MEG実験全データを用いた
荷電レプトンフレーバーを破る軽い新粒子の探索

Searching for a lepton flavour violating muon decay
mediated by a new light particle with the MEG I full datasets

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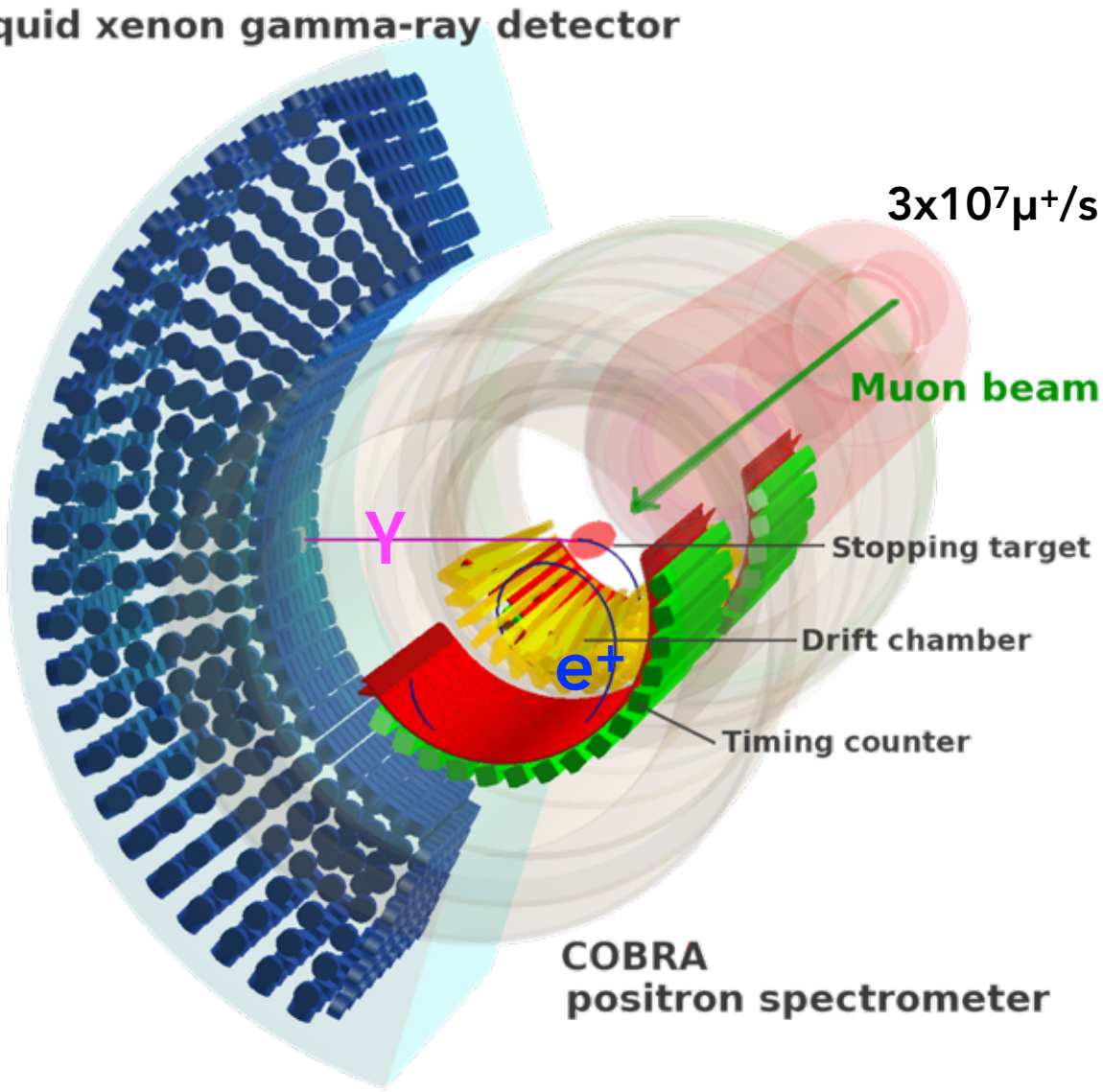
Introduction (1/2)

- There is no clear evidence of new physics to date (except for some anomalies).
- Therefore it is important to search any possibility of BSM using existing experimental setups.
  - Displaced vertex/long-lived particles search in ATLAS/CMS, FCC.
  - LHC + X facilities (Codex-b, MATHUSLA, MilliQan, SHiP, FASER)
  - Long-lived particles search in KOTO.
  - Dark sector search in Belle2 (B2TiP).
  - ……
  - **MEG can do the similar thing!**

The MEG experiment

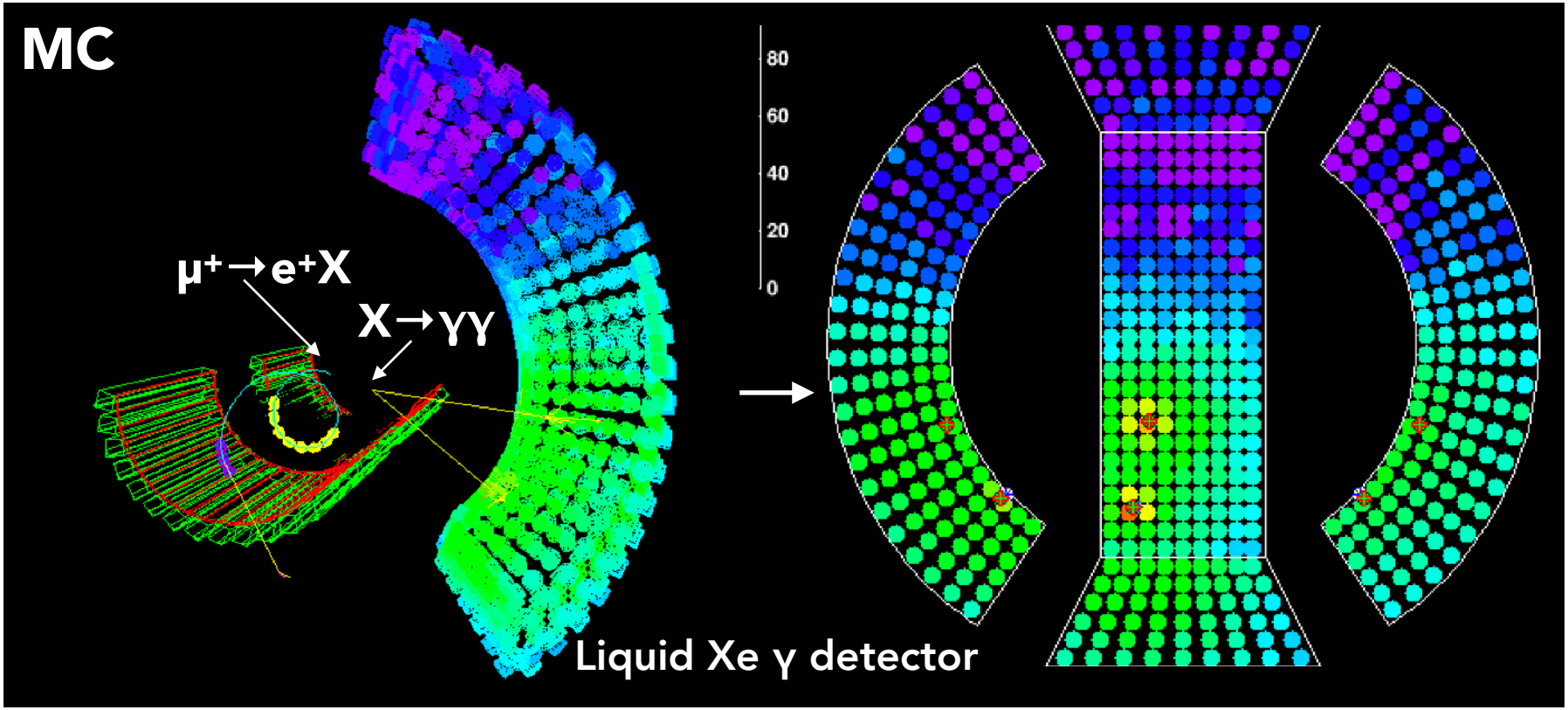
- The MEG experiment searched for charged lepton flavour violating muon decay ($\mu^+ \rightarrow e^+\gamma$).
- Physics data taking: **2009–2013**
  - 7.5×10^{14} stopped muons
- No excess was found and the most stringent upper limit, **4.2×10^{-13} (90% C.L.)** was set on Br($\mu^+ \rightarrow e^+\gamma$) in 2016.

At Paul Scherrer Institut in Switzerland



The final results: A. M. Baldini et al. (MEG Collaboration), Eur. Phys. J. C 76 (2016) 434

Introduction (2/2)



- We have started studying **a search for $\mu^+ \to e^+ X$, $X \to \gamma\gamma$ using the MEG full datasets.**

Physics motivation

- **Main motivation:** LFV is one of the key tools to search for BSM.
- However, we have not yet observed LFV mediated by heavy particles.
- LFV mediated by new light particle X ~O(10−100) MeV might been left undiscovered as a loophole.

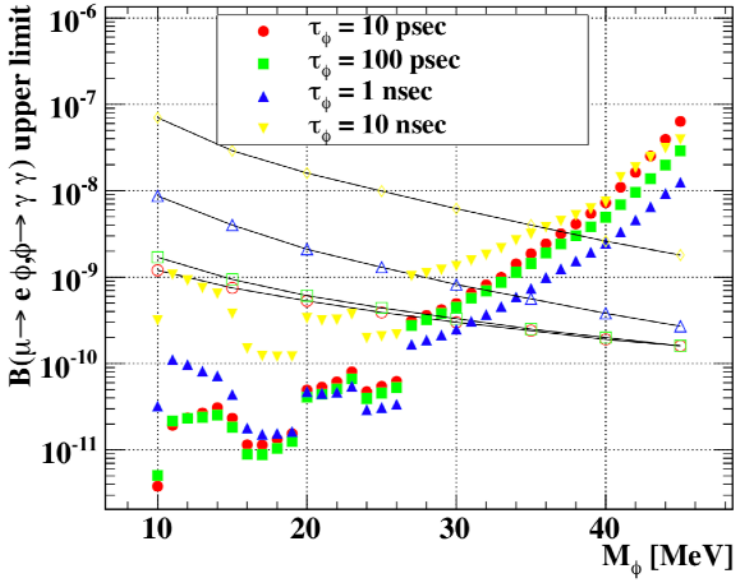
- A possible search in MEG: $\mu \to eX$, $X \to \gamma\gamma$ (hereafter we call it "MEx2G")
  - X is generated via LFV coupling and the on-shell X decays back into SM particles.
  - In this search, we assume decay width is narrow and X is long-lived.

- A possible mechanism of the light mass: Nambu-Goldstone boson generated via spontaneously symmetry breaking of approximate global symmetry (i.e. relatively light mass of π)

- Possible candidates of X: axion-like particle, majoron, familon, flaxion, and strongly interacting DM (SIDM)

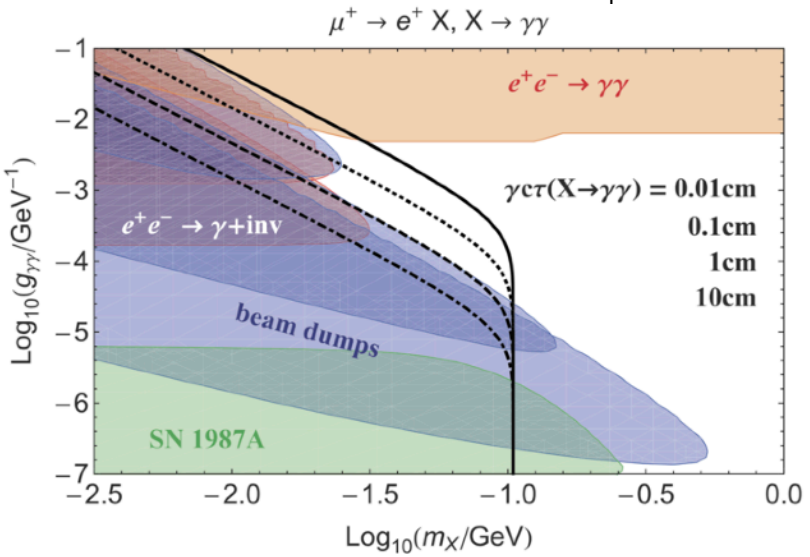
Previous studies

- Crystalbox (1988): μ→eγγ decay search
  - This upper limits are converted into MEx2G taking into account the difference of the detector efficiency (solid line in left plot).
- H. Natori (2012): μ→eX, X→γγ decay search using the MEG 2009/2010 datasets
  - the first in the world, available in a Ph.D thesis (not published yet).
- SN1987A/beam dumps: ">1 cm or <20 MeV" is excluded (right plot).
  - Target parameter space should be "<1 cm and >20 MeV".



Ph.D. thesis by H. Natori (UTokyo, 2012)

10 ps ~ a few mm



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Today's topic

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Today's topic

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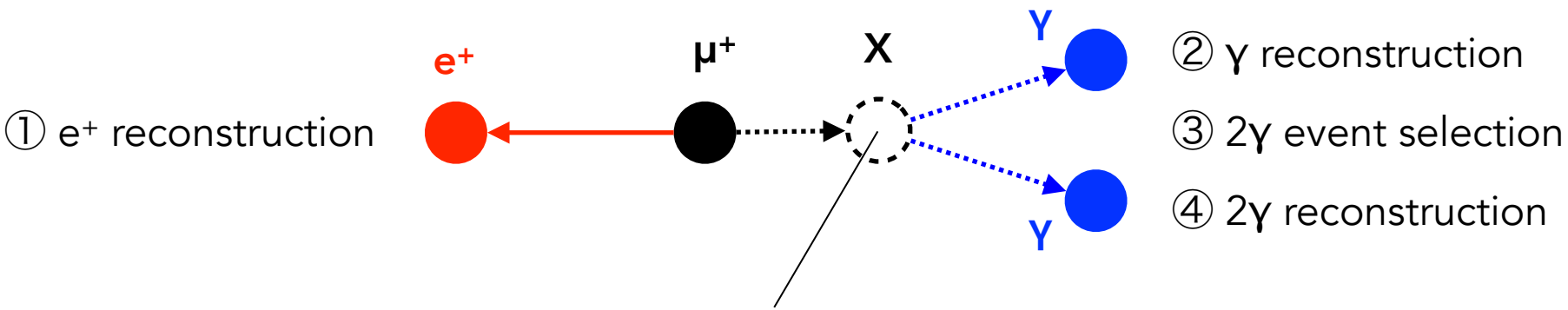
focusing on

- expected Br sensitivity
- possible updates
- schedule

※The physics results will not be presented today.

Signal reconstruction & BG



- Signal e+, X:
  - back-to-back
  - the same momentum
  - coincidence in time
- Possible BG:
  - e^+ is accidental
  - one of γ is accidental
  - e+, γ, and γ is accidental
- BG is estimated with time sideband.

Updates from the previous study

- **~5 times larger statistics**
- **Refined reconstruction methods**
  - e^+ events
    - ✓ noise subtraction, refined tracking
  - 2γ event selection
    - ✓ A better algorithm to select 2γ events.
  - 2γ event reconstruction
    - ✓ rejection of biases, additional corrections.
  - X vertex reconstruction

Red: already implemented

Black: work in progress

- **Corrections/modifications on the estimation of efficiencies**
  - Additional corrections (trigger, e^+ efficiency).
  - Taking additional correlations b/w variables into account.
  - More data-driven estimation.

Expected Br sensitivity

- The purpose of this study is to estimate expected Br sensitivity with the MEG full datasets.
- Updates included in this calculation:
  - ~5 times larger statistics.
  - Analysis updates (mainly on the positron side).
  - A change of trigger conditions after 2010.

- $<N_{BG}>$ is calculated based on the analysis in 2012 (using 2009/2010 data), assuming it is proportional to the statistics (=k)
- The expected Br sensitivity is calculated using the Feldman-Cousins (FC) approach*.

*G.J.Feldman,R.D.Cousins, Phys. Rev. D 57(7), 3873–3889 (1998)

- Br sensitivity: $\mathcal{B} = 1/k \times N_{\mathrm{sensitivity}}$
  - **k**: normalisation
    - ✓ 1/k: single event sensitivity
  - $\mathbf{N_{sensitivity}}$: expected N_{signal} upper limit when no signal is assumed

Normalisation

- To get the relative normalisation, Michel events (Br($\mu^+ \to e^+\nu\nu$)~100%) are used.

$\mu^+ \to e^+\nu\bar{\nu}$: Michel decay, Br ~ 100%

$\mu^+ \to e^+X, X \to \gamma\gamma$: MEx2G signal

$$\mathcal{B}_{\mathrm{Signal}} = \frac{1}{k} \times N_{\mathrm{Signal}}$$

$$\frac{1}{k} = \frac{1}{N_{\mathrm{Michel}}} \times \boxed{\text{ratio of e+ efficiency}} \times \frac{1}{\boxed{\gamma\ \text{efficiency}}} \times \boxed{\text{ratio of trigger}} \times \frac{\epsilon_{\mathrm{Michel}}}{\epsilon_{\mathrm{Signal}}}$$

Efficiency of selected e^+ energy region used for the normalisation. **7%–10%** depending on the assumed m_X.

The number of Michel events ~ 1

Efficiency of γγ events. **0.1%–9%** depending on the assumed m_X and τ.

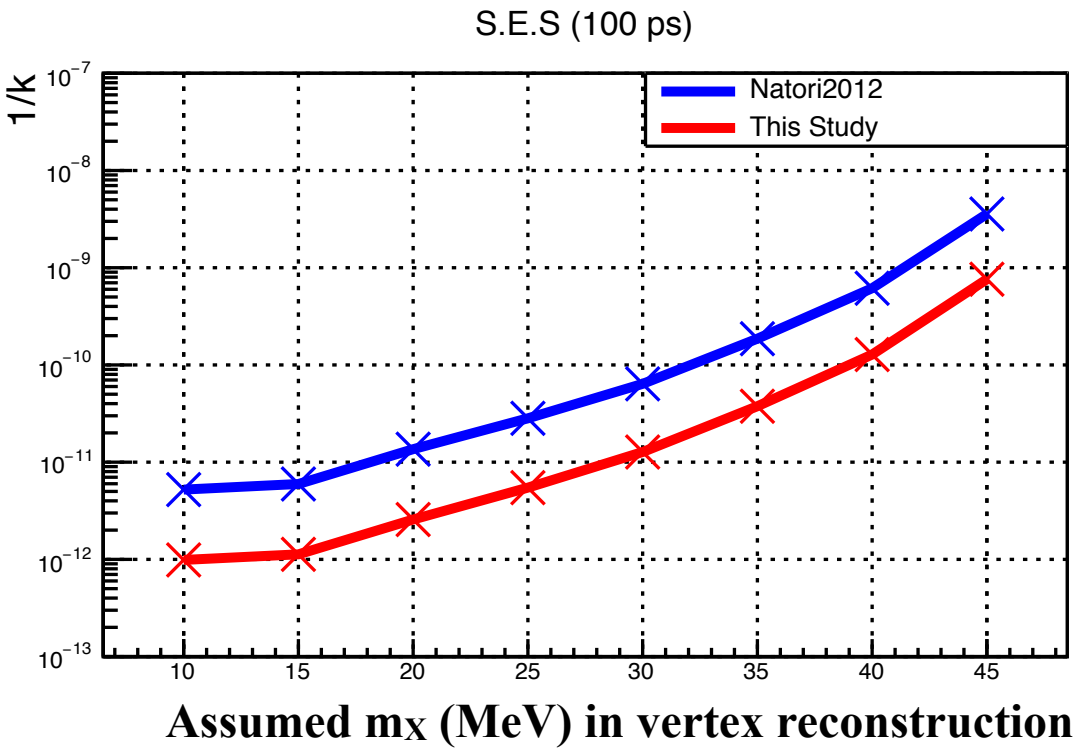
~ 10^{-7}

Efficiency of analysis cut on energy, time, vertex quality, momentum conservation. **20%–40%** depending on the assumed m_X and τ.

- By using Michel positrons as a normalisation, the estimation is independent of beam rate (stopped muons), and insensitive to absolute positron detection efficiency.

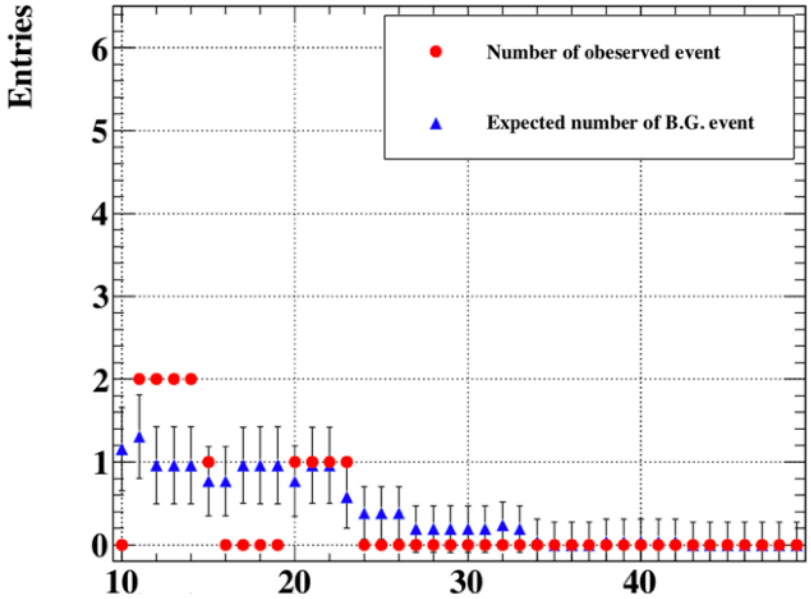
Single event sensitivity

- S.E.S.: Single Event Sensitivity = 1/k
  - $k_{\text{Natori2012}} = k_{2009a}+k_{2009b}+k_{2010a}+k_{2010b}$
  - $k_{\text{This study}} = k^{new}_{2009a}+k^{new}_{2009b}+k^{new}_{2010a}+k^{new}_{2010b}+k_{2011}+k_{2012/2013}$
- **Blue**: S.E.S. estimated in the previous analysis in 2012.
- **Red**: updated results with more statistics (**x4.7–5.3**).



Expected N_{BG}

1. N_{BG} in the previous study is shown in **blue**:



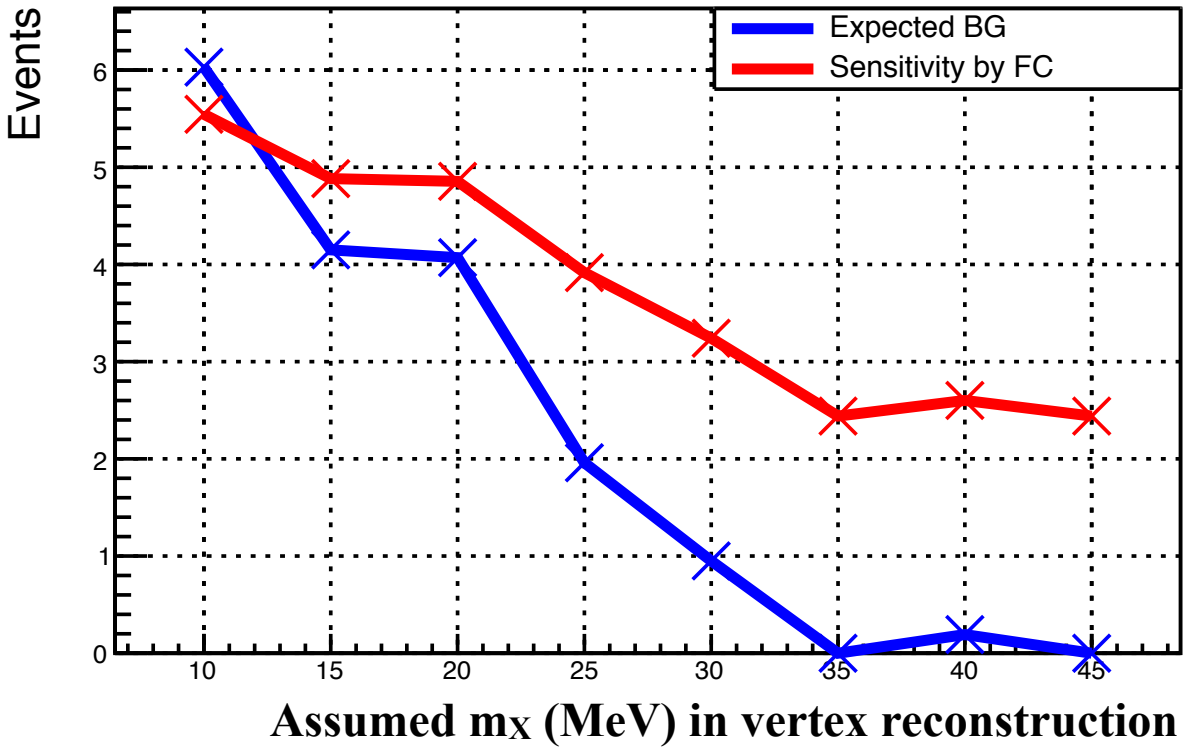
2. Assume N_{BG} is proportional to the statistics*, then we get expected N_{BG} **in the full datasets** (see the next):
   - expected N_{BG} = previous N_{BG} * $k_{\text{This study}}$ /$k_{\text{Natori2012}}$
   - 4.7–5.3 times larger statistics than the previous results.

3. Calculate the sensitivity (see the next).

*In the final analysis, it will be estimated using sideband data.

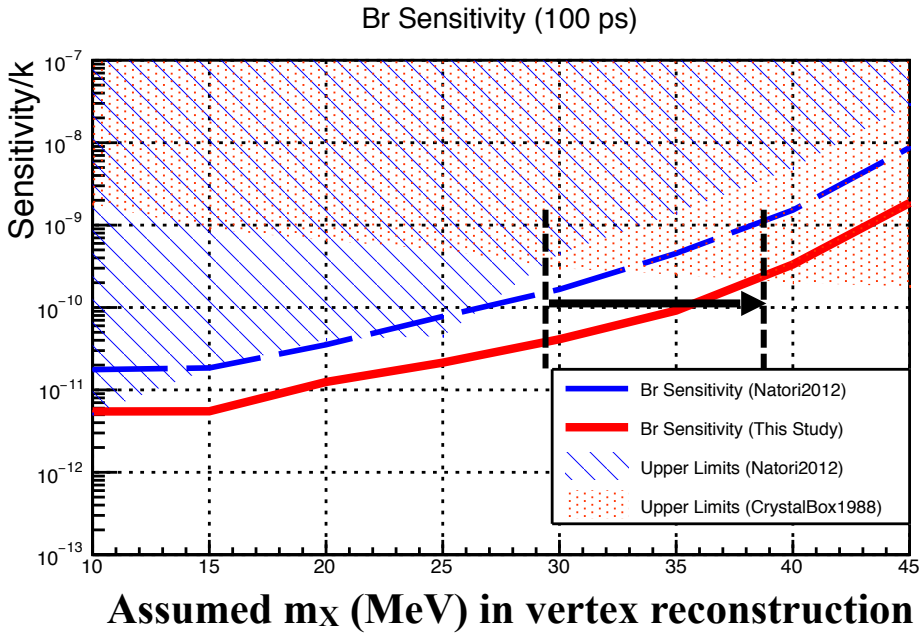
Sensitivity

- Sensitivity is defined as the average upper limit that would be obtained by an ensemble of experiments with the expected background and no true signal.
- **Sensitivity** is calculated using **estimated N_{BG}** and Feldman-Cousins approach.
- Sensitivity at 90% C.L. is shown in right plot together with expected N_{BG}.



Br sensitivity

- We can get Br sensitivity with $\mathcal{B} = 1/k \times N_{\mathrm{sensitivity}}$
- Br sensitivity is expected to be improved by a factor of **3.2–5.0**.
- Lower mass: N_{BG} is larger and it should be decreased to get the better sensitivity.
- Higher mass: new analysis can update crystal box results, which cannot be updated in Natori2012.



Worse sensitivity in the higher mass region due to

- Cut efficiency
- Trigger efficiency
- Gamma acceptance

Summary & Prospects

- Recently, it is important to search any possibility of BSM with existing experimental setups.
- We have started thinking the search for $\mu^+ \rightarrow e^+X$, $X \rightarrow \gamma\gamma$ using the MEG I full datasets.
- Br sensitivity is expected to be improved by a factor of **3.2–5.0** from the previous study in 2012.
- It will be updated with refined analyses.
- Updates on reconstruction tools: **on going**
- Physics results: **this year**