New PDFs of the real photon

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University of Jyväskylä

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Centre of Excellence in Quark Matter

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HELSINKI INSTITUTE OF PHYSICS

Outline

Deep Inelastic Electron-Photon Scattering

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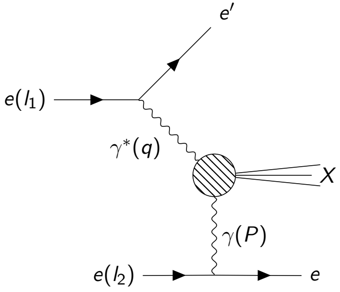

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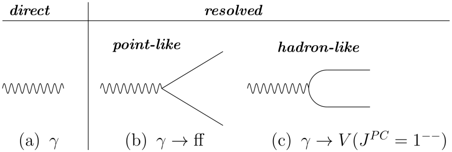

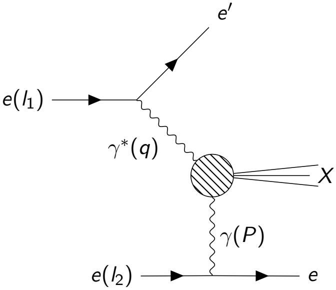

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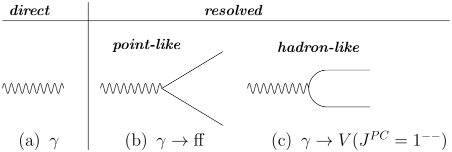

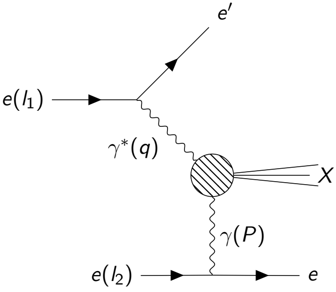

- The most recent global QCD analysis of photon PDFs is now almost 20 years old, uncertainities are not quantified, parameterizations are not flexible Nisius,1999 (Review); M.Gluck et al.,1983; SAL,2005; CJK,2004, CJKL,2003 and so on.

Towards a Global QCD Analysis

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Theory:

$$q^{\gamma}(x,Q^2) = \int_x^1 \frac{d\xi}{\xi} q_0(\xi)\left[\delta(1-z) + \frac{\alpha_s}{2\pi}P_{qq}\log\frac{Q^2}{\mu^2} + \frac{\alpha_s}{2\pi}\left(-\frac{1}{\hat{\epsilon}}P_{qq}(z)\right)\right]$$
$$+ \int_x^1 \frac{d\xi}{\xi} g_0(\xi)\left[\frac{\alpha_s}{2\pi}P_{qg}\log\frac{Q^2}{\mu^2} + \frac{\alpha_s}{2\pi}\left(-\frac{1}{\hat{\epsilon}}P_{qg}(z)\right)\right]$$
$$+ N_c e_q^2 \frac{\alpha_e}{2\pi}\left\{\left(-\frac{1}{\hat{\epsilon}} + \log\frac{Q^2}{\mu^2}\right)P_{q\gamma} + C_{\gamma}(x)\right\}$$

$$Q^2\frac{\partial q(x,Q^2)}{\partial Q^2} = \frac{\partial q(x,Q^2)}{\partial \log Q^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{d\xi}{\xi}\left[q_0(\xi)P_{qq}(z) + g_0(\xi)P_{qg}(z)\right] + \frac{\alpha_e}{2\pi}N_c e_q^2 P_{q\gamma}(x)$$
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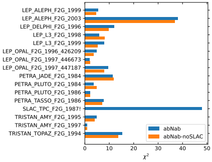
since, $q_0(\xi) \equiv q(\xi,Q^2) + \mathcal{O}(\alpha_s)$.

Experiment:



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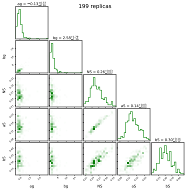

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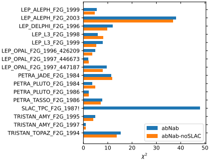

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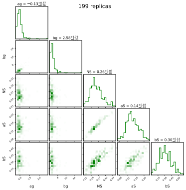
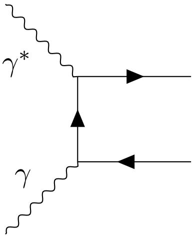


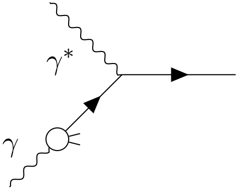
Framework

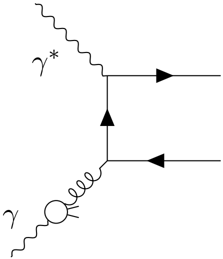
Candidate PDF $f^{\gamma}(Q_0^2)$ → Make theory predictions → Compare to world data (Minimize χ^2)

Repeat until fit converges!

Structure of the Photon in QCD







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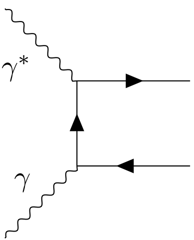

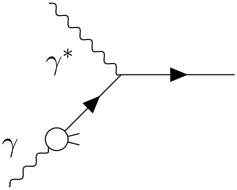

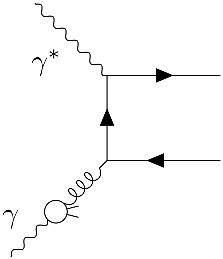

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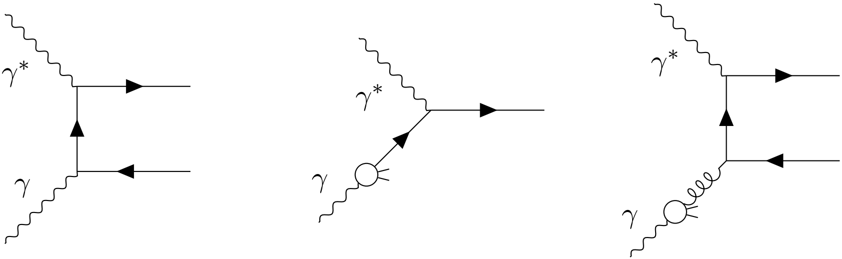

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- The observable also receives a point-like contribution, $C_\gamma(x)$, due to the direct coupling of the photon to quarks.

$$C_\gamma(z) = P_{q\gamma}(z)\log\frac{z}{1-z} + \underbrace{6z(1-z) - P_{q\gamma}(z)}_{-1+8z(1-z)}$$

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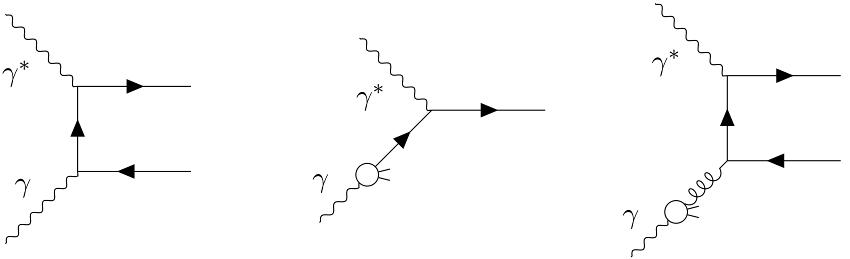

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- To avoid numerical instabilities, we work in the DIS_γ factorization scheme GRV, 1982 , where C_γ is absorbed into the photon PDFs.

Q^2 Evolution of Photon PDFs (DGLAP)

- The point-like contribution also propagates to the DGLAP evolution equations as an inhomogeneous term:

$$\frac{\mathrm{d}\mathbf{f}^{\gamma}(\mu_f^2)}{\mathrm{d}\ln\mu_f^2} = P \otimes \mathbf{f}^{\gamma} + \mathbf{k}(\mu_f^2) \xrightarrow[\text{transform}]{\text{Mellin}} \frac{\mathrm{d}\tilde{\mathbf{f}}^{\gamma}(\mu_f^2)}{\mathrm{d}\ln\mu_f^2} = -\gamma(\alpha_s(\mu_f^2))\tilde{\mathbf{f}}^{\gamma}(\mu_f^2) - \tilde{\mathbf{k}}(\mu_f^2)$$

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$$\frac{\mathrm{d}}{\mathrm{d}\alpha_s}\tilde{\mathbf{f}}(\alpha_s) = \frac{\mathrm{d}\ln(\mu_F^2)}{\mathrm{d}\alpha_s} \cdot \frac{\mathrm{d}\tilde{\mathbf{f}}(\mu_F^2)}{\mathrm{d}\ln(\mu_F^2)} = -\frac{\gamma(a_s)}{\beta(a_s)} \cdot \tilde{\mathbf{f}}^{\gamma}(a_s) - \frac{\mathbf{k}(a_s)}{\beta(a_s)}$$

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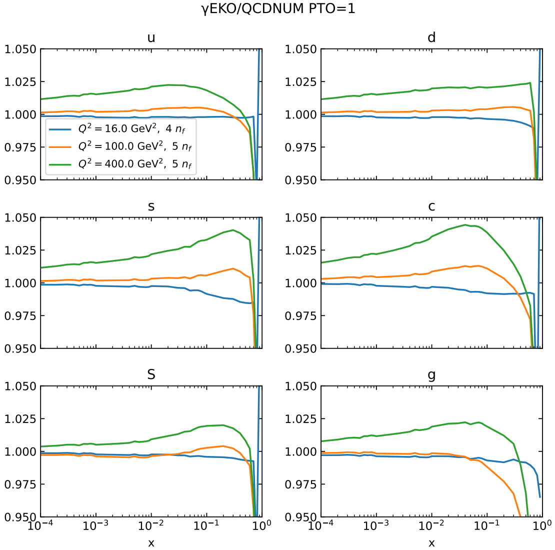
- The solution is written in terms of an evolution operator $\tilde{E}^\gamma$:

$$\tilde{\mathbf{f}}^\gamma(\alpha_s) = \tilde{\mathbf{E}}^\gamma(\alpha_s \leftarrow \alpha_s^0)[\tilde{\mathbf{f}}^\gamma(\alpha_s^0)] = \tilde{\mathbf{E}}(\alpha_s \leftarrow \alpha_s^0)\tilde{\mathbf{f}}^\gamma(\alpha_s^0) + \int_{\alpha_s^0}^{\alpha_s} d\alpha_s' \, \tilde{\mathbf{E}}(\alpha_s \leftarrow \alpha_s') \frac{-\tilde{\mathbf{k}}(\alpha_s')}{\beta(\alpha_s')}$$

Benchmarking γEKO at NLO

- Comparison of evolution with modified QCDNUM (c/o V. Guzey) M. Botje-2010
- GRV PDFs as input Gluck, Reya, Vogt-1991
- γEKO evolves in the ZM-VFNS scheme



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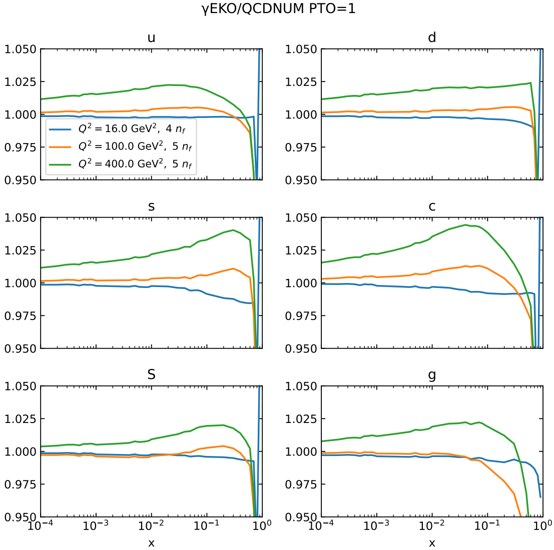

- Evolution can be seen to be stable within $< 5\%$ compared to existing codes
- At LO, the agreement is within 2 %

Fit Methodology

- Trial photon PDFs are parametrized at input scale, $Q_0 = 1$ GeV, using a functional form, with parameters fitted to data: $x\mathbf{f}(x,\mu) = Nx^{\alpha}(1-x)^{\beta}$
- 6 parameters, 3 each for the gluon & the singlet;

  No flavour seperation possible in quark PDF = fit singlet!! and, valence quark = zero !!

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$$\frac{1}{\alpha_{\text{em}}}\int_0^1 dx(xS + xG) = \frac{1}{\pi}\sum_q e_q^2 \ln\frac{Q^2}{Q_0^2} + c, \quad c \approx 1 \text{ (VMD model)}$$

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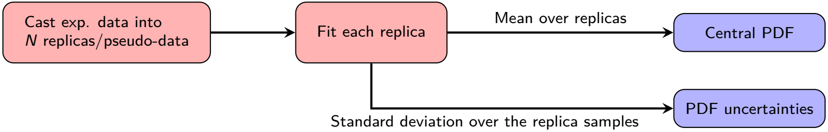
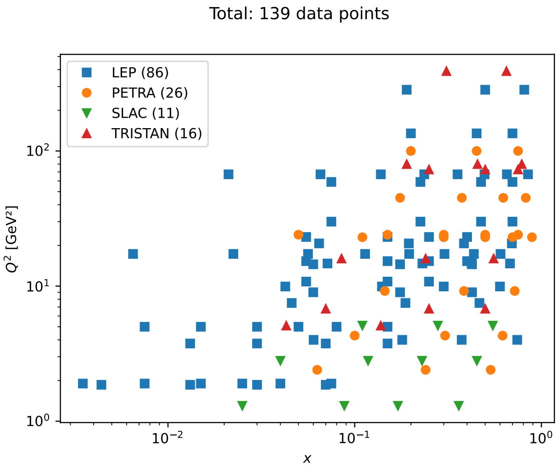
- For uncertainties, we employ the use of Monte Carlo replicas:



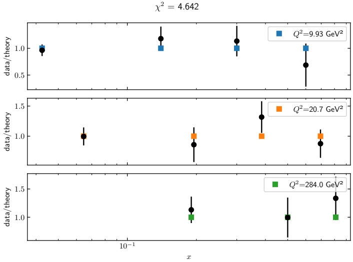
Global F_2^γ data

- Available e^+e^- data on F_2^γ Nisius,1999, HepData

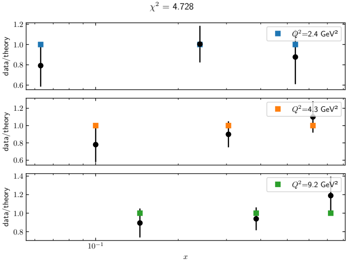


- We did not include data under $Q^2 = 1\,\mathrm{GeV}^2$ in our fits.

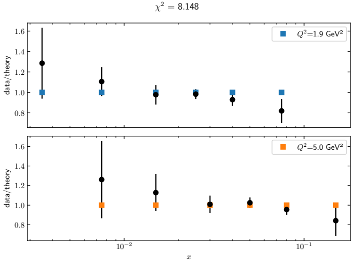
Preliminary fit comparisons with data (F_2^γ) at LO



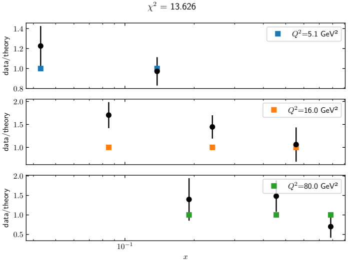
Barate, R. et al. (LEP-ALEPH), 1999



Berger, Christoph et al. (PETRA-PLUTO), 1984



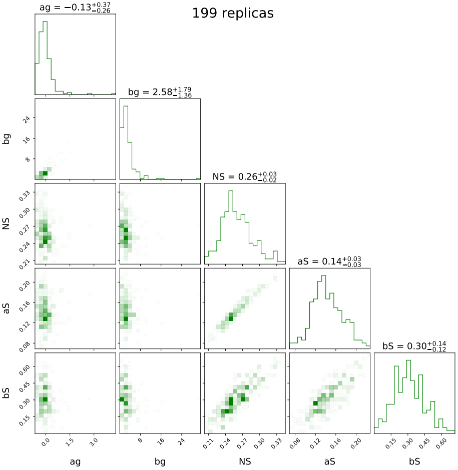
Acciarri, M. et al. (LEP-L3), 1998

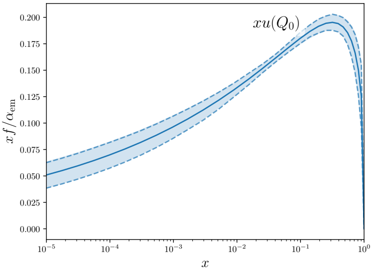


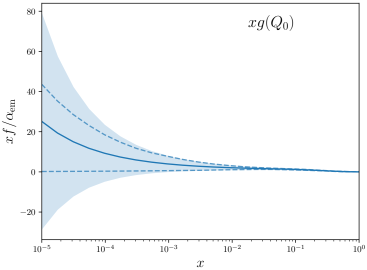
Muramatsu, K. et al. (TRISTAN-TOPAZ), 1994

Preliminary results at LO (1)

- PDFs at input scale, $Q_0 = 1.0$ GeV







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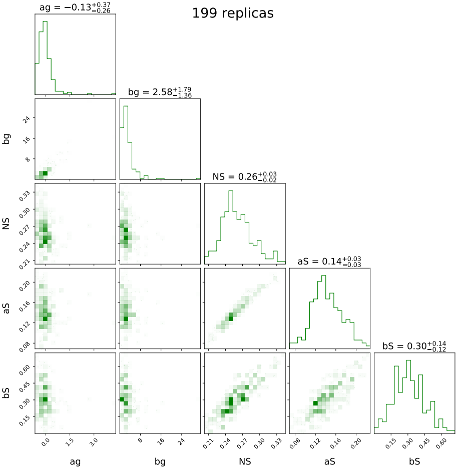
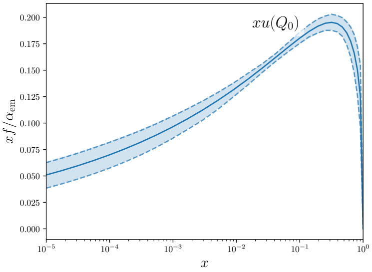
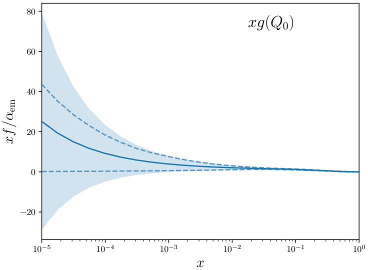


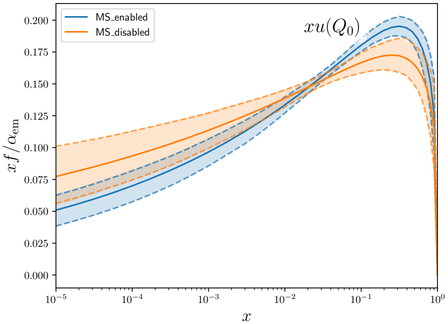




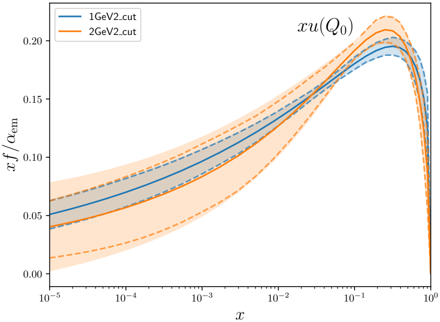
- **e^+e^- data sufficiently constraints quark distributions, less so for the gluon: NO direct probe of gluon content at LO!!**

Preliminary results at LO (2)

- momentum-sum rule effect



- Imposing a higher cut Q^2 on datasets



- Scale-dependent momentum-sum rule suppresses gluon distribution; enhances singlet
- Quark PDF fit mostly stable to varying data; uncertainity heavily dependent on Q^2 cut

Conclusions

Summary:

- A robust new evolution code, γEKO: extends EKO to solve the point-like contribution in DGLAP (Q^2) evolution of photon PDFs at LO and at NLO.
- A framework to fit and extract LO and NLO photon PDFs with uncertainties through MC replicas
- Studies on the flexibility of parameter choice, effects of varying Q^2 cuts on exp. data, and on the number of MC iterations $\rightarrow$ Singlet sector well constrained through e^+e^- data.

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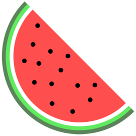
Outlook:

- Probe and constrain photon PDFs, especially the gluon distributions through di-jet photoproduction in *ep* scattering from HERA data.
- Make predictions for photon-induced processes: UPCs at the LHC and for the future EIC

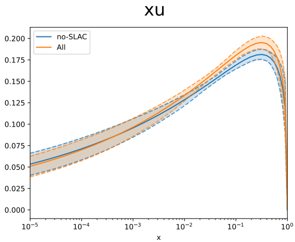


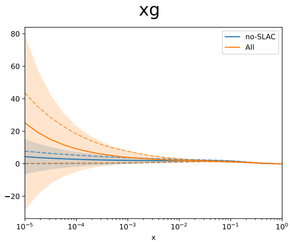
Thank you!

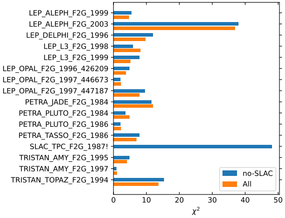
Questions?

Or feel free to approach me in the hallway, or on the streets, preferably not sneaking up from the back :)

Removing SLAC data







compare Q^2 cuts