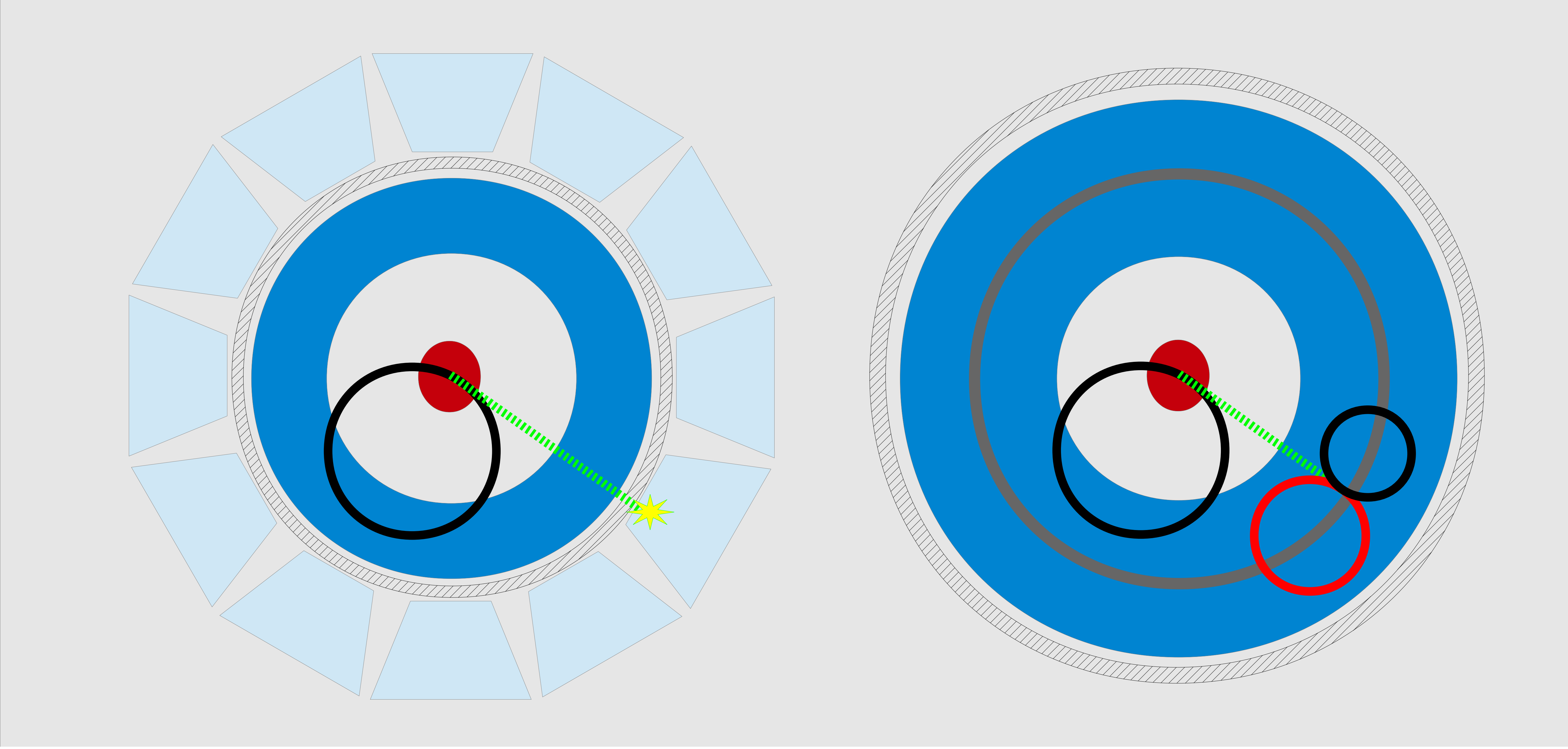
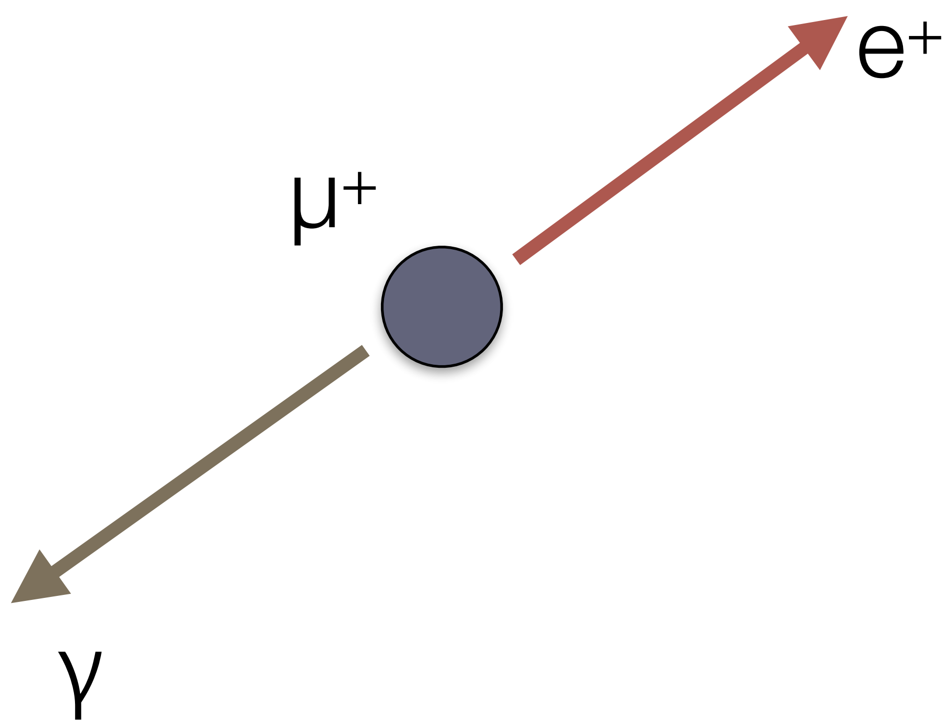


The Quest for μ -> e γ and its Experimental Limiting Factors at Future High Intensity Muon Beams

Francesco Renga
INFN Roma

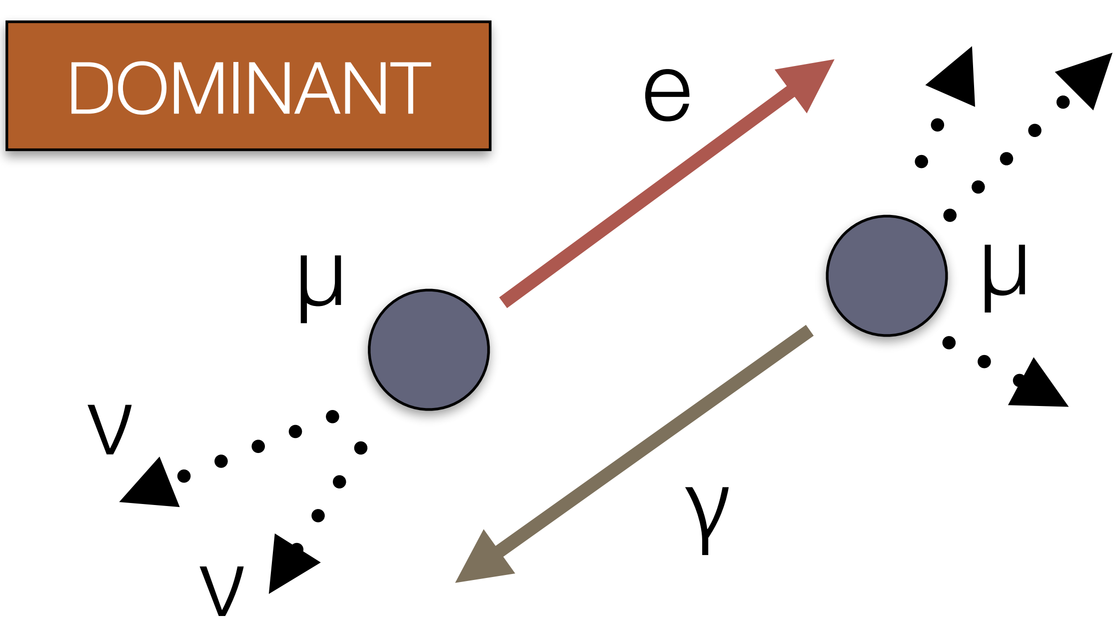
μ -> e γ searches



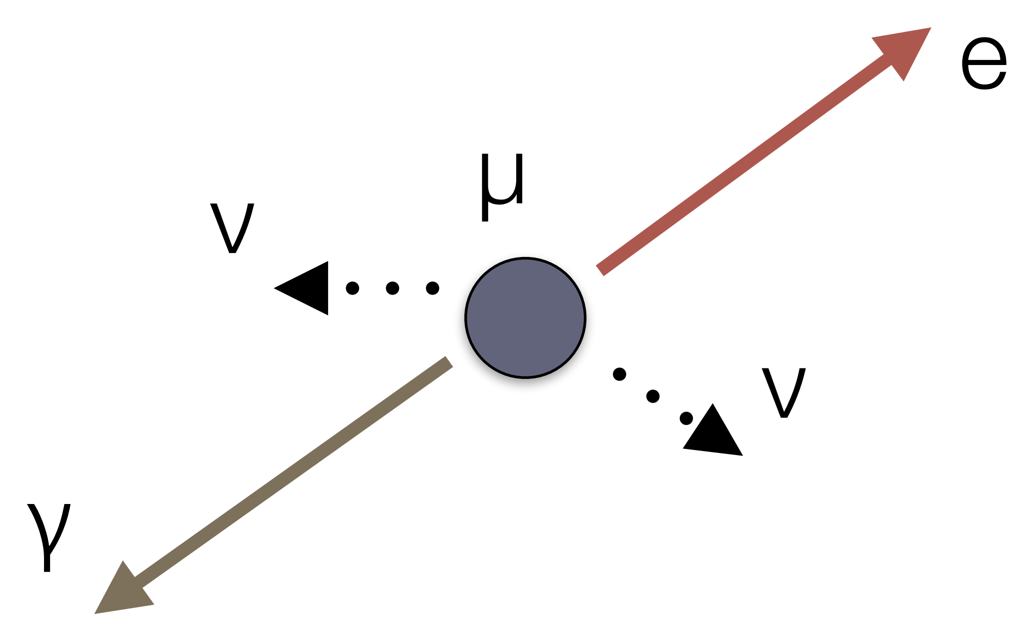
28 MeV/c muons are stopped on a thin target

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

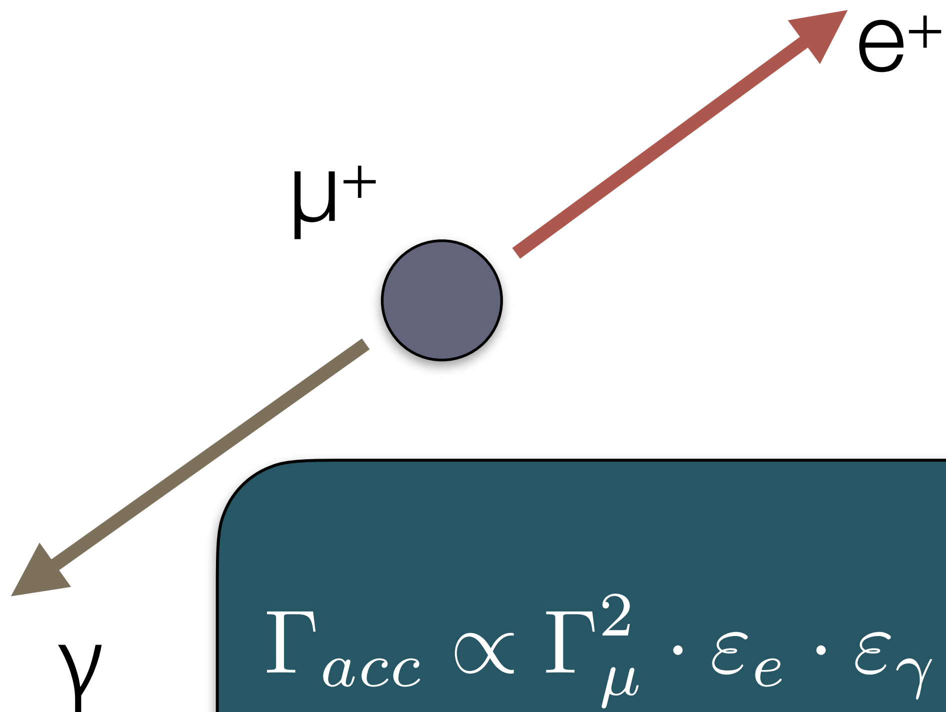
Accidental Background



Radiative Muon Decay (RMD)



μ -> e γ searches



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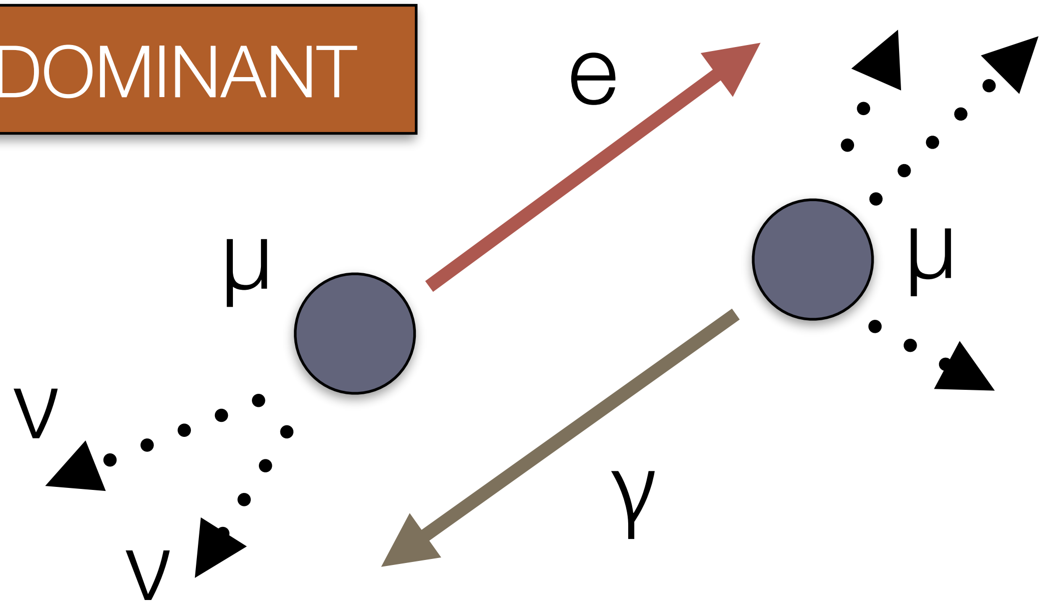
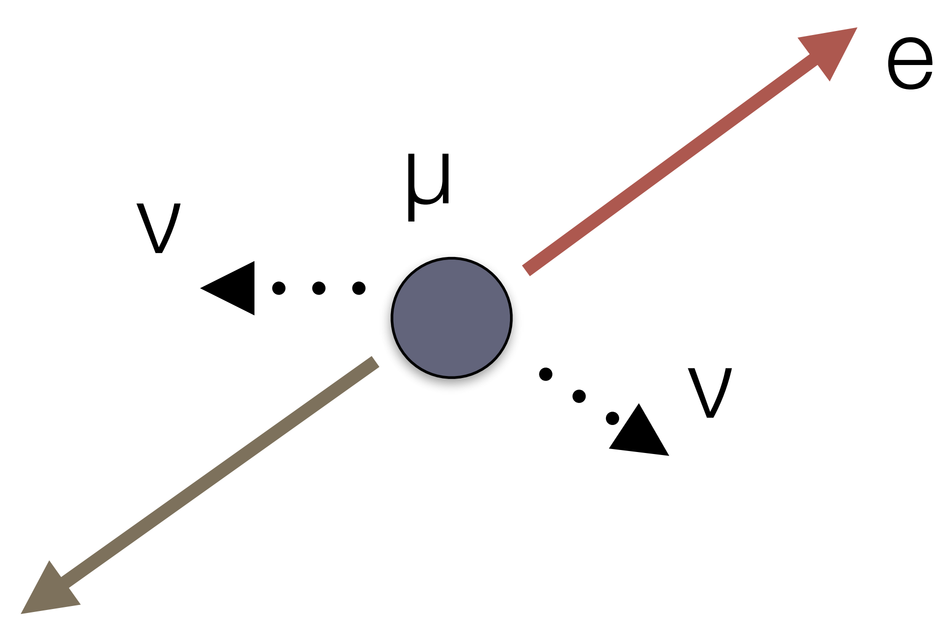
Positron and photon are **monochromatic** (52.8 MeV),
d
time;

$$\Gamma_{acc} \propto \Gamma_{\mu}^{2} \cdot \varepsilon_e \cdot \varepsilon_\gamma \cdot \delta E_e \cdot (\delta E_\gamma)^2 \cdot (\delta \Theta_{e\gamma})^2 \cdot \delta T_{e\gamma}$$

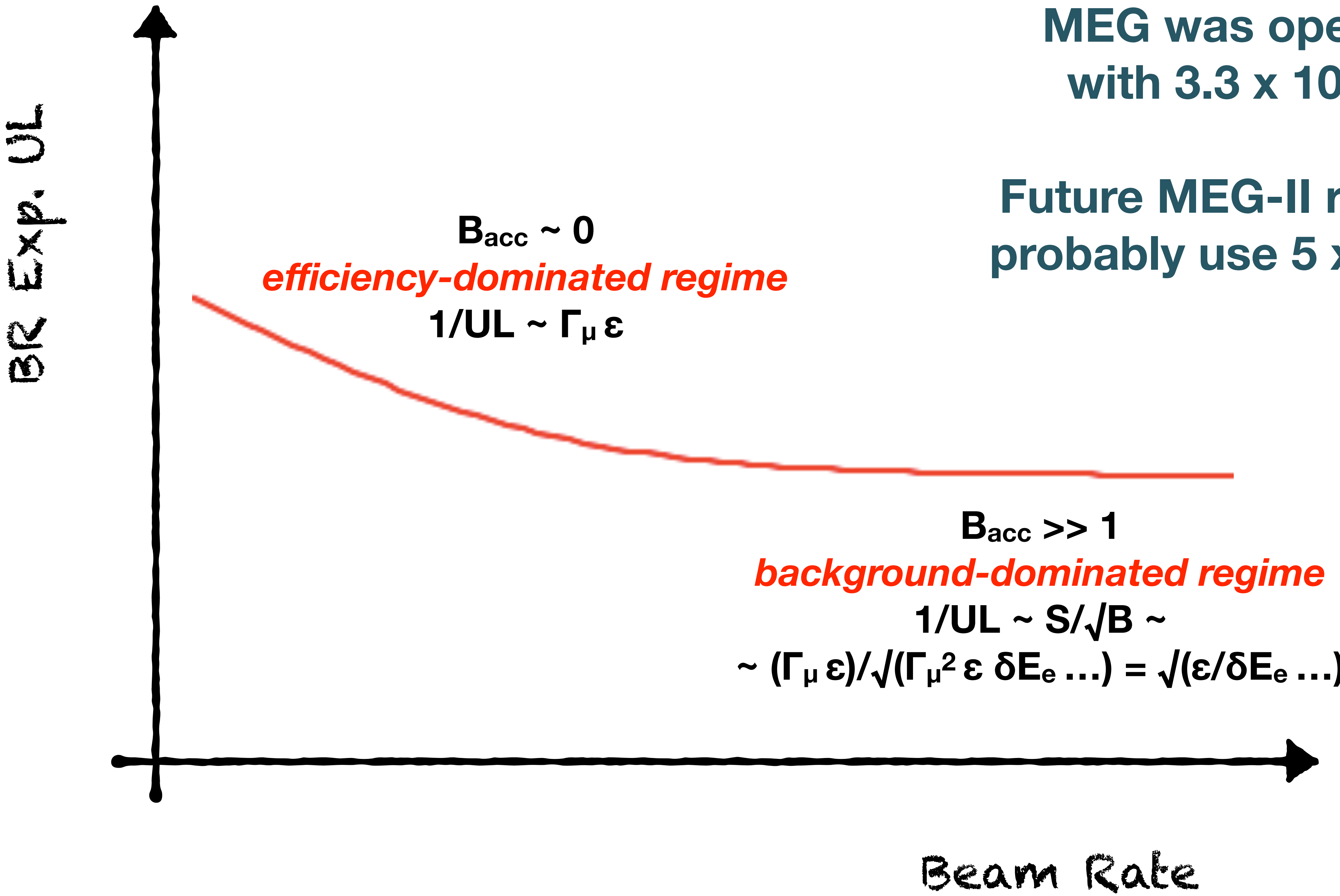
Acci **ay (RMD)**

DOMINANT





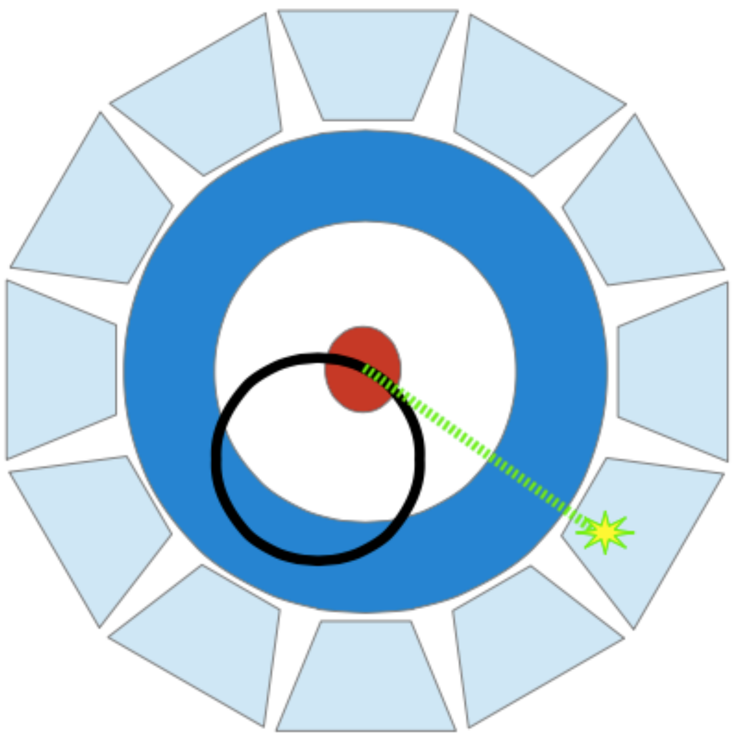
μ -> e γ searches



MEG was operated with 3.3 x 10^7 μ/s

Future MEG-II runs will probably use 5 x 10^7 μ/s

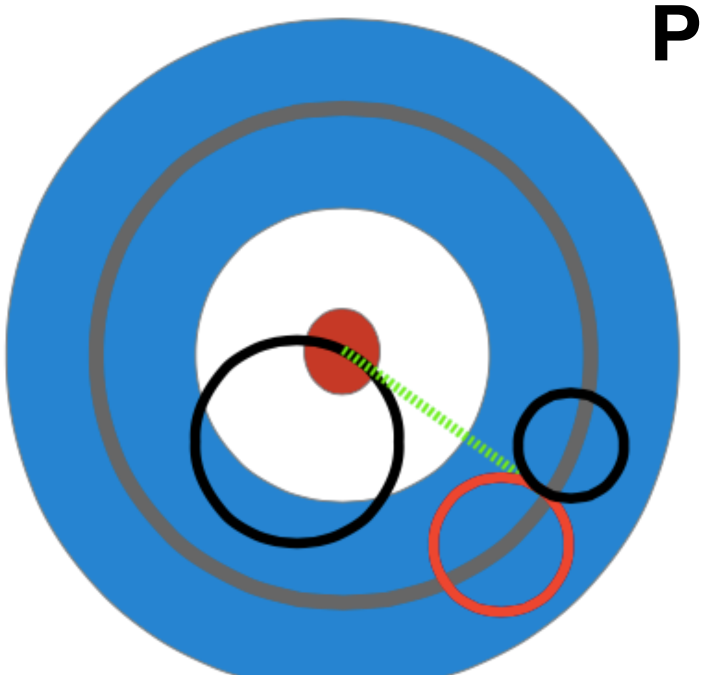
Toward the next generation of μ -> e γ searches: Photon Reconstruction



Calorimetry

High efficiency
Good resolutions

MEG:
LXe calorimeter
10% acceptance



Photon Conversion

Low efficiency (~ %)
Extreme resolutions
+ eγ Vertex

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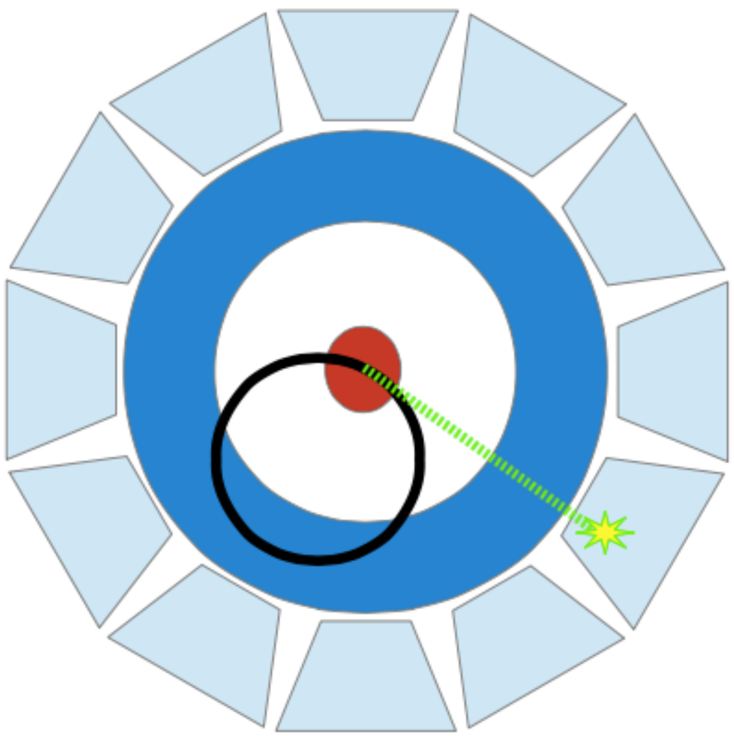

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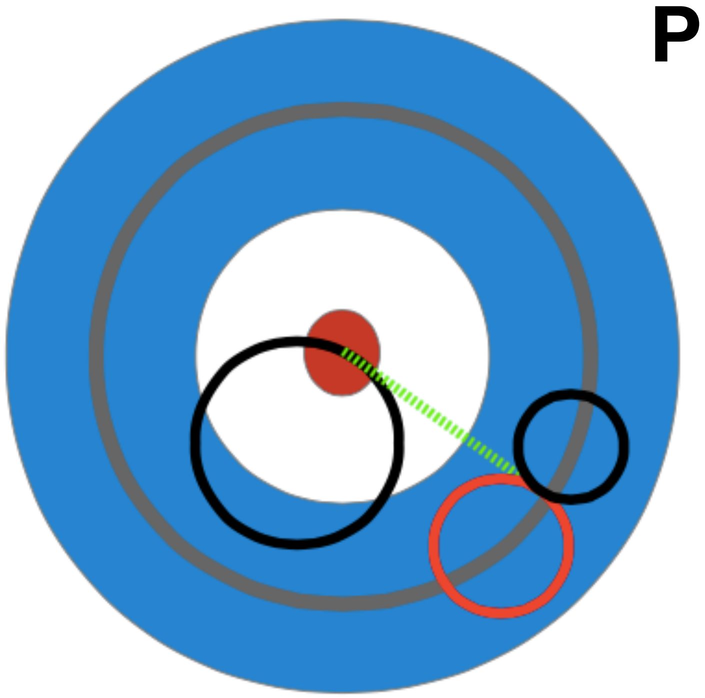

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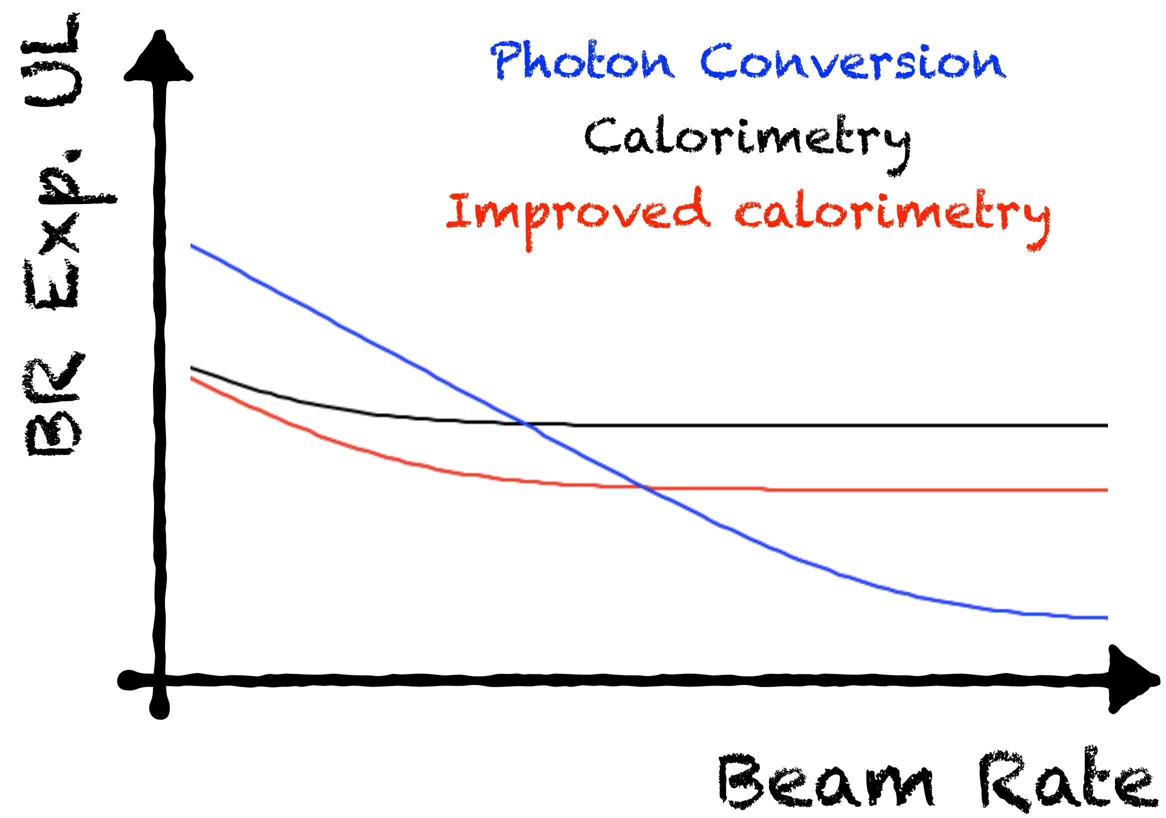


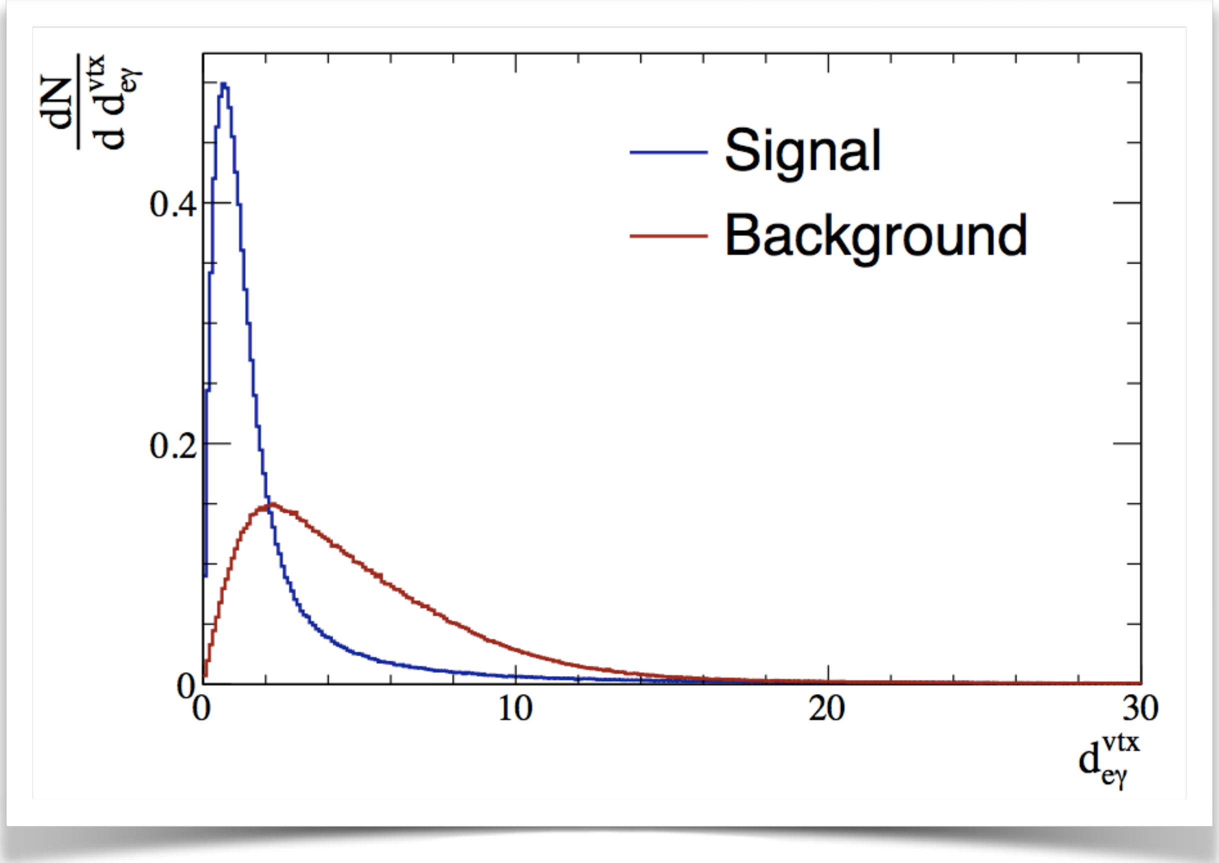
Limiting factors — Photon calorimetry

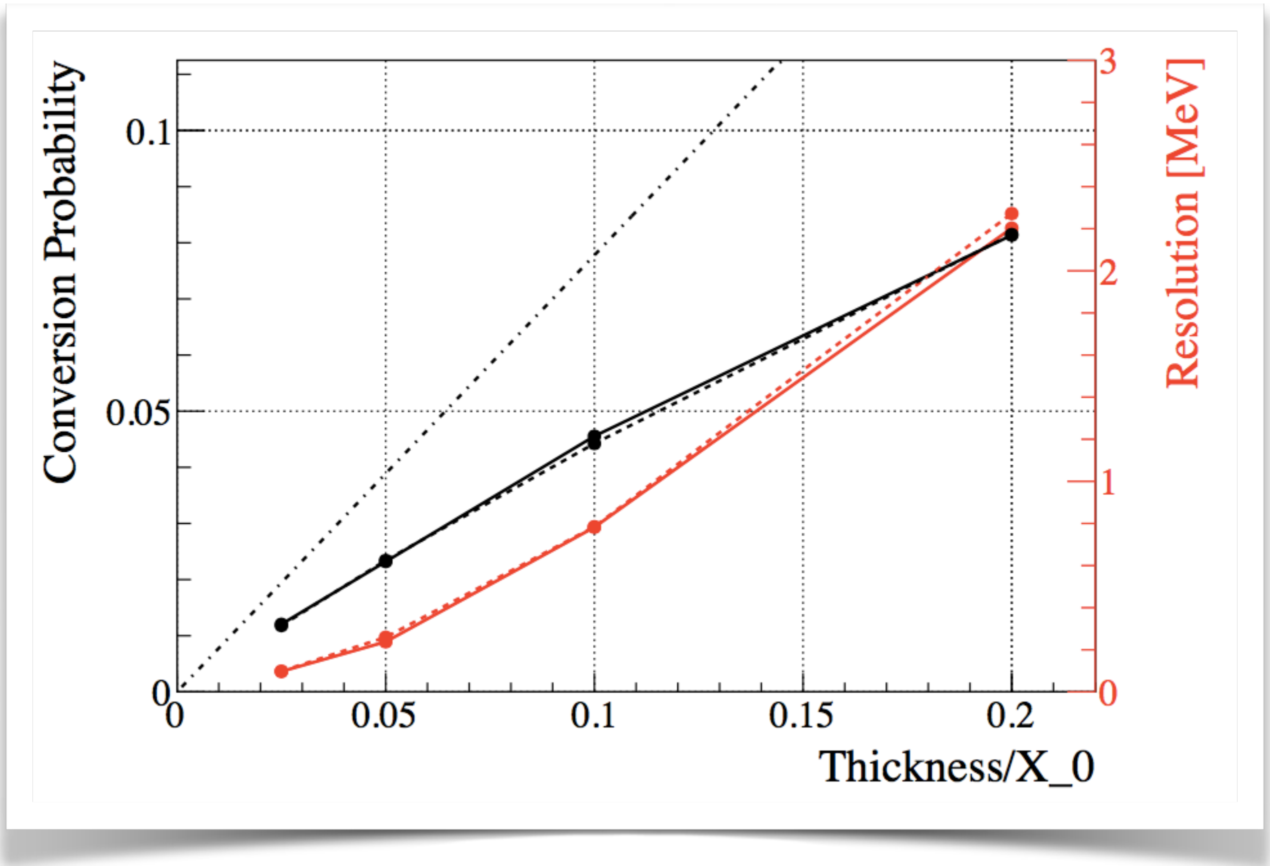
- MEG (LXe) could not get yet a photon energy resolution much better than 1 MeV:
  - not completely understood
  - limited acceptance due to large cost and complex infrastructure
- Innovative crystals like $LaBr_3(Ce)$ — a.k.a. *Brillance* look a very good candidate for future experiments
  - 800 keV resolution could be within the reach
  - cost can be again an issue
- Time and position resolution looks less problematic
  - 30 ps is possible

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

Limiting factors — Photon conversion

- Interactions in the converter (conversion probability, e+e- energy loss and MS)
- Possible improvement with active converter (see W. Ootani's talk)



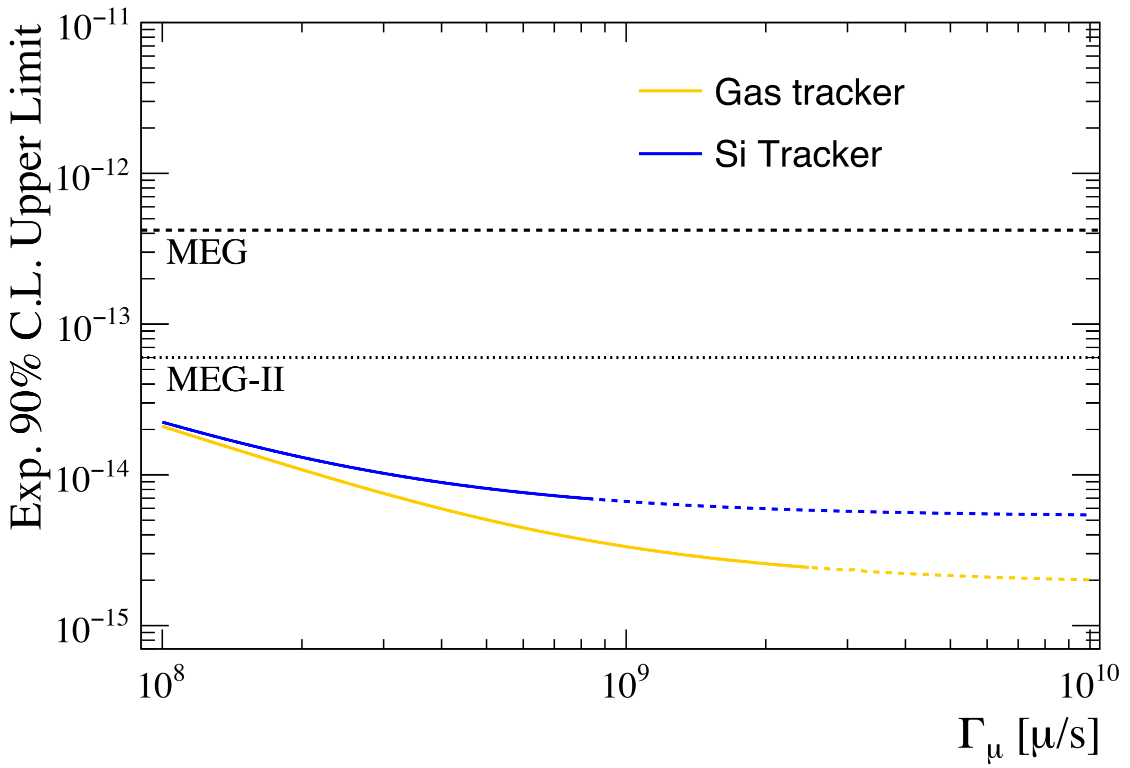


- Can take advantage of the photon direction determination form the e+e- reconstruction

$$d_{e\gamma}^{\rm vtx} = \sqrt{\left(\frac{X_e - X_\gamma}{\sigma_X}\right)^2 + \left(\frac{Y_e - Y_\gamma}{\sigma_Y}\right)^2}$$

Limiting factors — Positron

- Gaseous tracking detectors currently provide the best resolutions
  - very light gas mixtures
  - 100 keV energy resolution in MEG II



***modified from G. Cavoto et al., Eur.Phys.J.C* 78 (2018)**

Limiting factors — Positron

- Gaseous tracking detectors currently provide the best resolutions
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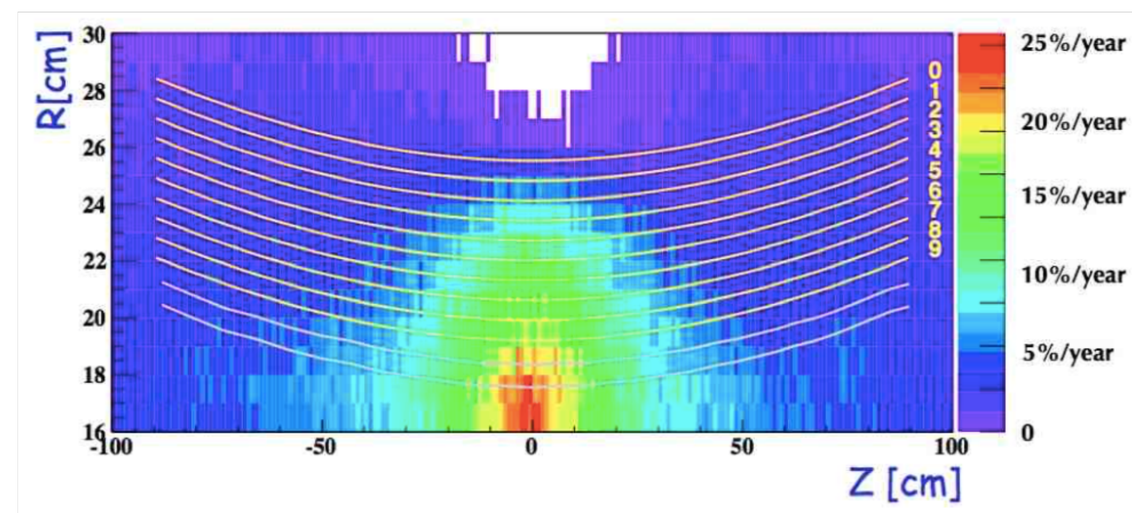
    - 100 keV energy resolution in MEG II
    - aging and pattern recognition are a severe issue at large rates
- Silicon detectors are becoming competitive with expected developments
    - going toward 25 μm HV-MAPS

Expected aging (gain loss) in MEG II

A. Baldini et al., arXiv:1301:7225



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  - very light gas mixtures
  - 100 keV energy resolution in MEG II
  - aging and pattern recognition are a severe issue at large rates
- Silicon detectors are becoming competitive with expected developments
  - going toward 25 μm HV-MAPS
- Multiple scattering before the detector (target + gas + detector walls)
  - ~ 4 mrad contribution to the angular resolutions

Expected aging (gain loss) in MEG II

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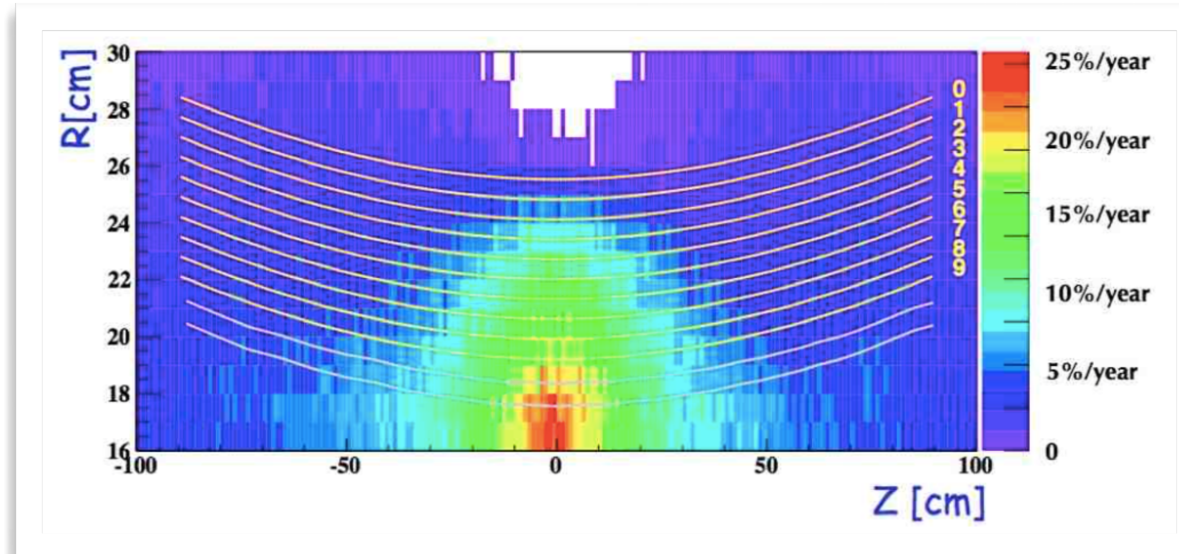
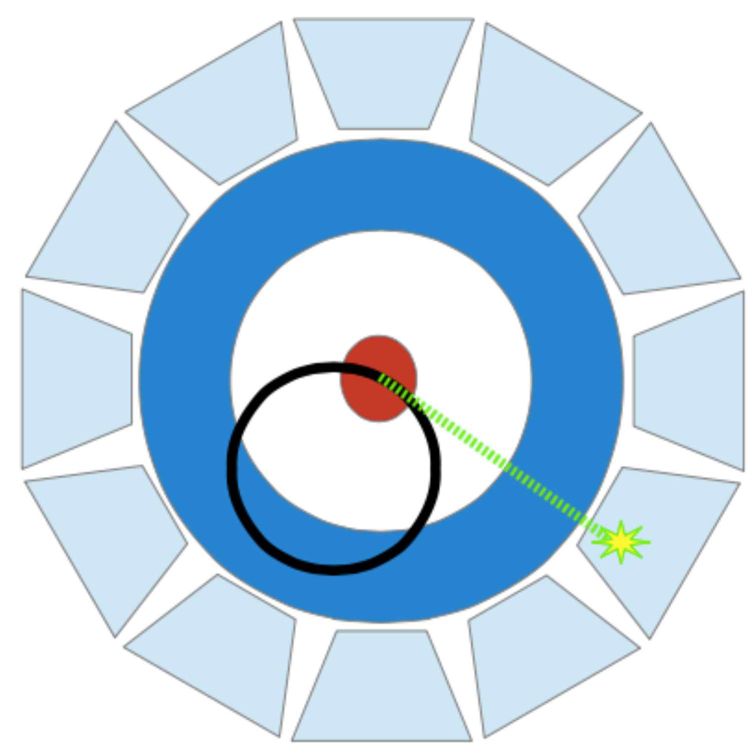
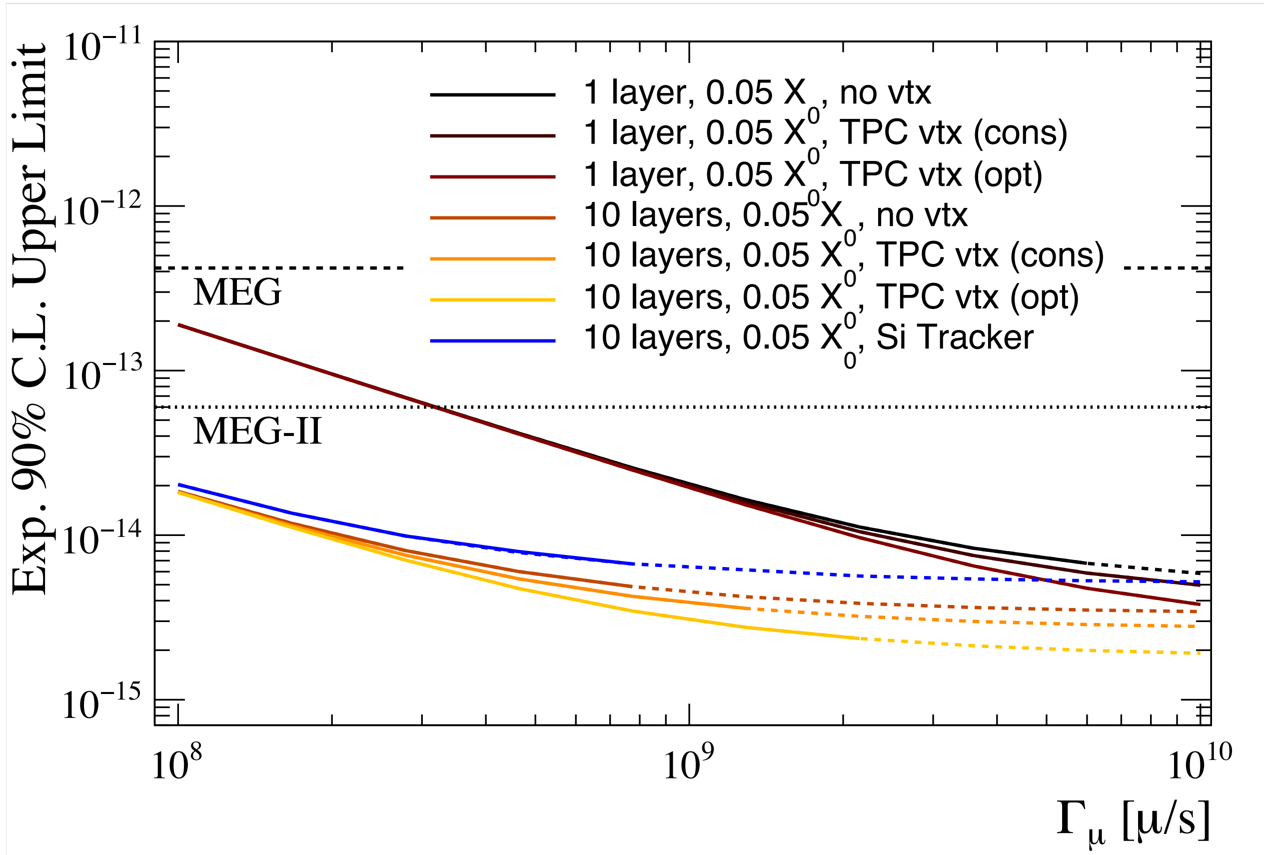


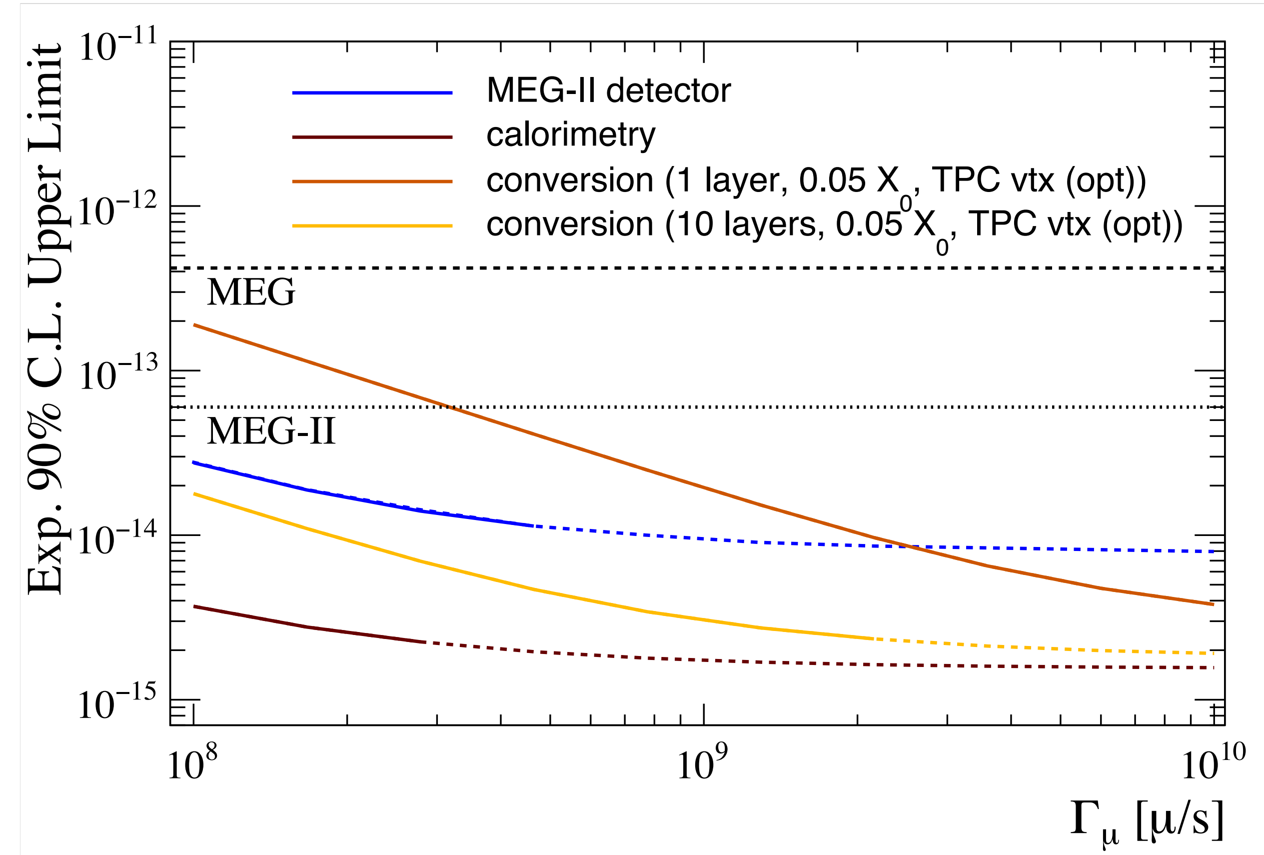


MS in target and beam requirements

- In MEG and MEG II muons are stopped by a combination of a degrader and the target
- The degrader slows down the muons (—> thinner target to stop the average muon) but increases the momentum bite (—> thicker target to contain the Bragg peak)
  - optimization of degrader thickness to minimize the target thickness
- Starting from a lower beam momentum with comparable momentum bite can result in a thinner target

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***

Some futurology

Random ideas for futuristic μ -> e γ searches

- Active targetry
  - μ/e separation
  - very thin
- Target + detector in vacuum
  - containing the Bragg peak would not be needed anymore (—> thinner target and compensate with more intensity)
  - multiple target option
  - could next-generation straw tubes be a good option for tracking also in μ -> e γ? Too much supporting material? What about silicon detectors (cooling)?
- What about spreading muon stops over a very large surface?
- Stored vs. stopped muons?
- μ -> e γ + μ -> 3e
  - possible in a detector with 2π acceptance in φ
  - give up the low-energy cut of the MEG spectrometer —> higher rate tolerance needed, should be not a problem in a Mu3e-like design

Miscellanea

- We already had regular meetings (every three months on average) where we discussed ideas and R&D progresses:
  - an informal setting, with lively discussions
  - ~ 30 people from MEG and Mu3e joined the last meeting at PSI on January
  - to be protracted, trying to involve even more people
- Common tools (simulation frameworks, track fit tools, document repositories) would be extremely useful for the next steps
- Ongoing activities should be efficiently advertised at the upcoming cLFV and muon physics workshops
  - also an occasion to produce some written document

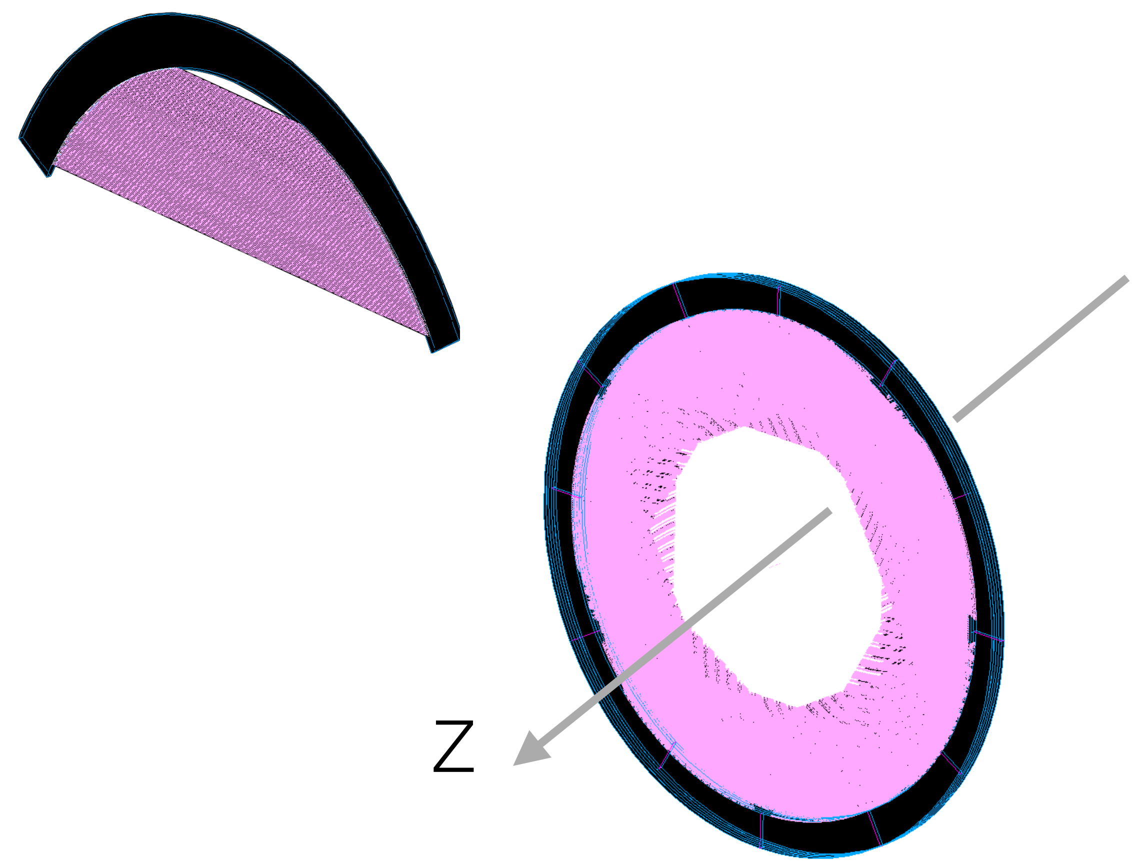
Backup

Gaseous positron trackers toward 10^9 - 10^{10} μ/s

- Some improvement in the resolution could come from the cluster counting technique (not a huge factor), then we are at the ultimate performances for drift chambers
- Future R&D should aim to:
  - preserve such good resolutions
  - keep the same (or reduce the) material budget
  - **operate at extremely high rates**

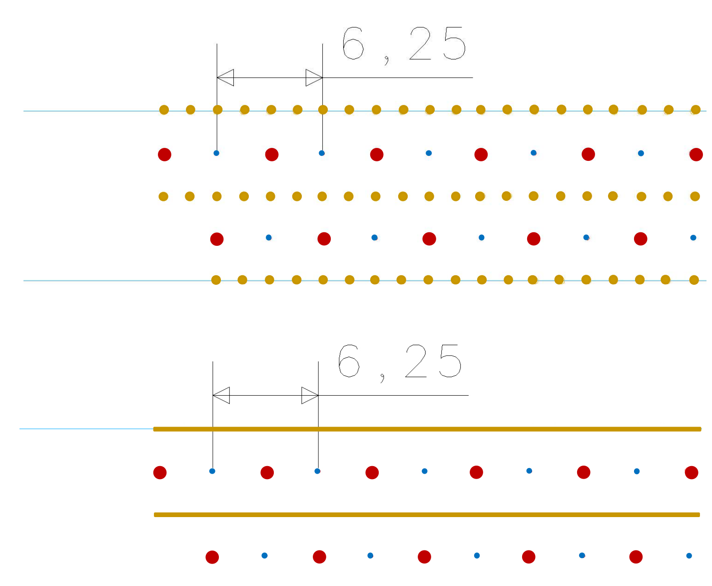
Drift chamber

- The rate per wire can be reduced with an alternative arrangement of the wires
- Transverse wires (in the xy plane):
  - inspired to the geometry of the Mu2e tracker
  - more, shorter wires -> lower rate per wire
- Same rate per wire as MEG II with $\gtrsim$ 10 times larger muon rate

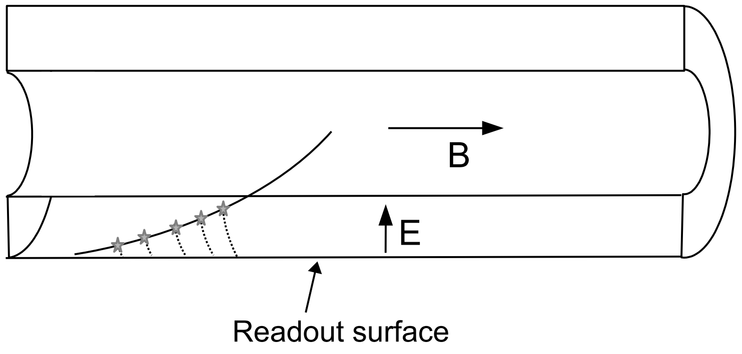


The main challenge is the material budget

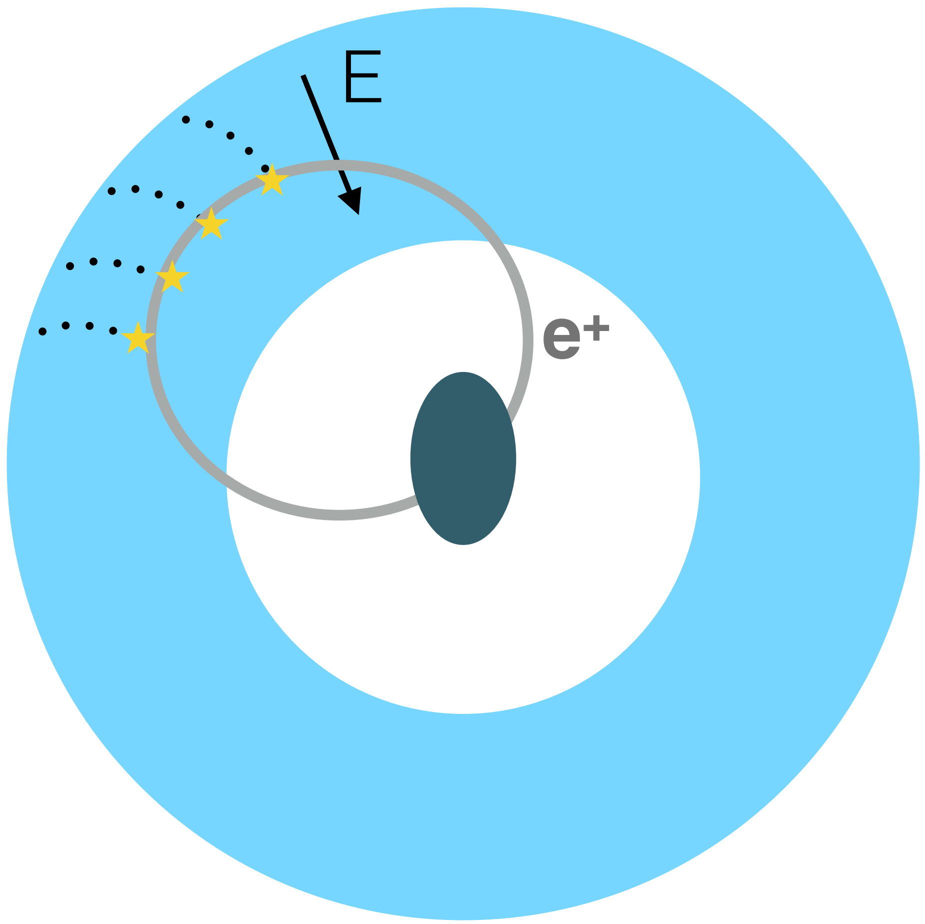
- very light wire supports
- no electronics in the tracking volume —> long transmission lines



Radial Time Projection Chamber



- Unconventional radial geometry to mitigate effects related to long drifts (diffusion, space charge)
  - radial extension O(10 cm):



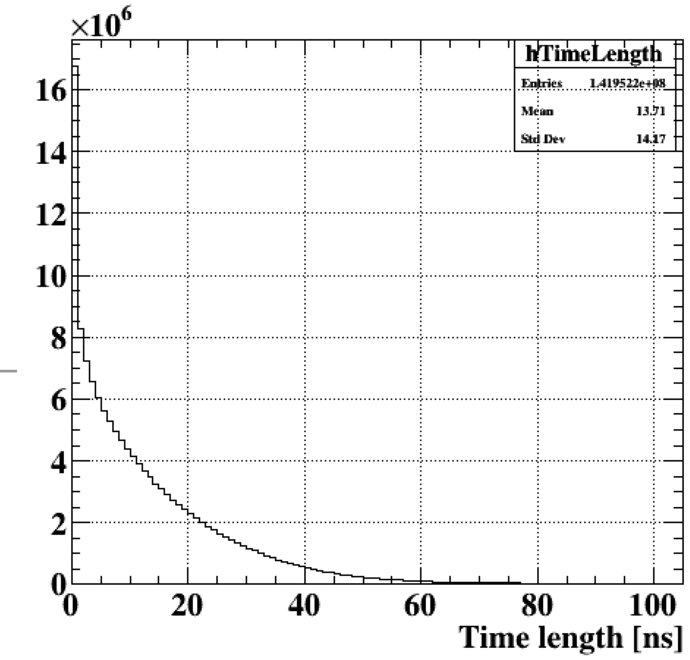
Need to develop a radial TPC with cylindrical MPGD readout, ~ 2 m long and ~ 30 cm radius

Need to find a very light gas mixture to operate it with reasonably low diffusion

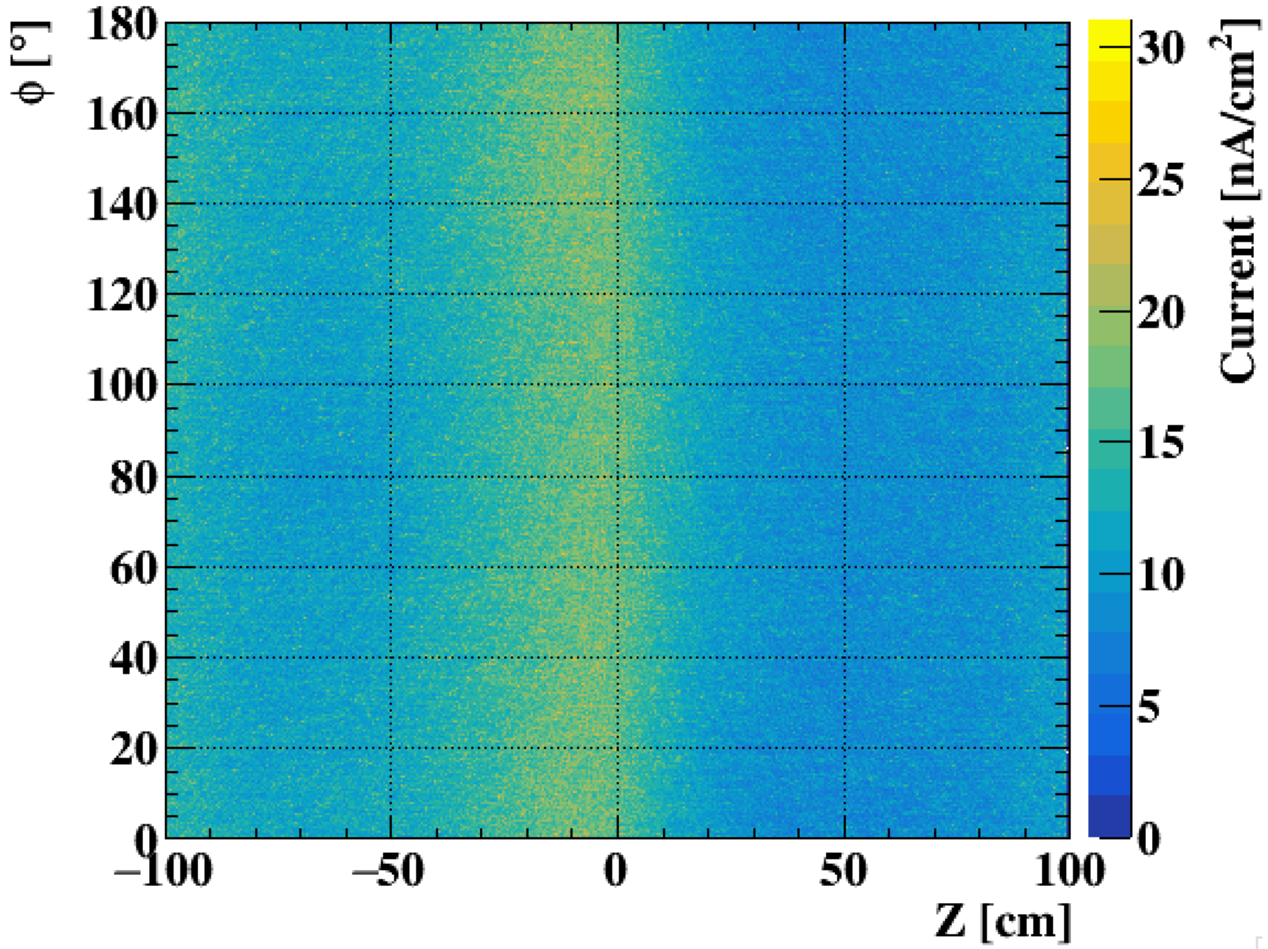
Need to develop advanced algorithms for correcting field deformations

Feasibility studies

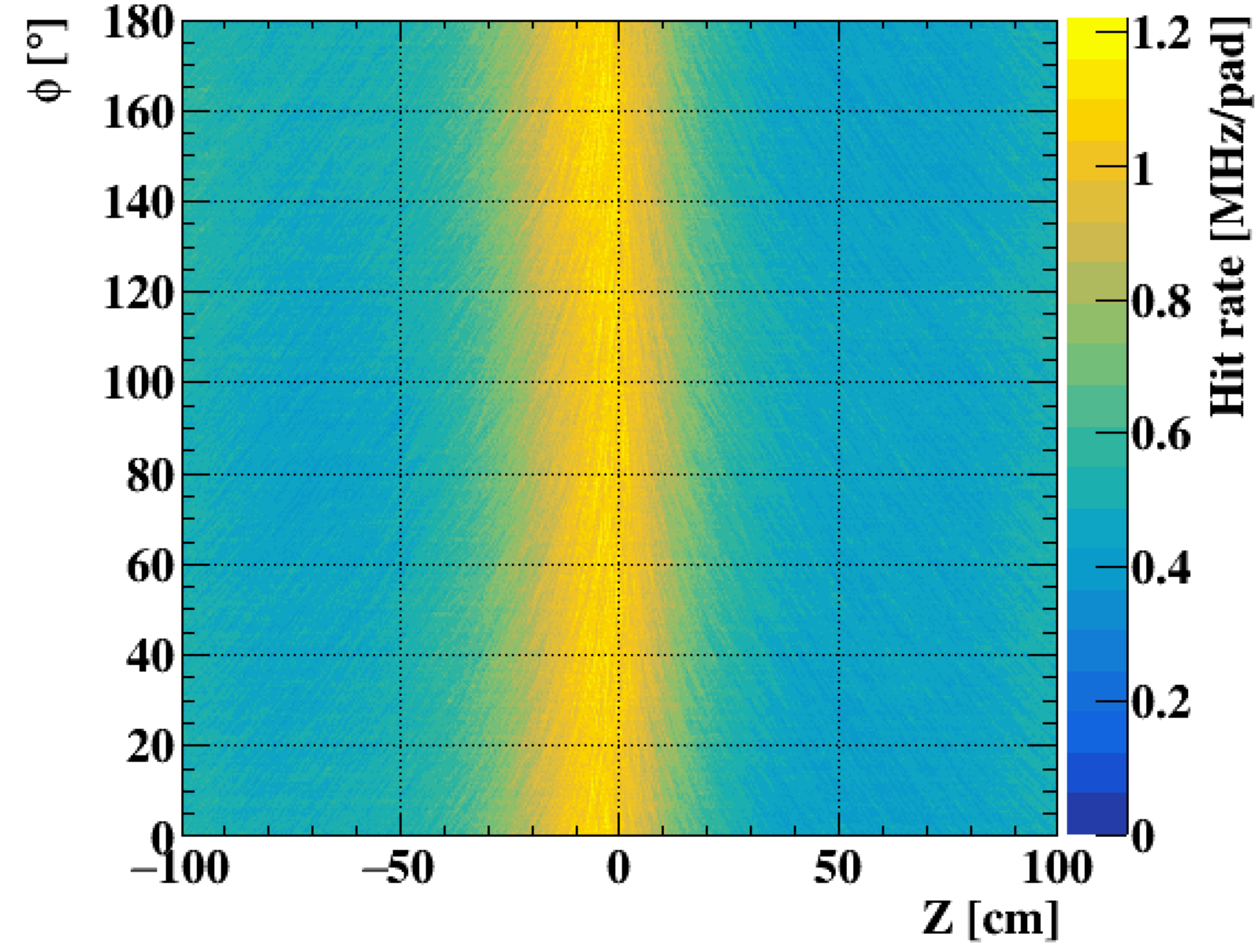
Time spread of electrons arriving to the same pad



- Simulation at 10^9 μ/s
- One should consider ~ 250k readout channels
    - challenging **FE integration** and **cooling** in the outer surface of the cylinder with a reasonable material budget (~ few % X_0)



cfr. ALICE GEM-TPC ~ 10 nA/cm²

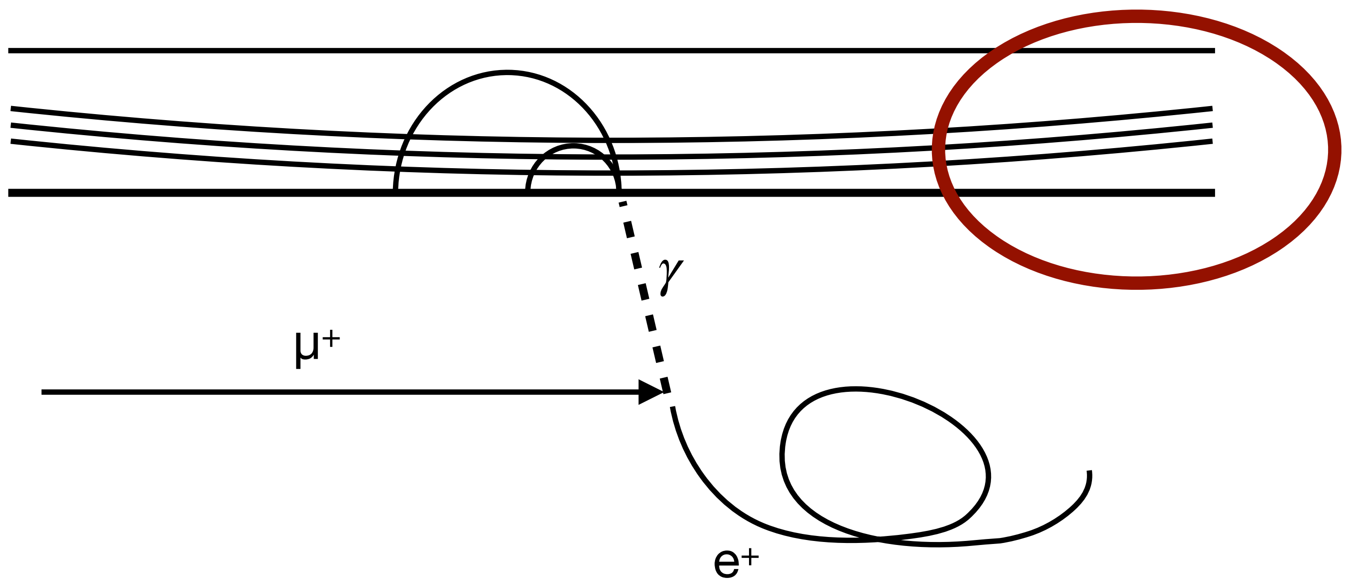


Assuming 5 x 3 mm² pads

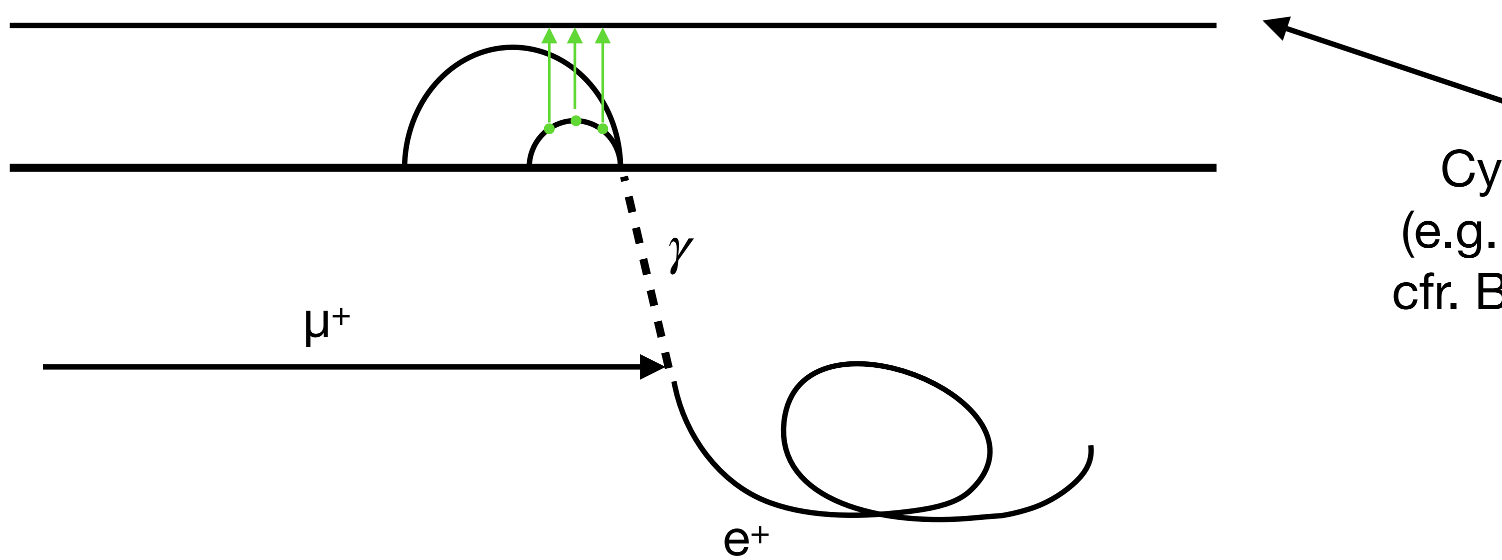
Gaseous tracker for photon reconstruction

- Low rate —> much less demanding w.r.t. positron trackers

Wire chamber



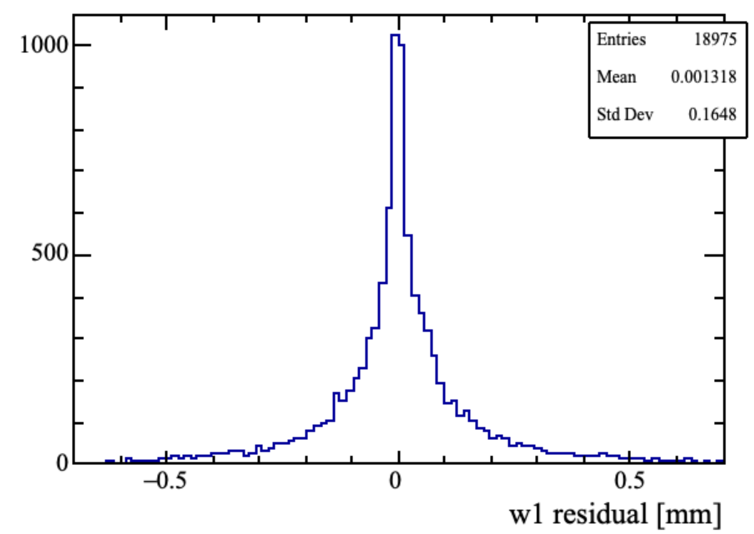
Radial TPC

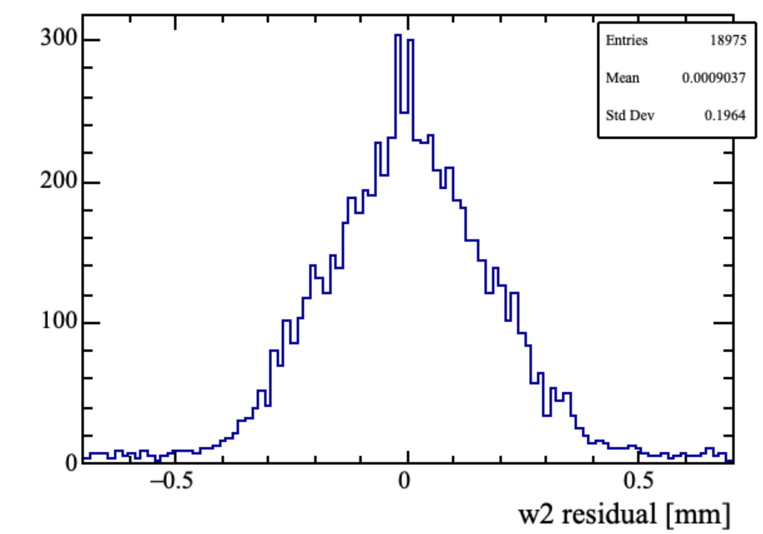


Feasibility studies

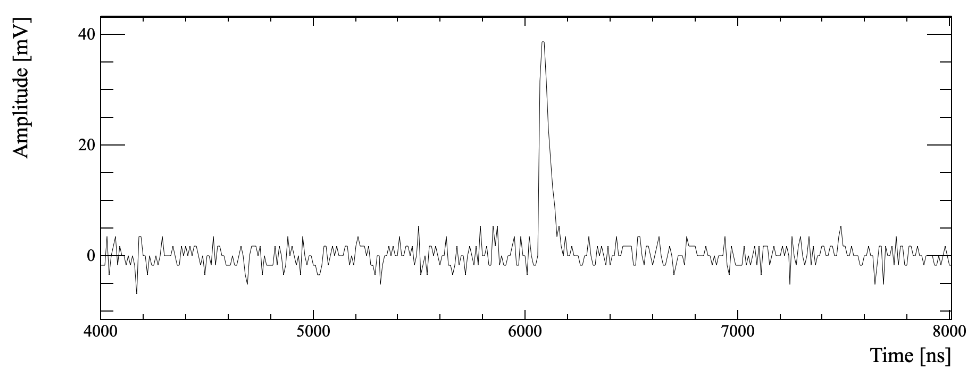
e+e- reconstruction in a radial TPC with strip readout

WORK IN PROGRESS

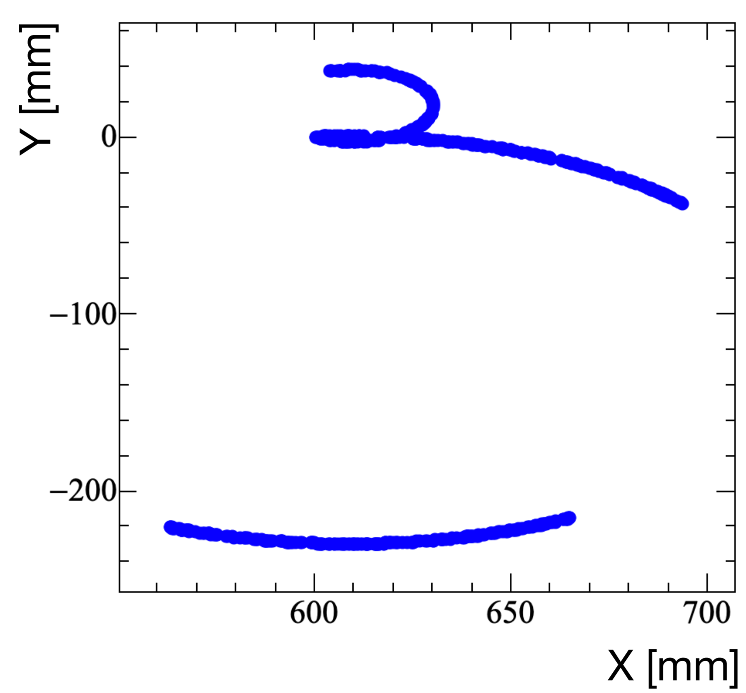




Typical waveform



True tracks



Reco track (time resolved CoG)