

# Exclusive photon-induced $\mu^+\mu^-$ production (MC studies)

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# Motivation

- General  $pp \rightarrow p^{(*)} p^{(*)} \ell^+ \ell^-$  processes:

- Can be a non-negligible background for DY processes [Parisi, 1978] or any other dilepton analysis

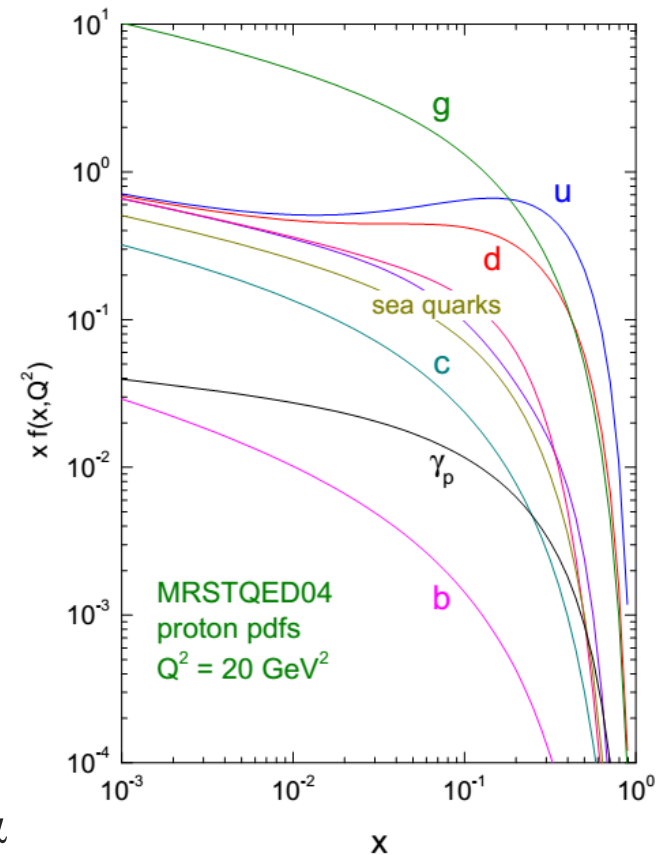
- In proton dissociated cases, photons entering to the hard reaction ( $\gamma\gamma \rightarrow \mu^+\mu^-$ ) can also couple to quarks inside the proton  
-> gives an access to QCD EW PDF's (LPAIR approach: **form factor** at  $\gamma$ -p dissociative vertices)

- Important to get a better experimental knowledge of such processes in high energies

- Also we know that  $dn_\gamma \sim \frac{\alpha}{\pi} \frac{d\omega}{\omega} \frac{dQ^2}{Q^2}$

- > With Pb on one side (p-Pb)  $\alpha$  becomes  $Z^2\alpha$  in this formula

- > Potential measurement of such reactions at lower luminosities



# MC studies for $pp \rightarrow pp \mu^+ \mu^-$

- Generators used

- Exclusive (all with BudnevPDF):

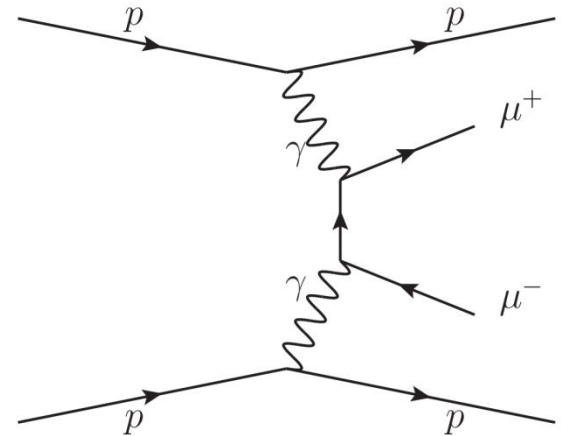
- HERWIG++ (ver 2.5, MEgg2ff matrix element)
- FPMC (default exclusive  $l^+l^-$ , based on HERWIG 6.500)
- LPAIR (ver 4.0, default elastic)

- Proton-dissociative:

- LPAIR (both **single** and **double diss**, Suri-Yenni + Brasse form factor at diss-vertices, JETSET 7.408 for the fragmentation of excited protons – according to the LUND model)
- PYTHIA8 (**double diss**, gm2mumu with MRST2004QED PDF)

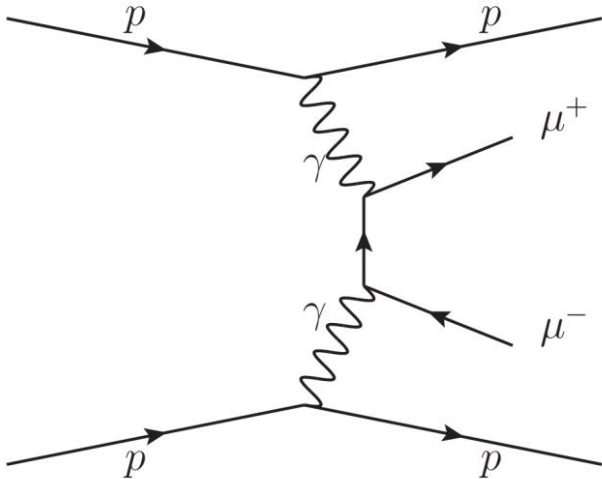
- DY  $Z/\gamma$ :

- PYTHIA8 with AU2:MSTW2008LO



# Elastic processes: $pp \rightarrow pp \mu\mu$

Via quasi-real photons exchange (diagram)



The cross section for this process is calculated:

**(1)** Using the number of equivalent photons (EPA) by integration over the whole virtuality range:

$$Q_{min}^2 \simeq m_p^2 \frac{x^2}{1-x} \quad Q_{max}^2 = 2 \text{ GeV}^2$$

Integrand contains the proton EM form factors (calculations done by Budnev et al., 74')

**(2)** And the QED  $\gamma\gamma \rightarrow \mu^+\mu^-$  cross section

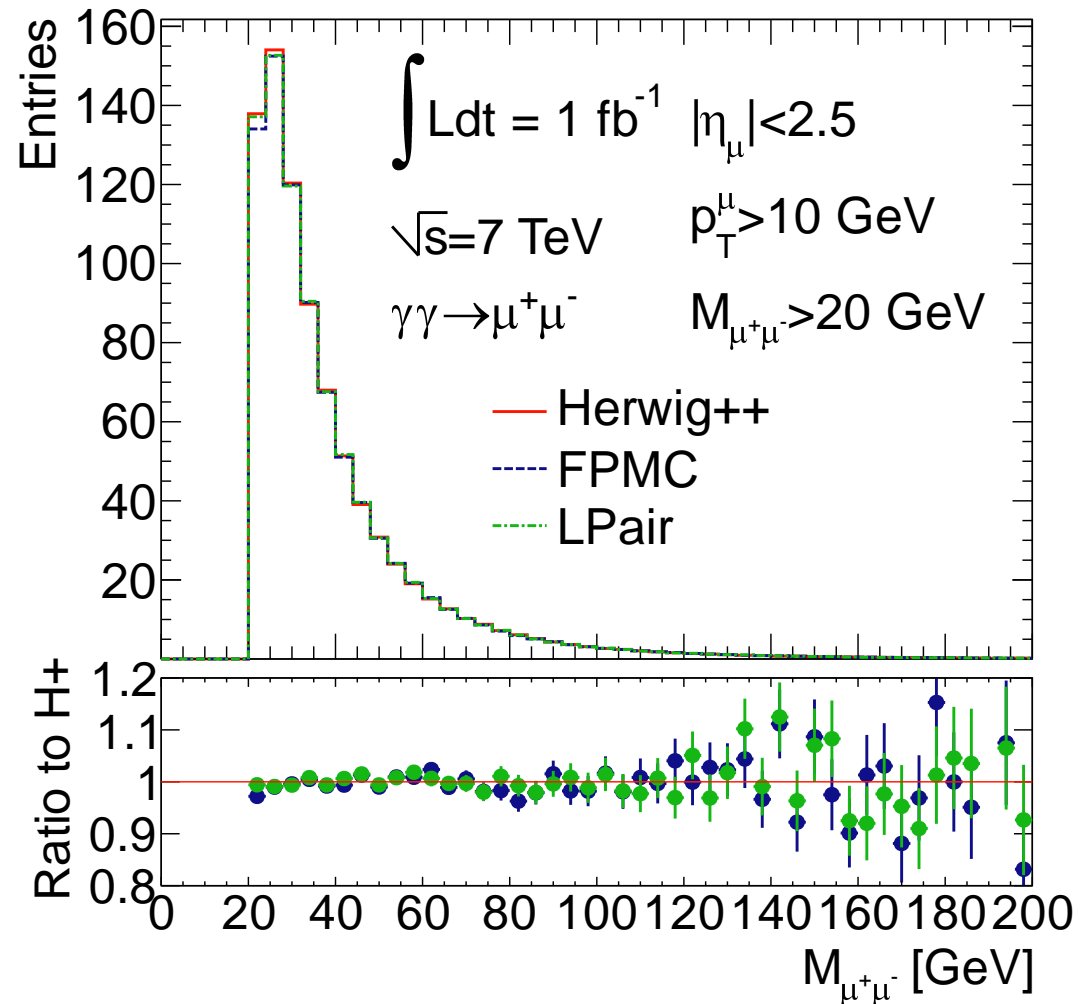
Implemented in HERWIG++, LPAIR (used at HERA, Tevatron and CMS) and FPMC

Cross checks between HERWIG++ and LPAIR done

# Elastic processes: $pp \rightarrow pp \mu\mu$

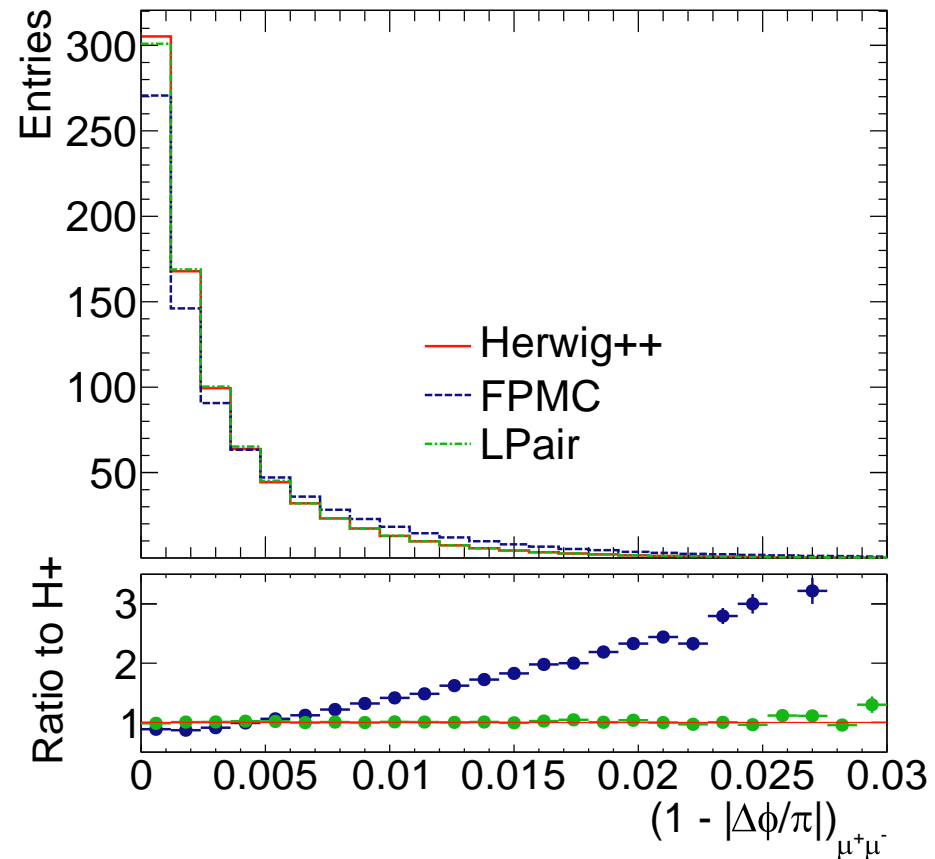
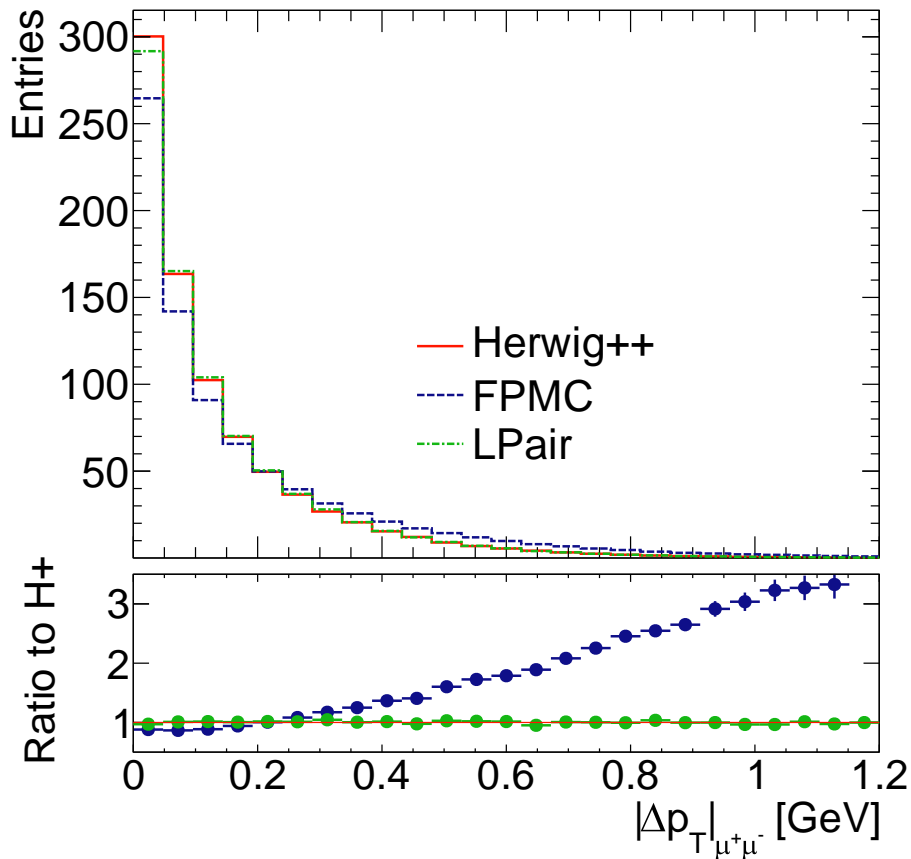
## ▪ MC comparison

- $pp$  @  $\sqrt{s}=7\text{TeV}$
- Event distributions normalized to  $1 \text{ fb}^{-1}$
- Kinematics:
  - $p_T^\mu > 10 \text{ GeV}$
  - $M_{\mu\mu} > 20 \text{ GeV}$
  - $|\eta_\mu| < 2.5$
- Total cross section for exclusive  $\gamma\gamma \rightarrow \mu^+\mu^-$  (with cuts above) = **0.83 pb**



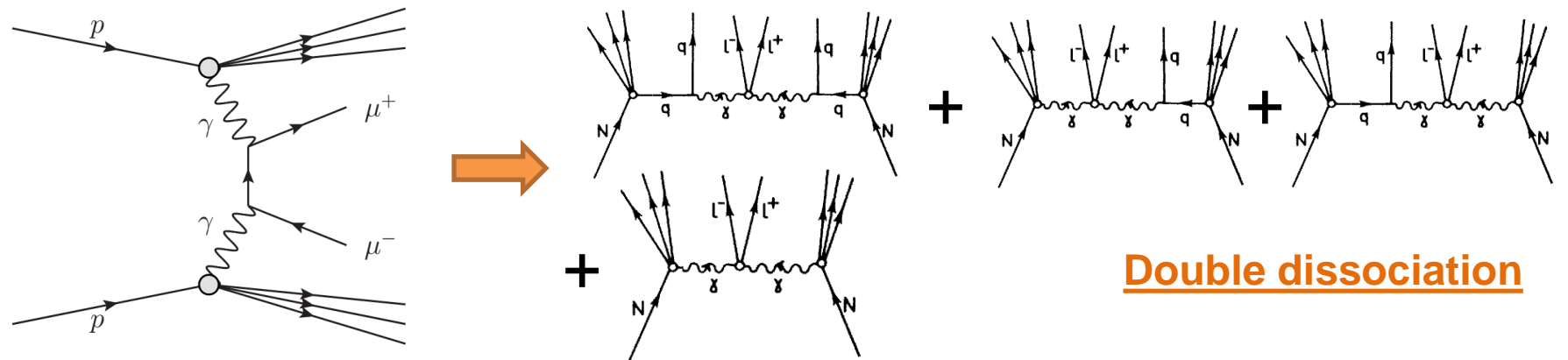
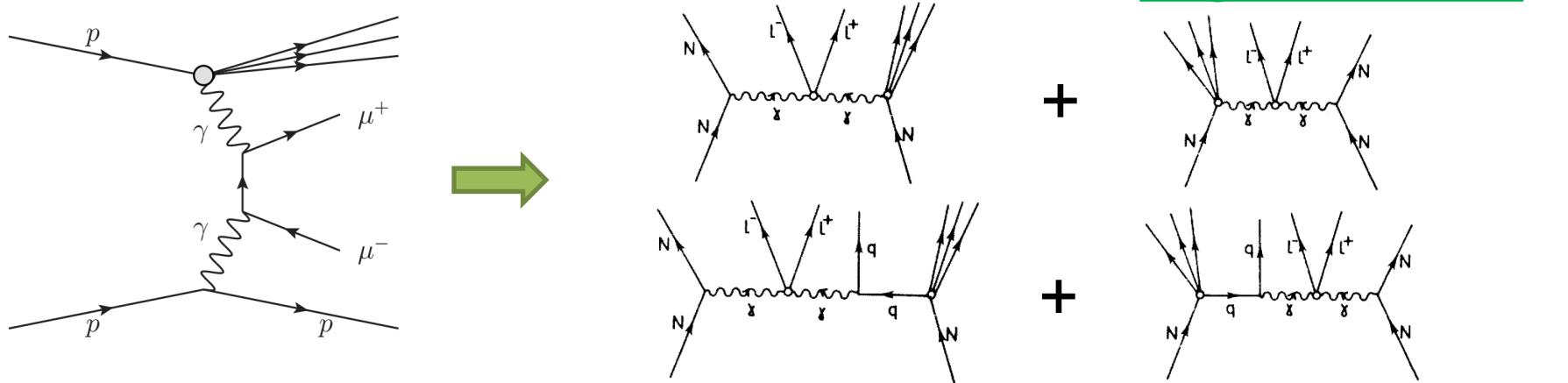
# Elastic processes: $pp \rightarrow pp \mu\mu$

- $\Delta p_T$  (left), acoplanarity (right) of the muon pairs
- Different slope in FPMC; H++ fully compatible with LPAIR



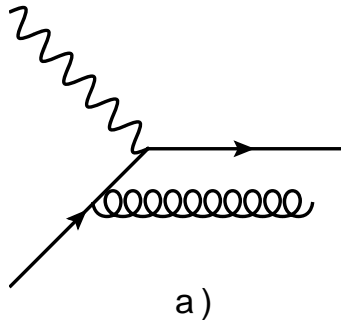
# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

- Photons in the proton(s) can also couple to q/anti-q (diagrams)
  - Calculations need to be done using QED corrections: like PDF MRST2004QED
  - Here  $\langle Q^2 \rangle$  depends also on the partons momenta  $\Rightarrow$  spread in  $\Delta p_T$  of the muons, very subtle check of the proton structure

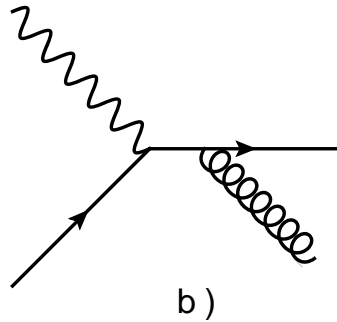


# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

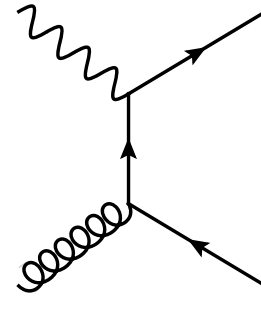
- $O(\alpha_s)$  corrections to the  $\gamma q \rightarrow q$  process should have to be also considered



a)



b)



c)

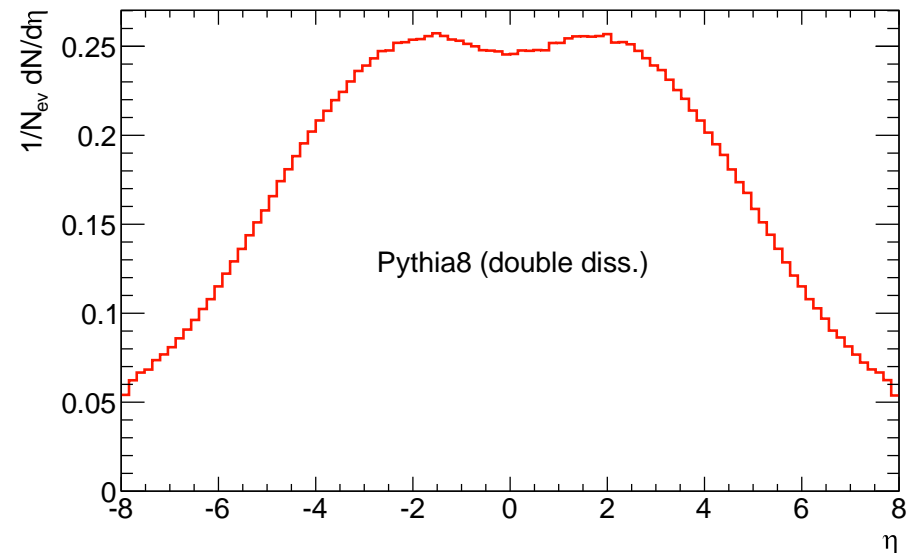
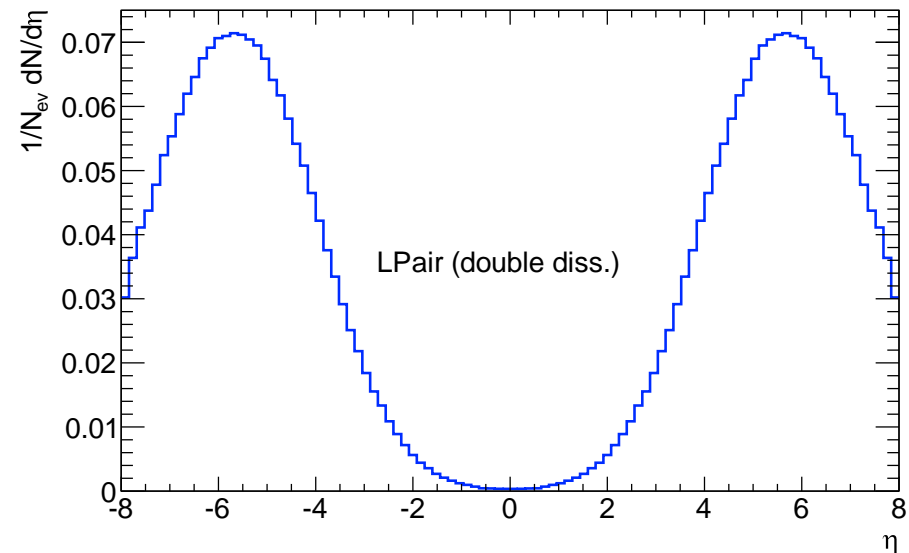
- a) Initial state radiation
- b) Final state radiation
- c) Quark pair production

- Enhancement of the cross section (diss part)
- Increased underlying event activity in the central detector



# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

- Pseudorapidity distribution of particles produced in the proton(s) fragmentation
- LPAIR  $\rightarrow$ 
  - $\Delta^+$  ( $\Delta^{++}$ ) resonances produced for the low-mass system  $\rightarrow$  low multiplicity fwd states
  - For higher masses, multiple resonances production
- PYTHIA8  $\rightarrow$ 
  - Includes also  $\gamma$ - $q/\bar{q}$  interactions +  $O(\alpha_s)$  corrections
  - Production of particles also in the central direction

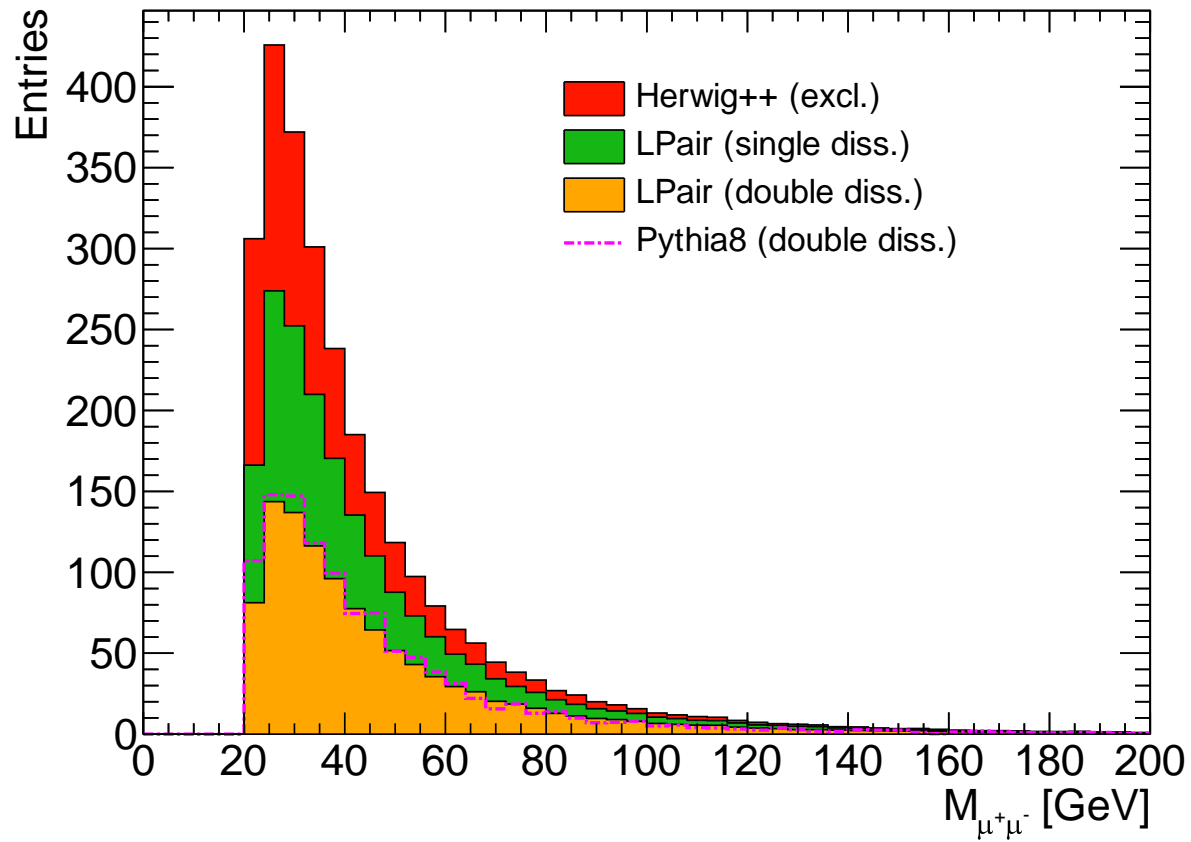


# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

- **Additional cuts** (to compare PYTHIA8 with double-diss LPAIR):

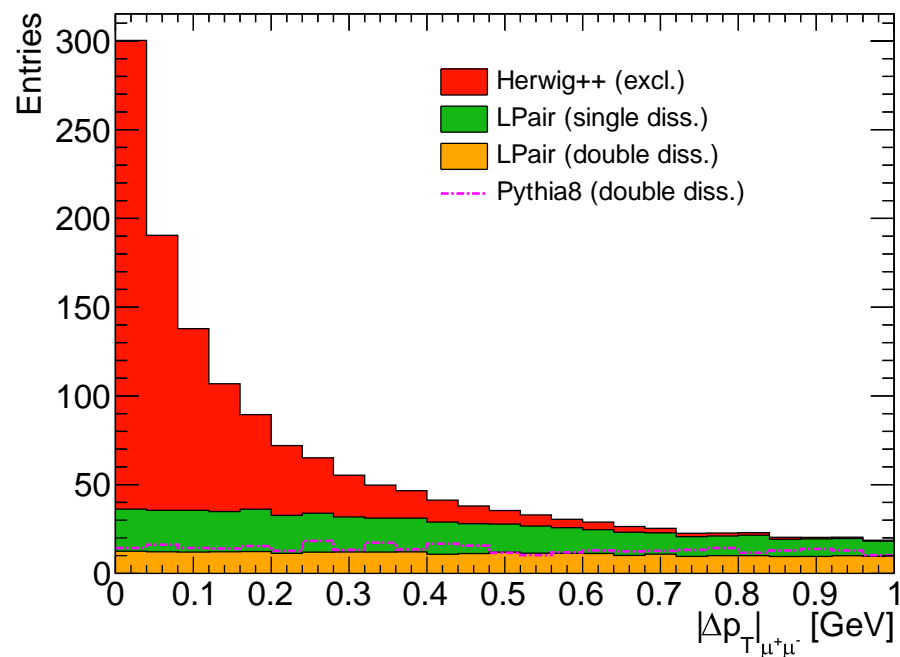
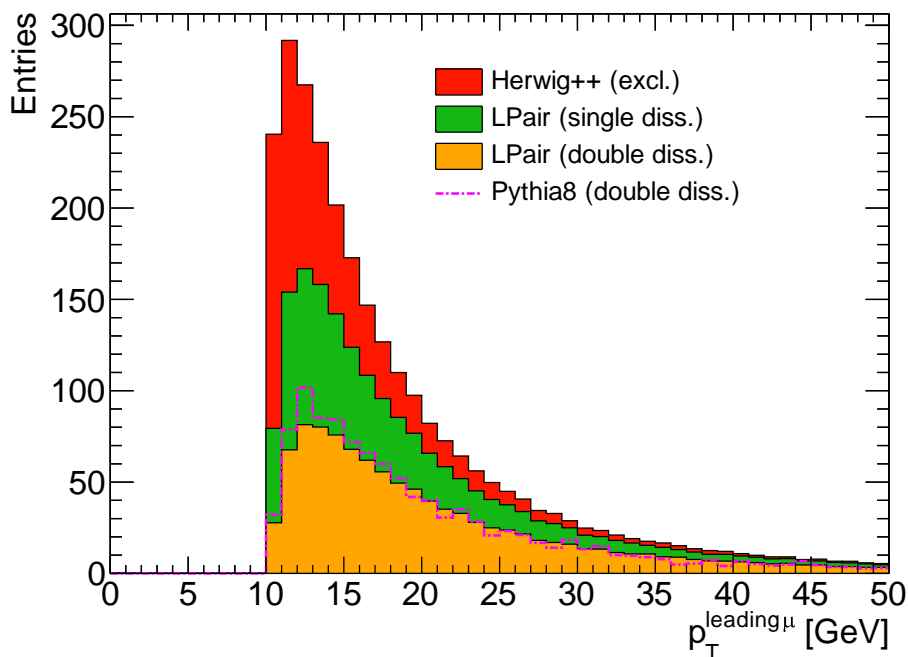
- „Exclusivity” requirement:  
no additional particles with  $p_T > 200$  MeV and  $|\eta| < 2.5$

- Single diss is at the same level as the exclusive part
- PYTHIA8 is comparable with the double-diss LPAIR (after exclusivity req.)



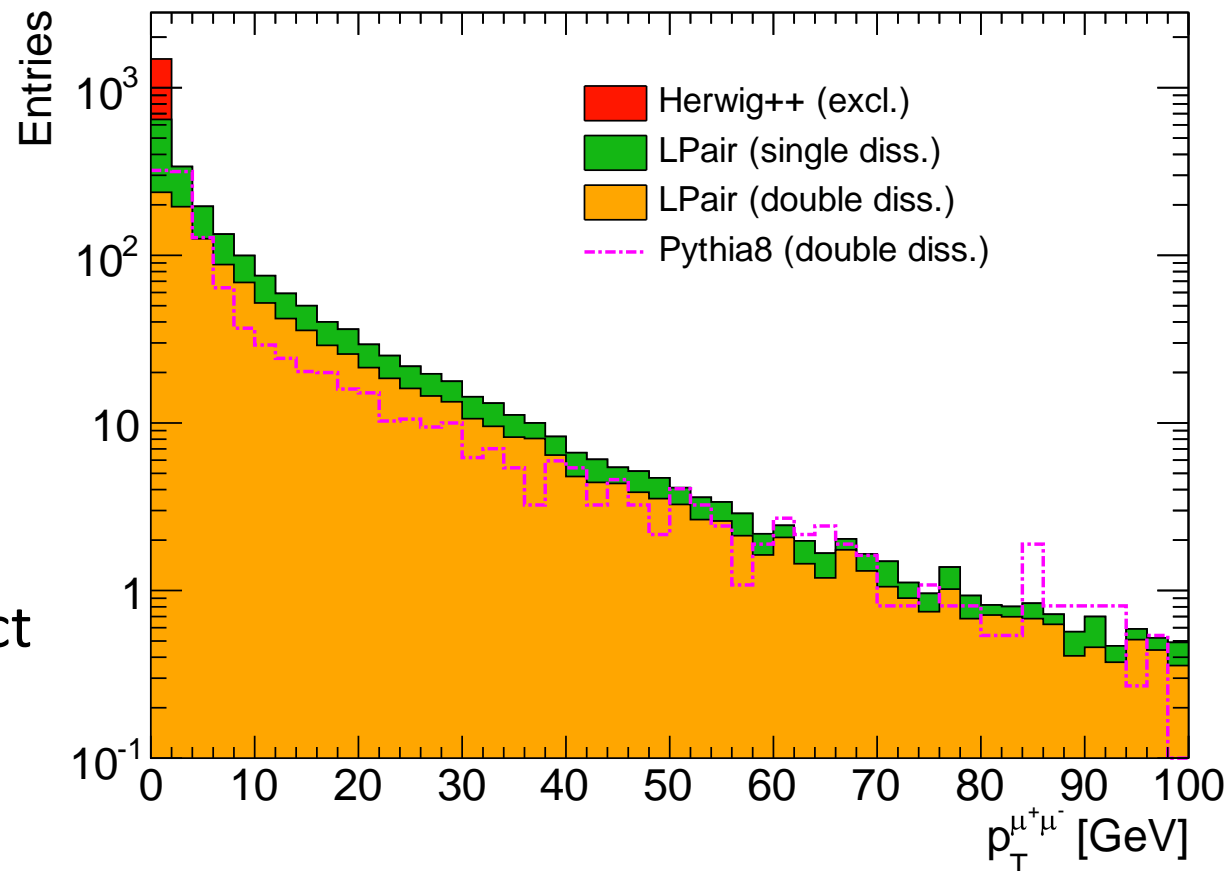
# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

- Leading lepton  $p_T$  (left) and  $\Delta p_T$  of the muon pairs (right)
- (after exclusivity requirement)



# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

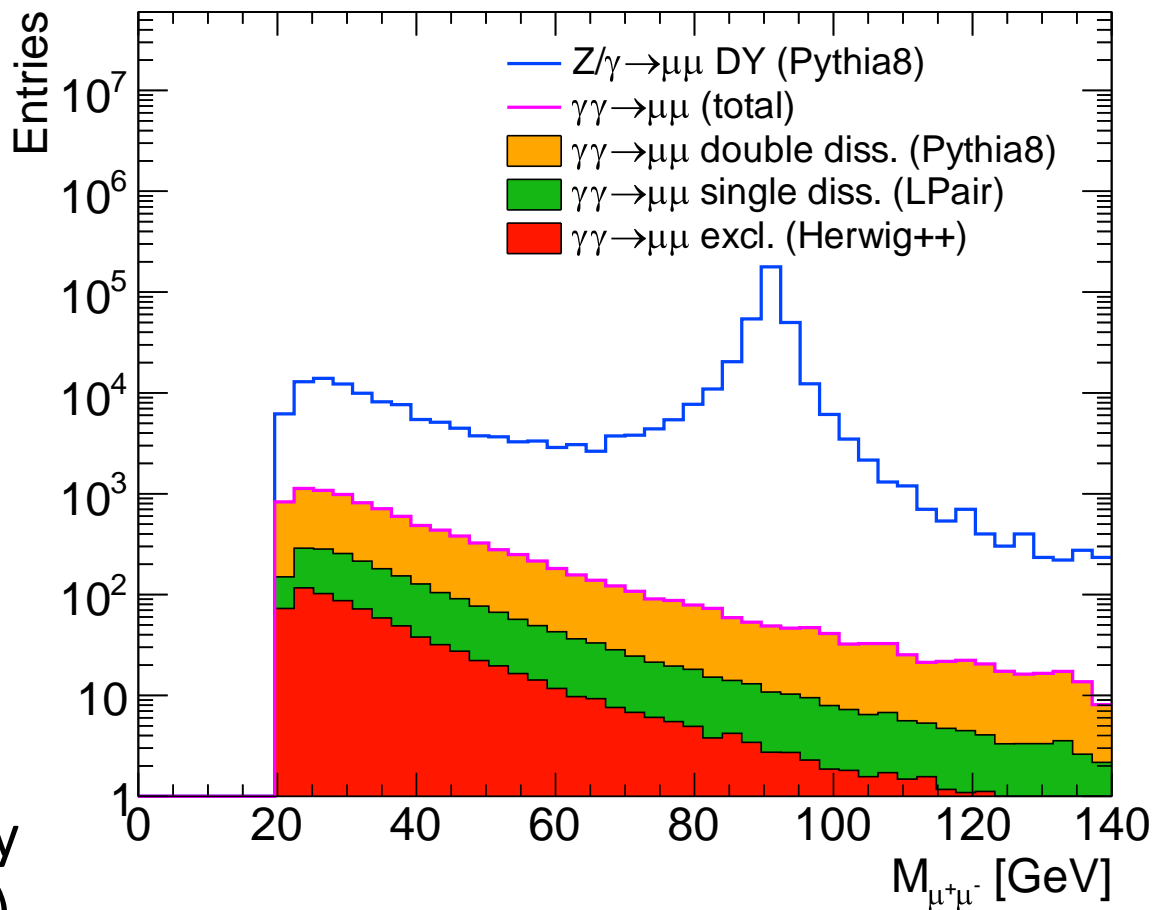
- Transverse momentum of the dimuon system
- Sensitive to the QCD EW PDF (reminder: form factor at  $\gamma$ -p dissociative vertices in LPAIR)
- Dissociative events hard to distinguish from the std DY processes...
- Single proton tag should give us a direct access to the diss content



# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

## ▪ Comparison with DY

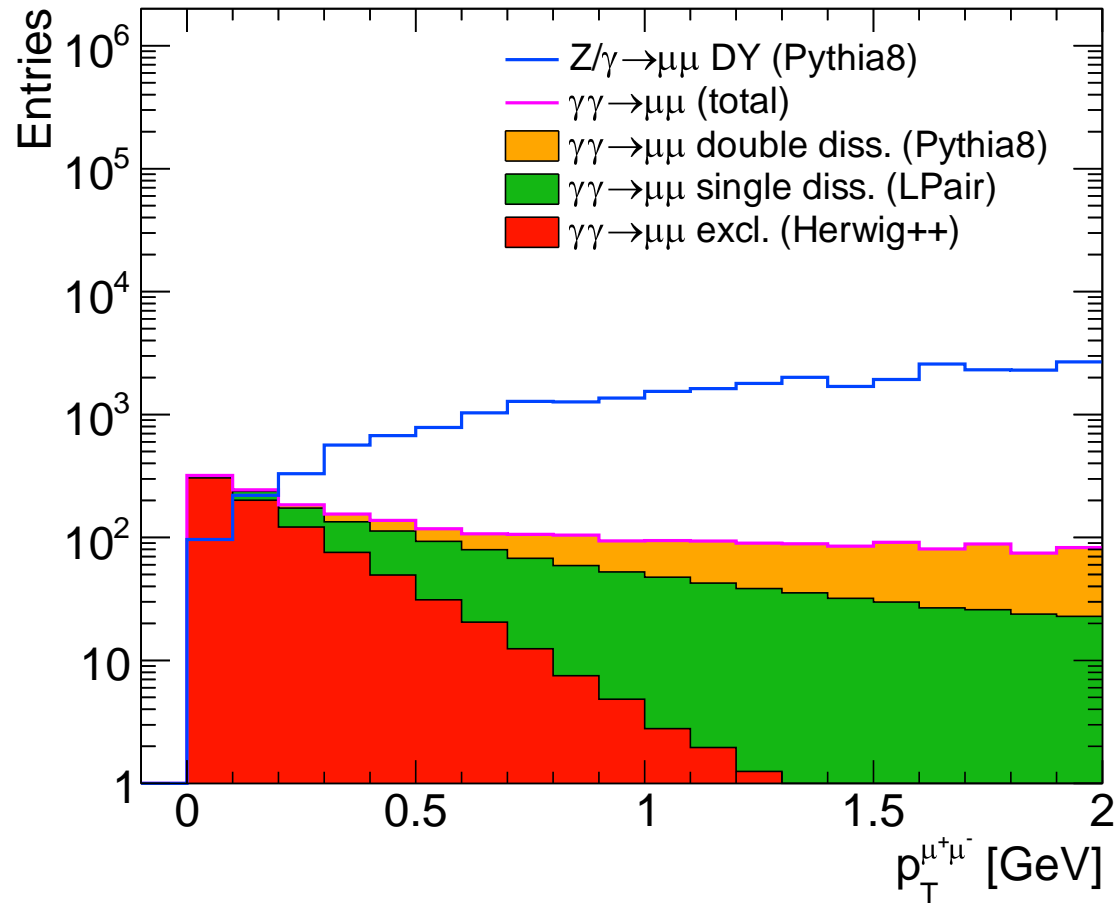
- $pp$  @  $\sqrt{s}=7\text{TeV}$
- Event distributions normalized to  $1\text{ fb}^{-1}$
- Kinematics:
  - $p_T^\mu > 10\text{ GeV}$
  - $M_{\mu\mu} > 20\text{ GeV}$
  - $|\eta_\mu| < 2.5$
  - No specific selection (exclusivity, DY)
- $\gamma\gamma$  is a sizeable especially at low mass (about 10%)



# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

## ▪ Comparison with DY

- $p_T$  of the dimuon system distribution (low system  $p_T$  region)
- No additional cuts imposed
- Good variable to separate exclusive and DY events



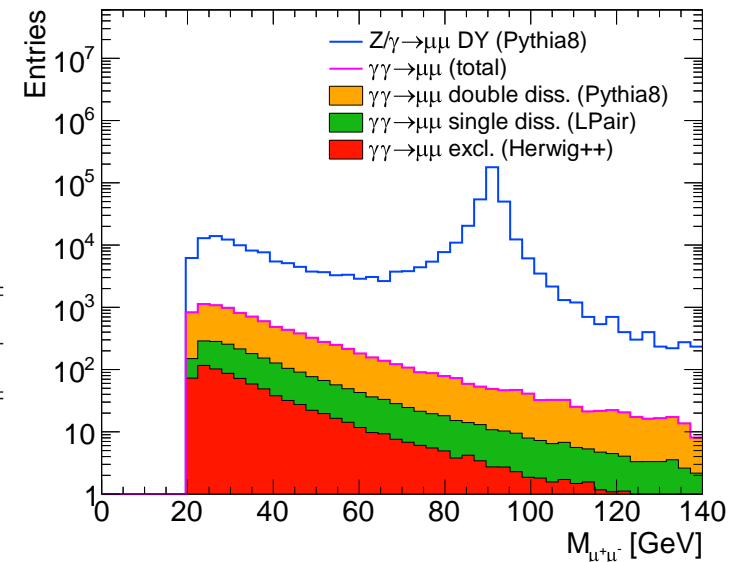
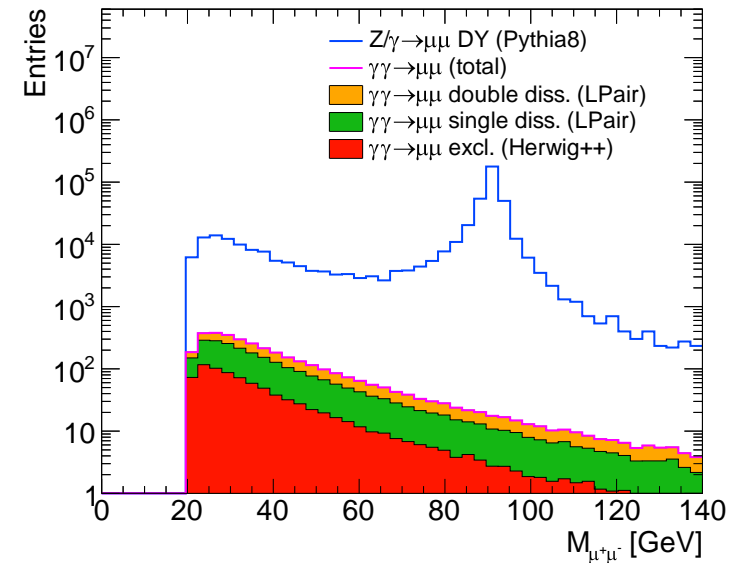
# Inelastic (pdiss) processes: $pp \rightarrow XY \mu\mu$

## ▪ PYTHIA vs LPAIR

- **LPAIR: only  $\gamma$ -p** inelastic processes with a given form factor at p-diss vertex (Suri-Yenni, ...)
- **PYTHIA8:** includes **also  $\gamma$ - $q/\bar{q}$**  interactions +  $O(\alpha_s)$  corrections
  - MRST2004QED PDF
- Total cross section comparison:
  - $M_{\mu\mu} > 20 \text{ GeV}$ ,  $p_T^\mu > 10 \text{ GeV}$ ,  $|\eta_\mu| < 2.5$

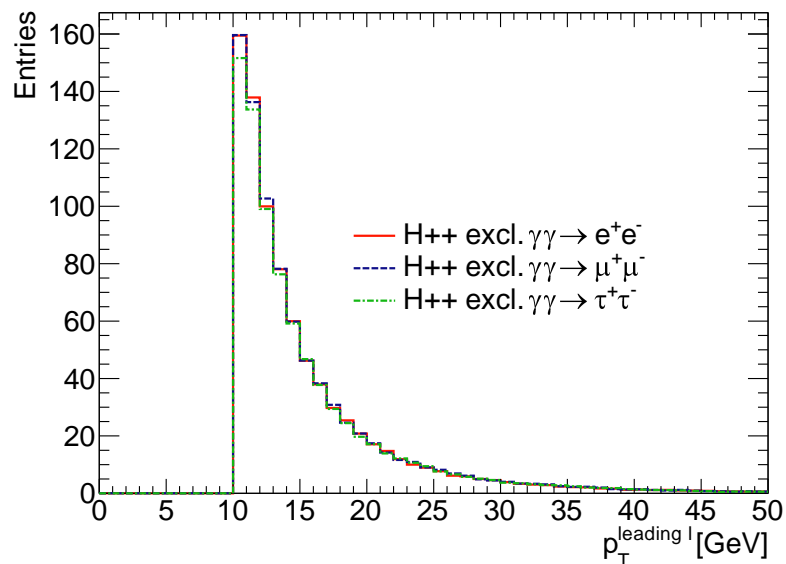
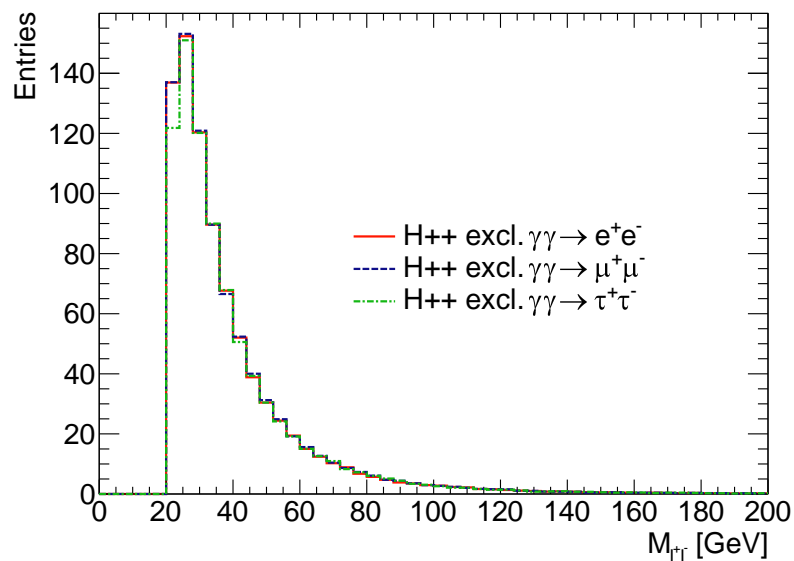
Generator	LPAIR (s-diss)	LPAIR (d-diss)	PYTHIA 8 (d-diss)
Cross-section	0.87 pb	1.02 pb	7.72 pb

- Note: no implementation of single-diss processes in PYTHIA...



# Other dilepton channels

- Different lepton channels have been also studied
- Small differences expected at low dilepton masses (t+u leptons exchange)
- Total (exclusive) cross section comparison
  - $M_{\mu\mu} > 20$  GeV
  - $p_T^\mu > 10$  GeV,  $|\eta_\mu| < 2.5$



Leptons	$ee$	$\mu\mu$	$\tau\tau$
Cross-section	0.83 pb	0.83 pb	0.82 pb



# Summary

- $\gamma\gamma \rightarrow \ell^+\ell^-$  is an important process to consider to achieve high precision measurement of DY
- Potential source of background for any other dilepton analysis
- MC studies done:
  - Fully exclusive  $\gamma\gamma \rightarrow \mu^+\mu^-$ : process is well described by the variety of (available) generators
  - Dissociative  $\gamma\gamma \rightarrow \mu^+\mu^-$ : PYTHIA8+MRST2004QED should be the right choice, but no single-diss process implemented yet
- Single proton tagger should provide a direct access to the proton-dissociative part -> precise measurement of the  $\gamma_p$  content of the proton PDF

# Backup

# $\cos(\theta^*)$ distribution

- Polar scattering angle in the Collins-Soper (CS) frame
- One could expect quite different shape in the Drell-Yan processes (spin 1 vs spin 1/2 particle exchange)...
- Differences mainly at high  $|\cos(\theta^*)|$  values  
->suppressed by the presence of the dilepton kinematic cuts

