Prompt Photon Production in γ p, e p and hadronic collisions

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Overview

- Introduction
- Photoproduction of prompt photons (+jet)
- Prompt photons in DIS
- Diphoton production in hadronic collisions
- Photon (+jet) production in hadronic collisions (Tevatron, RHIC, LHC)
- Summary and outlook

- not covered: final states without photons (single-inclusive jet, dijets, mesons, quarkonia, . . .)

Introduction

- Photons are of major importance in particle physics
- "dual nature" :
  - pointlike particle described by QED
  - hadronic structure
    $\Rightarrow$ photon structure- and fragmentation functions
- ideal to study QCD ($\rightarrow$ gluon pdfs ...)
- H $\rightarrow \gamma\gamma$ discovery channel for light Higgs
- important in New Physics searches
  (e.g. decay of SUSY particles or excited states)
- ...

Photoproduction of prompt photons

high energy $e\,p$ scattering at HERA dominated by photoproduction processes:

electron scattered at small angles $\Rightarrow$
quasi-real photon interacts with proton

spectrum of quasi-real photons:

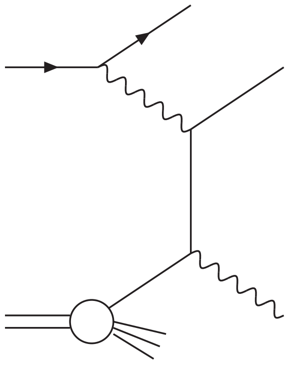
Weizsäcker-Williams approximation

$$f_{\gamma/e}(y) \;=\; \frac{\alpha}{2\pi}\left\{\frac{1+(1-y)^2}{y}\,\mathrm{Log}\frac{Q^2_{\max}(1-y)}{m_e^2 y^2} - \frac{2(1-y)}{y}\right\}$$

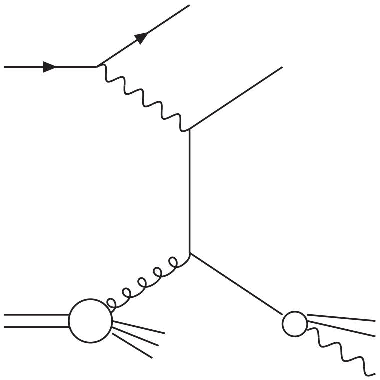
photoproduction: $Q^2_{\max} \sim 1\,GeV^2$

Photoproduction of prompt photons

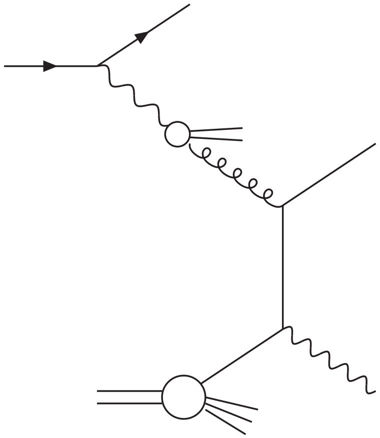
four categories of subprocesses:



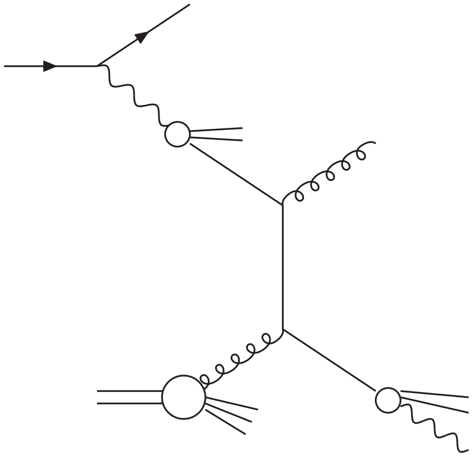
direct-direct



direct-fragmentation



resolved-direct



resolved-fragmentation

collinear factorisation

$$d\sigma^{AB\to\gamma\,j}(P_A, P_B, P_\gamma, P_j) =$$

$$\sum_{a,b,c}\int dx_a \int dx_b\, F_{a/A}(x_a, M)F_{b/B}(x_b, M)$$

$$\left\{ d\hat{\sigma}^{\mathrm{dir}} \; + \; d\hat{\sigma}^{\mathrm{frag}} \right\}$$

$$d\hat{\sigma}^{\mathrm{dir}} = d\hat{\sigma}^{ab\to\gamma\,j}(x_a, x_b, P_\gamma, P_j, \mu, M, M_F)$$

$$d\hat{\sigma}^{\mathrm{frag}} = \int dz\, D_{\gamma/c}(z, M_F) \; d\hat{\sigma}^{ab\to c\,j}(x_a, x_b, P_\gamma/z, P_j, \mu, M, M_F)$$

M/M_F initial/final state factorisation scales, μ renormalisation scale

Photoproduction

- resolved photon ($a =$ quark, gluon):

$$F_{a/e}(x,M) = \int dx^\gamma \int dy\, \delta(x^\gamma y - x)\, f_{\gamma/e}(y)\, F_{a/\gamma}(x^\gamma, M)$$

$F_{a/\gamma}(x^\gamma, M)$: parton distributions in the photon

- direct photon ($a = \gamma$): $F_{a/e}(x,M) = f_{\gamma/e}(x)$, $x^\gamma = 1$

possibility to "switch on/off" resolved photon by suppressing/enhancing large x^γ

$$x^\gamma_{obs} = \frac{p_T^\gamma\, \mathrm{e}^{-\eta^\gamma} + p_T^{jet}\, \mathrm{e}^{-\eta^{jet}}}{2E^\gamma}$$

Photon isolation

to single out prompt photon events from background of secondary photons produced by decays of π^0, η, ω mesons:

impose isolation cuts

commonly used isolation criterion:

inside a cone around the photon

$$(\eta - \eta_\gamma)^2 + (\phi - \phi_\gamma)^2 \leq R_{\rm exp}^2 : \quad E_T^{had} \leq E_{T\,max}$$

$E_{T\,max}, R_{\rm exp}$ fixed by experiment

e.g. $E_{T\,max} = \epsilon\, p_T^\gamma$, $\epsilon = 0.1$, $R_{\rm exp}$ = 1

isolation also reduces the fragmentation component

correspondence between theo. and exp. isolation delicate

(e.g. due to hadronic activity from underlying event in isolation cone)

Theoretical (parton level) programs beyond LO

photoproduction only !

- Baer, Ohnemus, Owens 1990 (NLL only)
- Aurenche, Chiappetta, Fontannaz, Guillet, Pilon 1992
  (inclusive only)
- Gordon, Storrow 1994 (inclusive only)
- Gordon, Vogelsang 1995 (isolated γ in collinear approximation)
- Gordon 1998 (γ+jet)
  (isolated γ in collinear approximation)
- Krawczyk, Zembrzuski 2001, 2003 (γ incl, γ+jet)
  (fragmentation not at NLO)
- Fontannaz, Guillet, GH 2001 (γ incl, γ+jet)
  EPHOX: partonic Monte Carlo program

PHOX programs

The PHOX Family

NLO Monte Carlo programs (partonic event generators) to calculate cross sections for the production of large-p_T photons, hadrons and jets

http://wwwlapp.in2p3.fr/lapth/PHOX_FAMILY/main.html

P. Aurenche, T. Binoth, M. Fontannaz, J.Ph. Guillet, GH, E. Pilon, M. Werlen

- DIPHOX

  $h_1\, h_2 \to \gamma\ \gamma\ + X$, $h_1\, h_2 \to \gamma\ h_3\ + X$, $h_1\, h_2 \to h_3\, h_4\ + X$

- JETPHOX

  $h_1\, h_2 \to \gamma$ jet $+X$, $h_1\, h_2 \to \gamma\ + X$

  $h_1\, h_2 \to h_3$ jet $+X$, $h_1\, h_2 \to h_3 + X$

- EPHOX

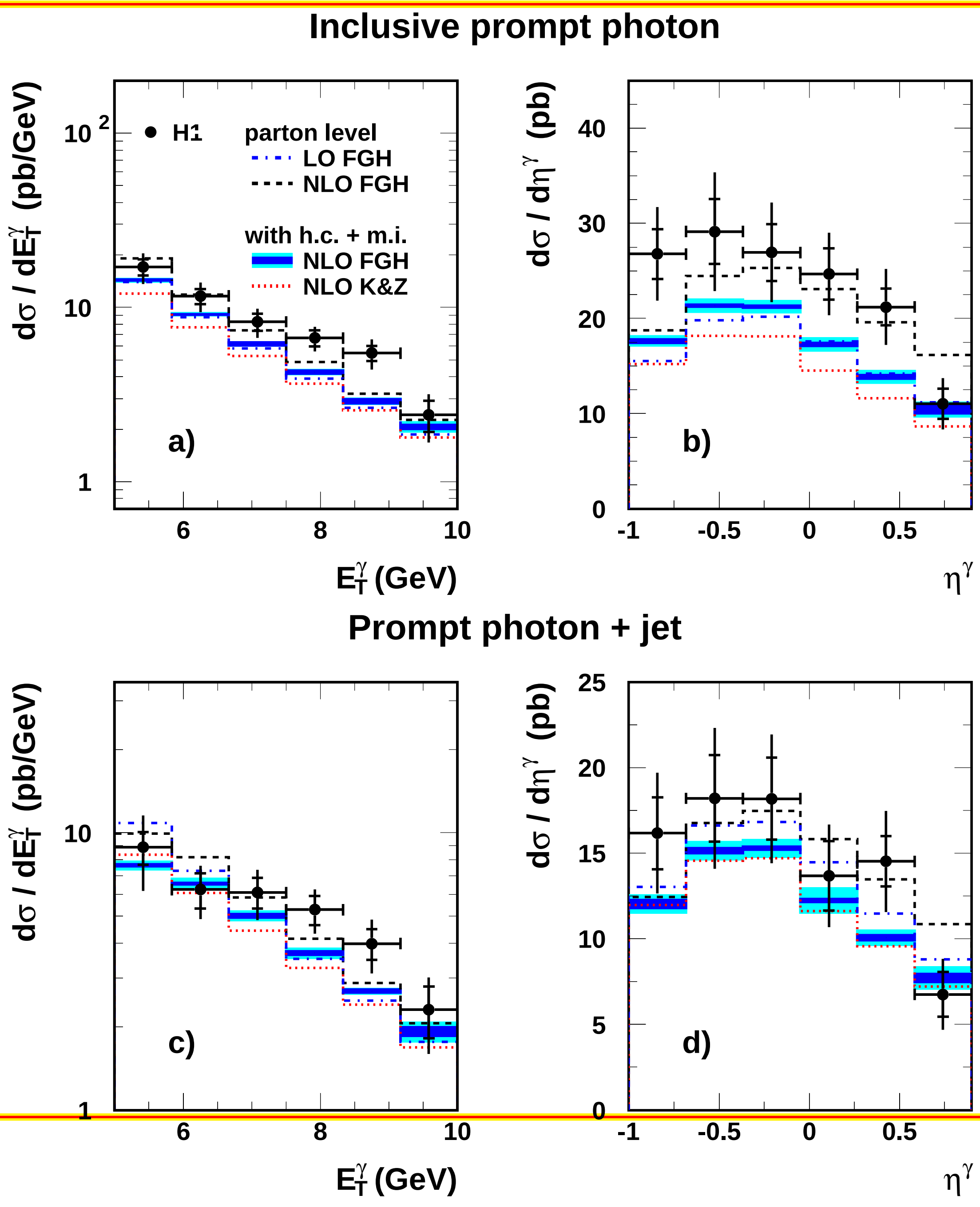
  $\gamma\, p \to \gamma$ jet $+X$, $\gamma\, p \to \gamma\ + X$

  $\gamma\, p \to h$ jet $+X$, $\gamma\, p \to h + X$

- TWINPHOX

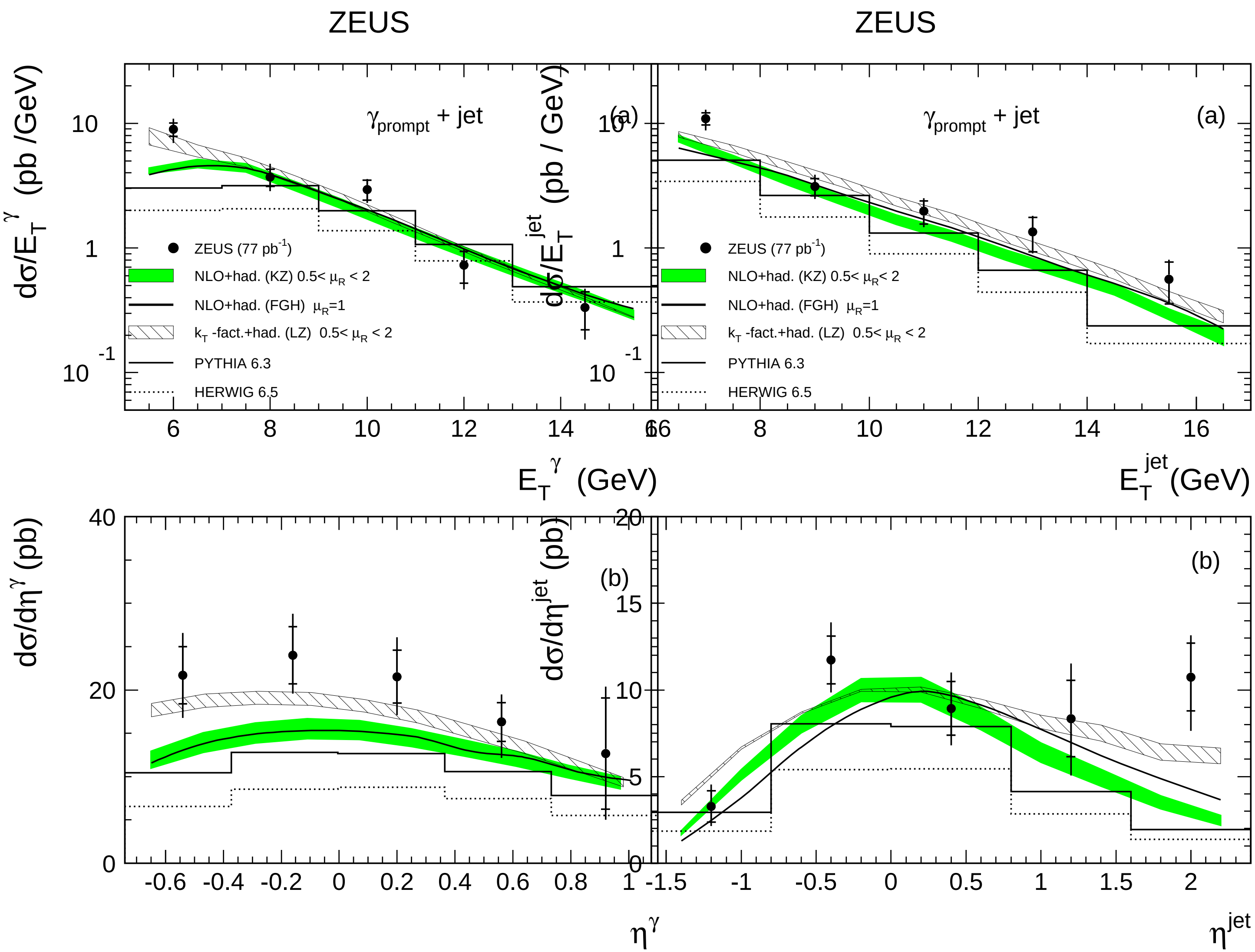
  $\gamma\,\gamma \to \gamma$ jet $+X$, $\gamma\,\gamma \to \gamma\ + X$

Photoproduction of inclusive γ and γ + jet: H1



H1 (A. Aktas et al.) '05

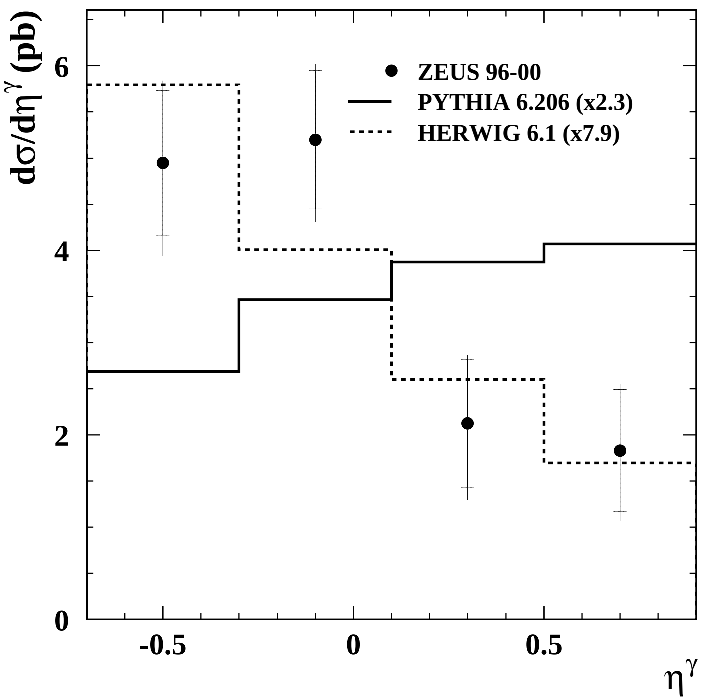
Photoproduction of $\gamma +$ jet: ZEUS

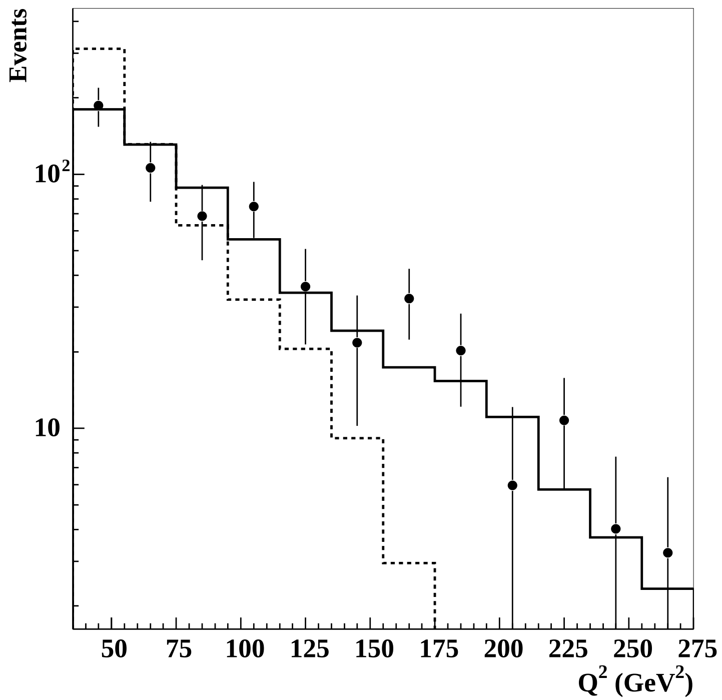


ZEUS (S. Chekanov et al.) '07

Prompt photons in DIS

- recent ZEUS data Chekanov et al. '04
- γ+jet: fair agreement with NLO theory
  Gehrmann-De Ridder, Kramer, Spiesberger 2000
- inclusive γ : disagreement with PYTHIA 6.206 (η^γ distribution) and HERWIG 6.1 (too soft Q^2 distribution) both in normalisation and shape





Prompt photons in DIS

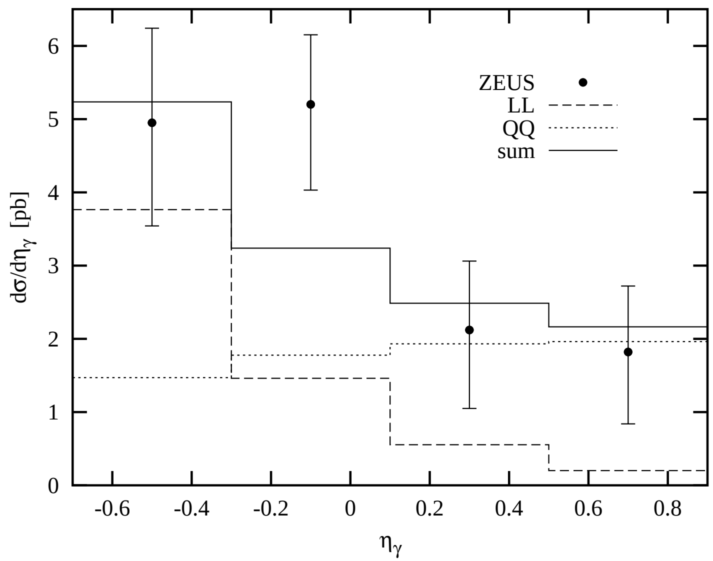
partonic subprocess (LO): $q + l \rightarrow \gamma + q + l$

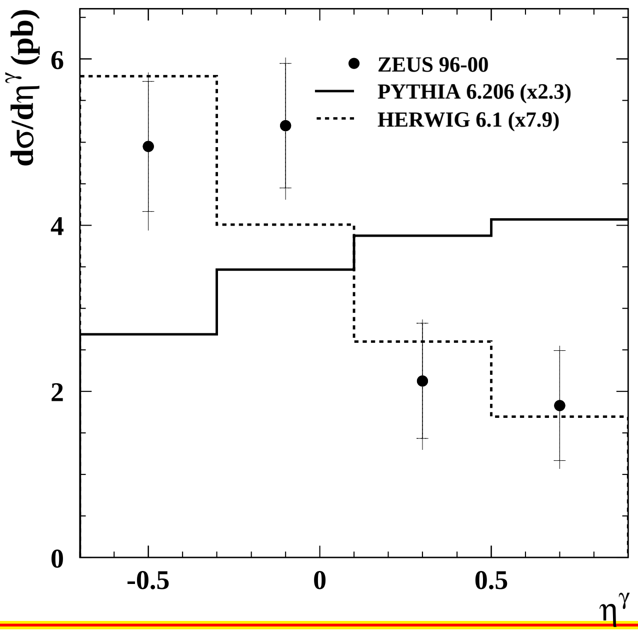
photon radiation: off quarks (QQ), off leptons (LL) or interference (QL) (small)

result of partonic calculation: (large angle rad. + frag. photons)

A. Gehrmann-De Ridder, T. Gehrmann, E. Poulsen 2006

- QQ and LL each contribute $\sim 50\%$, shapes quite different
- QQ shape PYTHIA-like, LL shape HERWIG-like





Prompt photon production in hadronic collisions

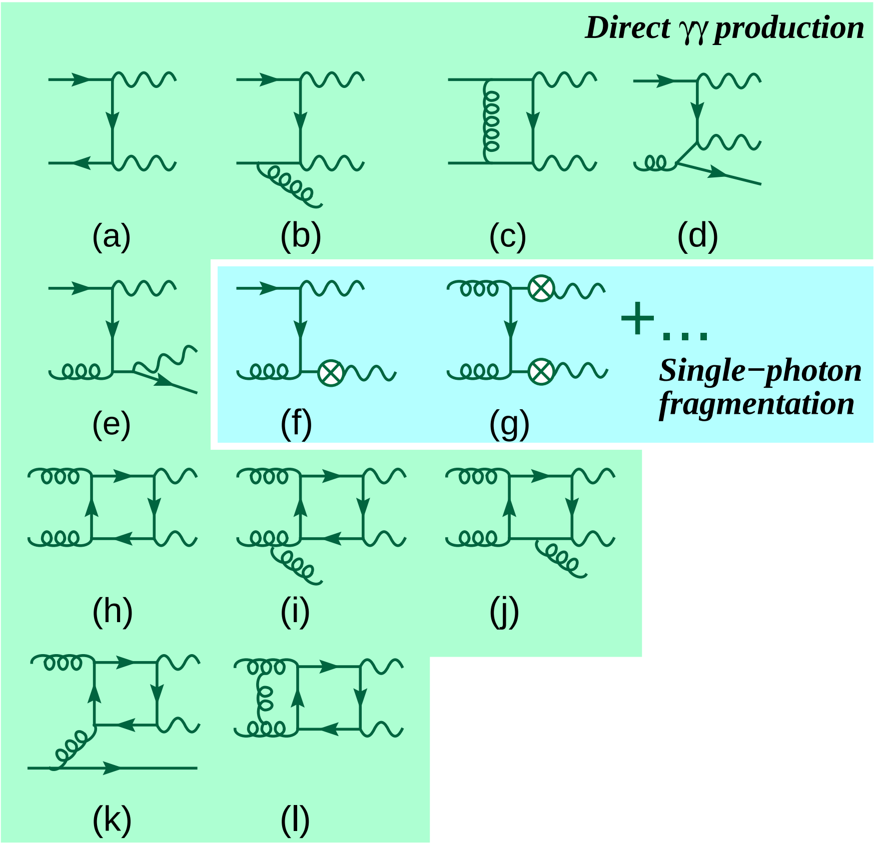
- background to $H \to \gamma\gamma$ and New Physics
- access to gluon pdfs (LO: $q\,g \to q\gamma$)
- free from systematic errors related to jet identification/calibration
- lower p_T range accessible
- ...

Diphoton production in hadronic collisions

available codes:

- DIPHOX Binoth,Fontannaz,Guillet,Pilon,Werlen 2000
  - inclusion of fragmentation components fully at NLO
- RESBOS Balazs, Berger, Mrenna, Nadolsky, Schmidt, Yuan 1998, 2000
  update 2007: Balazs, Berger, Nadolsky, Yuan
  - NNLL resummation of initial-state singularities at small q_T
  - inclusion of NLO $gg \to \gamma\gamma$ diagrams Bern, Dixon, Schmidt 02
  - approximation for fragmentation contributions

Diphoton production in hadronic collisions

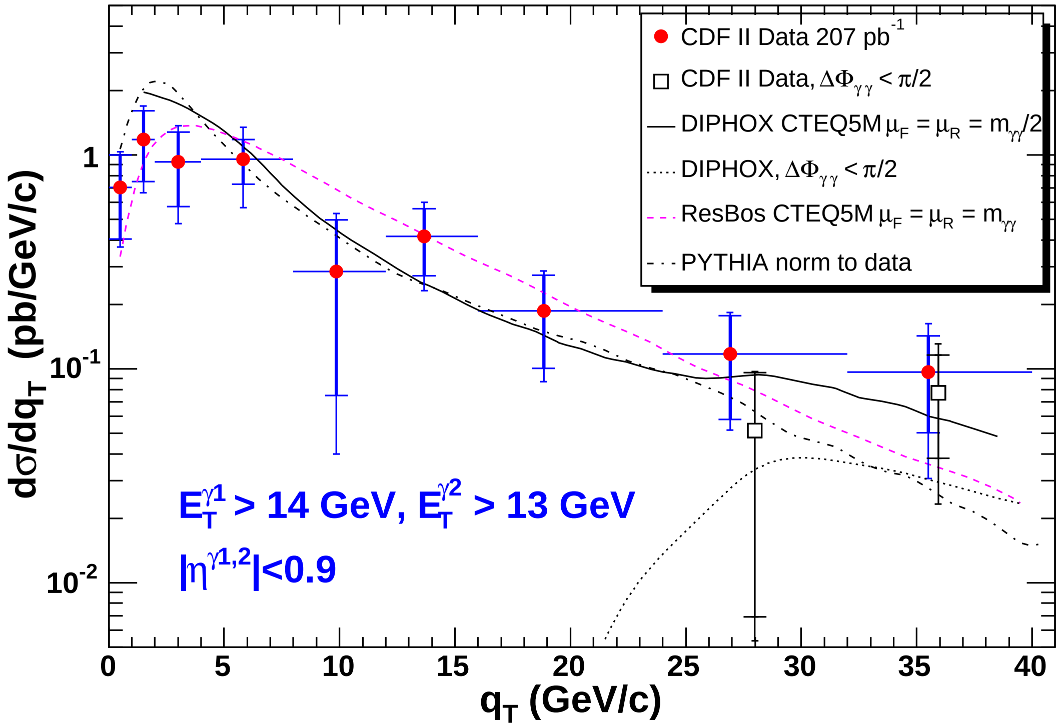


(f),(g): absent in RESBOS

(i),(j),(k),(l): absent in DIPHOX

$p\,\bar{p} \to \gamma\gamma$ at CDF, q_T distribution

DIPHOX
PYTHIA
RESBOS



CDF 05

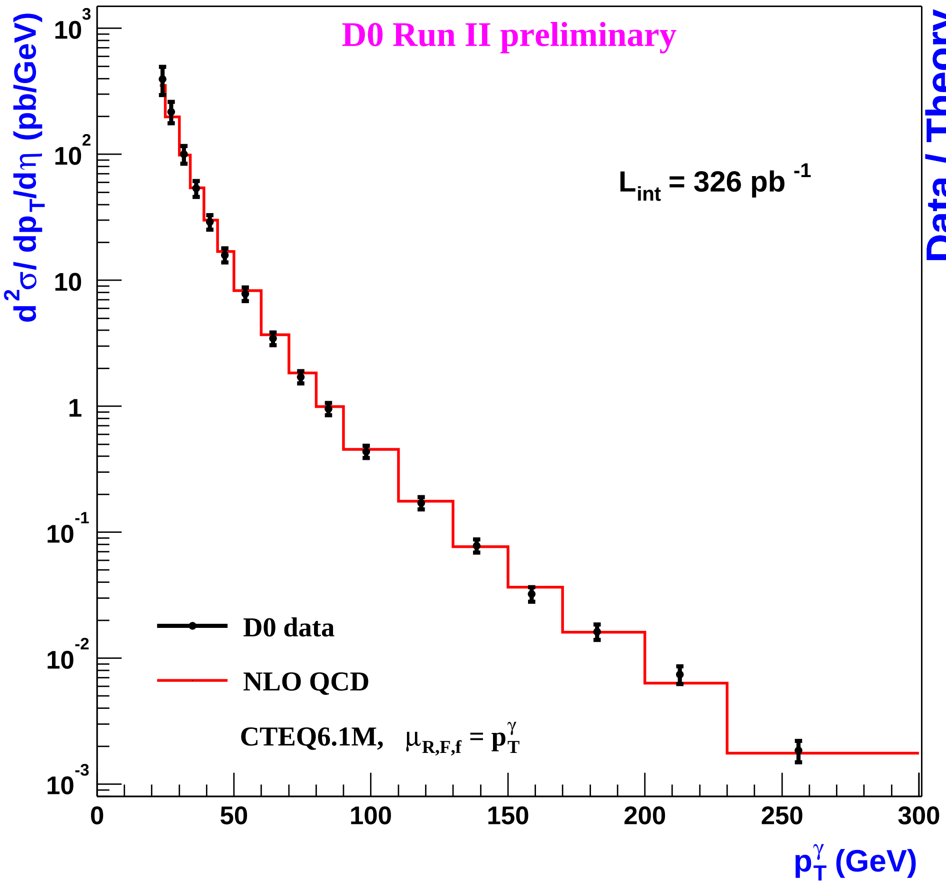
isolation cuts: $E_{T,\max}^{had} = 1\,GeV, R = 0.4$

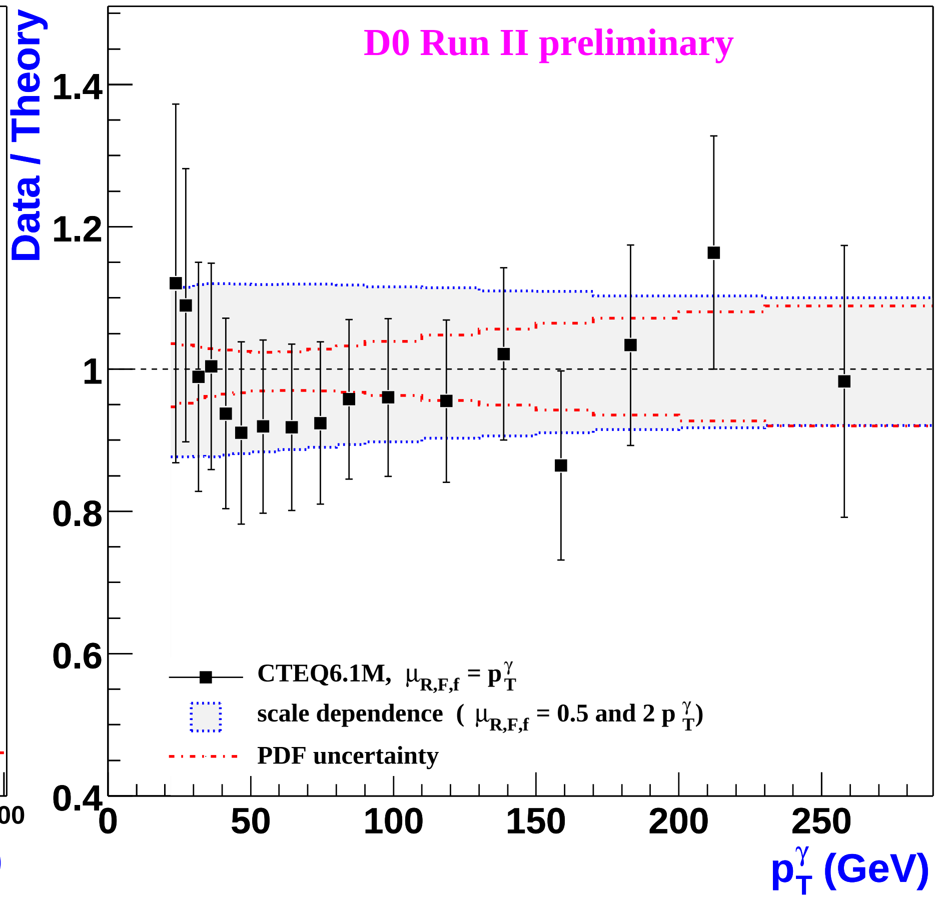
anti-collinearity cuts: $(\eta_{\gamma_1} - \eta_{\gamma_2})^2 + (\Delta\phi_{\gamma\gamma})^2 \geq R^2_{\min},\; R_{\min} = 0.3$

bump interpretation:

interplay between collinear enhancement of NLO fragmentation component and anti-collinearity cut

Inclusive prompt photon production: Tevatron





$$23\,GeV \leq p_T^\gamma \leq 300\,GeV\,,\ |\eta^\gamma| < 0.9$$

widest p_T^γ range ever !

Prompt photon + jet production: D0

measurement of $p\,\bar{p} \to \gamma + \mathrm{jet} + X$ for

30 GeV $\leq p_T^{\gamma} \leq 300$ GeV $(|\eta^{\gamma}| < 1,\ p_T^{\mathrm{jet}} > 15$ GeV$)$

$g\,q \to q\gamma$ dominates in wide kinematical range

division into 4 regions: $(0 < \eta^{\gamma} < 1)$

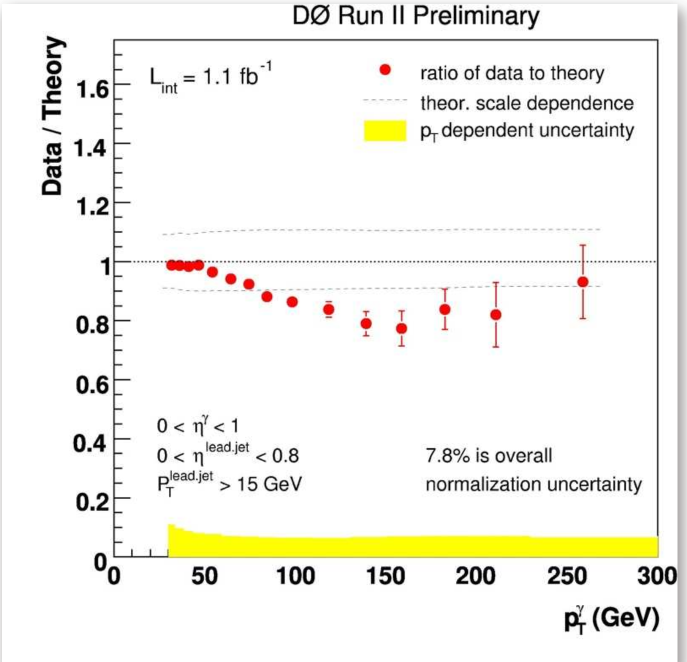
1. $0 < \eta^{\mathrm{jet}} < 0.8$
2. $-0.8 < \eta^{\mathrm{jet}} < 0$
3. $1.5 < \eta^{\mathrm{jet}} < 2.5$
4. $-2.5 < \eta^{\mathrm{jet}} < -1.5$

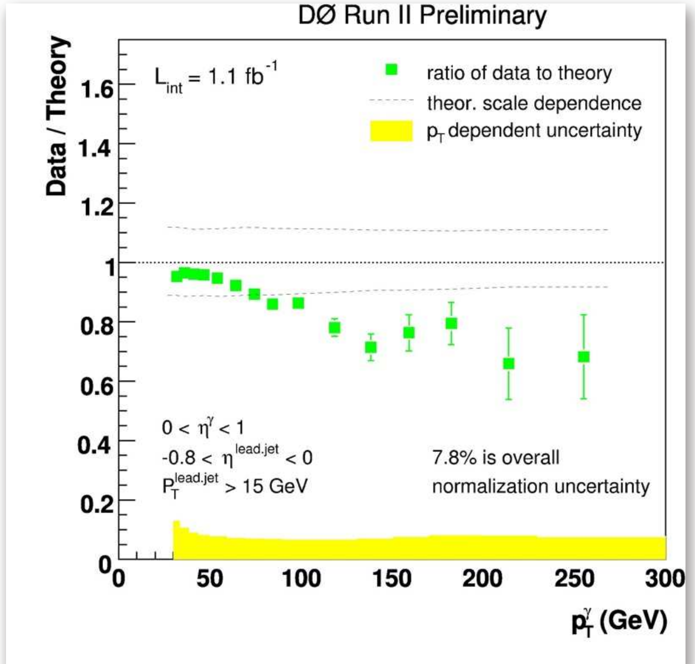
regions 3 & 4 : $x_{1/2} \gg x_{2/1}$

$$x_{1/2} \quad \sim \quad \frac{p_T^{\gamma}\,\mathrm{e}^{\pm\eta^{\gamma}} + p_T^{\mathrm{jet}}\,\mathrm{e}^{\pm\eta^{\mathrm{jet}}}}{\sqrt{s}}$$

Prompt photon + jet production: D0

Comparison with theory

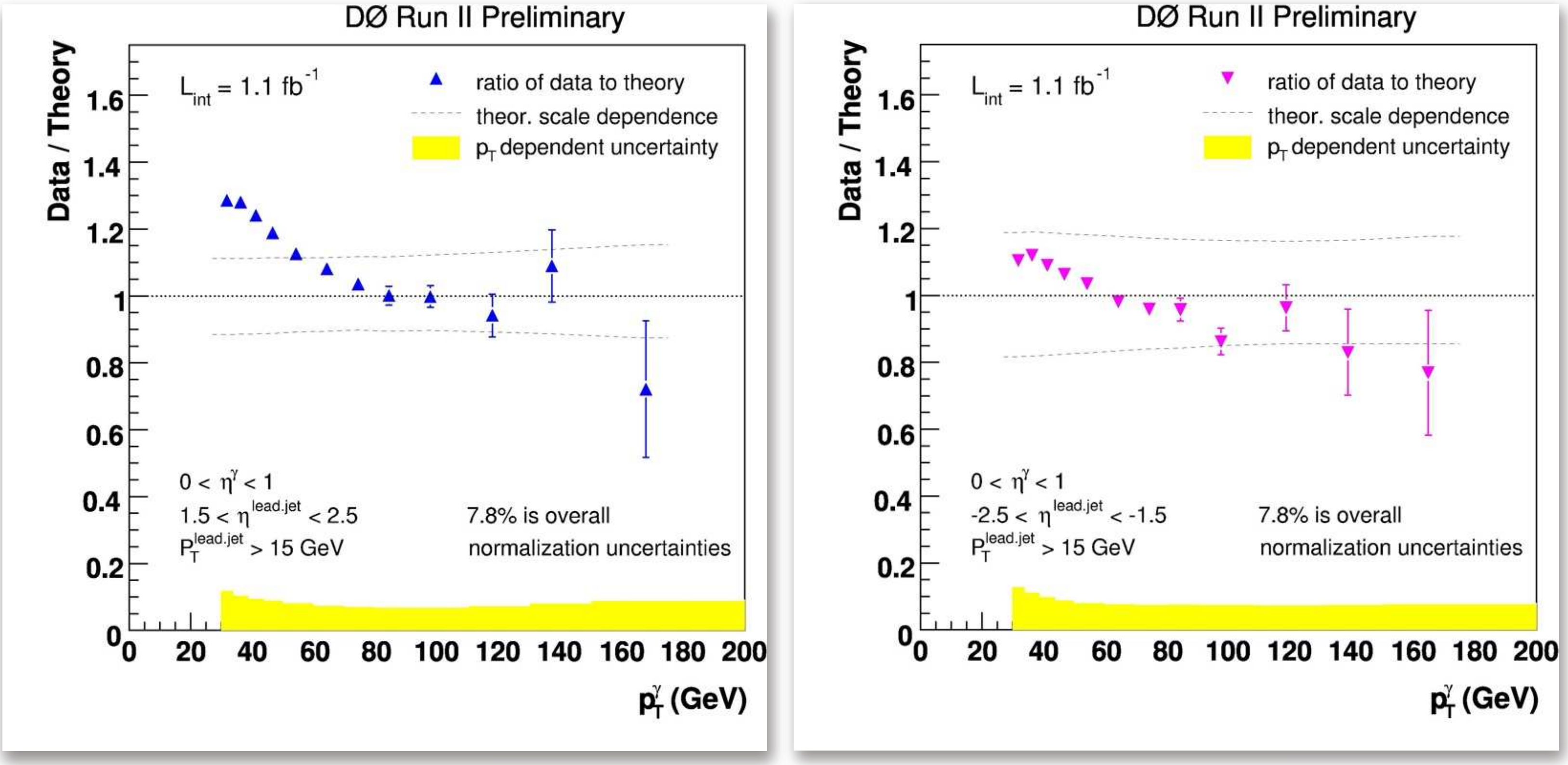




- shown here only statistical and correlated uncertainties
- the cross sections show deviation from the theory predictions for pT>100 GeV for these two regions where jets are located in the central rapidity region
- shape of the data-to-theory above has the same structures as observed earlier in UA2, CDF, and D0 RunII (erratum is to be released soon) in inclusive photon measurements

Prompt photon + jet production: D0

Comparison with theory



- deviation is also seen for pT<50GeV for Region 3
- same shape, although within error bands in Region 4

Prompt photon production at RHIC (PHENIX)

RHIC pp collisions at $\sqrt{s} = 200$ GeV :

- cover intermediate energy range between fixed target and Tevatron collider energies
- use different isolation method $\Rightarrow$ study systematics
- possibility to measure photon-hadron azimuthal correlations
  exp: J. Jin (PHENIX), May ’07
  theo: Pietrycki, Szczurek, June ’07 + this conference
- baseline to study direct photons in relativistic heavy ion collisions

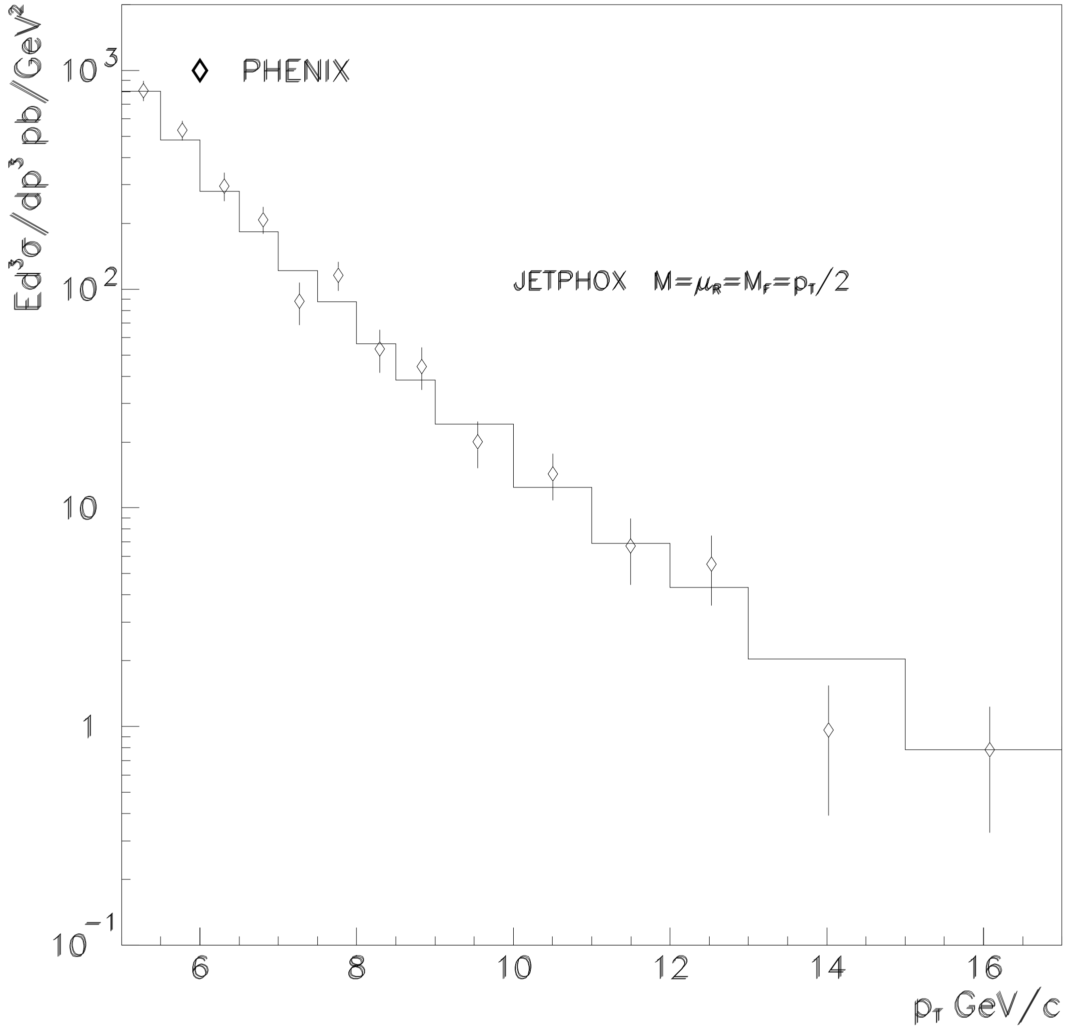
Prompt photon production at RHIC

heavy ion collisions:

photons emitted at different stages:

- in initial state, well described by NLO pQCD
- in the hot, dense medium (mostly thermal emission)
- interaction of photons from jet fragmentation with dense matter
- in the final hadron-gas phase

Prompt photon production at RHIC (PHENIX)



Prompt photons in hadronic collisions

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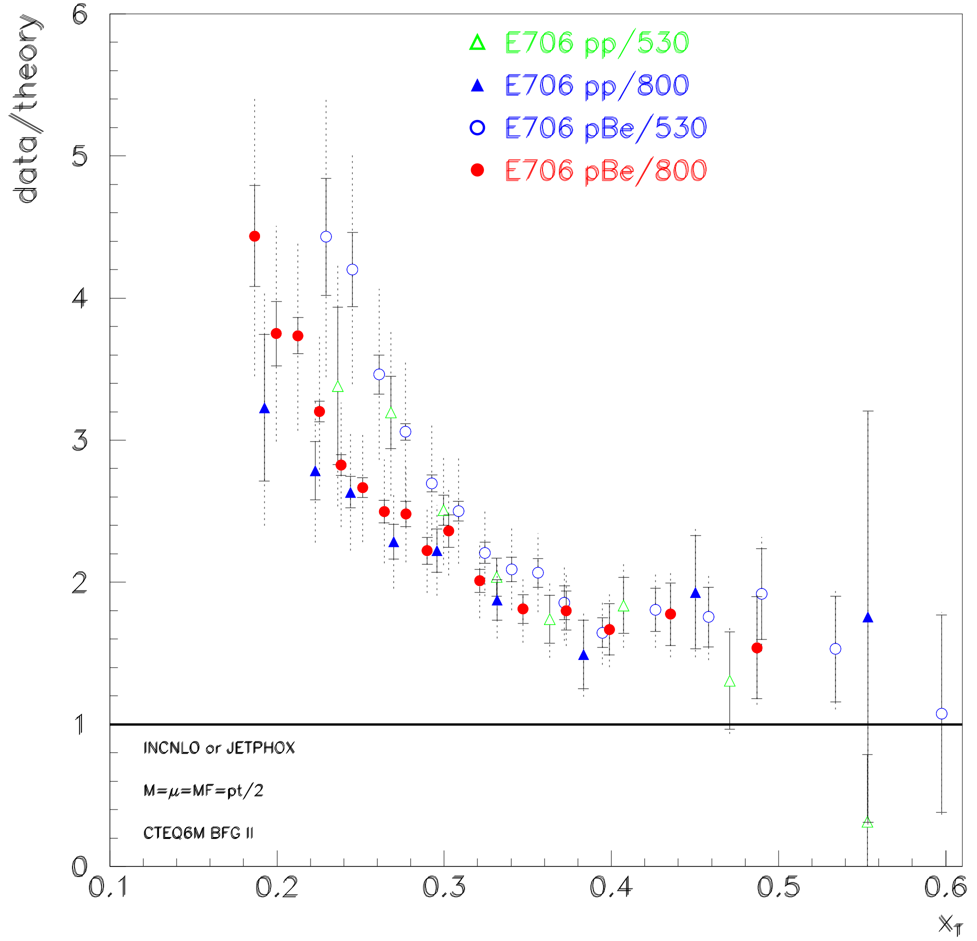
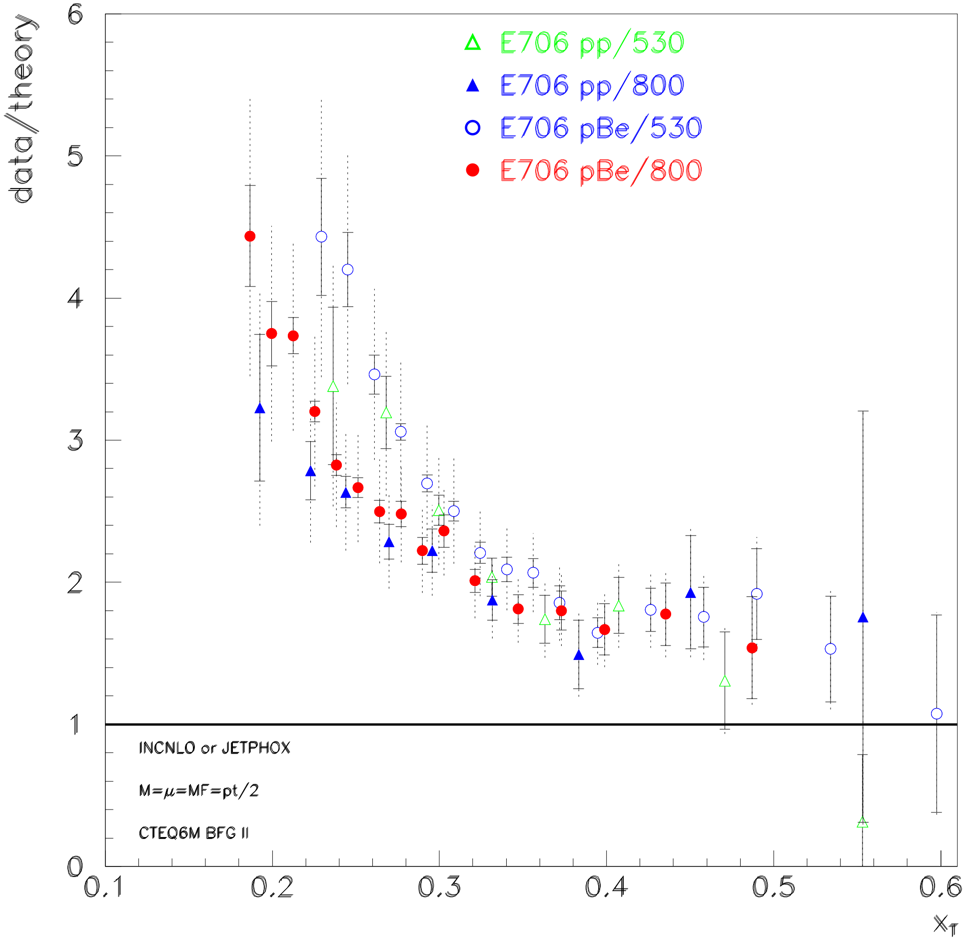


Prompt photons in hadronic collisions

- wasn't there a problem ?
- disagreement of NLO theory and data in normalisation and shape?
- large effects from multiple soft gluon emission, necessity for large "intrinsic k_T" to account for these plus non-perturbative effects ?



Prompt photons in hadronic collisions

theory efforts: resummation for $x_T = 2p_T/\sqrt{s} \to 1$:

Laenen, Oderda, Sterman ’98

Catani, Mangano, Nason, Oleari, Vogelang ’99

Kidonakis, Owens 2000

Sterman, Vogelsang 2001

De Florian, Vogelsang 2005 (frag)

effect of resummation extends down to $x_T \gtrsim 10^{-1} \Rightarrow$ covers fixed target range

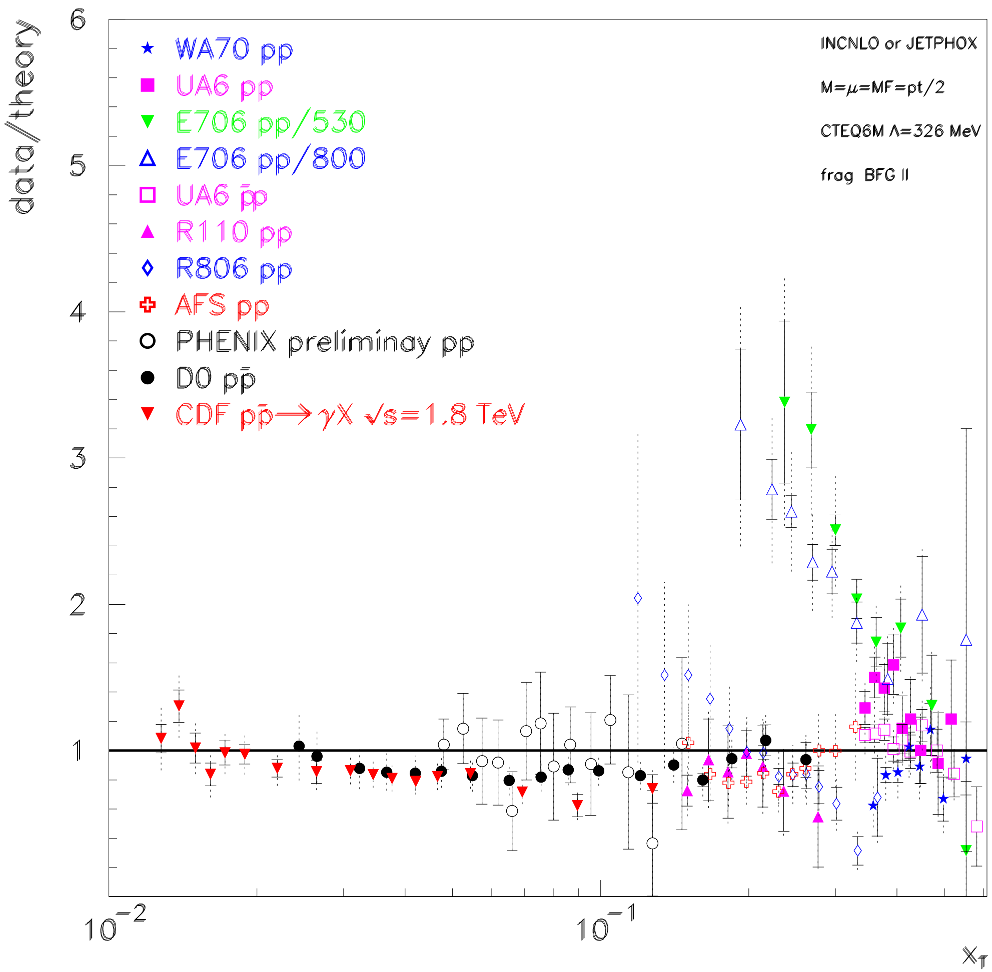
joint resummation of threshold and recoil effects (multiple soft-gluon emission): Sterman, Vogelsang 2005

result:

- scale dependence considerably reduced
- recoil effects in inclusive γ production relatively small
- agreement with almost all prompt photon data

Prompt photons in hadronic collisions

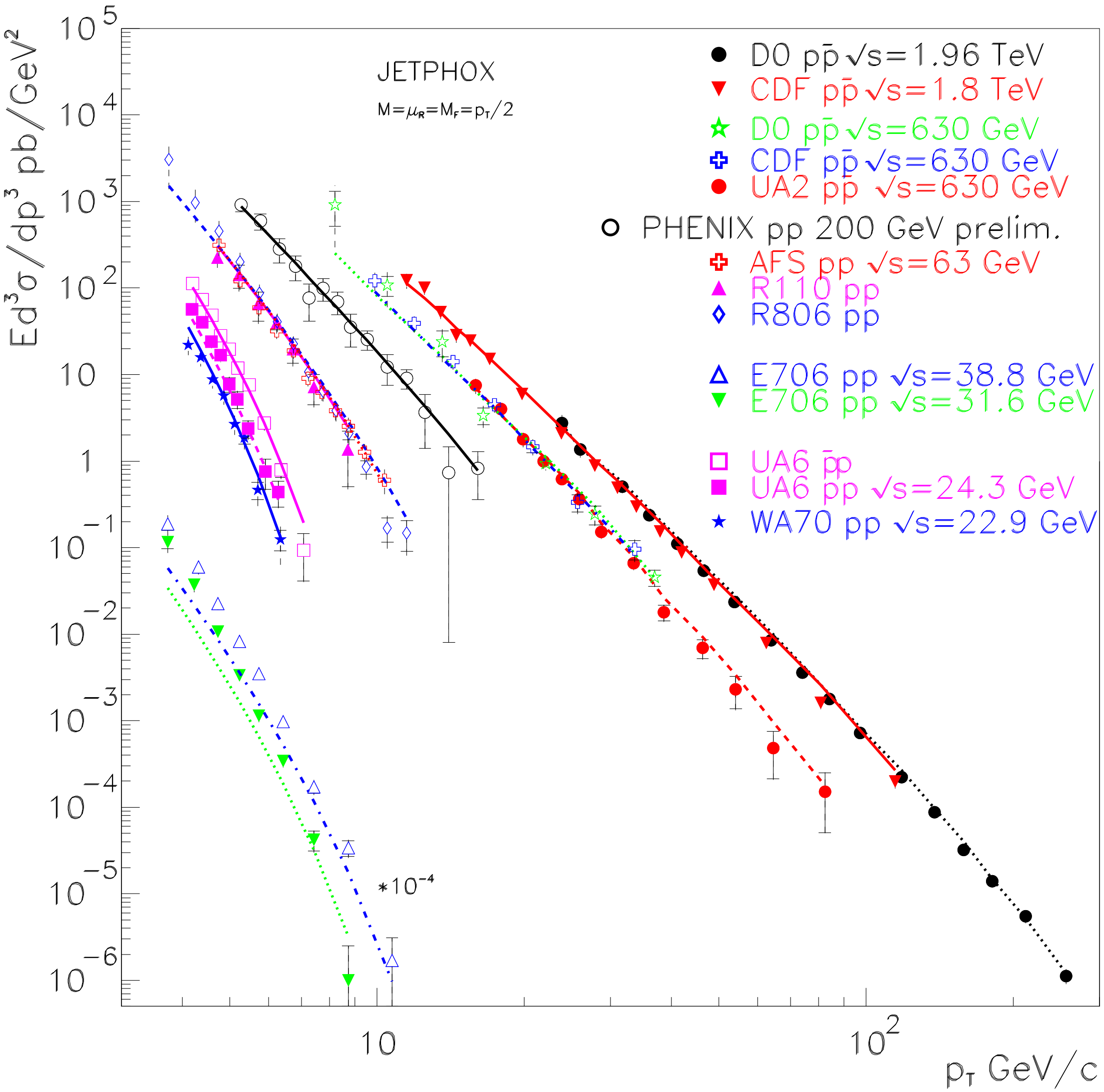
data/theory from fixed target to collider energies



Aurenche, Fontannaz,

Guillet, Pilon, Werlen 06

Prompt photons in hadronic collisions



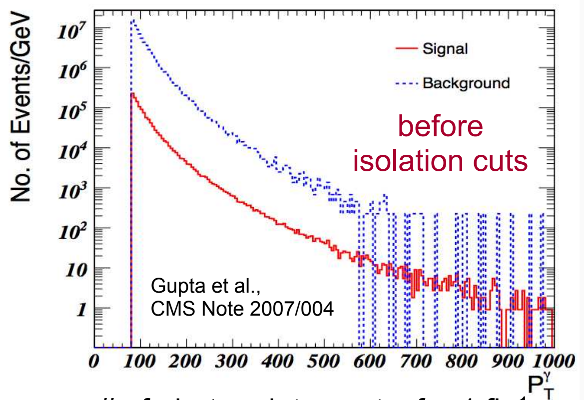
Aurenche, Fontannaz, Guillet, Pilon, Werlen 06

Photon plus jet production: LHC

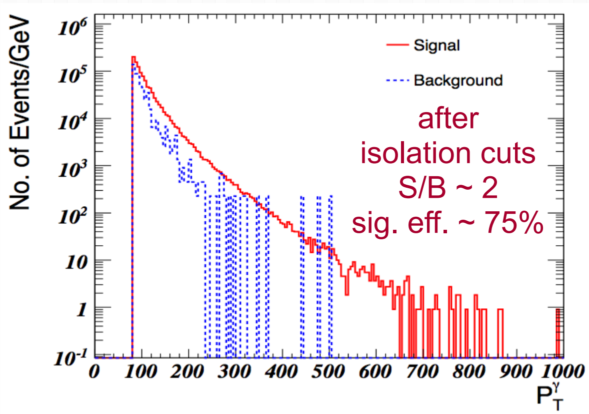
Prompt Photon Production

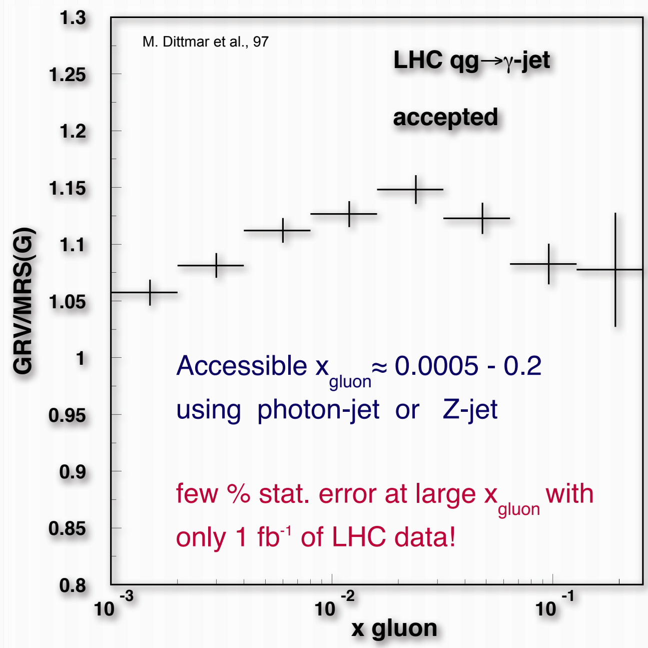
ETH Institute for Particle Physics

- it's all about isolation
- reduce background by combination of isolation requirements using Tracker, ECAL and HCAL



# of photon+jet events, for 1 fb^{-1}





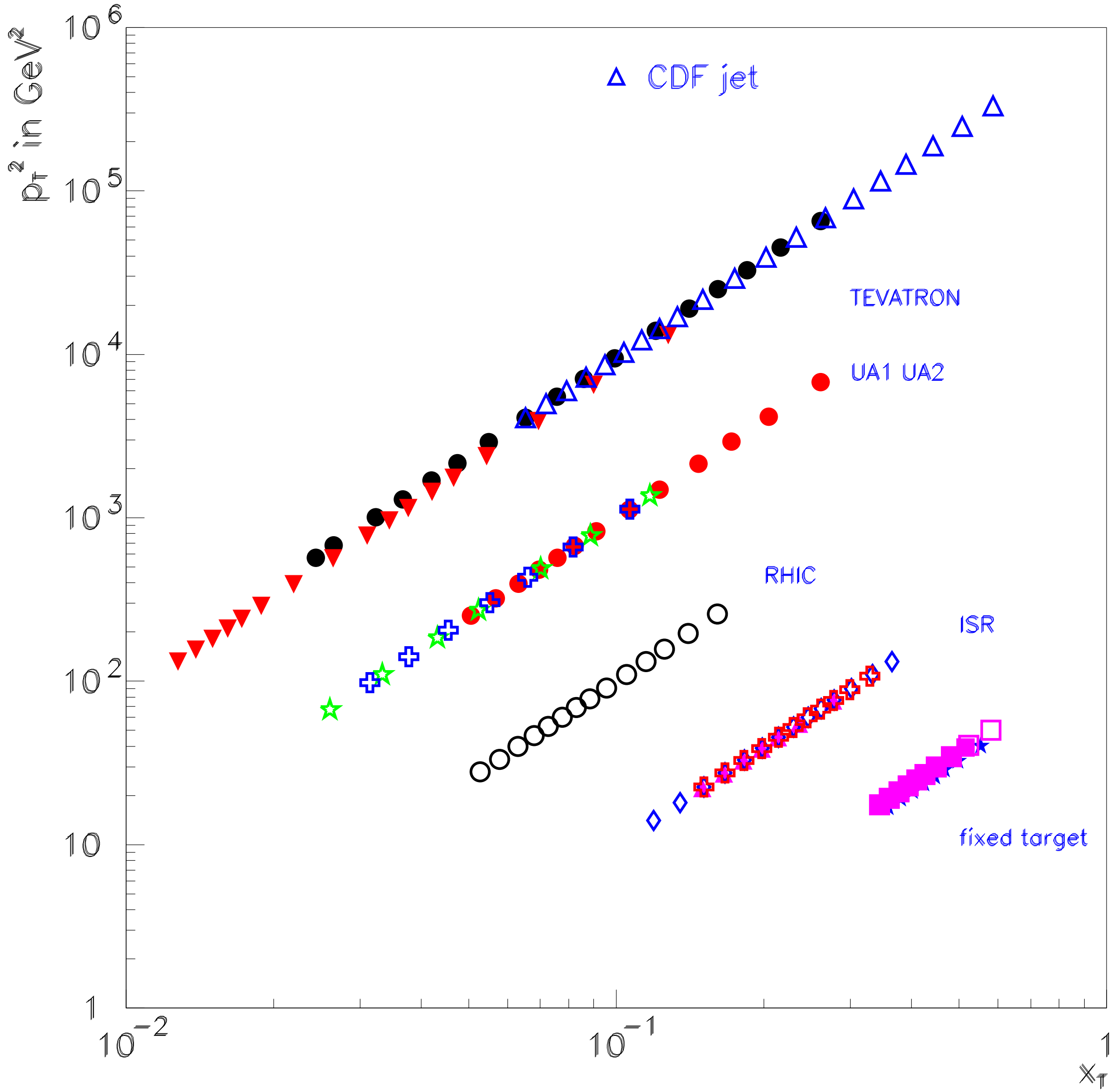
- constrain gluon pdf
- energy scale well controlled by photon
- other issues there: interplay real radiation - fragmentation
- Z+jet : smaller rate, best possible prediction needed

June 07 Dissertori 8

G. Dissertori

Les Houches 07

kinematical range covered by photon/jet data



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  NLO QCD does a pretty good job where it is expected to do so !
- very recent D0 data on photon+jet show interesting features
- photons will play a crucial role at the LHC and the ILC (resp. PLC, hopefully !)

additional slides

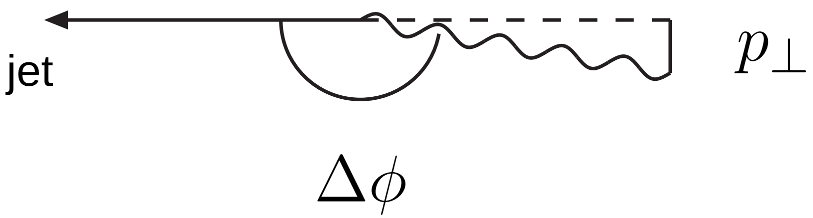
EPHOX compared to ZEUS data

study of intrinsic $\langle k_T \rangle$ (parton transverse momenta in proton)

$\langle k_T \rangle$ - sensitive observables:

$p_\perp$ photon momentum component $\perp$ to jet direction

$\Delta\phi$ azimuthal acollinearity between photon and jet

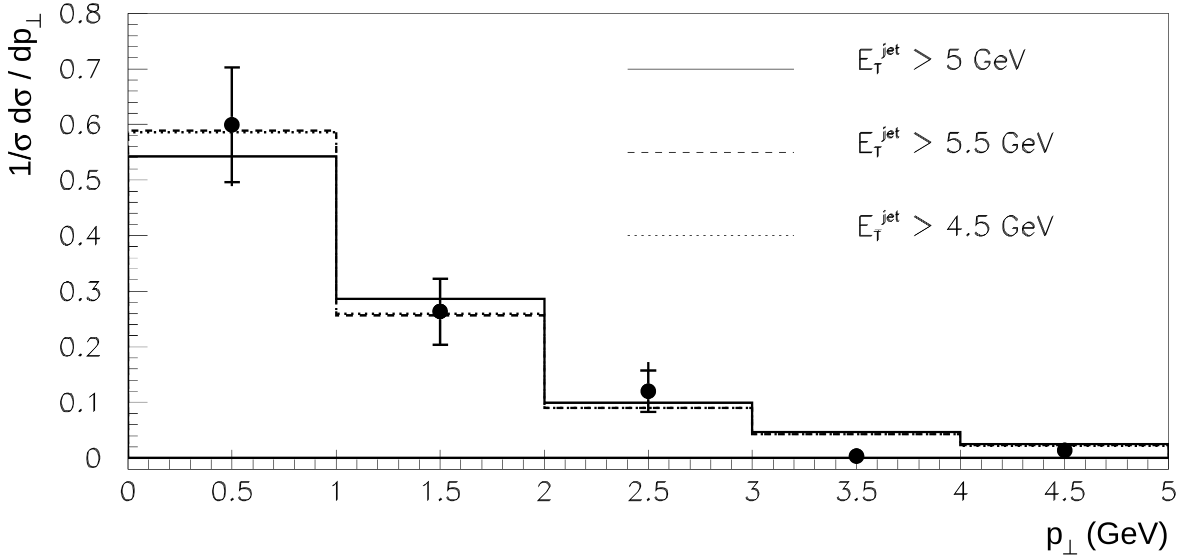


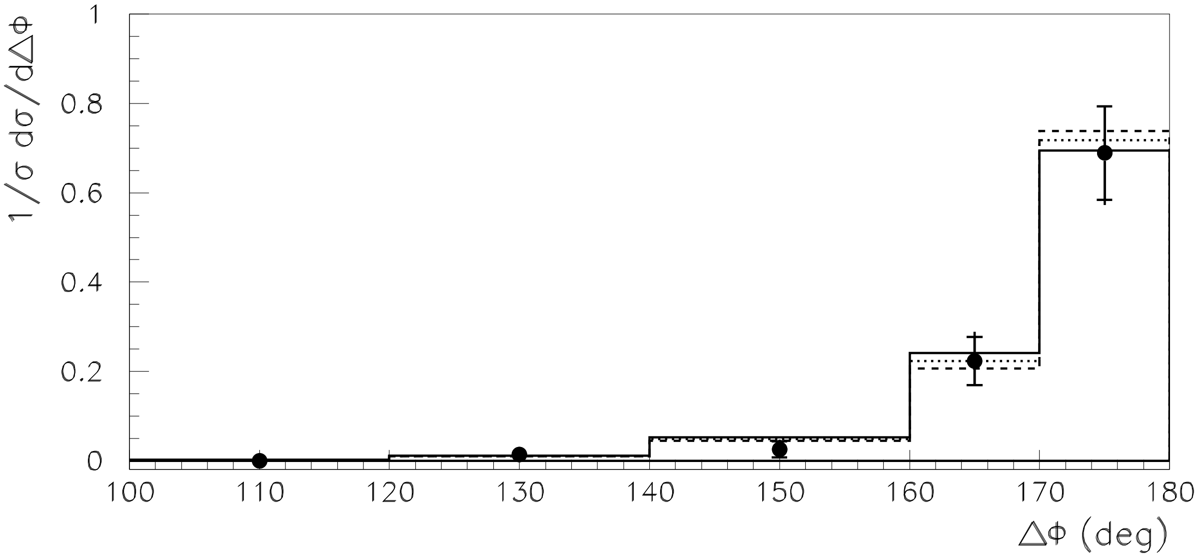
ZEUS :

to suppress contributions to $\langle k_T \rangle$ from resolved photon : $x_\gamma^{obs} > 0.9$

normalized cross sections to minimize calibration uncertainties

ZEUS data vs Ephox





NLO describes data w

without extra $\langle k_T \rangle$

observable x^p, x^γ

$$x^p_{obs} = \frac{p_T\,\mathrm{e}^{\eta} + p_T^{jet}\,\mathrm{e}^{\eta^{jet}}}{2E^p}$$

$$x^\gamma_{obs} = \frac{p_T\,\mathrm{e}^{-\eta} + p_T^{jet}\,\mathrm{e}^{-\eta^{jet}}}{2E^\gamma}$$

$$x^{p,\gamma}_{LL} = \frac{p_T\,(\mathrm{e}^{\pm\eta} + \mathrm{e}^{\pm\eta^{jet}})}{2E^{p,\gamma}}$$