The MEG experiment at PSI: Status and Prospects

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on behalf of the MEG collaboration

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The MEG collaboration

Tokyo U.
Waseda U.
KEK

INFN & U Pisa
INFN & U Roma
INFN & U Genova
INFN & U Pavia
INFN & U Lecce

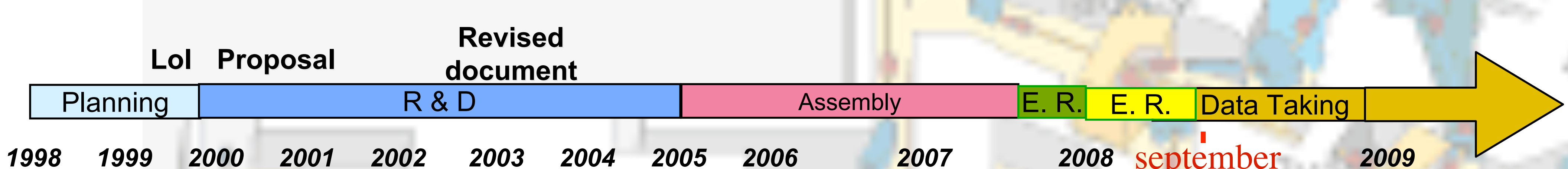
PSI

UCIrvine

JINR Dubna
BINP Novosibirsk

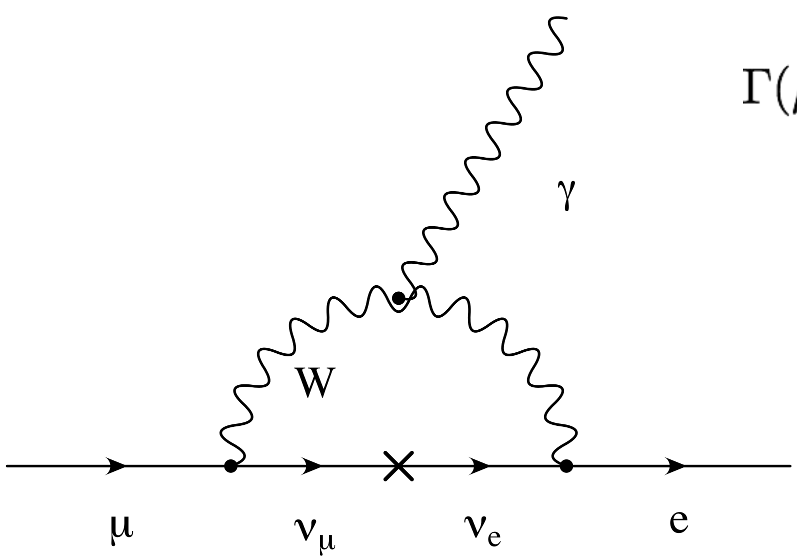
Outline

- Physics motivation for a $\mu \rightarrow e\gamma$ experiment
- The $\mu \rightarrow e\gamma$ decay
- The detector
  - Beam line & target
  - Spectrometer
  - Timing Counter
  - LXe calorimeter
  - Calibrations
  - Electronics
- Status
- Future



The μ→eγ decay

- The μ→eγ decay is forbidden in the Standard Model of elementary particles because of the (accidental) conservation of lepton family numbers;
- The introduction of neutrino masses and mixings induces μ→eγ radiatively, but at a negligible level



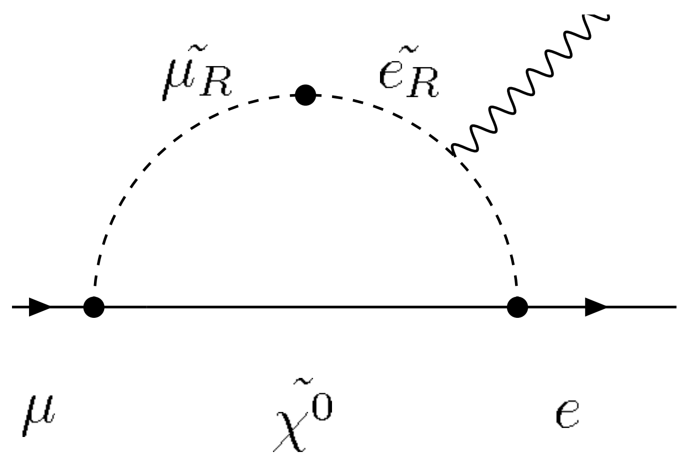
$$\Gamma(\mu \to e\gamma) \approx \underbrace{\frac{G_F^2 m_\mu^5}{192\pi^3}}_{\mu-\text{decay}} \underbrace{\left(\frac{\alpha}{2\pi}\right)}_{\gamma-\text{vertex}} \underbrace{\sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2}{M_W^2}\right)}_{\nu-\text{oscillation}}$$

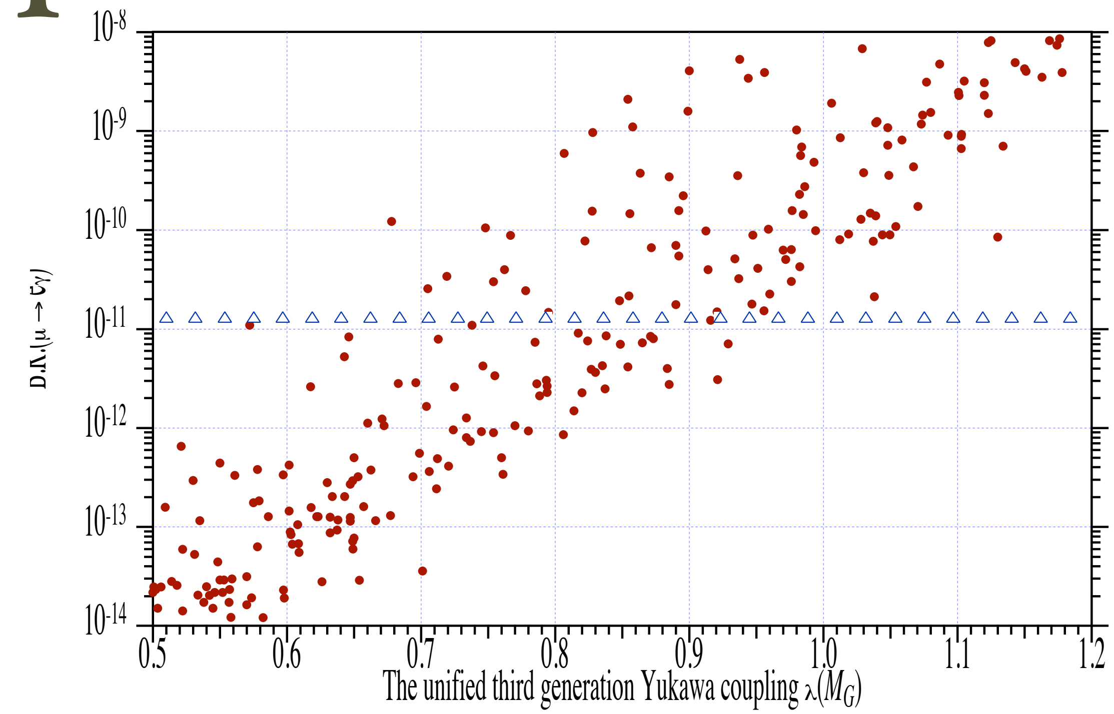
$$\approx \frac{G_F^2 m_\mu^5}{192\pi^3}\left(\frac{\alpha}{2\pi}\right)\sin^2 2\theta_\odot \left(\frac{\Delta m^2}{M_W^2}\right)^2,$$

Relative probability ~ 10^{-55}

- All SM extensions enhance the rate through mixing in the high energy sector of the theory

For instance... predictions

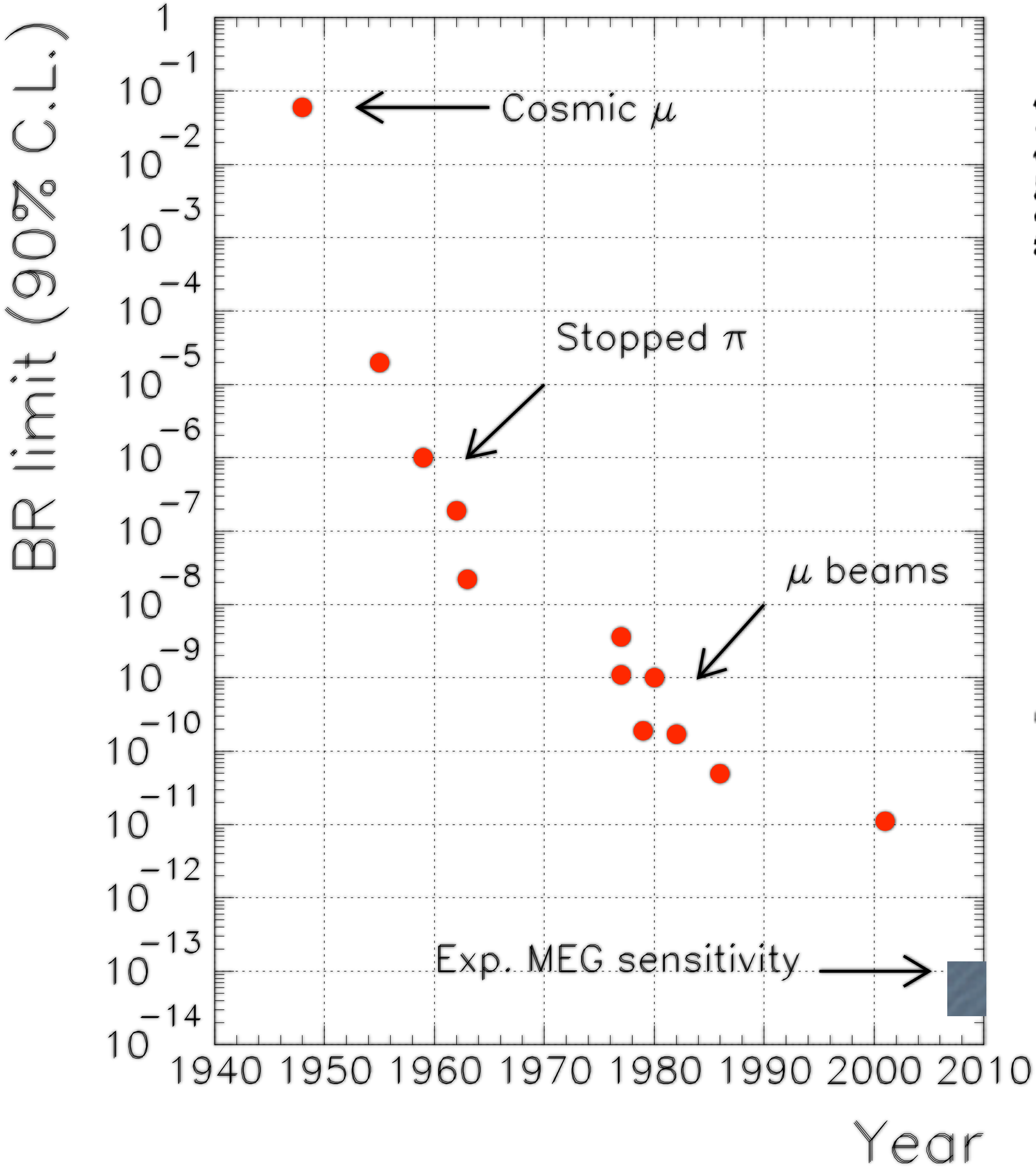




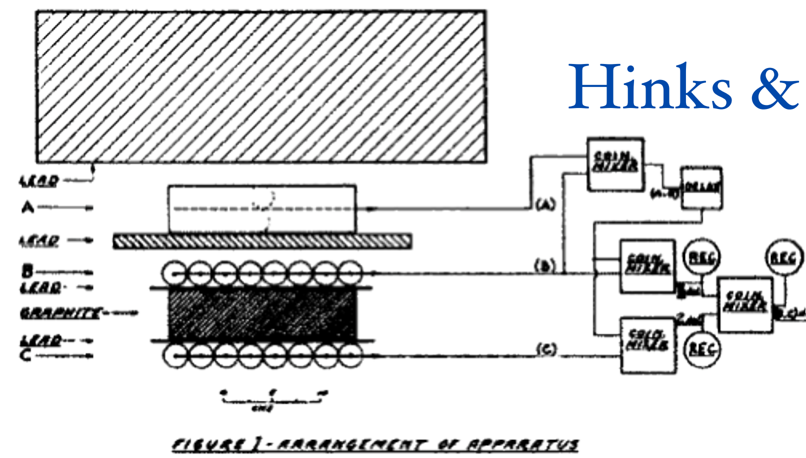
- SUSY SU(5) predictions: LFV induced by finite slepton mixing through radiative corrections. The mixing could be large due to the top-quark mass at a level of 10^{-12} - 10^{-15}
- SO(10) predicts even larger BR:
  - m(τ)/m(μ) enhancement
- Models with right-handed neutrinos also predict large BR
- ⇒ clear evidence for physics beyond the SM.

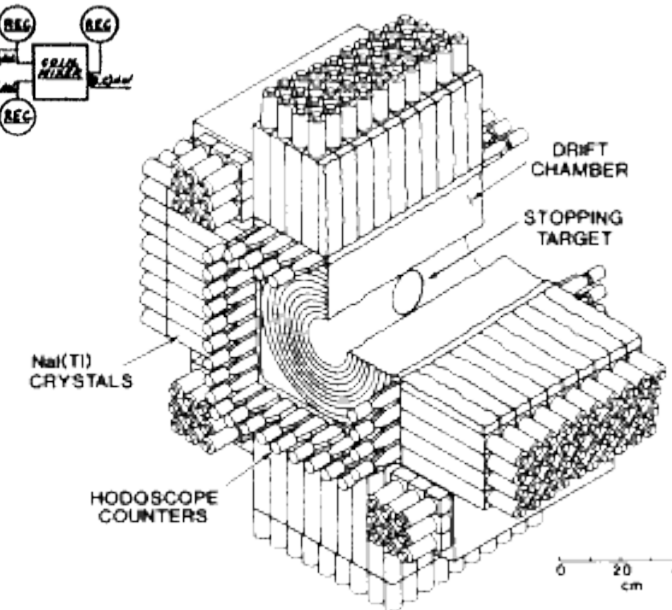
- In principle possibility to distinguish between various models e.g. angular distribution of the photon with respect to the muon spin

Historical perspective

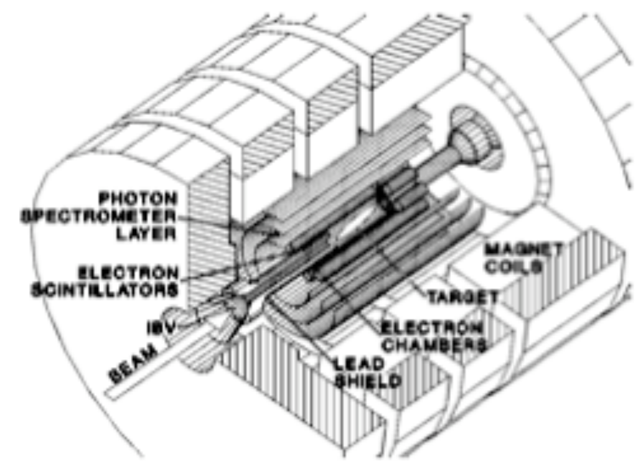


Hinks & Pontecorvo

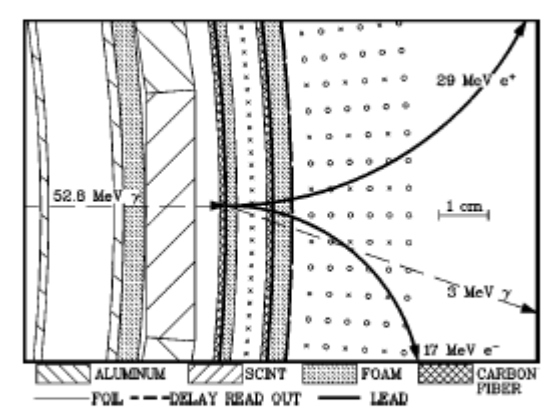




Crystal Box



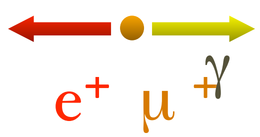
MEGA

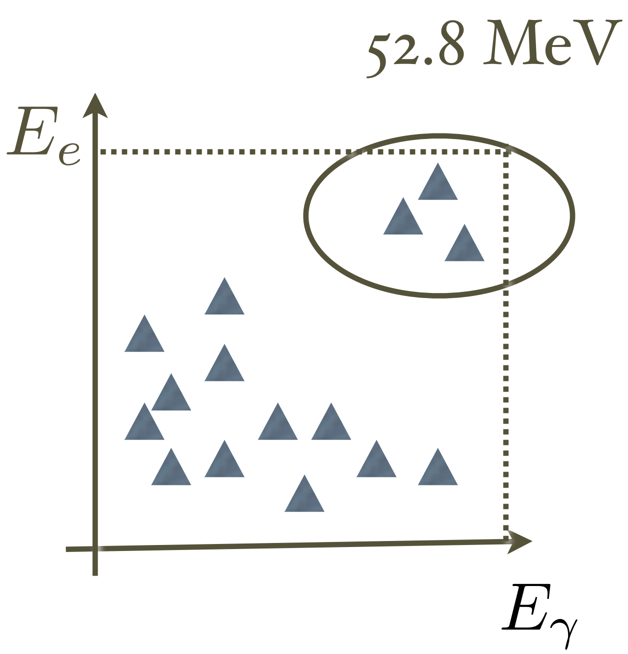


Each improvement linked to an improvement in the technology either in the beam or in the detector

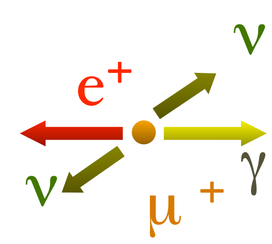
Signal and Background

"Signal"



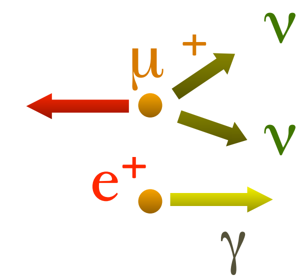


"Prompt"



$$\mu \to e\bar{\nu}\nu\gamma$$

"Accidental"



$$e^+e^- \to \gamma\gamma$$
$$\mu \to e\bar{\nu}\nu\gamma$$
$$e\mathcal{N} \to e\mathcal{N}\gamma$$

$$\mu \to e\bar{\nu}\nu$$

$$B_{\text{prompt}} \approx 0.1 \times B_{\text{acc}}$$

$$B_{\text{acc}} \approx R_\mu \Delta E_e \Delta E_\gamma^2 \Delta\theta^2 \Delta t$$

The accidental background is dominant and it is determined by the experimental resolutions

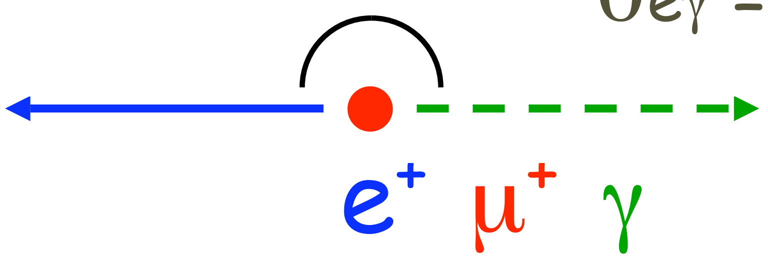
Exp./Lab	Year	ΔEe/Ee (%)	ΔEγ /Eγ (%)	Δteγ (ns)	Δθeγ (mrad)	Stop rate (s^{-1})	Duty cyc. (%)	BR (90% CL)
SIN	1977	8.7	9.3	1.4	-	5×10^5	100	3.6×10^{-9}
TRIUMF	1977	10	8.7	6.7	-	2×10^5	100	1×10^{-9}
LANL	1979	8.8	8	1.9	37	2.4×10^5	6.4	1.7×10^{-10}
Crystal Box	1986	8	8	1.3	87	4×10^5	(6..9)	4.9×10^{-11}
MEGA	1999	1.2	4.5	1.6	17	2.5×10^8	(6..7)	1.2×10^{-11}
MEG	2009	1	4.5	0.15	19	3×10^7	100	2×10^{-13}

FWHM

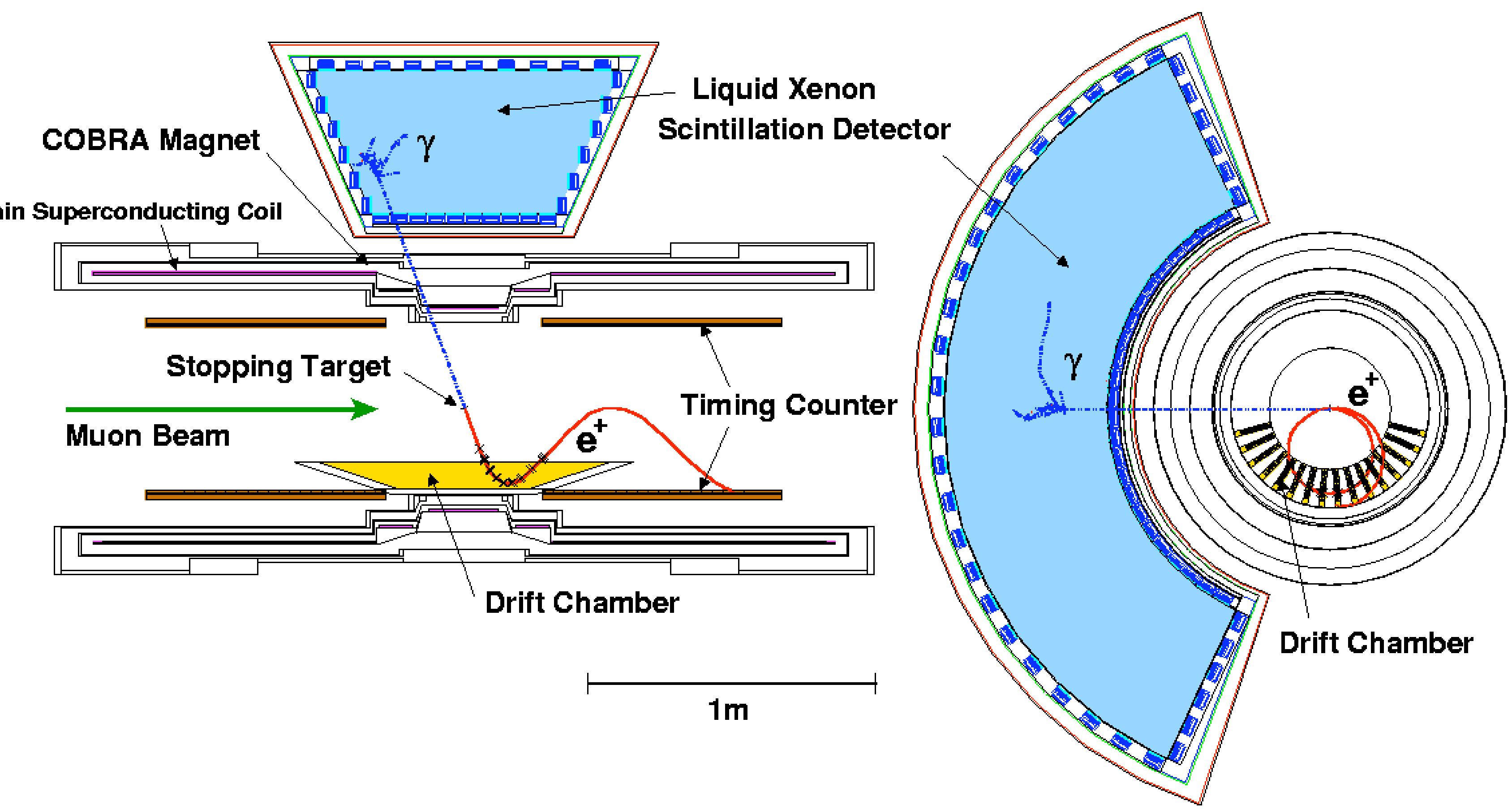
MEG experimental method

Easy signal selection with μ^+ at rest

$\theta_{e\gamma} = 180°$



$E_e = E_\gamma = 52.8$ MeV

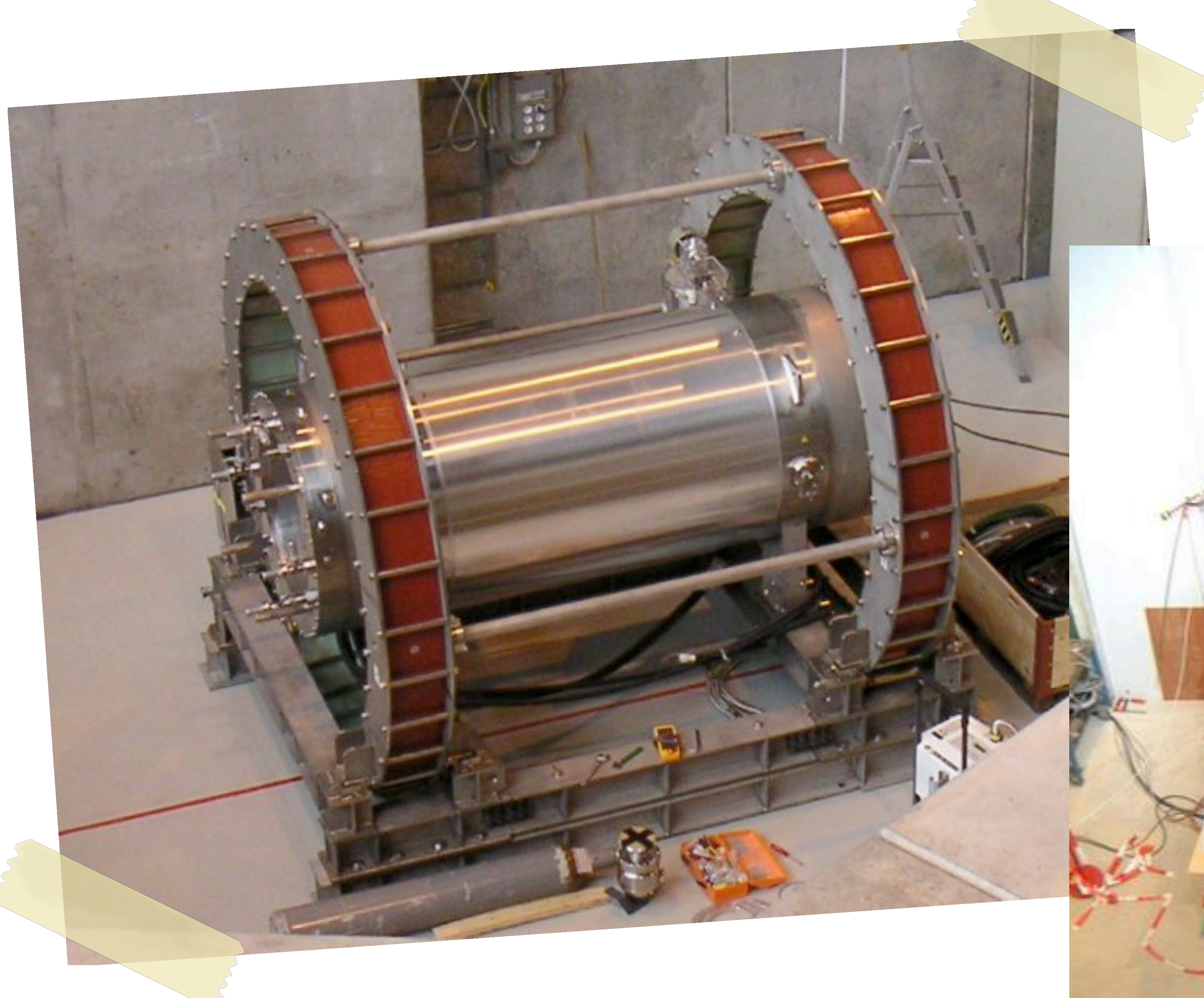


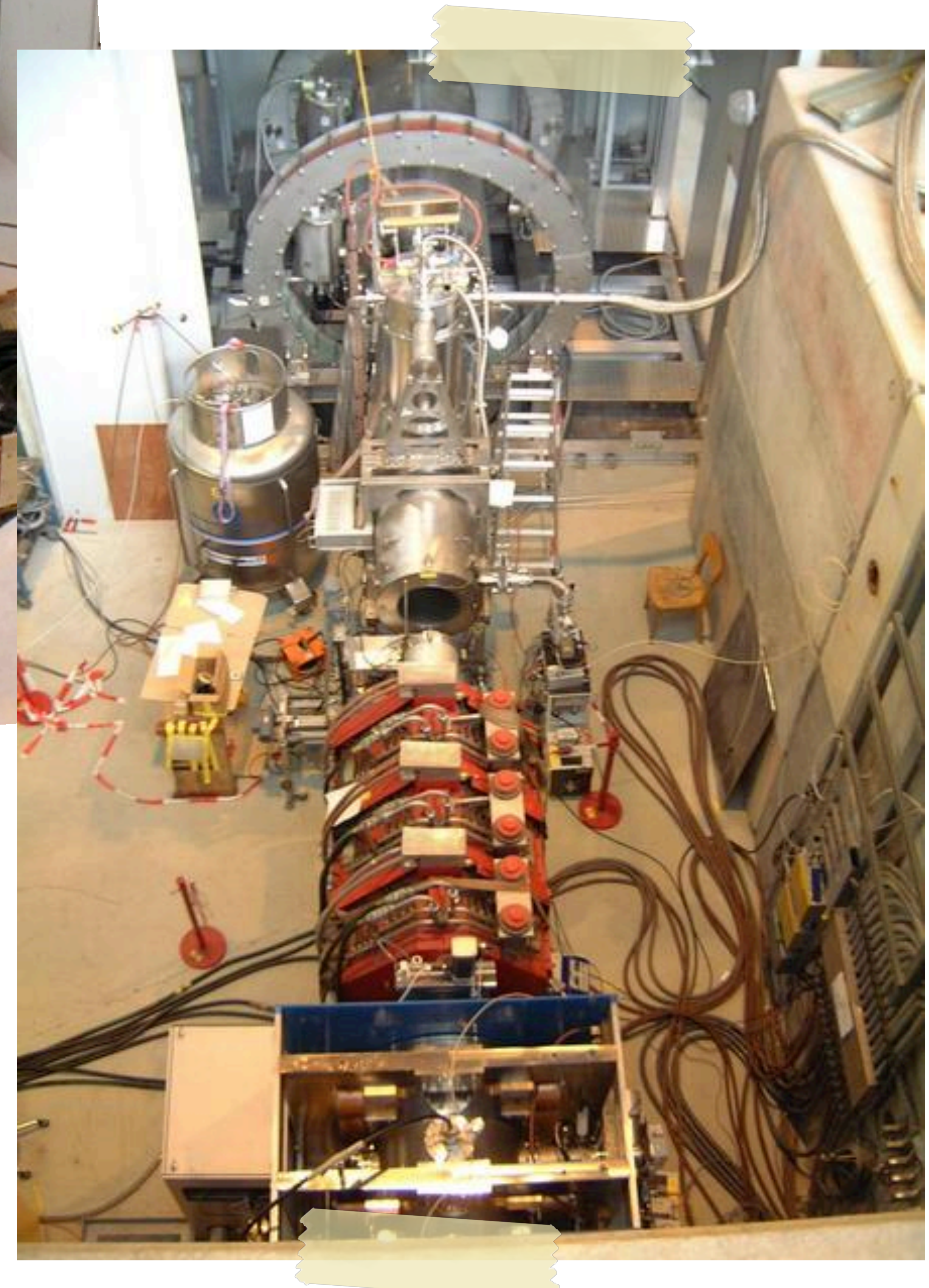
- Stopped beam of $>10^7$ μ /sec in a 175 μm target
- γ detection

  Liquid Xenon calorimeter based on the scintillation light
  - fast: 4 / 22 / 45 ns
  - high LY: ~ 0.8 * NaI
  - short X_0: 2.77 cm
- e^+ detection

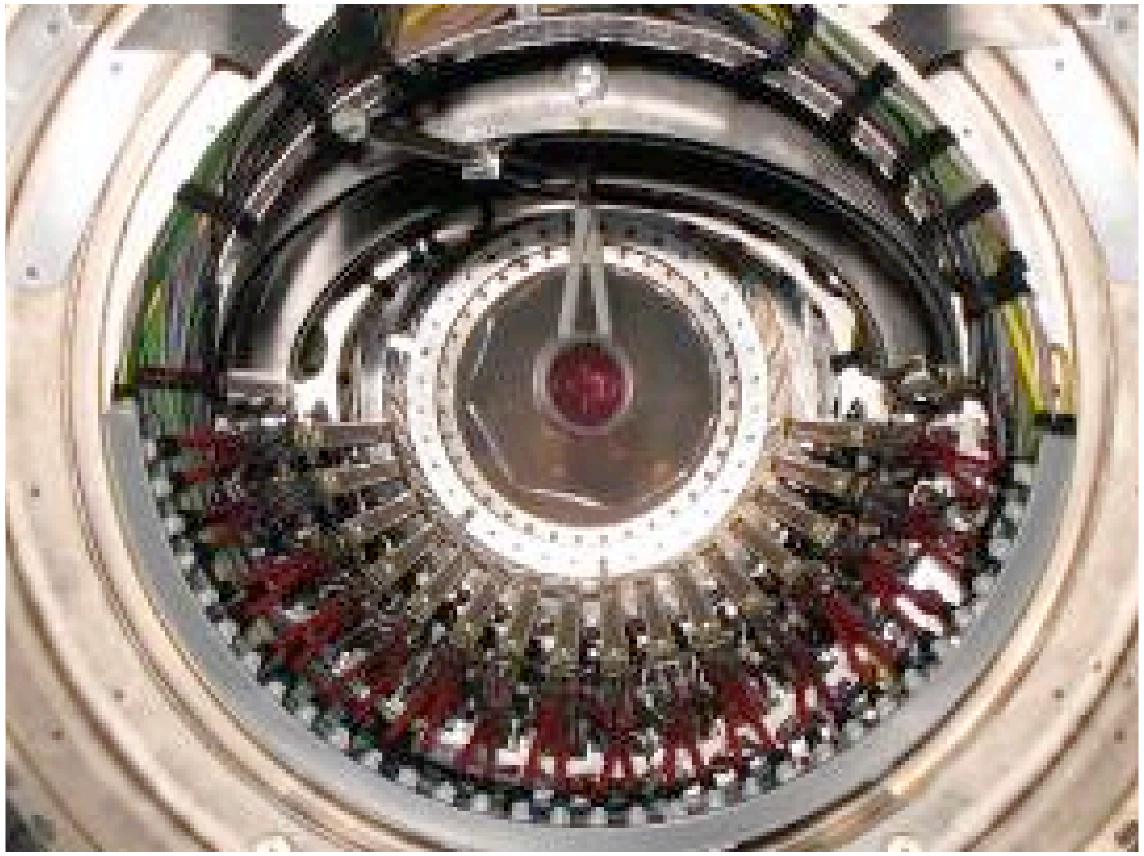
  magnetic spectrometer composed by solenoidal magnet and drift chambers for momentum

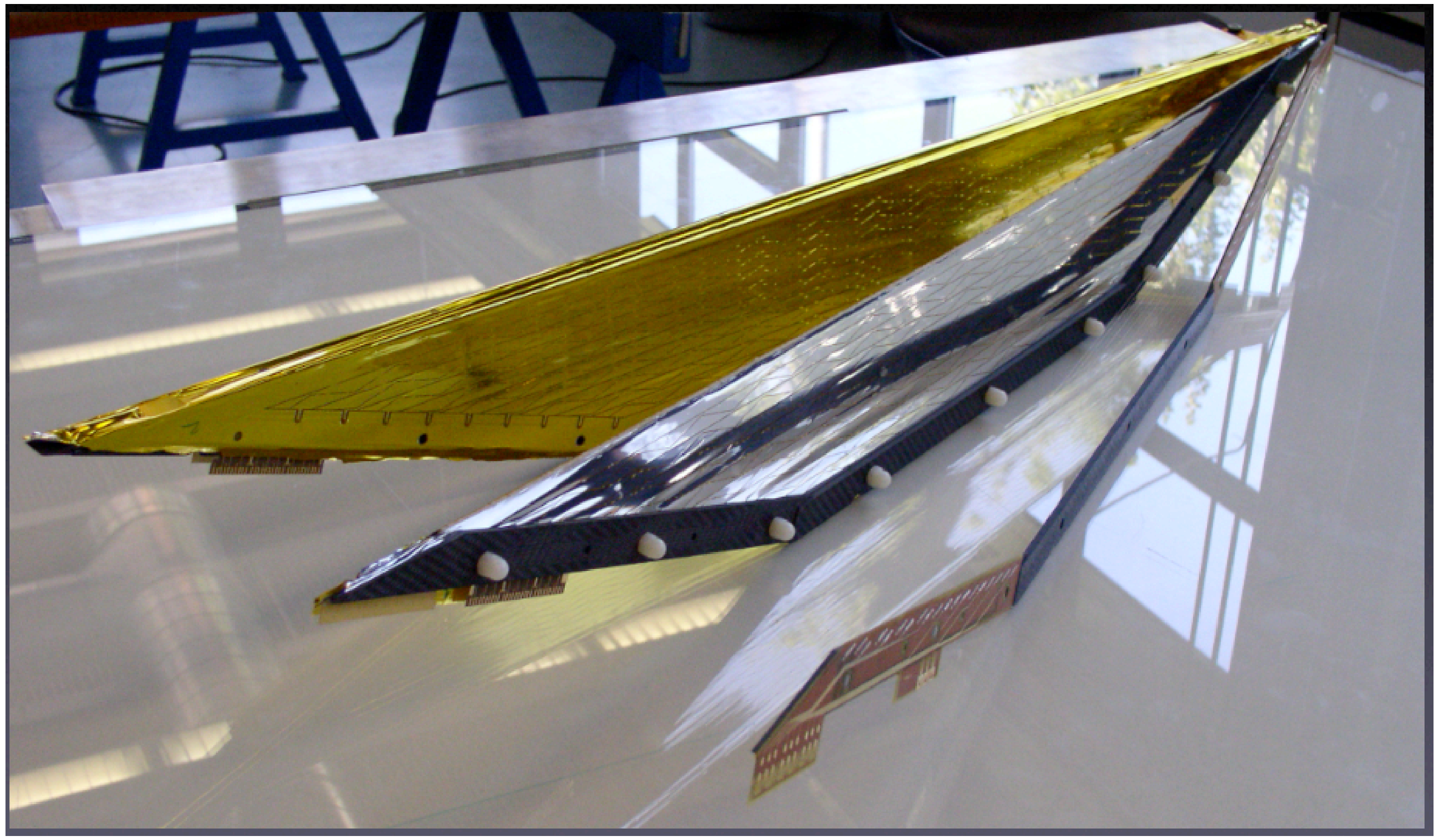
  scintillation counters for timing

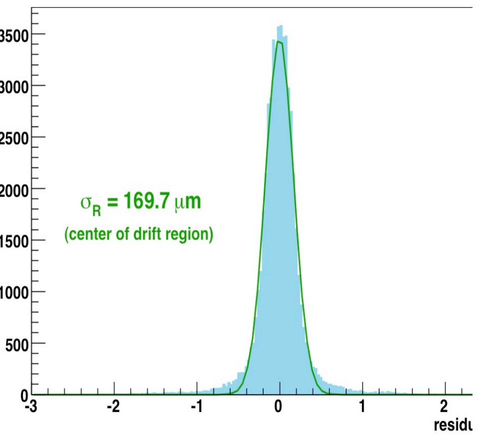


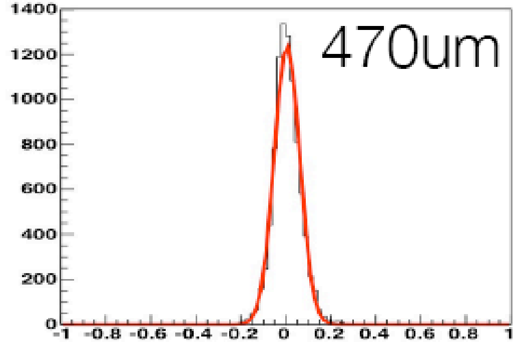


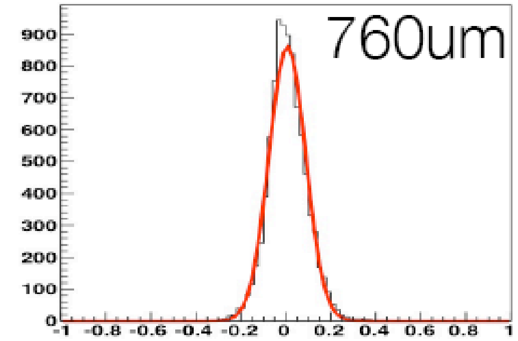
Drift chambers

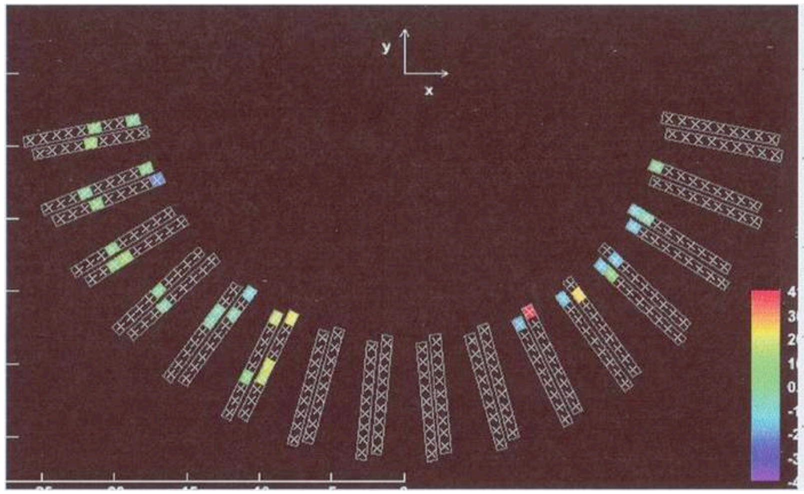


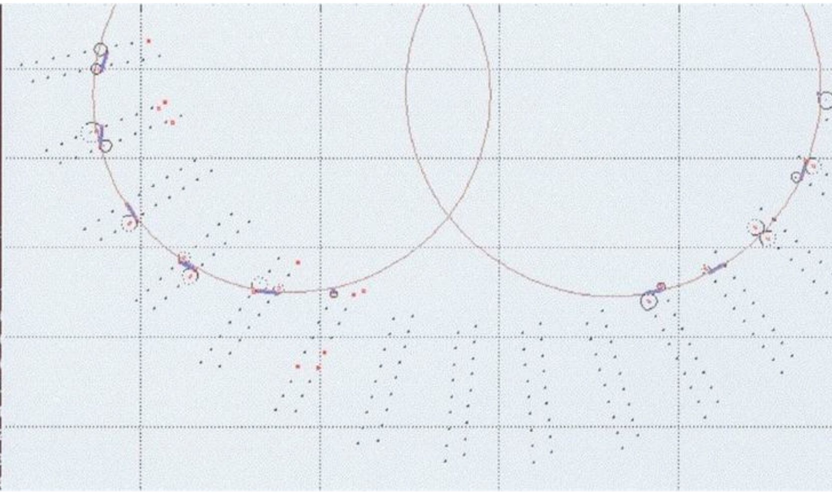






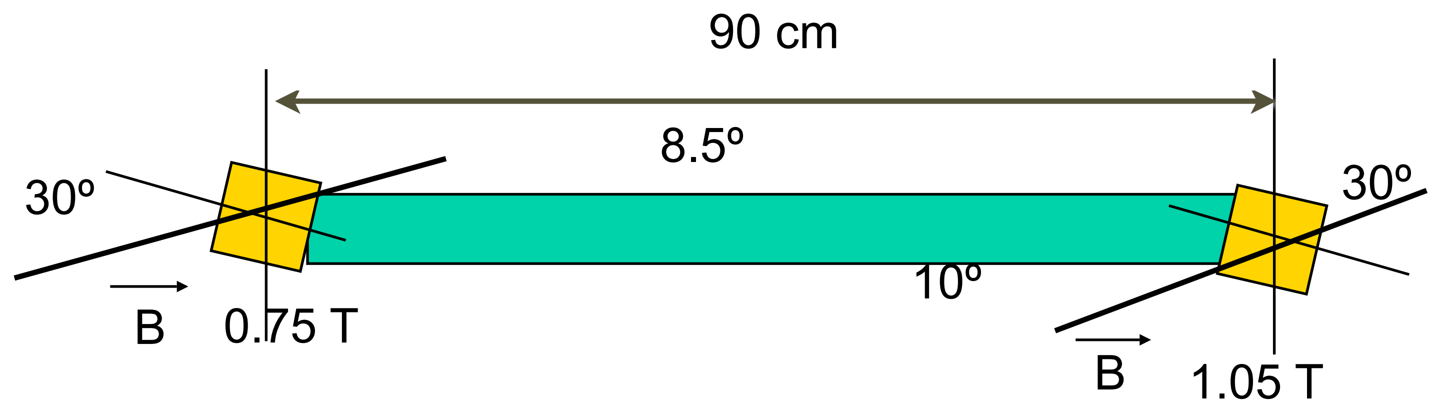


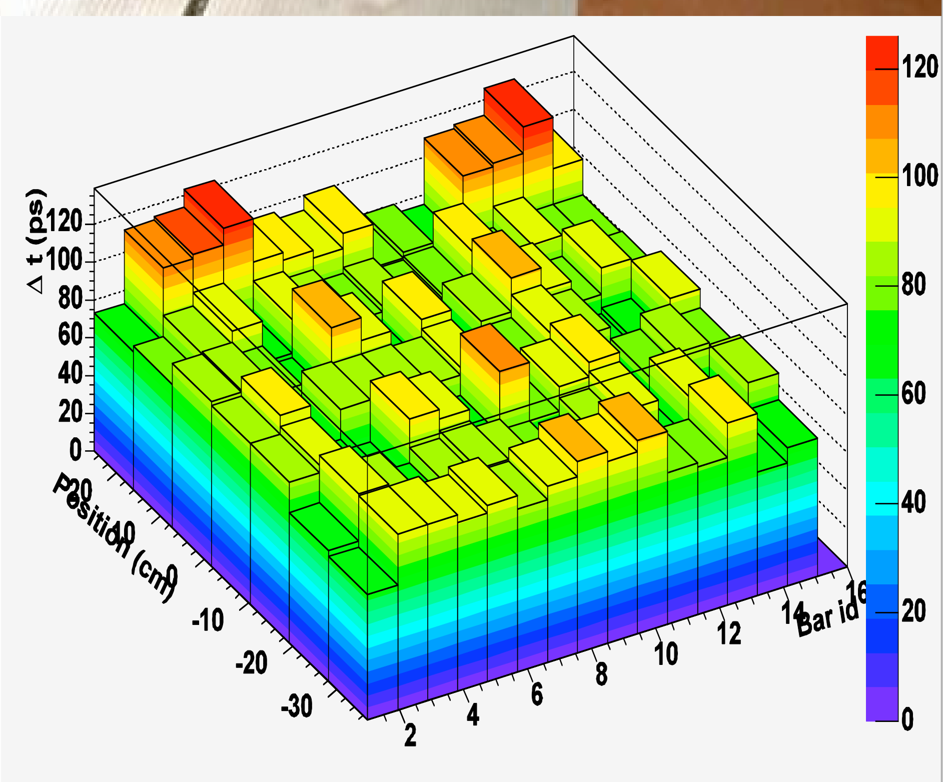




Timing Counter

- Must give excellent rejection
- Two layers of scintillators:
  - Outer layer, read out by PMTs: timing measurement
  - Inner layer, read out with APDs at 90°: z-trigger
- Obtained goal σ_{time}~ 40 psec (100 ps FWHM)



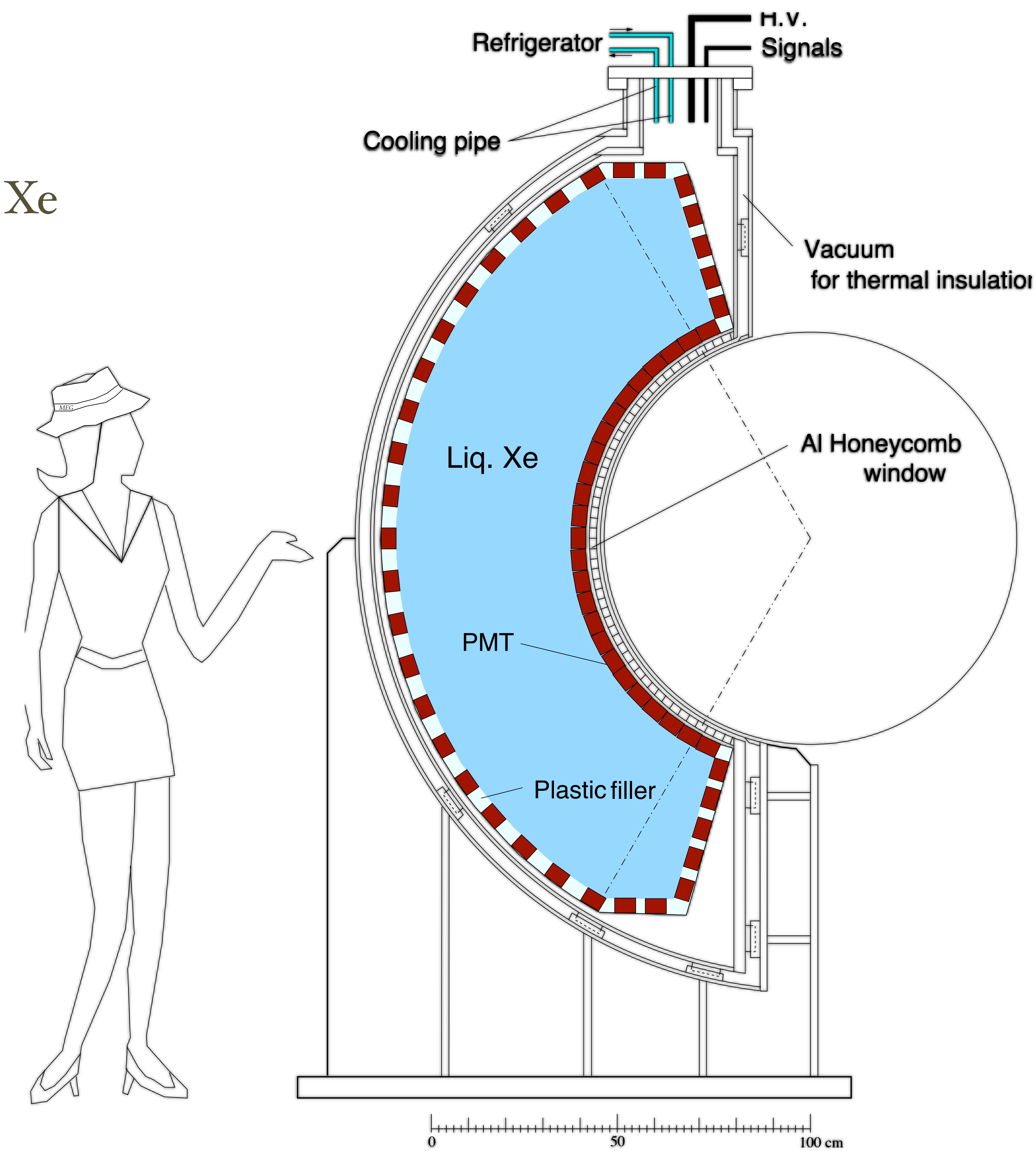


Exp. application (*)	Counter size (cm) (T x W x L)	Scintillator	PMT	λ_{att} (cm)	σ_t(meas)	σ_t(exp)
G.D.Agostini	3x 15 x 100	NE114	XP2020	200	120	60
T. Tanimori	3 x 20 x 150	SCSN38	R1332	180	140	110
T. Sugitate	4 x 3.5 x 100	SCSN23	R1828	200	50	53
R.T. Gile	5 x 10 x 280	BC408	XP2020	270	110	137
TOPAZ	4.2 x 13 x 400	BC412	R1828	300	210	240
R. Stroynowski	2 x 3 x 300	SCSN38	XP2020	180	180	420
Belle	4 x 6 x 255	BC408	R6680	250	90	143
MEG	**4 x 4 x 90**	**BC404**	**R5924**	**270**	**38**	

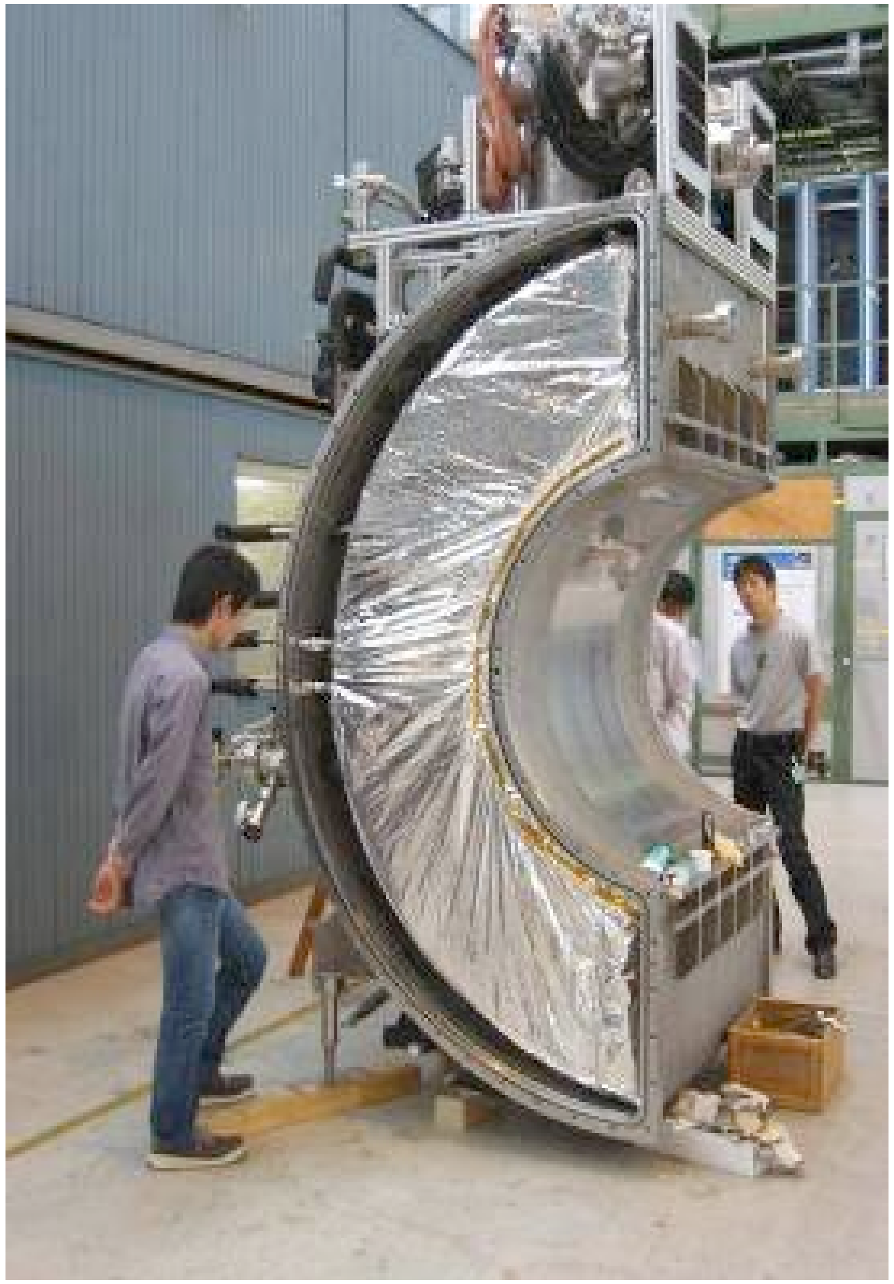
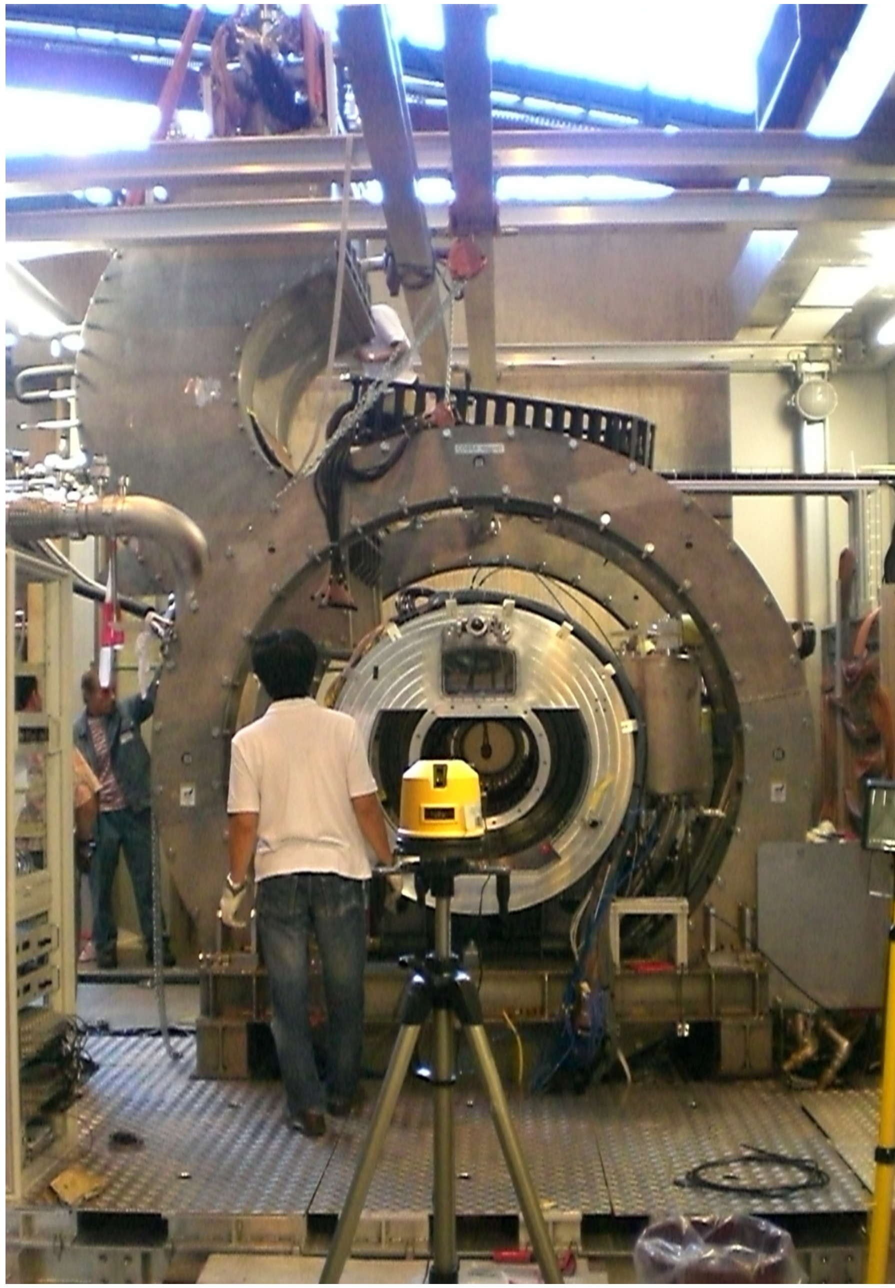
Best existing TC

The calorimeter

- γ Energy, position, timing
- Homogeneous 0.8 m^3 volume of liquid Xe
  - 10 % solid angle
  - $65 < r < 112$ cm
  - $|\cos\theta| < 0.35$ $|\varphi| < 60^o$
- Only scintillation light
- Read by 848 PMT
  - 2” photo-multiplier tubes
  - Maximum coverage FF (6.2 cm cell)
  - Immersed in liquid Xe
  - Low temperature (165 K)
  - Quartz window (178 nm)
- Thin entrance wall
- Singularly applied HV
- Waveform digitizing @2 GHz
  - Pileup rejection

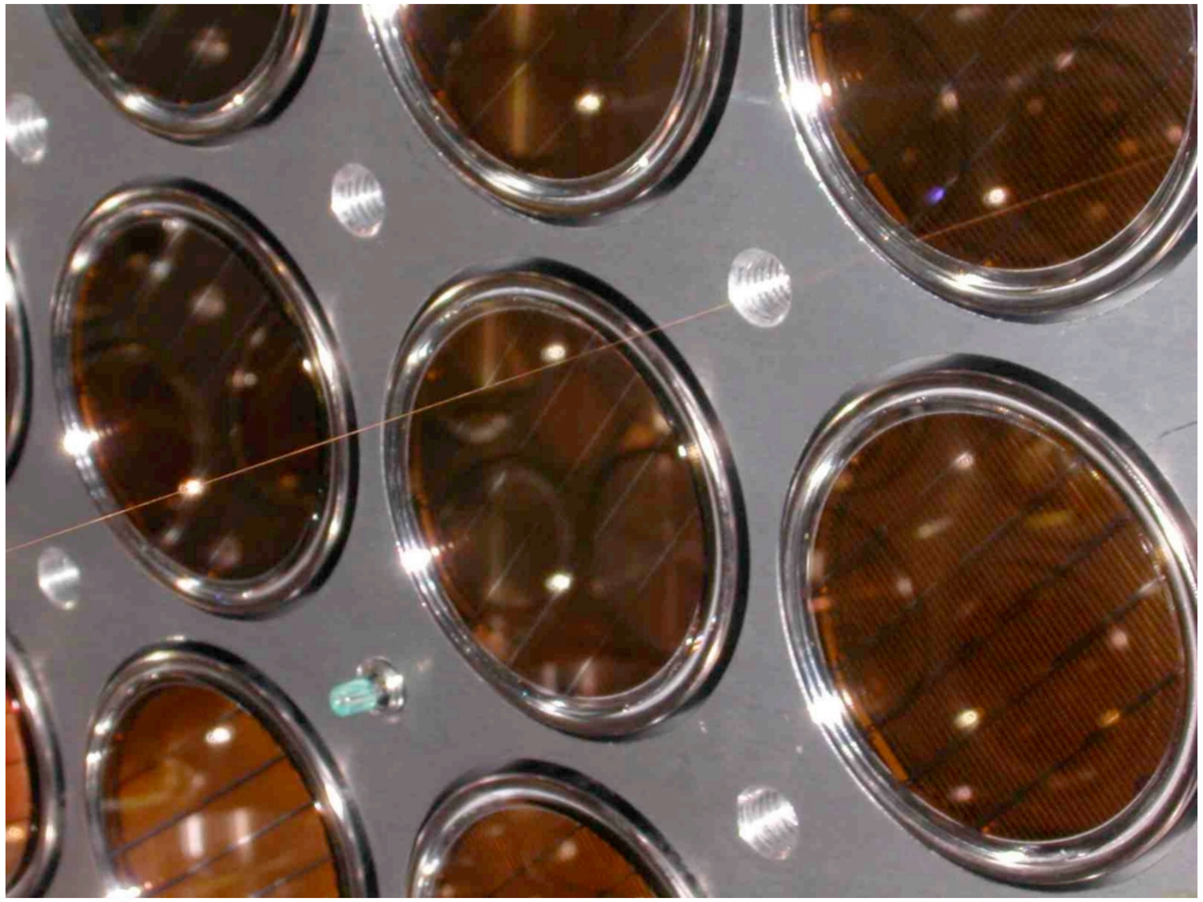


Calorimeter construction

Calibrations

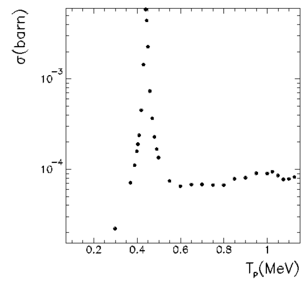
- It is understood that in such a complex detector a lot of parameters must be constantly checked
- We are prepared for redundant calibration and monitoring
- Single detector
  - PMT equalization for LXe and TIC
  - Interbar timing (TIC)
  - Energy scale
- Multiple detectors
  - relative timing

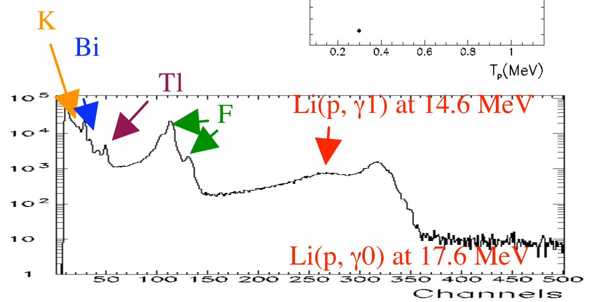


Calibrations

Xenon Calibration

Proton Accelerator





Li(p,γ)Be

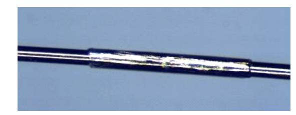
LiF target at COBRA center

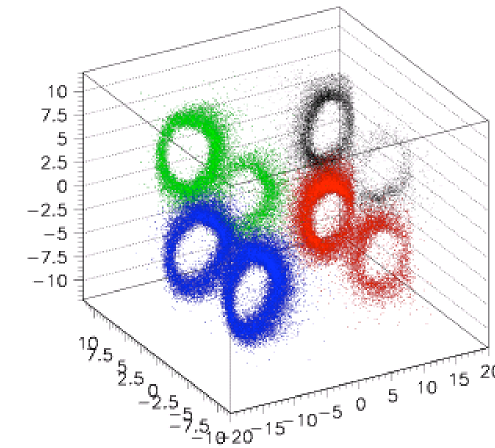
17.6MeV γ

~daily calib.

also for initial setup

Alpha on wires



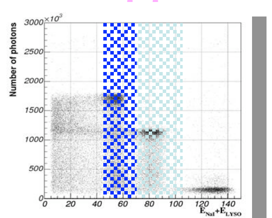


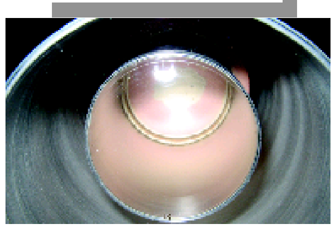
PMT QE & Att. L

Cold GXe

LXe

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



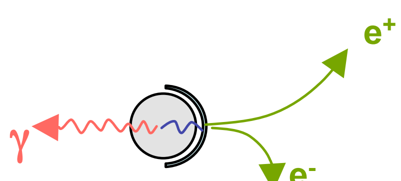


$\pi^- + p \rightarrow \pi^0 + n$

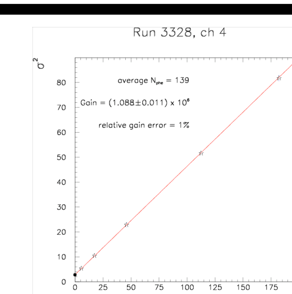
$\pi^0 \rightarrow \gamma\gamma$ (55MeV, 83MeV)

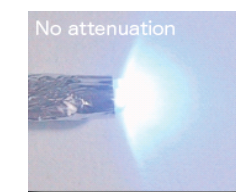
$\pi^- + p \rightarrow \gamma + n$ (129MeV)

LH_2 target



LED



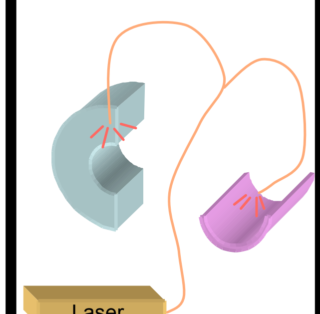


PMT Gain

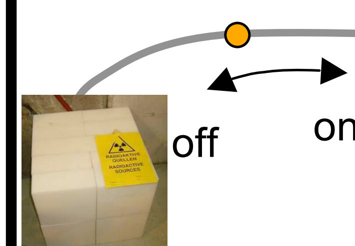
Higher V with light att.

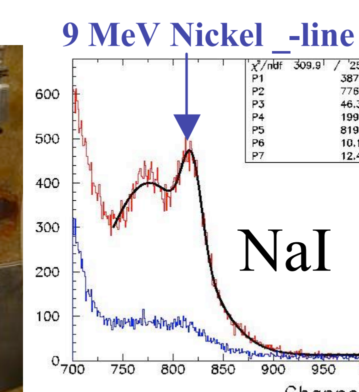
Laser

relative timing calib.



Nickel γ Generator

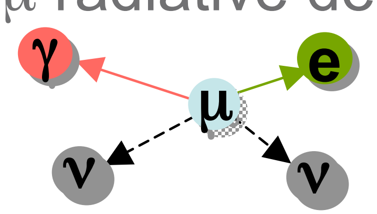


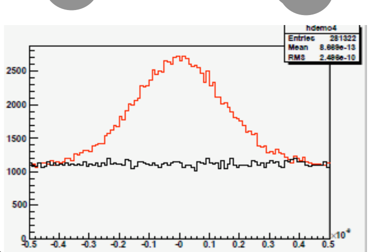


Illuminate Xe from the back

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

μ radiative decay



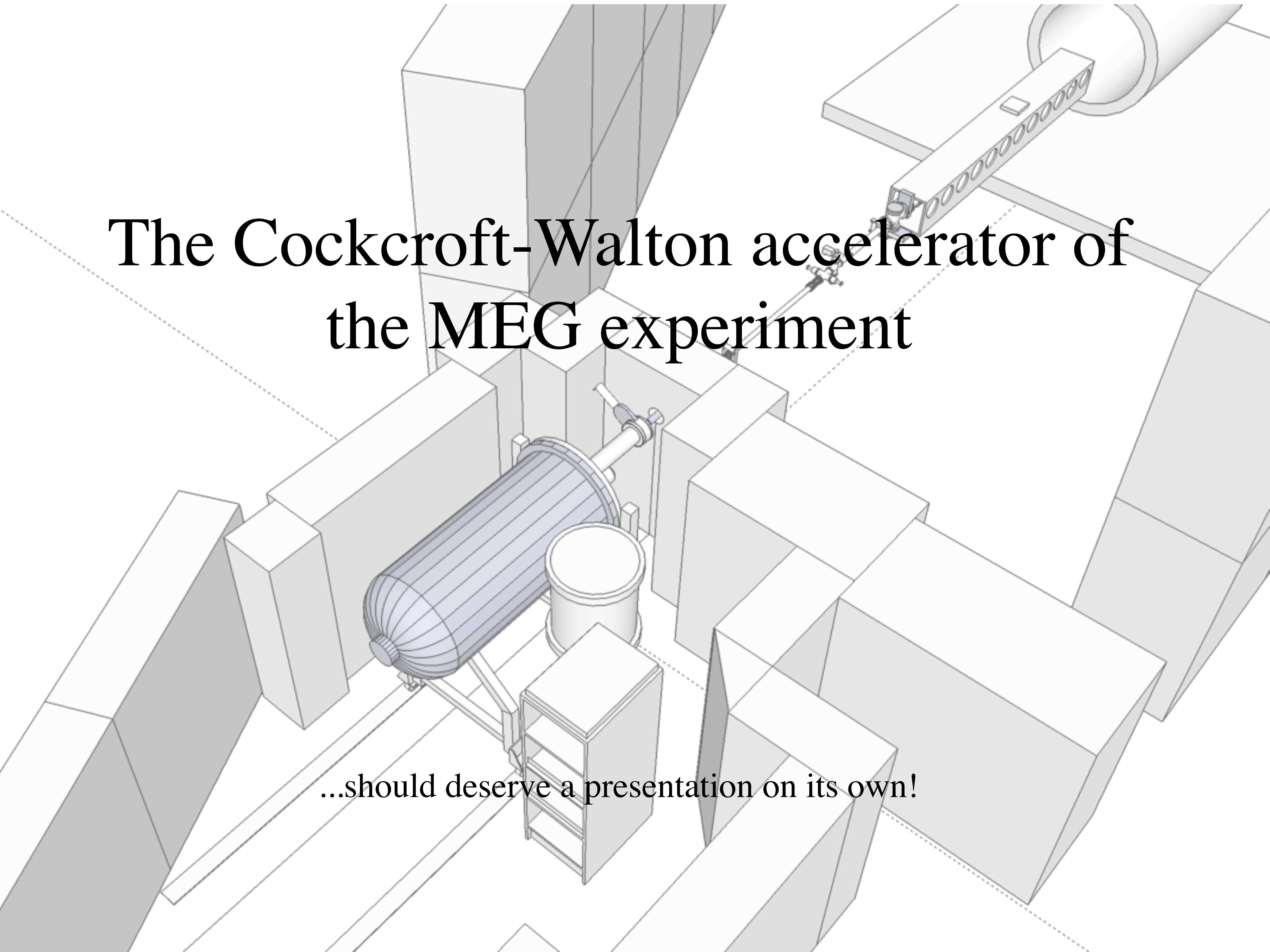


Lower beam intensity < 10^7

Is necessary to reduce pile-ups

A few days ~ 1 week to get enough statistics

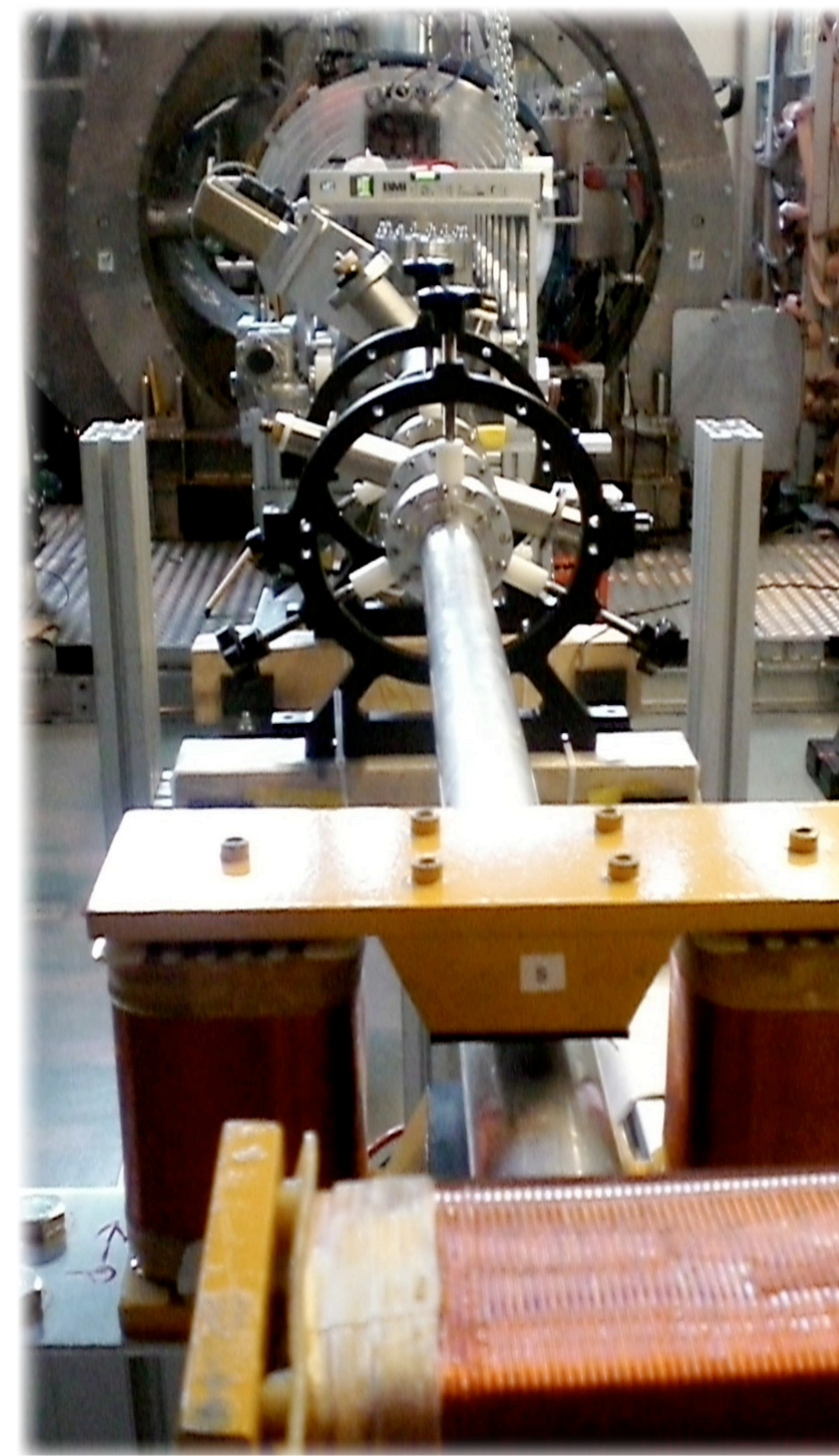
The Cockcroft-Walton accelerator of the MEG experiment



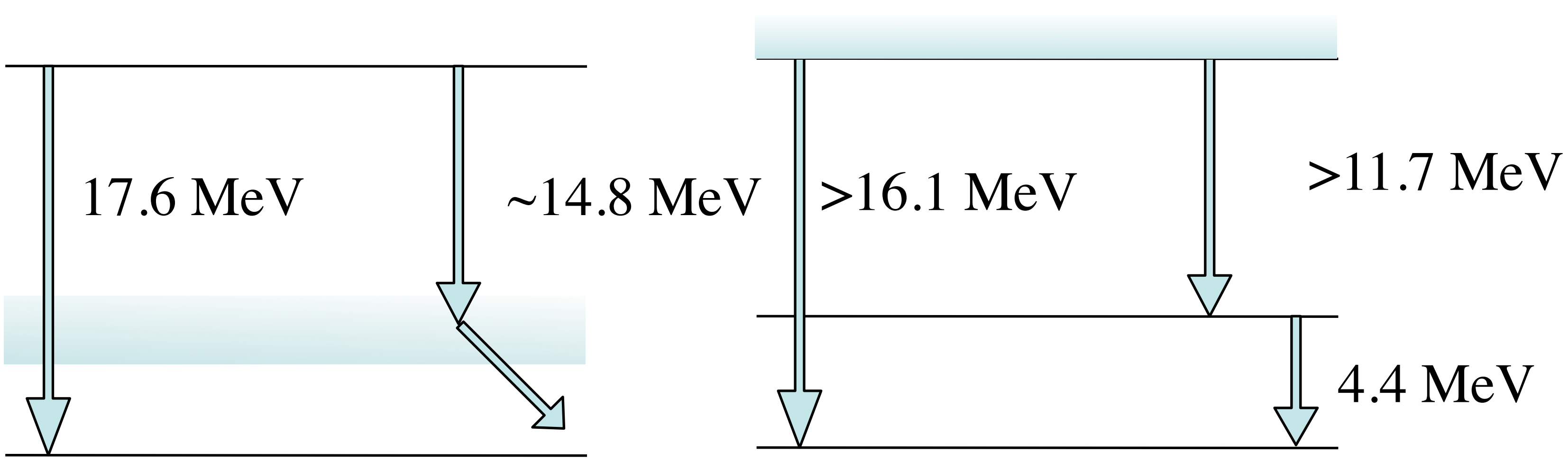
...should deserve a presentation on its own!

Intro & reactions

- The Cockcroft-Walton is an extremely powerful tool, installed for monitoring and calibrating *all* the MEG experiment
- Protons on Li or B
  - Li: high rate, higher energy photon
  - B: two (lower energy) time-coincident photons

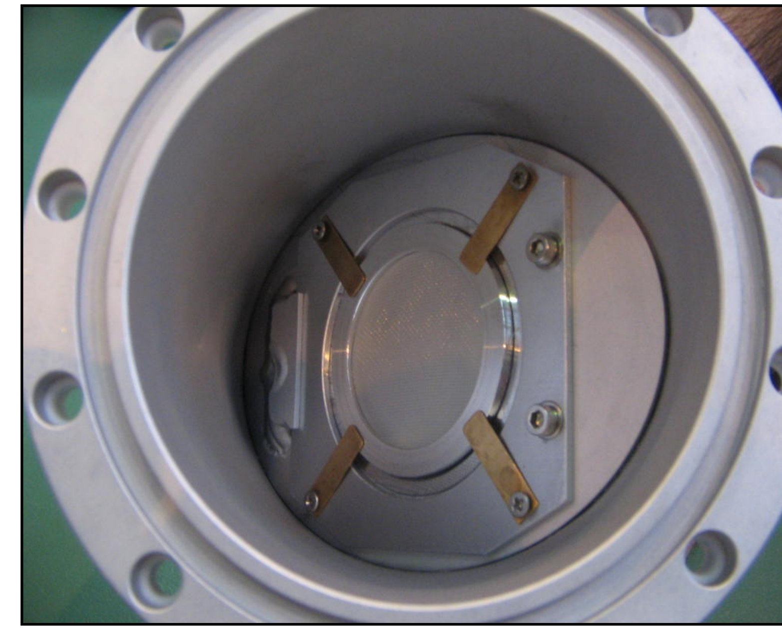


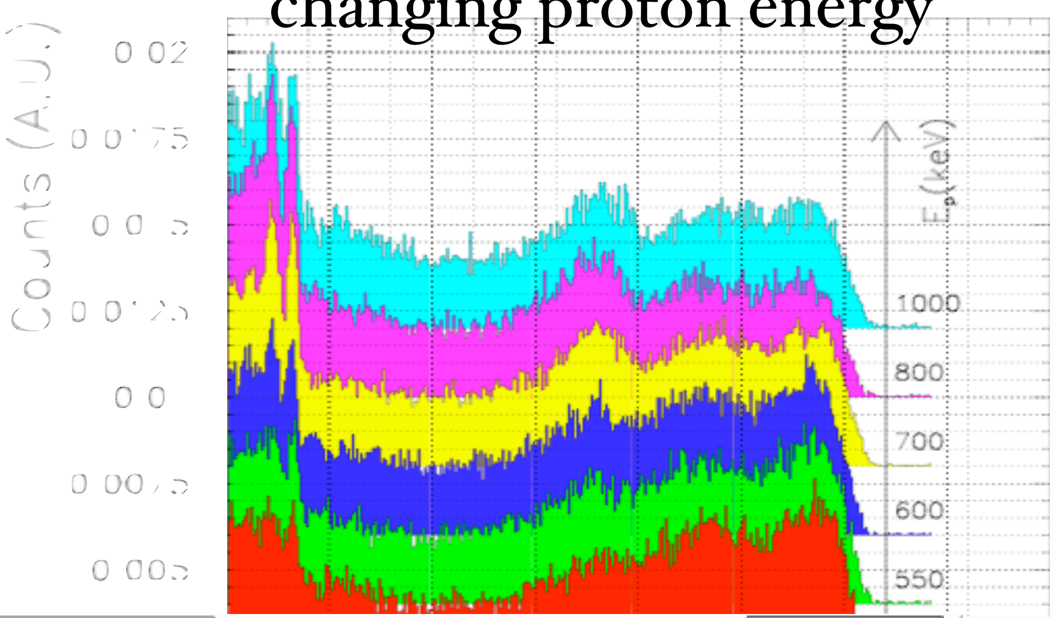
Reaction	***Peak energy***	**σ peak**	**γ-lines**
Li(p,γ)Be	*440 keV*	5 mb	(17.6, 14.6) MeV
B(p,γ)C	*163 keV*	2 10^{-1} mb	(4.4, 11.7, 16.1) MeV



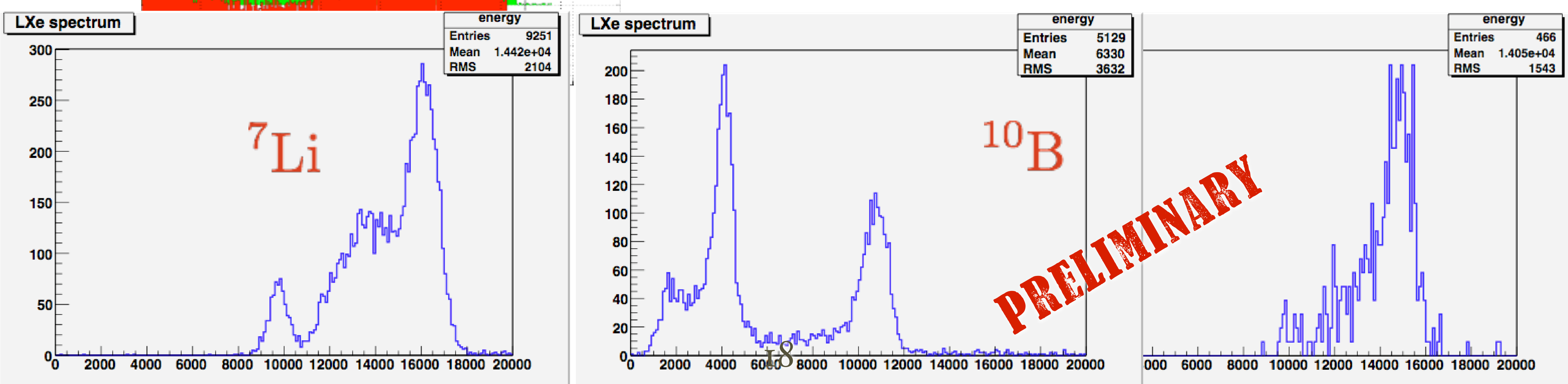
CW - daily calibration

- This calibration is performed every other day
  - Muon target moves away and a crystal target is inserted
- Hybrid target ($Li_2B_4O_7$)
  - Possibility to use the same target and select the line by changing proton energy





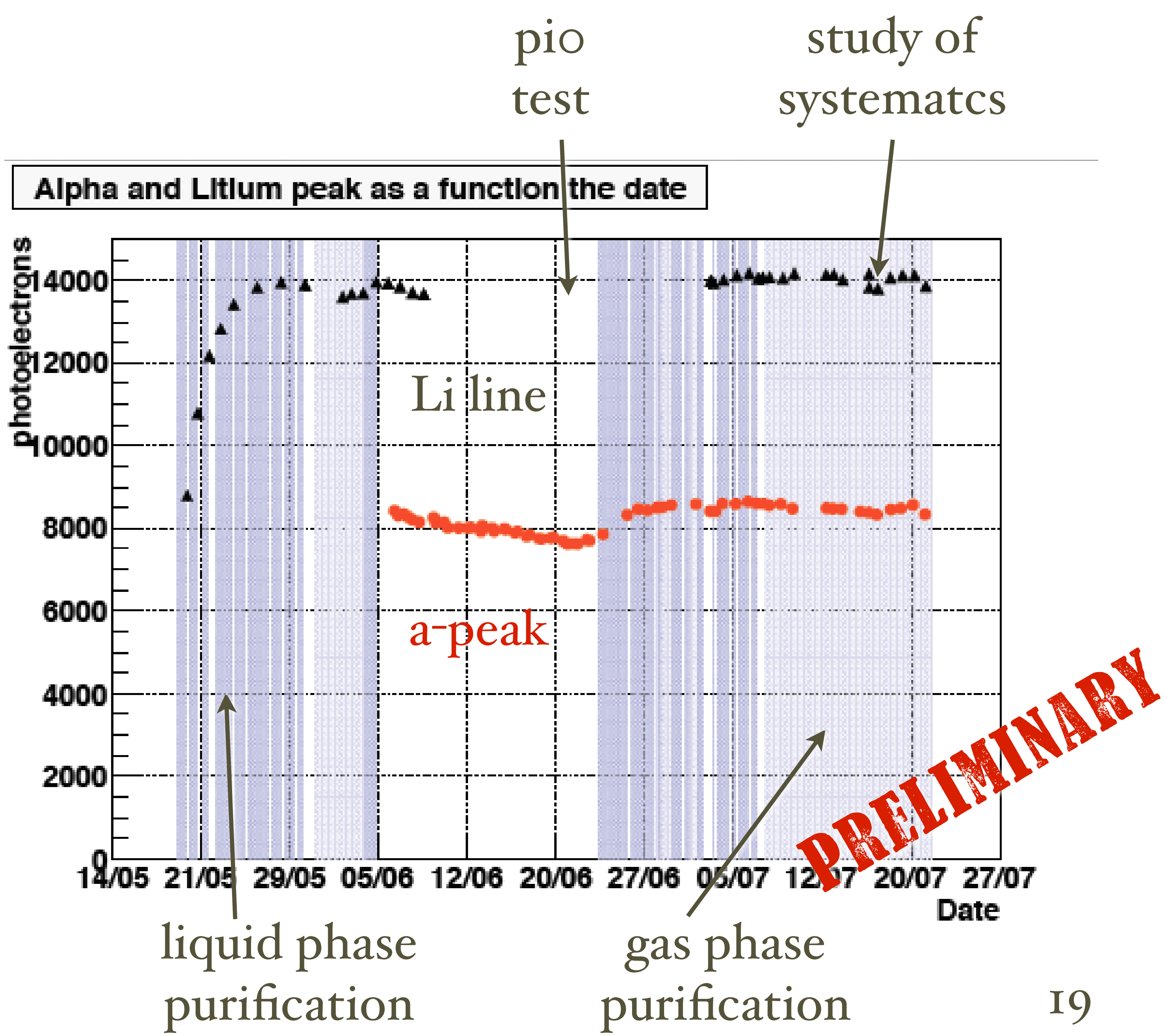
When p energy increases B lines appear

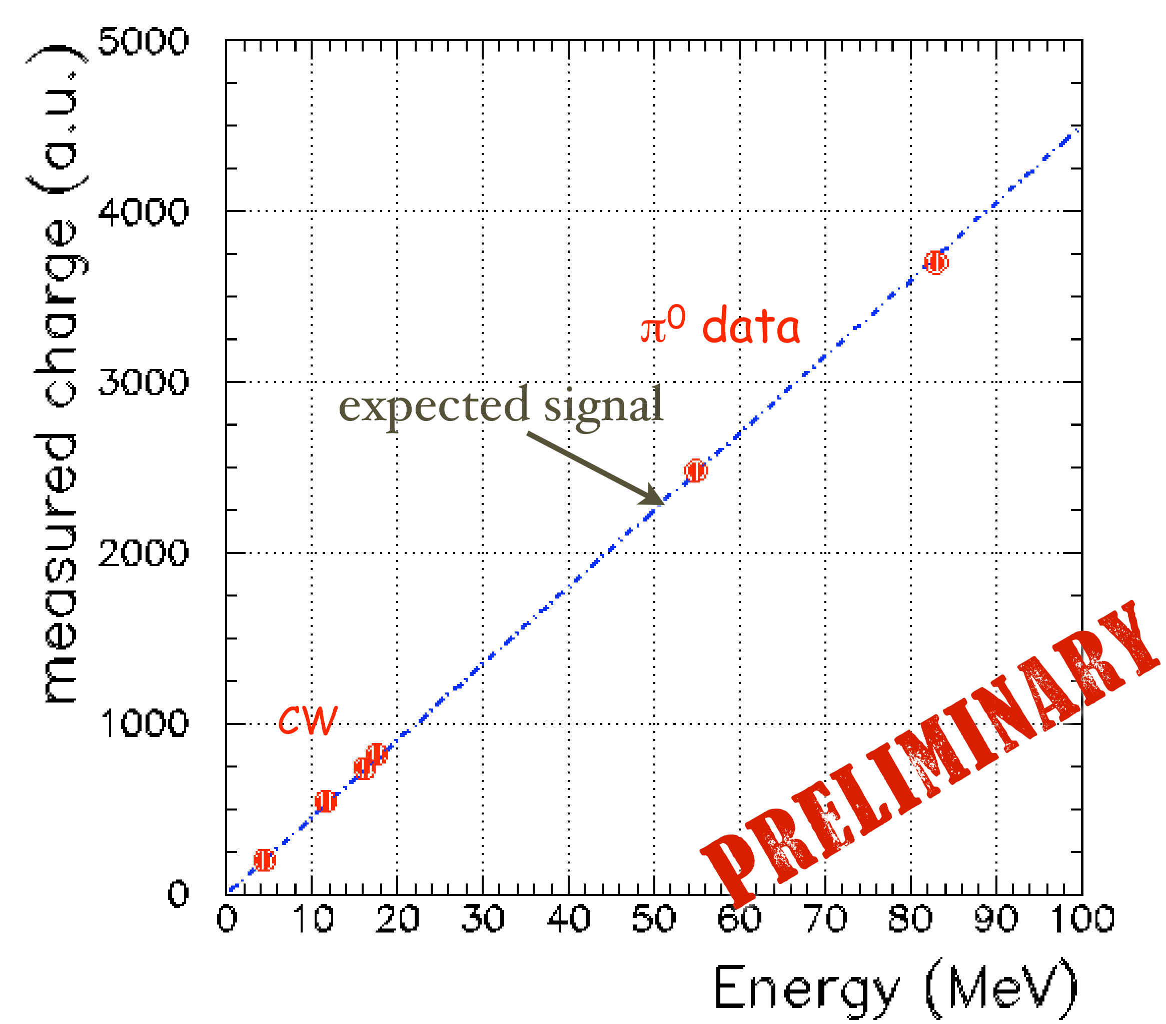


Daily monitoring

- Monitor Xe light yield
  - liquid/gas purification studies
  - stability studies

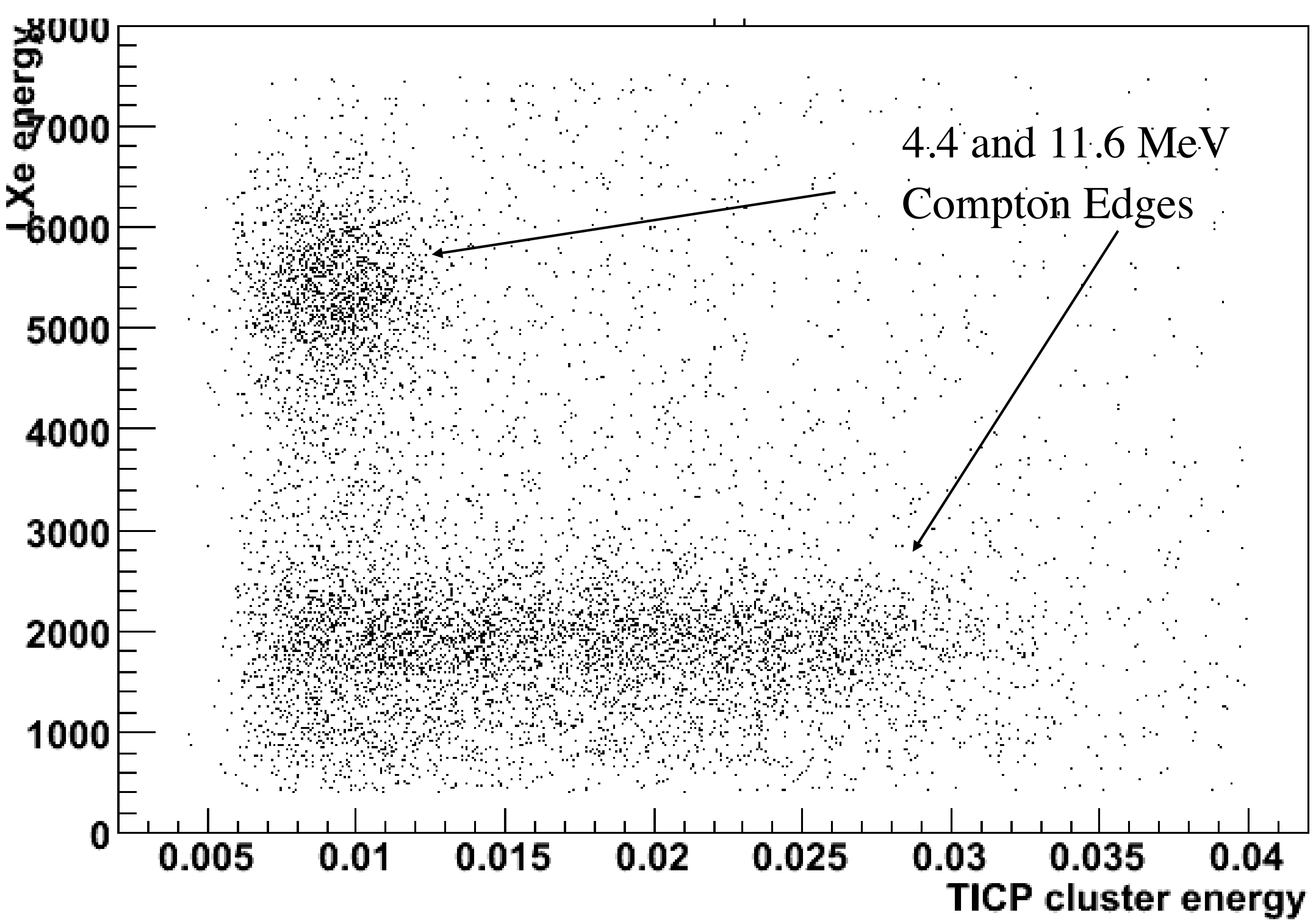
< 1% knowledge of l.y. and energy scale

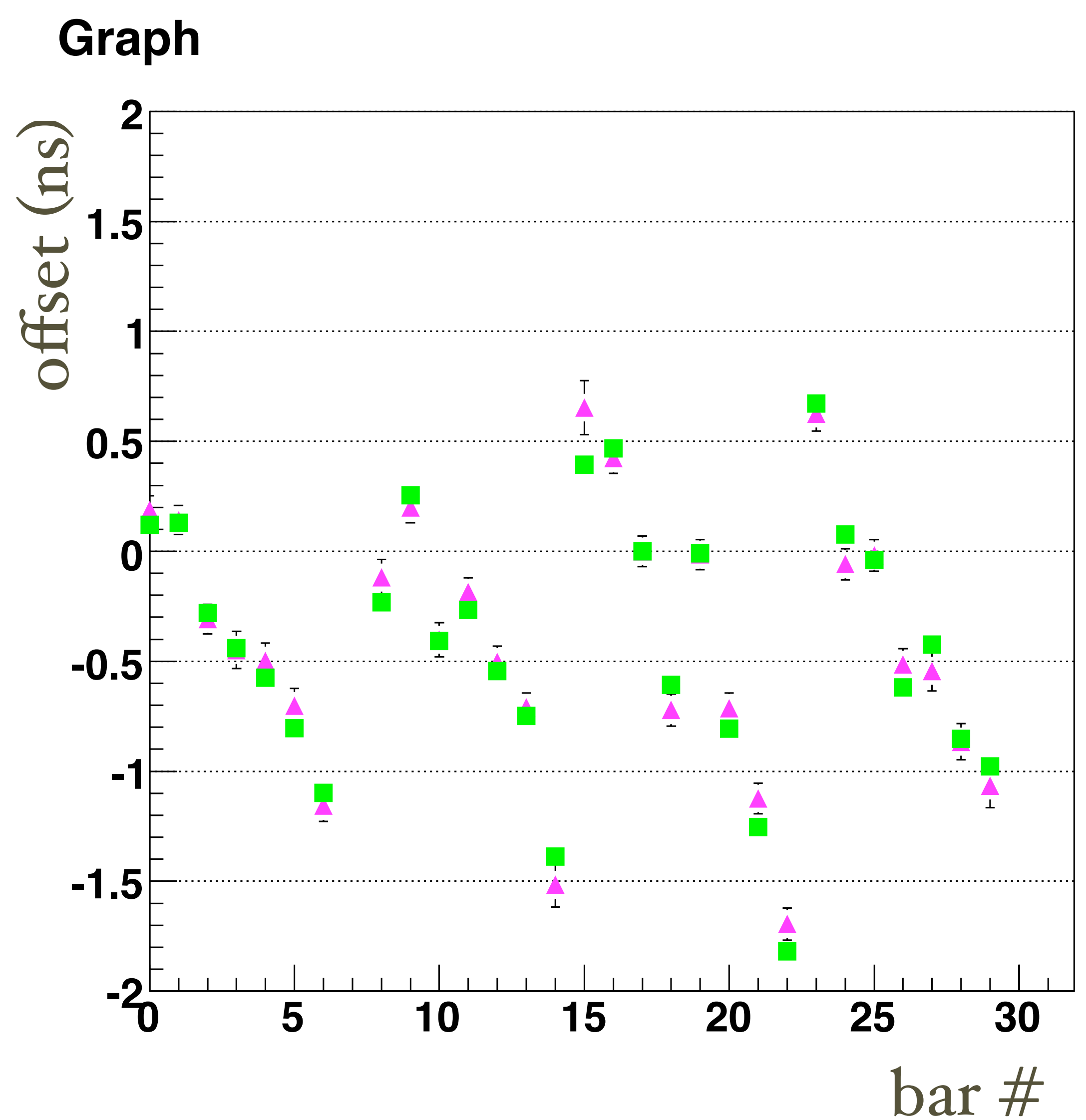




CW and timing counter

- The simultaneous emission of two photons in the Boron reaction is used to
  - determine relative timing between Xe and TIC
  - Inter-calibrate TIC bar (LASER)

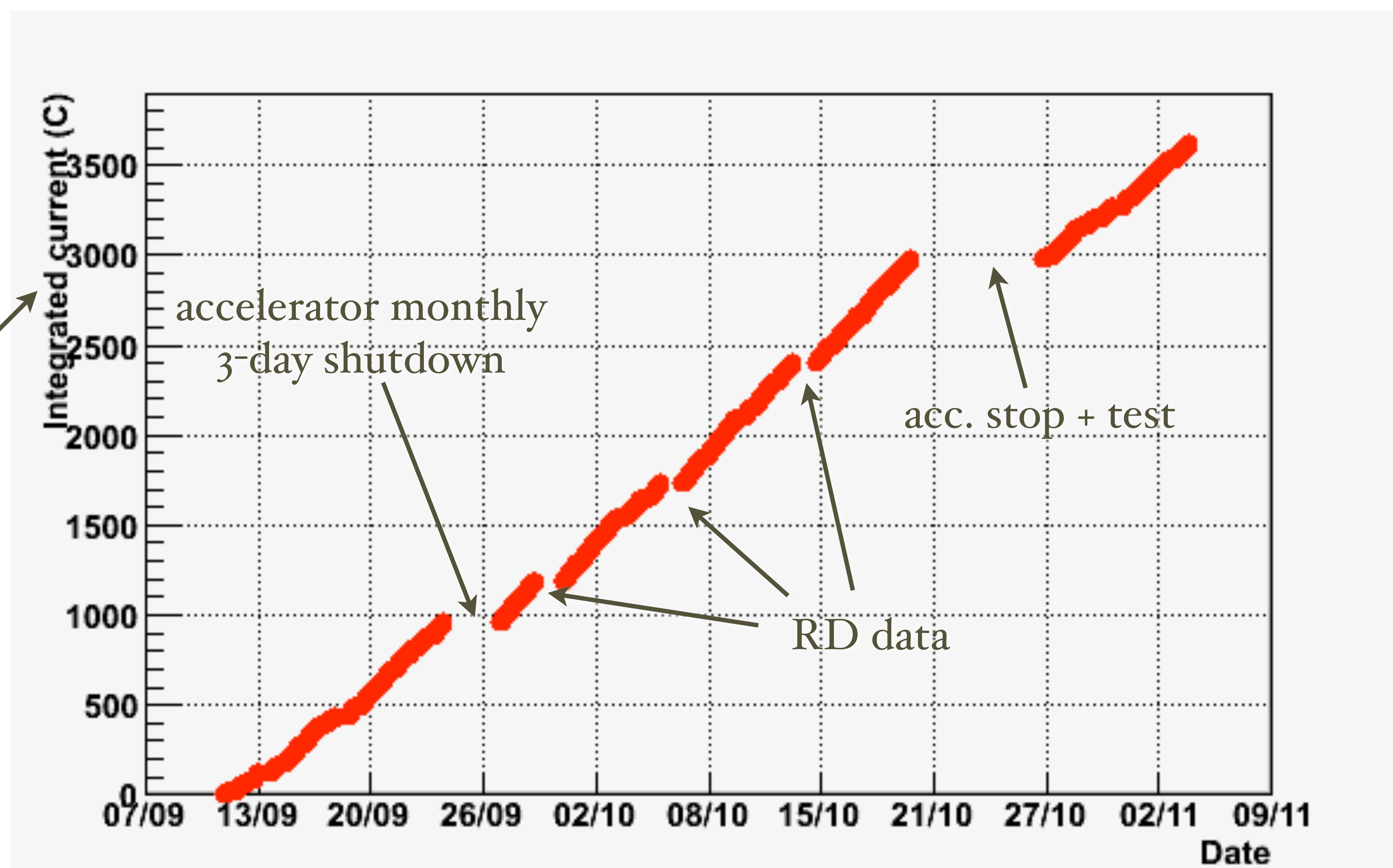




Selected results from 2007 engineering run

- We are presently taking data but I cannot show you any plot from this year "physics" data set
- Our strategy is masking some of the data
    - *blind* & *likelihood* analysis

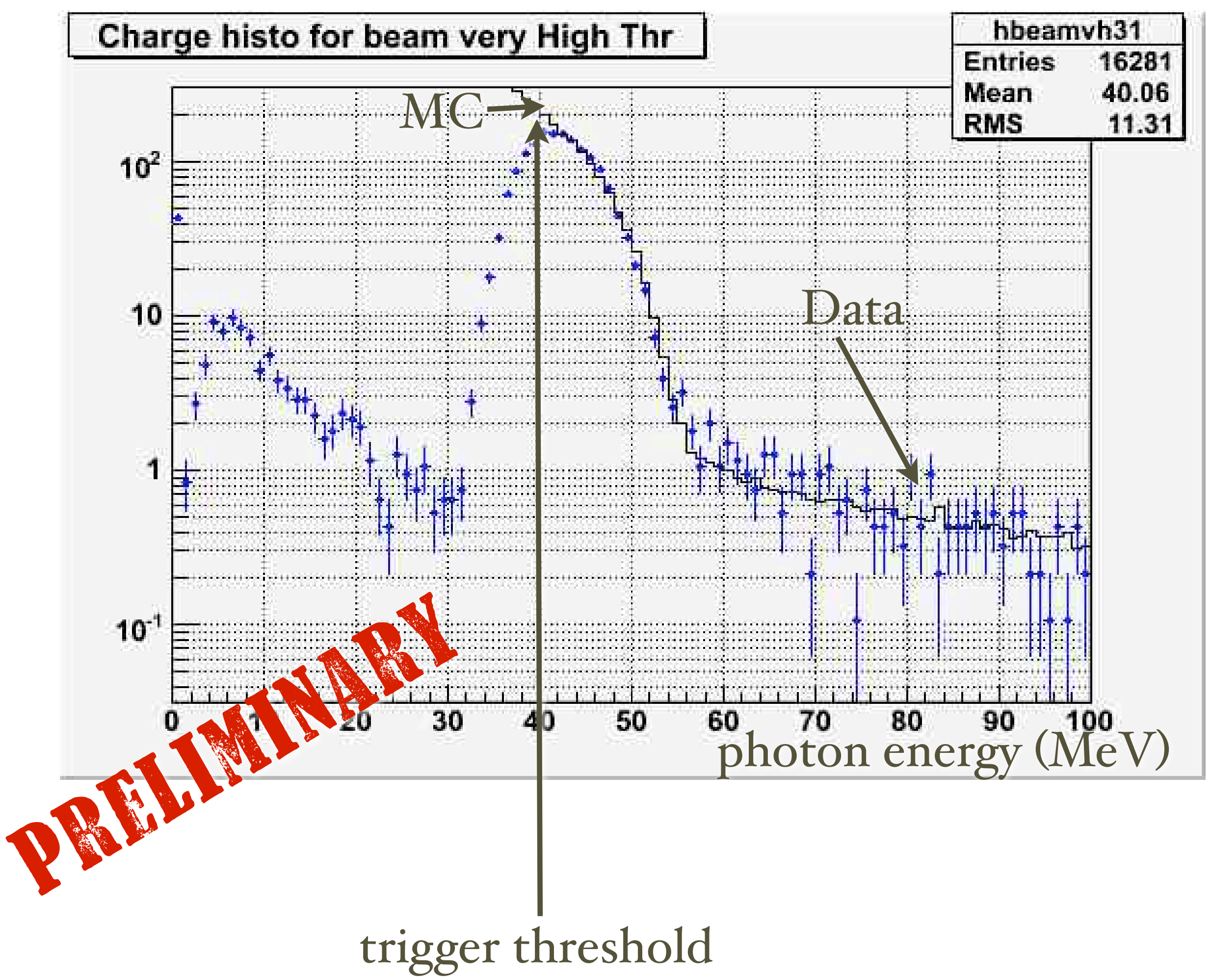
proportional to our data sample



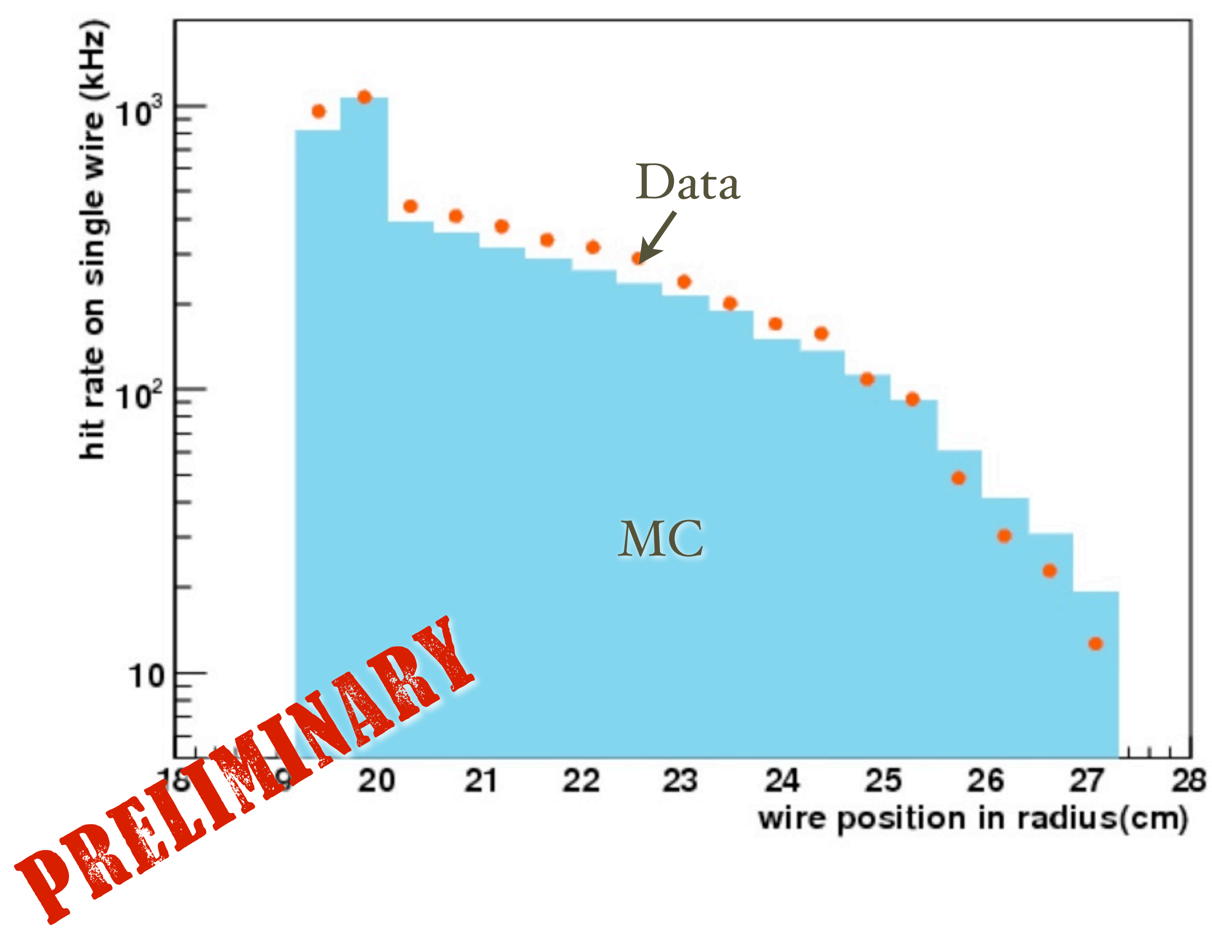
First: the rates

- Since our is a counting experiment we must be sure to have the background under control
- The *trigger* rate scales as expected
- Absolute wire rate in the chambers ok, details to be understood

calorimeter energy spectrum



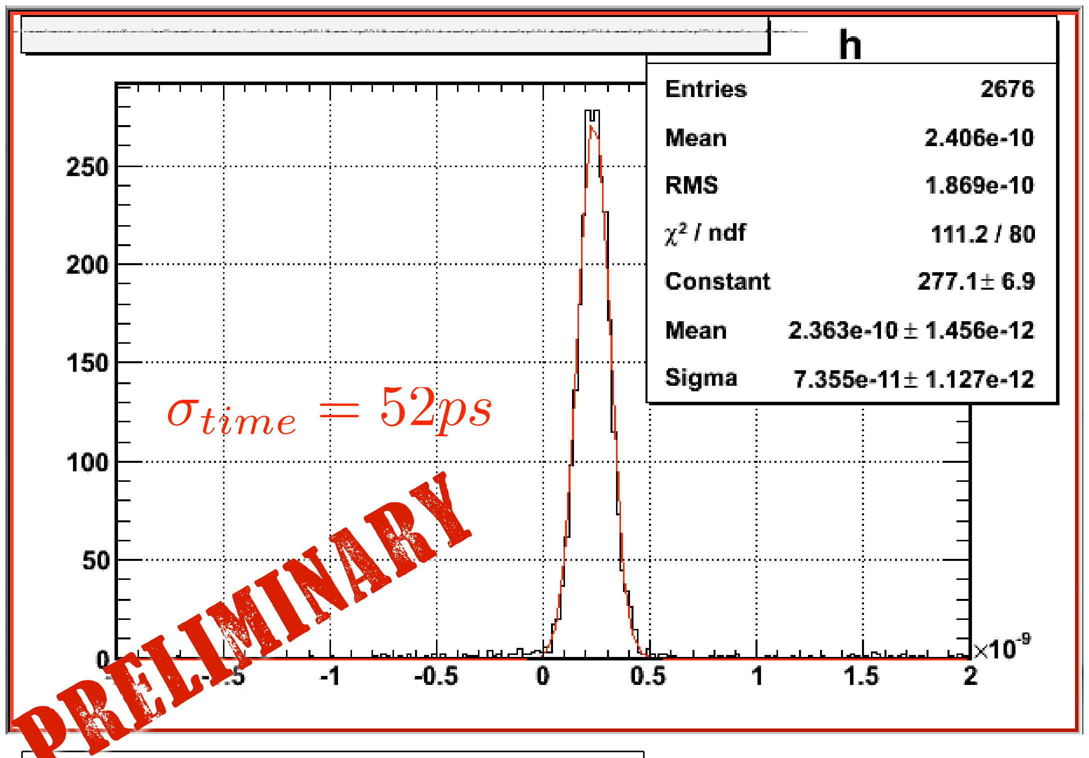
rate on DCH wires

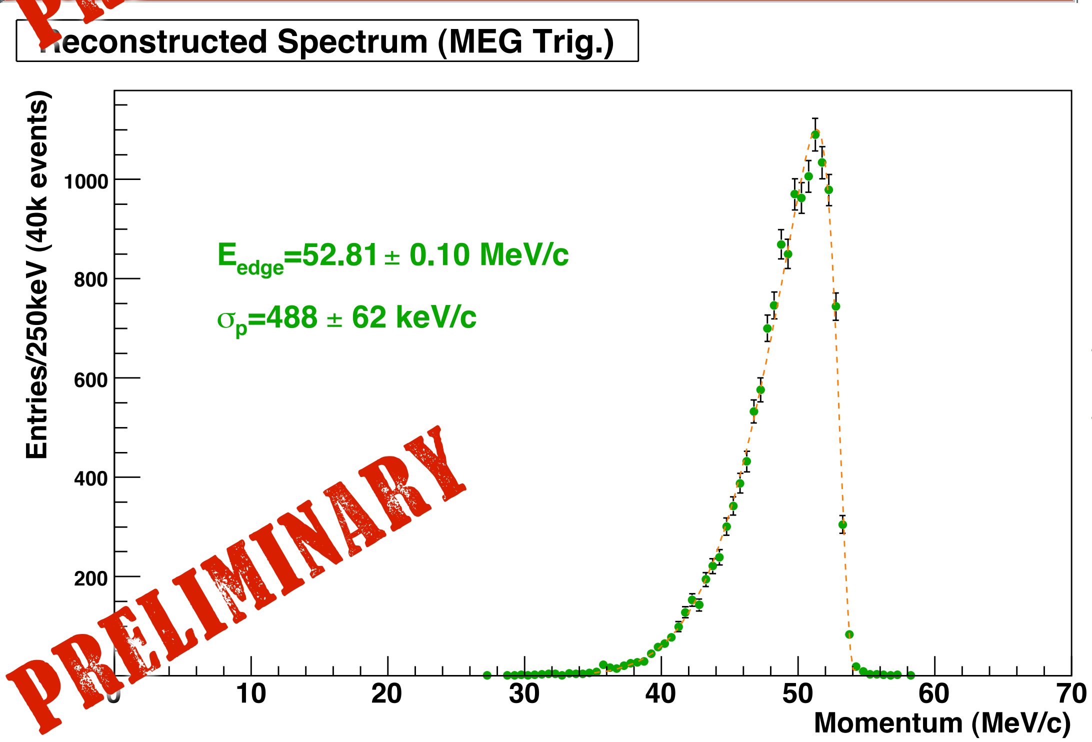


Detector performance in 2007

Spectrometer

Michel e+ Run

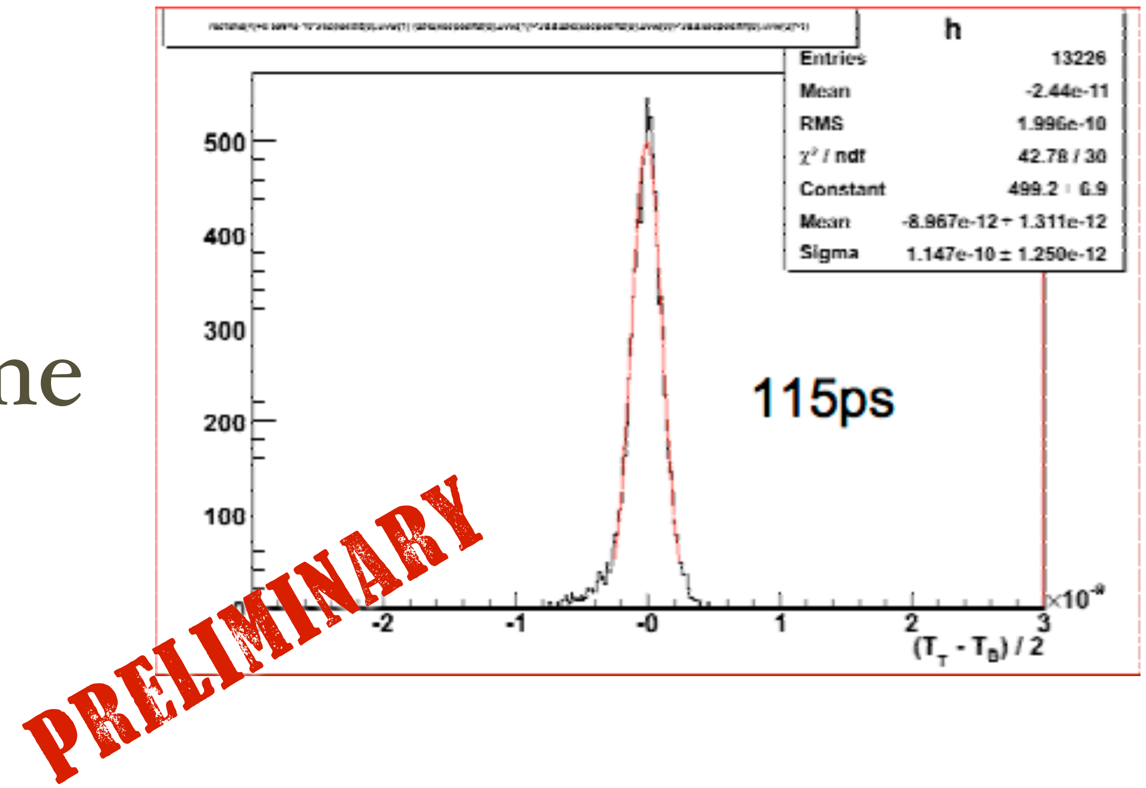




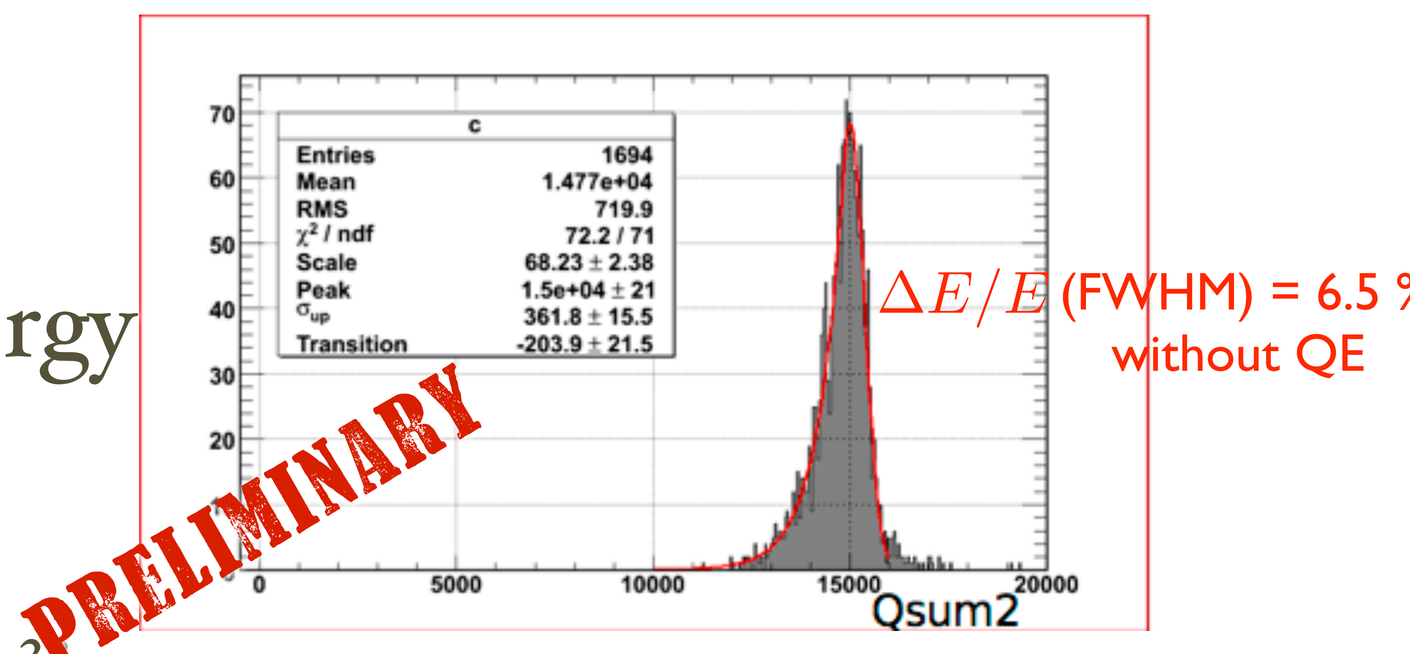
Calorimeter

π^0 Run

time



Energy



...a comment

- In 2007 we had an engineering run with (almost) all the apparatus running for ~1 month
  - no fiber TC detector, no laser, no QEs
  - Xe light yield < than expected
  - DCH failures, noisy electronics

partly solved

- In 2008 run
  - intensive study of detector stability (LXe) l.y. almost recovered
  - all detector & calibrations operational
  - "new" electronics available only at the end of the run
  - DCH system: some sparking chambers
  - but... more months of data taking to get a physics result!

Background and Sensitivity

	" Goal "		Perspectives for 2008	
	Measured	Simulated	Measured 2007	Applied to 2008
Gamma energy %	4.5 – 5.0		6.5	<
Gamma Timing (ns)	0.15		0.27*	<
Gamma Position (mm)	4.5 – 9.0		15	<
Gamma Efficiency (%)	>40		>40	>
e^+ Timing (ns)	0.1		0.12*	=
e^+ Momentum (%)		0.8	2.1	<
e^+ Angle (mrad)		10.5	17.**	=
e^+ Efficiency (%)		65	65	<?
Muon decay Point (mm)		2.1	3.**	=
Muon Rate (10^8/s)	0.3		0.3***	0.26***
Running Time (weeks)	100			12
Single Event Sens (10^{-13})	0.5			20-40
Accidental Rate (10^{-13})	0.1 – 0.3			10
# Accidental Events	0.2 - 0.5			O(1)
90% CL Limit	2 10^{-13}			< 10^{-11}

1 week = 4 x 10^5 s

* Added 250 ps due to present estimate of DRS systematics

** Very pessimistic

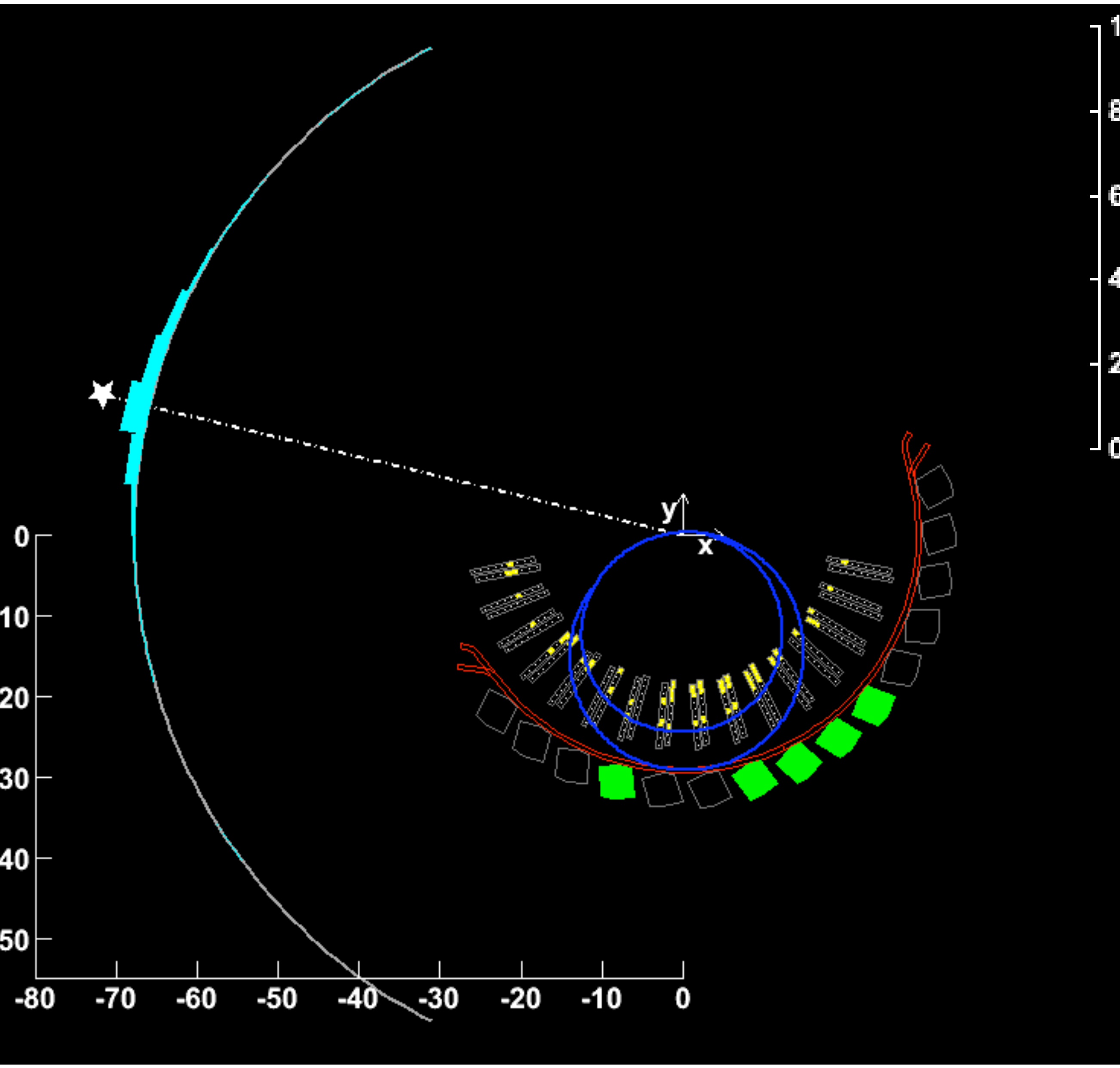
*** The muon rate is optimized to improve the limit

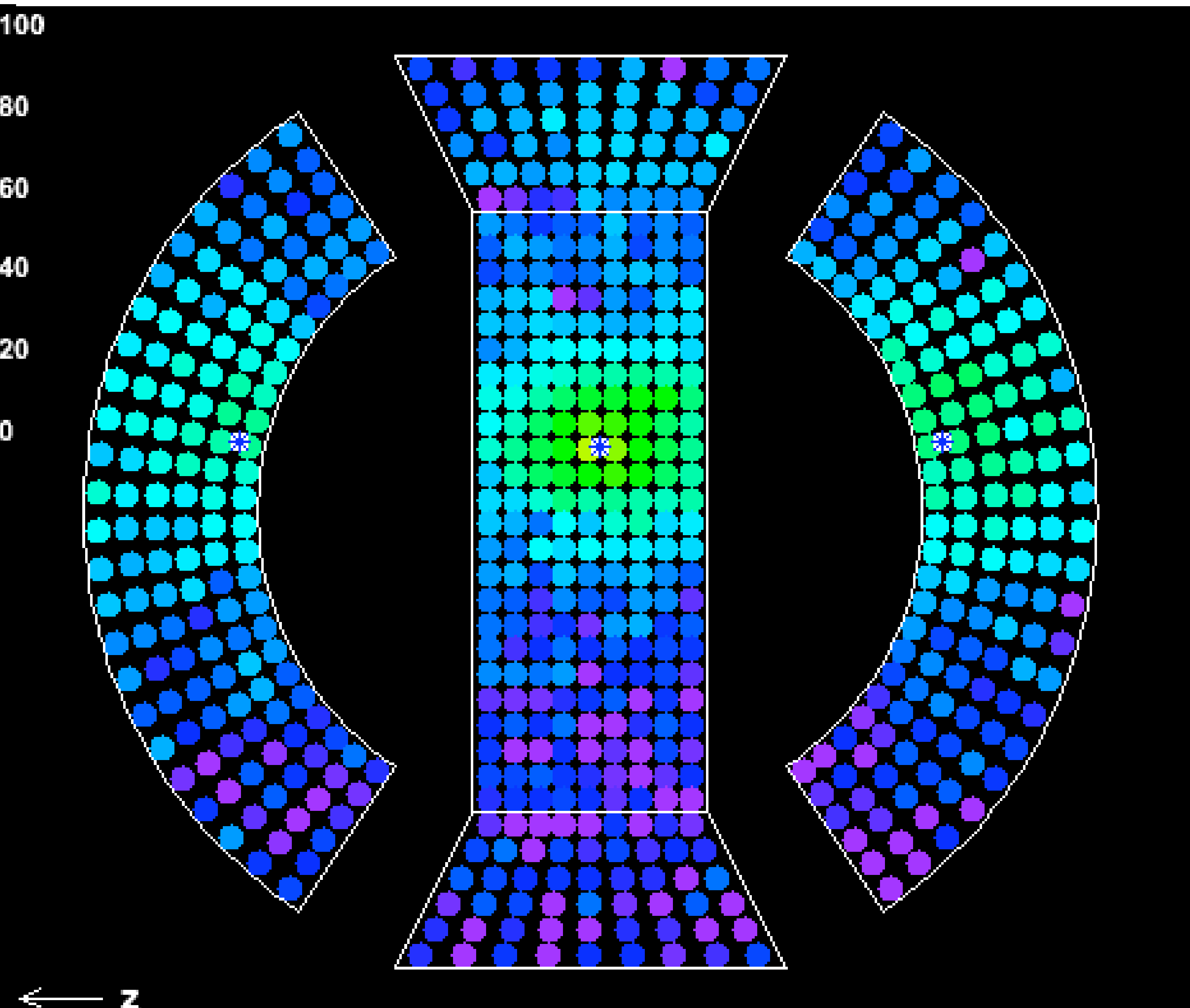
Perspective

- We had an engineering run in 2007 and a second engineering and calibration run between April and August 2008;
- We started the physics data taking on 9/12;
  - the detector is getting more and more in its optimal shape
- We expect first results in 2009
  - use the beginning of 2009 to deal with few upgrades
- We are confident to reach a sensitivity of few $\times 10^{-13}$ in $\mu \to e\gamma$ BR in 3 years of acquisition time.

A 2008 candidate event

- A good hint for this year!





Thanks