Four-lepton production from photon-induced reactions in *pp* collisions at the LHC

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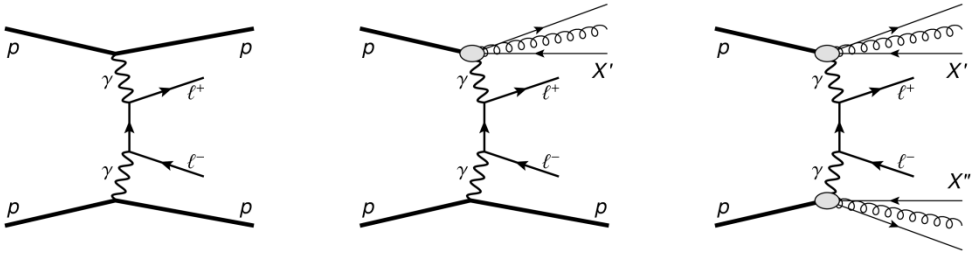
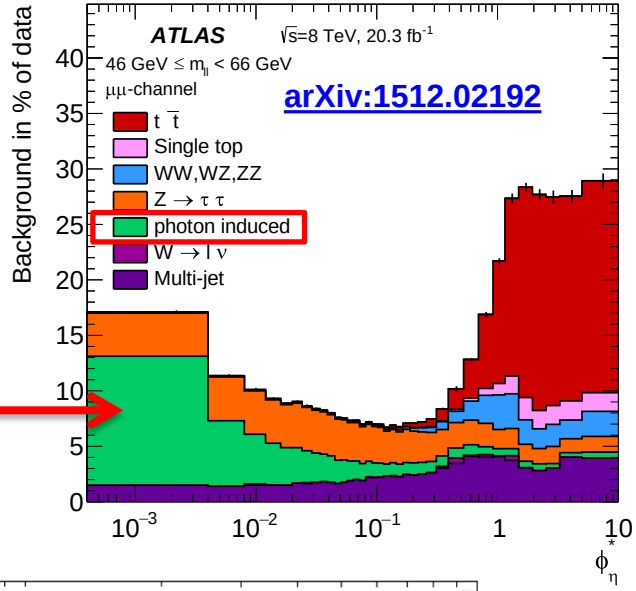
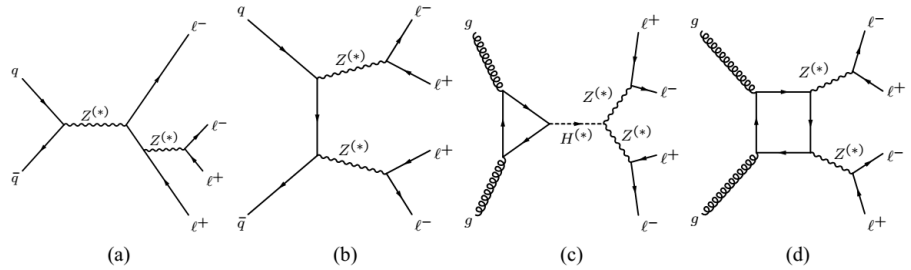
Motivation

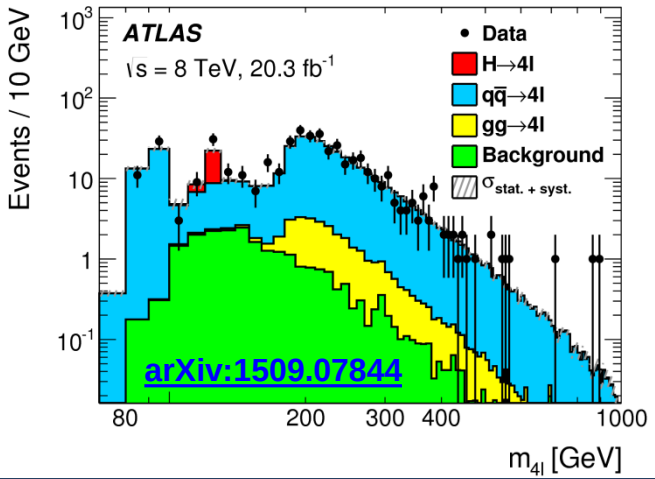
- Photon-induced dilepton production in *pp* collisions
  - **O(3%)** contribution to inclusive Drell-Yan (low-mass and high-mass regions)
  - Dominated by **proton-dissociative** reactions





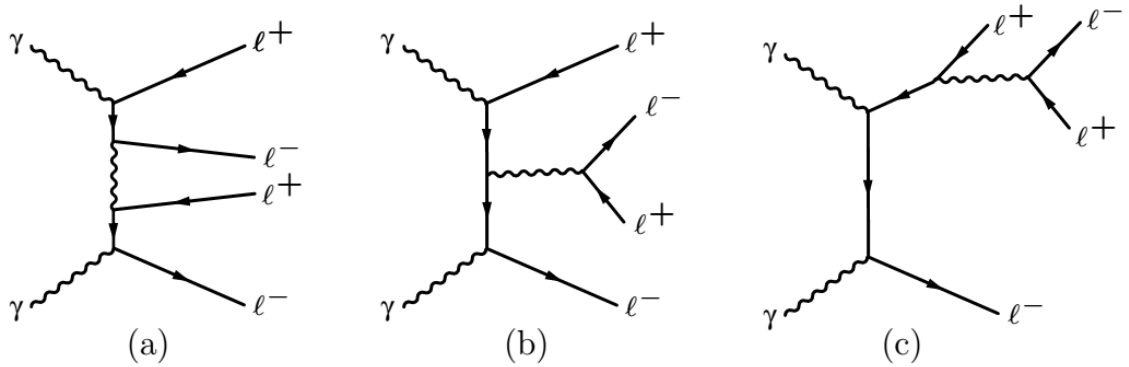
- By analogy, the **inclusive four-lepton production** at the LHC should also include photon-induced term…





Elementary $\gamma\gamma \rightarrow 4\ell$ cross-section

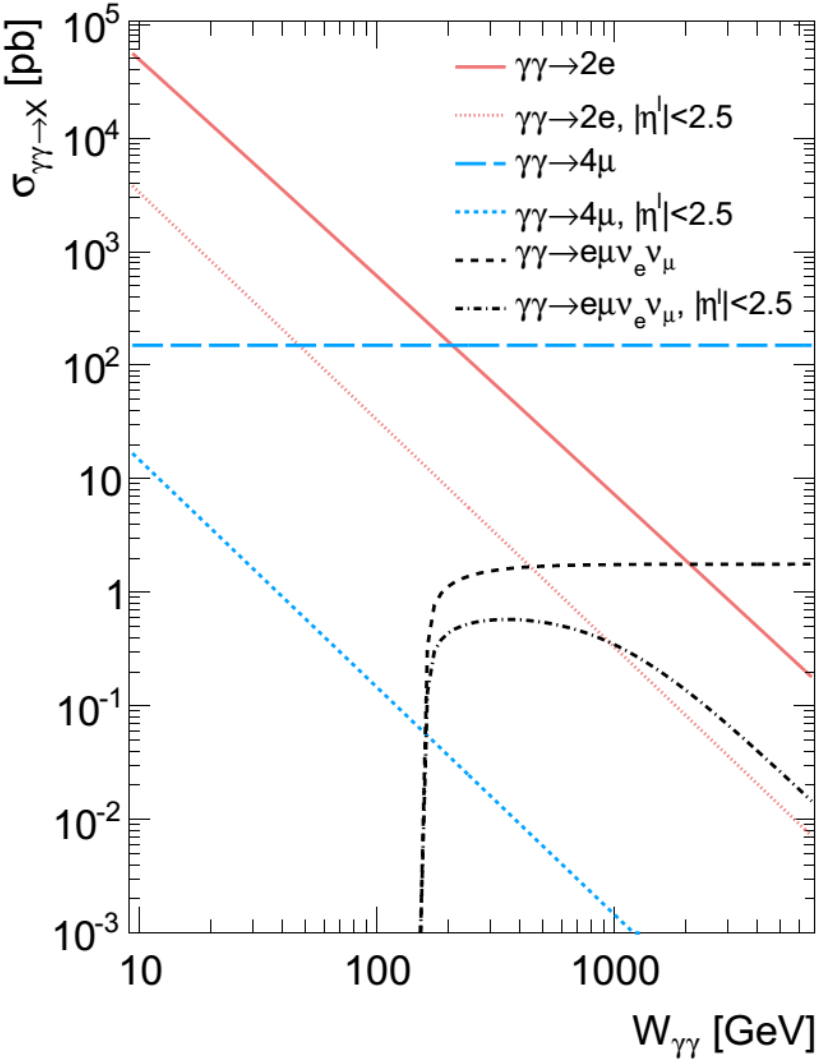
- Summation over various **leading-order** amplitudes
  - *t*-channel photon exchange (dominant)
  - Final-state radiation
  - $\gamma\gamma \rightarrow ZZ \rightarrow 4\ell$ process not included (forbidden at the tree-level, therefore highly suppressed)



- Calculations done using **Madgraph5_aMC@NLO**
  - Cross-checks made with independent calculations **Eur.Phys.J. C36 (2004) 341-363**
  - To take into account that the proton emits a photon, relevant **photon-PDFs** are used for dissociative part (**EPA** for elastic)
  - MG5 is interfaced with **Pythia8** to account for QCD effects (e.g. UE, PS)

Elementary $\gamma\gamma \rightarrow 4\ell$ cross-section

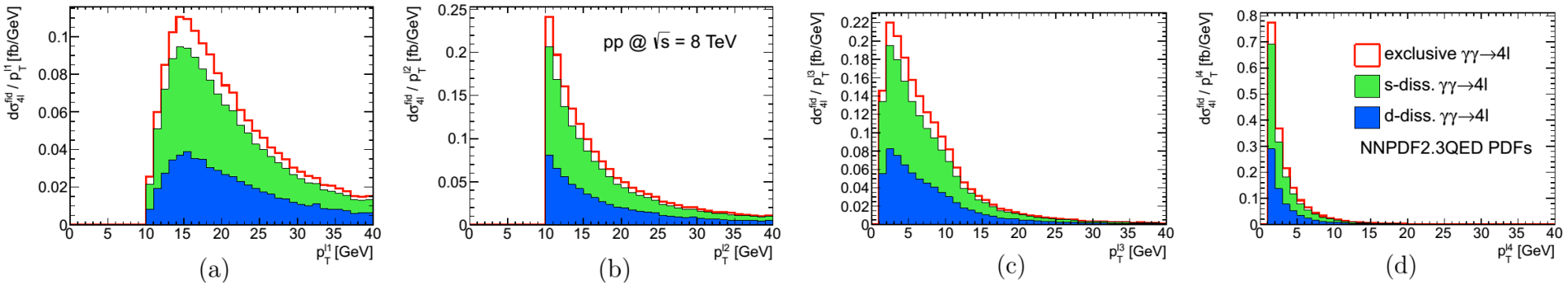
- Elementary cross-section behaviour as a function of $\gamma\gamma$ c.m.e. ($W_{\gamma\gamma}$)
  - **$\sigma_{\gamma\gamma \rightarrow 4\ell}$ constant with $W_{\gamma\gamma}$** and dominates the cross-section at large $W_{\gamma\gamma}$ for photon-induced multi-lepton production (no angular cuts applied)
  - This behaviour is due to the spin-1 *t*-channel exchange: **leptons are emitted in very forward directions**, almost collinear to the beam axis
  - When $|\eta| < 2.5$ requirement is applied to all leptons, the cross-sections are proportional to **$1/W_{\gamma\gamma}^2$**



$\gamma\gamma \to 4\ell$ in *pp* collisions (as a signal)

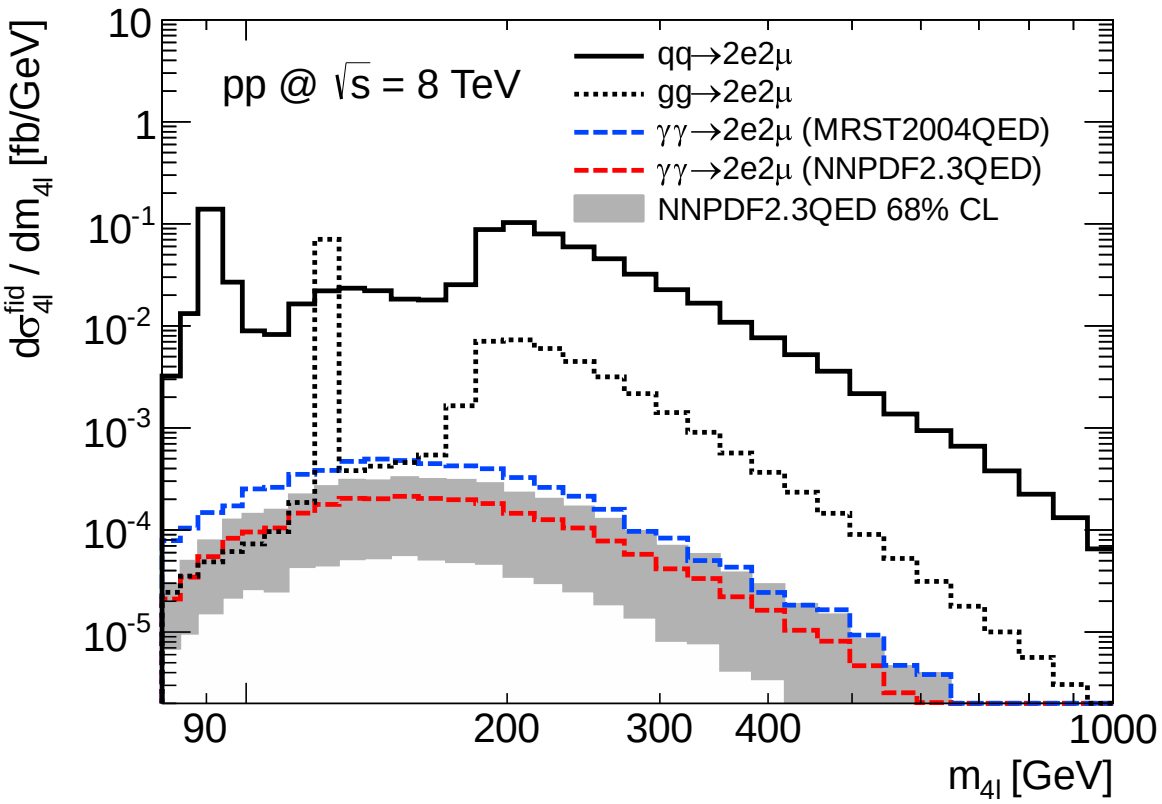
- A view what can be expected at the LHC.
  Assumptions wrt some possible measurement:
  - **Dilepton trigger used** (p_T **> 10 GeV** for leading and subleading lepton)
  - p_T **> 1 GeV** for third and fourth-leading lepton (due to tracking inefficiency)
  - $|\eta|$**< 2.5** for all leptons with **ΔR > 0.1** angular separation

$\sqrt{s}$	$\sigma^{\text{excl}}_{\gamma\gamma\to 4\ell}$	$\sigma^{\text{sdiss}}_{\gamma\gamma\to 4\ell}$ with NNPDF2.3QED (MRST2004QED)	$\sigma^{\text{ddiss}}_{\gamma\gamma\to 4\ell}$ with NNPDF2.3QED (MRST2004QED)
8 TeV	0.22 fb	0.91 (1.4) fb	0.71 (2.0) fb
13 TeV	0.29 fb	1.2 (1.8) fb	0.86 (2.7) fb



$\gamma\gamma \rightarrow 4\ell$ in *pp* collisions (as a bkgd)

- Background to inclusive production of four leptons at the LHC
  - Photon-induced contribution can reach **up to 5%** of the standard qq contribution in the non-resonant mass range of the Z boson (i.e. 70 GeV < m_{4l} < 80 GeV and 100 GeV < m_{4l} < 110 GeV) and **up to 3%** in the mass range of the Higgs boson
  - Here the specific kinematic cuts are applied, as in [arXiv:1509.07844]



$\gamma\gamma \to 4\ell$ in *pp* collisions (as a bkgd)

- Background to exclusive $\gamma\gamma \to WW \to e\mu\nu_e\nu_\mu$ production
  - 2ℓ final state (neutrinos avoid detection)
  - Enhancement of the elementary $\gamma\gamma \to 4\ell$ cross section at large lepton pseudorapidities:
    It is possible that some of the four leptons will **avoid the detection**, whereas other could **'mimic' the exclusive 2ℓ final state**
- Cross-section comparison for fiducial region definition from [JHEP 1307 (2013) 116](#) (exclusive WW from CMS at 7 TeV)
  - $p_T > 20$ GeV and $|\eta| < 2.4$ for each lepton
  - $|\eta| > 2.4$ veto on either $e\mu$ pair ($e\mu e\mu$ final state)

$$\sigma^{\rm fid}_{pp(\gamma\gamma)\to ppW^+W^-\to ppe^\pm\mu^\mp\nu_e\nu_\mu} = 0.66 \text{ fb}$$

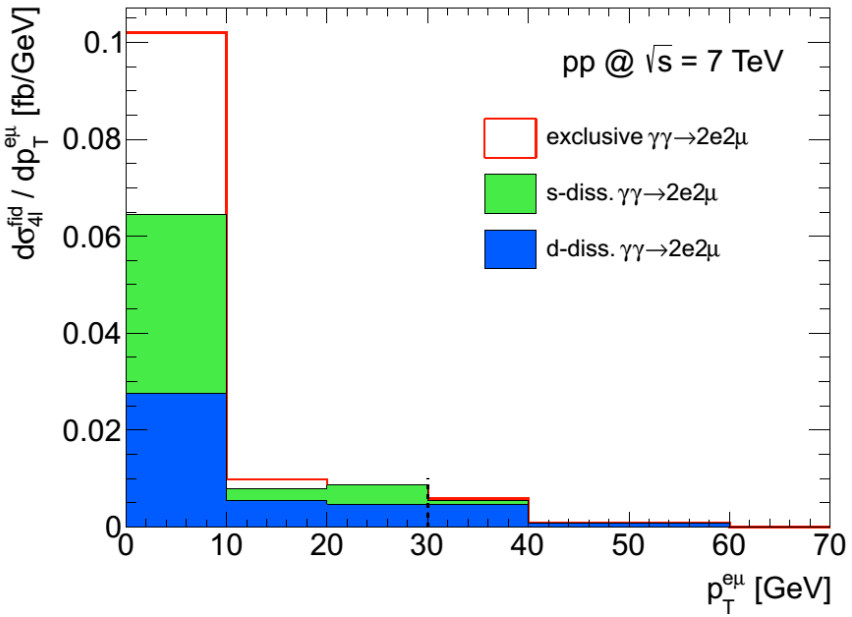
$$\sigma^{\rm fid}_{pp(\gamma\gamma)\to ppe^+e^-\mu^+\mu^-} = 0.4 \text{ fb}$$

→ ~60% contribution

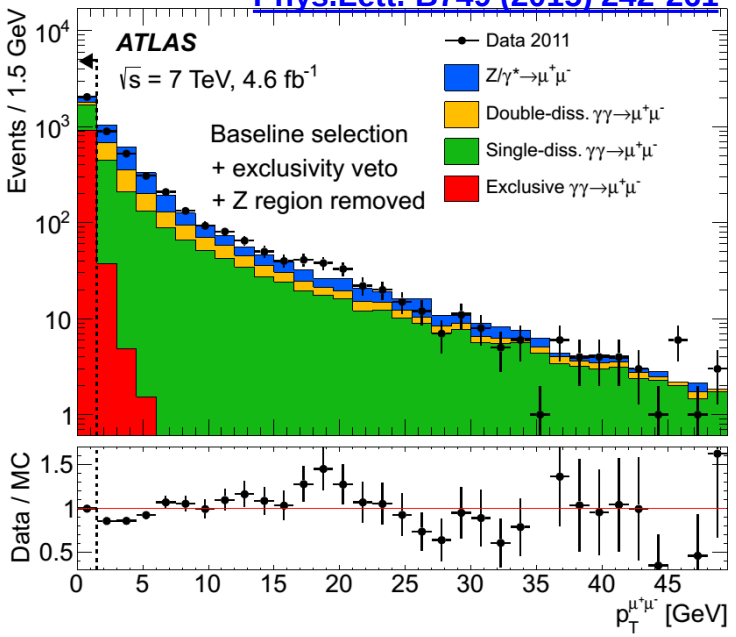
  - However, after imposing $p_T(\ell\ell) > 30$ GeV requirement (and/or MET > 30 GeV) the photon-induced four-lepton contribution is **suppressed below 5%**

$\gamma\gamma \to 4\ell$ in *pp* collisions - observation

- Dilepton veto in $\gamma\gamma \to 4\ell$ reactions: **vetoed leptons (with $|\eta| > 2.4$) typically have very small p_T's**
  - Almost no impact on the central lepton pair kinematics
  - Use **same-sign lepton pairs** to estimate the exclusive $\gamma\gamma \to 4\ell$ contribution?
    -> inclusive background should be significantly reduced…
    -> elastic part can be also separated from proton-dissociative components



Phys.Lett. B749 (2015) 242-261



Summary

- $\gamma\gamma \to 4\ell$ in *pp* collisions is a very interesting process to consider at the LHC

- Calculated cross-sections demonstrate that it should be possible to observe these reactions using high-luminosity LHC runs (ATLAS/CMS)
  - Alternatively, one can use same-sign dileptons with veto on the remaining lepton pair to enhance the cross-section (and measure the elastic part)

- This process can also constitute a background to different reactions:
  - Inclusive four-lepton production (non-resonant regions)
  - Exclusive WW production