Probing nuclear pdfs via photon and heavy quark production

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Outline

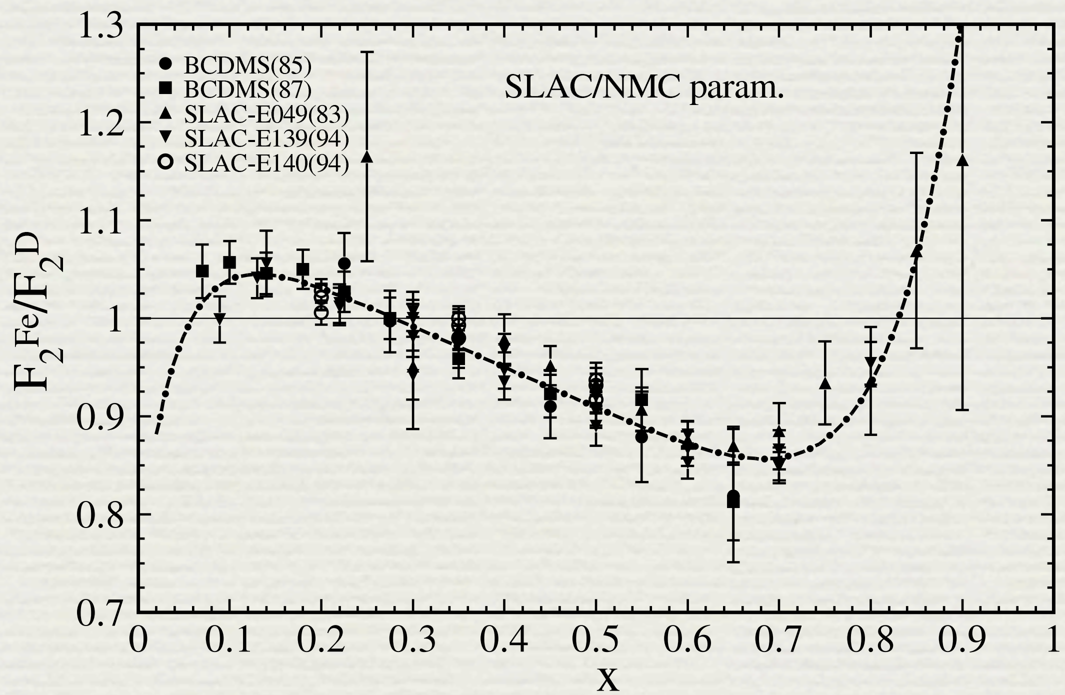
1. Constraining the gluon nPDF
2. Heavy quark energy loss

Constraining the gluon nPDF

(n)PDFs

- PDFs - integral part of all calculations involving colliding hadrons
- Non-perturbative objects - cannot be calculated by pQCD (lattice attempts on calculation not yet competitive)
- Extract PDFs via global fit to data & evolve using DGLAP

nPDFs: just using $f^{p/A} = \frac{Z}{A} f^p + \frac{A-Z}{A} f^n$ not enough



* Need a seperate global fit for nuclear targets

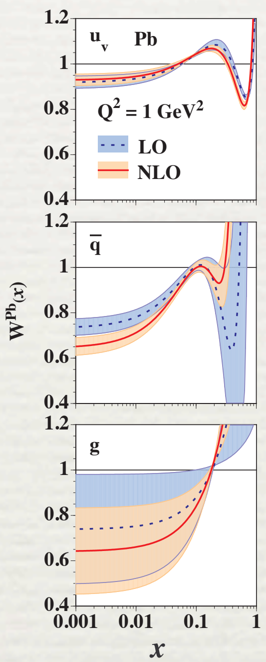
nPDF Fits on $l^{\pm}A$ & DY data

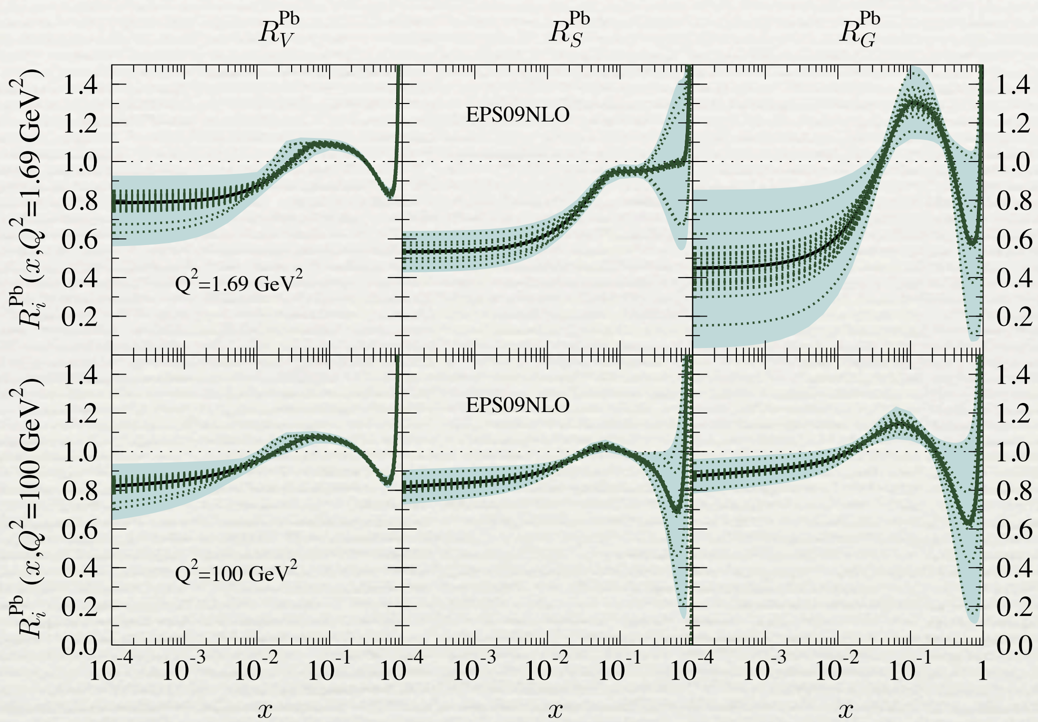
Global analyses of nPDFs by four groups:

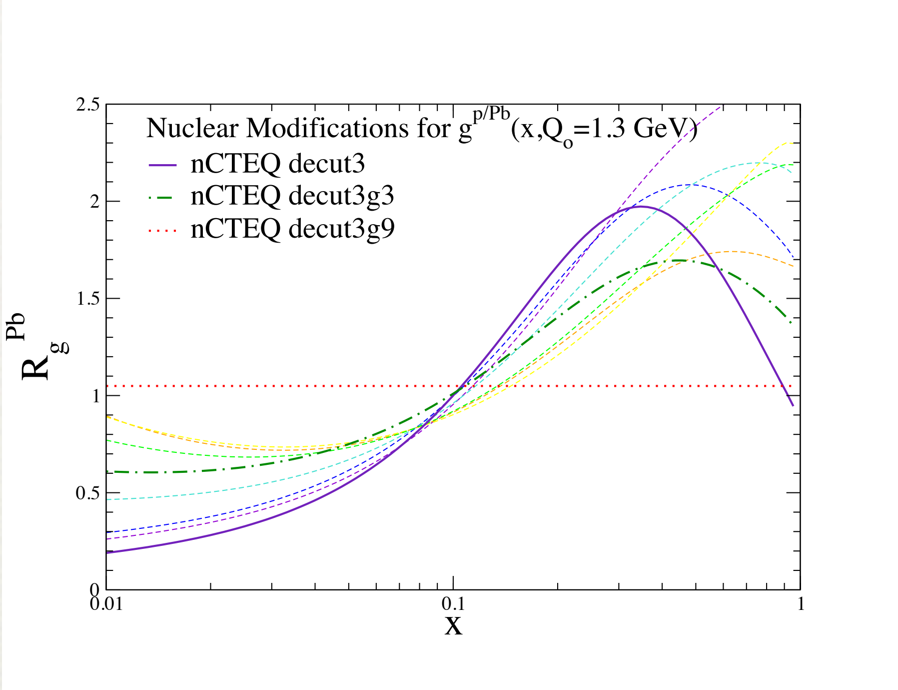
- HKN'07 [PRC76(2007)065207]
  LO, NLO, error PDFs, χ^2/dof=1.2
- EPS'09 [JHEP0904(2009)065]
  LO, NLO, error PDFs, χ^2/dof=0.8
- DS'04[PRD69(2004)074028]
  first NLO analysis, no error PDFs, χ^2/dof=0.76
- nCTEQ [PRD80(2009)094004]
  NLO, same data as HKN'07 (up to cuts), no error PDFs (so far), χ^2/dof=0.95

	R	Nucleus	Experiment	EPS09	HKN07	DS04
DIS		D/p	NMC		O	
	A/D	4He	SLAC E139	O	O	O
			NMC95	O (5)	O	O
		Li	NMC95	O	O	
		Be	SLAC E139	O	O	O
		C	EMC-88, 90		O	
			NMC 95	O	O	O
			SLAC E139	O	O	O
			FNAL-E665		O	
		N	BCDMS 85		O	
			HERMES 03		O	
		Al	SLAC E49		O	
			SLAC E139	O	O	O
		Ca	EMC 90		O	
			NMC 95	O	O	O
			SLAC E139	O	O	O
			FNAL-E665		O	
		Fe	SLAC E87		O	
			SLAC E139	O (15)	O	O
			SLAC E140		O	
			BCDMS 87		O	
		Cu	EMC 93	O	O	
		Kr	HERMES 03		O	
		Ag	SLAC E139	O	O	O
		Sn	EMC 88		O	
		Au	SLAC E139	O	O	O
			SLAC E140		O	
		Pb	FNAL-E665		O	
	A/C	Be	NMC 96	O	O	O
		Al	NMC 96	O	O	O
		Ca	NMC 95		O	
			NMC 96	O	O	O
		Fe	NMC 96	O	O	O
		Sn	NMC 96	O (10)	O	O
		Pb	NMC 96	O	O	O
	A/Li	C	NMC 95	O	O	
		Ca	NMC 95	O	O	
DY	A/D	C	FNAL-E772	O	O	O
		Ca		O (15)	O	O
		Fe		O (15)	O	O
		W		O (10)	O	O
	A/Be	Fe	FNAL E866	O	O	
		W		O	O	
π pro	dA/pp	Au	RHIC-PHENIX	O (20)		

The Nuclear Gluon Distribution







$$R_g^A = \frac{g^{p/A}(x,Q)}{g^p(x,Q)}$$

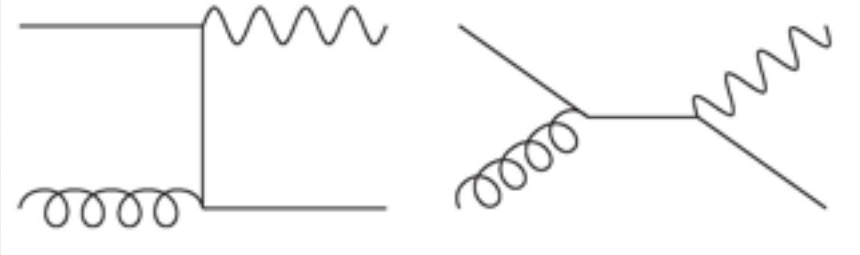
- Gluon nPDF : weakly constrained by data $\rightarrow$ large error bands !
- Plots HKN: [PRC76(2007)065207],EPS: [JHEP0904(2009)065] ,nCTEQ: [arXiv:1012.1178]

Hard Processes Constraining $g^{p/A}(x,Q)$

- Inclusive jet data (like Tevatron for free gluon)
- Inclusive hadron production
- Heavy quark ; Quarkonium production
- Isolated direct photons
- Direct Photons + jet
- **Direct Photons + Heavy Quark Jet**

γ+Q - how are they produced?

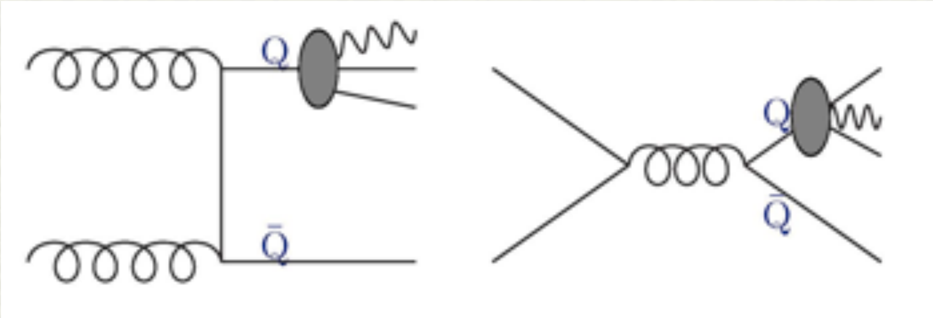
- To Leading Order - $\mathcal{O}(\alpha\alpha_s)$
  - Compton Subprocess $g + Q \to Q + \gamma$



- To Next to Leading Order - $\mathcal{O}(\alpha\alpha_s^2)$
  - Real Corrections - 2 → 3 body scattering subprocesses

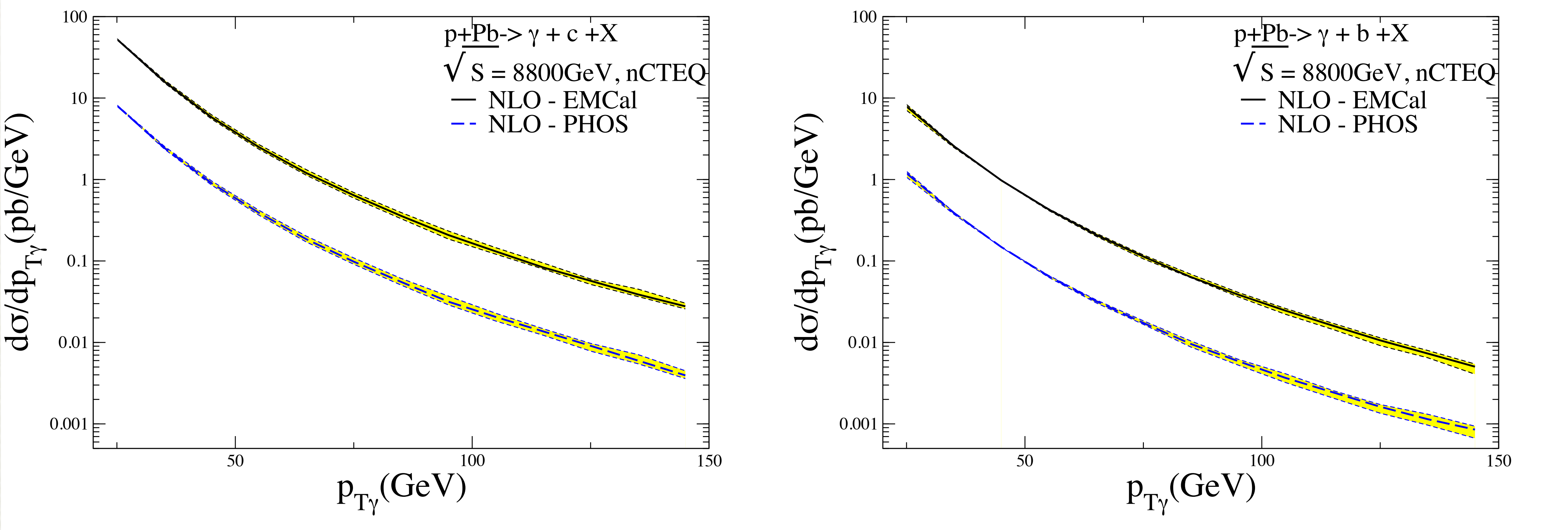
$$
\begin{array}{ll}
g + Q \to g + Q + \gamma & g + g \to Q + \bar{Q} + \gamma \\
Q + q \to q + Q + \gamma & Q + \bar{q} \to Q + \bar{q} + \gamma \\
Q + Q \to Q + Q + \gamma & Q + \bar{Q} \to Q + \bar{Q} + \gamma \\
q + \bar{q} \to Q + \bar{Q} + \gamma &
\end{array}
$$

  - Virtual Corrections -interference between LO Born diagram and virtual diagrams
- Via Fragmentation:



γ+Q at the LHC (p-Pb)

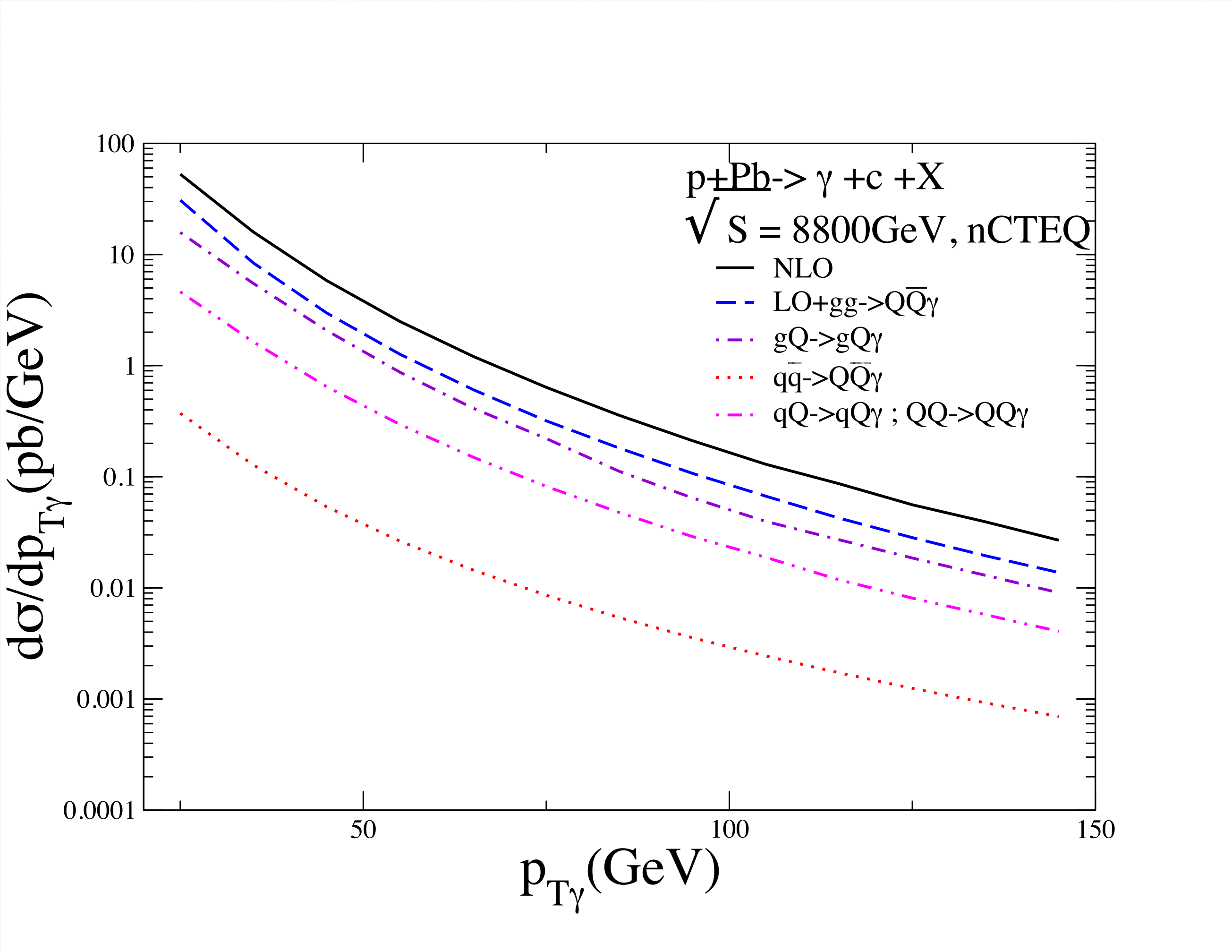
$$p_{T\gamma} > 20\ \text{GeV}, p_{TQ} > 15GeV, |y_\gamma| < 0.12, |y_Q| < 0.7$$



- σ sufficiently large for a measurement

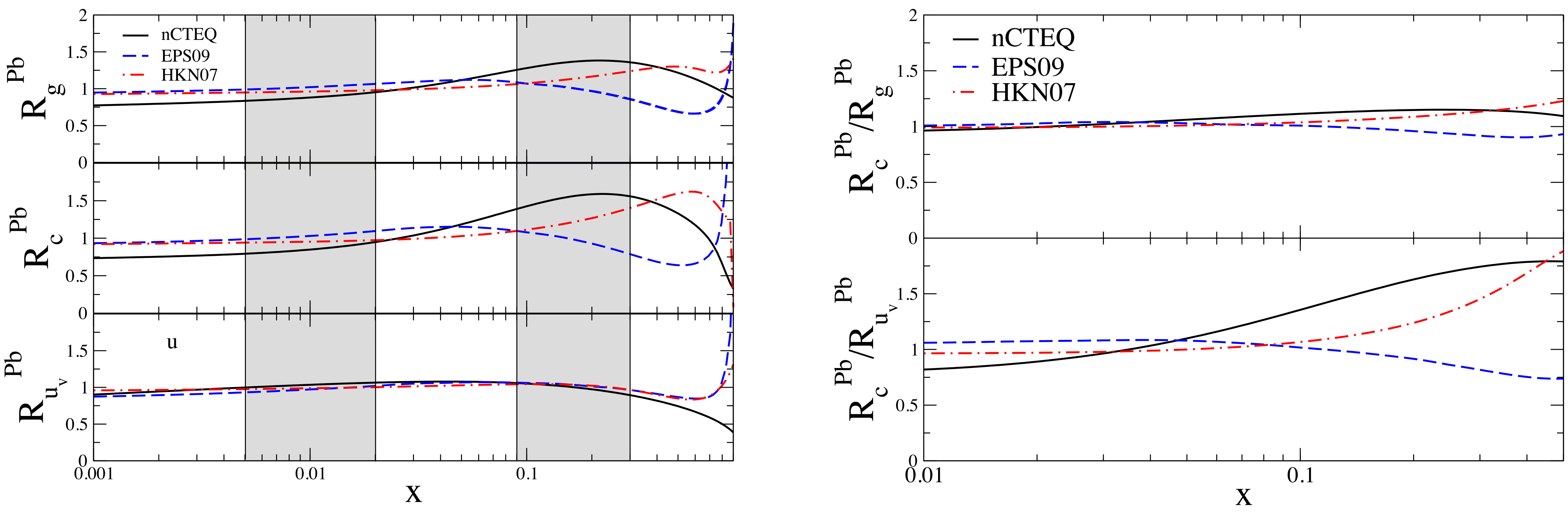
	σ^{tot}	N_{event}
$\gamma + c$ PHOS	131 pb	2700
$\gamma + b$ PHOS	20 pb	400
$\gamma + c$ EMCal	684 pb	14200
$\gamma + b$ EMCal	131 pb	2700

Subprocess Contributions



- Over 80 % of cross-section comes from gluon and/or HQ initiated subprocesses

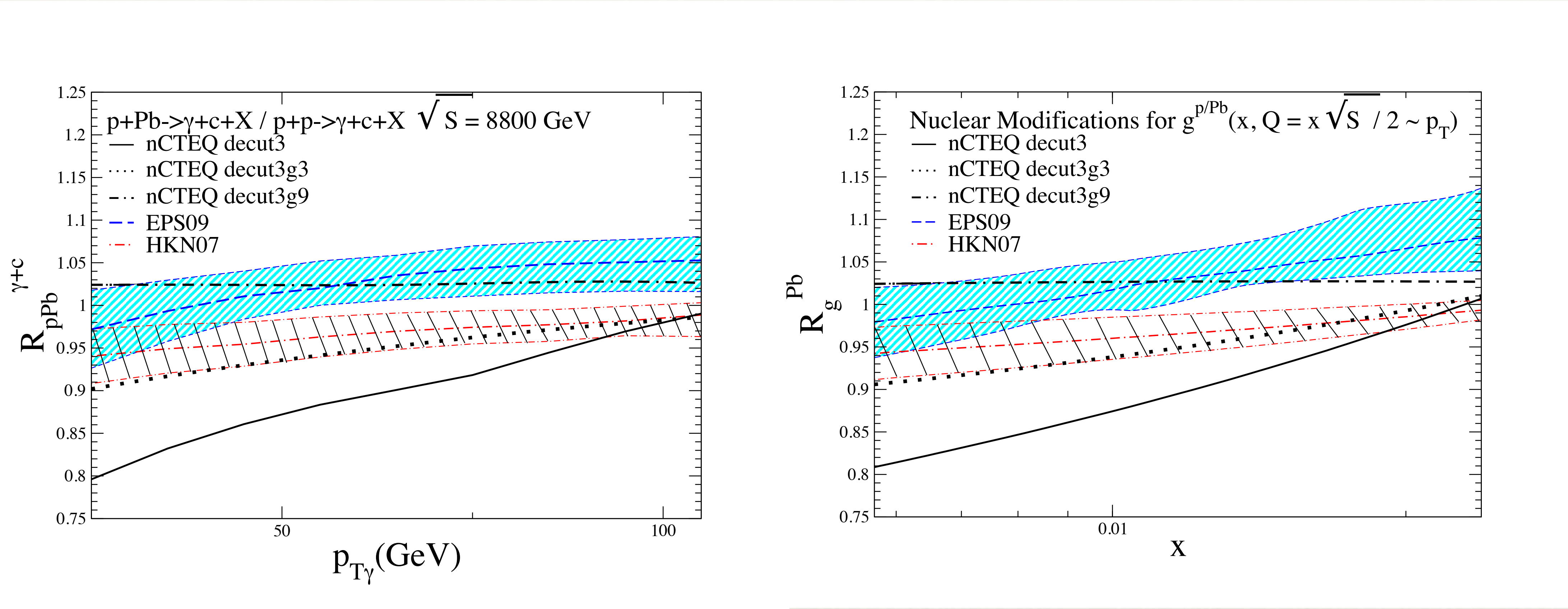
charm nPDF



- Standard approach: HQ nPDFs are generated radiatively → $R_g^{Pb} \simeq R_c^{Pb}$

γ+Q - constraining the gluon nPDF

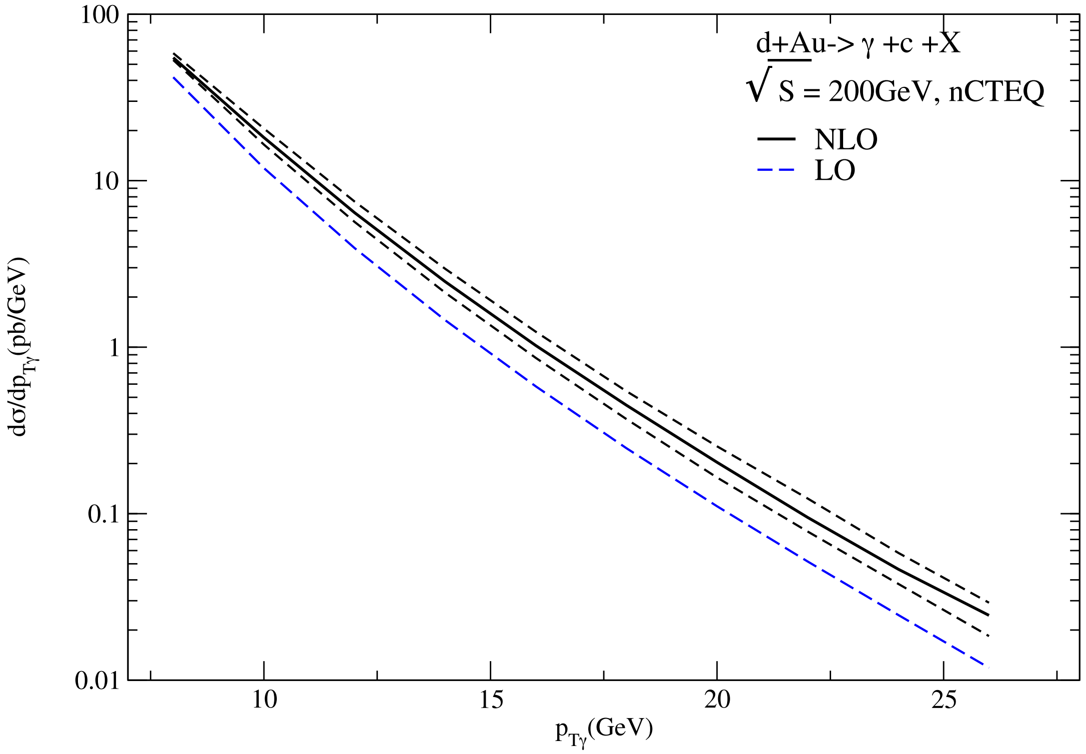
$$R_{pA}^{\gamma Q} = \frac{\sigma\,(pA \to \gamma\ Q\ X)}{A\ \sigma\,(pp \to \gamma\ Q\ X)}$$

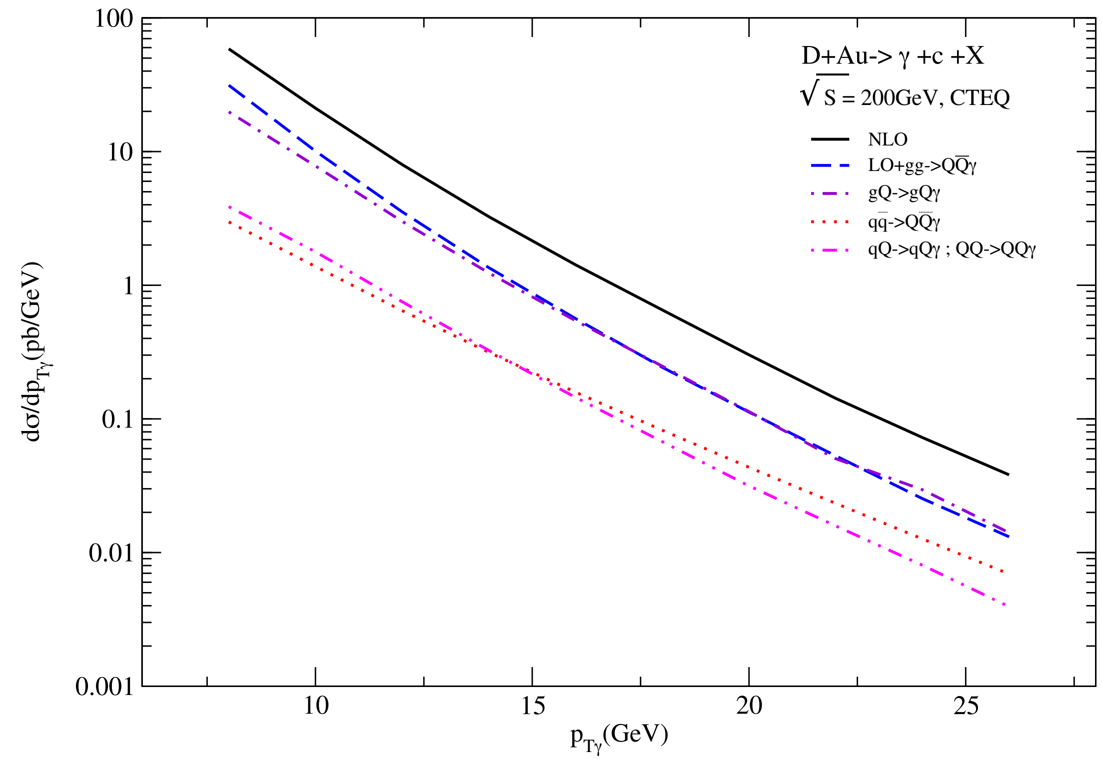


- $R_{pA}^{\gamma Q} \simeq R_g^{Pb}$ - in the x region probed at ALICE
- Measurements of γ+Q with appropriate error bars will allow to distinguish between the different nPDF sets and place useful constraints on the gluon nPDF [arXiv:1012.1178]

γ+Q at RHIC (d-Au)

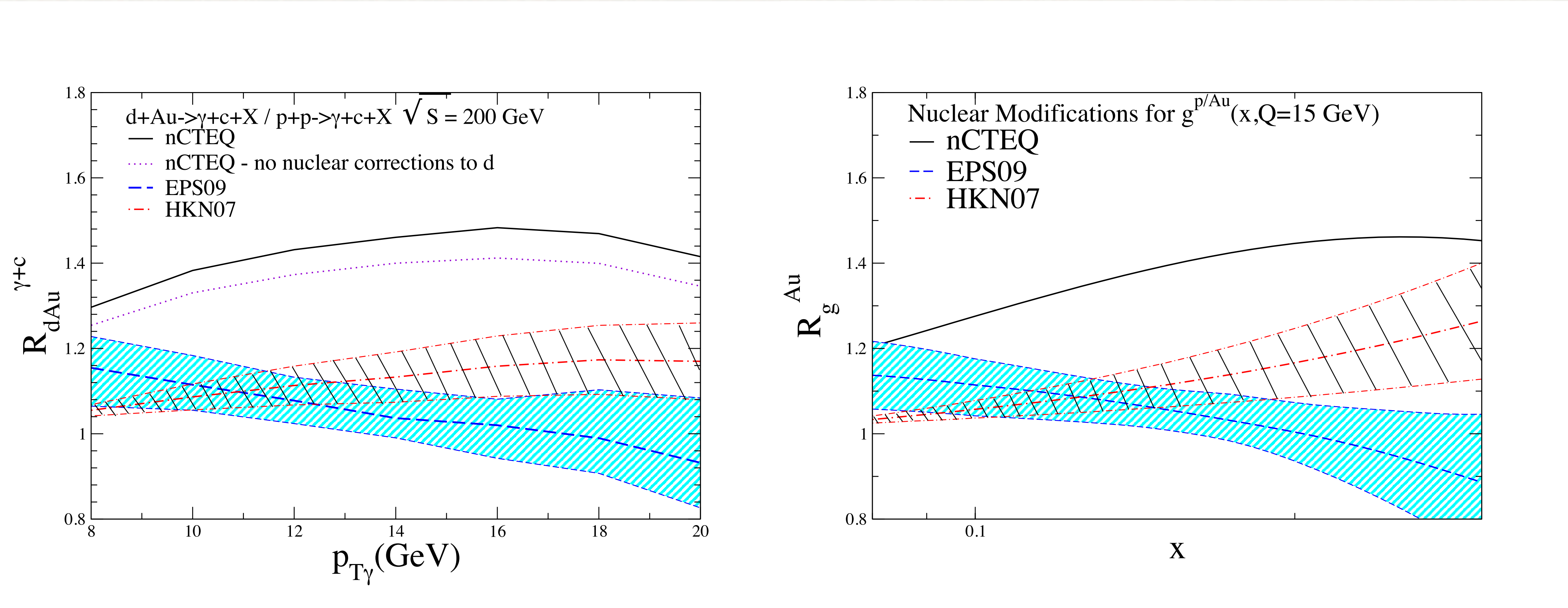
$$p_{T\gamma} > 7 \text{ GeV}, p_{TQ} > 5GeV, |y_\gamma| < 0.35, |y_Q| < 0.8$$





- $\sigma^{tot}_{\gamma+c} = 190pb$; naive event estimate - $\mathcal{N}_{events} = \sigma^{tot}_{\gamma+c}\mathcal{L}^{integ} \sim 55000$
- Again g & Q initiated subprocesses dominate

Constraining the gluon nPDF



- At RHIC higher x region is probed
- Complementary information to ALICE

γ+Q measurements in p-A collisions can reduce the gluon nPDF uncertainty when applied to a global fit

Heavy quark energy loss

AA Collisions

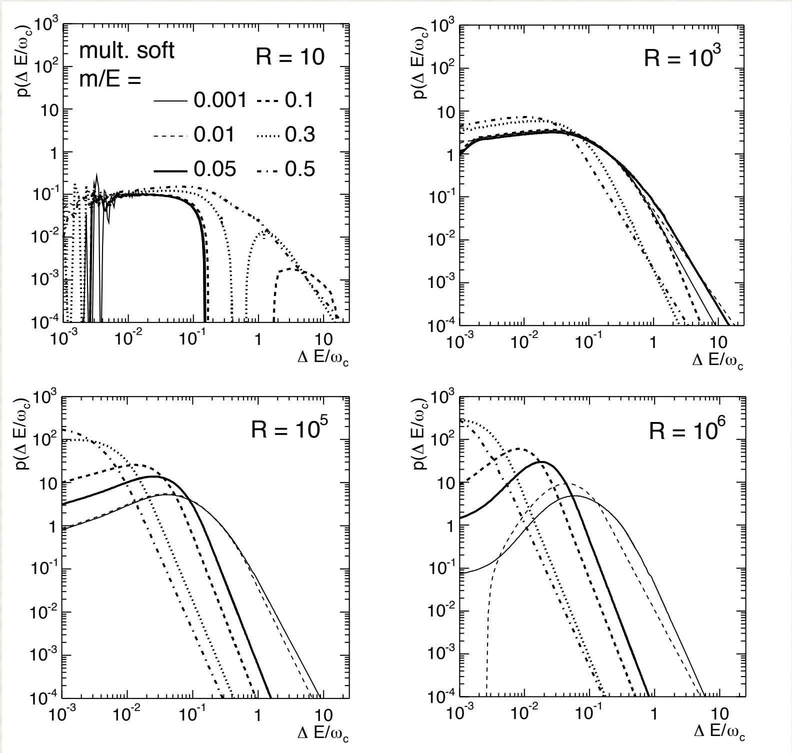
- QGP/Hot Matter created in nucleus-nucleus collisions
- Jet Quenching observed at RHIC and at the LHC
- Single particle inclusive x-section not enough
- Need more differential observables to quantify amount of energy loss, e.g. γ + jet correlations [**X.-N. Wang, Z. Huang, I. Sarcevic (hep-ph/9605213), F. Arleo, P. Aurenche, Z. Belghobsi, J.-P. Guillet (hep-ph/041008)**]; Dijet correlations

γ+Q in A-A Collisions

* γ is medium insensitive → can gauge initial energy of jet
* help clarify energy loss in the heavy quark sector ($\varepsilon_q > \varepsilon_c > \varepsilon_b$)[**Y. L. Dokshitzer, D.E. Kharzeev**]

γ+Q in A-A Collisions

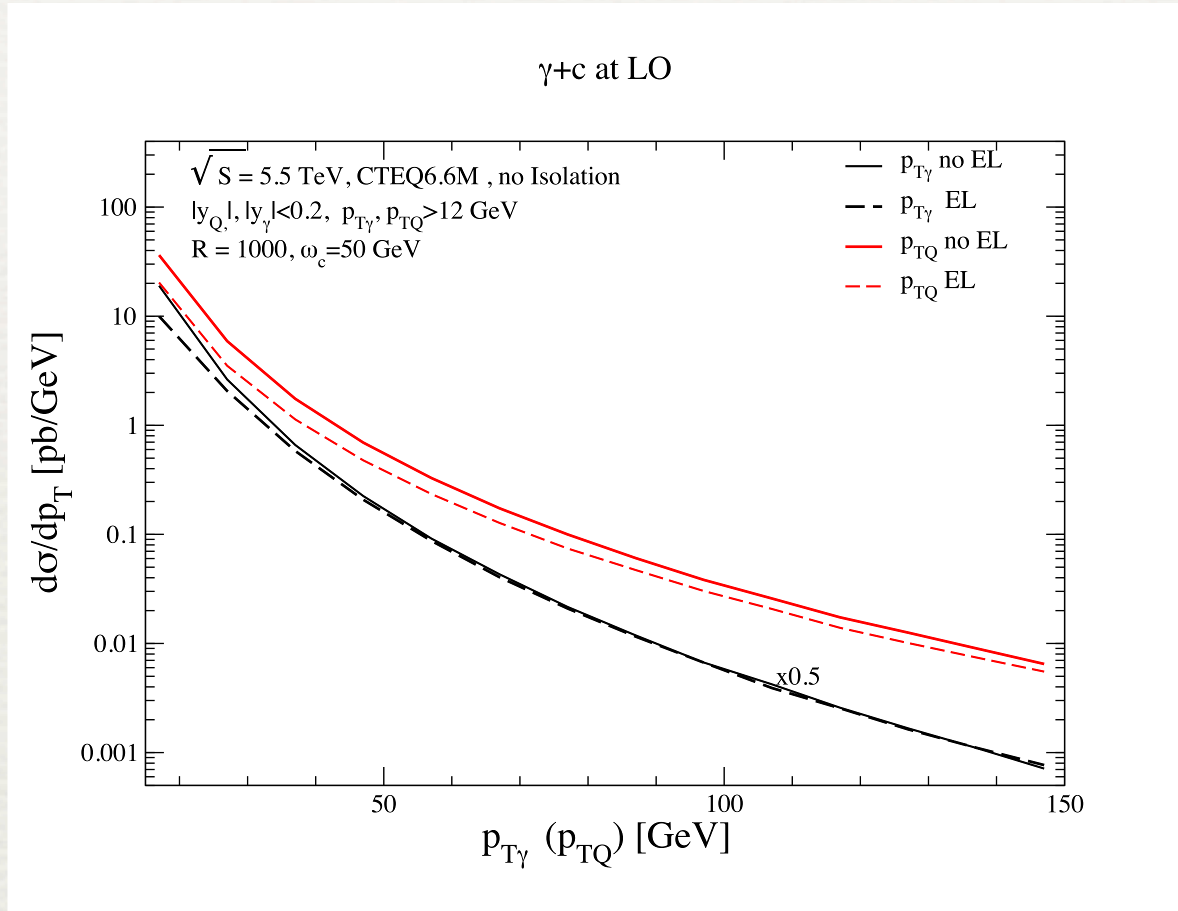
- Modify E_Q^{vac} so that $E_Q^{med} = E_Q^{vac} - \epsilon_Q$
- ϵ_Q computed on an event by event basis, with quenching weight obtained perturbatively [Armesto Dainese Salgado Wiedemann (arXiv:hep-ph/0501225)]
  - $P(\epsilon) = p_0\delta(\epsilon) + p(\epsilon)$
  - through multiple soft scattering - BDMPS-Z
  - Mass dependence enters as - m/E



- Parton keeps it's direction:

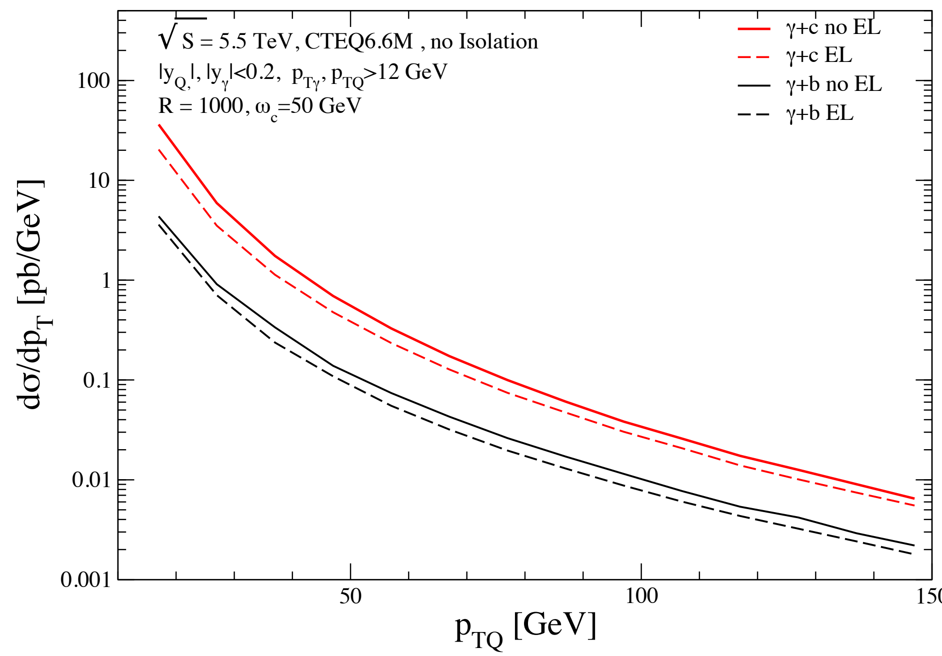
$$p^{vac} = p_T(\cosh y, \vec{e}_T, \sinh y) \rightarrow p^{med} = [p_T - \epsilon](\cosh y, \vec{e}_T, \sinh y)$$

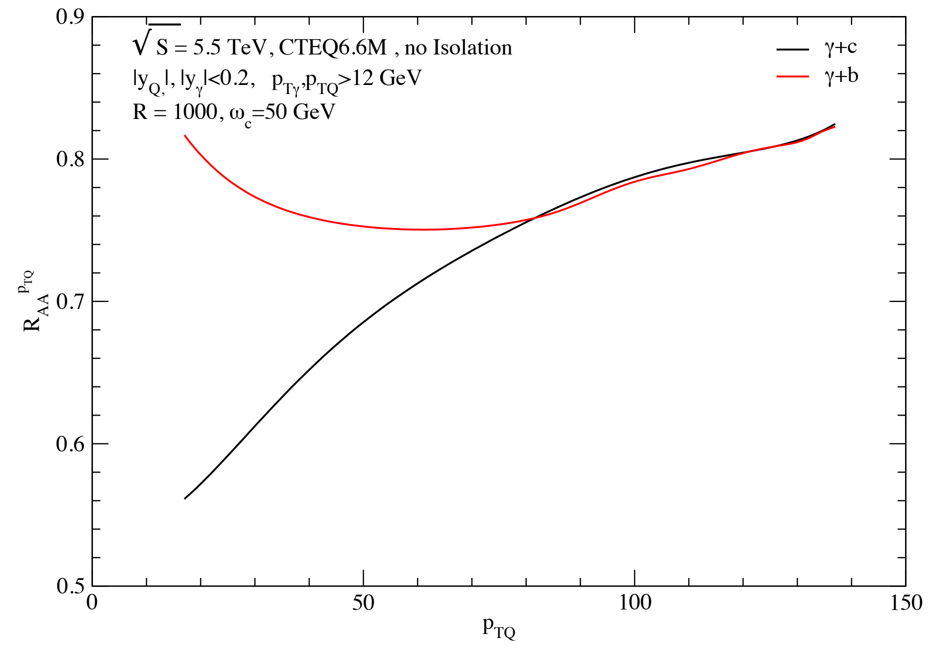
energy loss γ+Q - LO



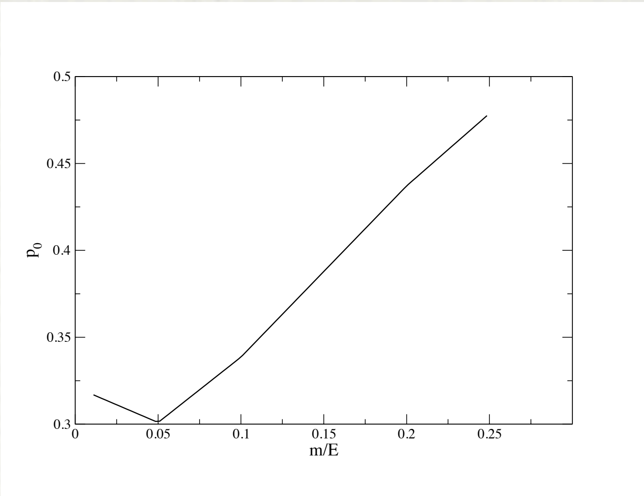
- Energy loss in $\frac{d\sigma}{dp_{TQ}}$ spectrum
  - manifests in horizontal shift between EL & no EL curve
- $\frac{d\sigma}{dp_{T\gamma}}$ spectrum unchanged, apart from at low $p_{T\gamma}$ due to cuts

Comparing γ+b & γ+c



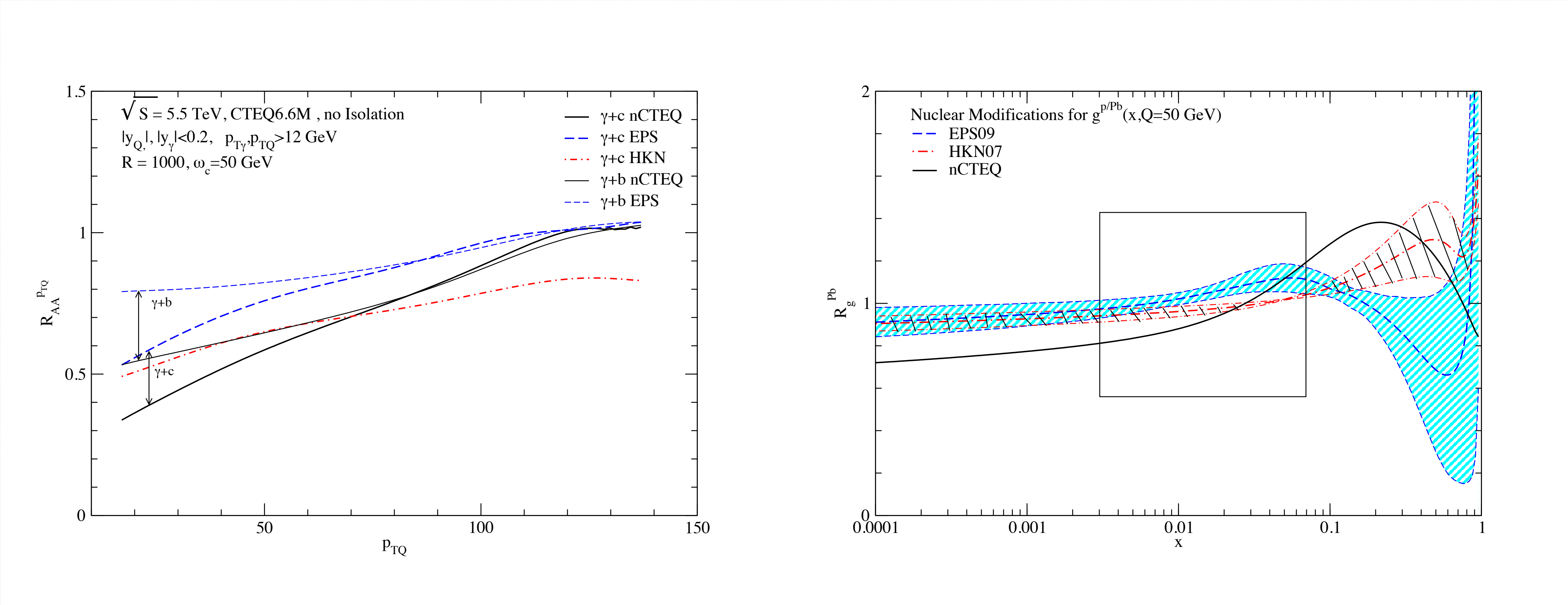


$$R^{*p_{TQ}}_{AA} = \frac{\frac{d\sigma^{Med}(pp\to\gamma\ Q\ \mathrm{X})}{p_{TQ}}}{\frac{d\sigma^{Vac}(pp\to\gamma\ Q\ \mathrm{X})}{p_{TQ}}}$$



- Effect visible at small p_{TQ}
- At larger p_{TQ} similar for both γ+b & γ +c
- Can revert to other more differential variables

nPDF effects



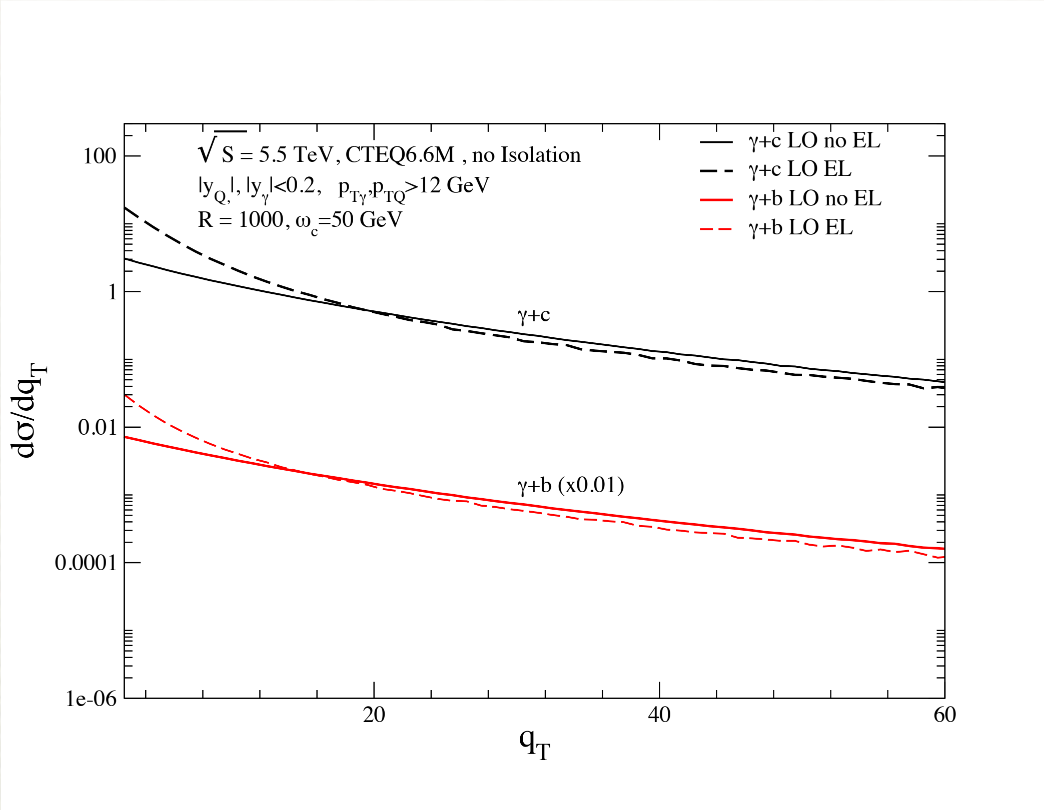
$$R_{AA}^{p_{TQ}} = \frac{1}{A^2} \frac{\frac{d\sigma^{Med}(AA\to\gamma\ Q\ \mathrm{X})}{p_{TQ}}}{\frac{d\sigma^{Vac}(pp\to\gamma\ Q\ \mathrm{X})}{p_{TQ}}}$$

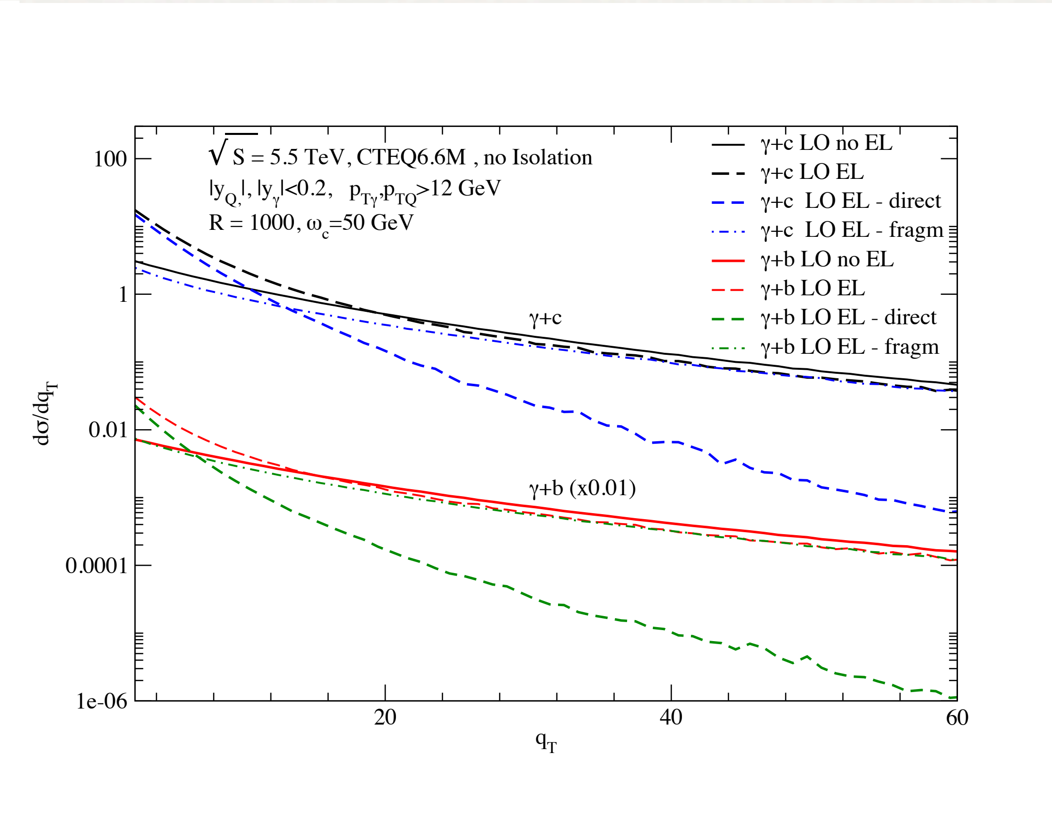
- x probed : $3\times10^{-3} \lesssim x \lesssim 0.07$
- Overlap of γ+b & γ +c within different nPDFs
- Need better constrained gluon nPDF!

2 particle final state observables

- The two-particle final state further offers a range of observables
  - Photon-jet energy asymmetry: $$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}, \Delta\phi > \pi/2$$
  - Momentum imbalance: $$z_{34} = -\frac{\vec{p}_{T\gamma} \cdot \vec{p}_{TQ}}{p_{T\gamma}^2}$$
  - Photon-jet pair momentum: $$q_\perp = |\vec{p}_{T\gamma} + \vec{p}_{TQ}|$$

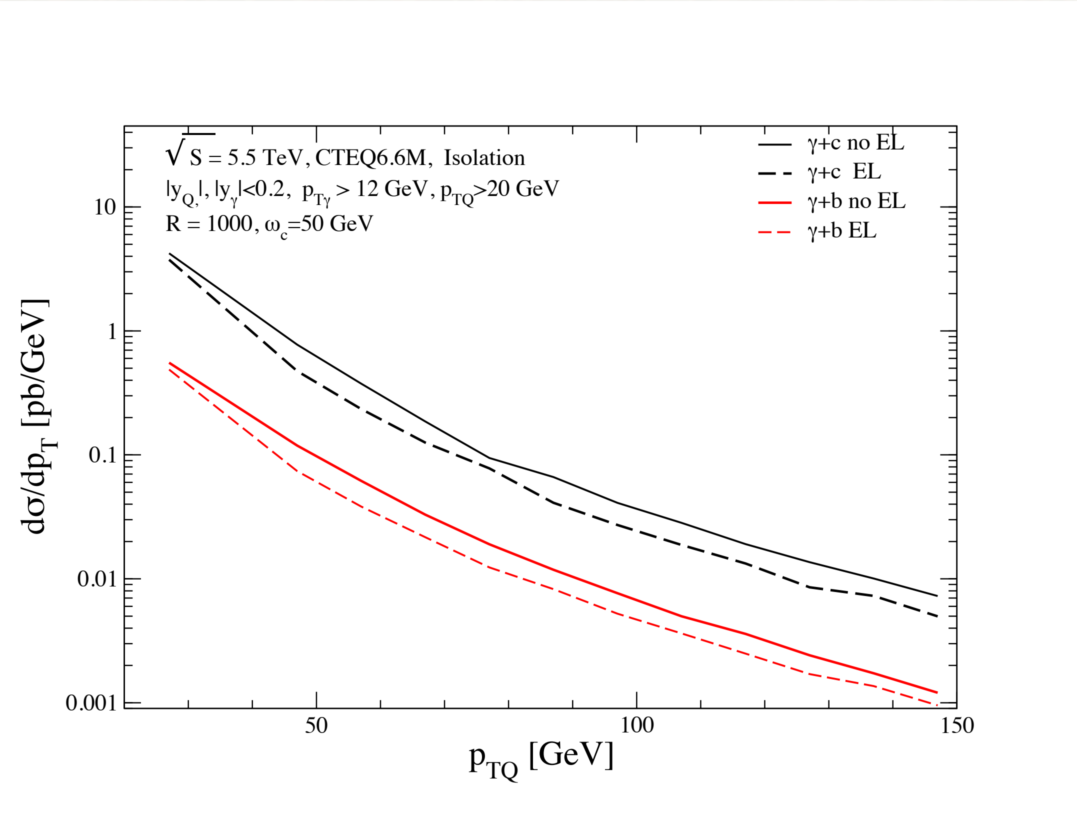
$q_T \approx \varepsilon$





- LO direct in Medium:
$$\begin{aligned} q_\perp &= (p_{T\gamma}) - p_{TQ} \\ &= (p_{TQ} + \epsilon) - p_{TQ} \\ &= \epsilon \end{aligned}$$
- LO direct Vacuum $\frac{d\sigma}{q_T} \neq 0$ only for $q_T = 0$ γ & Q always back-to-back
- $q_\perp^{FragmVac} = p_{TQ}(1-z)$, $\quad q_\perp^{FragmMed} = (1-z)p_{TQ} + z\epsilon$
- Need NLO

NLO EL



- Assume medium induced effects factorize from hard-scattering cross-section
- Short-distance part unmodified by the medium
- EL effects only in long distance final state, e.g. in fragmentation functions
- Work in progress → need to apply EL to Jet

In AA collisions γ+Q can be used for an estimate of the HQ energy loss & thus access the mass hierarchy of parton energy loss