Exploring the Underlying Event and Hadronization Using Di-jets at STAR

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for the STAR Collaboration

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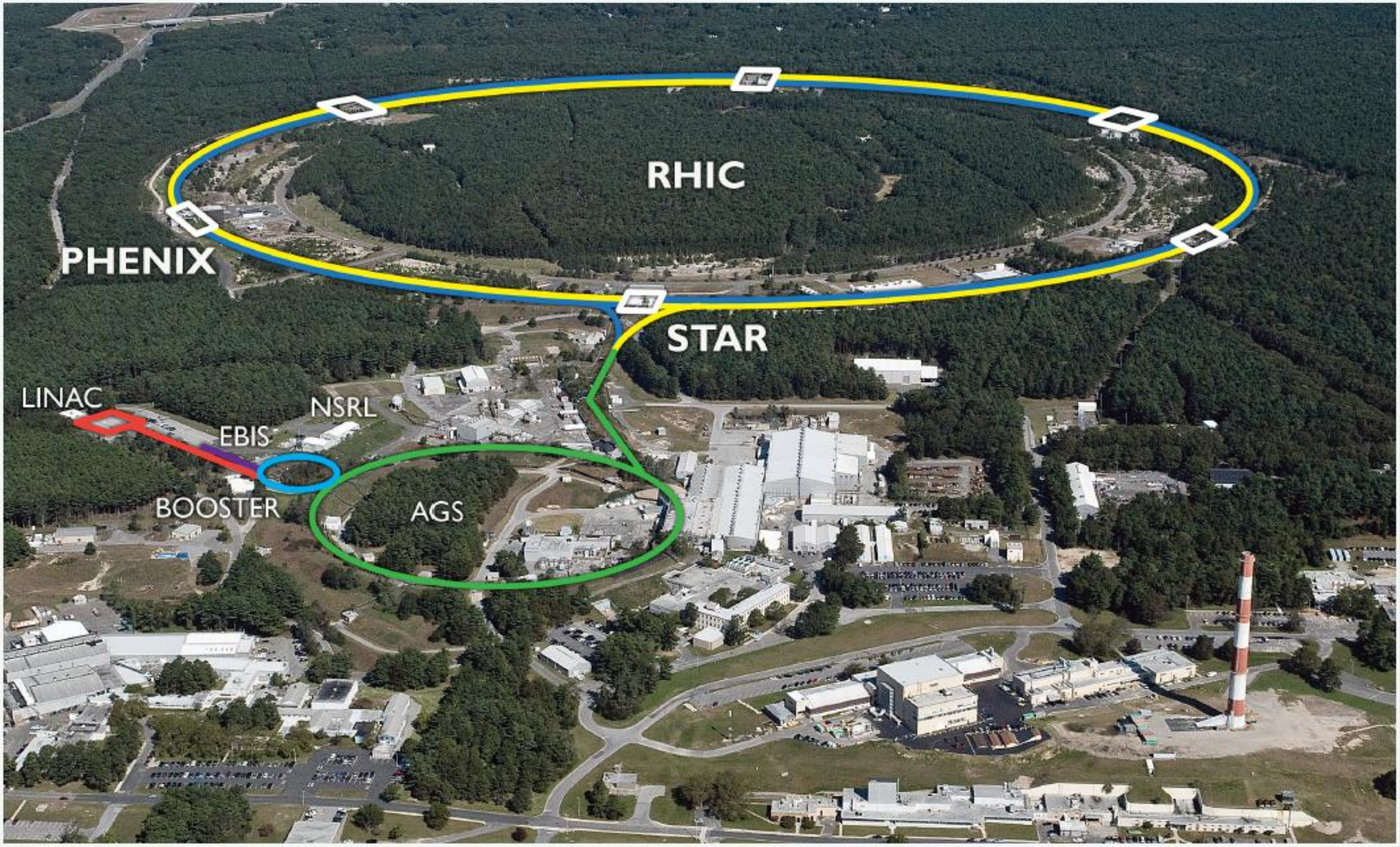
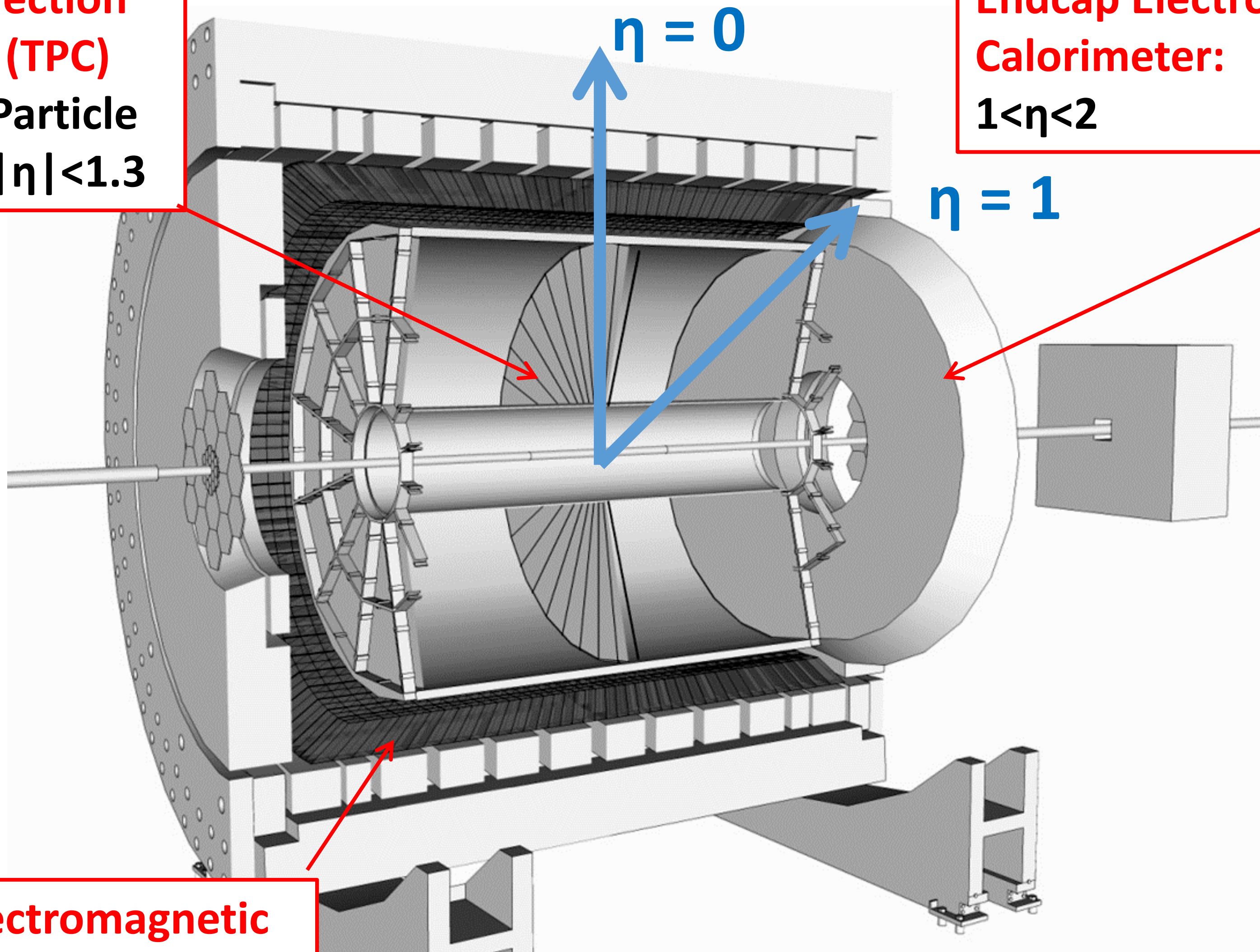
Outline

- Overview of RHIC and STAR
- Jet / Di-jet Reconstruction at STAR
- PYTHIA studies of di-jet sensitivity to underlying event and hadronization effects

RHIC: First Polarized pp Collider

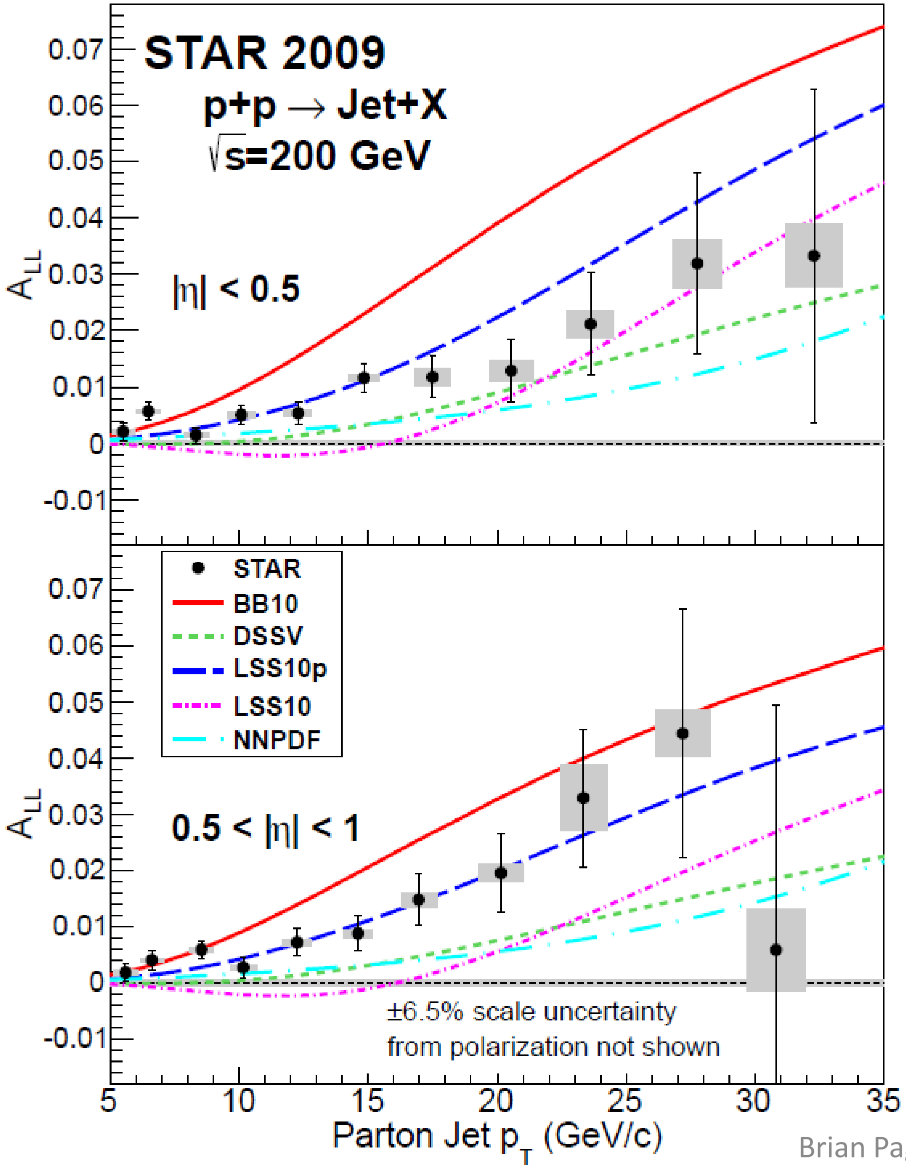


The STAR Detector

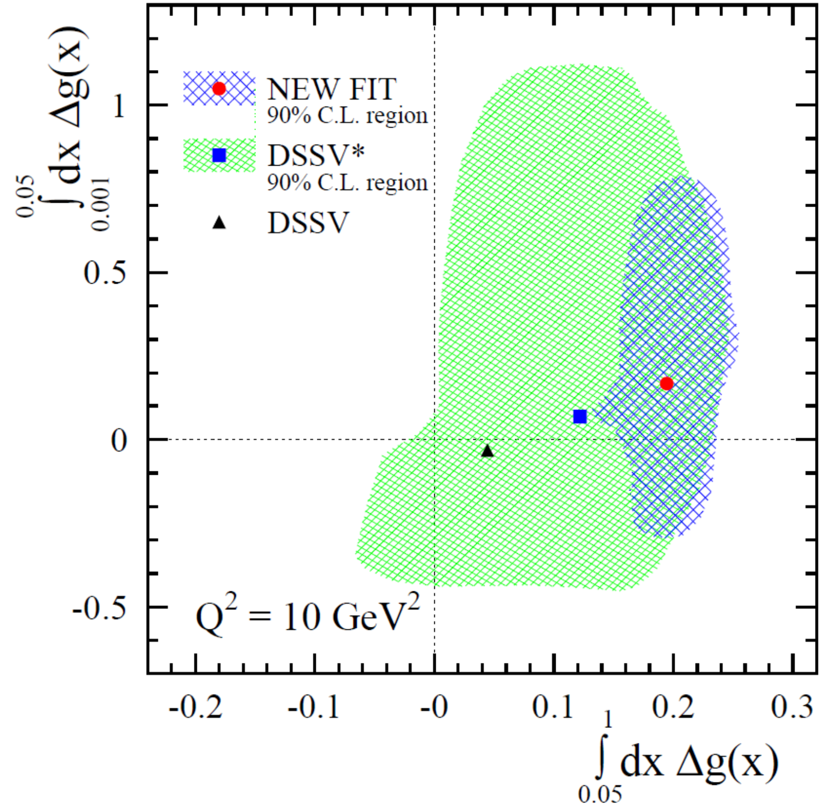


Probing ΔG: Inclusive Jet A_{LL}

Phys. Rev. Lett. 115, 92002

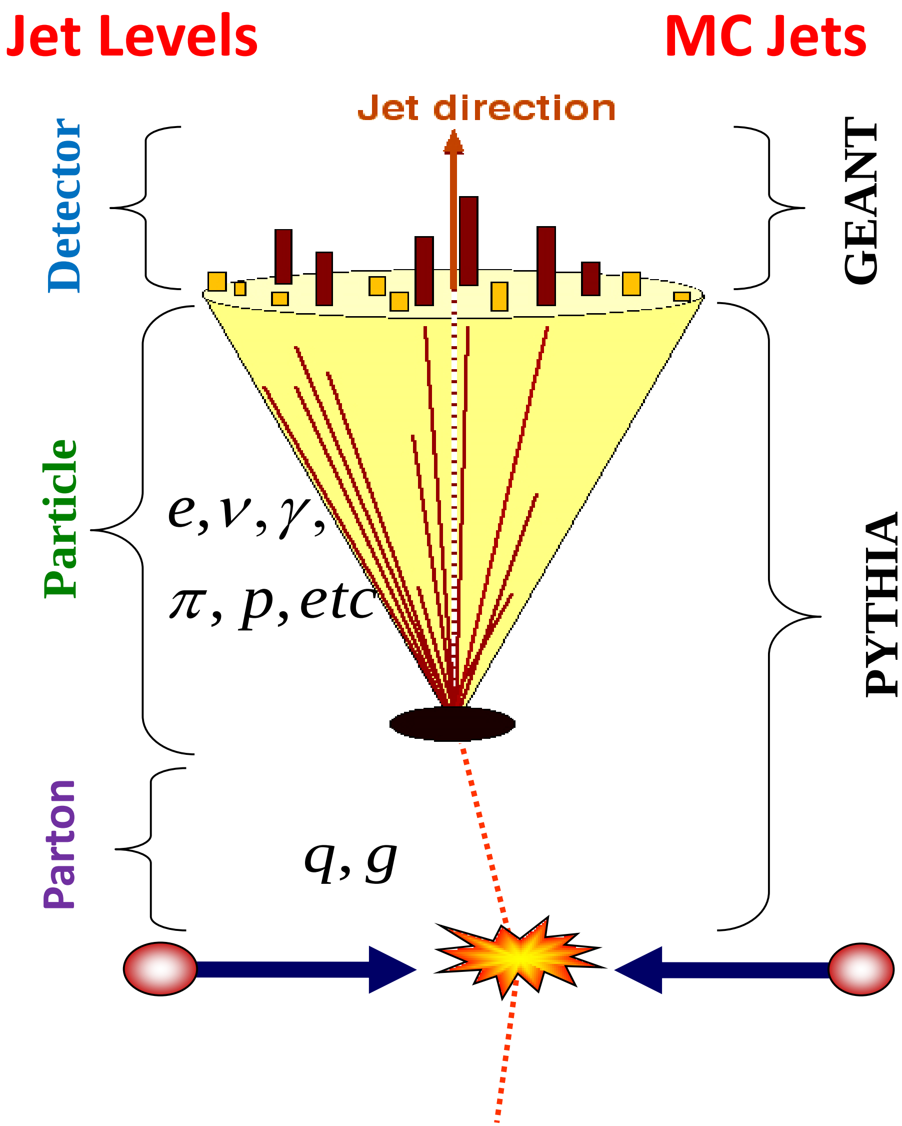


Phys. Rev. Lett. 113, 012001



- Latest A_{LL} results from RHIC (inclusive jets from STAR & inclusive π^0 from PHENIX) have been included in global fits by DSSV and NNPDF groups and give evidence of first non-zero values of gluon polarization in x range above 0.05

Jet Reconstruction



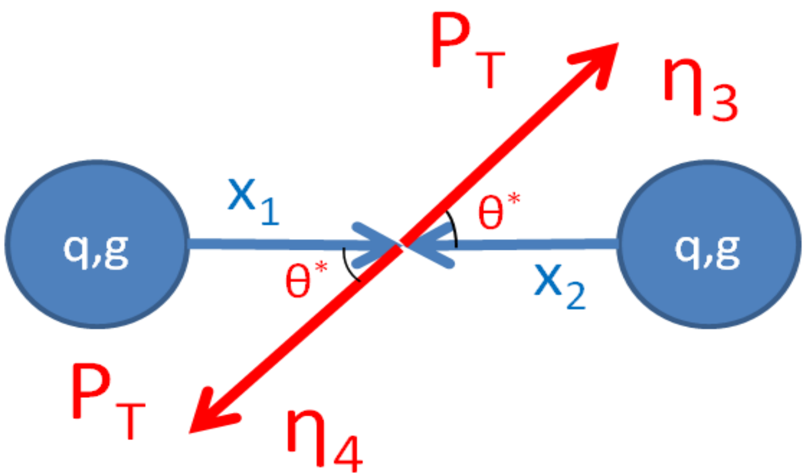
Anti-kT Algorithm:

- Radius = 0.6
- E-Scheme recombination
- Less sensitive to underlying event and pile-up effects
- Implemented using FastJet
- Used in both data and simulation

Jet Levels:

- Jets reconstructed at 3 levels – Detector, Particle, and Parton
- Detector jets constructed from charged particle tracks (assumed to have pion mass) and EMC tower energy deposits (assumed to have zero mass)
- Particle jets constructed from all final state particles (particles have correct mass)
- Parton jets constructed from partons originating with hard interaction and ISR / FSR

Beyond Inclusive Measures: Di-jets



$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{-\eta_3} + p_{T4}e^{-\eta_4}\right)$$

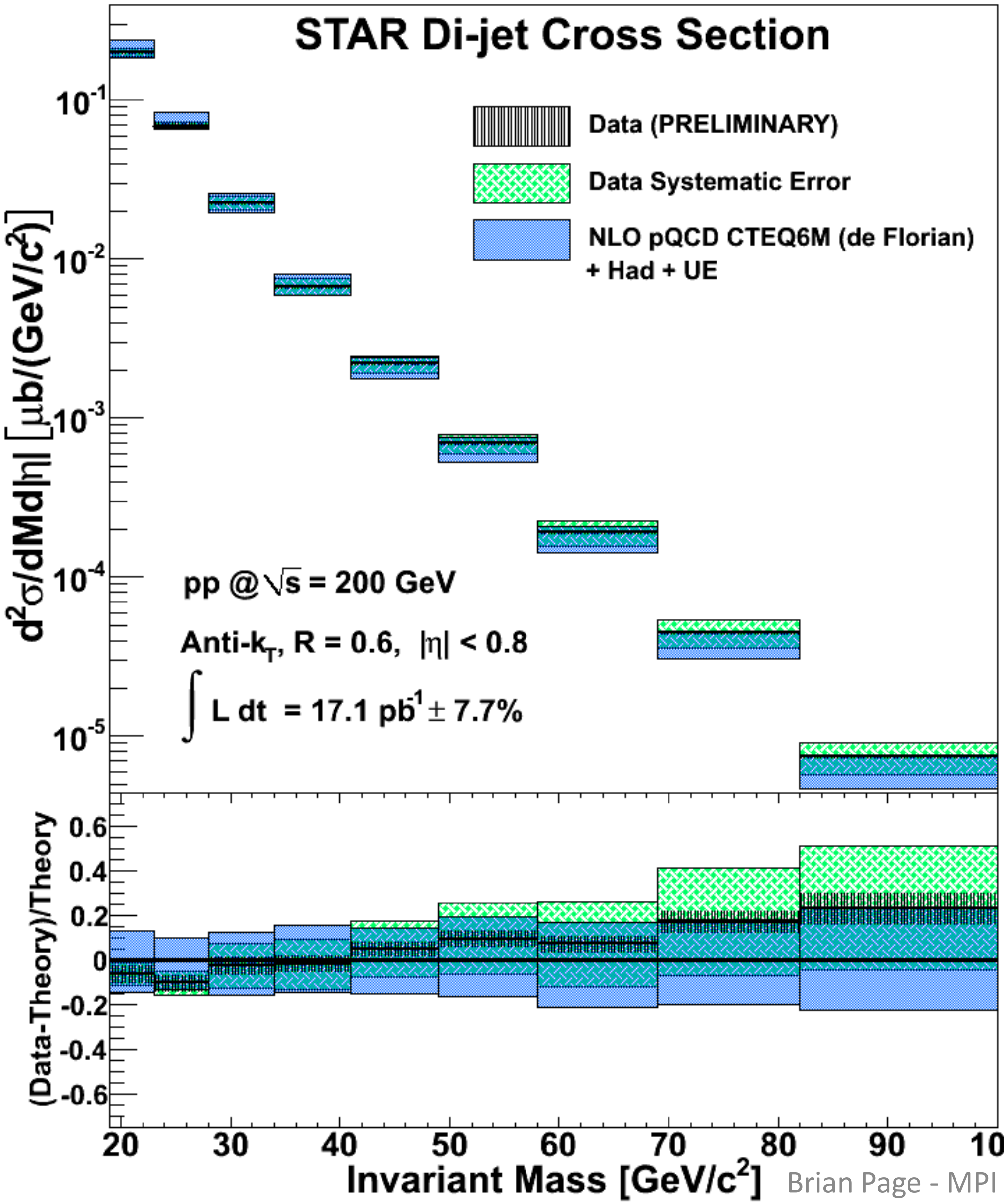
$$M = \sqrt{x_1 x_2 s}$$

$$\eta_3 + \eta_4 = \ln\frac{x_1}{x_2}$$

$$|\cos\theta^*| = \tanh\left|\frac{\eta_3 - \eta_4}{2}\right|$$

- Correlation measurements such as di-jets capture more information from the hard scattering – di-jet A_{LL} may place better constraints on the functional form of $\Delta g(x,Q^2)$
- Agreement between measured di-jet cross section and theoretical calculation gives confidence that observable is understood at STAR
- Realized that it may be possible to use the di-jet cross section to probe underlying event and hadronization effects due to the dependence of the di-jet mass on individual jet masses

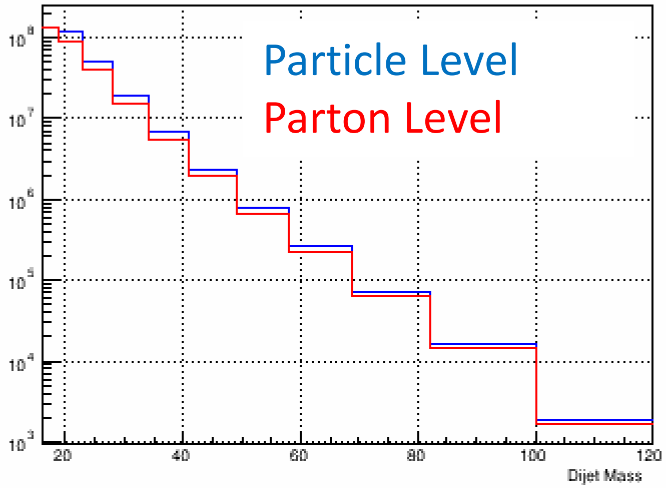
Di-jet Cross Section



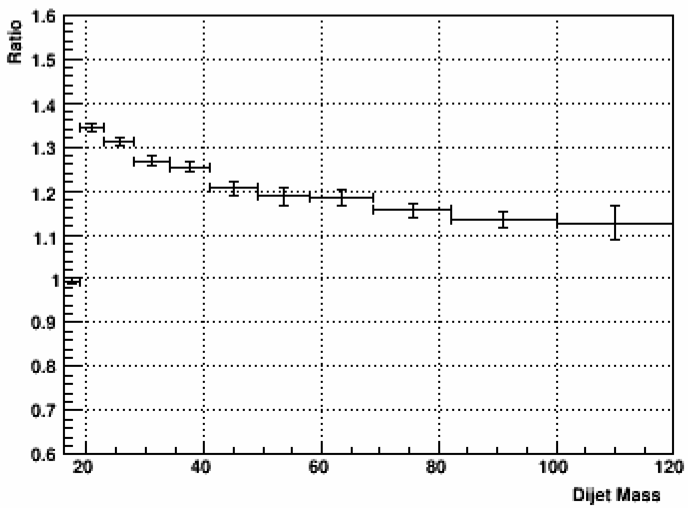
- Raw data yields corrected to particle level using the SVD unfolding method as implemented in RooUnfold
- Theory values from the NLO code of de Florian et al using the CTEQ6m PDF set
- Theory has been corrected for underlying event and hadronization effects

UEH Correction

Di-jet Mass: Particle & Parton Level

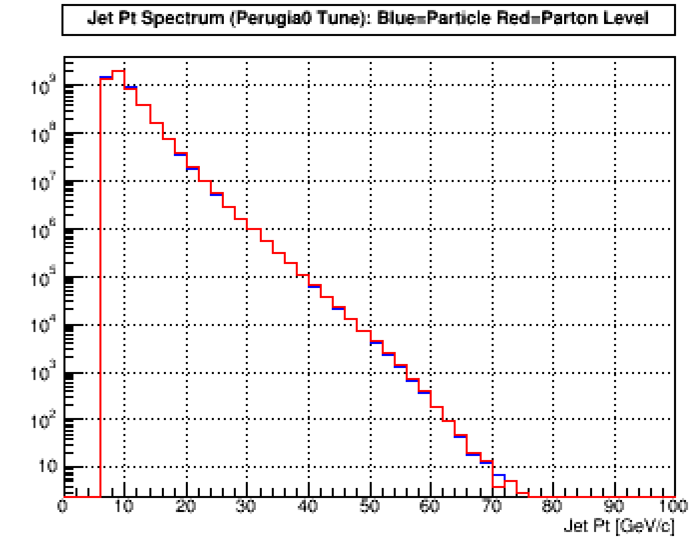


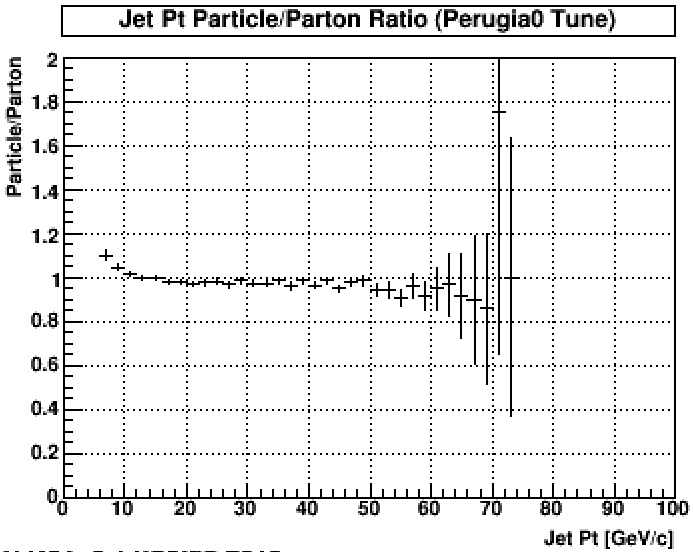
Di-jet Mass Ratio: Particle / Parton



- Di-jet cross section extracted to the particle level
- Theoretical calculations are at parton level, do not account for underlying event or hadronization (UEH)
- Need to apply UEH correction to theory so that comparison to data can be made
- UEH correction is the ratio of particle over parton level di-jet yield from PYTHIA
- UEH effects should be at lower mass, surprise that the ratio does not reach unity at highest masses

Jet p_T Spectra: Particle vs Parton





- Is discrepancy between particle and parton level di-jet mass caused by transverse momentum of jets?
- Look at p_T of the jets which make up the di-jet
- Very good agreement seen between jet p_T at particle and parton level
- Could jet masses be driving the discrepancy?

Di-jet Mass Formula

$$P = \begin{bmatrix} m_T\, Cosh(y) \\ p_T\, Cos(\varphi) \\ p_T\, Sin(\varphi) \\ m_T\, Sinh(y) \end{bmatrix}$$

$$M^2 = [P_1 + P_2]^2$$

- Di-jet mass constructed from the 4-vectors of both jets
- Full mass formula contains terms which depend on the individual jet masses
- Disregarding individual jet masses gives di-jet mass which depends only on transverse momenta and geometric orientation of both jets

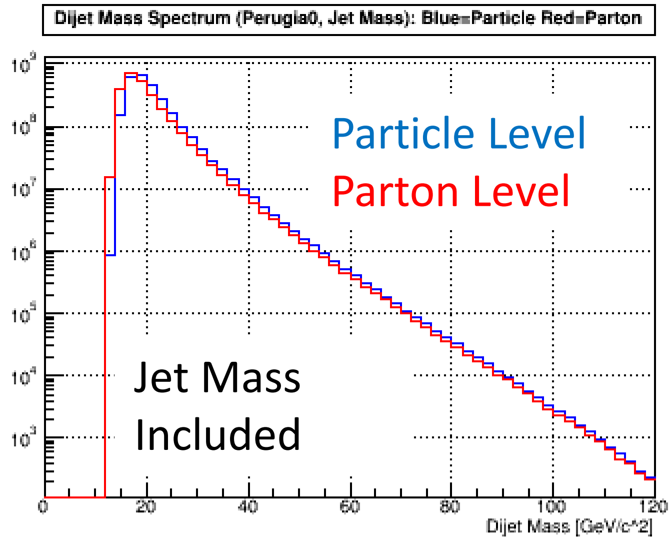
$$M = \sqrt{m_1^2 + m_2^2 + 2 * \sqrt{m_1^2 + p_{T1}^2} * \sqrt{m_2^2 + p_{T2}^2} * Cosh(\Delta y) - 2 * p_{T1} * p_{T2} * Cos(\Delta\varphi)}$$

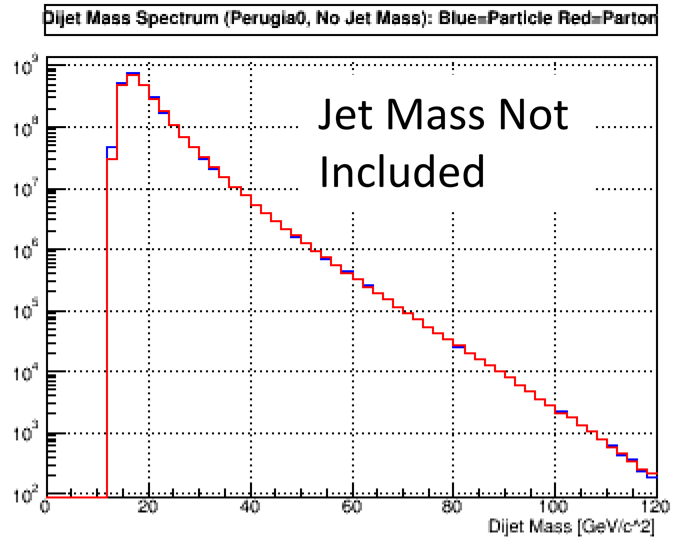
- Full Formula

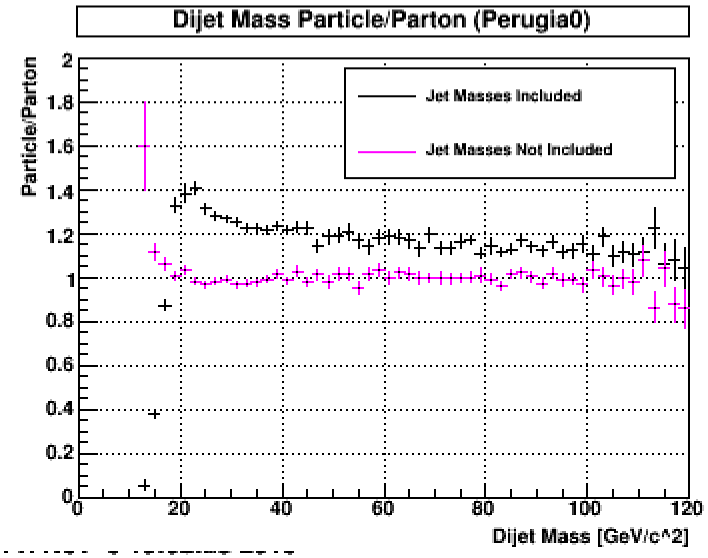
$$M = \sqrt{2 * p_{T1} * p_{T2} * [Cosh(\Delta\eta) - Cos(\Delta\varphi)\,]}$$

- Massless Formula

Di-jet Mass: Jet Mass Effect (Perugia0)

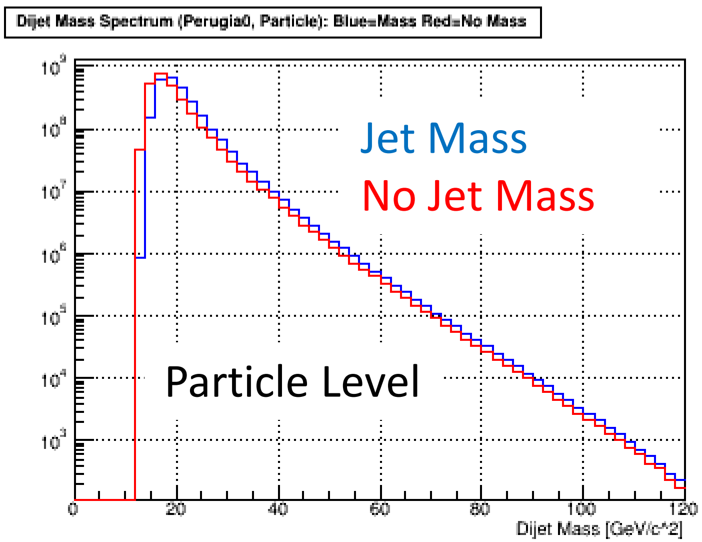


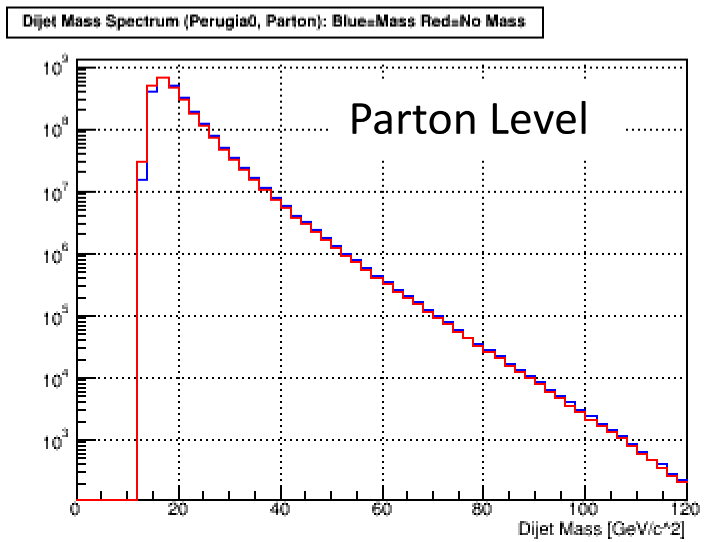


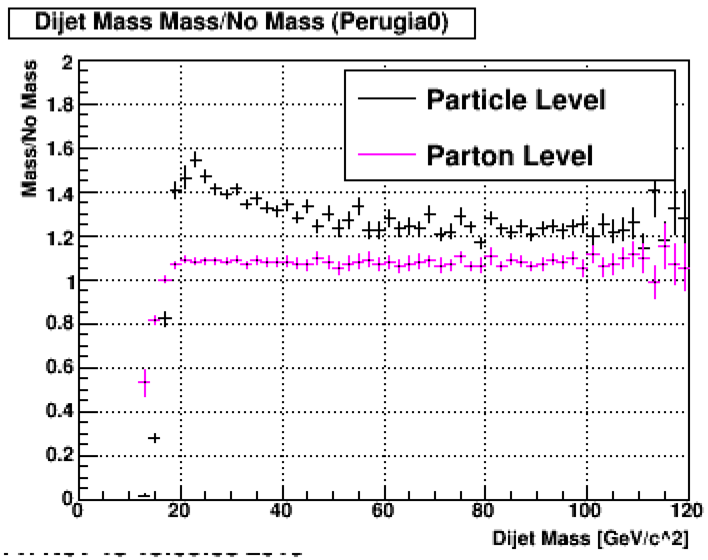


- Particle and parton level di-jet yields match very well when jet masses are excluded
- In Perugia0 tune (using L.O. CTEQ 5L PDFs) particle/parton discrepancy largely caused by jet mass terms arising from the hadronization of partons into massive final state particles
- Is behavior different for other tunes or PDFs?

Di-jet Mass: Jet Mass Effect (Perugia0)

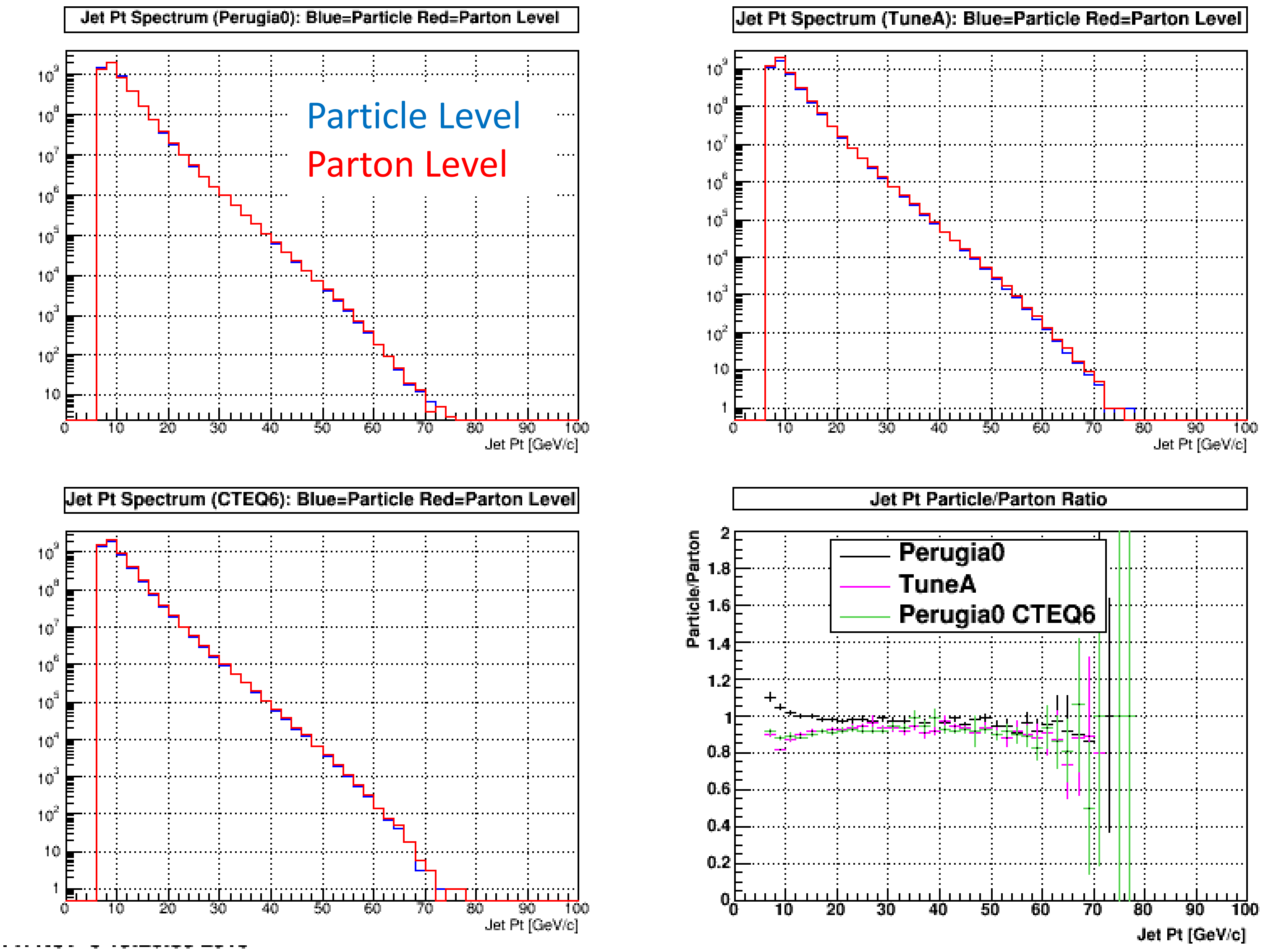




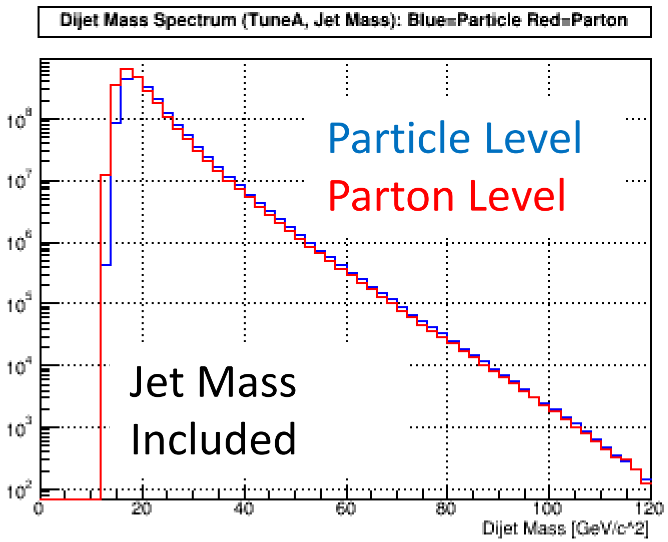


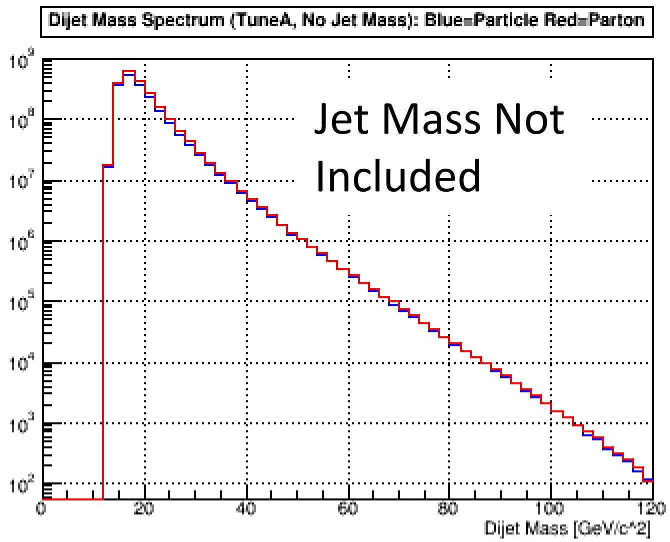
- See that the inclusion/exclusion of the jet mass terms in di-jet mass formula has much bigger effect at particle level than parton level
- This is expected as final state particles have greater mass than partons
- Behavior is statistically consistent between the three tunes / PDFs investigated

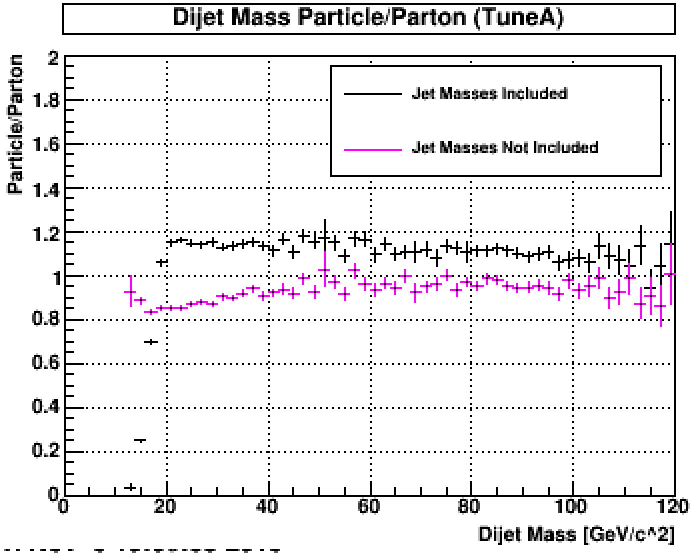
Jet p_T Spectra: Tune/PDF Dependence



Di-jet Mass: TuneA

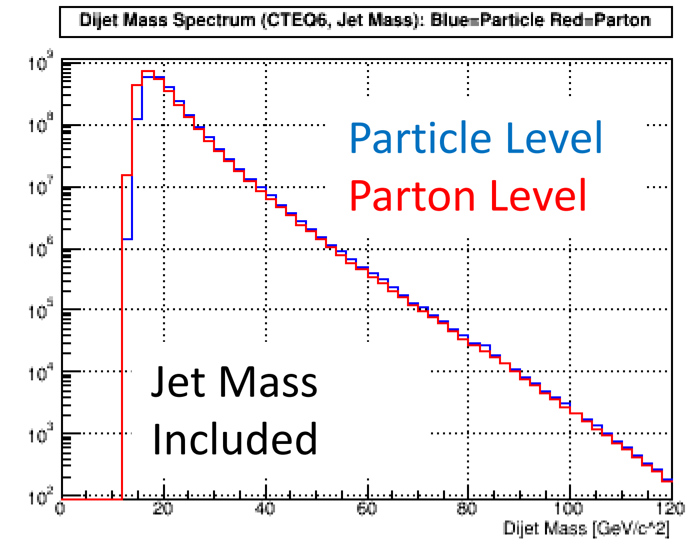


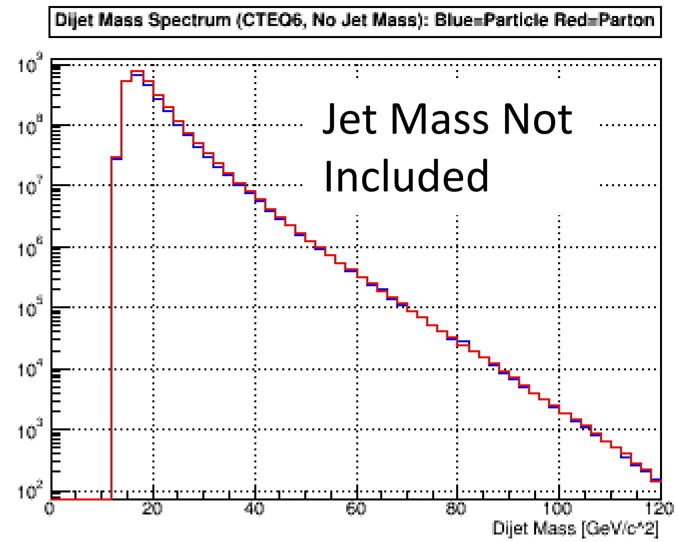


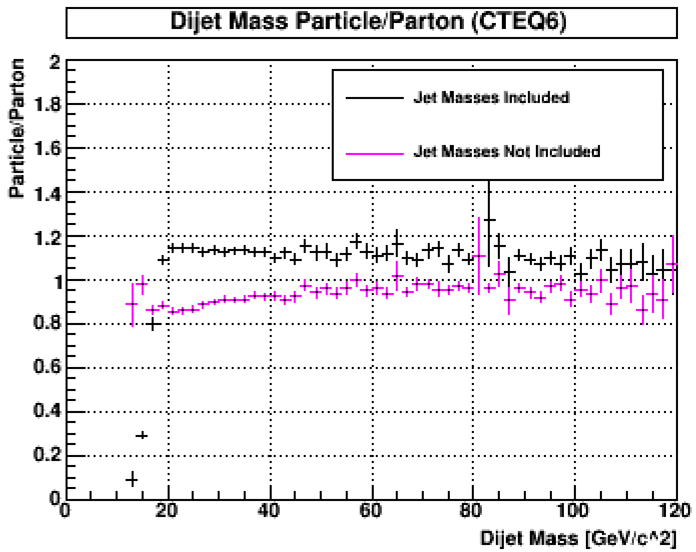


- Look at TuneA using L.O. CTEQ 5L PDF set
- As with Perugia0 tune, we see alignment of the spectra, however there is now an excess of events at parton level at low mass

Di-jet Mass: Perugia0 (CTEQ6)

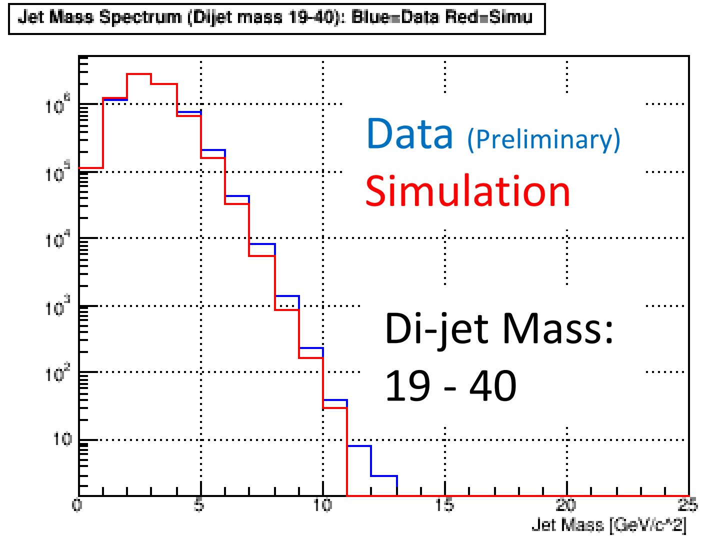


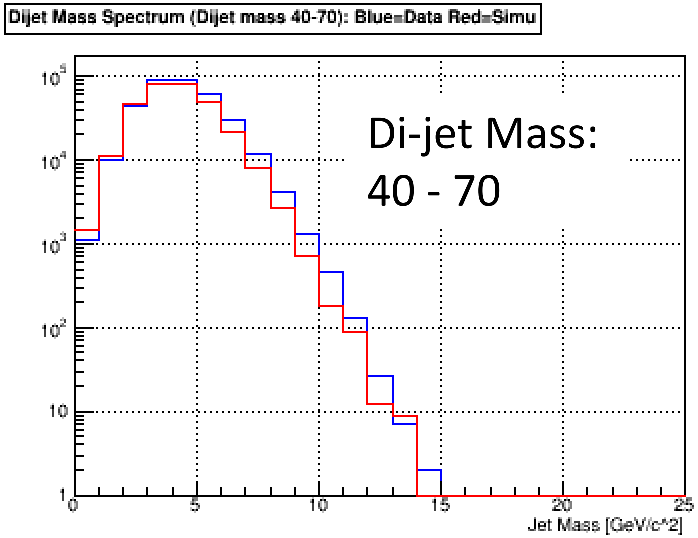


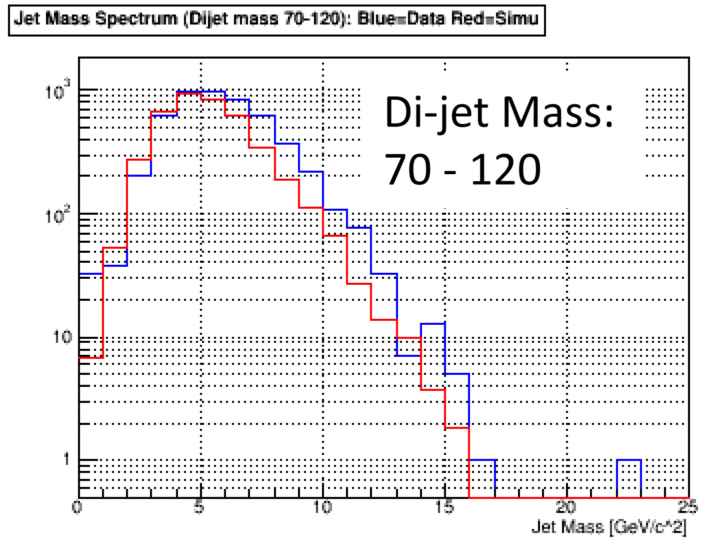


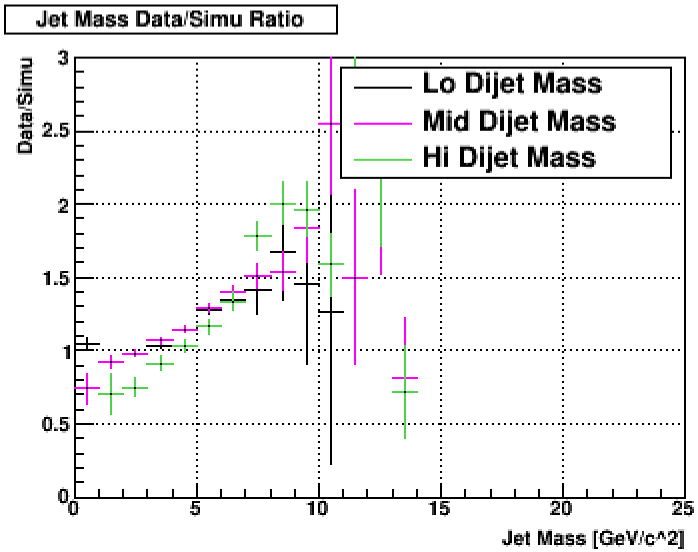
- Behavior seen when using Perugia0 tune parameters with CTEQ 6m PDF set very similar to TuneA

Jet Mass Spectra: Data / Simulation

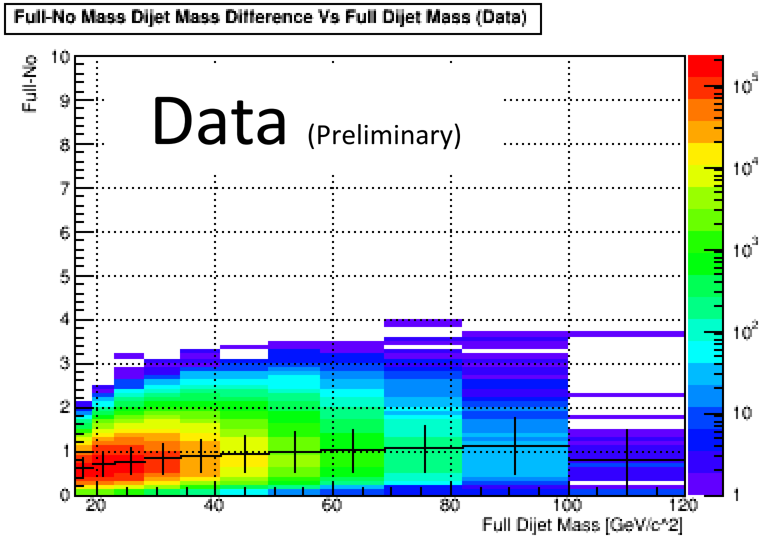


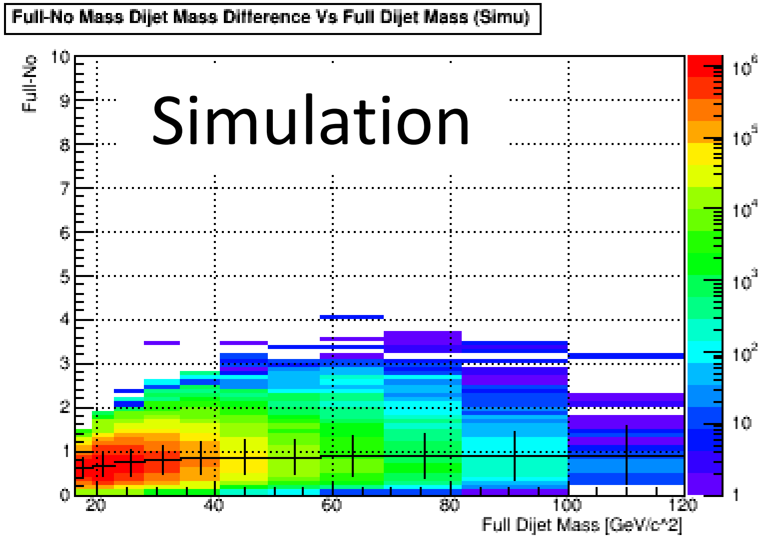


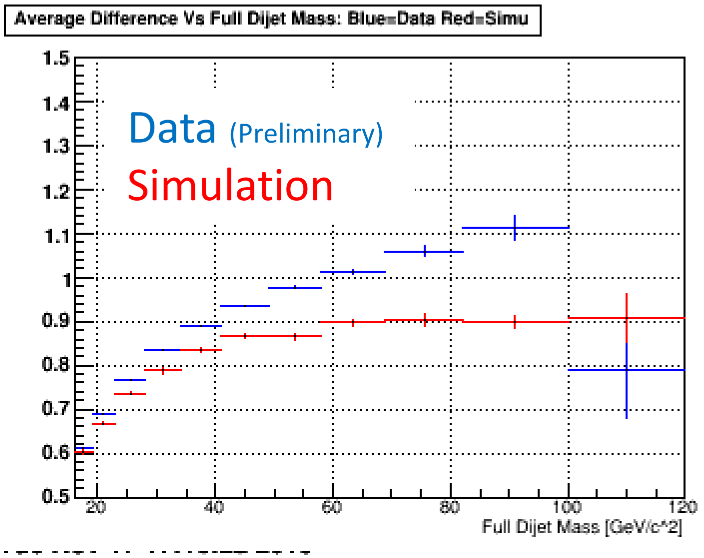




Dijet ΔM Vs M: Data / Simulation

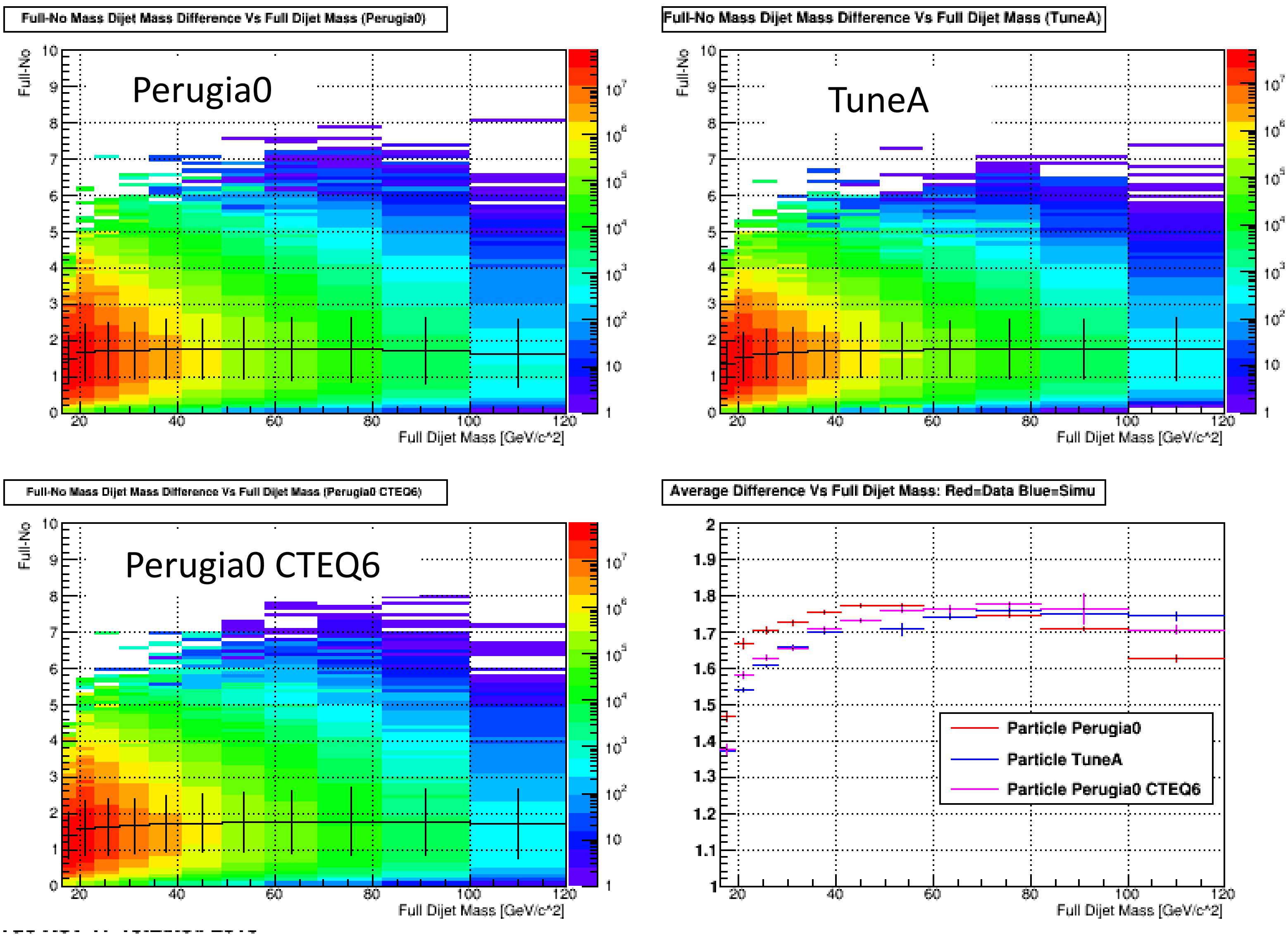






- Difference between di-jet mass with and without jet mass terms as a function of full di-jet mass
- Error bars on 2-D plots show RMS while error bars on bottom plot show error on the mean of the distribution

Dijet ΔM Vs M: Particle Level

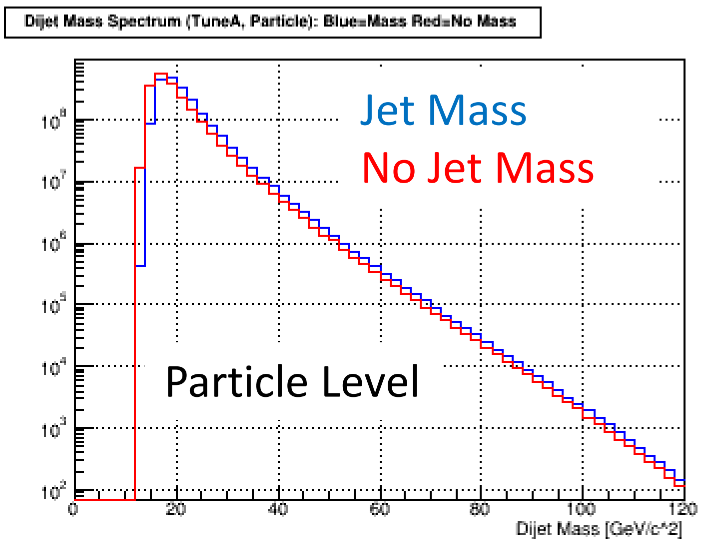


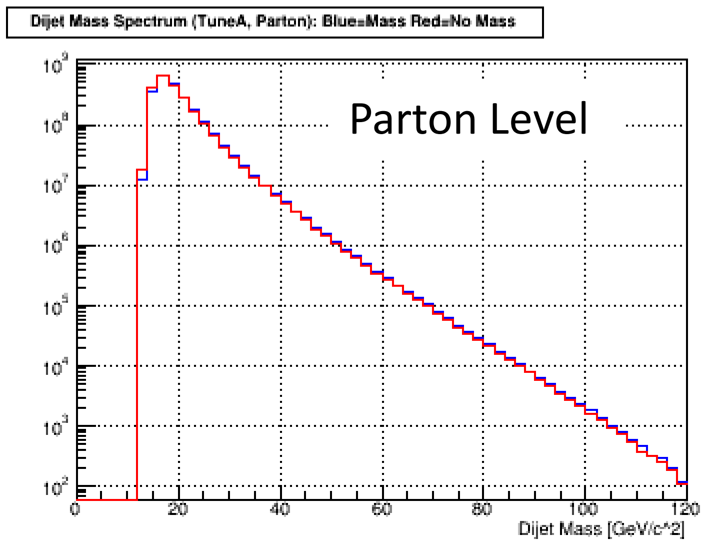
Summary

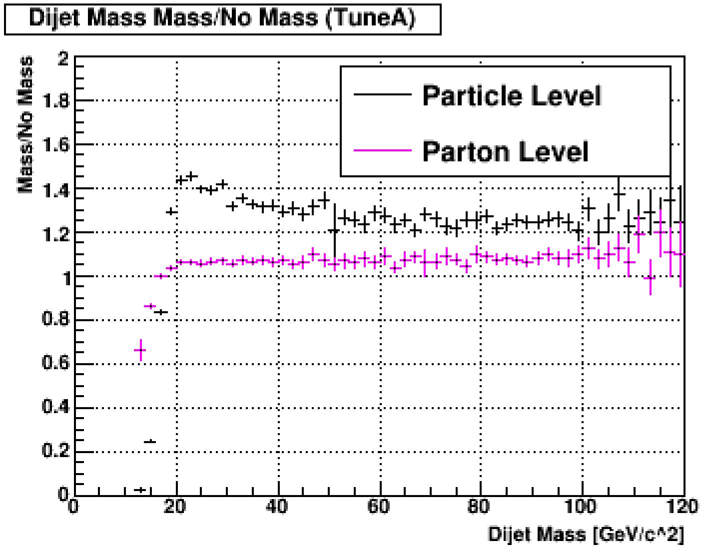
- Theory di-jet cross section needs to be corrected to account for underlying event and hadronization effects before comparison to data can be made
- These UEH corrections (particle/parton level di-jet yield ratio) persist to highest measured masses – found to be due to jet mass terms in di-jet mass formula
- UEH corrections vary substantially when including/excluding jet mass terms and when using different PDF sets and PYTHIA tunes
- Effect of the jet mass terms on individual particle and parton level spectra is independent of tune or PDF set studied

Backup

Di-jet Mass: TuneA

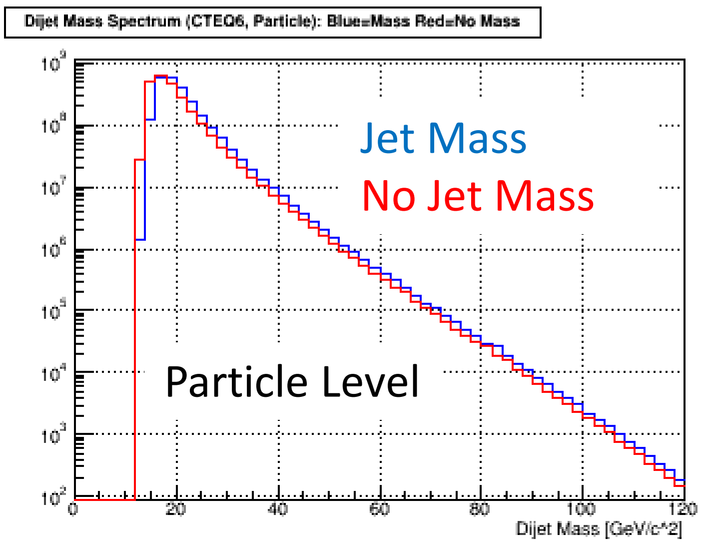


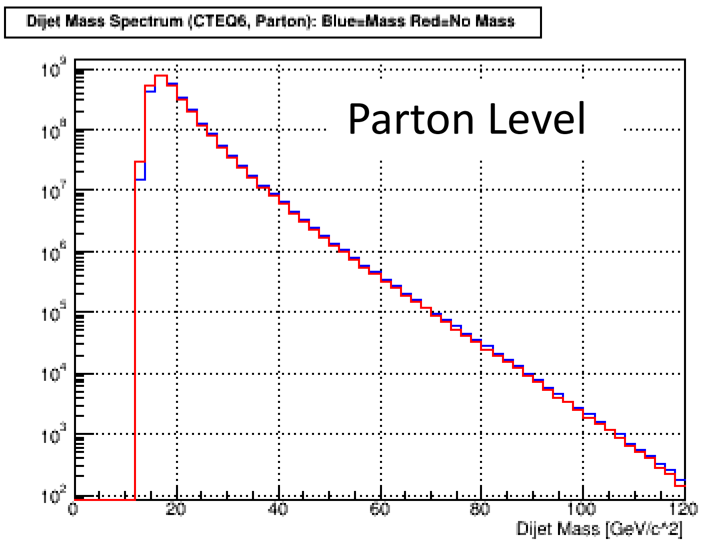


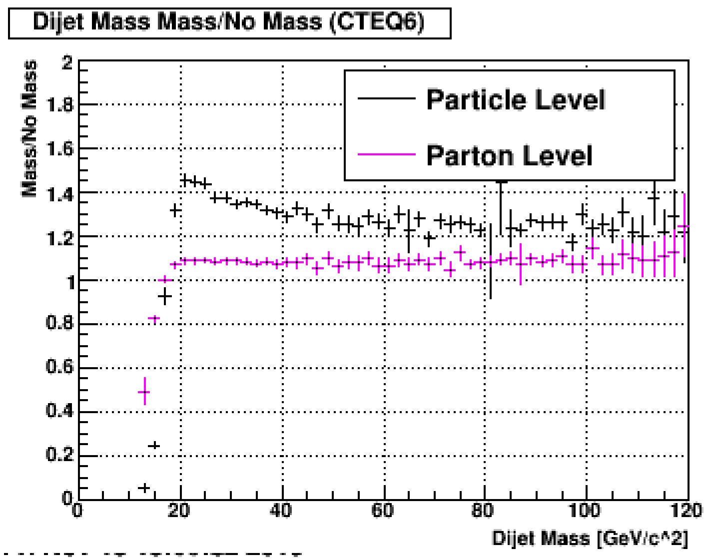


- Look at TuneA using L.O. CTEQ 5L PDF set
- As with the Perugia0 tune, the effect of including/excluding the jet mass is much more pronounced at particle level
- Particle and parton level ratios are consistent with Perugia0 results

Di-jet Mass: Perugia0 (CTEQ6)

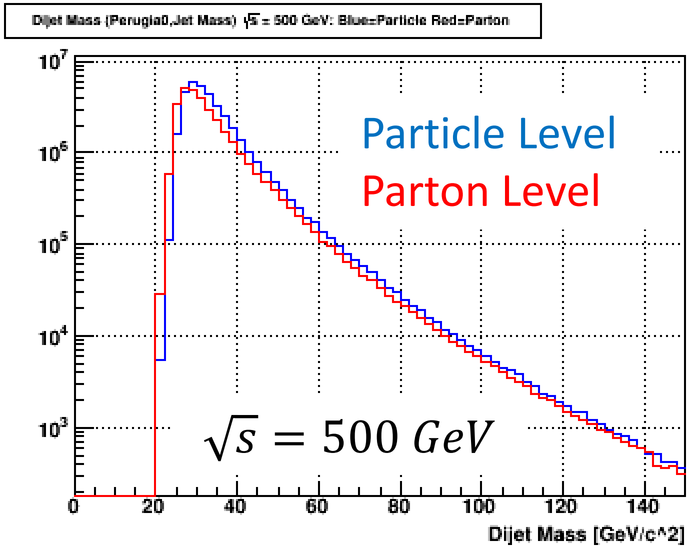


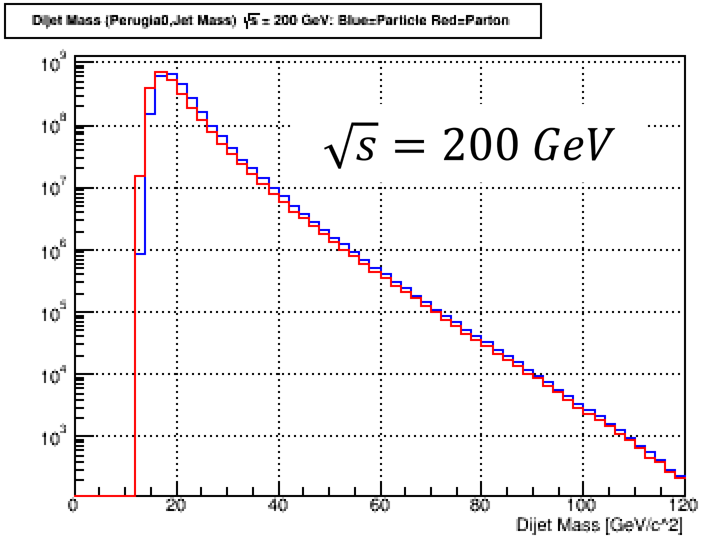


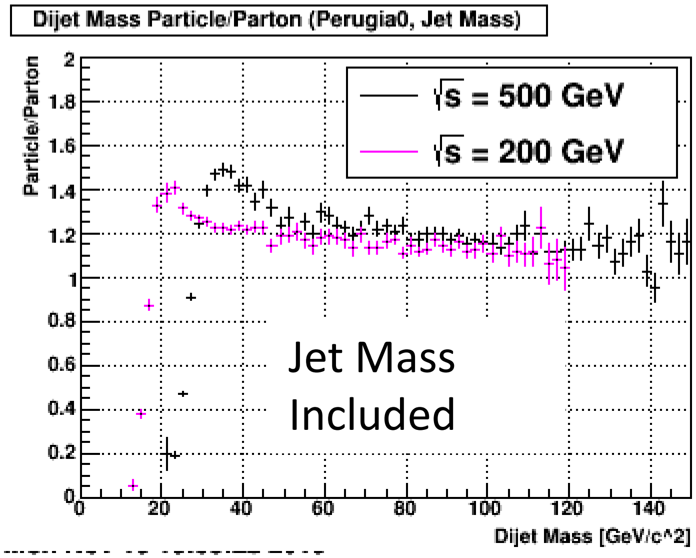


- The inclusion/exclusion of the jet mass has the same effect on the particle and parton spectra regardless of tune or PDF set

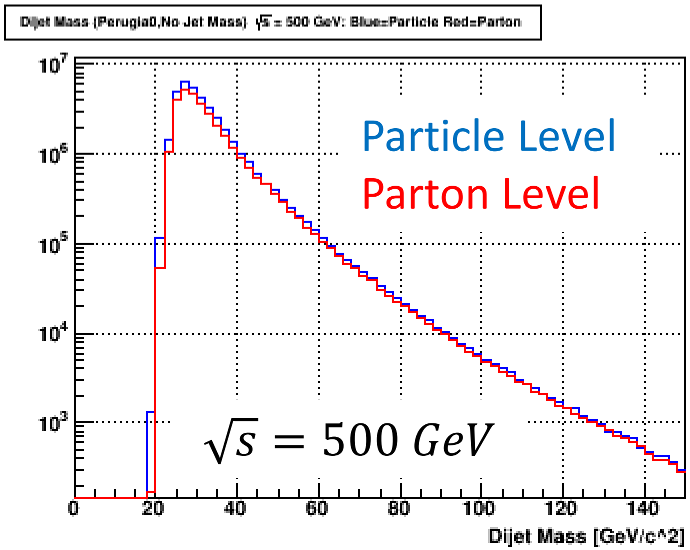
$\sqrt{s}$ Dependence: Jet Levels W/ Mass

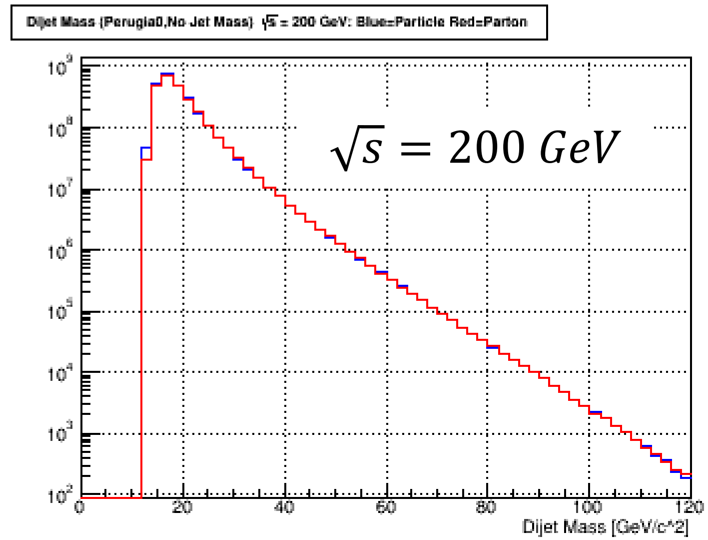


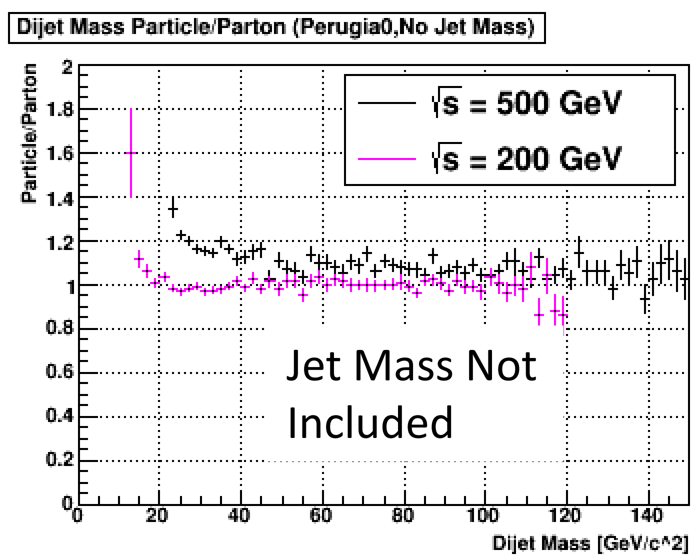




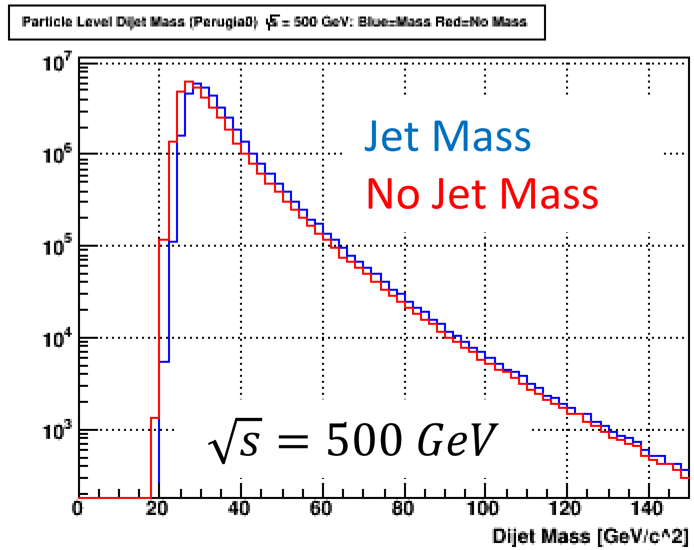
$\sqrt{s}$ Dependence: Jet Levels W/O Mass

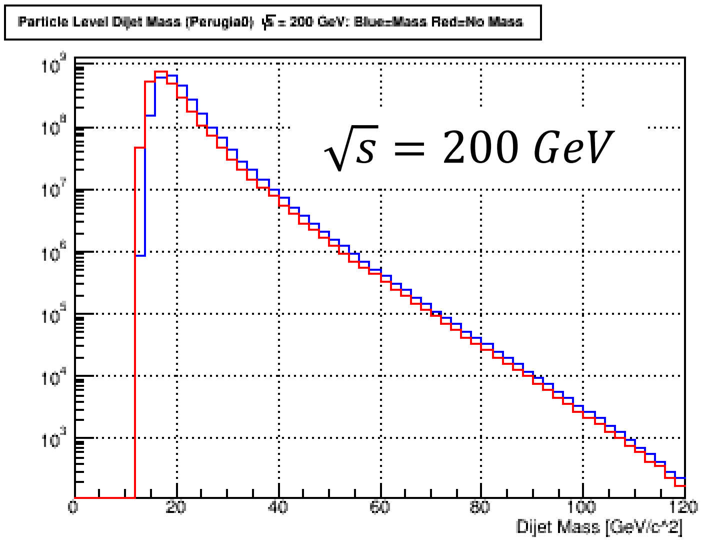


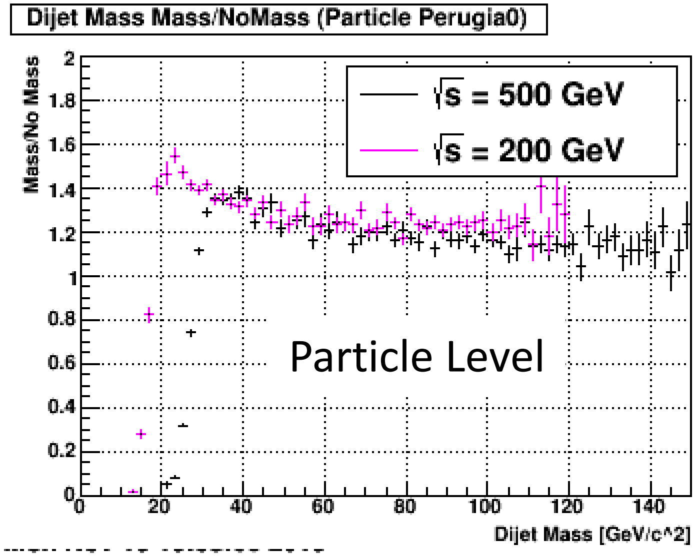




$\sqrt{s}$ Dependence: Jet Masses Particle







$\sqrt{s}$ Dependence: Jet Masses Parton