Photon and Diphoton Production at the TeVatron

Stephan L. Linn Florida State University

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Tests of pQCD with Photons

Cross Sections

- Isolated E_T (630/1800 GeV)
- Photon-Jet $cos\theta^*$
- Photon + Jet(s) - (new IA)
- Diphoton k_T (new IB)

Structure/Fragmentation

- Rapidity
- Isolation E_T

Cross Sections

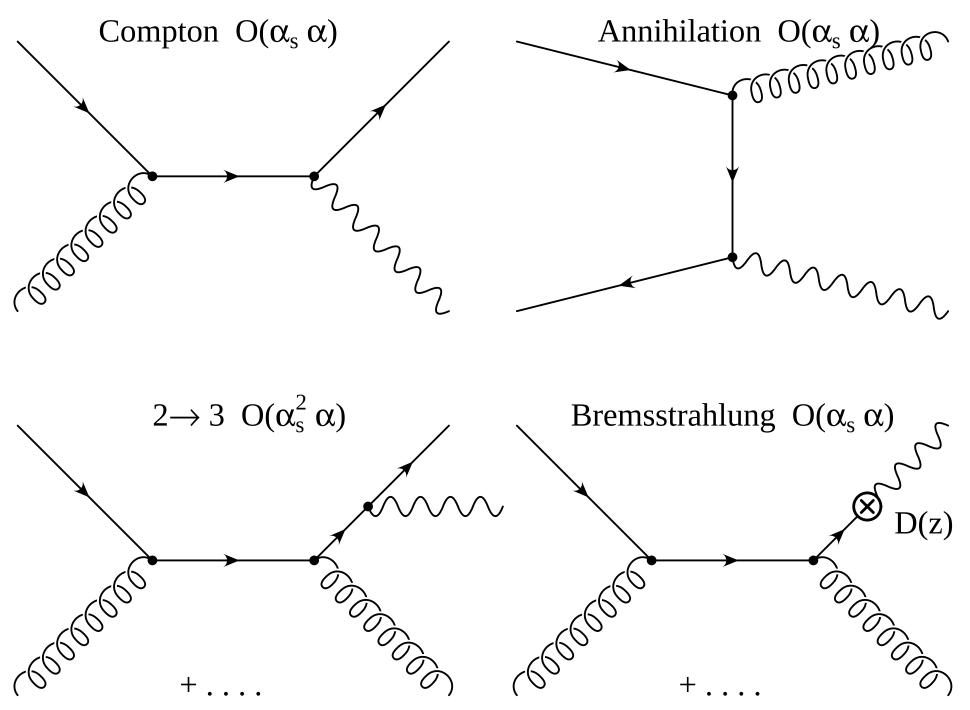
$$E\frac{d^3\sigma}{dp^3} = \sum_{a,b} x_a G(x_a) x_b G(x_b) \frac{d\hat{\sigma}}{d\hat{t}}(a\ b \rightarrow jet\ \gamma)$$

$= \frac{d^3\sigma}{dE_T^2 d\eta_\gamma d\eta_{jet}} \rightarrow$ **detector measures energy and position**

$= \frac{d^3\sigma}{dcos\theta^* dx_a dx_b} \rightarrow$ **physics variables are** $cos\theta^*$ **and** x

Matrix Elements:

- Compton (dominant)
- Annihilation
- $2 \rightarrow 3$
- Bremsstrahlung



Integrate $x_{a,b} \rightarrow \frac{d\sigma}{dcos\theta^*}$

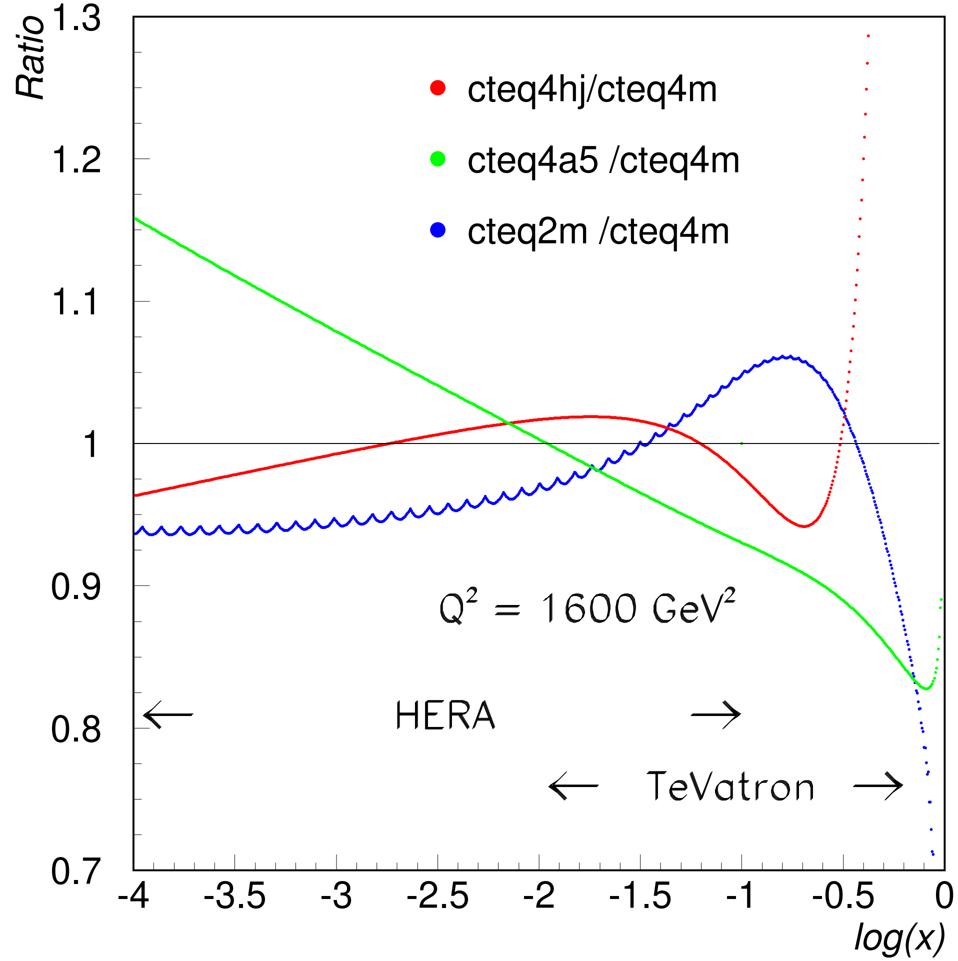
Gluon Structure Function

HERA:

- Measure F_2
- $Q^2 < 20\ GeV^2$
- $10^{-4} < x < 10^{-1}$

TeVatron:

- Measure $d\sigma/dE_T$, $d\sigma/d\eta$
- $Q^2 \sim E_T^2 > 100\ GeV^2$
- $x_{min} \sim \frac{2E_T}{\sqrt{s}} e^{-\eta} \sim 10^{-3}$



Integrate: $cos\theta^* \longrightarrow \frac{d^2\sigma}{dx_a dx_b}$

Photon Fragmentation Functions

$$D(z) \sim log(Q^2/\Lambda^2) \times f(z)$$

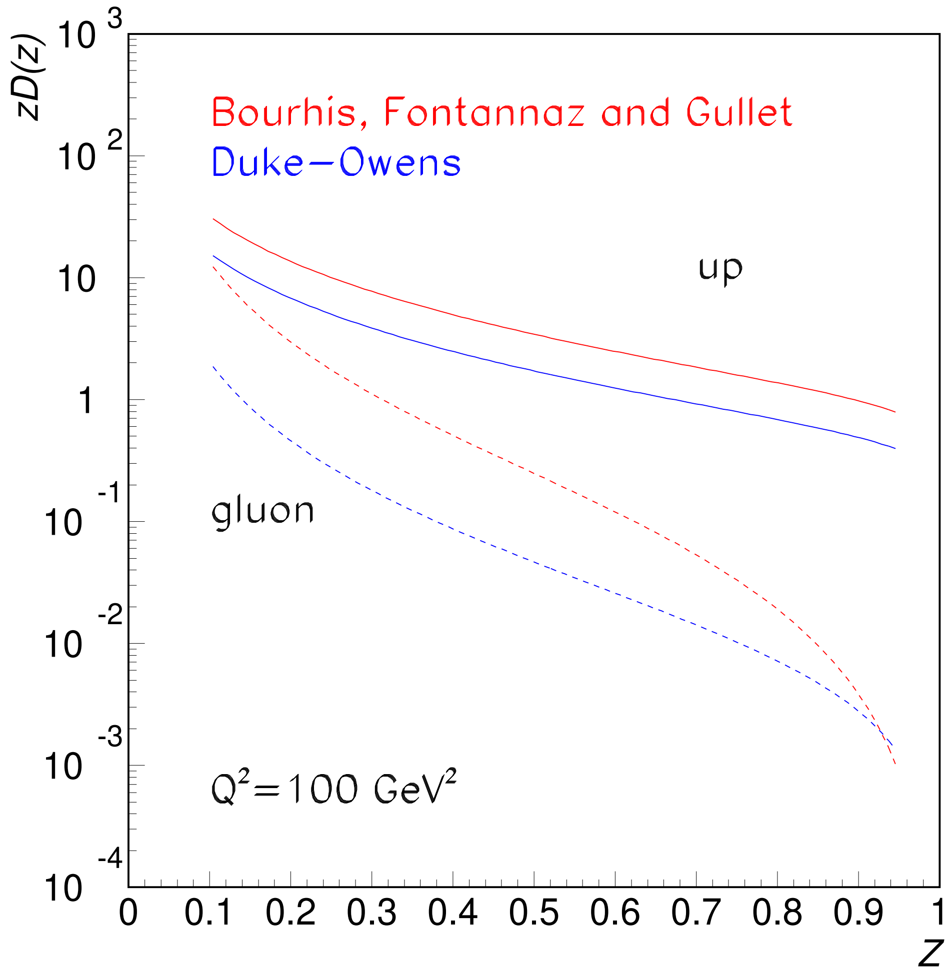
- Witten, Llewellyn-Smith,D-O....
- $log \sim \alpha^{-1}$ - another scale

LEP

- Measure $d\sigma/dz$
- $Q^2 = M_Z^2$, $0.7 < z < 0.95$

TeVatron

- Measure $d\sigma/dE_T(isolation)$
- $Q^2 \sim E_T^2 > 100\ GeV^2$, $0.8 < z < 0.98$



Background Subtraction

Large background: jets $\rightarrow \pi^0/\eta$

DØ Discriminant- Energy in first $2X_0$

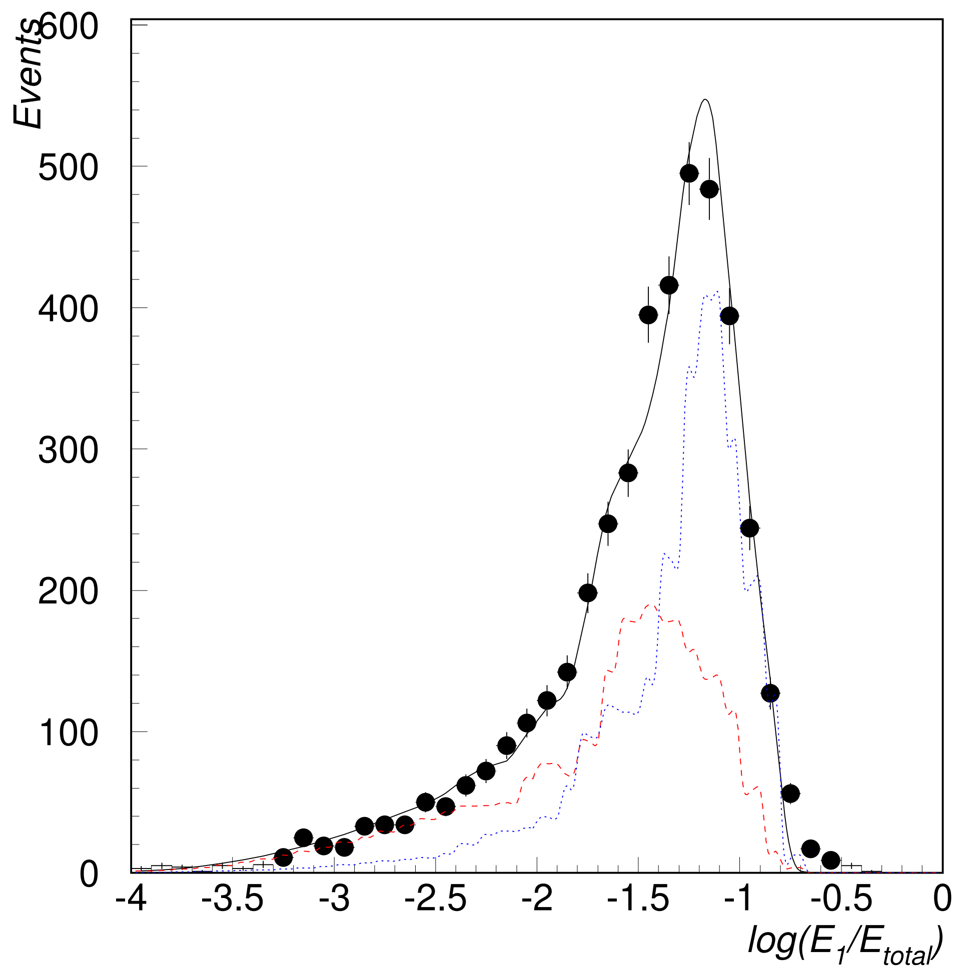
$log(E_1/E_{total})$

Fit with MC Distributions

$D_j = F_\gamma B_j^\gamma + (1 - F_\gamma) B_j^{jets}$

Where:

- F_γ - photon purity
- D_j - data
- B_j^γ - MC Photons
- B_j^{jets} - MC Background

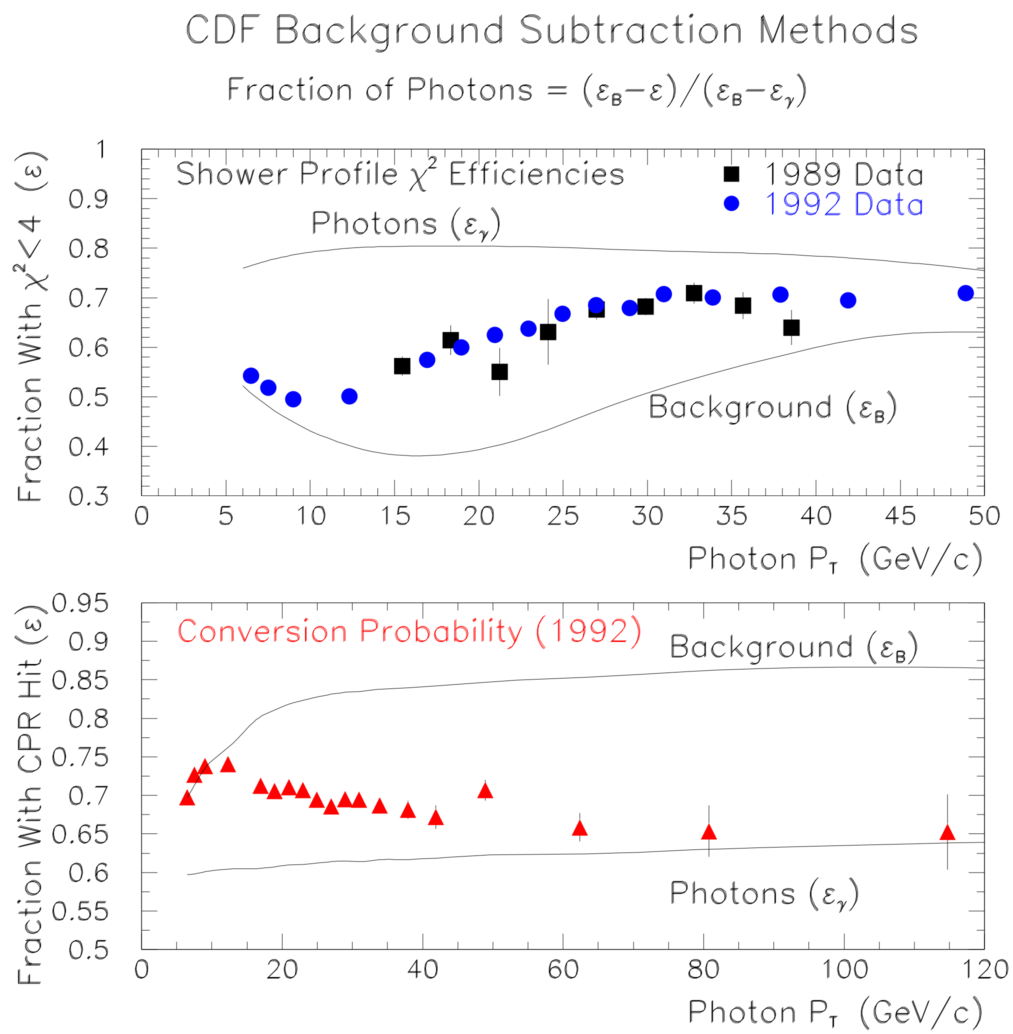


CDF Discriminants:

- CES - Profile (low E_T)
- CPR - Conversions

From simulation/data

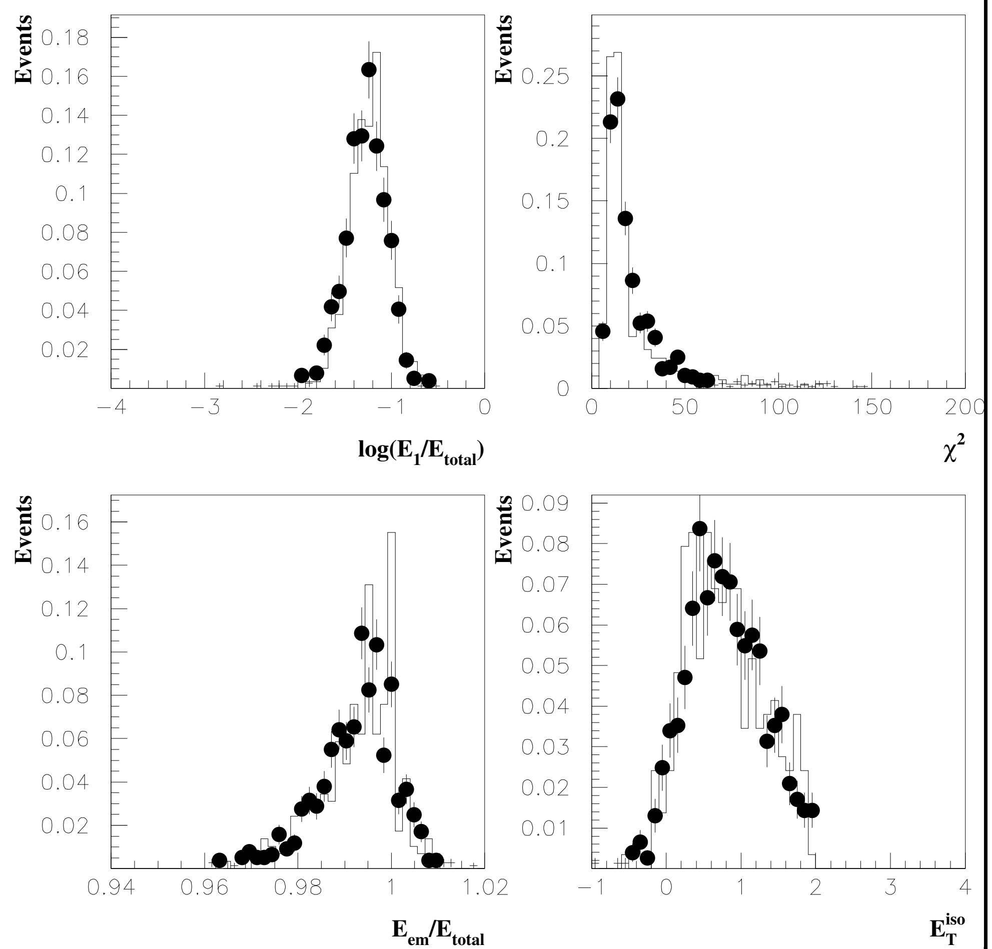
- $F = \frac{\epsilon_b - \epsilon}{\epsilon_b - \epsilon_\gamma}$
- $\delta F_{sta} \rightarrow$ data and MC



Calibration

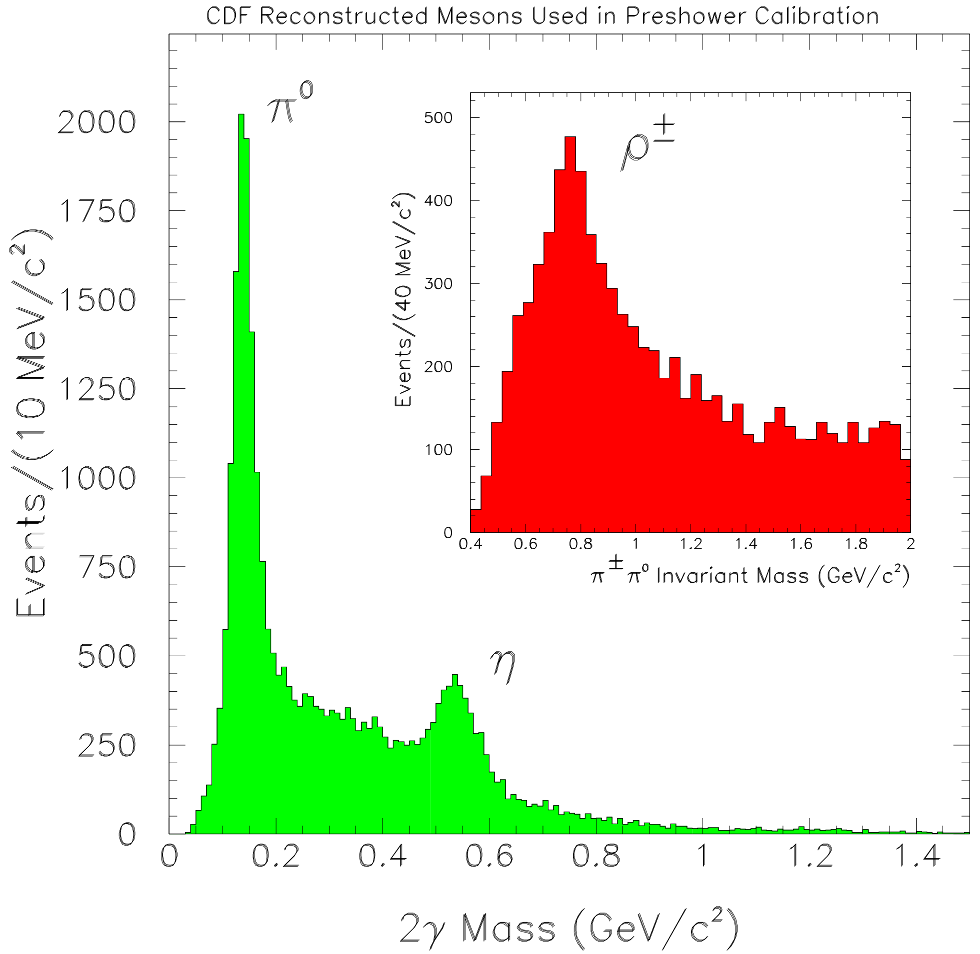
DØ Use: $W \rightarrow e\nu$

- $log(E_1/E)$ - discriminant
- χ^2 - Shower shape
- $EM/Total$ - EM fraction
- Isolation cone
  $E_T(R = 0.4) - E_T(R = 0.2)$



CDF Use:

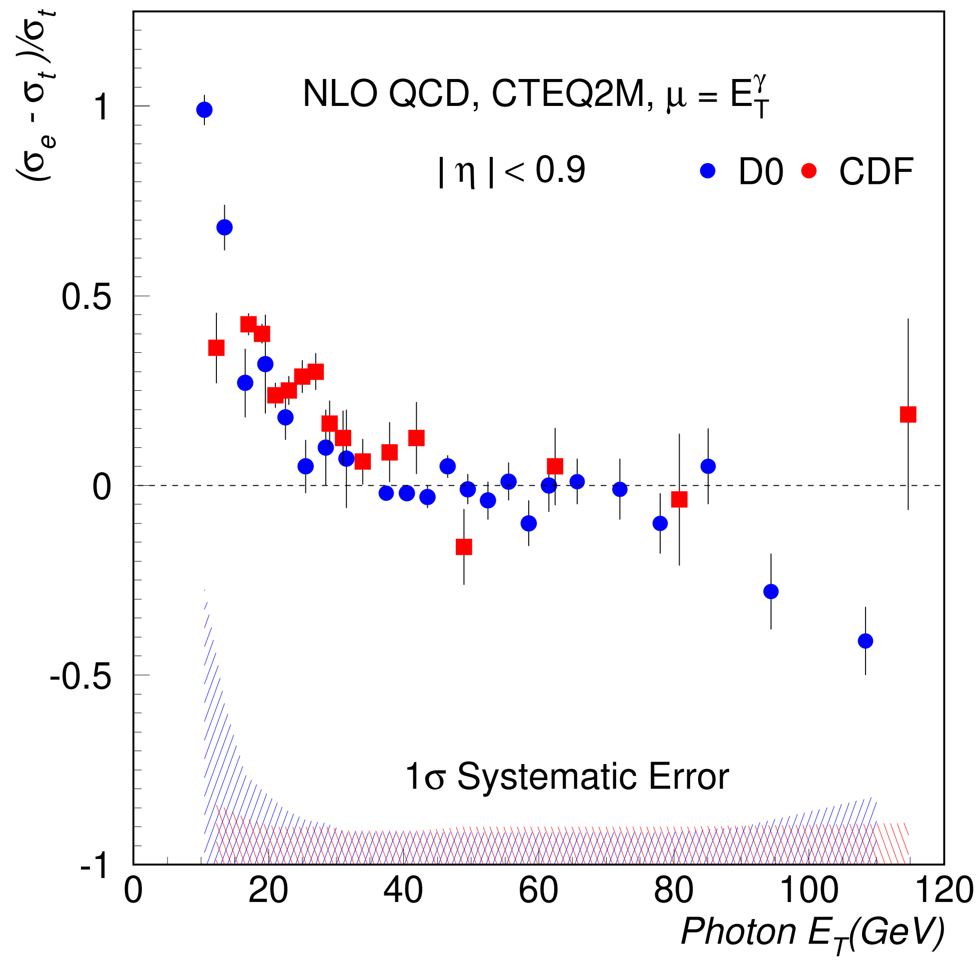
- π^0, η, ρ
- test beam electrons
- CES/CPR consistency



Isolated Photon Cross Section

Measurement: $\frac{d\sigma}{dE_T}$

- Isolation Cone
  $R = 0.7$(CDF)
  $R = 0.4$(DØ)
- Isolation $E_T \leq 2GeV$
- $|\eta| \leq= 0.9$



Results:

- Consistent
- low-E_T rise
- high-E_T dip?

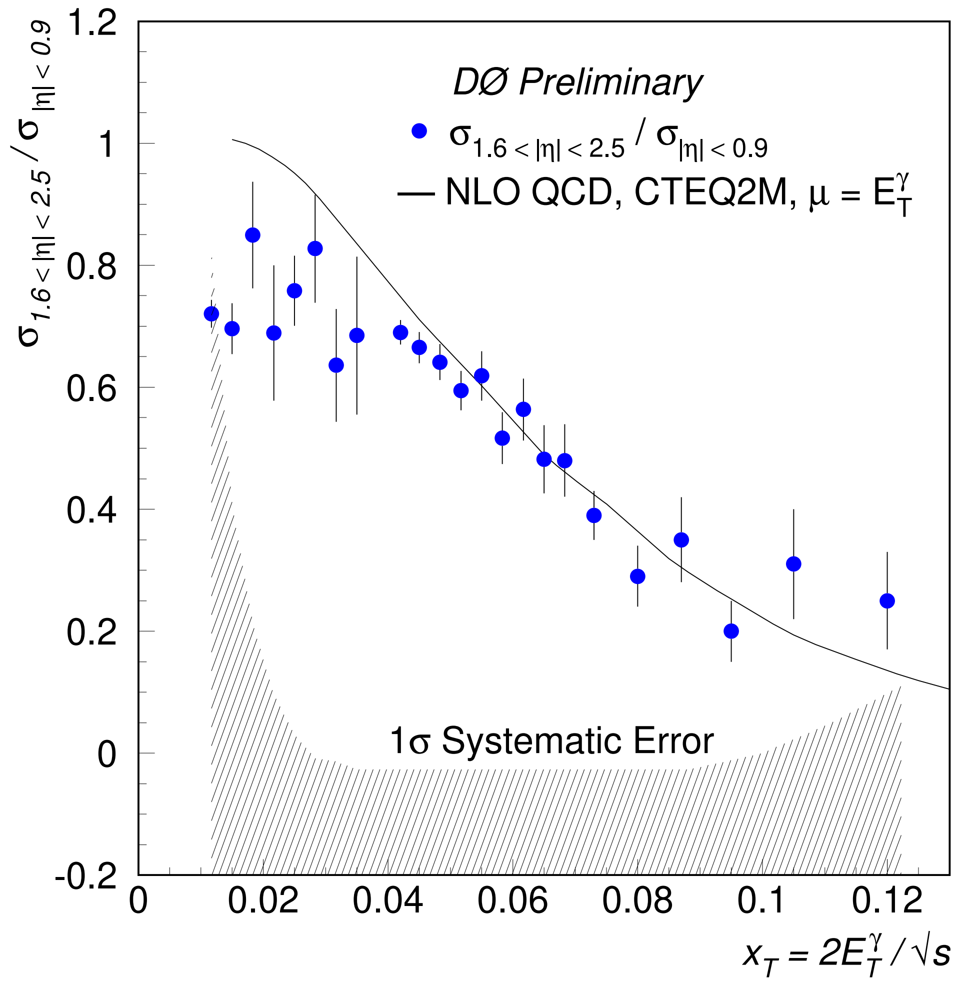
Forward Photons

Ratio: DØ Forward/Central

- Theoretical scale sensitivity cancels
- Some experimental errors cancel (Luminosity)

Results:

- Theory good for $E_T > 35\ GeV$
- Nothing conclusive about $G(x)$, $x \leq 0.04$

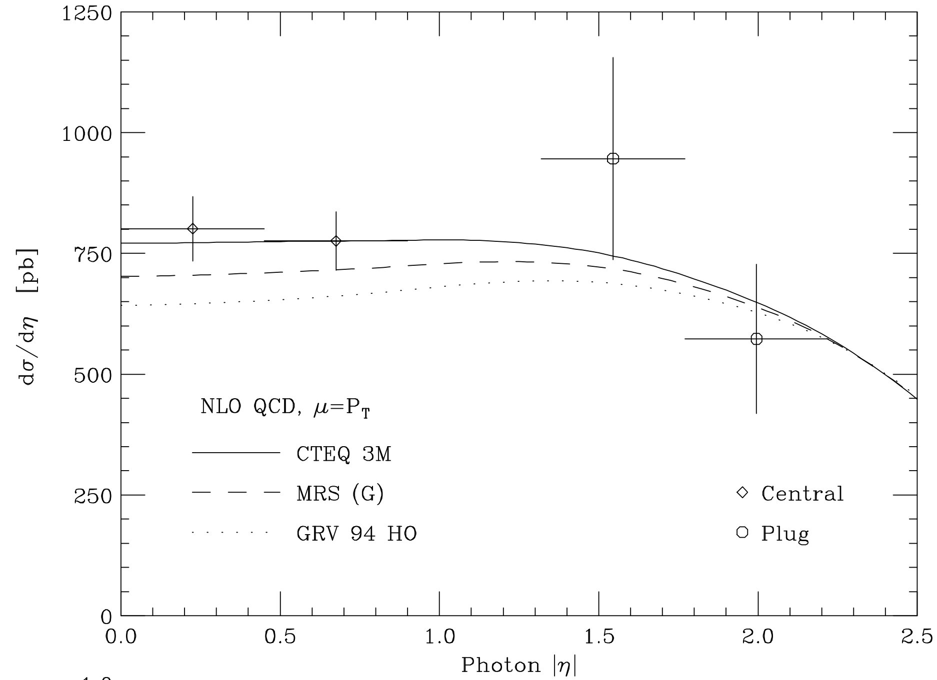


CDF Forward Photons

Preliminary

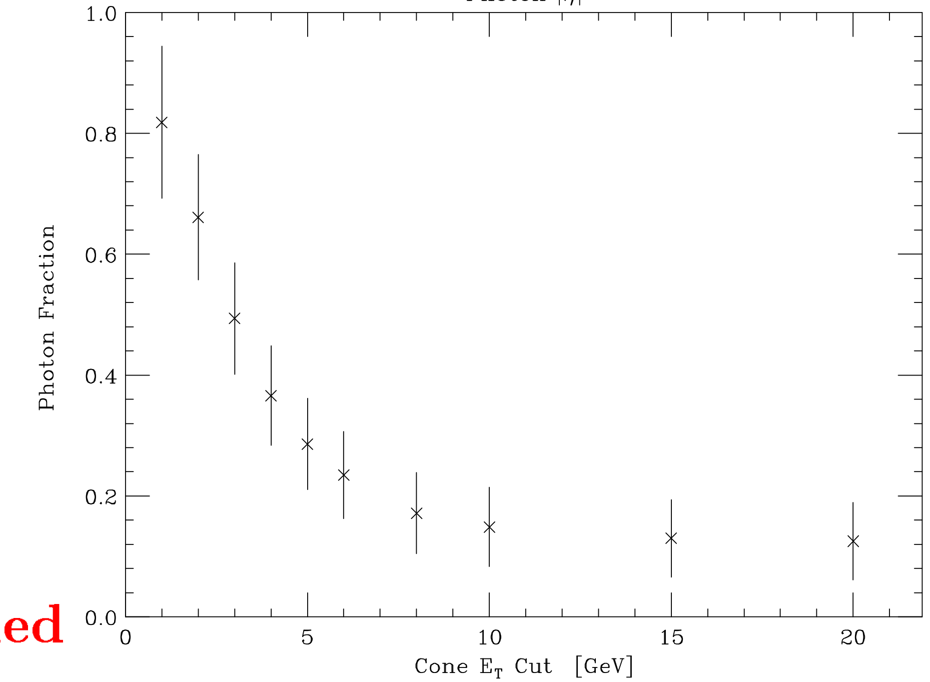
Measure: $d\sigma/d\eta$

Compare to PDF's



Measure: $d\sigma/dE_T(isolated)$

Compare with fragmentation

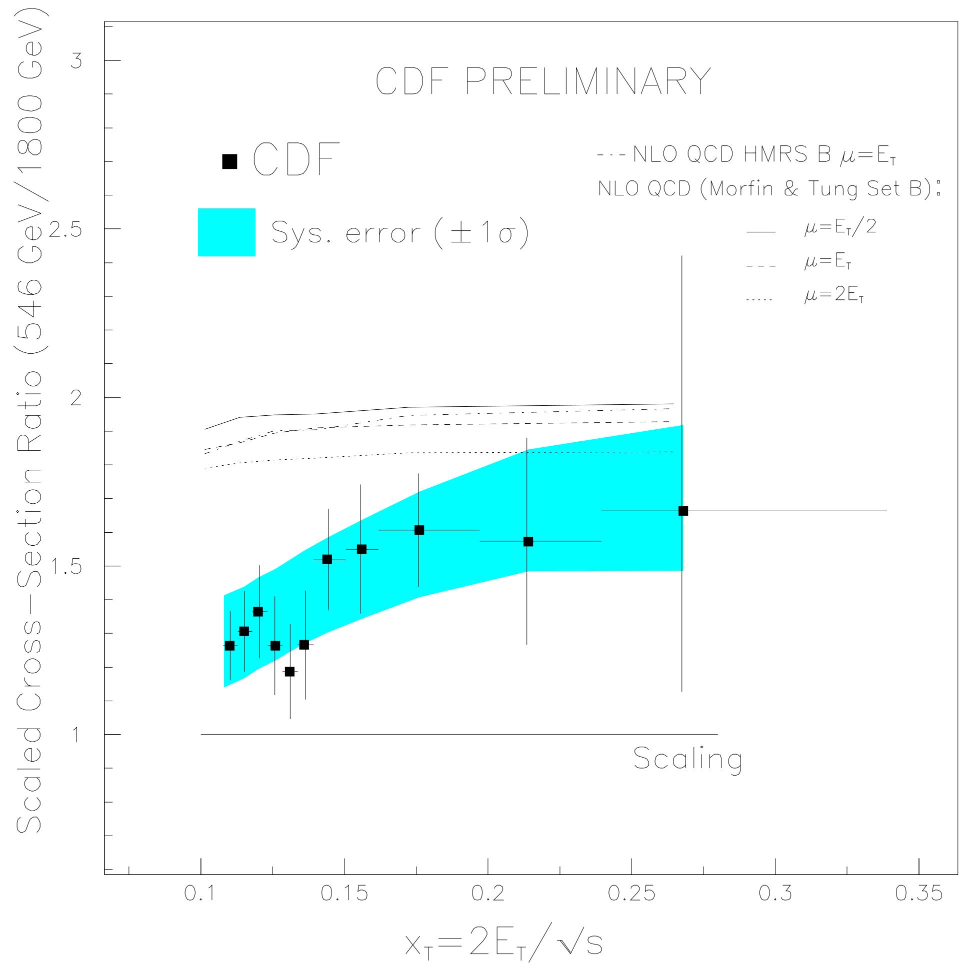


Important - more work needed

630 GeV Photons

Motivation:

- Check JET scaling predictions
- $Sp\overline{p}S$ confirmation
- Repeat with photons
- Check low-E_T rise



CDF Measurement:

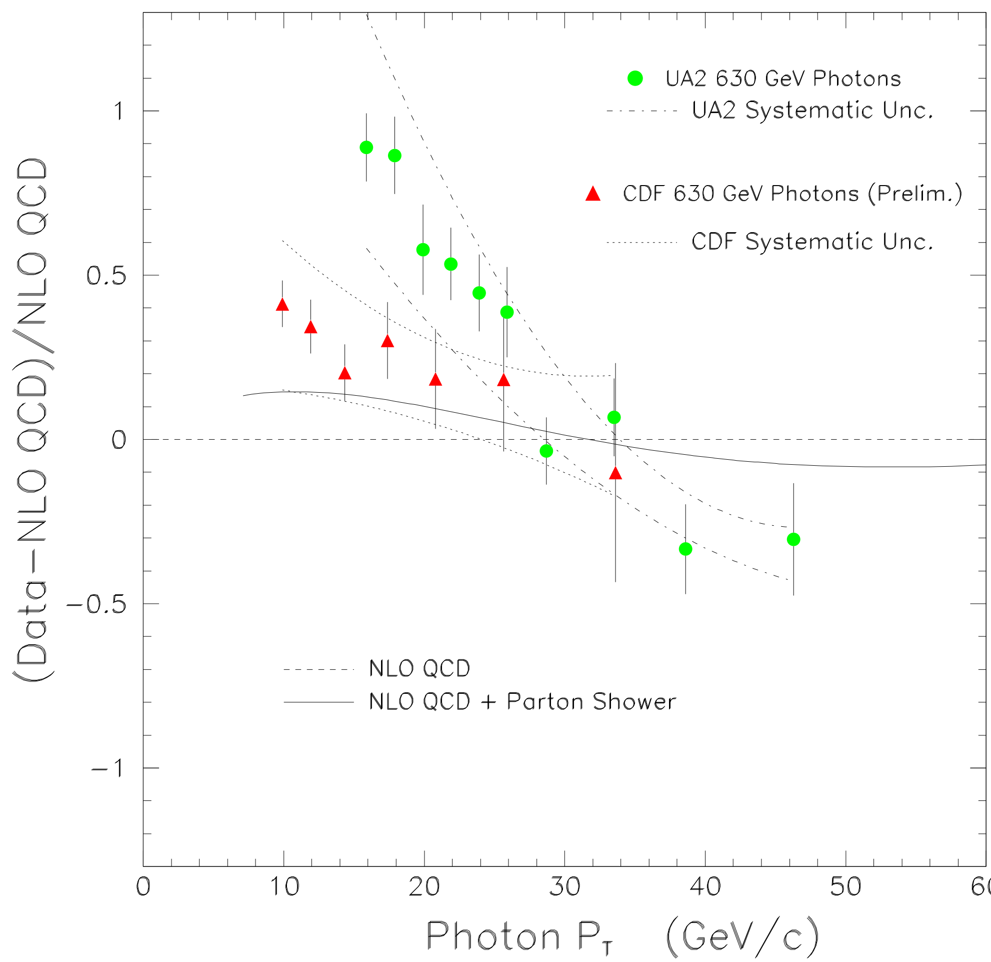
- $\int Ldt \sim 0.4pb^{-1}$
- $E_T(iso) < 2\ GeV,\ \Delta R = 0.7$
- $\eta < 0.9$
- $\eta/\pi^0 = 0.8$

UA2 Measurement:

- $\int Ldt = 7.1pb^{-1}$
- $E_T(iso) < 2\ GeV,\ \Delta R = 0.5$
- $\eta < 1.0$
- $\eta/\pi^0 = 0.6$

Baer and Reno

- NLO+parton shower
- rise at low E_T additional k_T
- loss at high E_T isolation cut
- introduces param $Q_0^2 = c_v \times min[s_{ij}]$



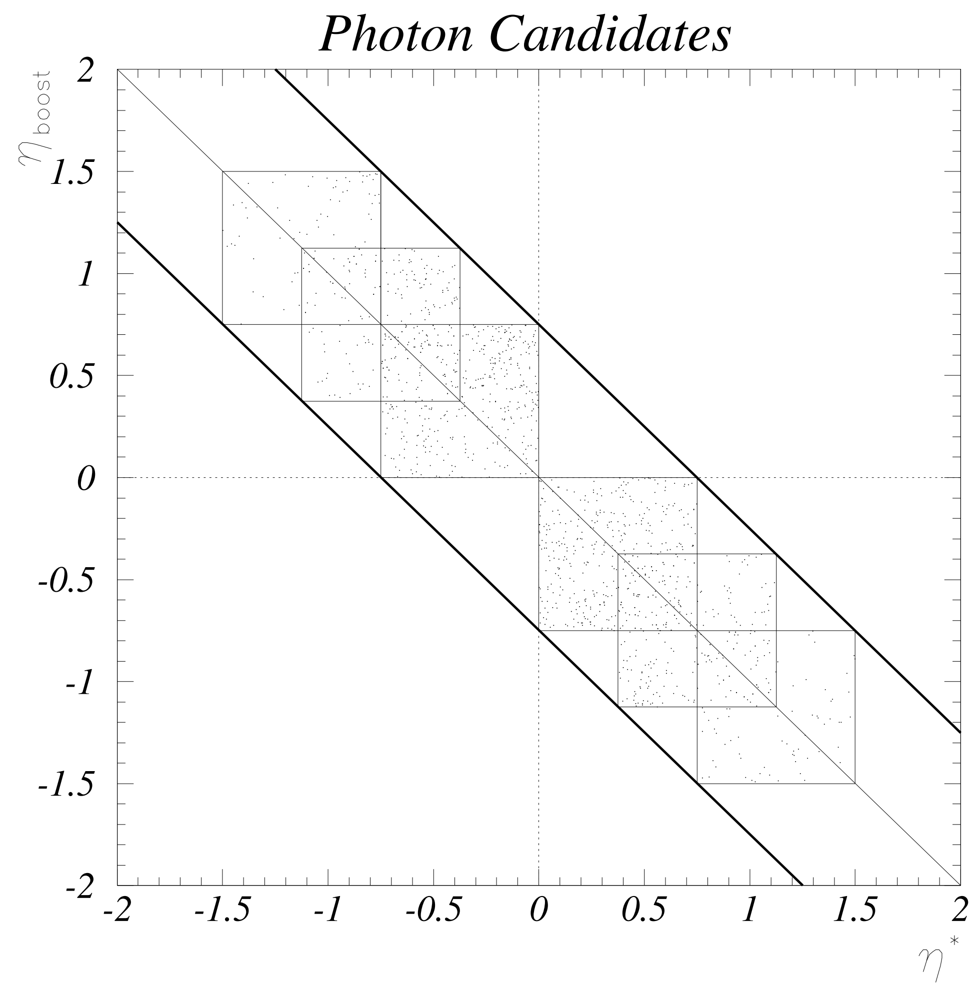
CMS Angular Distribution

Event Selection:

- CDF DØ
- $\eta_{\Sigma jet} < 1.5, 2.25$
- $\eta_\gamma < 0.9, 0.75$
- $E_{T\gamma} > 22$ GeV, 36 GeV

Acceptance:

- $\eta^* = (\eta_\gamma - \eta_{jets})/2$, $\eta^b = (\eta_\gamma + \eta_{jets})/2$
- $cos\theta^* = tanh\eta^*$
- $E_{T\gamma}^{min} cosh\eta^*_{max} < E^*_\gamma < E_{T\gamma}^{max} cosh\eta^*_{min}$
- Normalize overlap in three regions



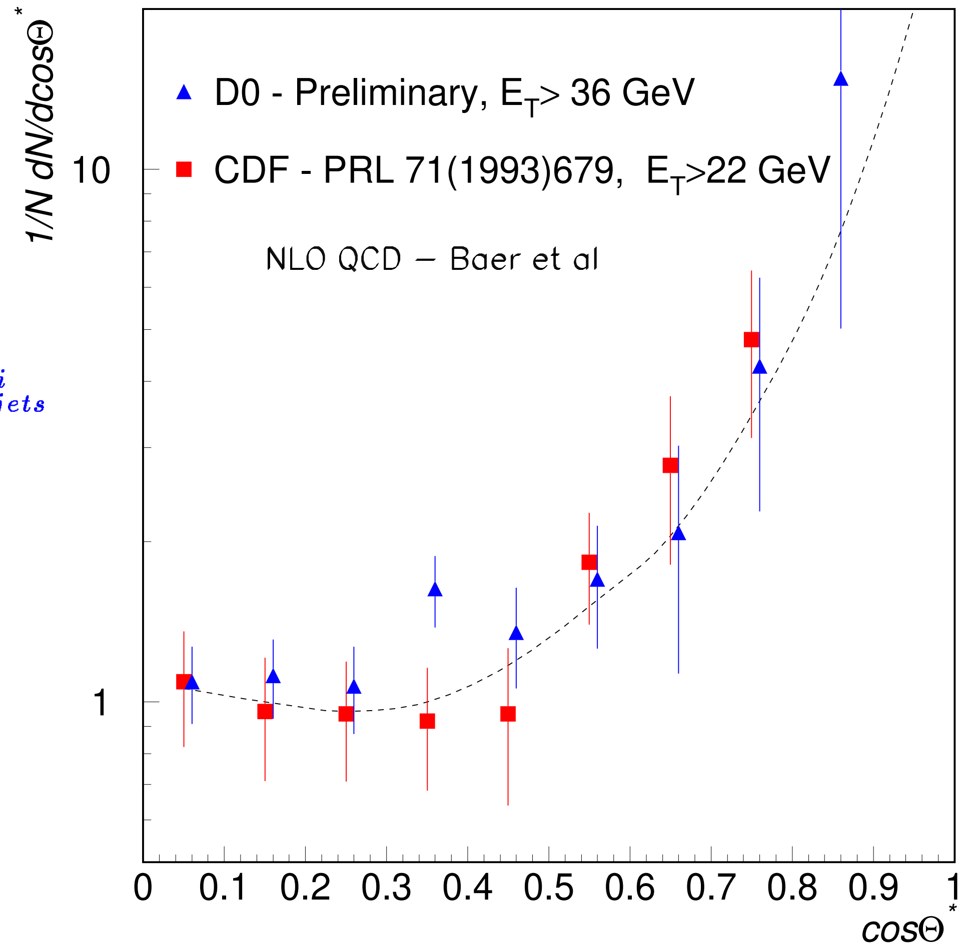
$$\frac{d\sigma}{dcos\theta^*} \sim s\frac{d\hat{\sigma}}{d\hat{t}}\sum_{a,b}\int dx_a dx_b x_a G(x_a,Q^2) x_b G(x_b,Q^2)$$

Background

- Apply $F_\gamma(E_T^\gamma, \eta^\gamma)$
- Subtract jet-jet background shape
- $N_\gamma^i = N_{data}^i(1-F_\pi^i),\ F_\pi^i = (1-F_\gamma)f_{jets}^i$

Sensitive to $\frac{d\hat{\sigma}}{d\hat{t}}$

- partonic cross section $\sim f(cos\theta^*)$
- $G(x, Q^2)$ evolve slowly with E_T
- $\delta(Q^2 - E_{Tmin}^2)$

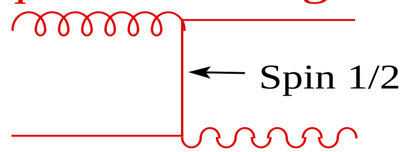


→ Data can accomodate more bremsstrahlung at high-cosθ^*

Diagrams:

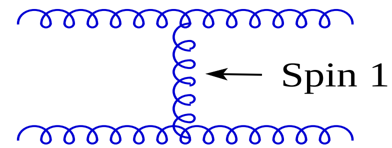
- jets - boson exchange
- photons - mixture
- W - fermion exchange

γ+ Jet and W+Jet: quark exchange

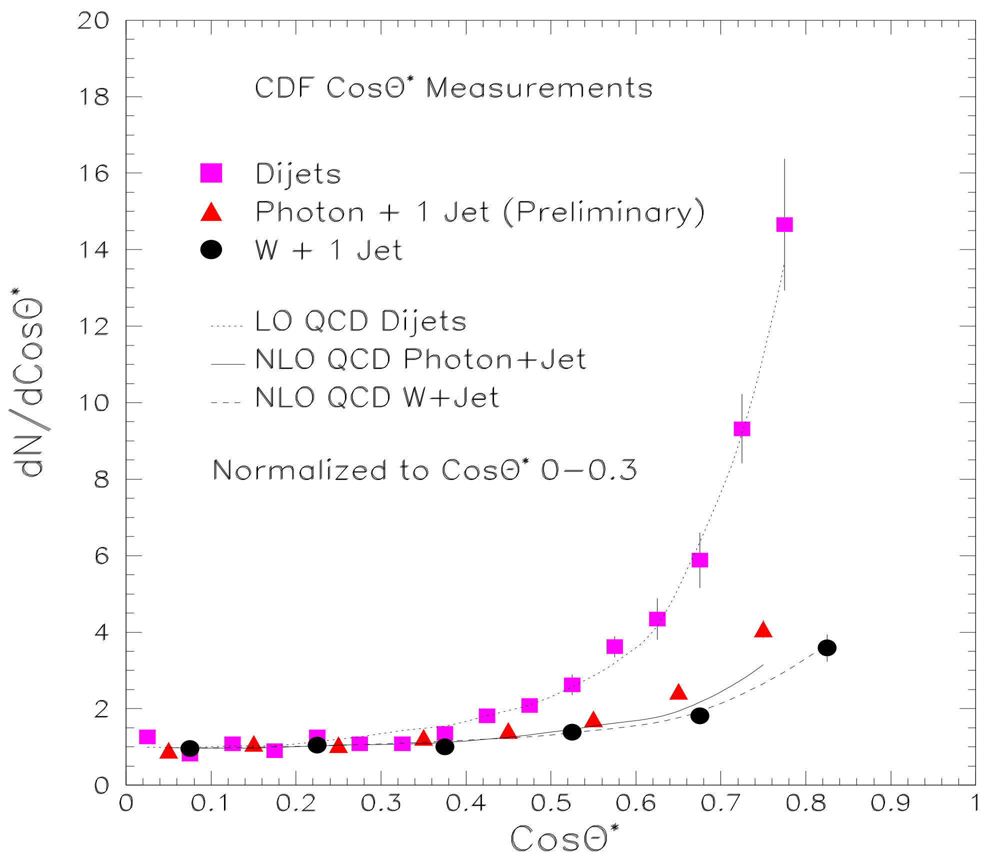


$$\frac{dN}{d\,\mathrm{Cos}\,\theta^*} \sim \frac{1}{(1 - \mathrm{Cos}\,\theta^*)}$$

Jet + Jet: gluon exchange



$$\frac{dN}{d\,\mathrm{Cos}\,\theta^*} \sim \frac{1}{(1 - \mathrm{Cos}\,\theta^*)^2}$$



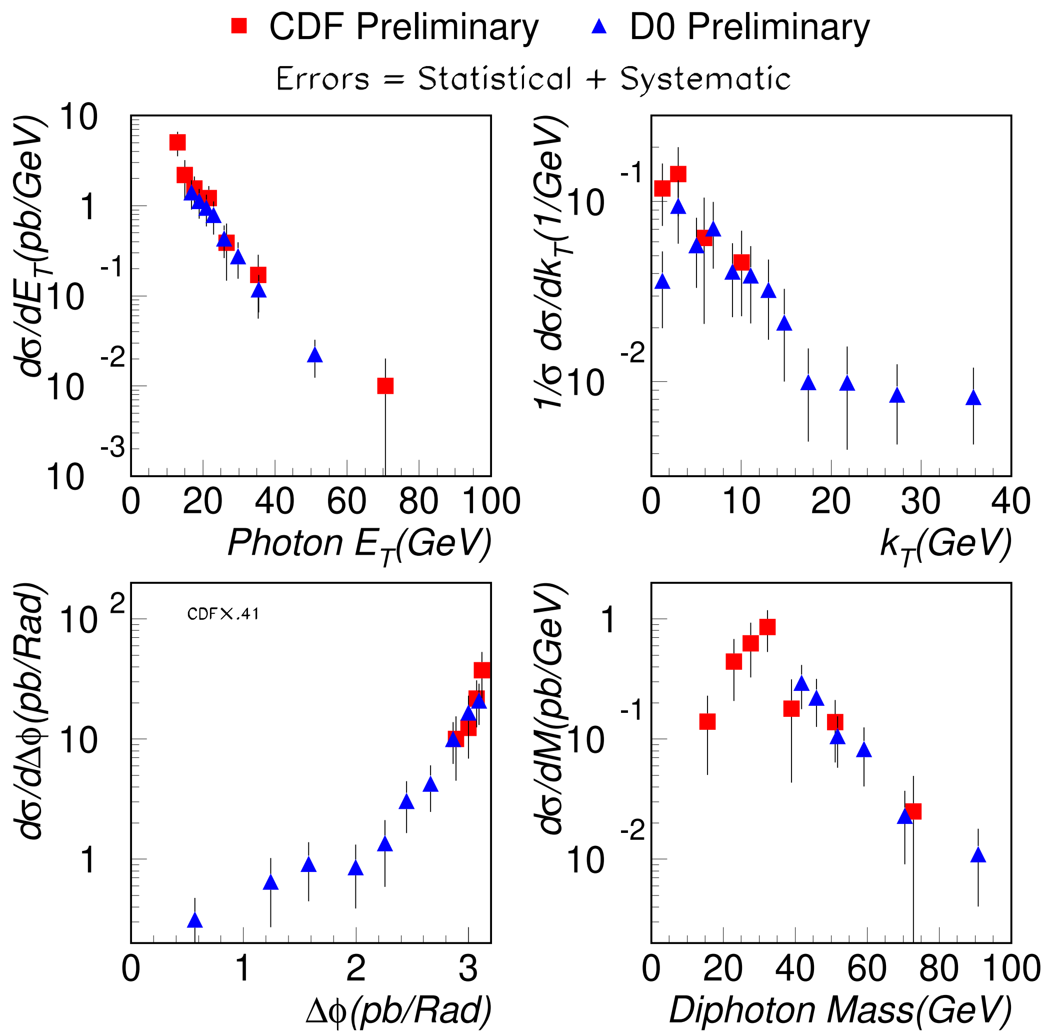
Diphotons

CDF Event Selection

- $\int Ldt = 84\ pb^{-1}$
- $\eta_\gamma \leq 0.9$
- $E_T > 12\ GeV$
- $E_T(iso) \leq 4\ GeV,\ R = 0.7$
- $CES < E_T = 35\ GeV > CPS$

DØ Event Selection

- $\int Ldt = 80\ pb^{-1}$
- $\eta_\gamma < 1.0$
- $E_{T1,2} > 13,\ 14\ GeV$
- $E_T(iso) < 2\ GeV,\ R = 0.4$
- $log(E_1^1/E^1) \times log(E_1^2/E^2)$



Measurement:

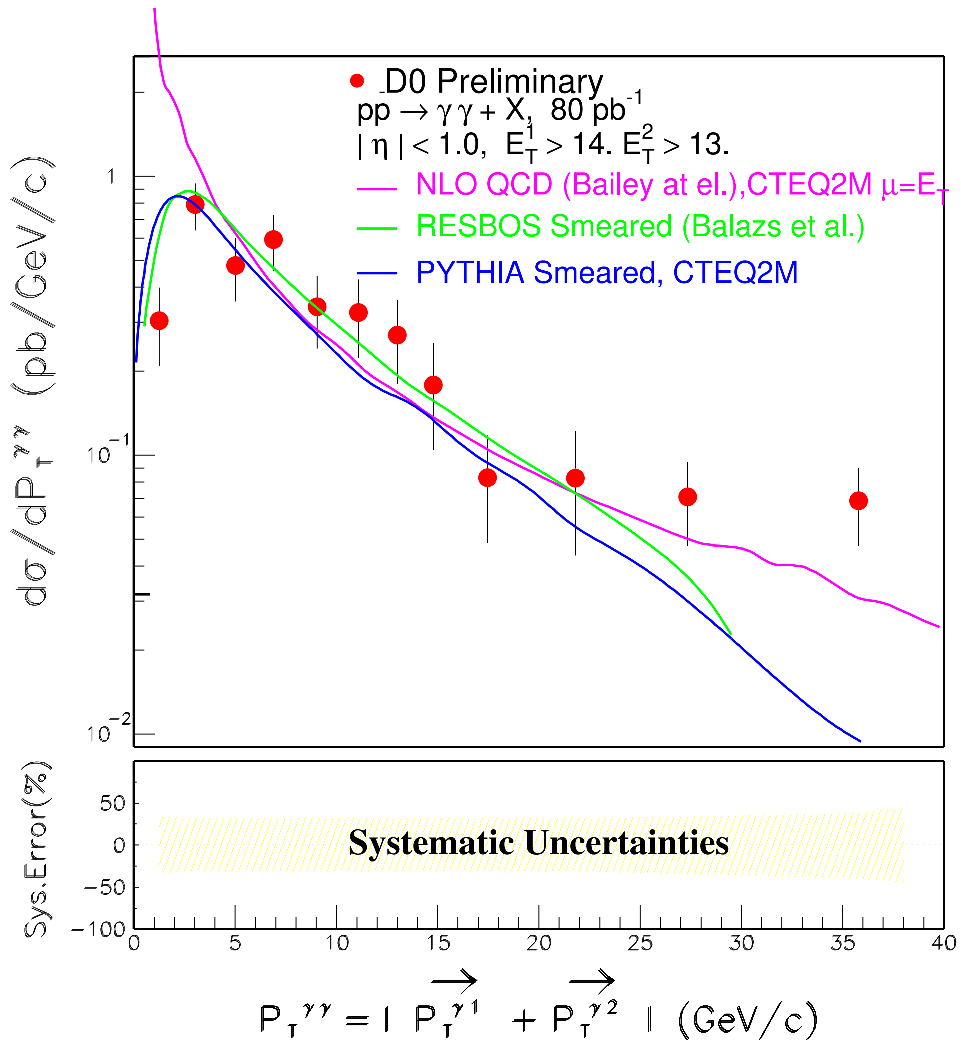
- $k_T = |\mathbf{E_{T1}} + \mathbf{E_{T2}}|$
- Direct - No jet ambiguities

Theory:

- Pythia - Parton Showers
- Balazs et al - Resummation
- Bailey et al - NLO QCD

Conclude:

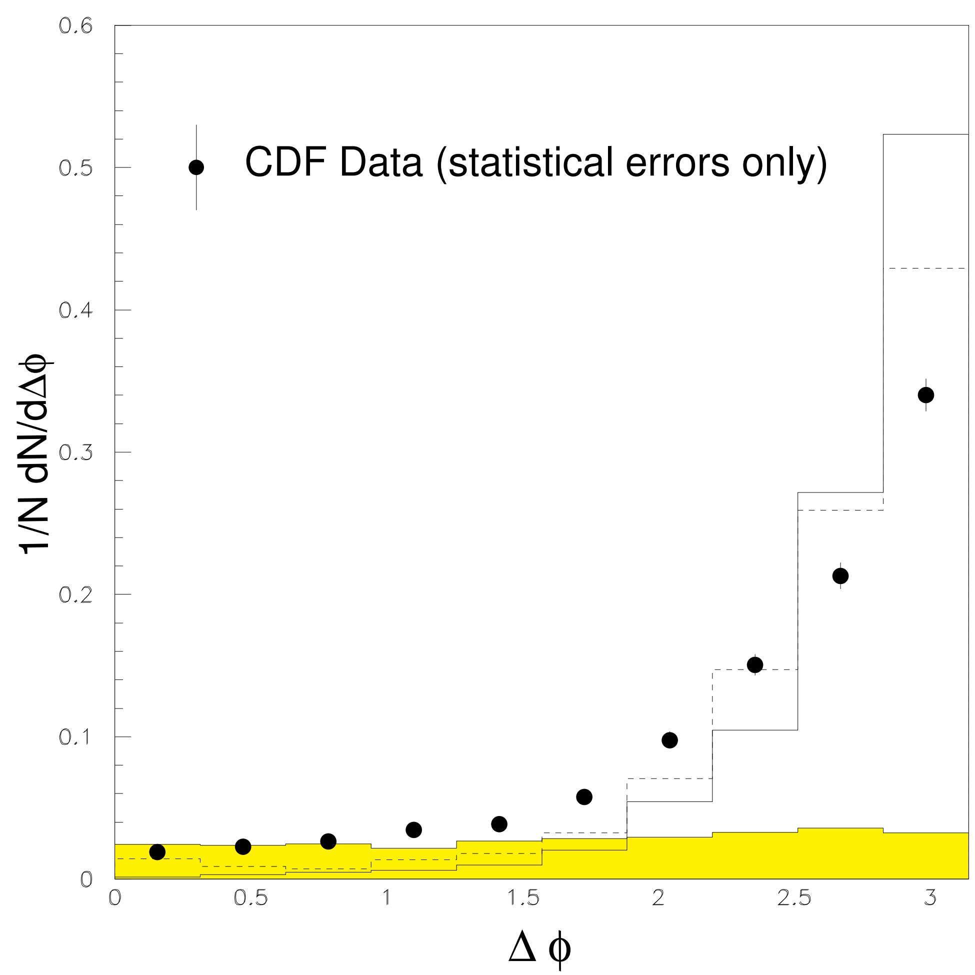
- →Consistent with NLO QCD *only* at high k_T
- →Consistent with resummatation at low k_T
- →Consistent with parton showers at low k_T



Photon Dijet Properties

Motivation: Dalitz analysis - see Keller & Owens

- Isolate Brem. - $jet1 > \gamma > jet2$
- Enhance k_T - $jet1 > jet2 > \gamma >$
- Color - $\gamma > jet1 > jet2$
- Background interesting(DPS)

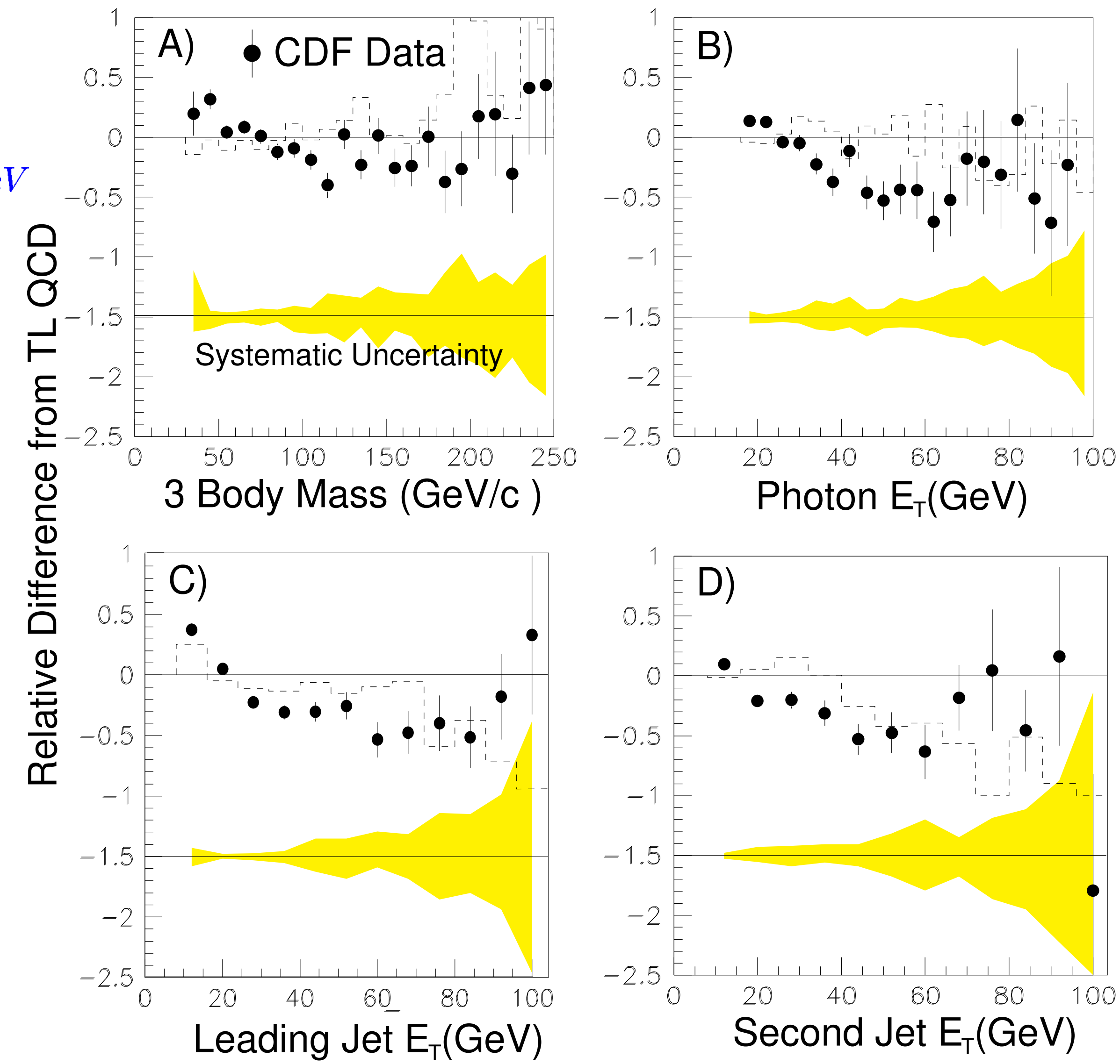


Background:

- $CES < E_T = 45\ GeV > CPS$
- $\Delta\phi = \phi_{\gamma+jet1} - \phi_{jet2} = \pi(LO)$
- Tree Level = NLO + Frag(solid)
- Pythia = LO + PS + DPS(dash)
- Double Scattering (14%)
- — multiple interactions
- — DPS ($\sigma_{eff} = 14.5\ mb$)

Event selection

- $\int L dt = 14\ pb^{-1}$
- jets - $\eta < 2.5$, $E_T > 8\ GeV$
- photon - $\eta < 0.9$, $E_T > 16\ GeV$
- $E_T(iso) < 2\ GeV,\ \ R = 0.7$
- $\Delta R_{sep} > 0.8$

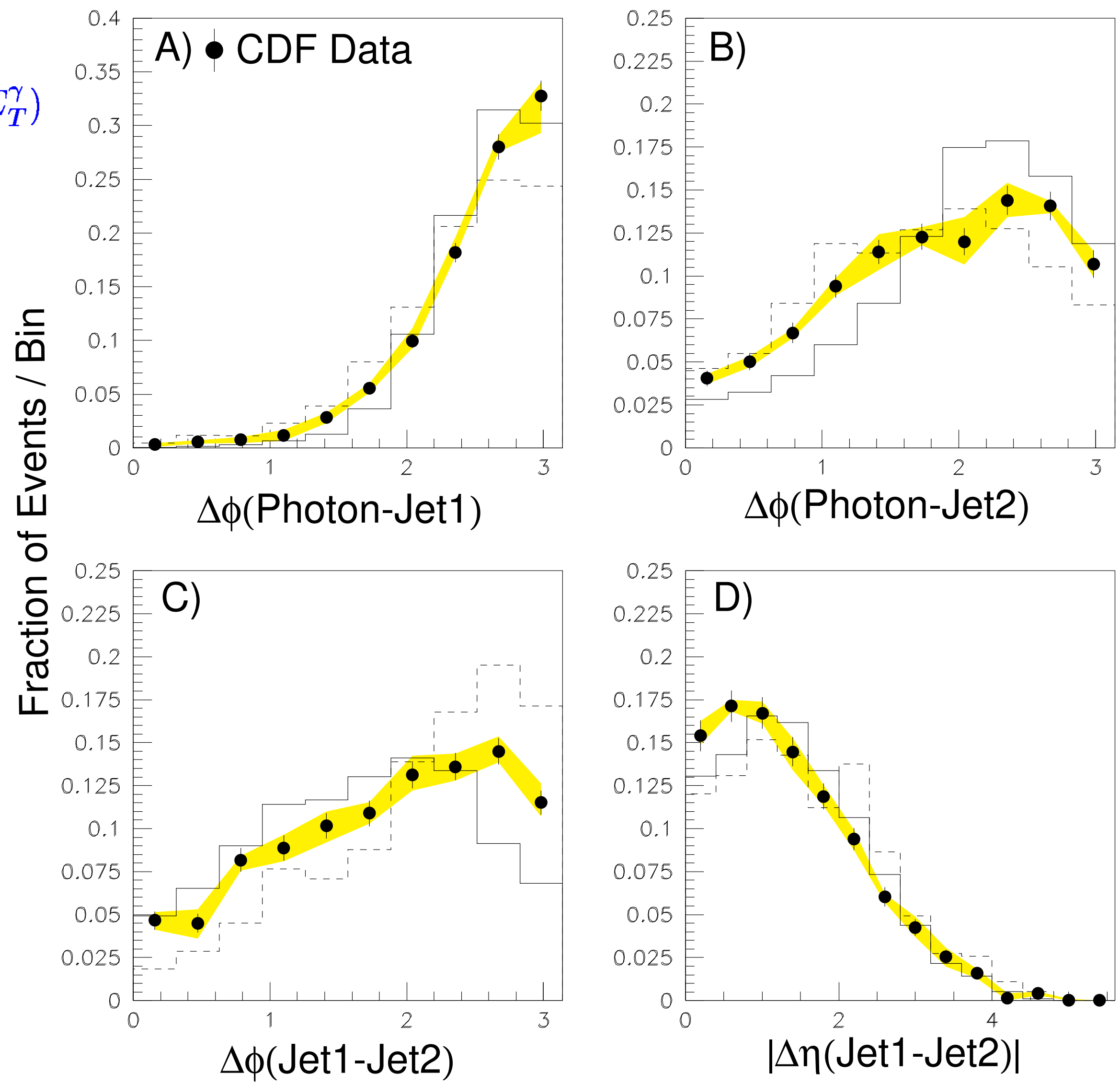


Models:

- Normalize Data/Theory
- Tree Level = $2 \rightarrow 3\ (\gamma jj)$ + + independent fragmentation (solid)
- Pythia = $2 \rightarrow 2\ (\gamma j)$ + + $2 \rightarrow 2\ (jjD(\gamma/q))$ + parton showers (dash)

Results:

- Data softer than all TL
- Data softer than Pythia(M,E_T^γ)
- Change admixture
  Direct(solid)
  Bremsstrahlung
  (Pythia predicts 57% Brem.)
- No fit to M, E_T distributions
- Fit to $\Delta\phi$ distributions
  yields $55 \pm 15^{+5}_{-10}\%$ Brem.
- Low-E_T^γ unexplained
  by parton showewrs (k_T) or
  additional Bremsstrahlung



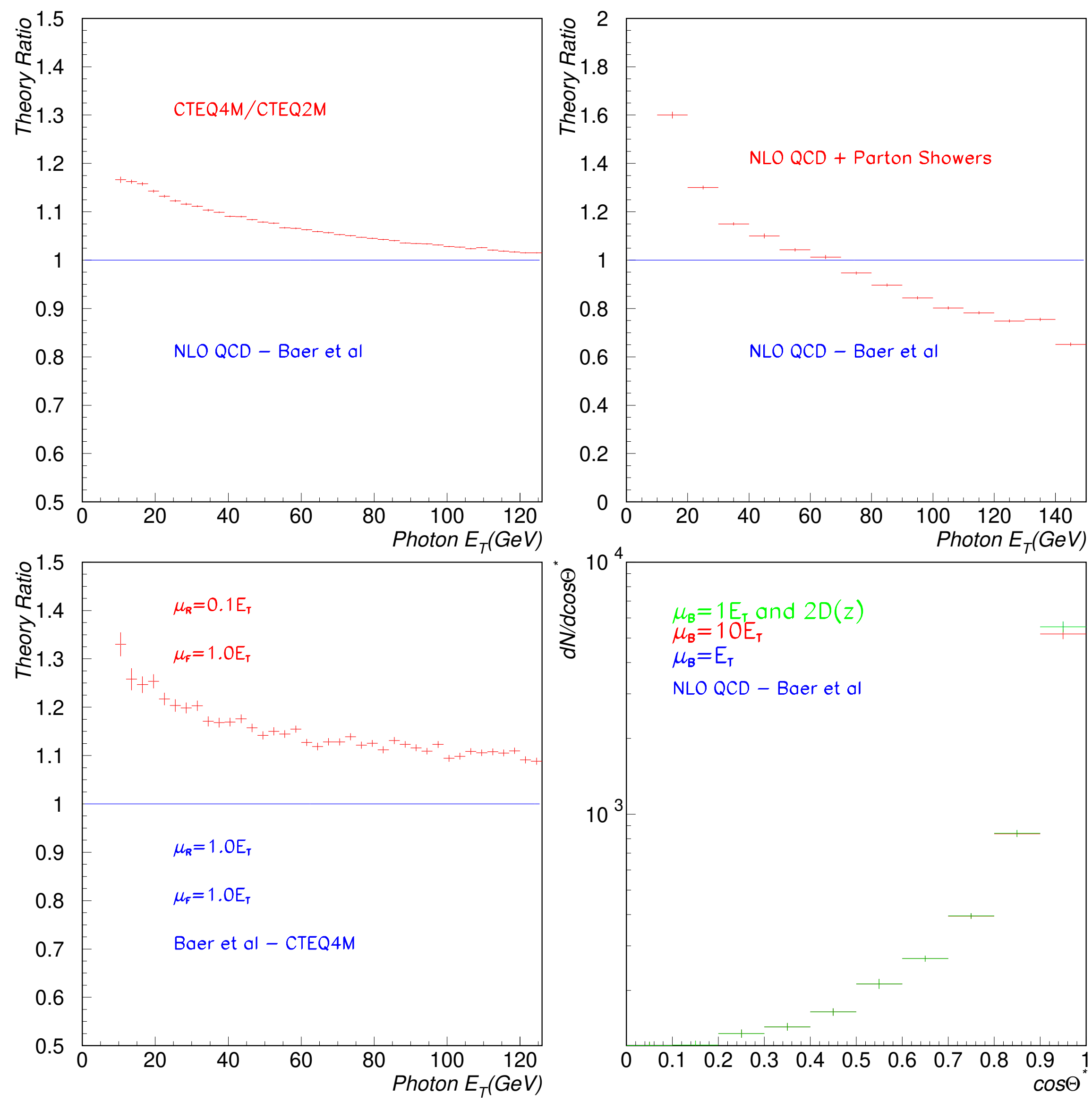
Summary

Recall:

- Isolated Photon excess (1 and 2 jets)
- Angular distribution excess

Theory Issues:

- PDF - CTEQ4, MRS, GRV
- Scales - Vogelsang and Vogt
- k_T- Baer and Reno
- New frag - ACFGP, GRV
- Resummation - Balazs et al



Conclude:

- Consistent measurements
- Pushing theory to limits of applicability
- E_T - k_T and/or NLO
- $cos\theta^*$ not enough Bremsstrahlung/Fragmentation
- Much to be done with IB data
- Run II + upgrades

Thanks to:

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