Antler Topology and Missing Mass Determination at Lepton Collider

CosPA 2017

Zhuoni Qian (Kyoto, Dec 13, 2017)

기초과학연구원
Institute for Basic Science

N. Christensen, Tao Han, J. Sayre, J. Song, Stefanus, ZQ, Phys. Rev. D 90, 114029 (2014)

Contents

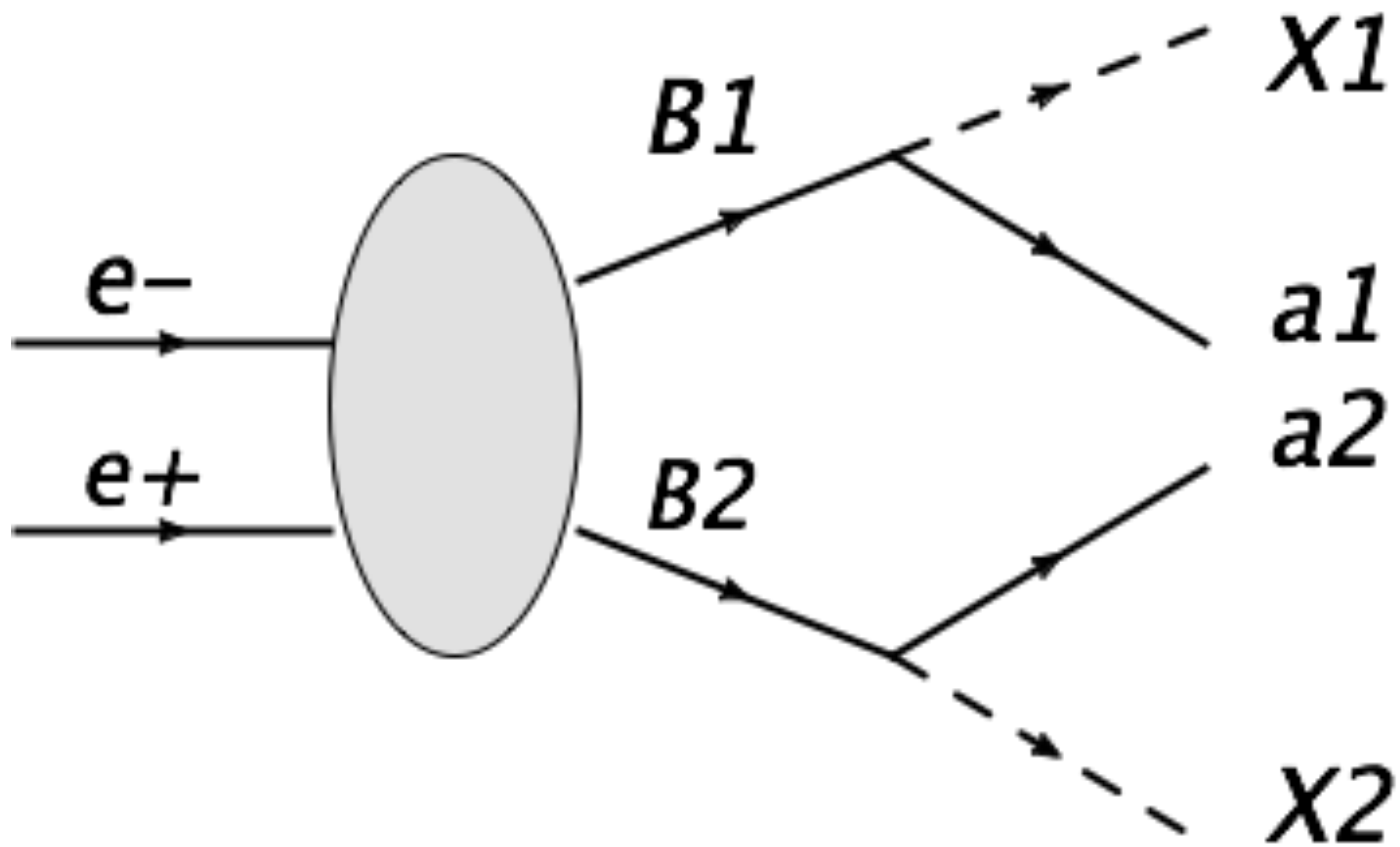
DM Searches and Measurements

1. Searches continue for particle DM, in Direct detection, indirect evidence, and collider experiments, until we find something, somewhere.

2. Once we see signals from multiple sources, it’s important to determine the properties of the observed state(s). e.g. Mass precisely, if there are (nearly) degenerate states in the spectrum

3. Lepton collider with sufficient vs will still be the optimal machine

Antler Topology at e⁻e⁺ Collider



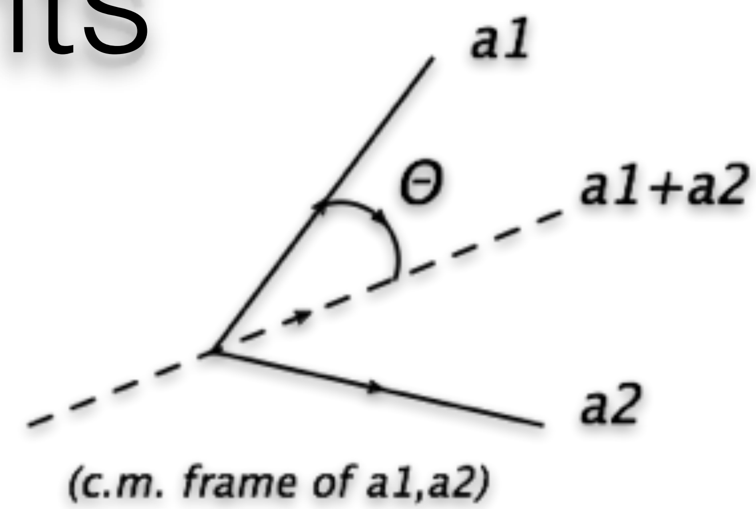
$$e^+e^- \rightarrow B_1 + B_2,$$

$$B_1 \rightarrow a_1 + X_1, \quad B_2 \rightarrow a_2 + X_2.$$

Symmetric Case:

$$m_{B_1} = m_{B_2} \equiv m_B, \quad m_{X_1} = m_{X_2} = m_X.$$

Cusps and Endpoints



- Singular kinematic structures:
cusps and endpoints in distributions of

$$m_{aa}, \; m_{\text{rec}}, \; \cos\Theta, \; E_a, \; E_{aa}$$

	1D configuration					m_{aa}	m_{rec}	E_{aa}	E_{XX}
(i)	$\overset{a_2}{\Longleftarrow}$	$\overset{B_2}{\longleftarrow}$	$\overset{e^+e^-}{\bullet}$	$\overset{B_1}{\longrightarrow}$	$\overset{a_1}{\Longrightarrow}$	max	min	max	min
(ii)	$\overset{a_2}{\Longrightarrow}$	$\overset{B_2}{\longleftarrow}$	$\overset{e^+e^-}{\bullet}$	$\overset{B_1}{\longrightarrow}$	$\overset{a_1}{\Longleftarrow}$	cusp	max	min	max
(iii)	$\overset{a_2}{\Longrightarrow}$	$\overset{B_2}{\longleftarrow}$	$\overset{e^+e^-}{\bullet}$	$\overset{B_1}{\longrightarrow}$	$\overset{a_1}{\Longrightarrow}$	min	cusp	cusp	cusp
(iv)	$\overset{a_2}{\Longleftarrow}$	$\overset{B_2}{\longleftarrow}$	$\overset{e^+e^-}{\bullet}$	$\overset{B_1}{\longrightarrow}$	$\overset{a_1}{\Longleftarrow}$	min	cusp	cusp	cusp

http://www.sps.ch/en/articles/nobel-prizes/the-2013-nobel-prize-in-physics/

Cusps and Endpoints

- Massive and Massless `a` case.

$$m_{aa}^{\min} = 0\,,$$

$$m_{aa}^{\text{cusp}} = m_B \left(1 - \frac{m_X^2}{m_B^2}\right) e^{-\eta_B}\,,$$

$$m_{aa}^{\max} = m_B \left(1 - \frac{m_X^2}{m_B^2}\right) e^{\eta_B}\,.$$

	$\mathcal{R}_1:\ \eta_B < \frac{\eta_a}{2}$	$\mathcal{R}_2:\ \frac{\eta_a}{2} < \eta_B < \eta_a$	$\mathcal{R}_3:\ \eta_a < \eta_B$
$m_{aa}^{\min}$	$2m_a$		$2m_a \cosh(\eta_B - \eta_a)$
m_{aa}^{cusp}	$2m_a \cosh(\eta_B - \eta_a)$	$2m_a \cosh \eta_B$	
$m_{aa}^{\max}$	$2m_a \cosh(\eta_B + \eta_a)$		

η_B : rapidity of B in the c.m. frame

η_a : rapidity of a in the B rest frame

http://www.sps.ch/en/articles/nobel-prizes/the-2013-nobel-prize-in-physics/

Cusps and Endpoints

Benchmark scenario from MSSM, √s = 500 GeV

Label	$\tilde{\mu}_R$	$\tilde{\mu}_L$	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$
Case-A (Case-B)	158	636 (170)	141	529	654	679	529	679
Case-C	–	–	139	235	504	529	235	515

* SUSY spectra chosen, while preferring the interested antler process of the study, or dominating over other SUSY processes.

Cusps and Endpoints

$\sqrt{s}$	500 GeV		
Production channel	$\tilde{\mu}_R\tilde{\mu}_R$	$\tilde{\mu}_L\tilde{\mu}_L$	W^+W^-
input (m_B, m_X)	$(158, 141)$	$(170, 141)$	$(m_W, 0)$
$\lvert\cos\Theta\rvert_{\max}$	0.77	0.73	0.95
$(m_{\mu\mu}^{\min}, m_{\mu\mu}^{\text{cusp}}, m_{\mu\mu}^{\max})$	$(0, 12, 91)$	$(0, 21, 137)$	$(0, 13, 487)$
$(m_{\text{rec}}^{\min}, m_{\text{rec}}^{\text{cusp}}, m_{\text{rec}}^{\max})$	$(408, 445, 488)$	$(363, 413, 479)$	$(0, 13, 487)$
$(E_{\mu}^{\min}, E_{\mu}^{\max})$	$(6, 46)$	$(11, 69)$	$(7, 243)$
$(E_{\mu\mu}^{\min}, E_{\mu\mu}^{\text{cusp}}, E_{\mu\mu}^{\max})$	$(12, 52, 92)$	$(21, 79, 137)$	$(13, 250, 487)$

realistic effects: spin correlation, acceptance cuts, detector etc.

Cusps and Endpoints

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modify shape

Cusps and Endpoints

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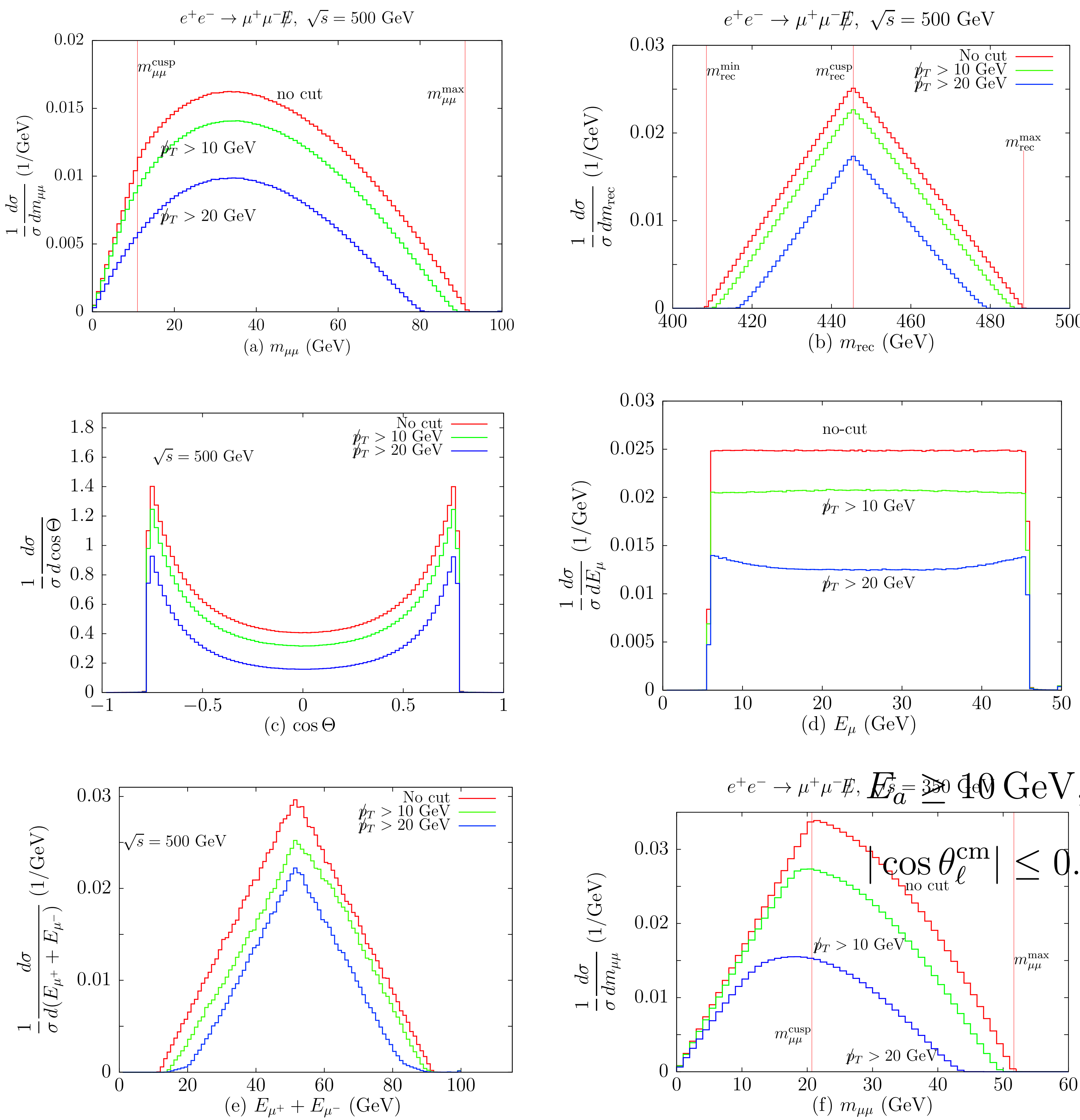
realistic effects: spin correlation, acceptance cuts, detector etc.

modify shape **shift disc. points**

Case-A: $\tilde{\mu}_R \tilde{\mu}_R$ pair production



Basic cuts:

$$E_a \geq 10\,\mathrm{GeV}, \quad \not{p}_T \geq 15\,\mathrm{GeV},$$

$$|\cos\theta_\ell^{\rm cm}| \leq 0.9962, \quad m_{aa} \geq 1\,\mathrm{GeV}, \quad m_{\rm rec} \geq 1\,\mathrm{GeV}.$$

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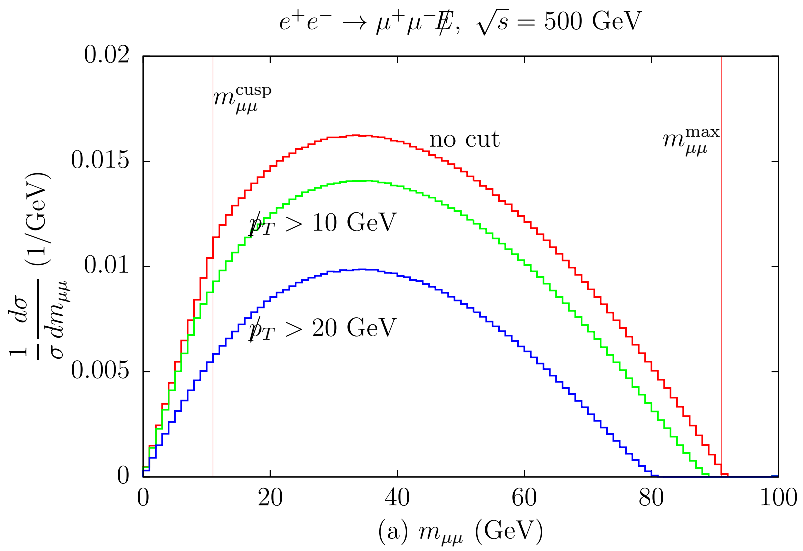
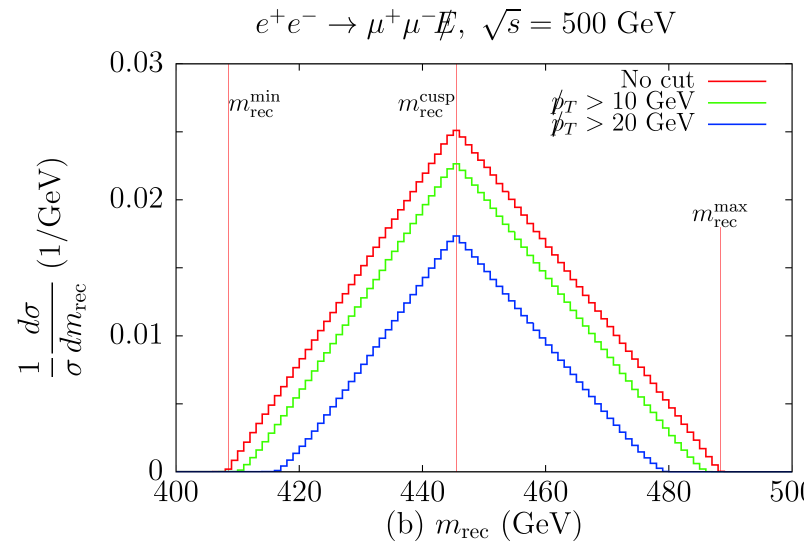
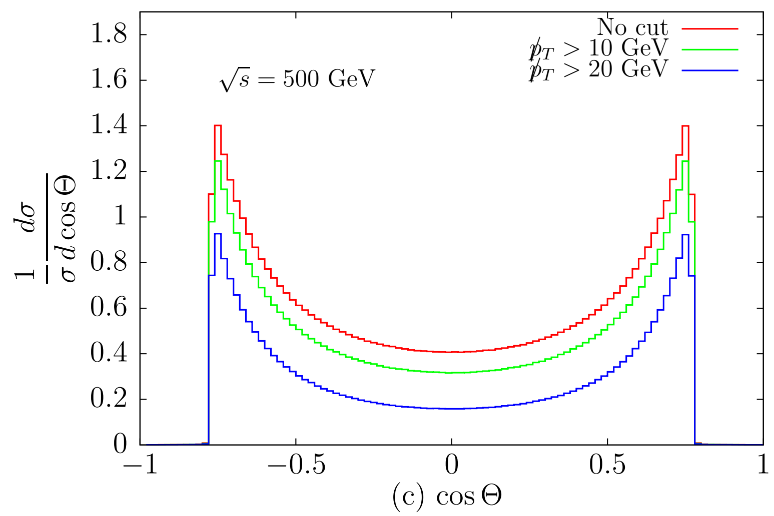
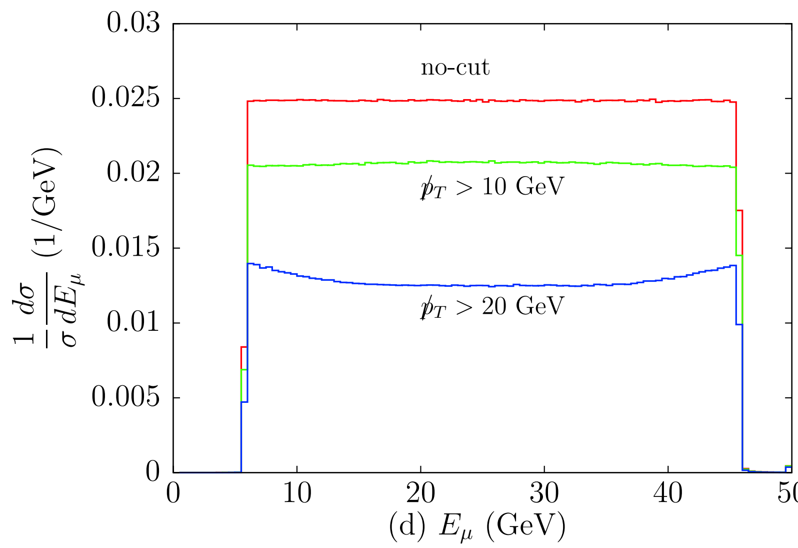




shift end points





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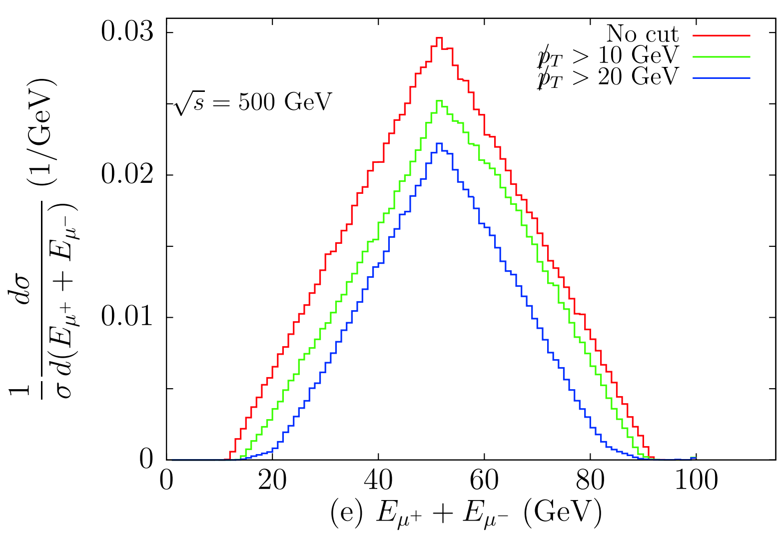
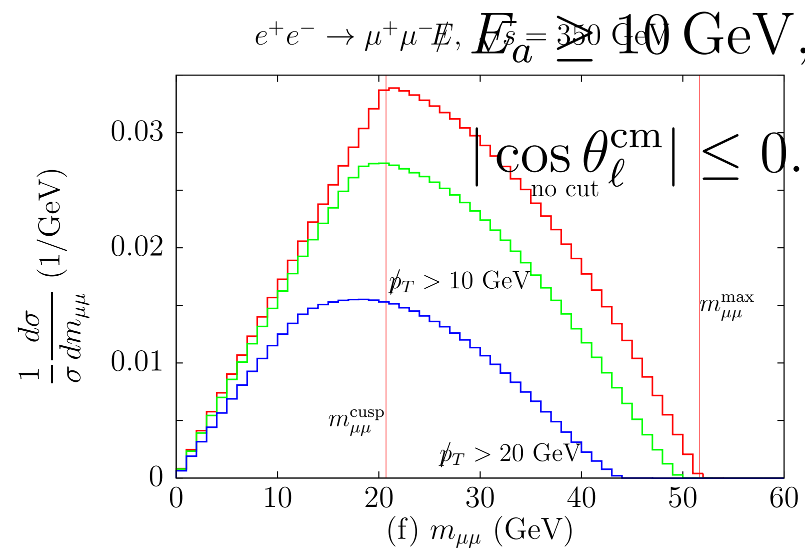
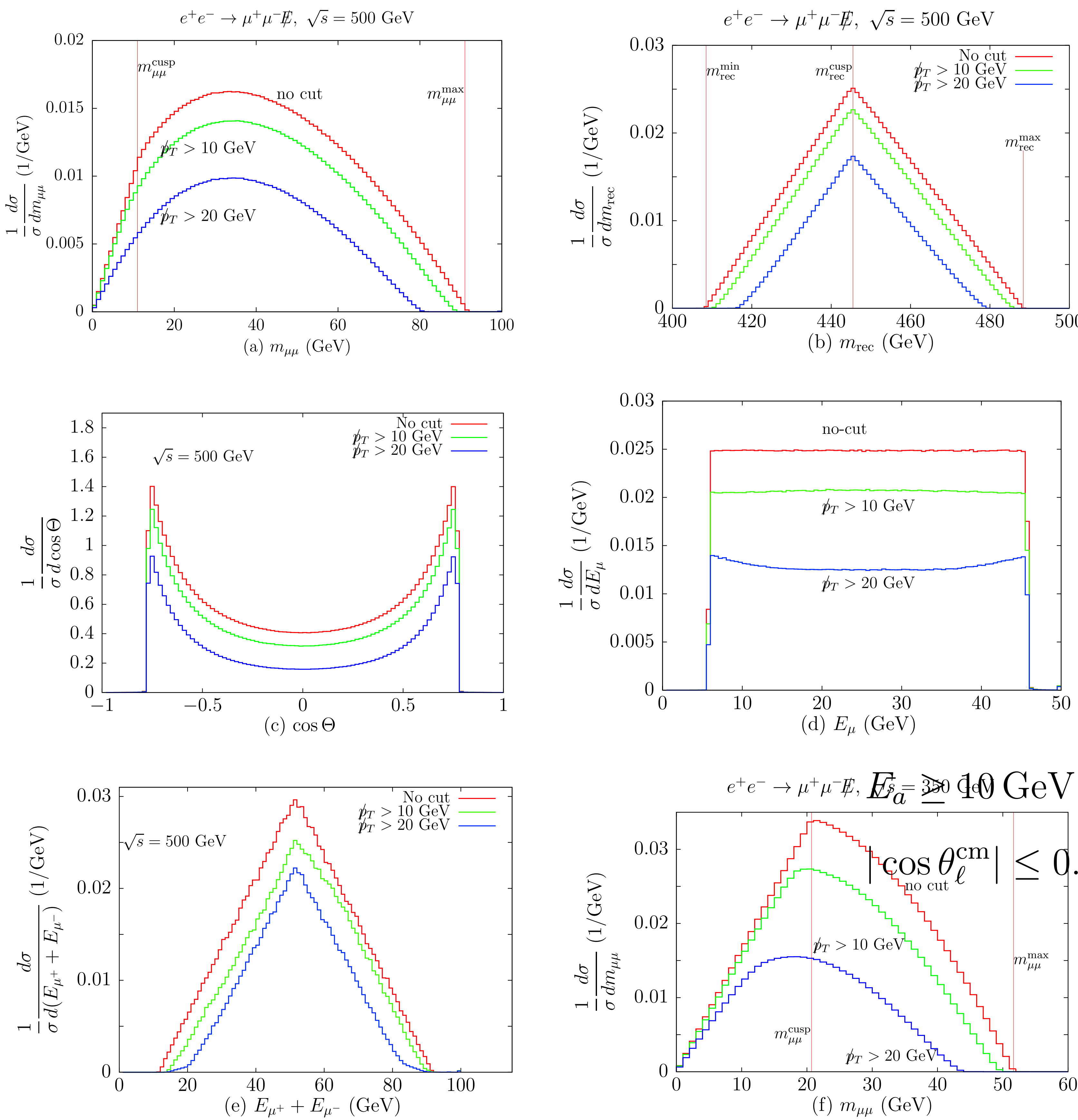




Case-A: $\tilde{\mu}_R\tilde{\mu}_R$ pair production



shift end points

Basic cuts:

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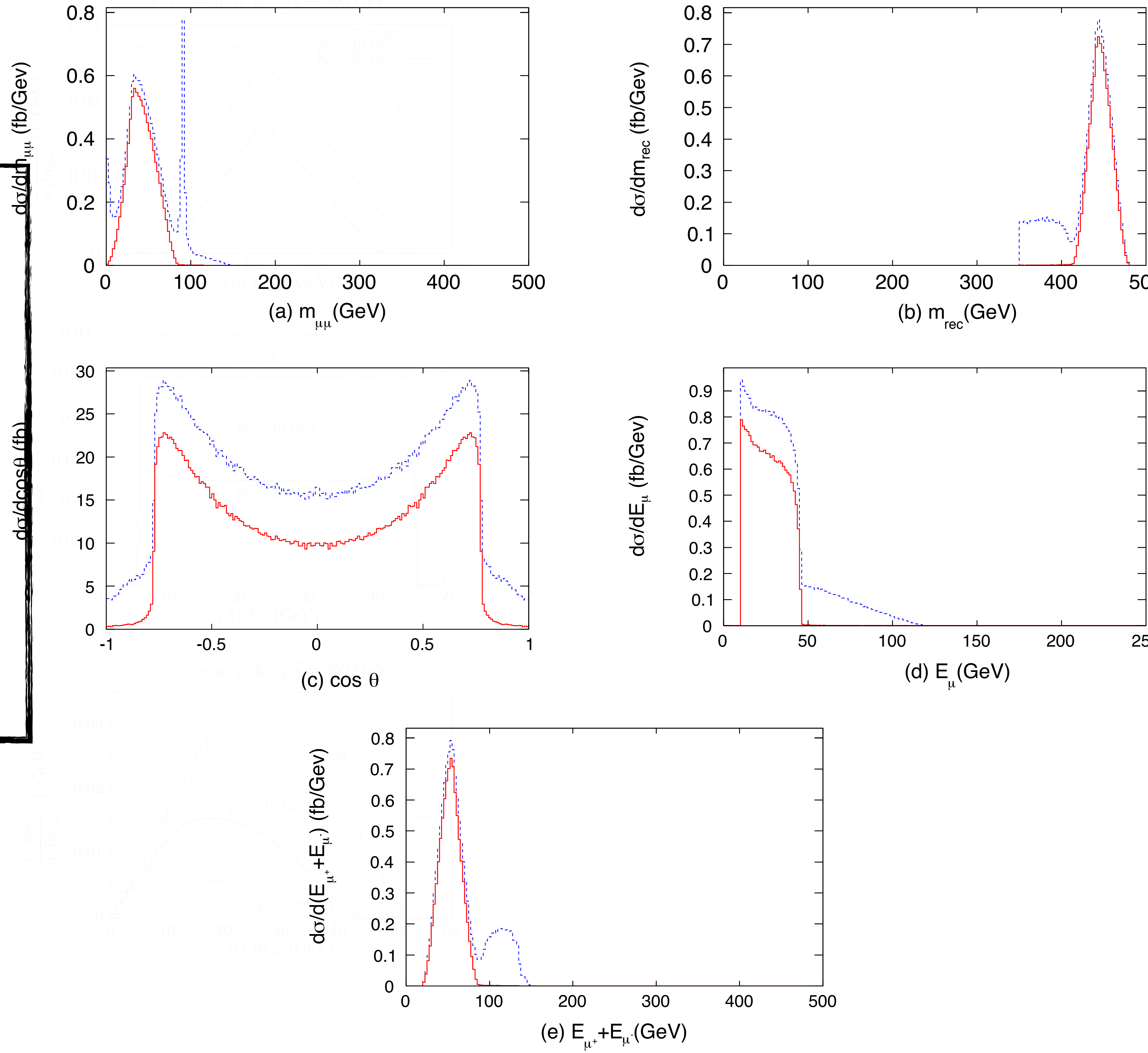
shift cusp

Case-A: $\tilde{\mu}_R\tilde{\mu}_R$ pair production

Realistic effects:

- **spin correlation**
- **acceptance cuts**
- **detector effects**
- **ISR, Beamstrahlung etc.**

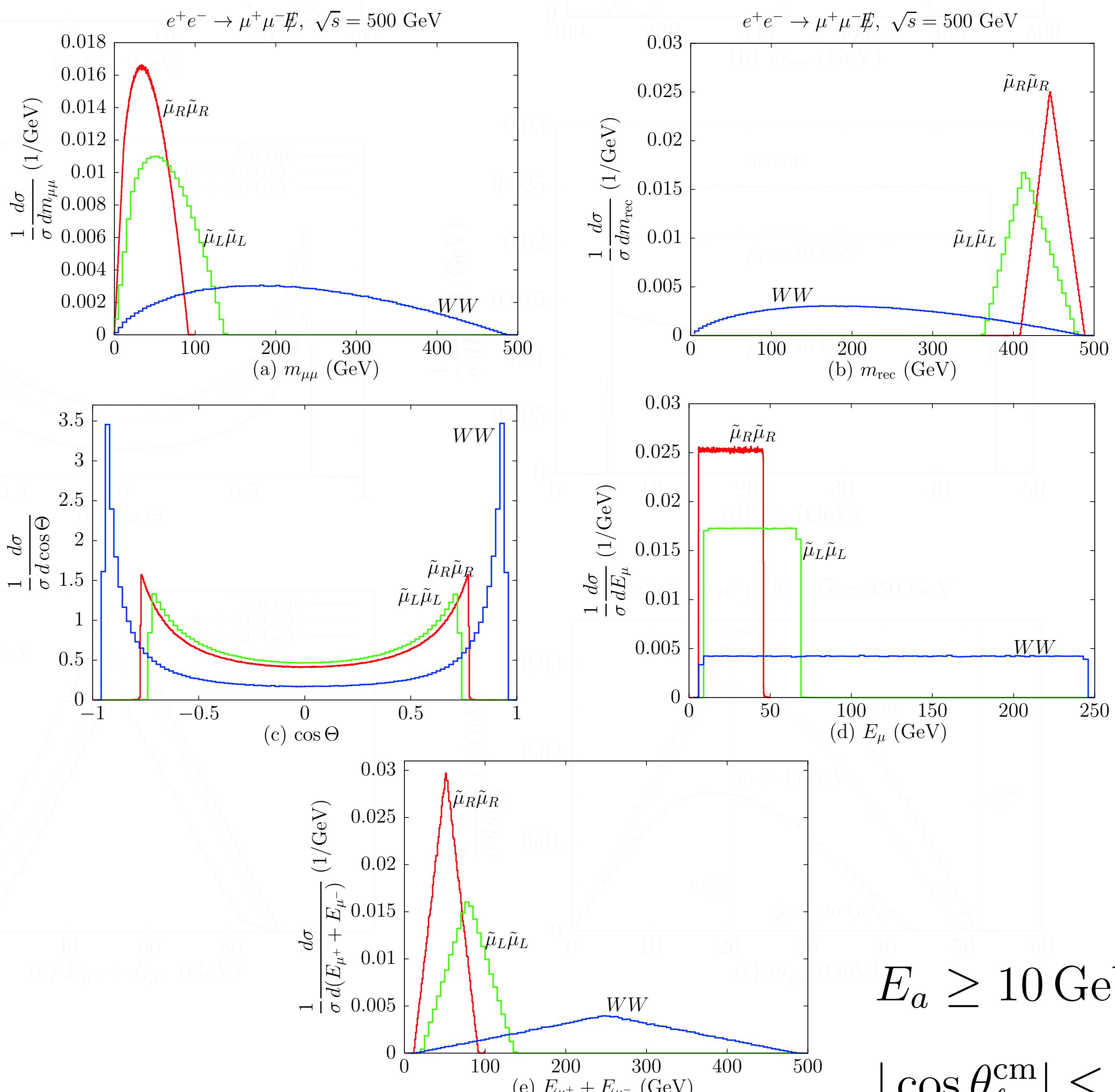


Case-B: production of $\tilde{\mu}_R\tilde{\mu}_R$ *and* $\tilde{\mu}_L\tilde{\mu}_L$

Similar masses

Similar left/right-chiral couplings $\tilde{\mu}_L\tilde{\mu}_L Z$ & $\tilde{\mu}_R\tilde{\mu}_R Z$

Compatible cross section



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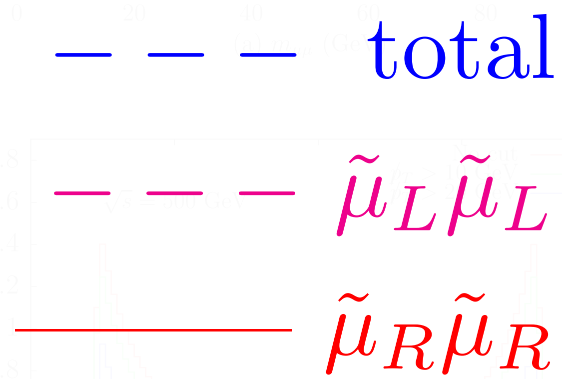
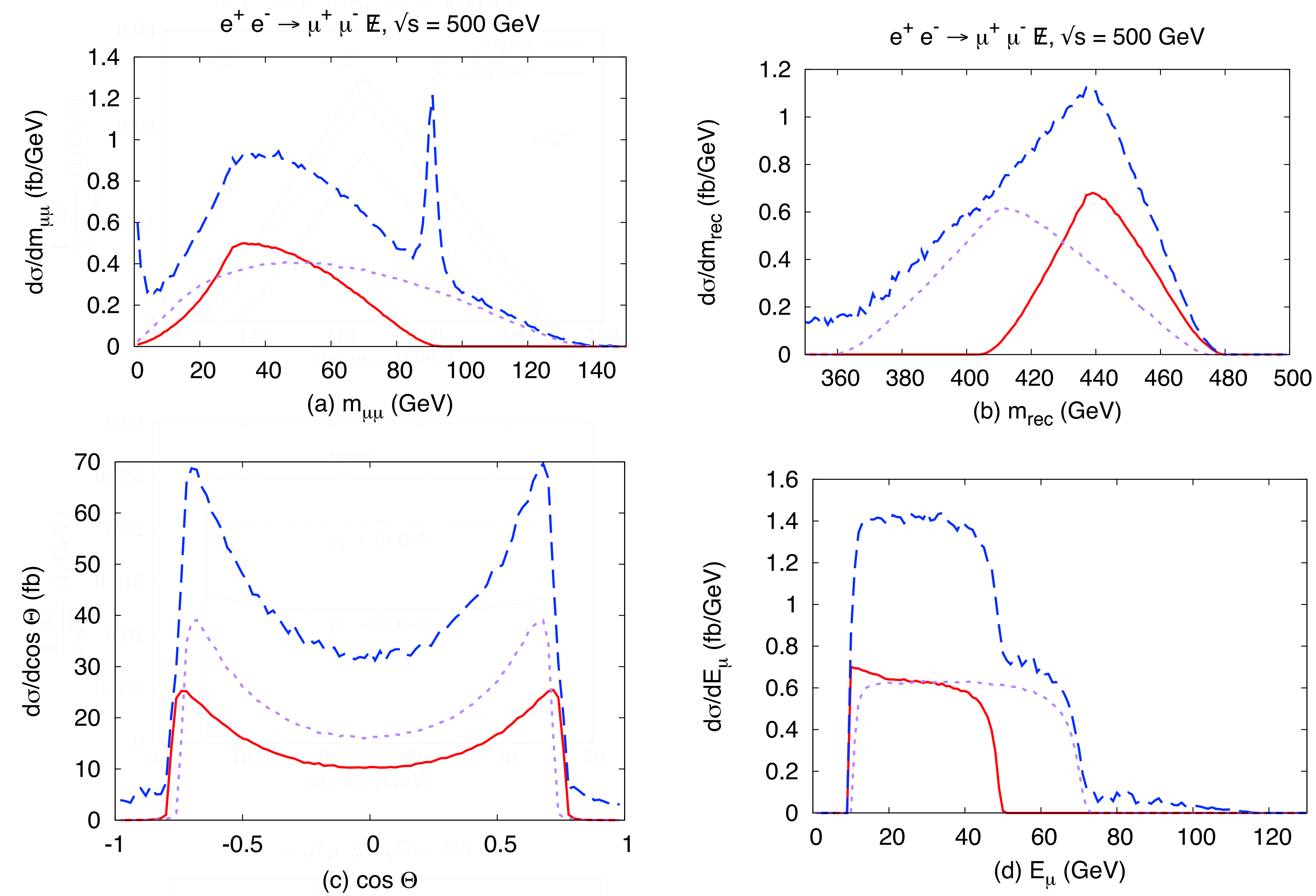
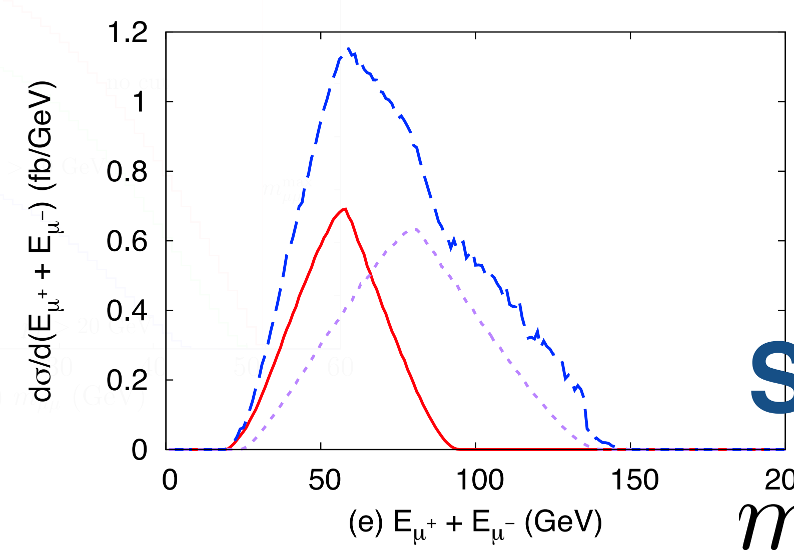


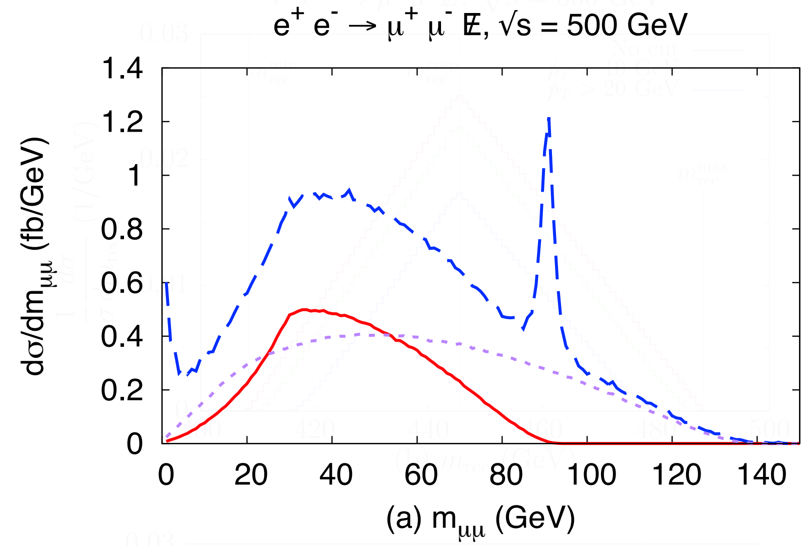


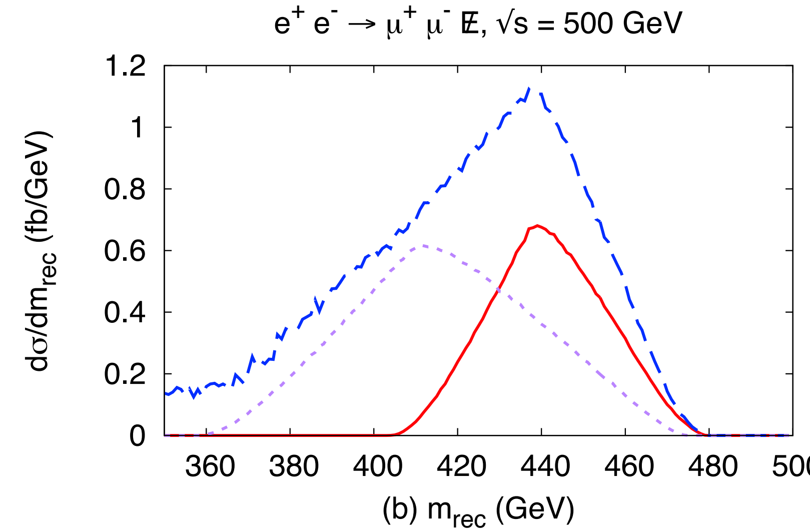


Selection cuts:

$$m_{\rm rec} > 350\,{\rm GeV}$$

Case-B: production of $\tilde{\mu}_R\tilde{\mu}_R$ *and* $\tilde{\mu}_L\tilde{\mu}_L$

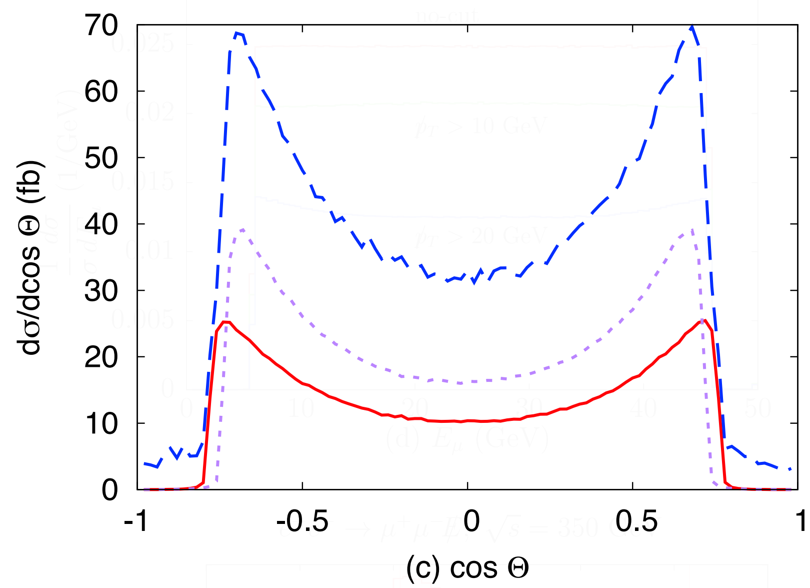


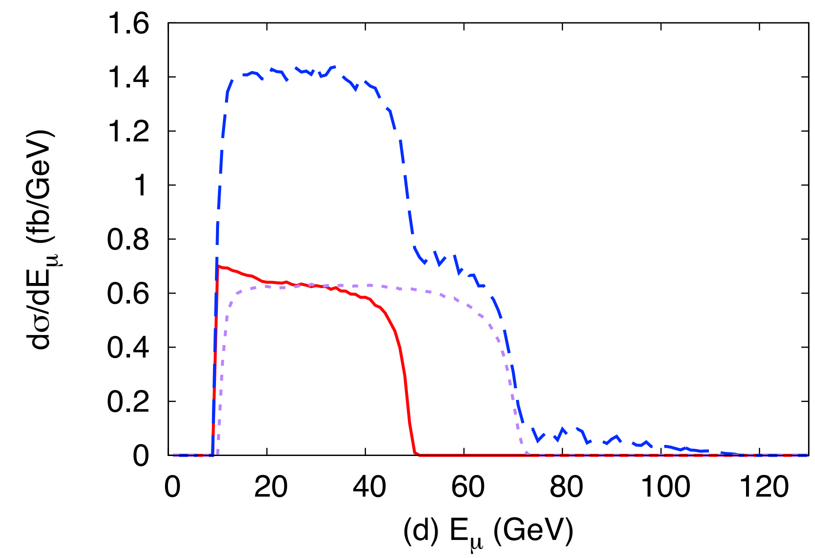


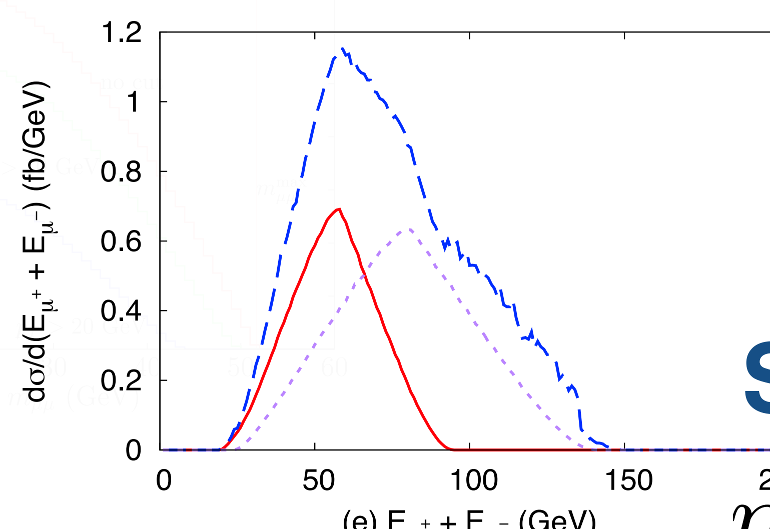
— — — total

— — — $\tilde{\mu}_L\tilde{\mu}_L$

——— $\tilde{\mu}_R\tilde{\mu}_R$





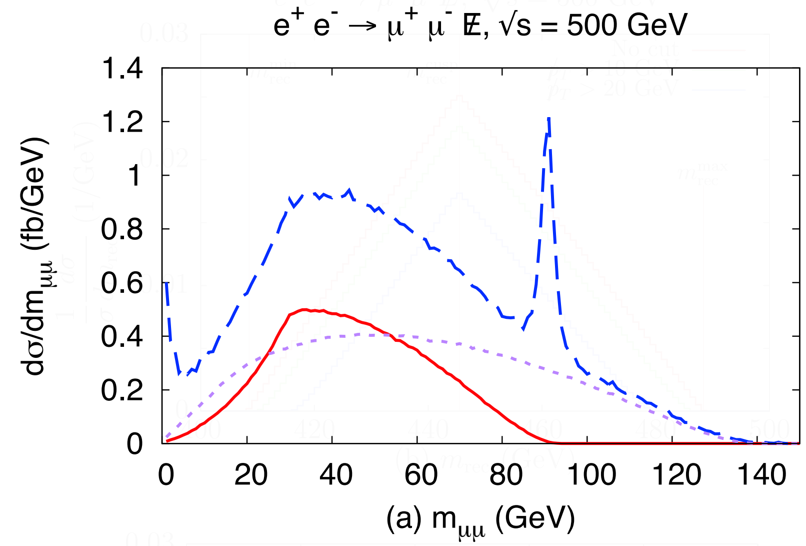


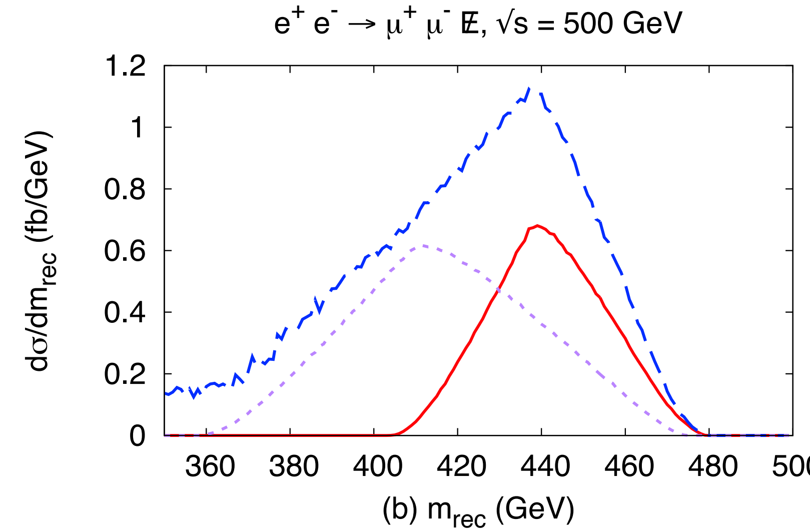
- **end points overlapped**
- **“twin peaks”**

Selection cuts:

$$m_{\rm rec} > 350\,{\rm GeV}$$

Case-B: production of $\tilde{\mu}_R\tilde{\mu}_R$ and $\tilde{\mu}_L\tilde{\mu}_L$

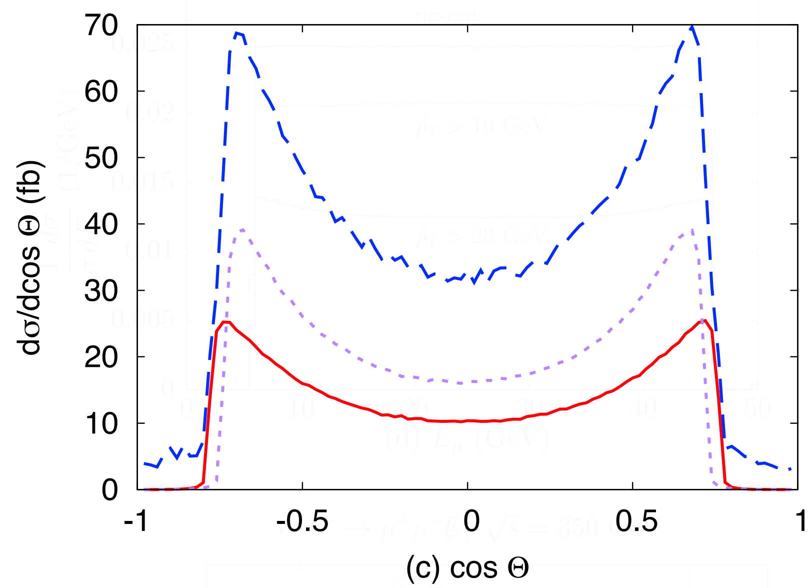


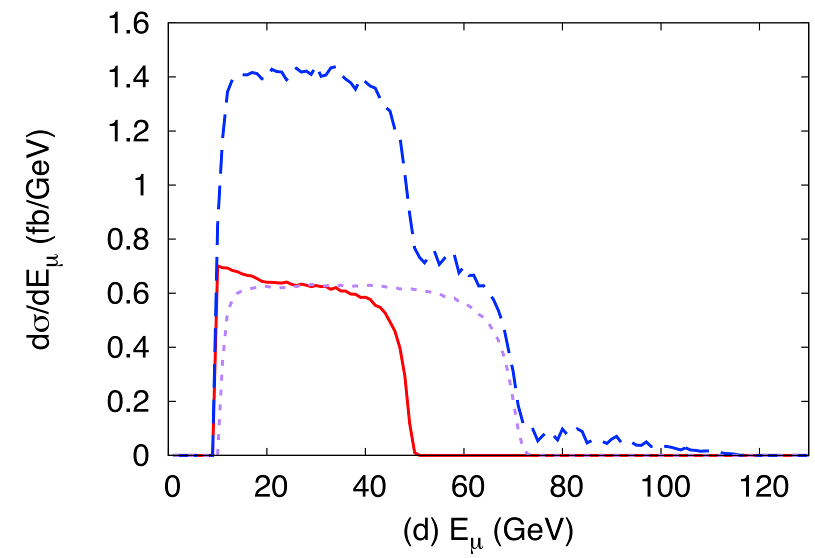


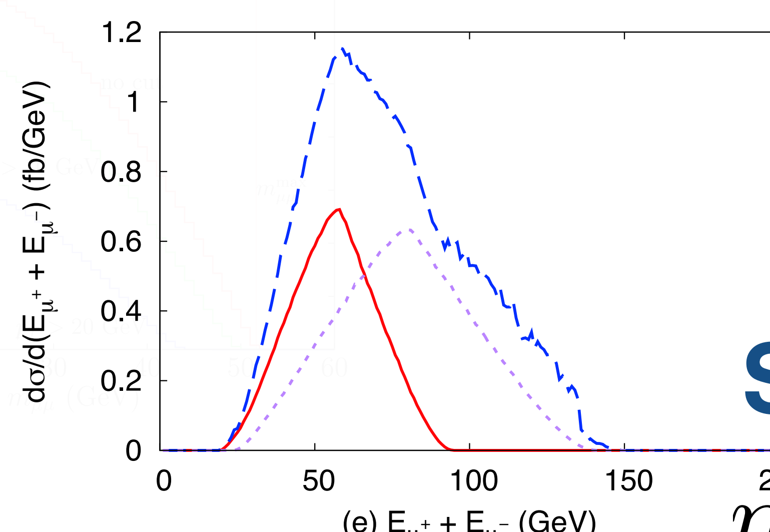
— — — total

— — — $\tilde{\mu}_L\tilde{\mu}_L$

——— $\tilde{\mu}_R\tilde{\mu}_R$







- **end points overlapped**
- **"twin peaks"**

→ **Fit the shape?**

Selection cuts:

$$m_{\rm rec} > 350\,{\rm GeV}$$

Case-B: production of $\tilde{\mu}_R\tilde{\mu}_R$ *and* $\tilde{\mu}_L\tilde{\mu}_L$

Employ polarized beams possibilities:

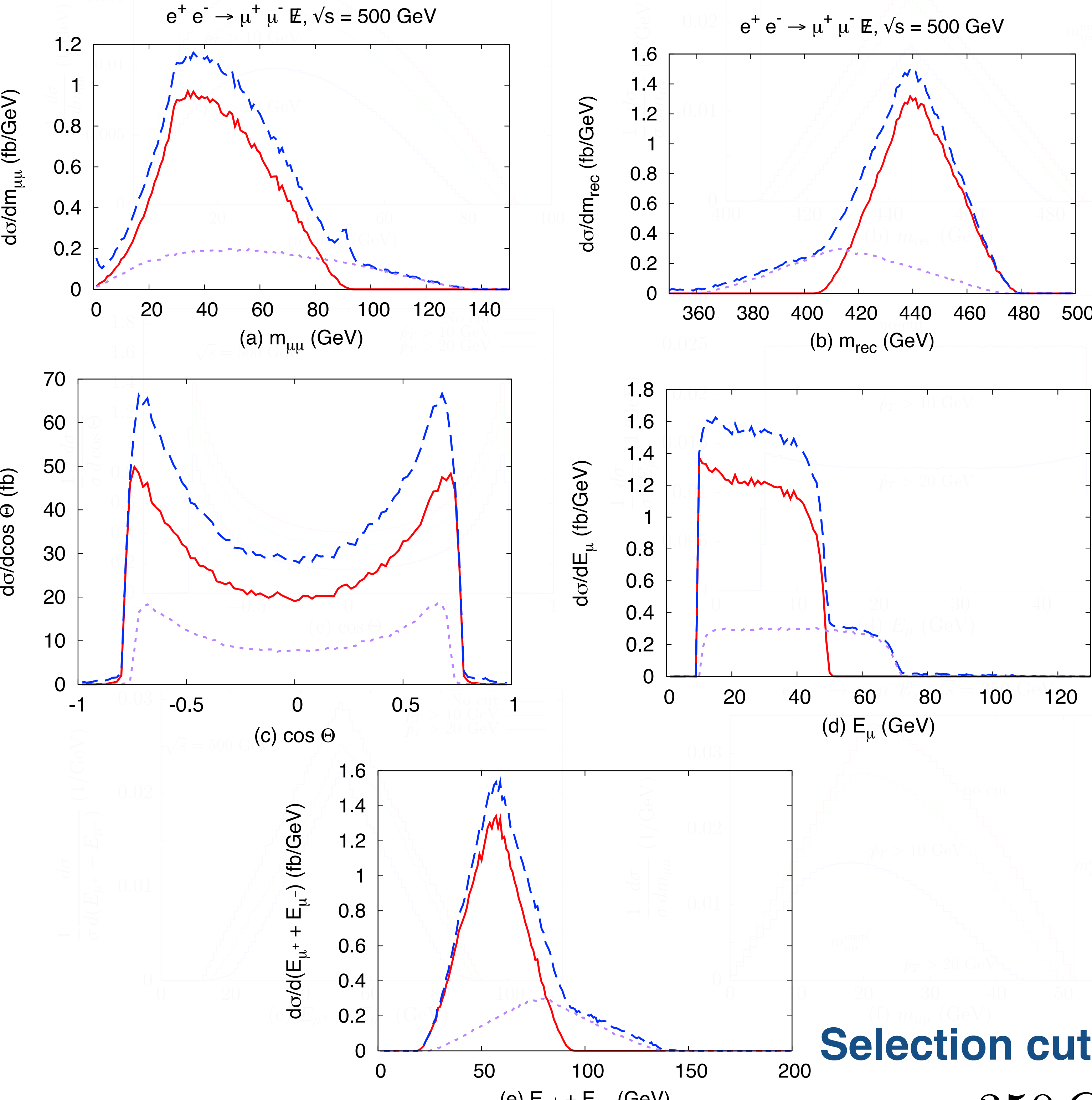
$\mathcal{P}_{e^-} = +80\%$ and $\mathcal{P}_{e^+} = -30\%$ favors $\tilde{\mu}_R\tilde{\mu}_R$
(RH e^- & LH e^+)

$\mathcal{P}_{e^-} = -80\%$ and $\mathcal{P}_{e^+} = +30\%$ favors $\begin{cases} \tilde{\mu}_L\tilde{\mu}_L \\ W^-W^+ \end{cases}$
(LH e^- & RH e^+)

Case-B: production of $\tilde{\mu}_R\tilde{\mu}_R$ *and* $\tilde{\mu}_L\tilde{\mu}_L$

$\mathcal{P}_{e^-} = +80\%$ and $\mathcal{P}_{e^+} = -30\%$

total
$\tilde{\mu}_L\tilde{\mu}_L$
$\tilde{\mu}_R\tilde{\mu}_R$



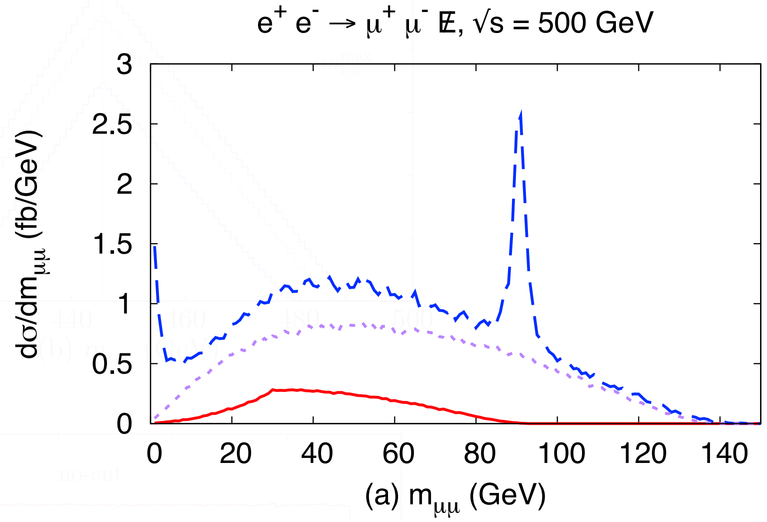
Selection cuts:

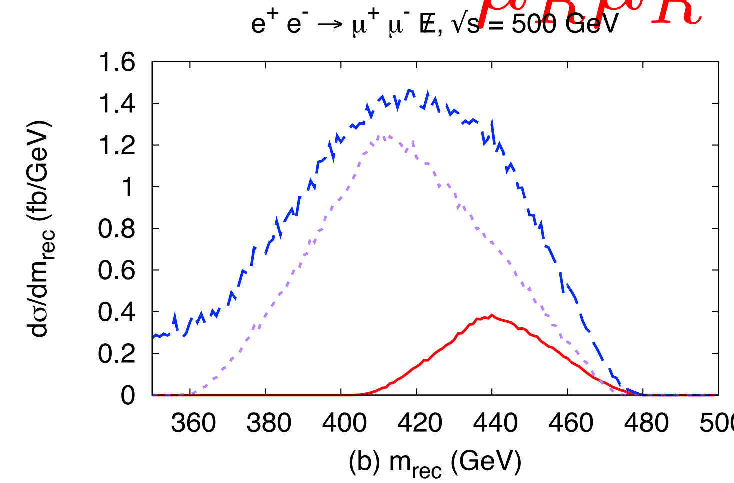
$$m_{\rm rec} > 350\,{\rm GeV}$$

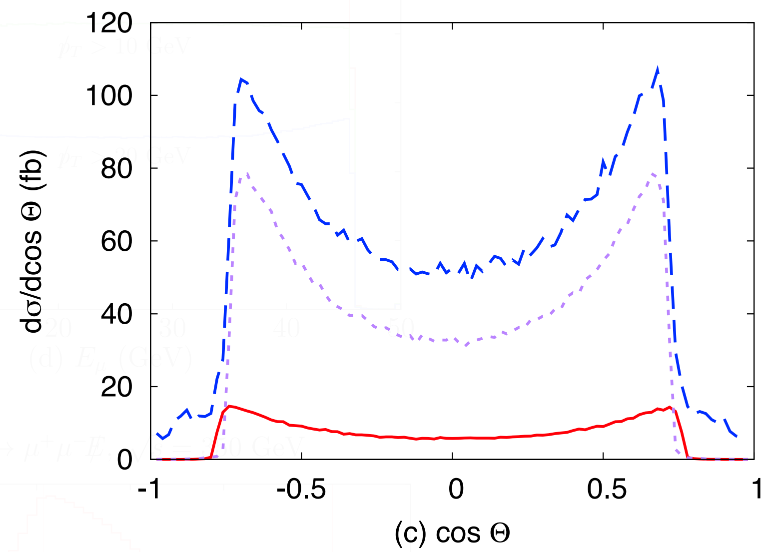
Case-B: production of $\tilde{\mu}_R\tilde{\mu}_R$ and $\tilde{\mu}_L\tilde{\mu}_L$

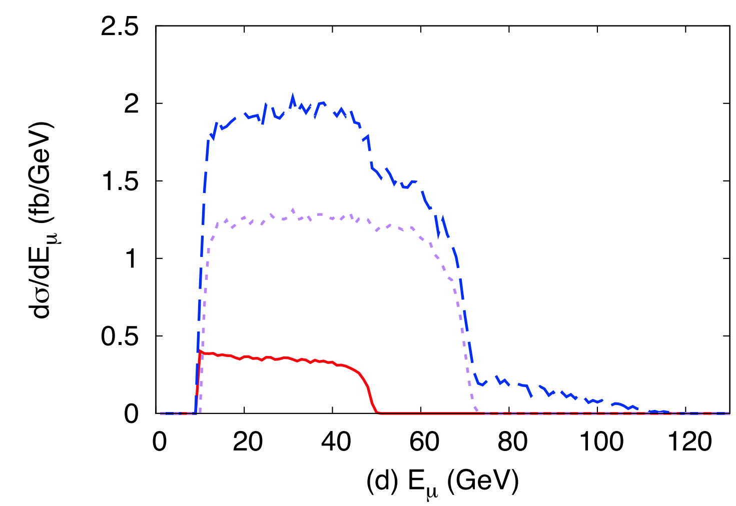
$\mathcal{P}_{e^-} = -80\%$ and $\mathcal{P}_{e^+} = +30\%$

total
$\tilde{\mu}_L\tilde{\mu}_L$
$\tilde{\mu}_R\tilde{\mu}_R$









Selection cuts:

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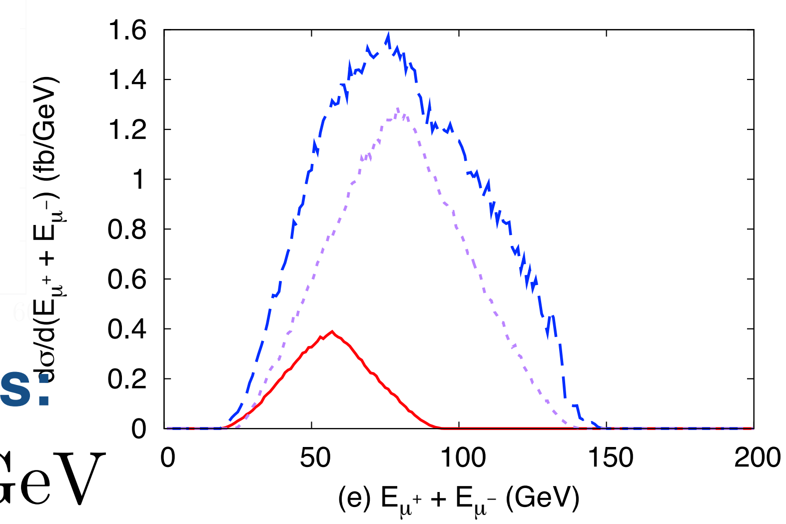


Mass Determination

Likelihood Fit on the distributions determining $\{\Delta m_B,\ \Delta m_X\}$

Massless visible particle (Case-A): 0.5 GeV sensitivity

Massive visible particle (Case-C): 5 GeV

As comparison to the mono-photon search
A likelihood fit on the photon spectrum gives ~ 50 GeV

The End

Thank you for the attention!

Some Questions

1.Cross section estimated for signal processes?

~20fb*100fb-1~2000 SG events

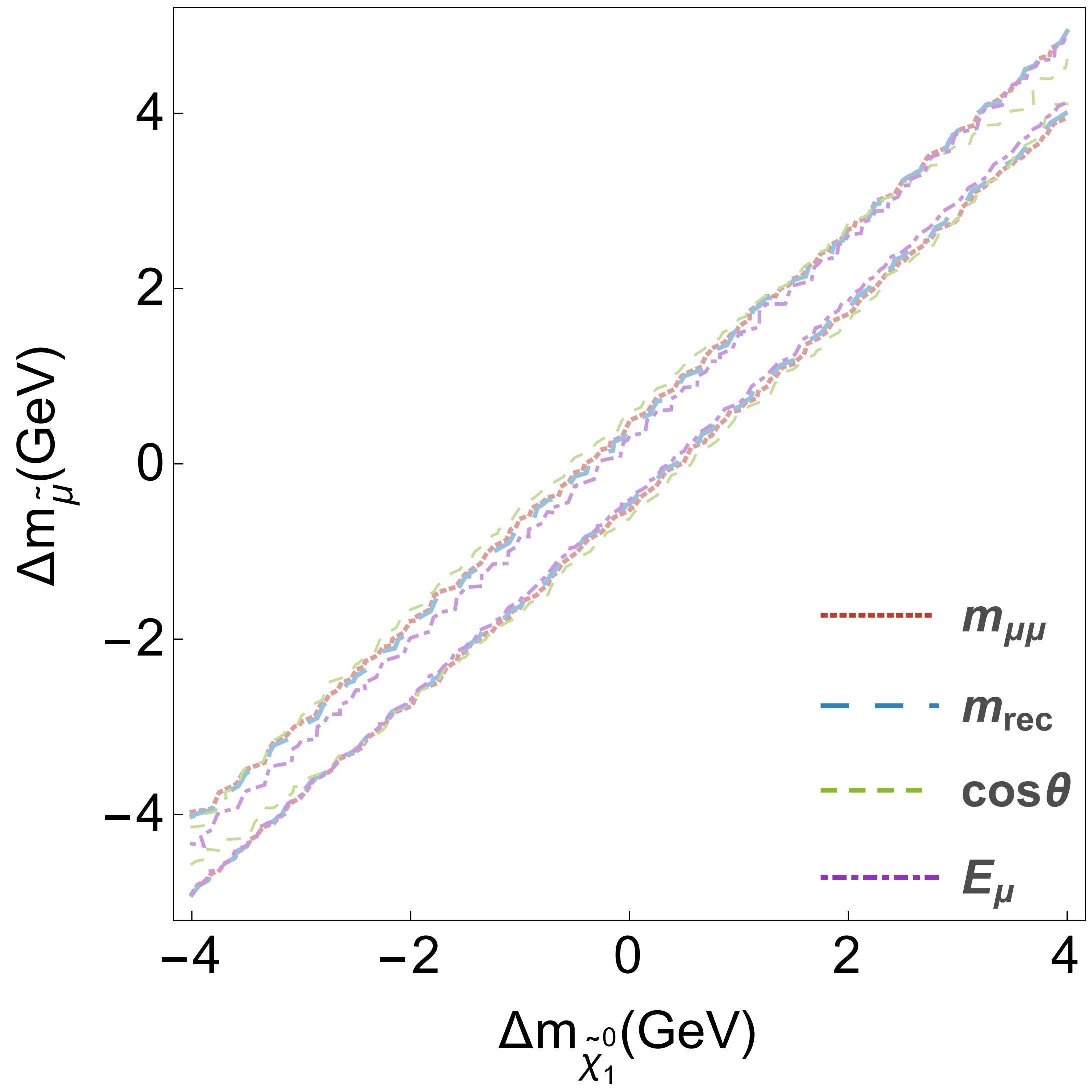
2. To compare with other ILC studies.

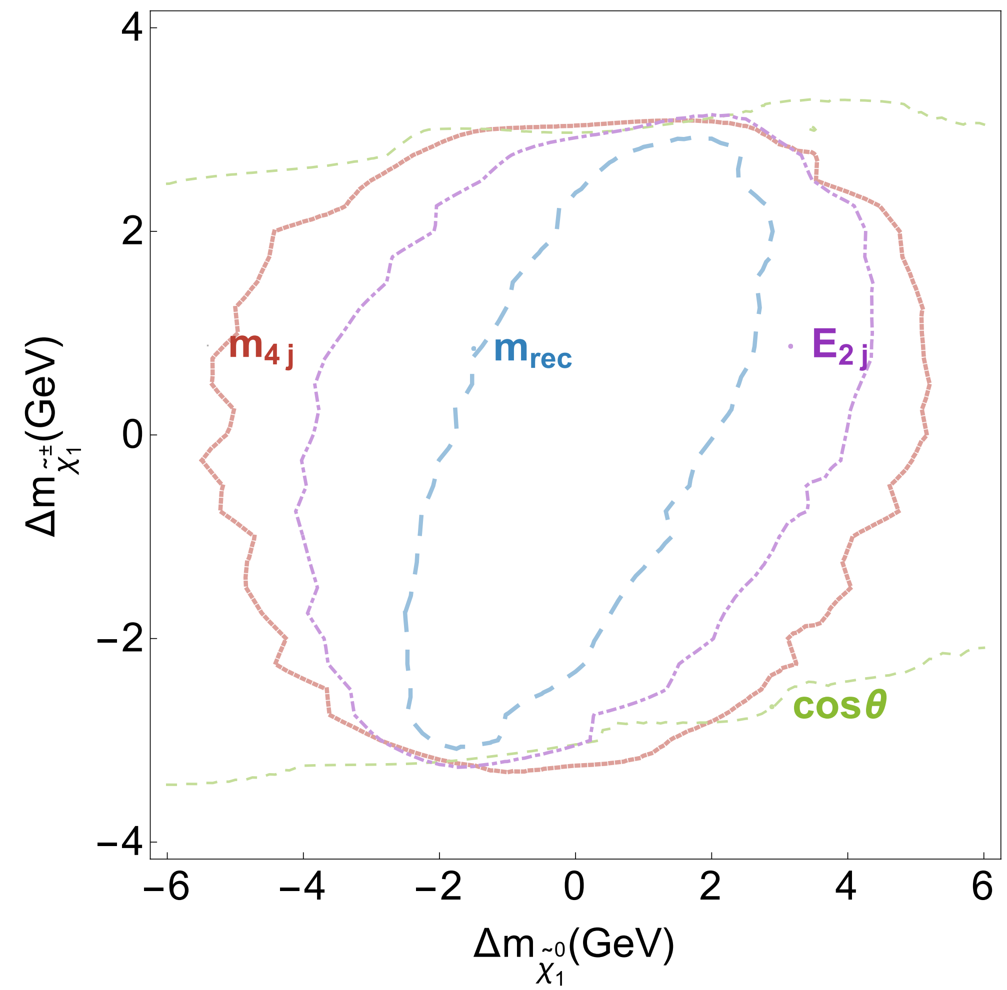
(Comparable to cascade, better than mono-photon)

3. Background:

- **other dominant SUSY background X_1X_j(X_j>ll +X_1) negligible with our vs, mass choice.**
- **SM: WW, ZZ, eemm (with ee missing down the beam pipe), eetautau**

Some Plots


4
2
0
−2
−4
Δm$_{\tilde{\mu}}$(GeV)
−4 −2 0 2 4
Δm$_{\tilde{\chi}_1^0}$(GeV)
$m_{\mu\mu}$
m_{rec}
cosθ
E_μ


4
2
0
−2
−4
Δm$_{\tilde{\chi}_1^\pm}$(GeV)
−6 −4 −2 0 2 4 6
Δm$_{\tilde{\chi}_1^0}$(GeV)
m_{4j}
m_{rec}
E_{2j}
cosθ