Diffractive excitation in proton/Lead collisions

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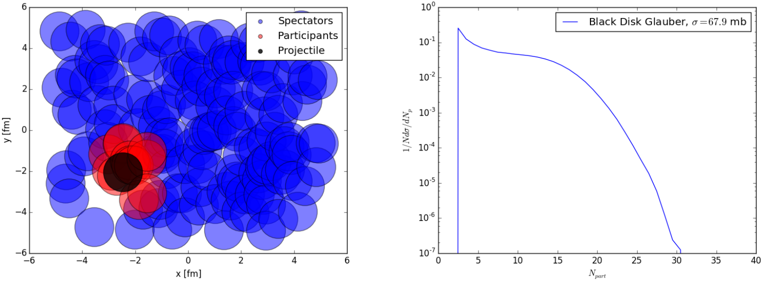
Introduction

- Very active heavy ion community at LHC and RHIC.
- Many theories and measurements involving collective phenomena.
- Few theories produce concrete, full final state predictions.
- Lack of MC "baseline" describing charged multiplicity and $p_\perp$.
- Goal: pA baseline $= N$ "binary" pp collisions.
- pA is stepping stone towards AA.
- Desirable for both theorists and experimentalists.
- Talk outline:
  1. The Glauber model.
  2. Some scattering theory.
  3. Diffractive excitation in Glauber.
  4. Comparison to DIPSY.
  5. Full final states using Pythia 8.
  6. Comparison to ATLAS and ALICE pA data.

The Glauber Picture

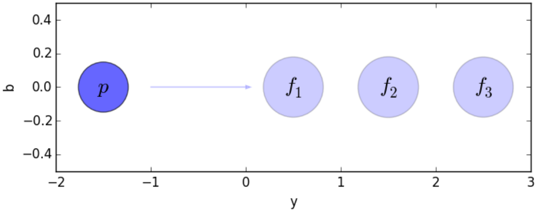
- Most common approach for including nuclear geometry.
- Calculates number of *wounded nucleons* from input σ_{abs}.
- Diffractive contributions neglegted.
- Collision amplitude: black disks.
- Nucleon distribution: Woods-Saxon potential.

$$T(b) = \Theta(\sqrt{\sigma/\pi} - b) \qquad \rho(r) \propto \frac{1}{1 + \exp\left(\frac{r-R}{a}\right)}$$



Reasoning behind Glauber (and some notation)

- Projectile scattering off a three-constituent target, at fixed b.
- Individial collision probabilities f_1, f_2 and f_3.



$$P_{abs} = \frac{d\sigma_{abs}}{d^2b} = f_1 + f_2 + f_3 - f_1 f_2 - f_2 f_3 - f_1 f_3 + f_1 f_2 f_3 =$$

$$1-(1-f_1)(1-f_2)(1-f_3) \approx 1-\Pi_i \exp(f_i) = 1-\exp\left(-\sum_i f_i\right) = 1-\exp(-2F)$$

The optical theorem

- Relate amplitudes and cross sections through the optical theorem.
- Real part of amplitude is negligible in high energy *pp* collisions.
- (Hence we can also view previous f_i as amplitudes.)

$$\Im(A_{el}) = \frac{1}{2}(|A_{el}|^2 + P_{abs}) \Rightarrow T(b) \equiv -iA_{el} = 1 - \sqrt{1 - P_{abs}}.$$

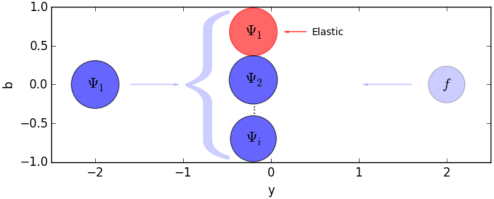
- Using $P_{abs} = 1 - \exp(-2F)$:

$$T(b) = 1 - \exp(-F(b)) \text{ and } \frac{d\sigma_{el}}{d^2b} = T^2, \ \frac{d\sigma_{tot}}{d^2b} = 2T$$

- Which allows extraction of: $\frac{d\sigma_{abs}}{d^2b} = 2T - T^2$.
- Formalism does not allow for fluctuations/diffractive excitation.

Diffractive excitation, Good-Walker formalism, back to *pp*

- Let the projectile fluctuate (both sides: Double diffraction).
- Diffractive eigenstates Φ_k, eigenvalues T_k.
- Mass eigenstates a linear combination $\Psi_i = \sum_k c_{ik}\Phi_k$.
- Transition to i'th mass eigenstate: $\langle\Psi_i|T|\Psi_1\rangle = \sum_k c_{ik}T_k c_{1k}$.



$$\frac{d\sigma_{el}}{d^2b} = \langle\Psi_1|T|\Psi_1\rangle^2 = \langle T\rangle^2$$

$$\frac{d\sigma_{diff}}{d^2b} = \sum_i \langle\Psi_1|T|\Psi_i\rangle\langle\Psi_i|T|\Psi_1\rangle = \langle T^2\rangle$$

$$\frac{d\sigma_{diff,p}}{d^2b} = \frac{d\sigma_{diff}}{d^2b} - \frac{d\sigma_{el}}{d^2b} = \langle T^2\rangle - \langle T\rangle^2.$$

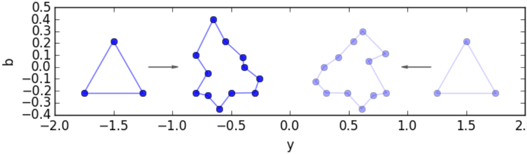
The DIPSY formalism

- DIPSY includes fluctuations through:

  Dipole evolution in **I**mpact **P**arameter **S**pace and rapidit**Y**.

- Fluctuations ⇒ Diffraction by construction.

$$\frac{dP}{dY} = \frac{3\alpha_s}{2\pi^2} d^2\vec{z} \frac{(\vec{x}-\vec{y})^2}{(\vec{x}-\vec{z})^2(\vec{z}-\vec{y})^2},\ f_{ij} = \frac{\alpha_s^2}{8}\left[\log\left(\frac{(\vec{x}_i-\vec{y}_j)^2(\vec{y}_i-\vec{x}_j)^2}{(\vec{x}_i-\vec{x}_j)^2(\vec{y}_i-\vec{y}_j)^2}\right)\right]^2$$



$$\frac{d\sigma_{tot}}{d^2b} = 2\left\langle T\right\rangle_{t,p},\ \frac{d\sigma_{el}}{d^2b} = \left\langle T\right\rangle_{t,p}^2,\ \frac{d\sigma_{SD,(p|t)}}{d^2b} = \left\langle\left\langle T\right\rangle_{(t|p)}^2\right\rangle_{(p|t)} - \left\langle T\right\rangle_{p,t}^2$$

$$\frac{d\sigma_{DD}}{d^2b} = \left\langle T^2\right\rangle_{p,t} - \left\langle\left\langle T\right\rangle_t^2\right\rangle_p - \left\langle\left\langle T\right\rangle_p^2\right\rangle_t + \left\langle T\right\rangle_{p,t}^2$$

Including diffractive excitations in Glauber

- Not always feasible to run "full DIPSY" - also FS uncertainties.
- Expand of a "wounded nucleons" to include diffractively excited.
- We reach a very simple expression.

$$\frac{d\sigma_w}{d^2b} = \frac{d\sigma_{abs}}{d^2b} + \frac{d\sigma_{SD,t}}{d^2b} + \frac{d\sigma_{DD}}{d^2b} = 2\left\langle T\right\rangle_{p,t} - \left\langle\left\langle T\right\rangle_t^2\right\rangle_p .$$

- Simpler model for proton fluctuations, no diffraction:

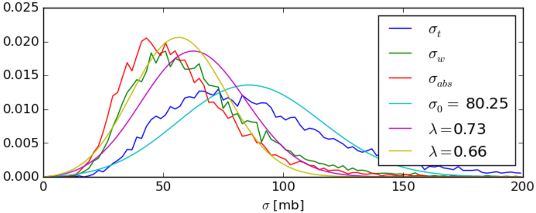
$$\text{Glauber-Gribov: } P(\sigma_{tot}) \propto \frac{\sigma}{\sigma+\sigma_0}\exp\left(\frac{(\sigma/\sigma_0-1)^2}{\Omega^2}\right)$$

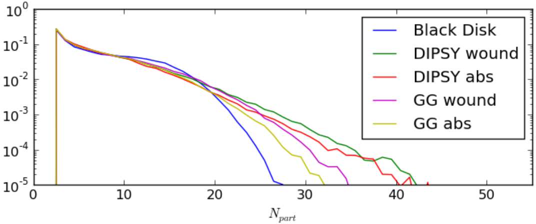
$$\text{with: } \sigma_w = \lambda\sigma_{tot}.$$

- Given reasonable values for $\langle\sigma_{tot}\rangle, \langle\sigma_w\rangle$ and $\langle\sigma_{el}\rangle$, all parameters can be fitted.

Comparison of σ_X and N_{part}

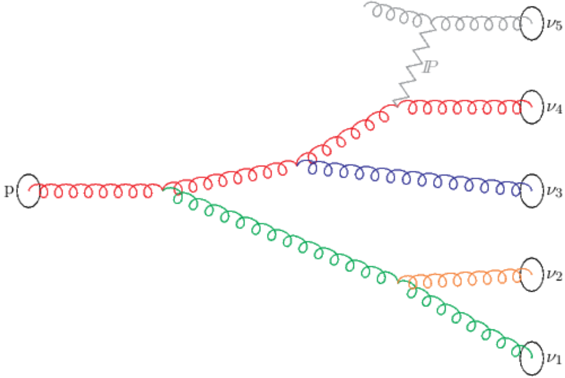
- Glauber-Gribov is fitted with DIPSY as truth.
- Glauber-Gribov can fit σ_w but not σ_{abs}.
- Diffractive excitation **is** important for counting N_{part}.
- Glauber-Gribov **can not** differentiate between $N_{part,dif}$ and $N_{part,abs}$.





Full final states: String-like interaction model

- One absorptive collision contributes to full rapidity span.
- The rest contributes similarly to diffrative excitation (plus a colour exchange).
- Full collision as a sum of Pythia 8 events.



Biasing the "hard" $p_\perp$

- Pythia MPI model generates via.

$$\frac{d\sigma_{2\to2}}{dp_\perp^2} \propto \frac{\alpha_s^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_s^2(p_\perp^2 + p_{\perp0}^2)}{(p_\perp^2 + p_{\perp0}^2)^2}.$$

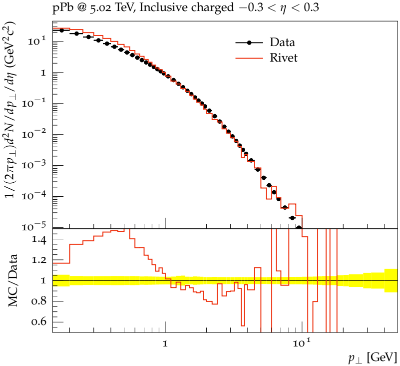
- $\sigma(\text{high } p_\perp) \propto$ wounded constituent partons.
- $\sigma(\text{low } p_\perp) \propto$ absorptively wounded nucleons.
- Another view: Main absorptive event is "biased", as it is the hardest of all absorptive sub-events.
- Introduce scaling factor ($\hat{p} \approx 1 - 3$ GeV):

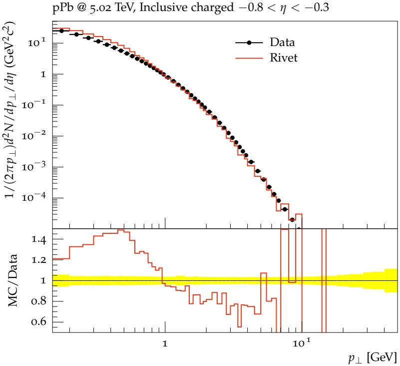
$$\frac{n_{abs} p_\perp^2 + \hat{p}_\perp^2}{p_\perp^2 + \hat{p}_\perp^2}.$$

- Recovers pp in the $n_{abs} = 1$ limit.

Data comparison I

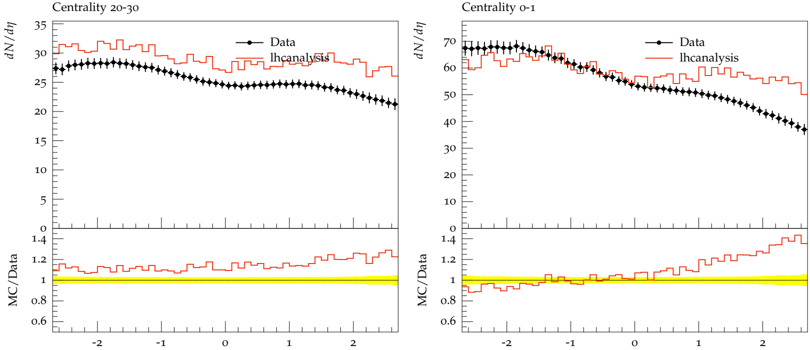
- pPb @ 5.02 TeV by ALICE, centrality inclusive.
- Distributions in $p_\perp$ for different rapidity intervals.
- Traditionally "nuclear modification factor"; ratio with pp.





Data comparison II

- Charged multiplicity @ 5.02 TeV by ATLAS:
- Very nice measurement with particle level centrality definition.
- Still preliminary: Good description is key goal.



Conclusions

- Precision Heavy Ion MC still in its infancy.
- Much can still be done, both on theoretical and experimental side.
- Schemes for counting $N_{part,abs}$ and $N_{part,diff}$.
- Simple interpretation in form of stacked Pythia events.
- Useful for baseline for advanced models of HI
  - Collective schemes.
  - Hadronization models.
  - Colour reconnection.

BONUS SLIDES