From deep-inelastic structure functions to two-photon dilepton production in proton-proton collisions

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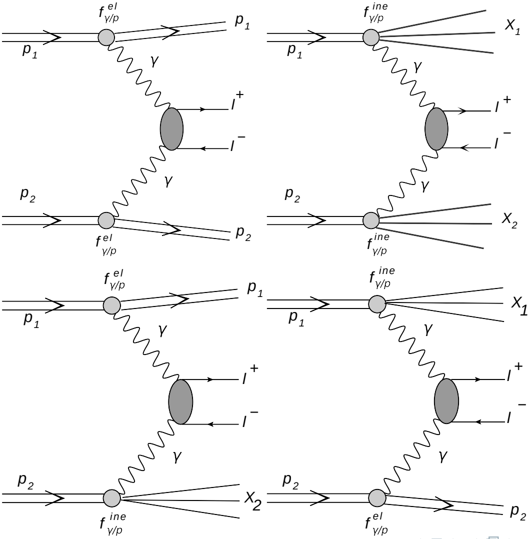
Content

- $pp \to ppl^+l^-$ (exclusive) and $pp \to l^+l^-$ (semiexclusive)
  double photon fusion
- k_t-factorization approach (LPAIR)
- this is background to Drell-Yan.
- Here main emphasis on structure function input

I will discuss our recent results and refer to other works

M. Luszczak, W. Schäfer and A. Szczurek, arXiv:1510.00294
in print in Phys. Rev. **D** (2016).

$pp \rightarrow l^+ l^-$



$pp \to l^+ l^-$

Two different approach:

- collinear - factorization:

(M. Łuszczak, A. Szczurek and Ch. Royon, JHEP 1502 (2015) 098, arXiv:1409.1803)

- k_t - factorization

(G. Gil da Silveira, L. Forthomme, K. Piotrzkowski, W. Schafer, A. Szczurek, JHEP 1502 (2015) 159,
M. Luszczak, W. Schafer and A. Szczurek, arXiv:1510.00294, in print in PRD)

In collinear - factorization approach one needs photons as parton in proton:

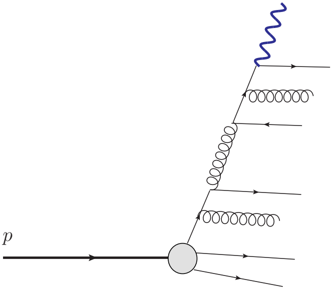
- MRST (first set)
- NNPDF(big uncertainties when fitted
- CTEQ (recently)

MRST parton distributions

The factorization of the QED-induced collinear divergences leads to QED-corrected evolution equations for the parton distributions of the proton.

$$\begin{aligned}
\frac{\partial q_i(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\left\{P_{qq}(y)\; q_i(\frac{x}{y},\mu^2) + P_{qg}(y)\; g(\frac{x}{y},\mu^2)\right\} \\
&+ \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left\{\tilde{P}_{qq}(y)\; e_i^2 q_i(\frac{x}{y},\mu^2) + P_{q\gamma}(y)\; e_i^2 \gamma(\frac{x}{y},\mu^2)\right\} \\
\frac{\partial g(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\left\{P_{gq}(y)\; \sum_j q_j(\frac{x}{y},\mu^2) + P_{gg}(y)\; g(\frac{x}{y},\mu^2)\right\} \\
\frac{\partial \gamma(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left\{P_{\gamma q}(y)\; \sum_j e_j^2\; q_j(\frac{x}{y},\mu^2) + P_{\gamma\gamma}(y)\; \gamma(\frac{x}{y},\mu^2)\right\},
\end{aligned}$$

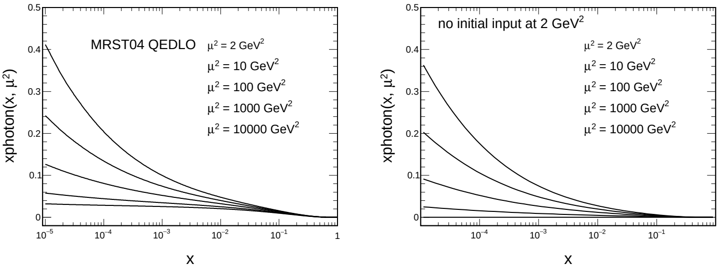
$pp \to l^+ l^-$



Diagramatic representation of the DGLAP with photons

$pp \to l^+l^-$

Collinear photon distribution in nucleon



initial input is crucial

MRST(QED) input overestimated (see discussion in our paper)

$pp \longrightarrow l^+ l^-$

$$\frac{d\sigma^{\gamma_{in}\gamma_{in}}}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2\hat{s}^2} x_1\gamma_{in}(x_1,\mu^2)\; x_2\gamma_{in}(x_2,\mu^2)\; \overline{|\mathcal{M}_{\gamma\gamma\to l^+l^-}|^2}$$

$$\frac{d\sigma^{\gamma_{in}\gamma_{el}}}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2\hat{s}^2} x_1\gamma_{in}(x_1,\mu^2)\; x_2\gamma_{el}(x_2,\mu^2)\; \overline{|\mathcal{M}_{\gamma\gamma\to l^+l^-}|^2}$$

$$\frac{d\sigma^{\gamma_{el}\gamma_{in}}}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2\hat{s}^2} x_1\gamma_{el}(x_1,\mu^2)\; x_2\gamma_{in}(x_2,\mu^2)\; \overline{|\mathcal{M}_{\gamma\gamma\to l^+l^-}|^2}$$

$$\frac{d\sigma^{\gamma_{el}\gamma_{el}}}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2\hat{s}^2} x_1\gamma_{el}(x_1,\mu^2)\; x_2\gamma_{el}(x_2,\mu^2)\; \overline{|\mathcal{M}_{\gamma\gamma\to l^+l^-}|^2}$$

The elastic photon fluxes are calculated using the Drees-Zeppenfeld parametrization, where a simple parametrization of nucleon electromagnetic form factors was used

$$\mathcal{F}_{\gamma^* \leftarrow A}(z, \boldsymbol{q}) = \frac{\alpha_{\rm em}}{\pi} (1-z) \left(\frac{\boldsymbol{q}^2}{\boldsymbol{q}^2 + z(M_X^2 - m_A^2) + z^2 m_A^2} \right)^2 \cdot \frac{p_B^\mu p_B^\nu}{s^2} W_{\mu\nu}(M_X^2, Q^2$$

The hadronic tensor is expressed in terms of the electromagnetic currents as:

$$W_{\mu\nu}(M_X^2, Q^2) = \overline{\sum_X} (2\pi)^3 \, \delta^{(4)}(p_X - p_A - q) \, \langle p | J_\mu | X \rangle \langle X | J_\nu^\dagger | p \rangle \, d\Phi_X \,, \quad (2)$$

$$W_{\mu\nu}(M_X^2, Q^2) = -\delta^{\perp}_{\mu\nu}(p_A, q)\, W_T(M_X^2, Q^2) + e^{(0)}_{\mu} e^{(0)}_{\nu}\, W_L(M_X^2, Q^2)\,. \quad (3)$$

The virtual photoabsorption cross sections are defined as

$$\begin{aligned} \sigma_T(\gamma^* p) &= \frac{4\pi\alpha_{em}}{4\sqrt{X}}\Big(-\frac{\delta^{\perp}_{\mu\nu}}{2}\Big) 2\pi W^{\mu\nu}(M_X^2, Q^2) \\ \sigma_L(\gamma^* p) &= \frac{4\pi\alpha_{em}}{4\sqrt{X}}\, e^0_\mu e^0_\nu\, 2\pi W^{\mu\nu}(M_X^2, Q^2)\,. \end{aligned} \quad (4)$$

It is customary to introduce dimensionless structure function $F_i(x_{\rm Bj}, Q^2)$, $i = T, L$ as

$$\sigma_{T,L}(\gamma^* p) = \frac{4\pi^2\alpha_{em}}{Q^2} \frac{1}{\sqrt{1 + \frac{4x_{\rm Bj}^2 m_A^2}{Q^2}}} F_{T,L}(x_{\rm Bj}, Q^2)\,, \quad (5)$$

In the literature one often finds structure functions $F_1(x_{\rm Bj}, Q^2)$, $F_2(x_{\rm Bj}, Q^2)$, which are related to $F_{T,L}$ through

$pp \to l^+ l^-$

The unintegrated fluxes enter the cross section for dilepton production as

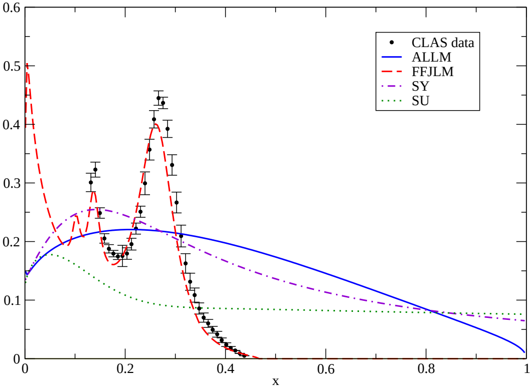
$$\frac{d\sigma^{(i,j)}}{dy_1 dy_2 d^2\boldsymbol{p}_1 d^2\boldsymbol{p}_2} = \int \frac{d^2\boldsymbol{q}_1}{\pi \boldsymbol{q}_1^2} \frac{d^2\boldsymbol{q}_2}{\pi \boldsymbol{q}_2^2} \mathcal{F}^{(i)}_{\gamma^*/A}(x_1, \boldsymbol{q}_1) \mathcal{F}^{(j)}_{\gamma^*/B}(x_2, \boldsymbol{q}_2) \frac{d\sigma^*(p_1, p_2; \boldsymbol{q}_1, \boldsymbol{q}_2)}{dy_1 dy_2 d^2\boldsymbol{p}_1 d^2\boldsymbol{p}_2} \quad (7)$$

where i,j=el,ine

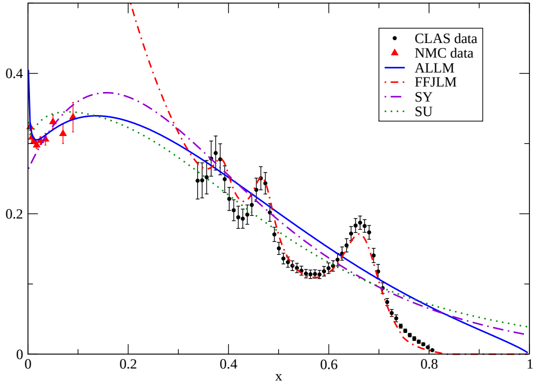
$$x_1 = \sqrt{\frac{\boldsymbol{p}_1^2 + m_l^2}{s}} e^{y_1} + \sqrt{\frac{\boldsymbol{p}_2^2 + m_l^2}{s}} e^{y_2} \,,$$

$$x_2 = \sqrt{\frac{\boldsymbol{p}_1^2 + m_l^2}{s}} e^{-y_1} + \sqrt{\frac{\boldsymbol{p}_2^2 + m_l^2}{s}} e^{-y_2} \,. \quad (8)$$

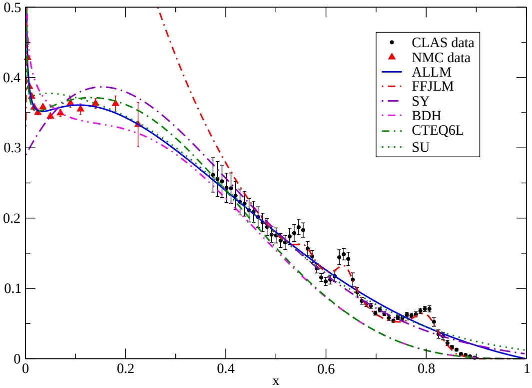
$pp \to l^+l^-$



$pp \to l^+l^-$



$pp \to l^+ l^-$



CLAS data
NMC data
ALLM
FFJLM
SY
BDH
CTEQ6L
SU
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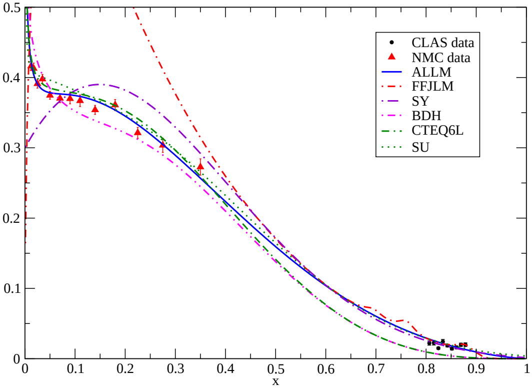
$pp \to l^+ l^-$



0.5
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x
CLAS data
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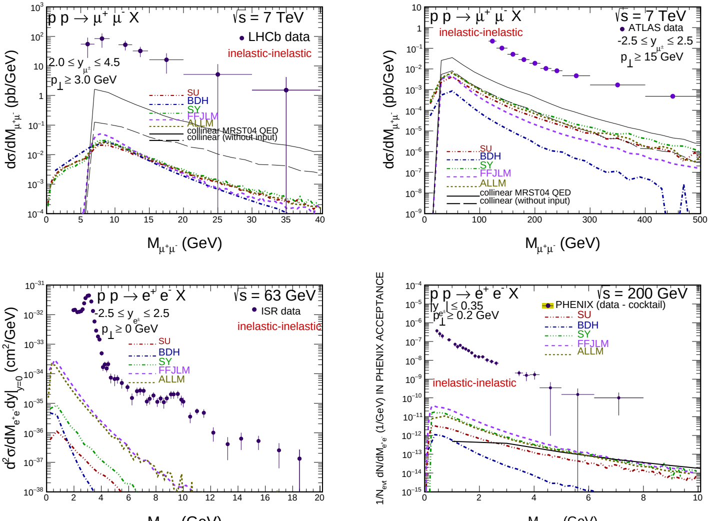
CTEQ6L
SU

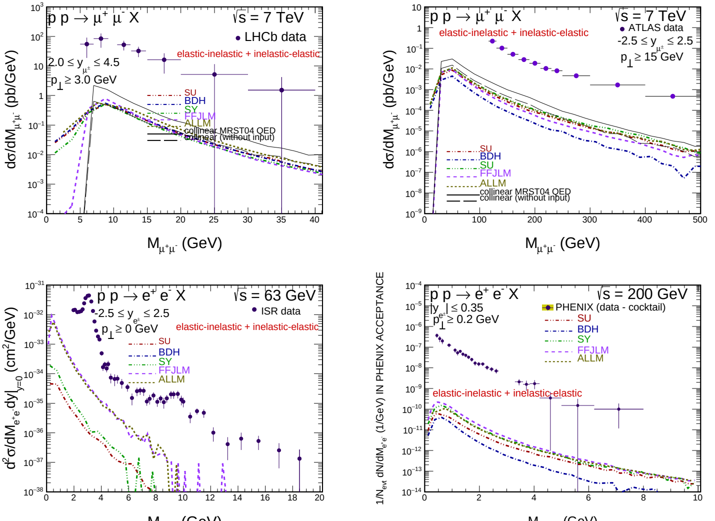
$pp \to l^+ l^-$

k_t-factorization, including photon transverse momenta

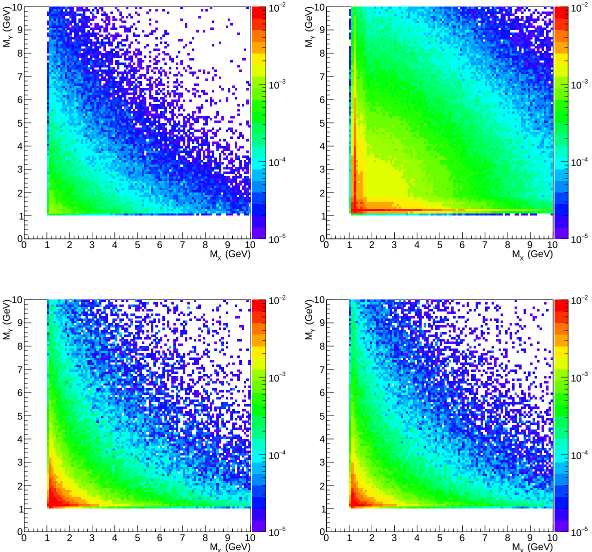


$pp \rightarrow l^+l^-$

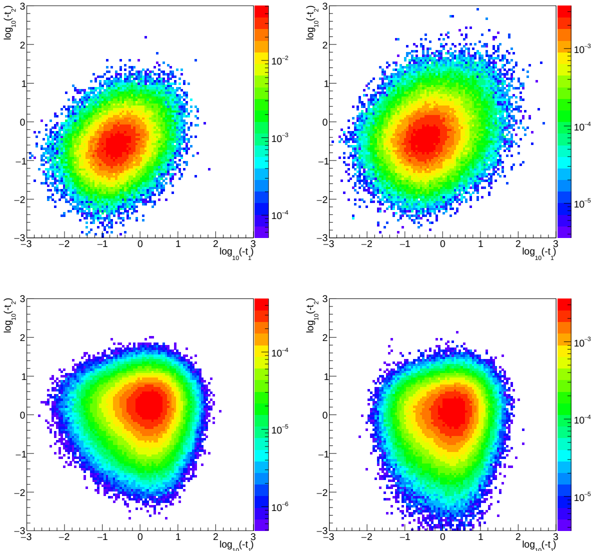
k_t-factorization, including photon transverse momenta



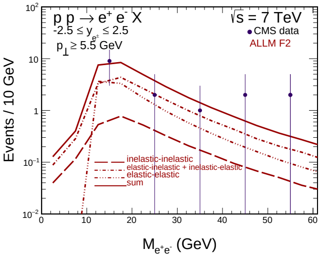
$pp \to l^+l^-$,SU,FFJLM,SY,ALLM

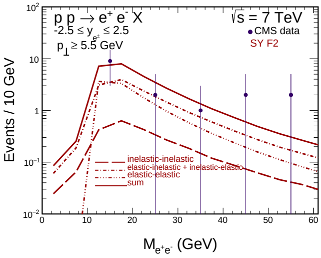


$pp \to l^+ l^-$, ISR, PHENIX, ATLAS, LHCb



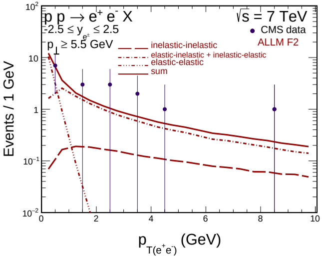
$pp \to l^+ l^-$

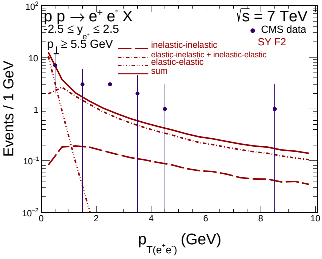




isolated electrons

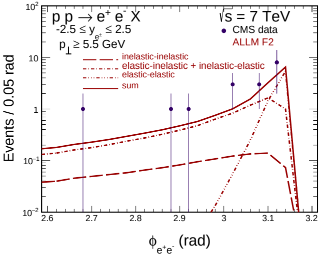
$pp \to l^+l^-$

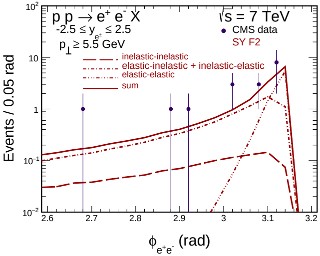




isolated electrons

$pp \to l^+ l^-$





isolated electrons

Domain of the structure function

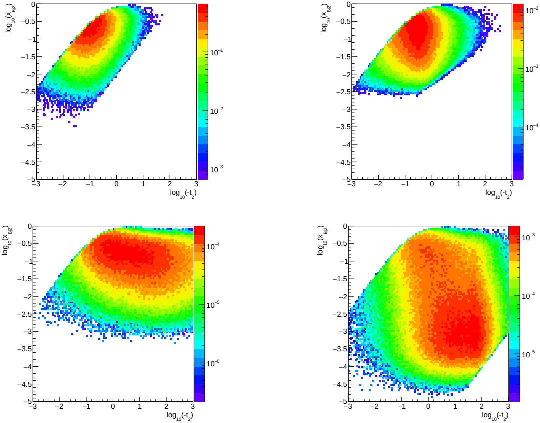


Figure: Distributions for $Q_2^2 \times x_{\mathrm{Bj2}}$ for different experiments: ISR (upper-left), PHENIX (upper-right), ATLAS (lower-left) and LHCb (lower-right) for the ALLM structure function for elastic-inelastic photon-photon contributions. Here $-t_2 = Q_2^2/(1\,\mathrm{GeV}^2)$

Domain of the structure function

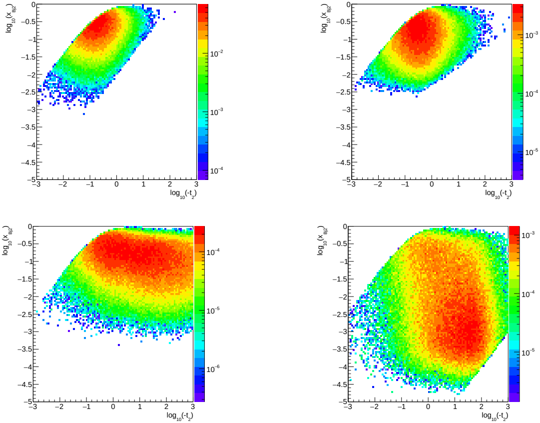


Figure: Distributions for $Q_2^2 \times x_{\mathrm{Bj}2}$ for different experiments: ISR (upper-left), PHENIX (upper-right), ATLAS (lower-left) and LHCb (lower-right) for ALLM structure function for inelastic-inelastic photon-photon contributions. Here $-t_2 = Q_2^2/(1\ \mathrm{GeV}^2)$

Domain of the structure function

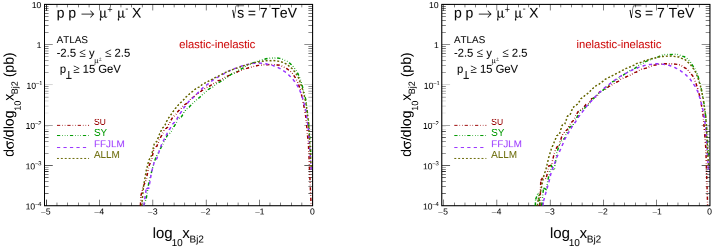


Figure: Distributions for x_{Bj} for the ATLAS experiment. The left panel is for elastic-inelastic and the right panel is for inelastic-inelastic components, respectively.

Conclusions

- Two different approaches for $\gamma\gamma$ processes discussed
- Strong dependence on the structure function input in the k_t-factorization approach
- Semi-exclusive contributions (with dissociation) large (lesson for $pp \to ppJ/\psi$)
- Photon-photon contribution rather small compared to Drell-Yan contribution but important in precision calculations (another parallel talk at DIS2016)
- Reasonable description of the CMS data with isolated electrons (recently also ATLAS)
- The regions of the arguments of the F_2 structure functions have been identified (photon virtualities in pQCD and non pQCD regions, x of the order of 10^{-2} - 10^{-1})
- So far only collinear approach applied to $pp \to (\gamma\gamma) \to W^+W^-XY$ processes