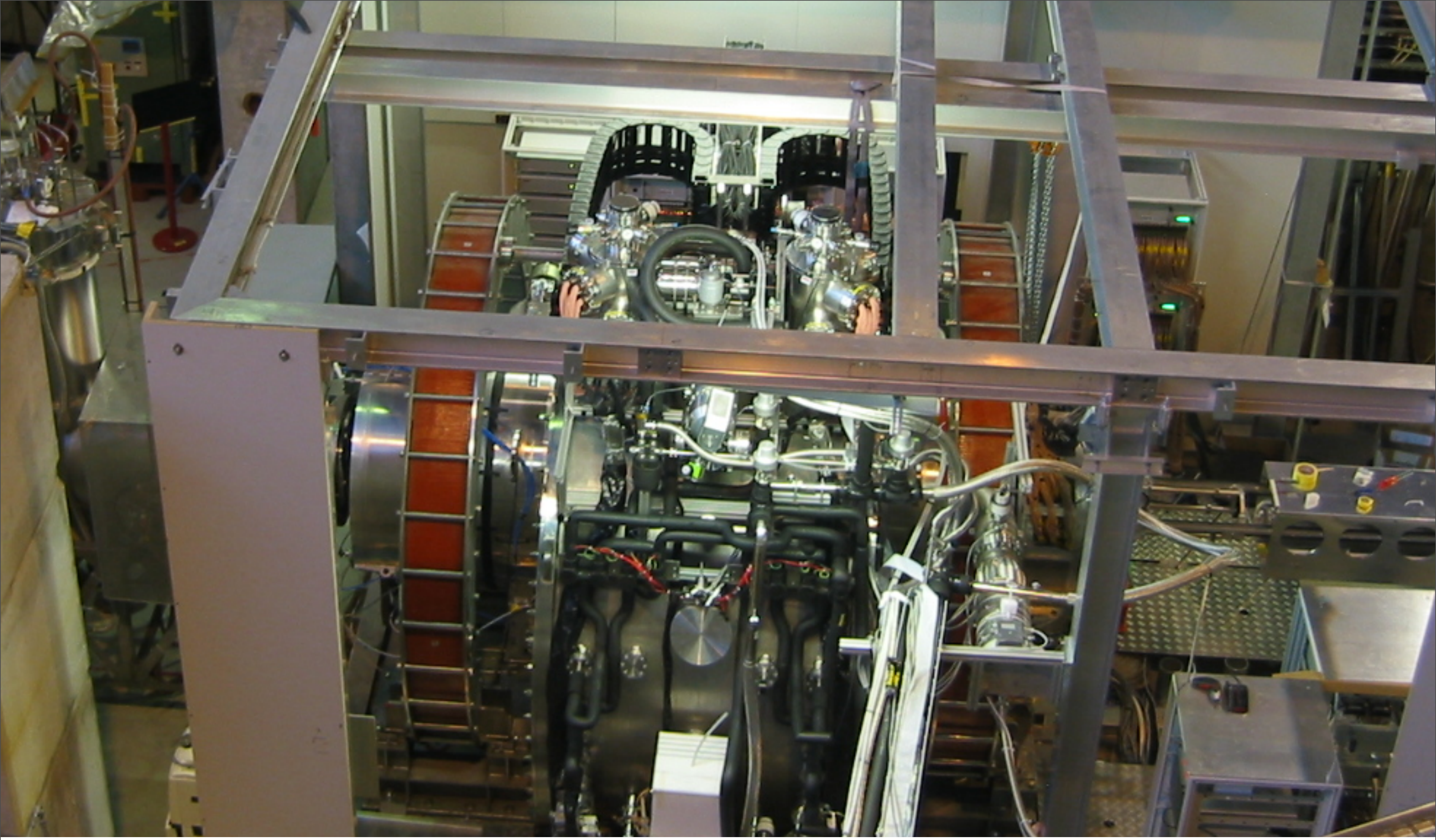

MEG Experiment at PSI

Status and Prospects

W. Ootani

on behalf of the MEG collaboration

3rd CHIPP Swiss neutrino workshop

Nov. 17th, 2008   ETH Zurich

Contents

- $\mu \to e \gamma$ search at MEG
- MEG Detector
- Run 2008
- Prospects

MEG Collaboration

~80 physicists from 12 institutes in 5 countries

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KEK
T. Haruyama, K. Kasami, A. Maki, Y. Makida, S. Mihara, H. Nishiguchi, A. Yamamoto, K. Yoshimura
Waseda Univ.
T. Doke, J. Kikuchi, S. Suzuki, K. Terasawa

INFN and University of Pisa
A. Baldini, C. Bemporad, F. Cei, M. Corbo, L. Galli, G. Gallucci, M. Grassi, F. Morsani, D. Nicolò, A. Papa, L. Perrozzi, F. Raffaelli, F. Sergiampietri, G. Signorelli
INFN and Univ. of Genova
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INFN and Univ. of Pavia
G. Boca, P. W. Cattaneo, A. De Bari, R. Nardò, M. Rossella, G. Musitelli, O. Barnaba
INFN and Univ. of Roma I
A. Barchiesi, G. Cavoto, A. Graziosi, G. Piredda, F. Renga, C. Voena, D. Zanello
INFN and Univ. of Lecce
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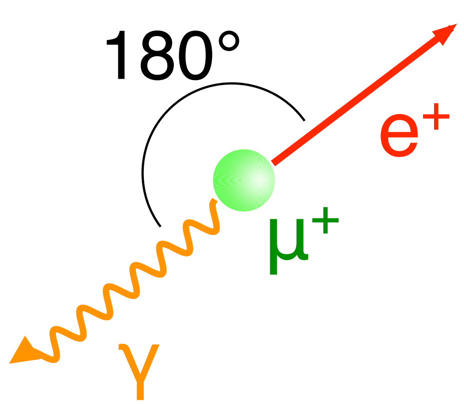
Paul Scherrer Institute
J. Adam, M. Hildebrandt, P.-R. Kettle, O. Kiselev, S. Ritt

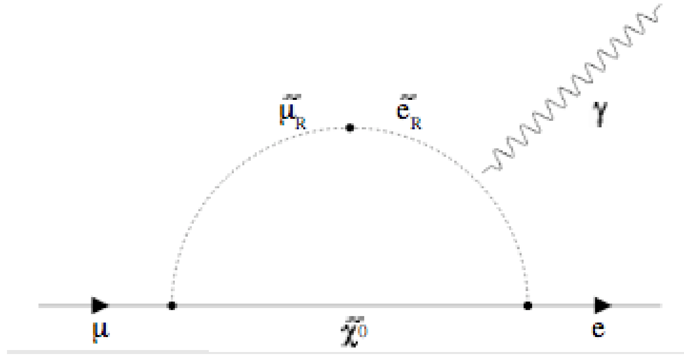
BINP Novosibirsk
D. N. Grigoriev, F. Ignatov, B. I. Khazin, A. Popov, Y. V. Yudin.
JINR Dubna
A. Korenchenko, N. Kravchuk, A. Moiseenko, D. Mzavia

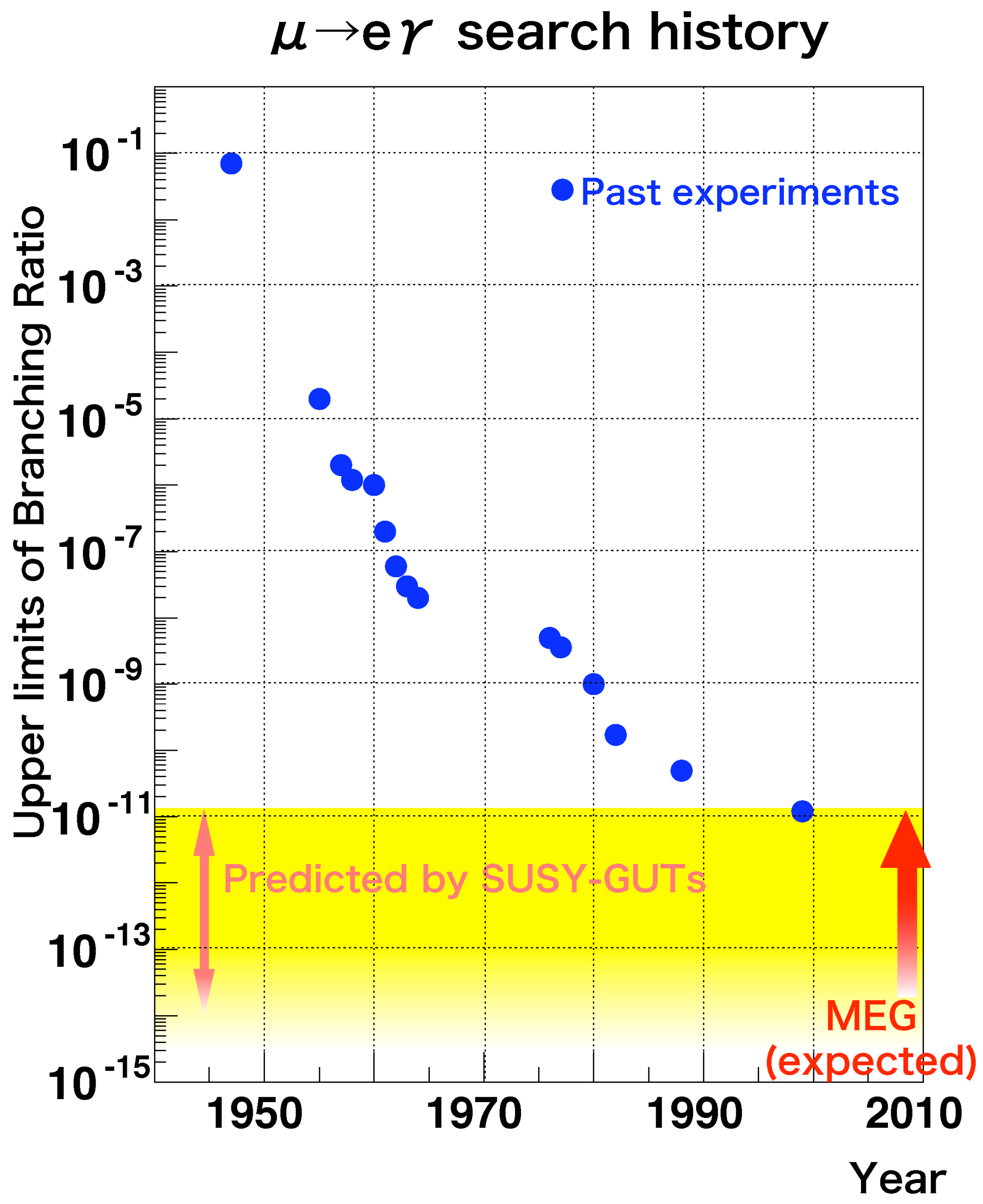
Univ. of California, Irvine
E. Baracchini, B. Golden, W. Molzon, C. Topchyan, F. Xiao, F. Yu

What Is MEG?

- MEG is an experiment to search for the lepton flavor violating (LFV) muon decay, $\mu \to e\gamma$.
- Target sensitivity at BR~10^{-13} improving the present limit by two orders of magnitude.
- There's a real chance to discover an evidence of new physics beyond the SM such as SUSY-GUTs.

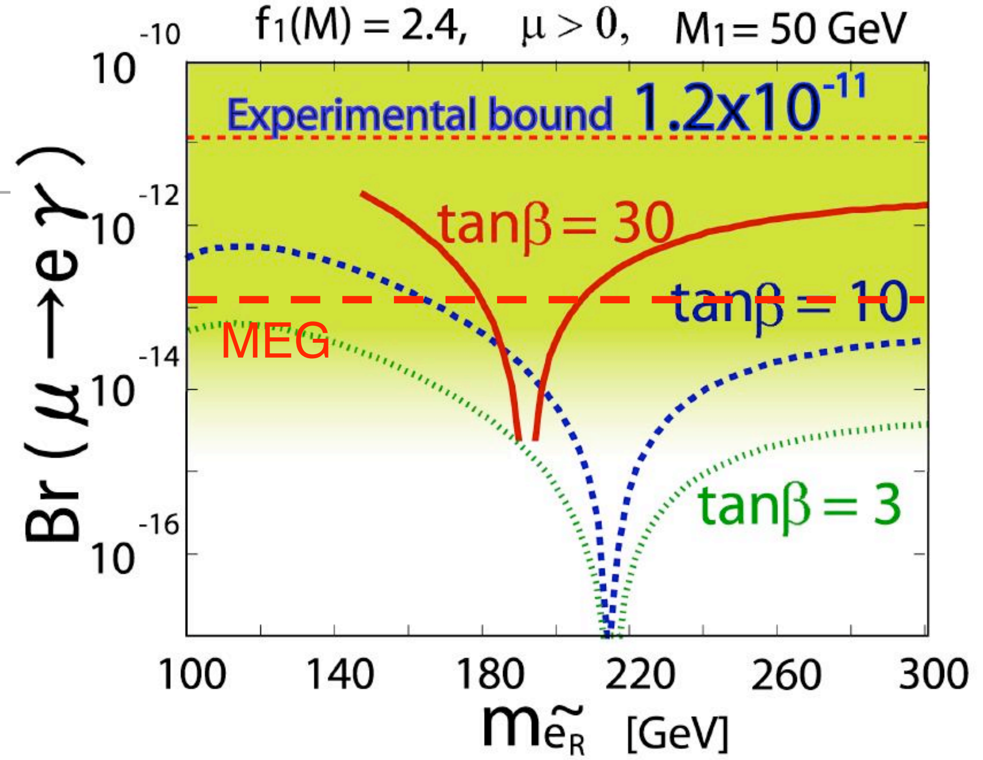




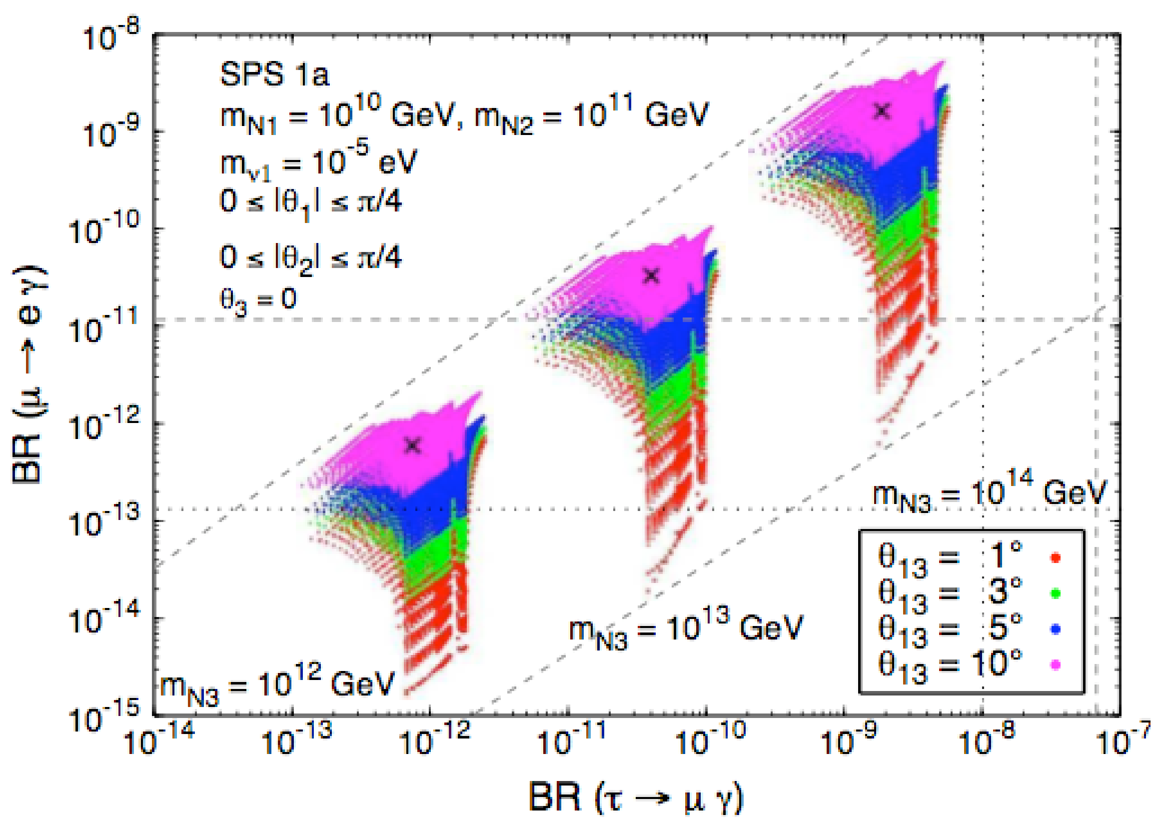


Why to Look for μ→eγ?

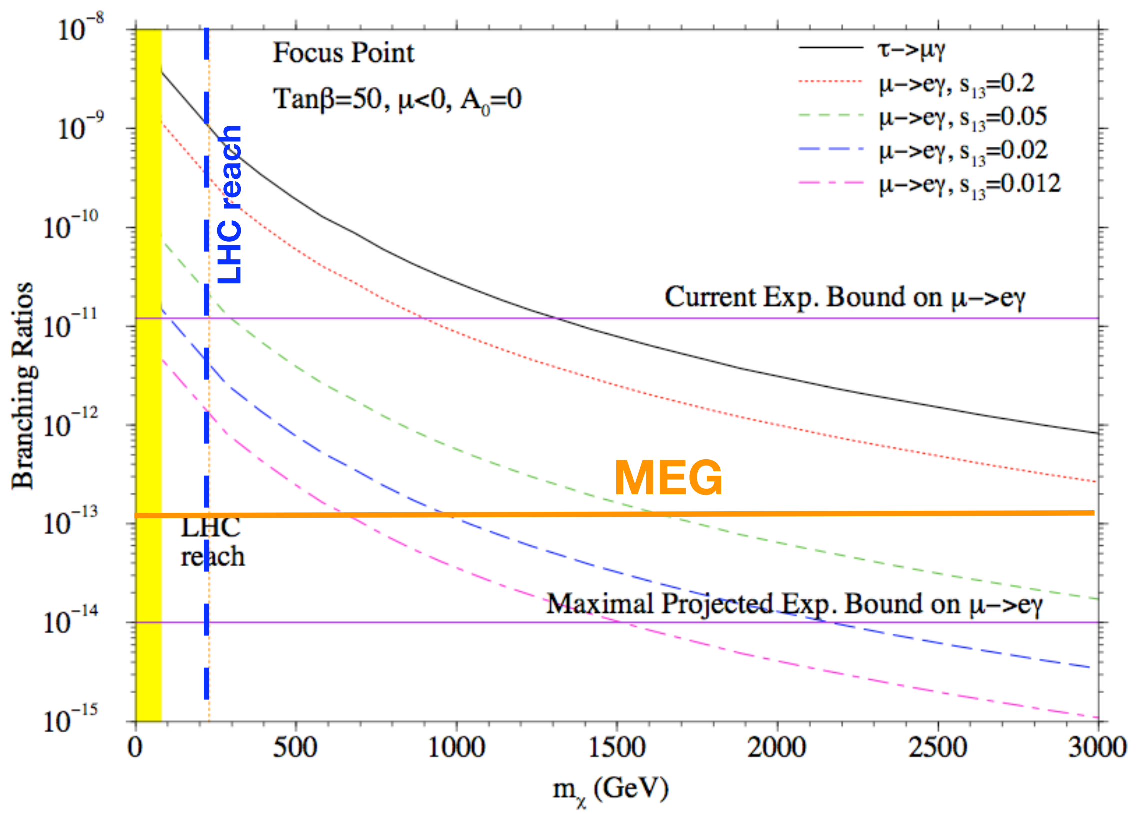
- LFV found in the neutral sector. Why not in the charged sector?
- Many “positive” SUSY predictions
- No BG from the standard model
- Complementary to LHC experiments at some parameter space



J.Hisano et al. PLB391(1997)341



S. Antusch, et al., JHEP11(2006)090



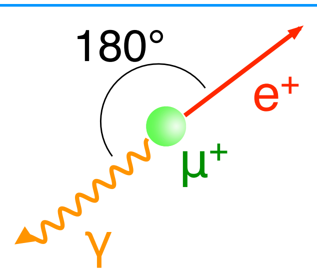
A.Masiero, JHEP 03(2004)046

What's Necessary for μ→eγ Search?

- A lot of muons
  - High intensity μ^+ beam
  - High duty factor to minimize accidental background
- Good detector
  - Precise measurements of energy, timing and angle both for positron and gamma
  - Capability to identify pileups

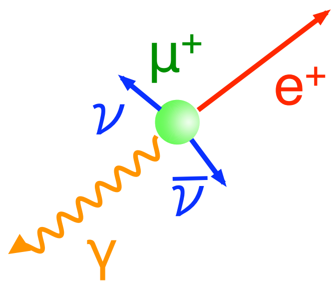
$$B_{acc} \propto \delta E_e \cdot \delta t_{e\gamma} \cdot (\delta E_\gamma)^2 \cdot (\delta \theta_{e\gamma})^2$$

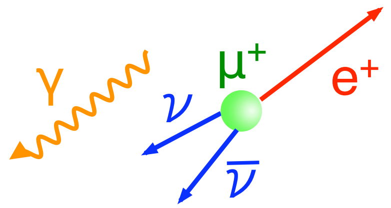
- Signal
  - Back-to-back
  - Mono-energetic E_e=52.8MeV E_γ=52.8MeV
  - Coincident in time



- Background
  - Prompt background: $\mu \rightarrow e\gamma\nu\nu$
  - "Accidental" overlap: $\mu \rightarrow e\nu\nu + \gamma$

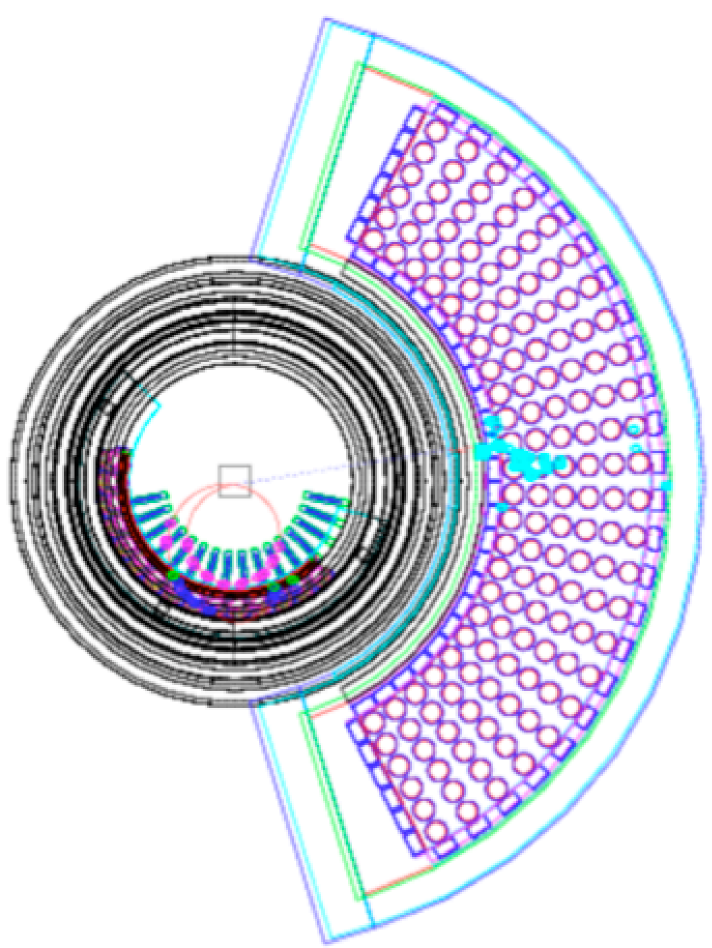
Predominant

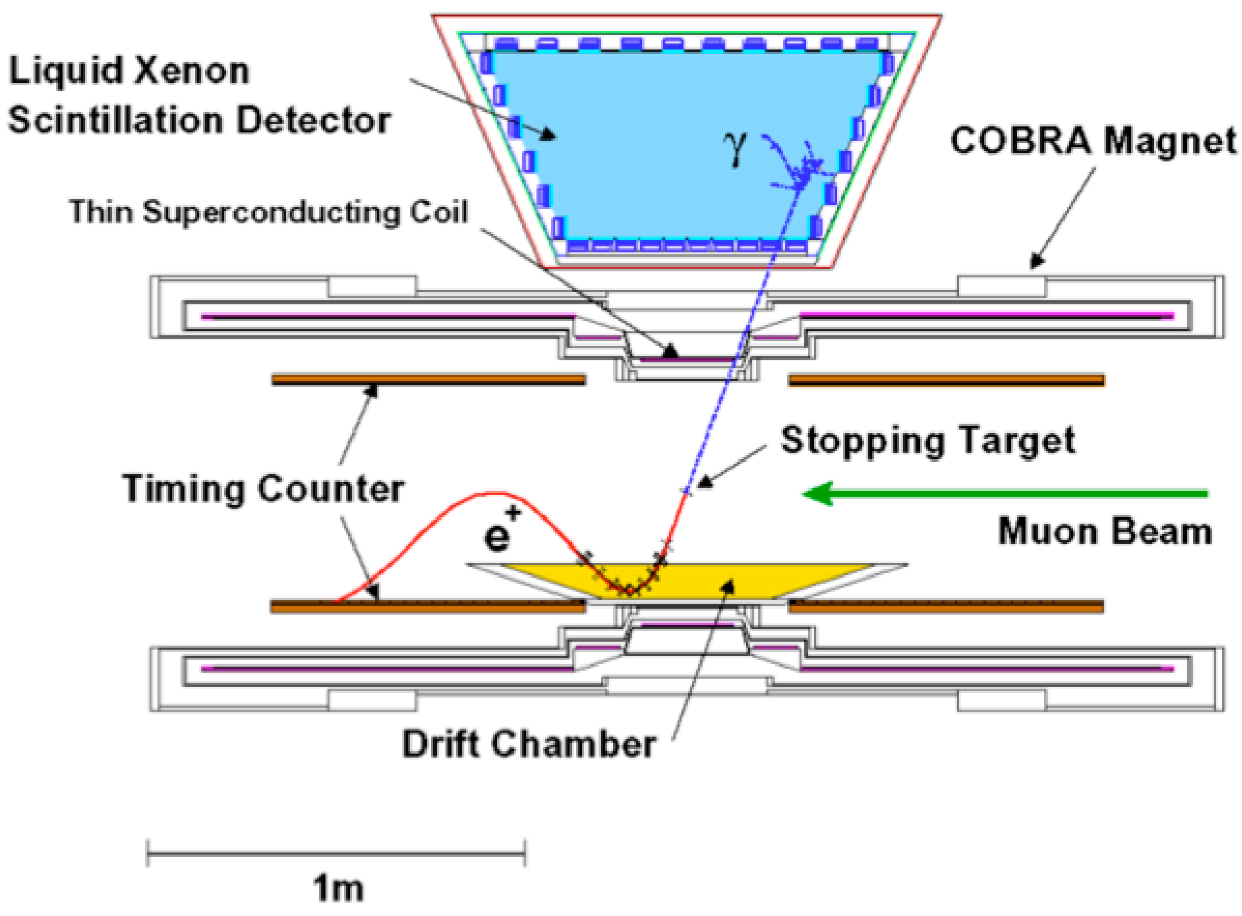




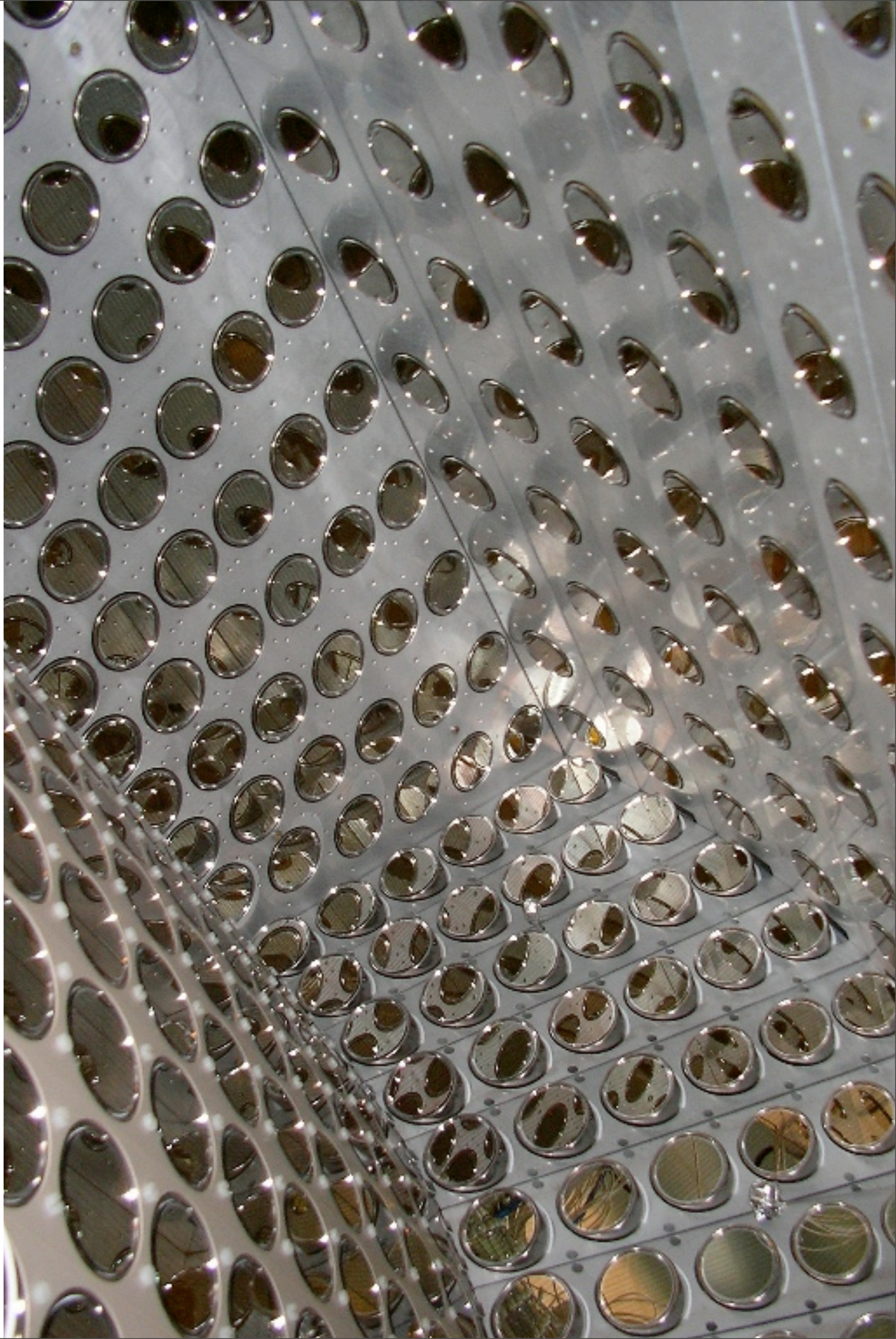
Our Solution

- World's most intense DC muon beam up to 10^8 μ^+/sec at Paul Scherrer Institute
- MEG detector
  - Gamma: LXe scintillation detector
  - Positron: COBRA positron spectrometer with gradient magnetic field.



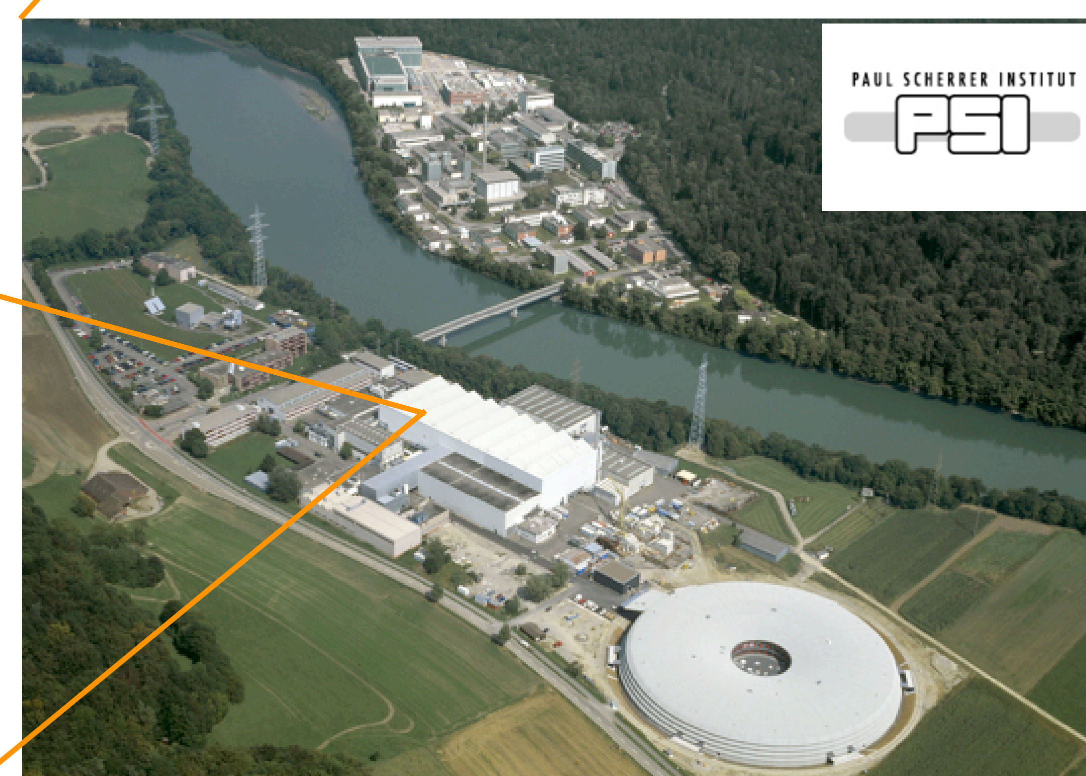


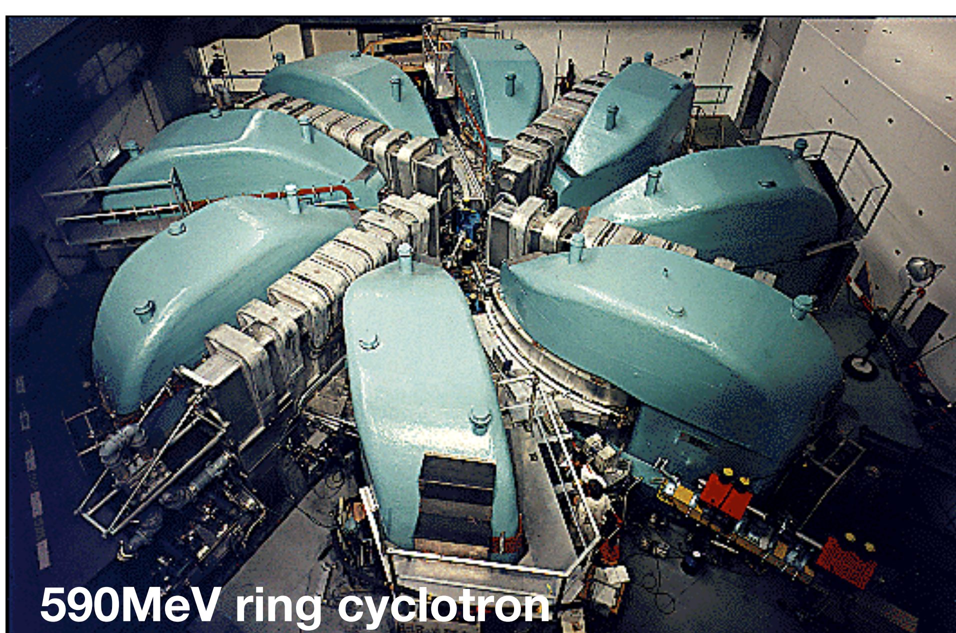
MEG Detector



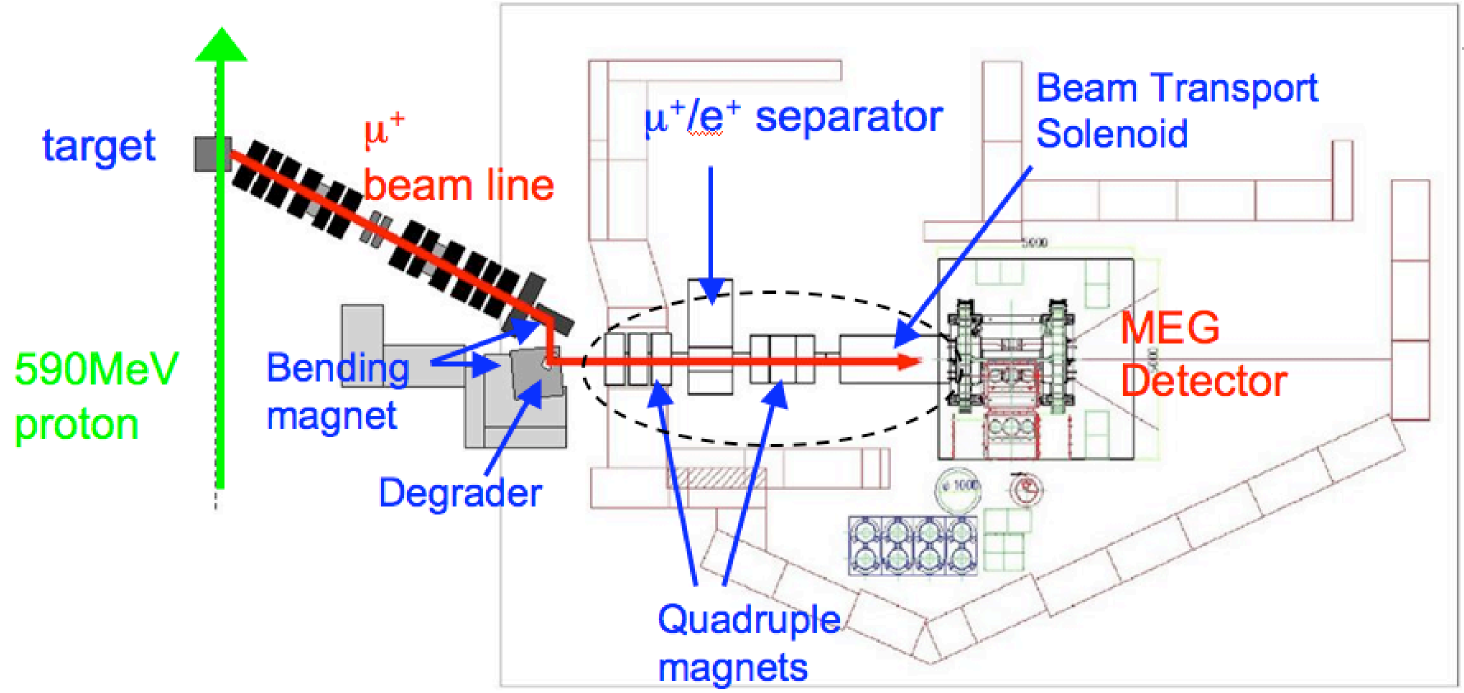
Accelerator

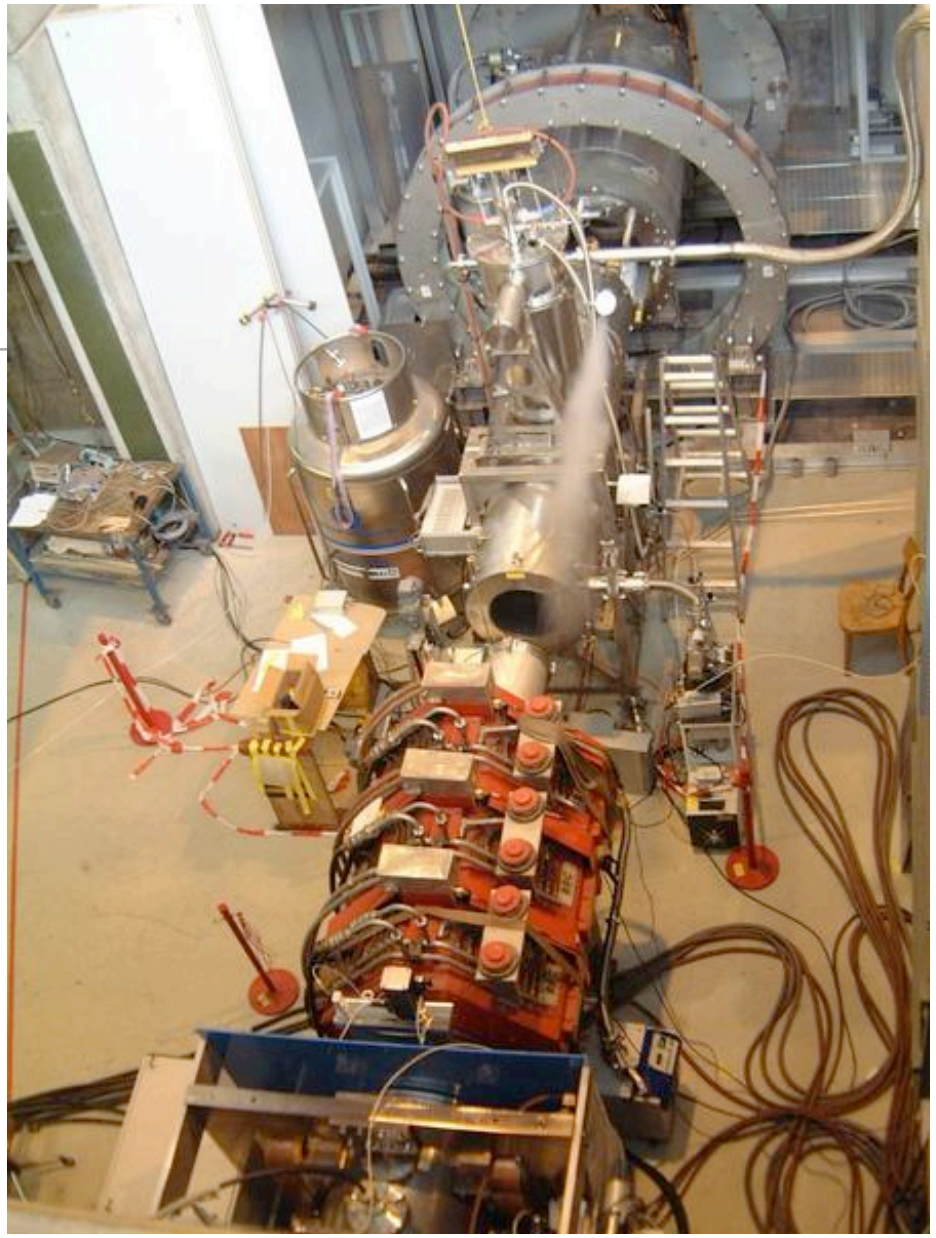
- PSI is the best place for μ→eγ search.
- 590MeV ring cyclotron
- Beam power over 1MW
- 2mA proton current (planned to go higher)
- Continuous muon beam
- MEG at PSI
  - 1998 LOI
  - 1999 Proposal
  - 1999 Approval



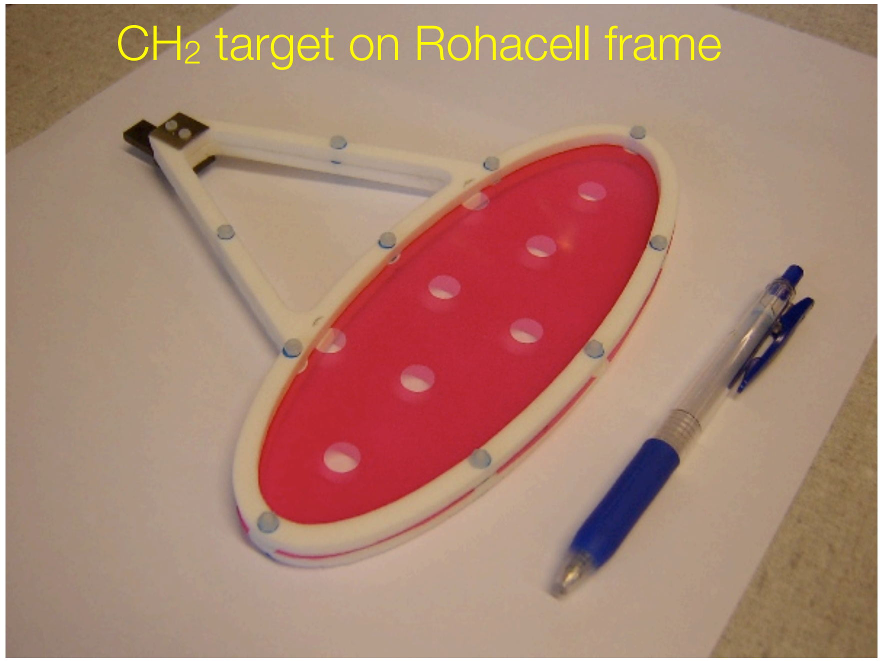

590MeV ring cyclotron

Beam Transport and Target

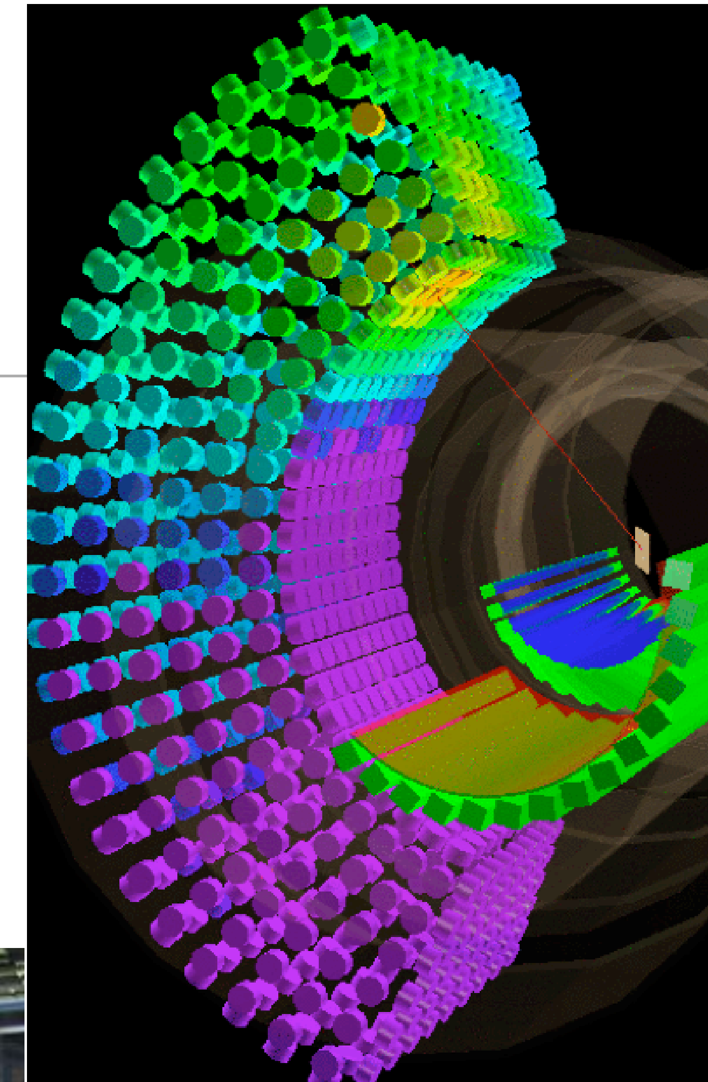




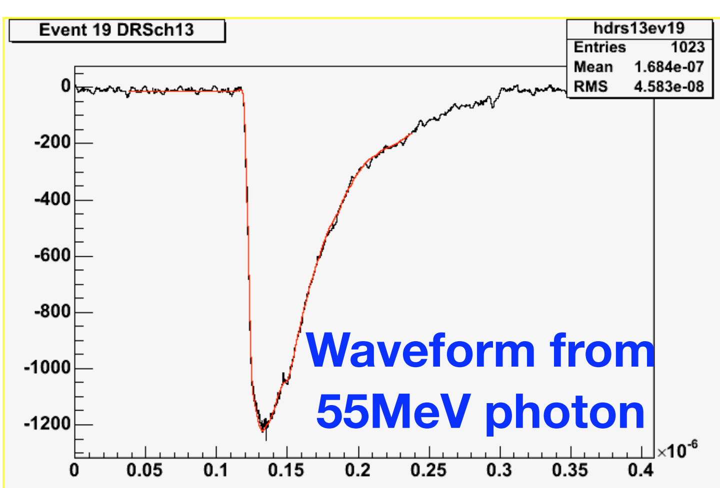
- Beam transport system
  - πE5 beam channel
  - 28MeV/c surface muon beam up to 10^8/sec
  - Wien filter for μ^+/e^+ separation
  - Superconducting transport solenoid with degrader
  - Beam spot size: σ~10mm
- Target
  - 205μm-thick polyethylene/polyester sandowitch target supported by Rohacell frame
  - Slanted angle 20.5°
  - holes (Φ10mm) to check vertex reconstruction

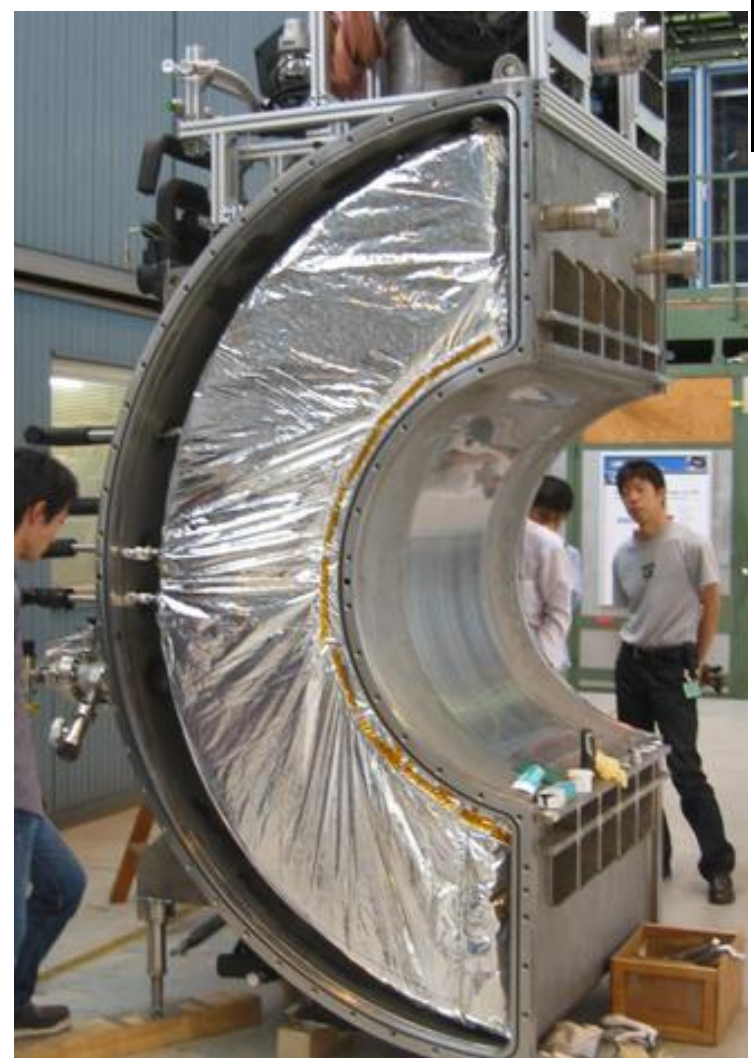


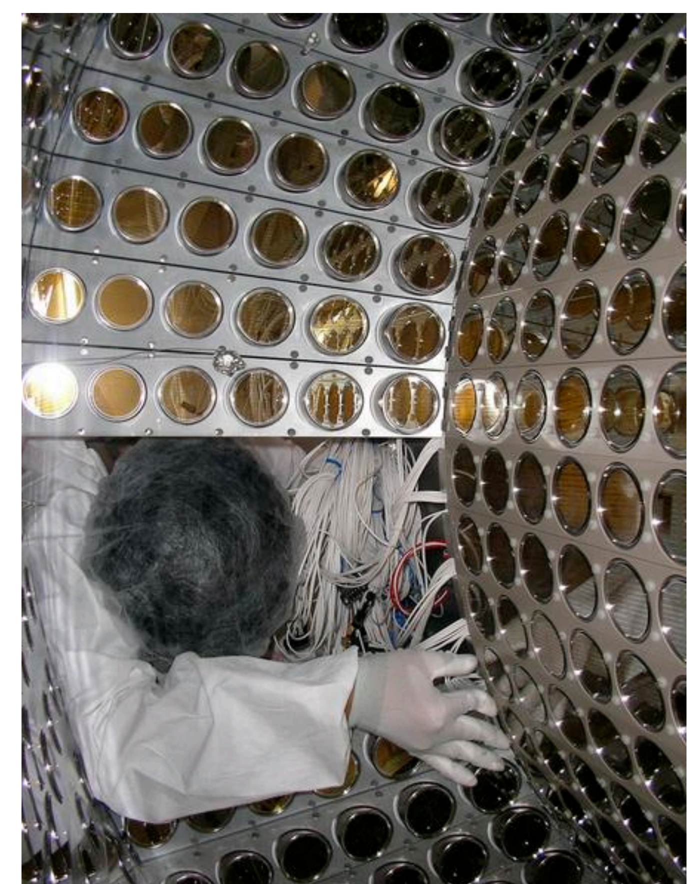
Liquid Xenon Scintillation Detector



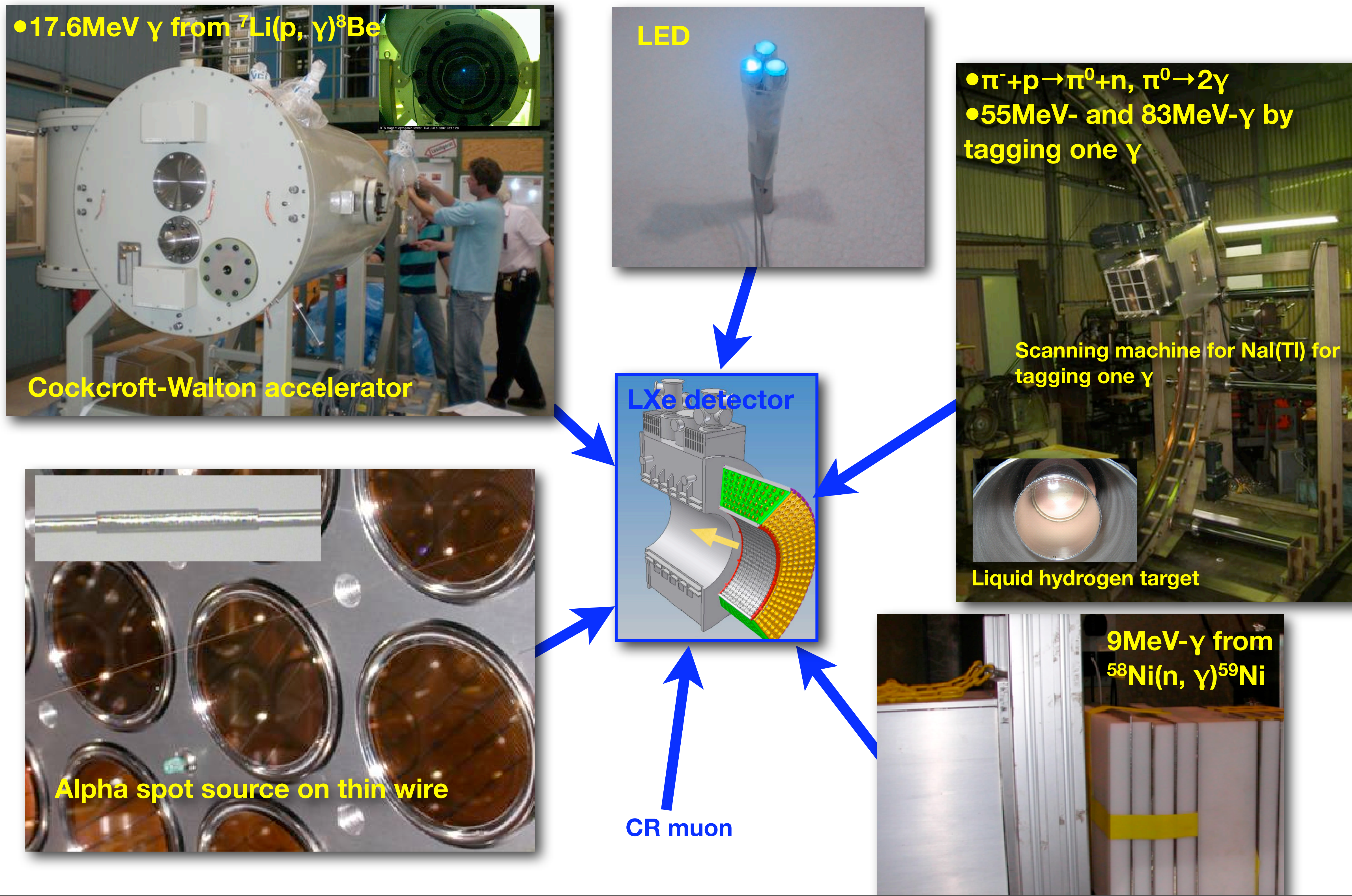
- World's largest LXe scintillation detector
- C-shape 800L LXe is surrounded by 846 photomulipliers (PMTs).
- How to measure high energy gamma-ray?
  - **Energy**: collect scintillation light as much as possible
  - **Position**: PMT output distribution
  - **Time**: average photon arrival time
- All PMTs are read out by waveform digitizer→pileup ID, particle ID



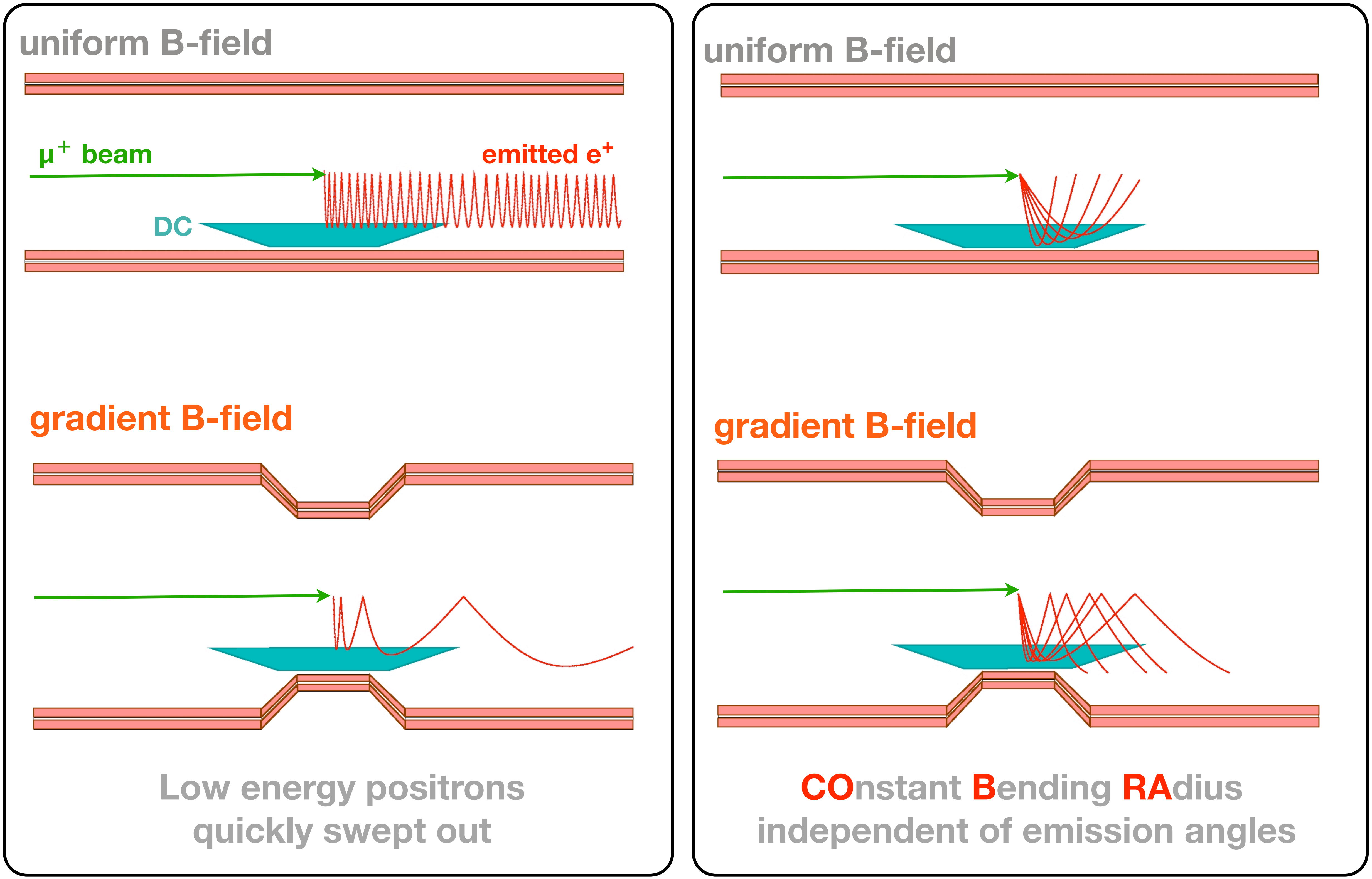




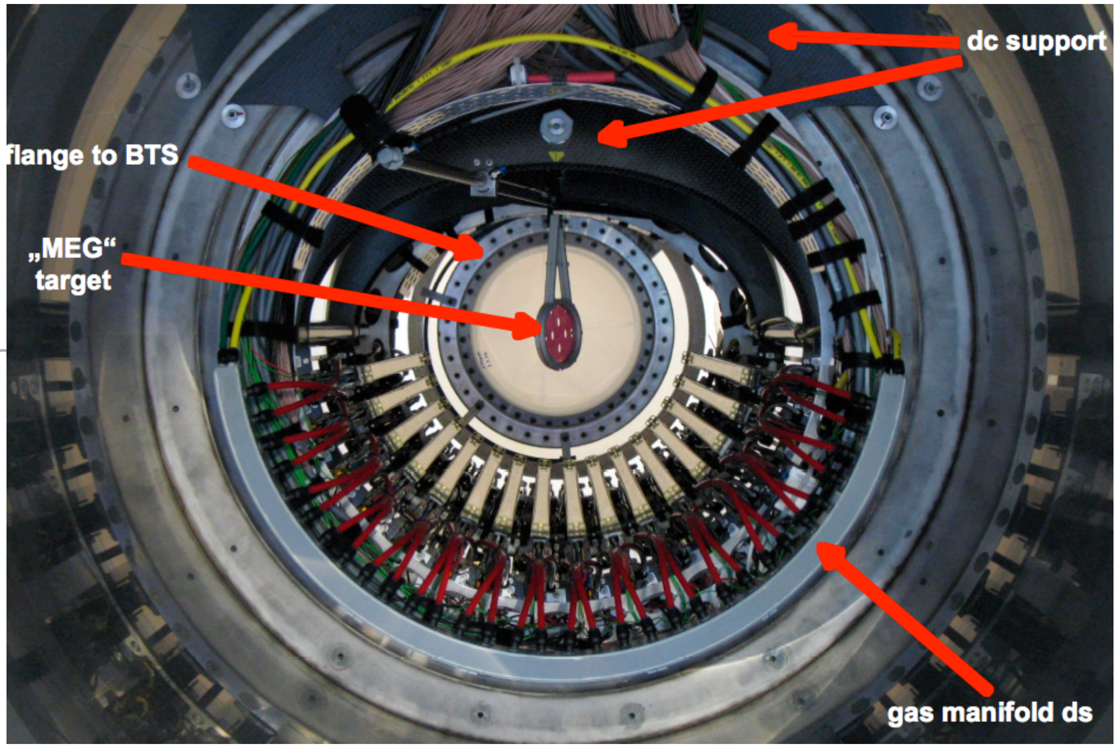
LXe Detector: Calibration and Monitoring



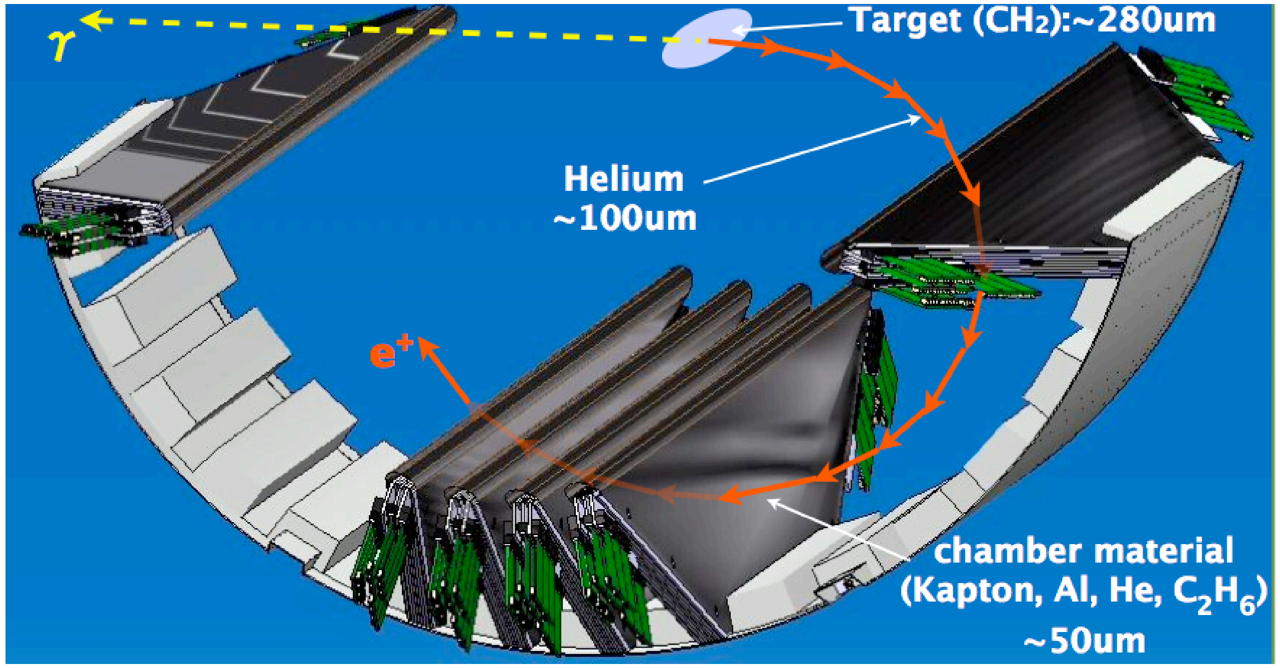
Positron Spectrometer: COBRA Concept

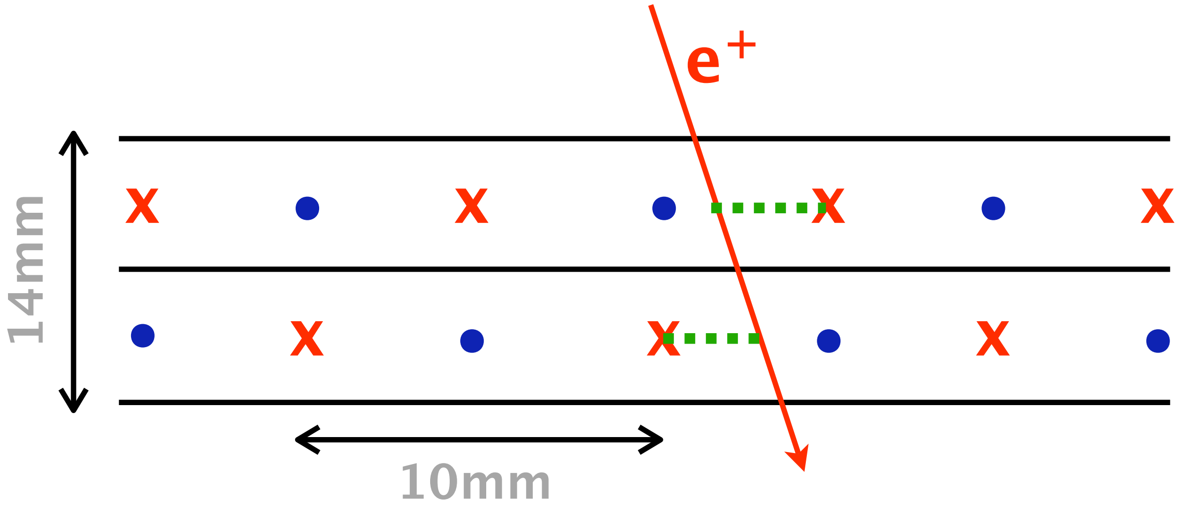


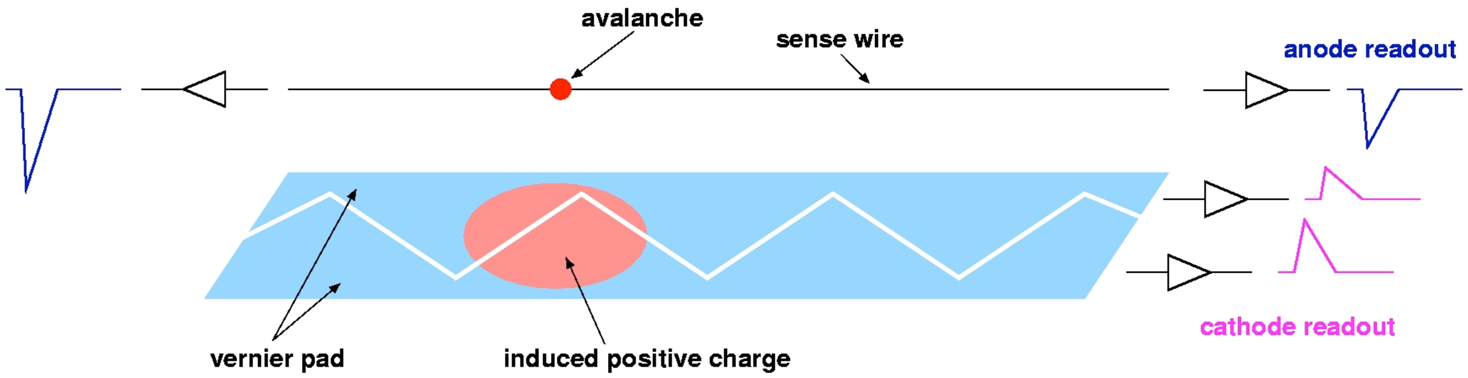
Drift Chamber System



- 16 chambers radially aligned with 10° intervals
- Minimize amount of material to avoid multiple-scattering and annihilation photon BG
- Two staggered layout of drift cells for R measurement (σ_R~100-200μm)
- Charge division on anode wire and Varnier pattern cathode pad to measure Z (σ_Z~300μm)

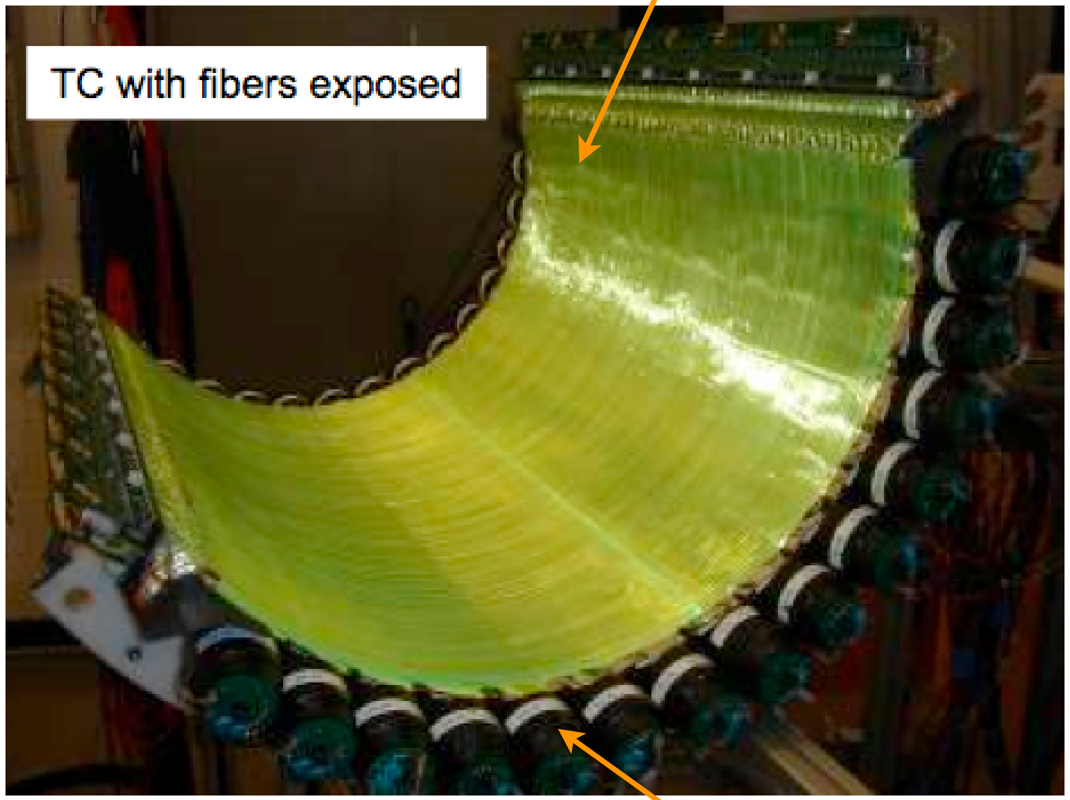






Timing Counter

- Fast timing counter for positron
- Phi-counter: scintillator bars read out by fine mesh PMTs at both ends to measure the positron timing.
- Z-counter: Scintillating fiber read out by APD for additional trigger information

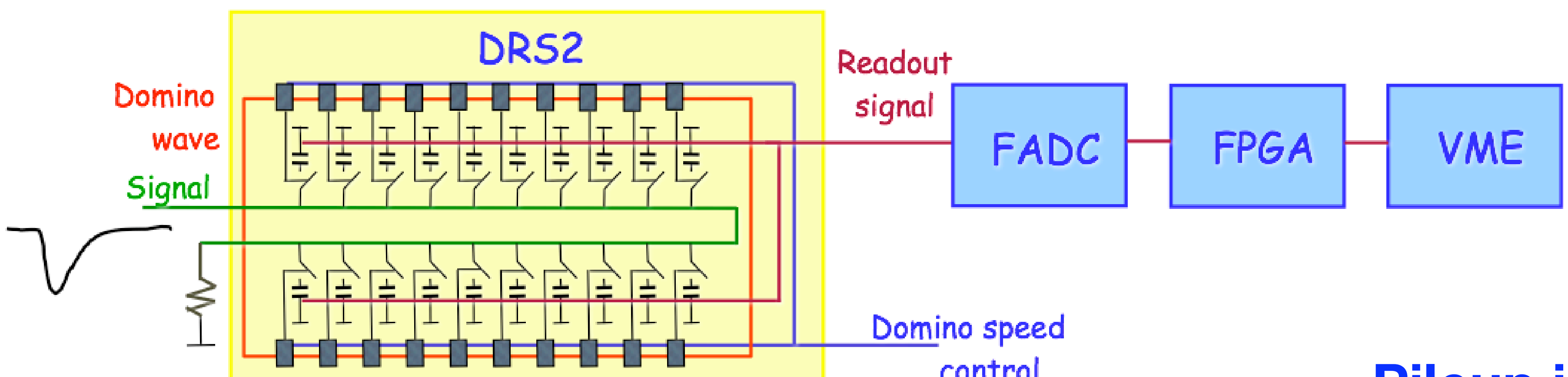


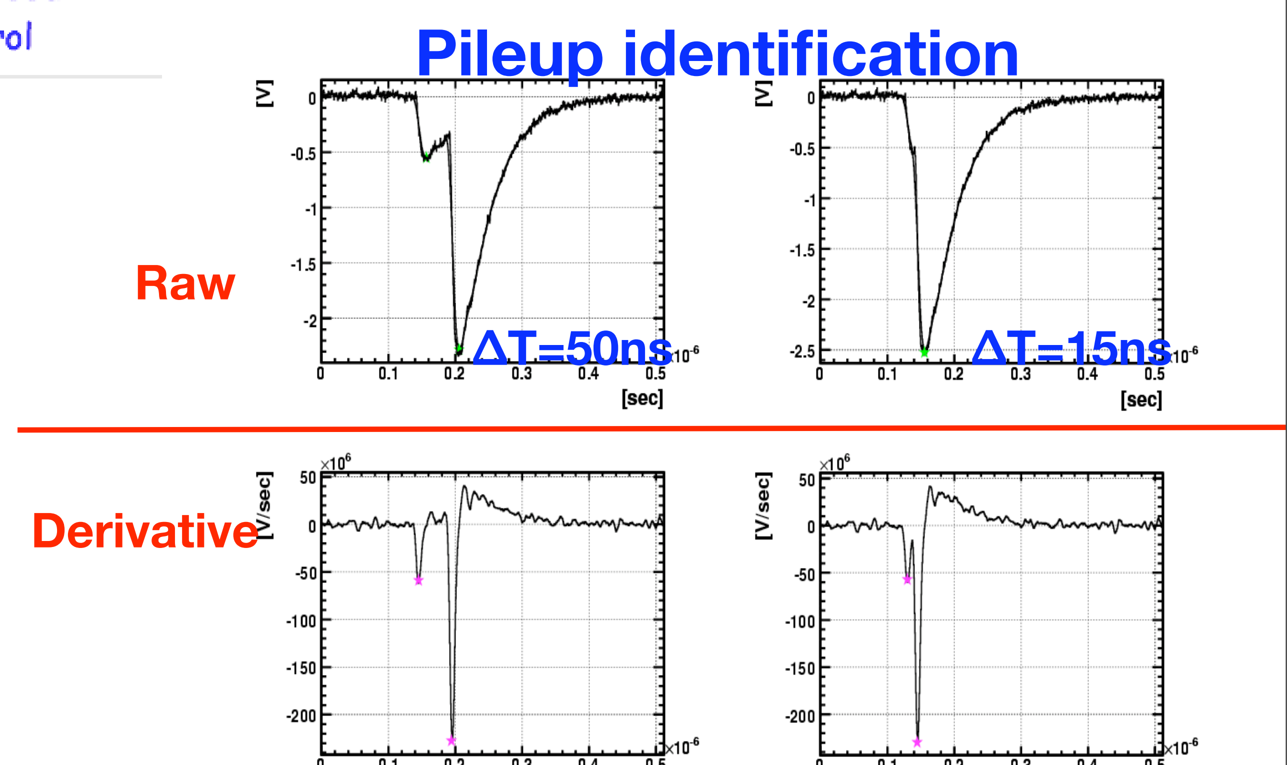
Comparison of long timing counters (from E. Nappi)

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	4x4x90	BC	R5924	270	38	

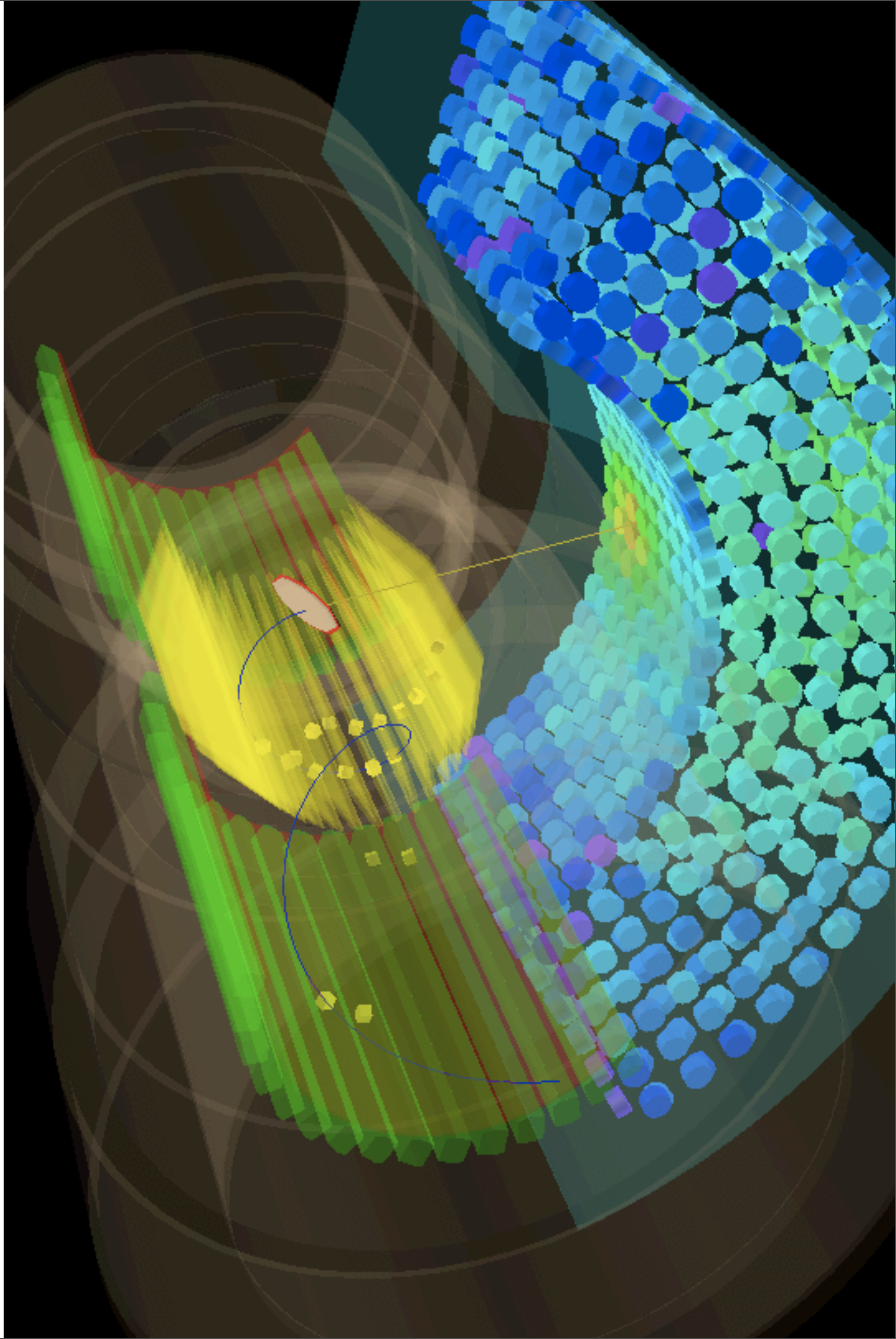
Waveform Digitizer

- All detectors will be read by Domino Ring Sampler (DRS) developed at PSI
  - Sampling speed: 1.6GHz for LXe and TC, 0.5GHz for DC
  - 1024 sampling cells





Run 2008



MEG in 2007

- Engineering run in 2007
- **All the main detector components assembled and operated.**
- **$\mu \to e\gamma$ trigger worked at expected rate.**
- Test physics run (~1-2days)
- Issues
  - LXe γ-detector
    - Low light yield due to impurity in LXe
    - HV feedthrough problem
  - e^+ spectrometer
    - Some layers were not operational in drift chamber system
    - Fiber counters in the TOF detector system are missing.
  - ...

MEG in 2008

- Solved (partly) the problems we had last year.
- **LXe detector**
  - Light yield recovered by a factor of two! by the purification
  - Calibration in full acceptance using high energy γ from π^0 decay
  - Long term stability
- **Drift chamber**
  - Some layers are not working at full efficiency due to tripping
- **Timing counter**
  - Fiber counters operational
- π^0 Dalitz decay for relative timing bw/ LXe detector and timing counter
- Reduced electric noise
- ...

MEG in 2008

- Solved (partly) the problems we had last year.
- **LXe detector**
  - Light yield recovered by a factor of two! by the purification
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  - Fiber counters operational
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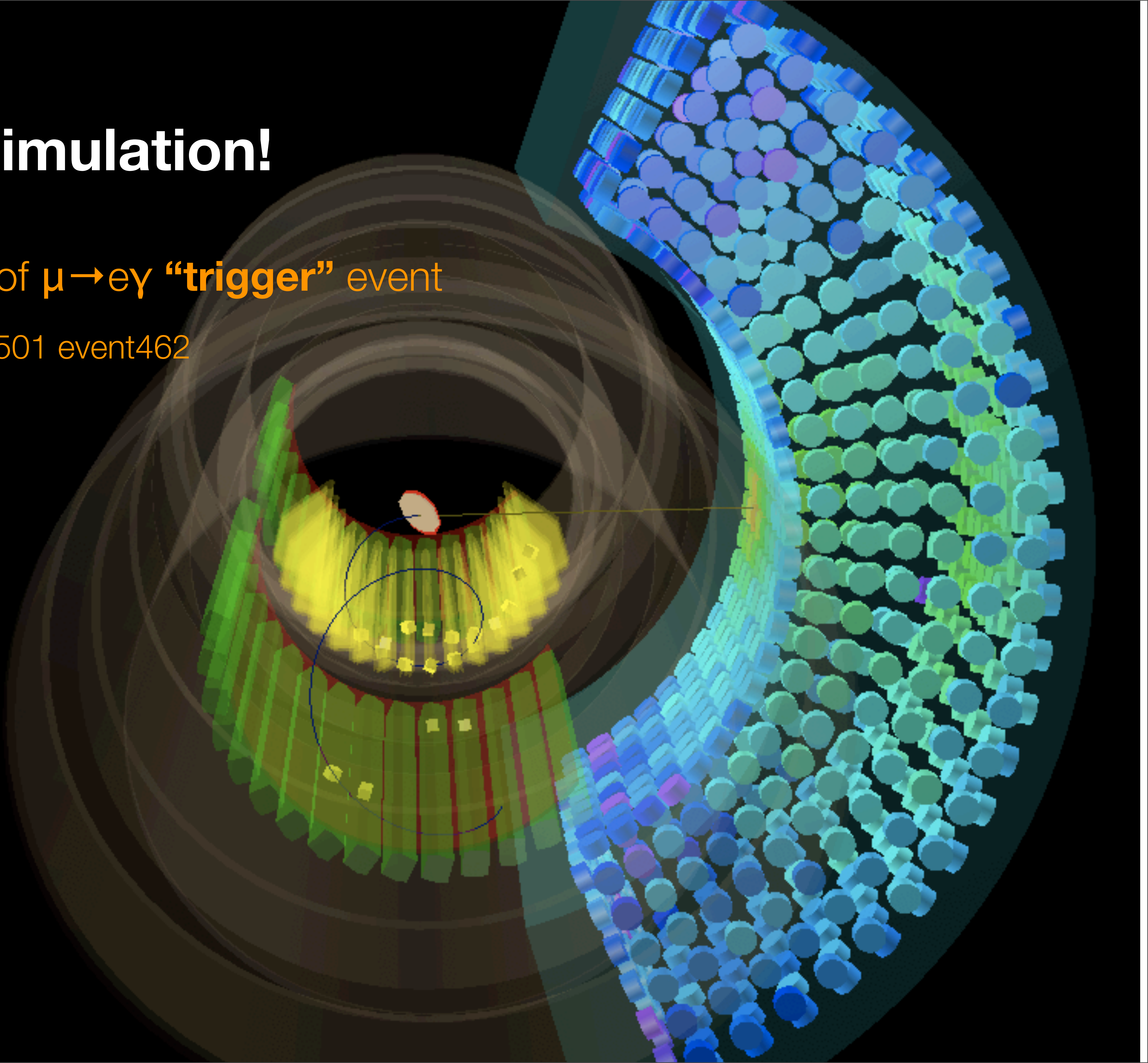
- Reduced electric noise
- ...

Started physics data production on Sep. 12th!

Not a Simulation!

Example of $\mu \rightarrow e\gamma$ **“trigger”** event

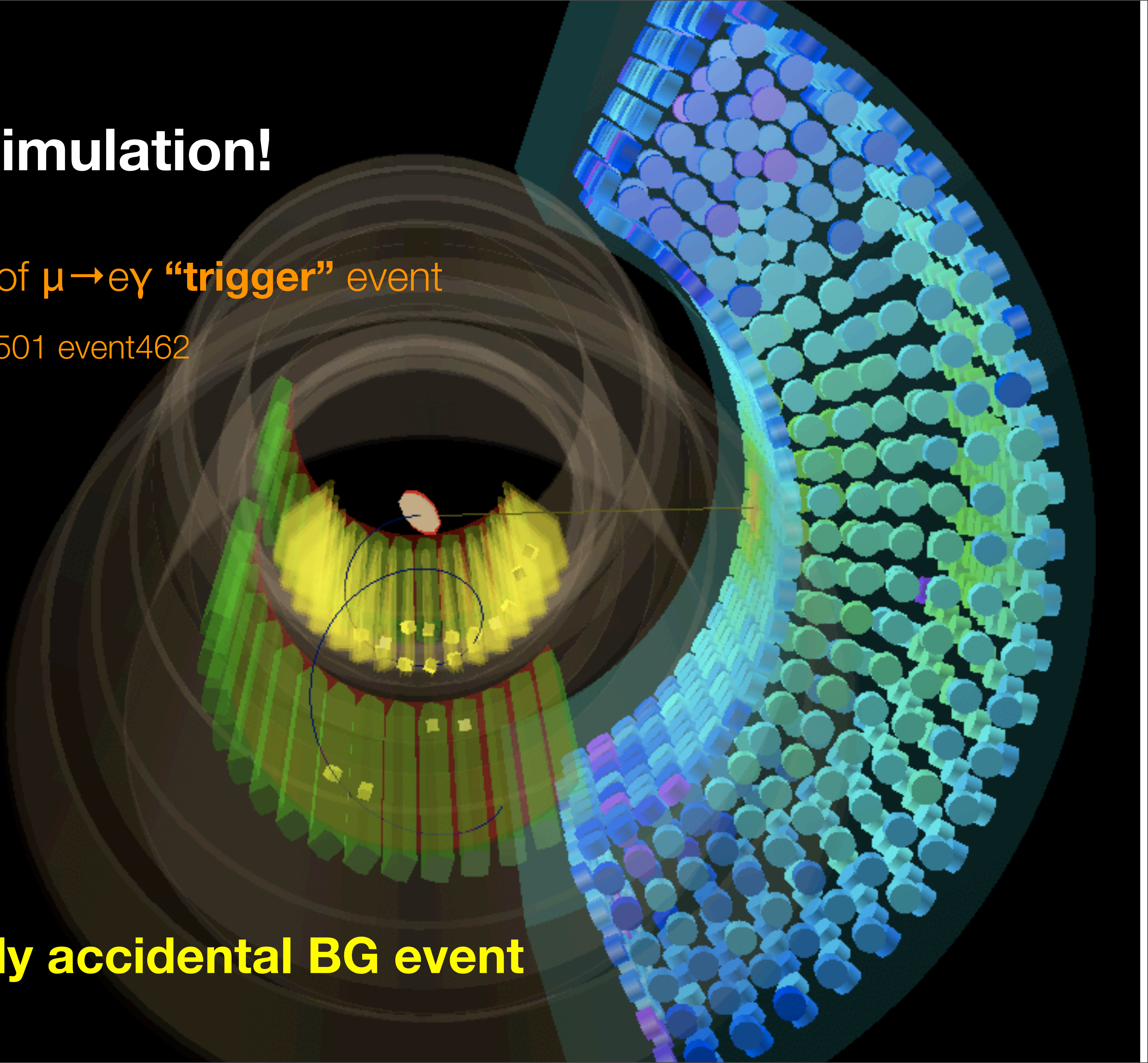
Run#24501 event462



Not a Simulation!

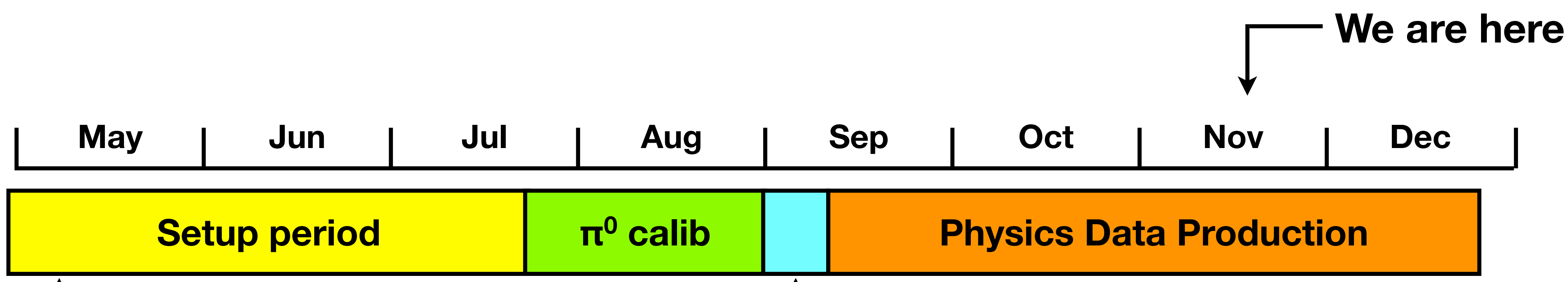
Example of μ→eγ **“trigger”** event

Run#24501 event462



Most likely accidental BG event

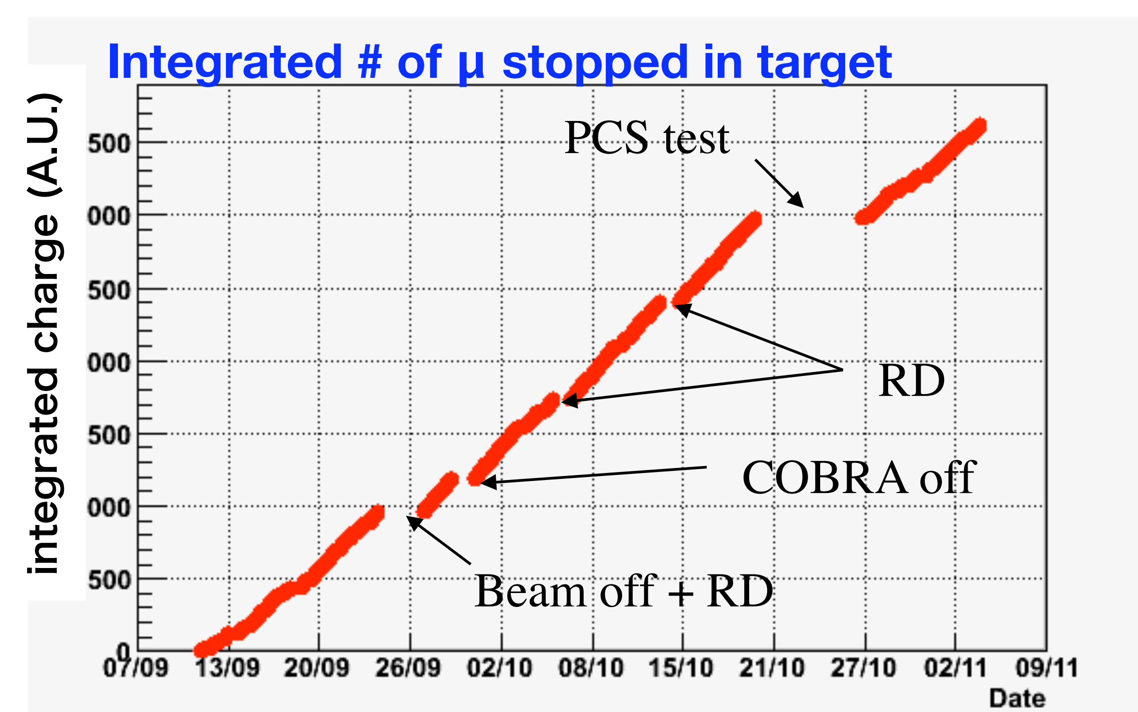
Run Schedule 2008



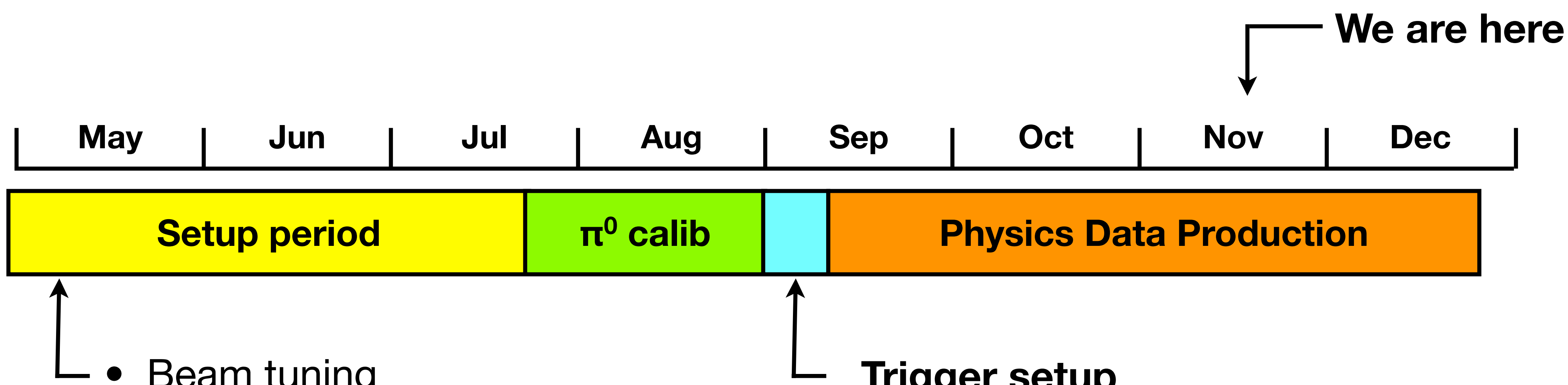
- Beam tuning
- Detector assembly
- Test and debugging
- LXe purification
- Electronics modification
- ...

Trigger setup

- Trigger setup
- Beam intensity study
- Single BG measurement



Run Schedule 2008



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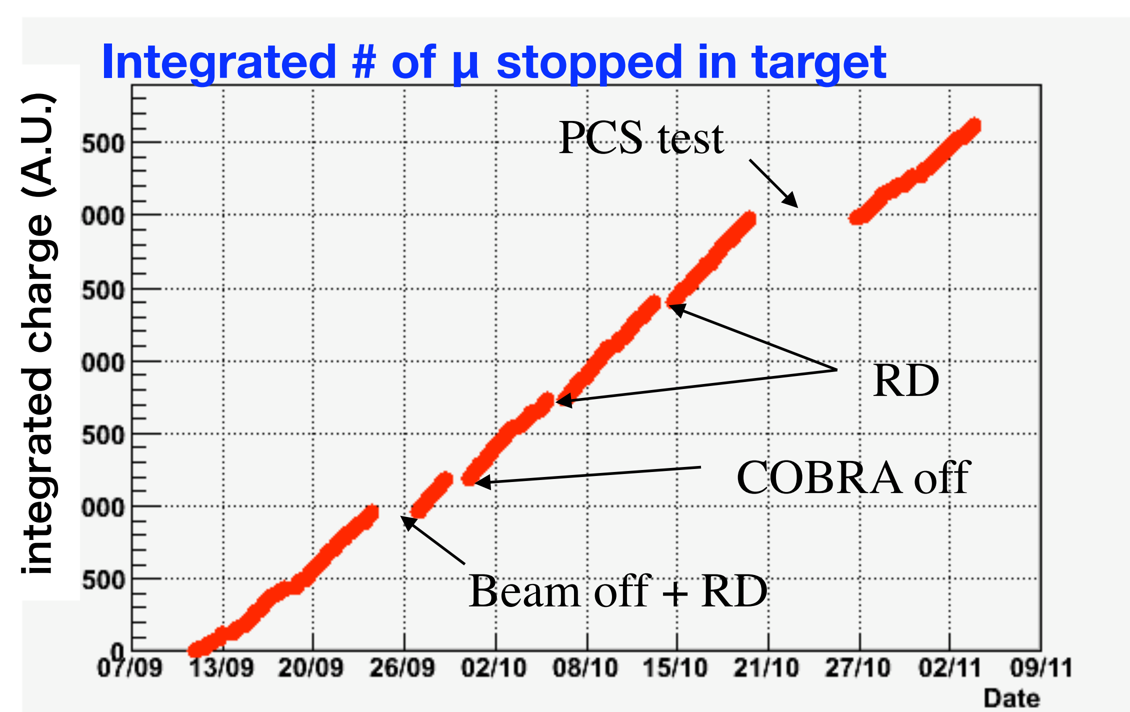


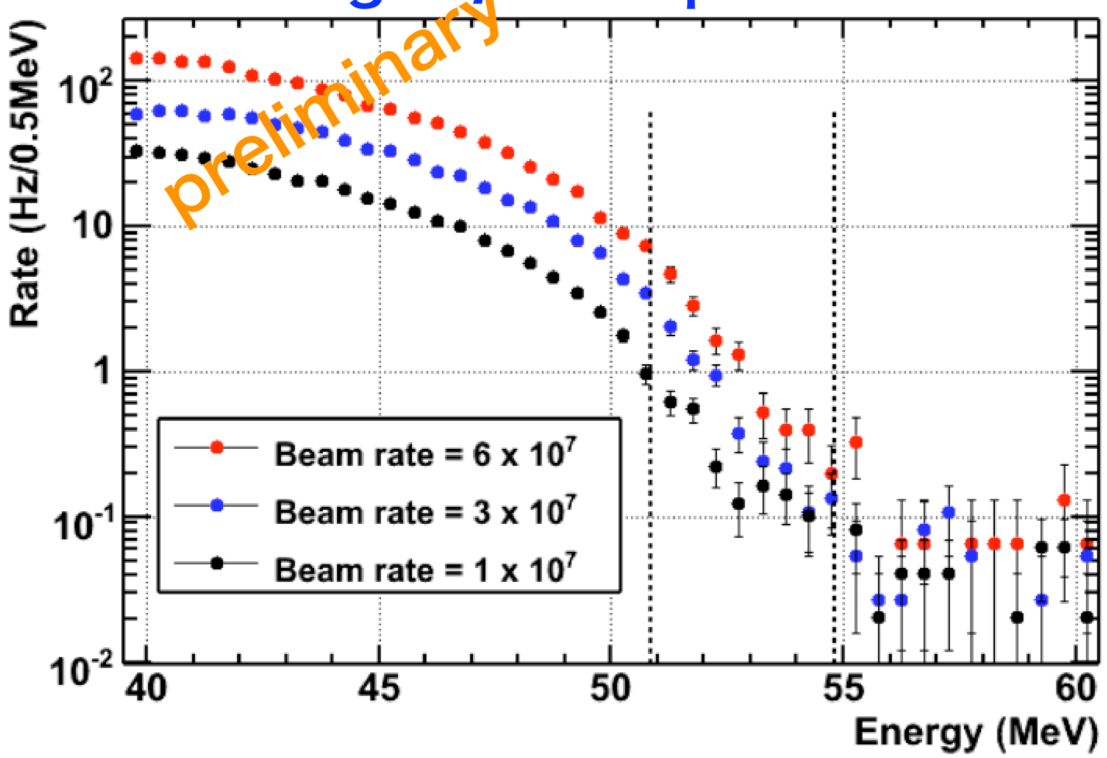
Goal of run 2008

- *First physics-data production (~12week)*
- ***"Significant" physics result***

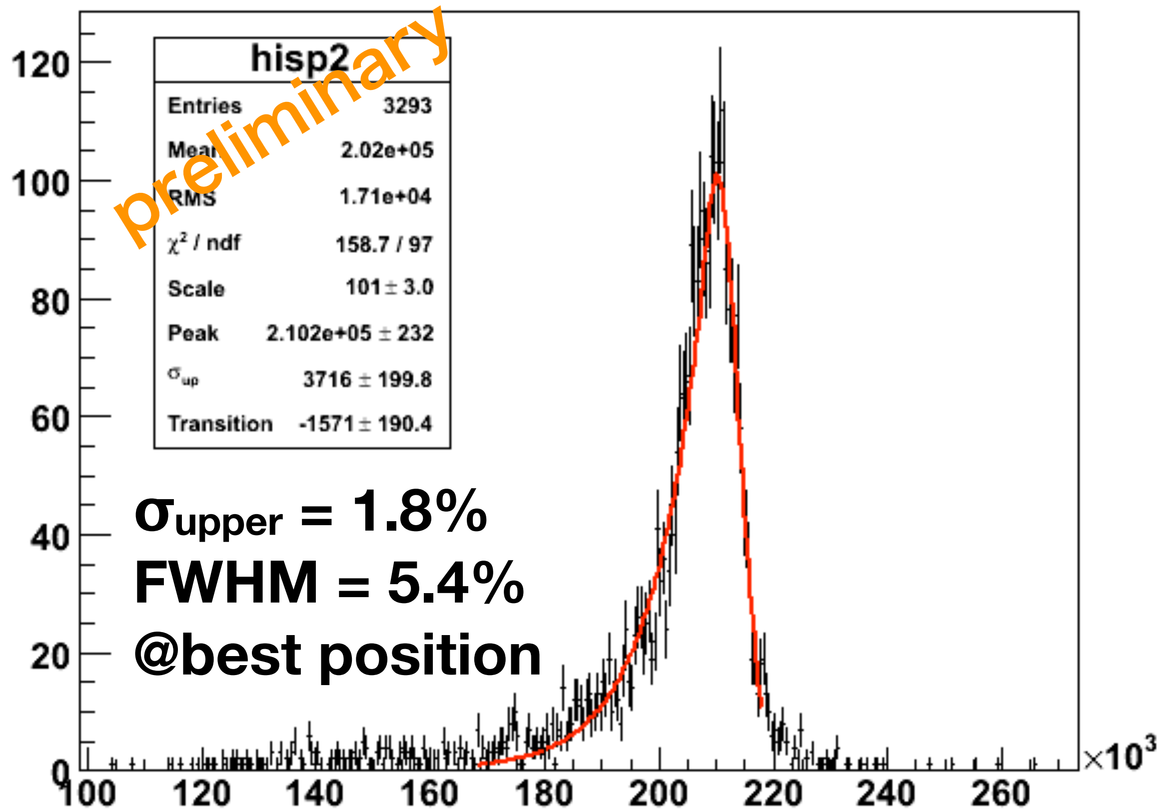
LXe Detector: Performance 2008

- LXe detector calibrated in full acceptance with 55- and 83-MeV γ from π^0 decay
- Systematic non-uniformity of detector response. Yet to be studied.

Single γ BG spectrum

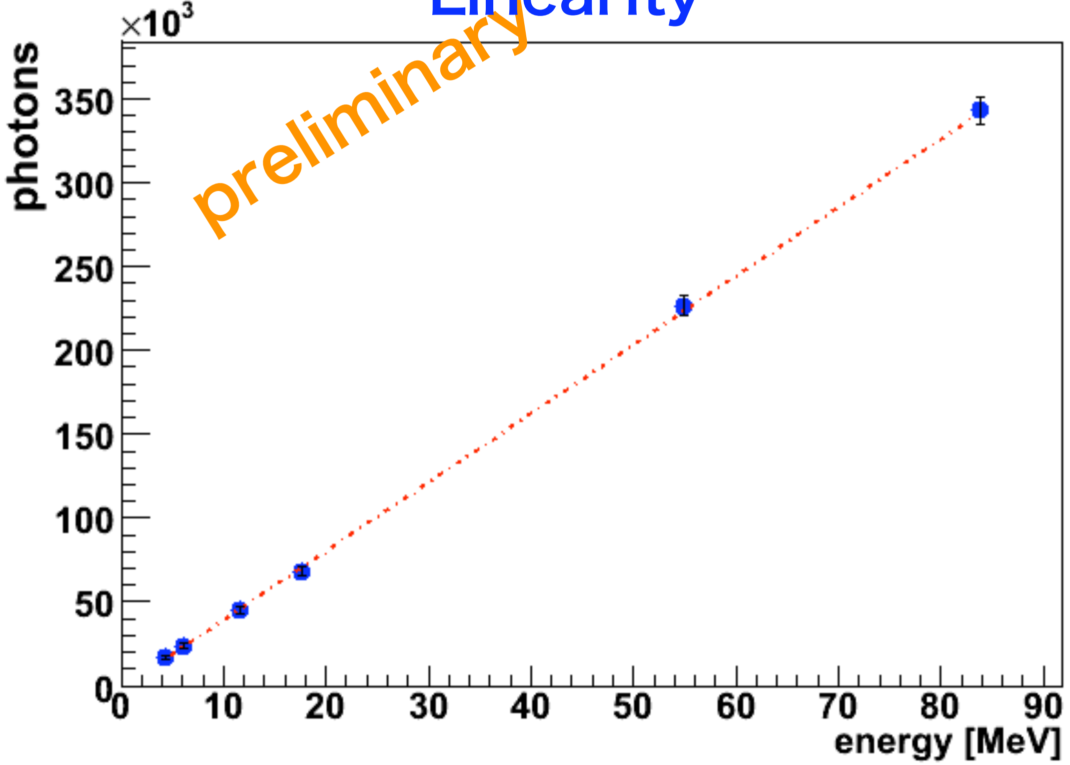


Energy resolution @55MeV-γ



cf.) σ_{upper} = 2.4% (last year)

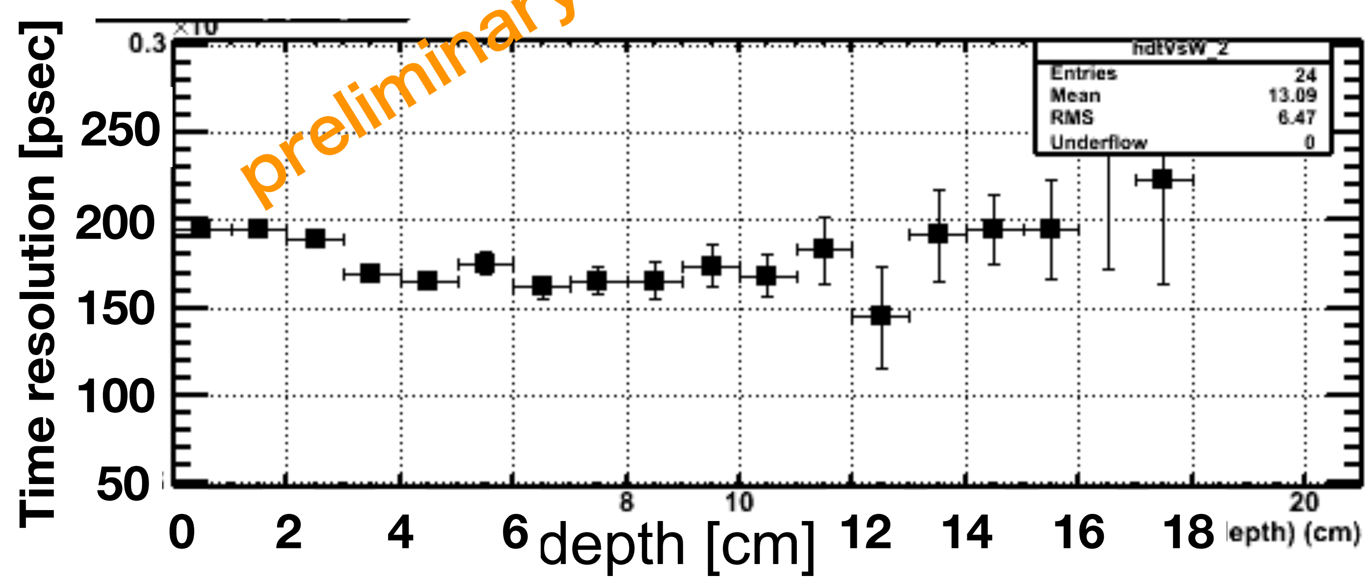
Linearity



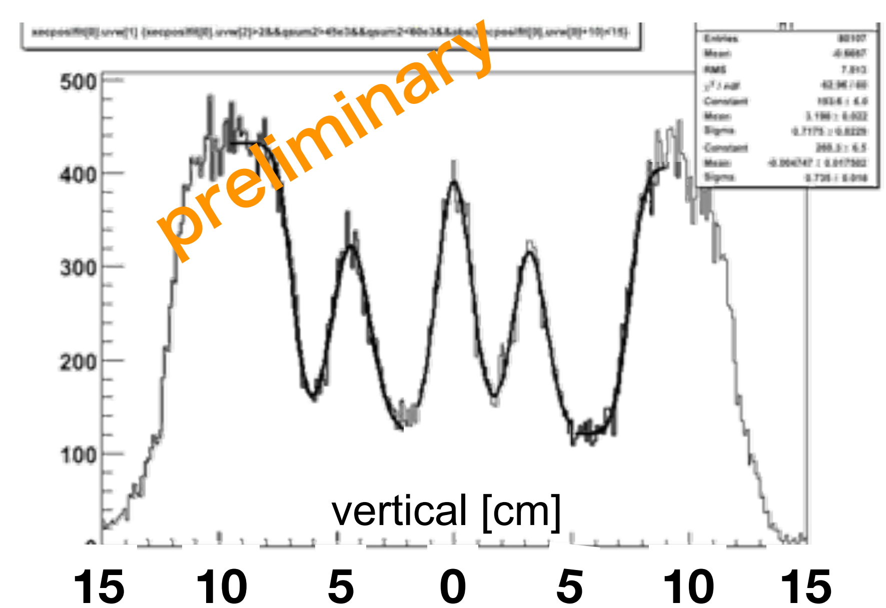
LXe Detector: Performance 2008

- **Timing resolution** for 55MeV-γ
  - Relative time between LXe and timing counter with pre-shower converter
  - LXe timing resolution = 160ps - 70ps(timing counter) - 60ps(target)

    = **130ps (σ)**



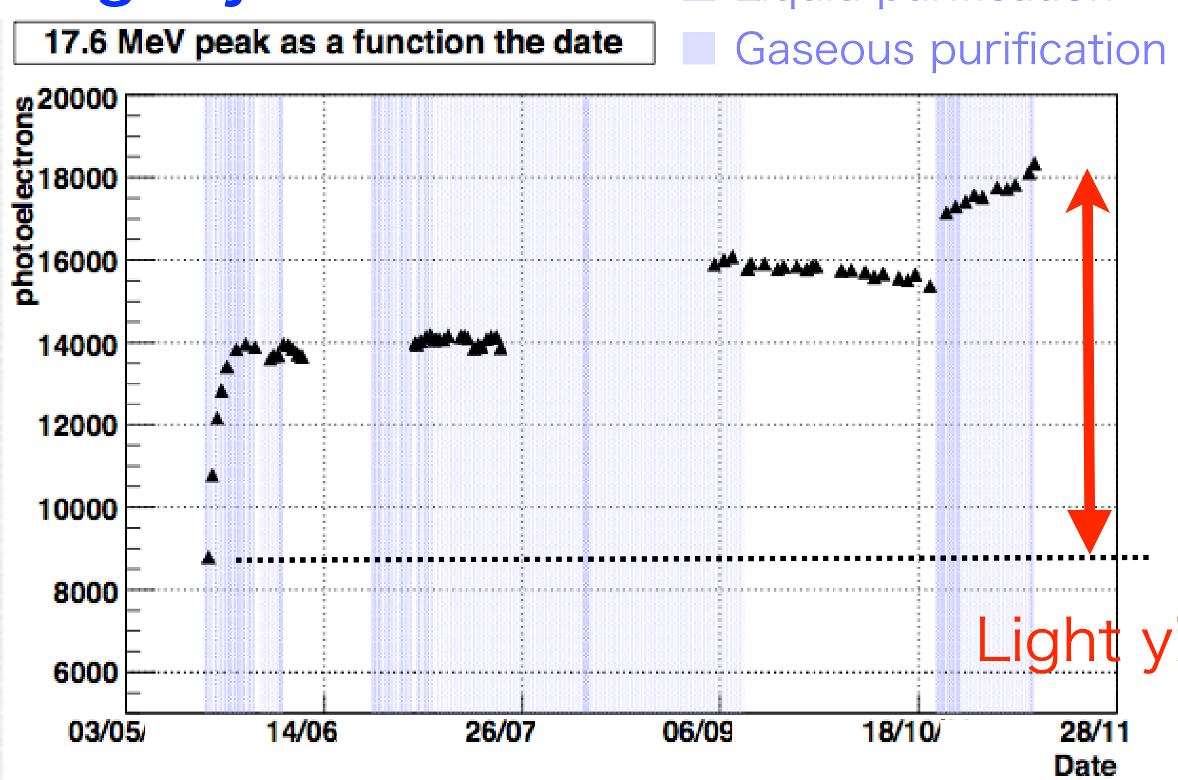
- **Position resolution** for 55MeV-γ
  - Shadows of lead collimator slits
  - LXe position resolution
    - **0.5cm (σ) @ edge**
    - 0.65cm (σ) @ slit (need further analysis)



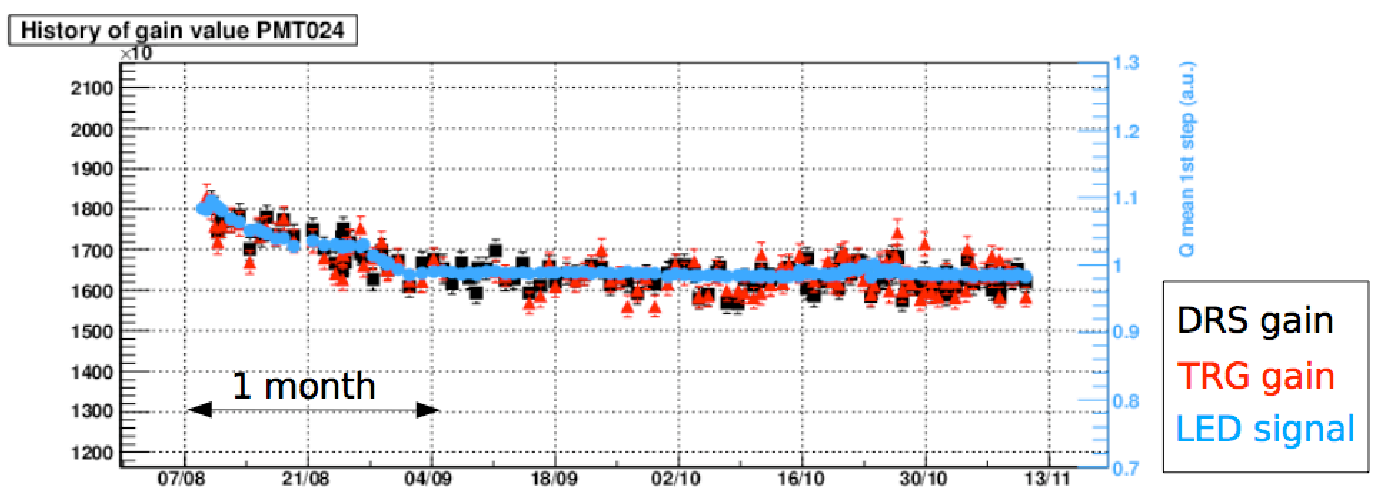
LXe Detector: Calibration and Monitoring

- **Continuous**: PMT gain monitoring with LED
- **Daily**: PMT gain measurement
- **Every second day**:
  - Calibration with monoenergetic γ from nuclear reaction using proton from Cockcroft-Walton accelerator
  - Alpha sources on wire

Light yield



PMT gain

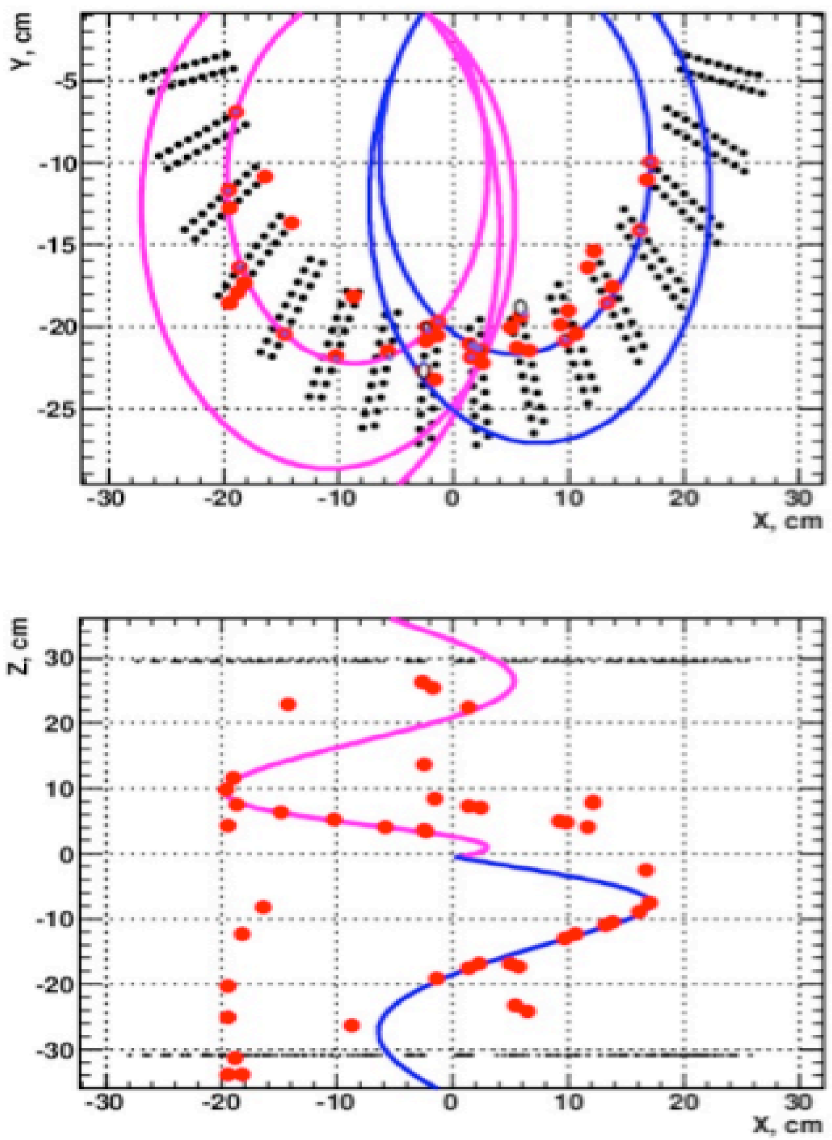


Light yield improved by a factor of two!

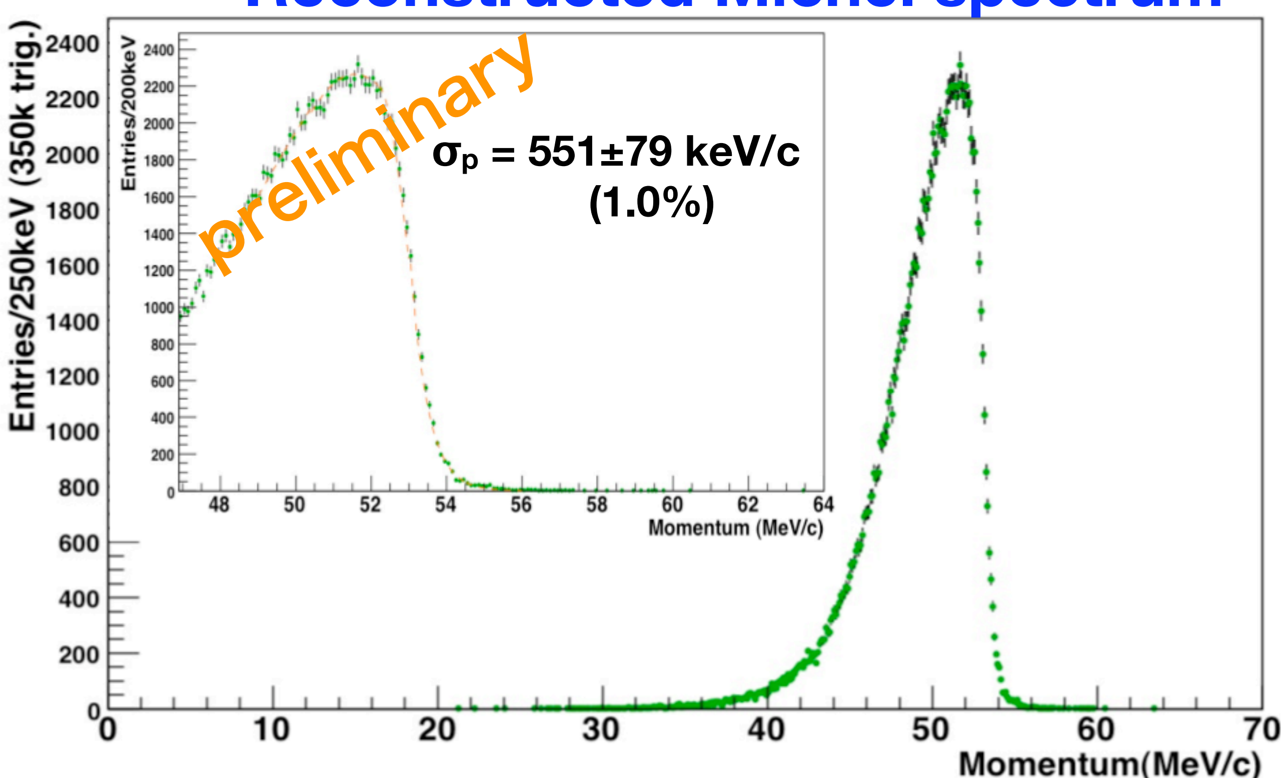
Drift Chamber: Performance in 2008

- Calibration
  - Alignment done with Michel-positron tracks
  - Z- and R-resolutions are measured with Michel positron
  - Momentum resolution measured at the edge of the Michel spectrum
- Low efficiency due to frequent tripping of some chambers

Reconstructed tracks



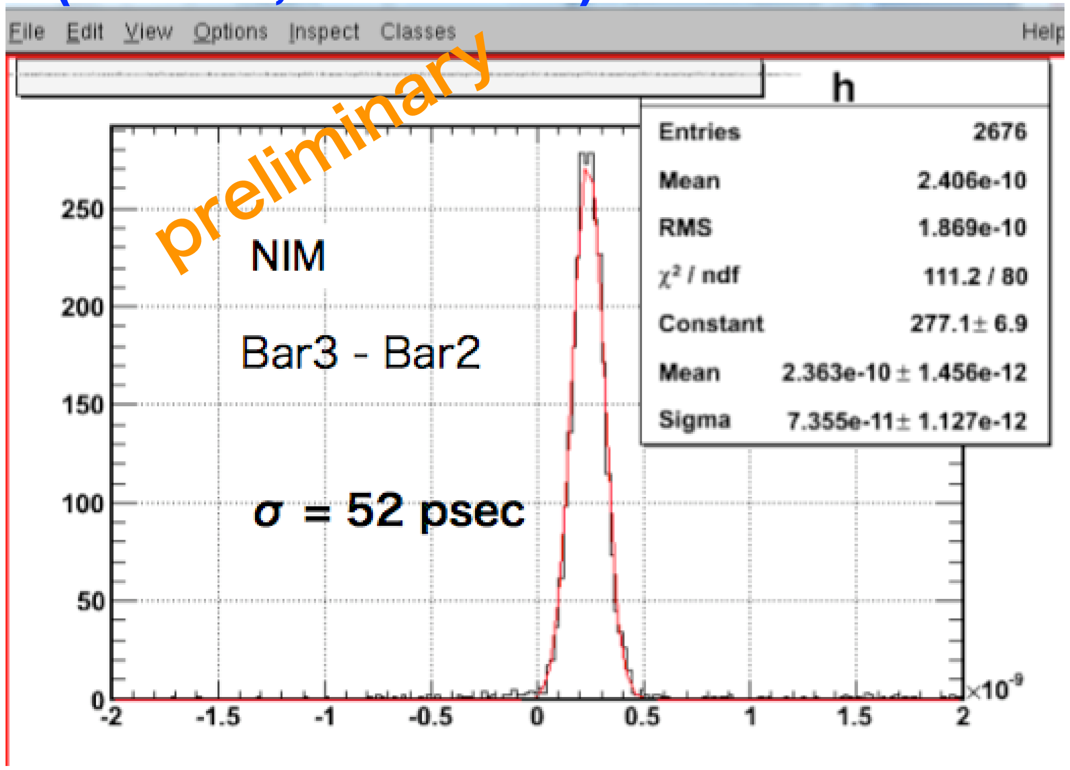
Reconstructed Michel spectrum



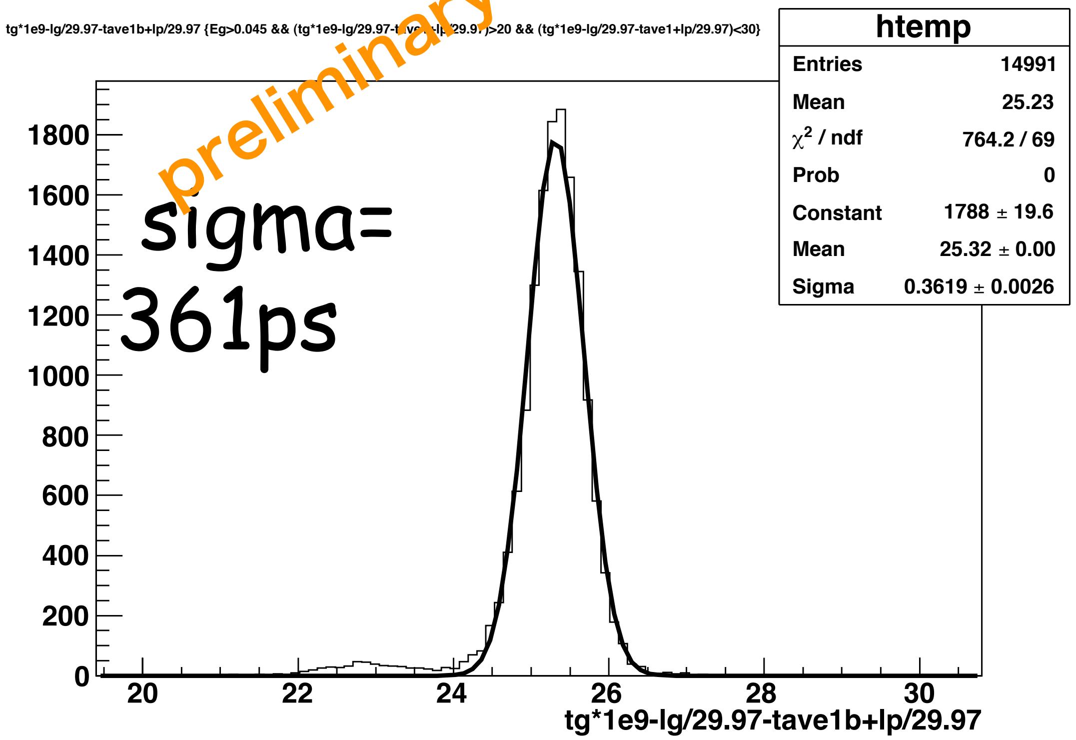
Timing Counter: Performance in 2008

- Time calibration
  - Time coincident γs (4.4 and 11.7MeV) from B(p, γ)C using protons from CW accelerator
  - Cosmic ray
  - Dalitz π^0 decay ($\pi^0 \rightarrow \gamma e^+ e^-$) for calibration of $T_{e\gamma}$
  - Radiative decay (to be studied)

TC time resolution (intrinsic, in run 2007)



$T_{e\gamma}$ distribution in Dalitz π^0 decay



Background and Sensitivity

To be updated

	Goal Measured	Goal Simulation	2007 Measured	2008 Prospects
Gamma Energy (%)	4.5-5.0		6.5	
Gamma Timing (nsec)	0.15		0.27*	
Gamma Position (mm)	4.5-9.0		15.	
Gamma Efficiency (%)	>40		>40	
e^+ Timing (nsec)	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 (sec^{-1})	3×10^7		3×10^7	2.8×10^7
Running Time (week) (1 week = 4×10^5 sec)	100			12
Single Event Sensitivity	0.5×10^{-13}			8.5×10^{-13}
Accidental Rate	$0.1\text{-}0.3 \times 10^{-13}$			
# of Accidental Events	0.2-0.5			
90% CL Limit	2×10^{-13}			$<10^{-11}$

* added another 0.25nsec for BG evaluation (DRS time synchronization)

Physics Analysis

- Do we find $\mu \to e\gamma$ event(s) in data 2008?

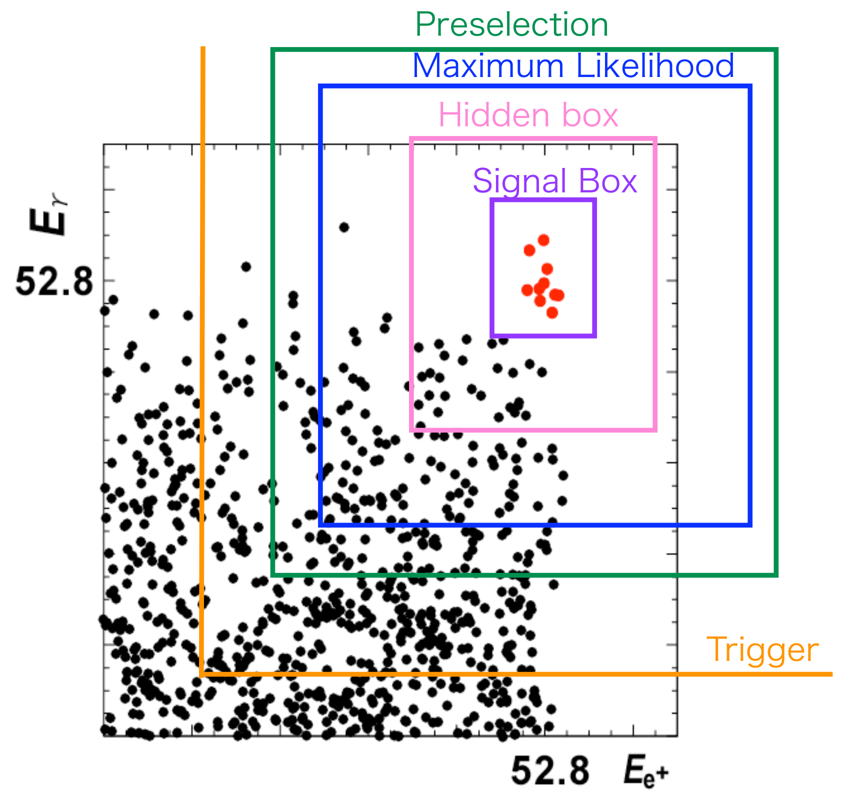
Physics Analysis

- Do we find $\mu \rightarrow e\gamma$ event(s) in data 2008?
  - $\rightarrow$ We don't know yet, because...

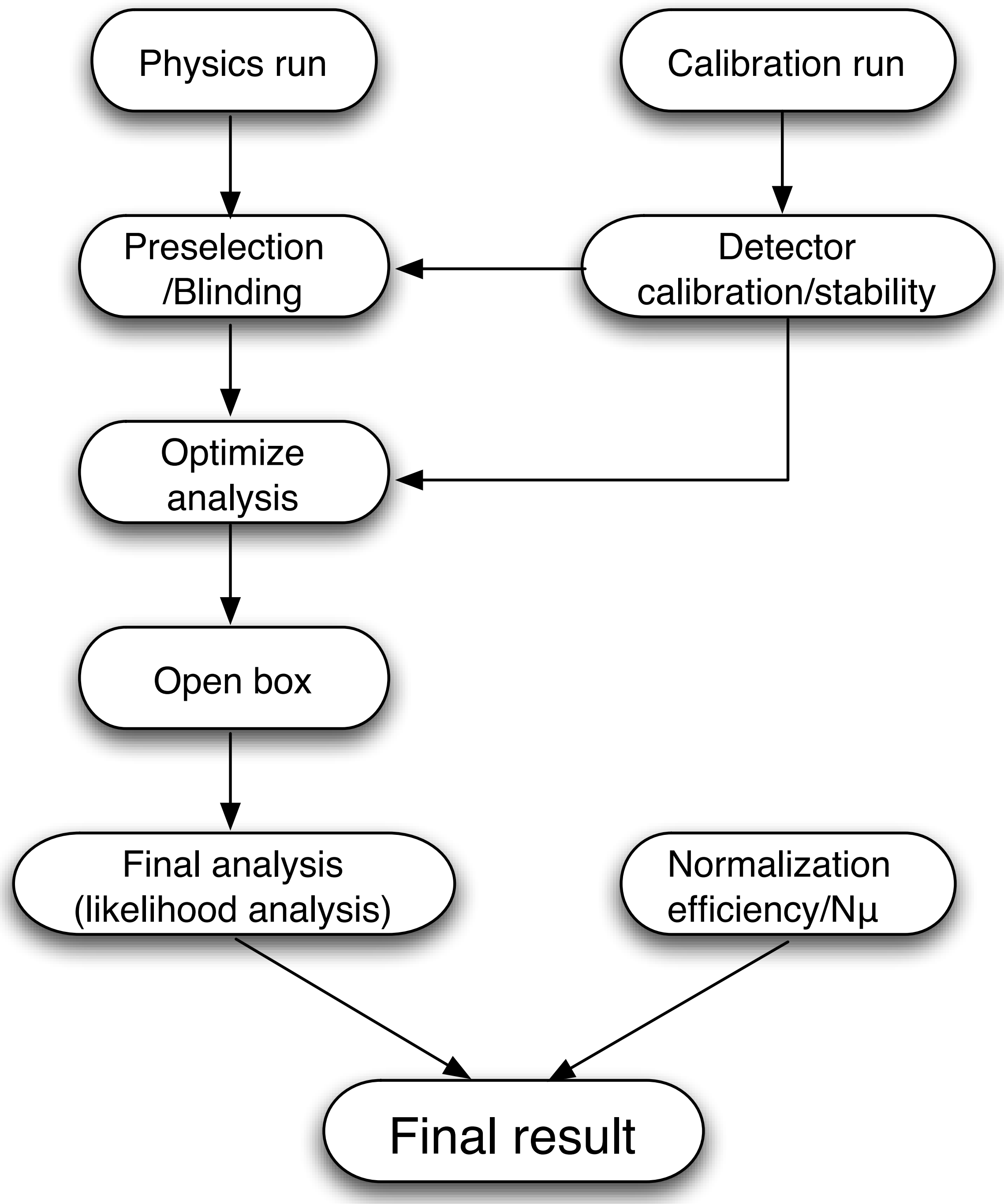
Physics Analysis

- Blind analysis: **Hidden signal box**
- **Maximum likelihood analysis**
- Preselection for data reduction and efficient analysis
- **Framework/tools are ready and being tested.**

Analysis Window Definition with MC data



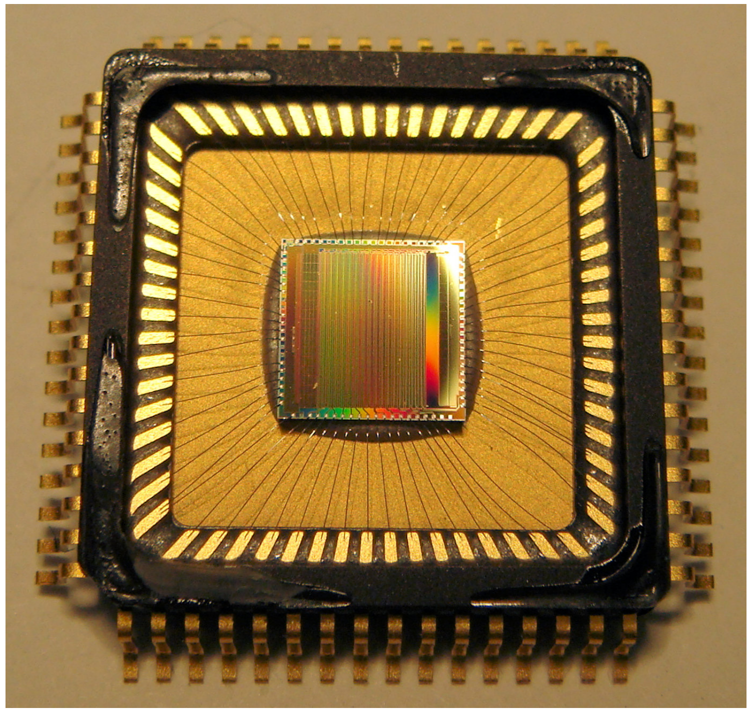
Planned analysis flow



How about Next Year or Later?

- **Various improvements in detector performance are expected next year**
  - Detector calibration still being improved.
  - New waveform digitizer (DRS4) will be installed for run 2009
    - Better time synchronization among the chips
    - Better temperature dependence
    - Ghost pulse problem solved
    - Prototype under testing.
  - Further improvement of light yield in LXe?
    - Still lower than expected (a factor of two).
  - Spectrometer performance
    - Problem of chamber tripping to be solved.
  - Reconstruction algorithms to be improved.

New digitizer chip (DRS4) Prototype



Summary

- MEG experiment seeks evidence for the LFV process, $\mu \to e\gamma$.
- All detectors assembled again and calibrated for run 2008.
- **We finally started physics-data production in September!**
- Detector performance is still to be optimized.
- Goal of run 2008
  - **Physics data production for ~12 weeks**
  - **Get the first but "significant" physics result with a sensitivity improving the present experimental bound (BR < 1.2×10^{-11})**
- MEG is expected to reach a sensitivity at a few x 10^{-13} branching ratio in a few years of data taking.

Conclusion

We hope to have the first physics results sometime next year.

Conclusion

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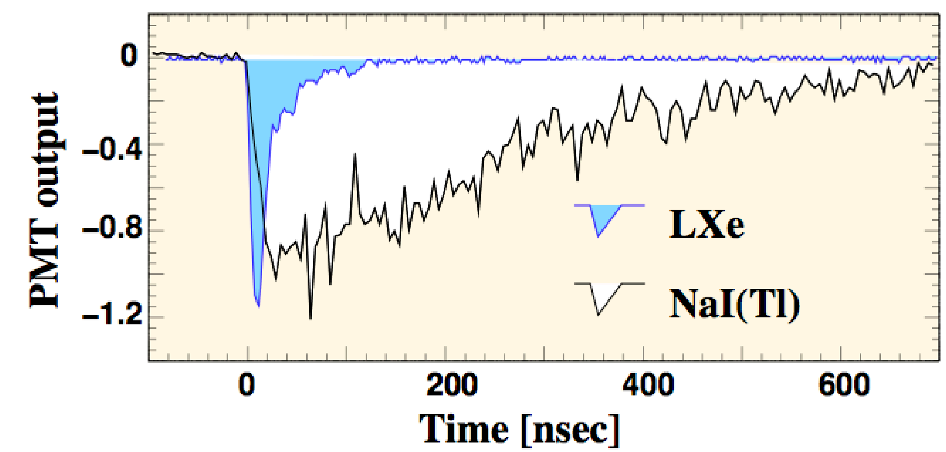
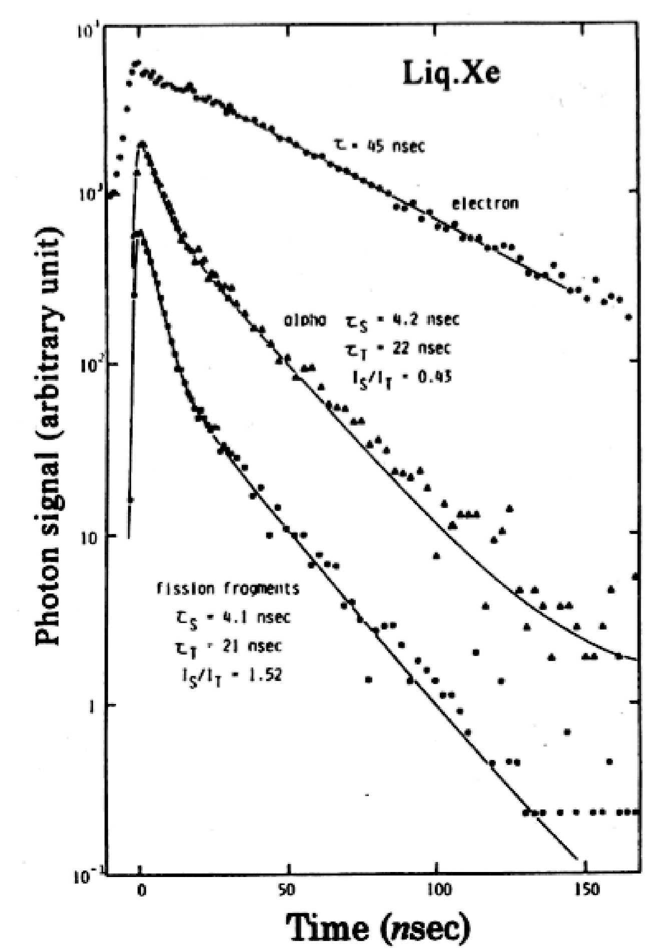
End of Presentation

Backup slides

Liquid Xenon Photon Detector, cont'd

- Why LXe?
  - High light yield (75% of NaI(Tl))
  - Short radiation length (X_0=2.77cm)
  - Fast response (τ=4.2ns, 22ns, 45ns)
  - Homogeneous
  - Can be large and non-segmented
  - Purification even after the construction
  - No self-absorption of scintillation light





Excitation

$$\begin{aligned} \mathrm{Xe} + \mathrm{Xe}^* &\rightarrow \mathrm{Xe}_2^*, \\ &\rightarrow 2\mathrm{Xe} + h\nu \end{aligned}$$

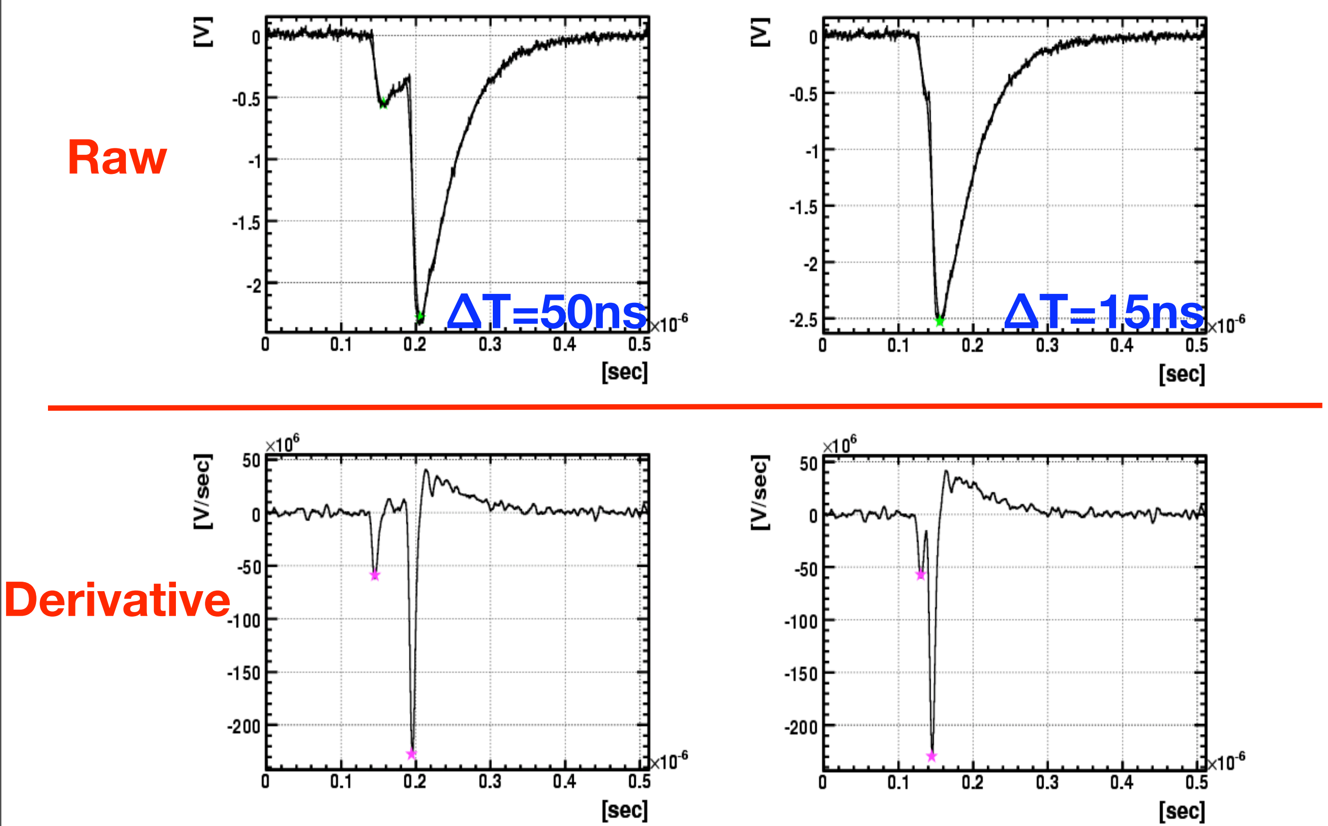
Ionization and recombination

$$\begin{aligned} \mathrm{Xe}^+ + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^+, \\ \mathrm{Xe}_2^+ + e &\rightarrow \mathrm{Xe}^{**} + \mathrm{Xe}, \\ \mathrm{Xe}^{**} &\rightarrow \mathrm{Xe}^* + \mathrm{heat}, \\ \mathrm{Xe} + \mathrm{Xe}^* &\rightarrow \mathrm{Xe}_2^*, \\ \mathrm{Xe}_2^* &\rightarrow 2\mathrm{Xe} + h\nu, \end{aligned}$$

Pileup Identification in LXe Detector

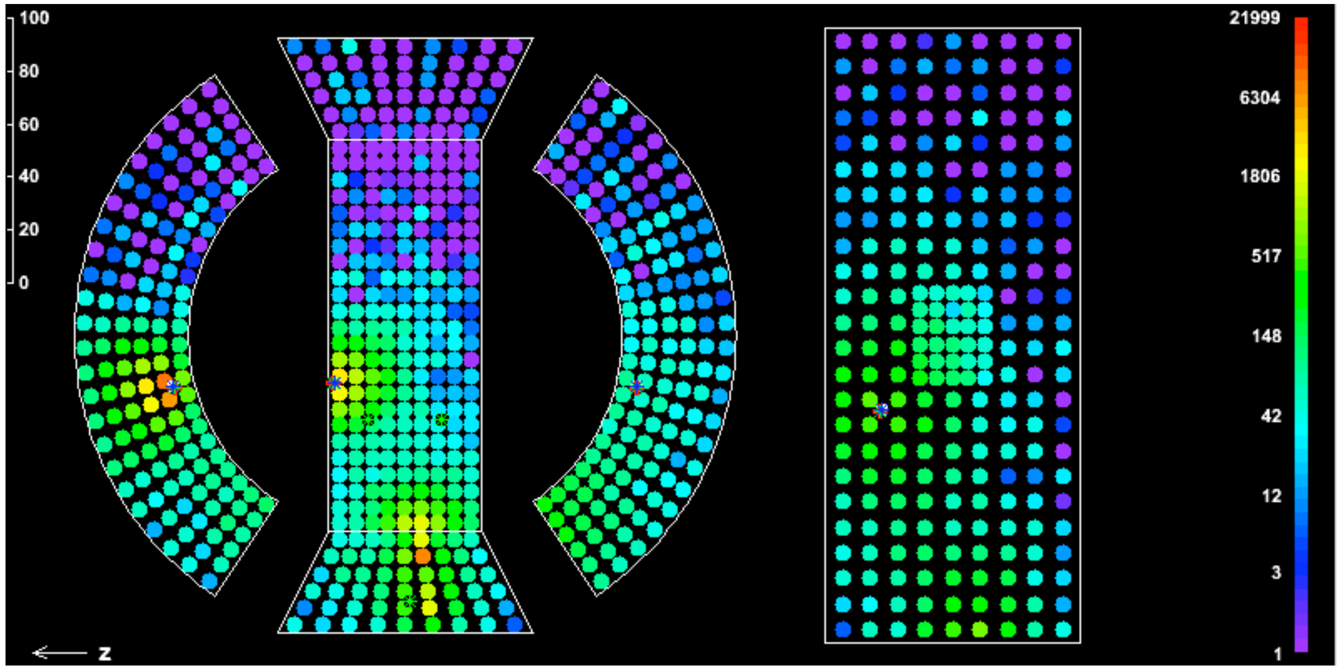
Waveform analysis

(peak finding and pulse shape fitting)



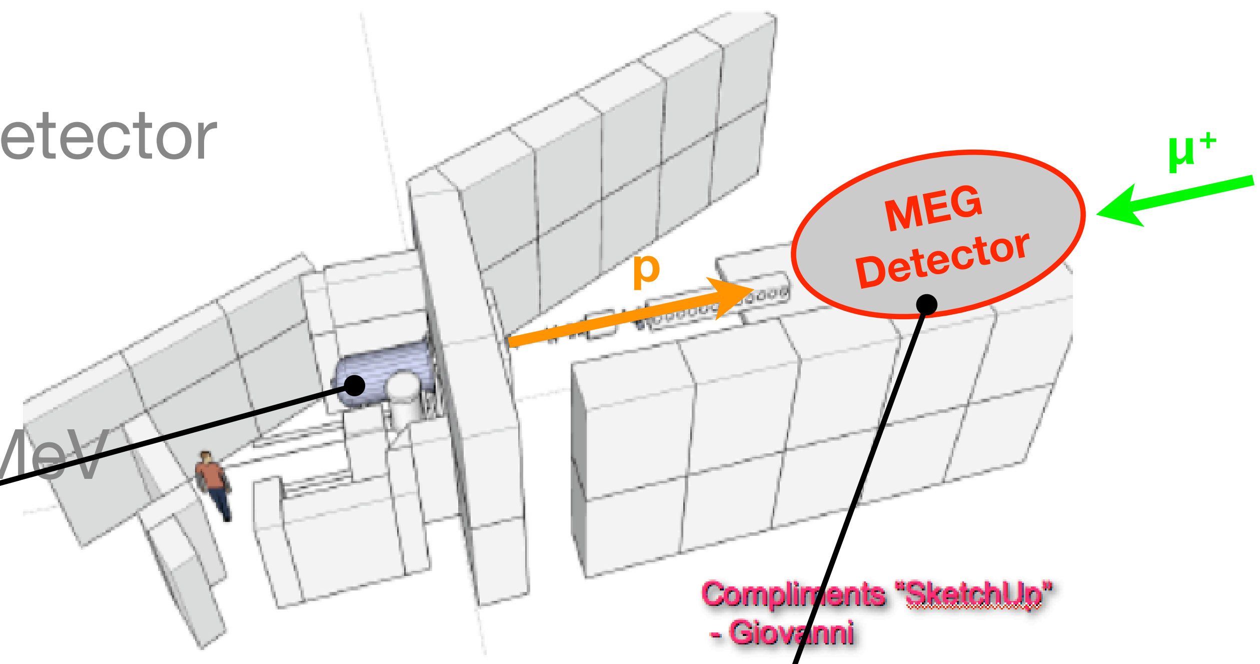
Peak finding in PMT output distribution

PMT output distribution in front face

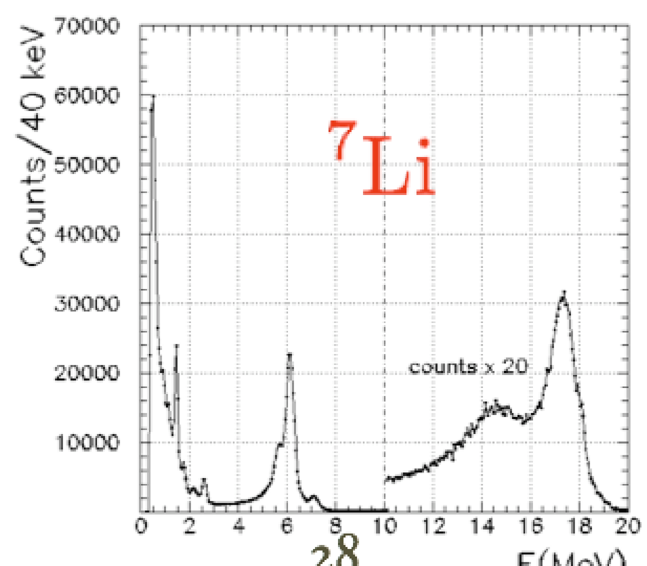


MEG Cockcroft-Walton Accelerator

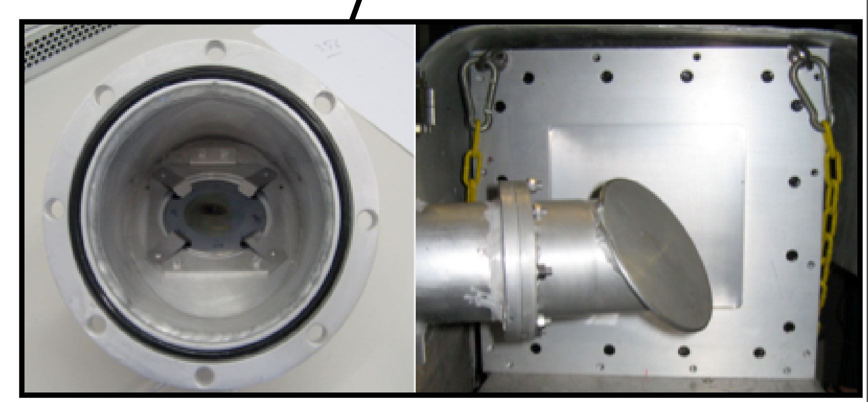
- Cockroft-Walton proton accelerator dedicated for calibration of LXe detector
- Placed at downstream side of the MEG detector
- Monoenergetic γ-ray from $^{7}Li(p, \gamma)^{8}Be$
    - Li(p, γ)Be : 17.6MeV and 14.6MeV
    - B(p, γ)C : 4.4MeV, 11.7MeV, and 16.1MeV



500keV Cockcroft-Walton accelerator



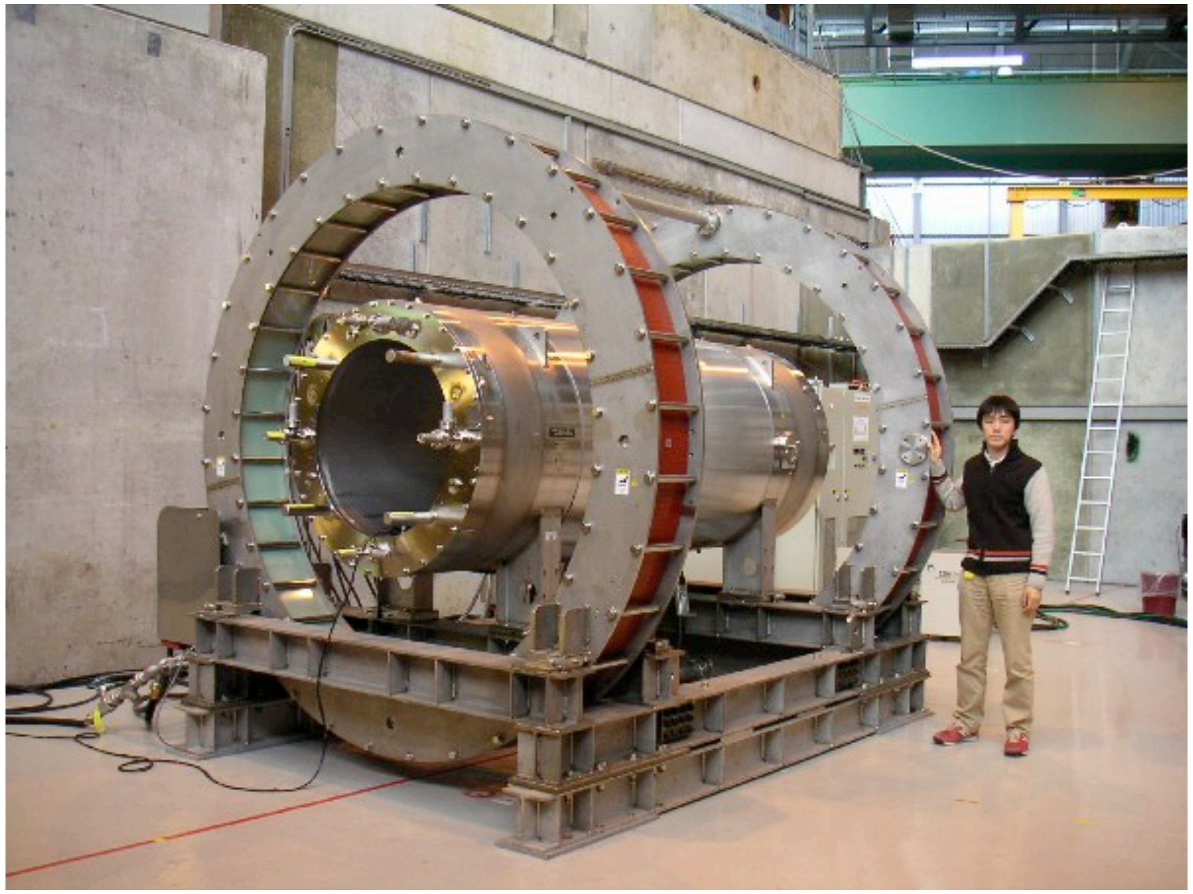
Spectrum taken with NaI(Tl)

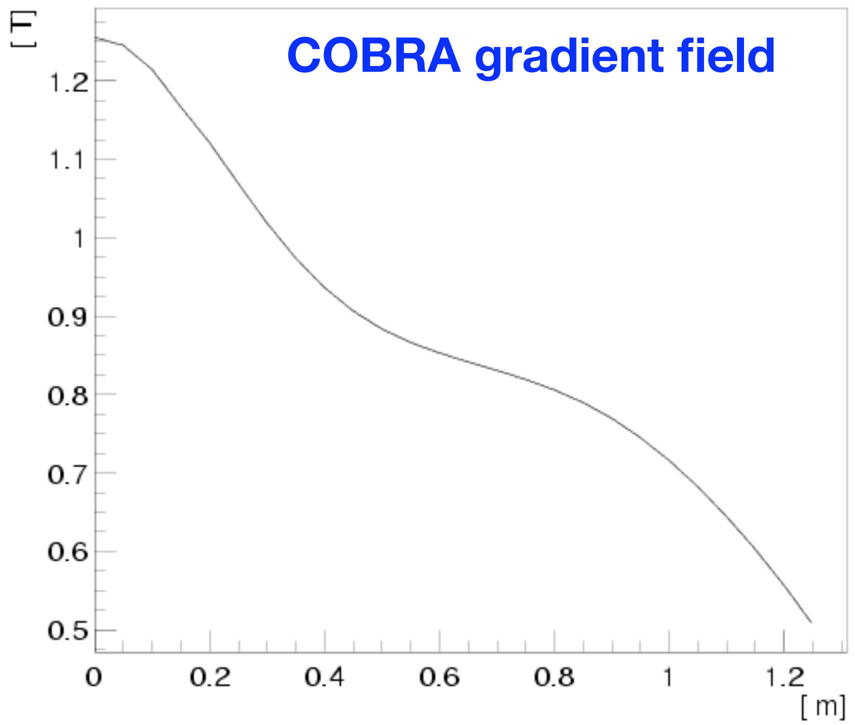


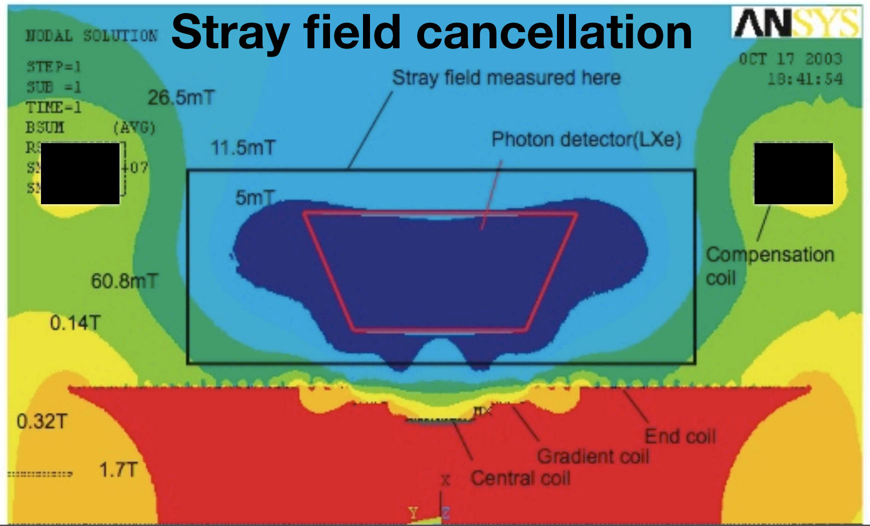
LiF target

COBRA Magnet

- Thin-wall superconducting magnet designed to form gradient field
- Material thickness within calorimeter acceptance: $0.19X_0$
- Field cancelation by compensation coils for stable operation of the PMTs in the calorimeter

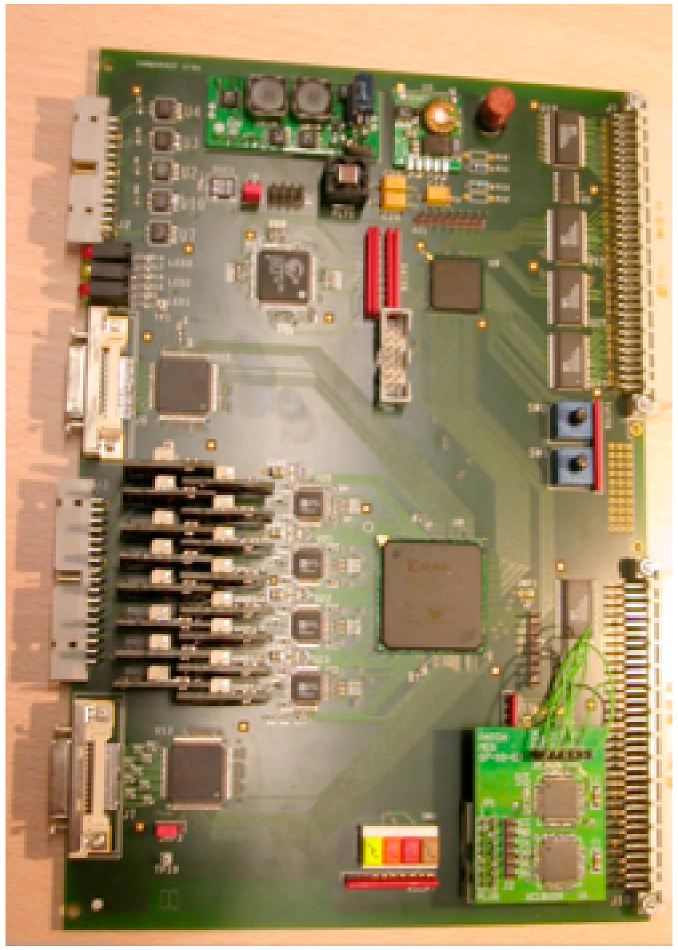






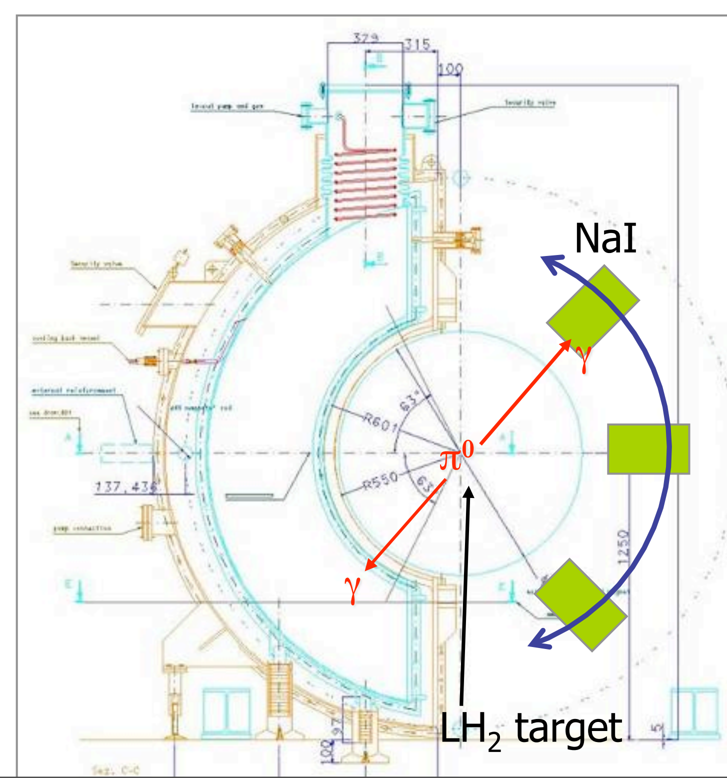
Trigger Electronics

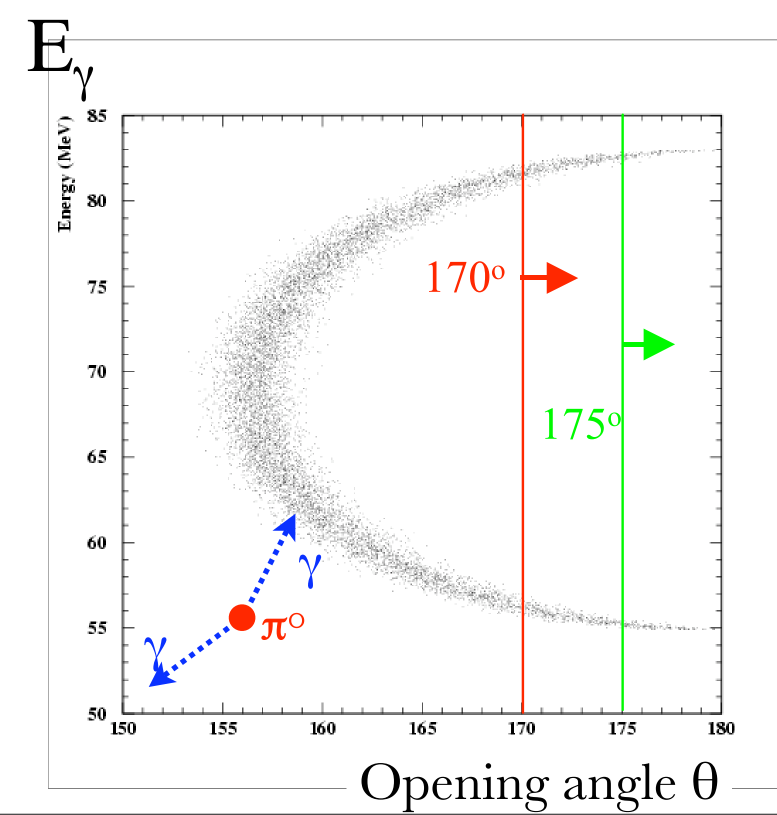
- Digital trigger based on FADC-FPGA architecture on VME boards
- Flexible trigger algorithm
- Trigger rate (for $\mu \to e\gamma$ trigger with 1×10^8 μ^+ sec^{-1}): 20Hz
  - LXe calorimeter energy cut $\wedge$ e^+-γ time correlation $\wedge$ e+-γ angular correlation bw/e+ and γ



LXe Detector: π^0 Calibration

- Two γs from π^0 produced in charge exchange (CEX) process, $\pi^- + p \rightarrow \pi^0 + n$.
  - Almost monochromatic 55MeV and 83MeV photons by selecting two photons with an opening angle θ~180°
- 129MeV photon from radiative capture process, $\pi^- + p \rightarrow \gamma + n$.
- Tagged one photon on the other side by movable NaI.
- We measured the performance over the acceptance
  - Resolutions (energy, timing and position)
  - Energy scale





Light Yield Recovery

- Filter: Molecular sieves + Oxyisorb (new) in LXe
- **Light yield is recovered by a factor of two!**
- **Now stable at 1% level at the maximum**
  - Confirmed by various methods
- **Still lower than expected by a factor of two**