Study of Potential Top Yukawa Coupling Deviations in Muon Colliders

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Introduction

$W^+W^- \rightarrow t\bar{t}$ Process

At Large Energies, the contribution from the γ, Z and t-channel contribution grows as:

$$\mathcal{M}^{\gamma+Z+b}(W_L^+W_L^- \rightarrow t\bar{t}) \;=\; \frac{m_t}{v^2}\sqrt{s} \qquad ; \sqrt{s} >> m_t$$

So, the Higgs diagram is needed to unitarize this contribution. But, if the top yukawa-coupling deviates from Standard Model value by δ_{yt} :

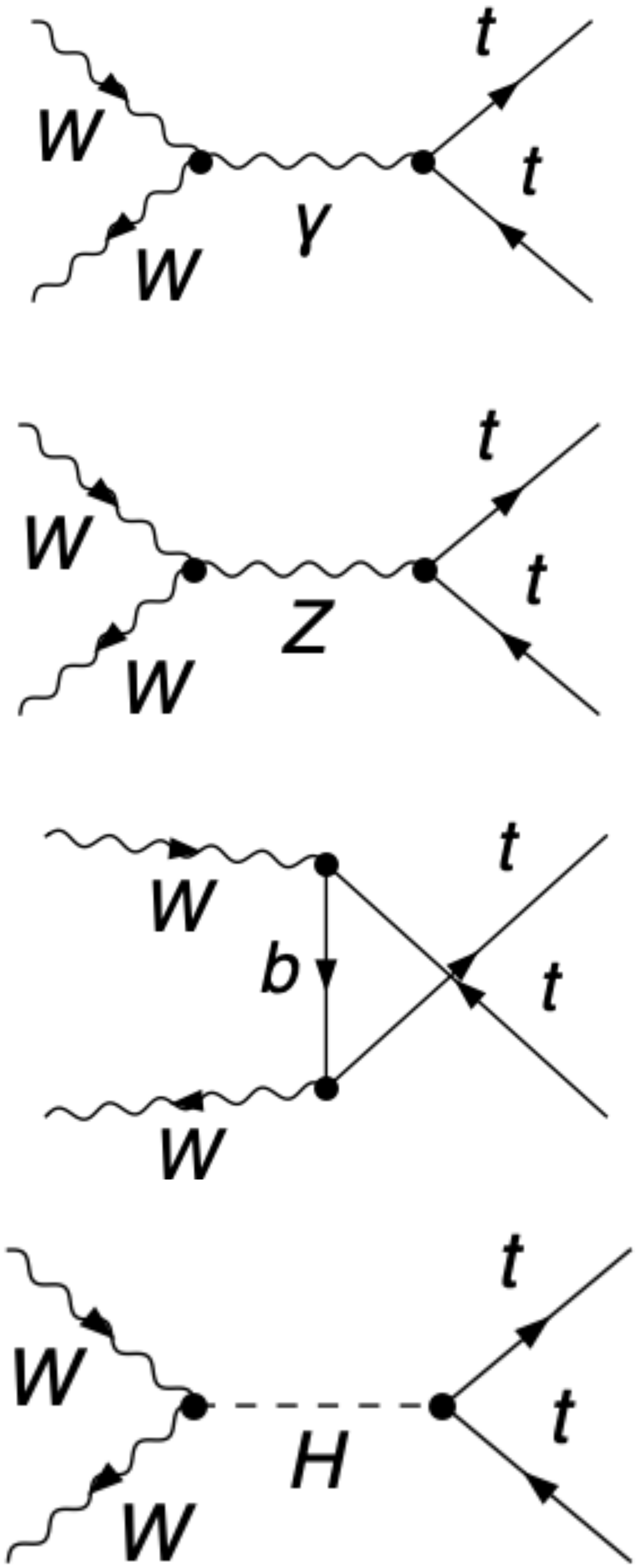
$$y_t \rightarrow y_t(1+\delta_{yt})$$

The scattering amplitude will scale as:

$$\mathcal{M}(W_L^+W_L^- \rightarrow t\bar{t}) \;=\; \frac{m_t}{v^2}\sqrt{s}\,\delta_{yt} \;\;;\;\; \sqrt{s} >> m_t$$

Then Perturbative unitarity will be broken at some scale:

$$\Lambda < \frac{10TeV}{\delta_{yt}}$$



Introduction

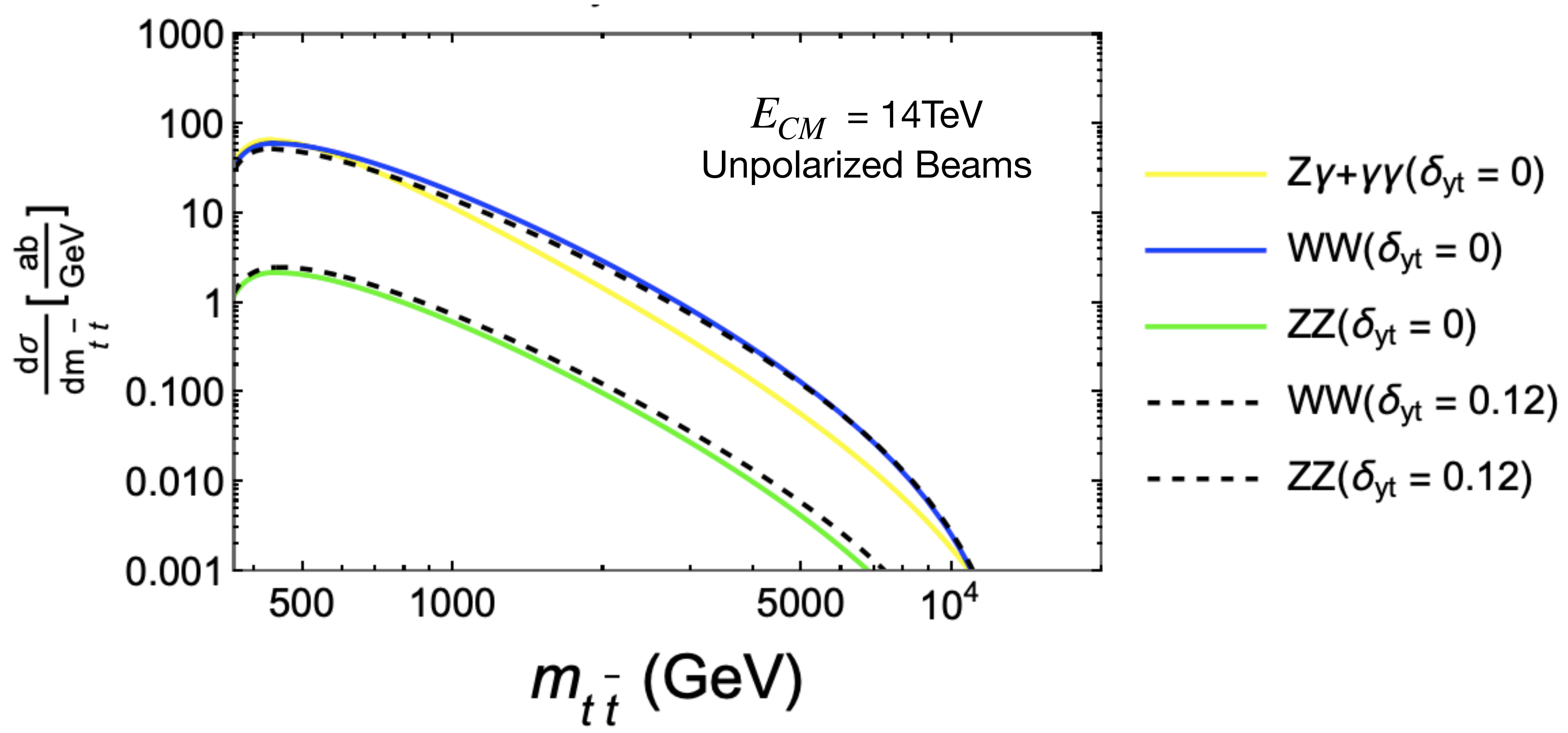
Objective

- **Obtain a precision constraint on the top Yukawa coupling for the future muon colliders**

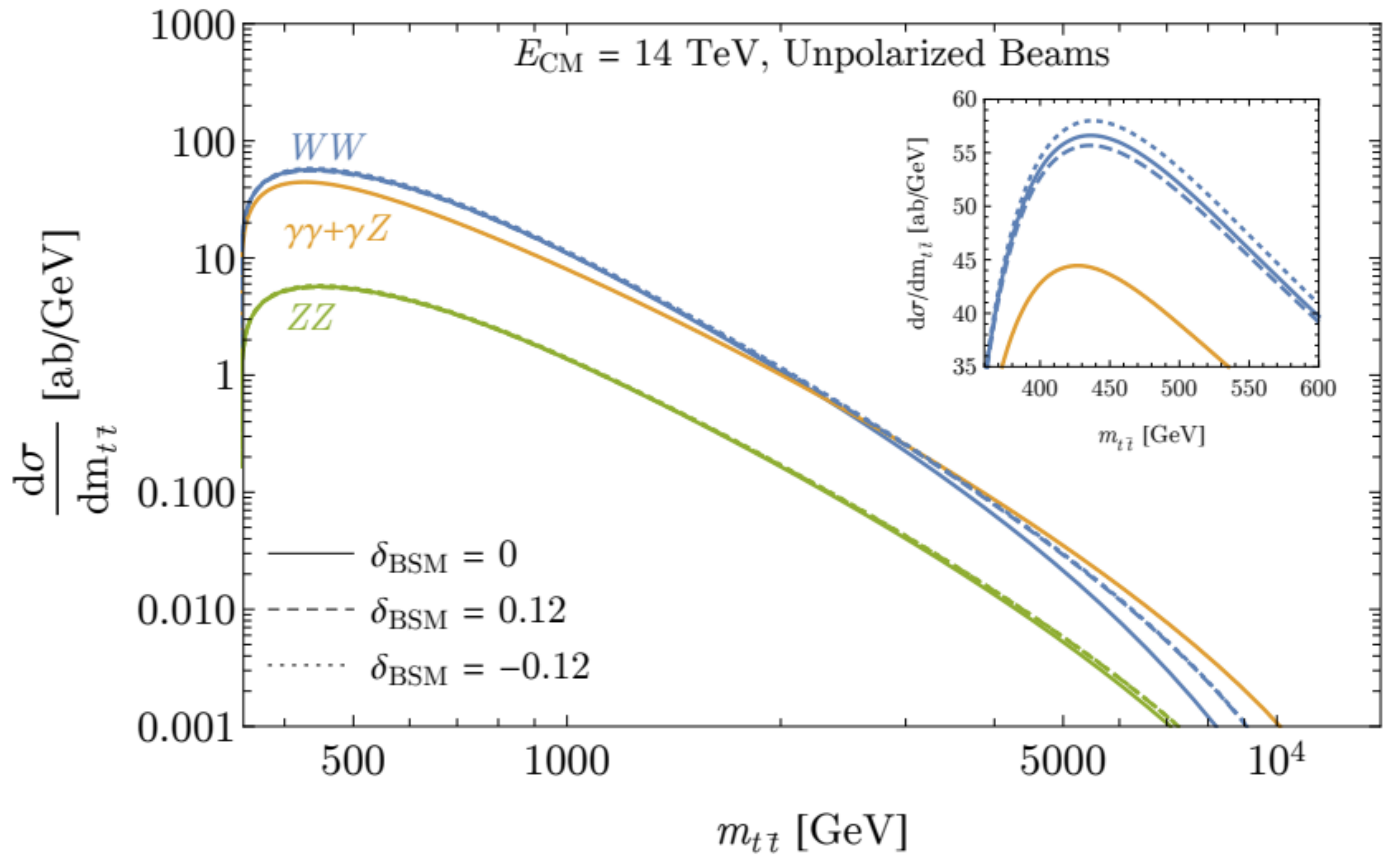
Steps

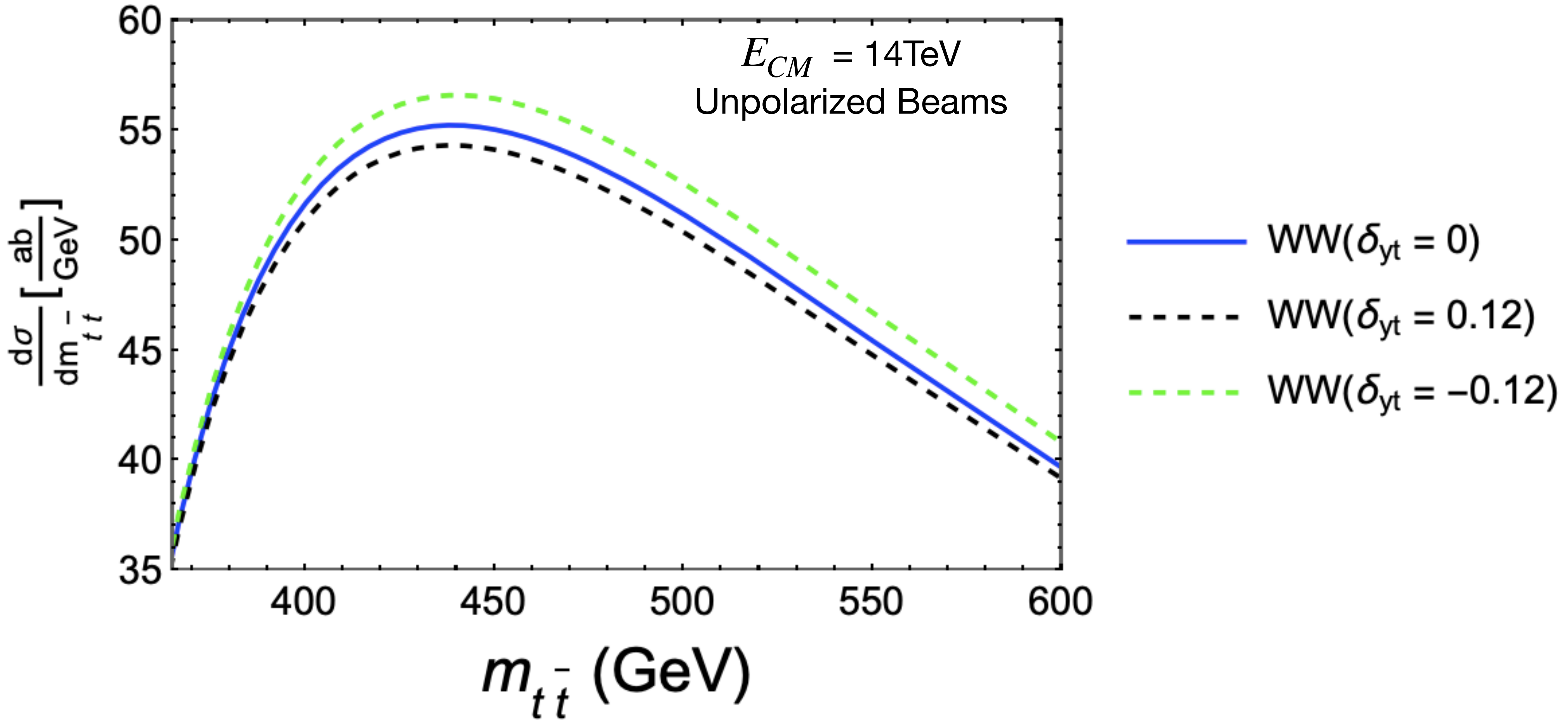
- **Find partonic level matrix elements for all possible helicity amplitudes. I wrote down all 36 helicity amplitudes in analytic form.**
- **Convolute these amplitudes with the muon PDF**
- **Perform a chi-square test to find 1σ deviation for δ_{yt}**

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



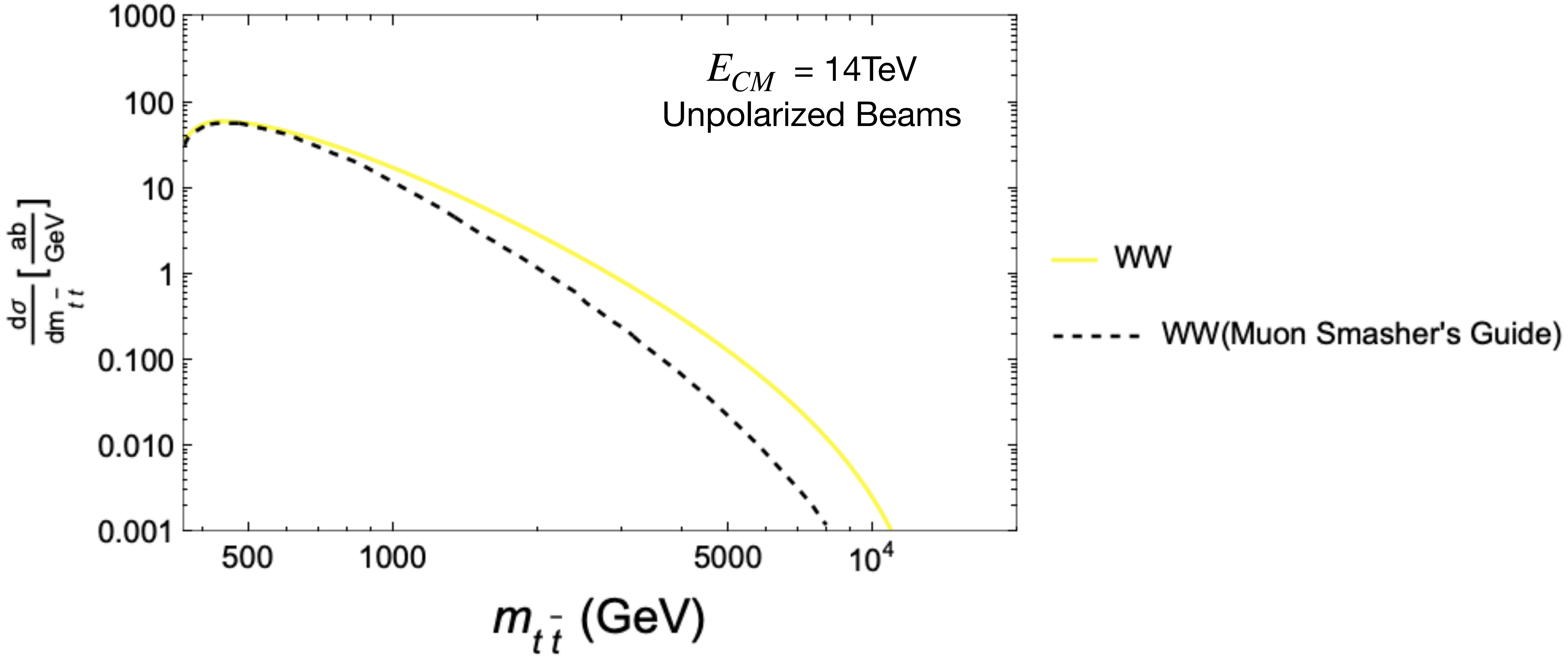
H. Al Ali et al. , "The Muon Smasher's Guide," arXiv:2103.14043 [hep-ph]

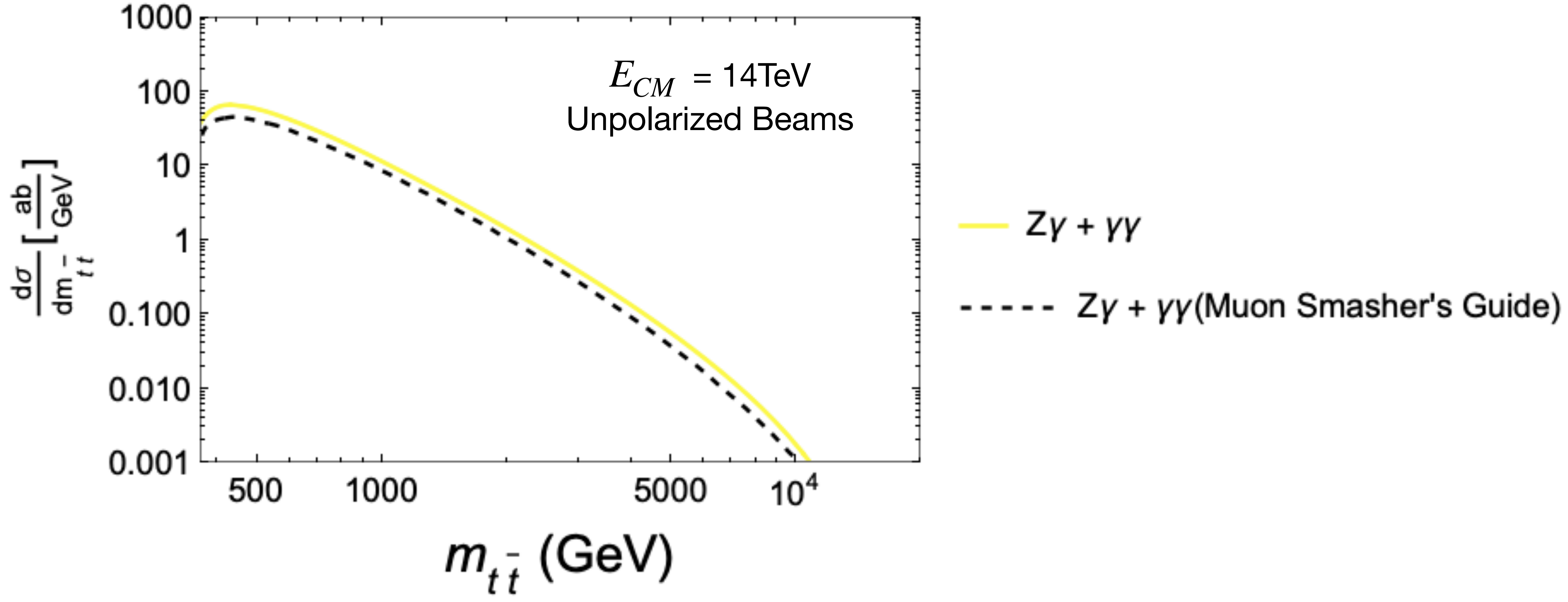


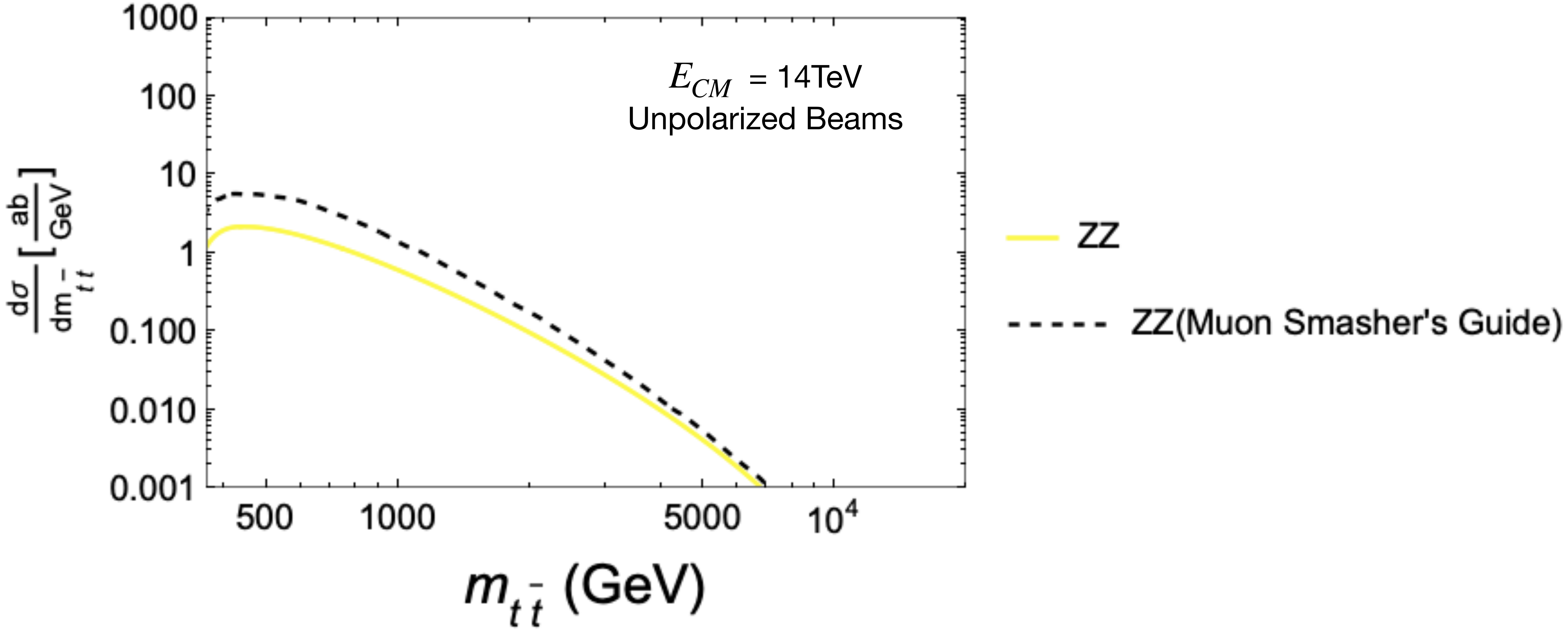


- The figures show convoluted cross-section at 14TeV (left).
- The dotted lines show deviations from SM predictions.
- The bottom left plot zooms in on 360-600GeV where the statistics is high and interference is visible
- The right plot is a comparison from the "Muon Smasher's Guide "

Comparison Between Muon Smasher's Guide





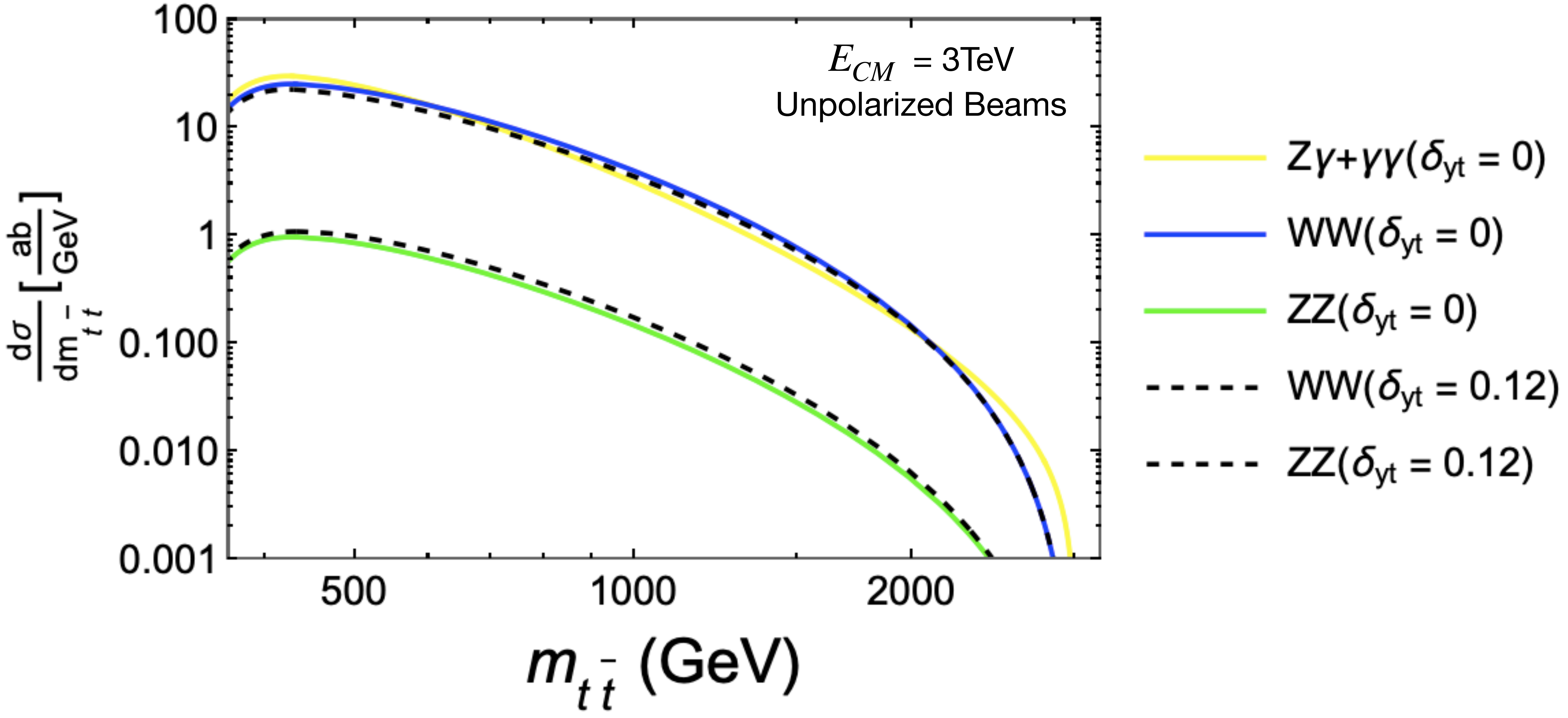


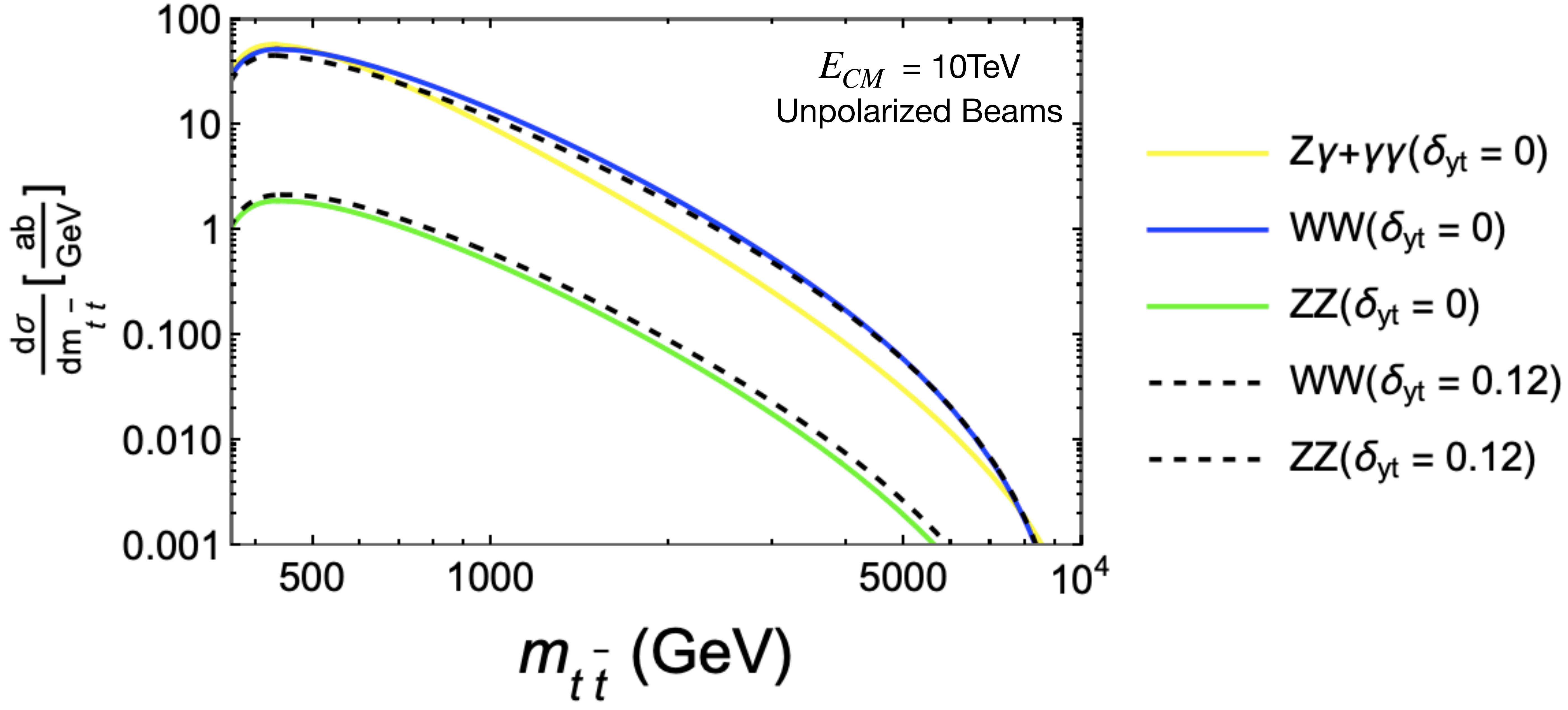
Discrepancies between Muon Smasher's Guide

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]

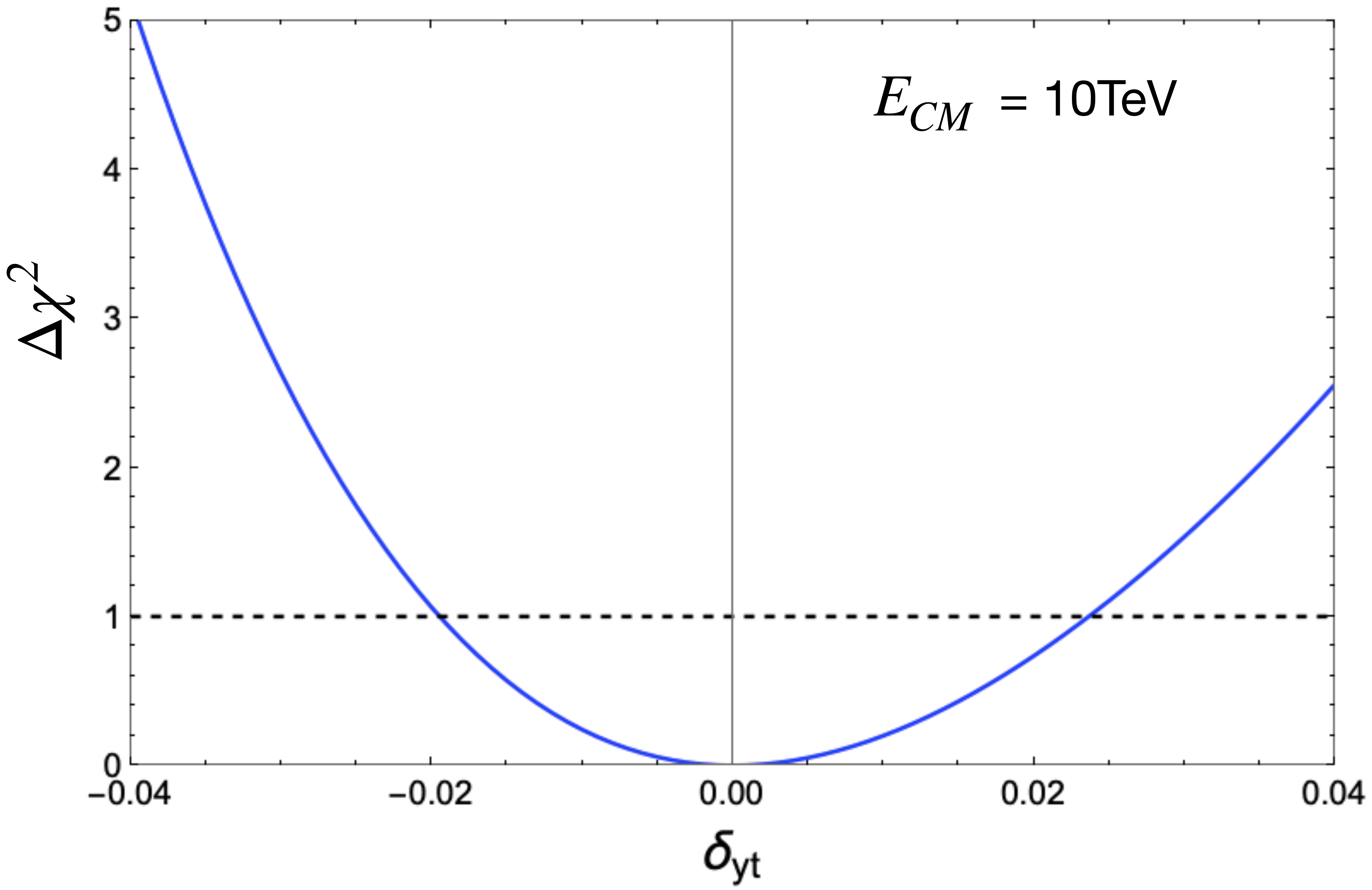
The Convoluted Cross-section at 3TeV and 10TeV



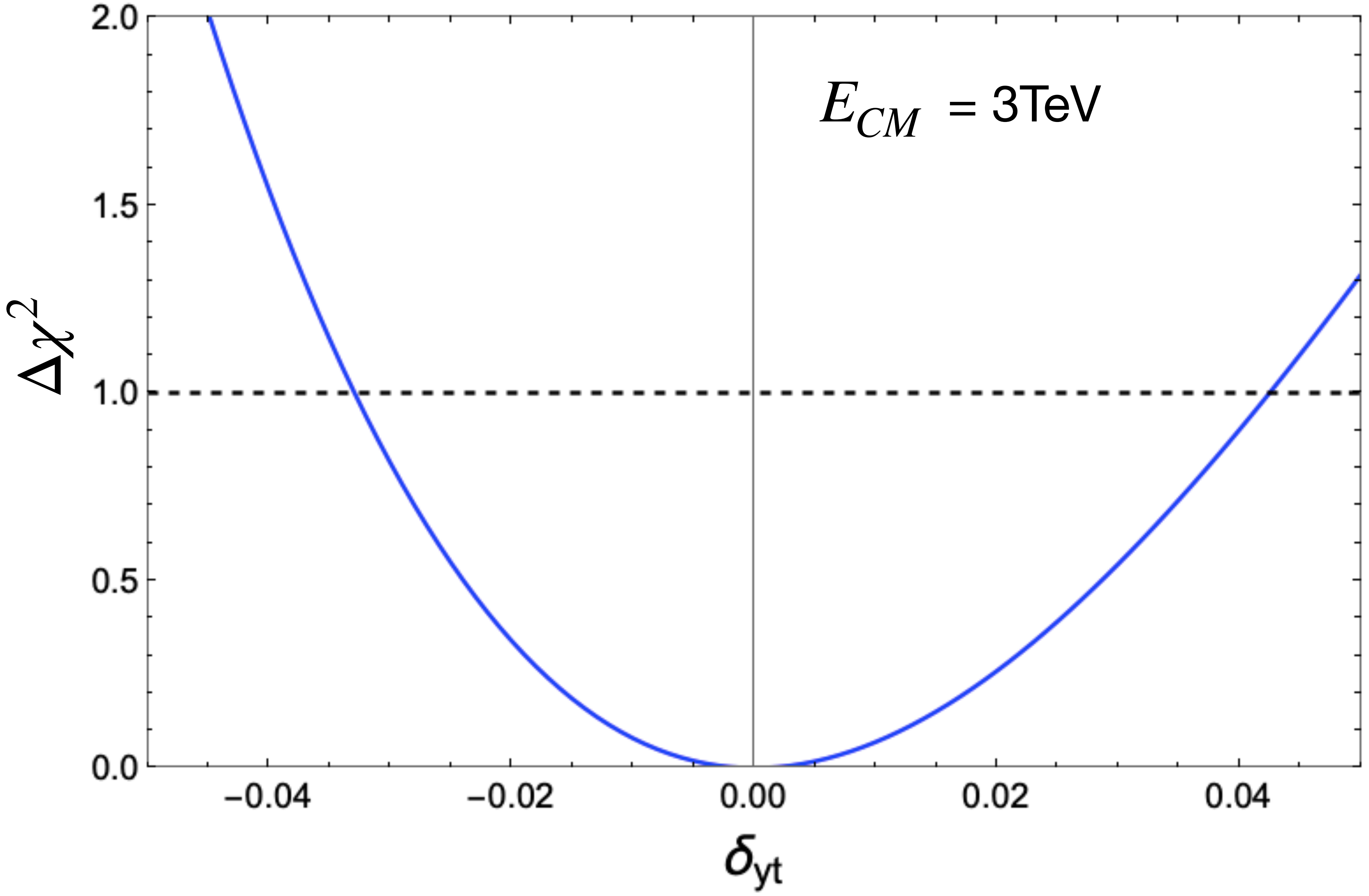


Sensitivity Test

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



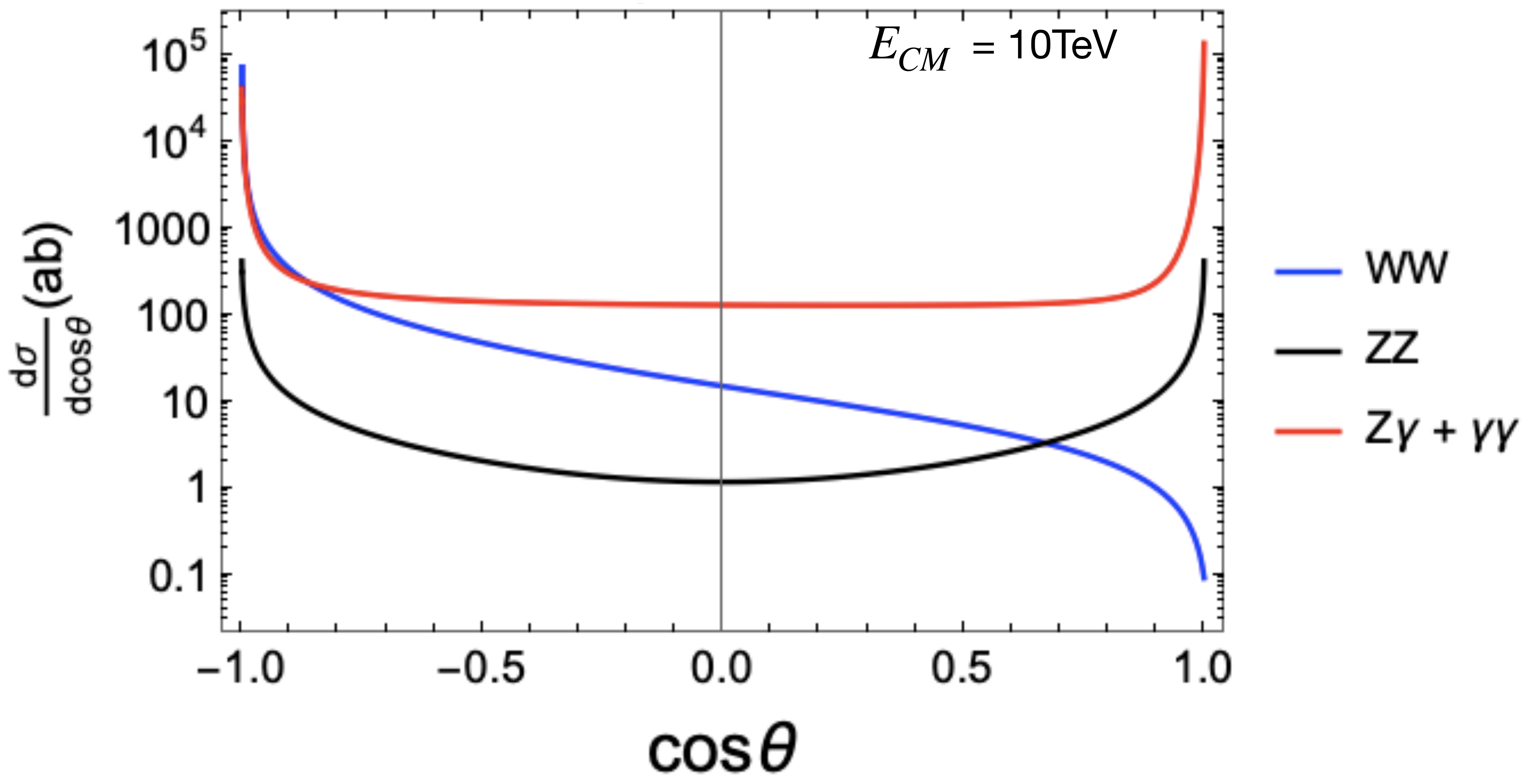
Sensitivity for Luminosity = 10ab^{-1} and E_{CM} = 3TeV

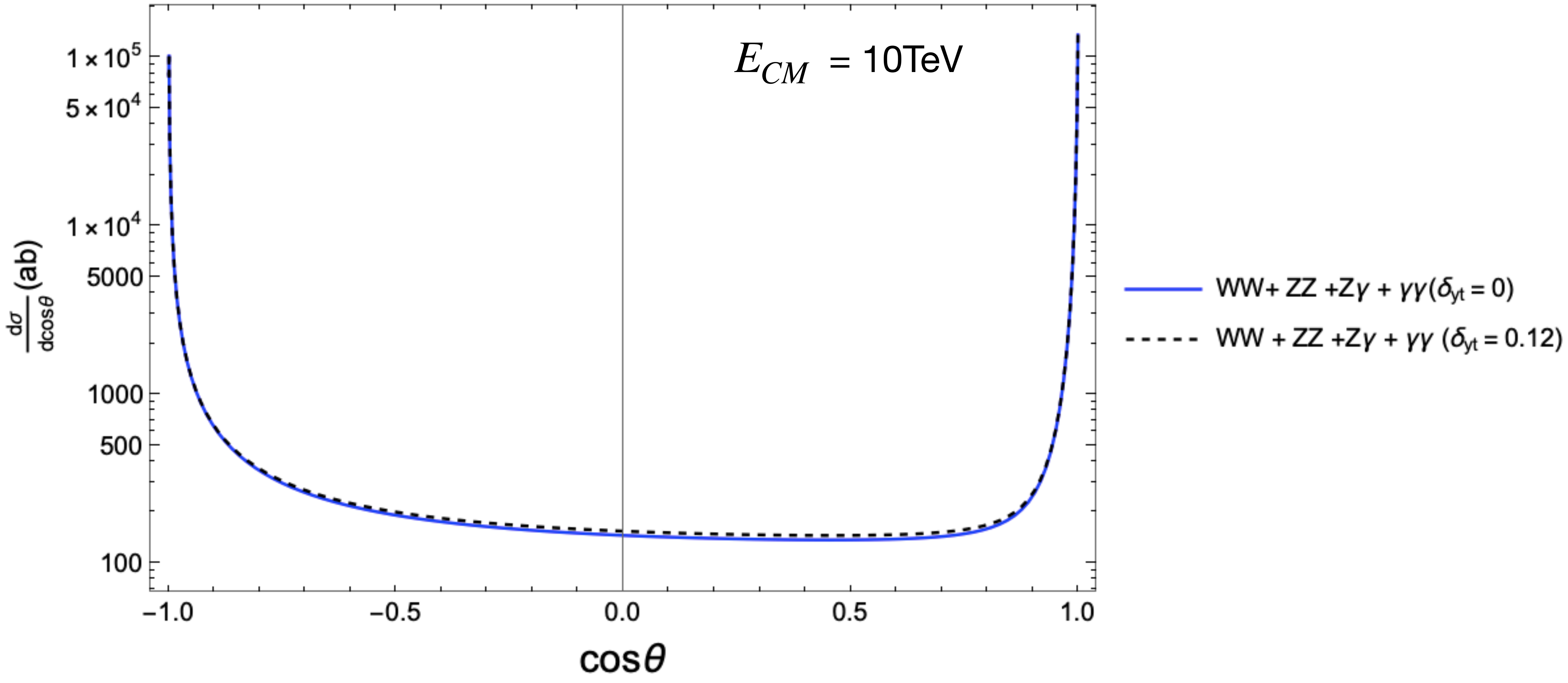


1σ Precision for E_{CM} = 3 TeV and E_{CM} = 10 TeV for Luminosity = 10ab^{-1}

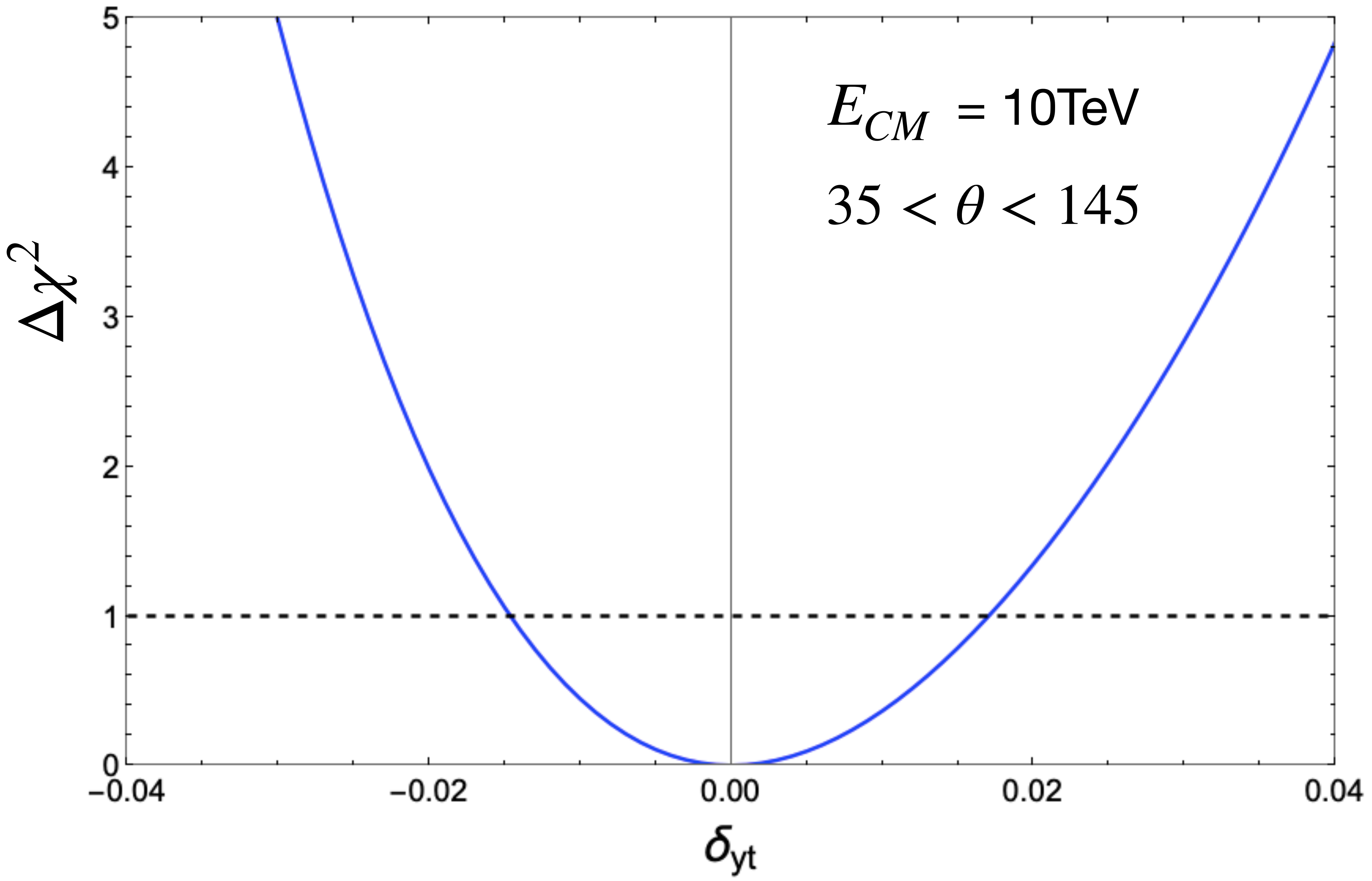
	δ_{yt}	δ_{yt}
E_{CM} = 3TeV	-3.3%	4.25%
E_{CM} = 10TeV	-1.95%	2.36%

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

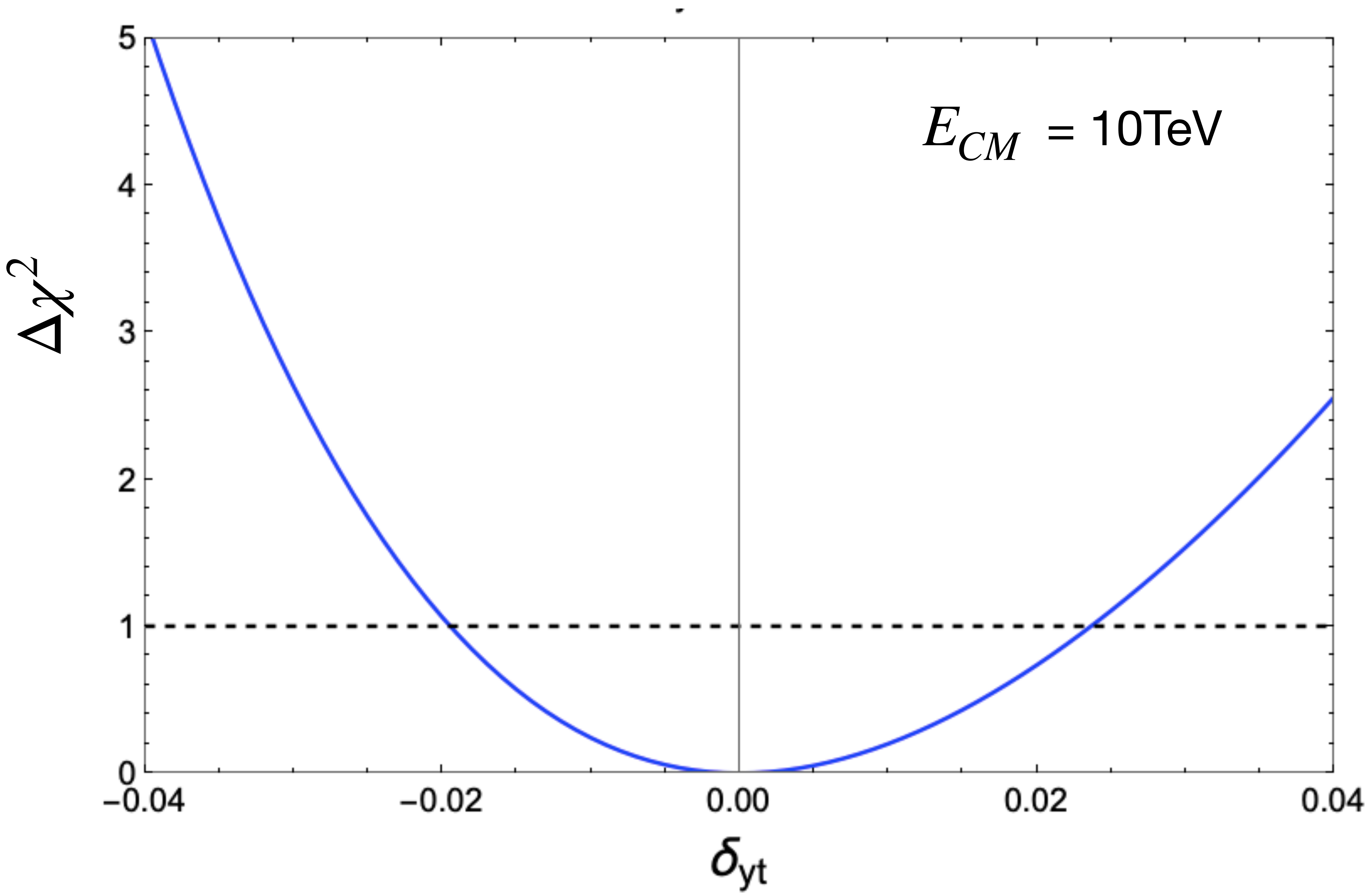




Sensitivity for Luminosity = $10ab^{-1}$ and E_{CM} = 10TeV with Angle Cuts



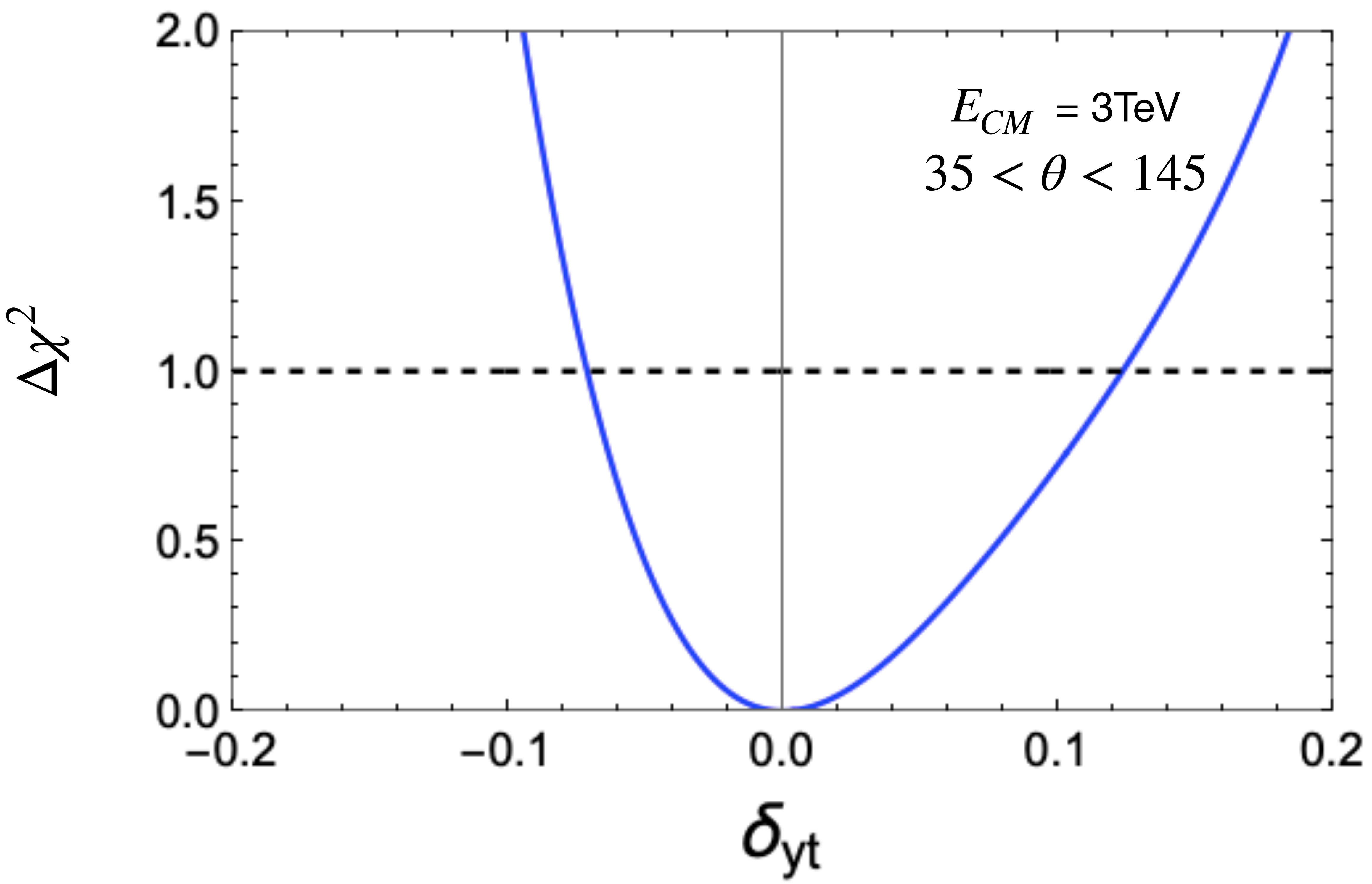
Sensitivity for Luminosity = $10ab^{-1}$ and E_{CM} = 10TeV without Angle Cuts



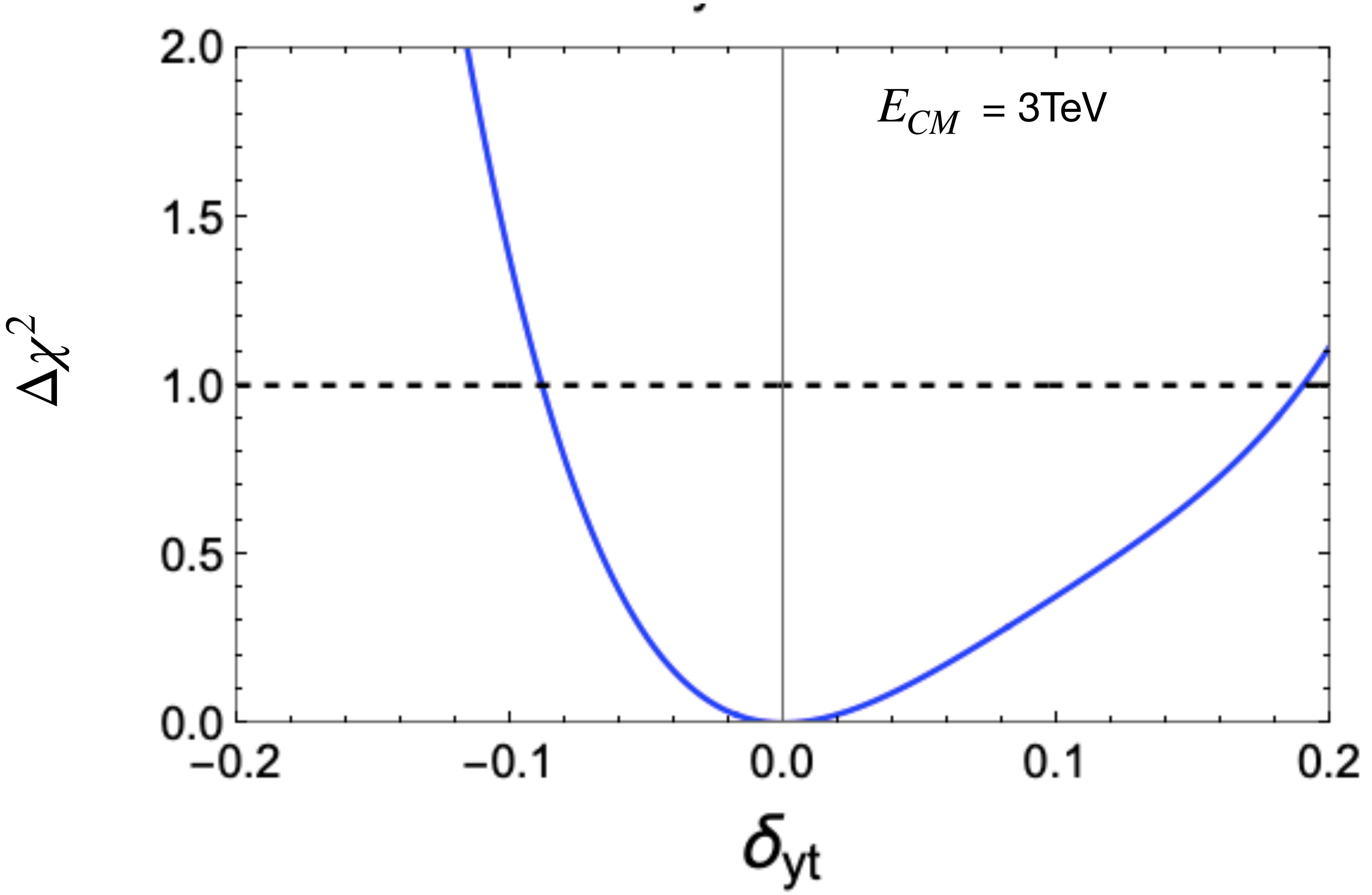
Comparing 1σ Precision for E_{CM} = 10 TeV, Luminosity = 10ab^{-1} with and without angle cuts

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

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



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



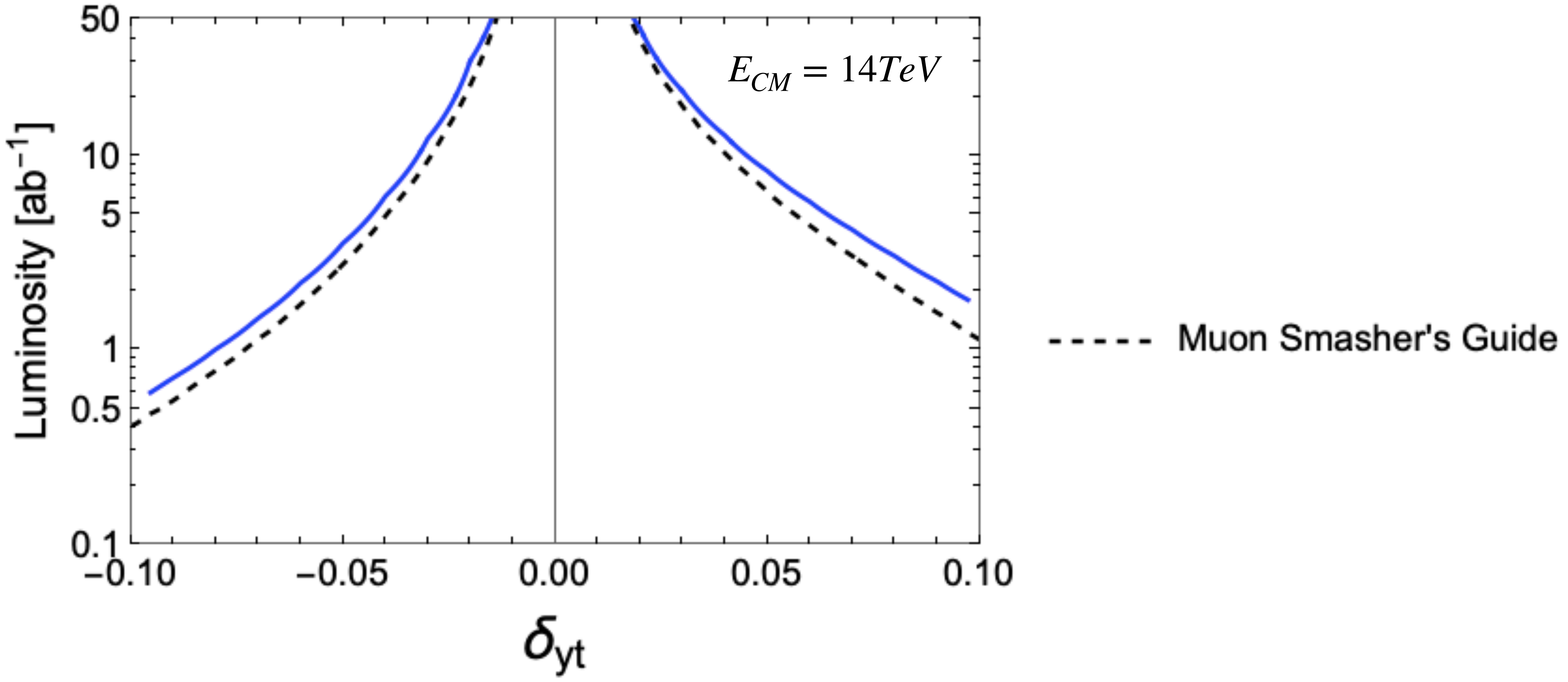
Comparing 1σ Precision for E_{CM} = 3 TeV, Luminosity = 1ab^{-1} with and without angle cuts

E_{CM} = 3TeV	δ_{yt}	δ_{yt}
Without Angle Cut	-8.9%	19.1%
With Angle Cut	-7.2%	12.4%

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 $E_{CM} = 10TeV$