Soft modifications to pp fragmentation

the shoving model

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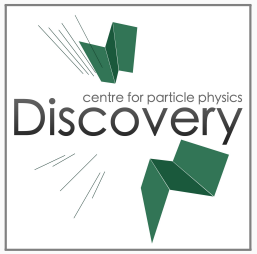
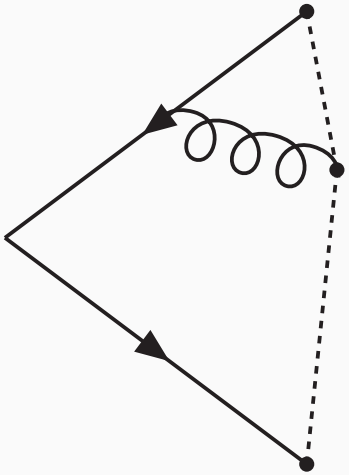


Introduction

- The missing piece of small system collectivity: Jet modifications.
- Small step on the way:
  - String shoving can describe some collective features in pp.
  - What are the effects on jet fragmentation?
- This talk:
  1. Lund strings and the shoving model.
  2. Some results for ridges.
  3. Adding a Z-boson to the mix.
  4. Adding an associated jet.
  5. Suggestions for observables.
- All results obtained with shoving as implemented in Pythia 8.

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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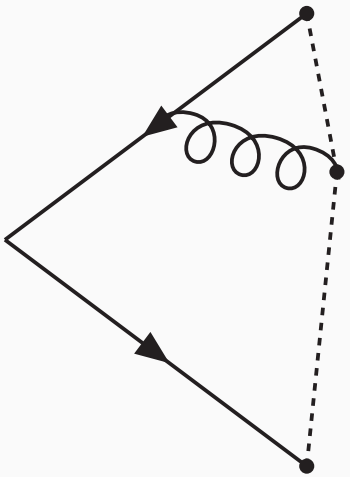

Lund symmetric fragmentation function

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

a and b related to total multiplicity.

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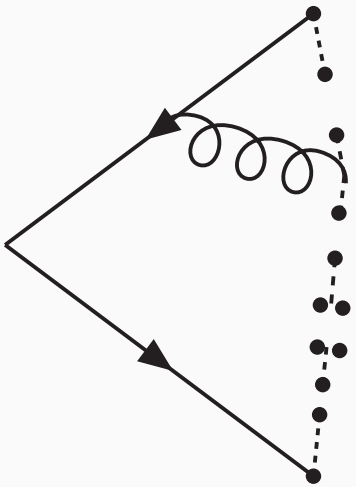

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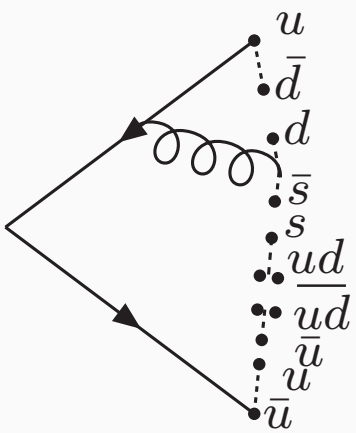

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Light flavour determination

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

Related to κ by Schwinger equation.

String shoving (CB, Gustafson, Lönnblad: 1612.05132, 1710.09725)

- Strings = interacting vortex lines.
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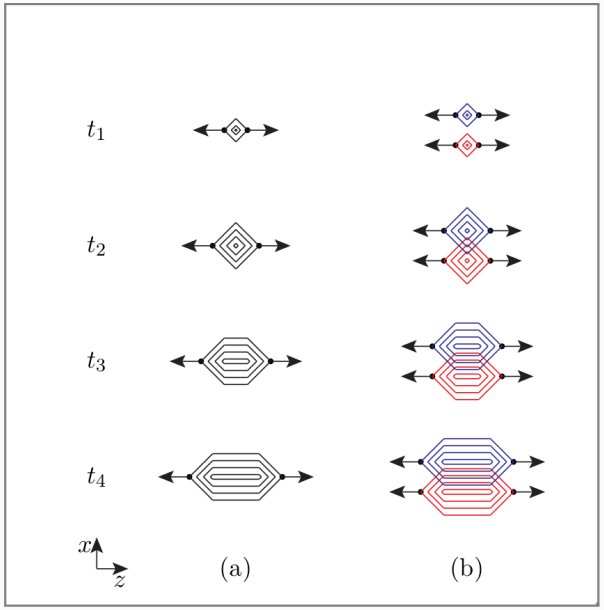

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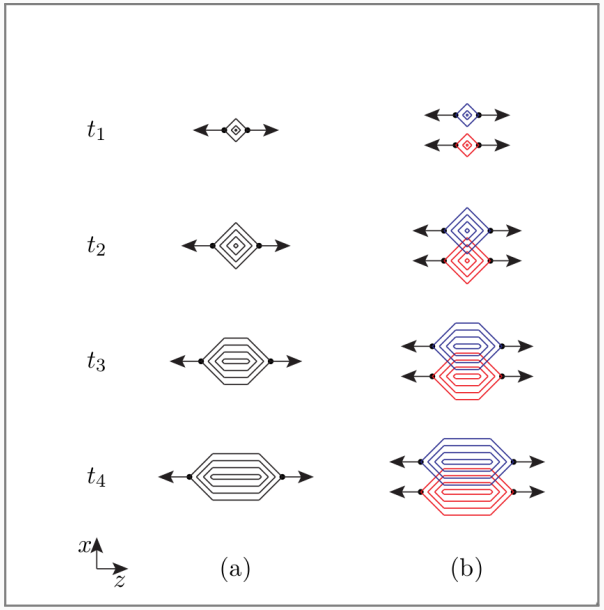

- Dominated by electric field $\to g = 1$.
- Reality:
  - **Type 1** Energy to destroy vacuum.
  - **Type 2** Energy in current.

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

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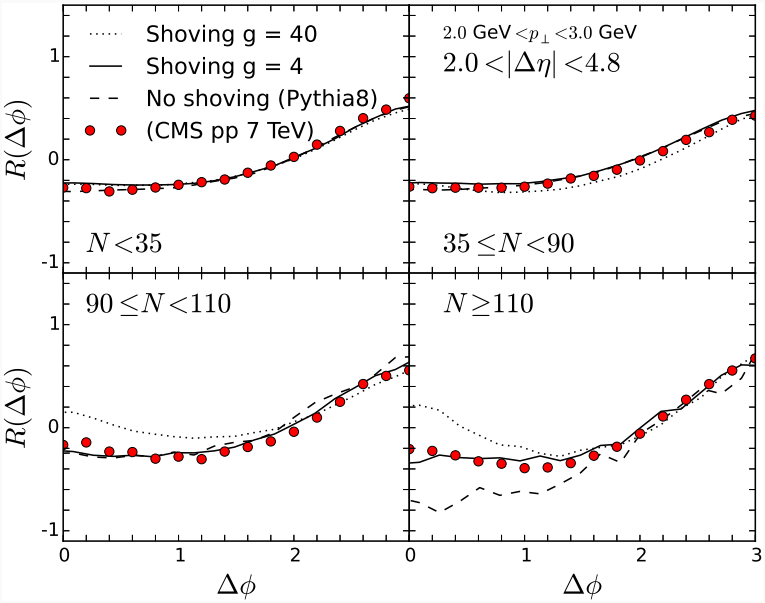
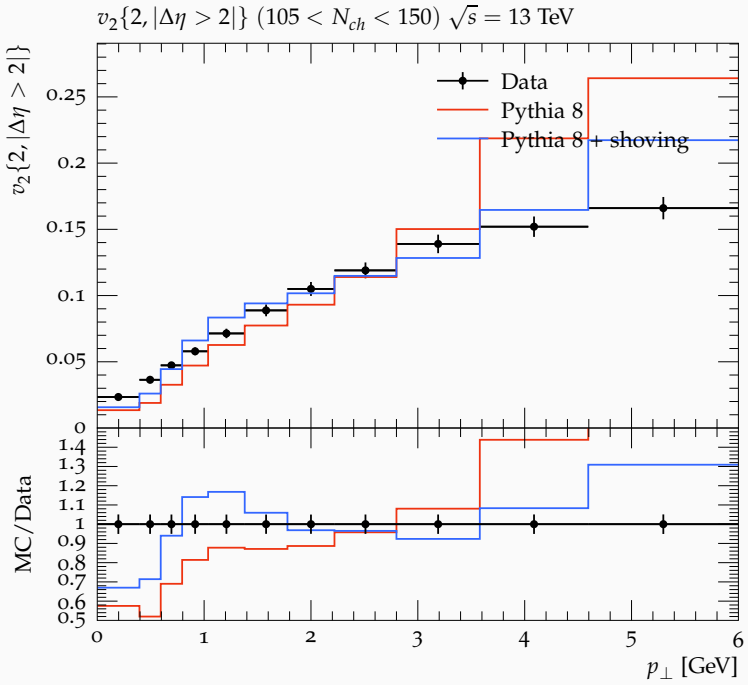
6. In an interaction of heavy nuclei with nuclei, many overlapping quark tubes form, and a large azimuthal asymmetry may be observed.[2)] Furthermore, since an $A \times A$ collision is noncentral on the average, the system of quark tubes fills a transversely anisotropic region. It is clear geometrically 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.

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?





What about jets? (CB: 1901.07447)

- String dynamics ought to be universal.
- Consider now:
  1. Events with a Z-boson present.
  2. Events with Z+jet.
- $Z \to l^+ l^-$ not affected by shoving.
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Common statement:

- ◇ FS interactions $\to$ flow should also affect jets.
- ◇ The shoving model provides a framework to study such effects.
- ◇ This does not mean that shoving is the full story.

Step 1: Just a Z-boson

- The presence of a Z should not change the physics.
- It *can* introduce kinematical biases.
- Recently measured by ATLAS (ATLAS-CONF-2017-068).

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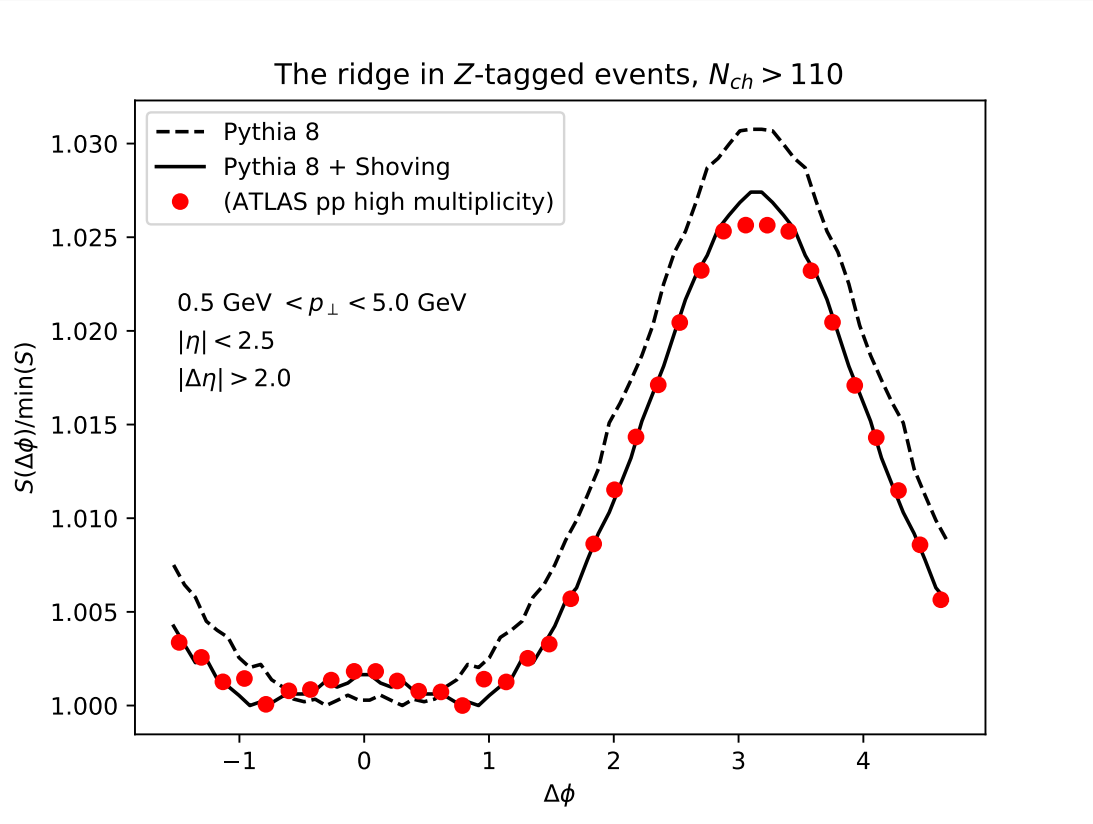
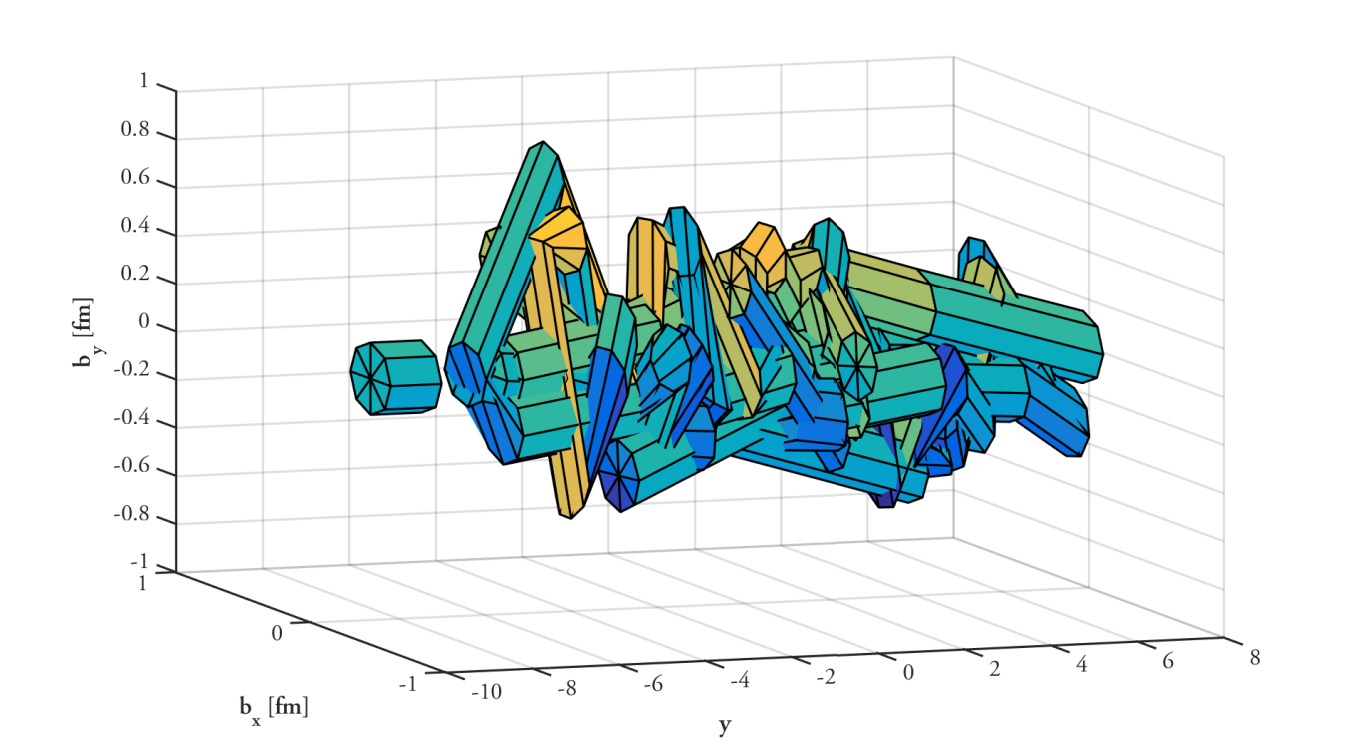


Before introducing a jet...

- Space–time information is important: We rely on models!
- Here: Overlapping 2D Gaussians (p mass distribution).
- Figure string $R = 0.1$ fm, reality $R \sim 0.5$ fm.



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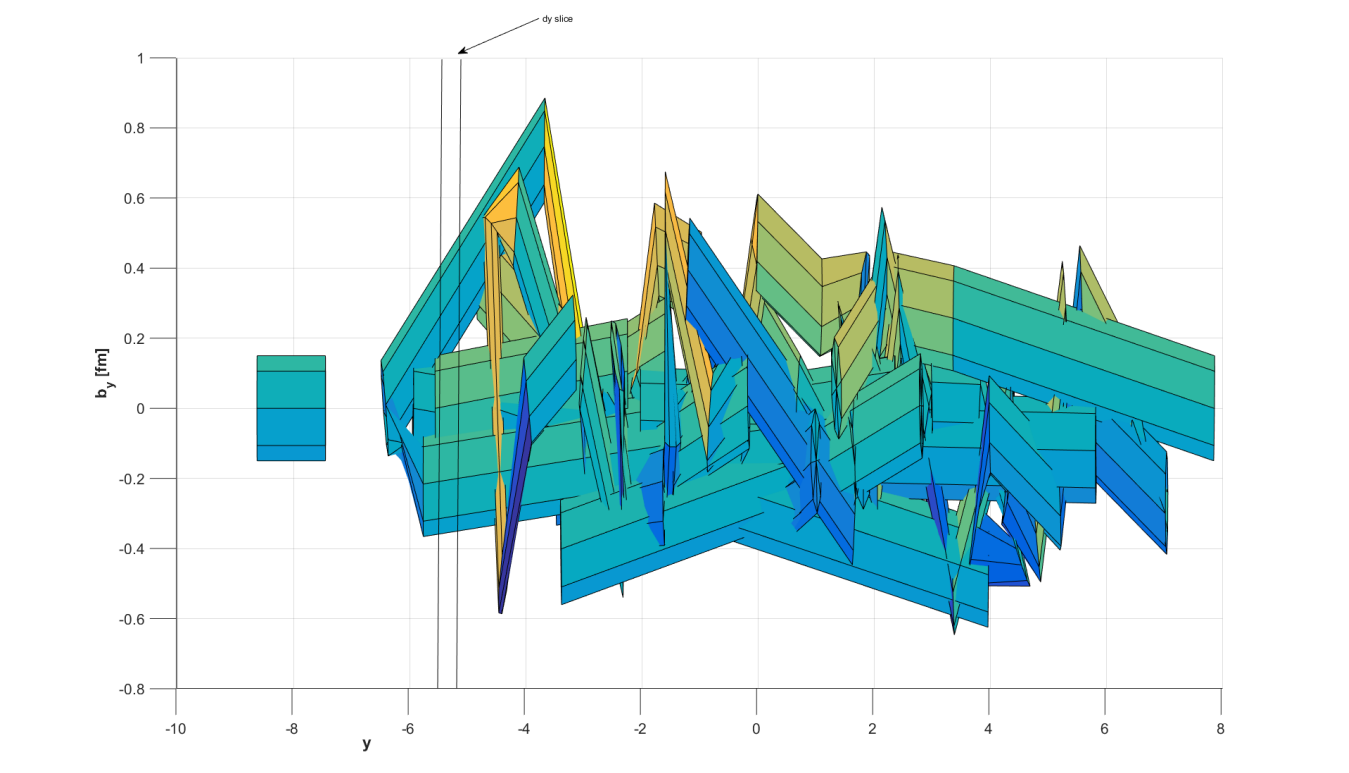

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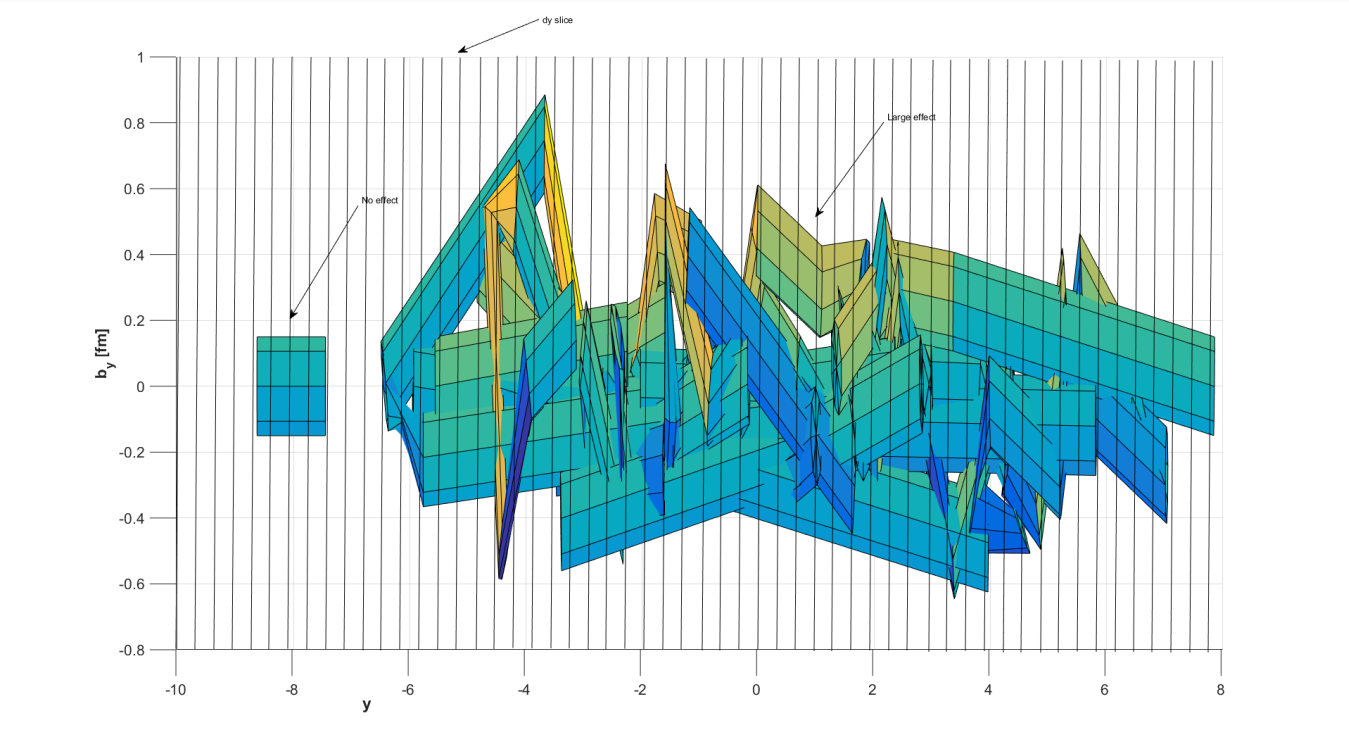

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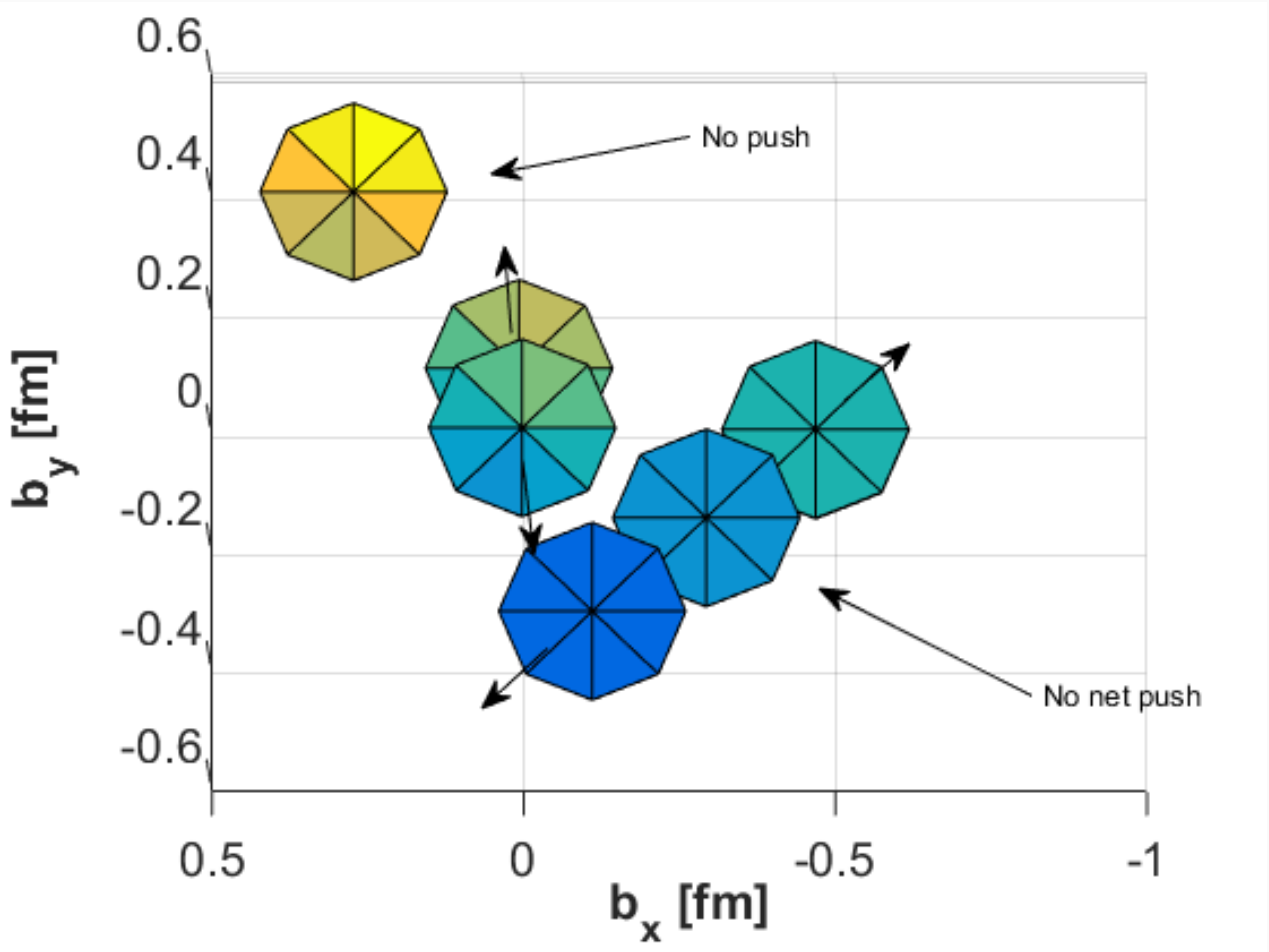

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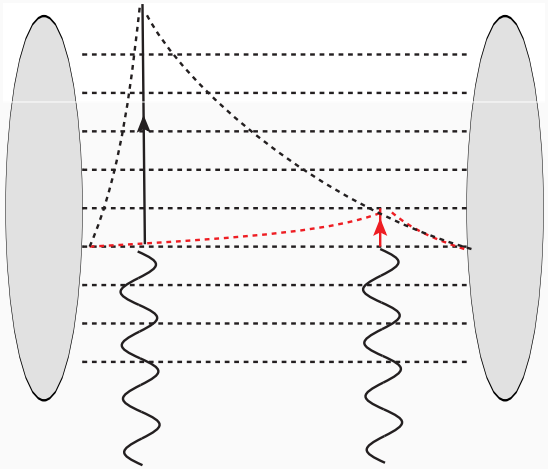
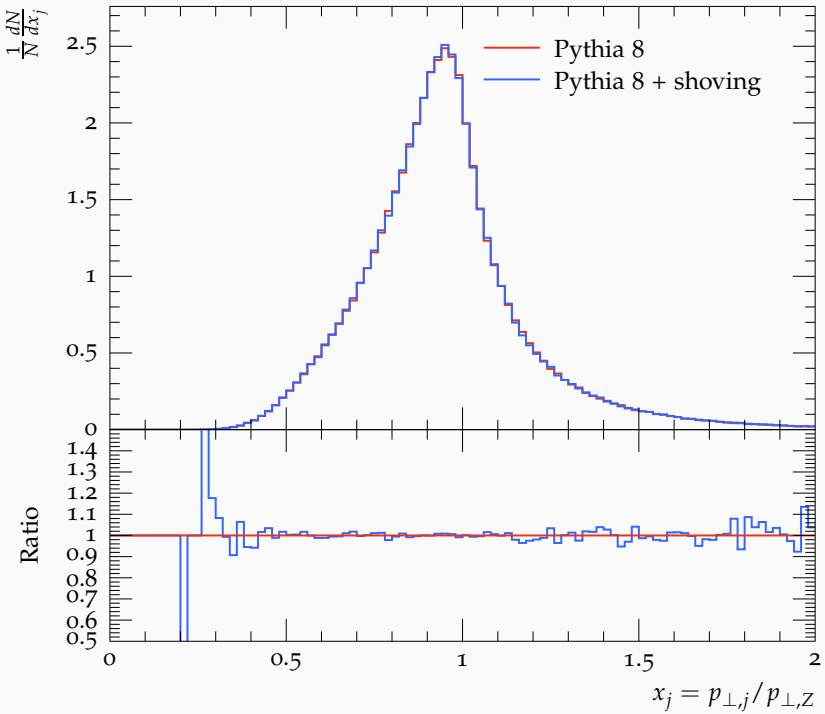
- Toy geometry: Let jet hadronize "inside".
- Mimic the effect in AA collisions.





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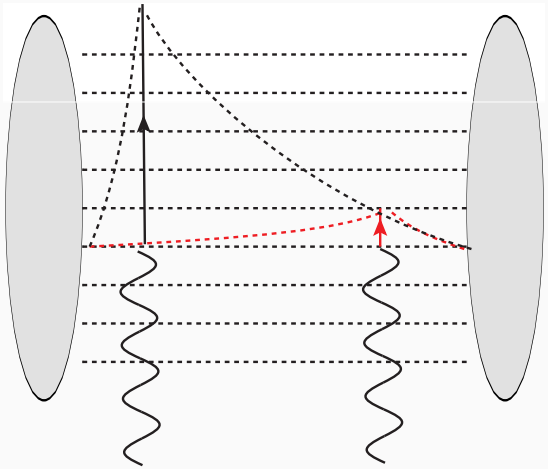
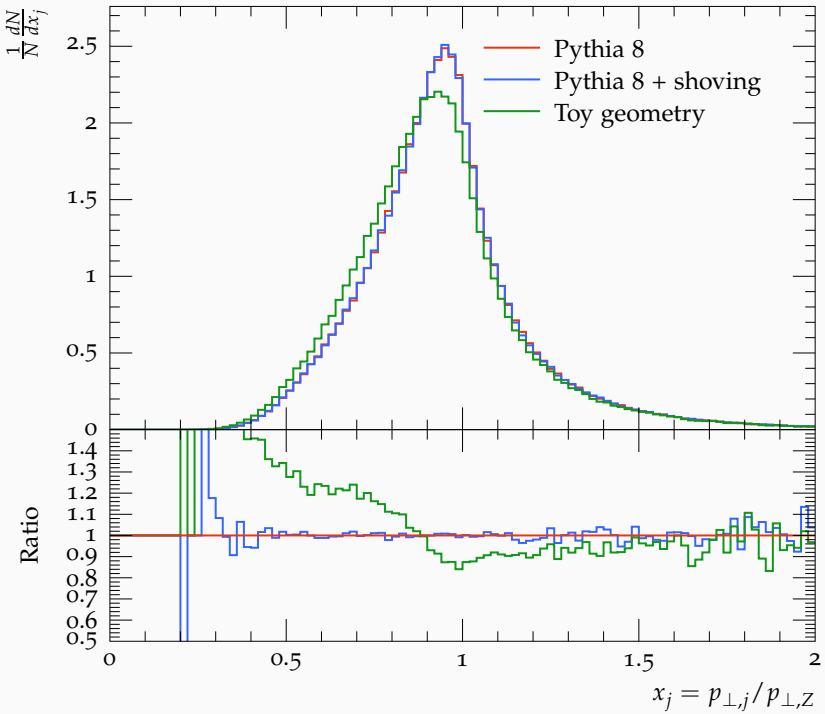
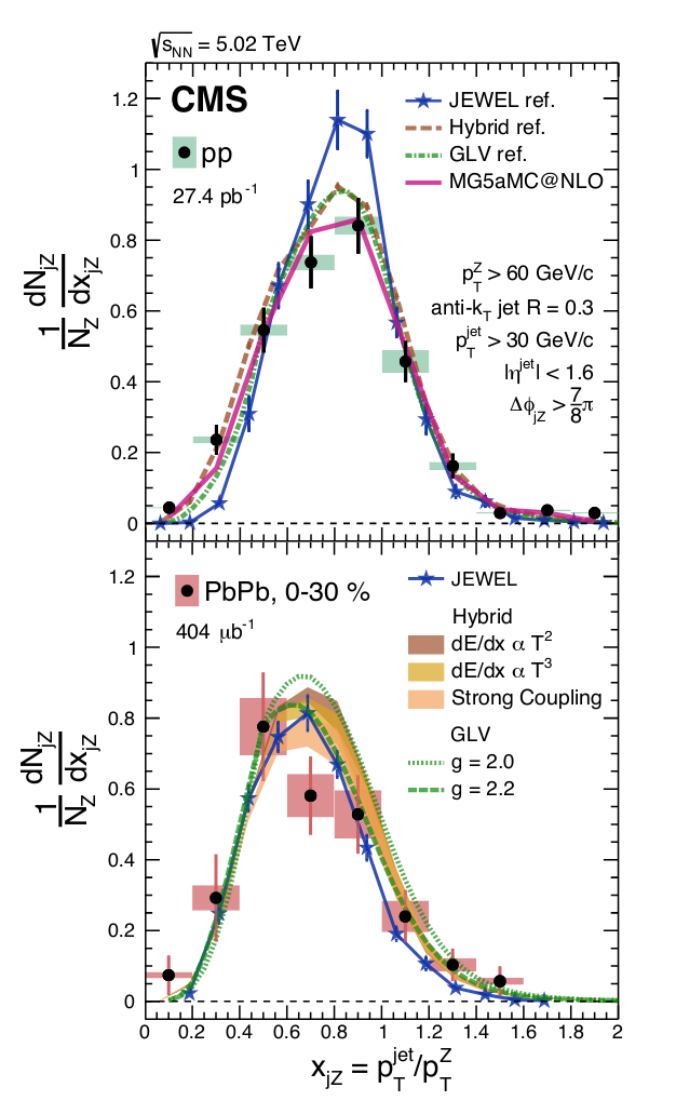
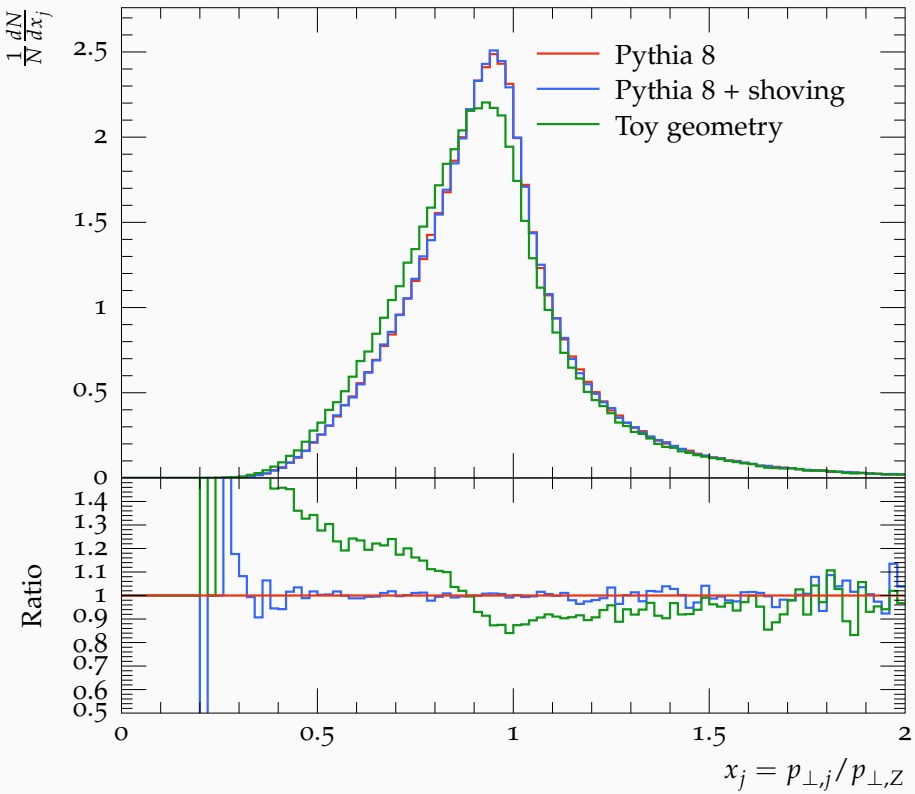




Qualitative similarities (CMS: 1702.01060)



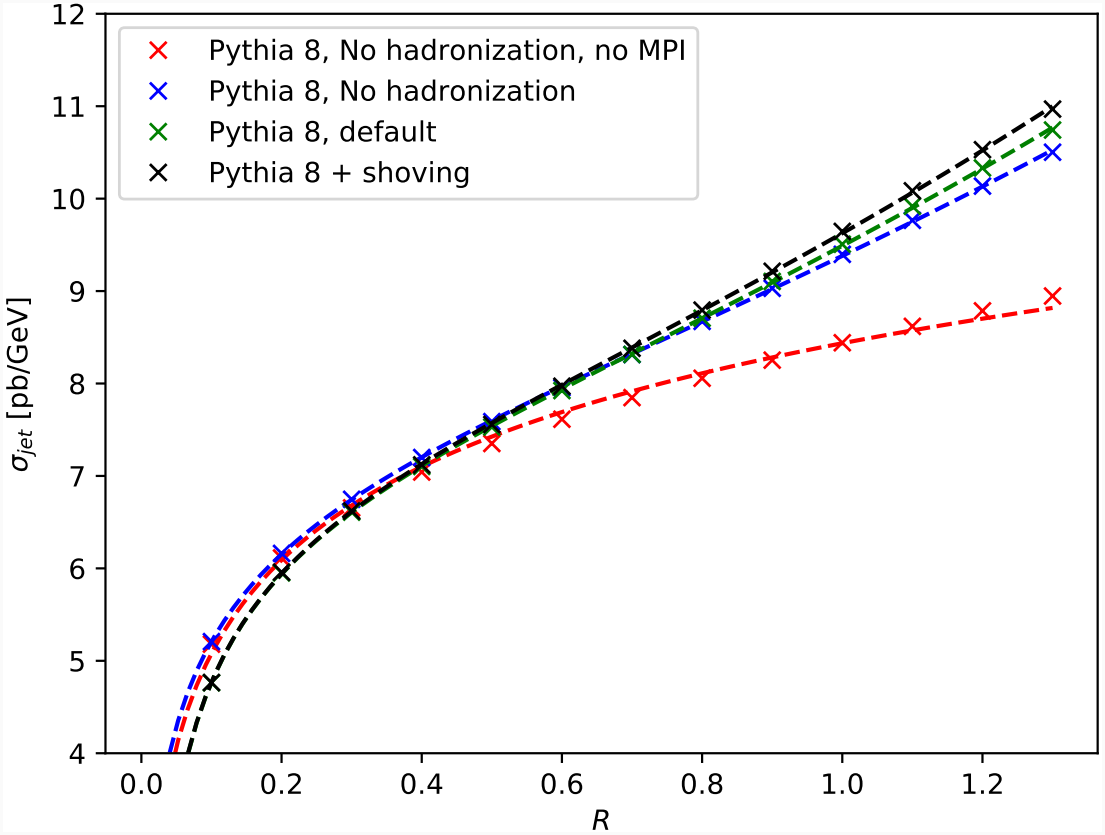
- Need better obsevables.
- Soft modifications on jet edge (large R).



Jet cross section

- Integrate leading jet spectrum: $\sigma_j = \int_{p_{\perp,0}}^{\infty} dp_{\perp,j} \frac{d\sigma}{dp_{\perp,j}}$

- Expectation: $\langle dp_\perp / d\eta \rangle \propto f\left(\langle d_\perp \rangle\right) \Rightarrow \Delta\sigma_j \propto R^2$
- Effect probably too small to measure.



Hadrochemistry

- Hadrochemistry indirectly affected through basic string equations.
- Study inclusive quantities: Average hadron mass and total jet charge: $\langle m_h \rangle = \frac{1}{N_p} \sum_i^{N_p} m_{h,i}$, $Q_j = \sum_i^{N_p} q_{h,i}$

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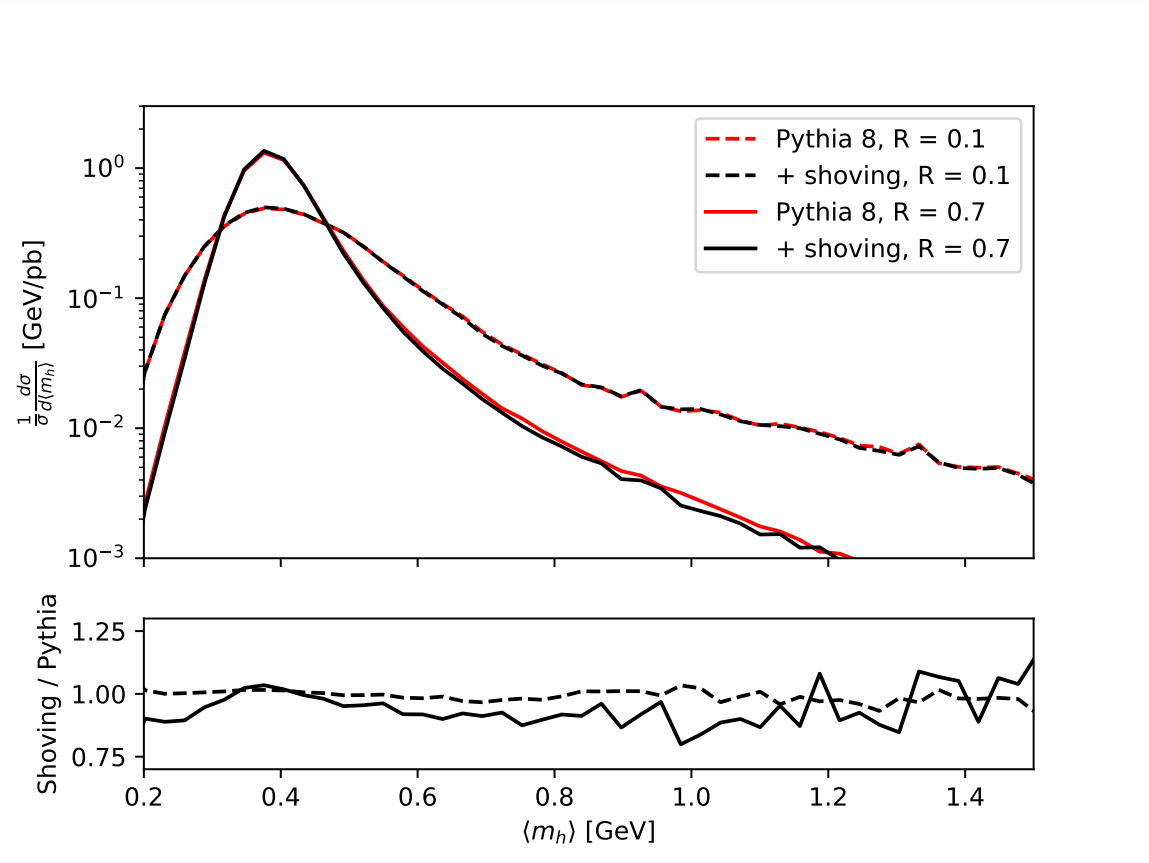

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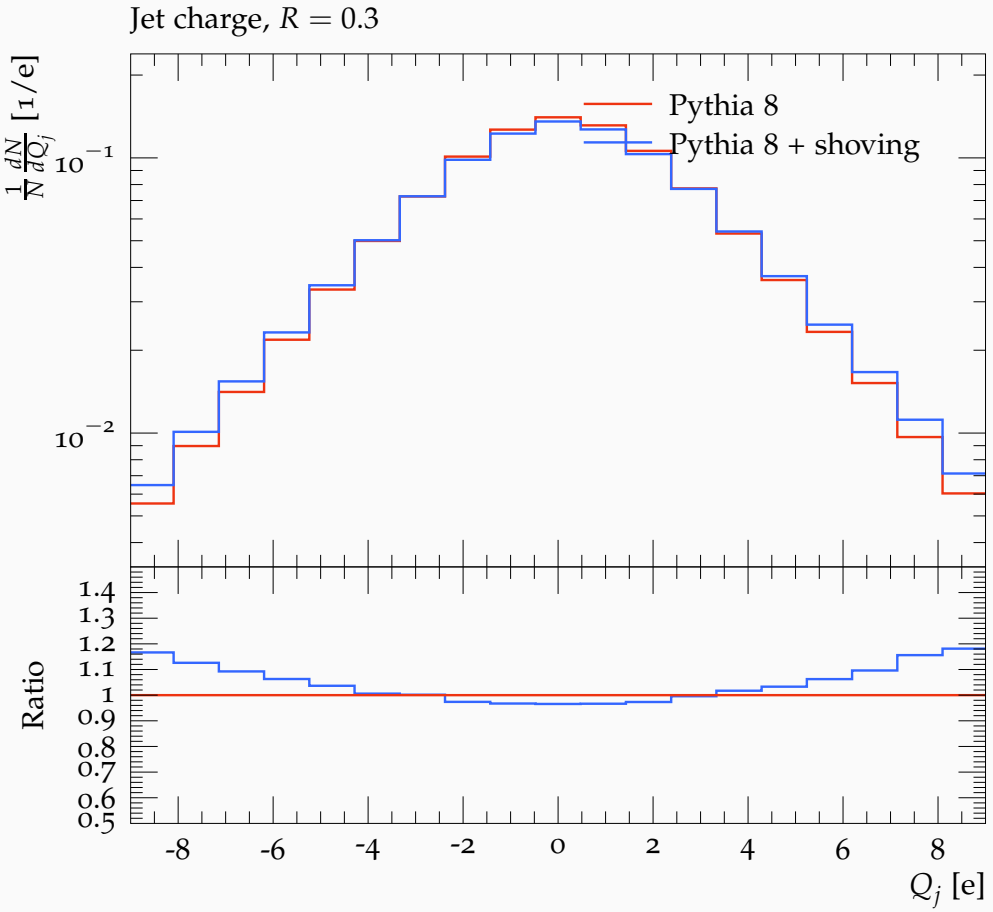

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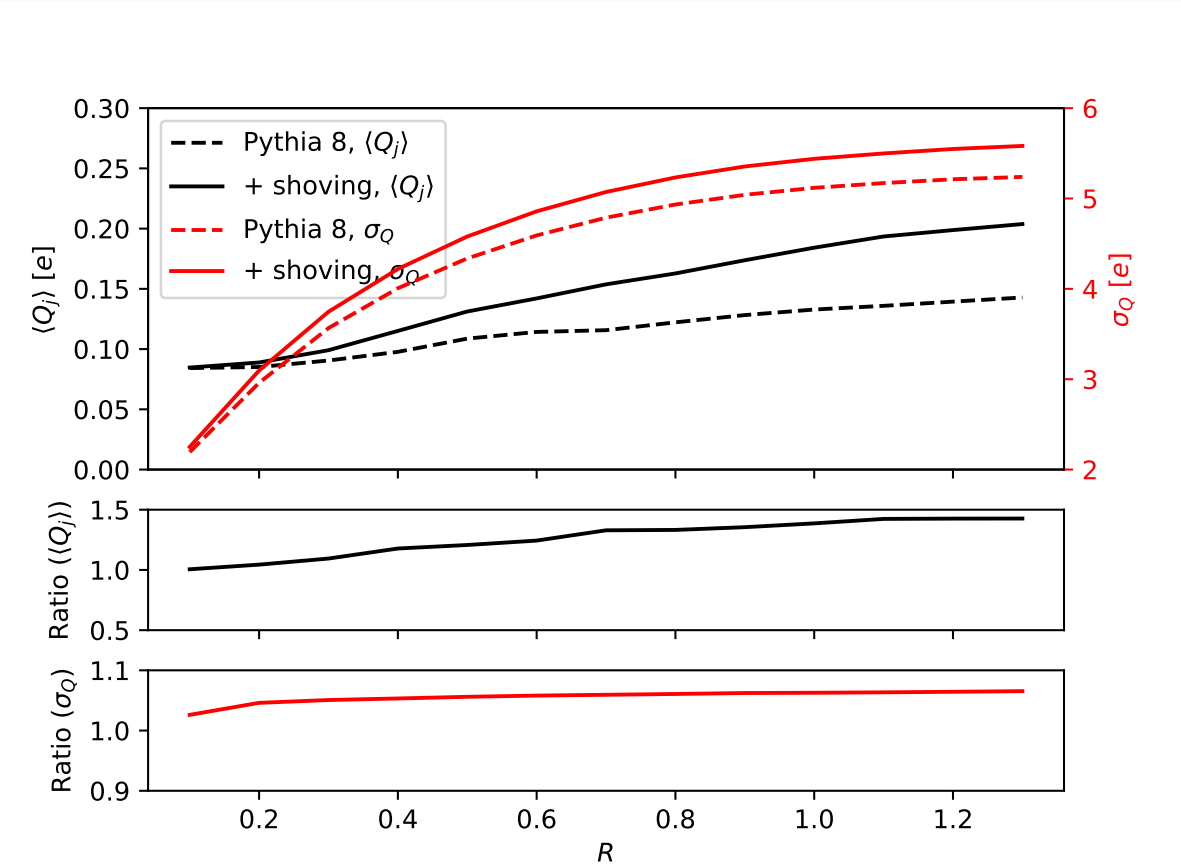

Summary

- String shoving produces a consistent ridge picture.
- Effects on jet fragmentation exists, MC implementation provides opportunity.
- Effects both on soft and hard production *very* sensitive to space–time picture.
- Outlook:
  1. Better control of space–time picture, perturbative input.
  2. Inclusion of rope effects for better hadrochemistry.
  3. Extension to pA and AA through Angantyr framework.

Thank you!