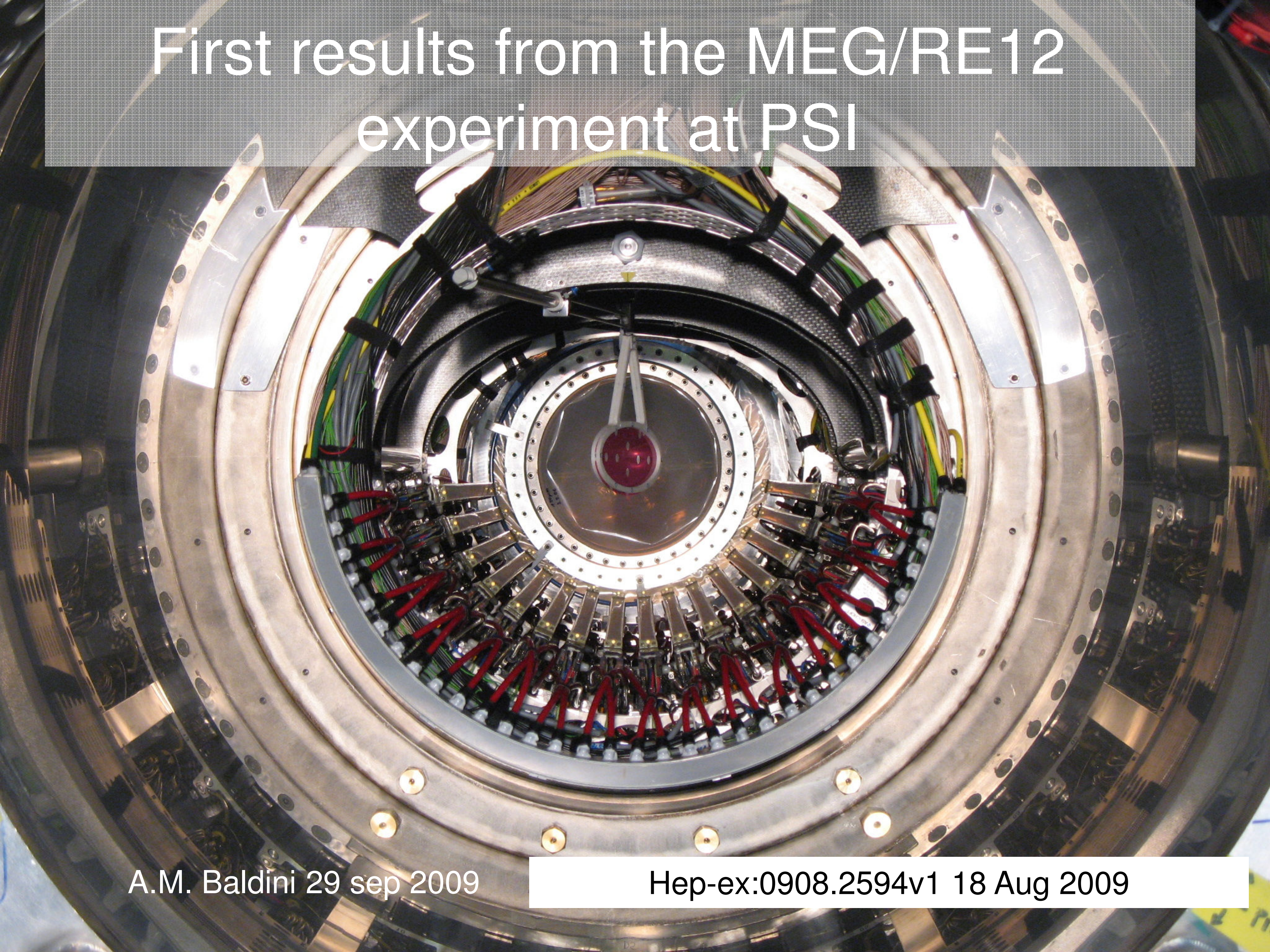
First results from the MEG/RE12 experiment at PSI



A.M. Baldini 29 sep 2009

Hep-ex:0908.2594v1 18 Aug 2009

Most recent $\mu^+ \to e^+ \gamma$ Experiments

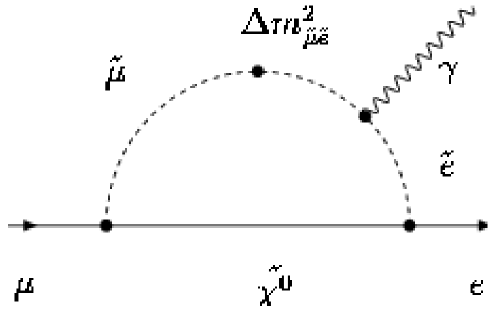
Lab.	Year	Upper limit	Experiment or Auth.
PSI	1977	$< 1.0 \times 10^{-9}$	A. Van der Schaaf *et al.*
TRIUMF	1977	$< 3.6 \times 10^{-9}$	P. Depommier *et al.*
LANL	1979	$< 1.7 \times 10^{-10}$	W.W. Kinnison *et al.*
LANL	1986	$< 4.9 \times 10^{-11}$	Crystal Box
LANL	1999	$< 1.2 \times 10^{-11}$	MEGA
PSI	~2011	$\sim 10^{-13}$	*MEG*

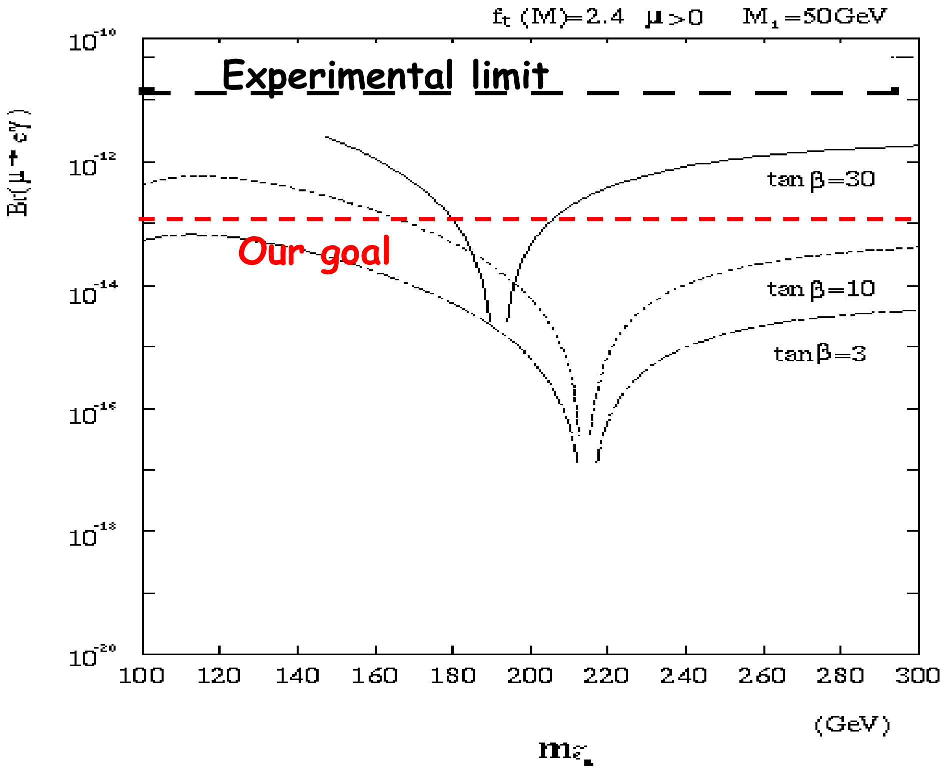
Two orders of magnitude improvement
tough experimental challenge! But

several SUSY GUT and SUSY see-saw models predict BRs at the reach of MEG

SUSY-GUT (SUGRA) First contribution: $V_{CKM} \rightarrow$ cLFV

LFV induced by slepton mixing





- SUSY SU(5) predictions

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

- SUSY SO(10) predictions

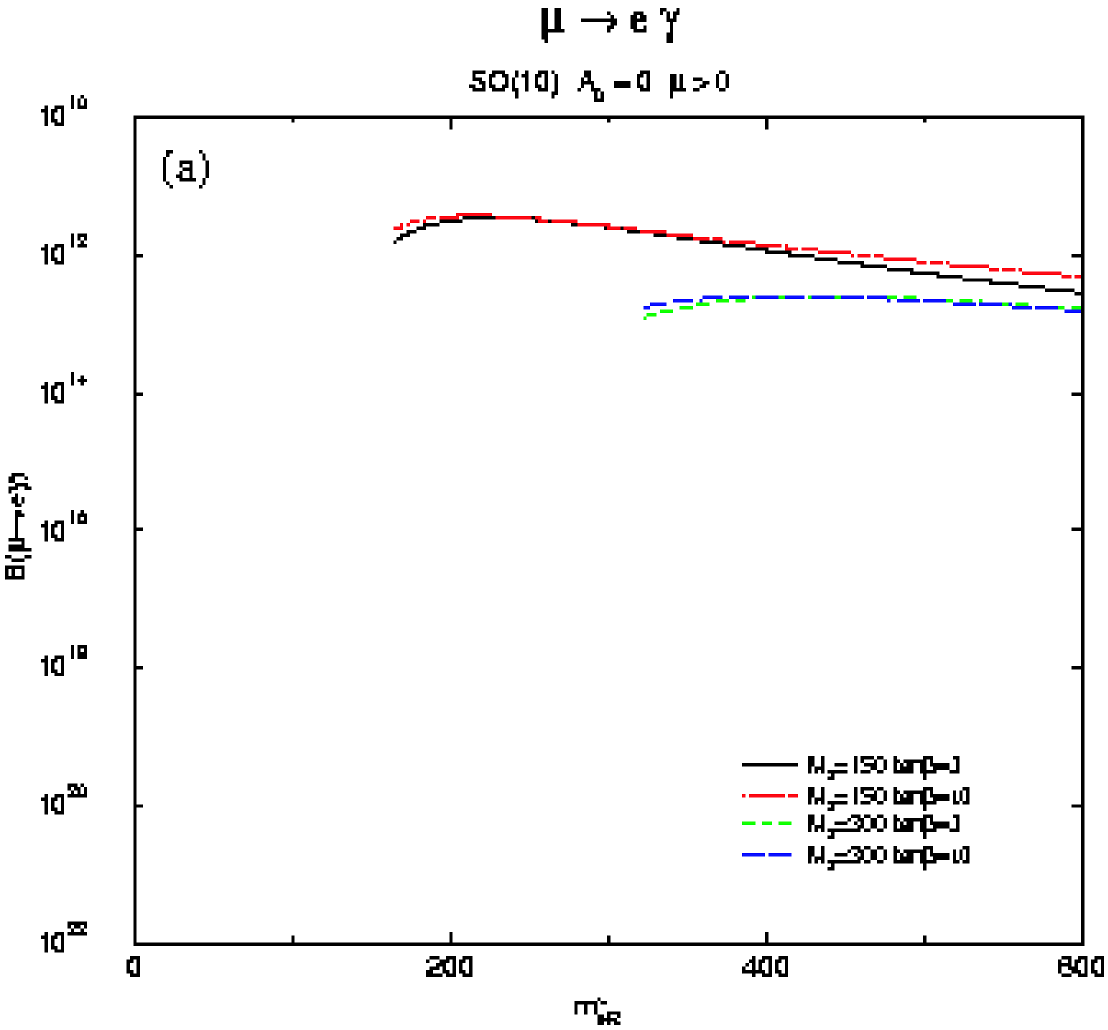
  $BR_{SO(10)} \approx 100\ BR_{SU(5)}$

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

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

combined LEP results favour tanβ>10

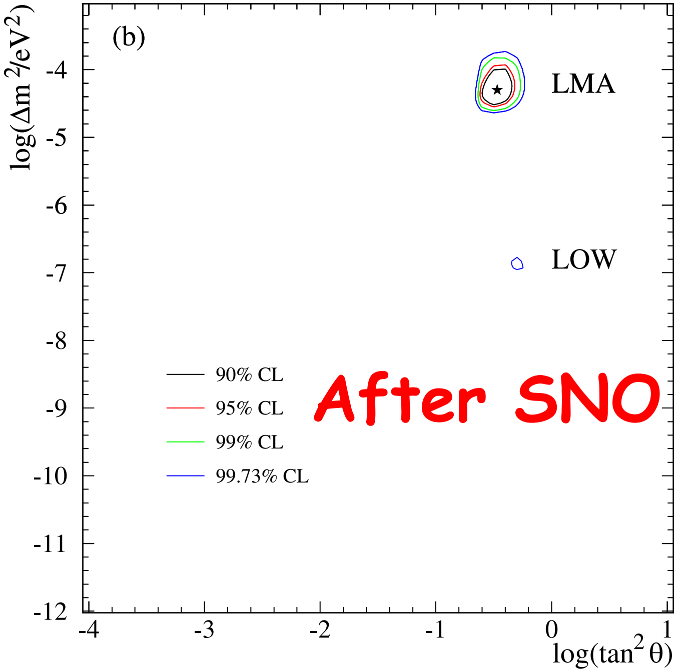
SO10


μ → e γ
SO(10) A0 = 0 μ > 0
(a)
10^10
10^12
10^14
10^16
10^18
10^20
10^22
B(μ→eγ)
0
200
400
600
m_eR
M2=150 tanβ=3
M2=150 tanβ=10
M2=300 tanβ=3
M2=300 tanβ=10

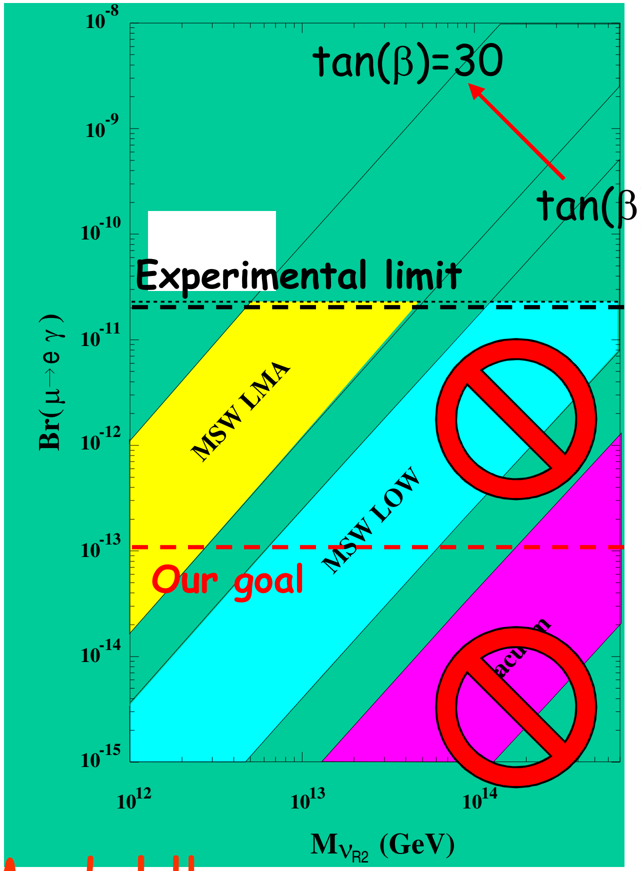
V_{PMNS} (ν oscillations)➔ cLFV

Independent contribution to slepton mixing from ν masses (see-saw model): V less known

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



After SNO



After Kamland

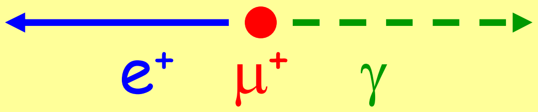
➔ $R \approx 10^{-54}$ in the Standard Model !!

If it is seen it is not SM!

Signal and background

signal

$\mu \rightarrow e\,\gamma$



$\theta_{e\gamma} = 180°$

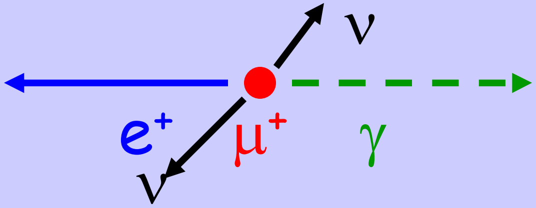
$E_e = E_\gamma = 52.8$ MeV

$T_e = T_\gamma$

background

physical

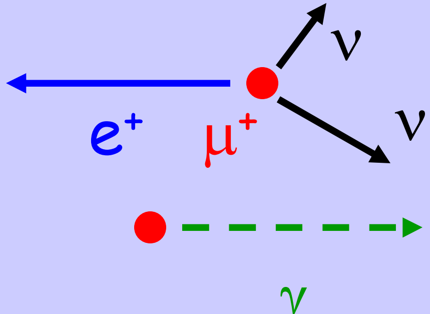
$\mu \rightarrow e\,\gamma\,\nu\,\nu$



accidental

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

$$\left\{\begin{array}{l}\mu \rightarrow e\,\gamma\,\nu\,\nu \\ ee \rightarrow \gamma\,\gamma \\ eZ \rightarrow eZ\,\gamma\end{array}\right.$$



The sensitivity is limited by the accidental background

$$n_{sig} \propto R_\mu \;, n_{phys.b.} \propto R_\mu \;,\; n_{acc.b.} \propto R_\mu^2$$

The n. of acc. backg events ($n_{acc.b.}$) depends quadratically on the muon rateand on how well we measure the experimental quantities: e-γ relative timing and angle, positron and photon energy

Effective BRback ($n_{back}/R\mu\,T$)

$$BR_{acc} \propto R_\mu \times \Delta t_{e\gamma} \times \Delta\theta_{e\gamma}^2 \times \Delta E_e \times \Delta E_\gamma^2$$

Integral on the detector resolutions of the Michel and radiative decay spectra

Required Performances

BR ($\mu \rightarrow e\gamma$) ≈ 10^{-13} reachable

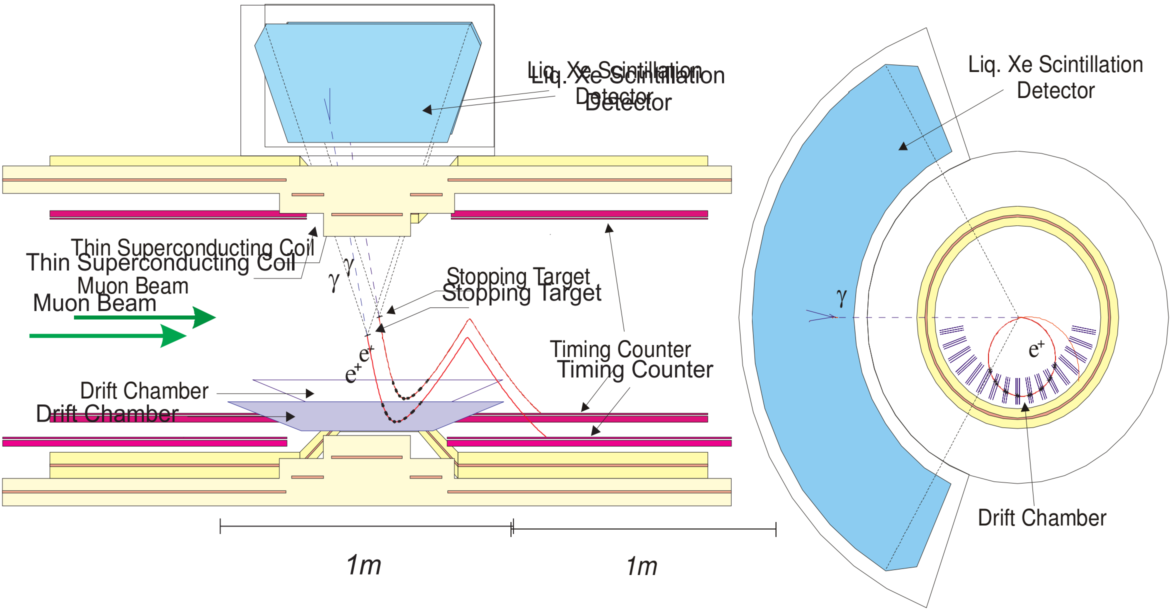
BRacc.b. ≈ 2 10^{-14} and BRphys.b. ≈ 0.1 BRacc.b. with the following resolutions

FWHM

Exp./Lab	Year	$\Delta E_e/E_e$ (%)	$\Delta E_\gamma/E_\gamma$ (%)	$\Delta t_{e\gamma}$ (ns)	$\Delta\theta_{e\gamma}$ (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	2011	0.8	4	0.15	19	2.5×10^7	100	1×10^{-13}

Need of a DC muon beam

Experimental method



Detector outline

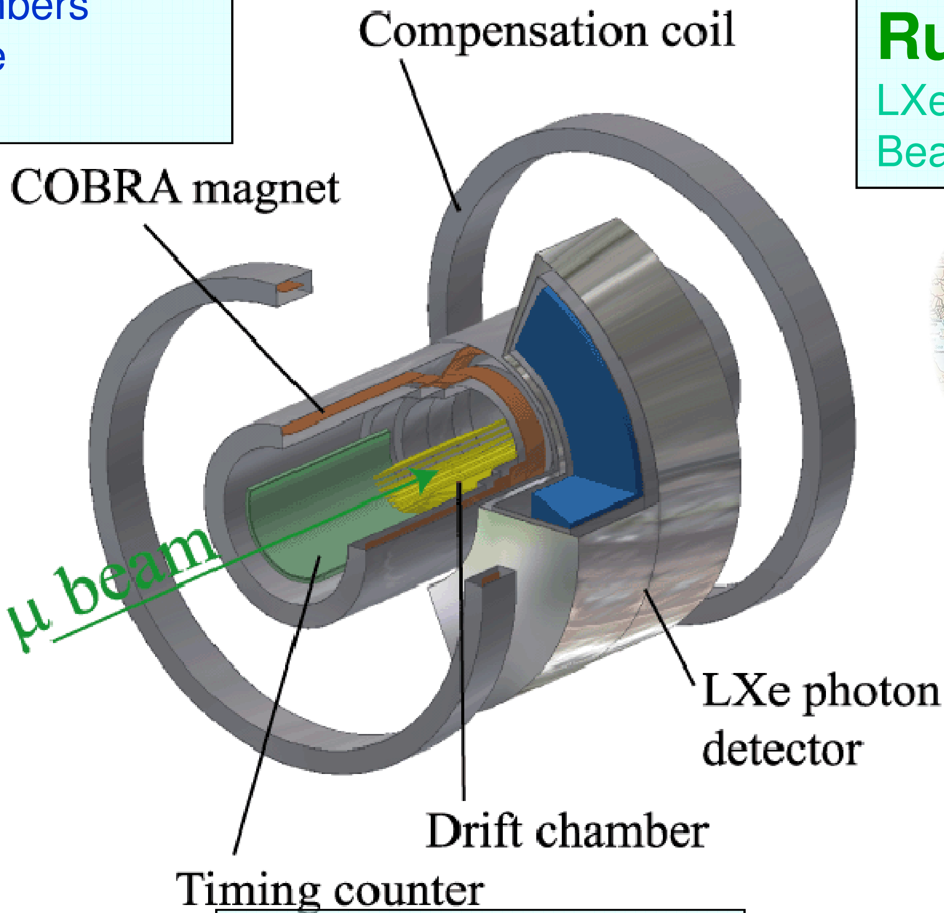
1. Stopped beam of $3\ 10^7\ \mu$ /sec in a 150 μm target
2. Solenoid spectrometer & drift chambers for e^+ momentum
3. Scintillation counters for e^+ timing
4. Liquid Xenon calorimeter for γ detection (scintillation)

- Method proposed in 1998: PSI-RR-99-05: 10^{-14} possibility
- MEG proposal: september 2002: 10^{-13} goal: A. Baldini and T. Mori spokespersons: Italy, Japan, Switzerland, Russia

Detector Construction

Switzerland

Drift Chambers
Beam Line
DAQ



Russia

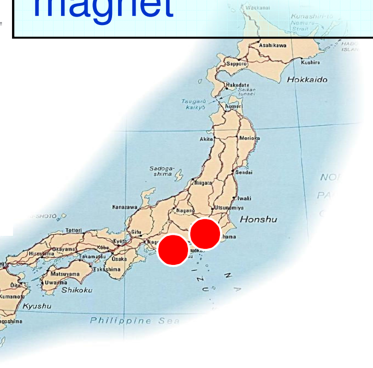
LXe Tests
Beam line

Italy

e+ counter
Trigger LXe
Calorimeter

Japan

LXe Calorimeter,
Spectrometer's
magnet



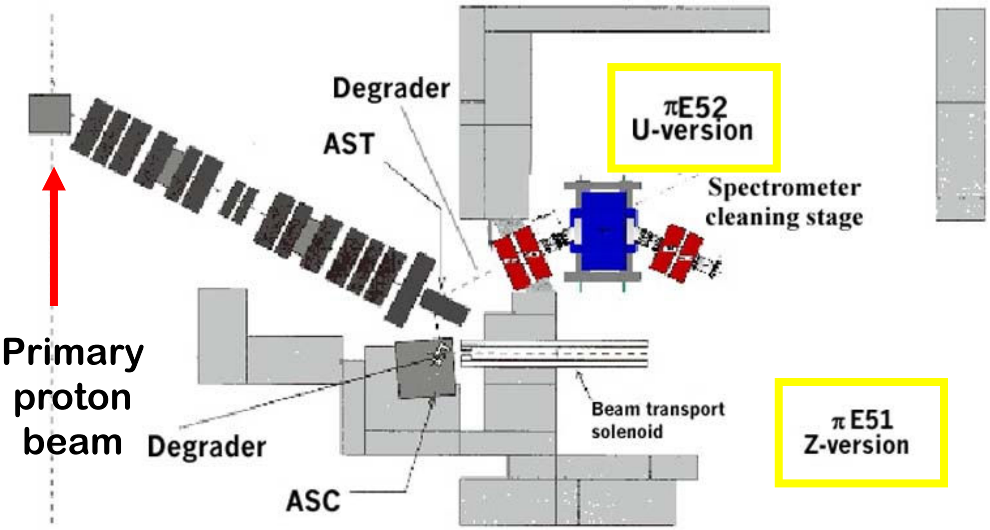
USA(UCI)

Calibrations/Target/DC
pressure system

Next slides…

1. The PSI πE5 beamline
2. The Positron spectrometer
3. The Liquid Xenon calorimeter
4. DAQ
5. The 2008 run
6. Future

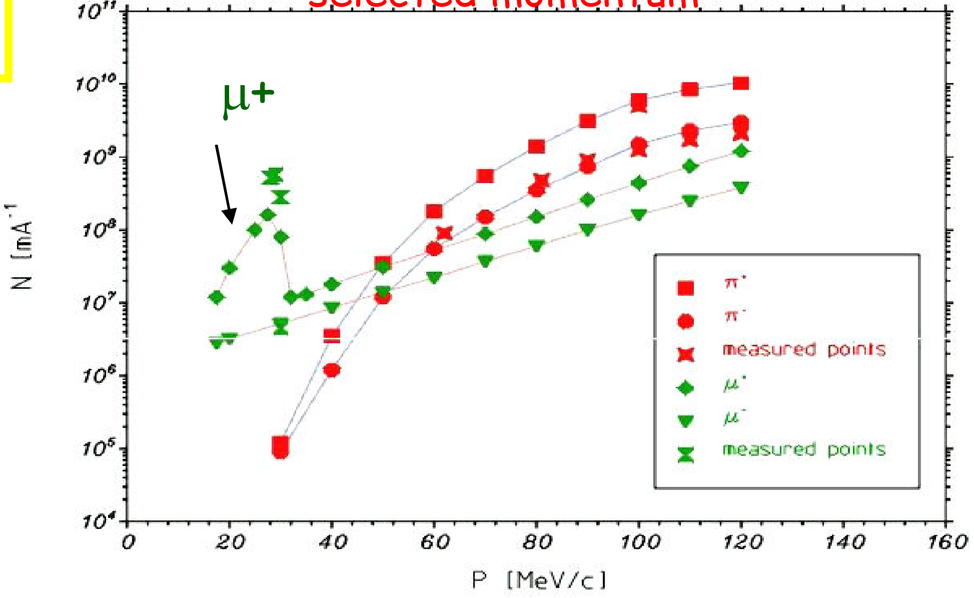
1) The PSI πE5 DC beam



The layout of πE5

- **1.8 mA of 590 MeV/c protons (most intense DC beam in the world)**
- **29 MeV/c muons from decay of π stop at rest: fully polarized**

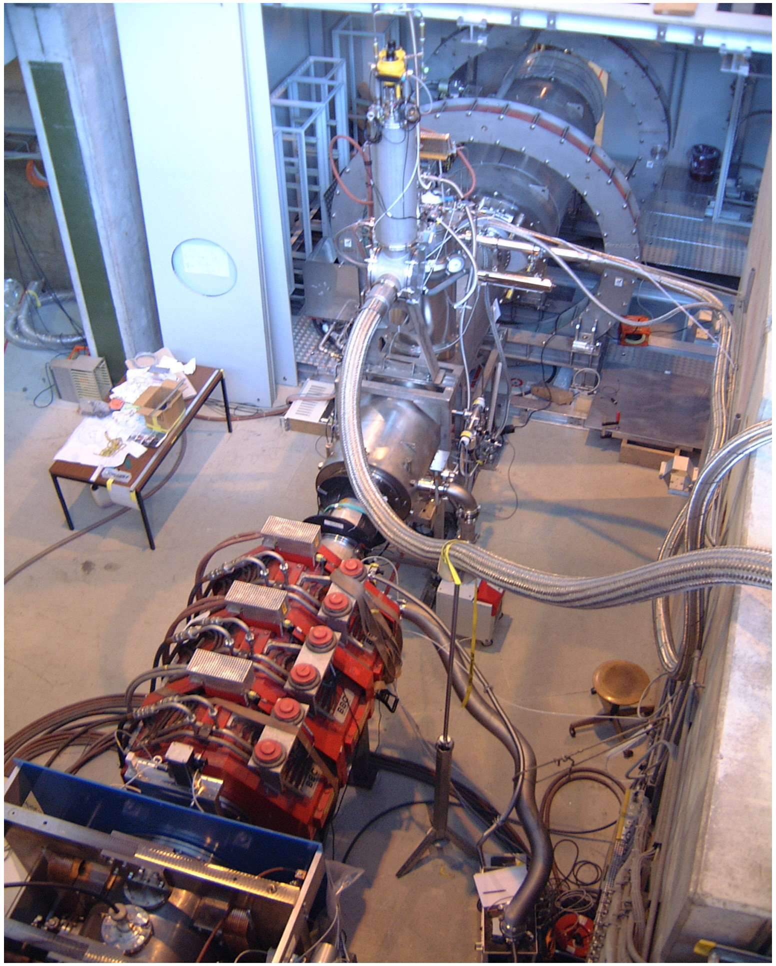
Particles intensity as a function of the selected momentum



Beam studies

Optimization of the beam elements:

- **Wien filter** for μ/e separation
- **Degrader** to reduce the momentum stopping in a 150 μm CH_2 target
- **Solenoid** to couple beam with COBRA spectrometer



Results (4 cm target):

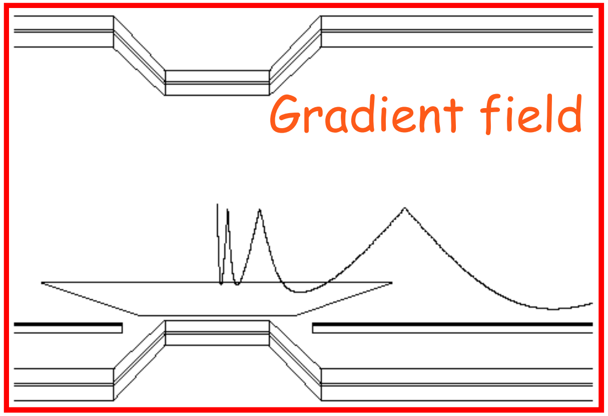
	Z-version
• R_μ (total)	1.3×10^8 μ^+/s
• R_μ (after W.filter & Coll.)	1.1×10^8 μ^+/s
• R_μ (stop in target)	6×10^7 μ^+/s
• Beam spot (target)	$\sigma \approx 10$ mm
□ μ/e separation (at collimator)	7.5 σ (12 cm)

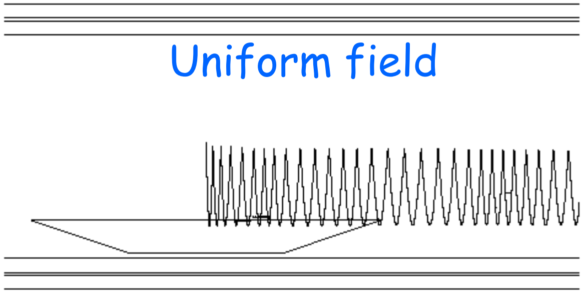
10^8 μ/s could be stopped in the target but only 3×10^7 are used because of accidental background

2) The positron spectrometer: COBRA spectrometer

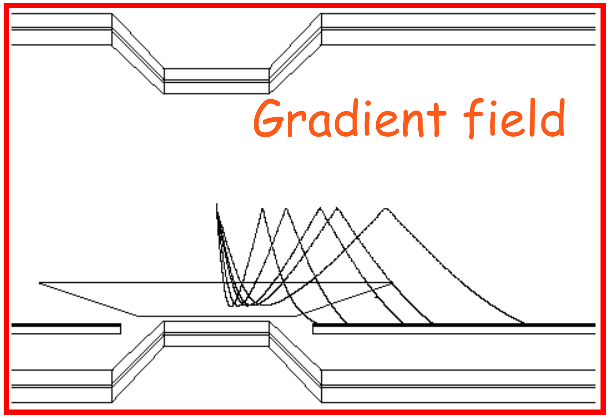
COnstant Bending RAdius (COBRA) spectrometer

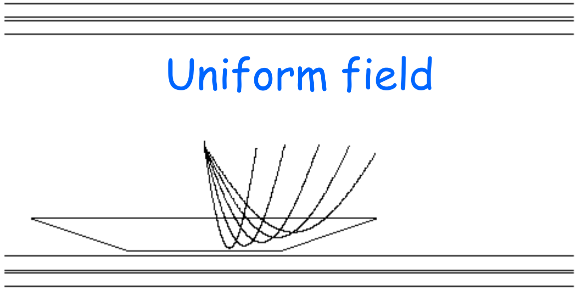
- High p_T positrons quickly swept out



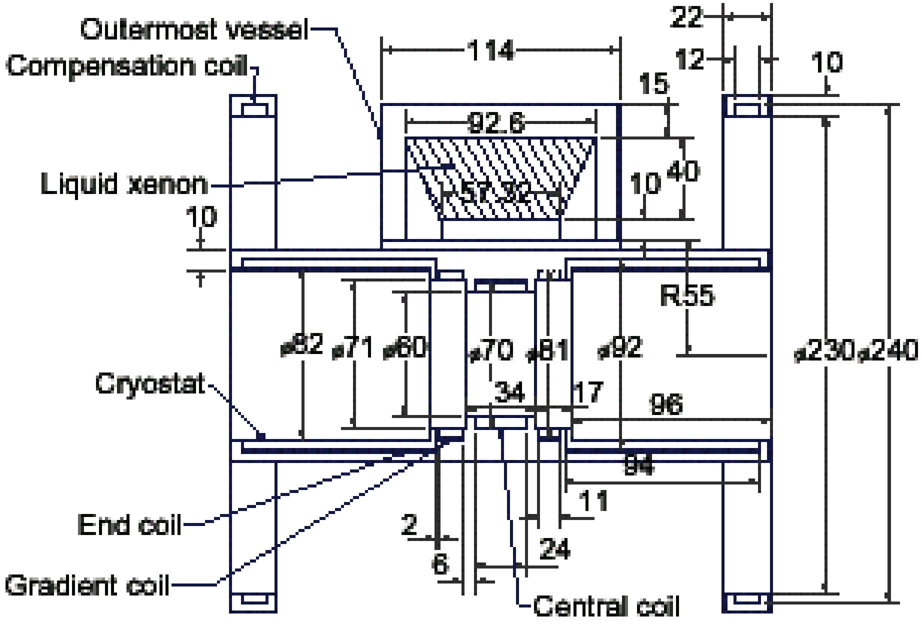


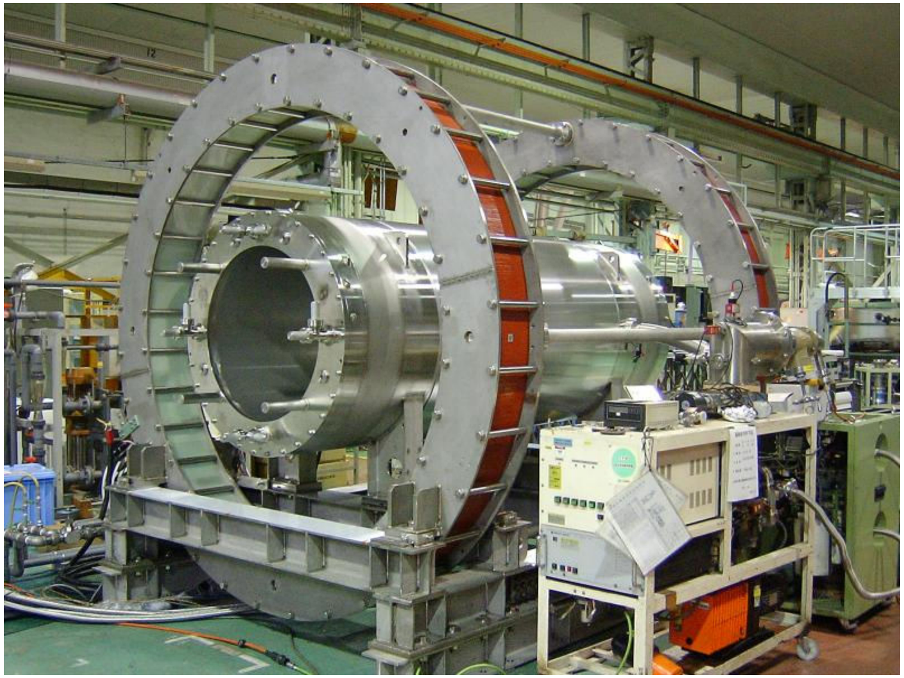
- Constant bending radius independent of emission angles





The magnet

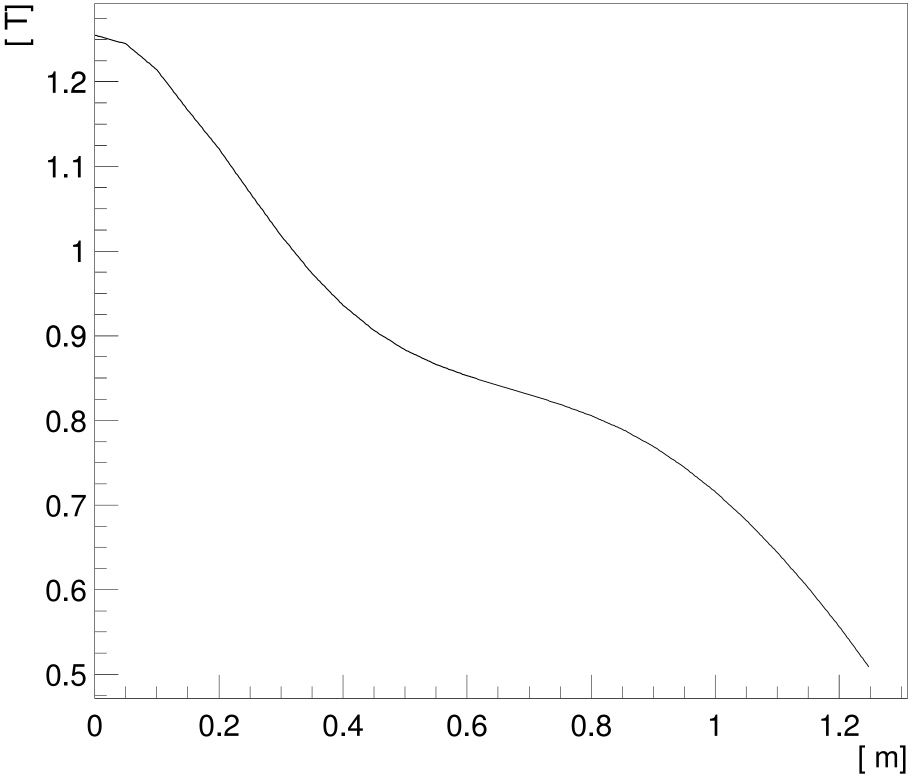


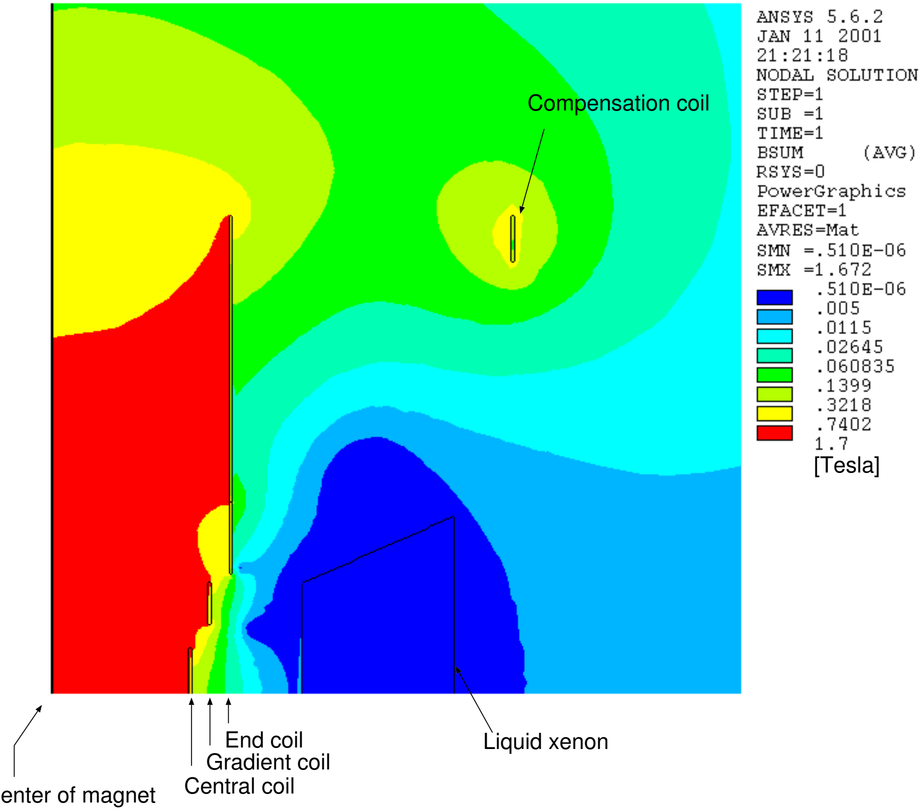


- B_c = 1.26T current = 359A
- Five coils with three different diameters
- Compensation coils to suppress the stray field around the LXe detector
- High-strength aluminum stabilized superconductor

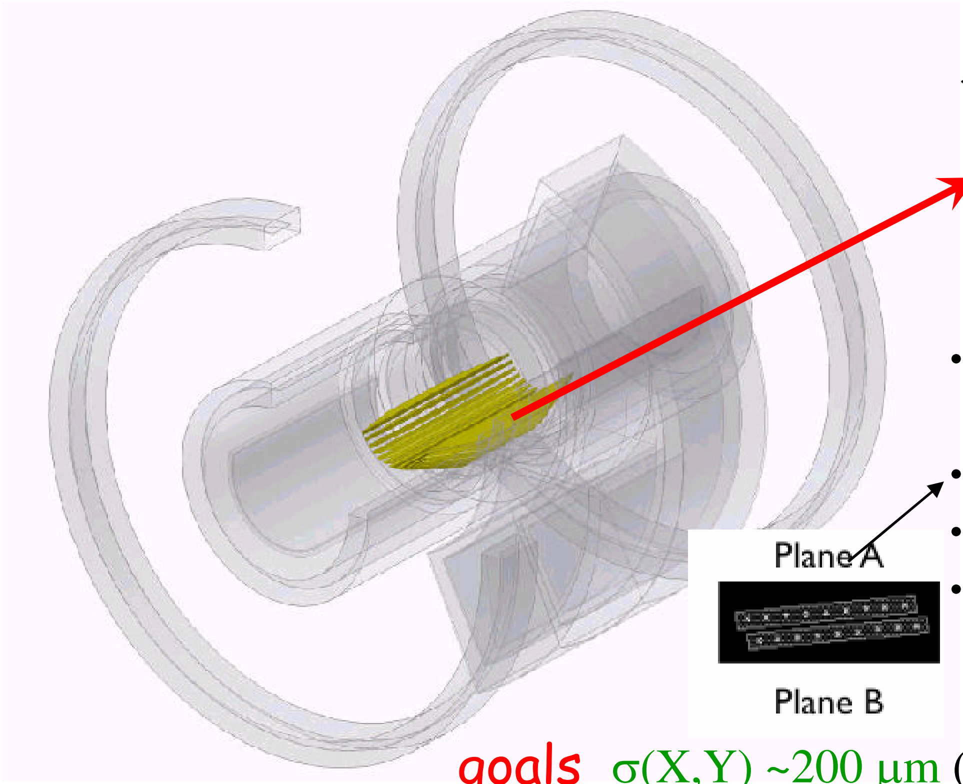
$\Rightarrow$thin magnet (**1.46 cm Aluminum**, 0.2 X_0)

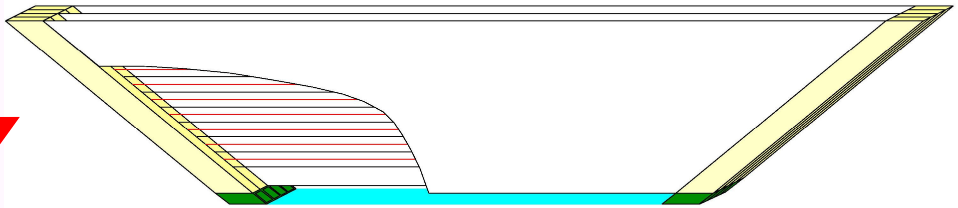
Gradient field





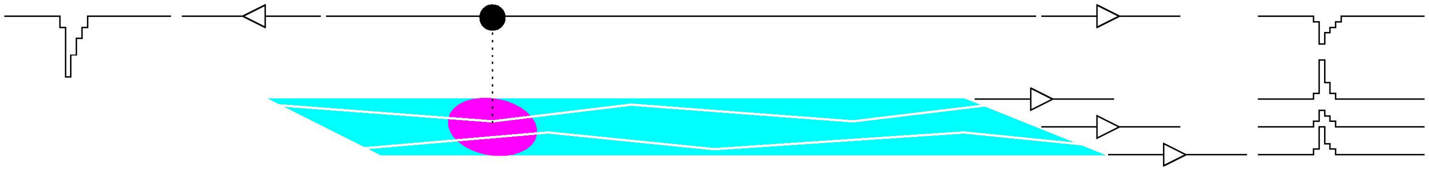
The drift chambers

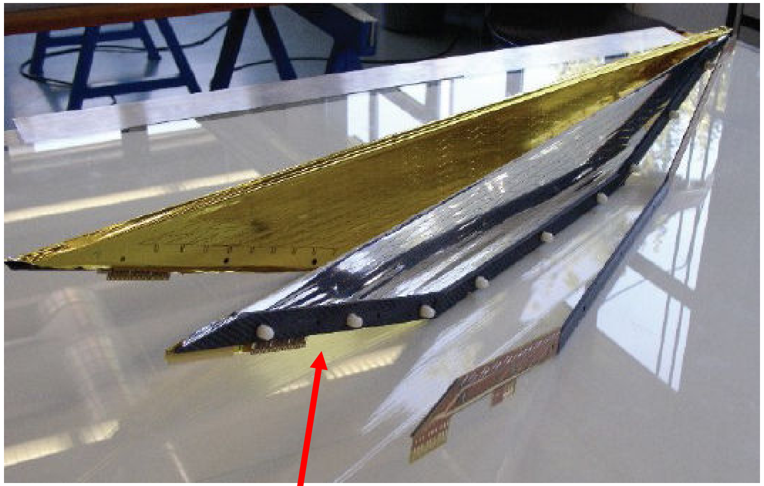


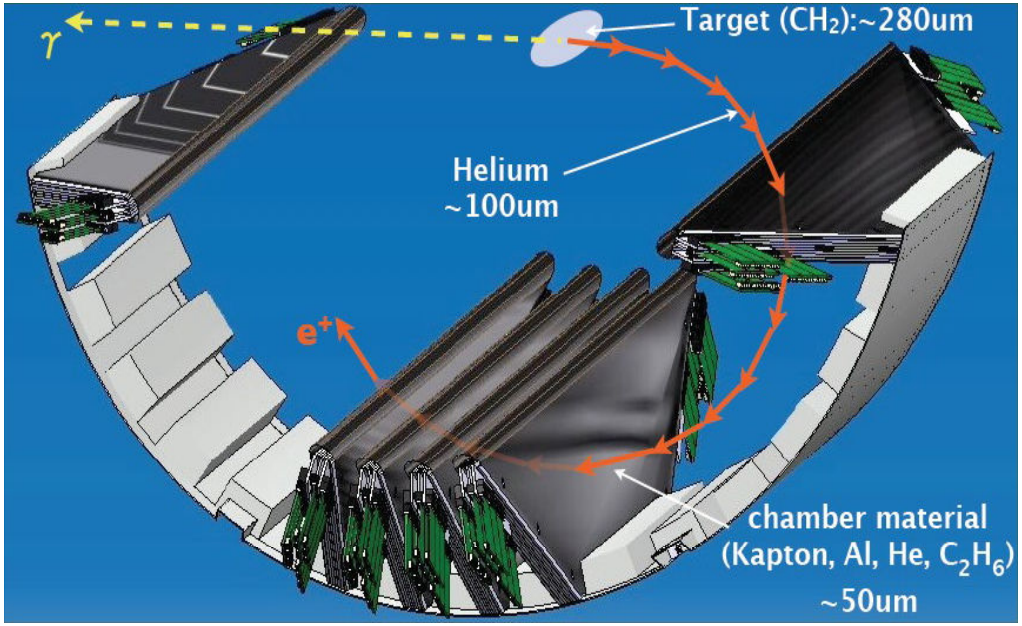


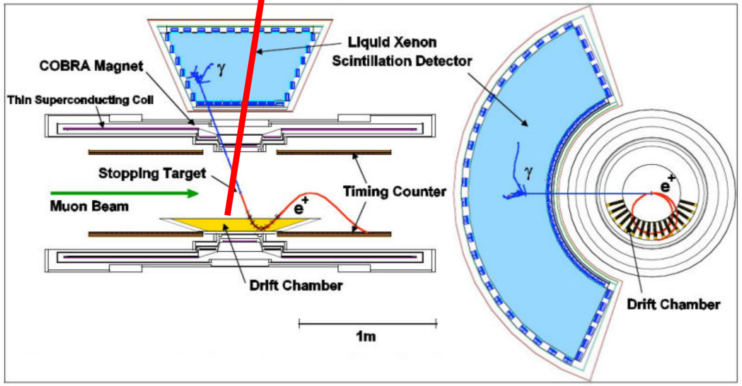
- 16 chamber sectors aligned radially with 10°intervals
- Two staggered arrays of drift cells
- Chamber gas: He-C_2H_6 mixture
- Vernier pattern to measure z-position made of 15 μm kapton foils

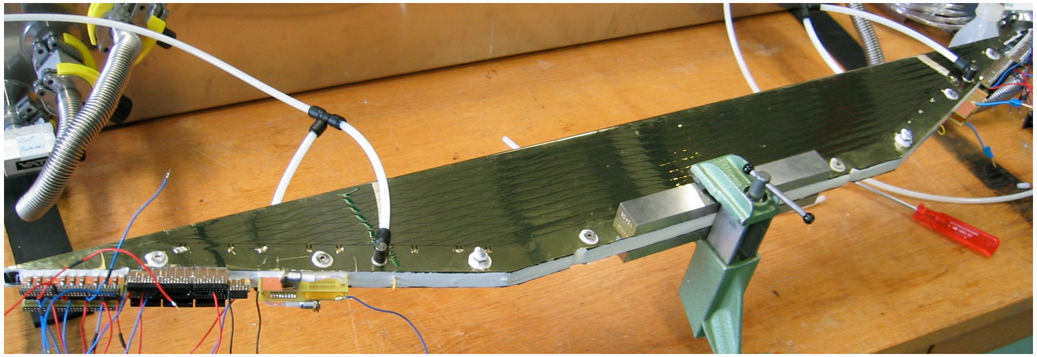
goals $\sigma(X,Y)$ ~200 μm (drift time) $\sigma(Z)$ ~ 300 μm (charge division vernier strips)





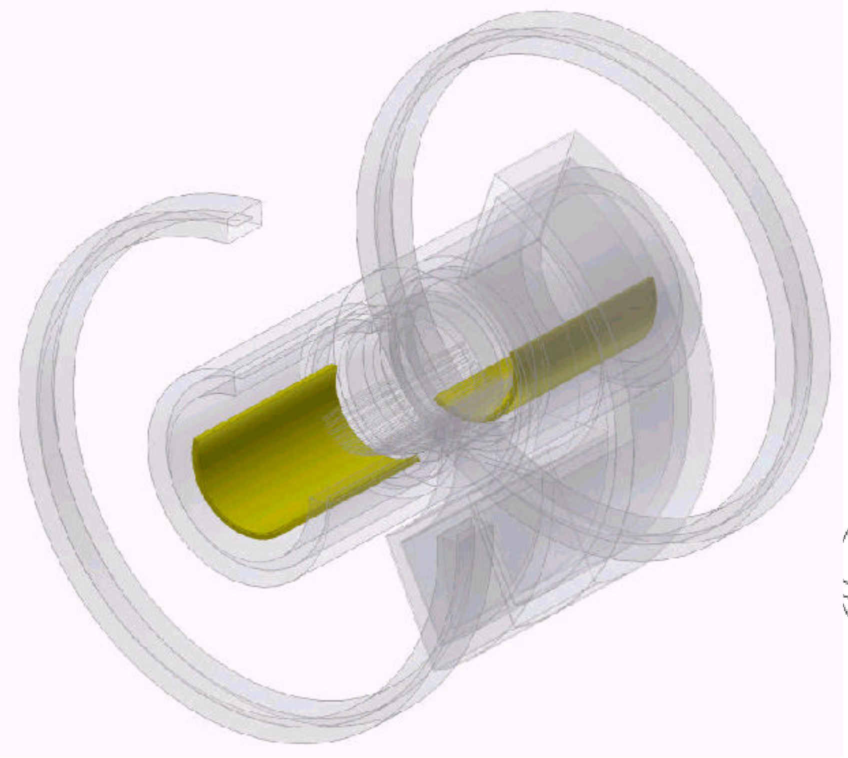


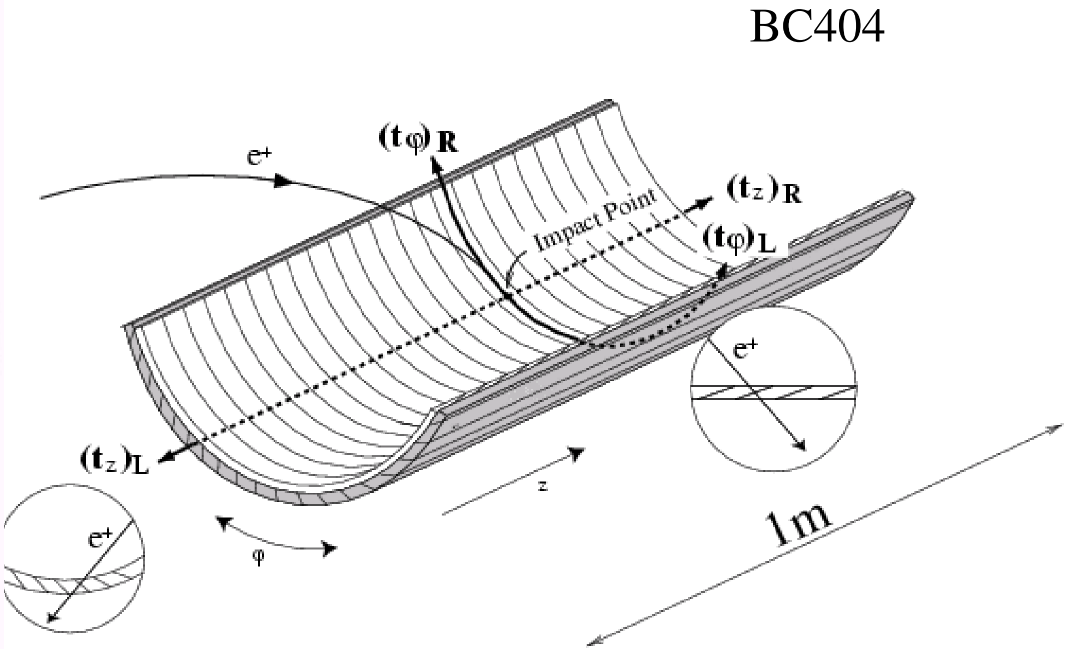




2 10^{-3} X_0 along positrons trajectory

The Timing Counter

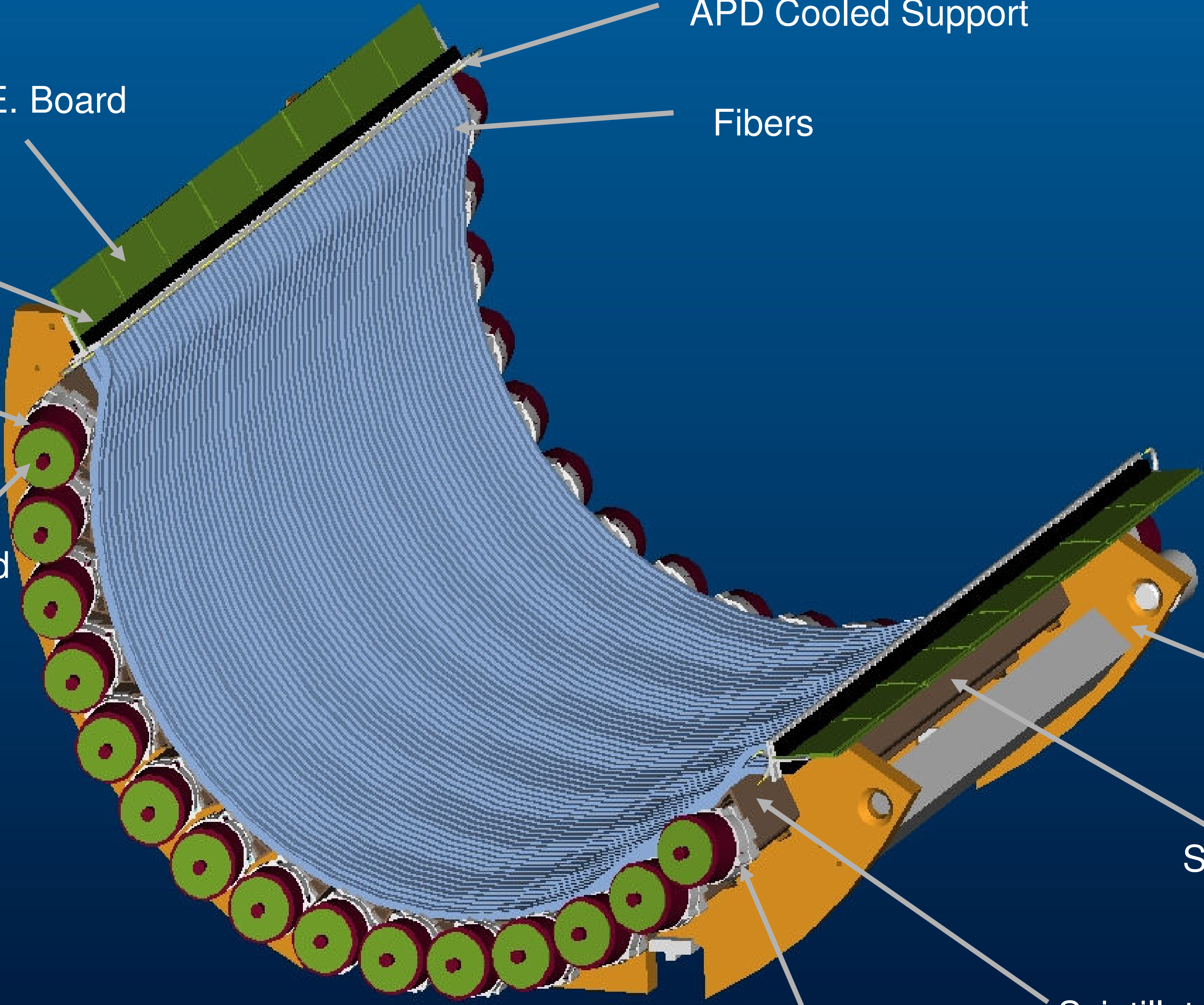




- One (outer) layer of scintillator read by PMTs : timing
- One inner layer of scintillating fibers read by APDs: trigger (the long. Position

5 x 5 mm^2

is needed for a fast estimate of the positron direction)
- Goal σ_{time}~ 40 psec (100 ps FWHM)



APD Cooled Support

APD F.E. Board

Fibers

APD

PM

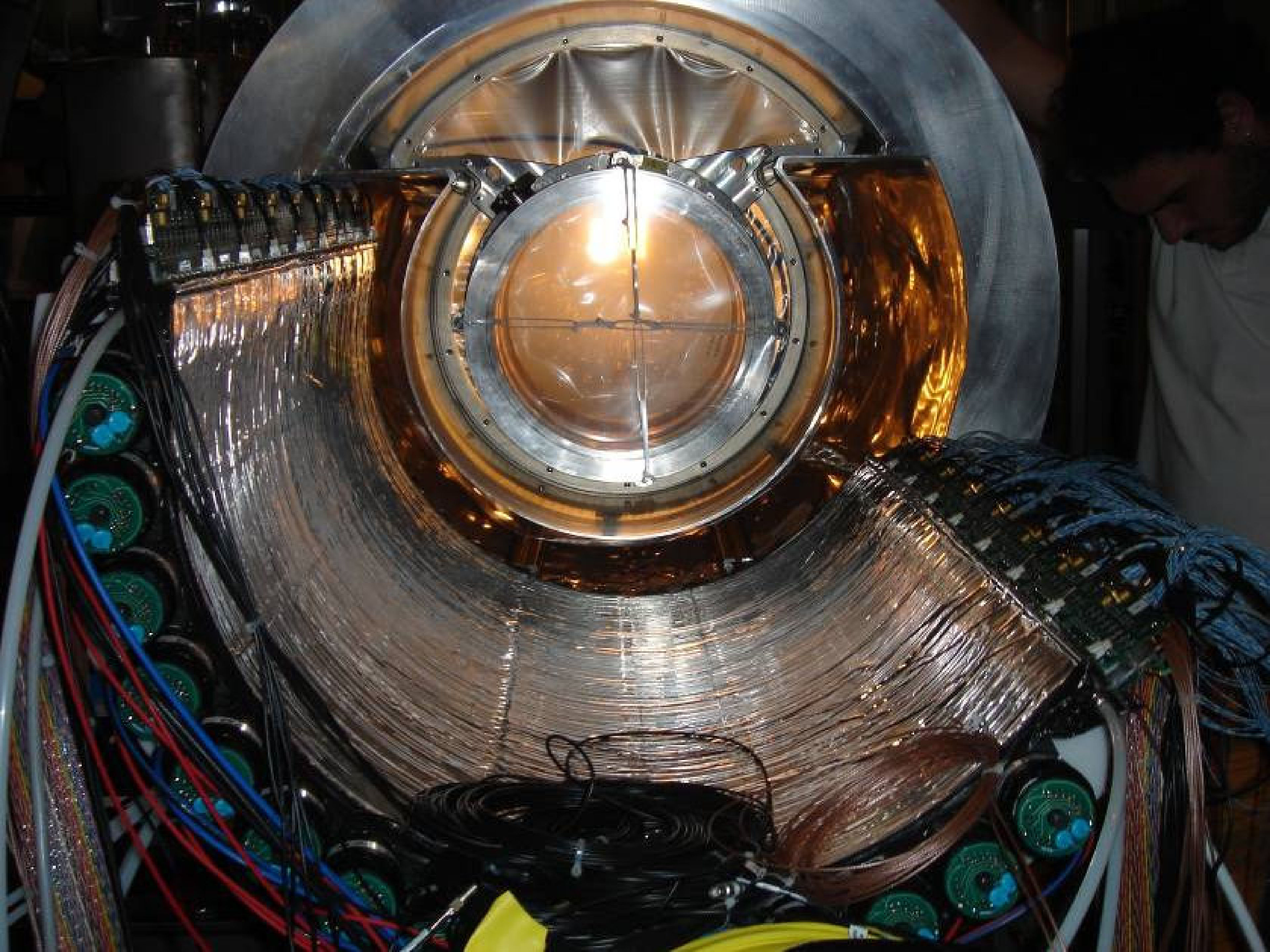
Divider Board

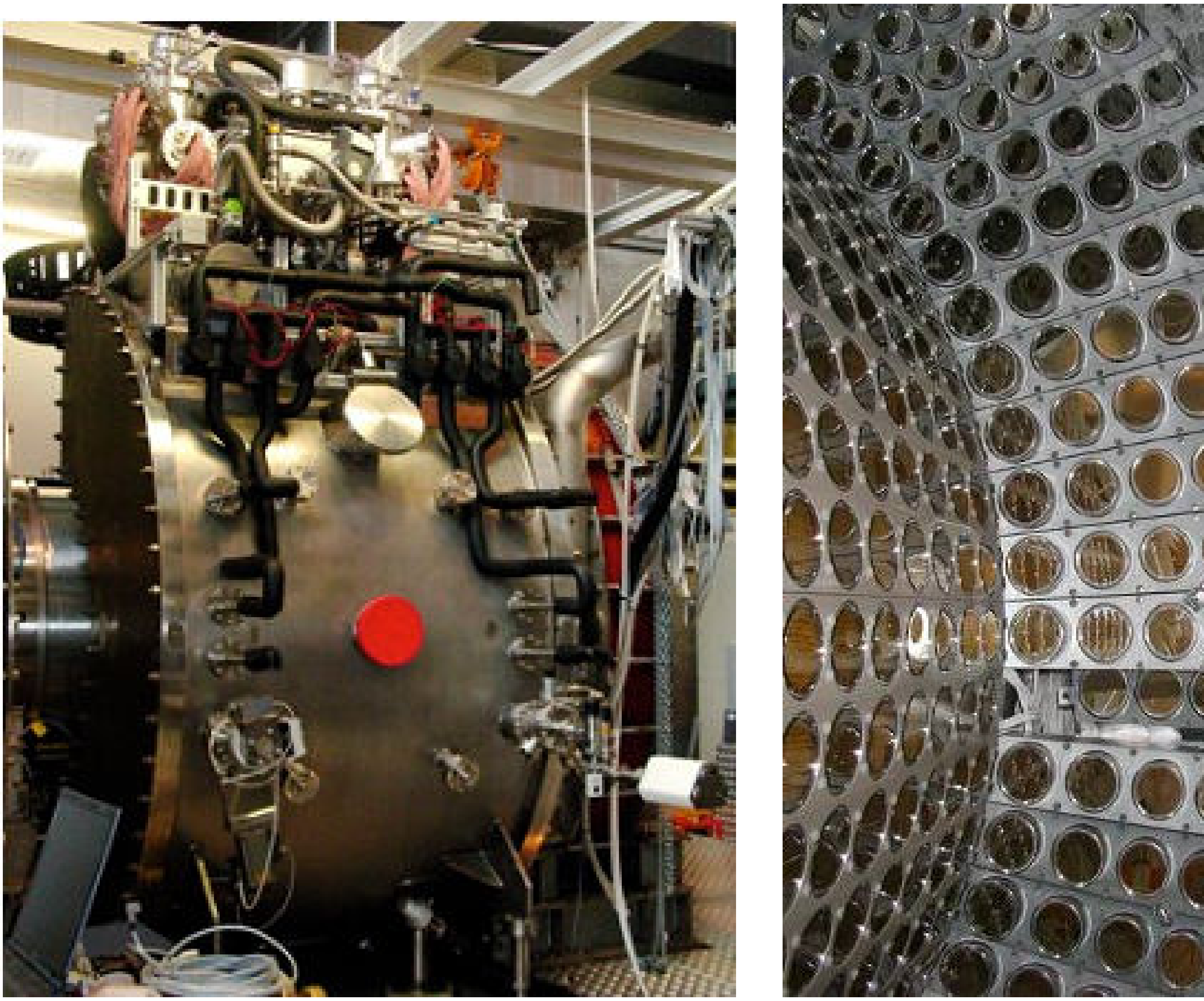
Main Support

Scintillator Sla

Scintillator Housing

PM-Scintillator Coupler





The liquid xenon calorimeter

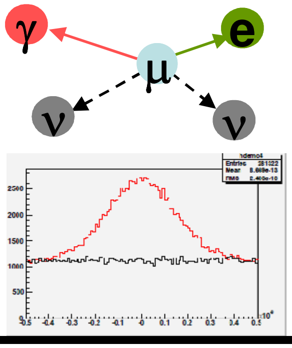
PMT development

~~1st generation R6041Q~~ 	2nd generation R9288TB 	3rd generati 
~~228 in the LP (2003 CEX and TERAS)~~ ~~127 in the LP (2004 CEX)~~	111 In the LP (2004 CEX)	Not used ye
~~Rb-Sc-Sb~~ ~~Mn layer to keep surface resistance at low temp.~~	K-Sc-Sb Al strip to fit with the dynode pattern to keep surface resistance at low temp.	K-Sc-Sb Al strip der 4% loss of
~~1st compact version~~ ~~QE~4-6%~~ ~~Under high rate background, PMT output reduced by 10 -20% with a time constant of order of 10min.~~	Higher QE ~12-14% Good performance in high rate BG Still slight reduction of output in very high BG	Higher QE Much bette high BG

Xenon purification

New (2009) liquid phase purification system completely made inside the collaboration (F. Sergiampietri)

μ radiative decay



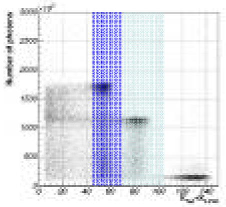
Lower beam intensity < 10^7

Is necessary to reduce pile-ups

Better σ_t, makes it possible to take data with higher beam intensity

A few days ~ 1 week to get enough statistics

$\pi^0 \rightarrow \gamma\gamma$



$\pi^- + p \rightarrow \pi^0 + n$

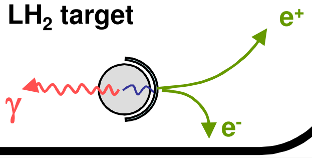
$\pi^0 \rightarrow \gamma\gamma$ (55MeV, 83MeV)

$\pi^- + p \rightarrow \gamma + n$ (129MeV)

10 days to scan all volume precisely

(faster scan possible with less points)

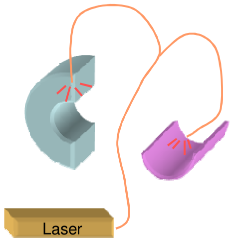
LH_2 target



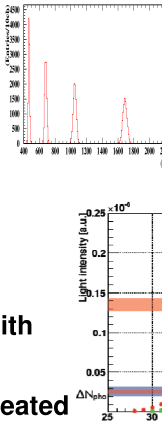
Laser

(rough) relative timing calib.

< 2~3 nsec



LED



PMT Gain

Higher V with light att.

Can be repeated frequently

Xenon Calibration

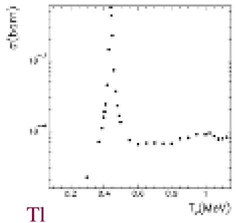
alpha

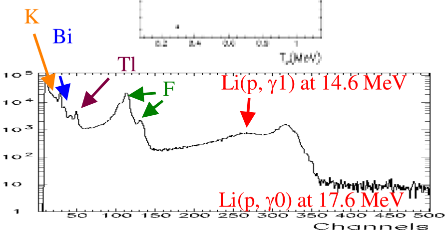
PMT QE & Att. L

Cold GXe

LXe

Proton Acc





Li(p,γ)Be

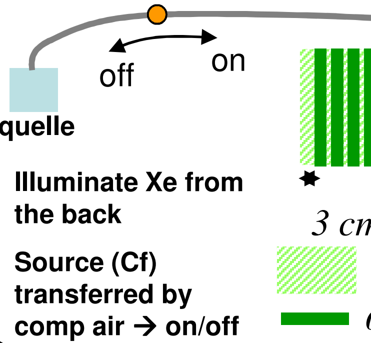
LiF target at COBRA center

17.6MeV γ

~daily calib.

Can be used also for initial setup

Nickel γ Generato

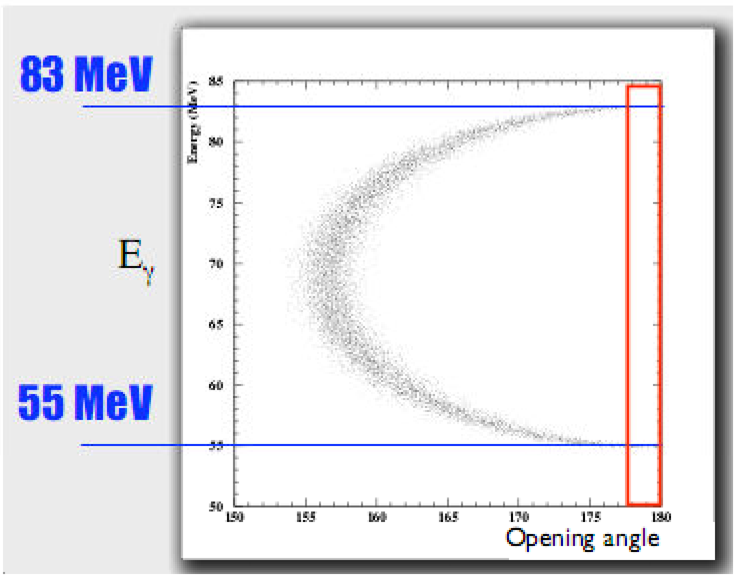


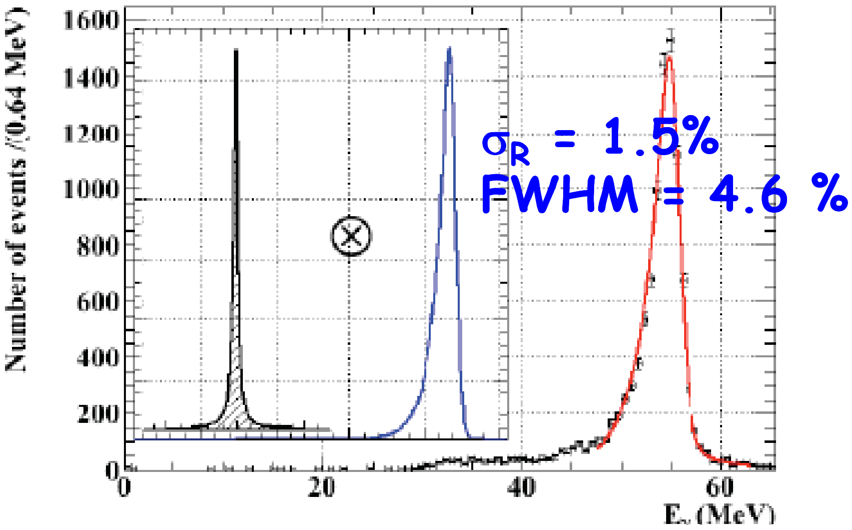
Illuminate Xe from the back

Source (Cf) transferred by comp air → on/off

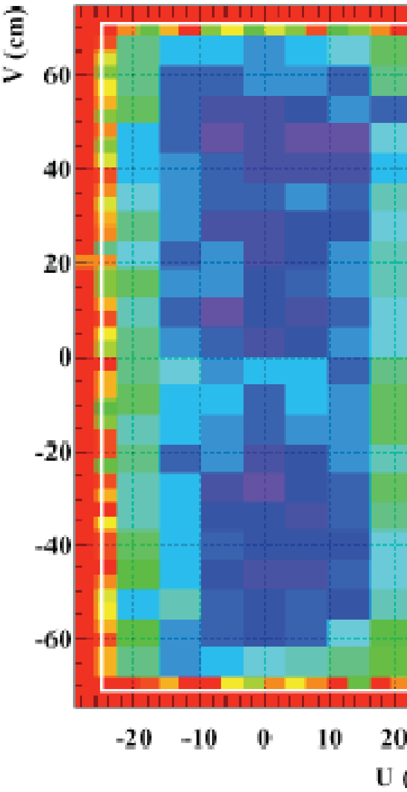
Calorimeter energy Resolution and unifo
MeV by means of

$$\pi^- p \rightarrow \pi^0 n \rightarrow \gamma\gamma n$$



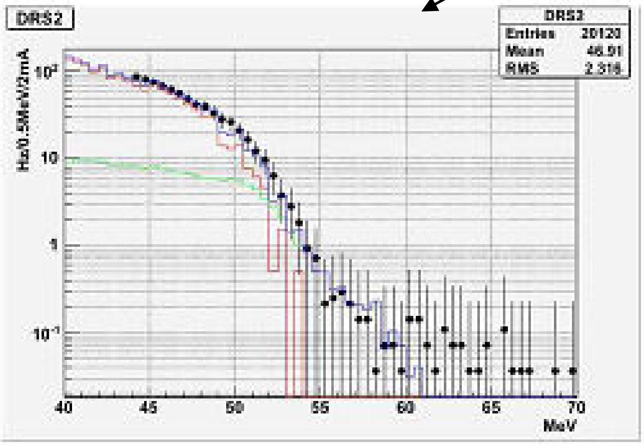


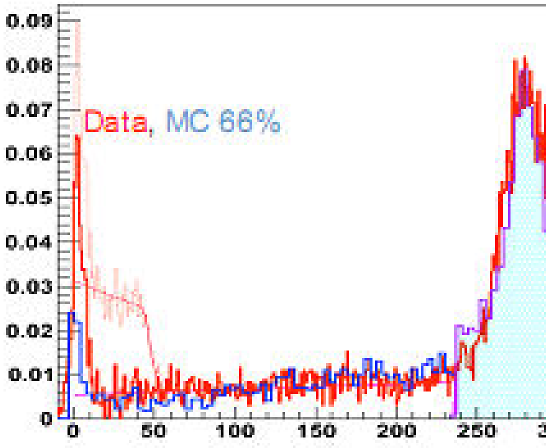
σ_R = 1.5%
FWHM = 4.6 %



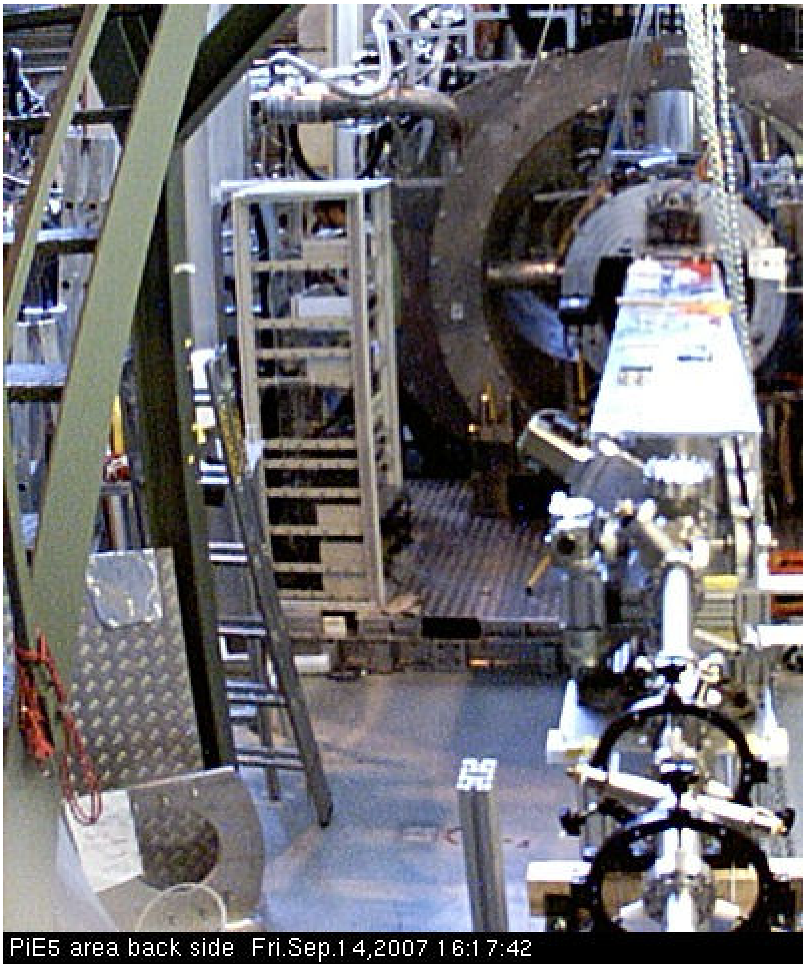
Detection efficiency

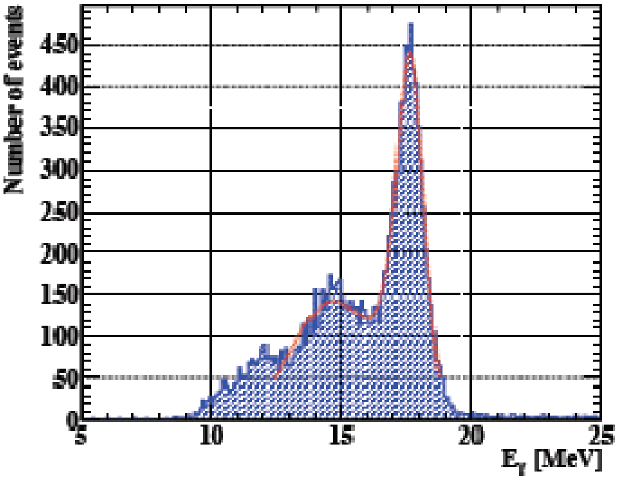
- The probability to detect a signal γ-ray within the detector acce
computed using the Monte Carlo simulation;
- The probability that the energy of a 52.8 MeV γ-ray is reconstru
MeV (0.66) is corrected by taking into account
  - position resolution smearing for the acceptance;
  - positron direction smearing;
- $\varepsilon_{(\gamma)} = 0.61 \pm 0.03$
  - confirmed by π^0 and RD spectra





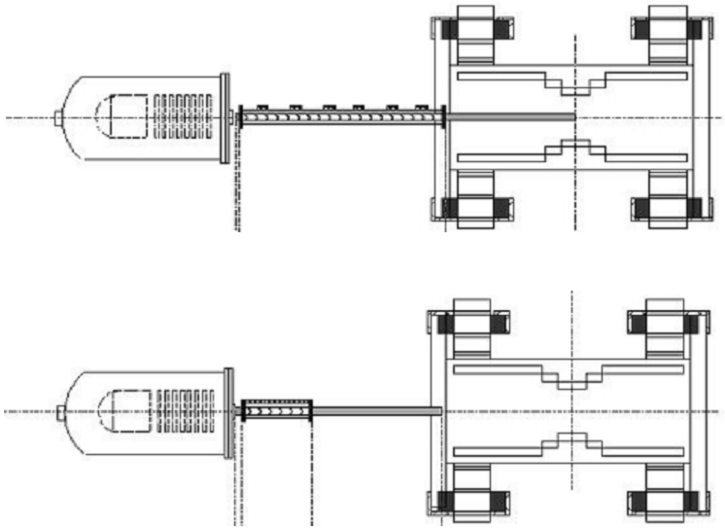
CW beam line





LiF targ

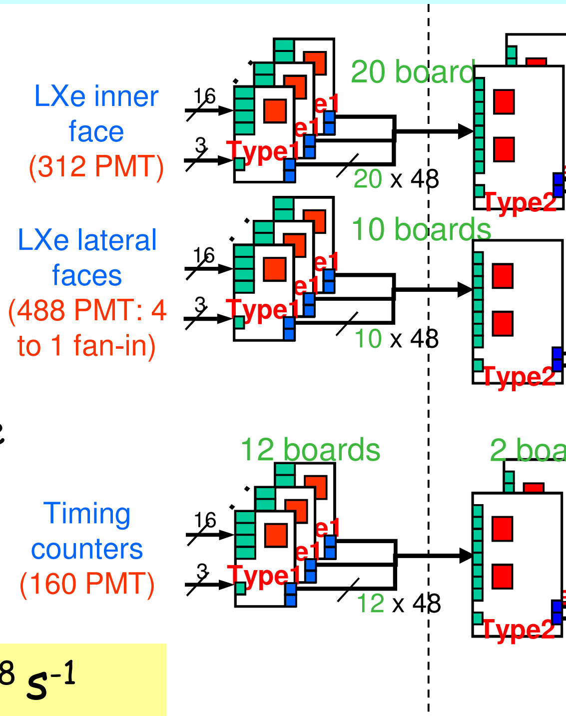
LITHIUM γ - spectrum +
FLUORINE γ - spectrum



inser
the

4) DAQ: trigger

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

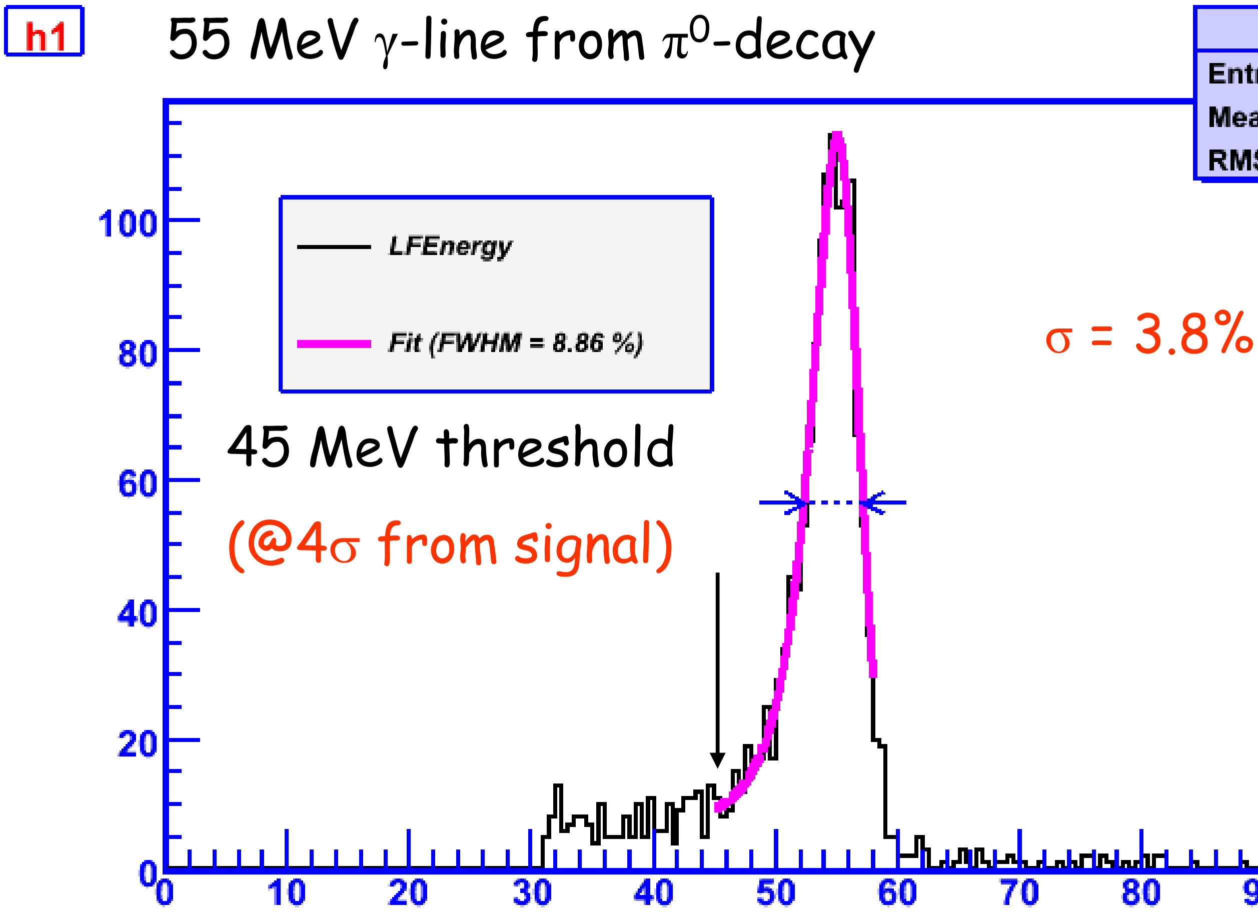


❖	Beam rate	$10^8\ s^{-1}$
❖	Fast LXe energy sum > 45MeV	$2\times10^3\ s^{-1}$
	g interaction point (PMT of max charge)	
	e^+ hit point in timing counter	
❖	time correlation γ – e^+	$200\ s^{-1}$
❖	angular correlation γ – e^+	$20\ s^{-1}$

~ 5 Hz in 2008 d

On-line E_γ resolution

55 MeV γ-line from π^0-decay

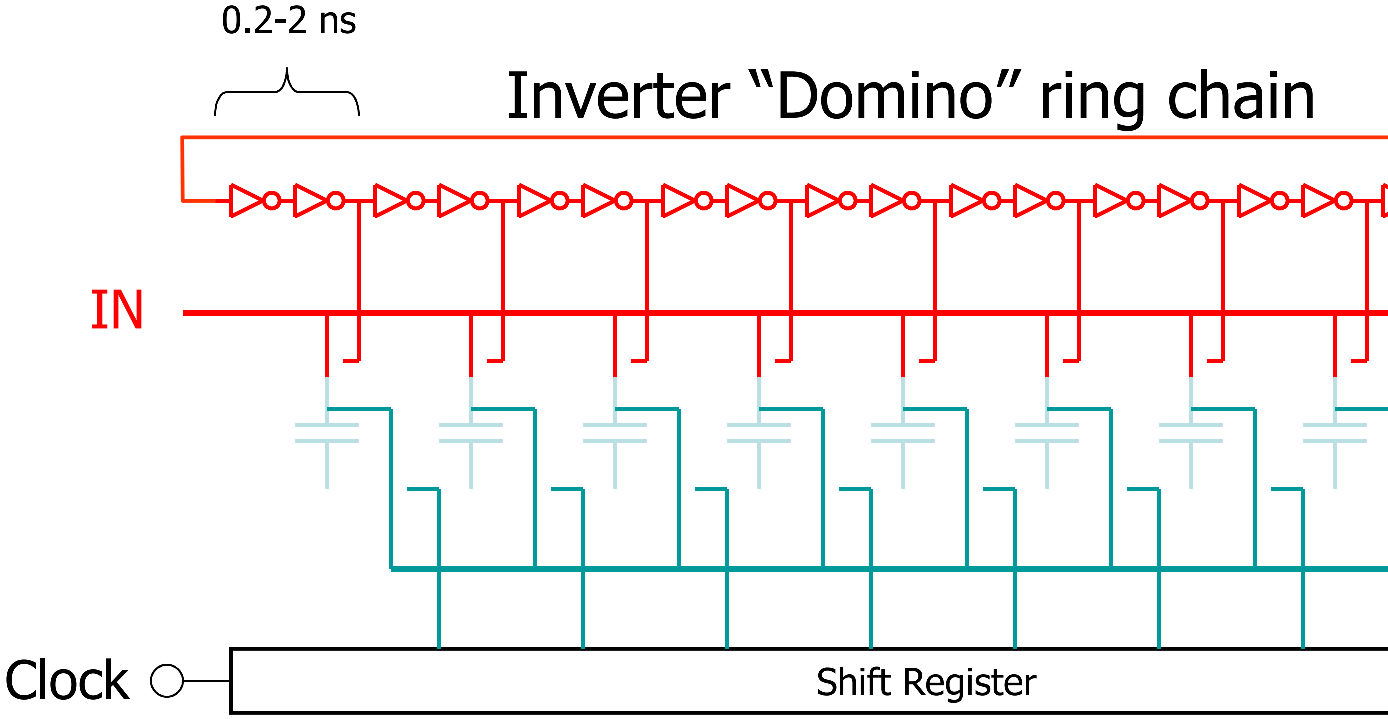


45 MeV threshold

(@4σ from signal)

σ = 3.8%

DAQ: readout The Domino Princ



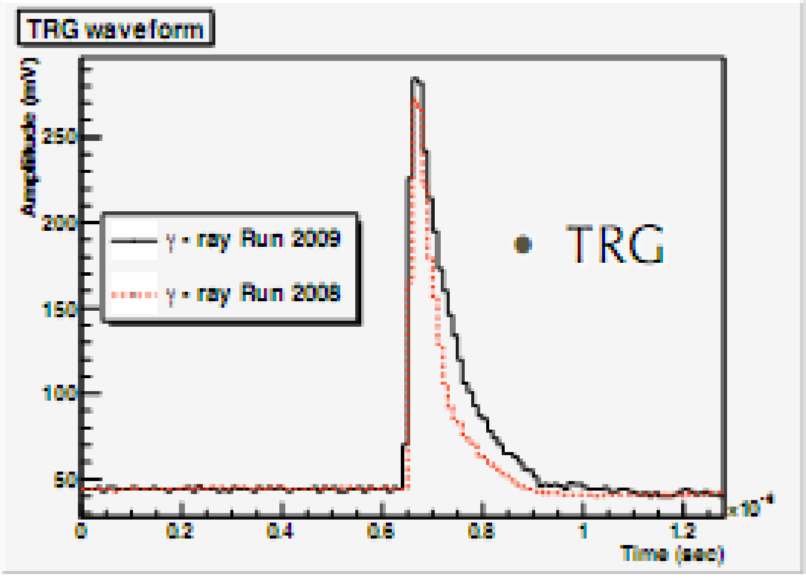
“Time stretcher” GHz → MHz

Keep Domino wave running in a circular fashio
stop by trigger → Domino Ring Sampler (DRS)

Low cost ➔One “oscilloscope” per channel

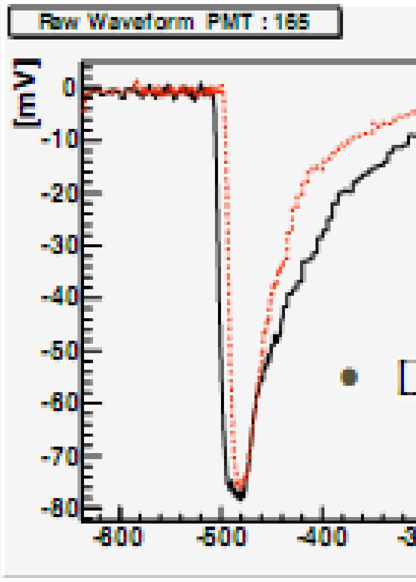
Liquid xenon: waveforms: 2 digitizers

Trigger@100 MHz



DRS2 @ 50

or <u>2 G</u>

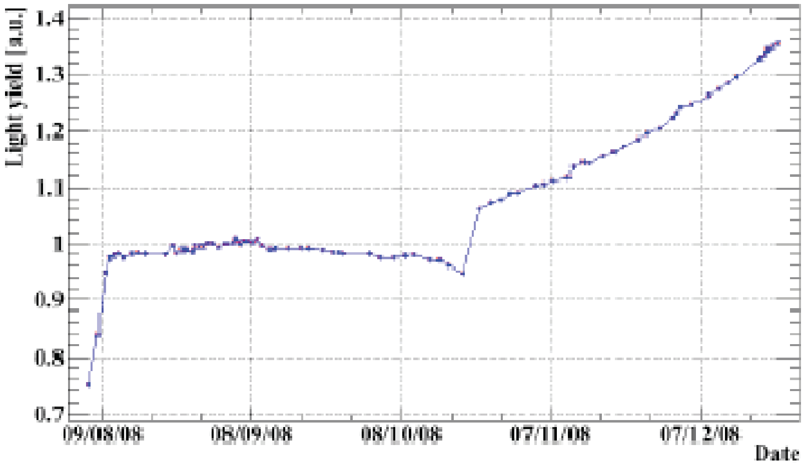


4) 2008 run

- First 3 months physics data taking (september-december 2008)

-DCHs instability on part of the chambers after some months of operation: reduction of efficiency to 30% (now 2009 corrected: new HV distribution system)

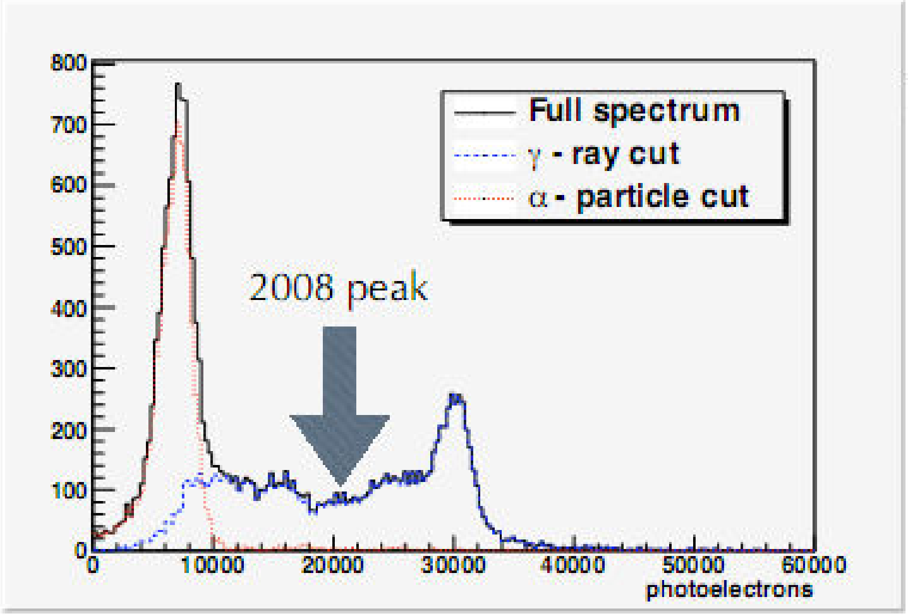
-Xe LY increase (now 2009 at the nominal value)



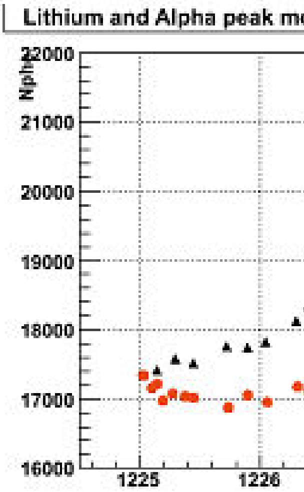
CW Calibration each three days during 2008 run

α-source and Li line

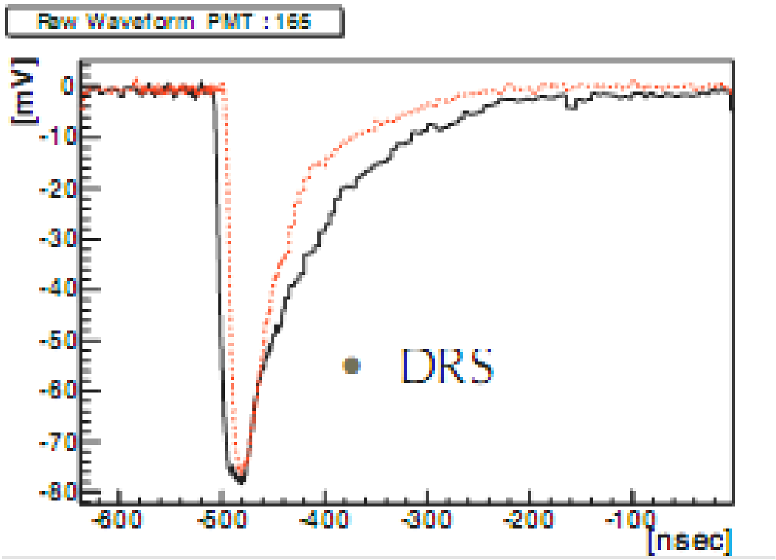
- The position of the α-source peak is ~the same as year 2008
- The Li peak (17.6 MeV) is higher!
  - around ~ 30k phe
  - it was at < 22k phe
  - integration still not optimized for this year's waveform

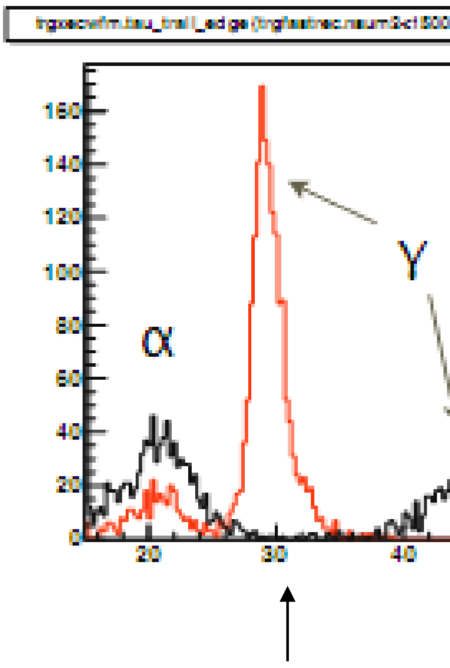


2009



In 2009 xenon scintillation wavefor
the right time decay constant: long
gammas

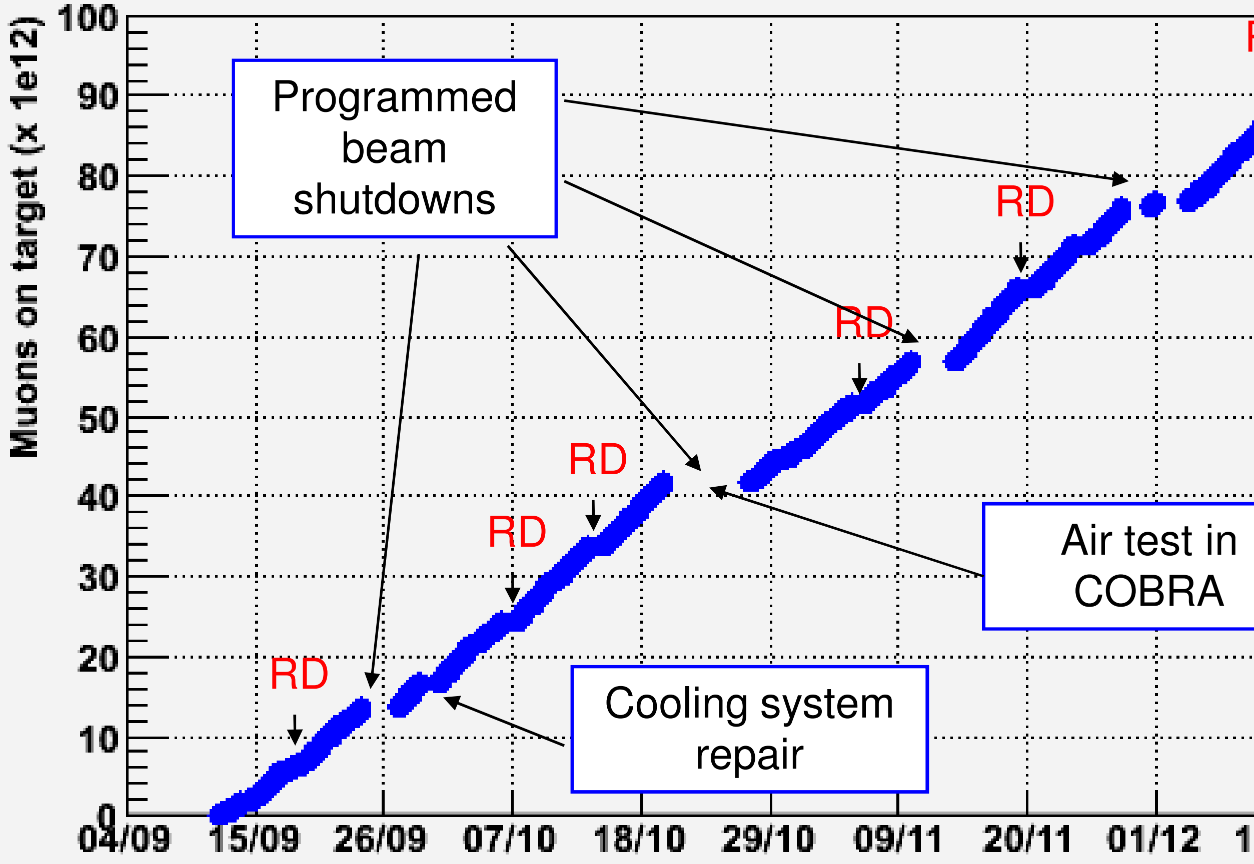




2008 2

2008 run : 10^{14} muons stopped in t

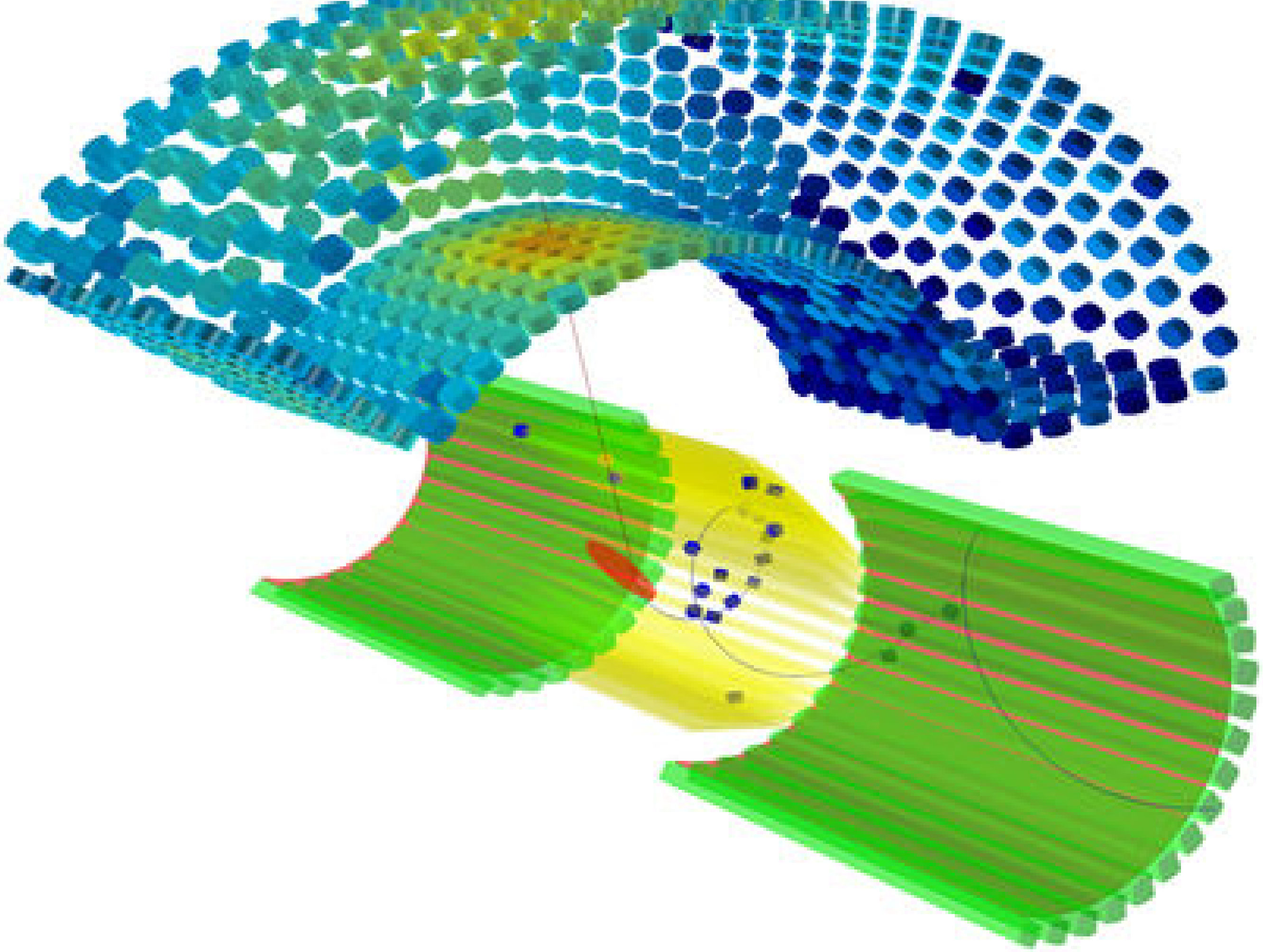
We also took RMD data once/week at reduced beam



Programmed beam shutdowns

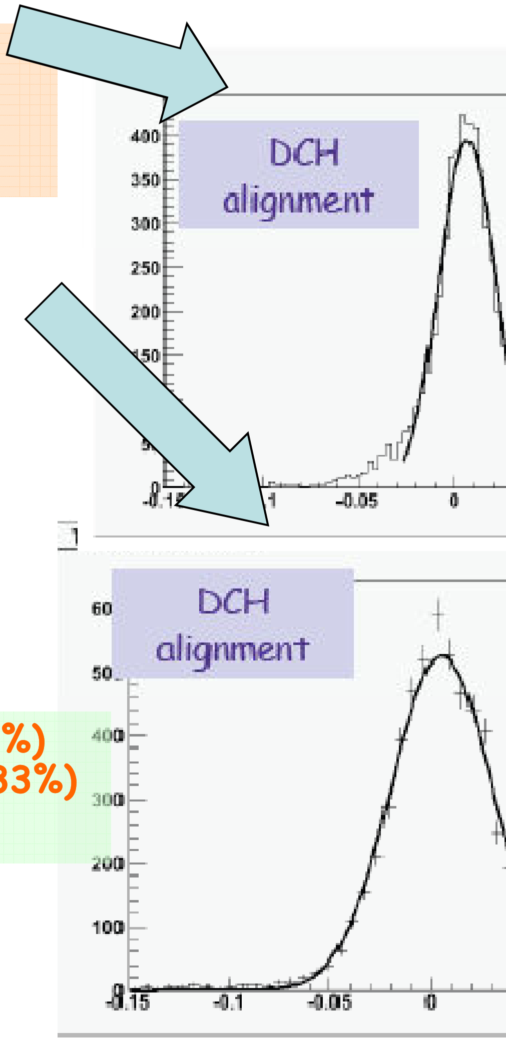
Cooling system repair

Air test in COBRA

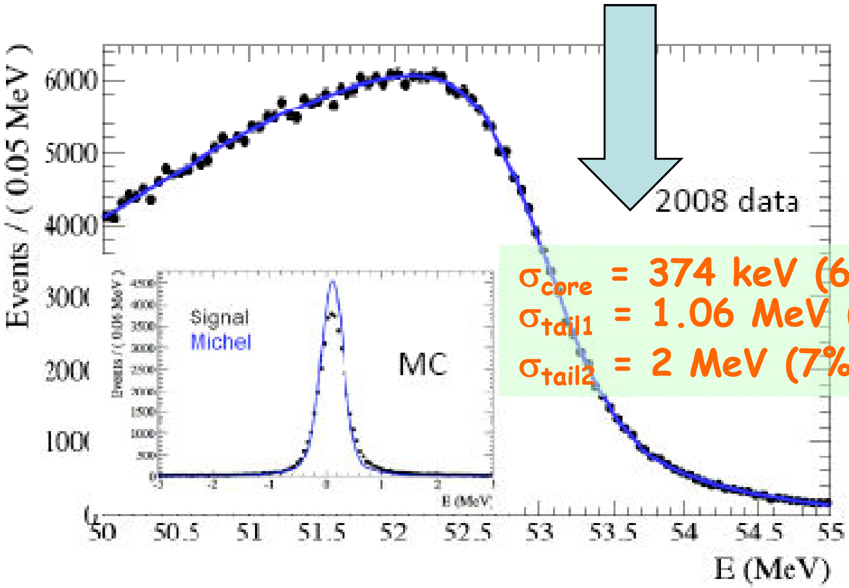


DCH resolutions from 2008

Tracks with two turns in the spectrometer are used to detetrmine the Angular resolutions



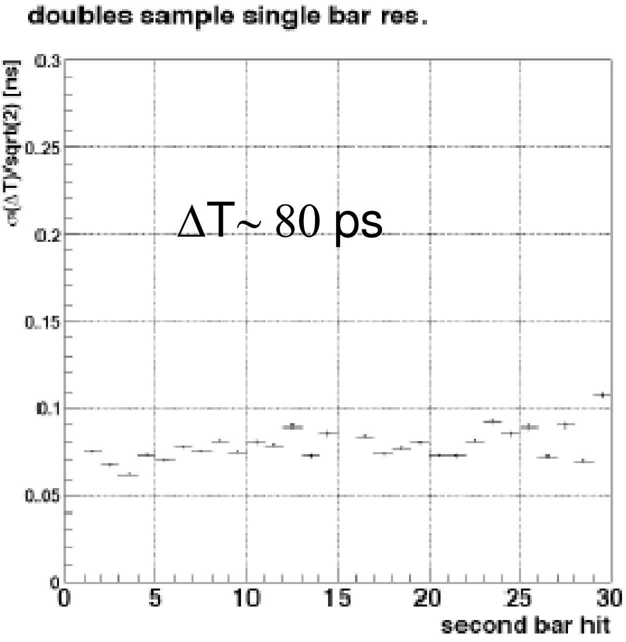
The edge of Michel positrons used to determine momentum resolution



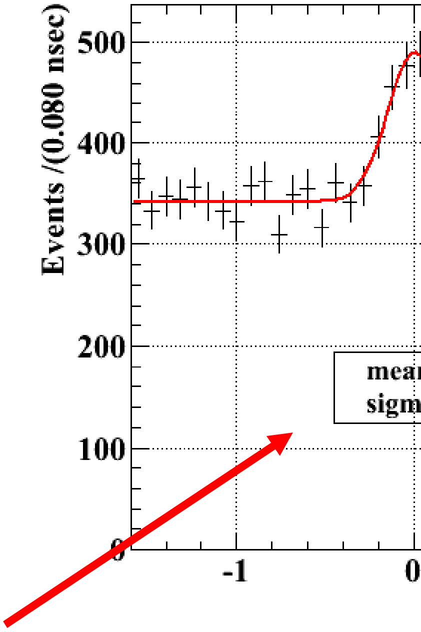
σ_{core} = 374 keV (60%)
σ_{tail1} = 1.06 MeV (33%)
σ_{tail2} = 2 MeV (7%)

Timing resolutions from 2008 dat

Intrinsic timing resolution by using positrons hitting several bars

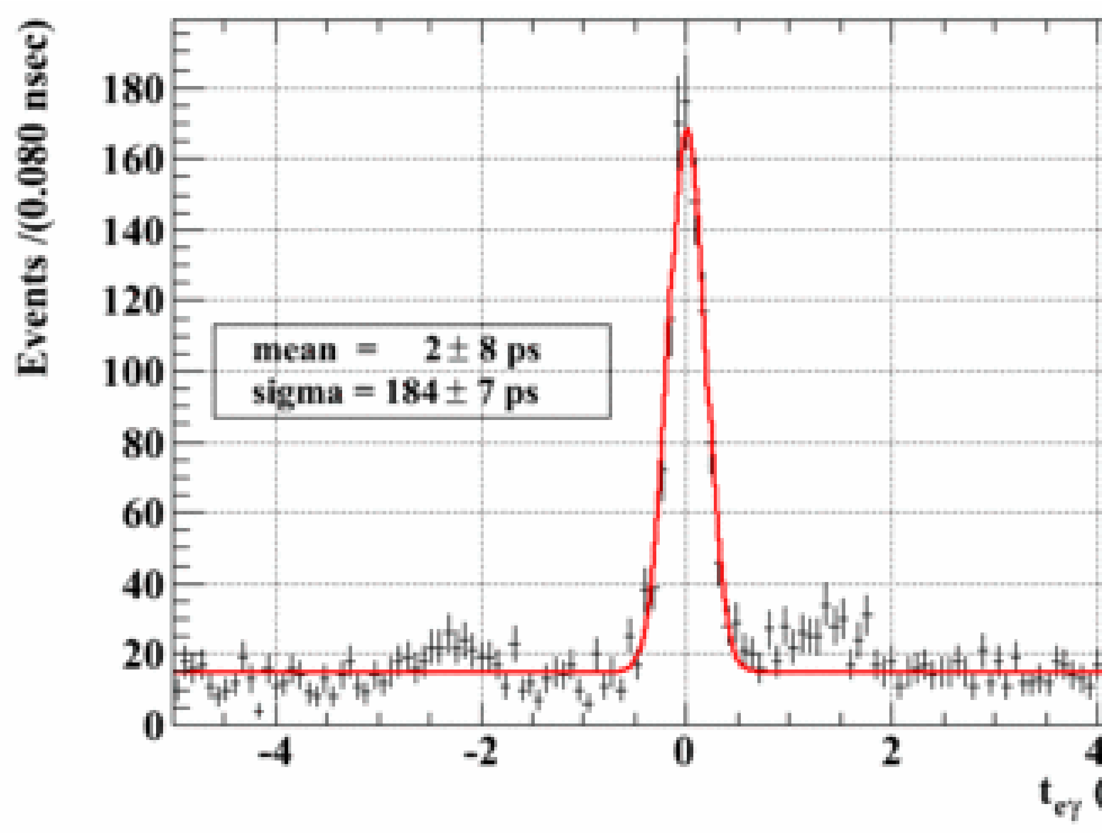


Photon - posit
resolution by u
Radiative muo
physical backg

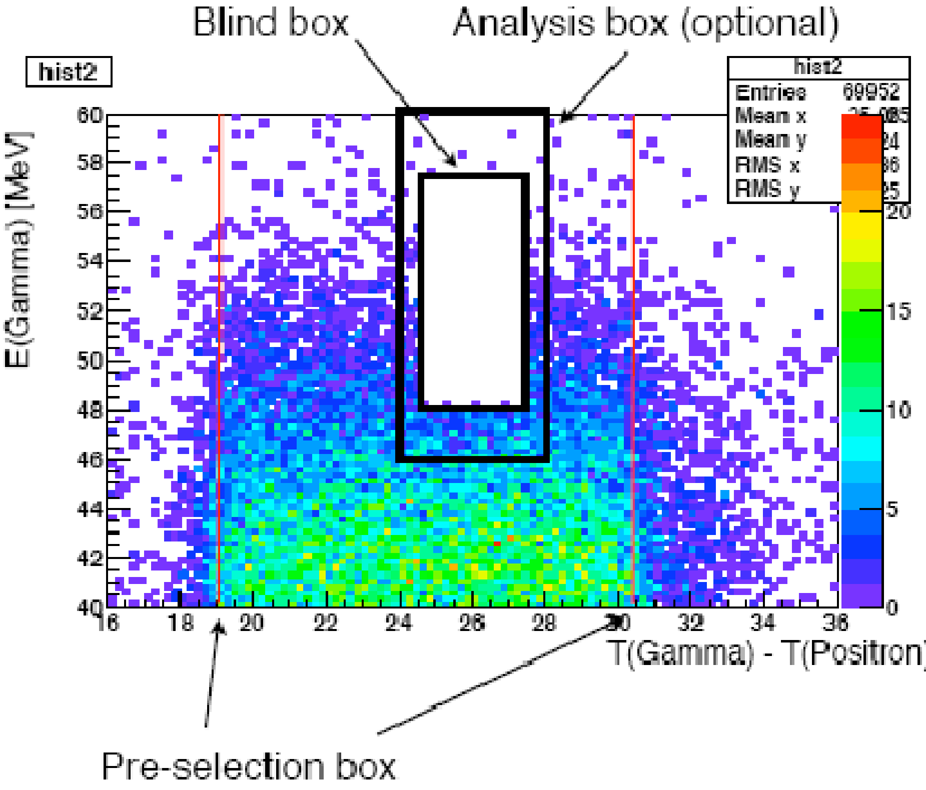


Problems with DRS2 :
DRS4

Dedicated RMD runs at lower thre



Blind analysis: E_γ vs $\Delta t_{\gamma e}$ wind

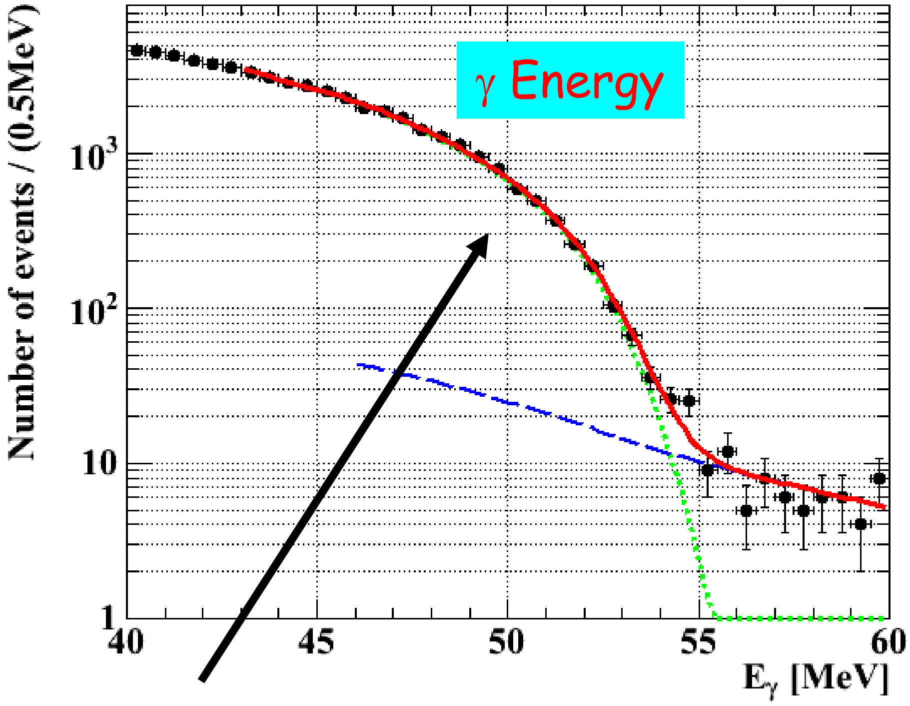


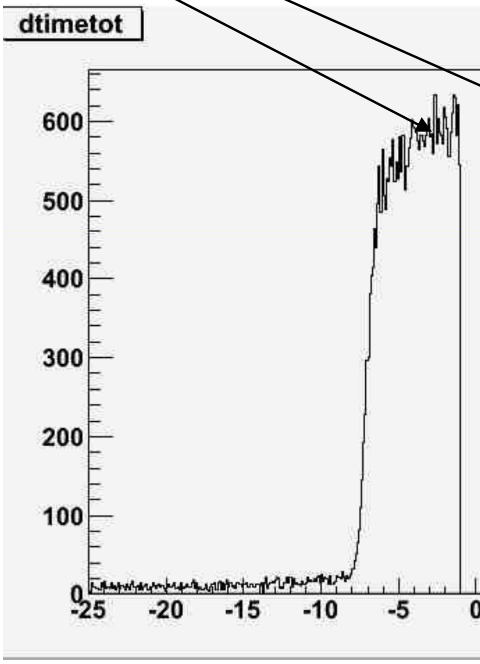
Blind box

Analysis box (optional)

Pre-selection box

Sidebands (|ΔTeγ| > 1 ns) are used
MEASURE accidental background distri

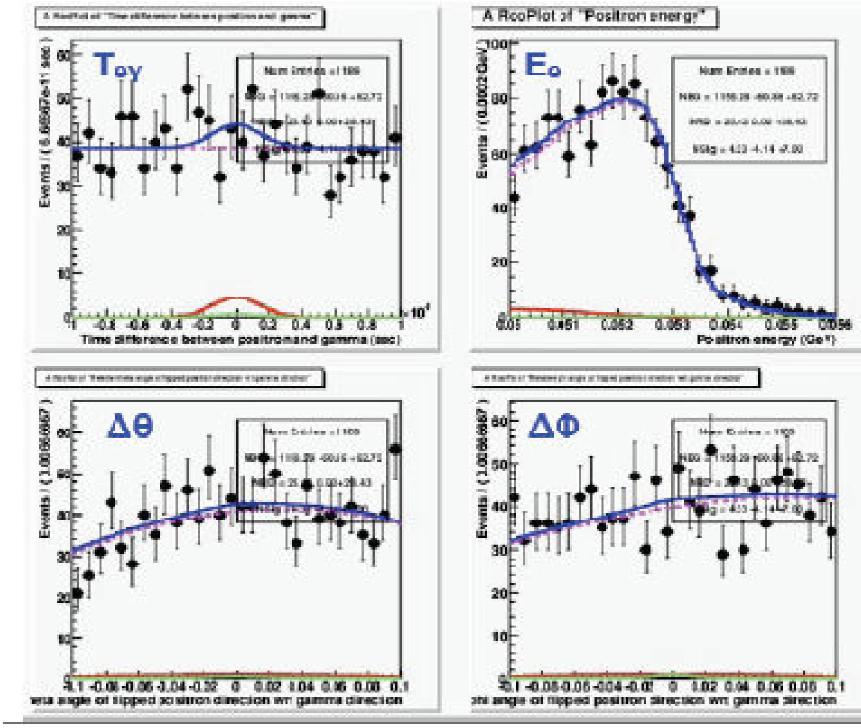




Radiative decay + In flight positron annihilation +
resolution + pileup: in agreement with MCs

Likelihood analysis: accidentals + ra
+ signal PDFs to fit data + Feldman

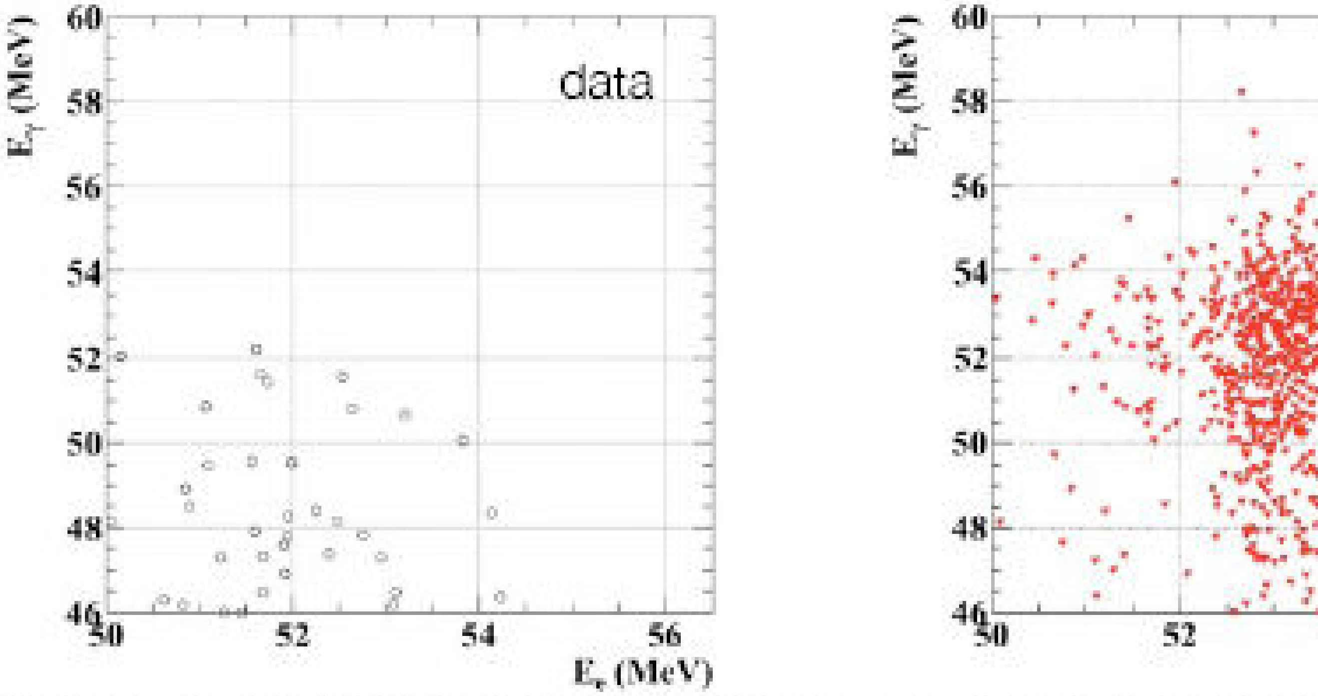
Best fit in the signal region



$$0 \le N_{Sig} \le 14.6$$

Agreement of 3
different analyses

E_γ vs E_{e+}



Note: all the other parameters are cut to select ~90% of signal ev

Normalization: measured Michel events simultan
the normal MEG trigger

$$N_{e\gamma} = BR(\mu^+ \to e^+\gamma)\cdot k$$

dove:

$$k \equiv N_{e\nu\nu} \times \left[\frac{f_S}{f_M}\right] \times \left[\frac{\varepsilon(TRG = MEG \mid e^+\gamma)}{\varepsilon(TRG = Michel \mid track \cap e^+_m \cap TC)}\right] \times A(\gamma \mid tra$$

$$f_S \equiv A(DC)\cdot\varepsilon(track, p_e > 50\mathrm{MeV} \mid DC)\cdot\varepsilon(TC \mid p_e > 5$$

$$f_M \equiv \ldots\big|_M$$

-Independent of instantaneous beam rate

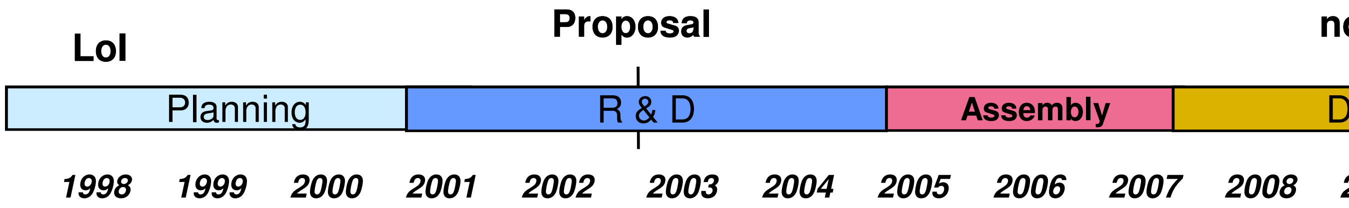
- Nearly insensitive to positron acceptance and efficiency factors
DCH and TC

90% CL limit

- 90 % C.L. $N_{Sig} \leq 14.6$ corresponds to BR($\mu \rightarrow e\gamma$
- Computed sensitivity 1.3 x 10^{-11}
- Statistical fluctuation 5%
- From side bands analysis we expected 0.9 (lef
(right) x 10^{-11}
- Bad luck

Future prospects

- Re-start of data taking in september, until december (as
- Instabilities eliminated: DRS2➔DRS4 (timing improveme reduction)
- Data taking and trigger efficiencies: 3-5 factor improve
- Corresponding improvement in sensitivity: 2-4 * 10^{-12} for
- Continue running in 2010 + 2011 for the final (10^{-13}) goal



More details at

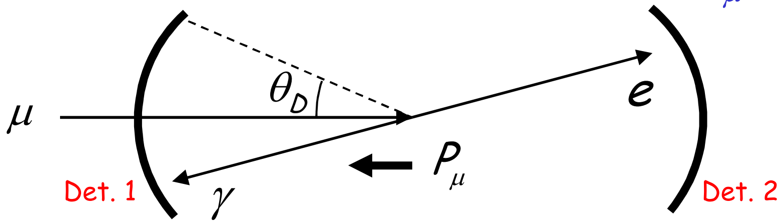
http://meg.p
http://meg.pi.
http://meg.icepp.s.u

Pμ

(Y. Kuno et al., MEG TN1, 1997 and references)

$$\text{H.E. } \gamma \text{ in } \mu^+ \to e^+ \nu \bar{\nu} \gamma : (1 + P_\mu \cos\theta_\gamma)$$

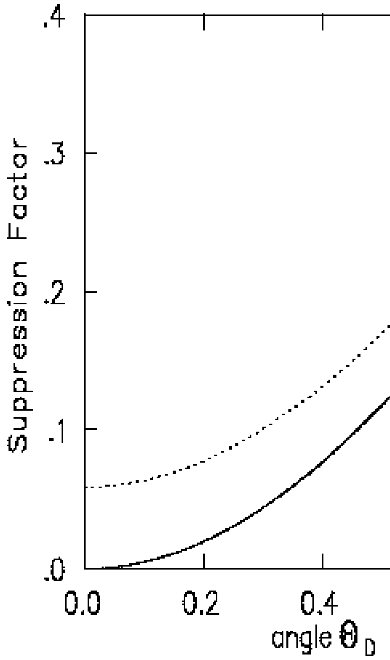
$$\text{H.E. } e^+ \text{ in } \mu^+ \to e^+ \nu \bar{\nu} : (1 + P_\mu \cos\theta_e)$$



$\Rightarrow$ *Suppression factor η (for isotropic $\mu \to e\gamma$ decay)*

$$\eta = \frac{\int_{\cos\theta_D}^{1} d\cos\theta_D (1 + P_\mu \cos\theta_D)(1 - P_\mu \cos\theta_D)}{\int_{\cos\theta_D}^{1} d\cos\theta_D}$$

Figure 1: Suppression factor for accidental



- For suitable geometry big η factors can be obtained
- This is not the case for MEG (detailed calculations are ne
- In some theories (minimal SU(5) model) the positron has

➔ Pμ is less effective

DRS charge vs Trigger WFM Charge (TC)