

Production of heavy particle pairs
via photon-photon processes at the LHC
in proton-proton scattering

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The banner features a background of particle tracks in shades of purple, red, and orange. A white semi-transparent box in the center contains the text 'ICHEP 2020 | PRAGUE'. Below this, a pinkish-red bar contains the text '28 July 2020 to 6 August 2020', 'virtual conference', and 'Europe/Prague timezone' in white.

ICHEP 2020 | PRAGUE

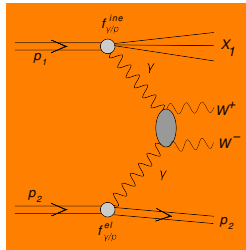
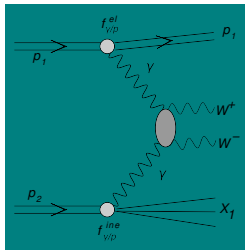
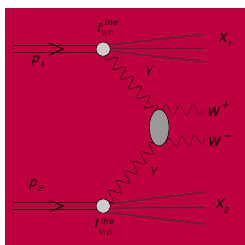
28 July 2020 to 6 August 2020
virtual conference
Europe/Prague timezone

Introduction ($p + p$ collisions)

- Precise calculations of various electroweak reactions in pp collisions at the LHC need to account for, on top of the higher-order corrections, the effects of photon-induced processes.
- production of lepton pairs
 - M. Luszczak, W. Schafer and A. Szczurek, *Phys.Rev. D93* (2016) 074018
- pairs of electroweak bosons
 - M. Luszczak, A. Szczurek and Ch. Royn, *JHEP* 1502 (2015) 098
 - M. Luszczak, W. Schafer and A. Szczurek, *JHEP* 1805 (2018) 064
 - L. Forthomme, M. Luszczak, W. Schafer and A. Szczurek, *Phys.Lett. B789* (2019) 300-307
- production of $t\bar{t}$ pairs
 - M. Luszczak, L. Forthomme, W. Schafer and A. Szczurek, *JHEP* 02 (2019) 100

Inclusive $\gamma\gamma \rightarrow W^+W^-$ mechanism

- $\gamma\gamma$ processes contribute also to inclusive cross section



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

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

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

- MRST-QED parton distributions

- QED-corrected evolution equations for the parton distributions of the proton

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

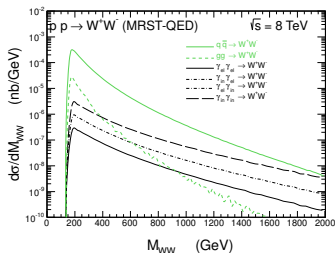
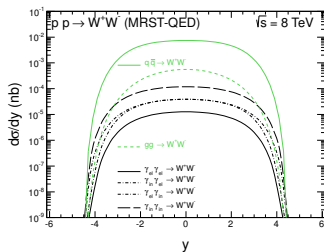
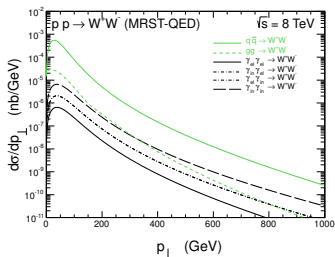
- NNPDF2.3 parton distributions

- fit to deep-inelastic scattering (DIS) and Drell-Yan data

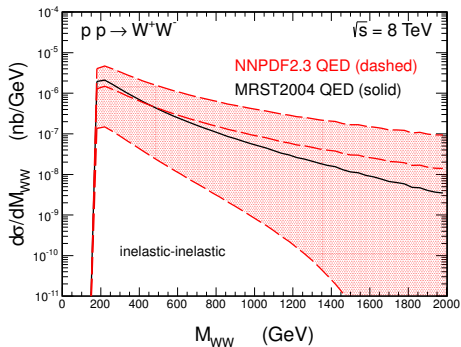
- LUXqed17 parton distributions

- integral over proton structure functions $F_2(x, Q^2)$ and $F_L(x, Q^2)$

Results for MRSTQ parton distributions



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



big uncertainties for large WW invariant masses

- very difficult to obtain the photon distributions from fits to experimental data

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

- the unintegrated photon fluxes can be expressed in terms of the hadronic tensor

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

- they enter the cross section for W^+W^- production

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

- the longitudinal momentum fractions of W^+W^- are obtained from the rapidities and transverse momenta of final state

$$x_1 = \sqrt{\frac{\mathbf{p}_1^2 + m_W^2}{s}} e^{y_W} + \sqrt{\frac{\mathbf{p}_2^2 + m_W^2}{s}} e^{y_W},$$
$$x_2 = \sqrt{\frac{\mathbf{p}_1^2 + m_W^2}{s}} e^{-y_W} + \sqrt{\frac{\mathbf{p}_2^2 + m_W^2}{s}} e^{-y_W}$$

Unintegrated photon fluxes

- the inelastic fluxes need the proton structure functions $F_2(B_j, Q^2)$ and $F_L(B_j, Q^2)$.

$$\mathcal{F}_{\gamma^* \leftarrow A}^{\text{in}}(z, \mathbf{q}) = \frac{\alpha_{\text{em}}}{\pi} \left\{ (1-z) \left(\frac{\mathbf{q}^2}{\mathbf{q}^2 + z(M_X^2 - m_A^2) + z^2 m_A^2} \right)^2 \frac{F_2(x_{B_j}, Q^2)}{Q^2 + M_X^2 - m_p^2} \right. \\ \left. + \frac{z^2}{4x_{B_j}^2} \frac{\mathbf{q}^2}{\mathbf{q}^2 + z(M_X^2 - m_A^2) + z^2 m_A^2} \frac{2x_{B_j} F_1(x_{B_j}, Q^2)}{Q^2 + M_X^2 - m_p^2} \right\}$$

- elastic pieces only require the standard electromagnetic form factors of a proton

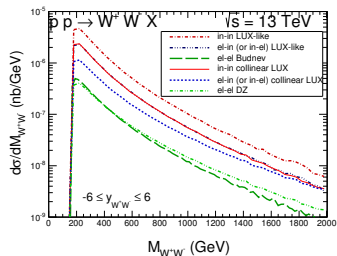
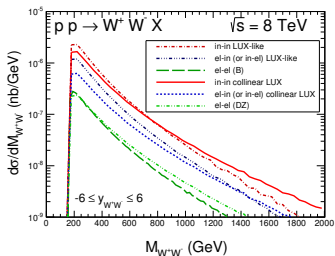
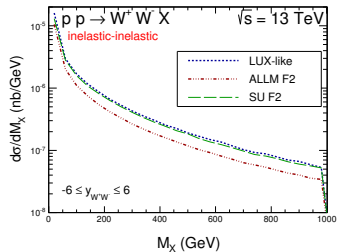
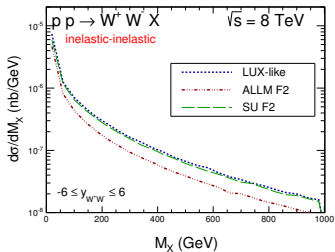
$$\mathcal{F}_{\gamma^* \leftarrow A}^{\text{el}}(z, \mathbf{q}) = \frac{\alpha_{\text{em}}}{\pi} \left\{ (1-z) \left(\frac{\mathbf{q}^2}{\mathbf{q}^2 + z(M_X^2 - m_A^2) + z^2 m_A^2} \right)^2 \frac{4m_p^2 G_E^2(Q^2) + Q^2 G_M^2(Q^2)}{4m_p^2 + Q^2} \right. \\ \left. + \frac{z^2}{4} \frac{\mathbf{q}^2}{\mathbf{q}^2 + z(M_X^2 - m_A^2) + z^2 m_A^2} G_M^2(Q^2) \right\}$$

Results, integrated cross sections

contribution	8 TeV	13 TeV
LUX-like		
$\gamma_{el}\gamma_{in}$	0.214	0.409
$\gamma_{in}\gamma_{el}$	0.214	0.409
$\gamma_{in}\gamma_{in}$	0.478	1.090
ALLM97 F2		
$\gamma_{el}\gamma_{in}$	0.197	0.318
$\gamma_{in}\gamma_{el}$	0.197	0.318
$\gamma_{in}\gamma_{in}$	0.289	0.701
SU F2		
$\gamma_{el}\gamma_{in}$	0.192	0.420
$\gamma_{in}\gamma_{el}$	0.192	0.420
$\gamma_{in}\gamma_{in}$	0.396	0.927
LUXqed collinear		
$\gamma_{in+el} \gamma_{in+el}$	0.366	0.778
MRST04 QED collinear		
$\gamma_{el}\gamma_{in}$	0.171	0.341
$\gamma_{in}\gamma_{el}$	0.171	0.341
$\gamma_{in}\gamma_{in}$	0.548	0.980
Elastic- Elastic		
$\gamma_{el}\gamma_{el}$ (Budnev)	0.130	0.273
$\gamma_{el}\gamma_{el}$ (DZ)	0.124	0.267

Table: Cross sections (in pb) for **different contributions** and **different F2 structure functions**: LUX-like, ALLM97 and SU, compared to the relevant collinear distributions with MRST04 QED and LUXqed distributions.

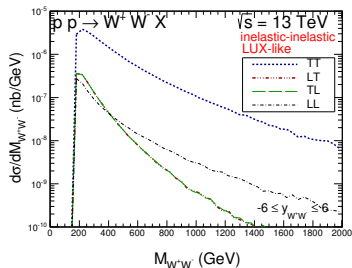
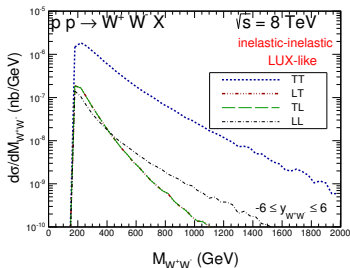
Results for k_T -factorization approach



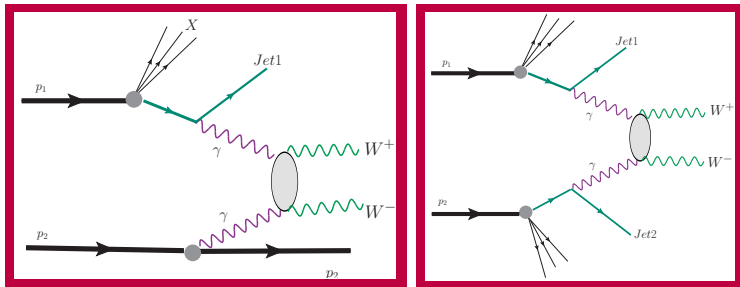
Results, spin decompositions

contribution	8 TeV	13 TeV
TT	0.405	0.950
LL	0.017	0.046
LT + TL	0.028 + 0.028	0.052 + 0.052
SUM	0.478	1.090

Table: Contributions of **different polarizations** of W bosons for the inelastic-inelastic component for the **LUX-like structure function**. The cross sections are given in pb .



Rapidity gap survival factors caused by remnant fragmentation



implementation of the above process

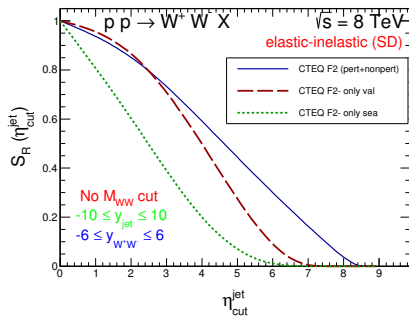
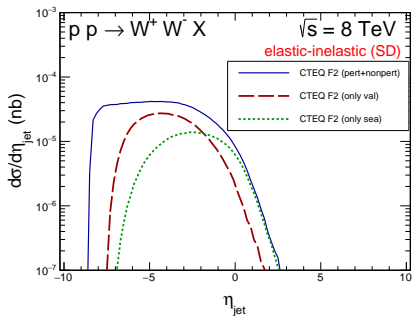
in CepGen for the Monte-Carlo generation of unweighted events

the hadronisation of remnant states X and/or Y systems

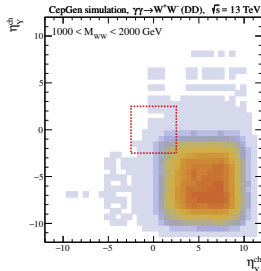
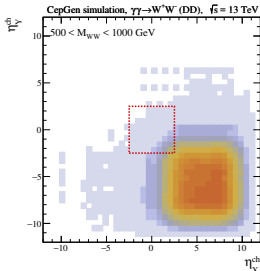
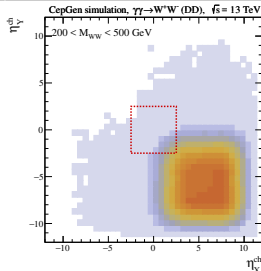
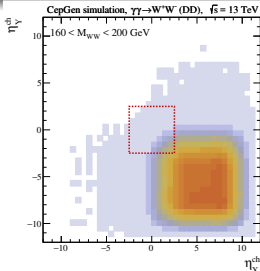
is performed using the Lund fragmentation algorithm implemented in Pythia8, and interfaced to CepGen.

Parton level approach for single dissociation

$$S_R(\eta_{\text{cut}}) = 1 - \frac{1}{\sigma} \int_{-\eta_{\text{cut}}}^{\eta_{\text{cut}}} \frac{d\sigma}{d\eta_{\text{jet}}} d\eta_{\text{jet}}$$

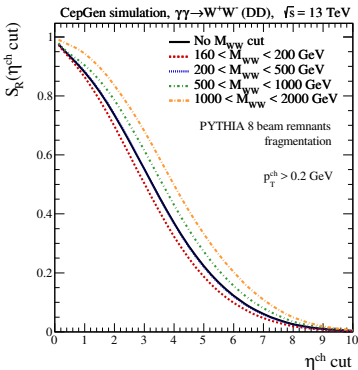
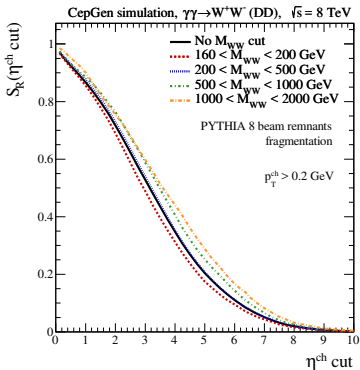


Double dissociation



- distributions in pseudorapidity of particles from X (η_X^{ch}) and Y (η_Y^{ch})

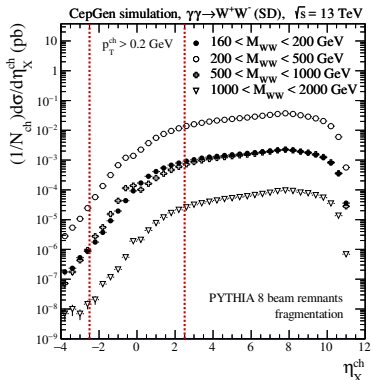
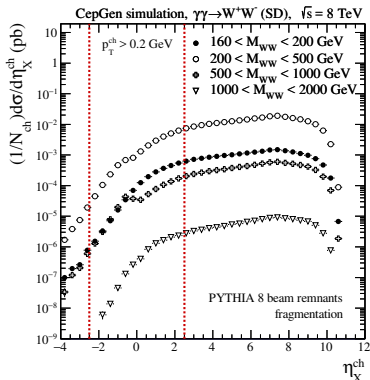
Double dissociation



we predict a strong dependence on η_{cut}

- it would be valuable to perform experimental measurements with different η_{cut}

Single dissociation



η_{ch} distribution for four different windows of M_{WW} :

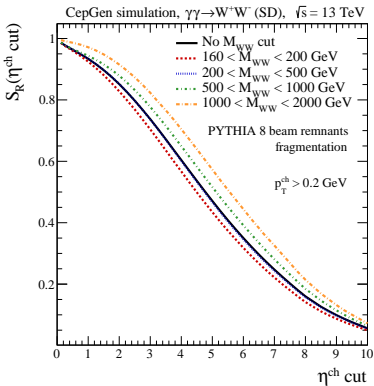
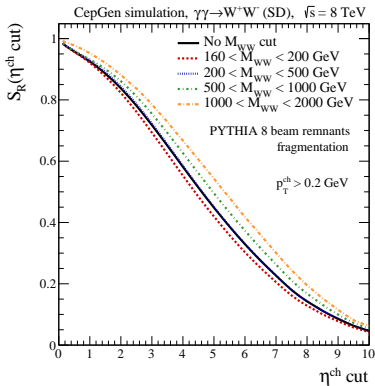
($2M_W, 200$ GeV)

(200, 500 GeV)

(500, 1000 GeV)

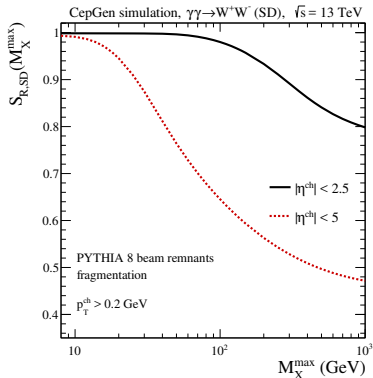
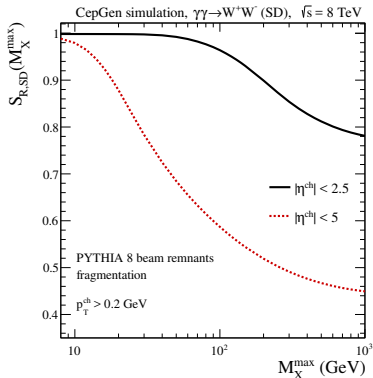
(1000, 2000 GeV)

Single dissociation



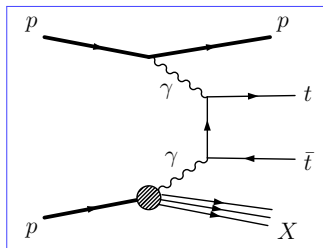
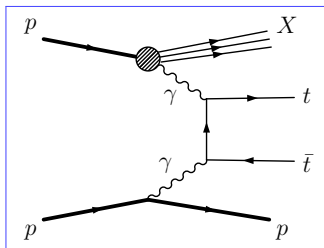
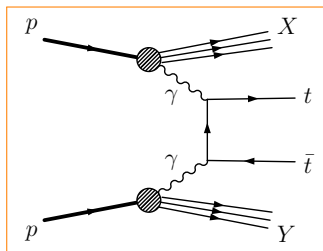
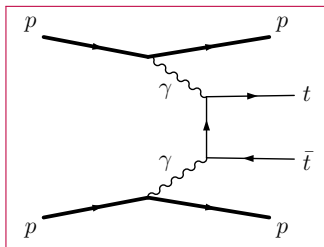
$$S_{R,DD} \approx (S_{R,SD})^2$$

Single dissociation



- for an η_{cut} value of 2.5 the rapidity gap survival factor S_R stays very close to 1 for $M_X^{\max} < 100$ GeV

Production of $t\bar{t}$ pairs



Production of $t\bar{t}$ pairs

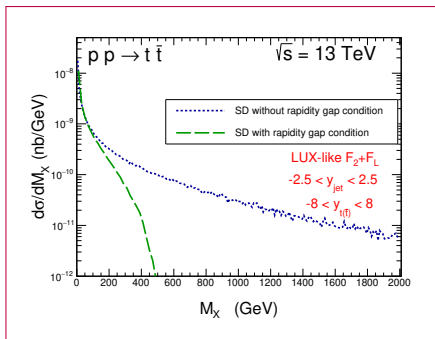
Contribution	No cuts	y_{jet} cut
elastic-elastic	0.292	0.292
elastic-inelastic	0.544	0.439
inelastic-elastic	0.983	0.622
inelastic-inelastic	2.36	1.79
all contributions		

Table: Cross section in fb at $\sqrt{s} = 13$ TeV for different components (left column) and the same when the extra condition on the outgoing jet $|y_{\text{jet}}| > 2.5$ is imposed.

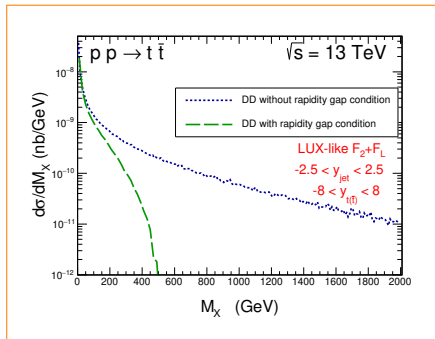
right panel → results when a rapidity gap (that means no additional particle production except the t or \bar{t}) in the central region, for $-2.5 < y < 2.5$ is required in addition

Production of $t\bar{t}$ pairs

SD (left)

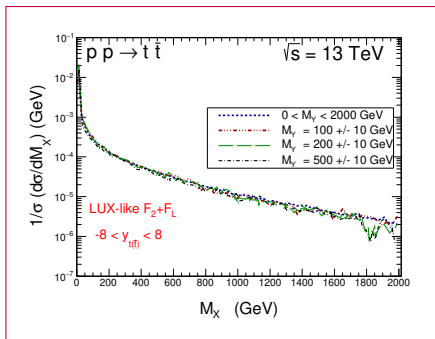


DD (right)

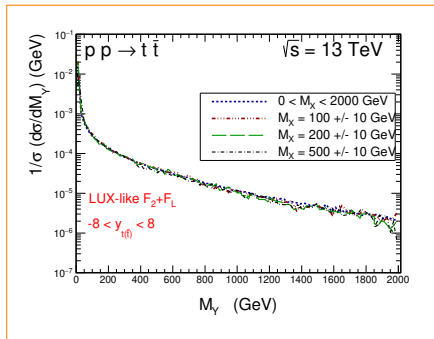


Production of $t\bar{t}$ pairs

M_X for a fixed M_Y (left)

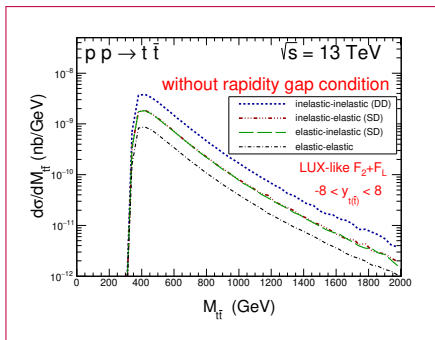


M_Y for a fixed M_X (right)

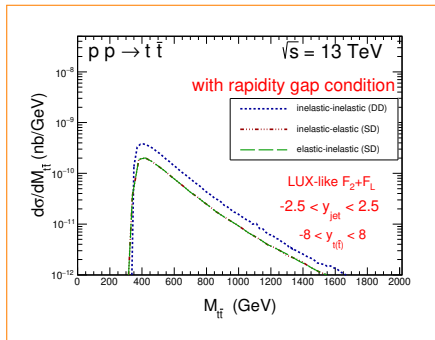


Production of $t\bar{t}$ pairs

without rapidity gap condition



with rapidity gap condition



- We have discussed the quantity called **remnant gap survival factor** for the $pp \rightarrow W^+W^-$ and $pp \rightarrow t\bar{t}$ reaction initiated via photon-photon fusion.
- We use a recent formalism developed for the inclusive case which includes **transverse momenta of incoming photons**.
- First we have calculated the gap survival factor for single dissociative process on the parton level. In such an approach the outgoing parton (jet/mini-jet) is **responsible for destroying the rapidity gap**.
- We have found that the hadronisation only mildly modifies the gap survival factor calculated on the parton level. This may justify approximate treatment of hadronisation of remnants.