Direct Photon Production at Colliders

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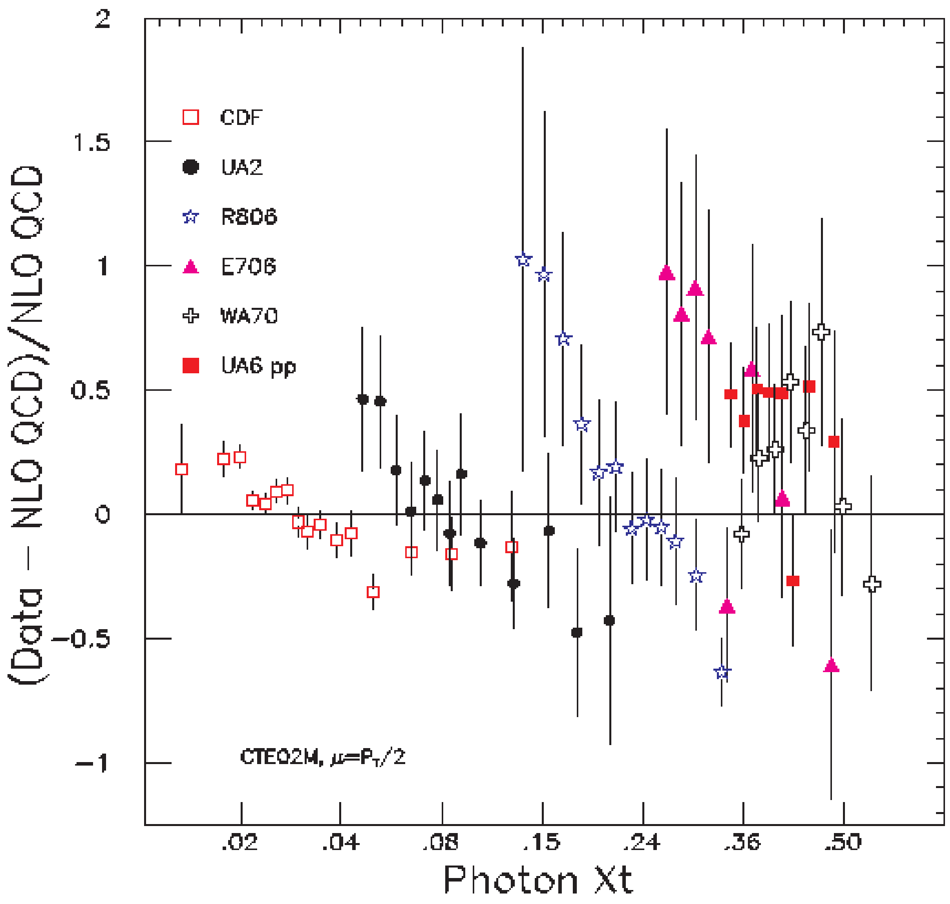
- Motivation
- Production Processes
- Results from CDF, ZEUS
- Summary

Motivation - Experiment vs NLO Theory



NLO QCD unable to describe fixed target and collider prompt photon experimental data

--> common problem is an excess in the data at low values of scaled photon Et ($Xt = 2\ Et,\gamma / \sqrt{s}$)

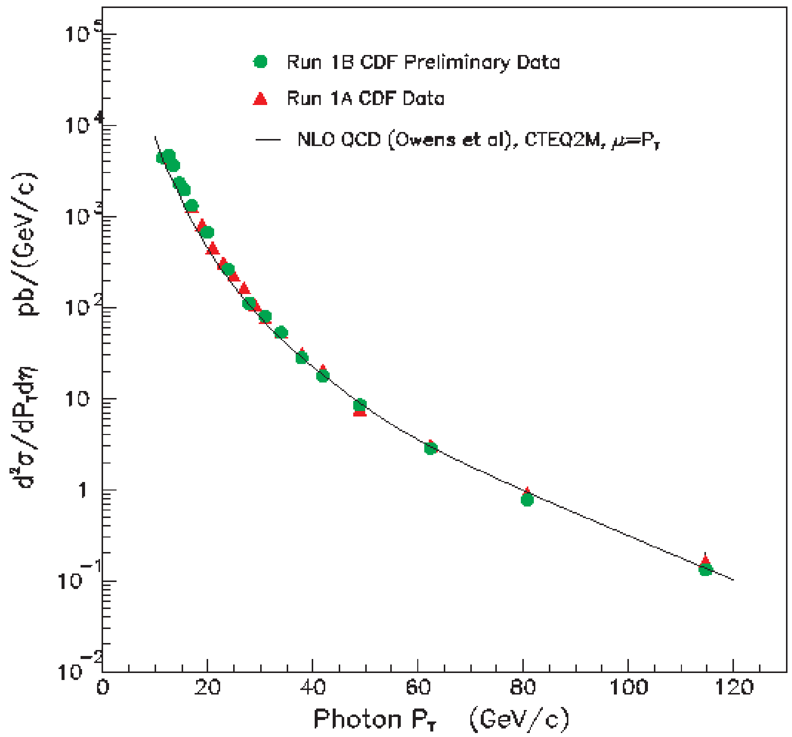
Due to effects of initial-state soft gluon radiation?

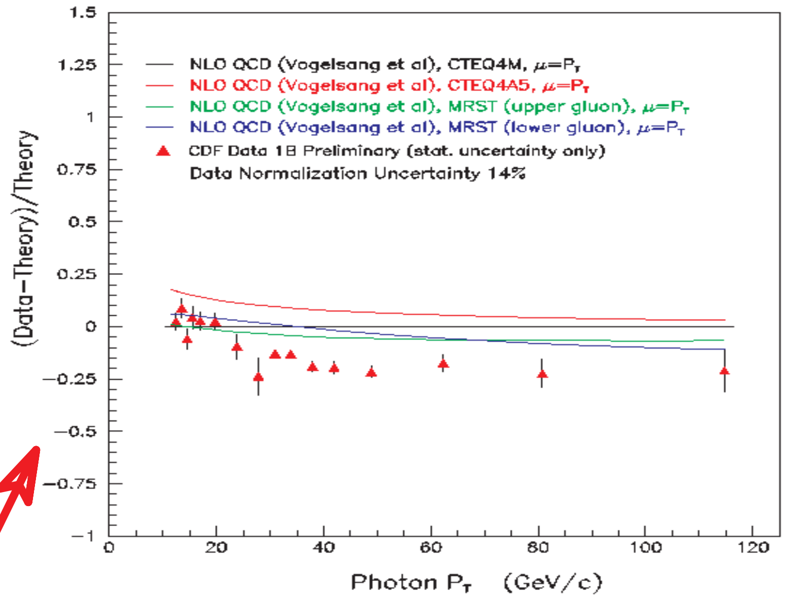
--> modelled by parton showers, intrinsic kT effects (recoil effects), resummed ISR soft gluons in NLO QCD calculations

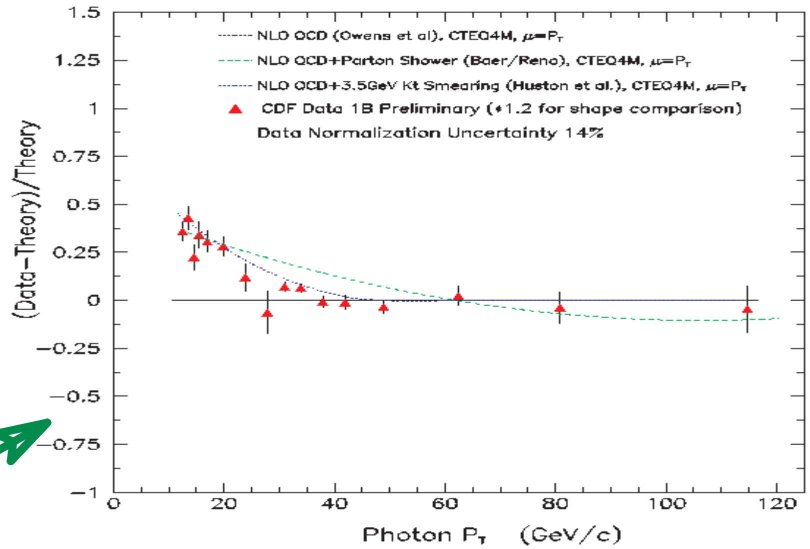
Processes :

CDF	$\bar{p}\ p \to \gamma + X$	C
UA2	$\bar{p}\ p \to \gamma + X$	C
R806	$p\ p \to \gamma + X$	C
E706	$p\ Be \to \gamma + X$	FT
WA70	$\pi^{+-}\ p \to \gamma + X$	FT
UA6	$p\ p \to \gamma + X$	FT

Motivation - CDF data vs. NLO QCD





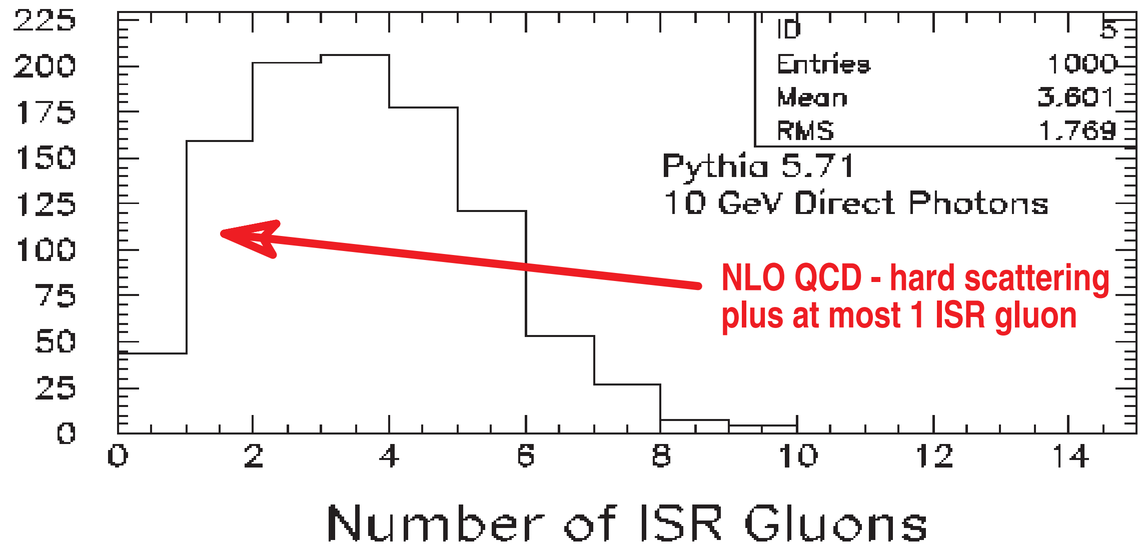


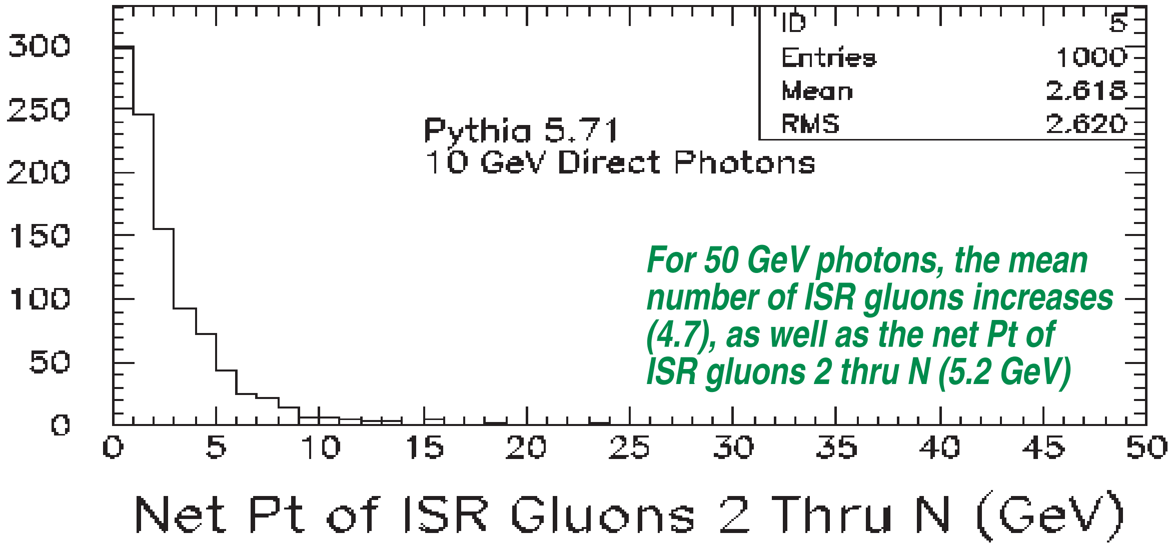
Recent CDF (Run 1b) data extends coverage to lower photon P_T

Try to fix excess with pdfs

Fix with additional k_T (gaussian smearing of average k_T of soft gluon radiation)
- simulates size of effective intrinsic transverse momentum of colliding partons

Motivation - Parton Showers and Intrinsic kT





Process p $\bar{p}$ --> γ X in PYTHIA

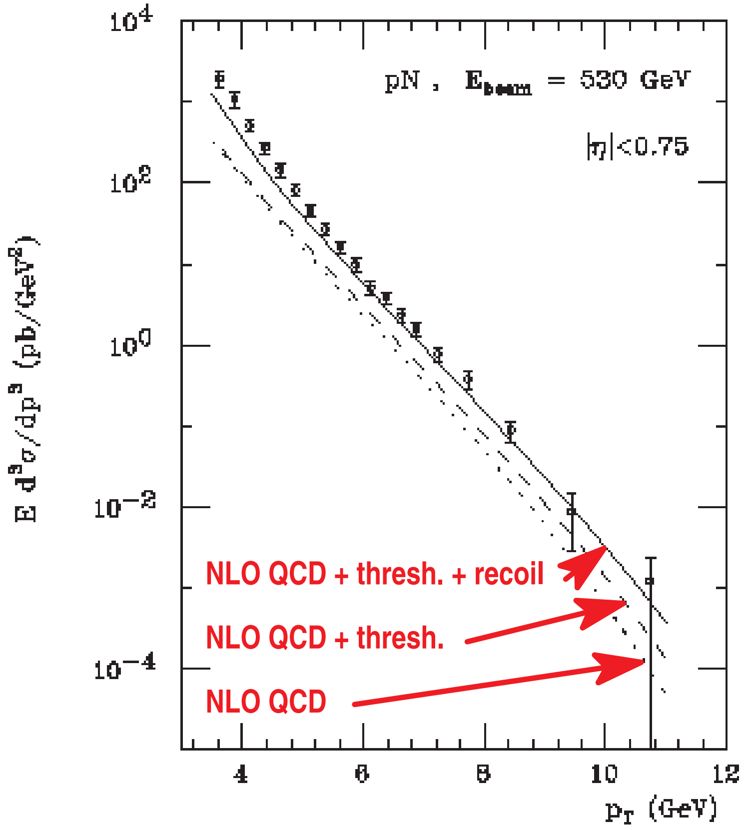
How to simulate recoil effect :

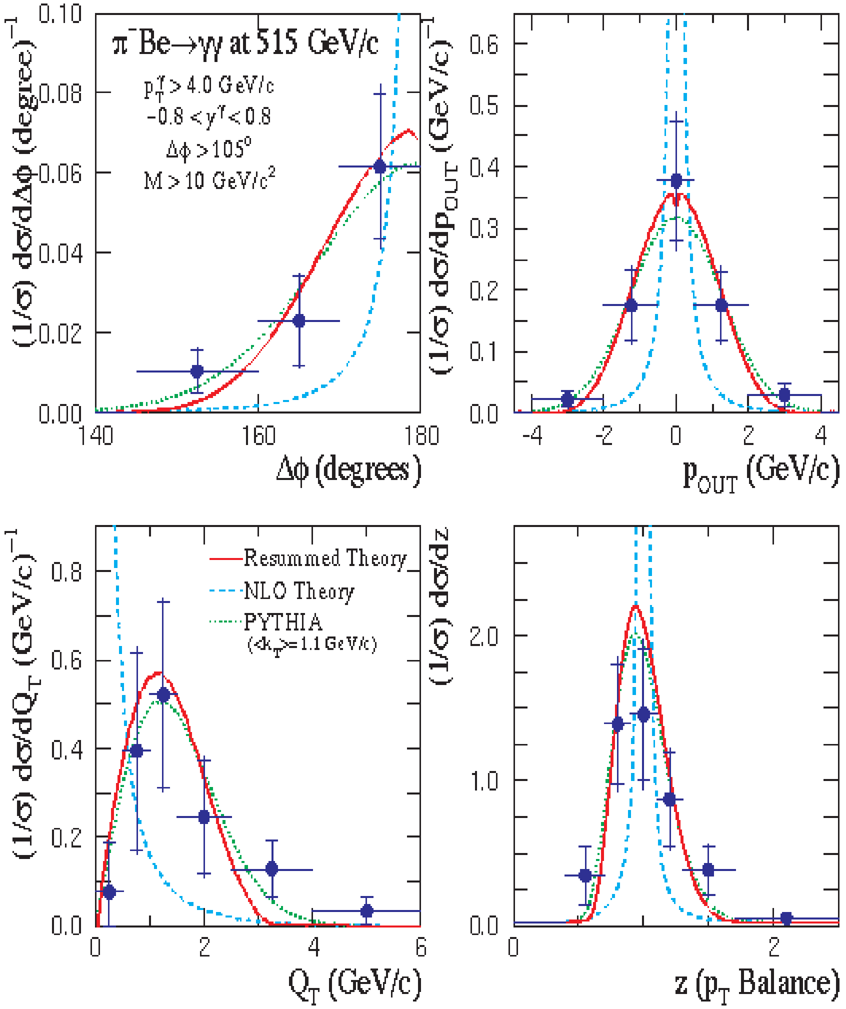
Parton showers in MC with increased <kT>

Net Pt of parton showers

Incorporation of recoil effects into NLO QCD calculations through resummation

Motivation - Soft Gluon Resummation

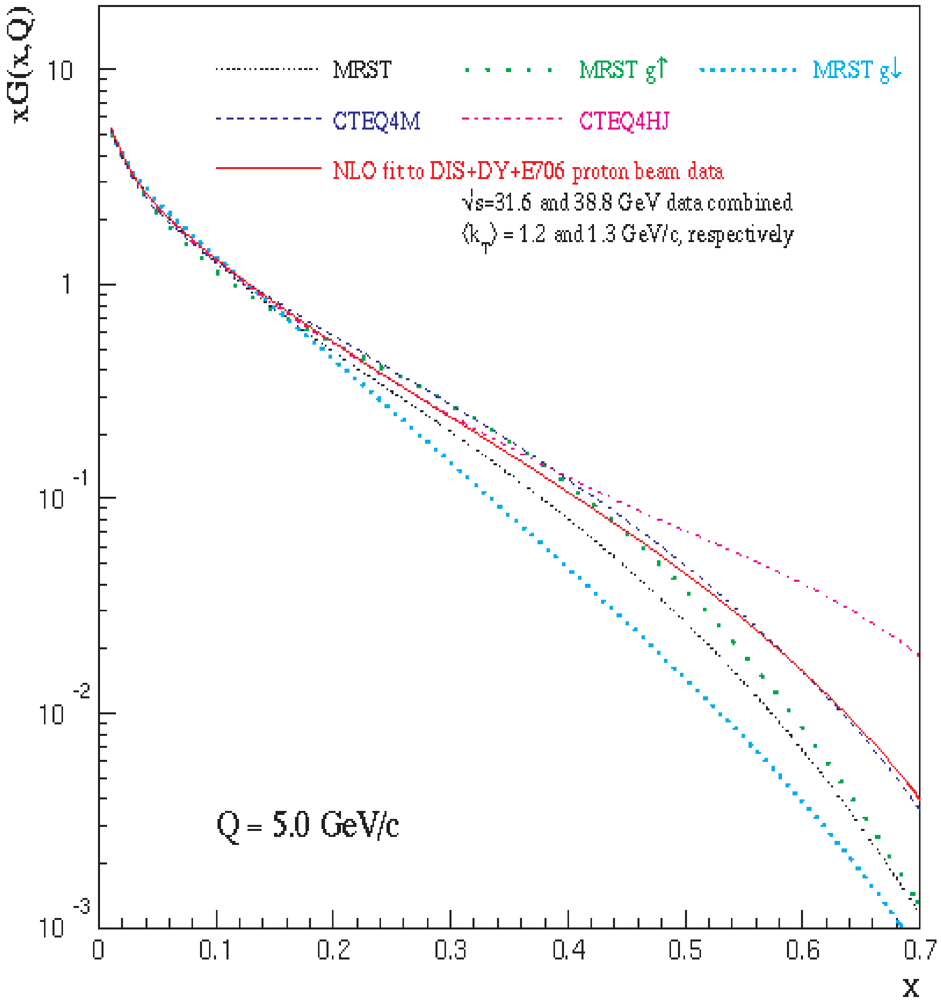




Resummed calculations are available and/or under development for many photon production processes

references : E. Laenen, et al; PRL 84 (2000)
C. Balazs, et al; PRD 57 (1998)

Motivation - Why it's Important

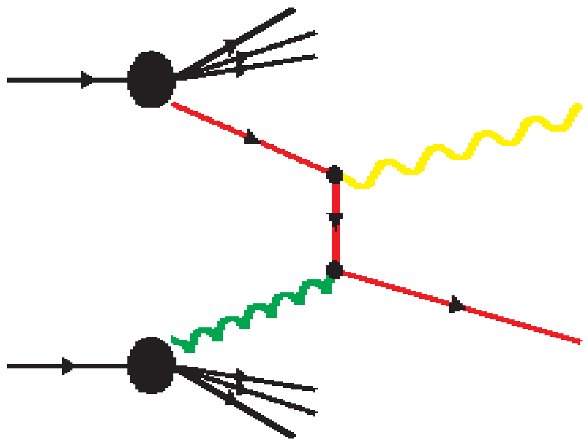


Understanding the dynamic properties of partons in the proton by using prompt photon production to determine the effects of soft gluon ISR can lead to reduced pdf uncertainties at large x :

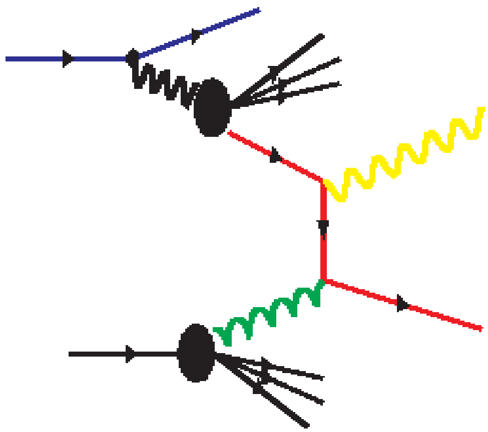
--> improved new physics searches at the Tevatron and LHC

Production Processes - γ p and $\bar{p}$ p

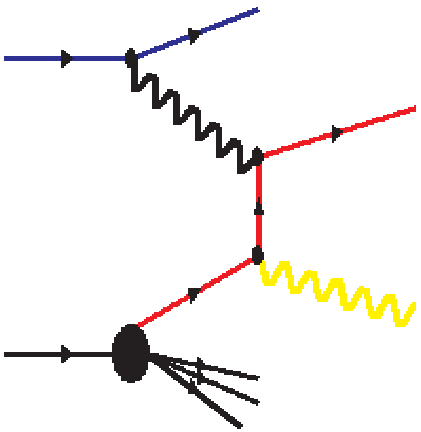
$\bar{p}\, p \to \gamma + jet + X$ at Tevatron



$\gamma\, p \to \gamma + jet + X$ at HERA



Resolved Process
(γ structure)



Direct Process
(pointlike incoming γ)

At Tevatron/HERA :

Prompt γ is a direct probe of the parton-level hard scattering process

Clean test of QCD since final state is less sensitive to hadronization

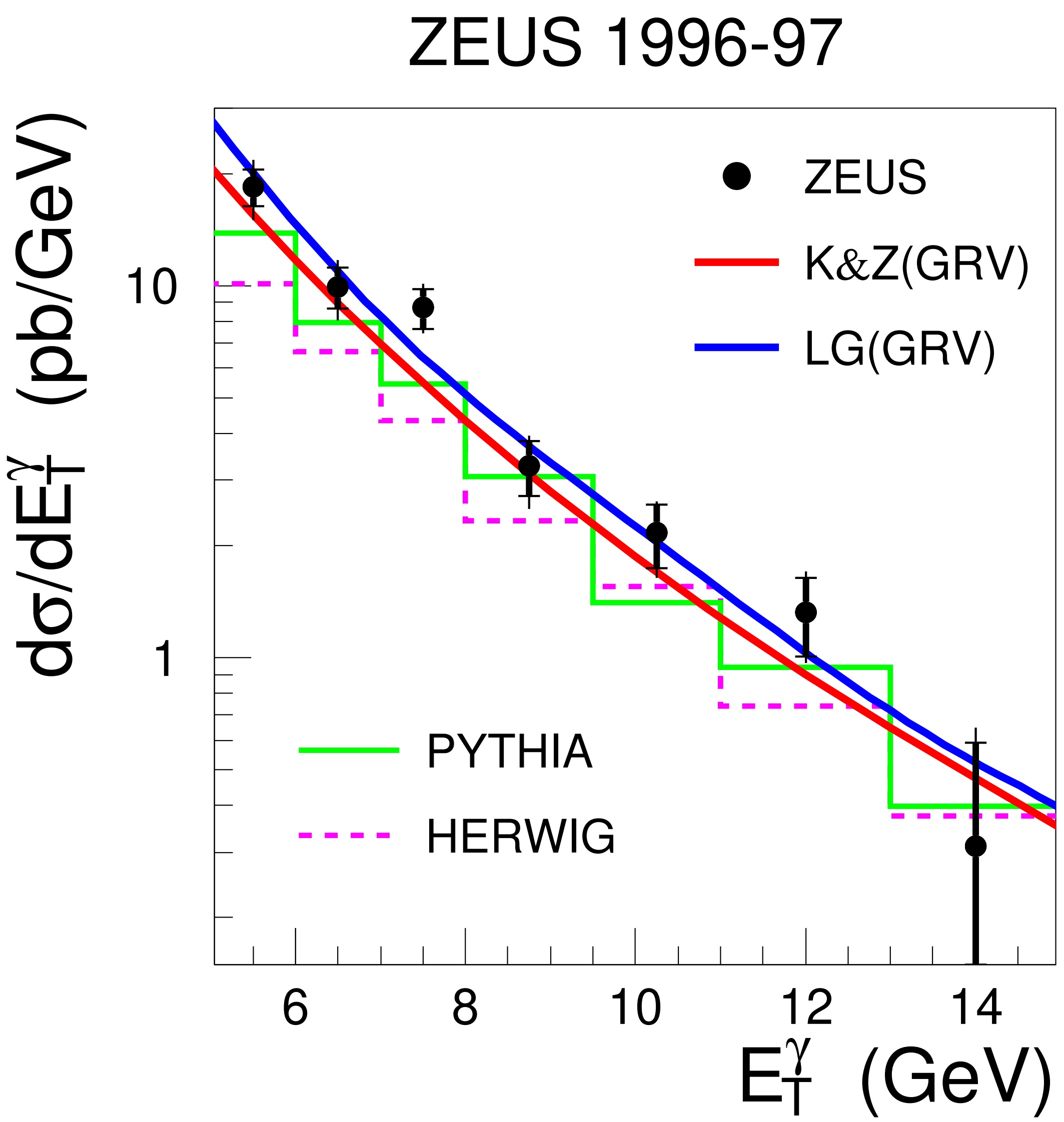
$\gamma/\pi/\eta$ separation done by 1) comparing shower widths in the electromagnetic calorimeter, and 2) hit rate in preshower detector (independent methods)

Many resolved processes
- kinematics favors g from proton and q from incoming photon

Only one LO direct process - $\gamma\, q \to \gamma\, q$

$\gamma/\pi/\eta$ separation done by comparing shower widths in the electromagnetic calorimeter (preshower method coming soon)

ZEUS Results - Inclusive Prompt Photon Production*



$\gamma\, p \to \gamma\, X$

--> photoproduction of prompt photons (Q^2 median ~10^{-3} GeV^2)

Event Selection :

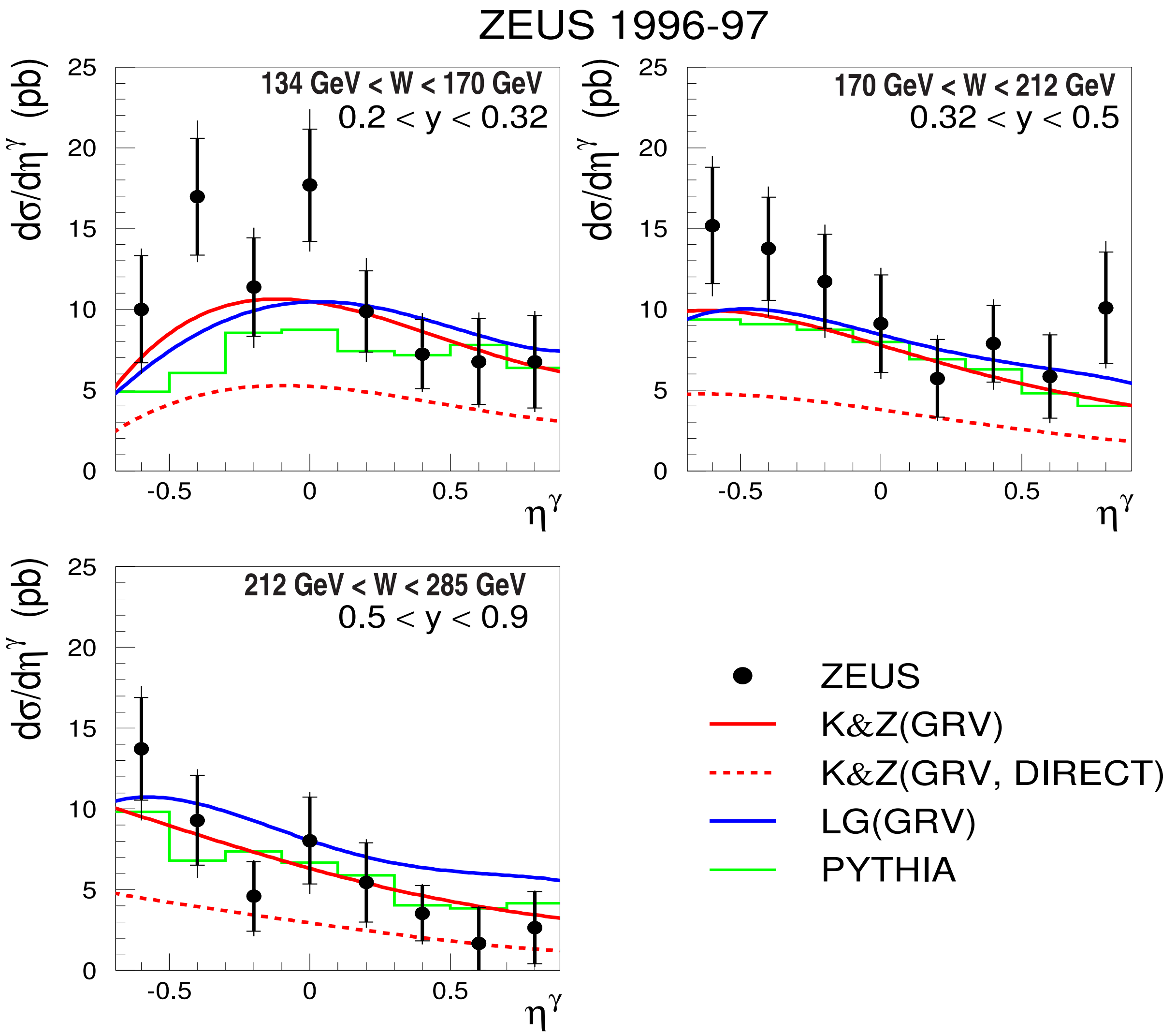
- EM cluster in central region; no track within 0.3 radians, $E_{T,\gamma} > 5$ GeV
- $0.2 < y$ (= $E_{\gamma, in}$ / E_e) < 0.9
- isolation cone of 1 unit ($E_T < 0.1\, E_{T,\gamma}$)

--> PYTHIA and HERWIG evaluated at hadron level (LO matrix elements plus parton showers in initial and final states)

--> NLO QCD parton level calculations by Gordon (LG), Krawczyk and Zembrzuski (K&Z); GRV photon pdfs, HO corrections to resolved terms (LG)

* PLB 472 (2000)

ZEUS Results - Inclusive Prompt Photon Production



Separate into y ranges from low to high y (~5 GeV to ~25 GeV incoming photons)

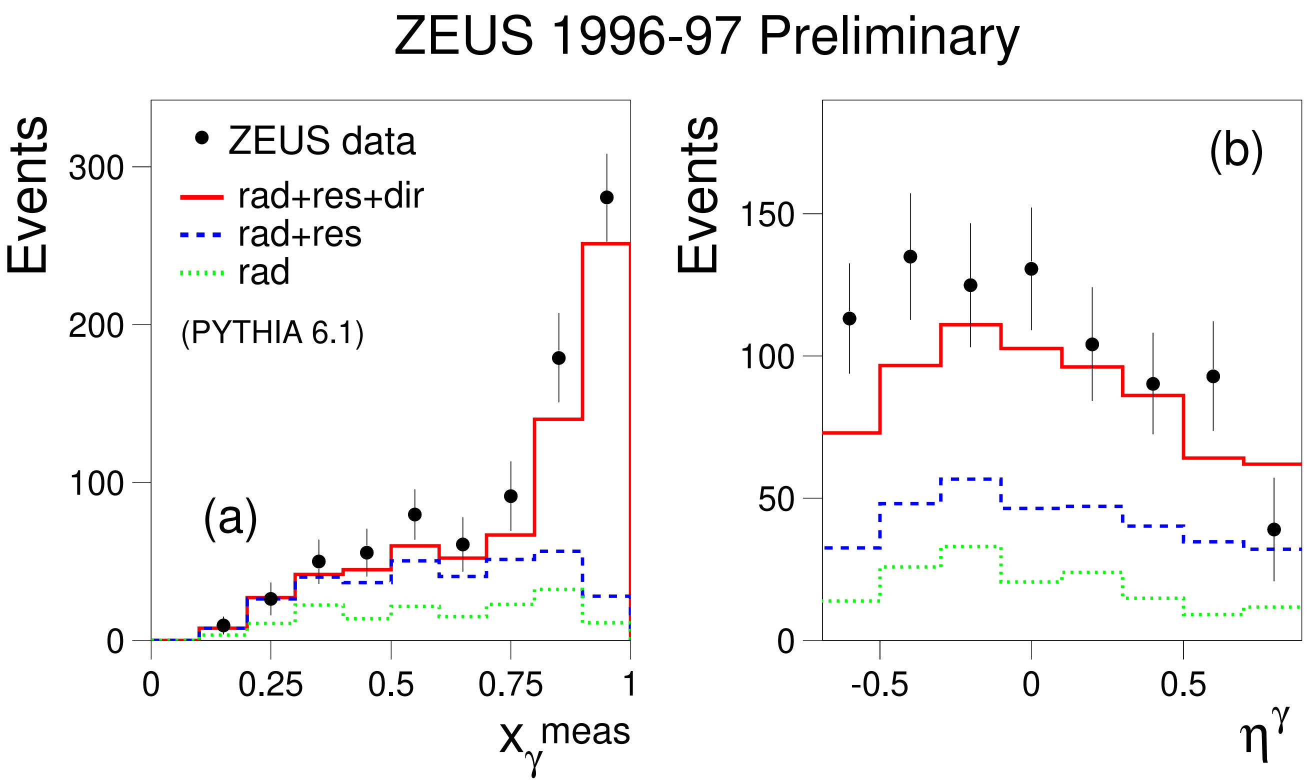
--> Low η_γ peak moves to lower η_γ as y increases.

--> All calculations and PYTHIA MC results lie below the data at low y and low η_γ.

--> Could correspond to insufficient high x_γ partons in the resolved photon

Systematic study of recoil effects in the photon and proton at HERA

ZEUS Results - γ + jet



γ p --> γ + Jet + X

--> photoproduction of photon plus jet

γ + Jet --> measure of x_γ (fraction of photon momentum participating in hard scatter)

High x_γ - direct photoproduction dominates

Low x_γ - resolved photoproduction

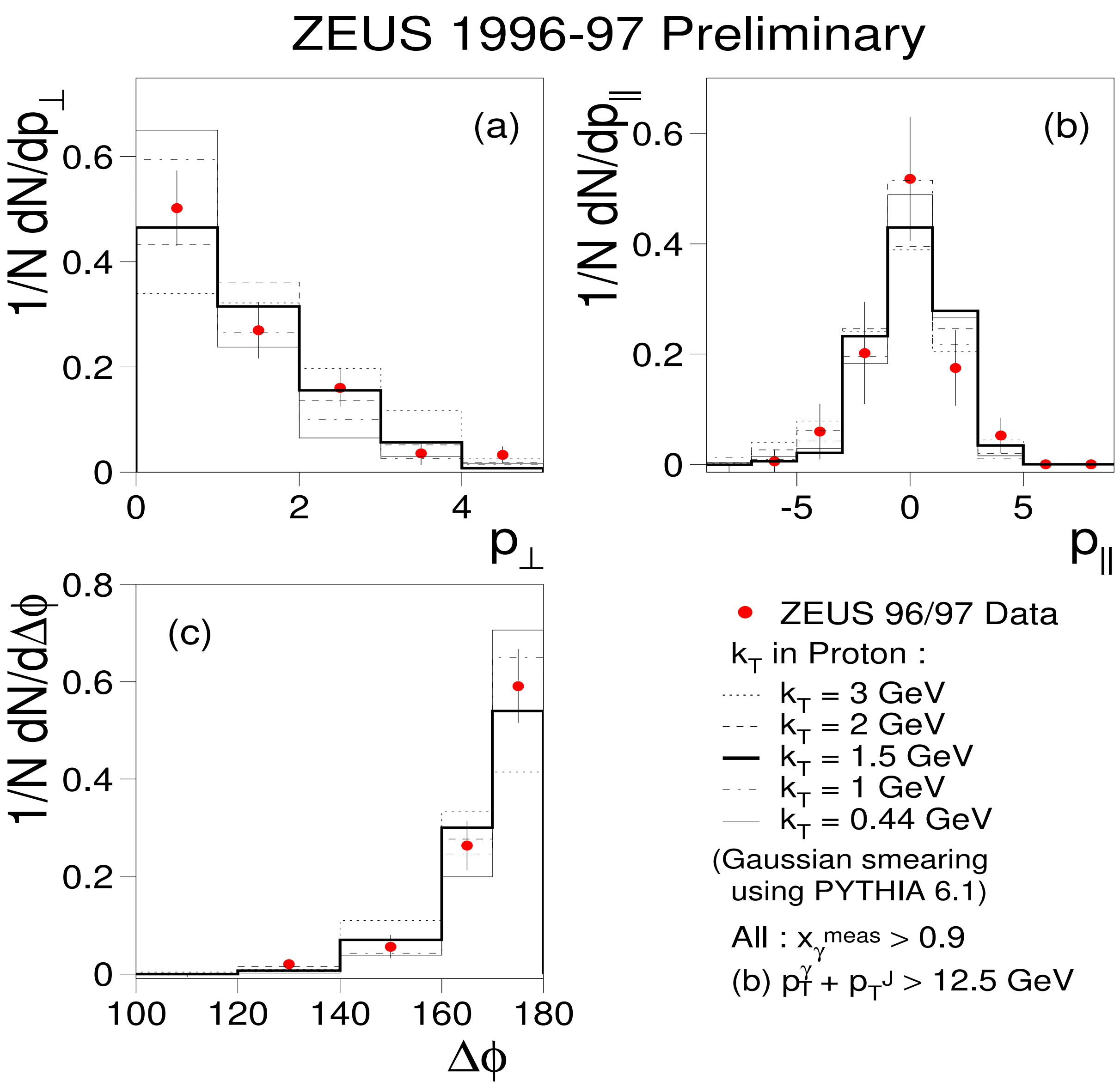
PYTHIA MC includes :

dir - direct photoproduction
res - resolved photoproduction
rad - dijet + radiative photon

MRSA pdfs for proton, GRV for photon
default k_T = 0.44 GeV

Study k_T effects in the proton only using events with $x_\gamma > 0.9$
--> no kT effects in point-like photon

ZEUS Results - γ + jet



$x_\gamma > 0.9$

Test of kT effects with recoil-sensitive variables :

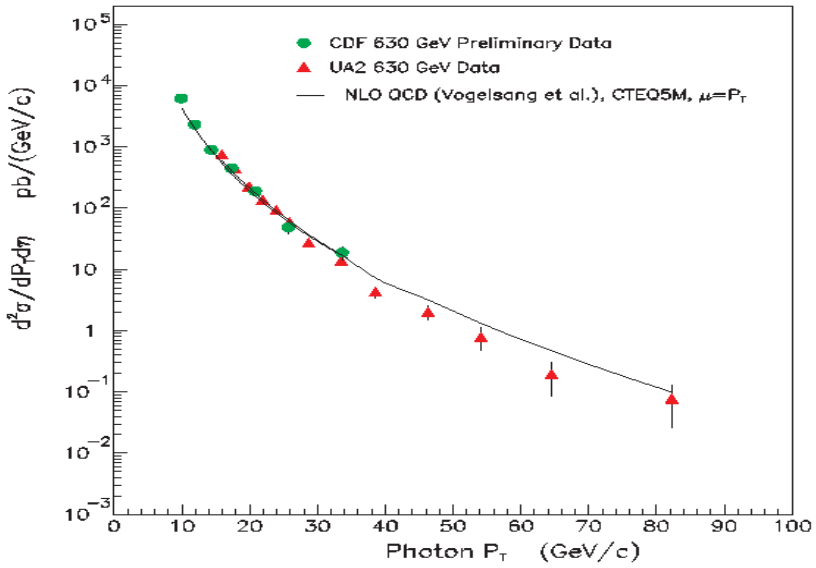
- **p⊥ - transverse momentum imbalance of photon and jet**
- **p|| - longitudinal photon-jet momentum imbalance**
- **Δφ - azimuthal angle between photon and jet**

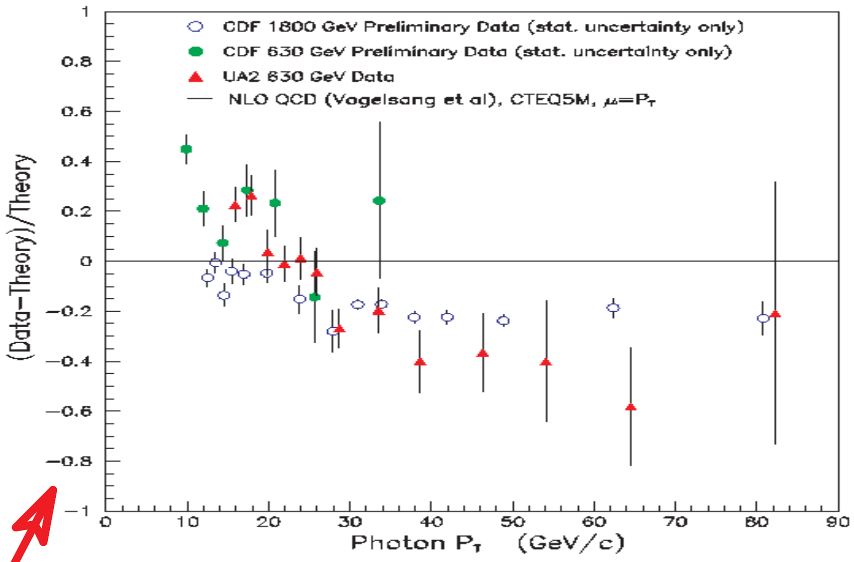
--> normalized to number of events after background subtraction

Poor agreement between PYTHIA and data using default kT value (0.44 GeV) and for kT = 3 GeV

Data favors a kT value of between 1 and 2 GeV

CDF Results - 630 and 1800 GeV



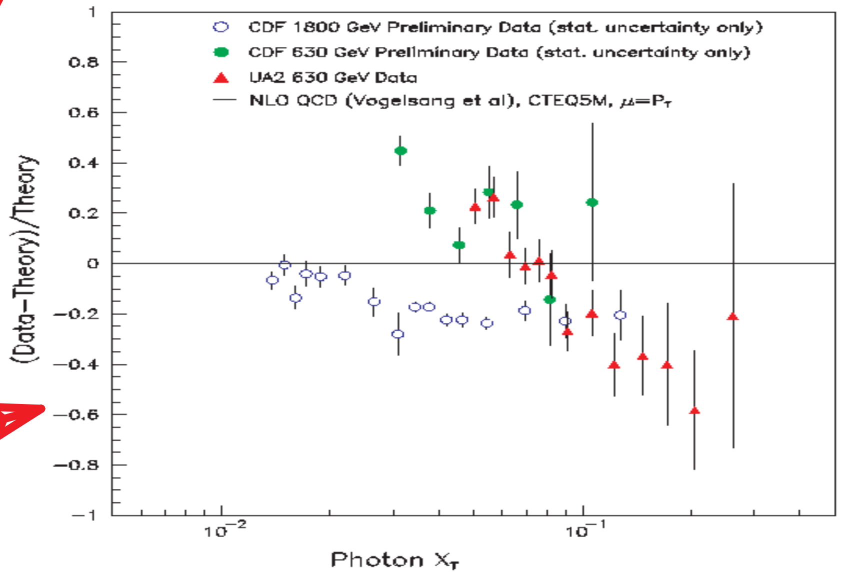


Recent results from CDF - $\sqrt{s}$ = 630 GeV

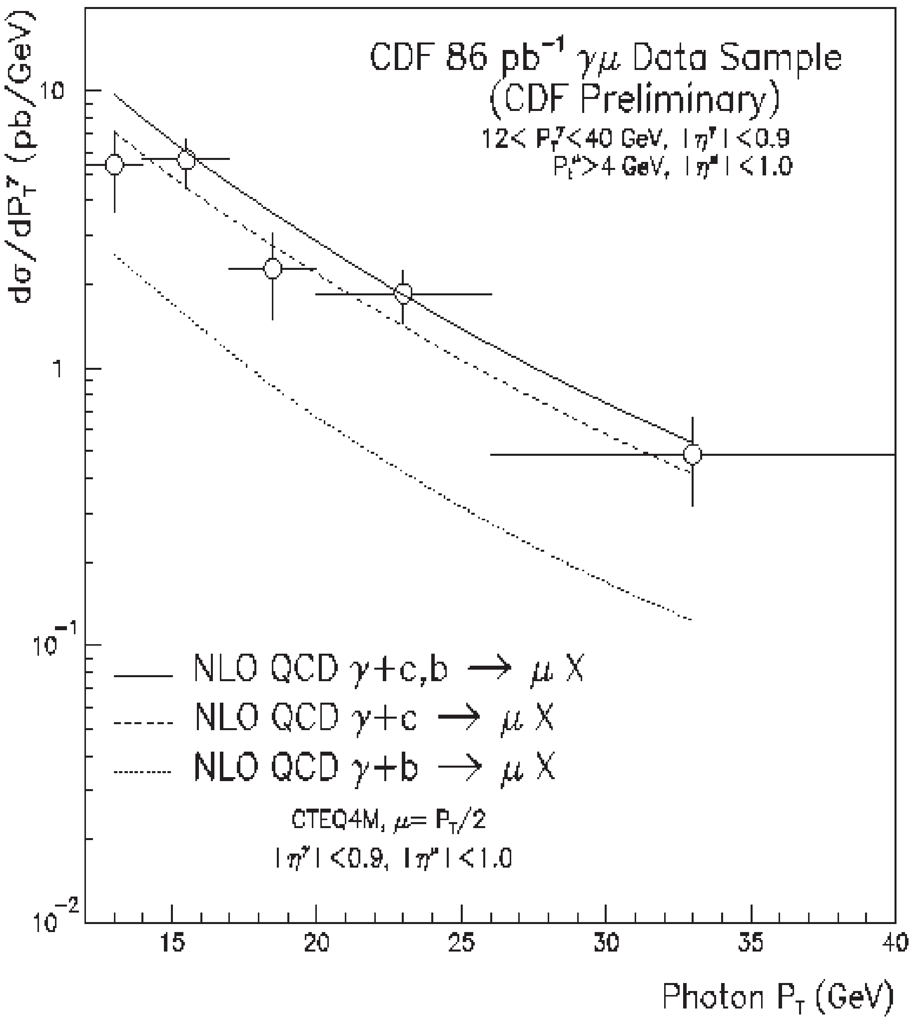
--> agrees with UA2 results

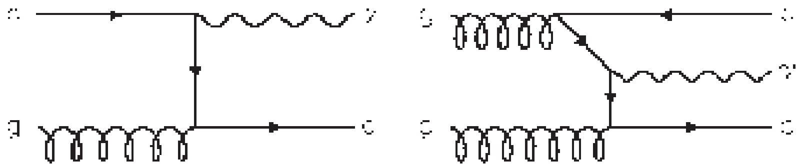
Difference between data and NLO QCD clearly a function of P_T

Large differences at constant X_T
--> not pdf-dependent



CDF Results - Photon + Muon





a) c g --> γ c

b) g g --> γ c $\bar{c}$

Event Selection :
- central muon with P_T > 4 GeV
- 12 GeV < $P_{T,\gamma}$ < 40 GeV
- isolation cut - E_T < 2 GeV in a cone of radius 0.4 units around photon candidate

Data dominated by diagram b) above at high Q values (lots of gluon evolution)

Large P_T requirements on muon

--> no recoil effect observed

Summary

Prompt photon production has proven to be a valuable tool in the evaluation of QCD effects in the absence of hadronization.

Recent results from CDF ($\sqrt{s}$ = 630 GeV) and ZEUS (direct photoproduction of photon + jet) are consistent with the need for additional initial state radiation of soft gluons from the proton when compared to simulations modified by inclusion of parton showers, additional intrinsic kT, or NLO QCD calculations which include ISR soft gluon resummation.

From ZEUS inclusive prompt photon production, there are indications that our current understanding of the photon structure is also lacking - with additional photon + jet data, a systematic investigation of effects from both the proton and photon can be done by extending the analysis to low x_γ - dominated by resolved photoproduction.