A sensitive search for $m \rightarrow eg$ decay: the MEG experiment

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INFN, Pisa

on behalf of the MEG Collaboration

Les Rencontres de Physique de la Vallée d'Aoste,

La Thuile, March 10-15 2003

Outline

Physics motivations
- SUSY predictions
- Connection with neutrino oscillations

$\mu \to e\gamma$ signature
- Signal and Background

The experimental setup
- The beam
- The positron spectrometer
- The timing counter
- The e.m. calorimeter (LXe)
- Trigger and DAQ

Conclusions
- Sensitivity
- Time profile

Physics motivation

Lepton Flavour Violation (LFV) processes, like $\mu \to e\gamma$, $\tau \to e\gamma$, $\mu \to eee$, $\mu \to e$ conversion, are negligibly small in the extended Standard Model (SM) with massive Dirac neutrinos (BR $\approx 10^{-50}$)

Super-Symmetric extensions of the SM (SUSY-GUTs) with right handed neutrinos and see-saw mechanism may produce LFV processes at significant rates

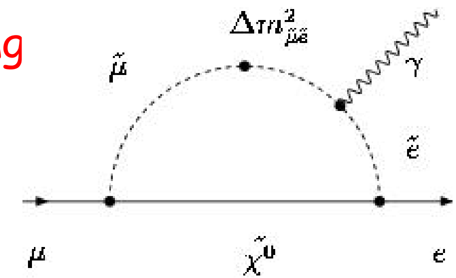
A $\mu \to e\,\gamma$ decay is therefore a clean (no SM contaminated) indication of Super Symmetry

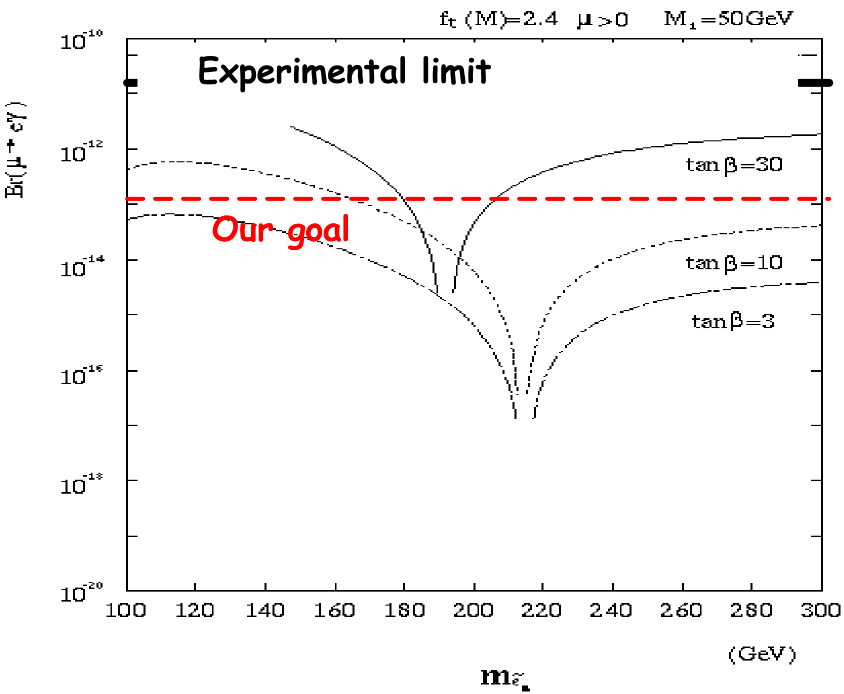
But…

Are these rates accessible experimentally?

SUSY indications

LFV induced by finite slepton mixing
through radiative corrections





small tan(β) excluded by LEP results

- SUSY SU(5) predictions

  BR ($\mu \rightarrow e\gamma$) $\approx 10^{-14} \div 10^{-13}$

- SUSY SO(10) predictions

  $BR_{SO(10)} \approx 100\ BR_{SU(5)}$

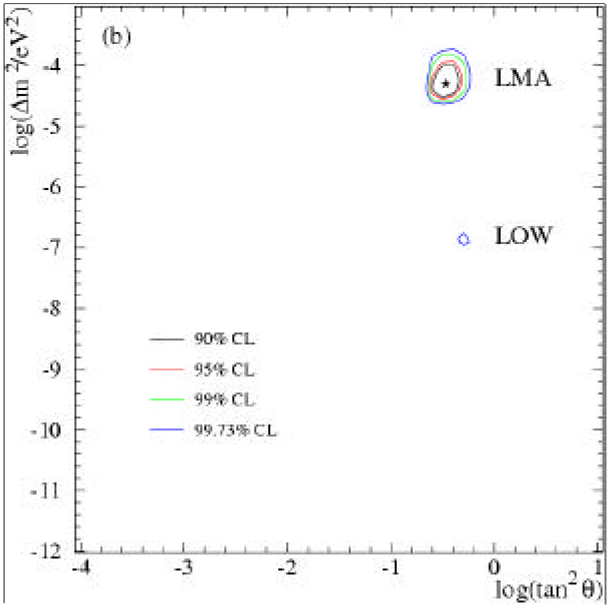
R. Barbieri et al., Phys. Lett. B338(1994) 212

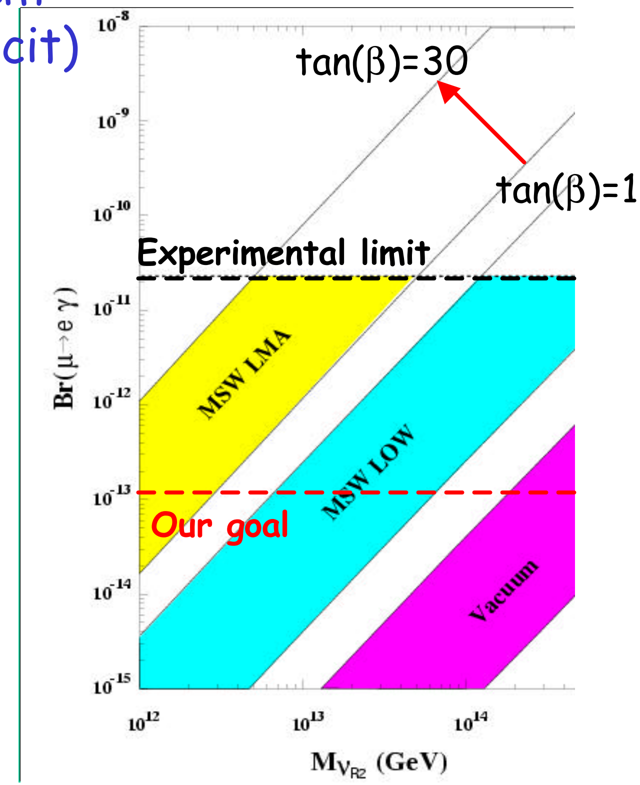
R. Barbieri et al., Nucl. Phys. B445(1995) 215

ν-oscillation connection

Additional contribution to slepton mixing from V_{21} (the matrix element responsible for solar neutrino deficit)

J. Hisano, N. Nomura, Phys. Rev. D59 (1999)

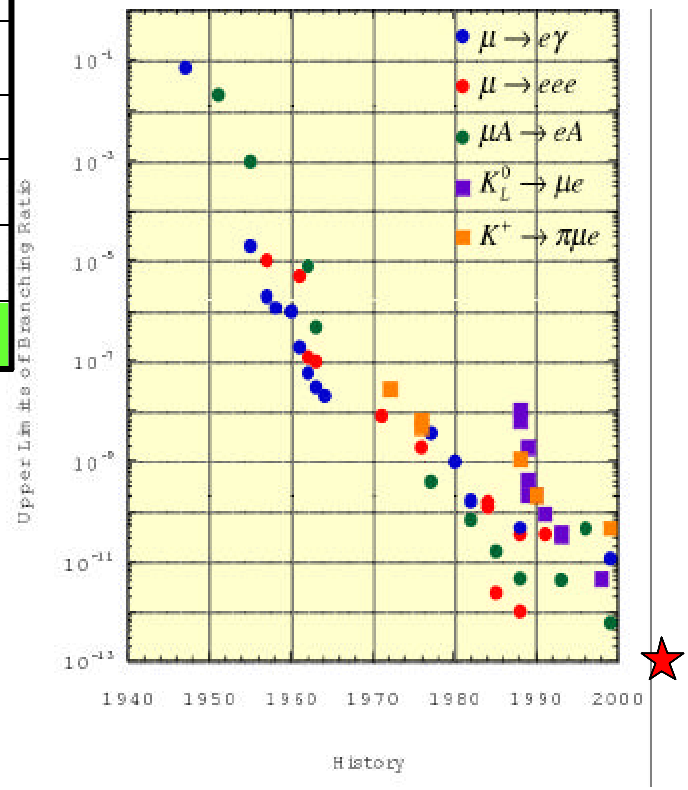




$m^+ \to e^+ \gamma$ Experiments

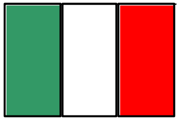
Lab.	Year	Upper limit	Experiment or Auth.
PSI	1977	$< 1.0 \times 10^{-9}$	A. Van der Schaaf et al.
TRIUMF	1977	$< 3.6 \times 10^{-9}$	P. Depommier et al.
LANL	1979	$< 1.7 \times 10^{-10}$	W.W. Kinnison et al.
LANL	1986	$< 4.9 \times 10^{-11}$	Crystal Box
LANL	1999	$< 1.2 \times 10^{-11}$	MEGA
PSI	~2005	$\sim 10^{-13}$	MEG

Comparison with other LFV searches:

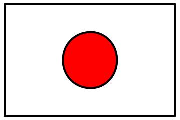


Two orders of magnitude improvement is required: experimental challenge!

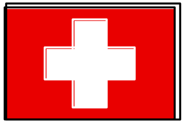
The MEG Collaboration



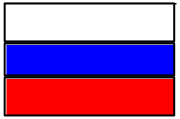
INFN & Pisa University A. Baldini, C. Bemporad, F.Cei, M.Grassi, F. Morsani, D. Nicolo', R. Pazzi, F. Sergiampietri, G. Signorelli
INFN & Pavia University A.de Bari, P. Cattaneo, G. Cecchet
INFN & Genova University S. Dussoni, F. Gatti, D. Pergolesi
INFN Roma I D. Zanello



ICEPP, University of Tokyo T. Mashimo, S. Mihara, T. Mitsuhashi, T. Mori, H. Nishiguchi, W. Ootani, K. Ozone, T. Saeki, R. Sawada, S. Yamashita
KEK, Tsukuba T. Haruyama, A. Maki, Y. Makida, A. Yamamoto, K. Yoshimura
Osaka University Y. Kuno
Waseda University T. Doke, J. Kikuchi, H. Okada, S. Suzuki, K. Terasawa, M. Yamashita, T. Yoshimura



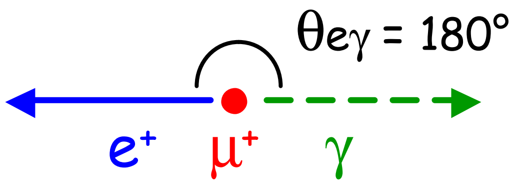
PSI, Villigen J. Egger, P. Kettle, H. Molte, S. Ritt



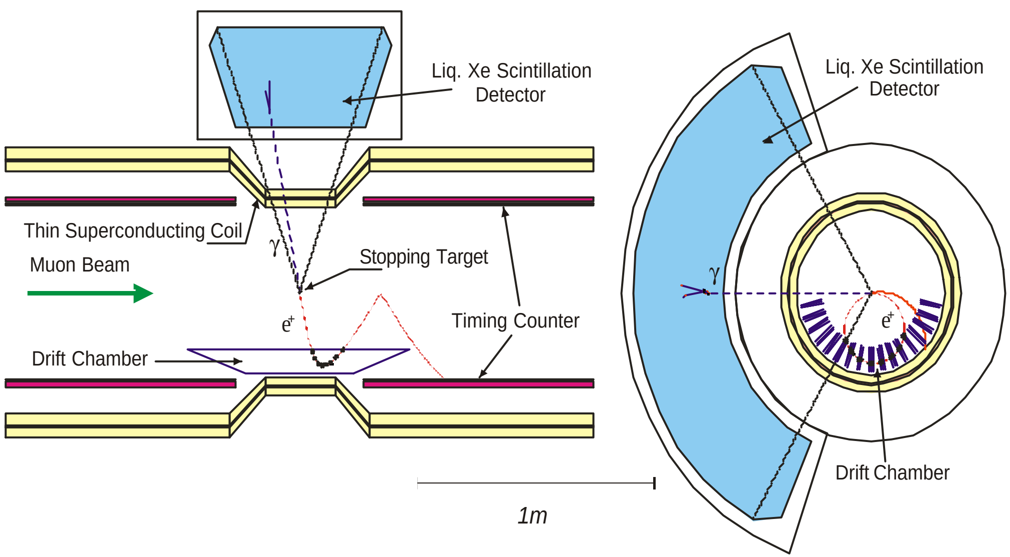
Budker Institute, Novosibirsk L.M. Barkov, A.A. Grebenuk, D.G. Grigoriev, B, Khazin, N.M. Ryskulov

Experimental method

Easy signal selection with μ^+ at rest



$E_e = E_\gamma = 52.8$ MeV



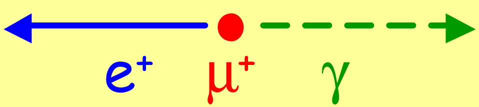
Detector outline

- Stopped beam of >10^7 μ /sec in a 150 μm target
- Liquid Xenon calorimeter for γ detection (scintillation)
  - fast: 4 / 22 / 45 ns
  - high LY: ~ 0.8 * NaI
  - short X_0: 2.77 cm
- Solenoid spectrometer & drift chambers for e^+ momentum
- Scintillation counters for e^+ timing

Signal and background

signal

$\mu \rightarrow e\,\gamma$



$\theta_{e\gamma} = 180°$

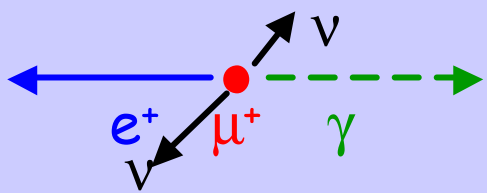
$E_e = E_\gamma = 52.8$ MeV

$T_e = T_\gamma$

background

correlated

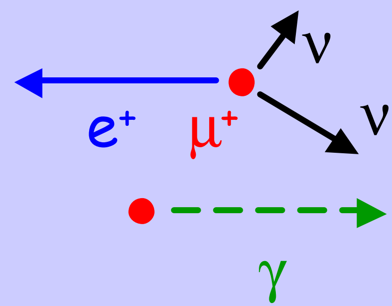
$\mu \rightarrow e\,\gamma\,\nu\,\nu$



accidental

$\mu \rightarrow e\,\nu\,\nu$

$$\begin{cases} \mu \rightarrow e\,\gamma\,\nu\,\nu \\ ee \rightarrow \gamma\,\gamma \\ eZ \rightarrow eZ\,\gamma \end{cases}$$



Required Performances

The sensitivity is limited by the by the accidental background

The $BR_{acc} \propto R_{m} \times \Delta E_{e} \times \Delta E_{g}^{2} \times \Delta J_{eg}^{2} \times \Delta t_{eg} \approx 3\times 10^{-14}$

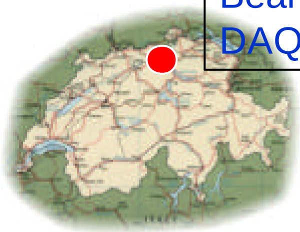
allows $BR\ (\mu \to e\gamma) \approx 10^{-13}$ but needs

FWHM

Exp./Lab	Year	DE_e/E_e (%)	DE_γ/E_γ (%)	$Dt_{e\gamma}$ (ns)	$Dq_{e\gamma}$ (mrad)	Stop rate (s^{-1})	Duty cyc.(%)	BR (90% CL)
SIN	1977	8.7	9.3	1.4	-	5×10^{5}	100	3.6×10^{-9}
TRIUMF	1977	10	8.7	6.7	-	2×10^{5}	100	1×10^{-9}
LANL	1979	8.8	8	1.9	37	2.4×10^{5}	6.4	1.7×10^{-10}
Crystal Box	1986	8	8	1.3	87	4×10^{5}	(6..9)	4.9×10^{-11}
MEGA	1999	1.2	4.5	1.6	17	2.5×10^{8}	(6..7)	1.2×10^{-11}
MEG	2005	0.8	4	0.15	19	2.5×10^{7}	100	1×10^{-13}

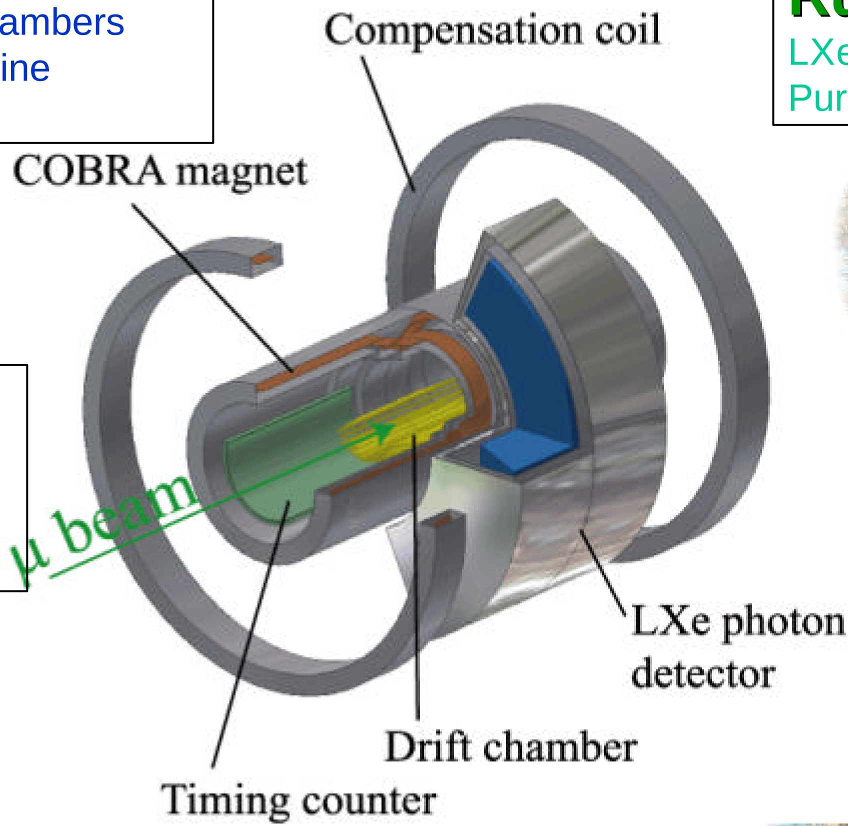
Detector Construction

Switzerland
Drift Chambers
Beam Line
DAQ

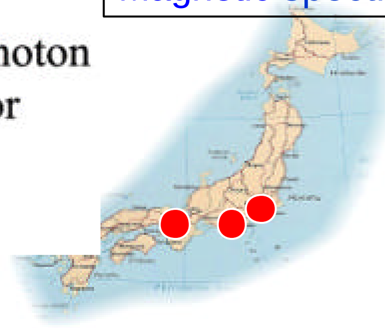


Russia
LXe Tests
Purification

Italy
e+ counter (Ge+Pv)
Trigger (Pi)
LXe Calorimeter (Pi)

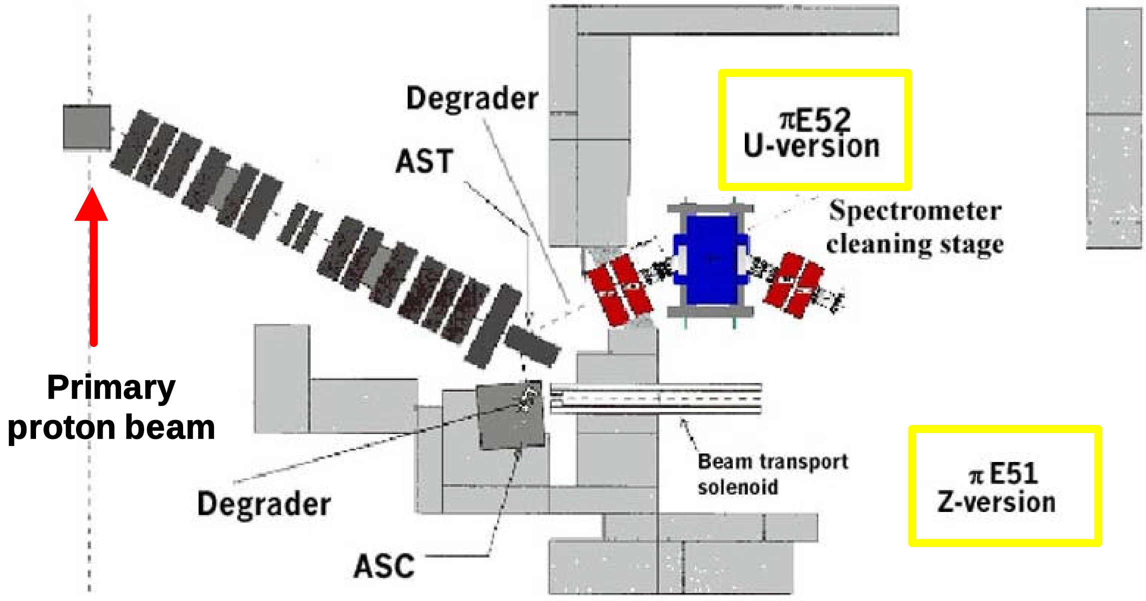


Japan
LXe Calorimeter,
Magnetic spectrometer



The muon beam

- Exist
- Provide continuous $>10^8$ μ/s (with e^+ contamination)
- Two separate configurations of the πE5 beam line
- Muon momentum 29 MeV/c

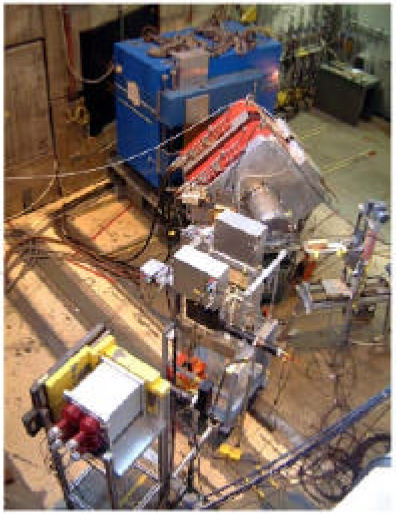


The layout of πE5

Beam studies

Optimization of the beam elements:

- Wien filter for μ/e separation
- Solenoid to couple beam and spectrometer
- Degrader to reduce the momentum for a 150 μm target



Intermediate results:

	U-version	Z-version
• R_μ (total)	$1.3 \cdot 10^{8}$ μ^+/s	$1.3 \cdot 10^{8}$ μ^+/s
• R_μ (after filter)	$7.3 \cdot 10^{7}$ μ^+/s	$9.5 \cdot 10^{7}$ μ^+/s
• R_μ (after solenoid)	$\sigma_V \approx 6.5$mm, $\sigma_H \approx 5.5$mm	to be studied
• μ/e separation	11 σ	7 σ

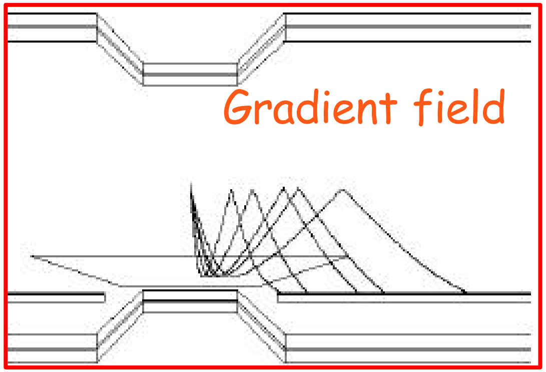
OK

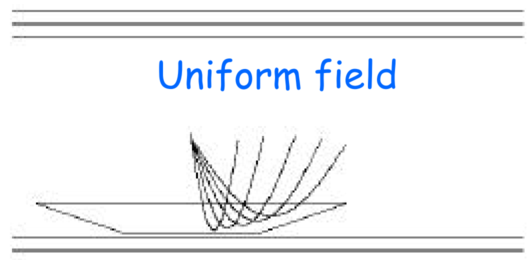
Final measurements on Z-branch are planned in Apr/May 2003
Design of the transport solenoid is started

COBRA spectrometer

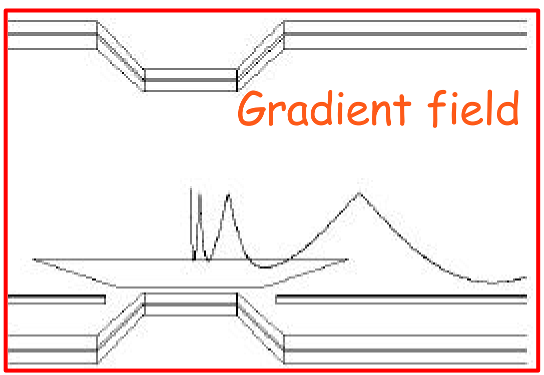
COnstant Bending RAdius (COBRA) spectrometer

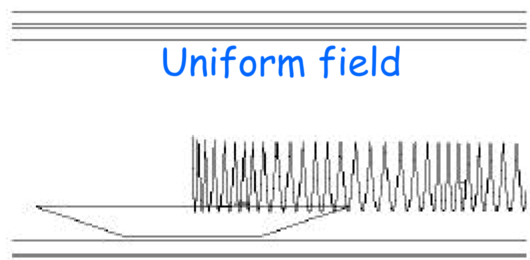
- Constant bending radius independent of emission angles



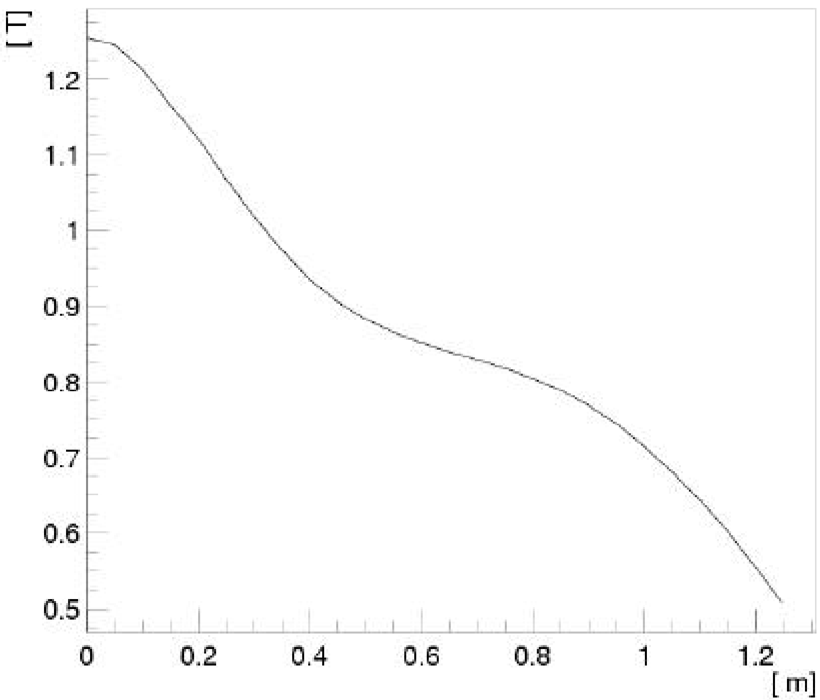


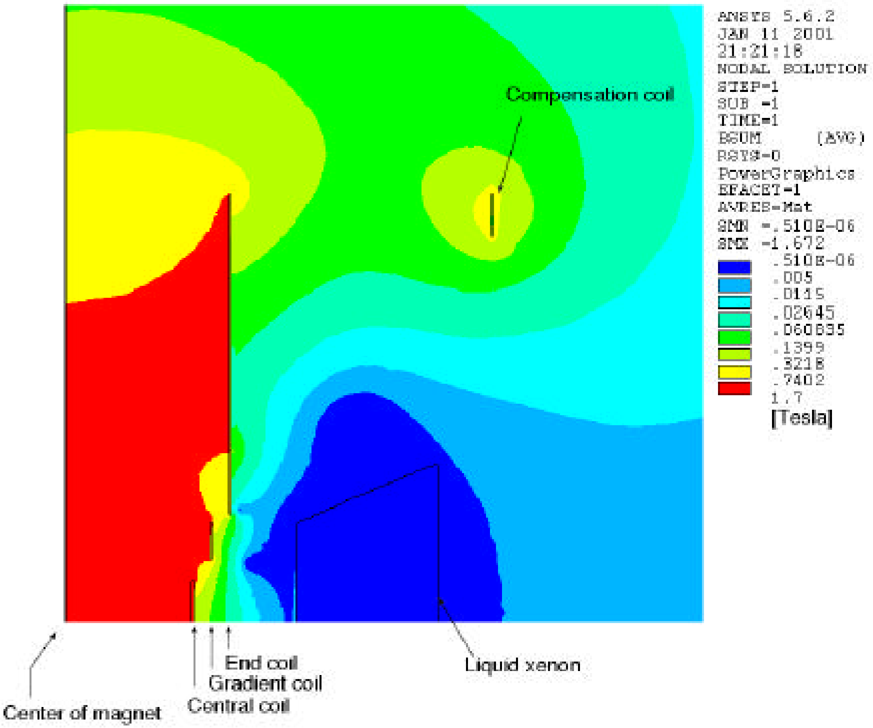
- High p_T positrons quickly swept out



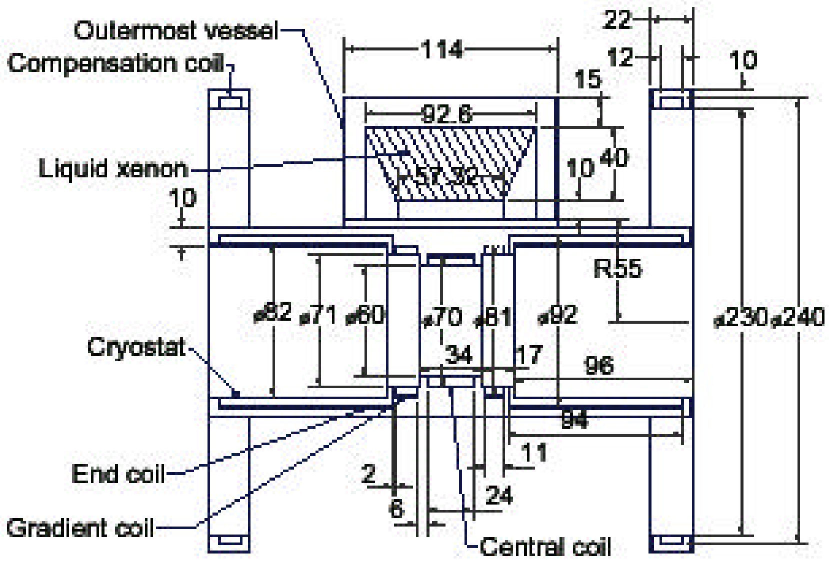


Gradient field





The solenoids



- B_c = 1.26T current = 359A
- Five coils with three different diameter
- Compensation coils to suppress the stray field around the LXe detector
- High-strength aluminum stabilized superconductor
  ⇒thin magnet
  (**1.46 cm Aluminum**, 0.2 X_0)

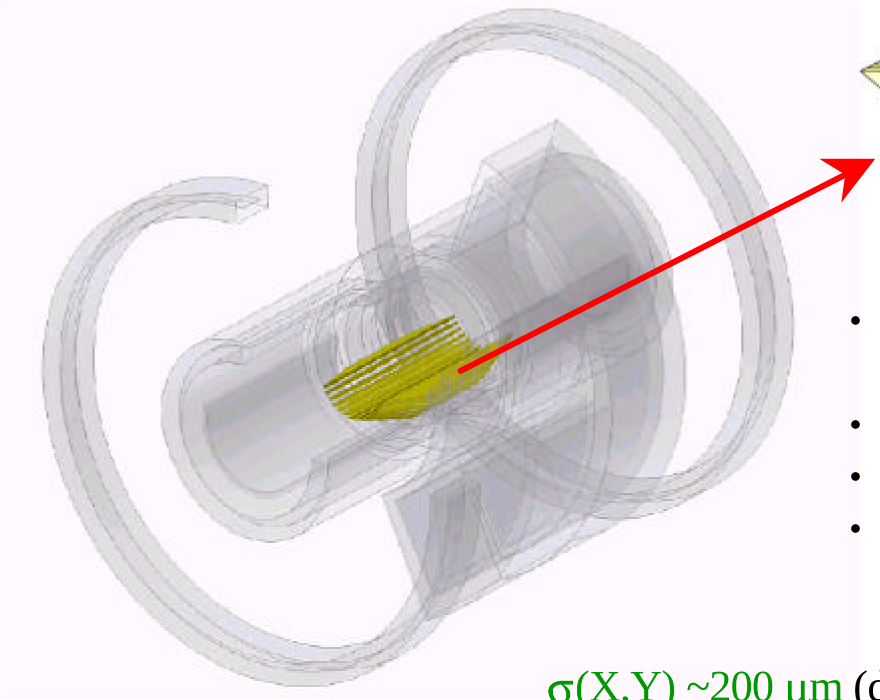
•"Crash" Tests completed

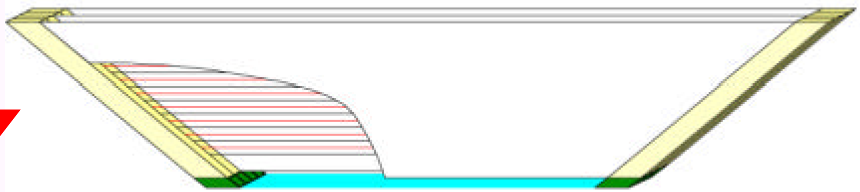
•Winding completed @TOSHIBA

•Spectrometer ready to be shipped at PSI within this year

OK

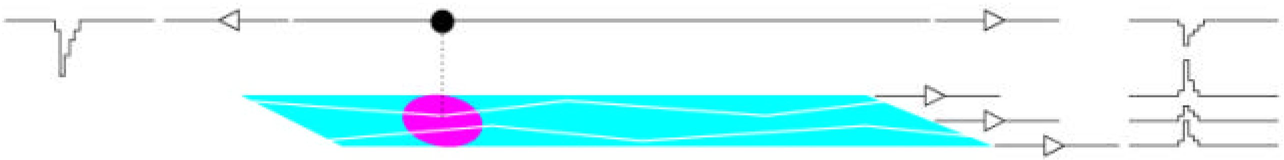
Positron Tracker



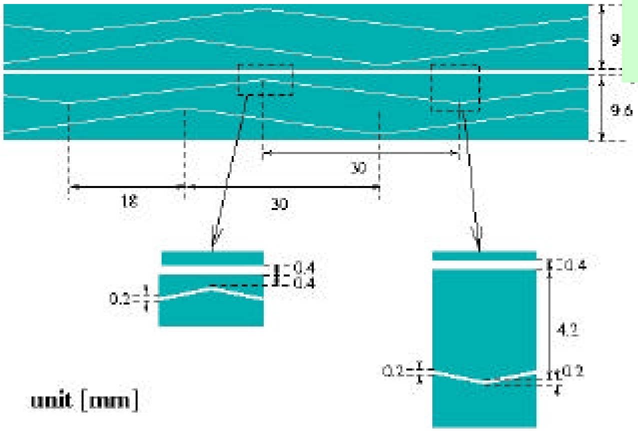


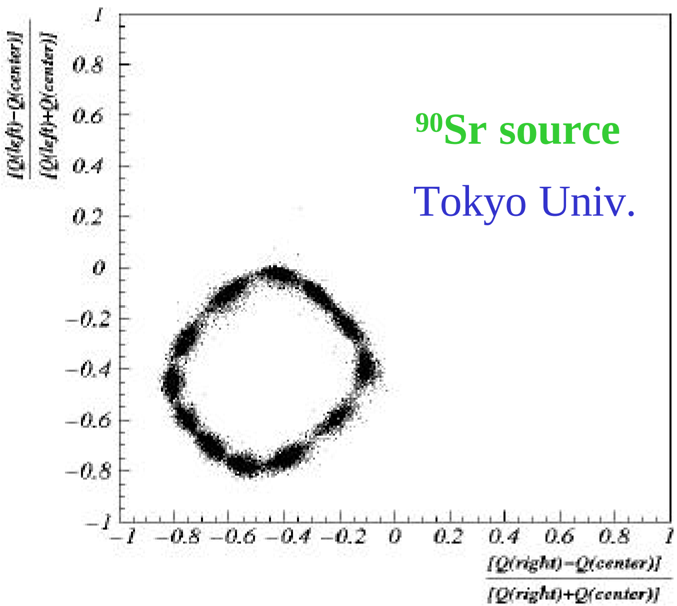
- 17 chamber sectors aligned radially with 10°intervals
- Two staggered arrays of drift cells
- Chamber gas: He-C_2H_6 mixture
- Vernier pattern to measure z-position made of 15 μm kapton foils

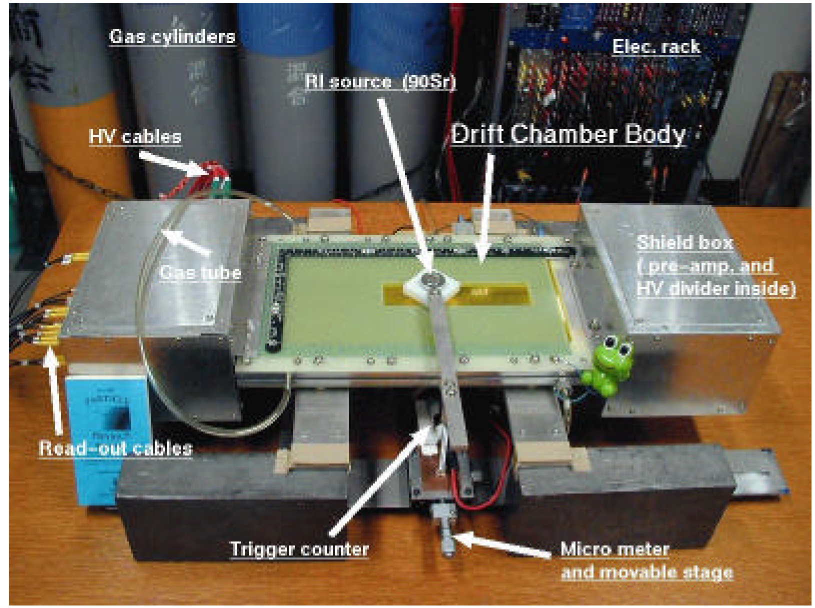
σ(X,Y) ~200 μm (drift time) σ(Z) ~ 300 μm (charge division vernier strips)



Drift chambers R&D (1)





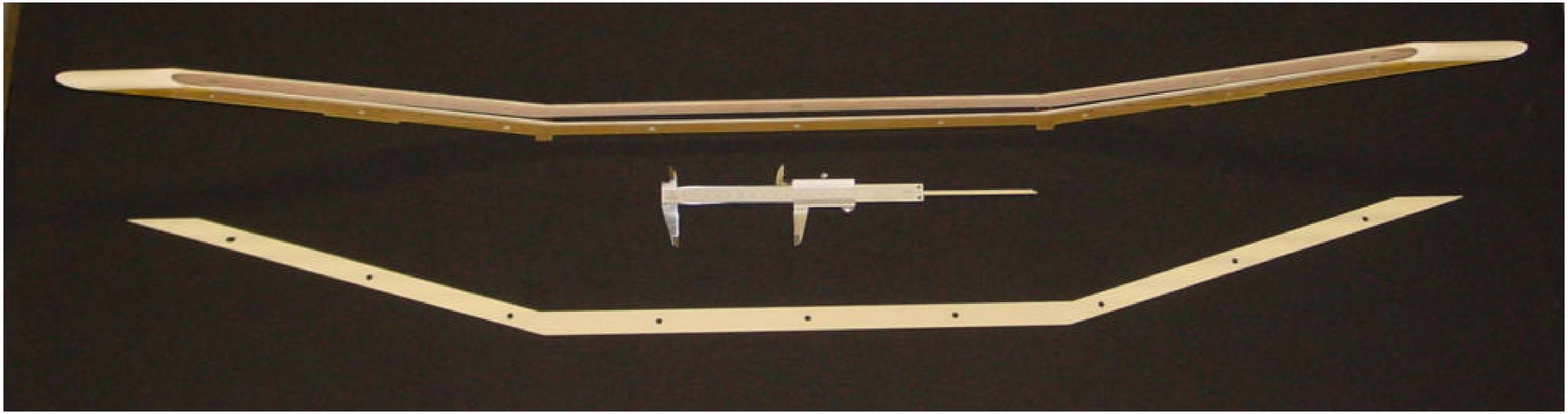


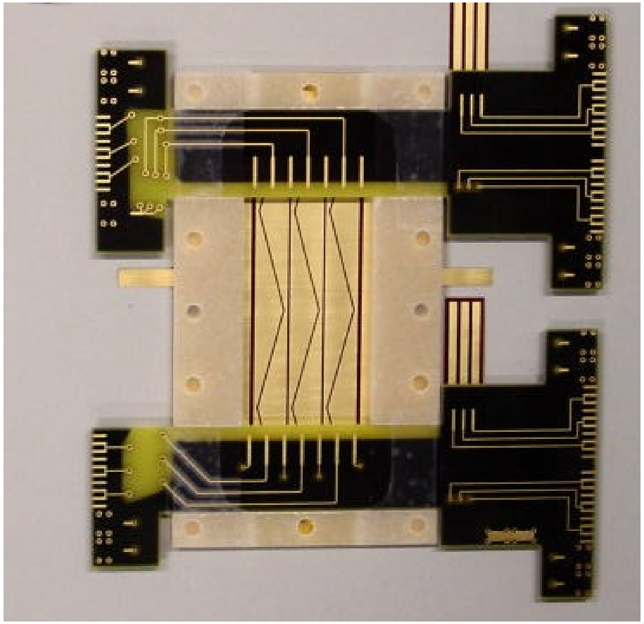
$s_R = 93 \pm 10 mm$ OK

$s_Z = 425 \pm 7 mm$

(no magnetic field ⇒ full prototype test at PSI at the end of the year)

Drift chambers R&D (2)





- Full scale test in November
- Improved vernier strips structure (uniform resolution)
- Summary of Drift Chamber simulation

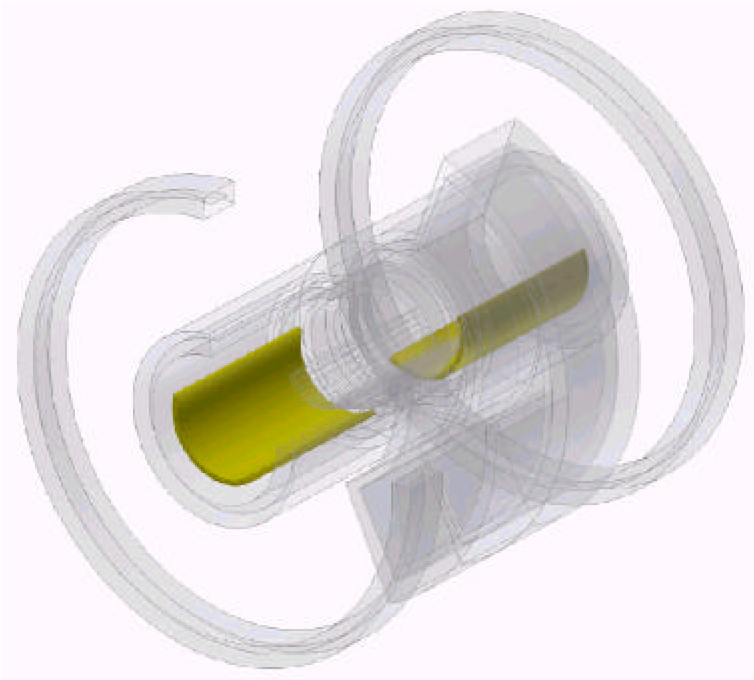
FWHM

$$dP_{e^+} / P_{e^+} = 0.7 \div 0.9\%$$

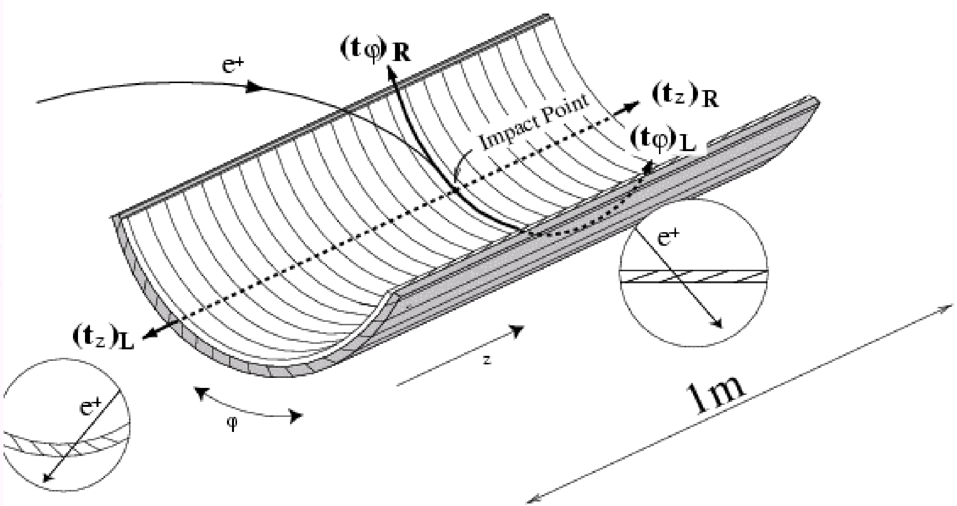
$$dq_{e^+} = 9 \div 12\, mrad$$

$$dx_{orig} = 2.1 \div 2.5\, mm$$

Positron Timing Counter



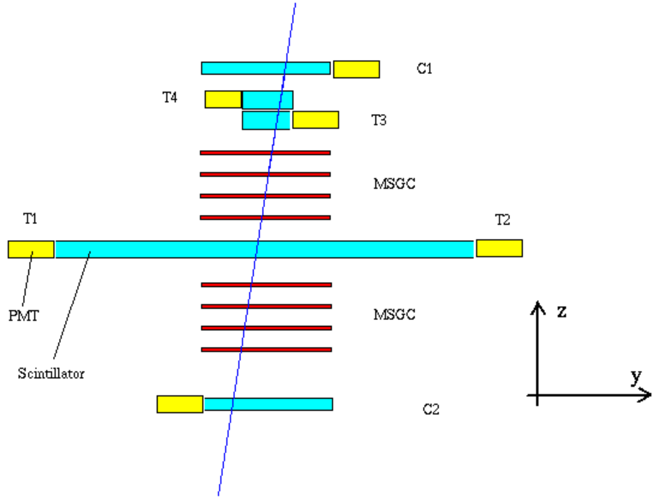
BC404

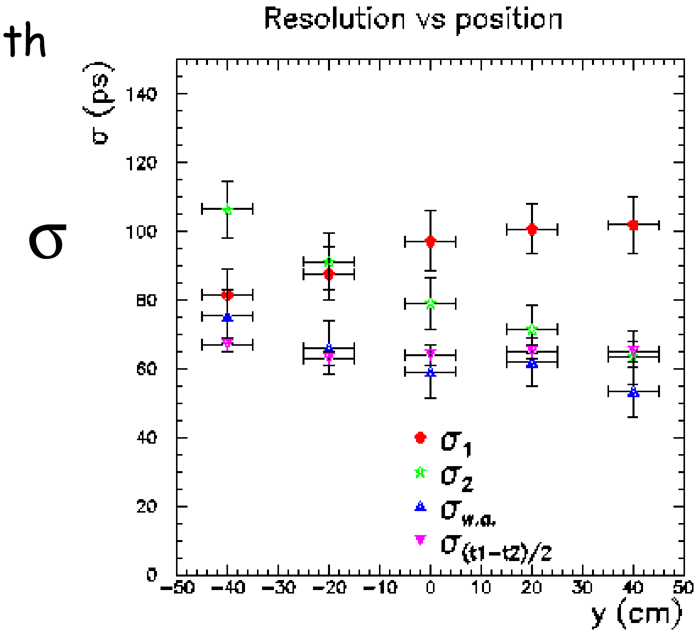


- Two layers of scintillator read by PMTs placed at right angles with each other
  Outer: timing measurement
  Inner: additional trigger information
- Goal σ_{time}~ 40 psec (100 ps FWHM)

Timing Counter R&D

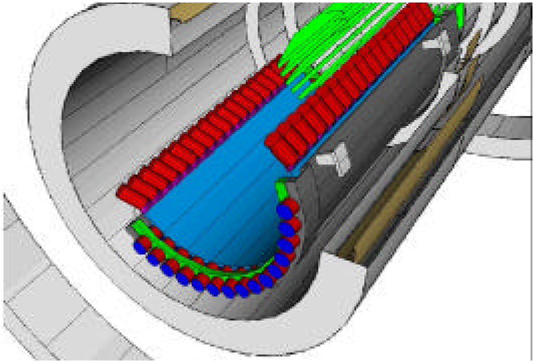
CORTES: Timing counter test facility with cosmic rays





- Scintillator bar (5cm x 1cm x 100cm long)
- Telescope of 8 x MSGC
- Measured resolutions

  σ_{time}~60psec independent of incident position
- σ_{time} improves as ~1/√Npe ⇒ 2 cm thick **OK**

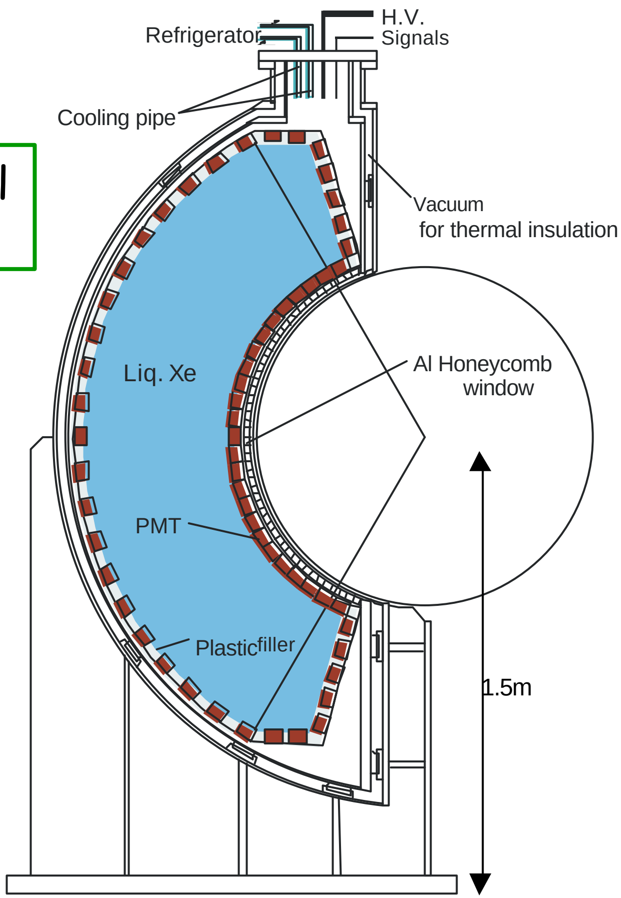


Liquid Xe calorimeter

- 800 l of Liquid Xe
- ~800 PMT immersed in LXe
- Only scintillation light
- High luminosity
- Unsegmented volume

Experimental check

Density	2.95 g/cm^3
Boiling and melting points	165 K, 161 K
Energy per scintillation photon	24 eV
Radiation length	2.77 cm
Decay-time	4.2 nsec, 22 nsec
	45 nsec
Scintillation light wave length	175 nm
Scintillation absorption length	> 100 cm
Attenuation length (Rayleigh scattering)	30 cm
Refractive index	1.74

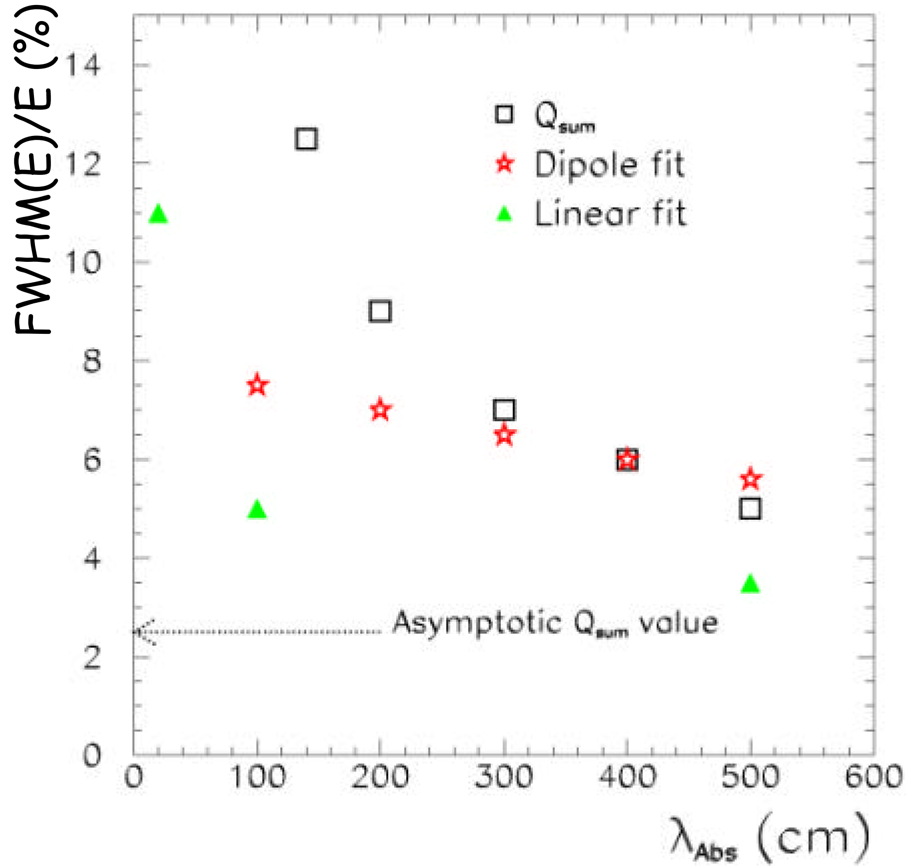


LXe performance

Energy resolution strongly depends on optical properties of LXe

- Complete MC simulations
- At l$_{abs}$® ¥ the resolution is dominated by photostatistics FWHM(E)/E ≈ 2.5% (including edge effects)
- At $\lambda_{abs} \approx L_{det}$ limits from shower fluctuations + detector response ⇒ need of reconstruction algorithms

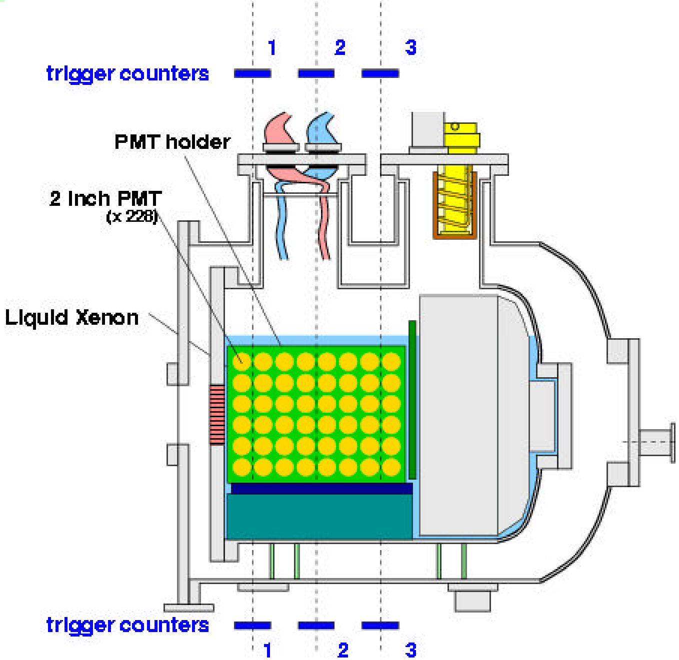
  FWHM(E)/E ≈ 4.5%



Xenon Calorimeter Prototype

The Large Prototype (LP)

- $40 \times 40 \times 50$ cm^3
- 228 PMTs, 100 litres Lxe
  (the largest in the World)

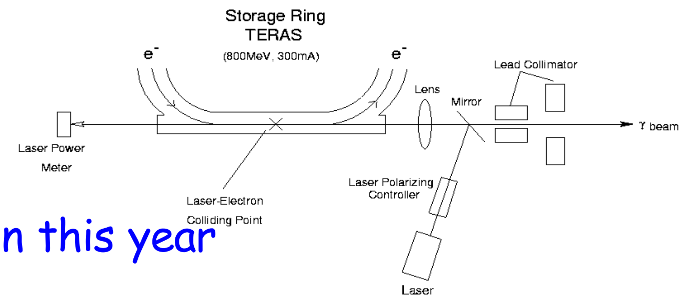


- Purpose
  - Test cryogenic operation on a long term and on a large volume
  - Measure the Lxe properties
  - Check the reconstruction methods
  - Measure the Energy, Position and Timing resolutions

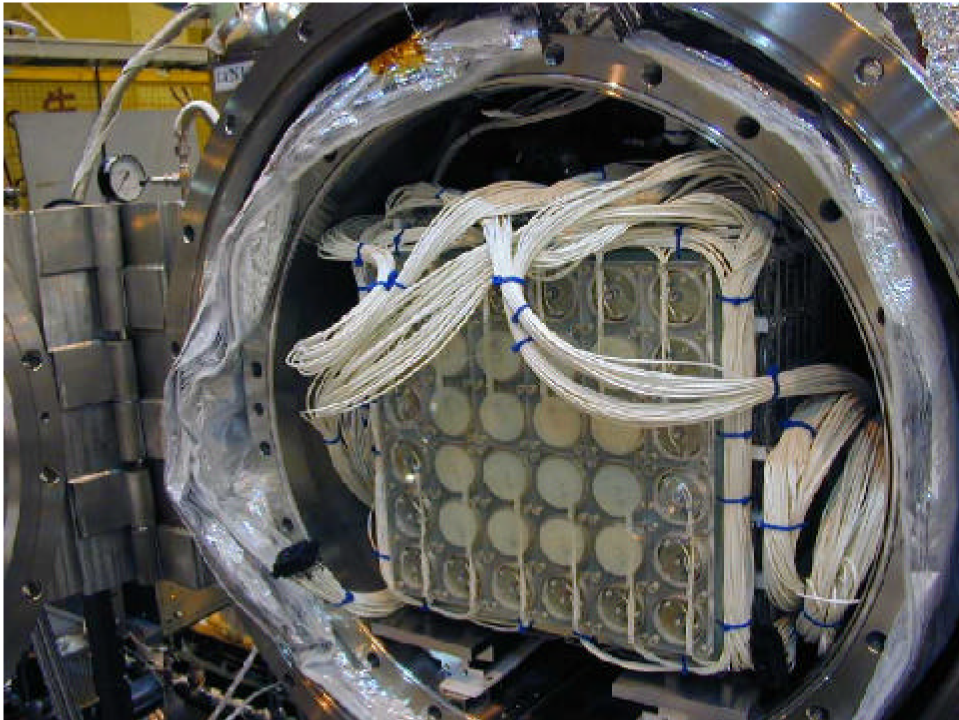
with:

- Cosmic rays
- α-sources
- 60 MeV e^- from KSR storage ring
- 40 MeV γ from TERAS Compton Backscattering
- e^+ and 50 MeV γ from π^0 at PSI

Planned in this year

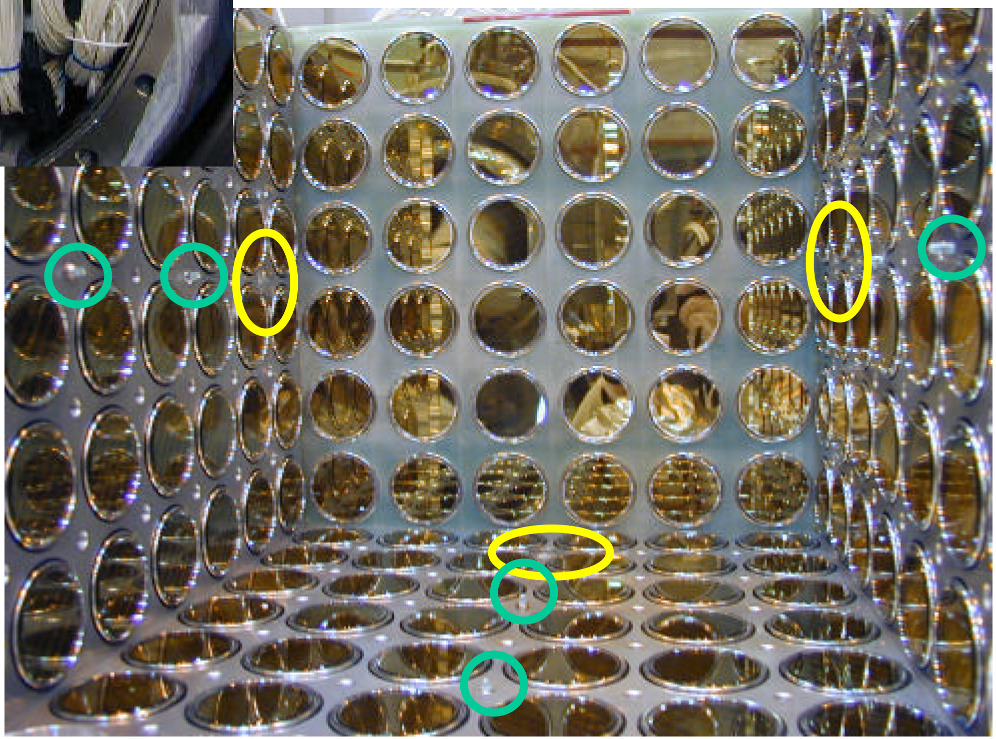


The LP



α-sources

LEDs

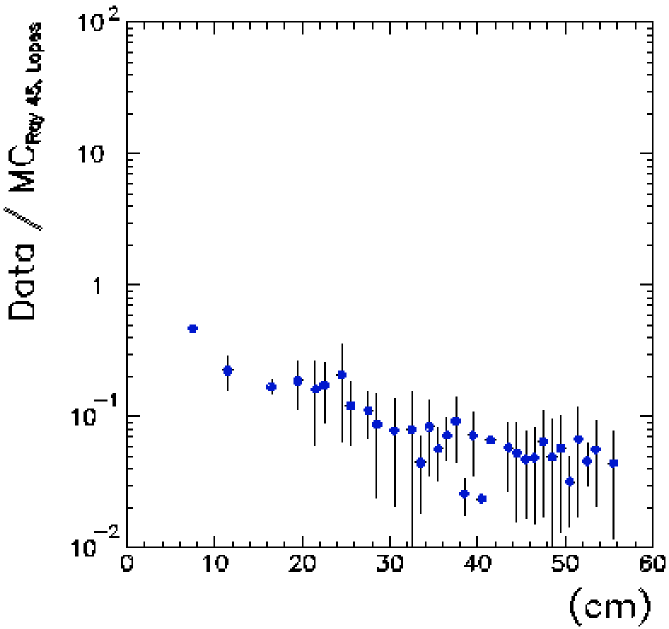


M. Grassi – INFN Pisa

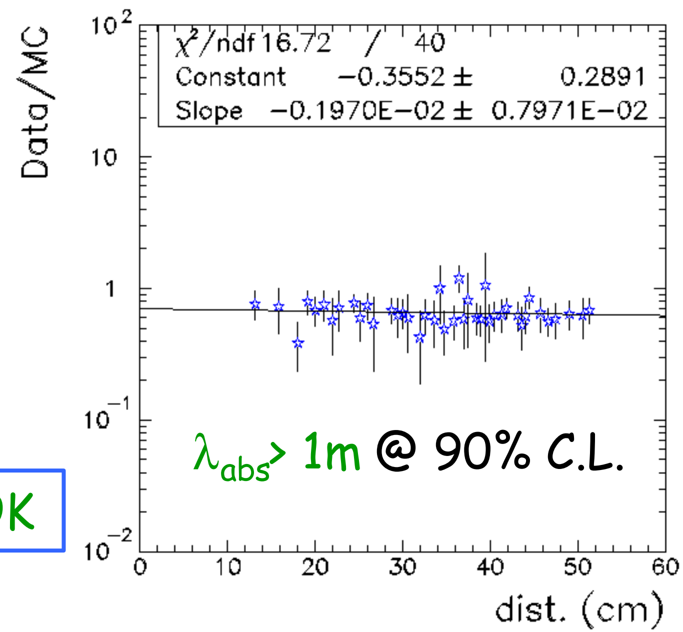
LP: LXe optical properties

- First tests showed that the number of scintillation photons was MUCH LESS than expected
- It improved with Xe cleaning: Oxysorb + gas getter + re-circulation (took time)
- There were a strong absorption due to contaminants (mainly H_2O)

March 2002



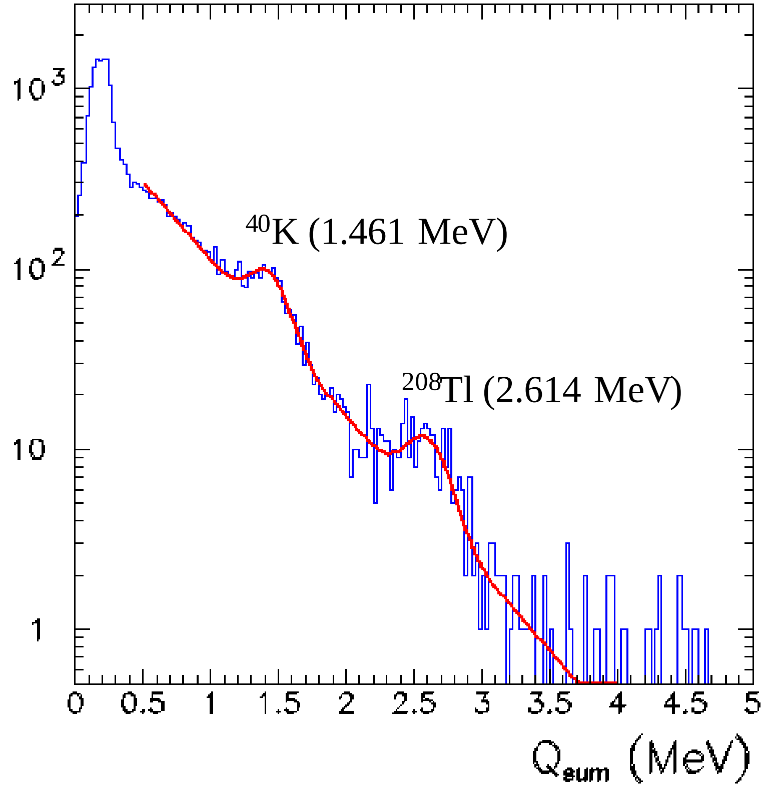
Present...



OK

LP: Radioactive background

- α-trigger with 5×10^6 gain
- Geometrical cuts to exclude α-sources
- Energy scale: α-source
  - ^{208}Tl (2.59±0.06) MeV
  - ^{40}K (1.42 ± 0.06) MeV
  - ^{214}Bi ^{208}Tl ??
- uniform on the front face
- few 10 min (with non-dedicated trigger)
- nice calibration for low energy γ's



Seen for the first time! Studies are going on: spatial distribution of background inside the detector

Timing resolution test

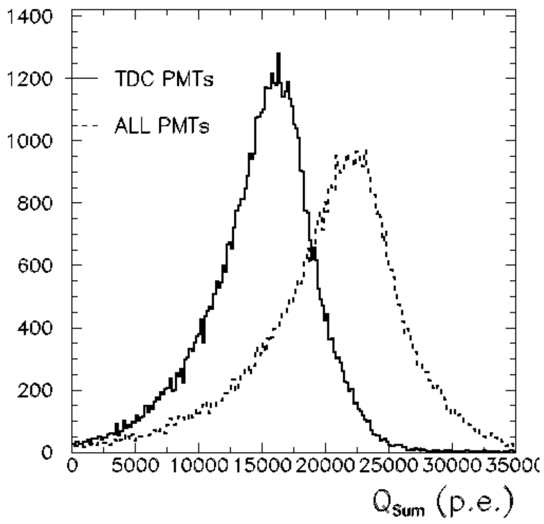
$\sigma_t = (\sigma_z^2 + \sigma_{sc}^2)^{1/2} = (80^2 + 60^2)^{1/2}$ ps = 100 ps (FWHM)

our goal

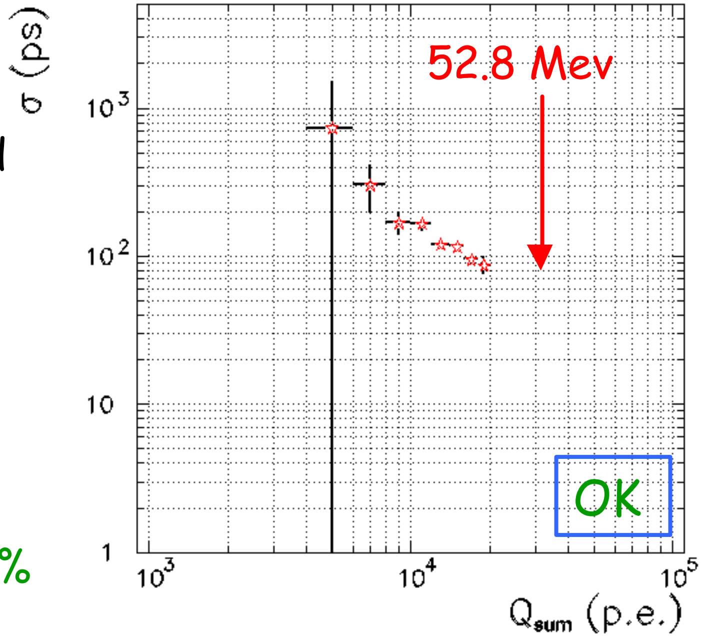
σ_z Time-jitter due to photon interaction point

σ_{sc} Scintillation time and photon statistics

Measurement of σ_{sc}^2 with 60 MeV electron beam

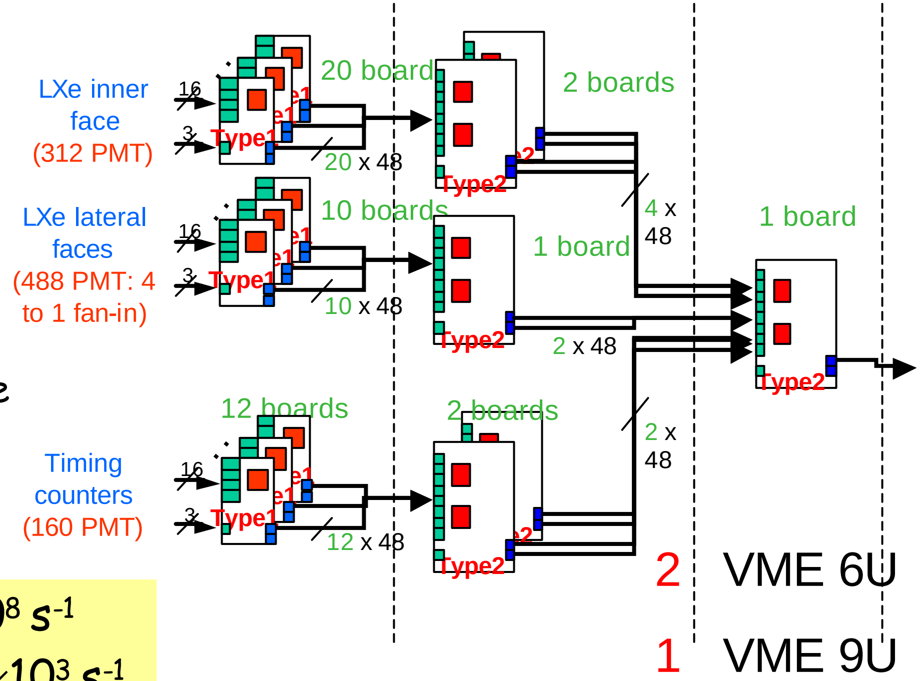


- weighted average of the PMT TDCs time-walk corrected
- σ_{sc} vs ph.el.
- extrapolation at 52.8 Mev is ok
- new PMT with improved QE 5 ⇒10%



Trigger Electronics

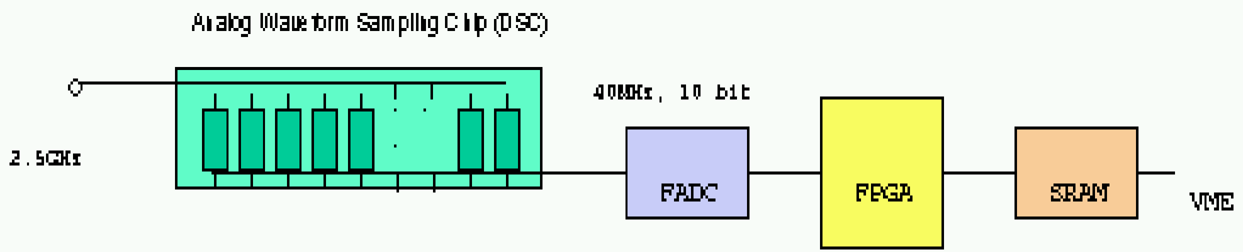
- Uses easily quantities:
  - γ energy
  - Positron- γ coincidence in time and direction
- Built on a FADC-FPGA architecture
- More complex algorithms implementable



❖	Beam rate	10^8 s^{-1}
❖	Fast LXe energy sum > 45MeV	2×10^3 s^{-1}
	g interaction point (PMT of max charge)	
	e^+ hit point in timing counter	
❖	time correlation $\gamma - e^+$	200 s^{-1}
❖	angular correlation $\gamma - e^+$	20 s^{-1}

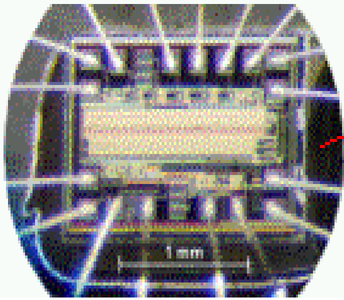
- Design and simulation of type1 board completed
- Prototype board delivered by late spring

Readout electronics



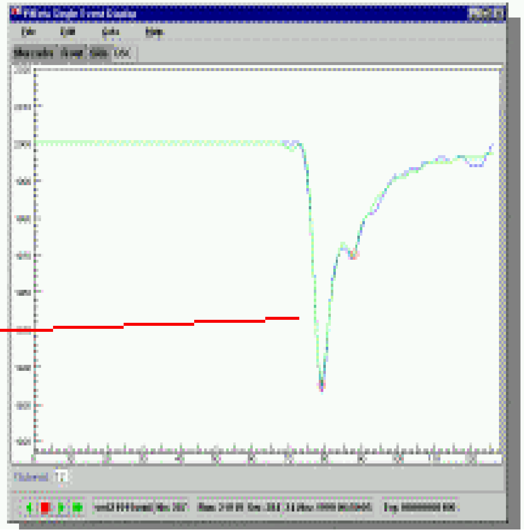
- Waveform digitizing for all channels
- Custom domino sampling chip designed at PSI
- Cost per DSC ~ 1 US$
- 2.5 GHz sampling speed @ 40 ps timing resolution
- Sampling depth 1024 bins
- Readout similar to trigger

Prototypes delivered in autumn



Previous Version

1.2 GHz



Sensitivity Summary

Detector parameters

$T = 2.6 \cdot 10^{7}\,s \qquad R_{\mu} = 0.3 \cdot 10^{8}\,\mu/s \qquad \frac{O}{4p} = 0.09$

$e_e \approx 0.9 \qquad e_{sel} \approx (0.9)^3 = 0.7 \qquad e_? \approx 0.6$

Cuts at 1,4×FWHM

Signal

$$N_{sig} = BR \cdot T \cdot R_{\mu} \cdot \frac{\Omega}{4p} \cdot e_e \cdot e_g \cdot e_{sel}$$

Single Event Sensitivity

$$SES = 1 \Big/ T \cdot R_m \cdot \frac{\Omega}{4p} \cdot e_e \cdot e_g \cdot e_{sel} \approx 4\times10^{-14}$$

Backgrounds

$$BR_{acc} \propto R_m \times \Delta E_e \times \Delta E_g^{\,2} \times \Delta J_{eg}^{\,2} \times \Delta t_{eg} \approx 3\times10^{-14}$$

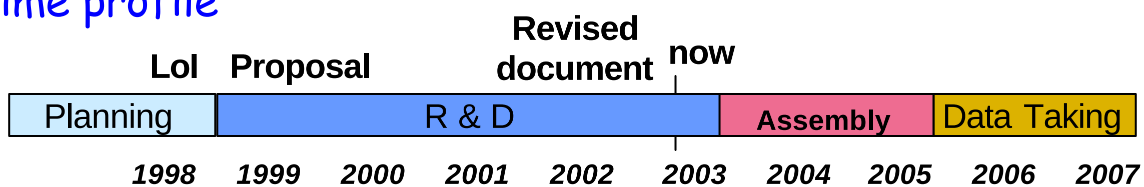
$$BR_{corr} \approx 3\times10^{-15}$$

Upper Limit at 90% CL $BR(\mu\to e\gamma) \approx 1\times10^{-13}$

Discovery 4 events ($P = 2\times10^{-3}$) correspond $BR = 2\times10^{-13}$

Summary and Time Scale

- The experiment may provide a clean indication of New Physics
- Measurements and detector simulation make us confident that we can reach the SES of 4×10^{-14} to $\mu \rightarrow e\gamma$ (BR 10^{-13})
- Final prototypes will be measured within November 2003
  - Large Prototype for energy, position and timing resolutions of γs
  - Full scale Drift Chamber
  - μ-Transport and degrader-target
- Final approval requested to INFN-CSN1
- Tentative time profile



More details at

http://meg.psi.ch
http://meg.pi.infn.it
http://meg.icepp.s.u-tokyo.ac.jp