Soft QCD from e^+e^- to AA

with focus on recent Pythia developments

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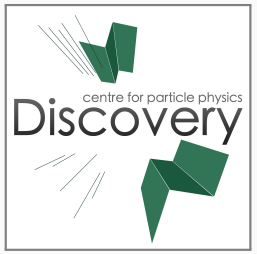
December 10 2018, MPI@LHC Perugia

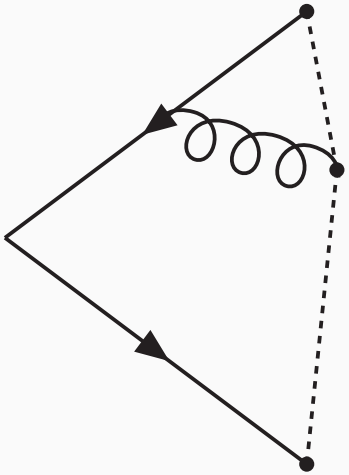


Introduction

- Small system collectivity = surge of interest in soft QCD.
  - Event generator (e^+e^- picture) under pressure.
  - Pressure = possibilities! Microscopic insight to QGP.
- Modifications to clean picture already in pp.
  - MPI@LHC 2008: Color reconnection $\rightarrow$ single particle observables.
  - MPI@LHC 2018: Ropes, shoving $\rightarrow$ multi particle observables, hadrochemistry.
  - MPI@LHC: Multi-Nucleon Interactions $\rightarrow$ Extending the Pythia MPI model to HI.
- This talk:
  1. Short review on Lund soft QCD (string model).
  2. Ropes / shoving.
  3. Some pp results.
  4. The Angantyr extension to AA.
  5. Some pA and AA results.

The Lund String (80's: Andersson, Bo et al. Z.Phys. C3 (1980) 223, Z.Phys. C20 (1983) 317)

- Non-perturbative phase of final state.
- Confined colour fields $\approx$ *strings* with tension $\kappa \approx 1$ GeV/fm.



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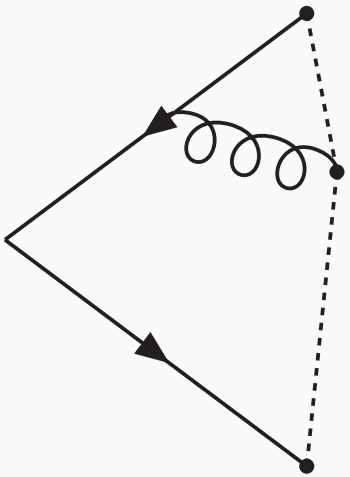

Lund symmetric fragmentation function

$$f(z) \propto z^{-1}(1-z)^a \exp\left(\frac{-bm_\perp}{z}\right).$$

a and b related to total multiplicity.

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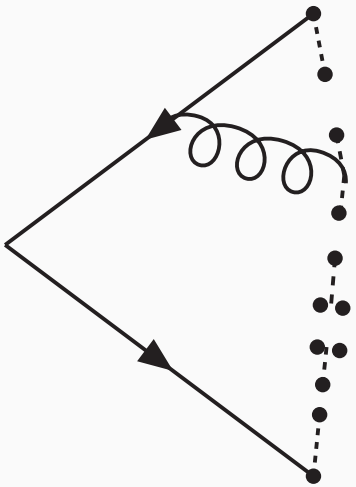

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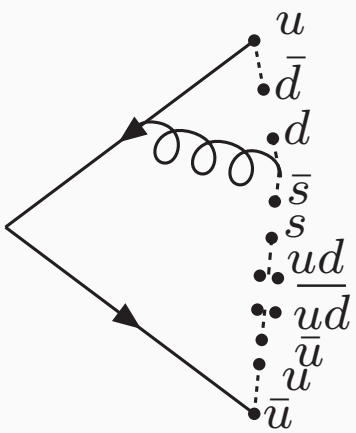

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Light flavour determination

$$\rho = \frac{\mathcal{P}_{\text{strange}}}{\mathcal{P}_{\text{u or d}}}, \xi = \frac{\mathcal{P}_{\text{diquark}}}{\mathcal{P}_{\text{quark}}}$$

Related to κ by Schwinger equation.

MPIs and microscopic collectivity

- Works well in e^+e^- – but pp is full of MPIs!
- String properties from lattice important input...
- ... as well as initial geometry.
- Microscopic dynamics with interacting Lund strings (In Pythia v. 8.235; CB, Gustafson, Lönnblad: PLB779 (2018) 58-63; CB: arXiv:1606.09456 [hep-ph]; CB, Gustafson, Lönnblad, Tarasov: JHEP 1503 (2015) 148)

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$\tau \approx 0$ **fm:** Strings no transverse extension. No interactions, partons may propagate.

$\tau \approx 0.6$ **fm:** Parton shower ends. Depending on "diluteness", strings may shove each other around.

$\tau \approx 1$ **fm:** Strings at full transverse extension. Shoving effect maximal.

$\tau \approx 2$ **fm:** Strings will hadronize. Possibly as a colour rope.

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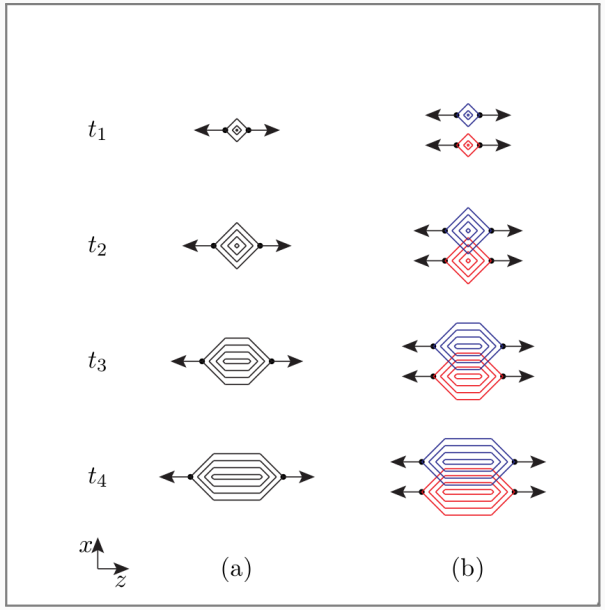

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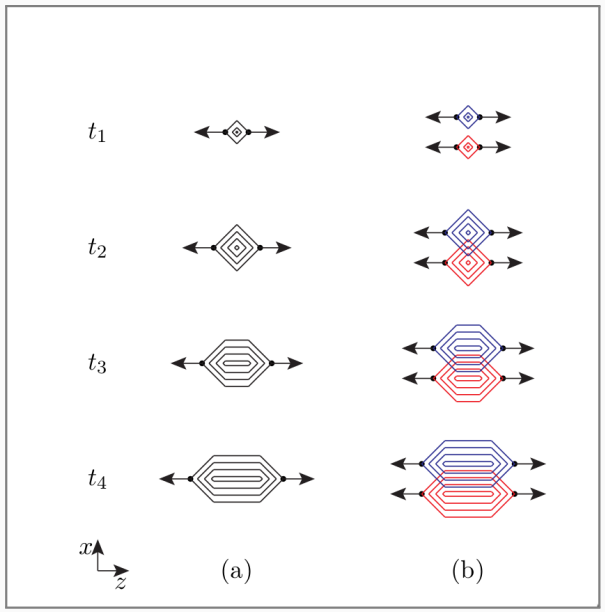

- Dominated by electric field $\to g = 1$.
- Reality:
  - **Type 1** Energy to destroy vacuum.
  - **Type 2** Energy in current.

Early origins

- 1st law of phenomenology: When you think you have a good idea...

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- Highly underappreciated paper – $\mathcal{O}(10)$ citations.

Long-range azimuthal correlations in multiple-production processes at high energies

V. A. Abramovskiĭ, É. V. Gedalin, E. G. Gurvich, and O. V. Kancheli
Institute of Physics, Academy of Sciences of the Georgian SSR

(Submitted 18 January 1988)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 6, 281–283 (25 March 1988)

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6. In an interaction of heavy nuclei with nuclei, many overlapping quark tubes form, and a large azimuthal asymmetry may be observed.[2)] Furthermore, since an $A \times A$ collision is noncentral on the average, the system of quark tubes fills a transversely anisotropic region. It is clear geometrically that its anisotropy is oriented along the impact parameter of the collision. We might thus expect correlations between the azimuthal distribution of secondary hadrons and the azimuthally anisotropic distribution of the decay products of the nucleus.

Again, we wish to emphasize that data on the azimuthal asymmetry in soft multiple-production processes may contain some very nontrivial information.

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- Combines into multiplet.

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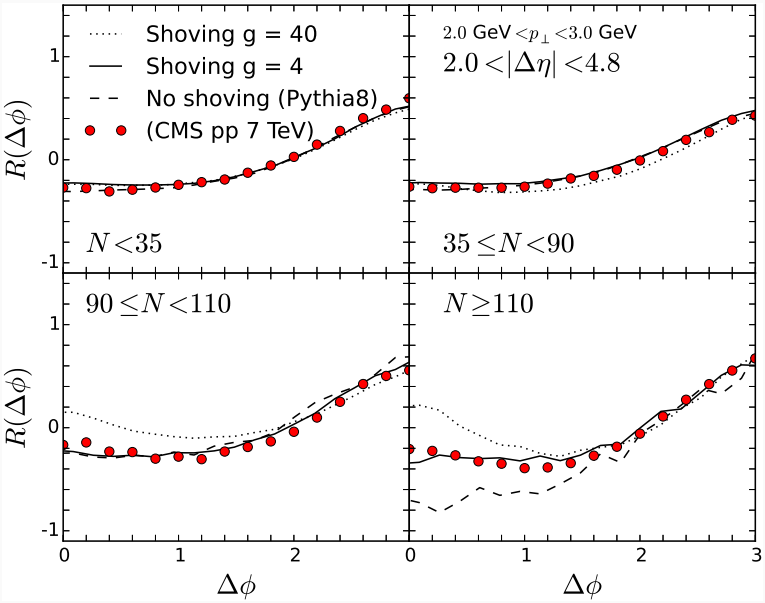
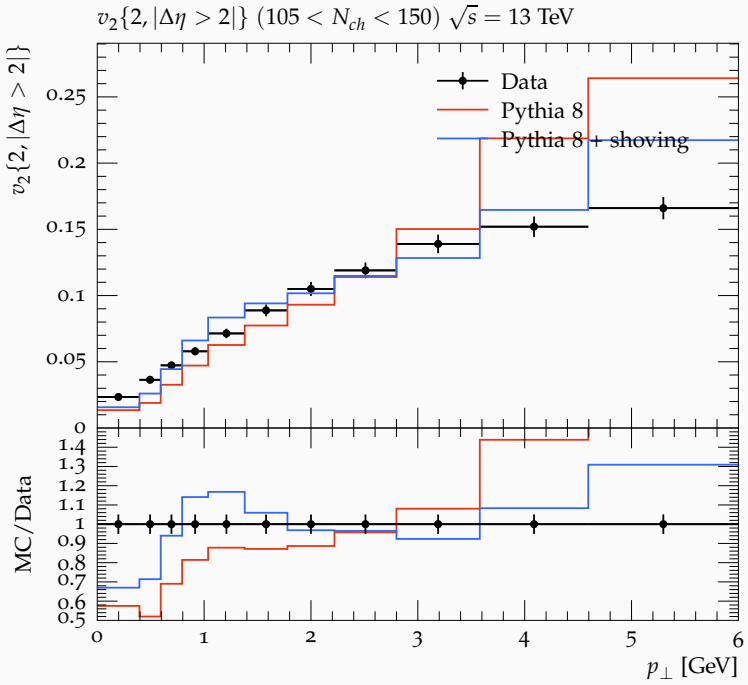
Biro et al. Nucl.Phys. B245 (1984) 449-468., Bialas et al. Phys.Rev. D31 (1985) 198, Kerman et al. Phys.Rev.Lett. 56 (1986) 219, Gyulassy et al. Phys.Lett. 165B (1985) 157-161, Amelin et al. Sov.J.Nucl.Phys. 52 (1990) 172-178, Andersson et al. Nucl.Phys. B355 (1991), Braun et al. Nucl.Phys. B390 (1993) 542-558, Braun et al. Phys.Rev. D47, Amelin et al. Z.Phys. C63 (1994), Armesto et al. Phys.Lett. B344 (1995) 301-307, Kajantie et al. Phys.Lett. 164B (1985) 373-378, Gatoff et al. Phys.Rev. D36 (1987) 114, Braun et al. Int.J.Mod.Phys. A14 (1999) 2689-2704, Mohring et al. Phys.Rev. D47 (1993), Sorge et al. Phys.Lett. B289 (1992), Avay et al. Z.Phys. A348 (1994) 201-210, Sorge Phys.Rev. C52 (1995) 3291-3314, Top Phys.Rev. C52 (1995) 1618-1629, Csizmadia et al. J.Phys. G25 (1999), Bleicher et al. Phys.Rev. C62 (2000) 061901, Soff et al. Phys.Lett. B551 (2003) 115-120.

Some Results: shoving

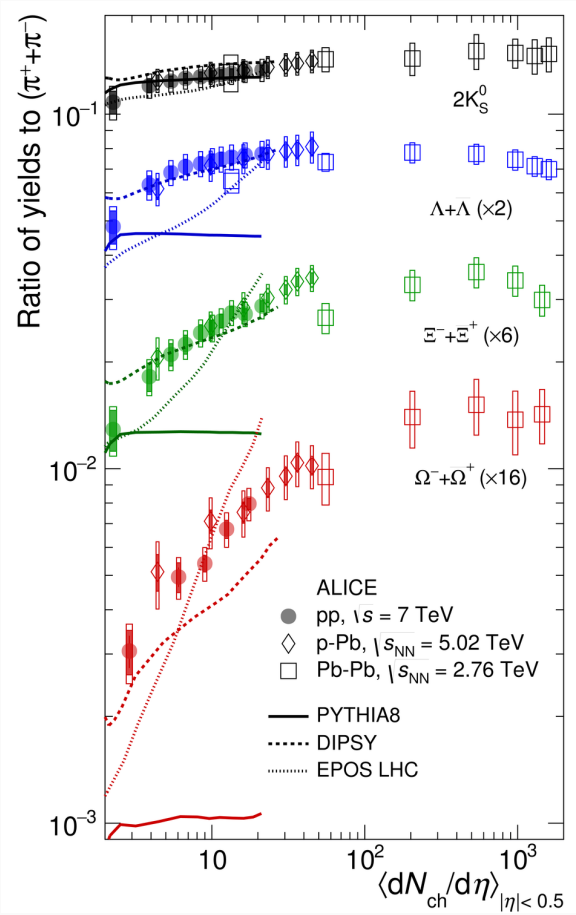
- Reproduces the pp ridge with suitable choice of g parameter.
- Improved description of $v_2 2|\Delta eta| > 2.(p_\perp)$ at high multiplicity.
- Low multiplicity not reproduced well – problems for jet fragmentation?





More results: Strangeness enhancement

- Less sensitive on geometry – a game of *density*.
- Described strangeness enhancement from pp to *AA* (DIPSY).
- No direct comparison to unfolded data ... yet.



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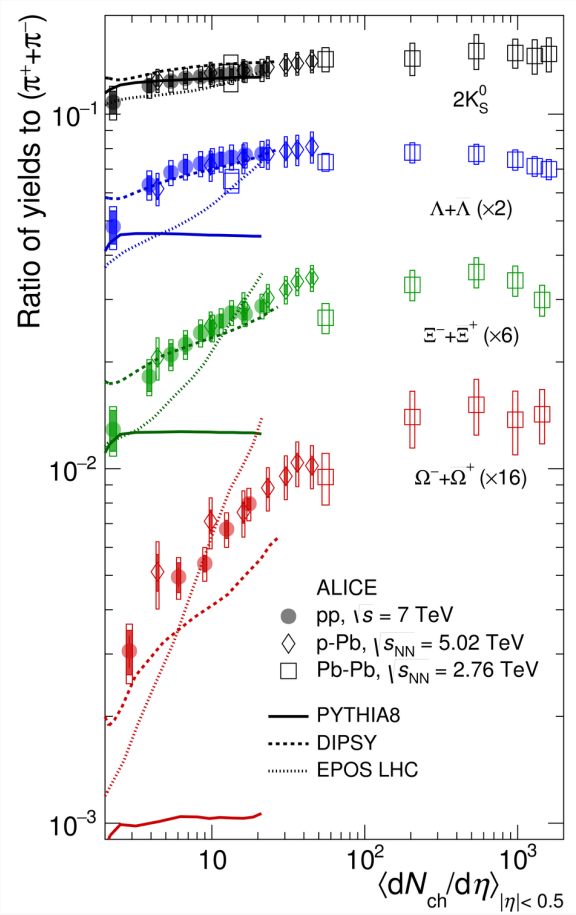
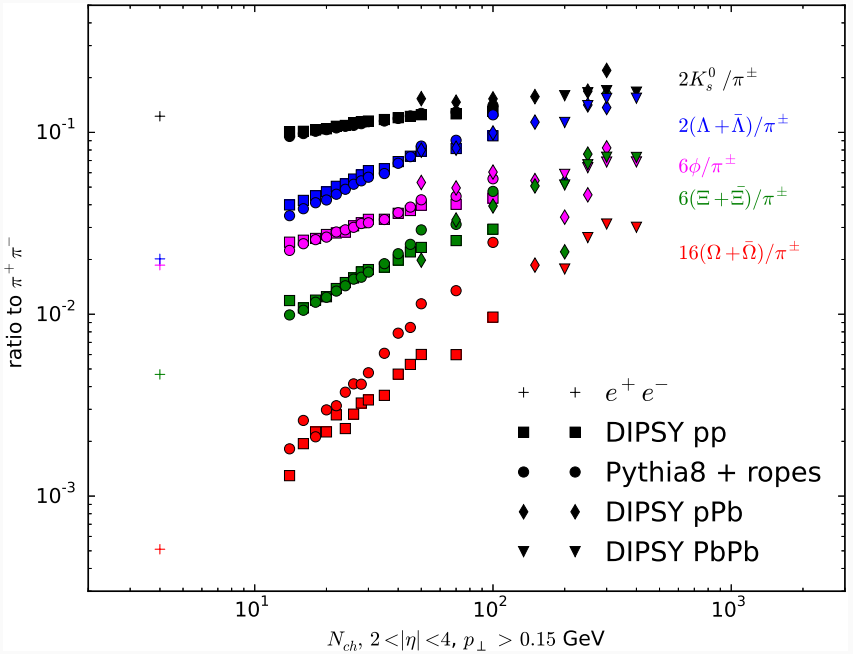
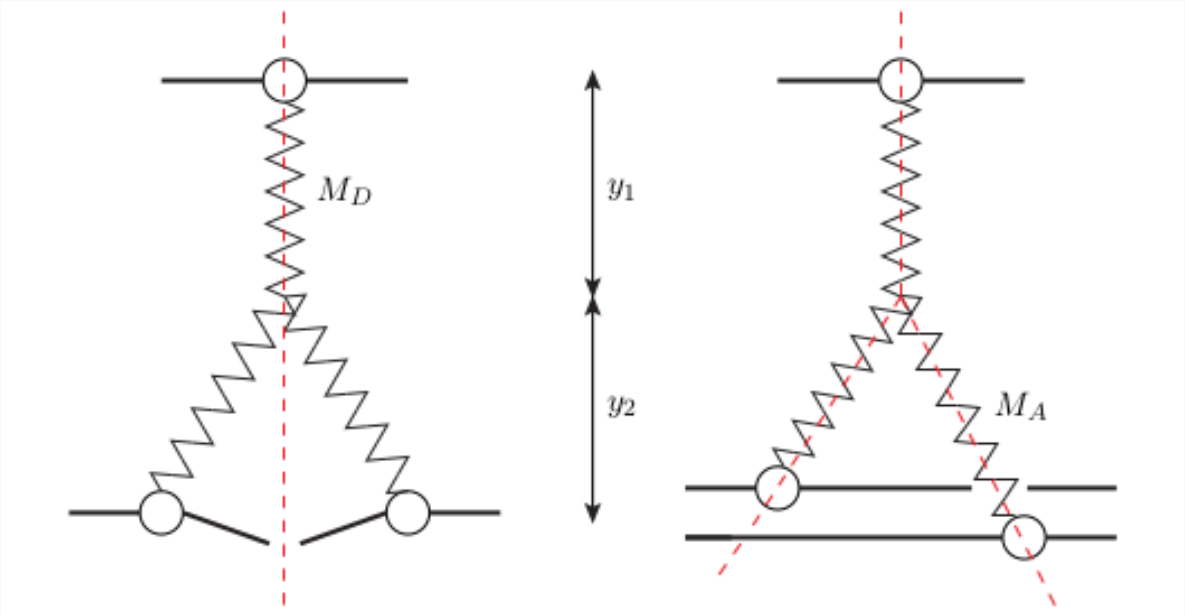




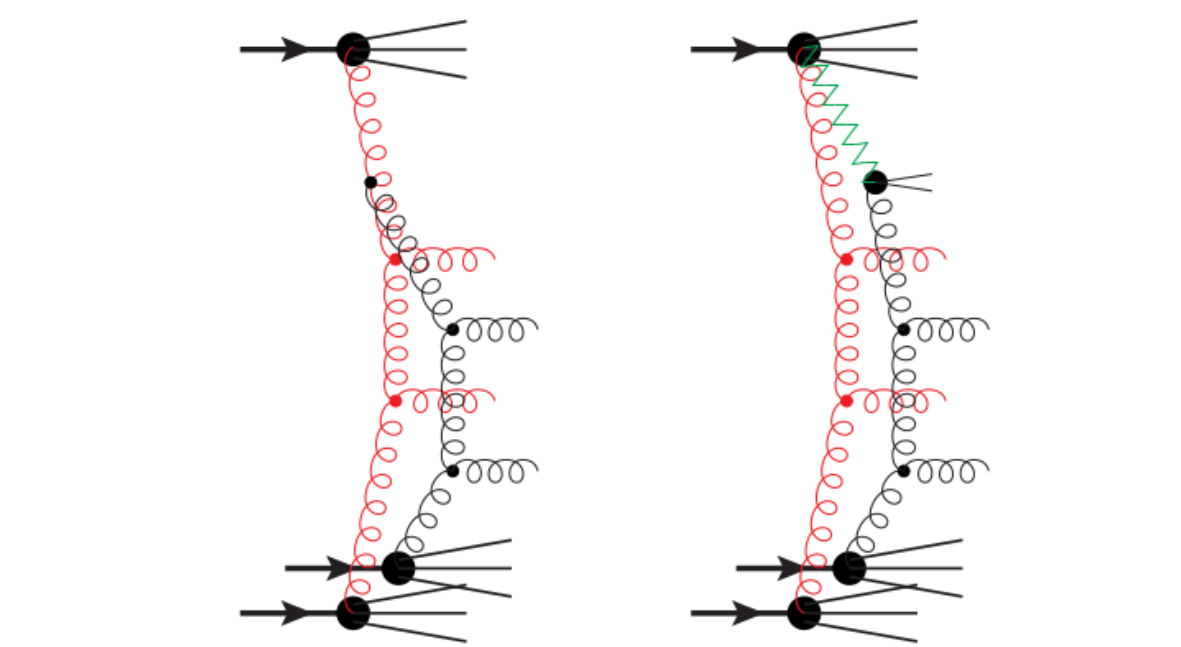
Multi–Nucleon Interactions (CB, Gustafson, Lönnblad: JHEP 1610 (2016) 139, += Shah: JHEP 1810 (2018) 134)

- Pythia MPI model extended to heavy ions since v. 8.235.
- Based on Glauber geometry with Gribov colour fluctuations.
- Focus on correct handling of diffractive processes and forward production.
- Particle production: Similarity between:
  1. Single diffractive excitation.
  2. Secondary absorption.



Secondary absorptive interactions

- Use similarity to construct partonic final states.
- Hadronize with normal string (no collectivity yet).



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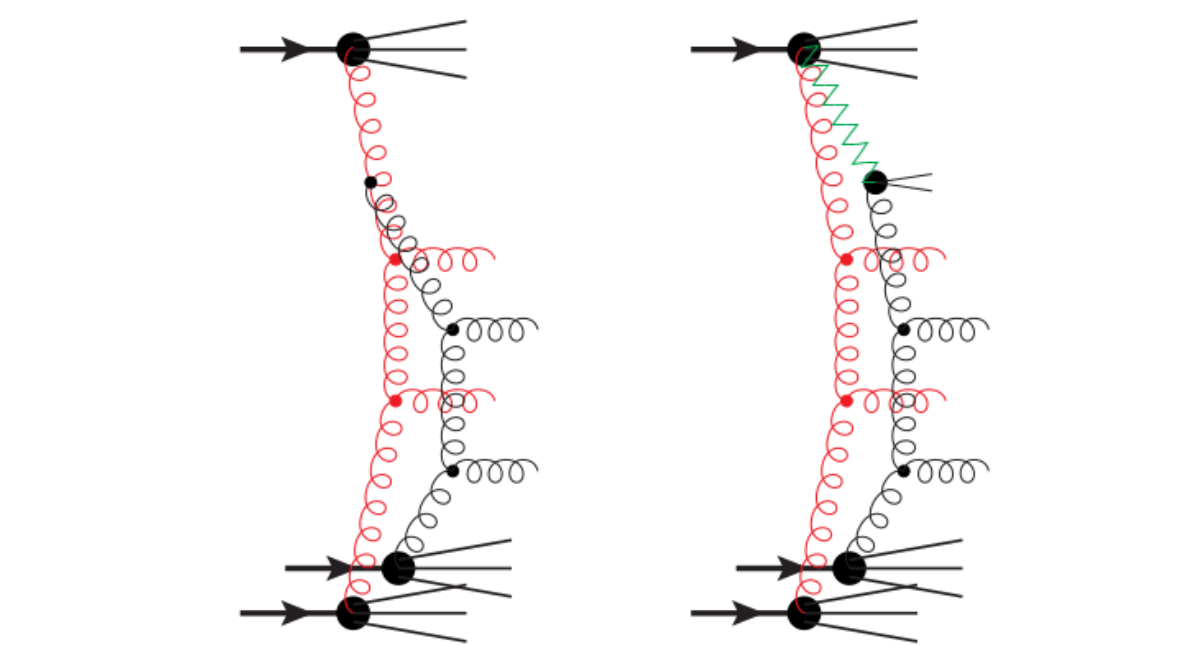


Angantyr the Berserker!

- Same poem as Fritiof.
- Yields the sword Tyrfing, kills every time it is drawn.

Easy to use!

File Edit Tools Syntax Buffers Window Help

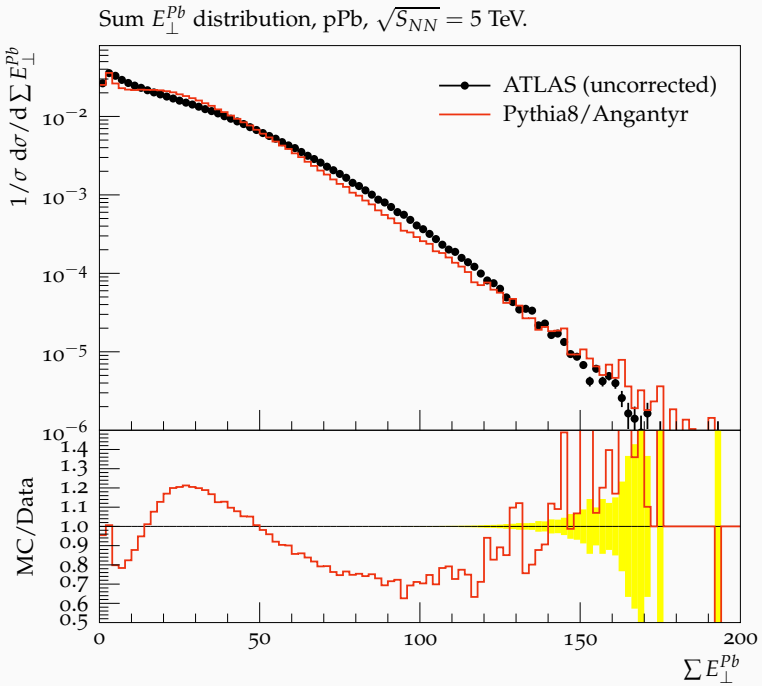
```
#include "Pythia8/Pythia.h"
#include "Pythia8/HeavyIons.h"

using namespace Pythia8;

// This is a one-slide example program demonstrating Heavy Ion
// functionality.
int main() {
  Pythia pythia;
  // Setup the beams.
  pythia.readString("Beams:idA = 1000822080");
  pythia.readString("Beams:idB = 1000822080"); // The lead ion.
  pythia.readString("Beams:eCM = 2760.0");
  // Sum up the weights of all generated events.
  double sumw = 0.0;
  // Count the number of charged particles.
  double ncEvent = 0.0;
  // Initialise Pythia.
  pythia.init();
  for ( int iEvent = 0; iEvent < 1000; ++iEvent ) {
    if ( !pythia.next() ) continue;
    double nc = 0.0;
    for (int i = 0; i < pythia.event.size(); ++i) {
      Particle & p = pythia.event[i];
      if ( p.isFinal() ) {
        if ( p.isCharged() && p.pT() > 0.1 && abs(p.eta()) < 0.5 ) ++nc;
      }
    }
    sumw += pythia.info.weight();
    ncEvent += nc * pythia.info.weight();
  }
  cout << "Charged multiplicity density at mid-eta: " << ncEvent / sumw << endl;
  return 0;
}
```

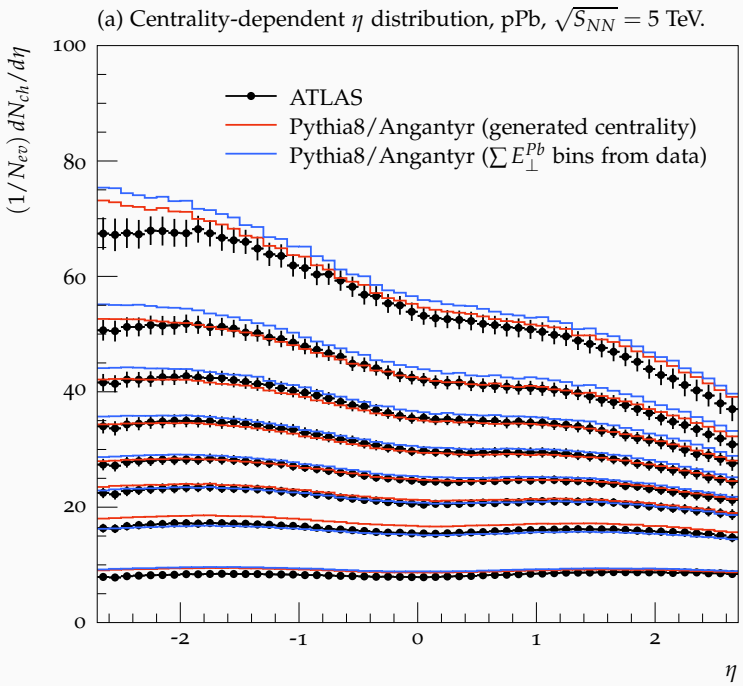
28,5 All

- Fully integrated with Pythia.
- Internal or external ME's.
- Support for several nuclei.
- C++, Python interface distributed w. Pythia.
- Output: Rivet, HepMC, ROOT6 trees.

Results pA

- Centrality dep't multiplicity reproduced well.
- Using actual centrality measure important in pA.





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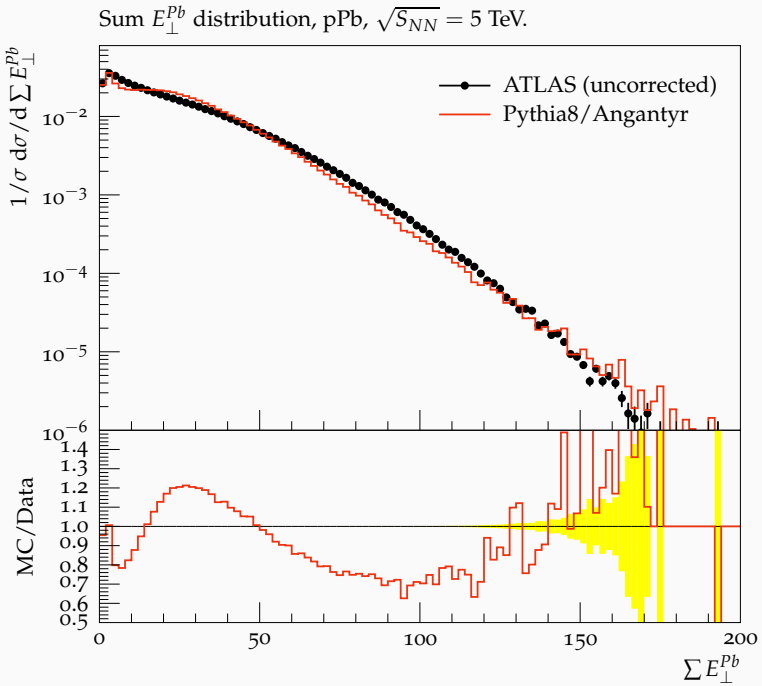
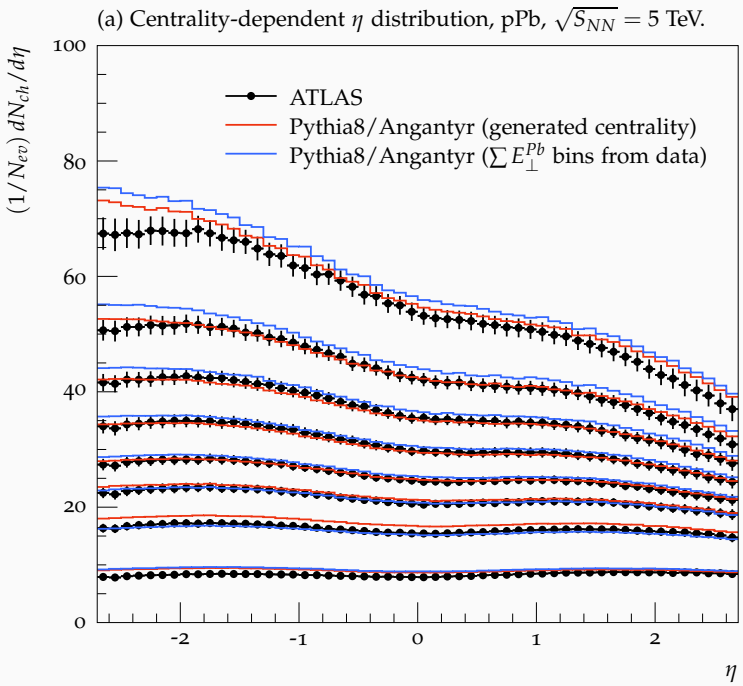


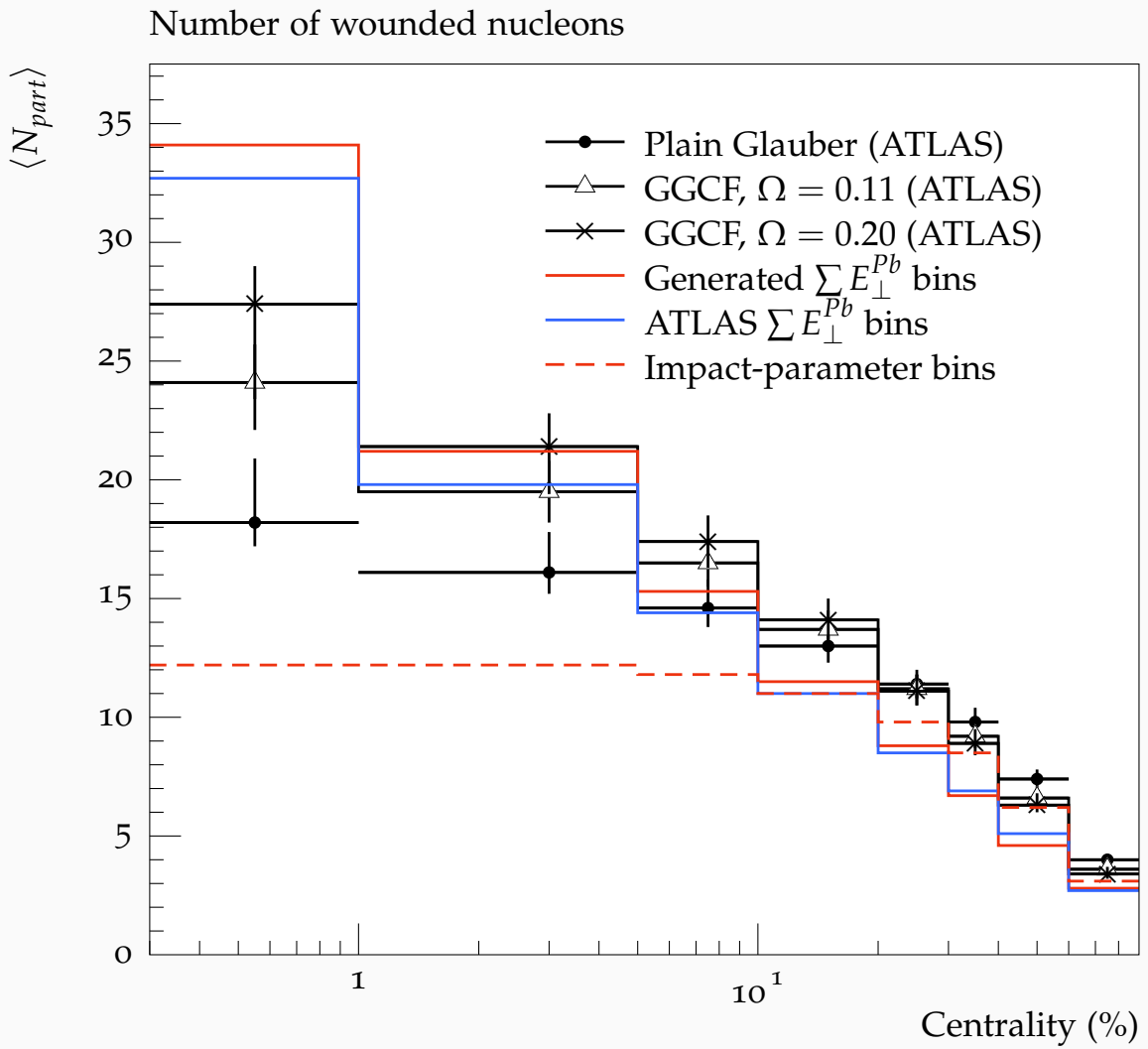


WANTED: Unfolded, particle level centrality measures

- Preferably in Rivet.

Centrality bias

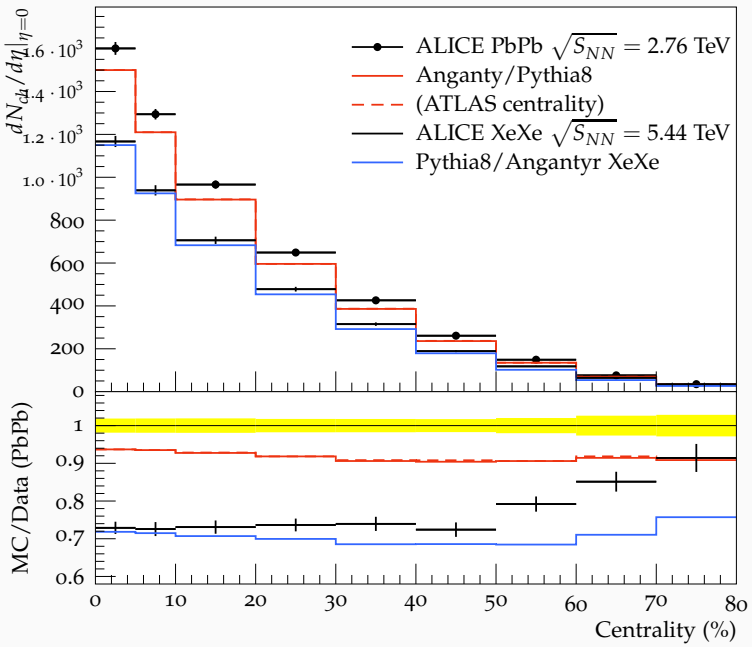
- Enables detailed study of centrality bias.
- Highlights importance of initial state fluctuations.



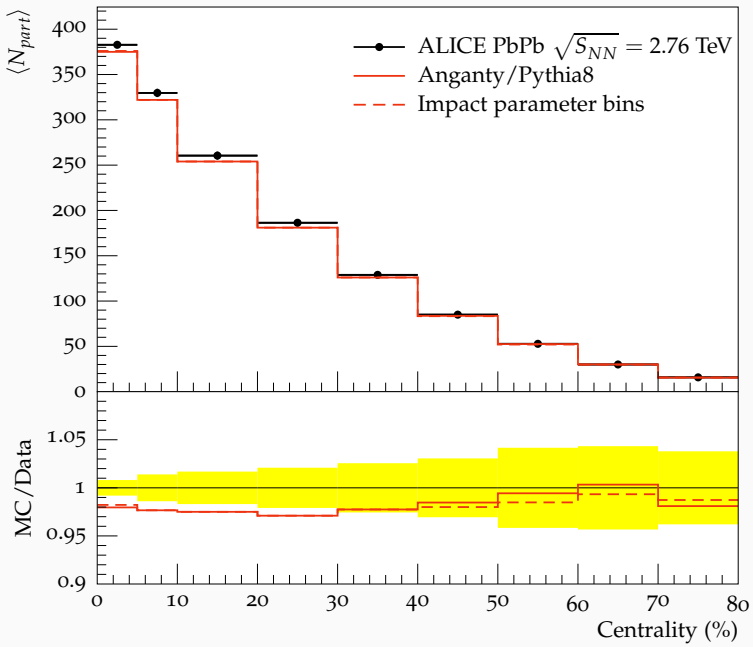
Results *AA*

- Several nuclei, mid-η particle production.
- Centrality bias not as important.

(a) Central Multiplicity

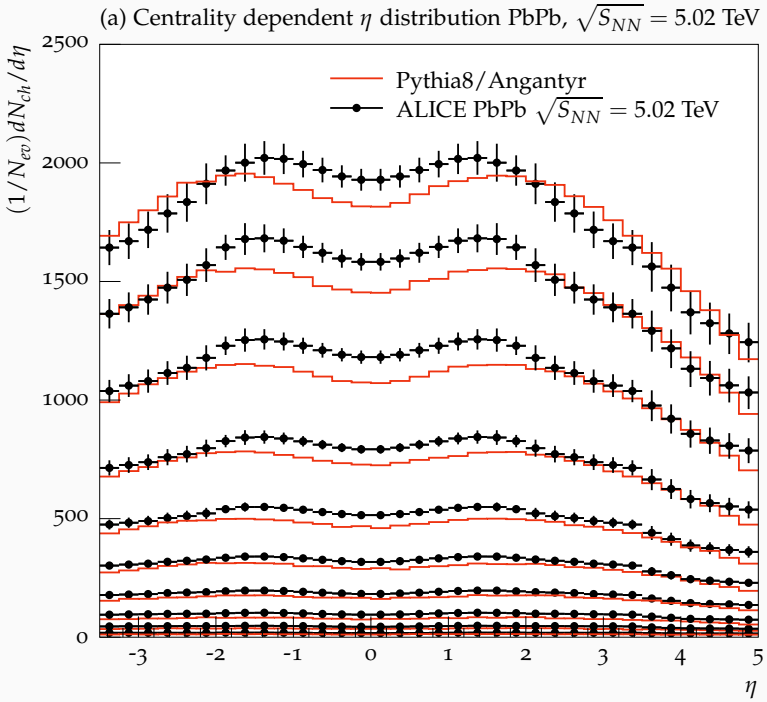


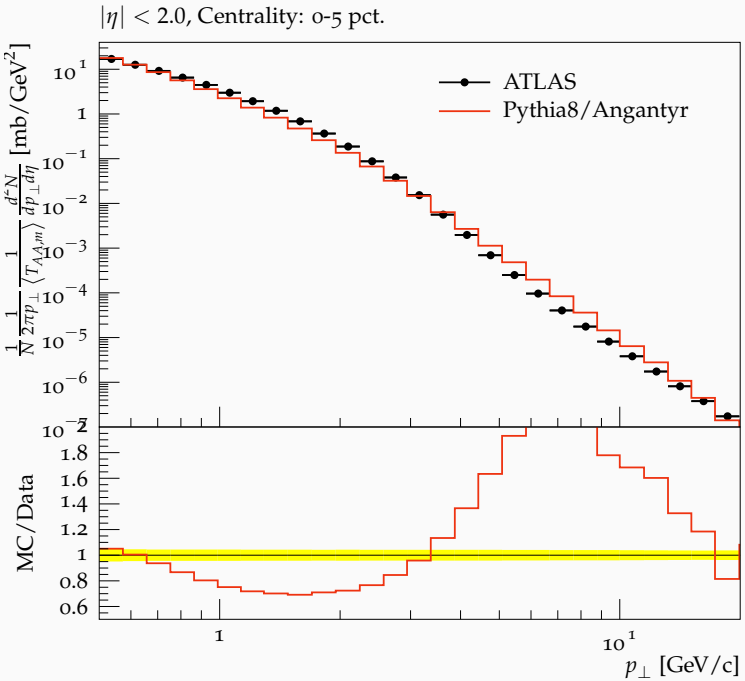
(b) Number of wounded nucleons



Results *AA*

- Spectra not equally well reproduced.
- Currently no QGP effects (ropes, shoving) in AA.





Summary

- String–string interactions = effects similar to collectivity in small systems.
  1. Shoving: The "ridge" and small system flow.
  2. Ropes: Hadrochemistry, strangeness enhancement.
- Issue: Better models for initial state geometry.
- Wishlist: Models with (a) perturbative input (b) more than 1 class of observables.
- The Angantyr extension to pA and AA.
  1. Download and use today.
  2. Does well for soft particle production.
  3. No collective effects yet.