# MEG測定器

KEK測定器開発室セミナー @ KEK,筑波
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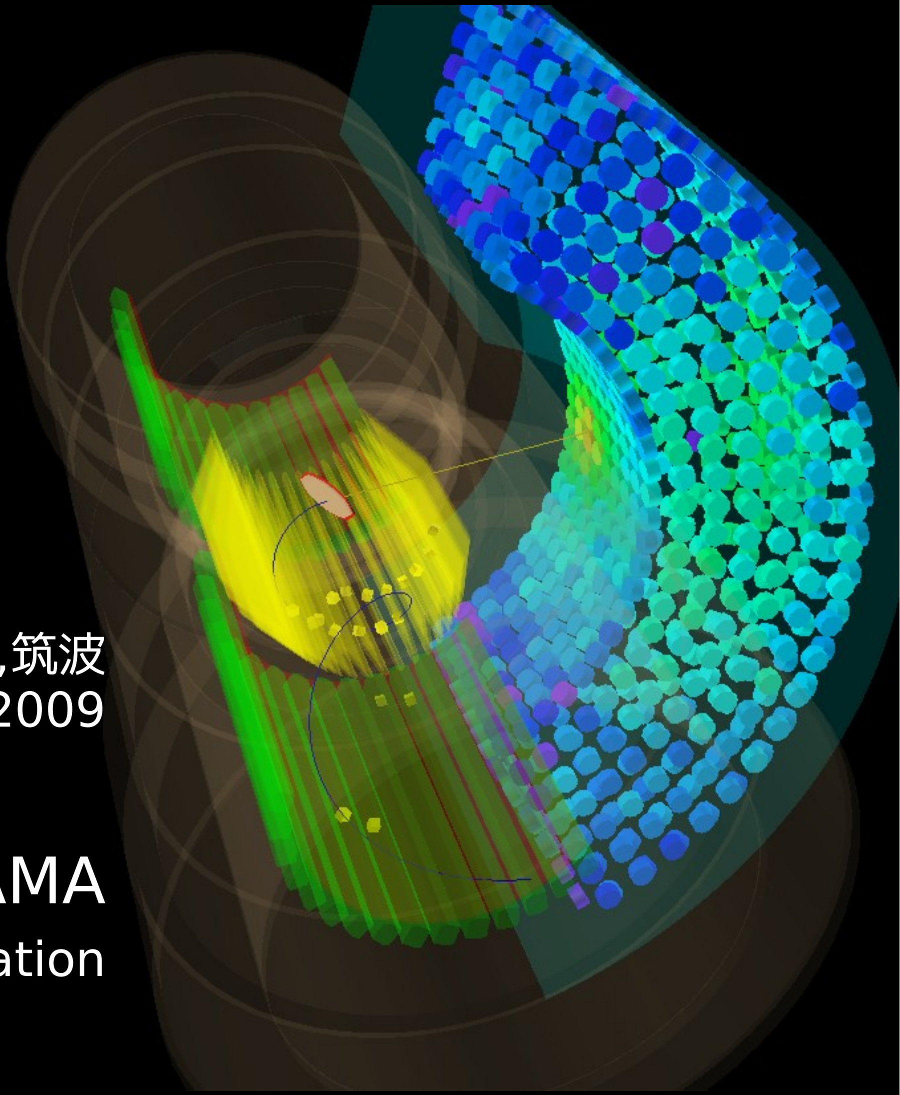
ICEPP

Yusuke UCHIYAMA
On behalf of MEG collaboration



# Theme

- $\mu^+ \rightarrow e^+ \gamma$ **search experiment, MEG started physics data taking in 2008.**

  **In this talk, we report the detector and measurement techniques used in MEG.**

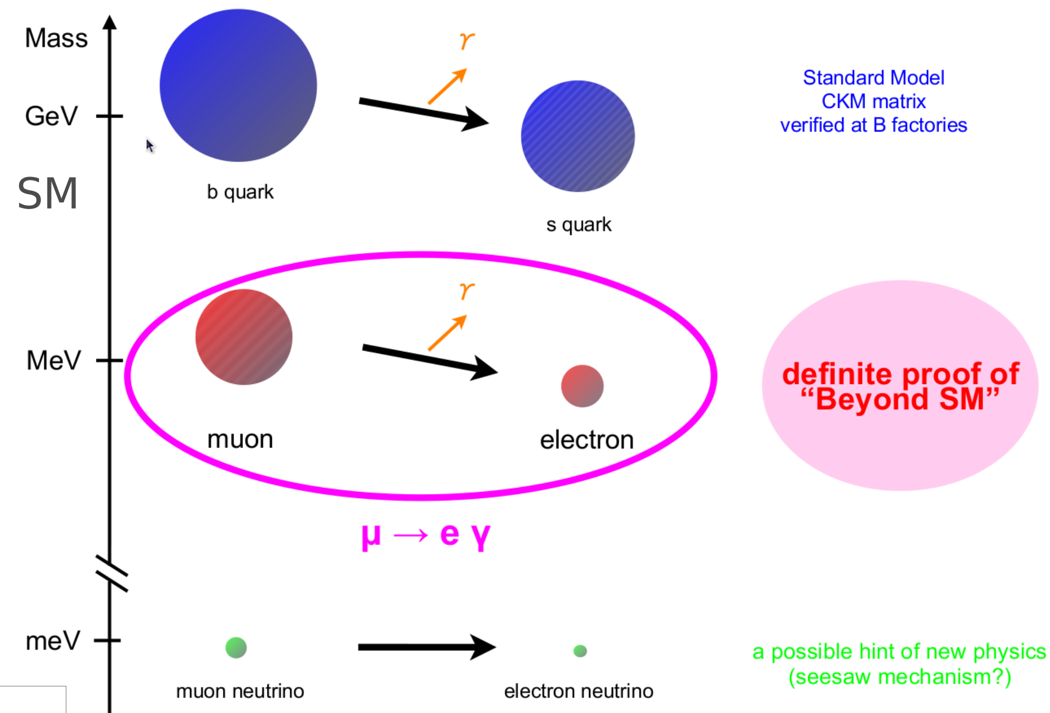
## Contents

- Introduction
  - Subject and purpose
- Overview of MEG
- Performance of detector
- Waveform Analysis
- Conclusion

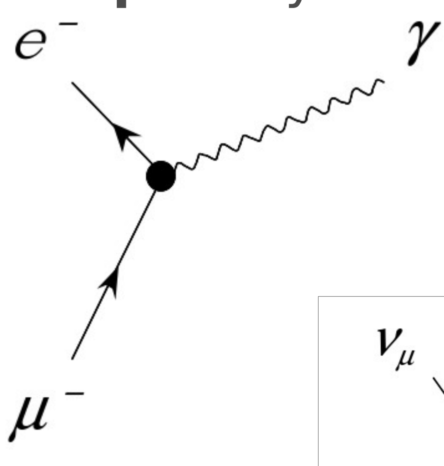
# Introduction

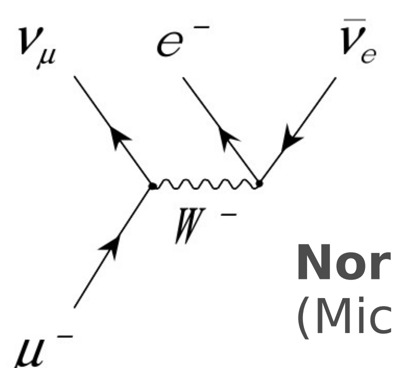
# Subject of research

- Lepton-flavor violating muon decay : **$\mu \rightarrow e\,\gamma$**
  - cLFV : Forbidden in SM
  - Out of experimental reach with finite $\nu$ mass (BR$<10^{-50}$)
  - Clear probe to new physics beyond SM




- **$\mu \rightarrow e\gamma$** decay



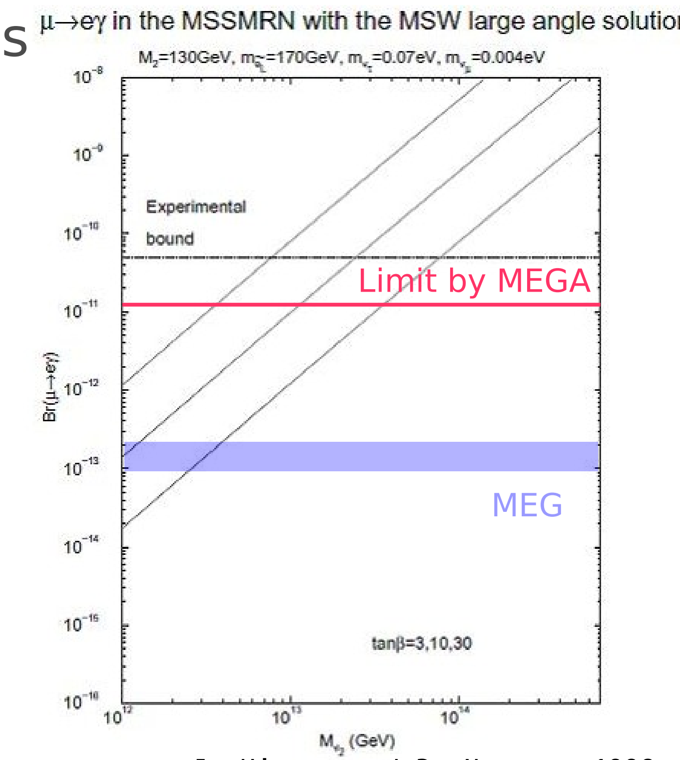




**Normal muon decay**
(Michel decay)

⇨ Lepton flavors are conserved

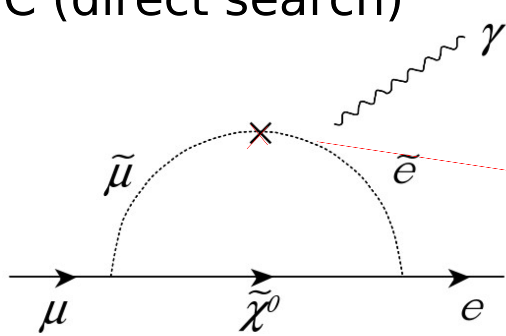
# Physics Motivation

- Large BR is predicted with many new Pysics
  - SUSY-GUT, SUSY-seesaw ,,,
  - Possibility from just below current limit.
    - Current exp. limit : $10^{-11}$
    - ex)SU(5) SUSY-GUT: $10^{-15}$~$10^{-13}$,
      SO(10): $10^{-13}$~$10^{-11}$,
      SUSY-seesaw: >$10^{-14}$
    - Large *tanβ* → larger BR




J. Hisano and D. Nomura, 1998

- Connection to other physics
  - cLFV : μ-e Conversion, τ-LFV (τ→lγ,etc) ..
  - g-2, EDM
  - LHC (direct search)

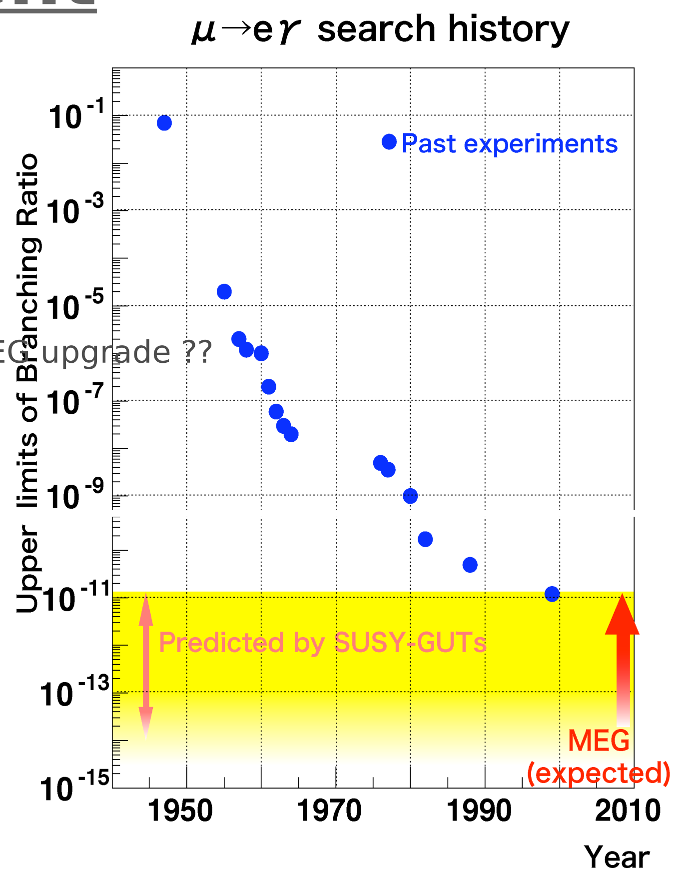



Mixing through slepton

$$m_{\tilde{l}}^2 = \begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & m^2_{\tilde{e}\tilde{\mu}} & m^2_{\tilde{e}\tilde{\tau}} \\ m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & m^2_{\tilde{\mu}\tilde{\tau}} \\ m^2_{\tilde{\tau}\tilde{e}} & m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$

# Position of the MEG Experiment

- Current experimental upper limit :
  - Br(μ→eγ) < $1.2\times10^{-11}$ (1999, MEGA@LAMPF)
- Target : down to a sensitivity of **$10^{-13}$**
- In 2008, started physics data taking ~2011? → MEG upgrade ??
- No other experiments (nor future program)




Other cLFV search
- μ-e conversion
  - ~300 times smaller BR
  - Current U.L.~$10^{-13}$(@PSI)
  - Future exp. ~$10^{-16}$
    - COMET @J-Parc
    - mu2e @Fermilab
- τ-LFV
  - Many different modes
  - BR ~ O($10^{3\text{-}5}$)xBr(μ)
  - Current U.L.~$10^{-7\sim-8}$ (B-factories)
  - Future program : superB

5~10 years

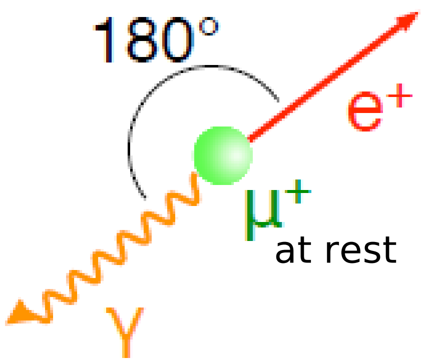
To conduct these experiments is important independent with MEG results

To be a pioneer of coming New physics era !

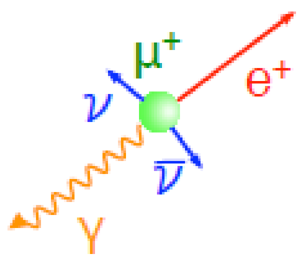
- Complementary with LHC
  - Possibility of SUSY particles discovery at the beginning of LHC

# μ→eγ Search

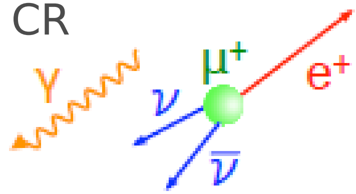
- Need a large number of muon
  - High rate experiment
  - Use positive muon ($\mu^+$)
    - Prevent from forming muonic atoms




- $\mu^+ \to e^+\gamma$ signal : a positron and a gamma
  - Clean 2 body decay
    - Both at 52.8MeV (monochromatic),
    - Back-to-back,
    - Time coincidence




- Backgrounds
  - Radiative muon decay (prompt BG)
    - Rapid decrease of phase space in signal region
    - We can control with reasonable resolutions
  - Accidental overlap of uncorrelated $e^+$ and $\gamma$ (accidental BG)
    - Source of γ: radiative decay, $e^+$ AIF, Bremsstrahlung, CR



# Accidental Background

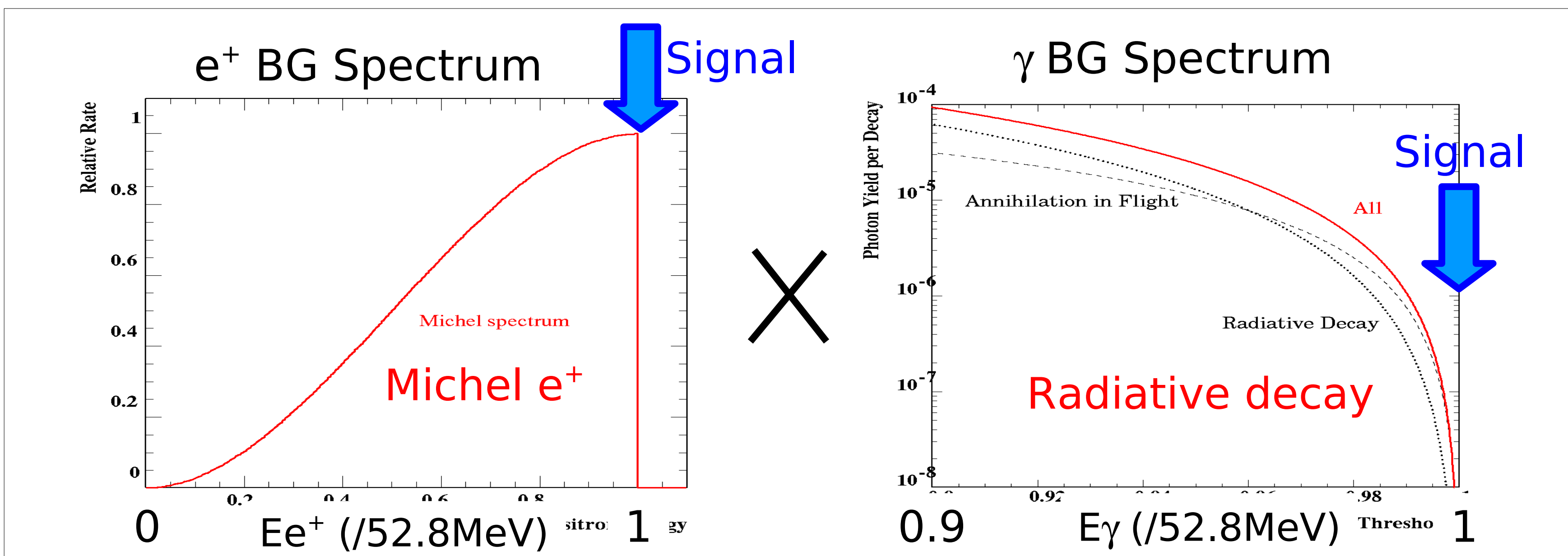
- Accidental BG limits the experiment
  - BG rate is proportional to the instant beam rate → DC beam is the best

$$B_{acc} = R_{\mu} \cdot f_{e}^{0} \cdot f_{\gamma}^{0} \cdot (\delta\omega/4\pi) \cdot (2\delta t)$$

$=N_{\mu}$ (DC beam)

Back to back
(quadratic to angular resolution)

Time overlap
(Linear to time resolution)




High rate $e^+$

$\gamma$ energy measurement is most important

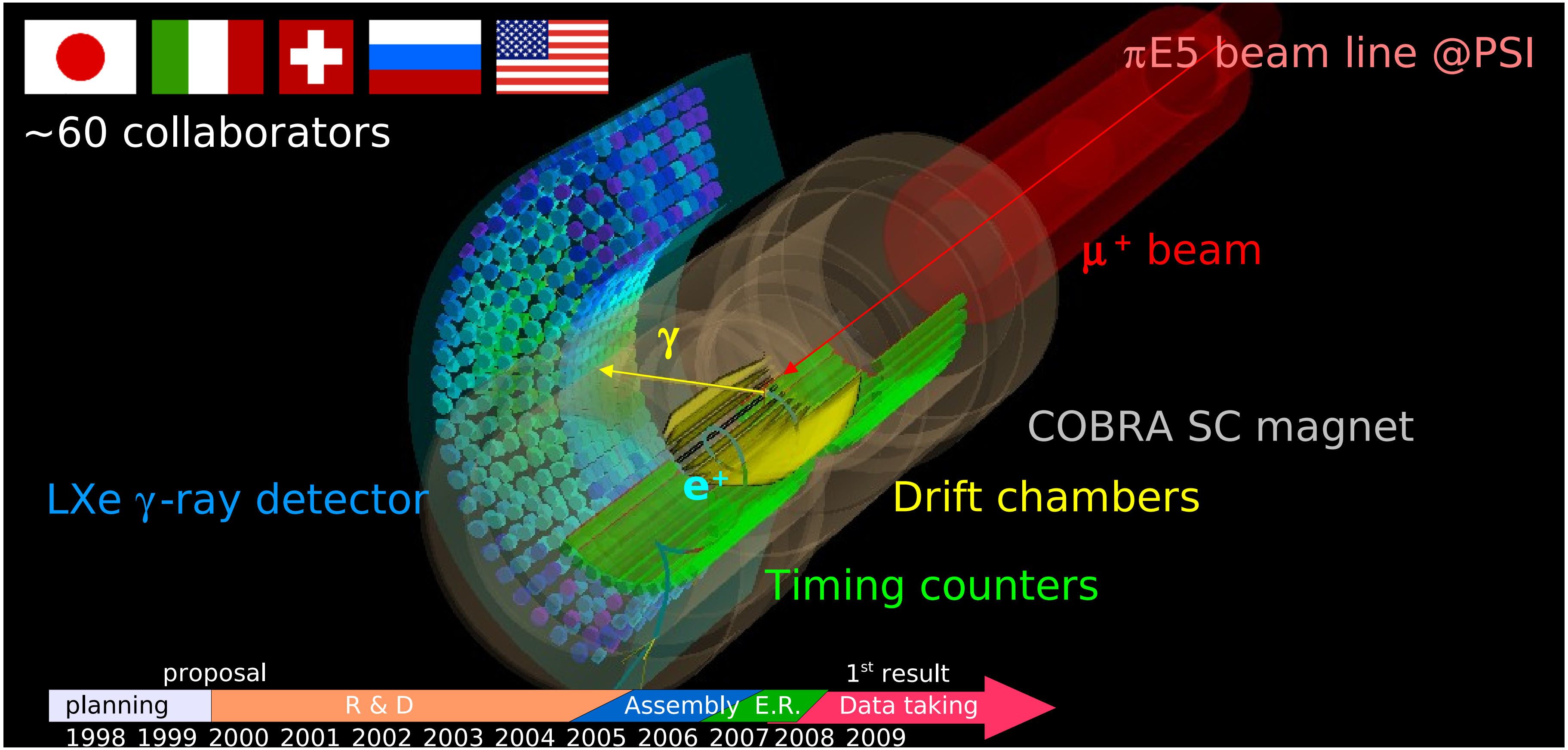
# Requirements for $\mu \to e\gamma$ experiment

- **High intensity DC $\mu^+$ beam**
  - $>10^7$/sec
- **High rate tolerable detectors**
  - All of $>10^7$/sec $\mu^+$ generate $e^+$
  - Pileup of γs become a source of high energy BG
- **High resolution detectors**
  - γ energy measurement is most important
  - Angle and time measurements are also effective

# The MEG Experiment

# MEG Experiment

- World's most intense DC $\mu^+$ beam @PSI (Switzerland)
- MEG detectors
  - Positron spectrometer
  - Liquid xenon $\gamma$-ray detector
- Started physics data taking in autumn 2008



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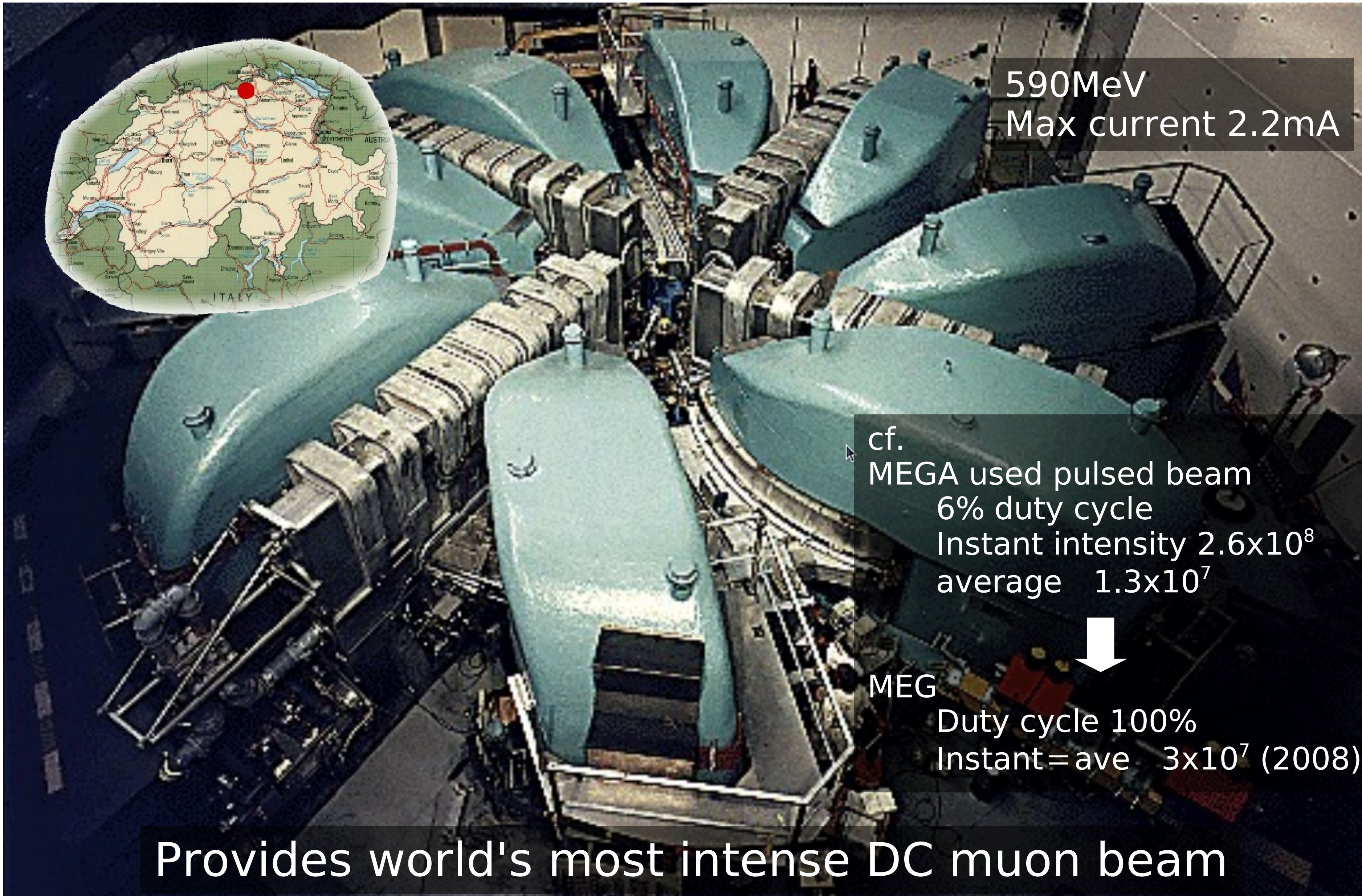
# 1.2MW proton Ring-Cyclotron at PSI

MEG
Mu-E-Gamma Collaboration



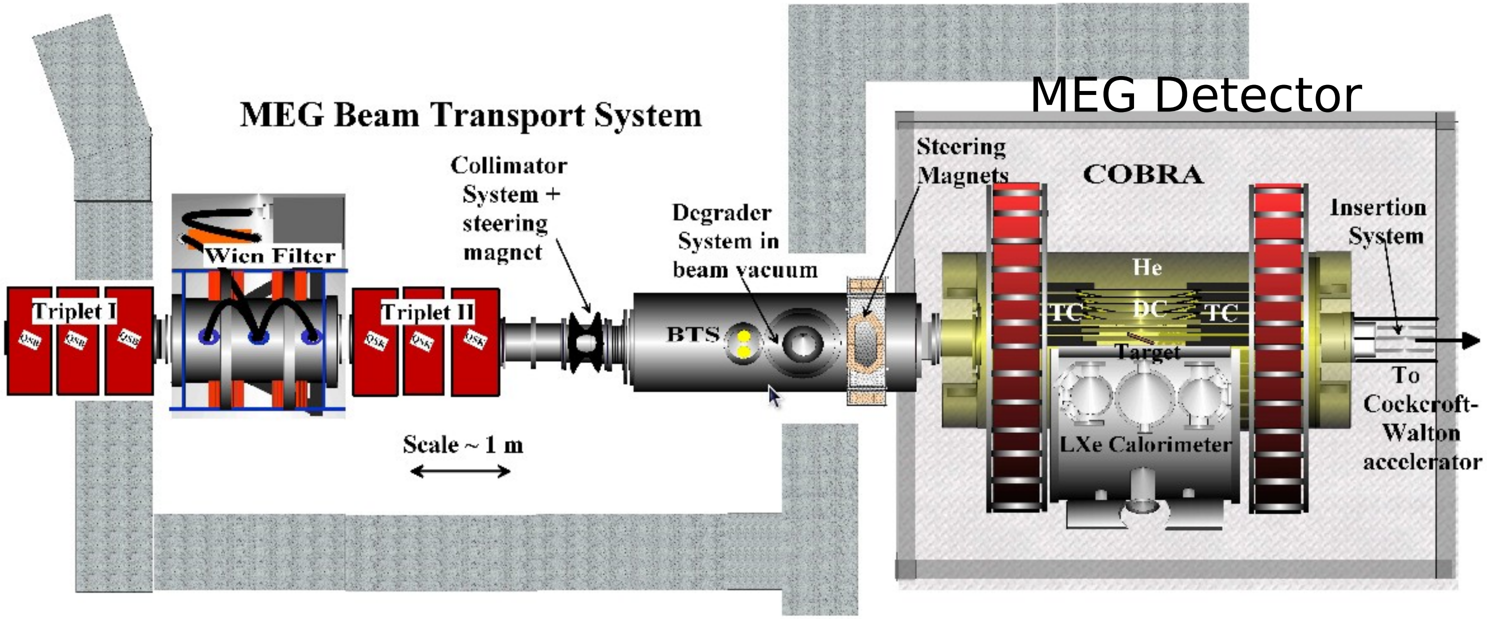

590MeV
Max current 2.2mA

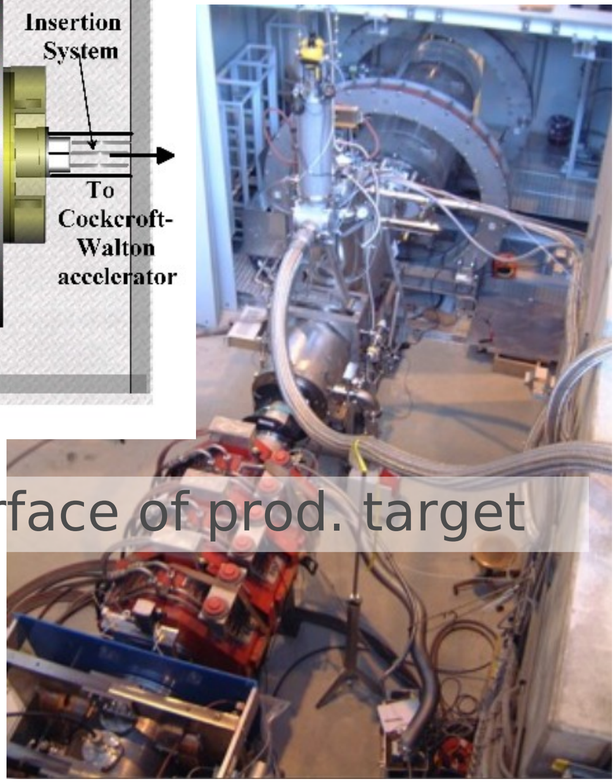
cf.
MEGA used pulsed beam
6% duty cycle
Instant intensity $2.6\times10^{8}$
average $1.3\times10^{7}$

MEG
Duty cycle 100%
Instant = ave $3\times10^{7}$ (2008)

Provides world's most intense DC muon beam

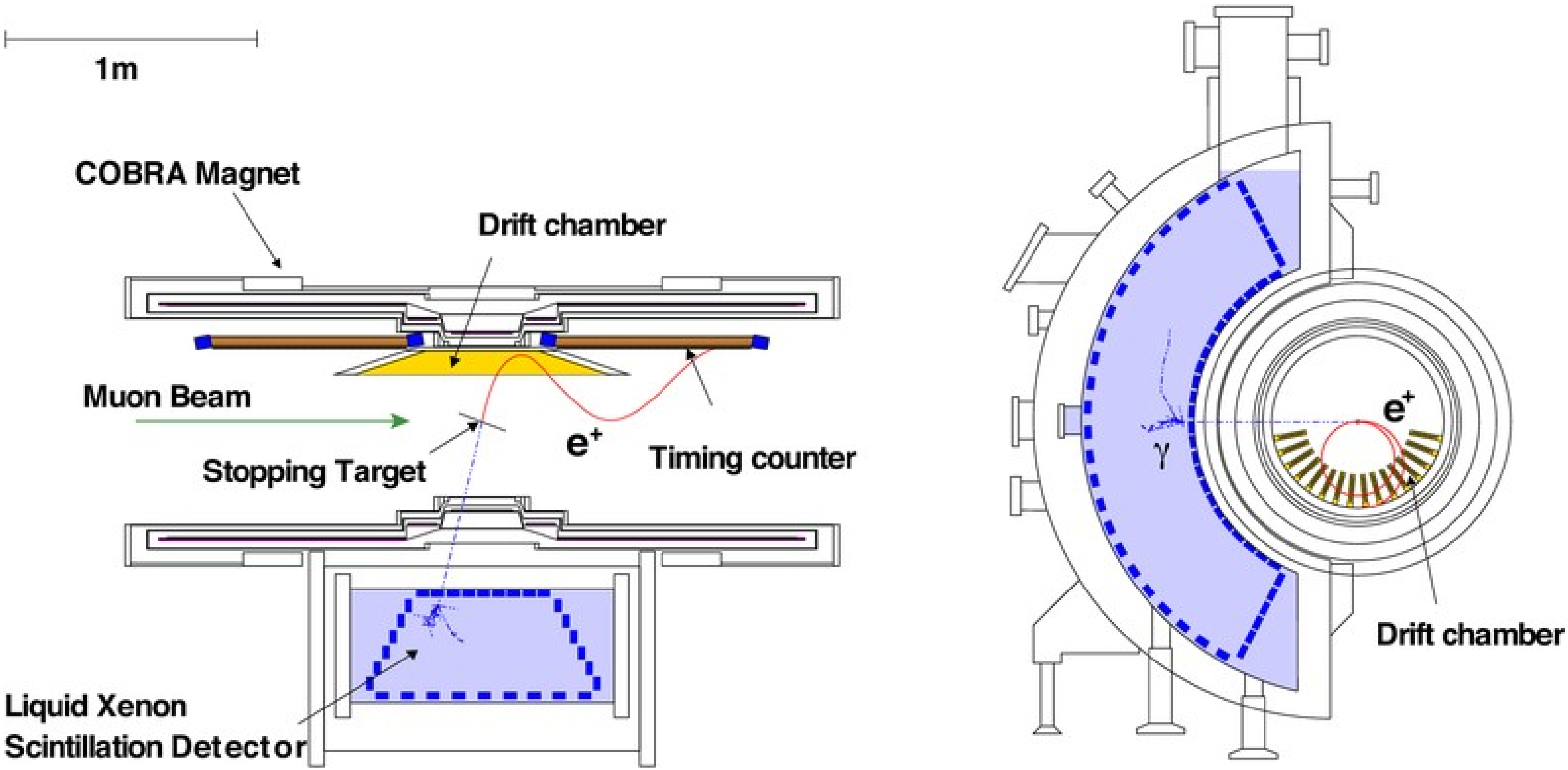
# 'Surface muon' Beam Transport System



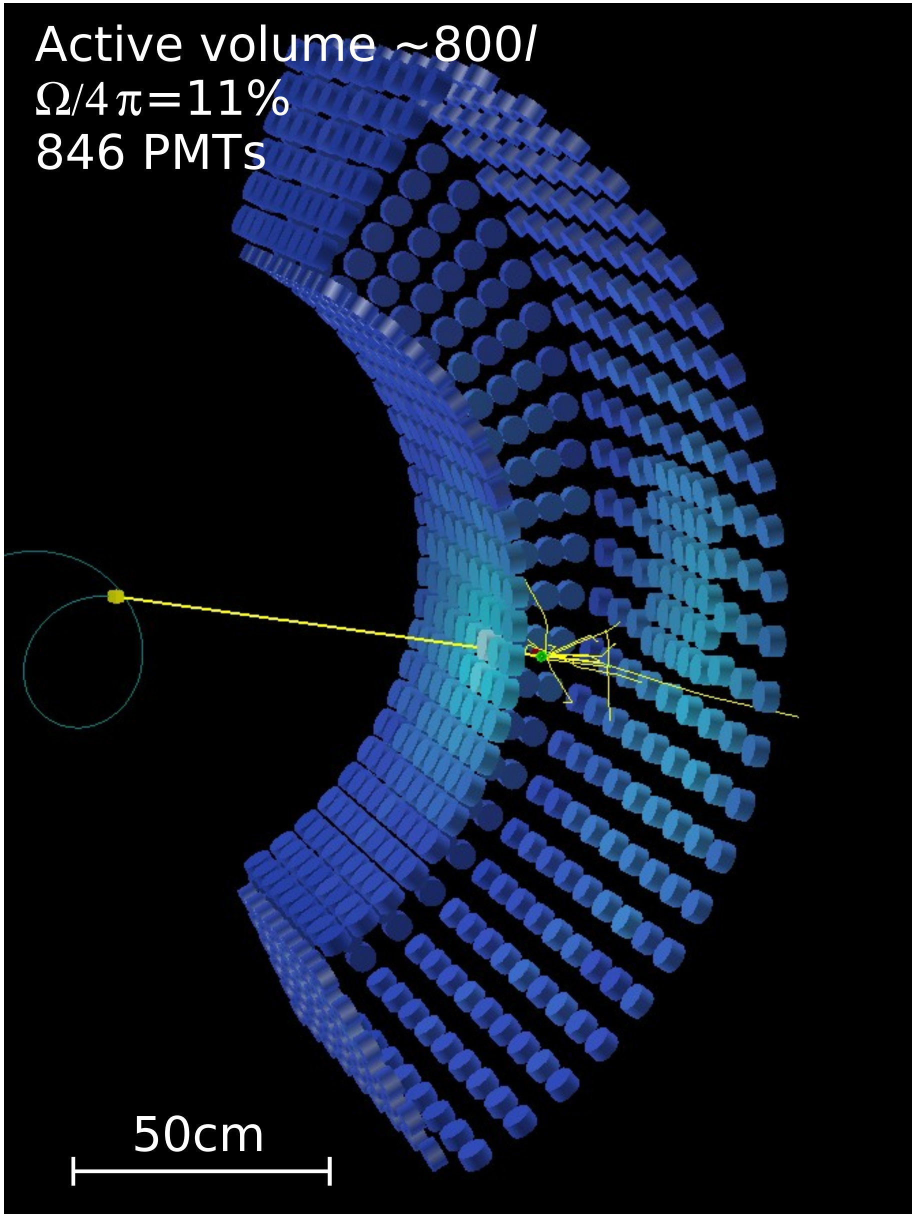
- Surface μ: μ produced from π at rest on the surface of prod. target
  - Extract at 175° from the primary p beam
  - Low momentum(29MeV/C) with small variance $\mu^+$ beam
- Through the beam transport system
  - Separate $e^+$ · degrade · tune beam profile
- **$3\times10^7$** $\mu^+$/sec stop on target
  - 10mm spot size
  - 200μm polyethylene film target , placed at 20.5°slant angle from beam-axis
    - Suppression of scatter & BG VS stopping power

# MEG Detector



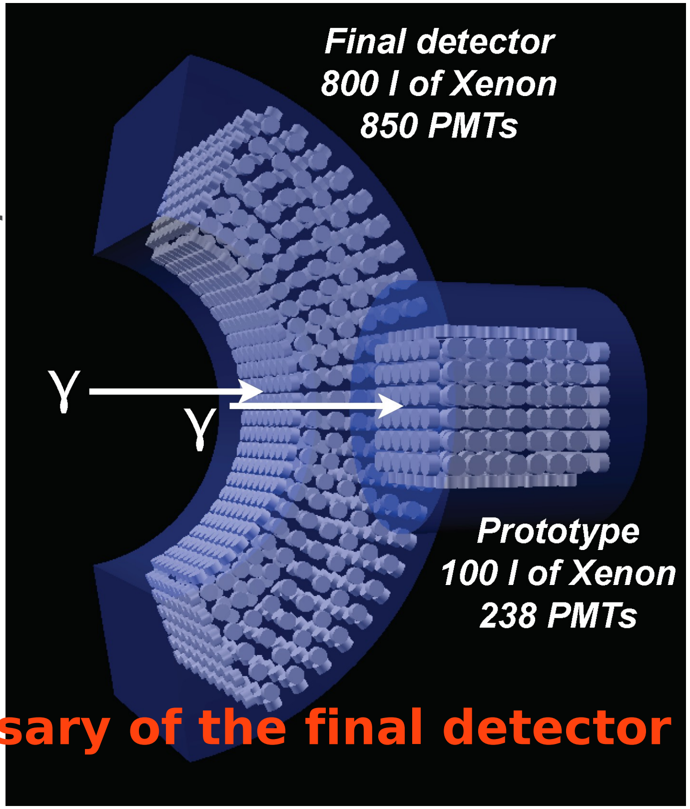
# Liquid Xenon Detector

- 900 liter liquid xenon
  - Scintillation medium
    - High light yield (75% of NaI(Tl))
    - Fast response ($\tau_{decay}$=45ns)
    - High stopping power ($X_0$=2.8cm)
    - No self-absorption
    - Uniform, no-aging
  - Challenges
    - Vacuum ultraviolet (178nm)
    - Low temperature (165K)
    - Need high purity
  - No segmentation
- Measure energy,position,time at once
- Identify pileup events
  - Light distribution
  - time distribution
  - waveform

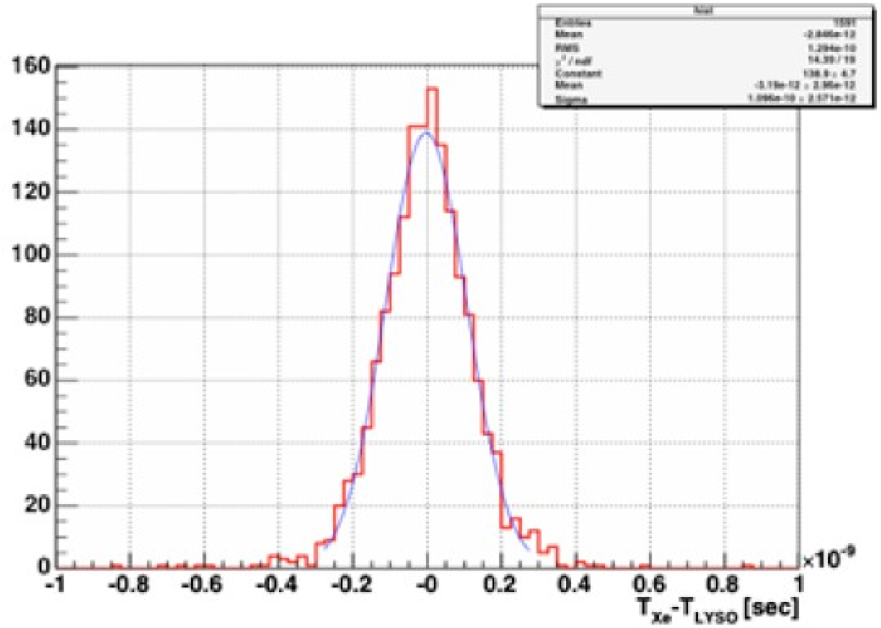


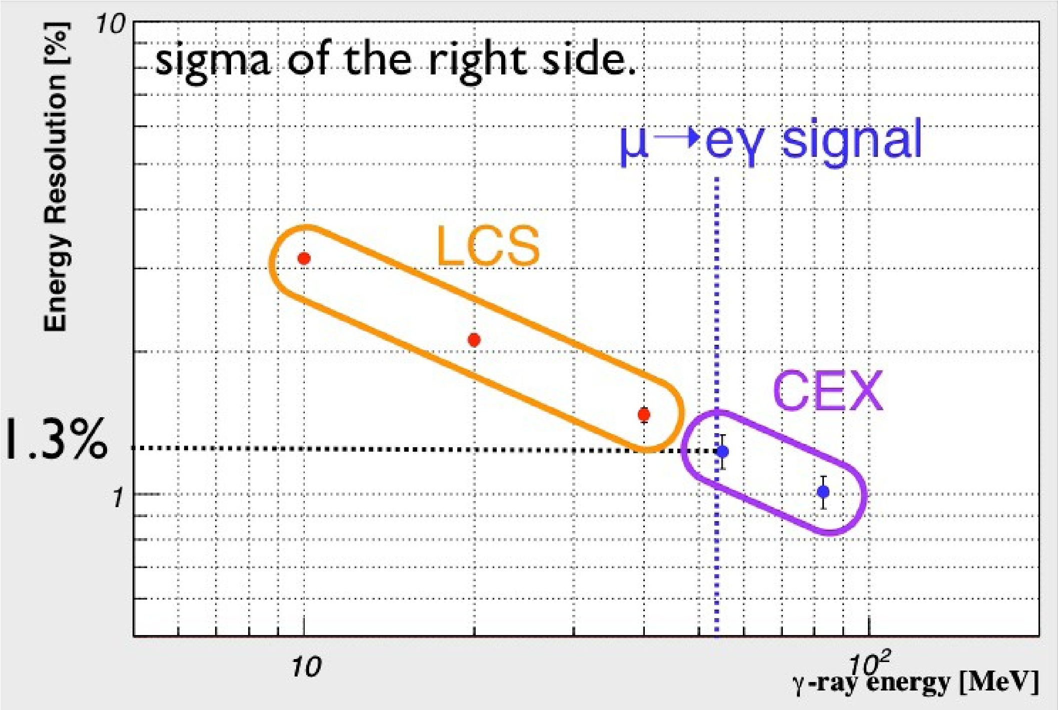
# Prototype / R&D

- Verified performance with prototype detector
  - Energy resolution @55MeV
    - $\sigma_{up}$ = 1.23%, FWHM = 4.8%
  - Time resolution @55MeV
    - $\sigma_t$ = 65 ps




**Various R&D, obtained a lot of know-how necessary of the final detector**



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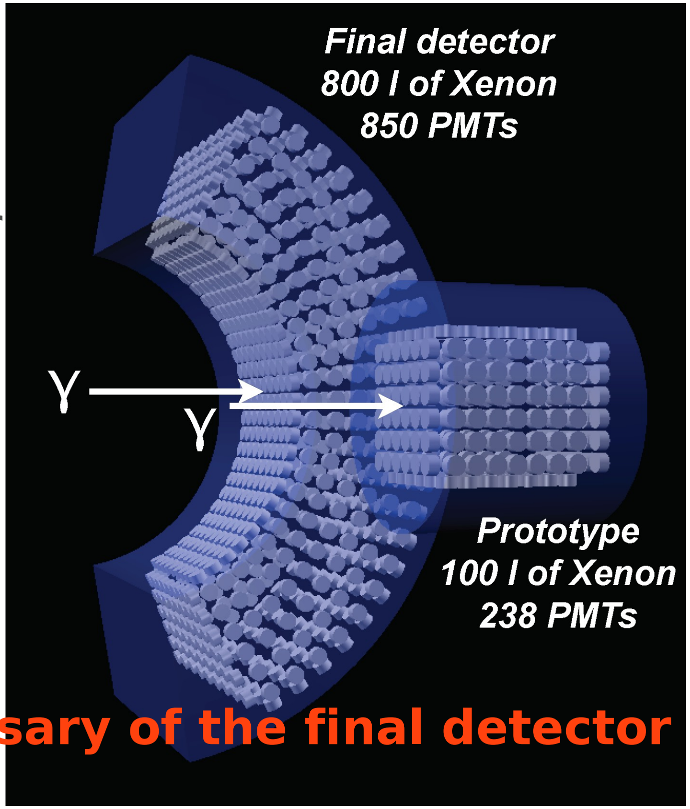
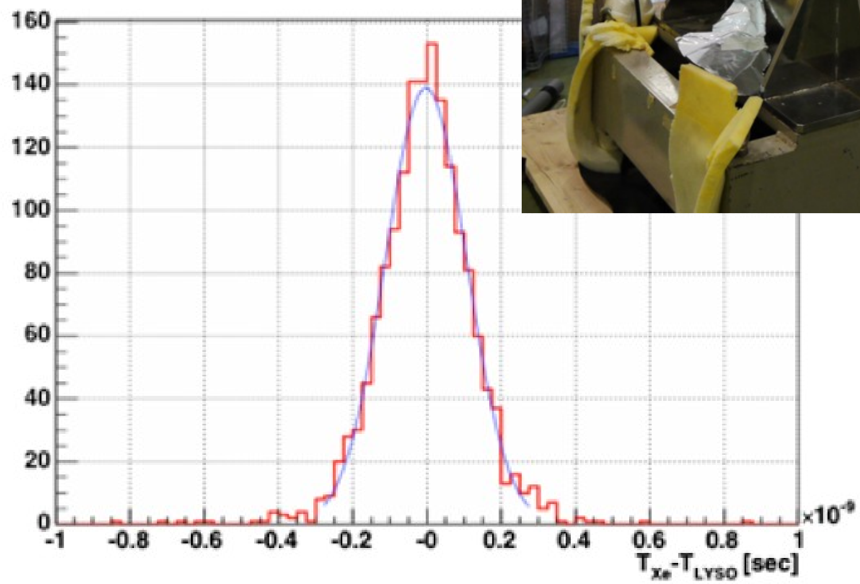
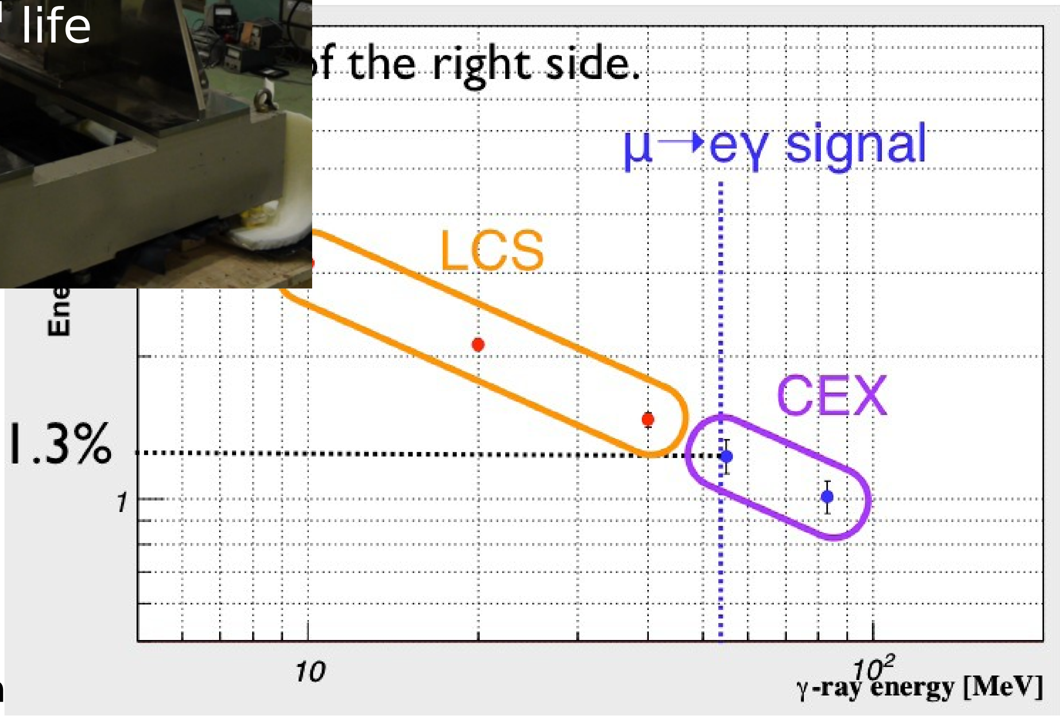



**Various R&D, obtai ... ecessary of the final detector**

# Cryostat

MEG
Mu-E-Gamma Collaboration

2 layers of vacuum-tight cryostat
Thin window for $\gamma$ entrance face

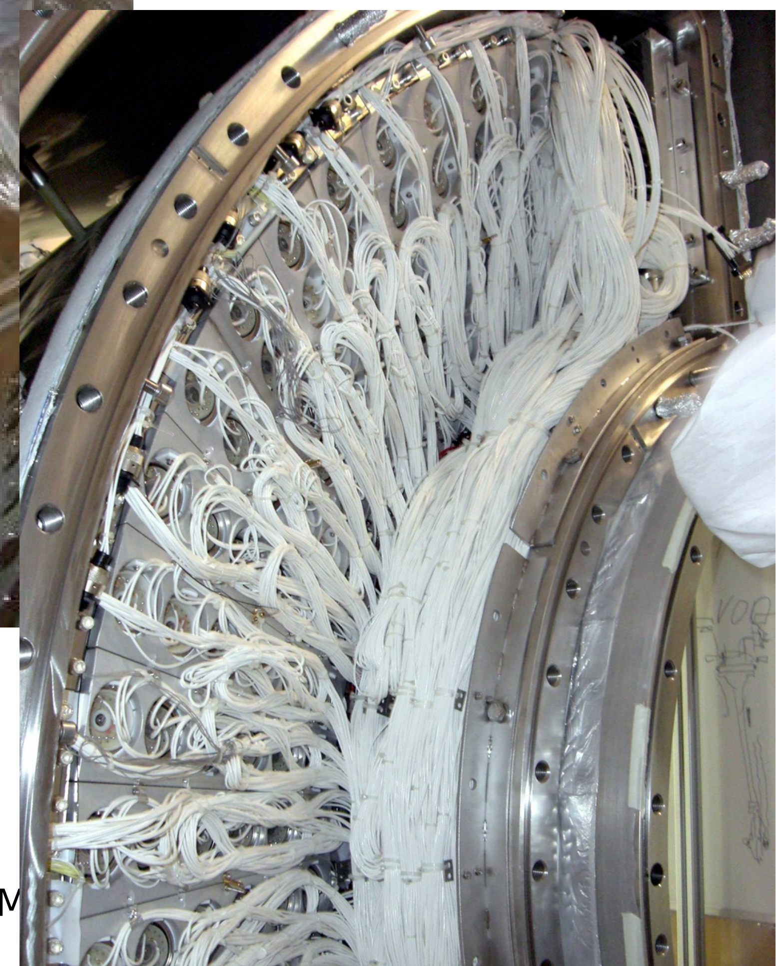
Inner vessel

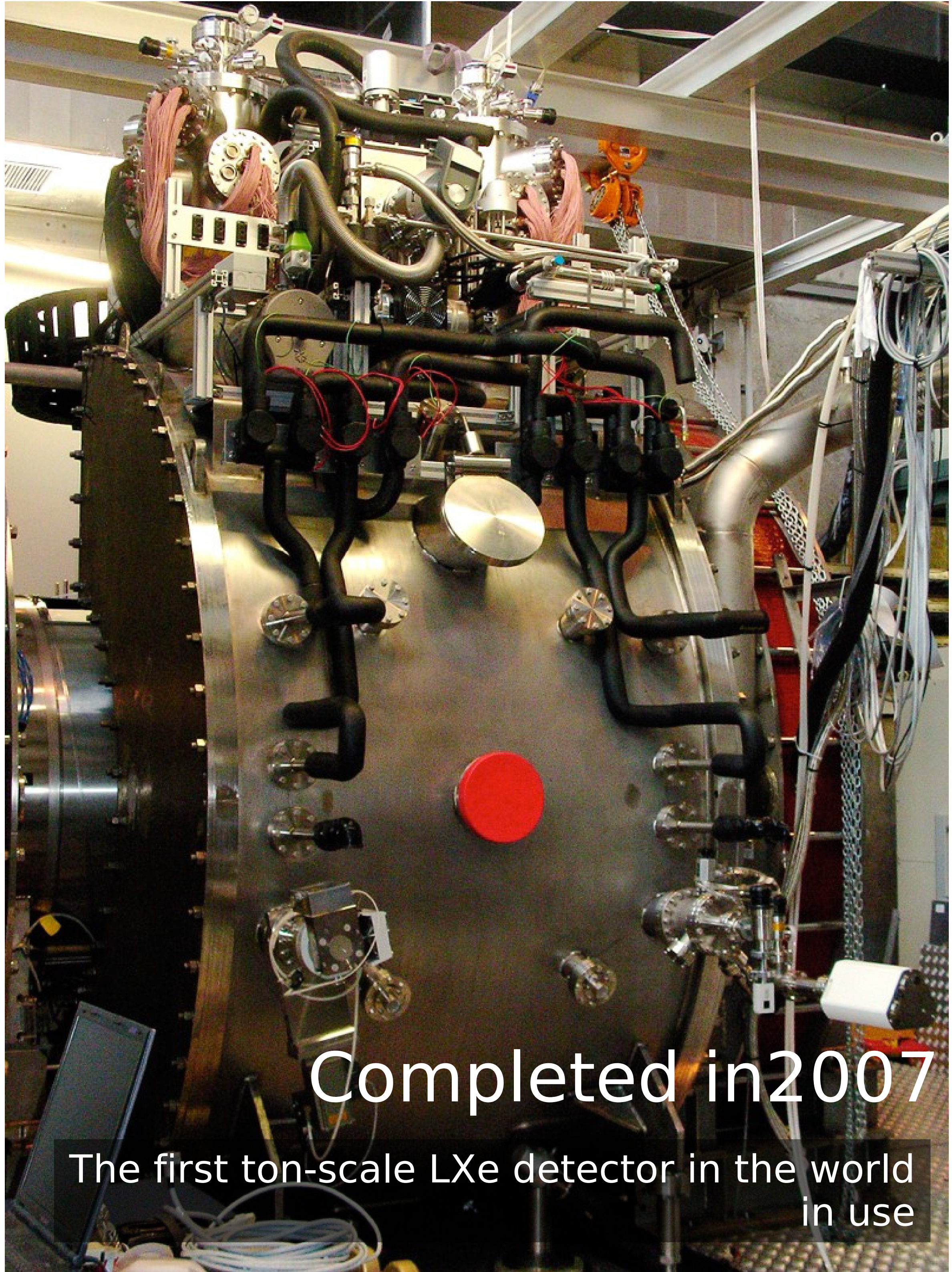
Entrance window with honeycomb structure

# PMT Installation

2”PMT developed for MEG

- Quartz window for VUV
- K-Cs-Sb photocathode
- Al strips on photocathode
- Metal-channel dynode
- Zener diode at last steps of Bleeder



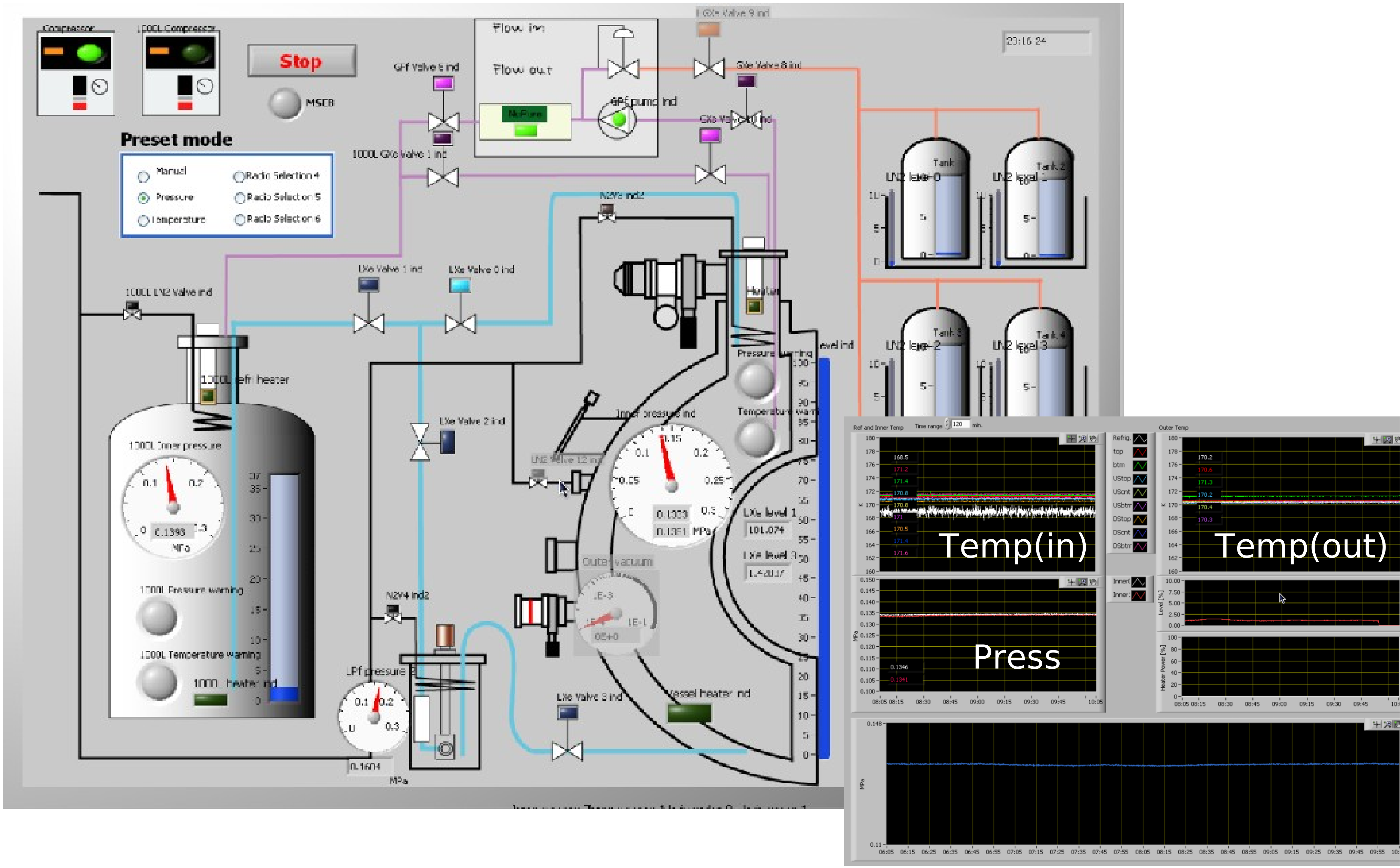


# Completed in2007

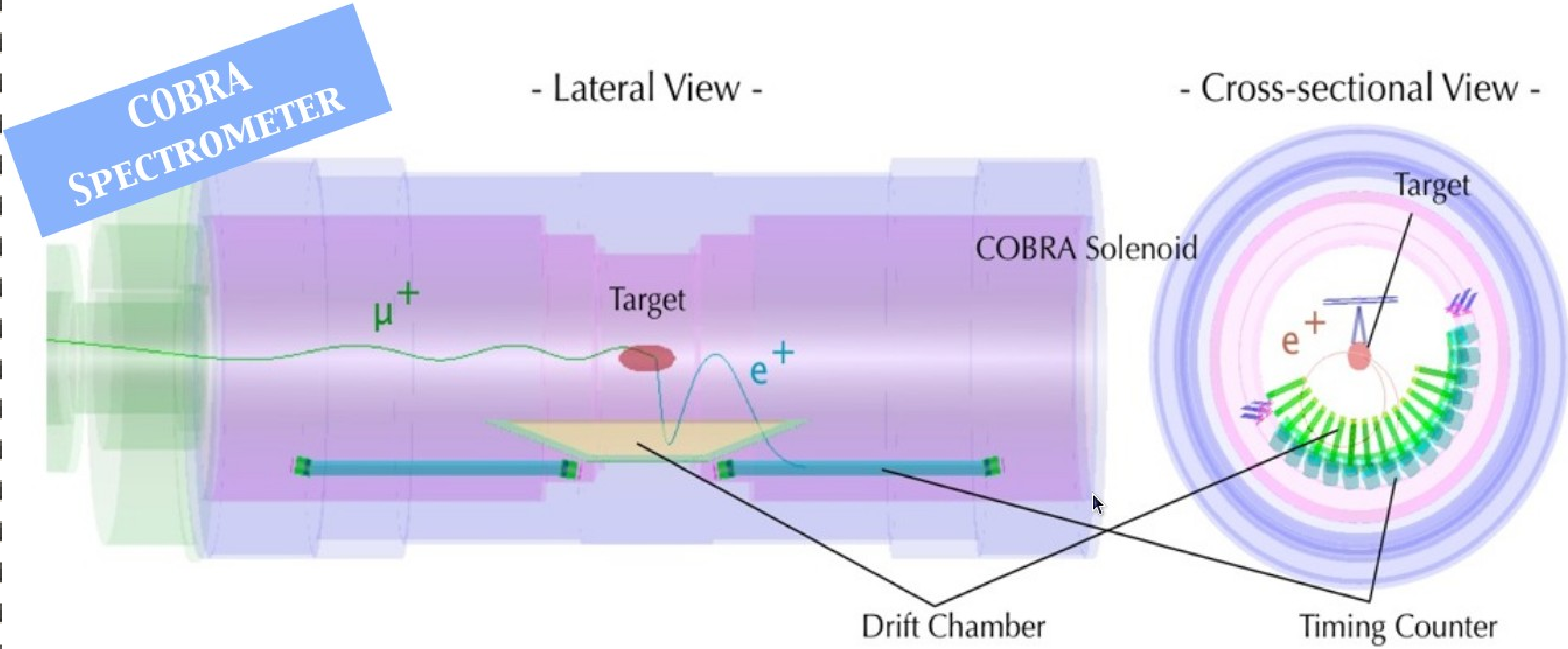
The first ton-scale LXe detector in the world in use

# Slow Control System

MEG
Mu-E-Gamma Collaboration



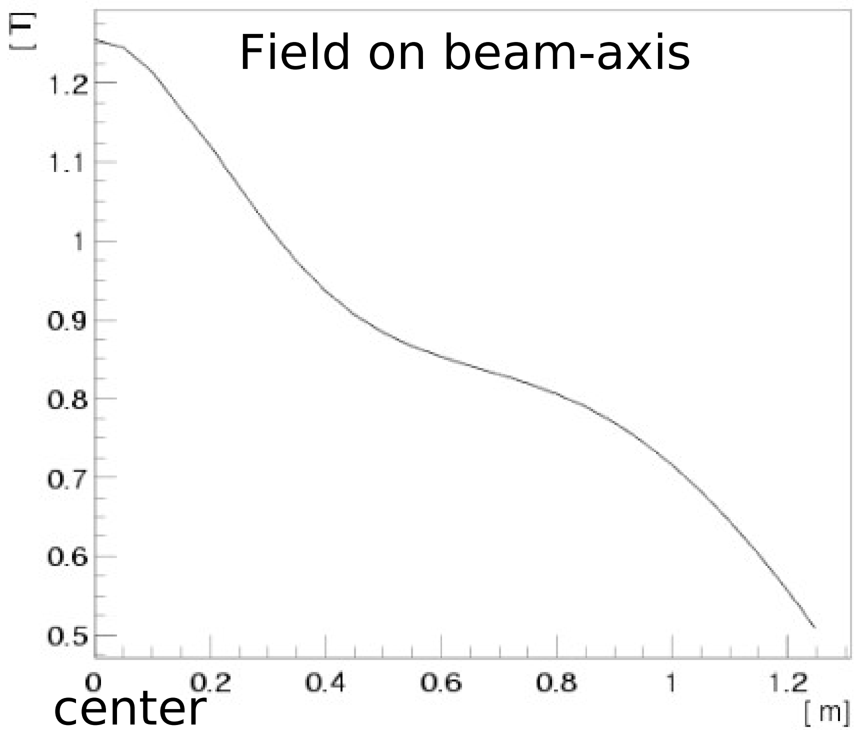
# Positron Spectrometer



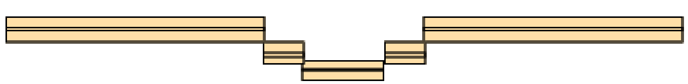

- A spectrometer efficiently measure $3\text{x}10^7$ high rate $e^+$
- Measure $e^+$ momentum · emission angle · $\mu^+$ decay time&position with high resolution

# “COBRA” Magnet

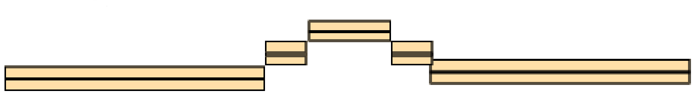
- Superconducting solenoid form highly gradient magnetic field
  - Center 1.27 T → edge 0.49 T

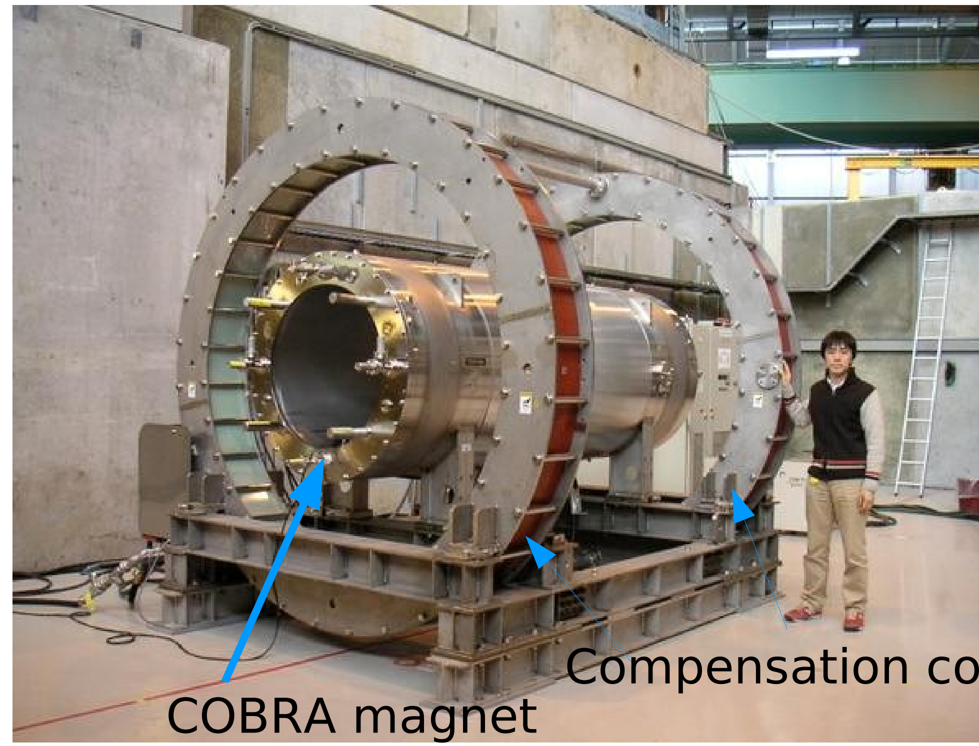



center



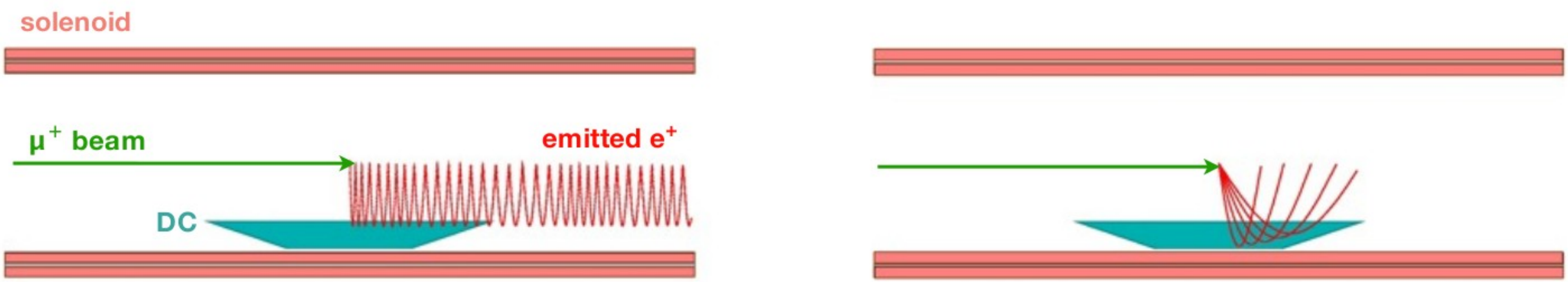
Step structure solenoid





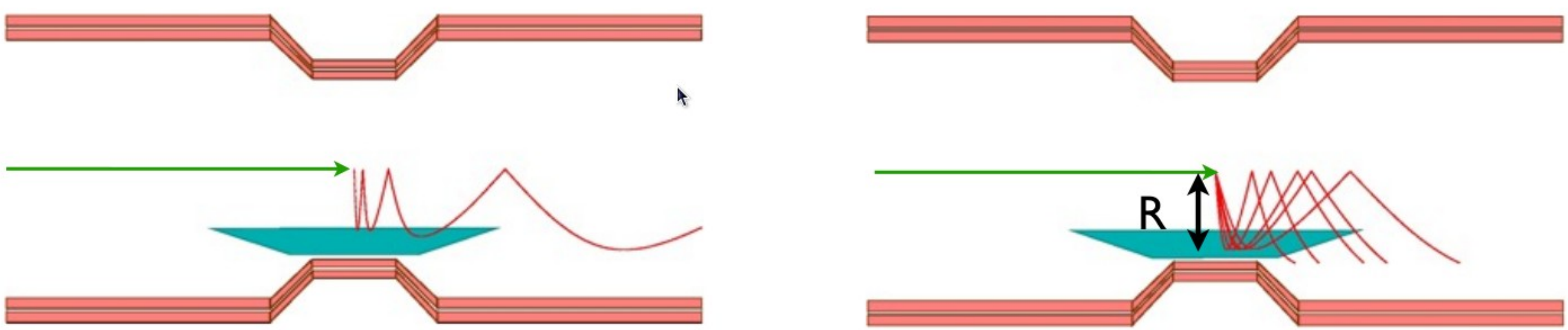

Other features
- Thin coil
  - $<0.2X_0$ to transmit γ-ray(85%)
- Rapid switch on/off
  - stabilize ~30min (cooling with GM ref.)
- Two compensation coils suppress fringe field (no return yoke)
  - Low B around LXe detector for PMT <50Gauss

# Specially Gradient B-Field




Uniform B-field

Gradient B-field

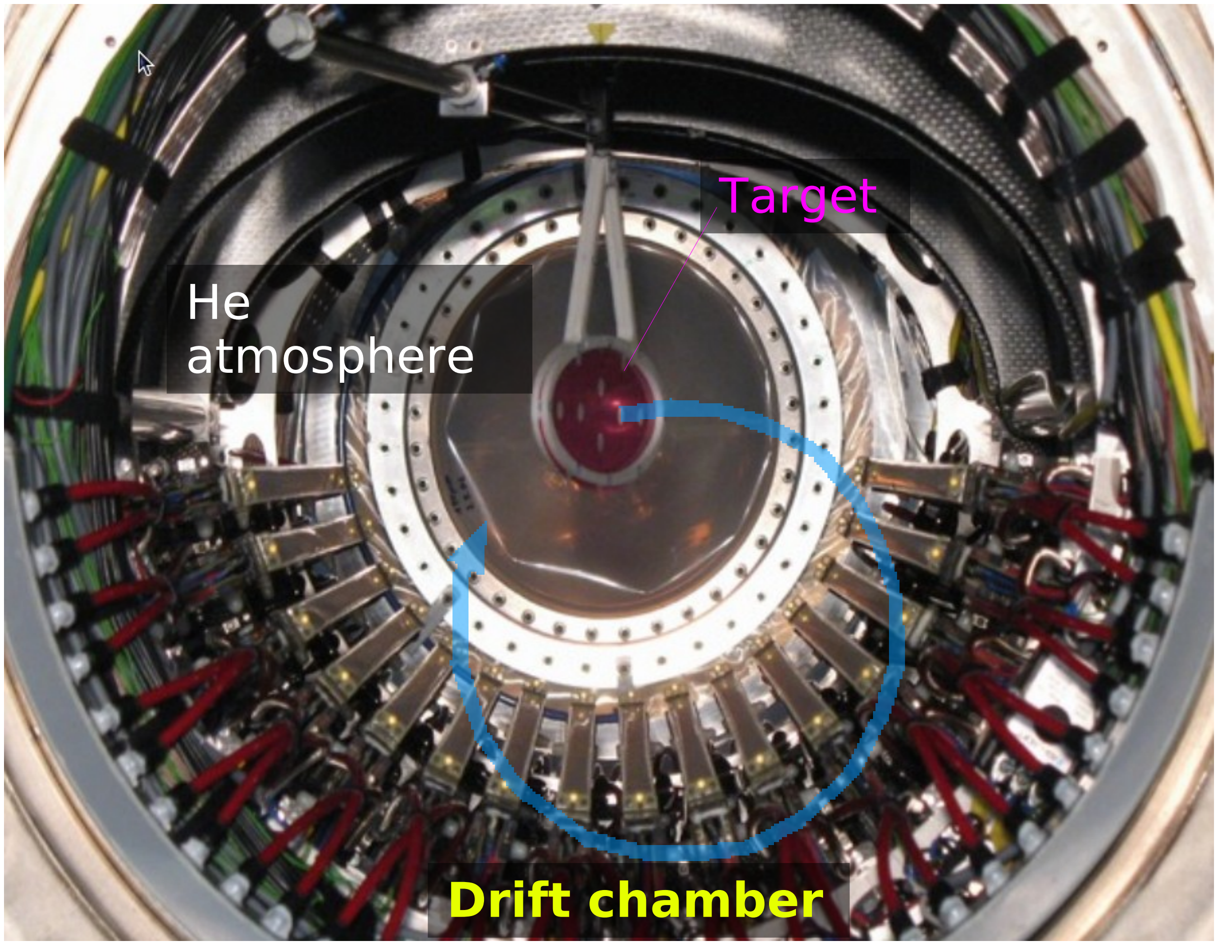



$e^+$ quickly swept out

Same momentum⇒same radius
(**CO**nstant **B**ending **RA**dius)

Enable measurement in high rate

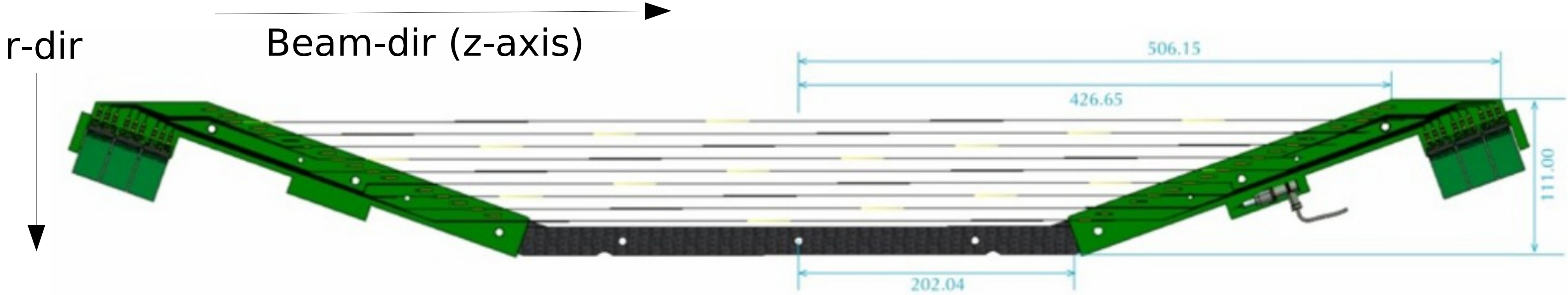
# Drift Chamber(DCH)

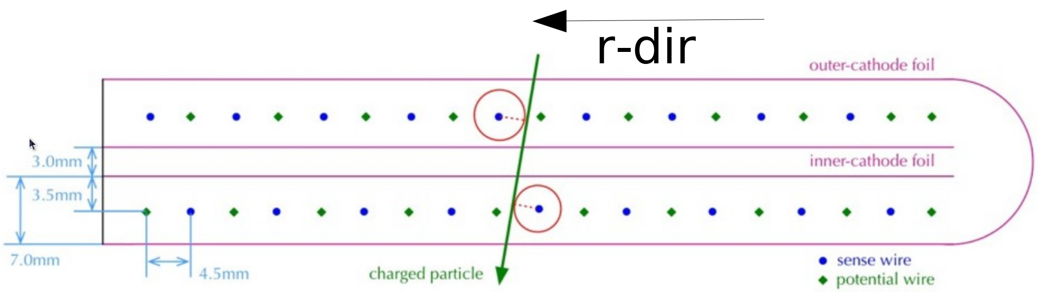



- 16 modules
  - Arranged concentrically (10.5°interval)
  - 2 layers per 1 module
  - 
- Chamber gas
  - He:ethane(50:50)
  - Pressure control
    - Outside He atmosphere
- Ultra low mas chamber
  - Multiple-scattering limits the performance
  - To suppress $\gamma$ BG source
  - In total along $e^+$ trajectory

    $\sim 2.0 \times 10^{-3}\ X_0$

# DCH Design

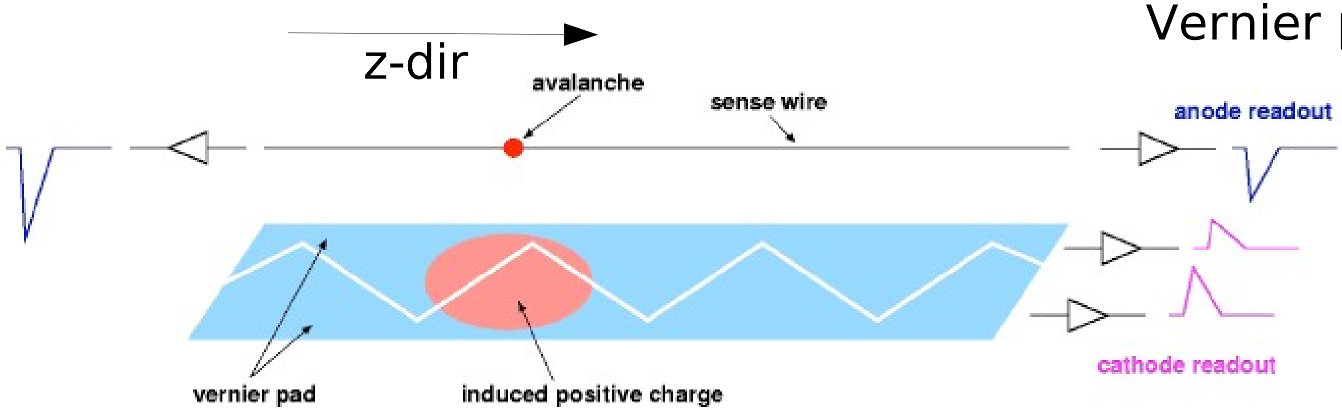


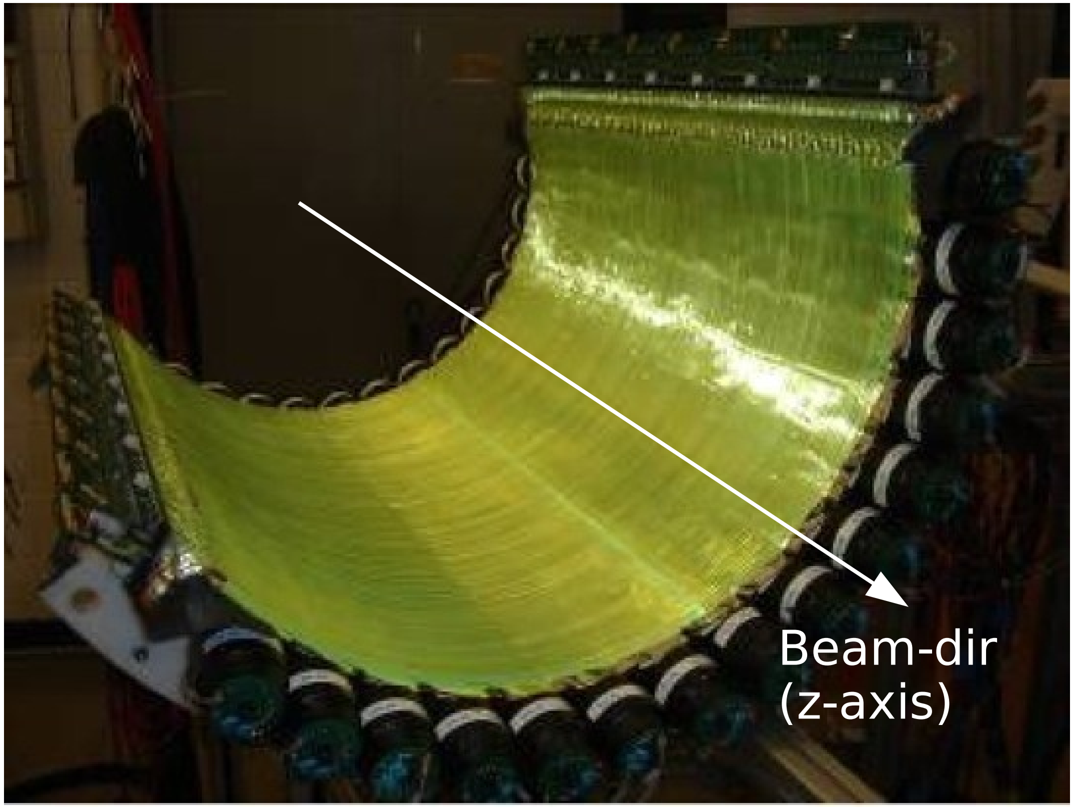

2 layers staggered by half cell
9 drift-cells in 1 layer

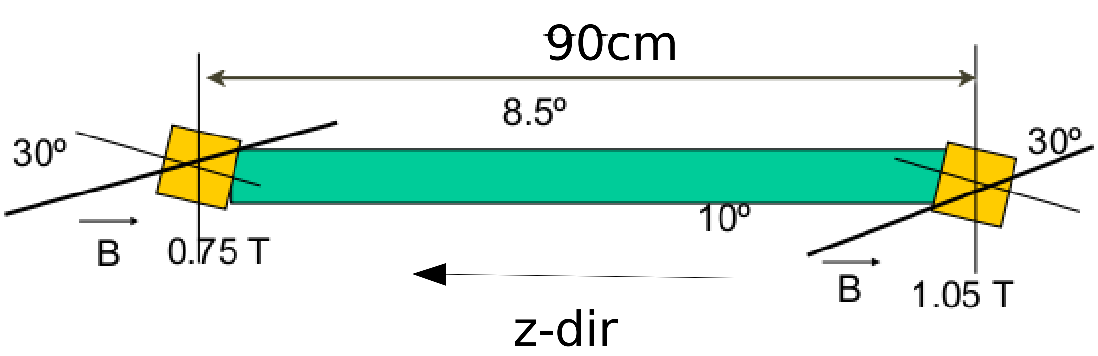
Open-frame structure
Form cell only with cathode foils

12.5µm cathode foil
Vernier pattern → z reconstruction



# Timing Counter

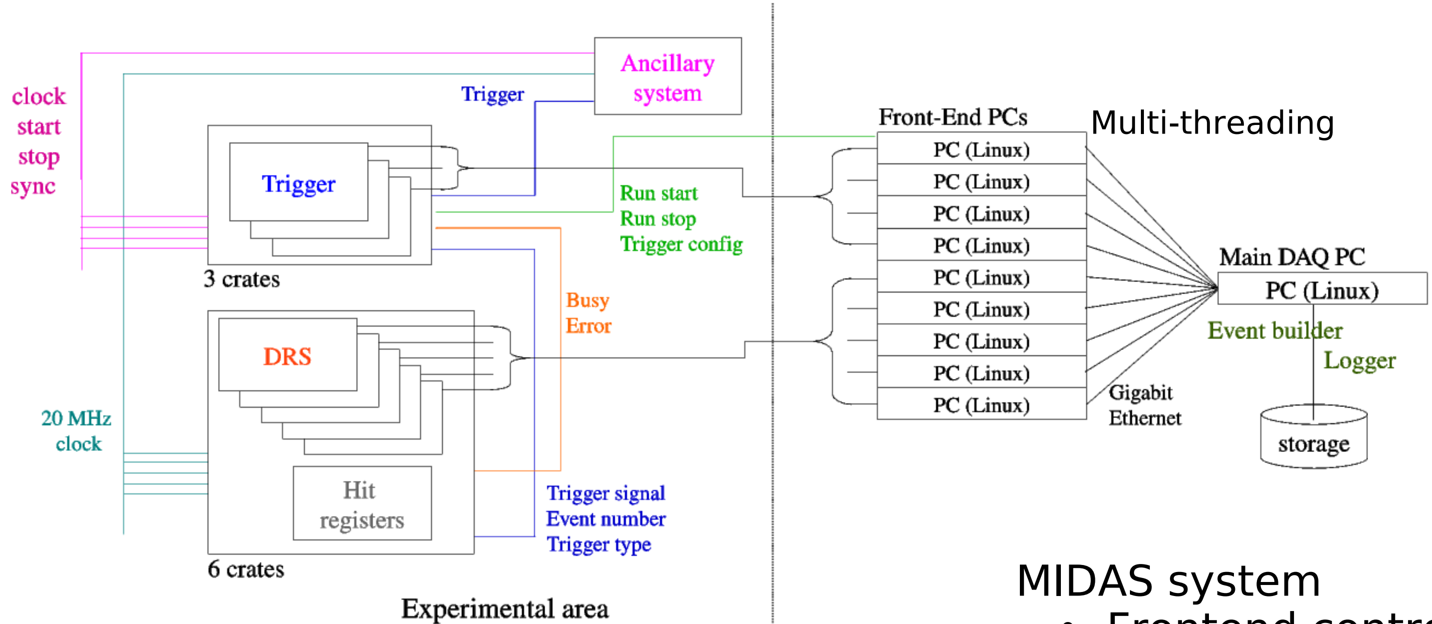



- Hit timing counter one turn after exit of DCH. Measure hit timing
- Two layers of plastic scintillater arrays
  - Outer : Scintillation bars
    - $4x4x80cm^3$, BC404
    - 15bars concentrically (10.5°interval)
    - Fine-mesh PMT at two ends
    - High precision time measurement
  - Inner : Scintillating fiber
    - $5x5mm^2$
    - 128 fibers along z-dir.
    - Readout by APD
    - Hit pattern → trigger

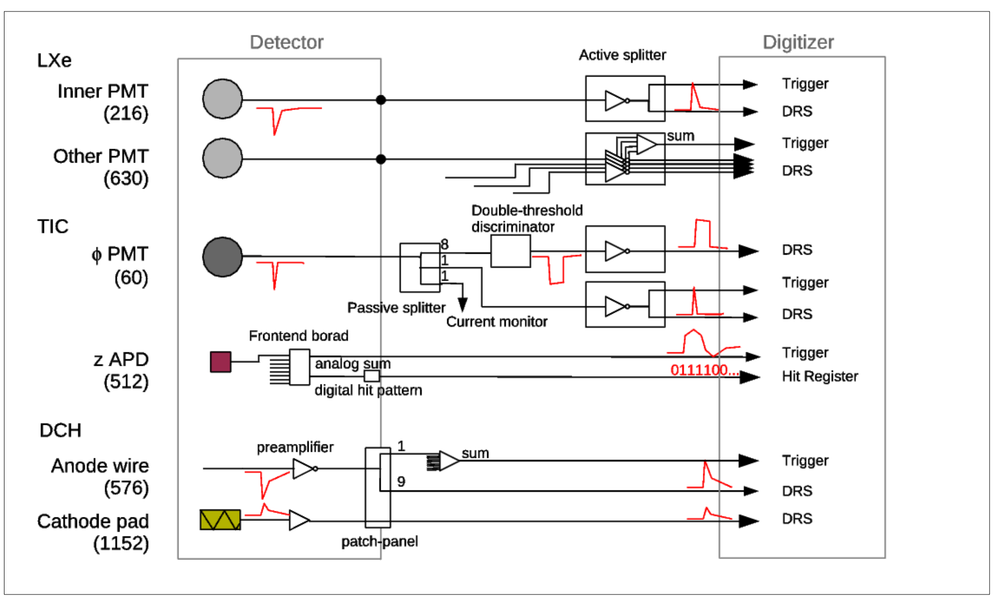
Not used in 2008 analysis
Defects in APD readout

# Data Acquisition

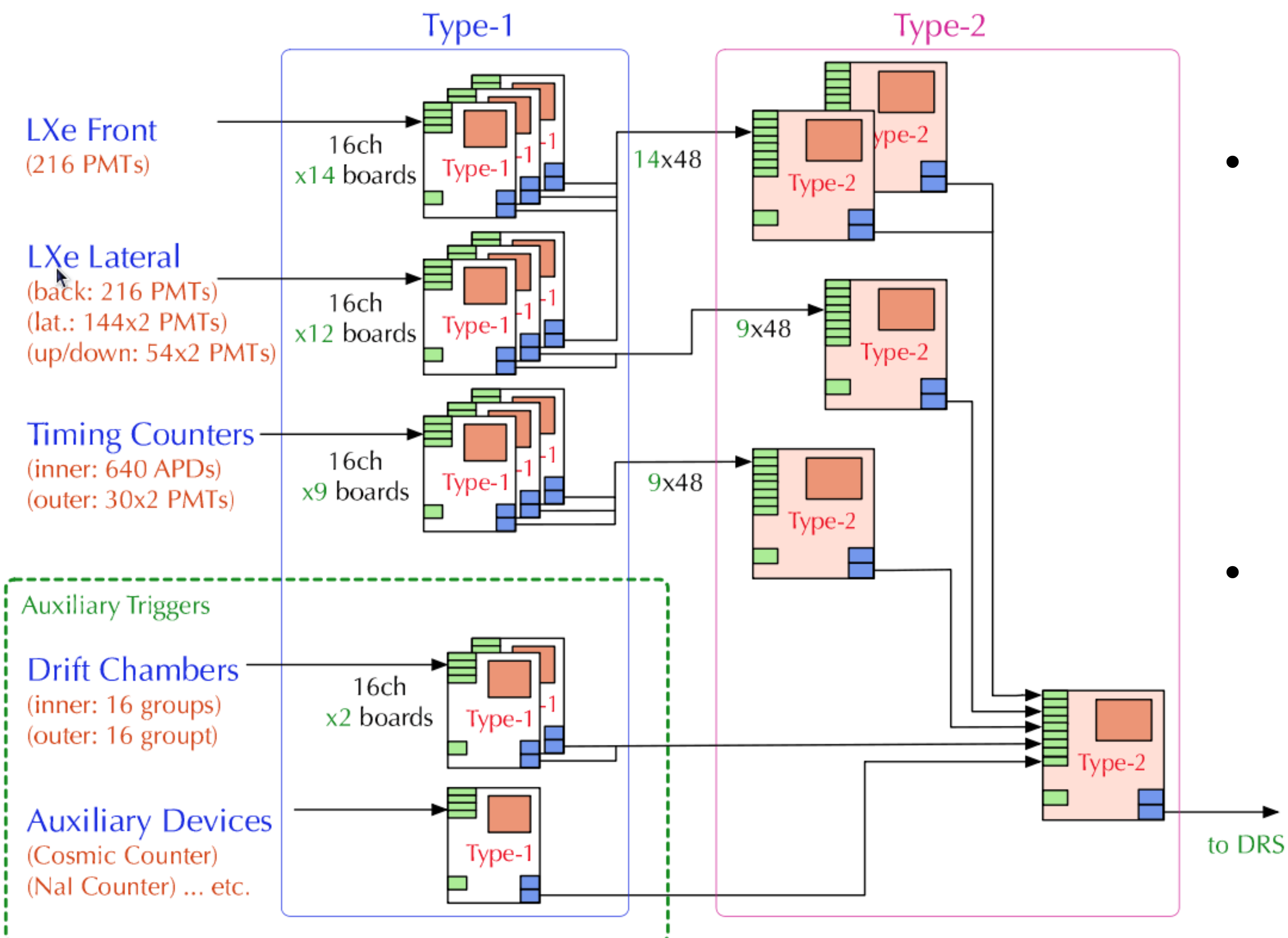



Multi-threading

MIDAS system
- Frontend control
- Event building
- Logging
- Online database
- Slow control
- History monitoring
- Web interface



# Trigger

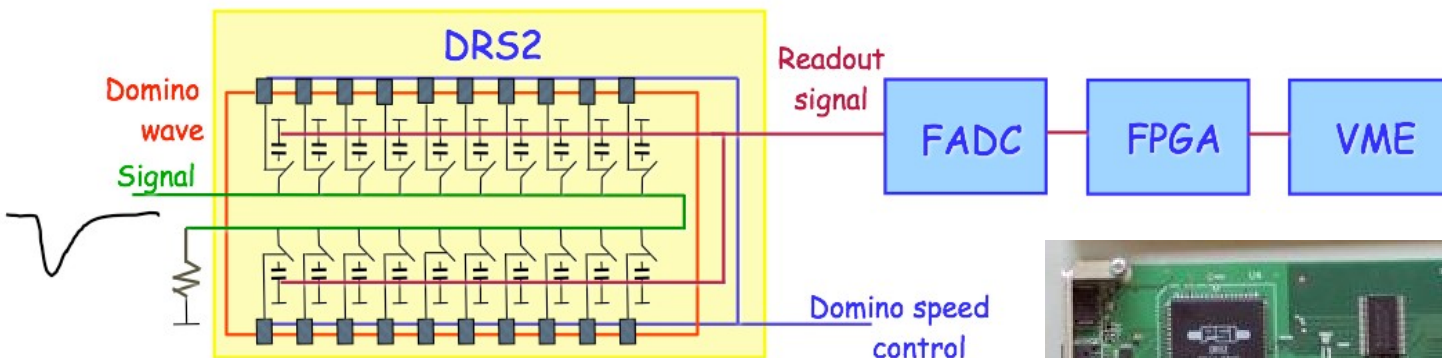


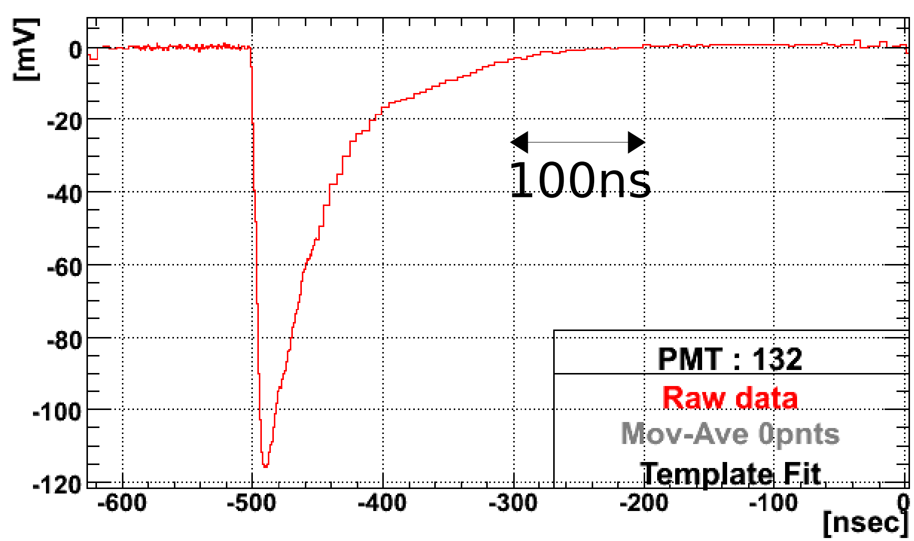

- FPGA-FADC architecture
  - 100MHz FADC on VME boards
- MEG trigger
  - $\gamma$ energy
  - $e^+$-$\gamma$ coincidence
  - $e^+$-$\gamma$ direction match (back-to-back)
    - Max output PMT in LXe
    - TC hit position
- In addition, 10 trigger types are mixed in normal data taking
  - Calibration, normalization

| | |
|---|---|
| Beam rate | $3\text{x}10^7 s^{-1}$ |
| Fast LXe Q sum (>40MeV) | $2\text{x}10^3 s^{-1}$ |
| Time coincidence | $100 s^{-1}$ |
| Direction match | $10 s^{-1}$ |

# Readout Electronics

- Record <u>waveform</u> from all sub-detectors (no ADC,TDC)
  - DRS chip (Domino Ring Sampler)
    - Up to 5GSPS, 1024cell, 8ch/chip
  - Sampling speed : 1.6GHz for LXe&TC, 500MHz for DCH
  -

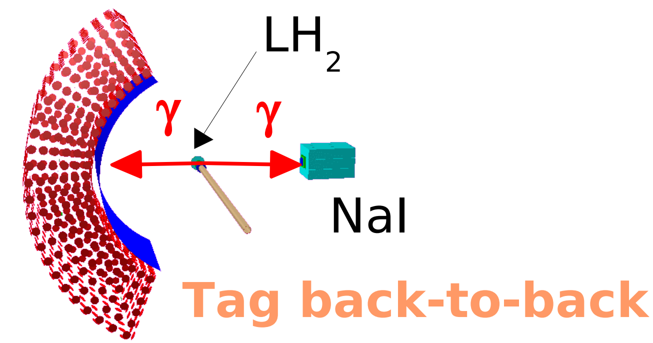


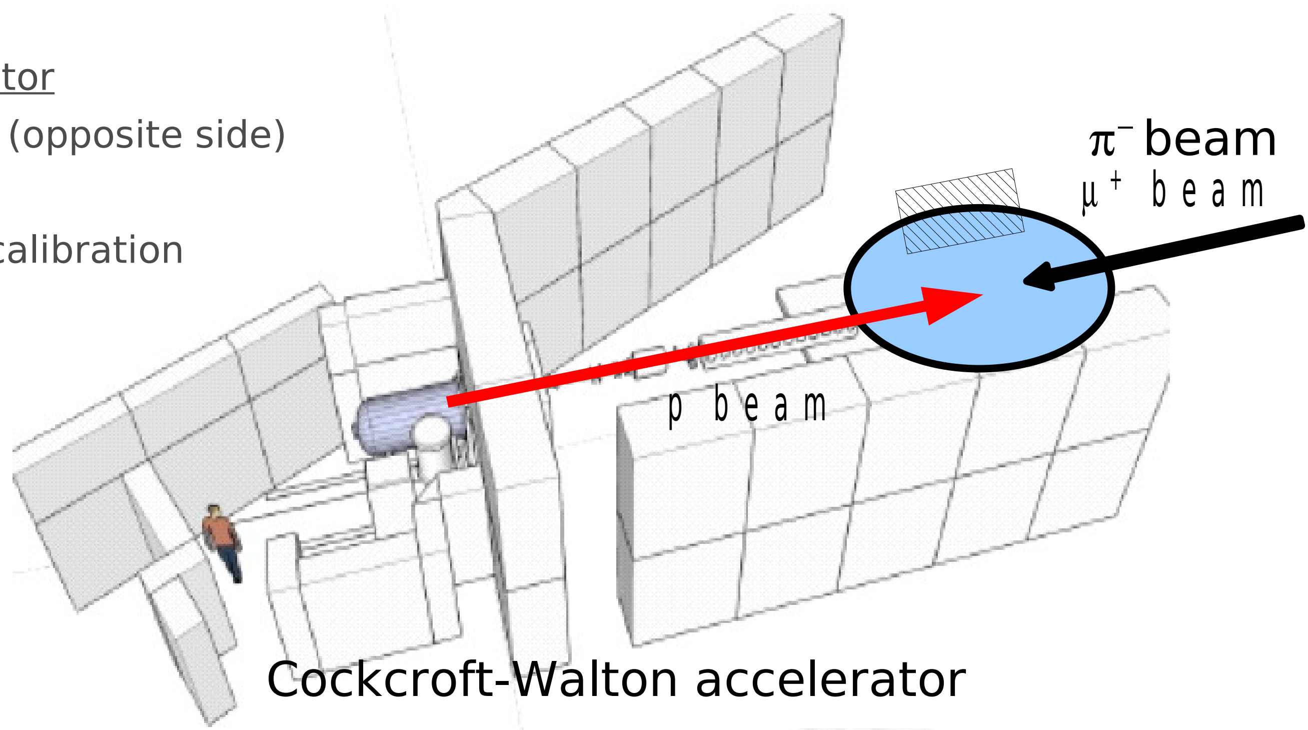

# Calibration

- 55MeV high-energy $\gamma$ from $\pi^0$ decay
  - Evaluation of resolutions (energy, position, timing)
  - Calibrate energy scale
  - Use same beamline as $\mu^+$
  - Take some time for setup (~5days)
    - Conducted at beginning & end of physics run.
  - More BG than normal $\mu^+$ run.

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

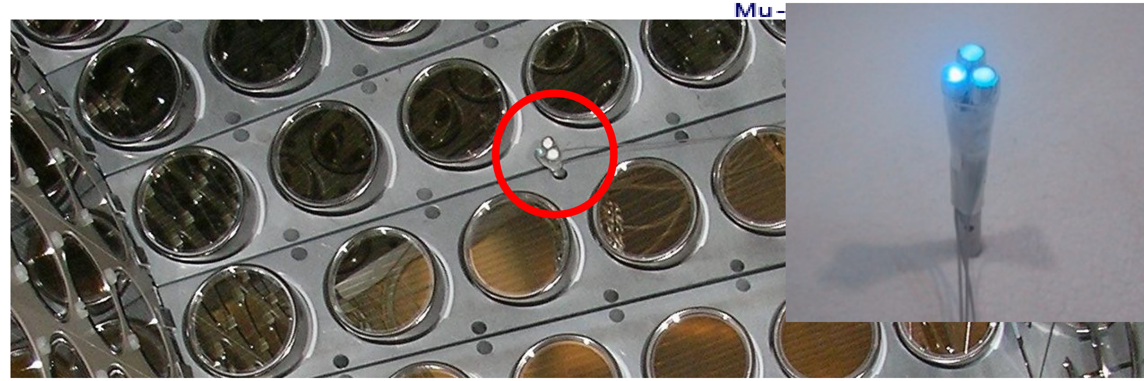



- 17.6 MeV $\gamma$ from Li(p,$\gamma$)Be reaction
  - Lower energy (1/3)
  - Uniformity, light yield monitor
  - MEG dedicated p-beamline (opposite side)
  - Easy to switch (~20min)
  - 3 times per week, regular calibration

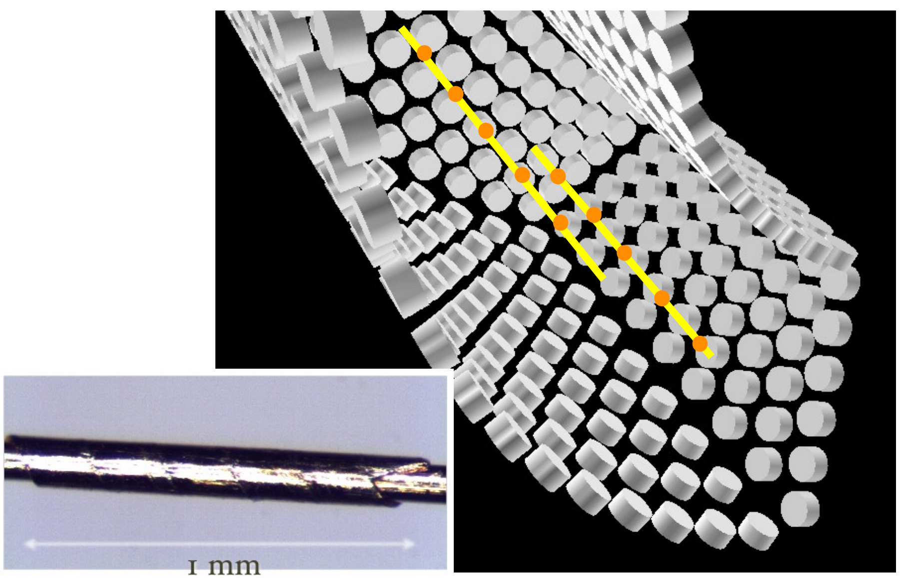



- $\mu$ Michel decay
  - Calibrate $e^+$ (DCH&TC)
- $\mu$ radiative decay
  - Time calibration
- LED, $\alpha$ source
  - PMT calibration

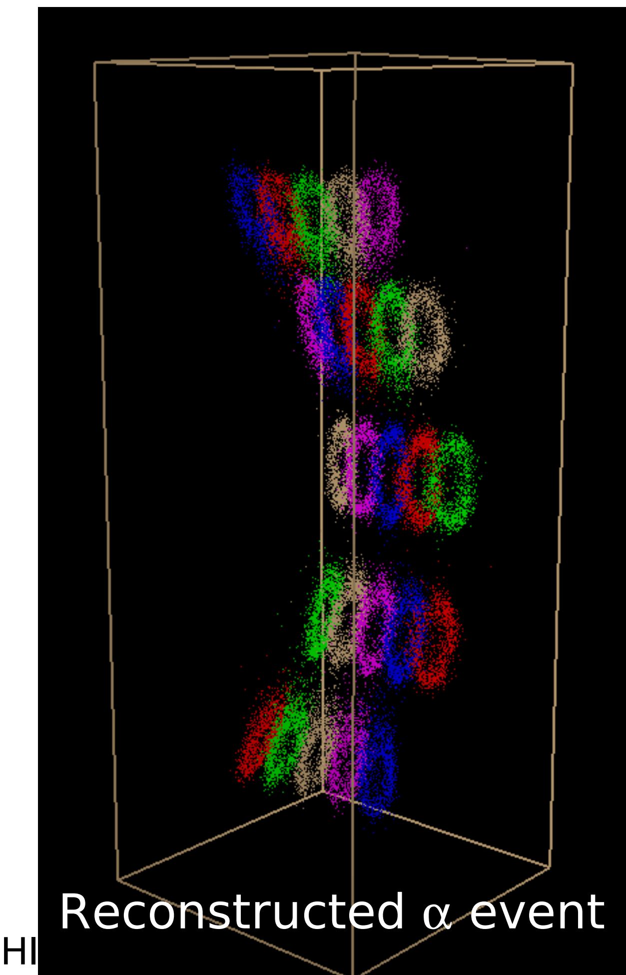
# PMT Calibration



- LED
  - PMT gain calibration
  - Time offset calibration
- Alpha
  - PMT Q.E. calibration
  - LXe attenuation length measurement




Am source on wire



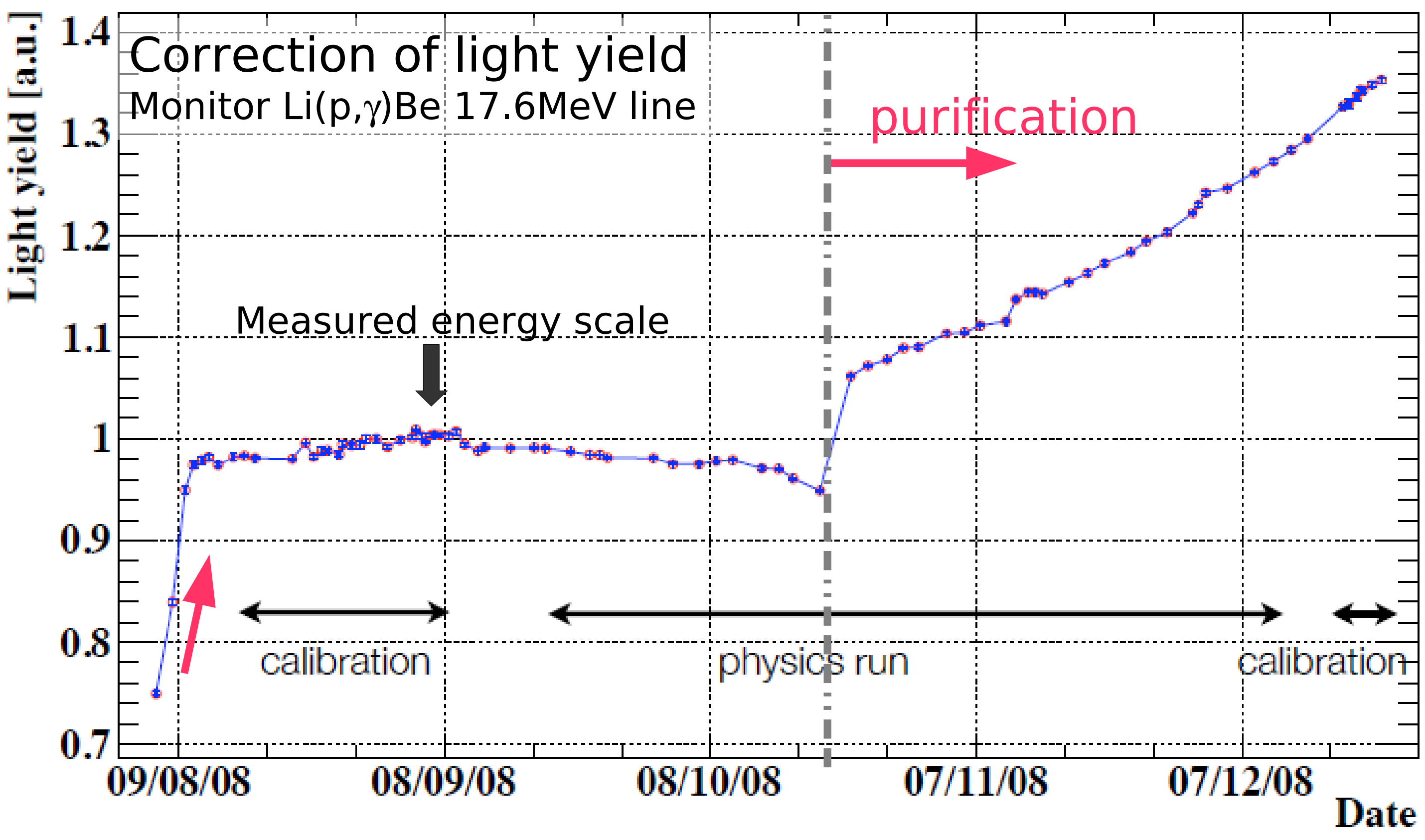
Reconstructed α event

# Variation of LXe light yield

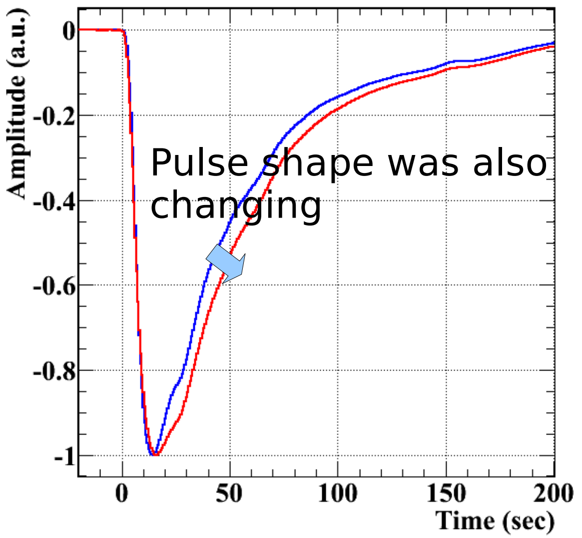
- Lower than expected
- Recover by purification
- Decrease by (possible) leak

Confirmed we can monitor light yield using several kinds of daily calibration.

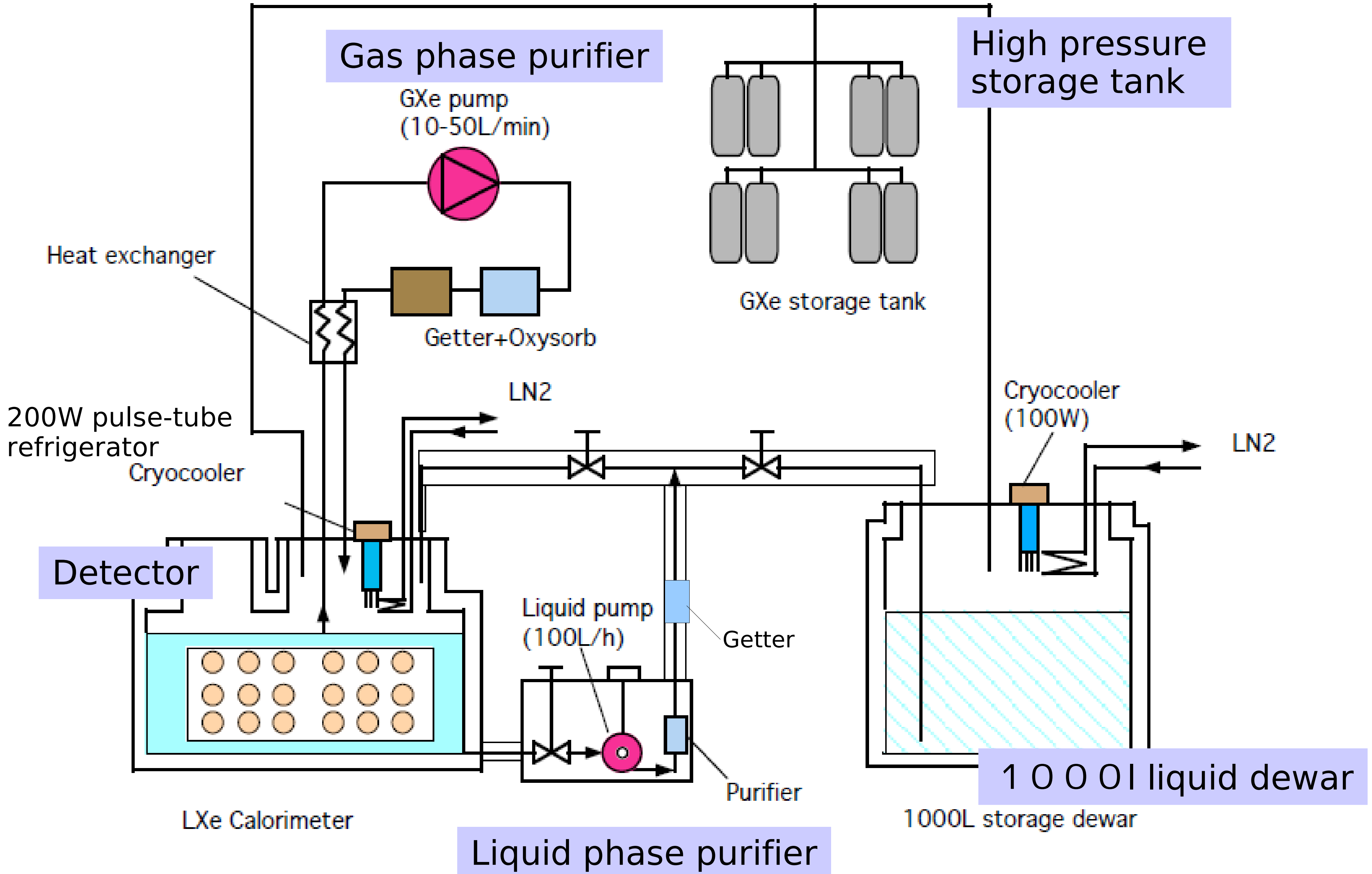
We decided to continue purification during data taking
(gas phase:continuously, liquid phase:intermittently(beam shutdown))



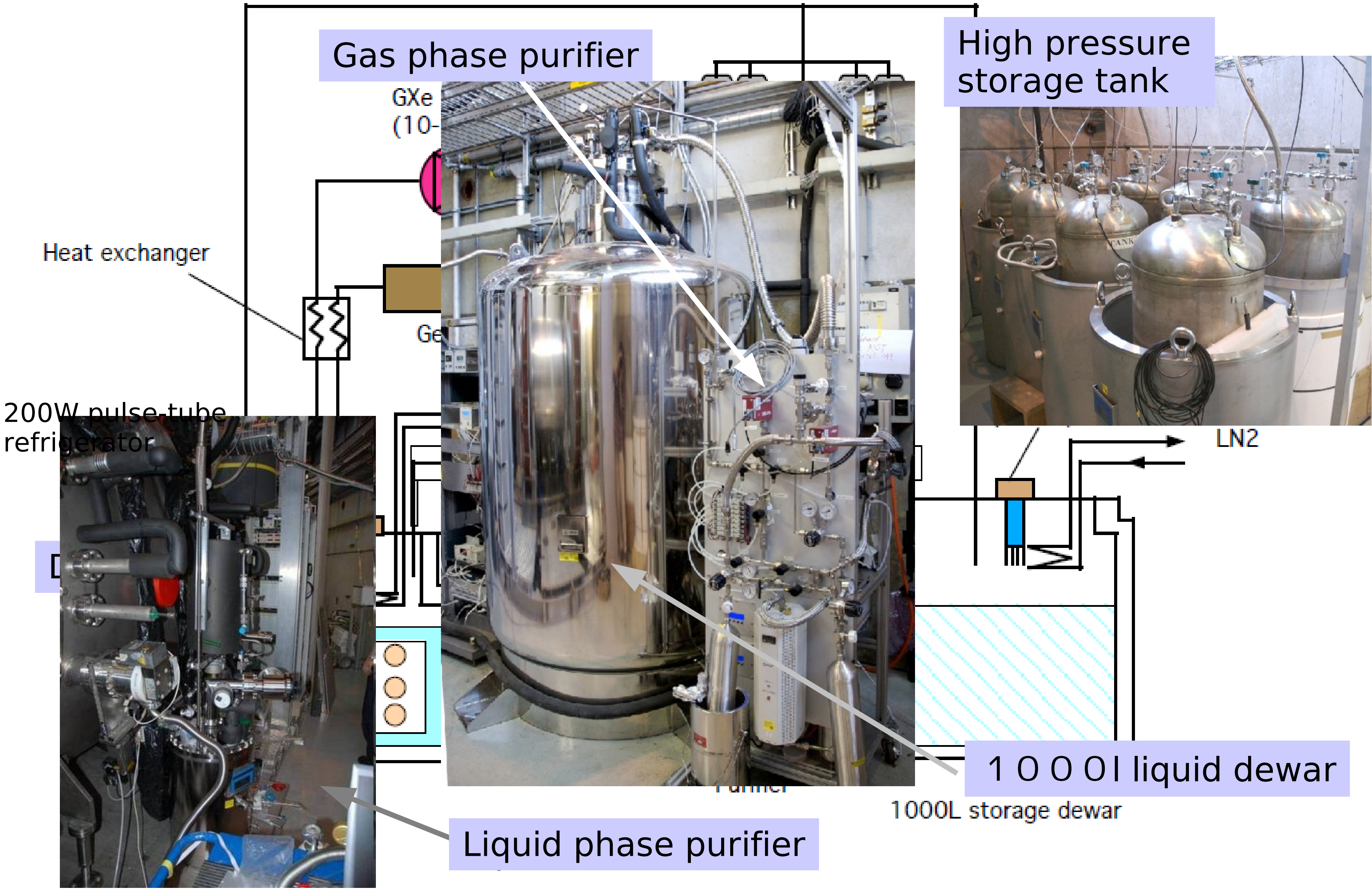

Finally, keep overall energy scale uncertainty under 0.4%



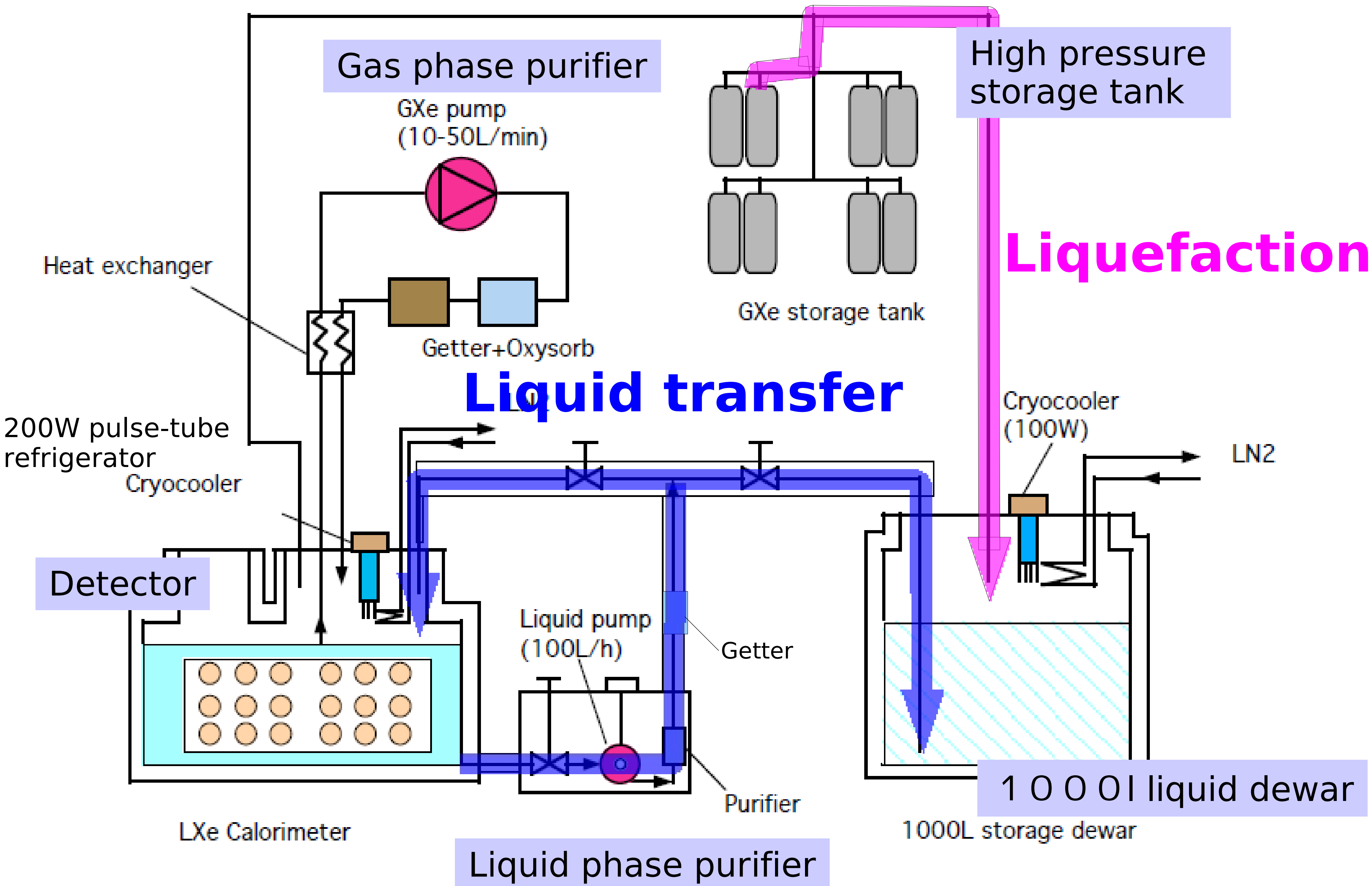
# Xenon System



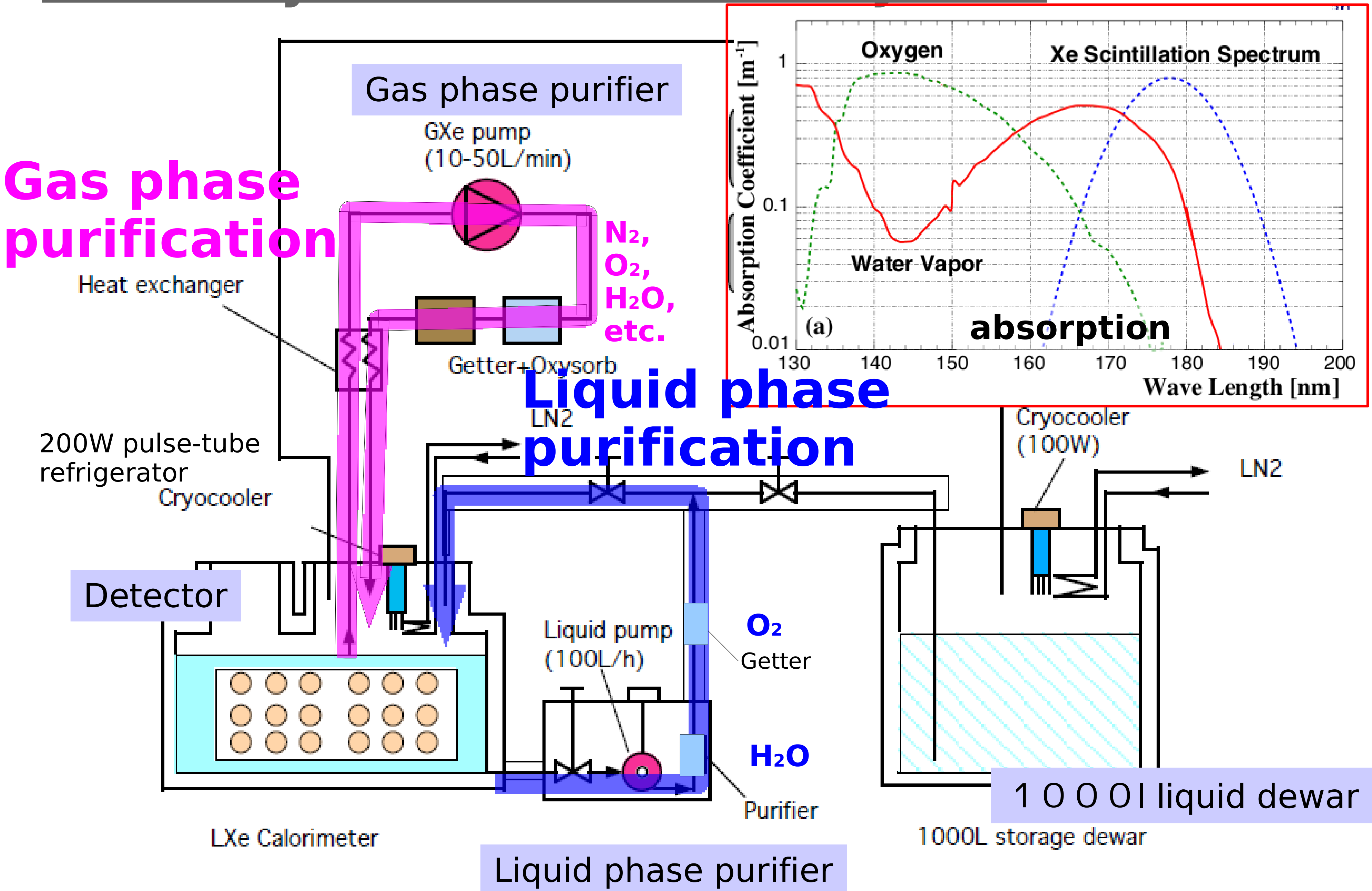
# Xenon System



# Xenon System:Liquefaction/Transfer



# Xenon System:Purification System



# Xenon Scintillation

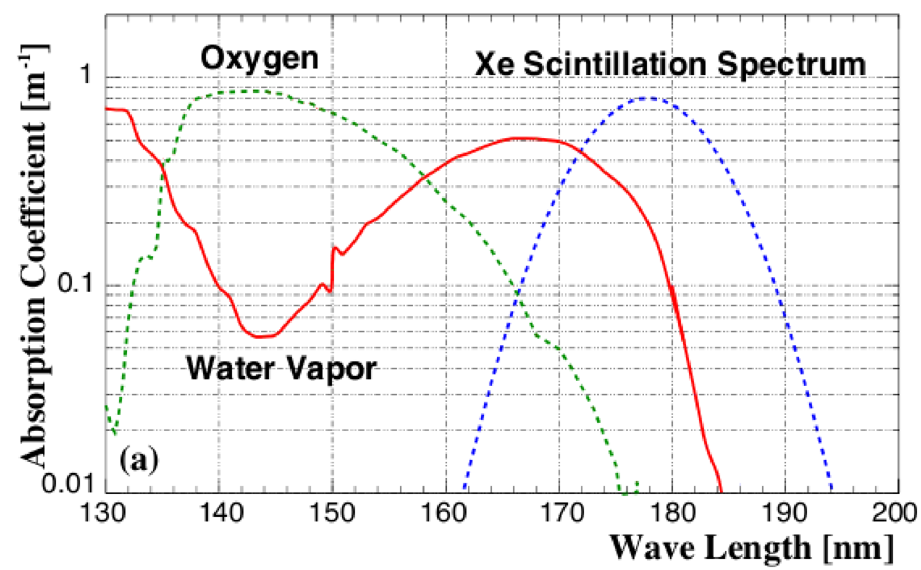
Mu-E-Gamma Collaboration

- De-excitation process (fast)
  - Xe + Xe* → $Xe_2^*$ → 2Xe + hν
- Recombination process (slow)
  - $Xe^+$ + Xe → $Xe_2^+$
  - $Xe_2^+$ + $e^-$ → Xe** + Xe
  - Xe** → Xe* + heat
  - Xe + Xe* → $Xe_2^*$ → 2Xe + hν

Quench
- $Xe_2^* + N_2 \rightarrow 2Xe + N_2$
  $O_2 \qquad\qquad O_2$

(two-body collision)

Absorption

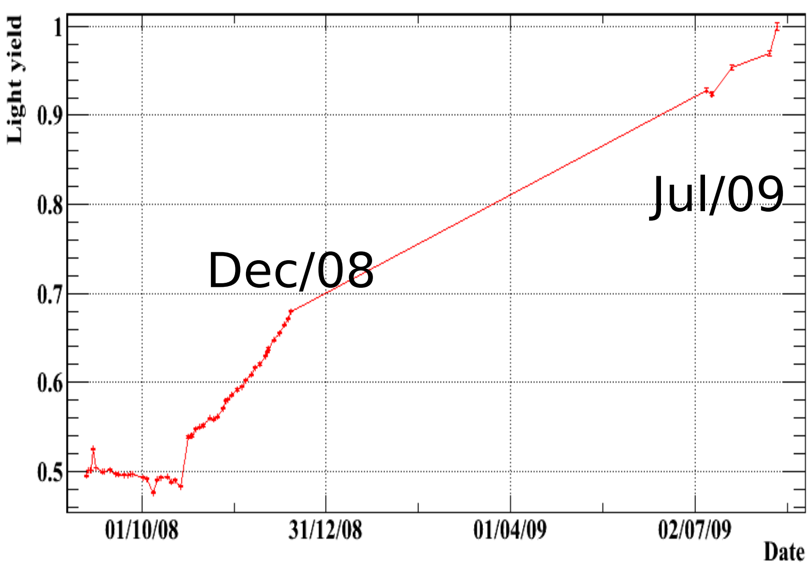




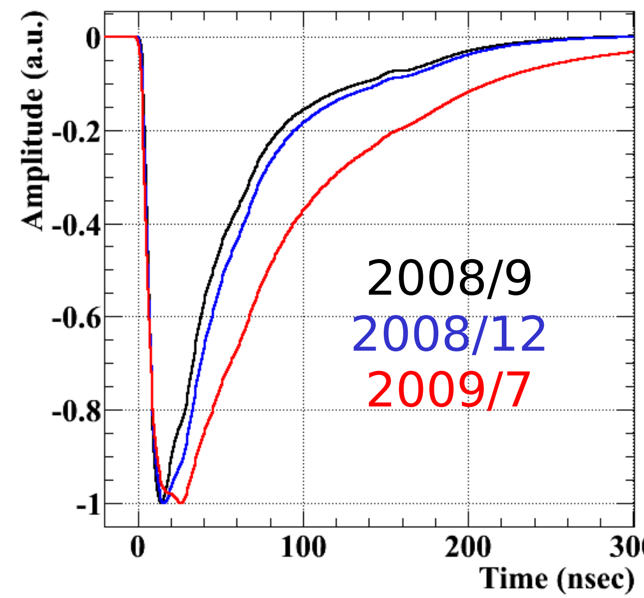
$O_2$ $O_2$
(two-body collision)

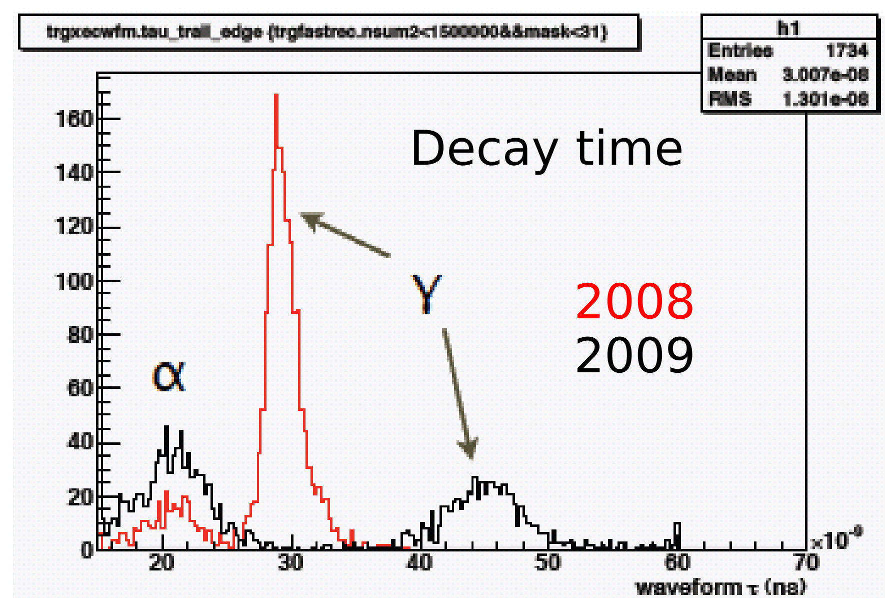
# Light yield & pulse shape

- Further purification during shut down
  - Whole volume passed gas purification system (getter).



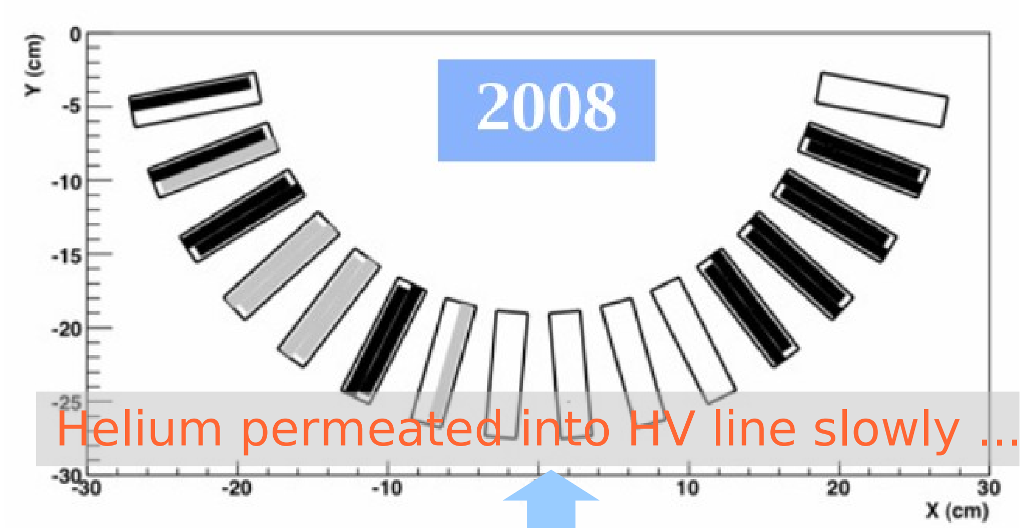

Waveform



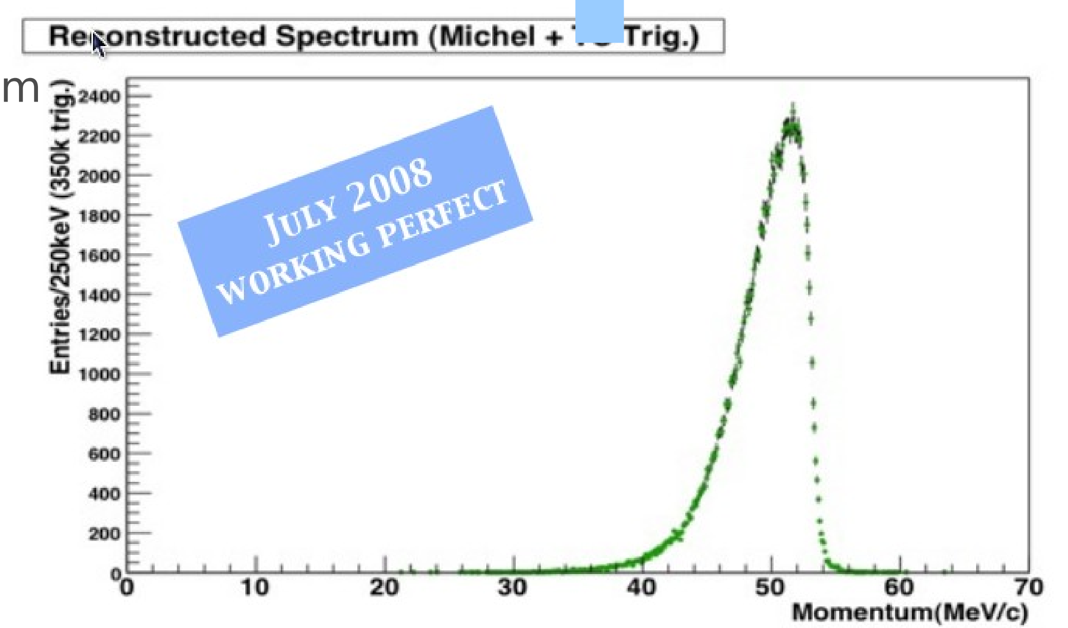



# DCH Discharge Problem

- DCH frequently discharged
  - Inside magnet is filled with pure-He.
  - DCH-outside is exposed in He atmosphere. (HV line)
- It happened also in 2007 engineering run.
  - Repaired in maintenance period
  - At the beginning of 2008, every chamber could be operated
  - We thought we could fix the problem …,
- In 2008, after a few months
  - Gradually some chambers starts to discharge again.
- Finally, out of 32 planes
  - 18 planes were operational
  - Only 12 planes worked at nominal voltage



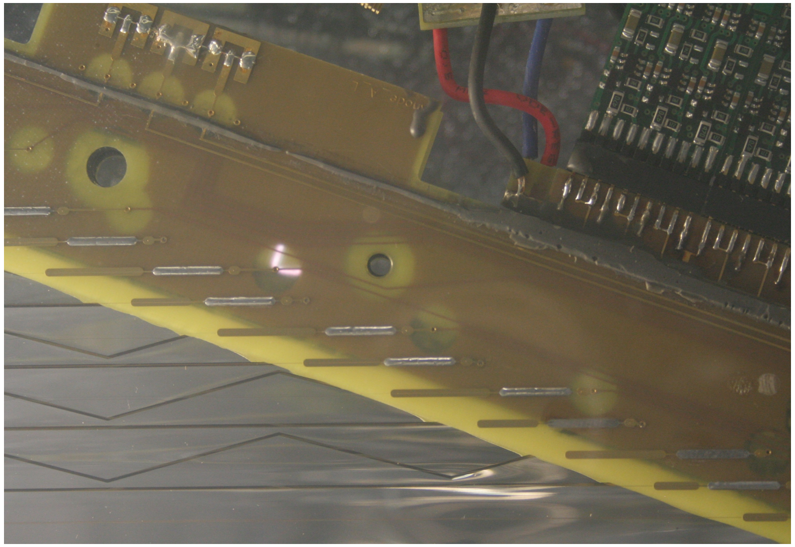

Helium permeated into HV line slowly …

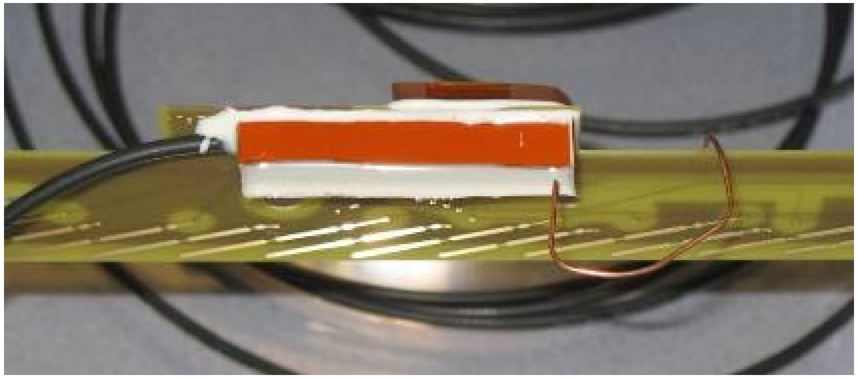



Degradation of e$^+$ measurement (**efficiency** · resolution)

# Solution for the Discharge problem

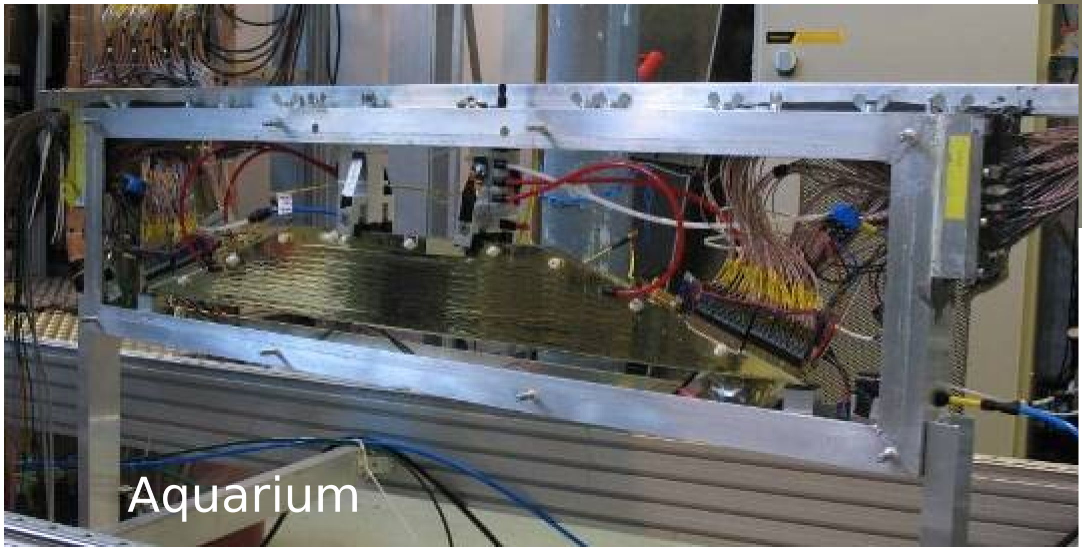
- Exhaustively investigated weak points for all HV connections.
- HV soldering spot on PCB and HV via on PCB are suspicious.
- Discharge was reproduced at Lab. test finally after many trial.
- Solutions
  - New design of PCB
    - Separate layers for HV and GND completely
      - (3 → 4 layers)
  - Potting HV soldering spot with epoxy





# After modification

- Two chambers with new HV PCB into “Aquarium” to see long term operation with He/Ethane inside and pure-He outside and nominal HV
- 16 chambers are mounted on the support structure inside the “He cabin”. Signal check with nominal HV


Stable operation for ~7 months

# Reconstruction & Performance

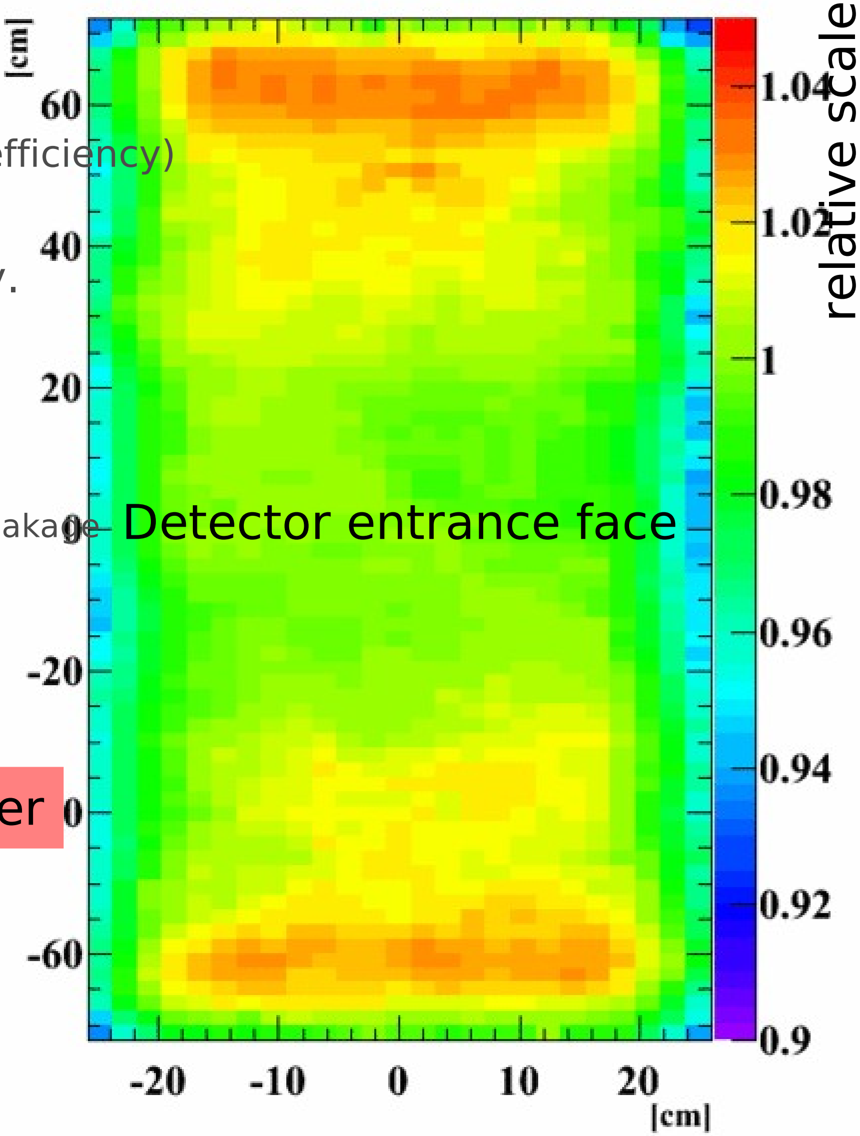
## In 2008

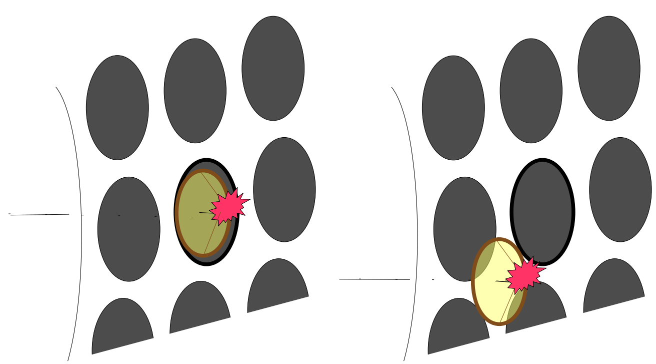
# Gamma energy I

- Reconstruction
  - Sum of PMT outputs
  - Correction of non-uniformity (collection efficiency)
    - Use 17.6MeV $\gamma$ from Li(p,$\gamma$)Be reaction
      - It illuminate the detector uniformly.
  - Treatment of shallow events
    - Low resolution at shallow part
      - Shower escape
      - Large variation of photon collection, Photon leakage
      - Saturation of signal(dyn.range of elec.)
    - But want to use for statistics.
    - Recovered saturation using waveform
    - Correct photon collection efficiency by calculating solid angle

$\varepsilon$~30% recover

Energy response map (before corr.)



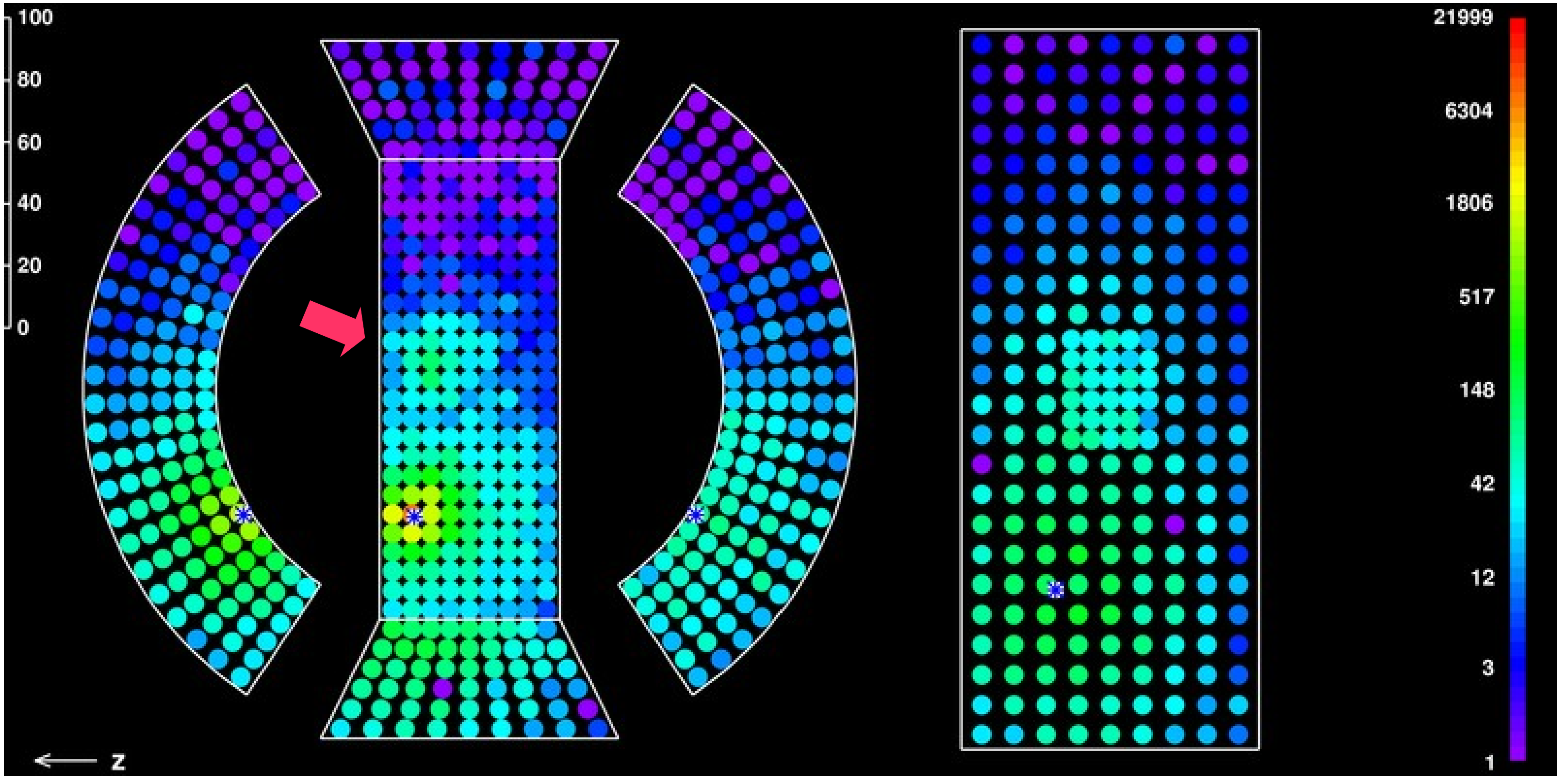



In front of a PMT intermediate

# Gamma energy II

- Recover of pileup events
  - Not discard pileup events, but use with unfolding.
  - Improve efficiency

ε ~8% gain

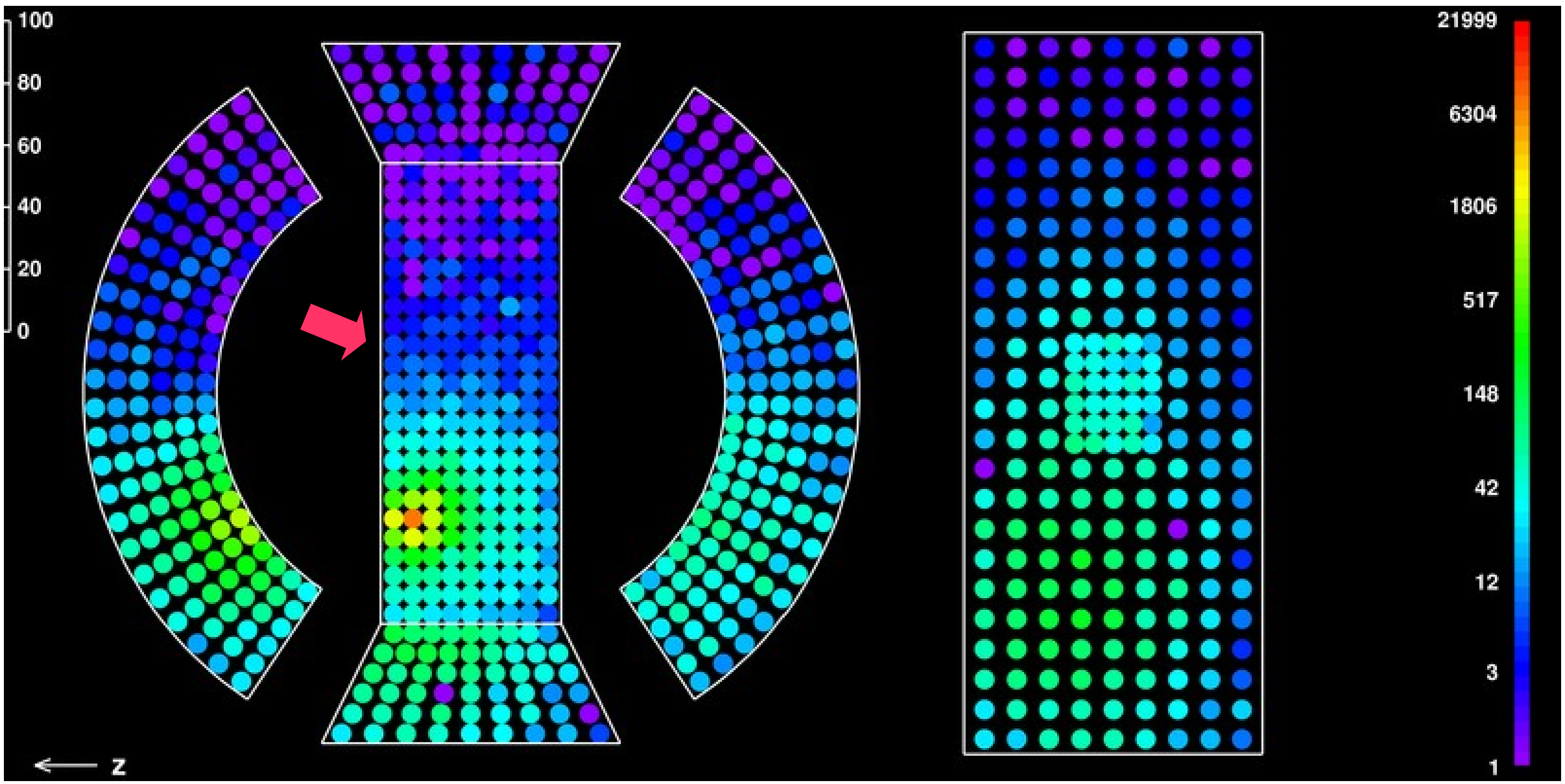



- ID pileup → reconstruct energy using region without pileup → replace PMT outputs for pileup region with estimated charge → then normal reconstruction

# Gamma energy II

- Recover of pileup events
  - Not discard pileup events, but use with unfolding.
  - Improve efficiency

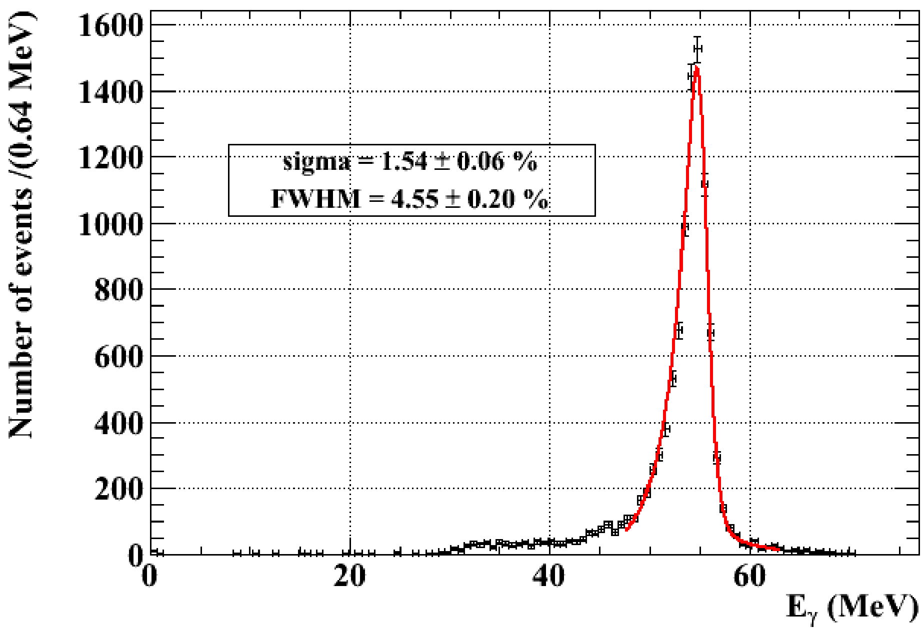
ε ~8% gain

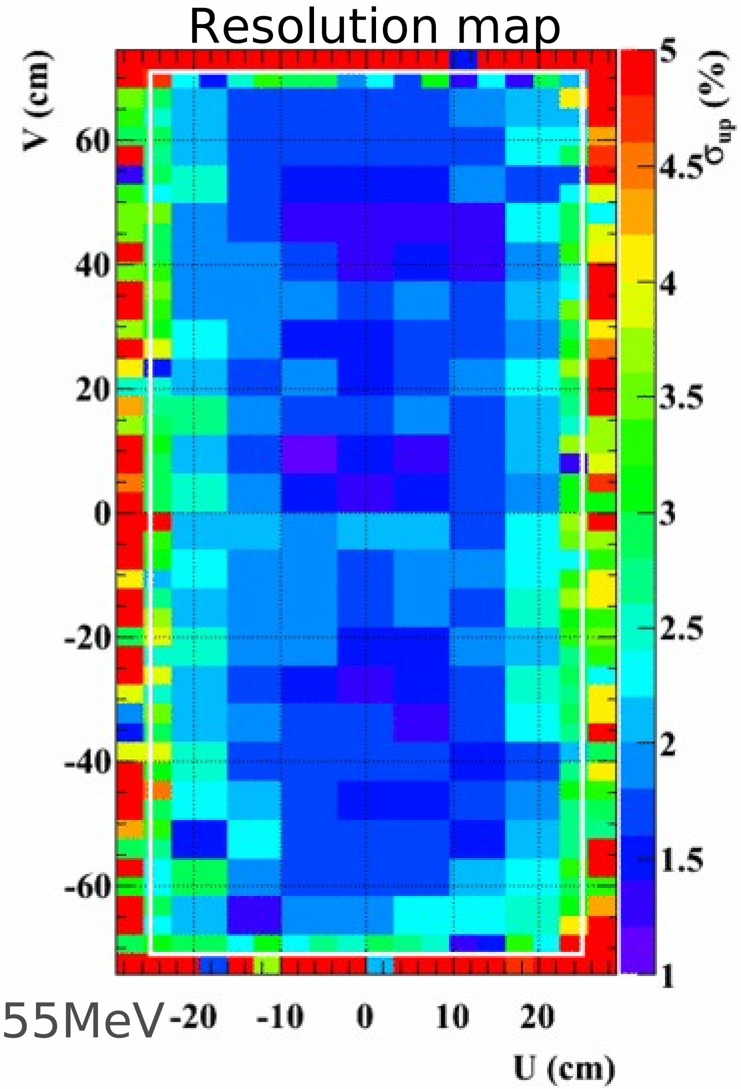



- ID pileup → reconstruct energy using region without pileup → replace PMT outputs for pileup region with estimated charge → then normal reconstruction

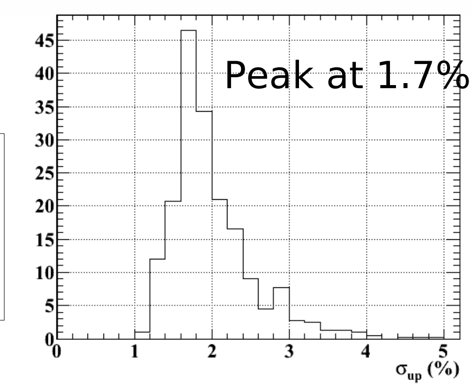
# Gamma energy III

- $\pi^0$ 55MeV



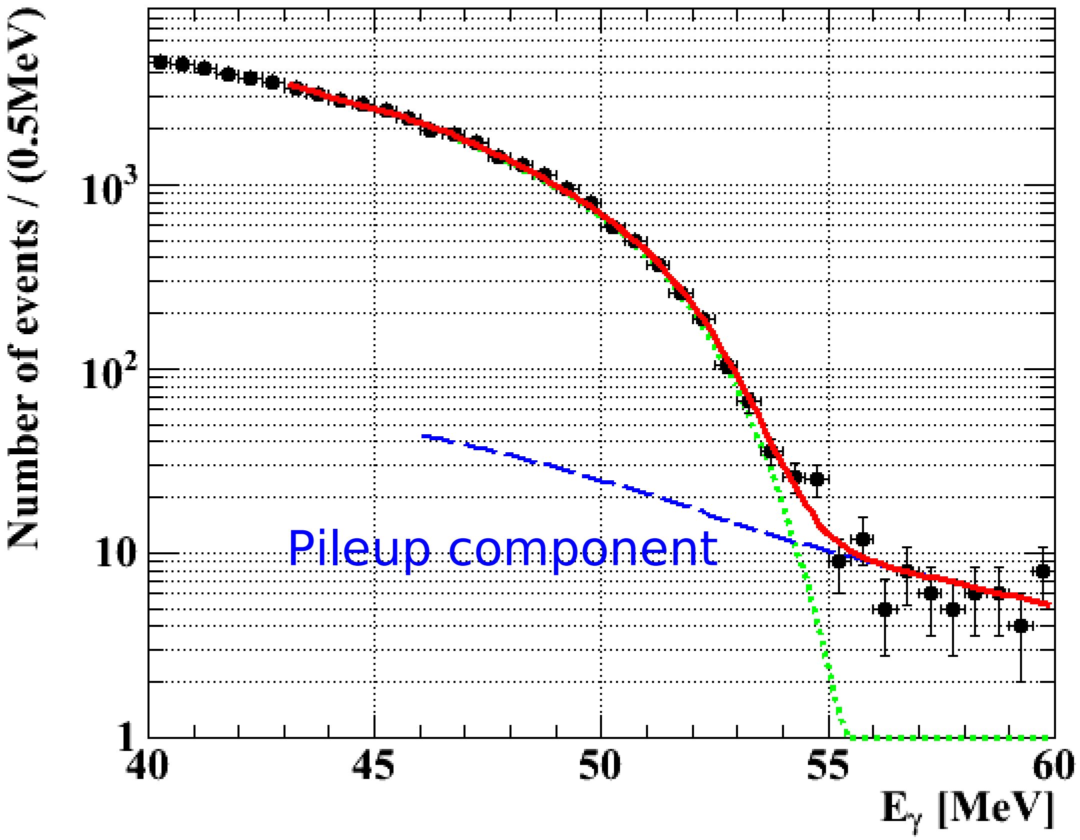

  - Evaluate energy resolution as a response to 55MeV
  - Evaluate res for all over the entrance face
  - Average res (averaged over the event distri. in MEG run)




**$\sigma_{up}$=2.0% for deep(>2cm), 3.0% (1~2cm), 4.2% (0~1cm)**
**Determine energy scale**

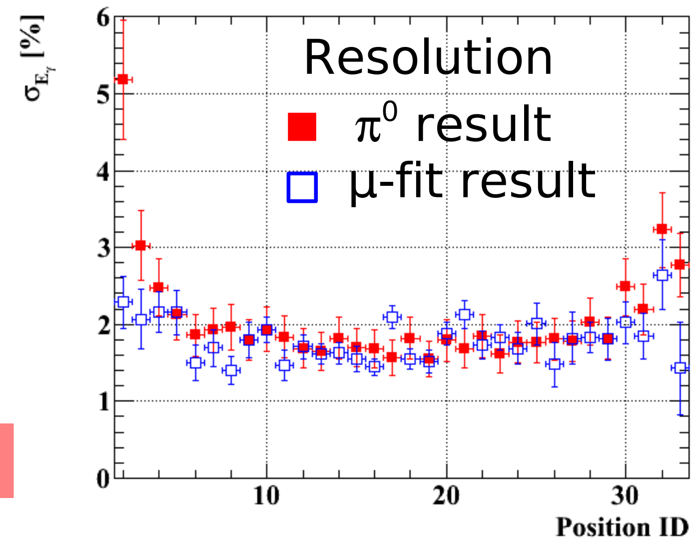
# Gamma energy IV

- Using γ spectrum of **μ** decay (side-band)
  - Check those correction, resolution and energy scale



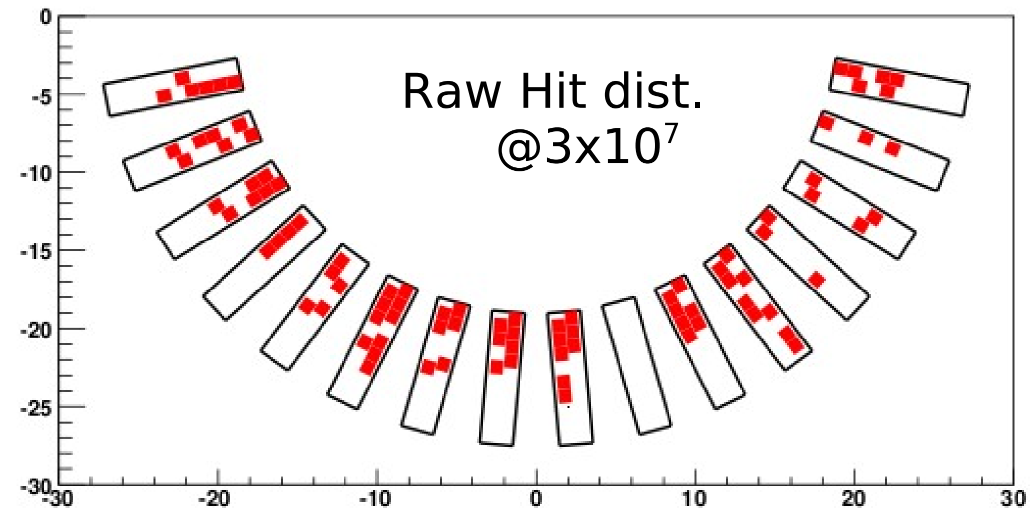

Fit spectrum with the expected one from MC

- Parameters
  - Energy scale
  - Resolution
  - Fraction of pileup




Well consistent → validation of analysis

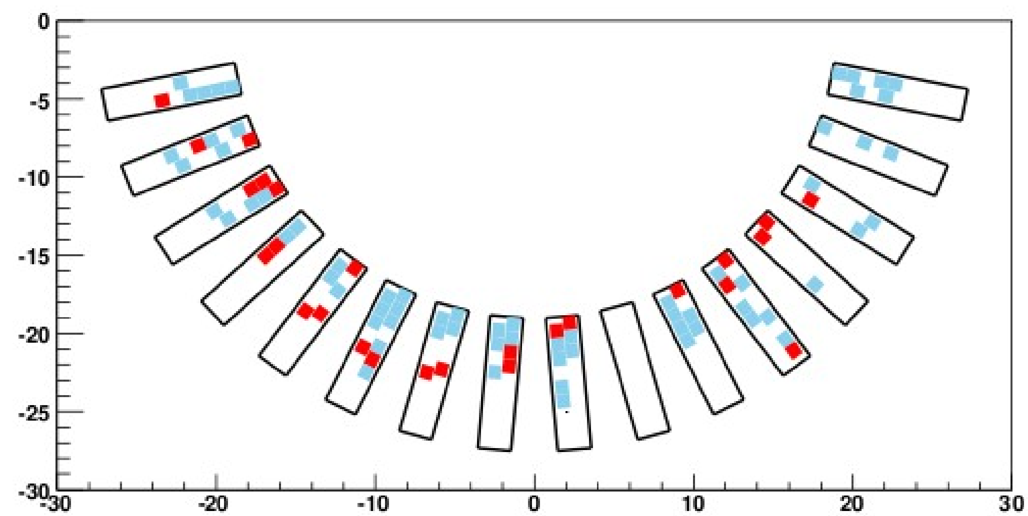
# Positron Tracking:pattern recognition




Select hits with time and z info.

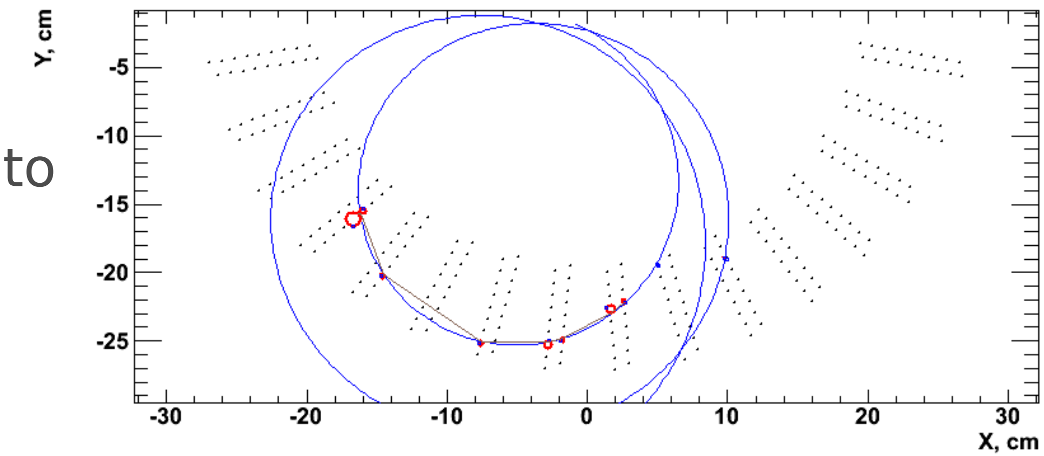
Clustering, connecting

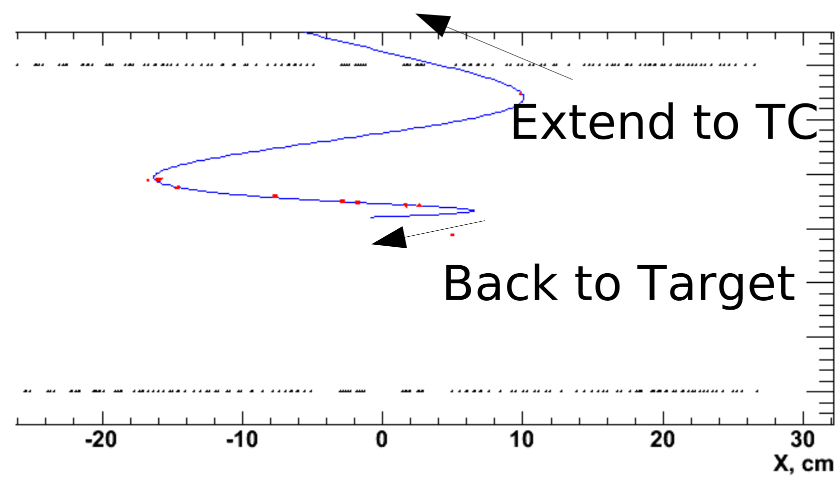
Find track candidates

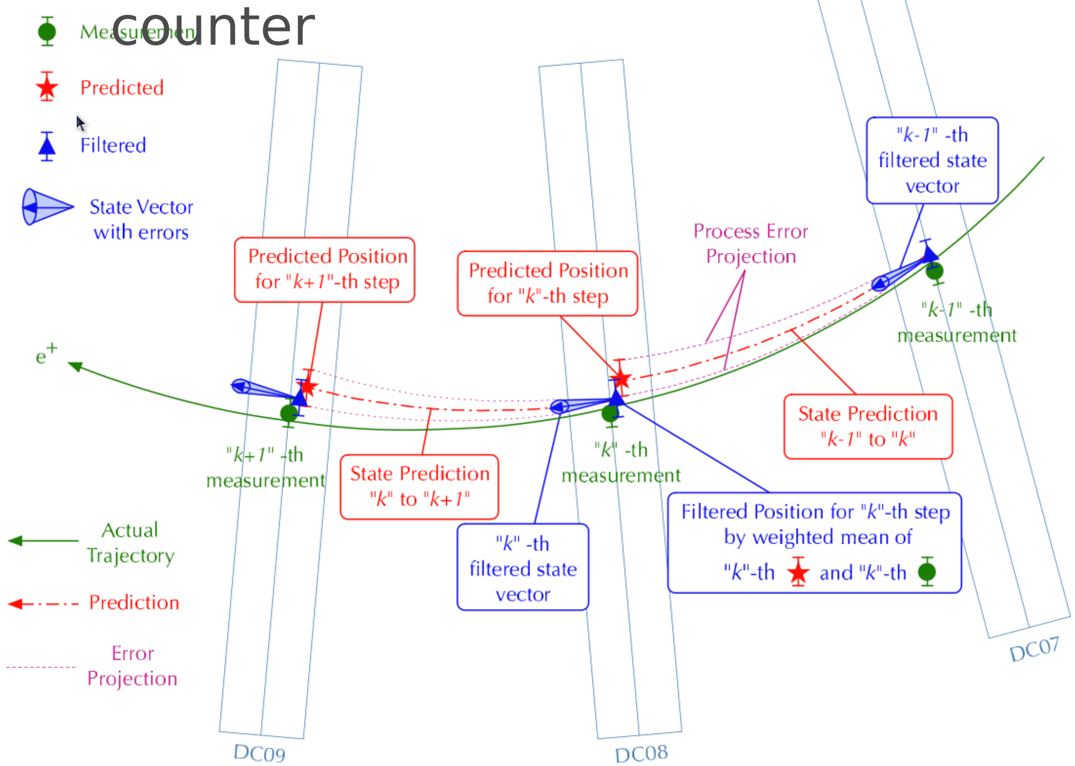


# Positron Tracking:Kalman Filter

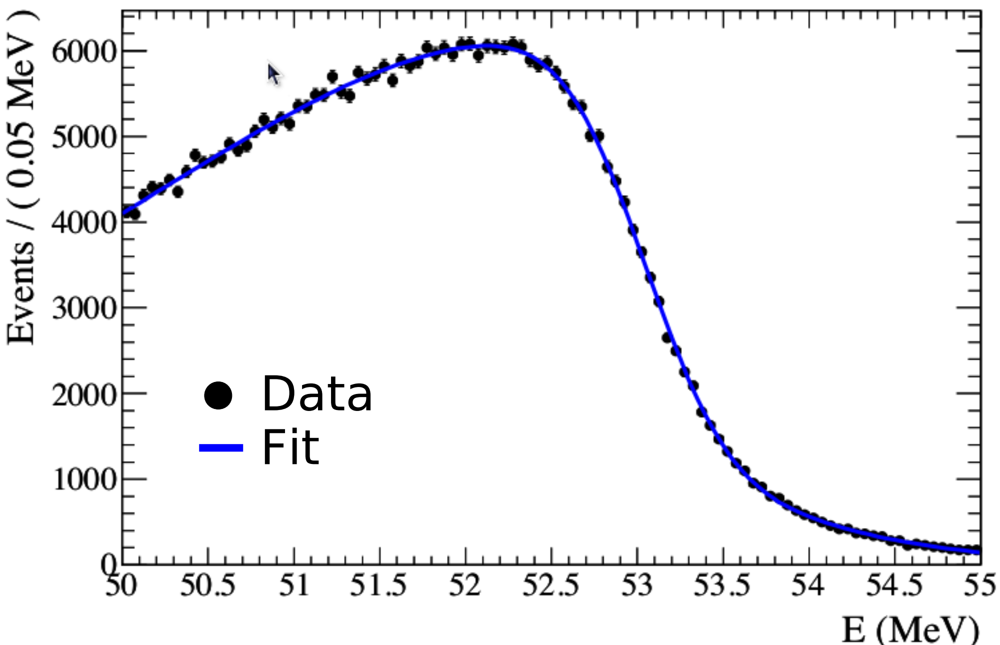
- Reconstruct $e^{+}$ trajectory by track fitting with Kalman-filter
- Extrapolate the track up/down to timing counter / target.
- Reconstruct **momentum · emission angle · vertex** on target
- Reconstruct **ToF** to timing counter



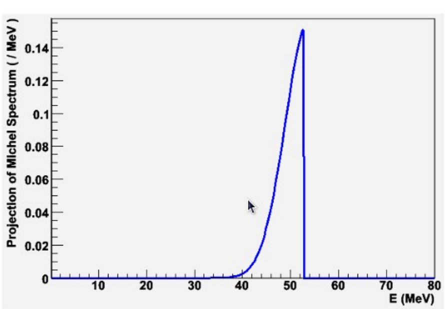



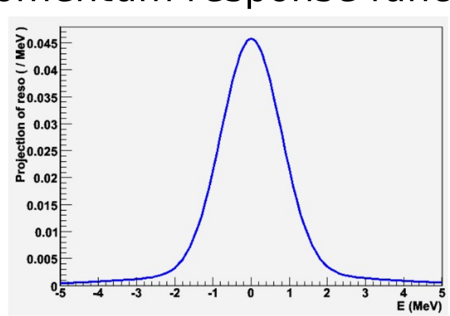
# Positron momentum




Momentum response function



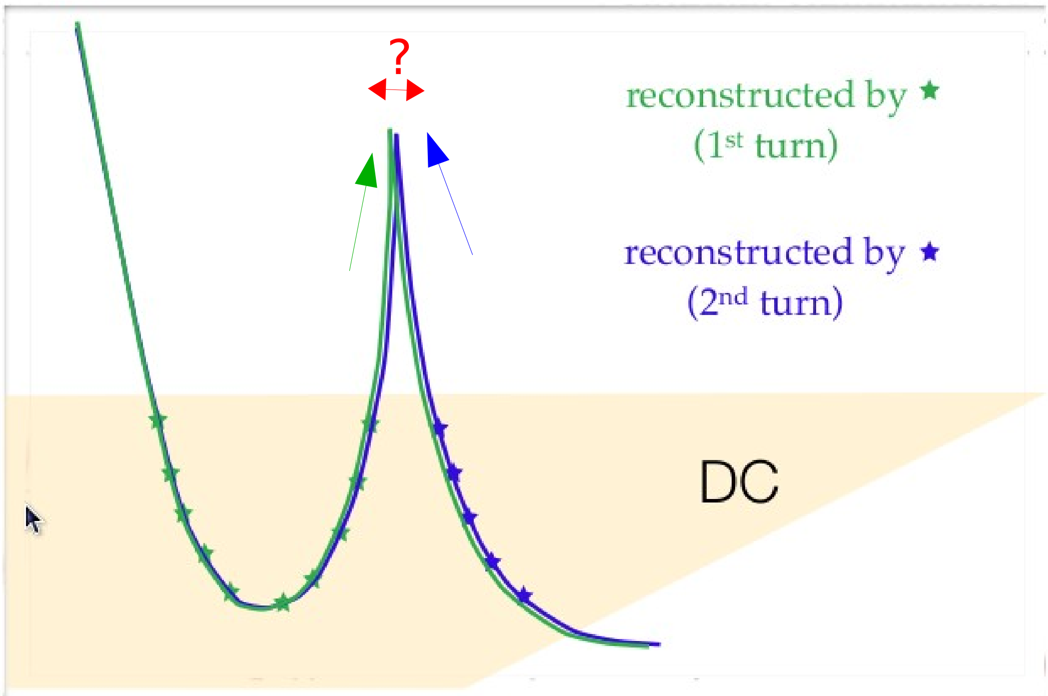

$\otimes$

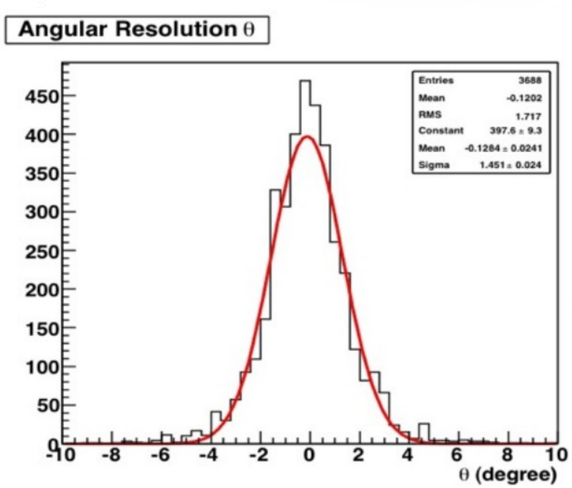


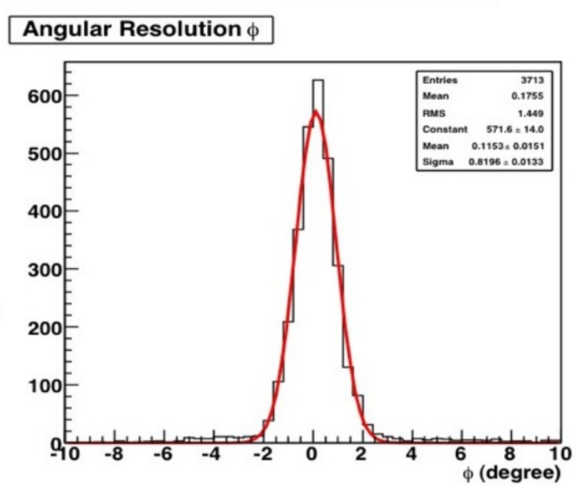

$$P(E) = (P_{\rm theo}(E) \times P_{\rm acc}(E)) \otimes P_{\rm res}(E)$$

- Evaluate momentum response (resolution) by fitting kinematical edge (52.8MeV) of Michel spectrum
- Response function : triple Gaussian
  - Core = 374keV (60%)
  - Tail = 1.06MeV (33%), 2.00MeV (7%)

# Positron emission angle



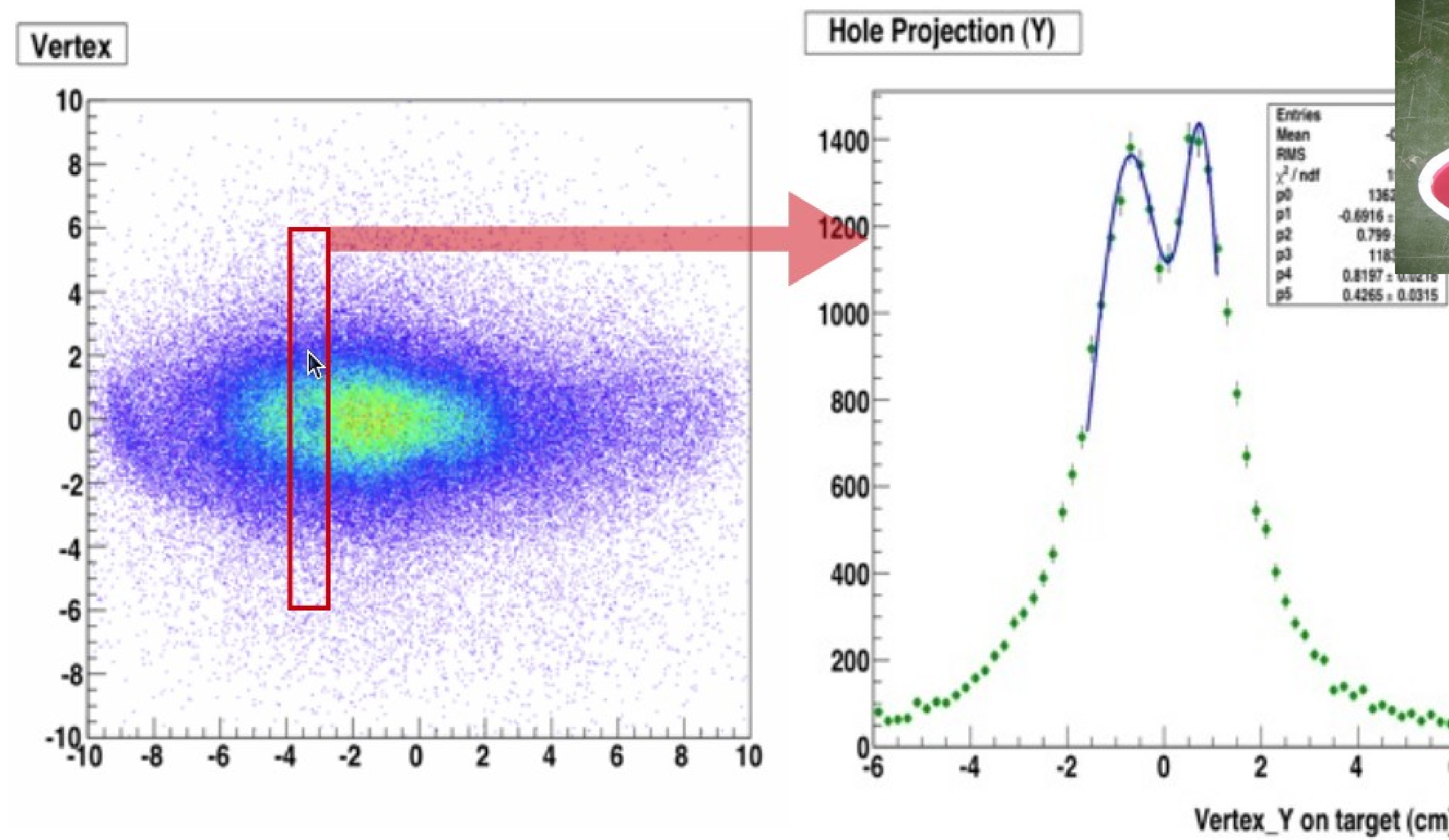




- $\sigma_\theta = 1.45$ deg. $/\sqrt{2}$ $\approx$ **18 mrad.**
- $\sigma_\phi = 0.81$ deg. $/\sqrt{2}$ $\approx$ **10 mrad.**

- Evaluate angular resolution using 2 turn events
  - See difference of angle between reconstruction with each turn

$\sigma_\theta$ = 18 mrad
$\sigma_\phi$ = 10 mrad

# Muon decay vertex



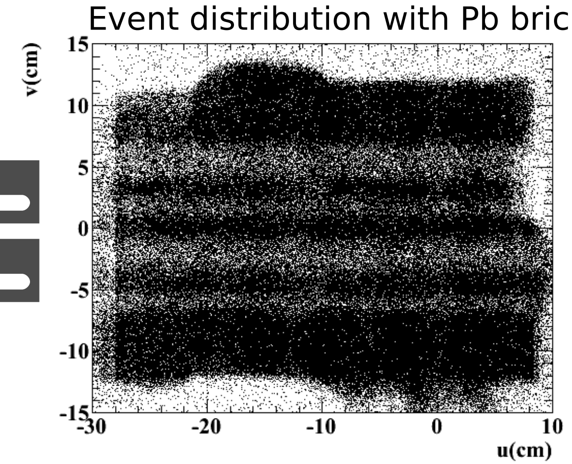

- Reconstruct μdecay vertex as a point crossing $e^+$ track and target plane
- Evaluate resolution with
  - Using holes on target
  - Using 2 turn events

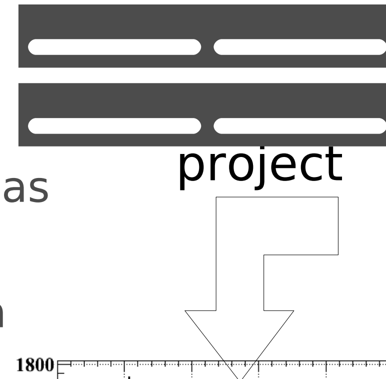
$\sigma_x$ = 4.5 mm
$\sigma_y$ = 3.2 mm

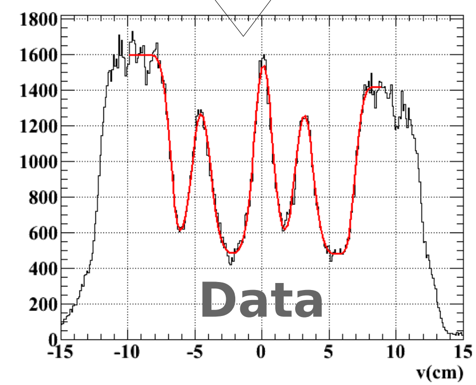
# Gamma position

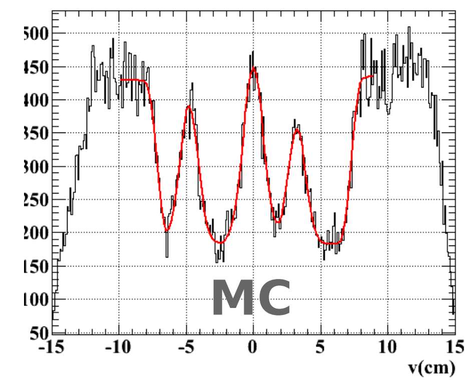
- Reconstruction : Fit with solid angle
- Evaluate resolution
  - $\pi^0$ run with Pb bricks
  - Shadow of slits gives resolution and bias
  - Results
    - $\sigma_{xy}$=4.5~5mm, bias(RMS)=0.7mm
    - Compared with MC:
      - Reduce systematic.
      - 1.8mm worse than MC
        - QE uncertainty
- Detailed study with MC
  - Take in the difference with data
  - Resolution variation by the relative position to PMT
  - Shape of the response
    - Double Gaussian

$\sigma_{xy}$~5mm
(position dependent)

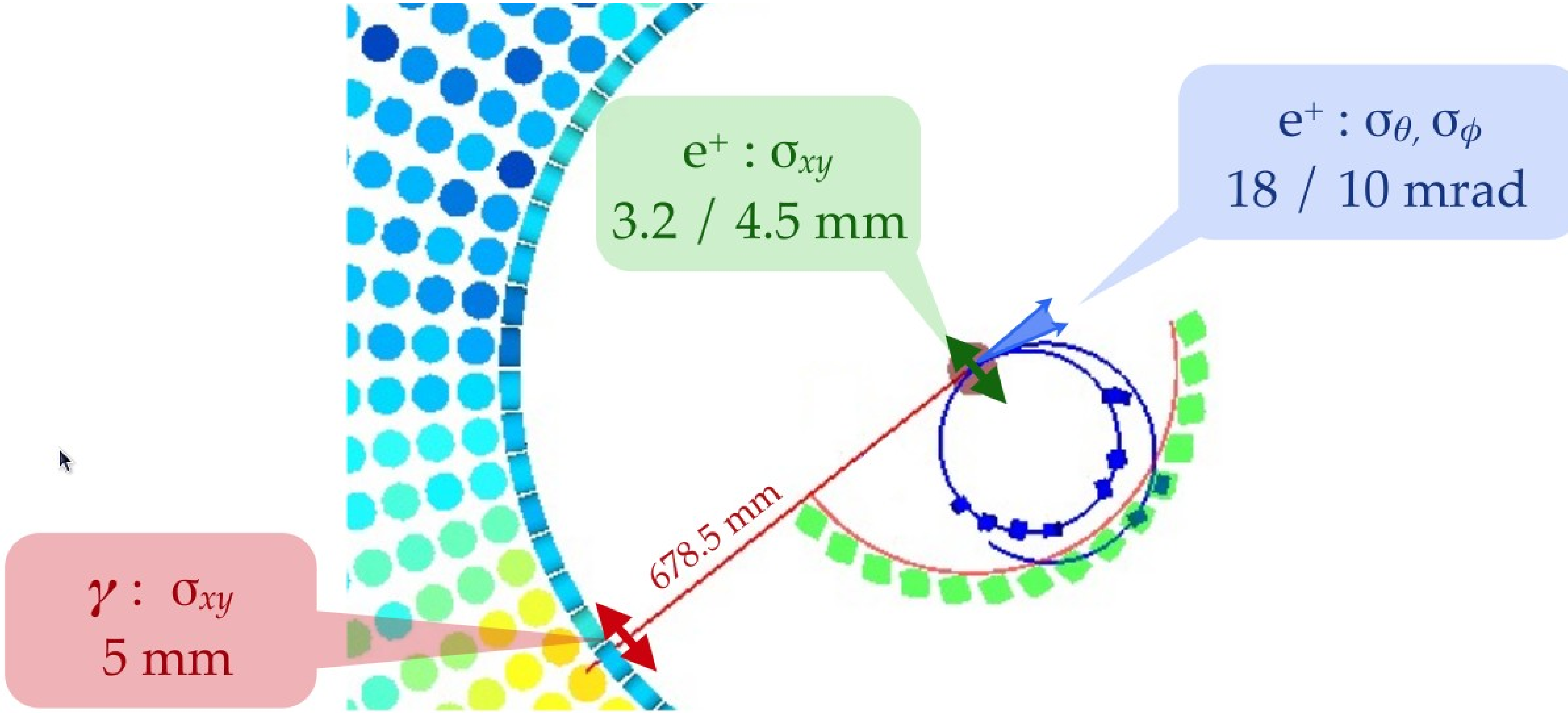


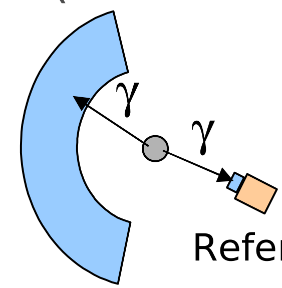
# Opening Angle



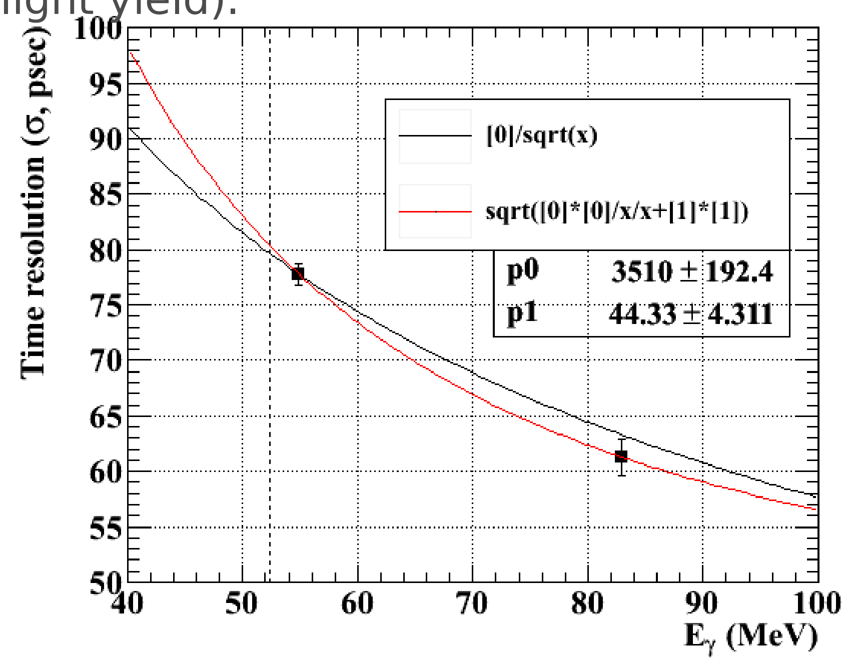

- Not possible to reconstruct direction of gamma
  - Direction of the line b/w μ vertex and γ interaction point
- Combined resolution : $\sigma\theta_{e\gamma}$ = 20.6 mrad, $\sigma\phi_{e\gamma}$ = 13.9 mrad

# Gamma timing I

- Reconstruction
  - Subtract scinti photon propagation time from PMT hit time.
  - Combine a lot of measurement by different PMTs (~150PMTs) ($\chi^2$ fit).
- $\pi^0 \rightarrow \gamma\,\gamma$
  - Time difference b/w the reference counter
  - Results
    - Gaussian
    - $\sigma_t$ = 78ps @55MeV, 61ps @83MeV
    - Better resolution at December (high light yield).
      - $\sigma_t$=68ps @55MeV

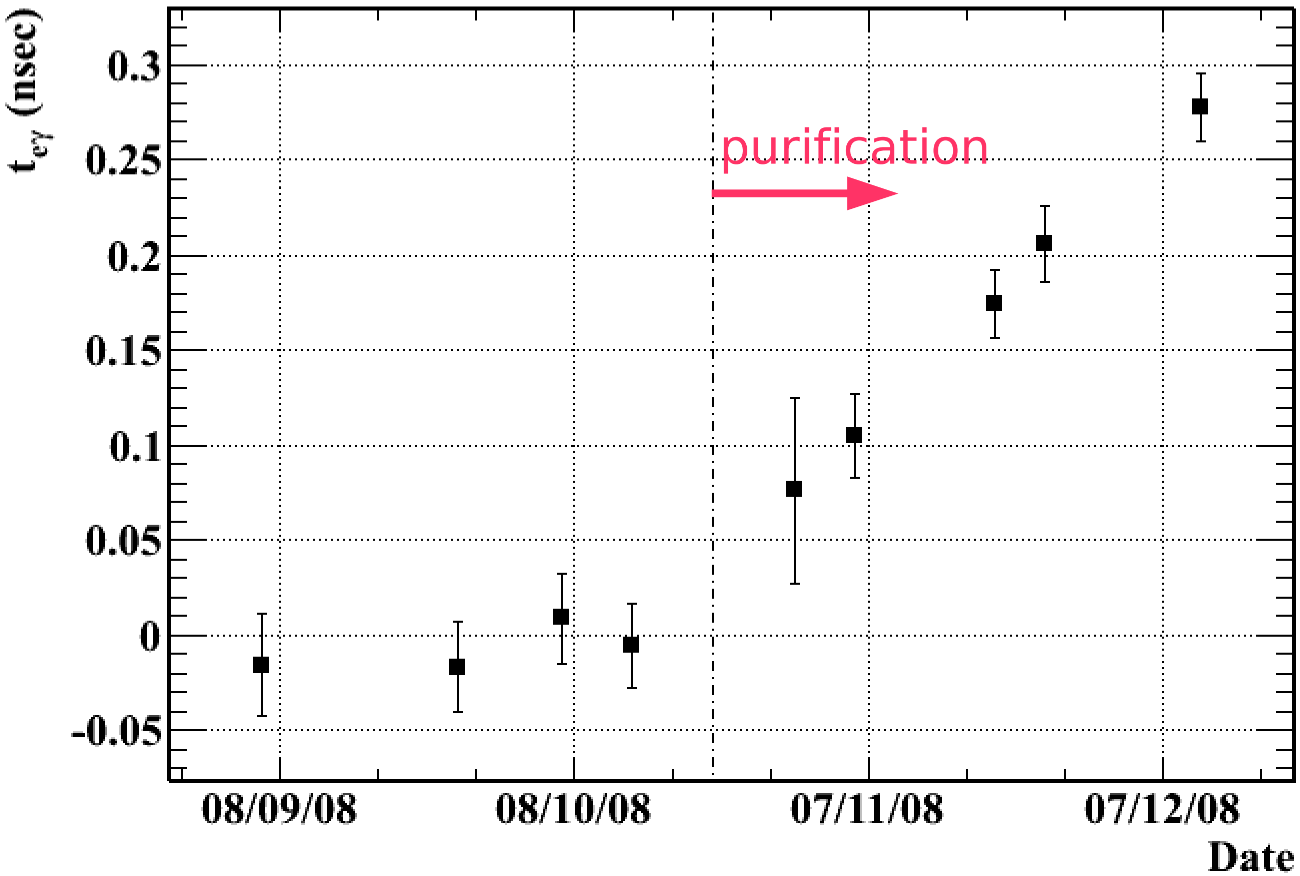


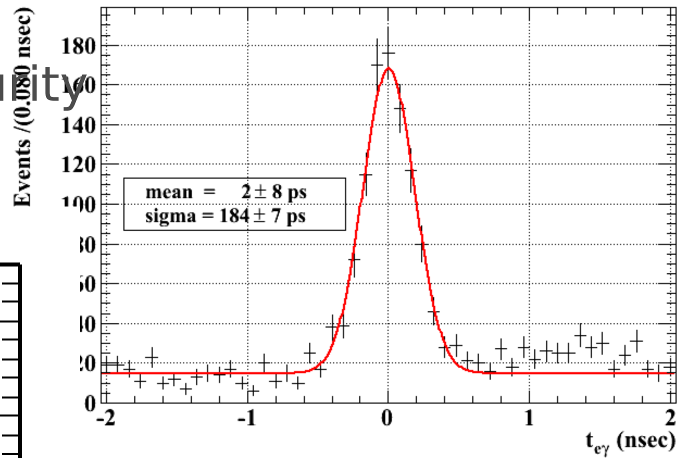

$\sigma_t$=80ps @52.8MeV
(This value is not used directly.)
Energy dependence



# Gamma timing II

- Correction by μ radiative decay
  - Change of pulse shape as improvement of purity
  - Observed drift of t0




Low intensity RD run
- 24h /1week
- Better S/N, better precision of t0

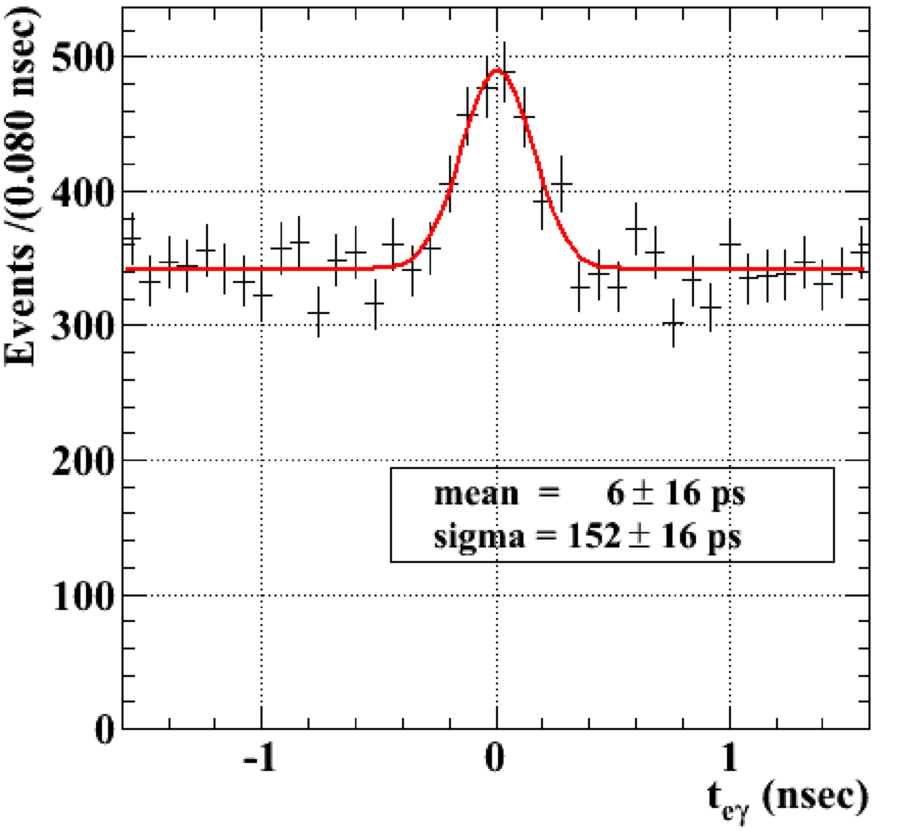
Correct with linear function

- Stability after the correction <20 ps

# Time resolution

- $t_{e\gamma}$ : time difference b/w $e^+$ and $\gamma$ time on target
  - $e^+$ : TC measurement, subtract ToF from track length
  - $\gamma$ : LXe interaction time, subtract ToF
- Observe RD peak in normal data taking
  - Correct small dependence of $\gamma$ energy

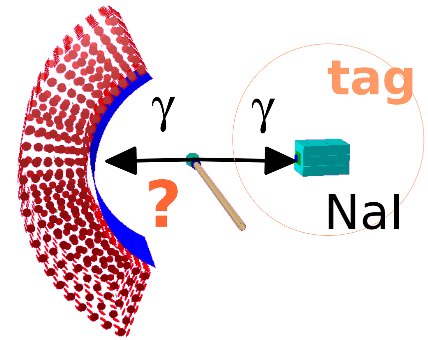
$$\boxed{\sigma t_{e\gamma} = 148 \pm 17 \text{ ps}}$$



# Gamma efficiency

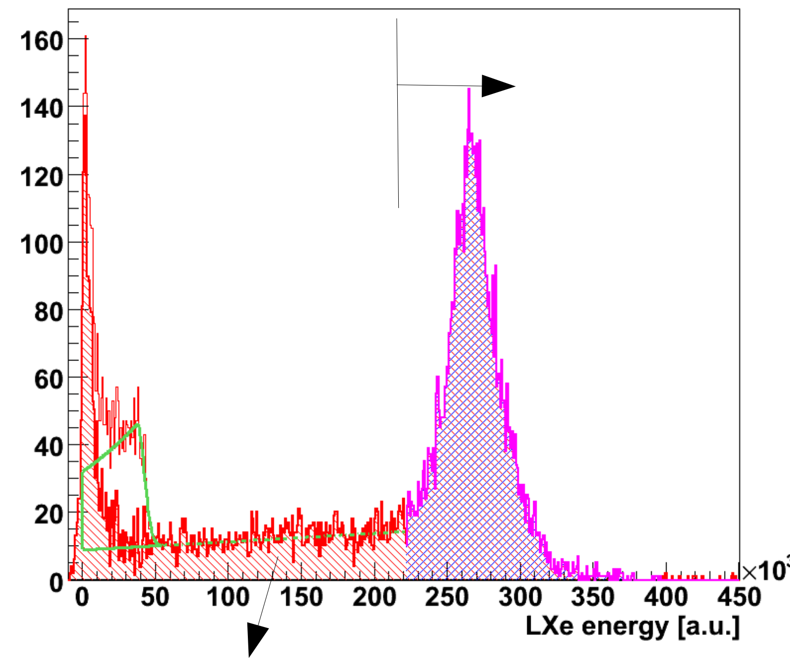
- Detection efficiency
  - $\pi^0$ 2γ : NaI single trigger
  - MC
  - μ data single spectrum
  - Calculate position dependent efficiency with MC
  - Multiply with $e^+$ event distribution
  - In analysis region of $46 < E_\gamma < 60$MeV
    - $\varepsilon_{det} = 66$ %

Consistent within 5%




- Analysis efficiency
  - Inefficiency (pileup, CR cut)
    - 9%

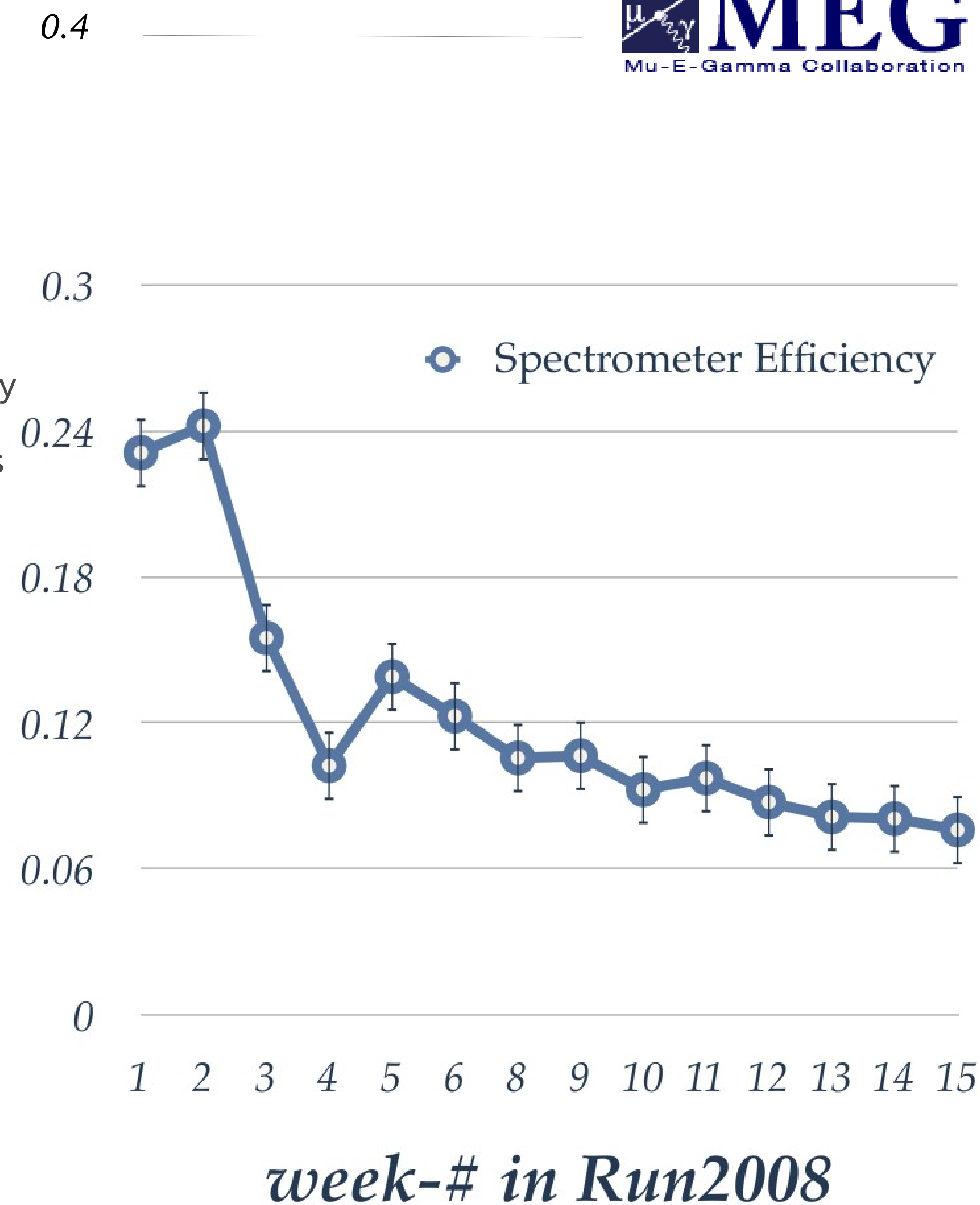
$$\boxed{\varepsilon_\gamma = (60 \pm 3)\ \%}$$




Interact with some material before active volume

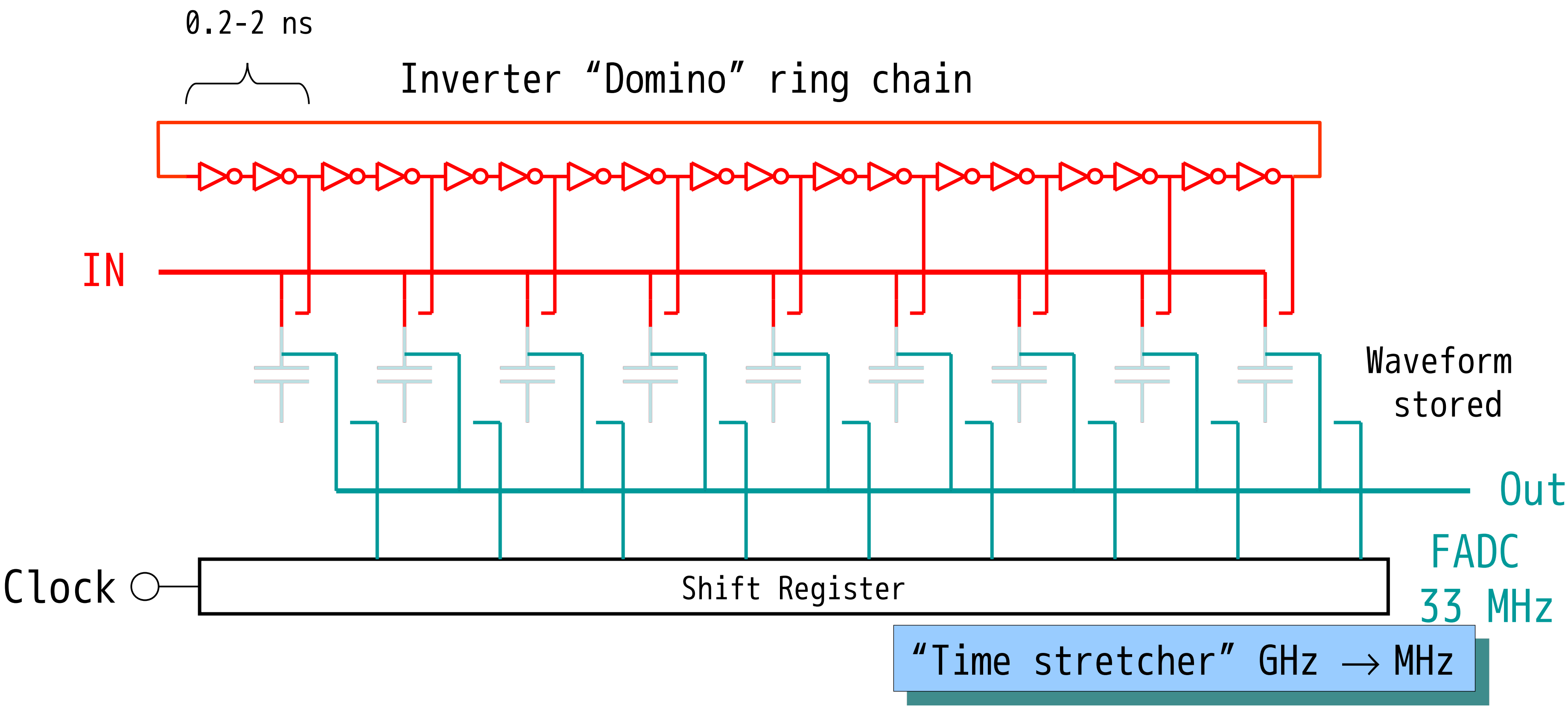
# Positron efficiency

- $e^+$ detection efficiency
  - $\varepsilon_{e+} = \varepsilon_{DCH} \times A_{DCH\text{-}TC}$
    - $\varepsilon_{DCH}$ : tracking efficiency
    - $A_{DCH\text{-}TC}$ : DCH-TC matching probability. Make inefficiency if $e^+$ interacts with material and annihilates or changes its direction largely.
- $\varepsilon_{e+}$ decreased gradually during the run
  - DCH discharge problem
- Expectation (full DCH) :
  ~40% (= 80x50)



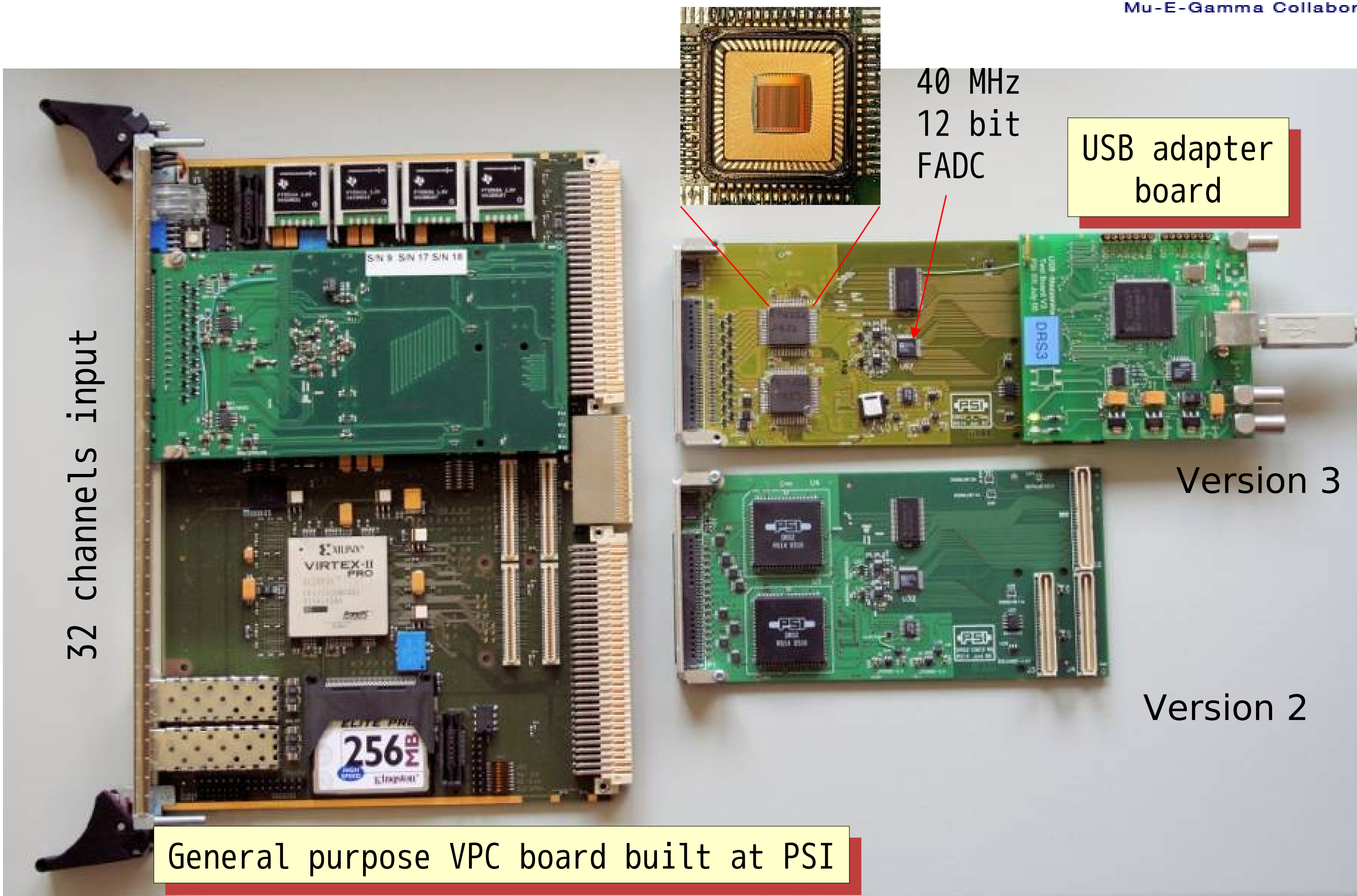
# Waveform Analysis

# Domino Ring Sampler




- Switched Capacitor Arrays
  - High speed sampling
  - Low power consumption
  - Low cost
  - High channel density
  - No precise timing

- FADC



40 MHz
12 bit
FADC
USB adapter board
Version 3
Version 2
32 channels input
General purpose VPC board built at PSI

# Calibration

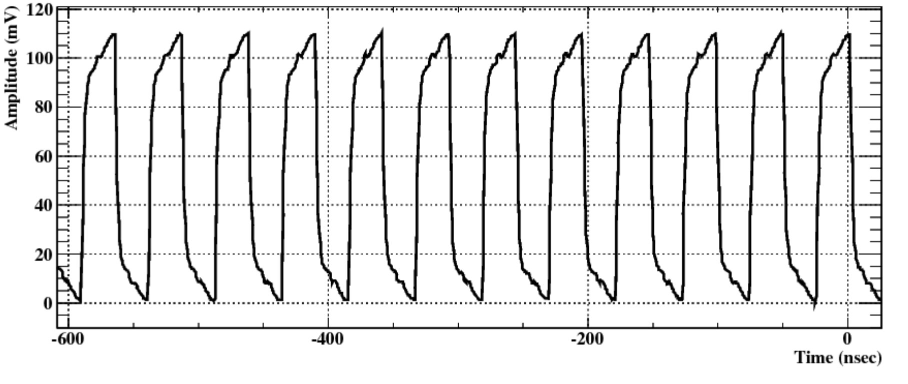
- Non-linear response in amplitude & time

  → Calibrate the response

  - Measure response to reference voltages
  - Measure response to sine wave
    - Not constant sampling intervals (but fixed over time)

- Synchronization among chip by a reference clock
  - Trigger system distributes a global reference clock (20MHz)
  - Each chip digitizes the clock
  - Clock analysis (offline)
    - Global synchronization
    - Event-by-event time calibration

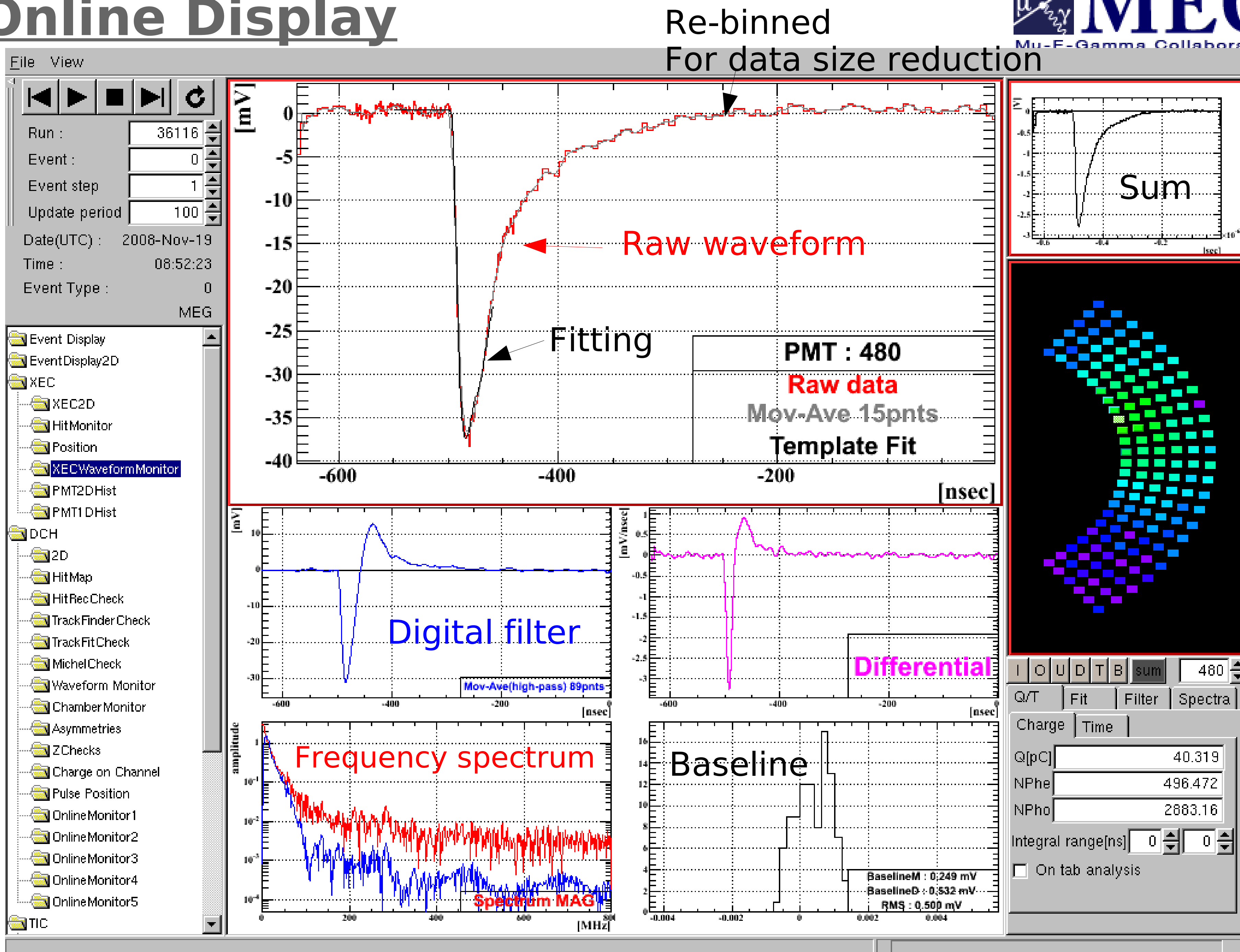
Synchronization precision
$\sigma \sim 40$ psec



# What is the merits?

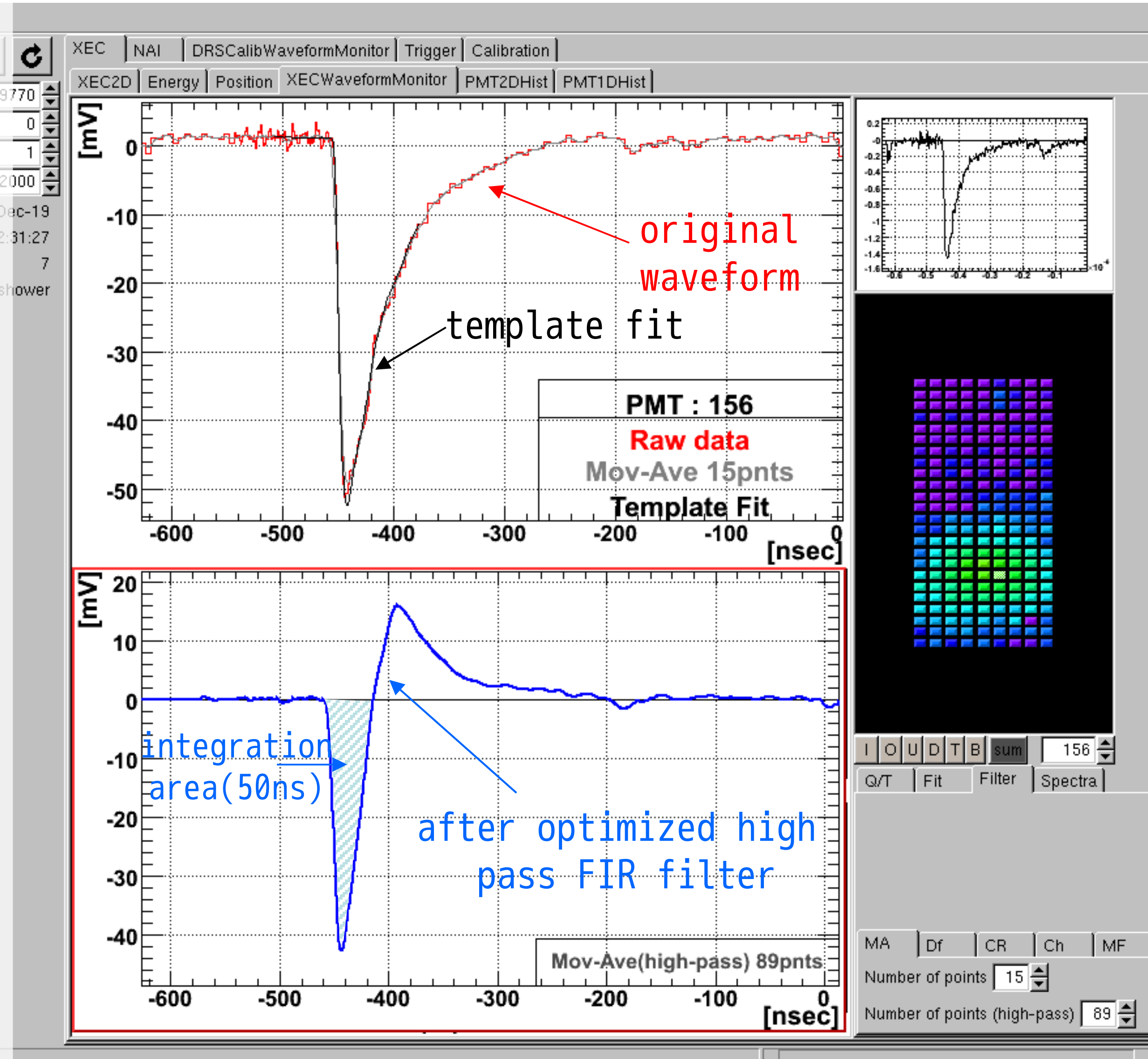
- Pileup identification
- Particle identification (PSD)
- Noise
  - Can investigate noise (online oscilloscope)
  - Event-by-event baseline subtraction
  - Additional noise reduction
- Precise waveform analysis in offline
  - Digital filter
  - Various timing algorithms
  - Fitting waveform

# Online Display



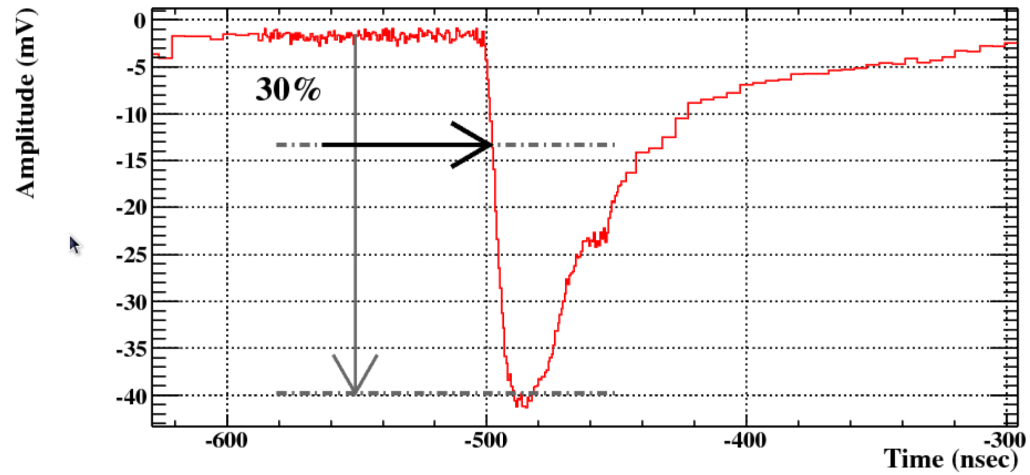
# Charge Integration

- Use high-pass filter
  - Remove low freq noise
  - Make pulse sharp
    - Narrow integration window
    - Low noise
    - Robust to pileup

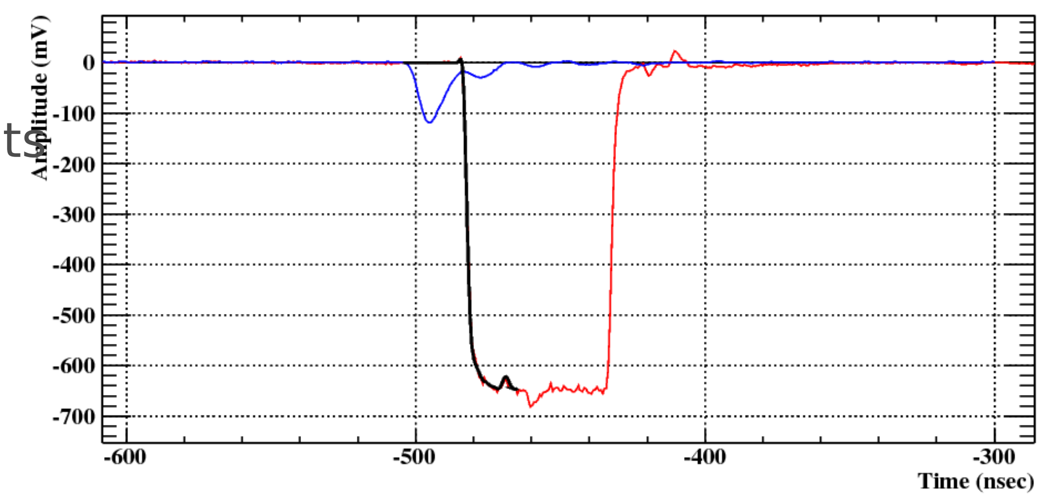


# Time Extraction

- digital constant fraction
  - Eliminate time-walk effect
  - Parameter adjustable
  - Interpolate sample points
    - Linear or cubic

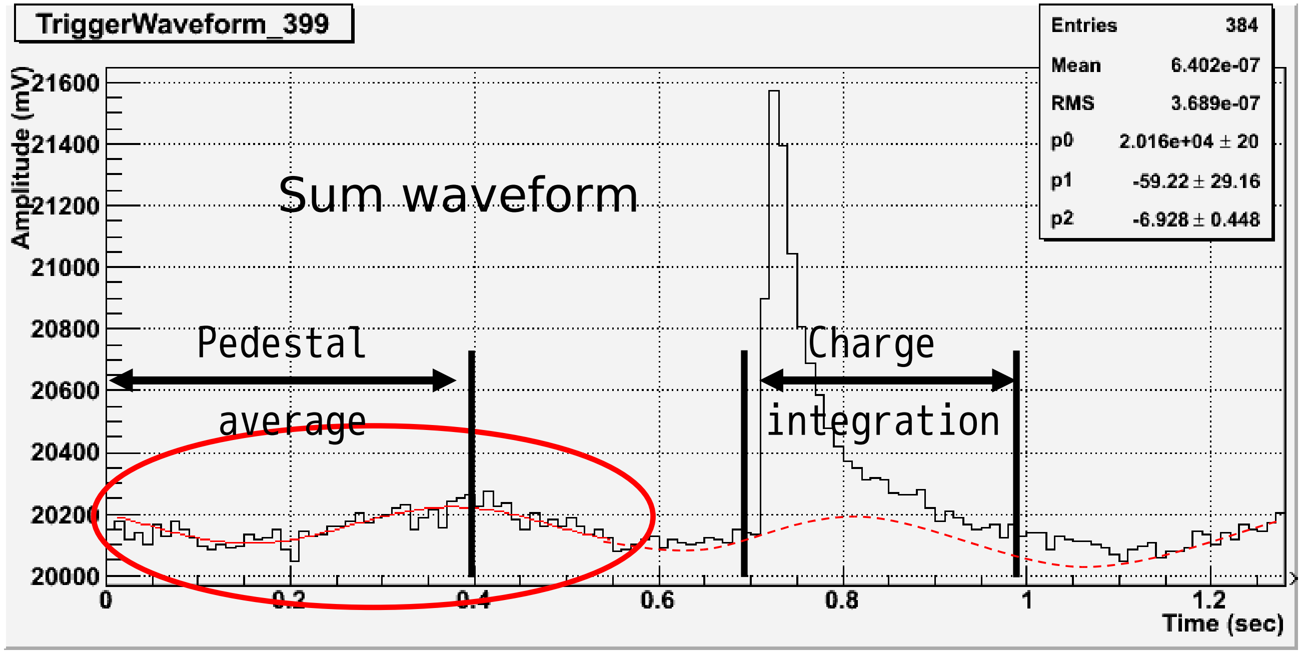



- Template fitting
  - Maximal usage of sample points
  - Robust to noise



# Coherent noise subtraction

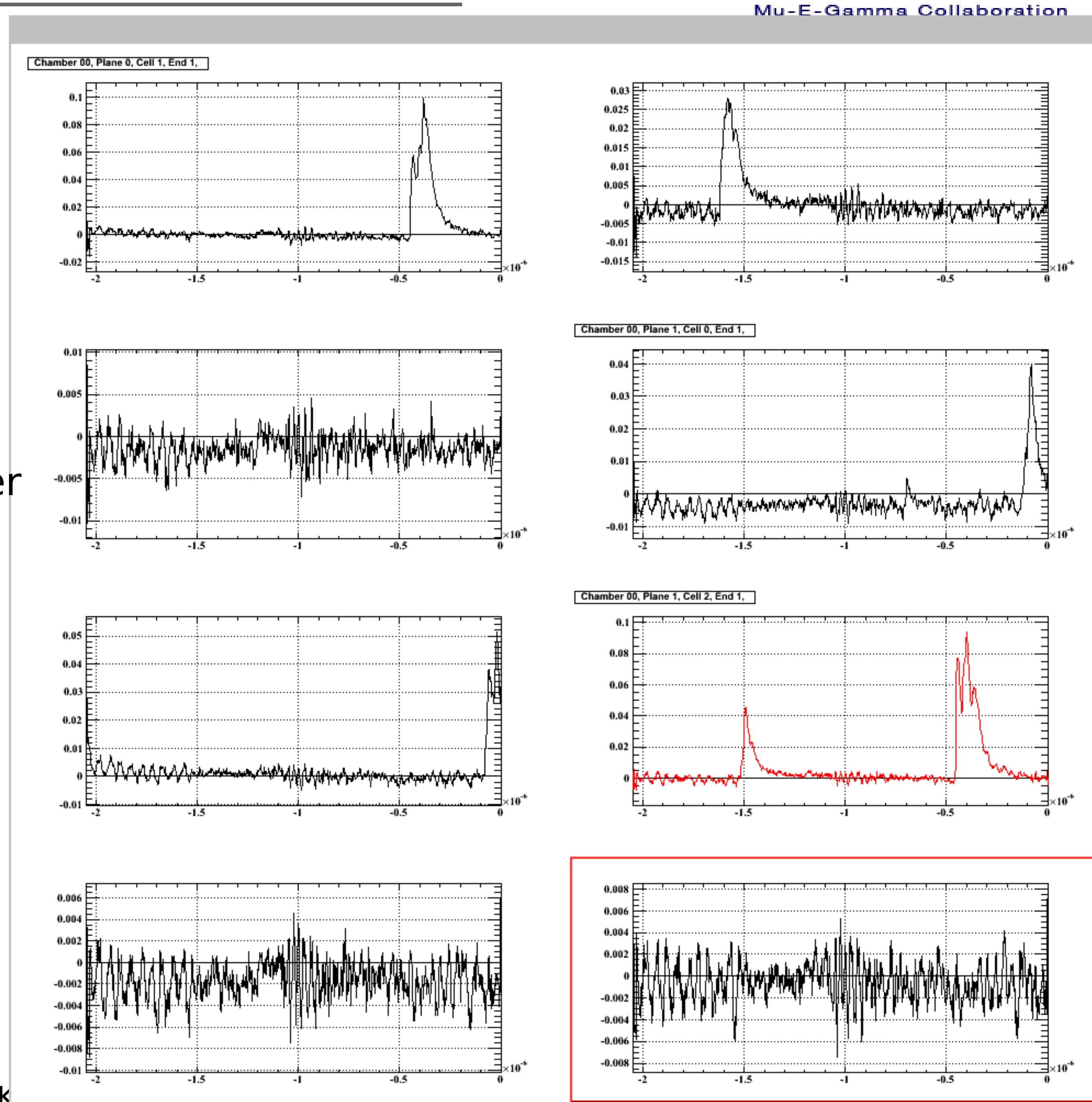
- Estimate coherent noise using baseline region



# Coherent noise subtraction

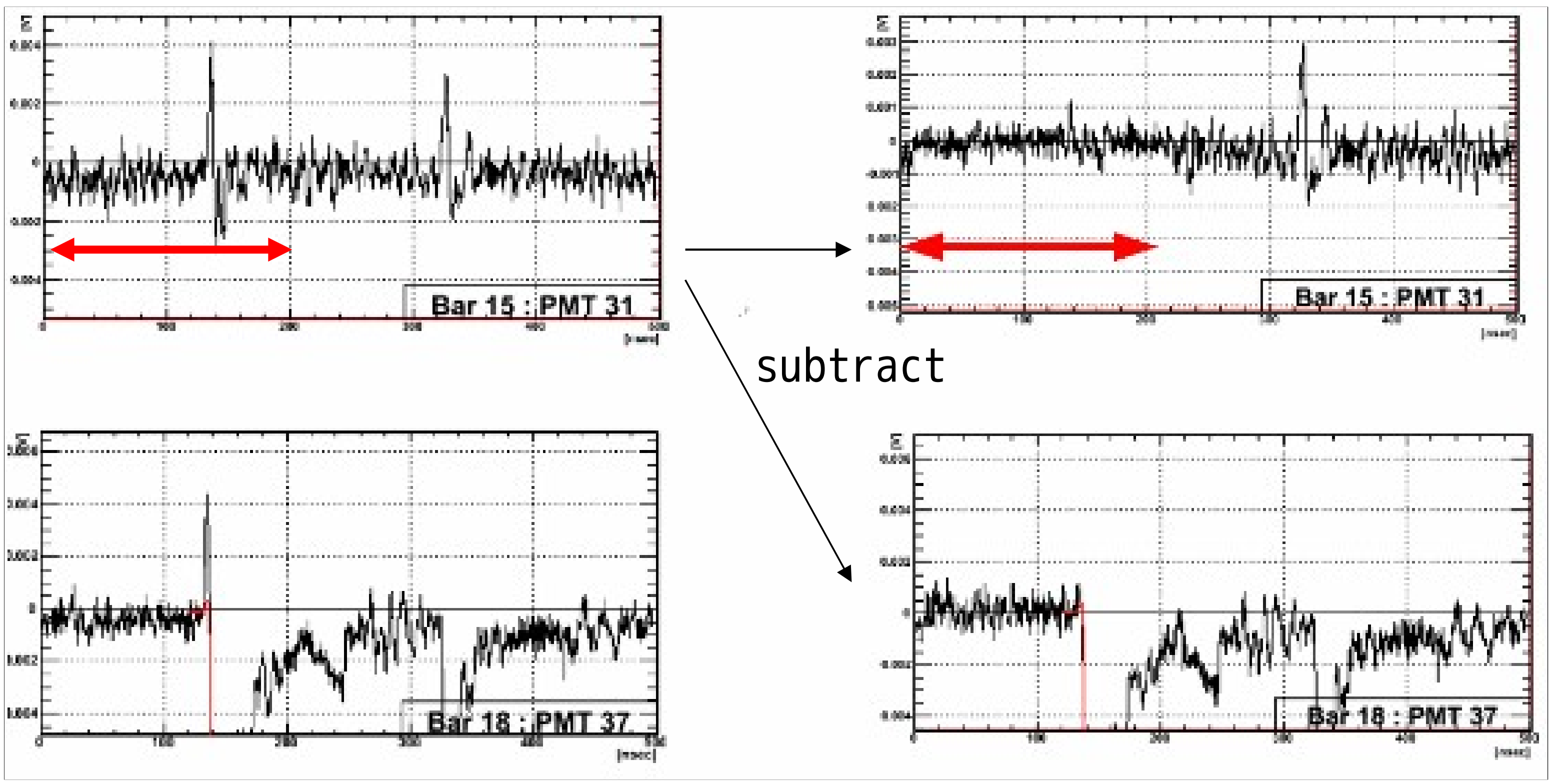
- Coherent noise subtraction using no hit channel

Signal from drift chamber



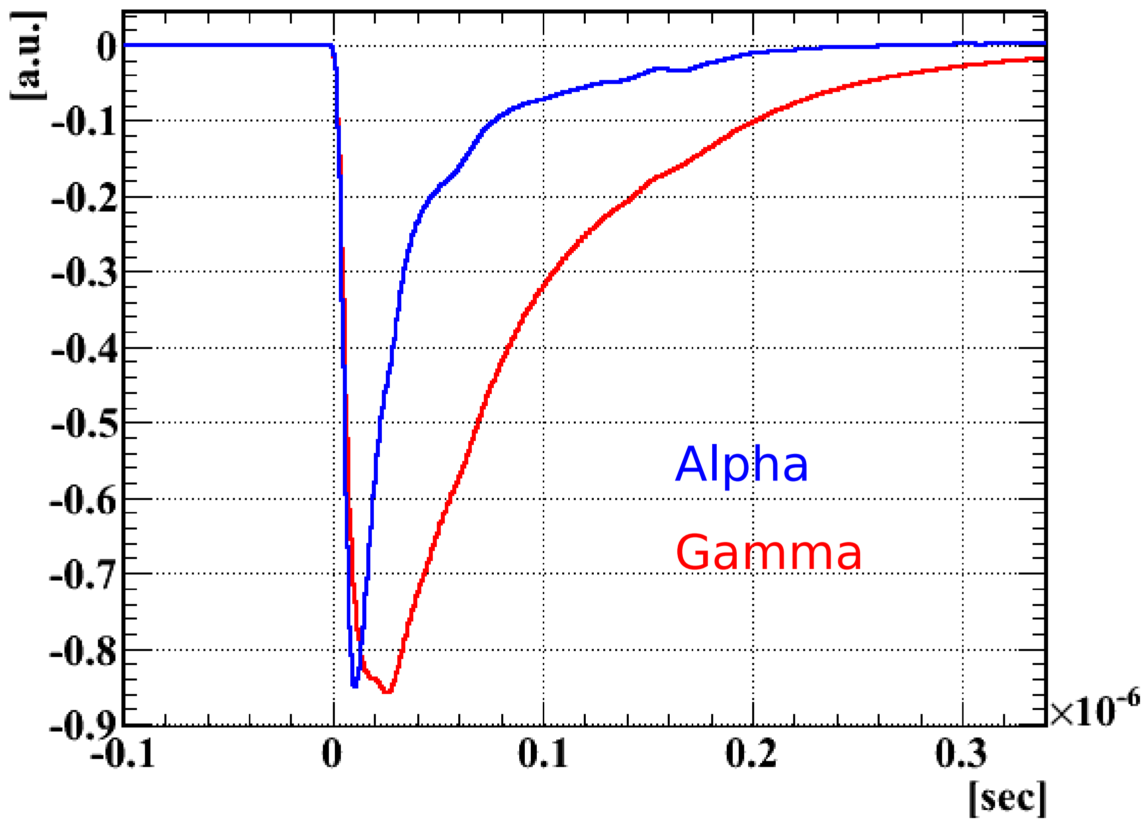
# Cross talk removal

Signal from timing counter




Hit Hit

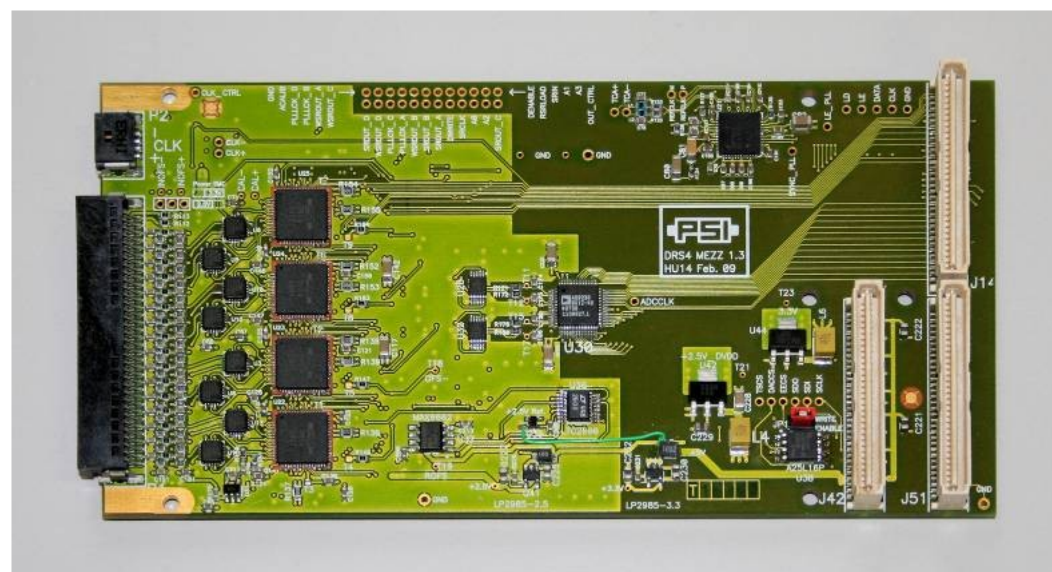
# Pulse Shape Discrimination




- PSD by
  - Q/A, pulse width, decay time

# Digitizer upgrade

- DRS2 → DRS4
  - Many modifications are applied from the experience with DRS2
    - DRS2 have been used since 2004
  - Replaced all DRS2 with DRS4 in September
  - But not yet full performance
    - Eliminate temperature drift
    - Linearity improve (upto 1 V)
    - Differential input
    - Timing accuracy (?)
    - Double cell (twice sampling speed or twice window)
  - It takes longer than expected to install
    - Completely new system
    - Several problems to debug



# Conclusion

MEG Mu-E-Gamma Collaboration

- MEG実験は2008年秋、物理データ取得を開始。
  RUN2008ではMEG最初の3ヶ月分のデータをとった。
- 3 ton LXe detector の実用化に世界初成功。安定に運転している。
- SCAを用いた高速波形取得。波形解析手法を開発。
- 検出器の解析手法を確立。
  - RUN2008を一通り解析し結果を出した。
    - RUN2008のsensitivity : 1.3 x 10-11
    - 実際のデータからのupper limit : Br(μ→eγ) < 3.0 x 10-11 @90% C.L. (preliminary)
- 今年はこの4倍の統計をためる。(11月頭から物理ラン再開)
  - これに応じてsensitivityの向上
  - sensitivityの詳細は今年の検出器の性能に依存する(現在、校正・評価中)が性能向上も見込めるため今年も統計で制限されるだろう。

http://arxiv.org/abs/0908.2594.

Thank you.