Direct Photon Production

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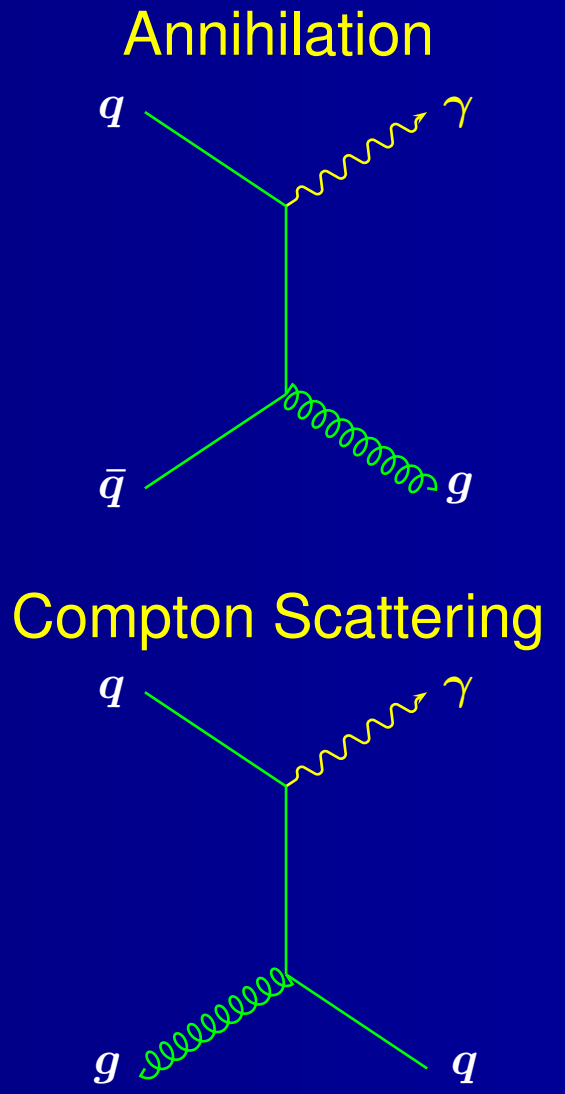
for the E706 Collaboration

DAVIS ★ DELHI ★ FERMILAB ★ MICHIGAN STATE ★ NORTHEASTERN
OKLAHOMA ★ PENNSYLVANIA STATE ★ PITTSBURGH ★ ROCHESTER

Direct Photon Production

- Data at large-p_T test pQCD calculations and help constrain parton density (PDF) and fragmentation (FF) functions.
- Only two processes contribute at leading order to the direct-photon cross section: $q\bar{q}$ Annihilation, and qg Compton Scattering.
- Direct photon production is sensitive to the gluon distribution.



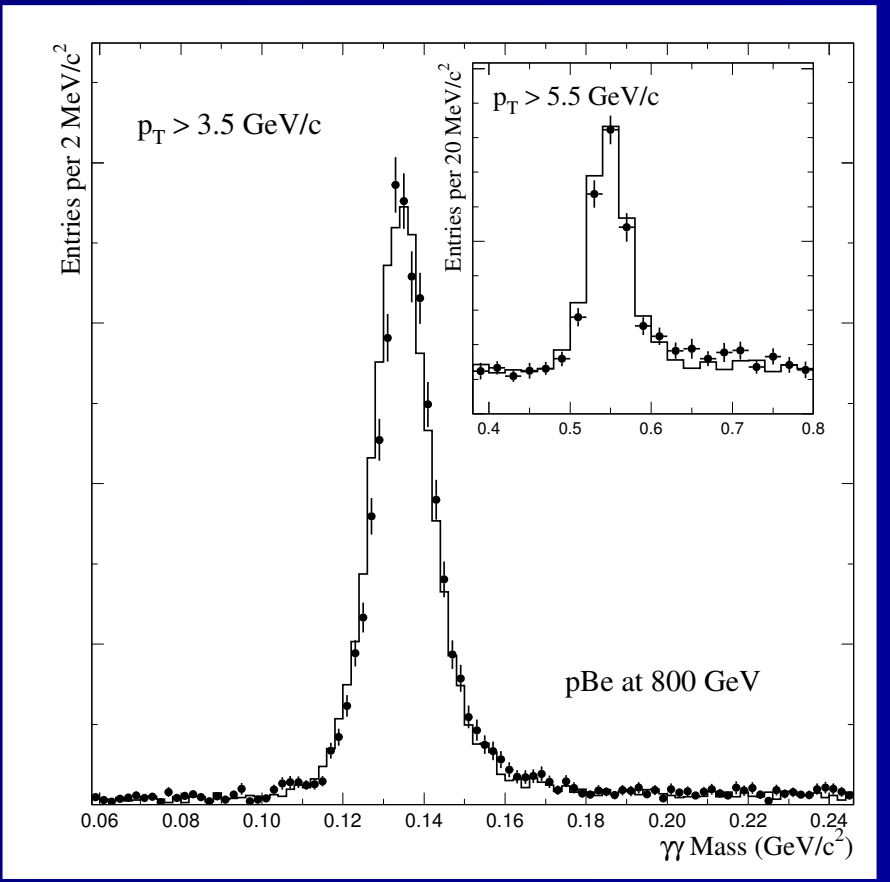
Experimental Issues

- Direct photon cross section small relative to jets $\sigma(\gamma)/\sigma(\mathrm{jets}) \approx 10^{-3}$
- Potentially significant backgrounds from jet fragments (primarily π^0 and η decays)
- Detect individual photons and reconstruct neutral meson decays
- Statistically subtract remaining background via a detailed Monte Carlo simulation

Detailed Monte Carlo Simulation

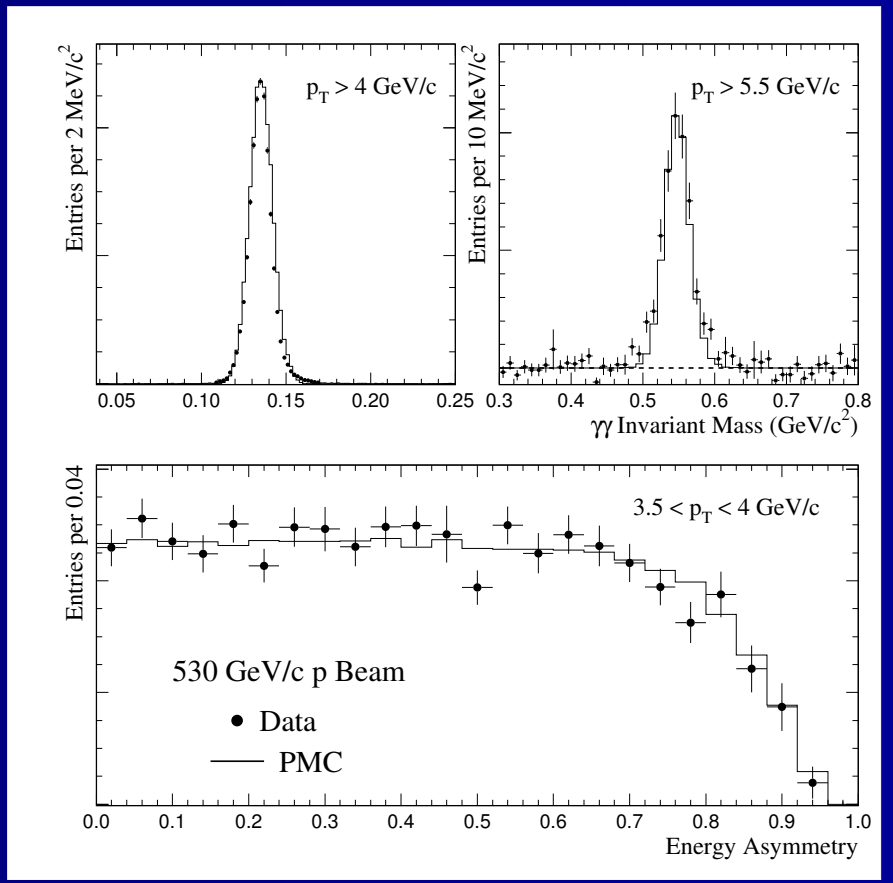
Detailed GEANT detector simulation with HERWIG event generator

- Used to calculate efficiencies, unsmearing, and backgrounds
- π^0 and η spectra weighted to match data

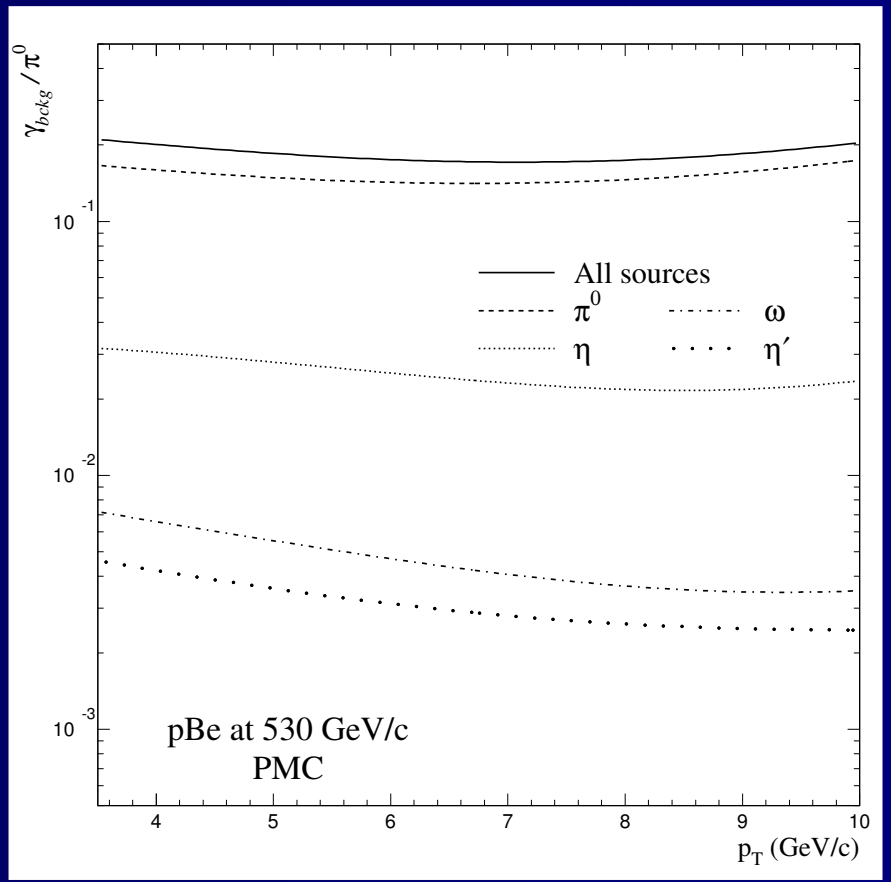


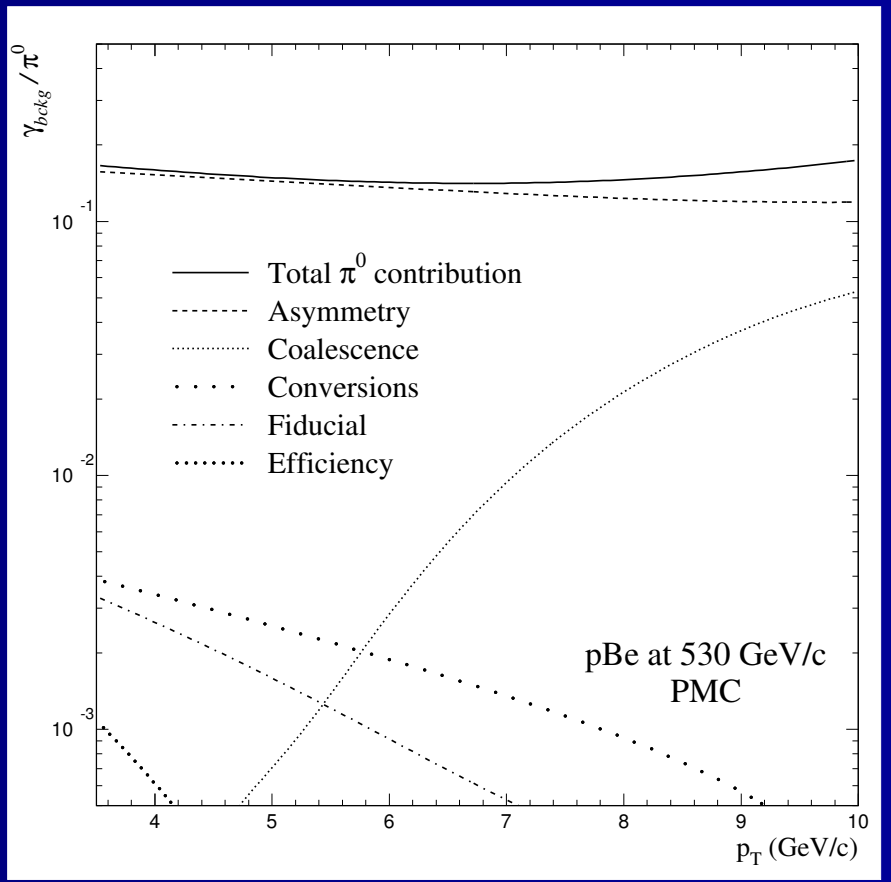
Parameterized Simulation

- Parameterized detector response
- Fits to measured data
- Used for systematic studies
  - calorimeter energy calibration
  - resolution unsmearing
  - direct photon backgrounds



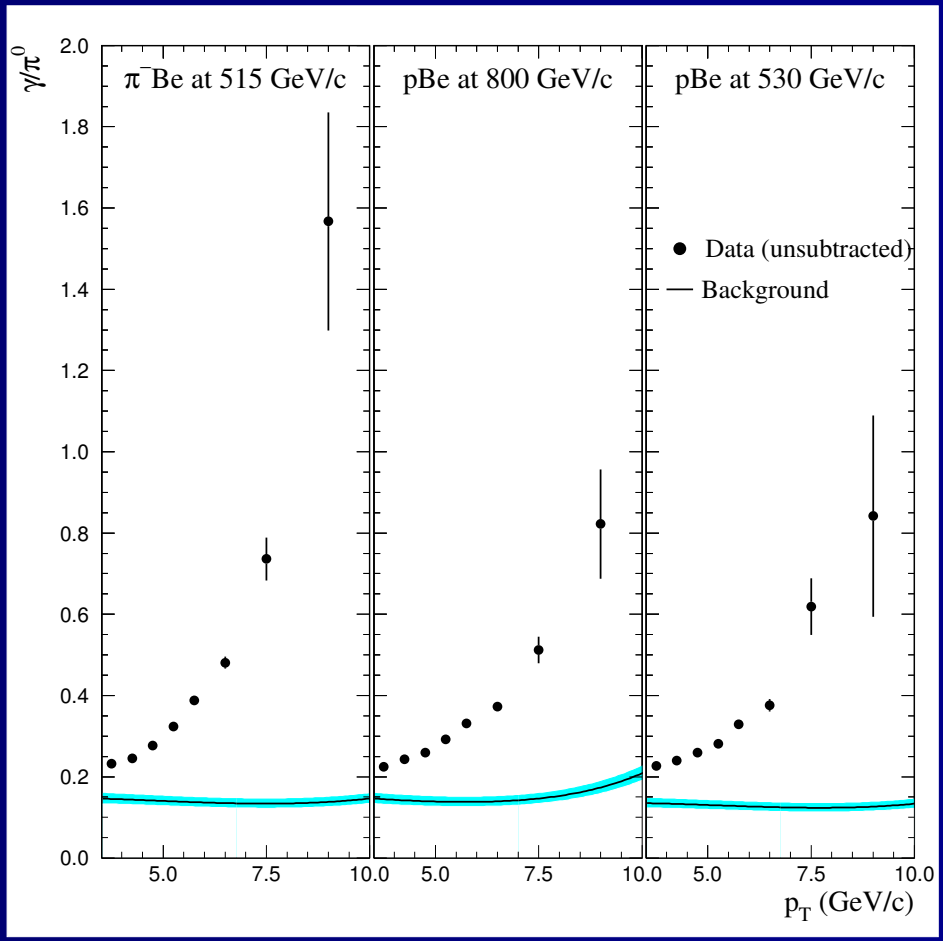
Direct Photon Backgrounds





Vast majority of the background is due to π^0 decays where one decay photon is too small to reconstruct

Direct Photon Signal

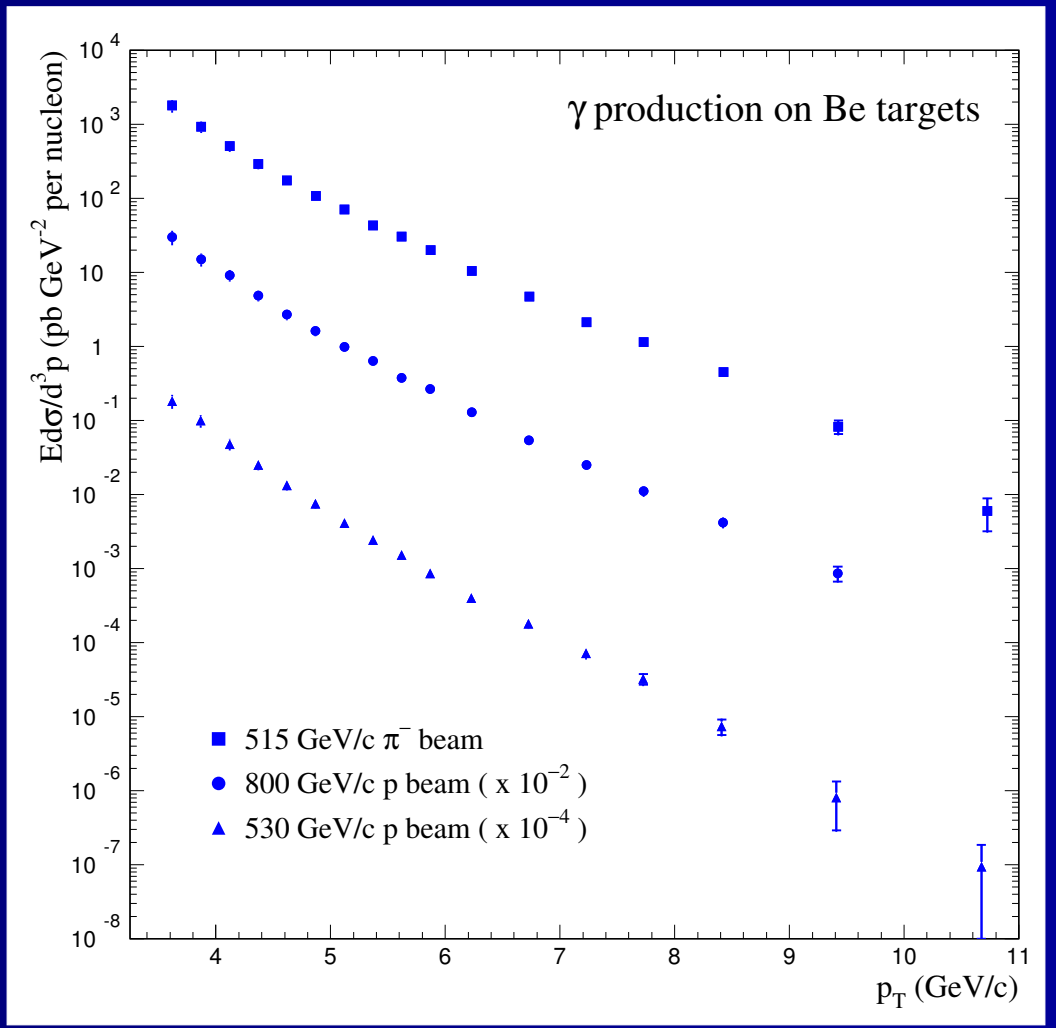


Large signal to background in all samples

Results

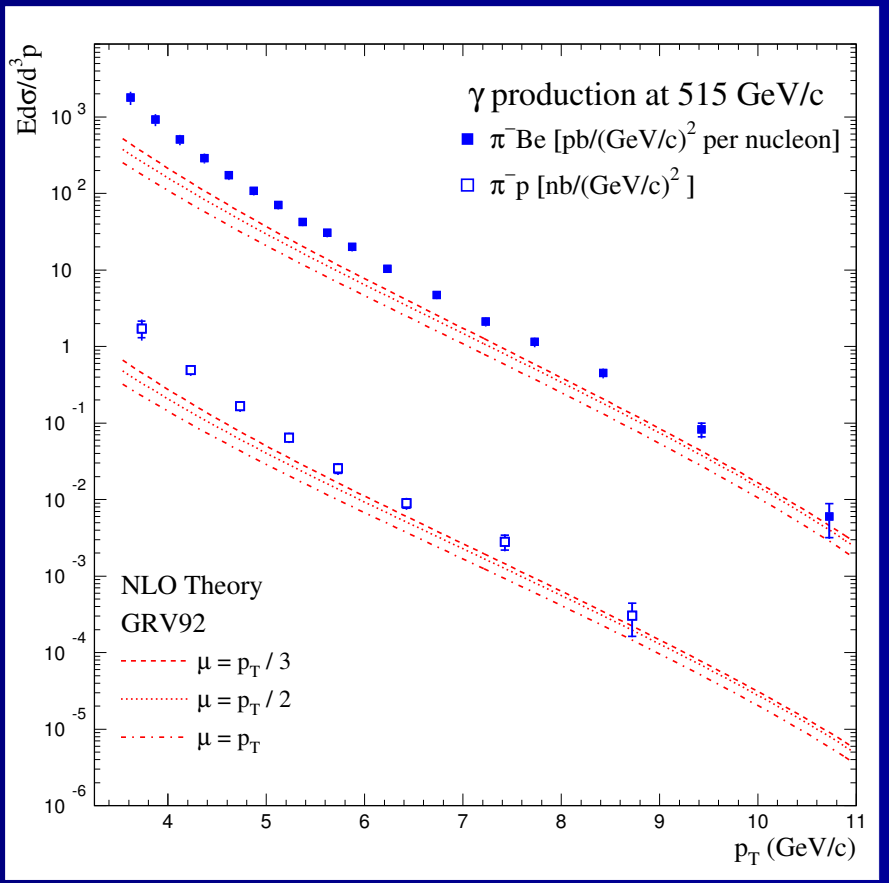
Direct-photon cross sections were extracted statistically using using fits to Monte Carlo simulations of backgrounds

- 515 GeV/c π^-Be $(-0.75 \leq y_{cm} \leq 0.75)$
- 800 GeV/c pBe $(-1.0 \leq y_{cm} \leq 0.5)$
- 530 GeV/c pBe $(-0.75 \leq y_{cm} \leq 0.75)$



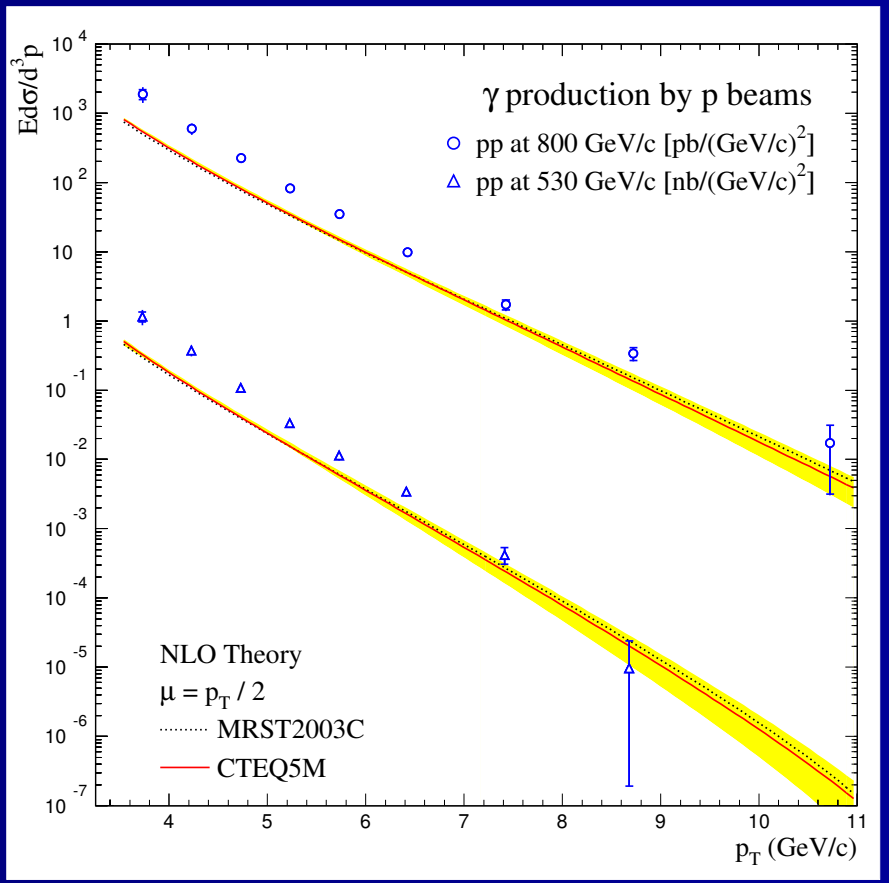
Comparisons with NLO pQCD

- NLO pQCD calculations do not agree with measurements of direct photon production and exhibit large scale dependence.

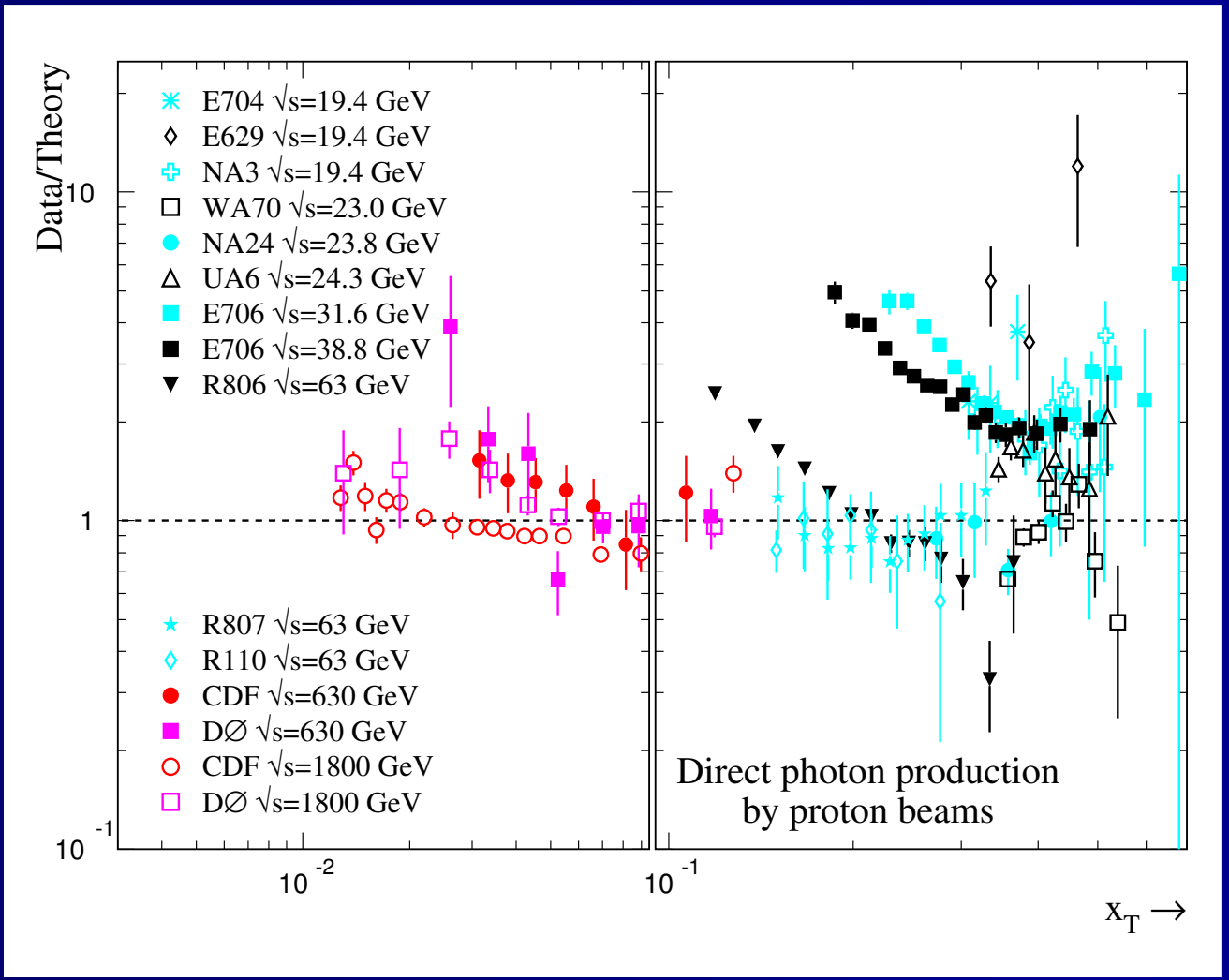


Comparisons with NLO pQCD

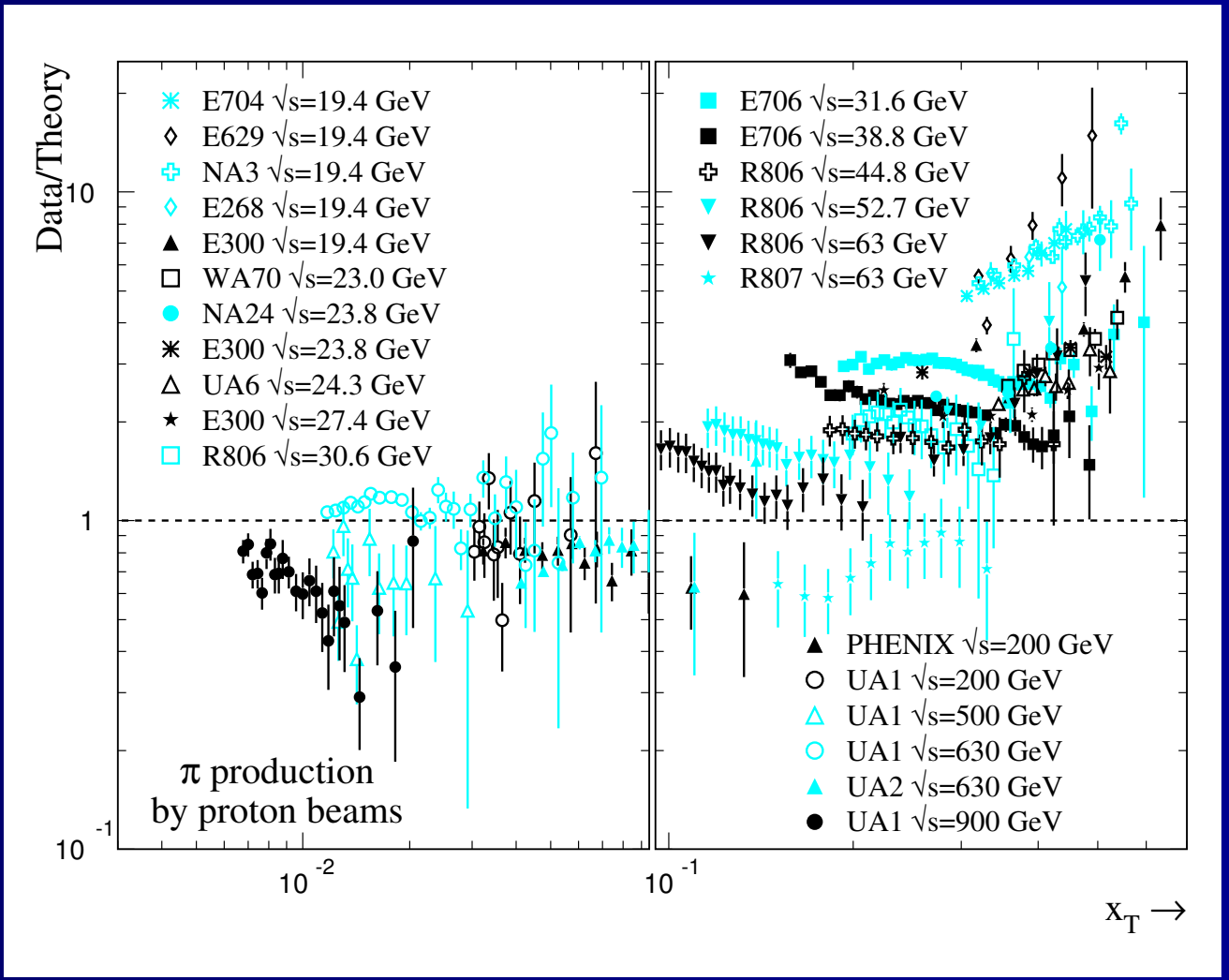
- NLO pQCD calculations do not agree with measurements of direct photon production and exhibit large scale dependence.
- PDF uncertainties, while large, do not have sufficient flexibility to make up the difference.



Photon Production at Hadron–Hadron Experiments

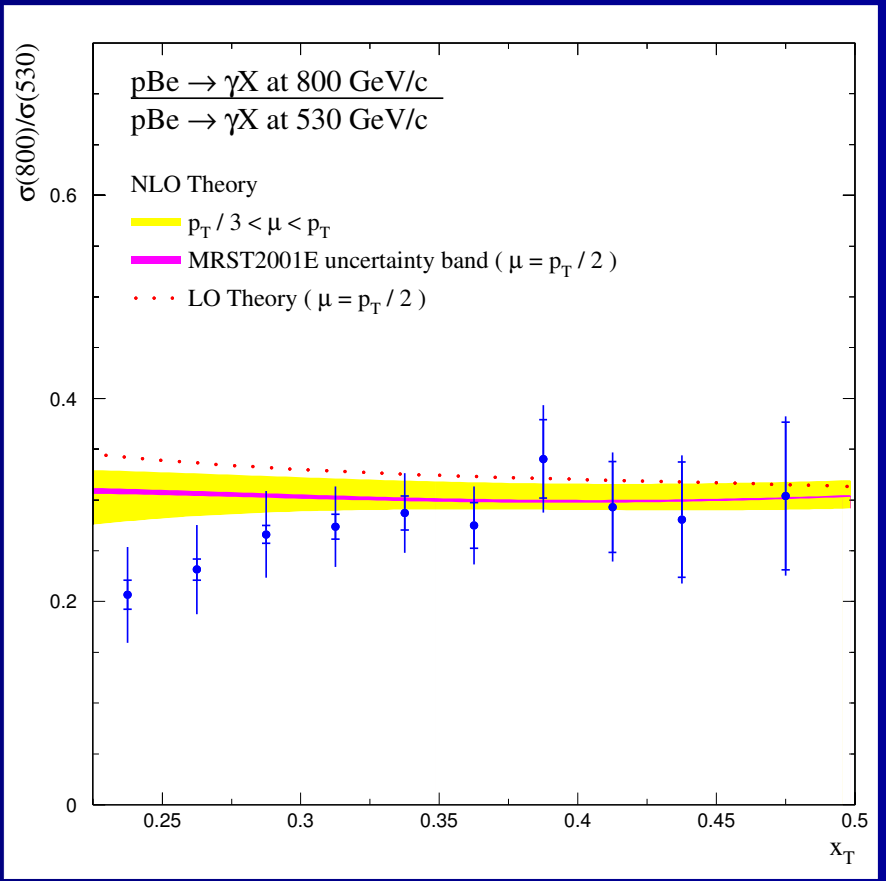


π^0 Production at Hadron–Hadron Experiments



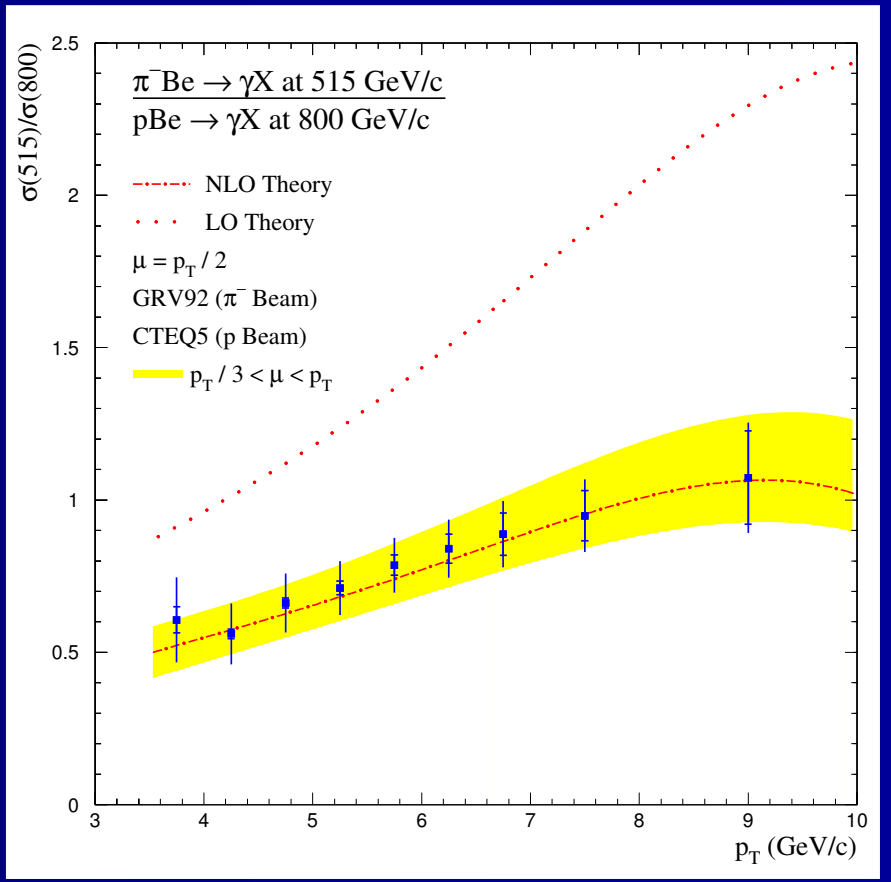
Beam Ratios

- NLO pQCD has reduced scale dependence and significantly improved agreement when compared to ratios of direct-photon cross sections.
- Plotted vs $x_T = 2p_T/\sqrt{s}$ to compensate for different average parton-parton collision energies.
- Little difference between LO and NLO pQCD.



Beam Ratios

- NLO pQCD has reduced scale dependence and significantly improved agreement when compared to ratios of direct-photon cross sections.
- Plotted vs p_T since the average energy per colliding valence quark is similar.

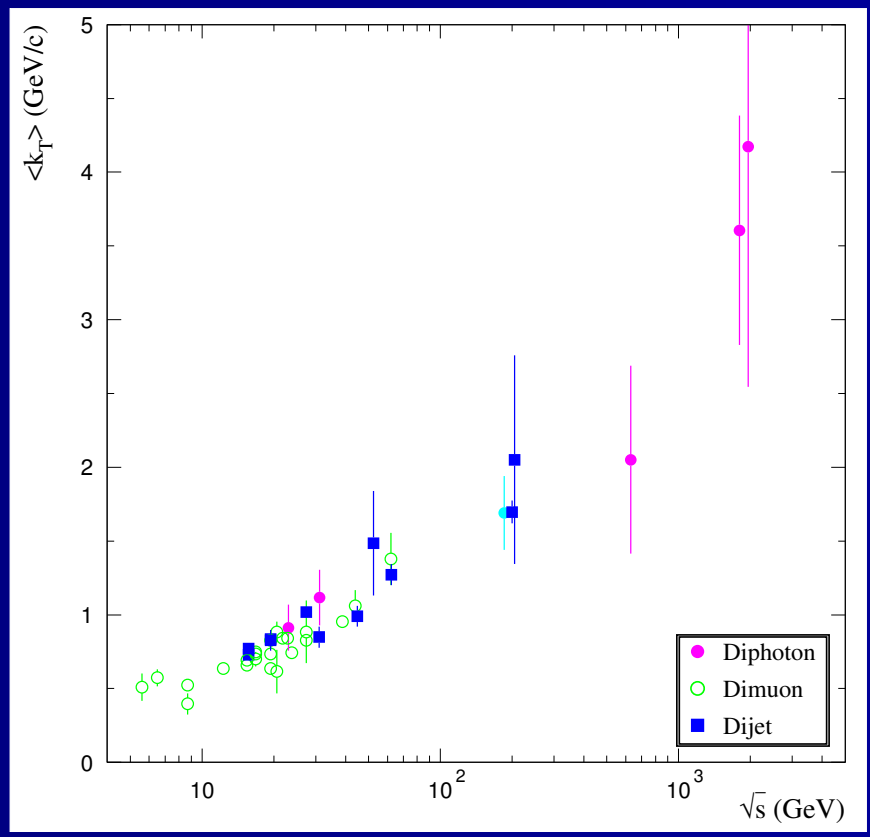


- Large difference between LO and NLO pQCD.

About k_T Effects

k_T refers to the magnitude of the effective transverse momentum vector of each of the two colliding partons

Average k_T values significantly larger than expected from non-perturbative hardon-size effects have been observed in Drell-Yan and diphoton production, and have been interpreted as resulting from multiple soft gluon emissions.



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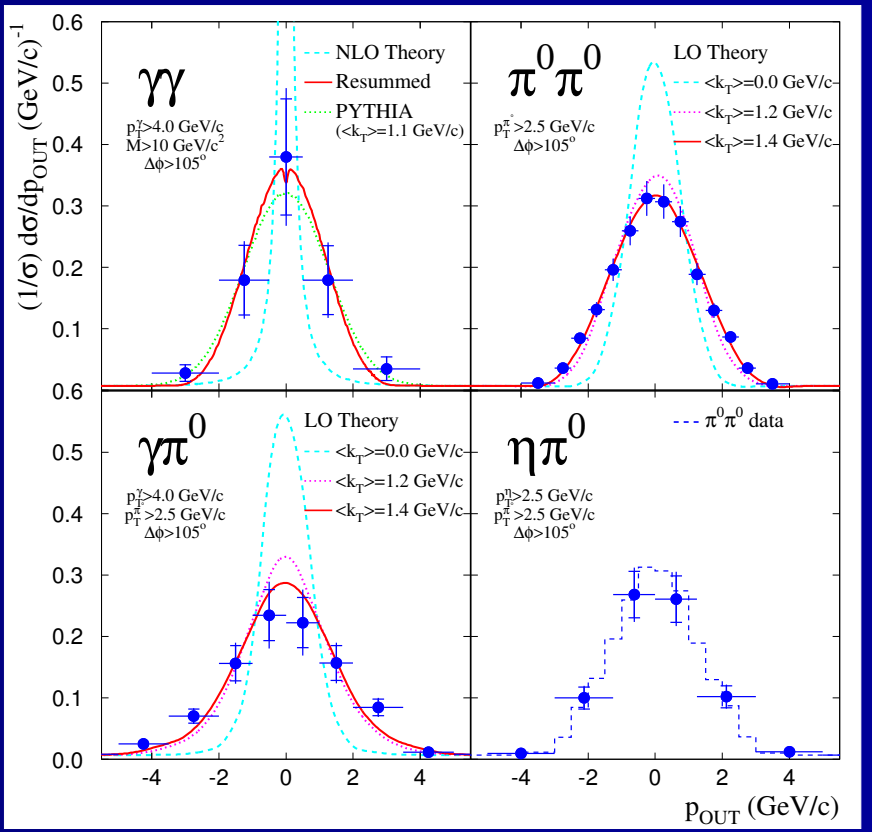


k_T is expected to modify

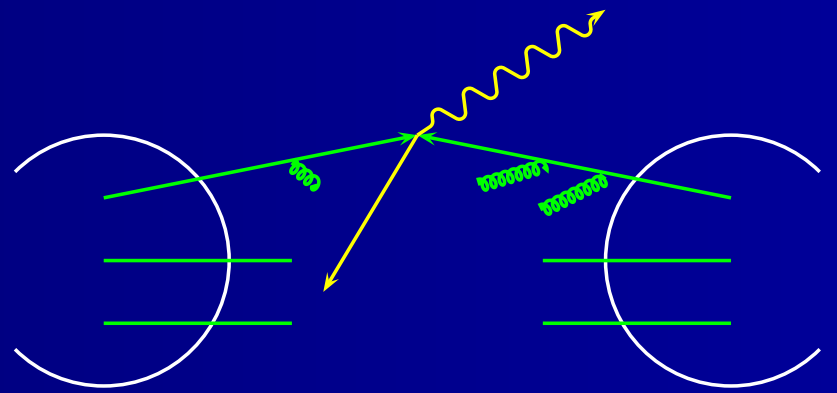
- back-to-back alignment of final state objects
- magnitude and shape of high-p_T inclusive cross sections
- fragmentation distributions in jets recoiling against high-p_T triggers

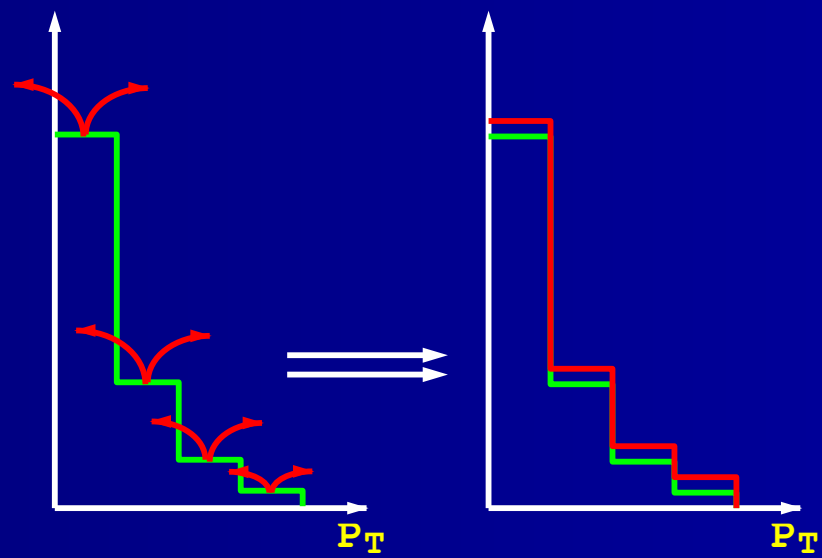
Single Particle Inclusive Production

In many respects, k_T affects p_T distributions like resolution smearing. Distributions may show an effect for $p_T \gg \langle k_T \rangle$.

Resummed pQCD calculations should properly include k_T effects.

High-order pQCD calculations partially represent this effect by including additional radiation.





Modeling k_T Effects

LO pQCD calculations model incident-parton k_T using Gaussian smearing. This smearing is not available in current NLO pQCD calculations. Approximate treatment:

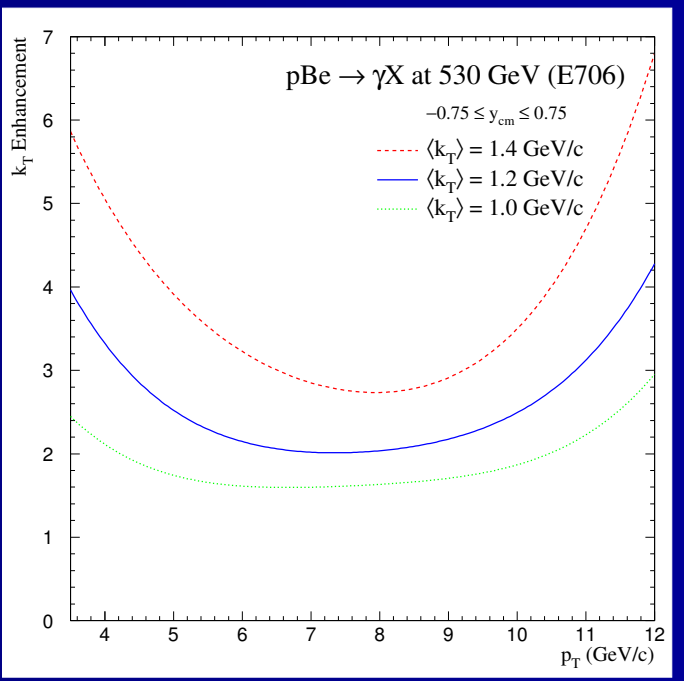
$$\sigma^{\mathrm{NLO}} \times K^{\mathrm{LO}}(p_T),$$

where,

$$K^{\mathrm{LO}}(p_T) = \frac{\sigma^{\mathrm{LO}}\left(\langle k_T \rangle\right)}{\sigma^{\mathrm{LO}}\left(\langle k_T \rangle = 0\right)}.$$

Double-counting of contributions is expected to be small:

- $\langle p_T \rangle^{\mathrm{NLO}} \sim$ a few hundred MeV/c
- $\langle p_T \rangle^{\mathrm{RESUMMED}} \approx 1.5$ GeV/c ($\sqrt{s} = 31.1$ GeV)

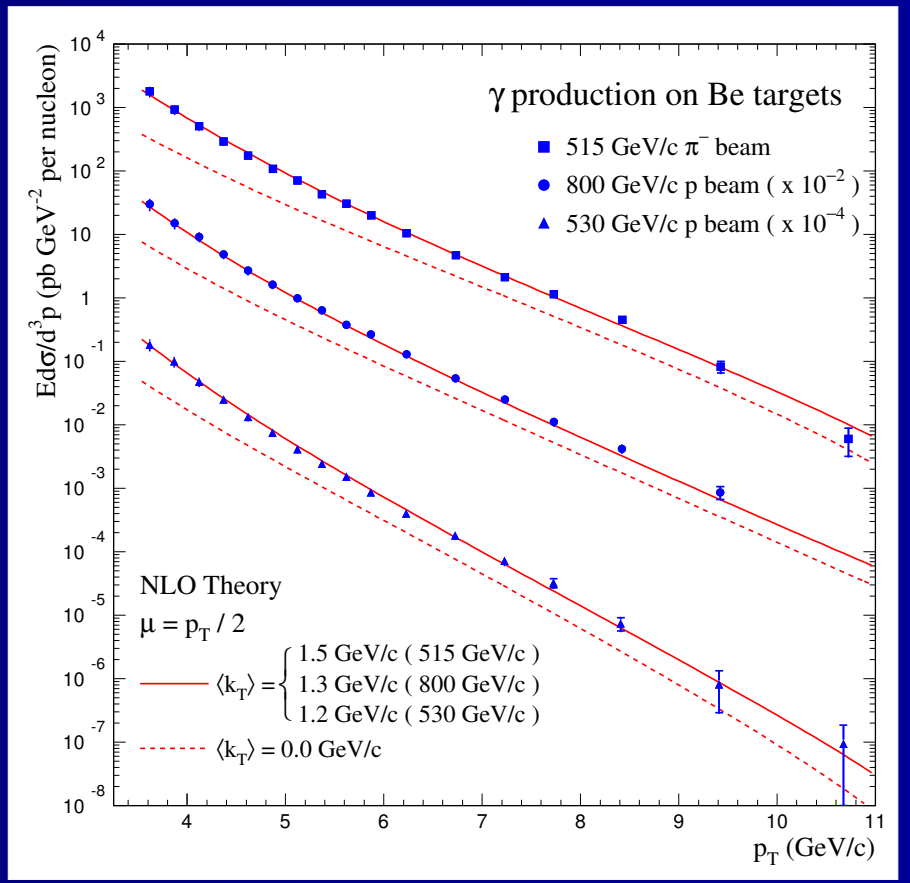


$\langle k_T \rangle$ for calculations of $K^{\mathrm{LO}}(p_T)$ taken from data (match distributions of high-mass pairs to LO calculations)

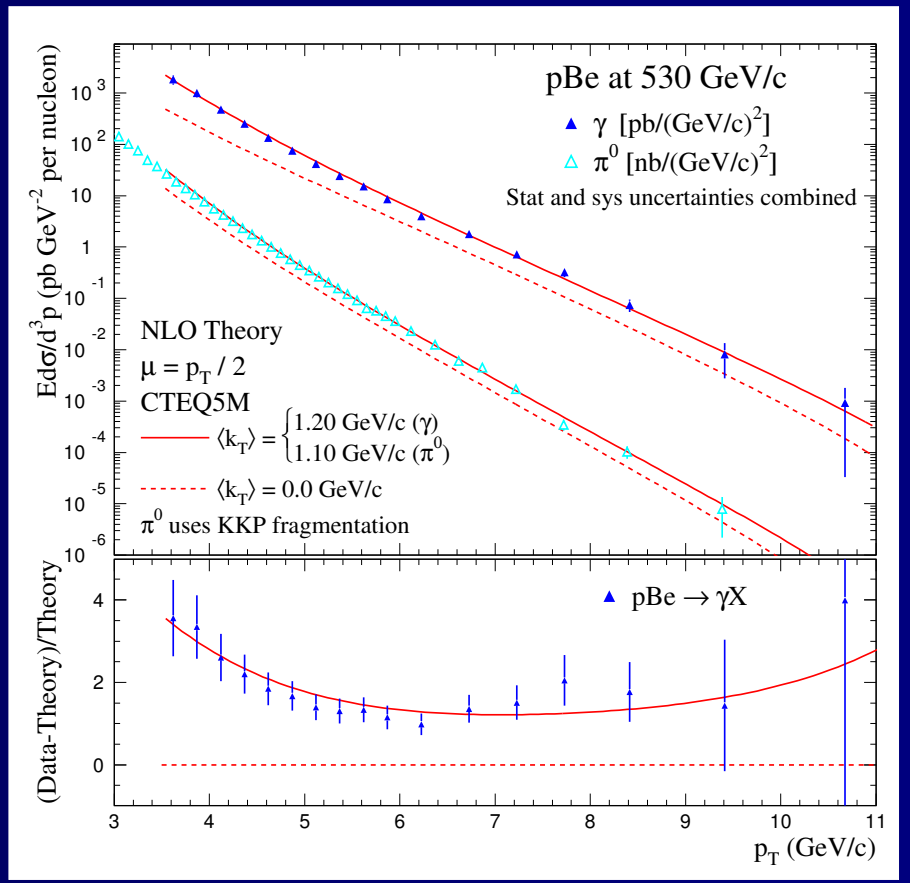
Inclusive Production with k_T

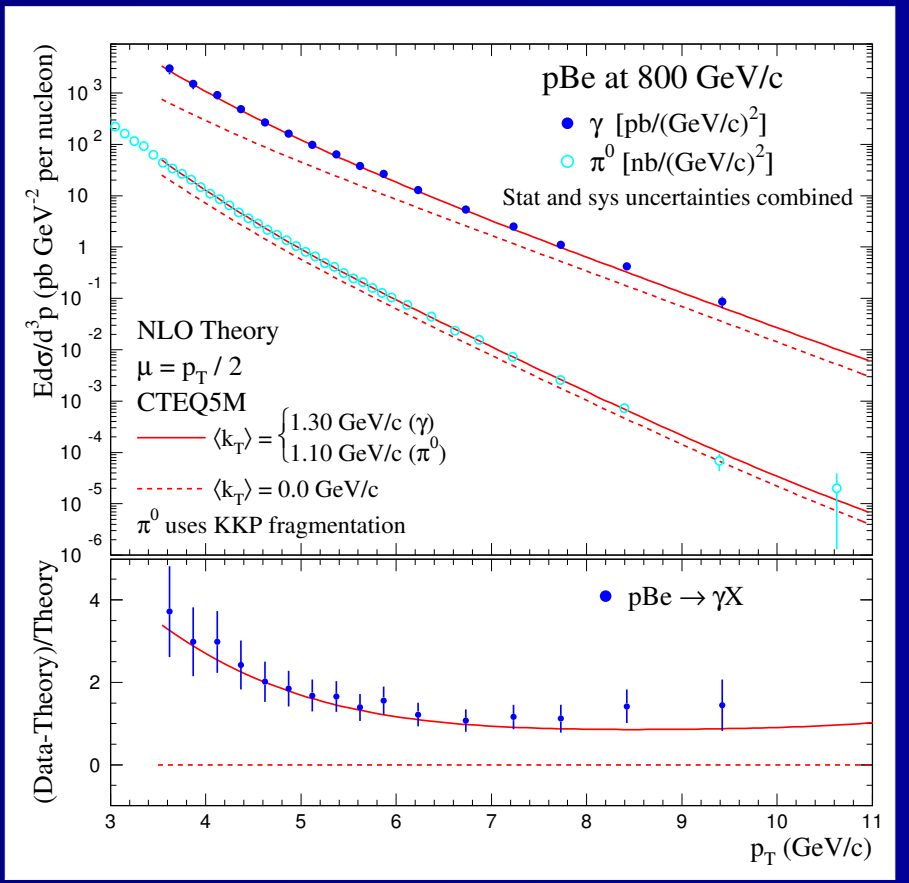
k_T-enhanced NLO pQCD compares well with both direct-γ and π^0 data.

Chosen k_T values were influenced by studies of two particle correlations but are model dependent. This is not a measurement of k_T.

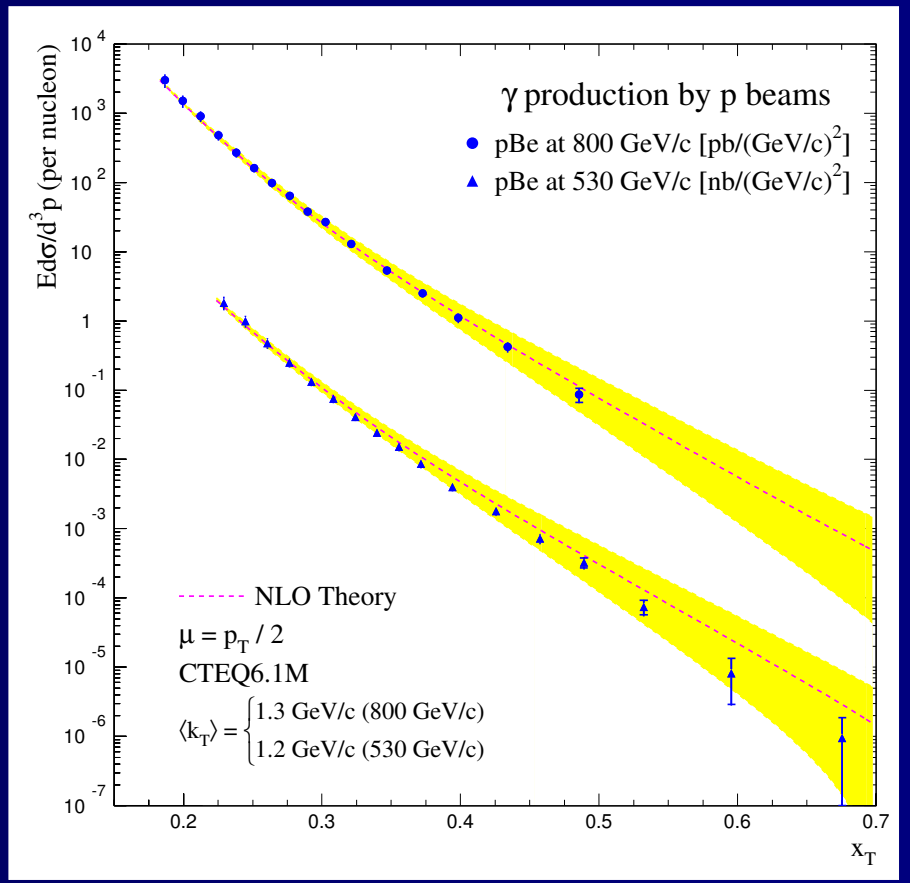


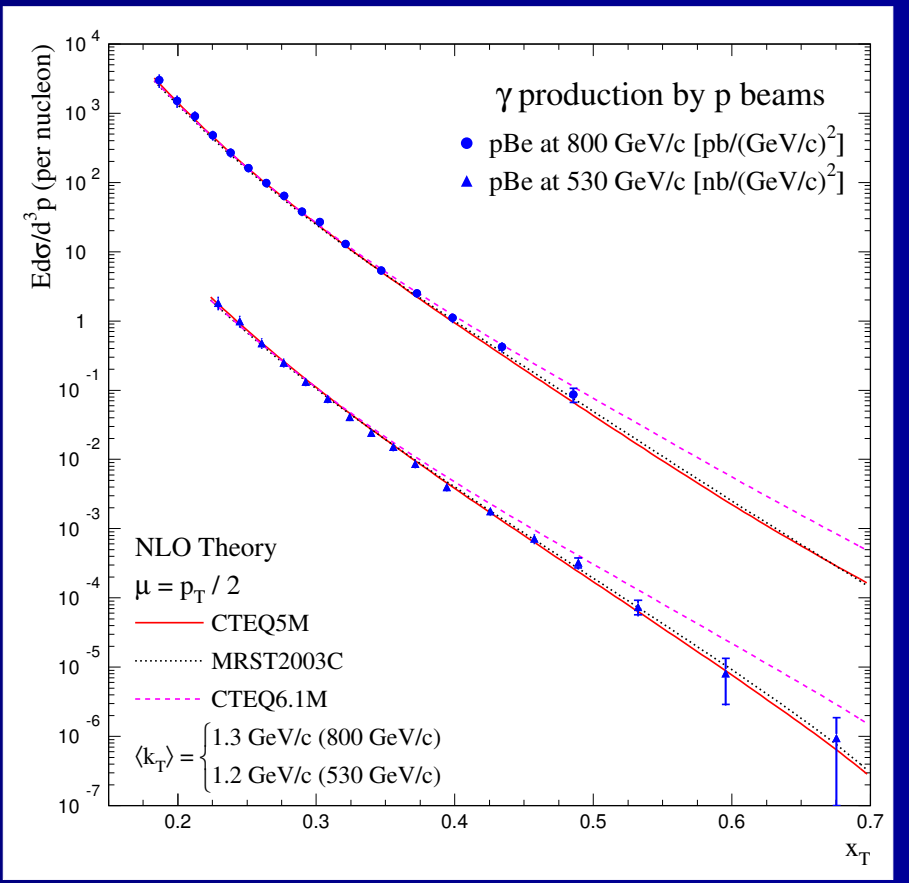
Inclusive Production with k_T





PDF Comparisons with k_T



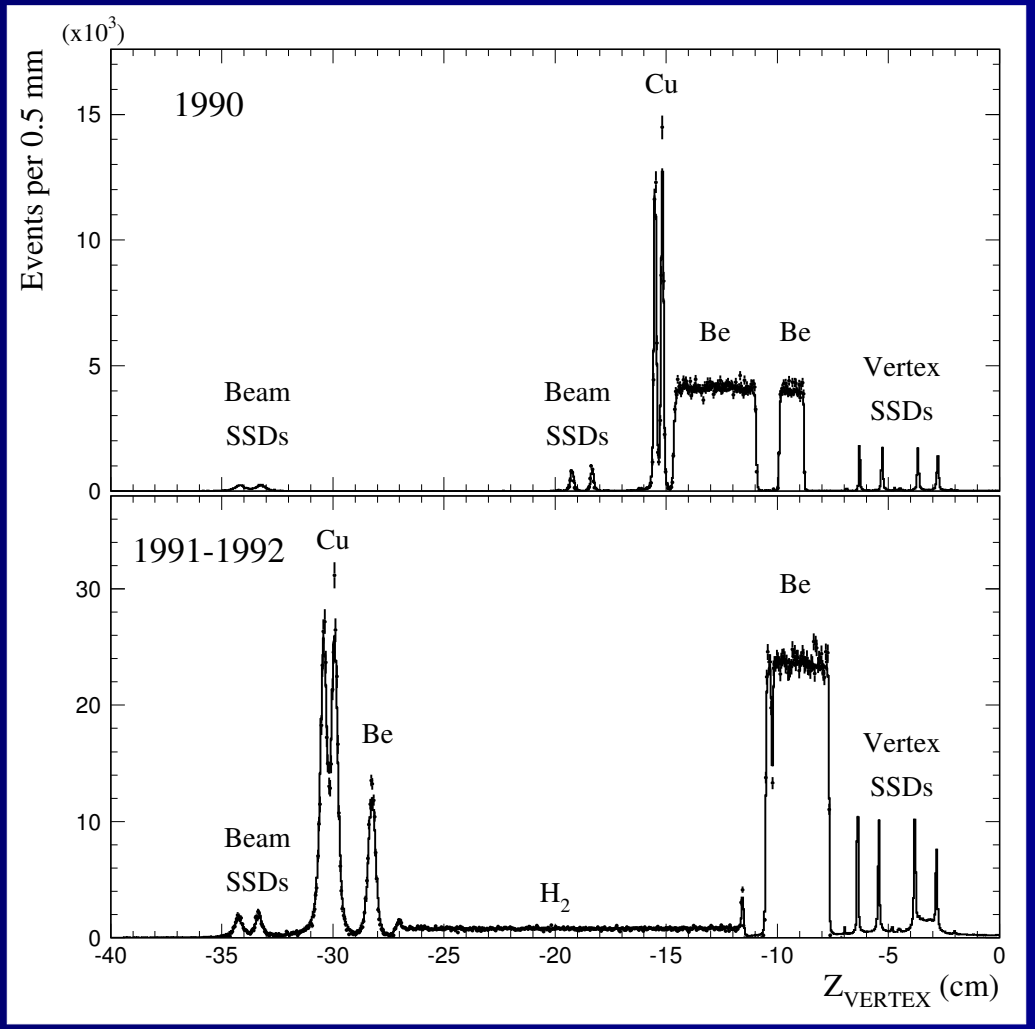


Conclusions

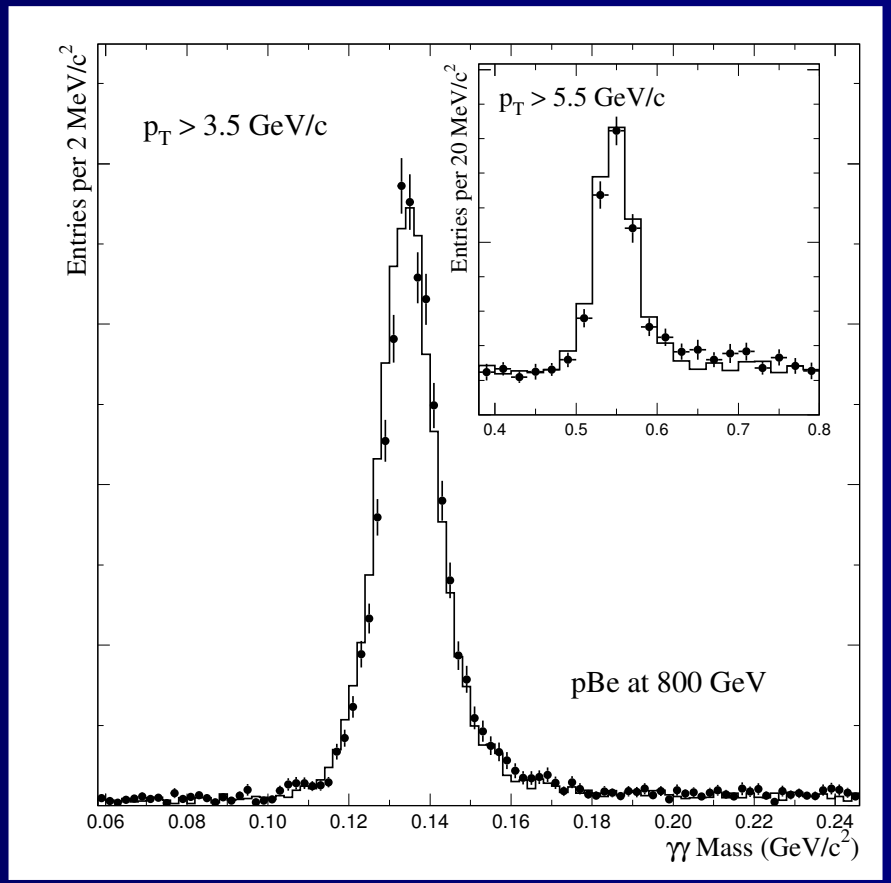
- High-p_T direct-photon production has been measured in interactions of 515 GeV/c π^- and 530 GeV/c and 800 GeV/c protons with beryllium and hydrogen targets (hep-ex/0407011).
- NLO pQCD does not satisfactorily represent our data.
- The data are described better by k_T-enhanced NLO pQCD calculations using the softer gluons of CTEQ5 and MRST2003 than the harder gluons of CTEQ6.1.
- Inclusion of direct-photon data in global fits would provide additional constraints on the gluon distribution, independent of the Tevatron jet data, thereby enhancing the discovery potential of the jet data being acquired in Tevatron Run II.

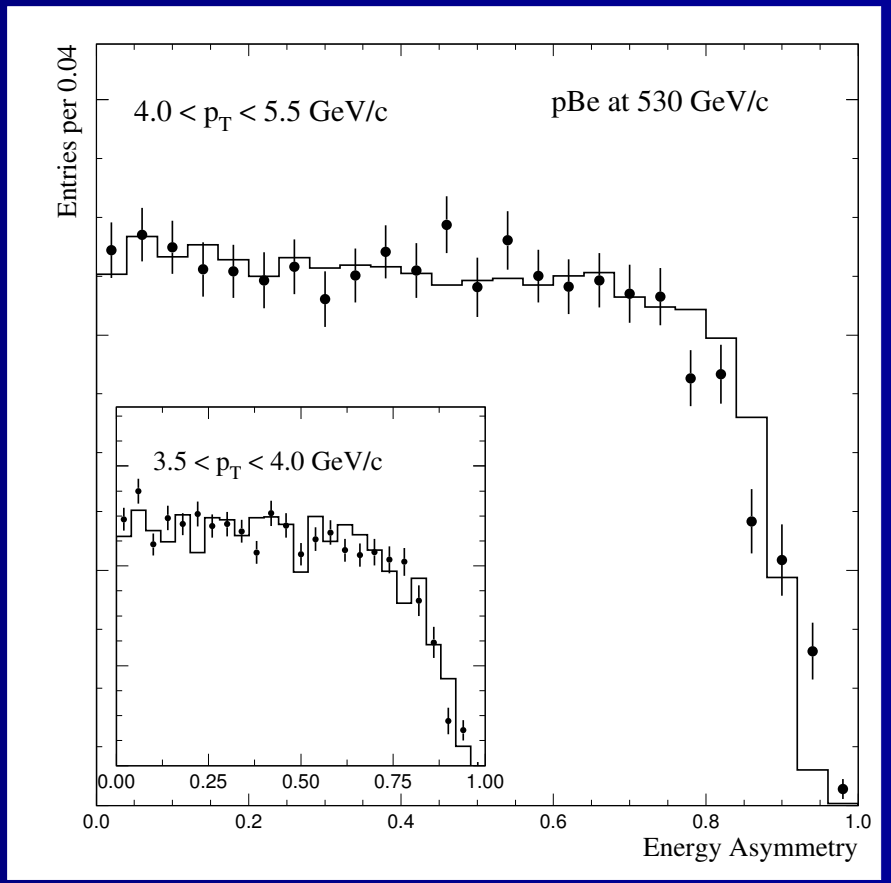
Backup Slides

Vertex Distributions

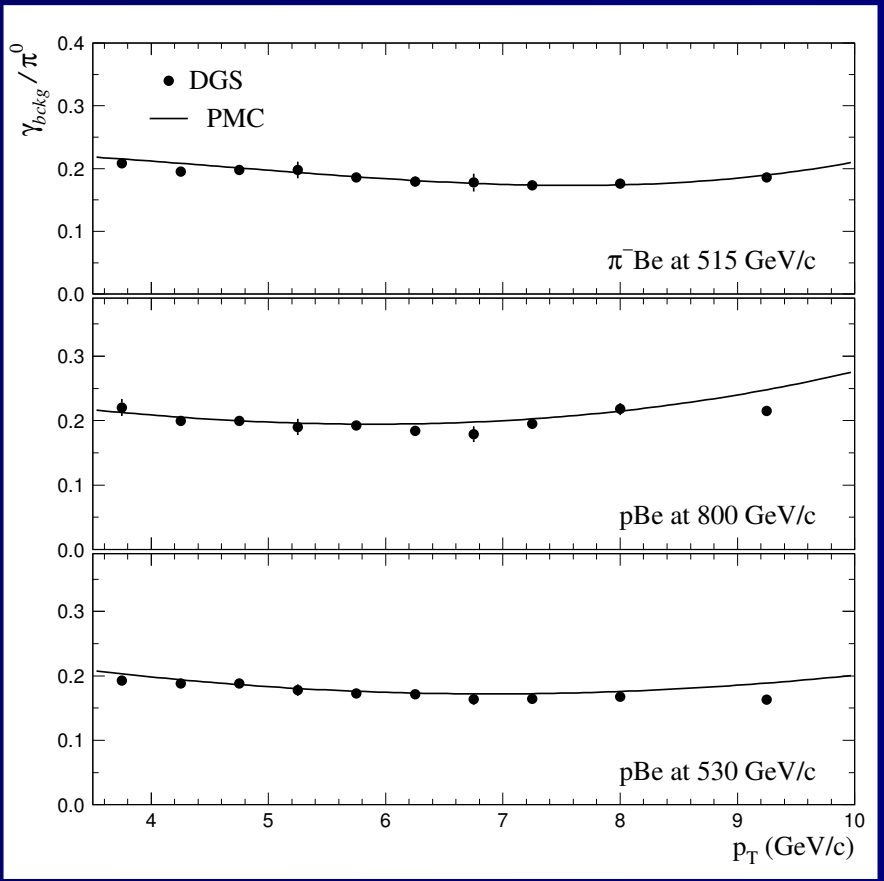


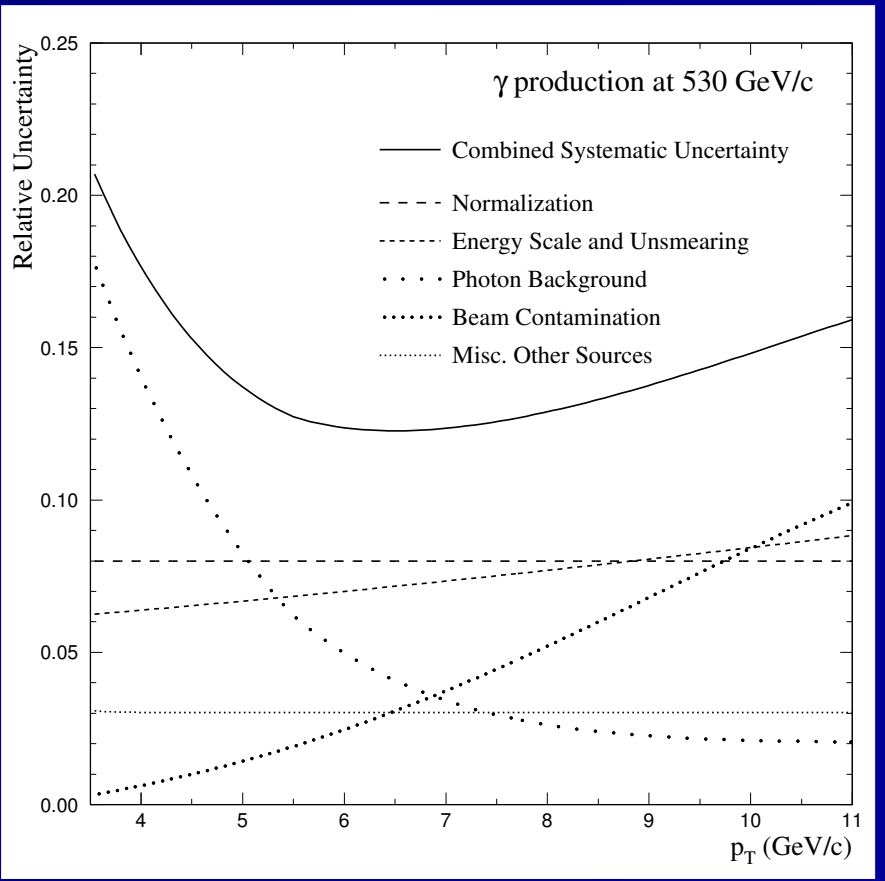
Detailed Simulation



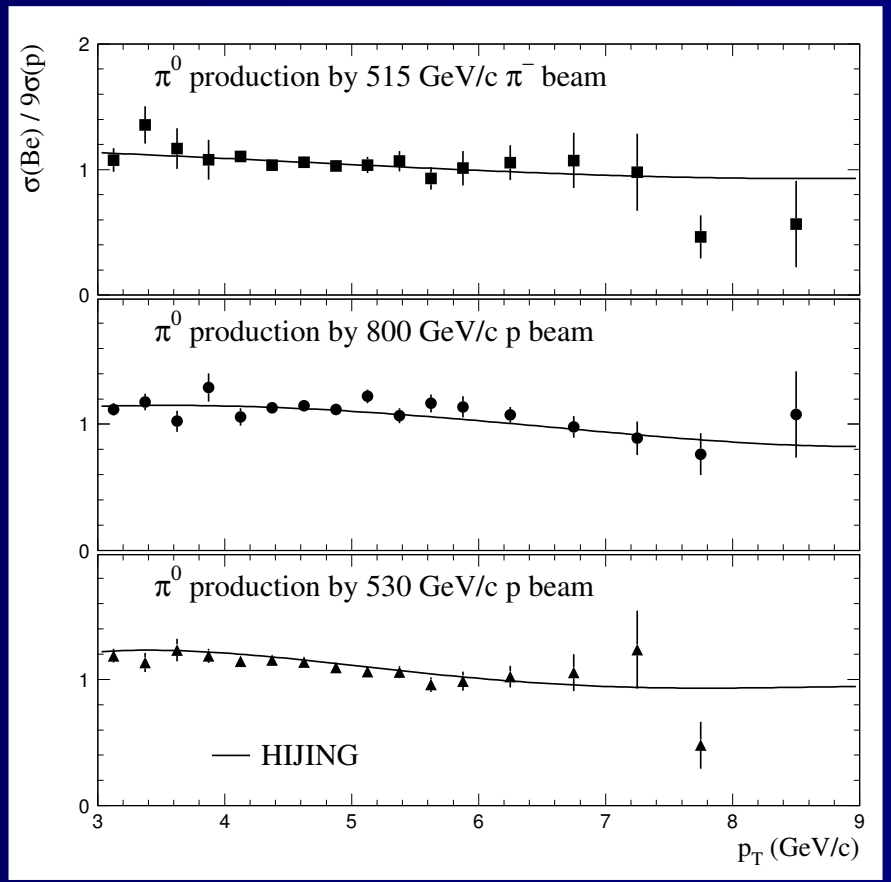


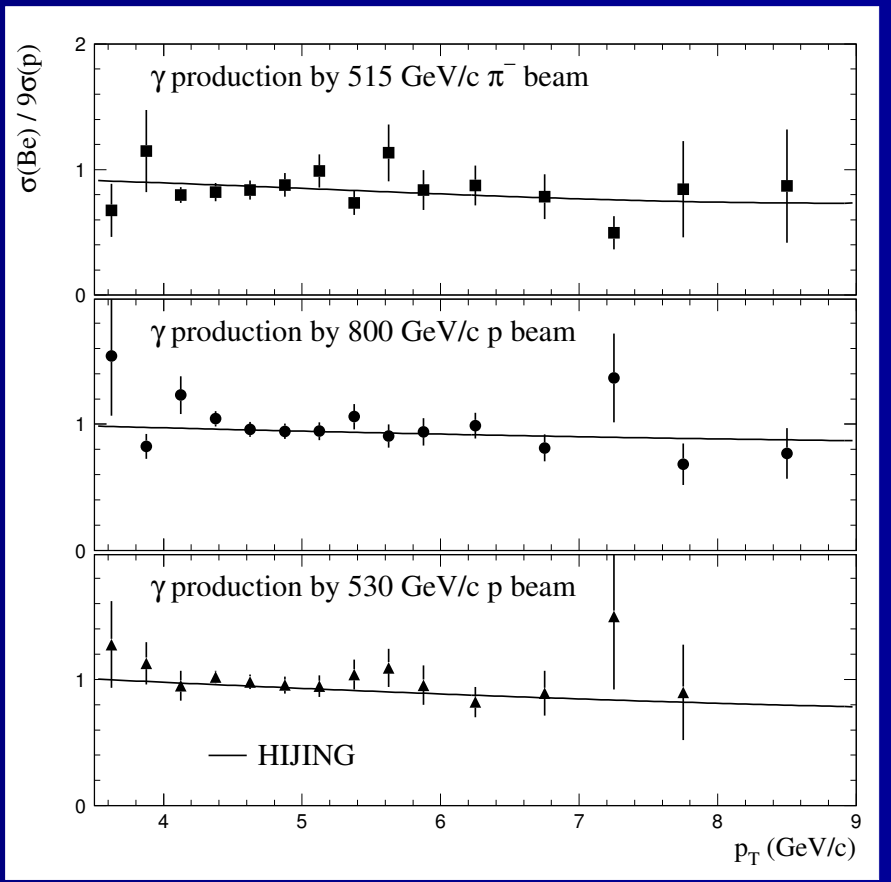
Systematic Uncertainty





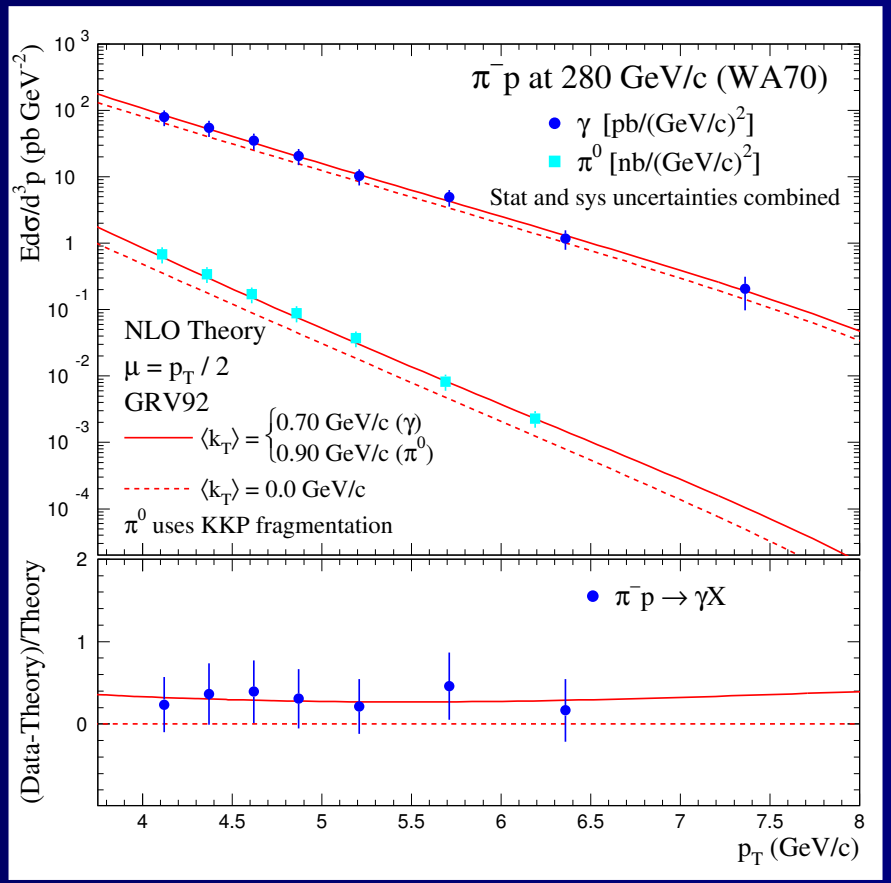
Nuclear Dependence

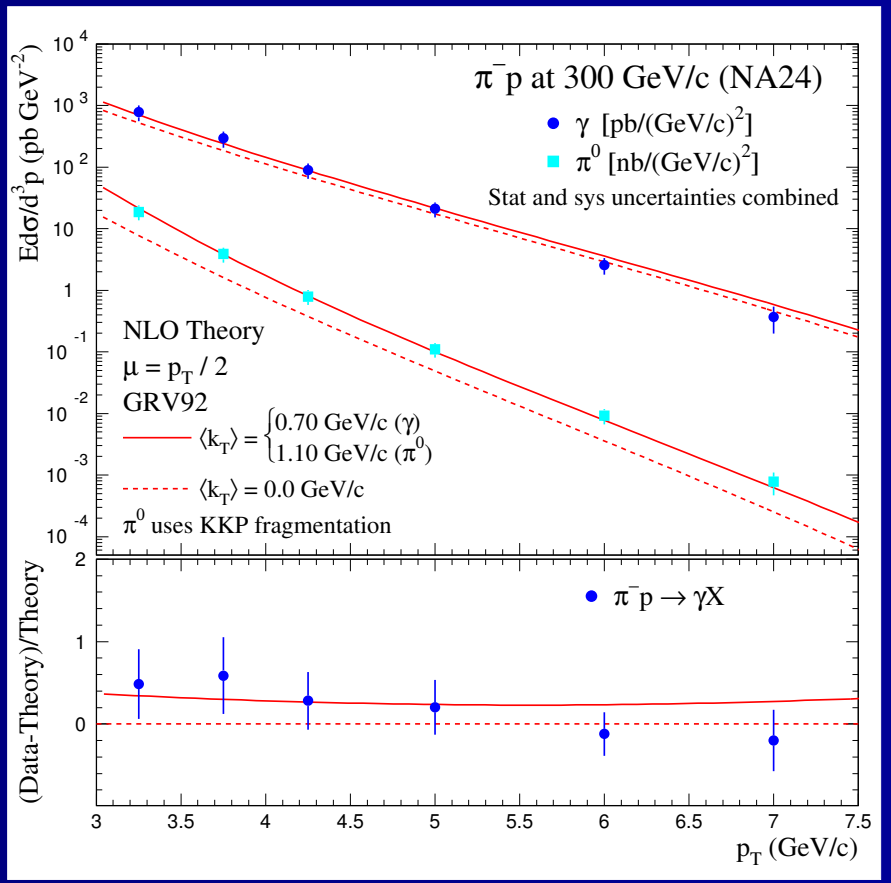




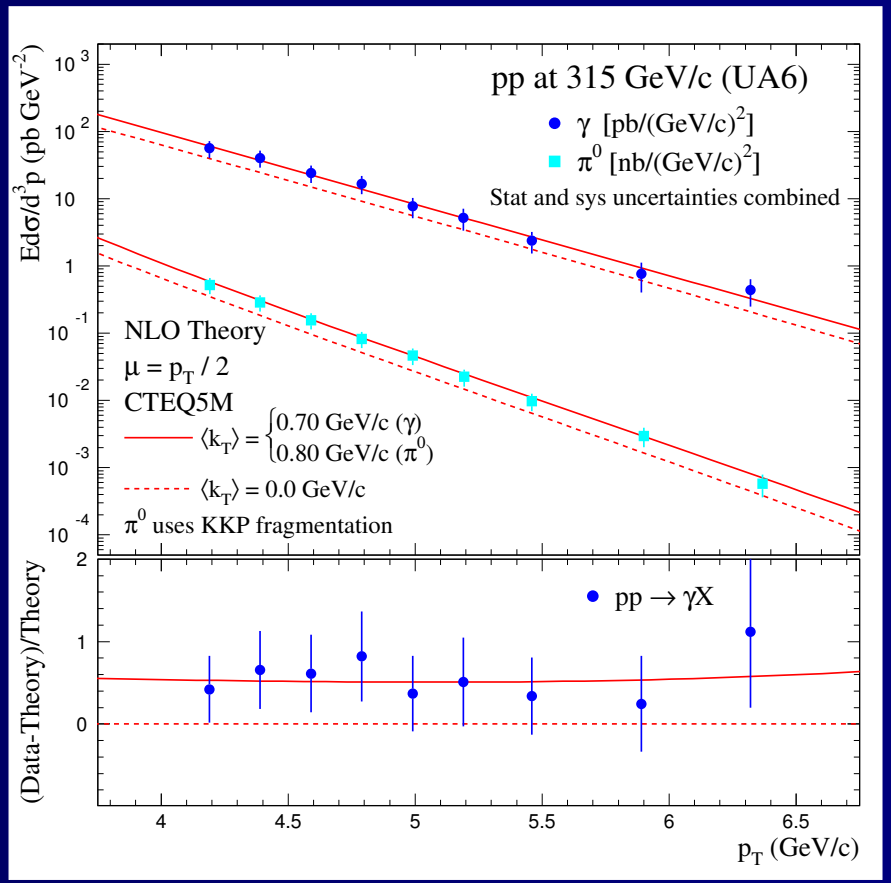
HIJING is a PYTHIA-based event generator for nuclear interactions. HIJING results compare well with data.

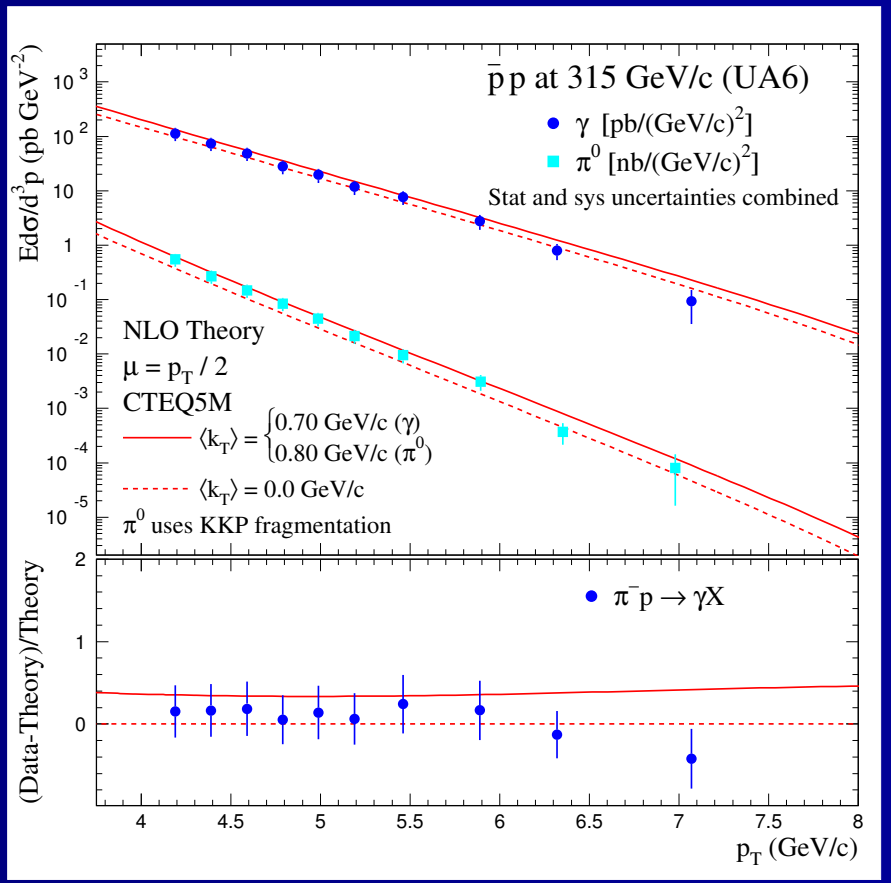
WA70 & NA24 at $\sqrt{s} \approx 23$ GeV



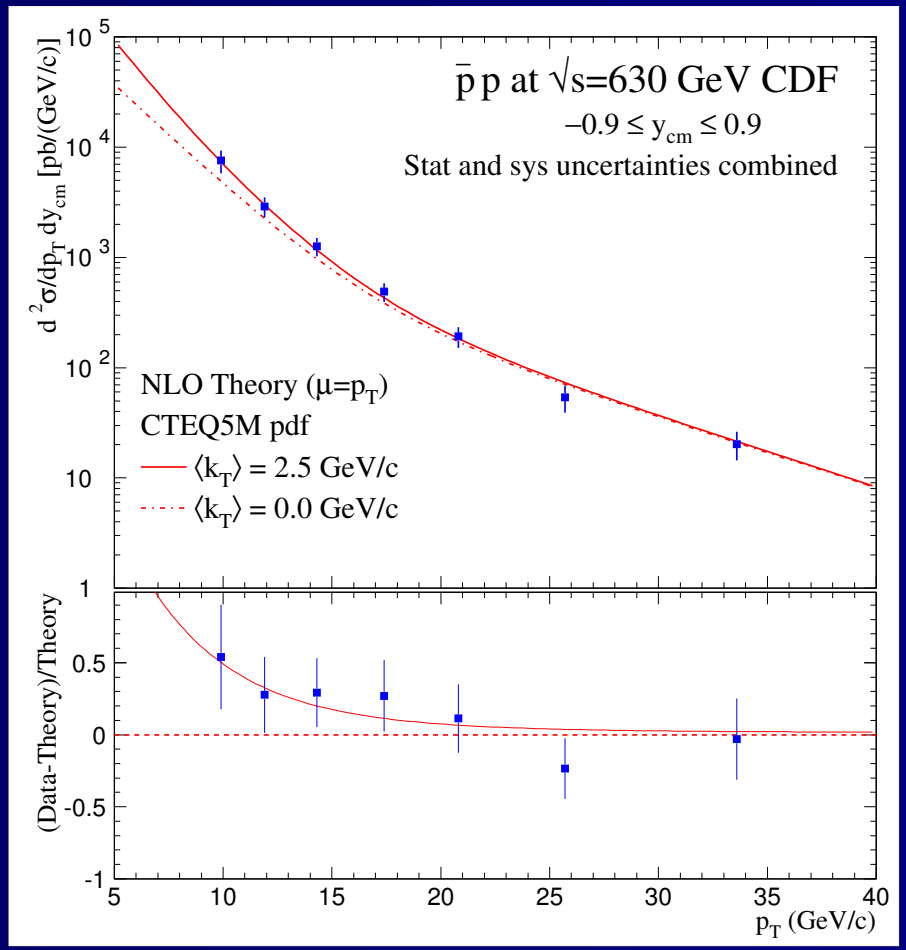


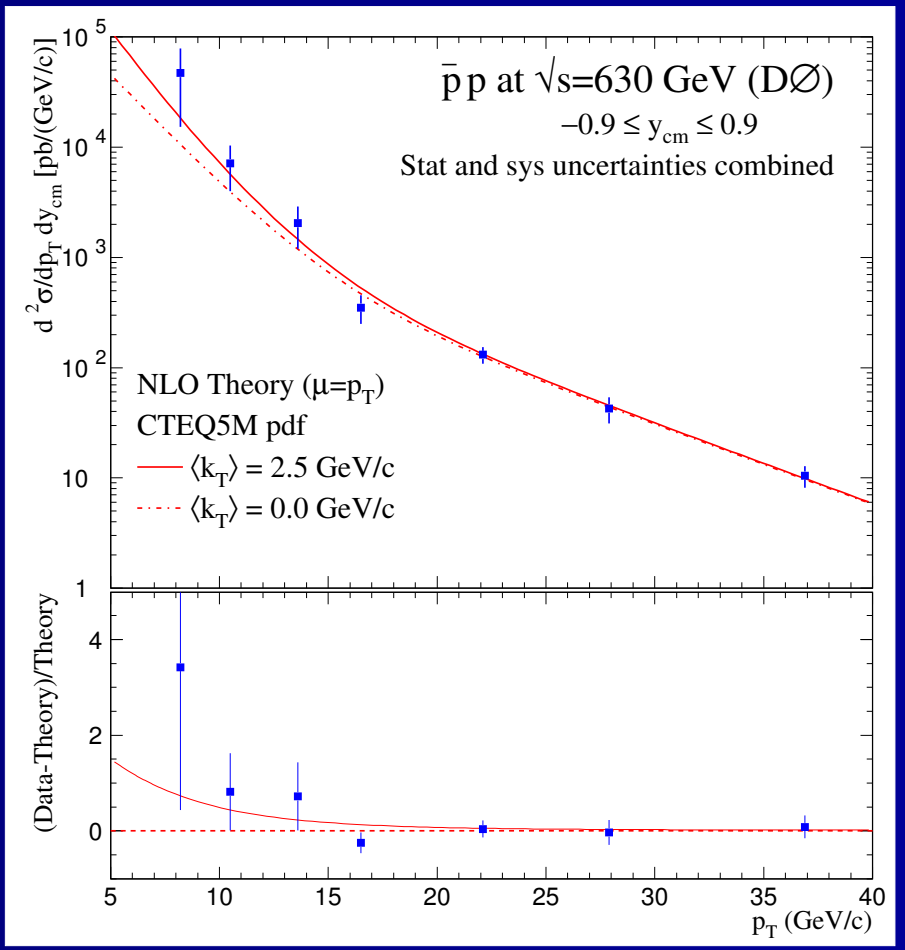
UA6 at $\sqrt{s} = 24.3$ GeV





CDF & DØ at $\sqrt{s} = 630$ GeV





CDF & DØ at $\sqrt{s} = 1800$ GeV