Search for muon-philic light boson at Belle II

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Based on arXiv:1904.13053 [hep-ph]

Collaboration with Youngjoon Kwon (Yonsei U.),
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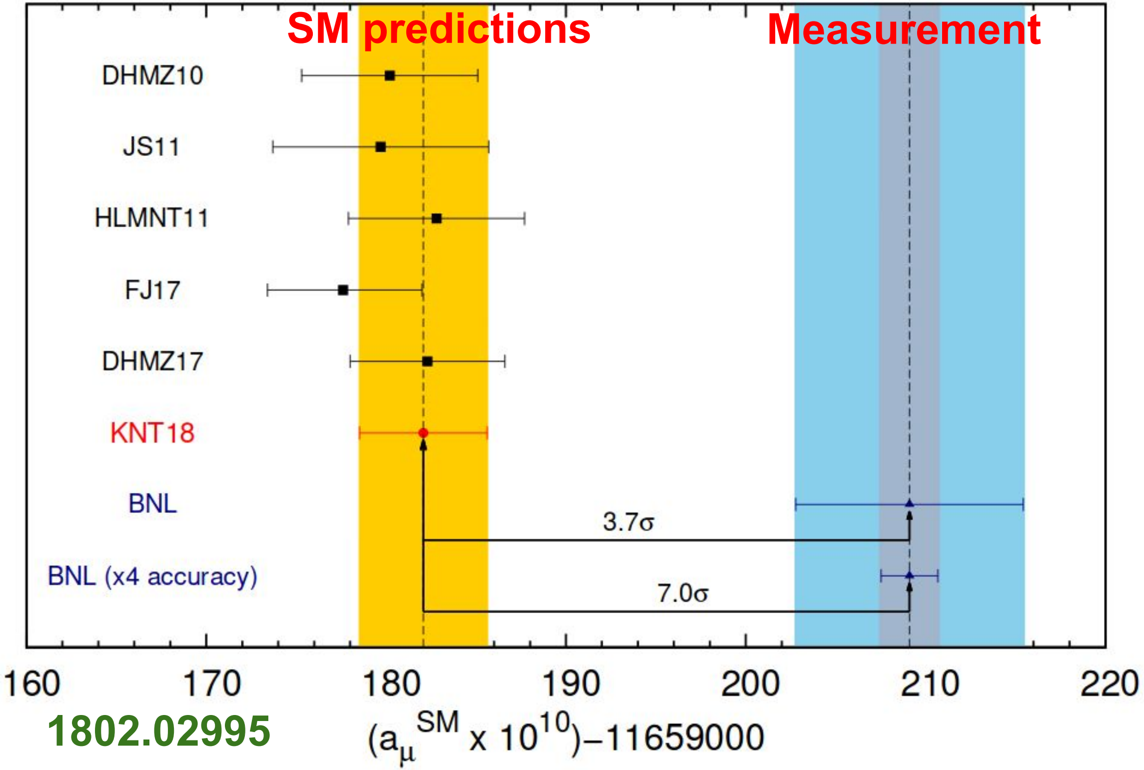
Summer Institute 2019
2019 Aug 19 - Aug 23
Gangneung, Republic of Korea

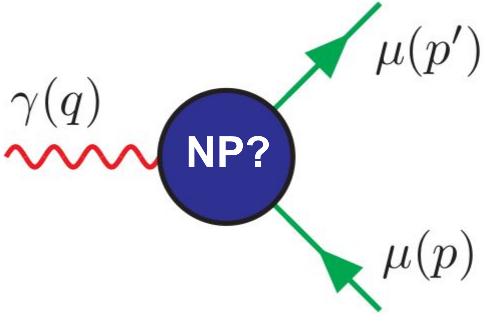
Muon g-2 and New Physics

- Current status of muon g-2 (SM prediction & measurements)

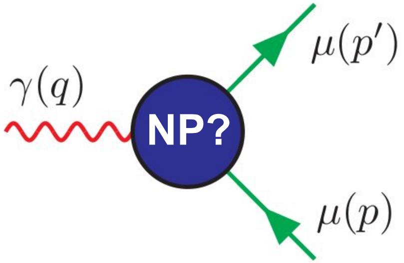


1802.02995

- ❑ 3.5 ~ 3.7 sigma discrepancy between SM prediction and Measurements
  (New result from Fermilab in Late 2019? or Early 2020?)
- ❑ Very sensitive to New Physics



Muon g-2 and New Physics



- **Many New Physics possibilities have been suggested**

  - ❑ **TeV scale new physics**
    (Supersymmetry, Extra dimensions, Compositenes, ...)

  - ❑ **Sub-GeV scale (with small coupling) new physics** — 0811.1030 M. Pospelov

    - Dark photon with kinetic mixing ← most cases are disfavored by recent experiments (e.g., NA64)

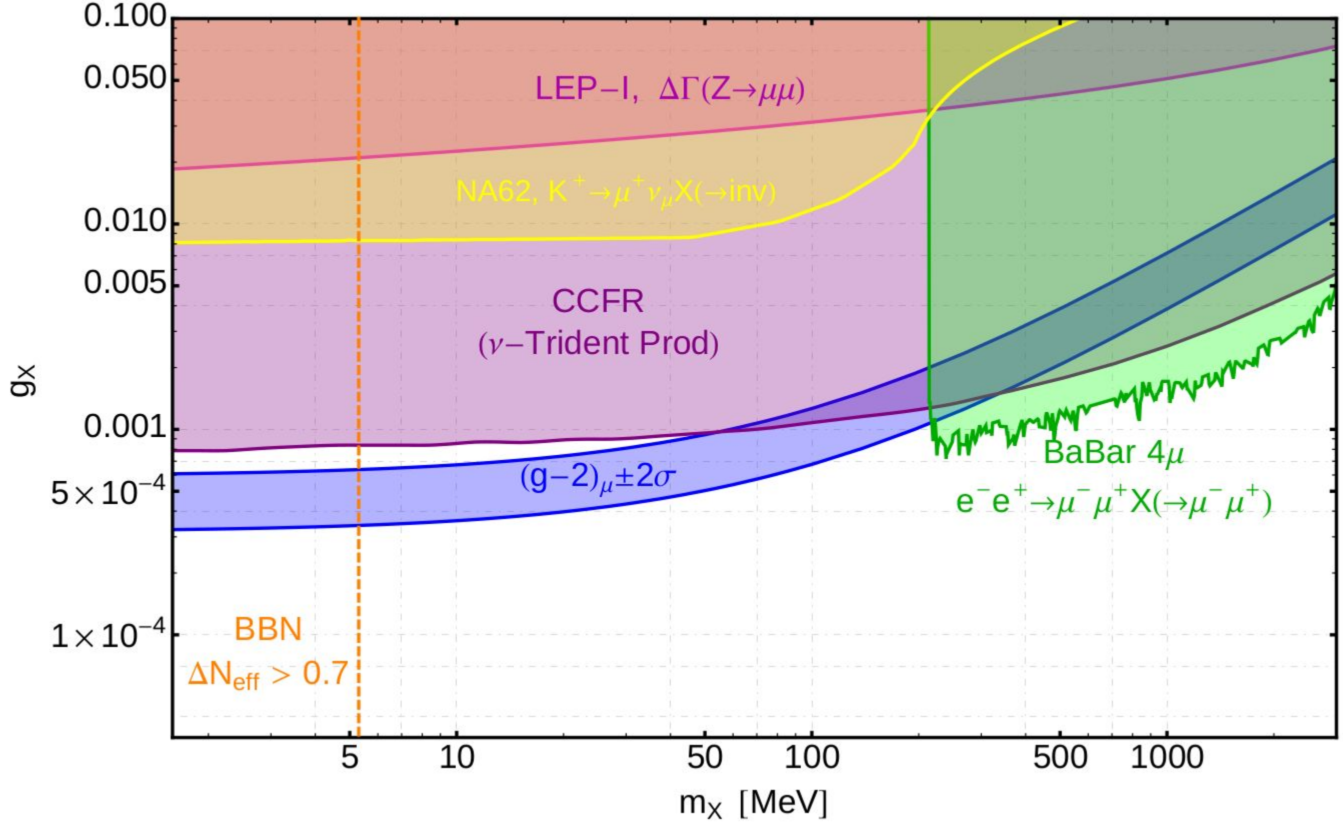
    - Flavor-specific light mediators (We will focus on $U(1)_{L_\mu - L_\tau}$ case.)

X.-G. He et al. (1991)

$$\mathcal{L} \supset \mathcal{L}_{\rm SM} - \frac{1}{4} X_{\mu\nu} X^{\mu\nu} - \frac{1}{2} m_X^2 X_\mu X^\mu - g_X X_\mu J_X^\mu,$$

$$J_X^\mu = \bar{\mu}\gamma^\mu \mu - \bar{\tau}\gamma^\mu \tau + \bar{\nu}_\mu \gamma^\mu \nu_{\mu L} - \bar{\nu}_\tau \gamma^\mu \nu_{\tau L}.$$

Constraints on Muon-specific light boson



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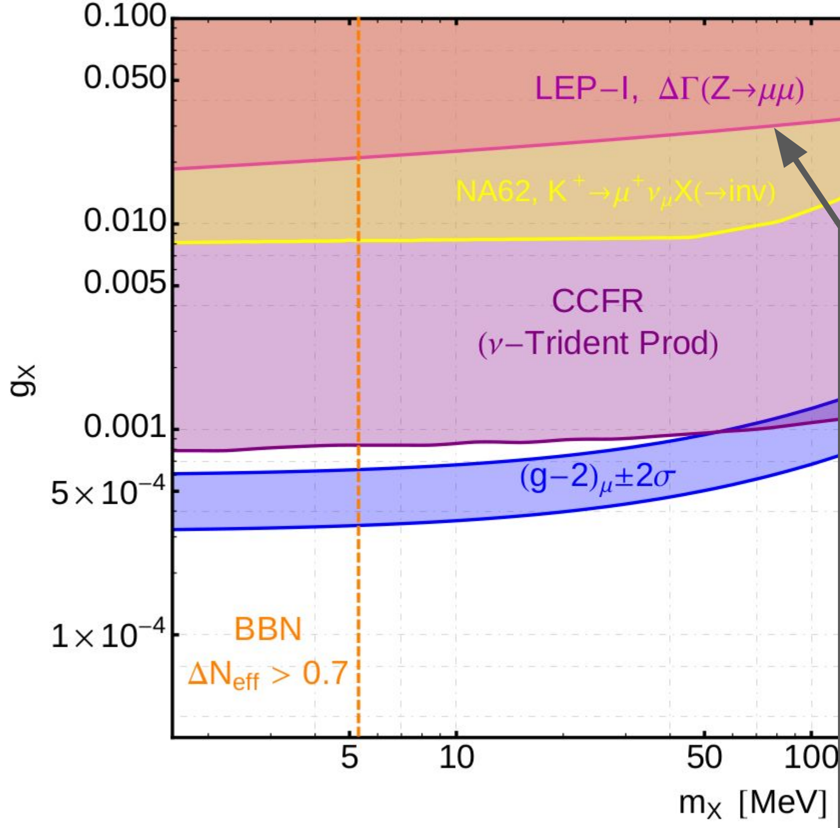
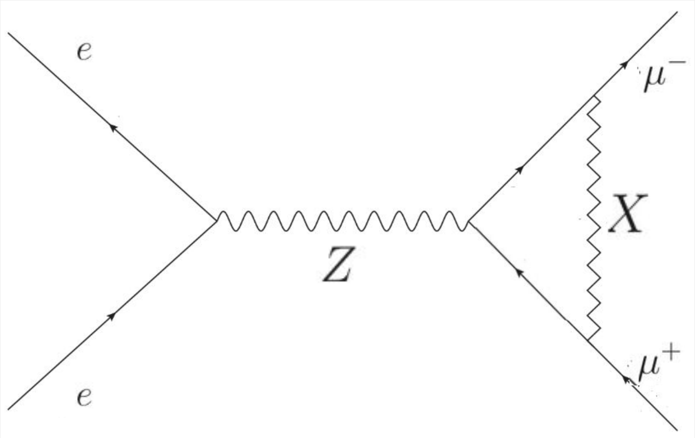


Virtual correction of leptonic decay width at Z pole search (LEP-I)



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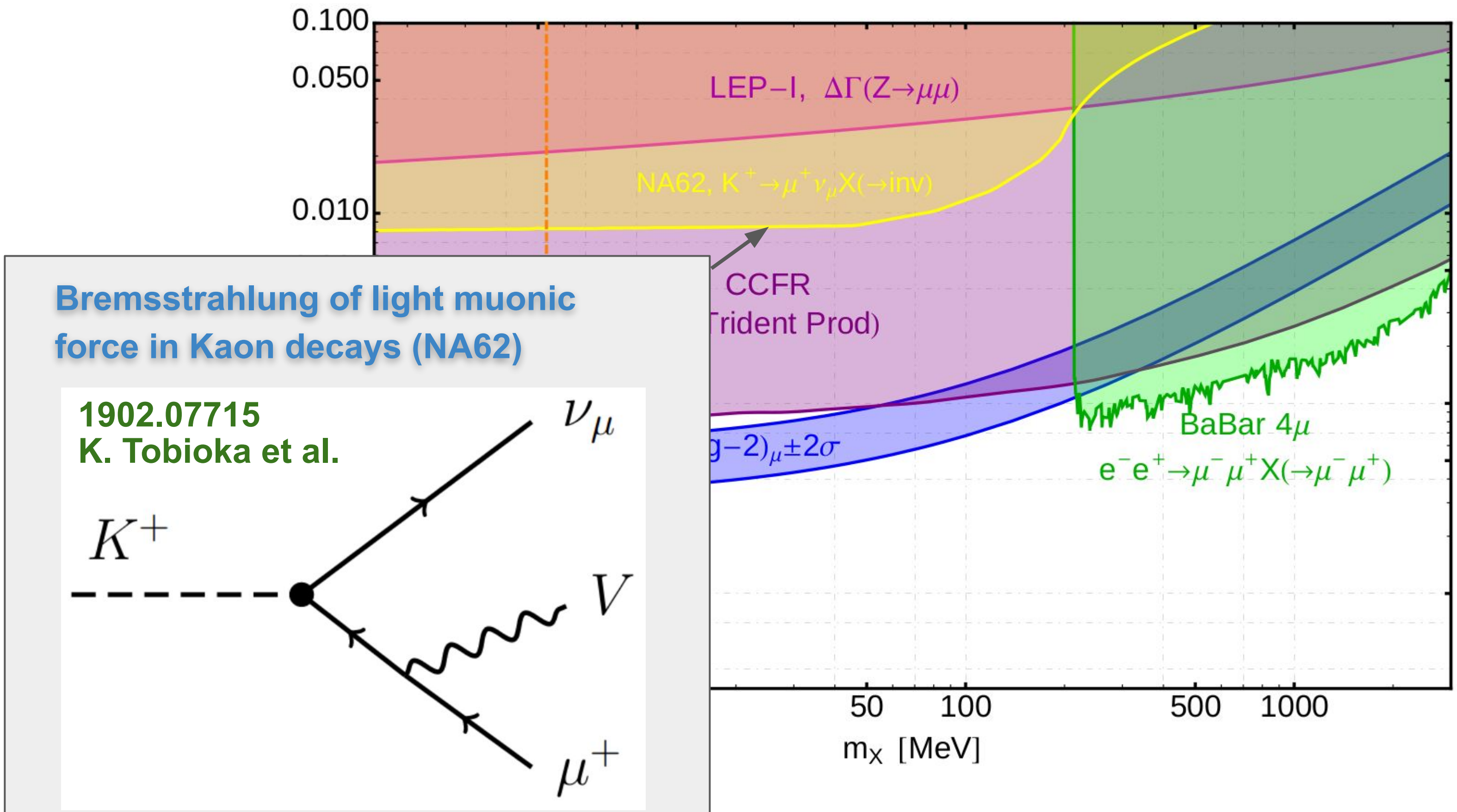
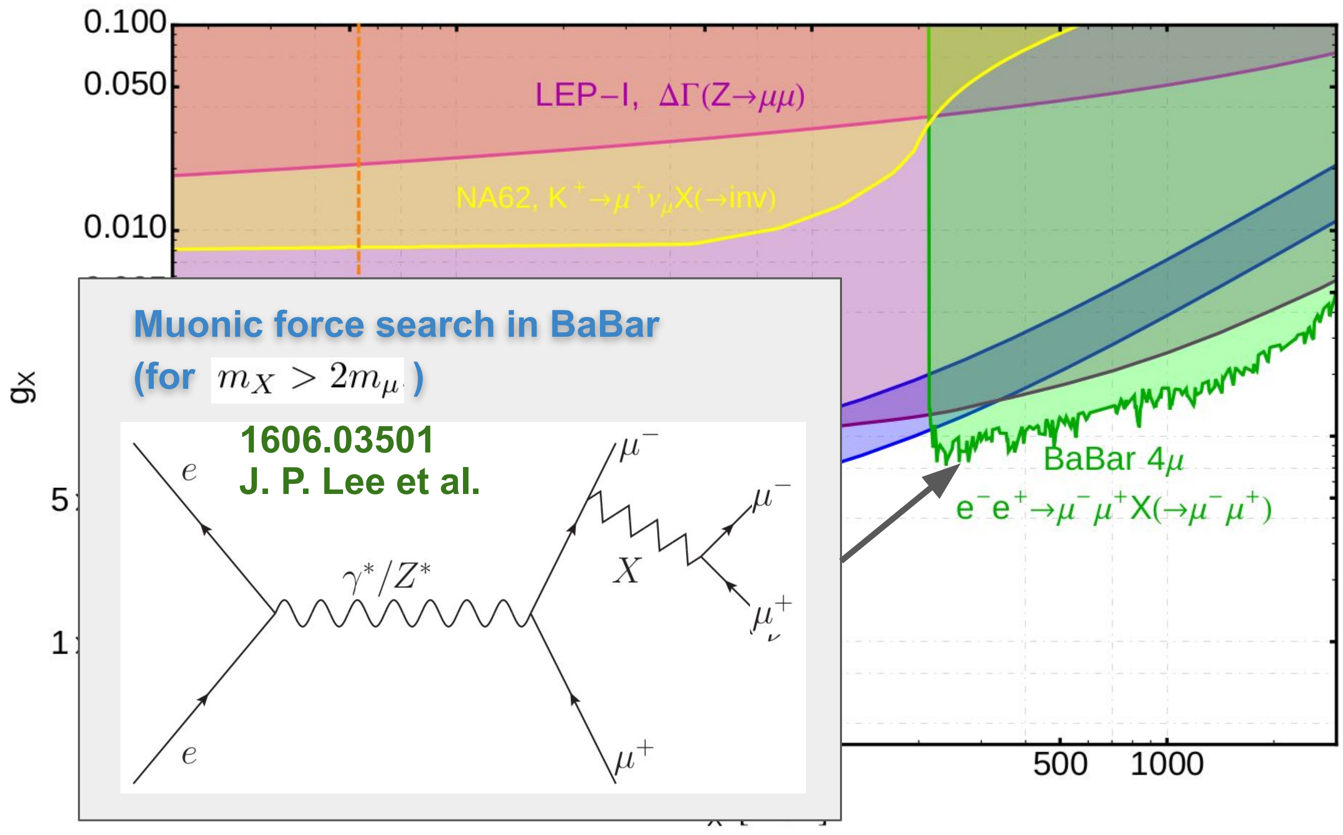
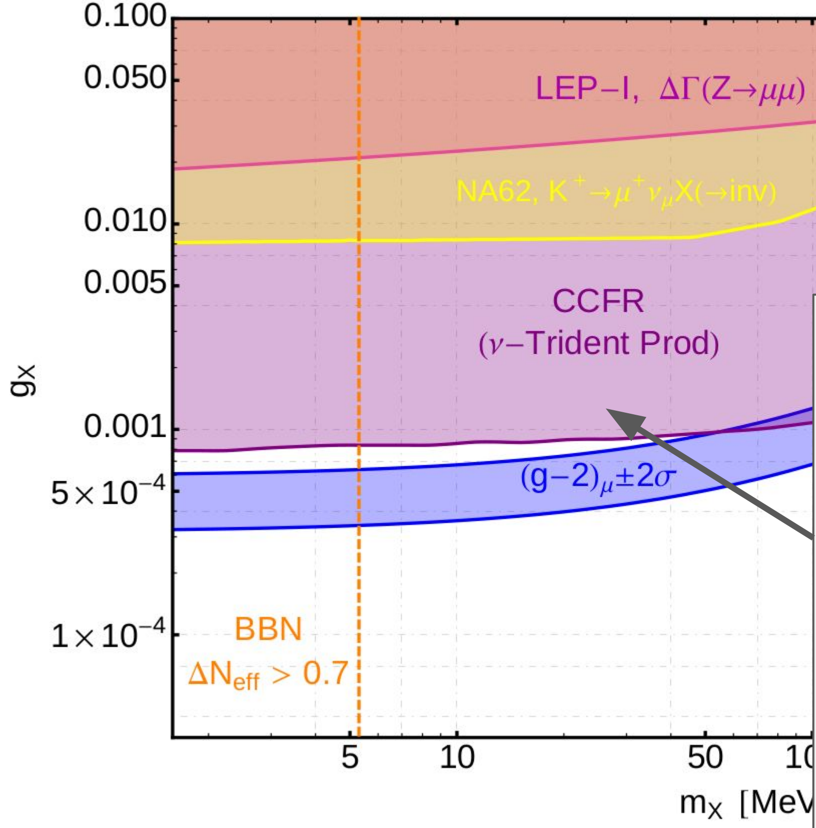


Bremsstrahlung of light muonic force in Kaon decays (NA62)

Constraints on Muon-specific light boson

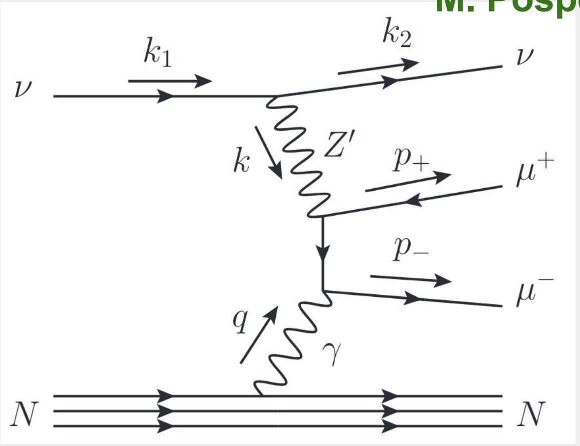


Constraints on Muon-specific light boson

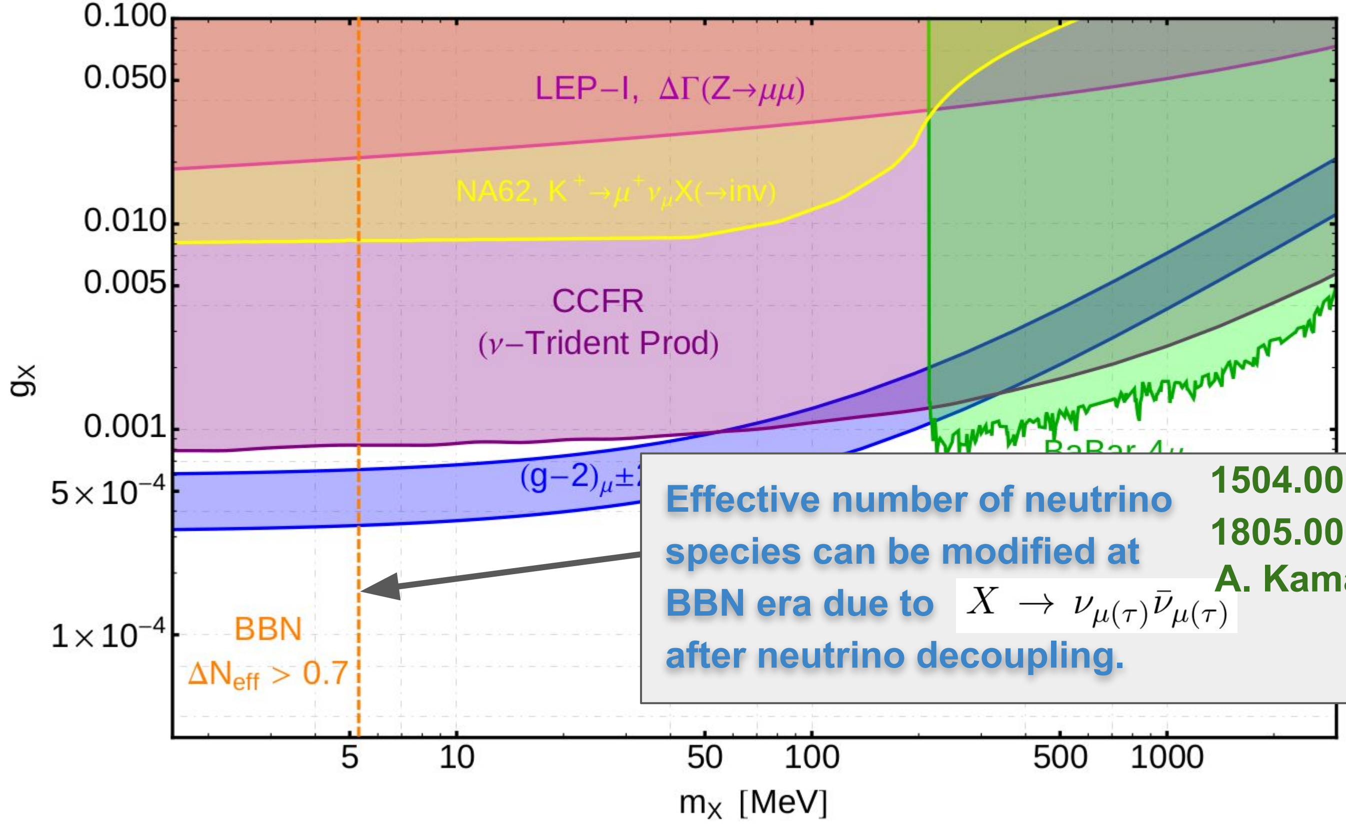


Neutrino trident production

1406.2332
M. Pospelov et al.



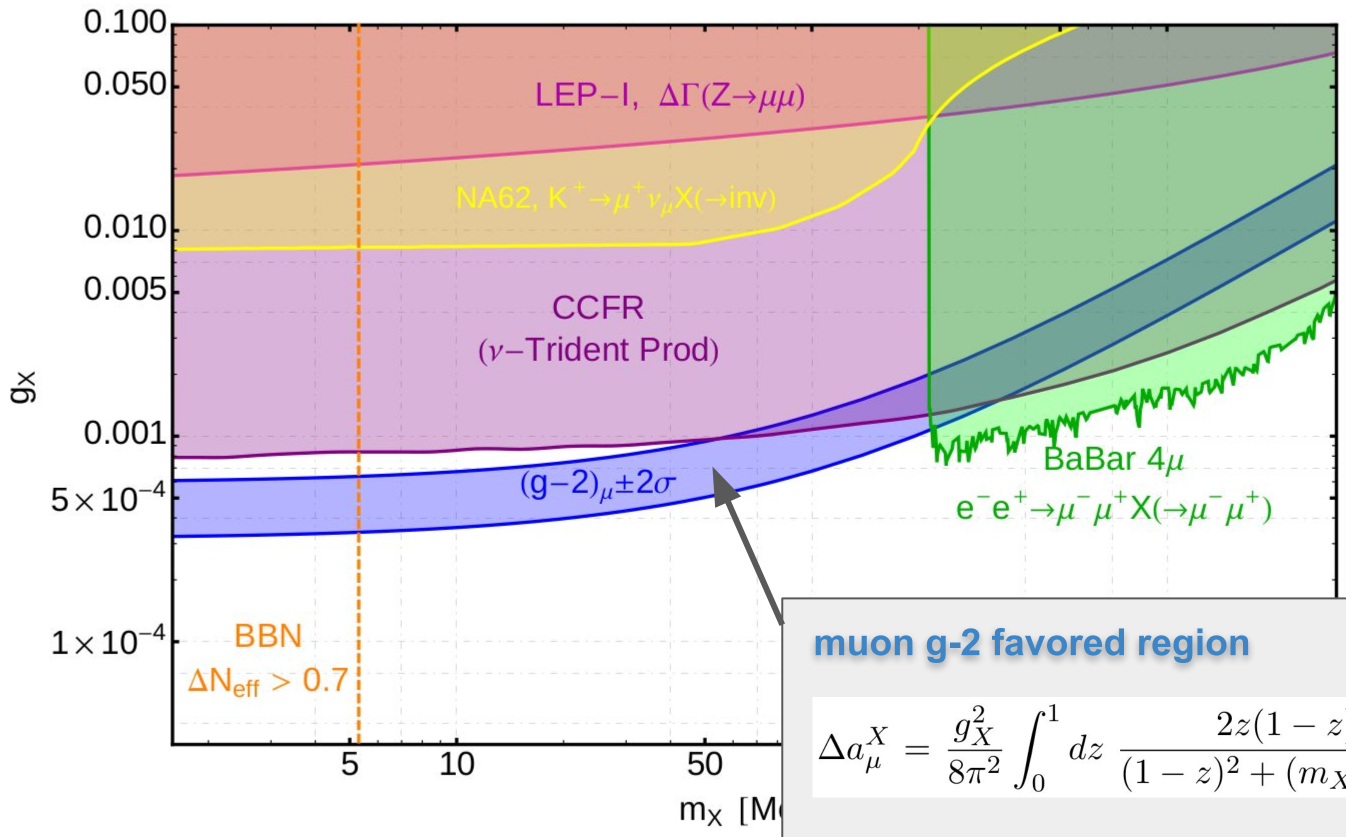
Constraints on Muon-specific light boson



Effective number of neutrino species can be modified at BBN era due to $X \to \nu_{\mu(\tau)}\bar{\nu}_{\mu(\tau)}$ **after neutrino decoupling.**

1504.00711
1805.00651
A. Kamada et al.

Constraints on Muon-specific light boson

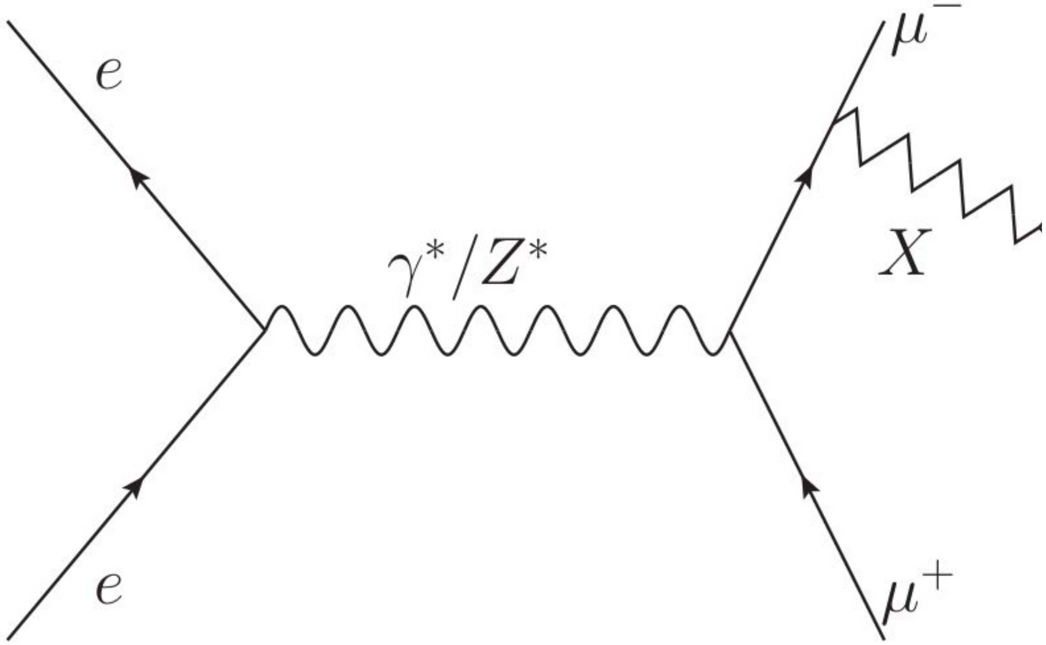


muon g-2 favored region

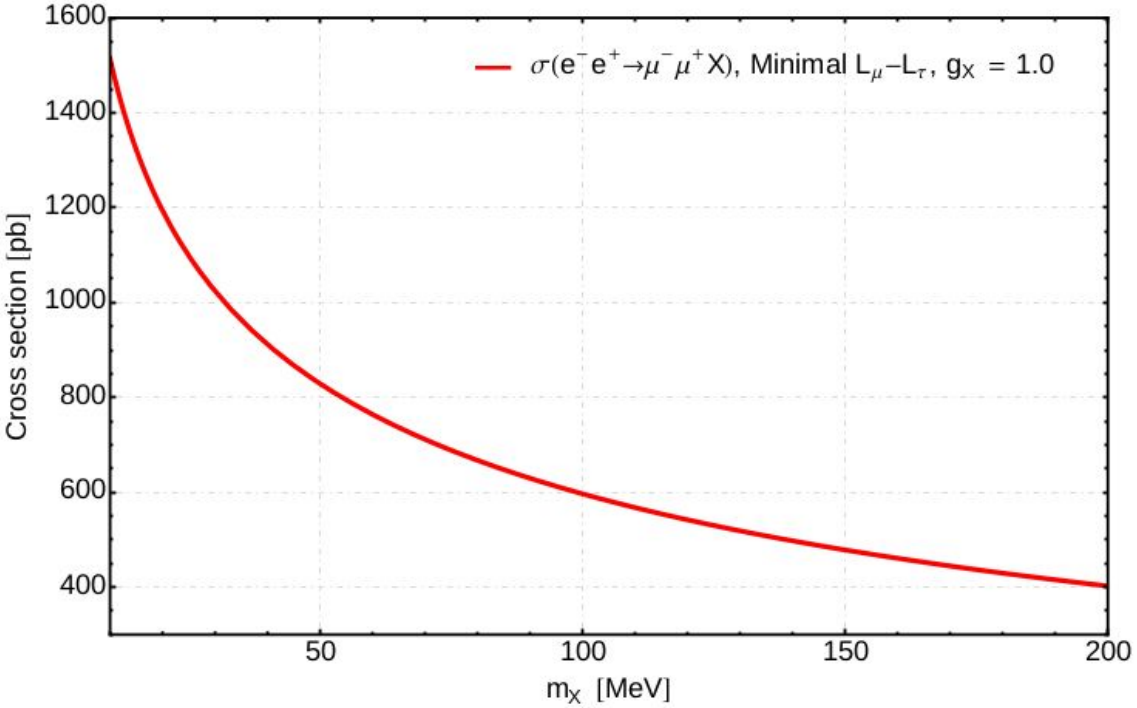
$$\Delta a_\mu^X = \frac{g_X^2}{8\pi^2}\int_0^1 dz\, \frac{2z(1-z)^2}{(1-z)^2+(m_X/m_\mu)^2 z}$$

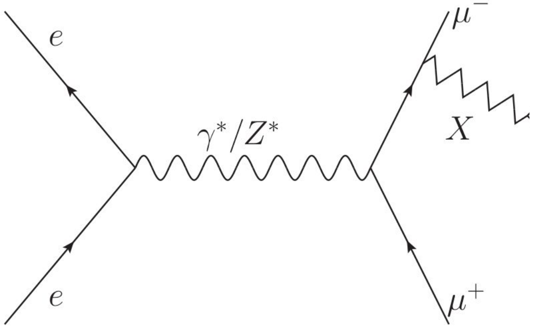
Signal process for "di-muon + Missing E" channel at low-E e-e+ collider

- ❑ **Main production channel : X boson emission from energetic muons.**



Signal process for "di-muon + Missing E" channel at low-E e-e+ collider





- **Soft and collinear emission is preferred, due to the double-log IR divergence for a light particle emission.**

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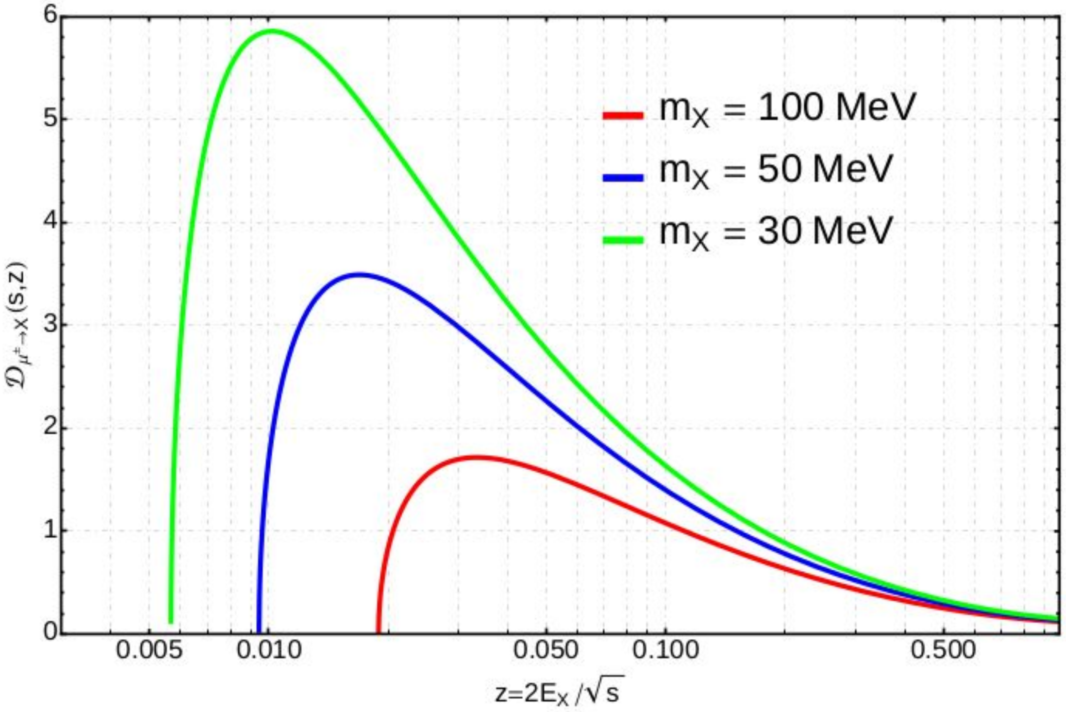

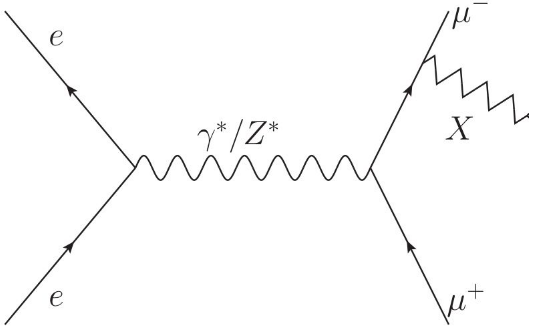

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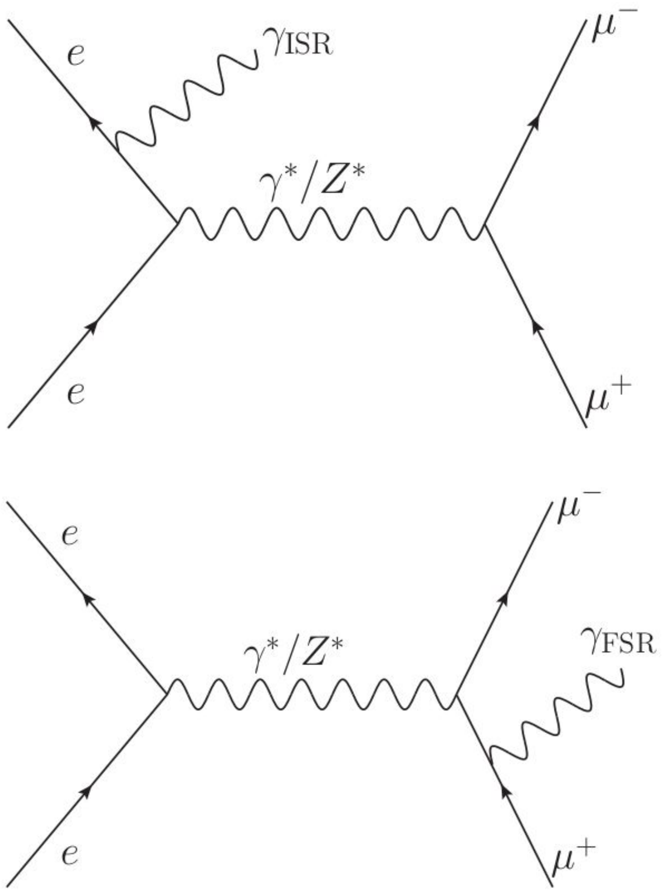
Estimation of SM backgrounds

$$e^- e^+ \to \mu^- \mu^+ (\gamma)$$

- Very soft and collinear
- large MET cut can remove all of collinear bkgs
- High photon detection efficiency is needed to suppress unobserved bkgs



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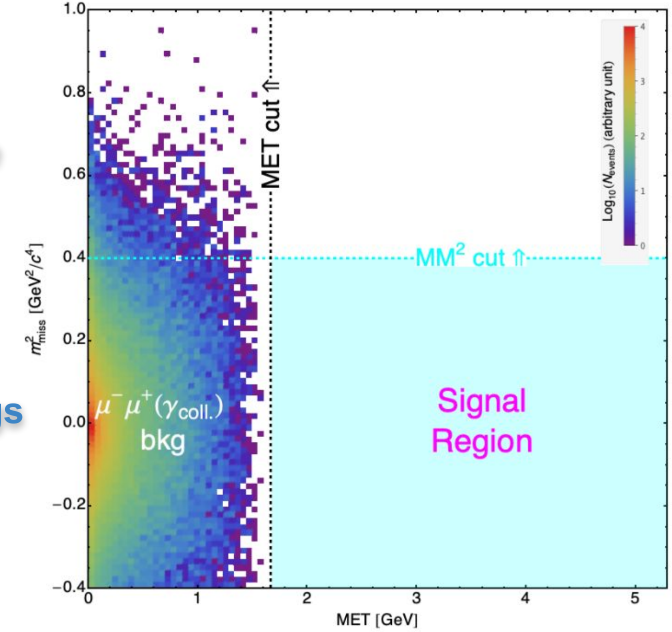
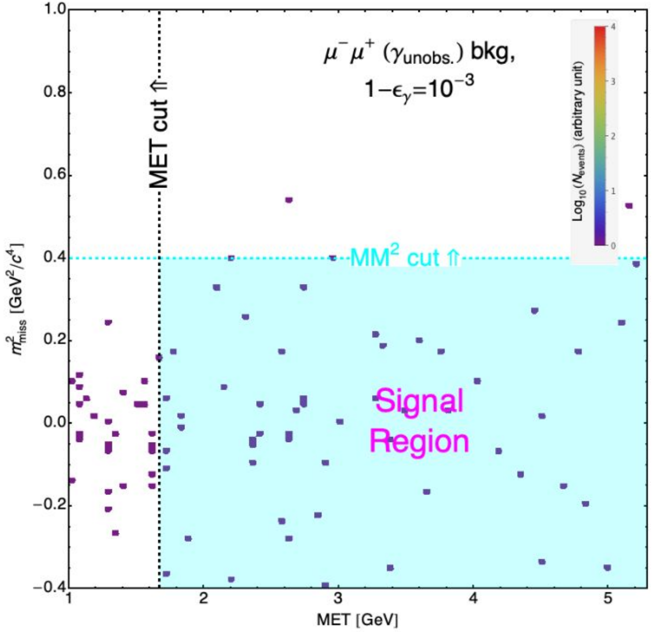


(a) $\mu^-\mu^+\gamma$ with $|\eta^*_\gamma| > 1.94$



(b) $\mu^-\mu^+\gamma$ with $|\eta^*_\gamma| < 1.94$

Estimation of SM backgrounds

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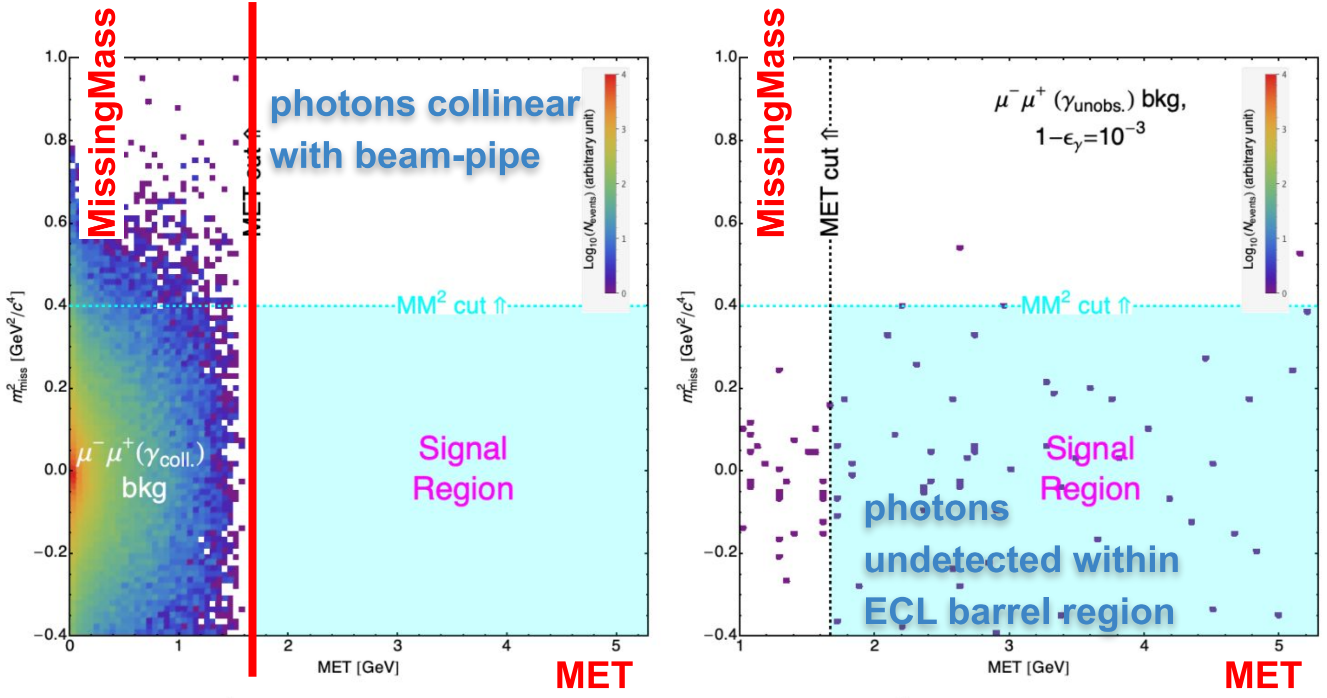
$$i)\ \not{E}_T > 1.67\ \mathrm{GeV},$$

$$ii)\ m^2_{\mathrm{miss}} < 0.4\ \mathrm{GeV}^2/c^4$$



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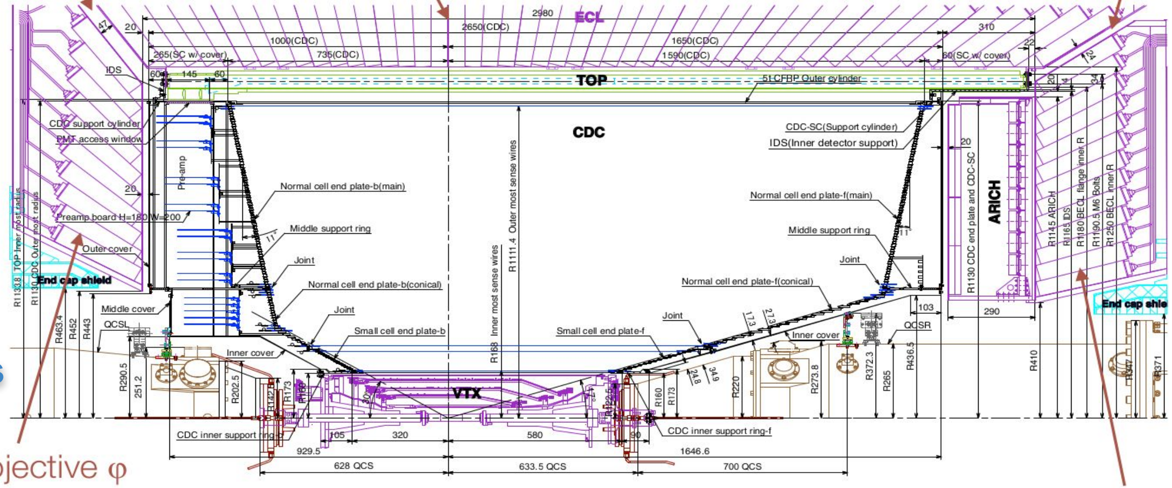

from 2017 U.S. Cosmic Vision Workshop slides (by C. Hearty)

Estimation of SM backgrounds

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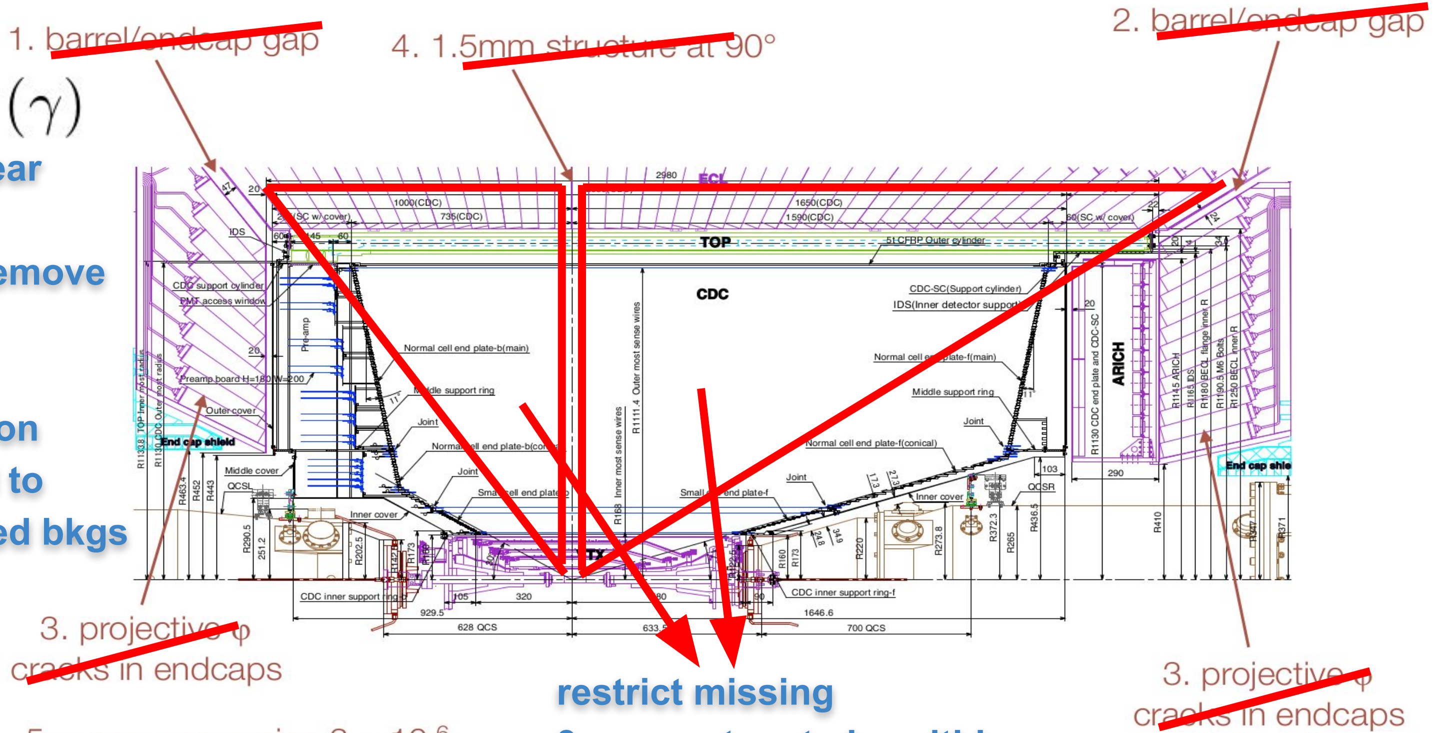


5. γ non-conversion 3 × 10⁻⁶

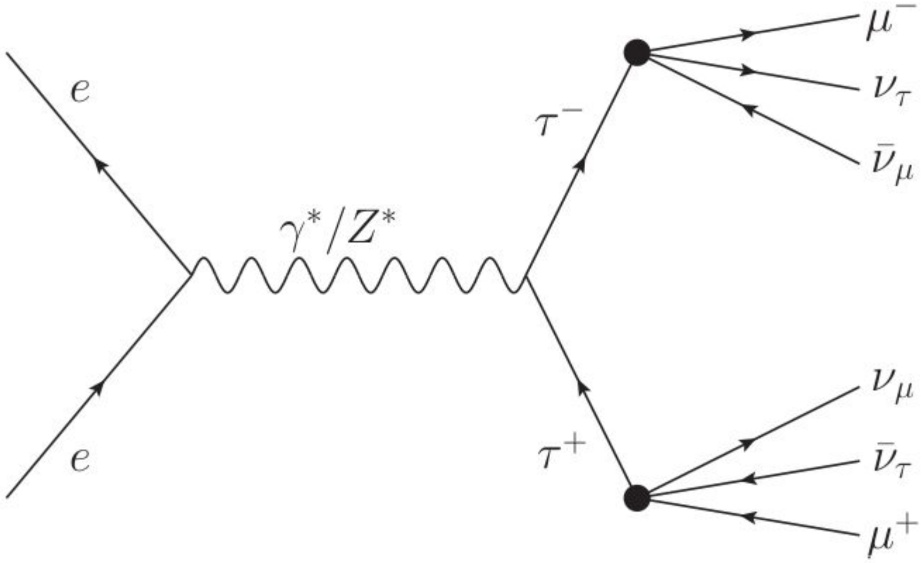
$$N_{bk} \sim 179.5 \left(\frac{1-\epsilon_\gamma}{10^{-5}}\right)\left(\frac{\int \mathcal{L}\, dt}{1\ \text{ab}^{-1}}\right)$$

from 2017 U.S. Cosmic Vision Workshop slides (by C. Hearty)

Estimation of SM backgrounds

$$e^- e^+ \to \tau^- \tau^+ (\to \mu^- \mu^+ \nu_\mu \nu_\tau \bar{\nu}_\mu \bar{\nu}_\tau)$$

- dimuon + large Missing E
- Missing Mass is typically larger than 1 GeV/c^2
- With MET and Missing Mass, Remaining Event number is N_{bkg} ~ O(1) even at 50 ab^{-1}



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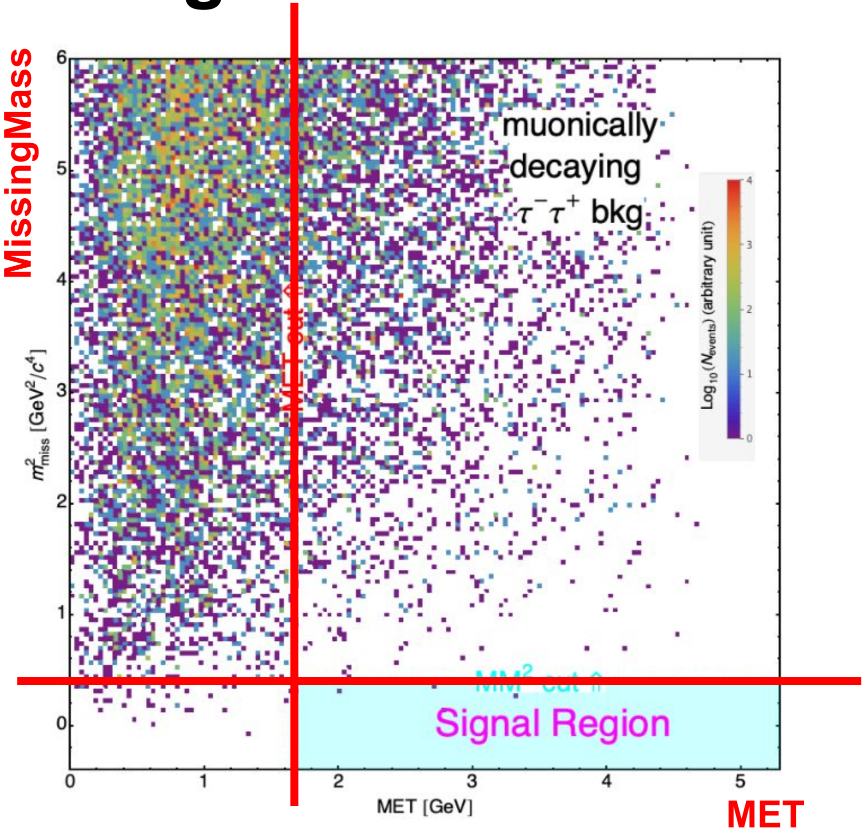

(c) $\tau^-\tau^+(\to \mu^-\mu^+\nu\nu\bar{\nu}\bar{\nu})$

Signal Event distribution

$i)\ \not{E}_T > 1.67\ \text{GeV},$

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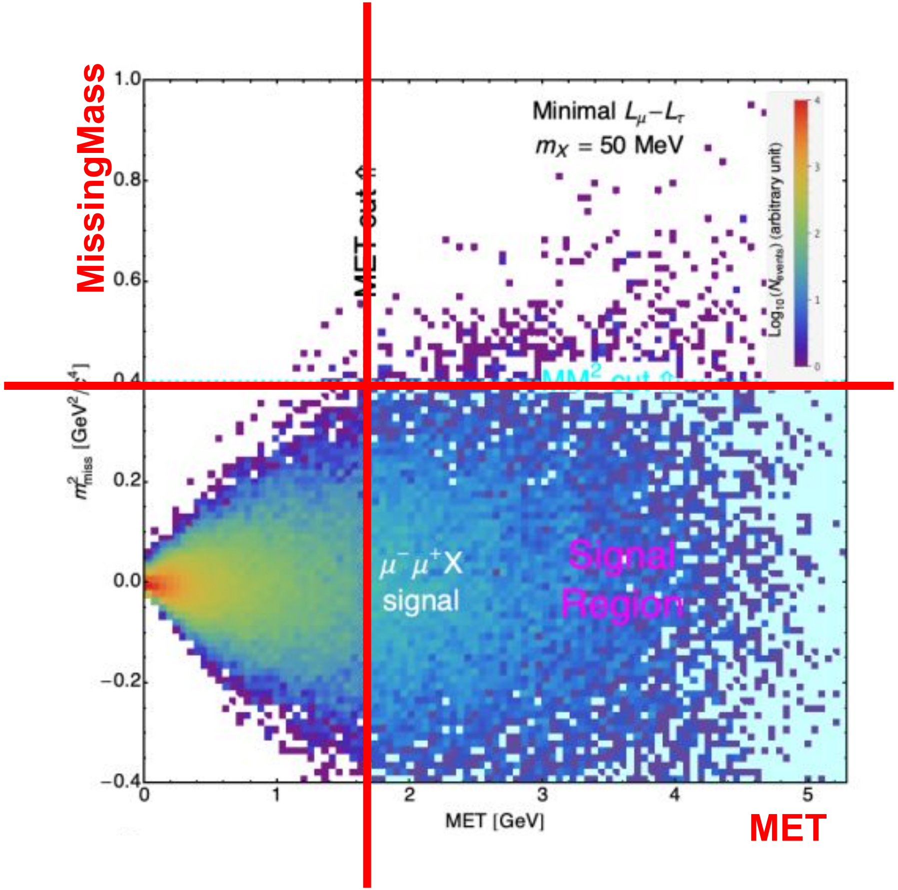
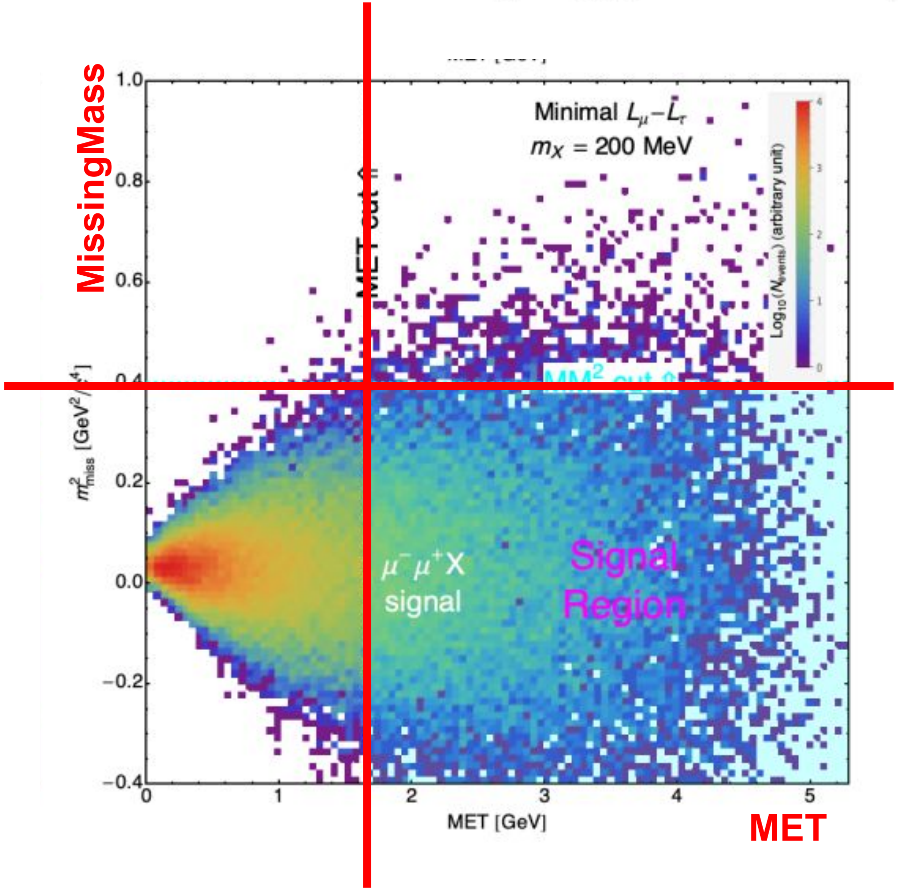
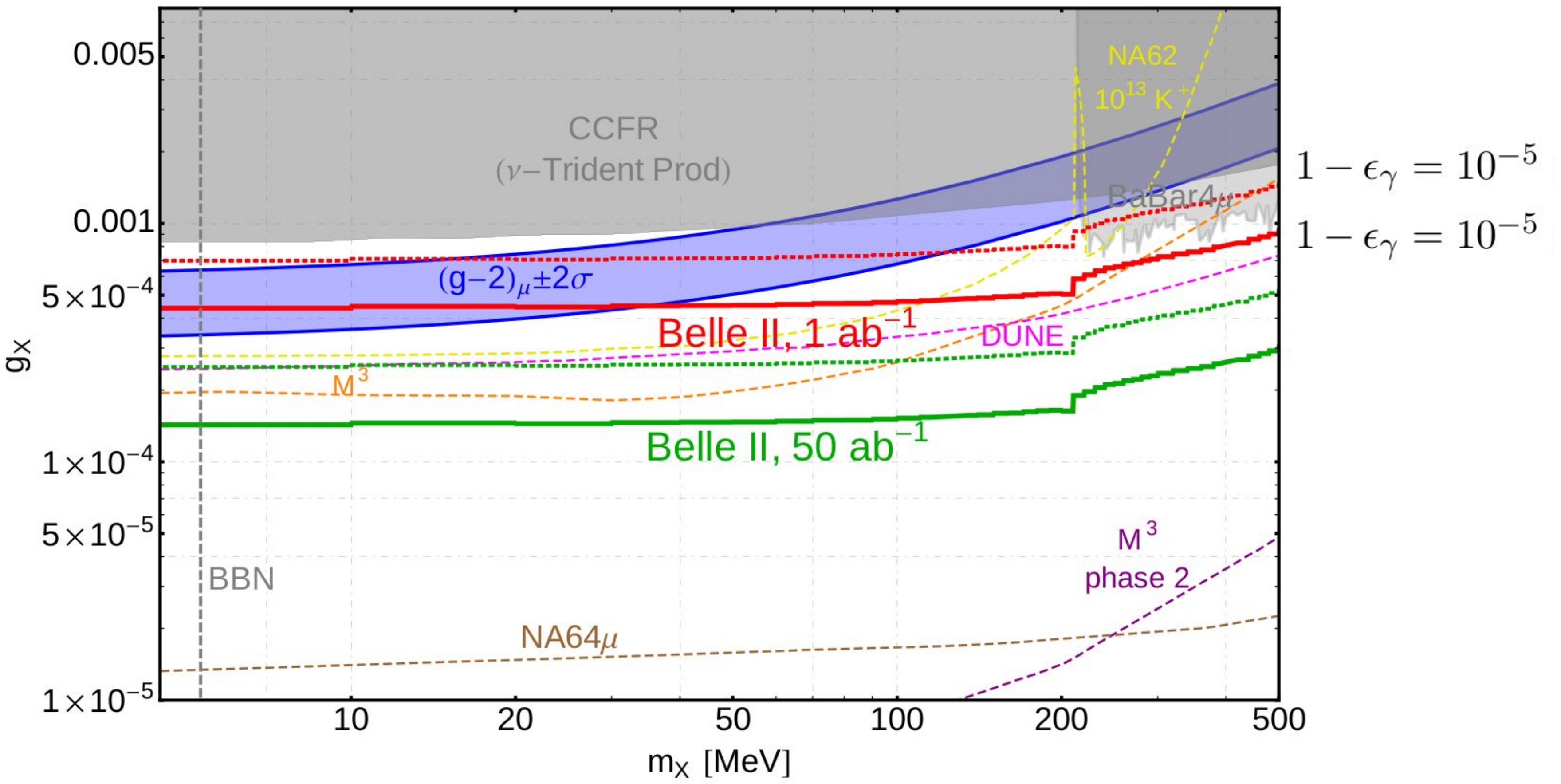




Expected Sensitivity limit



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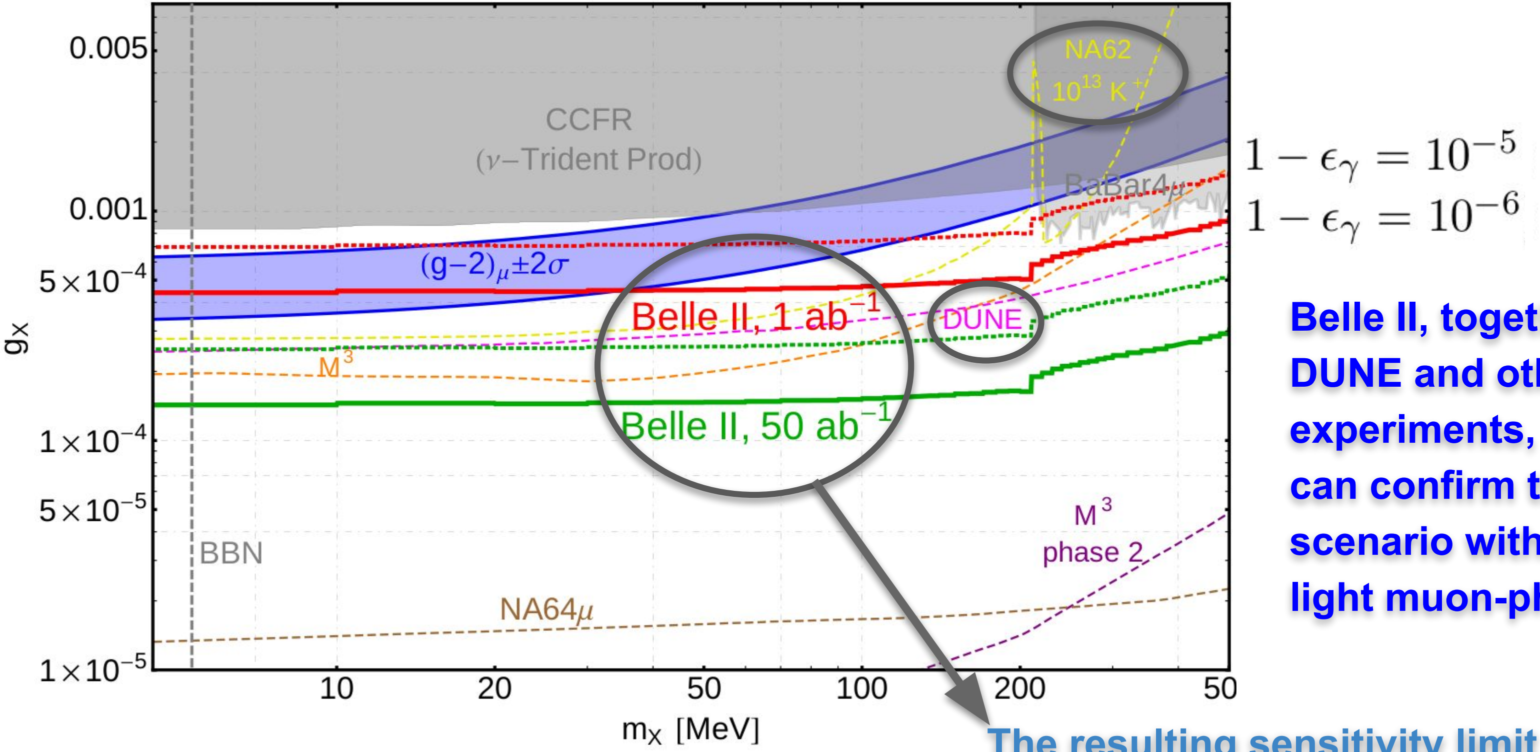


Belle II, together with NA62, DUNE and other beam-dump experiments, can confirm the muon g-2 scenario with light muon-philic boson.

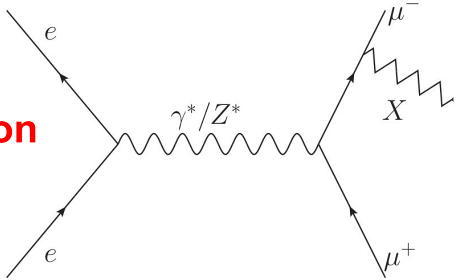
The resulting sensitivity limit depends on the systematic uncertainties.

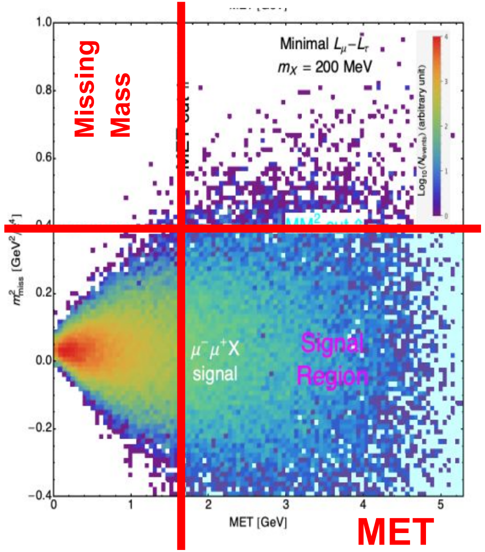
Conclusion

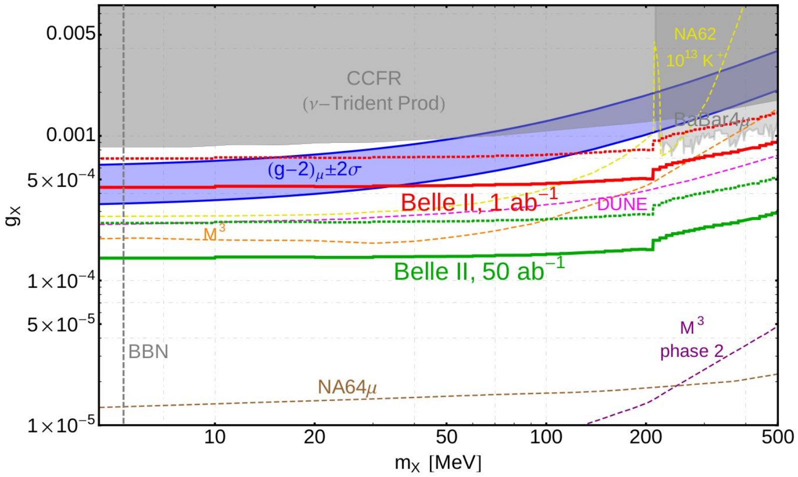
- **Muon g-2** shows a long lasting discrepancy between SM prediction and measurements and implies **various NP possibilities**.

- **A light gauge boson weakly coupled to muon** could explain muon g-2. Especially, muon-specific light boson can be explored with the "dimuon+Missing E" channel.

- **We suggest that Belle II have discovery potential and muon g-2 favored region can be explored, although it requires high photon detection efficiency to suppress backgrounds. The expected sensitivity limit is comparable to other approved future-coming experiments (NA62, DUNE, etc.)**

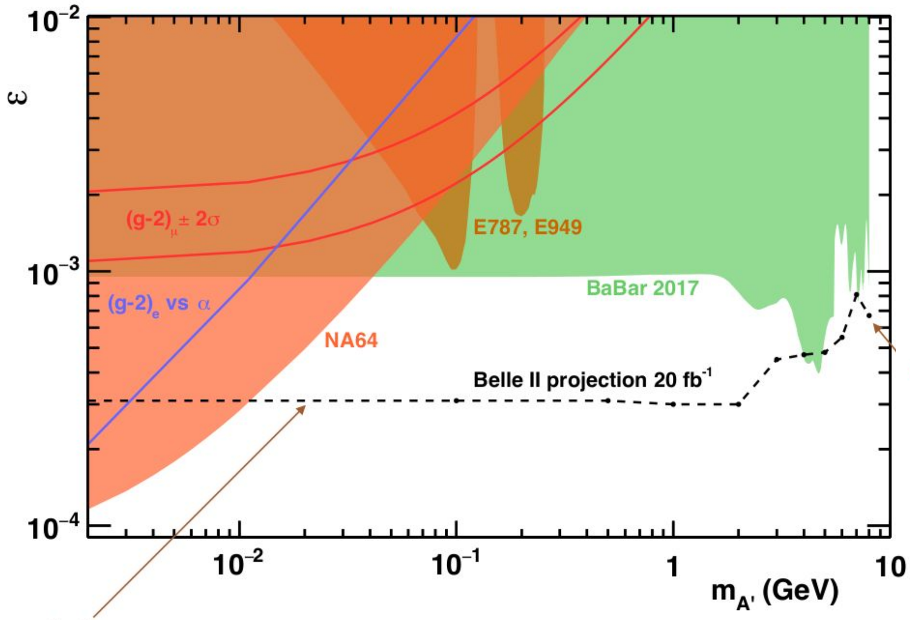


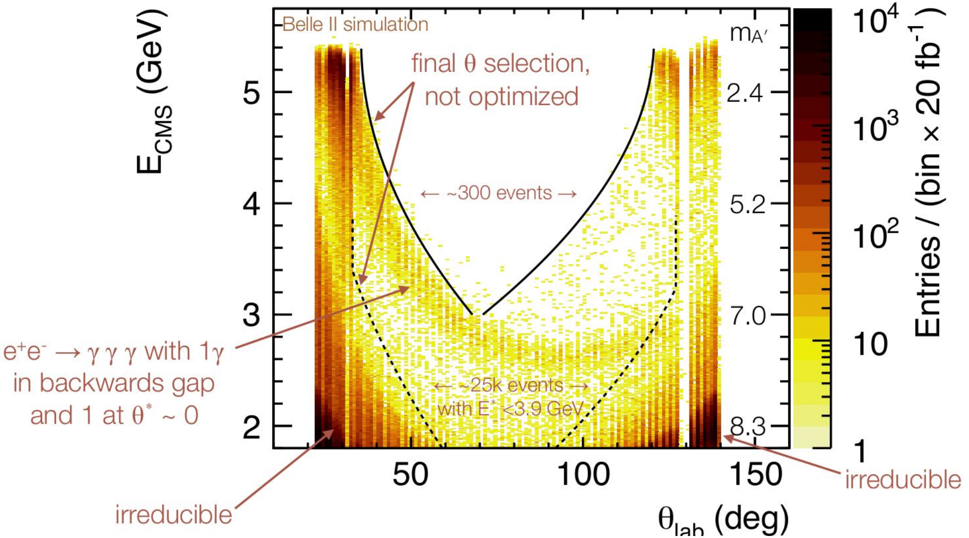




Thank you for your attention

Mono-photon search at Belle II (prospect)

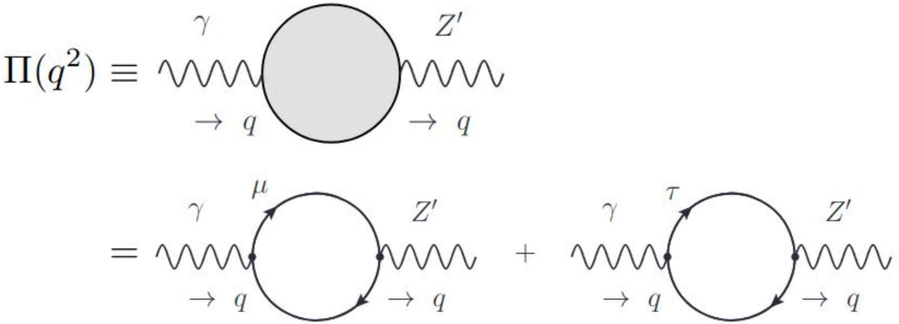




from 2017 U.S. Cosmic Vision Workshop slides (by C. Hearty)

- Most backgrounds come from endcap and gap between barrel and endcap regions.
- By using KLM (KL and muon detector) together, inefficiency of photon detection can be suppressed up to ~ 10^{-4} - 10^{-6}

Mono-photon search of Lmu - Ltau boson

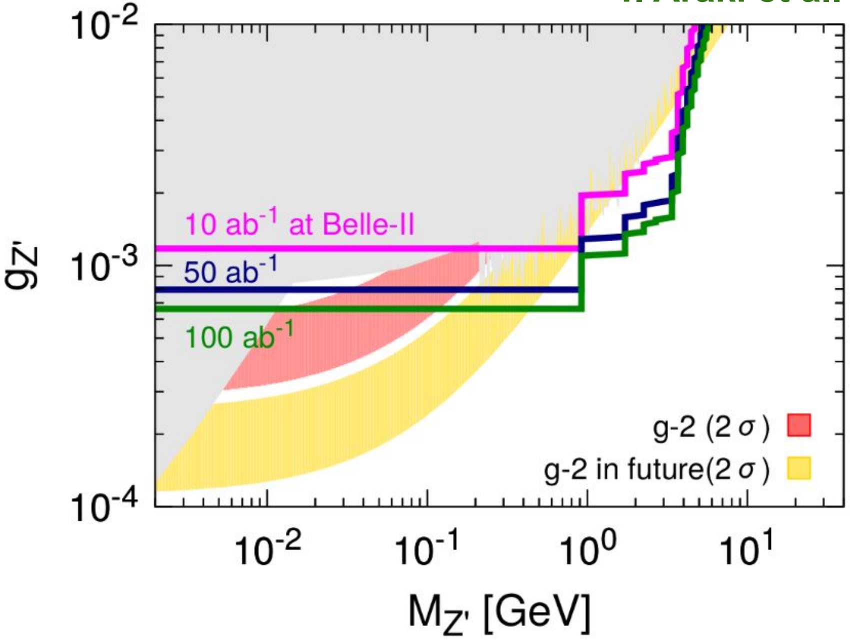


$$= \frac{8 e g_{Z'}}{(4\pi)^2}\int_0^1 x(1-x)\ln\frac{m_\tau^2 - x(1-x)q^2}{m_\mu^2 - x(1-x)q^2}\,dx, \quad (5)$$

"minimal" kinetic mixing case

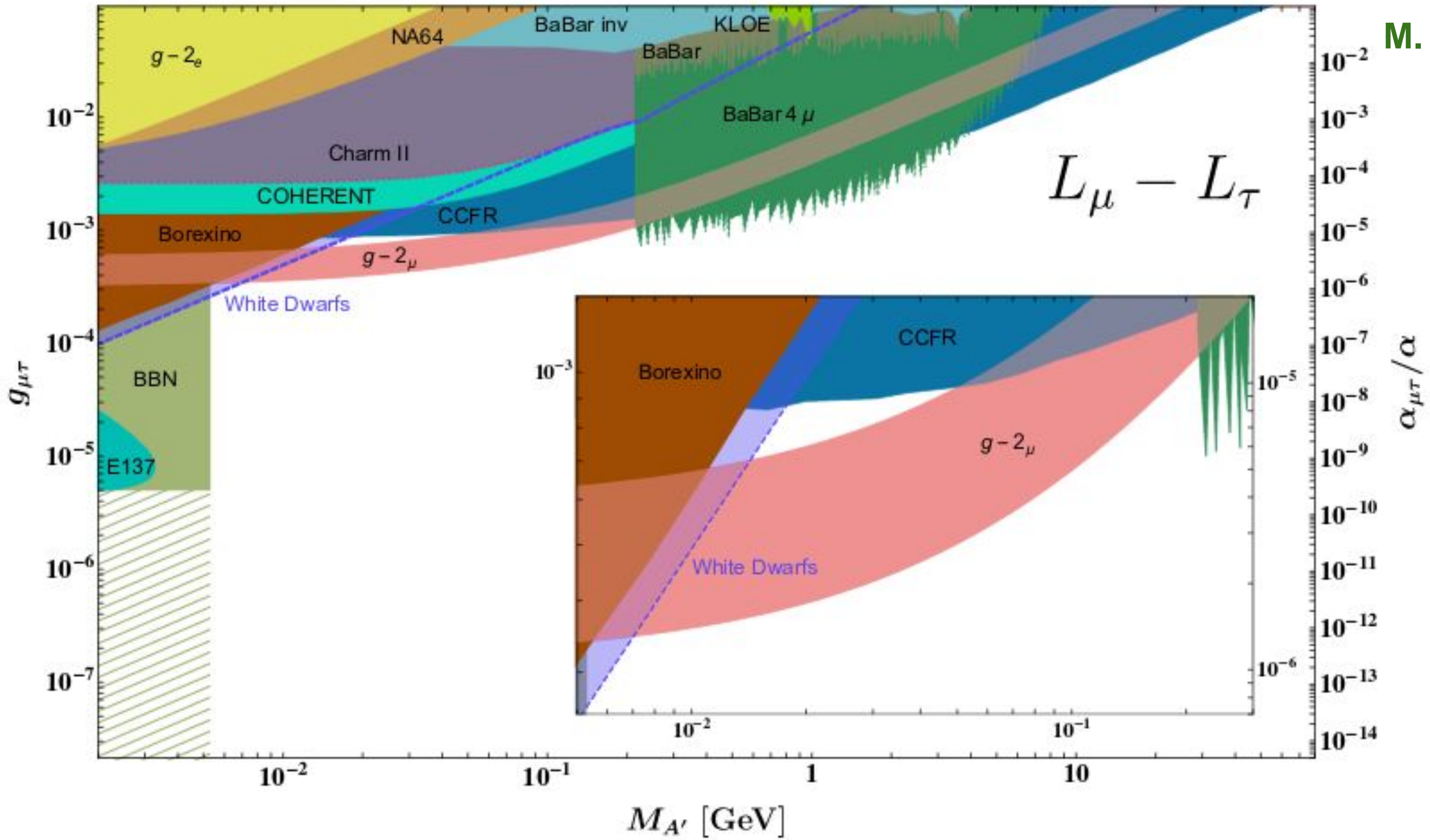
1702.01497

T. Araki et al.



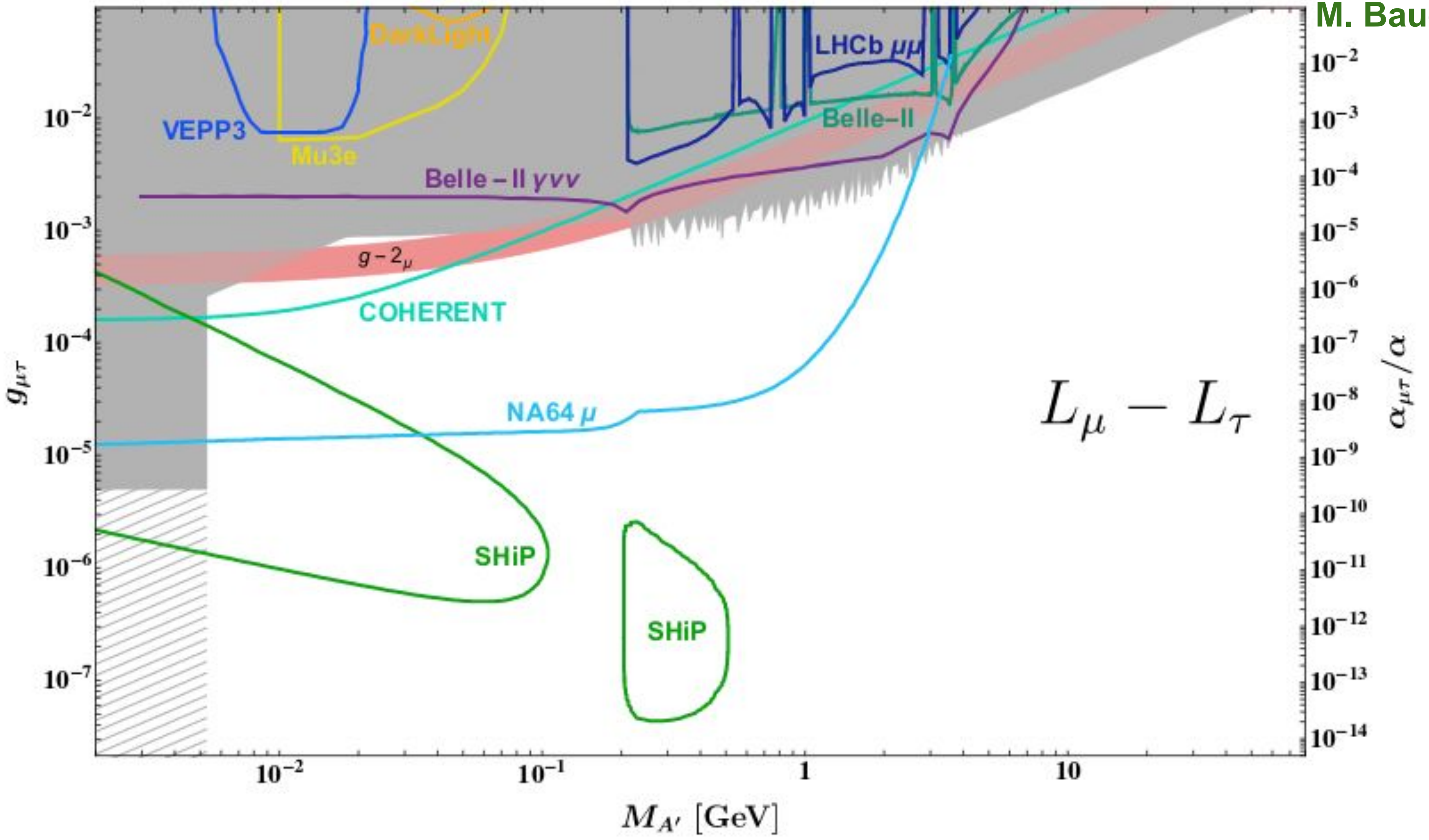
Constraints with Kinetic mixing

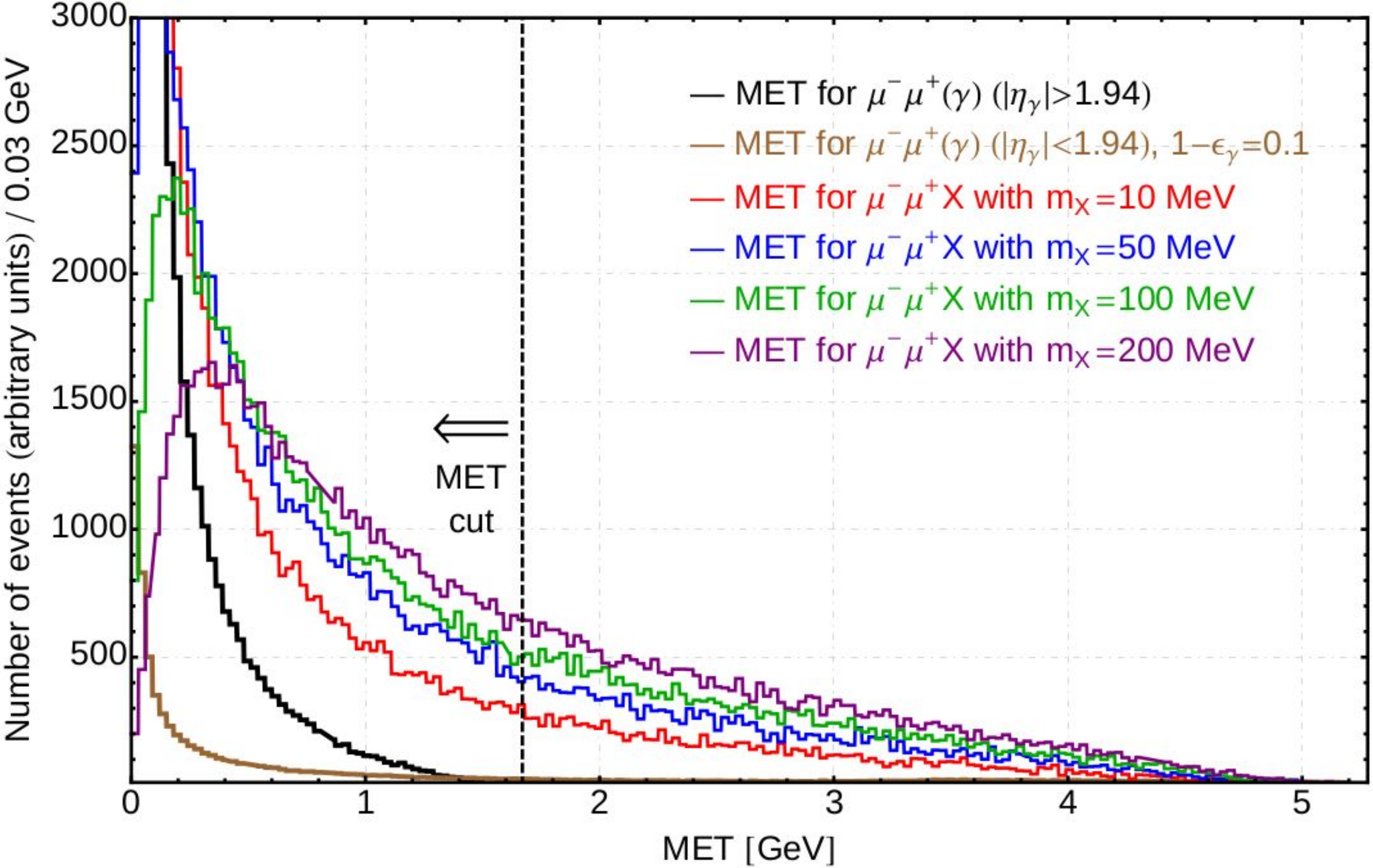
1803.05466
M. Bauer et al.



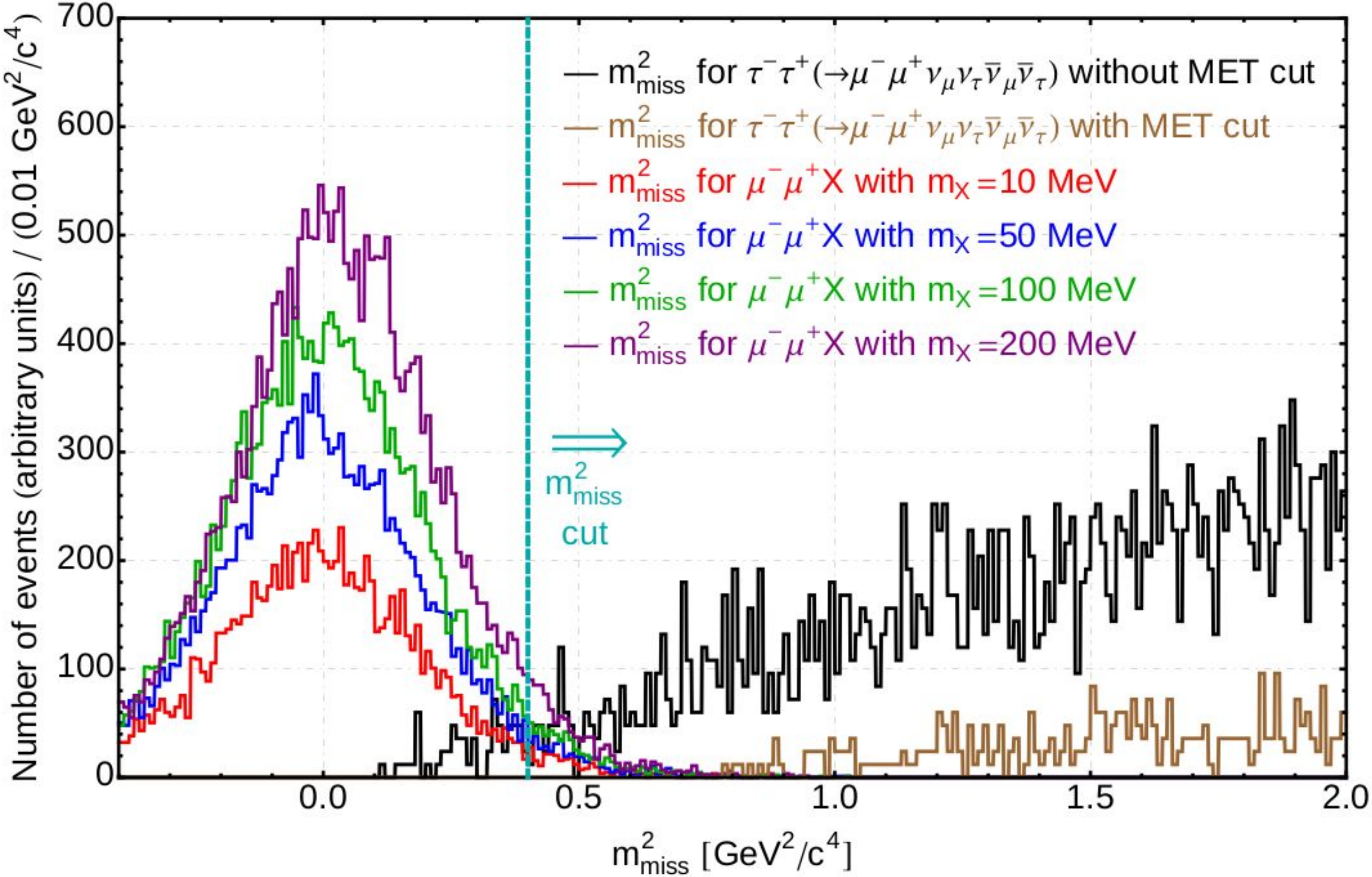
1803.05466

M. Bauer et al.





3000
2500
2000
1500
1000
500
0
1
2
3
4
5
Number of events (arbitrary units) / 0.03 GeV
MET [GeV]
MET for $\mu^-\mu^+(\gamma)$ ($|\eta_\gamma|>1.94$)
MET for $\mu^-\mu^+(\gamma)$ ($|\eta_\gamma|<1.94$), $1-\epsilon_\gamma=0.1$
MET for $\mu^-\mu^+X$ with $m_X=10$ MeV
MET for $\mu^-\mu^+X$ with $m_X=50$ MeV
MET for $\mu^-\mu^+X$ with $m_X=100$ MeV
MET for $\mu^-\mu^+X$ with $m_X=200$ MeV
MET
cut



Number of events (arbitrary units) / (0.01 GeV^2/c^4)
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
m^2_{miss} [GeV^2/c^4]
m^2_{miss} for $\tau^-\tau^+(\rightarrow\mu^-\mu^+\nu_\mu\nu_\tau\bar{\nu}_\mu\bar{\nu}_\tau)$ without MET cut
m^2_{miss} for $\tau^-\tau^+(\rightarrow\mu^-\mu^+\nu_\mu\nu_\tau\bar{\nu}_\mu\bar{\nu}_\tau)$ with MET cut
m^2_{miss} for $\mu^-\mu^+$X with m_X =10 MeV
m^2_{miss} for $\mu^-\mu^+$X with m_X =50 MeV
m^2_{miss} for $\mu^-\mu^+$X with m_X =100 MeV
m^2_{miss} for $\mu^-\mu^+$X with m_X =200 MeV
m^2_{miss}
cut