

# LHC Constraints on $L_\mu - L_\tau$ Interactions

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with Adam Martin

## Why $L_\mu - L_\tau$ ?

An accidental global symmetry of SM.

Anomaly free! Can be gauged.

$L_\mu - L_\tau$  is not realized in nature (i.e. tau decay to electron), so it must be broken.

predicts a  $Z'$  that only couples to muon and tau family.

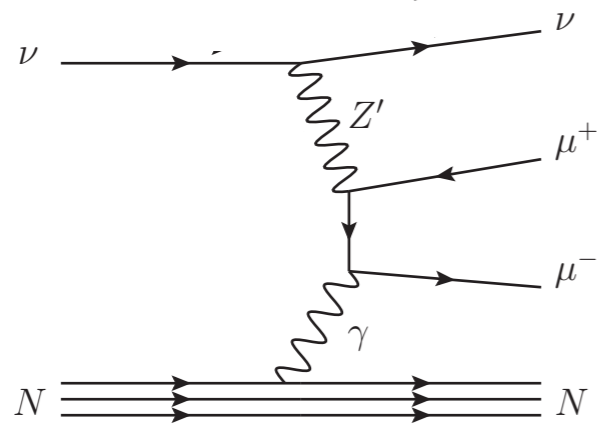
Currently not very constrained, because it does not couple at tree level to quarks (LHC) and electron (BaBar II).

Also motivated because of  $(g - 2)_\mu$  anomalous magnetic moment of muon

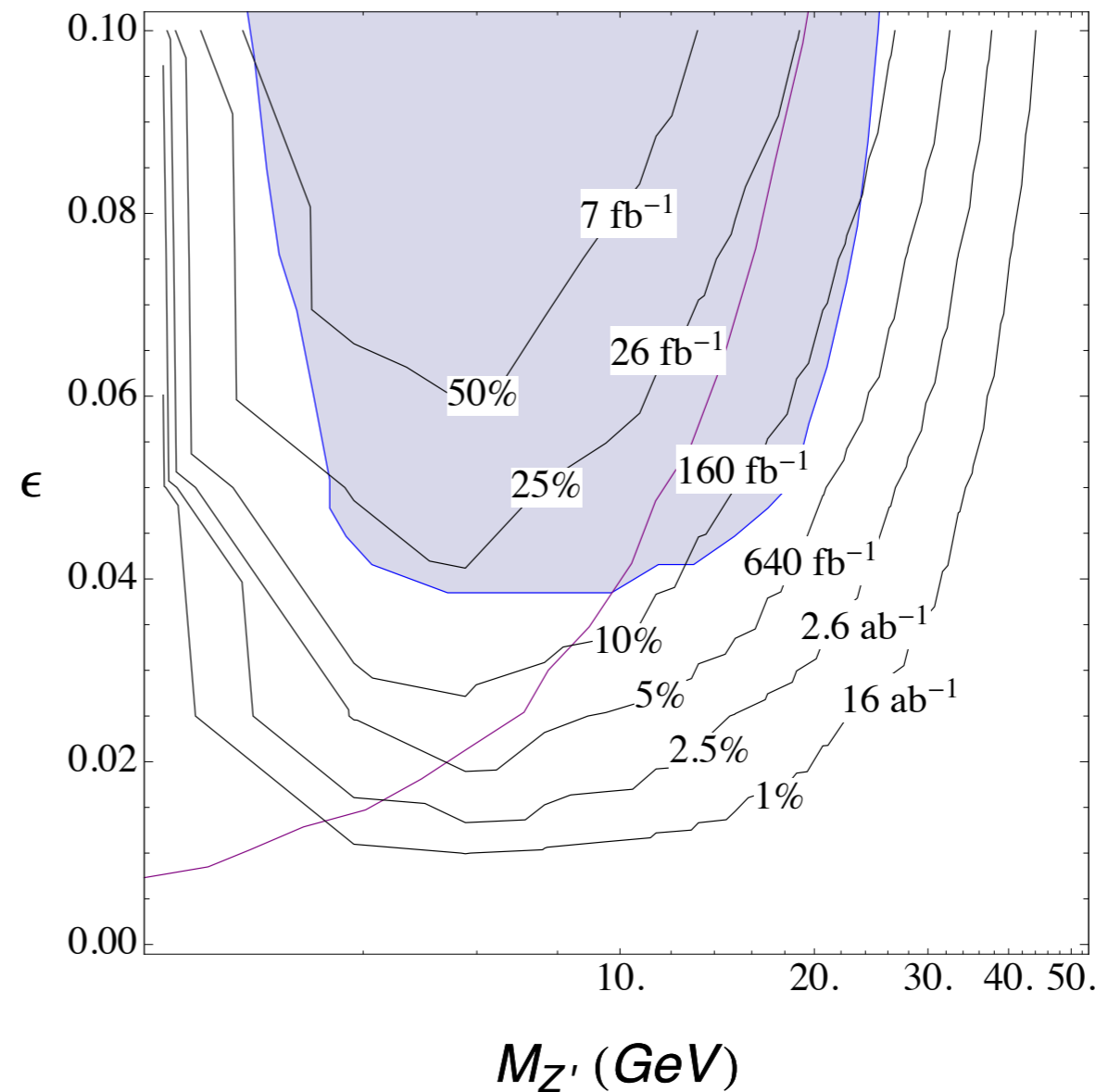
# Current Bounds on $Z'$ of $L_\mu - L_\tau$ :

Shaded region: Bounds from LHC 8, from recasting  $pp \rightarrow Z \rightarrow 4\mu$

Purple Line: CCFR bound from Neutrino trident production:



Black contour lines: the percent increase in the rate of cross section including  $Z'$  and the needed luminosity to get  $5\sigma$ .

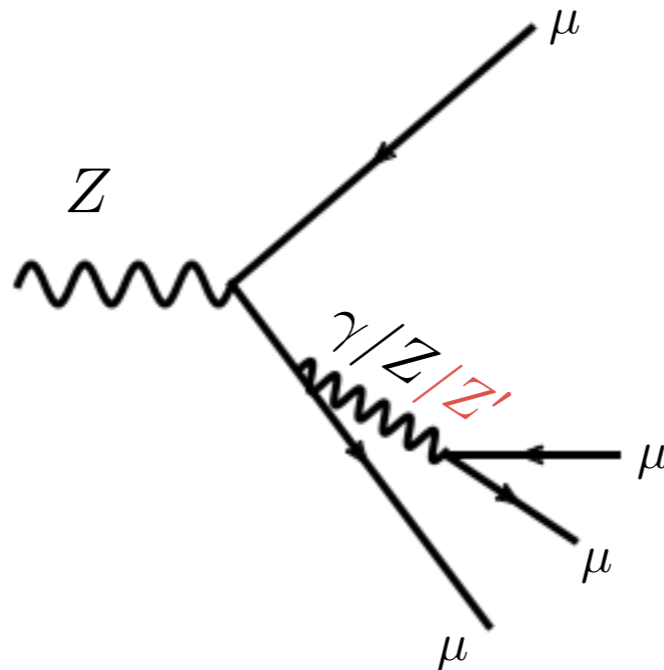


$\epsilon g'$  : the coupling of  $Z'$  to  $\mu$  and  $\tau$  family

# Optimized Search at the LHC

$pp \rightarrow Z \rightarrow 4\mu$  is clean and well-measured.

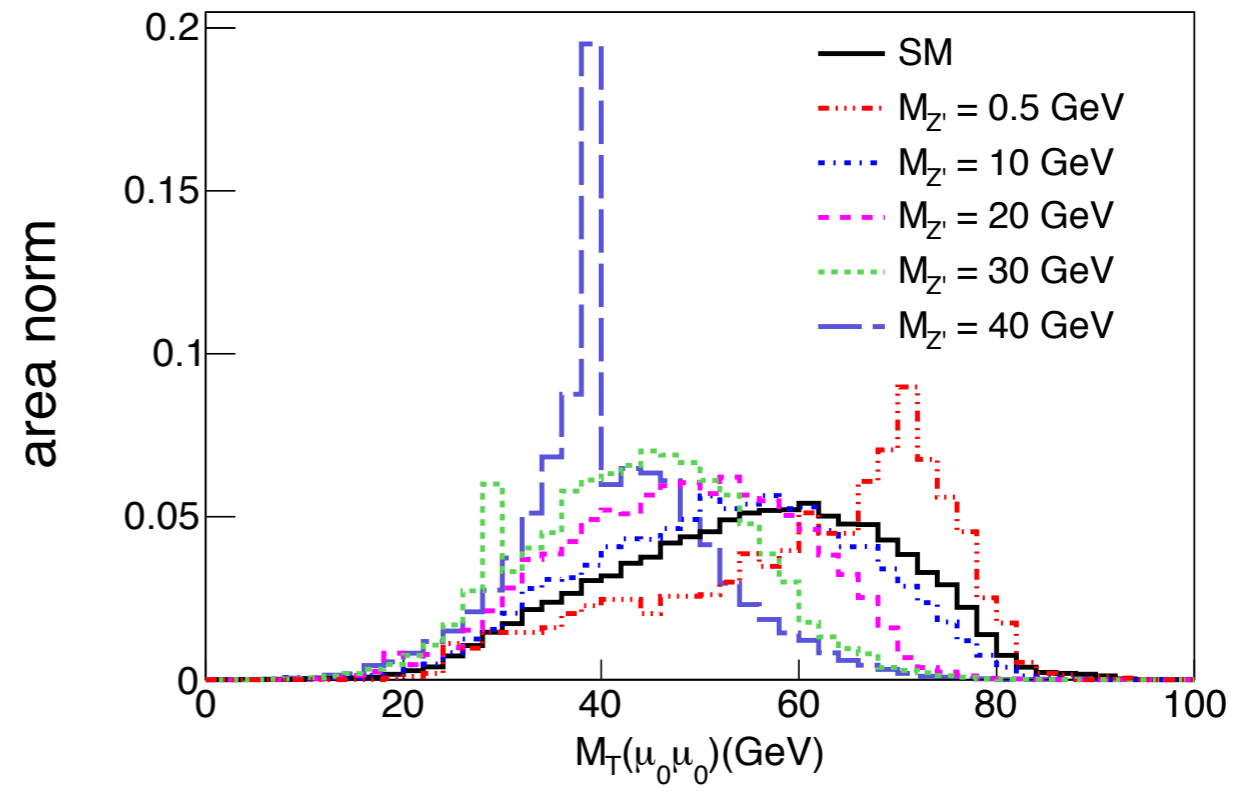
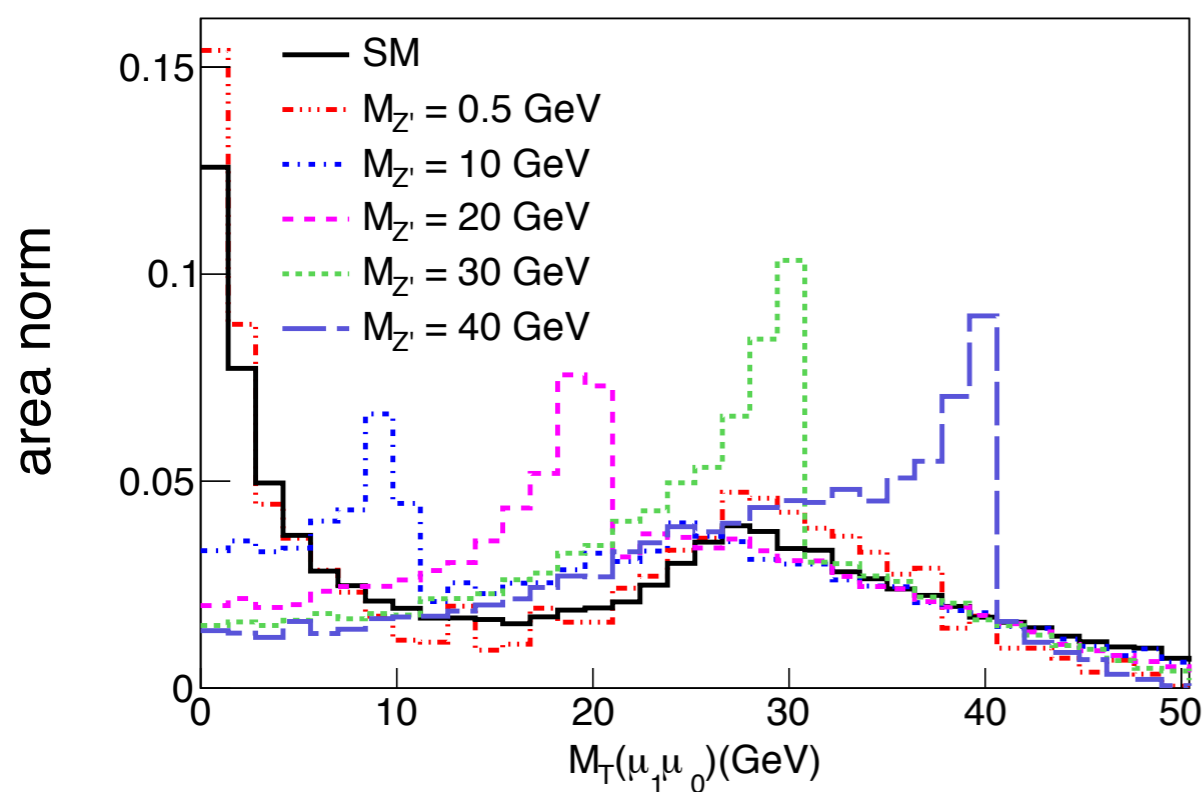
$pp \rightarrow Z \rightarrow 4e$  and  $pp \rightarrow Z \rightarrow 2e2\mu$  can be used as background control sample.



# Optimized $Z'$ search in $pp \rightarrow 4\mu$

The main difference between  $Z'$  and photon (the biggest background), is that  $Z'$  is massive.

**We cannot tell which pair of muons should reconstruct  $Z'$  mass.**

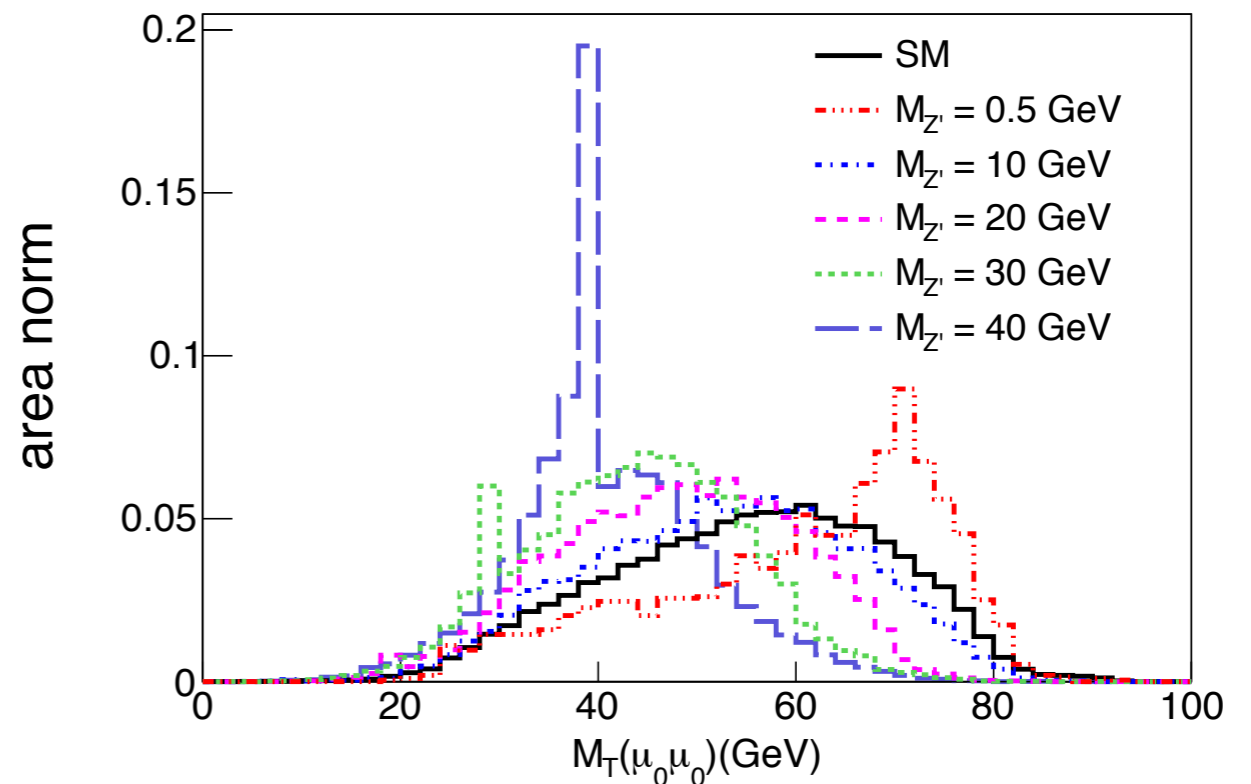
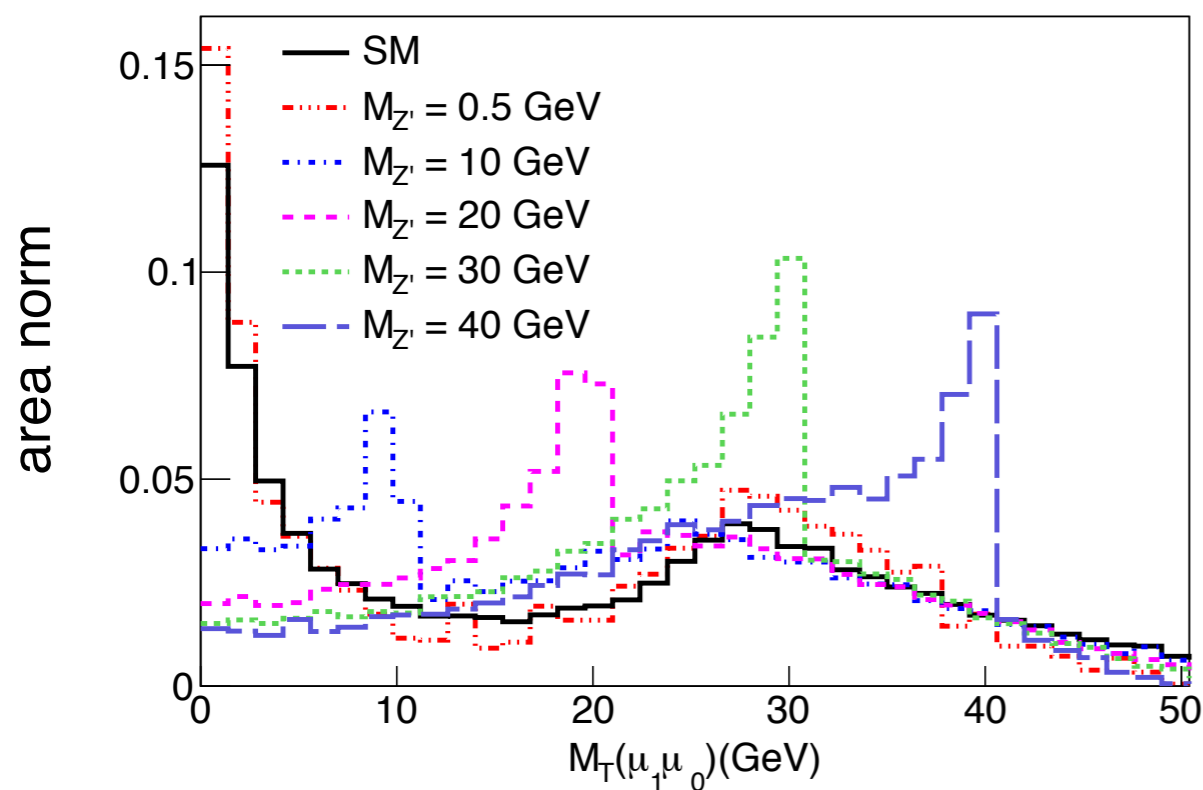


$$M_T^2(\mu_i^+ \mu_j^-) = 2p_T^{\mu^+} p_T^{\mu^-} (1 - \cos \Delta\phi(\mu_i^+, \mu_j^-))$$

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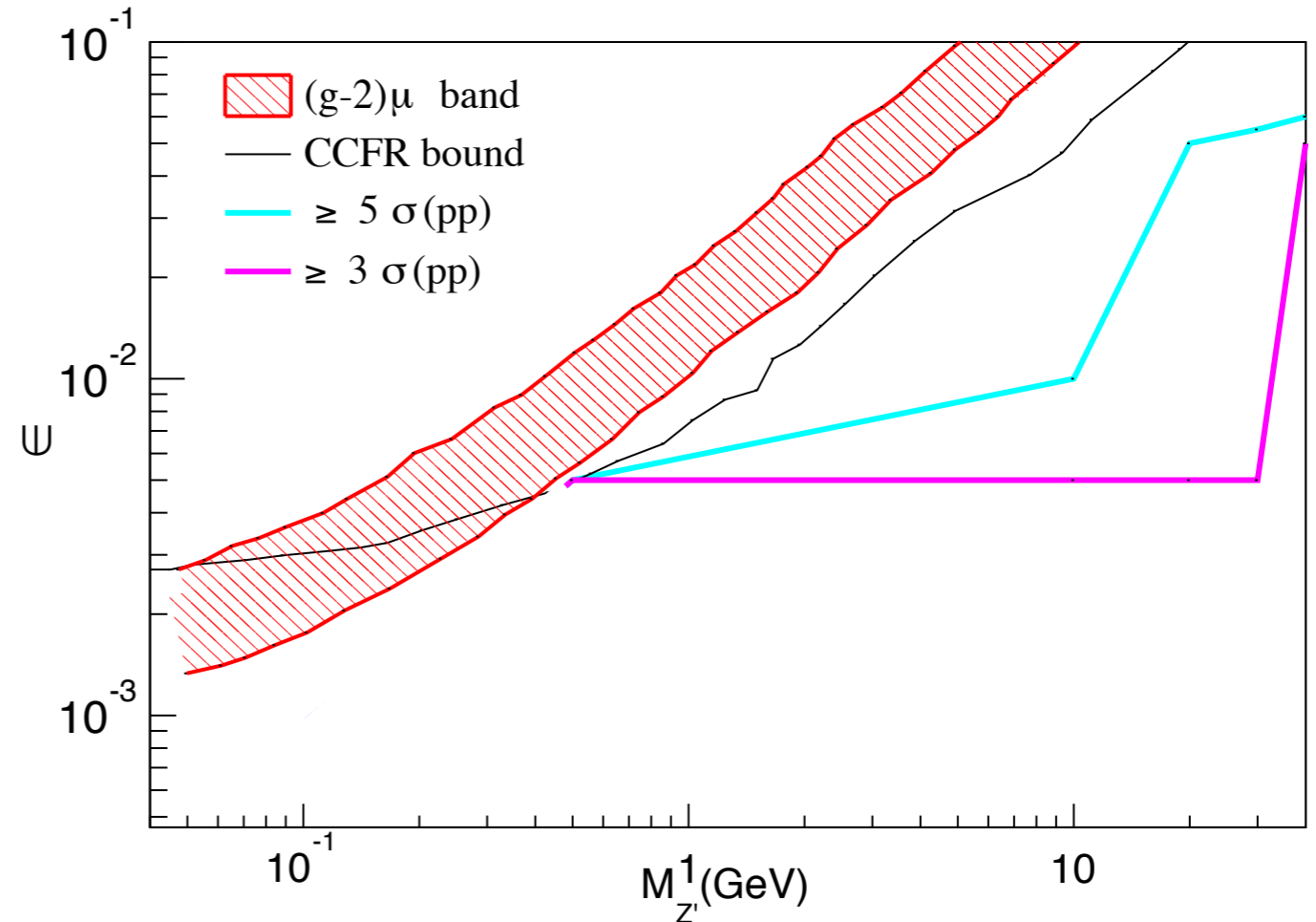


$M_T(\mu^+, \mu^-)$  turned out to be more useful than  $m_{\mu^+\mu^-}$  because of its broader distribution, resulting in more interference between signal and SM.

# New bounds from our study in LHC

The exclusion contour assuming full HL-LHC luminosity of  $3 \text{ ab}^{-1}$ , utilizing  $M_{Z'}$  - dependent cuts.

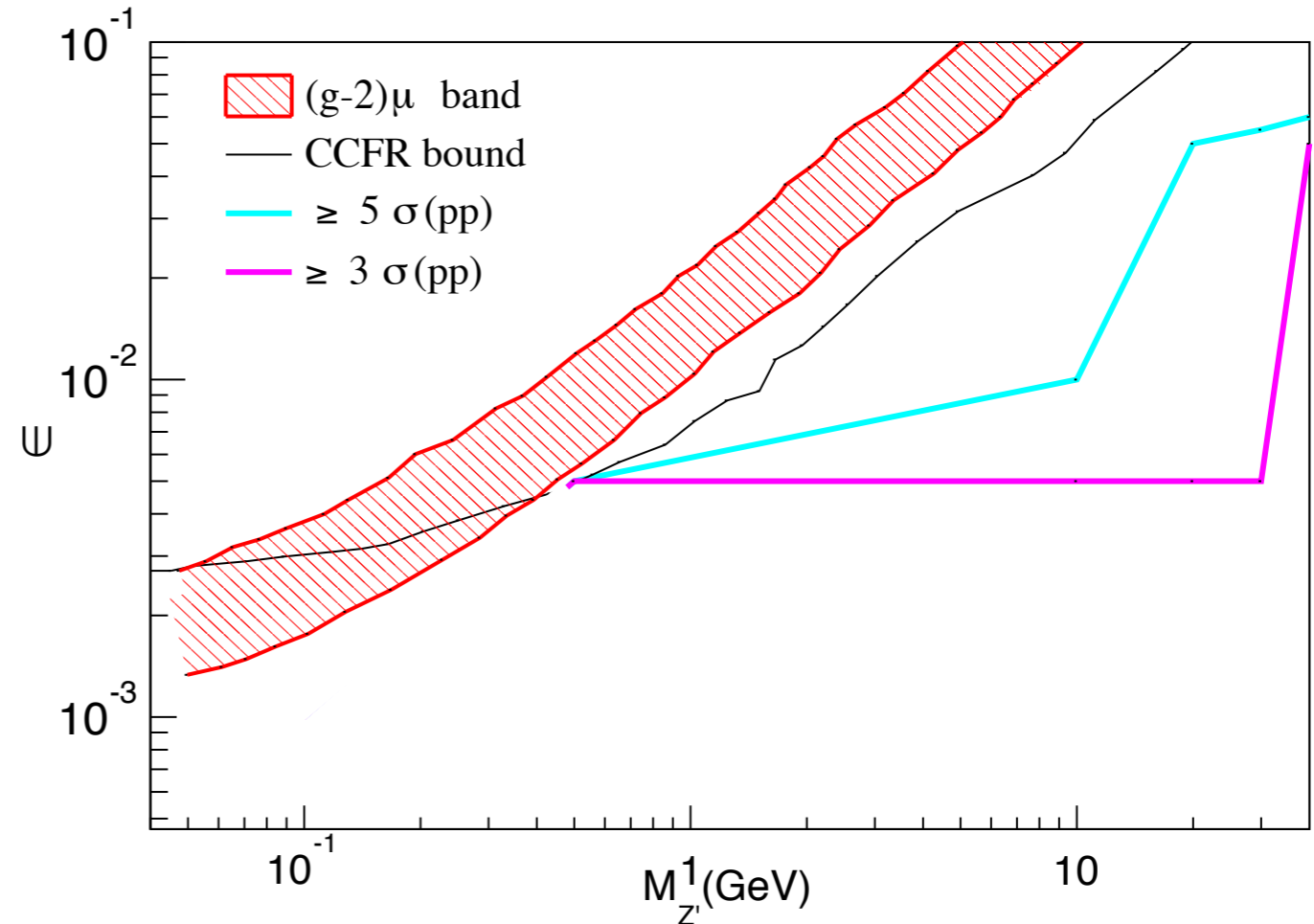
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How about  $M_{Z'} < 2m_\mu$ ?



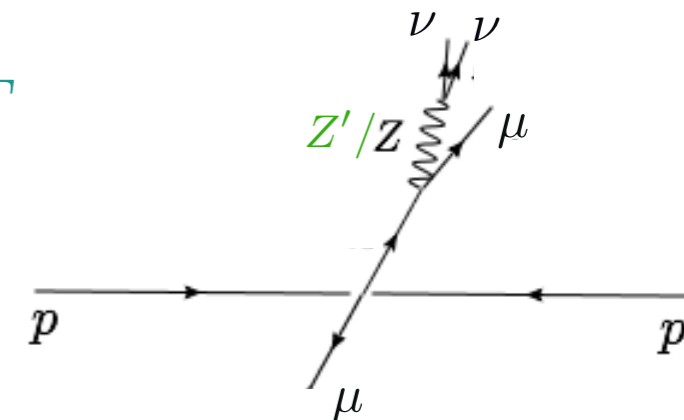
# Optimized Search for $M_{Z'} < 2m_\mu$

Want  $Z'$  to be on-shell.

$$\text{Br}(Z' \rightarrow \nu_\ell \nu_\ell) = 100\%$$

no photon background.

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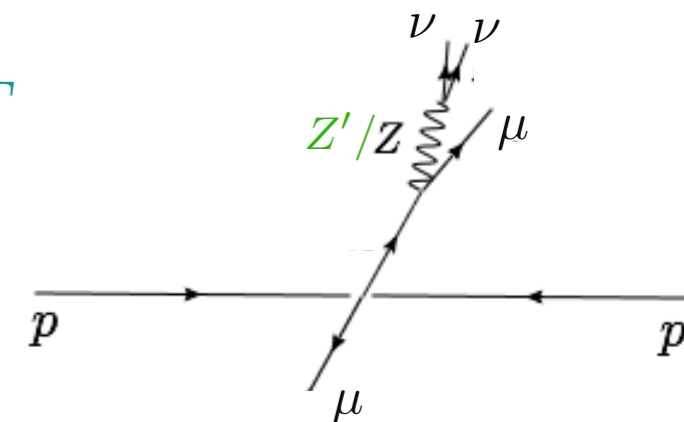
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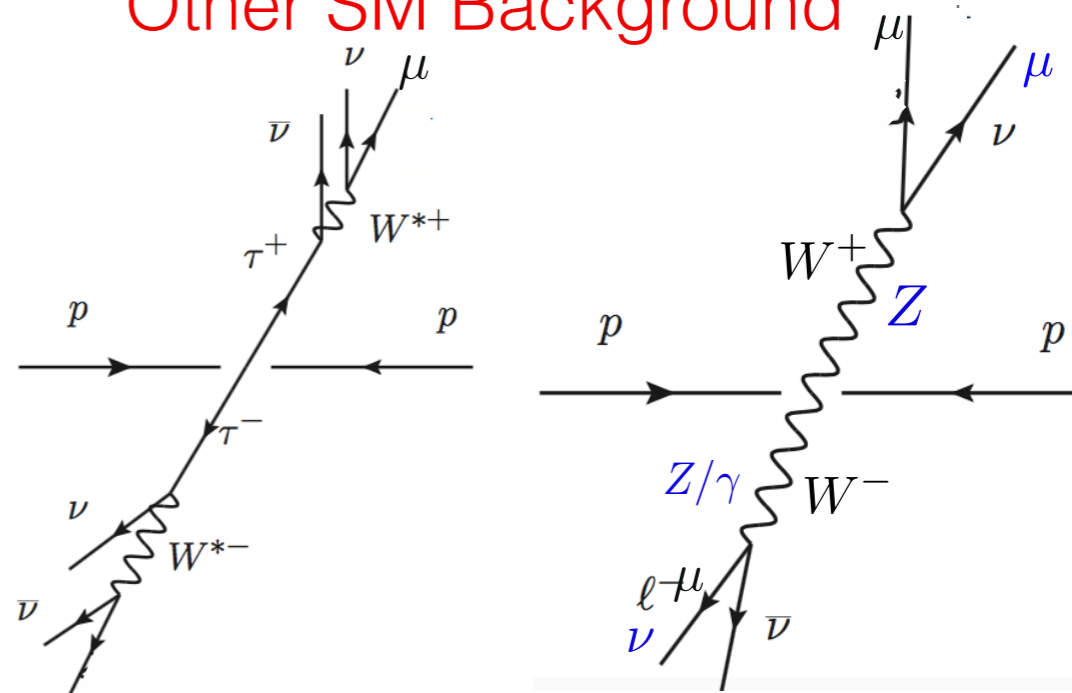
$$pp \rightarrow \tau^+ \tau^- \Big|_{\text{dilepton decay}}$$

$$pp \rightarrow W^{*+} W^{*-} \Big|_{\text{dilepton decay}}$$

$$pp \rightarrow Z^* (Z^* / \gamma^*)$$

$$pp \rightarrow \mu^+ \mu^- + \text{jets}$$

## Other SM Background



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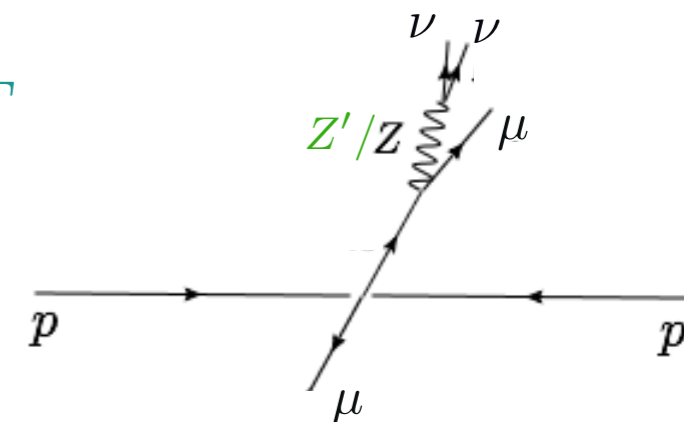
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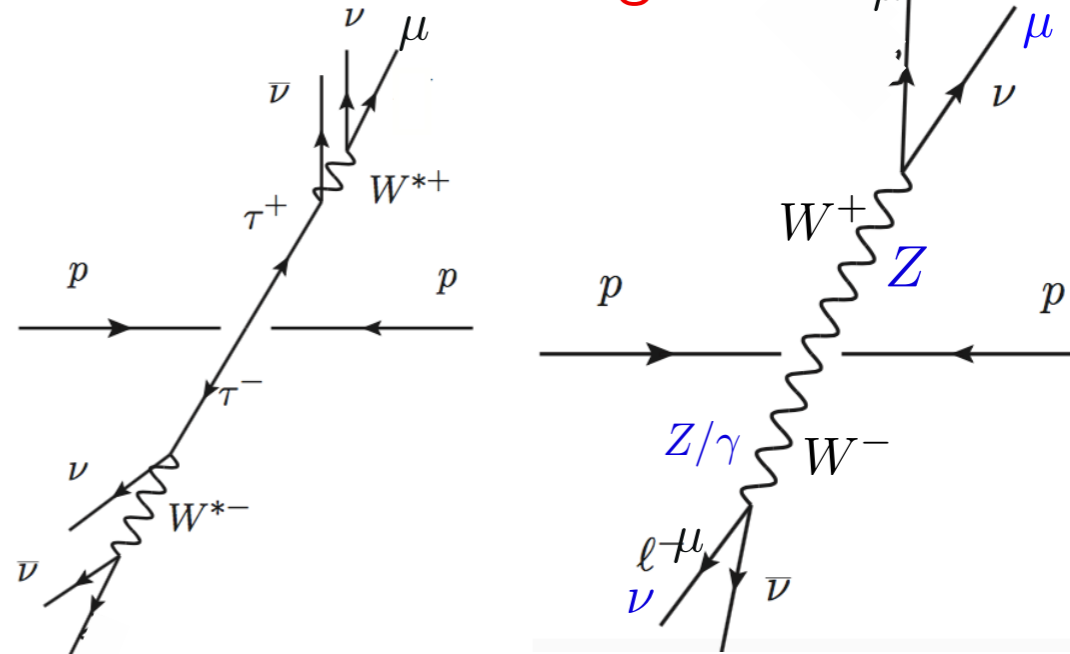
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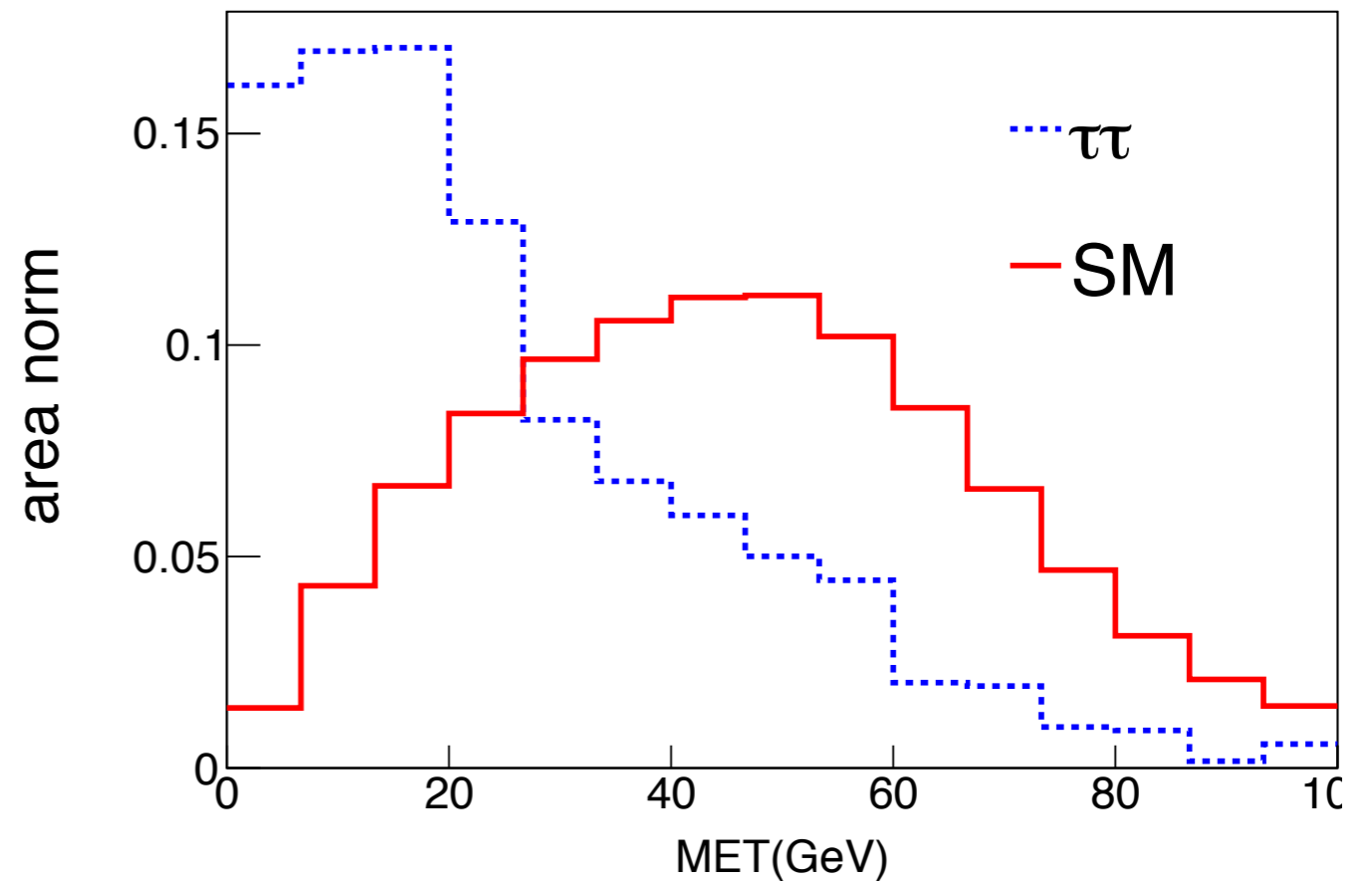
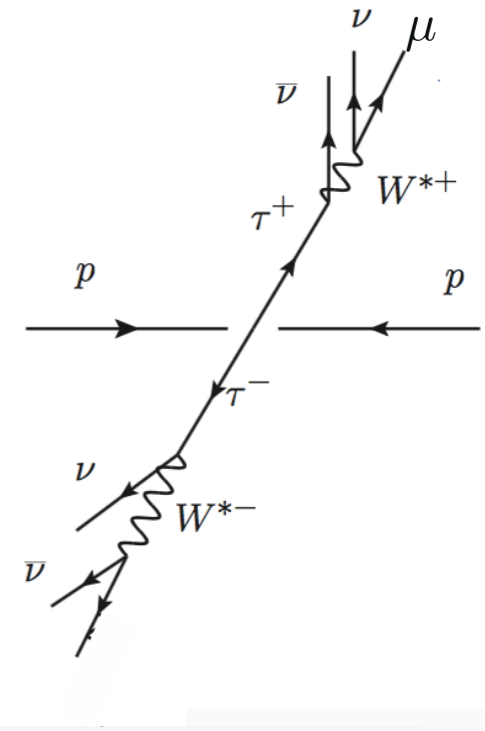
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# Effective Cuts in $pp \rightarrow \mu\mu\cancel{E}_T$

High MET

to reduce  $pp \rightarrow \mu\mu + \text{jets}$   
and  $pp \rightarrow \tau\tau$  background.

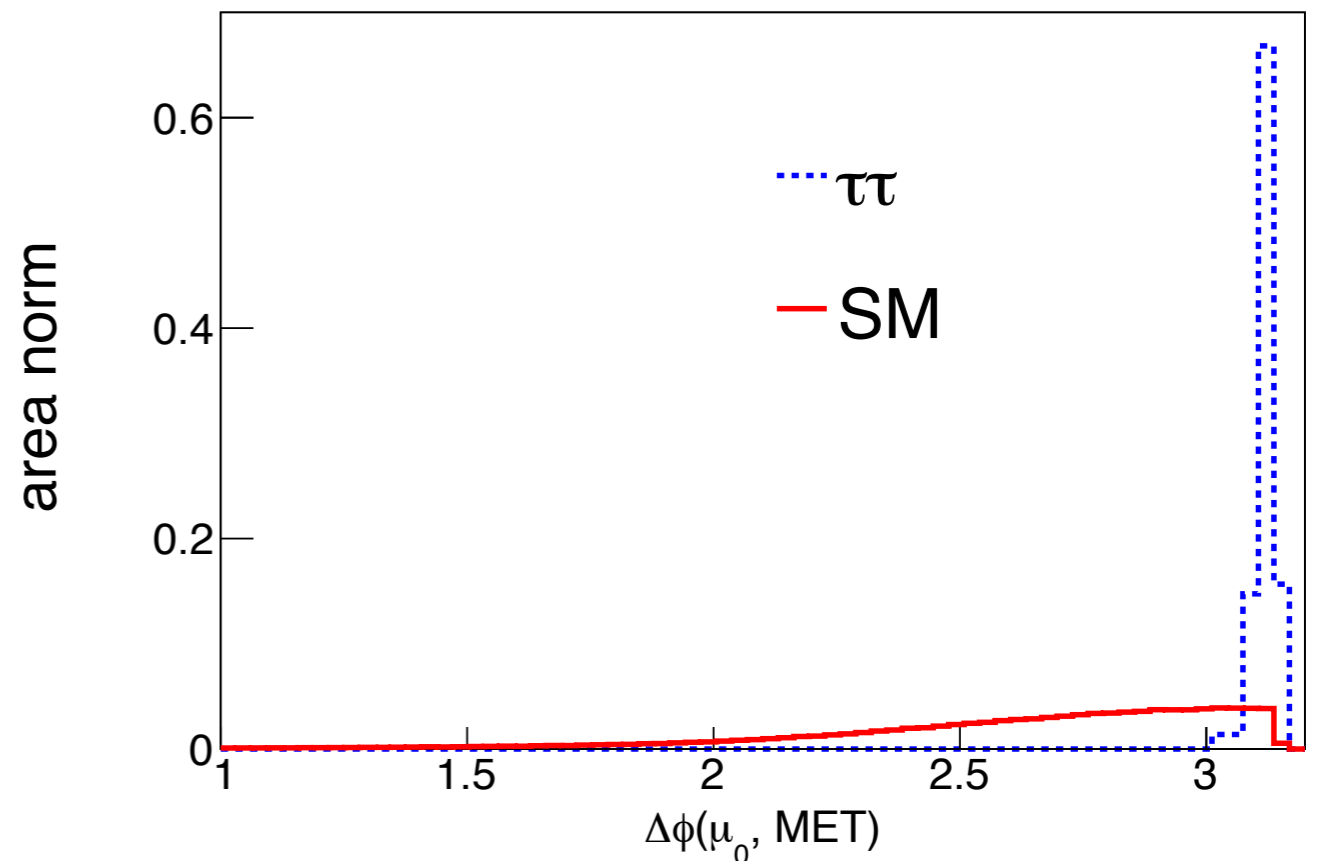
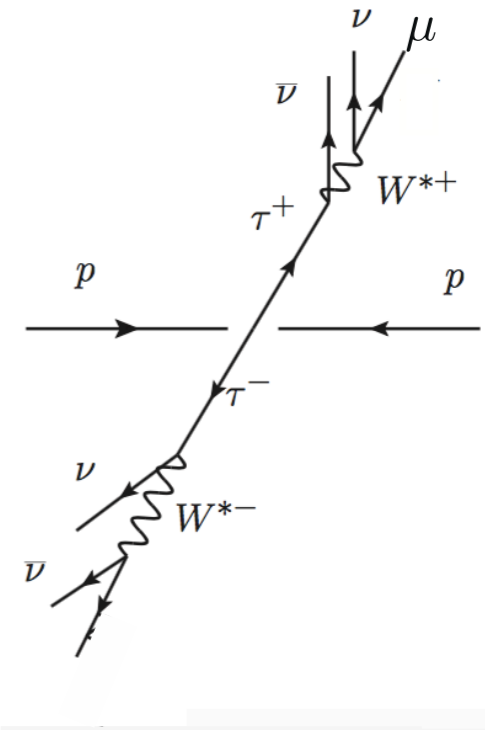


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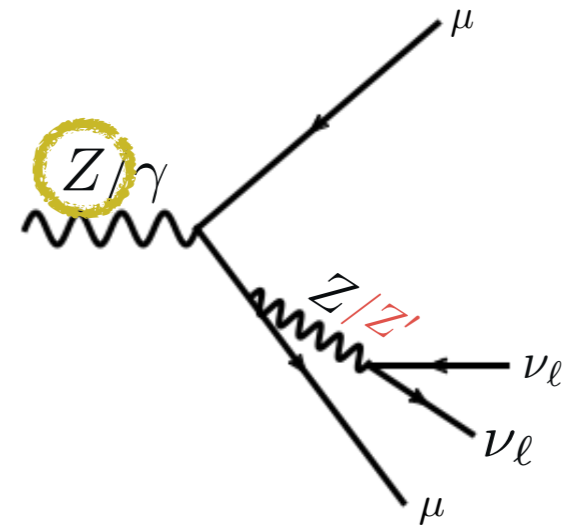
$\Delta\phi(\mu_0, \cancel{E}_T)$   
make  $pp \rightarrow \tau\tau$  negligible.



# Effective Cuts in $pp \rightarrow \mu\mu\cancel{E}_T$

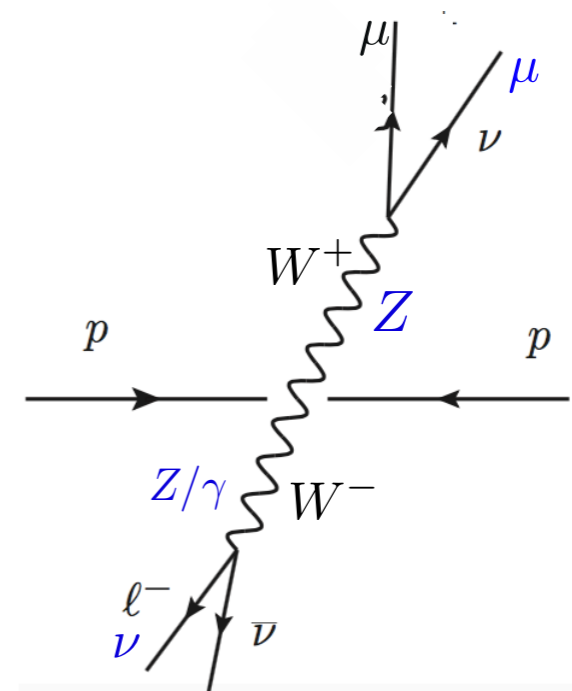
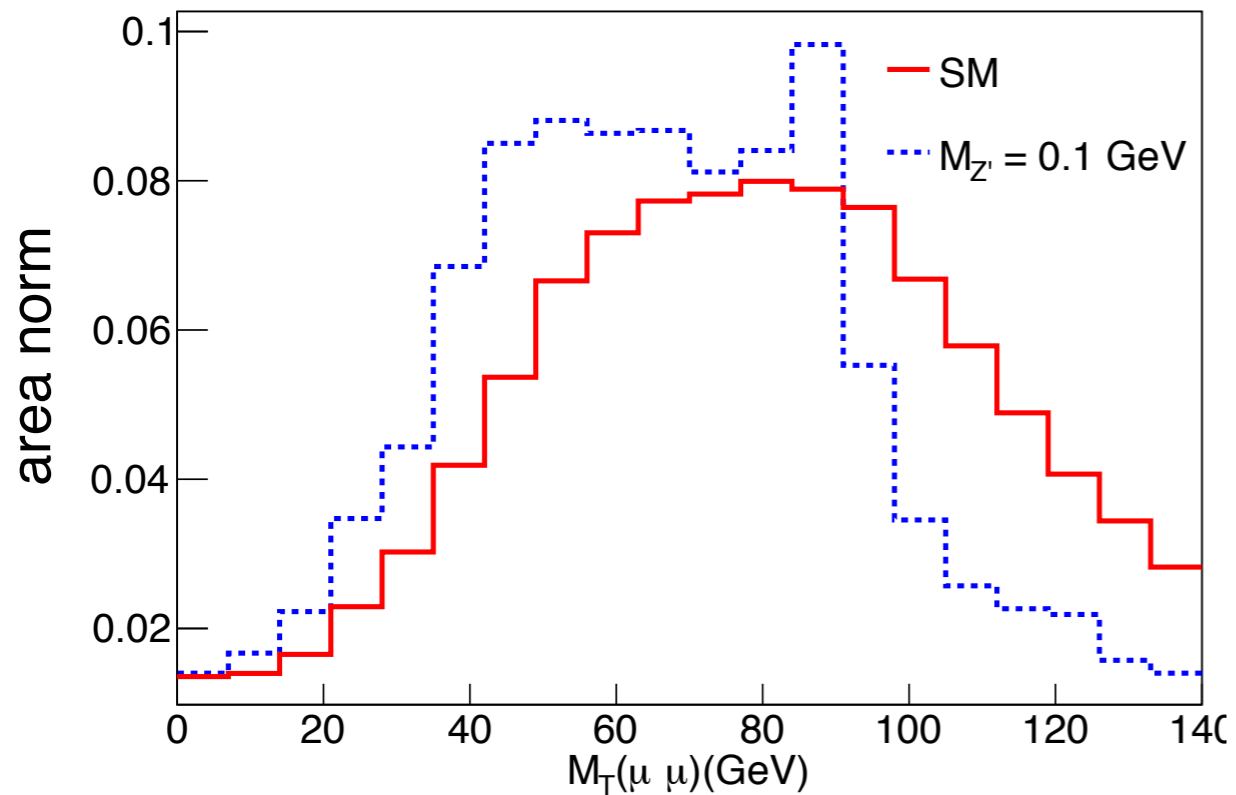
Signal enhanced when Z is on-shell.

$$M_T(\mu\mu) \lesssim M_Z - \cancel{E}_T$$



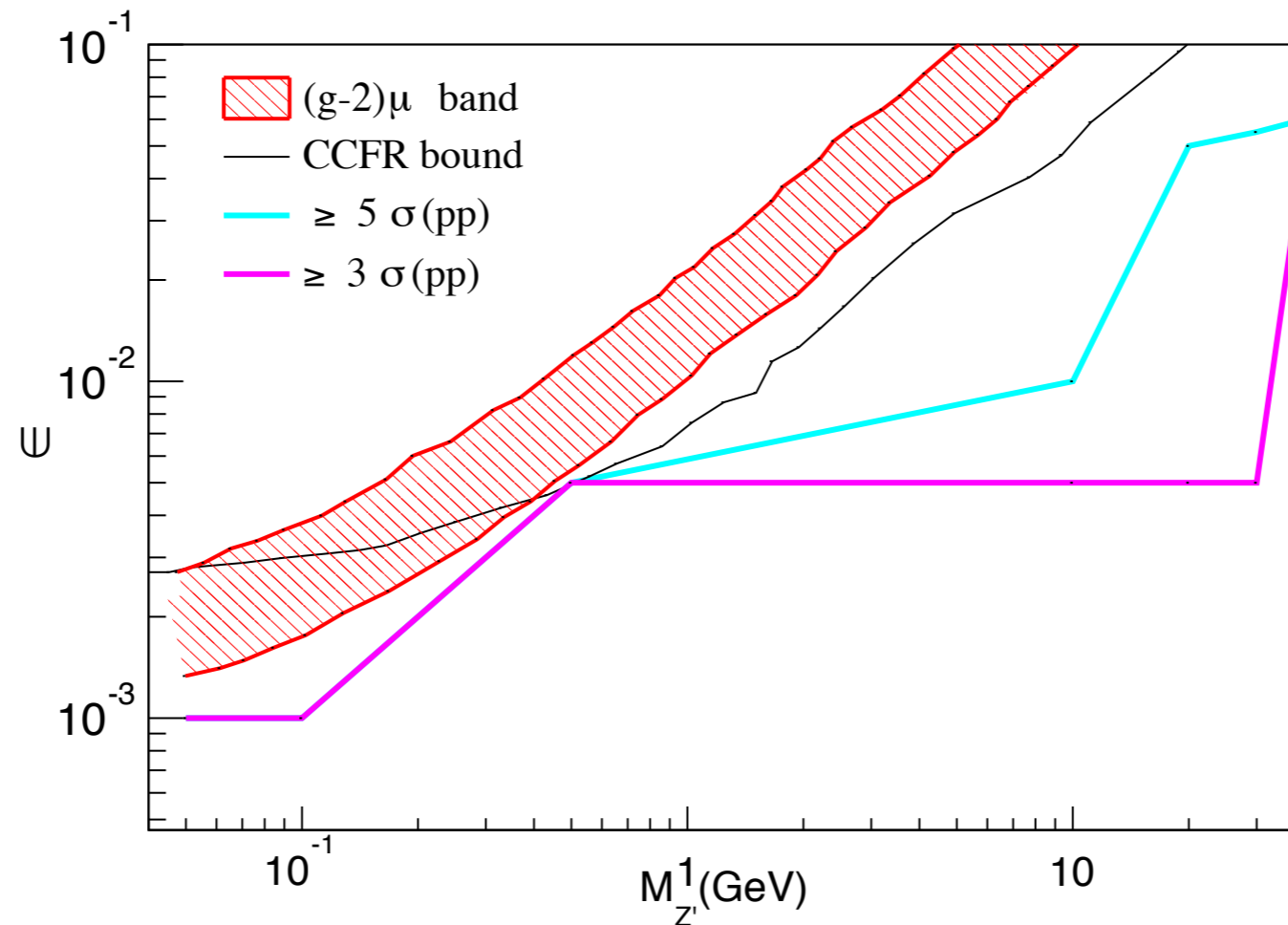
Signal

VS.



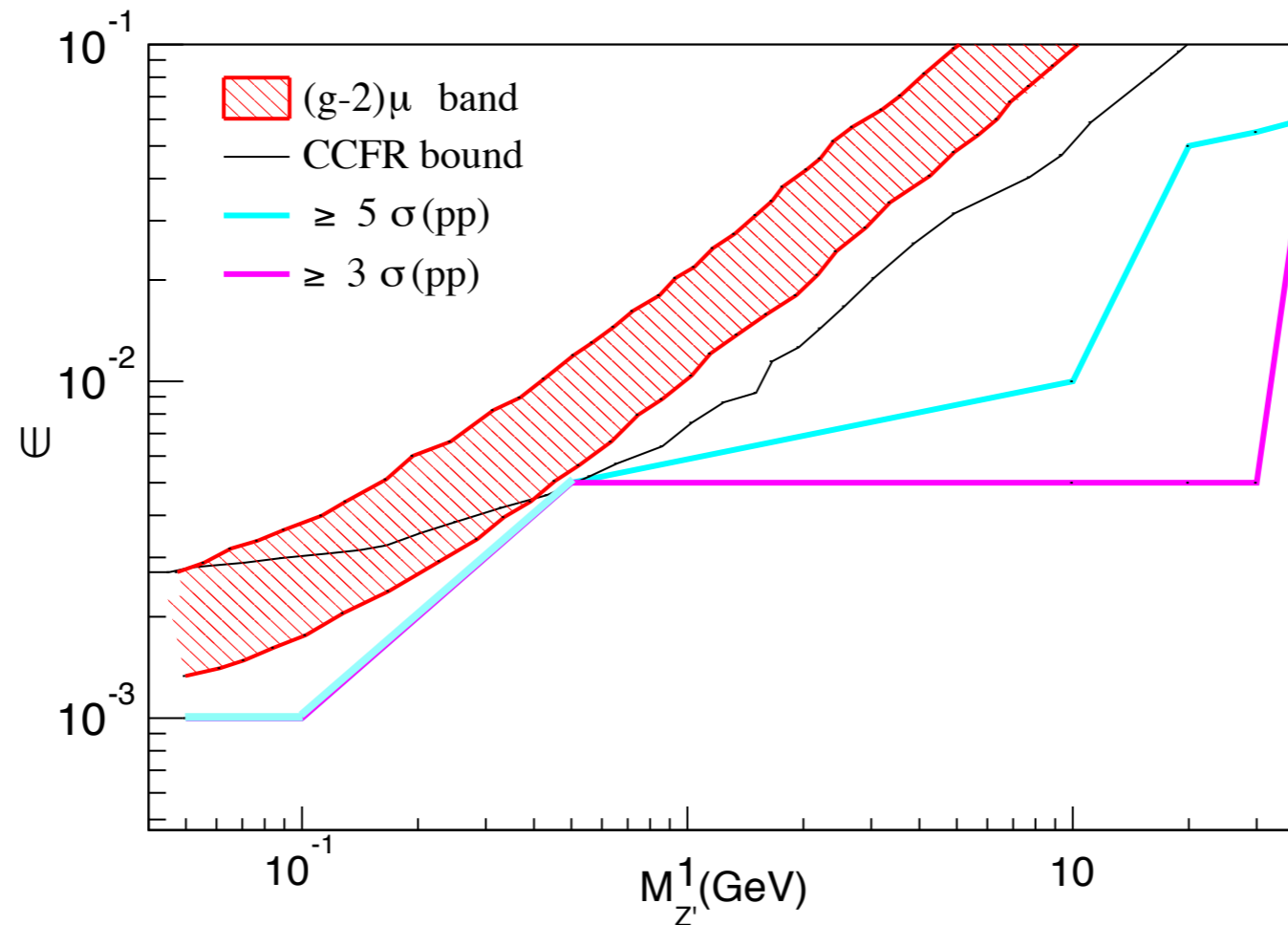
SM

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Can we do even better?!



# Matrix Element Method (MEM)

Assuming a model (i.e. SM), use matrix element of a process to distinguish signal from background.

$$|\mathcal{M}|^2 = |\mathcal{M}(p_i, p_f)|^2$$

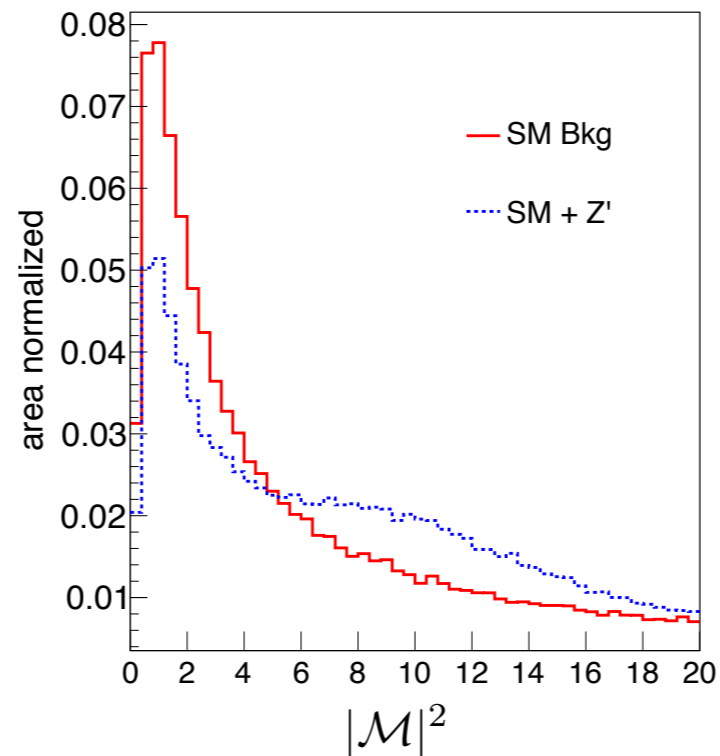
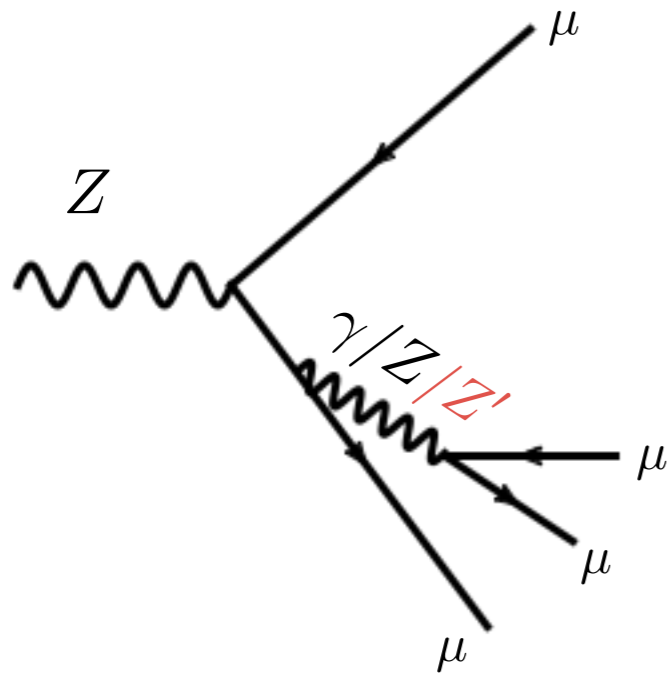
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$$\frac{S}{B} = \frac{\sigma_{SM+Z'}}{\sigma_{SM}} = 1.95$$

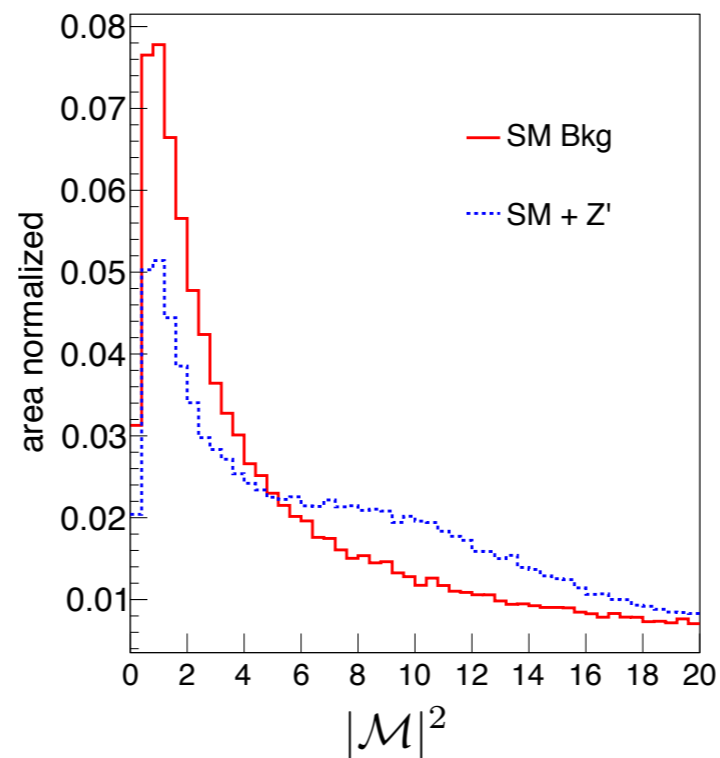
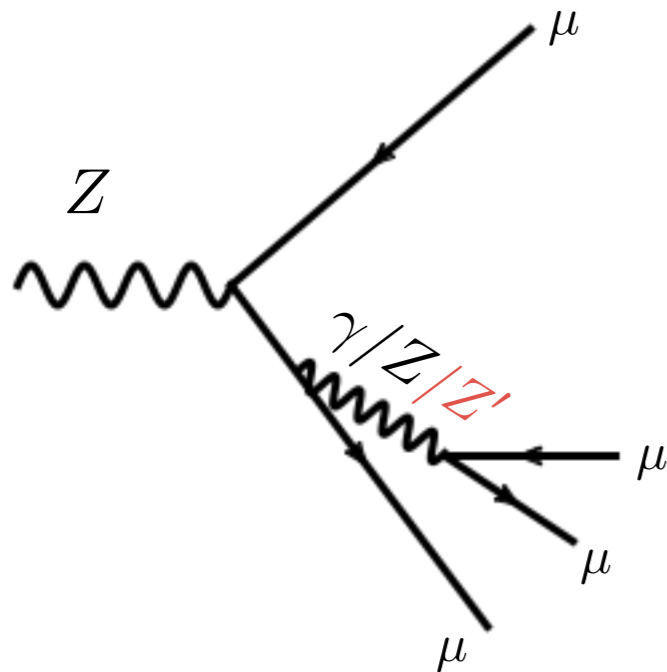
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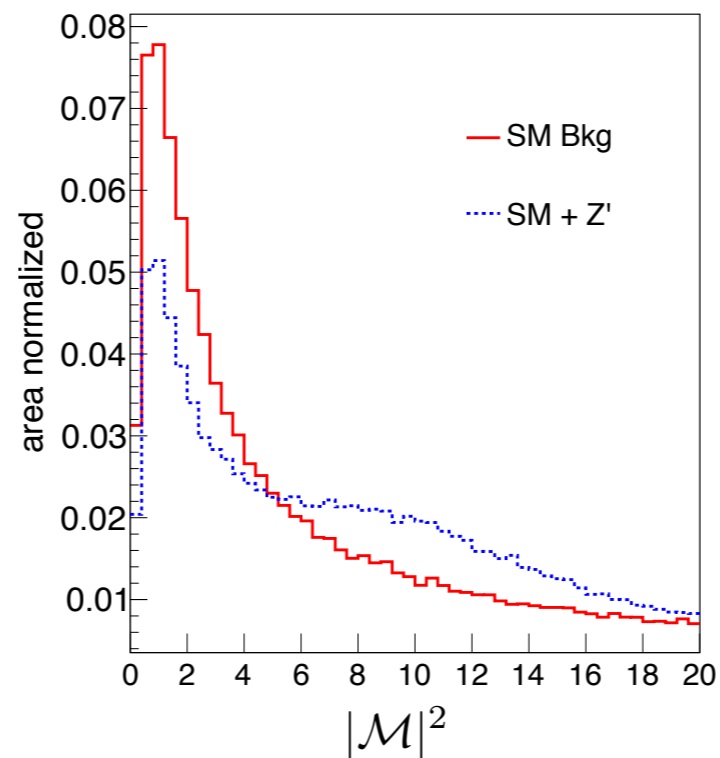
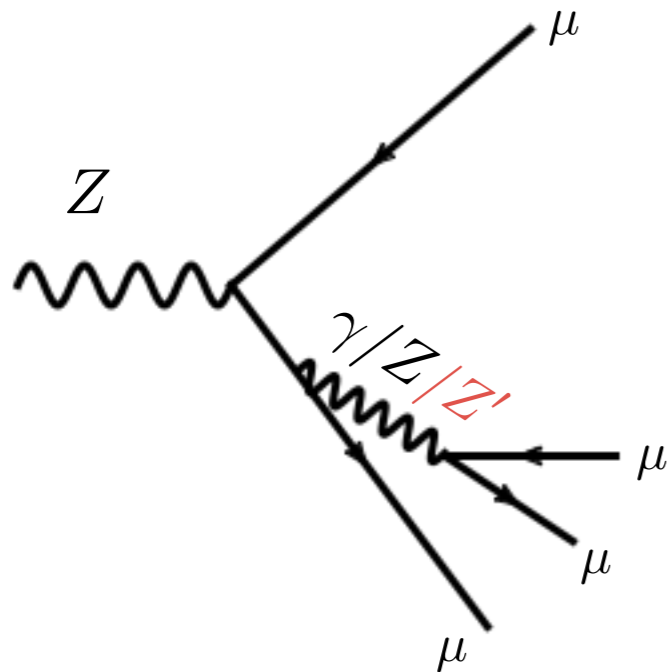
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$pp \rightarrow Z \rightarrow 4\mu$  search can significantly be enhanced using MEM

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**Current on-going project!!**



# Conclusions

- Gauged  $L_\mu - L_\tau$  is a simple extension of SM.
- This model is also motivated because of the anomaly in  $(g - 2)_\mu$
- The current constraints on this model are not very strong.
- For  $2m_\mu < M_{Z'} < M_Z/2$ , the process  $pp \rightarrow Z \rightarrow 4\mu$  can be used to set bounds on  $Z'$ . Because it is well-understood and  $Z \rightarrow 4e, 2e2\mu$  can be used as background control sample.
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**Thank You**