A Spatially Constrained QCD Colour Reconnection in Pythia8/Angantyr Model for Heavy-ion Collisions

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AGH Krakow, June 2023

Outline

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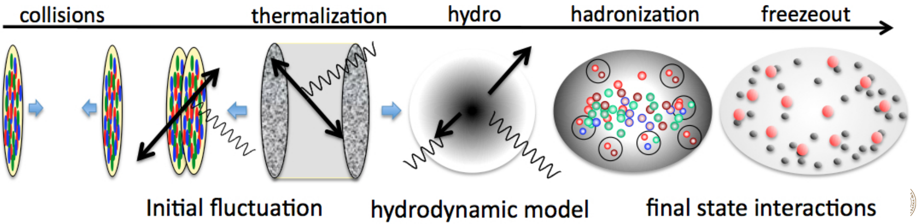

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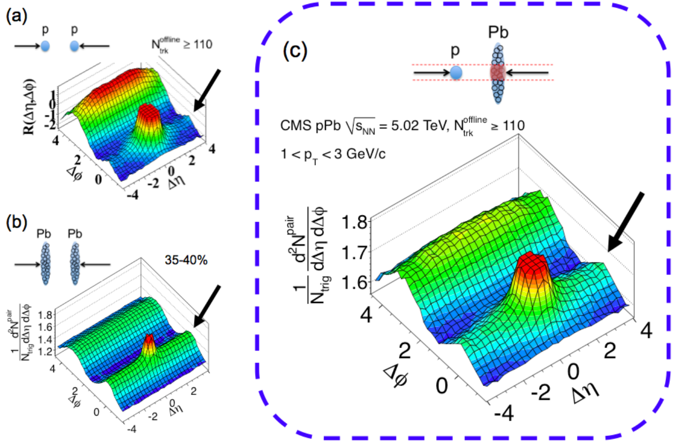

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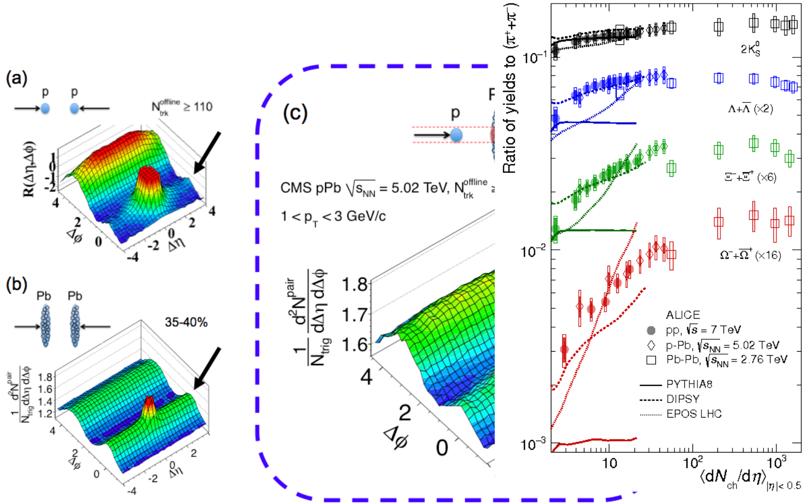
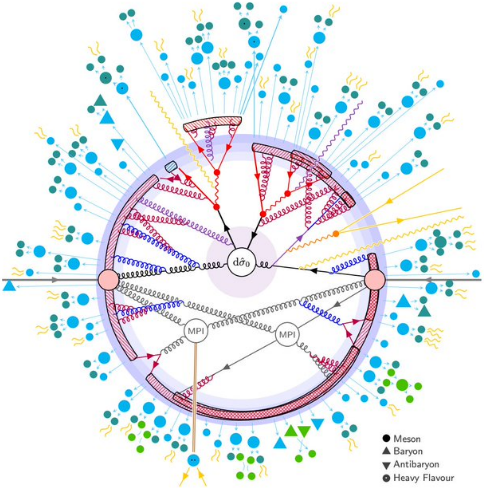


pp collisions in Pythia

Pythia8.3 manual



- Hard Interaction
- Resonance Decays
- MECs, Matching & Merging
- FSR
- ISR*
- QED
- Weak Showers
- Hard Onium

- Multiparton Interactions

- Beam Remnants*
- Strings
- Ministrings / Clusters
- Colour Reconnections
- String Interactions
- Bose-Einstein & Fermi-Dirac
- Primary Hadrons
- Secondary Hadrons
- Hadronic Reinteractions

(: incoming lines are crossed)*

Types of interactions

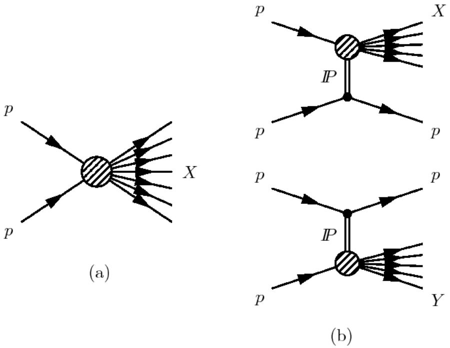


Figure: (a) Non-Diffractive (b) Single-Diffractive (c) Double-Diffractive (d) Central-Diffractive

Angantyr model

Angantyr paper (1806.10820)

Angantyr model-I

- Wounded nucleons: A way of extrapolation from pp to AA
- Wounded nucleon model[1] by Białas and Czyż, which was implemented in Fritiof used to create exclusive final states.

$$\frac{dN}{d\eta} = F(\eta) \quad \text{(for a wounded nucleon)}$$

[1] [Nucl.Phys.B111(1976)461, J.Phys.G35(2008)044053, Nucl.Phys.B281(1987)289.]

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$$\frac{dN}{d\eta} = w_t F(\eta) + F(-\eta) \quad \text{(pA)}, \qquad \frac{dN}{d\eta} = w_t F(\eta) + w_p F(-\eta) \quad \text{(AA)}$$

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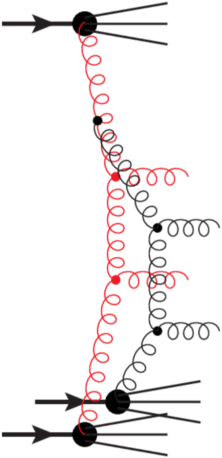
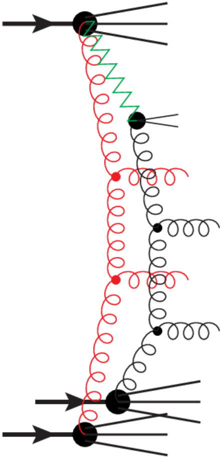
Angantyr model-II

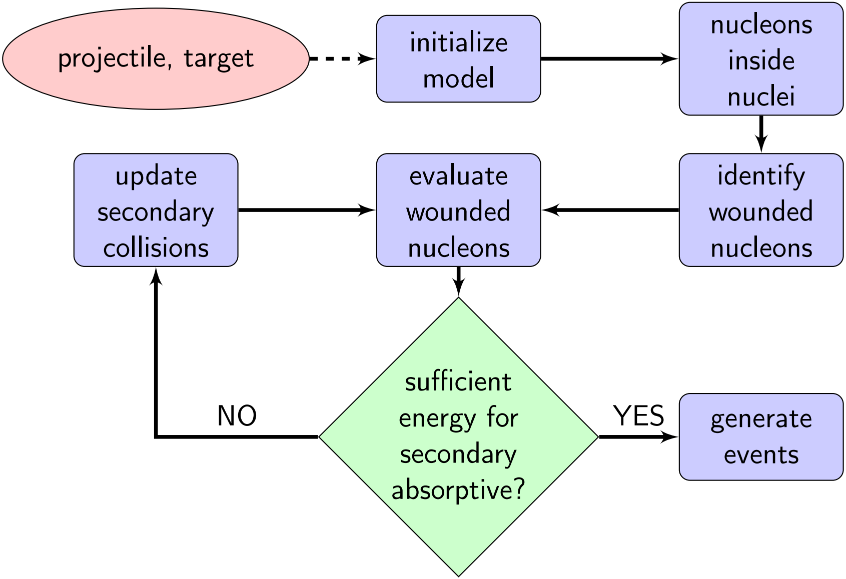
- Glauber model with Good-Walker formalism: For event-by-event fluctuations
- Distinguish every NN interaction as absorptive, single/double diffractive, and elastic scatterings
- Also differentiates absorptive interactions as:
  - Primary: is modelled as a PYTHIA non-diffractive pp event
  - Secondary: an interaction with a nucleon which has already a non-diffractive interaction with another nucleon. Modelled as a (modified) diffractive excitation event
- Model tuned its parameters to small systems only

Angantyr model-III

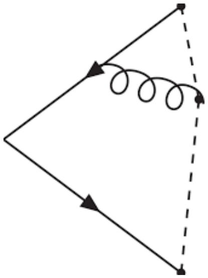

(a)


(b)

Angantyr in Nut-shell



Hadronization in the Lund strings



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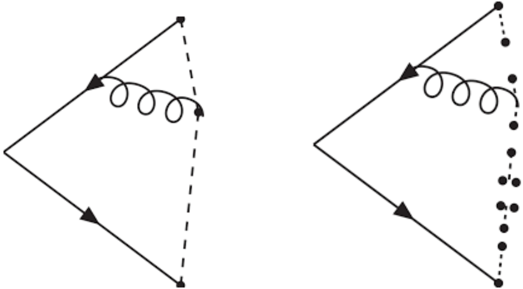

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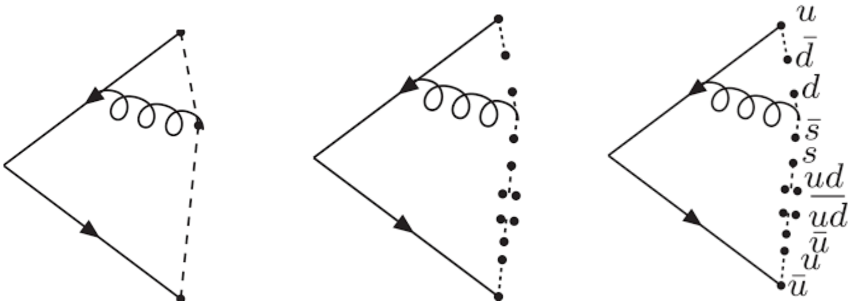

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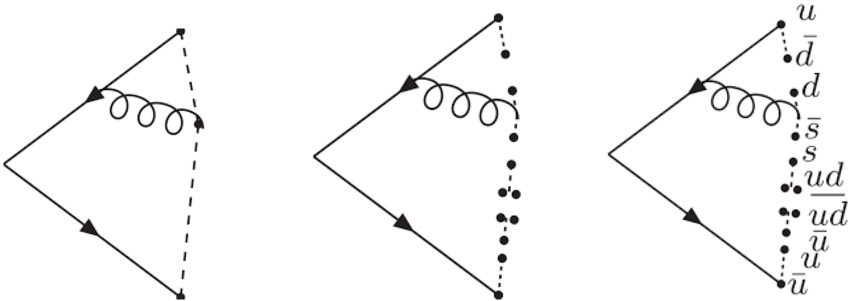
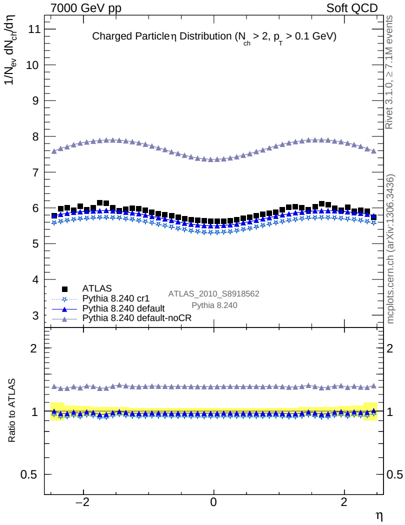


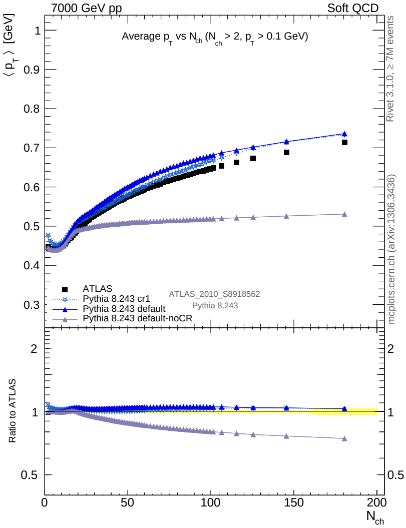
$$\rho_q \propto exp\left(\frac{-\pi m_{\perp}^2}{\kappa}\right) = exp\left(\frac{-\pi p_{\perp}^2}{\kappa}\right) exp\left(\frac{-\pi m_q^2}{\kappa}\right)$$

$\kappa \approx 1 GeV/fm$

Only light flavours (u, d, s) are produced during the fragmentation
heavy flavours (c, b, t) can only be produced via the hard scattering

Colour Reconnection





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Consider $e^+e^- \to W^+W^- \to q_1\bar{q}_1'q_2\bar{q}_2'$ events,
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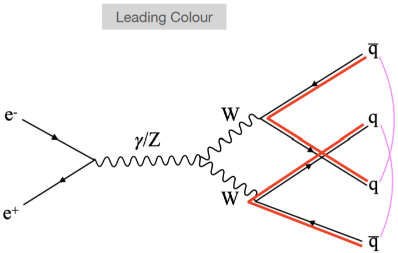

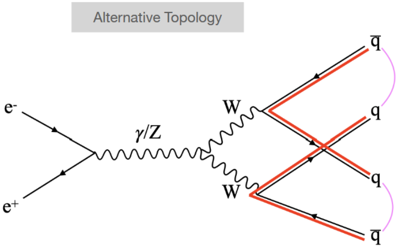

A simple case with LC ($N_c \to \infty$) connections
But colours are finite and the probability of rearrangement of the colour configuration is given by $1/\mathrm{N_c^2} = 1/9 \approx 10\%$

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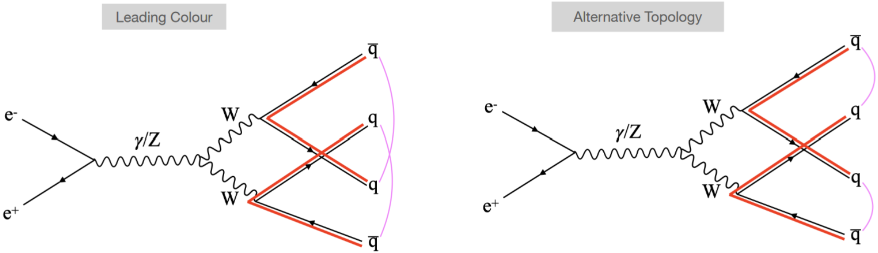

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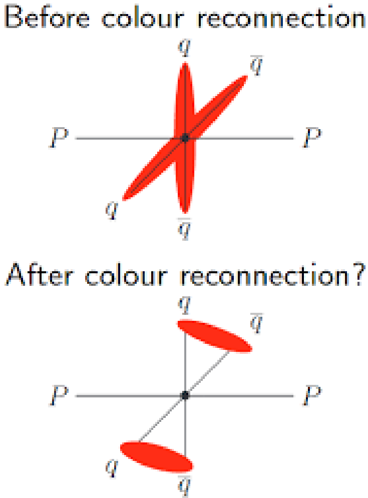
Let's apply the same idea to pp collisions!

A simple CR case in pp



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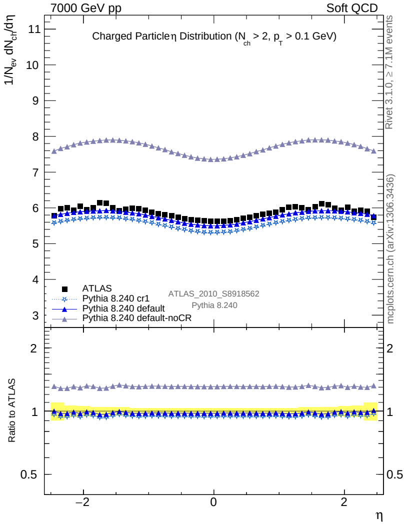

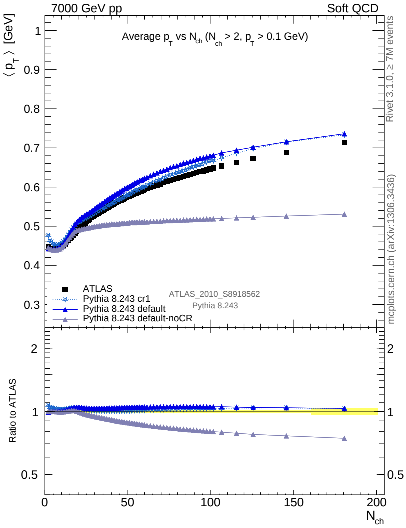

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QCD-CR model (1505.01681)

So far in pp collisions: MPIs + parton showers
Rearrangement of the colour dipoles using LC approximation and minimising the "effective string length", the λ measure

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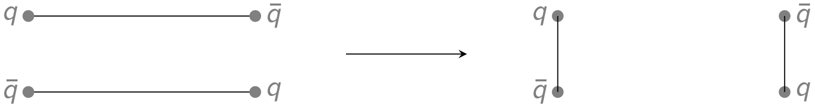
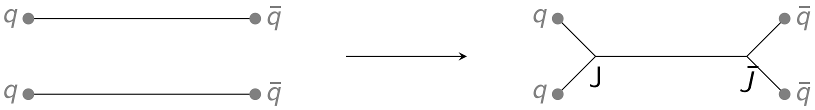


Colour colour $\rightarrow 3 \otimes 3 = 6 \oplus \bar{3} \rightarrow$ allows junction topology



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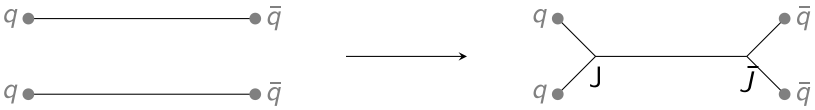
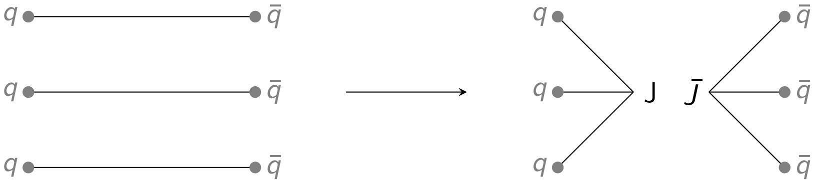


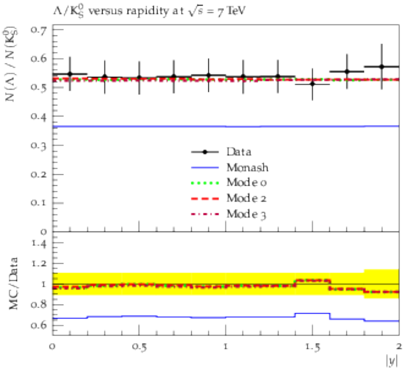
A similar idea can be extended for 3 dipoles



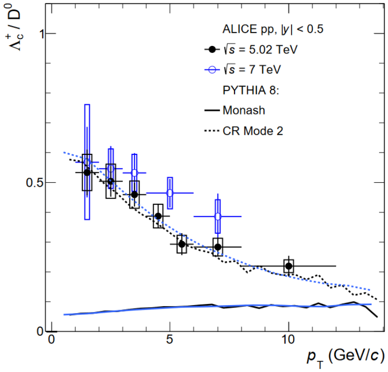
For the technical details I request to go through QCD-CR model (1505.01681)

What do we gain from all these exercises?

These are pp collision events.



(a) QCD-CR model(1505.01681)



(b) ALICE 2021(2011.06079)

What do we gain from all these exercises?

QCD CR produces a large number of junction systems with low-p_t baryons.

Λ_b^0 *asymmetry*

$$A_{prod} = \frac{\sigma(\Lambda_b^0) - \sigma(\Lambda_{\bar{b}}^0)}{\sigma(\Lambda_b^0) + \sigma(\Lambda_{\bar{b}}^0)}$$

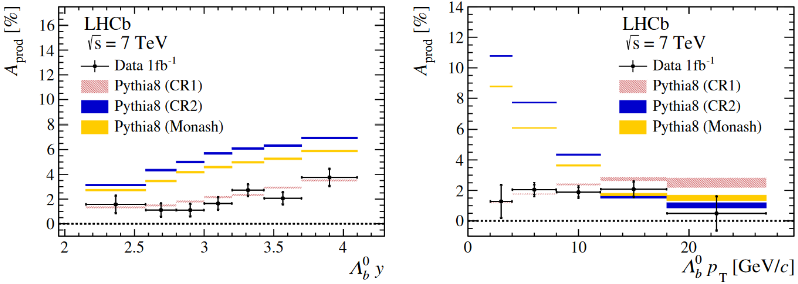


Figure: pp collision LHCb (2107.09593)

CR1 → QCD CR, CR2 → Gluon-move CR.

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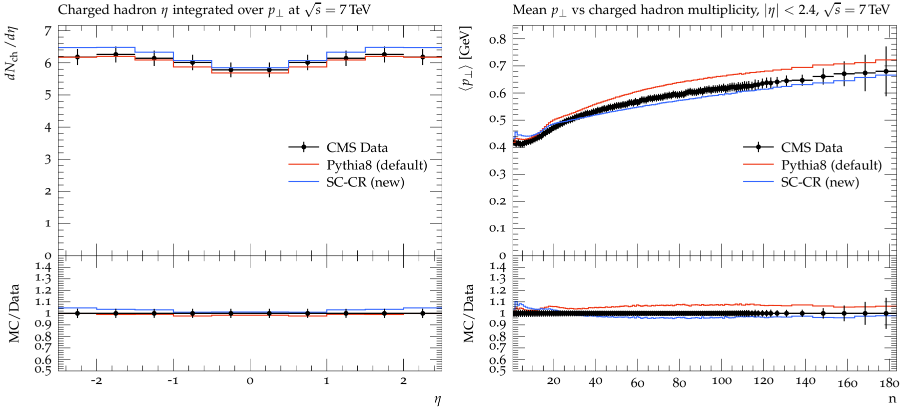
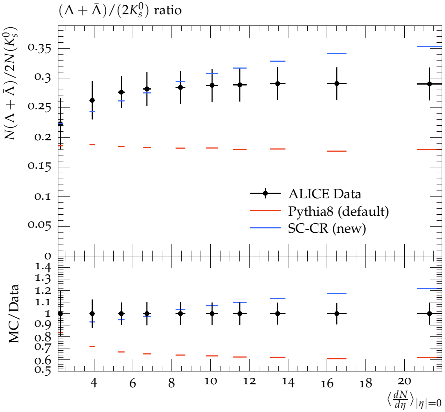
Let's pause and talk about the effects of such a constraint in the Pythia and in the Angantyr events.
Especially when the model has to be tuned to small systems.

pp results

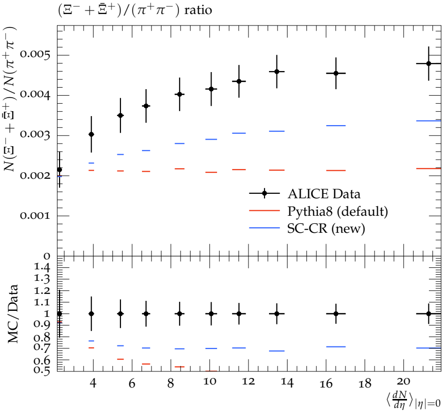


Charged hadron η integrated over $p_\perp$ at $\sqrt{s} = 7$ TeV
$dN_{ch}/d\eta$
MC/Data
η
CMS Data
Pythia8 (default)
SC-CR (new)
Mean $p_\perp$ vs charged hadron multiplicity, $|\eta| < 2.4$, $\sqrt{s} = 7$ TeV
$\langle p_\perp \rangle$ [GeV]
MC/Data
n
CMS Data
Pythia8 (default)
SC-CR (new)

pp results



$(\Lambda + \bar{\Lambda})/(2K_s^0)$ ratio
$N(\Lambda + \bar{\Lambda})/2N(K_s^0)$
ALICE Data
Pythia8 (default)
SC-CR (new)
MC/Data
$\langle \frac{dN}{d\eta} \rangle_{|\eta|=0}$



$(\Xi^- + \bar{\Xi}^+)/(\pi^+\pi^-)$ ratio
$N(\Xi^- + \bar{\Xi}^+)/N(\pi^+\pi^-)$
ALICE Data
Pythia8 (default)
SC-CR (new)
MC/Data
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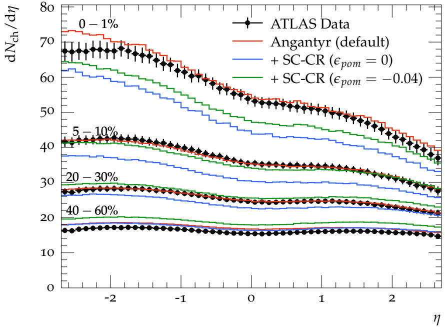
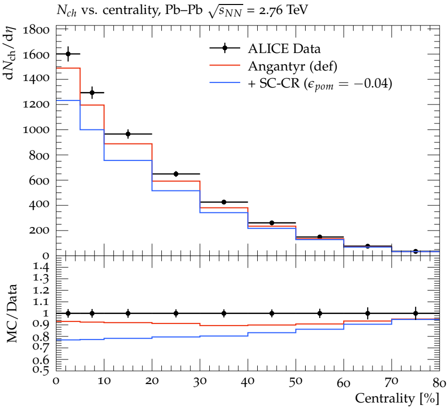
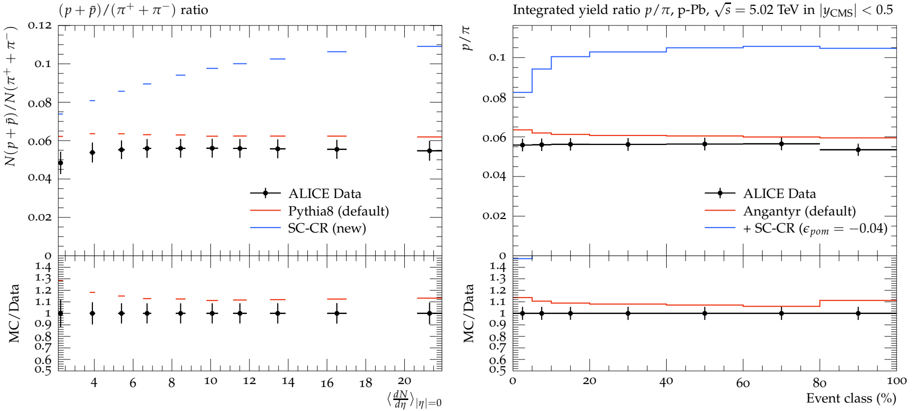
pPb and PbPb results





shortcomings- p/π ratio



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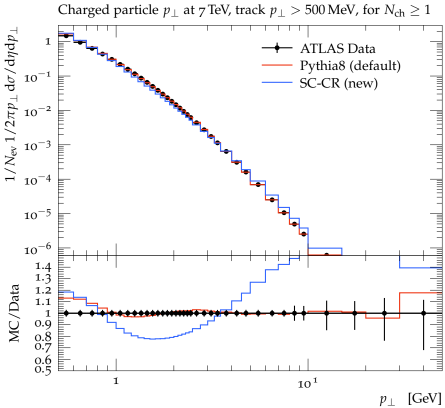
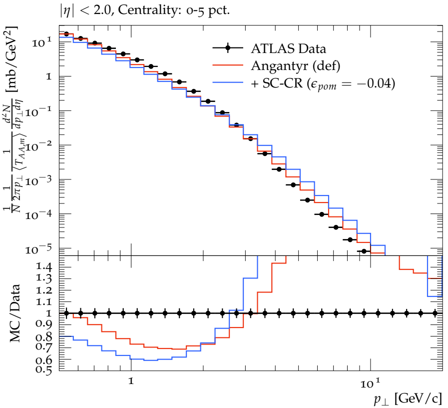
shortcomings-p_t distribution

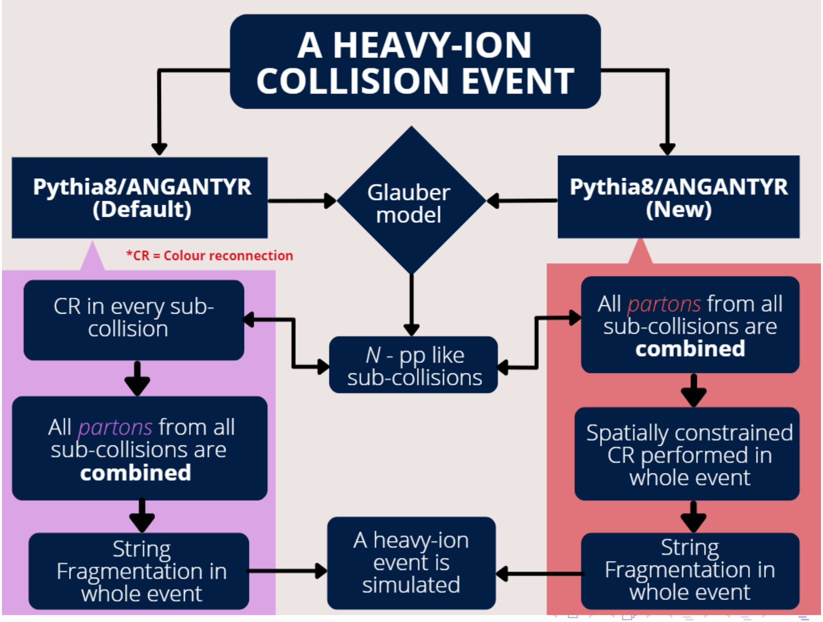
(a) pp at 7 TeV



(b) PbPb at 2.76 TeV



Summary


A HEAVY-ION COLLISION EVENT
Pythia8/ANGANTYR (Default)
Glauber model
Pythia8/ANGANTYR (New)
*CR = Colour reconnection
CR in every sub-collision
N - pp like sub-collisions
All partons from all sub-collisions are combined
All partons from all sub-collisions are combined
Spatially constrained CR performed in whole event
String Fragmentation in whole event
A heavy-ion event is simulated
String Fragmentation in whole event

Key information

- We have recently extended the Angantyr model with a global colour reconnection[2]. It will soon be available as a public version.
- The global CR enables interactions among colour strings from different sub-collisions after the superposition of pp-like events.
- The Angantyr model with global CR is not able to reproduce the multiplicity (in AA) and p_t distributions, but this is the first step towards a unification at the parton level.
- Using the QCD CR model, we can observe an enhancement in the Baryon-to-meson ratio, which is a by-product of the additional junction topology due to the CR.

[2] arXiv:2303.11747

Outlook

- There are models like string shoving and rope-hadronization, and hadronic rescattering in Pythia/Angantyr which will act on top of the CR in the event simulation.
- Hadronic re-scattering is available in the public version of the Pythia/Angantyr model.
  The next step is to merge it with the global CR, test observables like multiplicity, p_t distribution, flow, and quarkonia suppression[3], and if require re-tune the Pythia parameters.
- Further studies include the implementation of string shoving and rope-hadronization to provide a description of strangeness enhancement and flow.

[3] A possibility to reproduce it without QGP.

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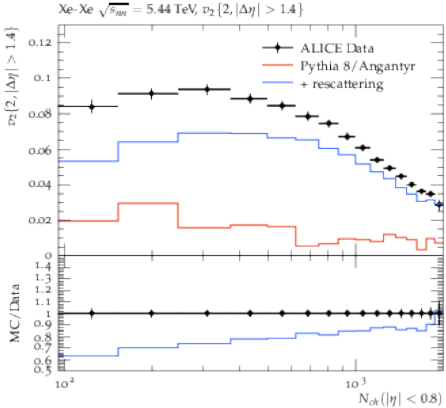
- Further studies include the implementation of string shoving and rope-hadronization to provide a description of strangeness enhancement and flow.
- We are working on improving the angular correlation distributions in pp collision events in Pythia.
- We are also actively invested to improve the "charm baryons" production in Pythia/Angantyr.

[3] A possibility to reproduce it without QGP.

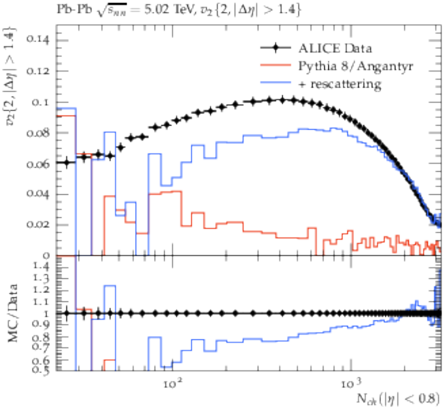
Dziękuję

Hadronic Rescattering-I 2103.09665

(a) $v_2\{2\}$ in XeXe

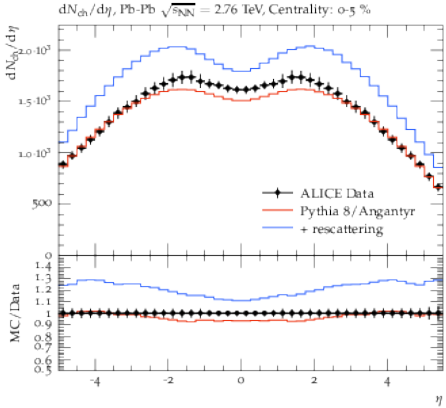


(b) $v_2\{2\}$ in PbPb

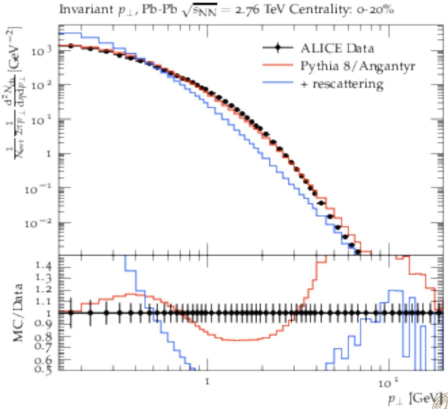


Hadronic Rescattering-II 2103.09665

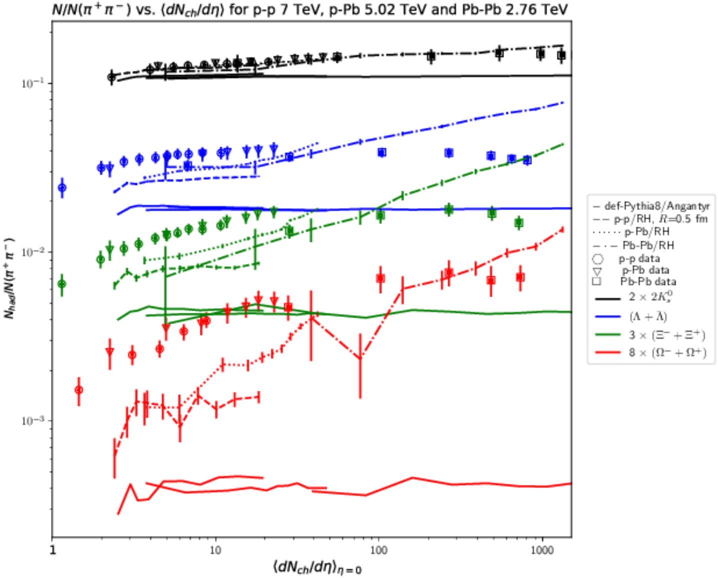
(a) Charged multiplicity in the central PbPb events



(b) p_t distribution in the central PbPb events

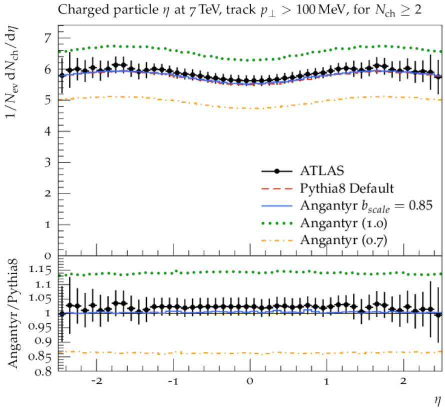


Strangeness enhancement 2205.11170

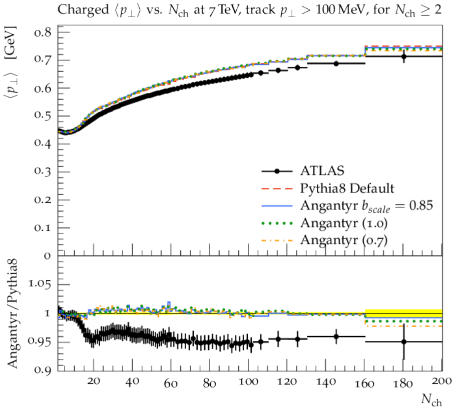


pp events

(a) Multiplicity distribution for pp collisions

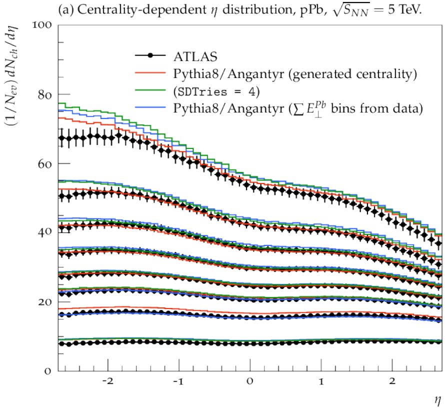


(b) $\langle p_T \rangle$ as a function of multiplicity

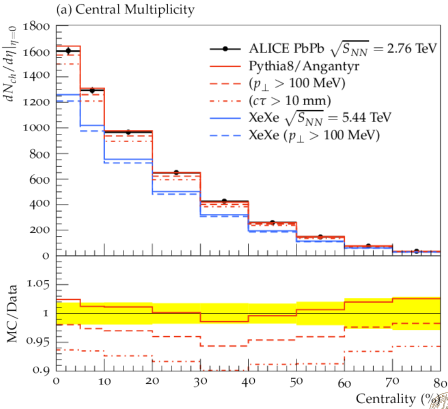


pA and AA events

(a) Centrality-based multiplicity distribution for pPb collisions



(b) Multiplicity distribution in PbPb and XeXe collisions



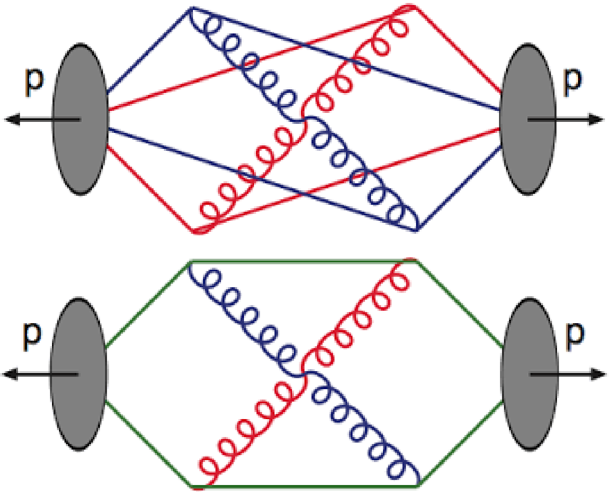
Tuning of the model parameters

We selected the following parameters to re-tune against pp data:

1. $p_{\perp 0}^{\text{ref}}$, low-$p_\perp$ suppression for MPIs,
2. m_0, a scale parameter used in the λ-measure and a mass cut-off for pseudo-particles (in the QCD CR model),
3. C_j, a parameter reducing the λ-measure for junction systems,
4. δb_c, the allowed dipole separation.

Earlier we modified the Pomeron parton distribution functions (PDFs) for SND events.
In this work, we have decided to rather modify the Pomeron flux in SND events, and modify the so-called ϵ_{pom} parameter.

Simple CR



Simple CR