PROBING GLUON NPDF WITH PHOTON+HEAVY QUARK PRODUCTION

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arXiv:1012.1178 [hep-ph]

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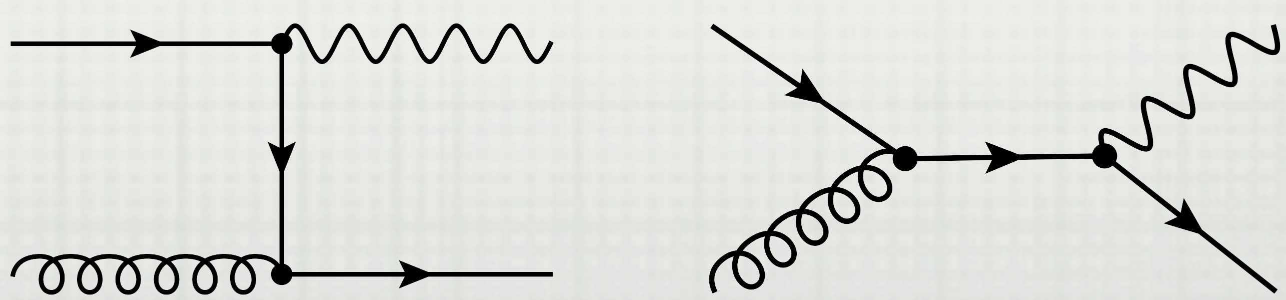
OUTLINE

1. Direct photon & heavy quark production
2. Constraining heavy quark PDF in pp collisions
3. Constraining nuclear gluon PDF
4. Conclusions and Outlook

DIRECT PHOTON - LO

- Direct photons
  - any photon produced during the hard scattering process or via fragmentation
  - photons escape confinement & probe the hard scattering
  - ideal to determine gluon PDFs
- Direct photons & heavy quark jets
  - photons + heavy quark jets simpler than with light quark jets - less contributing processes
  - more direct access to the gluon PDF
  - access to the heavy quark PDF
- Leading order Compton hard-scattering subprocess $\mathcal{O}(\alpha_s \alpha)$

$$g + Q \to Q + \gamma$$



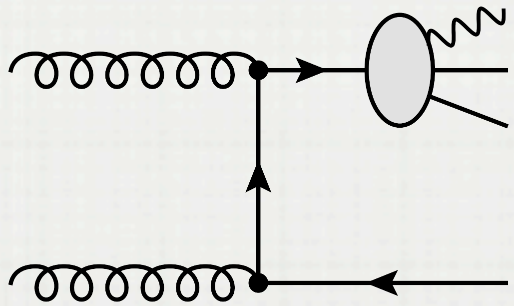
DIRECT PHOTON - LO

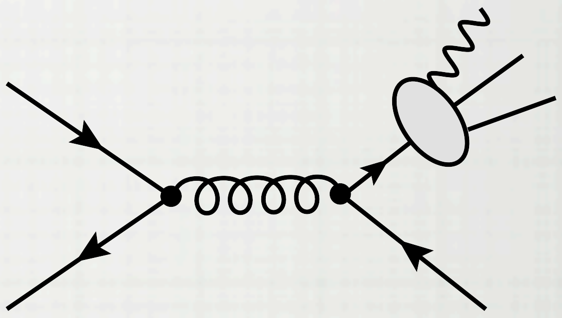
- Photon fragmentation contribution to leading order
  - photons emitted collinear to a quark → singularity
  - singularities absorbed in the fragmentation function $D_{\gamma/q,g}(x, \mu_F)$ & logs resumed via DGLAP
  - photon coupling to quark

$$D_{\gamma/q,g}(x, \mu_F) \sim \mathcal{O}(\alpha/\alpha_s)$$

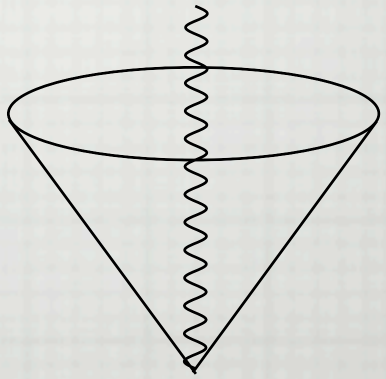
contributes already at leading order

$$\mathcal{O}(\alpha_s^2) \otimes D_{\gamma/q,g} \sim \alpha_s^2 \frac{\alpha}{\alpha_s} = \alpha_s \alpha$$





- Photon isolation suppresses fragmentation
  - isolation criteria necessary to separate direct photons from photons from hadronic decays e.g. $\pi^0 \rightarrow \gamma\gamma$
  - hadronic energy $E_h < E_{iso}$, separation radius $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$

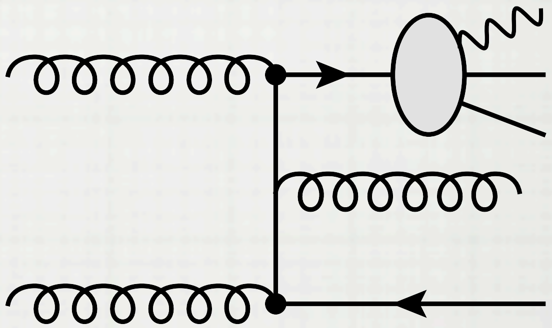


DIRECT PHOTON - NLO

- NLO real contributions $\mathcal{O}(\alpha_s^2\alpha)$

$$gQ \to Qg\gamma \qquad Q\bar{Q} \to Q\bar{Q}\gamma \qquad Qq \to Qq\gamma$$
$$gg \to Q\bar{Q}\gamma \qquad QQ \to QQ\gamma \qquad Q\bar{q} \to Q\bar{q}\gamma$$
$$q\bar{q} \to Q\bar{Q}\gamma$$

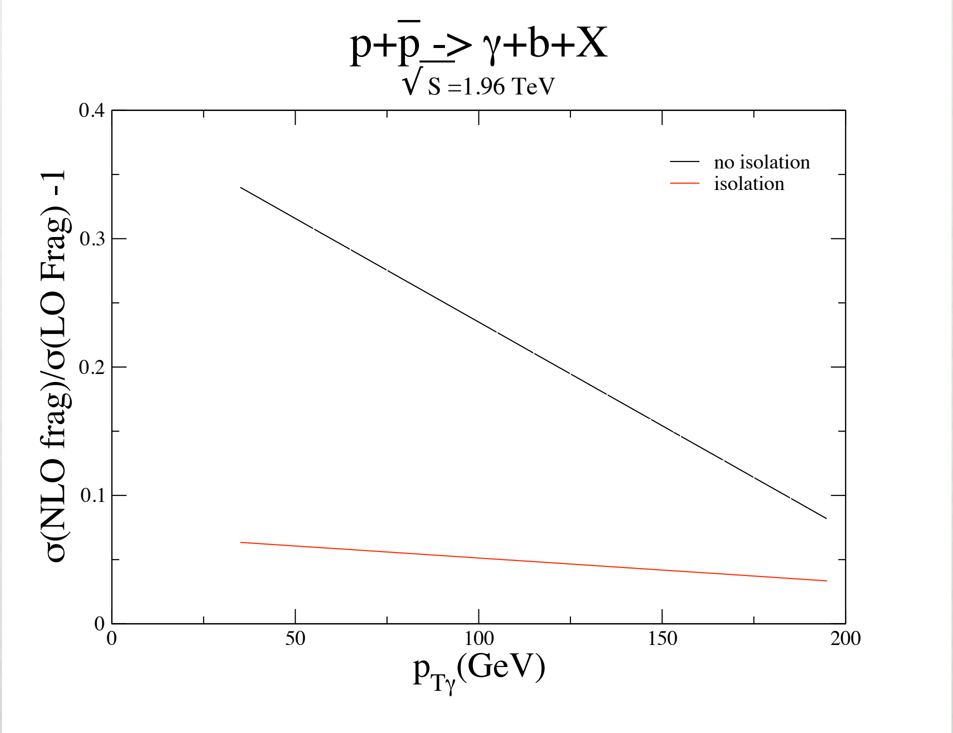
- Fragmentation contributions to NLO



  - fragmentation function convoluted with 2→3 process

$$\mathcal{O}(\alpha_s^3) \otimes D_{\gamma/q,g} \sim \mathcal{O}(\alpha_s^2\alpha)$$

  - without isolation NLO fragmentation increases cross-section by 30%
  - isolation reduces NLO fragmentation to a few %



HEAVY QUARK PDF

- Heavy quark PDF
  - usually no intrinsic heavy quark PDF at the initial scale $c(x, \mu = m_c) = 0$
  - heavy quark PDF at higher scale is generated via DGLAP from the gluon PDF

$$\frac{dc(x,Q)}{dt} = \frac{\alpha_s}{2\pi} \int \frac{dy}{y} \left[c(x/y) P_{QQ}(y) + g(x/y) P_{Qg}(y) \right]$$

  - some data (EMC charm structure function at high x) suggest presence of intrinsic charm in nucleons
  - non-perturbative models of intrinsic charm quark

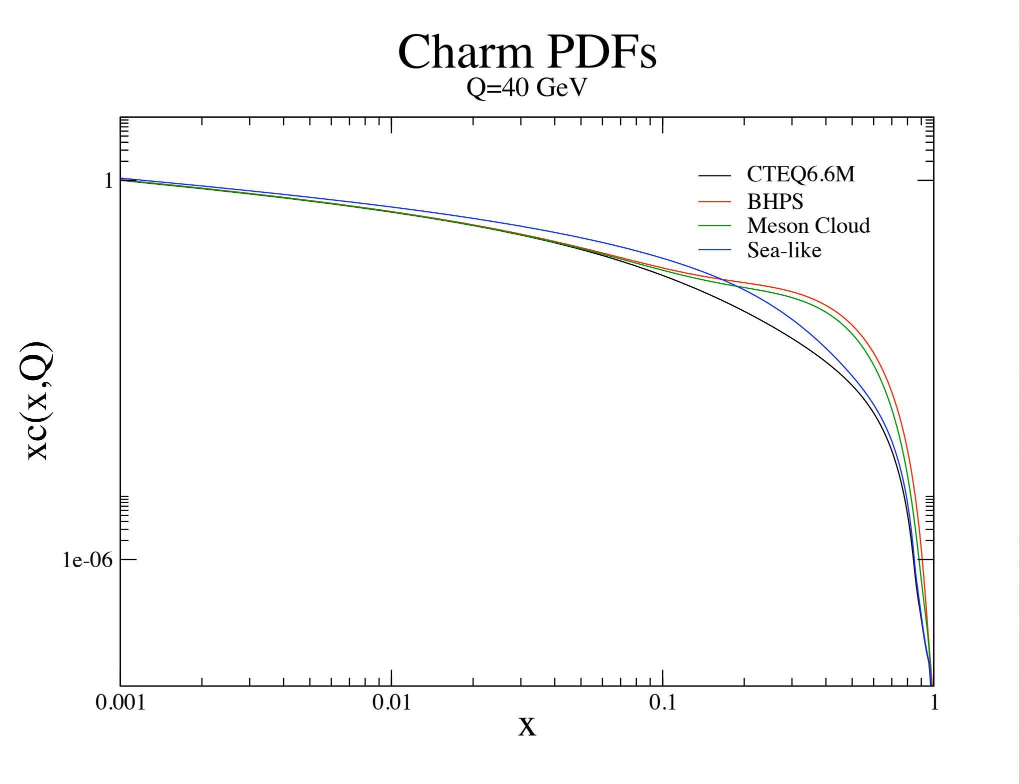
BHPS model (CTEQ6.6C0, CTEQ6.6C1)

[Brodsky et.al]

Meson Cloud model (CTEQ6.5C2, CTEQ6.5C3)

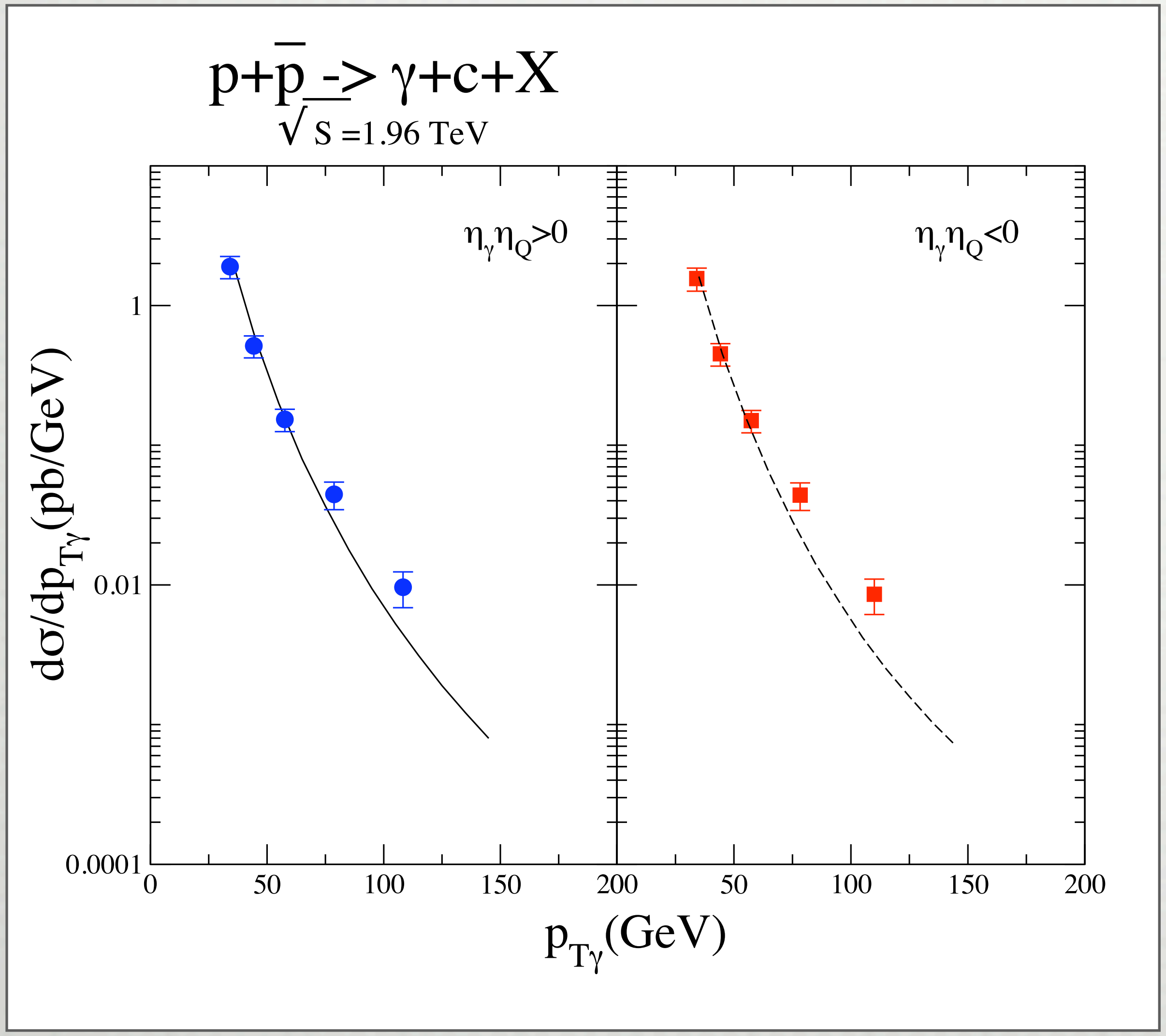
Sea-like model (CTEQ6.6C2, CTEQ6.6C3)

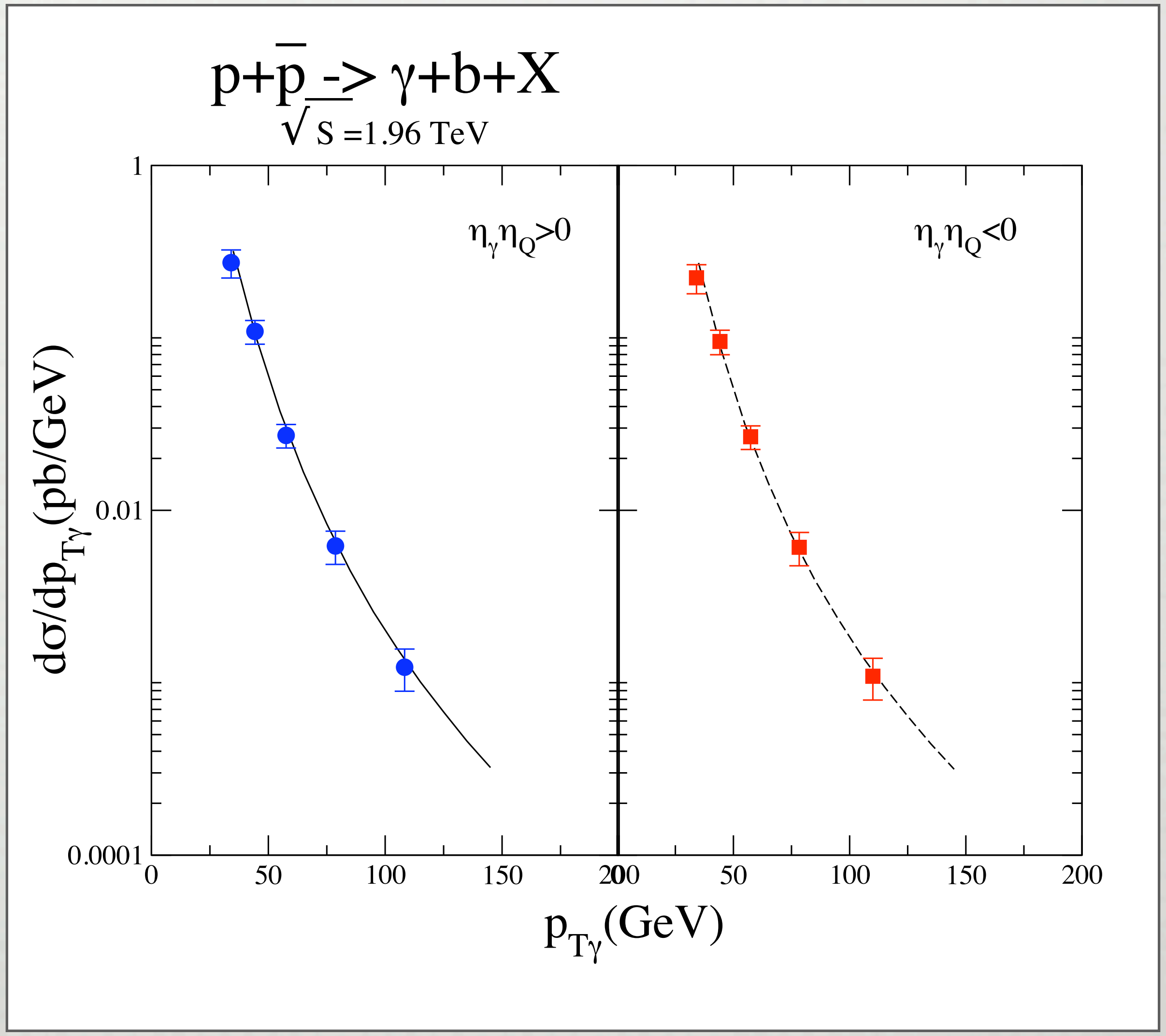
$$c(x) \sim \bar{d}(x) + \bar{u}(x)$$



TEVATRON-D0

- Direct photon in association with charm / bottom quark jets @ D0
  - comparison of NLO theory predictions with D0 measurements [arXiv:0901.3791, arXiv:0901.0739]
  - bottom quark agrees well but charm quark theory is off
  - discrepancy in photon+charm description allows for testing models of intrinsic charm





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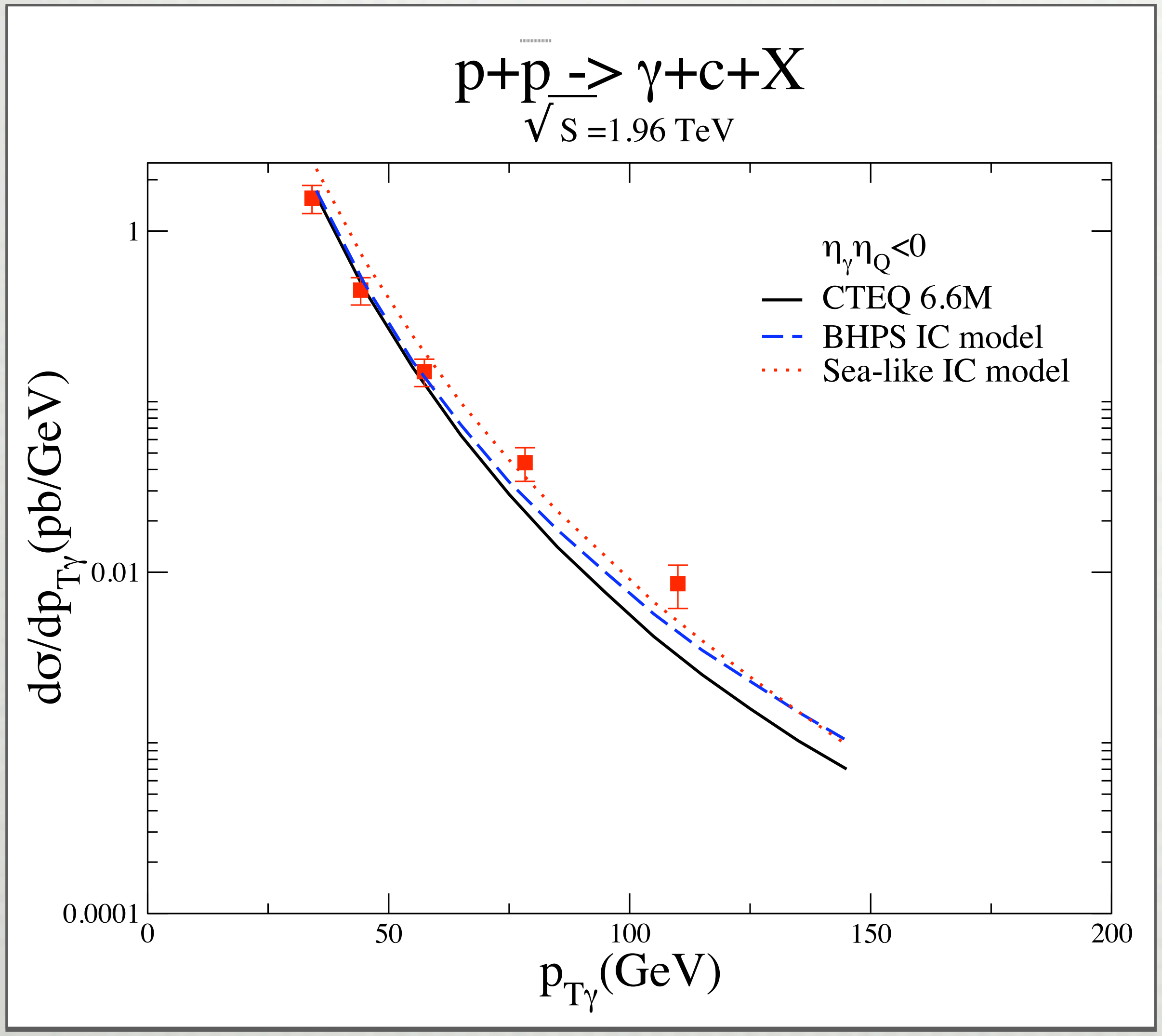
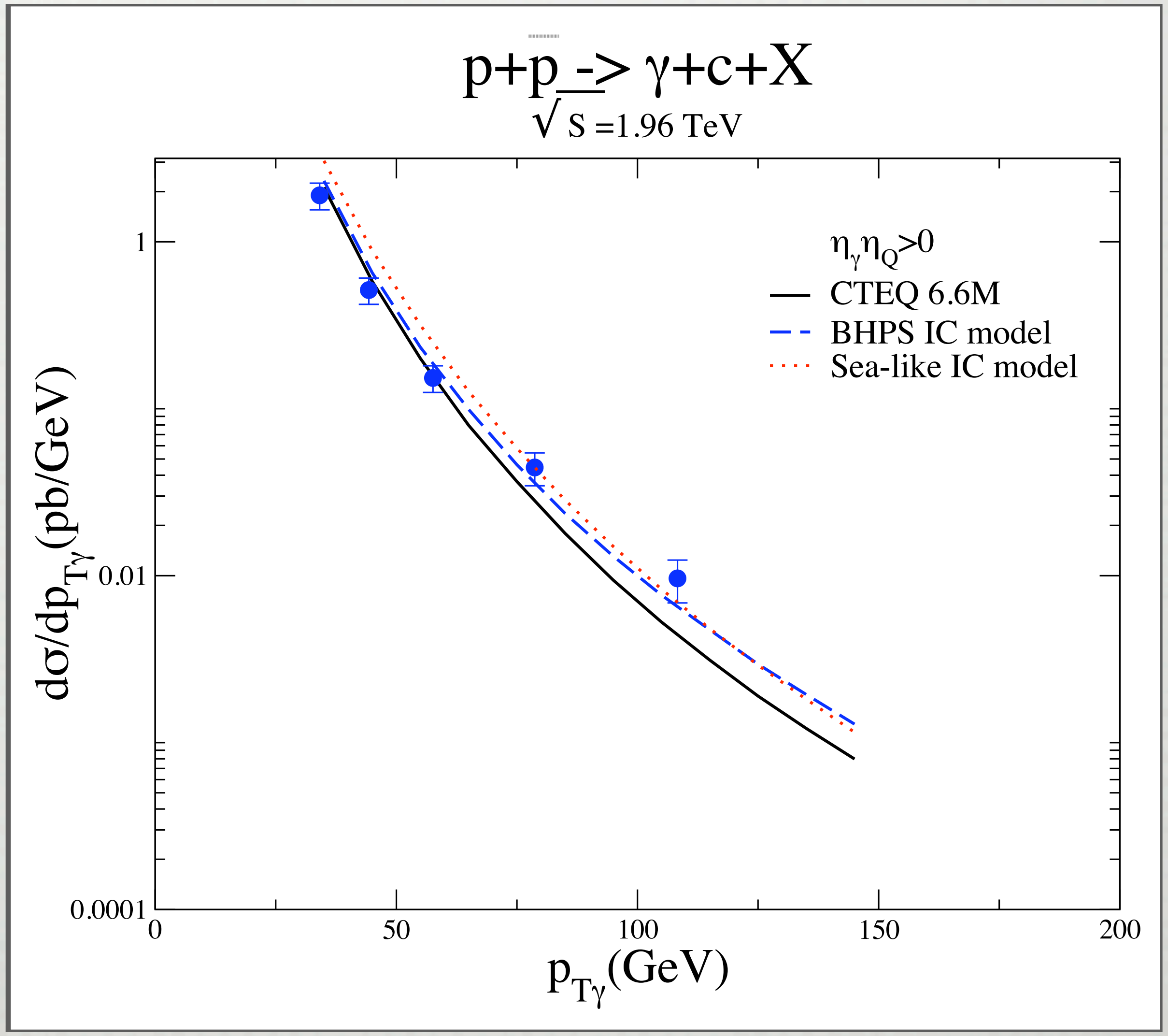
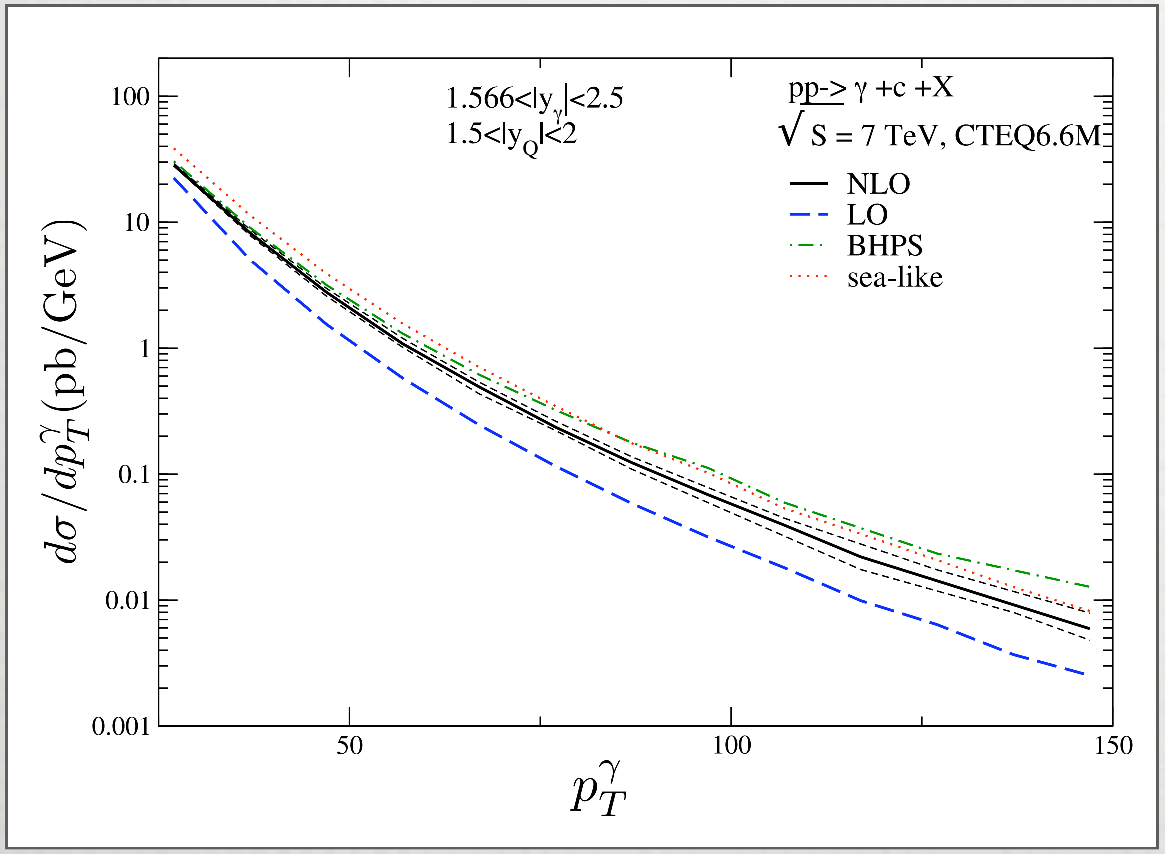


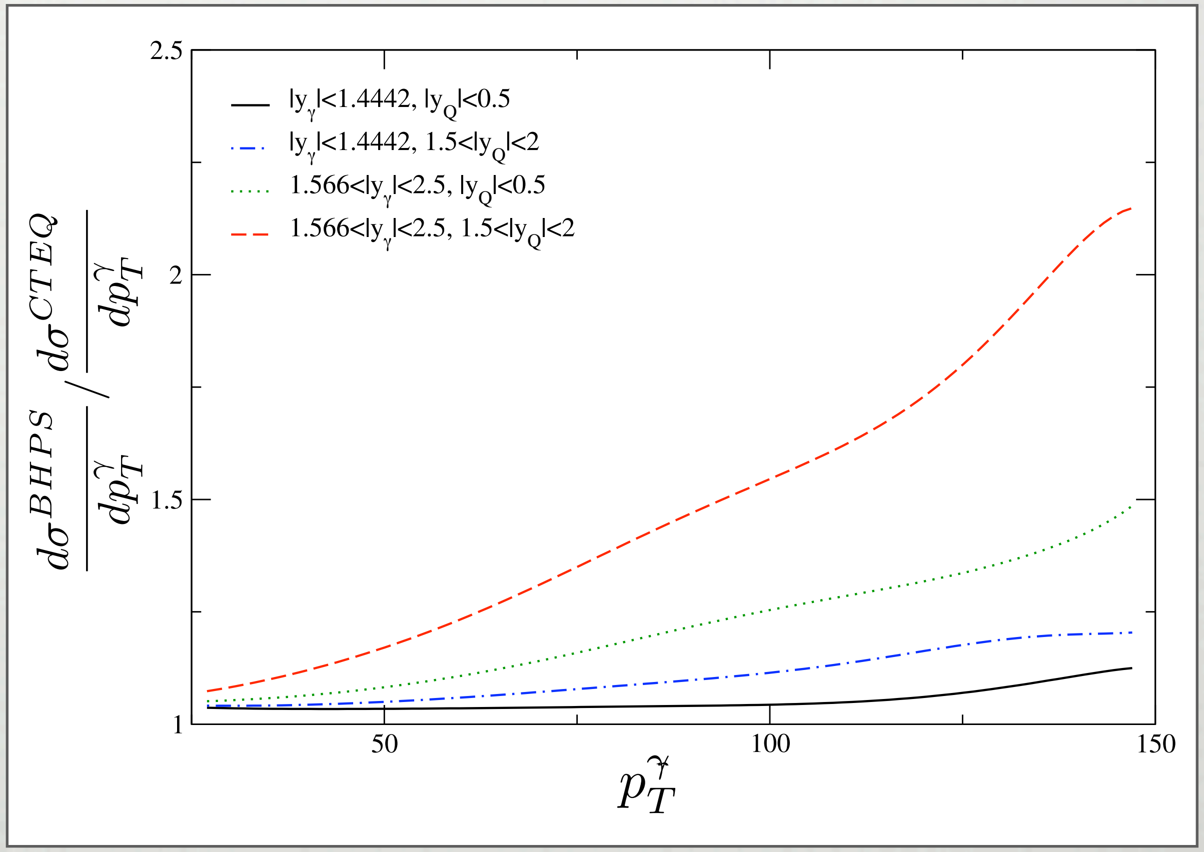


LHC-CMS

- Direct photon in association with charm / bottom quark jets @ CMS
  - CMS cuts on photon & HQ transverse momentum, rapidity & isolation cuts

	p_T min	Rapidity	Isolation
Photon	20 GeV	$\lvert y_\gamma \rvert < 1.4442$	R=0.4, p_T = 4.2GeV
		$1.56 < \lvert y_\gamma \rvert < 2.5$	
Heavy Jet	18 GeV	$\lvert y_Q \rvert < 2.0$	---





[CMS notes: CMS PAS EGM-10-005, CMS PAS BPH-10-009]

NPDFS

- CTEQ framework for nuclear PDF - based on CTEQ6M proton fit [arXiv:0907.2357]
  - functional form for bound protons same as for free proton PDF (restrict x to 0<x<1)

$$x\, f_k(x, Q_0) = c_0\, x^{c_1} (1-x)^{c_2} e^{c_3 x} (1 + e^{c_4} x)^{c_5} \qquad k = u_v, d_v, g, \bar{u} + \bar{d}, s, \bar{s}$$

$$\bar{d}(x, Q_0)/\bar{u}(x, Q_0) = c_0\, x^{c_1} (1-x)^{c_2} + (1 + c_3 x)(1-x)^{c_4}$$

  - coefficients with A-dependance (reduces to proton for A=1)

$$c_k \to c_k(A) \equiv c_{k,0} + c_{k,1} \left(1 - A^{-c_{k,2}}\right), \quad k = \{1, \ldots, 5\}$$

  - PDF for a nucleus with A-nucleons out of which Z-protons

$$f_i^{(A,Z)}(x, Q) = \frac{Z}{A} f_i^{p/A}(x, Q) + \frac{A-Z}{A} f_i^{n/A}(x, Q)$$

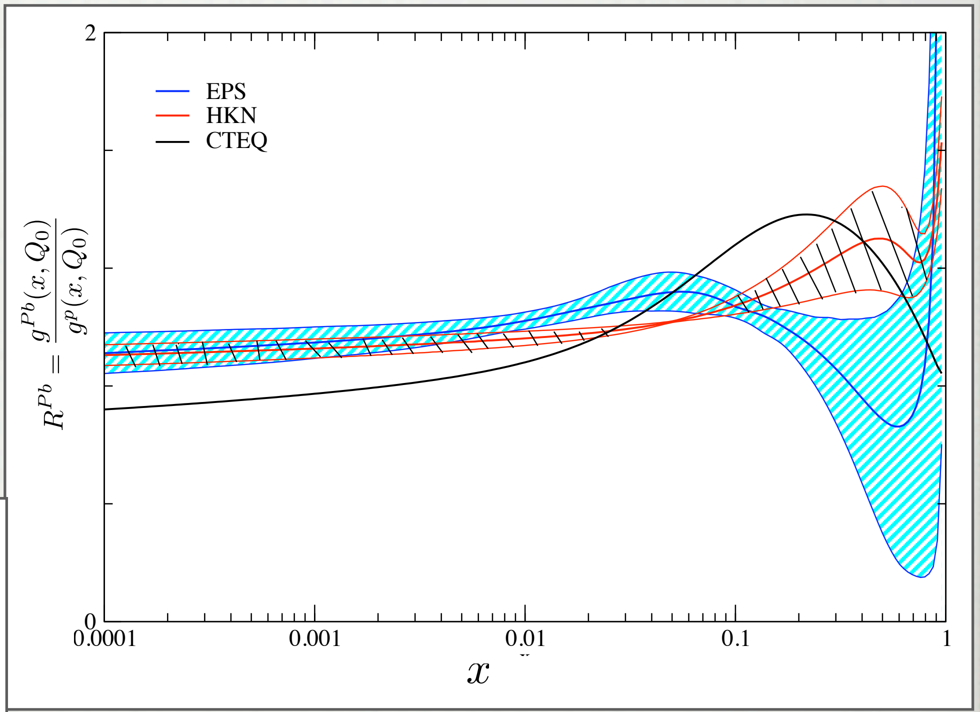
Note: PDF of neutron are related to the proton by isospin symmetry

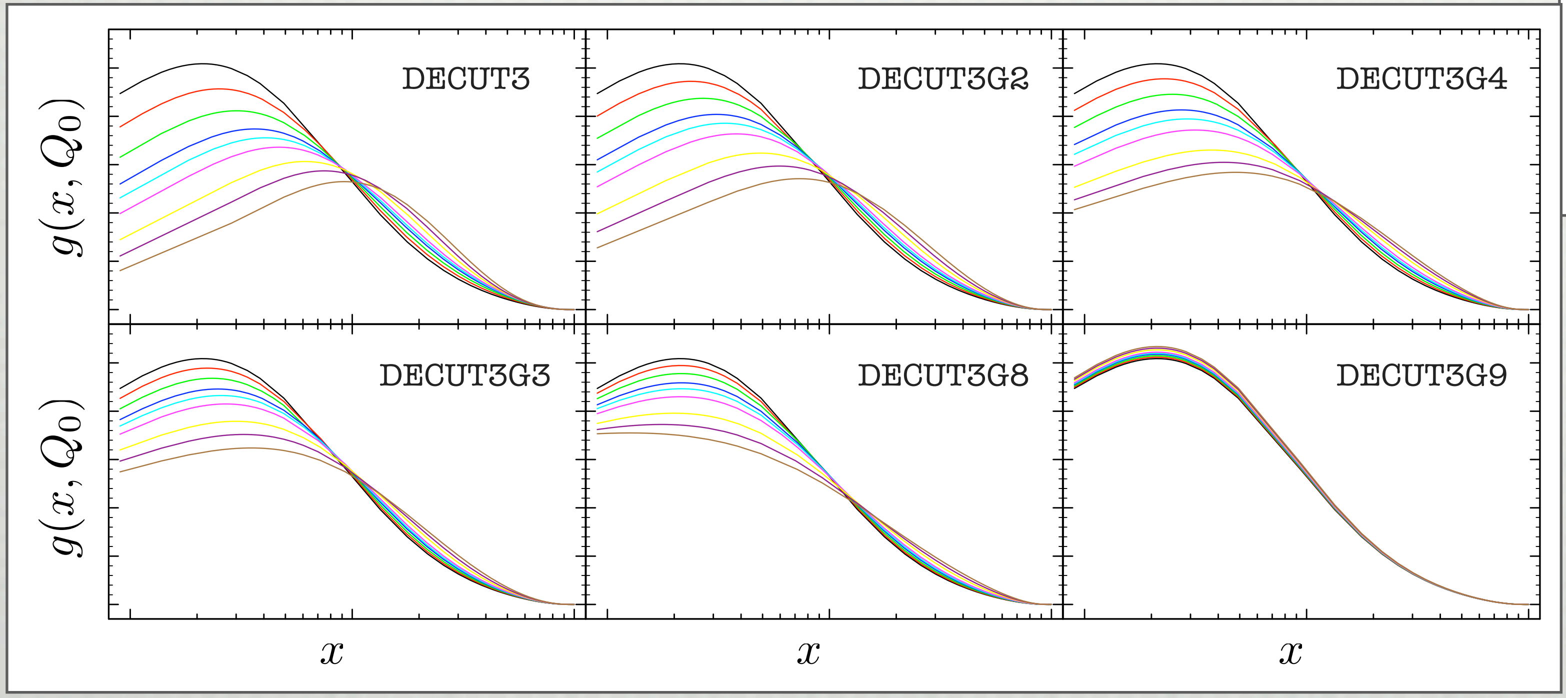
  - Input scale and other input parameters as in CTEQ6M proton analysis

$$Q_0 = m_c = 1.3\text{GeV} \qquad m_b = 4.5\,\text{GeV} \qquad \alpha_s(m_Z) = 0.118$$

NUCLEAR GLUON

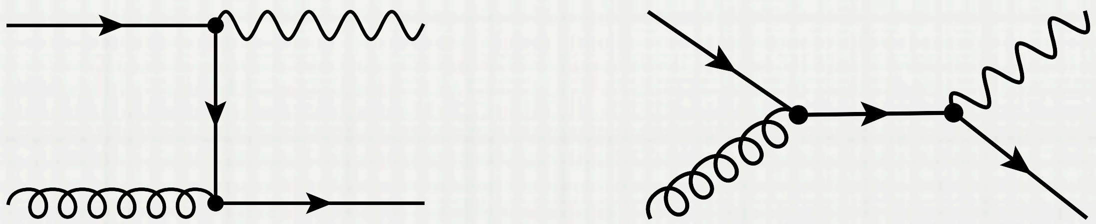
- Nuclear gluon PDF is badly constrained by data
  - only constrained by scale variations in Sn/C DIS data
  - uncertainty larger than indicated by error PDF of different nPDF analysis
- nCTEQ estimate of gluon nPDF uncertainty
  - vary gluon nPDF assumptions & parametrizations
  - large uncertainty for low x<0.1 in nCTEQ framework
  - need further data to constrain gluon nPDF



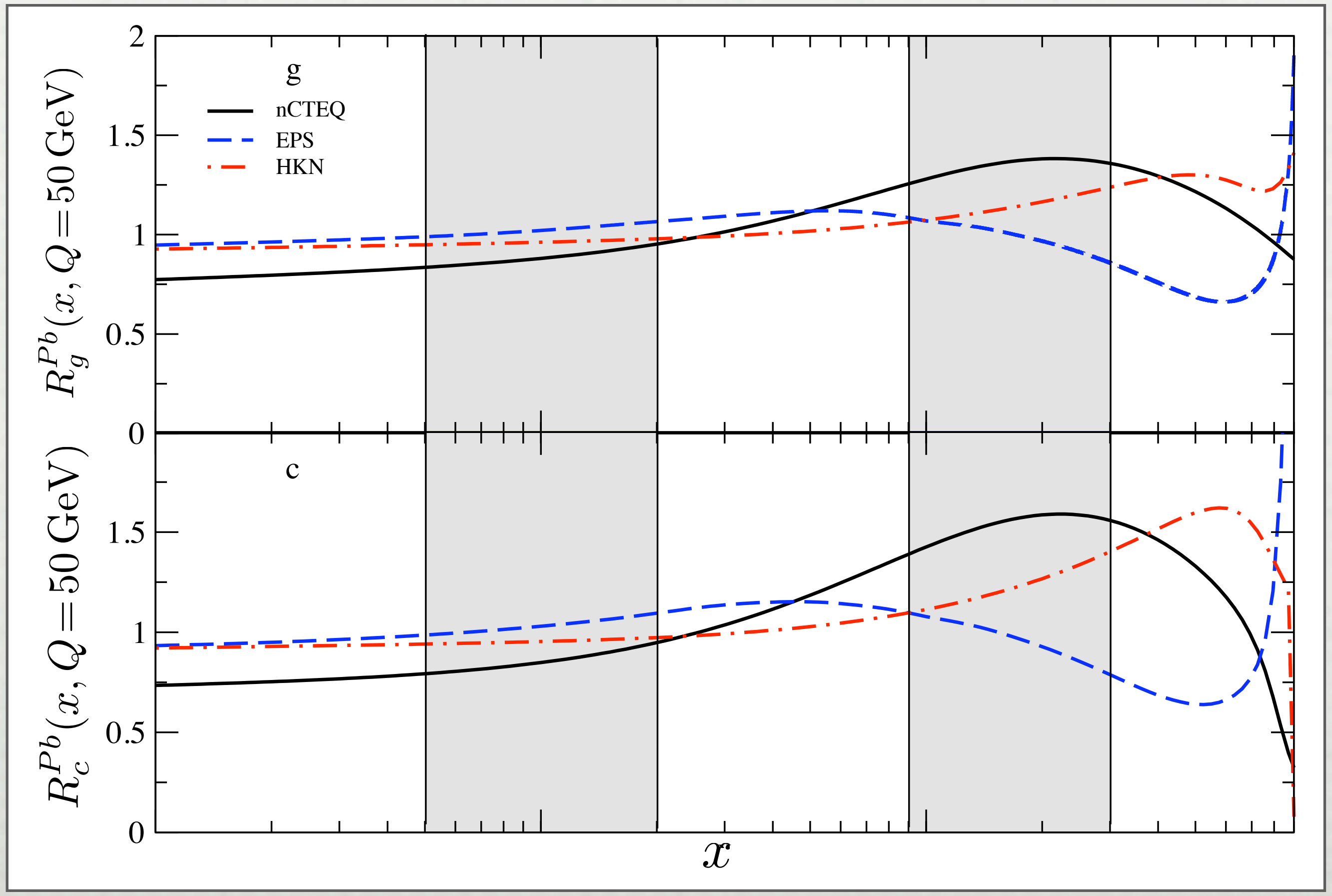


NUCLEAR GLUON

- Direct photon+heavy quark in pPb collisions - very sensitive to gluon nPDF
  - no intrinsic heavy quark PDF in nuclear case & gluon nuclear PDF is unconstrained
  - direct photon initial state depends almost exclusively on gluon nPDF



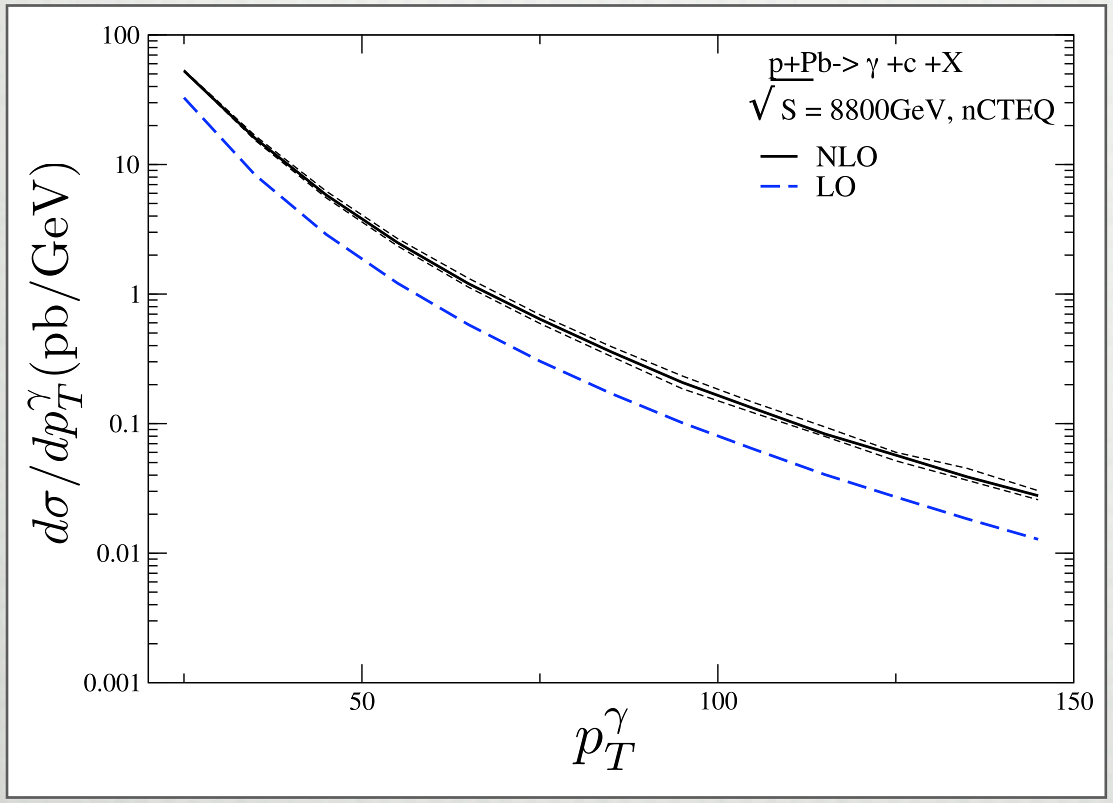
  - proton-Pb collisions at LHC ideal to help constrain gluon nPDF

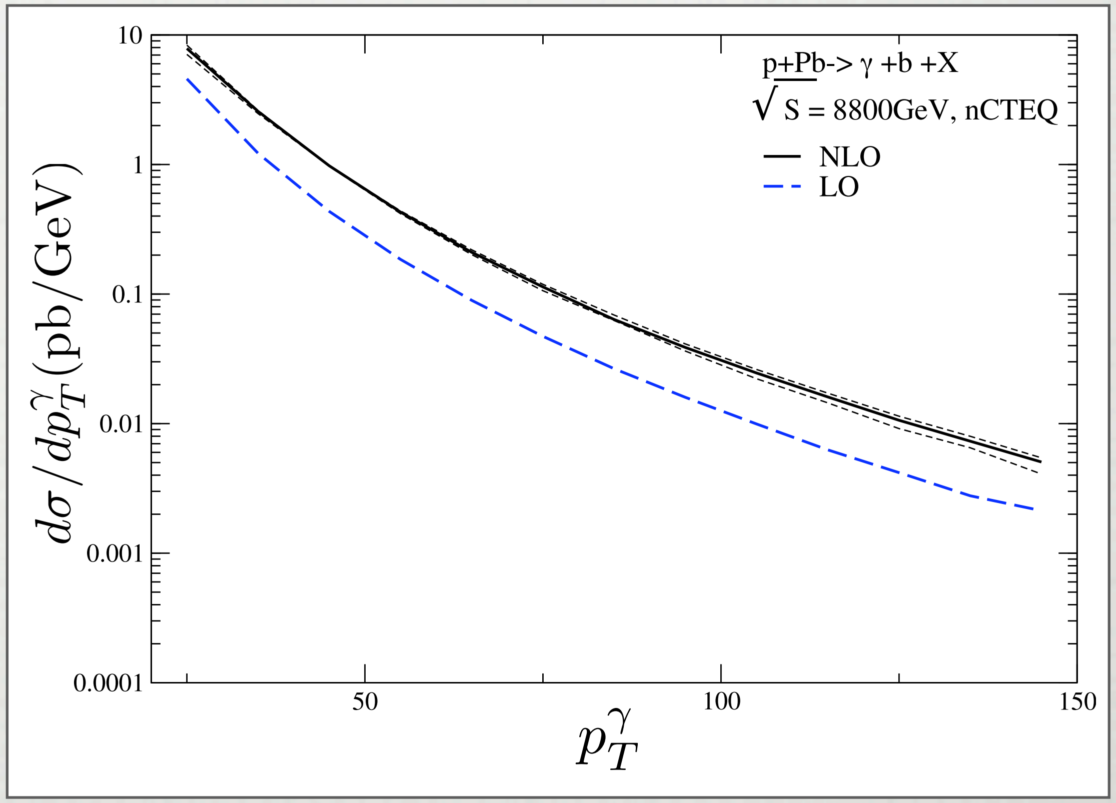


LHC-ALICE

- Direct photon in association with charm / bottom quark jets @ ALICE
  - ALICE cuts on photon & HQ transverse momentum, rapidity & isolation cuts

	p_T min	Rapidity	Φ	Isolation
PHOS	20 GeV	$\lvert y_\gamma \rvert<0.12$	220°<Φ<320°	R=0.2, p_T= 2GeV
EMCAL	20 GeV	$\lvert y_\gamma \rvert<0.7$	60°<Φ<180°	R=0.2, p_T= 2GeV
Heavy Jet	15 GeV	$\lvert y_Q \rvert<0.7$	---	---

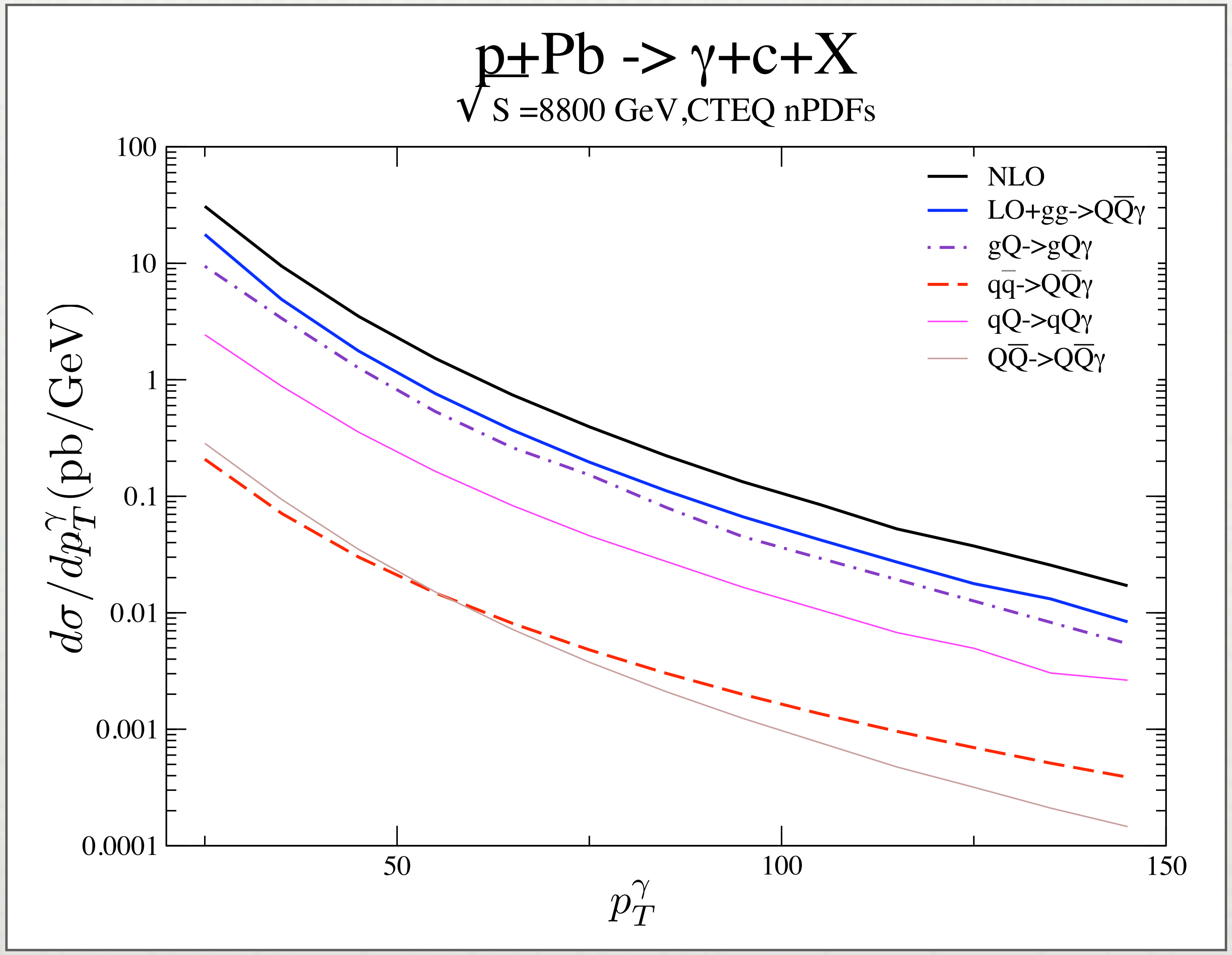




- Total cross-sections EMCAL: $850\,pb$ & PHOS: $130.5\,pb$

LHC-ALICE

- Direct photon - contributing NLO subprocesses
  - most of the cross-section is dominated by gluon/charm quark initiated subprocesses (80%)
  - direct photon + HQ @ LHC is sensitive to gluon nuclear PDF



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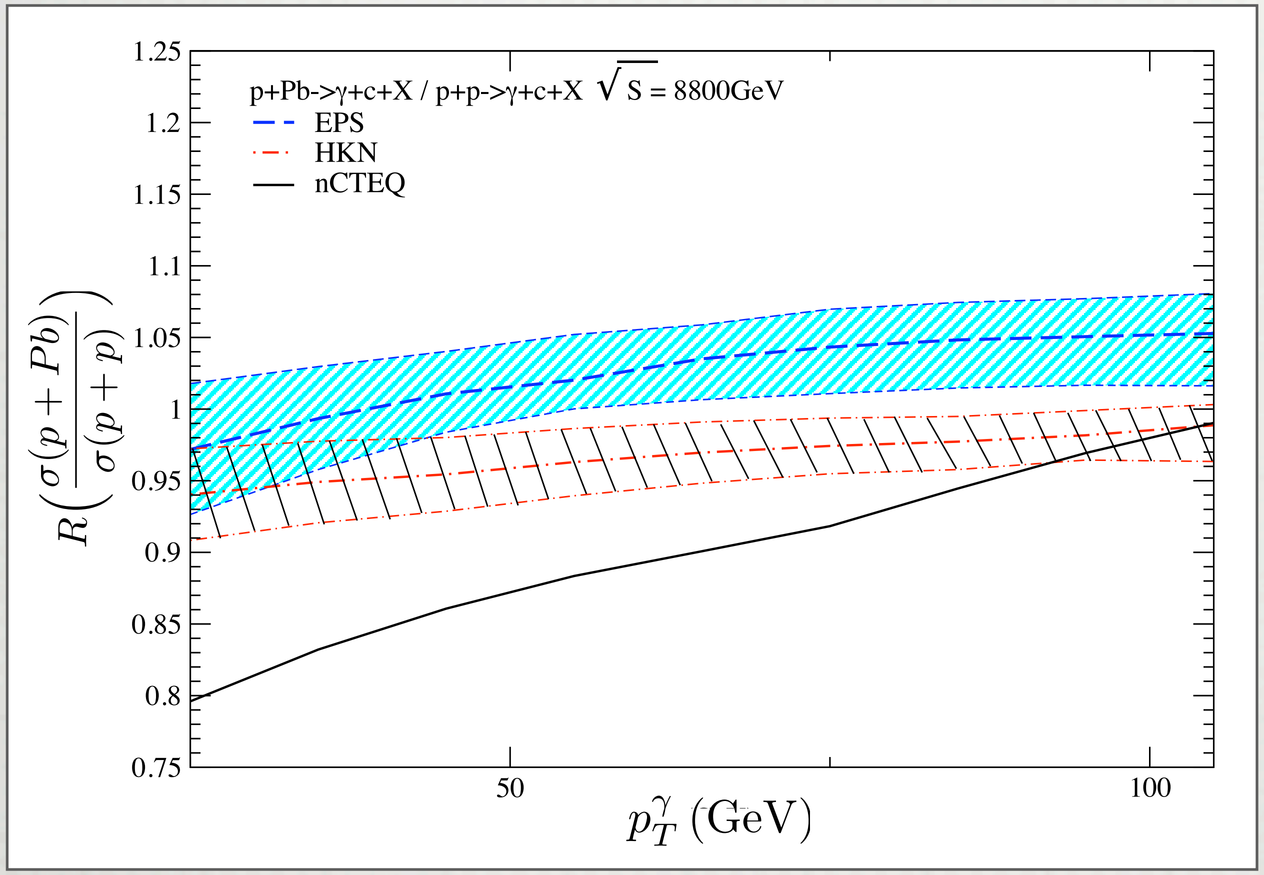

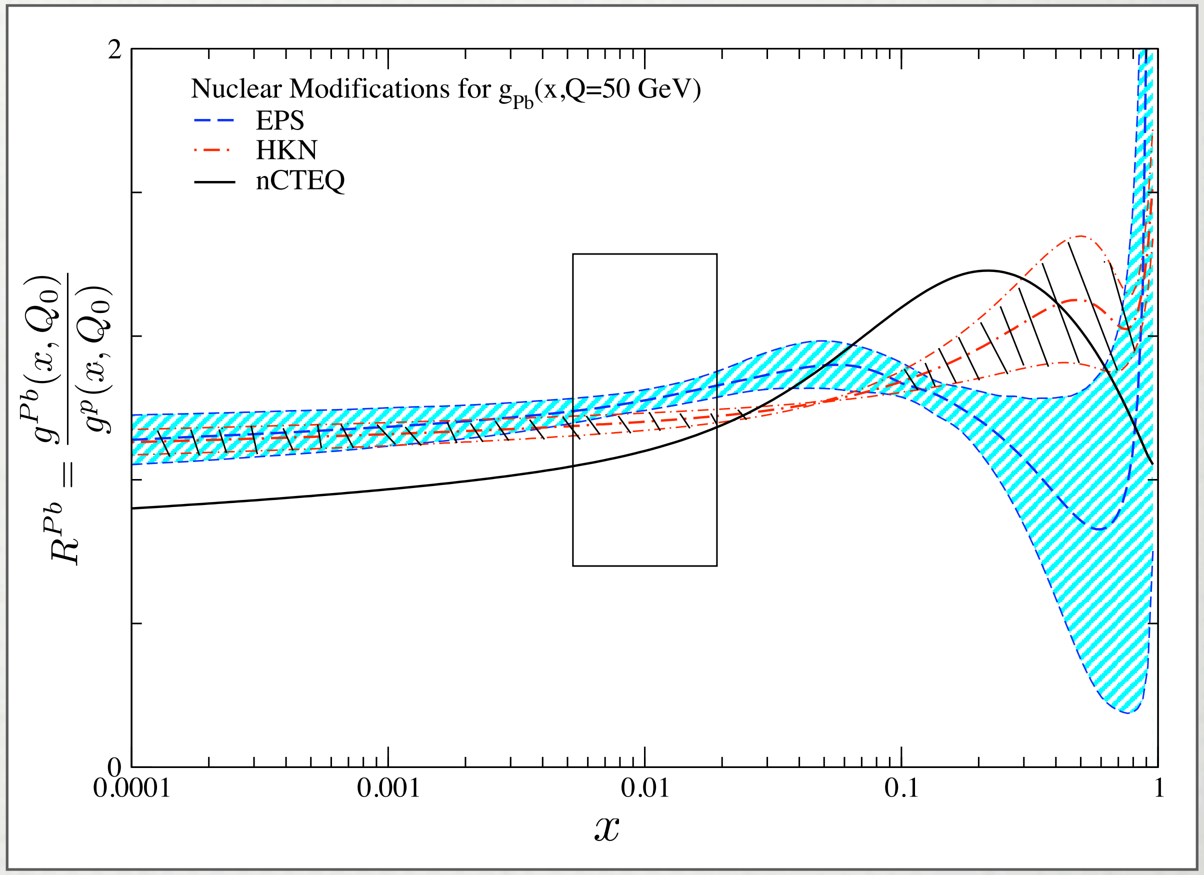

- direct photon + HQ @ ALICE test nuclear gluon PDF at $x \sim 0.01$

CONCLUSIONS

- Direct photon in association with a heavy quark jet is a useful tool

  TEVATRON - D0 → good distinction between different IC models
  can test BHPS, Sea-like IC models

  LHC - CMS → better sensitivity to gluon & HQ PDF than Tevatron
  can test IC models

  LHC - ALICE → pPb collisions one of few possibilities out there
  to constrain nuclear gluon PDF

- Direct photon in association with a heavy quark jet can be used to investigate jet quenching in PbPb collisions