String shoving effects on jets in pp collisions in PYTHIA8

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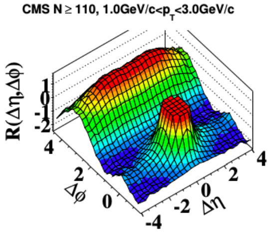
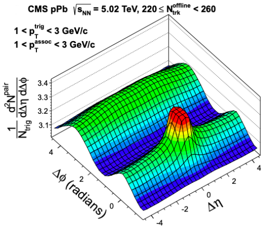
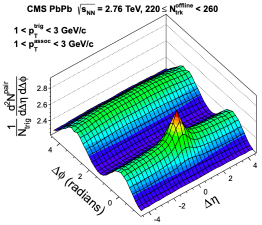
Questions to answer:

1. Explanation of possible collective effects in high multiplicity p-p collisions with string model
2. Is there any jet quenching in high multiplicity p-p events? Explanation in string model?
3. String model to study A-A systems
4. Quest for a unified model: from $e^+ - e^-$ to A-A collision systems

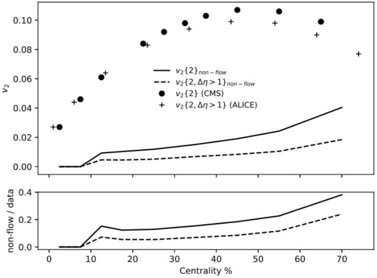






Angantyr and advancements

- Aspects of Angantyr:
  ✓A-A is treated as a collection of overlaid p-p collisions
  ✓Modifications needed when one nucleon in one nucleus collides with several nucleons in the other
  ✓No collective effects



The elliptic flow coefficient $v_2\{2\}$ at $\sqrt{s_{NN}} = 2.76\,TeV$, as measured by CMS (without $\Delta\eta$-gap) and ALICE (with $\Delta\eta = 1$), compared to the non-flow contribution calculated by Angantyr

Bierlich, et al., J. High Energ. Phys. 2018, 134 (2018)

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Signatures		**Underlying mechanisms**
Final-state collective effects	⇒	**String shoving**
Jet quenching		Colour reconnection
Strangeness enhancement		Rope hadronization*

*Bierlich et al. J. High Energ. Phys. 2015, 148 (2015)

Ingredients

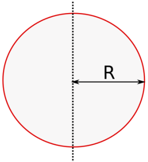
Steps involved in implementing string shoving (for massless partons):

1. Symmetric topology for strings ➔ **Parallel frame**
2. Giving strings **width** ➔ calculate interaction force
3. **Push distribution among hadrons**

2.Interaction energy

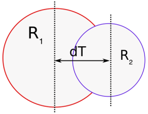
1. A string of width R:

$$\text{Field}\ E(r_\perp) = C \exp\left(-\frac{r_\perp^2}{2R^2}\right) \quad (1)$$



2. Force $f(d_\perp)$ per unit length:

$$f(d_\perp) = \frac{dE_{int}}{dd_\perp} = \frac{g\kappa d_\perp}{R^2} exp\left(-\frac{d_\perp^2(t)}{4R^2}\right) \quad (2)$$



where g is a tunable parameter.

Bierlich et. al., Physics Letters B, Volume 779, 10 April 2018

1. Lorentz invariant frame - the parallel frame

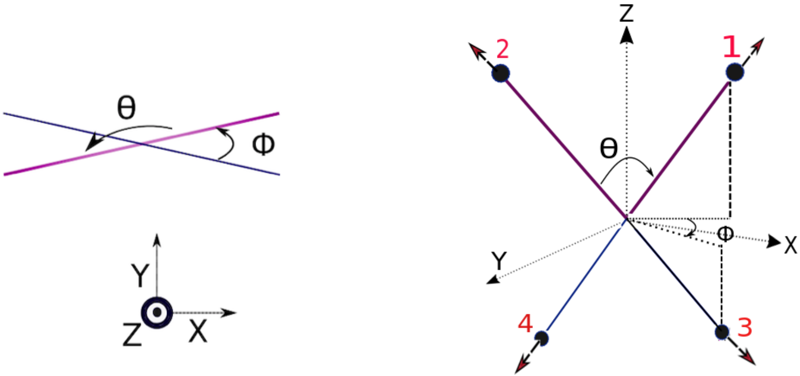
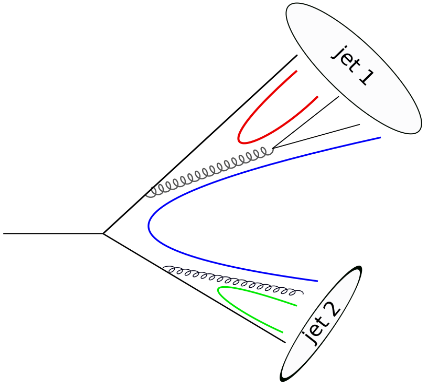


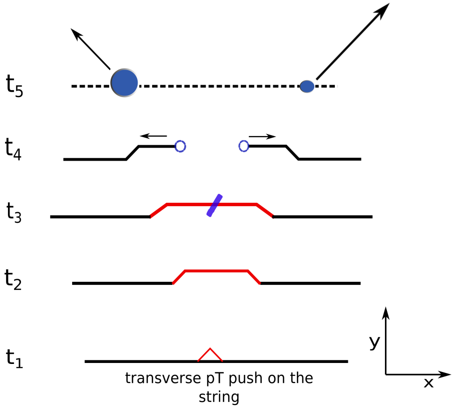
Figure: 1,2,3,4 are partons(string-ends), θ = opening angle, ϕ = skew angle.
Left: view from above. **Right**: Schematic view of two strings in the parallel frame

Role of parallel frames in jets



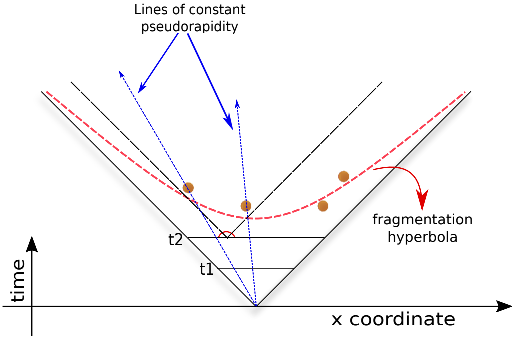
- Jets → quarks and gluons
- Interaction with partons following rule of least string length → modifies jets

3. 'Push' distribution among hadrons



- t_1 is earliest and t_5 is the latest time
- String extends in the longitudinal direction along x and the shoving kink is along y
- Kink extends over t_i
- String breaks following fragmentation function and the push is distributed following energy-momentum conservation

Parton vertices and hadronization



- Eg. a kink produced at t_2 will spread in a lightcone
- The hadrons produced in this lightcone will carry the pT push in a way such that they keep moving along their original pseudorapidity

PRELIMINARY RESULTS

Set 1: What are we looking at?

1. $S_N = \frac{1}{N(N-1)} \frac{d^2 N^{signal}}{d\Delta\phi d\Delta\eta}$

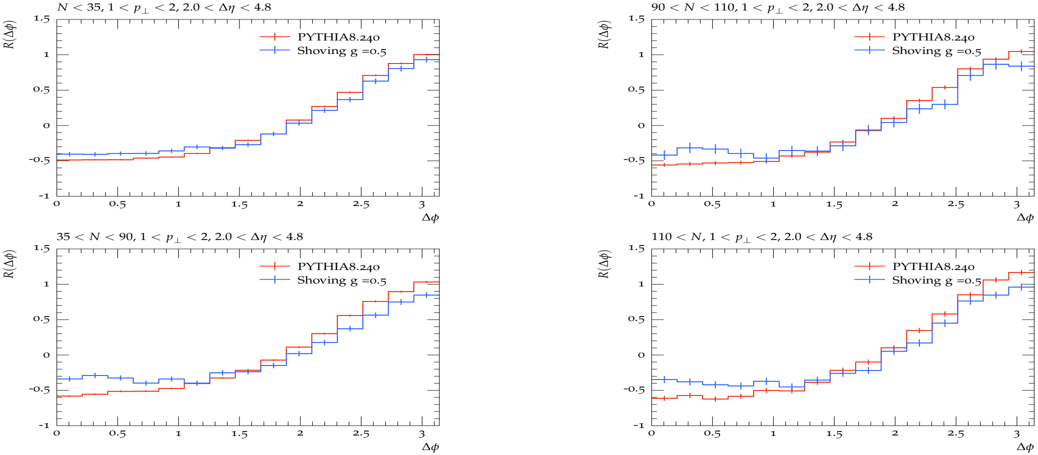
2. $B_N = \frac{1}{N^2} \frac{d^2 N^{mixed}}{d\Delta\phi d\Delta\eta}$

3. $\mathrm{R}(\phi) = \left\langle (\langle N \rangle - 1) \left(\frac{S_N}{B_N} - 1 \right) \right\rangle$

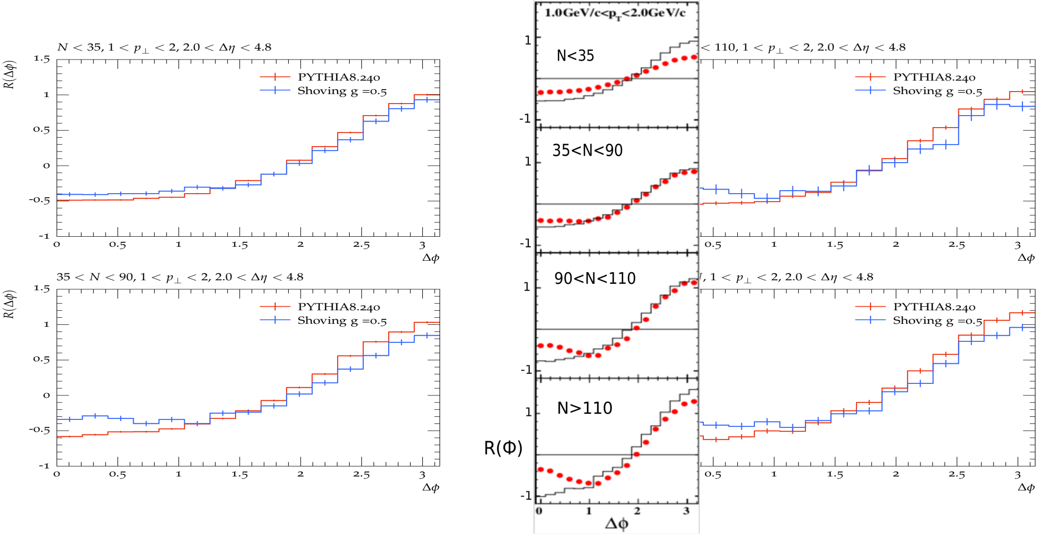
   where $<$N$>$ is the number of tracks per event averaged over the multiplicity bin, and the final $R(\Delta\eta, \Delta\phi)$ is found by averaging over multiplicity bins

4. Analysis follows from: CMS Collaboration, J. High Energ. Phys. 2010, 91 (2010)

Set 1: Di-hadron correlations in p-p at 7 TeV at minbias



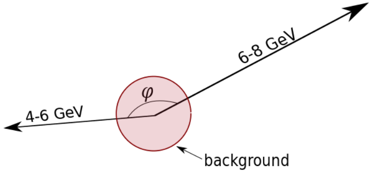
Di-hadron correlations in p-p at 7 TeV at minbias



CMS collaboration. J. High Energ. Phys. 2010, 91 (2010)

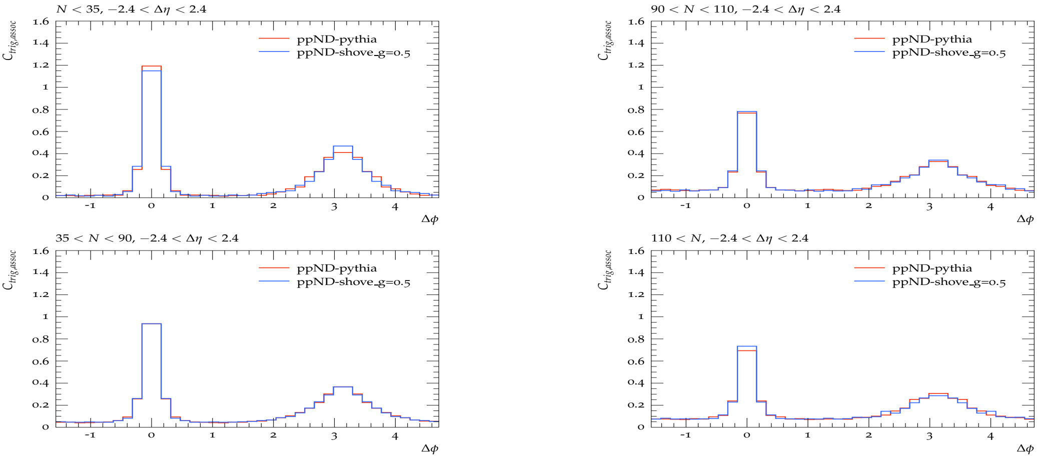
Set 2: Charged hadron correlation in p-p at 7 TeV

1. Pick charged hadron in $|\Delta\eta| < 2.4$ with 6 GeV $< p_T <$ 8 GeV
2. Pick associated charged hadron in $|\Delta\eta| < 2.4$ with 4 GeV $< p_T <$ 6 GeV



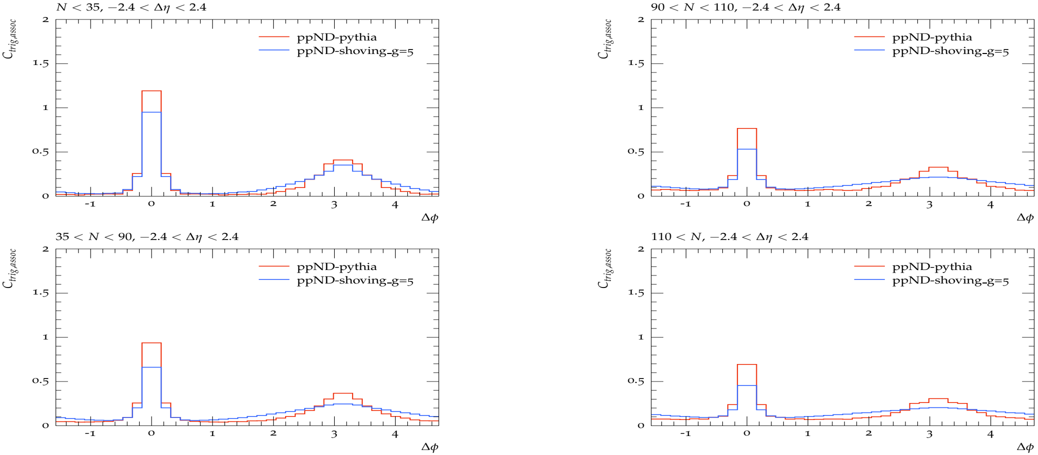
3. Calculate $\Delta\phi$ between high pT hadron and associated lower pT hadron
4. No background subtraction performed

Set 2: Charged hadron correlation in p-p at 7 TeV for g=0.5



No 'jet' suppression predicted in high-multiplicity p-p collisions

Set 2: Charged hadron correlation in p-p at 7 TeV for g=5



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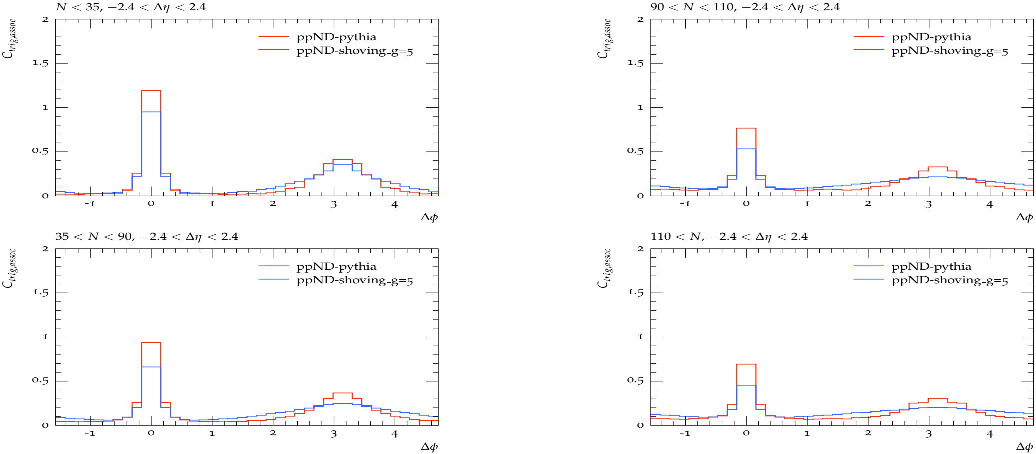
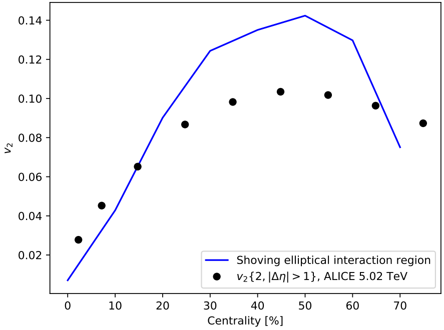


g=5 gives a feel about the shoving effects in jets in larger systems such as heavy-ion collisions even with g=0.5, hence shoving could contribute to some jet quenching effects

Set 3: v_2 in Pb-Pb at 5.02 TeV

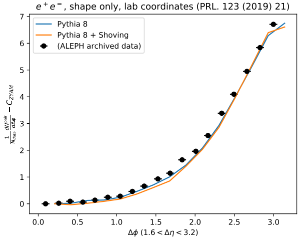
- Example case in Pb-Pb: initial state with long parallel strings
- Calculate force on a string cutting through such an environment
- Calculate v_2



* Christian Bierlich's plenary talk on Wednesday

Set 4: Two particle correlations in $e^+ - e^-$ at 91 GeV

- Applicable to all systems: the parallel frame allows shoving in e^+e^- geometries
- Recent re-analysed ALEPH data is important for cross checks



- Possibility of dedicated predictions for more elaborate observables
- Opportunities for FCC-ee with more statistics
- **Wanted: Rivet implementation of analyses with archived data**

Conclusions

1. Summary:

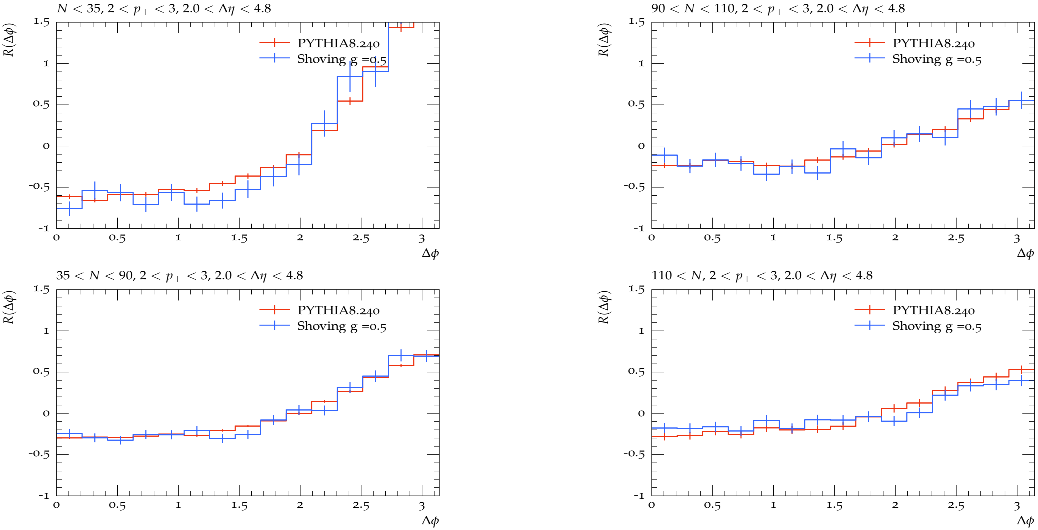
   - Parallel frame formalism extends the baseline to study jets including string interactions
   - Space-time dependent string width gives better grip in calculation of interaction force
   - Shoving gives an observable collective effect in high multiplicity p-p
   - Two particle correlations in high-pT hadrons do not predict any suppression in jets in string interaction picture

2. Coming soon:

   - Shoving in p-A and A-A systems
   - Jet observable analysis for p-A and A-A systems

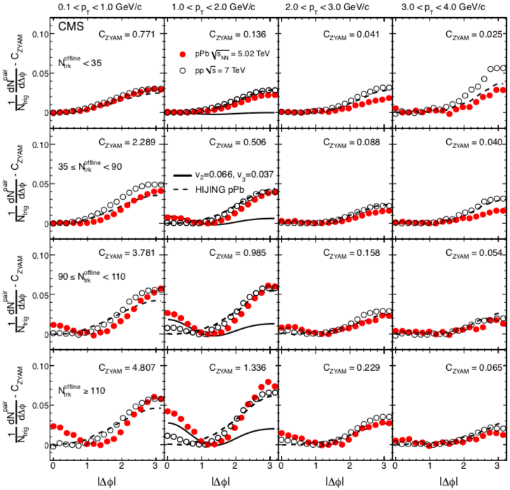
EXTRAS

Di-hadron correlations in p-p at 7 TeV



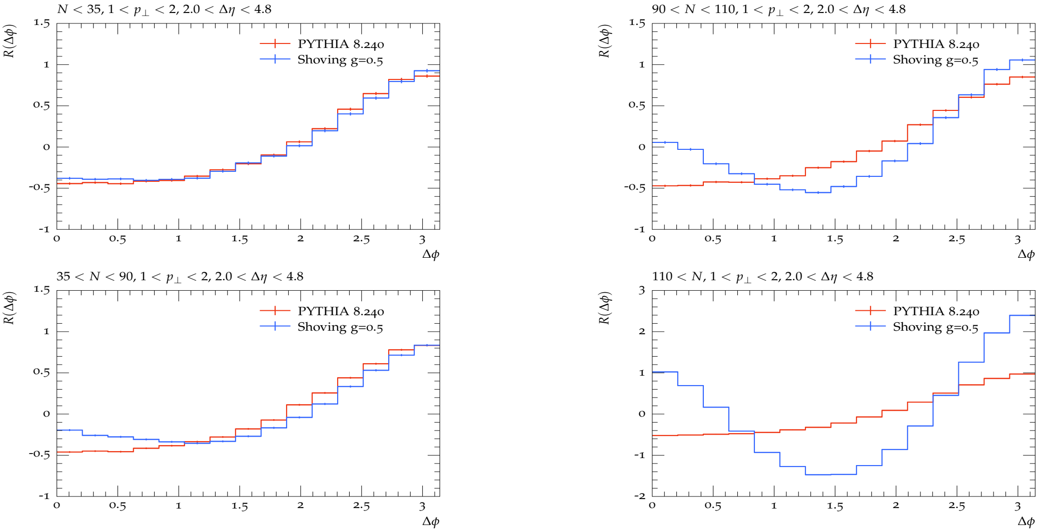
CMS collaboration. J. High Energ. Phys. 2010, 91 (2010)

Di-hadron correlations in p-Pb



CMS collaboration, Physics Letters B, Volume 718, Issue 3, 2013

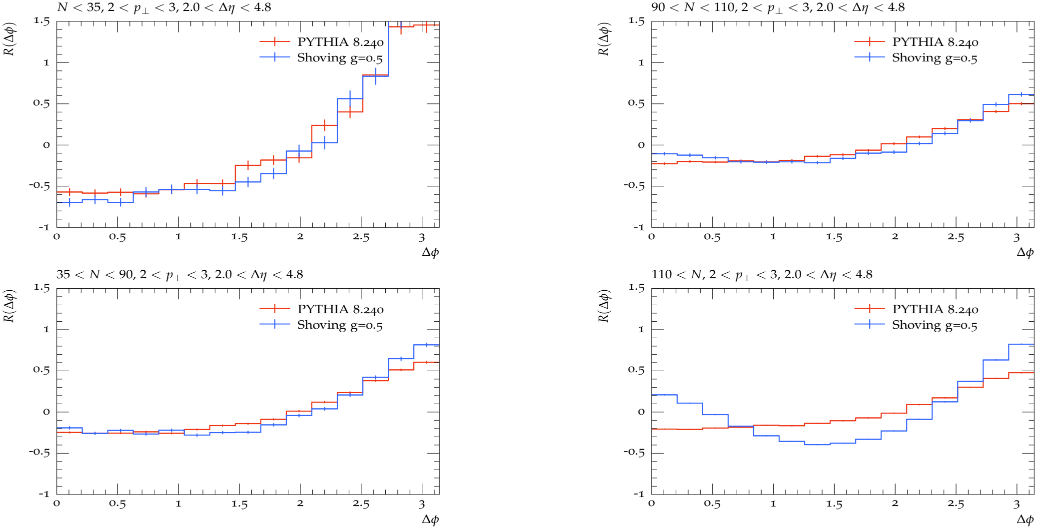
Di-hadron correlations in p-Pb



Note: Rivet analysis used is for p-p!

CMS collaboration, Physics Letters B, Volume 718, Issue 3, 2013

Di-hadron correlations in p-Pb



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