Developing an experiment for a future search for μ->eγ: Overview and simulation

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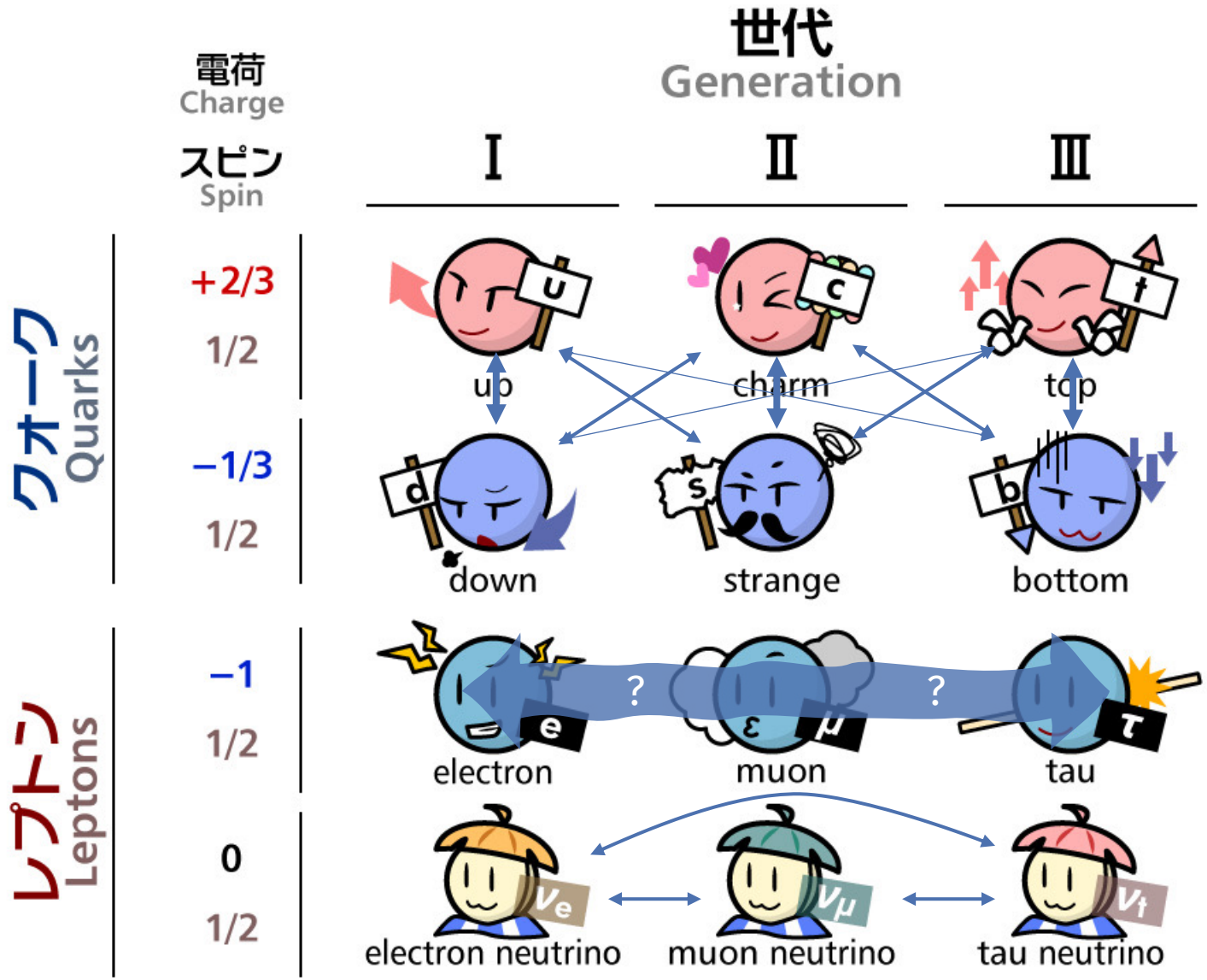
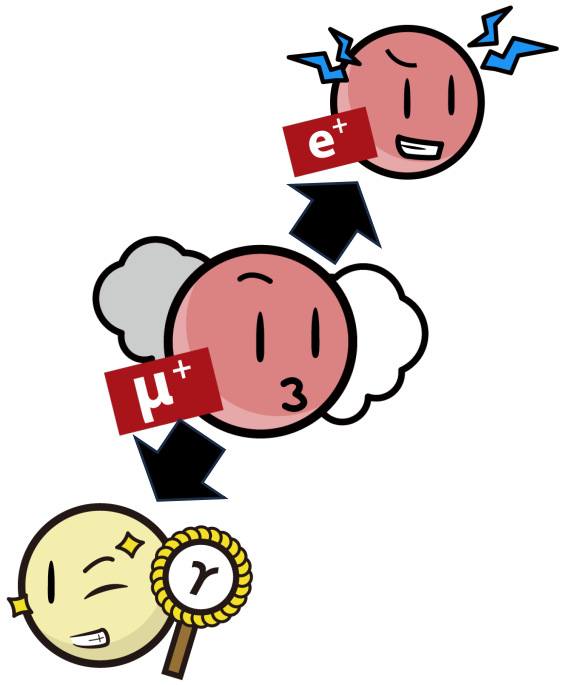
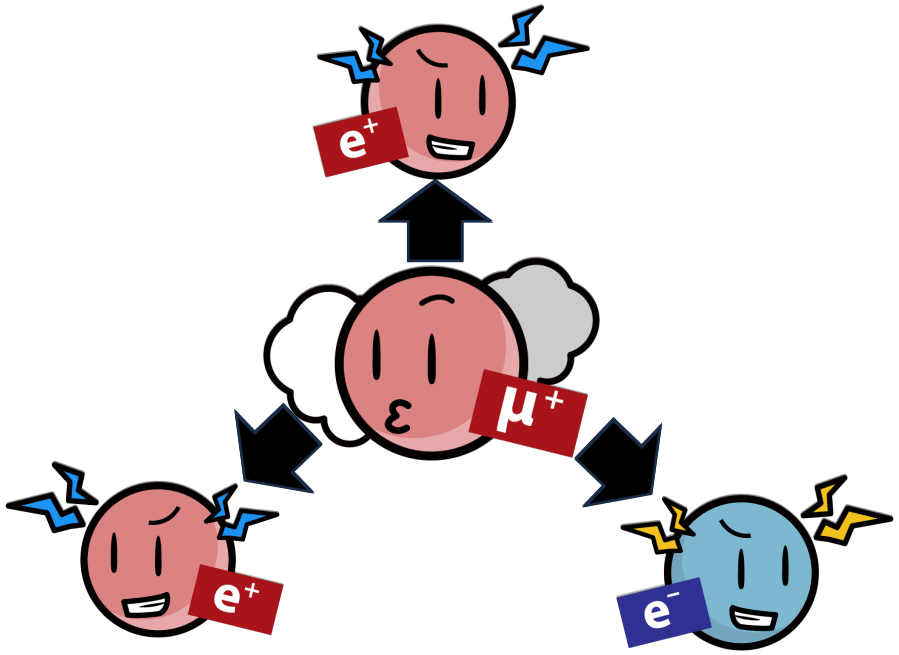
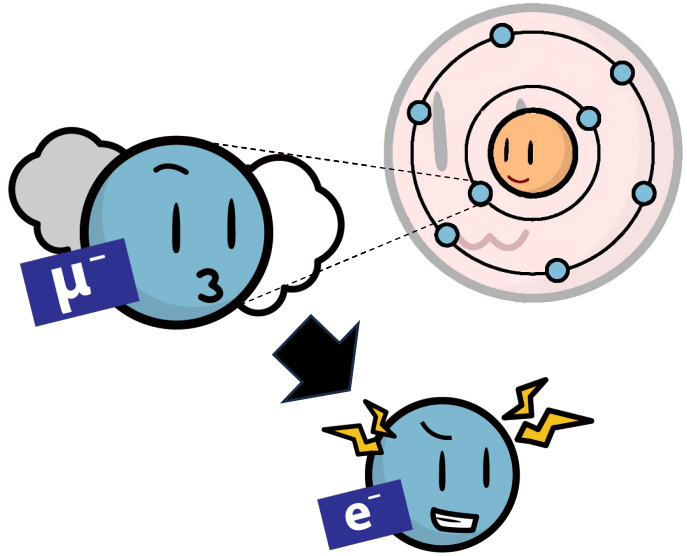

世代
Generation
電荷
Charge
スピン
Spin
Ⅰ
Ⅱ
Ⅲ
クォーク
Quarks
+2/3
1/2
−1/3
1/2
up
charm
top
down
strange
bottom
レプトン
Leptons
−1
1/2
0
1/2
electron
muon
tau
electron neutrino
muon neutrino
tau neutrino

Muons: Three “Golden Channels”



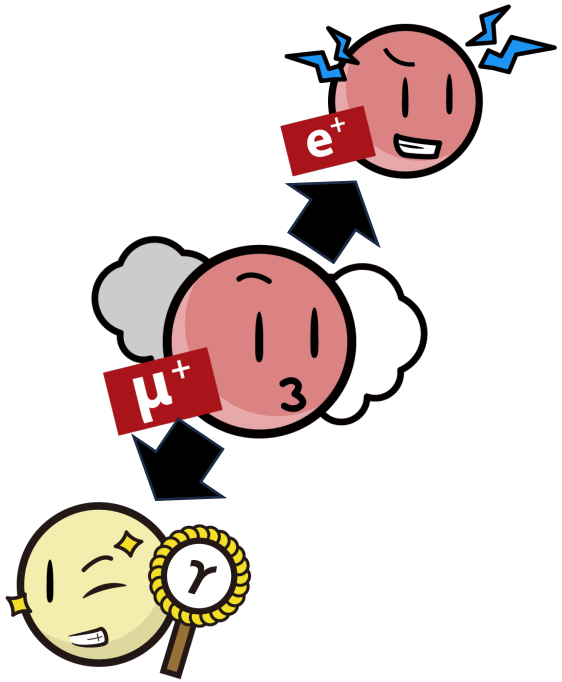




Adapted from HiggsTan

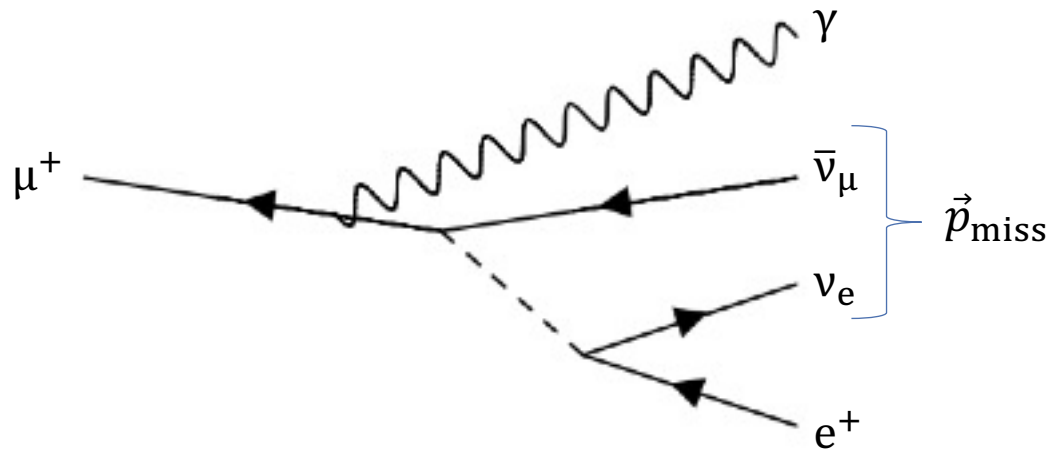
Signal $\mu^+ \to e^+\gamma$

- Muon decays at rest
- Back-to-back $p = \frac{m_\mu}{2} \approx 53\ \mathrm{MeV}$
- $\sum E = m_\mu c^2$
- $\sum \vec{p} = 0$
- $\Delta t = 0$



Irreducible background

- $\mu^+ \rightarrow e^+ \bar{\nu} \nu \gamma$
- $E < m_\mu c^2$
- $\sum \vec{p} \neq 0$
- $\Delta t = 0$
- Not back-to-back
- Same vertex



⇒ Need excellent energy and momentum resolution

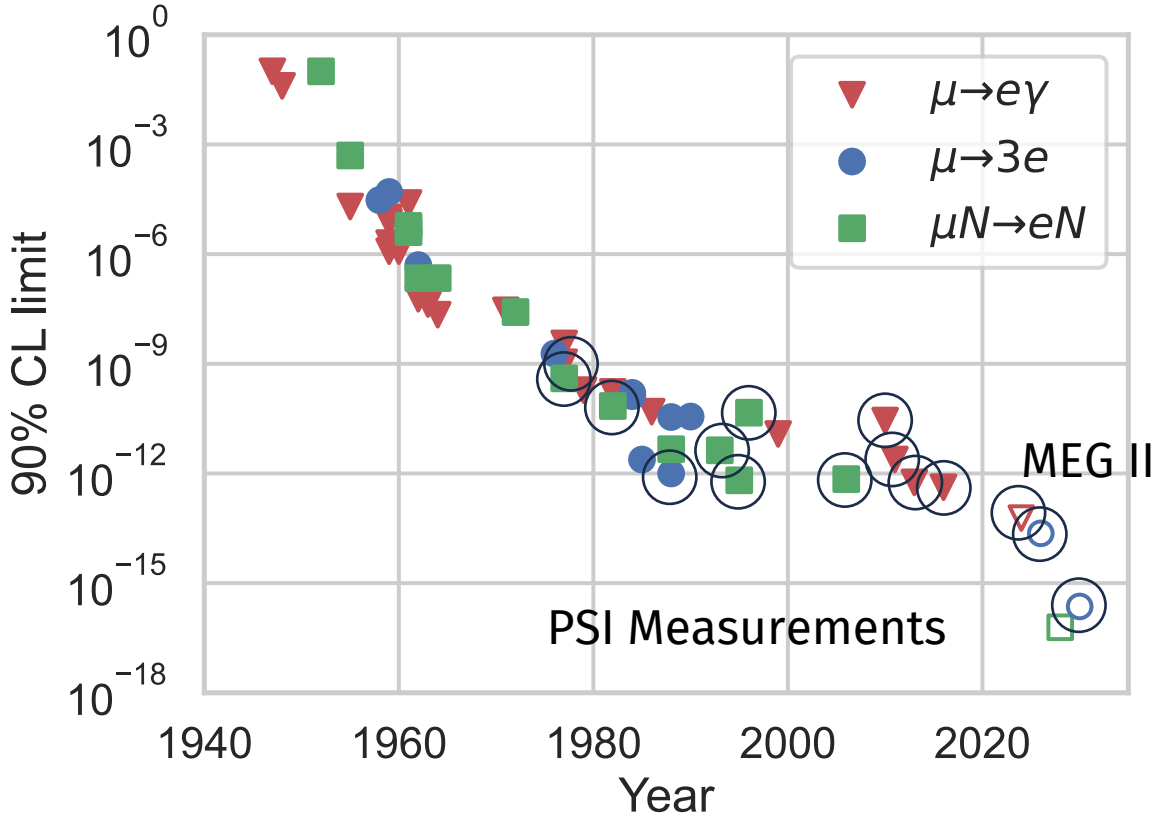
Accidental background

- Particles from unrelated processes
- $E \neq m_{\mu}c^2$
- $\sum \vec{p} \neq 0$, therefore not back-to-back
- $\Delta t \neq 0$
- No common vertex
- Rate dependent

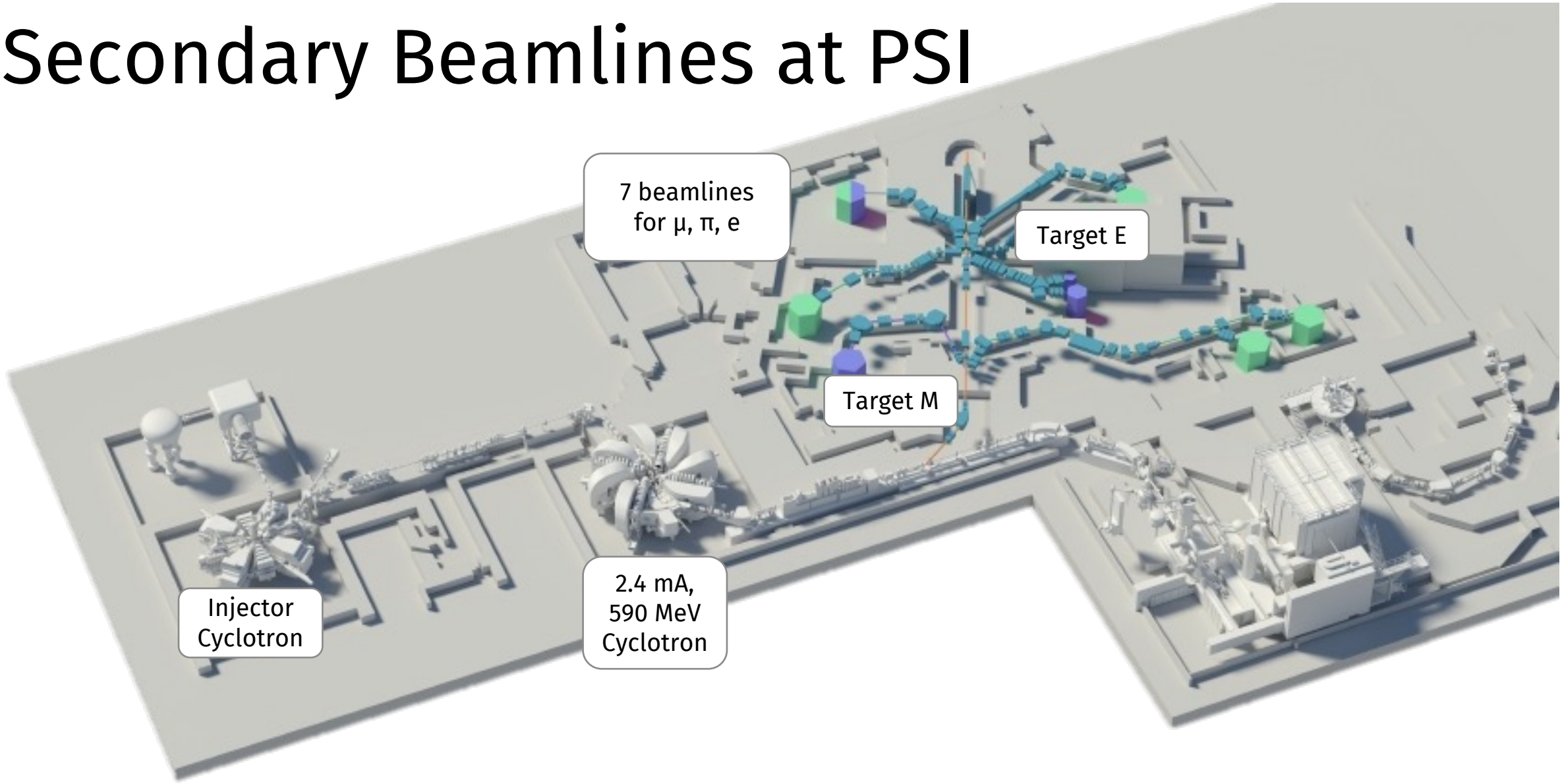
⇒ Time and vertex resolution

*Without muonium

Searches for cLFV in Muons*

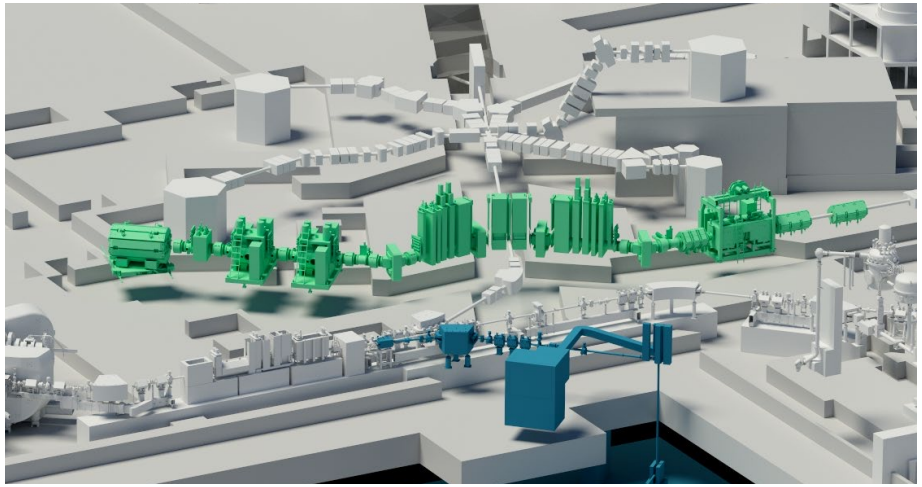


Secondary Beamlines at PSI



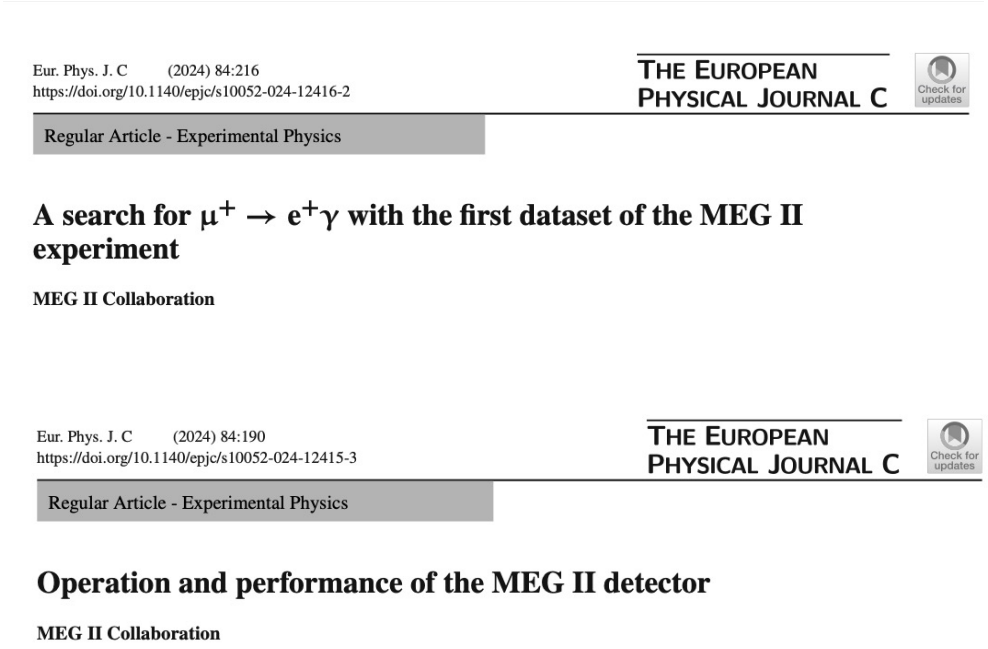
High-intensity Muon Beams (HIMB)

- Part of IMPACT project
- Replace target M with new target H
- Can deliver 10^{10} surface muons per second
- New possibilities for cLFV searches
- Start planned for 2028



Current status of MEG II

- Two major publications accepted in January 2024:
  - First MEG II results
  - Detector performance
- Long beam times in 2023 & 2024
- Long shutdown at PSI after 2026


Eur. Phys. J. C (2024) 84:216
https://doi.org/10.1140/epjc/s10052-024-12416-2
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Experimental Physics

A search for $\mu^+ \to e^+\gamma$ with the first dataset of the MEG II experiment

MEG II Collaboration

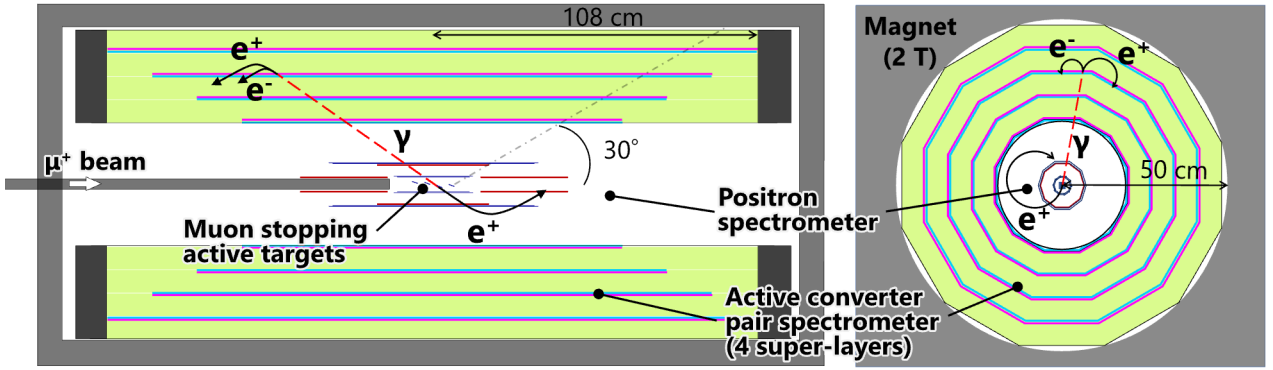
Eur. Phys. J. C (2024) 84:190
https://doi.org/10.1140/epjc/s10052-024-12415-3
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Experimental Physics

Operation and performance of the MEG II detector

MEG II Collaboration

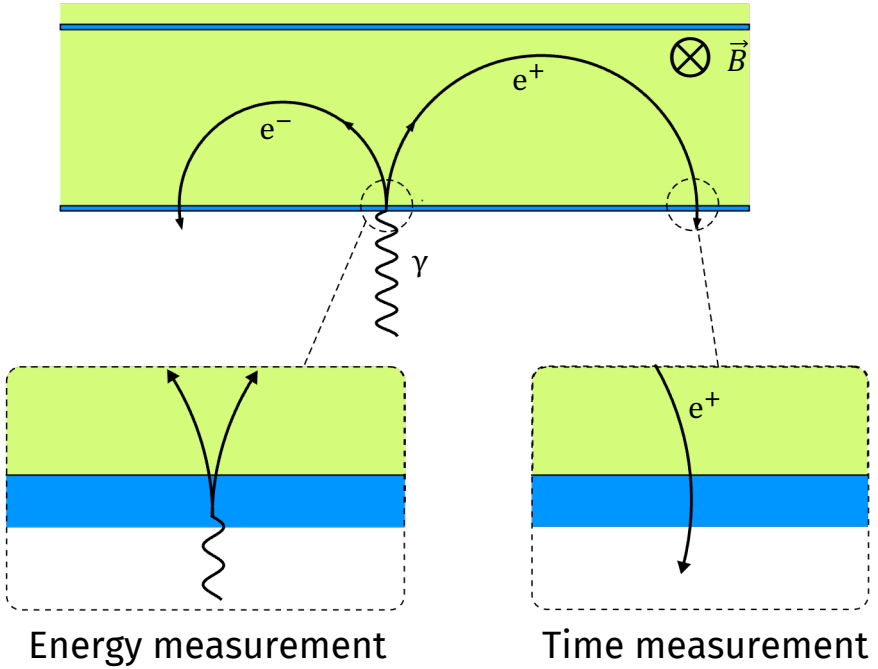
Concept for a new experiment

- Continue search of MEG II with HIMB
- For high rates: Photon pair spectrometer
- Positron side: Pixel sensor (HV-MAPS, similar to Mu3e)
- Tentative requirements:
  - $\Delta E_\gamma < 210\ \mathrm{keV}$
  - $\Delta t_\gamma < 30\ \mathrm{ps}$
  - $\Delta x_\gamma < 2\ \mathrm{mm}$



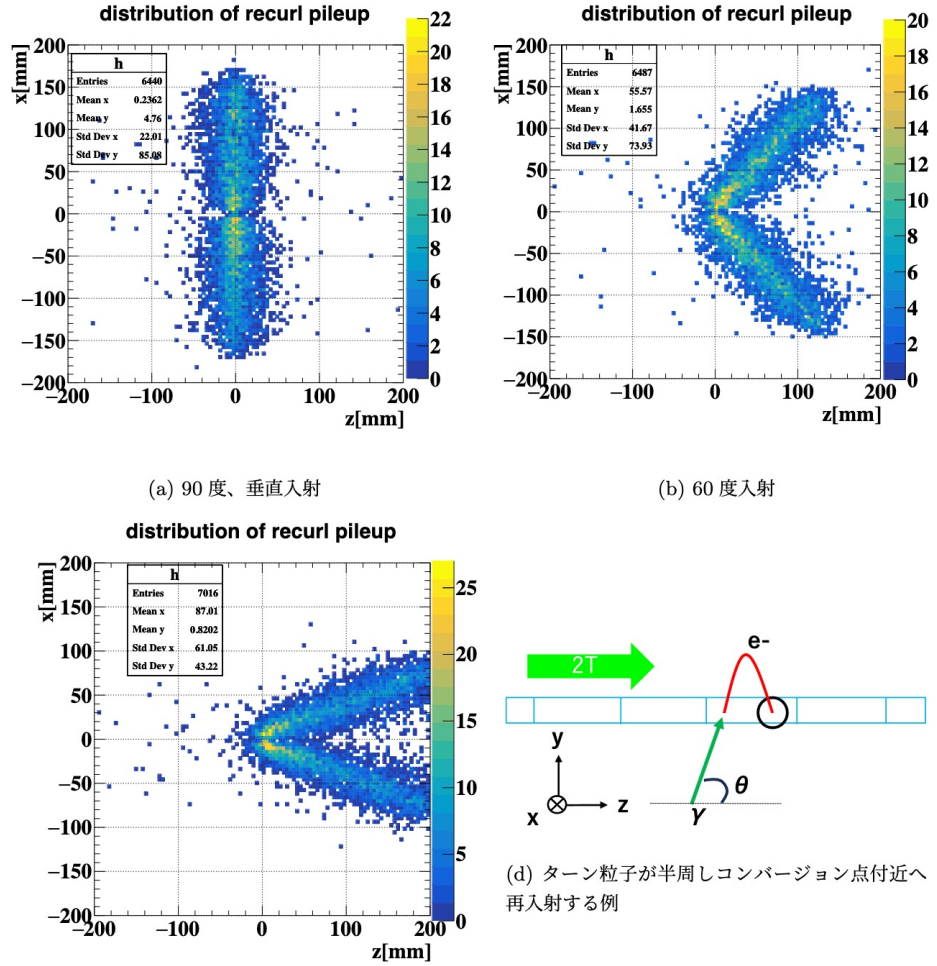
Pair spectrometer with active converter

- Dilemma of pair spectrometer:
  Efficiency vs. Energy loss in converter
- Solution: Active converter



Past Simulation Efforts

- Started with standalone Geant4 simulation
  - Studies concerning segmentation & converter thickness



(a) 90 度、垂直入射

(b) 60 度入射

(c) 30 度入射

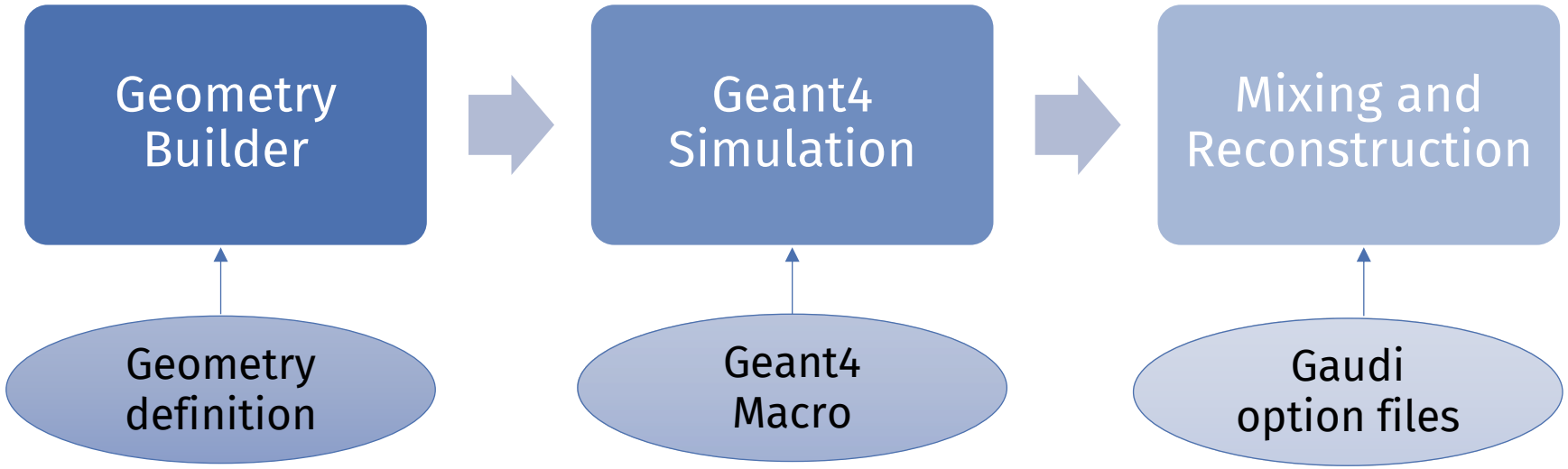
(d) ターン粒子が半周しコンバージョン点付近へ再入射する例

図 5.6: ターン粒子が半周しコンバージョン点付近へ再入射した位置の入射角度別分布。入射角はビーム軸からの角度。原点はガンマ線入射点。

[R. Yokota's Master Thesis]
https://meg.web.psi.ch/docs/theses/yokota_master.pdf

Simulation Efforts

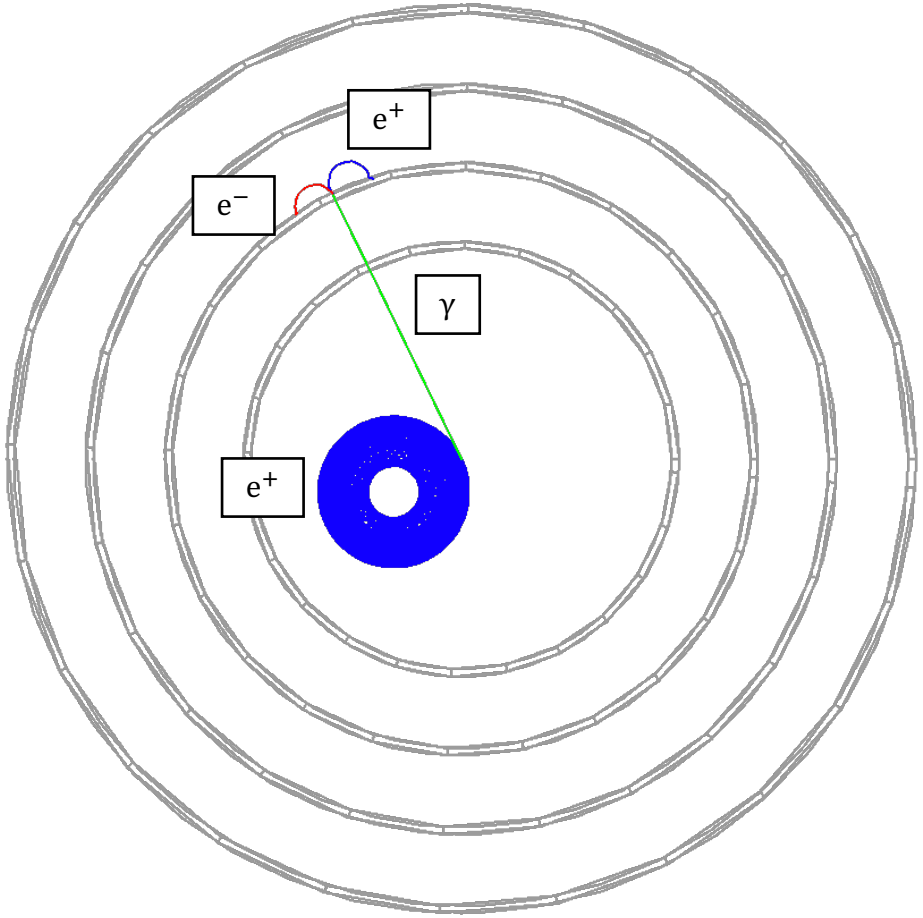
- Currently developing more modern framework for full simulation and reconstruction

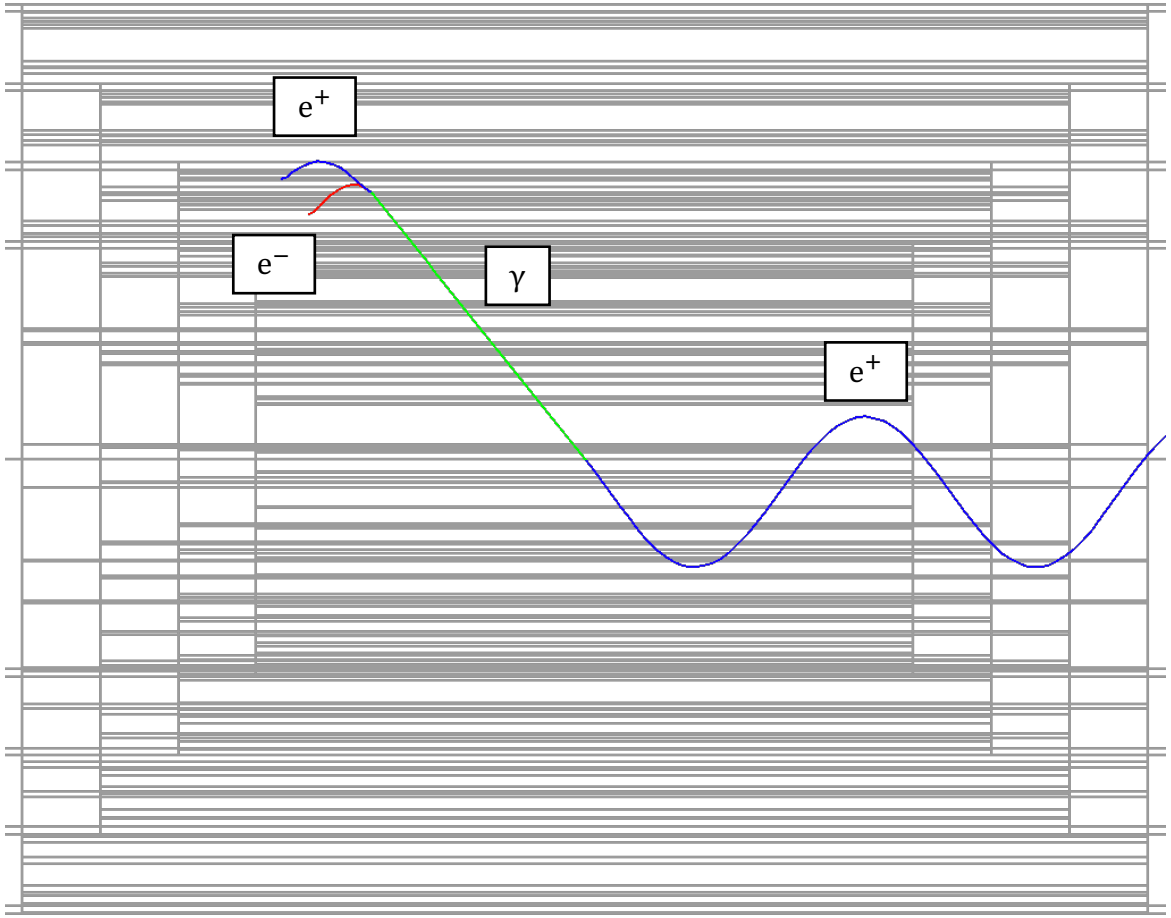


Software Considerations

- Modular
  - Early stage of detector design: design studies
- Modern
  - Previously, only moderate connection with HEP development
  - Want to use more well-maintained software (e.g. Gaudi)
  - Looking into other Key4HEP parts

Event Display





Conclusion

- Search for μ→eγ currently done by MEG II
- New development is needed to utilize new beamlines and extend reach
- Development of hardware and software has started
- Next step: Work with collaborators for other detector parts

Backup

Spectrometer or calorimeter?

$$\left(\frac{\sigma_p}{p}\right)^2 = \left(\frac{\sigma_p}{p}\right)^2_{\mathrm{MS}} + \left(\frac{\sigma_p}{p}\right)^2_{\mathrm{defl}}$$

const. ~p

$$\frac{\sigma_E}{E} = \frac{A}{\sqrt{E}} \oplus B \oplus \frac{C}{E}$$

stochastic; calibration/ nonuniformity; noise

In muon decays: dominated by multiple scattering
Downside for photon detectors: energy loss in converter

Generally perform worse at μ decay energies

Generally not straight-forward, e.g. MEGA used photon pair spectrometer, also considered for future μ→eγ experiment, PIONEER will use positron calorimeter