Update on the CT14 QED PDFs

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In collaboration with
CTEQ-TEA

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CERN, Switzerland

CTEQ-TEA group

- CTEQ – Tung et al. (TEA)

in memory of Prof. Wu-Ki Tung,
who established CTEQ Collaboration in early 90's

- Current members:

Sayipjamal Dulat (Xinjiang U.),
Tie-Jiun Hou, Pavel Nadolsky (Southern Methodist U.), Jun Gao (Argonne Nat. Lab.), Marco Guzzi (U. of Manchester), Joey Huston, Jon Pumplin, Dan Stump, Carl Schmidt, CPY (Michigan State U.)

Outline

- **CT14 photon PDFs:** arXiv: 1509.02905

  CT14QED and CT14QEDinc

- **Implications of CMS W^+W^- data to photon PDFs**

arXiv: 1603.04874

CT14QED and CT14QEDinc PDFs

CT14QED PDFs from Isolated Photon Production in Deep Inelastic Scattering

CT14QED: inelastic contributions only

CT14QEDinc: inclusive

Schmidt et al., arXiv: 1509.02905

Measurement of isolated photon production in deep inelastic ep scattering

ZEUS Collaboration, arXiv:0909.4223 [hep-ex].

$$e\,p \rightarrow e\,\gamma + X$$

At least one reconstructed track, well separated from the electron, was required, ensuring some hadronic activity which suppressed deeply virtual Compton scattering (DVCS) to a negligible level.

Isolated photons can also be produced at values of WX less than 5GeV in 'elastic' and 'quasi-elastic' processes (ep → ep) such as DVCS and Bethe–Heitler photon production. Such events were simulated using the GenDVCS and Grape-Compton generators. The contribution of these elastic processes was negligible after the selections described in Section 3.

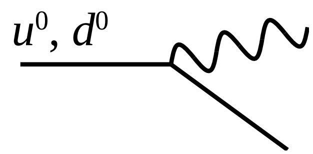
→ **CT14QED: inelastic contributions only**

CT14QED Photon PDF Parametrization

"Radiative ansatz" for initial Photon PDFs (generalization of MRST choice)

$$\gamma^p = \frac{\alpha}{2\pi}\left(A_u e_u^2 \tilde{P}_{\gamma q} \circ u^0 + A_d e_d^2 \tilde{P}_{\gamma q} \circ d^0\right)$$

$$\gamma^n = \frac{\alpha}{2\pi}\left(A_u e_u^2 \tilde{P}_{\gamma q} \circ d^0 + A_d e_d^2 \tilde{P}_{\gamma q} \circ u^0\right)$$



where u^0 and d^0 are "primordial" valence-type distributions of the proton.
Assumed approximate isospin symmetry for neutron.
Here, we take A_u and A_d as unknown fit parameters.

MRST choice: $A_q = \ln\left(Q_0^2 / m_q^2\right)$ "Radiation from **C**urrent **M**ass" – **CM**

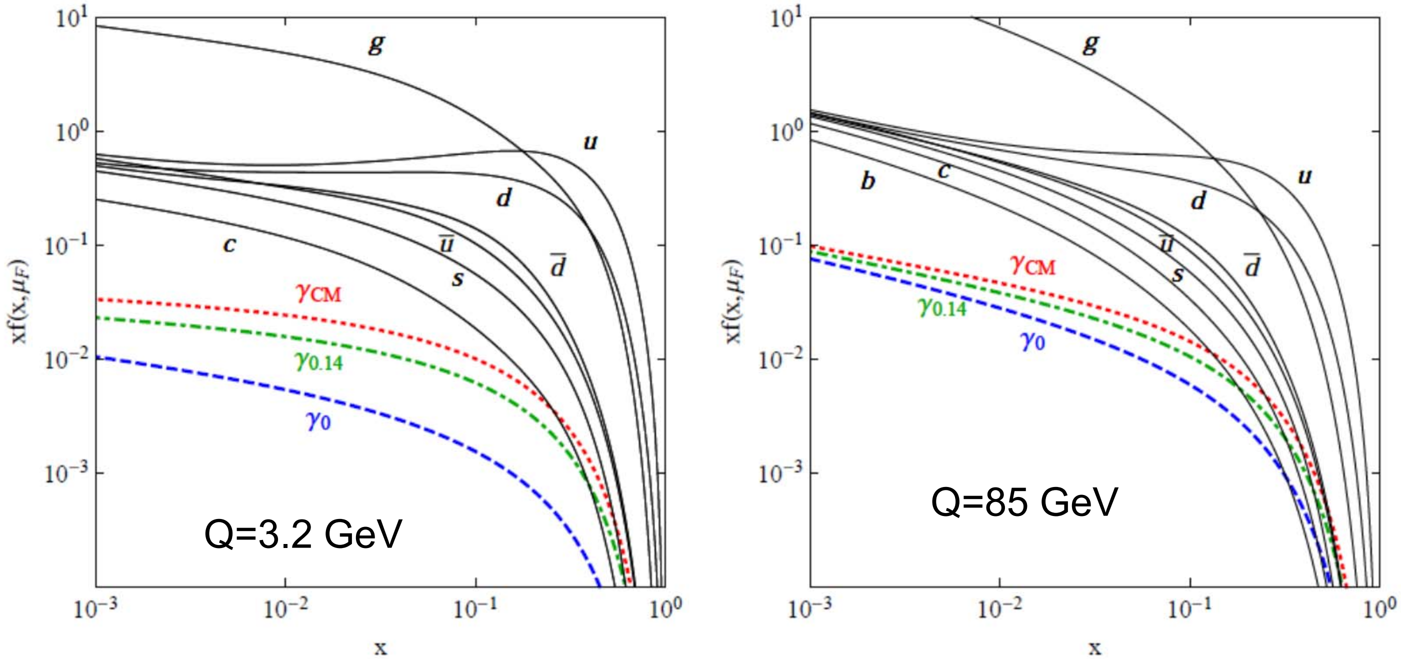
We use $u^0 = u^p \equiv u^p(x, Q_0)$, $d^0 = d^p \equiv d^p(x, Q_0)$
and reduce the number of parameters further (for initial study) by setting

$$A_u = A_d = A_0$$

Now everything effectively specified by one unknown parameter:

$$A_0 \Leftrightarrow p_0^\gamma \equiv p^{\gamma/P}(Q_0)$$ (Initial Photon momentum fraction)

CT14QED Photon PDFs (in proton)



γ momentum fraction:

$p^{\gamma}(Q)$	$\gamma(x,Q_0)=0$	$\gamma(x,Q_0)_{CM}$
Q = 3.2 GeV	0.05%	0.34%
Q = 85 GeV	0.22%	0.51%

Photon PDF can be larger than sea quarks at large x!

← Initial Photon PDF still significant at large *Q*.

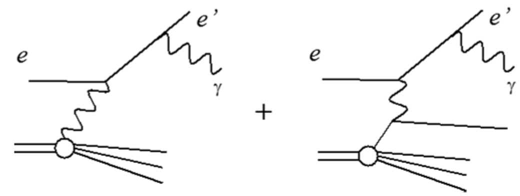
Constraining Photon PDFs

1) Global fitting
   - Isospin violation, momentum sum rule lead to constraints in fit
   - We find p_0^γ can be as large as ~ 5% at 90%CL, much more than **CM** choice

2) Direct photon PDF probe
   - DIS with observed photon, $ep \to e\gamma + X$
   - Photon-initiated subprocess contributes at LO, and no larger background with which to compete
   - But must include quark-initiated contributions consistently
   - Treat as NLO in α, but discard small corrections, suppressed by $\alpha\,\gamma(x)$.

$$ep \rightarrow e\gamma + X$$

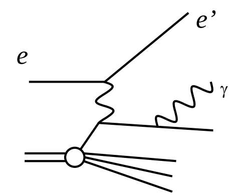
Subprocess contributions:



LL Emission off Lepton line

Both quark-initiated and photon-initiated contributions are $\sim \alpha^3$ if $\gamma(x) \sim \alpha$

Collinear divergence cancels (in d=4-2ε) by treating as NLO in α with $\gamma^{\text{bare}}(x) = \gamma(x) + \frac{(4\pi)^{\varepsilon}}{\varepsilon}\Gamma(1+\varepsilon)\frac{\alpha}{2\pi}\left(P_{\gamma q} \circ q\right)(x)$ (MSbar)



QQ Emission off Quark line

Has final-state quark-photon collinear singularity

QL Interference term

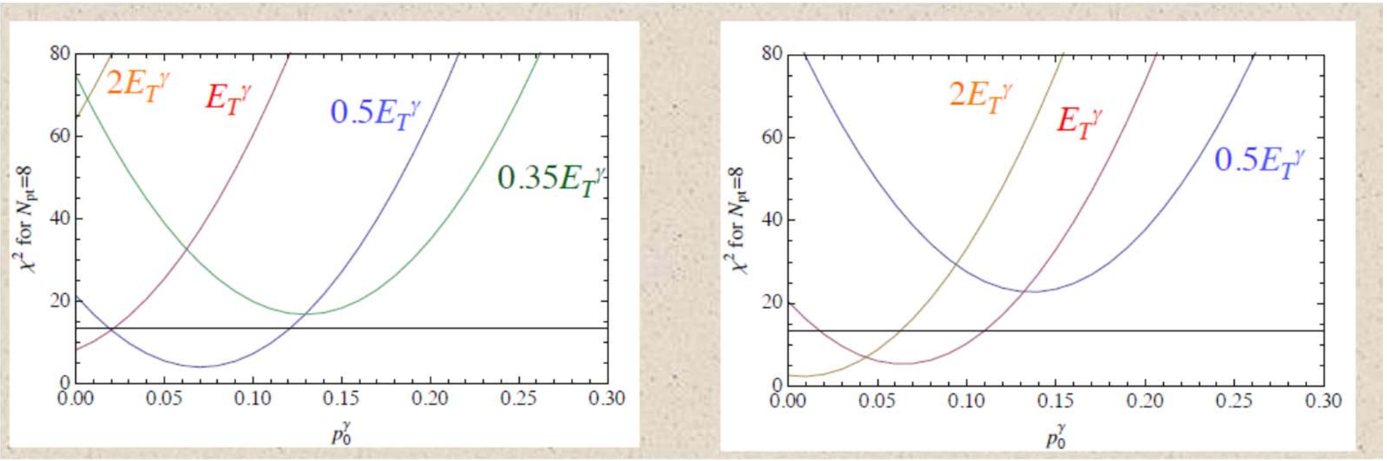
Negligible < about 1% (but still included)

Previous calculations:

quark-initiated only – (GGP) Gehrmann-De Ridder, Gehrmann, Poulson, PRL 96, 132002 (2006)

photon initiated only – (MRST), Martin, Roberts, Stirling, Thorne, Eur. Phys. J. C 39, 155 (2005)

Limits on Photon PDF



Smooth Isolation | Sharp Isolation

- Different χ^2 curves for choice of isolation and scale μ_F
- 90% C.L. for N_{pt} = 8 corresponds to $\chi^2 = 13.36$

- Obtain $p_0^\gamma \leq 0.14\%$ at 90 % C.L. and $p_0^\gamma \leq 0.11\%$ at 68 % C.L.

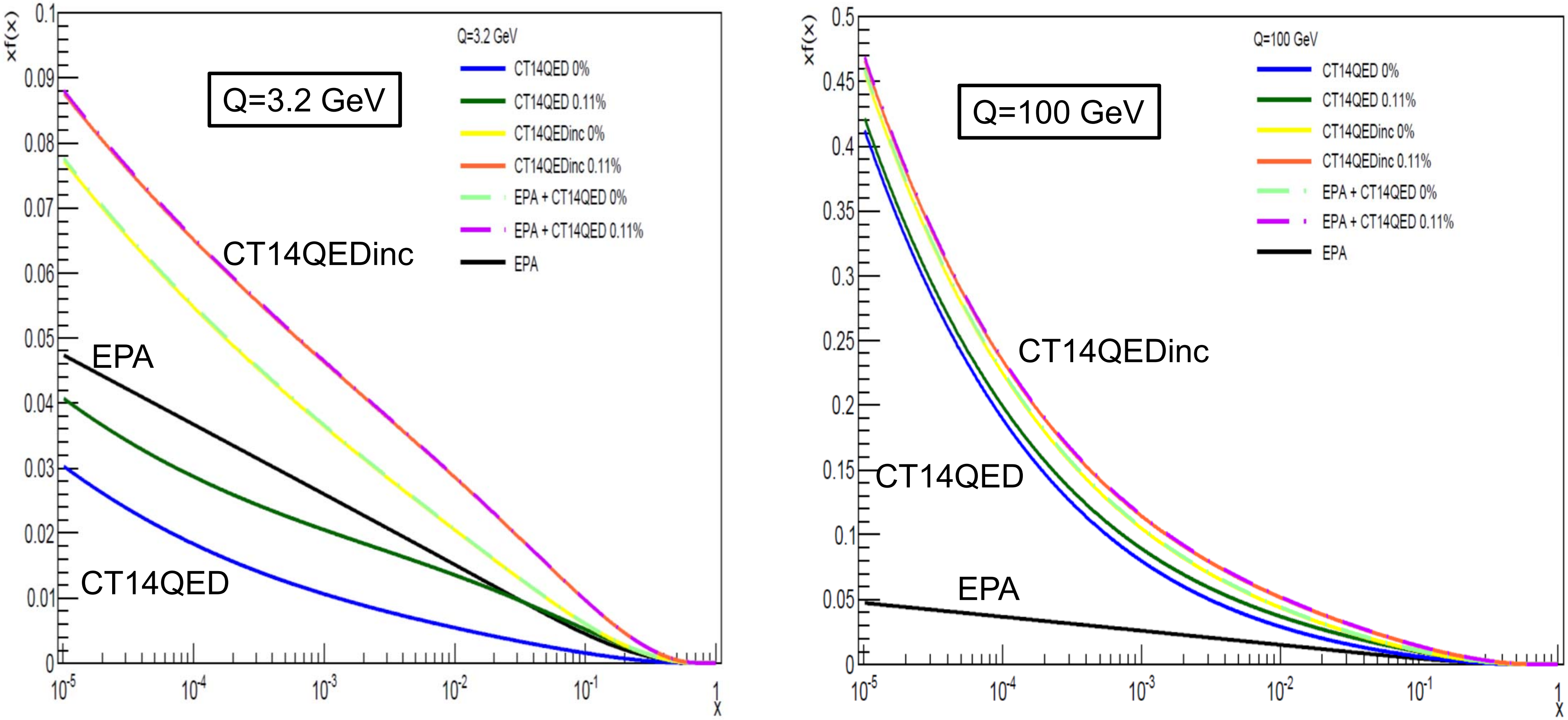
independent of isolation prescription
(More generally, constrains $\gamma(x)$ for $10^{-3} < x < 2\mathrm{x}10^{-2}$.)

CT14QEDinc PDFs

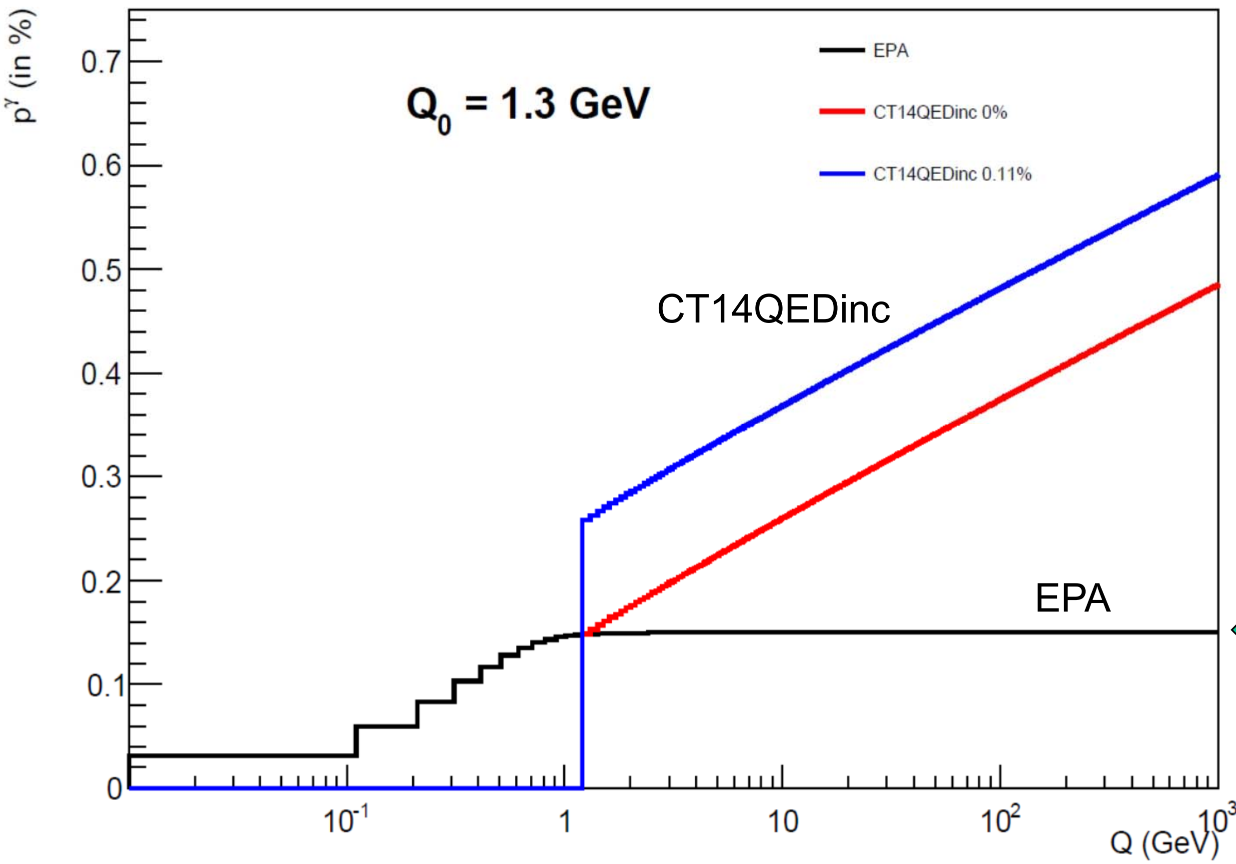
- To obtain the inclusive photon PDFs, we added the elastic component, obtained from the Equivalent Photon Approximation (EPA), Budnev et al. (1975), at $Q_0 = 1.3$ GeV, to CT14QED.
- Then evolve it to any larger Q value using DGLAP evolution at LO in α and NLO in α_s

→ **CT14QEDinc: inclusive**

CT14QED and CT14QEDinc PDFs

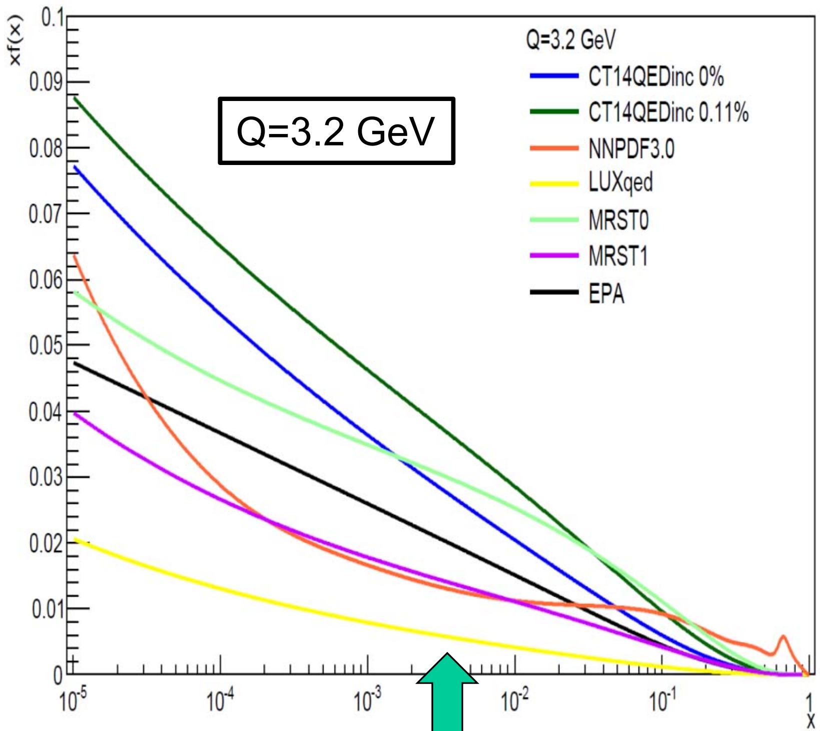


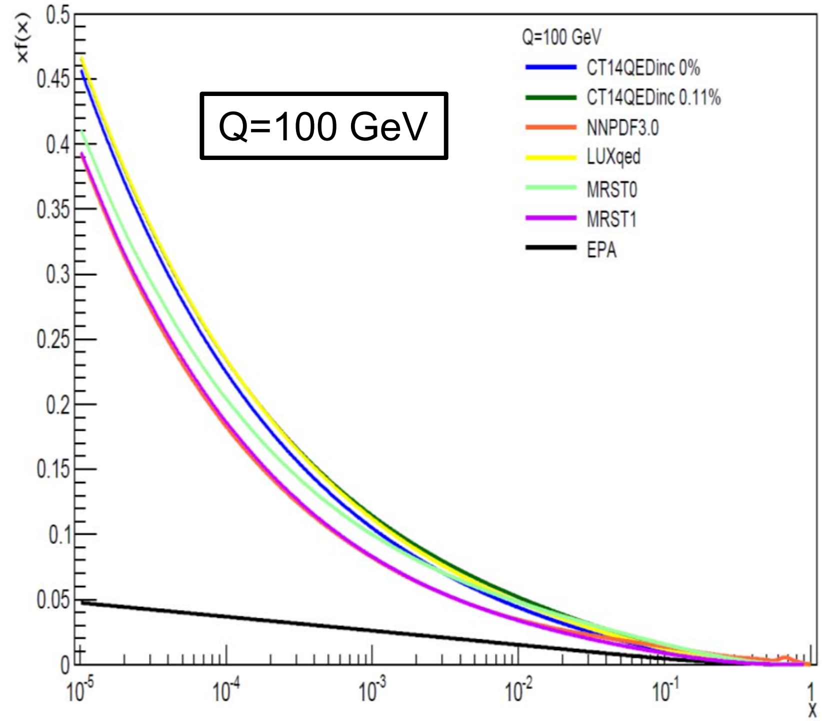
Fraction of photon momentum in proton CT14QEDinc



About 0.15%

Compare various photon PDFs





LUXqed is smaller than EPA in low Q region!!

Ababekri, et al., arXiv: 1603.04874

Implications of CMS W^+W^- data to photon PDFs

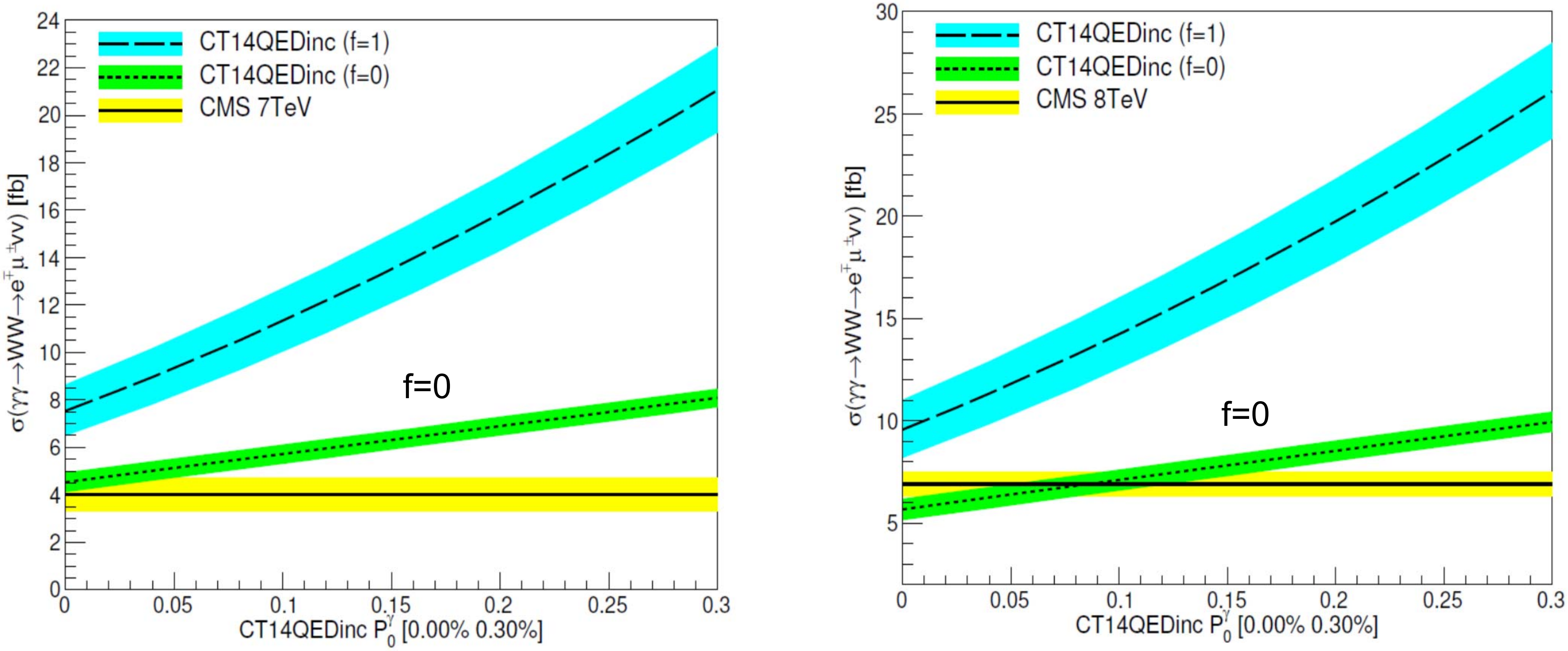
A search for exclusive or quasi-exclusive $\gamma\gamma \rightarrow W^+W^-$ production

$$pp \rightarrow p^{(*)}W^+W^-p^{(*)} \rightarrow p^{(*)}\mu^\pm e^\mp p^{(*)}.$$

CMS Collaboration, arXiv:1305.5596 [hep-ex] (at 7 TeV)
and CMS-PAS-FSQ-13-008 (at 8 TeV)

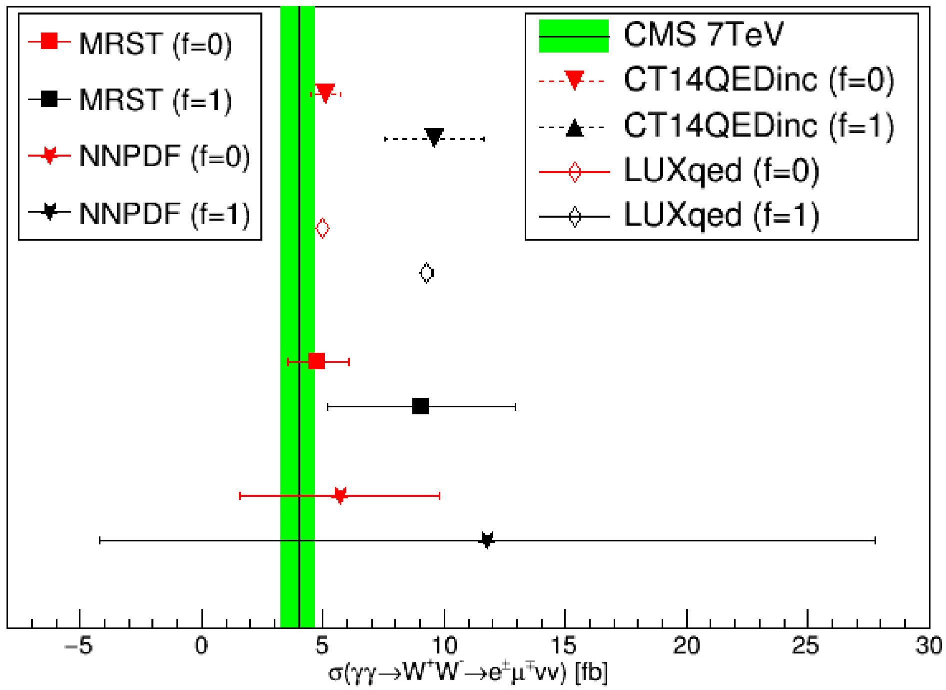
requiring zero extra tracks at the $\mu^\pm e^\mp$ vertex

Scale uncertainty in CT14QEDinc PDFs



Theory bands indicate scale uncertainties, varying around WW invariant mass by a factor of 2.

Compare CMS Data (at 7 TeV) to various photon PDFs



f=0 does not include double-dissociation contribution.

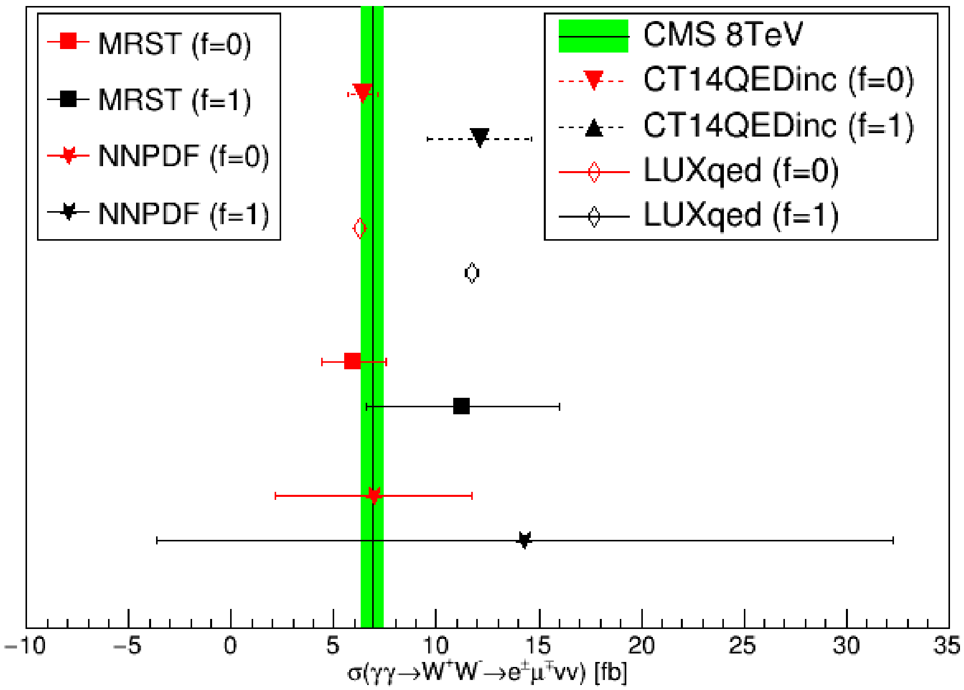
f=1 includes single- and double-dissociation contributions.

Prefer f=0 than f=1

requiring zero extra tracks at the $\mu^{\pm}e^{\mp}$ vertex

Compare CMS Data (at 8 TeV) to various photon PDFs

C T E Q



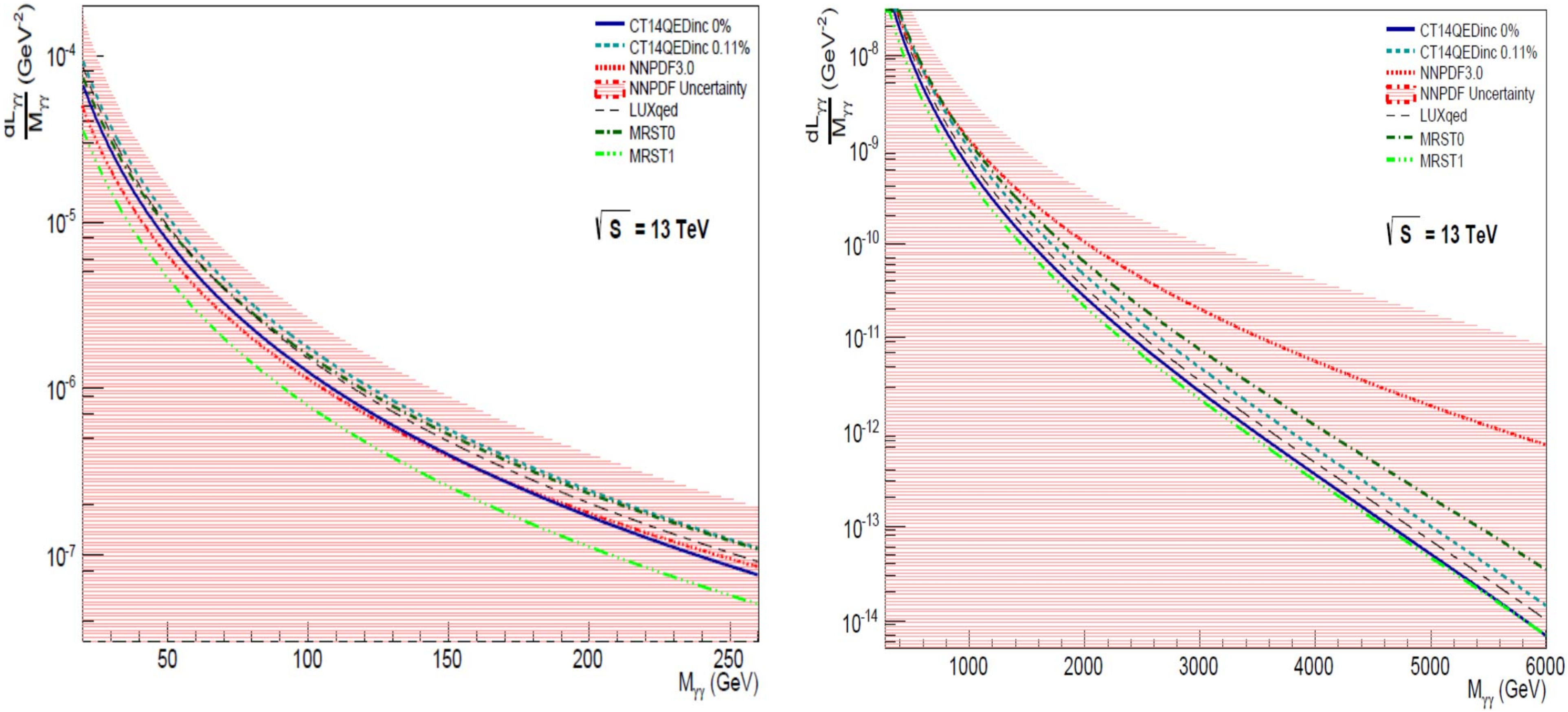
f=0 does not include double-dissociation contribution.

f=1 includes single- and double-dissociation contributions.

Prefer f=0 than f=1

requiring zero extra tracks at the $\mu^{\pm}e^{\mp}$ vertex

Photon-Photon Luminosity



Thanks for your attention!