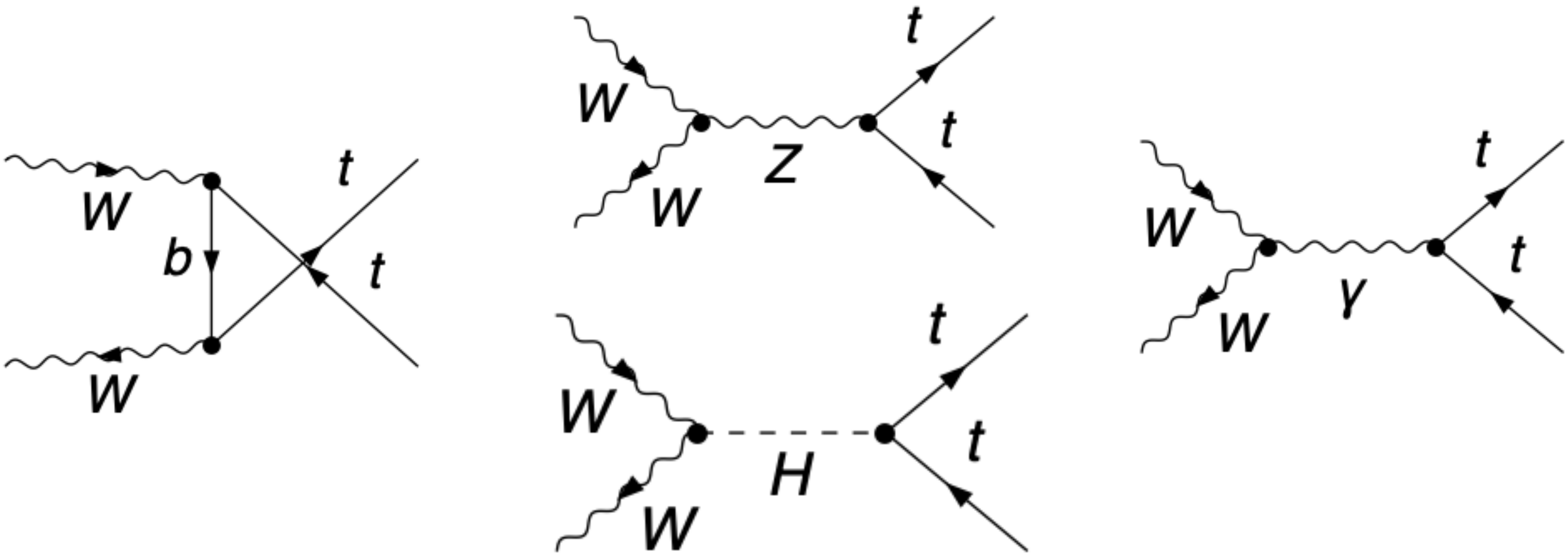
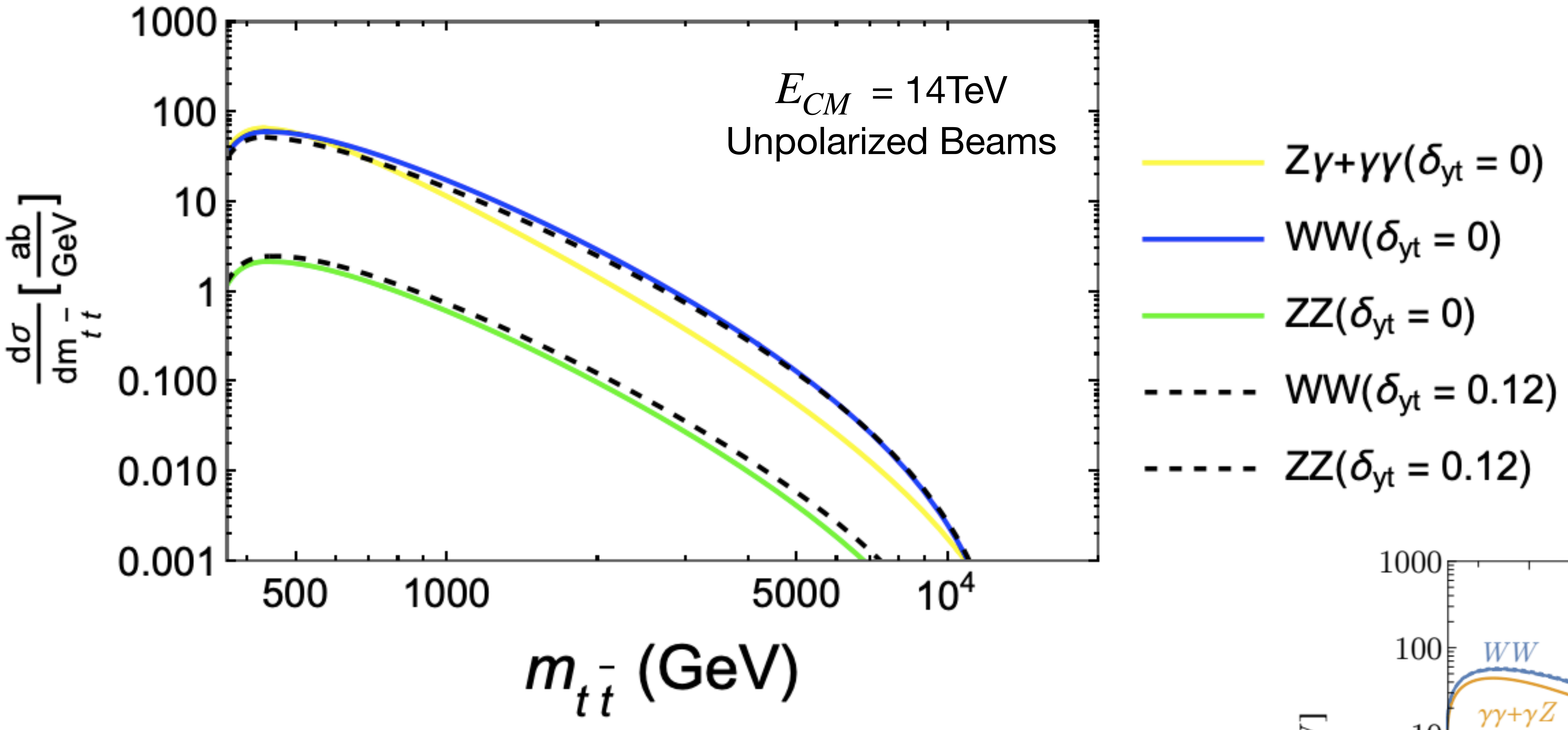
Analytic Expressions for Helicity Amplitudes for $W^+W^- \to t\bar{t}$

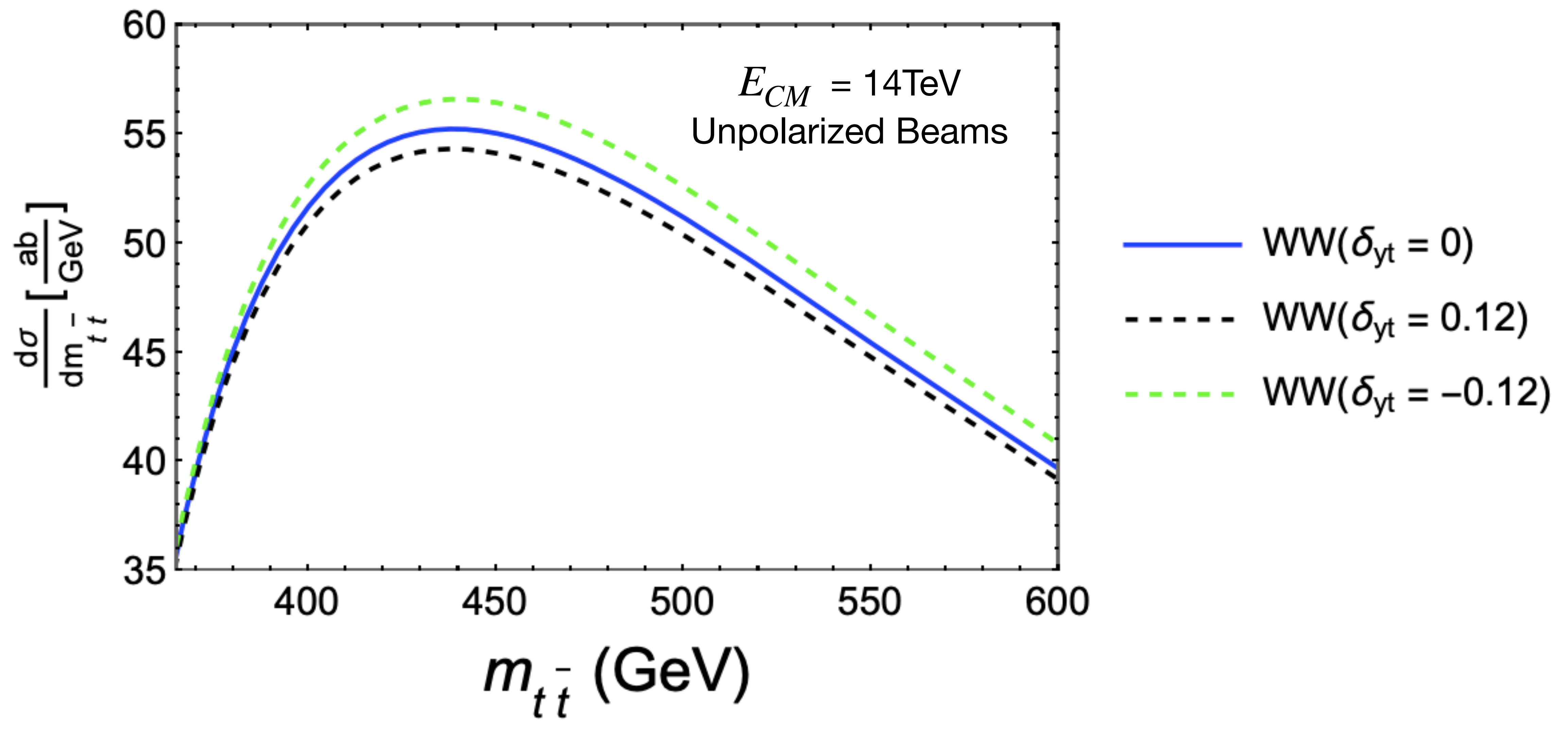


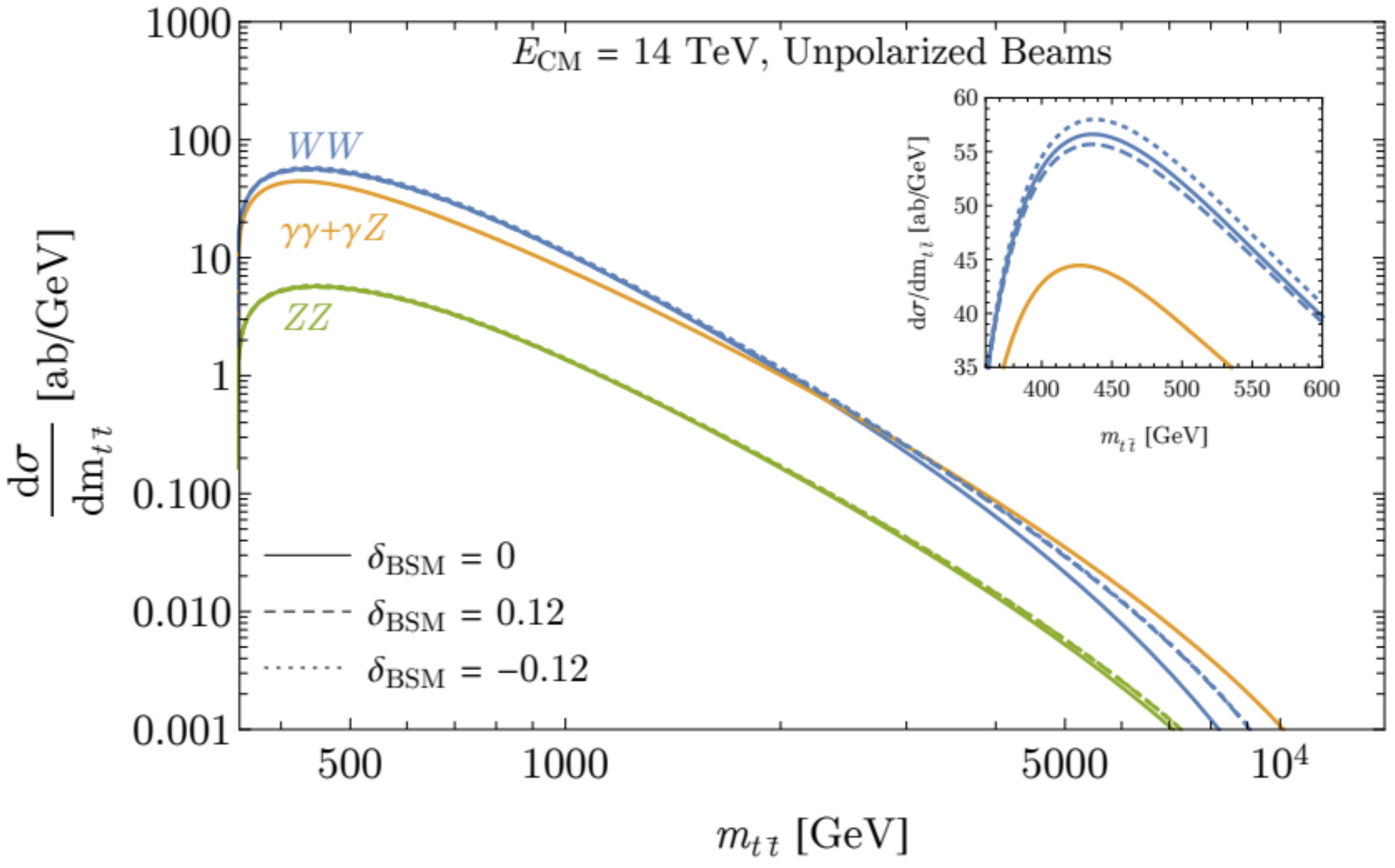
Updated and Rechecked the 36 helicity amplitudes

- Reversed the process
- Looked for symmetry

$\mu^+\mu^- \to t\bar{t} + X$ at 14TeV

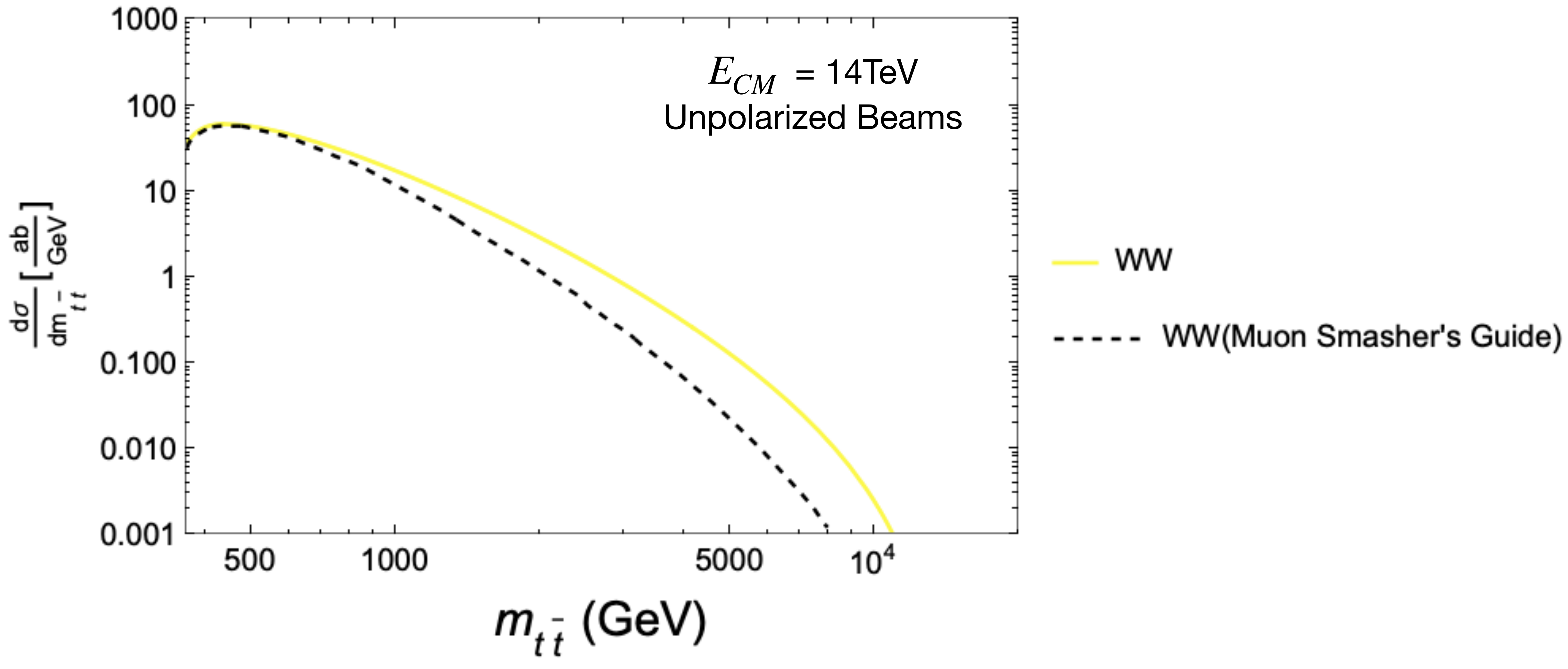


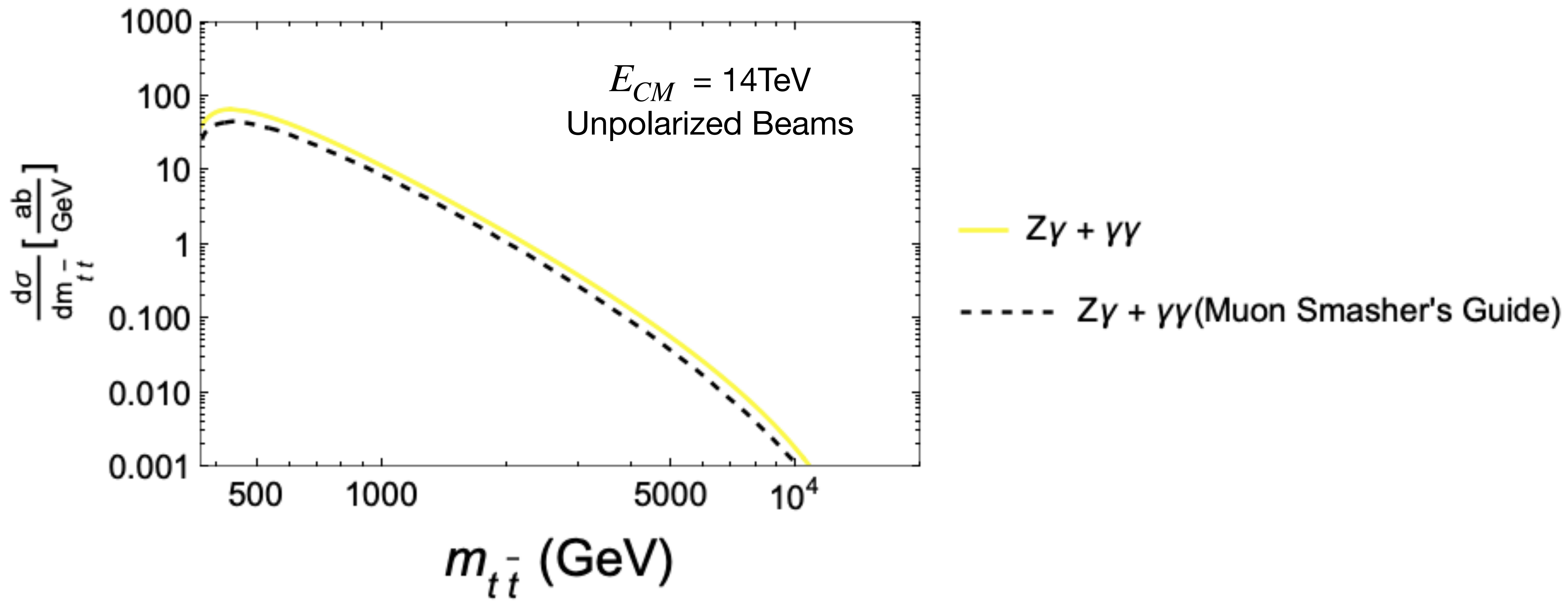


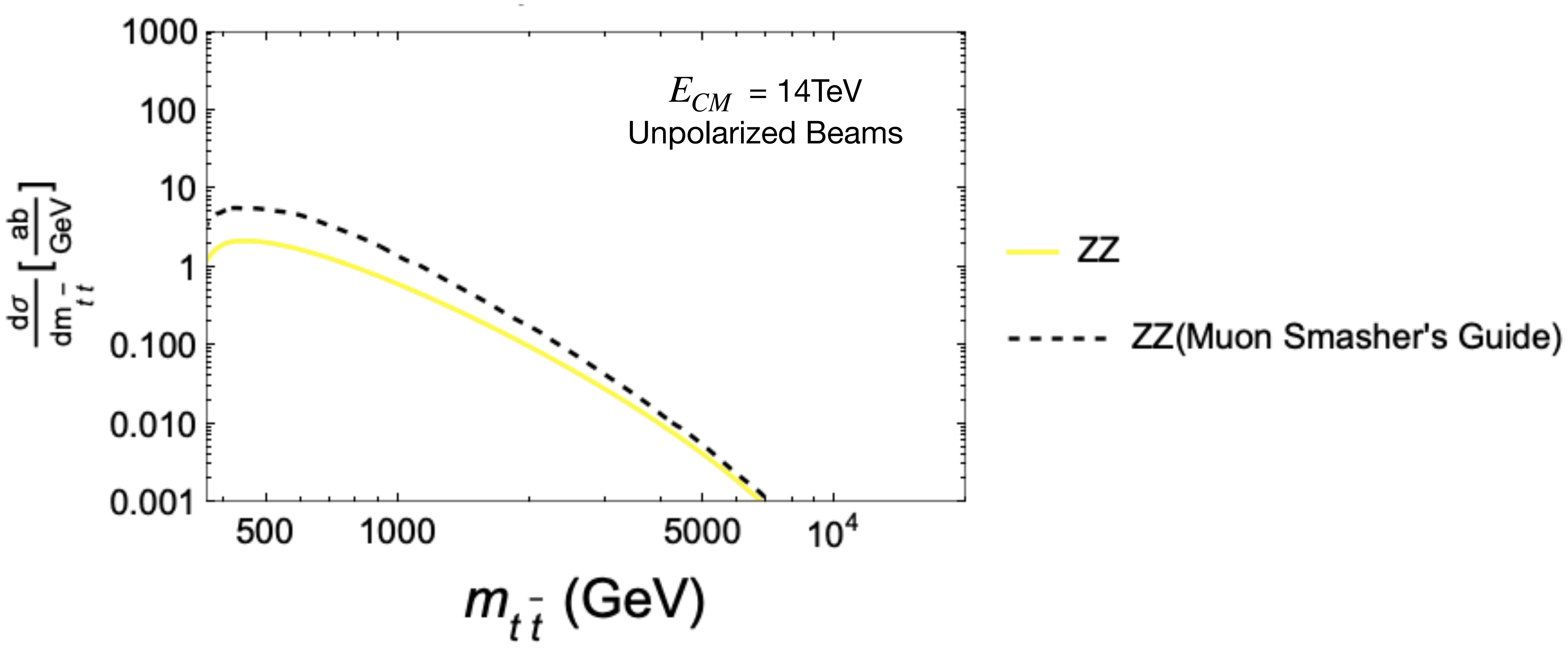


H. Al Ali et al. , "The Muon Smasher's Guide," arXiv:2103.14043 [hep-ph]

Comparison Between Muon Smasher's Guide





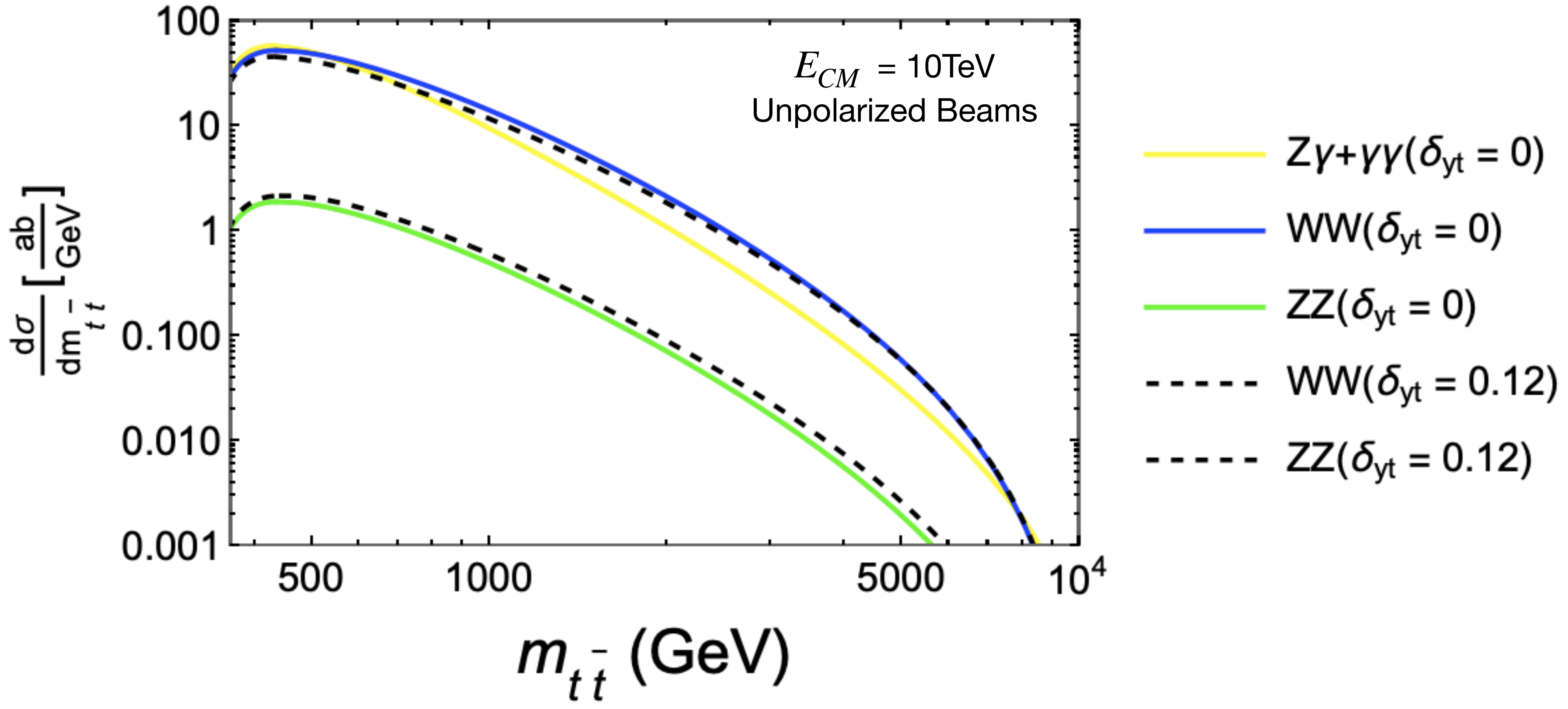


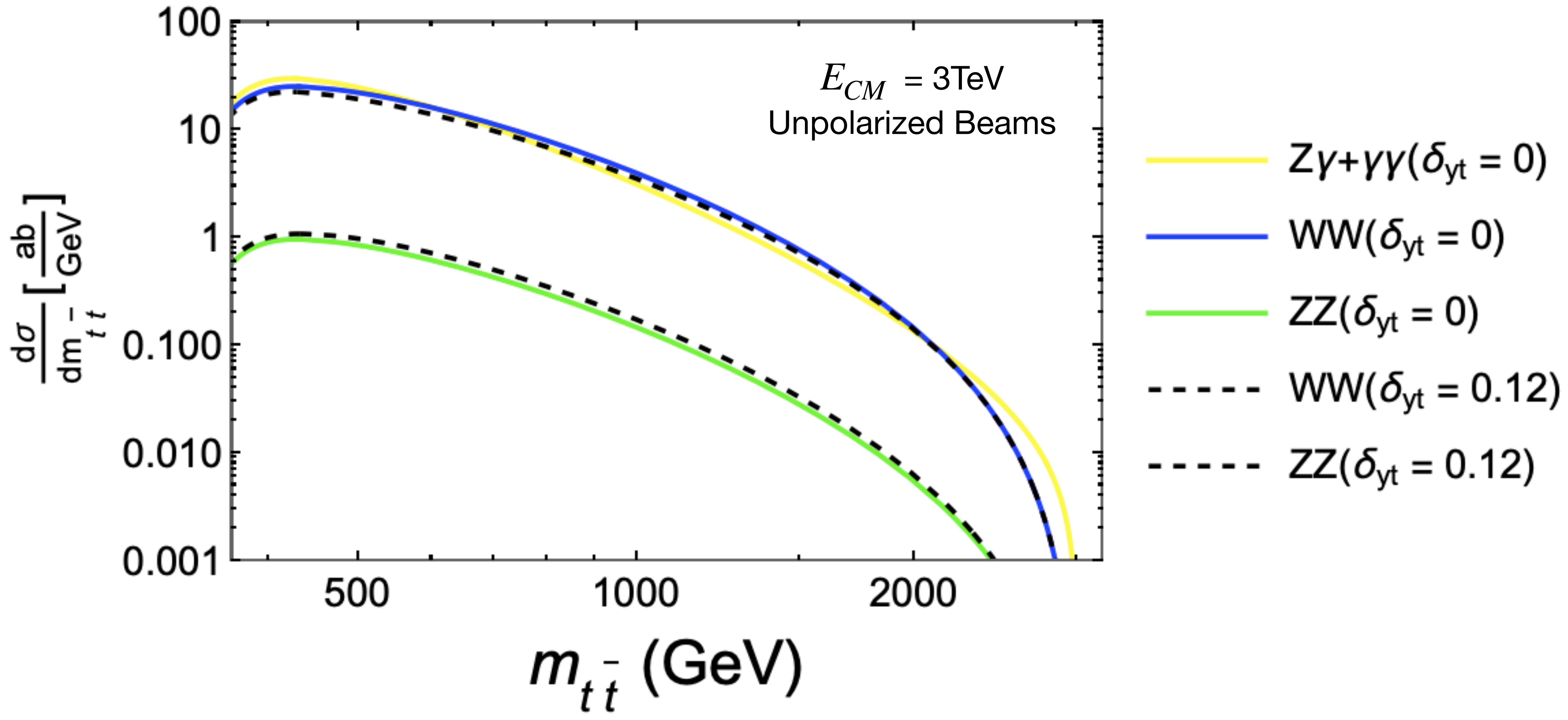
Discrepancies between Muon Smasher's Guide

Channels	Average Deviation
WW	67%
ZZ	60%
$Z\gamma + \gamma\gamma$	29%

H. Al Ali et al. , "The Muon Smasher's Guide," arXiv:2103.14043 [hep-ph]

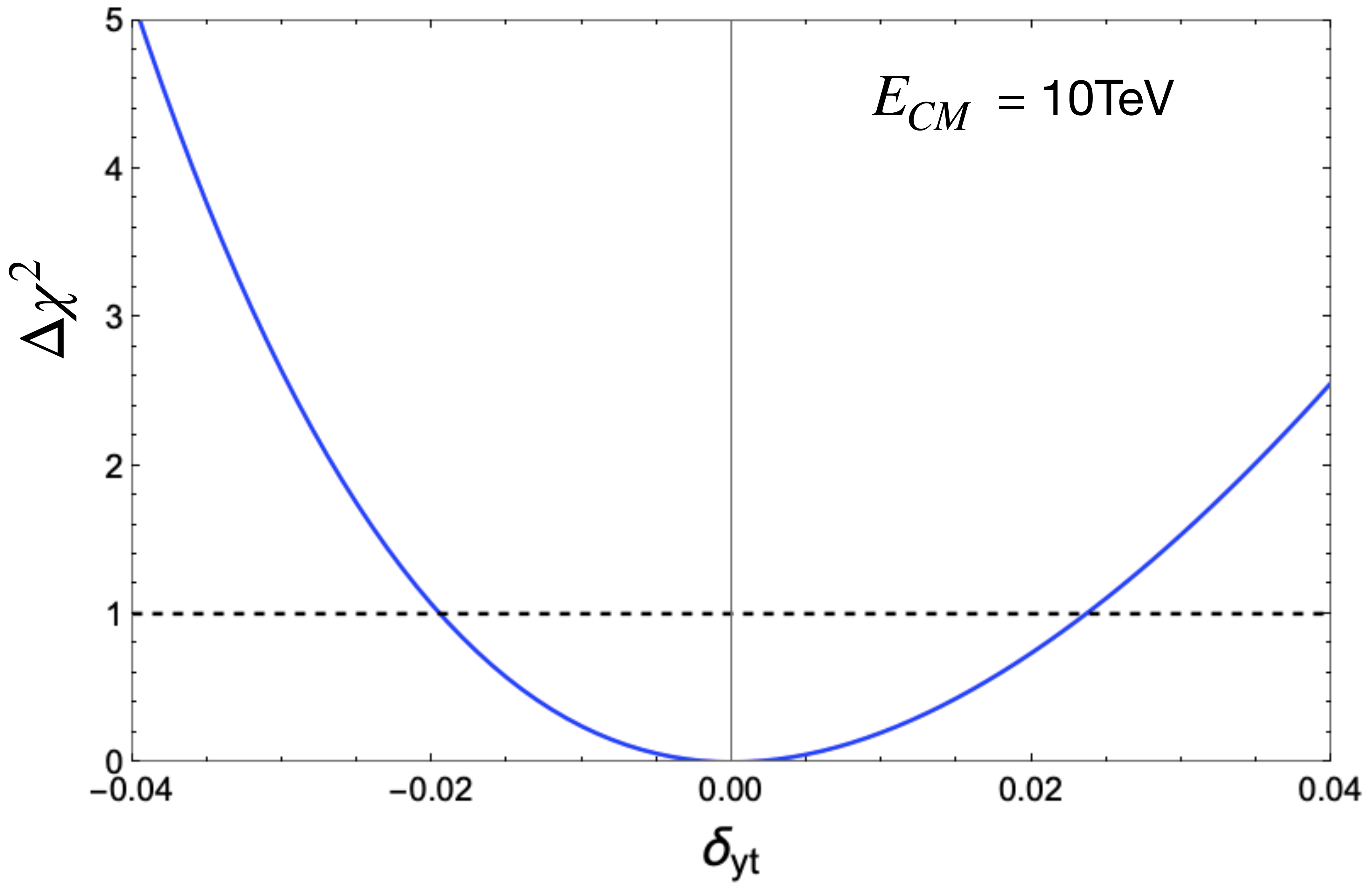
$\mu^+\mu^- \to t\bar{t} + X$ at 10TeV and 3TeV



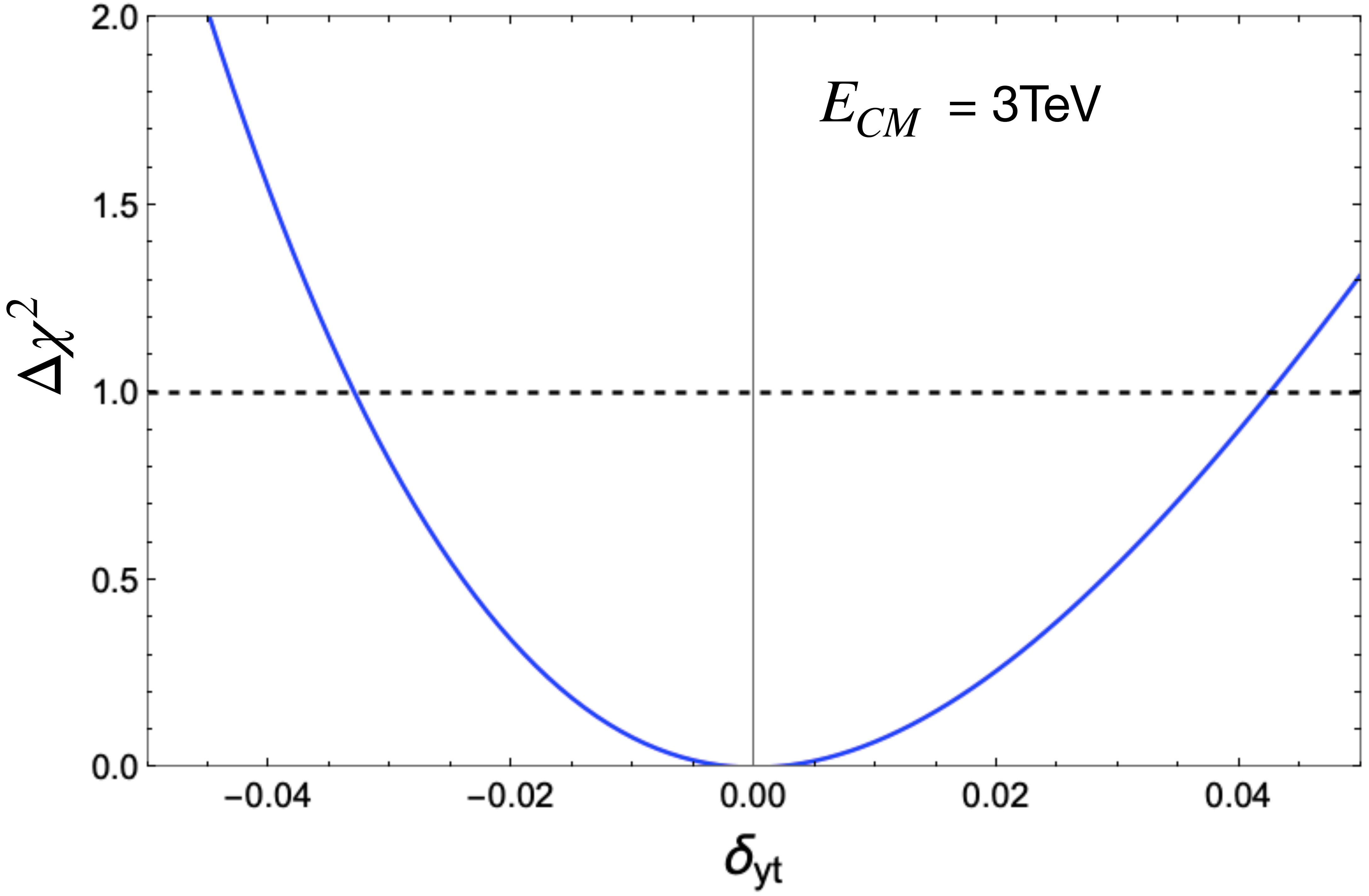


Sensitivity Test

Sensitivity for Luminosity = 10ab^{-1} and E_{CM} = 10TeV



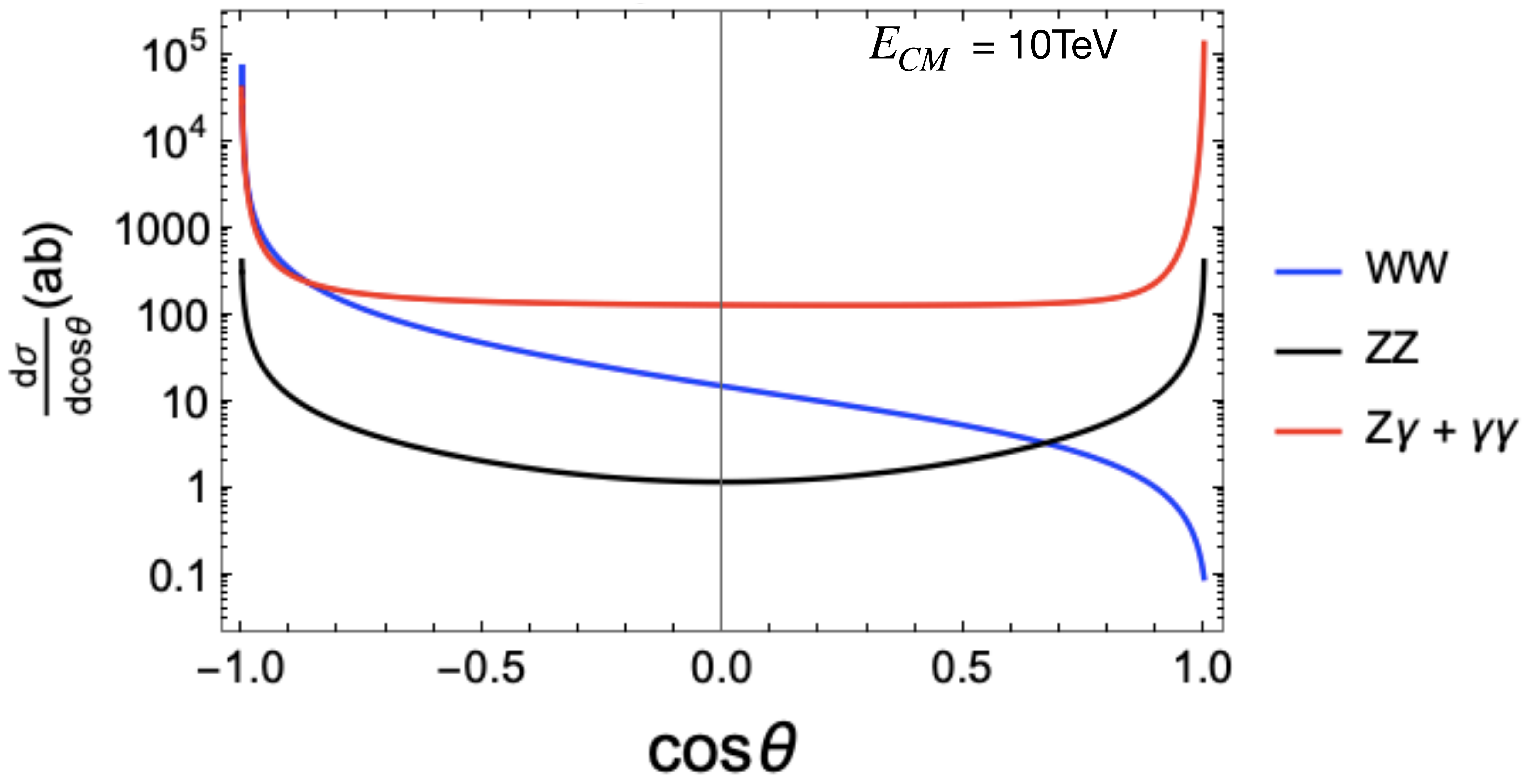
Sensitivity for Luminosity = 10ab^{-1} and E_{CM} = 3TeV

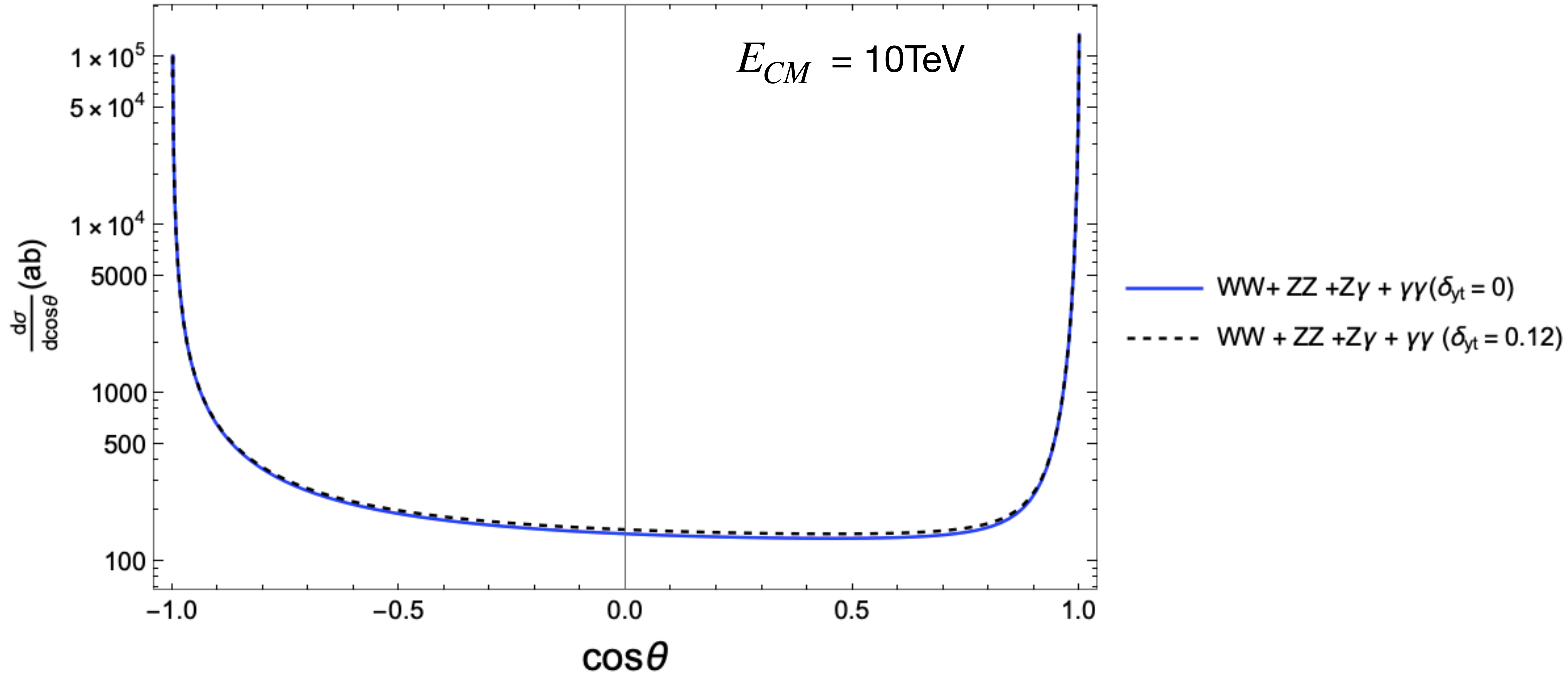


1σ Precision for E_{CM} = 3 TeV and E_{CM} = 10 TeV for Luminosity = 10ab^{-1}

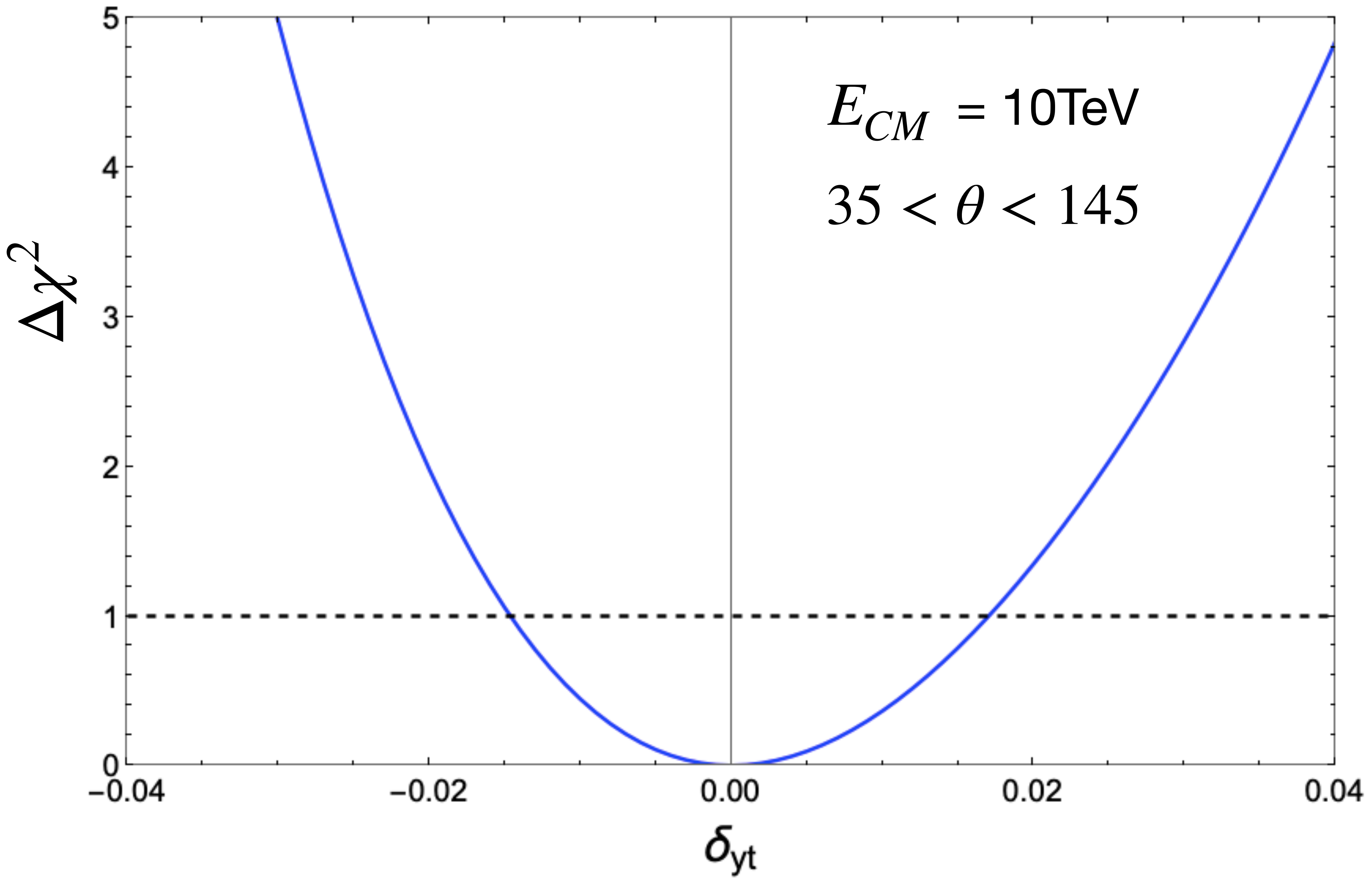
	δ_{yt}	δ_{yt}
E_{CM} = 3TeV	-3.3%	4.25%
E_{CM} = 10TeV	-1.95%	2.36%

Angular Distribution for $\mu^+\mu^- \to t\bar{t} + X$ at 10TeV

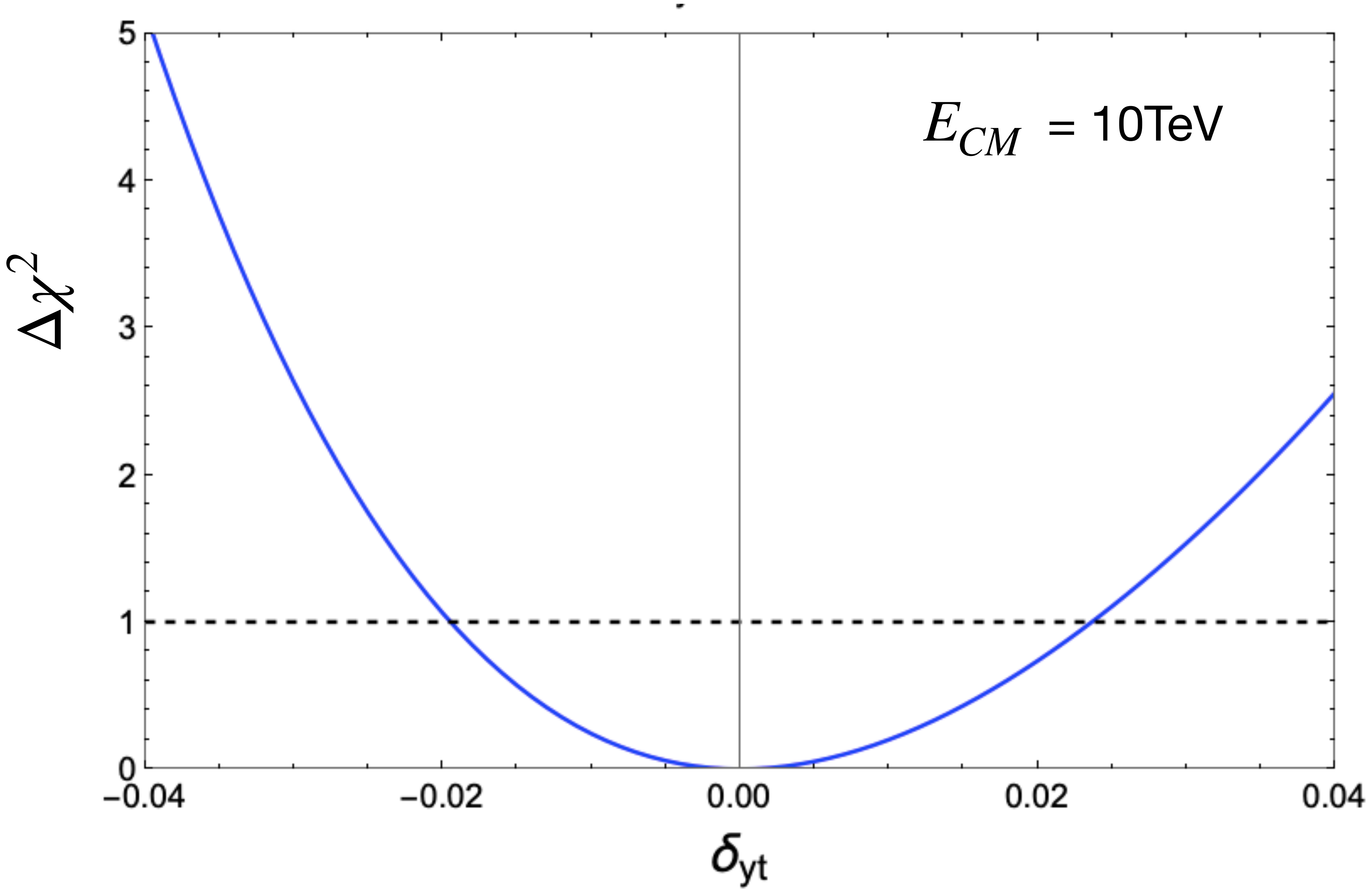




Sensitivity for Luminosity = $10ab^{-1}$ and E_{CM} = 10TeV with Angle Cuts



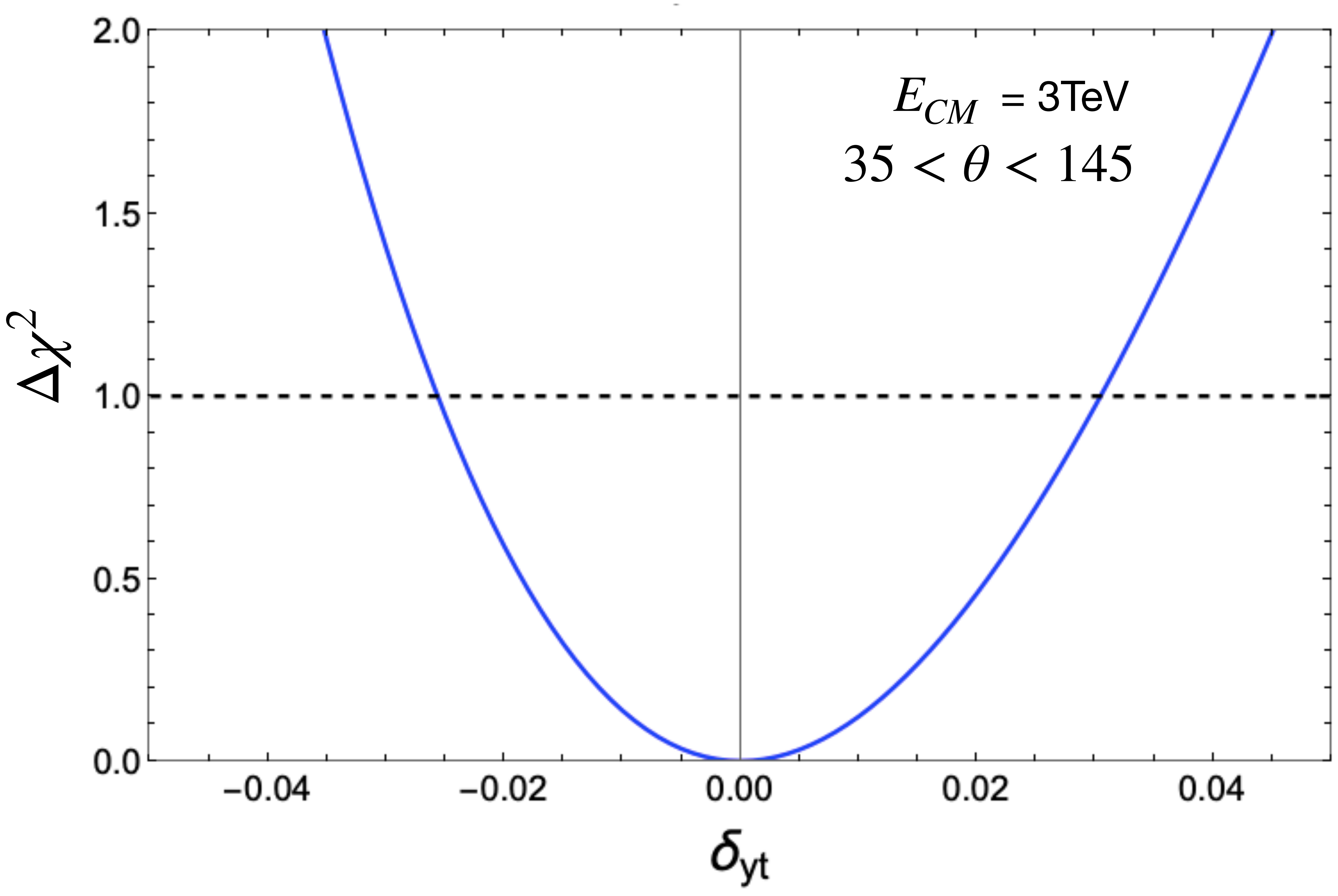
Sensitivity for Luminosity = $10ab^{-1}$ and E_{CM} = 10TeV without Angle Cuts



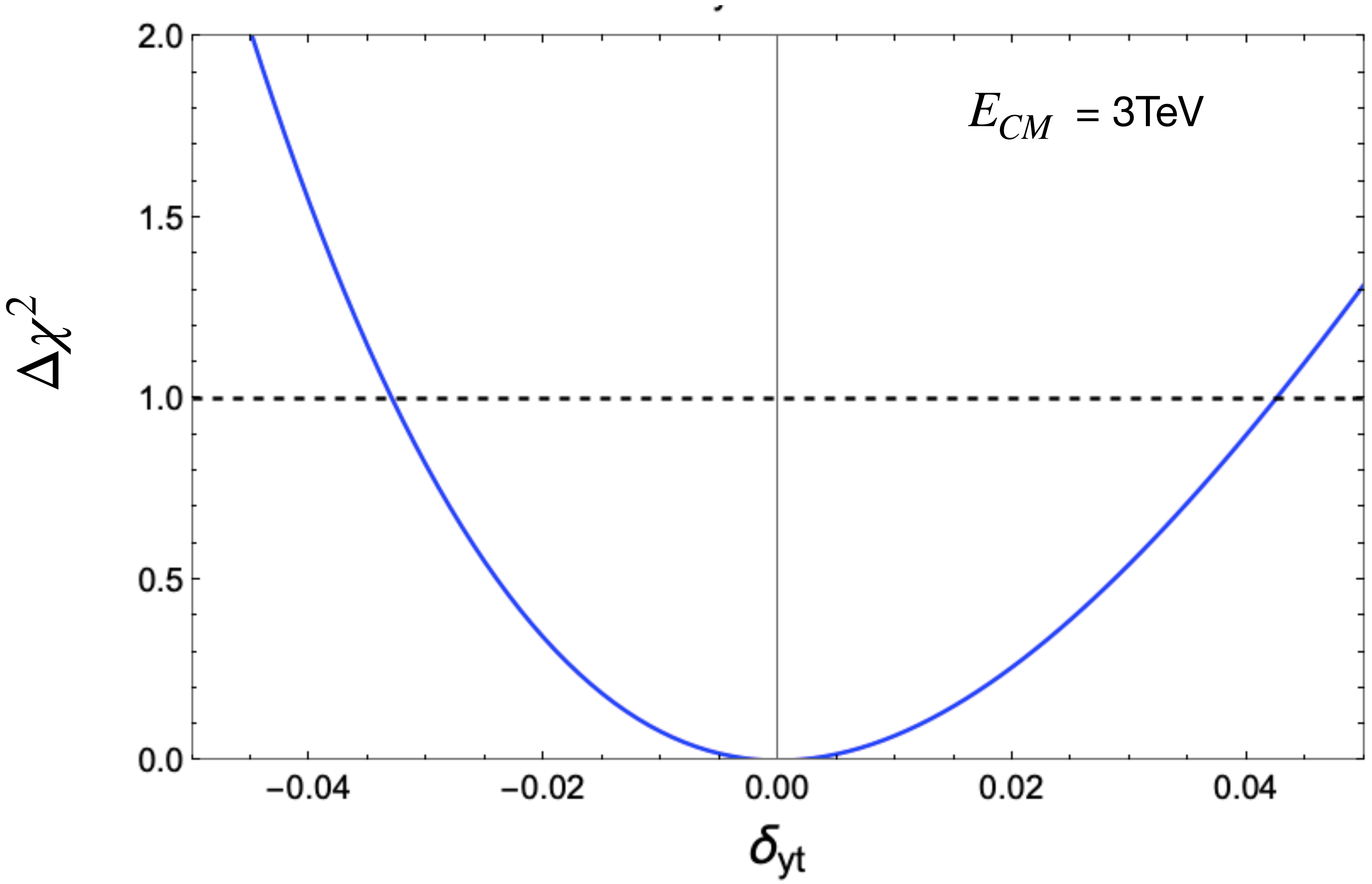
Comparing 1σ Precision for E_{CM} = 10 TeV, Luminosity = 10ab^{-1} with and without angle cuts

E_{CM} = 10TeV	δ_{yt}	δ_{yt}
Without Angle Cut	-1.95%	2.36%
With Angle Cut	-1.46%	1.7%

Sensitivity for Luminosity = $10ab^{-1}$ and E_{CM} = 3TeV with Angle Cuts



Sensitivity for Luminosity = $10ab^{-1}$ and E_{CM} = 3TeV without Angle Cuts

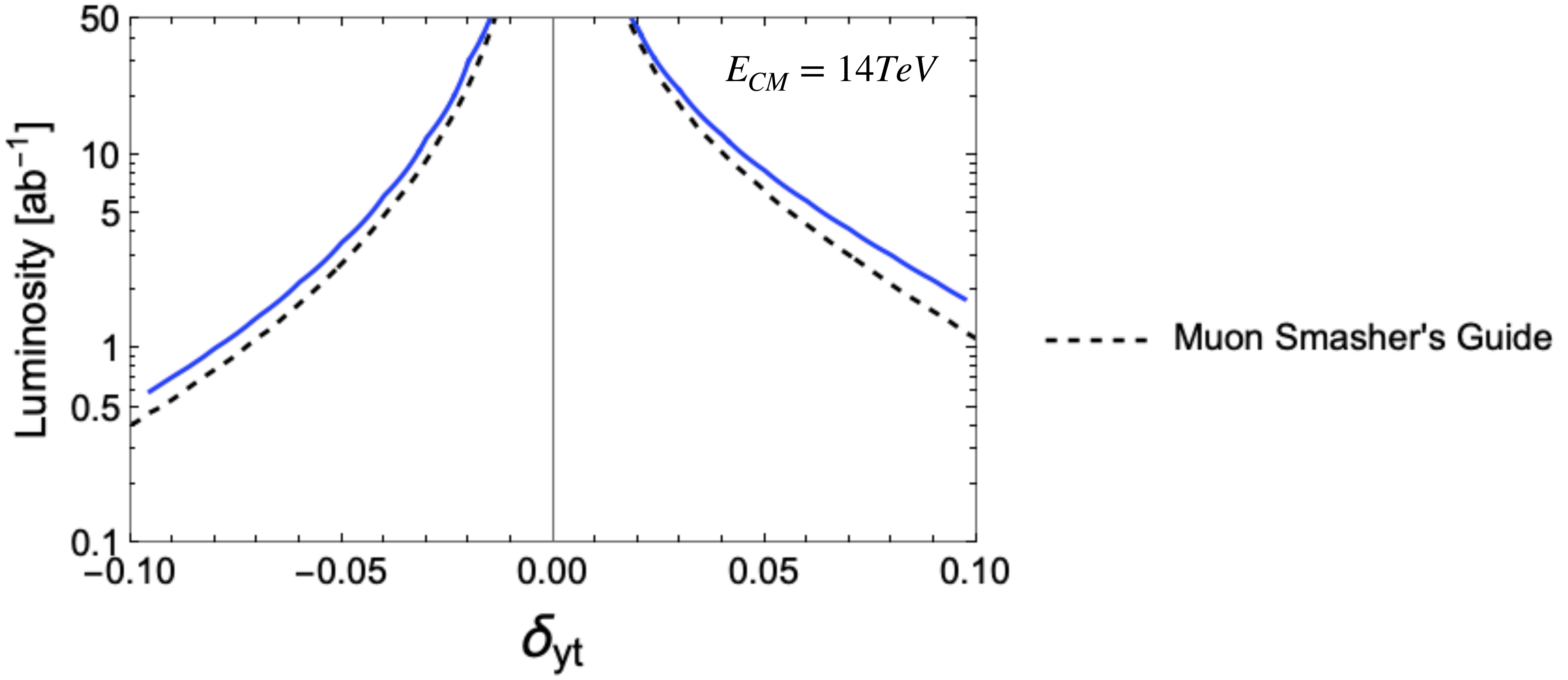


Comparing 1σ Precision for E_{CM} = 3 TeV, Luminosity = $10ab^{-1}$ with and without angle cuts

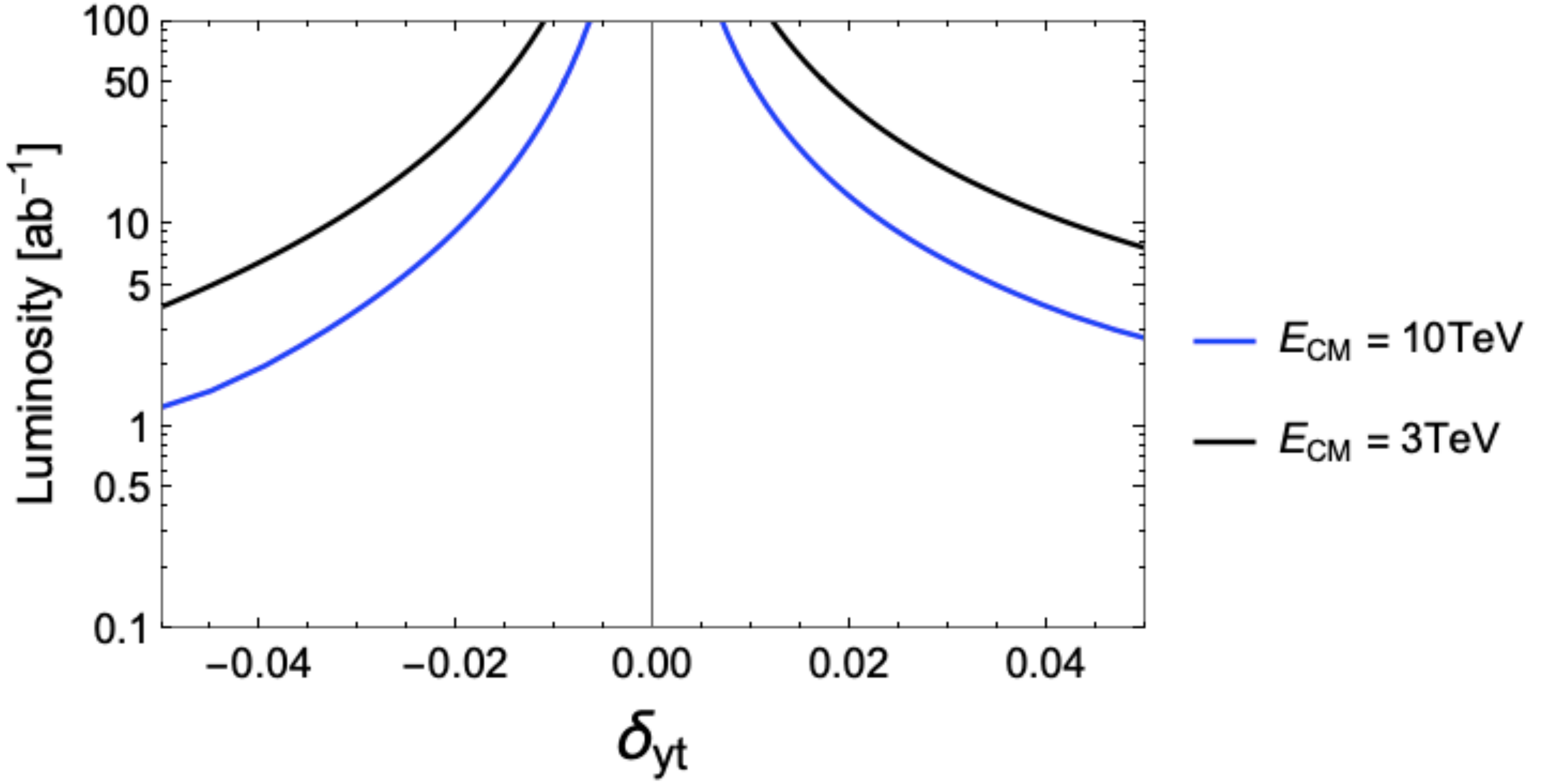
E_{CM} = 3TeV	δ_{yt}	δ_{yt}
Without Angle Cut	-3.3%	4.25%
With Angle Cut	-2.56%	3%

Sensitivity for Varying Luminosity

- 2σ crossing for varying δ_{yt} and luminosity at $E_{CM} = 14TeV$
- The dashed line compares results from Muon Smasher's Guide paper



- 1σ crossing for varying δ_{yt} and luminosity at $E_{CM} = 3TeV$ and $E_{CM} = 10TeV$



Symmetry

$$u_+(E,p,\theta) \;=\; \begin{pmatrix} \sqrt{E(1-\beta_t)}\ cos(\theta/2) \\ \sqrt{E(1-\beta_t)}\ sin(\theta/2) \\ \sqrt{E(1+\beta_t)}\ cos(\theta/2) \\ \sqrt{E(1+\beta_t)}\ sin(\theta/2) \end{pmatrix} \qquad u\_(E,p,\theta) \;=\; \begin{pmatrix} -\sqrt{E(1+\beta_t)}\ sin(\theta/2) \\ \sqrt{E(1+\beta_t)}\ cos(\theta/2) \\ -\sqrt{E(1-\beta_t)}\ sin(\theta/2) \\ \sqrt{E(1-\beta_t)}\ cos(\theta/2) \end{pmatrix}$$

Under the transformation $\beta_t \to -\beta_t$ and $\theta \to \theta + \pi$

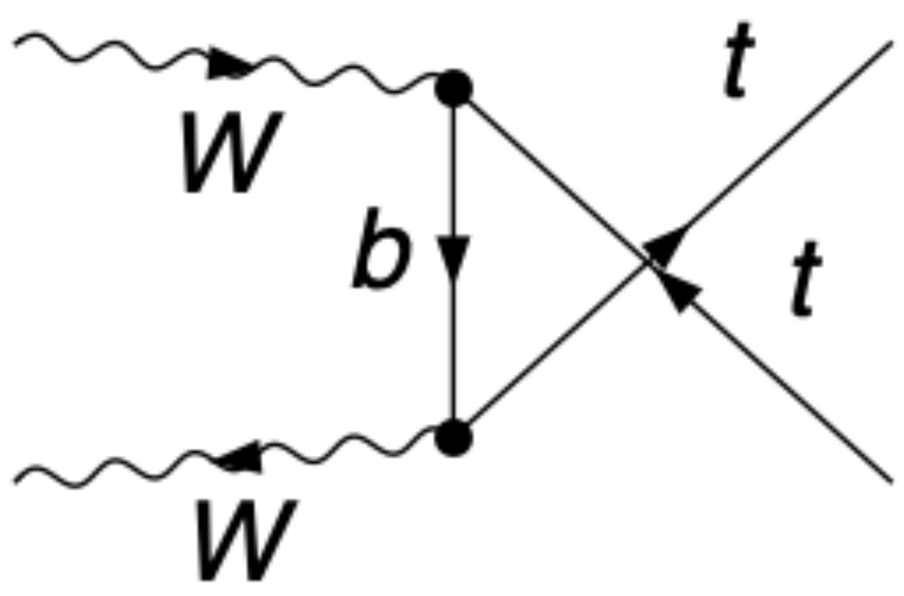
$$u_+(E,p,\theta) \to u\_(E,p,\theta)$$

$$u\_(E,p,\theta) \to -u_+(E,p,\theta)$$

Under the transformation $\beta_t \to -\beta_t$ and $\theta \to \theta + \pi$

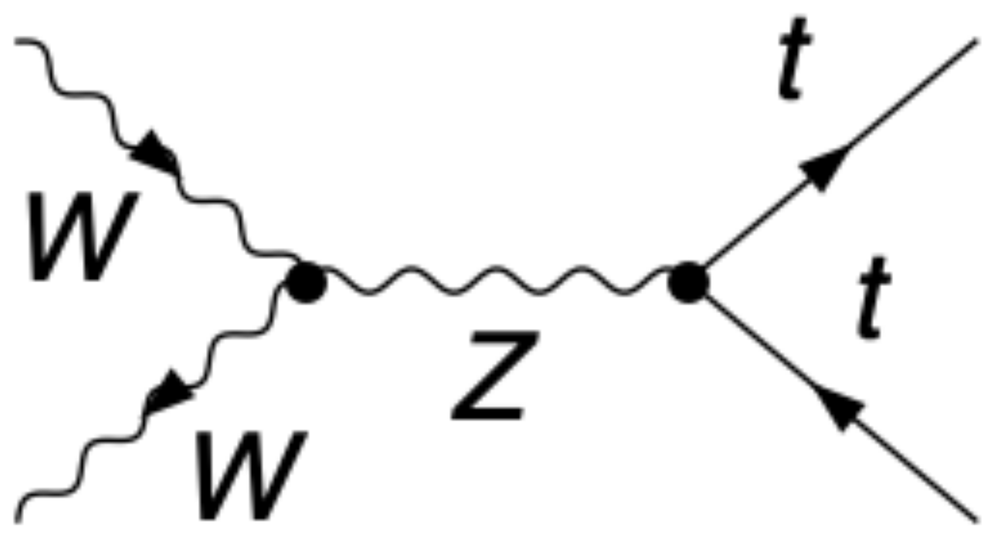
$$\mathcal{M}^b_{++,-10} = \frac{1}{2} G_F m_W m_t \frac{s}{(t - m_b^2)} sin\theta(\beta_t(\beta_W - 2cos(\theta) - 1) - \beta_W(1 + \beta_W))$$

$$\mathcal{M}^b_{--,-10} = -\frac{1}{2} G_F m_W m_t \frac{s}{(t - m_b^2)} sin\theta(\beta_t(-\beta_W - 2cos(\theta) + 1) - \beta_W(1 + \beta_W))$$



$$\mathcal{M}^Z_{+-,11} = -\frac{2}{3} [\sqrt{2} G_F m_W^2 \beta_W \frac{s}{s - M_Z^2} sin\theta(\frac{3}{2}(1 - \beta_t) - 4s_w^2)]$$

$$\mathcal{M}^Z_{-+,11} = -\frac{2}{3} [\sqrt{2} G_F m_W^2 \beta_W \frac{s}{s - M_Z^2} sin\theta(\frac{3}{2}(1 + \beta_t) - 4s_w^2)]$$

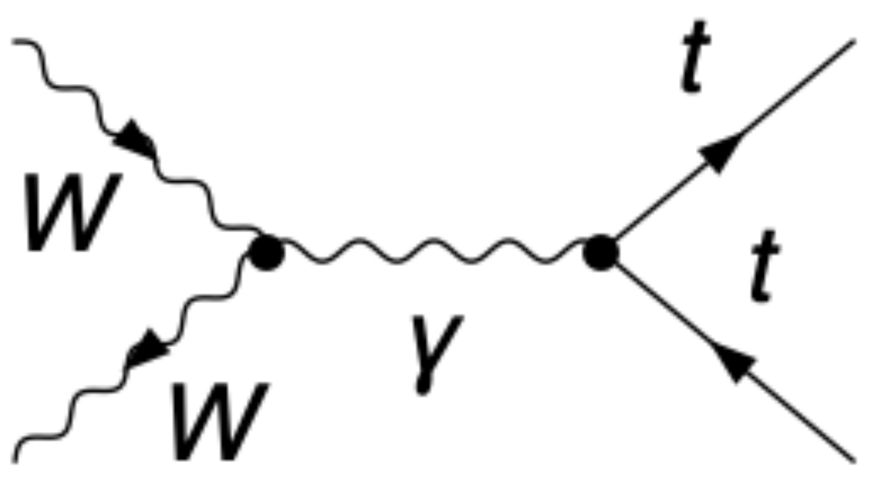


Symmetry

Under the transformation $\beta_W \to -\beta_W$ and $\theta \to \theta + \pi$

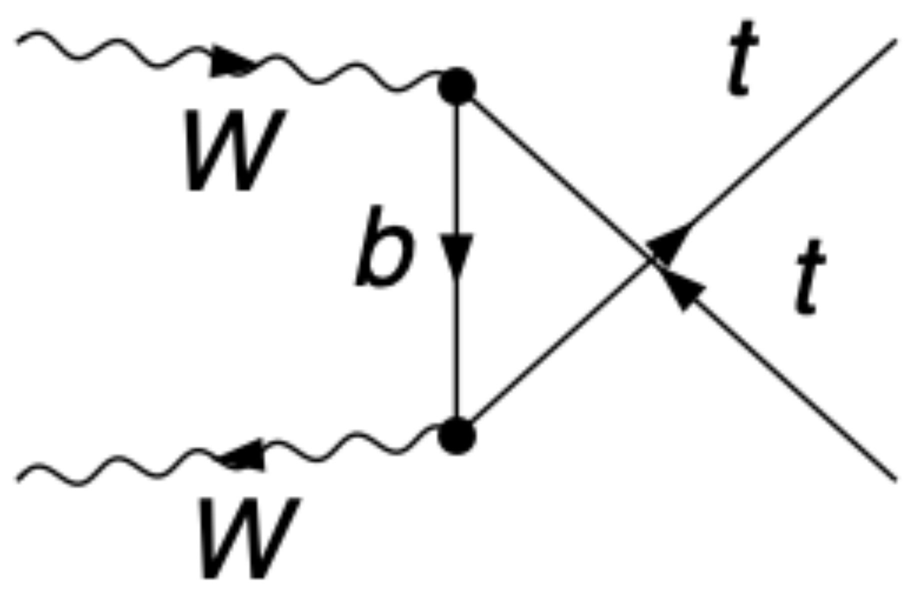
$$\mathcal{M}^{\gamma}_{-+,-10} = -\frac{2}{3}\,[8G_F s_W^2 m_W \beta_W \sqrt{s} cos^2\frac{\theta}{2}]$$

$$\mathcal{M}^{\gamma}_{-+,10} = -\frac{2}{3}\,[8G_F s_W^2 m_W \beta_W \sqrt{s} sin^2\frac{\theta}{2}]$$



$$\mathcal{M}^{b}_{-+,-1+1} = \frac{1}{\sqrt{2}} G_F m_W^2 \frac{s}{(t-m_b^2)} sin\theta(cos\theta+1)\beta_t(1+\beta_t)$$

$$\mathcal{M}^{b}_{-+,1-1} = -\frac{1}{\sqrt{2}} G_F m_W^2 \frac{s}{(t-m_b^2)} sin\theta(-cos\theta+1)\beta_t(1+\beta_t)$$



- **(+,-,1,0)**

$$\mathcal{M}^{\gamma}_{+-,10} = \frac{2}{3}\ [8G_F s_W^2 m_W \beta_W \sqrt{s} cos^2\frac{\theta}{2}]$$

$$\mathcal{M}^{Z}_{+-,10} = \frac{2}{3}\ [2G_F m_W \beta_W (\frac{3}{2}(1-\beta_t) - 4s_w^2)\frac{s\sqrt{s}}{s-M_Z^2} cos^2\frac{\theta}{2}]$$

$$\mathcal{M}^{b}_{+-,10} = -2G_F m_W m_t^2 \frac{\sqrt{s}}{(1+\beta_t)(t-m_b^2)} cos^2(\frac{\theta}{2})(1-\beta_W - \frac{4m_W^2}{s} + \beta_t(\beta_W - 2cos(\theta)+1))$$

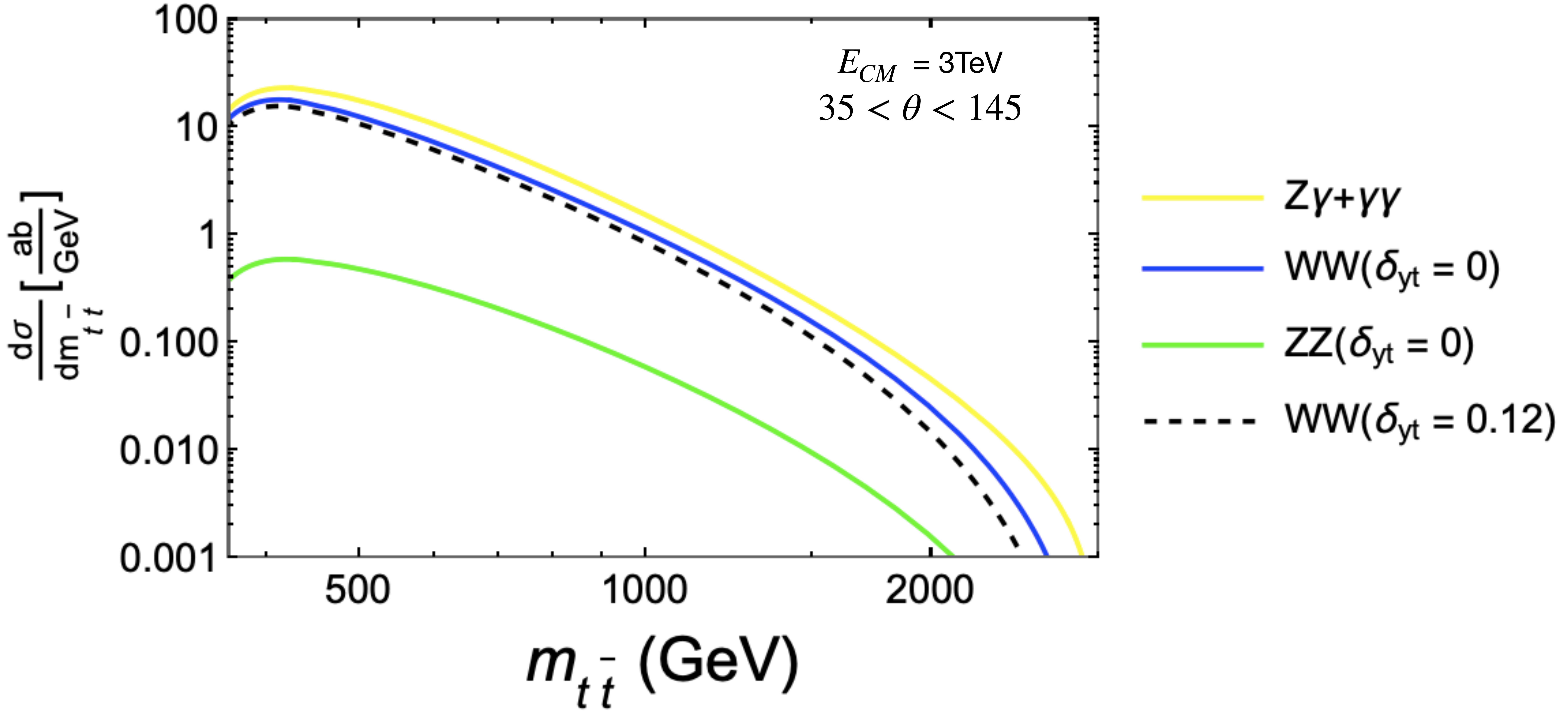
- **(+,-,0,-1)**

$$\mathcal{M}^{\gamma}_{+-,0-1} = -\frac{2}{3}\ [8G_F s_W^2 m_W \beta_W \sqrt{s} cos^2\frac{\theta}{2}]$$

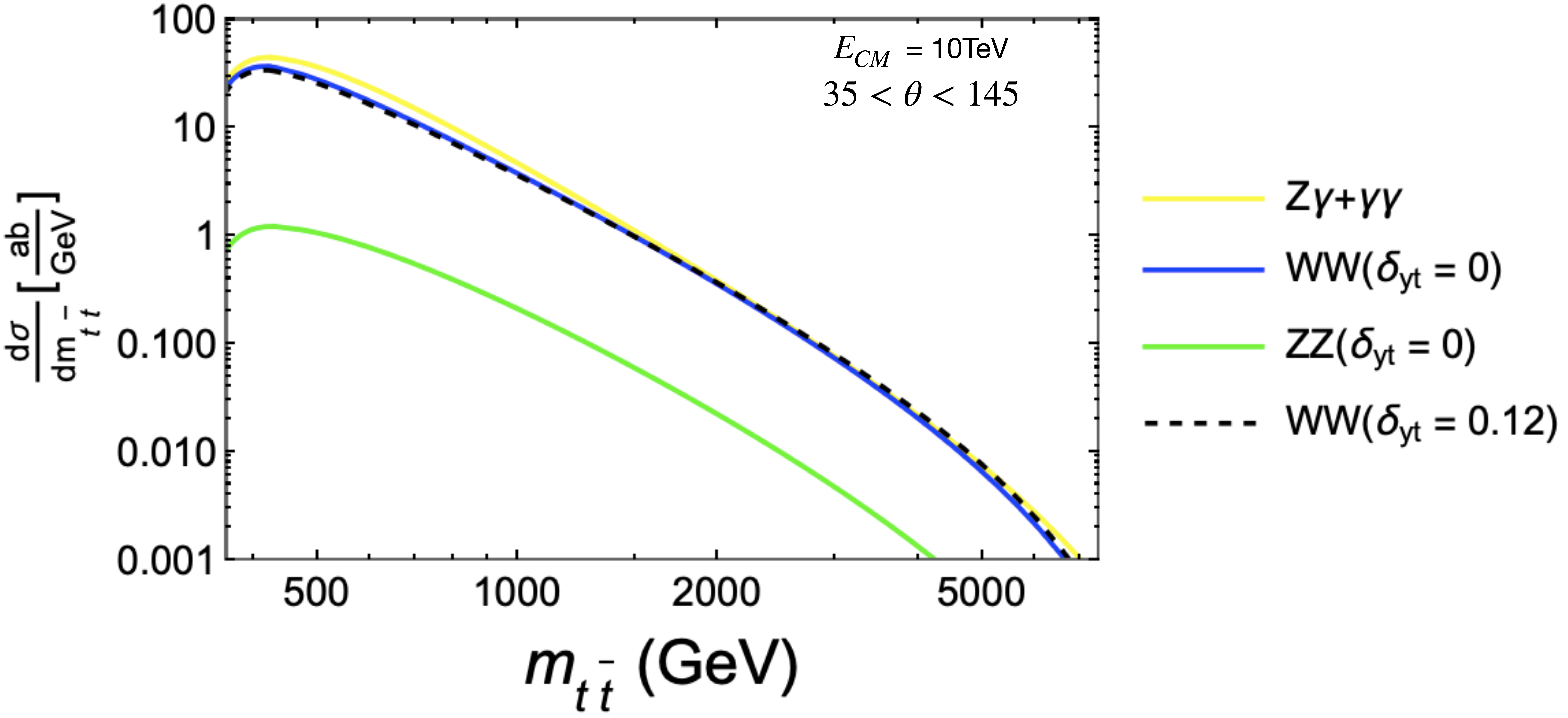
$$\mathcal{M}^{Z}_{+-,0-1} = -\frac{2}{3}\ [2G_F m_W \beta_W (\frac{3}{2}(1-\beta_t) - 4s_w^2)\frac{s\sqrt{s}}{s-M_Z^2} cos^2\frac{\theta}{2}]$$

$$\mathcal{M}^{b}_{+-,0-1} = 2G_F m_W m_t^2 \frac{\sqrt{s}}{(1+\beta_t)(t-m_b^2)} cos^2(\frac{\theta}{2})(1-\beta_W - \frac{4m_W^2}{s} + \beta_t(\beta_W - 2cos(\theta)+1))$$

BACKUP



E_{CM} = 3TeV
$35 < \theta < 145$
100
10
1
0.100
0.010
0.001
500
1000
2000
$\frac{d\sigma}{dm_{t\bar{t}}}\left[\frac{ab}{GeV}\right]$
$m_{t\bar{t}}$ (GeV)
$Z\gamma+\gamma\gamma$
$WW(\delta_{yt} = 0)$
$ZZ(\delta_{yt} = 0)$
$WW(\delta_{yt} = 0.12)$



100
10
1
0.100
0.010
0.001
500
1000
2000
5000
$\frac{d\sigma}{dm_{t\bar{t}}}\left[\frac{ab}{GeV}\right]$
$m_{t\bar{t}}$ (GeV)
E_{CM} = 10TeV
$35 < \theta < 145$
$Z\gamma+\gamma\gamma$
$WW(\delta_{yt} = 0)$
$ZZ(\delta_{yt} = 0)$
$WW(\delta_{yt} = 0.12)$