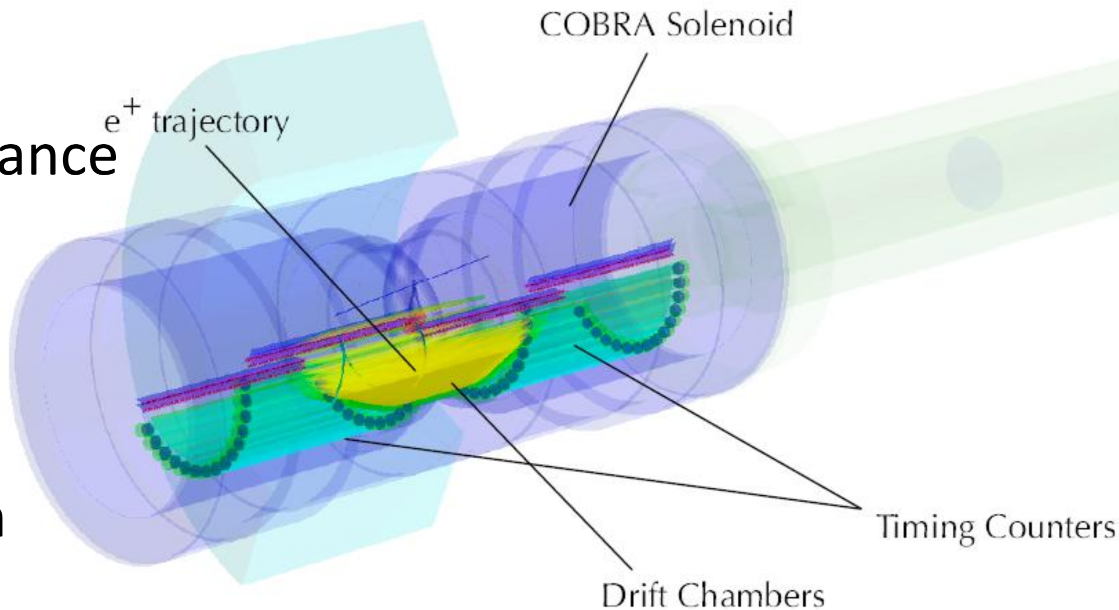
MEG実験
陽電子スペクトロメータの性能評価

東京大学 藤井 祐樹
他 MEG コラボレーション
2010年9月13日
日本物理学会 秋季大会
九州工業大学戸畑キャンパス

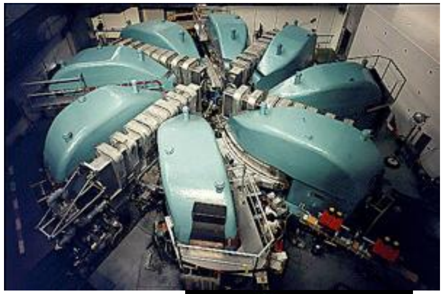
Contents

- Introduction
- Run 2009
  - Spectrometer performance
- Run 2010
  - Expected performance
  - Mott scattering
  - Offline noise reduction
- Prospects
- Summary

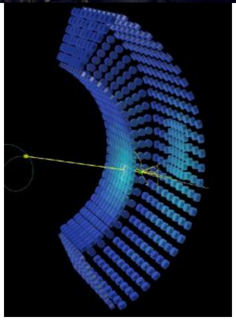


Introduction

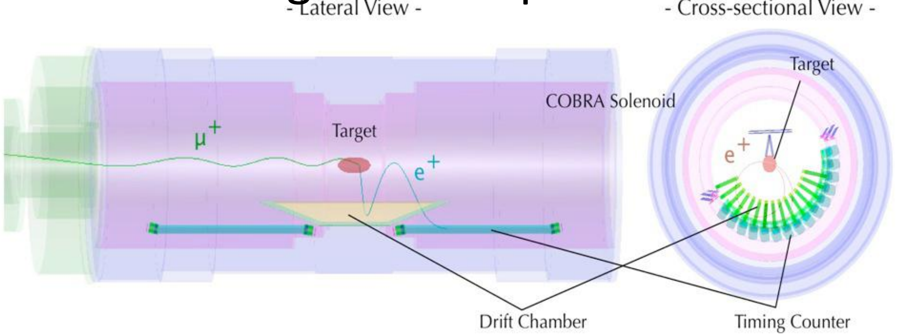
- MEG experiment started to hunt the muon rare decay which indicate the cLFV ($\mu \rightarrow e + \gamma$) in 2008



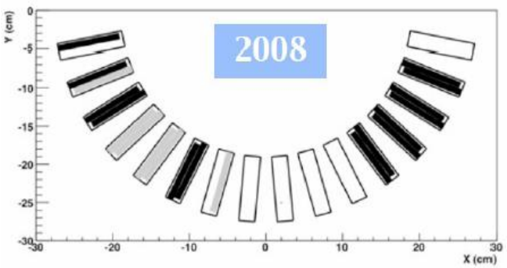
- Requirements to get a few*10^{-13} branching ratio
  - High intensity DC muon beam
    - Realized by most intense proton accelerator @ PSI
  - Good resolution gamma detector --> see next talk
    - Using large LXe calorimeter (~ 900 litter)

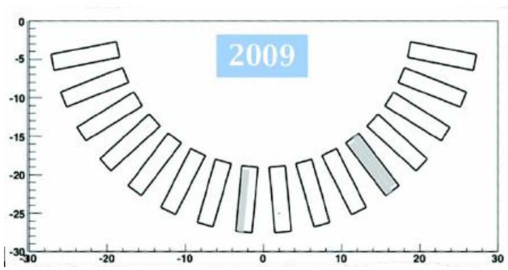


  - Good resolution and less material positron spectrometer
    - COBRA magnet , drift chamber (for tracking) and timing counter (for trigger) constitute the MEG spectrometer to get this requirements

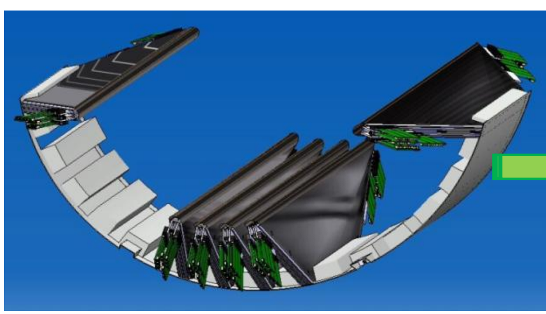


Run 2009

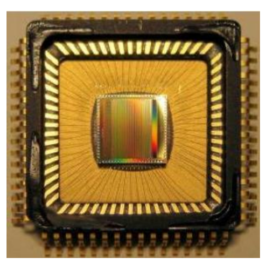




- Stable data acquisition succeeded
- Waveform digitizers for DCH were replaced from DRS2 to DRS4
  - DRS internal noise were reduced
- Spectrometer performance improved by solving discharge problem which suffered some drift chamber modules in 2008
- Higher spectrometer efficiency and better resolution were expected than in 2008



MEG drift chamber

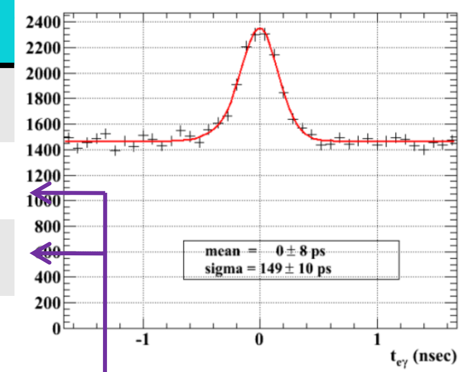


DRS4 waveform digitizer

Spectrometer performance in 2009

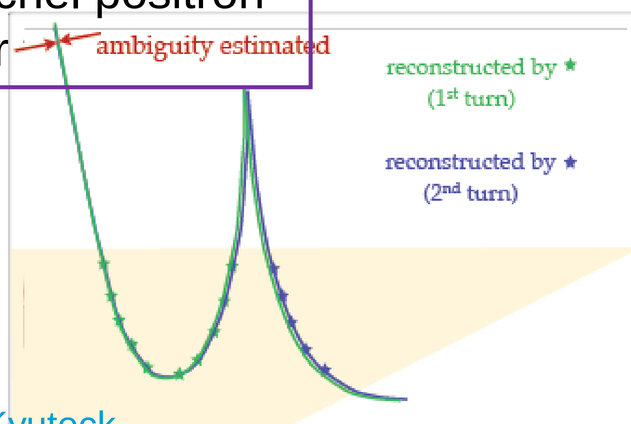
Estimated by radiative muon decay indirectly

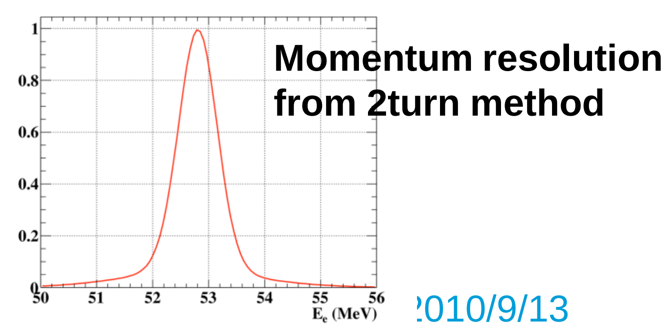
	2008	2009
e+ timing (psec)	125<	95<
e+ momentum (%)	1.6	0.74 (core)
e+ angle (mrad)	10 (ϕ) / 18 (θ)	7.4 (ϕ, core) / 11.2 (θ)
e+ efficiency (%)	14	40
μ+ decay point (mm)	3.2 (R) / 4.5 (Z)	2.3 (R) / 2.8 (Z)



Calculated by #of Michel positron mixed in MEG trigger

Extract from residuals of two turn track





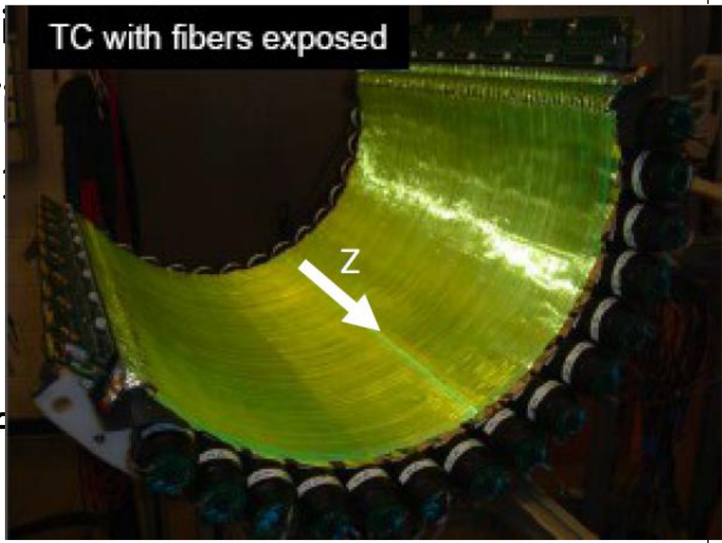
MEG
Mu-E-Gamma project group

Run 2010

- MEG data taking started in Aug. → 2.7 times longer than in 2009
- 5 chambers replaced to new one → almost all chambers working fine
- Remaining problems for positron spectrometer
  - Noisy waveform baseline
    - Large periodic noise found around 14 MHz (related to HV supply modules) → replaced after this years run
    - try to reduce by offline analysis for this run → in this talk
  - Materials between DCH and TC affect low efficiency (~ 40 %)
    - hardware update is needed (will be done in 2012 hopefully)
- Update for 2010
  - Mott scat. analysis (to calibrate and estimate performance) --> in this talk
  - Digitizers for Timing counters were changed from DRS3 to DRS4
  - TC Z-fibers started to work (under studying)

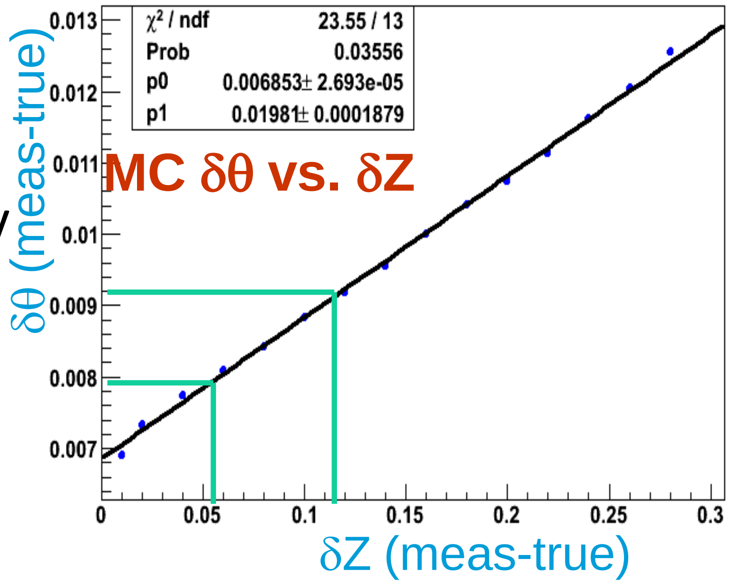
Run 2010

- MEG data taking started in Aug. → 2.7 times longer than in 2009
- 5 chambers replaced to new one → almost all chambers working fine
- Remaining problems for positron spectrometer
  - Noisy waveform baseline
    - Large periodic noise found around 14 MHz (related to HV supply modules) → replaced after this years run
    - try to reduce by offline analysis for this run → i
  - Materials between DCH and TC affect low eff
    - hardware update is needed (will be done in 20
- Update for 2010
  - Mott scat. analysis (to calibrate and estimate
  - Digitizers for Timing counters were changed f
  - TC Z-fibers started to work (under studying)



Expected performance

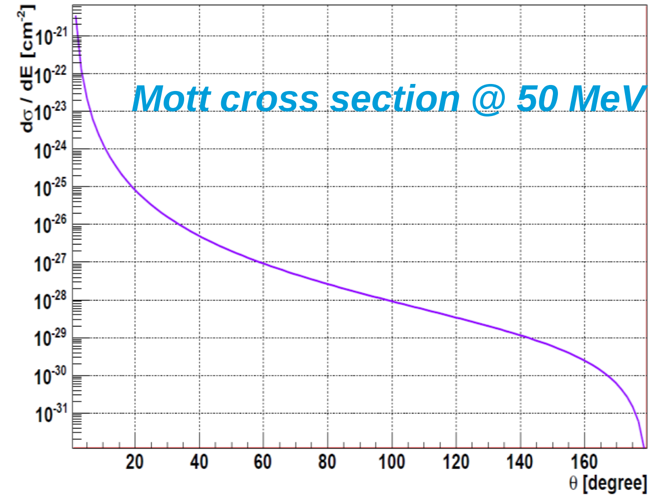
- Assuming lower noise level
  - Noise makes ~2 times worse Z resolution
  - Z resolution related to θ resolution strongly
  - Lower noise bring better vertex resolution too
- TC Z-fibers will bring more precisely position information

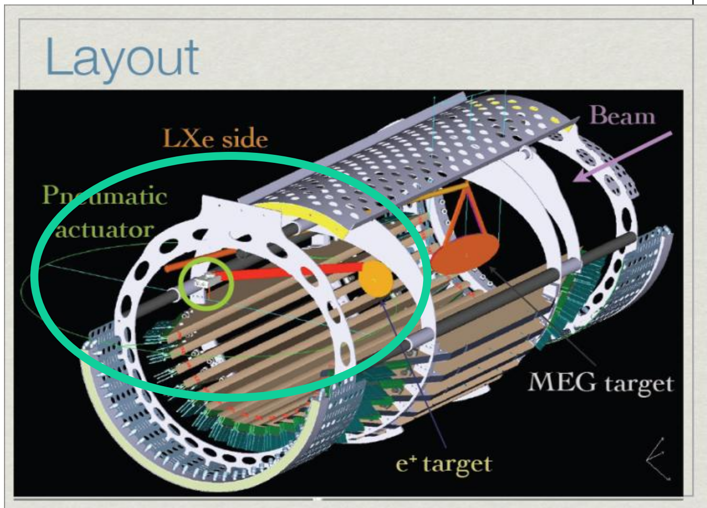


	2008	2009	2010 (Expected)
e+ timing (psec)	125<	95<	←
e+ momentum (%)	1.6	0.74 (core)	0.7
e+ angle (mrad)	10 (ϕ) / 18 (θ)	7.4 (ϕ, core) / 11.2 (θ)	8 (ϕ) / 8 (θ)
e+ efficiency (%)	14	40	40
μ+ decay point (mm)	3.2 (R) / 4.5 (Z)	2.3 (R) / 2.8 (Z)	1.4 (R) / 2.5 (Z)

Mott scattering analysis

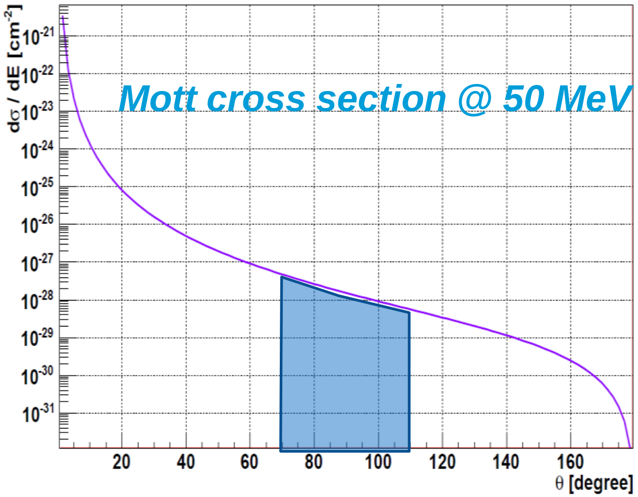
- Introduction of Mott scattering
- Mott scattering is coherent and elastic
  - It has well known distribution monochromatic e+ for calibration and checking performances !
  - Further, momentum of positron is tunable with O(100keV)
- Mott target placed COBRA center position and MEG target moved to “parking position”
  - Setup
  - Slant angle : ~ 50^{o} for beam axis
  - Thickness : 2 mm
  - Material : pure CH_2

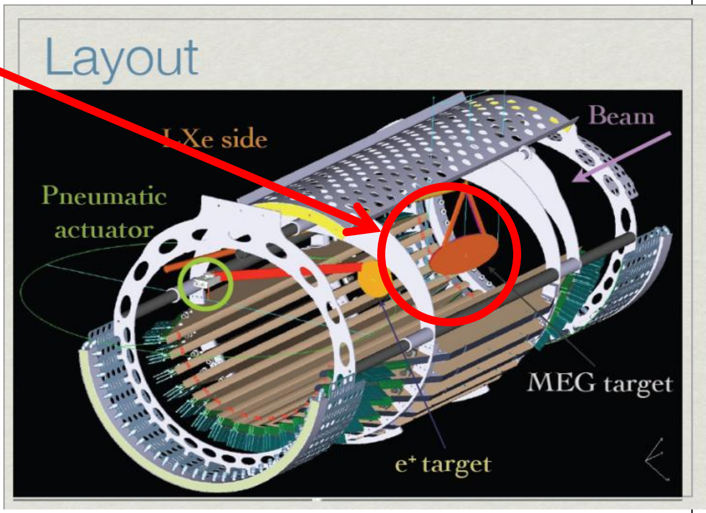




Mott scattering analysis

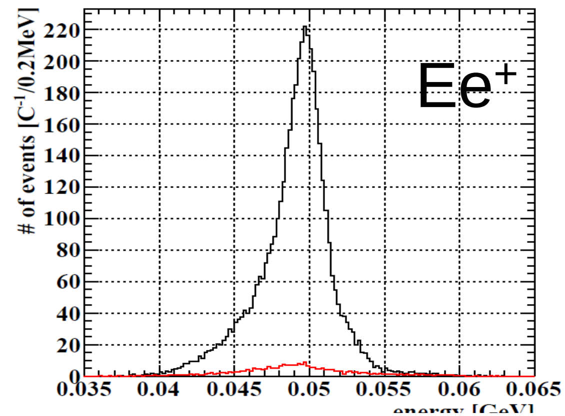
- 50 MeV monochromatic positron beam with 160 keV momentum byte
- MEG fiducial volume 70° – 110°
- Background source
  - Cloud muons Michel decay (forward direction dominant)
  - Mott scat. from MEG target (on its “parking position”)
- Background data (w/o target) was also taken
  - Michel positron from cloud muons can be subtracted

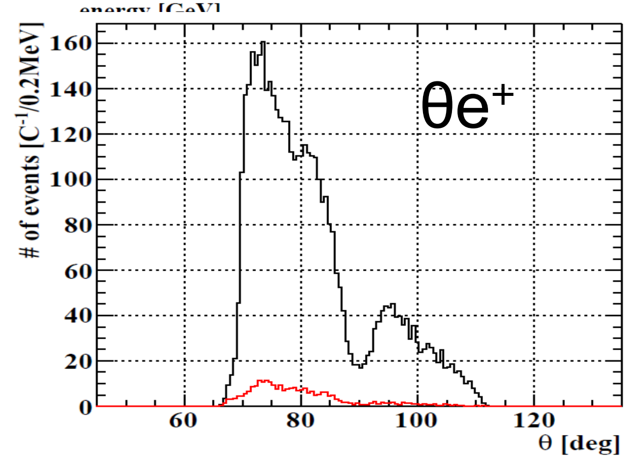




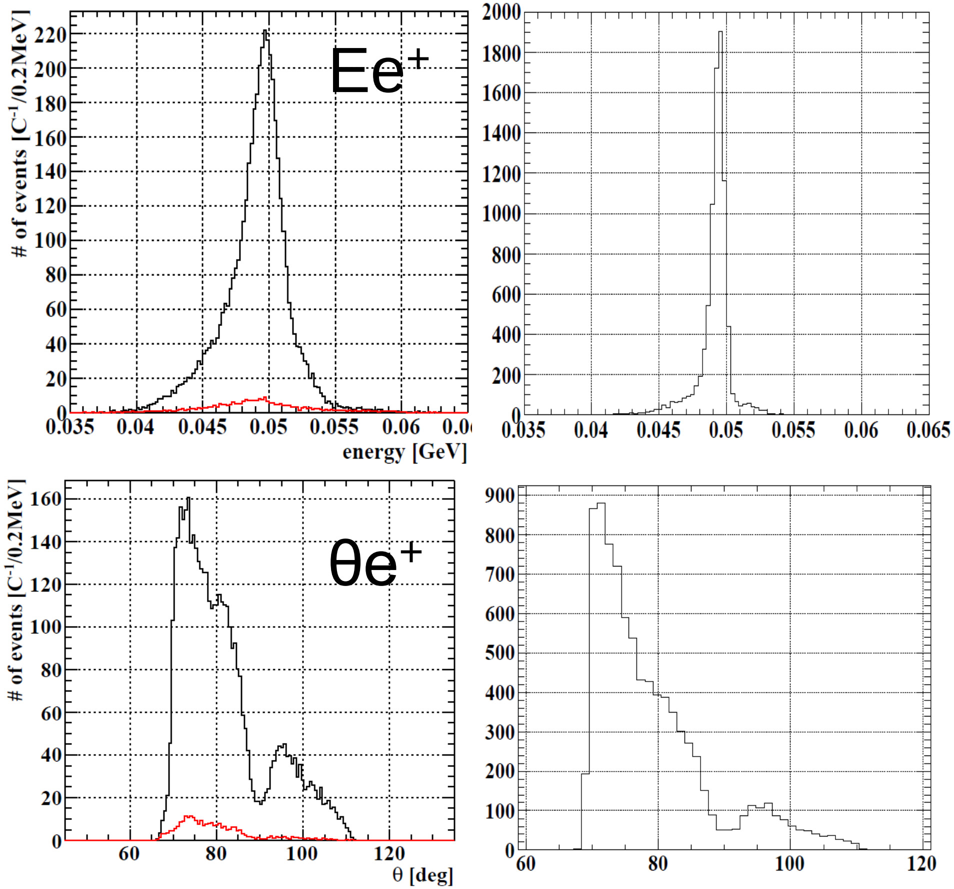
Mott scattering analysis

- Energy spectrum
  - Selection criteria
    - generated on the target plane
    - MEG fiducial volume
    - 35 MeV < $E_{positron}$ < 65 MeV
    - # of turn < 3
- Subtract the background energy spectrum
  - Red line, very small contribution
  - Forward dominant
    - Michel e+ form cloud muons
- After that, Mott peak and Mott background form MEG target remain





Mott MC comparison

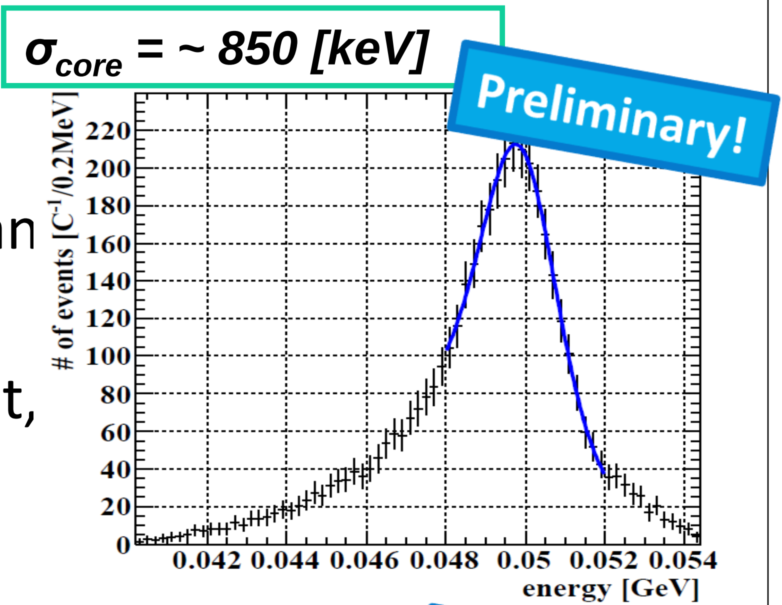


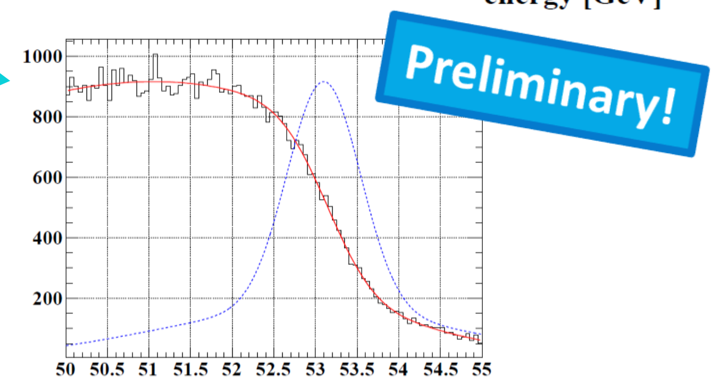
data MC

- MC status
  - w/o cloud μ+ & MEG target
  - Simulation also has tail and asymmetry, but it is sharper than data
  - asymmetry : Energy loss in target
  - tail : From analysis
- θ → almost same shape
- Few differences may be from uncalibrated detector resolutions and MEG target (on "parking position")

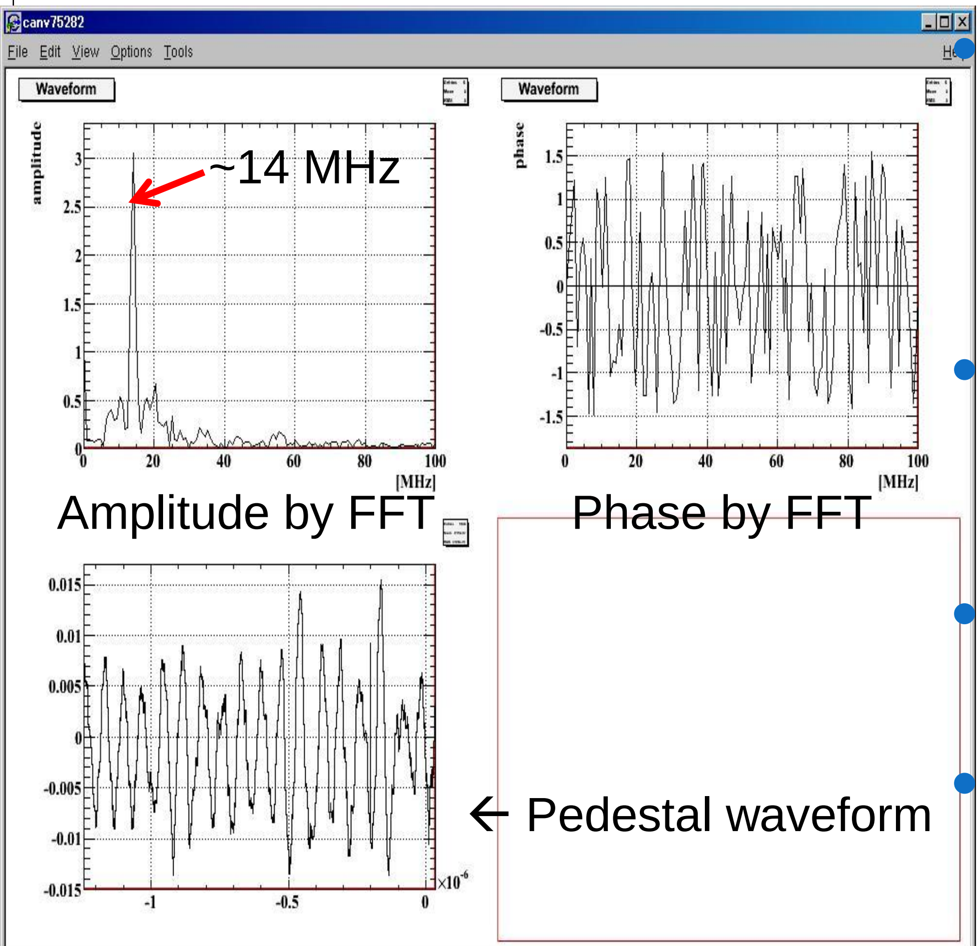
Preliminary result of Mott analysis

- It is important that positron tracks were reconstructed by assuming MEG target centered
- Energy spectrum fitted by double gaussian (considering asymmetry and tail)
- Although DCH has not been calibrated yet, momentum resolution estimated approximately 1.7 % (σ_{core}) for 50 MeV
  - 0.84 % (σ_{core}) from Michel data
- Need better understanding about tail and influence of MEG target
  - After that, we can use it as a "signal like" calibration source





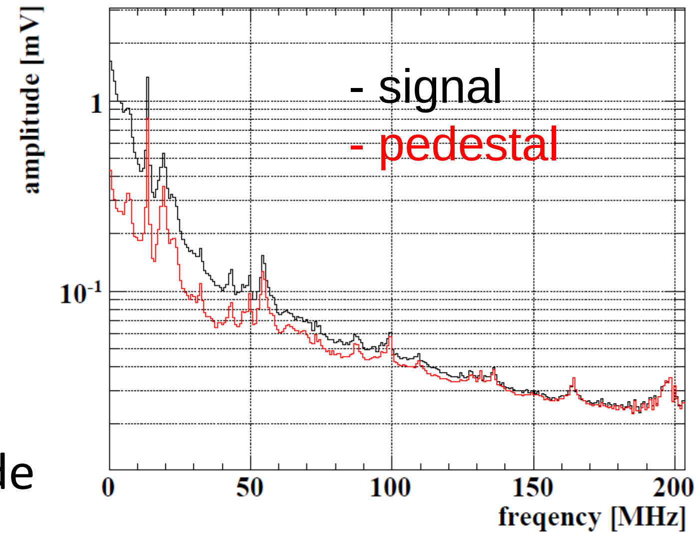
Offline noise reduction



- All data taken as a “waveform” in our experiment
  - It may be possible to reduce the noise by offline analysis
- Result of FFT
  - Clearly periodic noise exist around 14 MHz
- Previous peak can be seen at FFT analysis result
- This sample figure shows event by event and channel by channel FFT results

Offline noise reduction

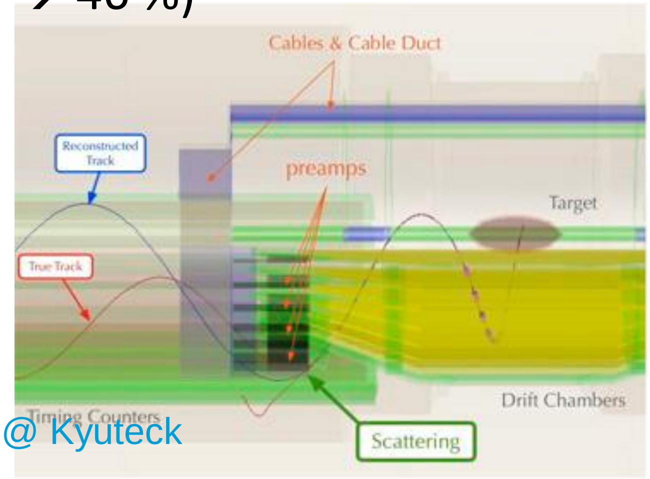
- Fitting needs huge amount of time to analyze
  - nonrealistic solution
- Filtering
  - Need to divide signals and noise clearly
    - At the point of frequency, signal cannot divide from noise easily → see right figure
- Subtraction
  - Less time for analysis but need to adjust timing between each channels and need pedestal channels
  - How to adjust phase ??

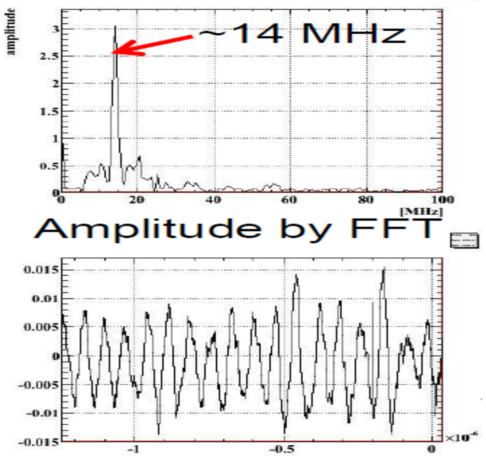


Result of Fourier transform for all channels few events accumulation
(peak → coherent noise)

Prospects

- Improvement of performance predicted by some updates
  - Reduce noise in terms of hardware
    - It will be replaced to new HV modules after this years run
    - Better grounding, Gain optimization …
  - To reduce materials between DCH and TC, we will change thinner cables and new design support structure hopefully
    - After that, we expected spectrometer efficiency will be improved about 15 % (40 → 46 %)





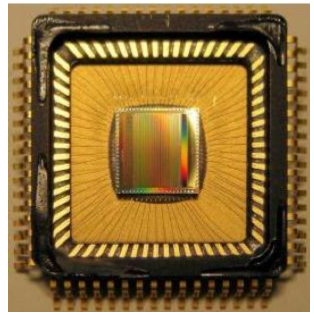
Summary

- Feasibility check for monochromatic calibration started
  - Momentum resolution from Mott is ~2.3 times worse than in 2009
    - However it from Michel is already nearly equal to last year's one
  - DCH calibration has not been finished yet
  - Need more study to use for calibration as a "signal like event"
- To get better performance, offline noise reduction needed
  - Noise components are analyzed by Fourier transform
    - We need fast algorithm except the filtering method
  - 1/3 noise suppression bring the improvement numbers below …
    - Momentum [%] : 0.74(core) → 0.7 Angle [mrad] : 11.2(θ) → 8(θ)
    - Vertex point [mm] : 2.3(R)/2.8(Z) → 1.4(R)/2.5(Z)
- Planning for further improvement is underway
- Better spectrometer performance will realize better sensitivity

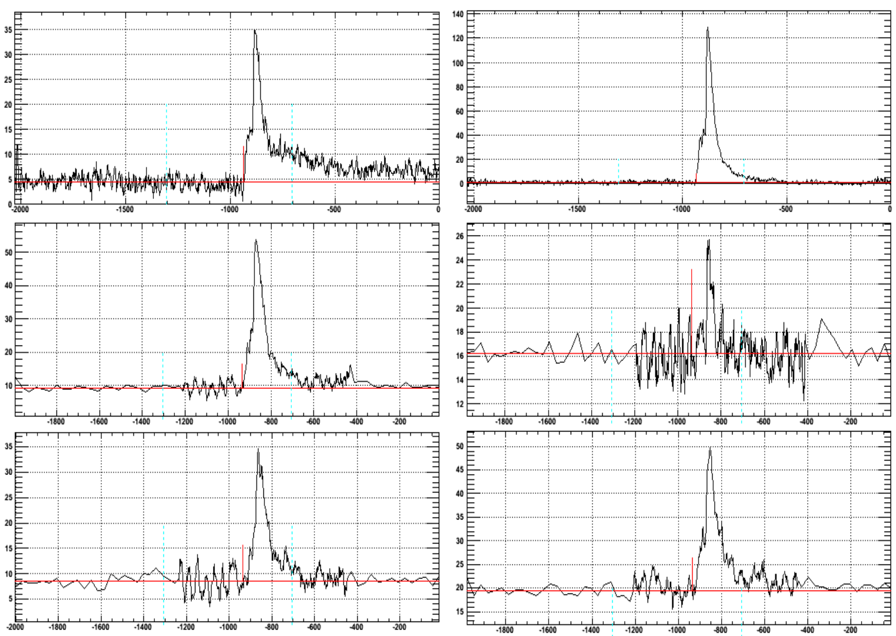
Backup

測定原理(1)

MEG drift chamber



DRS4 waveform digitizer

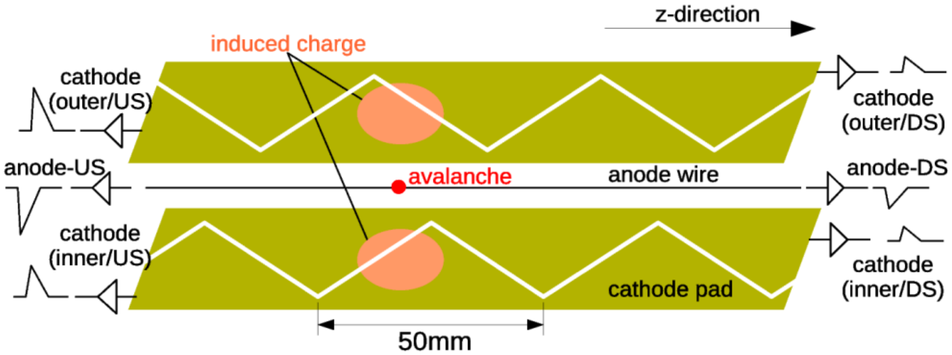


- Waveform analysis
  - MEG実験ではすべてのdrift chamber cellでwaveform digitizer(DRS4)によってデータ収集を行っている.
  - Waveformから
    1. Charge
    2. Drift time

    の情報を得ることができる

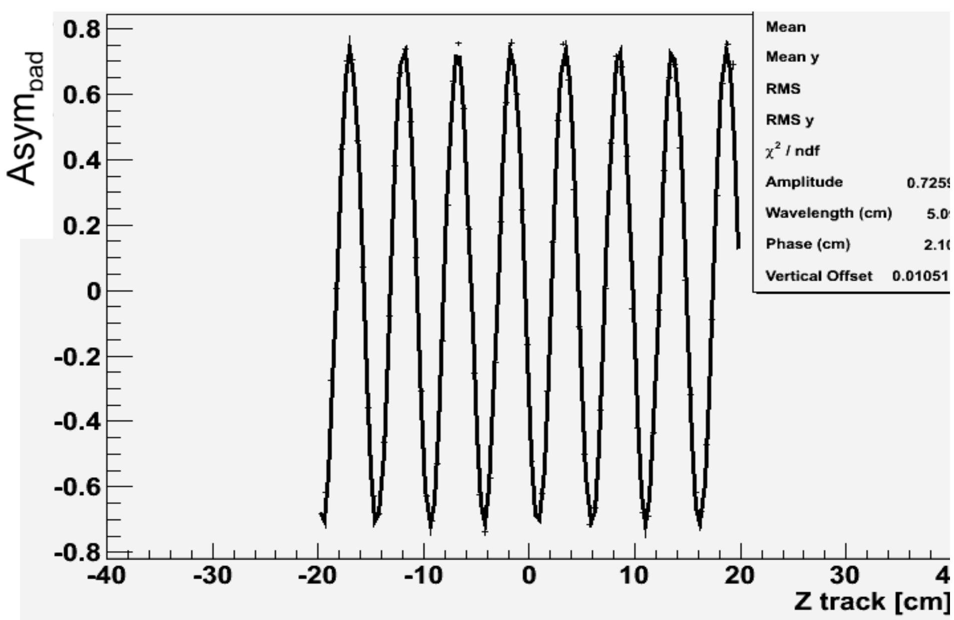
測定原理(2)

- Hit reconstruction
  - Z方向 : charge division
    - Vernier methodにより1mm以下のZ resolutionを達成する

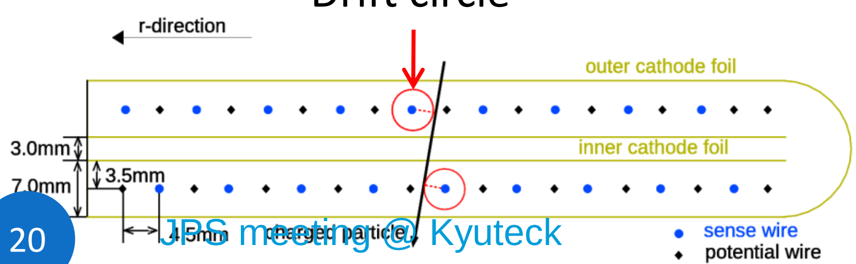


  - XY方向 : drift時間

$$A = \frac{Q_u - Q_d}{Q_u + Q_d}$$



Drift circle



Detector performance

- Efficiency
  - Spectrometer Efficiency
  - Drift Chamber Tracking Efficiency
- Resolution
  - Drift Chamber Position Resolution
  - Momentum Resolution
  - Angular Resolution
  - Vertex Resolution

Efficiency

- Michel positron trigger mixed in MEG physics run
- Spectrometer efficiency　：再構成されたMichel positronの数と、targetに止まったmuon数から計算できる
- Target muonの数はproton beamのcurrentから見積もることができる
  - $N_{obs} = 6.677 \times 10^{10} = N_{stop\mu} \times \Omega_{acc} \times \varepsilon_{(e+)}$
  - $N_{stop\mu} \times \Omega_{acc} = (15.5 \pm 0.7) \times 10^{10}$

$$\varepsilon_{(e+)} \approx (43 \pm 2)[\%]$$

$$\varepsilon_{DCH} \approx (93 \pm 4)[\%]$$

$$\varepsilon_{(matching)} \approx 46[\%]$$

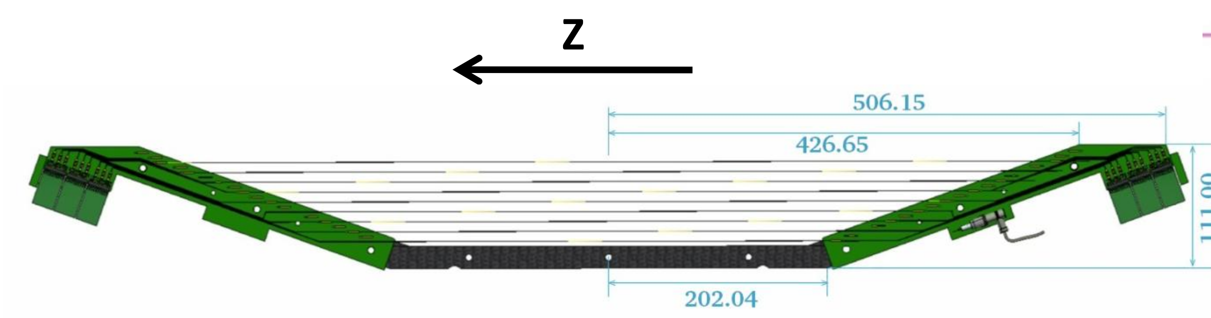
3 times larger!

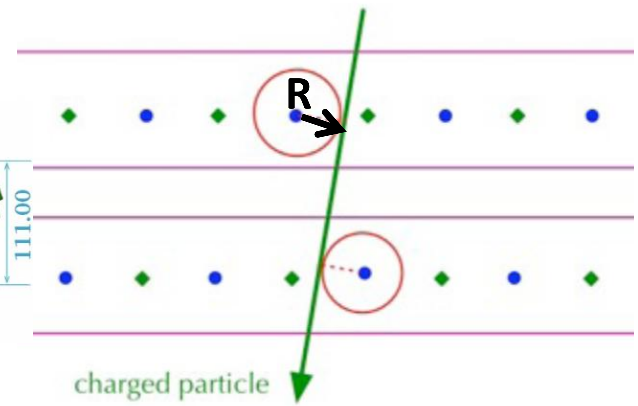
$\varepsilon_{(e+)} \approx 14[\%]$ In 2008

Resolution

- Z resolution
- R resolution

Drift chamber's intrinsic position resolution



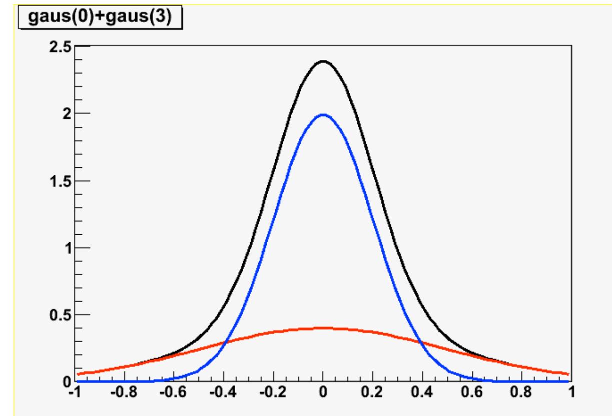


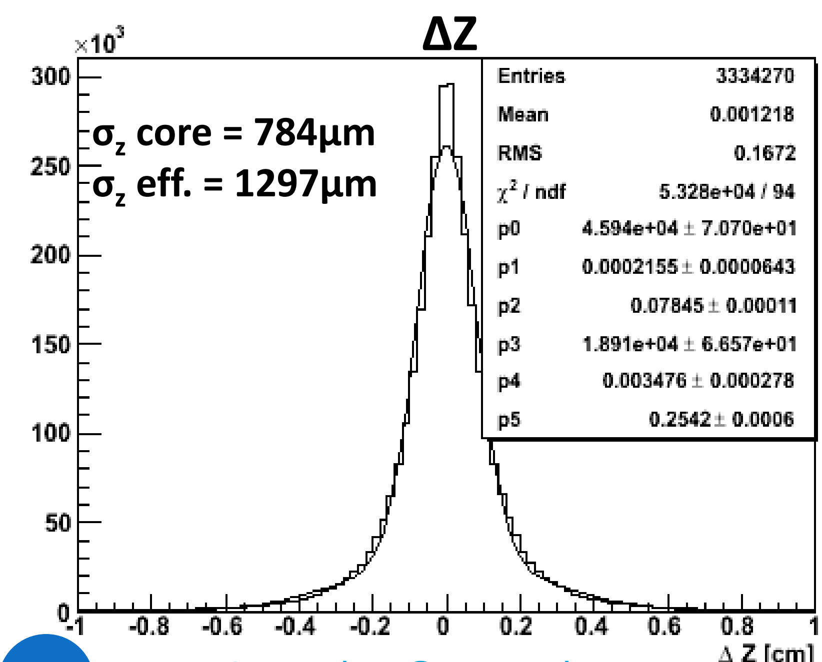
- Angular resolution
- Vertex resolution

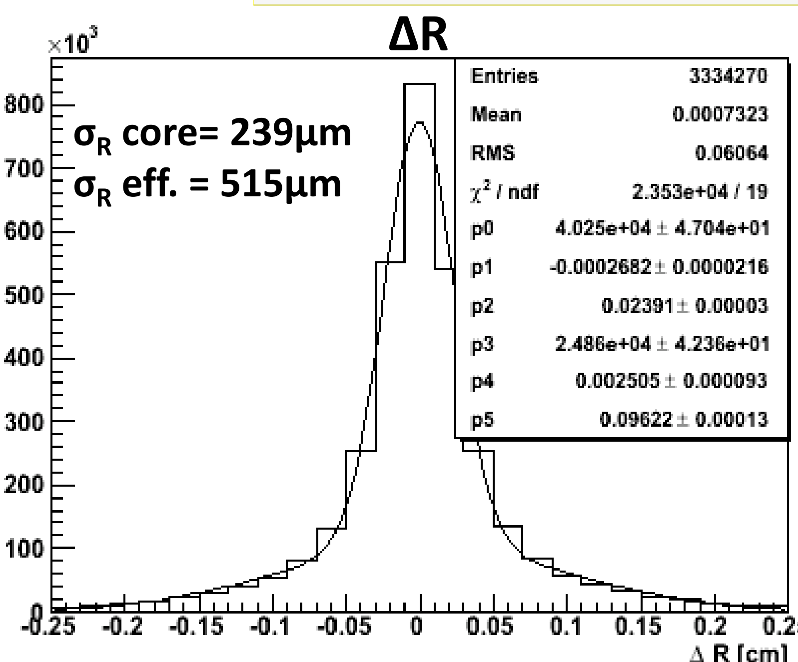
Spectrometer performance

Z/R resolution

- Z resolution : charge divisionで再構成されたZとZ in Trackの残差
- R resolution : drift timeから再構成されたRとR in Trackの残差
- Tailを考慮して2 gaussianでfitする







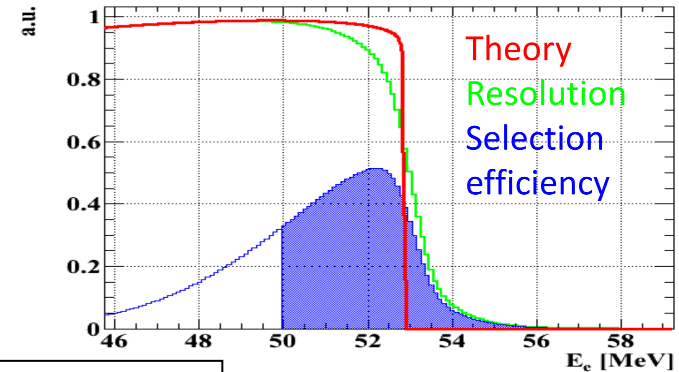
Momentum resolution

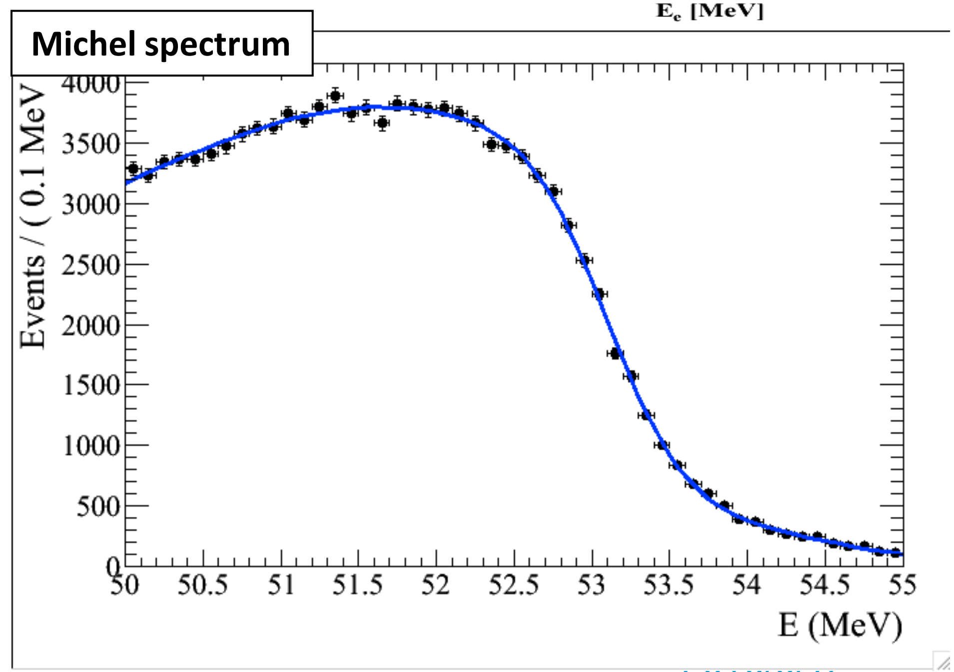
- MichelのtheoreticalなspectrumにSelection efficiencyの関数とresolutionをかけたものが実際のe^+ energy spectrumとなる

  → Michel Energy spectrum から resolutionを評価することができる
- Resolution functionとして3 gaussianを用いる
- 結果 : σ_p eff.=(0.57±0.02) [MeV]
- 52.8 [MeV] に対しては 1.08 % の resolutionとなる

今後MCとの比較等、quality checkを行う

$$\left(F_{Michel}(E)\times\Omega(E)\right)\otimes R(E)$$

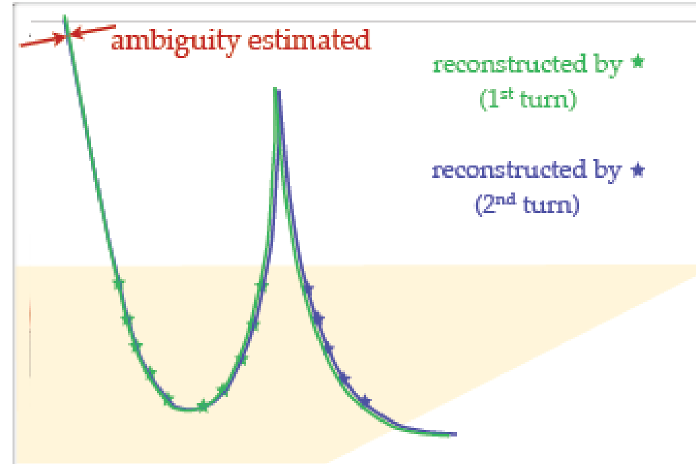


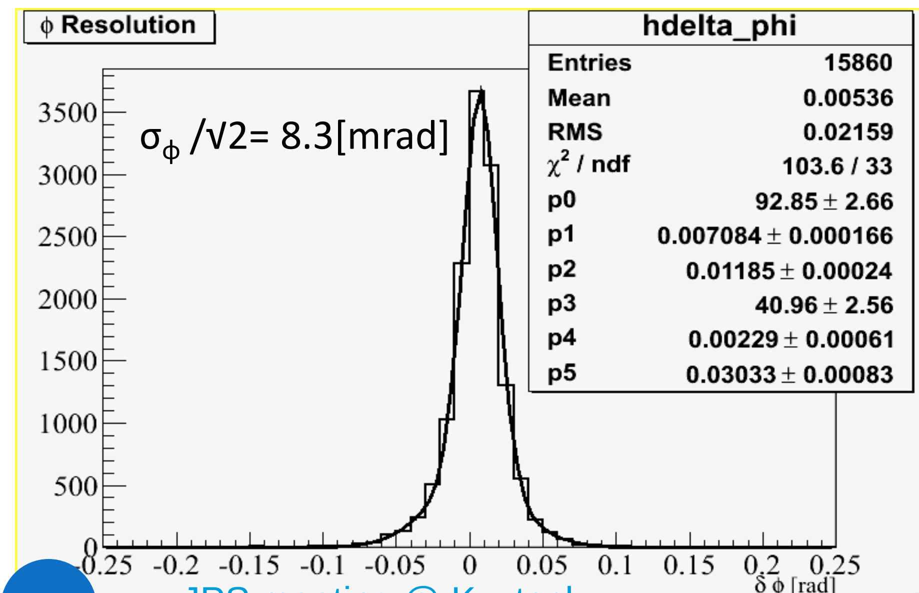


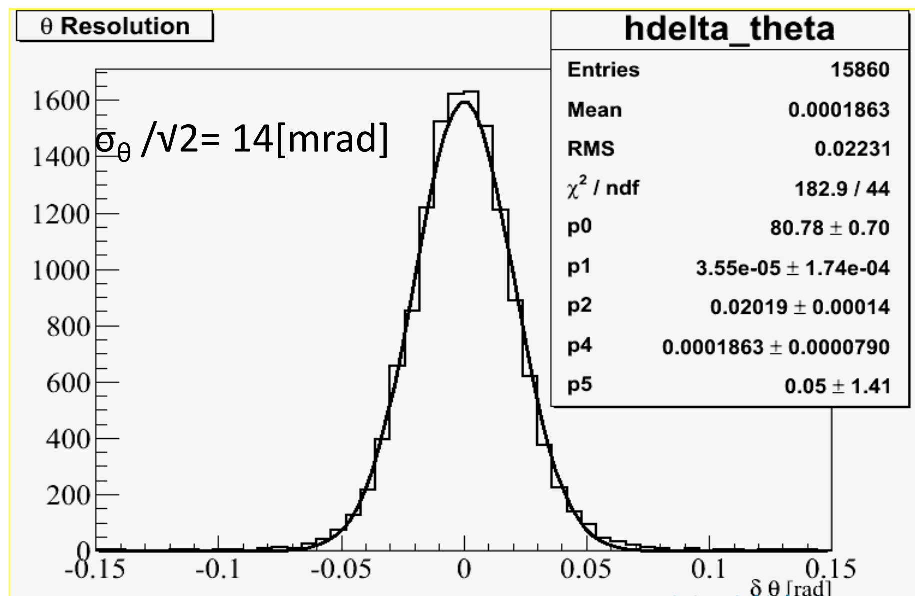
Angular resolution

- Angular resolution is estimated by double turn track
  - Compare 1st turn and 2nd turn
- MCによるstudyから、2 turn methodではθの角度分解能を実際より少し悪く見積もっていることがわかっている

  → これを補正する

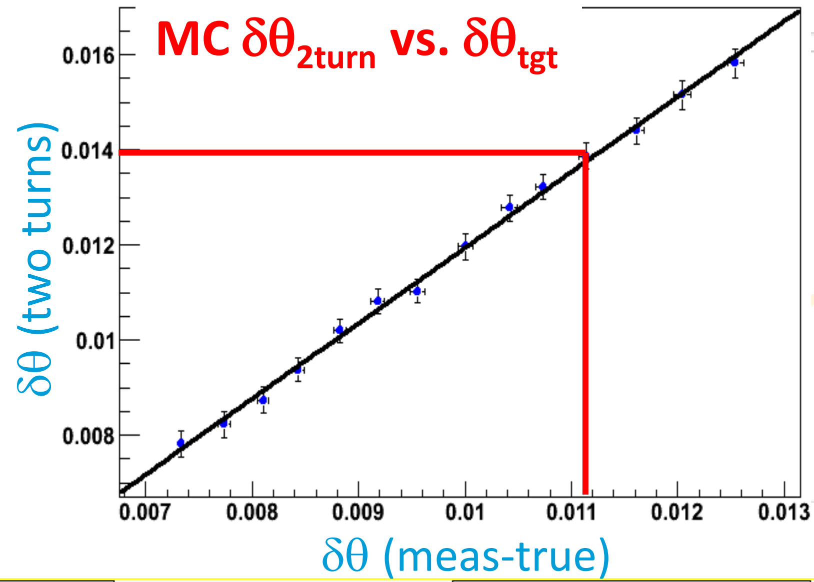


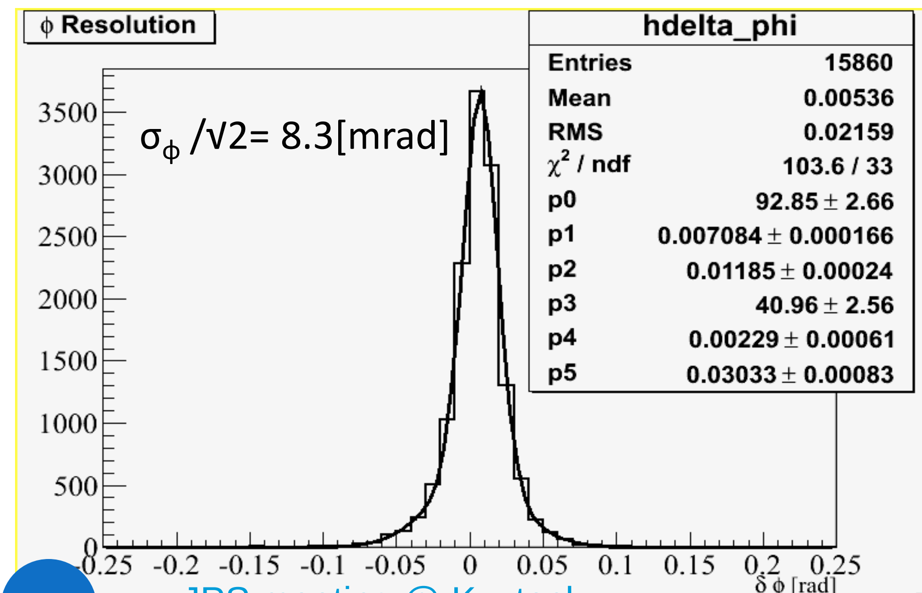


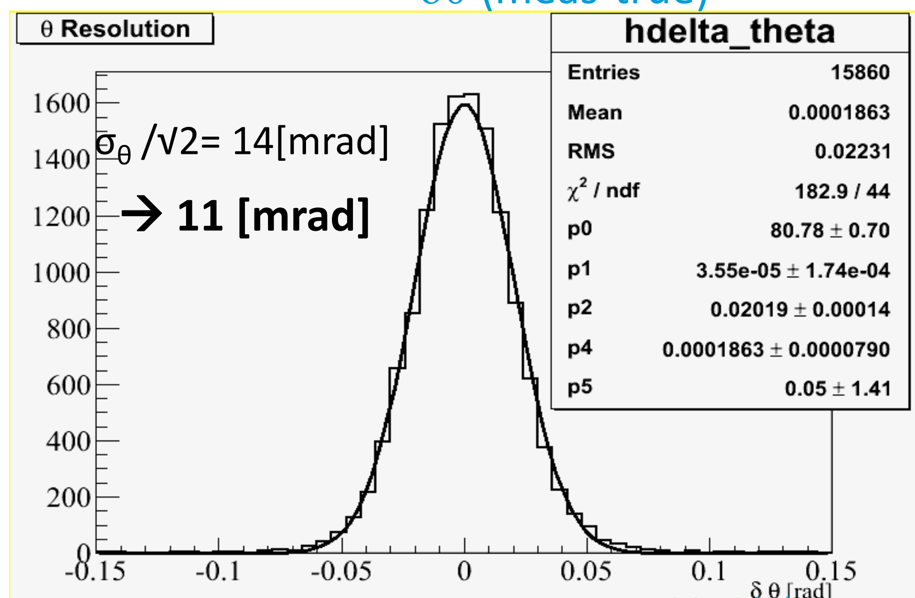


Angular resolution

- Trackをtargetまで戻した時の角度分解能
Track自身から求める
  - 2 turn method
- MCによるstudyから、2 turn methodでは角度分解能を実際より少し悪く見積もっていることがわかっている
  → これを補正する

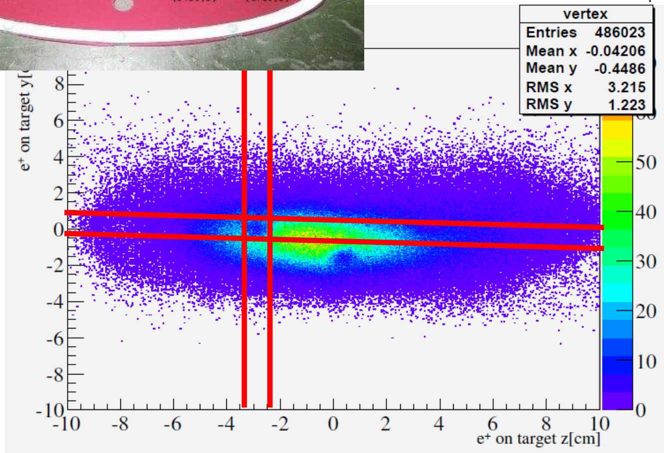






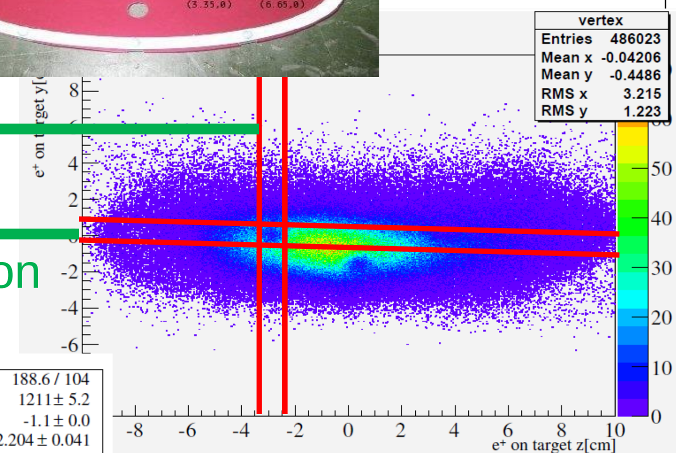
Vertex resolution

- Hole method
  - Target上にあけている穴を再構成されたvertexがどれほど再現できるかで、target上でのposition resolutionを見積もることができる



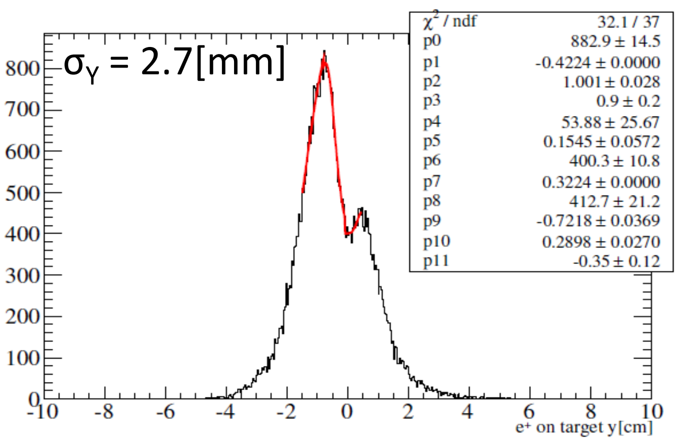
Vertex resolution

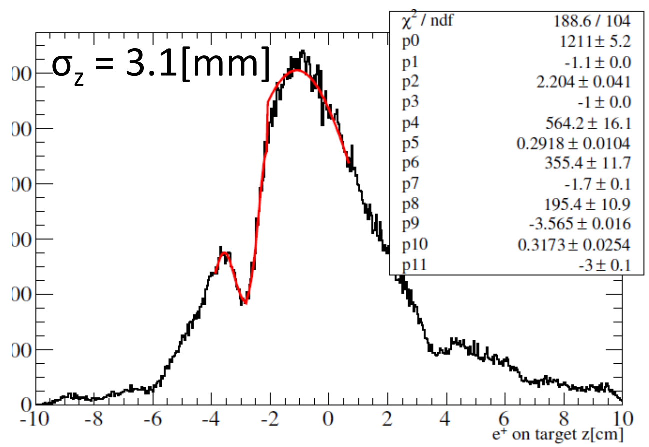
- Hole method
  - Target上にあけている穴を再構成されたvertexがどれほど再現できるかで、target上でのposition resolutionを見積もることができる



Y projection

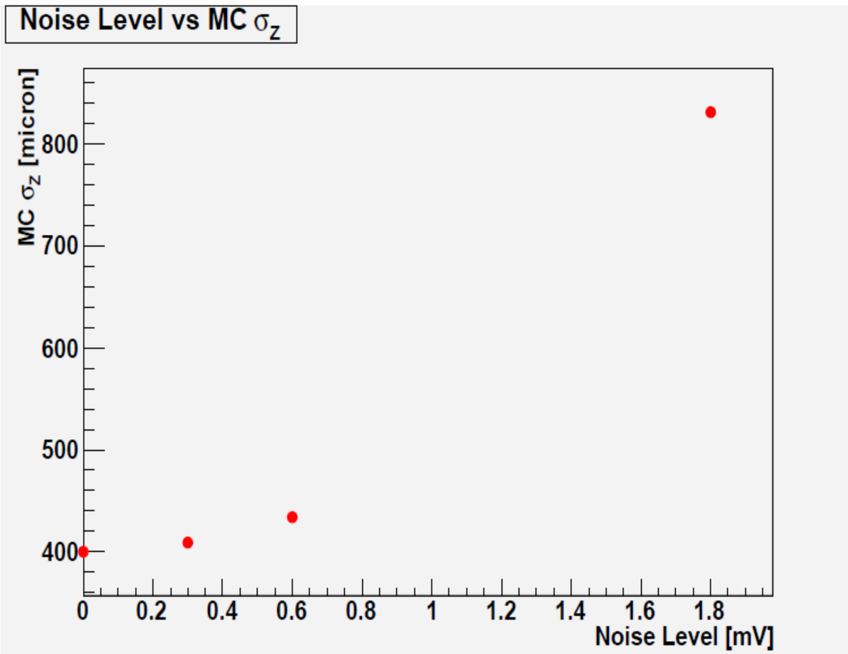
Z projection

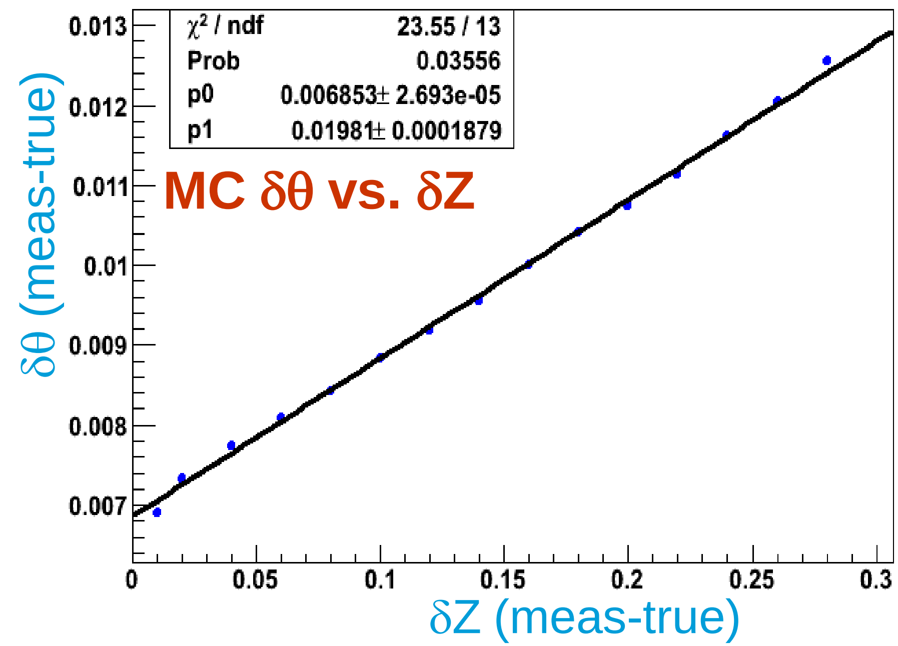




Noise

- 現在、drift chamberの分解能はnoiseによって強く制限されている





- Noise levelを1/3まで落とせればZ resolutionが2倍良くなる(MC simulation)
- Z resolutionが良くなればθ　resolutionも良くなる
- MEG実験ではdrift chamberからの信号をwaveformとして取得しているため、offline analysisで取り除ける可能性がある

Future prospects

- Calibrationが完璧では無いので、2009年のresolutionはまだ改善の余地あり
- 放電問題の解決によりEfficiency, Resolutionが改善した現在、Resolutionを主に制限しているのはnoiseである
- Ground 強化等、hard面でnoiseの低減を行う
- Drift chamberは先に述べたようにすべてのデータをwaveformとして収集しているため、offlineでnoiseを低減することも可能で、現在そのためのstudyを進めているところである

Summary

- 2009年runでの陽電子スペクトロメータの性能評価を行った
- 各値の2008年runとの比較を表に示す

Preliminary!

	2008	2009
Efficiency (%)	14	43
Z/R resolution (μm)	819/202	784/239
e^+ momentum (%)	1.6	1.08
e^+ Angle (mrad)	10(ϕ)/18(θ)	8(ϕ)/11(θ)
Vertex resolution (mm)	3.2(R)/4.5(Z)	- /3.1(Z)

- これらの結果はpreliminaryなものであり、calibrationや解析方法の改善等により、向上する可能性がある
- さらにresolutionを向上させるために現在soft wareによるnoise reduction algorithmのtestを進めているところである