Liquid Xenon Scintillation Detector for the MEG Experiment

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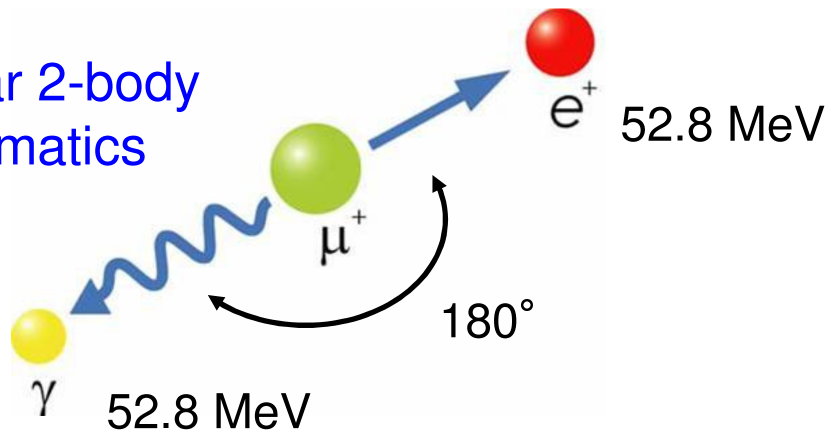
Motivation & Event Signature

- LFV process
- Forbidden in the SM
- Sensitive to SUSY-GUT, SUSY-seesaw etc.
- Our goal : $Br(\mu \to e\gamma) > 10^{-13} \sim 10^{-14}$

Clear 2-body kinematics



Michel decay ($\mu^+ \to e^+ \nu_e \nu_\mu$) + random γ

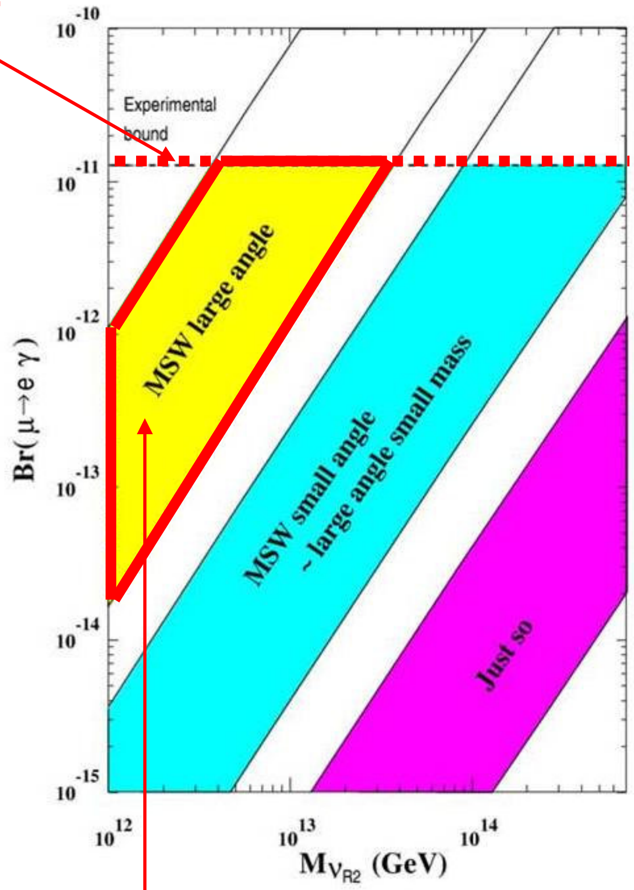
Background Rate ~ 10^{-14}

Radiative muon decay ($\mu^+ \to e^+ \nu_e \nu_\mu \gamma$)

Background Rate < 10^{-14}

$\mu \to e\gamma$ branching ratio

Present limit: 1.2×10^{-11}



Only allowed after KamLAND

MEG Experiment & Detector

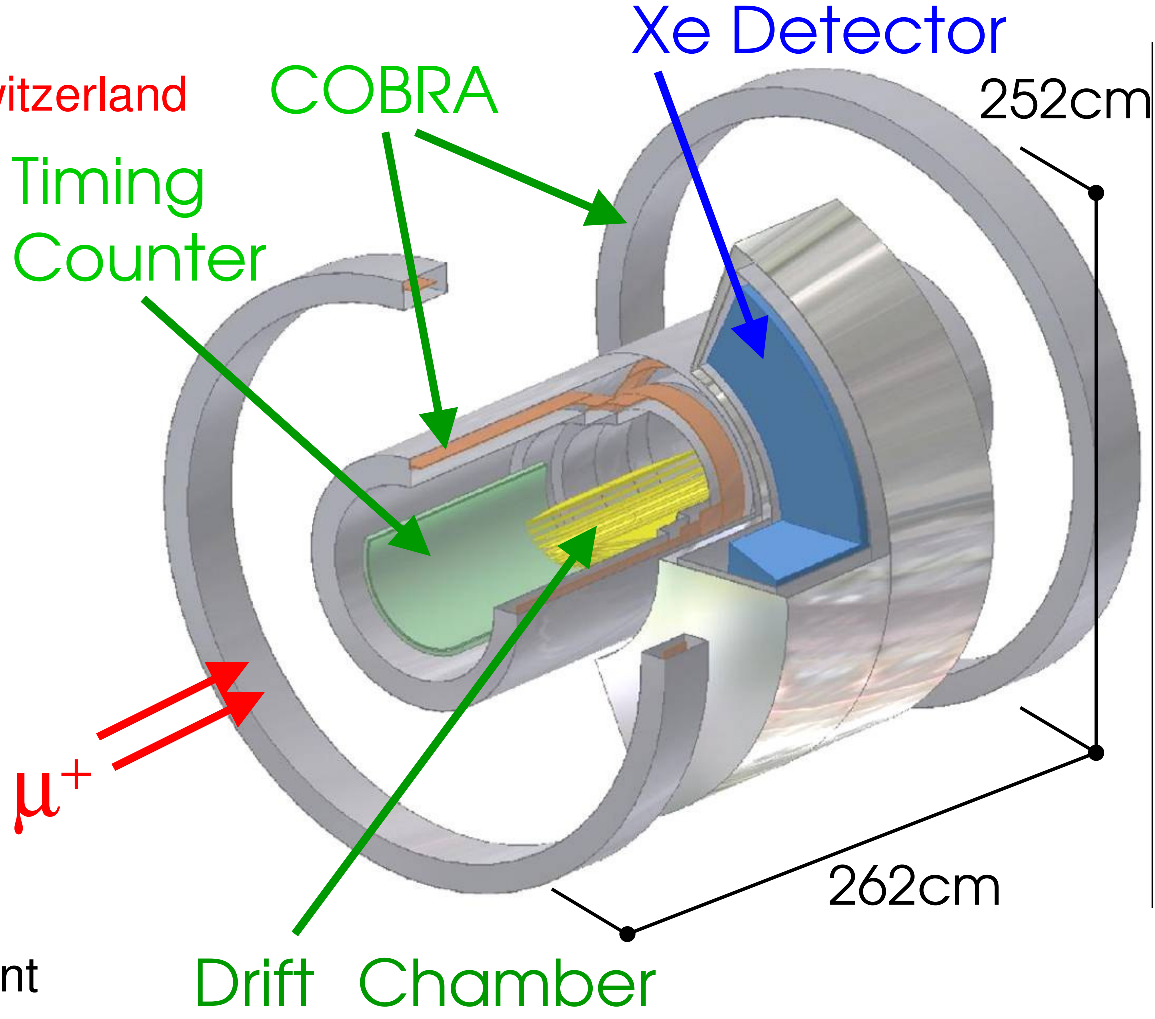
Approved in 1999,
at Paul Scherrer Institut, in Switzerland

Physics run in 2006
Initial goal at 10^{-13},
finally to 10^{-14}

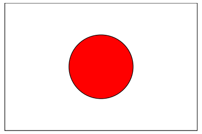
μ^+ beam :
World's most intense
DC Beam 10^8 μ^+ /s

γ detector :
800liter liquid xenon
scintillation detector
with 830 PMTs

e^+ detector :
solenoidal magnetic
spectrometer with a gradient
magnetic field (COBRA)



The MEG Collaboration

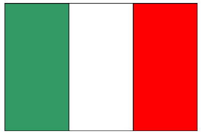


ICEPP, University of Tokyo Y. Hisamatsu, T. Iwamoto, T. Mashimo, S. Mihara, T. Mori, H. Nishiguchi, W. Ootani, K. Ozone, T. Saeki, R. Sawada, S. Yamada, S. Yamashita

KEK, Tsukuba T. Haruyama, A. Maki, Y. Makida, A. Yamamoto, K. Yoshimura, K. Kasami

Osaka University Y. Kuno

Waseda University T. Doke, J. Kikuchi, S. Suzuki, K. Terasawa, A. Yamaguchi, T. Yoshimura



INFN & Genova University S. Dussoni, F. Gatti, D. Pergolesi, R. Valle

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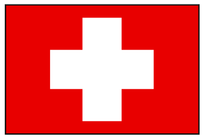
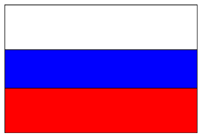


PSI, Villigen J. Egger, P. Kettle, M. Hildebrandt, S. Ritt



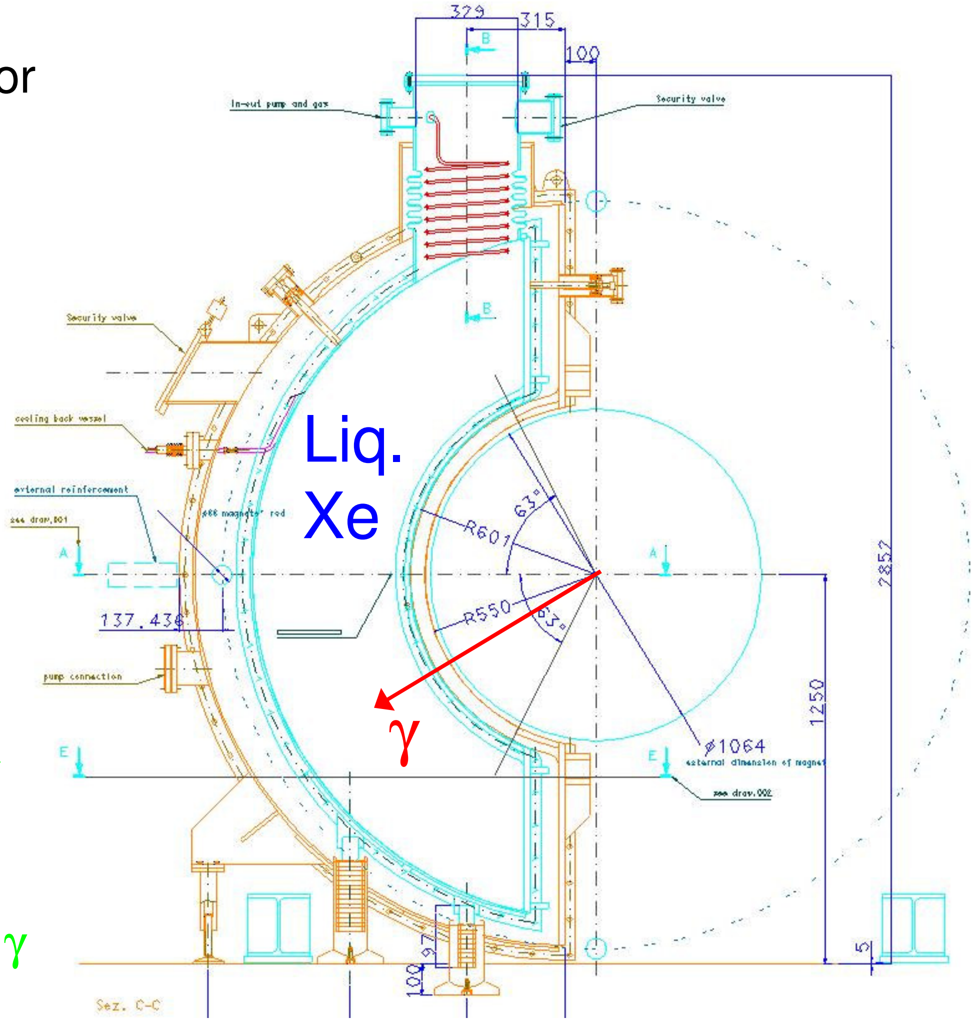
Budker Institute, Novosibirsk L.M. Barkov, A.A. Grebenuk, D.G. Grigoriev, B, Khazin, N.M. Ryskulov

Photon Detector

- 800 liter liquid xenon scintillation detector
  830 PMTs directly filled into the liquid
  (effective coverage ~ 35%)
- High light yield (75% of NaI(Tl)),
  fast response (decay time ~4ns)
  and good uniformity

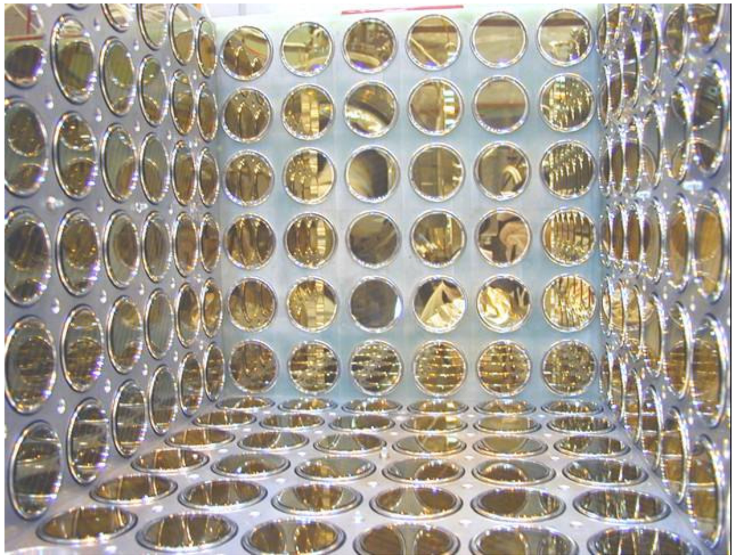
The strategy of R&D

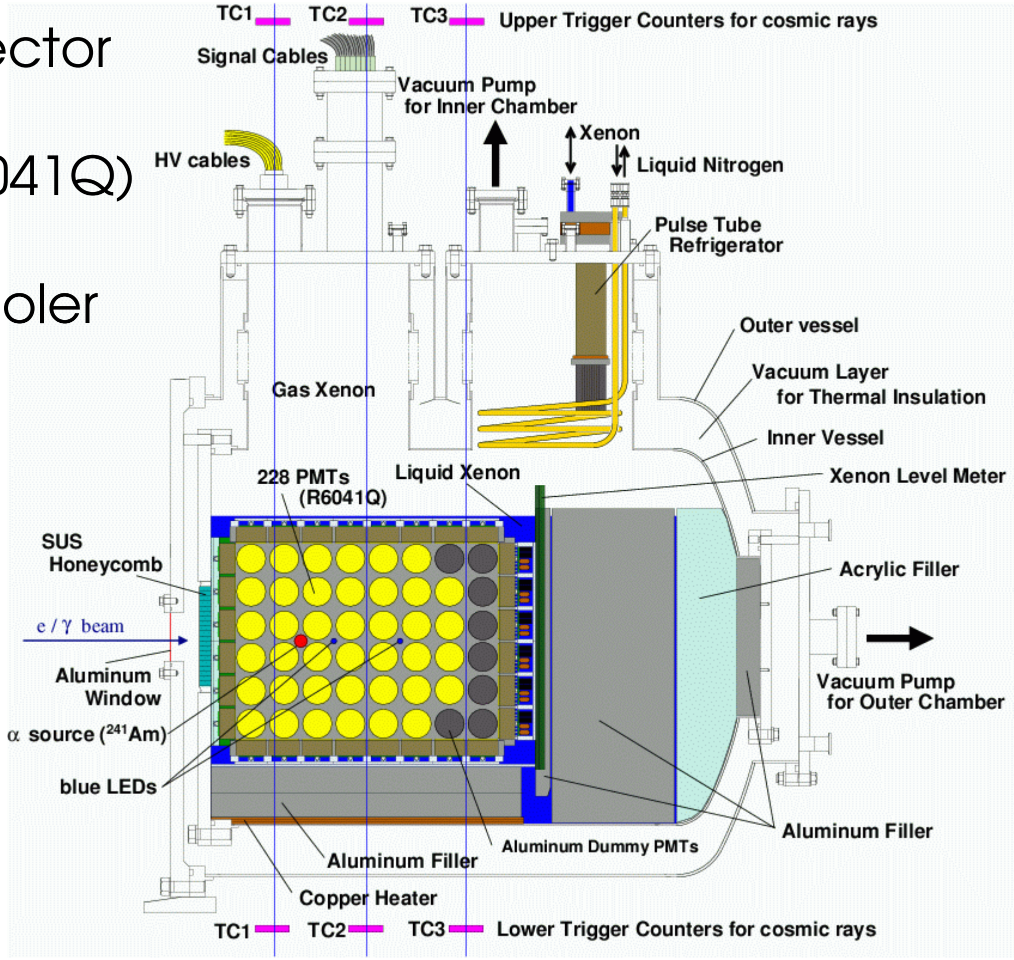
- Small prototype (2.3 liter size)
  ~MeV region study with sources
- Large prototype (68.6 liter size)
  1. TERAS beam test
     energy resolution of 10~40MeV γ
     timing and vertex resolution
  2. π^0 beam test in PSI
     energy resolution of 53~129MeV γ



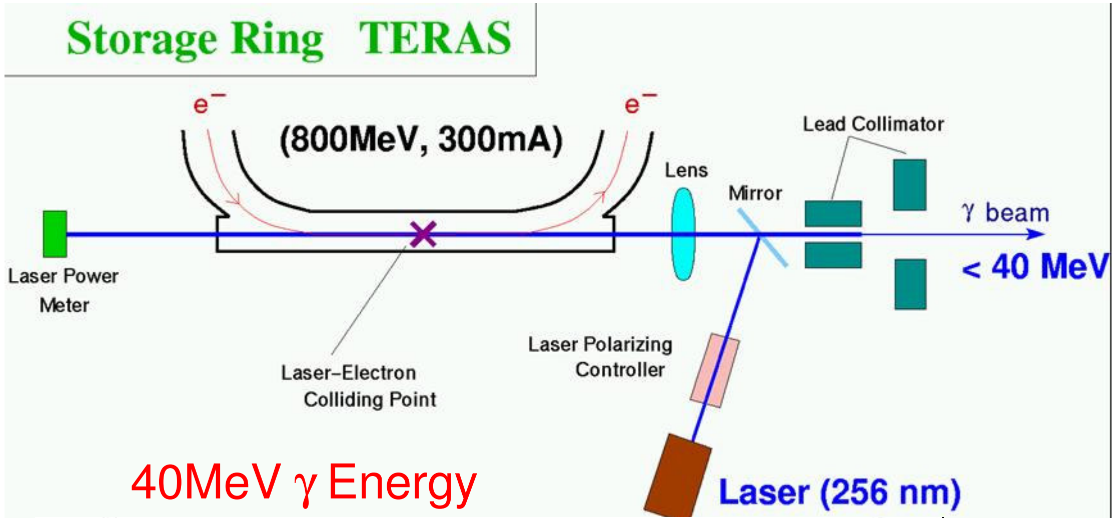
Large Prototype Detector

Large Prototype
- Smaller acceptance Xe detector
- Active volume : 68.6 liter
- 228 2" PMTs (Hamamatsu R6041Q)
- To check performances and
- LN_2 free operation by cryocooler





1. TERAS Beam Test

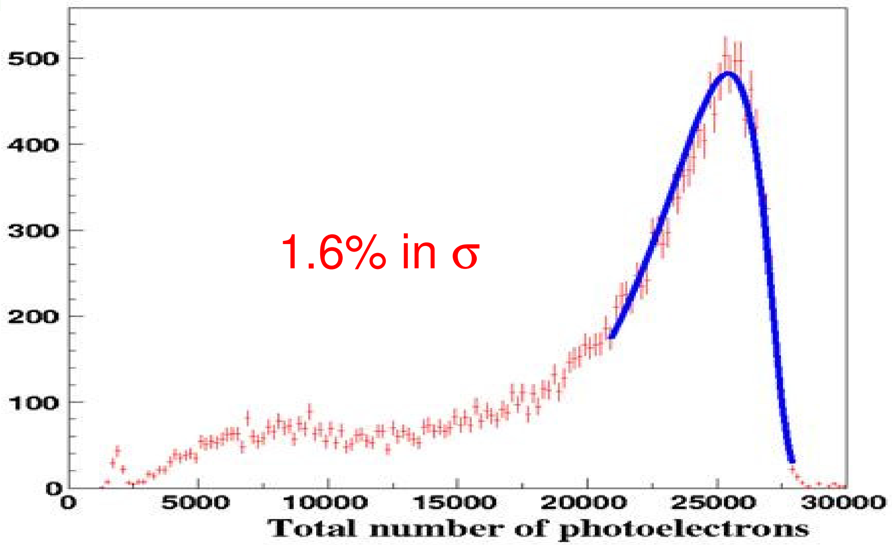


Inverse Compton γ Energy : 10, 20, 40 MeV

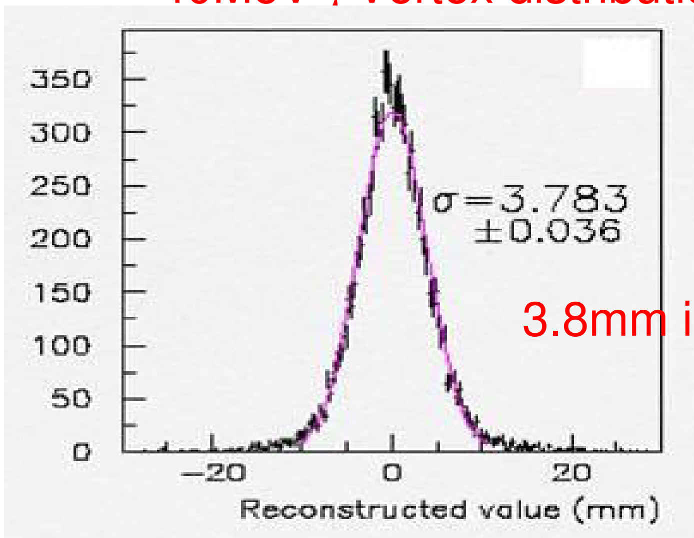
Incident Position : Detector Center

Estimate Energy Resolution using Compton Edge

40MeV γ Energy



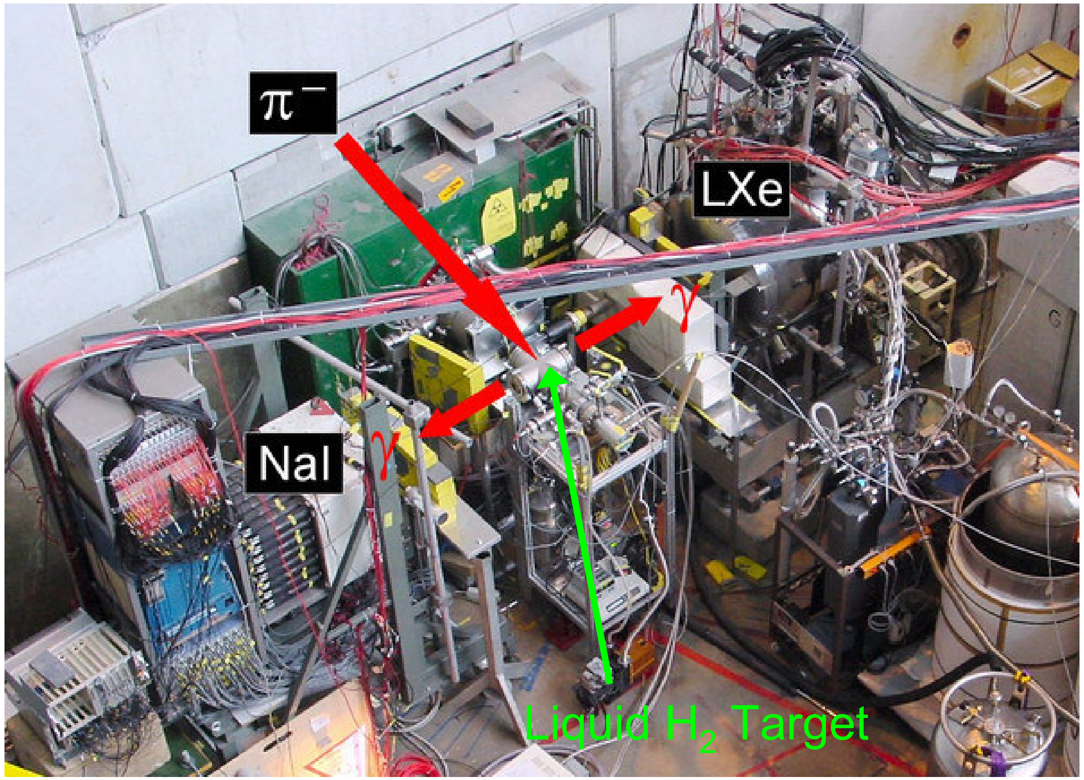
40MeV γ Vertex distribution

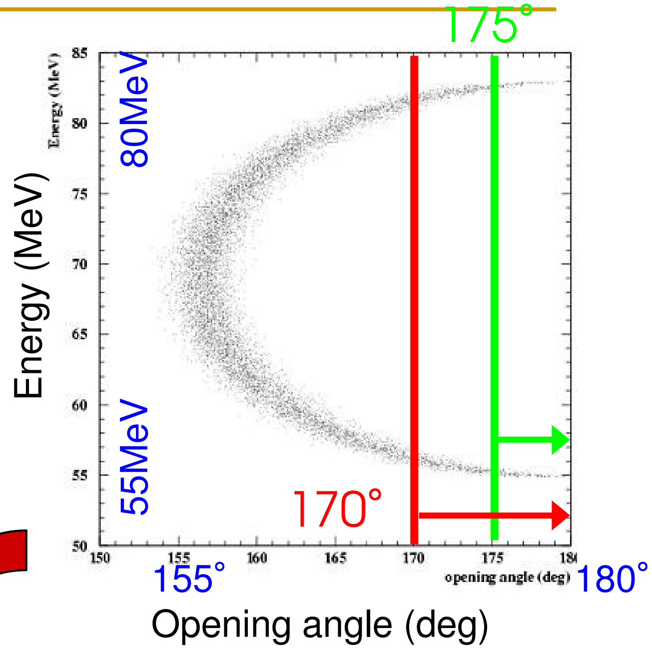


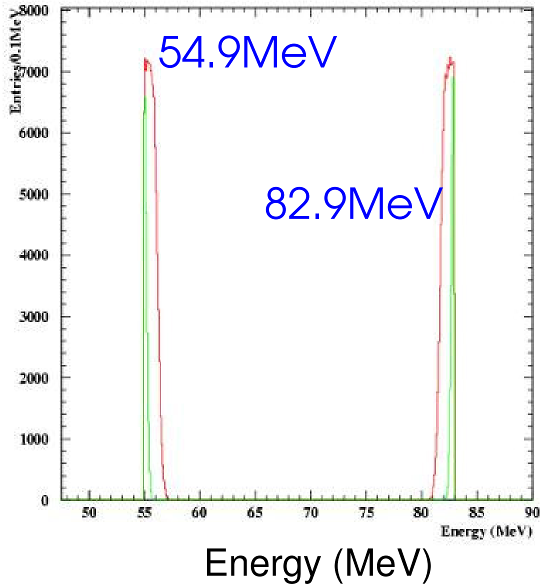
π^0 Beam Test at PSI

Concept π^- (at rest) + p -> π^0 + n,
π^0(28MeV/c) -> $\gamma + \gamma$

Opening angle selection of two γ's → monochromatic γ

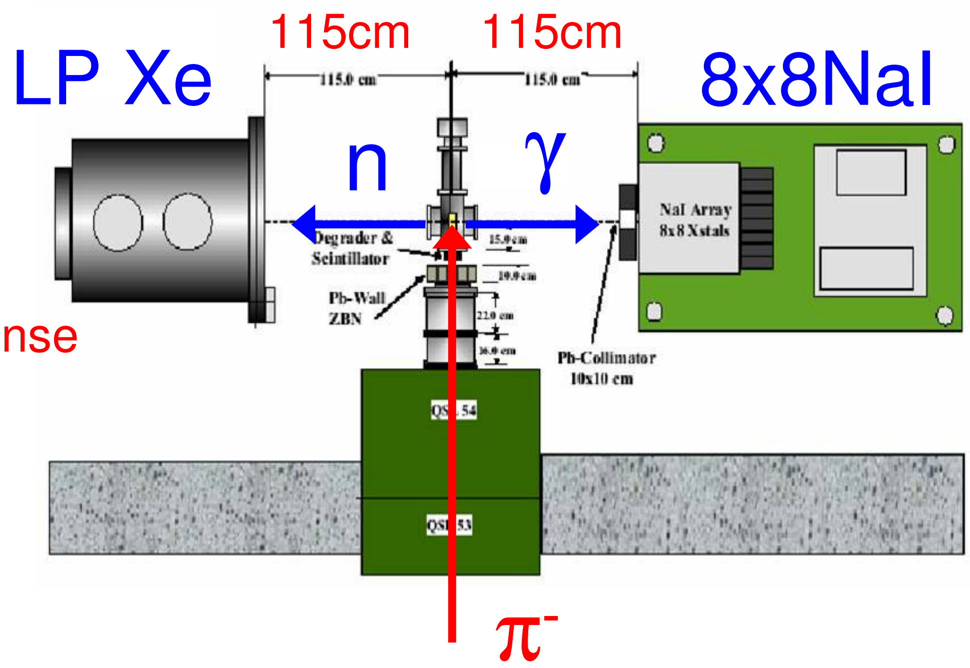


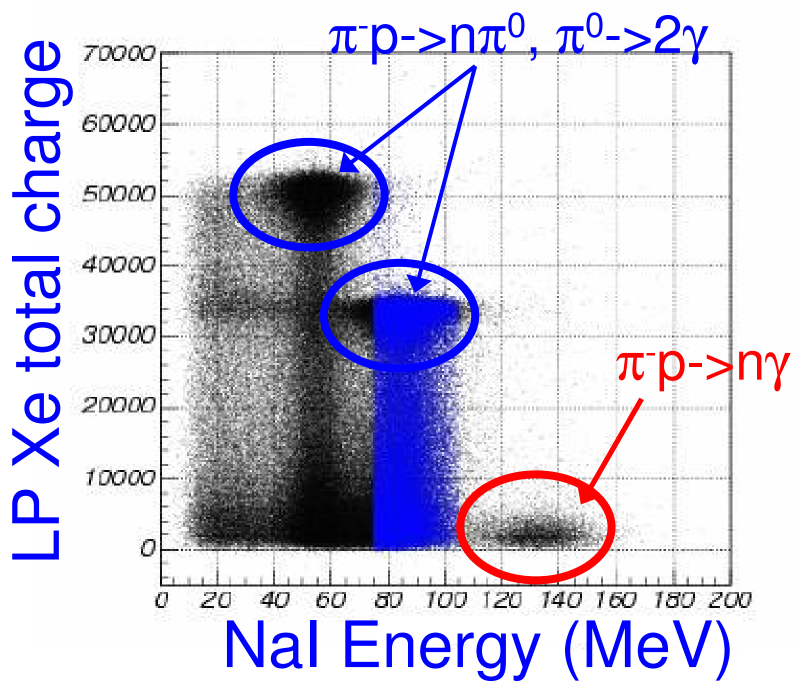




π^0 Beam Test at PSI

- π^- (at rest) + p -> π^0 + n,
  π^0(28MeV/c) -> γ + γ
  monochromatic γ calibration
  of around 52.8MeV
- π^- + p -> n(8.9MeV) + γ (129MeV)
  linearity check & neutron response





To get Energy Resolution

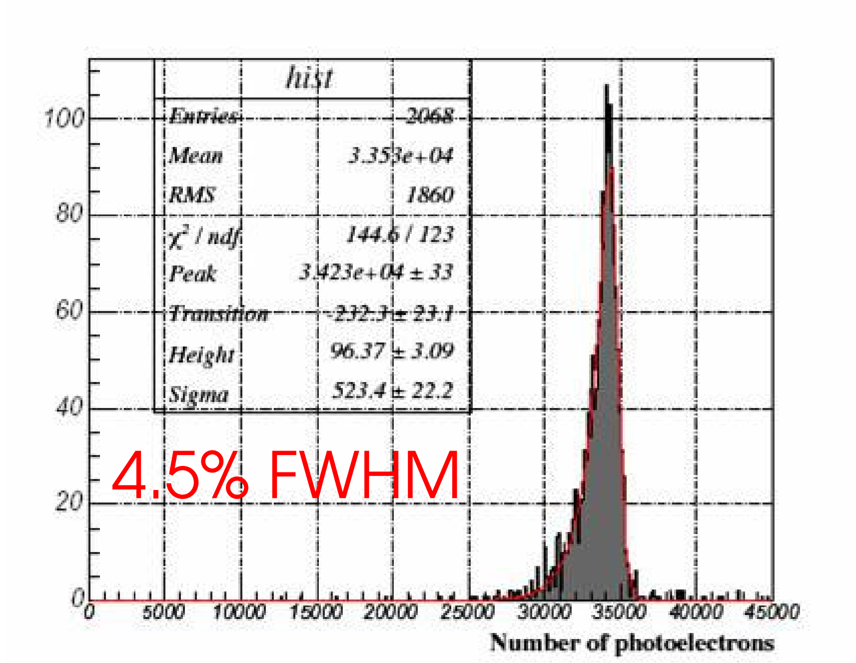
Select π^0 events

Select NaI energy

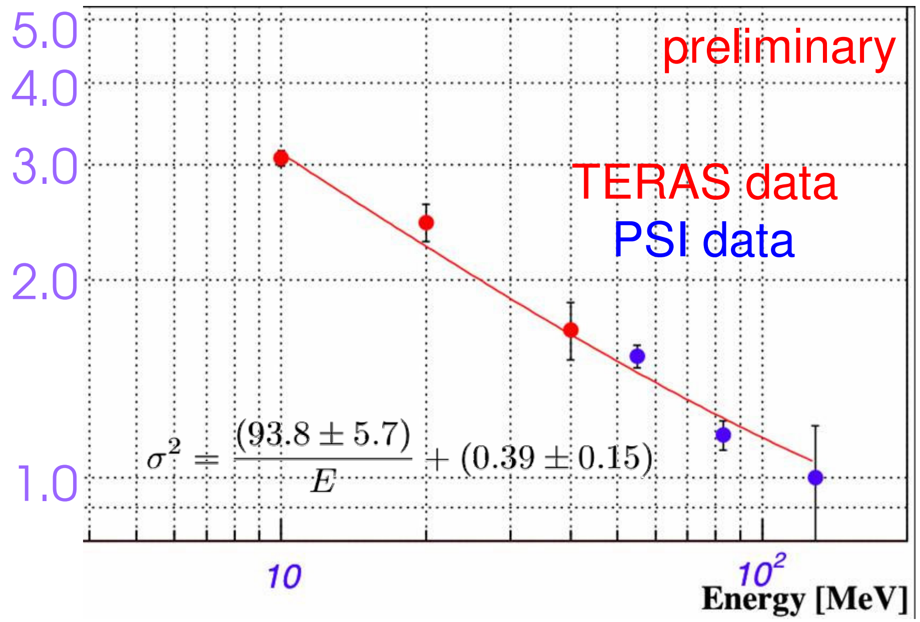
Select incident position in Xe detector

Remove too shallow and too deep events

Energy Resolution



Energy resolution in right σ(%)



Energy spectrum @ 54.9 MeV γ

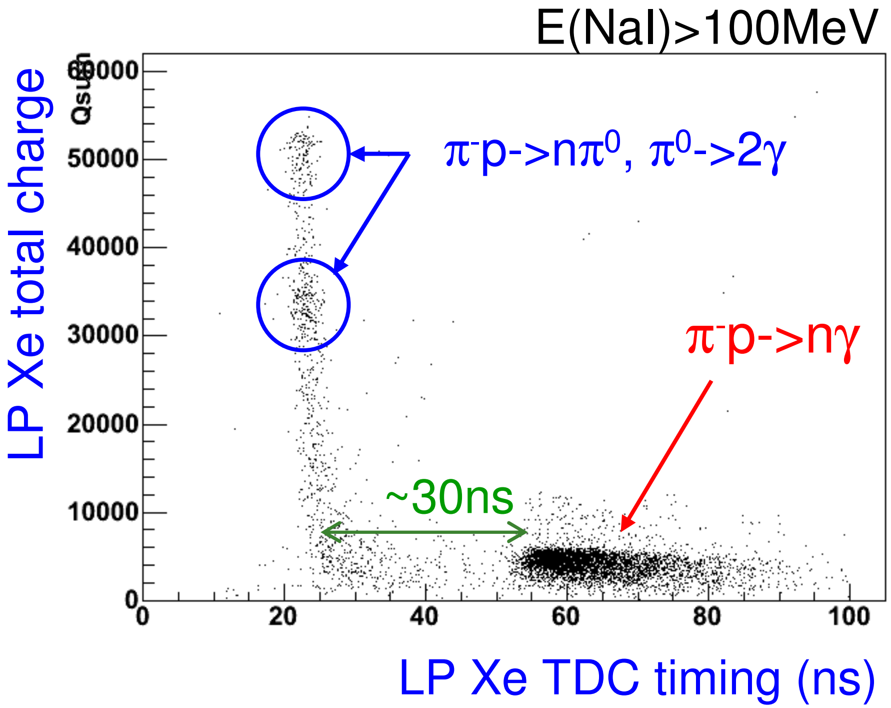
FWHM = (4.5±0.3)%

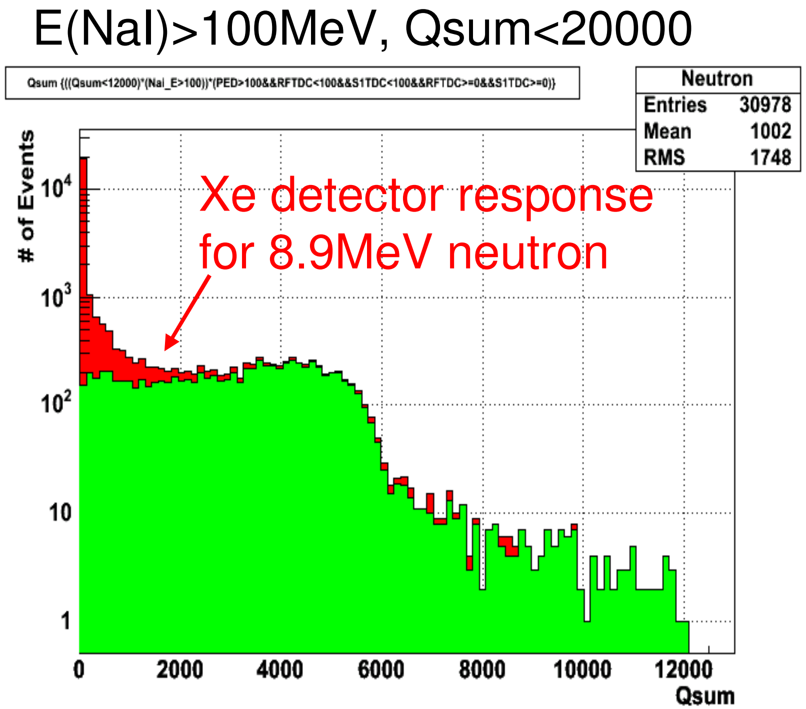
σ (right)=(1.6±0.1)%

This result satisfied our requirement

Right σ is a good function of energy photon statistics are still dominant, further improvement is expected by ~ 3xQ.E. PMT(R9288)

Neutron Response in Large Prototype





Neutron TOF ~ 30ns (115cm/0.14c)
Neutron Kenergy=8.9 MeV
No bias data for Xe
Require the beam correlation

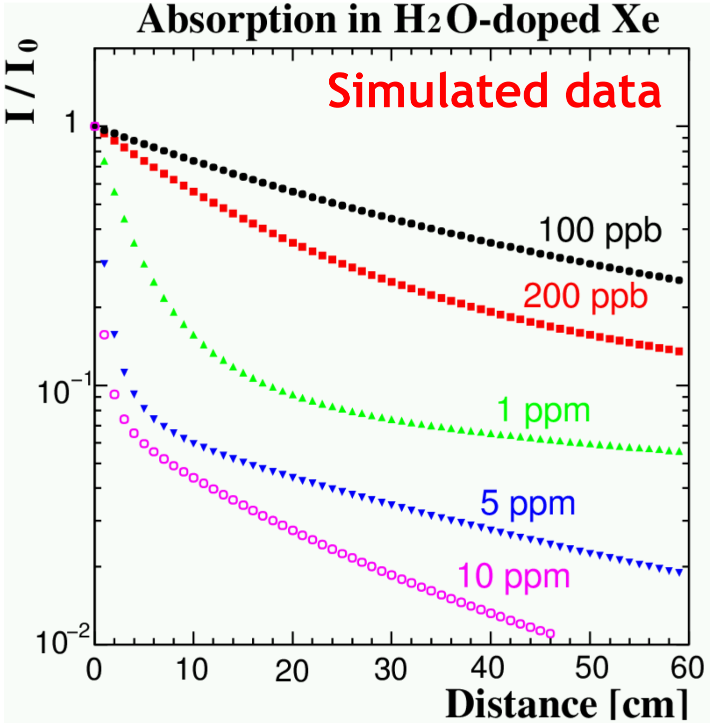
It might be the first time to detect the fast neutron like 8.9MeV in such a large scale Xe detector.
45% detection efficiency @0MeV th.
30% @1MeV th.

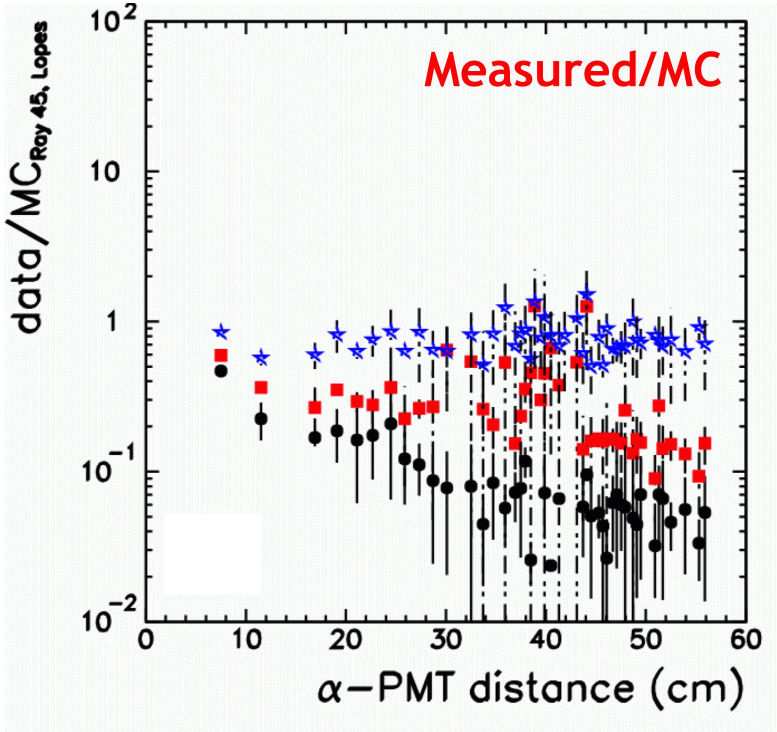
Summary

- MEG experiment will search for $\mu \to e\gamma$ decay, to explore SUSY-GUT, and currently being prepared at Paul Scherrer Institut in Switzerland.
- Large prototype of the xenon detector has been tested from 10MeV to 129MeV, and the excellent energy resolution at around 52.8MeV was shown in the PSI beam test.
- Physics run will start in 2006.

End of Transparency

How much water contamination?

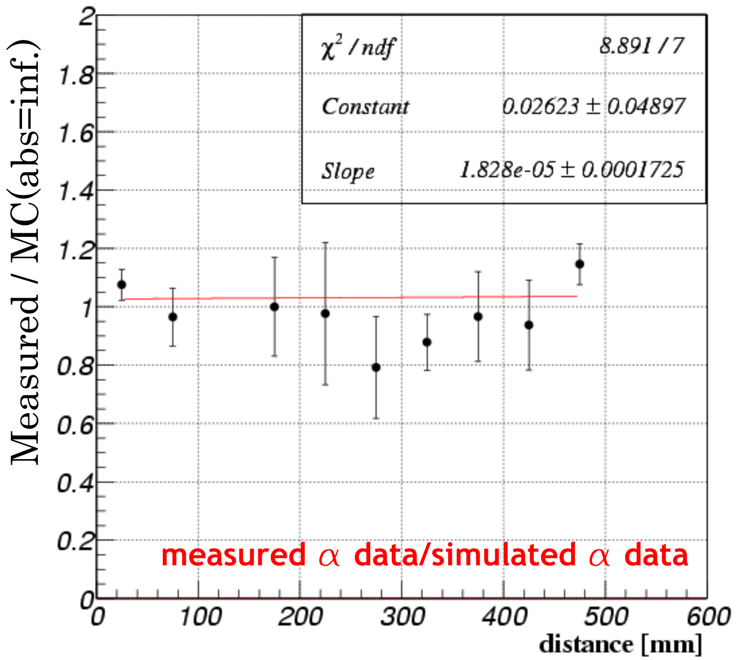


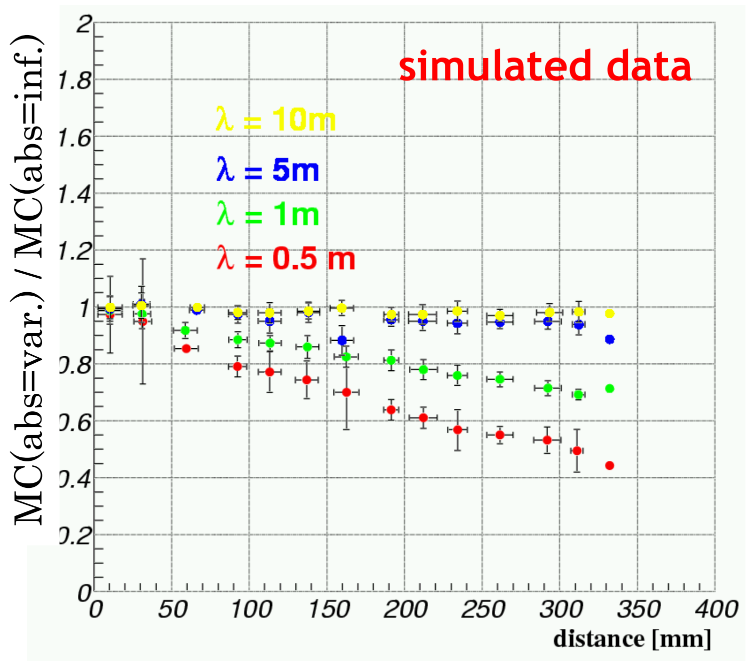


Before purification: ~10 ppm

After purification: ~10 ppb

Absorption length estimation



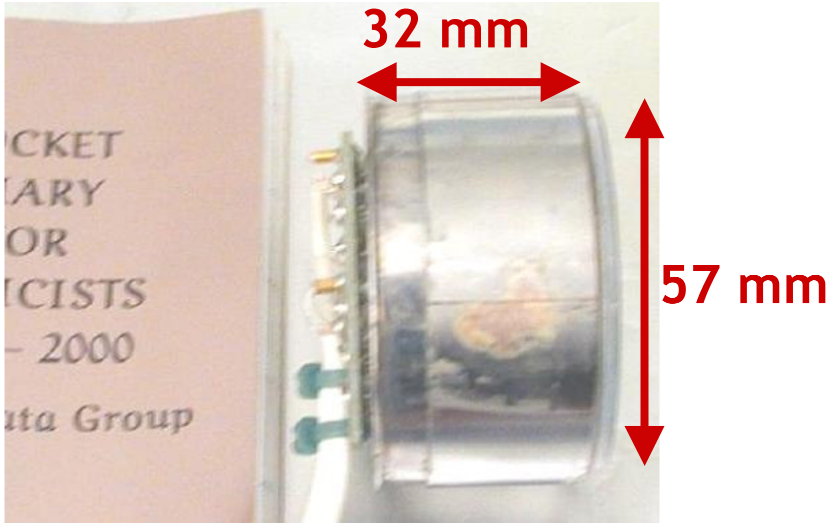


Comparing the two results,

the absorption length is estimated to be

over 3m (97.8% C.L.).

PMT (HAMAMATSU R6041Q)



Features

- 2.5-mmt quartz window
- Q.E.: 6% in LXe (TYP)

  (includes collection eff.)
- Collection eff.: 79% (TYP)
- 3-atm pressure proof
- Gain: 10^6 (900V supplied TYP)
- Metal Channel Dynode → thin and compact
- TTS: 750 psec (TYP)
- Works stably within a fluctuation of 0.5 % at 165K

Motivation

➢Under high rate background, PMT output (old Type PMT, R6041Q) reduced by 10-20%.

➢This output deterioration has a time constant (order of 10min.):

→ Related to the characteristics of photocathode whose surface resistance increases at low temperature.

- ➢Rb-Sc-Sb + Mn layer used in R6041Q
- ➢Not easy to obtain "high" gain. Need more alkali for higher gain.
- ➢Larger fraction of alkali changes the characteristic of PC at low temp.

So, New Type PMTs, R9288 (TB series) were tested under high rate background environment.

Al Strip Pattern

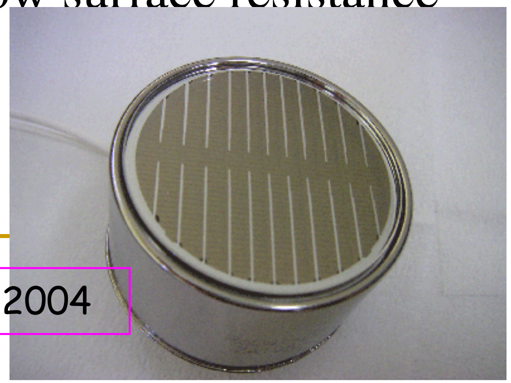
➢Low surface resistance

- ➢K-Sc-Sb + Al strip used in R9288
- ➢Al strip, instead of Mn layer, to fit with the dynode pattern

Confirmed stable output. (Reported in last BVR)
But slight reduction of output in very high rate BG

→ Add more Al Strip

R9288 ZA series

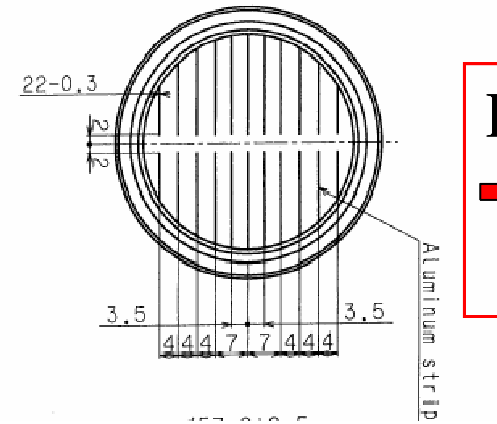


Works on Final! Design of PMT

Two Issues to be solved:

1. Output deterioration caused by high rate background. (Effects of ambient temperature on Photocathode)

Ans. Reduce Surface Resistance by adding Aluminum Strip Pattern



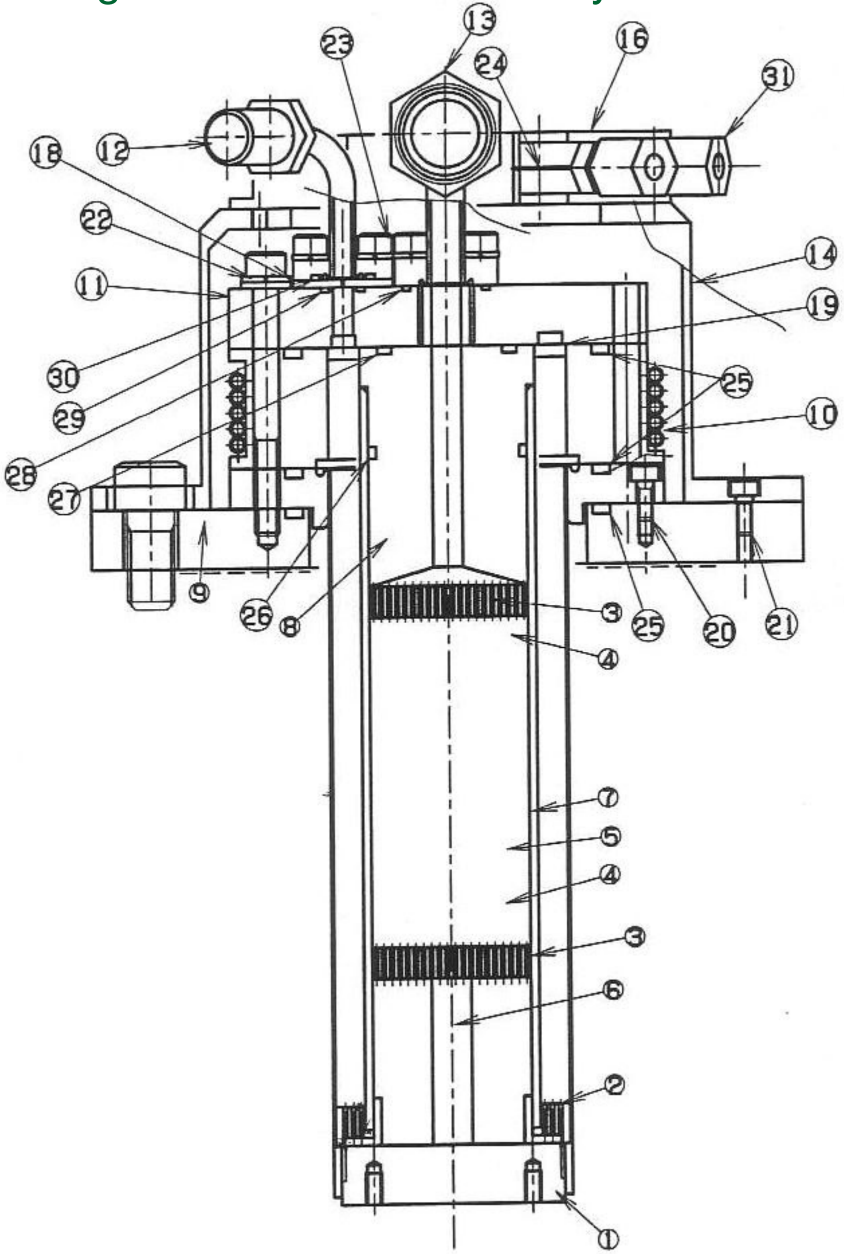
Delivered from HPK in April
➡Rate Dependence Test @ Liq.Xe

2. Shortage of Bleeder Circuit Current

Ans. Improve Design of the Circuit by adding Zener Diode

➡ HPK has started to work on new bleeder circuit design

Large Power Pulse Tube Cryocooler

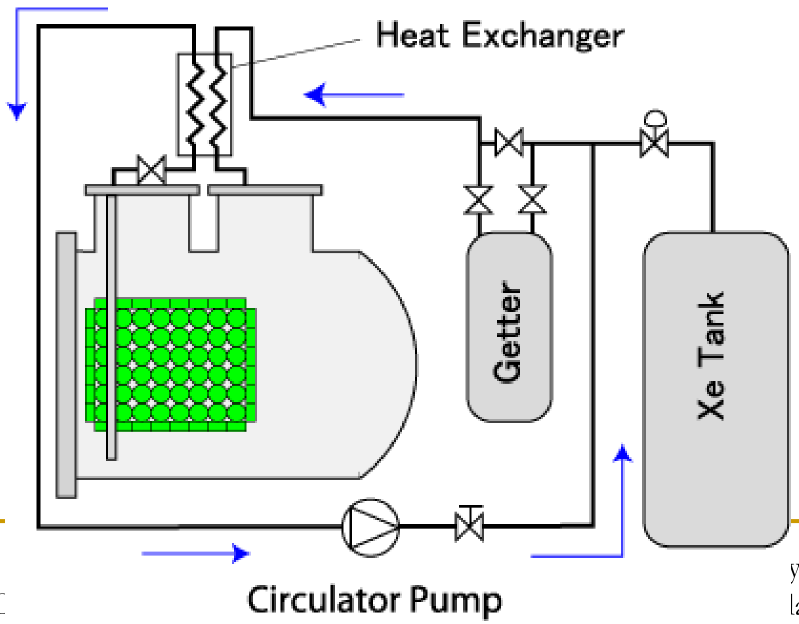


Technology transfered to Iwatani Co., Ltd

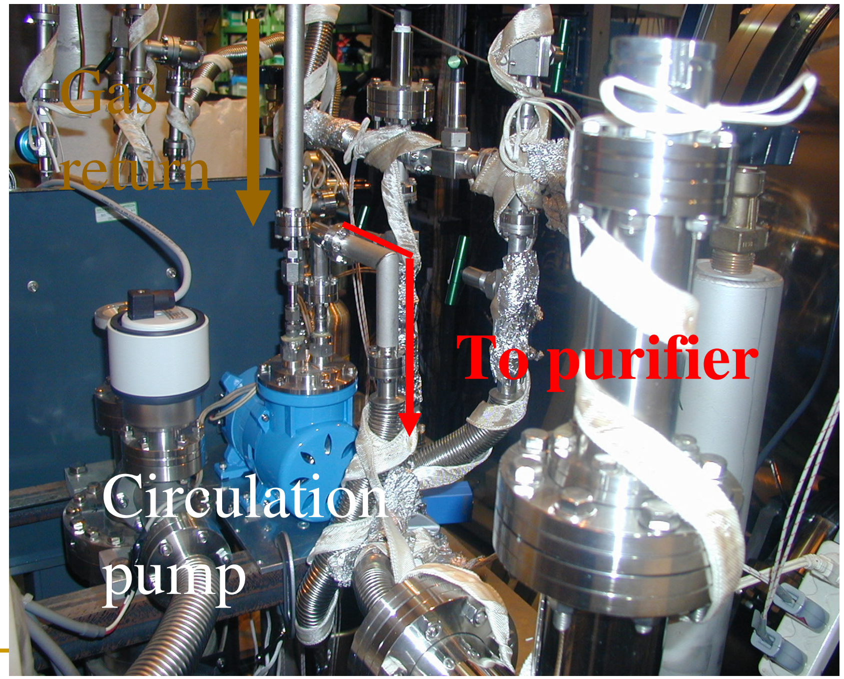
Designed:
150 W @165K

Purification System

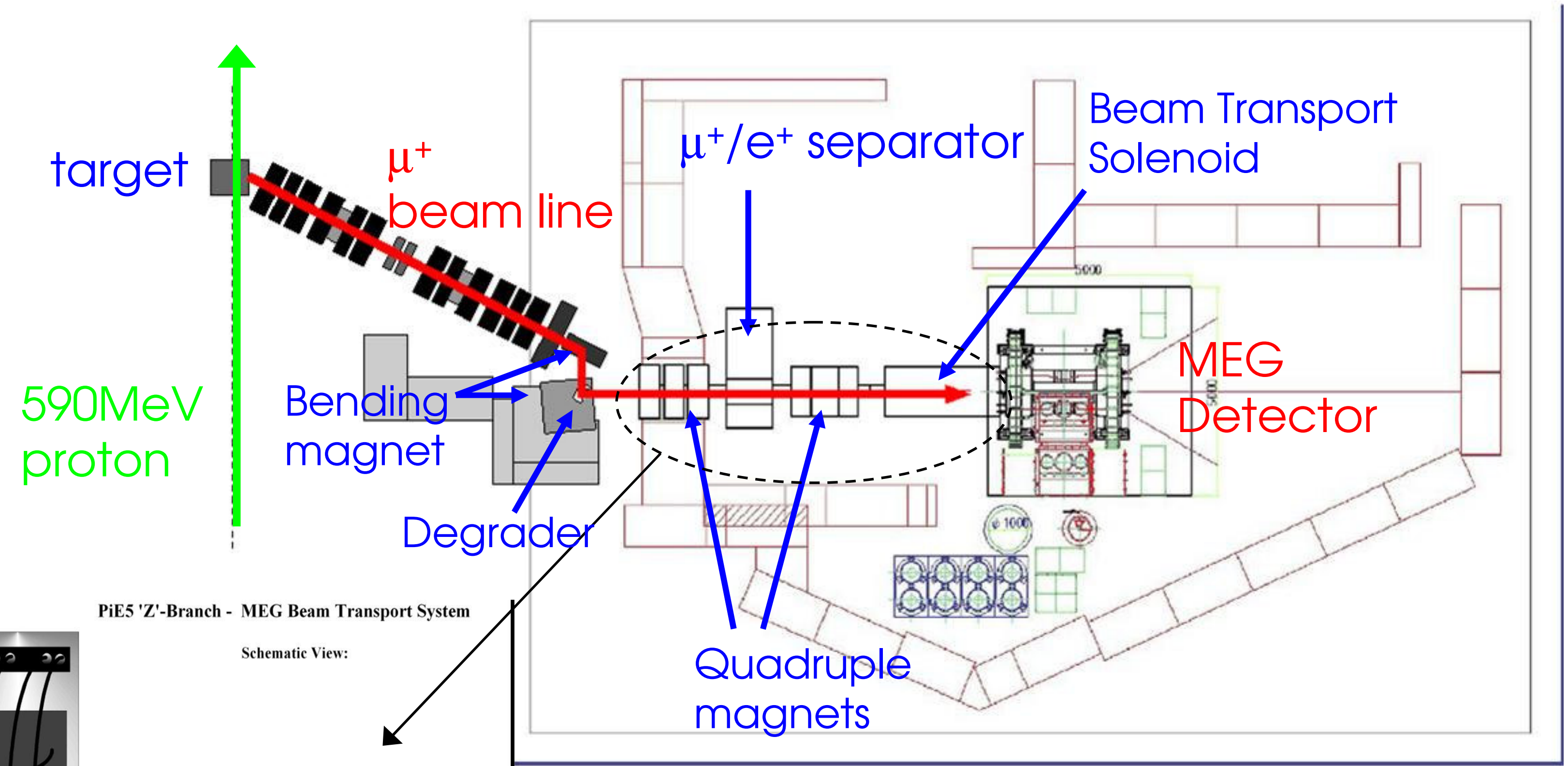
- Xenon extracted from the chamber is purified by passing through the getter.
- Purified xenon is returned to the chamber and liquefied again.
- Circulation speed 5-

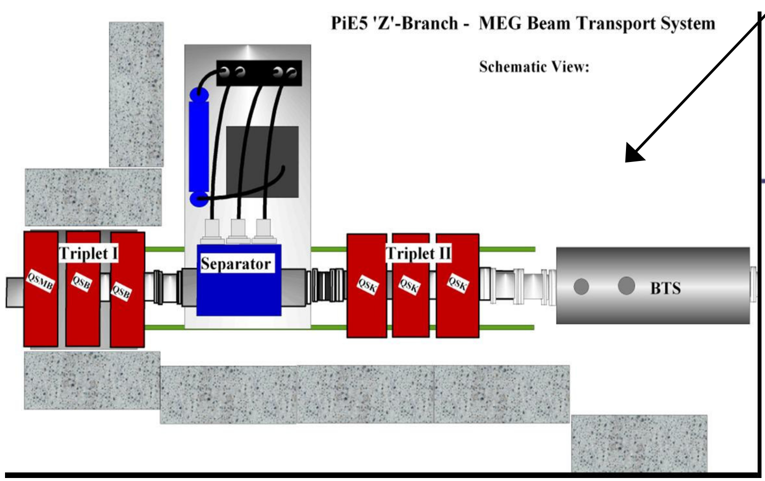


- Enomoto Micro Pump MX-808ST-S
  - 25 liter/m
  - Teflon, SUS



Beam Line





Surface muon beam : 28MeV/c
Beam line design established
World's most intensive μ^+ beam: $10^{7\sim8}$/s

COBRA Spectrometer

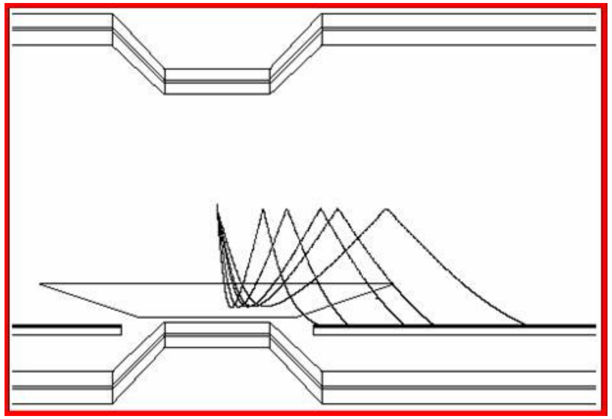
COBRA magnet was already installed into the πE5 area in PSI.

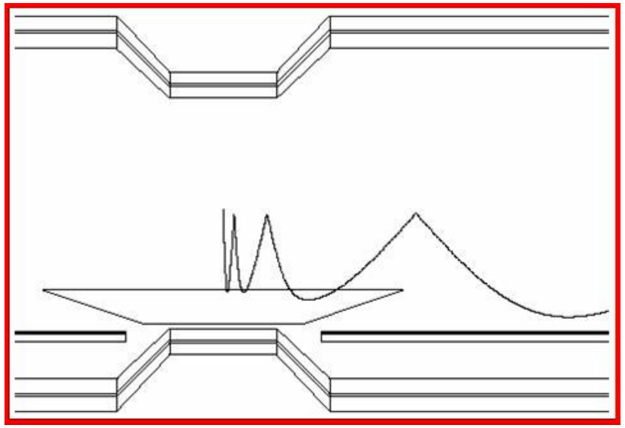
Constant bending radius independent of the emission angle

- e^+ momentum easily used at trigger level

Michel positrons are quickly swept out

- reduce the hit rate for stable operation





Signal & Background

- Single event sensitivity

  $N\mu \sim 2.5\times10^{7}$/s, $T=2.6\times10^{7}$s, $\Omega/4\pi = 0.09$, $\varepsilon_{\gamma}=0.6$, $\varepsilon_{e}=0.9$

  Sensitivity ($\mu \to e\gamma$) ~ 4.5×10^{-14} (1st phase, capable to $N\mu \sim 1\times10^{8}$/s)

- Background

  Accidental :

  Michel decay ($\mu^{+} \to e^{+} \nu_{e} \nu_{\mu}$) + random γ

  Background Rate ~ 10^{-14}

  Radiative muon decays :

  $\mu^{+} \to e^{+} \nu_{e} \nu_{\mu} \gamma$

  Background Rate < 10^{-14}

Expected detector resolution

- ΔE_{γ} : 4.5% (FWHM)
- ΔE_{e} : 0.8% (FWHM)
- $\Delta \theta_{e\gamma}$: <19mrad (FWHM)
- $\Delta t_{e\gamma}$: <230ps (FWHM)

- Good energy, time and position resolutions are required for γ, e^{+} detector.