Institute of High Energy Physics,
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Majoron Searching at the COMET Experiment

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CONTENTS

Motivation

Two explanation for neutrino mass:

- Dirac mass term and Majorana mass term

Popular model of Majorana:

- Seesaw model:
  - Neutrnio mass: M and m_D^2/M
  - Can’t explain why neutrino is Majorana particle.

Try to explain Majorana mass term:

- In 1981, extension of Higgs sector was proposed (1-2 model and 2-3 model), which lead to Majoron
- In 1983, using SUSY and R parity violation, also lead to Majoron, but were excluded after the Z-width measurementat LEP.
- In 1990, a new model for spontaneous R parity breaking was proposed.

Experiment verification:

- $\mu^- \to e^- + J$

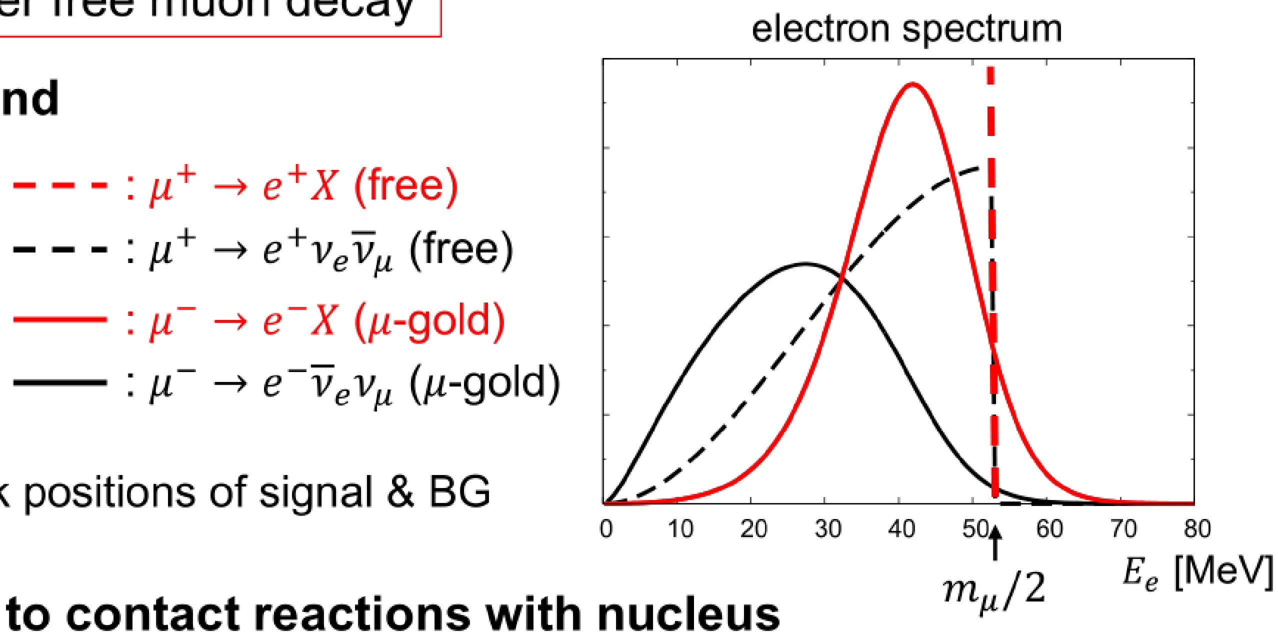
Motivation

$\mu^- \to e^- X$ in a muonic atom

cf. X. G. i Tormo *et al.*, PRD **84**, 113010 (2011).
& H. Natori, Talk at 73th JPS meeting (2018).

Advantage over free muon decay

1. less background



- different peak positions of signal & BG

2. also sensitive to contact reactions with nucleus

3. more information : "spectrum" & "dependence on nucleus"

Reference: Report "New promising CLFV modes in muonic atoms" by Yuichi Uesaka(Saitama U.)

Disadvantage

- ✓ non-monochromatic signal
- ✓ shorter life time of muonic atom

Analysis Method

Single bin counting method:

- Consider this search as a single bin counting experiment
- Very fast, simple calculation with given parameters
- Ignore shapes of energy spectra, which leads to a little worse result

Likelihood analysis method:

- Compare theory spectra and data spectra by calculating likelihood
- Slow, need an analysis program
- Compare shapes of spectra in detail and give a better result

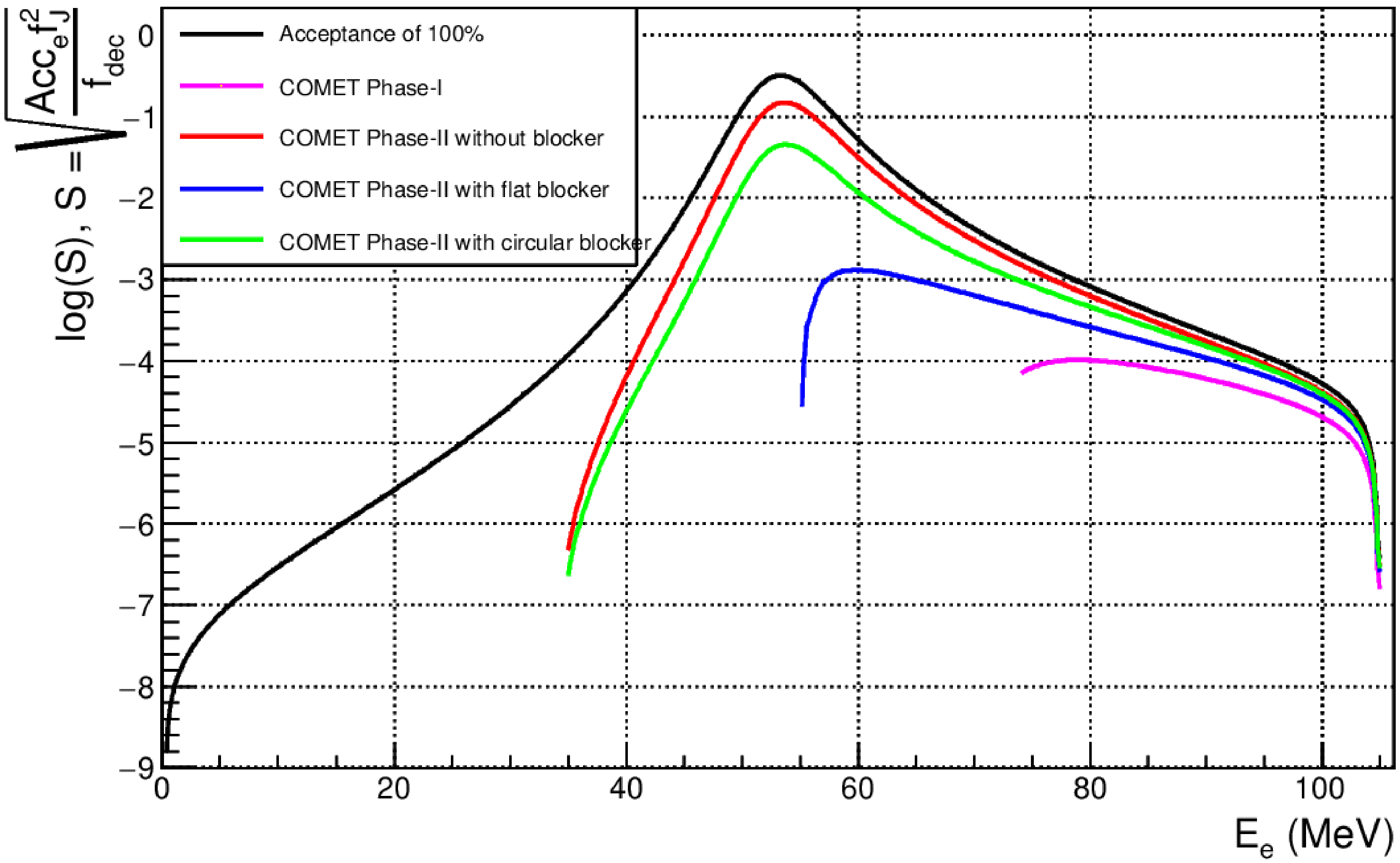
Analysis Method

Single bin counting method:

- Generally we have $B(\mu \to eJ) = \frac{N_J/f_J/Acc_J}{N_{dec}}$
- In single-bin analysis $B(\mu \to eJ) = 1.645 \times \sqrt{\frac{1}{N_{dec}Acc_{dec}f_{dec}}}\frac{Acc_{dec}f_{dec}}{Acc_J f_J}$
  - Statistics: $\sqrt{\frac{1}{N_{dec}Acc_{dec}f_{dec}}}$, limited by beam and detector's tolerance to trigger rate
    - $N_{dec}Acc_{dec}f_{dec}$ is the number of tracks to be examined
  - Significance factor: $\frac{Acc_{dec}f_{dec}}{Acc_J f_J}$, decided by spectra and detector's acceptance bias
- In mu-e conv experiment, $N_{dec} = \frac{1}{S.E.S._{\mu e}Acc_{\mu e}}\frac{\Gamma_{decay}}{\Gamma_{capture}}$
- If we only look at a narrow energy region at E, $Acc_J = Acc_{dec} = Acc_E$

$$\mathcal{B}(\mu \to eJ) = 1.645 \times \sqrt{\frac{\Gamma_{\text{capture}}Acc_{\mu e}S.E.S._{\mu e}}{\Gamma_{\text{decay}}}\frac{1}{S}}, \quad S = \sqrt{\frac{Acc_e f_J^2}{f_{\text{dec}}}}$$

Analysis Method

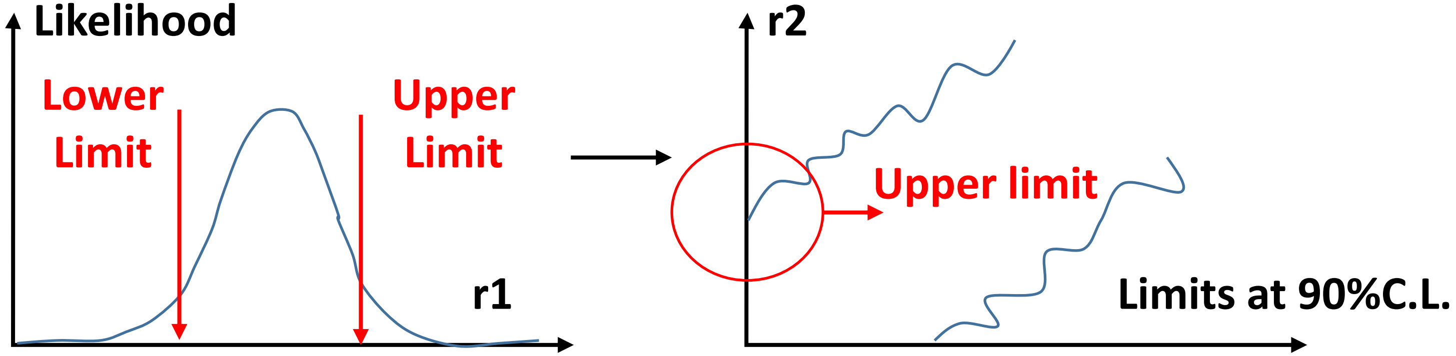


Distributions of the significance factor with different acceptances

Analysis Method

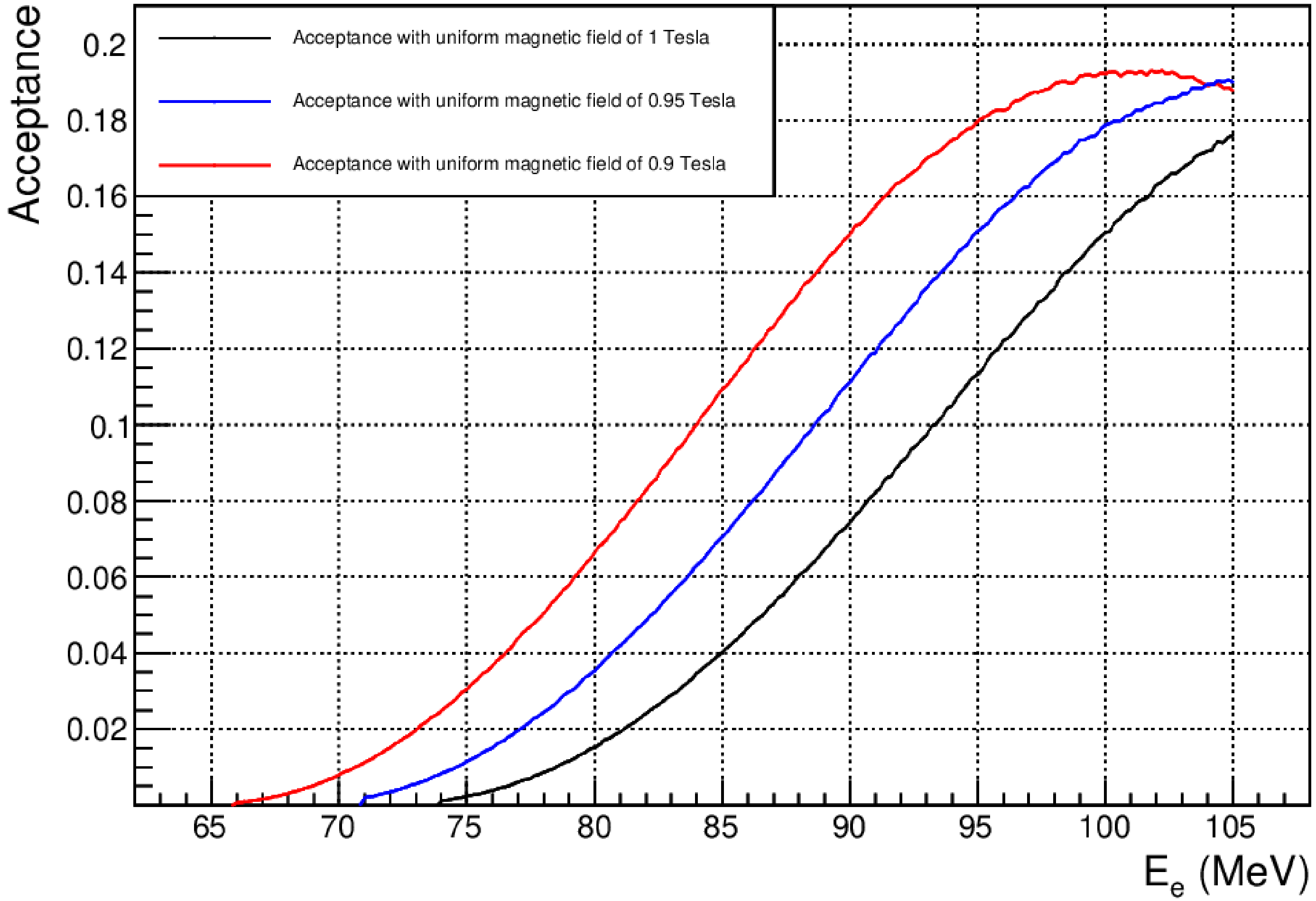
Likelihood analysis method:

- The spectrum of signal and background $f(E)_{MEIO}$ and $f(E)_{DIO}$ are generated by smearing theory spectrum with acceptance, energy loss and resolution(optional)
- The excepted spectrum is supposed to be the sum of the spectra of MEIO and DIO with a ratio r_1, so $f(E)_{excepted} = f(E)_{DIO} + r_1 * f(E)_{MEIO}$
- Since there's no real data, so the measured spectrum is also supposed to be the sum of the spectra of MEIO and DIO with a ratio r_2, so $f(E)_{measured} = f(E)_{DIO} + r_2 * f(E)_{MEIO}$
- For each $f(E)_{measured}$ with certain r_2, compared with $f(E)_{excepted}$ *with different* r_1 using likelihood method, and then get the lower and upper limit at 90% C.L.
- Draw all the limits with different r_2 as a confidence belt and get final result



Results of Phase-I

Acceptance with different magnetic fields:



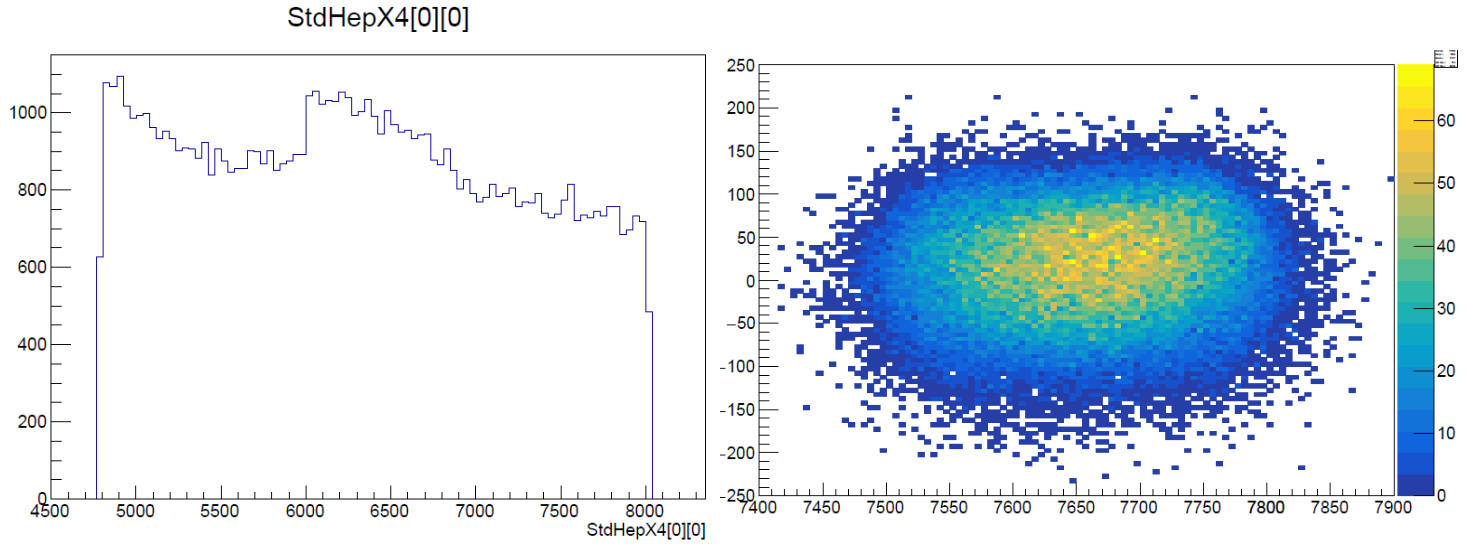
Likelihood analysis results:

- Using acceptance with uniform magnetic field
- Resolution of reconstruction is considered as Gaussian distribution with sigma of 150 keV

Magnetic field	**1 T**	**0.95 T**	**0.9 T**
Upper limit	**$2.3*10^{-5}$**	**$1.4*10^{-5}$**	**$6.9*10^{-6}$**

Results of Phase-I

- Muons (and pi-) stopping in helium are simulatd using MC5A
  - /CylindricalDetector
  - /CylindricalDetector/CylindricalDriftChamber
  - /CylindricalDetector/MuonStoppingTargetSystem/MuonStoppingTarget
  - /CylindricalDetector/MuonStoppingTargetSystem



- Get 74289 muons stopping in helium from $1*10^9$ POT, not enough
- Using MC4O to simulate MuInHe, get 3000 muons from $1*10^7$ POT

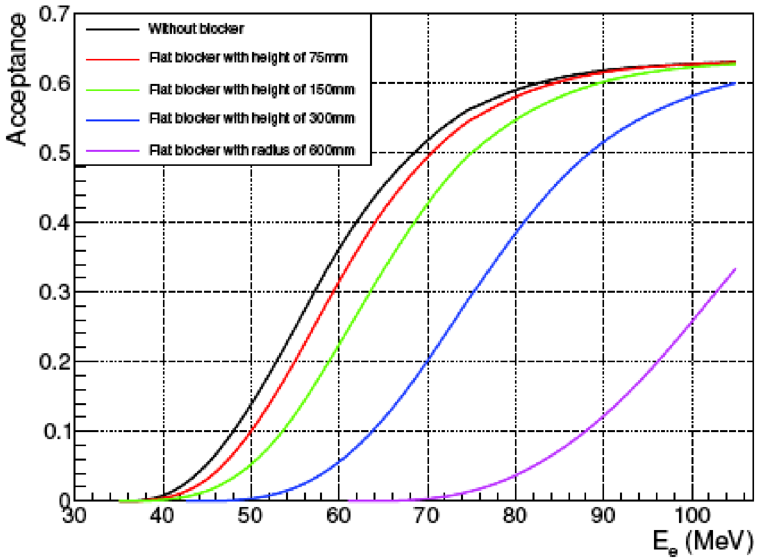
Results of Phase-II

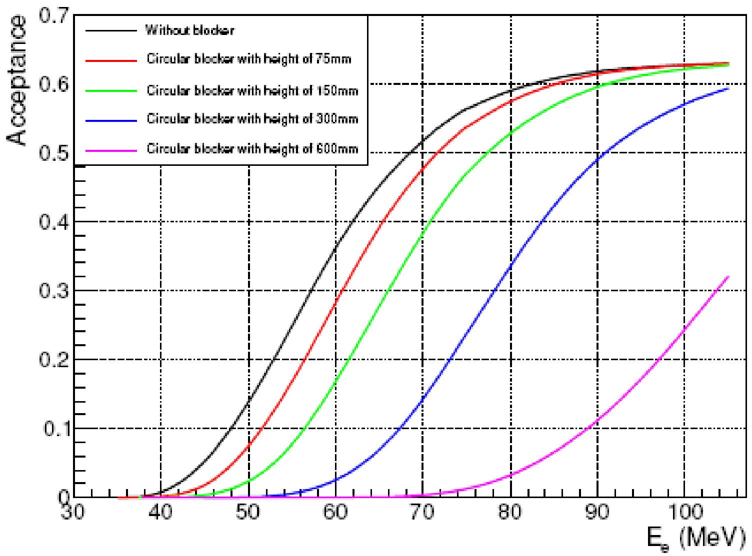
Fast simulation:

- The tracks of electrons are considered as standard helices
- Material effects and uncertainty of magnetic field are not considered
- The drift of trajectory in the direction perpendicular to the plane of curvature is estimated as:

$$D = \frac{1}{qB}\left(\frac{s}{R}\right)\frac{p}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

- A flat blocker and a circular blocker is considered

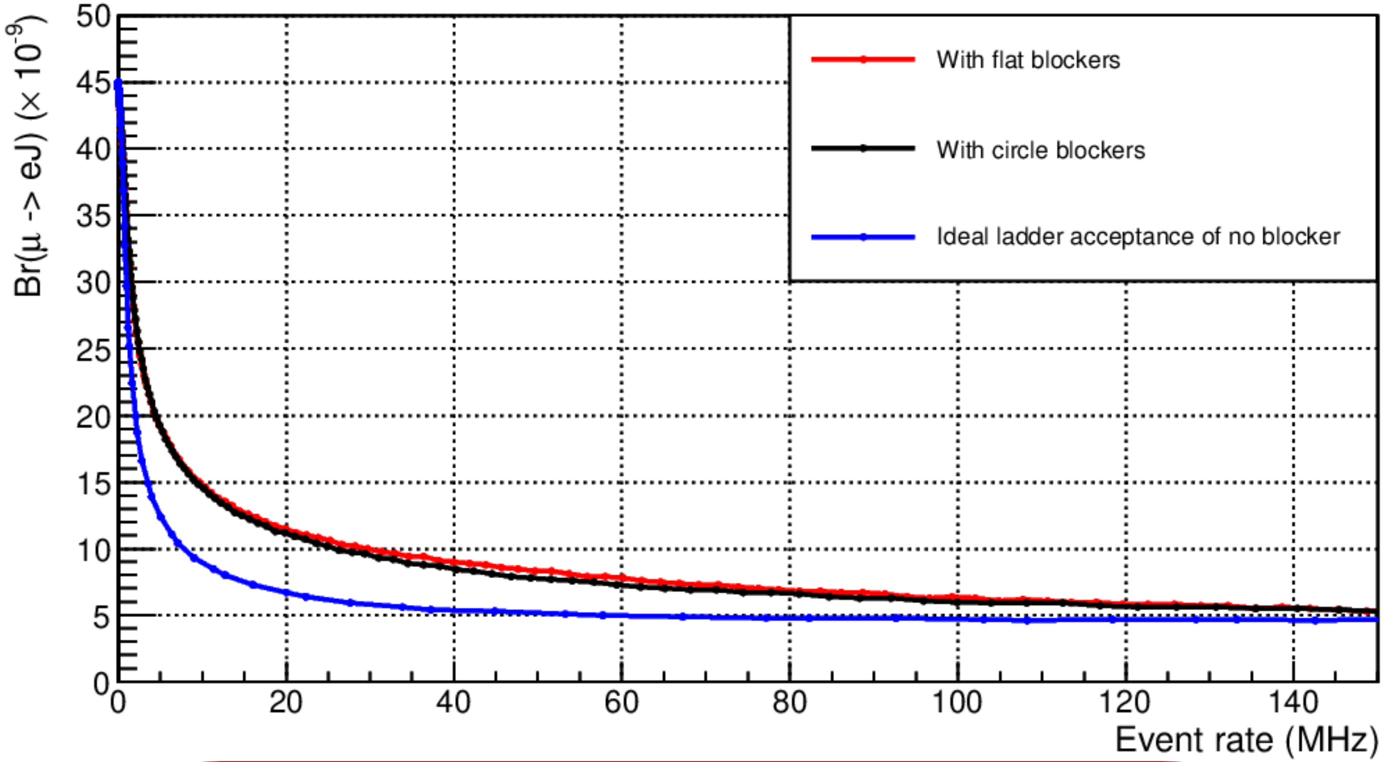




Results of Phase-II

Likelihood analysis results:

- Resolution of reconstruction is considered as Gaussian distribution with sigma of 150 keV
- Efficiency of reconstruction is estimated according to Kou's study
- Without blocker, the upper limit of Majoron searching could be $4.6*10^{-9}$, with estimated event rate of 232.4 MHz



Conclusion

- The sensitivity to search for Majoron on COMET Phase-I could be at least in the same order of magnitude as the current best experimental result
- There could be an improvement of 100 times on COMET Phase-II, while the blocker should be optimized in detail to reduce event rate
- This study only consider DIO as the major background, while muon stopping in helium and RMC are ignored
- Uncertainty is also not studied
- The draft of paper has been submitted to Chinese Physics C and waiting for publication

THANK YOU!