$\mu^+ \to e^+\gamma$ Experiment at PSI

(Search for $\mu^+ \to e^+\gamma$ decay down to 10^{-14} branching ratio)

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Contents of Talk

1, Introduction

2, Concept and development of Detectors

- *Beam line*
- *COBRA spectrometer*
  - *– Magnet*
  - *- Drift chamber system*
  - *- Timing counter*
- *Liq. Xe photon detector*

3, Summary

Introduction

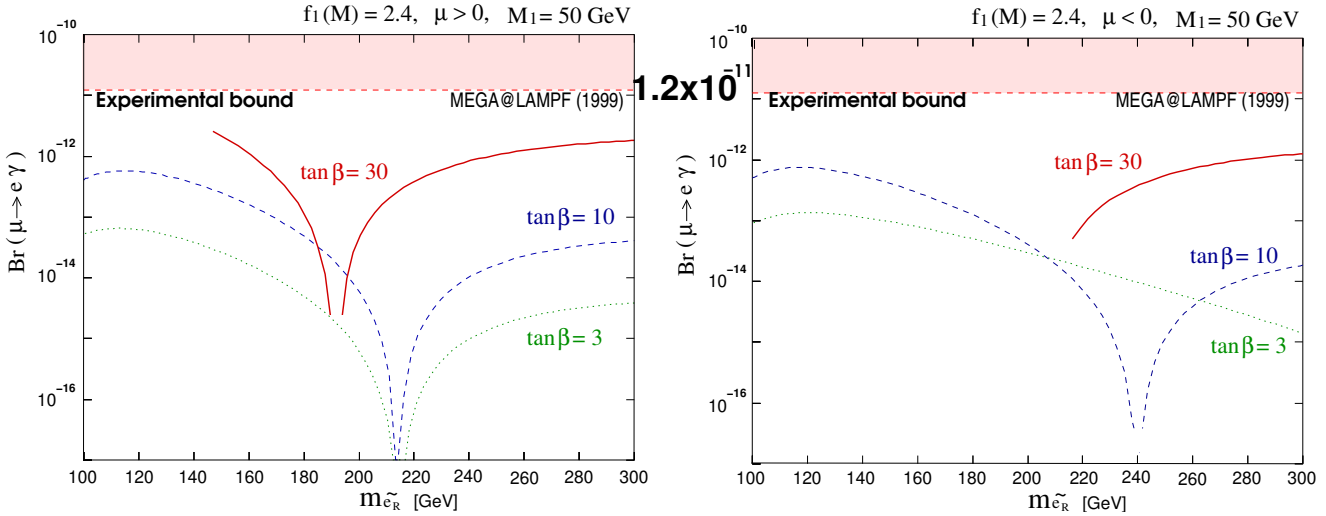
- In the Minimal Standard Model, ***Lepton flavor is conserved.***
- ***Many extension of Standard model*** predict ***Lepton Flavor violation***.

  Predictions of ***SUSY-GUT*** imply that

  branching ration of $\mu^+ \to e^+\gamma$ ***ranges from*** 10^{-15} ***to*** 10^{-12}

Compared with current upper limit

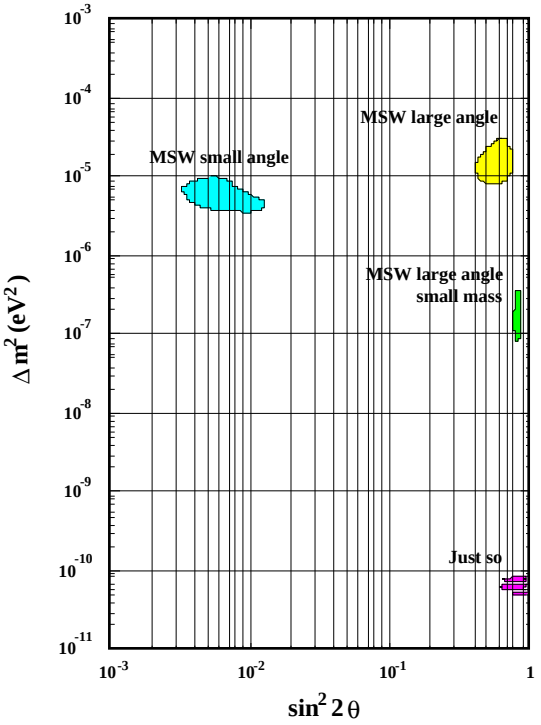
$$Br(\mu \to e\gamma) < 1.2 \times 10^{-11} \qquad \text{@ MEGA 1999}$$

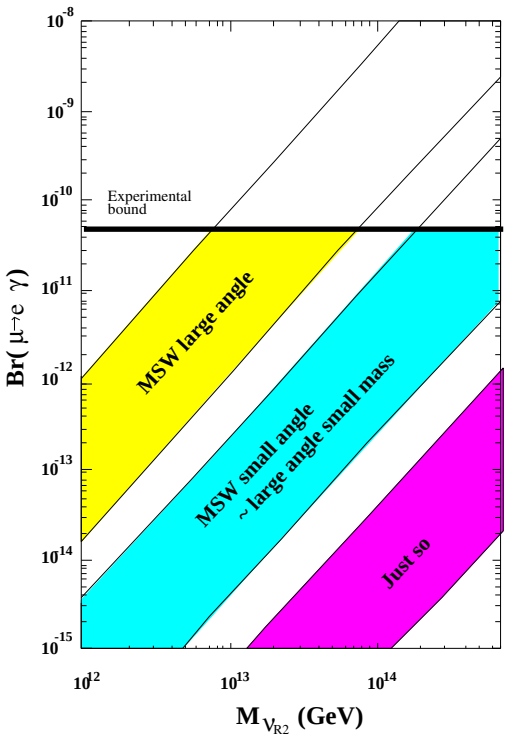


SU(5) SUSY model

The prediction is just below the current experimental limit

ν Oscillation and See-Saw Mechanism





MSW large angle solution is favored
with 95% confidence level.

⇓

Discovery of $\mu \to e\gamma$

somewhere above 10^{-14} branching ratio.

Search for $\mu \to e\gamma$ decay just below current limit
will give us significant information beyond the Standard model

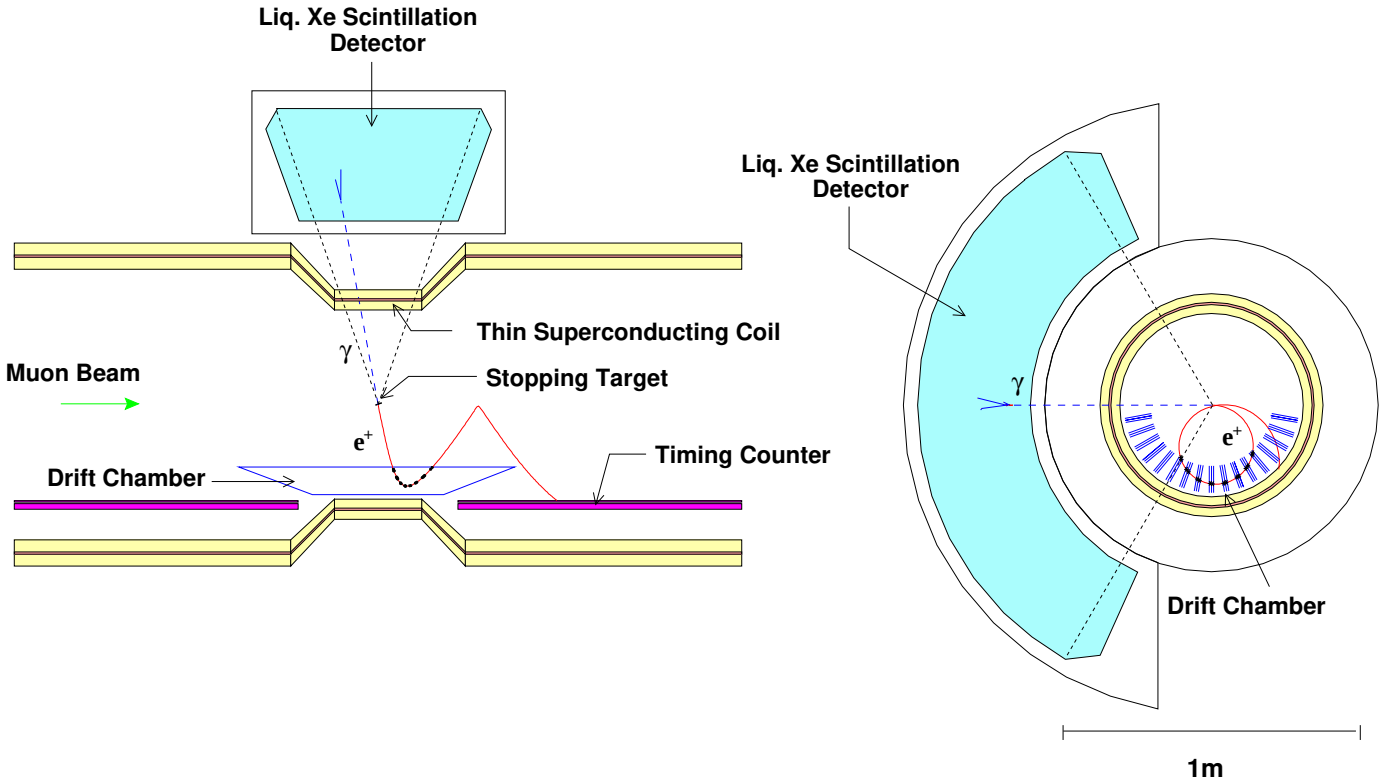
We propose to search for $\mu \to e\gamma$ with a sensitivity of 10^{-14}

Jun. 1999 : Submitted the proposal to Paul Scherrer Institute(PSI) committee,
and it was approved.

1999~2002 : Start Detailed technical design of detectors.
Investigate performance of detectors.
Start Construction of detector components

2003 : Engineering / Physical run will start.

Design of Detector



Continuous μ beam with high intensity

e^+ : COnstant Bending RAdius(COBRA) Spectrometer

- Magnet for gradient magnetic field
- Drift Chamber
- Timing counter

γ : Liq. Xe photon detector

High performance is needed

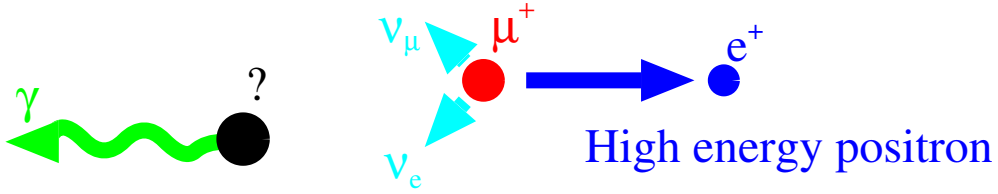
Expected performance

To achieve a sensitivity of 10^{-14}

It is important to

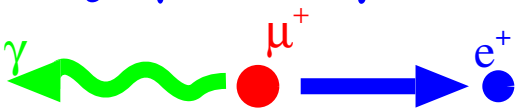
reject the background event from Michel decay.

Major backgrounds is Accidental background.



γ from annihilation,
radiative decay of μ, photon pile-up ....

The case of $\mu \rightarrow e\,\gamma$ decay



back to back ⇒ Position resolution

energy of half μ mass ⇒ Energy resolution

at a same time ⇒ Timing resolution

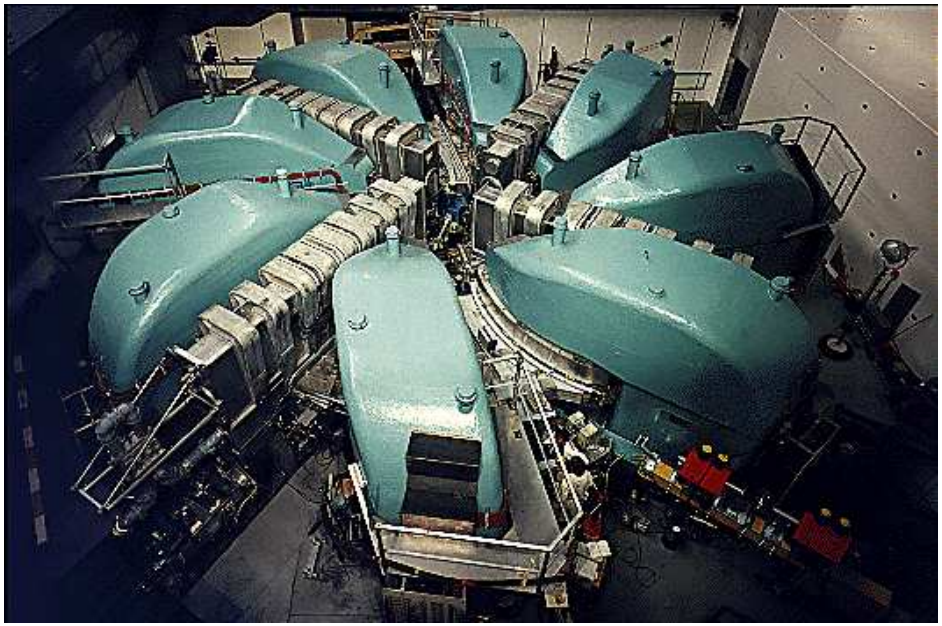
High resolutions are essential.

Expected and essential performance of detectors are

	FWHM
ΔE_e	*0.7 %*
ΔE_γ	*1.4 %*
$\Delta\theta_{e\gamma}$	*12 mrad*
$\Delta t_{e\gamma}$	*150 psec*

Accidental background can be rejected to 5×10^{-15}

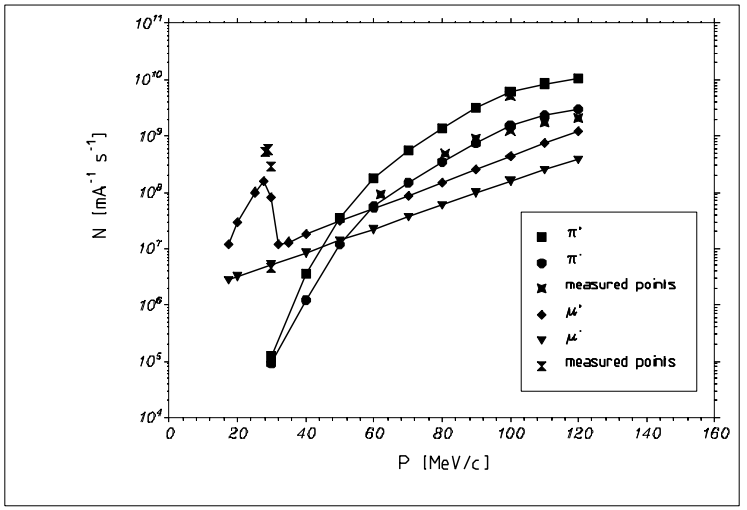
Beam Line



Ring Cyclotron

provide primary proton
with Beam current of ***1.8 mA*** (1MW)

Fluxes in πE5



The beam line will deriver
high intensity and continuous μ beam
with momentum of 28 MeV/c

Continuous beam will reduce accidental backgrounds
to avoid consentration of μ decay

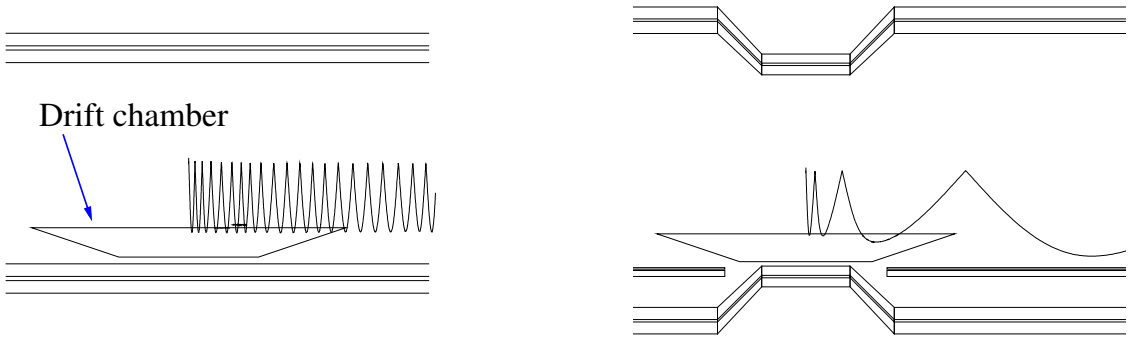
COBRA spectrometer

Magnet

- ***Thin wall*** at central region for γ detection
- Specially designed to form a ***Gradient magnetic field*** of 1.1 Tesla at center, decreasing as z increases.

2 major advantages of Gradient field

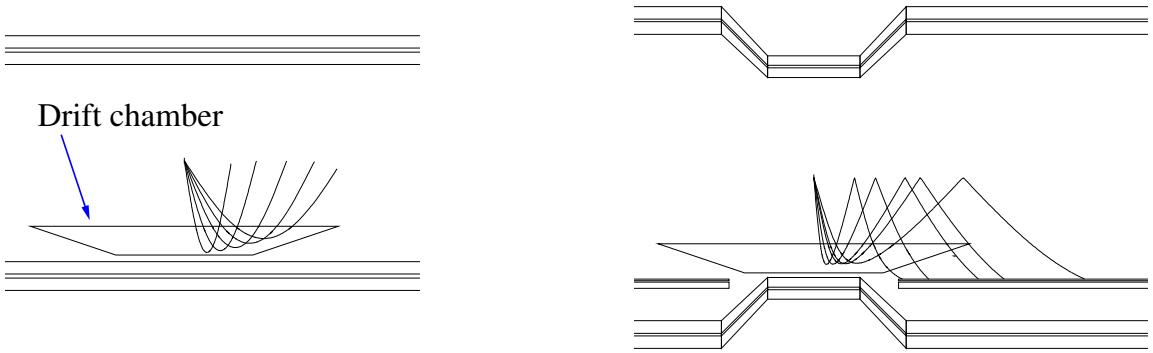
The case that e is emitted close to 90°



Uniform field
make a lot of hits in DC

Gradient field
Swept away quickly

Bending radius of e^+

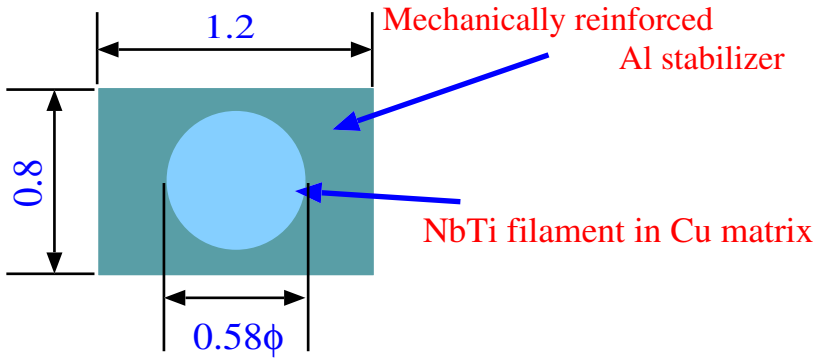


Uniform field
depend on track momentum
and emission angle

Gradient field
depend only on momentum of e^+
Constant bending radius
⇒ ***easy to select high momentum tracks***

Development of Magnet

High-strength superconductor for thin-wall solenoid



- The Al stabilizer is reinforced by "micro-alloying" technology. Additive materials provide reinforcement.
- The high-strength superconductor reduces the support material.

Radiation length ~ 0.15

95% transparent to a 52.8 MeV γ ray

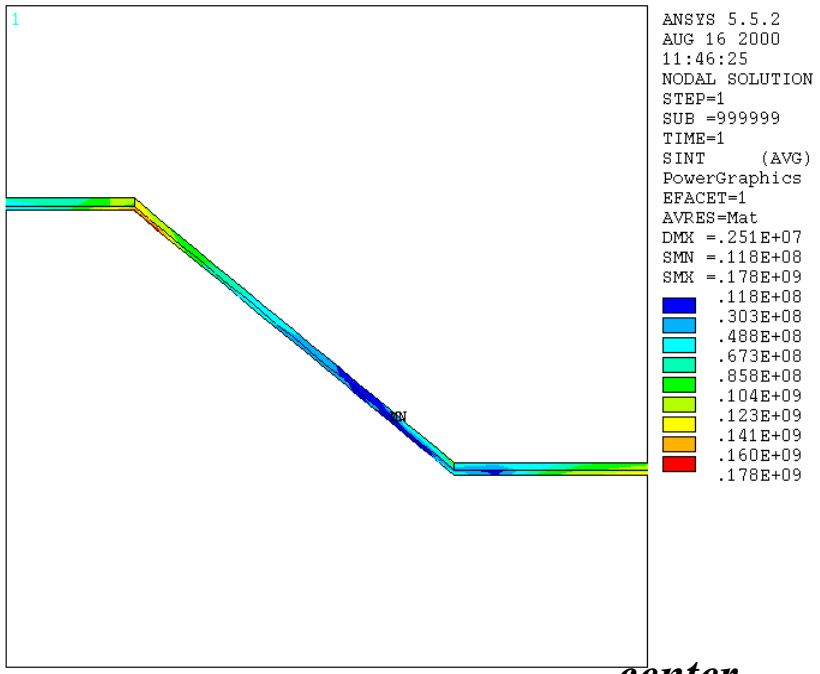
Estimation of Materials in central region

	Eff.Thick.(mm)	$X(X_0)$	$w(g/cm^2)$
Superconduting Coil :			
Support Cylinder	1.85	0.021	0.5
Al-stabilizer	2.51	0.028	0.68
NbTi/Cu	0.81	0.051	0.57
Insulator	0.5	0.0018	0.071
Epoxy-resin	1.5	0.0077	0.255
Cryostat :			
Outer Vessel	1.0	0.0112	0.27
Outer Rad. Sheld	2× 0.3	0.00674	0.16
Inner Rad. Sheld	2× 0.3	0.00674	0.16
Inner Vessel	1.0	0.0112	0.27
Super Ins.	1.4	0.0072	0.238
total :		0.153	3.18

Mechanical analysis

Maximum stress is less than 180 MPa

Acceptable level

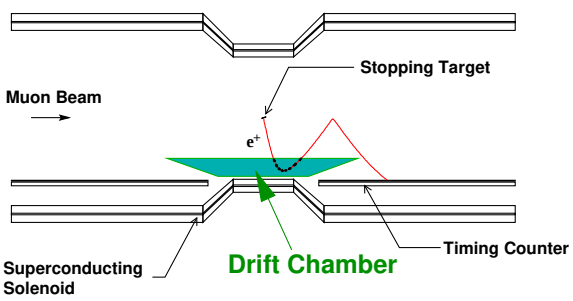


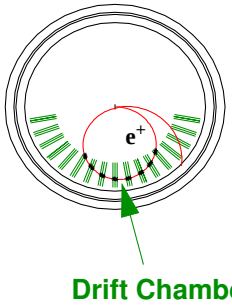
Stress distribution in the coil

detailed design is under progress.

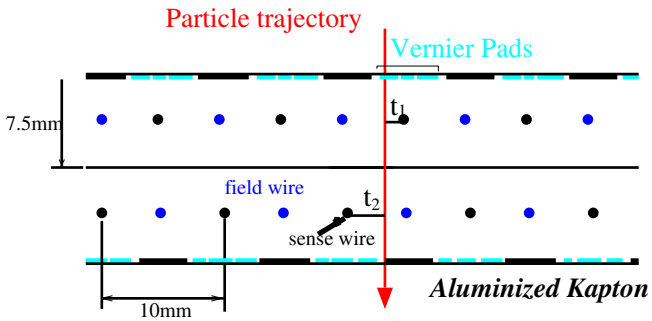
Construction will start in 2001

Drift Chamber system





- *Detect high energy e^+ emitted in $|\cos\theta| < 0.35$*
- *Consists of drift chamber sectors,*
  which is composed by
  2 staggered array of drift cells.
- *Walls are made of thin Aluminized Kapton foil.*
- *Al is shaped to make vernier pattern.*
  Charge deposited on 3 pads determine position along the wire.
- *He based gas.*



Expected position resolution

r-coordinate : 200 μm

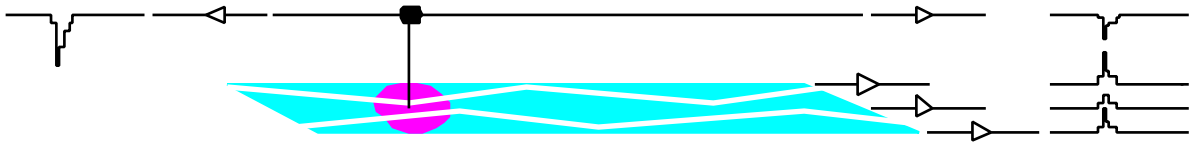
z-coordinate : 300 μm

⇓

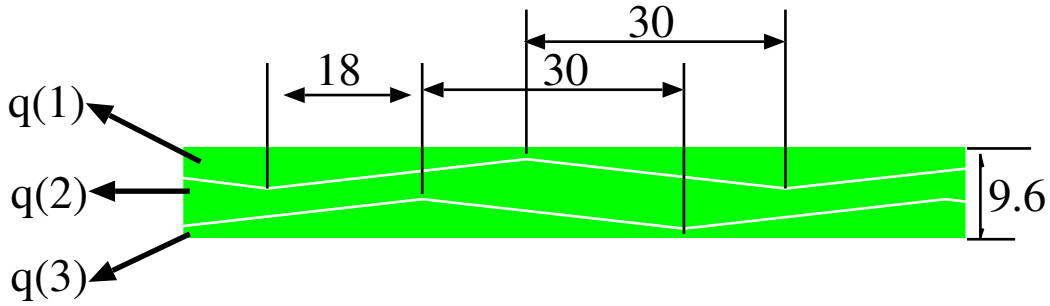
Momentum resolution : 0.7 % (FWHM)

Angular resolution : 9 mrad (FWHM)

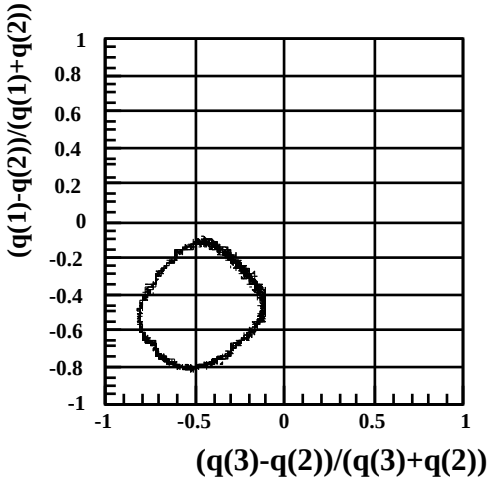
limited by Multiple scattering

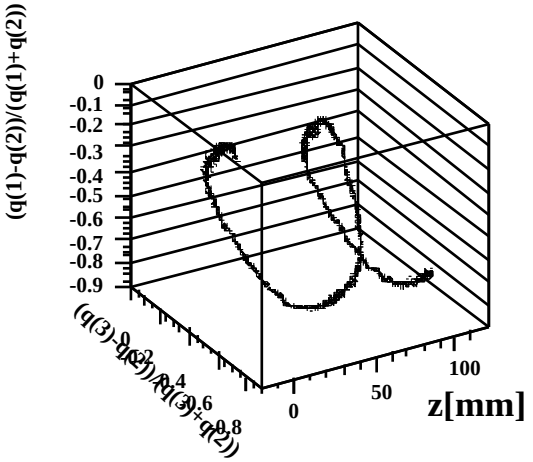


Vernier Pad



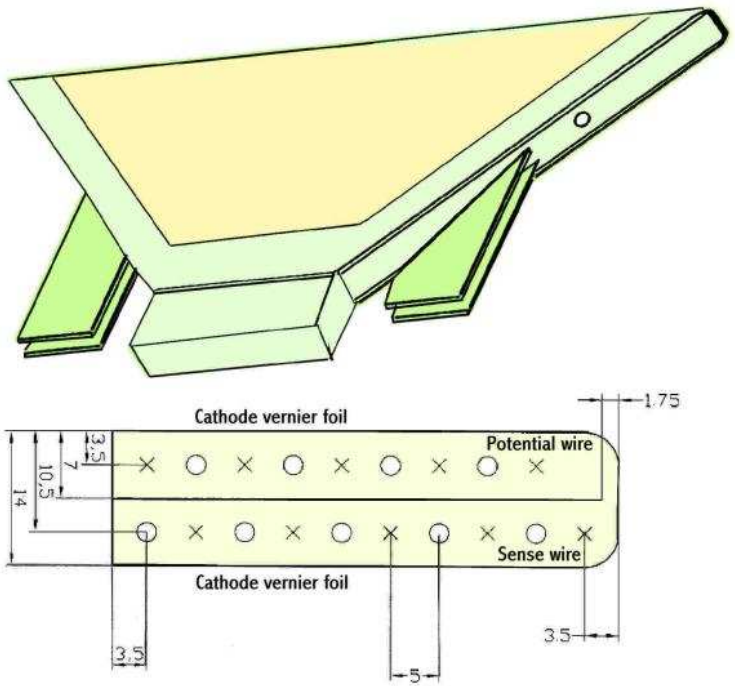
Correlation of charges on 3 pads (MC)





Prototype drift chamber

Prototype has been developed at PSI.



- ***Engineering Problems***
  - ♣ It is required that materials are as low as possible.
  - ♣ Special figure

    Construction is difficult.

    ⇒ ***Same configuration*** of Final chamber expect for # of wires in the sector.

- ***Beam test is planed at PSI.***
  - ♣ ***To check the performance in a Magnetic field of approximately 1T.***
  - ♣ ***Study of Gas mixture. (He based gas)***
  - ♣ ***Study of Vernier pad.***

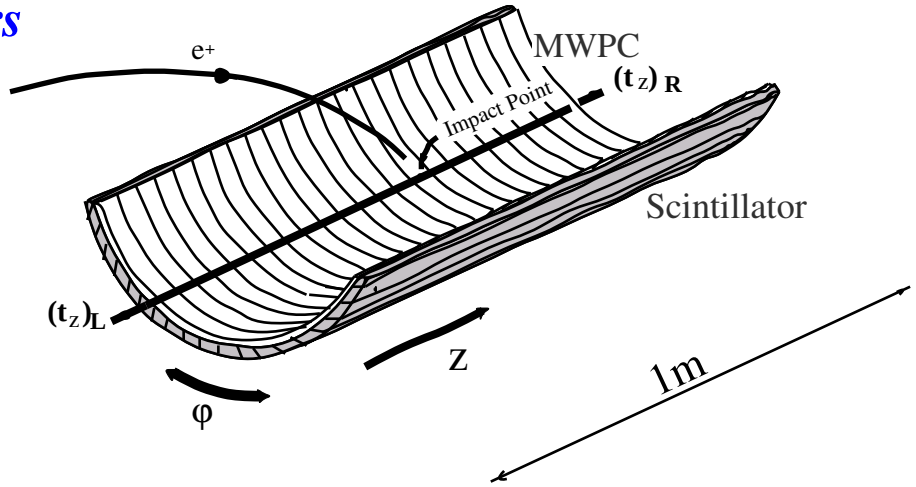
Beam test will performed Oct. 2000.

Positron timing counter

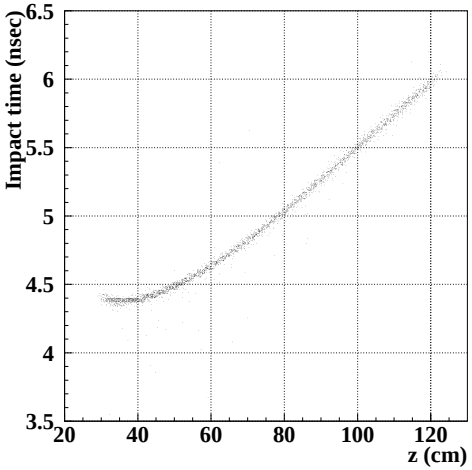
Consists of ***MWPC***
and ***hodoscope arrays of scintillators***

Inner MWPC
Determination of impact point
with an accuracy of 1 cm

Outer scintillator
Timing determination
with an accuracy of ***45 psec (σ)***
(Spread caused by multiple scattering is estimated to be 16psec)

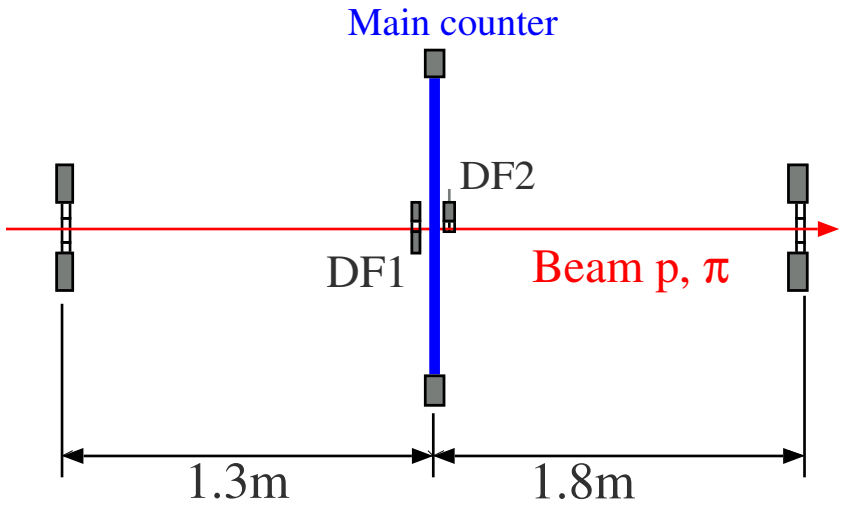


Configuration of the timing counter

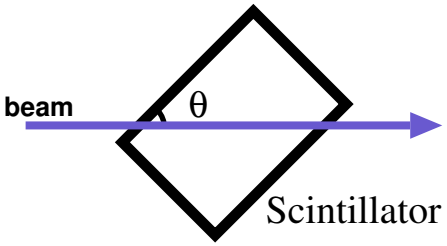


Time and z position are
correlated to each other

Beam test for timing counter at KEK (1999)



Set up of beam test



slanted to study effect of inclined incident particle

$\theta = 30^{o}, 45^{o}, 90^{o}$

Purpose of beam test

Intrinsic performance of scintillator

PMTs are placed both end of scintillator ***directly***

Scintillator : BC404 95×2×3.5 cm

PMTs : HAMAMATSU R6504S

(2 inch, 19 stages of fine-mesh dynode,

gain : 6×10^{6})

Realistic performance of timing counter

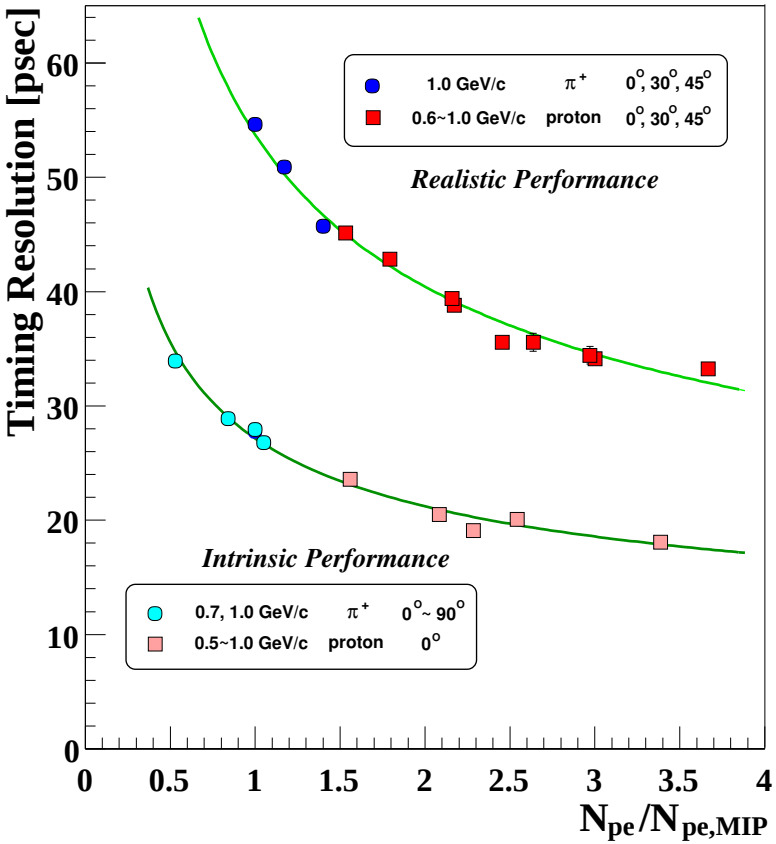
Light guides are installed

Scintillator : BC404, BC408

PMTs : HAMAMATSU H6152-01-MOD

(1 inch, 17 stages of fine-mesh dynode,

gain : 2×10^{6})



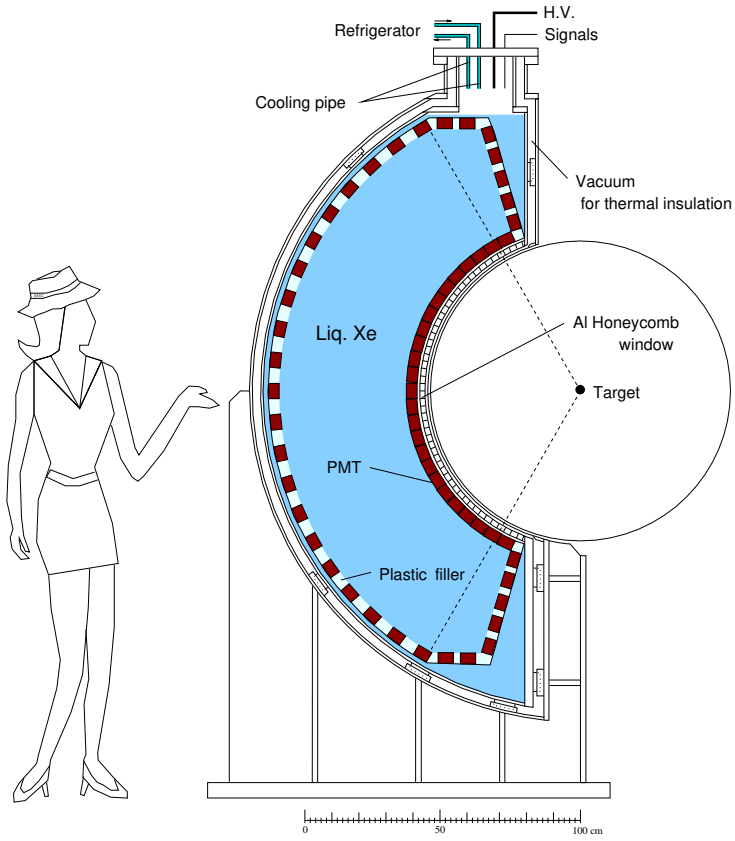
The results :

- ***Timing resolutions are determined by light yields, independent of incident angle and particles.***
- ***Binning effect of TDC limits the resolution.***

Next beam test is planed which employs 1 inch PMTs with higher gain.

Timing resolution of 45 psec is feasible

Liq. Xe photon detector (Mini-kamiokande)



Scintillation lights are detected by 800 PMTs surrounding the active area of detector
Volume of Liq. Xe ~ 800 liters

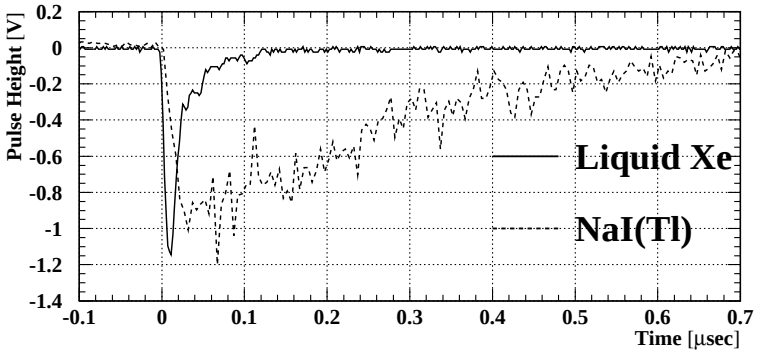
Advantage of Liq. Xe

- ***High light yield*, consistent with 75% of NaI(Tl)**
  Essential for high resolution of energy, position and timing.
- **Fast signal**
  Essential for precise timing determination.
- **Short decay-time (4.2 nsec, 22 nsec, 45nsec)**
  Indispensable to minimizing pile-up of γ ray
- **Free from non-uniformity problem**

⇒ ***Expected performance***
$\Delta E = 0.7\ \%,\ \Delta x = 2\ mm,\ \Delta t = 45psec\ (\sigma)$

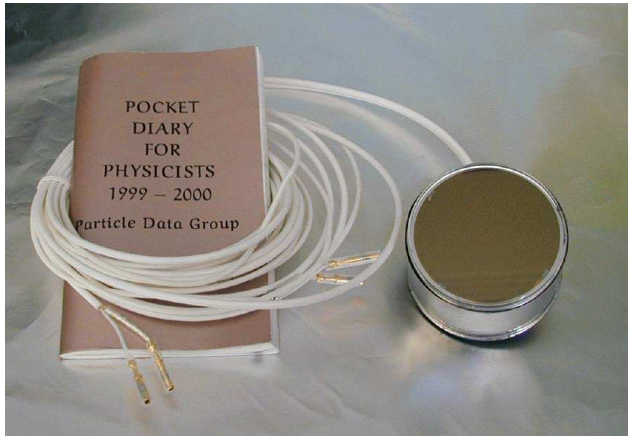
Disadvantage

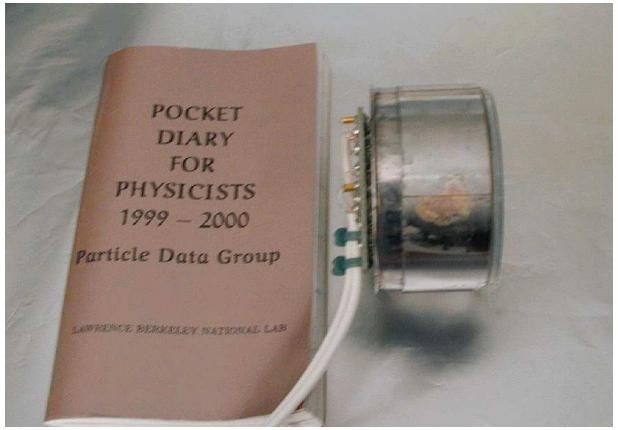
- **Wave length of scintillation light : 175 nm**
- **Boilng poing : 165 K**



PMT(R6041Q, HAMAMATU)

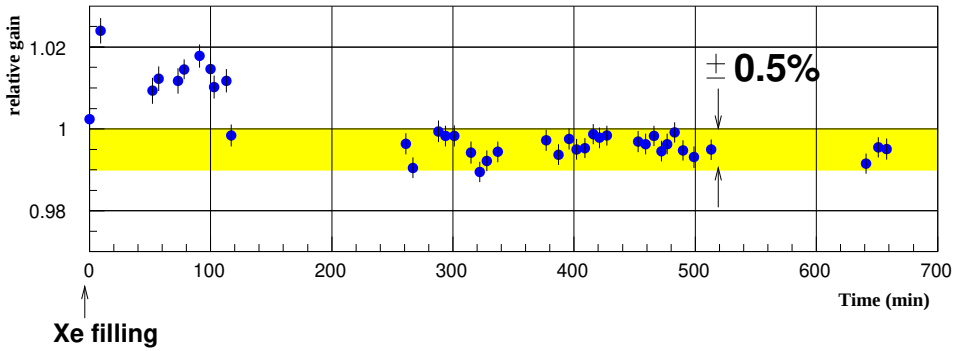
Operated in 165 K,
detect the lights with wave length of 175 nm





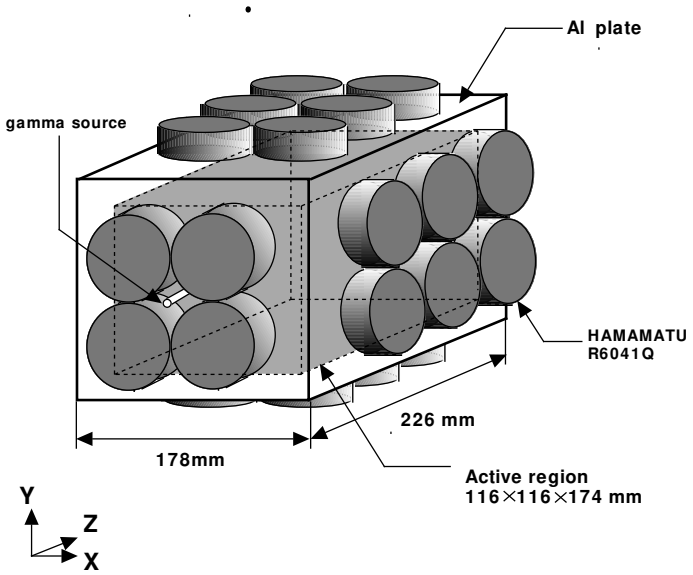
R6041Q (2 inch)

- ***Quartz window***
  to transmit the scintillation light of Xe
- ***Stably operated*** in the Liq. Xe
  (at temperature of 165K)
- ***Compact*** (Metal-channel dynode)
  Reduce materials as low as possible



PMTs are stable within ±0.5%

Small prototype of photon detector

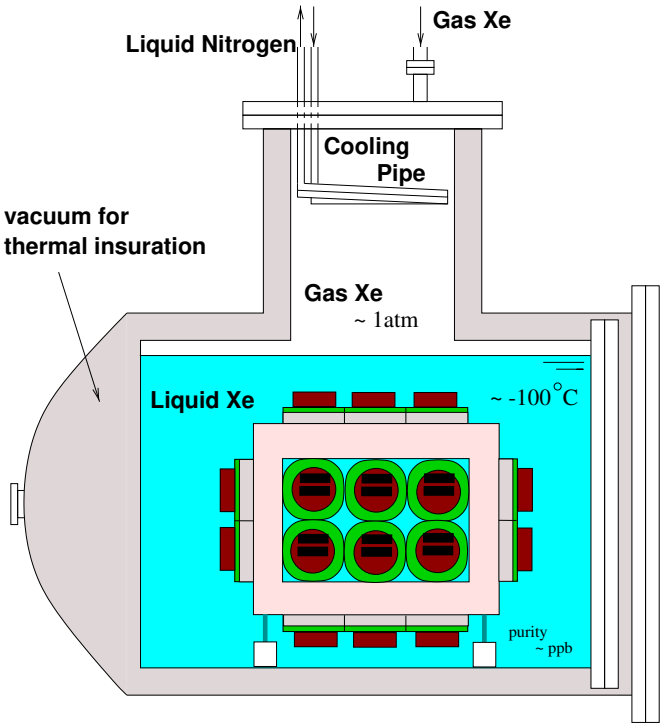


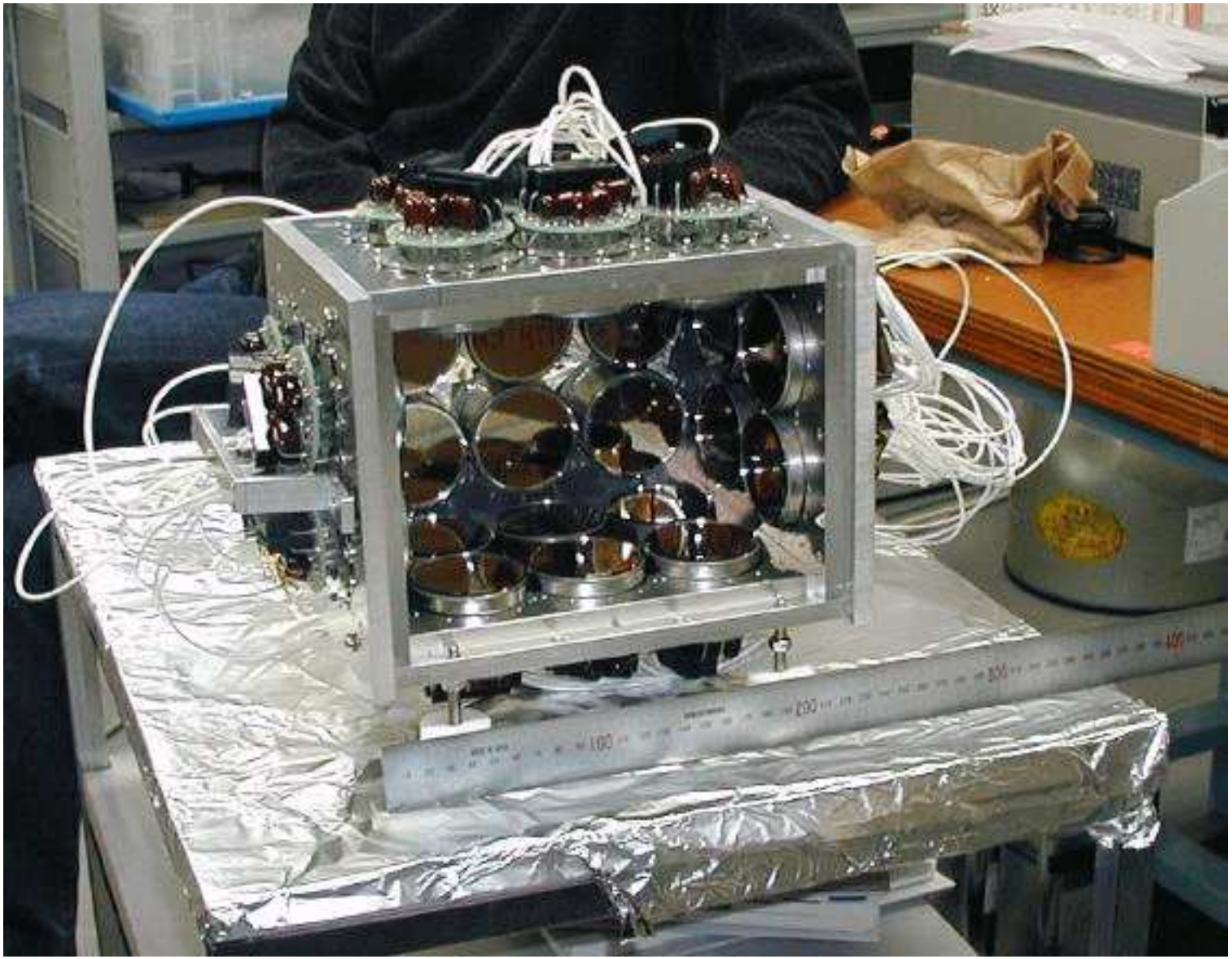
Constructed in 1998

- ***32 PMTs are placed on Al box***
- ***Resolutions are estimated with γ ray from sources***

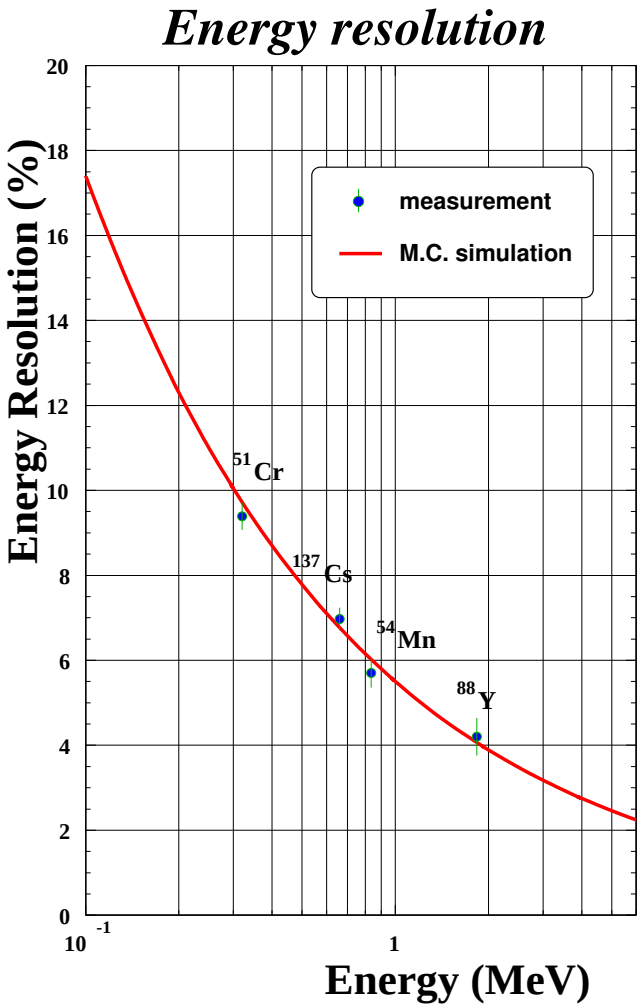
γ sources

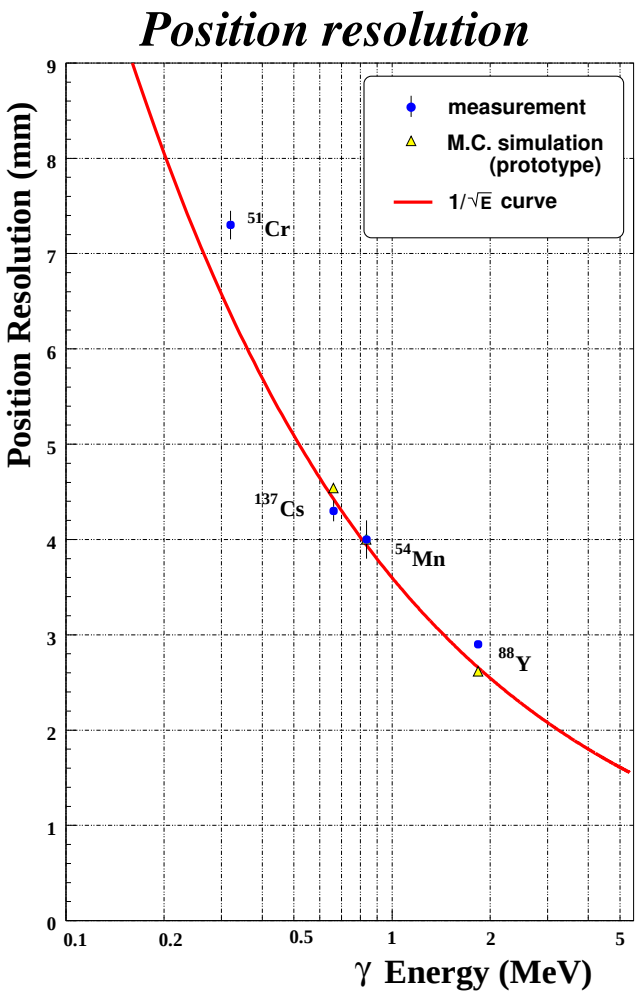
Nuclide	energy (keV)
^{51}Cr	320
^{137}Cs	662
^{54}Mn	835
^{88}Y	1836





Results of Small Prototype photon detector

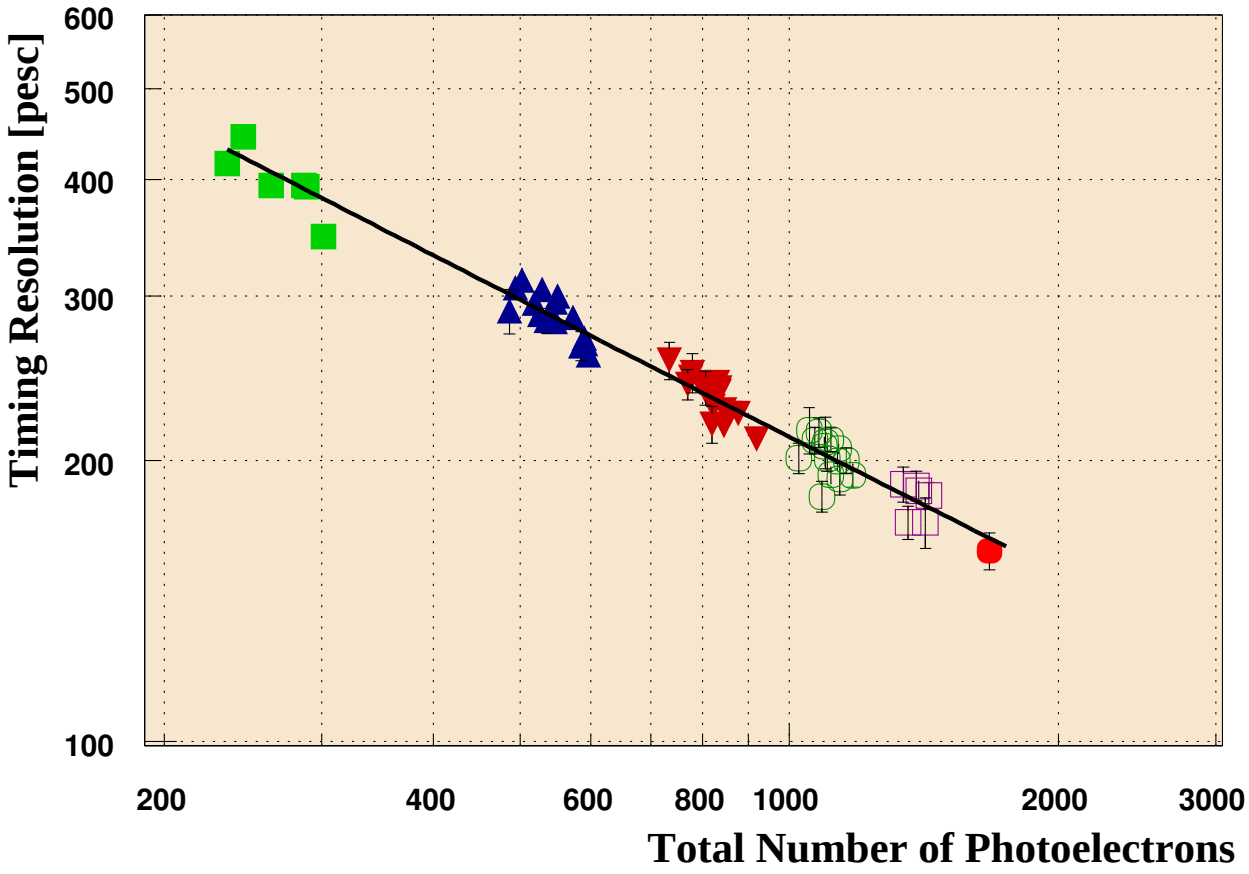




Extrapolations to 52.8 MeV γ ray indicate that

energy and position resolution of 0.7 % and 2 mm (σ) are feasible

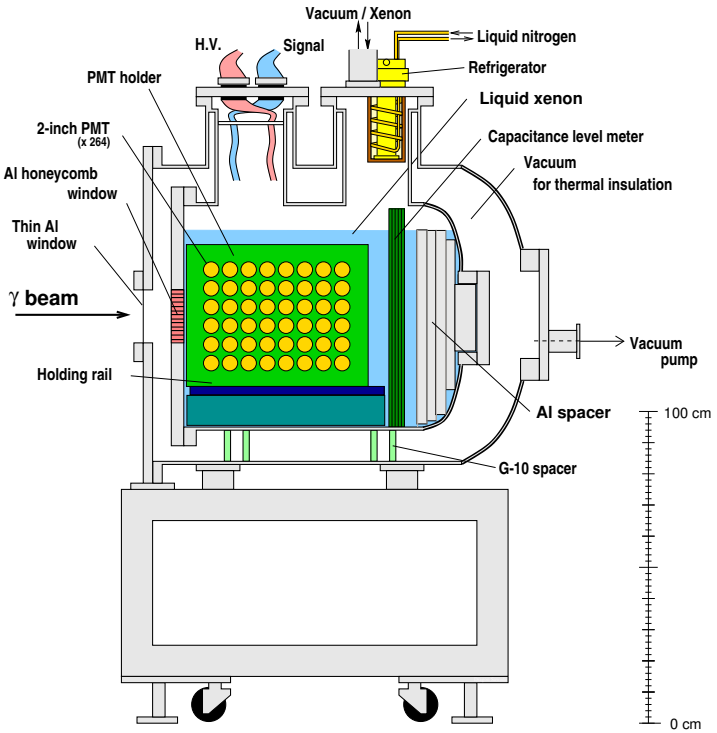
Timing resolution



A simple extrapolation indicates that
timing resolution of 45 psec (σ) will be achieved

Large Prototype photon detector

@ TERAS , Electrotechical Laboratory in Tukuba



Test with small proto. is limited to a low γ.

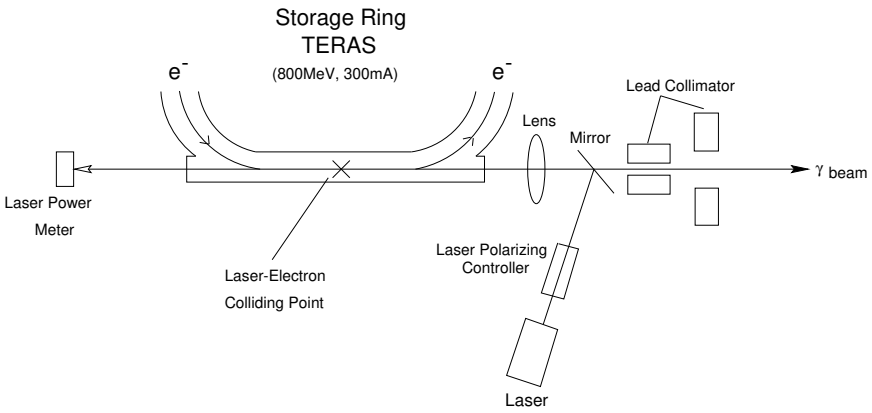
Large prototype is necessary

to demonstrate the performance with high energy γ.

- ***264 PMTs are placed.***
- ***γ of energy up to 40 MeV will be provide by TERAS.***
- ***Energy, position, timing will be measured.***
- ***Same components as final detector will be adopted.***

Cooling system, Feed-though ...

Start at early in 2001



Summary

- ***Search for*** $\mu \to e\gamma$ ***with a sensitivity of*** 10^{-14} ***will give us important and interesting information beyond S.M.***

- ***It is essential to reject Accidental background.***
  ⇒ High Performance detectors are necessary.

- ***Preparations of experiment are going smoothly.***
  - ***COBRA spectrometer***
    - ♦ ***Magnet***
      - ♣ ***Superconductor for thin-wall solenoid has been developed.***
      - ♣ ***Construction will start in 2001***
    - ♦ ***Drift Chamber***
      - ♣ ***Prototype have been constructed.***
      - ♣ ***Beam test will be performed at Oct. 2000***
    - ♦ ***Timing counter***
      - ♣ ***Beam tests were done at KEK in 1999.***
      - ♣ ***Timing resolution of 45 psec is feasible.***
  - ***Liq. Xe photon detector***
    - ♦ ***Small prototype***
      - ♣ ***The results indicate that requirements of energy, position and timing will be achieved***
    - ♦ ***Large prototype***
      - ♣ ***The test will start at the early in 2001***