Heavy Ions in PYTHIA8

Leif Lönnblad

(with Gösta Gustafson, Christian Bierlich and Harsh Shah)

Department of Astronomy
and Theoretical Physics
Lund University

MPI@LHC 2017-12-13

Outline

- Remeber Fritiof?
- Glauber model generation
- Stacking of parton-level *NN* events
- Some results
- Outlook

arXiv:1607.04434 [hep-ph], arXiv:18??.nnnnn

Outline

- Remeber Fritiof? — RIP
- Glauber model generation
- Stacking of parton-level *NN* events
- Some results
- Outlook — Long live Angantyr!

arXiv:1607.04434 [hep-ph], arXiv:18??.nnnnn

Remember Fritiof?

Simple picture of pp collisions

- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

Remember Fritiof?

Simple picture of pp collisions

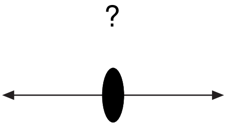
- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

Remember Fritiof?

Simple picture of pp collisions

- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

Remember Fritiof?



- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

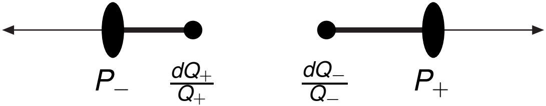
Remember Fritiof?

multiple soft gluon exchanges

- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

Remember Fritiof?

Longitudinal excitation of both protons



- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

Remember Fritiof?

String ends evenly distributed in rapidity

- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

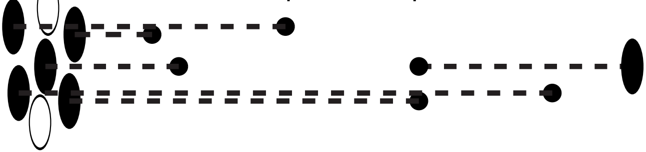
Remember Fritiof?

Hadronises as if doubly diffractive excitation

- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

Remember Fritiof?

The picture in pA



- Flat rapidity plateau — simple string fragmentation
- High mass diffractions $d\sigma/dM_X^2 \propto M_X^{-2(1+\epsilon)}$ were ϵ is small.
- Works surprisingly well for $\sqrt{s} \leq$ ISR.
- Fritiof + Glauber gives heavy Ion collisions.
- Works very well at low energies.

Tanking Fritiof into the 21st century (TeV energies)

- We need hard parton scatterings
- We need MPI
- We also want to do eg. top production
- Will building up non-diffractive *NN* scatterings with single diffractive excitations work at high energies?
- Do we need to treat real diffractive *NN* scatterings separately?

Tanking Fritiof into the 21st century (TeV energies)

- We need hard parton scatterings – PYTHIA8
- We need MPI – PYTHIA8
- We also want to do eg. top production – PYTHIA8
- Will building up non-diffractive *NN* scatterings with single diffractive excitations work at high energies?
- Do we need to treat real diffractive *NN* scatterings separately?

Tanking Fritiof into the 21st century (TeV energies)

- We need hard parton scatterings – PYTHIA8
- We need MPI – PYTHIA8
- We also want to do eg. top production – PYTHIA8
- Will building up non-diffractive *NN* scatterings with single diffractive excitations work at high energies?
- Do we need to treat real diffractive *NN* scatterings separately?

The Strategy: Parton-level stacking

- Distributing nucleons in nuclei.
- Determining which projectile nucleons interact with which target nucleons, and how.
- Generate (non-) diffractive parton-level min-bias events with PYTHIA8 for each *NN* scattering.
- Merge them together, and construct nuclei remnants.
- Hadronise everything together including rope and shoving effects.

The Strategy: Parton-level stacking

- Distributing nucleons in nuclei.
- Determining which projectile nucleons interact with which target nucleons, and how.
- Generate (non-) diffractive parton-level min-bias events with PYTHIA8 for each *NN* scattering.
- Merge them together, and construct nuclei remnants.
- Hadronise everything together.
  including rope and shoving effects.

Distributing nucleons in nuclei

This is the easy part. Or is it?

PYTHIA8 implements the GLISSANDO model with a “hard core”

PYTHIA8 allows for arbitrary nucleon models to be plugged in and be investigated.

[arXiv:1310.5475]

Distributing nucleons in nuclei

This is the easy part. Or is it?

PYTHIA8 implements the GLISSANDO model with a "hard core"

PYTHIA8 allows for arbitrary nucleon models to be plugged in and be investigated.

[arXiv:1310.5475]

Colliding Nucleons

We generate an nucleus–nucleus impact parameter, and for each pair of colliding nucleons we take their mutual impact-parameter distance and determine if they will interact and, if so, how:

- Absorptive (inelastic, non-diffractive)
- Double diffractive excitation
- Single diffractive excitation (on either side)
- Elastic? Central Diffraction?

PYTHIA8 allows you to plug in your own model.

Colliding Nucleons

We generate an nucleus–nucleus impact parameter, and for each pair of colliding nucleons we take their mutual impact-parameter distance and determine if they will interact and, if so, how:

- Absorptive (inelastic, non-diffractive)
- Double diffractive excitation
- Single diffractive excitation (on either side)
- Elastic? Central Diffraction?

PYTHIA8 allows you to plug in your own model.

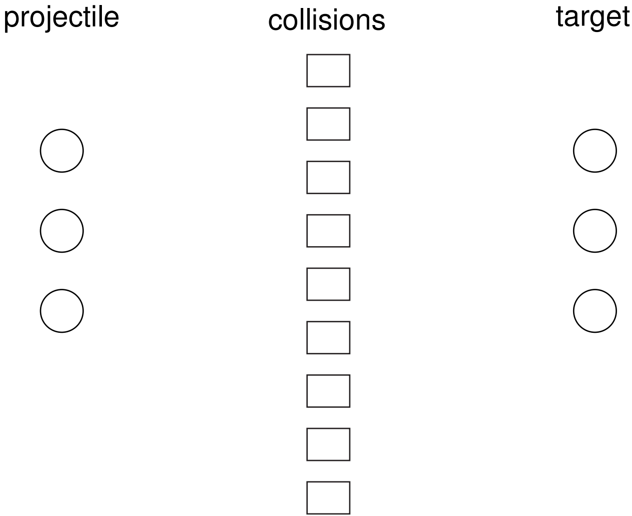
Diffraction and fluctuations

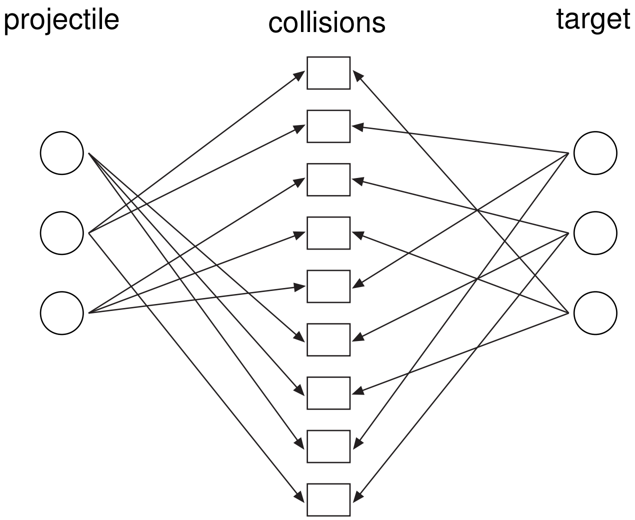
Fritiof only did single diffraction, we want to have a better treatment of non-diffractive interactions and we therefore want to differentiate.

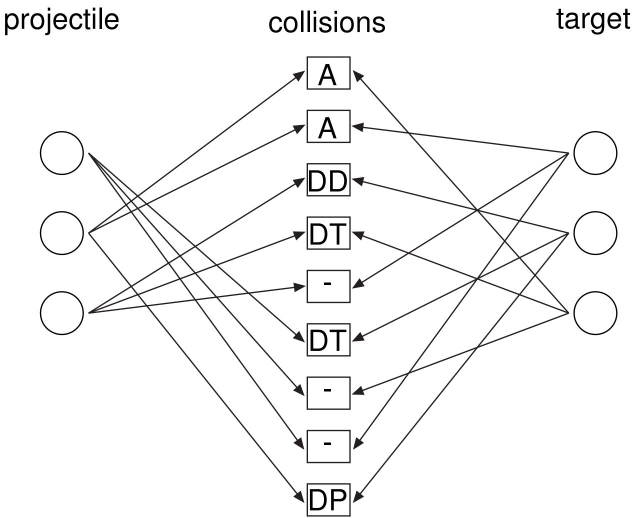
Diffraction is driven by the fluctuations in the cross section.

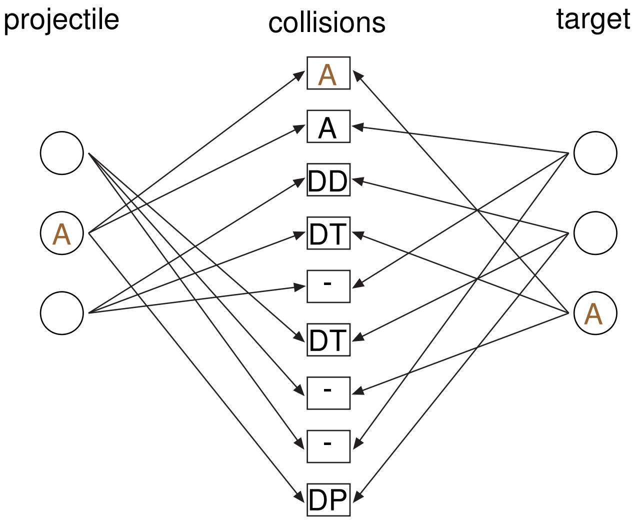
We use a model inspired by Strikman et al., where the cross section fluctuations are attributed to fluctuations in the projectile and target nucleon separately.

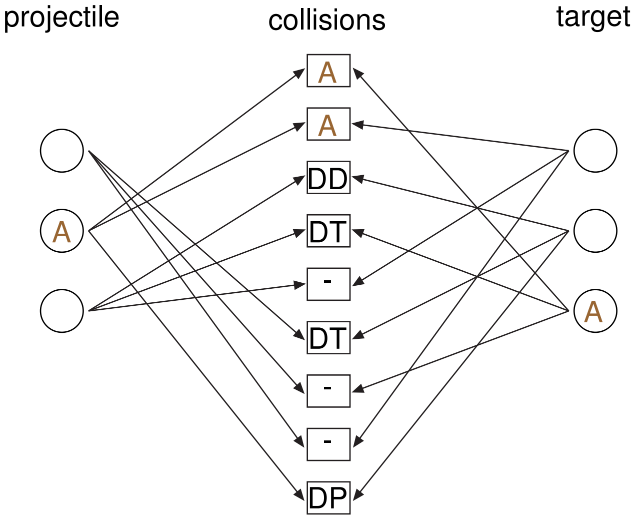
[arXiv:1301.0728, . . .]

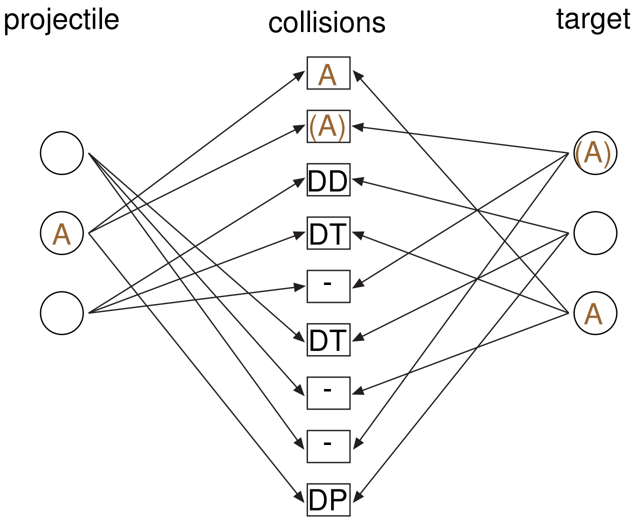

projectile
collisions
target

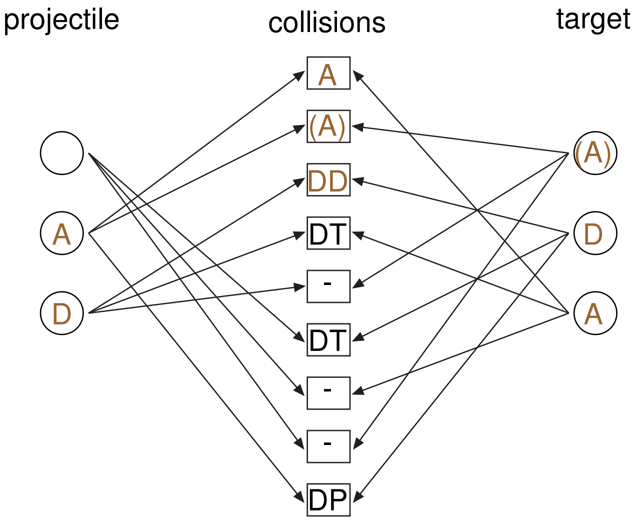

projectile
collisions
target


projectile
collisions
target
A
A
DD
DT
-
DT
-
-
DP


projectile
collisions
target
A
A
DD
DT
-
DT
-
-
DP
A
A


projectile
collisions
target
A
A
A
DD
DT
-
DT
-
-
DP
A


projectile
collisions
target
A
A
(A)
DD
DT
-
DT
-
-
DP
(A)
A


projectile
collisions
target
A
D
A
(A)
DD
DT
-
DT
-
-
DP
(A)
D
A

We generate the collisions in order

- If the participating nucleons has not participated in a previous collision
  - Ask PYTHIA to generate a corresponding event using the standard min-bias implementation.
- If one of the nucleons has interacted before, the other nucleon will add to the particle production as if it was diffractively excited (Fritiof)
  - Generate SD event with PYTHIA
  - Remove elastic proton
  - Merge with previous sub-event
- If both nucleons have interacted before, nothing happens.

Signal processes

Not only min-bias. Rather than just generating non-diffractive events, The first absorptive sub-event can be generated using any hard process in PYTHIA8, giving the final event a weight $N_A\sigma_{hard}/\sigma_{ND}$.

Secondary absorptive collisions

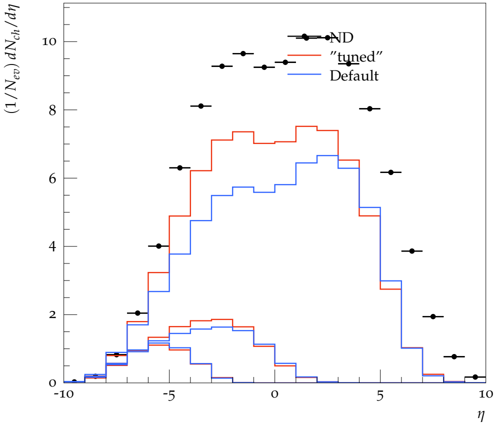
According to Fritiof this should look like a diffractively excited system. But there we only had flat strings in absorptive and diffractive scatterings.

Now we have much more complex string configurations.

In PYTHIA8 the diffractive states depend on

- Disribution in M_X.
- The assumed (non-diffractive) pomeron–proton cross section, $\sigma^{p\mathbb{P}}(M_X)$.
- The soft MPI-regularisation $p_{\perp,0}(M_x)$
- The parton densities of the pomeron

Comparing SD with ND in PYTHIA8

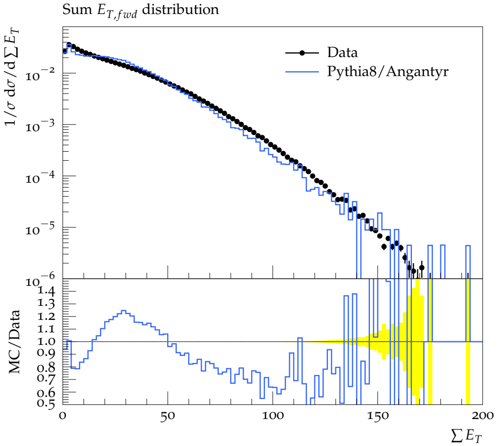


Comparison to data

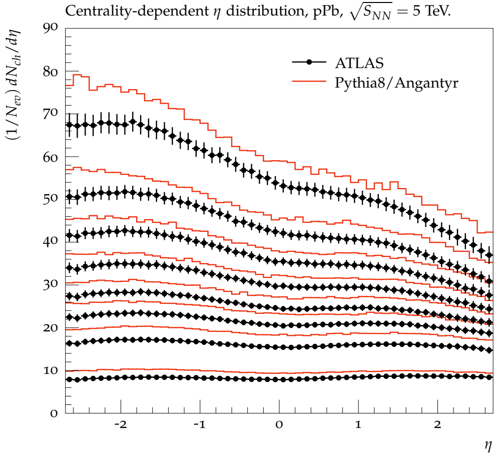
Several parameters in addition to the pp PYTHIA8 ones.

- Nucleon distributions can in principle be measured independently.
- *NN* cross section fluctuations are fitted to (semi-) inclusive pp cross sections (total, non-diffractive, single and double diffractive, elastic, and elastic slope) for given $\sqrt{s_{NN}}$.
- Diffractive parameters for secondary absorptive collisions, "tuned" to non-diffractive PYTHIA.
- M_X distribution: $dM_X^2/M_X^{2(1+\epsilon)}$, could be tuned (to p*A*), but we choose $\epsilon = 0$.
- Few other choices concerning energy momentum conservation which do not have large impact.

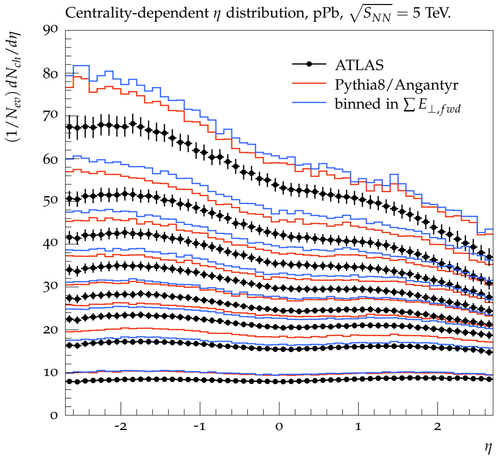
Centrality in pPb



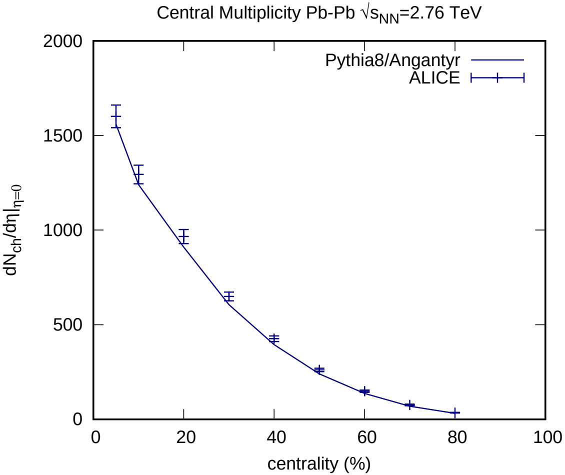
Eta distribution in pPb



Eta distribution in pPb



Central multiplicity in PbPb



Outlook

- Heavy Ions and the Angantyr model was introduced in PYTHIA8.230.
- Gives a reasonable baseline for HI collisions without collectivity in pp, p*A* and *AA*
- Please use it with your detector simulations to correct down to fiducial, particle level, observables. And yes! The centrality measure is an important observable!

Outlook

- Heavy Ions and the Angantyr model was introduced in PYTHIA8.230.
- Gives a reasonable baseline for HI collisions without collectivity in pp, pA and AA
- Please use it with your detector simulations to correct down to fiducial, particle level, observables. And yes! The centrality measure is an important observable!

Outlook

- Heavy Ions and the Angantyr model was introduced in PYTHIA8.230.
- Gives a reasonable baseline for HI collisions without collectivity in pp, p*A* and *AA*
- Please use it with your detector simulations to correct down to fiducial, particle level, observables. And yes! The centrality measure is an important observable!
- And then implement them in RIVET!