MEG実験
陽電子スペクトロメータ性能改善のスタディ

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他 MEGコラボレーション
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• Lepton flavor violating decay, $\mu \rightarrow e \gamma$ is forbidden in the SM
  
  • But some of models beyond the SM predict visible $\mu \rightarrow e \gamma$ in the range of $10^{-12}$-$10^{-15}$ sensitivity
  
  • Current upper limit of the $B(\mu \rightarrow e \gamma)$ is $2.4 \times 10^{-12}$, already in new physics region! (MEG experiment, 2009+2010 data)
  
  • $\mu \rightarrow e \gamma$ is a good probe to search for new physics

• Background
  
  • Radiative muon decay (prompt)
  
  • Michel decay + overlapped $\gamma$ (accidental)

• Experimental requirements
  
  • High resolution to suppress accidental background
  
  • High rate $\mu$ beam to get large statistics $\rightarrow$ DC muon beam @ PSI
- **Xenon calorimeter** (金子大輔 : 25pFA9)
- **Positron spectrometer**
  - **COBRA (CO\text{onstant} B\text{ending} \text{RA}\text{adius}) magnet**
    - gradient magnetic field to be optimized for 52.8 MeV signal e+
  - **Drift chamber**
    - high resolution tracker with low mass materials
  - **Timing counter**
    - precise timing measurement for e+
- **φ bar counter**, **Z fibre counter**
- **Uniform B field**
- **COBRA B field**
- **Drift chamber**
- **Vernier cathode**, **Waveform**
Upgrade MEG

- **Spectrometer performance**
  - current performance of the positron spectrometer

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2010</th>
<th>2011 (preliminary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum (%)</td>
<td>0.59 (core 80%)</td>
<td>0.61 (core 79%)</td>
<td>0.61 (core 86%)</td>
</tr>
<tr>
<td>Angle (φ/θ)(mrad)</td>
<td>6.7(core)/9.4</td>
<td>7.2(core)/11.0</td>
<td>6.5(core)/10.8</td>
</tr>
<tr>
<td>Vertex (Z/Y) (mm)</td>
<td>1.5/1.1</td>
<td>2.0/1.1</td>
<td>1.9/1.0</td>
</tr>
<tr>
<td>T_{e\tau} (ps)</td>
<td>146 (core)</td>
<td>126 (core)</td>
<td>133</td>
</tr>
<tr>
<td>ε_{e+} (%)</td>
<td>40</td>
<td>35</td>
<td>~40</td>
</tr>
</tbody>
</table>

- **Upgrade plan**
  - MEG will finish physics data taking in a few years w/ current detectors (Goal sensitivity = 5×10^{-13})
  - We are thinking about minor upgrade during a few years data taking *(Short term upgrade)*
    - Main issue: Improve the efficiency by reducing the amount of materials between DC and TC
  - R&D for major upgrade is also started to improve the goal sensitivity! *(Long term upgrade)*
    - Everything should be improved to get less background
Short term upgrade

- **Short term upgrade plan**
  - Thinner cable idea
  - There are 2 candidates for new cable
  - Expected $\varepsilon_{e^+}$ improvements w/ thinner cable are evaluated w/ MC simulation based on Geant 4 in some cases (2 candidates + duct modification + cabling)

<table>
<thead>
<tr>
<th></th>
<th>diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial (present)</td>
<td>1.8</td>
</tr>
<tr>
<td>Bando</td>
<td>0.8</td>
</tr>
<tr>
<td>Junko</td>
<td>0.34</td>
</tr>
</tbody>
</table>

- **Summary**
  - $\varepsilon_{e^+}$ can be improved in 5-9 % relatively by replacing cable and modifying cable duct
  - Cabling also affect the efficiency $\rightarrow$ should be optimized
  - The effect of signal attenuation w/ thinner cable is not yet evaluated $\rightarrow$ waveform simulation is needed
Long term upgrade

- We are also thinking major upgrade (澤田龍：25pFA10)
  - Beam (muon rate: $3 \times 10^7 \rightarrow 1 \times 10^8$ already available @ beamline)
  - Target
  - Xenon calorimeter
  - Positron spectrometer
  - Additional detectors? (e.g. Si vertex detector)

- To get less background, everything should be improved
  - 2 times higher efficiency
  - 2 times better resolutions
  - Stable operation under 3 times higher muon rate

- New tracker is needed to achieve this goal!
  - Can we use TPC as one of the candidate for new tracker?
TPC concept

- **TPC is good for our aiming**
  - Good spacial resolution with light materials (Helium base)

- **Single volume, wider coverage region**
  - Much more # of measurement points (×10)
  - Good for higher efficiency

- **Longitudinal field**
  - Very popular and a lot of experience in other groups (e.g. ILC, ALICE, LHCb, ...)
  - Longer drift distance (Max ~100 cm)

- **Radial field**
  - Shorter drift distance (Max ~ 10 cm)
  - Only a several experiments (will) use radial design (NA49, BoNuS)
Gas

- Gas mixture
  - Some gas mixtures are simulated with Garfield

<table>
<thead>
<tr>
<th></th>
<th>@ 1kV</th>
<th>Radiation Length</th>
<th>Dτ um/√cm</th>
<th>DΛ um/√cm</th>
<th>v0 cm/us</th>
<th>Np /cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>He:CO2=70:30</td>
<td>0.09% X0</td>
<td>120</td>
<td>130</td>
<td>1.9</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>He:C2H6=70:30</td>
<td>0.07% X0</td>
<td>215</td>
<td>146</td>
<td>2.9</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>He:C2H6=50:50</td>
<td>0.10% X0</td>
<td>195</td>
<td>133</td>
<td>3.5</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

- Each case also have weak point & strong point

- Gas gain
  - Apply existing technology
    - Still under discussion
**Magnetic field effect**

- Drift line of ionized electron must be distorted by the COBRA magnetic field.
- B-field uncertainty is lower than 0.2%.
- Check how affect the B-field and its uncertainty in analytic way.
- Drift formula w/ magnetic field is defined below:
  
  \[
  u = \frac{E \tau / m}{1 + (\omega \tau)^2} \left[ \hat{E} + \omega \tau (\hat{E} \times \hat{B}) + (\omega \tau)^2 (\hat{E} \cdot \hat{B}) \hat{B} \right]
  \]
- Shift the field alignment in 1mm or scale the field strength in 0.2%.
- Compare position and drift time difference between original field and modified field ...

**Graph:**
- Red solid line: e- drift line w/ B-field.
- Black dotted line: drift line w/o B-field.
- \( E = 1 \text{ kV/cm} @ z = 0 \)
**Magnetic field effect**

<table>
<thead>
<tr>
<th></th>
<th>Radial/Long. shift in X</th>
<th>Radial/Long. shift in Y</th>
<th>Radial/Long. shift in Z</th>
<th>Radial/Long. scale 0.2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS x (um)</td>
<td>4.1 / 19</td>
<td>1.7 / 17</td>
<td>2.7 / 15</td>
<td>5.3 / 5.6</td>
</tr>
<tr>
<td>RMS y (um)</td>
<td>3.2 / 18</td>
<td>2.1 / 15</td>
<td>1.7 / 13</td>
<td>3.8 / 21</td>
</tr>
<tr>
<td>RMS z (um)</td>
<td>12 / 13</td>
<td>5.4 / 26</td>
<td>7.0 / 33</td>
<td>13 / 29</td>
</tr>
<tr>
<td>RMS t (ns)</td>
<td>0.2 / 2.7</td>
<td>&lt;0.1 / 1.9</td>
<td>0.2 / 2.1</td>
<td>0.3 / 3.8</td>
</tr>
</tbody>
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- Drift formula w/ magnetic field is defined below

\[
u = \frac{eE\tau/m}{1 + (\omega\tau)^2} \left[ \hat{E} + \omega\tau(\hat{E} \times \hat{B}) + (\omega\tau)^2(\hat{E} \cdot \hat{B}) \hat{B} \right]
\]

- Shift the field alignment in 1mm or scale the field strength in 0.2 %

- Compare position and drift time difference between original field and modified field ...

- **Radial case is much better than Long. case !**
Expected performance

- **Spatial resolution**
  - \( \delta R : \sim 200 \text{ um} \) (achievable if \( \delta t < 5 \text{ ns} \))
  - \( \delta (z-\phi) : \sim 500 \text{ um} \)

- **Momentum**
  - very rough estimation by assuming uniform B field
  - \( \delta p = \sqrt{(\delta p_{\text{Fit}})^2 + (\delta p_{\text{MAG}})^2 + (\delta p_{\text{MS}})^2} \)
  - 350 keV (DC) \( \rightarrow \) **180 keV** (TPC)

- **Efficiency**
  - Evaluated with Geant 4
  - 50 um thin mylar wall + 1 um cathode copper + He:CO2(70:30) + 3 gems (50um Kapton between 5 um copper) + 5um copper readout pad
  - 40 % (DC) \( \rightarrow \) **80 - 90 %** (TPC)

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2009 *JINST* 4 P11015

using timepix

\[ \delta k_{\text{res}} = \frac{\epsilon}{L^2} \sqrt{\frac{720}{N+4}} \]

- : true hits in TPC
- : true hits in TC
Expected performance

- **Multiplicity**
  - How many hits in one trigger? In the analysis or hardware point of view, are they acceptable?
  - Ionized electron travel about 10 cm in drift velocity ~ 3 cm/us
  - At least 3 us time window is needed to collect ionized electron generated at the farthest position

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![Raw hits](image)

`← How to reduce?`
- **Multiplicity**
  - How many hits in one trigger? In the analysis or hardware point of view, are they acceptable?
  - Ionized electron travel about 10 cm in drift velocity ~ 3 cm/us
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Expected performance

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  - Ionized electron travel about 10 cm in drift velocity ~ 3 cm/us
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\[ \text{(\# of signal hits)}/(\# of total hits) \]

- 0.058
- 0.117
- 0.201
Summary

- **Summary of TPC idea**
  - We are planning "**MEG upgrade**" to get better sensitivity
  - The study of Helium based TPC started as one of candidate for our new tracker
  - Radial type field is less affected by uncertainty of magnetic field
  - Twice better efficiency & twice better momentum resolution are expected roughly
    - $\delta p : 350 \text{ keV} \rightarrow 180 \text{ keV}$
    - $\epsilon_{e+} : 40 \% \rightarrow 80 - 90 \%$
  - More realistic estimation (w/ reconstruction) is needed
  - R&D with prototype is necessary
  - There are still a lot of things to be discussed
    - Gas gain
    - Readout
    - Support structure
  - Any cooperates or suggestions are welcome!
Backup
- energy loss @ inner TPC wall with copper cathode
  - case 1: 50 um Mylar + 1 um Copper
  - case 2: 50 um Mylar + 5 um Copper

- Calculate energy deposits in above 2 case in Geant4
  - case 1 looks fine
• Pileup probability

  • Some channels have pile up hits in time width of 1 trigger

  • I calculated this effect by mixing 1 triggered signal event and overlapping Michel event assuming $1 \times 10^8$ stopping muon rate

  • Readout pad is divided by 2.5x5 mm2 in Z-ϕ plane (typical value for Multi layers gem)

  • results

  • pileup probability : (#of pileup hits)/(#of signal hits) ~ 6%

  • If we can divide each hits in 30 nsec accuracy, it can be reduced to 1/100
Cylindrical GEM for NA49-Future

A possible "critical" experiment at the CERN SPS

- a precise determination of an event centrality (PSD)
- full acceptance for charged hadrons (VTS) and limited for identified hadrons (TPCs)
- a high event rate (DAQ)
- high precision measurements of inclusive spectra of identified hadrons (TPCs+TOF)

Cylindrical GEM Assembly 2

GEM at CERN
Leszek Ropelewski CERN PH-DT2-ST & TOTEM
**TACTIC and BoNuS**

TRIUMF Annular Chamber for Tracking and Identification of Charged particles
Measurement of nuclear cross sections for astrophysics

$^8\text{Li}(\alpha,n)^{11}\text{B}$

$^8\text{Li}$ ions (90-220 keV/u) interacting in He gas

Cylindrical GEM detector with pad readout:

H. Fenker, The BoNuS Detector

http://tactic.triumf.ca/about.html
- **Current issues**
  - Gas gain decreasing?
    - may be due to growing coating on anode wires
  - Strong electric field
    - huge #of avalanche in small region
    - space charge effect
  - Malter effect