HOW BRIGHT IS THE PROTON?

A precise determination of the Photon PDF

Based on 1607.04266, done in collaboration with

ANEESH MANOHAR, PAOLO NASON, GAVIN SALAM

XV LOOPFEST, BUFFALO 2016

Photon PDF

- Protons in LHC beams are charged fast-moving particles, so they generate an electromagnetic field ⇒ PHOTON PDF

- Note that a proton can emit photons without breaking apart (obviously not true for emission of q/g). This is the so-called ELASTIC COMPONENT (and we will see, it is not negligible)

Photon PDF

Photon distributions are small compared to other ones (suppressed by the EM coupling) but thanks to the high precision of LHC data they are becoming of increasing interest for

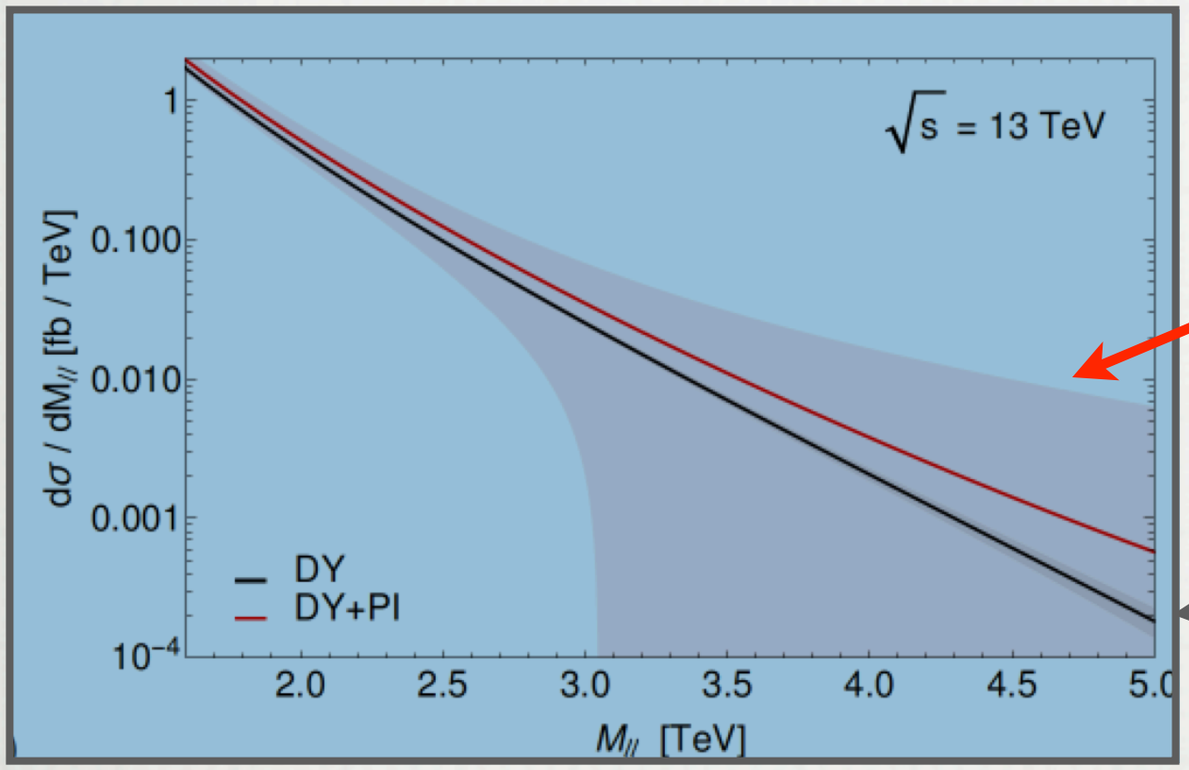
- VBF or associated Higgs production
- Lepton pairs (Drell Yan), Tops, Di-bosons, Di-photons ...
- Electroweak corrections to generic processes

Approaches to photon PDF

- the photon PDF has been partially modeled, e.g. assuming that photons are radiated from quarks above some mass scale (the scale is typically taken between constituent and current quark masses)-- this is essentially what CT10 and MRST2004 collaborations do

- or has been fit to LHC data (mostly Drell Yan). This is essentially what the NNPDF collaboration did. NB: since the photon induced component is small, even accurate data can not lead to a precise photon PDF determination

Impact of loose determination on DY



INCLUDING PHOTON INDUCED AND ITS UNCERTAINTY (NNPDF2.3)

WITHOUT PHOTON INDUCED

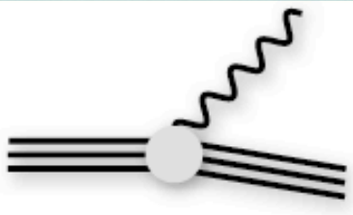
Accomando et al 1606.06646

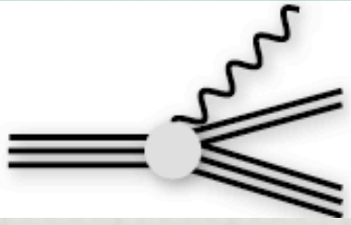
Could use high-mass Drell Yan data to further constrain photon PDF (at the risk of fitting new physics in the PDF)

Approaches to Photon PDF

	elastic	inelastic	in LHAPDF?
Gluck Pisano Reya 2002	dipole	model	✘
MRST2004qed	✘	model	✓
NNPDF23qed	no separation; fit to data		✓
CT14qed	✘	model (data-constrained)	✓
CT14qed_inc	dipole	model (data-constrained)	✓
Martin Ryskin 2014	dipole (only electric part)	model	✘
Harland-Lang, Khoze Ryskin 2016	dipole	model	✘

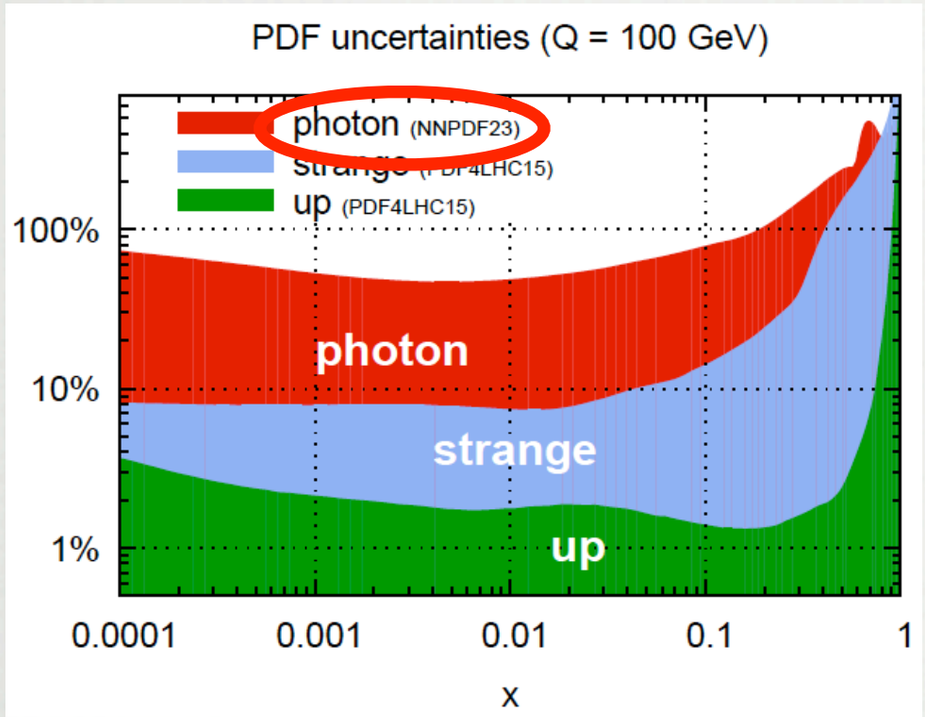
elastic: Budnev, Ginzburg, Meledin, Serbo, 1975





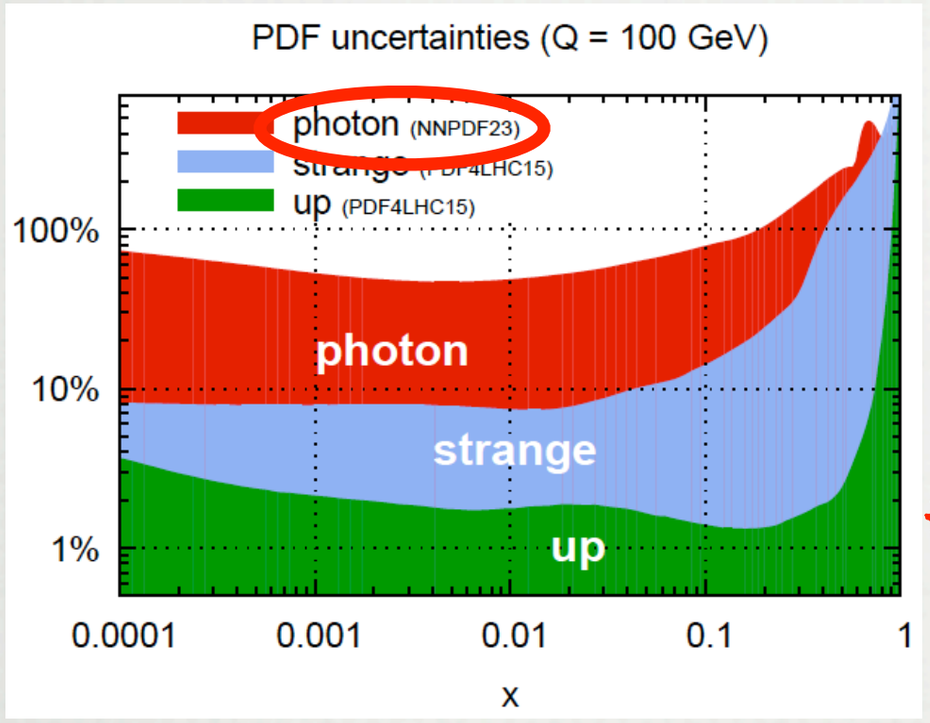
from talk given by G. Salam in Crete

How well is the photon known?

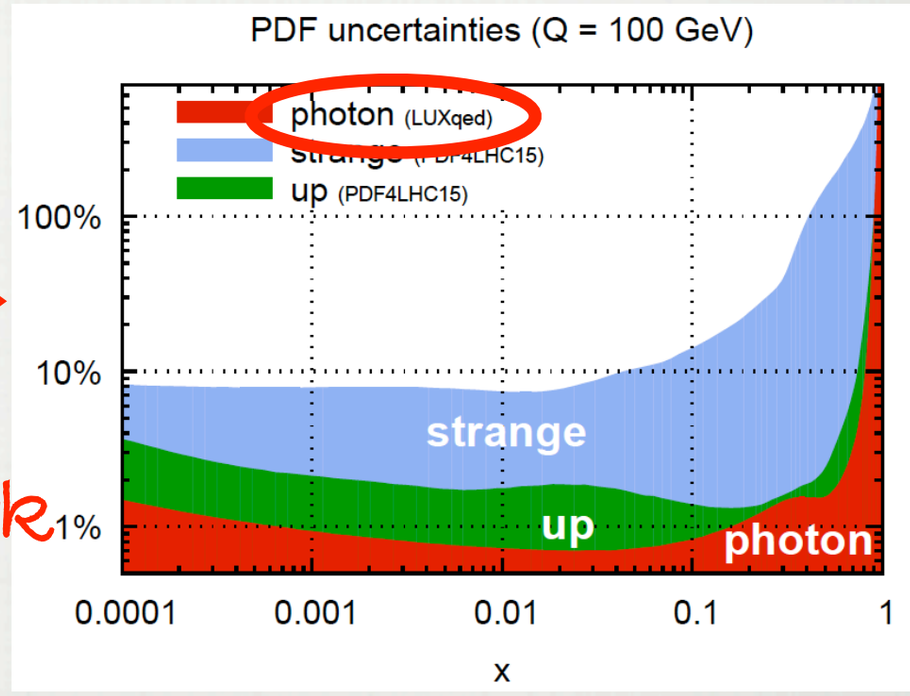


- valence quarks known to few percent
- others quarks to 10% over a large x-range
- THE ONLY DATA DRIVEN PHOTON DETERMINATION HAS A O(100%) UNCERTAINTY

How well is the photon known?



this work



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LUXqed photon PDF

HERE I WILL DISCUSS A MODEL INDEPENDENT, DATA-DRIVEN DETERMINATION BASED ON PRECISE DIS DATA

⇒ LUXqed PDF SET

FIRST THINK OF DIS AS AN ELECTRON PROBING THE PHOTON FIELD OF THE PROTON, THEN ONE OBSERVES THAT ...

Key observation

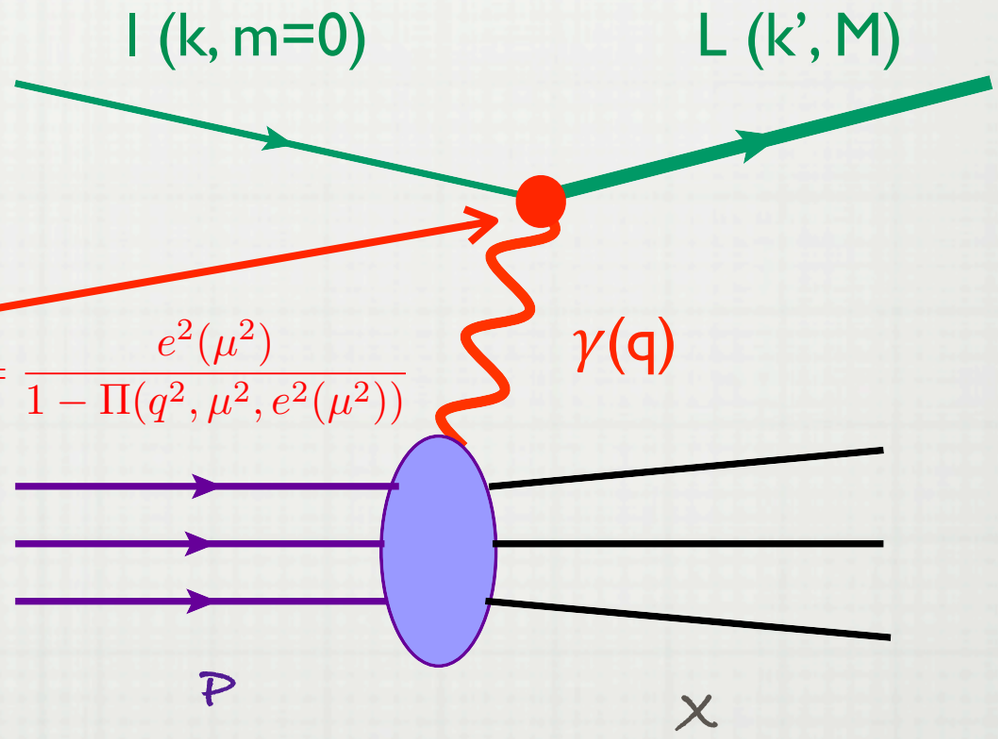
- IT IS POSSIBLE TO WRITE THE CROSS SECTION INVOLVING AN IMAGINARY (BSM) FLAVOUR-CHANGING NEUTRAL LEPTON-PHOTON VERTEX IN TERMS OF
  - EITHER PROTON STRUCTURE FUNCTIONS (F_2 AND F_L)
  - OR PHOTON PARTON DISTRIBUTION

- THE EQUIVALENCE BETWEEN THE TWO EXPRESSIONS LEADS TO AN EXPRESSION FOR THE PHOTON PDF IN TERMS OF AN INTEGRAL OVER PROTON STRUCTURE FUNCTIONS

Imaginary flavour changing process

TRANSITION MAGNETIC MOMENT

$$\mathcal{L}_{\rm int} = \frac{e}{\Lambda}\bar{L}\sigma^{\mu\nu}F_{\mu\nu}l$$



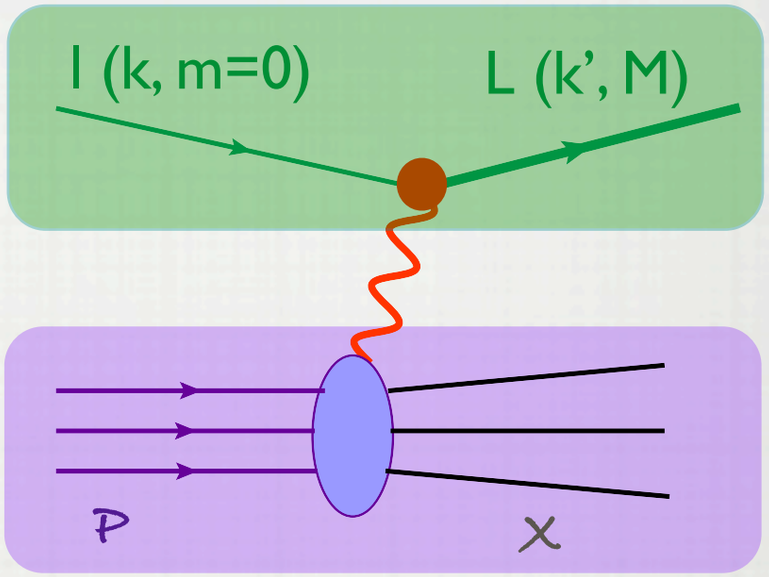
Λ NEEDED TO PRESERVE DIMENSIONS.

Λ LARGER THAN ALL OTHER SCALES

NB: could alternatively consider Higgs production with photon fusion (p γ → H X)

Cross section using form factors

$$L^{\mu\nu}(k,q) = \frac{1}{2}\frac{e^2_{\rm ph.}(q^2)}{\Lambda^2}\mathrm{Tr}\left(\not{k}'[\not{q},\gamma^\mu](\not{k}'+M)[\gamma^\nu,\not{q}]\right)$$



$$W_{\mu\nu}(p,q) = -g_{\mu\nu}F_1(x_B,Q^2) + \frac{p_\mu p_\nu}{pq}F_2(x_B,Q^2) + \text{long. terms}$$

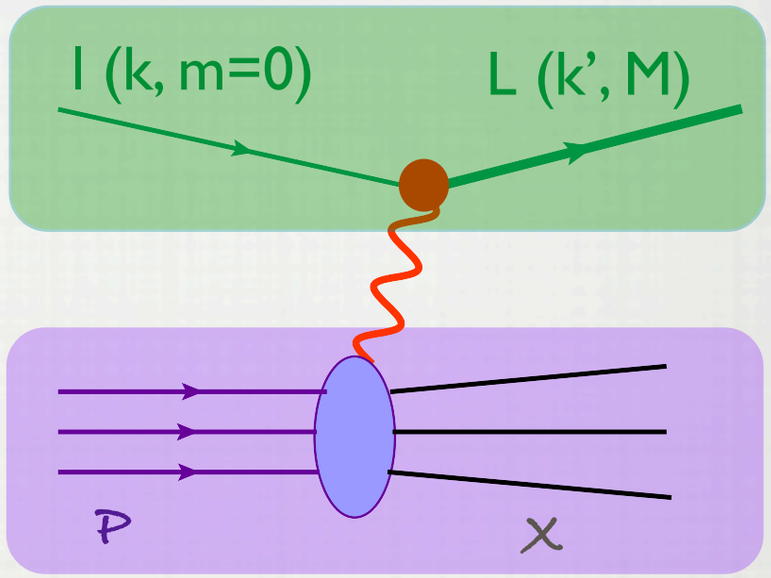
$$\sigma = \frac{1}{2s}\int d\Phi_q e^2_{\rm ph}(q^2) W_{\mu\nu}(p,q)\frac{1}{q^4}L^{\mu\nu}(k,q)\delta((k-q)^2 - M^2)$$

NB:

1. the expression is exact in QCD
2. since the leptons are neutral, this result is accurate up to terms $O(s/\Lambda^2)$

Cross section using PDFs

$$\sigma = \frac{16\pi^2}{\Lambda^2} \sum_a \int_x^1 \frac{dz}{z} \hat{\sigma}_a(z, \mu^2) \frac{M^2}{zs} f_{a/p}\left(\frac{M^2}{zs}, \mu^2\right)$$



- compute partonic cross section in the MSbar scheme
- drop subleading terms
- equate the two expressions
- derive the photon PDF in terms of an integral over proton structure functions

Power counting and accuracy

We are interested in hard collider processes, we work in the regime:

$$s, M^2 \gg m_p^2$$

$$s, M^2 \ll \Lambda^2$$

(further photon exchanges are suppressed)

We introduce

$$L \equiv \ln \mu^2 / m_p^2 \sim 1/\alpha_s$$

The Photon PDF starts at $O(\alpha L)$ and we keep NLO $O(\alpha_s)$ corrections, hence all terms of the order

$$\alpha L (\alpha_s L)^n \sim \alpha L \qquad \alpha (\alpha_s L)^n \sim \alpha \qquad \alpha^2 L^2 (\alpha_s L)^n \sim \alpha^2 L^2$$

and neglect terms beyond this order

The photon PDF

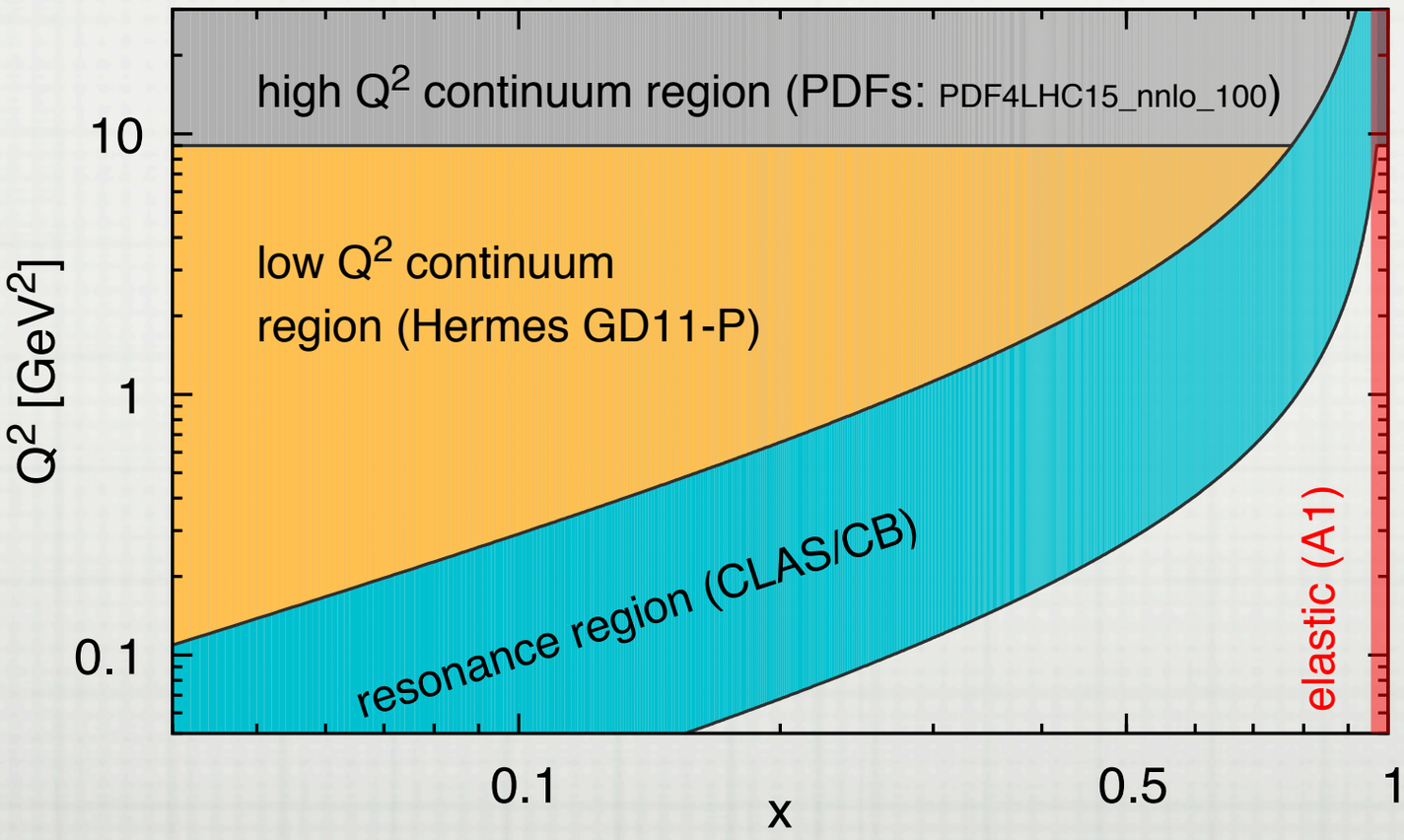
Main result of this work is the following expression of the photon PDF in terms of proton form factors and structure functions (measured accurately in DIS):

$$x f_{\gamma/p}(x,\mu^2) = \frac{1}{2\pi\alpha(\mu^2)}\int_x^1 \frac{dz}{z}\left\{\int_{Q^2_{\rm min}}^{\frac{\mu^2}{1-z}} \frac{dQ^2}{Q^2}\alpha^2(Q^2)\right.$$
$$\left[\left(2-2z+z^2+\frac{2x^2m_p^2}{Q^2}\right)F_2(x/z,Q^2)\right.$$
$$\left.\left.-z^2F_L\left(\frac{x}{z},Q^2\right)\right] - \alpha^2(\mu^2)z^2F_2\left(\frac{x}{z},\mu^2\right)\right\}$$

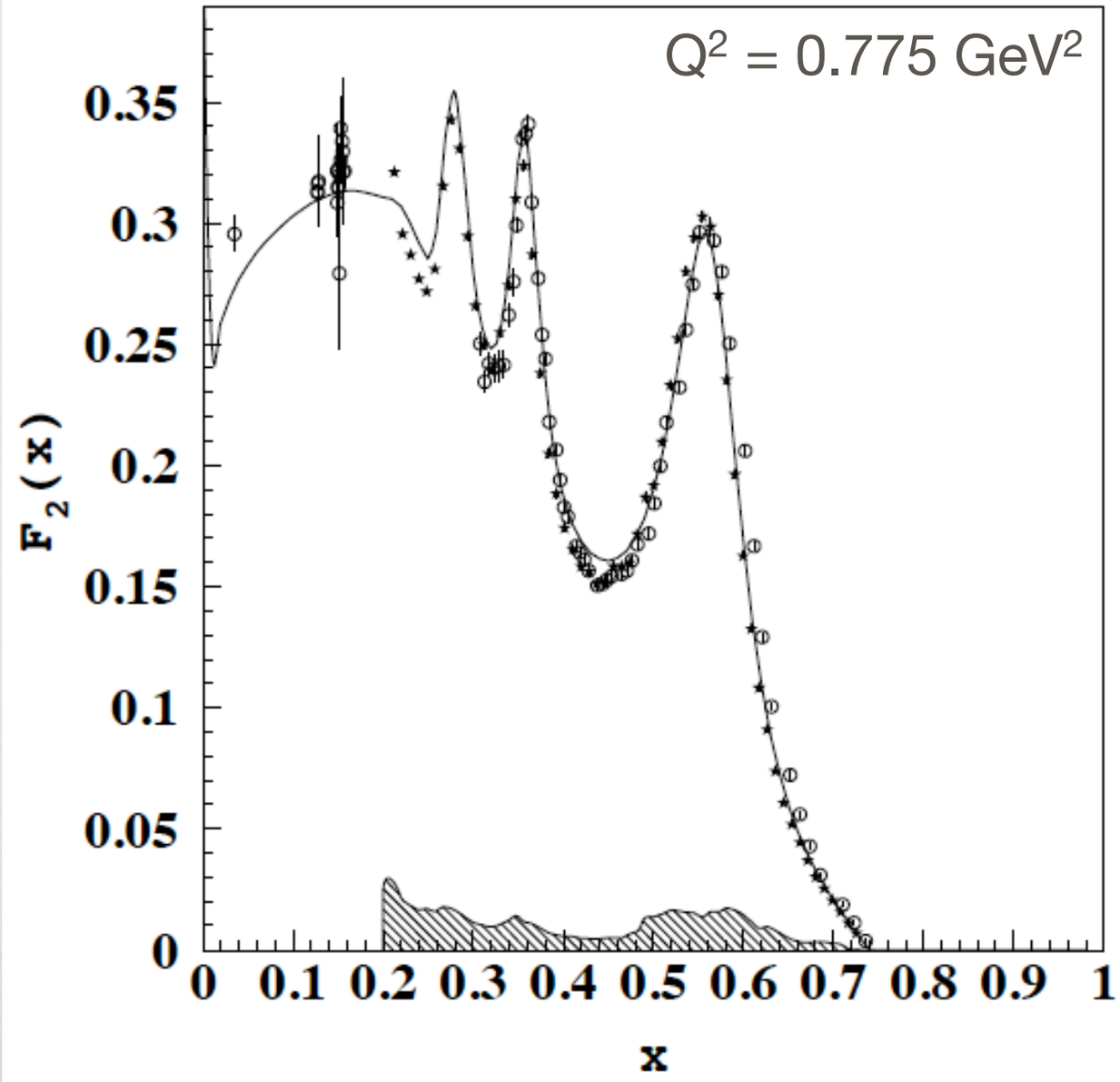
Input data

Form factors determined by different experiments in different kinematic regions (in general good agreement in overlap regions)

DATA USED IN OUR DETERMINATION:



CLAS data



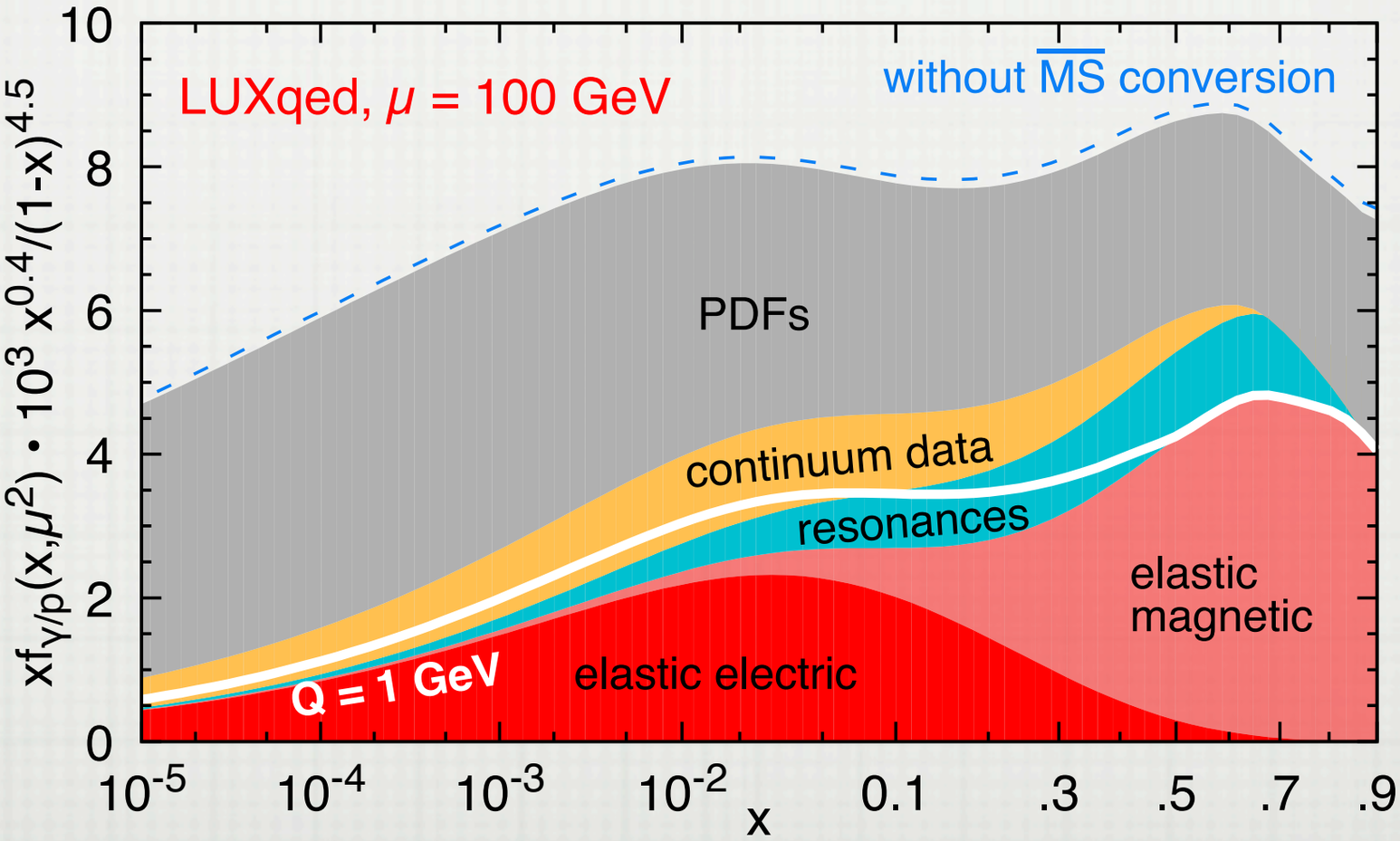
Source of uncertainties	Variation range [%]	Average [%]
Efficiency evaluation	1-9	4.3
e^+e^- pair production correction	0-3	0.3
Photoelectron correction	0.1-2.2	0.6
Radiative correction	1.5-20	3.2
Momentum correction	0.1-30	3.5
Uncertainty of $R = \frac{\sigma_L}{\sigma_T}$	0.5-5	2.4
Total	2.5-30	7.7

Range and average of systematic errors on F_2

* CLAS data
  - previous measurements

Separate contributions

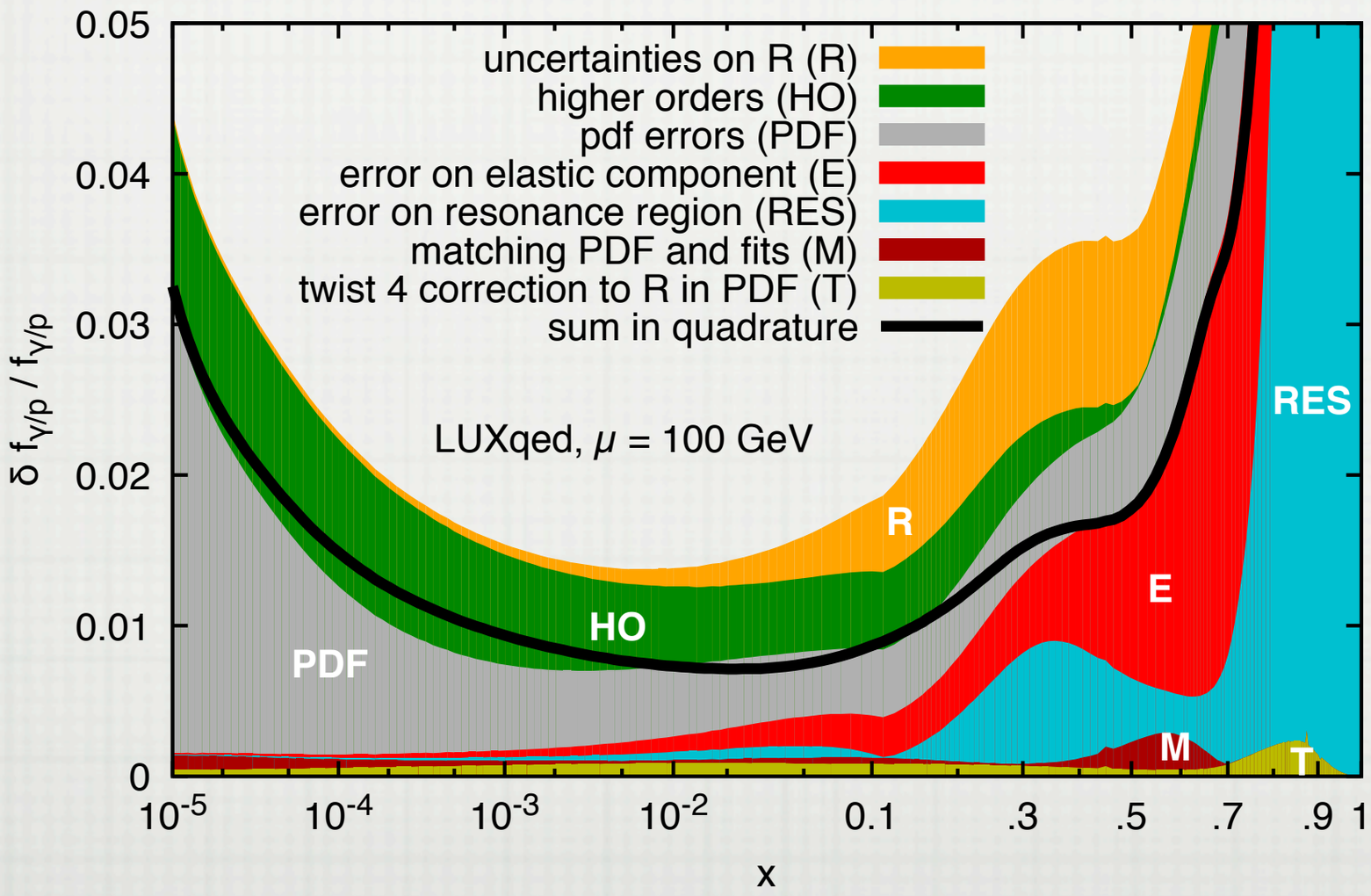
RELATIVE SIZE OF DIFFERENT CONTRIBUTIONS:



ALL MUST BE INCLUDED TO ACHIEVE % ACCURACY

Breakdown of uncertainty

SOURCES OF ERRORS INCLUDED:



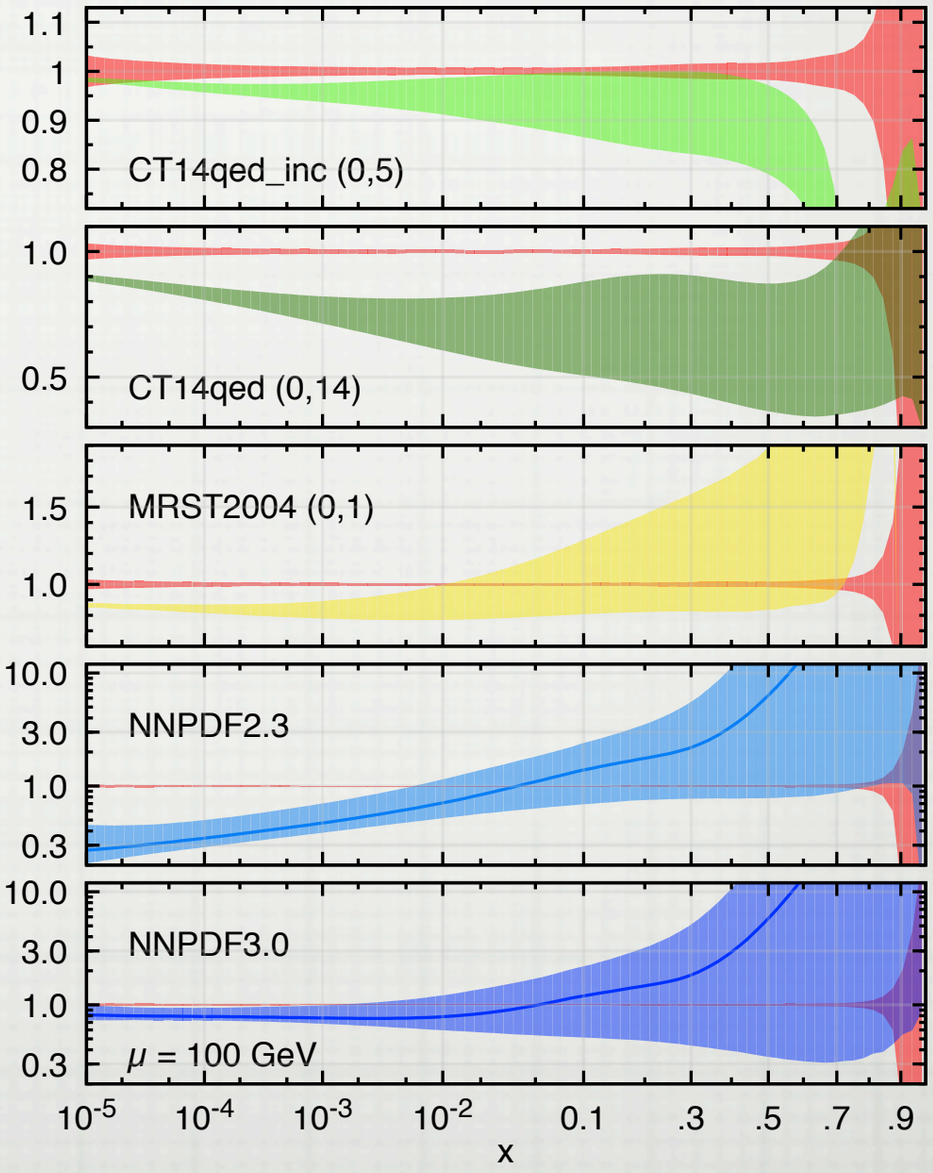
1-2% ACCURACY OVER A LARGE RANGE OF X VALUES

Comparison to other PDFs

RATIOS OF OTHER PDFS TO LUXpdf

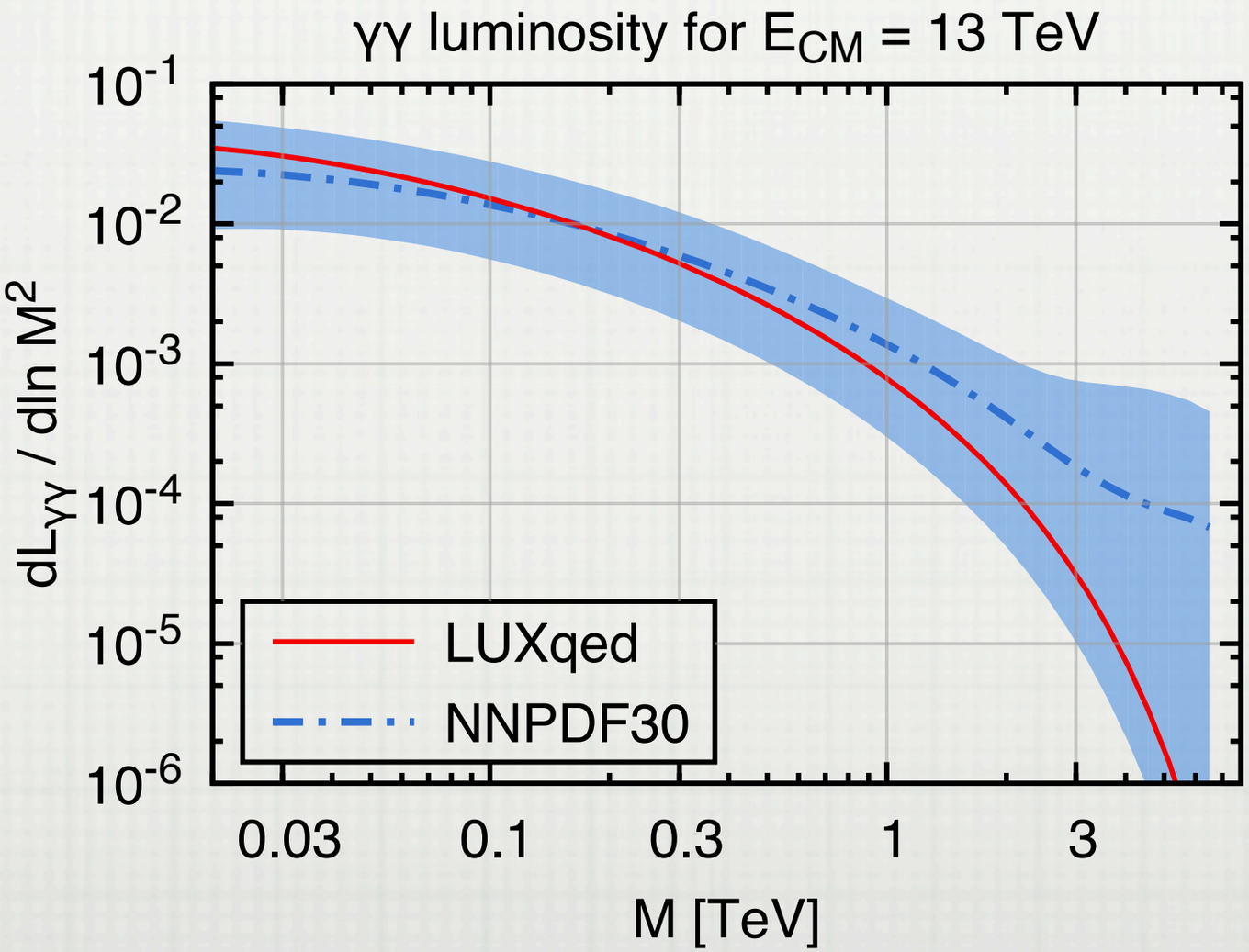
Best agreement with

- CT14qed_inc (also includes elastic component, but neglects magnetic component for neutron)
- NNPDF3.0 (extends NNPDF2.3 with treatment of $a(a_s L)^n$ terms in the evolution



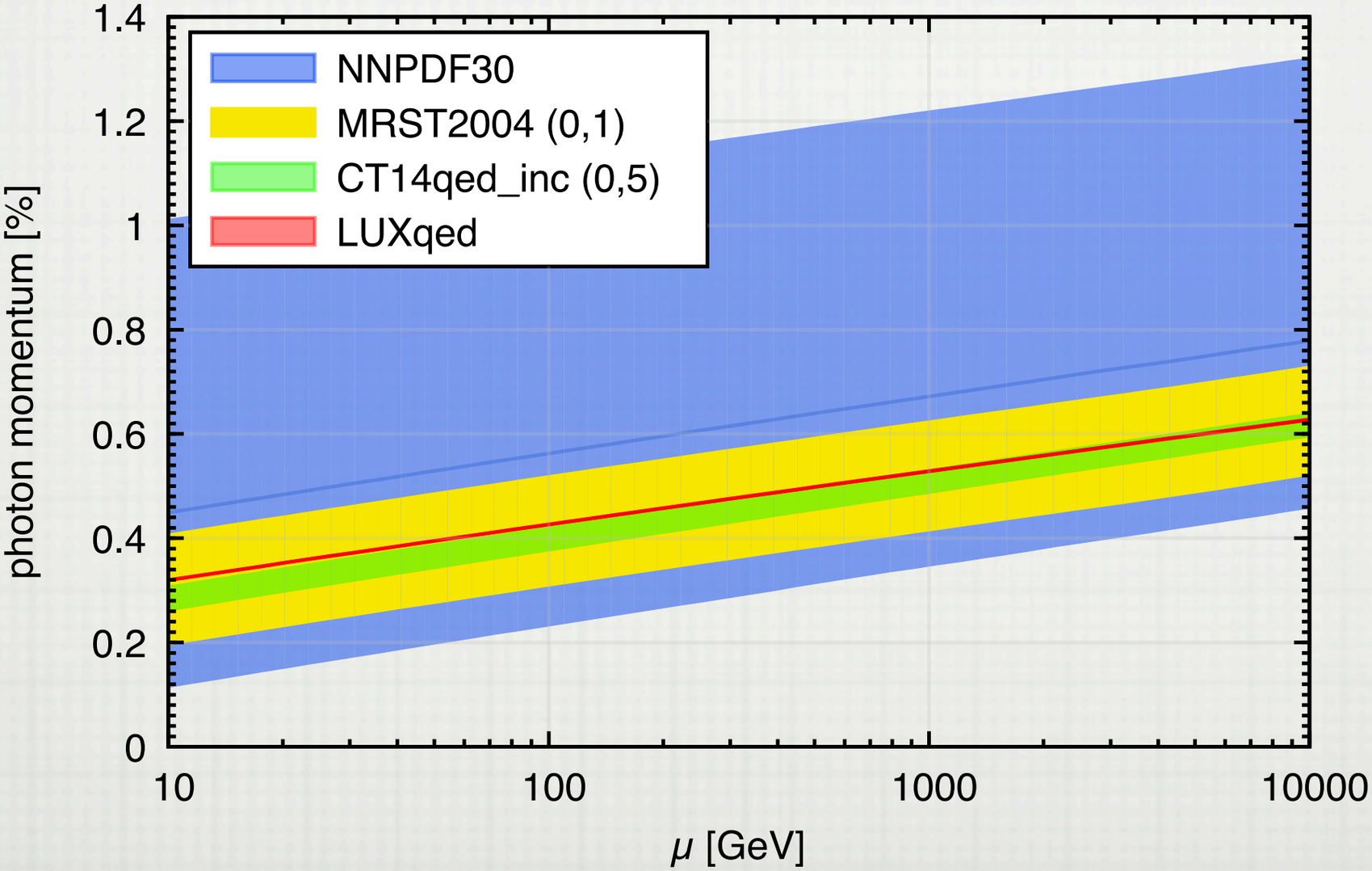
Luminosity plot

PHOTON LUMINOSITIES AT 13 TEV:



NB: LUXqed ERROR BAND SMALLER THAN WIDTH OF LINES

Percentage of photon momentum



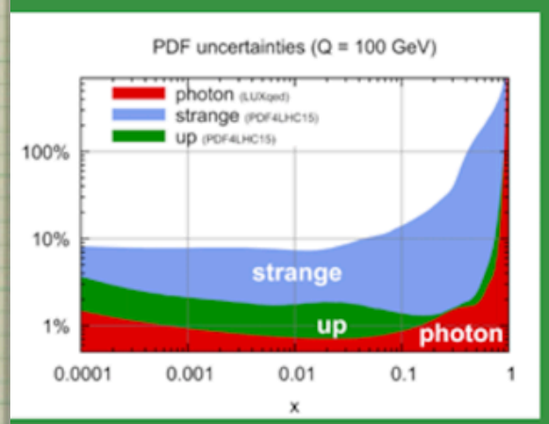
E.G. PHOTON CARRIES 0.43% OF PROTON MOMENTUM AT 100 GEV

LHAPDF LUXqed library

http://cern.ch/luxqed

LUXqed

Precise photon distribution inside the proton



LUXqed provides a model-independent determination of the photon parton distribution function (PDF) inside the proton. It is based on structure function and elastic form factor fits in electron-positron scattering, as described in arXiv:1607.04266.

There is currently one complete PDF set, `LUXqed_plus_PDF4LHC15_nnlo_100` in LHAPDF v6 format. It combines QCD partons from `PDF4LHC15_nnlo_100` with the LUXqed photon determination.

The low Q^2 LUXqed photon component is determined from A1, CLAS and Hermes GD11-P fits. The high-Q^2 part is determined from the input QCD PDF with standard (massless) NNLO coefficient functions. The photon was generated at scale 100 GeV, and other partons matched at scale 10 GeV. Momentum conservation is enforced by adjusting $g(x) \to 0.99299\, g(x)$ at scale 10 GeV. The DGLAP evolution includes the $O(\alpha\, \alpha_s)$ splitting functions from arXiv:1512.00612.

PDF members:

- 0: *central*
- 1-100: *map to original PDF4LHC15_nnlo_100 members*
- 101: *replacement of CLAS resonance fit with Christy-Bosted fit*
- 102: *rescale R in low-Q^2 region by 1.5*
- 103: *rescale R in high-Q^2 region with a higher-twist component*
- 104: *use an elastic fit result without the two-photon exchange corrections*
- 105: *use the lower edge of the elastic fit error band*
- 106: *lower the transition from Hermes GD11-P to the PDF-based F_2, F_L determinations to 5 GeV^2*
- 107: *change the upper limit of the Q^2 integral in Eq.(6) of arXiv:1607.04266 to μ^2 (with appropriate change of last term of Eq.(6) to maintain accuracy)*

Additional plots:

- momentum fraction carried by the photon as a function of the factorisation scale (the various pages just show different vertical scales, with and without other photon determinations).
- validation plots, including a visualisation of the photon distribution and the impact of QED corrections on the various partons.

Sample application

http://cern.ch/luxqed

CROSS SECTION FOR ASSOCIATED HW(→ l ν) PRODUCTION AT 13 TEV

Cross section without photon induced	91.2 ±1.8 fb
Photon induced with NNPDF2.3	$6.0\ ^{+4.4}\ _{-2.9}$ fb
Photon induced with LUXqed	4.4 ± 0.1 fb

The photon induced contribution was the dominant source of error in HW. Now associated error negligible.

Conclusion

- LUXqed is a new photon pdf determination. It is purely data driven (uses DIS data) and is model independent
- Thanks to accurate DIS data, compared to LHC based determinations, the uncertainty goes from O(100%) to O(1-2%)
- LUX is available at http://cern.ch/luxqed and is now part of LHAPDF library

If you think about it, it's awesome: we are made of protons, and protons are, in some part, made of light... And now we know how much of it

http://www.science20.com/a_quantum_diaries_survivor/how_much_light_does_a_proton_contain-176396