MEG

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KEK physics seminar on 20/May/2008

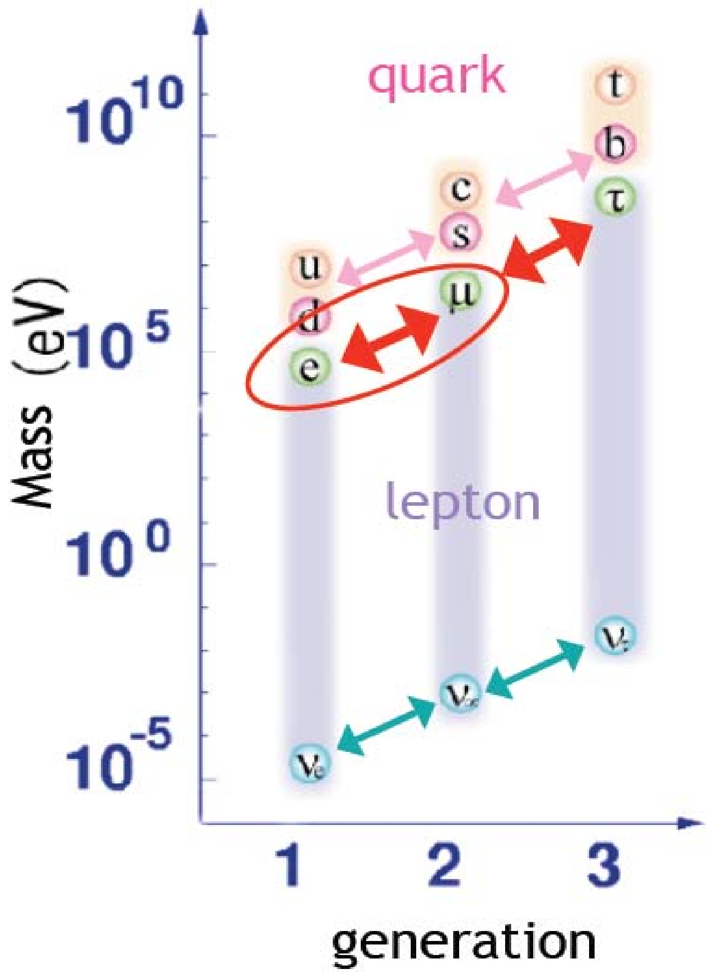
Overview

- What is MEG?
- MEG detector
- MEG status and future plan
- Summary

What is MEG ?

- Aiming at observing $\mu \rightarrow e\, \gamma$ event with a sensitivity of ~10^{-13}

Why do we want to search for μ→eγ?



Quark Mixing : B factories etc

Unification of quarks and leptons (GUT)

Charged Lepton Must Also Mix!

μ → e : most sensitive

Seesaw mechanism to make neutrinos light

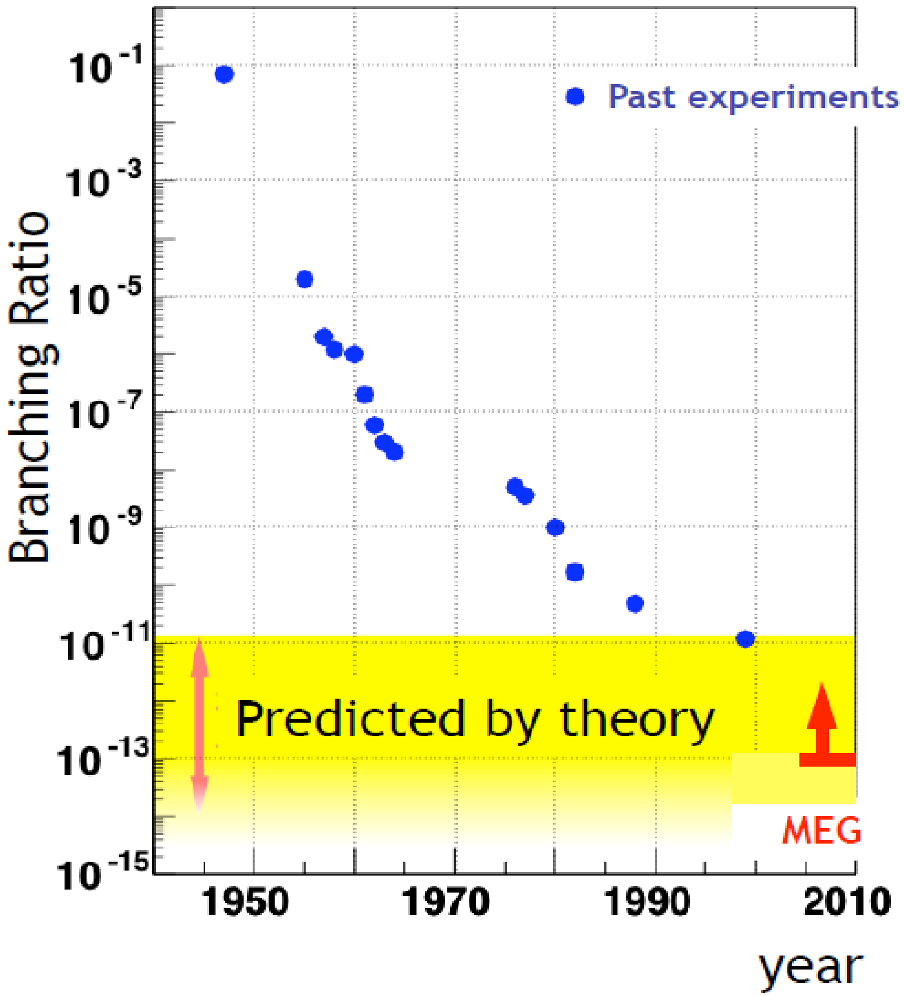
Neutrino Oscillation : SuperK etc

Explores GUT/seesaw via SUSY

S.Orito and T.Mori

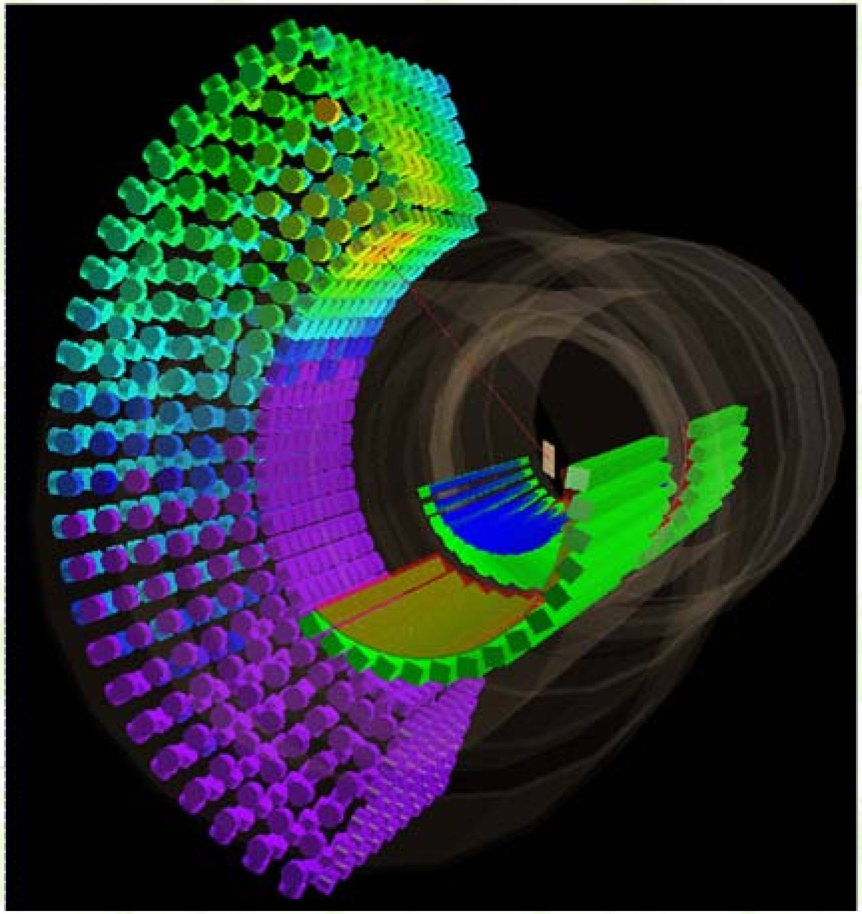
μ->eγ Search Chronology

- Muon discovery in 1937
- Order of 10 improvement in 50 years
- Best limit by MEGA collaboration, Br(μ->eγ) < 1.2×10^{-11}
  - $\mu Ti \rightarrow eTi$ < 7×10^{-13} (SINDRUM II)
- Strong motivation
  - Neutrino oscillation
  - SUSY GUT

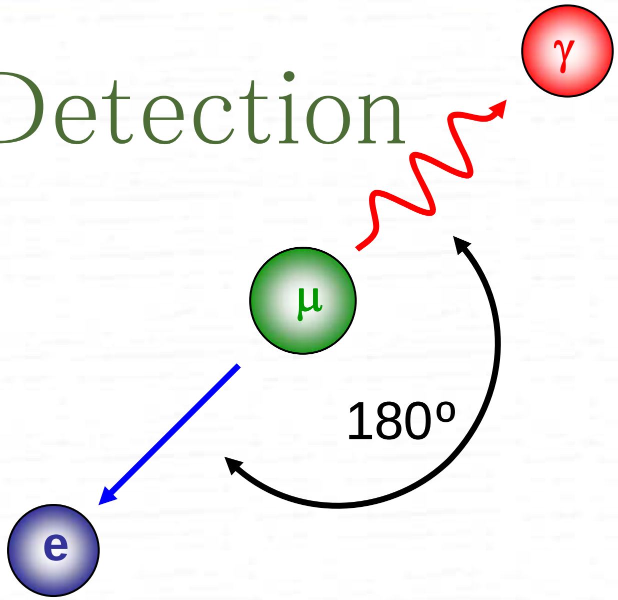


Y.Kuno

How do we search for $\mu \rightarrow e\gamma$?



μ → eγ Signal and Detection

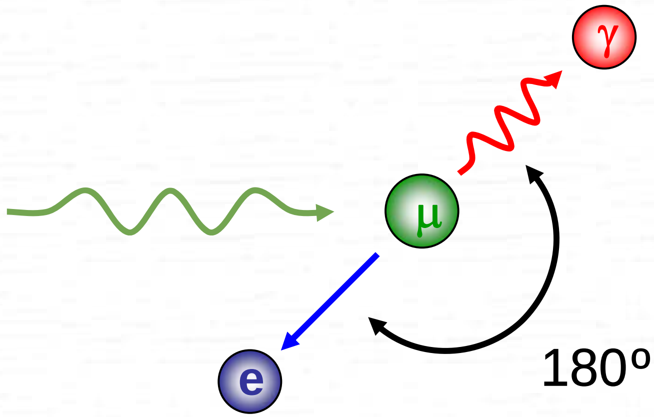


- High intensity muon beam
  - DC is better than plused
- Large acceptance of the detector system
- Good detector resolutions to suppress background

MEG Detector

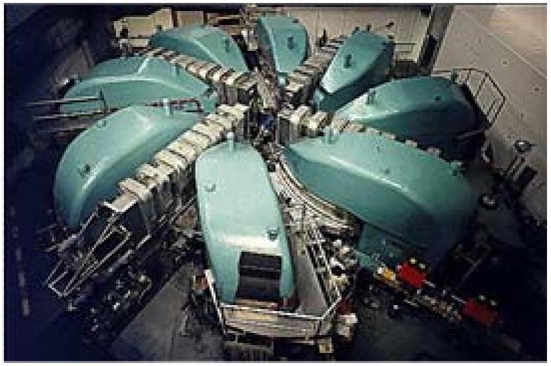
Three Major Components

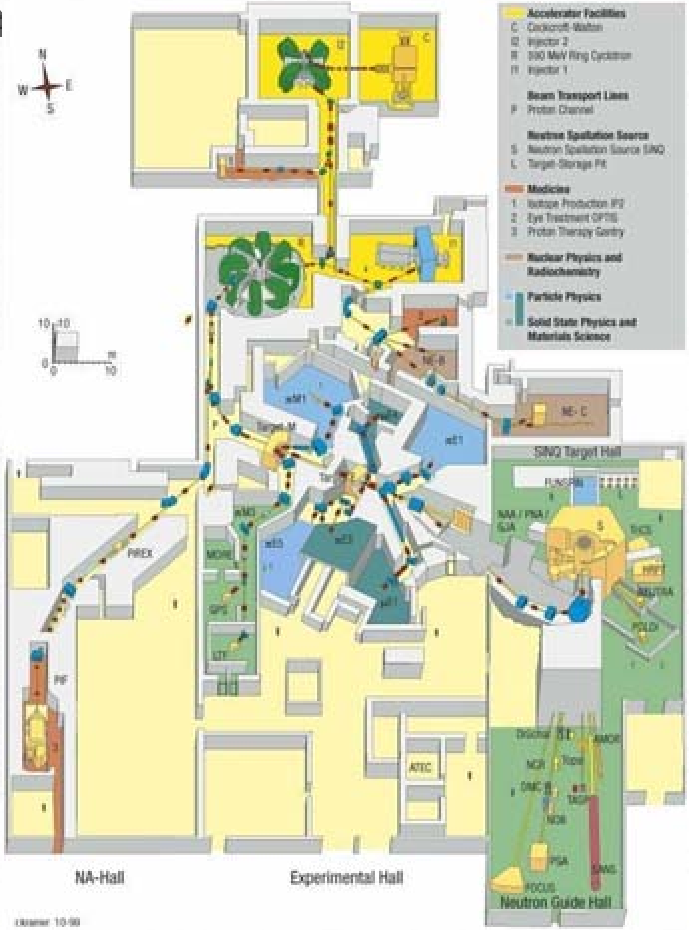
- Muon beam transport system
- Positron detector
- Photon detector



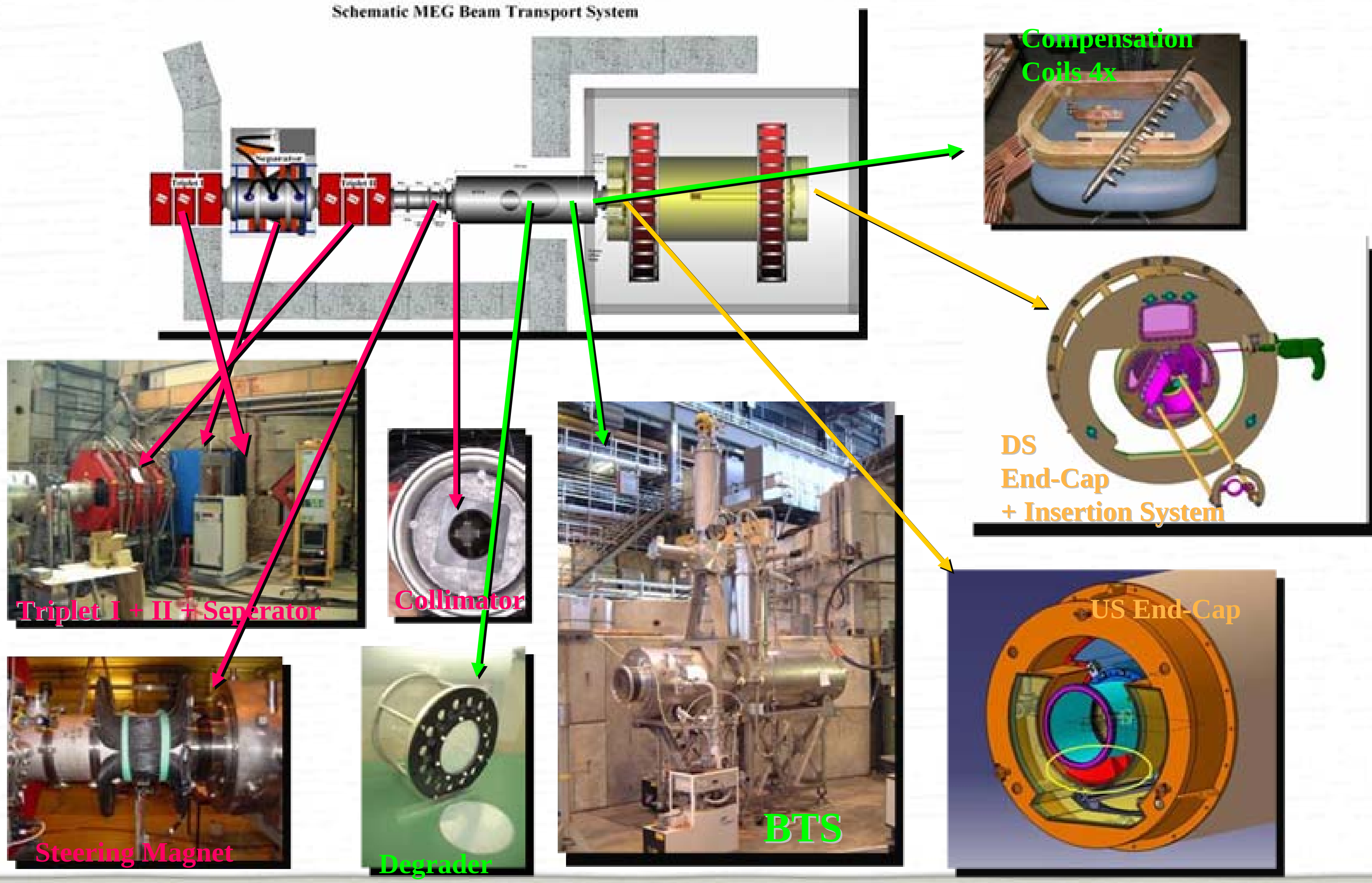
Muon Beam at Paul Scherrer Institute

- World most powerful proton cyclotron
  - 590MeV
  - > 2mA
- Particle physics experiment, π and μ
- μsR
- Neutron





Muon Transport System

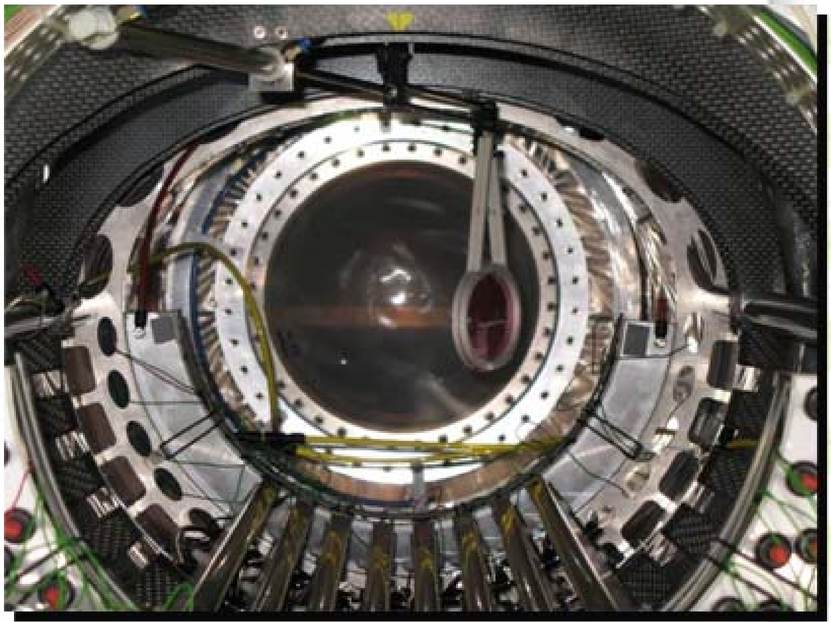


Target System

- Target System:
  - 175μm Polyester ellipse 210x70 mm
  - Rohacell support frame + stems
  - strain-relieved target mount
  - He-driven pneumatic insertion
  - electronic position end-markers

Polyester/Rohacell target

- Expected Muon Stop-rate: $Rs \sim 0.62R_0$
  - R_0 = incoming muon rate
- Decay + He interaction $\sim 12\% \, R_0$
- Stop in slanted target $\sim 70\% \, R_0$

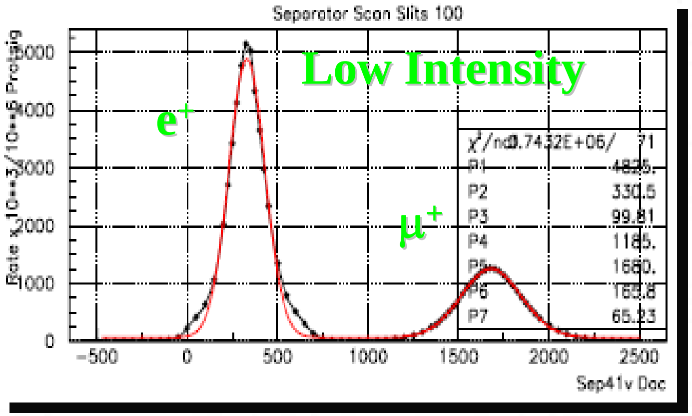


Inside COBRA in parking position

Beam Commissioning Run Results

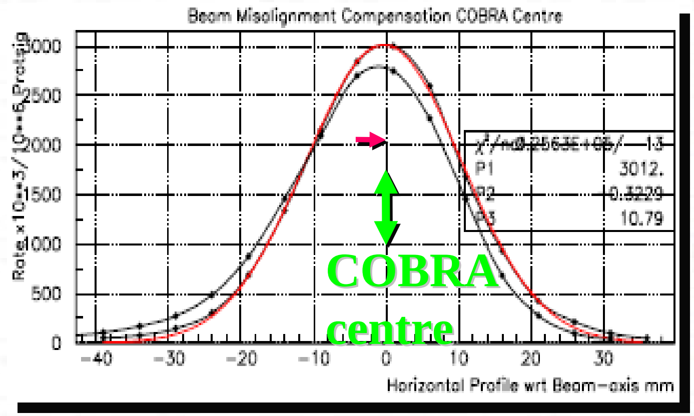
- Rate at Entrance COBRA $1.15 \cdot 10^{8}$ $\mu^{+}s^{-1}$ at 1.8mA, 4cm Tg
- Rate at COBRA centre > $6 \cdot 10^{7}$ $\mu^{+}s^{-1}$ at 1.8mA, 4cm Tg
- Beam Spot σ ~ 10.8 mm (as expected)

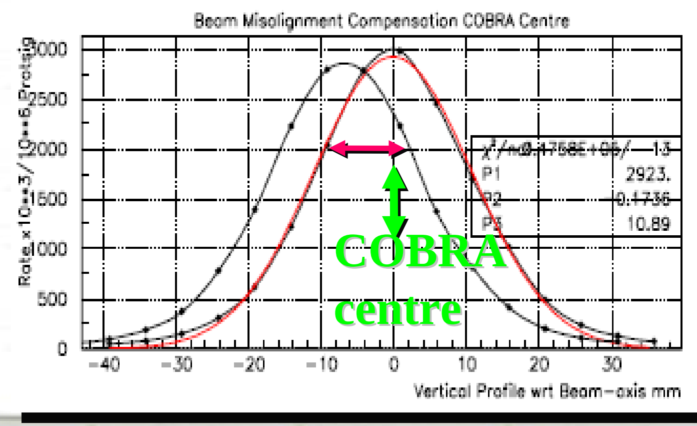
Collimator transmission ε = 95%



SMH41 SMV41 Correction at Centre of COBRA

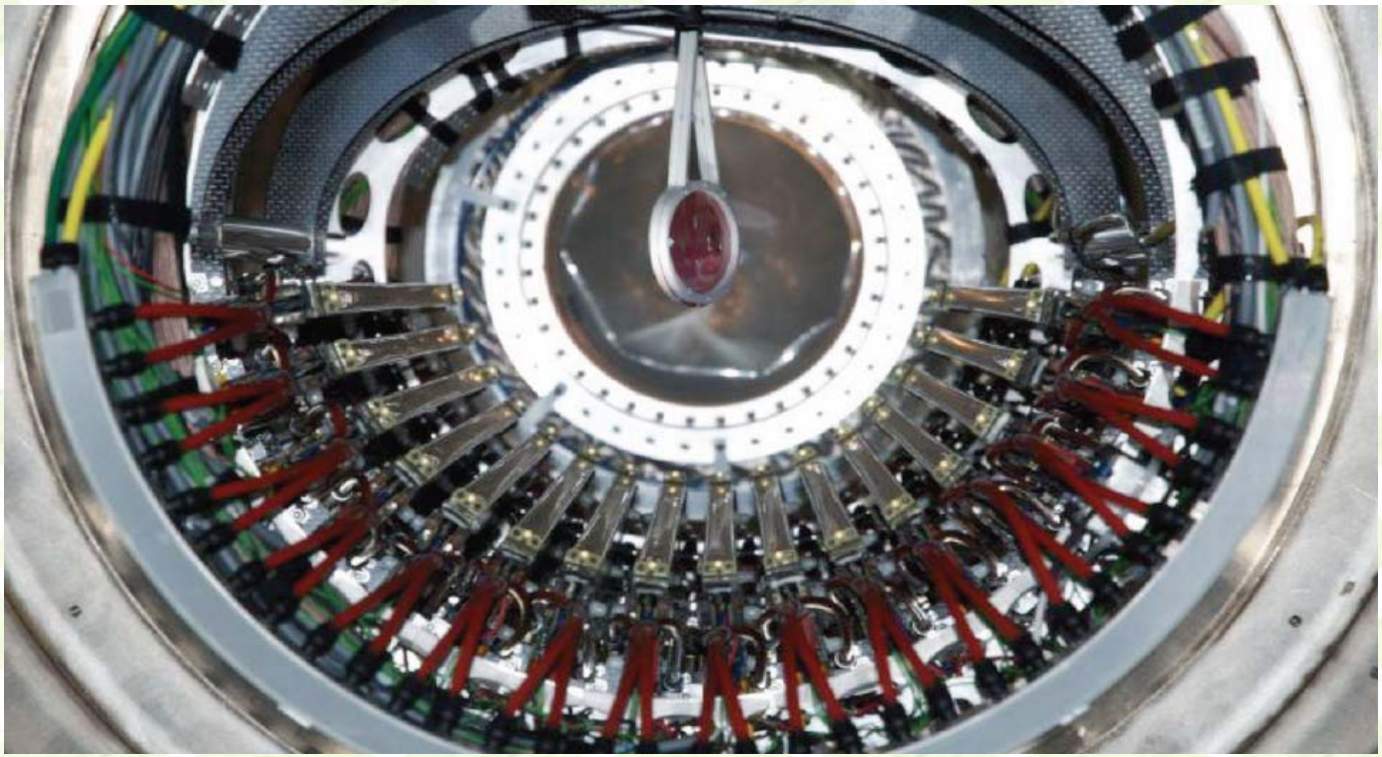
~ 2 mm Horizontally
~ 7 mm Vertically



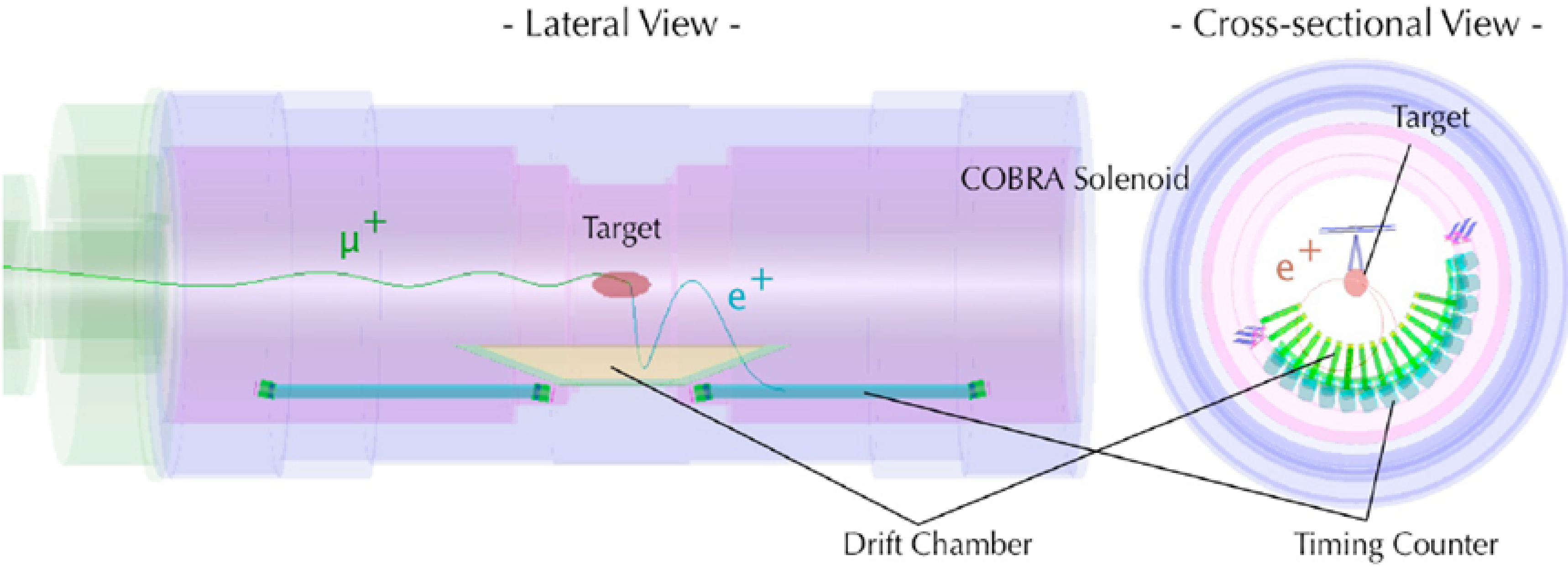


Separation Quality
High Intensity (slits open) 7.4 σ
Low Intensity 8.1 σ

Positron Detector



Positron Tracking System



Solenoid

superconducting solenoid
gradient B-field (0.5-1.7 T)
very thin conductor and
cryostat wall ($0.2X_0$)

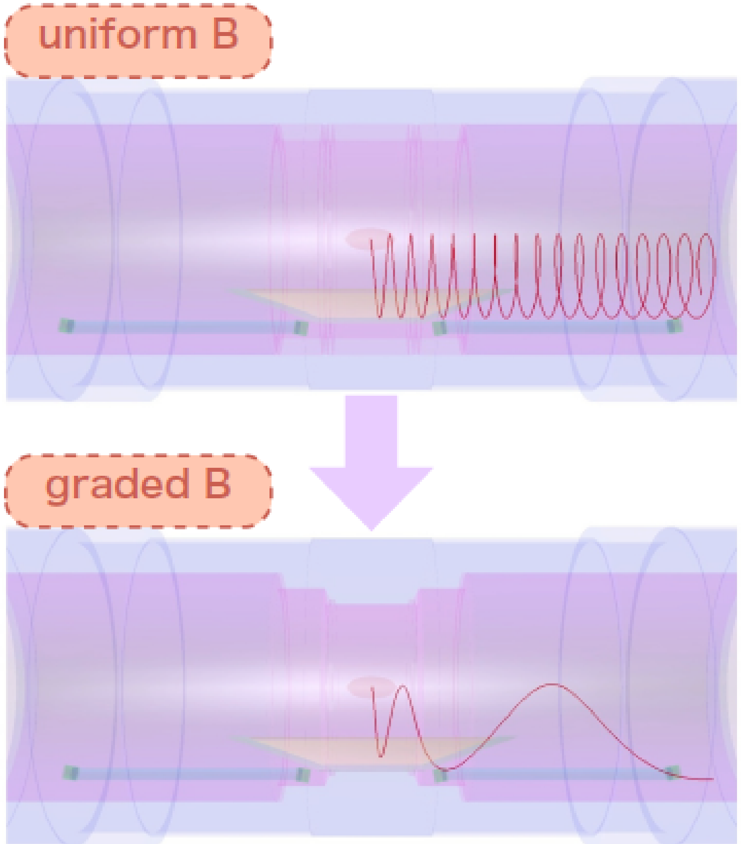
Drift Chamber

segmented radially (16 sectors)
helium:ethane (50:50)
opened-frame
very thin cathode foil with pads

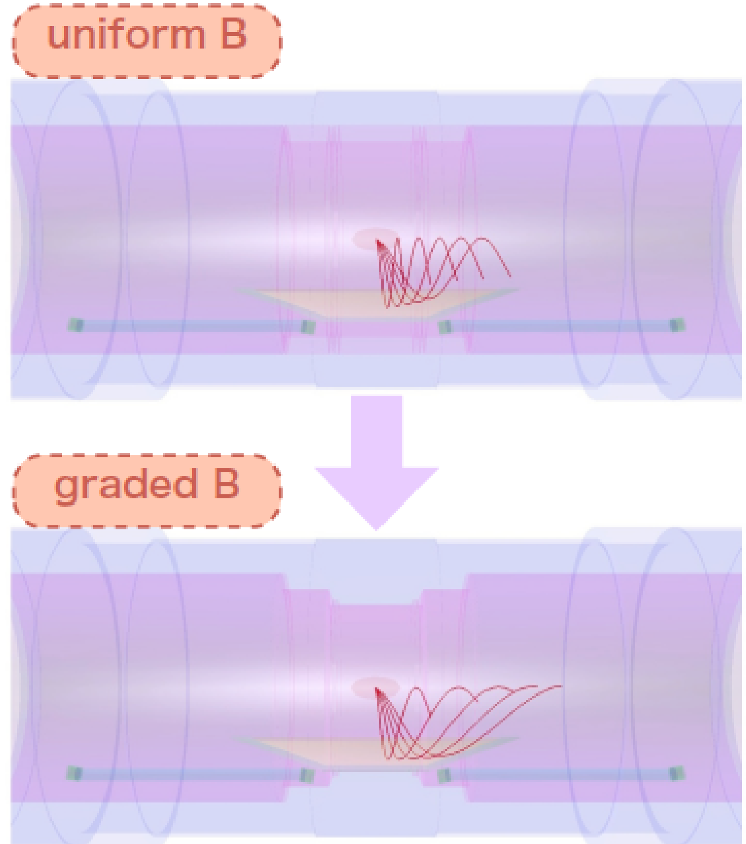
Timing Counter

2-layers of scintillators
- scintillator bars (outer)
- scintillator fibres (inner)

COBRA Magnet
(Constant Bending Radius)

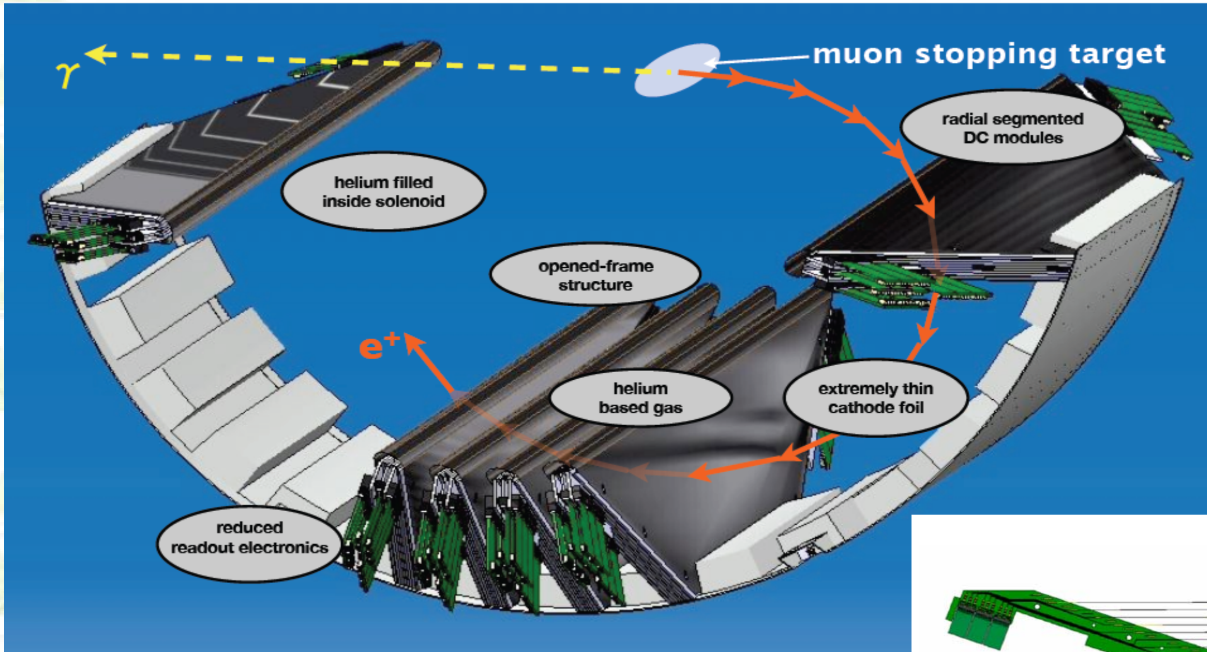


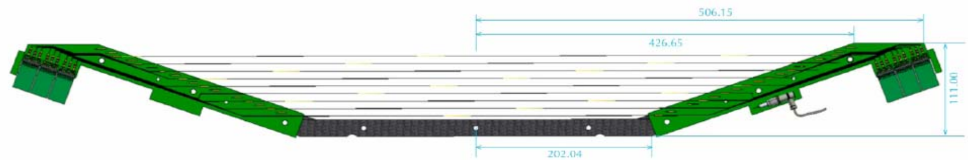
low energy e^+ quickly swept out

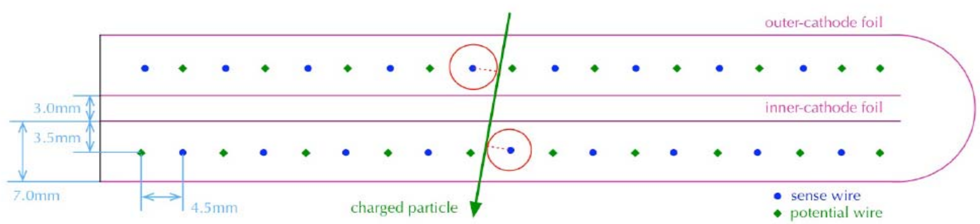


constant bending radius
independent of emission angles

Drift Chamber System

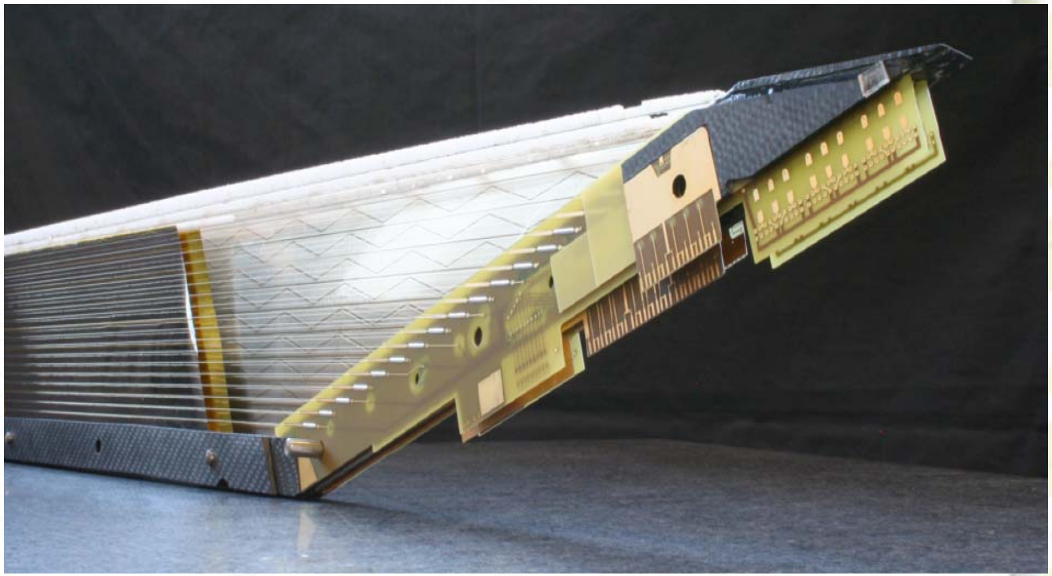




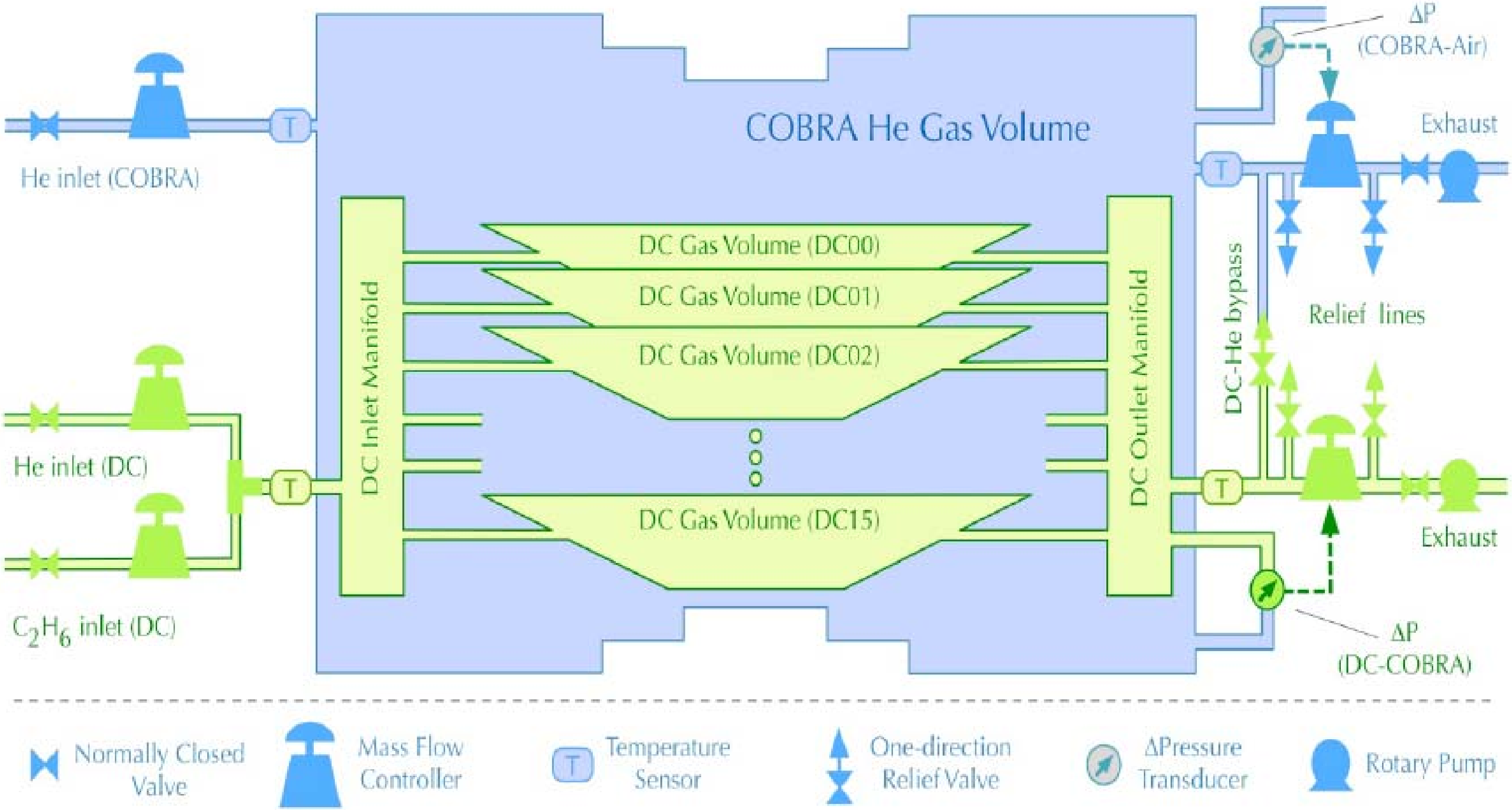


Drift Chamber Module

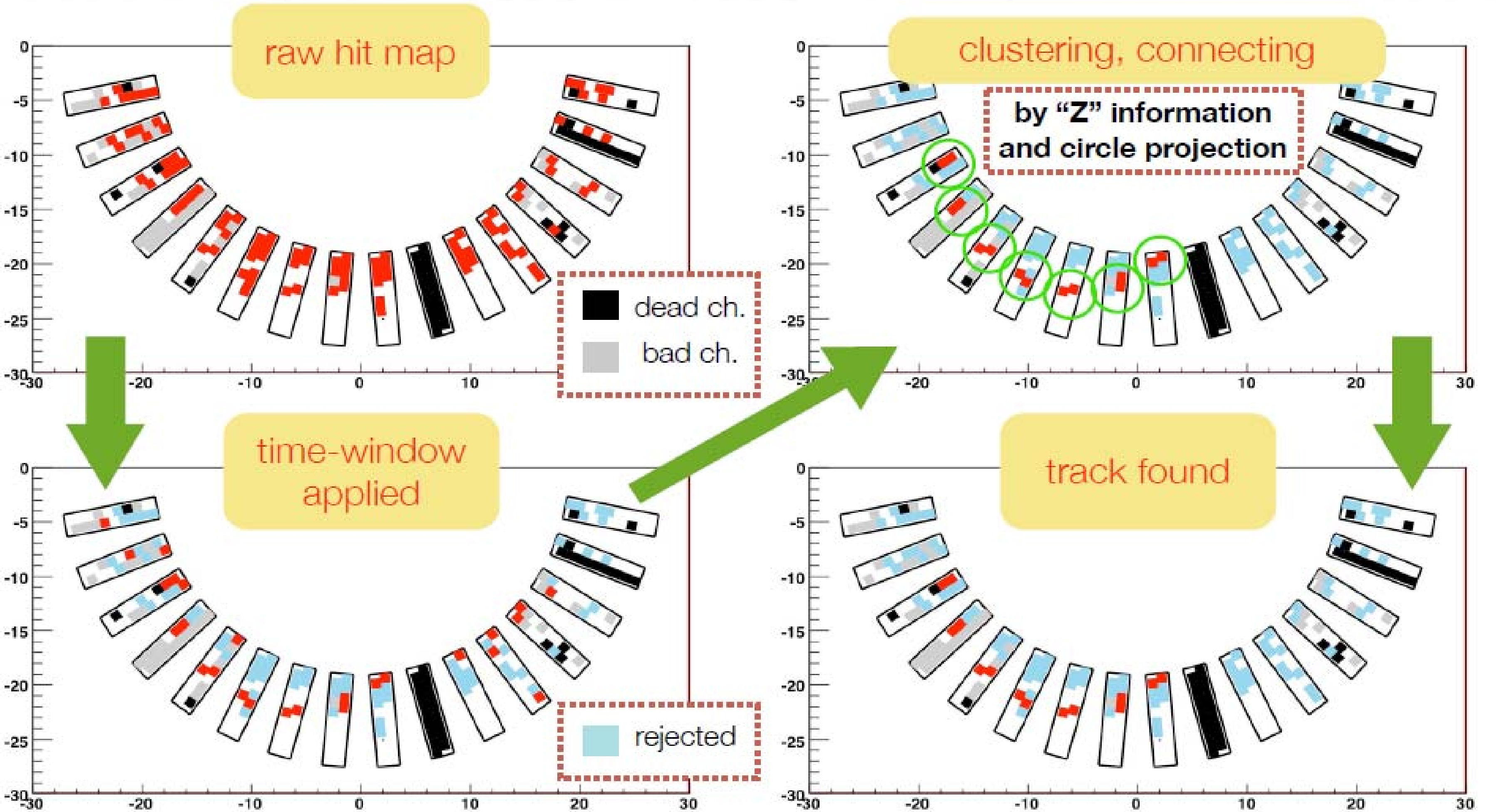
- No structure on muon stopping target side
- Precise pressure control system



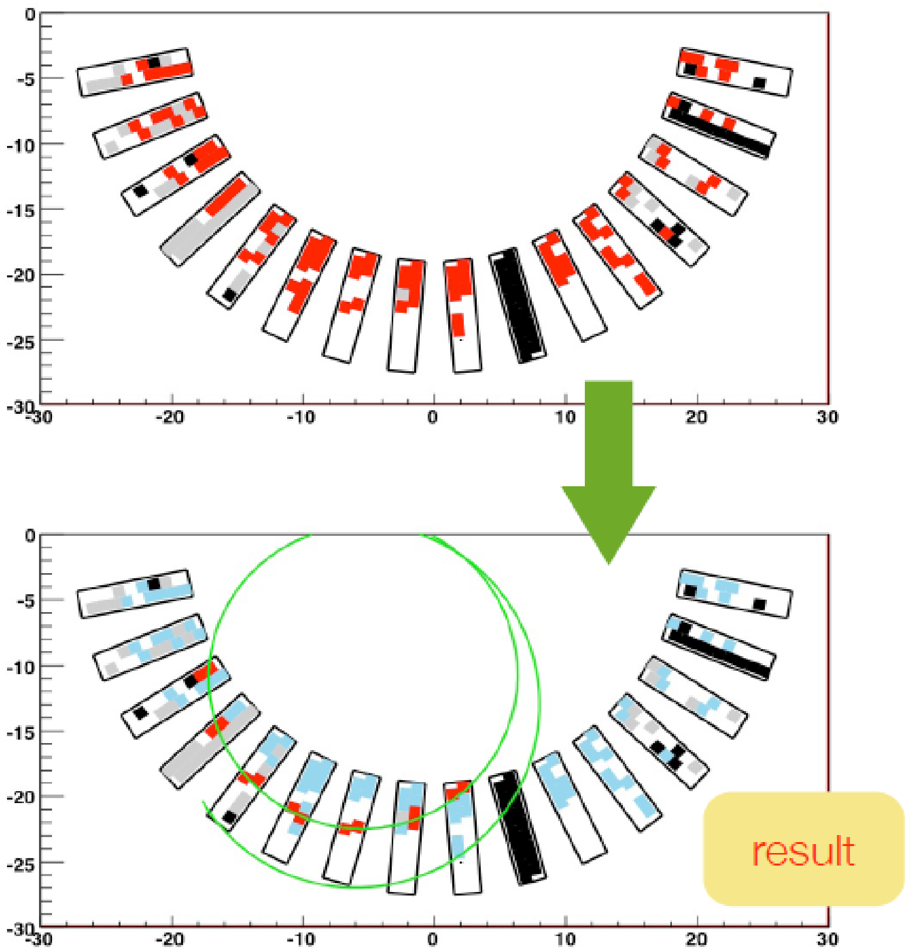
Gas Pressure Equalization System

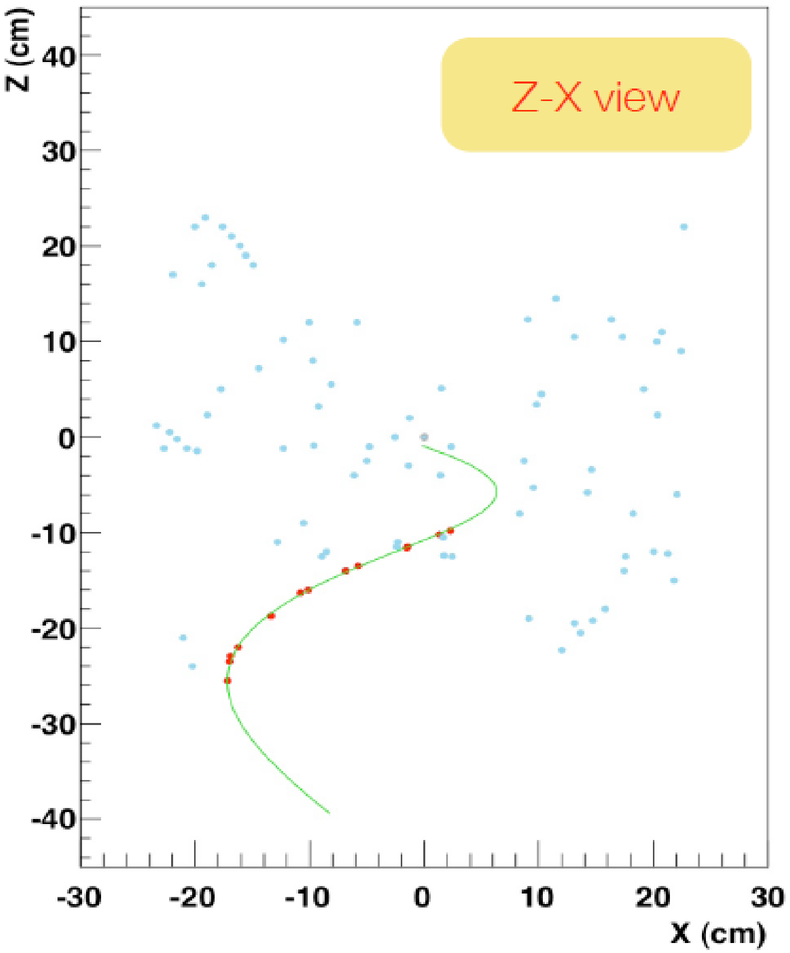


Track Finding

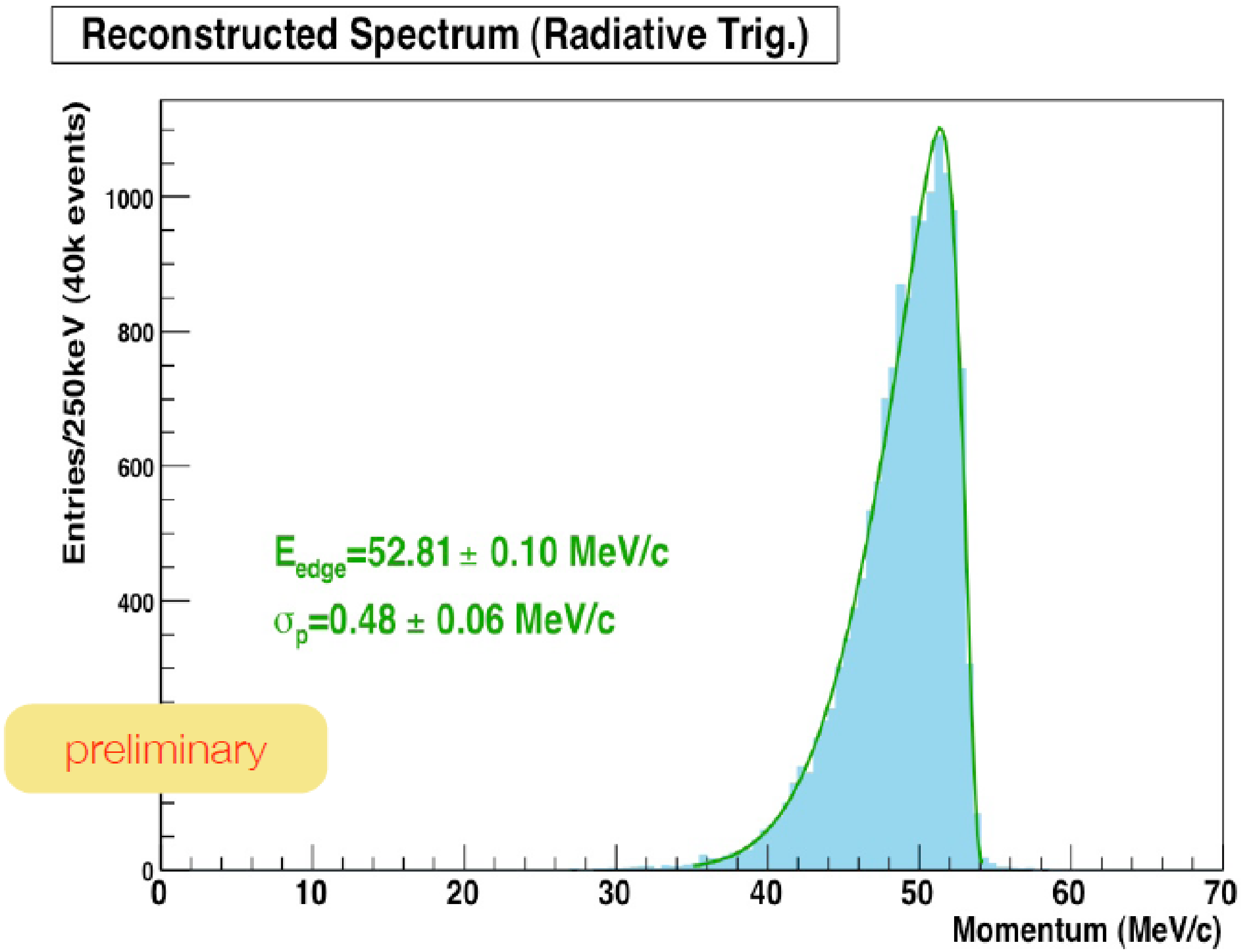


Track Fitting





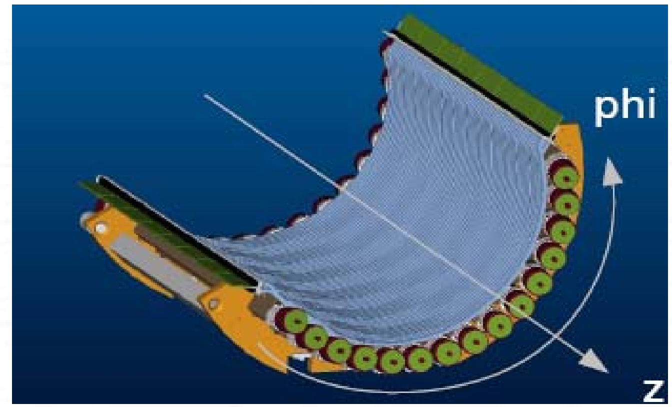
Performance in 2007

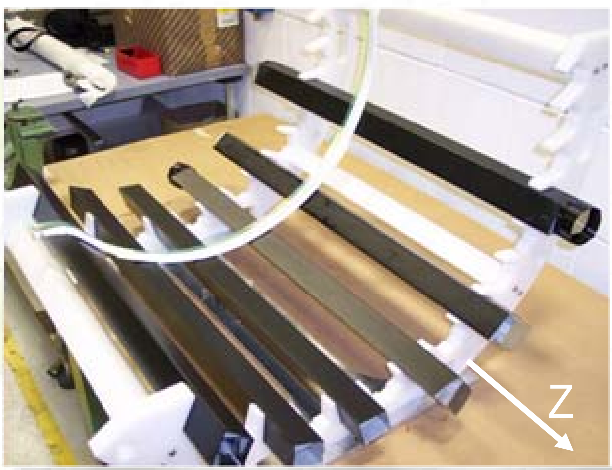


- End-point is fitted to the convolution of "theoretical response function" and "Gaussian", with three free parameters; "E_{edge}", "σ_p" and "Normalization"
- σ_p =480 keV (=0.9 %)

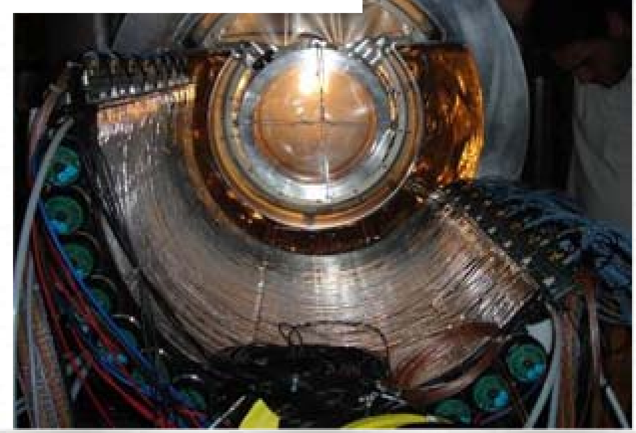
Timing Counter

- 30 plastic scintillation bars for timing
  - Read out by 2” PMTs at both ends
- 256 Scintillation fibers for z position
  - Read out by APDs at both ends
- Goal : $\sigma^{\sim}$40ps



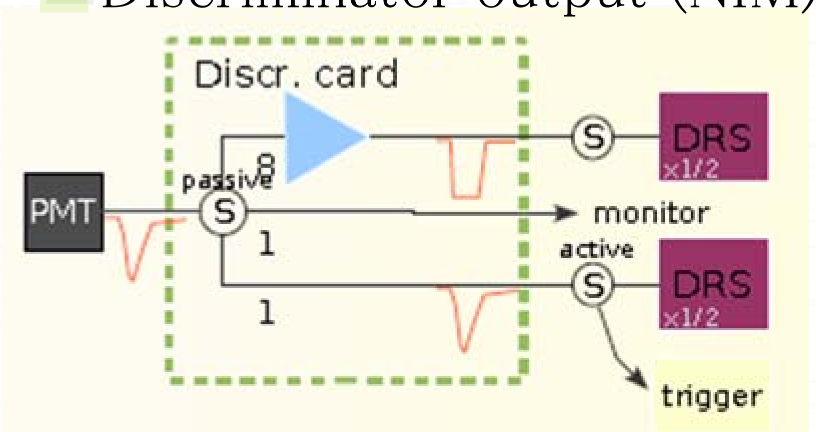


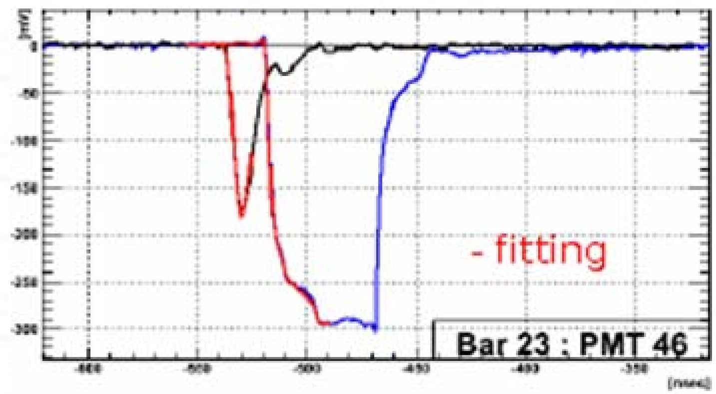

TC with fibers exposed


TC before insertion in COBRA

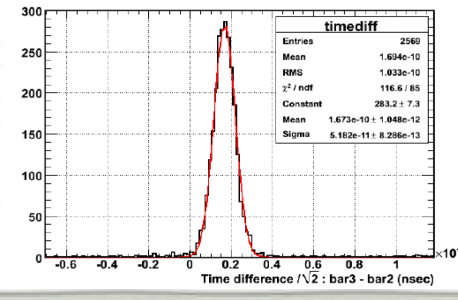
TC Waveform Analysis

- 2 kinds of waveform are recorded
  - Attenuated PMT waveform
  - Discriminator output (NIM)





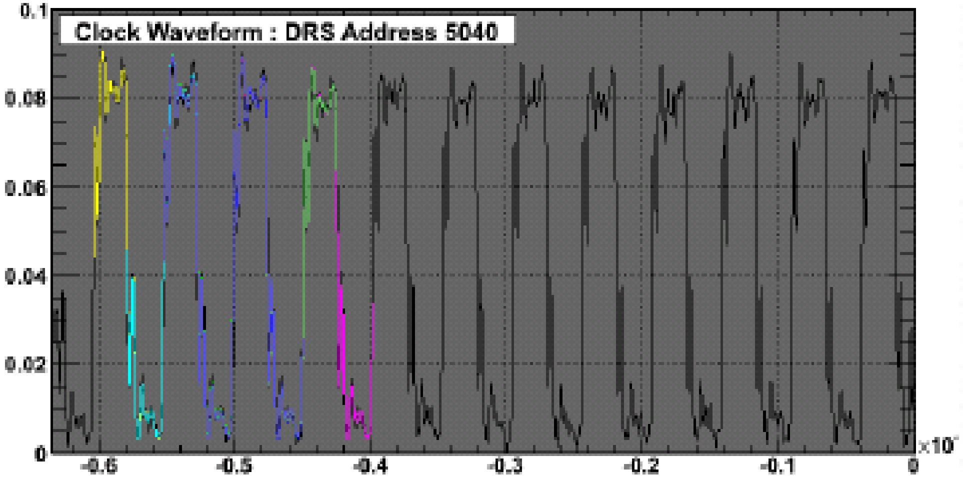
- σ_{time} in a single bar: 52 psec
- Better in 2 adjacent hit events



Synchronization in different chips

- Precise clock signal (20MHz) is distributed over the experiment
- Resolution evaluated by adjacent TC hits over different chips
  - σ_{clock}=110psec
- Bad clock quality
  - Distortion in chip
  - Improved in the next version of chip

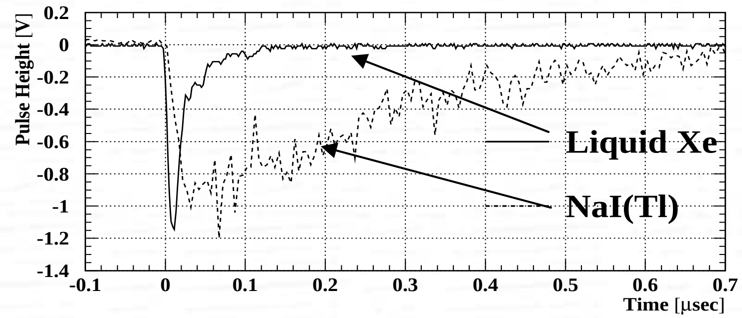
20MHz clock



Liquid Xenon Photon Detector

Why Liquid Xenon?

- Good resolutions
  - Large light output yield
  - W_{ph}(1MeV e) = 22.4eV
- Pile-up event rejection
  - Fast response and short decay time
  - τ_s = 4.2nsec, τ_T=45nsec (for electron, no E)
- Uniform



	NaI	BGO	GSO	LSO	LXe
Effective Atomic number	50	73	58	65	54
Density (g/cm3)	3.7	7.1	6.7	7.4	3.0
Relative light output (%)	100	15	20-40	45-70	80
Decay time (nsec)	230	300	60	40	4.2,22,45

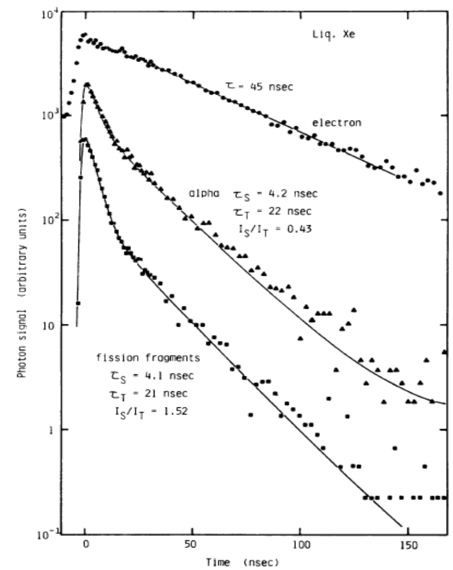
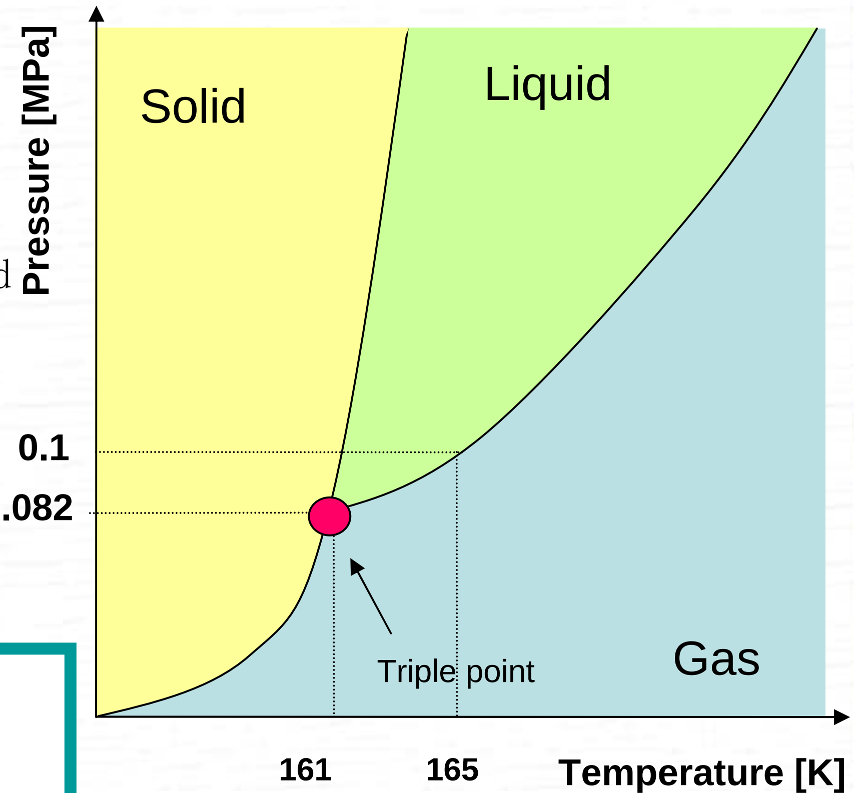


FIG. 4. Decay curves obtained for the luminescence from liquid xenon excited by electrons (●), α particles (▲), and fission fragments (■).

LXe and Scintillation light

- Density 3.0 g/cm^3
- Triple point 161K, 0.082MPa
- Normal operation at
  - T~167K P~0.12MPa
- Narrow temperature range between liquid and solid phases
  - Stable and reliable temperature control is necessary
- Scintillation light emission mechanism



Excitation

$$Xe + Xe^{*} \rightarrow 2Xe + h\nu$$

Recombination

$$Xe^{+} + Xe \rightarrow Xe_2^{+}$$

$$Xe_2^{+} + e \rightarrow Xe^{**} + Xe$$

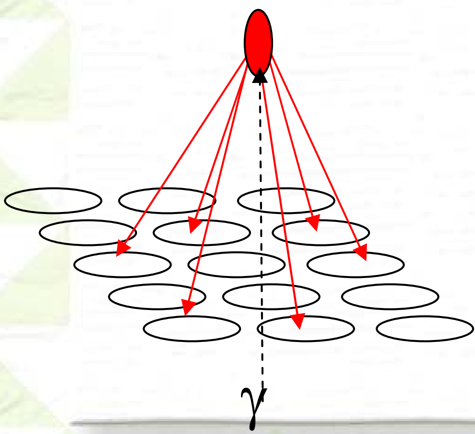
$$Xe^{**} \rightarrow Xe^{*}$$

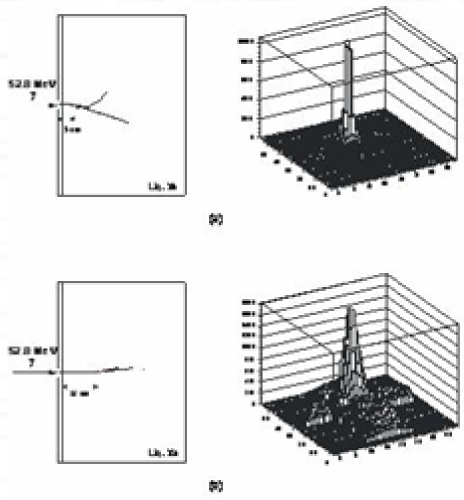
$$Xe + Xe^{*} \rightarrow Xe_2^{*} \rightarrow 2Xe + h\nu$$

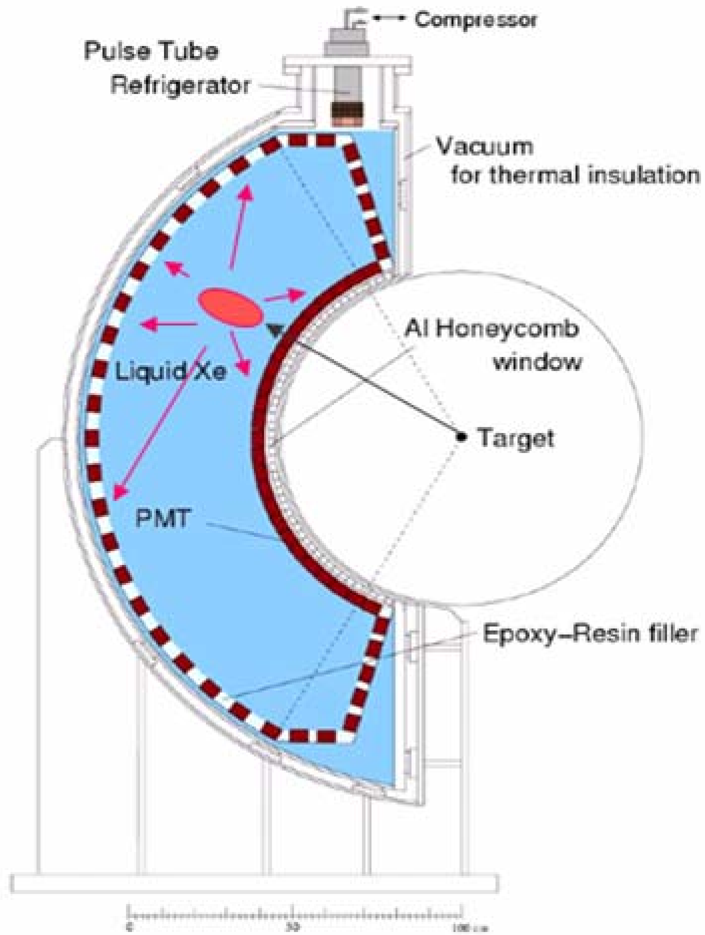
$$\lambda \sim 175 \pm 10\,nm$$

MEG LXe Detector

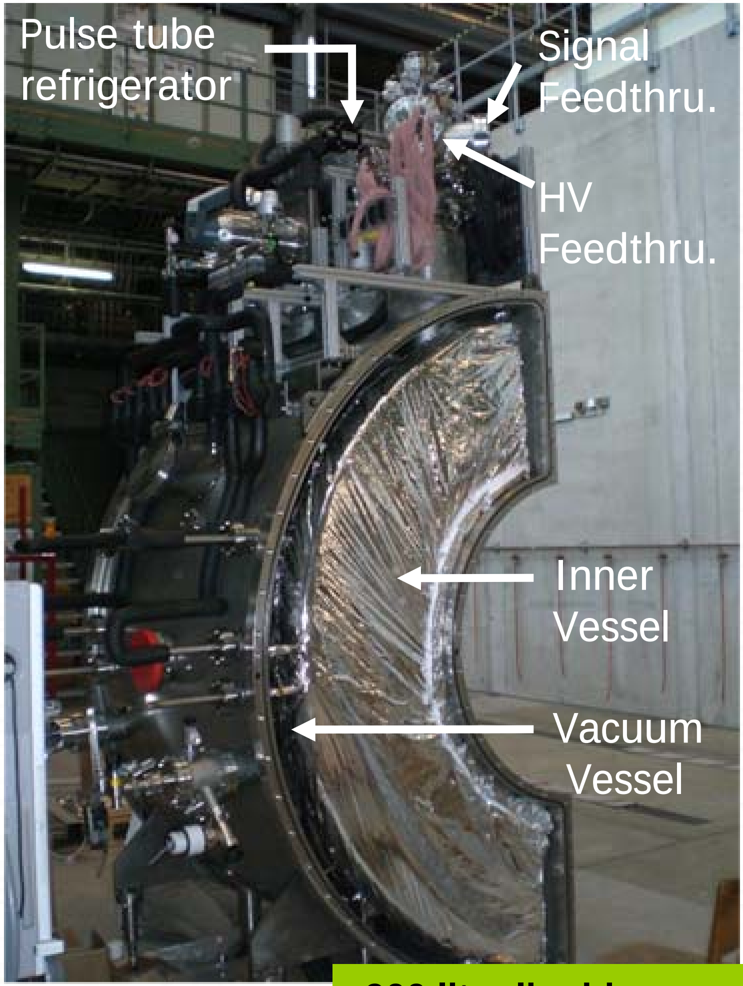
- Active volume ~800l is surrounded by PMTs on all faces
- 846 PMTs in the liquid
- No segmentation
- Energy
  - All PMT outputs
- Position
  - PMTs on the inner face
- Timing
  - Averaging of signal arrival time of selected PMTs





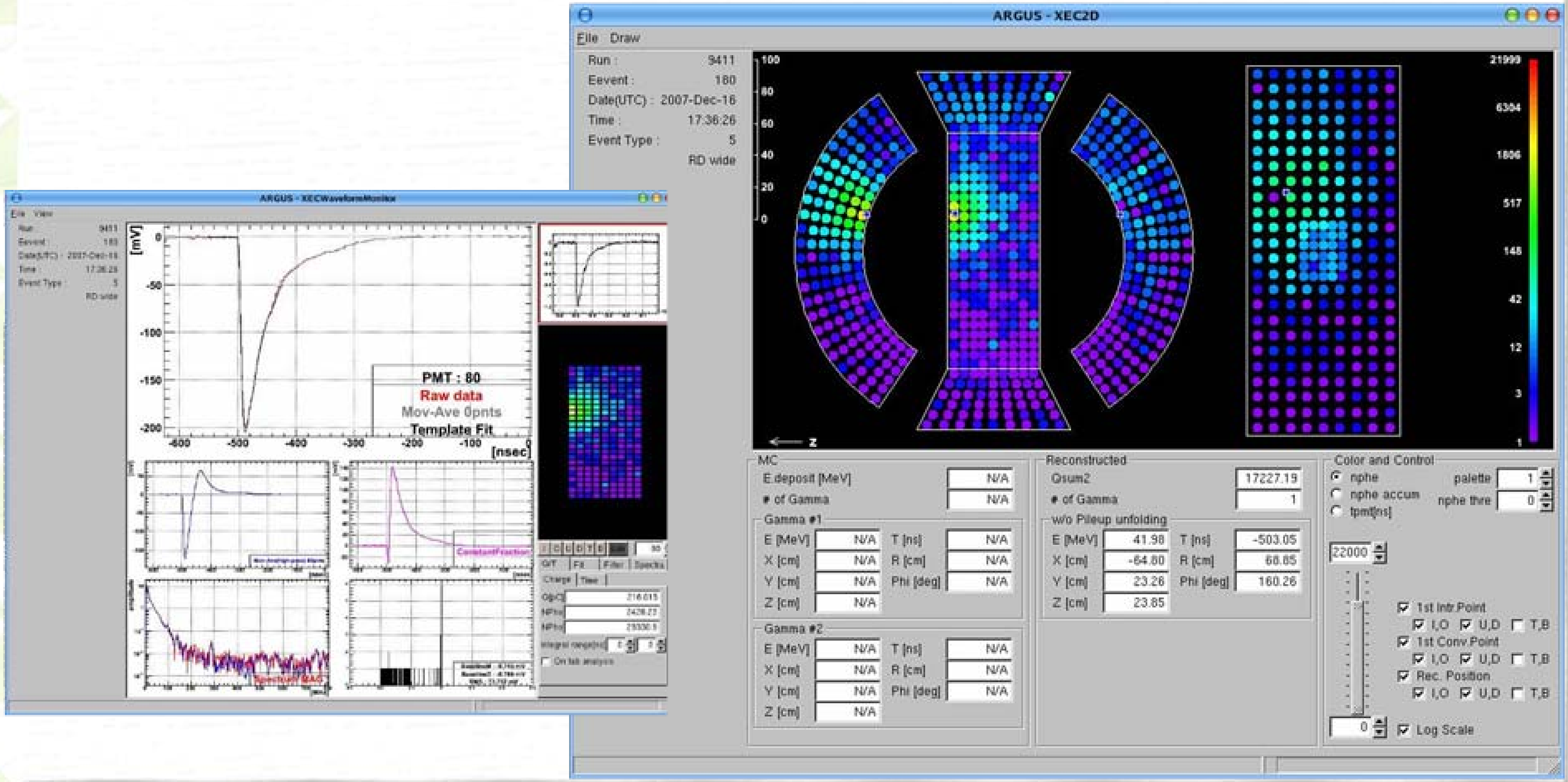


Detector Assembly



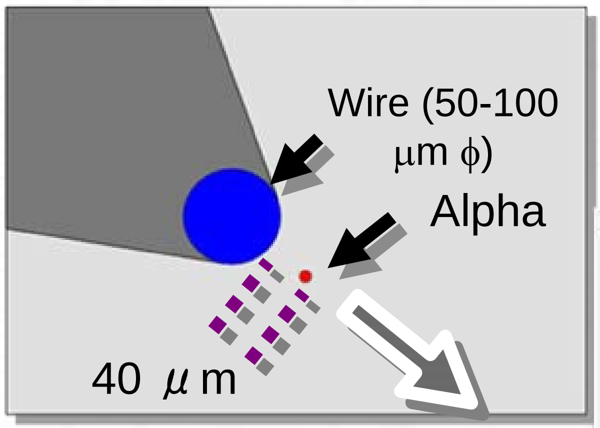
- **900 liter liquid xenon**
- **846 2”PMT in the liquid**

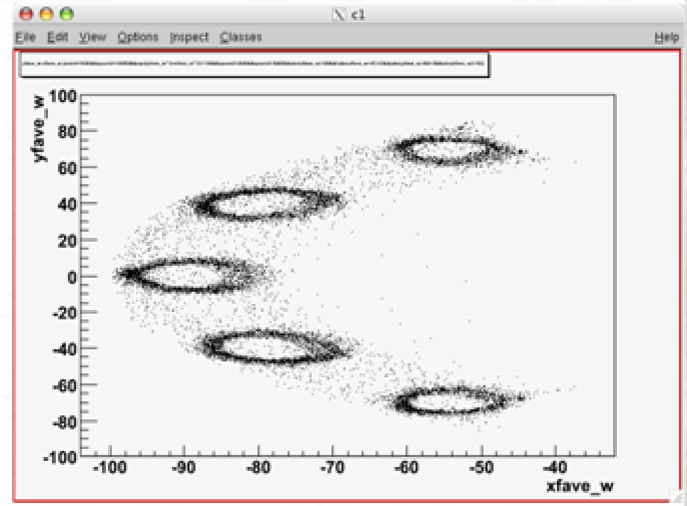
Typical Event

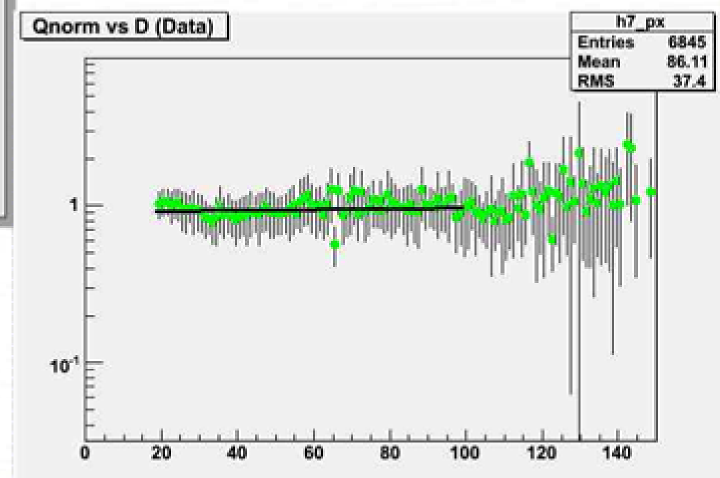


Xenon Detector PMT Calibration

- LEDs in the liquid for PMT gain calibration
- Alpha sources for PMT QE calibration and λabs monitor

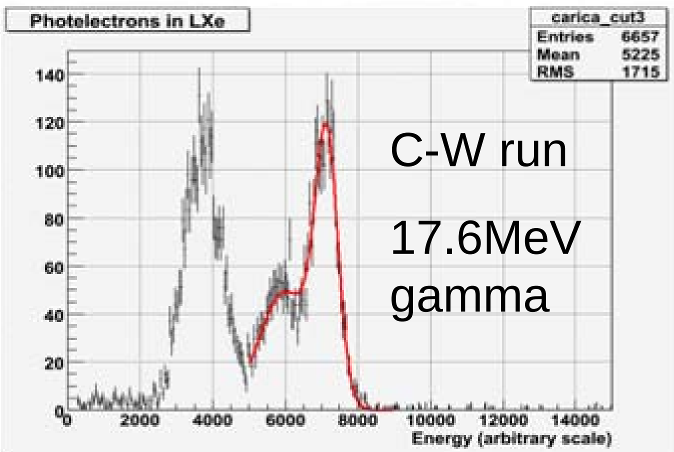


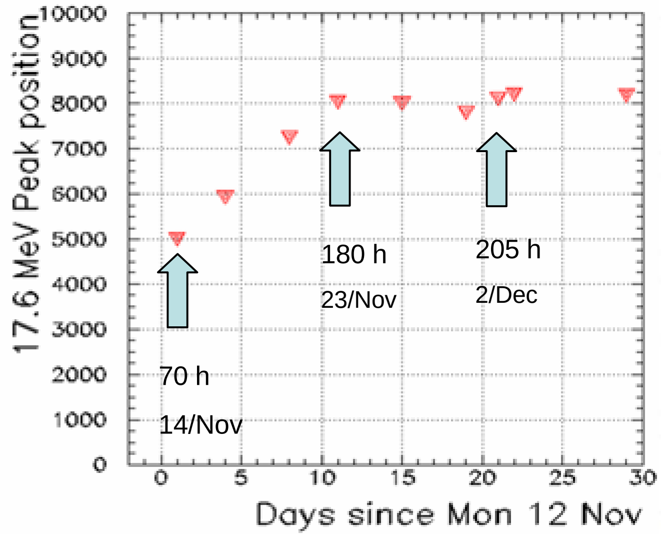




Liquid Purification

- Impurity contamination can cause absorption of scintillation light
  - H_2O, O_2
- Light yield for 17.6MeV γ is utilized to monitor
  - more precisely than using alpha source signal





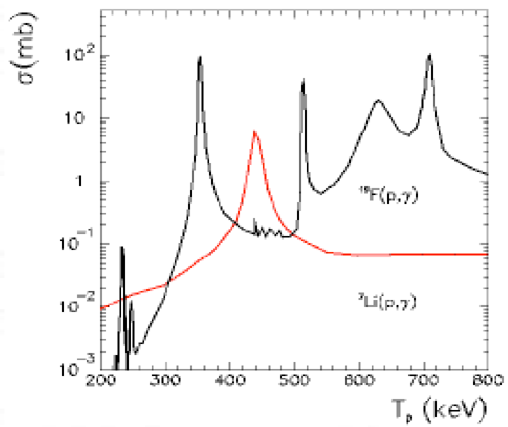
Xenon Liquid-phase purification
S.Mihara Cryogenics 688 46 2006

Xenon Detector Calibration/Monitor

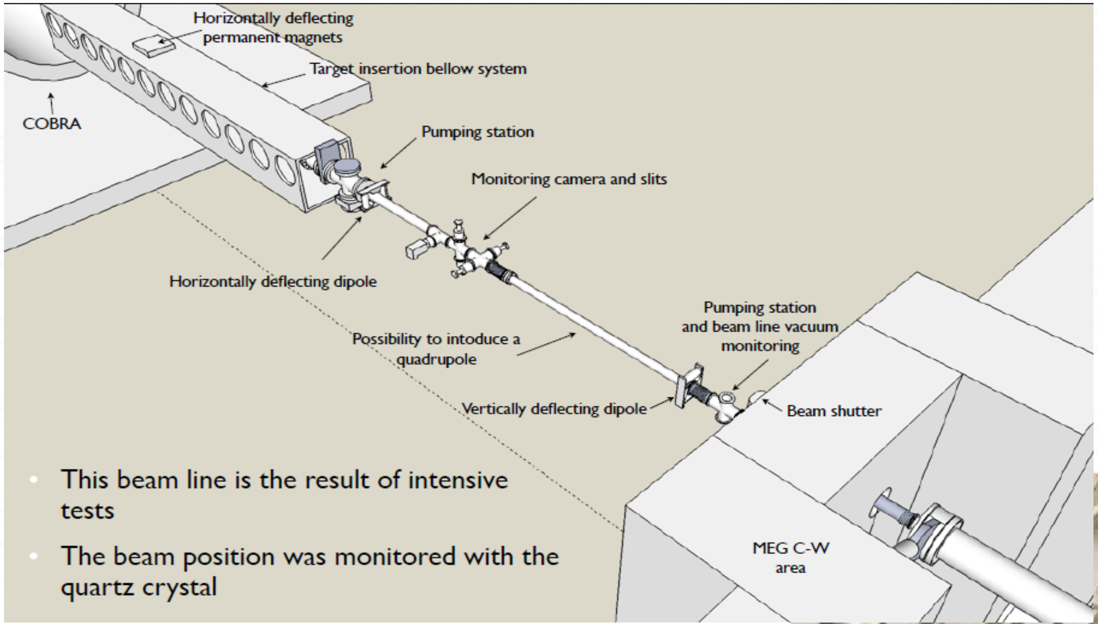
- Trace the detector response to gamma ray as frequently as possible

- The best way is to use "high energy" gamma ray (with known energy) emitted from the target
  - Gamma emission from excited nuclei
  - Particle decay

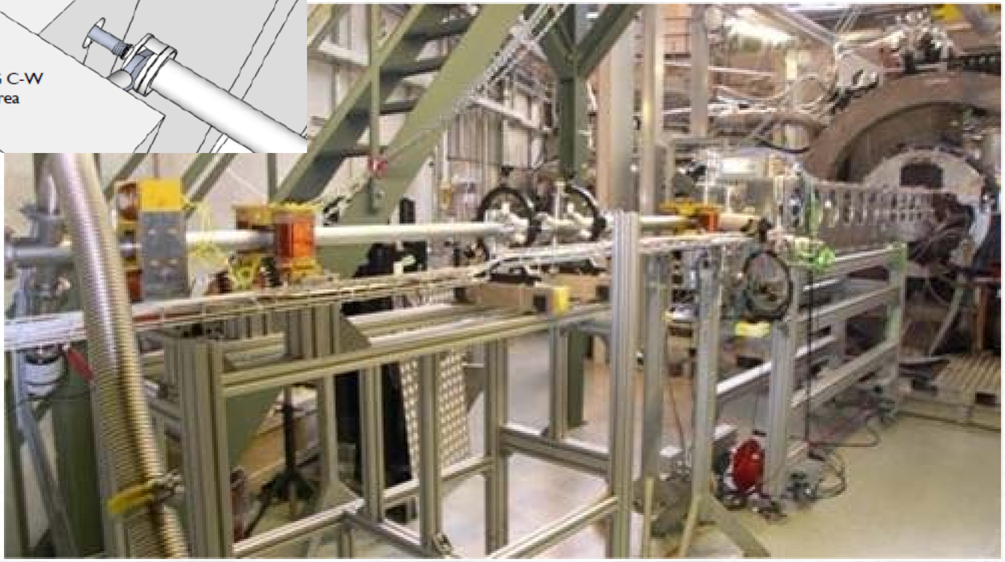
Reaction	*Resonance energy*	σ peak	γ-lines
Li(p,γ)Be	*440 keV*	5 mb	17.6 MeV, 14.6 MeV
B(p,γ)C	*163 keV*	$2\ 10^{-1}$ mb	4.4 MeV, 11.7 MeV, 16.1 MeV



C–W Accelerator

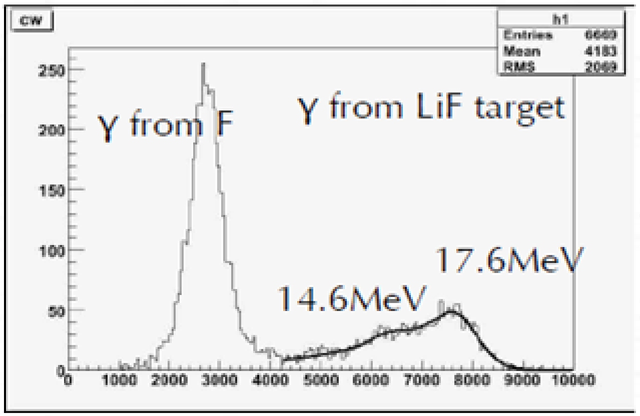


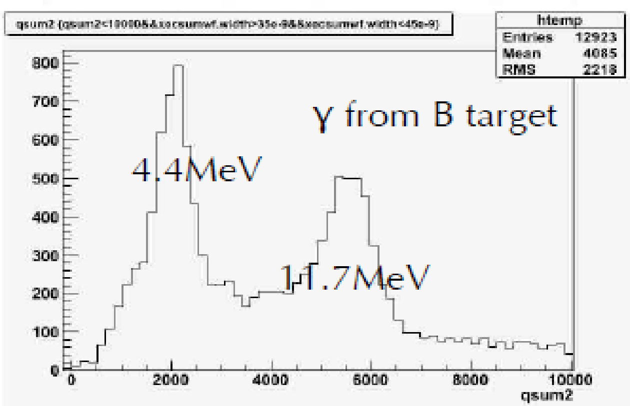
- This beam line is the result of intensive tests
- The beam position was monitored with the quartz crystal

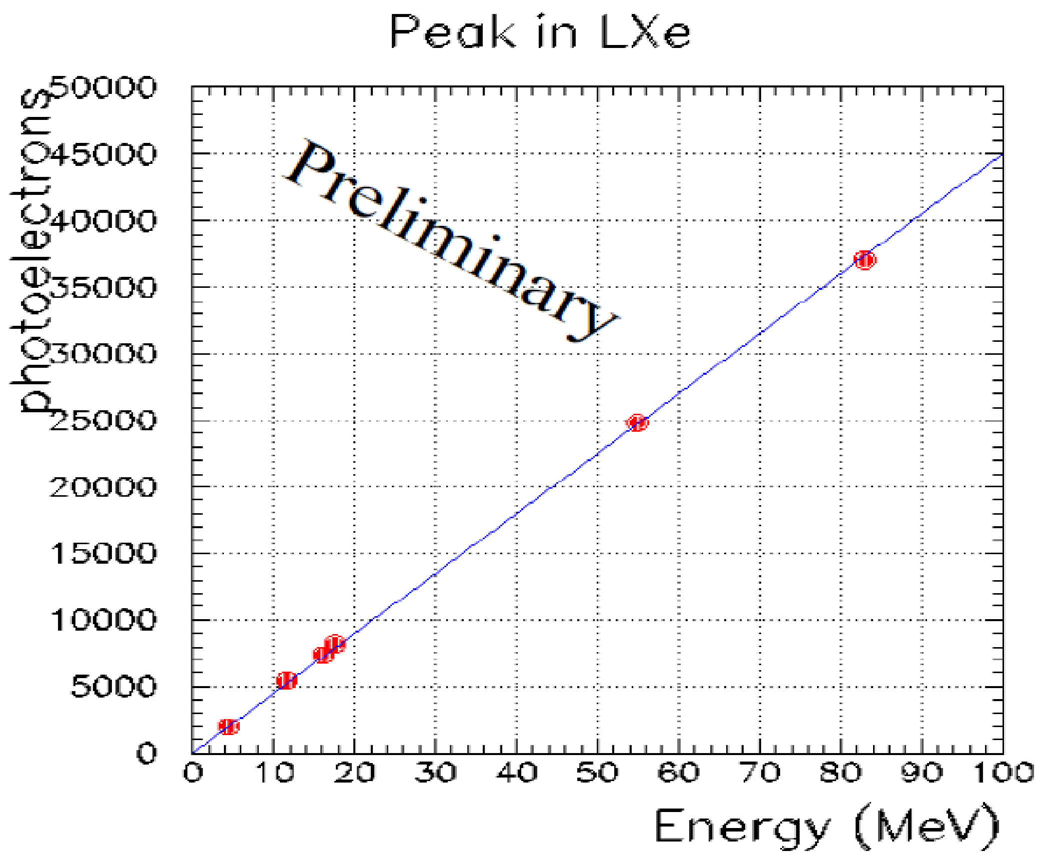


Linearity Check

- Li at 14.6, 17.6MeV
- B at 4.4, 11.7 (and 16.1) MeV

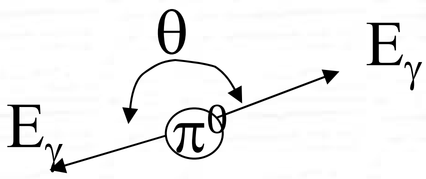




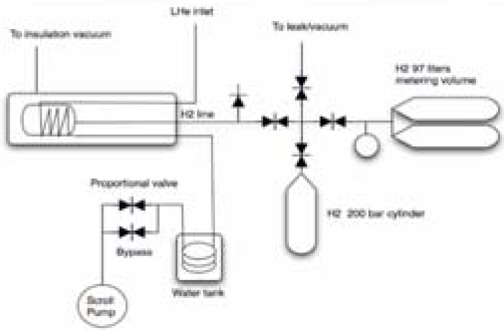


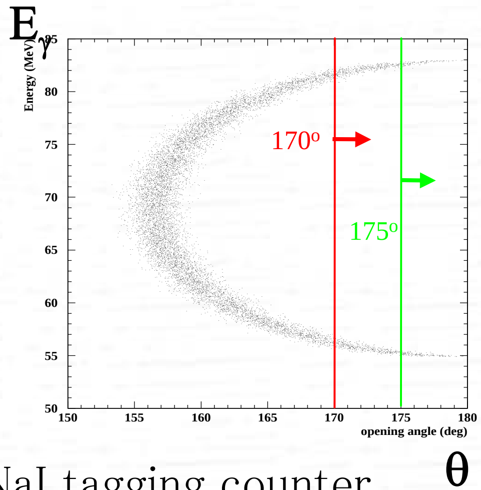
CEX run – Pi0 calibration

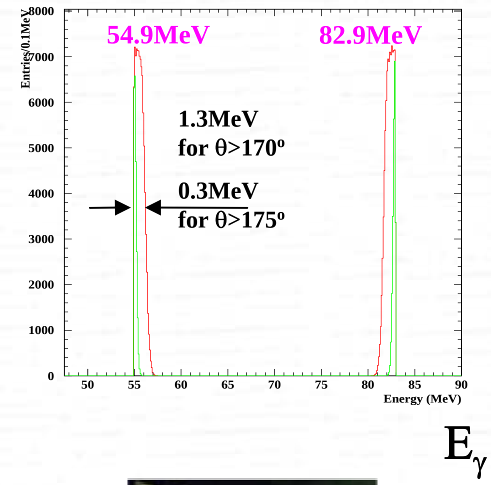
- CEX process
  - $\pi^- p \rightarrow \pi^0 n$
    - π^0(28MeV/c) $\rightarrow \gamma\,\gamma$
    - 54.9 MeV < E(γ) < 82.9 MeV



- LH_2 target





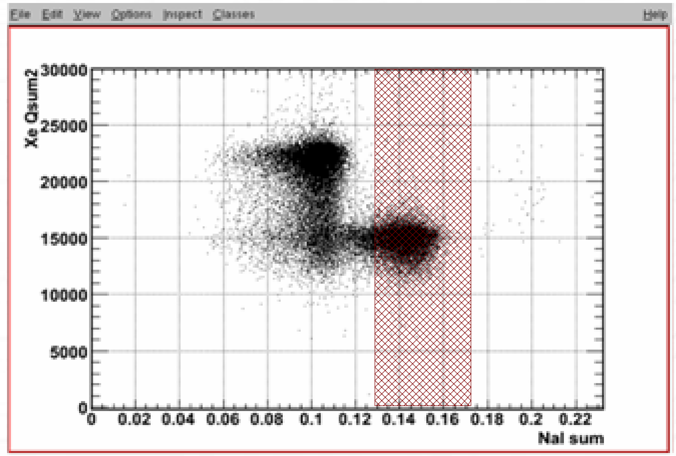


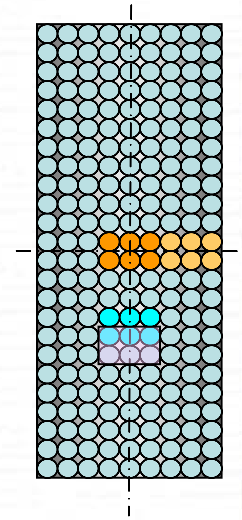
- NaI tagging counter
  - 3x3 crystals, APD readout

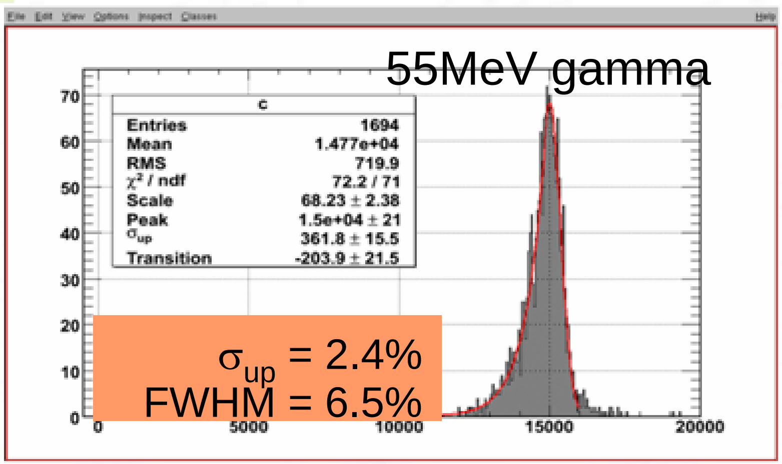
- Pb collimator panel in front of the Xe detector

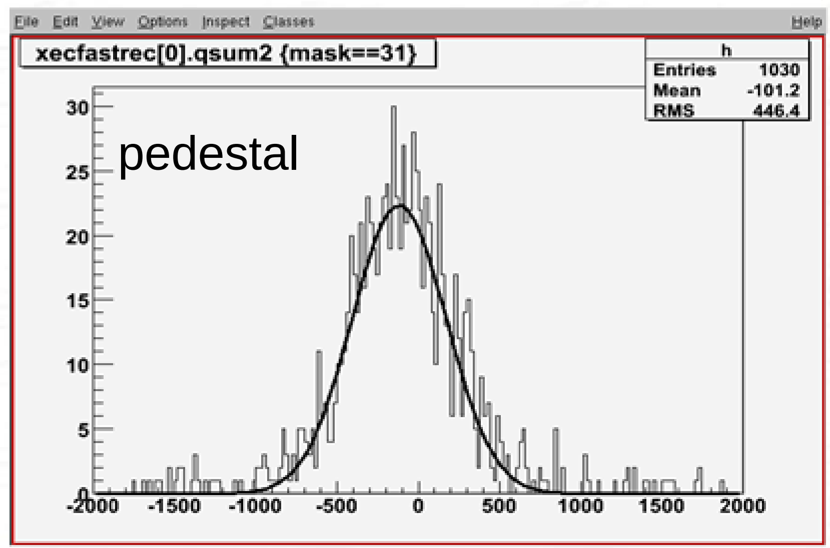
CEX run data analysis, preliminary

- Position cut
  - Cut shallow events (< 2cm)
  - Select only center events (|u|,|v| < 5cm)
- Position correction
- Pile-up rejection by light distribution
- Select center event on NaI detector
- Not applied QE correction
  - If applied worsen resolution.
- Pedestal has 2% spread
  - Needs better baseline evaluation
  - Check hardware for 2008 run









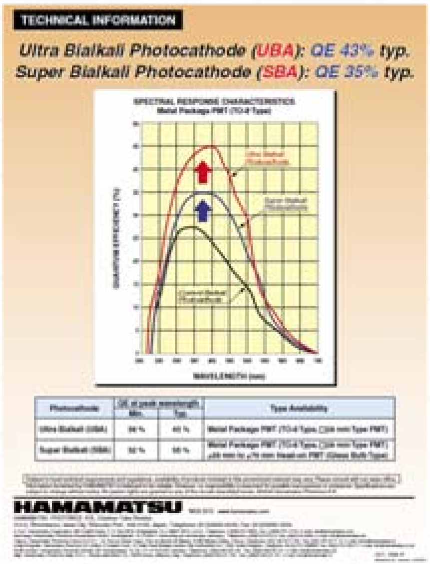
MEG status

- Successful data acquisition in 2007
  - All detector worked fine
  - 2×10^{12} muons stopped on the target
  - 630k MEG trigger
- 24 weeks DAQ time is scheduled in 2008
  - To improve performance
    - Better XEC PMT calibration
    - Further noise reduction in the experiment
    - New version of waveform digitizer will be ready

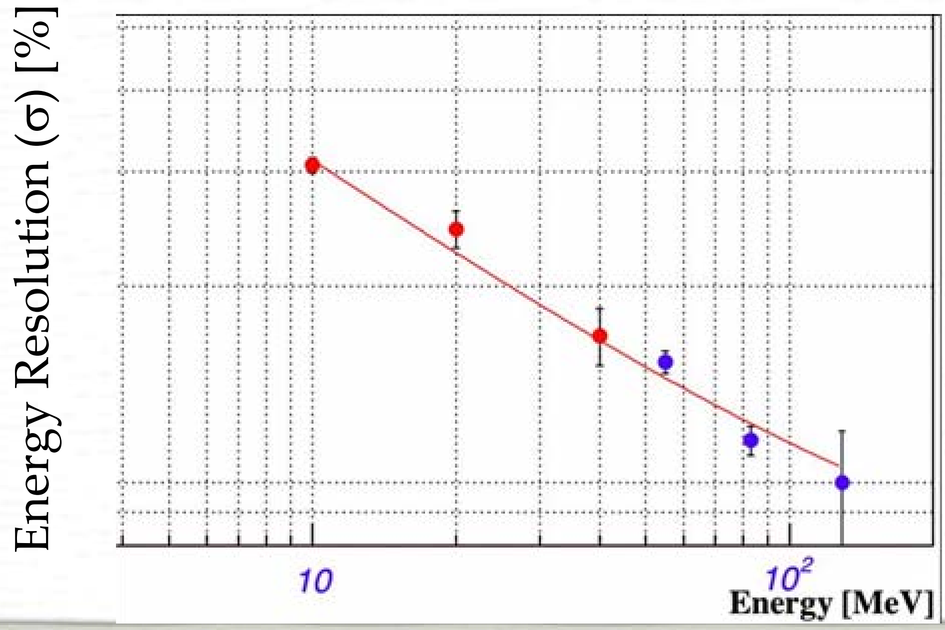
MEG future plan

Detector upgrade plan

- Improve resolutions by developing new devices
  - Higher QE PMT
  - APD

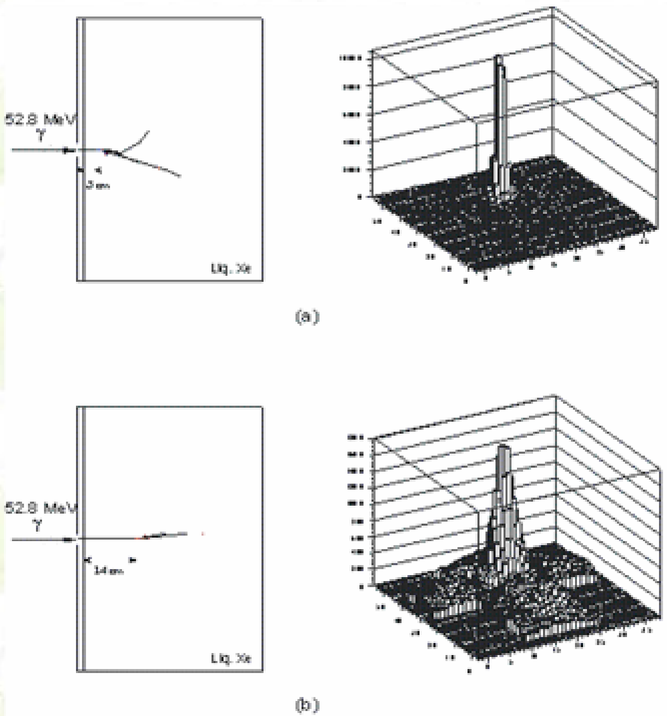


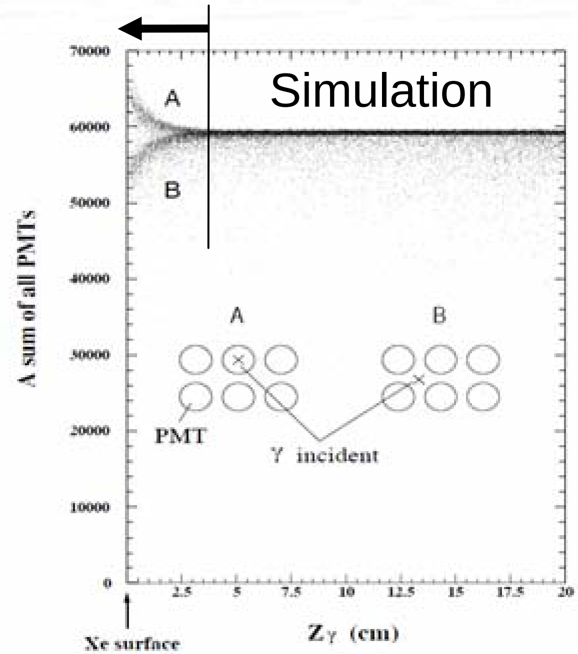
Energy resolution vs. Energy

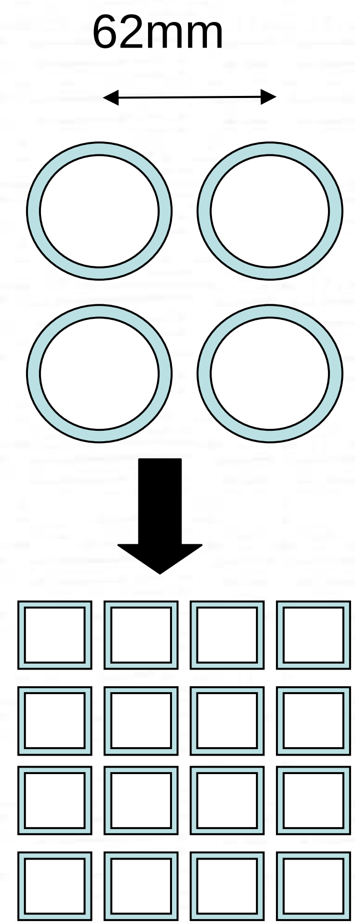


Event Reconstruction

- Shallow event reconstruction



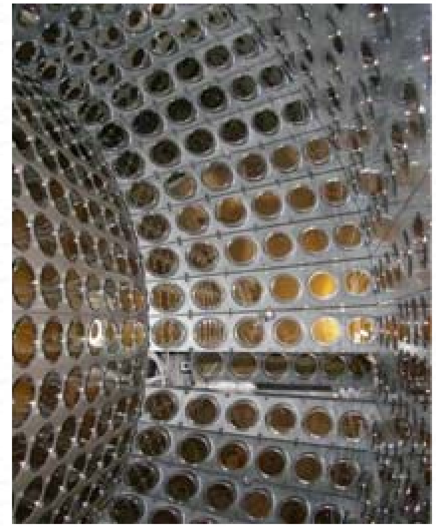




- Pile-up rejection can be improved

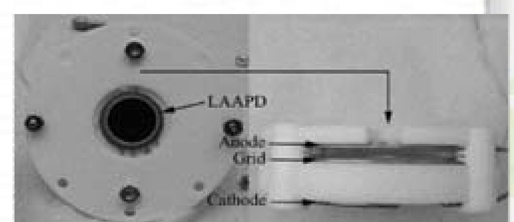
MEG Detector Upgrade

- Improve detector resolution and background rejection capability
- Finer granularity on the inner (entrance) face
  - APD
  - 1 inch PMT
- Prospects
  - Better event reconstruction
    - shallow event
    - Pile-up
  - Incident angle measurement



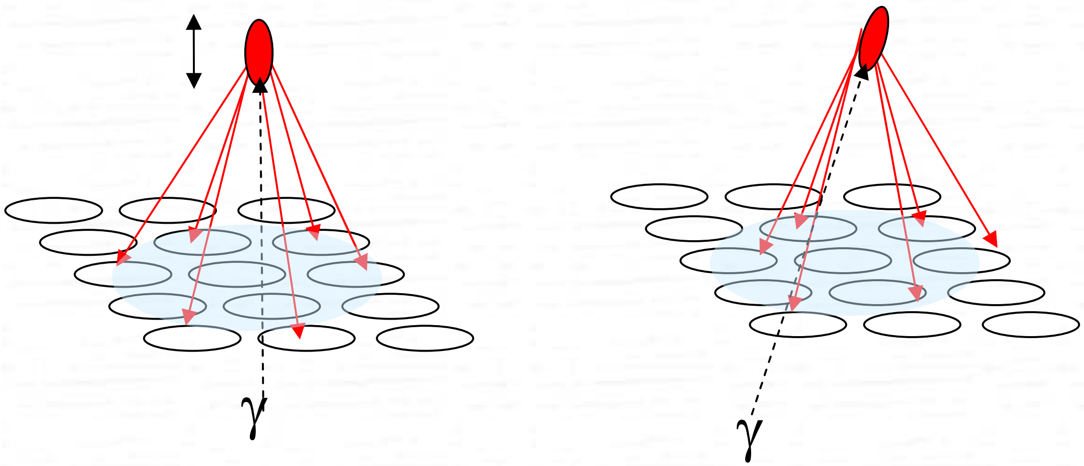
2 inch PMT

Hamamatsu R5900-06



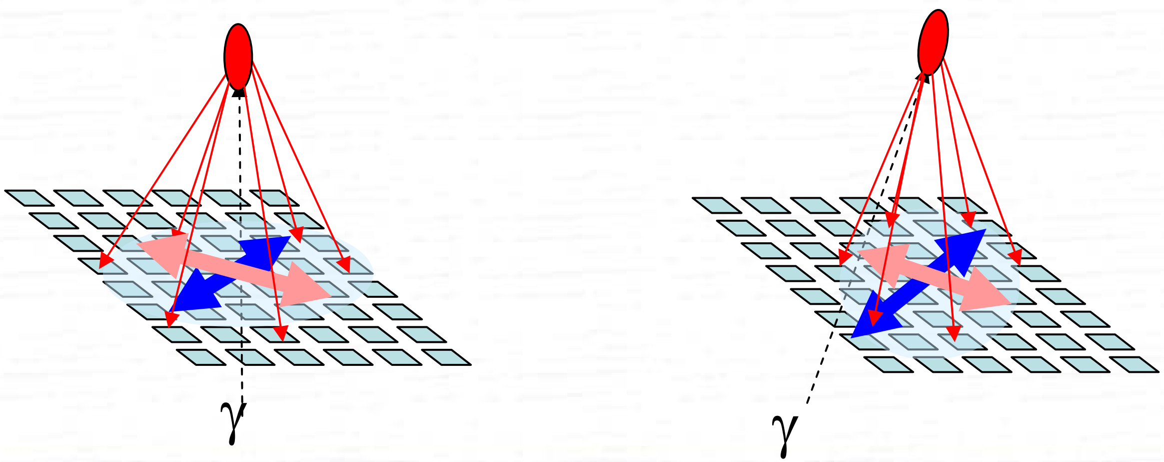
K. Ni et al NIM A551 (2005)356-363

Incident Angle Reconstruction



Photocathode Coverage

$\pi \times 23^2/64^2=41\%$



Photocathode Coverage

1inch PMT

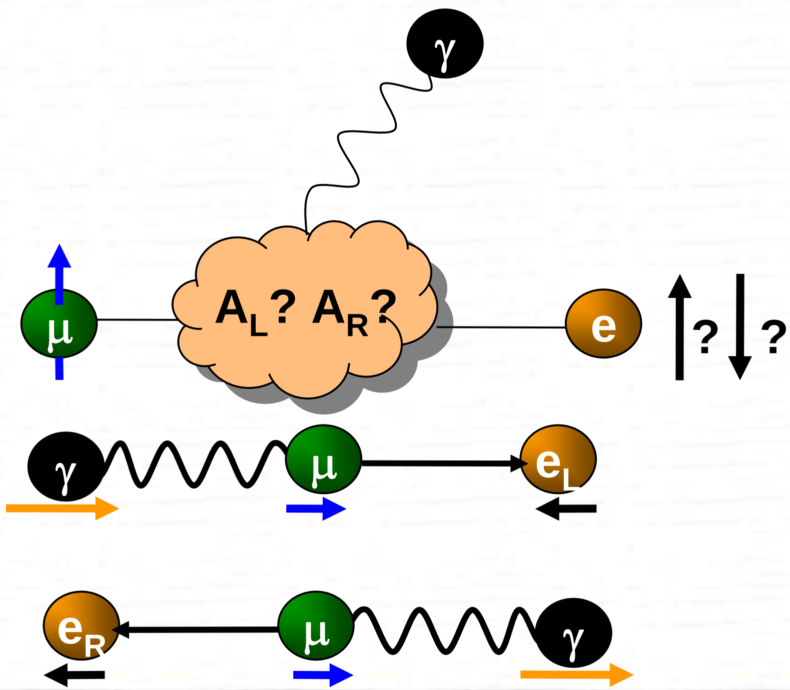
$18^2/30^2=36\%$

After Discovery of $\mu \rightarrow e \gamma$

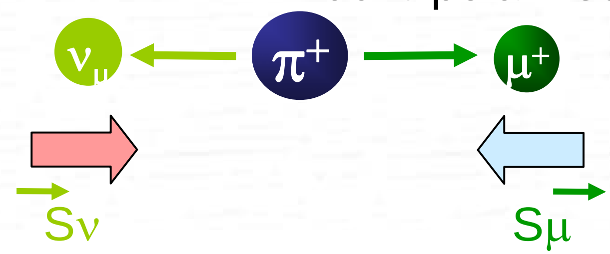
What's next?

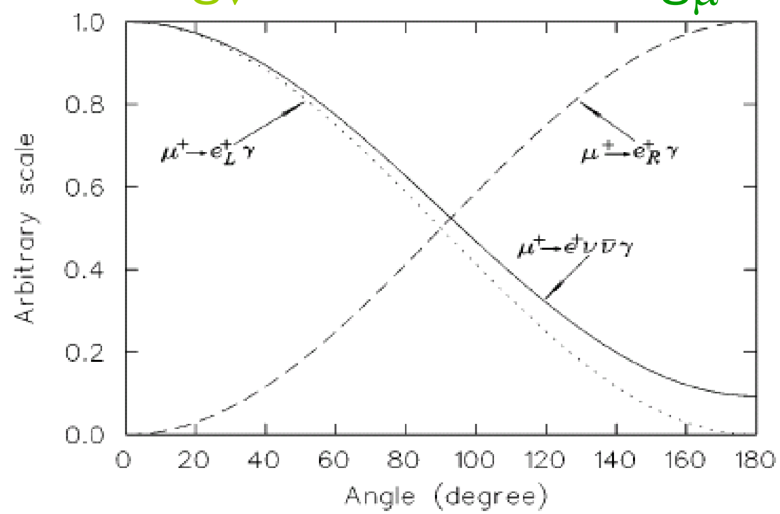
Polarized MEG

- If we succeed to observe enough number of events…
  - Is it possible to investigate "inside the loop" ?
- Produced muon itself is polarized



~100% polarized



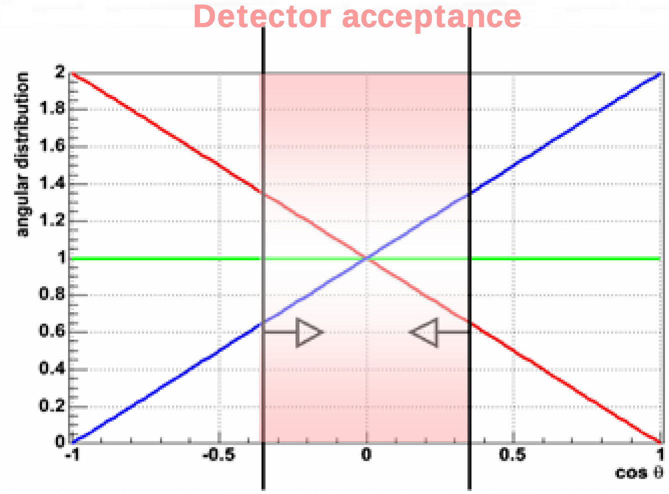


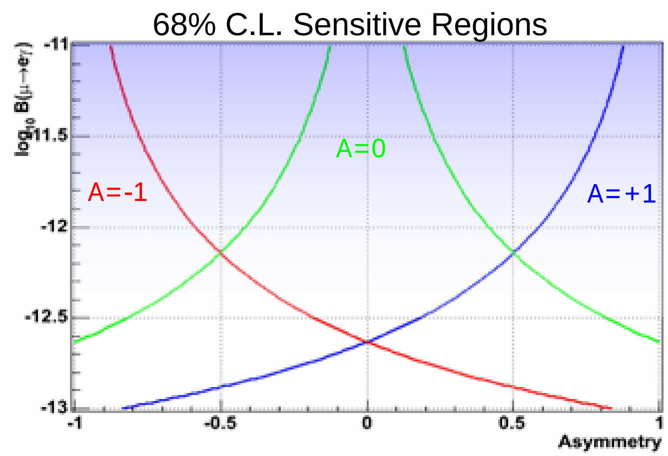
Kuno and Okada, PRL 77(1996)434

Angular Distribution

- $dN(\mu^+ \to e^+\gamma)\ /\ d\cos\theta_e \propto$
  $B(\mu^+ \to e^+\gamma)(1 + AP_\mu \cos\theta_e)/2$
  - $A = (|A_L|^2 - |A_R|^2)/(|A_L|^2 + |A_R|^2)$
    - $A = +1$ $(A_L \neq 0,\ A_R = 0)$
    - $A \approx 0$ $(A_L \approx A_R)$
    - $A = -1$ $(A_L = 0,\ A_R \neq 0)$
  - Radiative μ^+ decay
    - $N(\mu^+ \to e^+\nu\nu\gamma) \propto (1 + P_\mu \cos\theta_e)$

- Possible to distinguish A=−1, 0, +1 at 68% C.L. for $B(\mu^+ \to e^+\gamma) > 10^{-12.5}$





Summary

- MEG is ready to start full DAQ!
- Successful DAQ in 2007
  - 2×10^{12} muons stopped on the target

- 24 weeks DAQ is scheduled in 2008
  - Reach MEGA limit
  - Further development of analysis tools/better calibrations
  - Noise situation improved
  - Next version of waveform digitizer will be ready in 2008

- Detector upgrade is being considered

Comments

- After MEG result comes out,
  - Measure angular distribution with polarized muons
- It will also be important to confirm it with different physics process
  - μ–e conversion
  - $\mu \rightarrow 3e$