Production of dileptons via photon-photon processes in proton-proton collisions with one forward proton measurement at the LHC

Marta Łuszczak

Institute of Physics, University of Rzeszow, Poland

XI International Conference on New Frontiers in Physics (ICNFP 2022)

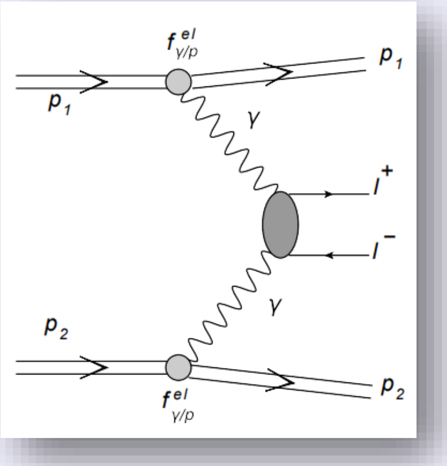
30 August 2022 - 11 September 2022

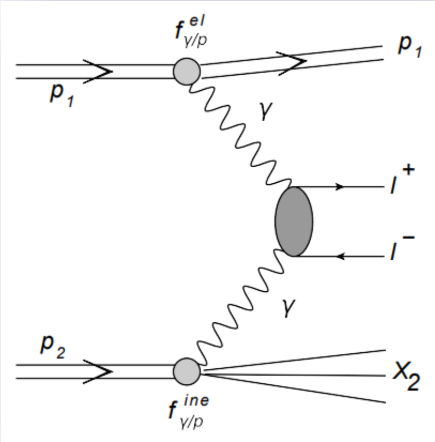
OAC, Kolymbari, Crete, Greece

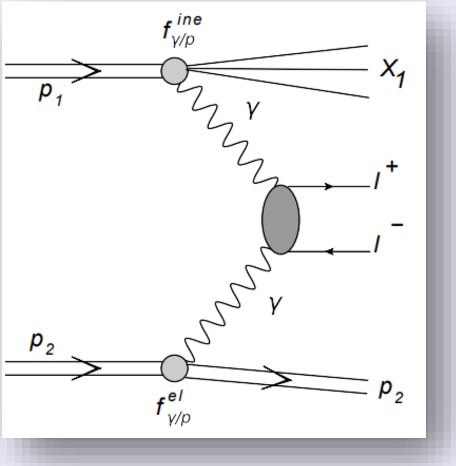
Introduction

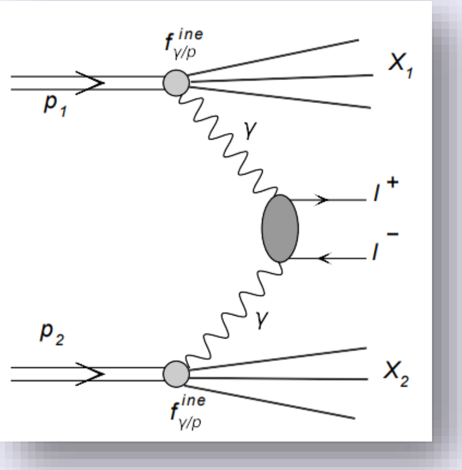
- We discuss photon-photon fusion mechanisms of dilepton production in proton-proton collisions with rapidity gap in the main detector and one forward proton in the forward proton detectors.
- Transverse momenta of the intermediate photons are taken into account and photon fluxes are expressed in terms of proton electromagnetic form factors and structure functions.
- Both double-elastic and single-dissociative processes are included in the analysis.
- The formalism that we used can be also used for W^+W^- and $t\bar{t}$ production processes.
- The soft rapidity gap survival factor is calculated for each contribution separately.
- The soft rapidity gap survival factor for the case of single proton measurement is significantly smaller than that for the inclusive case (no proton measurement).
- Our analysis include a comparison obtained by us with the results coming from Superchic generator.
- **Published in Phys. Rev. D 104 (2021) 7, 074009**

$\gamma\gamma \rightarrow l^+l^-$ mechanism and k$_T$ factorization approach









The cross section for production of l^+l^- in the k$_T$-factorization approach can be written as:

$$\frac{d\sigma^{i,j}}{dy_1 dy_2 d^2\boldsymbol{p_1} d^2\boldsymbol{p_2}} = \int \frac{d^2\boldsymbol{q_1}}{\pi \boldsymbol{q}_1^2} \frac{d^2\boldsymbol{q_2}}{\pi \boldsymbol{q}_2^2} \mathcal{F}^{(i)}_{\gamma^*/A}(x_1, \boldsymbol{q_1})\, \mathcal{F}^{(j)}_{\gamma^*/B}(x_2, \boldsymbol{q_2}) \frac{d\sigma^*(\boldsymbol{p_1}, \boldsymbol{p_2}; \boldsymbol{q_1}, \boldsymbol{q_2})}{dy_1 dy_2 d^2\boldsymbol{p_1} d^2\boldsymbol{p_2}} \qquad i, j \in \{el, in\}$$

The photon flux for inelastic case in this approach is integrated over the mass of the remnant

Photon fluxes

The elastic flux is expressed by the proton electromagnetic form factor:

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

The inelastic flux is expressed by the proton structure functions $F_2(x_{Bj},Q^2)$ and $F_L(x_{Bj},Q^2)$:

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

Photon fluxes

Unintegrated inelastic photon distribution (flux) depends also on the mass of the remnant system:

$$\boldsymbol{\mathcal{F}}_{ine}(x, q_t^2) = \int dM^2 \frac{d\boldsymbol{\mathcal{F}}_{ine}}{dM^2}(x, q_t^2, M^2)$$

The longitudinal momentum fractions and four-momenta of intermediate photons:

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

$$x_2 = \sqrt{\frac{\boldsymbol{p}_1^2 + m_l^2}{s}} e^{-y_1} + \sqrt{\frac{\boldsymbol{p}_2^2 + m_l^2}{s}} e^{-y_2}$$

$$q_1 \approx \left(x_1 \frac{\sqrt{s}}{2}, \vec{q}_{1t}, x_1 \frac{\sqrt{s}}{2} \right)$$

$$q_2 \approx \left(x_2 \frac{\sqrt{s}}{2}, \vec{q}_{2t}, -x_2 \frac{\sqrt{s}}{2} \right)$$

Structure functions arguments

Bjorken – x:

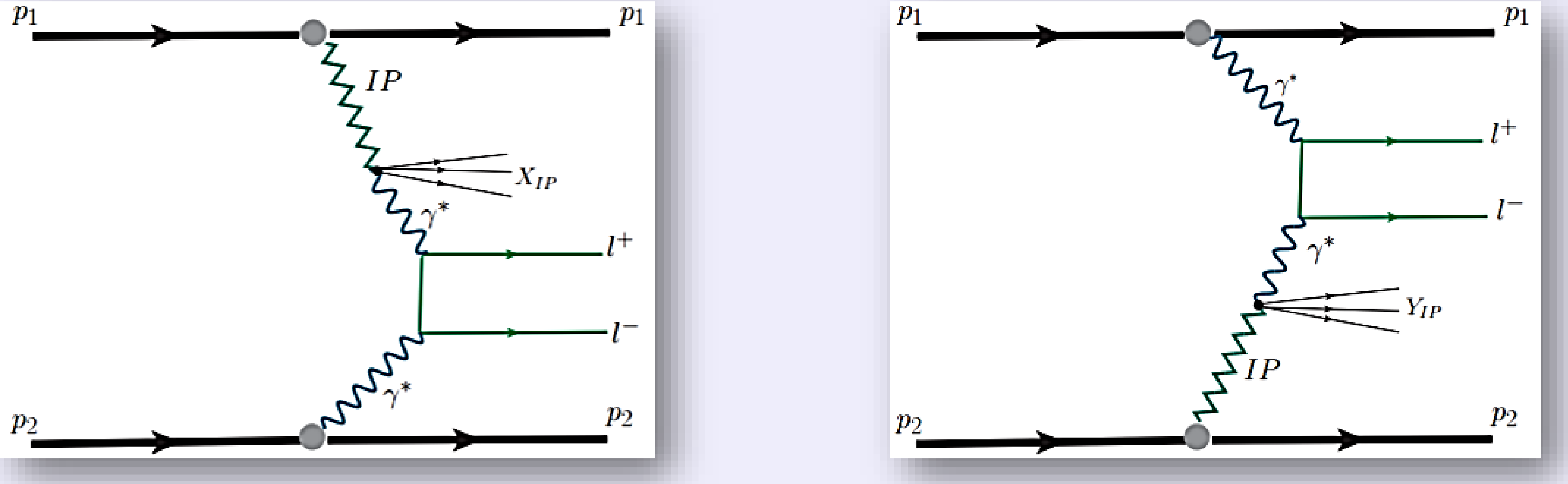
$$x_{Bj1} = \frac{q_{1t}^2}{\left(q_{1t}^2 + M_X^2 - m_p^2\right)}, \qquad x_{Bj2} = \frac{q_{2t}^2}{\left(q_{2t}^2 + M_Y^2 - m_p^2\right)},$$

Photon virtuality:

$$Q_1^2 \approx q_{1t}^2 \qquad Q_2^2 \approx q_{2t}^2$$

Proton emission from the remnant system

- Proton can be produce from the remnant system
- Those protons reduced longitudinal momentum fraction – cannot be measurement at the detectors
- Pomeron remnant destroys the rapidity gap
- $\frac{d\mathcal{F}_{diff}}{dM^2}(x, q_t^2, M^2) \ll \frac{d\mathcal{F}_{ine}}{dM^2}(x, q_t^2, M^2)$



Diffractive mechanisms of dilepton production in proton-proton collisions

Imposed cuts

We used the consistency requirements imposed by ATLAS collaboration:

$$\xi_1 = \xi_{\mathrm{ll}}^{+}, \qquad \xi_2 = \xi_{\mathrm{ll}}^{-}$$

The longitudinal momentum fractions of the photons were calculated in the ATLAS analysis as:

$$\xi_{\mathrm{ll}}^{+} = \left(\frac{M_{ll}}{\sqrt{s}}\right) e^{+Y_{ll}}$$

$$\xi_{\mathrm{ll}}^{-} = \left(\frac{M_{ll}}{\sqrt{s}}\right) e^{-Y_{ll}}$$

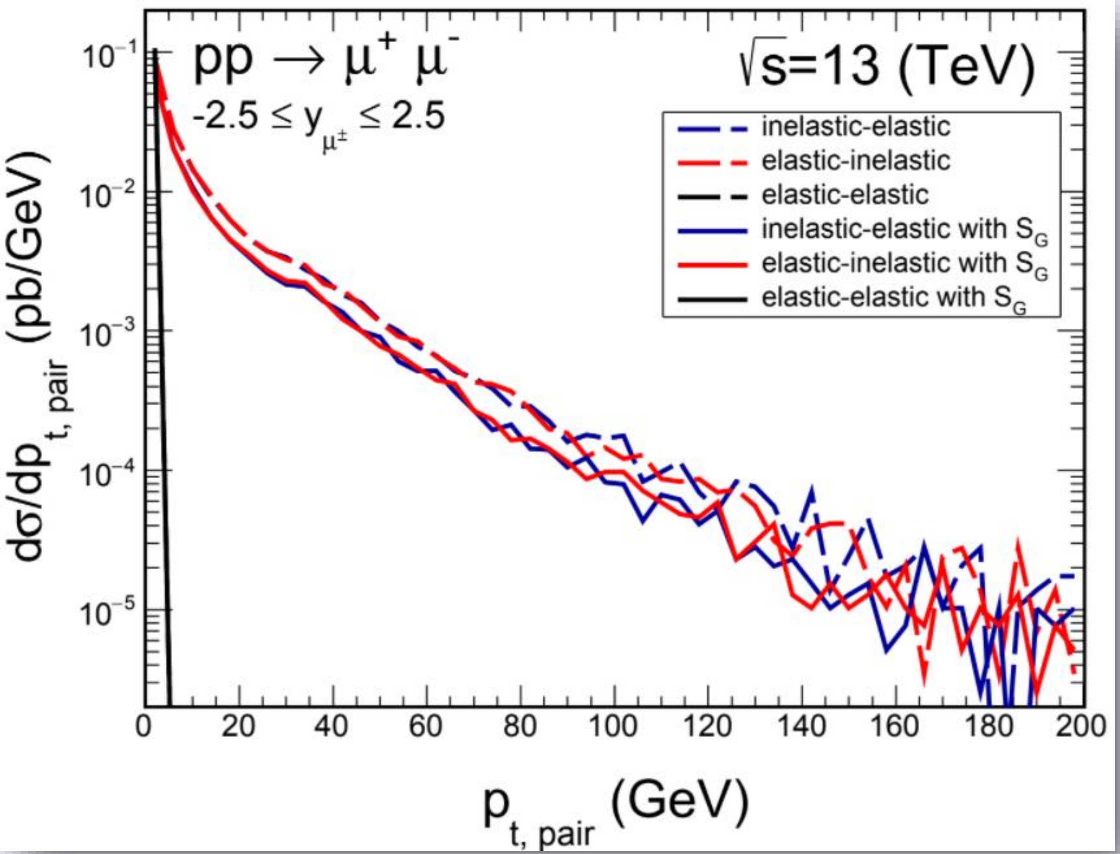
In our calculation, we imposed the following cuts:

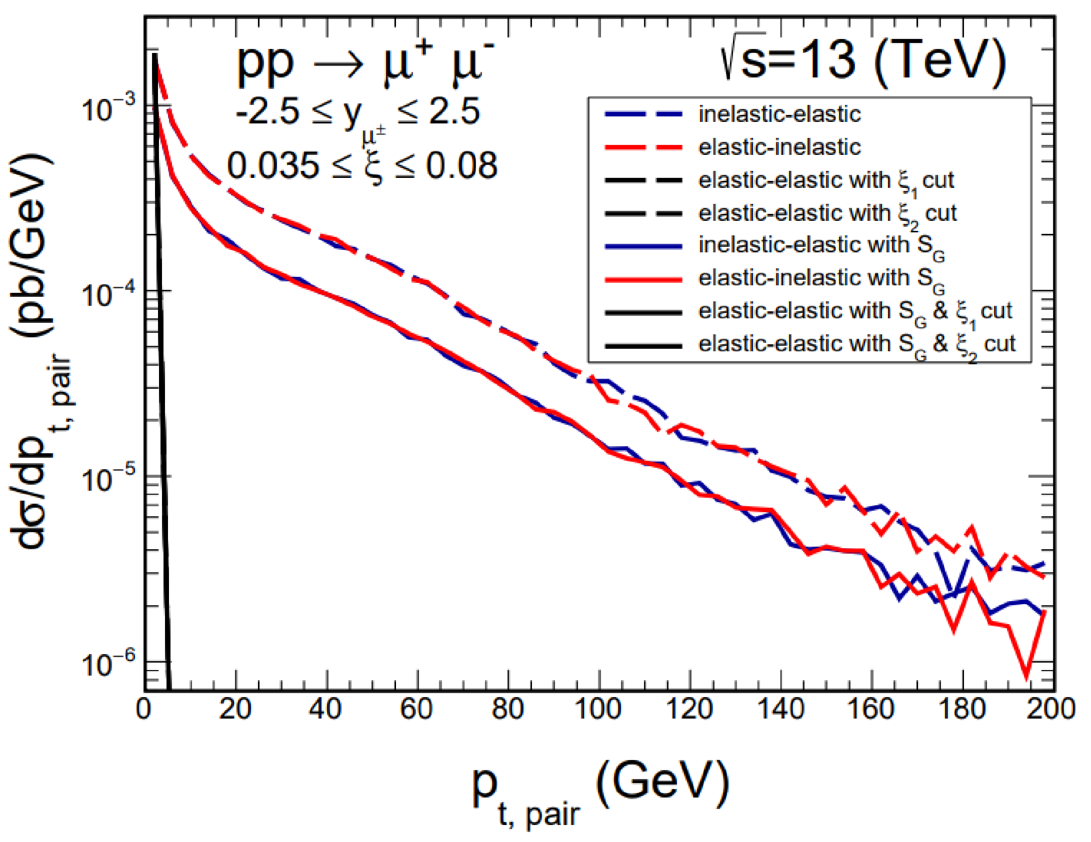
$$-2.5 < y_1, y_2 < 2.5$$

$$p_{1t}, p_{2t} > 15\ GeV$$

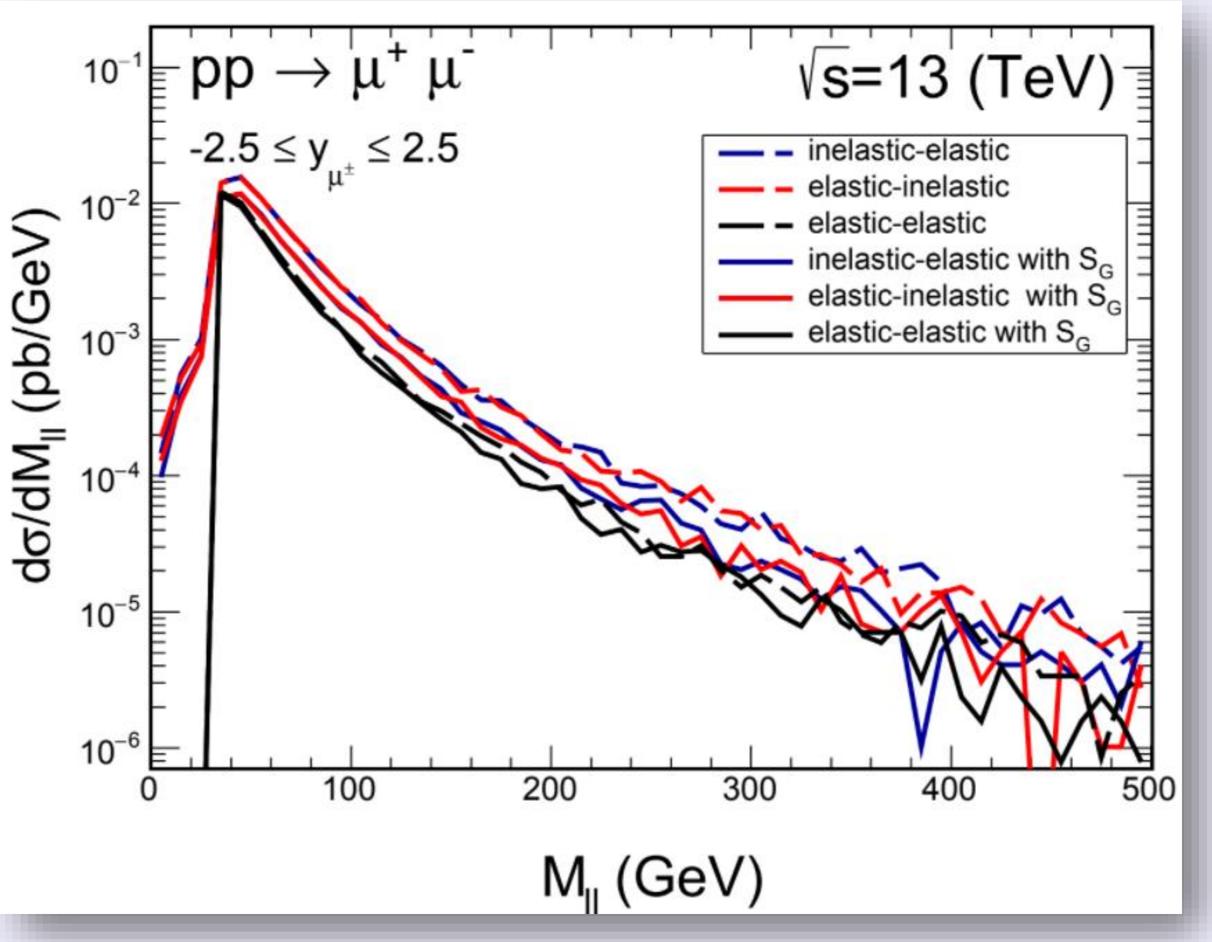
$$0.035 < \xi_{ll}^{+}, \xi_{ll}^{-} < 0.08$$

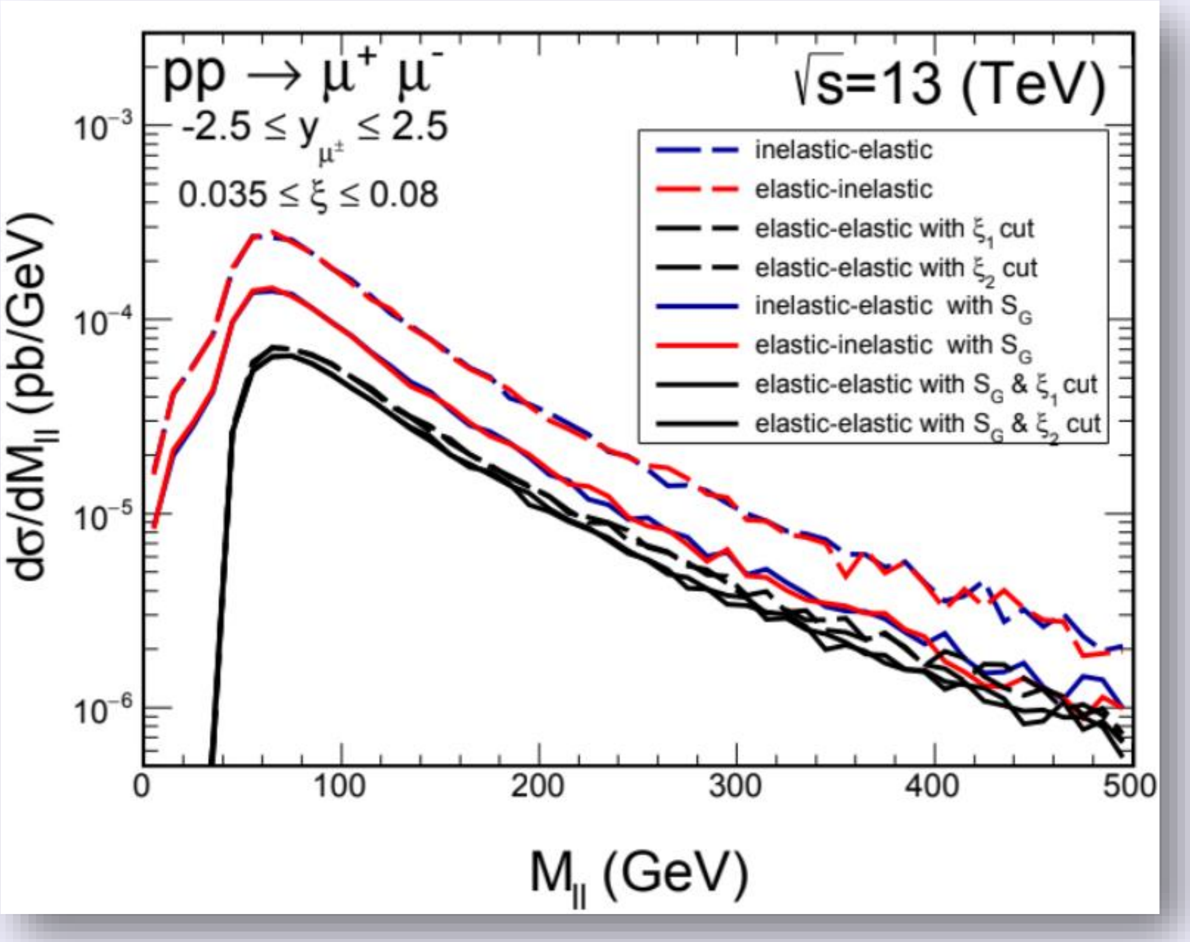
Distribution in $p_{t,pair}$ (Superchic)





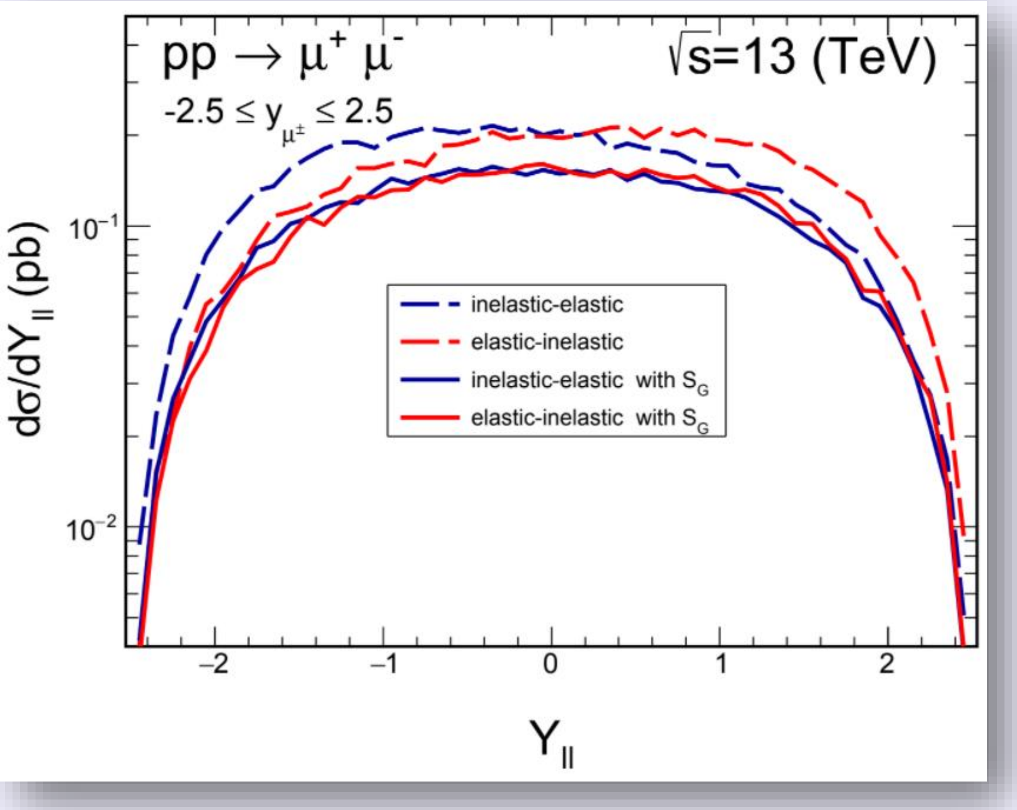
Distribution in M_{ll} (Superchic)



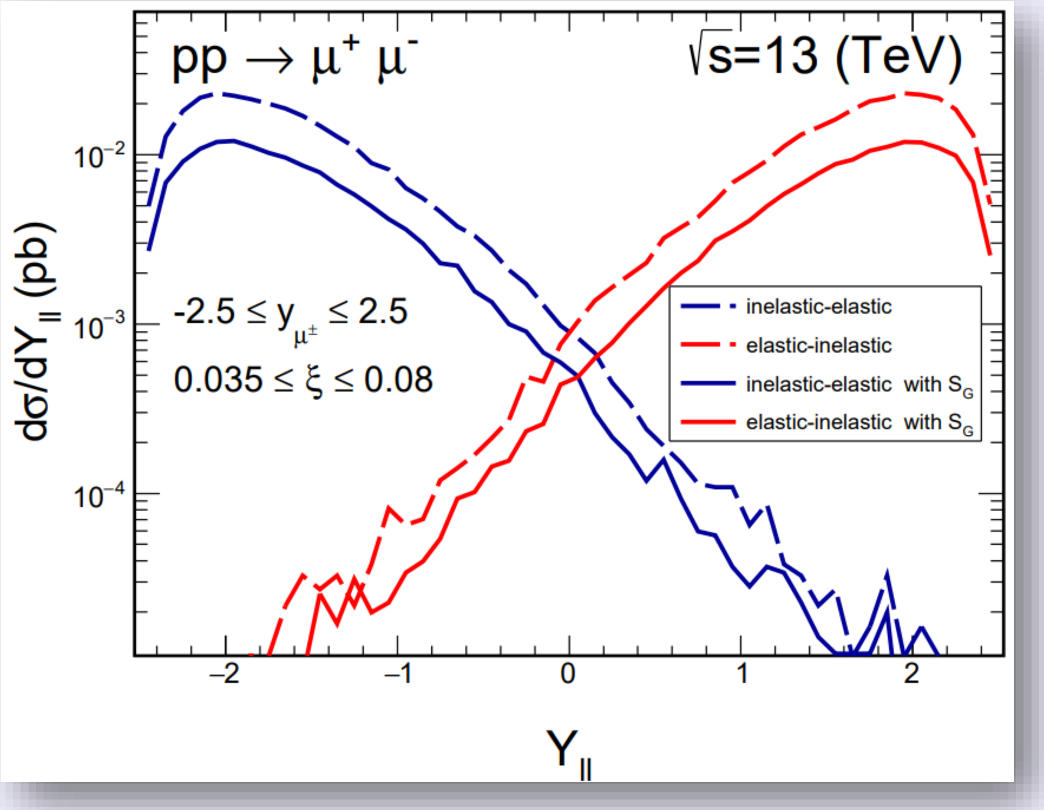


Distribution in Y_{ll} (Superchic)

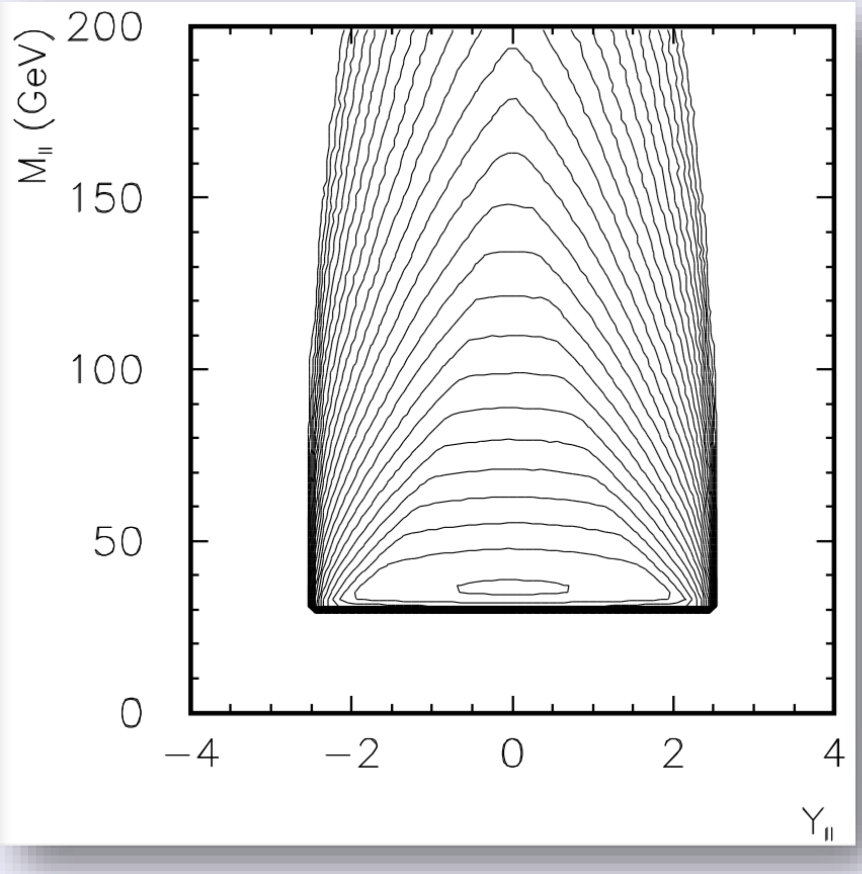
without ξ cuts (a single proton is not measured)

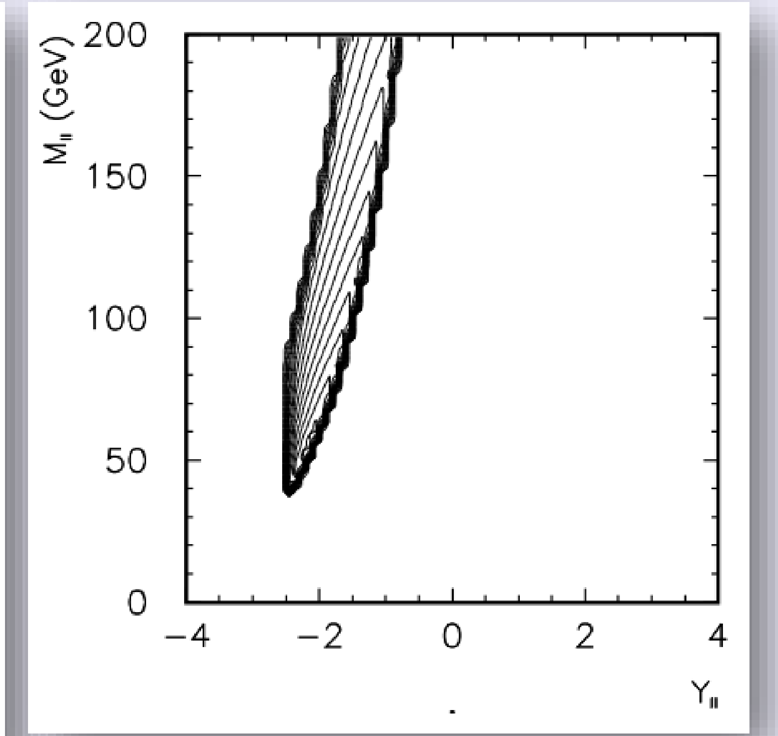


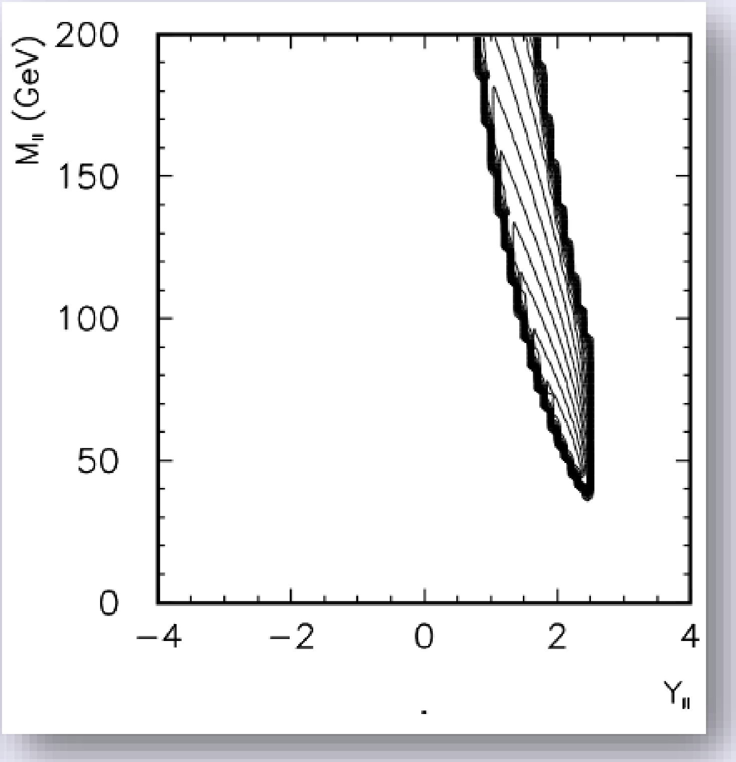
with ξ cuts



Two-dimension distribution in (M_{ll}, Y_{ll})



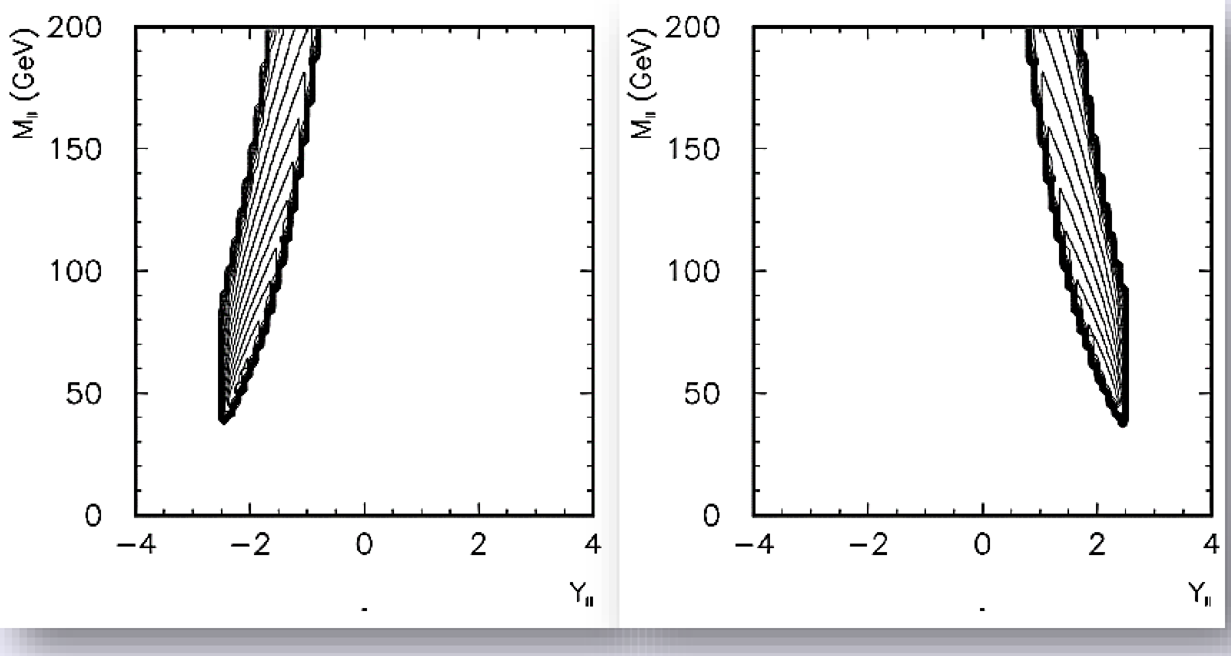




- no cuts on neither ξ1 or ξ2 were imposed
- the maximum of this contribution corresponds to a rapidity close to zero

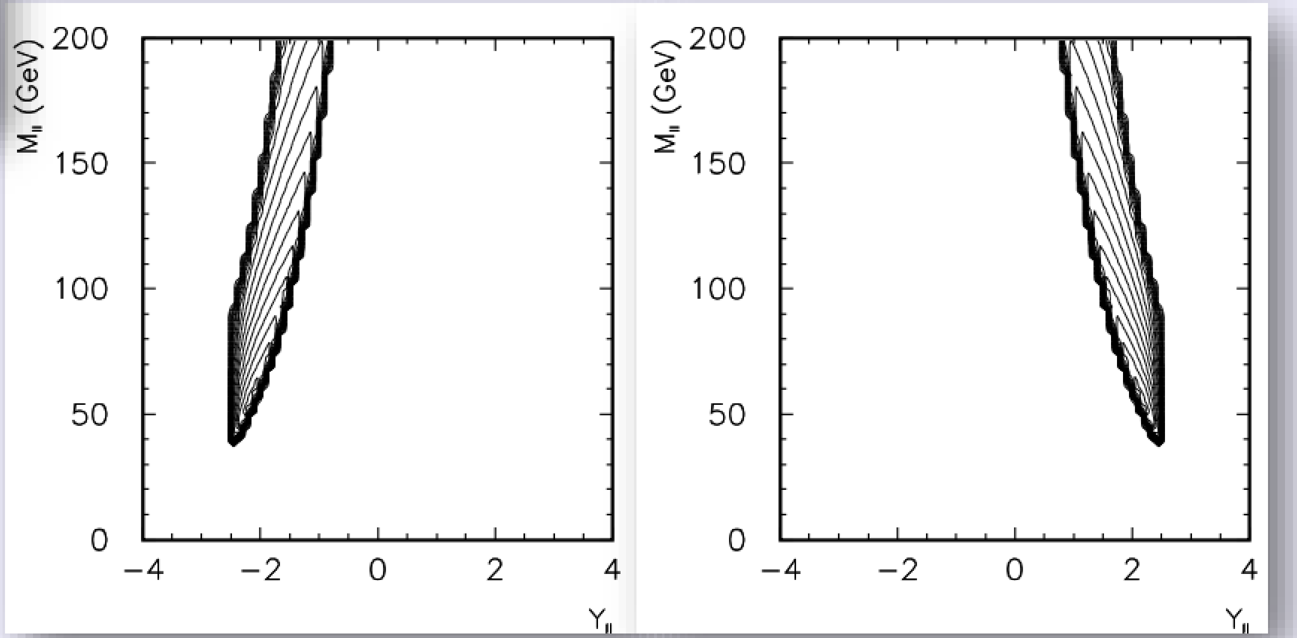
- cuts on ξ1 or ξ2 were imposed, one of the protons is measured
- any particles for masses less then 150 GeV

Two-dimension distribution in (M_{ll}, Y_{ll})



Two dimension distribution in (M_{ll}, Y_{ll}) for double-elastic contribution

Two dimension distribution in (M_{ll}, Y_{ll}) for single-dissociation contribution



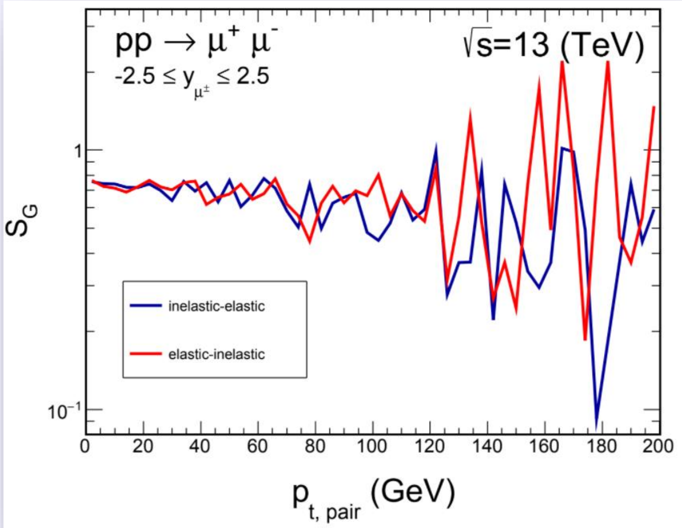
Gap survival factor

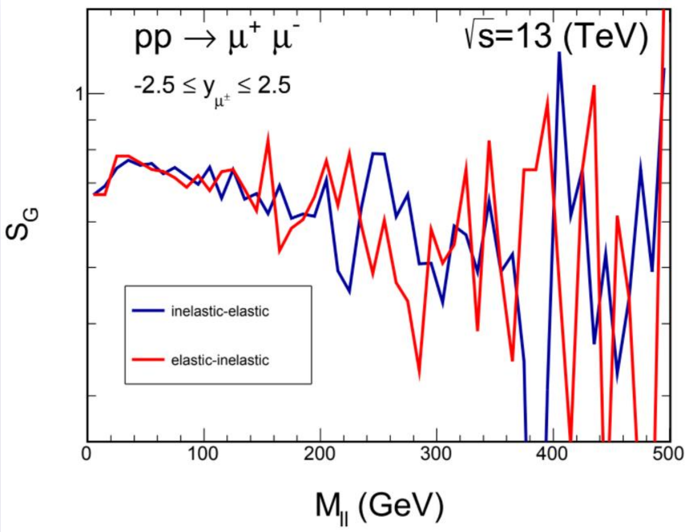
$$S_G(p_{t,pair}) = \frac{d\sigma/dp_{t,pair}|_{withSR}}{d\sigma/dp_{t,pair}|_{withoutSR}}$$

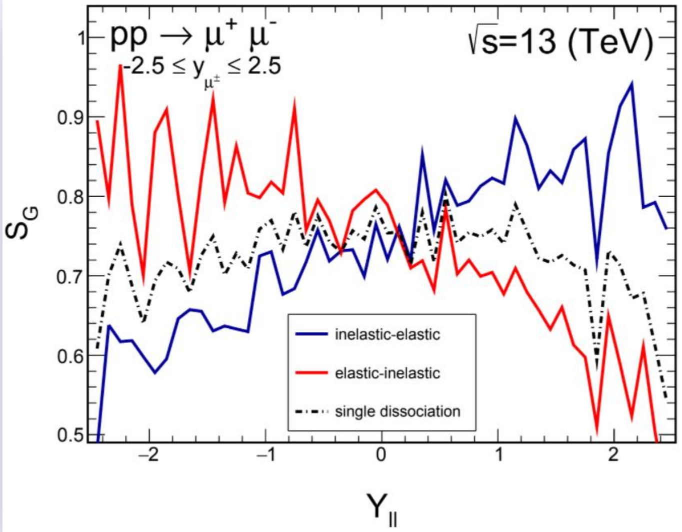
$$S_G(M_{ll}) = \frac{d\sigma/dM_{ll}|_{withSR}}{d\sigma/dM_{ll}|_{withoutSR}}$$

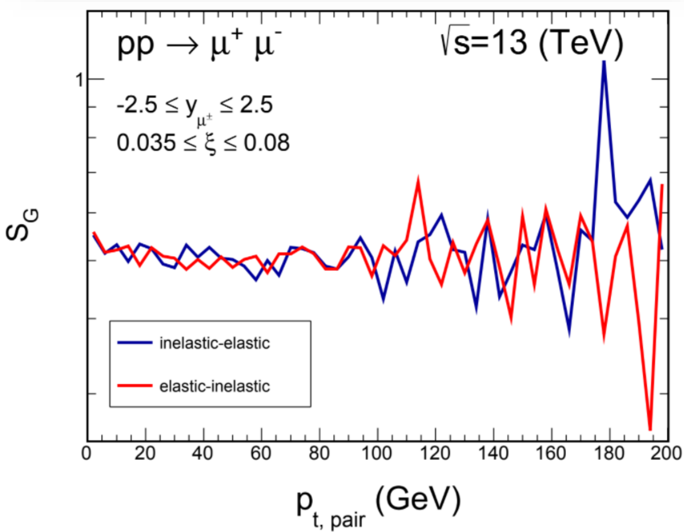
$$S_G(Y_{ll}) = \frac{d\sigma/dY_{ll}|_{withSR}}{d\sigma/dY_{ll}|_{withoutSR}}$$

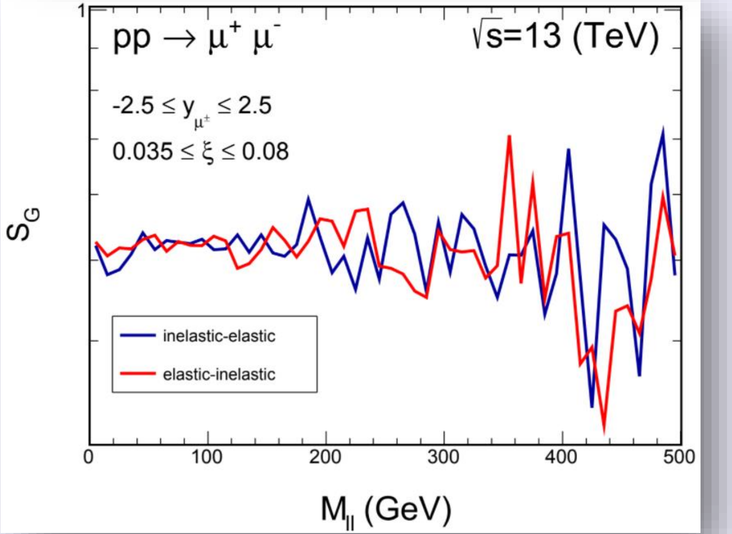
Gap survival factor – function of $p_{t,pair}$, M_{ll} and Y_{ll}

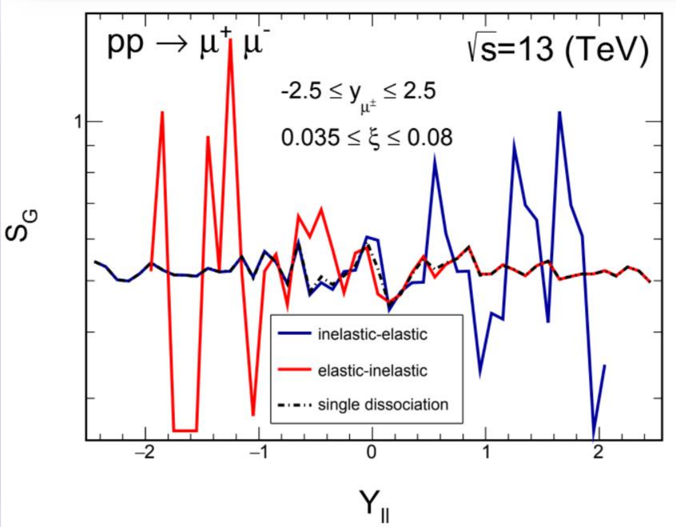




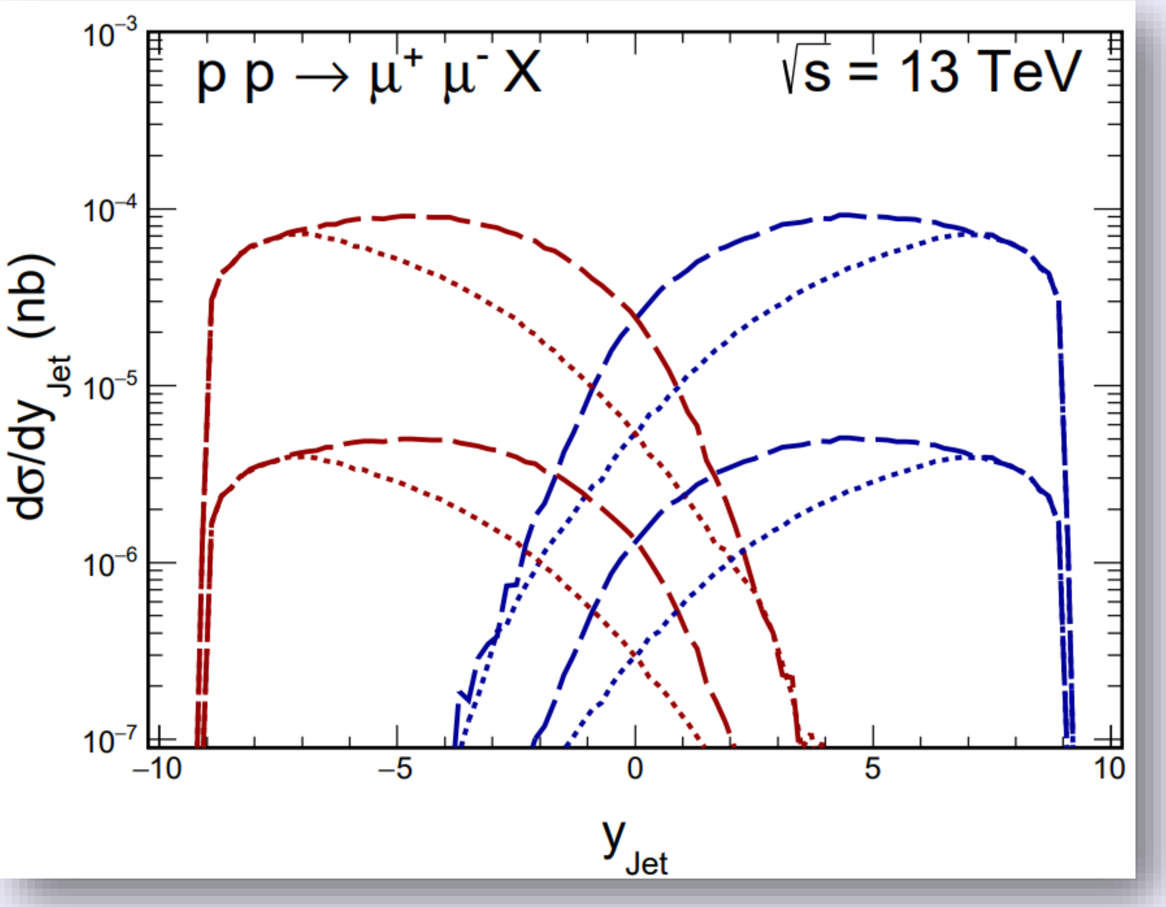




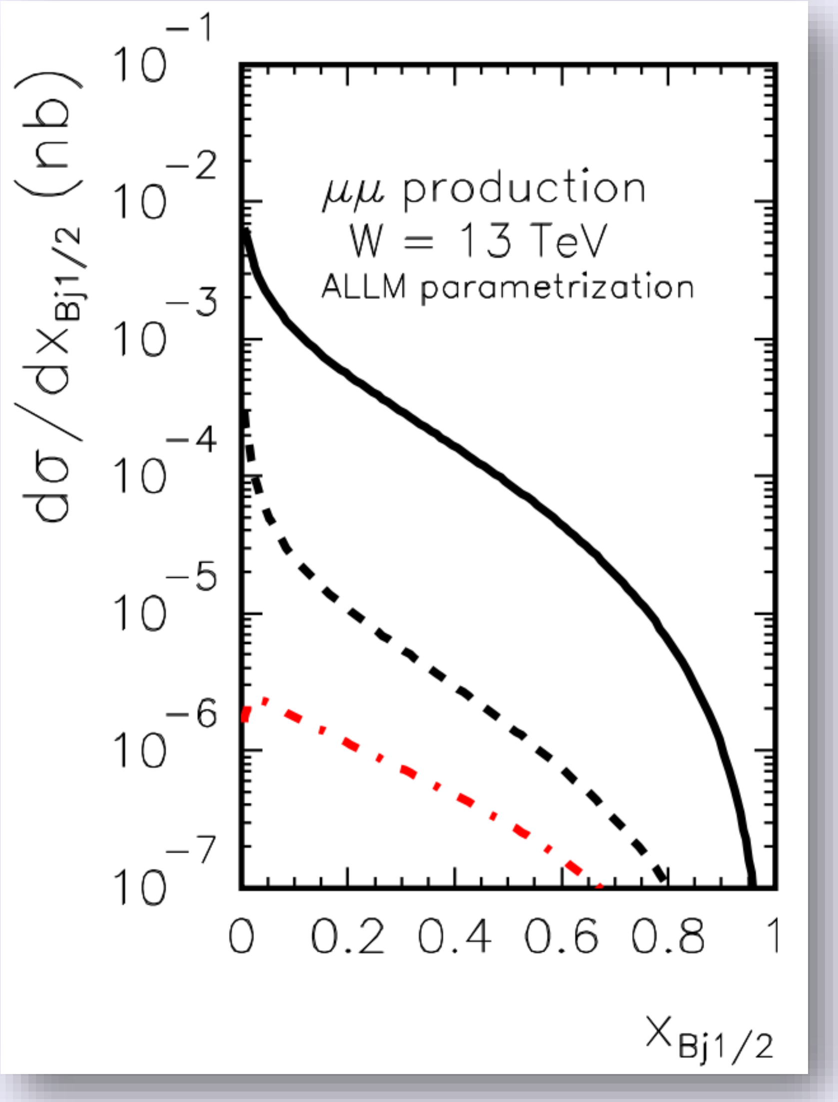


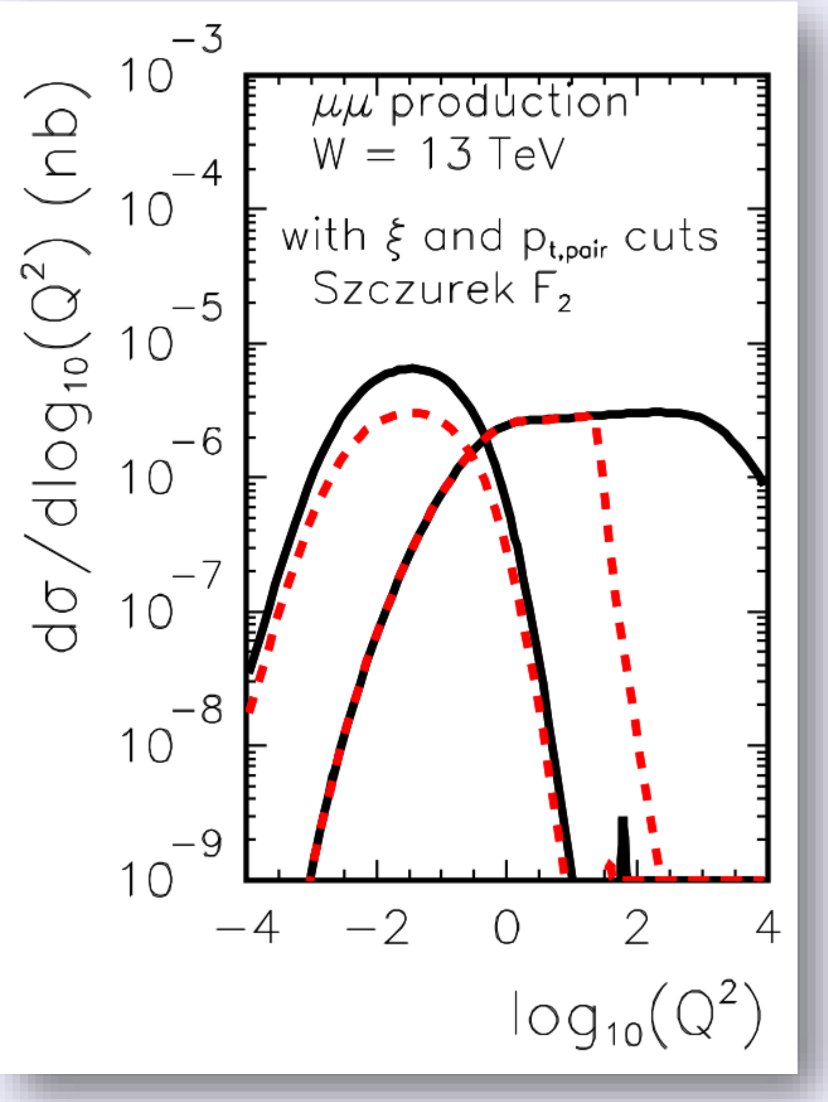


Distribution in the (mini)jet rapidity

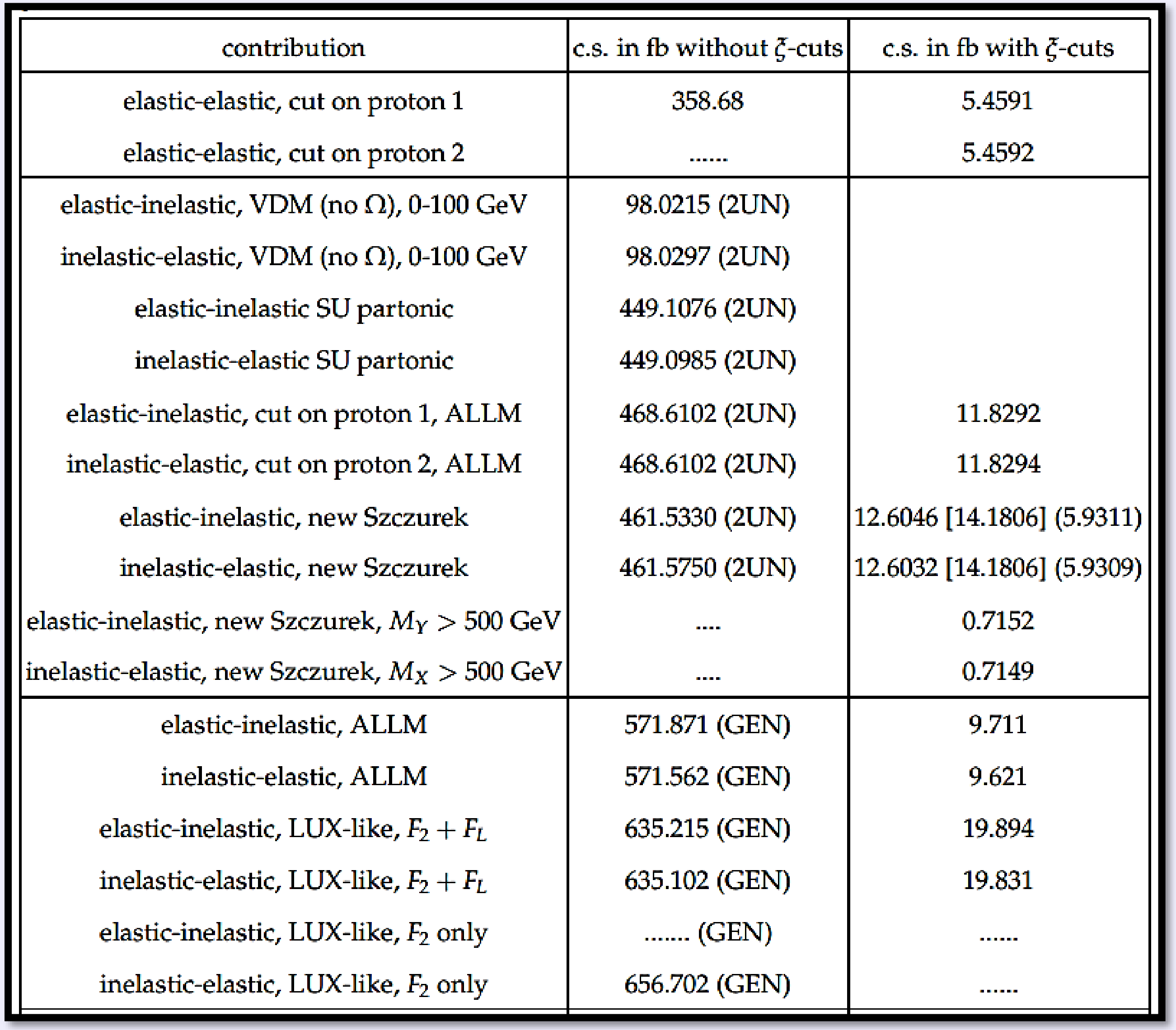


Distribution in the arguments of structure functions



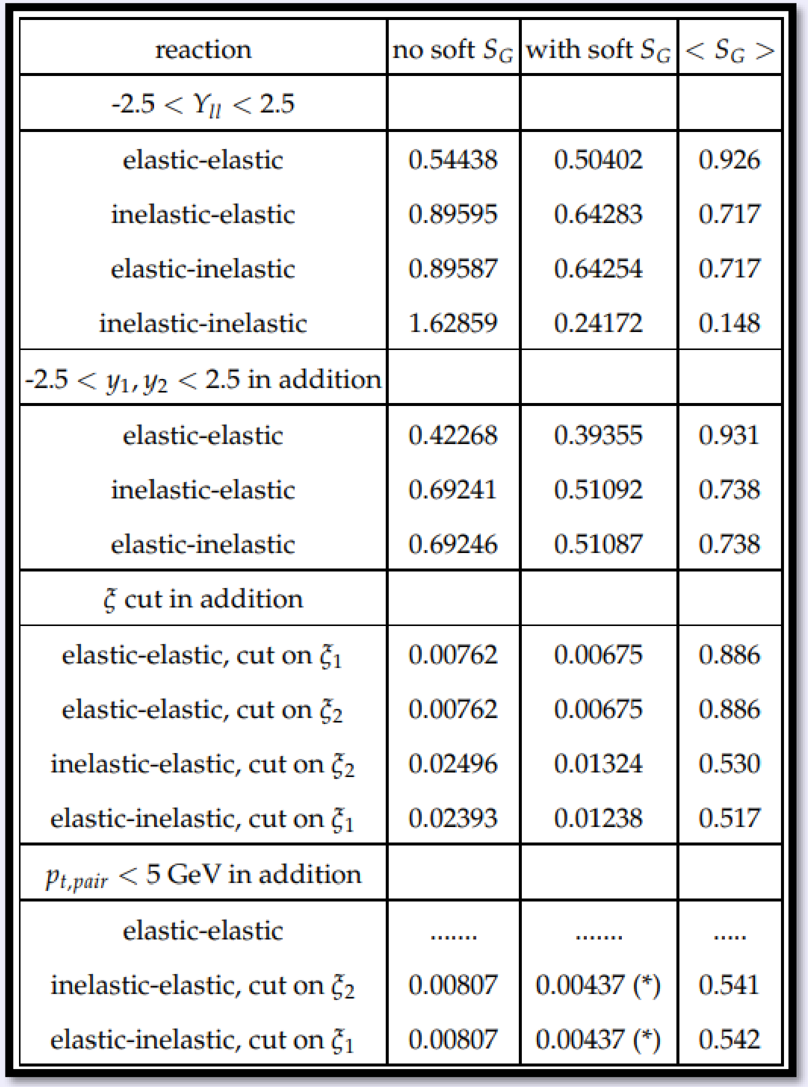


Integrated cross section

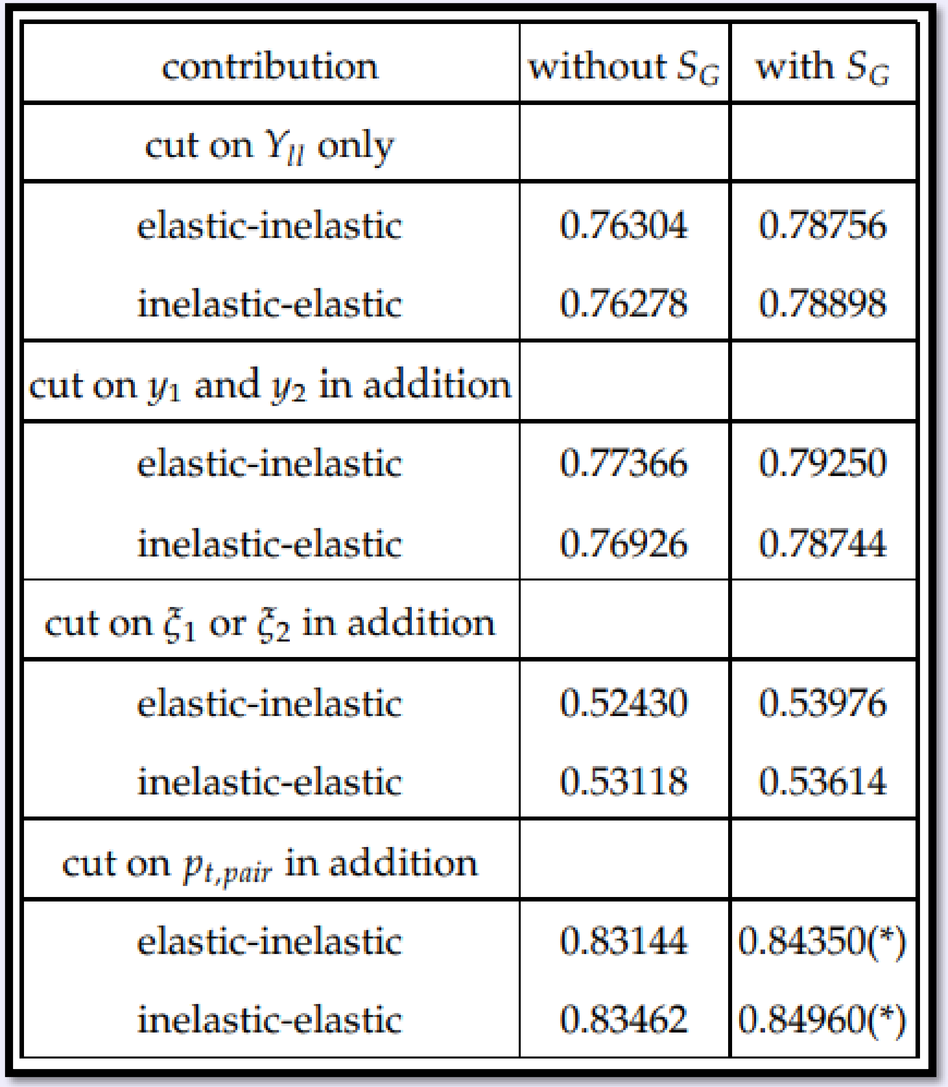


contribution	c.s. in fb without ξ-cuts	c.s. in fb with ξ-cuts
elastic-elastic, cut on proton 1	358.68	5.4591
elastic-elastic, cut on proton 2	……	5.4592
elastic-inelastic, VDM (no Ω), 0-100 GeV	98.0215 (2UN)	
inelastic-elastic, VDM (no Ω), 0-100 GeV	98.0297 (2UN)	
elastic-inelastic SU partonic	449.1076 (2UN)	
inelastic-elastic SU partonic	449.0985 (2UN)	
elastic-inelastic, cut on proton 1, ALLM	468.6102 (2UN)	11.8292
inelastic-elastic, cut on proton 2, ALLM	468.6102 (2UN)	11.8294
elastic-inelastic, new Szczurek	461.5330 (2UN)	12.6046 [14.1806] (5.9311)
inelastic-elastic, new Szczurek	461.5750 (2UN)	12.6032 [14.1806] (5.9309)
elastic-inelastic, new Szczurek, $M_Y > 500$ GeV	….	0.7152
inelastic-elastic, new Szczurek, $M_X > 500$ GeV	….	0.7149
elastic-inelastic, ALLM	571.871 (GEN)	9.711
inelastic-elastic, ALLM	571.562 (GEN)	9.621
elastic-inelastic, LUX-like, $F_2 + F_L$	635.215 (GEN)	19.894
inelastic-elastic, LUX-like, $F_2 + F_L$	635.102 (GEN)	19.831
elastic-inelastic, LUX-like, F_2 only	……. (GEN)	……
inelastic-elastic, LUX-like, F_2 only	656.702 (GEN)	……

Integrated corss section & gap survival factor(Superchic)



reaction	no soft S_G	with soft S_G	$< S_G >$
-2.5 $< Y_{ll} <$ 2.5			
elastic-elastic	0.54438	0.50402	0.926
inelastic-elastic	0.89595	0.64283	0.717
elastic-inelastic	0.89587	0.64254	0.717
inelastic-inelastic	1.62859	0.24172	0.148
-2.5 $< y_1, y_2 <$ 2.5 in addition			
elastic-elastic	0.42268	0.39355	0.931
inelastic-elastic	0.69241	0.51092	0.738
elastic-inelastic	0.69246	0.51087	0.738
ξ cut in addition			
elastic-elastic, cut on ξ_1	0.00762	0.00675	0.886
elastic-elastic, cut on ξ_2	0.00762	0.00675	0.886
inelastic-elastic, cut on ξ_2	0.02496	0.01324	0.530
elastic-inelastic, cut on ξ_1	0.02393	0.01238	0.517
$p_{t,pair} <$ 5 GeV in addition			
elastic-elastic	....	....	.....
inelastic-elastic, cut on ξ_2	0.00807	0.00437 (*)	0.541
elastic-inelastic, cut on ξ_1	0.00807	0.00437 (*)	0.542



contribution	without S_G	with S_G
cut on Y_{ll} only		
elastic-inelastic	0.76304	0.78756
inelastic-elastic	0.76278	0.78898
cut on y_1 and y_2 in addition		
elastic-inelastic	0.77366	0.79250
inelastic-elastic	0.76926	0.78744
cut on ξ_1 or ξ_2 in addition		
elastic-inelastic	0.52430	0.53976
inelastic-elastic	0.53118	0.53614
cut on $p_{t,pair}$ in addition		
elastic-inelastic	0.83144	0.84350(*)
inelastic-elastic	0.83462	0.84960(*)

Conclusions

- We have discussed dilepton production initiated by photon-photon fusion with one forward.
- We have consider both double-elastic and single-dissociative contributions.
- We have imposed conditions on ξ_1 or ξ_2 for the forward emitted protons.
- Particularly interesting is the distribution in M_{ll} and the distribution in Y_{ll} which has minimum at $Y_{ll} \sim 0$.
- We have made calculations with the SUPERCHIC generator and compared corresponding results to the results of our code(s). In general, the results are almost identical.
- We have calculated also the soft rapidity gap survival factor as a function of M_{ll}, $p_{t,\,pair}$ and Y_{ll}.
- The soft gap survival factor for the single dissociative contribution strongly depends on whether the proton is measured or not.
- No evident dependences on the variables have been found for the single dissociation, except of distribution in Y_{ll}.
- We have also calculated gap survival factor due to mini(jet) emission by checking whether the minijet enters or not the main detector.
- The second type of the gap survival also strongly depends on whether the outgoing proton is measured or not. It is about 0.8 for inclusive case and about 0.5 for the case with proton measurement in forward proton detector.