Measurement of jet cross-section and substructure in p+p collisions 200 GeV with the PHENIX experiment at RHIC

Alexandre Lebedev (Iowa State University)

for the PHENIX Collaboration

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PHENIX

Jets as a QCD Probe

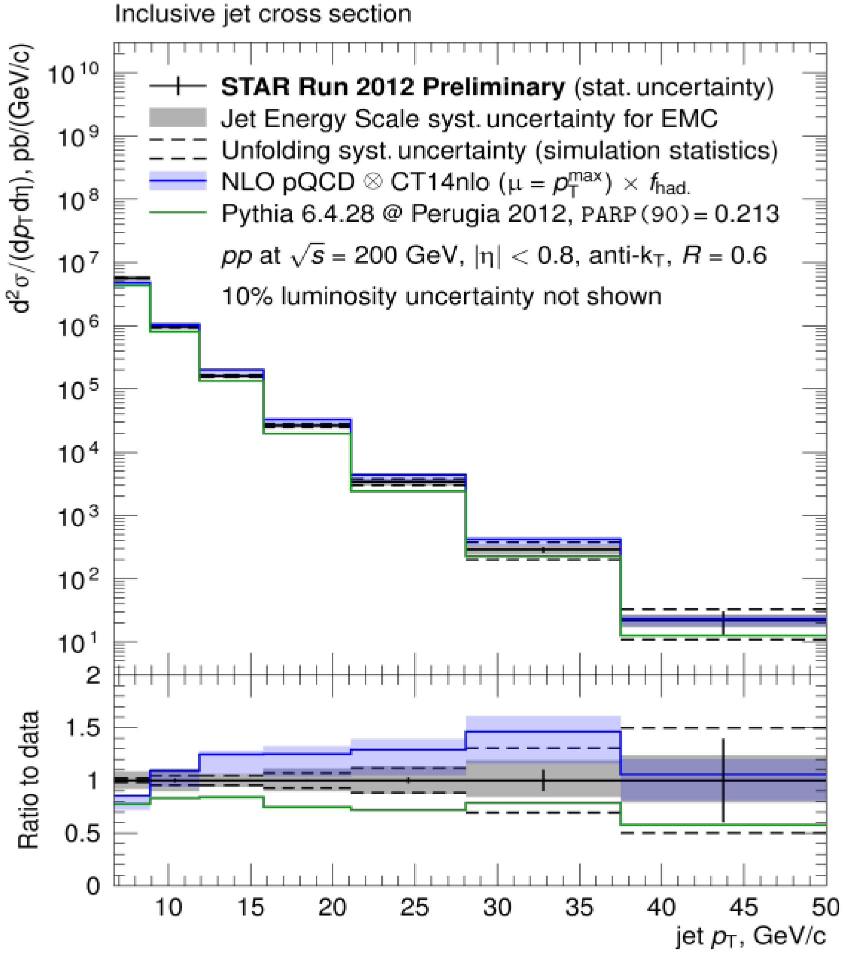
- High jet p_T and large R:
  - pQCD is broadly in good agreement with experiment.
- Lower jet p_T and small R:
  - need for good description of non-perturbative contributions, including pdf and hadronization process.
  - sensitive to UE, color reconnection, etc.
  - important for testing non-perturbative components of models of jet production.
- Study of energy distribution within jet (jet substructure):
  - single jet constituents – fragmentation function – hadronic level
  - groomed variables – subset of constituents – partonic level

Jets at RHIC energies give a good opportunity to study non-perturbative corrections.

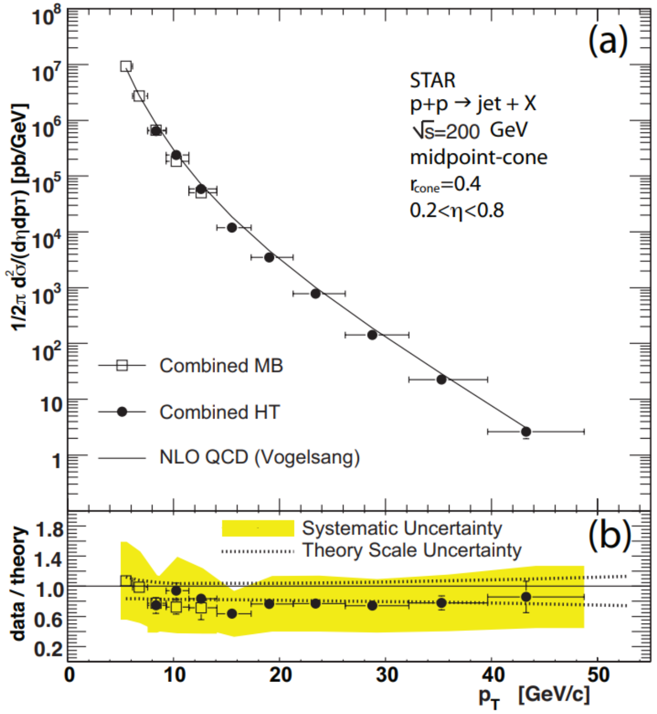
Jets in p+p collisions at RHIC

Jet cross-section and substructure at RHIC were studied in detail by STAR collaboration

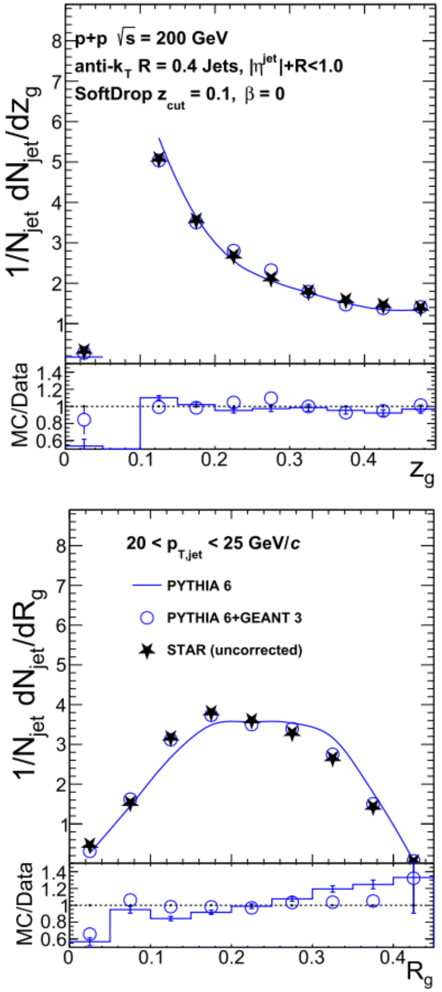
arXiv:2111.08149 (2021)



Phys. Rev. Lett. 97, 252001 (2006)



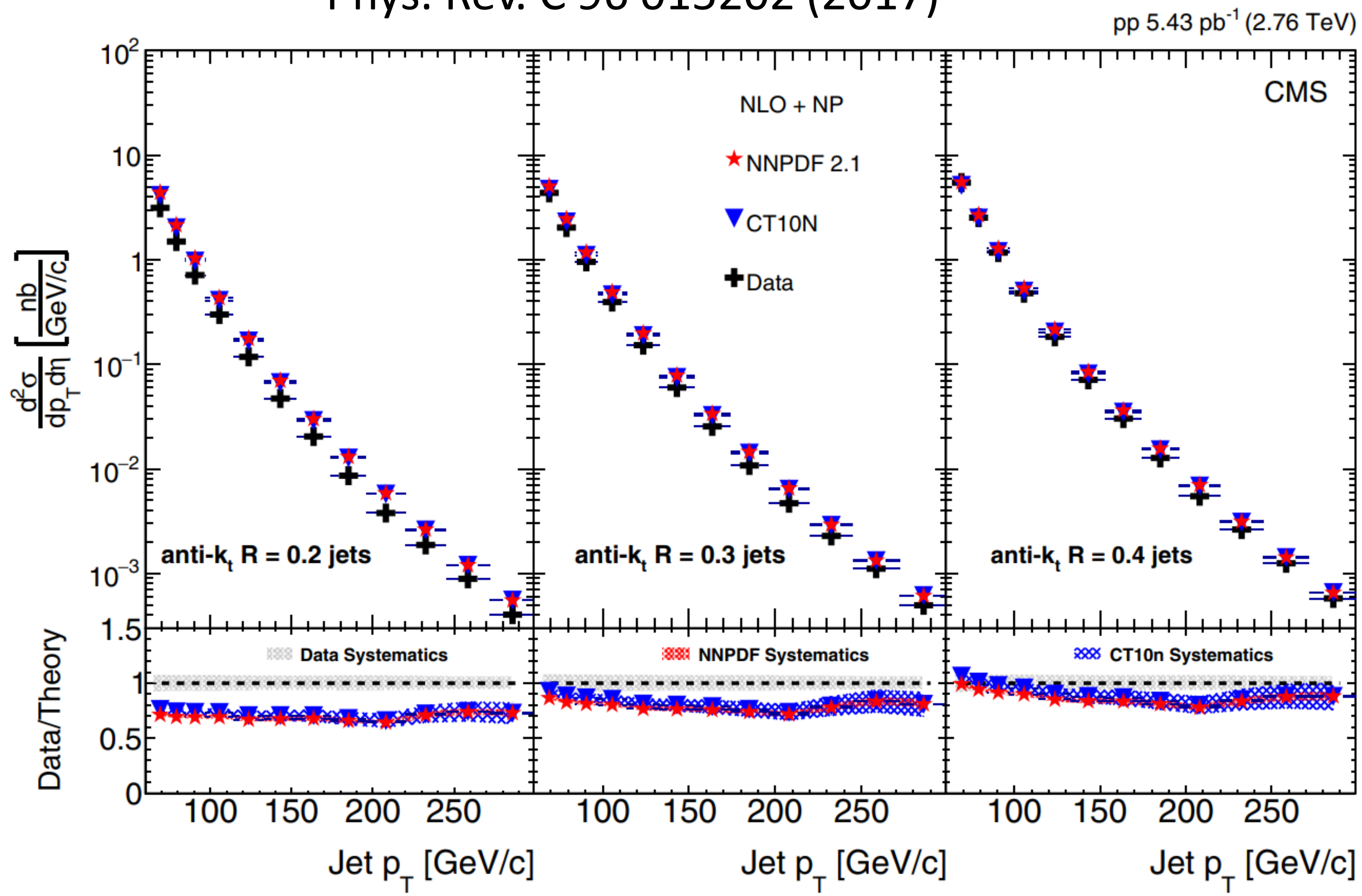
Phys. Lett. B 811 (2020) 135846



Jets in p+p collisions at LHC

Jets were extensively studied at LHC energies

Phys. Rev. C 96 015202 (2017)

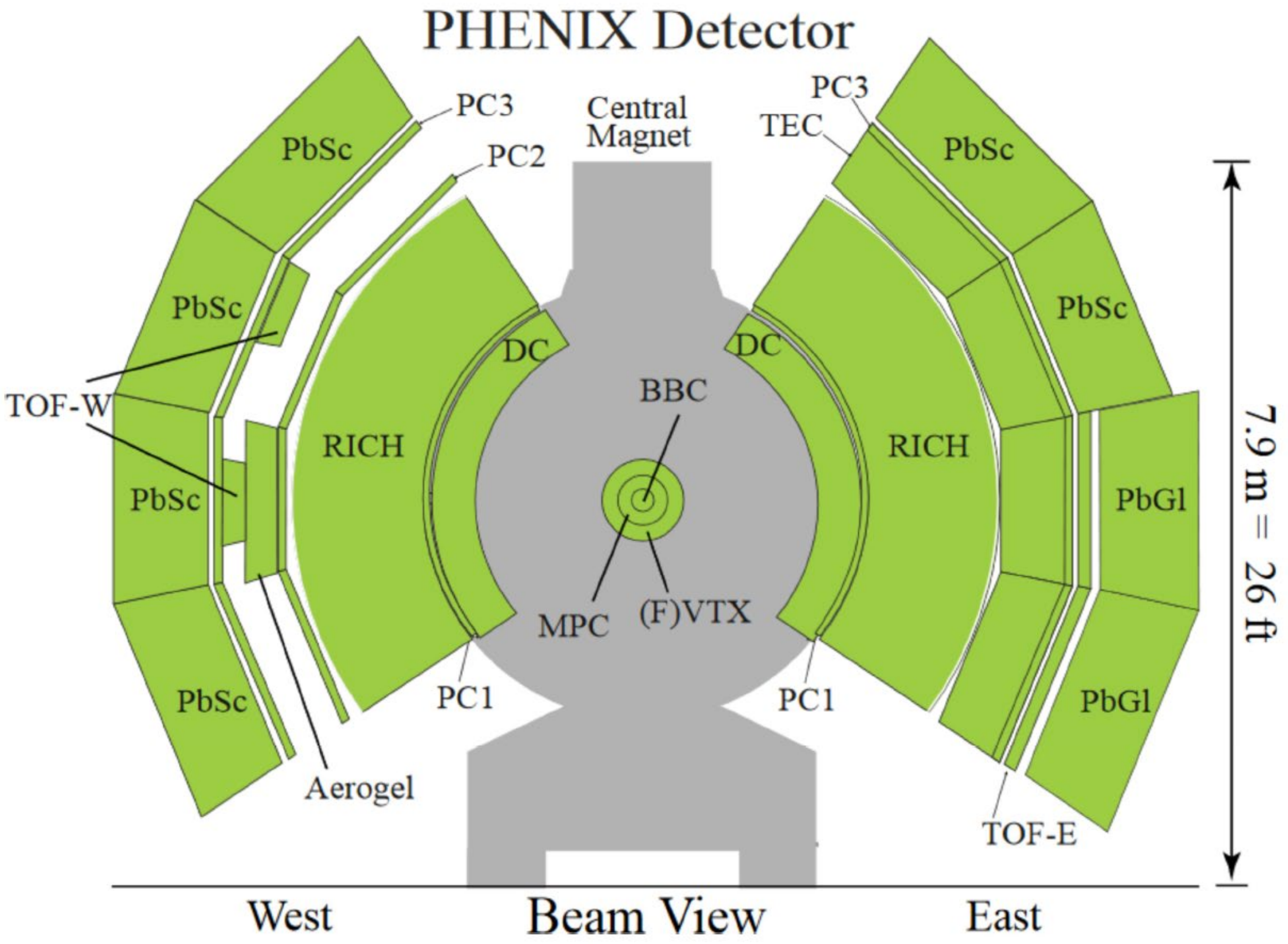


Small R anti-k_T jet cross-sections *are systematically lower than NLO predictions*.

Large R generally agrees better with NLO.

This seems to indicate that the distribution of particles in the jet is not accurately reproduced by NLO.

The PHENIX Detector



Two central arms
$|\eta| < 0.35$; $\phi \sim 90^o$

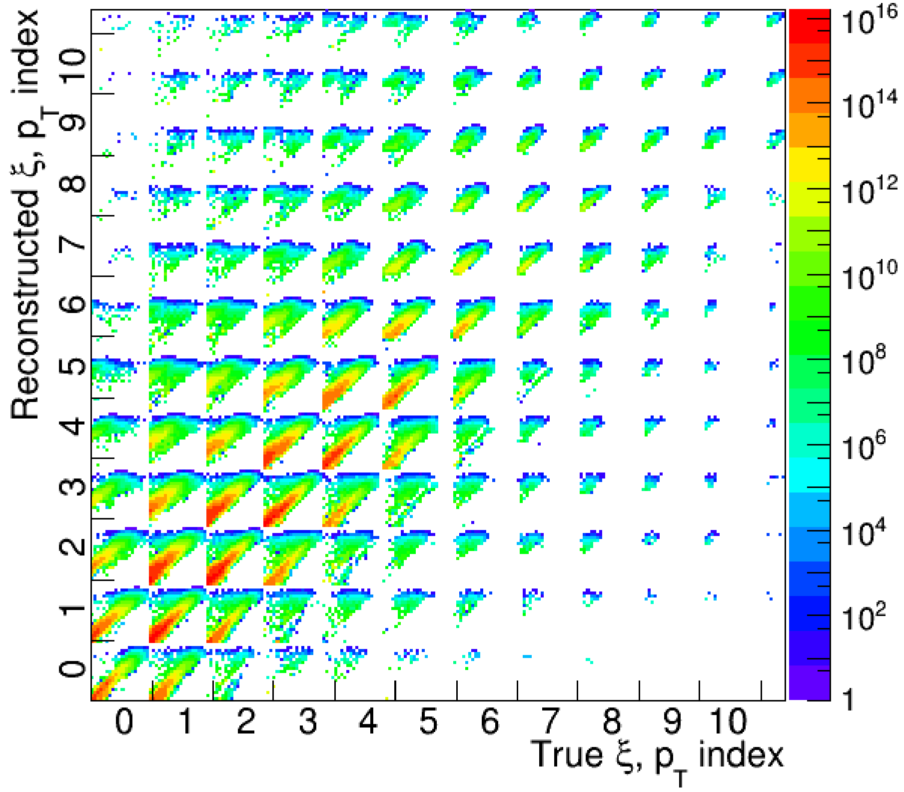
Drift and Pad Chambers track charged particles

EMCal for measuring EM energy and jet triggering

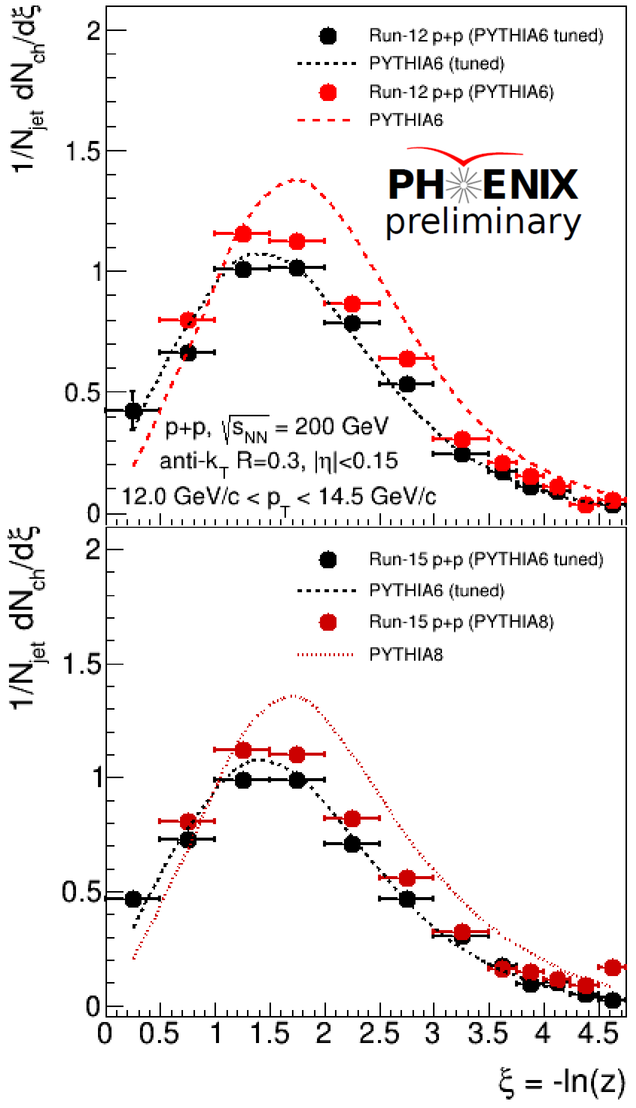
Limited acceptance
$\Rightarrow$ small R jets

Jet reconstruction in PHENIX

- FastJet anti-k_T algorithm with small R (R = 0.2,0.3)
- Tracks with p_T > 0.5 GeV and EMCal clusters with E > 0.5 GeV
  - *Jet level cuts: $0.3 < c_f < 0.7$; $n_c > 2$; $p_T^{reco} > 5$ GeV*
- Bayesian unfolding takes into account missing energy, bin migration, etc.
  - *RooUnfold package used*
- Unfolding matrix:
  - PYTHIA6 tune A with extra tuning to match PHENIX data better
  - Detector response simulated by GEANT3
  - For jet substructure distribution unfolding is done in a more complicated way.



PYTHIA tuning to match PHENIX data



Initial unfolding showed that integrals of the jet substructure distributions (avg. number of jet constituents) are systematically larger in PYTHIA than in the data for all distributions.

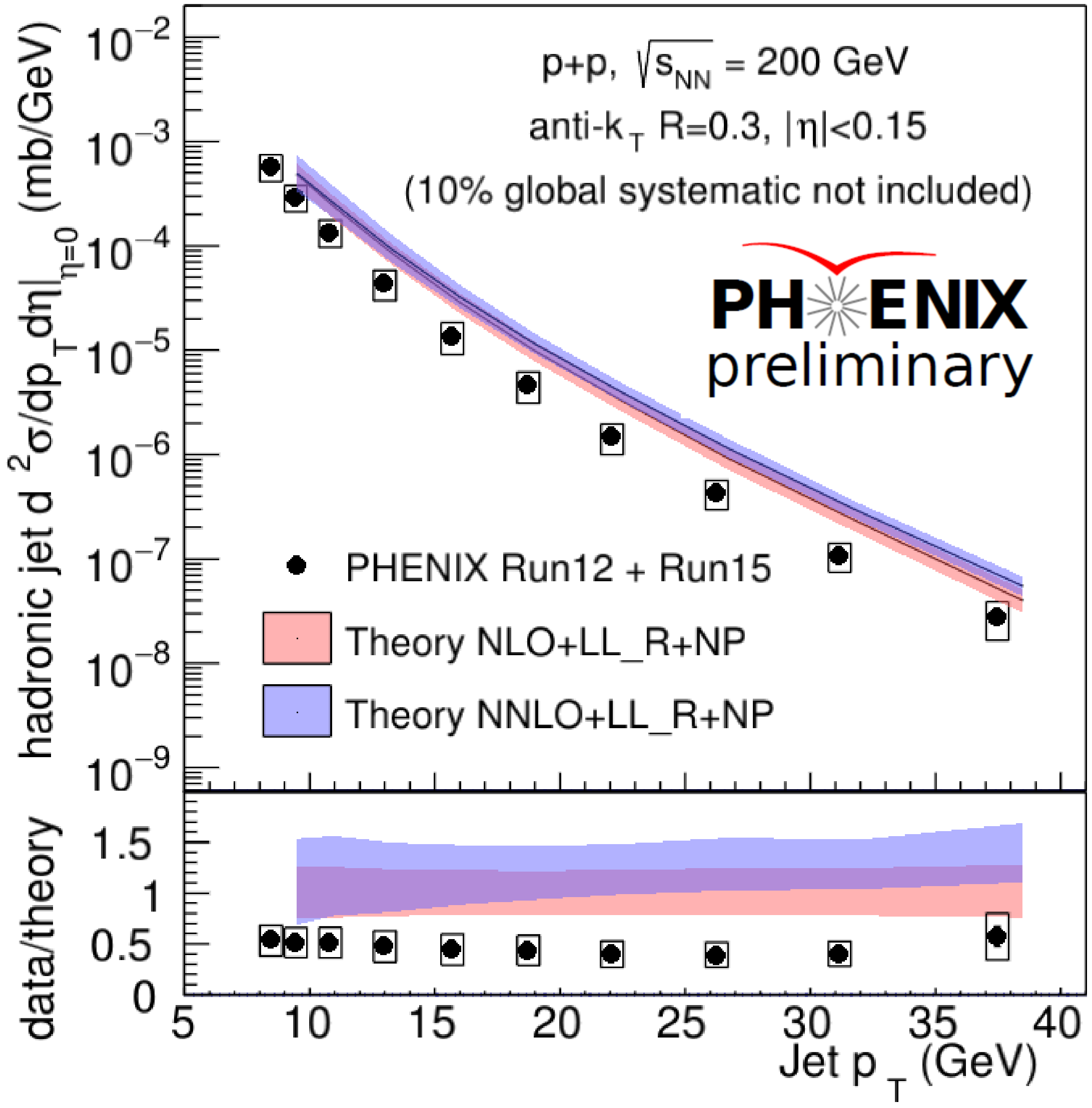
Similar for both PYTHIA6 and PYTHIA8.

Produces biased and inconsistent unfolding results.

“Tune” PYTHIA by randomly removing truth jet constituents until PYTHIA and data match.

Does not affect jet cross-section.

Jets cross-section by PHENIX



Both NLO and NNLO overpredicts data

Same trend as STAR data comparison to NLO without LL_R

At LHC, NLO predictions overestimate the jet cross section at small R, while the agreement is better at larger values of R.

The difference indicates importance of non-perturbative corrections at low jet p_T and R.

Theory bands:
Private communication from G. Soyez based on:
Phys. Lett. **B378**, 287 (1996) ; Nucl. Phys. **B485**, 291 (1997); JHEP **04**, 039 (2015)

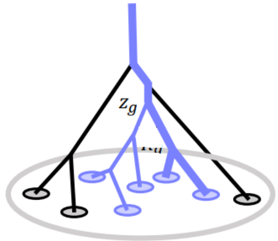
Obtained by matching the NLO and NNLO predictions to leading-logarithmic re-summation in the jet radius non-perturbative corrections from MC simulations averaging over several MC setups.

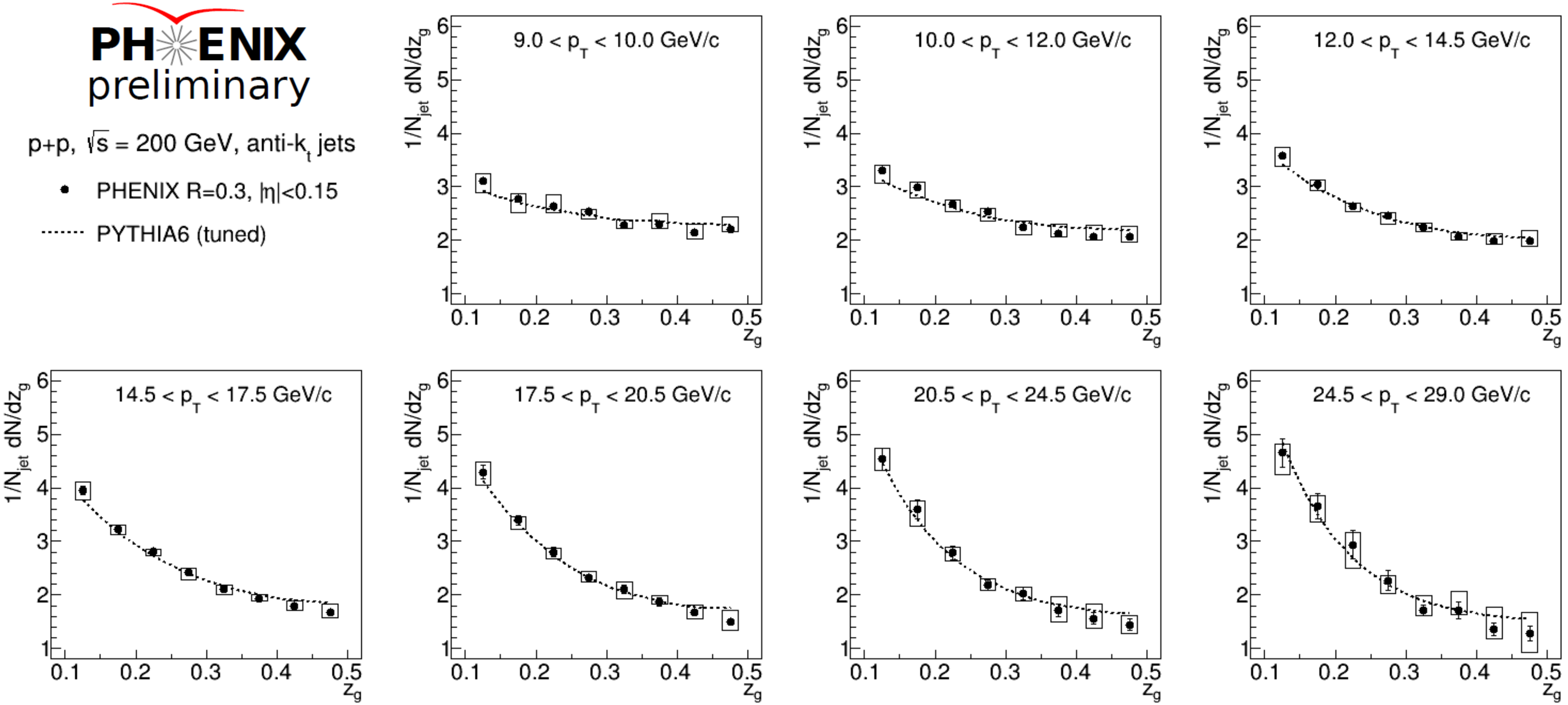
z_g distribution

SoftDrop groomed momentum fraction with z_{cut}=0.1 and β_{SD}=0

$$z_g \stackrel{\text{def}}{=} \frac{\min(p_T^1, p_T^2)}{p_T^1 + p_T^2} > z_{cut} \left(\frac{\Delta R_{12}}{R}\right)^{\beta_{SD}}$$

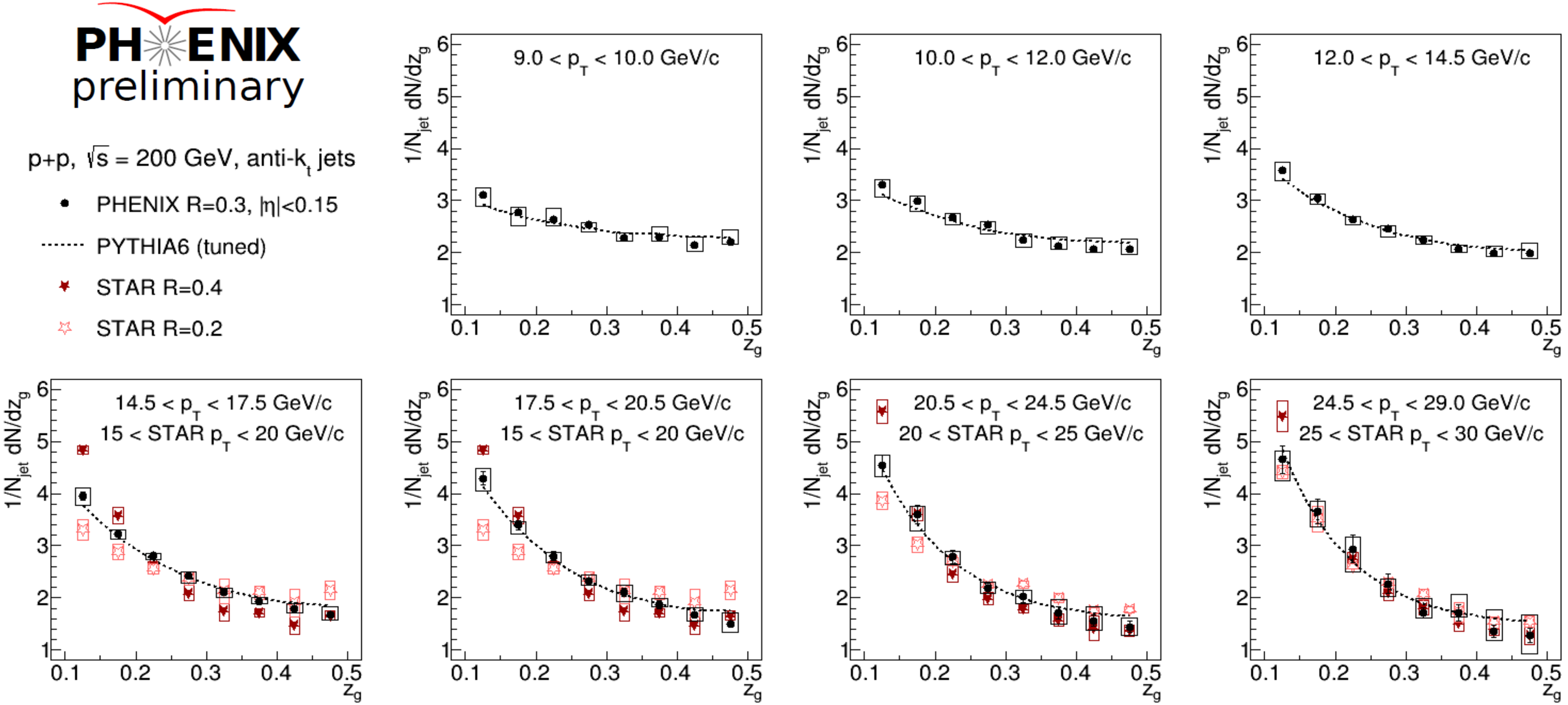
$$R_g \stackrel{\text{def}}{=} \Delta R_{12}$$





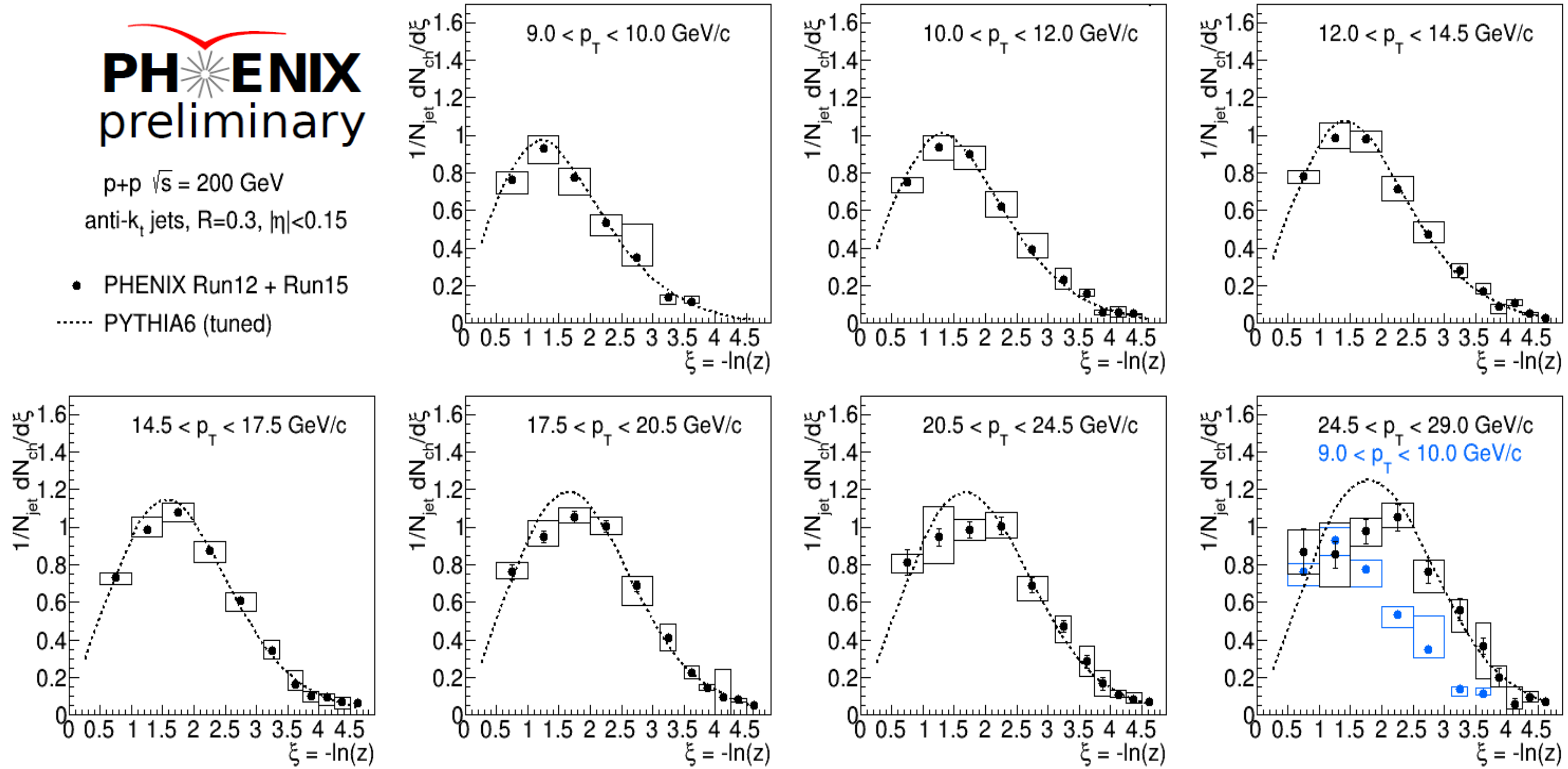
z_g distribution

- Good agreement with STAR results from Phys. Lett. B 811, 135846 (2020)
- Note different R for STAR and PHENIX
- Shift to lower z_g with increasing jet p_T

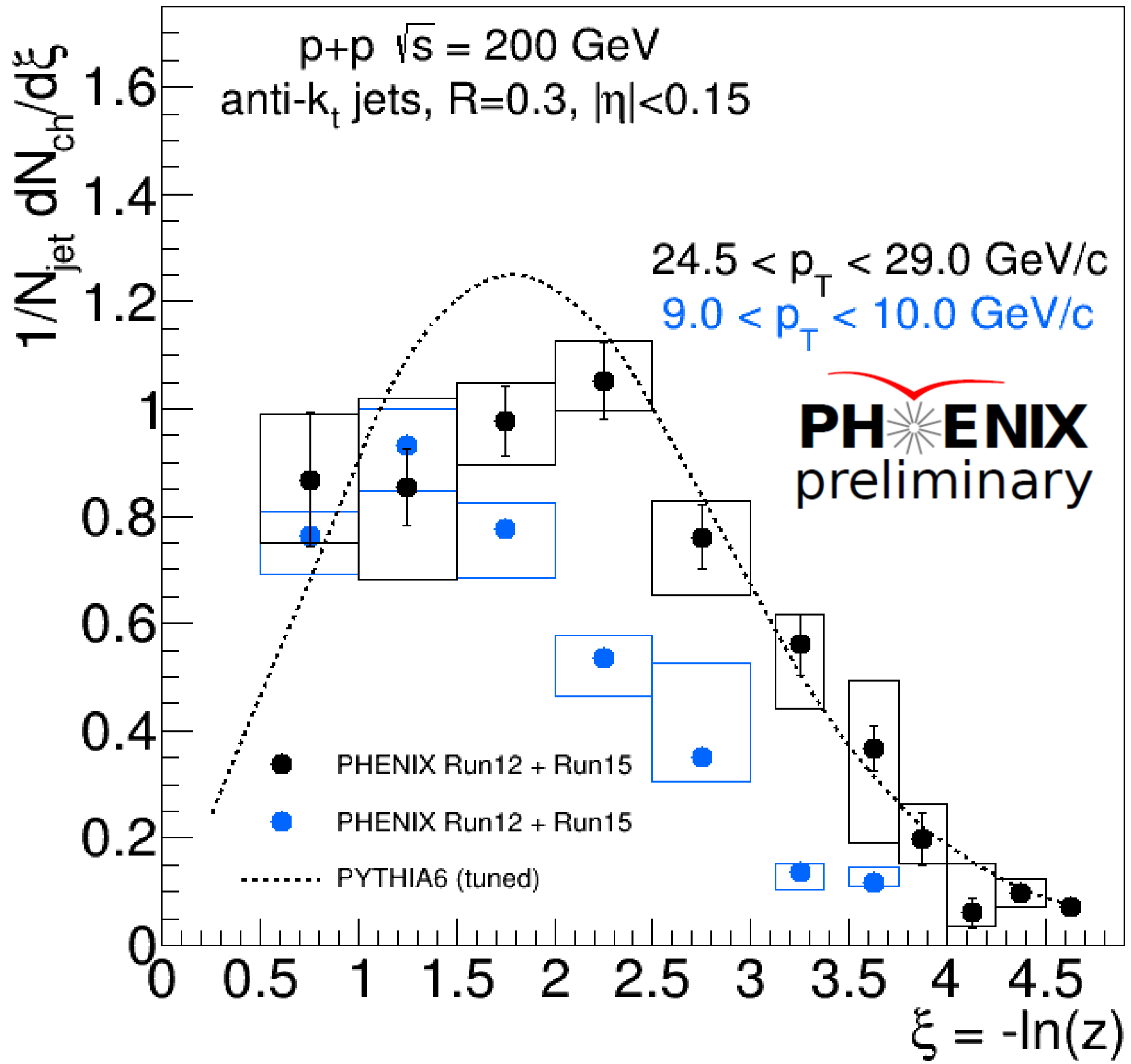


ξ distribution

The distribution of the variable $\xi = -\ln(z)$ for charged particles, where z is the fraction of the jet momentum carried by the charged particle.



ξ distribution dependence on jet p_T

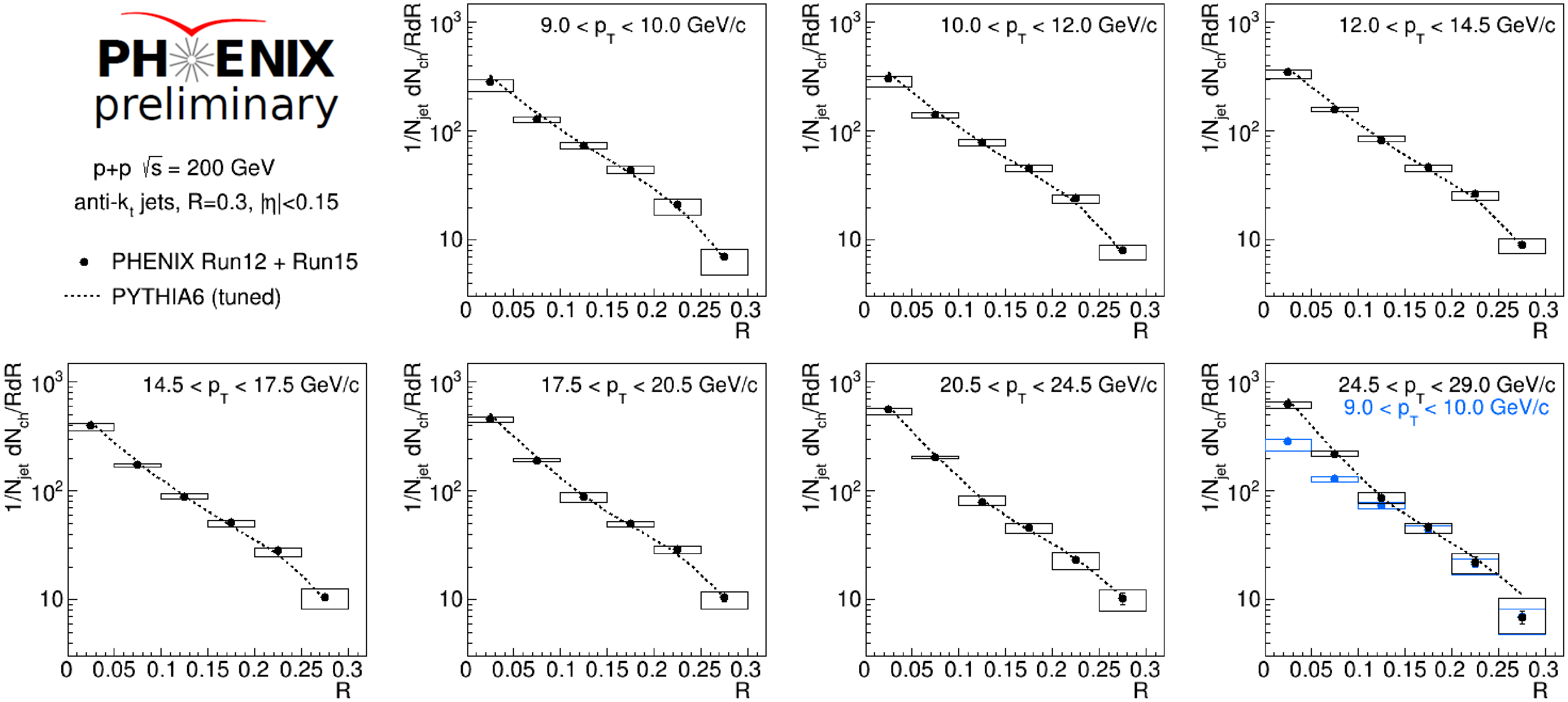


ξ distribution shifts toward lower momentum fraction carried by a jet constituent with increasing jet p_T

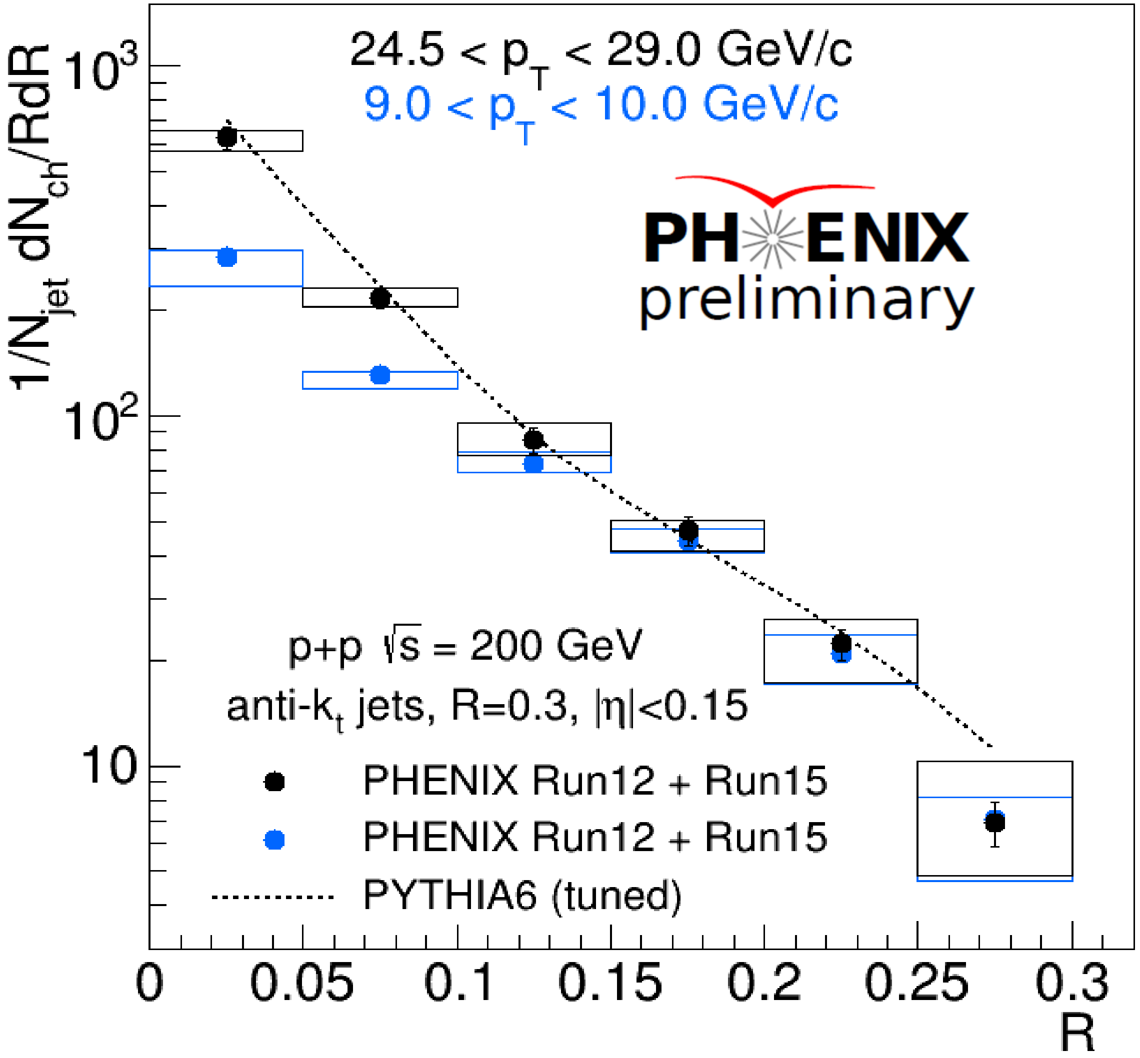
The trend is similar to z_g
but this is a "per constituent" variable.
Hadronic level vs partonic level

R distribution

Angular distribution of charged particles within the jet with respect to the jet axis $R = \sqrt{\Delta\varphi^2 + \Delta\eta^2}$



R distribution vs. jet p_T



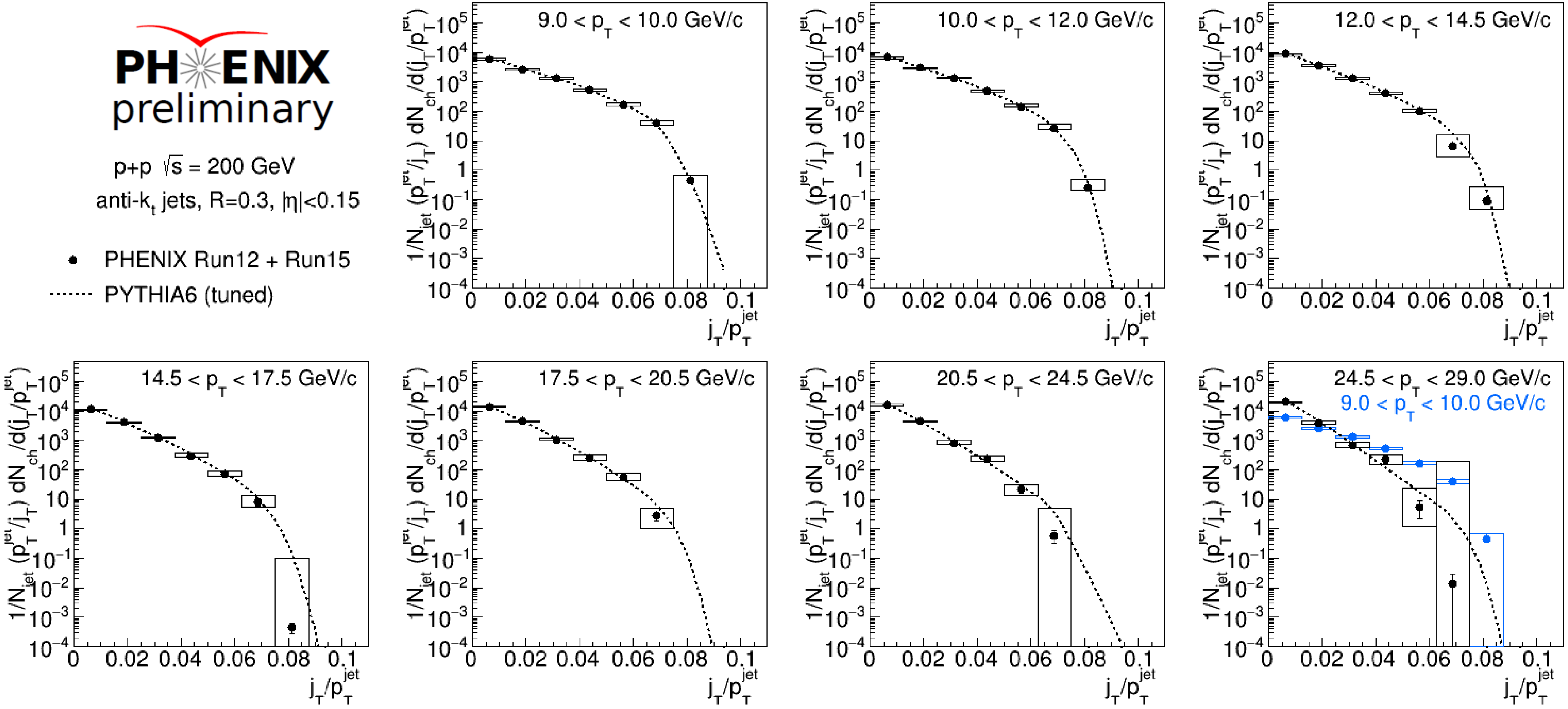
Not a groomed variable

Significant increase at low R with increasing jet p_T

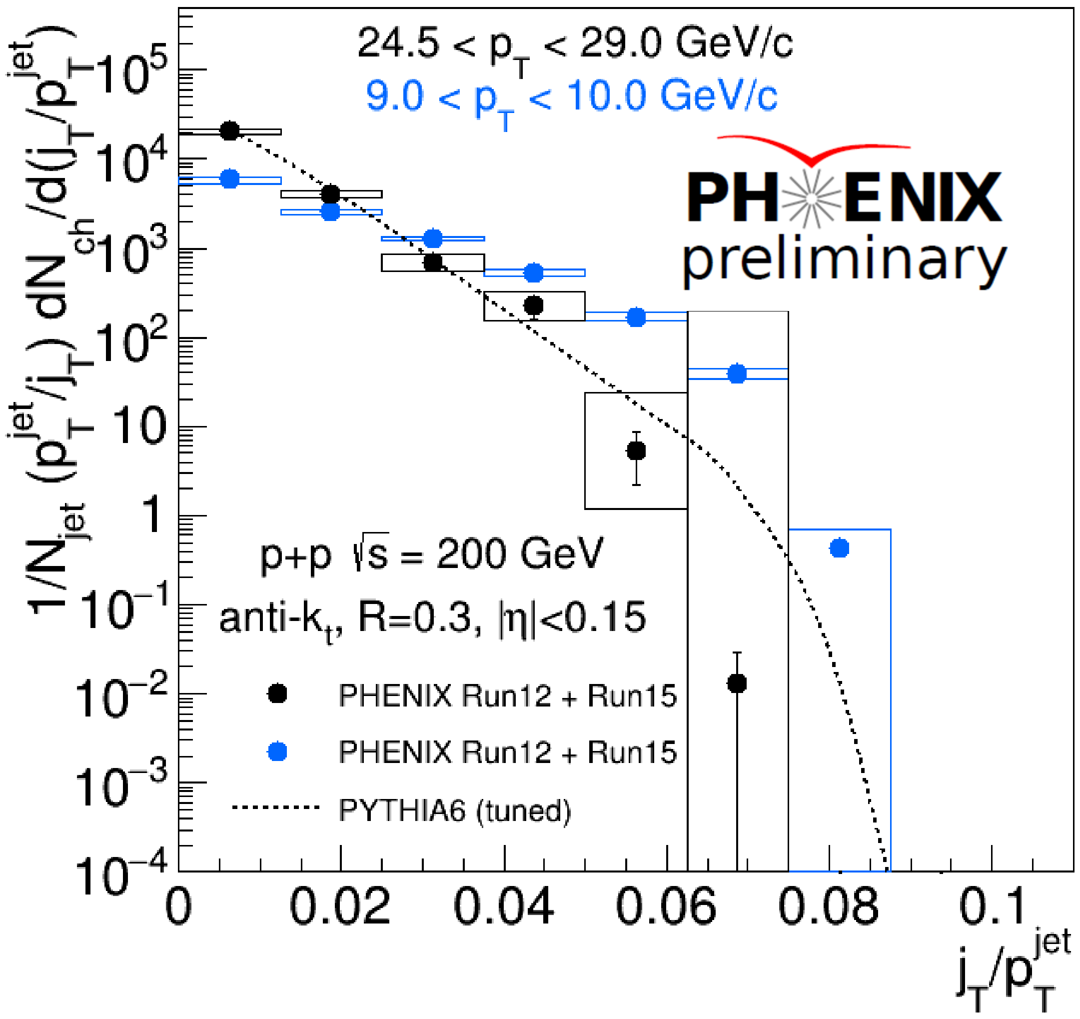
"Hard core" is developing, consistent with an increasing fraction of quark jets at higher jet p_T

j_T/p_T^{jet} distribution

The distribution of the charged particle transverse momentum j_T with respect to the jet axis normalized by jet p_T.



j_T/p_T^{jet} vs. jet p_T



Distribution gets more steep with less high j_T constituents as jet p_T increases.

Consistent with ξ and R distributions. Shows redistribution of momentum from transverse to longitudinal component with increasing jet p_T.

Conclusions

The PHENIX experiment has measured jet cross-section and jet substructure distributions in p+p collisions at $\sqrt{s}$ = 200 GeV

- anti-k_T jets with R=0.3 and $8.0 < p_T^{jet} < 40.0$ GeV and $|\eta^{jet}| < 0.15$

NLO/NNLO predictions are higher than the measured cross-section

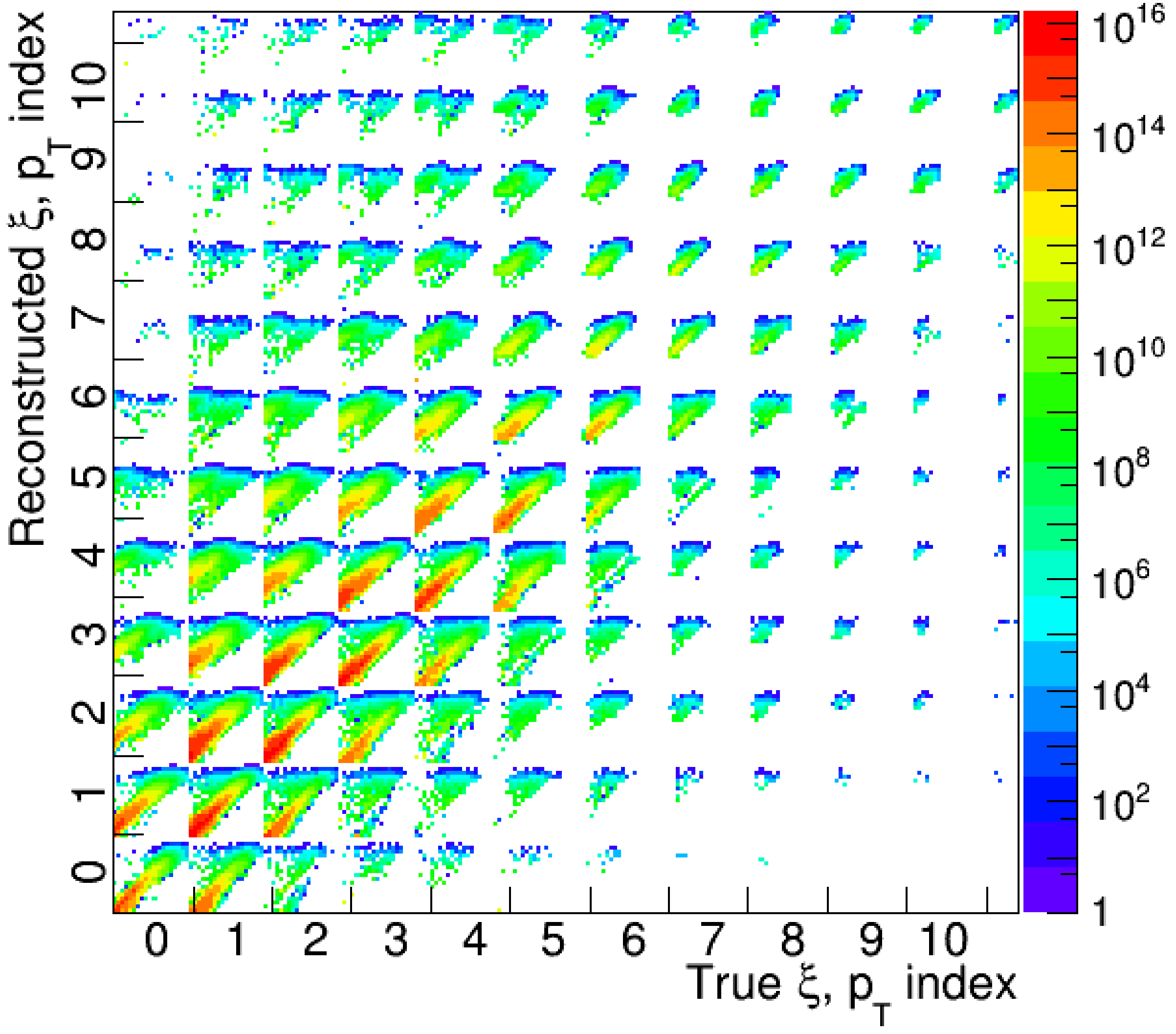
- may indicate a limitation of the procedure used to translate from the partonic to the hadronic cross-section, that is, non-perturbative corrections.

We presented unfolded distributions of z_g, ξ, j_T/p_T^{jet} and R in jets

- The unfolding indicates a lower average charged particle multiplicity in the PHENIX data than in the PYTHIA event generators.
- z_g agrees well with STAR and becomes steeper with jet p_T
- ξ distribution shifts toward lower momentum fraction
- R distribution shows increase at small R with increasing jet p_T
- j_T/p_T^{jet} gets more steep, indicating, together with ξ and R redistribution of momentum from transverse to longitudinal component with increasing jet p_T

Backup slides

Two-dimensional unfolding for jet substructure distributions



Example of 2D unfolding matrix for ξ distribution
(ξ = -ln(z) where z is the fraction of jet momentum carried by a jet constituent)

A set of one-dimensional unfolding matrices in jet p_T bins

Simultaneous unfolding in ξ and jet p_T

Run12 vs. Run15