An FPGA based Trigger for the search of the $\mu \rightarrow e\gamma$ decay in the MEG experiment

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on behalf of MEG collaboration

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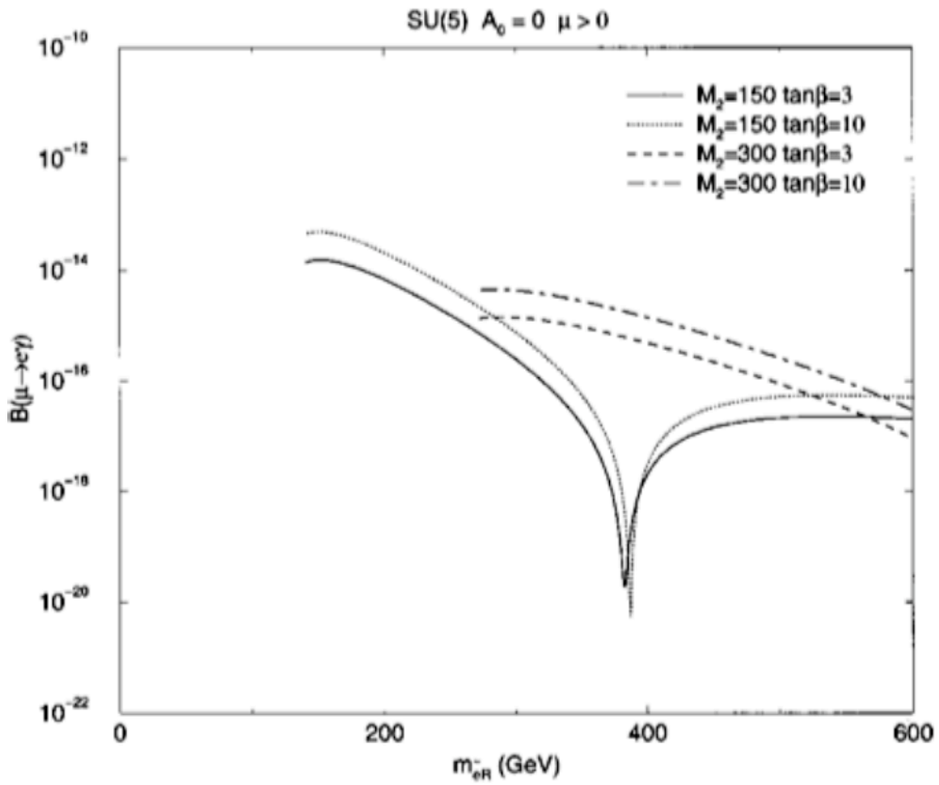
Outlook

- The MEG experiment
- Event signature and background
- The trigger system
  - Electronics
  - Algorithm implementation and system performances

MEG experiment

Search for $\mu \rightarrow e\gamma$ with unprecedented sensitivity BR $\approx 10^{-13}$

- Standard Model including neutrino oscillations
  ➜ BR $\approx 10^{-50}$
- SU(5) and SO(10) SUSY-GUT theories predictions
  ➜ BR $\approx 10^{-12} \div 10^{-14}$



An observation of this decay will be a clear evidence of physics beyond the Standard Model

MEG collaboration

International collaboration ≈ 60 physicists

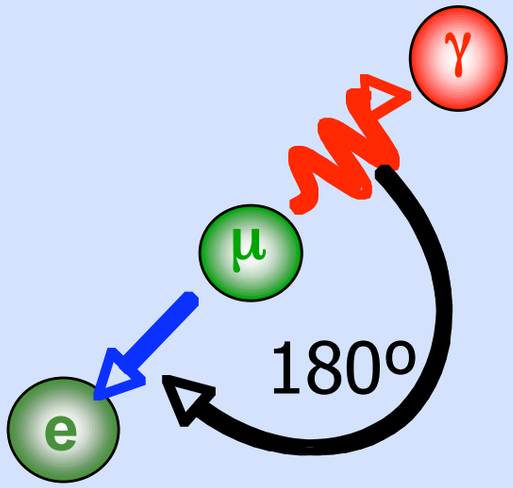
Experiment mounted in 2007
at Paul Scherrer Institute CH

PSI provides the most intense
low momentum muon beam
in the world

$$R_\mu \approx 3 \times 10^7 \mu/s$$

Event signature and background

$\mu \rightarrow e\,\gamma$

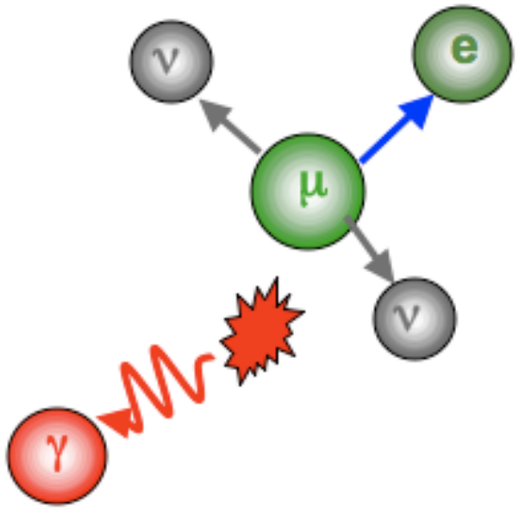


$$E_\gamma = E_{e^+} = 52.8 \text{ MeV}$$

$$\Delta t_{e\gamma} = 0 \text{ ns}$$

$$\theta_{e\gamma} = \pi \text{ rad}$$

Accidental Bkg

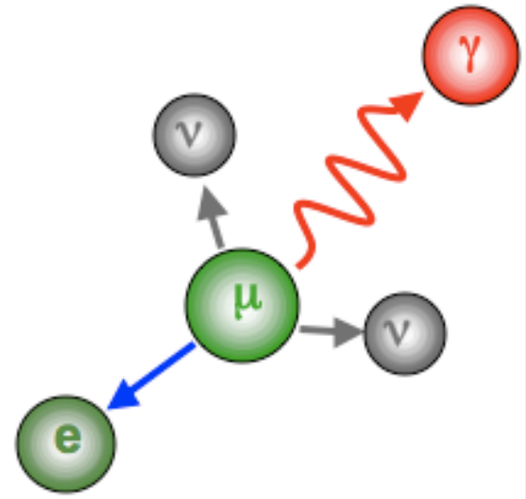


main ➜ Accidental Bkg

$$B_{Acc} \propto R_\mu \delta x (\delta y)^2 \delta\theta^2_{e\gamma} \delta t_{e\gamma}$$

$$x = \frac{2E_e}{m_\mu} \qquad y = \frac{2E_\gamma}{m_\mu}$$

Radiative Decay



Detector

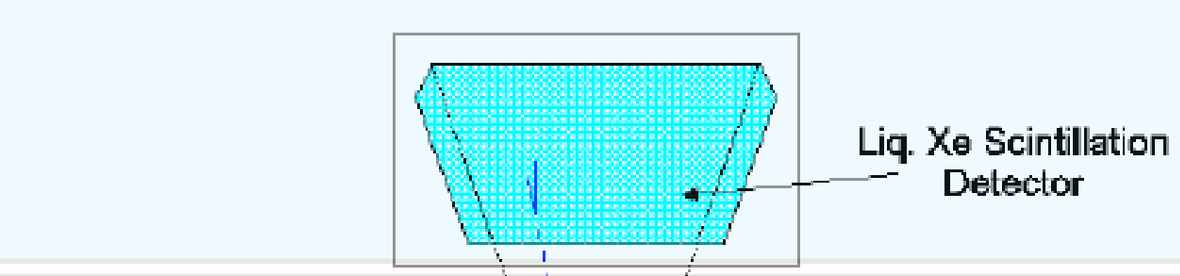
Project resolutions

	FWHM
ΔE_e	$0.7 \div 0.9\%$
ΔE_γ	4%
$\Delta\theta_{e\gamma}$	$17 \div 20.5$ mrad
$\Delta t_{e\gamma}$	0.15 ns

Largest homogeneous LXe detector ever
800l read by ≈ 850 PMTs

LXe ➜ fast scintillation light O(40 ns)
➜ 40000 phe/Mev

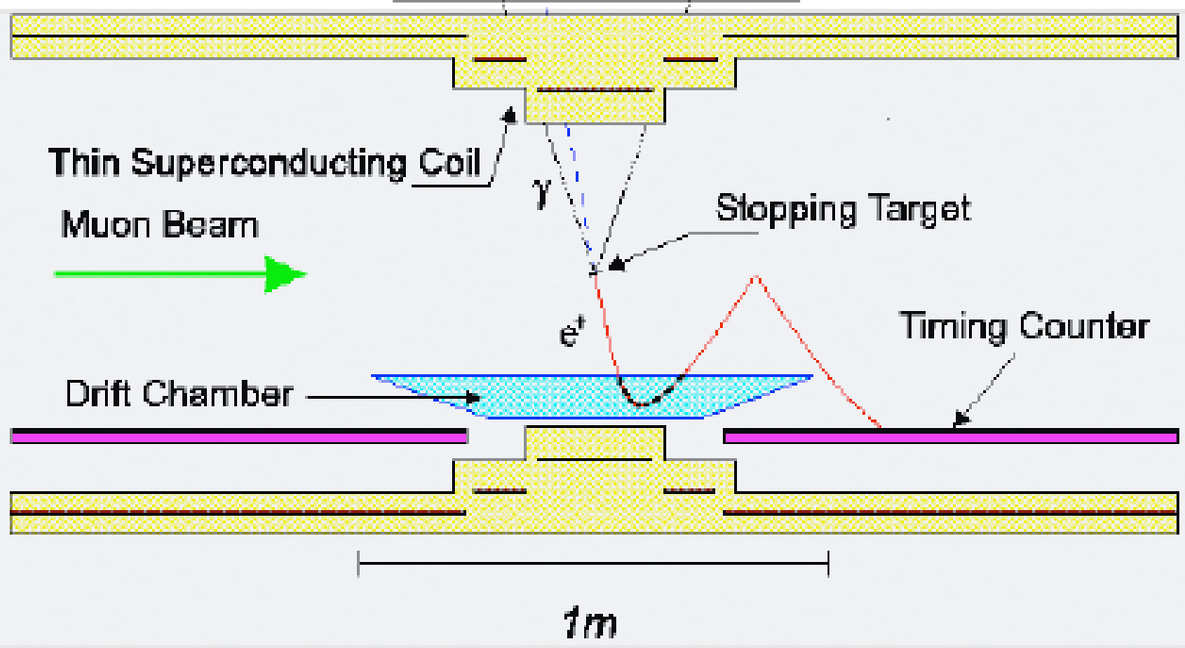
→ $E_\gamma, T_\gamma, \theta_\gamma$



Magnetic Spectrometer

- Non-uniform magnetic field
- Drift chamber for tracking
- Plastic Timing Counters

→ E_e, T_e, θ_e



Trigger system requirements

- Fast computation → DRS chip digitizer (PSI) requires trigger within 450 ns
- Good background rejection with high efficiency on signal
- flexibility to any experimental requests

System based on logic computation on FPGAs

♠ Use of fast devices: LXe detector and TC

♠ Final latency of 400 ns

♠ Background rejection at 10^7 level ➜ Lifetime ≈ 90% with 50 Hz DAQ

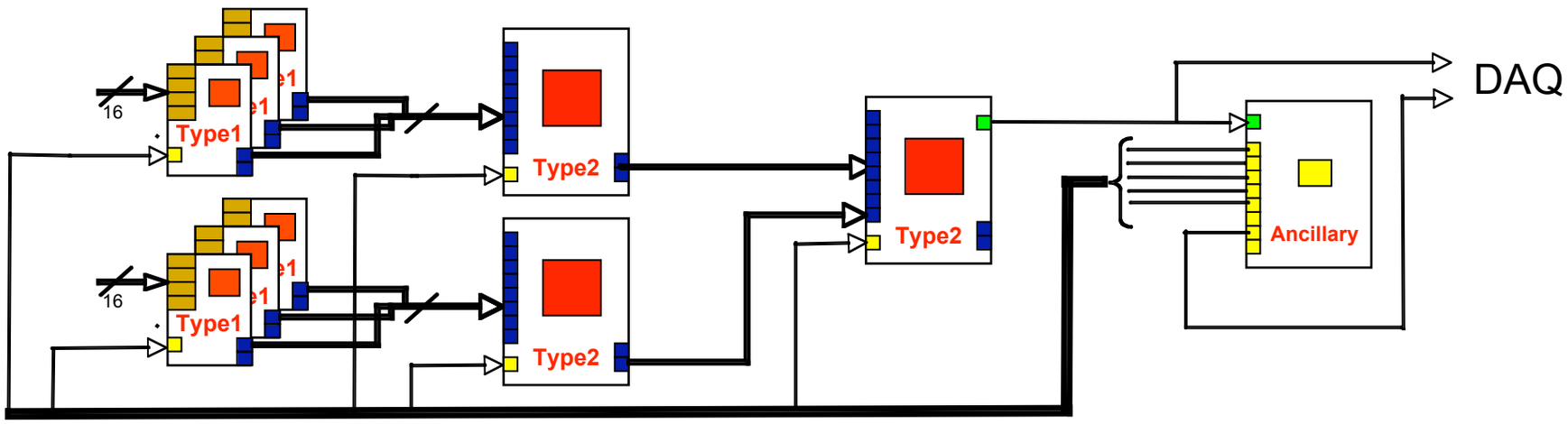
♠ Efficiency on signal > 90%

♠ Up to 32 different trigger types avalilable

Trigger electronics

Three different custom VME boards developed by INFN Pisa group

- **Type1 board**:
  - Front End receivers for PMT and aux signals
  - 100 MHz 10 bit waveform digitizer
  - first level of data processing (*e.g.* online channel calibration and pedestal subtraction)
- **Type2 boards**:
  - middle and final layer
  - connected to 9 boards from previous layer, 48bit 100 MHz LVDS trasmission
  - event reconstruction ➜ stop signal to DAQ
- **Ancillary boards**:
  - CLK and control signals fan-out to synchronize whole system



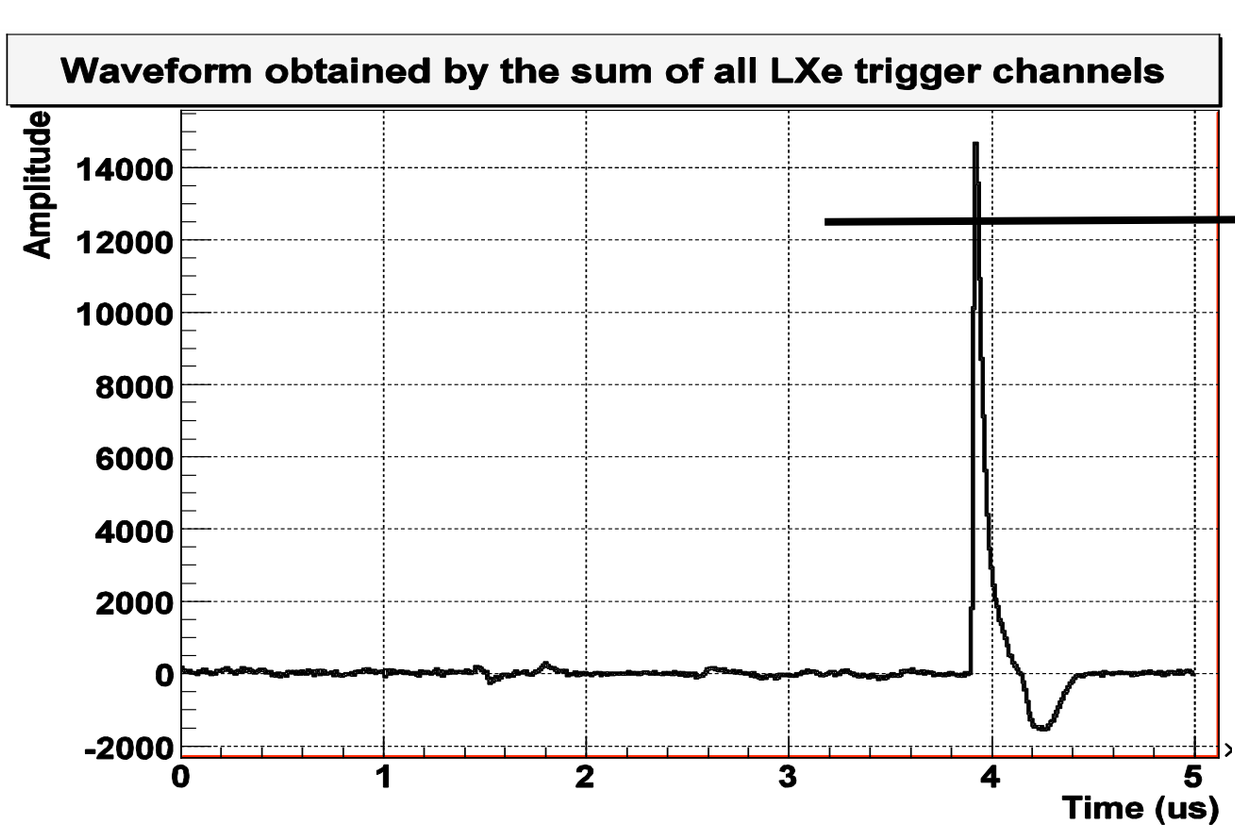
Selection variables

- Gamma energy deposit on LXe detector
- Time difference between photon and positron
- Collinearity of the event

Gamma energy

Coherent sum of LXe waveforms:

- single channel calibration for PMT gain and geometry
- energy estimator ➜ pulse height of waveform

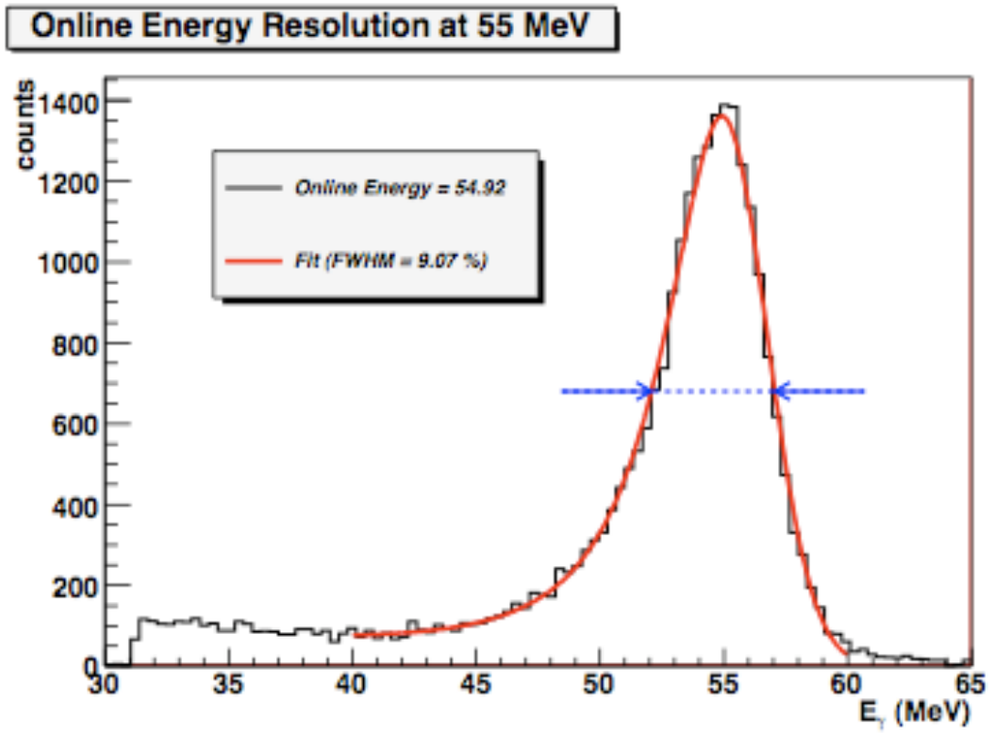


threshold on pulse height

Channel calibration: use of software programmable LUT

Charge estimator: parallel sum of 400 channels

Gamma energy (2)



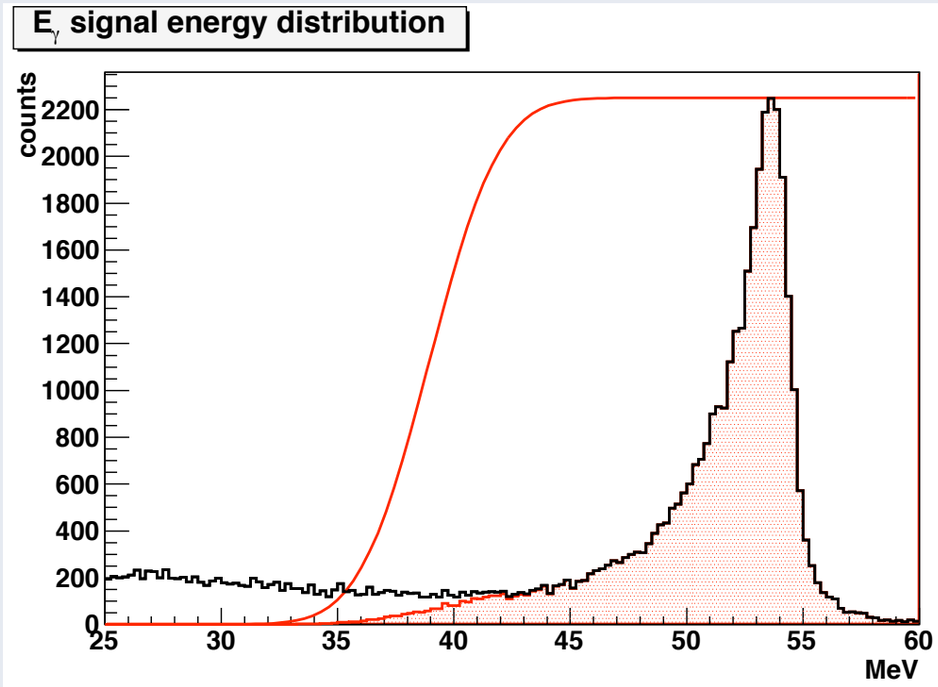
Online resolution on 55 MeV line

➜ $\Delta E/E$ = 9% FWHM

➜ full efficient for E_γ > 45 MeV

Conditional probability on signal PDF

➜ Efficiency > 99%

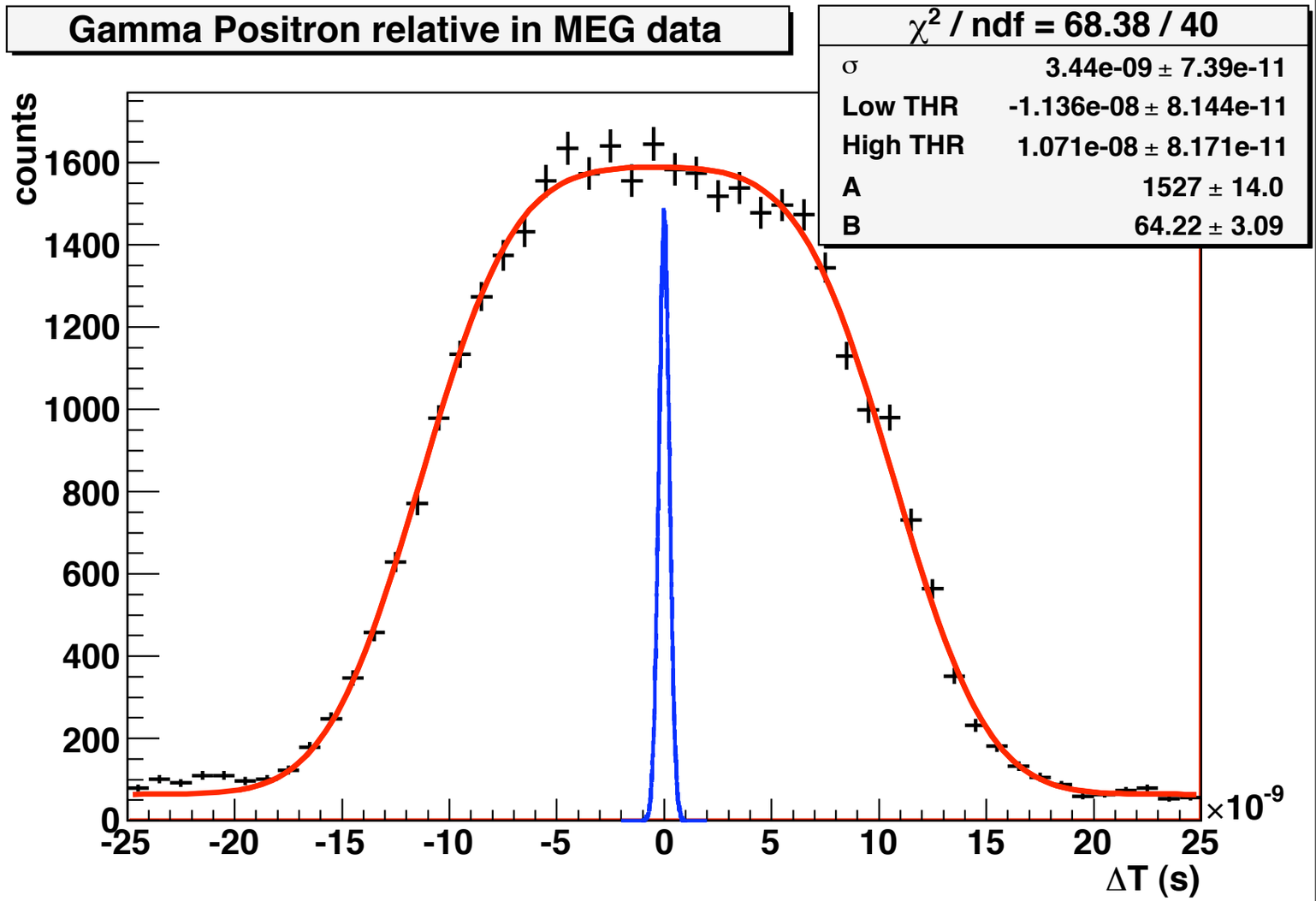


Relative time

T_γ = rising edge of higher LXe pulse

T_e = rising edge of TC waveform of hit bar

Maximum T0 difference between different channels < 1 ns



Shape of time condition on MEG data

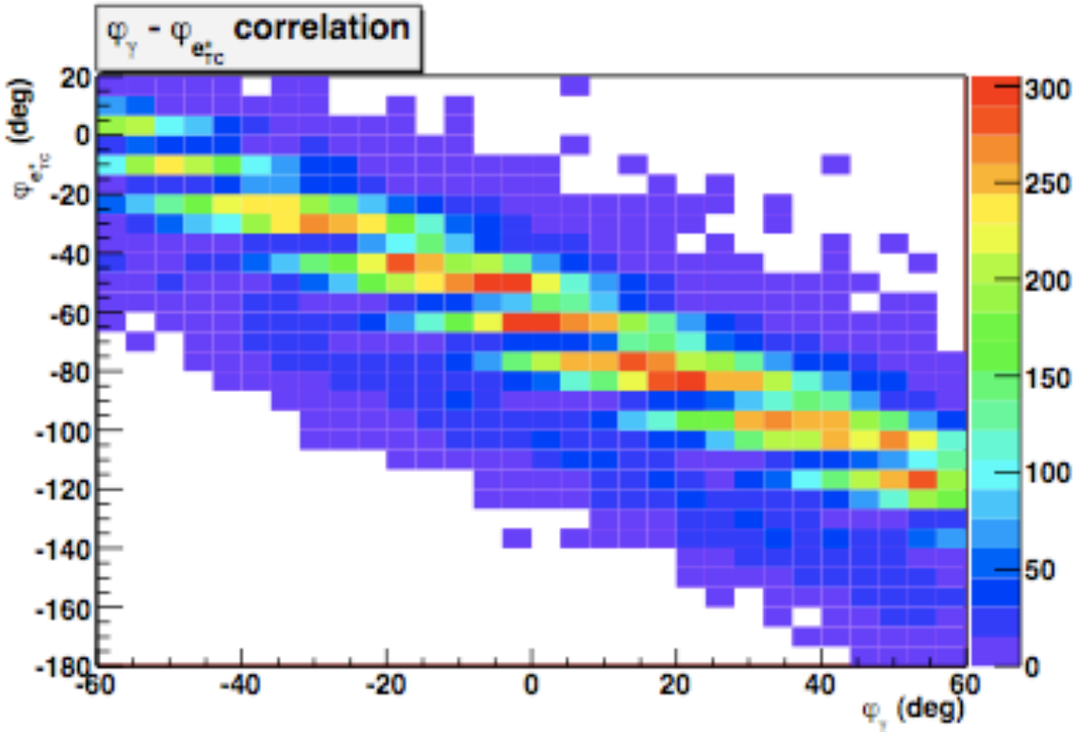
time window = +- 10 ns

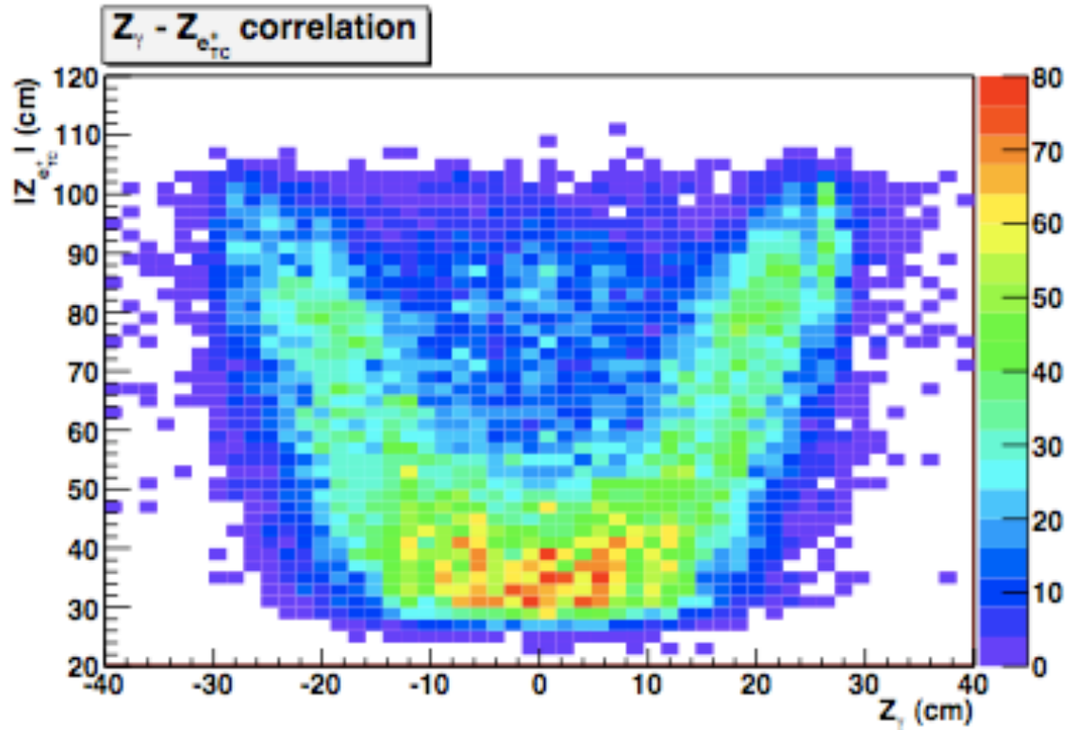
Efficiency > 99%

Collinearity

Correlation of LXe PMT index and (BAR,Z) hit on TC

LUTs implementation based on MC simulation





Gamma direction: LXe PMT collecting higher light (stack of comparators)

Positron direction: ➜ index of hit bar (discriminator + LUT for multi tracks)
➜ inpinging point on bar by charge ratio (LUTs)

Efficiency = 66%, maximize lifetime*efficiency for 2008 RUN

Trigger types

Physics data triggers

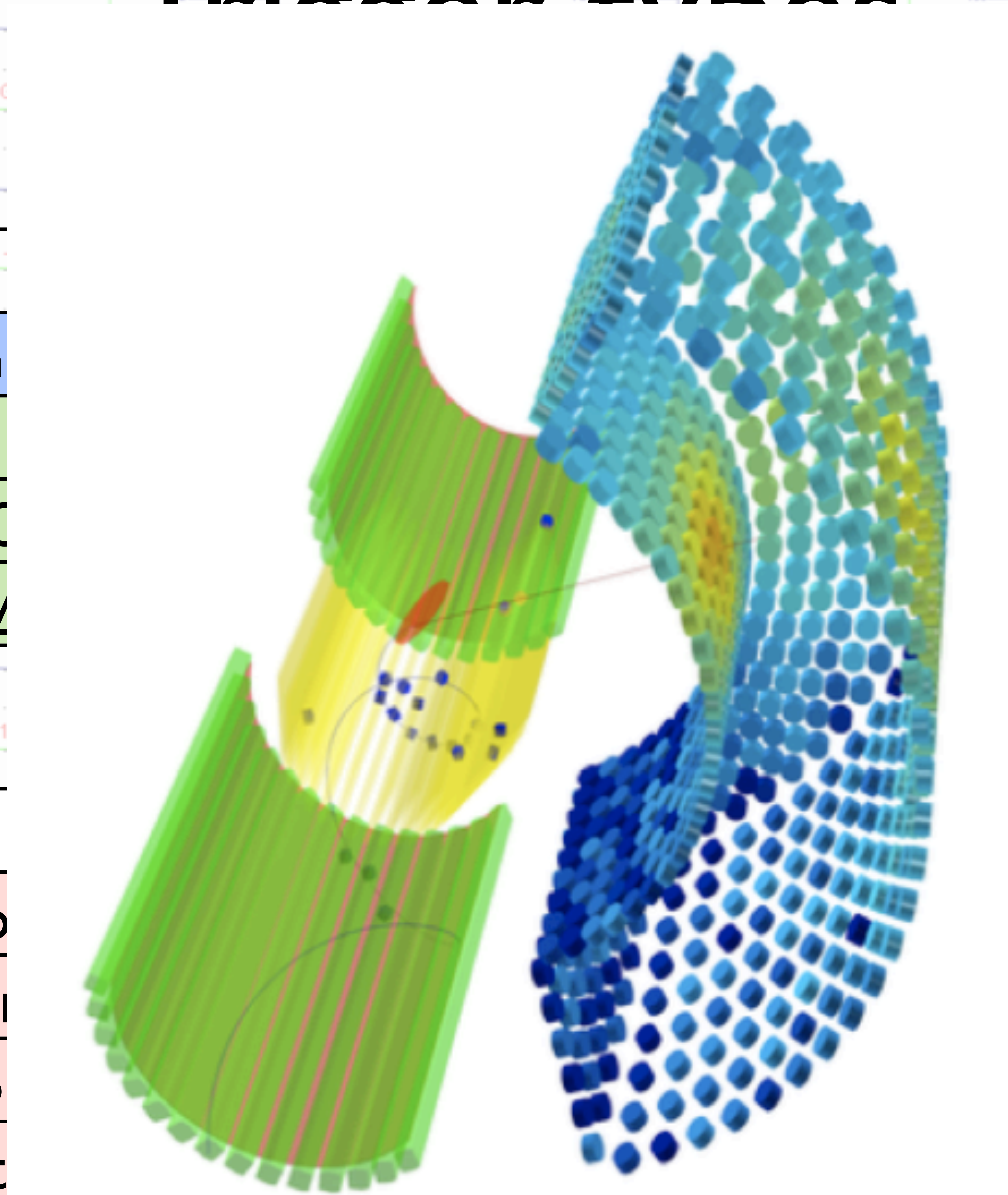
Type	E_γ Thr (MeV)	$\lvert\Delta T\rvert$ (ns)	Collinearity
MEG	40	10	LUT
Check E_γ	30	10	LUT
Check Coll	40	10	NO
Check ΔT	40	20	LUT

Example of calibration triggers

Type	Selection criteria
LXe alone	E_γ threshold as MEG
TC alone	Single hit on TC bars
DC alone	Track candidates on DCs
Pedestal	Random triggers

Trigger types

Type		llinearity
MEG		LUT
Check		LUT
Check C		NO
Check A		LUT



Type	
LXe alo	
TC alo	
DC alo	s
Pedest	

DAQ set-up

- Single mask and prescaling factor
- DAQ with different triggers mixed together
- ONLINE computation of total and lifetime
- The trigger system merged into MEG Midas DAQ system
  - exchange of control signals with MEG digitizers (DRS, PSI) through a dedicated bus
  - second MEG digitizing system for fast check of data, in particular for LXe energy

Conclusions

- A novel electronic trigger system developed for the MEG experiment
- Multi layer structure based on digital computation of detector signals
- Selection algorithms implemented into FPGAs ➜ fast computation and flexibility
- High efficiency on signal with 10^7 background rejection
- Trigger system inserted into experiment DAQ