Hadronic final states in pA collisions

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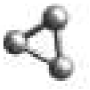
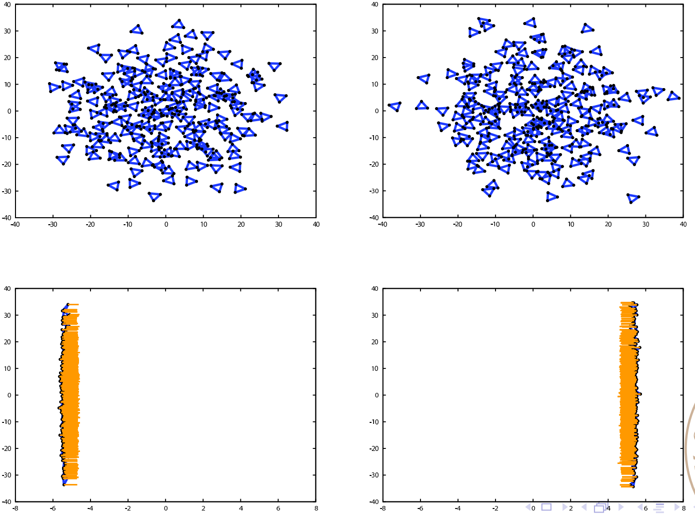
Outline

- DIPSY
- Glauber models
- Generating final states
- Reviving Fritiof

DIPSY



Sample Au-Au event



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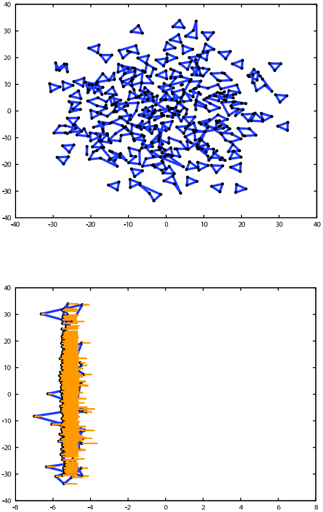

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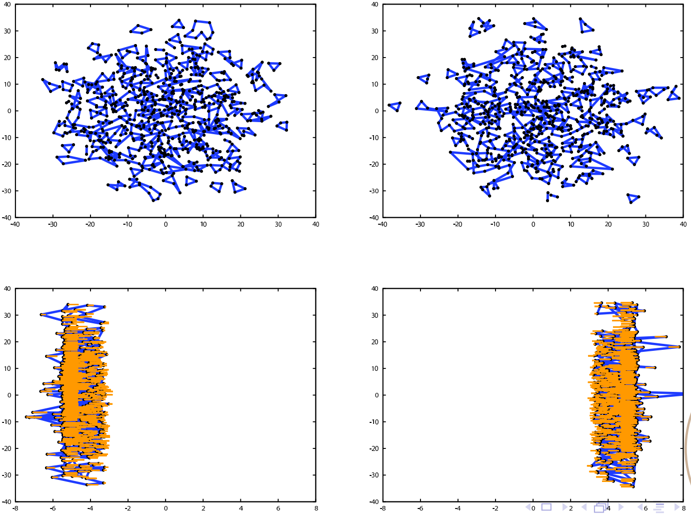

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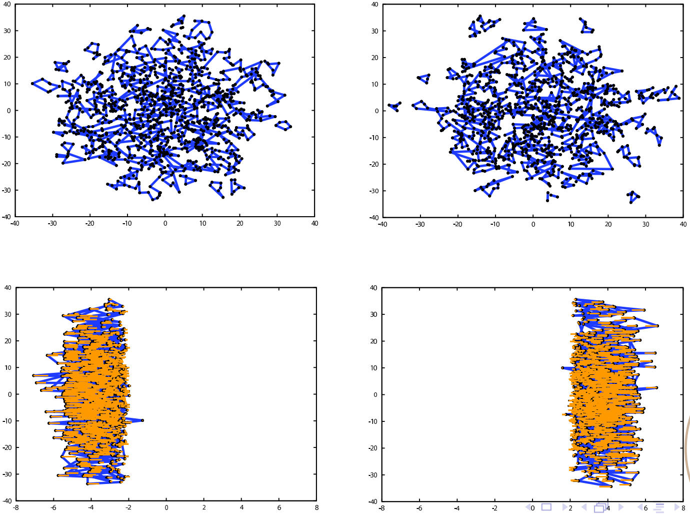

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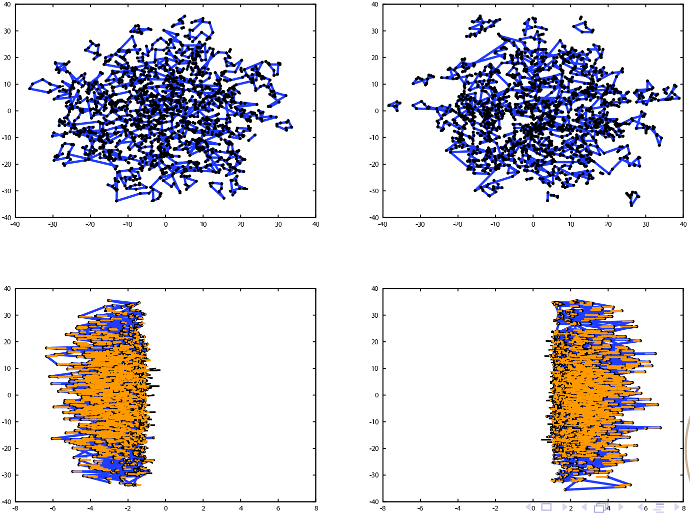
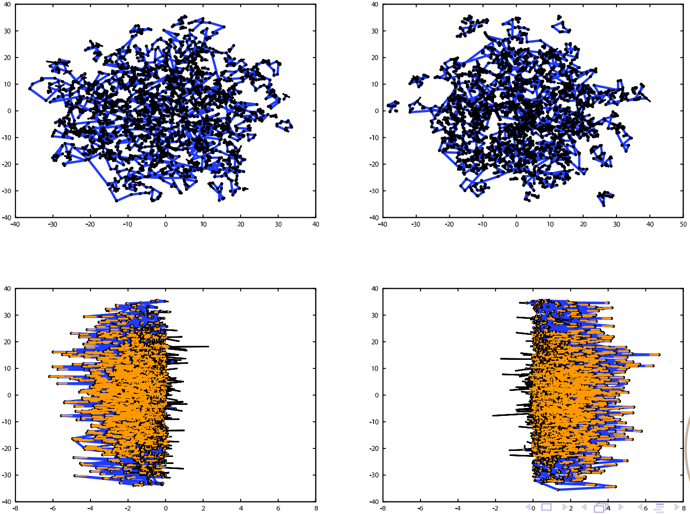


Sample Au-Au event



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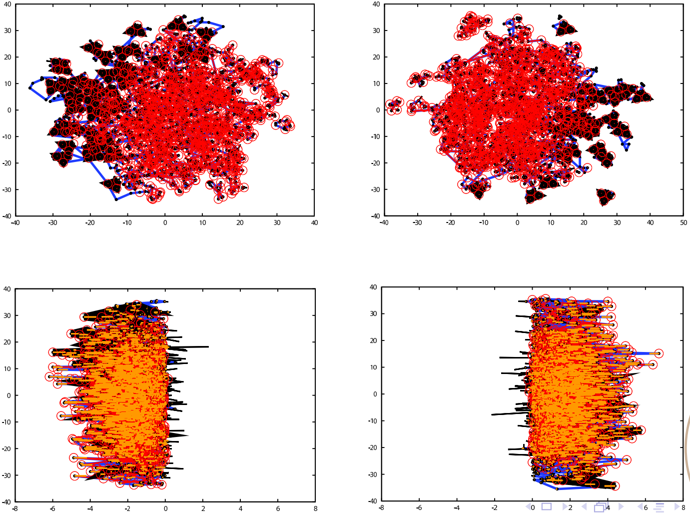

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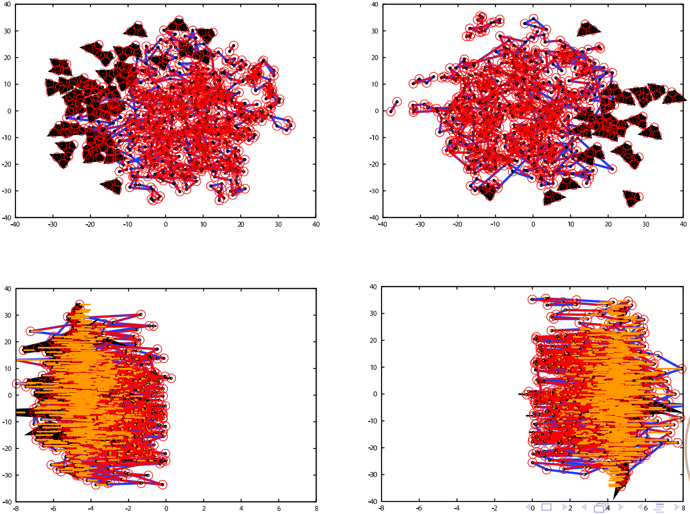
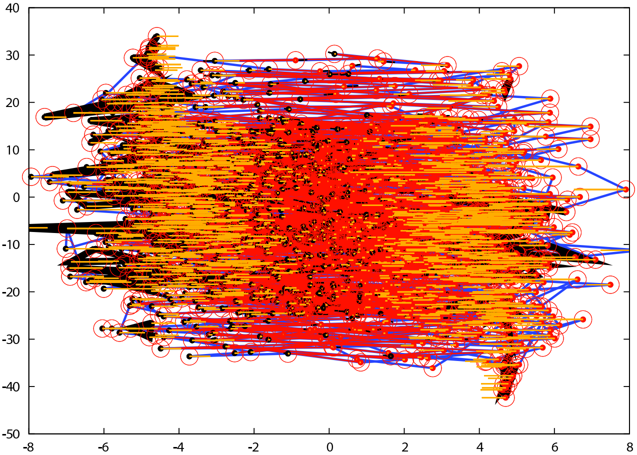
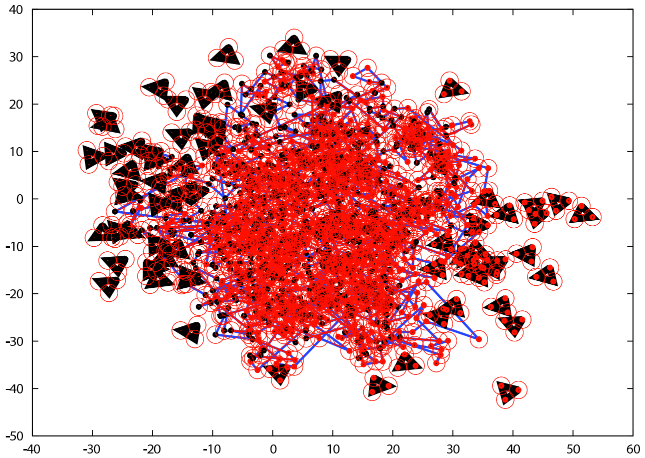


Sample Au-Au event



Sample Au-Au event



Hadron scattering cross sections

Working with the optical theorem in impact parameter space

$$T = -iA_{\text{el}}$$

In DIPSY, $T = 1 - \exp\left(-\sum_{i,j} f_{ij}\right)$, where f_{ij} are the dipole–dipole scattering probabilities.

$$\begin{aligned}
\frac{d\sigma_{\text{tot}}}{d^2b} &= 2\langle T(b)\rangle \\
\frac{d\sigma_{\text{el}}}{d^2b} &= \langle T(b)\rangle^2 \\
\frac{d\sigma_{\text{in}}}{d^2b} &= 2\langle T(b)\rangle - \langle T(b)\rangle^2
\end{aligned}$$

averaging over initial states of the target and projectile $T_{pt}(b)$.

Diffractive excitation

Following Good–Walker

$$
\begin{aligned}
\frac{d\sigma_{\mathrm{Dp}}}{d^2b} &= \left\langle \langle T_{pt}(b)\rangle_t^2 \right\rangle_p - \langle T_{pt}(b)\rangle_{pt}^2 \\
\frac{d\sigma_{\mathrm{Dt}}}{d^2b} &= \left\langle \langle T_{pt}(b)\rangle_p^2 \right\rangle_t - \langle T_{pt}(b)\rangle_{pt}^2 \\
\frac{d\sigma_{\mathrm{DD}}}{d^2b} &= \left\langle T_{pt}^2(b) \right\rangle_{pt} - \left\langle \langle T_{pt}(b)\rangle_t^2 \right\rangle_p - \left\langle \langle T_{pt}(b)\rangle_p^2 \right\rangle_t + \langle T_{pt}(b)\rangle_{pt}^2
\end{aligned}
$$

Diffractive excitation is related to fluctuations.

$$
\frac{d\sigma_{\mathrm{in,ND}}}{d^2b} \equiv \frac{d\sigma_{\mathrm{abs}}}{d^2b} = 2\,\langle T_{pt}(b)\rangle_{pt} - \left\langle T_{pt}^2(b) \right\rangle_{pt}
$$

How do we estimate nuclear effects?

- Estimate number distribution of wounded/participating nucleons *using Glauber*.
- Find a centrality observable that should be sensitive to the number of hit nucleons.
- Build up a reference sample by stacking pp-events, fudging them a bit to fit the centrality distribution.

The centrality measure is typically defined in terms of some multiplicity or energy in the nucleus direction.

Which nucleons are participating/wounded

The simplest Glauber model uses nucleons distributed with a Wood–Saxon and treating them as solid, fixed-size black disks.

Looking at the cross sections for a projectile on a single nucleon, we have $T(b) = \Theta(\sqrt{\sigma/\pi} - b)$, and for $\sigma = \sigma_{\mathrm{tot}}$ we get

$$\begin{aligned}
\sigma_{\mathrm{tot}} &= \int d^2b\, 2\,\langle T(b)\rangle \\
\sigma_{\mathrm{el}} &= \int d^2b\, \langle T(b)\rangle^2 = \sigma_{\mathrm{tot}}/2 \\
\sigma_{\mathrm{abs}} &= \int d^2b\, \left(2\,\langle T(b)\rangle - \langle T(b)\rangle^2\right) = \sigma_{\mathrm{tot}}/2 \\
\sigma_{\mathrm{diff}} &= \int d^2b\, \left(\left\langle T^2(b)\right\rangle - \langle T(b)\rangle^2\right) = 0
\end{aligned}$$

The black disk approach, clearly cannot properly take diffractive excitation into account

It can be fudged, by setting e.g. $\sigma = \sigma_{\mathrm{in}}$ or $\sigma = \sigma_{\mathrm{abs}}$, but we want to do better.

We want to be able to see which nucleons that contributes to the centrality observable.

- absorptively wounded nucleons.
- diffractively wounded nucleons.
- ...Not elastically scattered nucleons.

$$\sigma_{\mathrm{w}} \equiv \sigma_{\mathrm{abs}} + \sigma_{\mathrm{Dt}} + \sigma_{\mathrm{DD}} = \sigma_{\mathrm{tot}} - \sigma_{\mathrm{el}} - \sigma_{\mathrm{Dp}}$$

But setting $\sigma = \sigma_{\mathrm{w}}$ is not enough since we want to model also the fluctuations in the projectile.

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But setting $\sigma = \sigma_{\rm w}$ is not enough since we want to model also the fluctuations in the projectile.

The two-radii model

A simple extension of the black-disk Glauber model is to assume that the target and nucleus fluctuates between two states with different radii, r and R, with the probability c and $1 - c$ respectively.

Since we have four independent cross sections σ_{abs}, σ_{el}, $\sigma_{\mathrm{Dp}} = \sigma_{\mathrm{Dt}}$, and σ_{DD}, we introduce a fourth transparency parameter, α with

$$T_{pt}(b) = \alpha\Theta(r_p + r_t - b).$$

α, c, r and R can now be fit to reproduce all relevant cross sections.

But the fluctuations are very crude.

Glauber–Gribov and Colour Fluctuations

Arguable the most advanced model is by Strickman et al. — GGCF

Assume a fluctuating cross section:

$$\sigma_{\rm tot} = \int d\sigma P_{\rm tot}(\sigma) = \int d\sigma \rho \frac{\sigma}{\sigma + \sigma_0} \exp\left\{-\frac{(\sigma/\sigma_0 - 1)^2}{\Omega^2}\right\}$$

Experiments typically use this together with a black disk, $T(b) = \Theta(\sqrt{\sigma/\pi} - b)$, with $\Omega = 1.01$ or 0.55, with the $\mathrm{P}_{\rm tot}$ scaled to get the total inelastic cross section

$$\sigma_{\rm in} = \int d\sigma P_{\rm in}(\sigma) \equiv \int d\sigma P_{\rm tot}(\sigma/\lambda), \qquad \lambda = \sigma_{\rm in}/\sigma_{\rm tot}$$

GGCF vs. DIPSY

Let's analyse what GGCF does by comparing with DIPSY.

```
[Ptot(sigma) for DIPSY tp-flukt, Omega=1.01,
Omega=0.55]
```

Clearly there are much larger fluctuatios in DISPY.

But we want to use GGCF to model wounded nucleons which only depends on the fluctuations in the projectile.

Averaging over the target states in DIPSY will result in smaller fluctuations.

```
[Ptot(sigma) for DIPSY tp-flukt, Omega=1.01,
Omega=0.55]
```

Assuming that GGCF describes the fluctuations in the projectile only, we can fit the parameters to three cross section:

$$\begin{aligned}\sigma_{\mathrm{tot}} &= \int d^2b \int d\sigma P_{\mathrm{tot}}(\sigma) 2T(\sigma,b) \\ \sigma_{\mathrm{el}} &= \int d^2b \left| \int d\sigma P_{\mathrm{tot}}(\sigma) T(\sigma,b) \right|^2 \\ \sigma_{\mathrm{w}} &= \int d^2b \int d\sigma P_{\mathrm{tot}}(\sigma) \left(2T(\sigma,b) - T^2(\sigma,b) \right)\end{aligned}$$

We have tried

$$\begin{aligned}T(\sigma,b) &\propto \exp(-b^2/2B), \qquad \text{and} \\ T(\sigma,b) &= T_0 \Theta(\sqrt{\sigma/2\pi T_0} - b).\end{aligned}$$

But only with the latter was it possible to fit experimental cross sections.

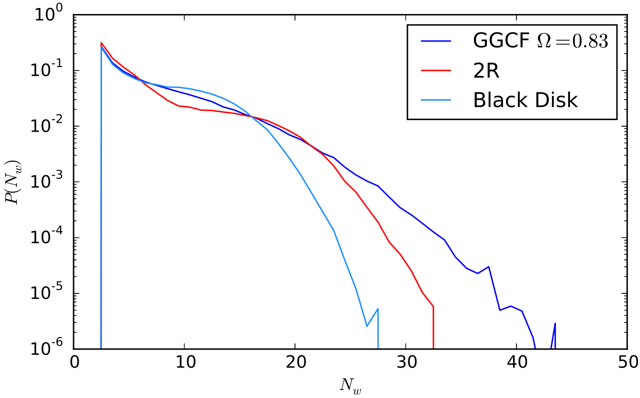
[Ptot(sigma) for DIPSY p-flukt, Omega=1.01, Omega=0.55, Omega=fit]

```
[Pwounded(sigma) for DIPSY p-flukt,
Omega=1.01, Omega=0.55, Omega=fit]
```

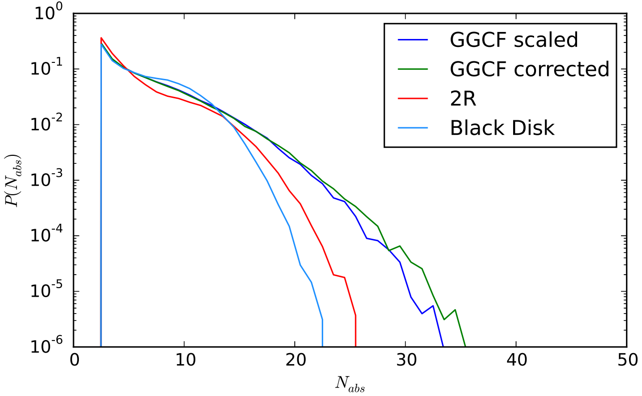
[Pabs(sigma) for DIPSY p-flukt, Omega=1.01, Omega=0.55, Omega=fit]

Distribution of wounded nucleons

We can now use our modified GGCF tuned to experimental data and obtain a distribution of wounded nucleons.



Absorptively wounded nucleons.



Generating finalstates in pA

How much does a wounded nucleon contribute to particle production?

An absorptive pN scattering would distribute particles evenly in η. But what about projectile wounding two nucleons absorptively?

For a diffractively wounded nucleon, we expect a high-mass tail:

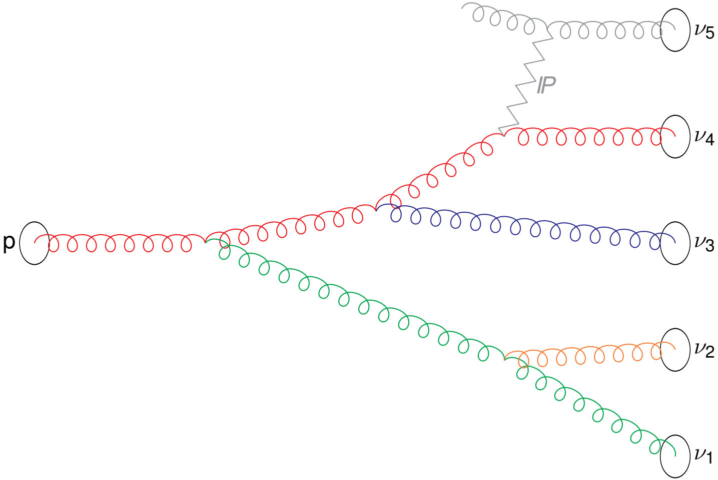
$$\frac{d\sigma}{dM_X^2} \propto \frac{1}{M_X^{2(1+\epsilon)}}$$

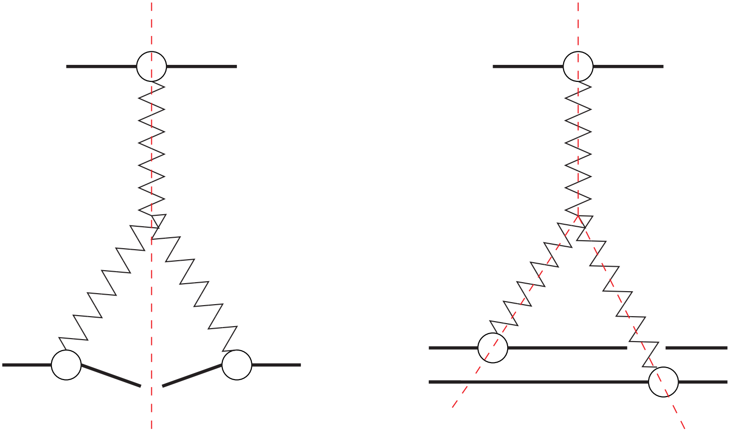
with $0 < \epsilon < 0.2$.

Fritiof

The old Fritiof model assumed that each wounded nucleon contributed with a string with a mass distribution corresponding to $\epsilon = 0$.

This worked very well for low energies, where perturbative effects were smallish. It does not work for LHC.


p
ν_5
$I\!P$
ν_4
ν_3
ν_2
ν_1

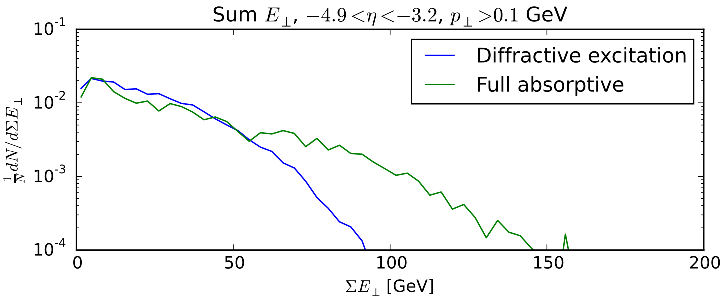


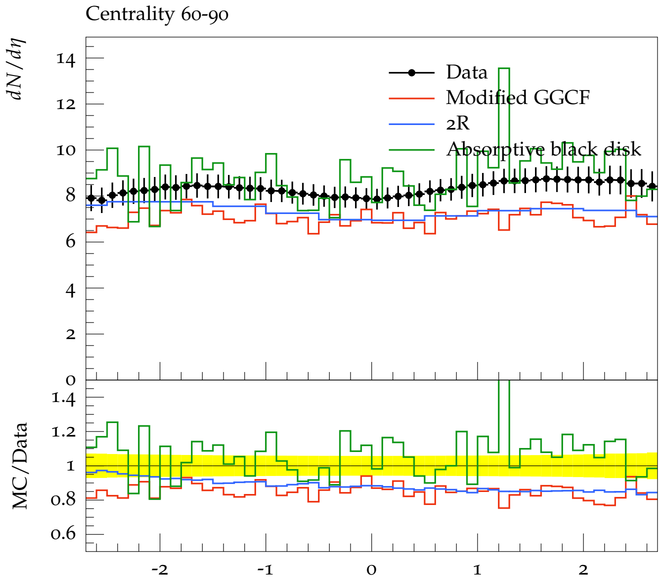
(a) (b)

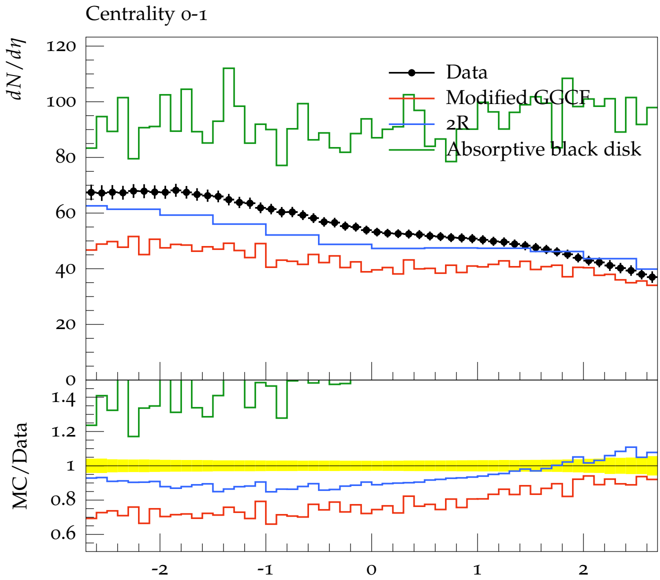
The New Model

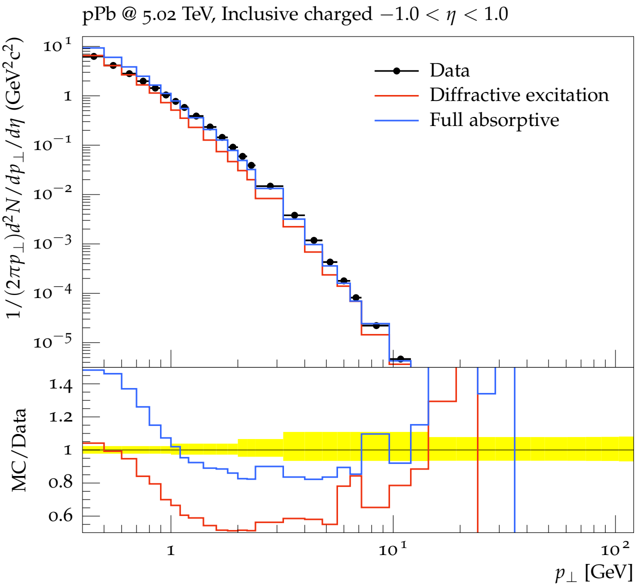
- Generate $N_{\rm abs}$ and $N_{\rm w}$.
- Let PYTHIA8 generate one absorptive pp event, But bias the hard ME with a factor $N_{\rm abs}$.
- Stack another $N_{\rm w} - 1$ diffractive events using $\epsilon = 0$ (the default in PYTHIA8).
- Make sure energy and momentum is conserved.

Centrality


Sum $E_\perp$, $-4.9 < \eta < -3.2$, $p_\perp > 0.1$ GeV
Diffractive excitation
Full absorptive
$\frac{1}{N} dN/d\Sigma E_\perp$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
$\Sigma E_\perp$ [GeV]


Centrality 60-90
$dN/d\eta$
14
12
10
8
6
4
2
0
Data
Modified GGCF
2R
Absorptive black disk
1.4
1.2
1
0.8
0.6
MC/Data
-2
-1
0
1
2


Centrality 0-1
dN/dη
Data
Modified GGCF
2R
Absorptive black disk
MC/Data
120
100
80
60
40
20
0
1.4
1.2
1
0.8
0.6
-2
-1
0
1
2


pPb @ 5.02 TeV, Inclusive charged $-1.0 < \eta < 1.0$
$1/(2\pi p_\perp) d^2N/dp_\perp/d\eta$ (GeV^{2}c^2)
Data
Diffractive excitation
Full absorptive
MC/Data
10^1
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1.4
1.2
1
0.8
0.6
1
10^1
10^2
$p_\perp$ [GeV]

Outlook

- Differentiate between wounded and absorbed nucleons
- GGCF with individually fluctuating projectile and target
- Implement simple FS effects (rope and swing)
- From pA to AA