Hadronic Rescattering in Pythia

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Outline

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Heavy ion research in Lund

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- Several projects in Lund are trying to explore heavy ion physics without a QGP, to see how well other effects can explain experimental data.
- Rescattering is one such effect. Other effects include string shoving and rope formation.
- The rescattering framework was released in Pythia 8.303, and we are now working on integrating with Angantyr.

Why rescattering in Pythia?

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- Our framework is fully integrated and is trivial to interface with other parts of Pythia
- Leverages other features of Pythia, such as the event record
- Some new physics features, such as interactions involving charm and bottom, and open for further extensions

The Lund string model

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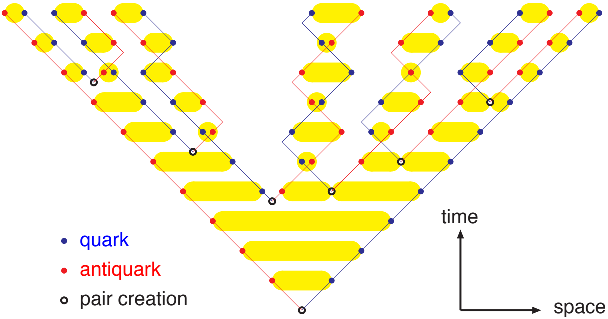
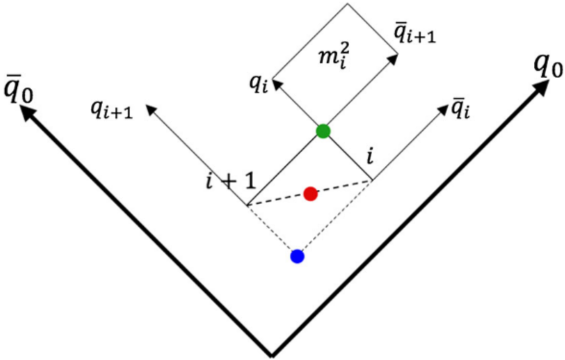


Spacetime picture of the Lund string model

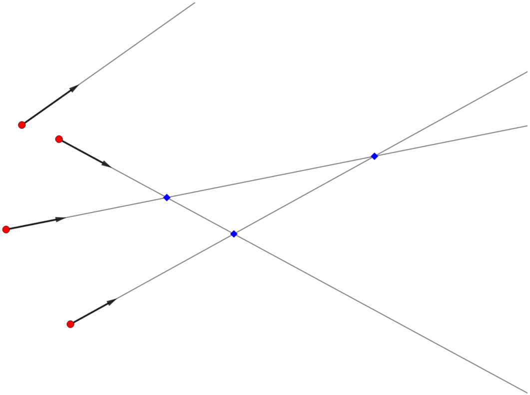


String tension κ 1 GeV/fm

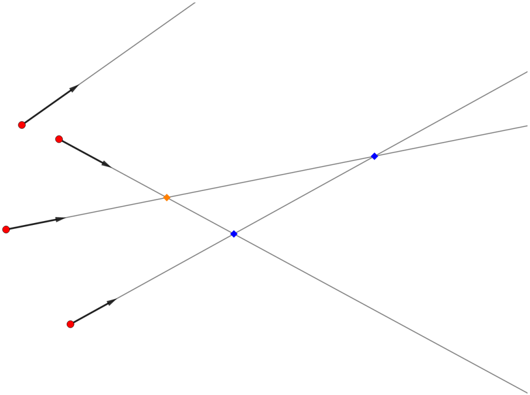
(Ferreres-Solé & Sjöstrand, arXiv:1808.04619)

Outline

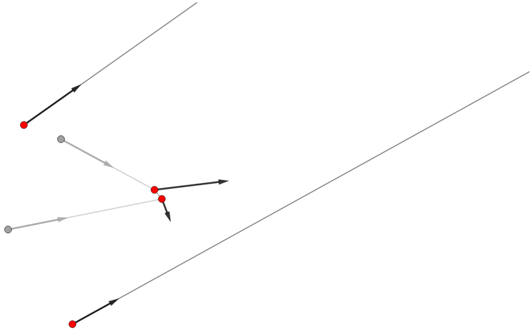
Rescattering overview



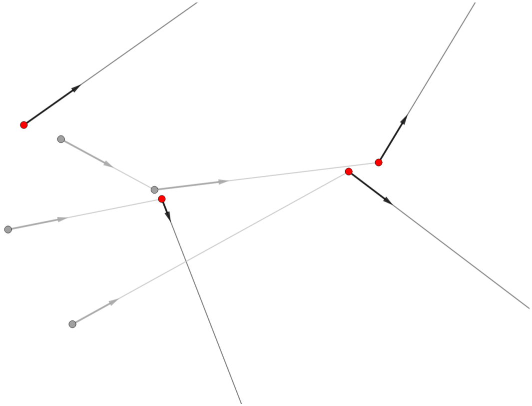
Rescattering overview



Rescattering overview

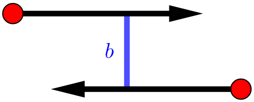


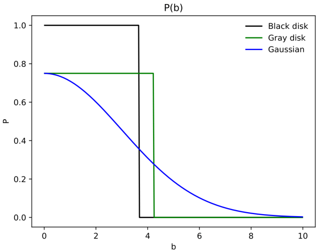
Rescattering overview



The collision criterion

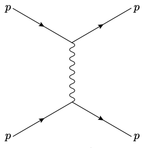
The probability of an interaction depends on the cross section σ and the impact parameter b



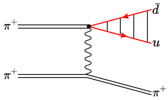


The characteristic range of the interaction is $b_{\text{crit}} = \sqrt{\sigma/\pi}$
The cross section σ depends on the particle types and the center-of-mass energy.

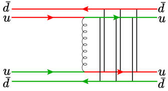
Low-energy interactions



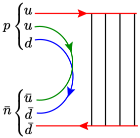
Elastic



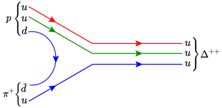
Diffractive



Non-diffractive

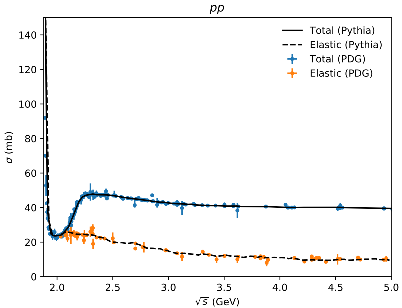


Annihilation



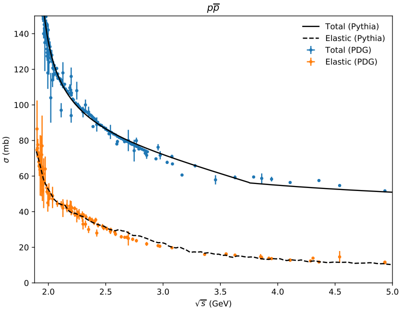
Resonant

Cross sections



Based on PDG data and HPR_1R_2 parameterization

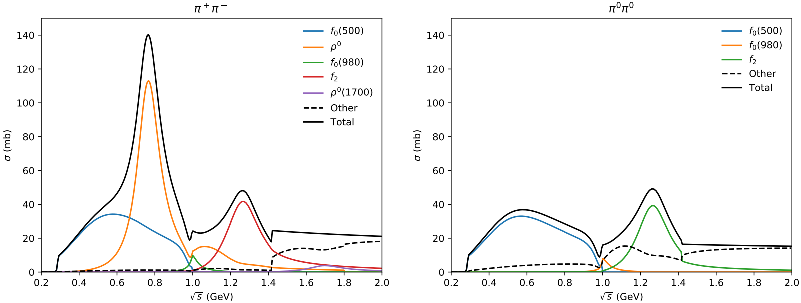
(DOI: 10.1103/PhysRevD.98.030001)



Based on UrQMD (arXiv:nucl-th/9803035) and CERN/HERA parameterization

(DOI 10.1103/PhysRevD.50.1173)

Cross sections



Based on work by Pelaez, Rodas, Ruiz de Elvira et al.
(arXiv:1102.2183, arXiv:1907.13162, arXiv:1602.08404)

Tuning

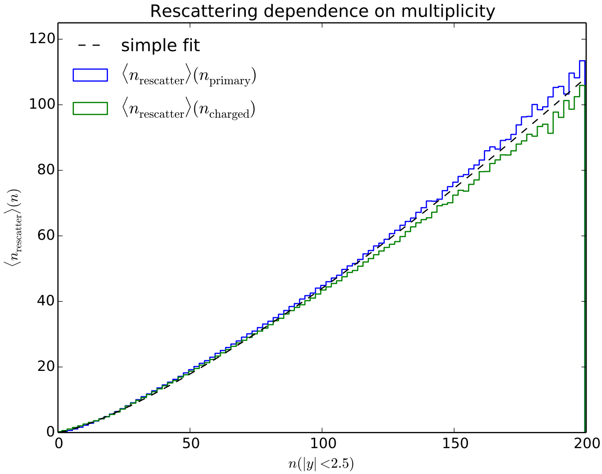
In our framework, we consider rescattering between only two particles at a time. This means that we can have two-to-many interactions, but not many-to-two. Therefore, rescattering increases charged multiplicity.

To compensate for this, we set `MultipartonInteractions:pT0Ref = 2.345` when doing our analyses (default is 2.28).

We have verified that this is not responsible for the results I am about to discuss.

Outline

Rescattering rates



nondiffractive events at 13 TeV, simple fit $n^{1.3}$

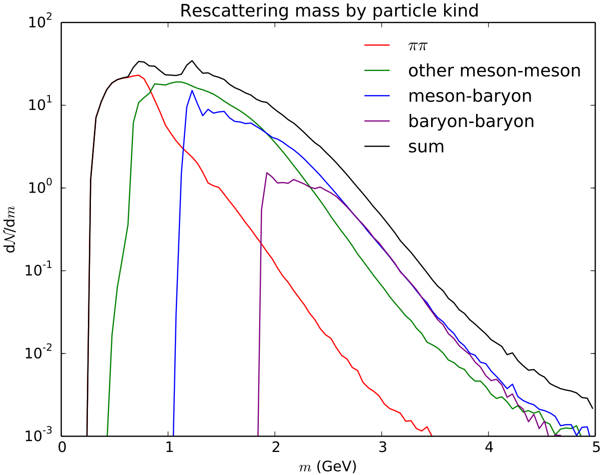
Rescattering rates

Mean number of interactions per nondiffractive event at 13 TeV

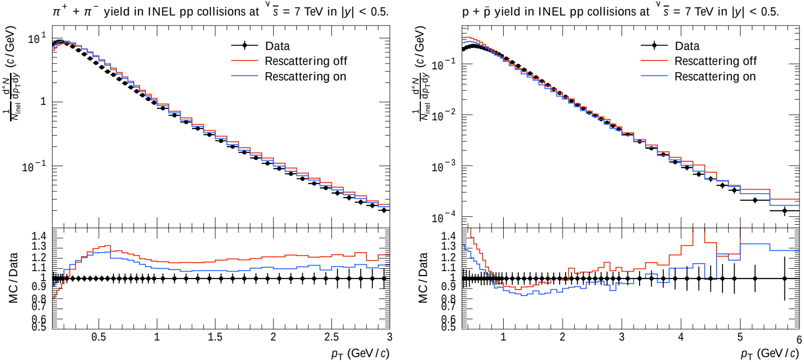
incoming	rate	incoming	rate
$\pi + \pi$	12.63	K + N	0.39
$\pi + \rho$	4.59	$\rho + \rho$	0.38
π + K	3.84	ρ + N	0.36
π + N	3.44	$\rho + \omega/\varphi$	0.34
$\pi + \omega/\varphi$	2.08	$\rho + \eta/\eta$	0.30
$\pi + \eta/\eta$	1.80	$\pi + f_0(500)$	0.29
π + K	1.33	K + ω/φ	0.27
$\pi + \Delta$	1.10	K + K	0.26
ρ + K	0.54	$\pi + \Lambda$	0.25
$\pi + \Sigma$	0.46	Other	3.70
N + N	0.46		
K + K	0.41	Total	39.22

process	rate
resonant	17.80
elastic	14.08
nondiffractive	6.92
annihilation	0.49
diffractive	0.05

Rescattering invariant mass

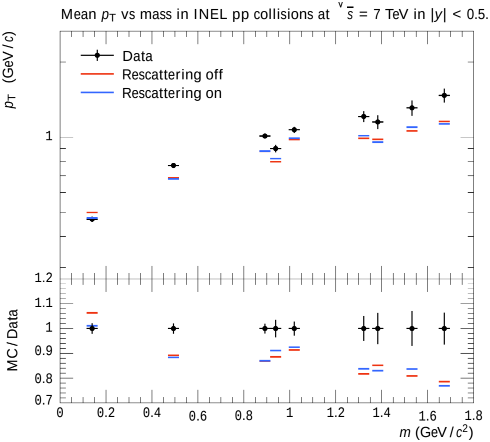


$p_\perp$ spectra



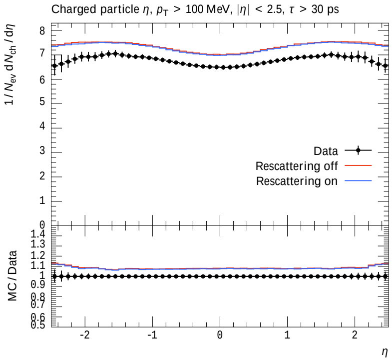
(Data from ALICE, arXiv:1504.00024)

Mean p



(Data from ALICE, arXiv:1504.00024, arXiv:1406.3206)

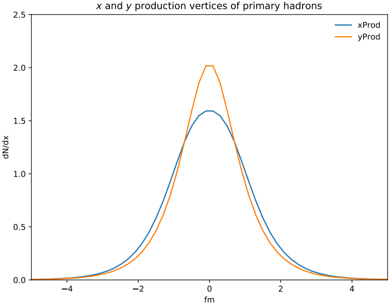
η spectra

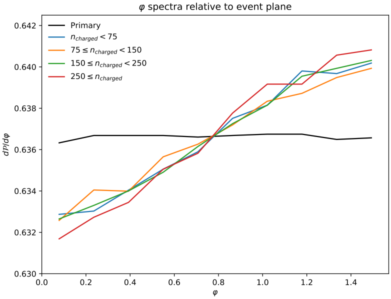


(Data from ATLAS, arXiv:1606.01133, arXiv:1602.01633)

Flow

We introduced an artificially strong anisotropy in the x-direction to see if rescattering can produce flow





Under more realistic conditions, we saw no clear signs of flow

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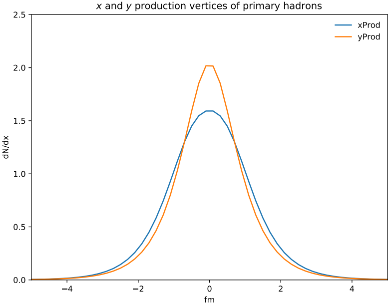
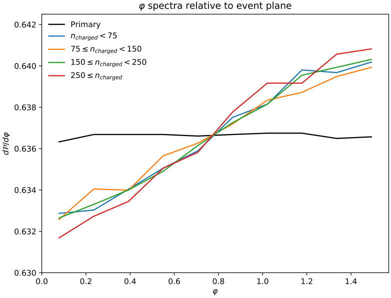
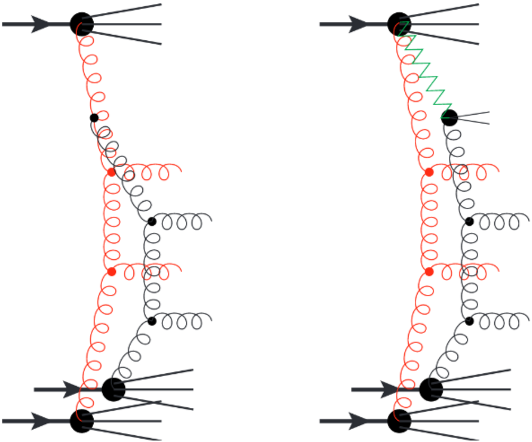




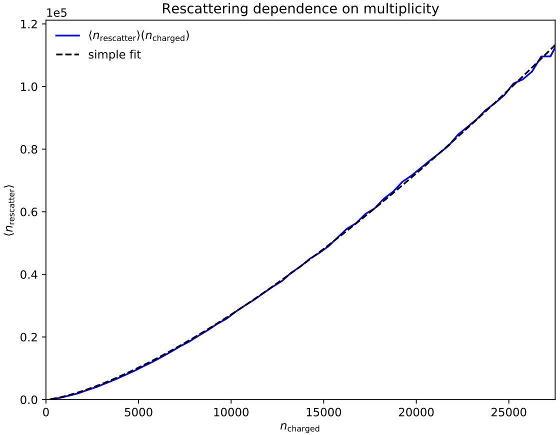
Under more realistic conditions, we saw no clear signs of flow
Rescattering can cause flow in principle, but is not the main source of flow in pp collisions!

Outline

Angantyr

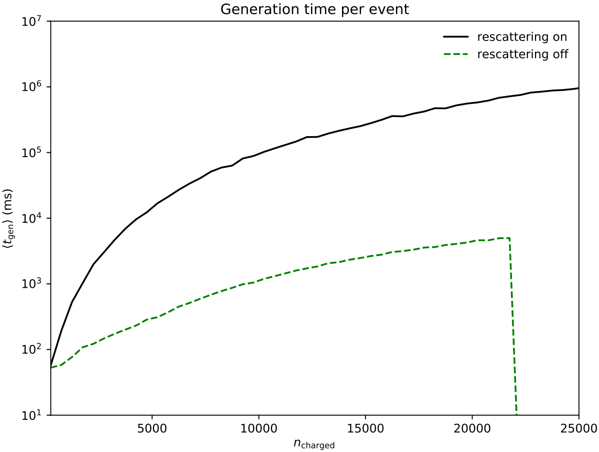


Rescattering rates



PbPb events at 3.140 TeV, simple fit $n^{1.4}$

Generation time



Rescattering rates

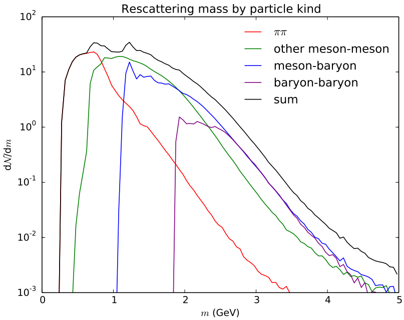
process	rate	fraction
resonant	17.80	45.2 %
elastic	14.08	35.8 %
nondiff.	6.92	17.6 %
ann.	0.49	1.2 %
diff.	0.05	0.1 %
Total	39.34	

Nondiffractive pp at 13 TeV

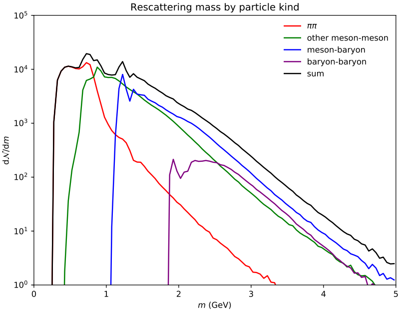
process	rate	fraction
resonant	8351.9	51.7 %
elastic	5721.2	35.4 %
nondiff.	1999.1	12.4 %
ann.	71.3	0.4 %
diff.	15.2	0.1 %
Total	16158.8	

PbPb at 3.140 TeV

Rescattering rates

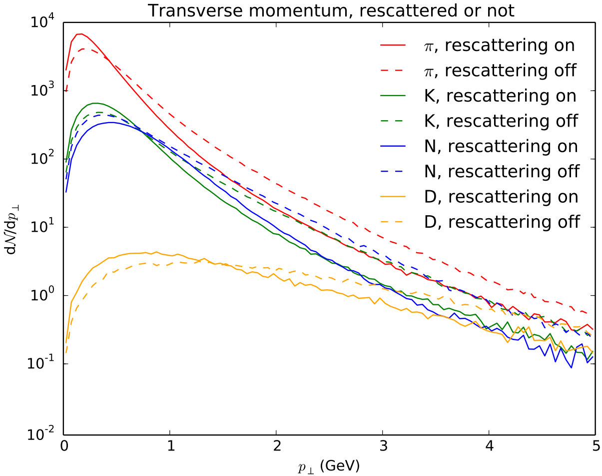


Nondiffractive pp at 13 TeV

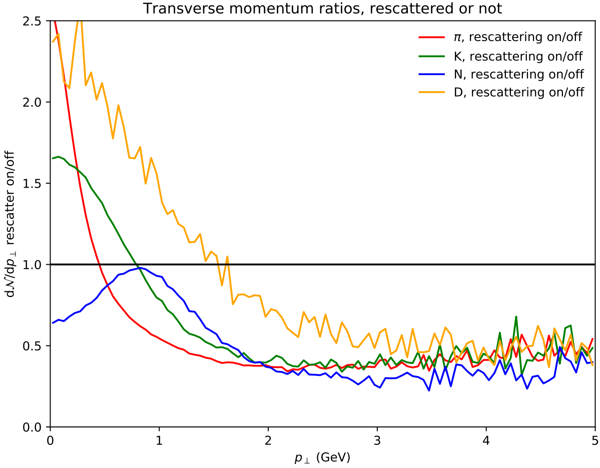


PbPb at 3.140 TeV

pT spectra


Transverse momentum, rescattered or not
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
dN/d$p_\perp$
0
1
2
3
4
5
$p_\perp$ (GeV)
π, rescattering on
π, rescattering off
K, rescattering on
K, rescattering off
N, rescattering on
N, rescattering off
D, rescattering on
D, rescattering off

pT spectra


Transverse momentum ratios, rescattered or not
π, rescattering on/off
K, rescattering on/off
N, rescattering on/off
D, rescattering on/off
d𝒩/d$p_\perp$ rescatter on/off
$p_\perp$ (GeV)
0.0
0.5
1.0
1.5
2.0
2.5
0
1
2
3
4
5

Longitudinal production time

$$(\quad = \sqrt{t^2 \quad z^2})$$

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- We have started doing analyses in Angantyr. One of the next things we want to look at is flow.
- The future of Angantyr will also involve shoving, ropes, and other effects.
- When these individual components are done, we will start putting it all together.