XXVI International Workshop On Deep Inelastic Scattering and Related Subjects (2018)

Ad Lucem

The Photon in the MMHT PDFs

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March 26, 2018

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Motivation

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$$\sigma_{pp\to X}^{(N^kLO)} = \Sigma_{a,b} \int x_1 x_2 f_a(x_1)^{(N^kLO)} \hat{\sigma}_{ab\to k}^{(N^kLO)} f_b(x_2)^{(N^kLO)} D(k \to X)$$

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Calculate hard processes to a given order in pQCD and match PDFs accordingly.

$$\hat{\sigma} = \hat{\sigma}^{Born}\left(1 + \frac{\alpha_S}{2\pi}\hat{\sigma}^{(1)} + \frac{\alpha_S^2}{2\pi}\hat{\sigma}^{(2)} + \frac{\alpha_S^3}{2\pi}\hat{\sigma}^{(3)} + ...\right)$$

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$\alpha_S^2 \simeq \alpha_{EM} \rightarrow$ Expect QED to become relevant
Introduces the photon as an interacting parton: $\gamma(x, Q^2)$

Input

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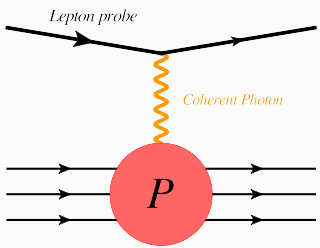
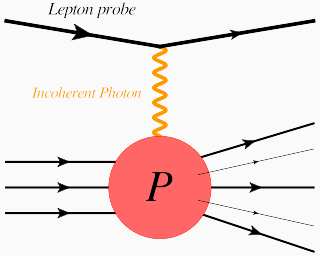
$\gamma(x, Q_0 = 1GeV^2)$ expressed in terms of experimentally determined structure functions. Prior work, e.g. Martin et al (ArXiV:1406.2118), Harland Lang et al (ArXiv: 1607.04635). Reformulated on stronger quantitative footing by LUXqed (ArXiv: 1607.04266). Coherent photon from elastic scattering, incoherent photon from inelastic scattering.





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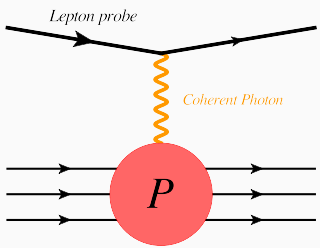

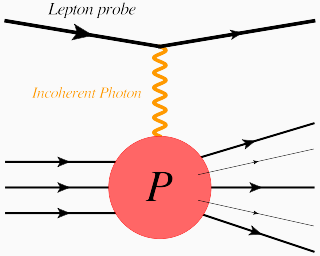

Errors ($\lessapprox 5\%$) are then propagated from measurements of F_2 and F_L structure functions.

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$$\left.\left.-z^2F_L(x/z,Q^2)\right]-\alpha^2(Q_0^2)z^2F_2(x/z,Q_0^2)\right\}$$

Differences in the integral limits compared to LUXqed (since we evolve in DGLAP from $Q_0 = 1$ GeV^2); higher twist/proton mass dependent terms more important, especially at high x.

DGLAP

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- Coupled **DGLAP** evolution in x-space:

$$\mu_F \frac{d}{d\mu_F} f_i(x,\mu) = \frac{\alpha_S}{2\pi} \sum_j P_{ij}(\alpha_S(\mu)) \otimes f_j$$

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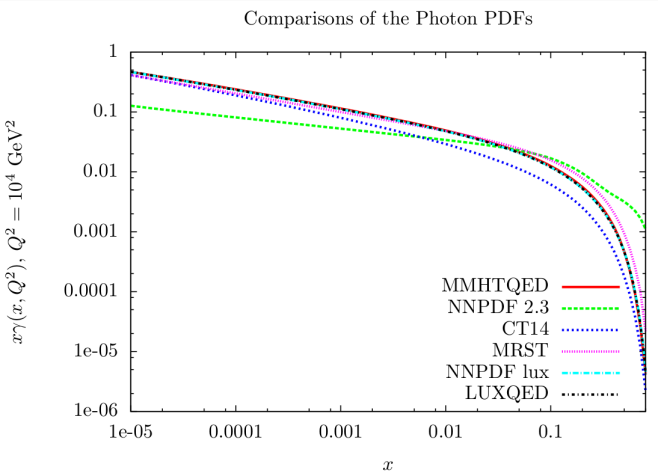
- **Non**-iterative process: single directional evolution in DGLAP from input.

MMHTQED

We have developed an equivalent photon PDF with full QED DGLAP evolution of all partons.



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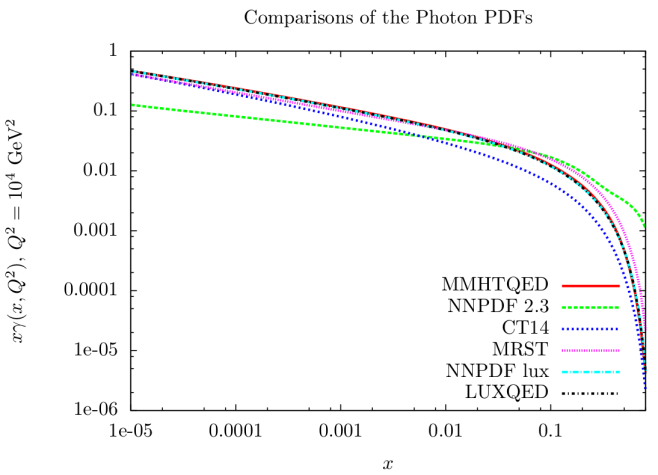

(All comparisons made to MMHT14+HERA I+II).

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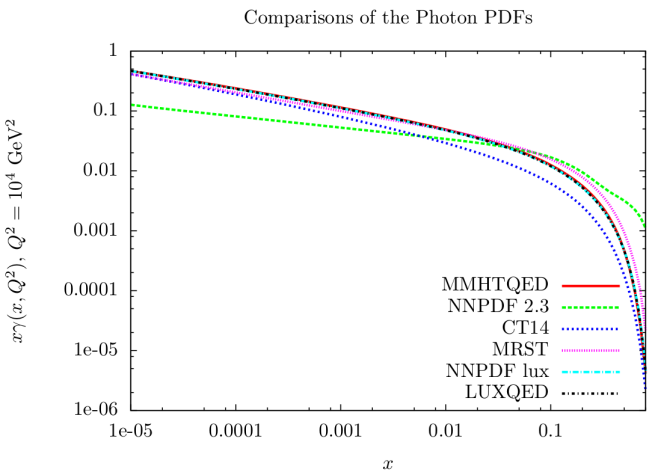

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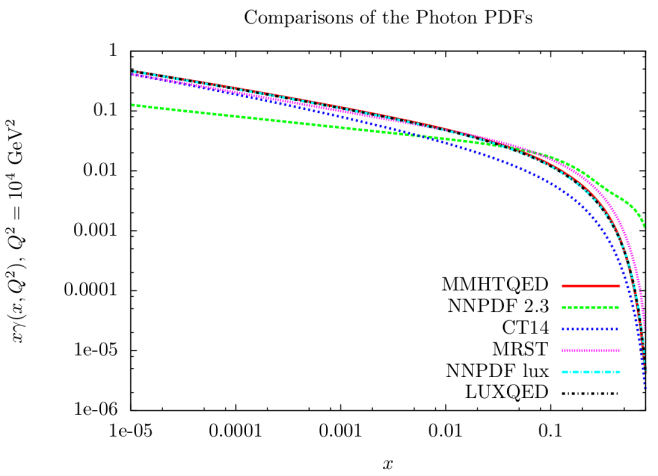

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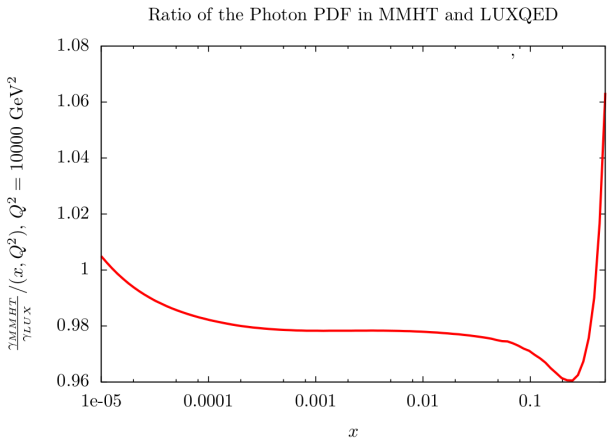
Comparison with LUX



Differences ascribable mainly to difference in the quark and gluon PDFs that contribute to $\gamma_{INCOHERENT}$.

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- Relate components of the photon in the proton to those in the neutron by charge re-weighting u and d quark contributions and use neutron structure function data.

$$\gamma_n(x, Q^2) = \frac{e_d^2}{e_u^2}\gamma_{u,p}(x, Q^2) + \frac{e_u^2}{e_d^2}\gamma_{d,p}(x, Q^2) + \gamma_{s/c/b,p}(x, Q^2)$$

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- Isospin violating terms in the neutron valence quark distributions taken proportional to QED evolved terms:

$$\Delta d_{V,n} = \epsilon(1-\frac{e_d^2}{e_u^2})\Delta u_{V,p}{}^{QED} \qquad \Delta u_{V,n} = \epsilon(1-\frac{e_u^2}{e_d^2})\Delta d_{V,p}{}^{QED}$$

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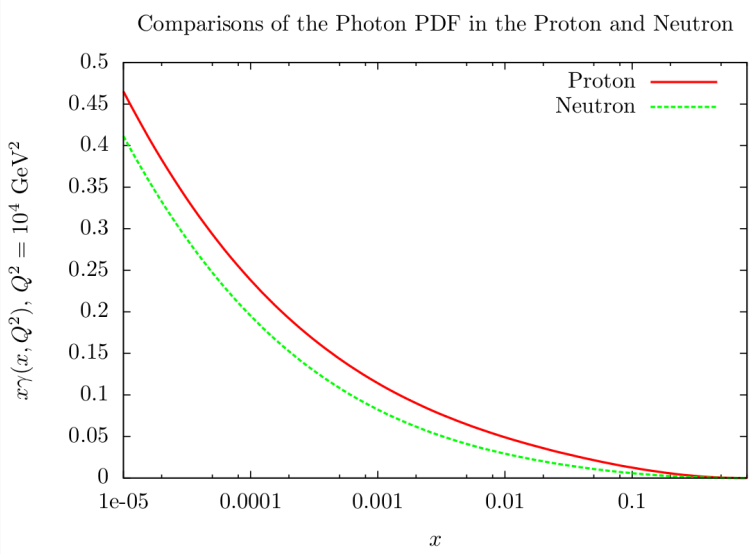
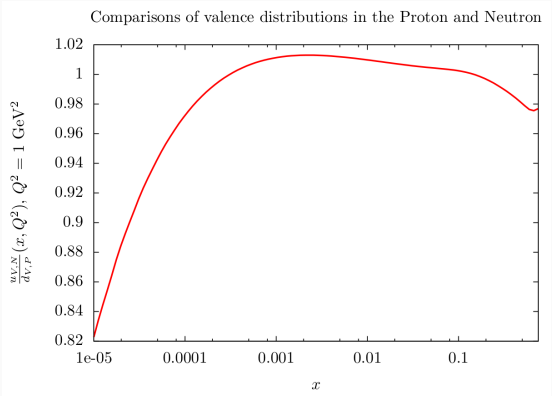


QED Isospin Violation

$\frac{u_{V,n}}{d_{V,p}}$, $Q^2 = 1$ GeV^2



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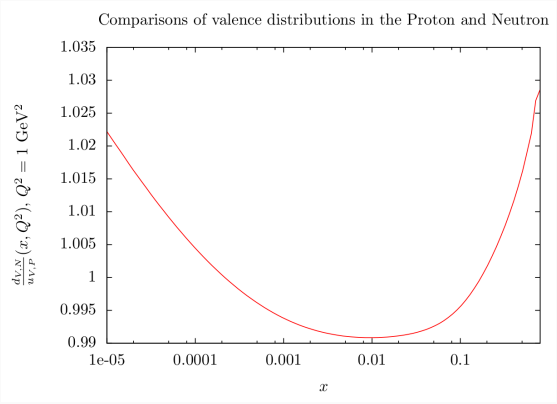
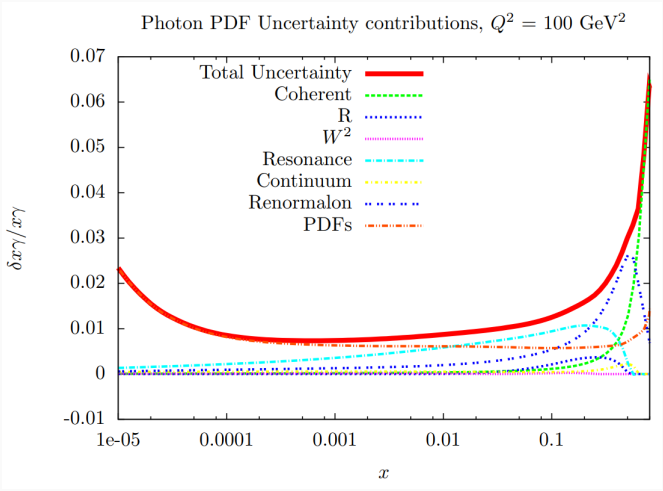


Uncertainty Contributions (Proton)

Relative contributions to the proton photon PDF uncertainty well controlled.



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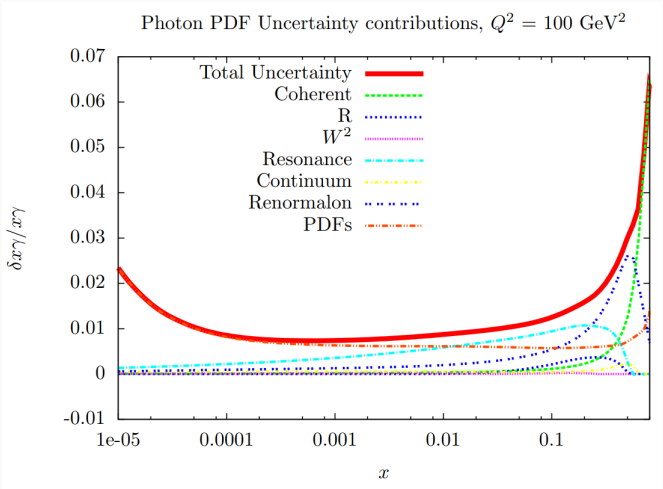

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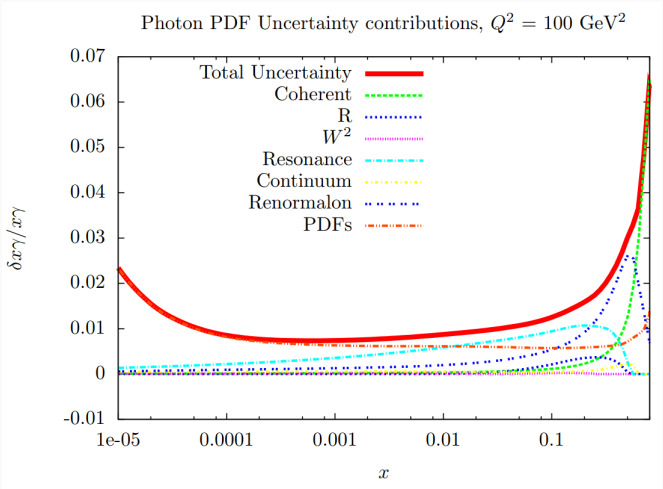

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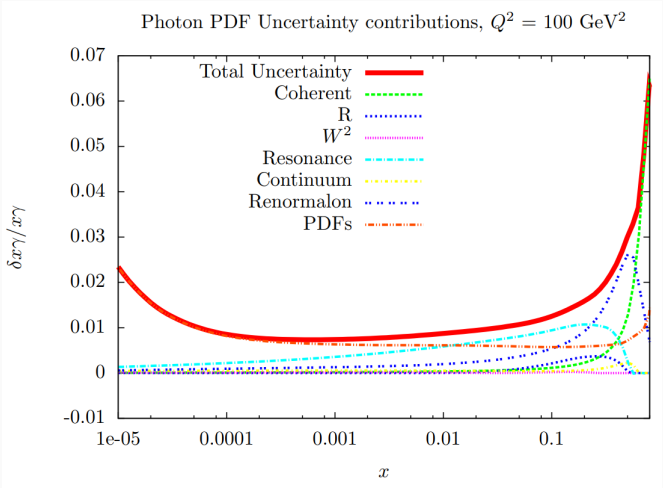

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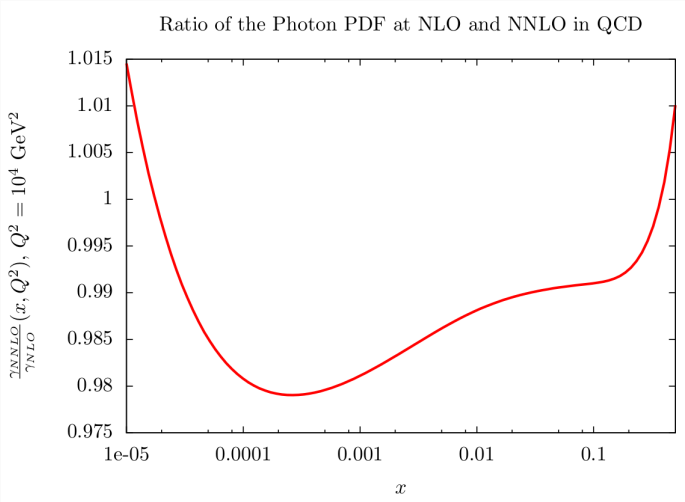
- Model parameters in the Renormalon contributions given a conservative uncertainty estimate.

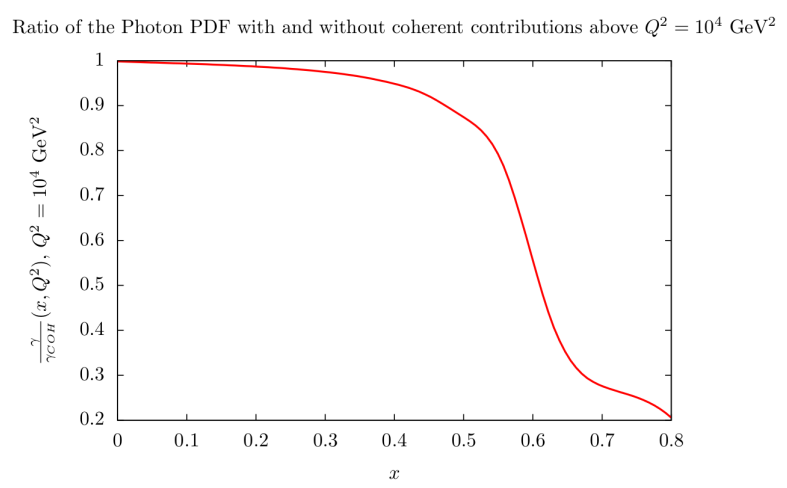
NNLO vs NLO

Percent level differences when using different orders of QCD in DGLAP.



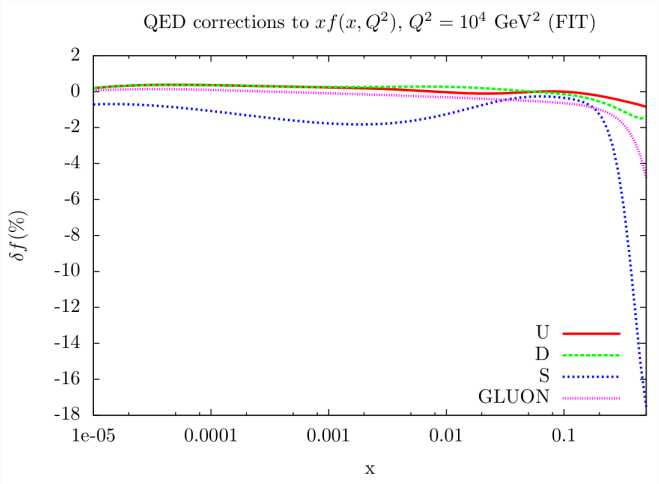
Coherent

Significant contributions at high x from $\gamma_{COHERENT}$



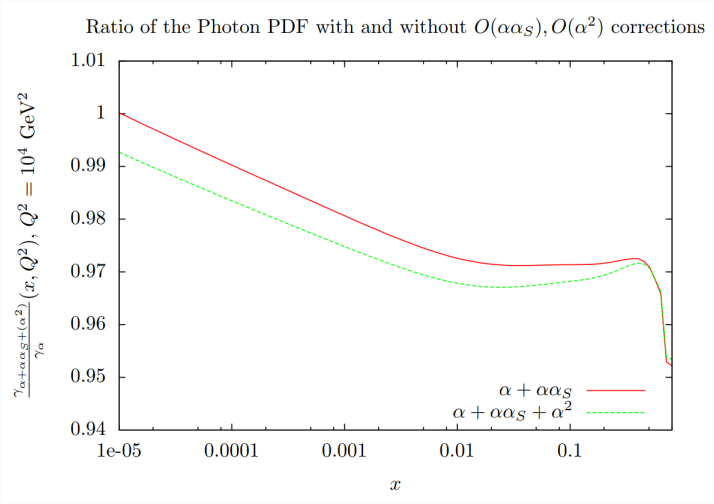
Measured effects on quarks

Calculated the effects of QED on parton momenta within the proton.



Higher orders

Included mixed order $\mathcal{O}(\alpha_S\alpha)$ and $\mathcal{O}(\alpha^2)$ corrections.



Phenomenological Importance

Anticipated experimental sensitivity to Electroweak correction		
Process	Observable(s)	Estimated % difference(s)
Low mass W/Z production	Charge asymmetry, dilepton mass uncertainty	$\sim$1%,$\sim$3%
High mass VV production	WW pair production rate	$\sim$2%
Higgs + W	Differential P_T Higgs distribution	$\sim$**10%**
High mass Drell-Yan	Dilepton mass spectrum	$\sim$**1-16%**
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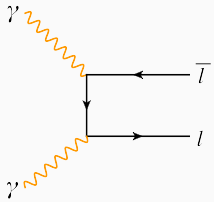

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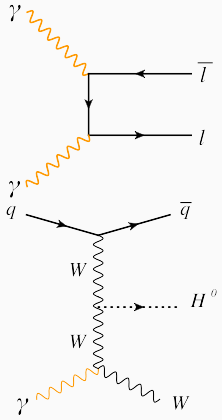

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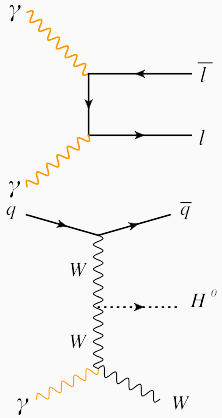

Inclusion of QED can give up to 1 - 2% reduction in (QCD) PDFs.

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- To be released later this year.

Thank you for your attention.
Any questions?

Backup: Neutron details

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What do we mean by QED evolved?

$$\gamma(x, \mu^2)_{q,p} = \int_{Q_0^2}^{\mu^2} \frac{\alpha(Q^2)}{2\pi}\frac{dQ^2}{Q^2}\int_x^1 \frac{dz}{z}\left(\mathbf{e_q^2}\tilde{P}_{\gamma,q}(z)\mathbf{q}(\frac{\mathbf{x}}{\mathbf{z}}, \mathbf{Q^2})\right)$$

Contribution to the evolved photon from a specific quark flavour. Isospin assumed but inherently broken by QED, accuracy assured only to $\mathcal{O}(\alpha)$.

Strange, Charm and Bottom contributions taken as identical.

Backup: Neutron details

Elastic contributions to the neutron photon input use neutron structure function data from A1 collaboration.

Inelastic contributions approximated by the ratio of neutron to proton quarks at input.

$$rF_2 = \frac{4(d+\bar{d})+(u+\bar{u})+(s+\bar{s})}{4(u+\bar{u})+(d+\bar{d})+(s+\bar{s})}$$

Backup: Isospin violation

QED naturally introduces isospin violation: $\Delta d_V^{(n)} = d_V^{(n)} - u_V^{(p)}$

Assume isospin violating terms are proportional to quark contributions from QED driven DGLAP:

$$\Delta u_{V,n} = \epsilon(1 - \frac{e_u^2}{e_d^2})\Delta d_{V,p}{}^{QED}$$

Constant of proportionality taken to preserve conservation of momentum:

$$\epsilon = \frac{\int_0^1 dxx(\gamma^p - \gamma^n)}{\int_0^1 dxx(\frac{3}{4}\Delta u_V^{QED} - 3\Delta d_V^{QED})} \tag{1}$$