Proton-nucleus collisions with PYTHIA8/Angantyr

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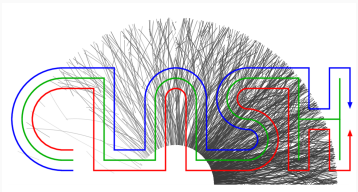
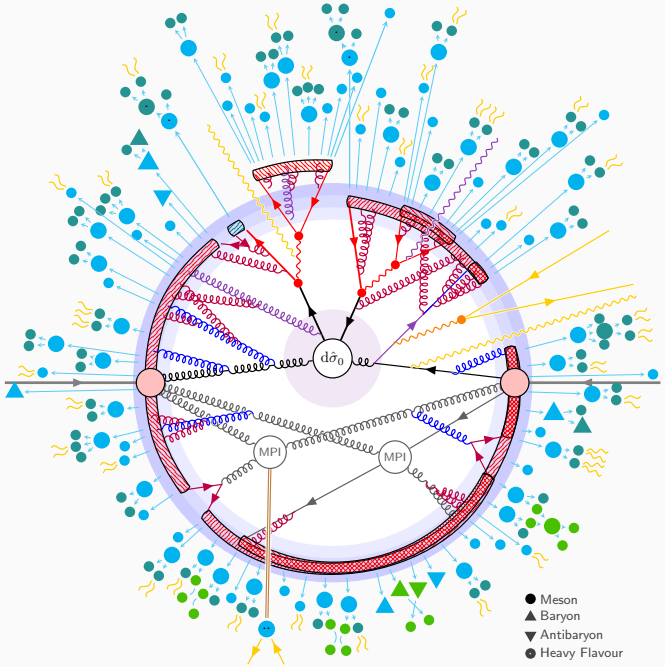
Jul 5, 2024, Proton-Nucleus at LHC, CERN



PYTHIA8/Angantyr: what and why?

- What is PYTHIA8/Angantyr?
  1. Angantyr: Code name for ion collision framework (since 2018).
  2. No "collectivity"/QGP by default. Coherent superposition of nucleon collisions.

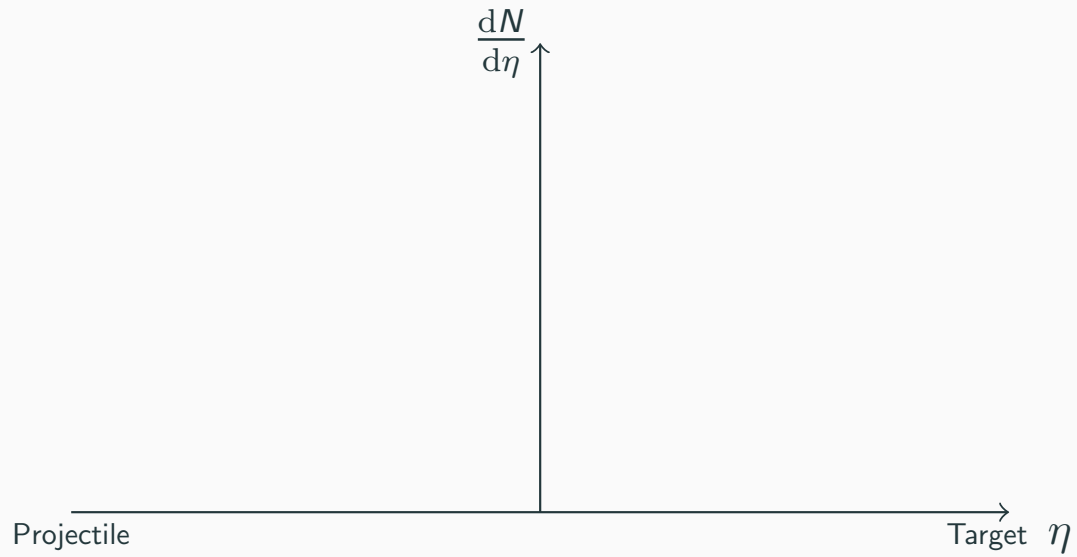


- PYTHIA philosophy:
  1. Build a "vanilla" collision event (Angantyr).
  2. Add effects on top: **Colour reconnection** , string shoving, rope hadronization, **hadronic rescattering** , deuterons from recombination...

Angantyr at a glance

- Lesson from pPb: Color fluctuations are important.
- Glauber MC w. fluctuating projectile and target.
- Particle production inspired by wounded nucleon model:

$$\rightarrow \frac{\mathrm{d}N}{\mathrm{d}\eta} = n_t F(\eta) + n_p F(-\eta).$$



Also AA, but another talk for another day.

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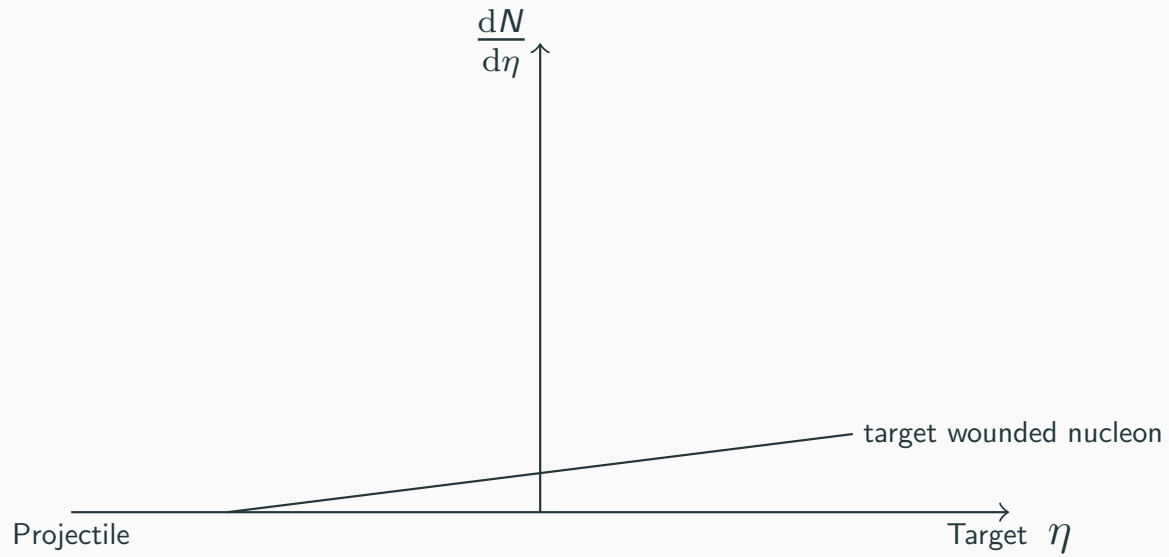

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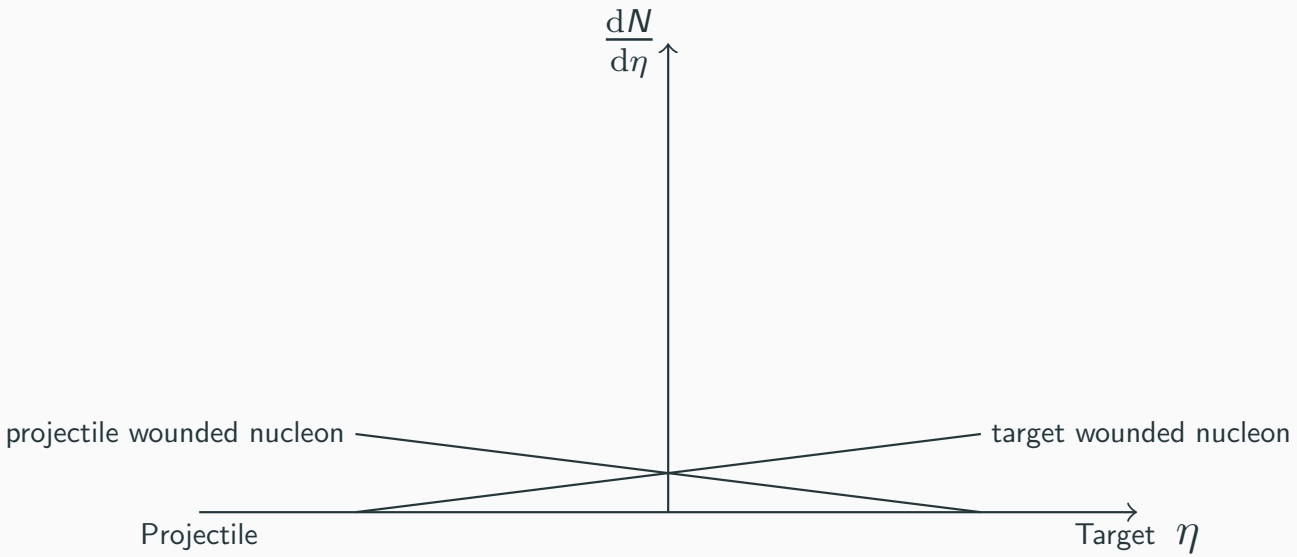

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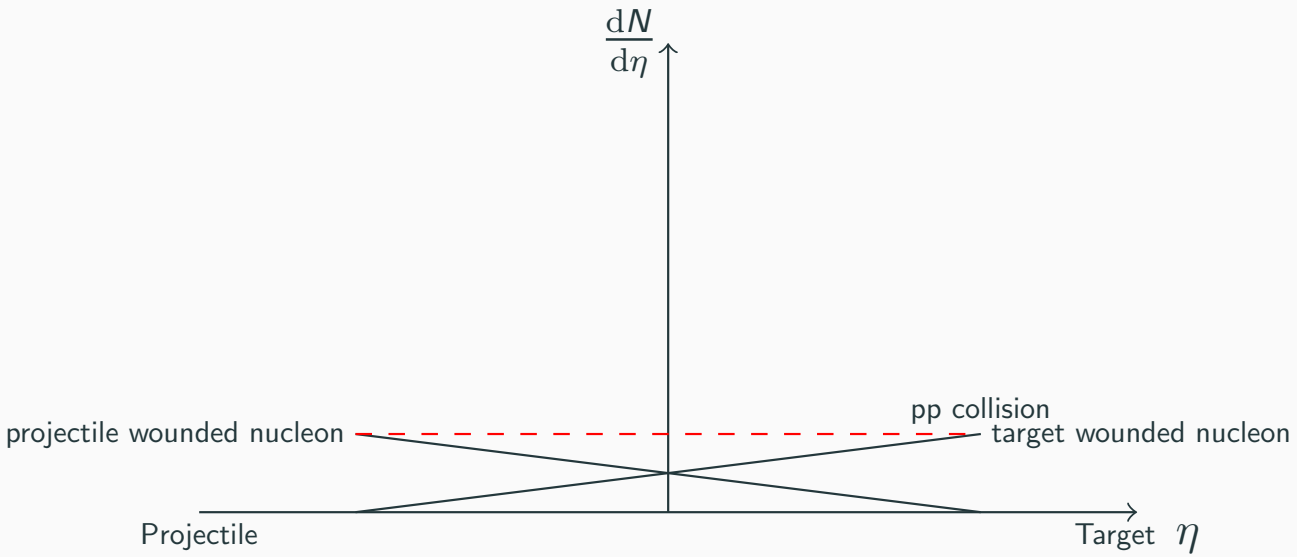

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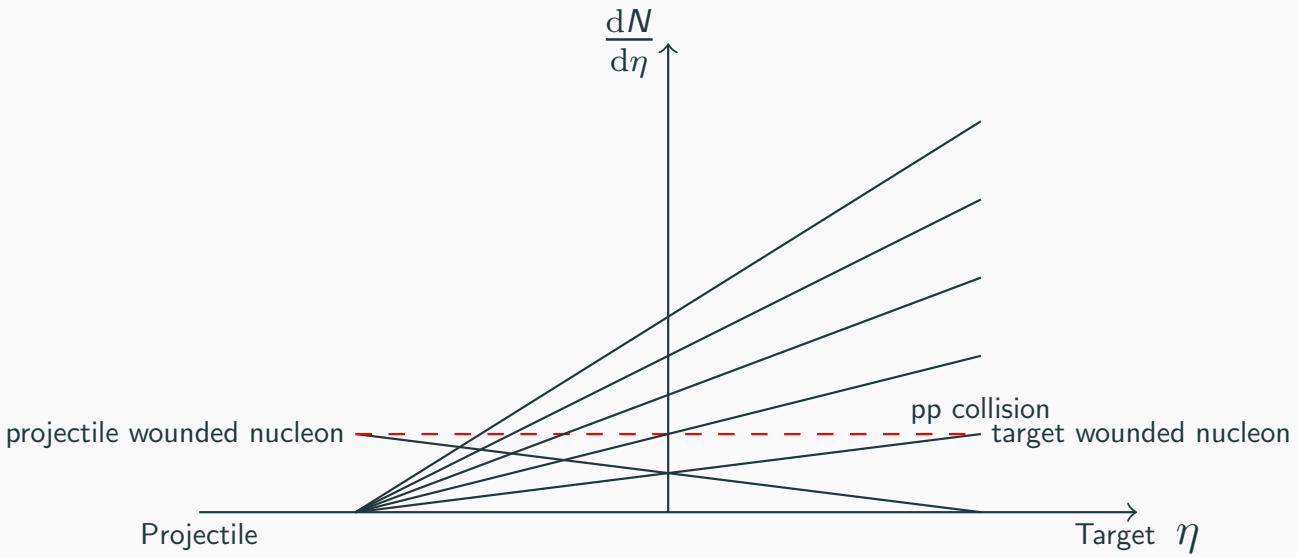

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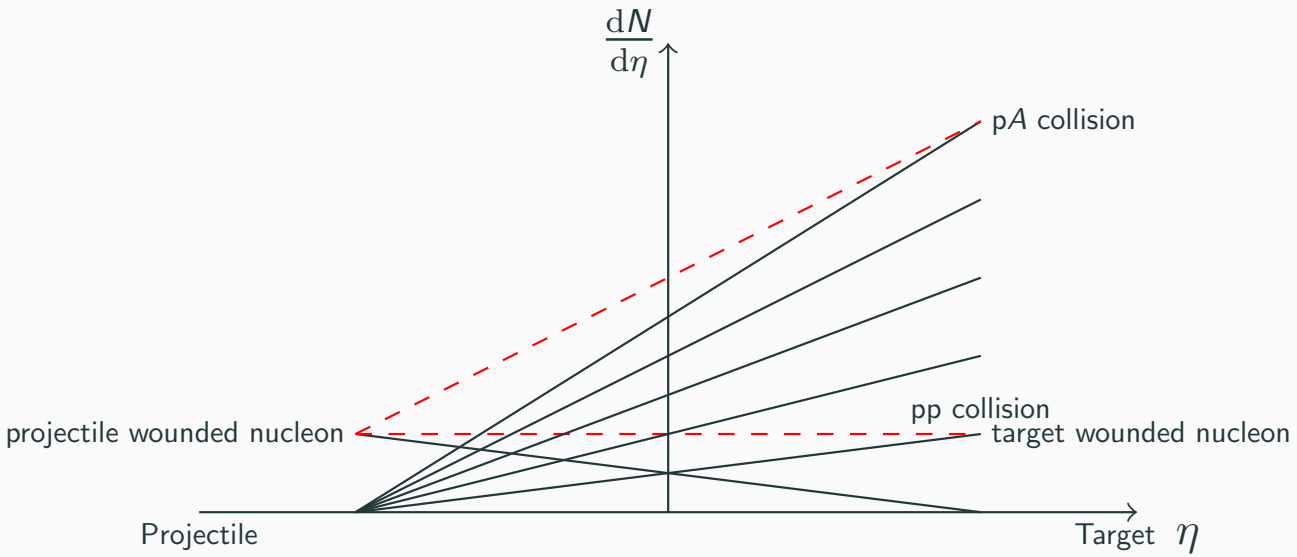

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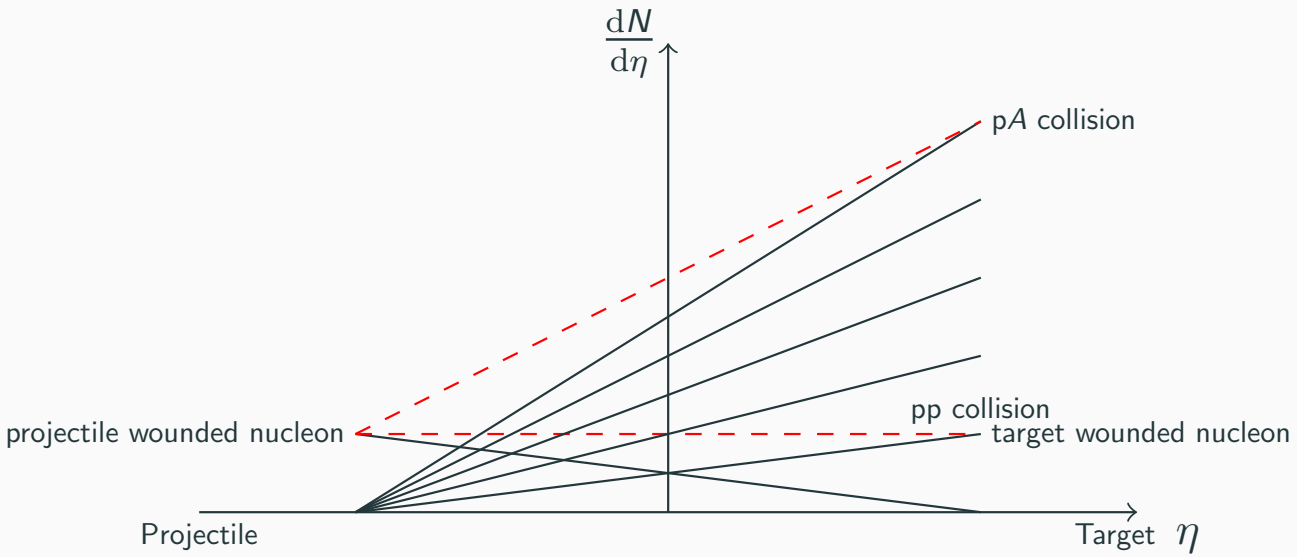

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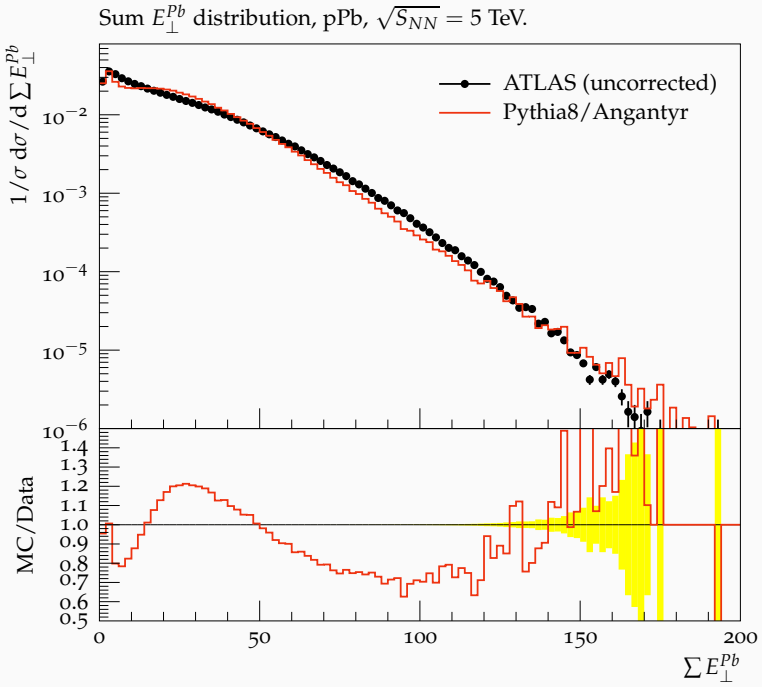
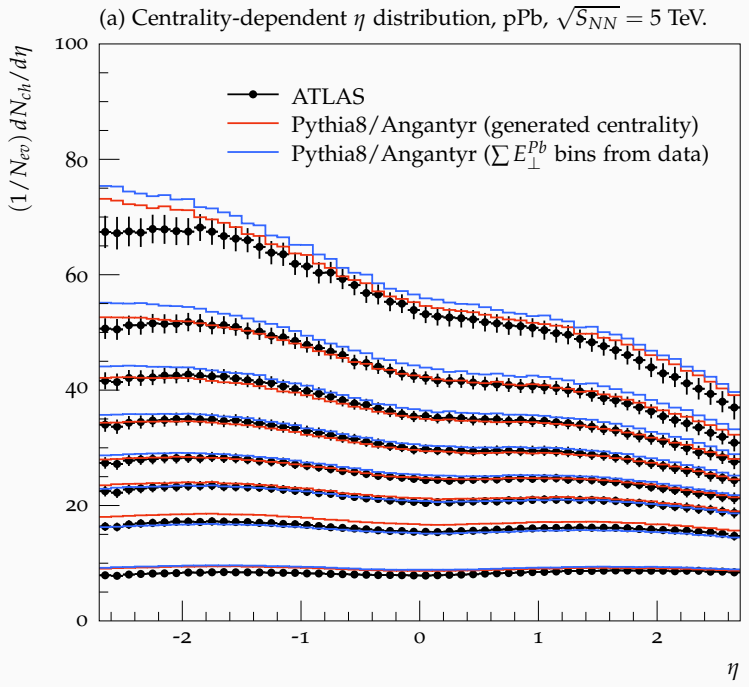
Final state multiplicities

- Works very well for centrality measures and final state multiplicities.

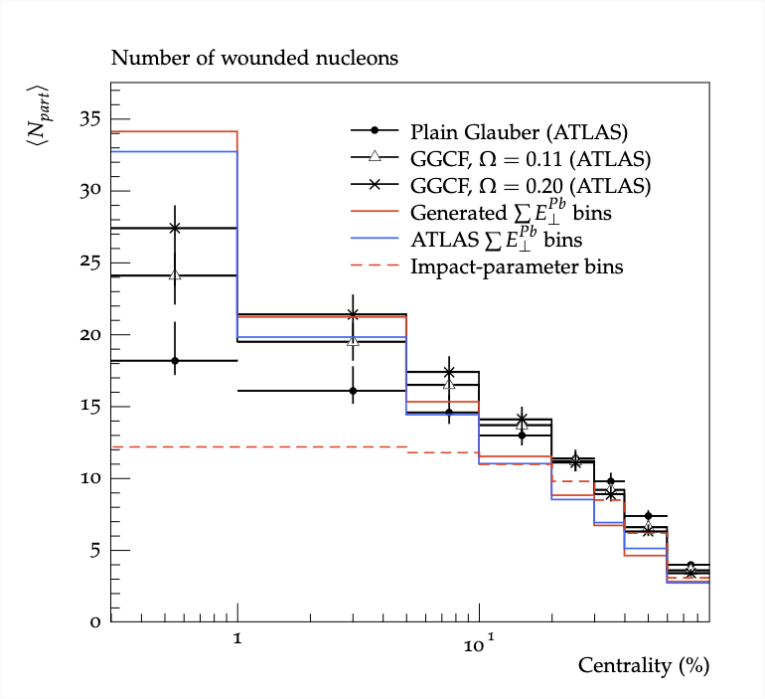




- Energy conservation **on top** of optical Glauber.
- N_{part}, N_{coll} etc. as always very model dependent statements.

Forward–central correlations and fluctuations

- Centrality measures and fluctuations inform A-A modeling.
- p-A most sensitive, poorly constrained.



Importance of p-A programme

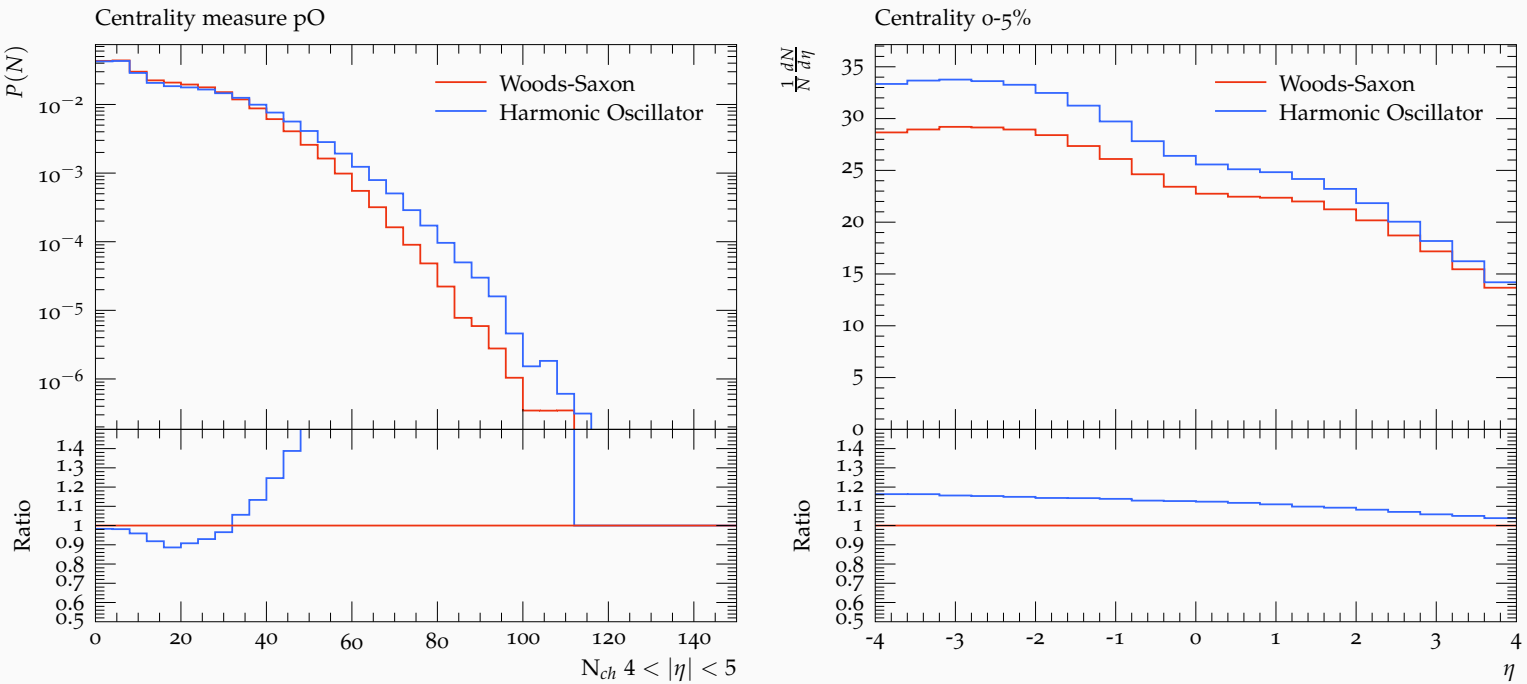
♠ p-A base building block for PYTHIA8/Angantyr.

♠ Fluctuations constrain model (+ pp cross sections).

♠ Different geometries are better.

Nuclear geometries: We treat geometry as input!

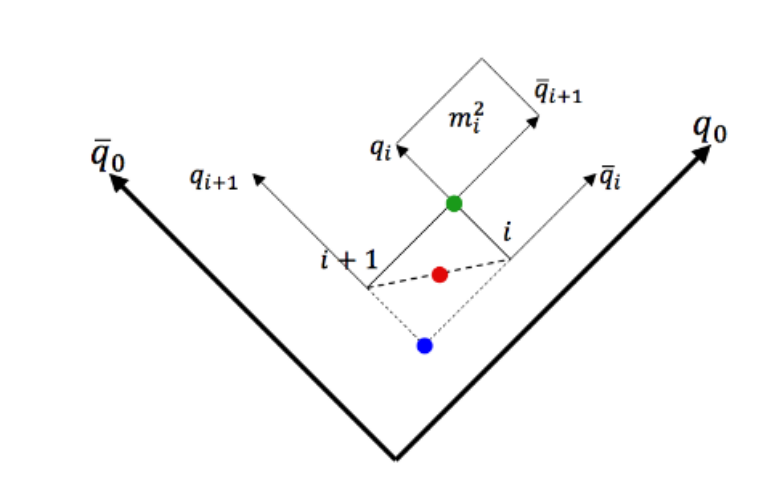
- Default: GLISSANDO Woods-Saxon. Large ($A > 16$), symmetric nuclei.
- Also included: Harmonic Oscillator Shell, Hulthén, Gaussian (Toy), nucleus-in-nucleus (e.g. for α-clusters) and external read-in. With and w/o hard core. Possibilities for extensions.

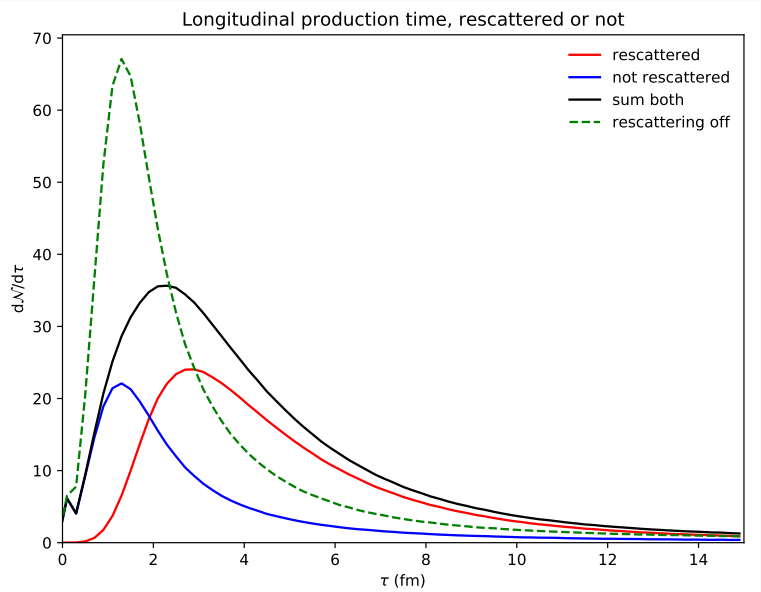


(Proton-^{16}O, $\sqrt{s_{NN}}$ = 5020 GeV, $\tau_{0\text{max}}$ = 10 mm/c, ≈ 3k events/minute/thread.)

Hadronic rescattering

- Internal PYTHIA framework, on top of Lund strings.
- Initial conditions: string break vertices from EOM.
- Technical infrastructure: Quick re-initialization, all systems.



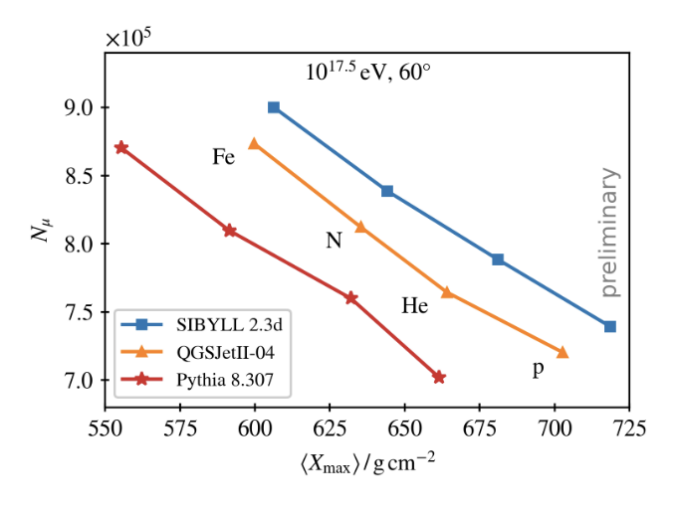


- Freezeout time: $\tau^2 = \tau_L^2 = t^2 - z^2$.
- Dense initial conditions = large effects!
- Charm/bottom hadron rescattering included.

The goal is cosmic rays

Part of larger goal to simulate:

1. Full hadronic, cosmic cascades (interest from cosmic community).
2. Ongoing work to integrate with GEANT (interest from special purpose exp., LDMX).



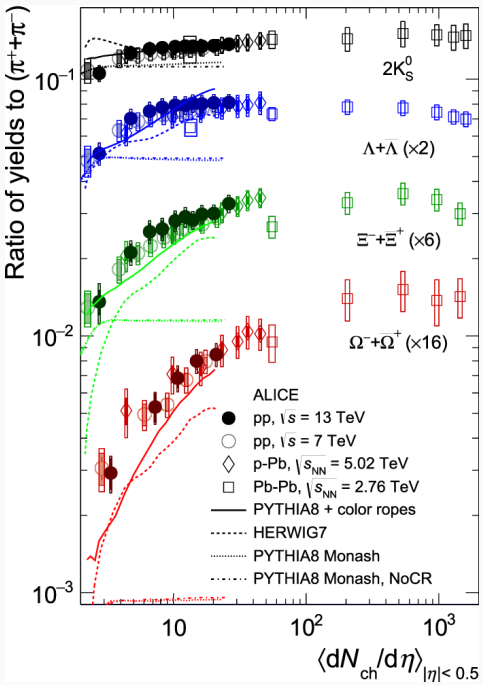
(N_μ on ground vs. shower maximum. PYTHIA in CORSIKA, Reininghaus, Sjöstrand, Utheim (2303.02792))

Importance of p-A programme

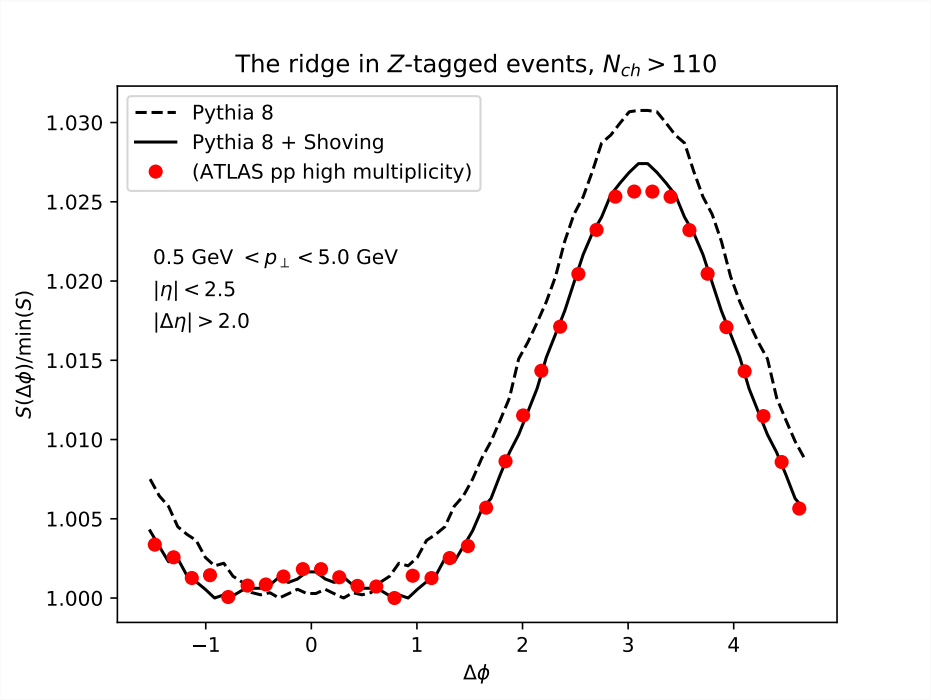
- ♠ New geometries ⟹ new opportunities.
- ♠ Importance of space-time structure.
- ♠ p-A will inform efforts beyond collider experiments.
- ♠ Complementary to e.g. SMOG2 efforts.

String interactions (See CB: 2401.07585 for an overview)

- Several models based on interacting strings.
- String shoving: geometry gives flow.
- Rope hadronization: overlap gives more strangeness.



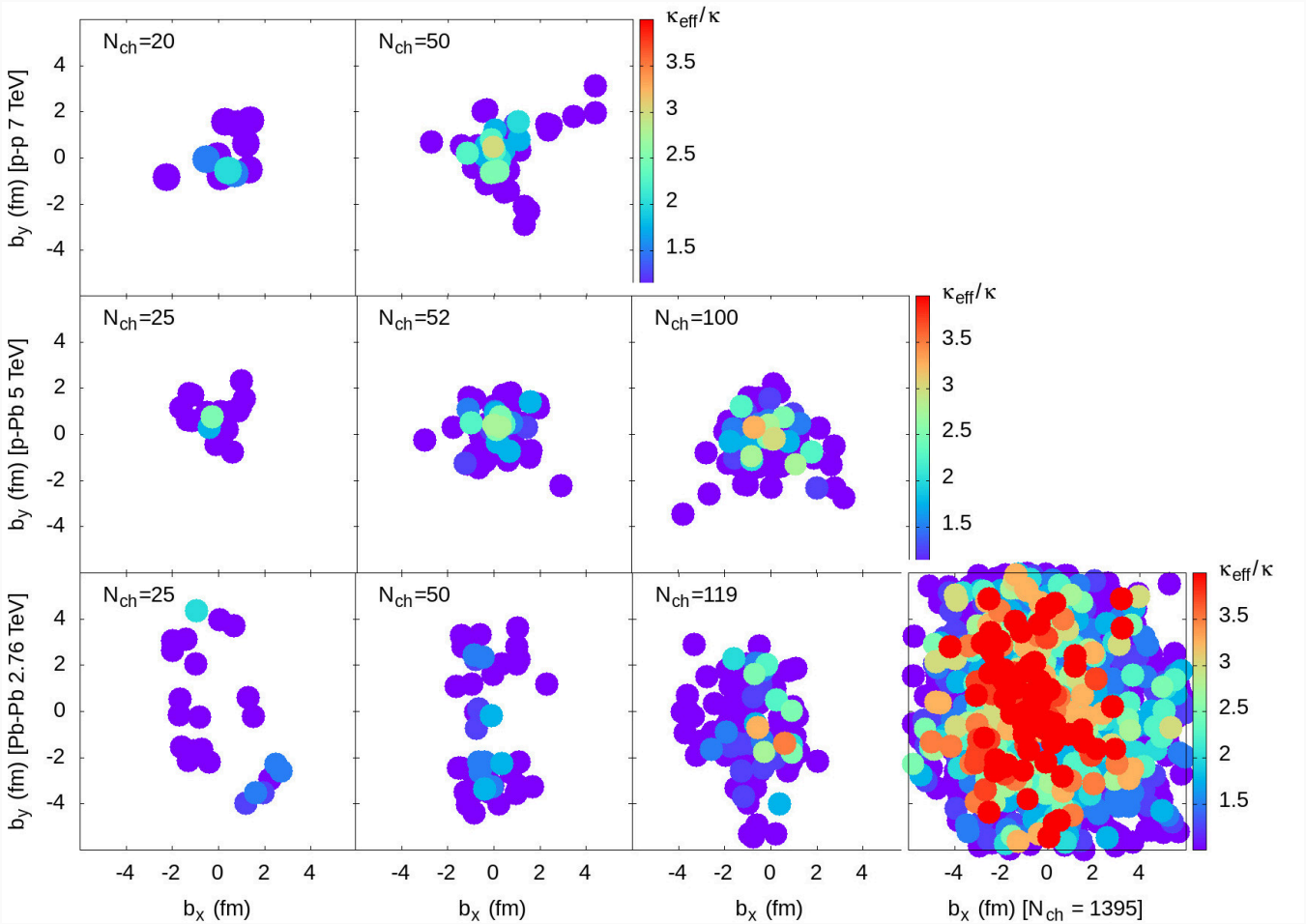
(ALICE (2003.02394))



(ATLAS (1906.08290))

- **Hot take:** Here pp or AA will always be better!
- Why p-A? Colour reconnection effects!

Differences between pp, pA and AA

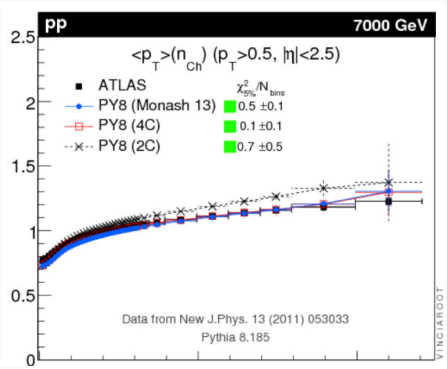


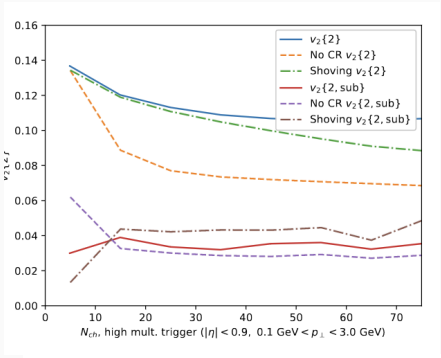
Shoving: geometry response (AA), ropes: energy density (pp).

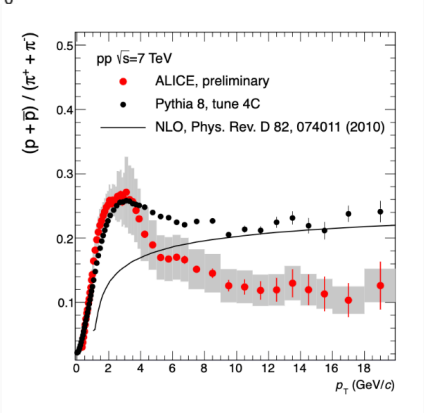
CR models: vicinity/λ-measure makes pA stand out!

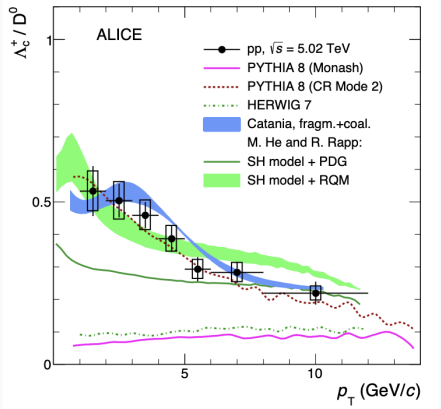
CR: history and surprises from LHC

- Reorganize string configuration to correct $N_c \to \infty$ in PS. Originally to correct $\langle p_\perp \rangle (N_{ch})$.









(Figures from: 1303.6326, 1404.5630, 1807.05271, 2011.06078)

CR increasingly important:

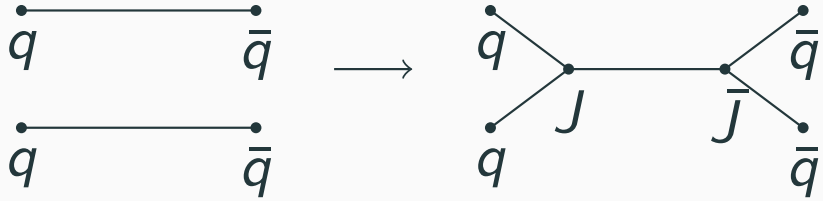
- Short-range flow, Charm baryon enhancement, leading contribution to top-mass uncertainty, (W-mass at FCC-ee?), ...

Has become an essential component of hadronization frameworks.

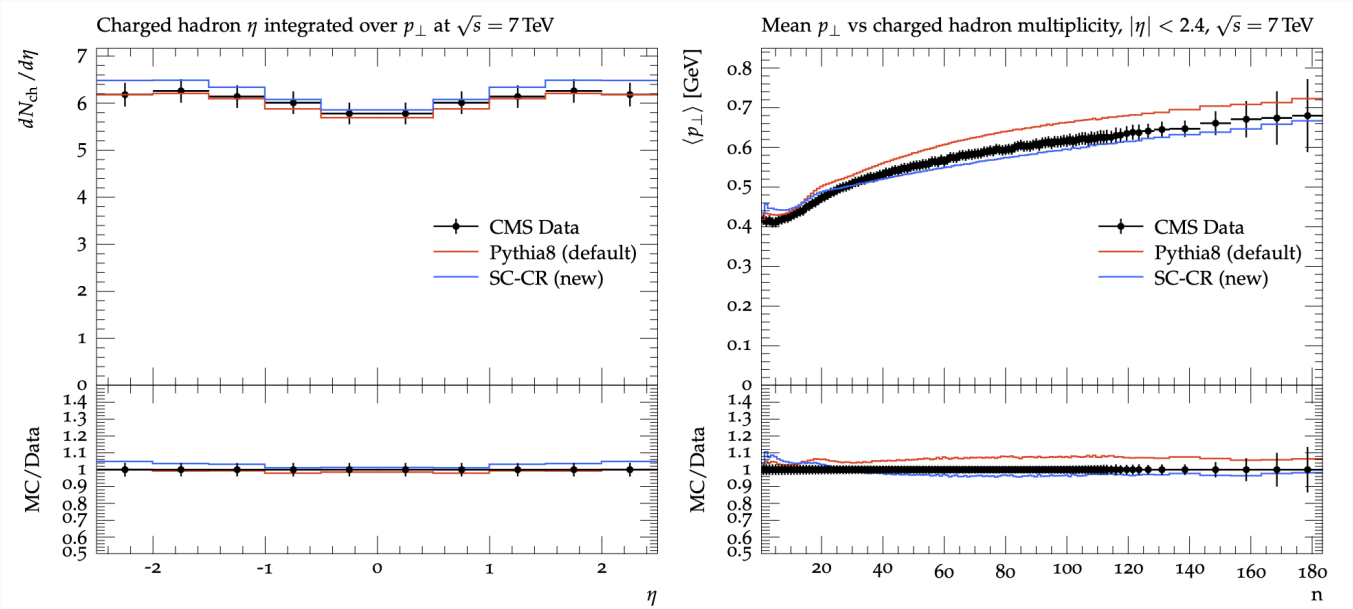
Note: CR introduces "collective behaviour" by definition.

Spatially constrained CR (2303.11747)

Starting point "QCD" CR:



- First CR model applied in ion collisions.
- Move from momentum space to real space: disallow reconnections separated in space.
- Also: technical handling of quark masses + pp retune



Charm in p-A the best CR laboratory? (2309.12452)

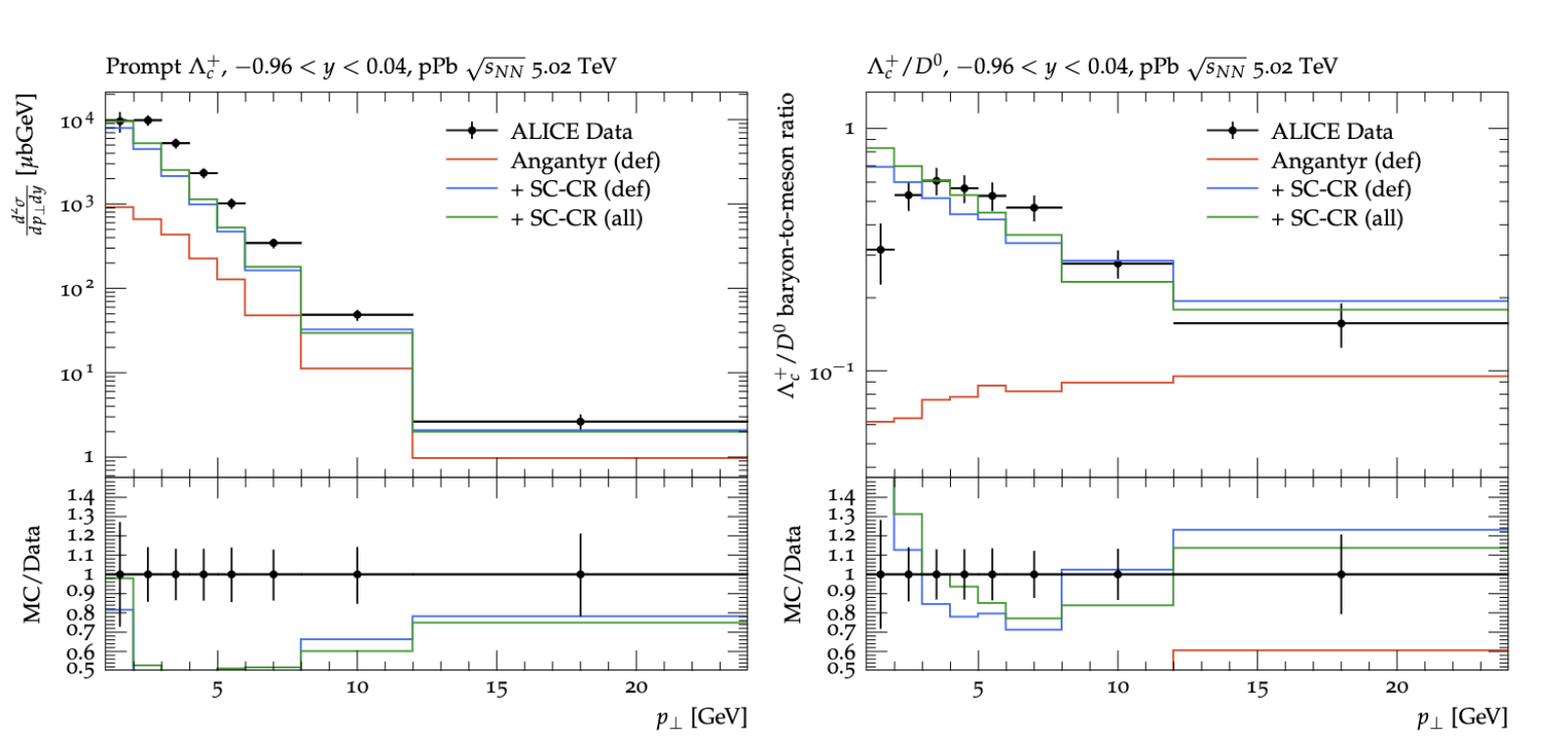
- All charm produced in hard process + shower.
- Bottom still too limited statistics.
- p-A unique geometrical structure.

Importance of p-A programme

♠ Increase statistics of charm and bottom.
♠ Rare baryons still limited/unmeasured.
♠ Will inform particle production for **all** systems.

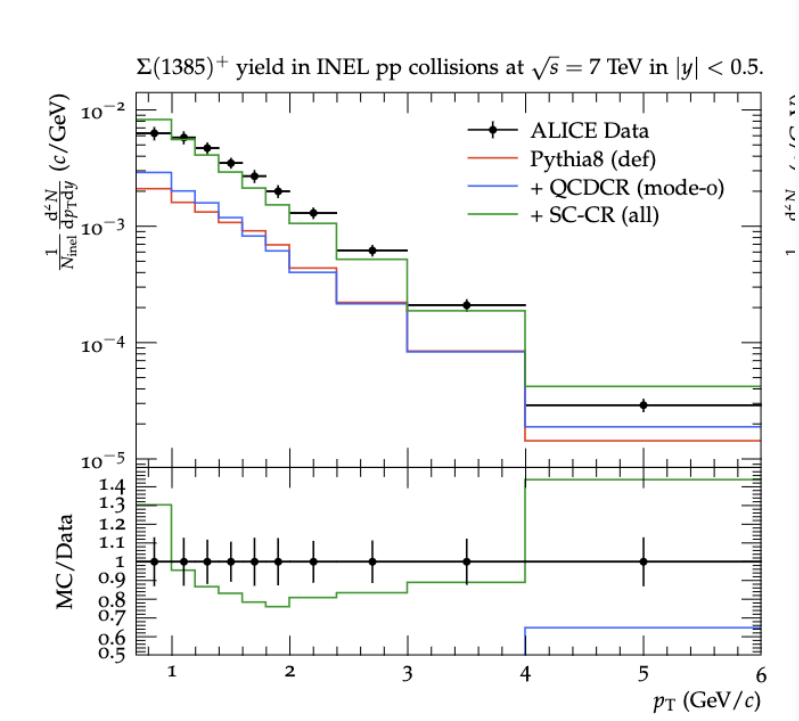
Results (2309.12452)

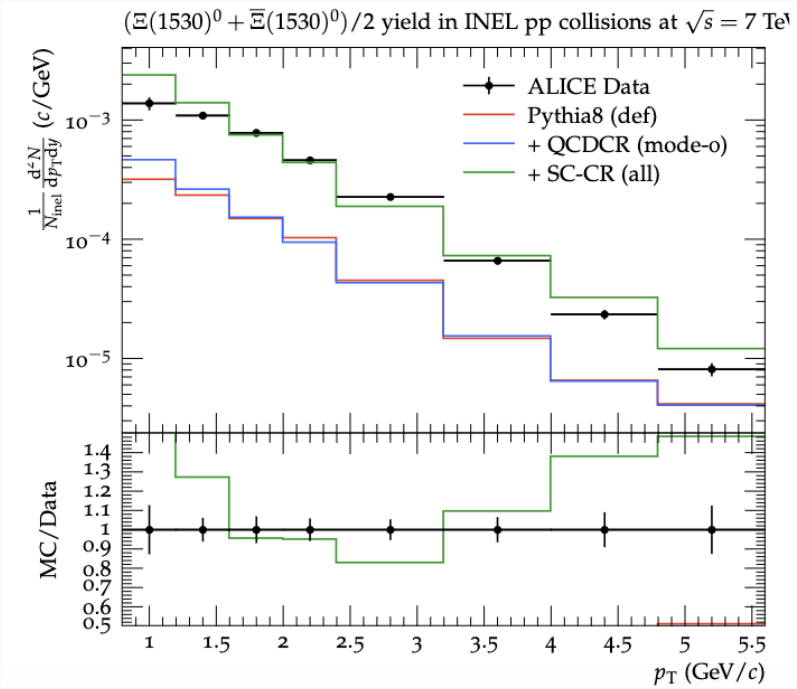
- p-Pb Λ_c/D now reasonably well reproduced.
- Also slight increase of strangeness, on par with pp.



Results II

- Revisiting some pp results with increased strangeness.
- This is p-Pb informing pp.





Wishlist: Summary measurement with detailed feeddown documentation. Preferably in Rivet.

Summary

- HL p-A programme can:
  1. Inform many adjecant fields: A-A, high energy pp, cosmics, radiation + matter.
  2. Carry important results in itself: CR/particle production mechanisms, high energy nuclear geometry, colour fluctuations.
- PYTHIA includes QGP-free microscopic models for all aspects.
- Not a perfect description, but works in progress.
- Available in public releases, continually updated.