Direct Photons at DØ and CDF:

New Results from the Tevatron Collider

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Direct Photons and QCD:

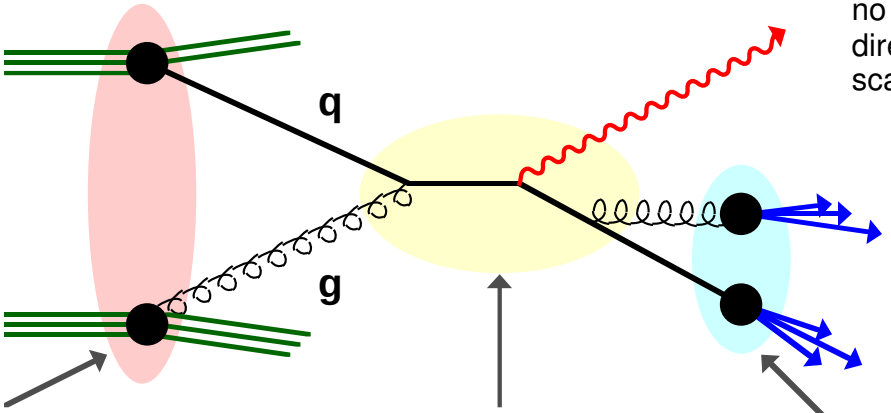
Outline

- very brief reminder: k_T, soft corrections, and the gluon - PDF…
- old data (and thus not covered):
  - inclusive photon cross section (1800 GeV & 630 GeV)
  - photon + 1 jet (angular dist., rapidity correlation)
  - photon + charm
- new measurements:
  - diphotons (DØ & CDF)
  - photon + 2 jets (CDF)
- summary & outlook

Direct Photon Production at the Collider

Photons directly probe the hard scattering

e.g. $\bar{p}p \rightarrow \gamma + jet + X$



photon
no fragmentation → direct probe of the hard scattering process

jet 2

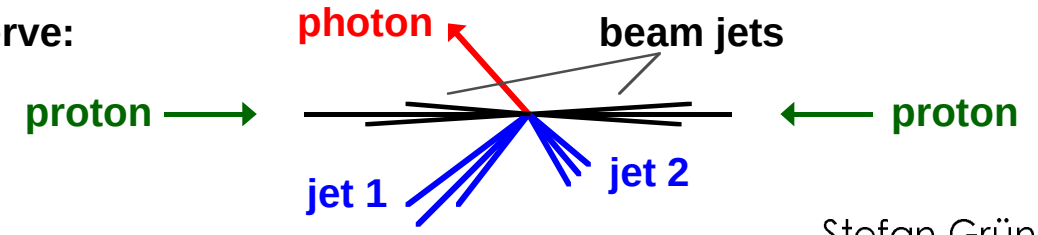
jet 1

Parton Distributions
Non-perturbative, must be experimentally determined, but are universal

Hard scattering
High momentum transfer Perturbative QCD

Fragmentation
(quark, gluon) → jet

What we observe:



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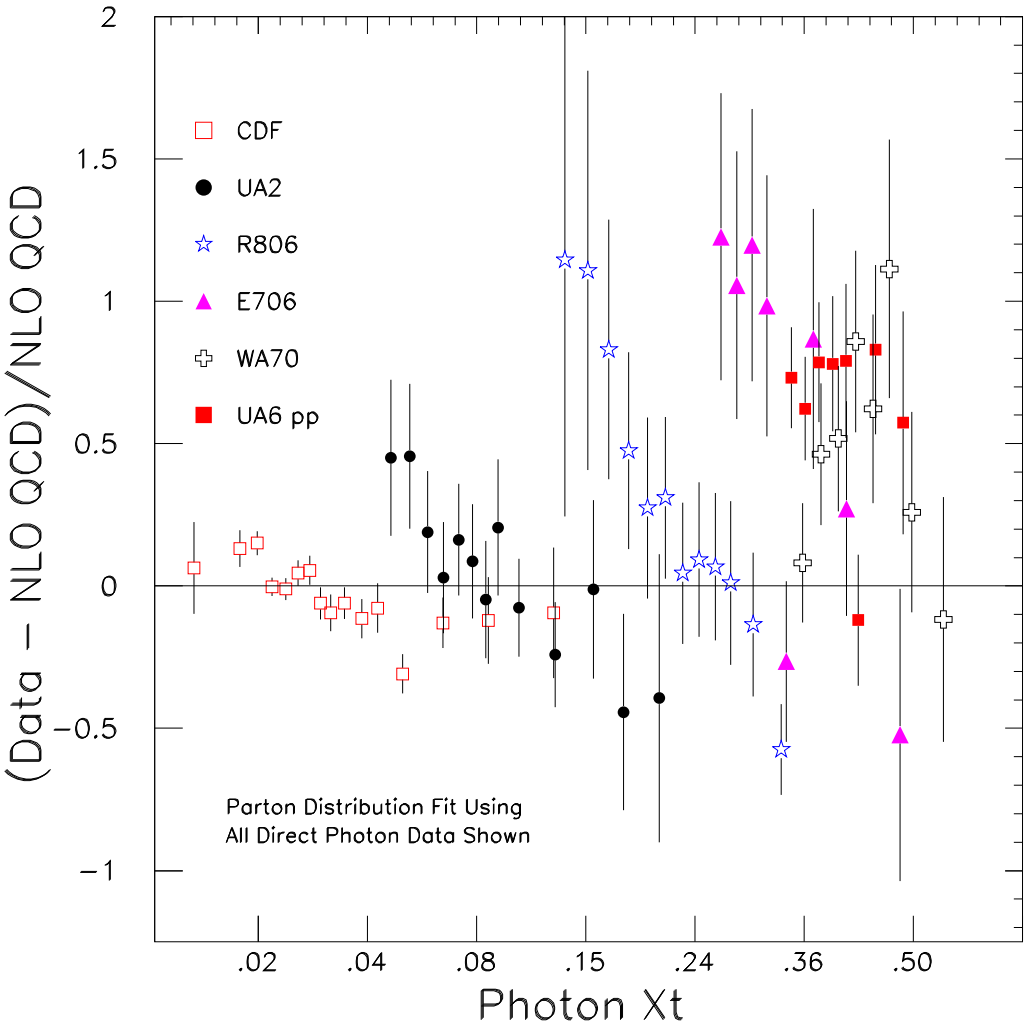
but: disagreement inclusive data - NLO QCD at low P_T^{γ}



⇒ **gluon - PDF ?** .....discrepancy too large (50% to 100 % vs. typ. 5% due to PDF-variability)

⇒ **more photons from fragmentation (I.e. larger NLO contribution)?** ... .γ+jet angular distribution agrees with NLO QCD

→ **new γ+2jet data**

⇒ **K_T ?** .....need resummed QCD model

→ **new $\gamma\gamma$ data + RESBOS**

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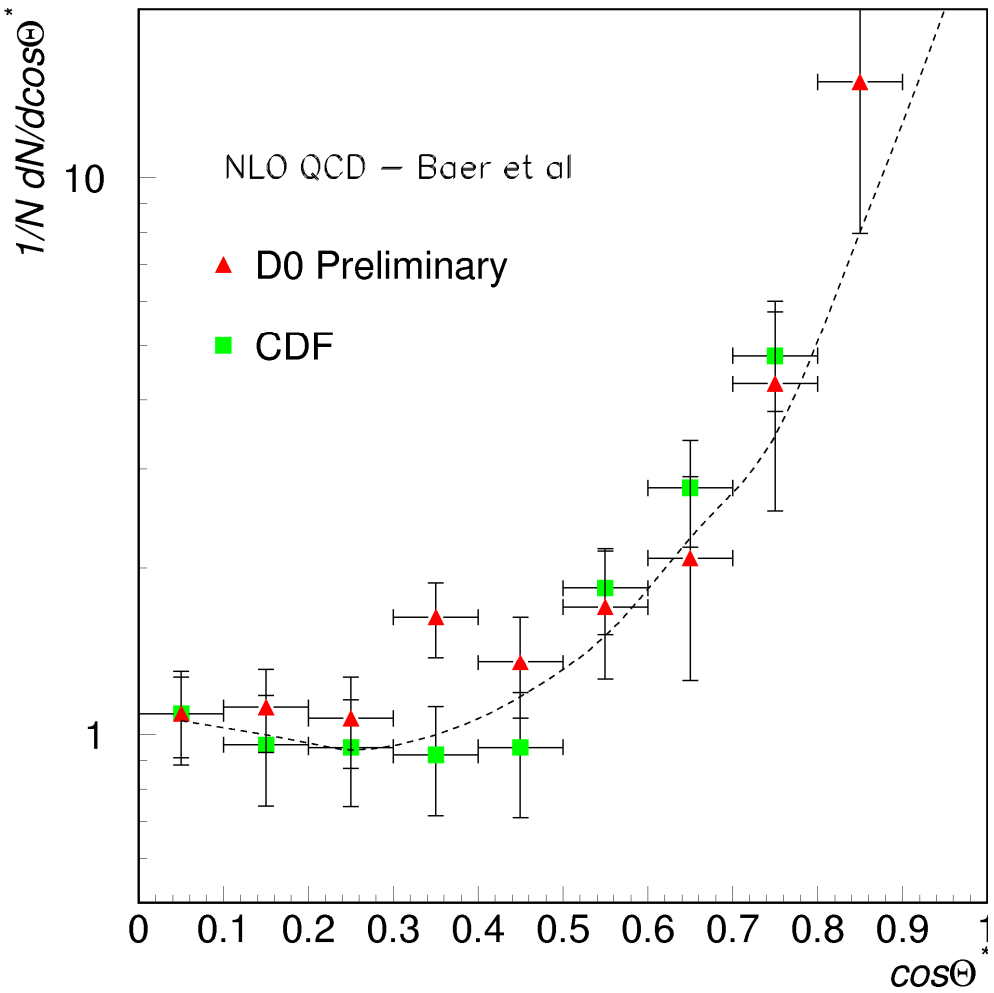
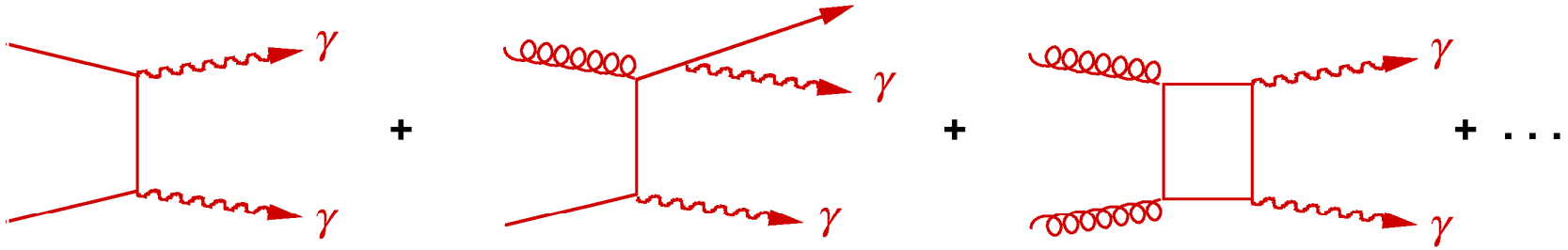
Photon + Jet Angular Distribution



- NLO QCD has correct mix of exchange particles
  - quark ~ $1/(1-\cos\vartheta^*)$
  - vs.
  - gluon ~ $1/(1-\cos\vartheta^*)^2$
- shown: DØ data vs. QCD prediction, with CDF data overlaid

Diphotons



Born **NLO** **Box**

DØ

Event Selection
80 pb $^{-1}$ Run 1B (1994--5)

Software Trigger: 2 EM clusters , $E_T > 12$ GeV

Offline Selection: 2 candidates $|\eta| < 1.0$, $E_{T1,2} > 14, 13$ GeV
Isolation, shower shape, EM fraction,
Drift Chamber hits cut (reject $Z \rightarrow ee$)

$\rightarrow$ 418 $\gamma\gamma$ candidates

Acceptance × efficiency ~ 0.48

Purity (from EM_1 / E_{total}):
$E_{T1} < 20$, $E_{T2} < 20$ P = 0.26 ± 0.10
$E_{T1} > 20$, $E_{T2} < 20$ 0.30 ± 0.11
$E_{T1} > 20$, $E_{T2} > 20$ 0.38 ± 0.22

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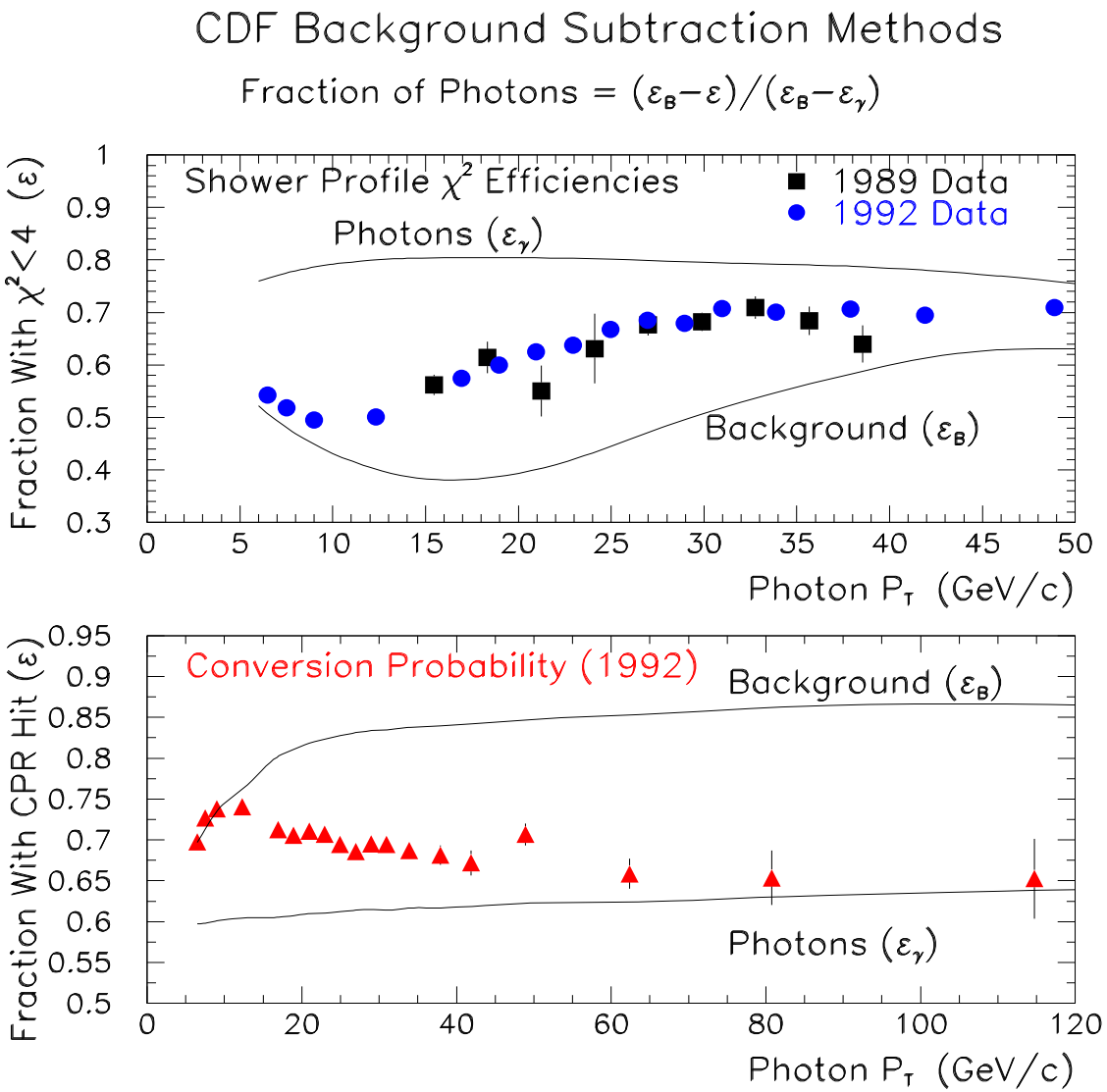
Photon Purity (example: CDF Diphotons)



Background subtraction

using shower_max profile $\chi^2 \leq 4$ ($E_T^\gamma \leq 35$ GeV) or hit in preshower ($E_T^\gamma \geq 35$ GeV) as discriminant

solve equation system for background and photon efficiencies, determine true number of diphotons from observed discriminant distribution (0,1,2 hits/γ-like showers)

standard method: background subtraction bin by bin (for each of the distributions studied)

alternative: assume signal purity (background fraction) is E_T^γ independent

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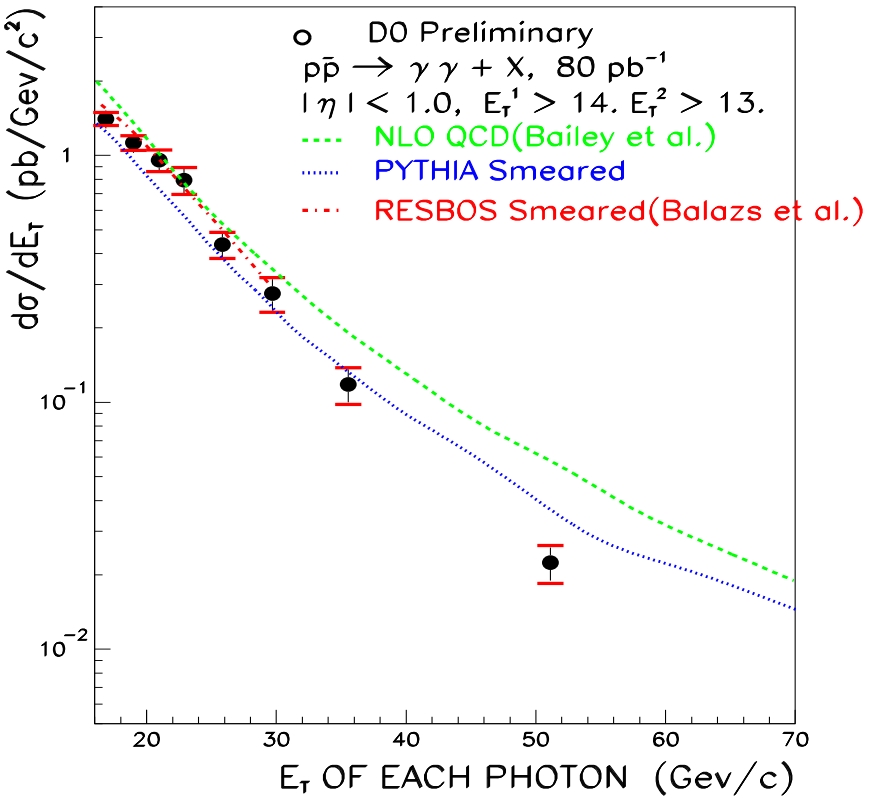
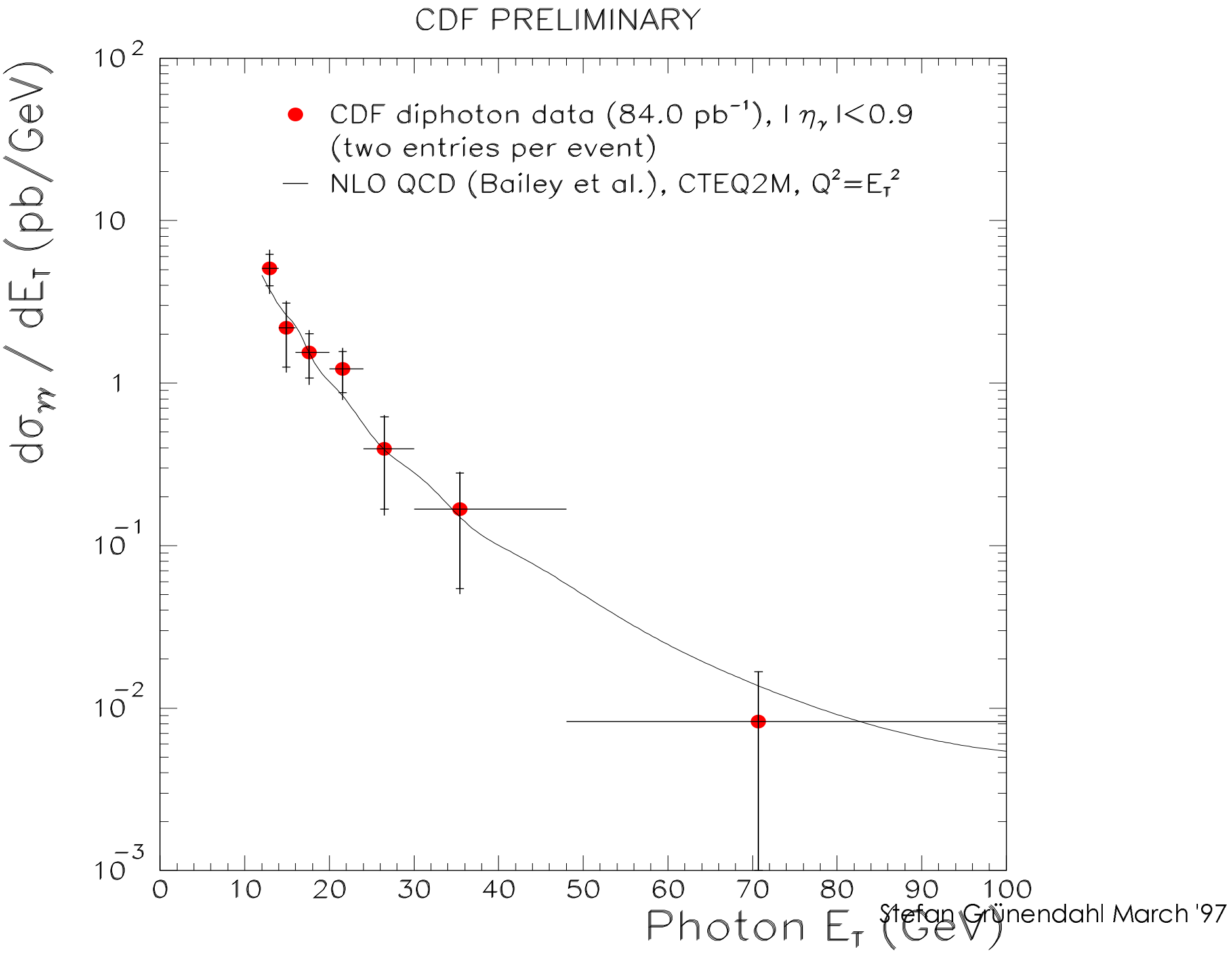
Diphoton Results



E_T spectrum

- stat. and syst. (purity) errors shown separately

- resummed NLO model available: RESBOS
  Phys.Lett.B355:548-554, 1995, hep-ph/9505203.
  resums multiple soft gluon emission in the initial state; originally for production of massive vectorbosons



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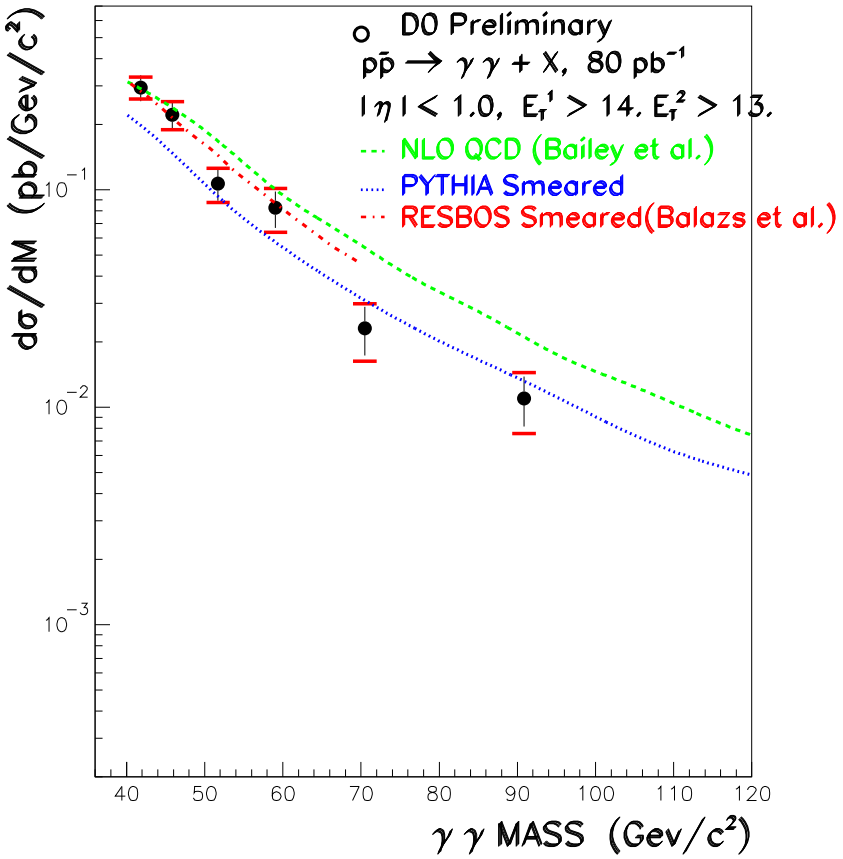
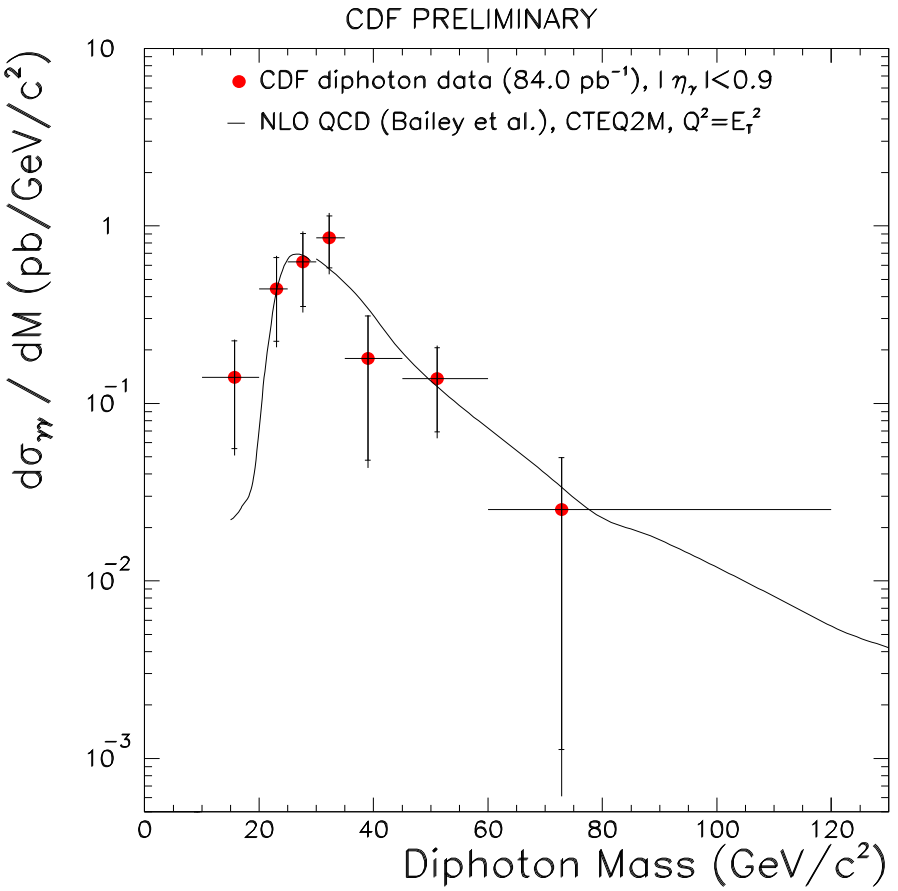
Diphoton Results: Mass





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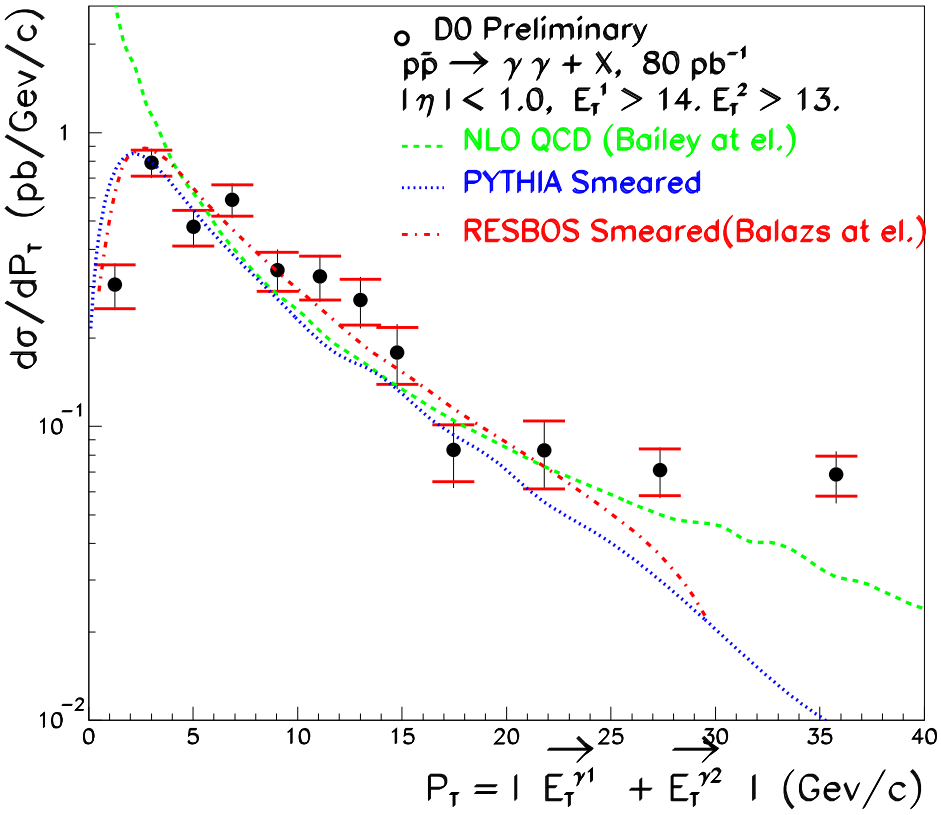
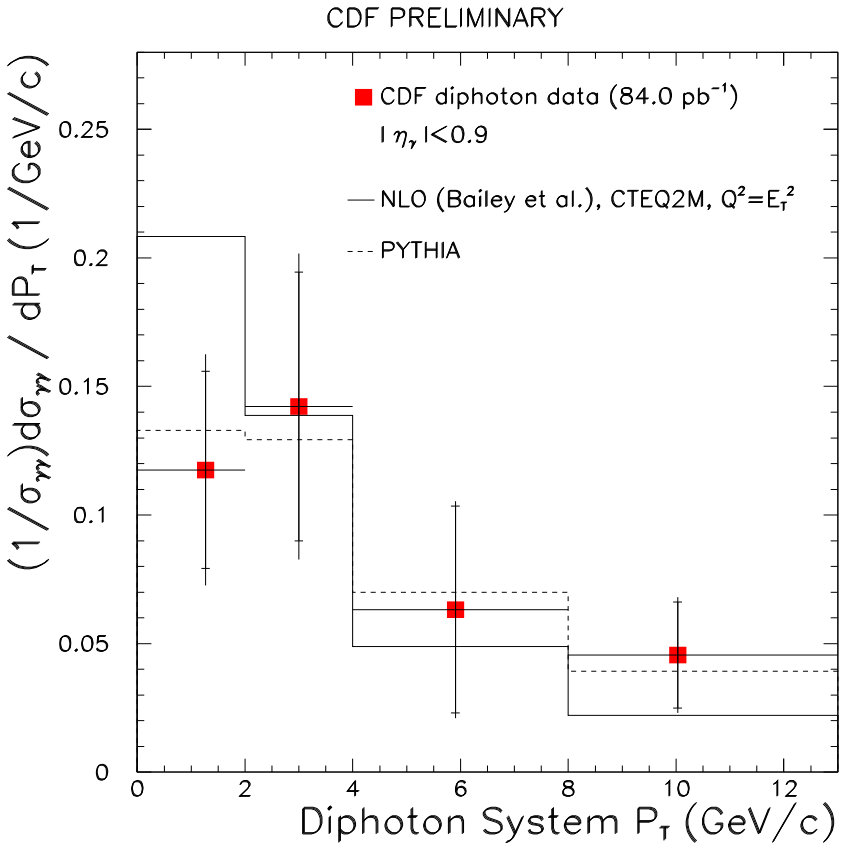
Diphoton k_T

RESBOS (and Pythia) describe lower part of k_T spectrum very well





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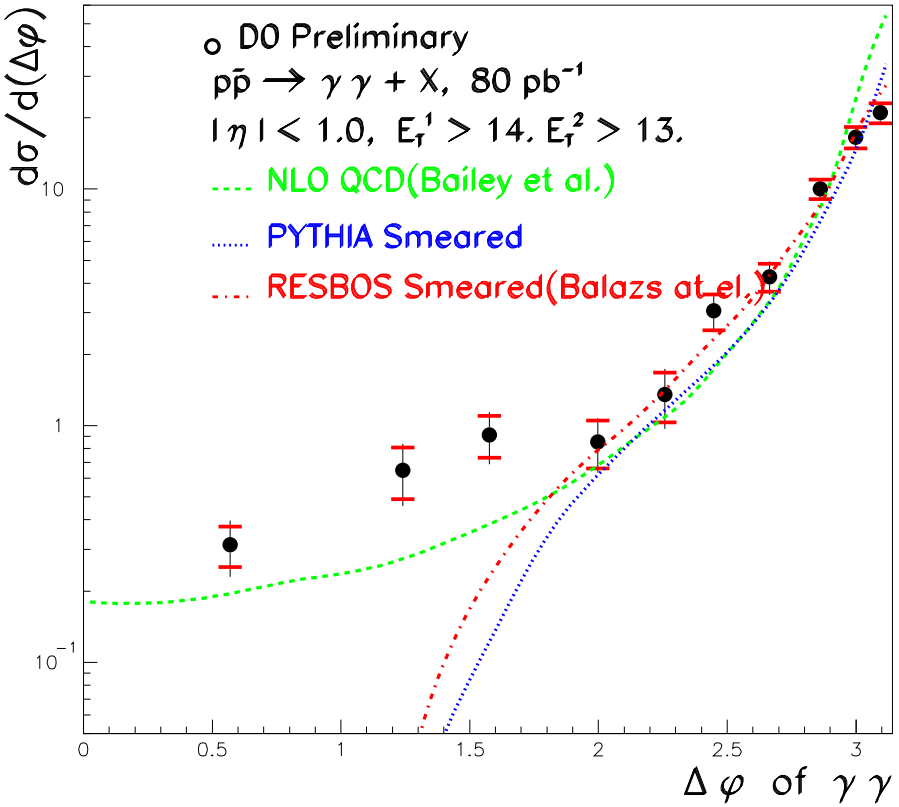
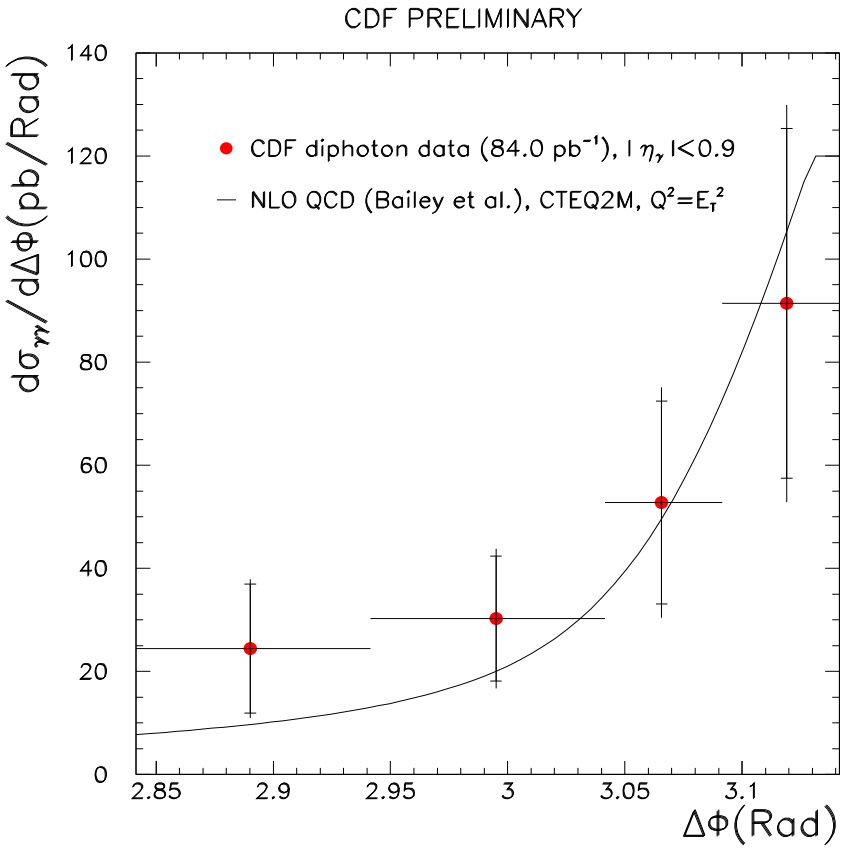
Diphoton Results: $\Delta\phi_{\gamma\gamma}$

RESBOS: some higher order terms missing (?); PYTHIA lacks explicit NLO contribution





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CDF: Photon + 2 jets

Run I (1992-1993), ~16 pb^{-1}

event selection:

- photon:
  - central EM cluster: $|\eta_{det}| < 1.1$, $E_T > 16$ GeV
  - isolation: extra transverse energy in $(\Delta\eta^2+\Delta\Phi^2)^{1/2} = 0.7 \leq 4$ GeV
  - no (3D) tracks; no 3D tracks pointing at preshower hit for $E_T^{\gamma} \geq 35$ GeV
  - transverse shower profile consistent with photon hypo. ($\chi^2 \leq 20$)
  - no extra clusters in shower_max chamber above 1 GeV
  - $|\eta_{\gamma}| \leq 0.9$
- $|z_{vertex}| \leq 60$ cm
- jets:
  - 2 jets with $|\eta_{jet}| < 2.5$, $E_T > 8$ GeV (R=0.7 cone)
  - strong isolation requirement: $\Delta \mathbf{R}_{\gamma\text{-jet}} \geq \mathbf{0.8}$

$\Rightarrow$ **34,116 photon + 2 jet - candidates**

(average purity: 0.42)

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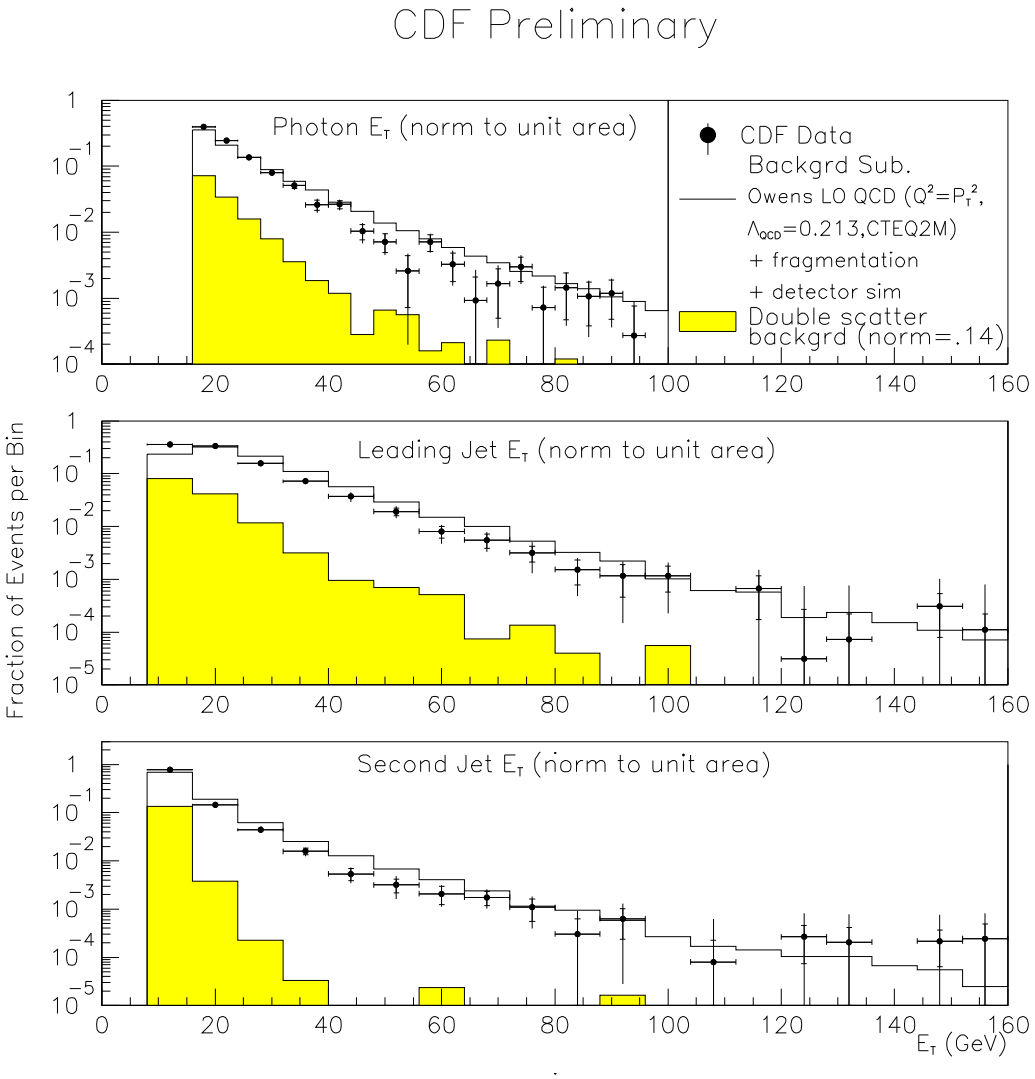
Photon + 2 jets: Kinematics



leading order QCD (=NLO for incl. production) describes data well , except for photon P_T :
data are significantly softer than theory

QCD prediction includes independent fragmentation and detector model

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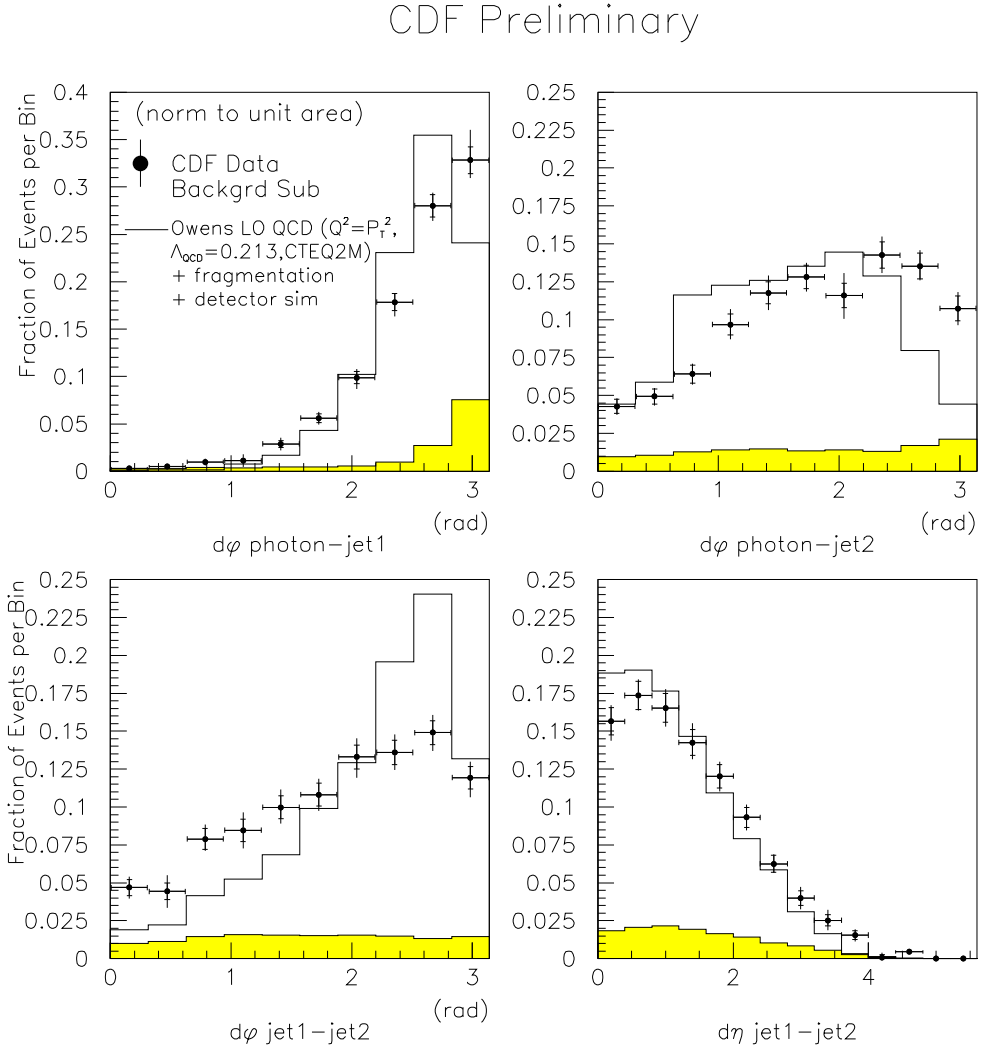
Photon + 2 Jets: Angular distributions



disagreement in ϕ-balancing

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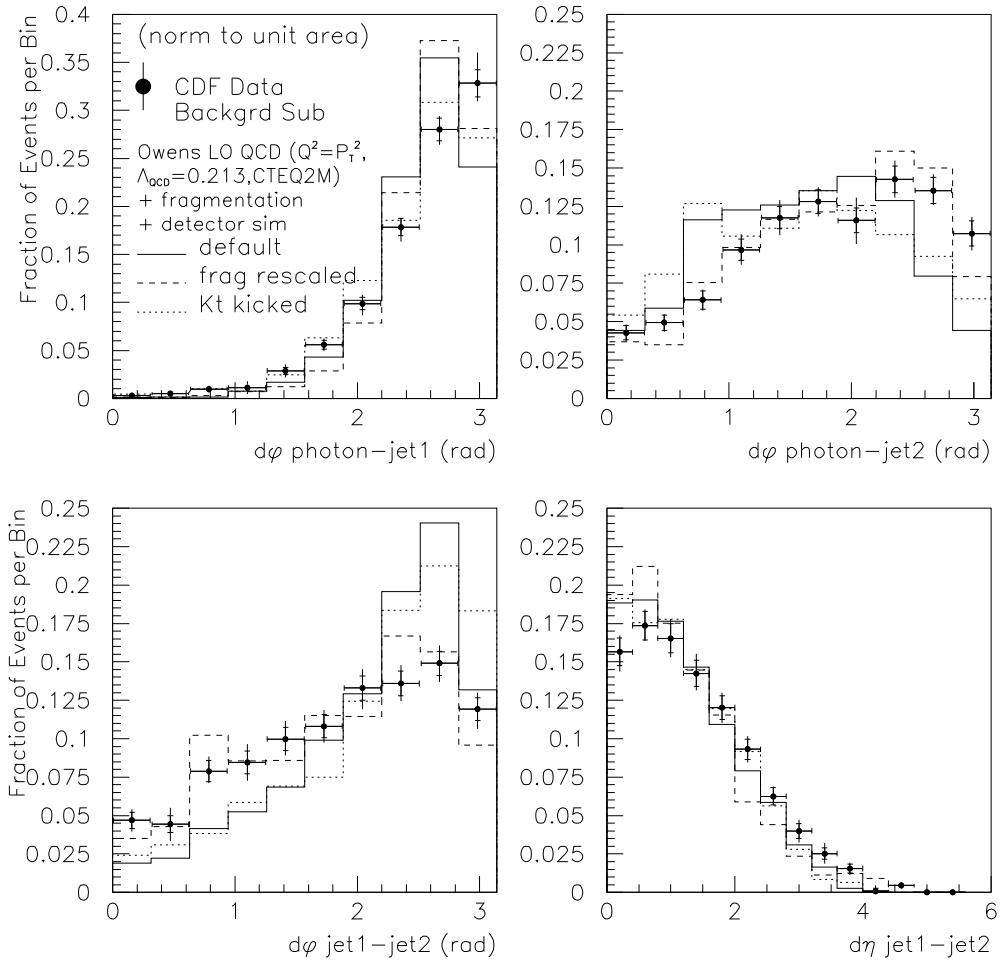
Photon + 2 Jets: k_T vs. jet mass correction

CDF Preliminary



description of ϕ-balancing improved by

a) intrinsic k_T or

b) change of jet fragmentation

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Conclusions

- diphotons:
  - good agreement with NLO QCD (and Pythia)
  - K_T understanding improved due to resummed NLO calculation
- photon + 2 jets:
  - good agreement with LO ($\alpha_s^2\alpha_{em}$) QCD, except for Photon P_T spectrum: QCD prediction is harder than data
- updated inclusive results to appear soon

Diphoton Results from CDF

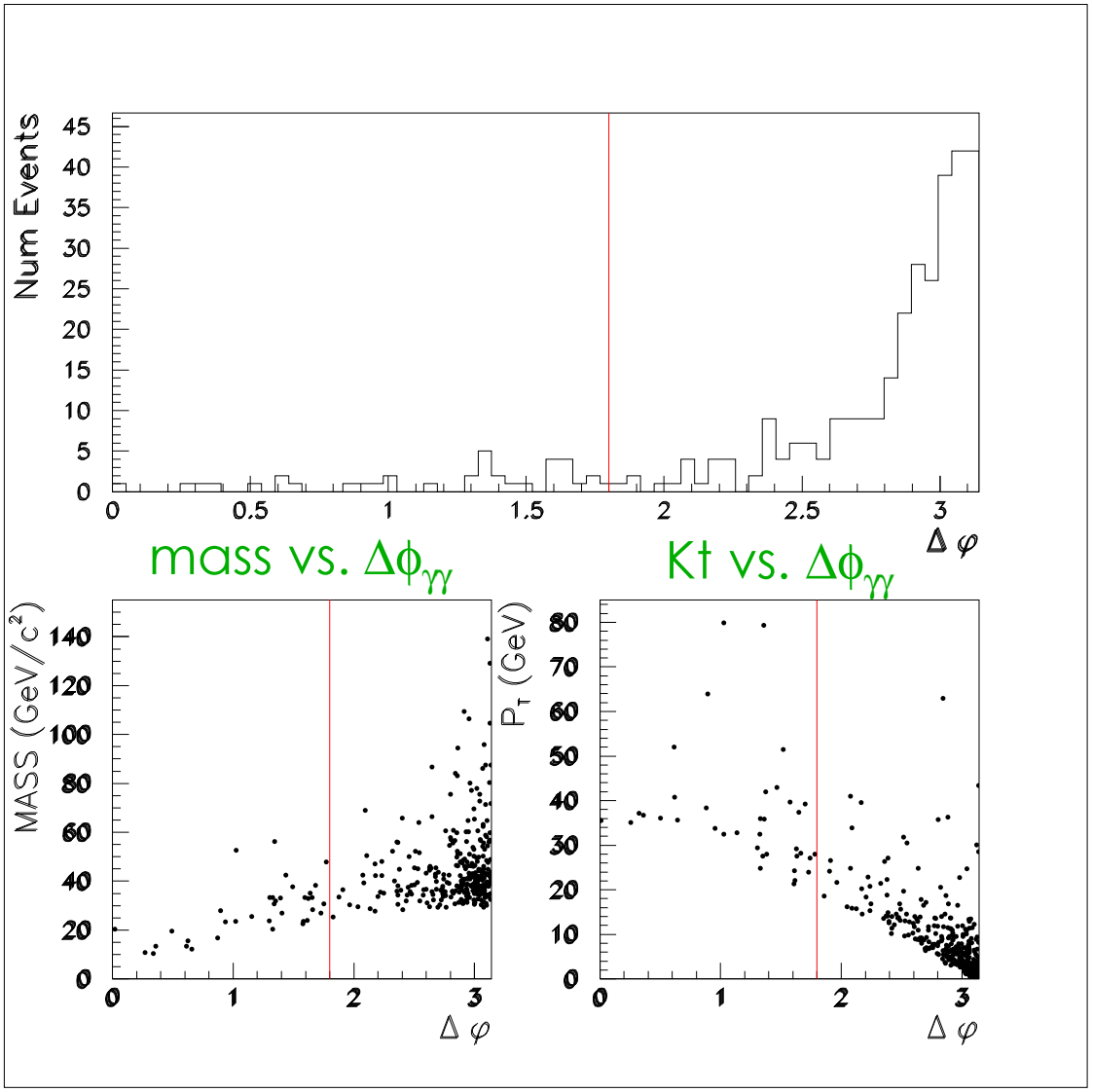
Run I (1992-1995), 84.0 pb^{-1}

event selection:

- 2 central EM clusters: $|\eta_{det}| < 1.1$, $E_T > 12$ GeV
- Level 2 diphoton trigger
- isolation: extra transverse energy in $(\Delta\eta^2+\Delta\Phi^2)^{1/2} = 0.7 \leq 4$ GeV
- no (3D) tracks; no 3D tracks pointing at preshower hit for $E_T^{\gamma} \geq 35$ GeV
- transverse shower profile consistent with photon hypo. ($\chi^2 \leq 20$)
- no extra clusters in shower_max chamber above 1 GeV
- $|z_{vertex}| \leq 60$ cm
- $|\eta_{\gamma}| \leq 0.9$

$\Rightarrow$ **918 diphoton candidates**

Diphoton Results



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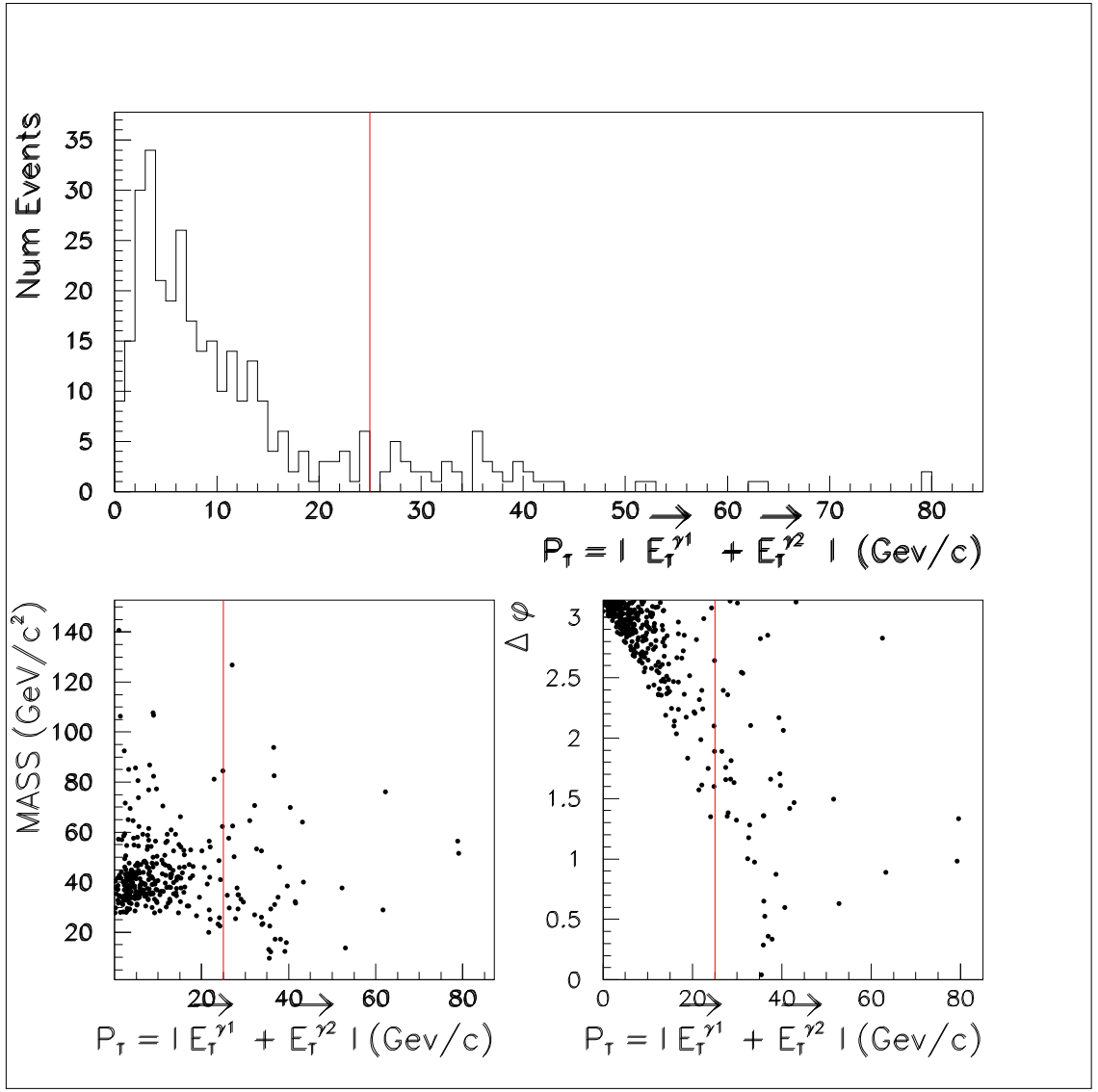
Diphoton Results



mass vs. k_T

$\Delta\phi_{\gamma\gamma}$ vs. K_T

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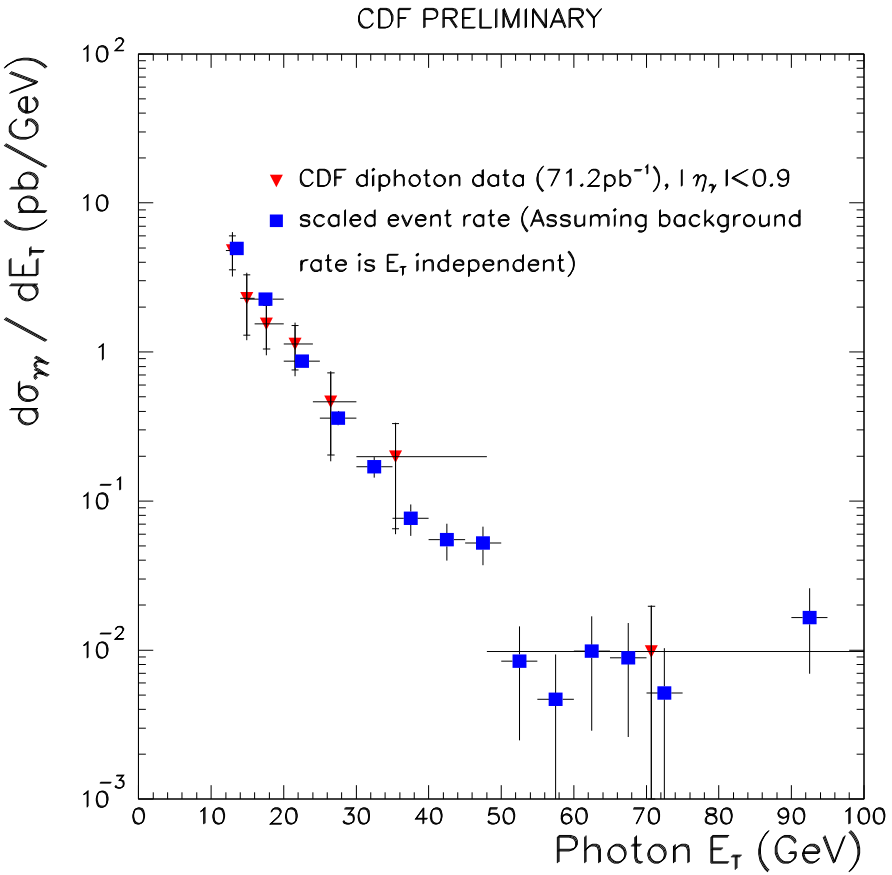
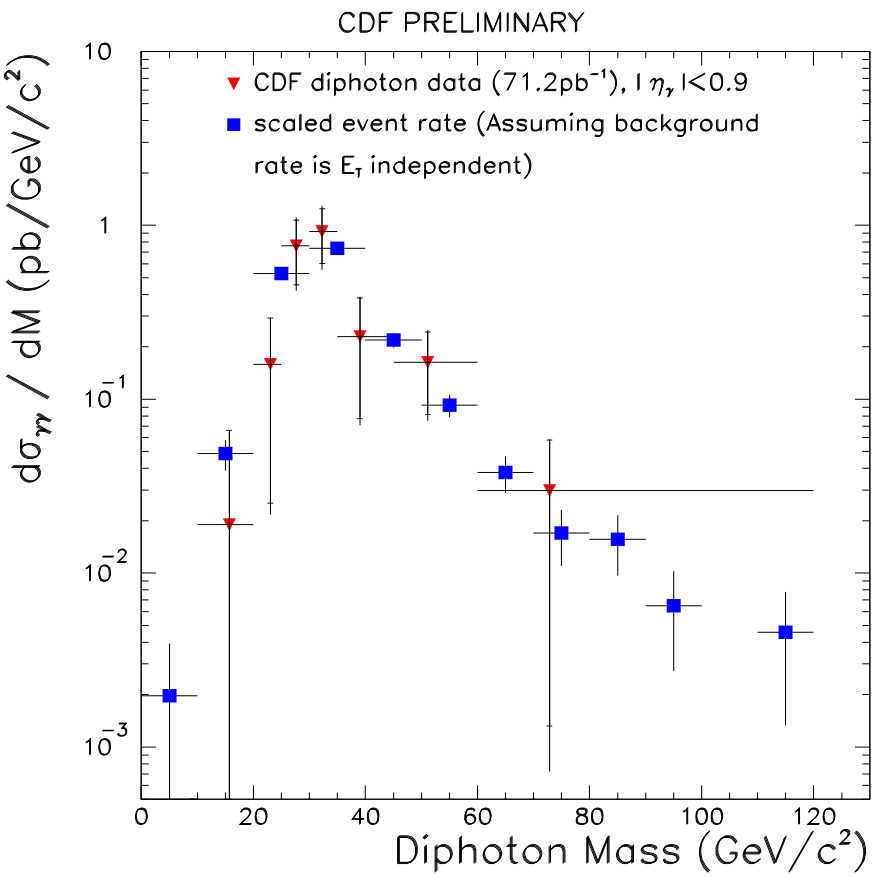
CDF: Diphotons

assumption of constant photon fraction across sample: smaller statistical error from background subtraction





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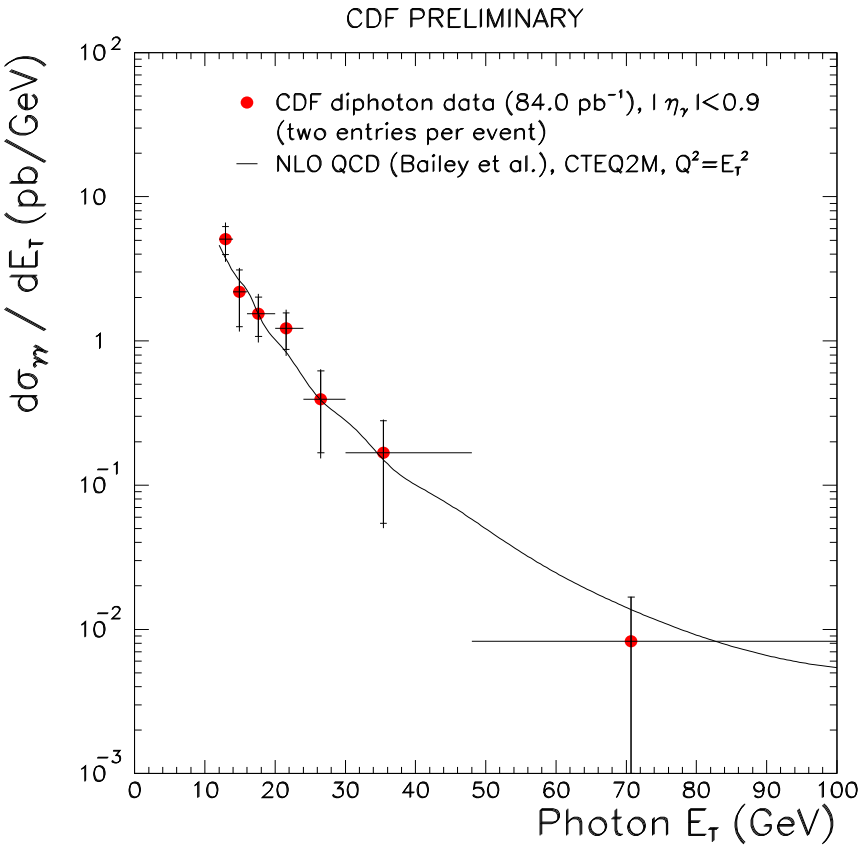
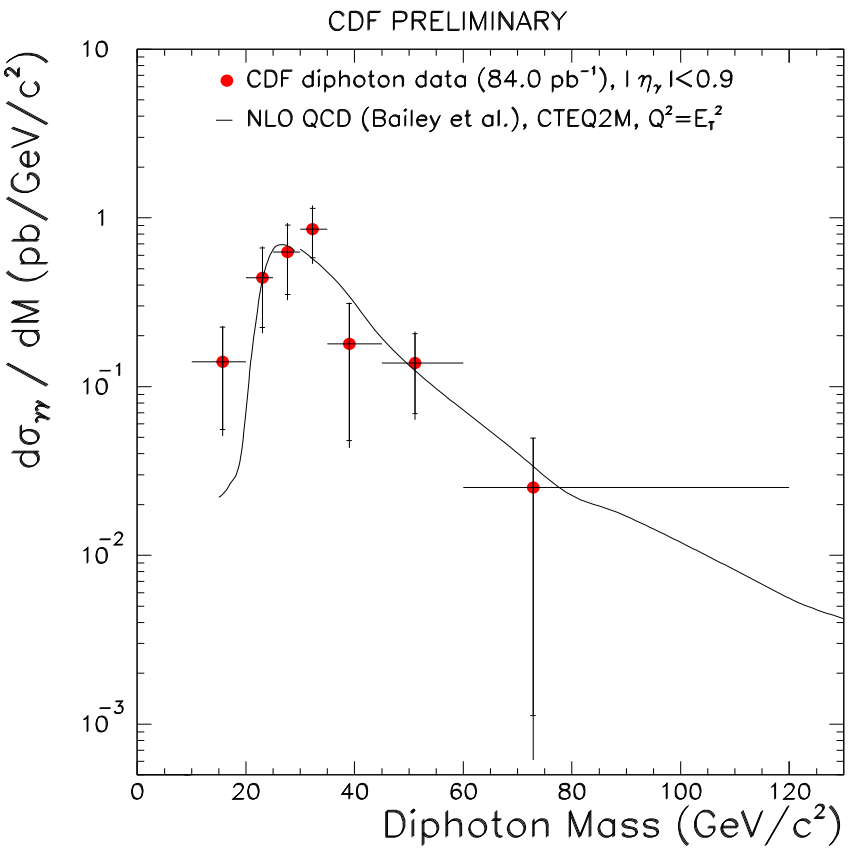
CDF Diphotons

E_T^{γ} and diphoton mass





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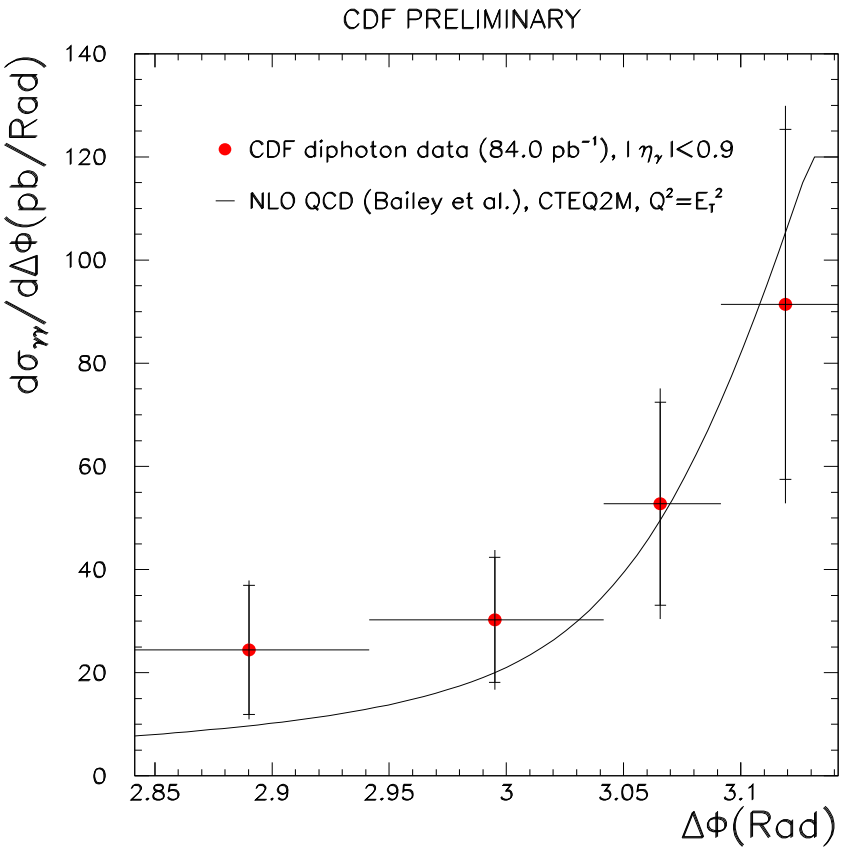
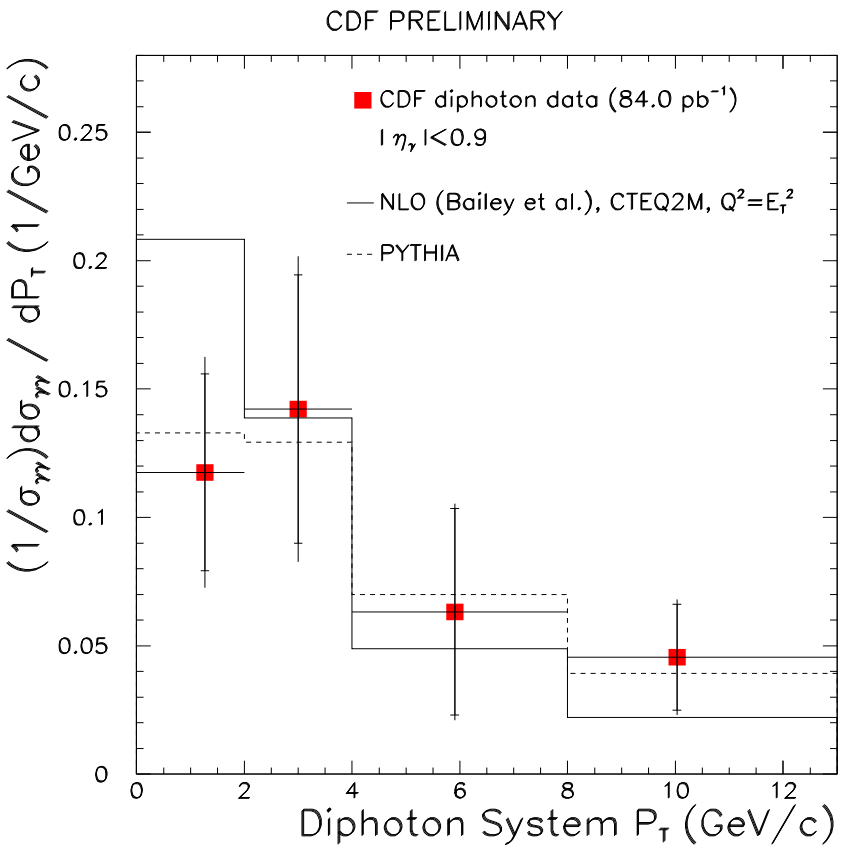
CDF Diphotons

$\Delta\Phi_{\gamma\gamma}$ and diphoton K_T





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Backgrounds to Direct Photons

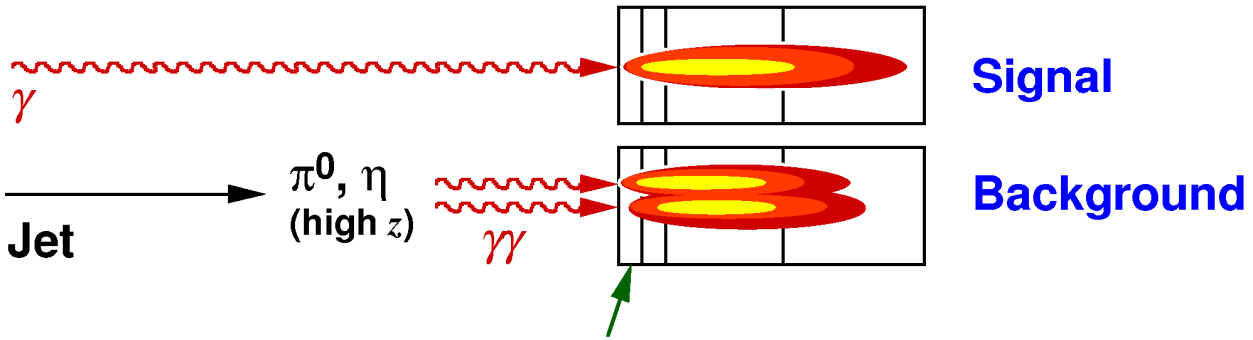
Background Estimation

Even after these cuts, significant background remains; predominantly from QCD jets fragmenting to isolated π^0, η^0

$\sigma_{jet} / \sigma_{\gamma} \sim 10^3$

$P(jet \rightarrow "\gamma", z \approx 1) \sim 10^{-3}$

Use longitudinal shower shape to estimate purity of sample:



Two photons → higher probability to convert and deposit energy in first layer ($2X_0$)