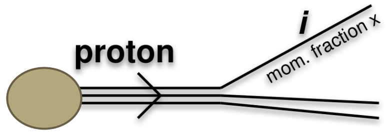
The polarized photon distribution function

Lucas Palma Conte

PhD supervisor: Dr. Daniel de Florian

Polarized Parton distribution functions (pPDFs)

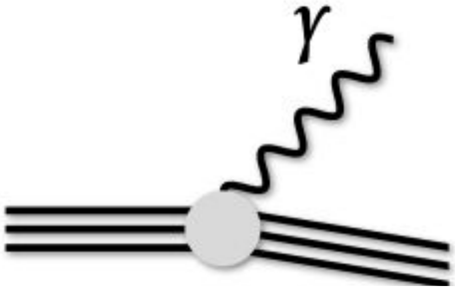
The polarized PDF are defined as the difference between the distributions of partons with positive and negative helicity inside a proton with positive helicity.



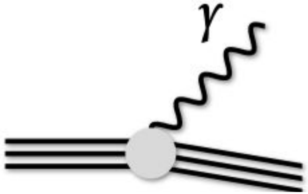
$$\Delta f_i(x,Q^2) = f_i^+ - f_i^-$$

The PDFs are fitted from the experiment and are **UNIVERSAL**, they must not depend on any process.

We usually hear about quark and gluon PDFs, but what about the photon PDF?



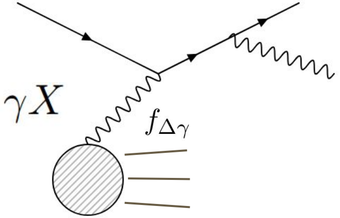
The polarized photon distribution function: Motivation



- No parameterization is available for the case of the polarized photon PDF
- QED corrections start to be important because many observables reached QCD corrections at NNLO, $\alpha_{QCD}^2 \sim \alpha_{QED} \sim \frac{1}{137}$. For this reason the PDF of the photon is a key density.
  - Calculate the evolution of polarized PDFs including QED corrections.
  - Some process are sensitive to these density, such as the productions of prompt photons in ep.

e.g.

$ep \rightarrow \gamma X$



D. Rein, M. Schlegel, and W. Vogelsang, Phys. Rev. D 110, 014041 (2024), arXiv:2405.04232 [hep-ph]

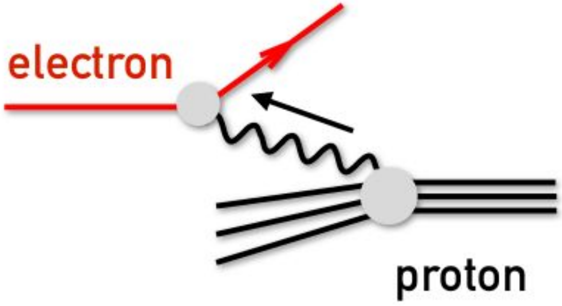
DIS and LuxQED approach

A. Manohar, P. Nason, G. P. Salam, and G. Zanderighi, Phys. Rev. Lett. 117, 242002 (2016), arXiv:1607.04266 [hep-ph]

The extraction from a global fit is difficult because it is a small amount compared to the PDFs of Quarks and Gluons. But...

- DIS is usually seen as a photon from electron probing proton structure, but can be viewed as an electron probing the photon PDF.

- The structure functions g_1 and g_2 encoded all the information about this process.



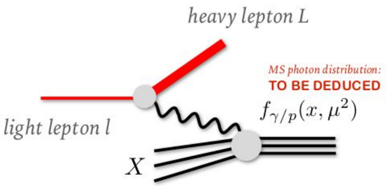
$$\frac{d^2\sigma_{LL}(x,Q^2)}{dx\,dQ^2} = \frac{8\pi\alpha^2 y}{Q^4} \times \left[\left(1 - \frac{y}{2} - \frac{y^2}{4}\gamma^2\right) g_1(x,Q^2) - \frac{y}{2}\gamma^2\, g_2(x,Q^2)\right]$$

LuxQED approach: Photon PDF

how to extract the photon pPDF from the DIS process?

A. Manohar, P. Nason, G. P. Salam, and G. Zanderighi, Phys. Rev. Lett. 117, 242002 (2016), arXiv:1607.04266 [hep-ph]

1. Propose a BSM process in which a massive lepton is produced from a light lepton and a photon. At LO there is an interaction with the photon PDF.



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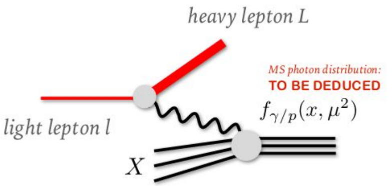

2. Calculate the process in terms of the structure function. ⇒

$g_1 \; g_2$ ⇑

$$\sigma_{lp} \propto \int \frac{d^4 q}{(2\pi)^4} \frac{e_{\rm ph}^4(q^2)}{q^4} (4\pi) W^{\mu\nu}(q,p) \, L_{\mu\nu}(q,k)$$

LuxQED approach: Photon PDF

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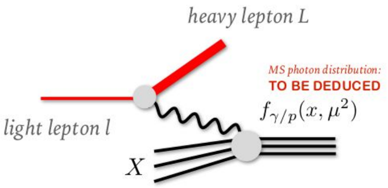


2. Calculate the process in terms of the structure function. ⇒

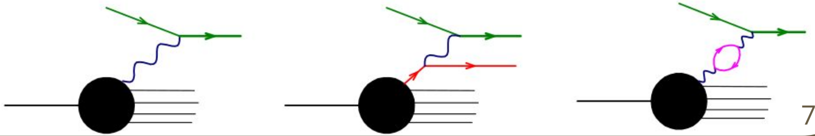
$g_1 \quad g_2$

$$\sigma_{lp} \propto \int \frac{d^4q}{(2\pi)^4} \frac{e^4_{\rm ph}(q^2)}{q^4} (4\pi) W^{\mu\nu}(q,p)\, L_{\mu\nu}(q,k)$$

3. Calculate the process using the factorization approach. The photon PDF appears at LO. ⇒

$$\sigma_{lp} = \sum_{i_s} \int dx\, \hat{\sigma}_{l_h i_s}(xp) f_{i_s/p_H}(x,\mu^2)$$

$$\sigma_{lp}(p) = \int dy\, \hat{\sigma}^{(0,0)}_{l\gamma}(yp) \boxed{f_\gamma(y,\mu^2)} + \frac{\alpha(\mu^2)}{2\pi} \sum_{j\in\{q,l\}} \int dy\, \hat{\sigma}^{(0,1)}_{lj}(yp)\, f_j(y,\mu^2) + \cdots$$



4. Finally equate them to get the photon distribution.

The polarized photon PDF

$$f_{\Delta\gamma}(x,\mu^2) = \frac{1}{2\pi\alpha(\mu^2)} \int_x^1 \frac{dz}{z}\left\{\int_{\frac{m_p^2 x^2}{(1-z)}}^{\frac{\mu^2}{1-z}} \frac{dQ^2}{Q^2}\alpha_{ph}^2(-Q^2)\right.$$

$$\left[\left(4-2z-\frac{4m_p^2x^2}{Q^2}\right)g_1(x/z,Q^2) - \left(\frac{8m_p^2x^2}{zQ^2}\right)g_2(x/z,Q^2)\right]$$

$$+\Delta\gamma^{\overline{MS}}(x,\mu^2)$$

The last term can be computed perturbatively,

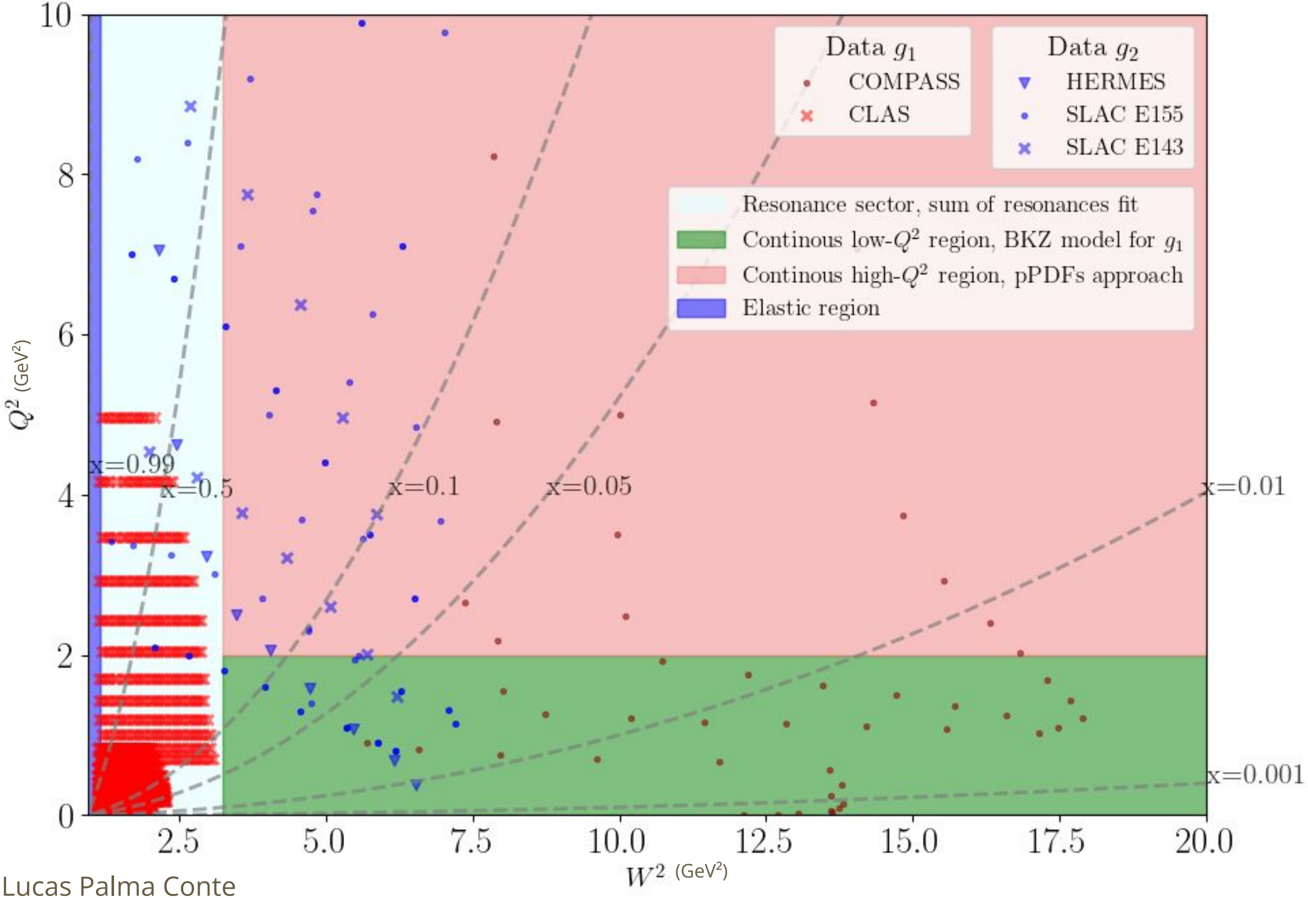
$$\Delta\gamma_{LO}^{\overline{MS}}(x,\mu^2) = \frac{\alpha(\mu^2)}{2\pi}\int_x^1 \frac{dz}{z} 4(1-z) g_1^{LO}(x/z,\mu^2) + \text{high orders}$$

Perturbative approach

$$g_1^{LO}(x_{bj},\mu^2) = \frac{1}{2}\sum_{\{q\}} e_q^2\left(\Delta q(x_{bj},\mu^2) + \Delta\bar{q}(x_{bj},\mu^2)\right)$$

- Must not depend in any parameter of the process.
- Necessary to know the structure functions in a wide range of parameter space.
- The behavior of the structure functions will be different in each region of the parameter space.

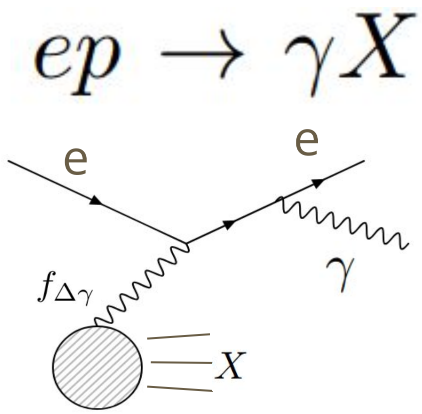
Parameter space



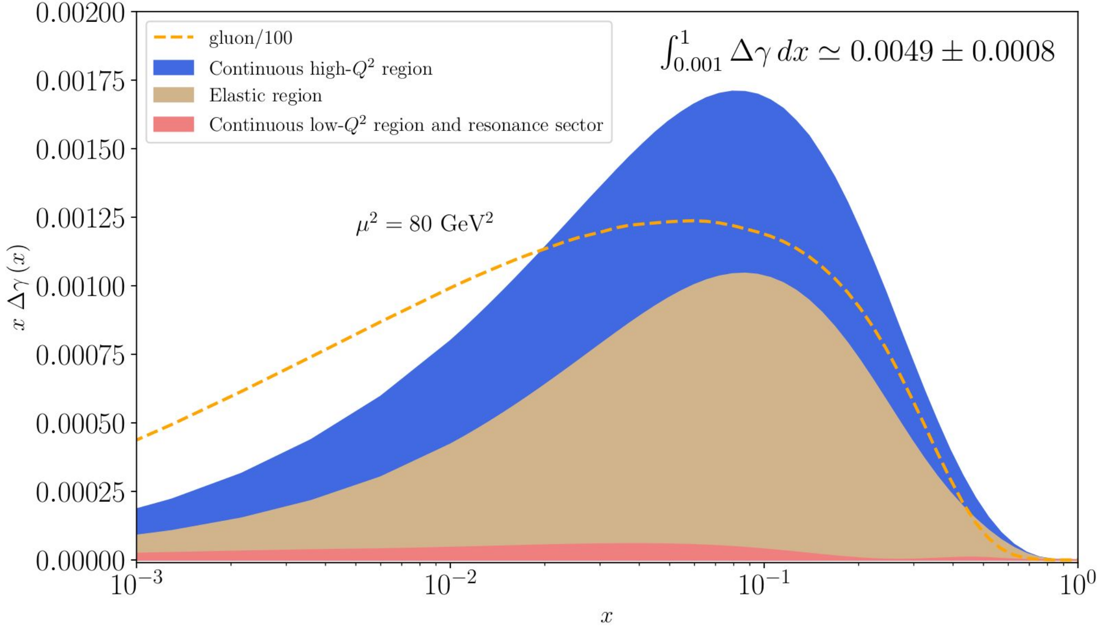
- We divide the parameter space into regions according to the behavior of the structure functions:
  Elastic, Resonance, Low-Q and High-Q.
- The idea is to model the structure functions g_1 and g_2 in each region. And compute the contribution to the photon PDF.

Results

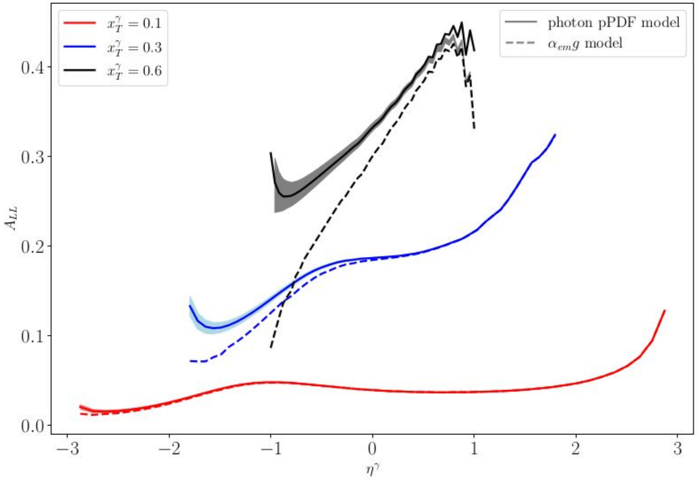
- The largest contributions are the perturbative and elastic region.
- The resonance and low-Q2 regions are of a lower order.



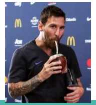
LO



D. de Florian, L. P. Conte and G. F. Volonnino, *The polarized photon distribution function*, Eur. Phys. J. C **84** (2024) 905, arXiv:2406.03414 [hep-ph], doi:10.1140/epjc/s10052-024-13294-4.



***D. Rein, M. Schlegel, and W. Vogelsang**, Phys. Rev. D **110** (2024) no.1, 014041, arXiv:2405.04232 [hep-ph], doi:10.1103/PhysRevD.110.014041.*



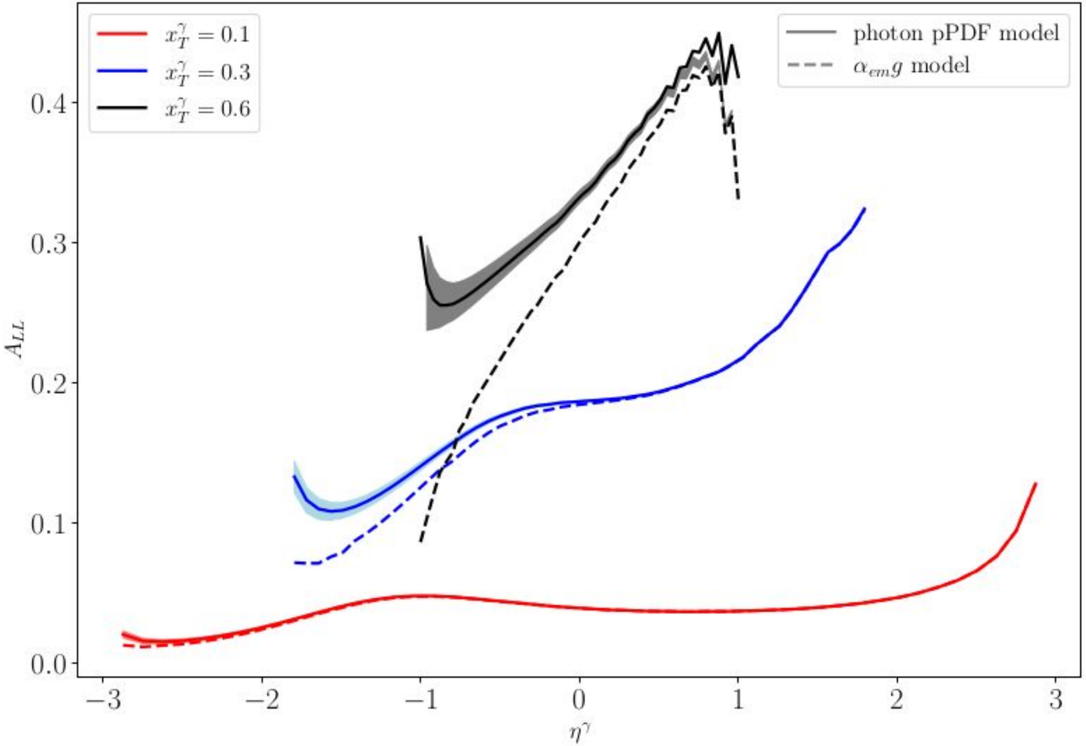
Conclusions

- We compute the polarized photon PDF using the LuxQED approach.
- We show that the photon pPDF is of the order gluon/100.
- The first momentum is small in comparison with the quarks and gluon momentum
- We apply the photon pPDF in Prompt Photon Production and observe significant differences with toy models.

¡Thanks!
¡Muchas Gracias!

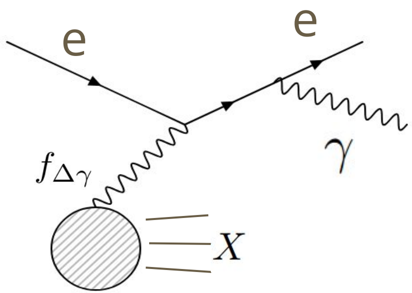
Questions?

Prompt photon production



D. Rein, M. Schlegel, and W. Vogelsang, *Phys. Rev. D* ***110*** *(2024) no.1, 014041, arXiv:2405.04232 [hep-ph], doi:10.1103/PhysRevD.110.014041.*

$$ep \to \gamma X$$



LO

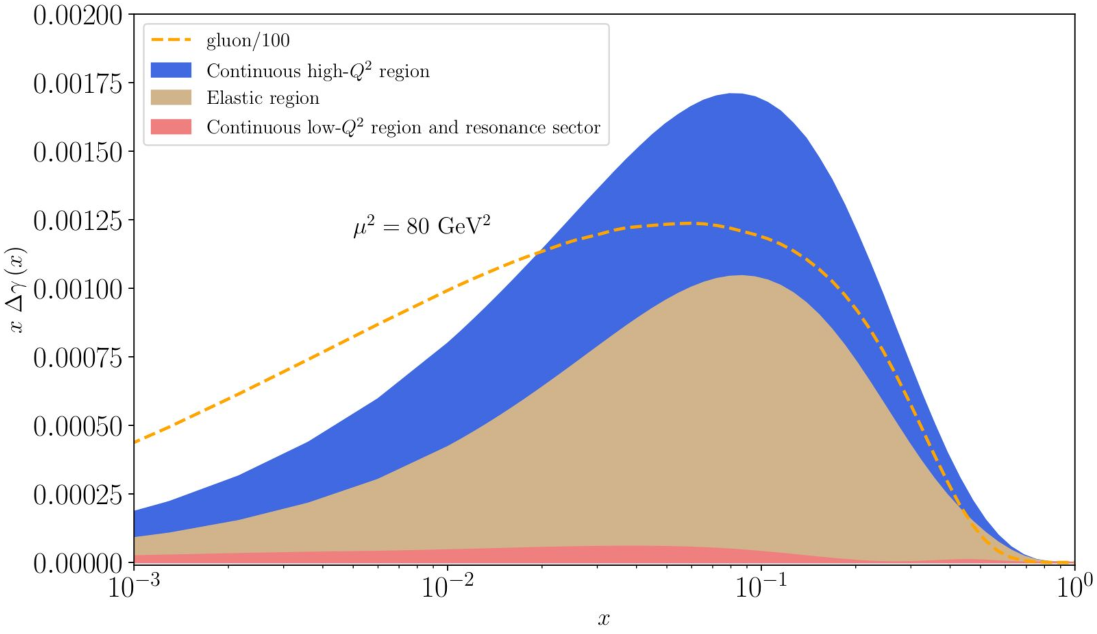
$$\sigma^{\gamma\mathrm{PDF}} = \frac{2\alpha_{\mathrm{em}}^2}{s(-u)}\, \hat{\sigma}^{\gamma\mathrm{PDF}}(v)\, f_1^{\gamma/p,\overline{\mathrm{MS}}}(x_0,\mu)$$

Results

- The largest contributions are the perturbative and elastic region.

- The resonance and low-Q2 regions are of a lower order.

$$f_{\Delta\gamma}(x,\mu^2) = \frac{1}{2\pi\alpha(\mu^2)} \int \frac{dz}{z} \left\{ \int_{\frac{m_p^2 x^2}{(1-z)}}^{\frac{\mu^2}{1-z}} \frac{dQ^2}{Q^2} \alpha_{\rm ph}^2(-Q^2) \left[\left(4 - 2z - \frac{4m_p^2 x^2}{Q^2}\right) g_1(x/z, Q^2) - \left(\frac{8m_p^2 x^2}{zQ^2}\right) g_2(x/z, Q^2) \right] + \Delta\gamma^{\overline{\rm MS}}(x,\mu^2) \right.$$

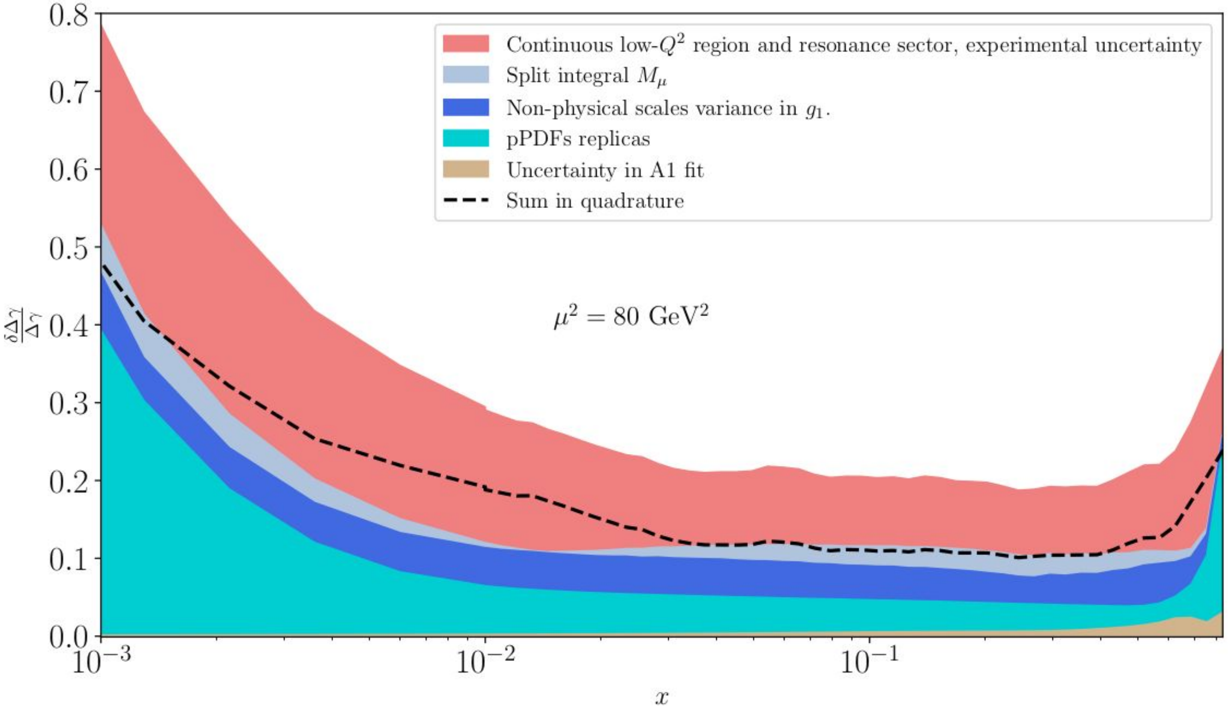


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g + \int \Delta\gamma\, dx$$

$$\int_{0.001}^{1} \Delta\gamma\, dx \simeq 0.0049 \pm 0.0008$$

The first momentum is much smaller than the quarks and gluon momentum.

Uncertainty of the calculation



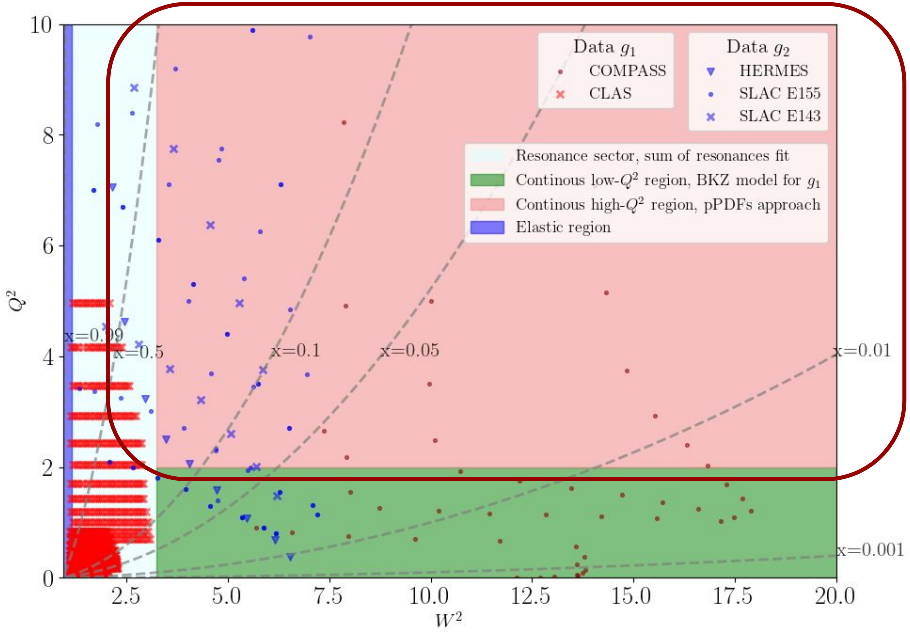
- The largest uncertainty comes from the the low Q2 region. These uncertainty arise from the experimental uncertainty.
- For the perturbative region the largest uncertainty arise from the PDF replicas. Also there are an uncertainty because the variation for the non physical scales.
- For the Elastic region the uncertainty is small, it arise from the experimental error in the A1 collaboration measurement of the Sachs factor.

High Q^2 region, Perturbative approach

I. Borsa, D. de Florian, R. Sassot, M. Stratmann, and W. Vogelsang, (2024), arXiv:2407.11635 [hep-ph]

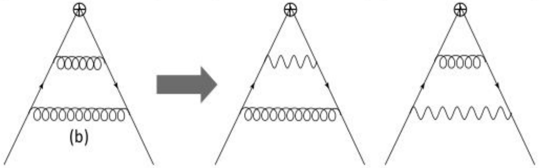
DSSV set

$$Q^2 > Q^2_{per} \text{ and } W^2 > W^2_{\rm res} = 3.24\,\mathrm{GeV}^2$$



$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2\{(\Delta q+\Delta\bar{q}) + 2\,a_S\,[\Delta C_q^{(1,0)}\otimes(\Delta q+\Delta\bar{q}) + \Delta C_g^{(1,0)}\otimes\Delta g]$$
$$+\; 2\,a\,[\Delta C_q^{(0,1)}\otimes(\Delta q+\Delta\bar{q}) + \Delta C_\gamma^{(0,1)}\otimes\Delta\gamma]$$
$$+\; 2\,a\,2\,a_S\,[\Delta C_q^{(1,1)}\otimes(\Delta q+\Delta\bar{q}) + \Delta C_g^{(1,1)}\otimes\Delta g + \Delta C_\gamma^{(1,1)}\otimes\Delta\gamma]\}.$$

We calculate them using the “Abelianization” mechanism.



$$\Delta C_q^{(2,0)} \rightarrow \Delta C_q^{(1,1)}$$

D. de Florian, G. F. R. Sborlini, and G. Rodrigo, Eur. Phys. J. C 76, 282 (2016), arXiv:1512.00612 [hep-ph]

Wandzura-Wilczek relation for g_2

$$g_2^{\rm WW}(x_{bj}) = -g_1(x_{bj}) + \int_{x_{bj}}^1 \frac{dy}{y} g_1(y)$$

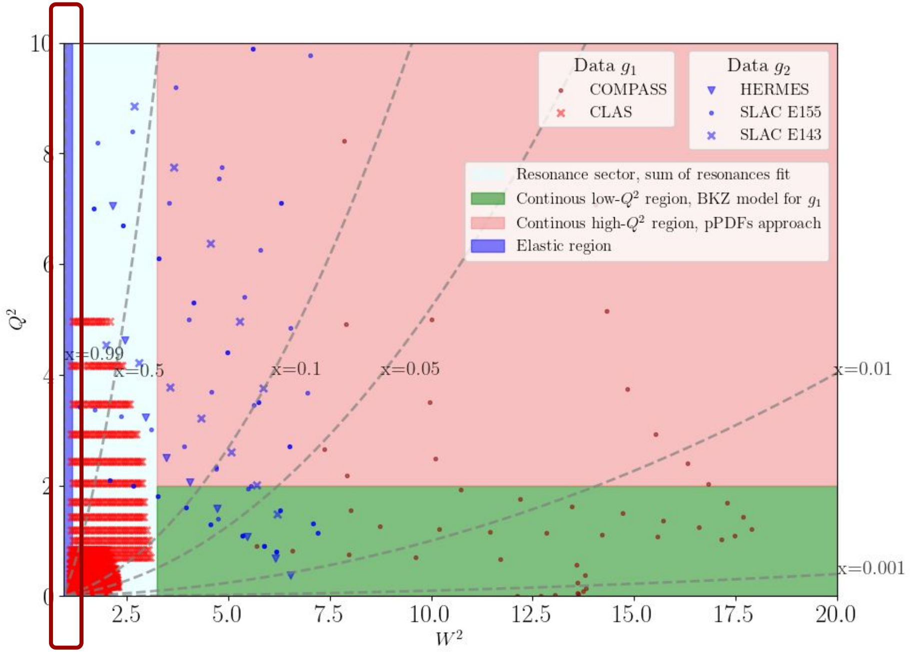
Elastic region

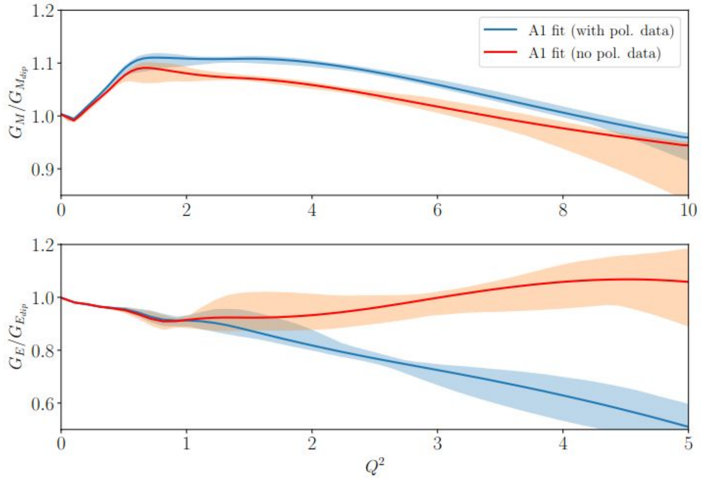
$$W^2 < (m_p + m_{\pi^0})^2$$

We can express g_1 and g_2 in terms of the Sachs form factors of the proton, GE and GM.

$$g_1^{\mathrm{ela}}(x_{bj}, Q^2) = \frac{1}{2}\frac{G_E(Q^2)\,G_M(Q^2) + \tau G_M(Q^2)}{1+\tau}\delta(x_{bj}-1),$$
$$g_2^{\mathrm{ela}}(x_{bj}, Q^2) = \frac{\tau}{2}\frac{G_E(Q^2)\,G_M(Q^2) - G_M(Q^2)}{1+\tau}\delta(x_{bj}-1),$$

$$f_{\Delta\gamma}^{\mathrm{el}} = \frac{1}{2\pi\alpha(\mu^2)}\int_{Q^2_{\mathrm{min}}}^{\frac{\mu^2}{1-x}}\frac{dQ^2}{Q^2}\left\{\alpha_{\mathrm{ph}}^2(-Q^2)\left[\frac{G_E G_M}{1+\tau}\left(2-2x-\frac{2m_p^2x^2}{Q^2}\right)+\frac{\tau G_M^2}{1+\tau}\left(2-\frac{2m_p^2x^2}{Q^2}\right)\right] + \alpha^2(\mu^2)[2(1-x)]\frac{G_E G_M+\tau G_M^2}{1+\tau}\right\}$$



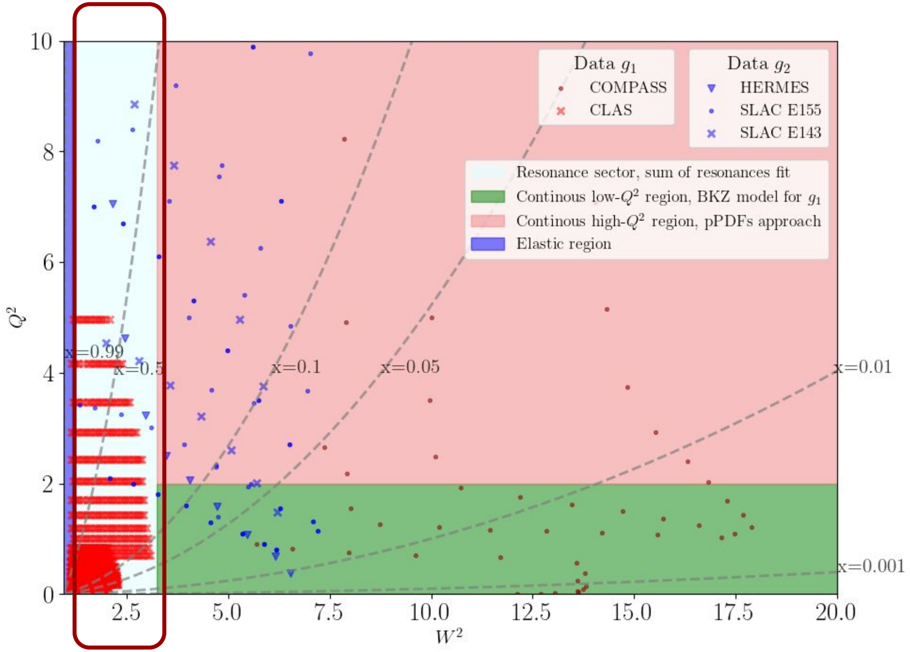


J. C. Bernauer et al. (A1), Phys. Rev. C 90, 015206 (2014), arXiv:1307.6227 [nucl-ex].

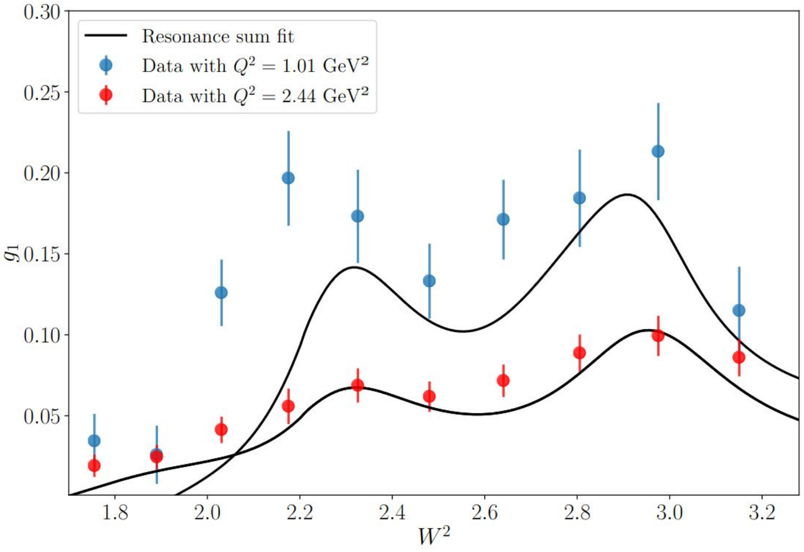
Resonance region

$$(m_p + m_{\pi^0})^2 < W^2 < W^2_{\text{res}} = 3.24\,\text{GeV}^2$$

We use a model for both g_1 and g_2 based on resonances sum.



Resonant contributions to polarized proton structure functions, A. N. Hiller Blin, V. I. Mokeev, and W. Melnitchouk, Phys. Rev. C 2023 107, 035202



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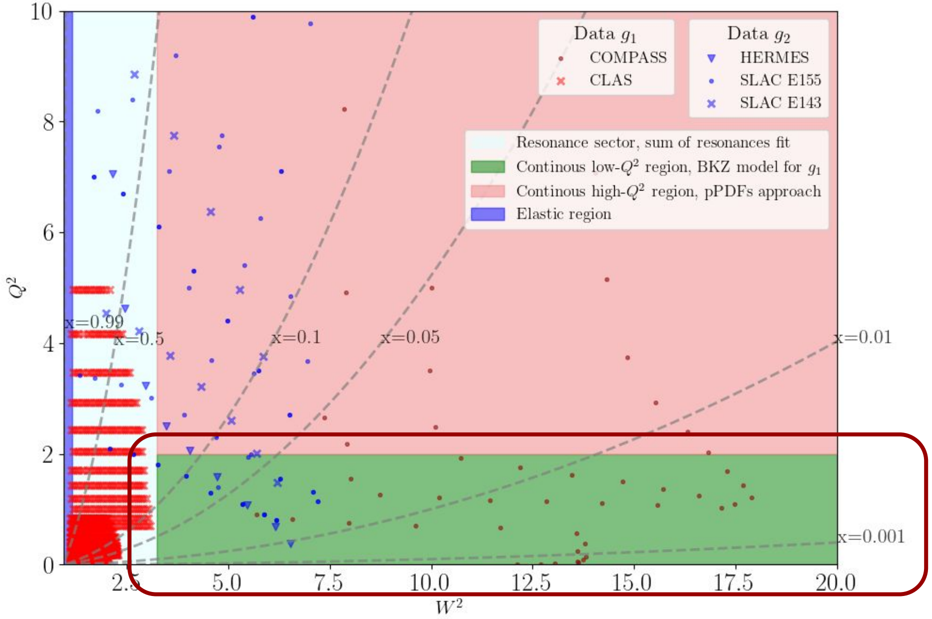
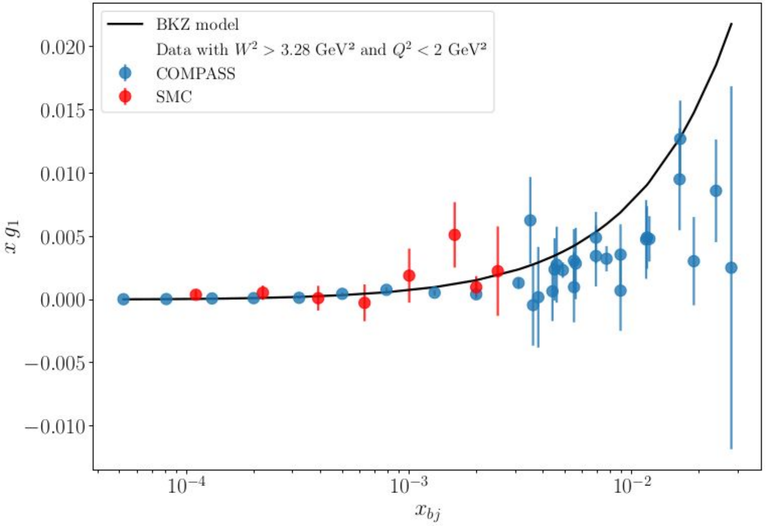
Low-Q^2 region

$$W^2 > W^2_{\text{res}} \text{ and } Q^2 < Q^2_{per} = 2\,\text{GeV}^2$$



Vector Meson Dominance (VMD):

The photon turns into an on-shell vector meson which interacts with the proton.



Using the VMD they arrive at this formula

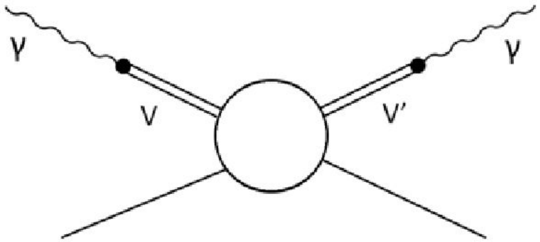
$$g_1^{\text{bkz}}(x_{bj}, Q^2) = C\left[\frac{4}{9}\left(\Delta u^{(0)}_{val}(x_{bj}) + \Delta\bar{u}^{(0)}(x_{bj})\right) + \frac{1}{9}\left(\Delta d^{(0)}_{val}(x_{bj}) + \Delta\bar{d}^{(0)}(x_{bj})\right)\right]\frac{M_\rho^4}{(Q^2+M_\rho^2)^2} + C\left[\frac{1}{9}\left(2\Delta\bar{s}^{(0)}(x_{bj})\right)\right]\frac{M_\phi^4}{(Q^2+M_\phi^2)^2}$$

B. M. Badelek, J. Kwiecinski, and B. Ziaja, Eur. Phys. J. C 26, 45 (2002), arXiv:hep-ph/0206188.

Vector Meson Dominance

The photon virtually dissociates into an on-shell vector meson that subsequently interacts with hadron A to yield the hadron state B.

$$[\gamma^* A \to B] = -e\frac{m_\rho^2}{2\gamma_\rho}\frac{1}{q^2 - m_\rho^2}[\rho^0 A \to B] + (\omega) + (\phi)$$



B. Badelek and J. Kwiecinski, Journal of Physics G: Nuclear and Particle Physics 25, 1533 (1999).

$$g_1(x, Q^2) = \frac{M\nu}{4\pi}\sum_V \frac{M_V^4 \Delta\sigma_V(W^2)}{\gamma_V^2 (Q^2 + M_V^2)^2}$$

$\Delta\sigma_V(W^2)$ interaction between mesons and nucleon

$$g_1^{\mathrm{bkz}}(x_{bj}, Q^2) = C\left[\frac{4}{9}\left(\Delta u_{val}^{(0)}(x_{bj}) + \Delta\bar{u}^{(0)}(x_{bj})\right) + \frac{1}{9}\left(\Delta d_{val}^{(0)}(x_{bj}) + \Delta\bar{d}^{(0)}(x_{bj})\right)\right]\frac{M_\rho^4}{(Q^2 + M_\rho^2)^2}$$
$$+ C\left[\frac{1}{9}\left(2\Delta\bar{s}^{(0)}(x_{bj})\right)\right]\frac{M_\phi^4}{(Q^2 + M_\phi^2)^2}$$
$$+ g_1^{\mathrm{per}}(x_{bj}, Q^2),$$

C is fitted from the experiment

High orders for the "MS" term

$$f_{\Delta\gamma}(x,\mu^2) = \frac{1}{2\pi\alpha(\mu^2)} \int \frac{\mathrm{d}z}{z} \left\{ \int_{\frac{m_p^2 x^2}{(1-z)}}^{\frac{\mu^2}{1-z}} \frac{\mathrm{d}Q^2}{Q^2} \alpha_{\mathrm{ph}}^2(-Q^2) \right.$$

$$\left[\left(4 - 2z - \frac{4m_p^2 x^2}{Q^2}\right) g_1(x/z, Q^2) - \left(\frac{8m_p^2 x^2}{zQ^2}\right) g_2(x/z, Q^2) \right]$$

$$+ \Delta\gamma^{\overline{\mathrm{MS}}}(x,\mu^2)$$

$$\Delta\gamma^{\overline{\mathrm{MS}}}(x,\mu^2) = \frac{8\pi\,(S\mu)^{-2\epsilon}}{\alpha(\mu^2)} \frac{1}{(4\pi)^{D/2}} \frac{1}{\Gamma(D/2-1)} \int_x^1 \frac{\mathrm{d}z}{z} (1-z)^{D/2-2} \int_{\frac{\mu^2}{1-z}}^{\infty} \frac{\mathrm{d}Q^2}{Q^2} \times$$

$$(Q^2)^{D/2-2}\, \alpha_D^2(Q^2) \left\{ \left(4 - 2z + 4\frac{\epsilon}{1-\epsilon}(1-z)\right) g_{1,D}(x/z, Q^2) \right\}$$

High orders in $g_{1,D}$

$$g_{1,D}^{(1,0)} = \left(\frac{\mu^2}{Q^2}\right)^{\epsilon} \left[-\frac{1}{\epsilon} \Delta B_{1,f=q,g}^{(1,0)}(z) + \Delta C_{1,f=q,g}^{(1,0)}(z) - \epsilon \Delta a_{1,f=q,g}^{(1,0)}(z) \right]$$

Adding LO in QCD

$$\Delta\gamma^{(1,1)} = \sum_{f\in\{q,g\}} \int_x^1 \frac{dz}{z} \int_{x'}^1 \frac{dz'}{z'} \frac{1}{12} \left\{ \left[2\pi^2 - 24 + 24z - z\pi^2 \right.\right.$$

$$\left. +24(z-1)\ln(1-z) + 6(z-2)\ln(1-z)^2 \right] \Delta B_{1,f}^{(1,0)}(z')$$

$$\left. \left[12(z-2)\right] \Delta a_{1,f}^{(1,0)}(z') + \left[24(1-z) - 12(z-2)\ln(1-z)\right] \Delta C_{1,f}^{(1,0)}(z') \right\} \Delta f(x'/z', \mu^2)$$

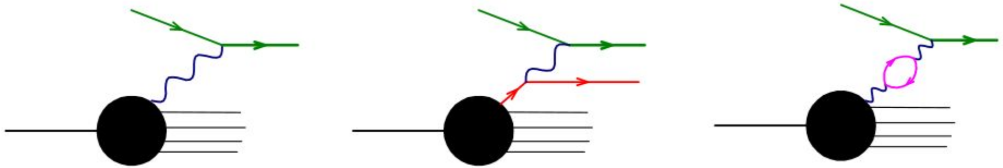
LuxQED details

$$\frac{1}{2}\left(\sigma_{l_R p_H} - \sigma_{l_L p_H}\right) = \frac{1}{2\pi\alpha(\mu^2)}\sigma_0 \int \frac{\mathrm{d}z}{z} \int_{Q^2_{\min}}^{Q^2_{\max}} \frac{\mathrm{d}Q^2}{Q^2} \alpha^2_{\mathrm{ph}}(-Q^2)$$
$$\left\{ H\left(4 - 2z - \frac{4m_p^2 x^2}{Q^2} - \frac{4m_p^2 x^2 Q^2}{M^4} - \frac{8m_p^2 x^2}{M^2} - \frac{2zQ^2}{M^2}\right) x g_1(x/z, Q^2) - H\left(\frac{8m_p^2 x^2}{zM^2} + \frac{8m_p^2 x^2}{zQ^2}\right) x g_2(x/z, Q^2) \right\}$$

In terms of the structure function.

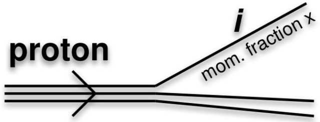
$$\frac{1}{2}\left[\sigma_{l_R p_H} - \sigma_{l_L p_H}\right] = \sigma_0 H \left\{ x f_{\Delta\gamma}(x, \mu^2) + \frac{\alpha(\mu)}{2\pi} \int_x^1 \frac{dz}{z} \left[z(2 - z)\left(\log \frac{M^2(1-z)^2}{z\mu^2}\right) - 3z(1-z)\right] \times \sum_i e_i^2 \frac{x}{z} f_{\Delta i}\left(\frac{x}{z}, \mu^2\right) + \mathcal{O}(\alpha\alpha_s, \alpha^2) \right\}$$

Using the factorization approach.



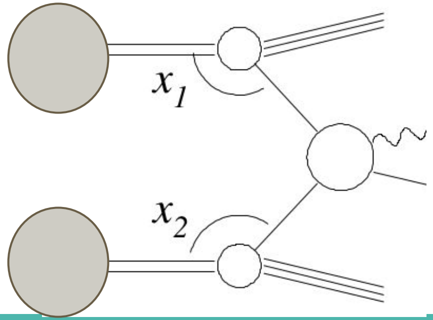
Polarized Parton distribution functions (pPDFs)

The polarized PDF are defined as the difference between the distributions of partons with positive and negative helicity inside a proton with positive helicity.

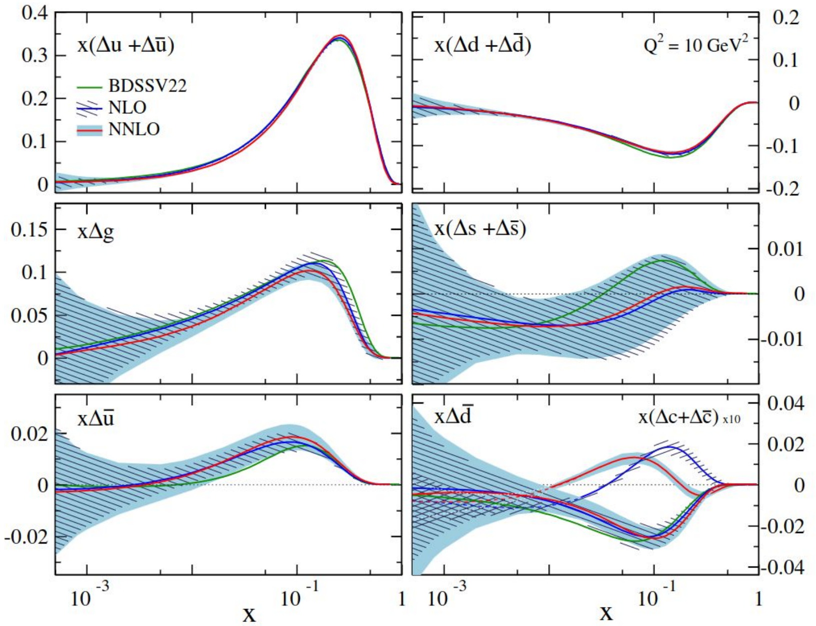


$$\Delta f_i = f_i^+ - f_i^-$$

$$d\sigma^H(S) = \sum_{i,j} \int dx_1 dx_2 f_{iA}(x_1) d\sigma_{ij}(s) f_{jB}(x_2)$$



The PDFs are fitted from the experiment and are universal.



I. Borsa, D. de Florian, R. Sassot, M. Stratmann, and W. Vogelsang, (2024), arXiv:2407.11635 [hep-ph]

QED corrections to polarised PDF evolution

Parton distribution functions (PDFs)

Parton Model

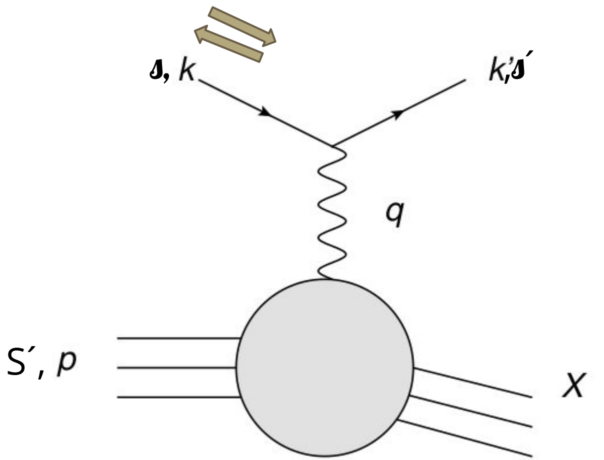
Factorization

$$\sigma(ep \to eX) = \int_0^1 dz \sum_i f_i(z)\, \hat{\sigma}(eq_i \to eX)$$

large distances: $f_i(z)$ → PDF

small distances: $\hat{\sigma}(eq_i \to eX)$

$$A_L = \frac{\sigma_{\Rightarrow}^{\leftarrow} - \sigma_{\Leftarrow}^{\leftarrow}}{\sigma_{\Rightarrow}^{\leftarrow} + \sigma_{\Leftarrow}^{\leftarrow}}$$



The PDFs are fitted from the experiment and are universal.

$$f_i = f_i^+ - f_i^-$$

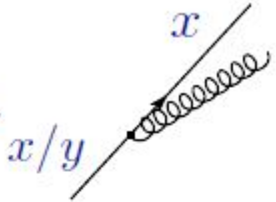
Modelo de Patrones y ecuaciones DGLAP

QCD does not tell us what shape PDFs have, but it does tell us how they evolve with energy.

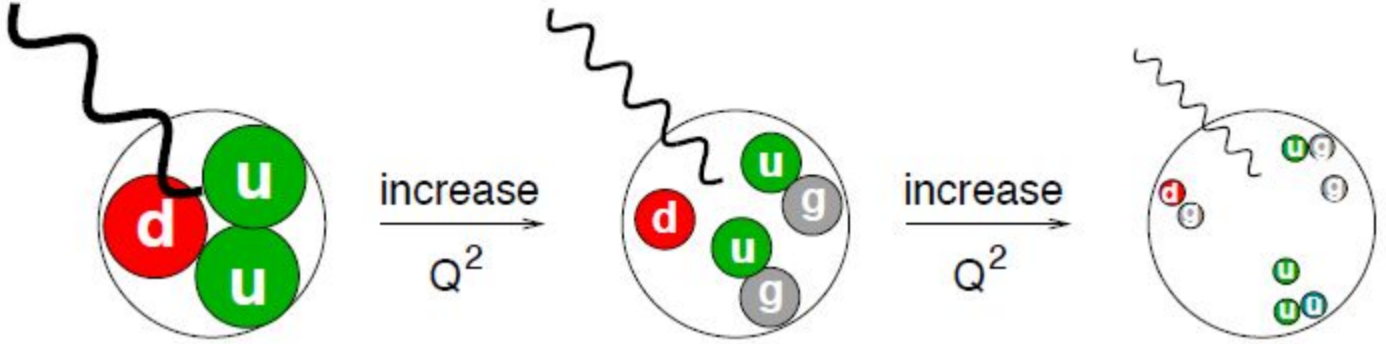
DGLAP : Dokshitzer, Grivov, Lipatov, Altarelli, Parisi

Kernel A-P

$$\frac{\partial q(x,\mu_F^2)}{\partial \log(\mu_F^2)} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y} P_{qq}(y)\, q\left(\frac{x}{y},\mu_F^2\right)$$



Increase "resolution" scale: resolve more details of "partonic structure"



QED corrections

$$\frac{\partial q(x,\mu_F^2)}{\partial \log(\mu_F^2)} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y} P_{qq}(y)\, q\left(\frac{x}{y},\mu_F^2\right)$$

$$\frac{dg}{dt} = \sum_{j=1}^{n_F} P_{gq_j}\otimes q_j + \sum_{j=1}^{n_F} P_{g\bar{q}_j}\otimes \bar{q}_j + P_{gg}\otimes g + P_{g\gamma}\otimes\gamma\,,$$

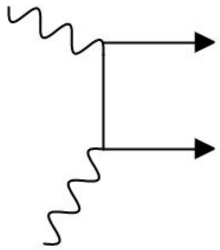
$$\frac{d\gamma}{dt} = \sum_{j=1}^{n_F} P_{\gamma q_j}\otimes q_j + \sum_{j=1}^{n_F} P_{\gamma\bar{q}_j}\otimes \bar{q}_j + P_{\gamma g}\otimes g + P_{\gamma\gamma}\otimes\gamma\,,$$

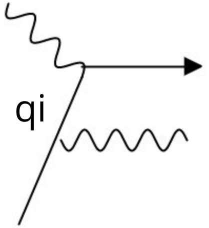
$$\frac{dq_i}{dt} = \sum_{j=1}^{n_F} P_{q_iq_j}\otimes q_j + \sum_{j=1}^{n_F} P_{q_i\bar{q}_j}\otimes \bar{q}_j + P_{q_ig}\otimes g + P_{q_i\gamma}\otimes\gamma$$

$$(f\otimes g)(x) = \int_x^1 \frac{dy}{y} f\left(\frac{x}{y}\right) g(y)$$

We solve them by passing to the MELLIN space, where the convolution is the product.

MT: a Mathematica package to compute convolutions





LO QED corrections

QED corrections

$$\frac{\partial q(x,\mu_F^2)}{\partial \log(\mu_F^2)} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y} P_{qq}(y)\, q\left(\frac{x}{y},\mu_F^2\right)$$

$$\frac{dg}{dt} = \sum_{j=1}^{n_F} P_{gq_j}\otimes q_j + \sum_{j=1}^{n_F} P_{g\bar{q}_j}\otimes \bar{q}_j + P_{gg}\otimes g + P_{g\gamma}\otimes \gamma$$

$$\frac{d\gamma}{dt} = \sum_{j=1}^{n_F} P_{\gamma q_j}\otimes q_j + \sum_{j=1}^{n_F} P_{\gamma\bar{q}_j}\otimes \bar{q}_j + P_{\gamma g}\otimes g + P_{\gamma\gamma}\otimes \gamma$$

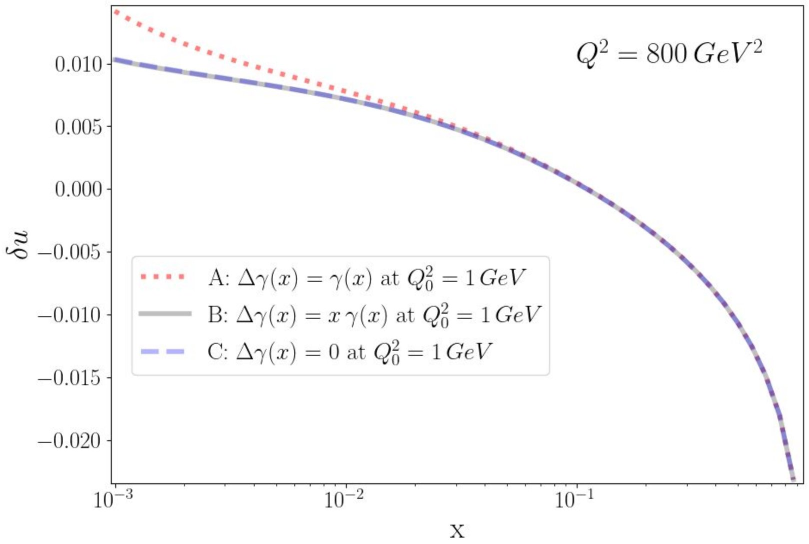
$$\frac{dq_i}{dt} = \sum_{j=1}^{n_F} P_{q_iq_j}\otimes q_j + \sum_{j=1}^{n_F} P_{q_i\bar{q}_j}\otimes \bar{q}_j + P_{q_ig}\otimes g + P_{q_i\gamma}\otimes \gamma$$

Photon distribution is a key density in the evolution with QED corrections

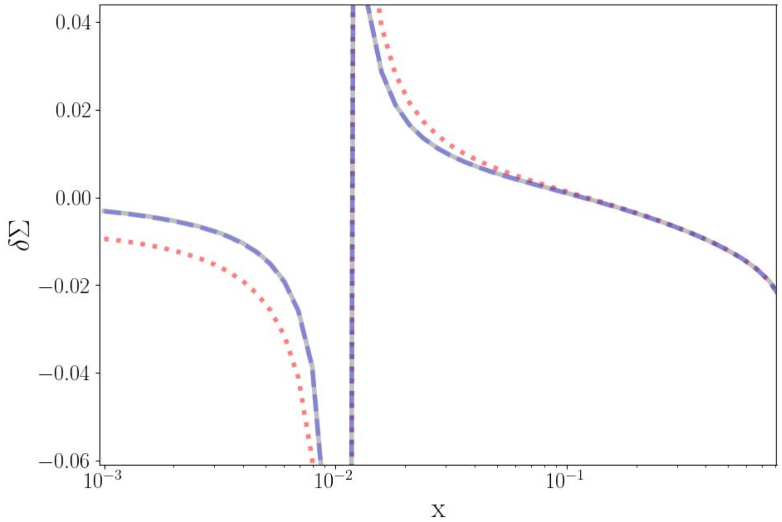
QED corrections: PDFs

$$\delta f = \frac{f_{withQED} - f_{noQED}}{f_{noQED}}$$

Corrections to quark u



Corrections to the sum of quarks



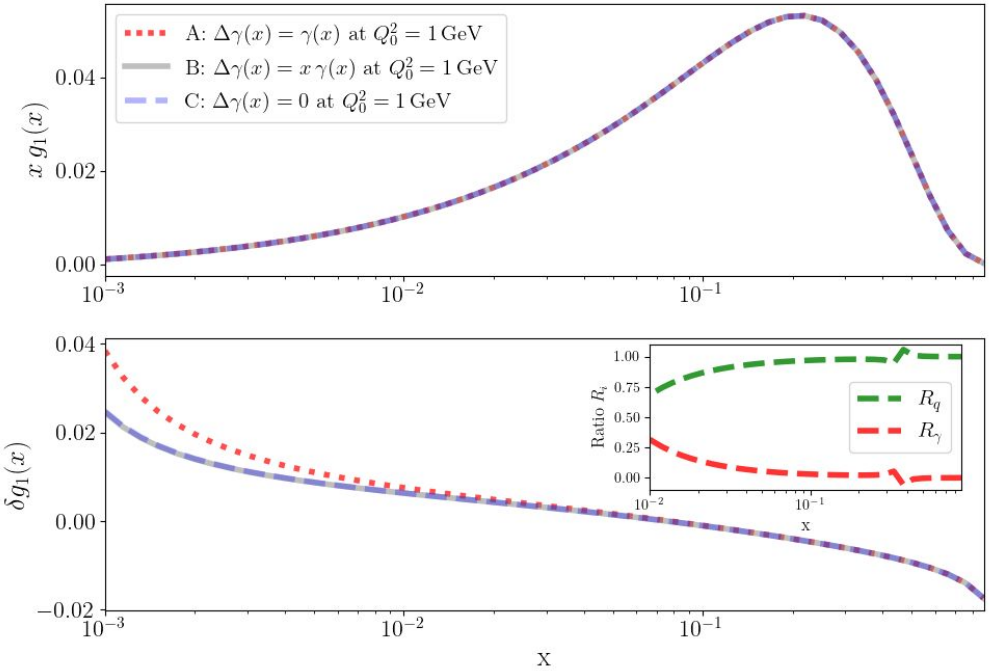
Corrections of the order of 4% in some sectors, same order of magnitude expected for the accuracy of the experimental data.

D. de Florian and L. P. Conte, Eur. Phys. J. C 83, 695 (2023), arXiv:2305.14144 [hep-ph]

Resultados QED: g1

$$g_1 = \frac{1}{2}\sum_q e_q^2\{(\Delta q + \Delta\bar{q}) + 2\,a_S\,[\Delta C_q^{(1,0)} \otimes (\Delta q + \Delta\bar{q}) + \Delta C_g^{(1,0)} \otimes \Delta g]$$
$$+2\,a\left[\Delta C_q^{(0,1)} \otimes (\Delta q + \Delta\bar{q}) + \Delta C_\gamma^{(0,1)} \otimes \Delta\gamma\right]\}.$$

Wilson's coefficients to LO QED



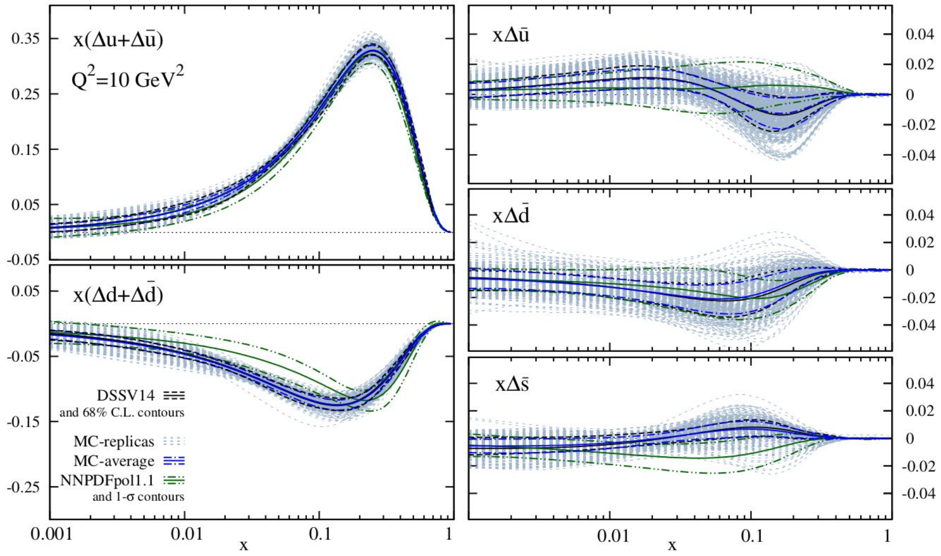
Ratio of the contribution of the quark PDFs

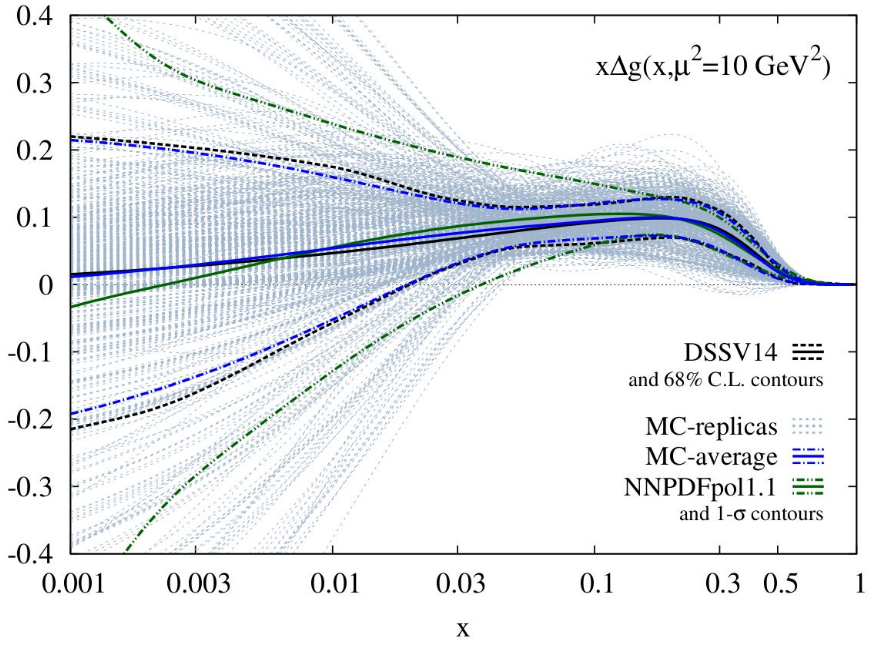
$$R_q = \frac{\Delta C_q^{(0,1)} \otimes (\Delta q + \Delta\bar{q})}{\Delta C_q^{(0,1)} \otimes (\Delta q + \Delta\bar{q}) + \Delta C_\gamma^{(0,1)} \otimes \Delta\gamma}$$

$$\delta f = \frac{f_{withQED} - f_{noQED}}{f_{noQED}}$$

Fiteo PDFs Polarizadas

Distribuciones de partones polarizadas





Evidence for polarization of gluons in the proton, 2014

Monte Carlo sampling variant of the DSSV14 set of helicity parton densities, de Florian, Sassot 2019

A first unbiased global determination of polarized PDFs and their uncertainties

Estas PDFs polarizadas van a estar relacionadas con el **Spin del protón.** Se ve una contribución de gluon no despreciable