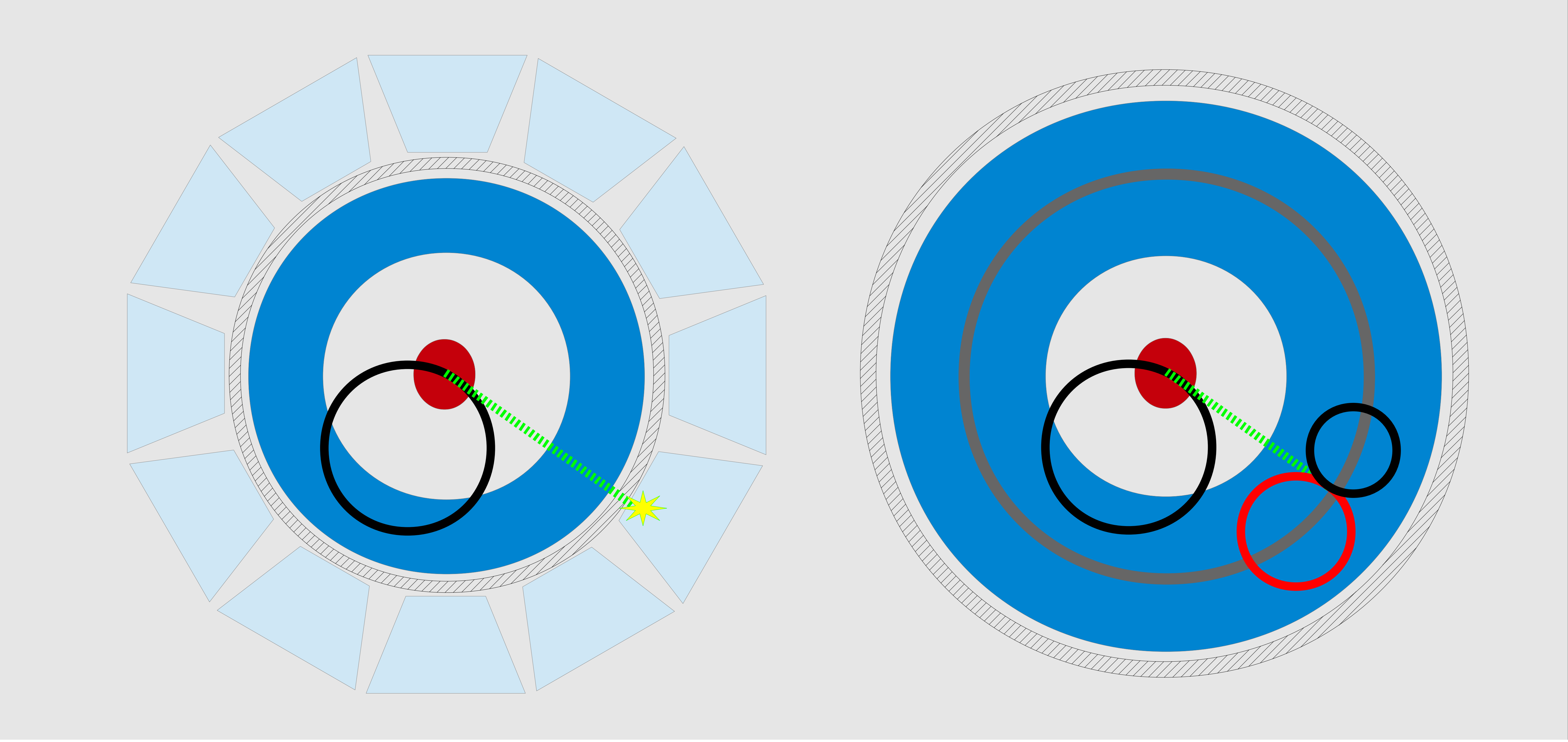


Experimental limiting factors for the next generation of μ -> e γ searches

arXiv:1707.01805

G. Cavoto
“Sapienza” Università di Roma

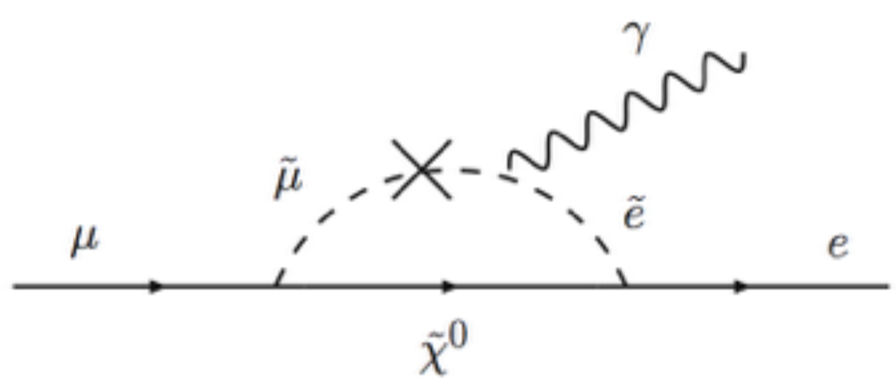
F. Renga, C. Voena
INFN Roma

A. Papa
Paul Scherrer Institut

E. Ripiccini
Université de Genève

Charged Lepton Flavor Violation

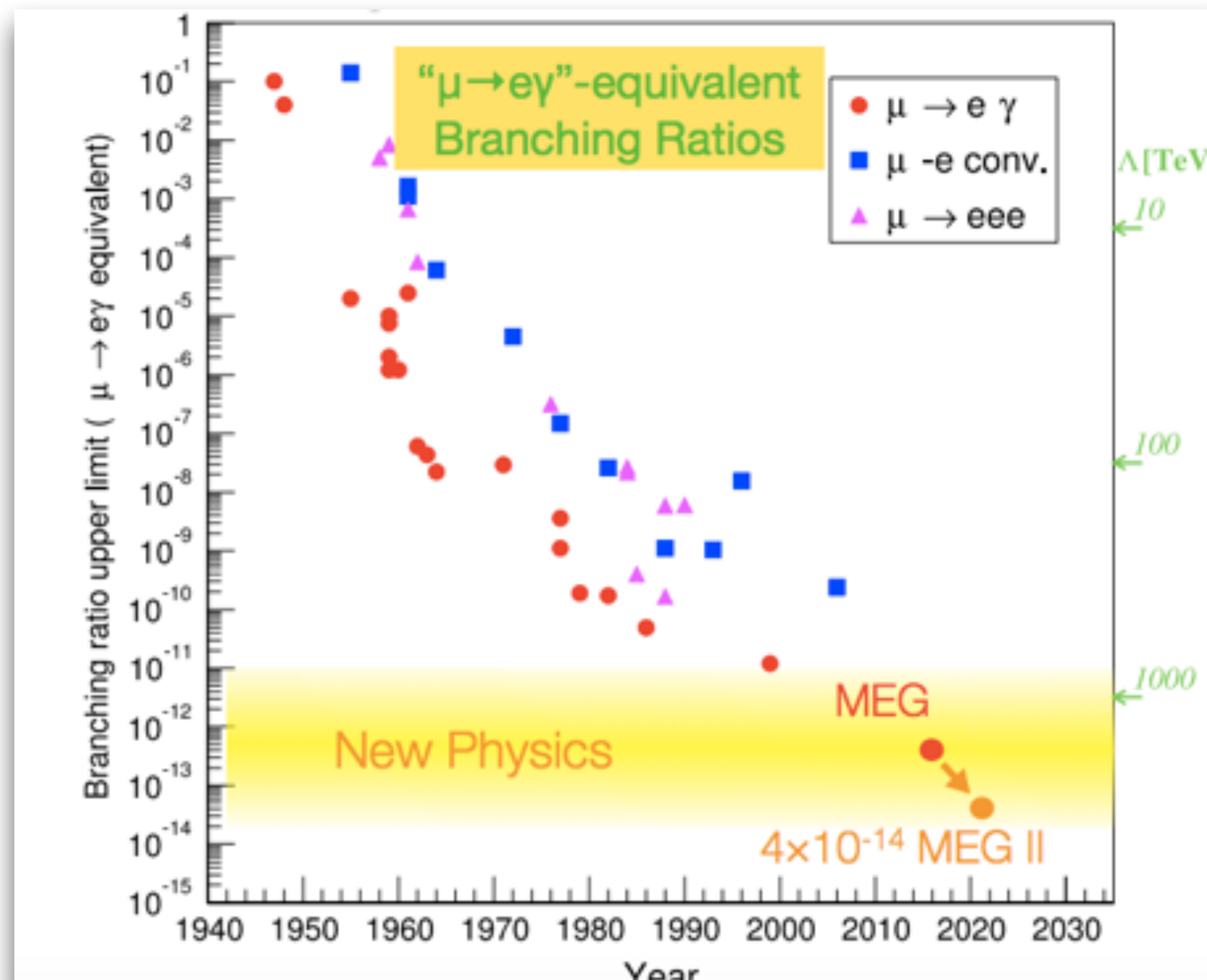
- Charge Lepton Flavor conservation in the Standard Model is an accidental symmetry, arising from the particle content of the model
  - cLFV almost unavoidable in most of New Physics models



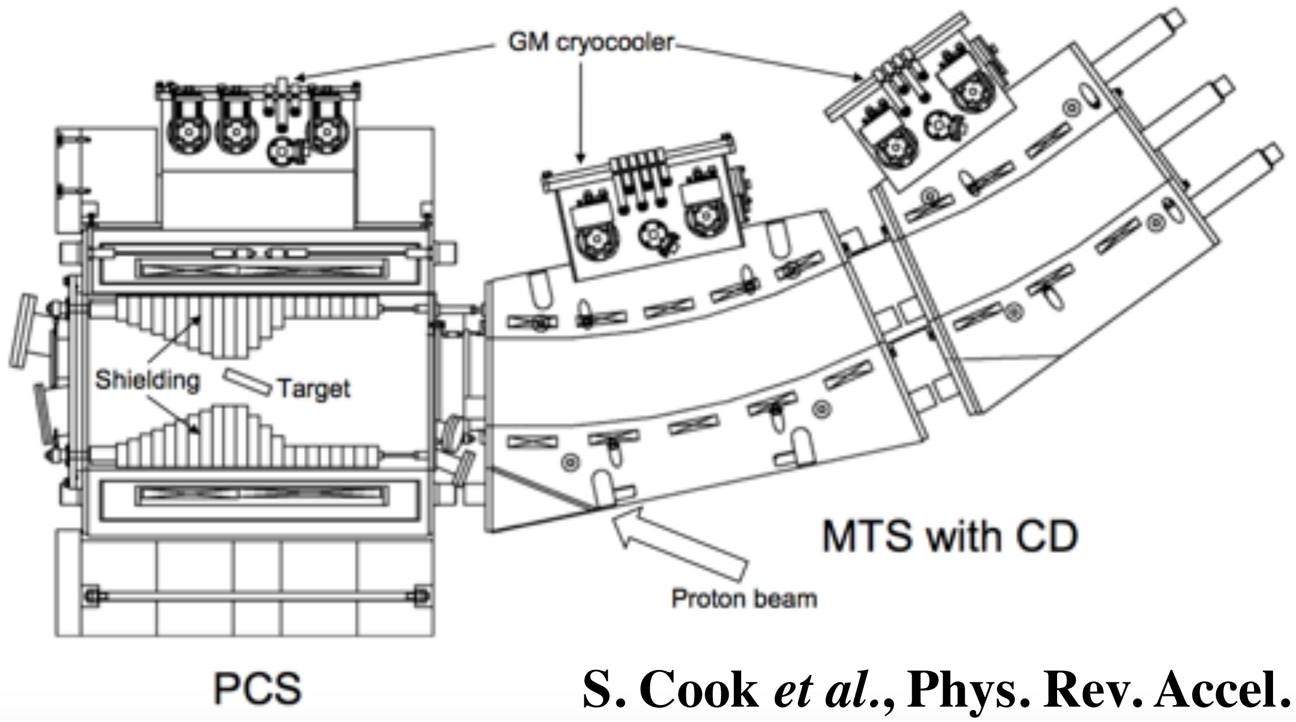
SUSY predictions ~ 10^{-11} - 10^{-15}

BR(μ -> e γ) < 4.2 x 10^{-13}

MEG @ PSI, 3 x 10^7 μ/s



The next generation of high intensity muon beams



S. Cook *et al.*, Phys. Rev. Accel. Beams 20 (2017)

MuSIC Project @ RCNP

Thick production target

π capture solenoid

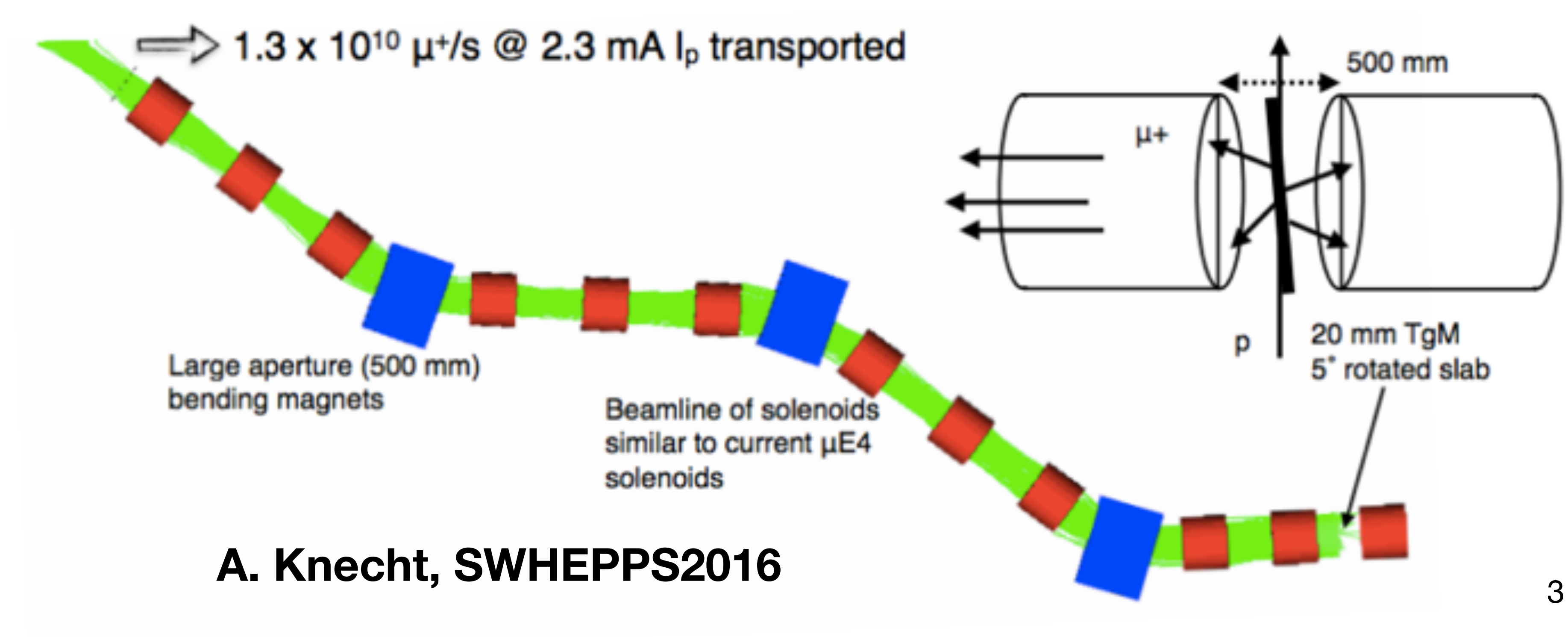
4×10^8 μ/s

HiMB Project @ PSI

x4 μ capture eff.

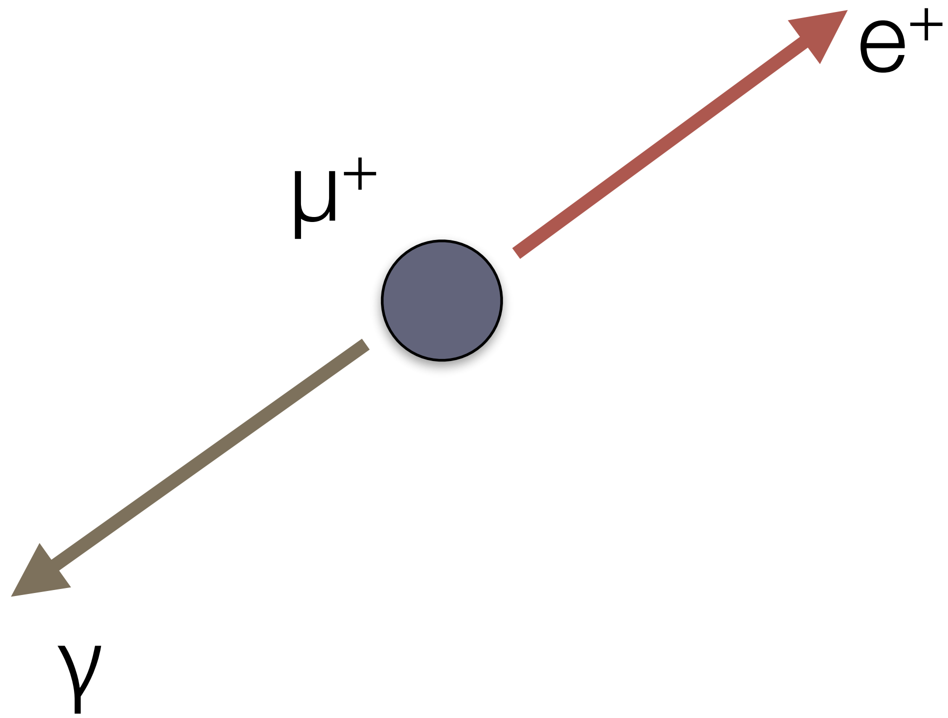
x6 μ transport eff.

1.3×10^{10} μ/s



A. Knecht, SWHEPPS2016

μ -> e γ searches

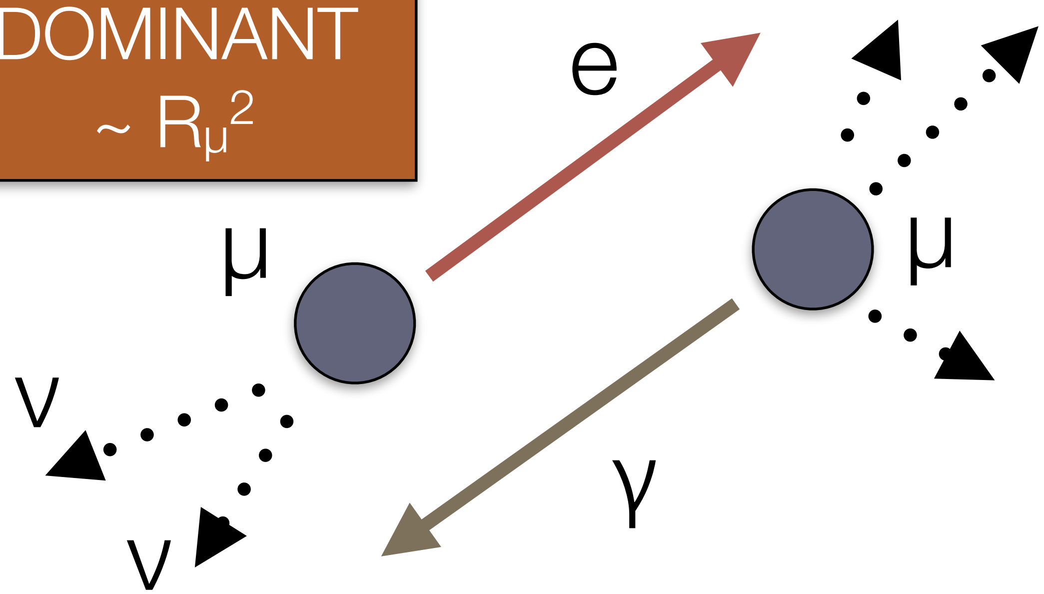


Positron and photon are **monochromatic** (52.8 MeV), **back-to-back** and produced at the **same time**;

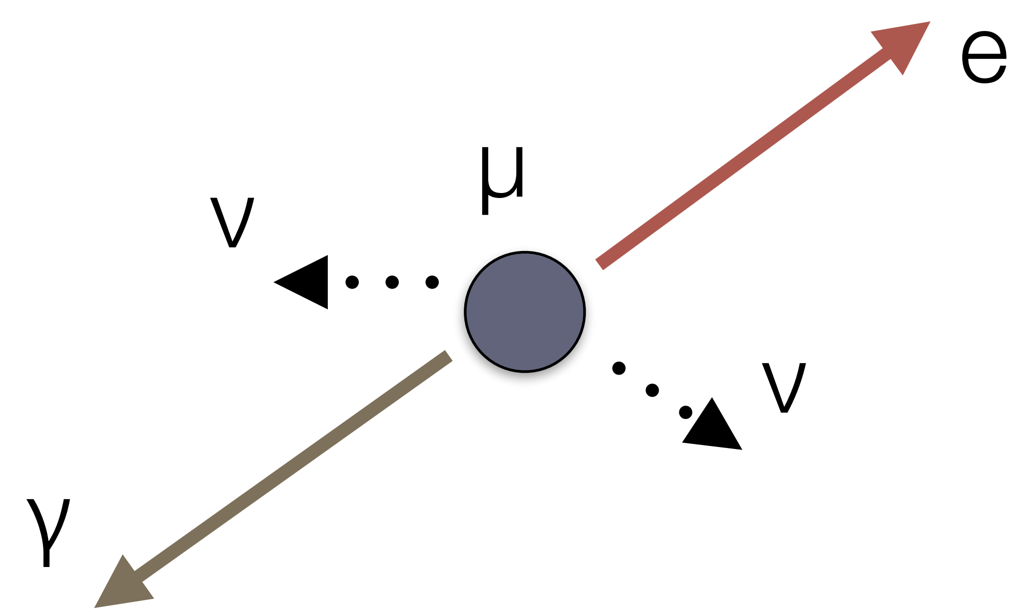
E_e, E_γ, $\Theta_{e\gamma}$, $T_{e\gamma}$

Accidental Background

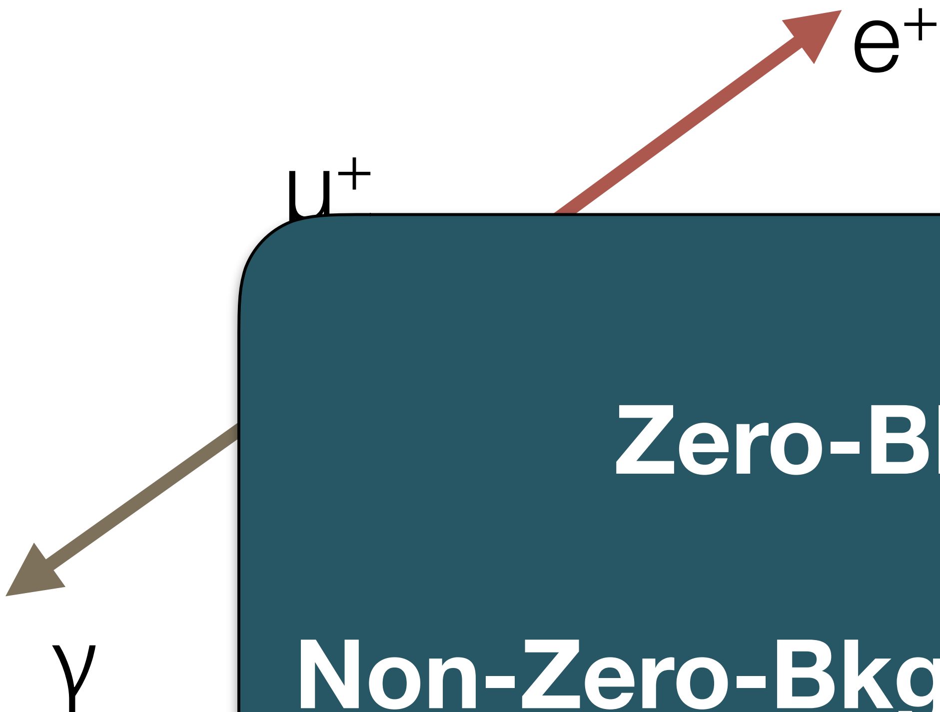
DOMINANT
$\sim R_\mu^2$



Radiative Muon Decay (RMD)



μ -> e γ searches



Positron and photon are **monochromatic** (52.8 MeV),

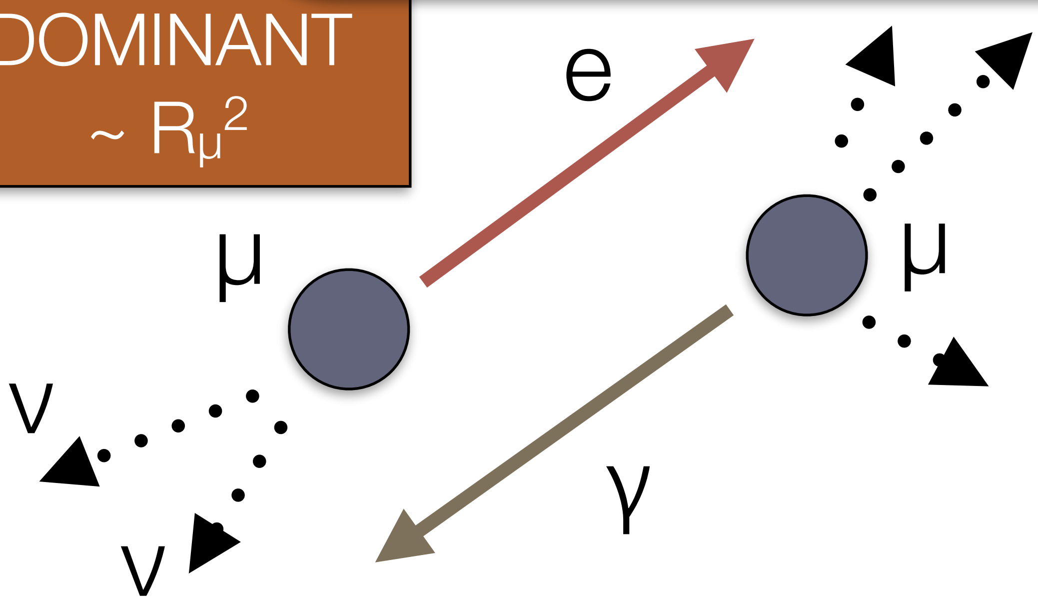
e;

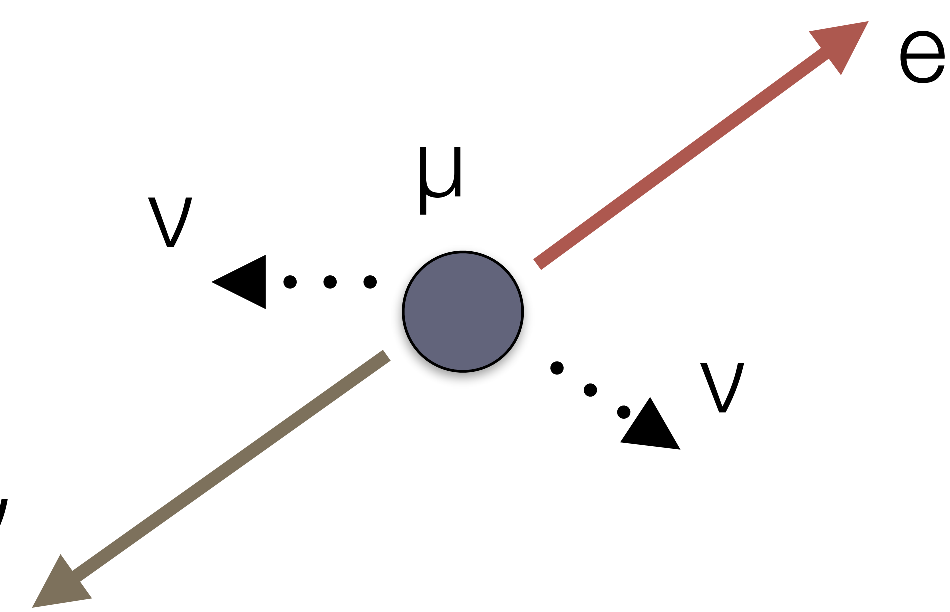
Zero-Bkg -> Sens. ~ 1/R_μ

Non-Zero-Bkg -> Sens. ~ S/√B ~ const.

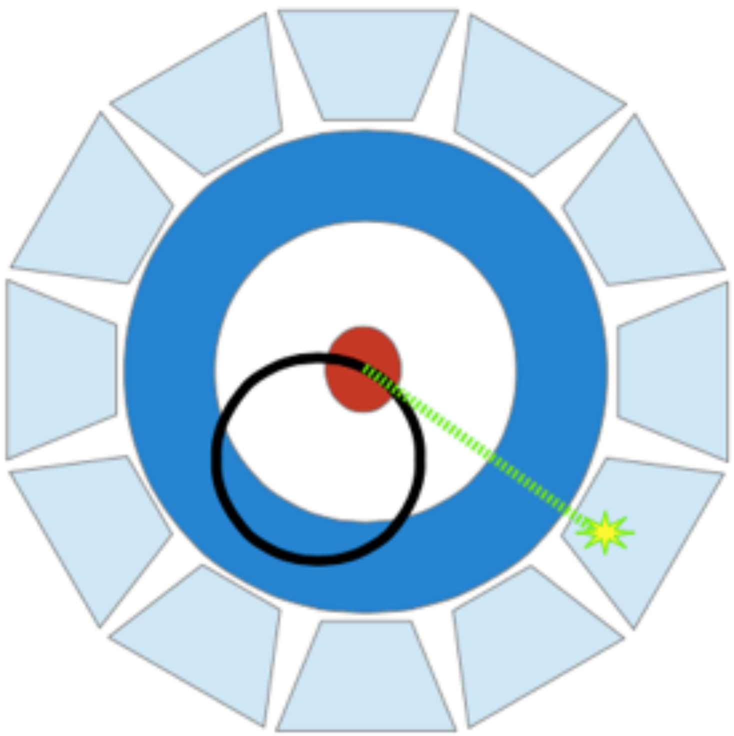
Accic **y (RMD)**

DOMINANT
~ R_μ^2





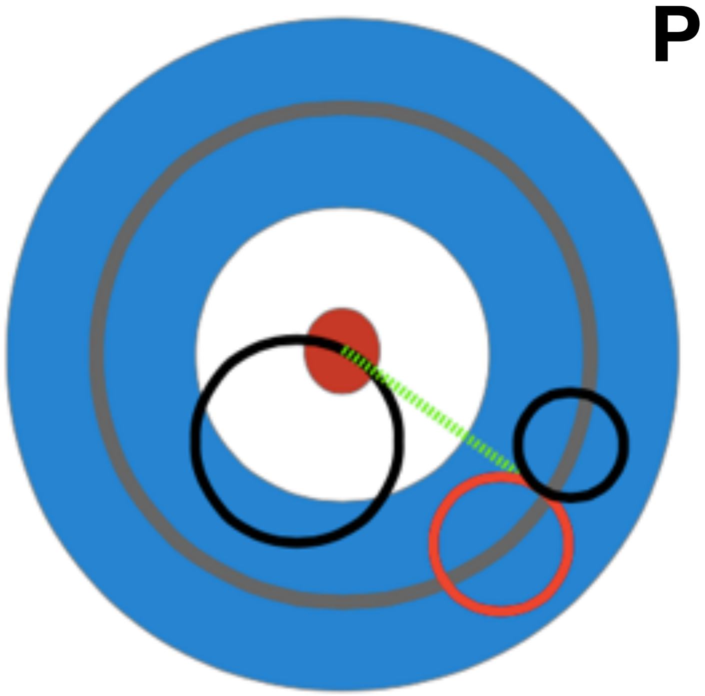
Toward the next generation of μ -> e γ searches: Photon Reconstruction



Calorimetry

High efficiency
Good resolutions

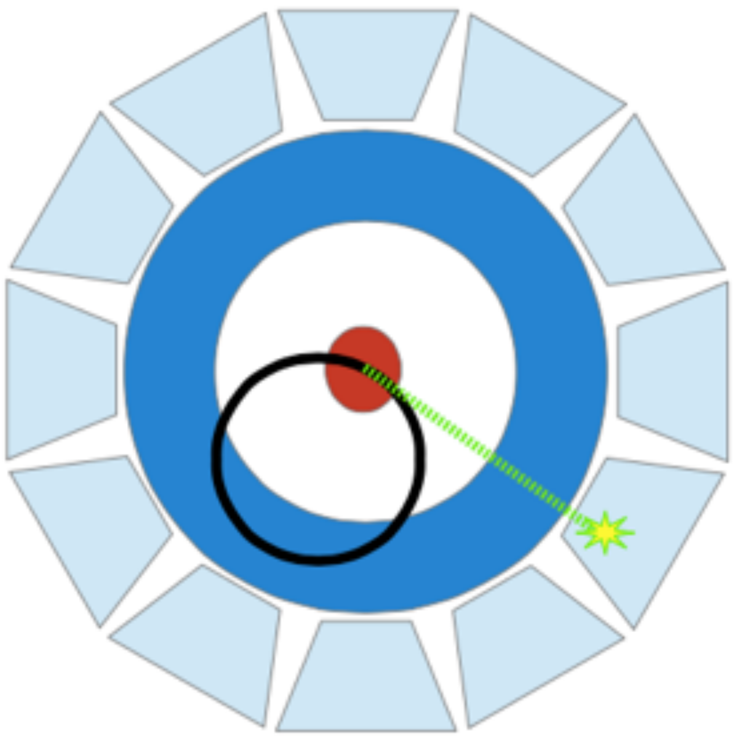
MEG:
LXe calorimeter
10% acceptance



Photon Conversion

Low efficiency (~ %)
Extreme resolutions
+ eγ Vertex

Toward the next generation of μ -> e γ searches: Photon Reconstruction



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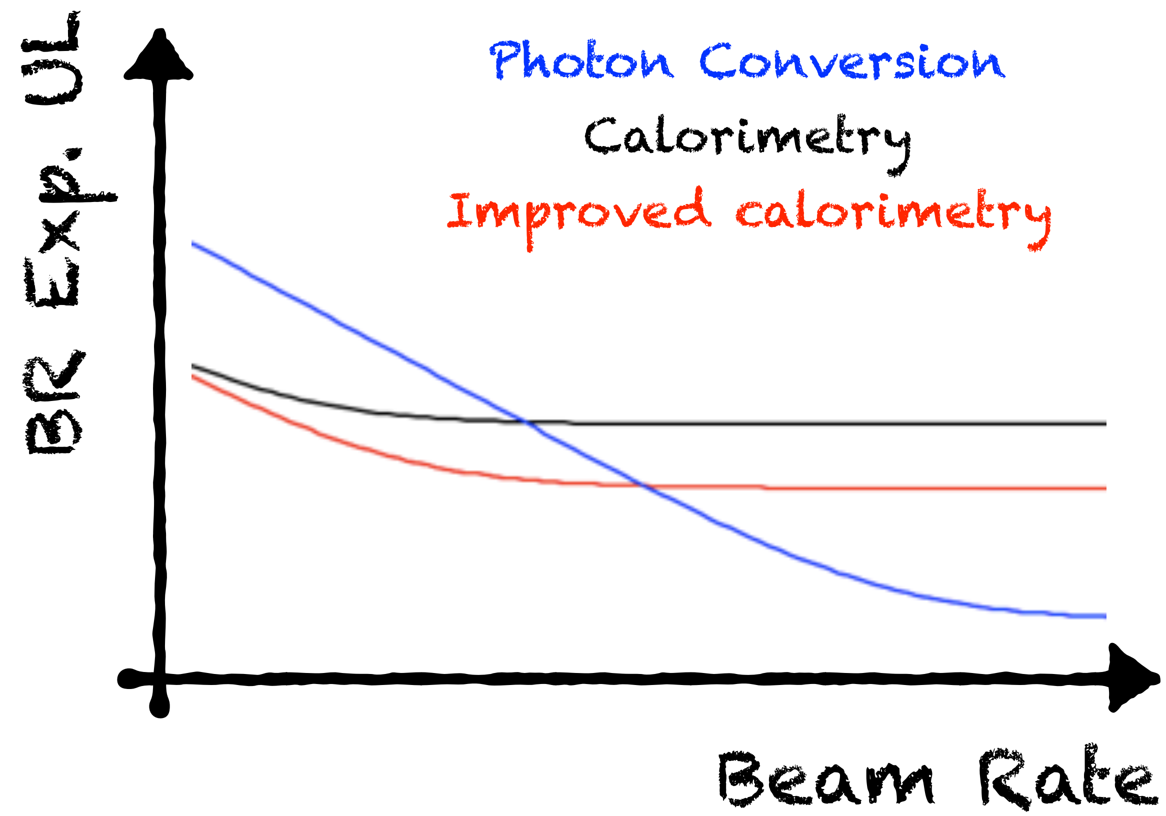
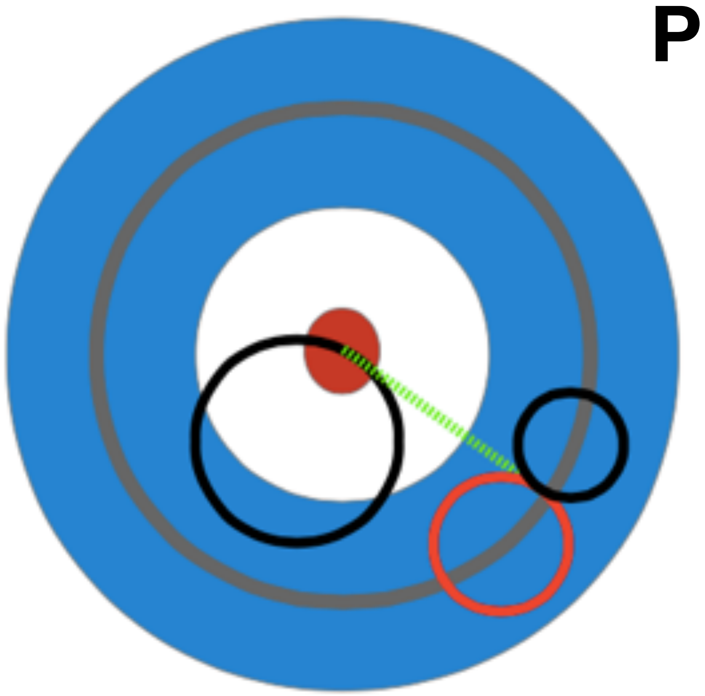




Photon Conversion

Low efficiency (~ %)
Extreme resolutions
+ eγ Vertex

Reminder:
Acc. Bkg. ~ R_μ^2

Photon Reconstruction: Limiting Factors

CALORIMETRY

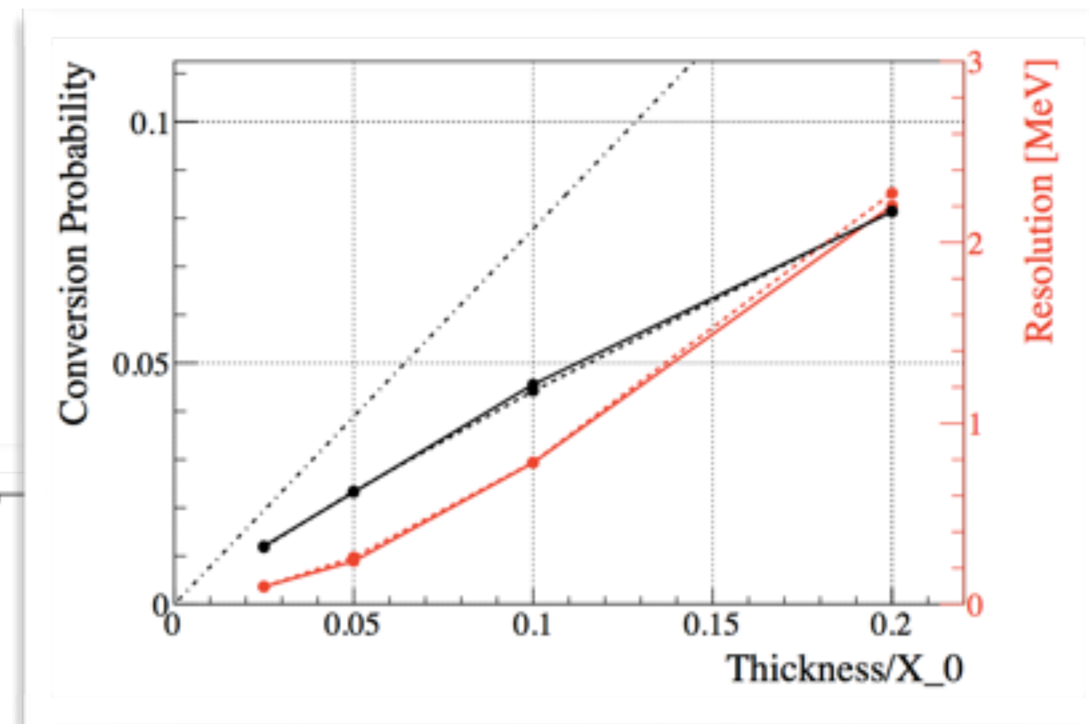
- Photon Statistics
- Scintillator time constant
- Detector segmentation

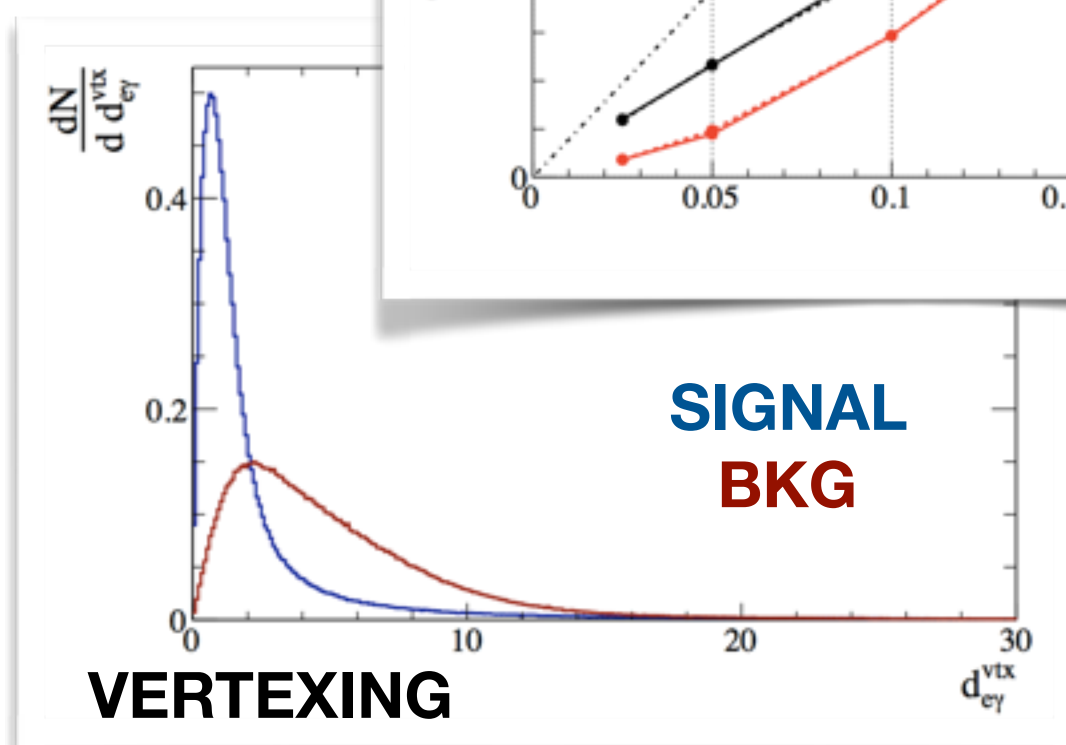
Scintillator	Density] [g/cm^3]	Light Yield [ph/keV]	Decay Time [ns]
$LaBr_3$(Ce)	5.08	63	16
LYSO	7.1	27	41
YAP	5.35	22	26
LXe	2.89	40	45
NaI(Tl)	3.67	38	250
BGO	7.13	9	300

- $LaBr_3$(Ce) looks a very good candidate:
  - our simulations & tests indicate that ~ 800 keV resolution can be reached
  - extreme time resolution (~ 30 ps)
  - large acceptance
  - very expensive

PHOTON CONVERSION

- Interactions in the converter (conversion probability, e^+e^- energy loss and MS)





Toward the next generation of μ -> e γ searches: Positron Reconstruction

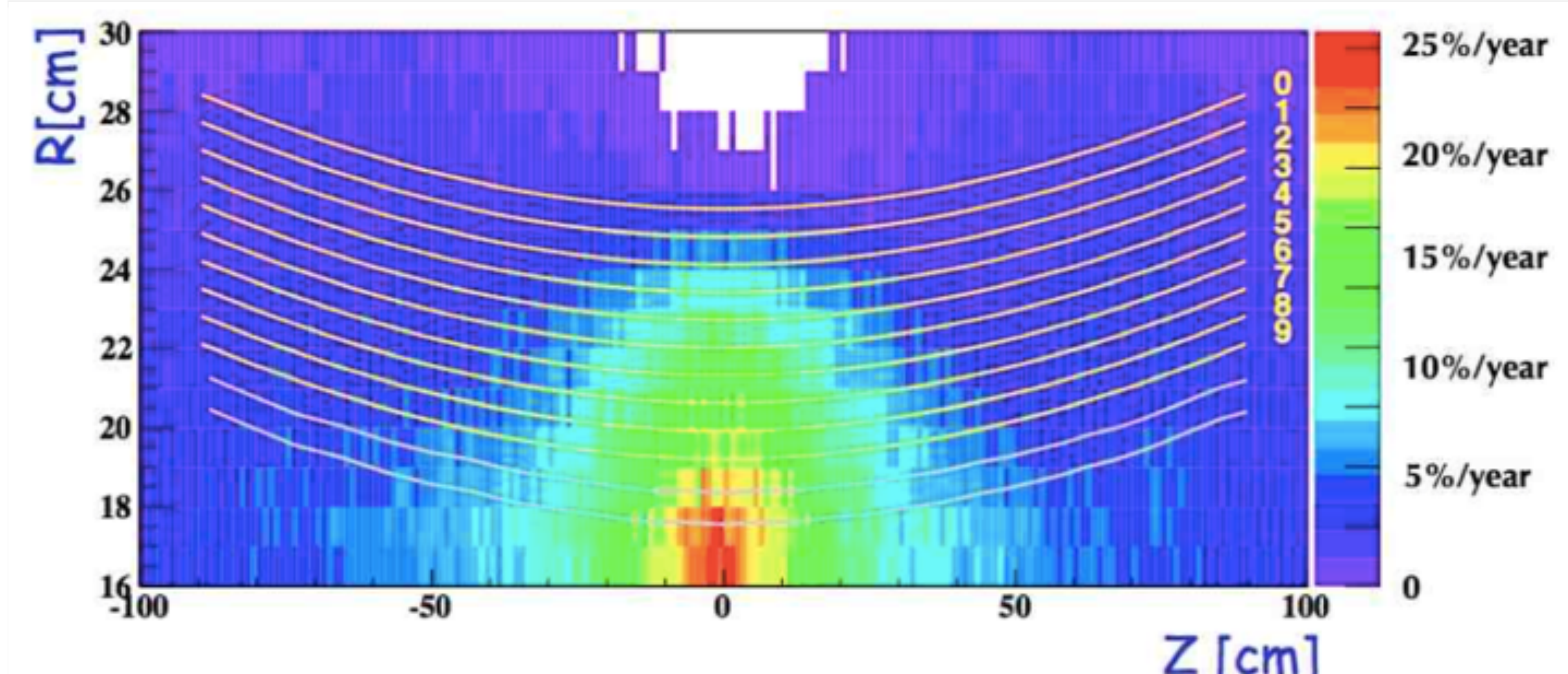
- Tracking detectors in a magnetic field are the golden candidates:
  - high efficiency
  - better resolutions w.r.t. calorimetry ($\sigma(E_e)$ down to 0.2% vs. > 1%)
- Need a very light detector in order to minimize the multiple scattering at E_e ~ 52.8 MeV
  - e.g. MEG drift chambers gave ~ 2 x 10^{-3} X_0 over the whole positron trajectory (200 μm silicon equivalent)

Limiting Factors: Positron Reconstruction

- Positron Reconstruction is ultimately limited by Multiple Scattering
  - MS in the target & tracker-> *angular resolutions*
  - MS in the tracker -> *momentum resolution*
- Silicon trackers are not competitive with gaseous detectors in terms of resolutions **(C-h. Cheng et al. arXiv: 1309.7679)**
  - e.g. worse momentum resolution by a factor ~ 2
  - …but maybe unique solution at high beam rate.

Relative Angle Resolution		
MS on target	2.6 / 2.8 mrad ($\theta_{e\gamma}$ / $\phi_{e\gamma}$)	
MS on gas & walls	3.3 / 3.3 mrad ($\theta_{e\gamma}$ / $\phi_{e\gamma}$)	R_e = 20 cm, R_γ = 30 cm, B = 1 T
Traking	6.0 / 4.5 mrad ($\theta_{e\gamma}$ / $\phi_{e\gamma}$)	
Alignment	< 1 mrad	< 100 μm target alignment

Positron Reconstruction at High Beam Rate



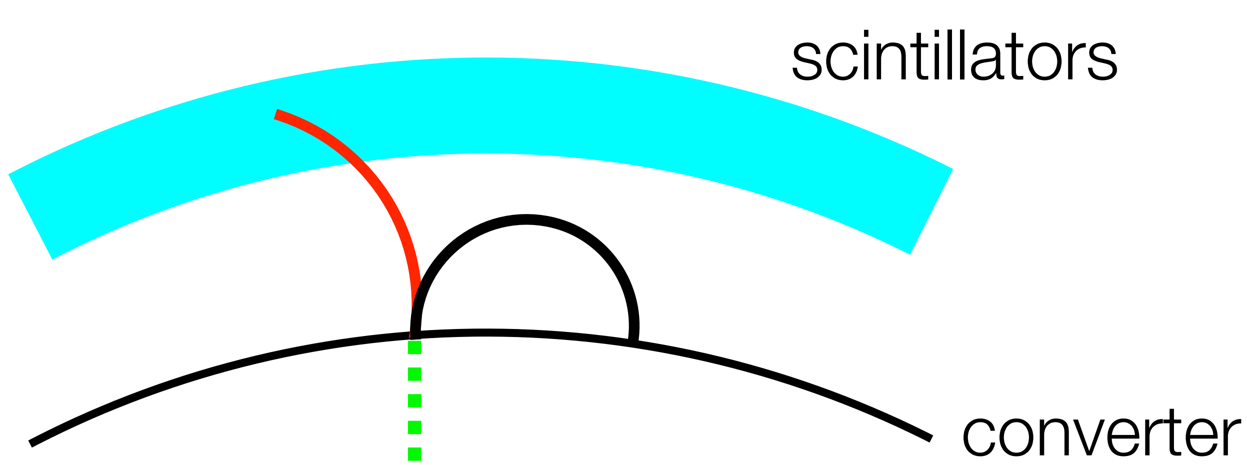
A. Baldini et al., MEG Upgrade Proposal, arXiv:1301:7225

Expected aging (gain loss) in the MEG-II Drift Chamber

Would a gaseous detector be able to cope with the very high occupancy at > 10^9 μ/s?

Photon and Positron timing

- Timing plays a crucial role in $\mu \to e \gamma$ searches (accidental coincidences!!!):
  - need a very good positron and photon timing
  - $\sigma(T_{e\gamma}) \sim 80$ ps in MEG-II
- $LiBr_3(Ce)$ calorimeters + positron scintillating counters like in MEG can give the required performances
- For photon conversion, need to detect e^+ or e^- in a **fast detector**



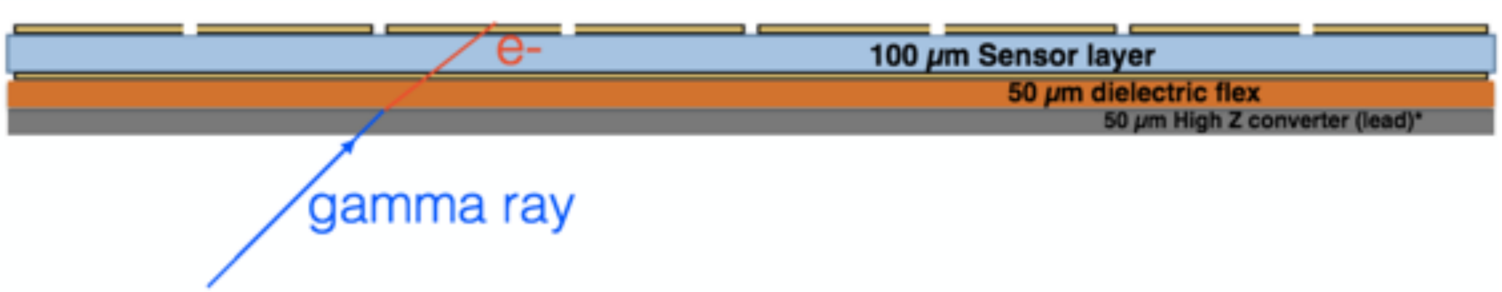
What about stacking multiple layers?

An active conversion layer

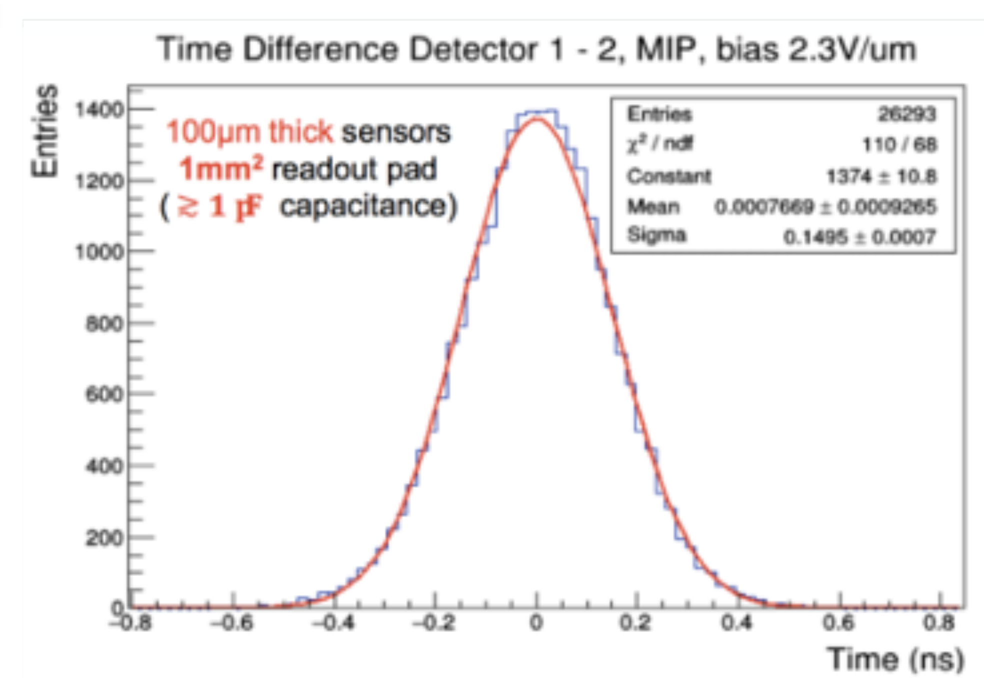
- Good photon timing in a detector with multiple conversion layers implies active material in the conversion layer:
  - thin, to not deteriorate the energy resolution
- Scintillating fibers have poor “timing to thickness” figures (~ 1 ns for 250 μm fibers)

FAST SILICON DETECTORS

- R&D on going for PET application (**TT-PET**)



M. Benoit et al., JINST 11 (2016) no. 03, P03011



$$\sigma_t = \frac{(150 \pm 1)ps}{\sqrt{2}} = (106 \pm 1)ps$$

Possible Scenarios

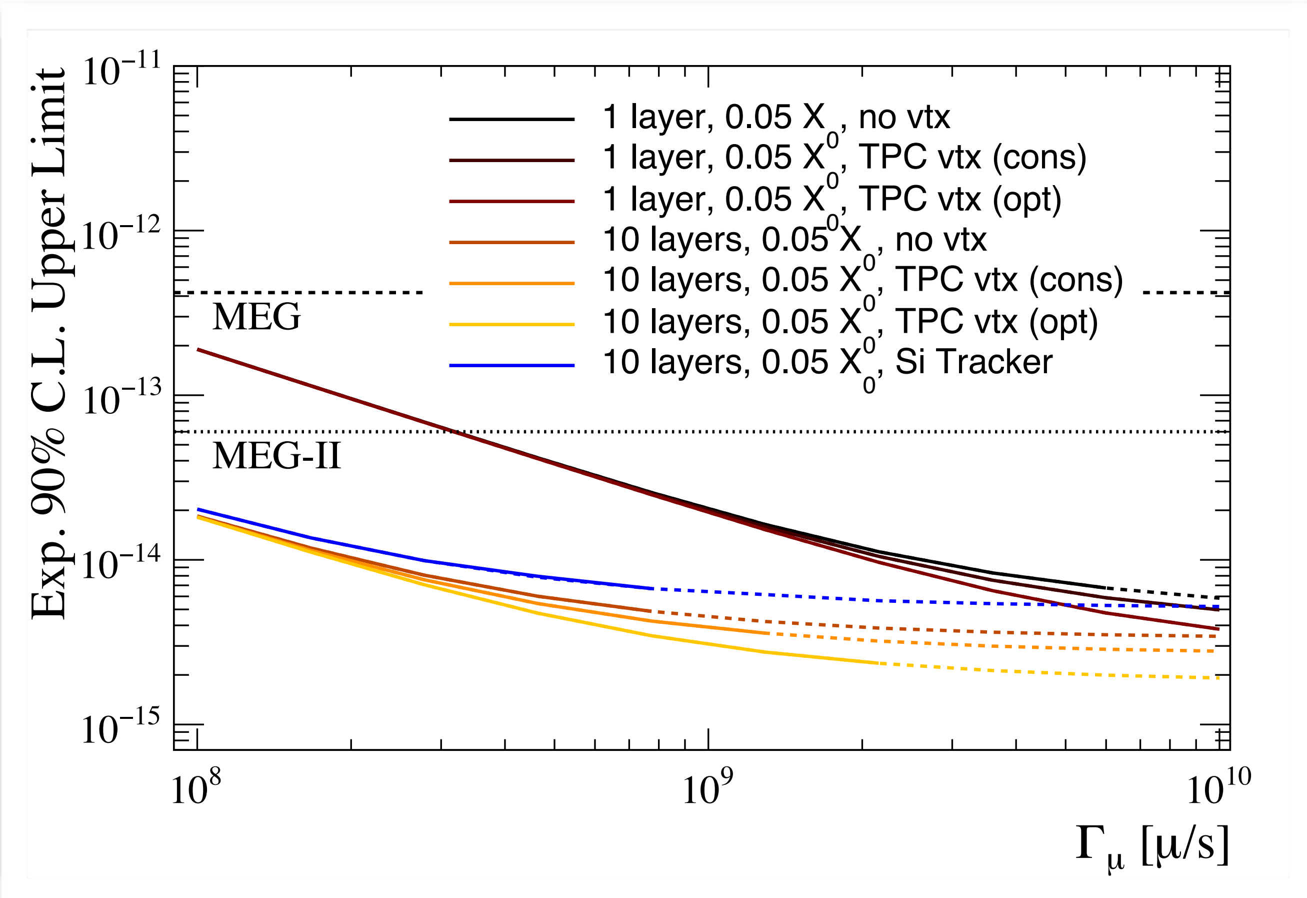
CALORIMETRY

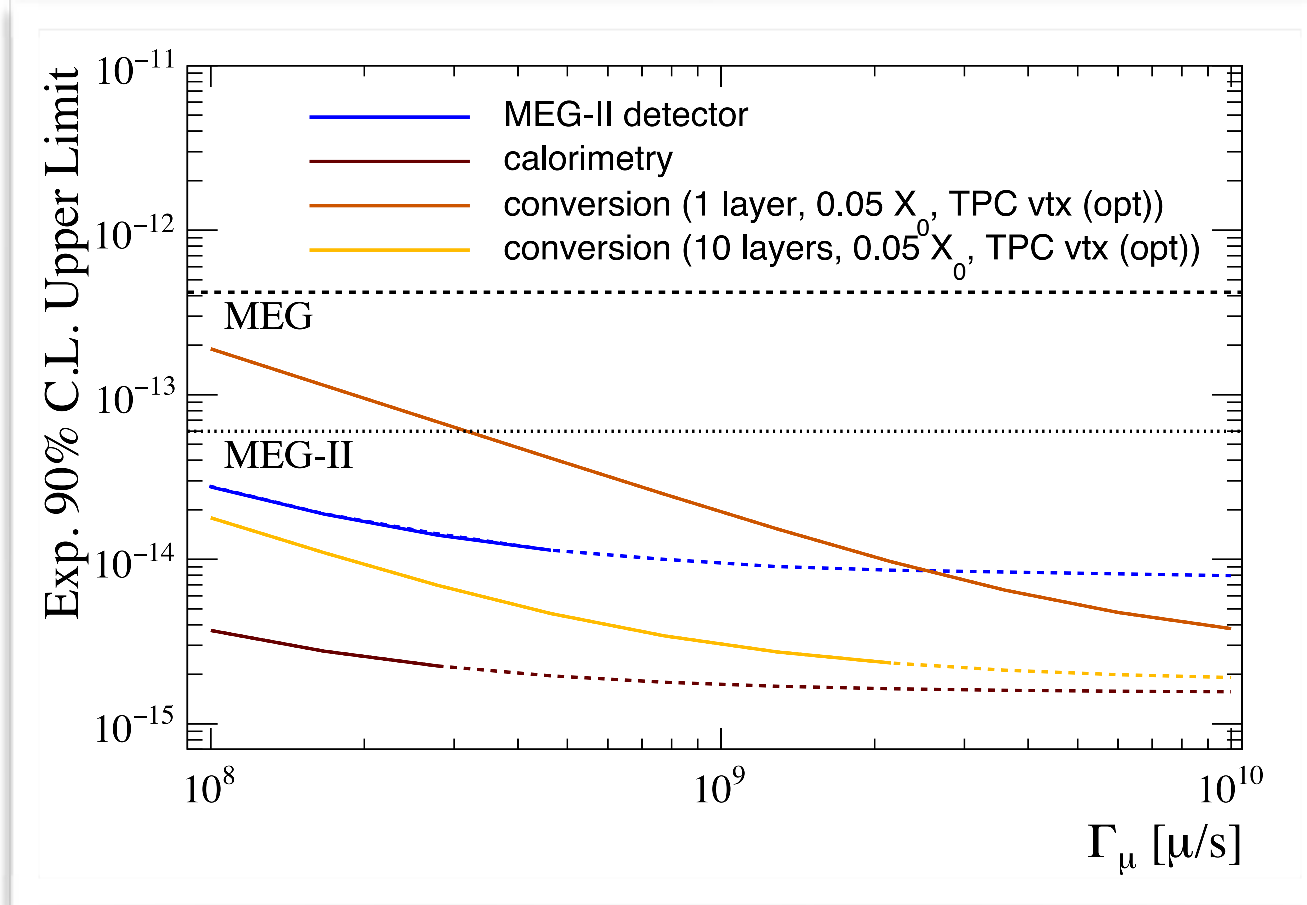
Variable	Resolution				
	w/o vtx detector	*w/ TPC vtx detector*		*w/ silicon vtx detector*	
		conservative	optimistic	conservative	optimistic
$\theta_{e\gamma}$ / $\phi_{e\gamma}$ [mrad]	7.3 / 6.2	6.1 / 4.8	3.5 / 3.8	8.0 / 7.4	6.3 / 6.9
$T_{e\gamma}$ [ps]	30				
E_e [keV]	100				
E_γ [keV]	850				
Efficiency [%]	42% **(70% γ acceptance)**				

PHOTON CONVERSION

Variable	Resolution				
	w/o vtx detector	*w/ TPC vtx detector*		*w/ silicon vtx detector*	
		conservative	optimistic	conservative	optimistic
$\theta_{e\gamma}$ / $\phi_{e\gamma}$ [mrad]	7.3 / 6.2	6.1 / 4.8	3.5 / 3.8	8.0 / 7.4	6.3 / 6.9
$T_{e\gamma}$ [ps]	50				
E_e [keV]	100				
E_γ [keV]	320				
Efficiency [%]	1.2 **(1 LAYER, 0.05 X_0)**				

Expected Sensitivity





A few 10^{-15} seems to be within reach for a 3-year run at ~ 10^8 μ/s with calorimetry (*expensive*) or ~ 10^9 μ/s with conversion (*cheap*)

Fully exploiting 10^{10} μ/s and breaking the 10^{-15} wall seem to require a ***novel experimental concept***