole interaction strength f_{ij}

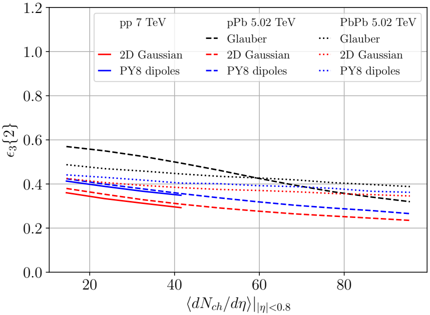
Dipole formulation

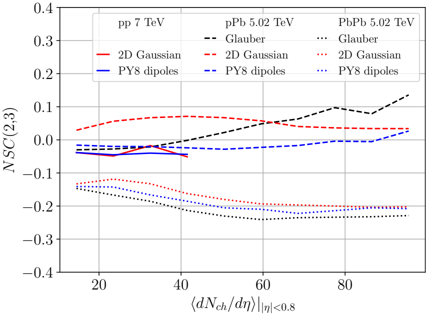


$\epsilon_2\{2\}$ as a function of average central multiplicity

- Asymmetry gives rise to more eccentricity
- Initial state fluctuations important in AA at low multiplicity
- If response function for pA equals that of pp at same average multiplicity, then
  - Eccentricity ratio should be comparable to flow ratios measured in data
  - Dipole model predicts flat pA/pp ratio also seen in data

Dipole formulation



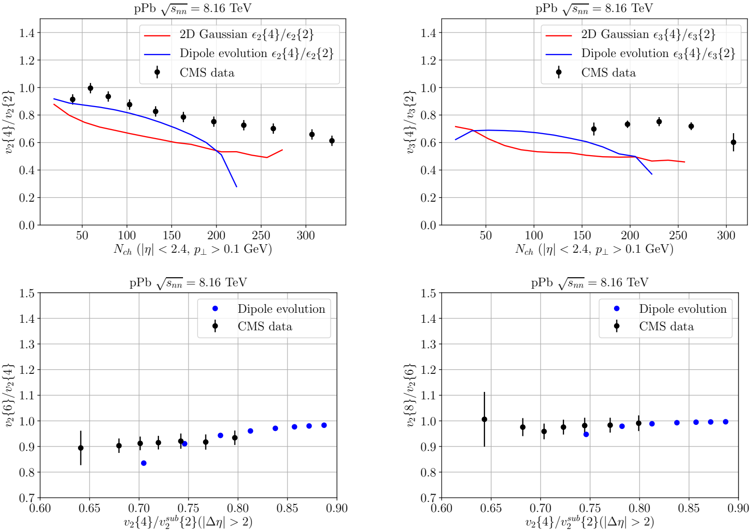


$\epsilon_3\{2\}$, $NSC(3,2)$ as a function of average central multiplicity

- ϵ_3 related to initial geometry
- Intial geometry not distinguishable in $NSC(3,2)$ for pp
- Very different behaviour in pA for symmetric and asymmetric initial states

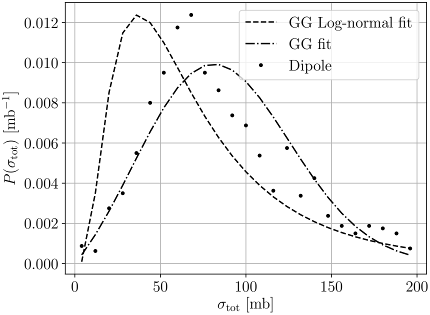
Dipole formulation

Ratios of higher order eccentricities: CMS $\sqrt{s_{NN}} = 8.16$ TeV.

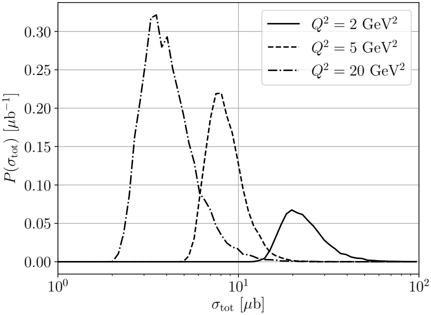


Coming soon

- Use dipole formulation in ANGANTYR instead of parametrization



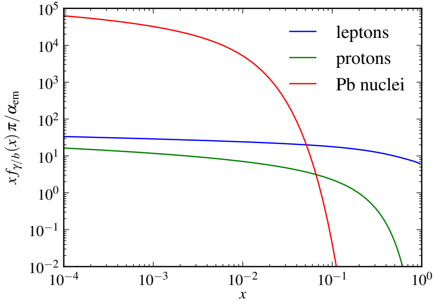
pp colour fluctuations.



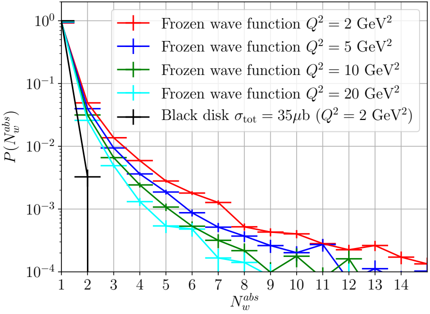
γp colour fluctuations.

- Define response function using the shoving model
- Opens up for predictions for $v_n\{m\}$

- UPCs using photon fluxes
- Full eA collisions with dipole model + ANGANTYR



PYTHIA photon fluxes.



No. wounded nucleons in γA collision.

Conclusion and outlook

- Full generation of pA and AA events with ANGANTYR [arXiv:1806.10820[hep-ph]].
- Good description of many HI observables.
- Recent implementation of Mueller dipole model [arXiv:1907.12871[hep-ph]].
- Dipole model allows for asymmetric initial states.
- Eccentricities with dipole model in agreement with data.
- Merging of dipole model with ANGANTYR opens up for collisions with photons.
- UPCs, eA next to come.

Thank you!

Thank you!

What do you want from us?