Evaluation of expected performance of positron spectrometer and achievable sensitivity of MEG II experiment

MEG II実験陽電子スペクトロメータに期待される性能と到達可能な探索感度の評価

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The University of Tokyo, ICEPP, D3

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MEG II Mu - E - Gamma collaboration

ICEPP The University of Tokyo

Core-to-Core Program

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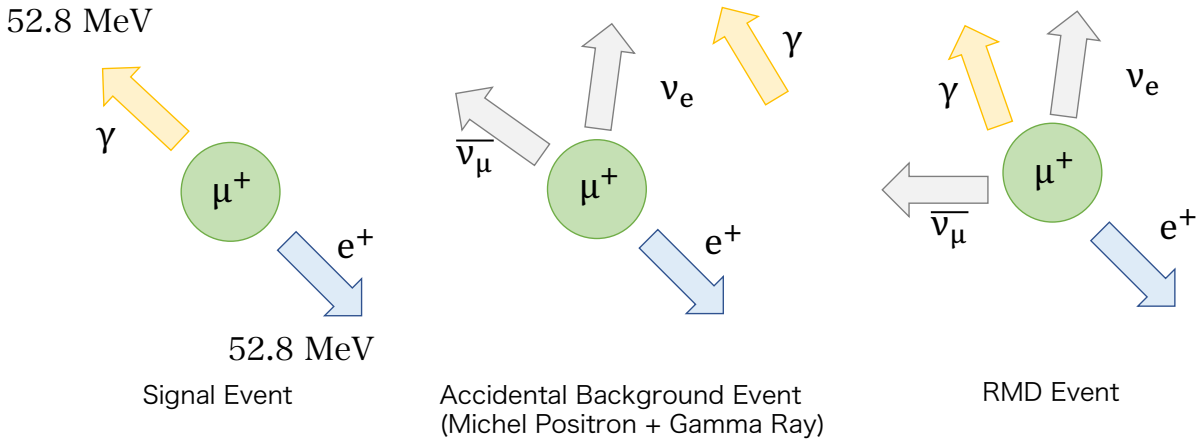
MEG II Experiment

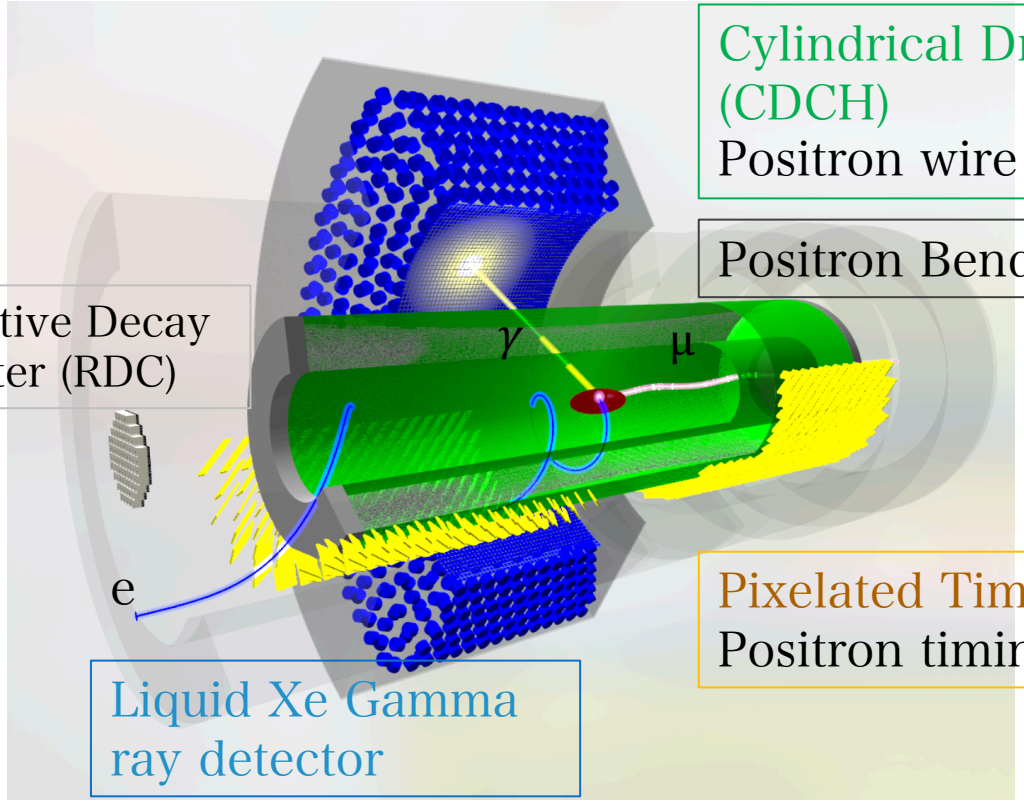
- Search for muon decay: $\mu \rightarrow e\gamma$
  - With the branching ration sensitivity Br ~ 6×10^{-14}
  - cLFV: charged Lepton Flavor Violation
    - Prohibited in the standard model, predicted in the new models
  - To find the $\mu \rightarrow e\gamma$ means to find the new physics !

Signal Kinematics

180° (back-to-back) at the same timing from the same position
-> Timing, Position, Momentum is the key parameters



Detector Overview



Cylindrical Drift CHamber (CDCH)
Positron wire tracker

Positron Bending Magnet

Pixelated Timing Counter
Positron timing detector

The most intense DC muon beam in the world available at PSI
MEG:$3\times10^7\mu^+/s$ →MEG II $7\times10^7\mu^+/s$

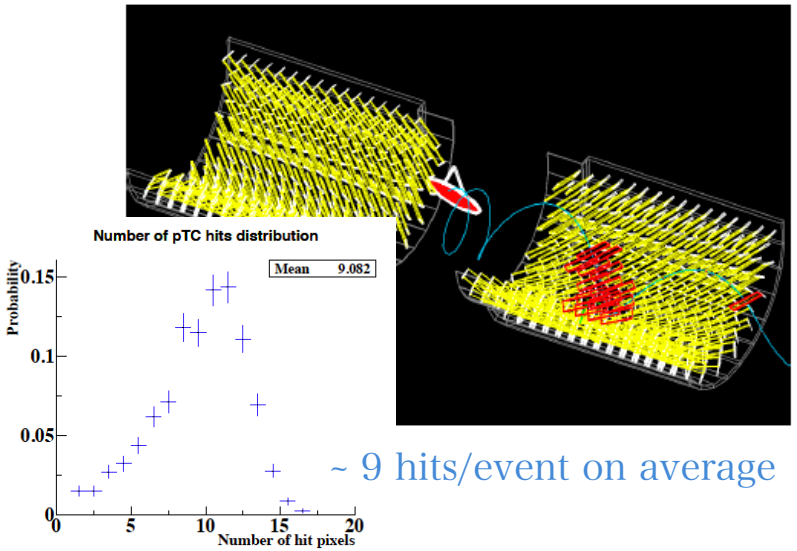
+

New Positron Spectrometer
Measure positron vertex position, momentum, and timing

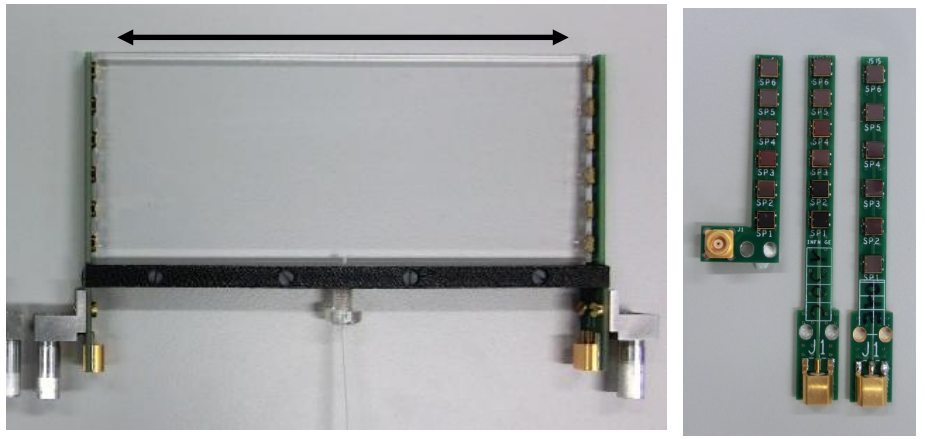
Positron Resolution / Efficiency	MEG	MEG II Design (CDCH 10 layer)
Theta (mrad)	9.4	5.3
Phi (mrad)	8.7	3.7
Momentum (keV)	380	130
Vertex Z (mm)	2.4	1.6
Vertex Y (mm)	1.2	0.7
Time (ps)	108	37
Efficiency (%)	30	70

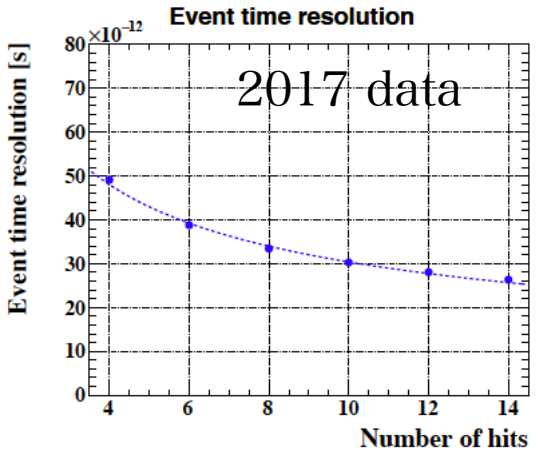
- Upgraded experiment from MEG, ~×10 sensitivity
  - 3-year DAQ period (20 week / year)
  - ×2 beam intensity, detector resolution, efficiency with new positron spectrometer

Pixelated Timing Counter (pTC)



~ 9 hits/event on average

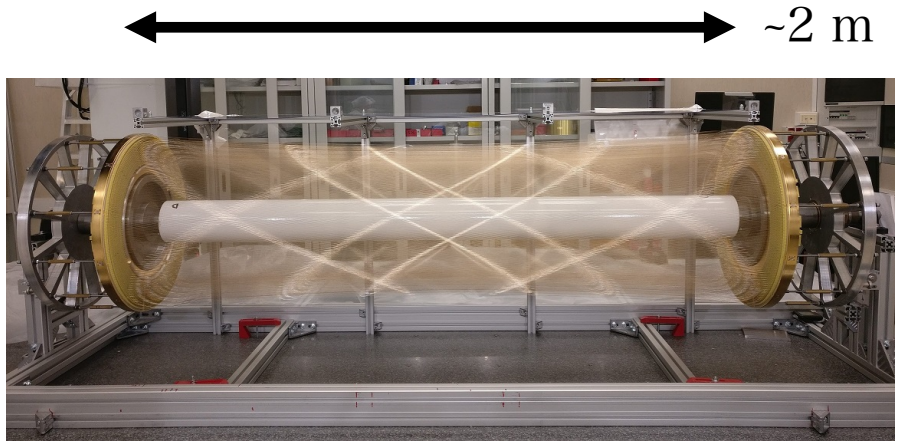


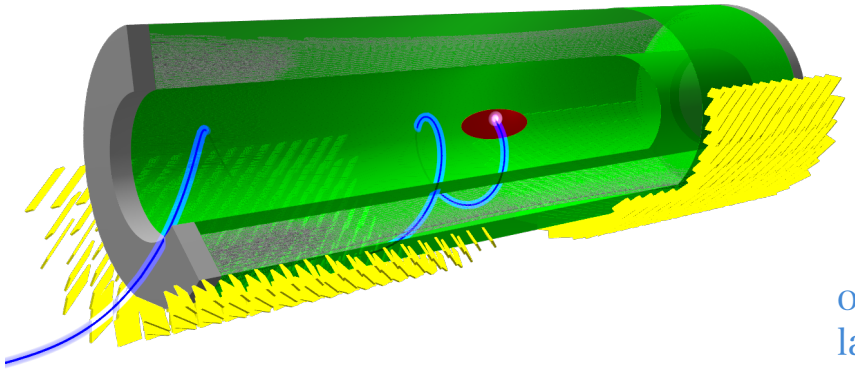


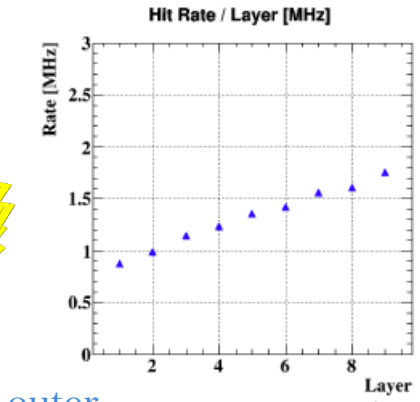
Expected timing resolution: 34.3 ps

- Composed of 512 scintillation counters with series connected SiPMs readout from both sides
  - 12 cm × 4 or 5 cm × 0.5 cm scintillator + 6 × 2 SiPMs (from AdvanSiD)
- Measure the positron crossing timing O(30 ps) from multiple hits
  - Single counter resolution is ~70 -- 90 ps
  - Performance of 34.3 ps was demonstrated in 2017 commissioning

Cylindrical Drift CHamber (CDCH)







outer layer → inner layer

1—2 MHz on average (MC)

- Ultra-low mass cylindrical stereo wire chamber to reconstruct the positron track
  - 90% helium-based mixture and 10% isobutane
  - 192 drift cell (7-9mm square shape) x 9 layers
  - Positrons with enough momentum turns inside the CDCH region, and after several turns they go into pTC region
- Detector instability was reported during 2018-2019, stable detector operation under muon beam was achieved in 2020
  - With small fraction of additive gases of O2 and propanol
  - Readout electronics strictly limited: impossible for track reconstruction

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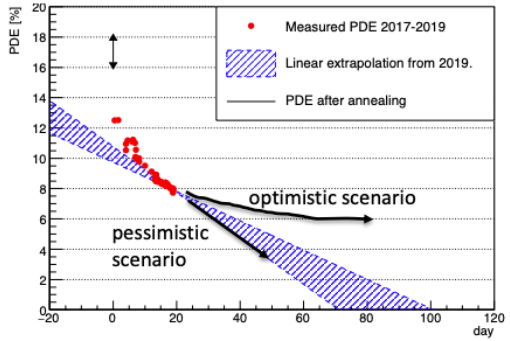
- Sensitivity Estimation of MEG II Experiment
  - Expected Performance of MEG II Positron Spectrometer
  - Sensitivity Estimation

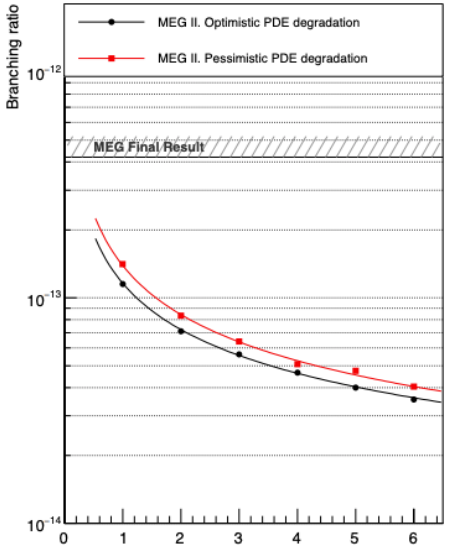
Sensitivity Estimation

- The upper limit sensitivity is estimated with maximum likelihood analysis
  - Number of signal event (Nsig) is estimated by likelihood fit with probability density functions (PDFs)
    - The upper limit of Nsig at 90% confidence level is calculated with generated toy-experiment, take median of O(1000) results
- Update:
  - Gamma-measurement
    - JPS Autumn 2020 by S. Ogawa (right plot)
    - Suggestion of half-rate DAQ scenario due to radiation damage
      - 6.6e-14 is expected with half-rate scenario w/o positron update
  - RDC-measurement
    - JPS Autumn 2020 by R. Onda
  - Positron spectrometer performance update
    - This talk!

VUV PDE of MPPC
vs. accumulated MEG II beam time



MEG II sensitivity vs. DAQ year
with measured LXe detector performance
& PDE degradation



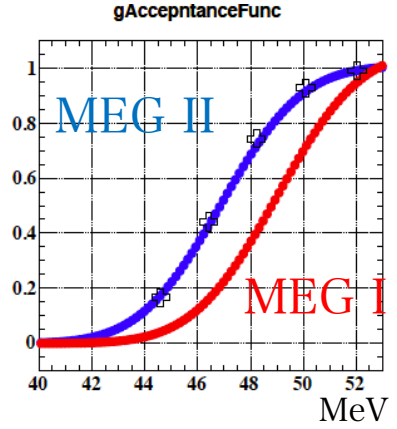
JPS Autumn 2020 by S. Ogawa

5.6-6.6e-14 expected
by 3-year DAQ

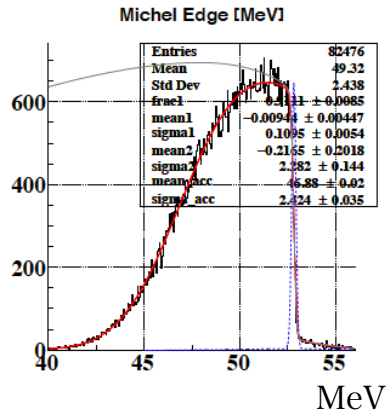
Expected Performance (MC)

Variable	Design	7×10^7	3.5×10^7 (Half rate scenario)	0.5% O_2 addition to 7×10^7
θ [mrad]	5.3	6.5	6.2	6.7
ϕ [mrad]	3.7	4.9	4.7	4.6
P [keV]	130	91	82	95
z [mm]	1.6	1.7	1.6	1.8
y [mm]	0.7	0.8	0.8	0.8
t [ps]	37	39.6	37	39.6
Efficiency [%]	70	65.2	74.0	62.4

Acceptance Function



Observed Michel Spectrum



Michel edge fitting (right) to obtain the acceptance function (left)

MC is updated based on 2018 – 2020 commissioning (JPS Autumn 2020 by M. Usami)

- The latest performance estimation summarized above
  - ~30% improvement of the momentum resolution
  - ~20 – 30 % deterioration of the angular resolution
  - ~5 - 8 % drop of the efficiency
    - The difference comes from the simulation settings and the improvement of fitting algorithms
  - The acceptance region was extended to the low-energy region
    - No significant effect on physics sensitivity, since likelihood fit region is 52.2 – 53.5 MeV for positron

Update

- Case 0: Design
- Case 1: Momentum (p) + Acceptance Update
- Case 2: Timing (t) Update with Maximum Radiation Damage
- Case 3: Angle (θ / ϕ) Update
- Case 4: Conclusion with Normal Scenario
- Case 5: Efficiency Improvement Scenario (Optional)
- Case 6: Half Rate Scenario (Optional)
- Case 7: Additive Gas Scenario (Optional)

Update Scenarios

※ XEC update is already included in all cases with PDE 6% scenario
※ DS-RDC PDF included
※ Error from statistics of median calculation

Resolution Update

Efficiency Update

Rate

Case 0: Design
$(5.9 \pm 0.1)\times10^{-14}$

Case 1: p
$(5.37 \pm 0.09) \times10^{-14}$

Case 2 (Worst): t
$< (6.2 \pm 0.1)\times10^{-14}$

Case 3: θ / ϕ
$(6.4 \pm 0.1)\times10^{-14}$

Case 4: Conclusion
$(5.97 \pm 0.08)\times10^{-14}$

Case 5: 65->80% Eff.
$(5.2 \pm 0.13)\times10^{-14}$

Case 6: Half Rate
$(5.99 \pm 0.09) \times10^{-14}$

Case 7: O2 impact
$(6.07 \pm 0.08)\times10^{-14}$

Half-Rate: Though total statistics were reduced, the significance $\frac{N_{sig}}{\sqrt{N_{BG}}}$ was improved

Summary and Prospect

- The expected positron spectrometer performance was obtained with updated MC after the commissioning in 2018 -- 2020
- The expected sensitivity of MEG II experiment was calculated with several scenarios:
  - Normal Scenario: $(\mathbf{5.97 \pm 0.08})\times\mathbf{10^{-14}}$
    - Additive gas impact (0.5% O2 in 2020): $(\mathbf{6.07 \pm 0.08})\times\mathbf{10^{-14}}$
    - Efficiency improvement impact (e.g. CDCH II): $(\mathbf{5.2 \pm 0.13})\times\mathbf{10^{-14}}$
  - Half-Rate Scenario: $(\mathbf{5.99 \pm 0.09}) \times\mathbf{10^{-14}}$
    - The efficiency recovered from 65% to 74%
    - Additional merit for hardware operation
      - less radiation damage on pTC, wire aging etc ...
- Final decision of DAQ scenario after 2021 engineering run, and the physics data accumulation soon

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