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Prompt Photons

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Introduction

Recent results in

γp, ep

pp, pN

Pb Pb

Au Au

Some Questions

(apologies for data not covered)

Light played always a central role in attempts to understand early states

Fastentuch, Zittau, 1472 AD

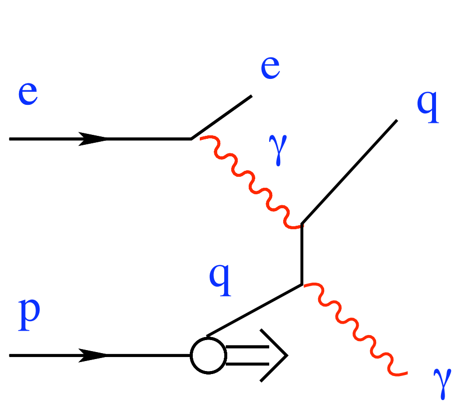
- Early reports on world creation
- Seeing the universe back from now to some 10^5 years after big bang
- Observing parton patterns through fire balls of nucleus-nucleus interactions
- Studying hard partonic interactions directly

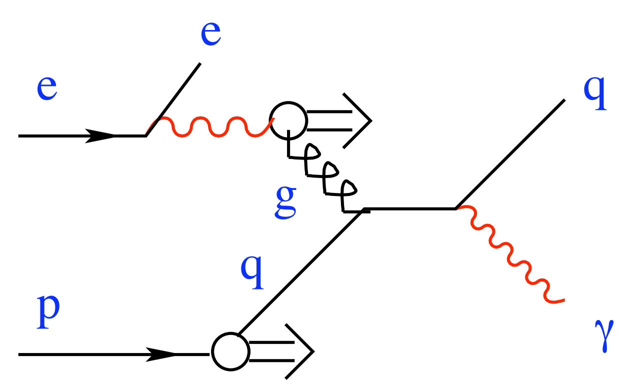
(consider the latter two)

Usually photons are called prompt (direct) if coupling to interacting partons

in contrast to photons from hadron decays or radiation from leptons

ep LO

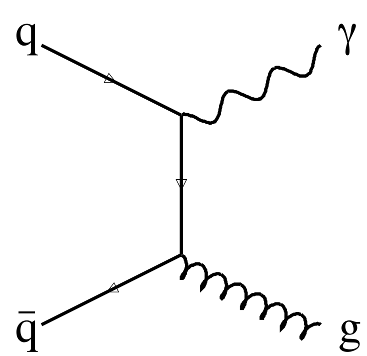


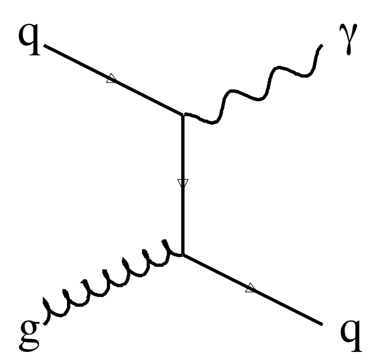


examples of direct and resolved photon interactions

sensitive to gluon content of photon

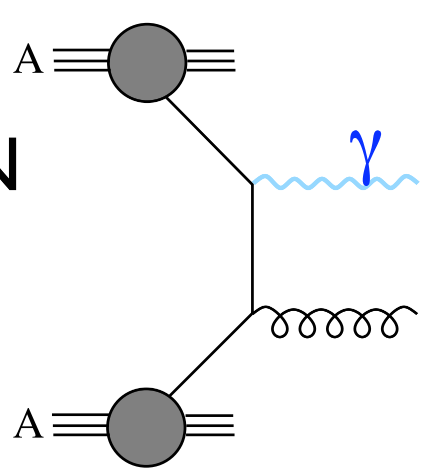
hh LO

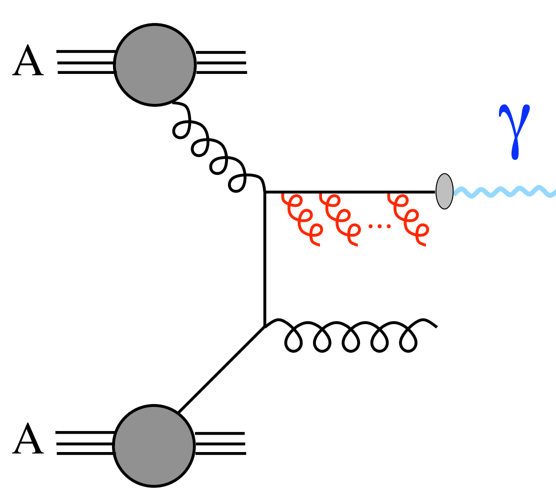




and of proton

NN





signal of hard interactions

but in all reactions contributions of non perturbative fragmentation processes

Interest in prompt photons, because

- more directly related to partonic interactions than jets
- sensitive to gluon content of proton (and resolved photon)
- important background for searches at LHC (e.g. Higgs $\rightarrow \gamma\gamma$)
- they help in nuclear interactions to disentangle different effects (initial/final states, QGP, hadron gas, ...), as not strongly interacting

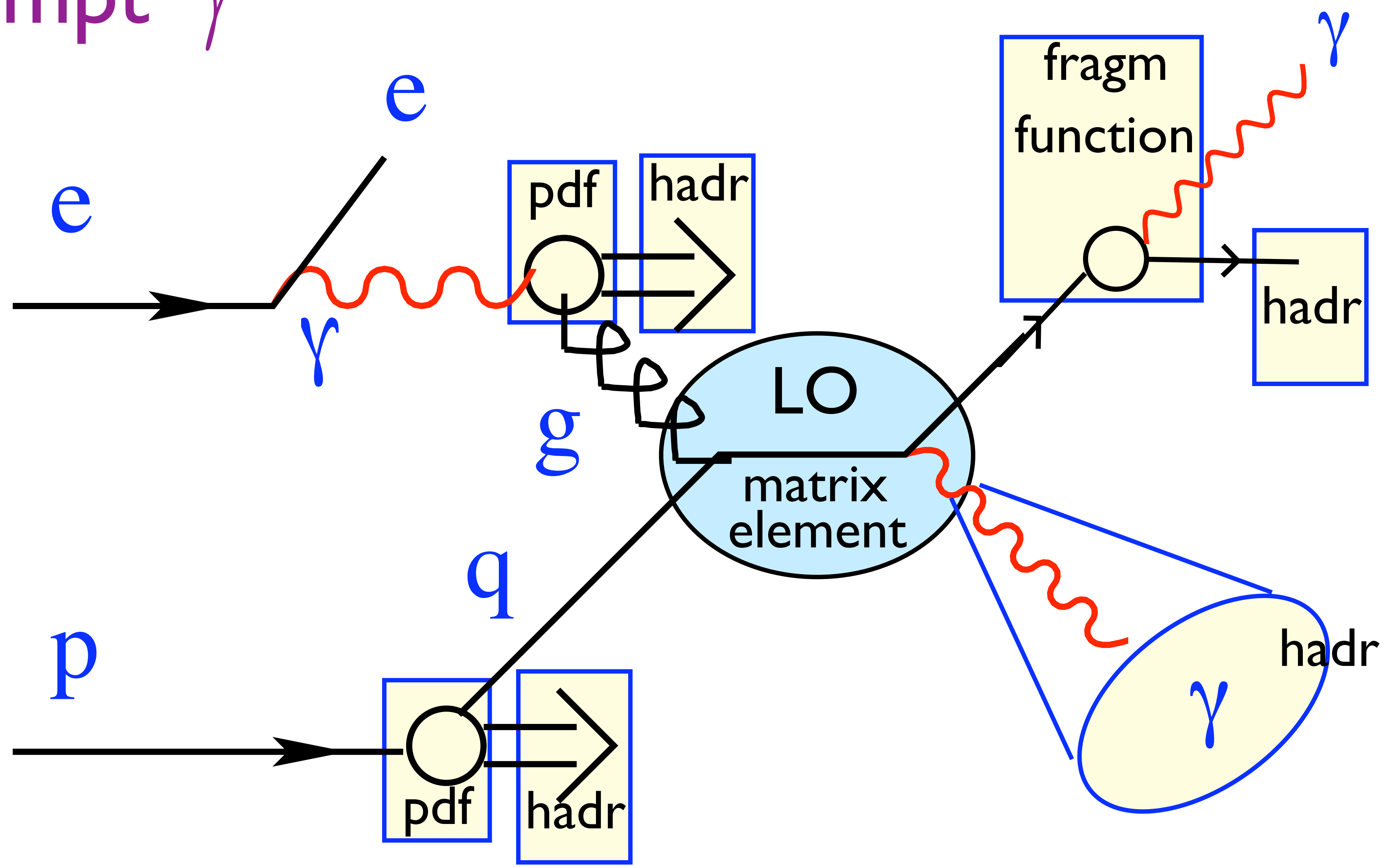
drawbacks

- small cross sections
- background from neutral hadrons ($\pi^0, \eta \ldots$)

→ needs careful subtraction of $\pi^0, \eta \ldots$

and/or sophisticated shower shape analyses

Example of prompt γ diagram



various calculations with NLO pQCD matrix elements and collinear pdfs (γp, ep, $\gamma\gamma$, hh)

improvements in hh by soft gluon resummations

non-perturbative elements

most recent analysis

Lipatov, Zotov(2005) : k_T factorisation for γp, pp

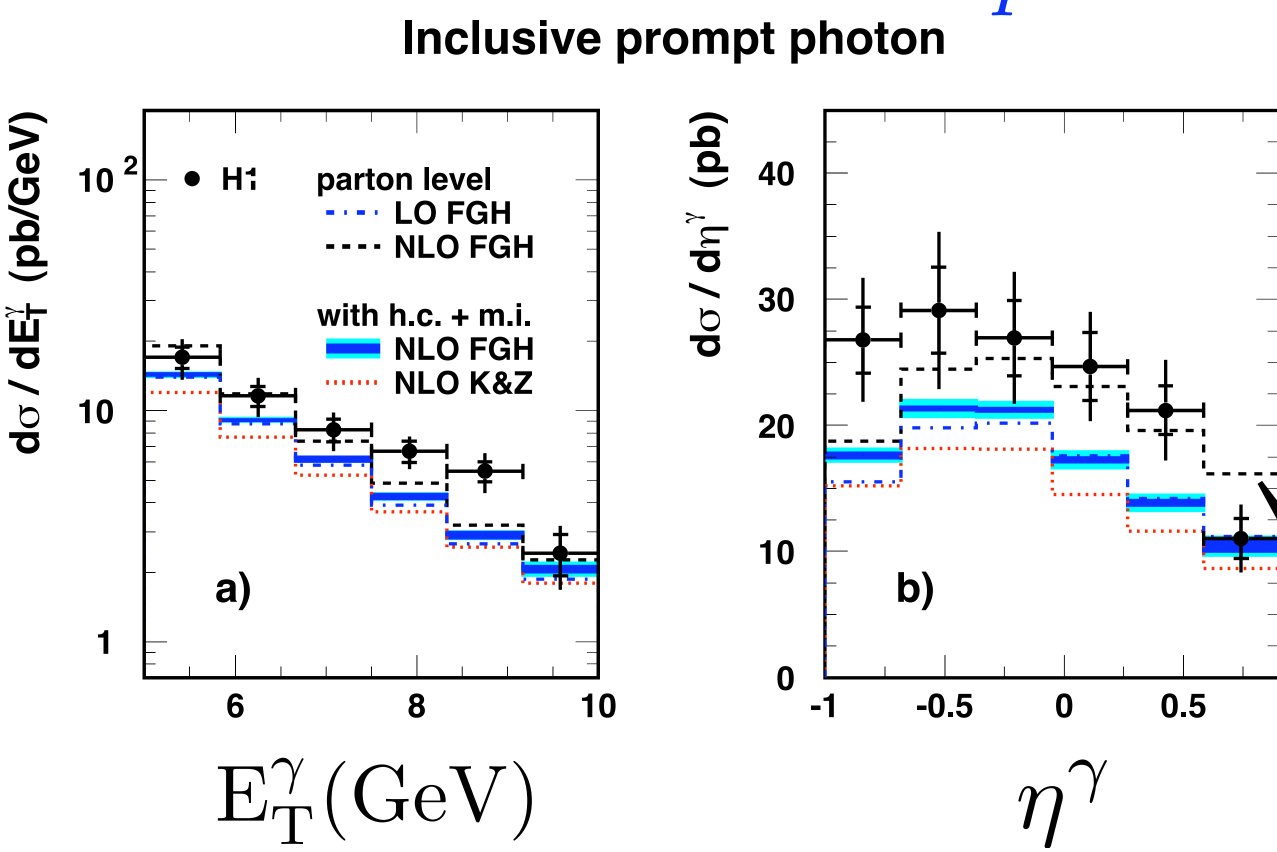
(earlier work: Kimber, Martin, Ryskin (2000))

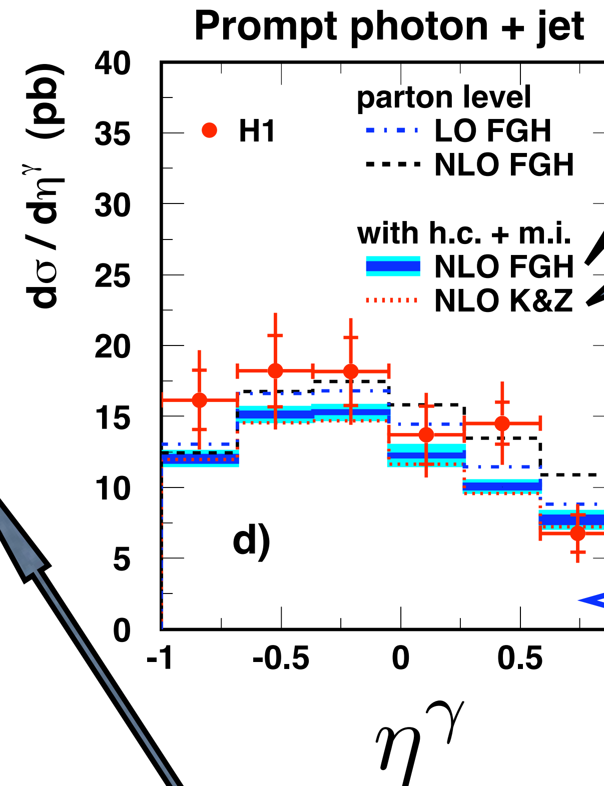
improved kinematics, off-shell matrix elements

LO results close to collinear NLO !

E_T and pseudorapidity distributions in $\gamma\ p$, HERA

$p \rightarrow\leftarrow \gamma \qquad \sqrt{s_{\gamma p}} \sim 200$ GeV



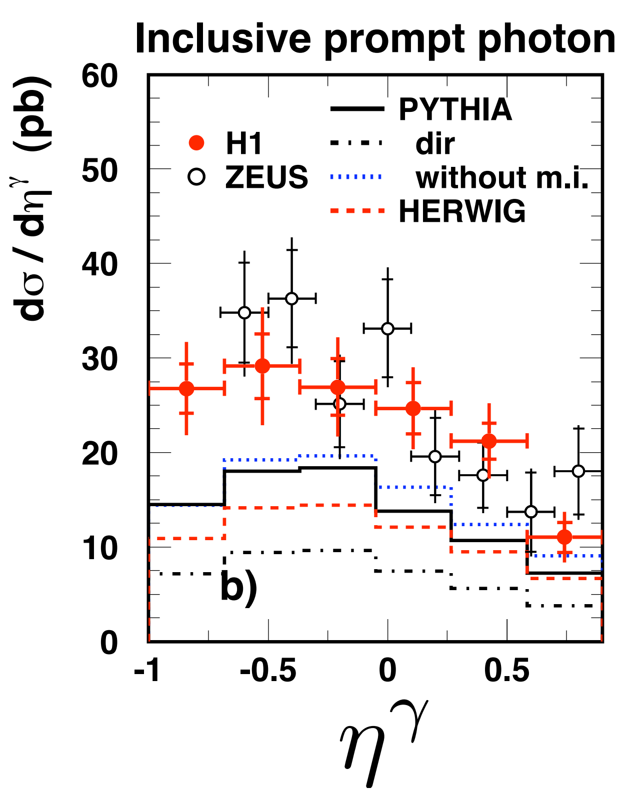


NLO pQCD

Fontanaz, Guillet, Heinrich

Krawczyk,Zembrzuski

description improved, if jet required



NLO and models PYTHIA, HERWIG describe shapes, but low in normalisation ~30...40%

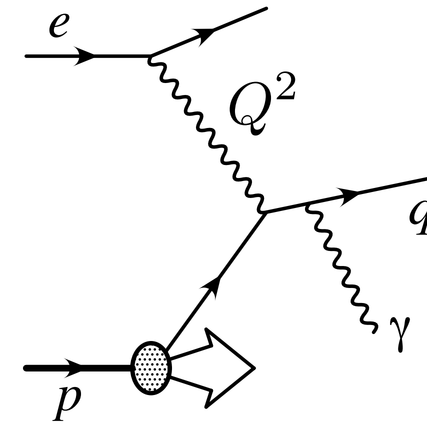
note :

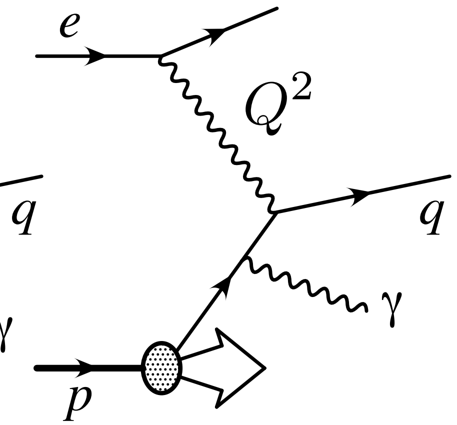
NLO before corrections for hadronisation is closer to the data

(H1 corrects with PYTHIA and HERWIG)

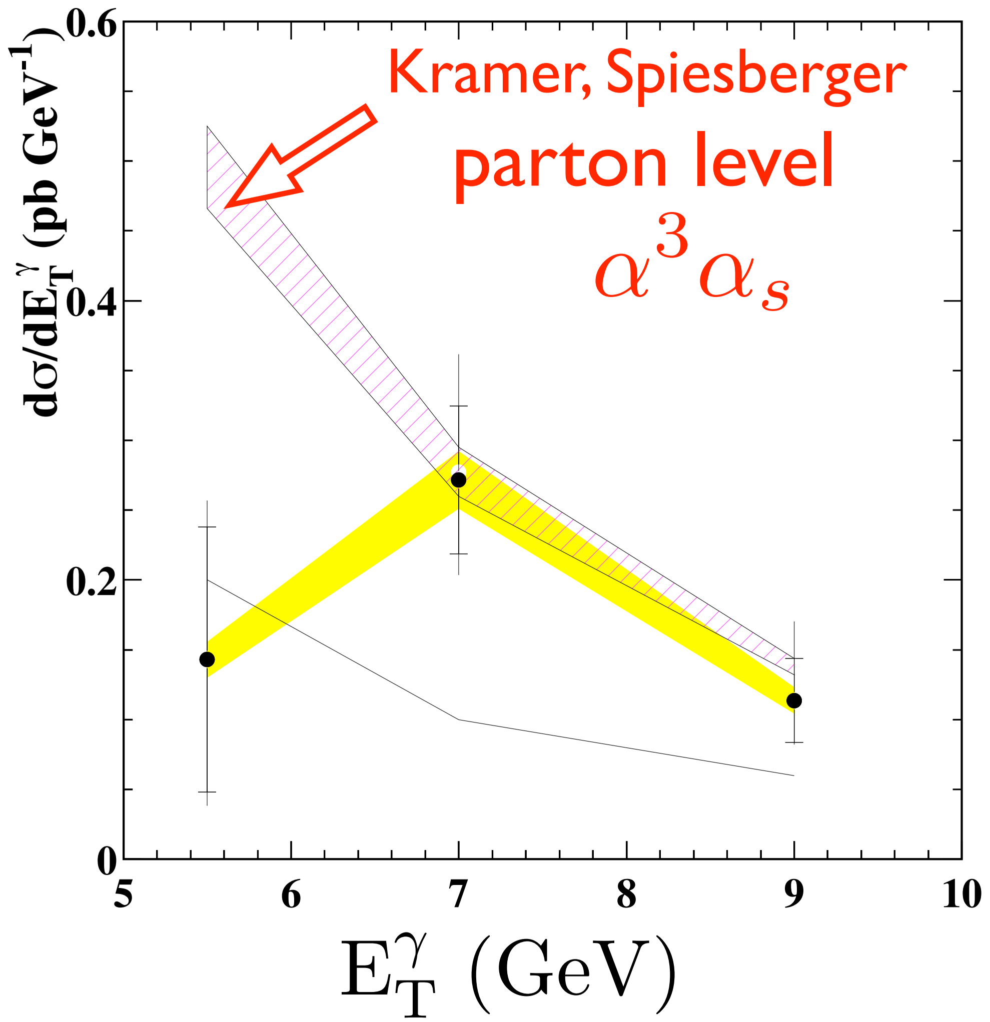
PYTHIA similarly low in $\gamma\gamma$ (OPAL)

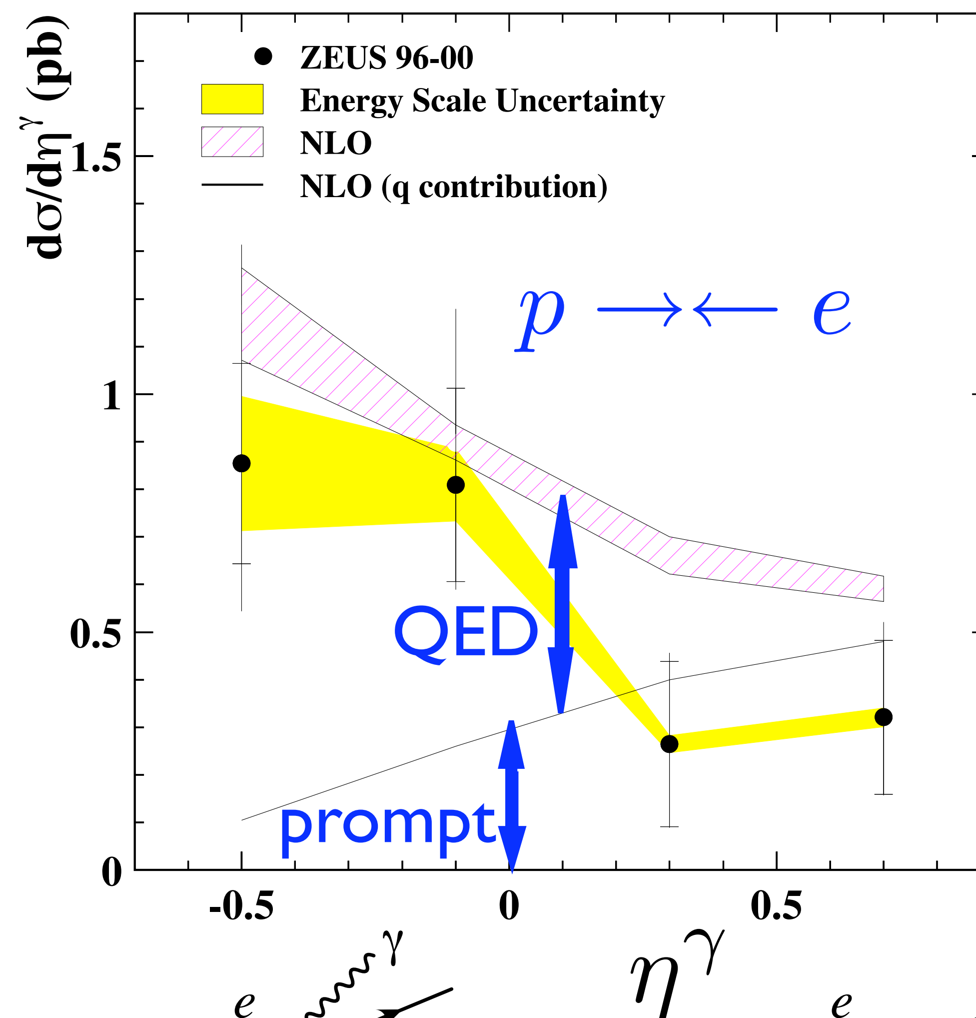
First results in DIS

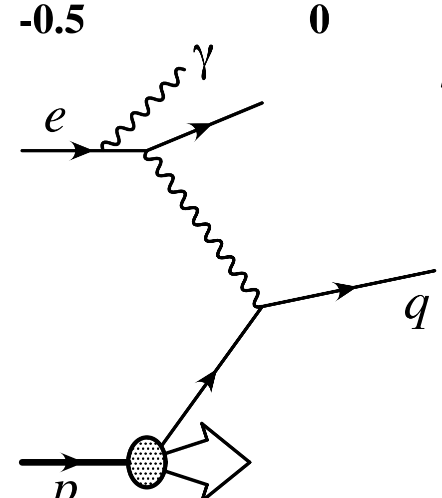


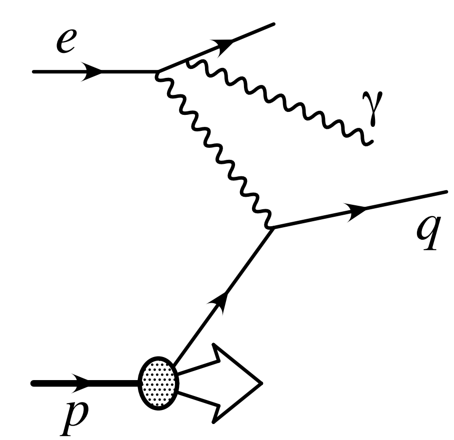


$Q^2 > 35\ \mathrm{GeV}^2$









substantial contribution of QED

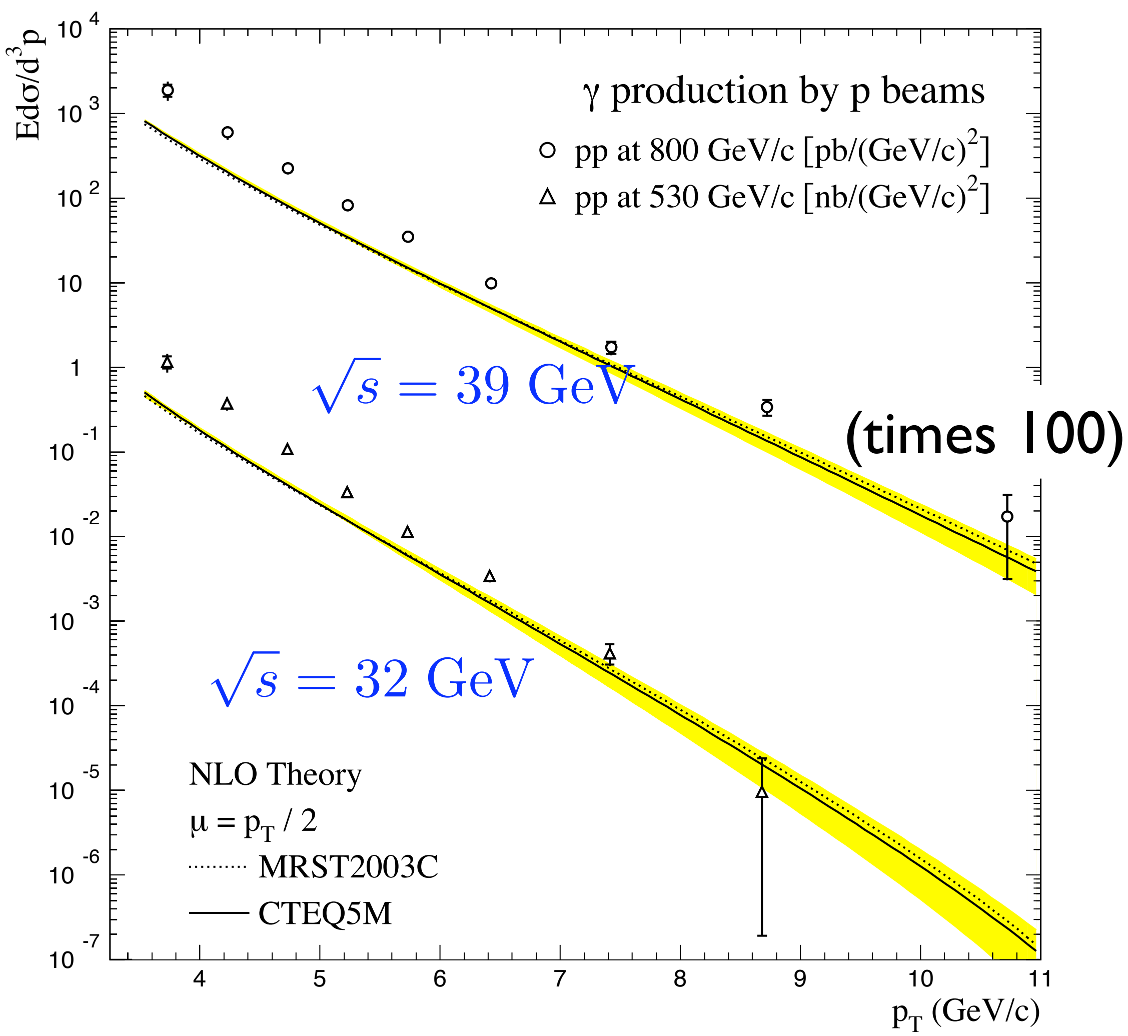
uncertainties still large

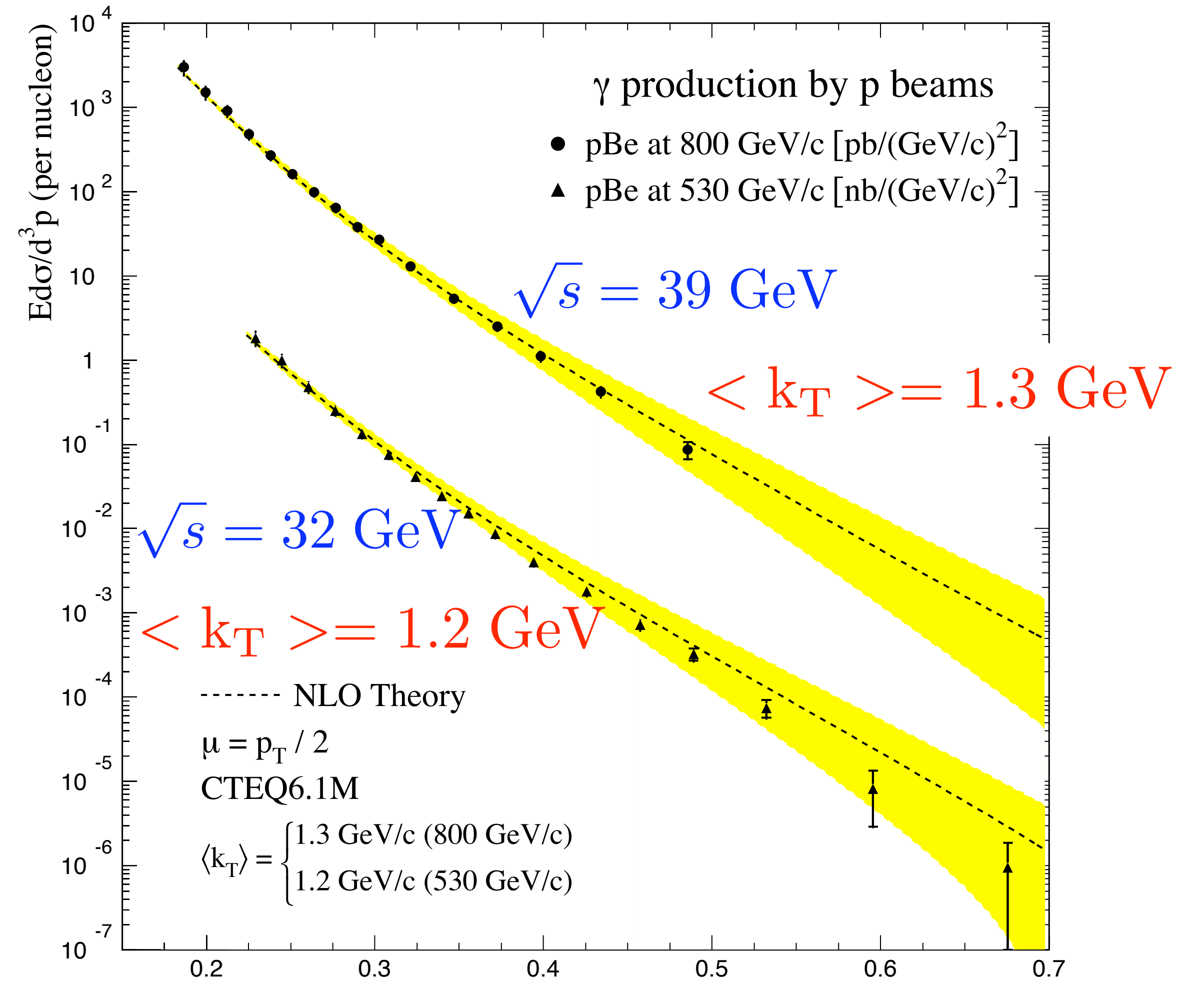
data consistent with NLO

$pN \to \gamma X$

notoriously difficult to describe low energy data

example of E706 Phys Rev D70 (2004), final report





p_T $\qquad$ $x_T = 2p_T/\sqrt{s}$

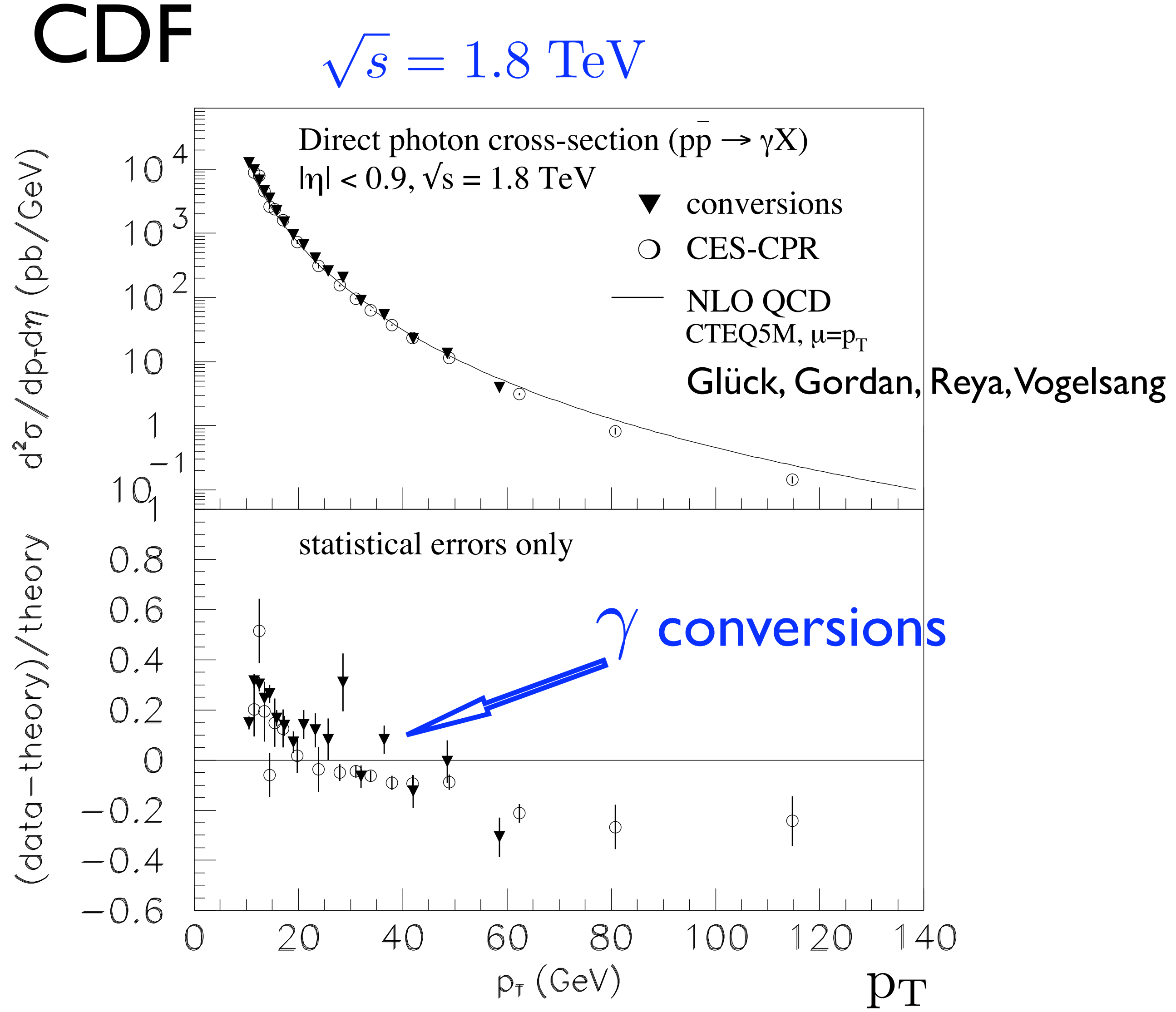
NLO (Aurenche et al., Berger, Quin) **far below data (< 50%) at small p_T**

Agreement reached by ad hoc smearing of initial $< k_T > \gtrsim 1$ GeV

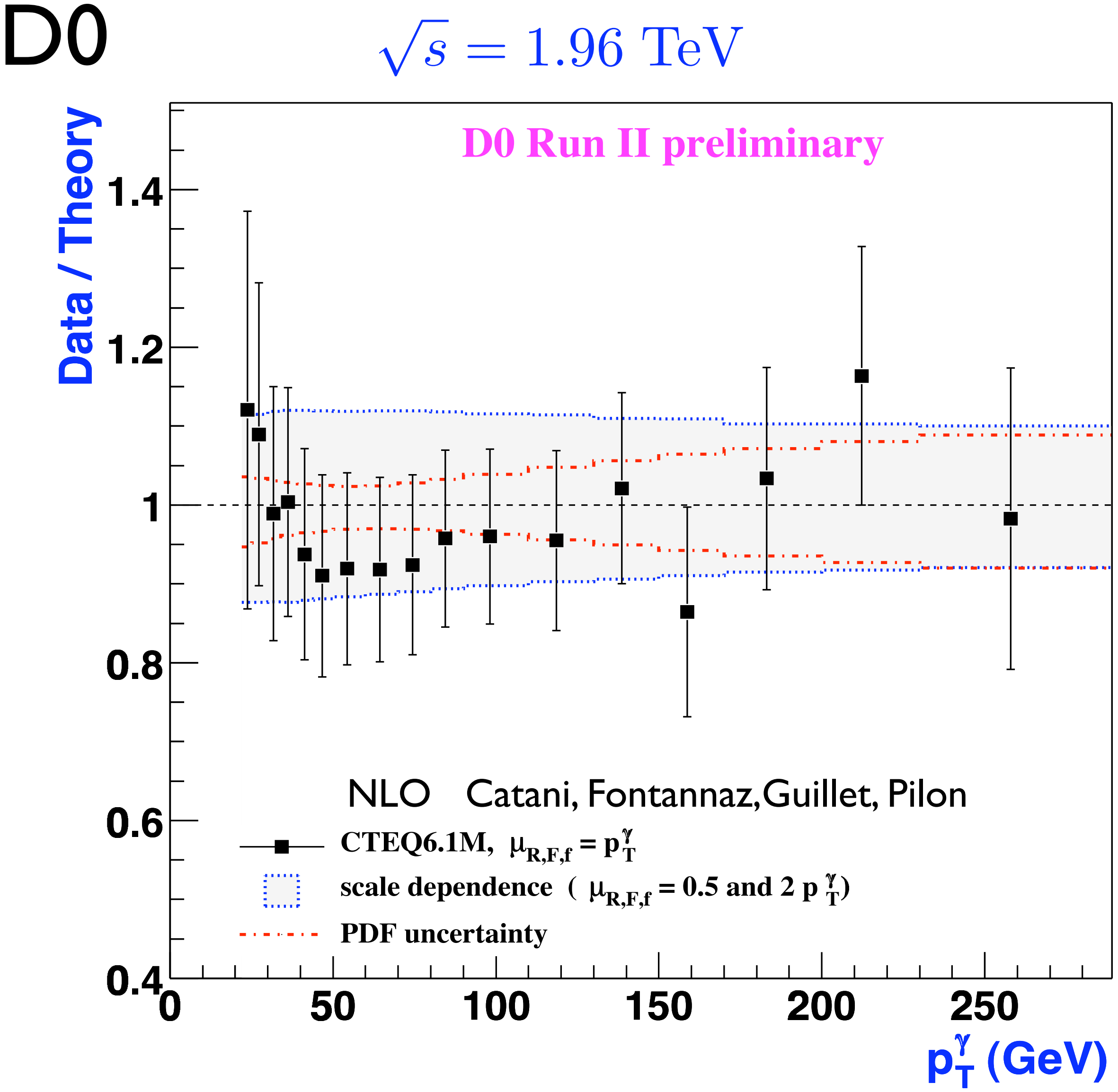
improvements by resummations (Lai,Li, 1998, Laenen, Sterman,Vogelsang, 2000 Kidonakis, Owens, 2003 ....Florian, Vogelsang, 2005, Sterman,Vogelsang 2005......)

$pp \to \gamma X$, high energies

CDF



D0



in old and new CDF data
steeper E_T dependence than NLO

prel. D0 consistent with NLO

but in general, agreement better at high s

less need for corrections like soft gluon resummations ?

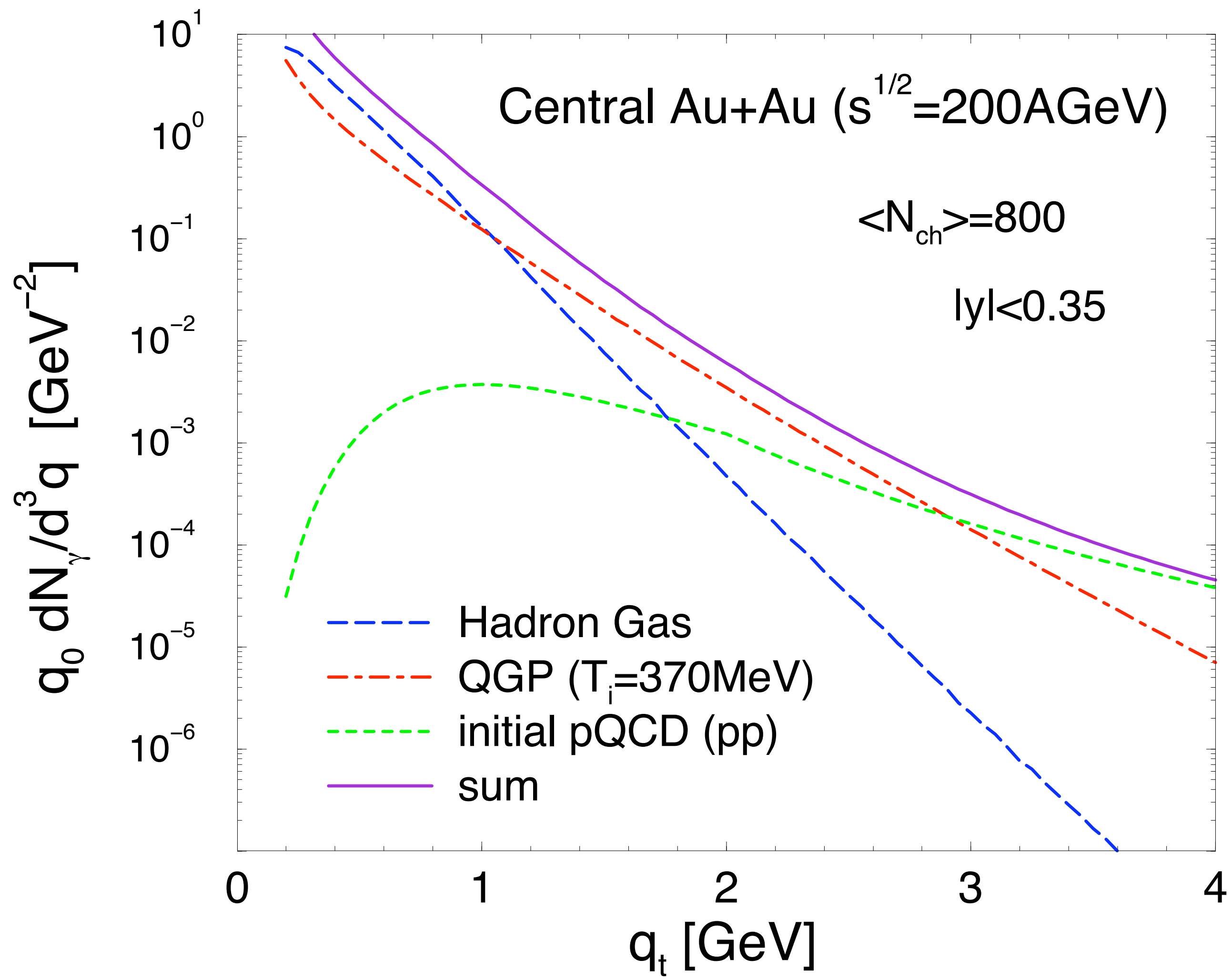
Nucleus-Nucleus Collisions

Turbide, Rapp, Gale

prompt photons may disentangle effects of nuclear medium

in particular
thermal photons are expected from

QGP (quark-gluon-plasma)
or Hadron Gas

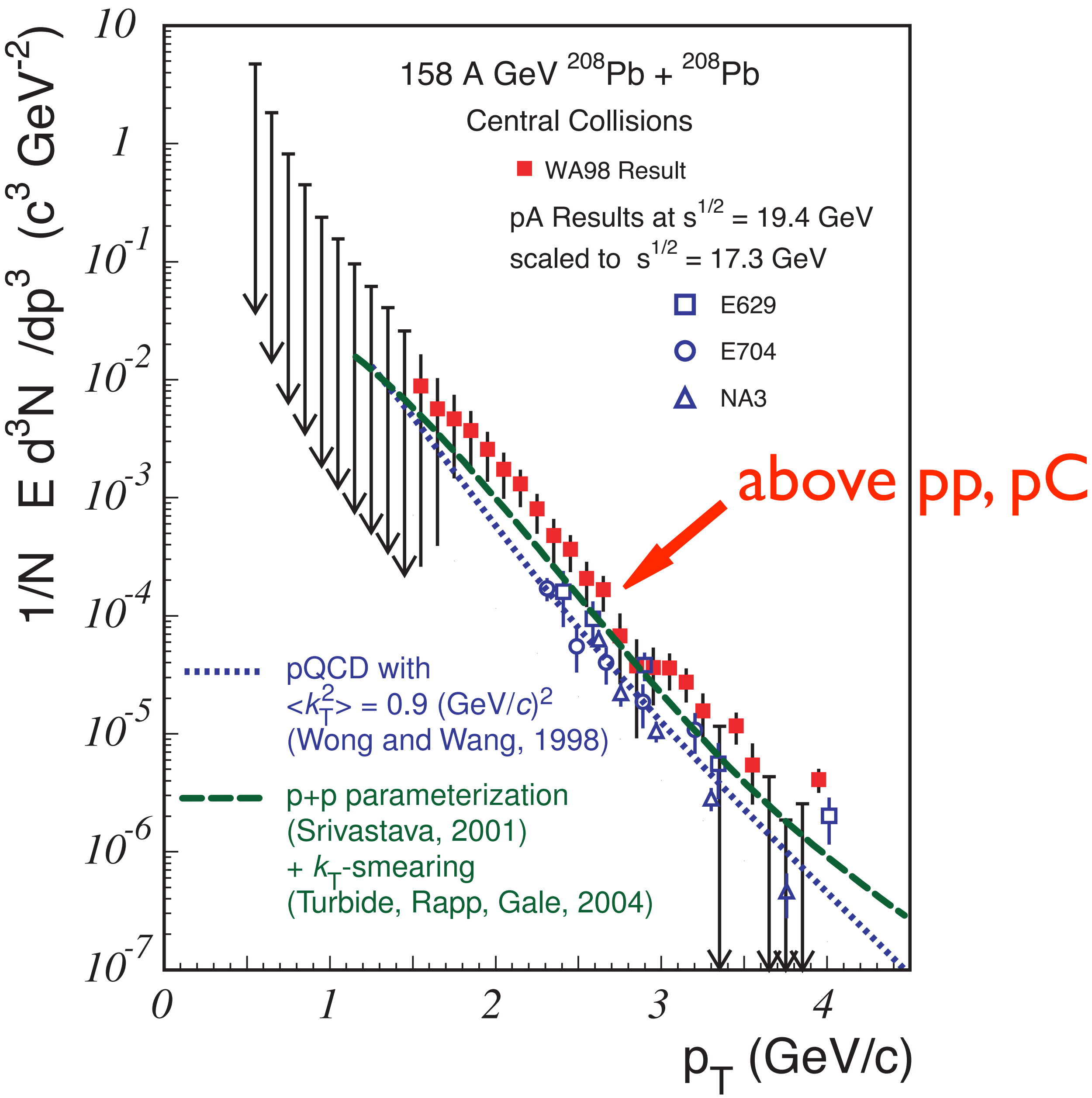


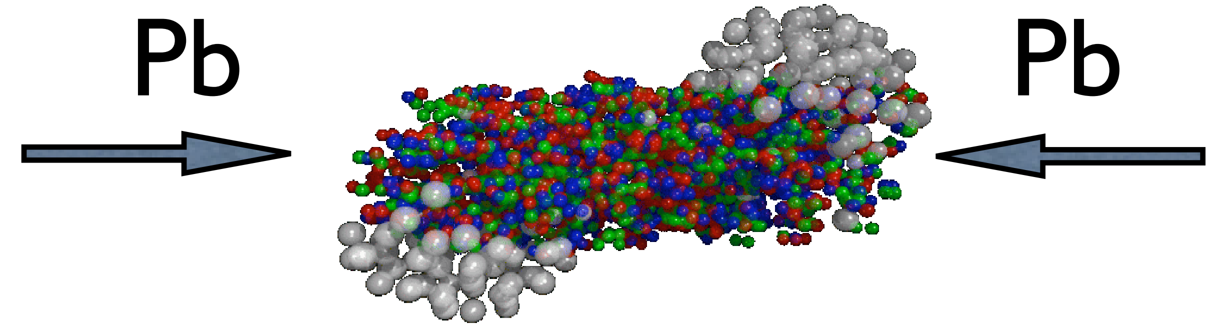
expect sensitivity for QGP at medium p_T

but pQCD (pp) dominates already at moderate p_T

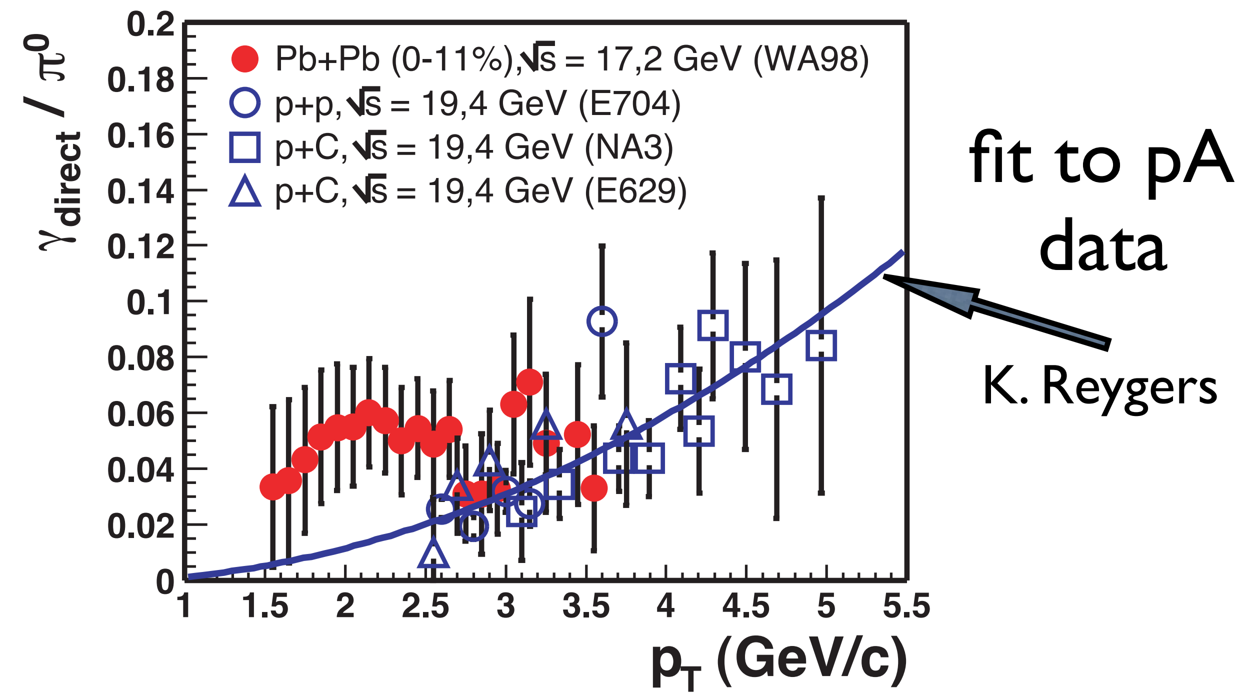
Pb-Pb Collisions

CERN SPS, WA98 $\sqrt{s_{NN}} = 17.3$ GeV





γ_{dir}/π^0

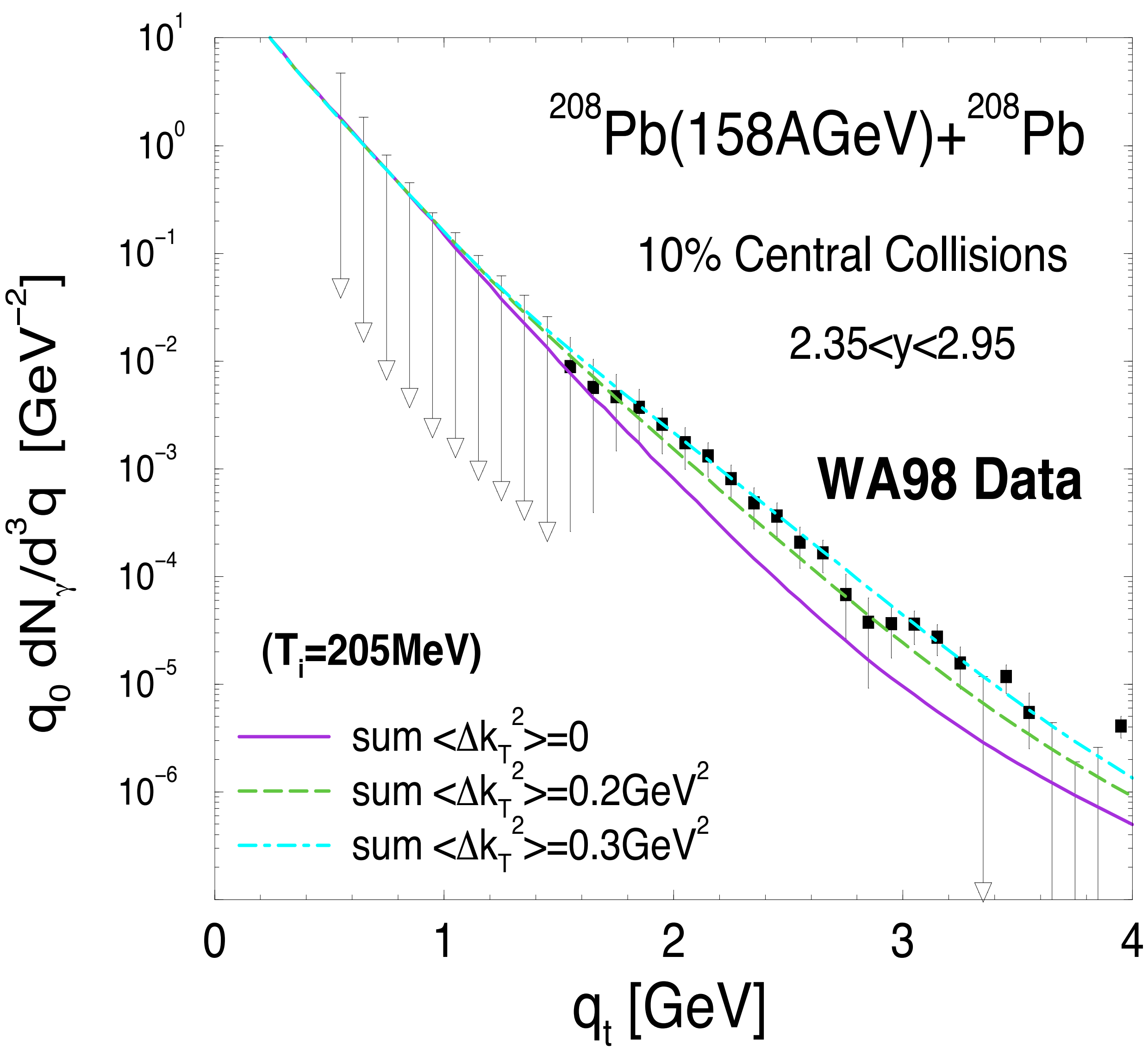


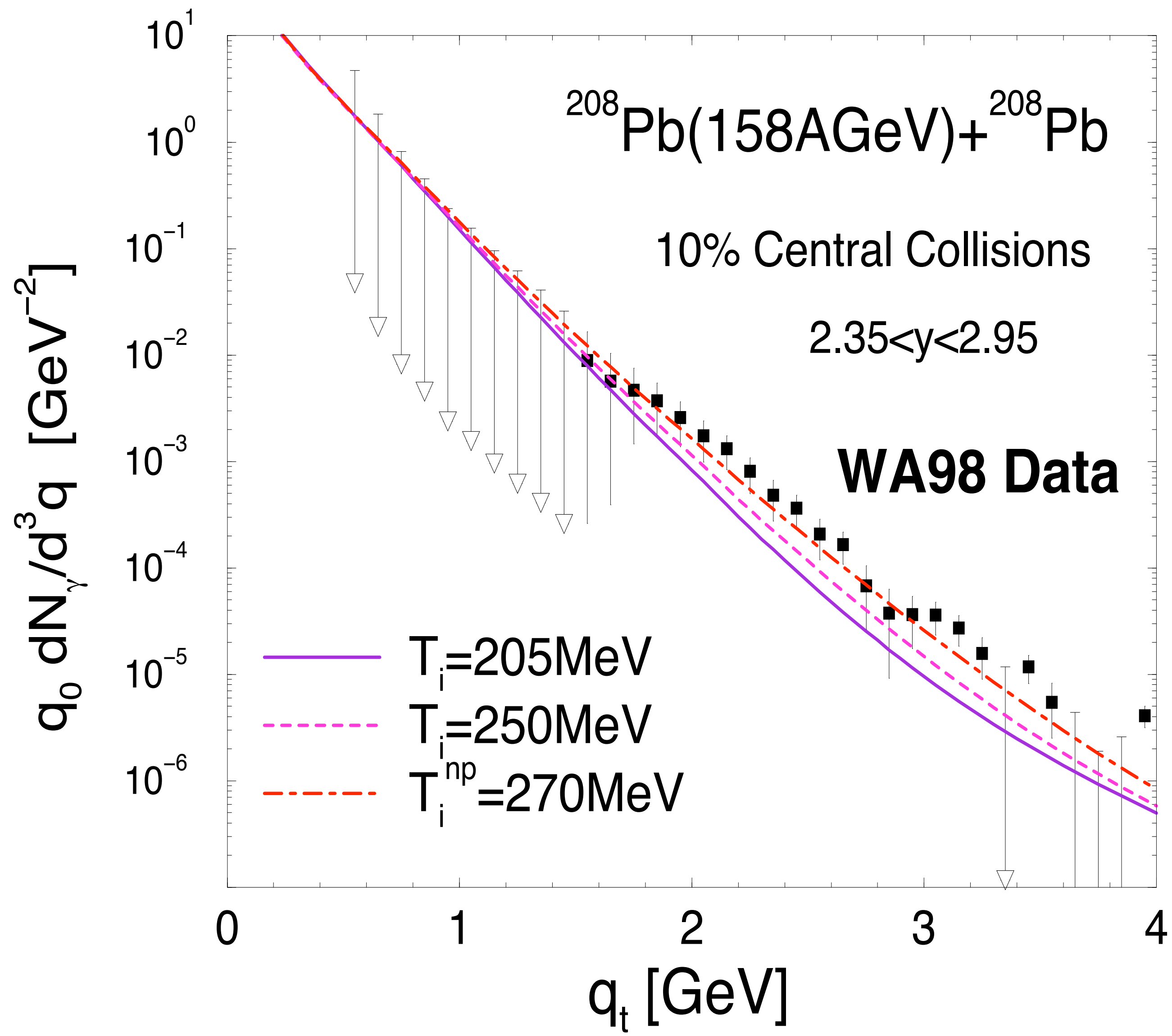
difficulties:

- large background at low pt
- no pA data at low pT
- no pPb data available

¿ QGP or hadron gas seen ?

WA98 data as convolution of thermal photons of QGP and hadron gas and pQCD (Turbine, Rapp, Gale)



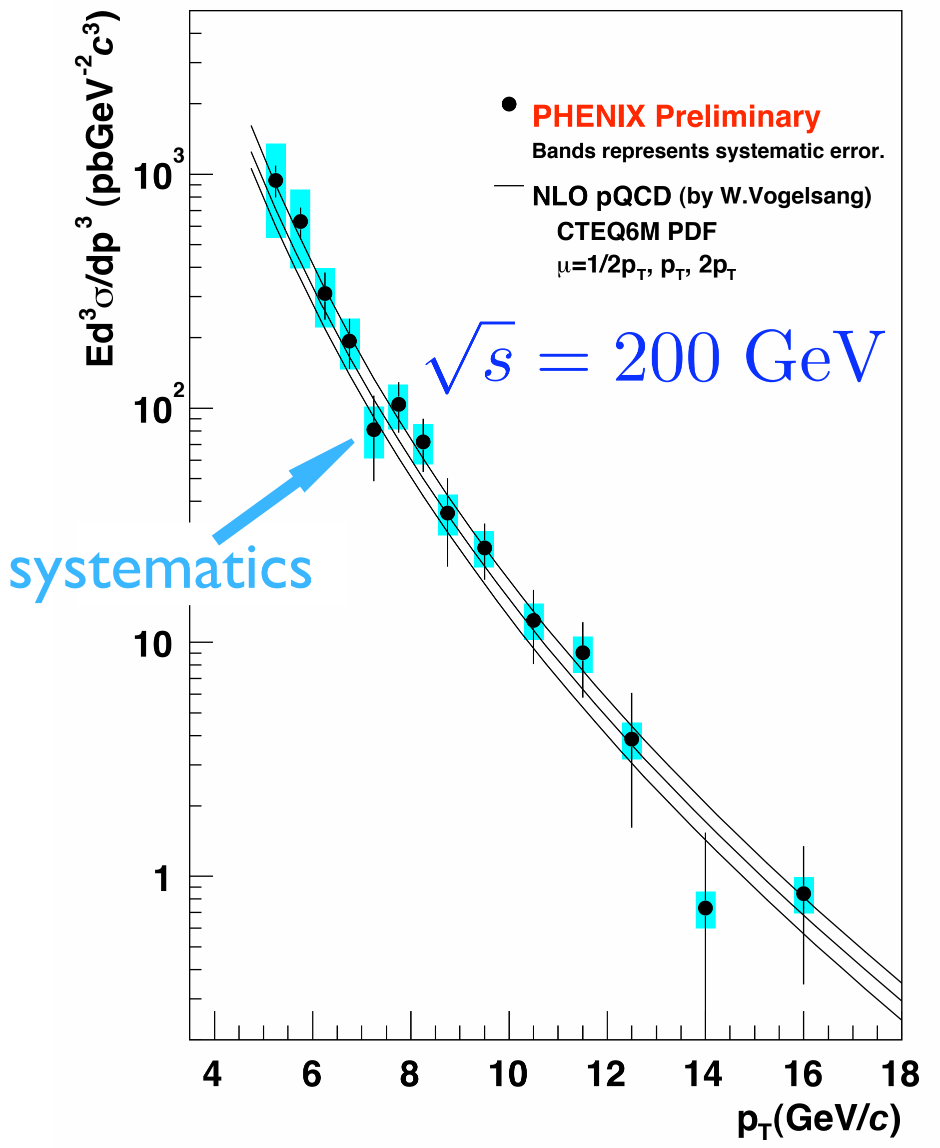


data described by
initial temperature 205 MeV
and k_T broadening

or
high initial temperature 270 MeV

Results from RHIC

pp PHENIX



consistent with NLO

Gordon and Vogelsang

but what happens with heavy nuclei at these ultra-relativistic energies ?

we know

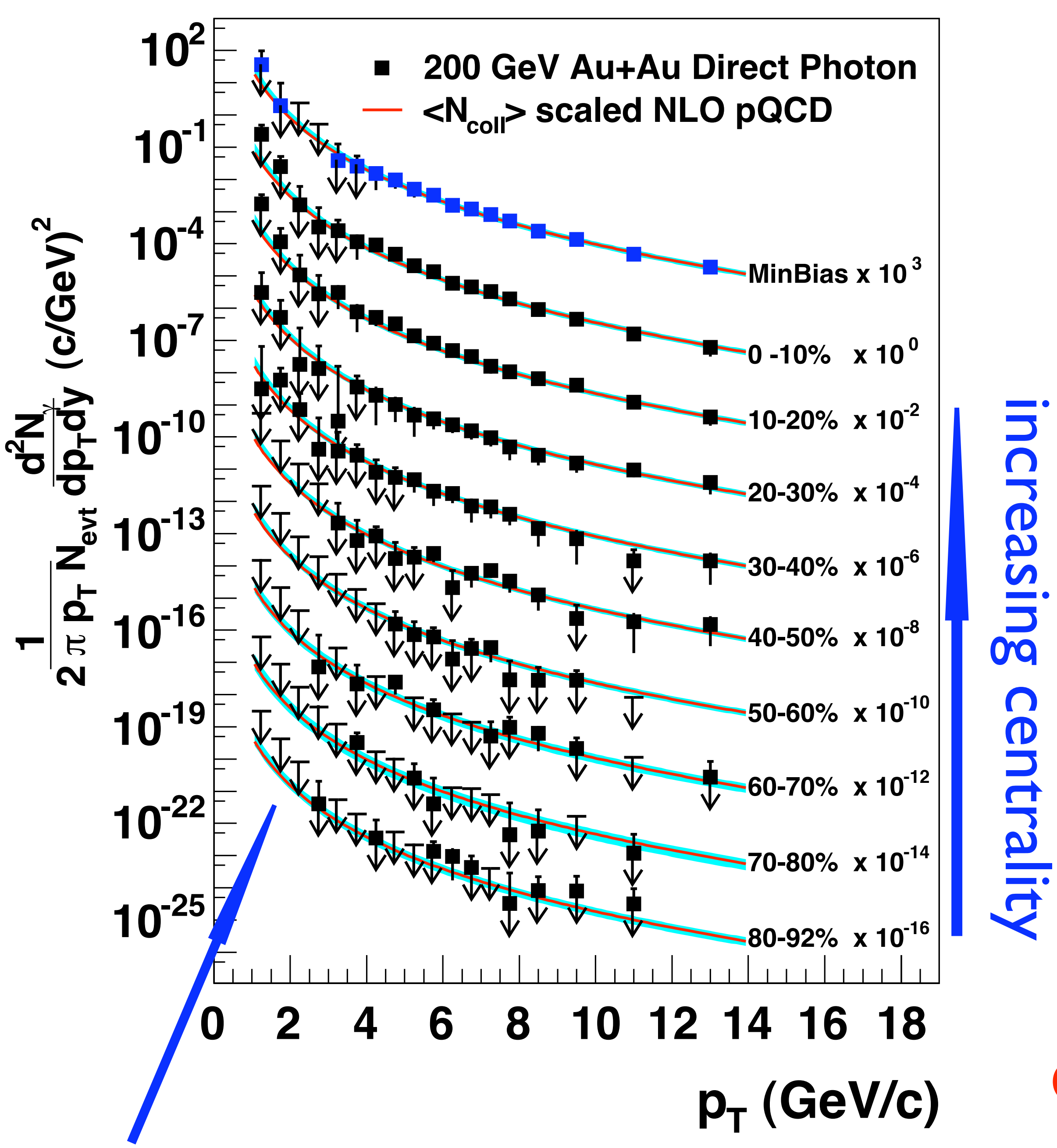
at central collisions

- high p_T hadrons are suppressed
- away side jets dissappear at high p_T indicative of "jet quenching" due to parton energy loss in coloured medium

initial state effects would suppress photons too

Au+Au collisions

PHENIX $\sqrt{s_{\rm NN}} = 200$ GeV



arrows : here consistent with zero (90% confid)

NLO (Gordon, Vogelsang)

scaled from pp to $< \mathrm{N_{coll}} >$ in AuAu

$\mathrm{N_{coll}}$

number of inelastic NN collisions ~ nuclear overlap,

deduced with Glauber theory from signals of

beam counters and zero degree calorimeters

remarkable consistency !

no sign of suppression

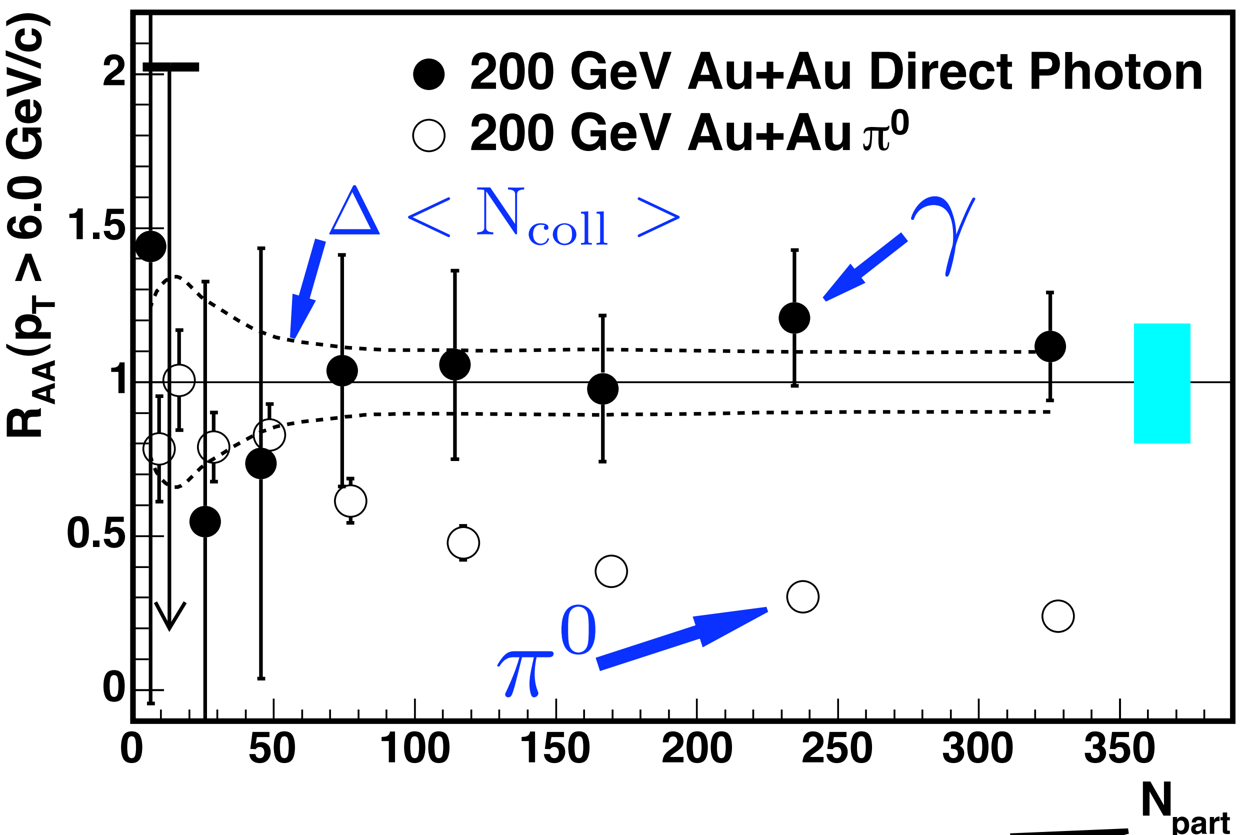
of prompt γ in nuclear medium

Comparison of direct photons with hadrons (π^0)

consider ratios of AA to pp yields scaled by $\mathrm{N_{coll}}$ for γ_{dir} and π^0

$$R_{AA}(p_T) = \frac{(1/N_{AA}^{evt})\, d^2N_{AA}/dp_T dy}{\langle N_{coll}\rangle/\sigma_{pp}^{inel} \times d^2\sigma_{pp}/dp_T dy}$$

$\mathrm{p_T} > 6$ GeV



participating nucleons

again from beam counters and zero deg calos

γ not suppressed

π^0 suppression

increasing with $\mathrm{N_{part}}$

interpretation :

initial high $\mathrm{p_T}$ γ creation unchanged

→ π^0 suppressed in final state

(hadron cloud transparent for gamma)

rules out explanations like gluon saturation in initial state

Characteristic differences of discussed prompt γ experiments

	reaction	hadronic energy[GeV]	d(vtx-calo) [m]	yield/bgd	isolation $\mathrm{R}(\eta, \phi)$
H1 ZEUS	$\gamma p, ep$	~200	1	shower analysis	1
D0	$p\bar{p}$	1800	1	shower analysis	0.4
CDF	$p\bar{p}$	1960	1.8	sh analysis +preshowr	0.4
CDF	$p\bar{p}$	1800	1.8	conversions	0.4
E607	pp, pN πN	31, 39	9	measure γ/π^0	--
WA98	$Pb\ Pb$	17.3	22	measure γ/π^0	--
PHENIX	$Au\ Au$	200	5	measure γ/π^0	--

experiments exploiting π^0 id, require no explicit isolation

impact on theory ? different contributions of fragmentgation, soft gluons especially at high (RHIC) energies

Questions concerning HERA results

Why NLO below the data (~30%)? Normalisation ok without hadronisation !

Is the hadronisation correction using PYTHIA/HERWIG too naive?

Can it reliably be applied to NLO partons, in particular for isolation cone?

Are there large ambiguities?

Are LO+parton shower models (PYTHIA, HERWIG) below data (~40%) for the same reason? Which?

They include hadronisation and should model cuts well.

Prompt γ + jet seem to be better described than inclusive prompt γ .

If so, is it that the jet requirements forces LO like configurations with less phase space for higher order effects?

Questions to results in hadron-hadron reactions

Low $\sqrt{s}$ (< 100 GeV) , pp or light nuclei :

Can good theoretical description at low pt (< 5 GeV) be achieved without ad hoc kt smearing?

Can be stated, which data can be accomodated with theory and which not ?

Does kt factorisation help (calculations a la Lipatov, Zotov) ?

High Energies :

Deviations from NLO seem to be smaller for preliminary D0 than CDF data.

Ways to clarification?

Heavy Nuclei :

How safe is the ~10% uncertainty estimate of $\mathrm{N_{coll}}$ scaling ?

Can future RHIC data establish plasma effects at low pt ?

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to summarize : prompt photons provide

an interesting pQCD laboratory,

enlightening results, more to come