Laboratoire d'Annecy-Le-Vieux de Physique THéorique

# Perturbative photons in pp (and AA) collisions at RHIC energies

Monique Werlen (LAPTH)



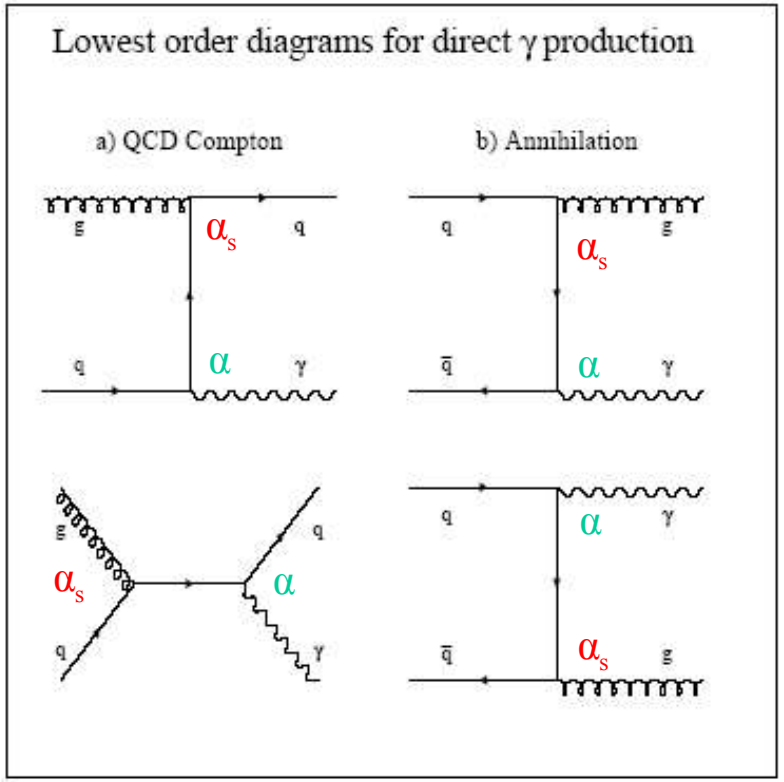
# Why are direct photons interesting?

- Photons produced in the partonic interaction probe QCD dynamic without hadronic complications

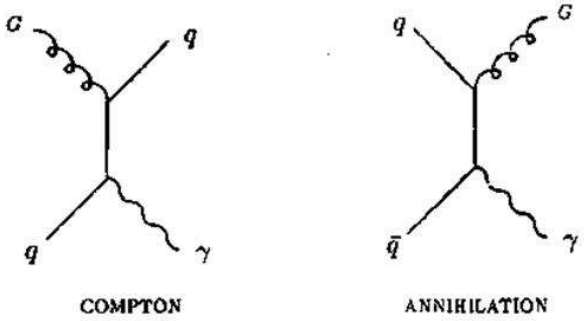
- $\gamma$ – quark: coupling precisely known (QED)

Two processes at lowest order:

- QCD Compton : sensitive to gluon distribution in the hadron
- Annihilation: sensitive to the QCD running coupling constant $\alpha_s$

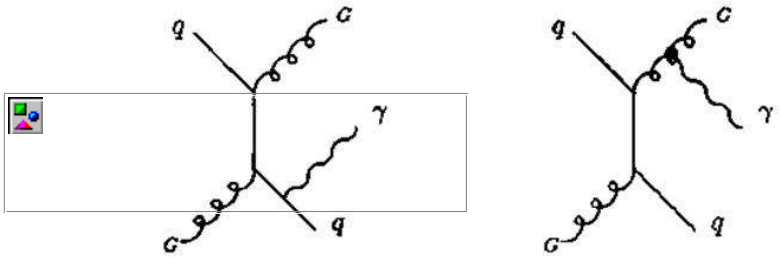





BORN APPROXIMATION

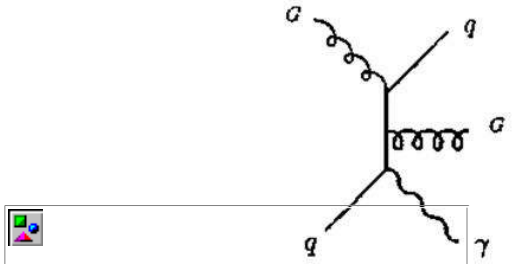
$O(\alpha\alpha_s)$



EXAMPLES OF BREMSSTRAHLUNG DIAGRAMS

$O(\alpha_s^2\alpha(1/\alpha_s+g))$

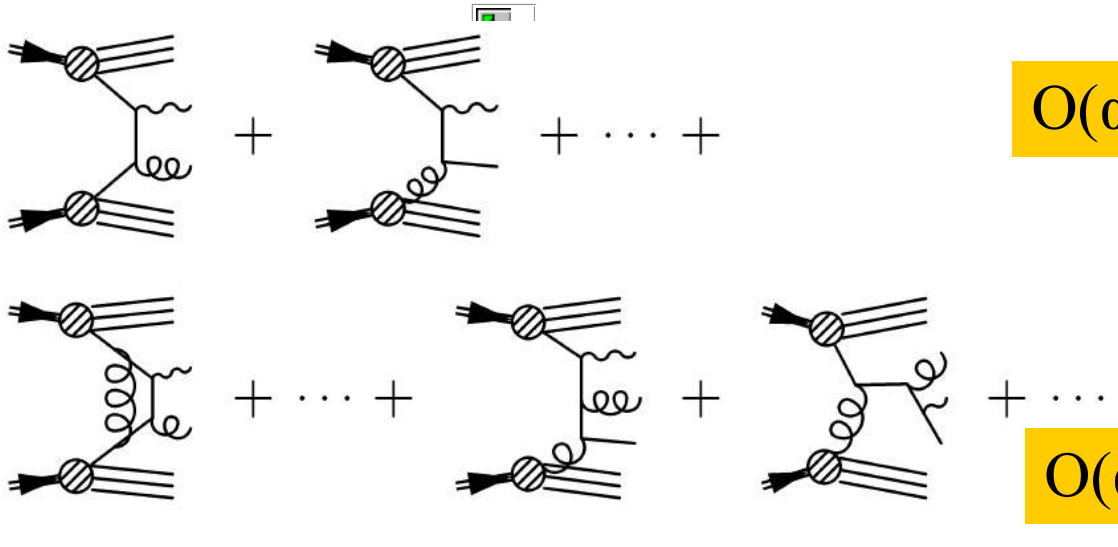
Important at high √s and low $p_t$
(NLO ACFGP NPB399,34)

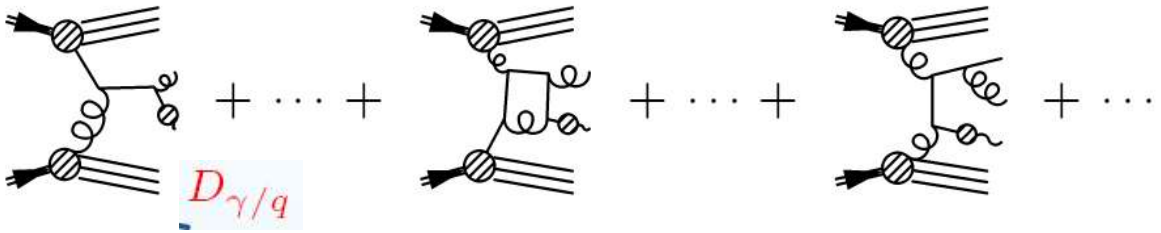


EXAMPLES OF HIGHER ORDER DIAGRAMS

$O(\alpha\alpha_s^2)$

# Direct photon production




Only the sum σ(D) + σ(F) is a physical observable

# Direct photon production

## NLO codes

| | type of code | Direct | Fragmentation |
|---|---|---|---|
| INCNLO (*) | I/FO | NLO | NLO |
| Vogelsang, Gordon (*) | I/FO | NLO | NLO |
| Owens et al. (*) | G/FO | NLO | LO |
| Frixione, Vogelsang | G/FO | NLO | LO |
| JETPHOX (*) | G/FO | NLO | NLO |

I : Inclusive
G : Generator
FO : Fixed Order

(*) http://wwwlapp.in2p3.fr/lapth/PHOX_FAMILY/main.html

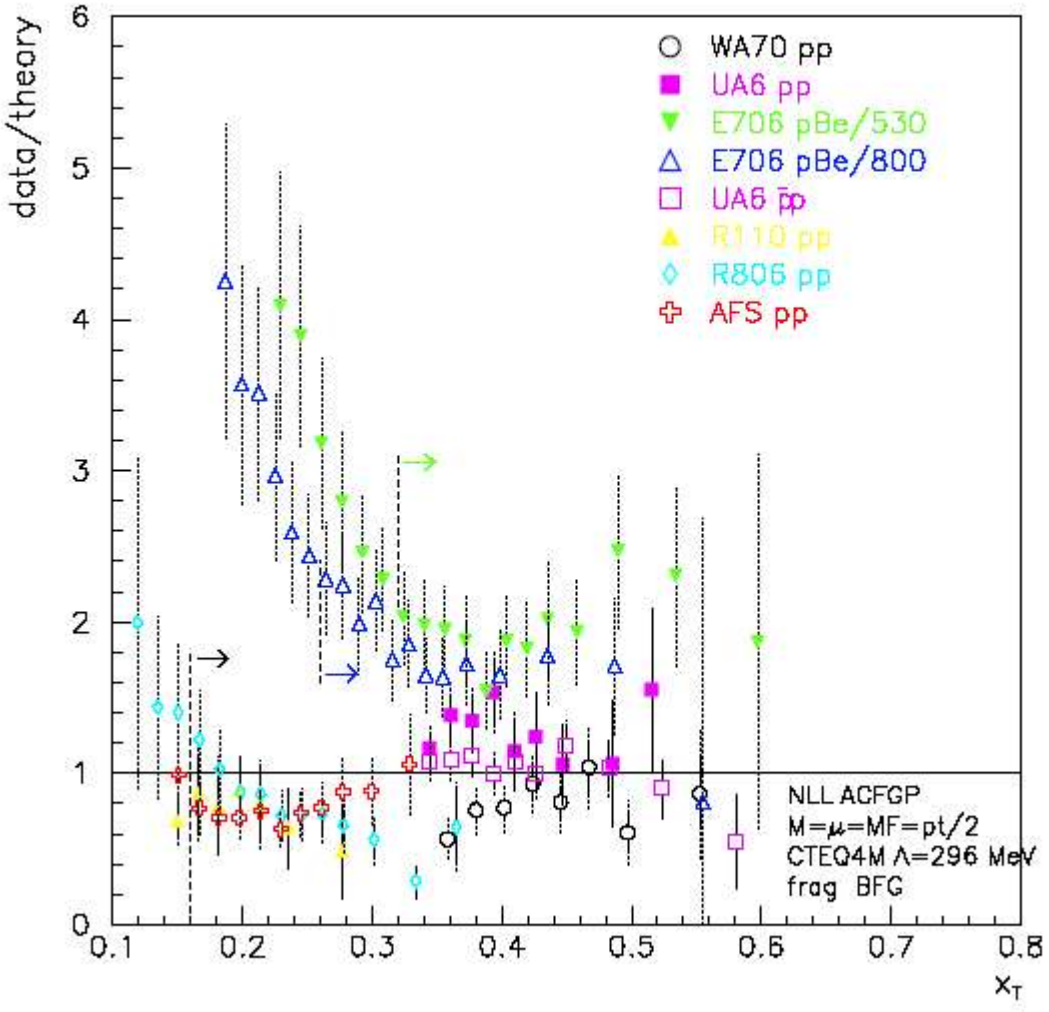
Threshold resummation: (*) Catani et al.
(*) Kidonakis, Owens

Guillet, DIS04



# World Data vs NLO QCD

**INCNLO**




$$pp, \bar{p}p \rightarrow \gamma X$$

23 GeV ≤√s≤ 63 GeV

*Aurenche, Fontannaz, Guillet, Kniehl, Pilon, M.W. Eur. Phys. JC9,107 (1999)*

Possible experimental problems?

Or theory misses the $\sqrt{s}$ dependence?

Arrows: perturbative predictions "STABLES" vs scale

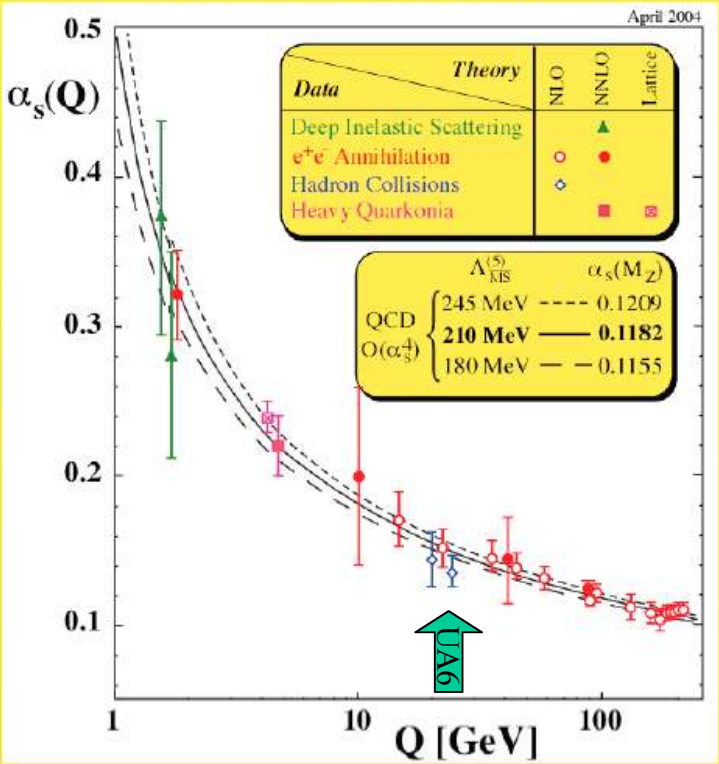
But NLO QCD has been proved correct!
including for direct photon
at least for the measurement of $\alpha_s$
(UA6 Phys.Lett. B452,201)

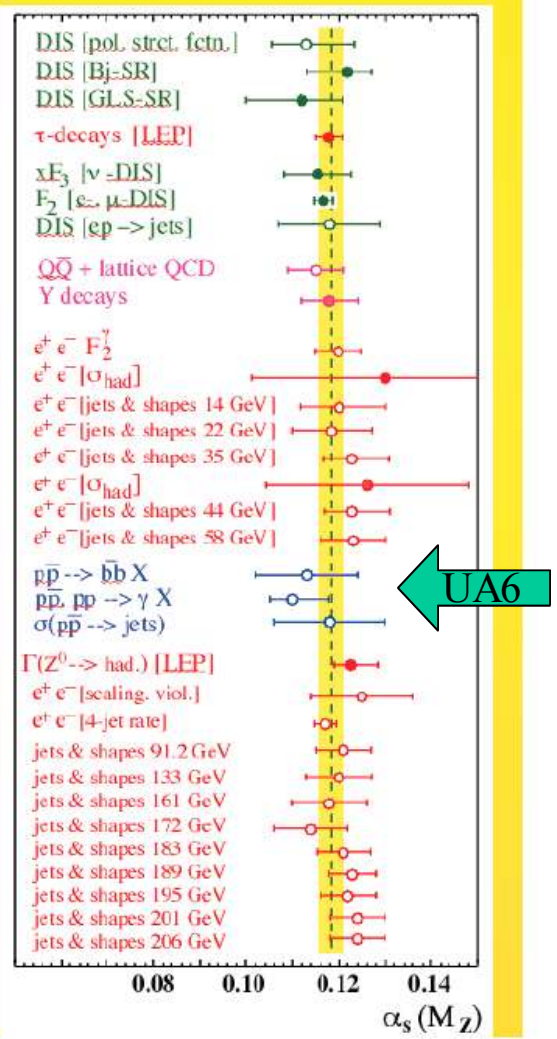
See Bethke plots (hep-ex/0407021)
on next slide



# Presented by David Gross (S.Bethke, hep-ex/0407021)

**THE DISCOVERY, EXPLORATION, VERIFICATION AND UNDERSTANDING OF QCD IS DUE TO THE REMARKABLE WORK OF MANY EXPERIMENTERS AND THEORISTS OVER 40 YEARS !**



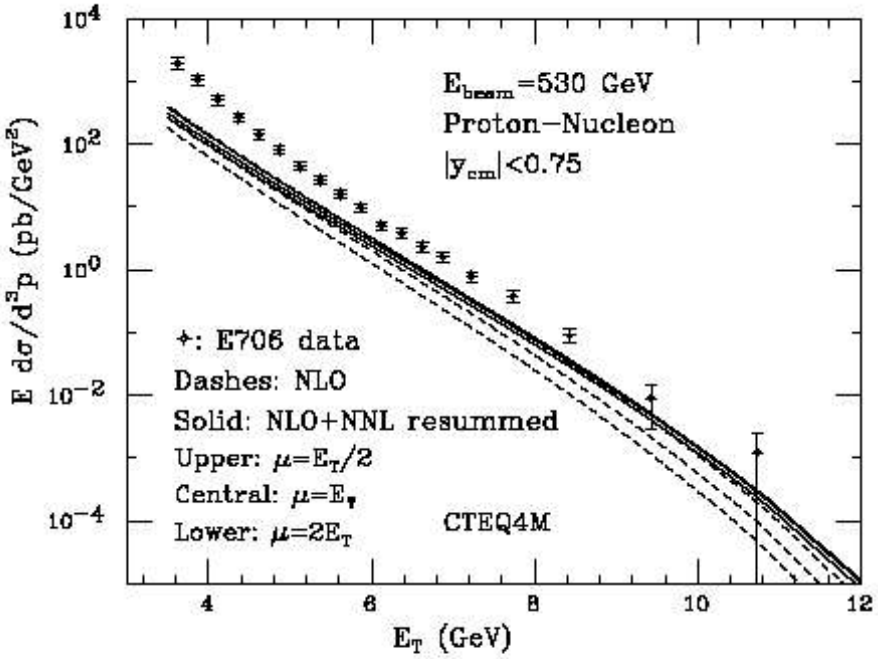



# Soft gluons resummation and E706

(hep-ph/9903436)

Catani, Mangano, Nason, Oleari, Vogelsang

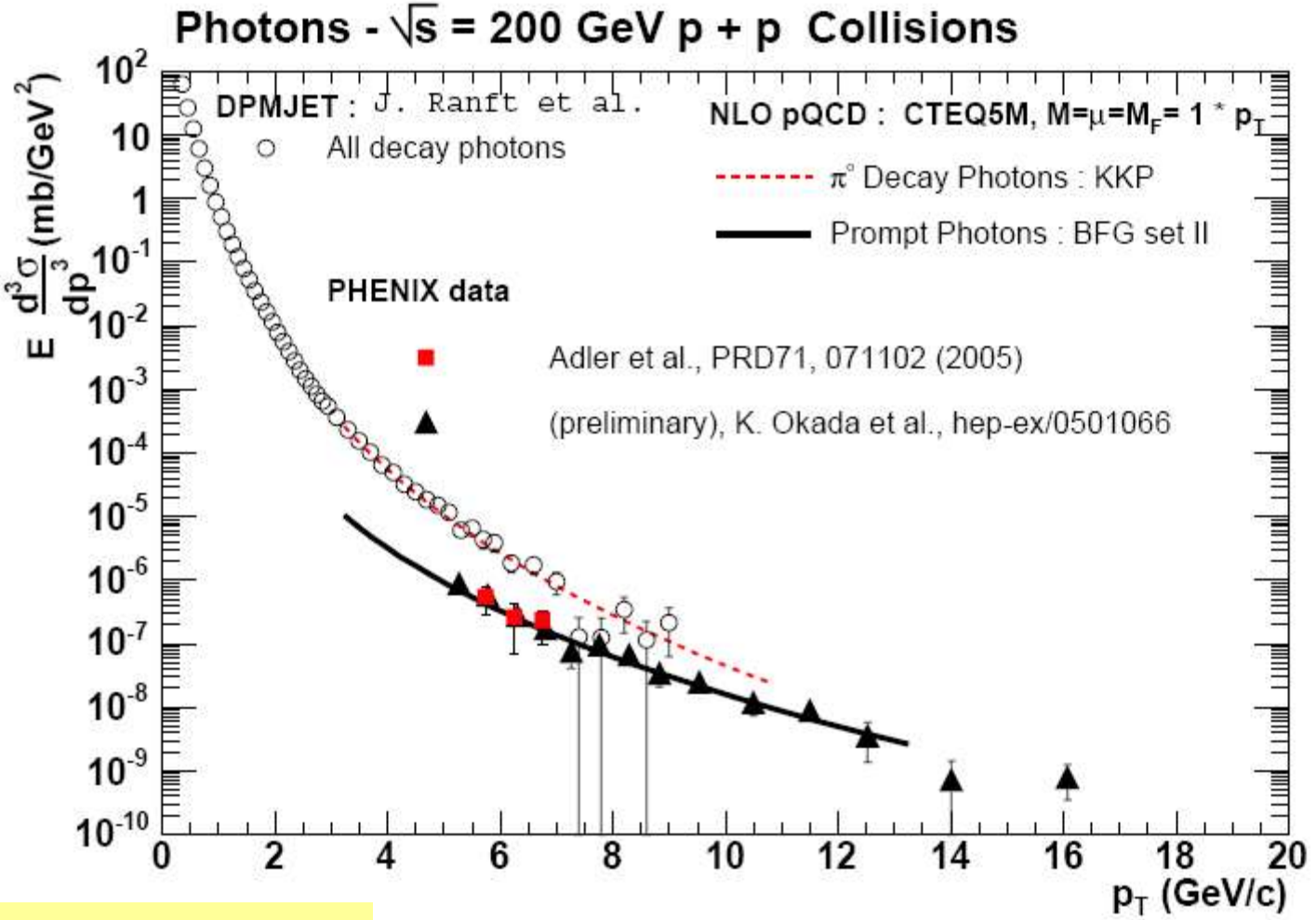
Additional contributions to solve the Pb? NNLres




- Takes into account soft gluons at large $x_T$
- Reduces scale dependence
- Small corrections for scales set to $p_T/2$

Main corrections at large $x_T$ (decreasing with scale)
does not help data/theory at small $x_T$
i.e. does not solve the "$k_T$ problem"

# New PHENIX data



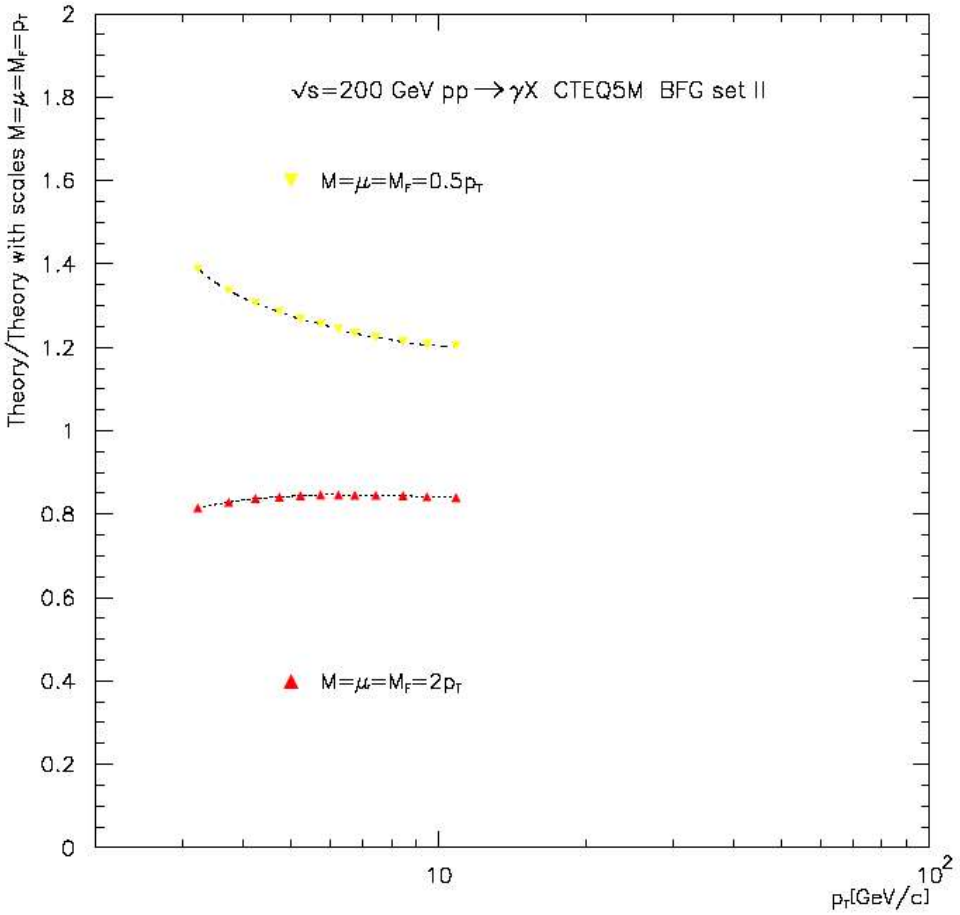

**INCNLO**

NLO QCD fine

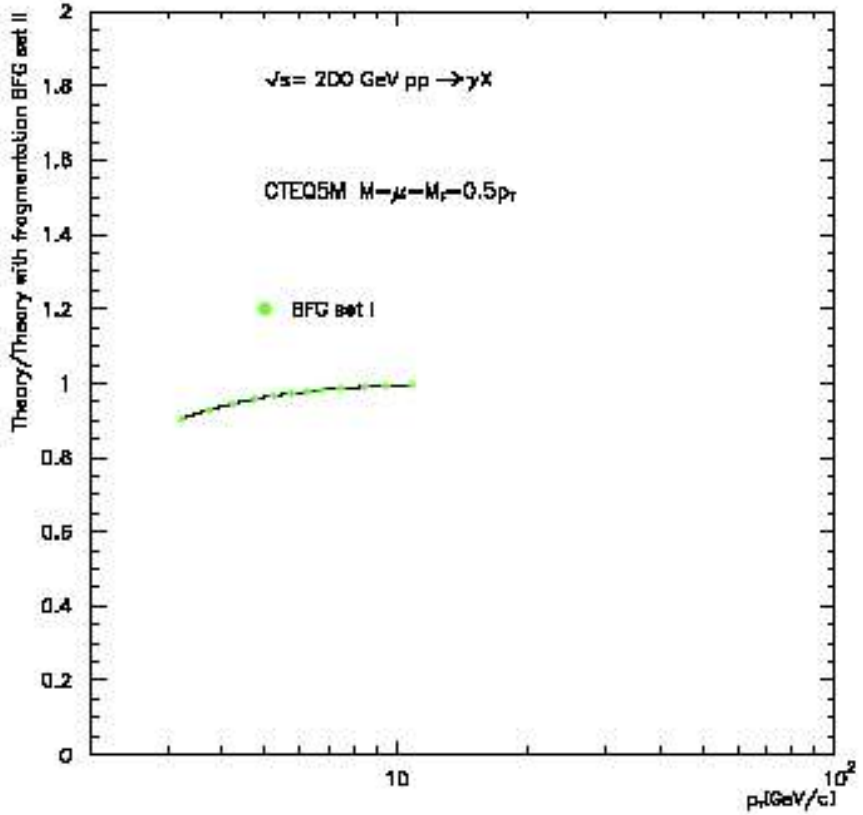
fig. 4.34 from hep-ph/0311131 CERN YR

# Theoretical uncertainties at RHIC energy

## Scales uncertainty



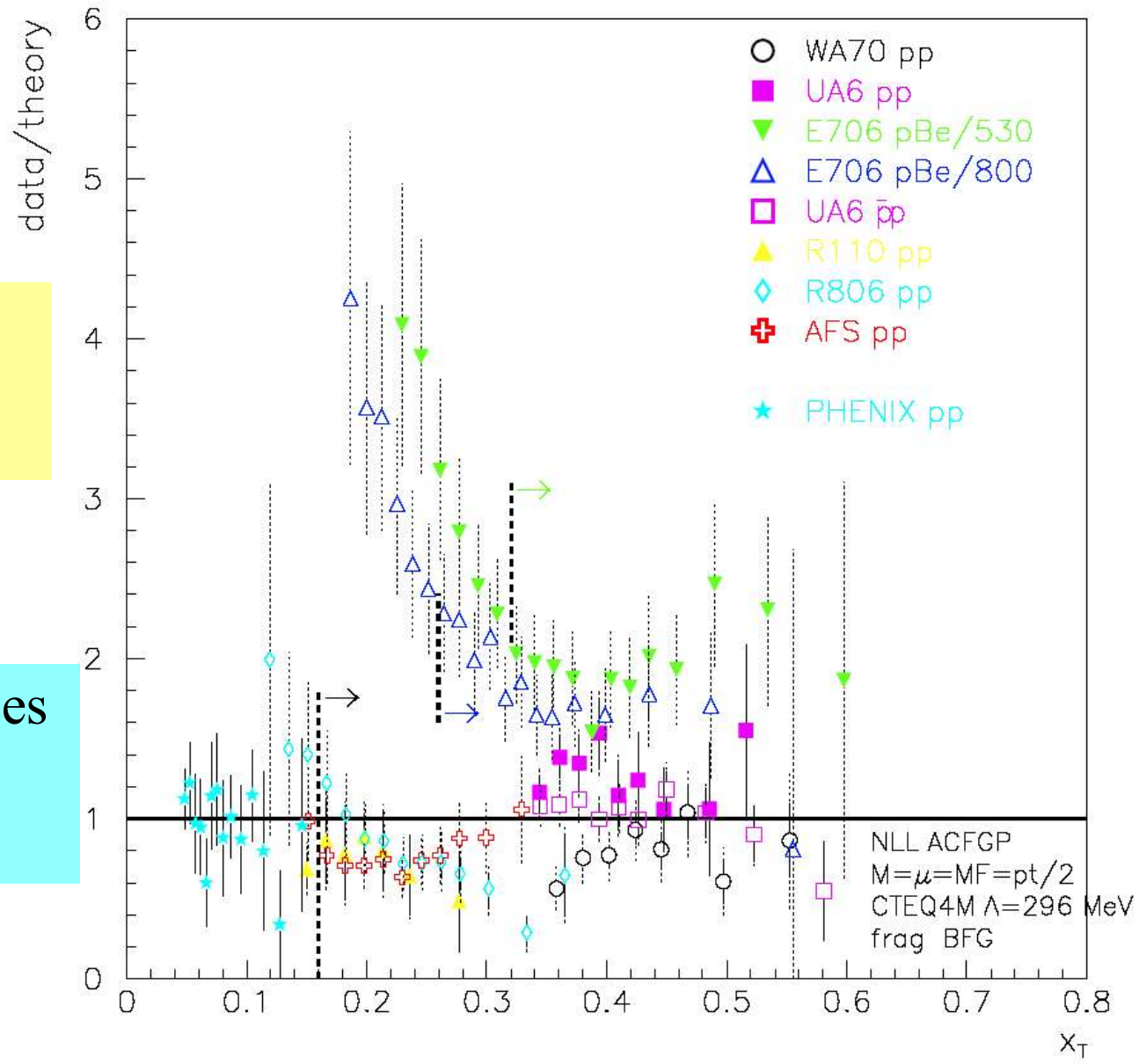

## Fragmentation BFGI/BFGII



Aurenche et al Eur. Phys. JC9,10(1999)

Updated with PHENIX prelim. K.Odaka et al. hep-ex/0501066 Stat. Err. only

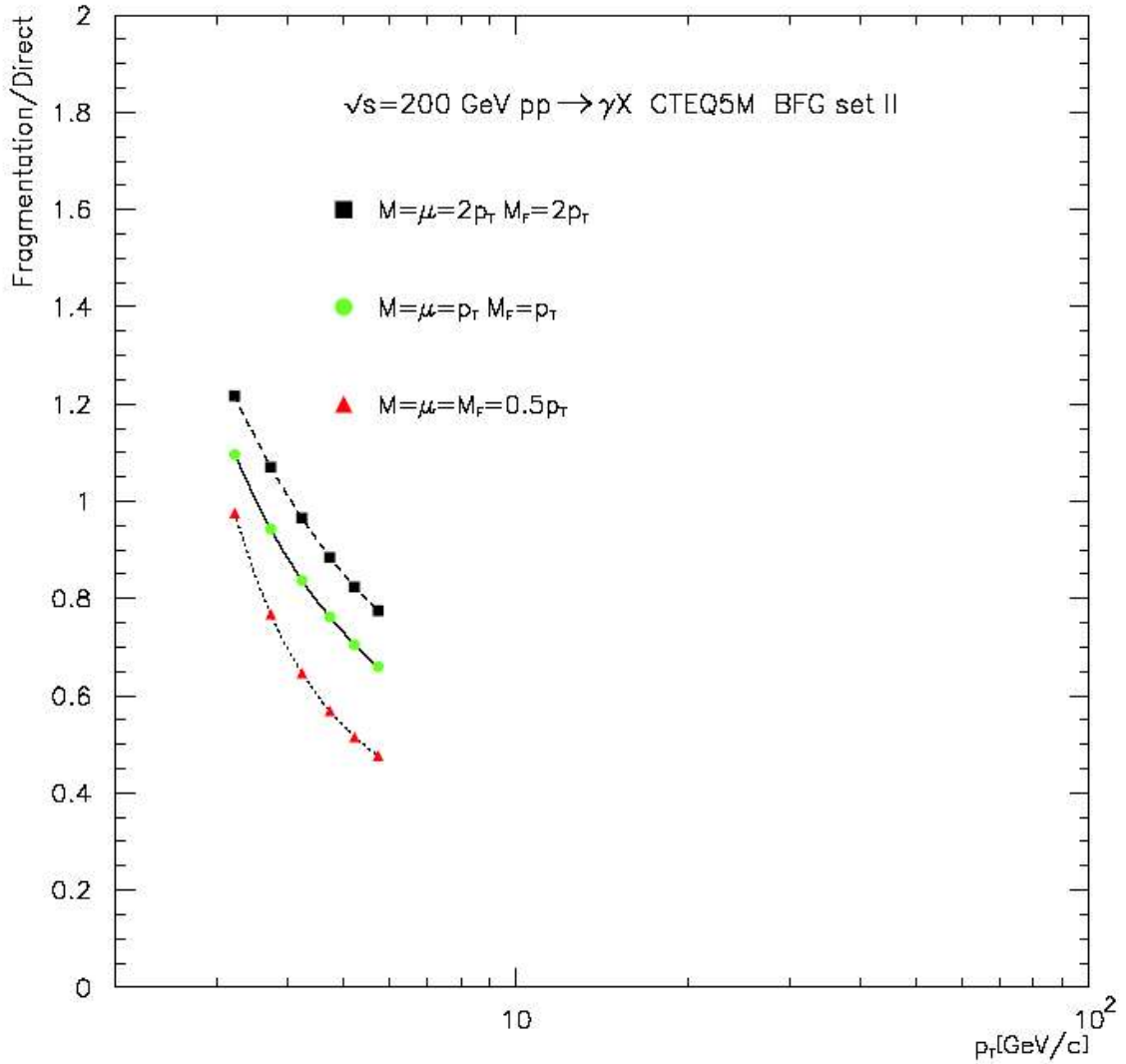
Phenix data clarifies the data/theory puzzle



# Remark:

Fragmentation vs direct depends on scales (specially M_F)

One cannot evaluate "the fraction due to fragmentation"!



# The PHOX Family

NLO event generators (parton level)
for large $p_t$ PHOton (hadron ou jet) X-sections

http://www.lapp.in2p3.fr/lapth/PHOX_FAMILY/main.html

P.Aurenche, T.Binot, M.Fontannaz, J.Ph.Guillet, G.Heindrich, E.Pilon, M.W.

DIPHOX:

$h_1 h_2 \rightarrow \gamma\ \gamma + X$

$h_1 h_2 \rightarrow \gamma\ h_3 + X$

$h_1 h_2 \rightarrow h_3 h_4 + X$

JETPHOX:

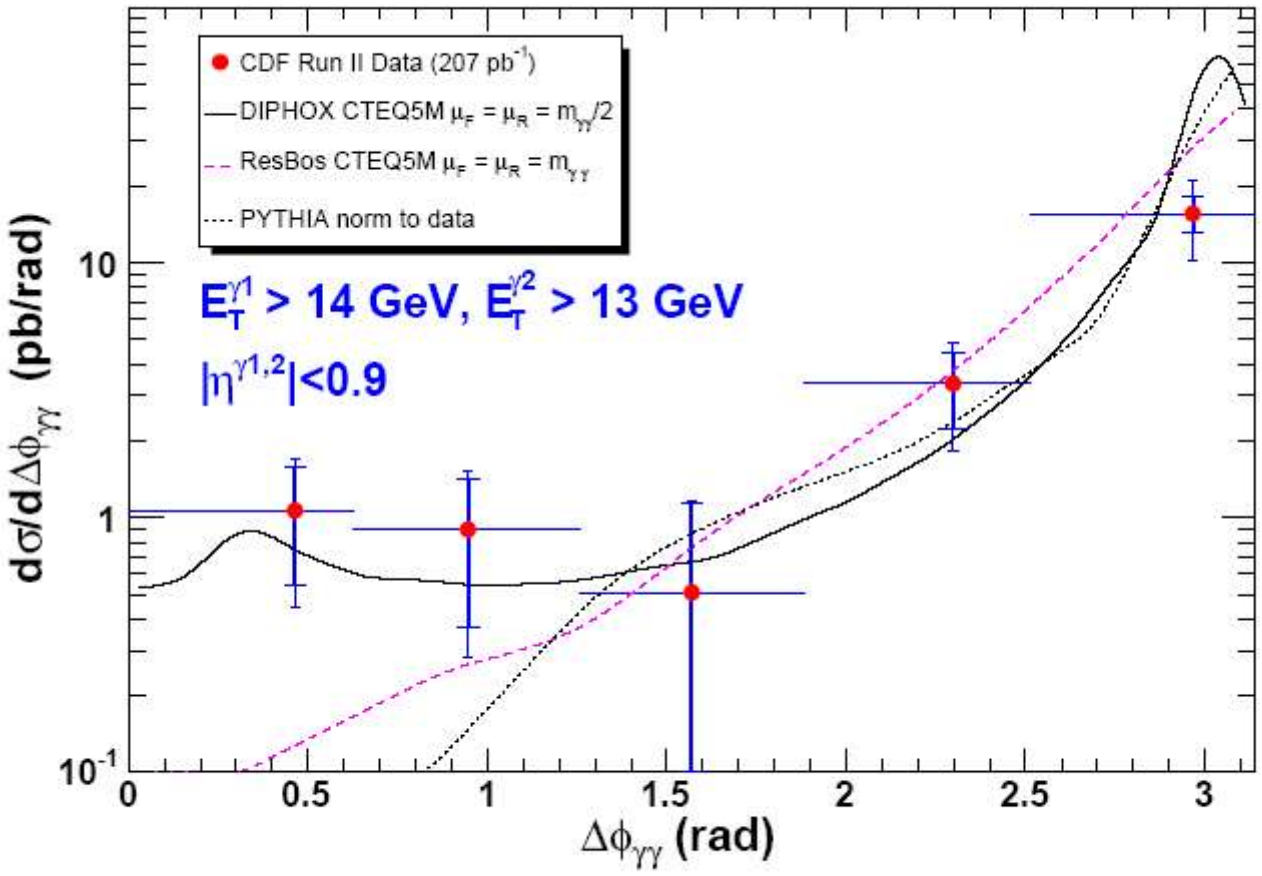
$h_1 h_2 \rightarrow \gamma + X$

$h_1 h_2 \rightarrow h_3 + X$



# DIPHOX vs CDF data azimuthal angle

[hep-ex/0412050]

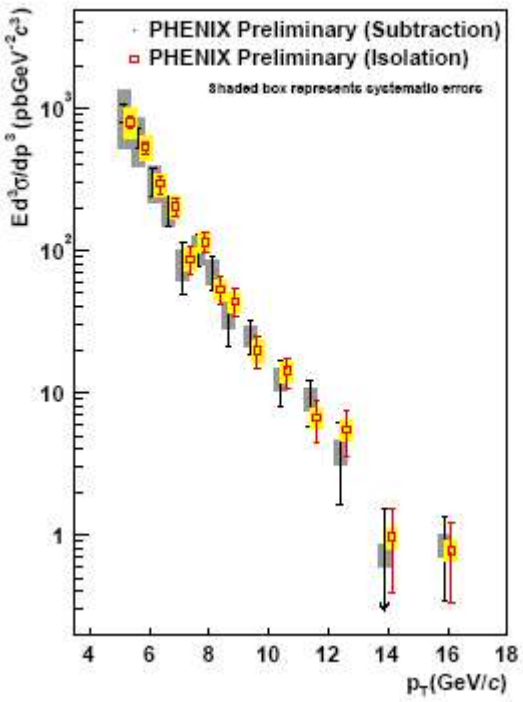


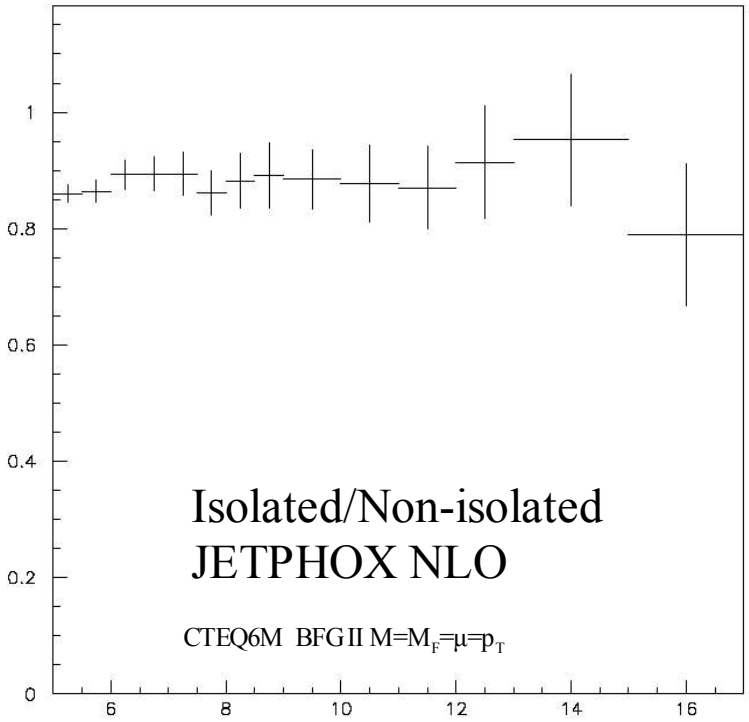

**Remark: resummation needed near π**

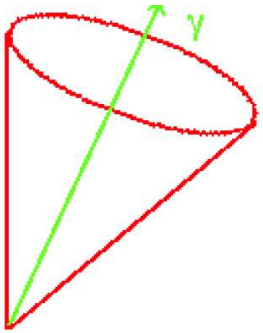


# Photon Isolation

K.Odaka hep-ex/0501066




in a cone around photon with:

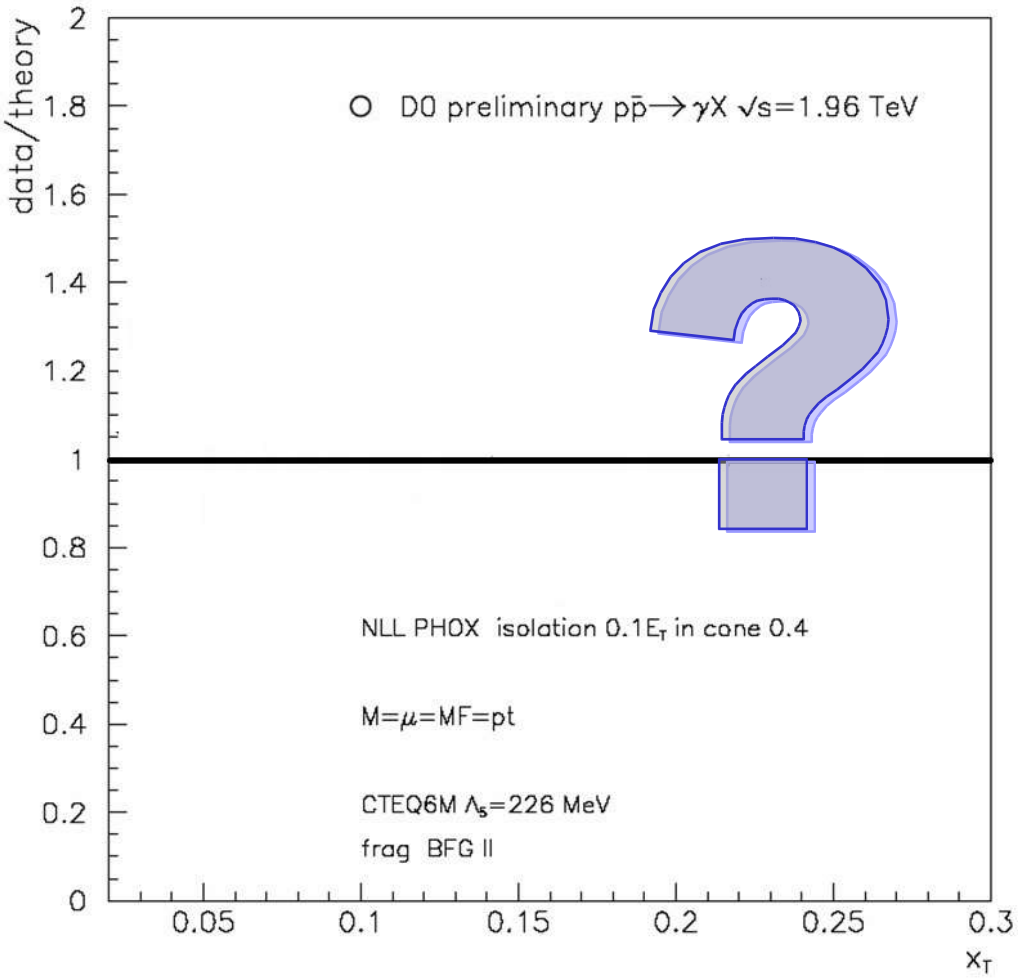
R $\sqrt{\Delta\eta^2 + \Delta\phi^2}$ =0.5

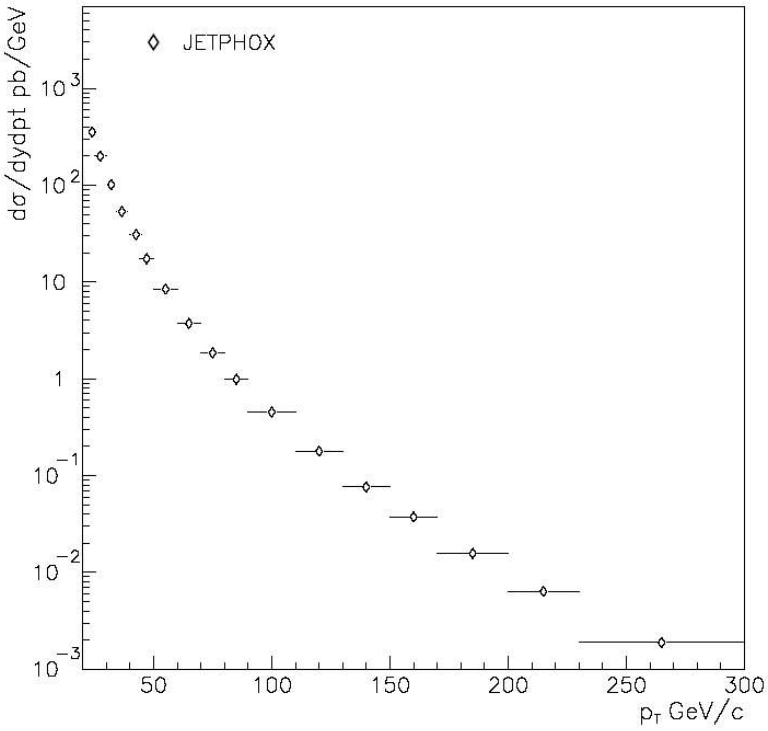
=

$E_T$ (parton) ≤ $E_T$ max =0.1$E_\gamma$

Isolated vs non-isolated: not much difference in data and in theory

# D0 very preliminary



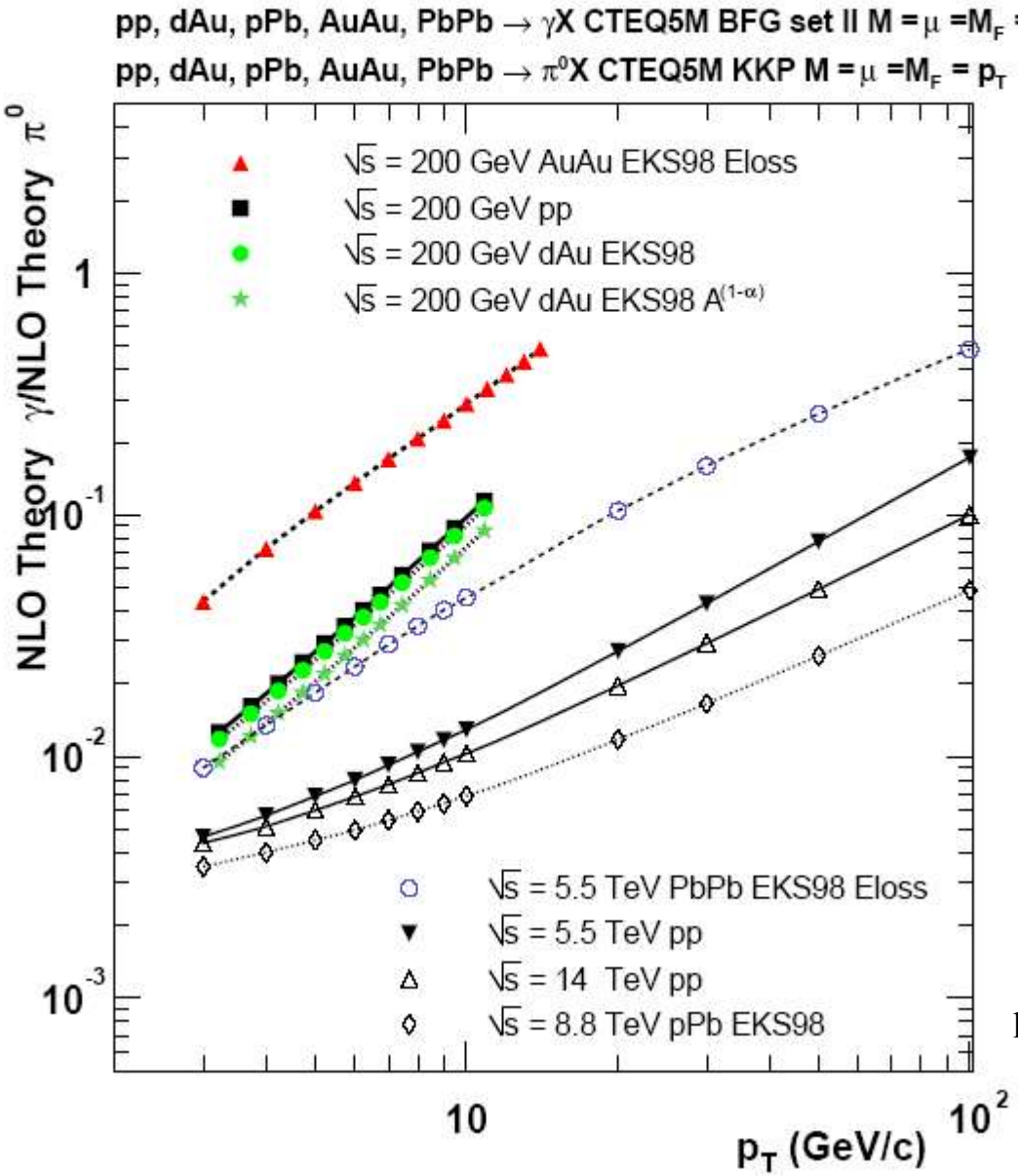



# Prompt Photons in AA collisions

hep-ph/0311131 CERN YR

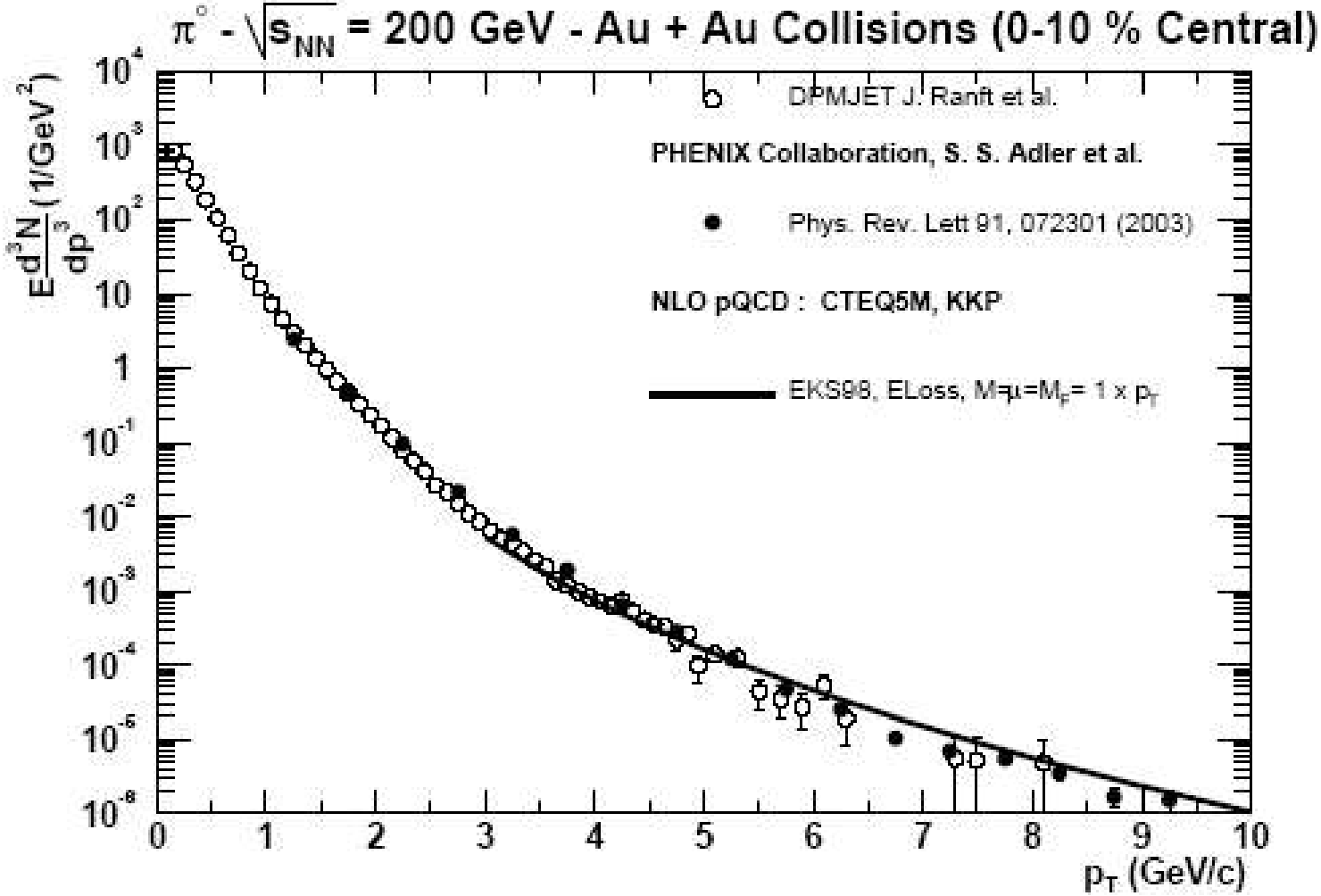
Includes:
- EKS98 : Structure Function modification
  in heavy nucleus (anti-)shadowing in Au
- parton energy loss





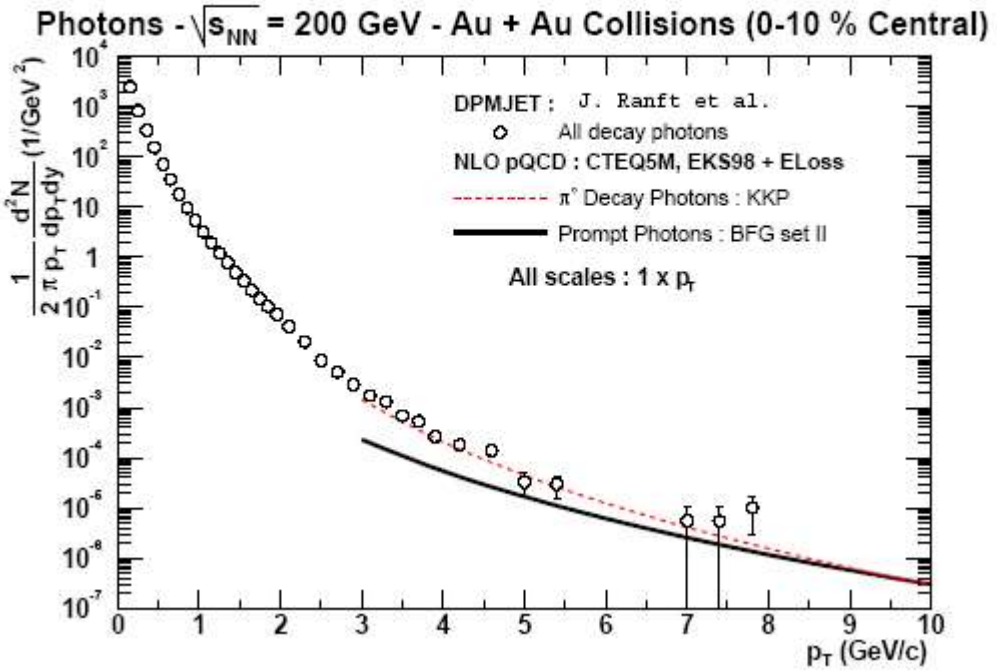

**γ/π⁰**

hep-ph/0311131 CERN YR




hep-ph/0311131 CERN YR



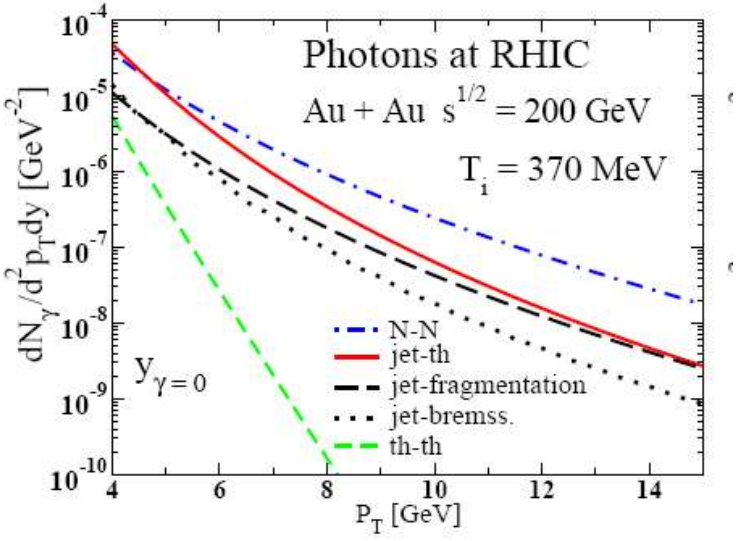



hep-ph/0311131 CERN YR

Not complete… for example:
no photon emission through Compton and Annihilation of partons in the plasma (jet-thermal in next slide)
no induced bremsstrahlung by the medium (next slide)

Simon Turbide[1], Charles Gale[1], Sangyong Jeon[1,2] and Guy D. Moore[1]

:hep-ph/0502248

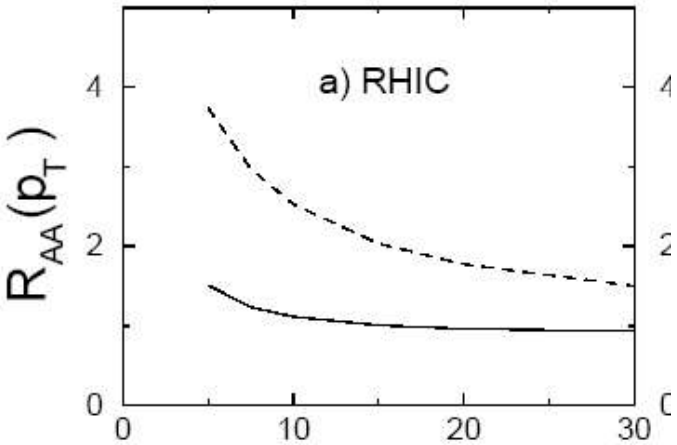



**All scales pt, CTEQ5M,**
**LO with k-factors from NLO**
**for direct and bremss**
**N-N:direct**

B.G. Zakharov

Induced γ bremsstrahlung

:hep-ph/0405101




---Without gluon suppression

# Summary

## Direct photon production

pp collisions:

- PHENIX preliminary data seems to favor the NLO QCD theory (like most of ISR and fixed target data)
- Isolation criteria induce only small effects

AA collisions:

- A lot of small effects to take into account… Work in progress

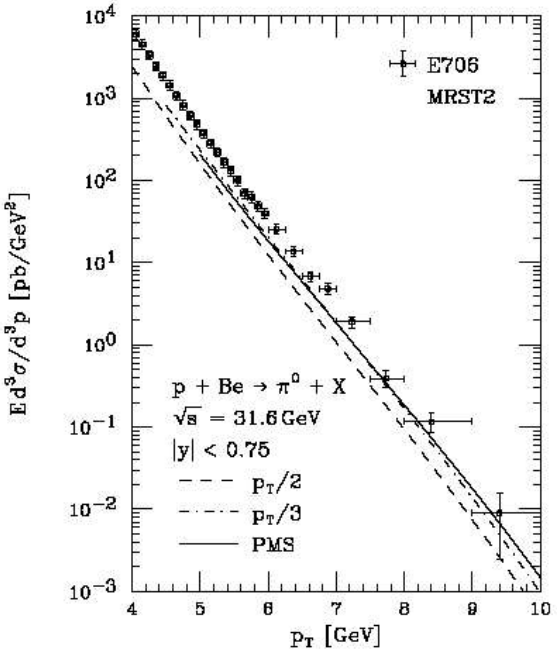


# $\pi^0$ phenomenology



# $\pi^0$ phenomenology (hep-ph/9910252)

(Aurenche, Fontannaz, Guillet, Kniehl, M.W.)




$z = E_{\pi^0}/E_{fragmenting\ parton} \approx 0.8$

BKK fragmentation (no constraining data for $z > 0.8$)

ln(1.-z) resummation not available

partly approximated with PMS scales

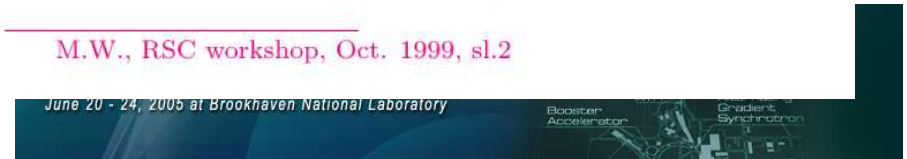
NLL $p_T/2 < \mu = M = M_F < p_T/3$ close to NLL PMS

with scales $p_T/3$ : Data/theory ($x_T > 0.3$) $\approx 1.4$ (UA6),

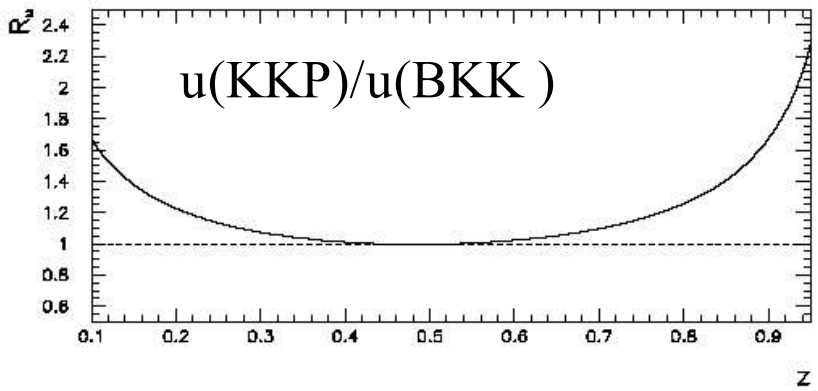
$\approx 1.7$ (WA70), $\approx 1.7$ (E706/530),$\approx 1.2$ (E706/800)

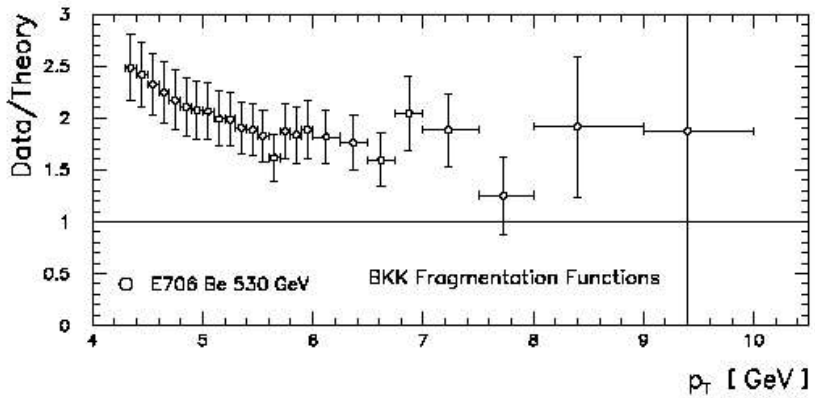
Data sets compatible.

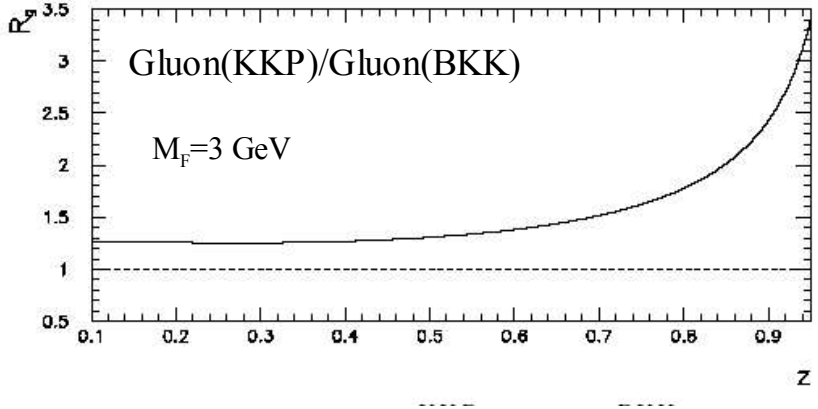
M.W., RSC workshop, Oct. 1999, sl.2

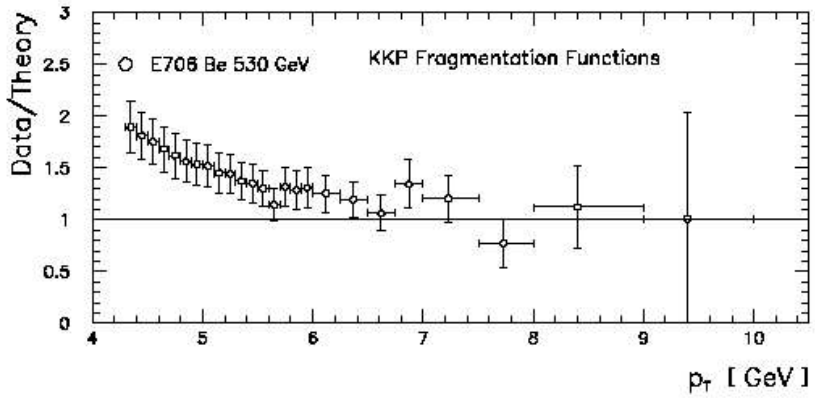


# Production of pions E706 data vs NLO theory




Better fit with fragmentation functions KKP than BKK

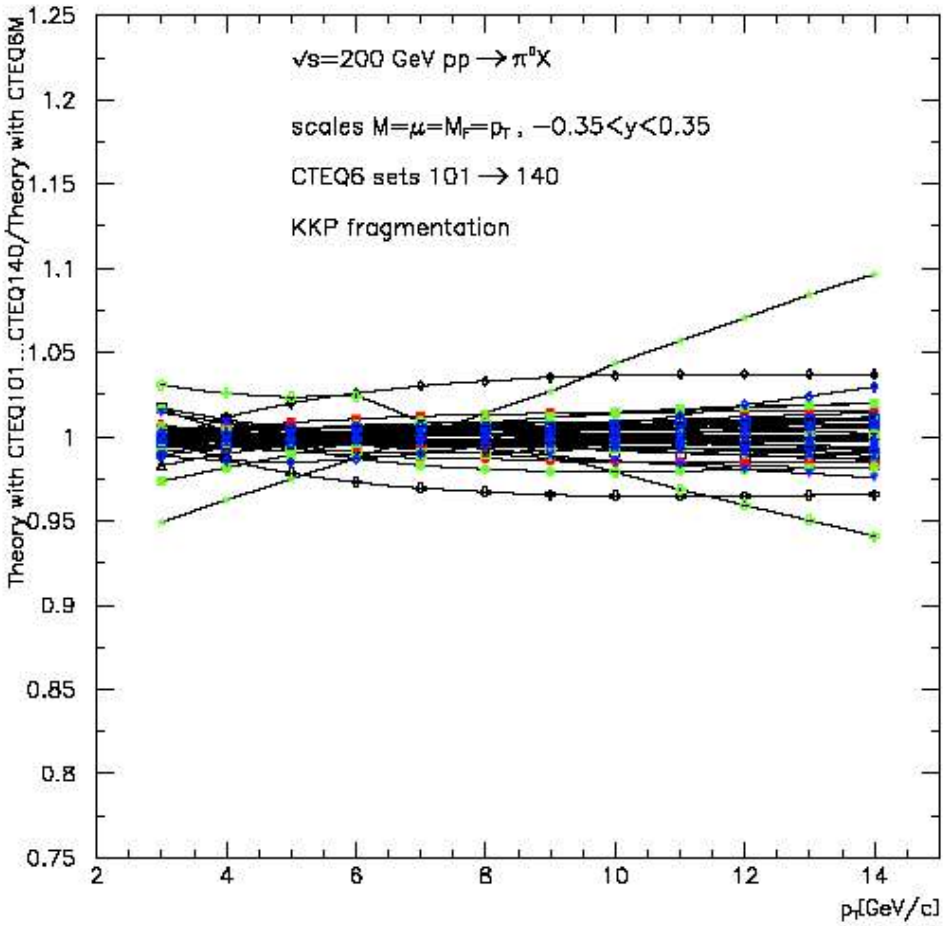
$M=M_F=\mu=p_T/3$

<z> 0.75-0.9

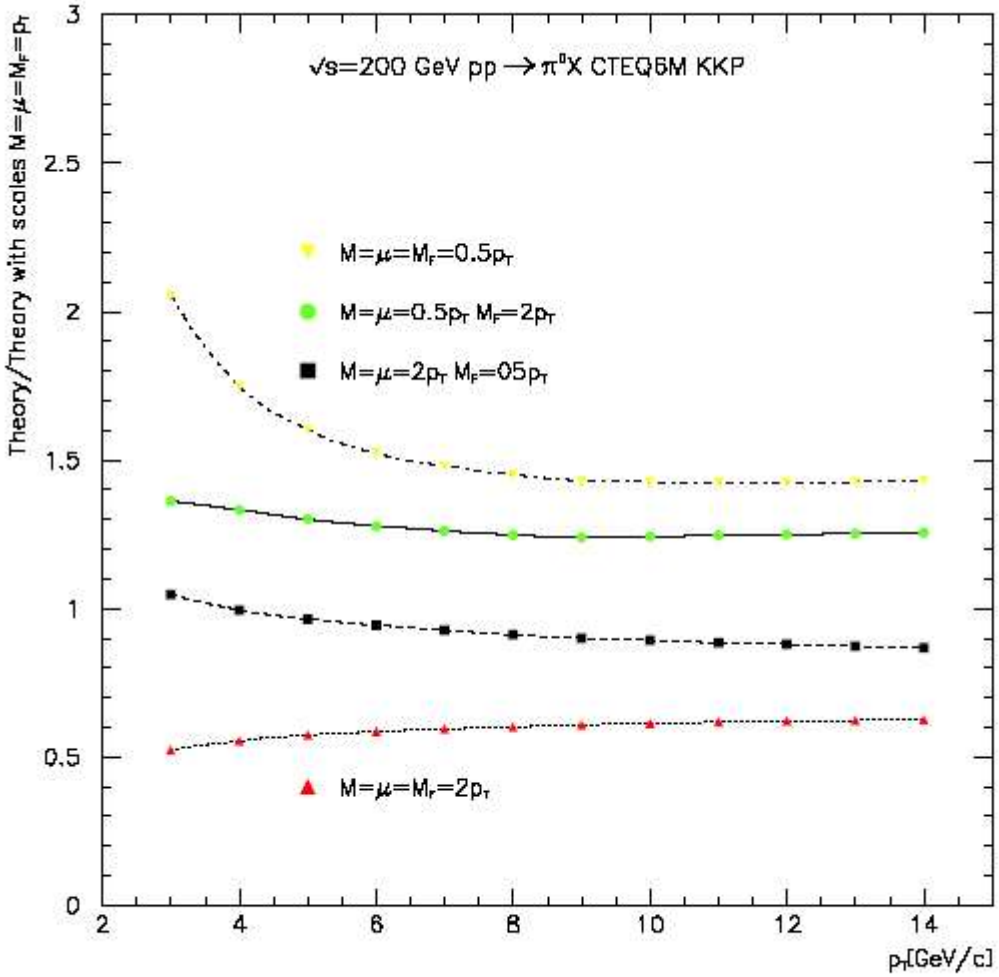
Binoth,Guillet,Pilon,M.W. EPJC24,245



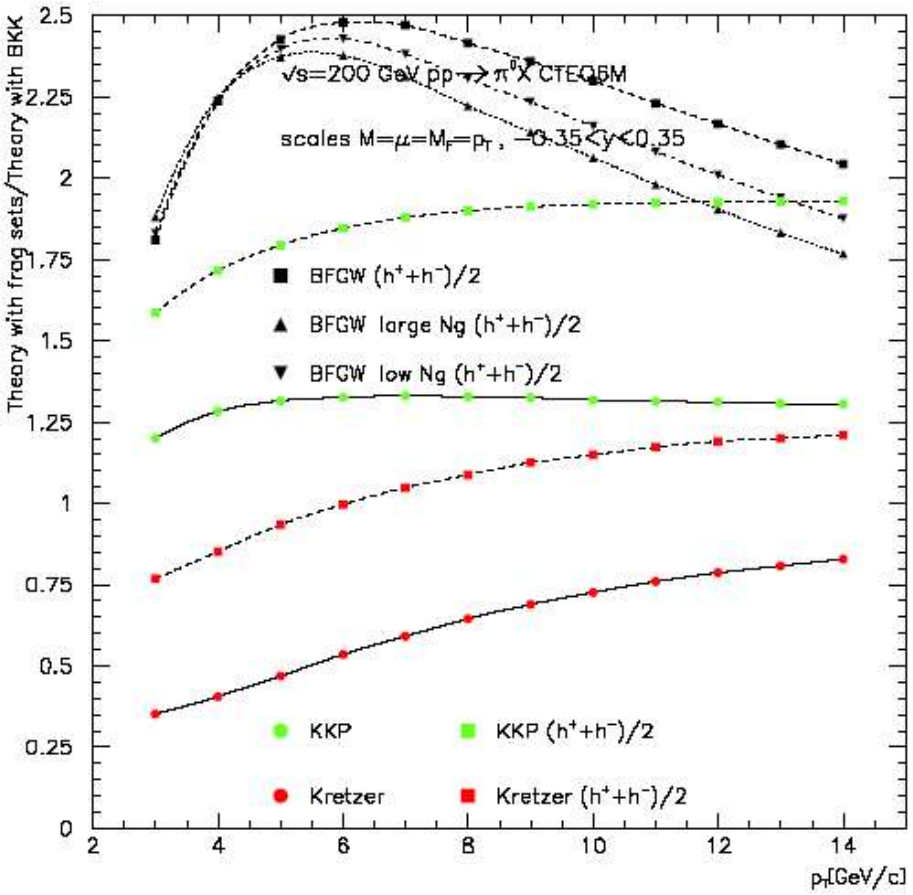
# Typical PDF uncertainties in pion production

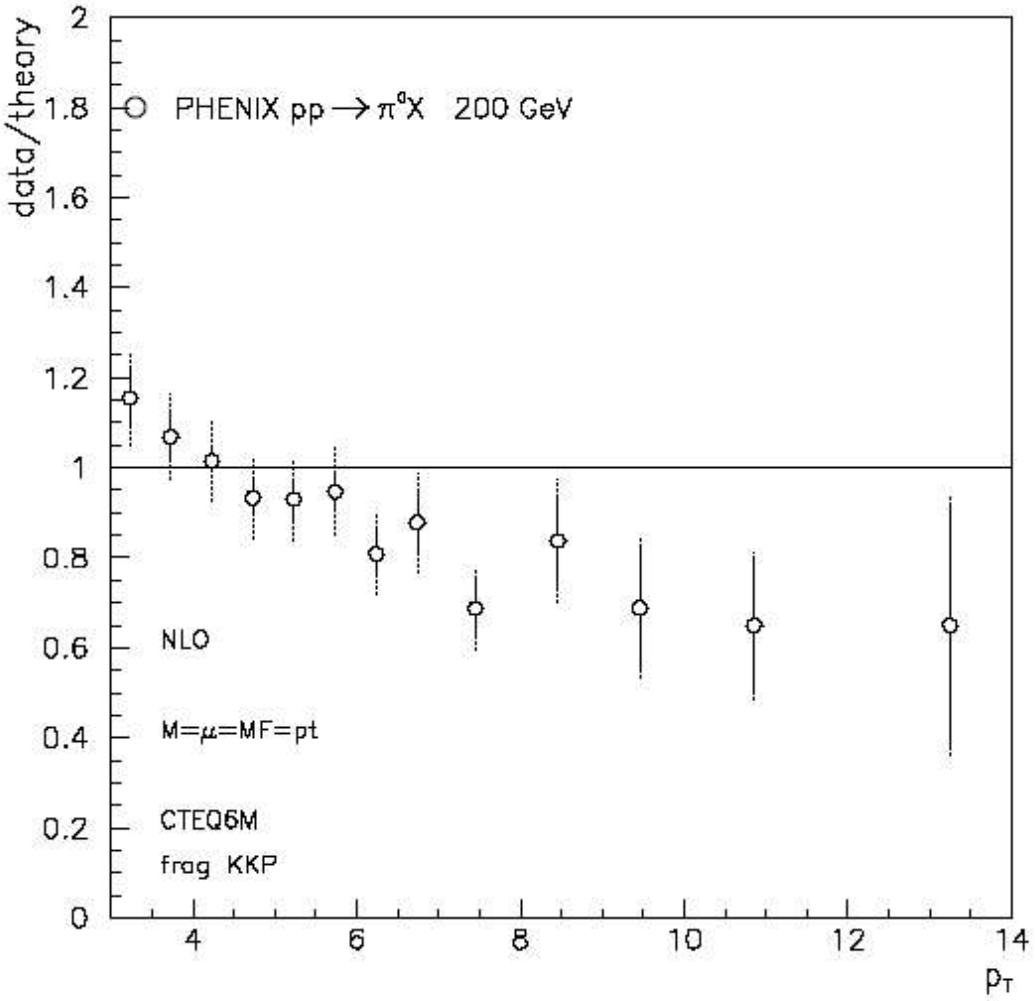


# Uncertainties due to fragmentation, renormalization and factorization scales



# Uncertainties due to fragmentation functions?



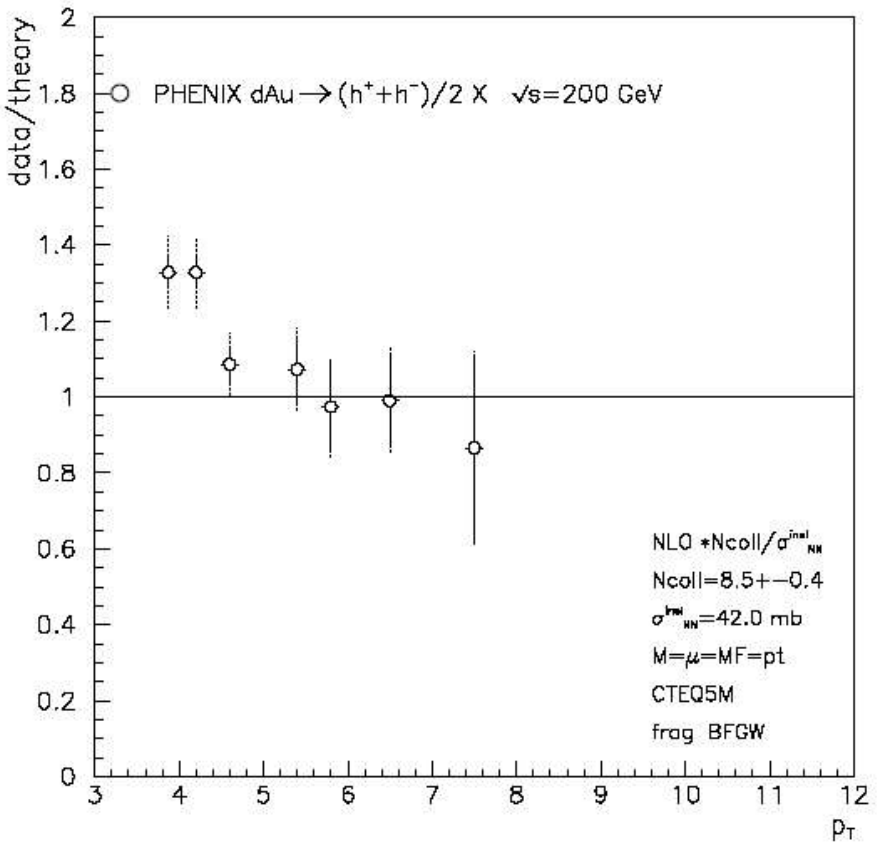


# Charged hadrons at RHIC energies



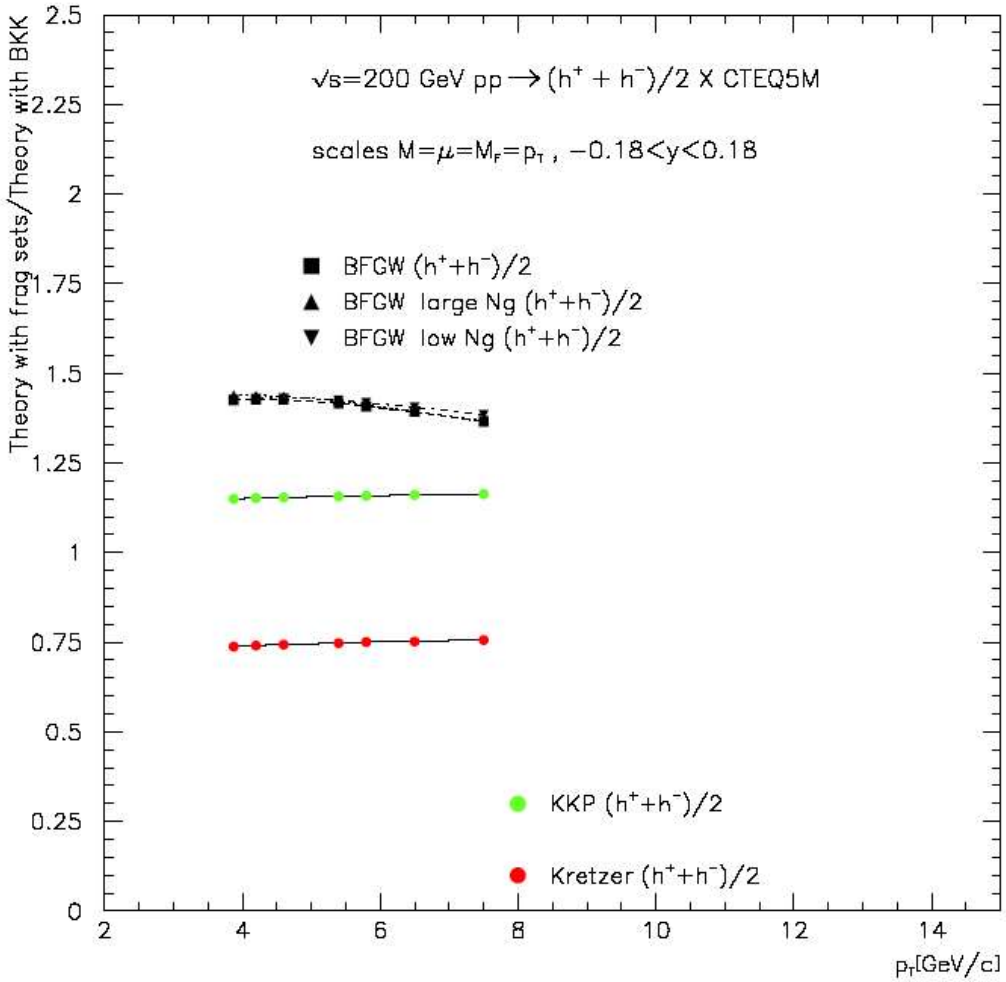
# Fragmentation function BFGW

Eur. Phys. J. C 19, 89–98 (2001)

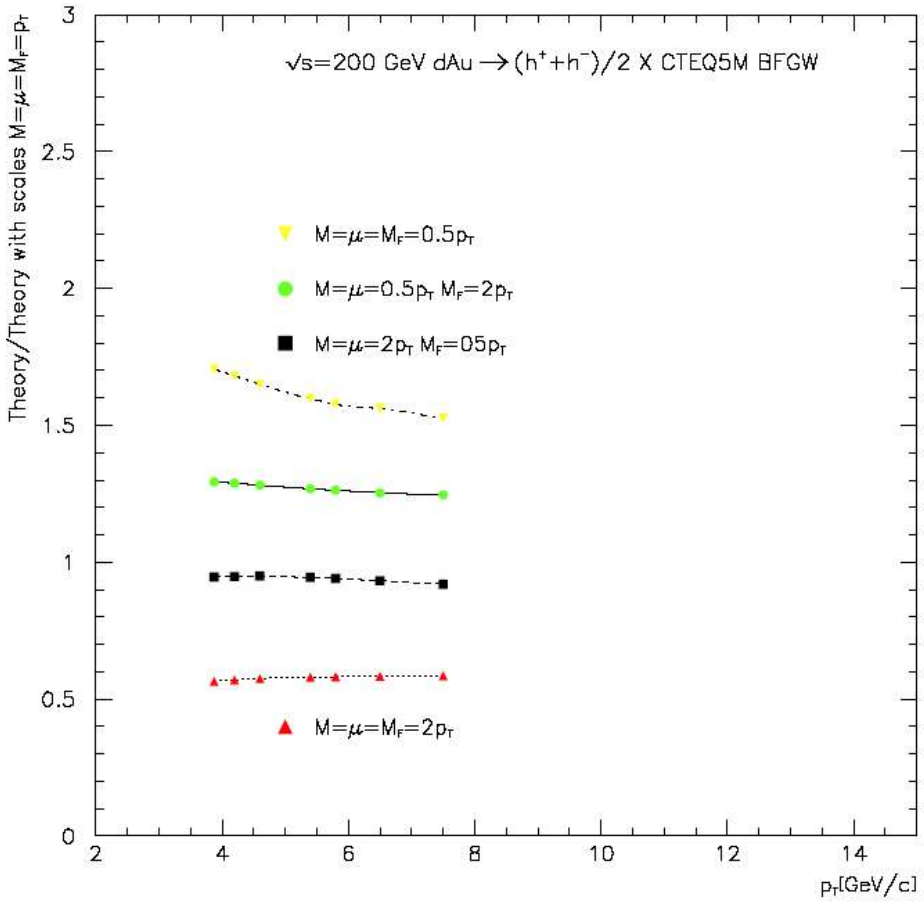



PHENIX:PRL 91,072303

# Typical fragmentation function uncertainties in charged hadron production



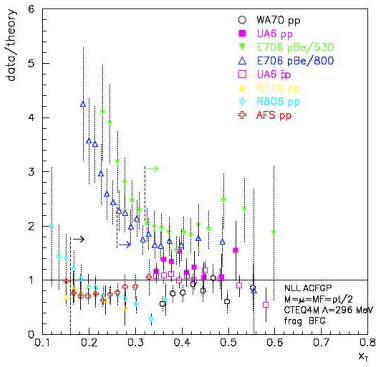
# Typical scales uncertainties in charged hadron production

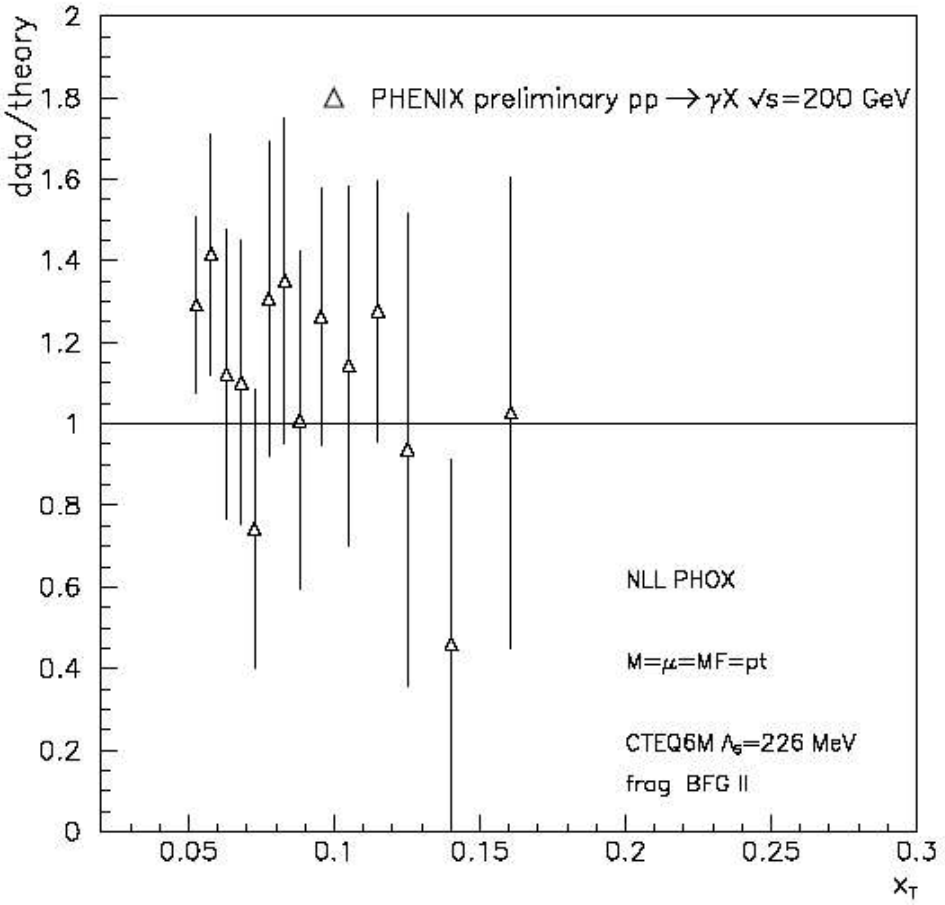


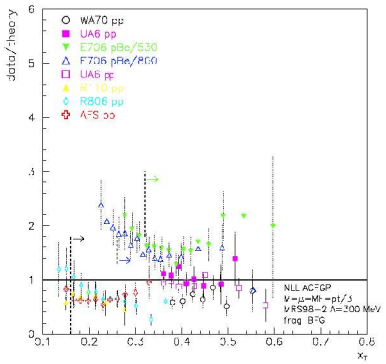



# Extra slide on photon production




data/theory
WA70 pp
UA6 pp
E706 pBe/530
E706 pBe/800
UA6 p̄p
R110 pp
R806 pp
AFS pp
NLL ACFGP
M=μ=MF=pt/2
CTEQ4M Λ=296 MeV
frag BFG
$x_T$


data/theory
PHENIX preliminary pp → γX √s=200 GeV
NLL PHOX
M=μ=MF=pt
CTEQ6M Λ5=226 MeV
frag BFG II
$x_T$


data/theory
WA70 pp
UA6 pp
E706 pBe/530
E706 pBe/800
UA6 p̄p
R806 pp
AFS pp
NLL ACFGP
frag BFG
$x_T$