ICEPP
The University of Tokyo

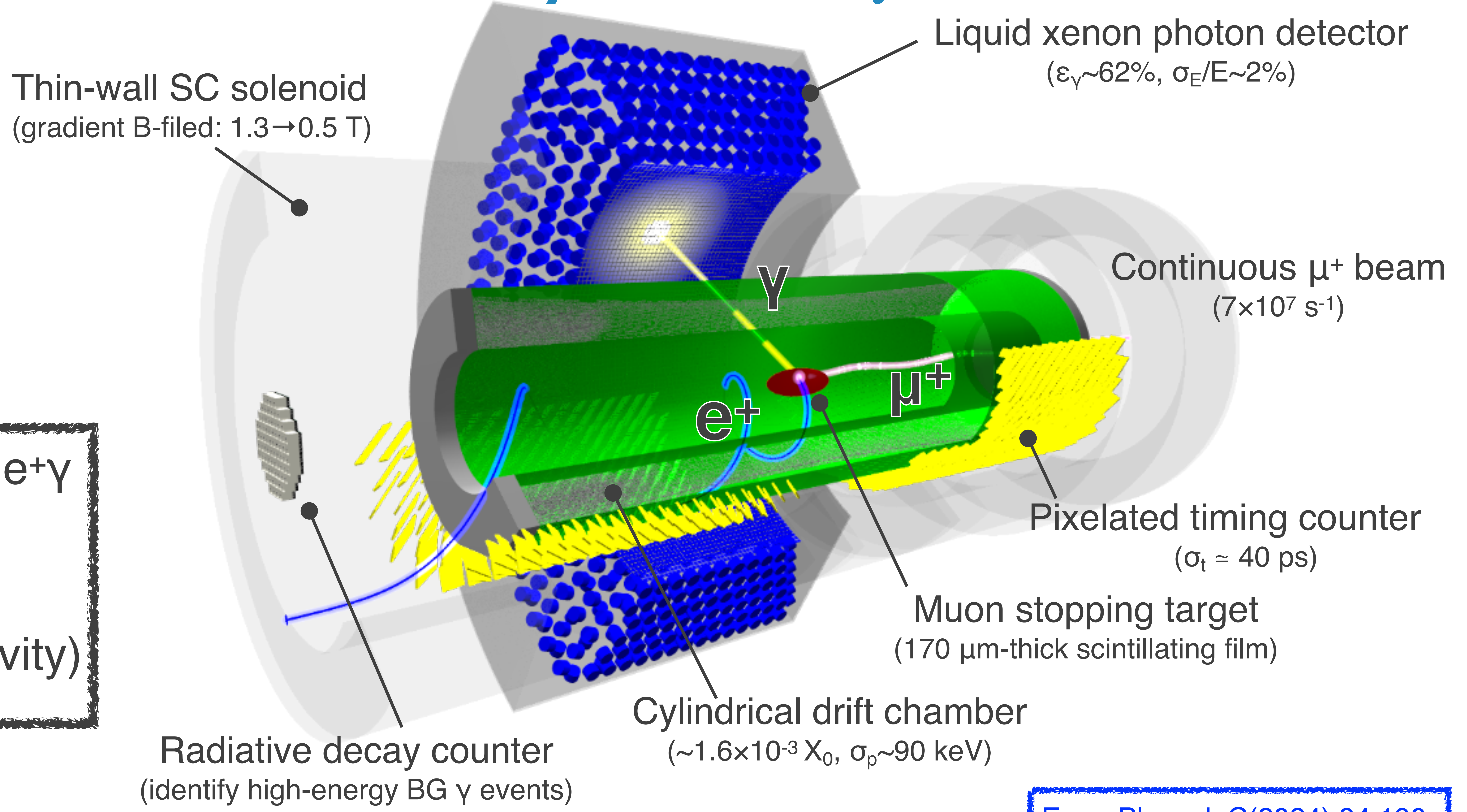
TOSHINORI MORI
THE MEG II COLLABORATION

ALP SEARCHES AT MEG II

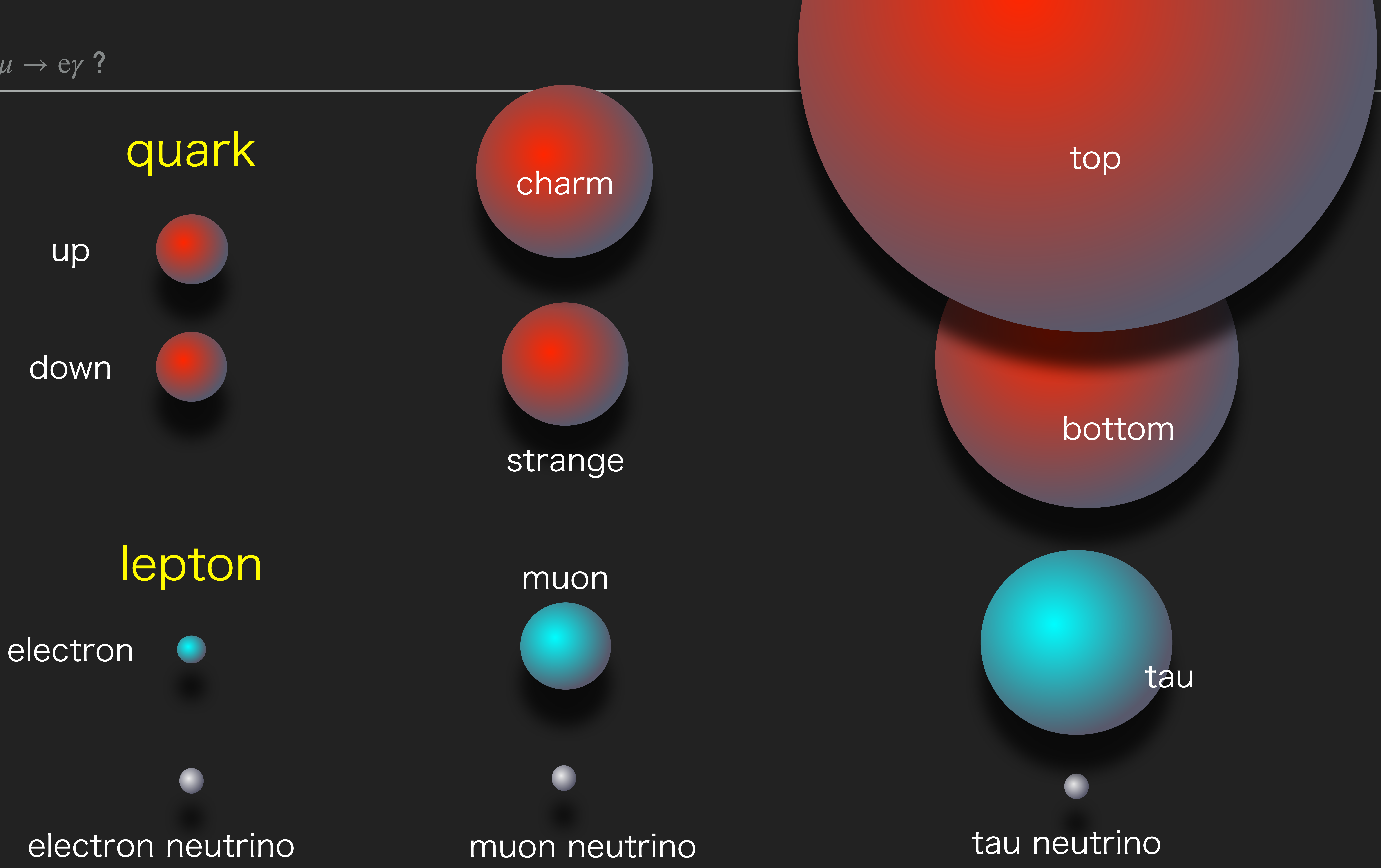
MEG II – SEARCHING FOR $\mu \to e\gamma$ DECAY

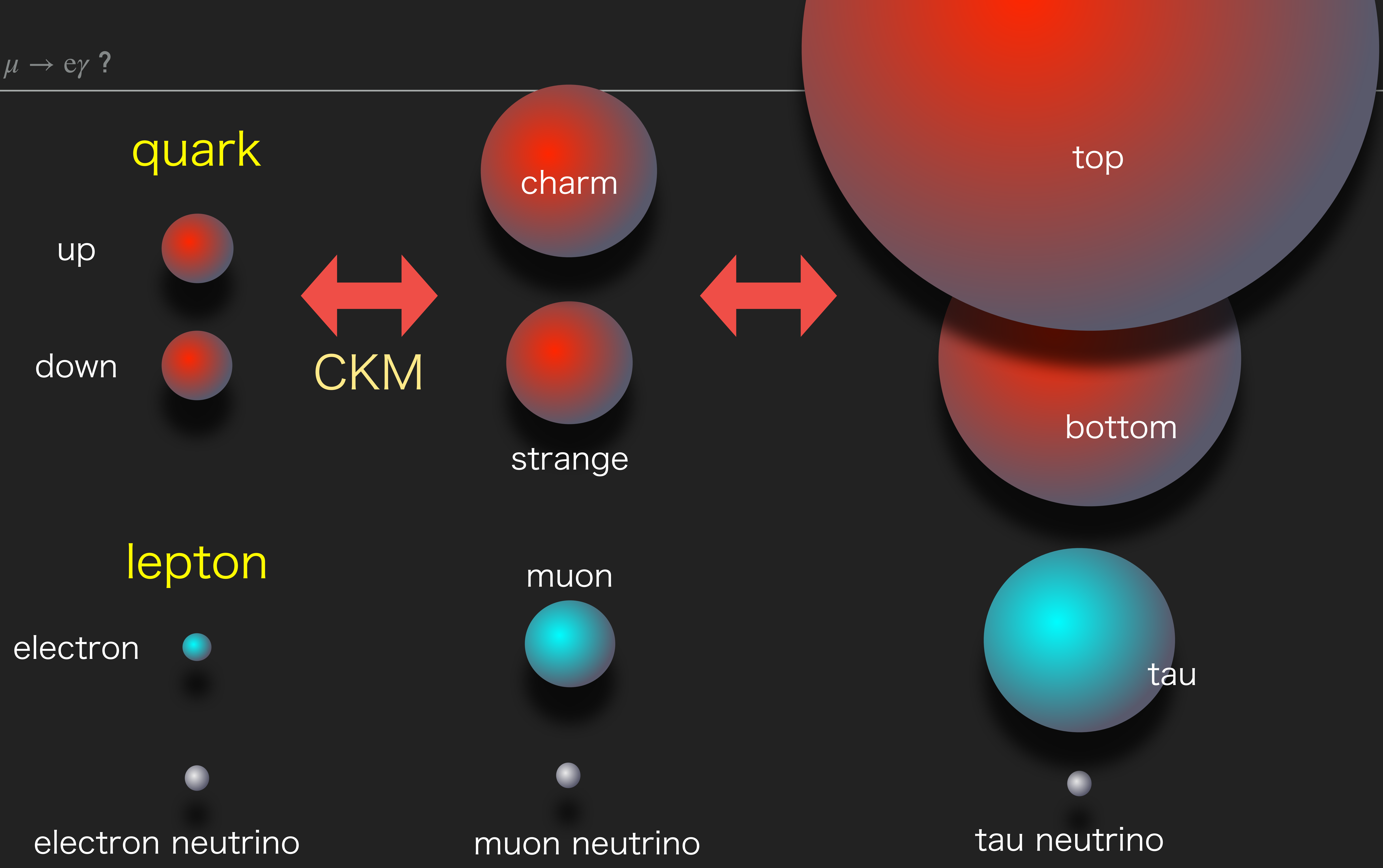
higher intensity
higher resolution
higher efficiency

Search for $\mu^+ \to e^+\gamma$
down to
6×10^{-14}
(90% C.L. sensitivity)



Euro. Phys. J. C(2024) 84:190


quark
up
down
charm
strange
top
bottom
lepton
electron
muon
tau
electron neutrino
muon neutrino
tau neutrino


quark
up
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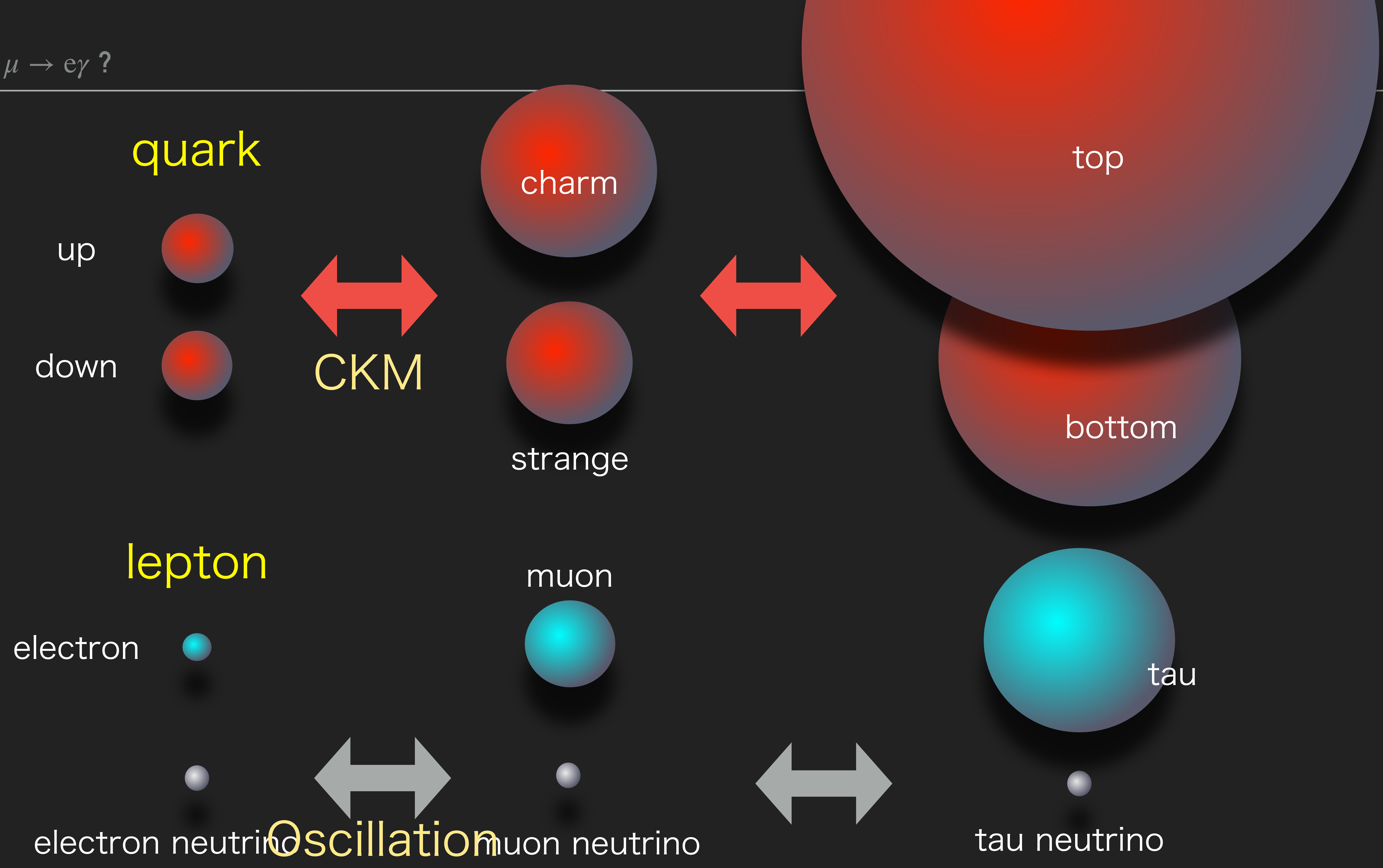
CKM
charm
strange
top
bottom
lepton
electron
muon
tau
electron neutrino
muon neutrino
tau neutrino


quark
up
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CKM
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strange
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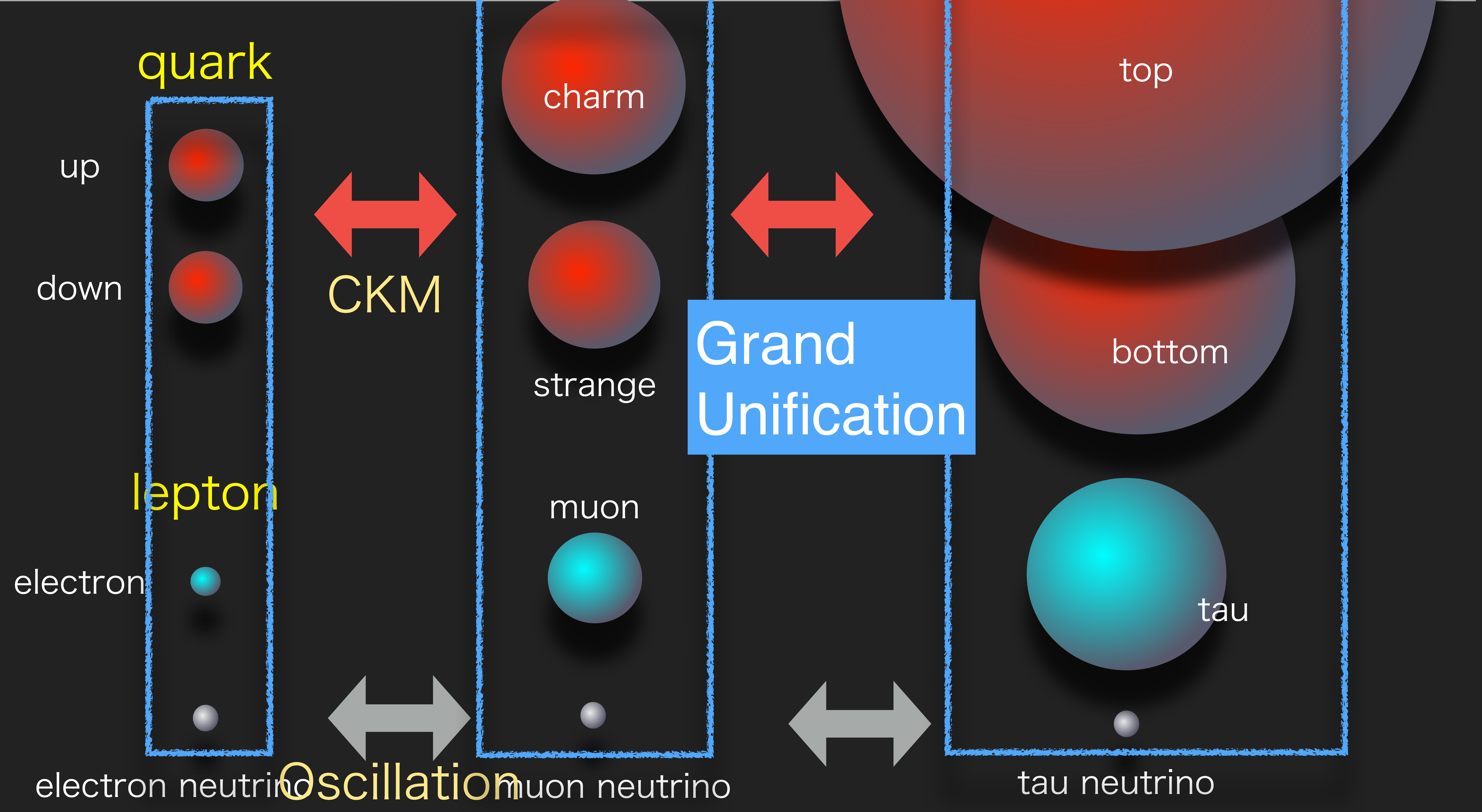
bottom
lepton
electron
muon
tau
electron neutrino
Oscillation
muon neutrino
tau neutrino


quark
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strange
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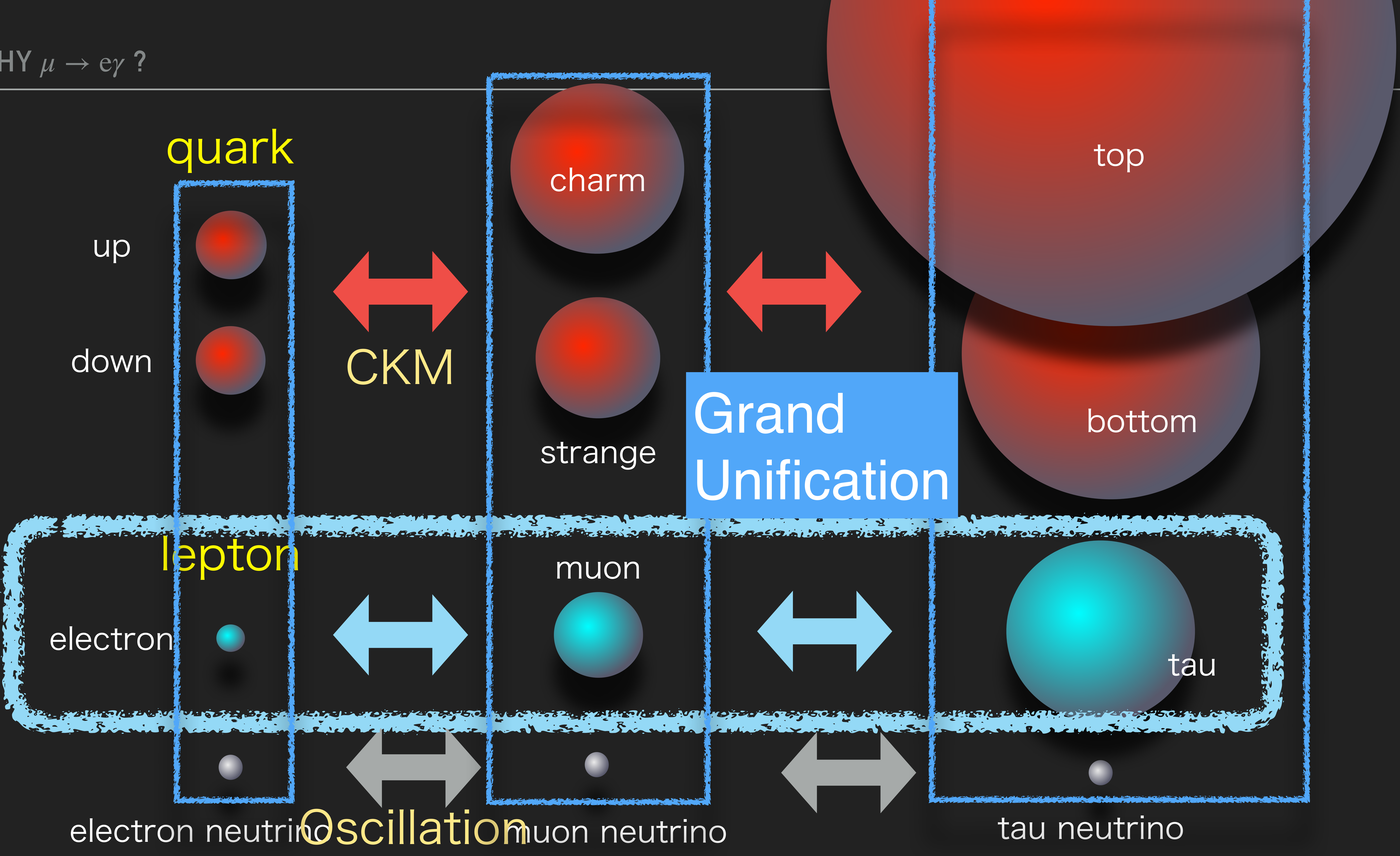
bottom
Grand Unification
lepton
electron
muon
tau
electron neutrino
Oscillation
muon neutrino
tau neutrino


quark
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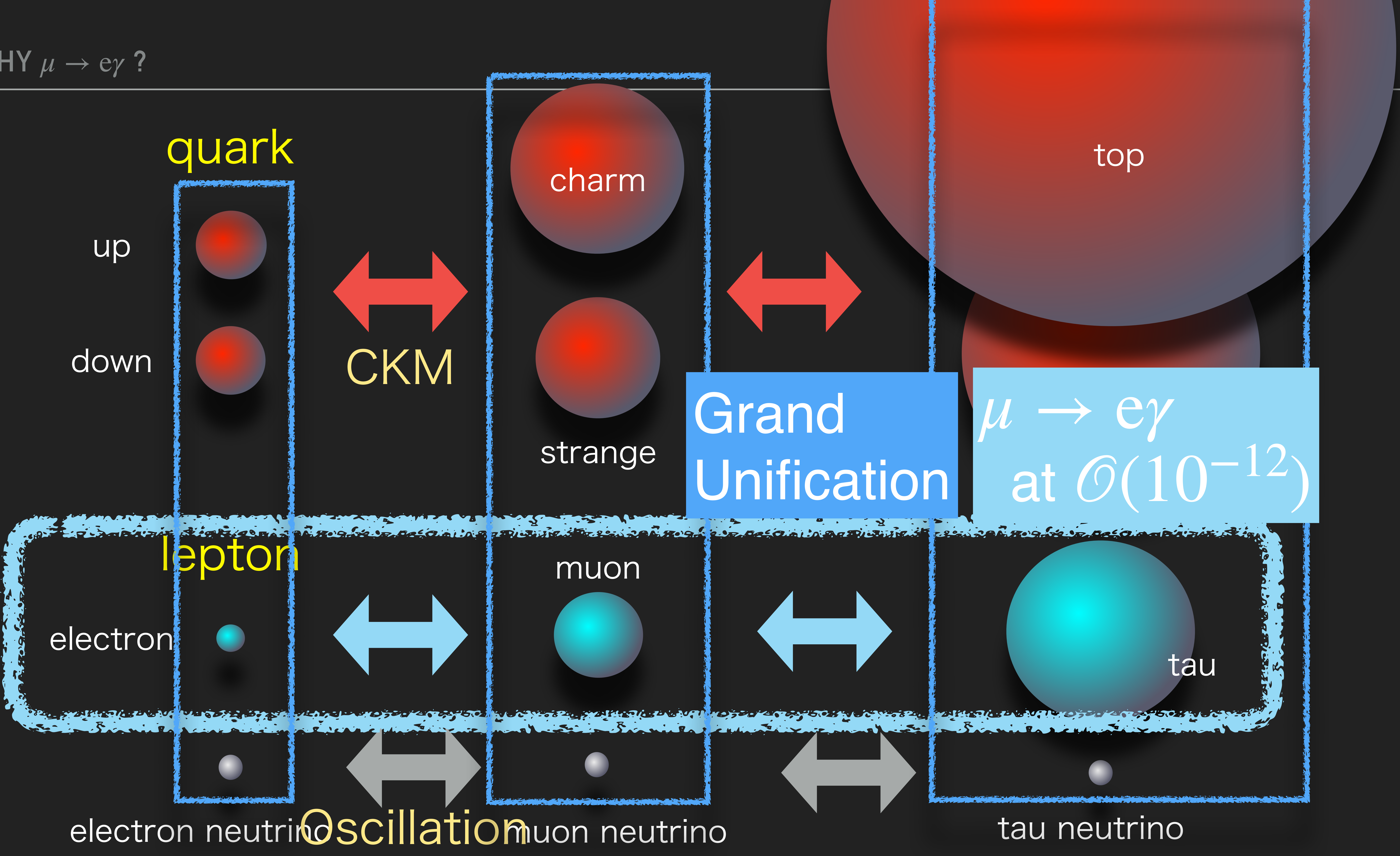

quark
up
down
CKM
charm
strange
top
Grand Unification
$\mu \to e\gamma$ at $\mathcal{O}(10^{-12})$
lepton
electron
muon
tau
electron neutrino
Oscillation
muon neutrino
tau neutrino

BIG PICTURE

GUT

grand unification
charge quantization

SUSY

Leptogenesis

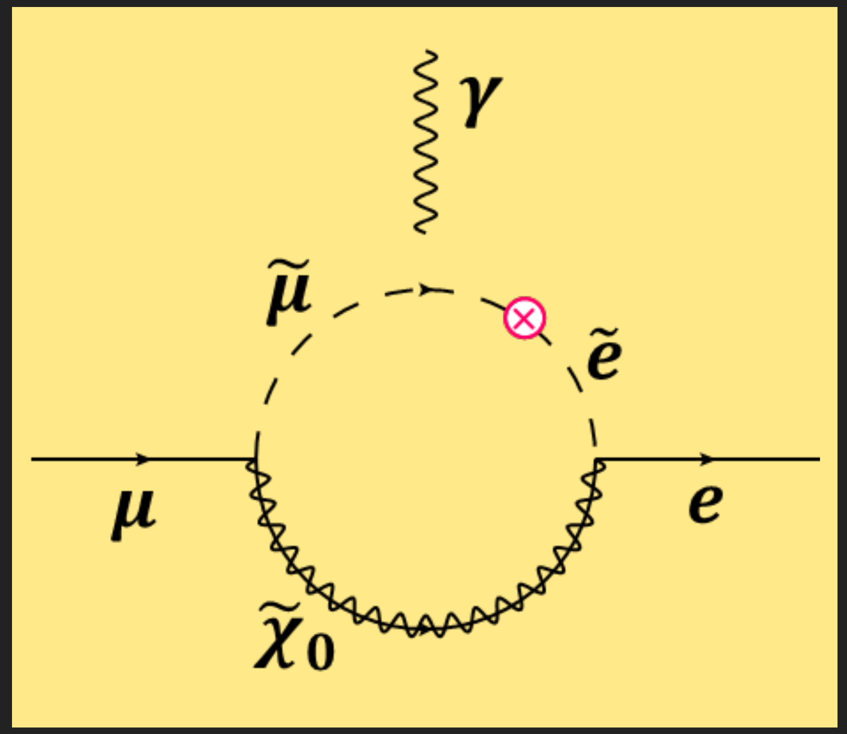
seesaw mechanism
neutrino masses

Flavor violation from
quark Yukawa

Flavor violation from
neutrino Yukawa

TeV scale physics
Dark Matter

$$\mu \to e\gamma$$



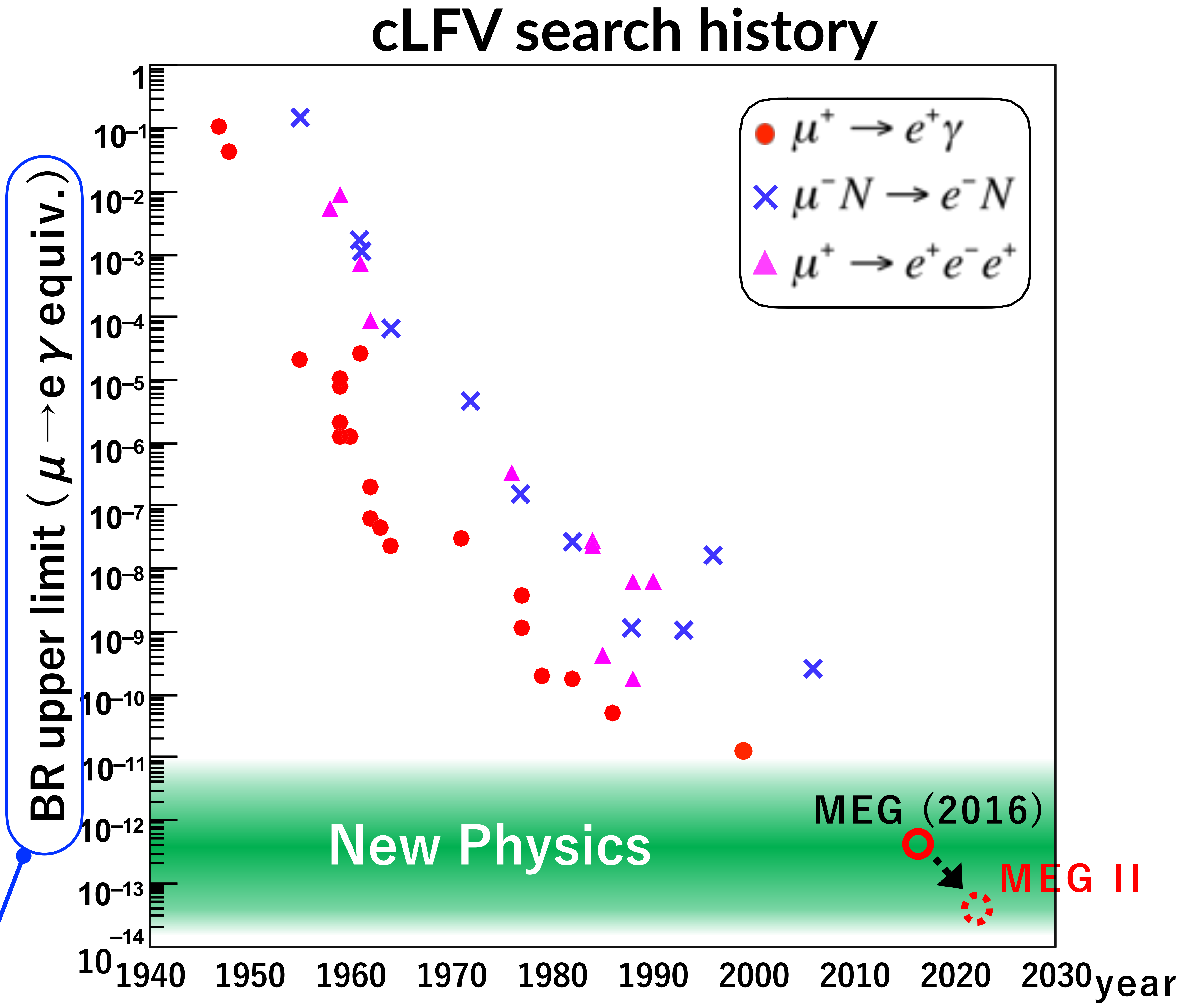
$$\simeq 10^{-12}$$

THE CURRENT STATUS:

$$\mu \to e\gamma$$

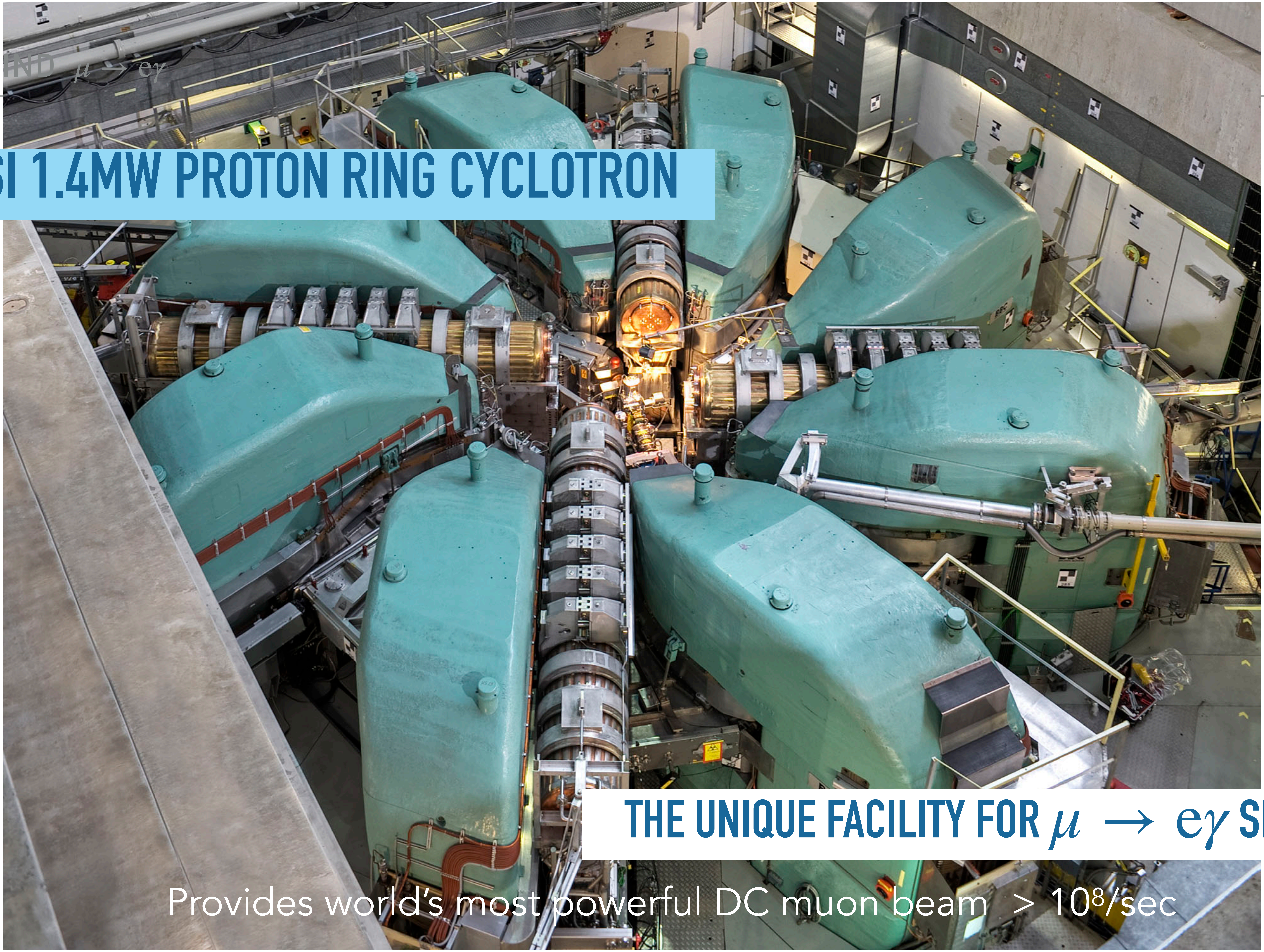
MEG II has been leading the world's efforts to discover lepton flavour violation in charged leptons (cLFV)

the smallest measured branching ratio for an elementary particle !



Normalised to $\mu^+ \to e^+\gamma$ rate assuming dipole interaction (à la SUSY)

(1) PSI 1.4MW PROTON RING CYCLOTRON

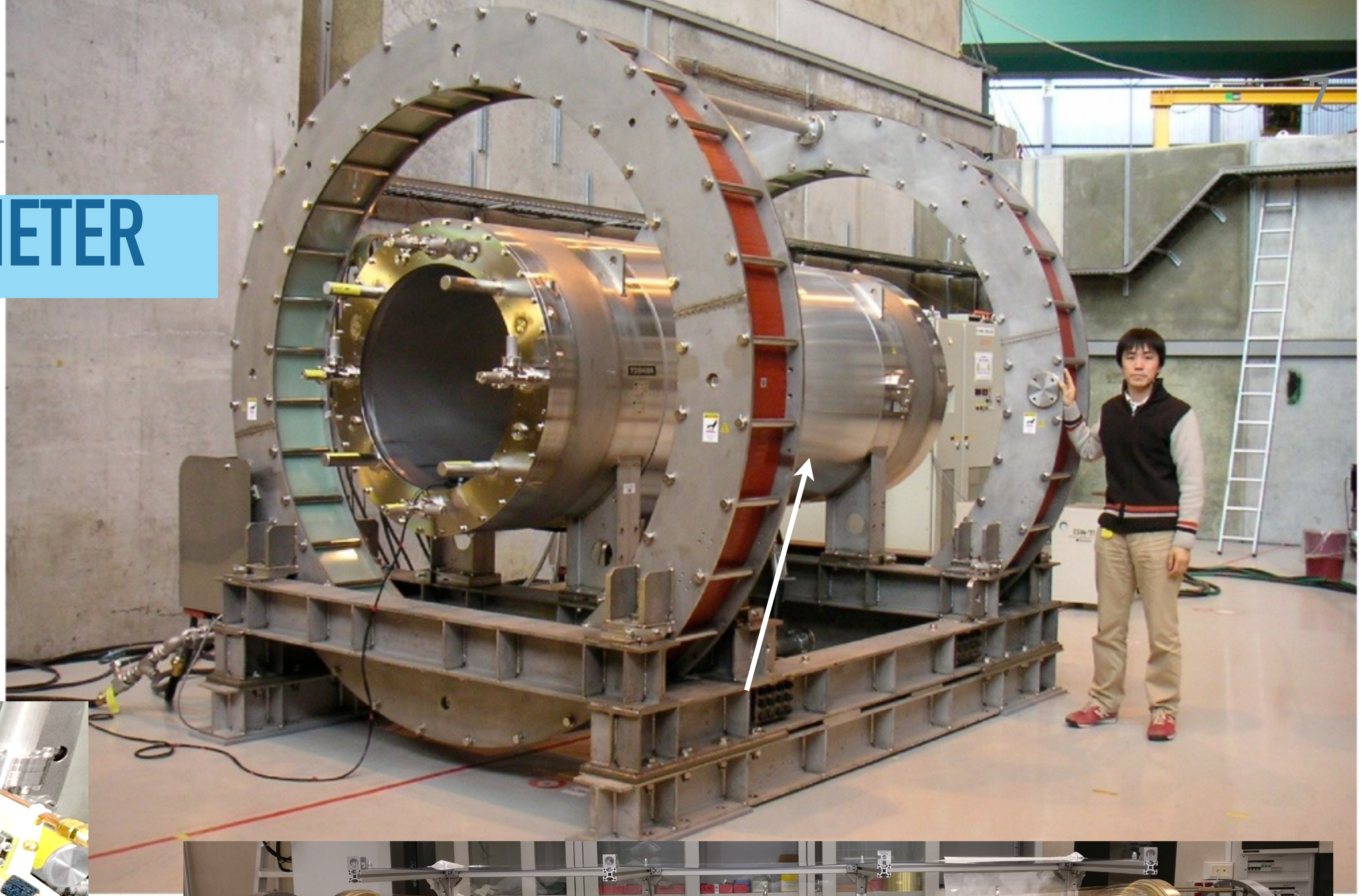


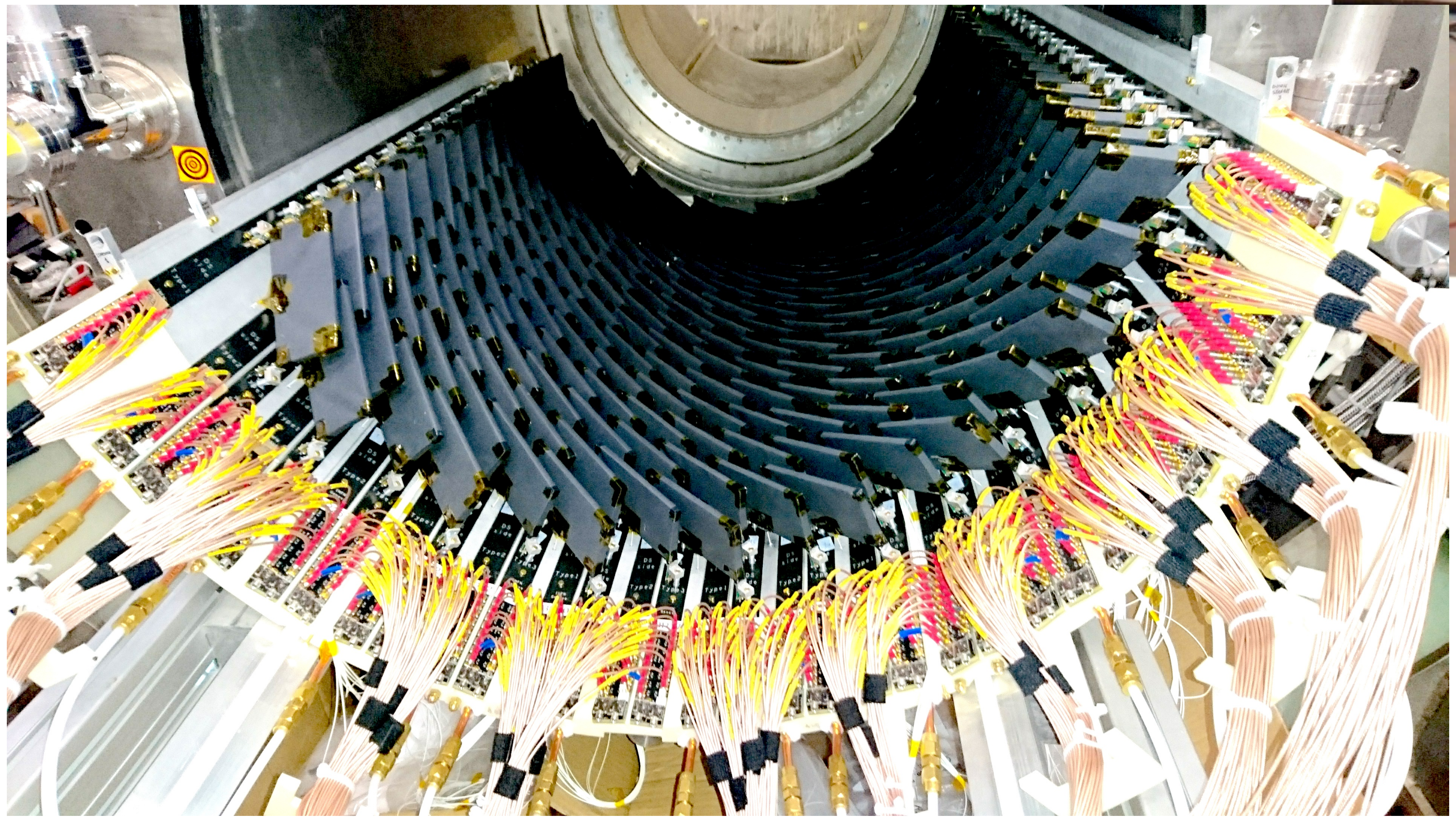
THE UNIQUE FACILITY FOR $\mu \to e\gamma$ SEARCH

Provides world's most powerful DC muon beam $> 10^8$/sec

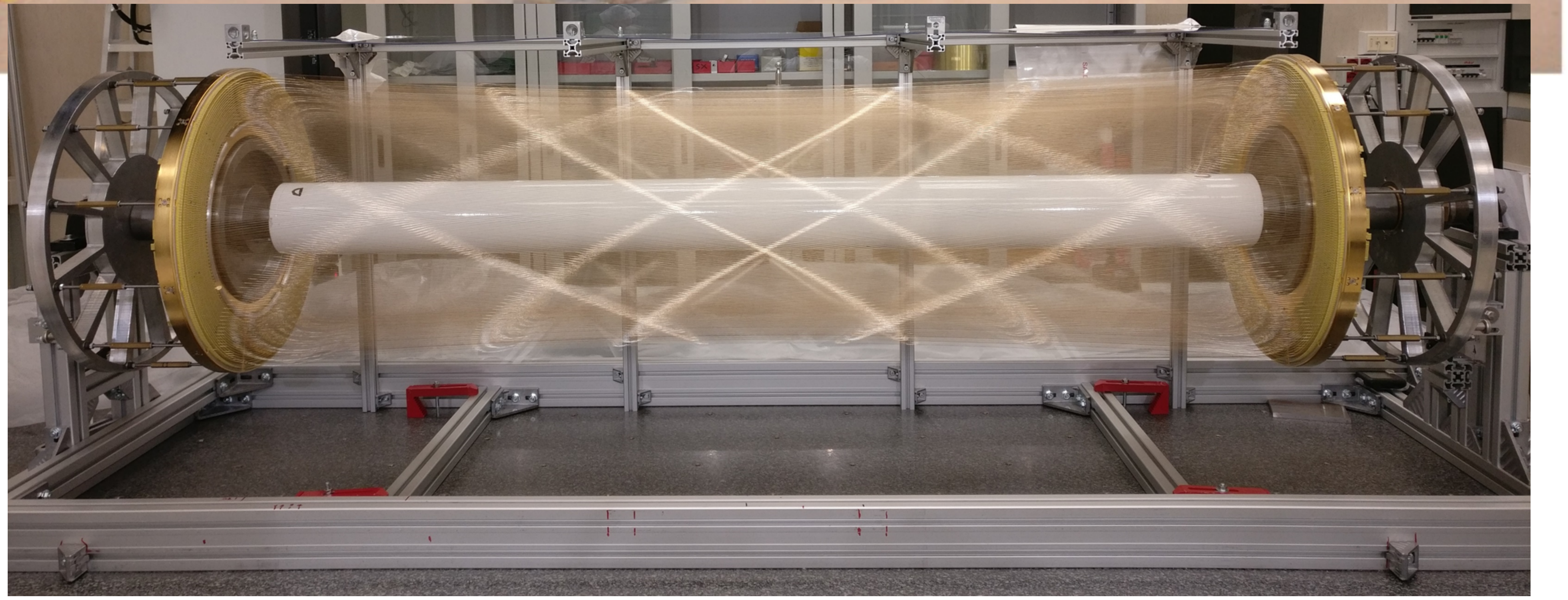
(2) COBRA POSITRON SPECTROMETER

- Thin-wall SC solenoid with a gradient magnetic field to measure only high-momentum positrons with minimum detector material





PIXELATED TIMING COUNTER

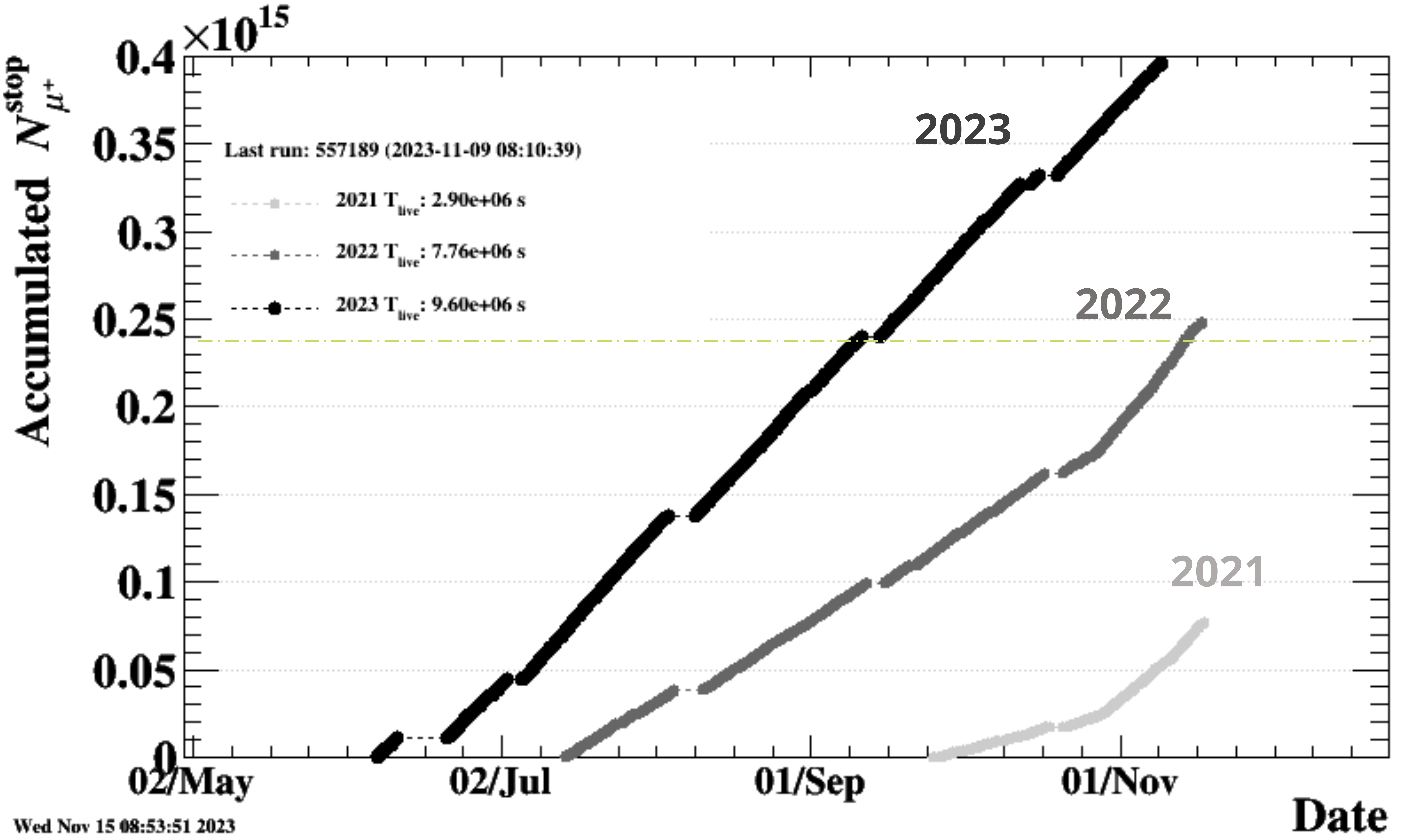


CYLINDRICAL DRIFT CHAMBER

(3) 2.7TON LIQUID XENON PHOTON DETECTOR (LXE)

- Scintillation light from 900 liter LXe is detected by SiPM & PMTs mounted on all surfaces
- Fast response & high light yield provide good resolutions of energy, time, & position
- Gas/liquid circulation system to purify xenon
    - Ultimate uniformity & purity unachievable by crystal calorimeter

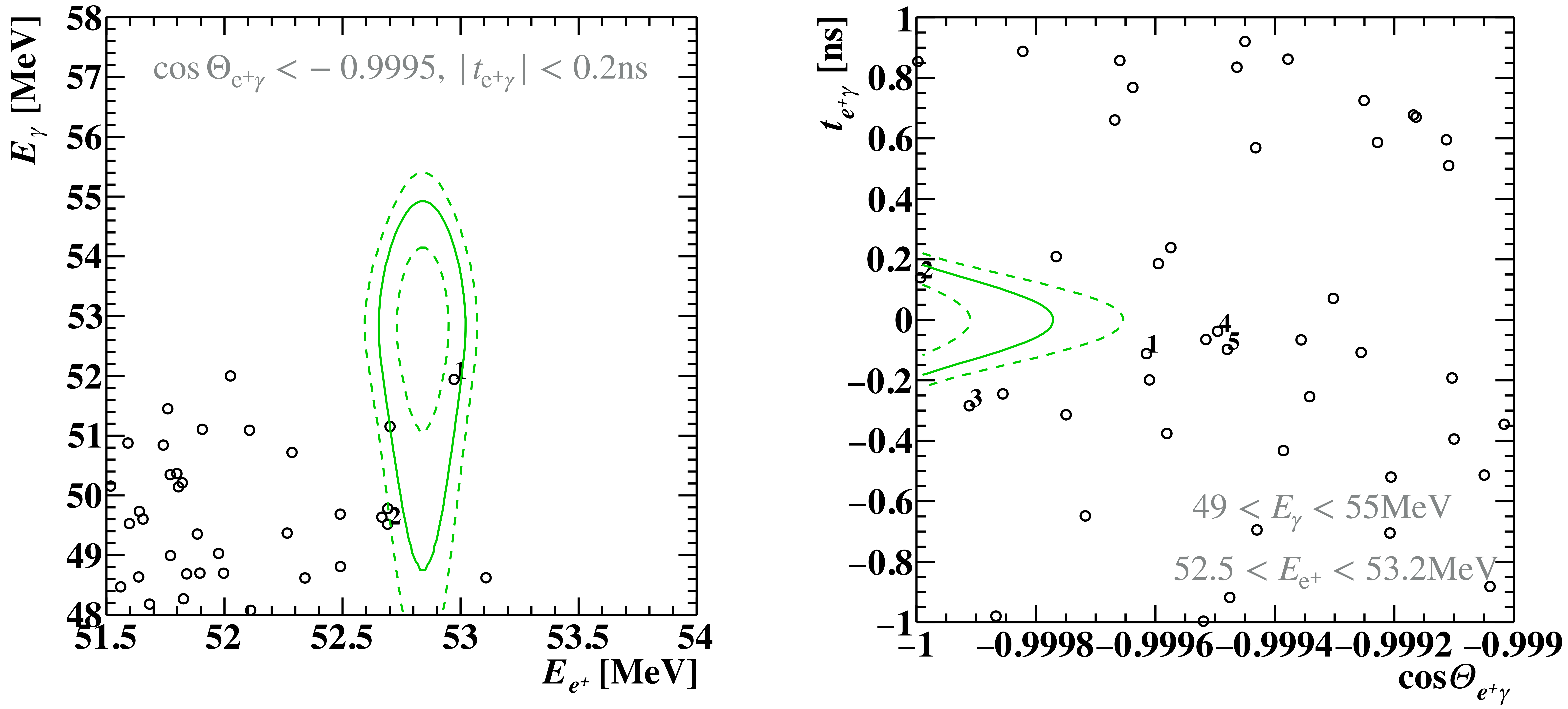
MEG II DATA


×10^15
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Accumulated $N_{\mu^+}^{stop}$
Last run: 557189 (2023-11-09 08:10:39)
2021 T_{live}: 2.90e+06 s
2022 T_{live}: 7.76e+06 s
2023 T_{live}: 9.60e+06 s
2023
2022
2021
02/May
02/Jul
01/Sep
01/Nov
Date
Wed Nov 15 08:53:51 2023

UNBLINDED 2021 PILOT DATA

4D distribution

66 events in Analysis Region
(Sideband estimate 68.0 ± 3.5)



SUMMARY AND PROSPECTS

- The first 7-week data in 2021 achieved a Sensitivity ~60% of MEG 2009-2013.

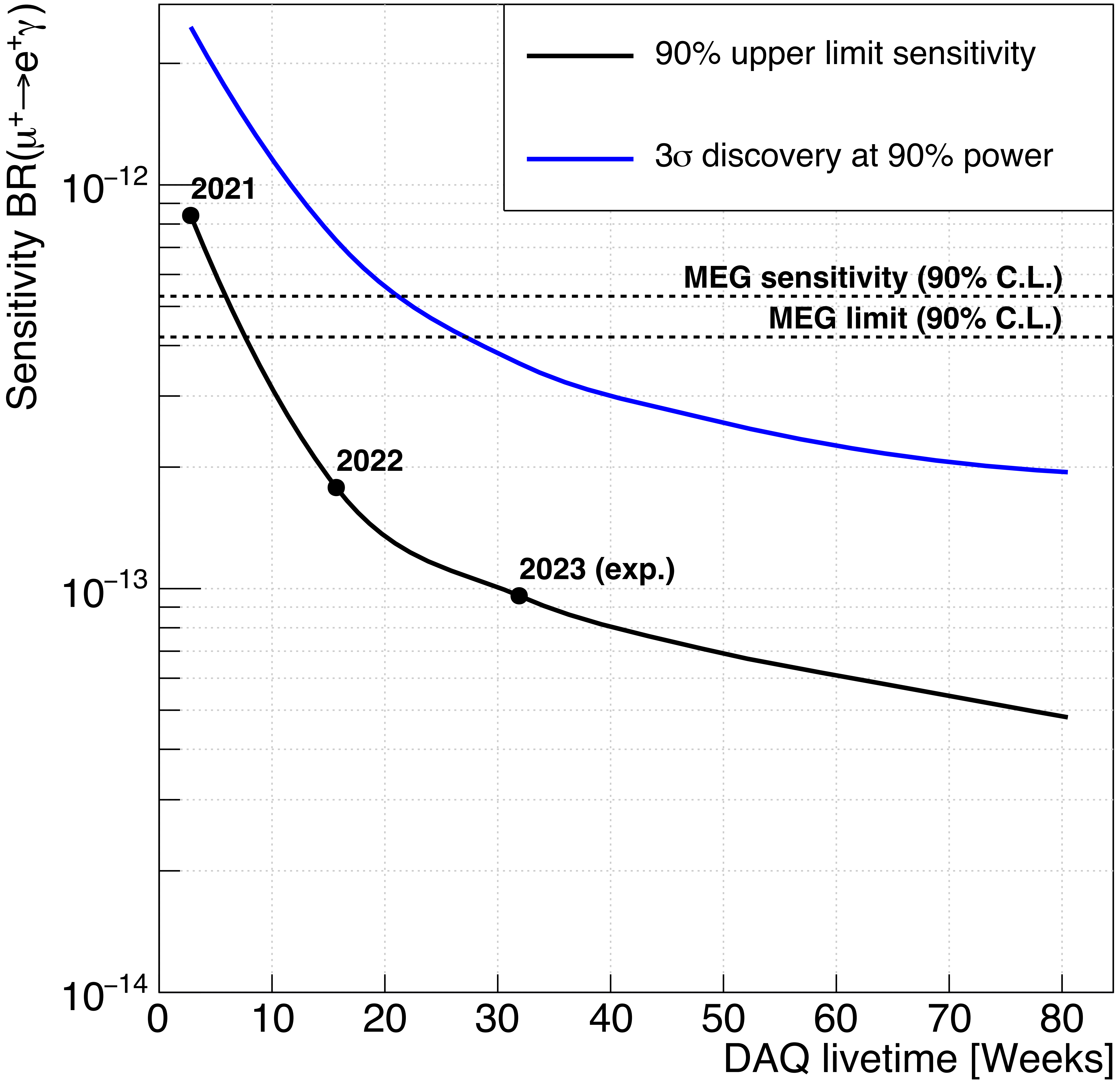
$$\boxed{\mathscr{B}_{90} = 7.5 \times 10^{-13}}$$

- A combination MEG + MEG II provides the most stringent limit on the branching ratio of $\mu^+ \to e^+\gamma$

$$\boxed{\mathscr{B}_{90} = 3.1 \times 10^{-13}}$$

- **Expect to finish the 2022 data analysis this autumn**

Euro. Phys. J. C (2024) 84:216



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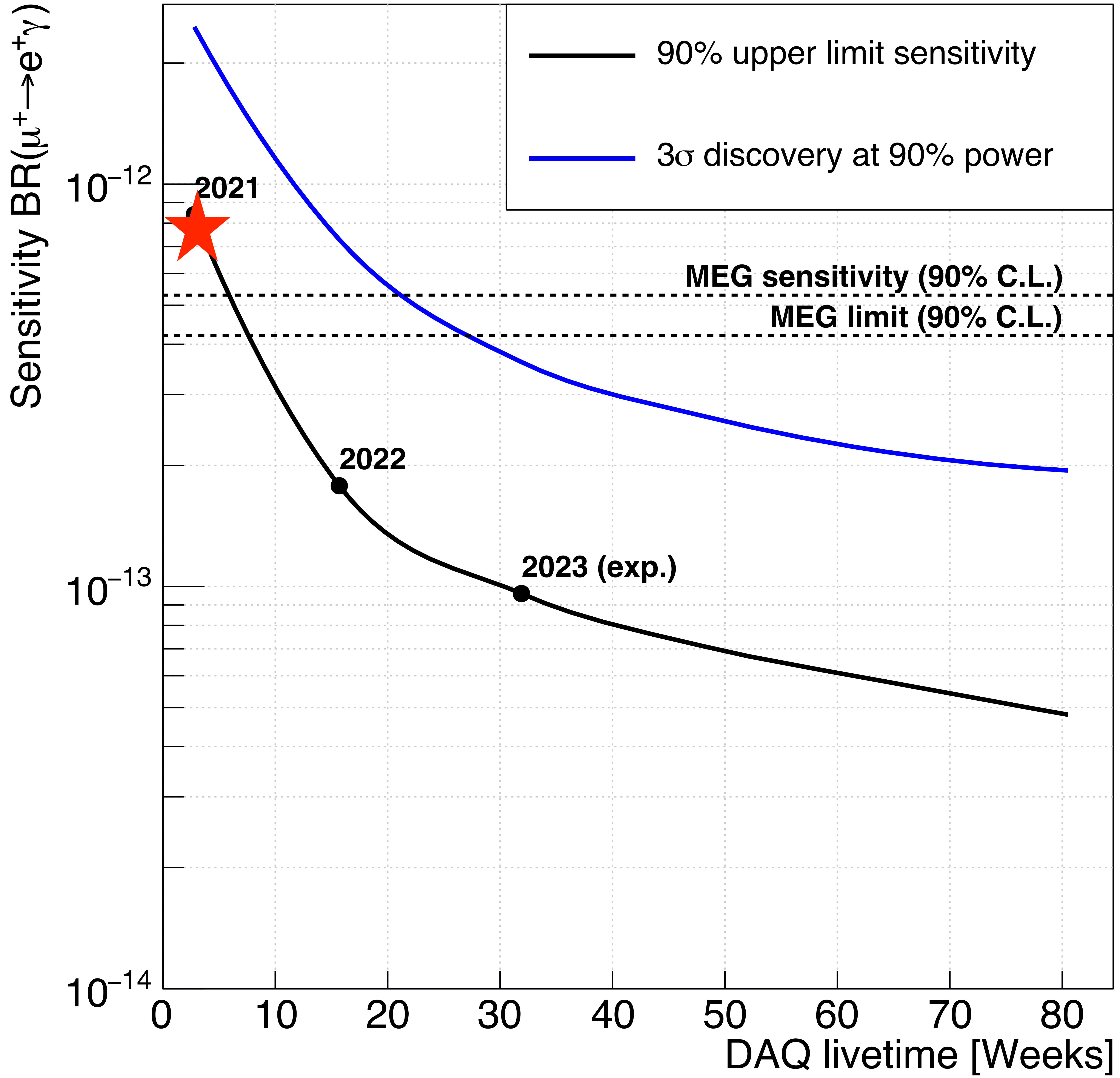

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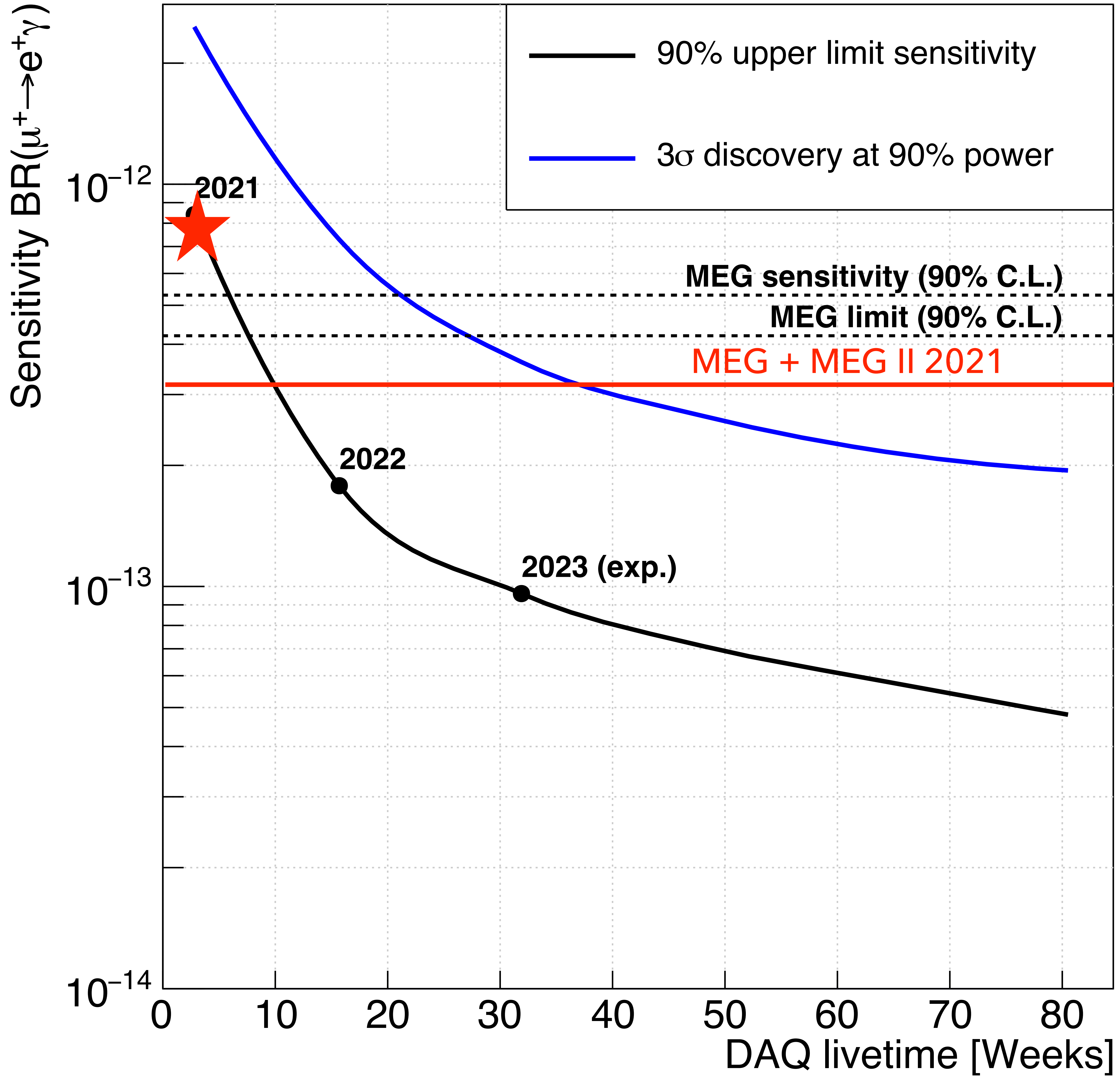
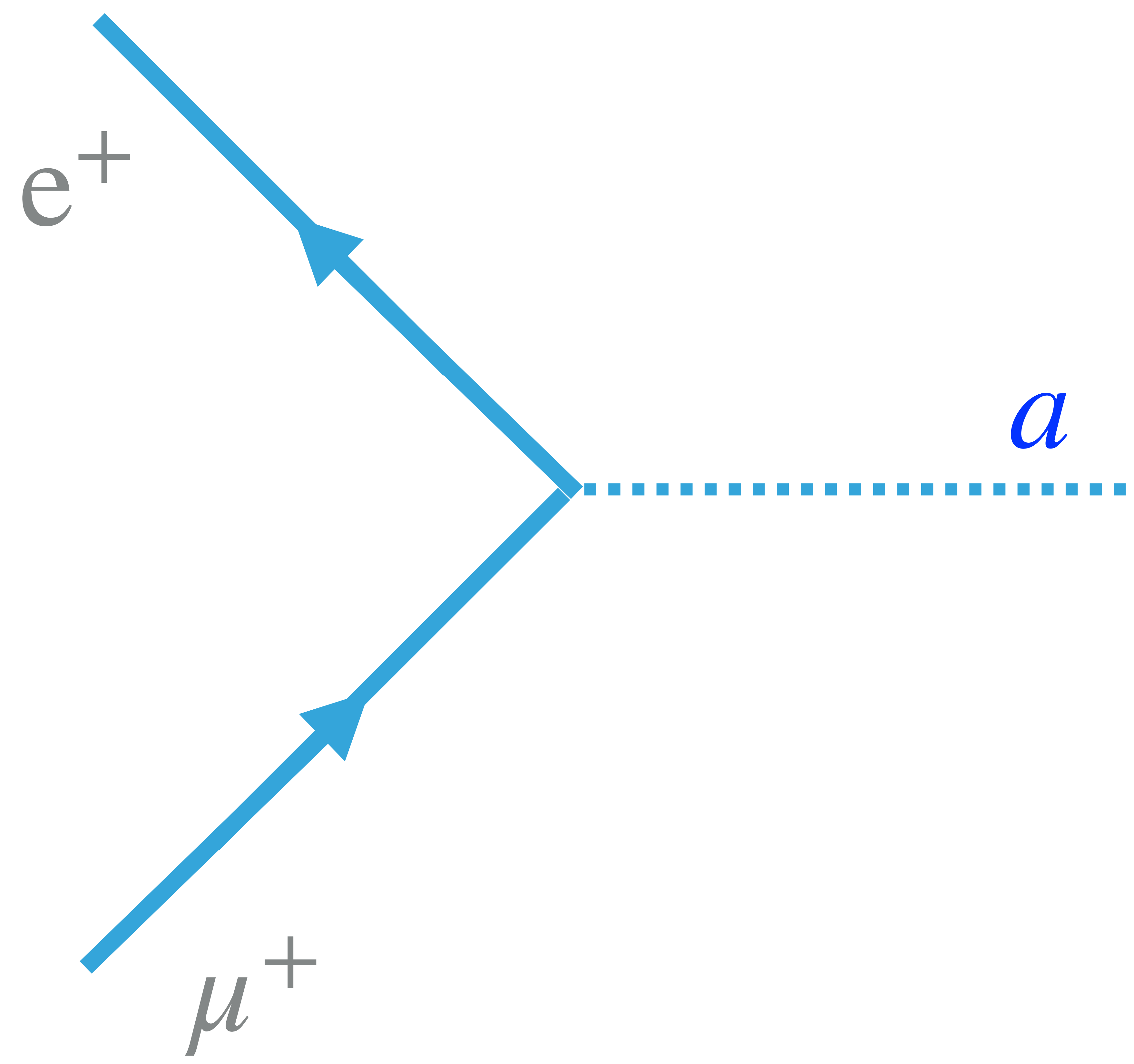
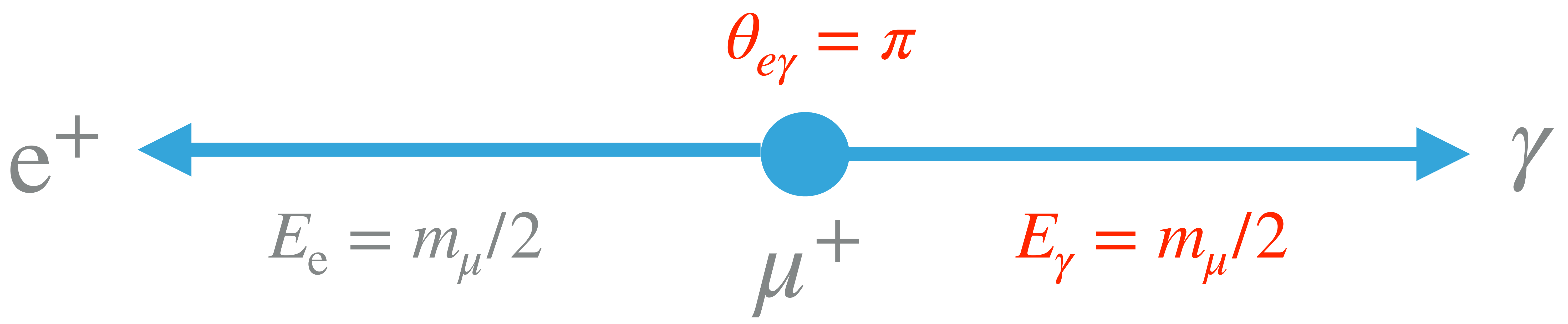


Euro. Phys. J. C (2024) 84:216

AXION-LIKE PARTICLES THAT VIOLATE LEPTON FLAVOUR



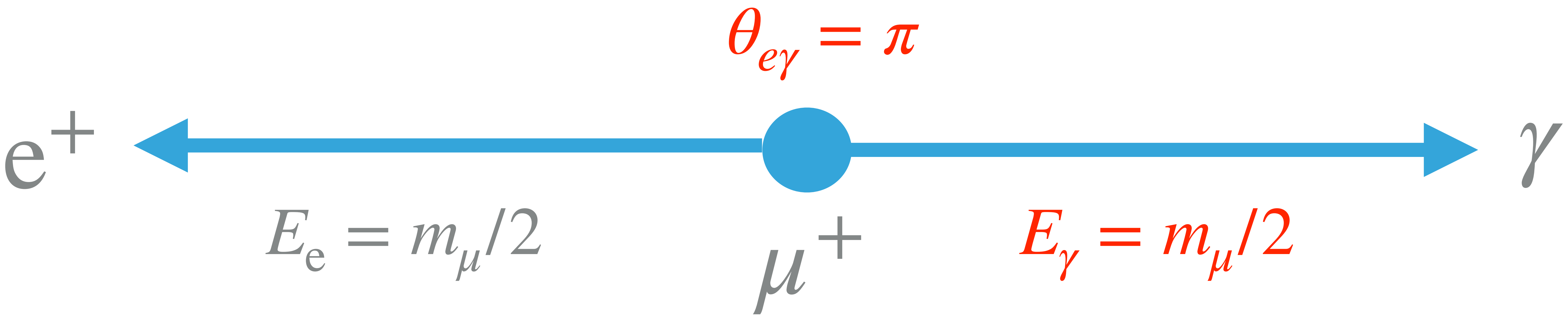
KINEMATICS OF ALP SEARCHES



$$\mu \to e\gamma$$

MEG II optimised
to measure this event!

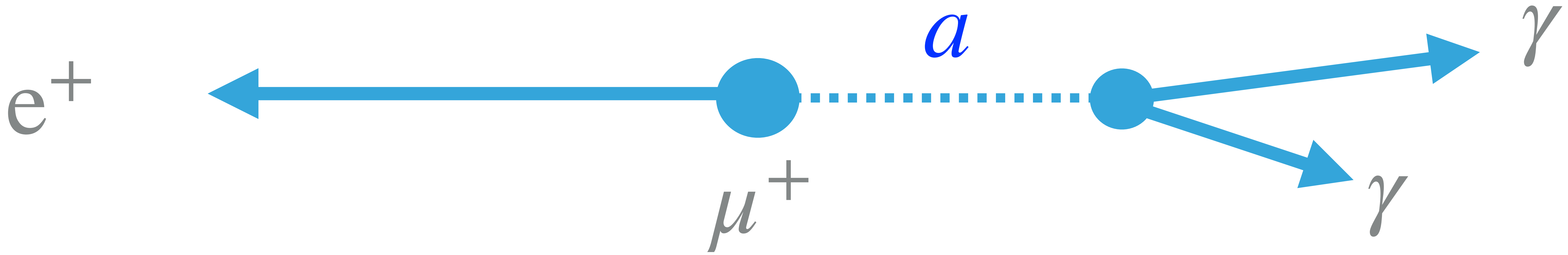
KINEMATICS OF ALP SEARCHES



$$\mu \to e\gamma$$

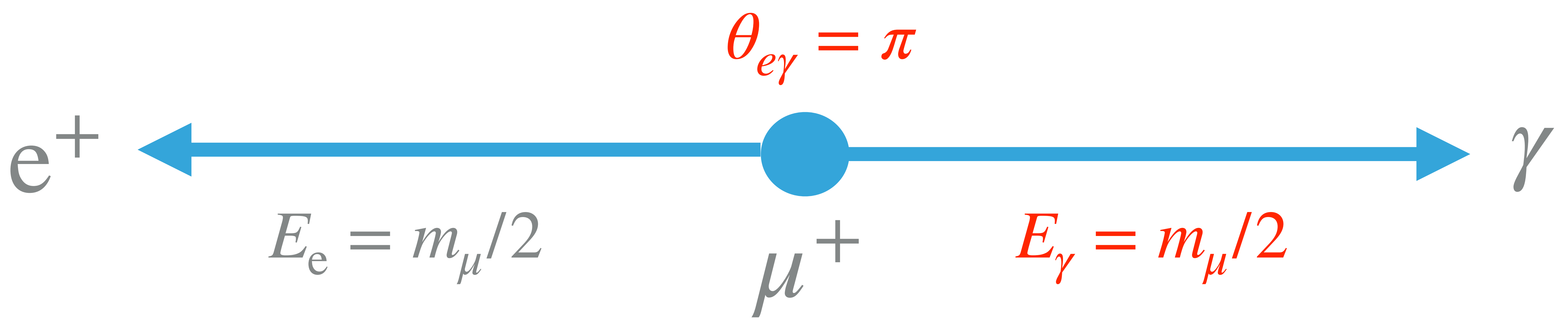
MEG II optimised to measure this event!

(1)



$$\mu \to ea \to e\gamma\gamma$$

KINEMATICS OF ALP SEARCHES



$\mu \to e\gamma$

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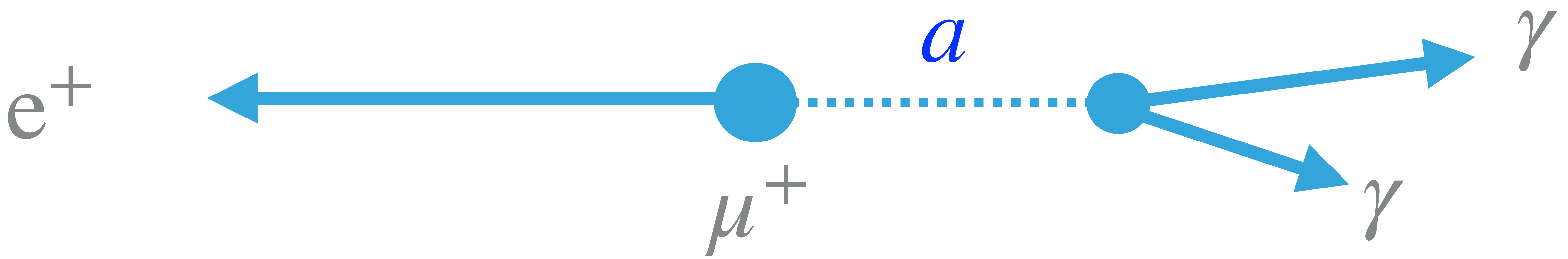
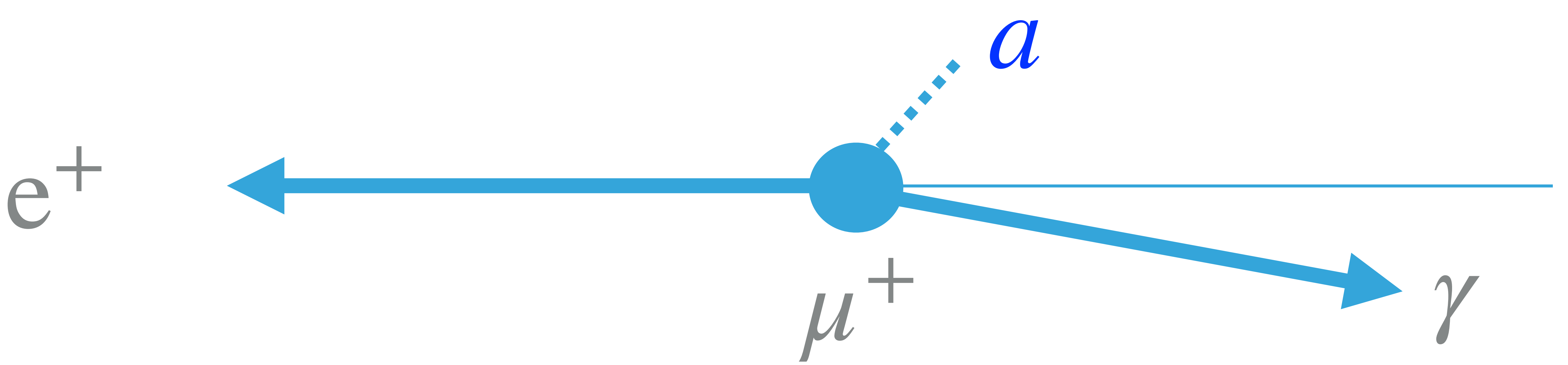


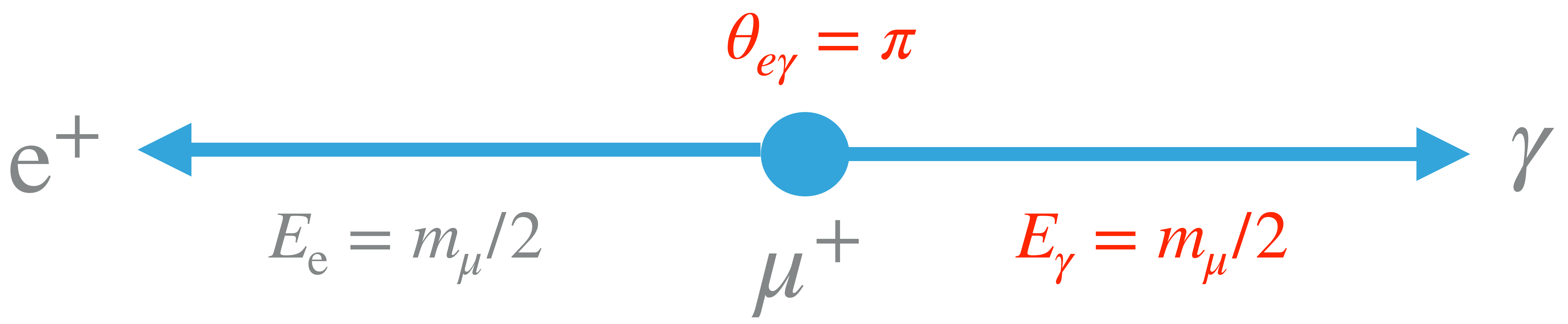
$\mu \to ea \to e\gamma\gamma$

(2)



$\mu \to ea\gamma$

KINEMATICS OF ALP SEARCHES



$\mu \to e\gamma$

MEG II optimised to measure this event!

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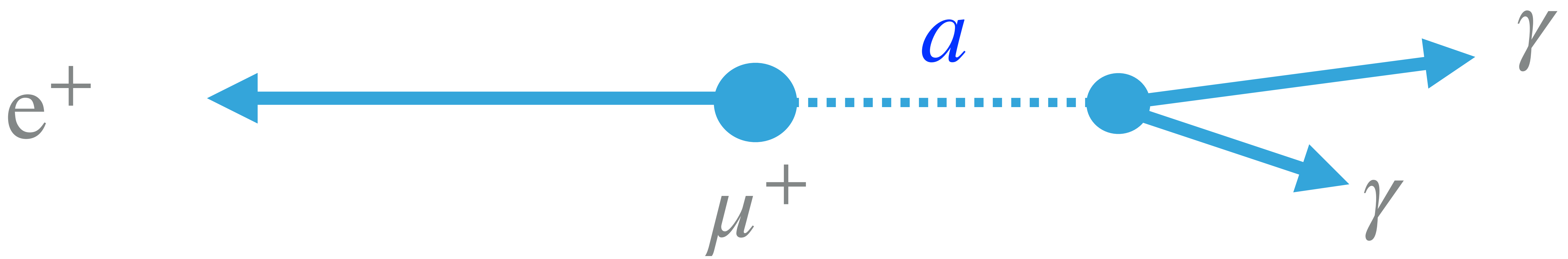
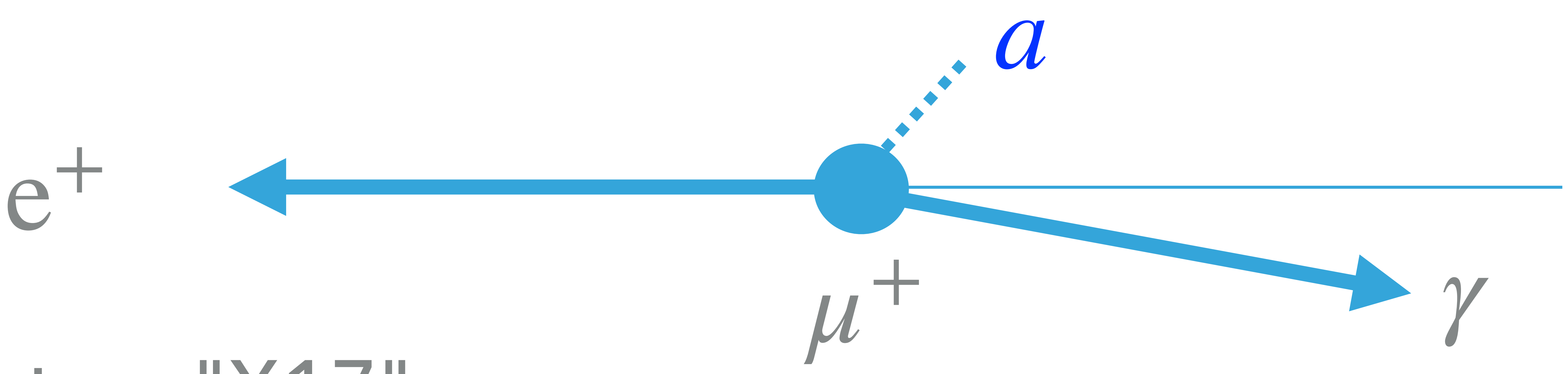


$\mu \to ea \to e\gamma\gamma$

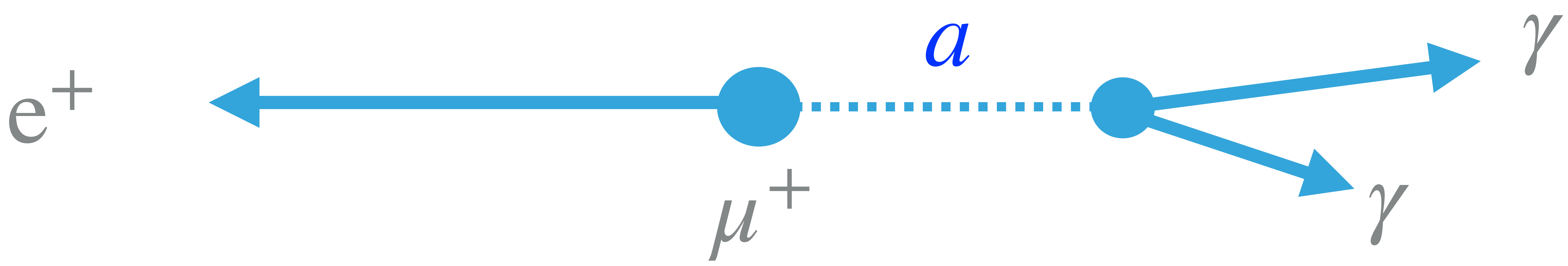
(2)



$\mu \to ea\gamma$

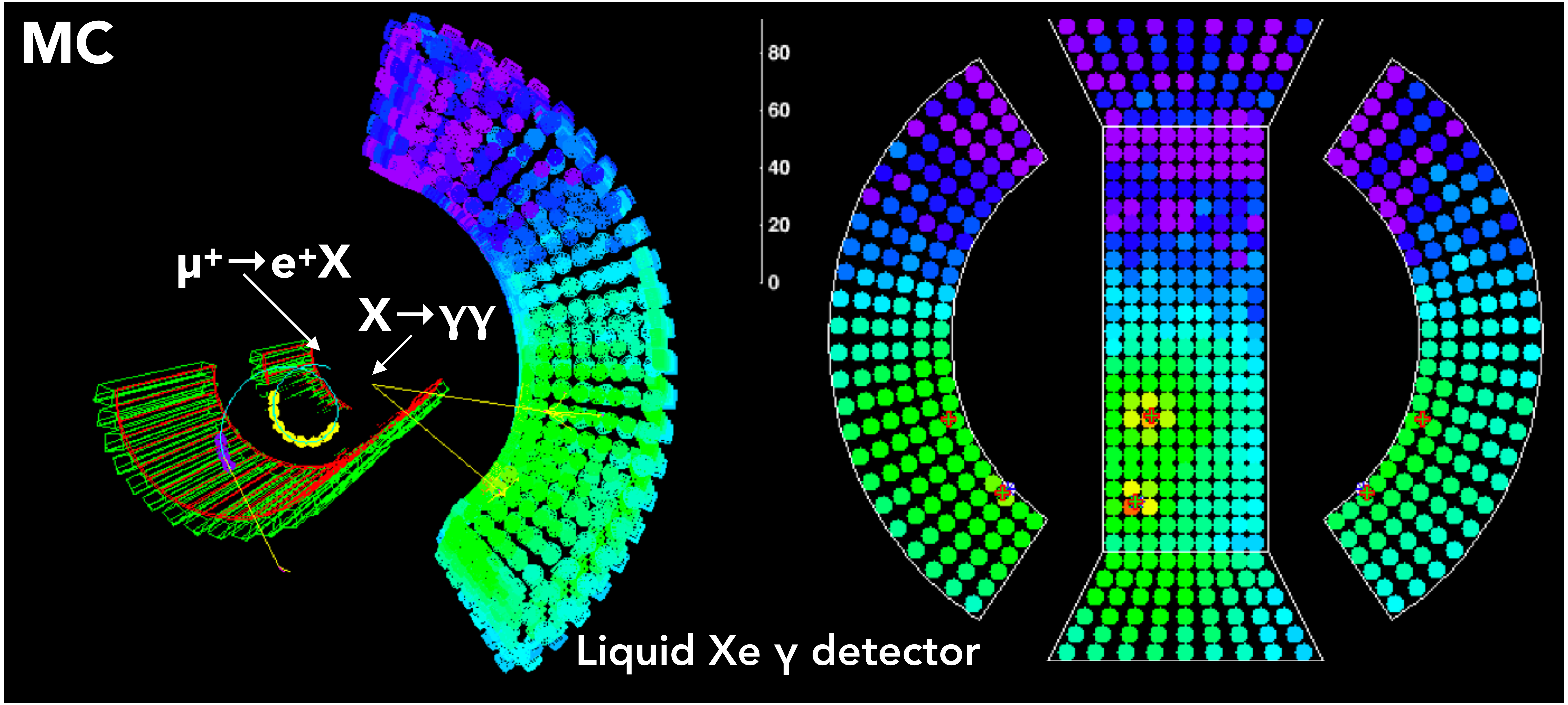
(3) extra - "X17"

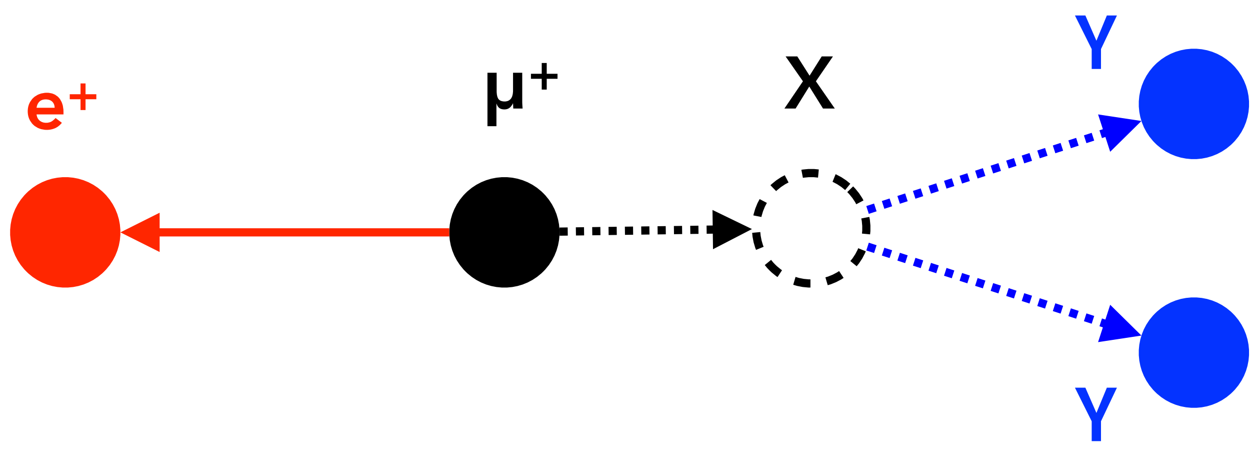
(1) $\mu \to ea \to e\gamma\gamma$



A back-to-back 2-body decay
The photon vertex cannot be measured

(1) $\mu \to ea \to e\gamma\gamma$ AT MEG I

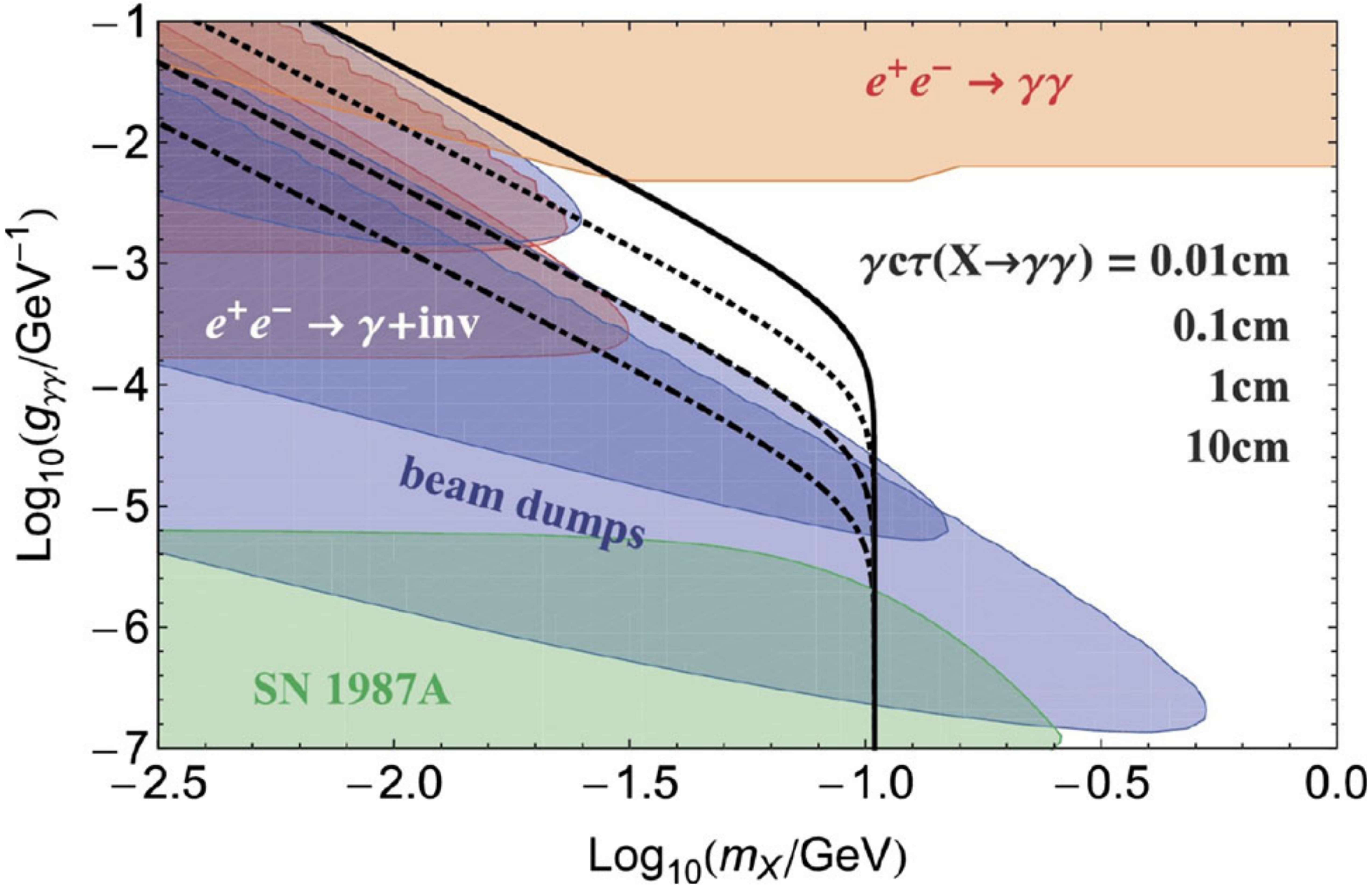




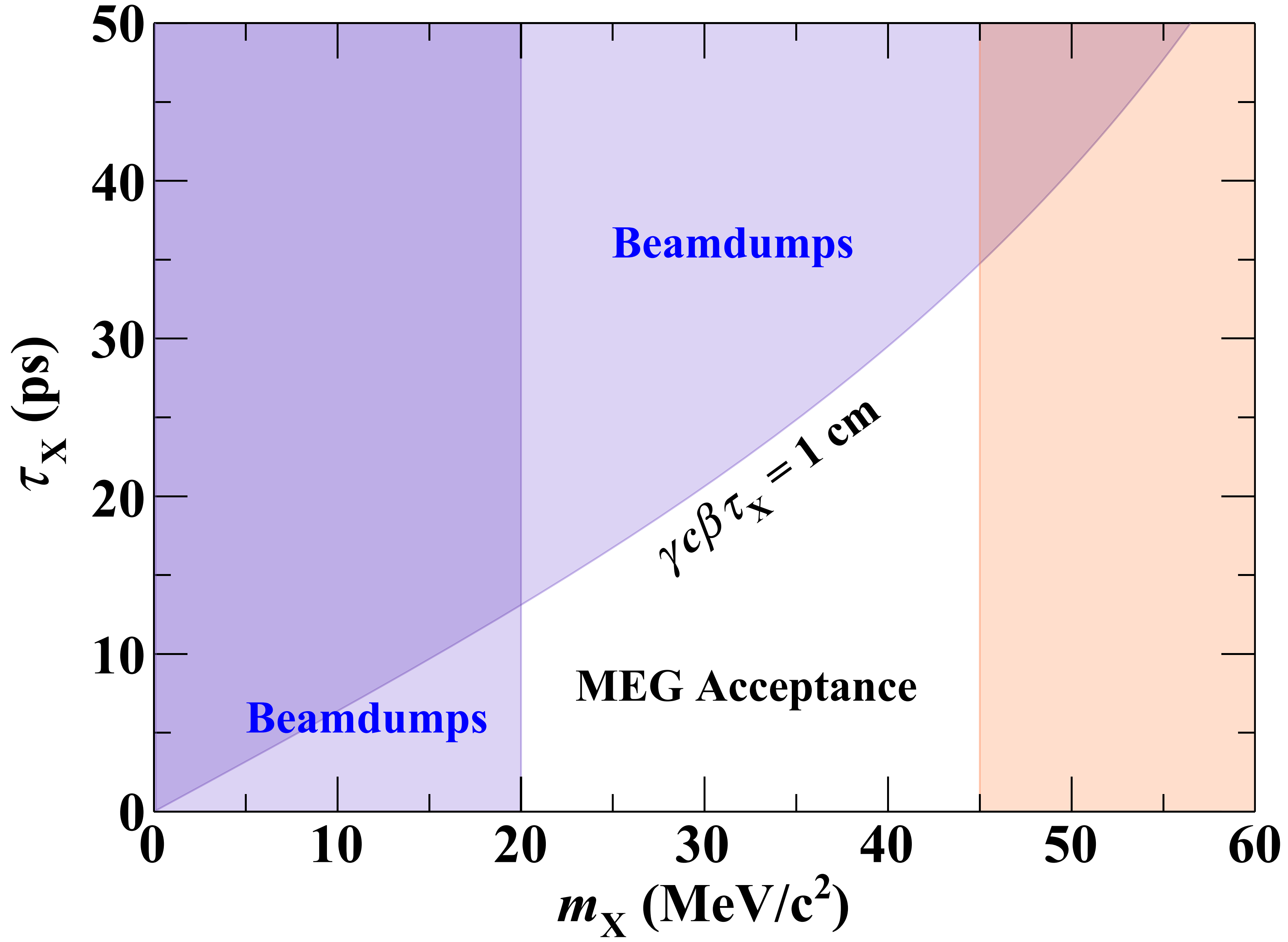
The photon vertex is not measured but is reconstructed to fit the 2-body kinematics

Euro. Phys. J. C80, 858 (2020)

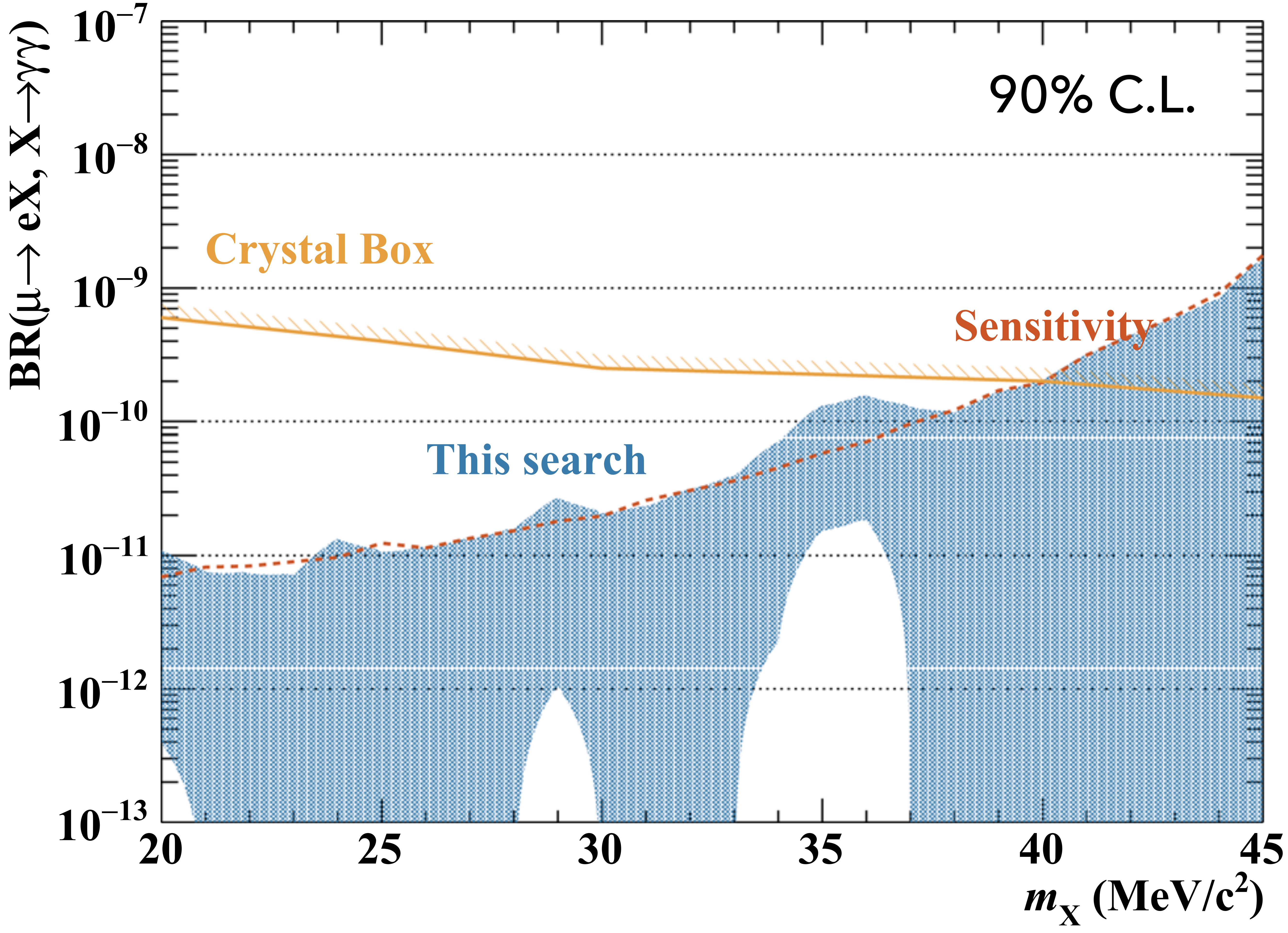
(1) $\mu \to ea \to e\gamma\gamma$ AT MEG I



The target region is
- mass = 20 - 45 MeV/c²
- life time < 1 cm



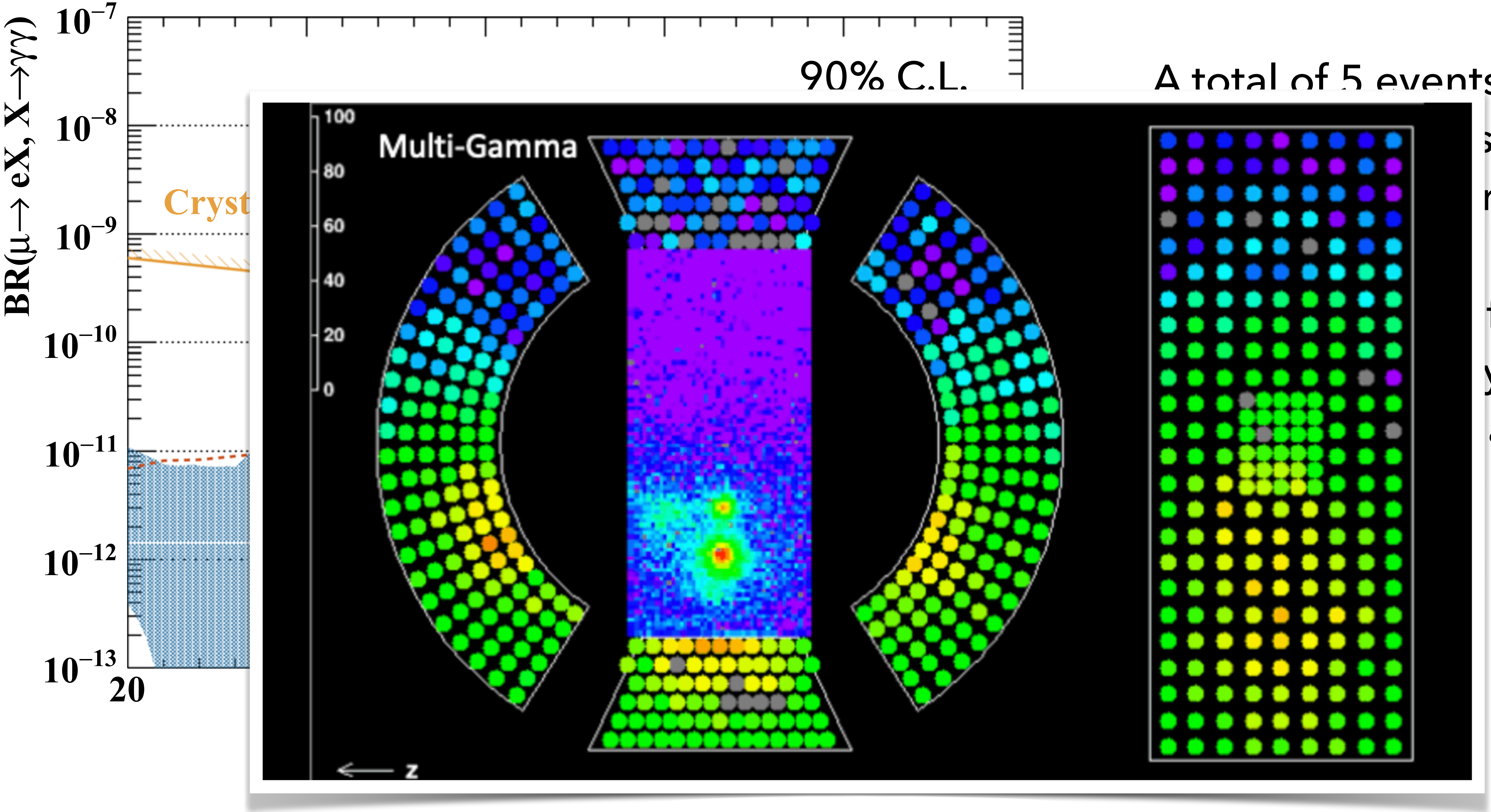
(1) $\mu \rightarrow ea \rightarrow e\gamma\gamma$ AT MEG I



A total of 5 events were found, but the significance is 1.3σ including the look-elsewhere effect.

Best upper limits for 20-40 MeV/c^2 exceeding the Crystal Box result that searched for a more generic 3-body decays

(1) $\mu \to ea \to e\gamma\gamma$ AT MEG I



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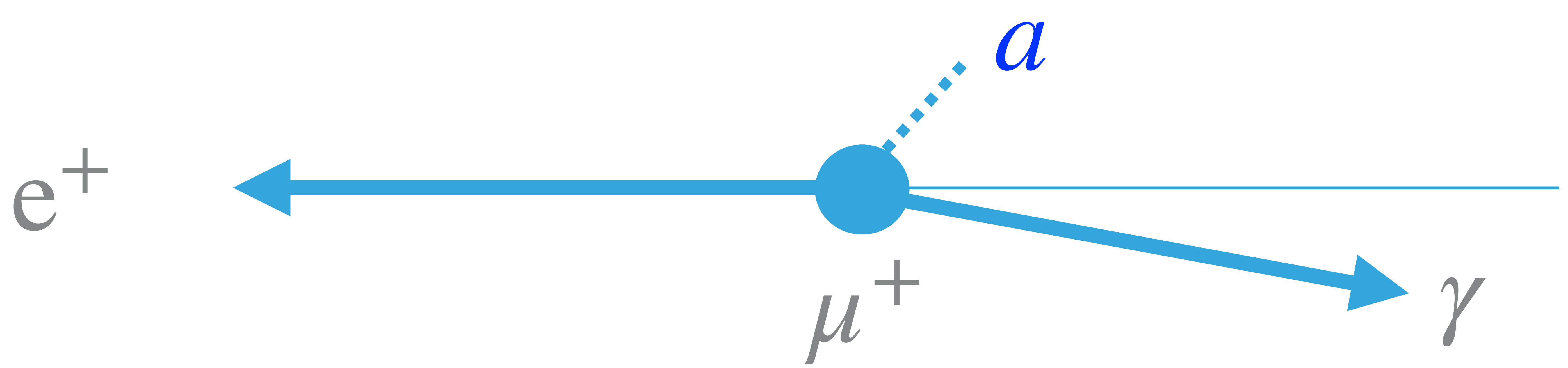
s 1.3σ including
re effect.

for 20-40 MeV/c²
ystal Box result
a more generic

MEG II will bring 10x statistics and better photon reconstruction to reject the background by better kinematical constraints

(2) $\mu \to ea\gamma$ AT MEG II



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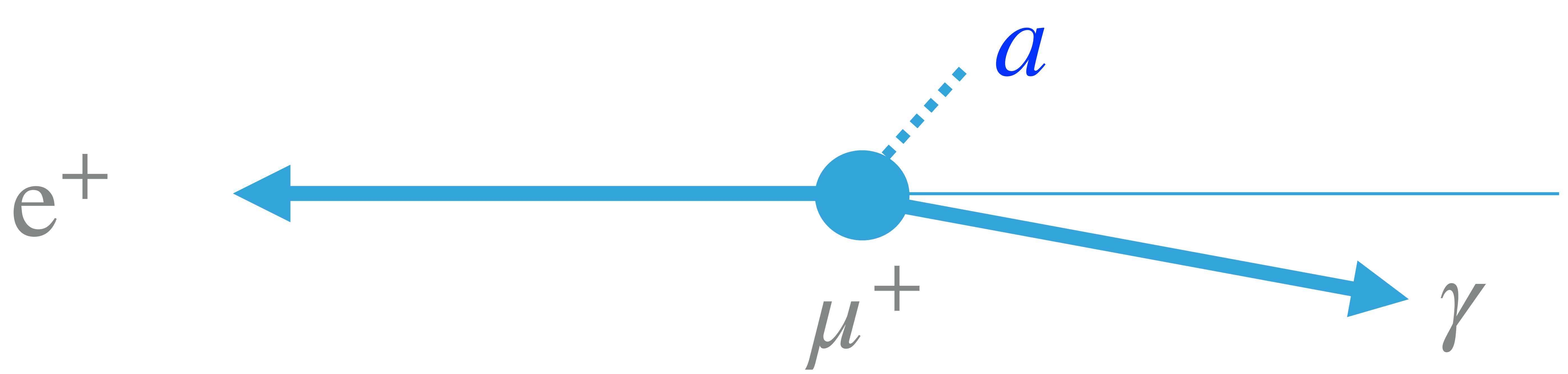
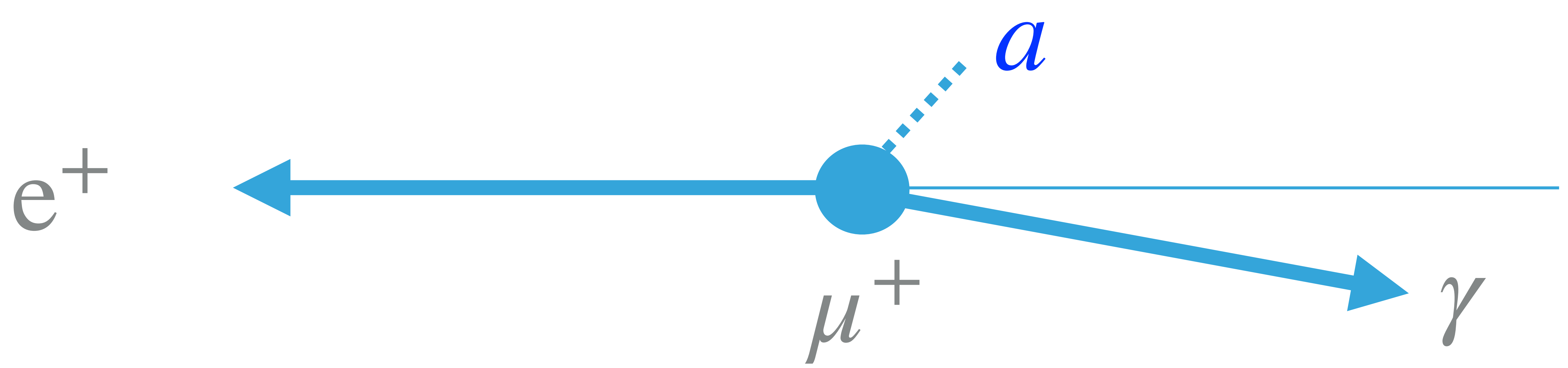


Trigger / selection need to be loosened:

- much lower photon energy
- no back-to-back topology

They just look like radiative muon decays (RMD):

(2) $\mu \to ea\gamma$ AT MEG II



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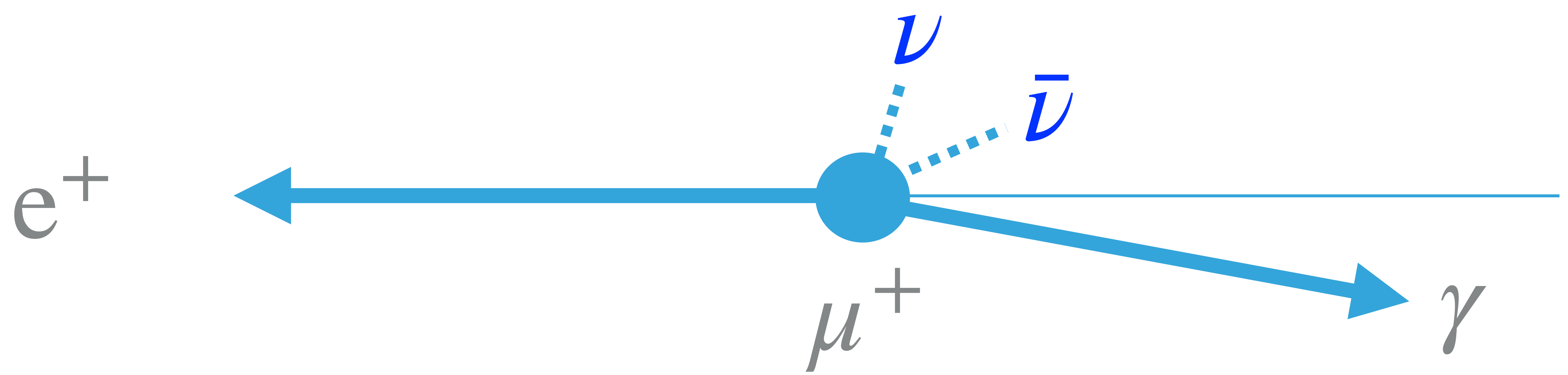
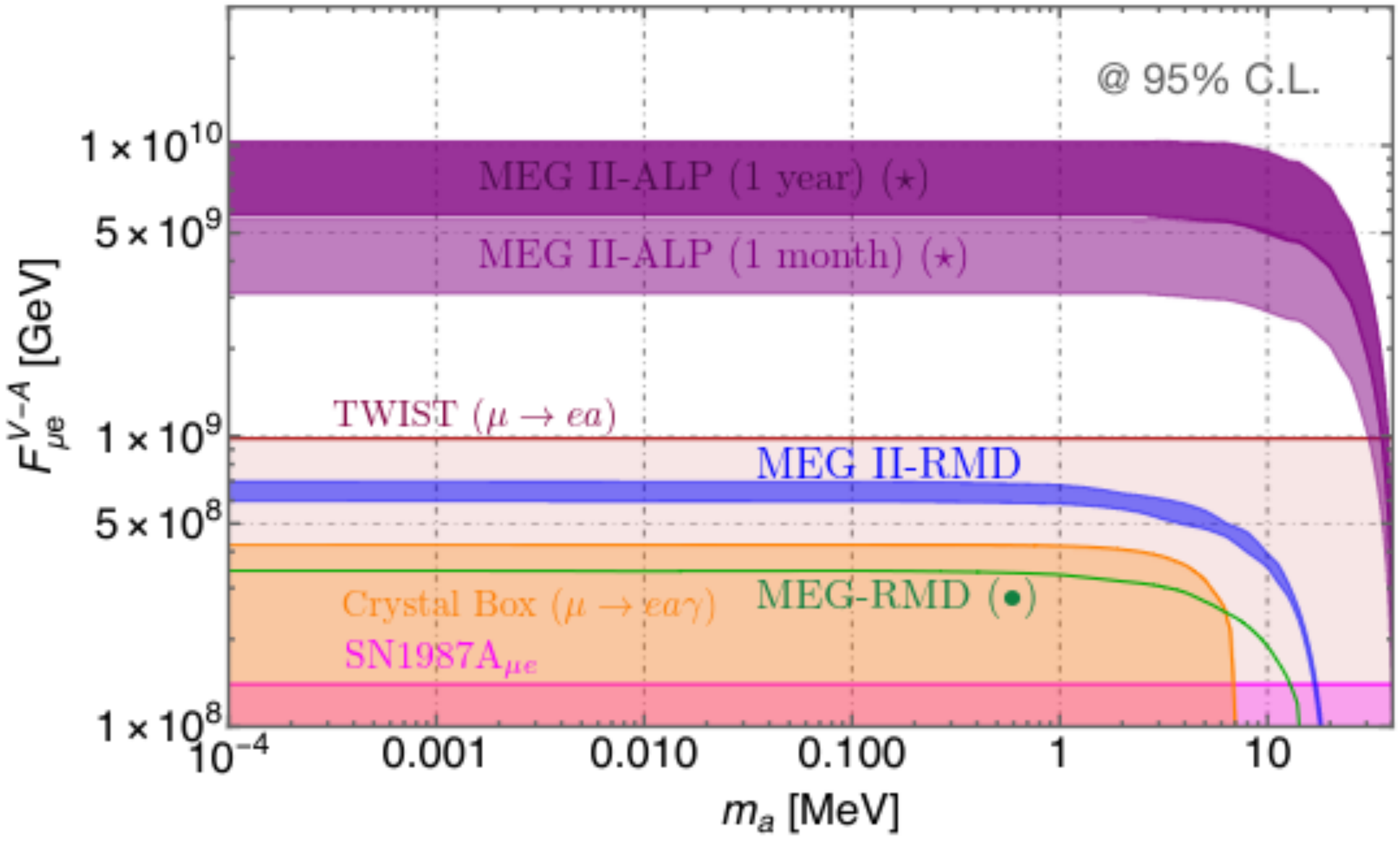


Study the RMD!

(2) $\mu \to ea\gamma$ AT MEG II



Our theorist friends kindly pointed out* that MEG's RMD study cannot exceed the existing TWIST's upper limit;
i.e. a dedicated run with loosened trigger conditions at lower beam rates might be needed.

LFV @ dimension 5

$$\mathcal{L}_{\rm eff}^{\rm LFV} \supset \frac{\partial_\mu a}{2 f_a} \bar{\mu}\gamma^\mu (C_{\mu e}^V + C_{\mu e}^A \gamma_5) e + \frac{\partial_\mu a}{f_a} \bar{e}\gamma^\mu \gamma_5 e + \frac{m_a^2}{2} a^2$$

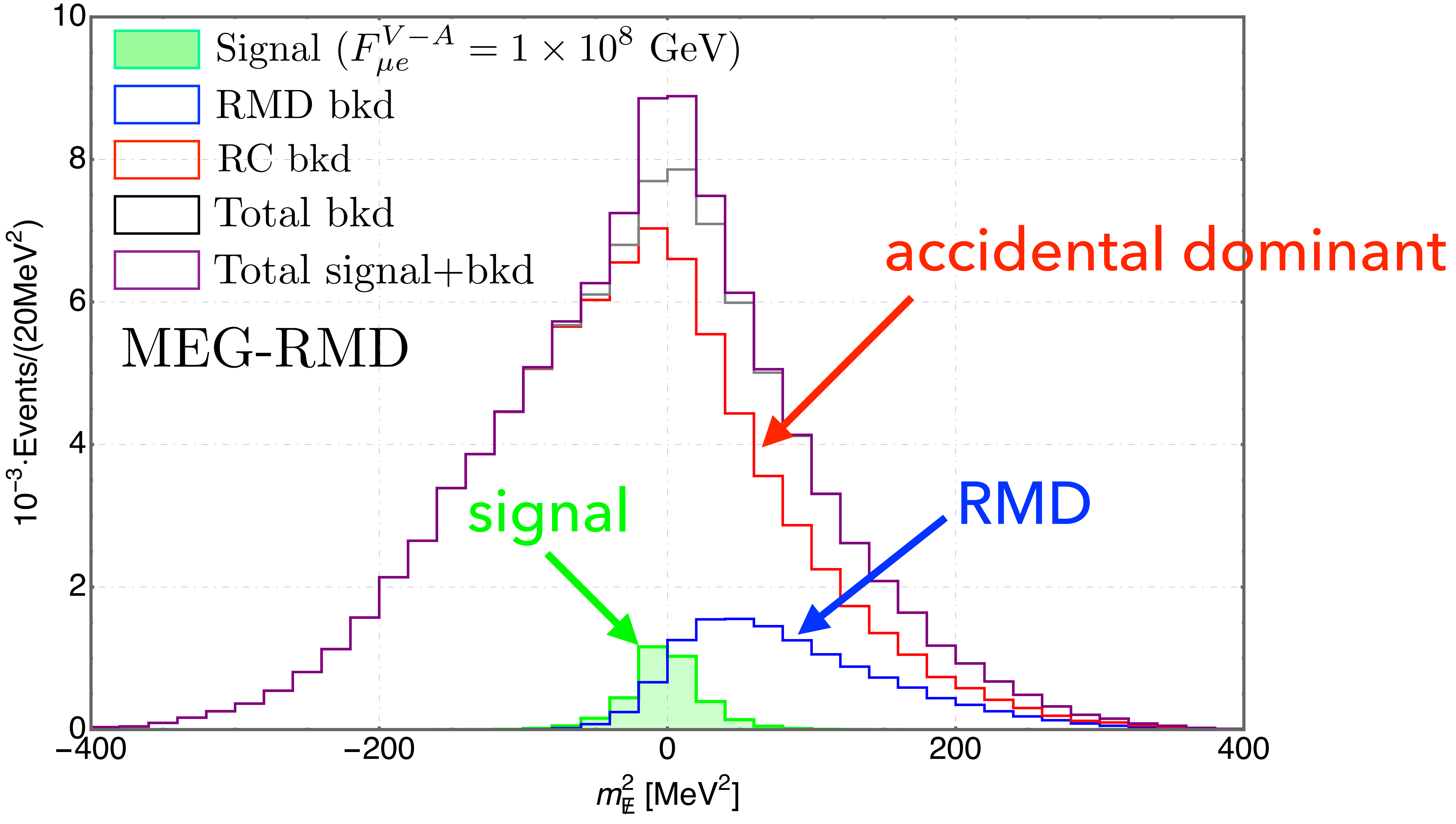
axial and vectorial LFV of the ALP

electron coupling of the ALP

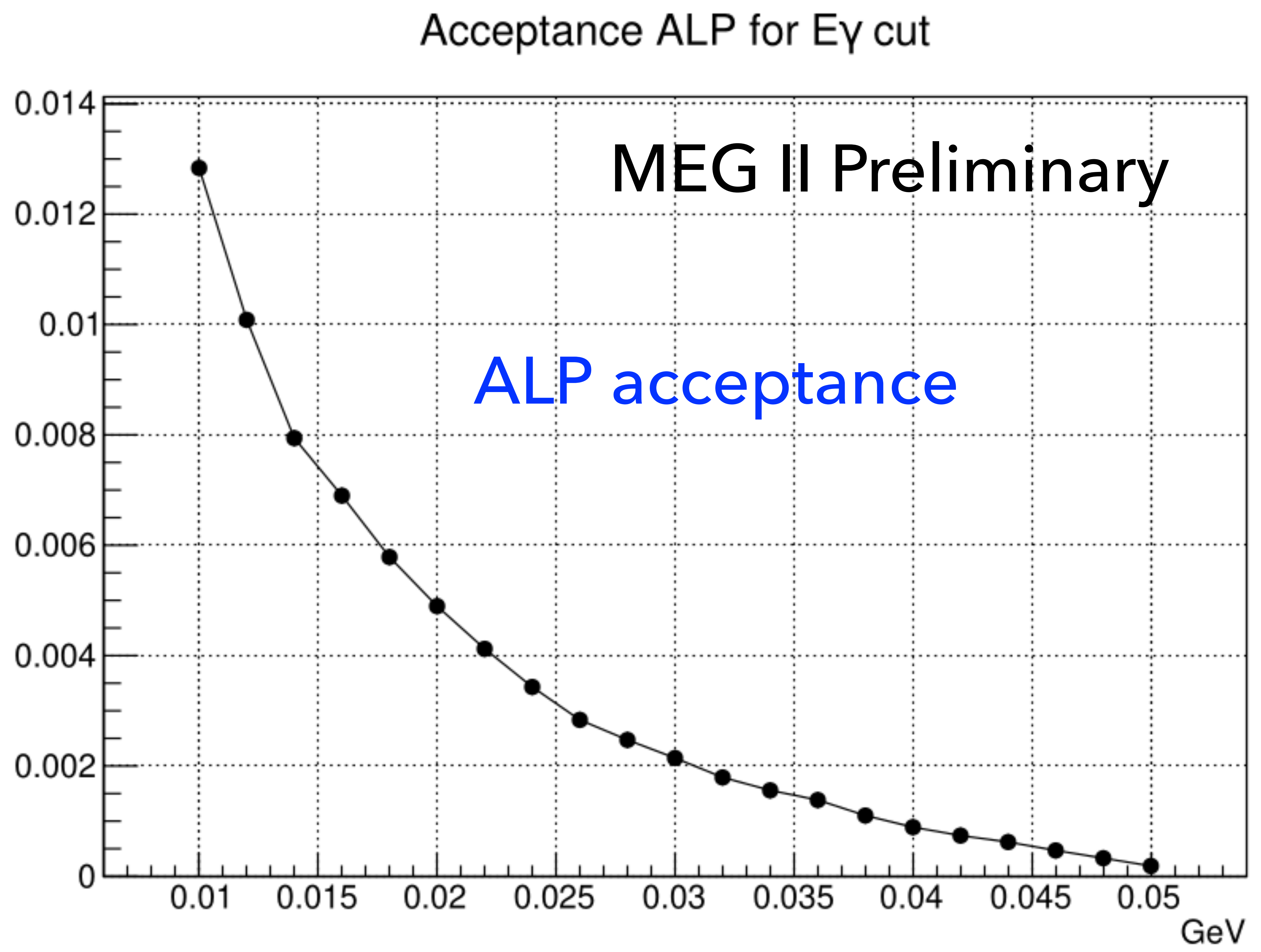
*Y. Jho, S. Knapen, D. Redigolo, arXiv:2203.11222
MEG, Eur. Phys. J. C76 (2016) 108
TWIST, Phys. Rev. D91 (2015) 052020

(2) $\mu \to ea\gamma$ AT MEG II

*Y.J., S.K., D.R., arXiv:2203.11222



missing mass squared (MeV²)



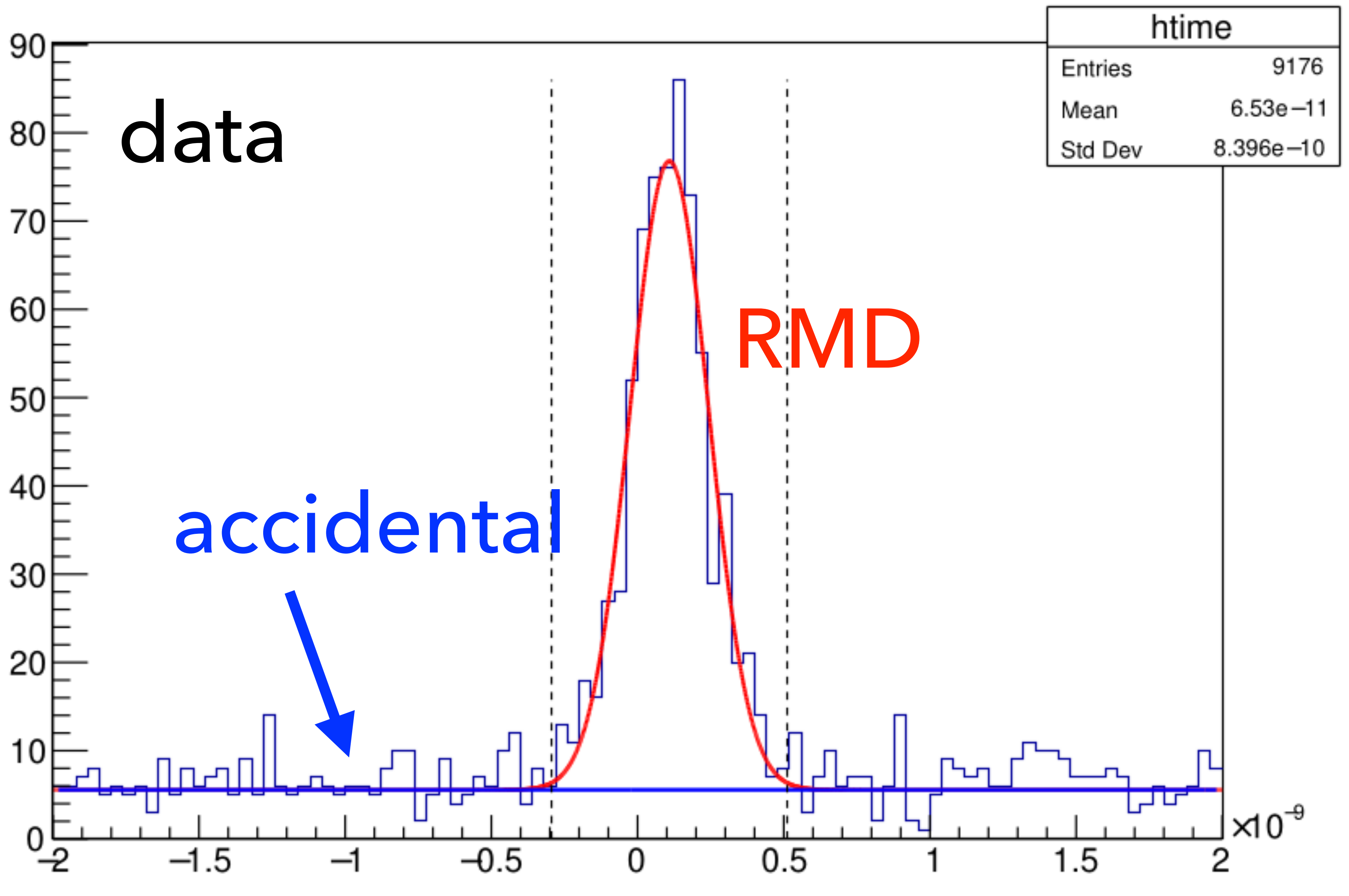
photon energy (GeV)

NEED TO RUN AT LOWER BEAM RATE & LOWER E_γ THRESHOLD

Actually we already have such data samples.

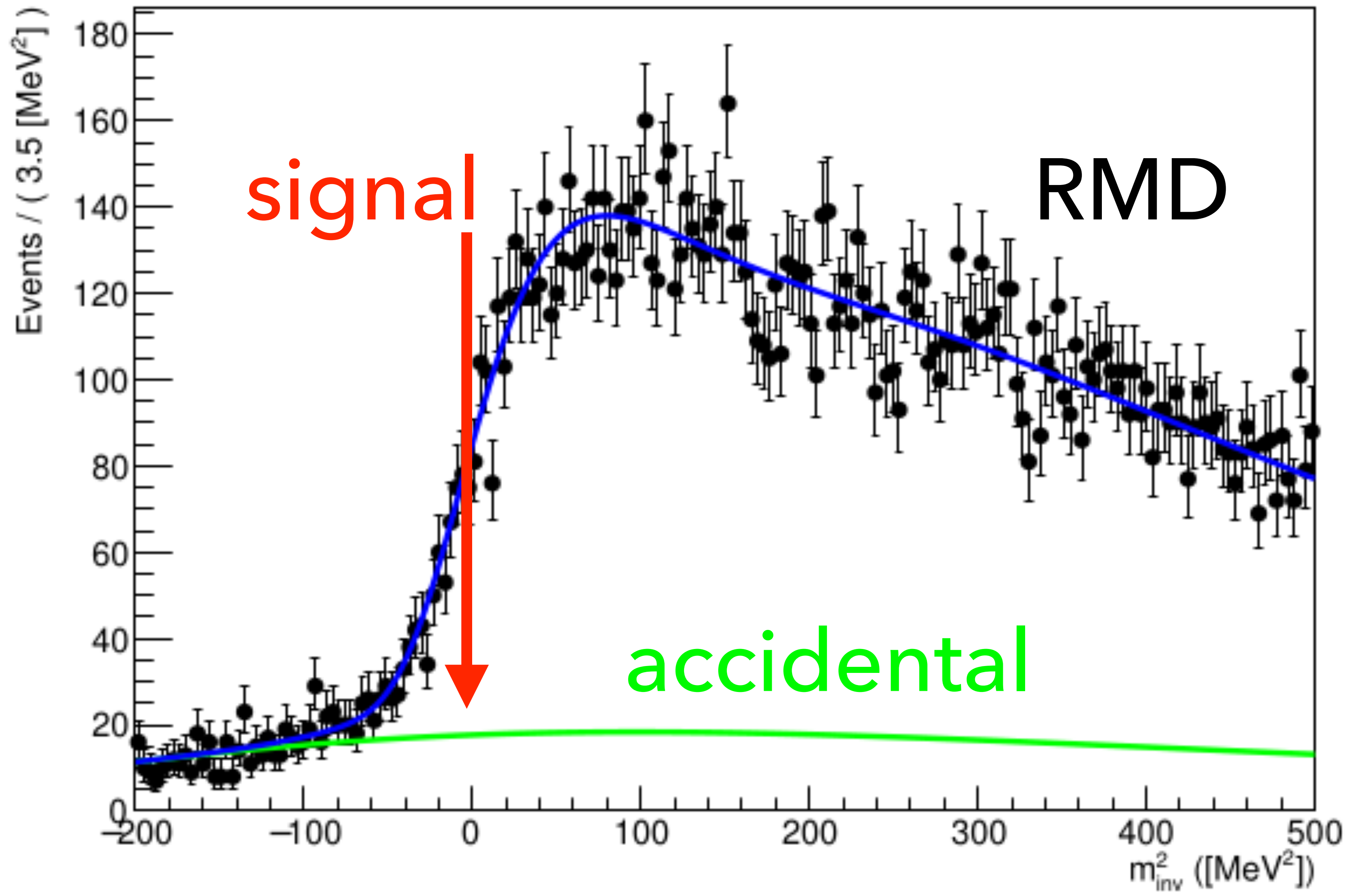
Taken for a total of 8-9 days in 2021-2023 for calibrations:

$$R_\mu = (0.9 - 2.0) \times 10^6\ \text{/sec}, \quad E_\gamma > 18 - 20\ \text{MeV}$$



time coincidence (nsec)

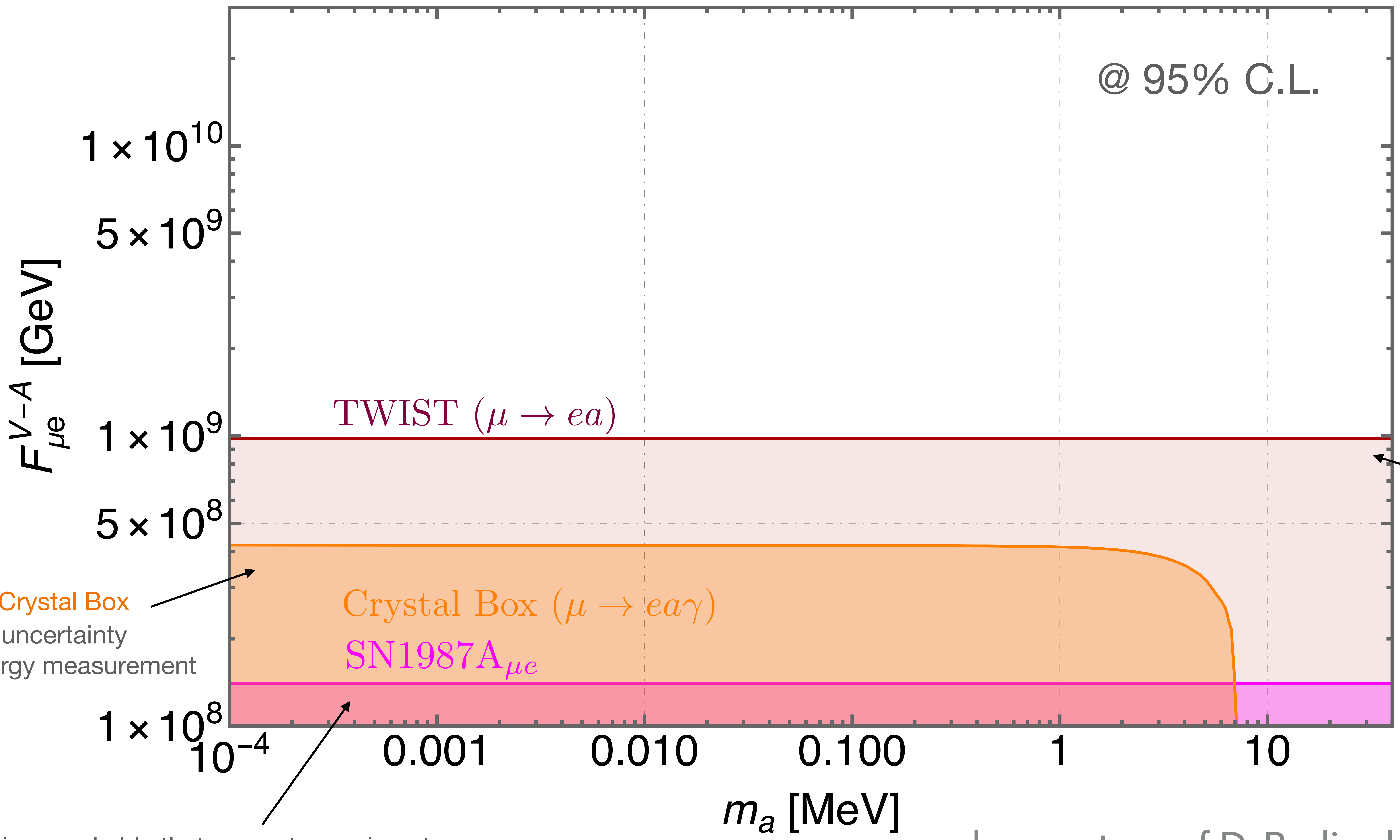
evaluation by toy MC



missing mass squared (MeV²)

(2) $\mu \to ea\gamma$ AT MEG II

A preliminary analysis indicates we can probably exceed TWIST with this sample!



Bound from Crystal Box suffers from uncertainty in the positron energy measurement

TWIST bound suffers from large systematic uncertainties

See. *TWIST 1409.0638*

It is remarkable that present experiments are already stronger than cooling bounds!

by courtesy of D. Redigolo

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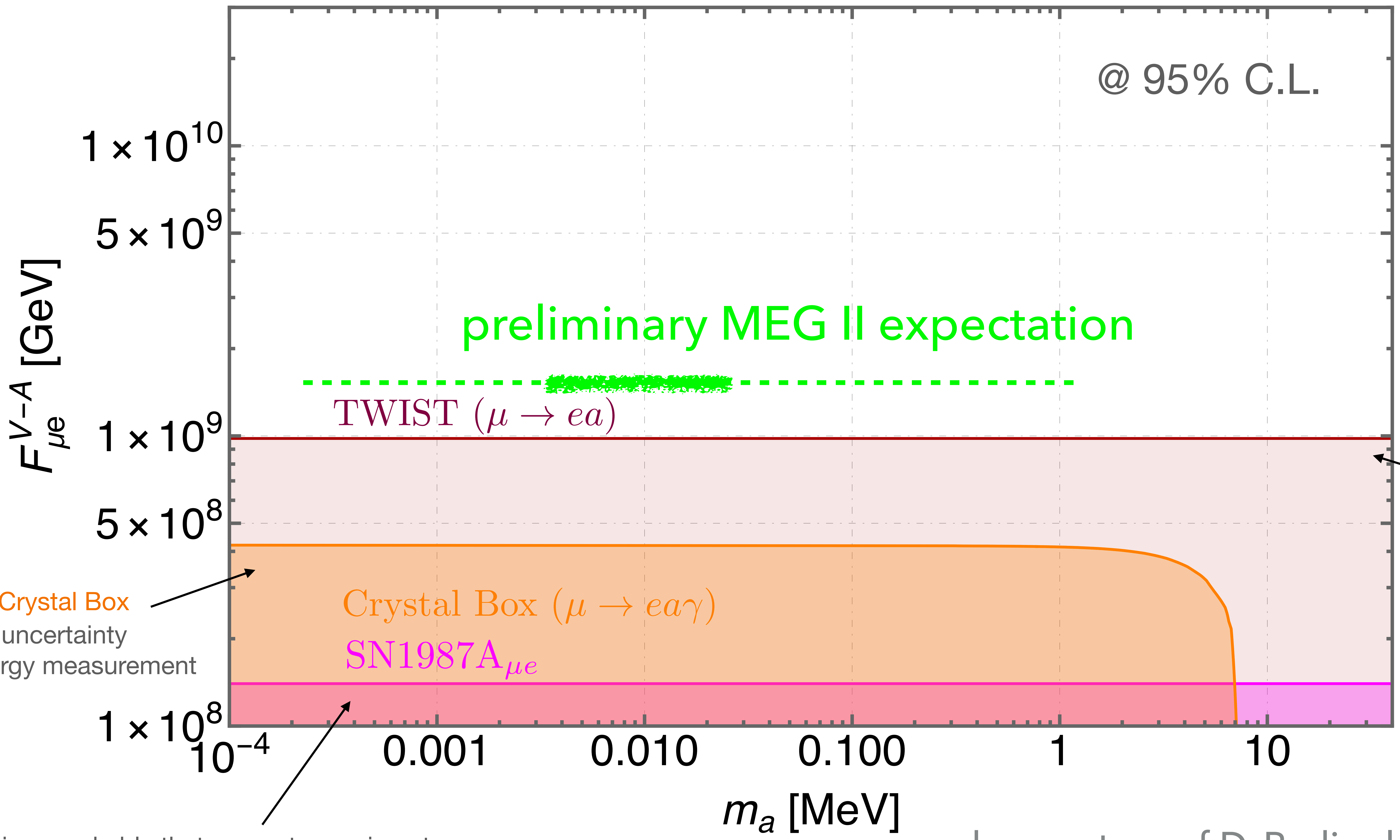

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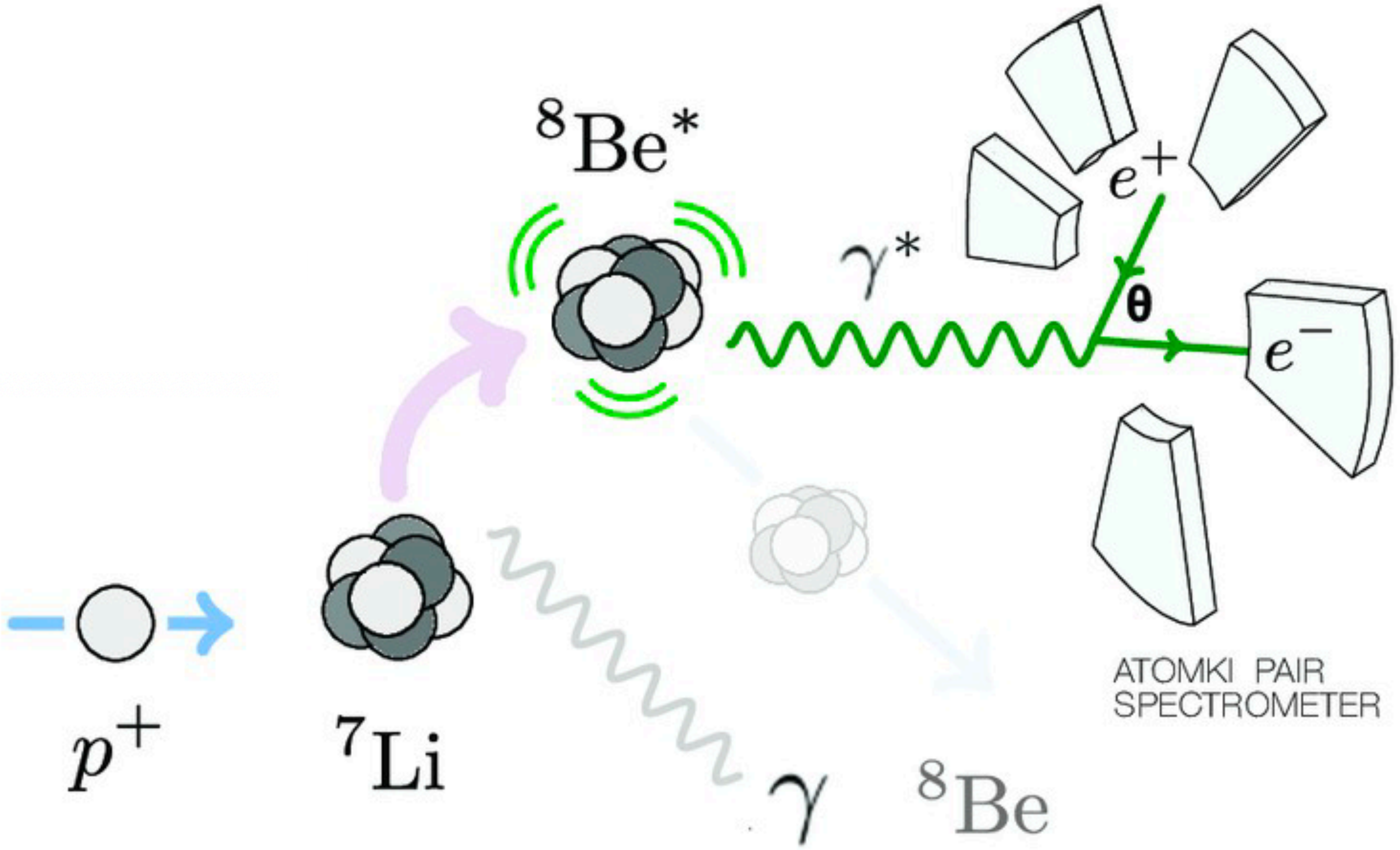
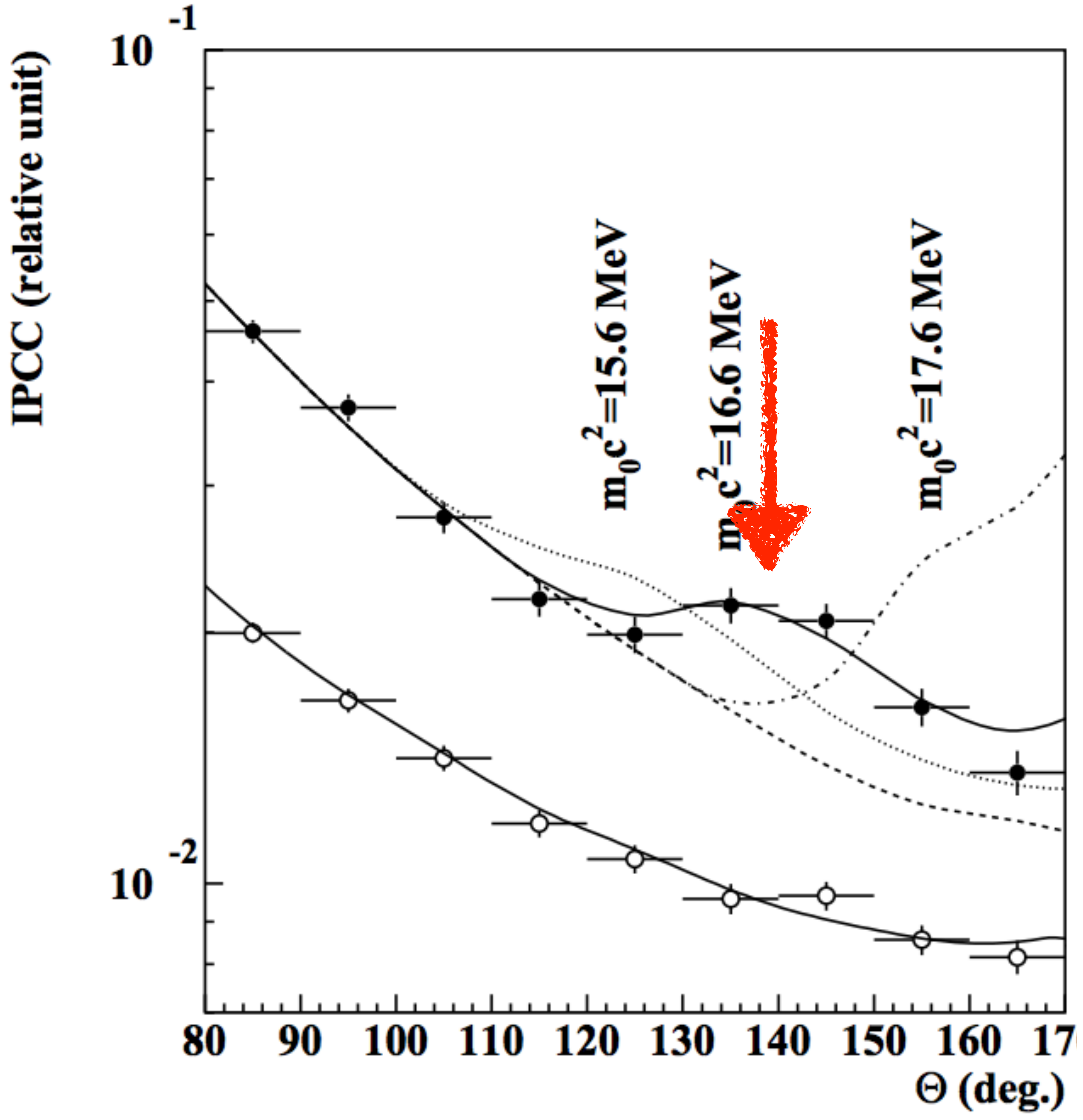
(3) EXTRA - ATOMKI'S "17MEV BOSON"



Phys. Rev. Lett. 116, 042501
arXiv:2205.07744

Phys. Rev. C 104, 044003

Phys. Rev. D 95, 035017



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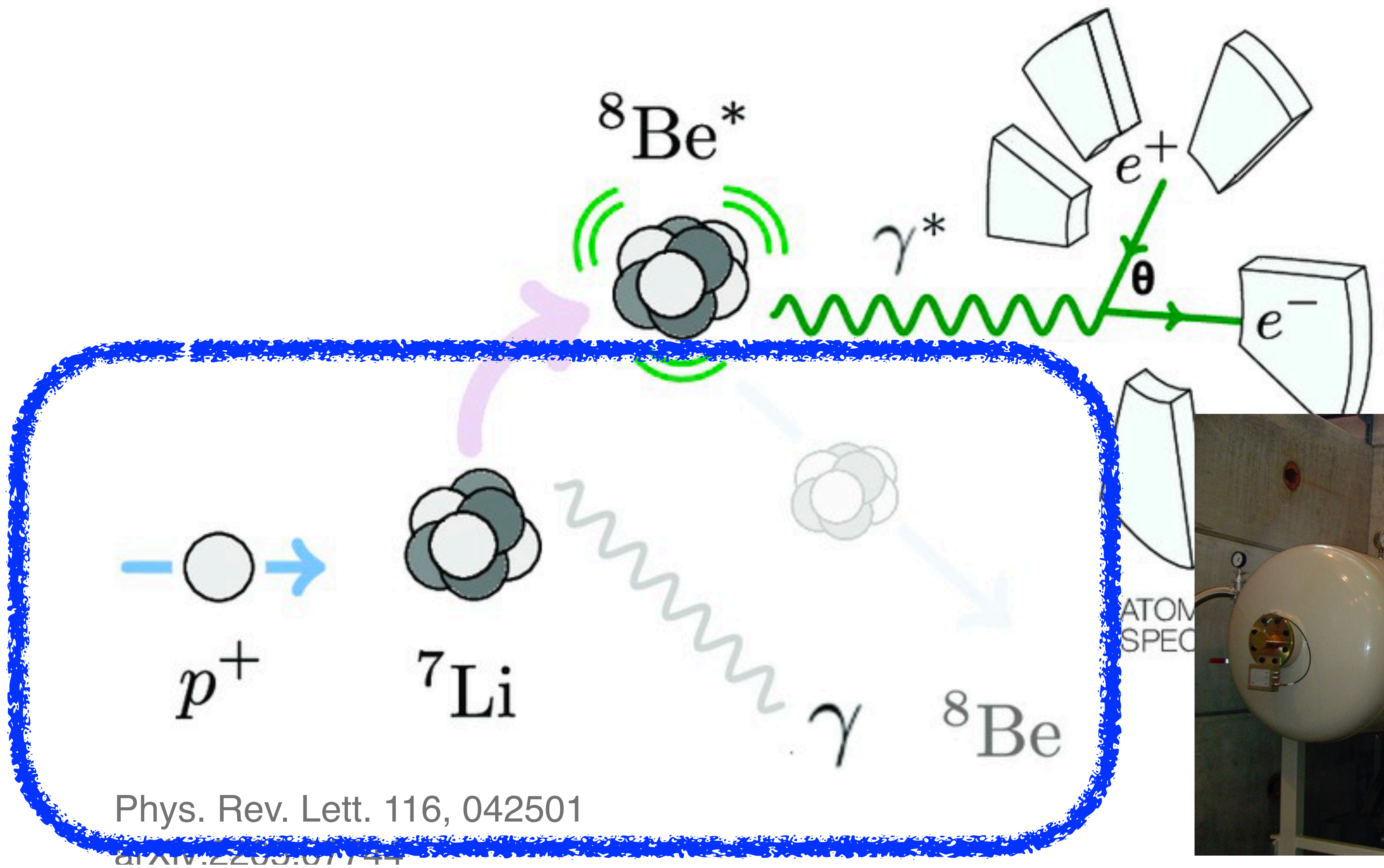
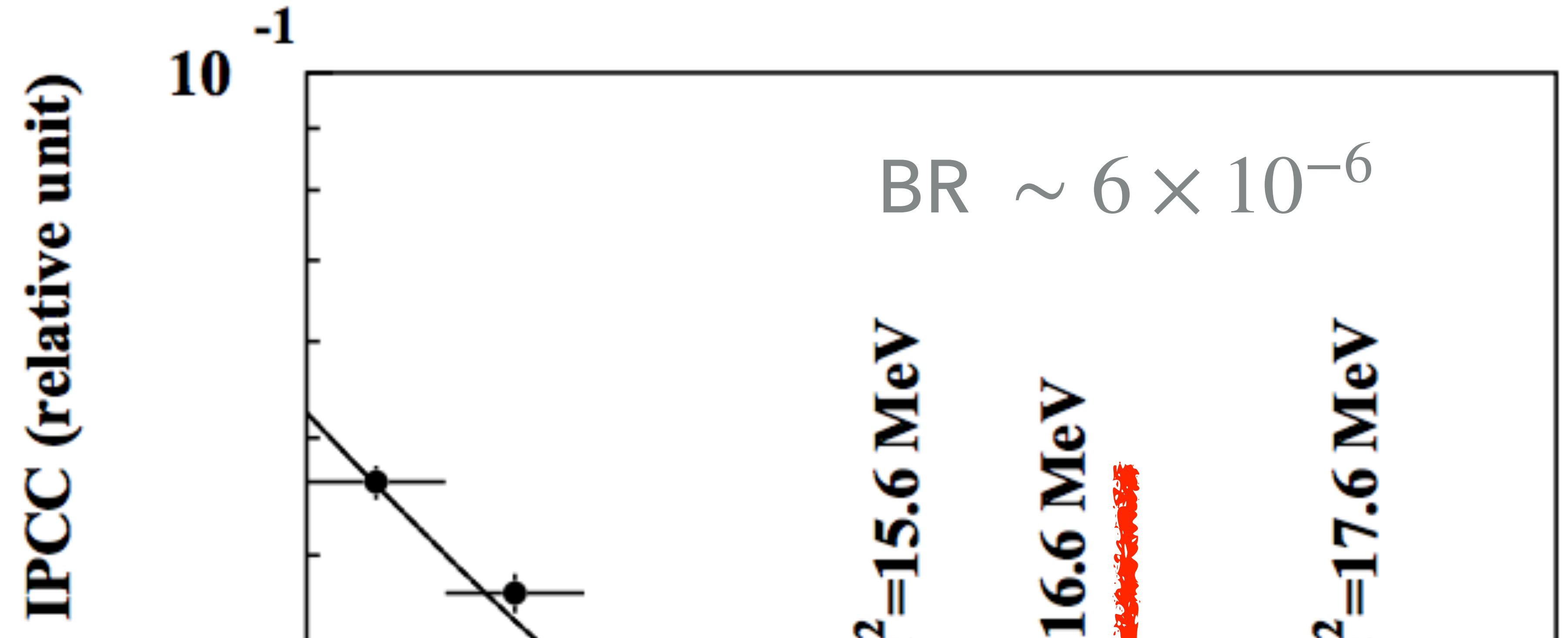
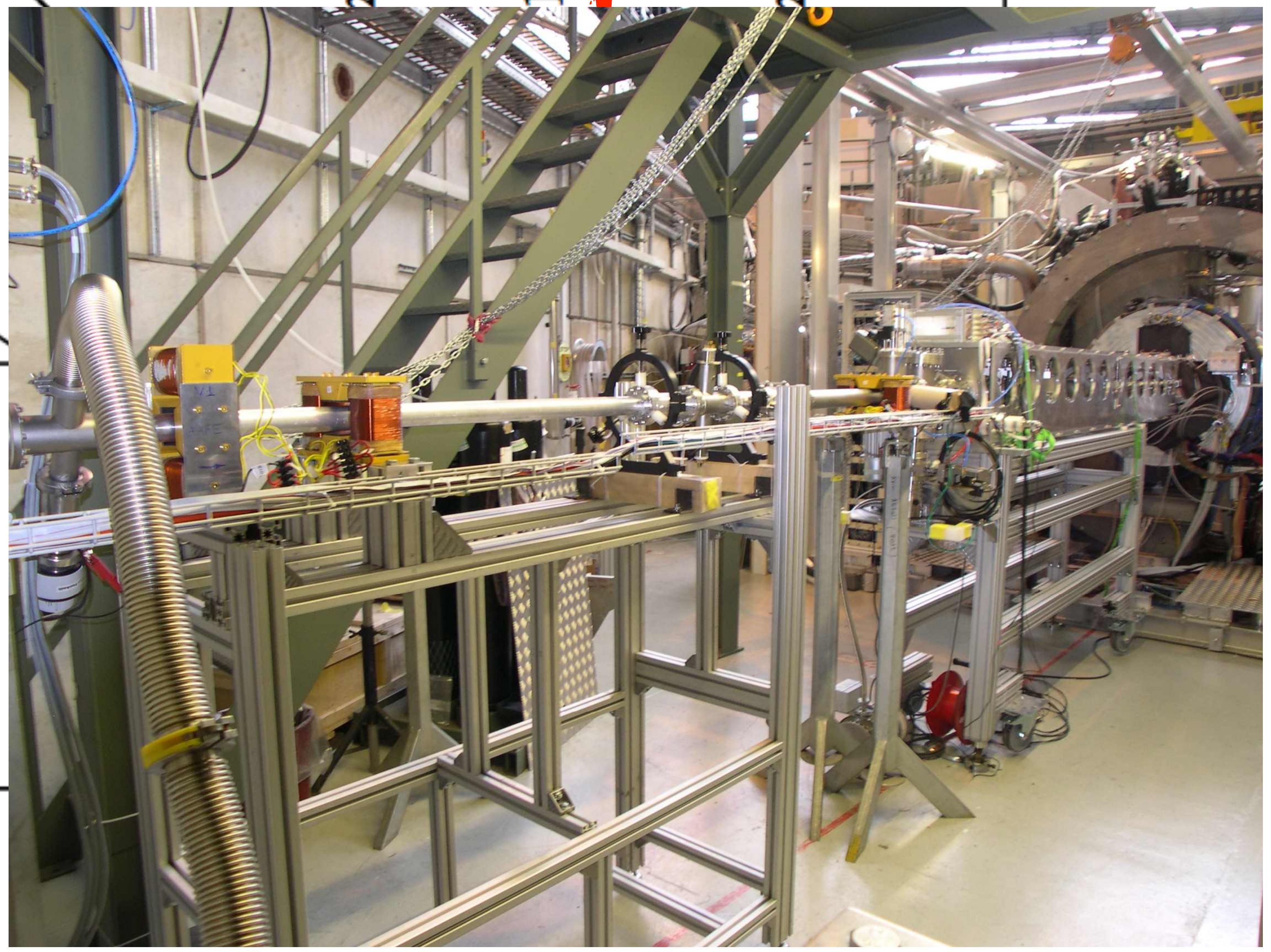


Phys. Rev. Lett. 116, 042501

We're using this process for calibration

Phys. Rev. D 95, 035017



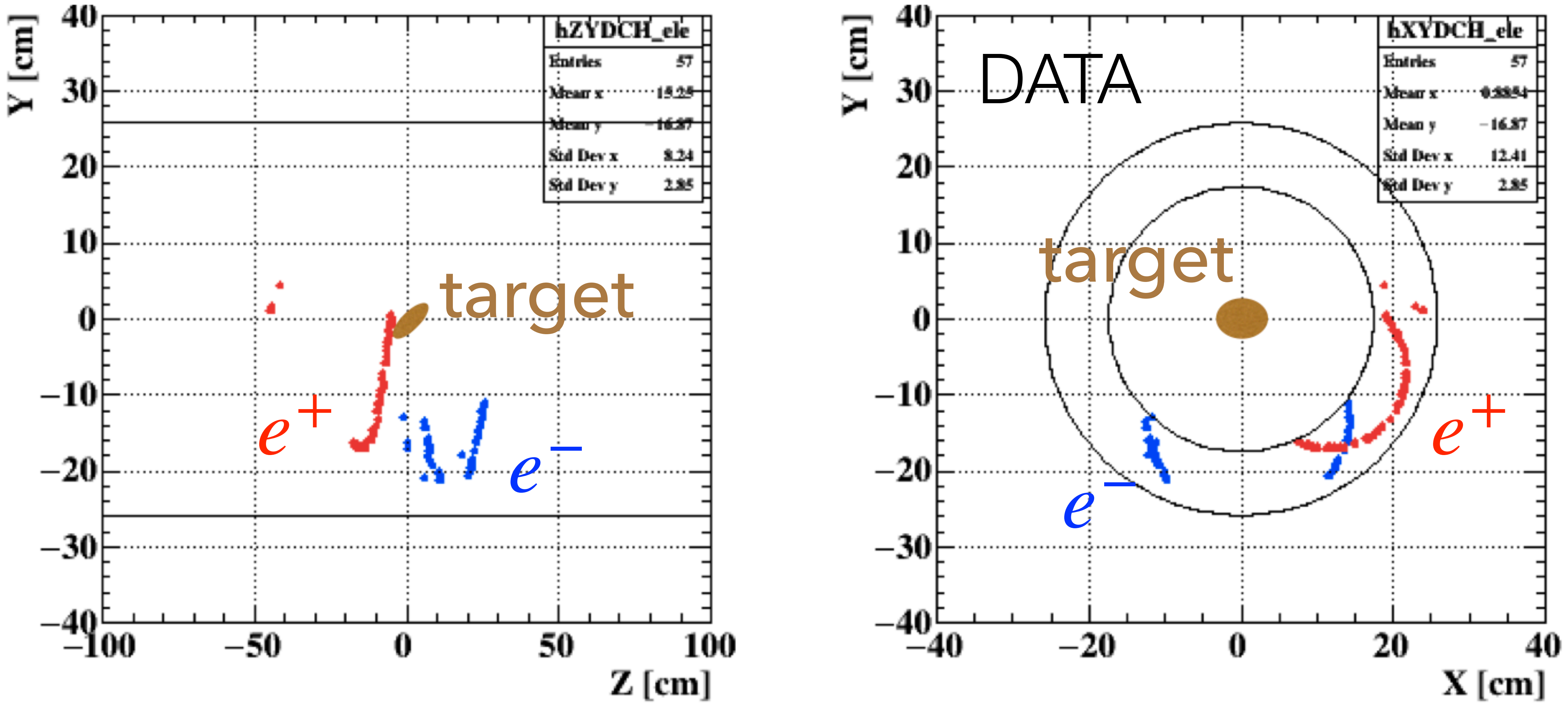


dedicated Cockcroft-Walton accelerator & beam line

(3) EXTRA – ATOMKI'S "17MEV BOSON"

- Event A

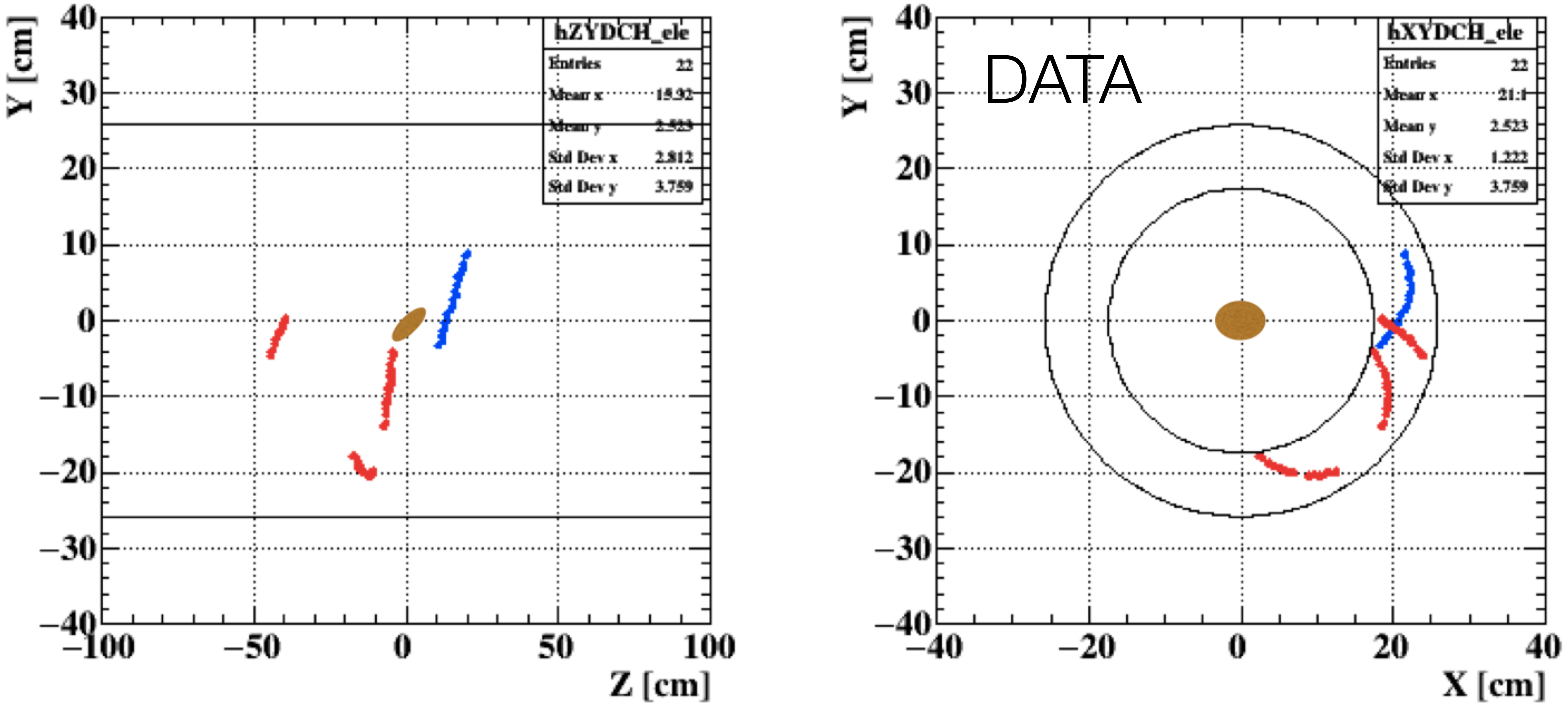
p+ = 6.7 MeV
p- = 8.3 MeV
angle = 141°



LiPON data 02/22

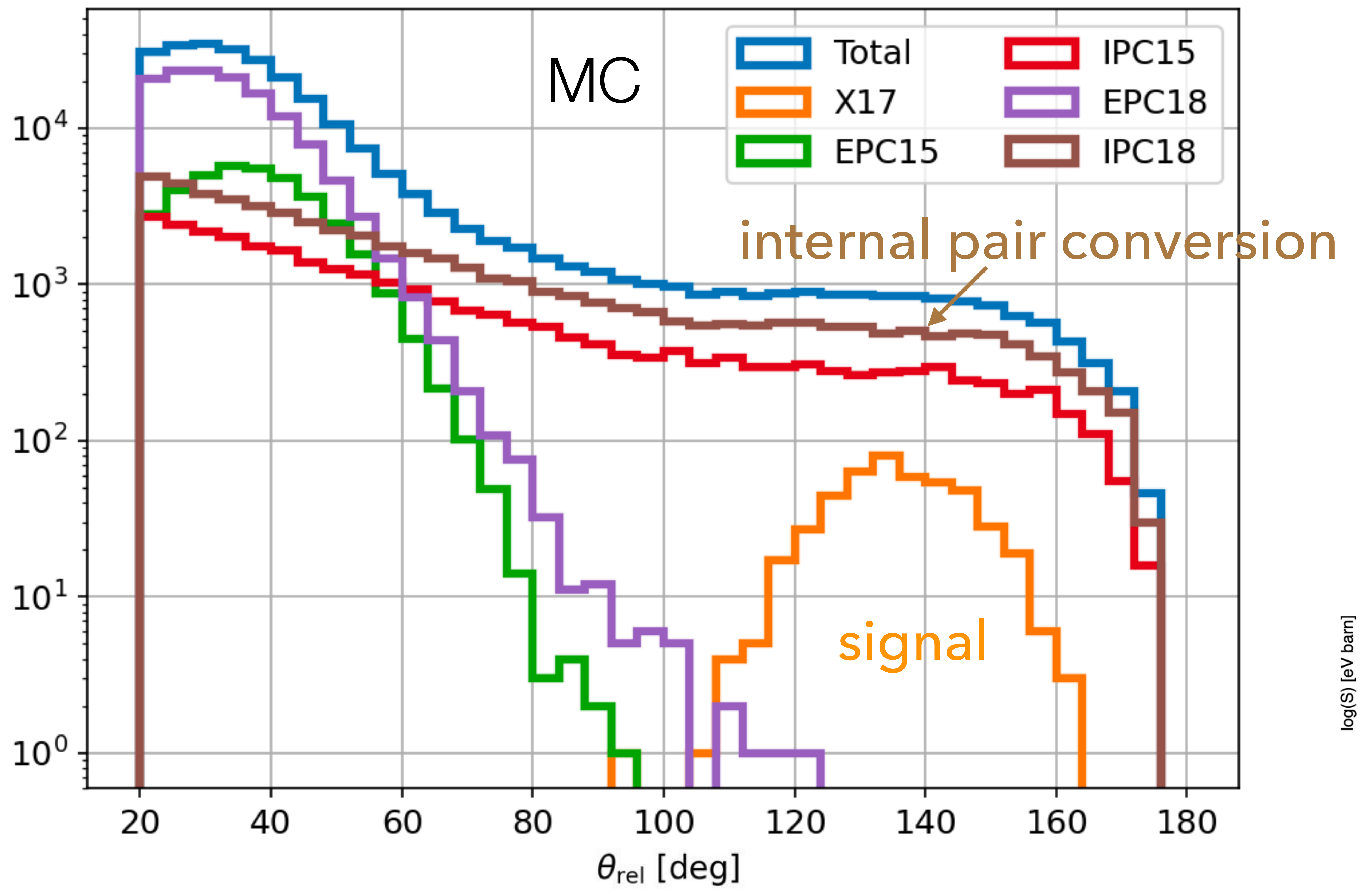
- Event B

p+ = 6.7 MeV
p- = 6.9 MeV
angle = 101°



The Strength of MEG II

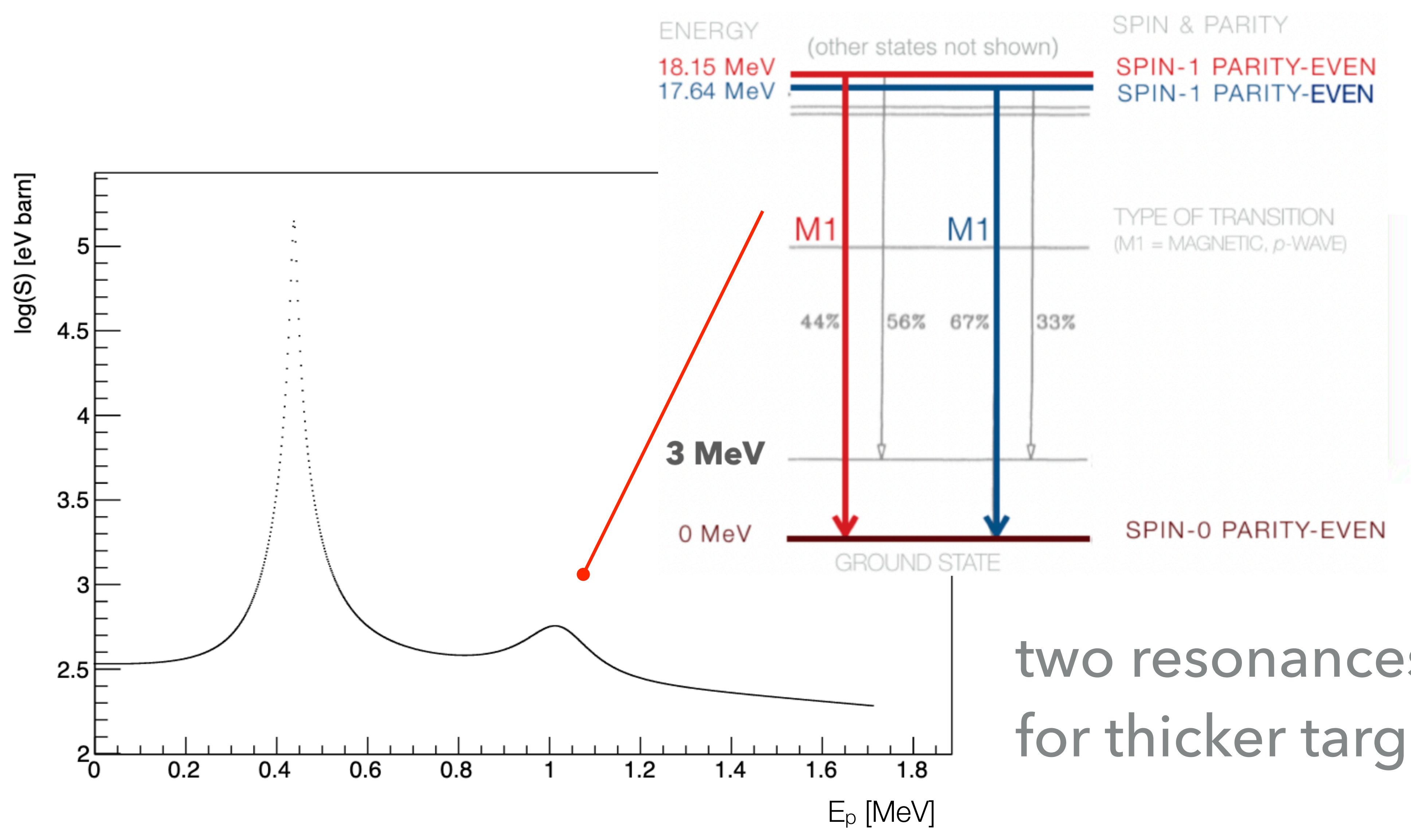
- reconstruct e^+e^- trajectories
- measure background photons
- properly normalise events



Physics run in 2023 after Pilot run in 2022

<u>Analysis at the final stage</u>

Another run foreseen focusing on 1030keV



two resonances occur
for thicker target

STAY TUNED FOR UPCOMING RESULTS OF MEG II !