Status of muon polarization monitor

SJTU-KEK Workshop

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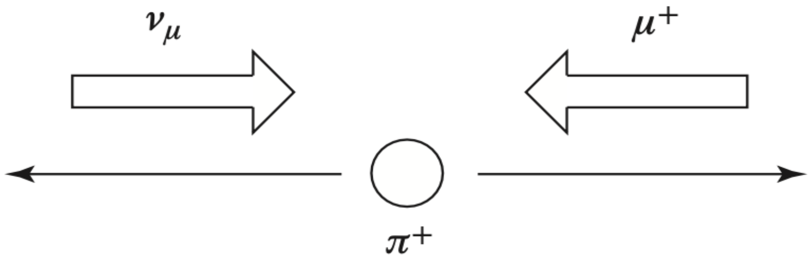
Outline

How to detect muon polarization

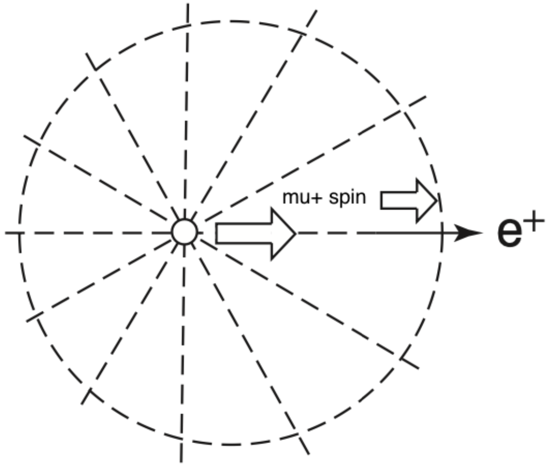
- Asymmetry angular distribution of e^+ from μ^+ decay:



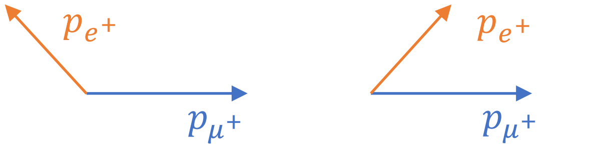
$$N_e(E_e) \propto [1 \mp A(E_e)\cos\theta_e]$$

$$A(E_e) = (E_e^{\max} - 2E_e)/(3E_e^{\max} - 2E_e)$$

upper sign: μ^+decay, lower sign: μ^-decay



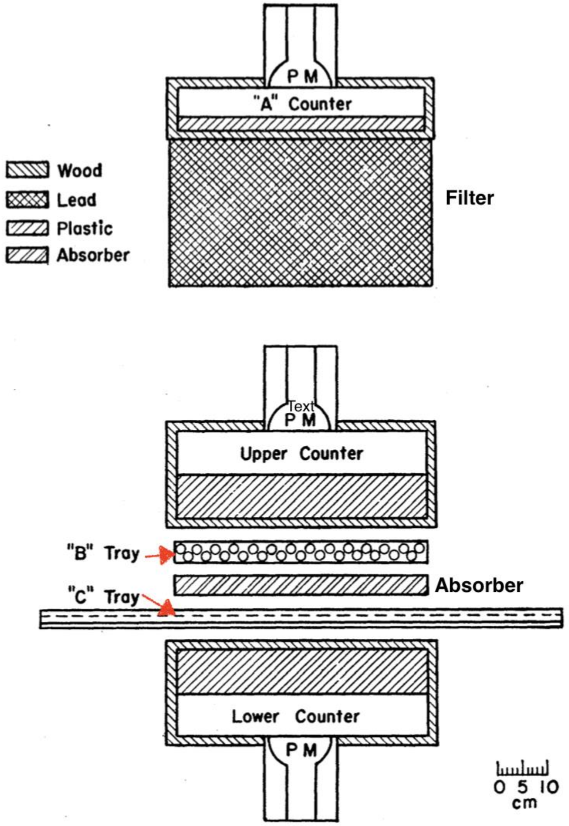
- By measuring the sign of e^+ velocity's projection on μ^+ momentum, we can indirectly get the polarization fraction P:
- N_F = Number of forward decay events
- N_B = Number of backward decay events
- $R = {}^{N_F}/_{N_B}$. In theory, $R|_{P=1} < R|_{P=0.5} < R|_{P=0} = 1$



Backward decay Forward decay

Use cosmic muon to validate detector

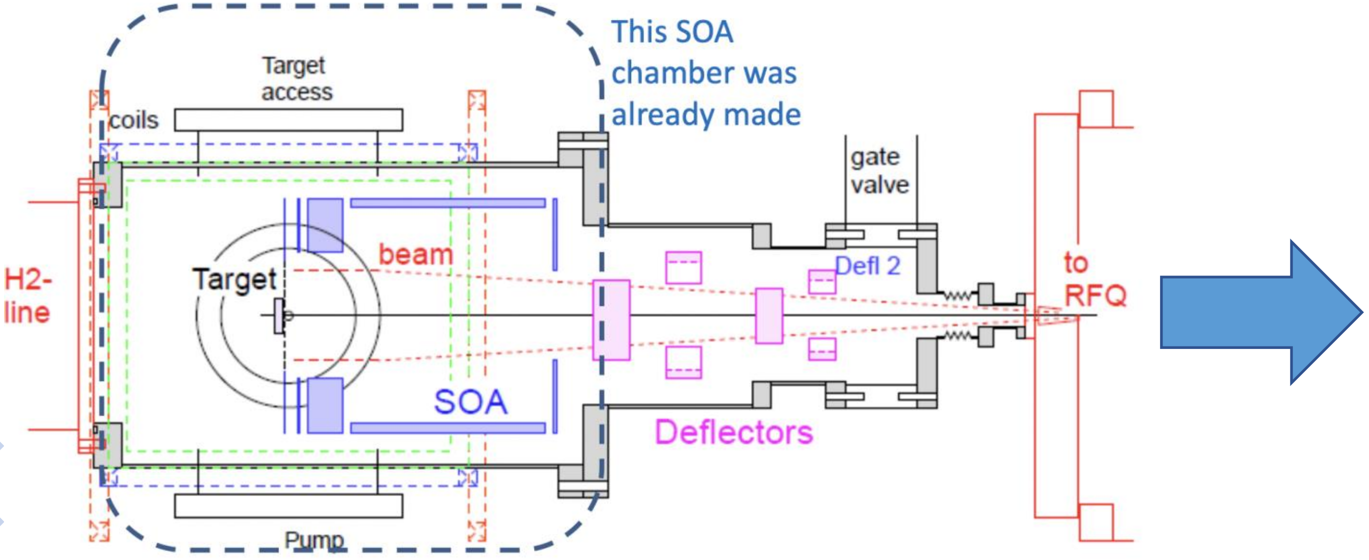
- There is no muon source in Shanghai, therefore we plan to use muon from cosmic rays to calibrate detectors
- The polarization of cosmic muon is around 0.2-0.3
- The filter is used to select the energy range for a better yield
- Cu absorber: keep the polarization of cosmic muon
- Fe absorber: depolarize cosmic muon
- Design goal:
  - Select muons decaying in the absorber
  - Detect differences between Cu and Fe absorber
  - Less error
- An effective signal: $AB\bar{C}$

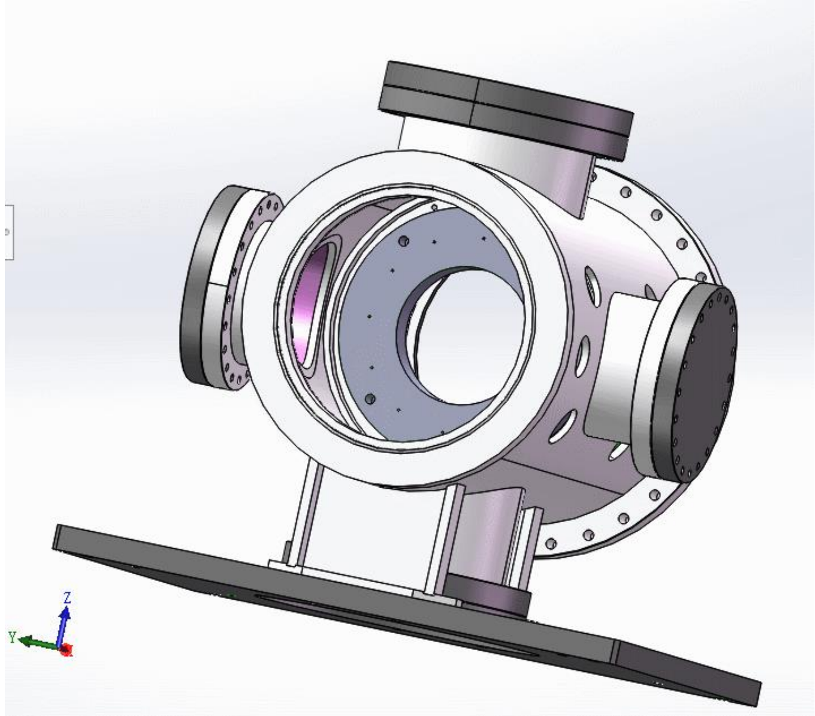


Outline

Muon source chamber and its simplification

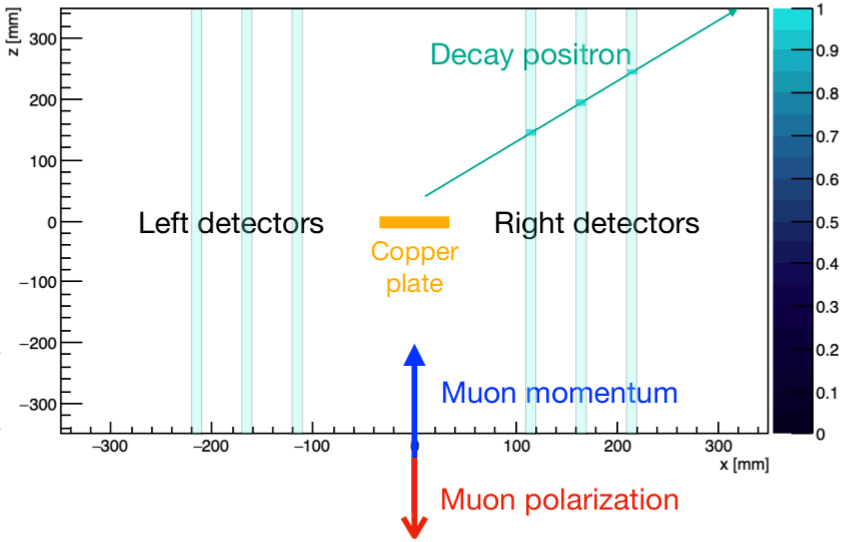
- Introduce chamber to simulation to study its absorbing and scattering influence on e^+
- Use SolidWorks to defeature the chamber to a simpler one
- Reduce its size from 300 MB to 26 MB
- Similar performance, faster simulation speed

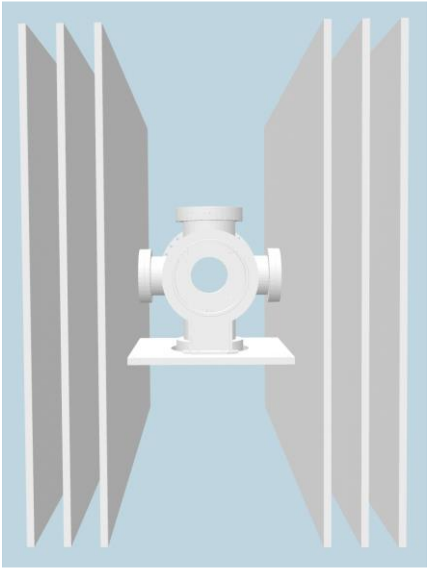


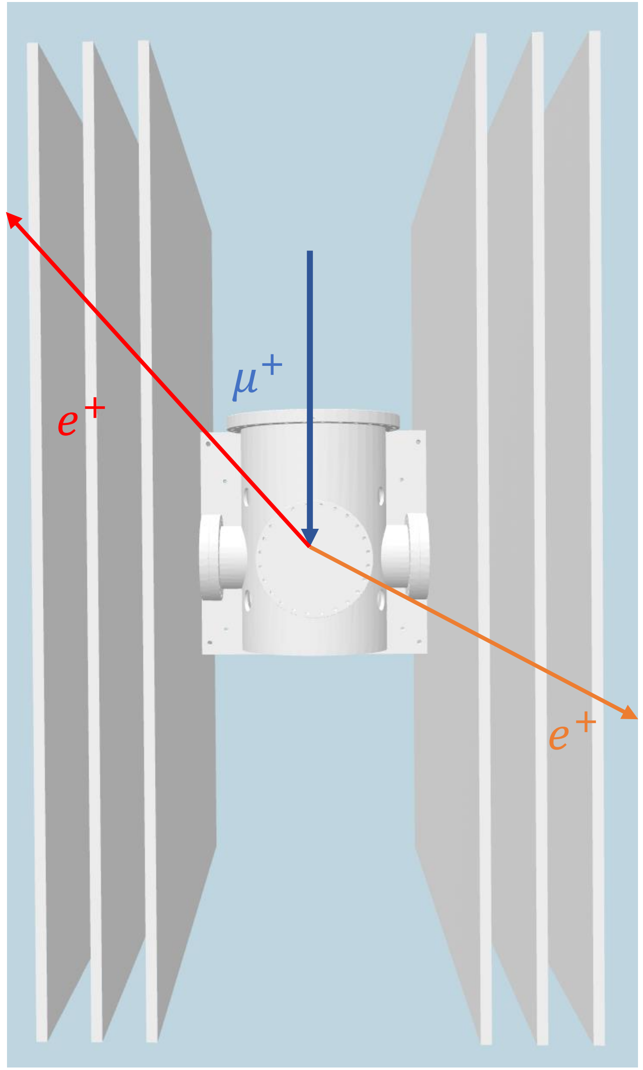


Detector design: parallel detector

- 6 detectors, 2 sides, parallel to μ^+ momentum direction
- Positive gradient in momentum direction: Forward decay
- Negative gradient in momentum direction: Backward decay
- Each detector size: 1800 mm × 1400 mm × 10 mm

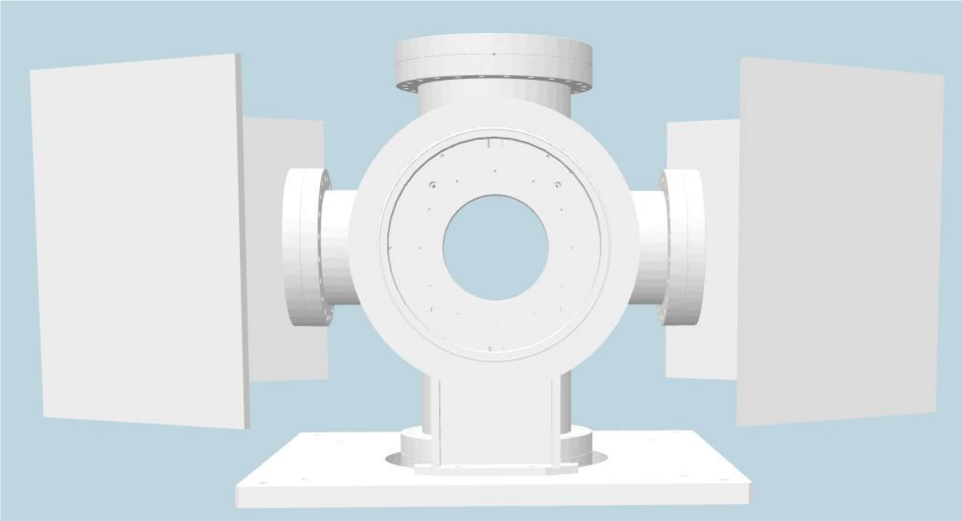


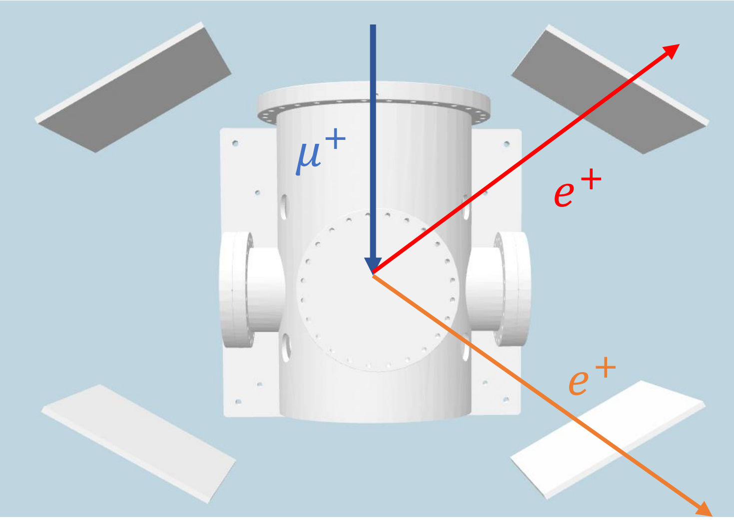




Detector design: corner detector

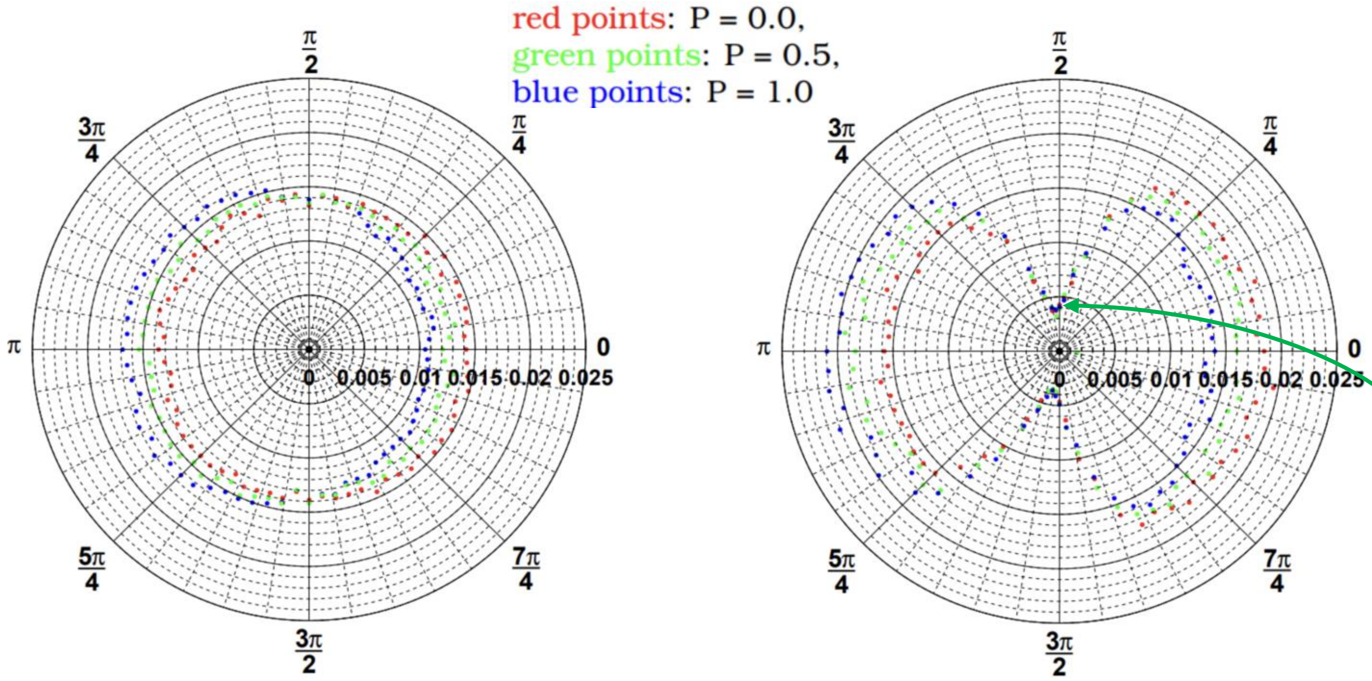
- 4 detectors at each corner
- Hit signal on forward corner detector: Forward decay
- Hit signal on backward corner detector: Backward decay
- Each detector size: 300 mm × 400 mm × 10 mm





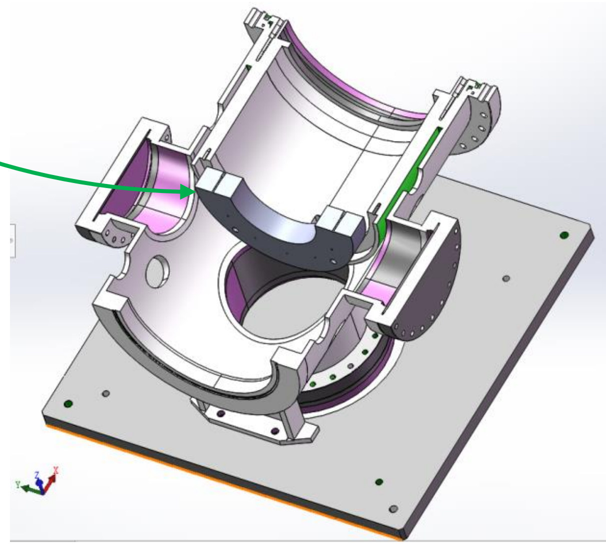
Outline

Angular distribution of e^+ from thermal muon



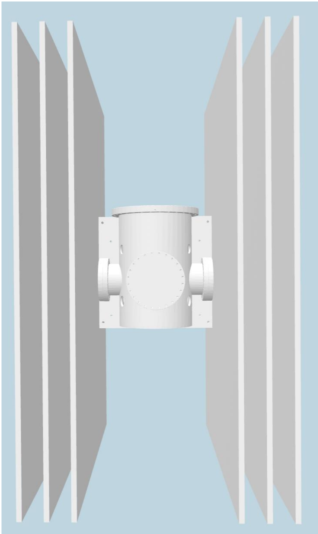
e^+ distribution without the chamber

e^+ distribution with the chamber



- After applying the chamber, asymmetry can still be detected outside the chamber
- The more e^+ close to z angle, the stronger asymmetry it will show

Parallel detector performance

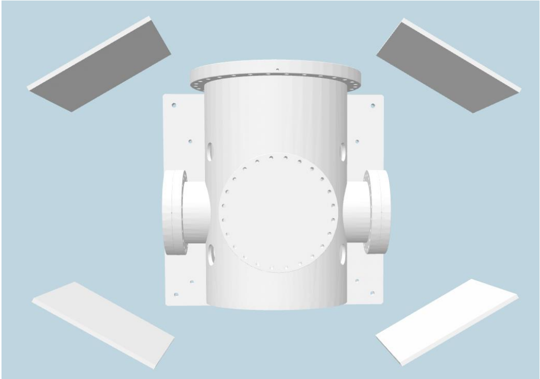


- Event number: 10^5
- F = Forward electron count; B = Backward electron count
- Asymmetry: $A = {}^{F-B}/_{F+B}$
- Detector efficiency $\epsilon = {}^{\text{Count number}}/_{10^5}$

Polarization	F	B	A	ϵ
0	6012	15535	-0.442	21.5%
0.5	5708	16805	-0.493	22.5%
1	5205	18056	-0.552	23.3%

- When $\Delta P = 0.5, \Delta A \approx 0.05$
- Costs high, but has lower SNR because of 3 layers
- Less influence on other parts of the apparatus

Corner detector performance



- Event number: 10^5
- F = Forward electron count; B = Backward electron count
- Asymmetry: $A = {}^{F-B}/_{F+B}$
- Detector efficiency $\epsilon = {}^{\text{Count number}}/_{10^5}$

Polarization	F	B	A	ϵ
0	2160	6984	-0.53	9.1%
0.5	1886	7343	-0.59	9.2%
1	1507	8266	-0.69	9.8%

- When $\Delta P = 0.5, \Delta A \approx 0.09$
- Lower cost with better distinction performance, but lower efficiency
- Lower SNR since each corner only has 1 layer

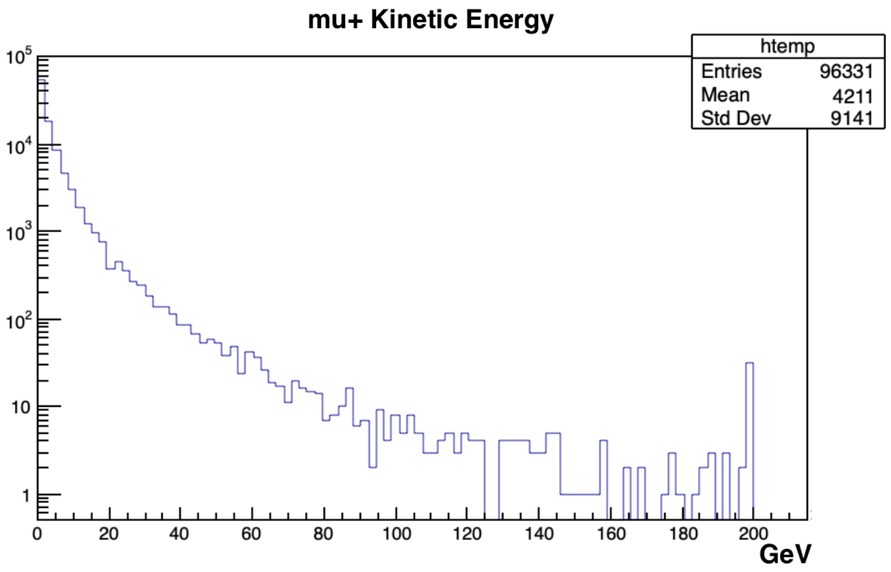
Outline

Cosmic muon energy distribution

- Formula from reference[2]:

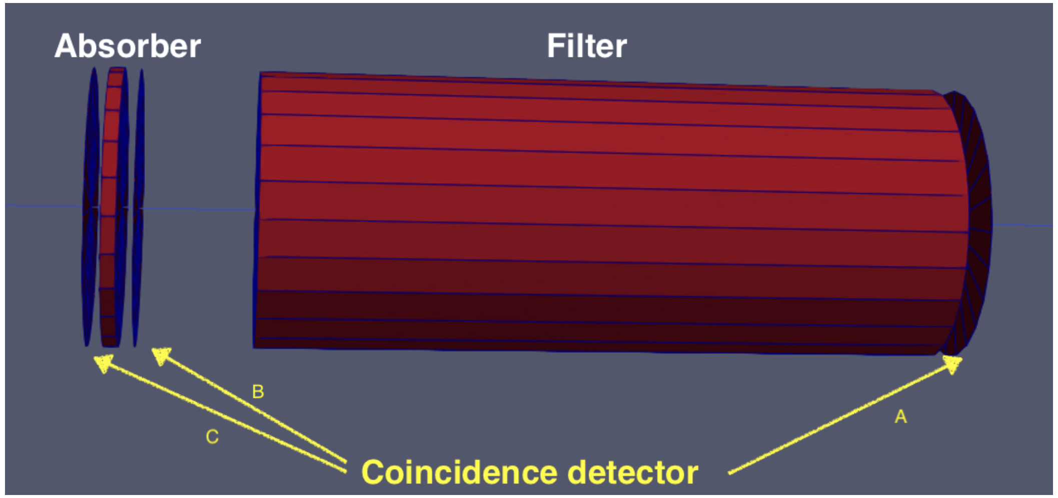
$$\frac{dI_\mu}{dE_\mu} = 0.14\left[\frac{E_\mu}{GeV}\left(1+\frac{3.64GeV}{E_\mu(\cos\theta^*)^{1.29}}\right)\right]^{-2.7} \times \left[\frac{1}{1+\frac{1.1E_\mu\cos\theta^*}{115GeV}}+\frac{0.054}{1+\frac{1.1E_\mu\cos\theta^*}{850GeV}}\right]$$

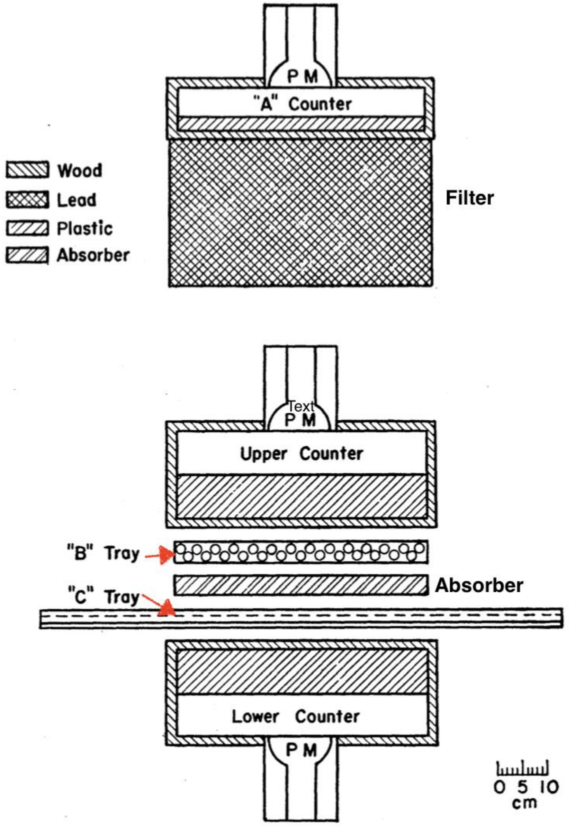
- Currently set angle $\cos\theta^* = 1$
- Simulation result:
  - Mean energy: 4.2 GeV, in agreement with the experiment
- This simulation is used as the muon source for further cosmic muon detector research



Study on filter and absorber structure

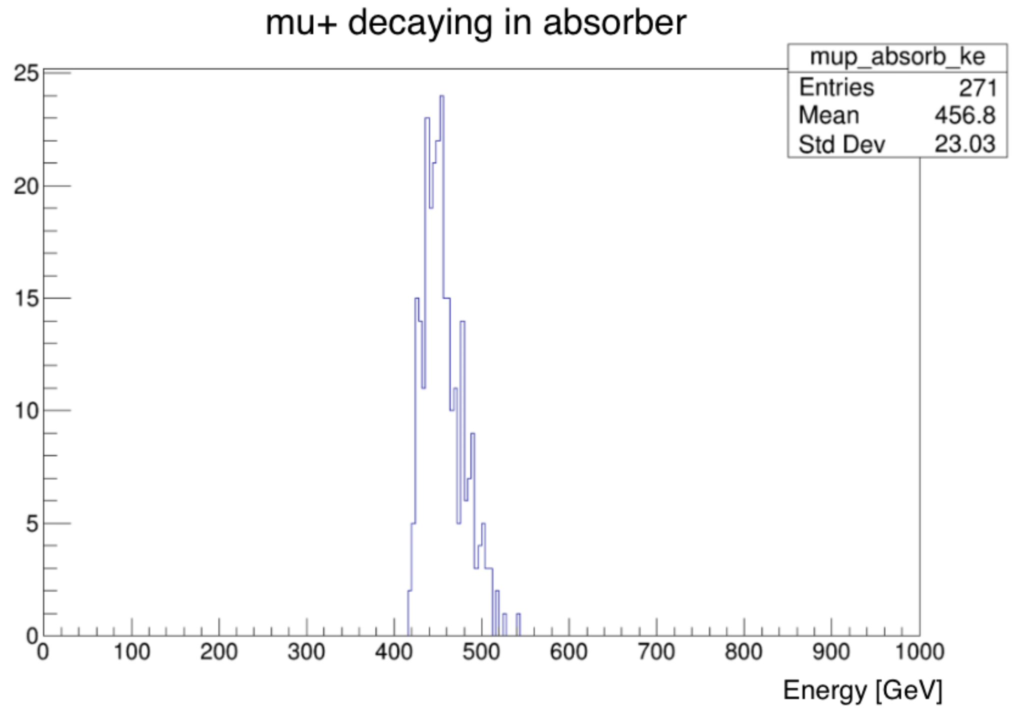
- Use the cosmic muon source mentioned above
- Filter: lead, 300 mm
- Absorber: Cu, 63.5 mm (0.25 inch)
- A signal decay in absorber: $AB\bar{C}$





Flux rate estimation

- The number of muons that decay in the absorber: 271 out of 10^5
- Energy range: 420 MeV – 520 MeV
- Assume absorber size: 50 cm × 50 cm
- Assume cosmic flux: 200 $\mathrm{m}^{-2}\mathrm{sec}^{-1}$
- Flux rate:
- $R = 200 \times 0.5 \times 0.5 \times {}^{271}/_{10^5} = 0.1355\,\mathrm{sec}^{-1}$
- A signal will appear around each 7.38 seconds



Outline

Overview of muon polarization monitor

Detector structure search

Thermal muon simulation

Cosmic muon simulation

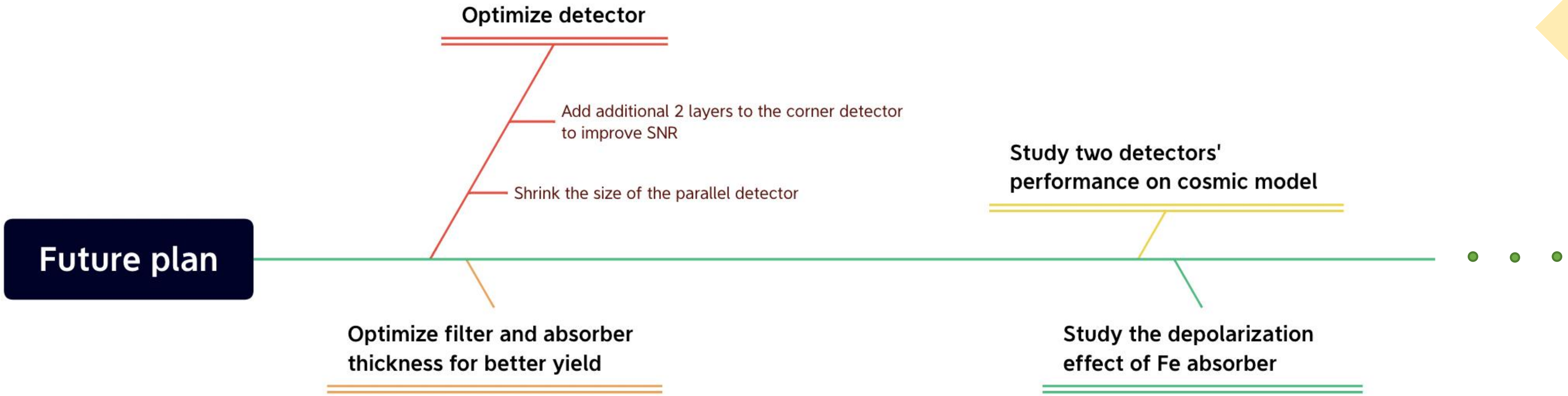
▷ Conclusion and Future plan

References

Conclusion

- ✓ $\mu^+ \rightarrow e^+$ decay asymmetry is the working principle of the detector
- ✓ We use cosmic muon to hit different absorbers to calibrate the polarization detector
- ✓ e^+ will still show asymmetry after adding the chamber
- ✓ The chamber will absorb most e^+ near angle $\pi/2$ and $3\pi/2$, therefore affecting the performance of the parallel detector
- ✓ Because of absorbing effect of the chamber, the corner detector performs better than the parallel detector with rather less cost
- ✓ Using given filter and absorber, we can obtain a mu+ decaying in the absorber each 7.38 seconds

Future plan


Optimize detector
Add additional 2 layers to the corner detector to improve SNR
Shrink the size of the parallel detector
Study two detectors' performance on cosmic model
Future plan
Optimize filter and absorber thickness for better yield
Study the depolarization effect of Fe absorber

Outline

- Overview of muon polarization monitor
- Detector structure search
- Thermal muon simulation
- Cosmic muon simulation
- Conclusion and Future plan
- ▷ References

References

[1] Nagamine, K. (2003). Introductory Muon Science. Cambridge: Cambridge University Press doi:10.1017/CBO9780511470776

[2] Johnson, C. Scott. (1961). Polarization of Cosmic-Ray Muons at Sea Level: PhysRev.122.1883

[3] Guan, Mengyun and Chu et al. (2015). A parametrization of the cosmic-ray muon flux at sea-level doi:10.48550/ARXIV.1509.06176

Thanks!