Hadronic Rescattering in Pythia/Angantyr

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(*Eur. Phys. J.* C 80, 907 (2020), arXiv:2103.09665 (2021))

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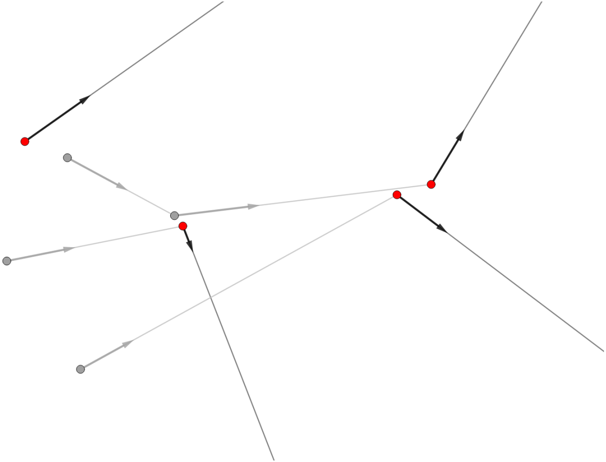
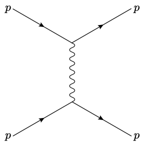
22nd MCnet Meeting, 20 April

Outline

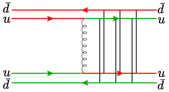
Rescattering overview



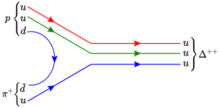
Rescattering overview - low energy processes



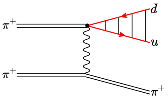
Elastic



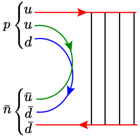
Non-diffractive



Resonant



Diffractive



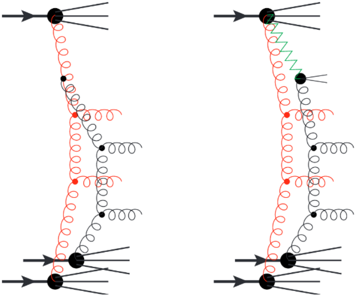
Annihilation

Why rescattering in Pythia?

- 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 has been shown to give rise to collective effects such as flow (da Silva et al., arXiv:1911.12824).
- Having rescattering in Pythia makes it more convenient to perform these studies, and is a starting point for further development.

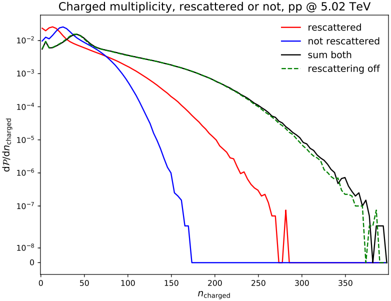
Angantyr

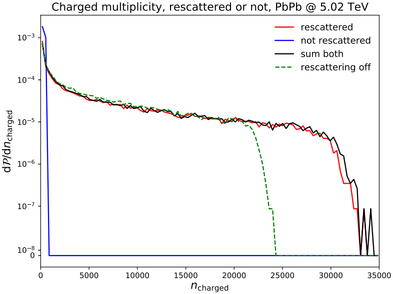
- Angantyr is the default heavy ion model for Pythia
- Basically Pythia's MPI model extended to heavy ions, using a Glauber model for the nucleon geometry
- First interaction modelled as non-diffractive pp event. Subsequent interactions modelled similar to single-diffractive.



Multiplicities - pp vs. PbPb @ 5.02 TeV

- Rescattering is implemented $2 \to n$ processes, but not $n \to 2$, so multiplicity will increase.

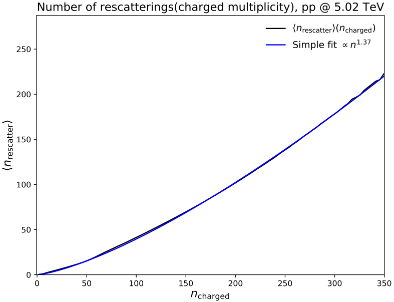


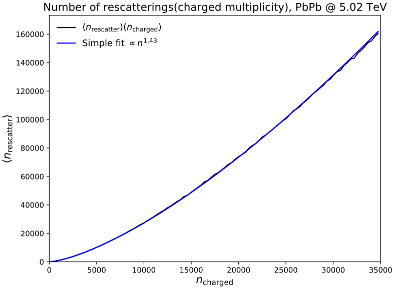


For pp we compensate by tuning $p_{\perp,0}$ from the MPI framework.
Other cases need a more detailed treatment

Rescattering rates - pp vs. PbPb @ 5.02 TeV

Naïvely expect $n_{\text{rescattering}} \sim n_{\text{hadron}}^2$.
In practice, assume n^p scaling for some other p



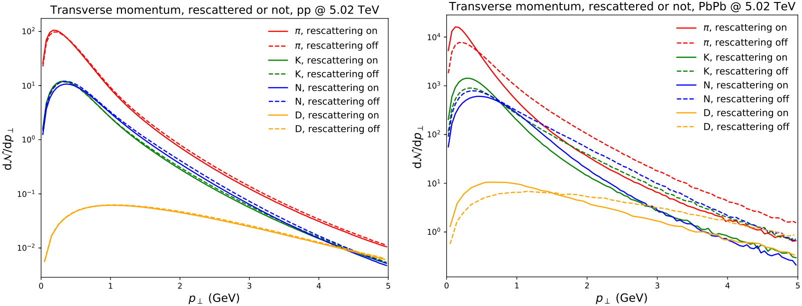


Case	p
pp	1.37
pPb	1.47
PbPb	1.43

- Scaling is faster for pPb than for pp.
- But slower for PbPb than pPb, since then higher multiplicity implies larger volume.

pT spectra - pp vs. PbPb @ 5.02 TeV

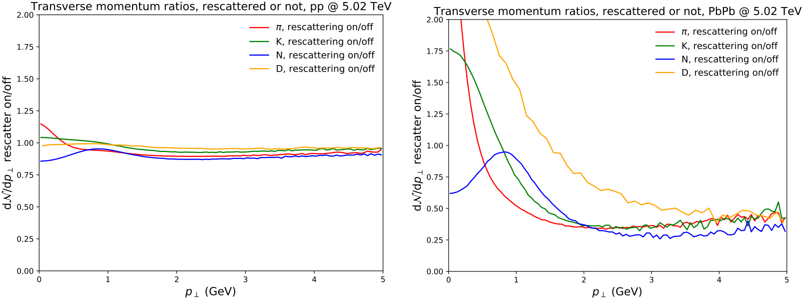
- Rescattering reduces mean $p_\perp$ since multiplicity increases
- D mesons start out at higher $p_\perp$ because charm is not produced in string fragmentation



To study this closer, let look at ratios between the two spectra...

pT spectrum ratios - pp vs. PbPb @ 5.02 TeV

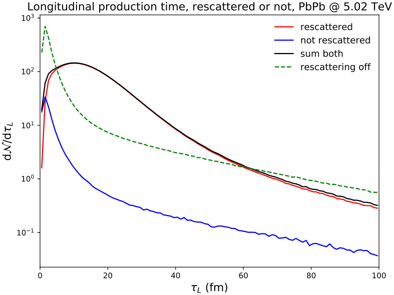
$dN/dp_\perp$ ratios with rescattering on : off

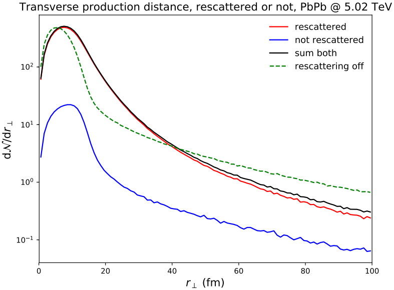


- Pion wind pushes pions to lower $p_\perp$ and nucleons to higher
- Nucleon depletion due to baryon–antibaryon annihilation
- D mesons start out at higher $p_\perp$ and are pushed to lower velocities

Spacetime distributions - PbPb @ 5.02 TeV

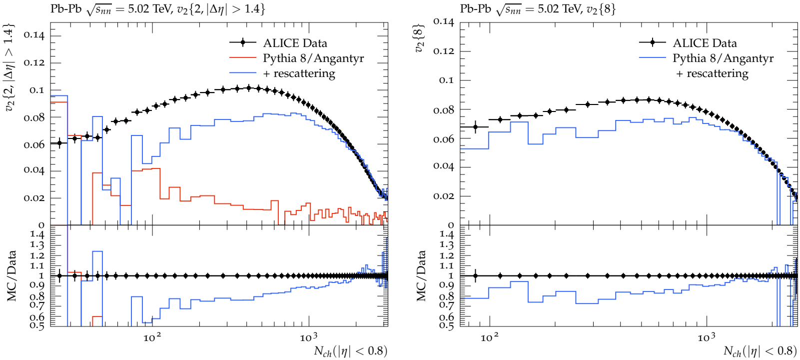
$$\tau_L^2 = t^2 - z^2, \qquad r_\perp^2 = x^2 + y^2$$





- Reduction in number of hadrons produced very early or late
- Particles produced at higher $r_\perp$ are less likely to rescatter
- Mean production time with rescattering $\langle \tau_L \rangle = 15.4$ fm

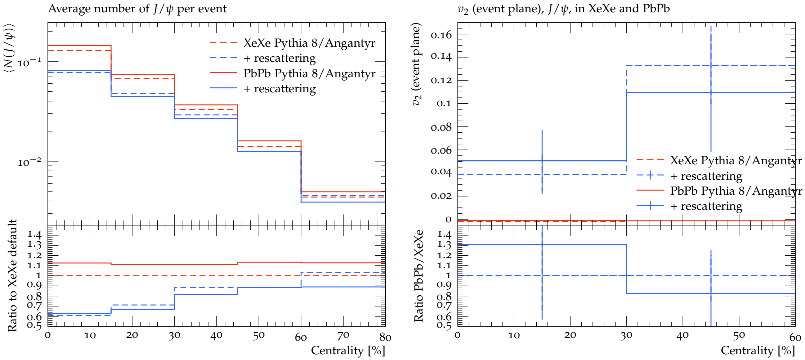
Flow - PbPb @ 5.02 TeV



(Data from arXiv:1903.01790)

- Very good description at high multiplicities, where there is more rescattering activity
- Other effects like ropes and shoving should also contribute, so the result with only rescattering should be below data

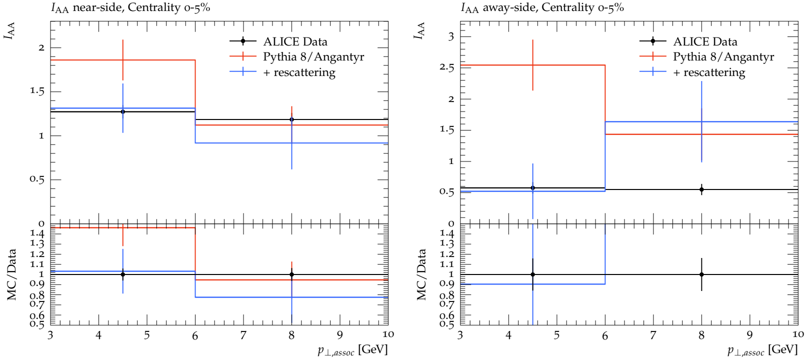
Flow for J/ψ - PbPb @ 2.76 TeV / XeXe @ 5.44 TeV



- Number of J/ψ depleted in rescattering
- Rescattering gives a flow effect for J/ψ

Jets I_{AA} - PbPb @ 2.76 TeV

I_{AA} is the PbPb/pp ratio of associated particle yield per trigger
$8\ \text{GeV} < p_{\perp,\text{trig}} < 15\ \text{GeV}, \qquad 4\ \text{GeV} < p_{\perp,\text{assoc}} < p_{\perp,\text{trig}}$



(Data from arXiv:1110.0121)

NB: $p_\perp$ spectrum modified by other mechanisms, and result must be taken with a grain of salt.

Outlook

- Rescattering in pp collisions has been available in PYTHIA 8.303. Starting from 8.304, heavy ions are also supported.
- We have seen that rescattering has non-negligible effects, perhaps most significantly giving rise to collective flow
- Framework still under development. Especially $3 \to 2$ processes are a high priority
- There are also other ways to go from here, such as cosmic ray physics and pentaquark formation
- The future of Angantyr will involve shoving, ropes, and other effects. The question is, *how far can one get without a QGP?*