Latest results from the MEG experiment

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INFN Sezione di Pisa

LPNHE Paris

10 March 2011

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
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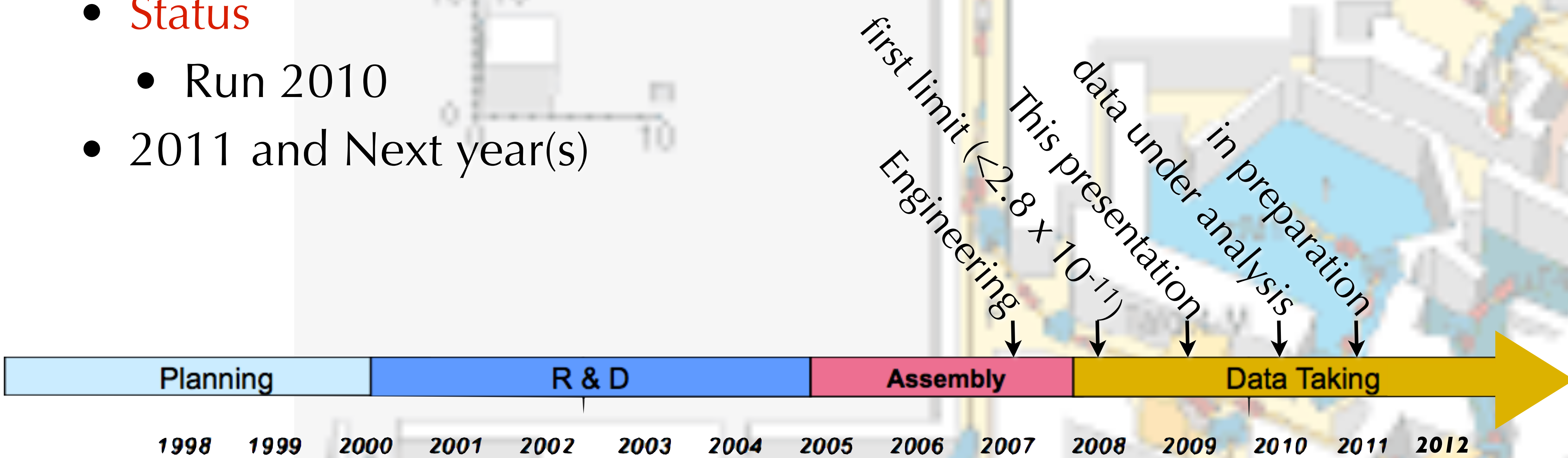
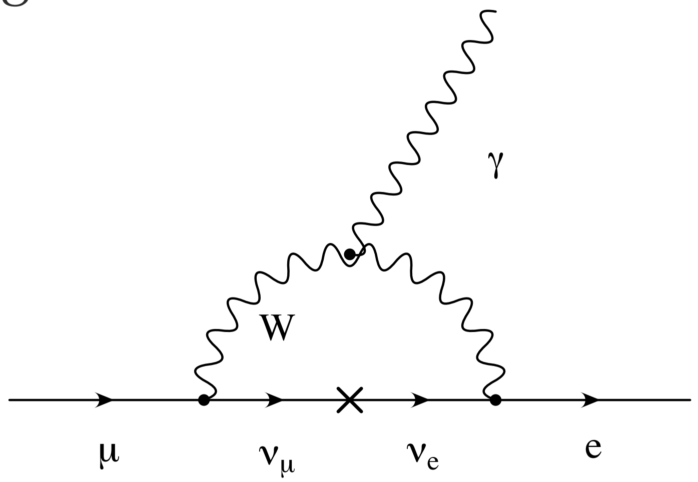
Outline

- Physics motivation for a $\mu \to e\gamma$ experiment
- The $\mu \to e\gamma$ decay
- The detector
  - Overview of sub-detectors
  - Calibration methods
- Analysis of 2009 run
- Status
  - Run 2010
- 2011 and Next year(s)



The μ→eγ decay

- The μ→eγ decay in the SM is radiatively induced by neutrino masses and mixings at a negligible level

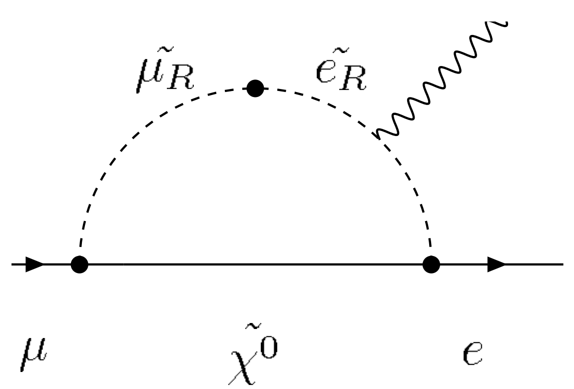


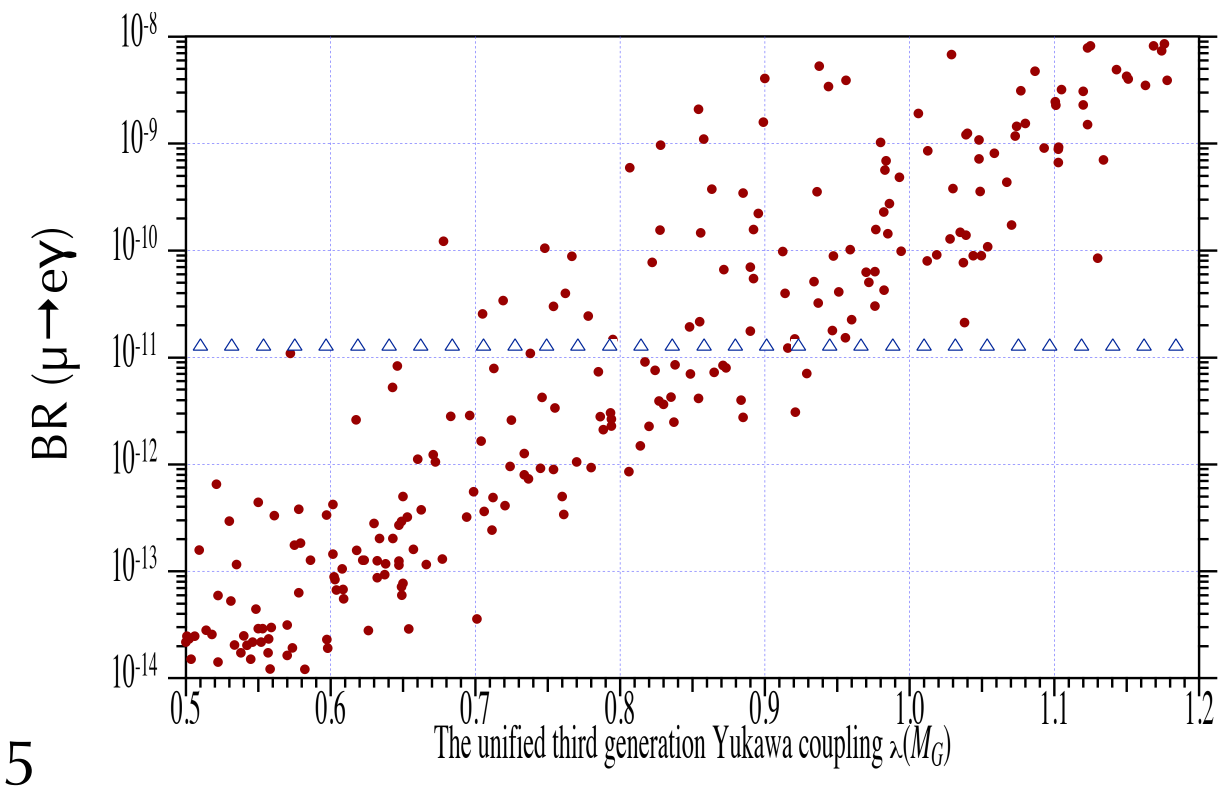
$$\Gamma(\mu \to e\gamma) \approx \underbrace{\frac{G_F^2 m_\mu^5}{192\pi^3}}_{\mu-\text{decay}} \underbrace{\left(\frac{\alpha}{2\pi}\right)}_{\gamma-\text{vertex}} \underbrace{\sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2}{M_W^2}\right)}_{\nu-\text{oscillation}}$$

$$\approx \frac{G_F^2 m_\mu^5}{192\pi^3} \frac{3\alpha}{32\pi} \left(\frac{\Delta m_{23}^2 s_{13} c_{13} s_{23}}{M_W^2}\right)^2$$

relative probability ~ 10^{-54}

- All SM extensions enhance the rate through mixing in the high energy sector of the theory (other particles in the loop...)

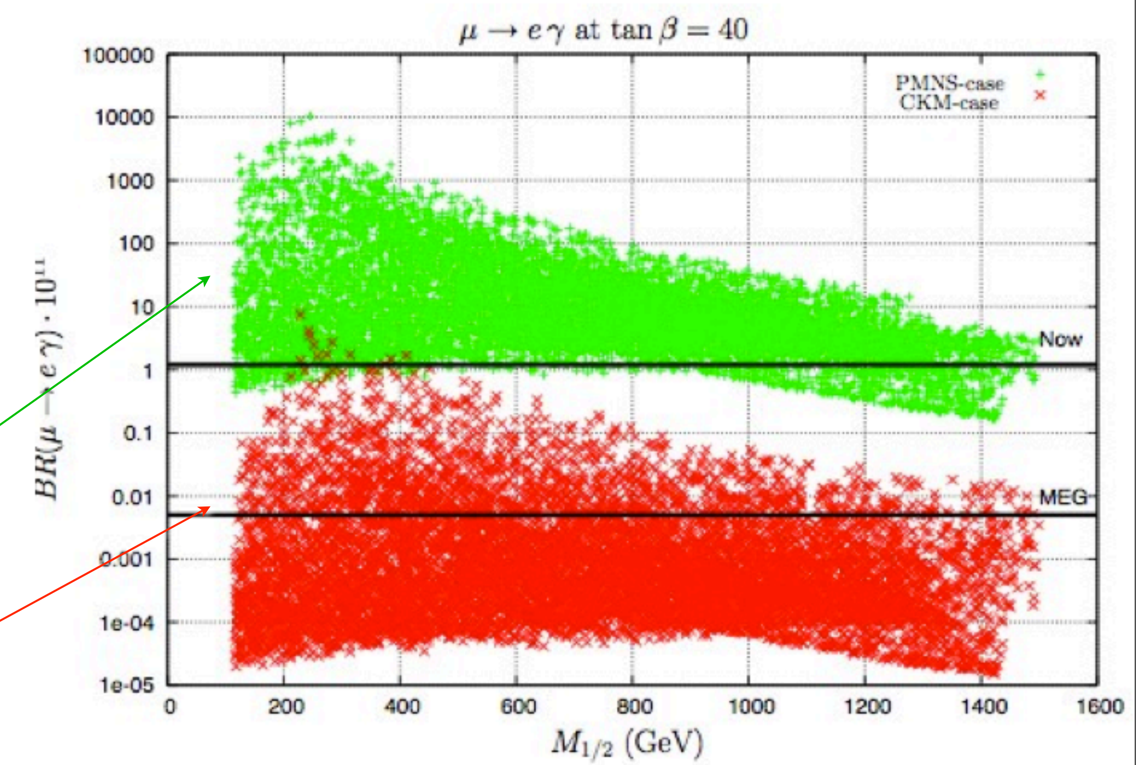




- Clear evidence for physics beyond the SM
- Restrict parameter space of SM extensions

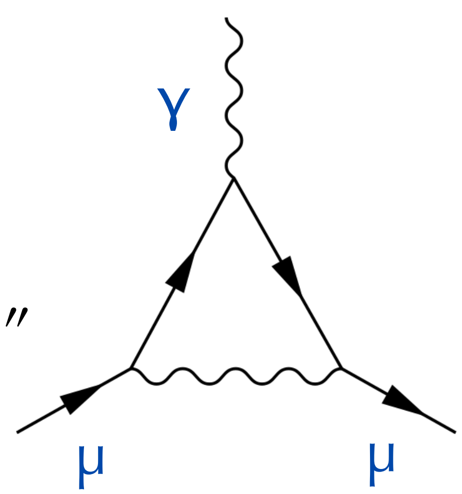
Connections

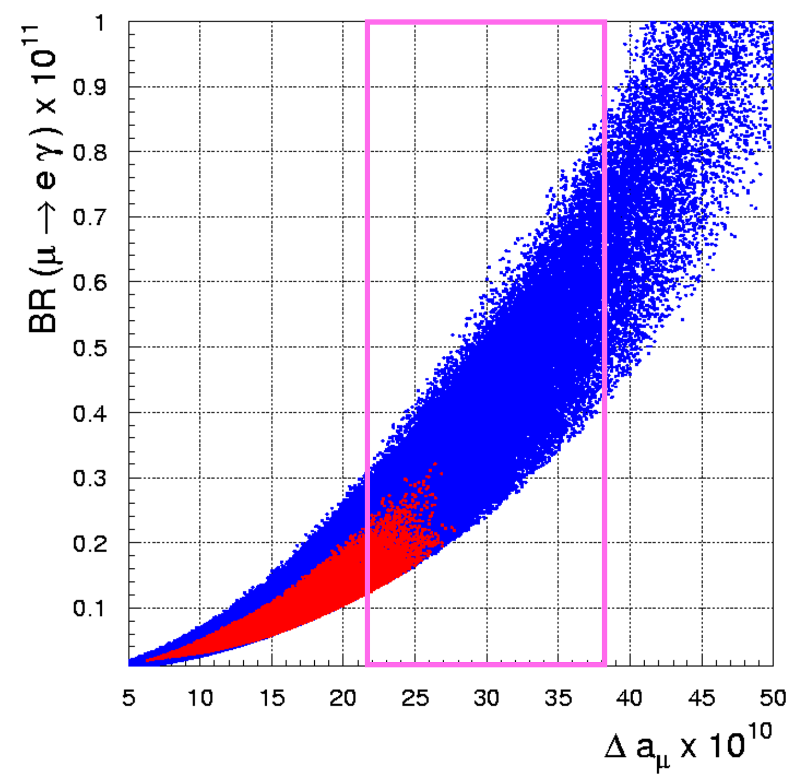
- Collider physics
  - it is Super Symmetry + Grand Unification that predicts new particles in the loop.
  - alternate search for (E/M_{SUSY}) suppressed effects



- neutrino oscillations
  - mixing matrix in charged sector can be proportional to
    - PMNS
    - CKM

- muon g–2
  - a_μ is the "diagonal" term
  - $\mu \to e\gamma$ diagram is the "off-diagonal"





Barbieri *et al,*, Nucl. Phys B445 (1995) 225
Hisano *et al.*, Phys. Lett. B391 (1997) 341
Masiero *et al.*, Nucl. Phys. B649 (2003) 189
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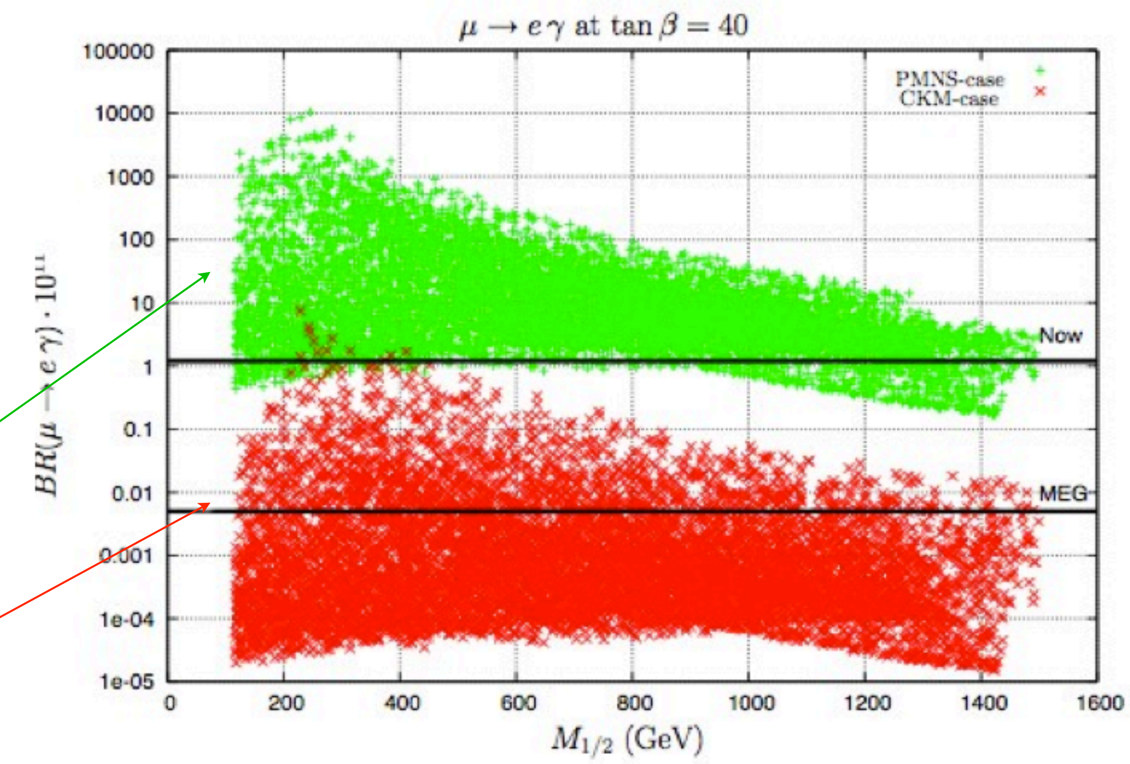

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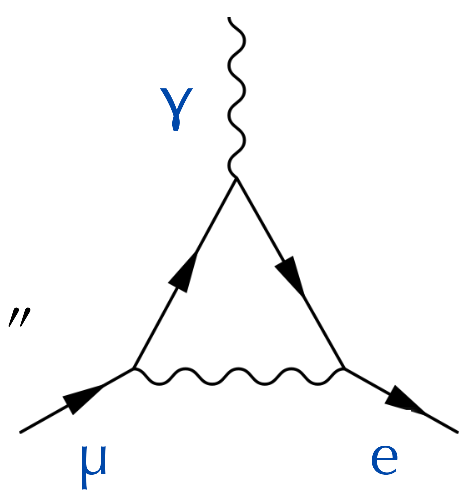

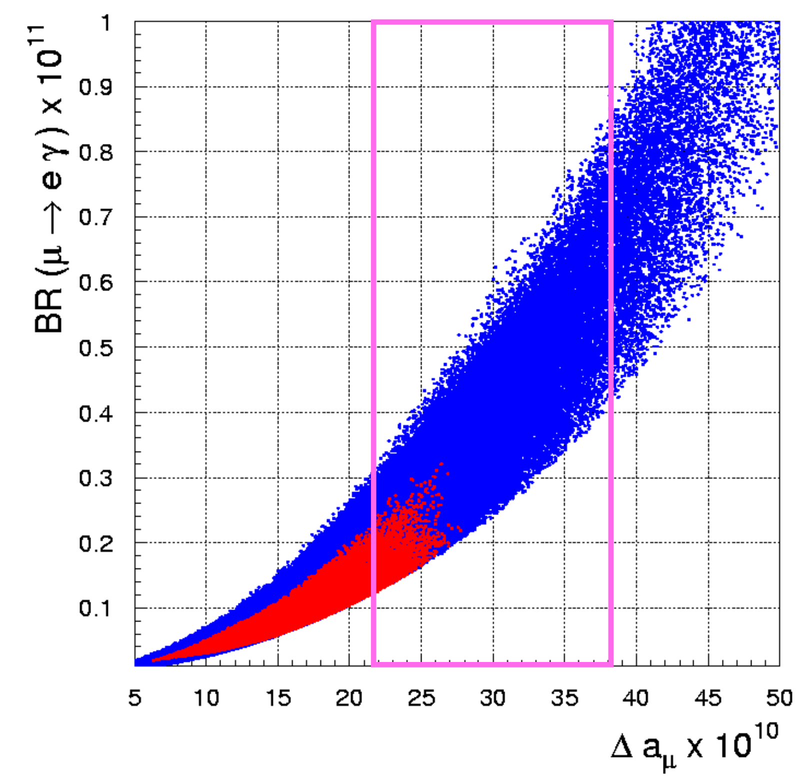

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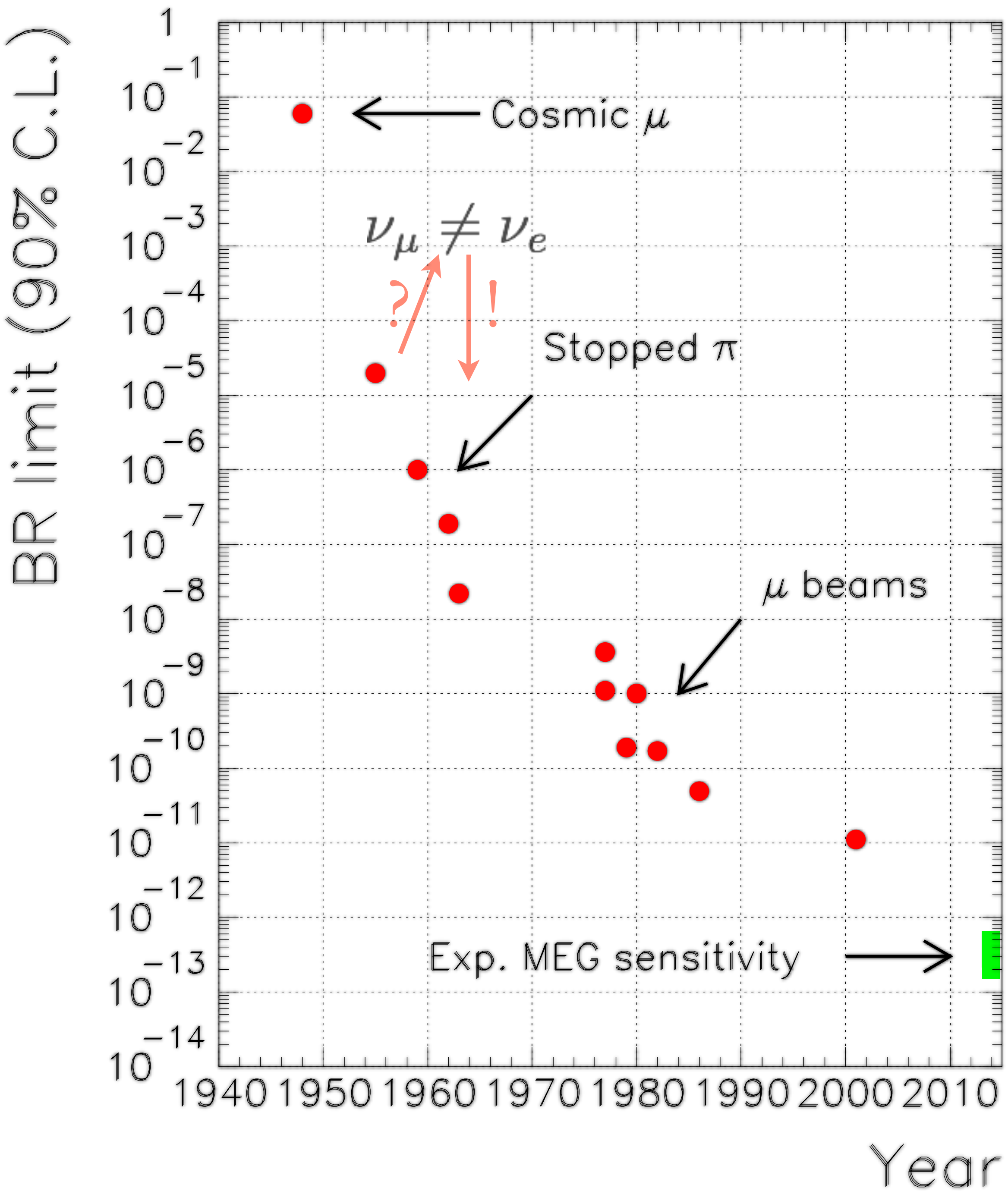
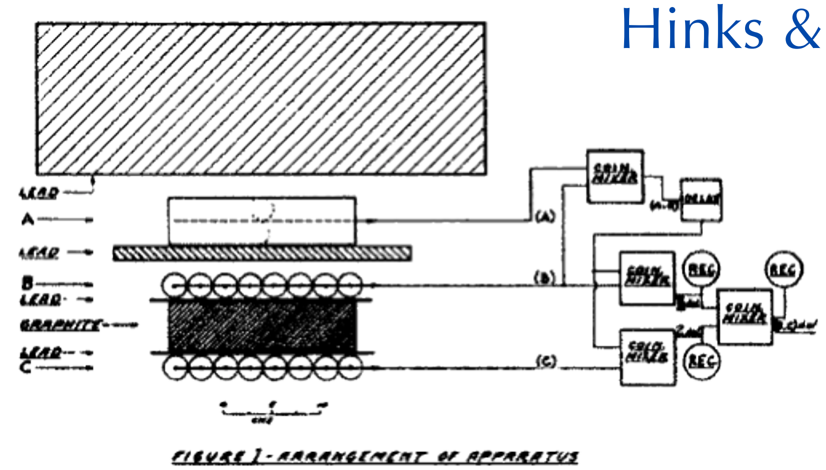
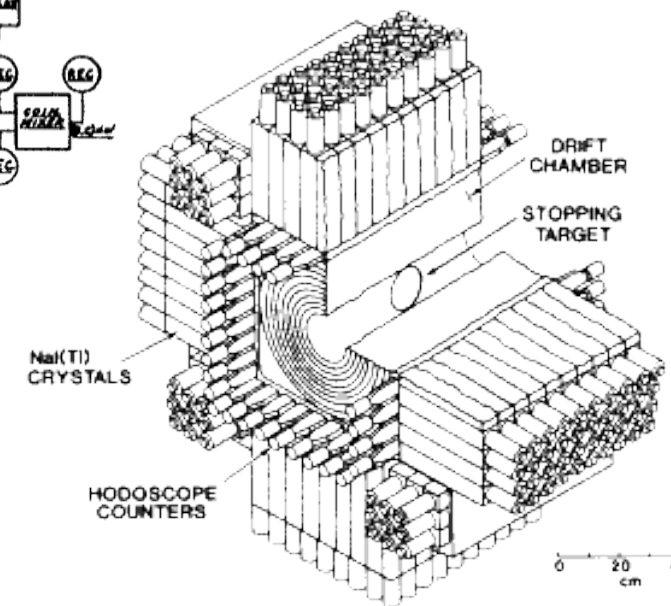
Historical perspective

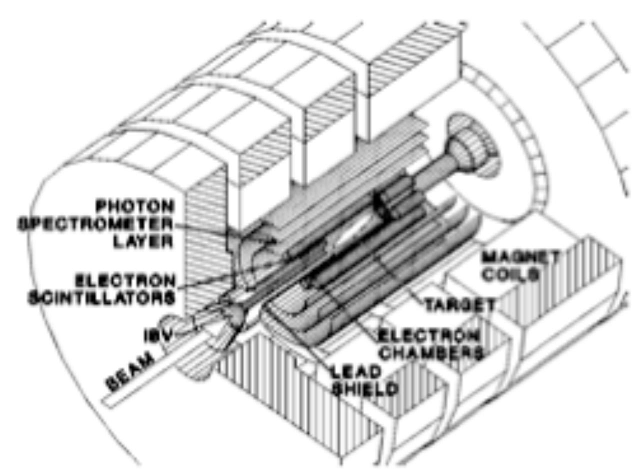


Hinks & Pontecorvo

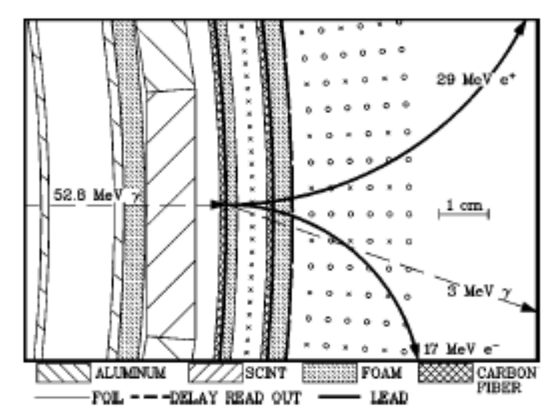


Crystal Box





MEGA

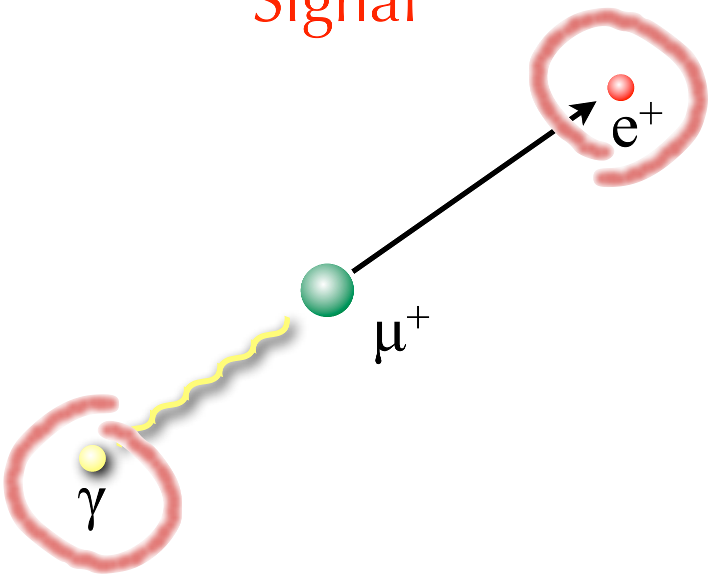


Each improvement linked to the technology either in the beam or in the detector

Always a trade-off between various elements of the detector to achieve the best "sensitivity"

Signal and Background

“Signal”

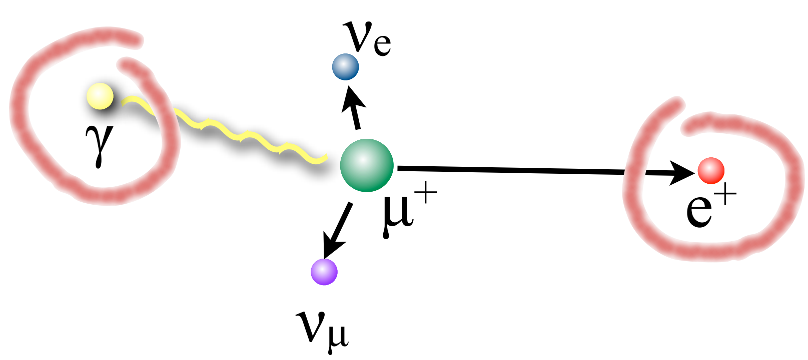


$E_e = E_\gamma = 52.8$ MeV

$\theta_{e\gamma} = 180°$

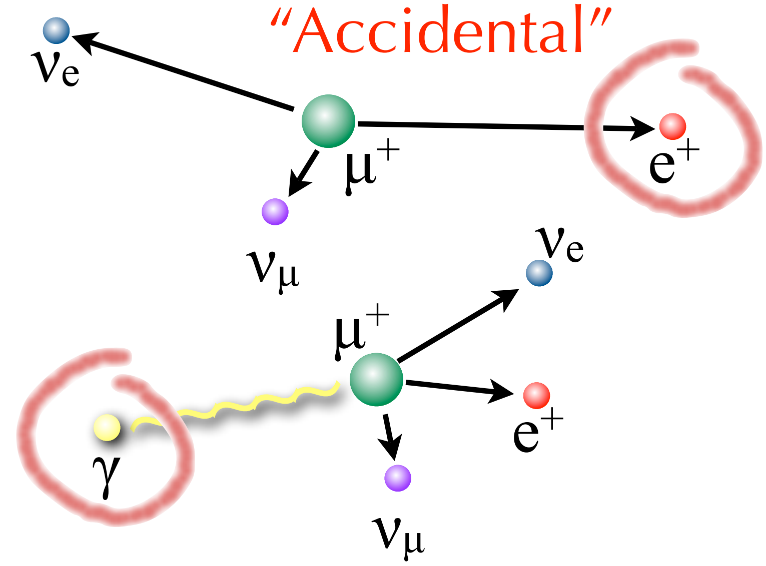
$t_{e\gamma} \sim 0$

“RMD”



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

“Accidental”



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

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

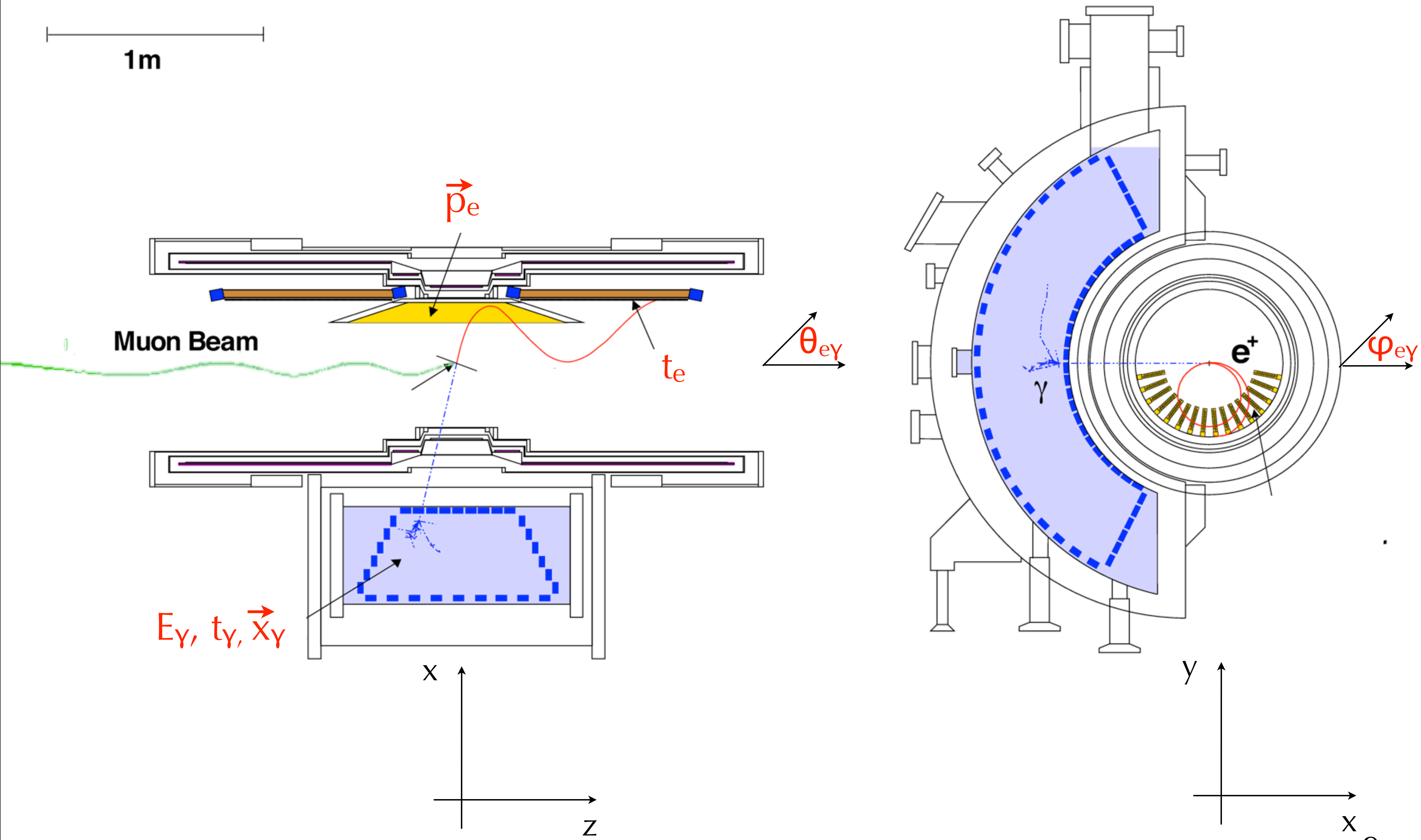
$e\mathcal{N} \to e\mathcal{N}\gamma$

$e^+e^- \to \gamma\gamma$

$$B_{\mathrm{prompt}} \approx 0.1 \times B_{\mathrm{acc}} \qquad B_{\mathrm{acc}} \approx R_\mu \Delta E_e \Delta E_\gamma^2 \Delta\theta^2 \Delta t$$

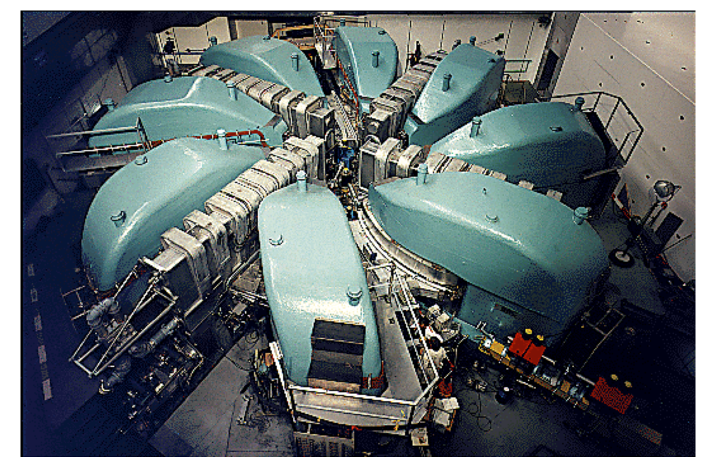
The accidental background is dominant and it is determined by the experimental resolutions

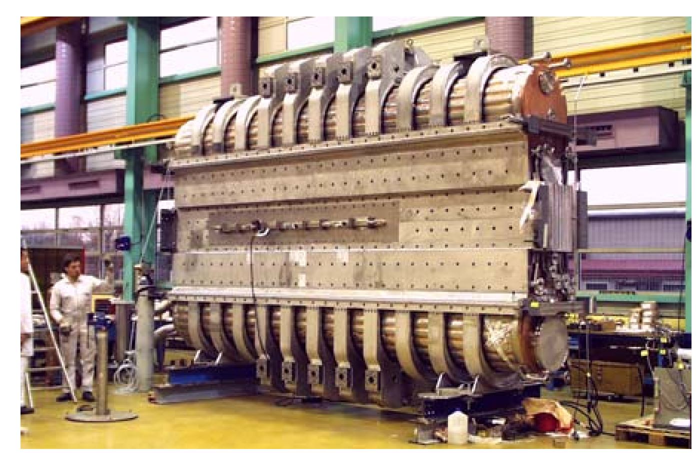
MEG scheme


1m
Muon Beam
$\vec{p}_e$
t_e
E_γ, t_γ, $\vec{x}_\gamma$
$\theta_{e\gamma}$
x
z
γ
e+
$\varphi_{e\gamma}$
y
x

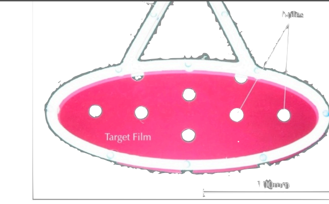
Machine

- "Sensitivity" proportional to the number of muons observed
- Find the most intense (continuous) muon beam: Paul Scherrer Institut (CH)
- 1.6 MW proton accelerator
  - 2 mA of protons - towards 3 mA (replace with new resonant cavities)!
  - extremely stable
  - $> 3 \times 10^8$ muons/sec @ 2 mA

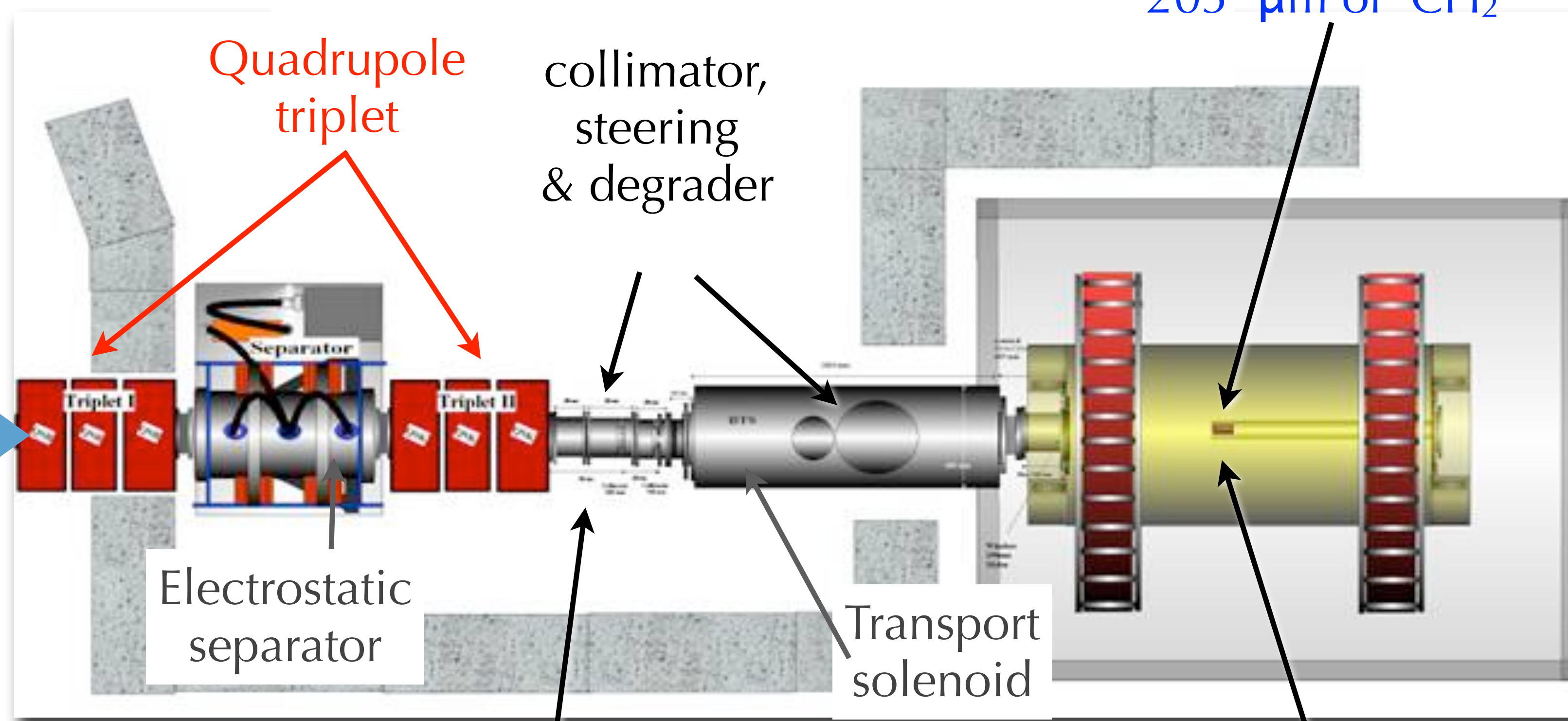




Beam line



target
205 µm of CH_2



πE5 beam line at PSI

Optimization of the beam elements:

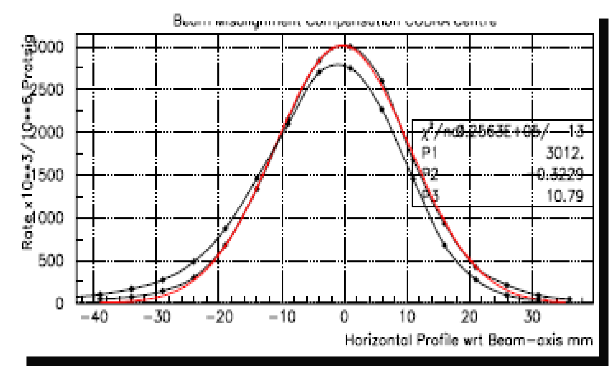
- Muon momentum ~ 29 MeV/c
- Wien filter for µ/e separation
- Solenoid to couple beam and spectrometer (BTS)
- Degrader to reduce the momentum for a 205 µm target

µ/e separation 11.8 cm (7.2 σ)

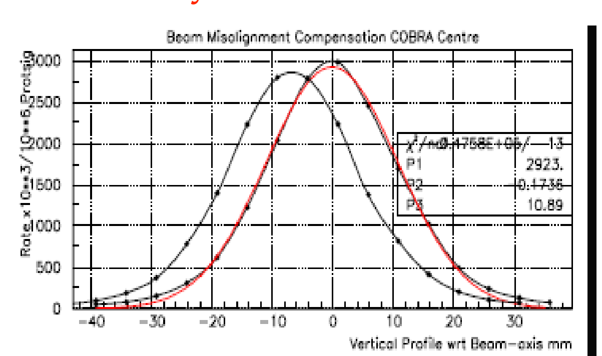
R_μ (exp. on target) $3 \times 10^7\ \mu^+/s$

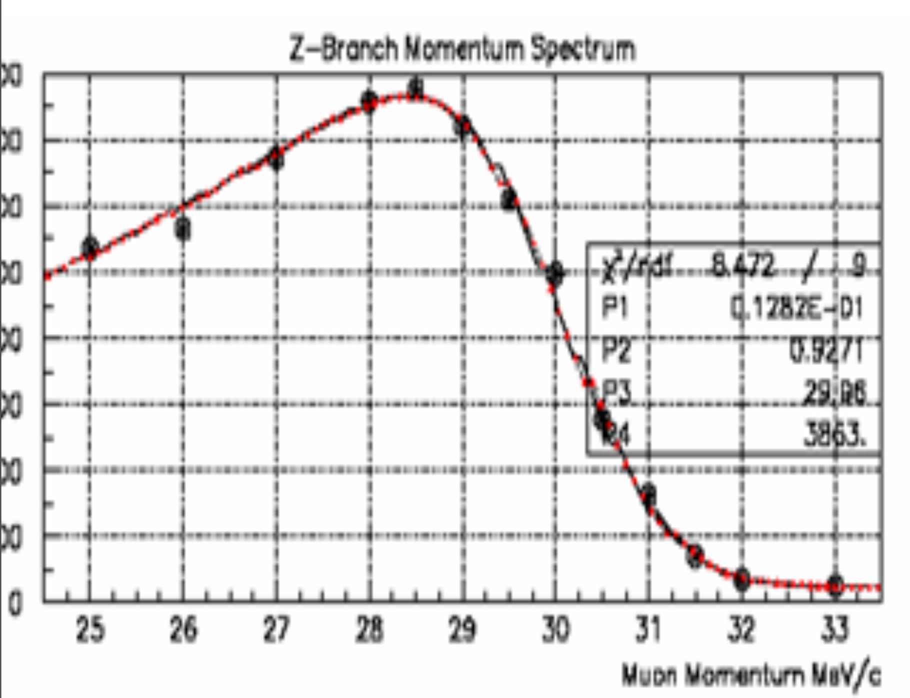
µ spot (exp. on target) $\sigma_V \approx \sigma_H \approx 11$ mm

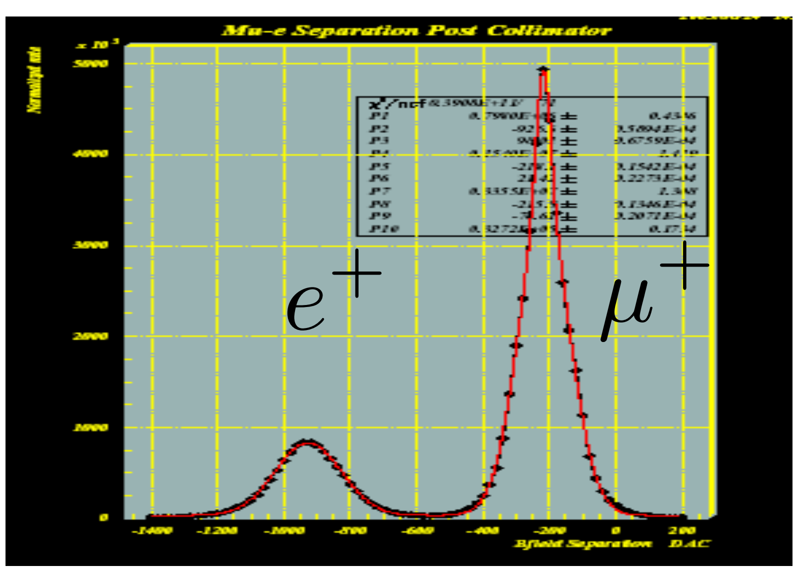
$\sigma_x = 11$ mm



$\sigma_y = 11$ mm

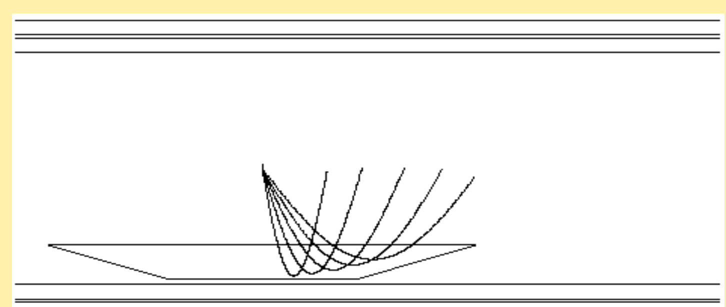
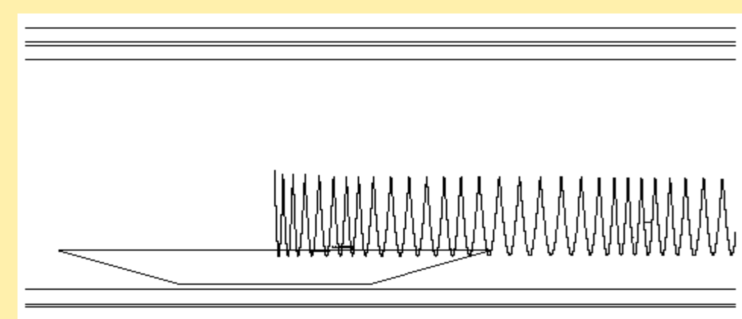
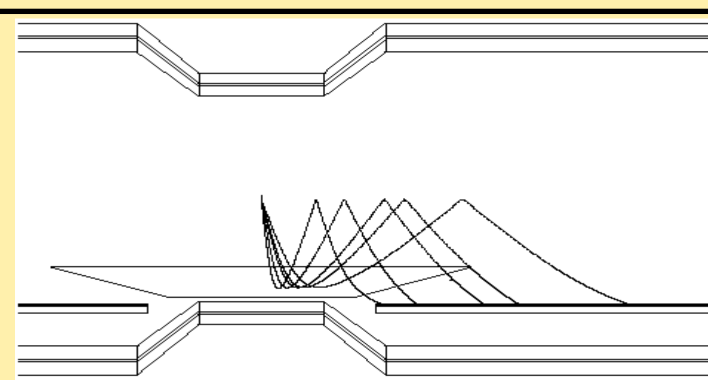
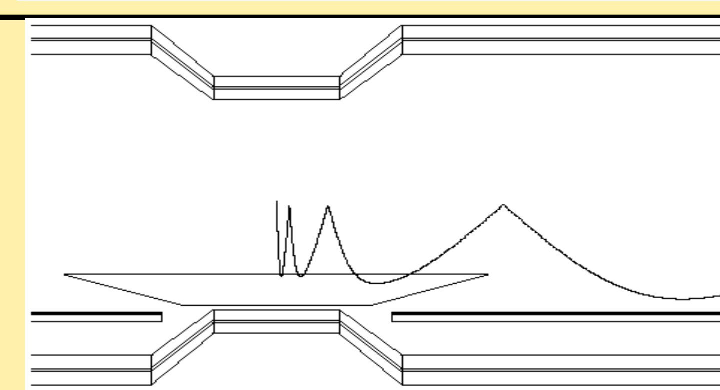


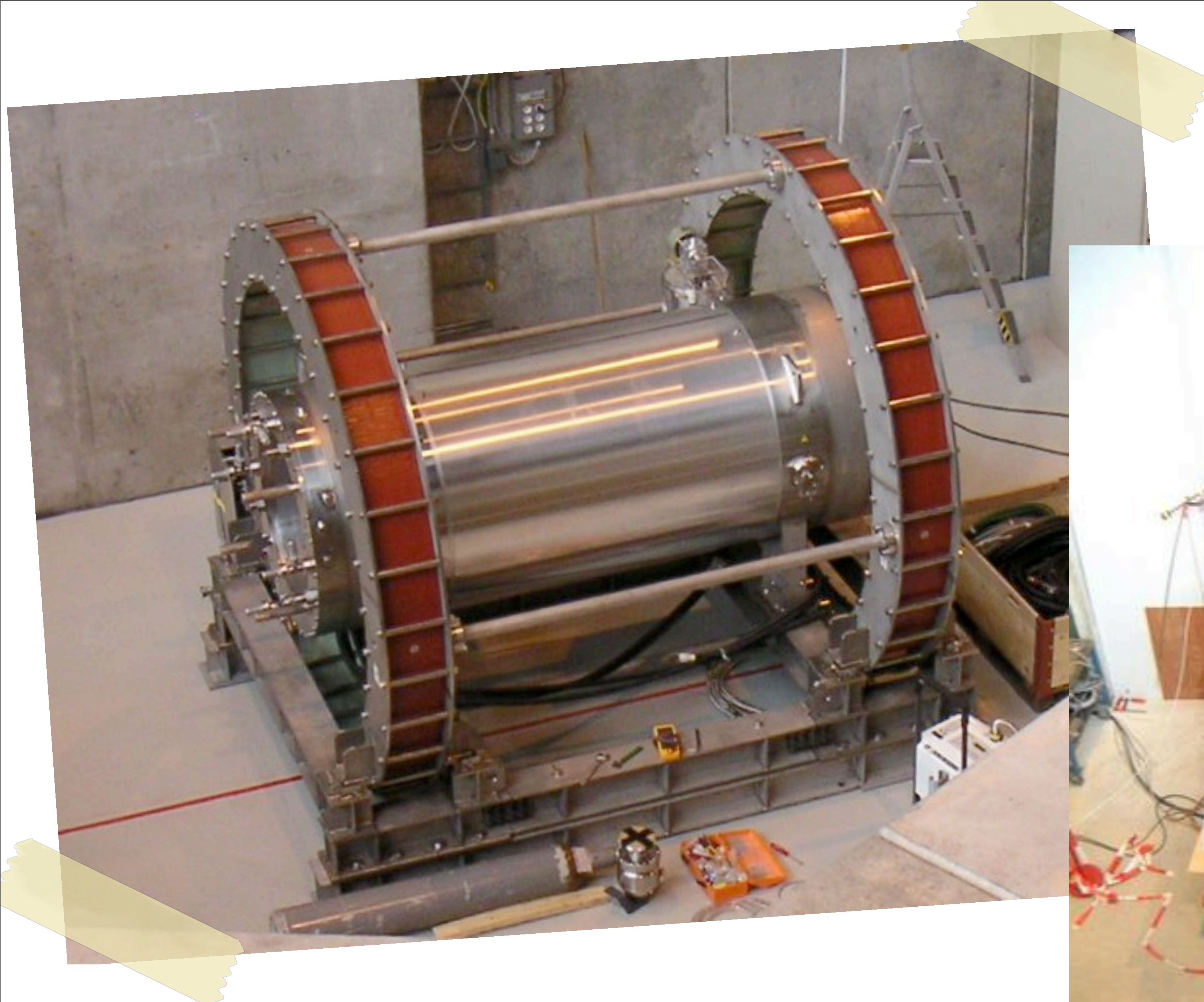


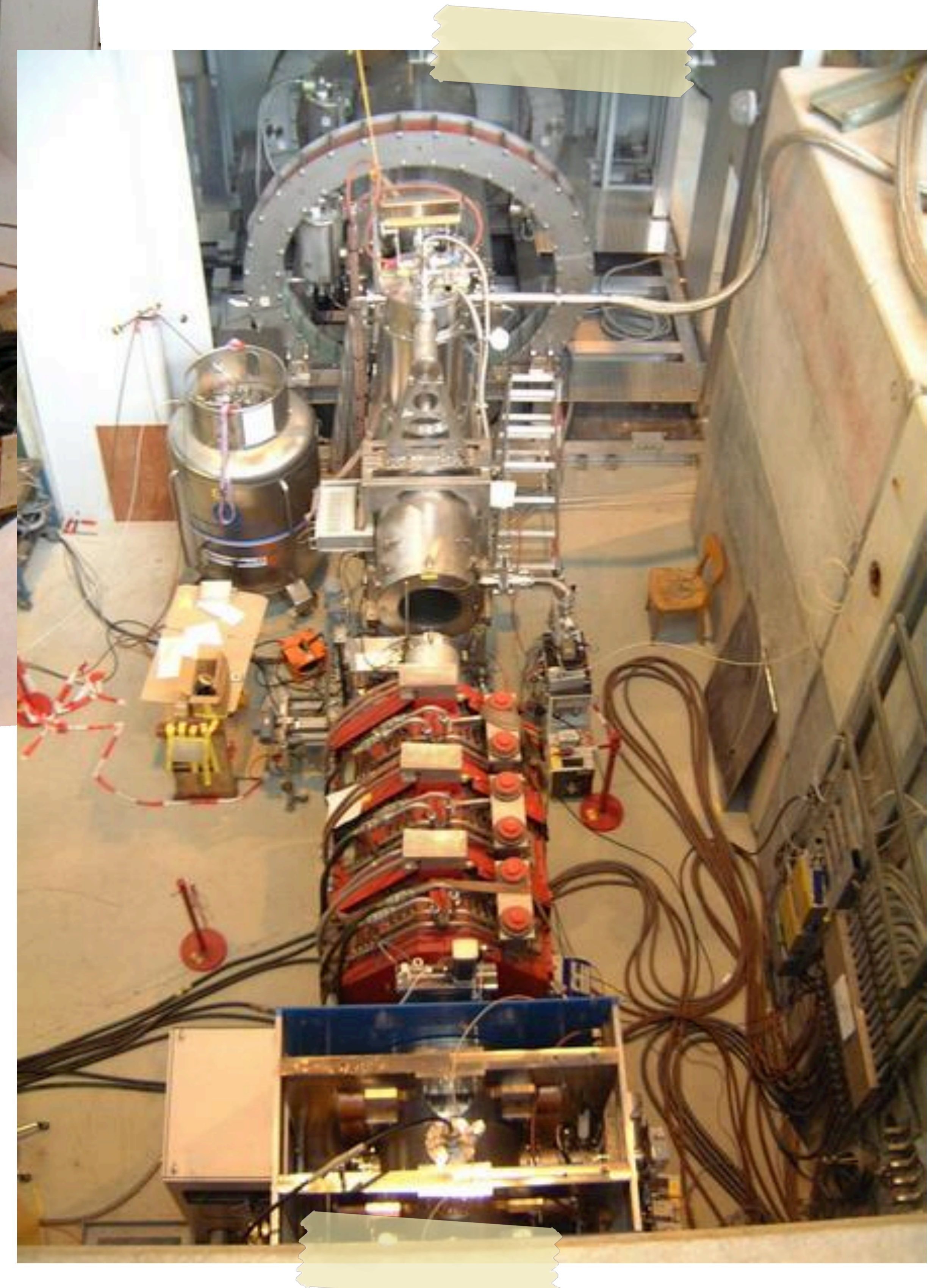


COBRA spectrometer

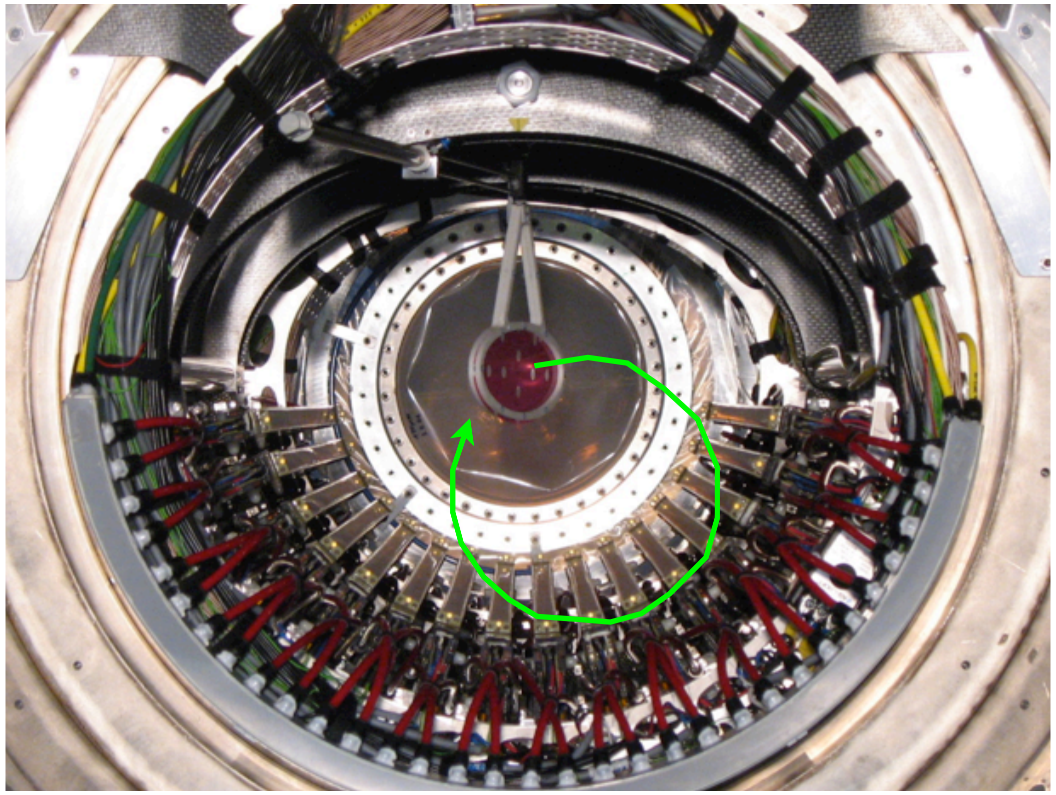
- The emitted positrons tend to wind in a uniform magnetic field
  - the tracking detector becomes easily “blind” at the high rate required to observe many muons
- A non uniform magnetic field solves the rate problem
- As a bonus: COnstant Bending RAdius

	Constant $\|p\|$ track	High p_T track
Uniform field		
CoBRa: Constant bending quick sweep away		





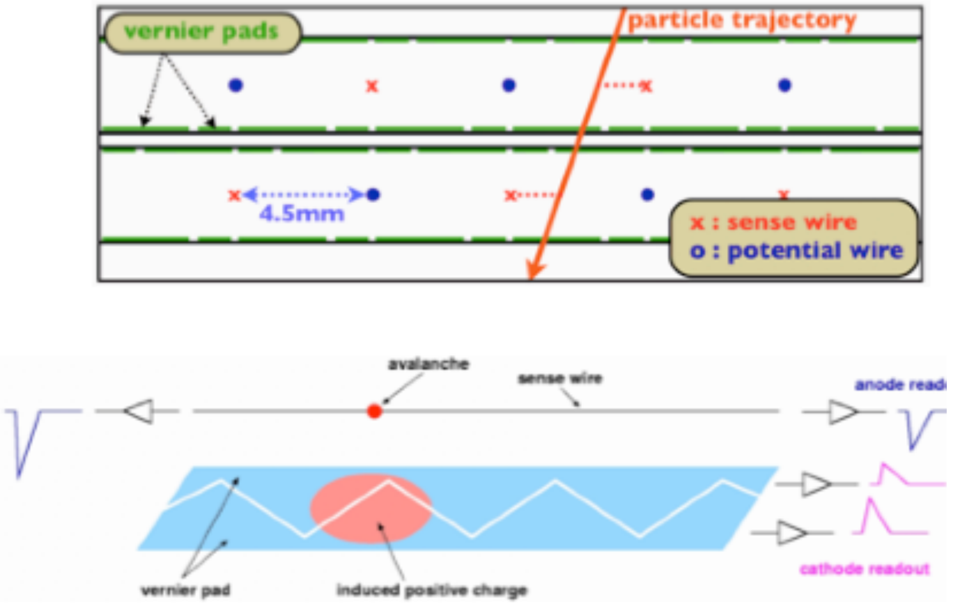
Positron Tracker

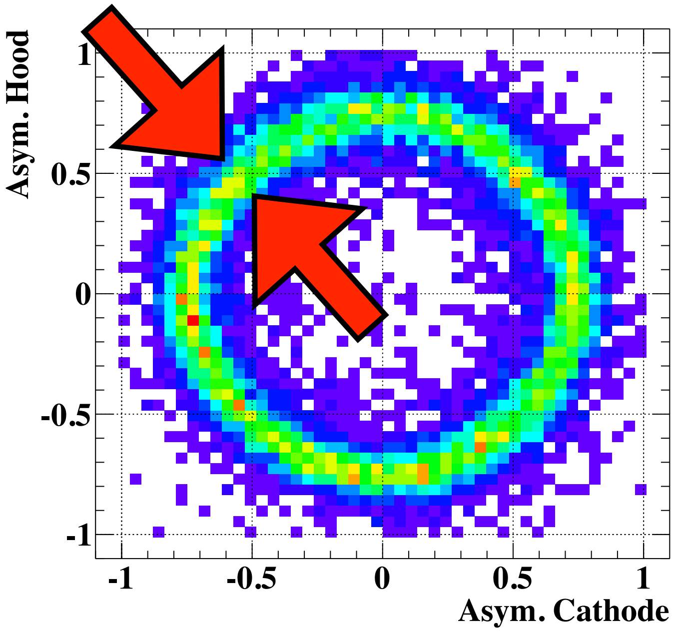


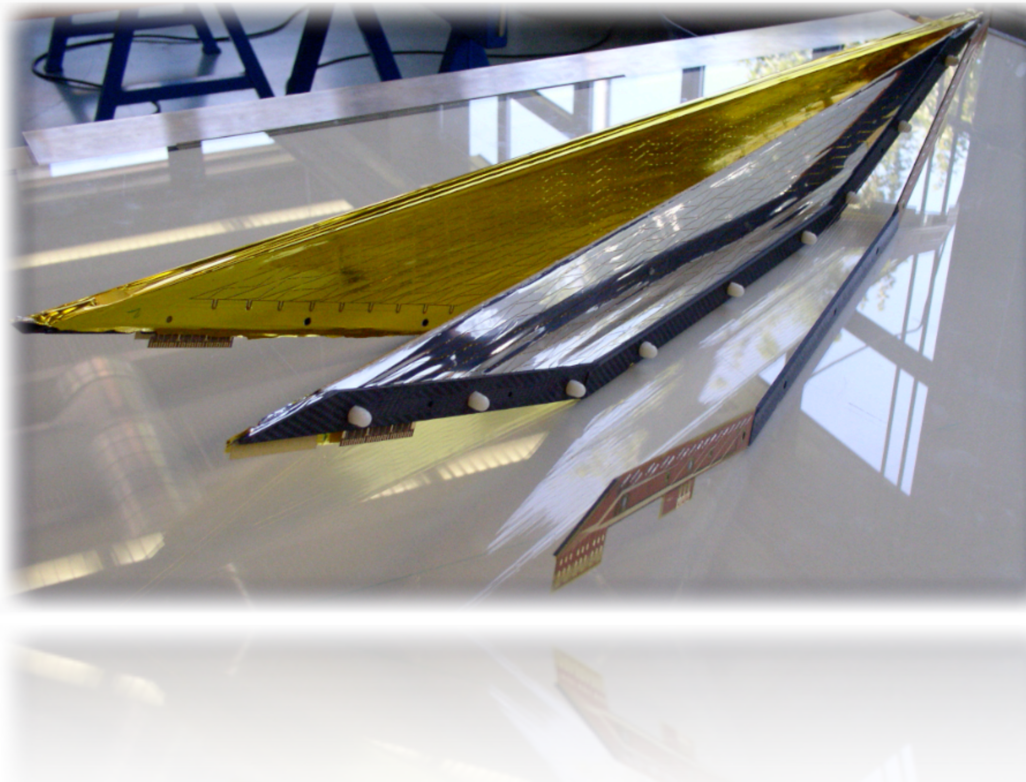
- 16 chambers radially aligned with 10° intervals
- 2 staggered arrays of drift cells
- 1 signal wire and 2 x 2 vernier cathode strips made of 15 μm kapton foils and 0.45 μm aluminum strips
- Chamber gas: He-C_2H_6 mixture
- Within one period, fine structure given by the Vernier circle

$\sigma_R \sim 300\ \mu m$ transverse coordinate (t drift)

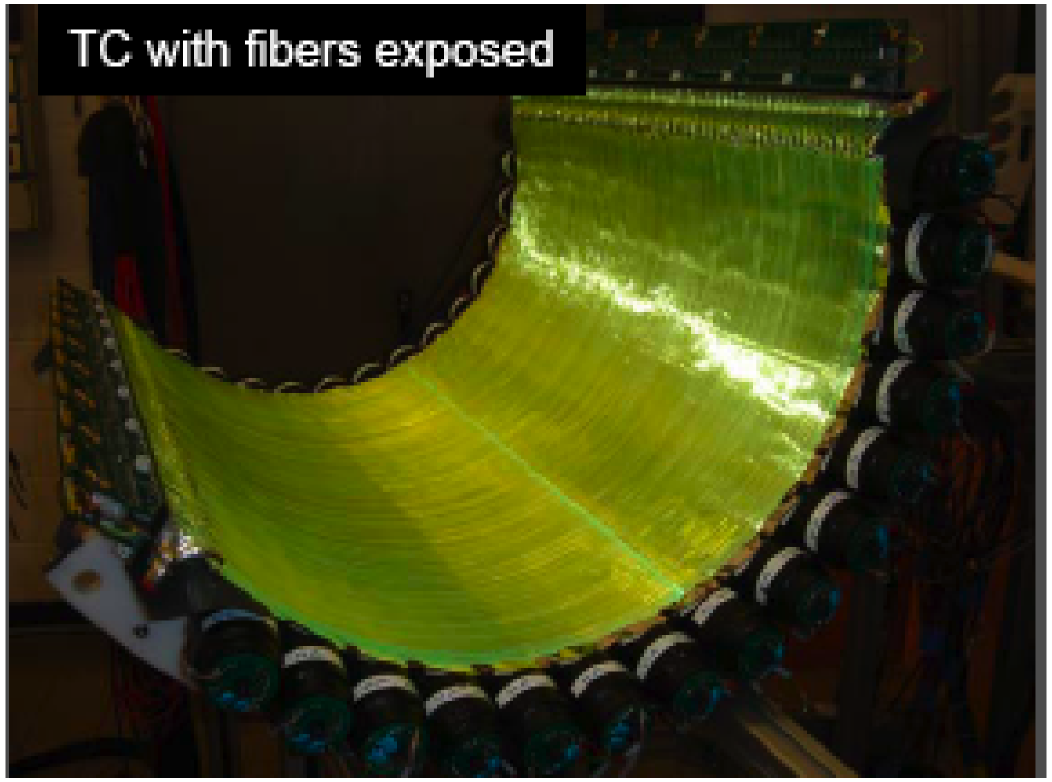
$\sigma_z \sim 700\ \mu m$ longitudinal coordinate (Vernier)

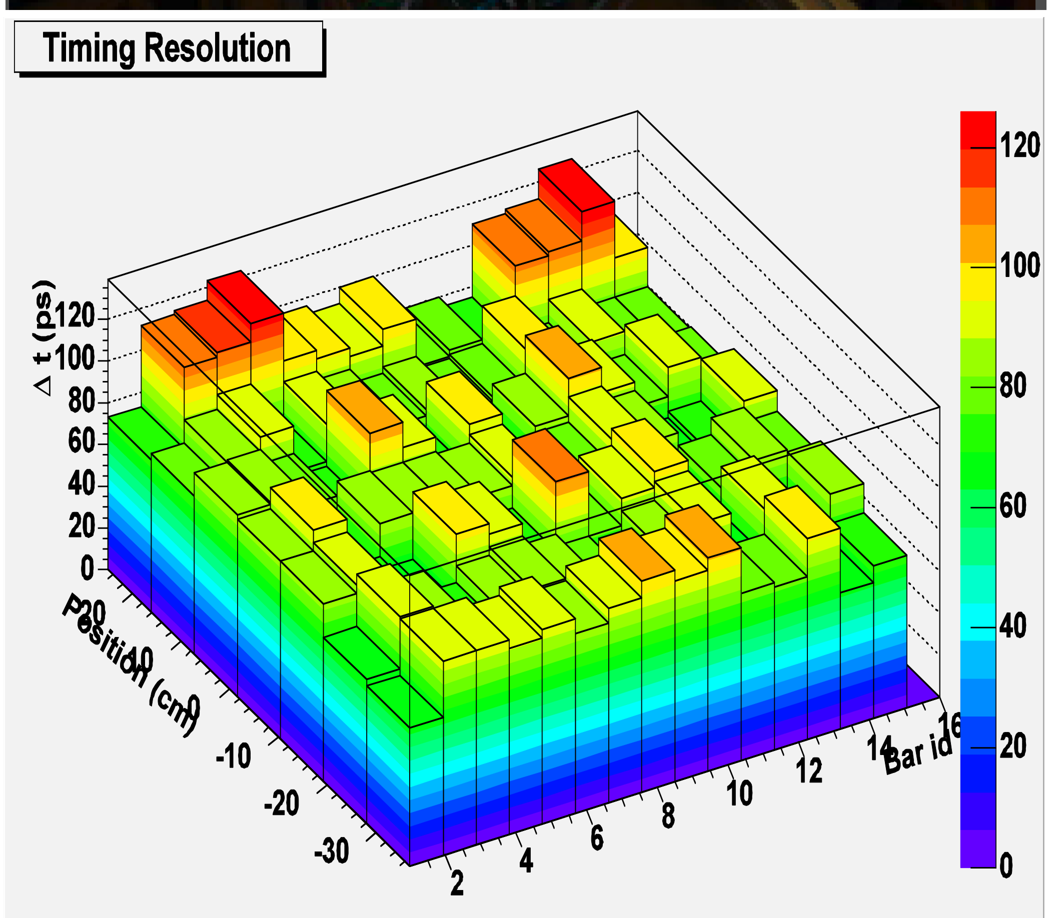




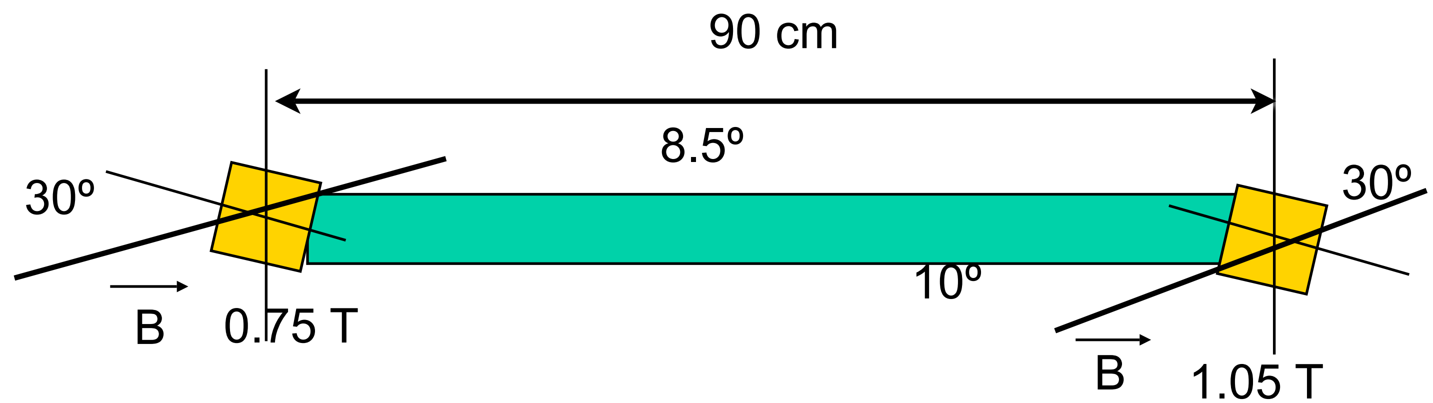


Timing Counter





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

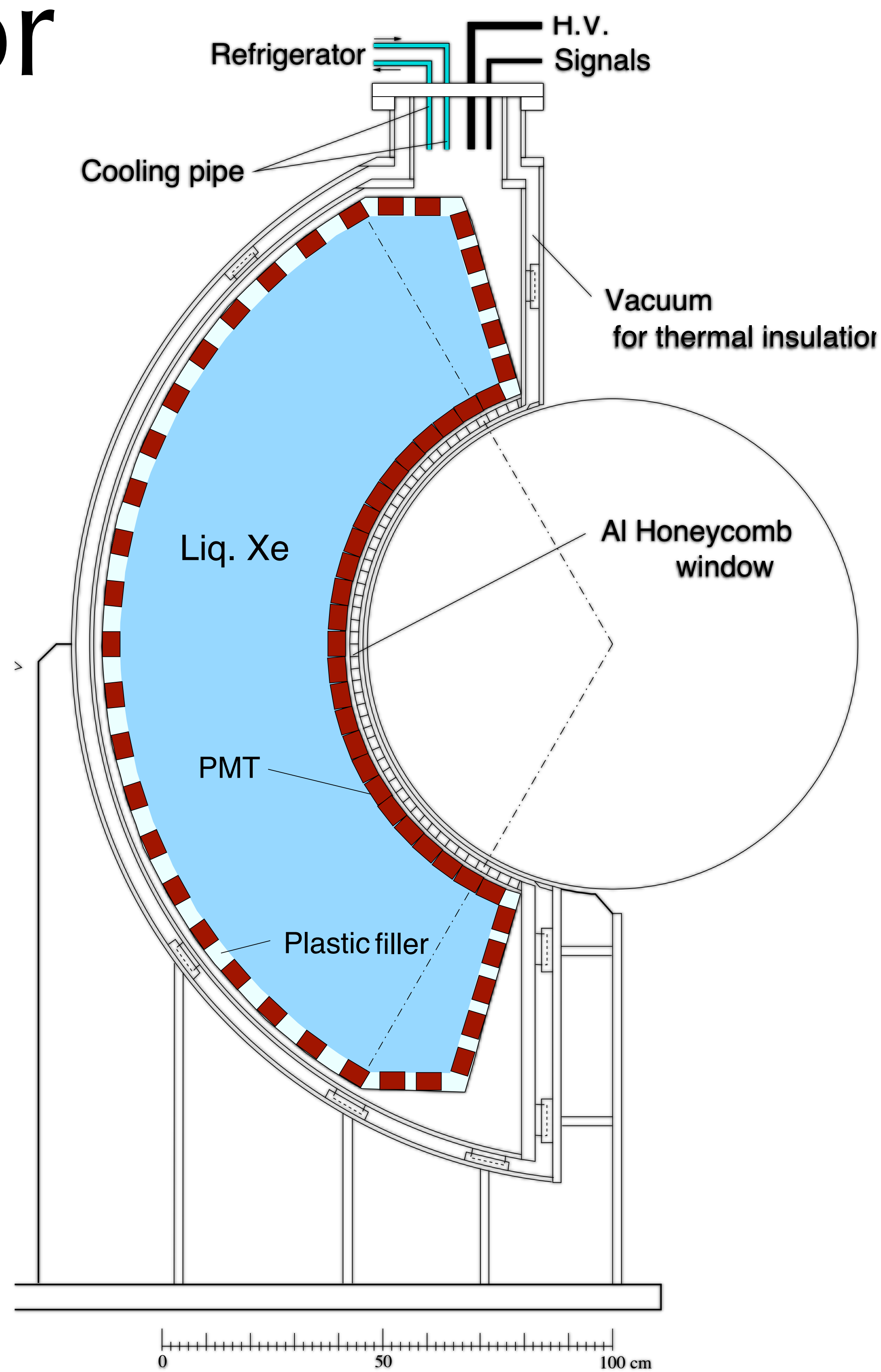


Exp. application (*)	Counter size (cm) (T x W x L)	Scintillator	PMT	λ_{att} (cm)	σ_t(meas)	σ_t(exp)
G.D.Agostini	3x 15 x 100	NE114	XP2020	200	120	60
T. Tanimori	3 x 20 x 150	SCSN38	R1332	180	140	110
T. Sugitate	4 x 3.5 x 100	SCSN23	R1828	200	50	53
R.T. Gile	5 x 10 x 280	BC408	XP2020	270	110	137
TOPAZ	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

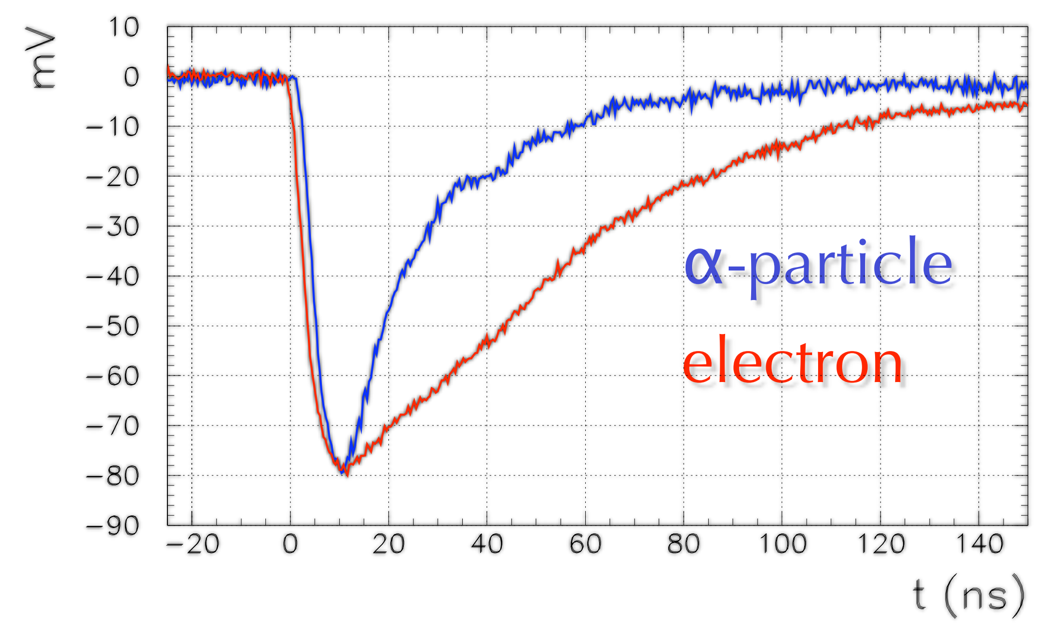
The photon detector

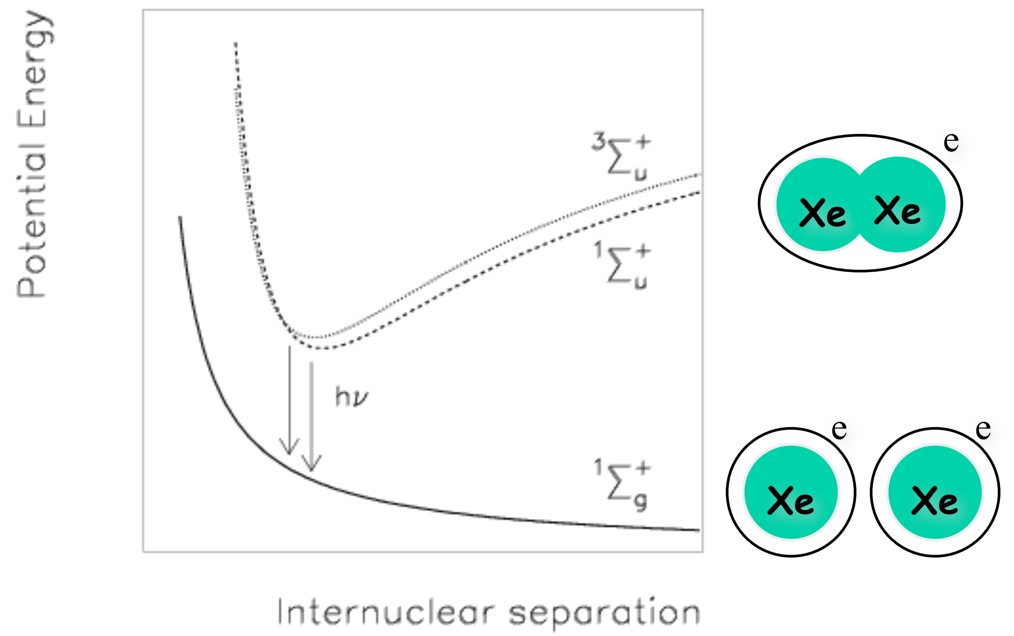
- γ Energy, position, timing
- Homogeneous 0.8 m^3 volume of liquid Xe
  - 10 % solid angle
  - $65 < r < 112$ cm
  - $|\cos\theta| < 0.35$ $|\phi| < 60^o$
- Only scintillation light
- Read by 848 PMT
  - 2″ photo-multiplier tubes
  - Maximum coverage FF (6.2 cm cell)
  - Immersed in liquid Xe
  - Low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



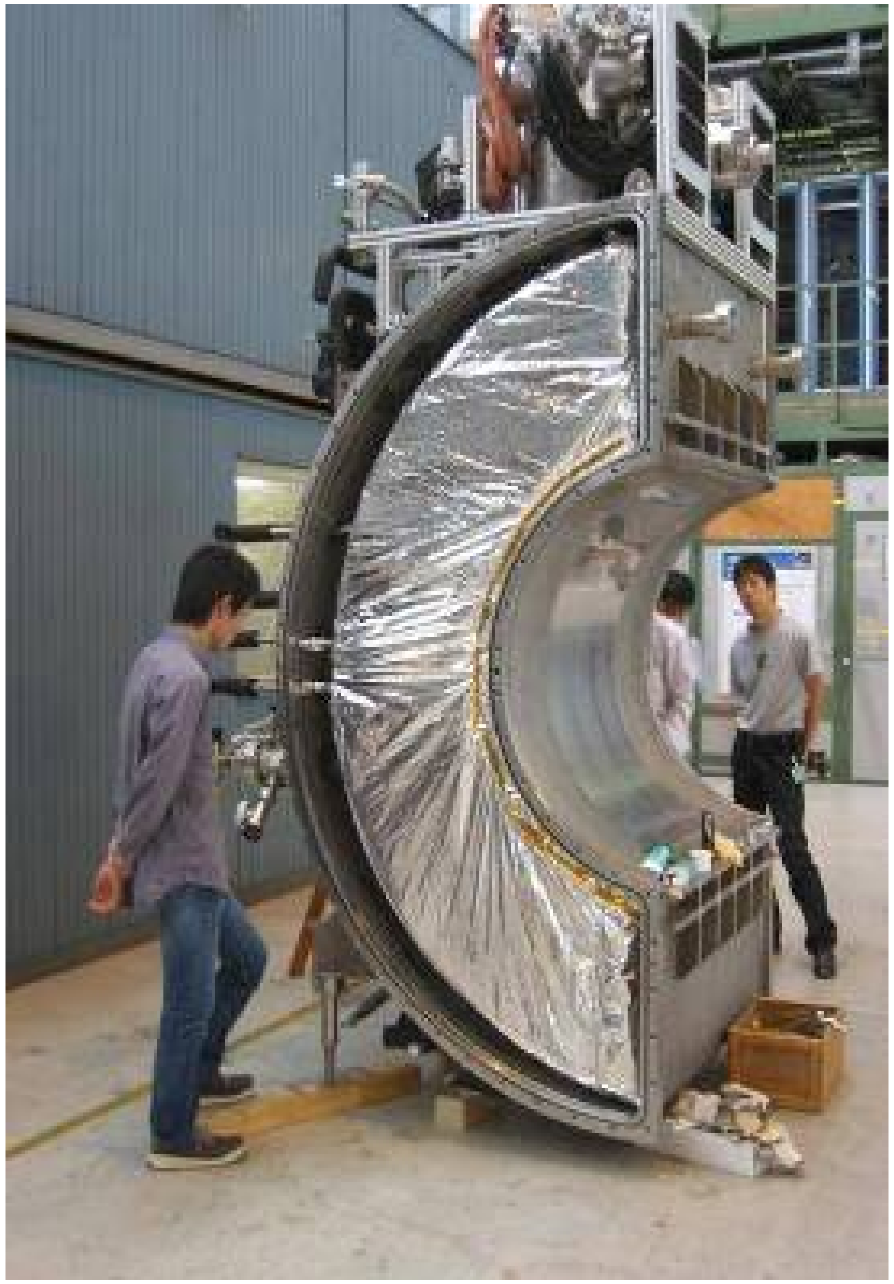
Xe properties

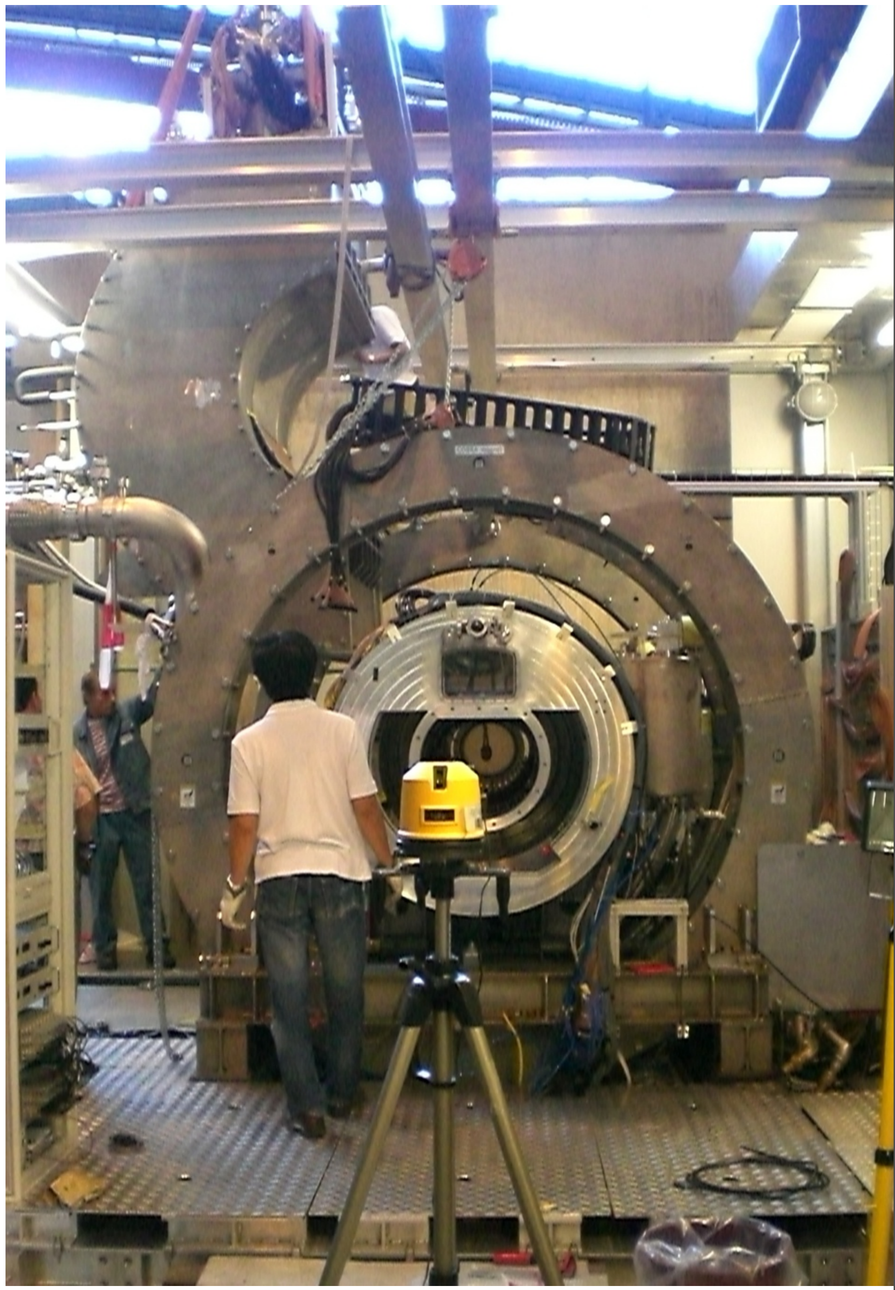
- Liquid Xenon was chosen because of its unique properties among radiation detection active media
- $Z=54$, $\rho=2.95\ \mathrm{g/cm^3}$ ($X_0=2.7$ cm), $R_M=4.1$ cm
- High light yield (similar to NaI)
  - 40.000 phe/MeV
- Fast response of the scintillation decay time
  - $\tau_{singlet}= 4.2$ ns
  - $\tau_{triplet}= 22$ ns
  - $\tau_{recomb}= 45$ ns
- Particle ID is possible
  - α ~ singlet+triplet, γ ~ recombination
- Large refractive index n = 1.65
- No self-absorption ($\lambda_{Abs}=\infty$)





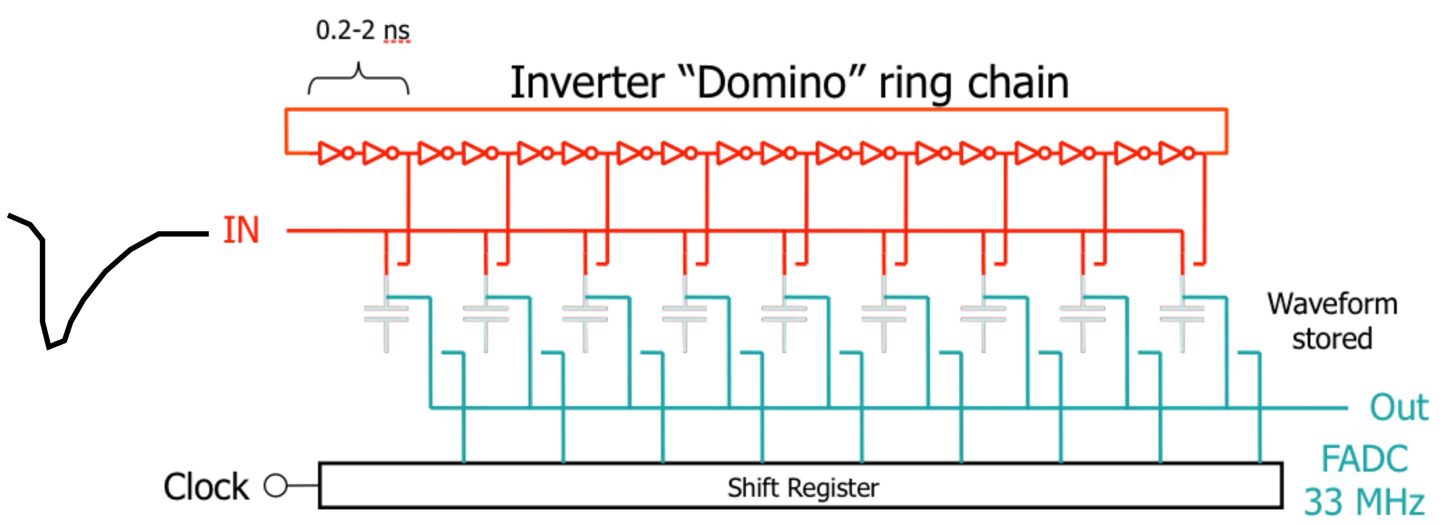
γ-detector construction





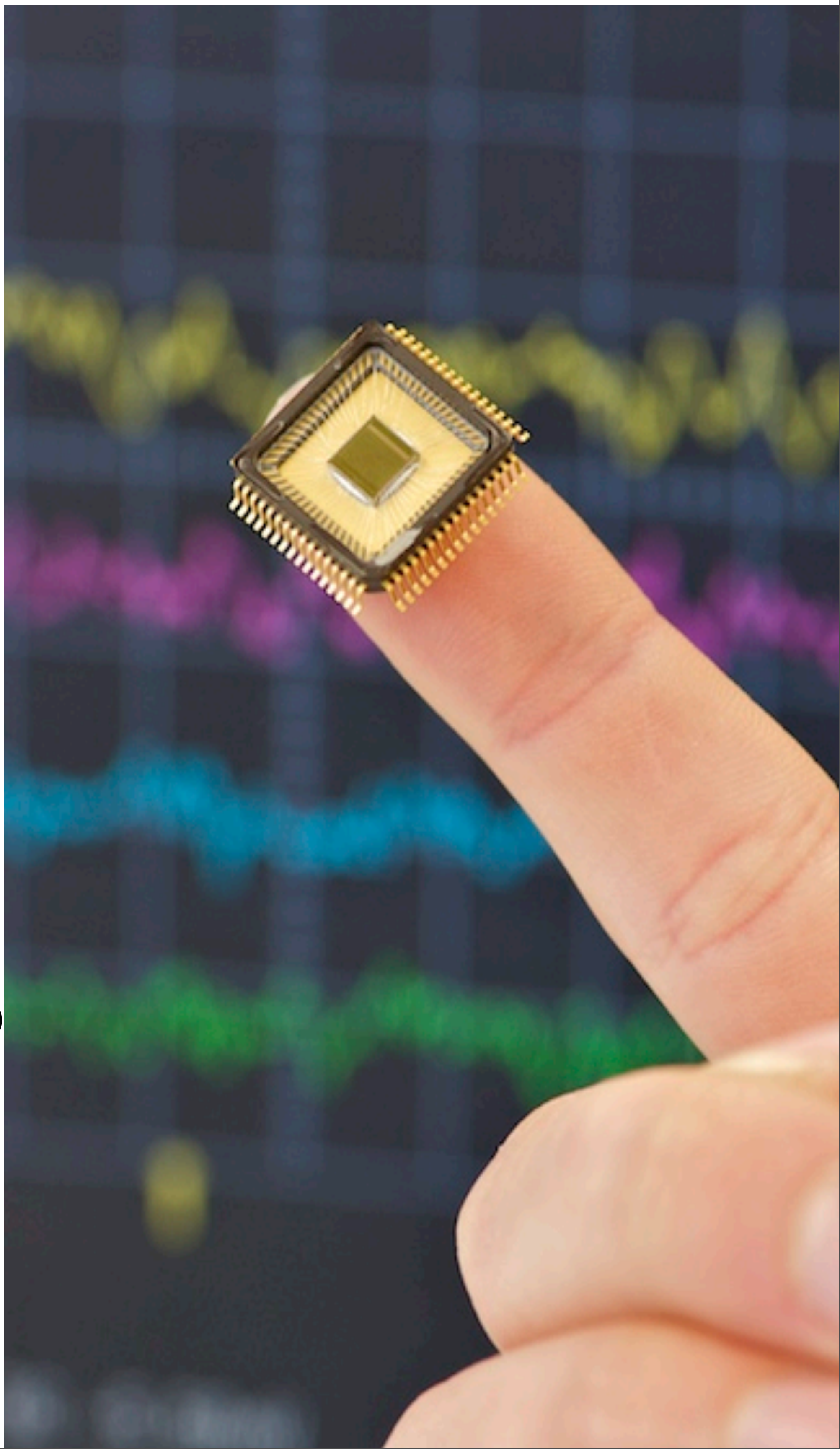
Readout electronics

every channel is connected to a GHz WFD



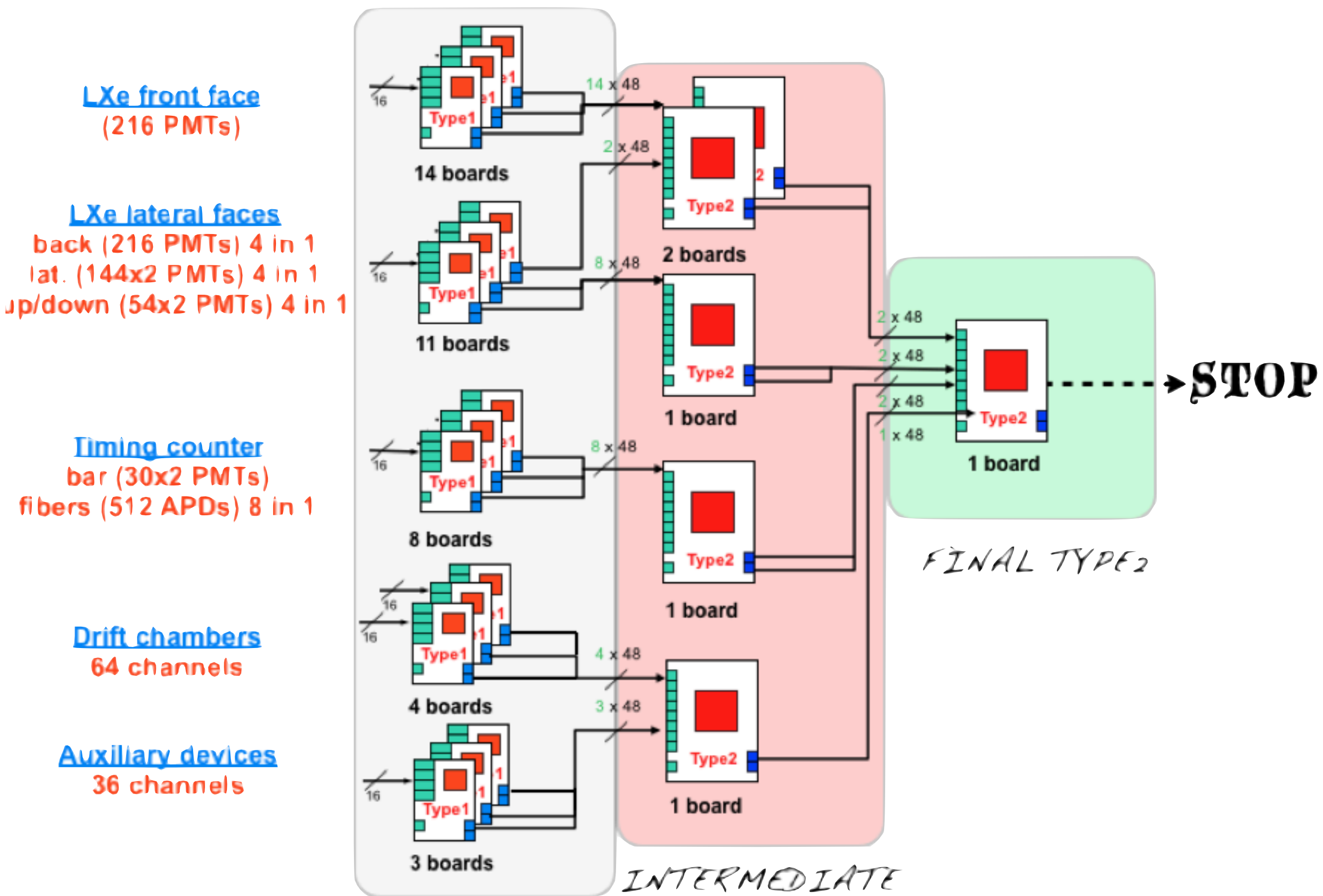
DRS chip (Domino Ring Sampler)

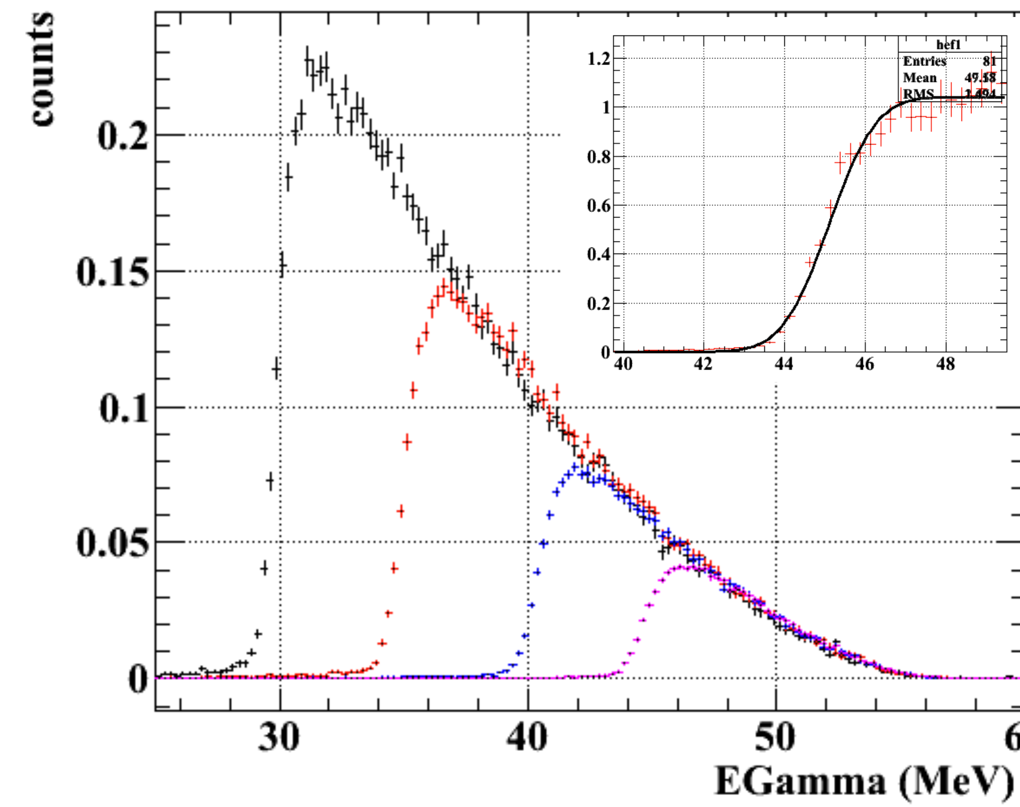
- Custom sampling chip designed at PSI (bw of 950 MHz)
- 0.2→5GHz sampling. →40 ps timing resolution
- Sampling depth 1024 bins for 9 channels/chip
- Full waveform is a handle to do pile-up rejection



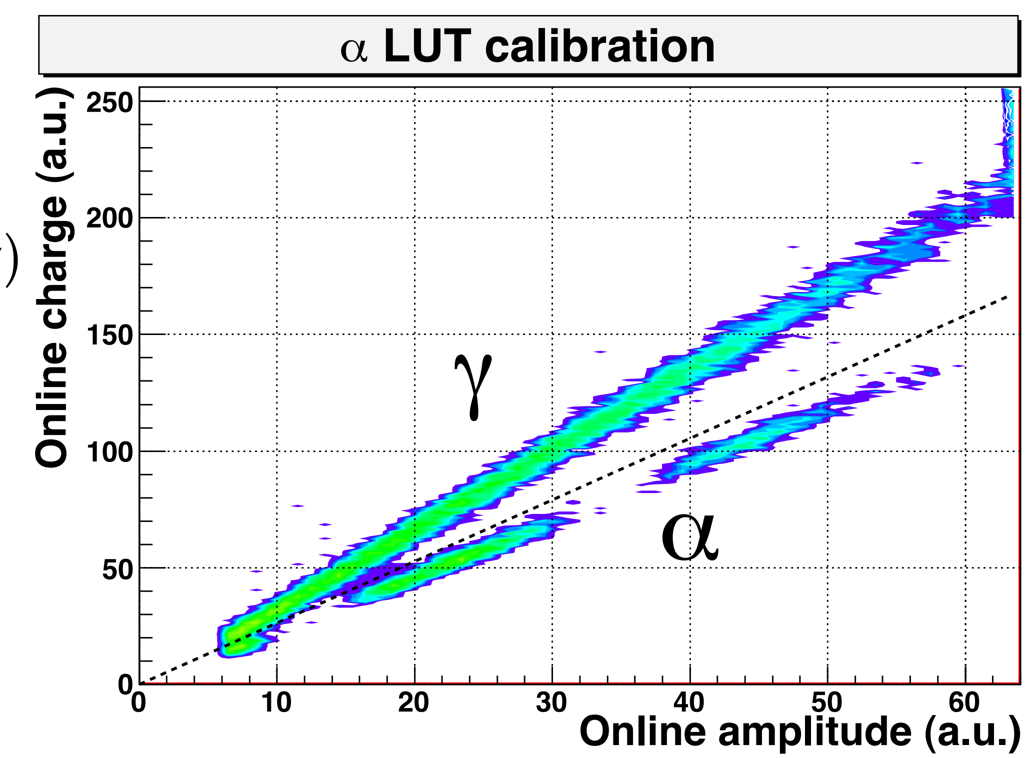
Trigger

- 100 MHz waveform digitizer on VME boards
  - perform online pedestal subtraction



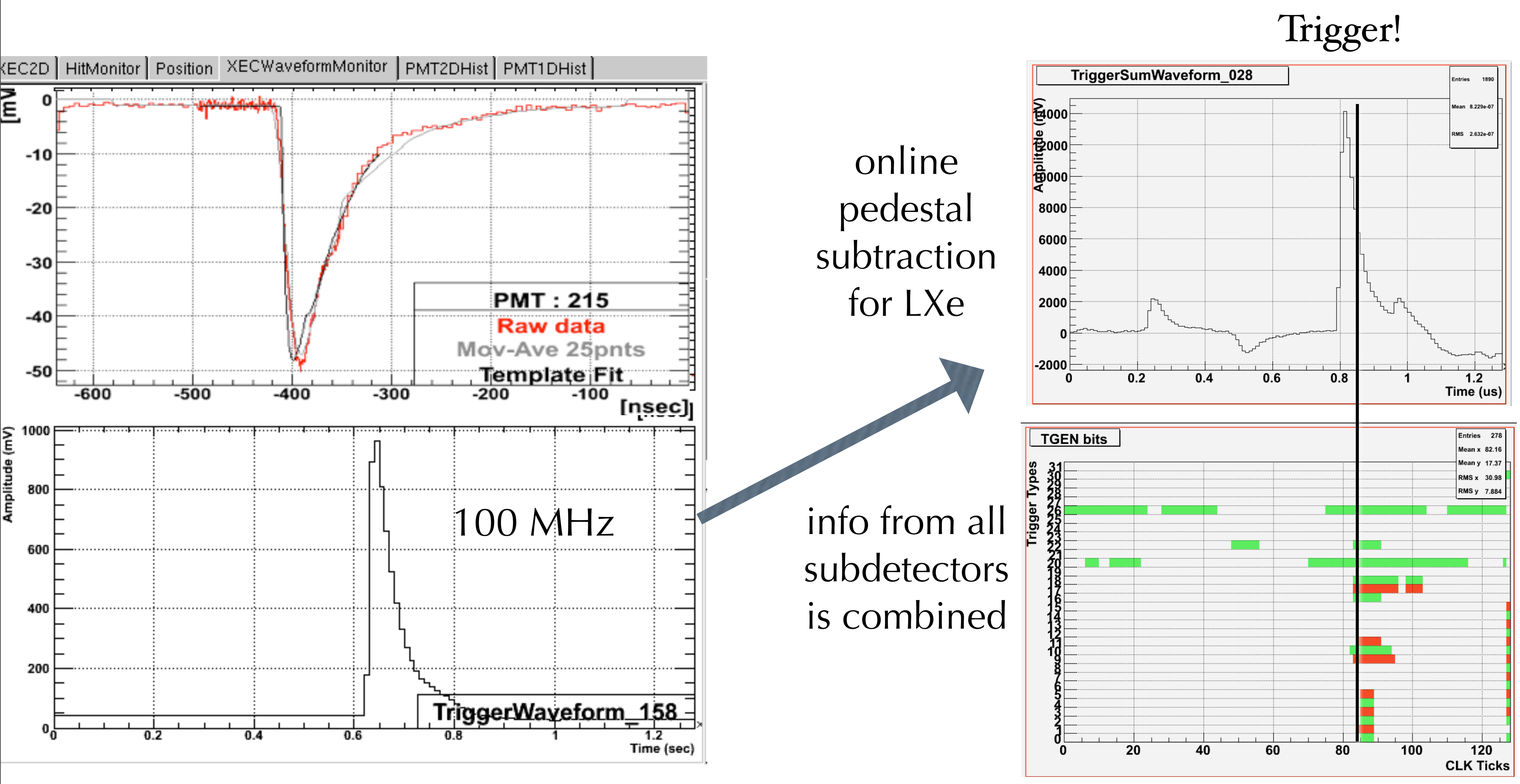


- Built on a FADC-FPGA architecture (500 ns latency)
  - γ energy, $e^+\gamma$ coincidence, $e^+\gamma$ collinearity
  - 2.5% resolution at the E_γ = 45 MeV threshold
  - Fully efficient on the signal region
- Complex algorithms implemented
  - online α/γ discrimination



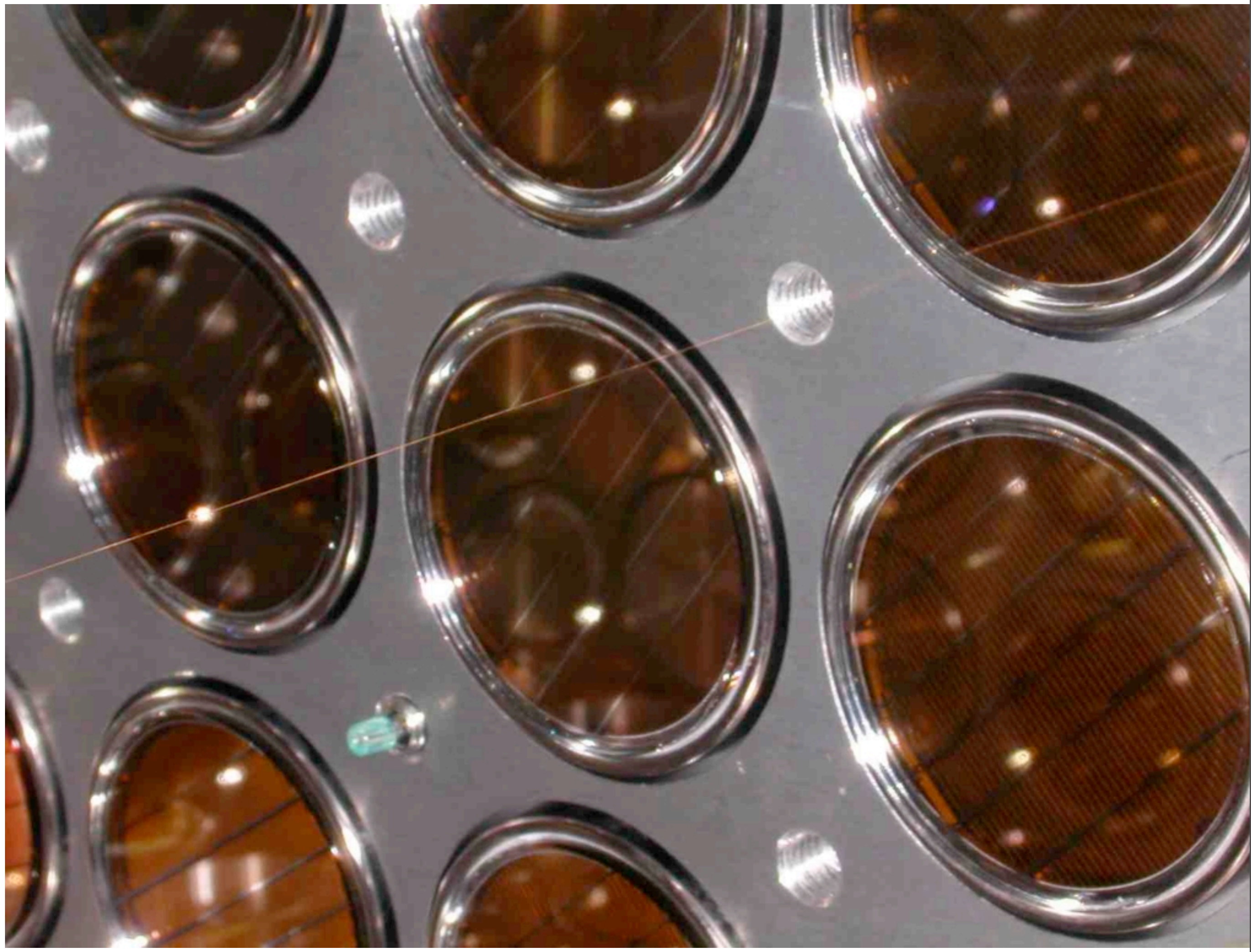
TRG + DAQ example

- For (almost) all channels, for each sub-detector we have two waveform digitizers with complementary characteristics



Calibrations

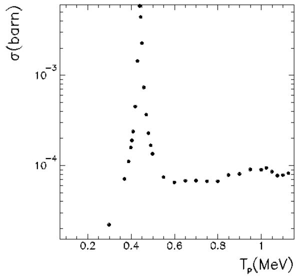
- It is understood that in such a complex detector a lot of parameters must be constantly checked
- We are prepared for redundant calibration and monitoring
- Single detector
  - PMT equalization for LXe and TIC
  - Inter-bar timing (TIC)
  - Energy scale
- Multiple detectors
  - relative timing

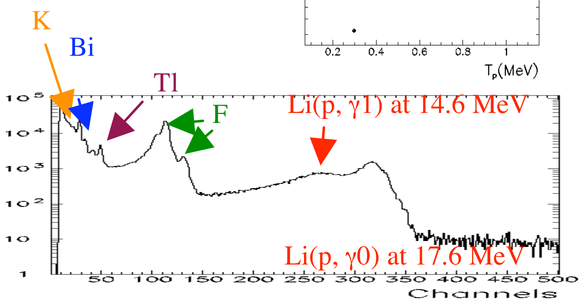


Calibrations

Xenon Calibration

Proton Accelerator





Li(p,γ)Be

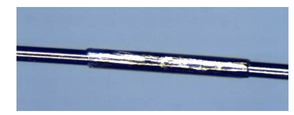
LiF target at COBRA center

17.6MeV γ

~daily calib.

also for initial setup

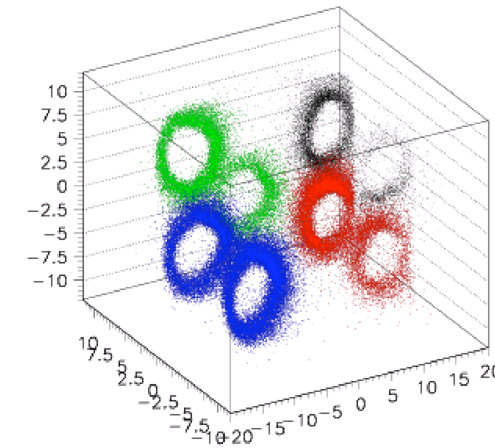
Alpha on wires



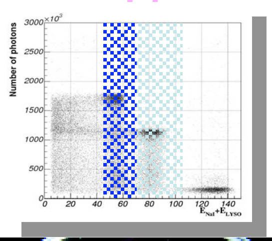
PMT QE & Att. L

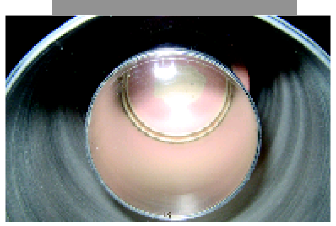
Cold GXe

LXe



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



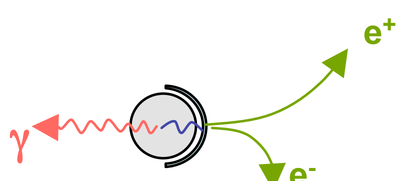


$\pi^- + p \rightarrow \pi^0 + n$

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

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

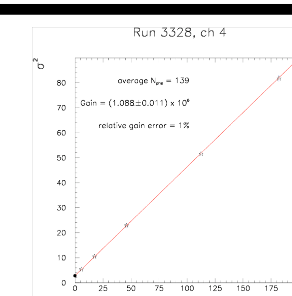
LH_2 target

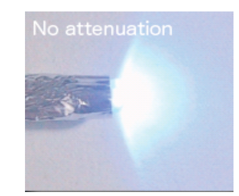


LED

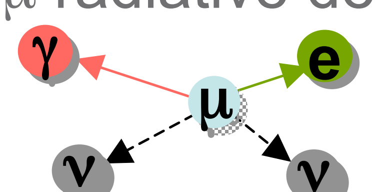
PMT Gain

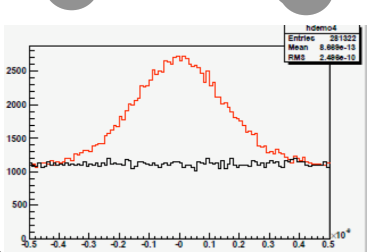
Higher V with light att.





μ radiative decay





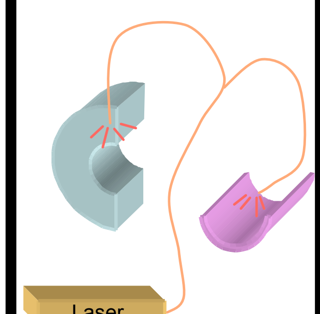
Lower beam intensity < 10^7

Is necessary to reduce pile-ups

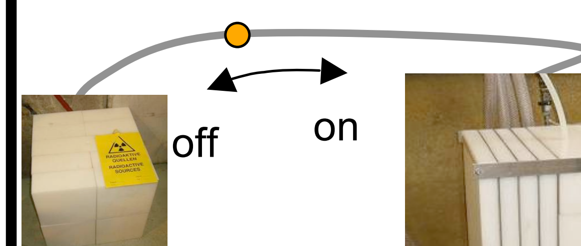
A few days ~ 1 week to get enough statistics

Laser

relative timing calib.



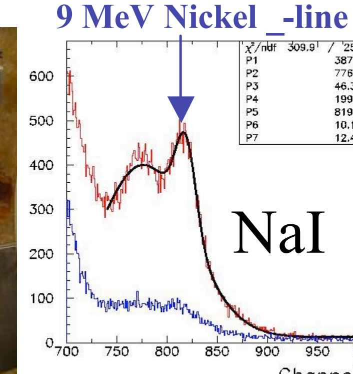
Nickel γ Generator



Illuminate Xe from the back

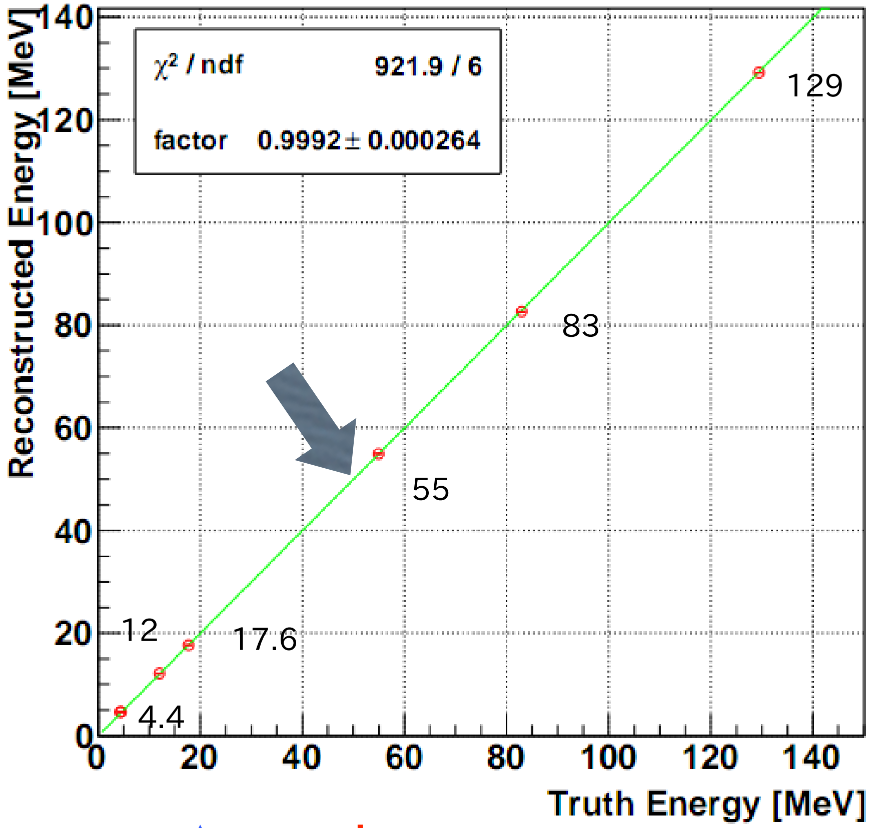
Source (Cf) transferred by comp air → on/off

9 MeV Nickel _-line

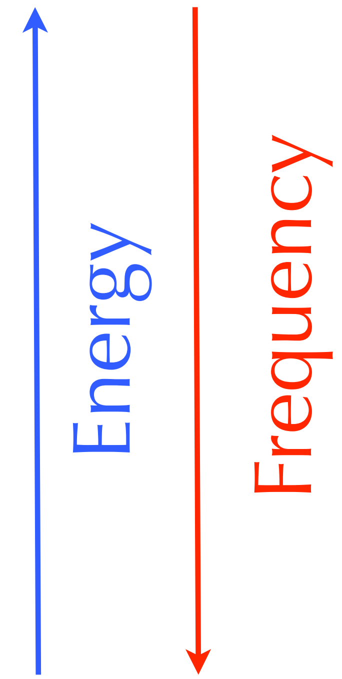


γ-energy scale calibration

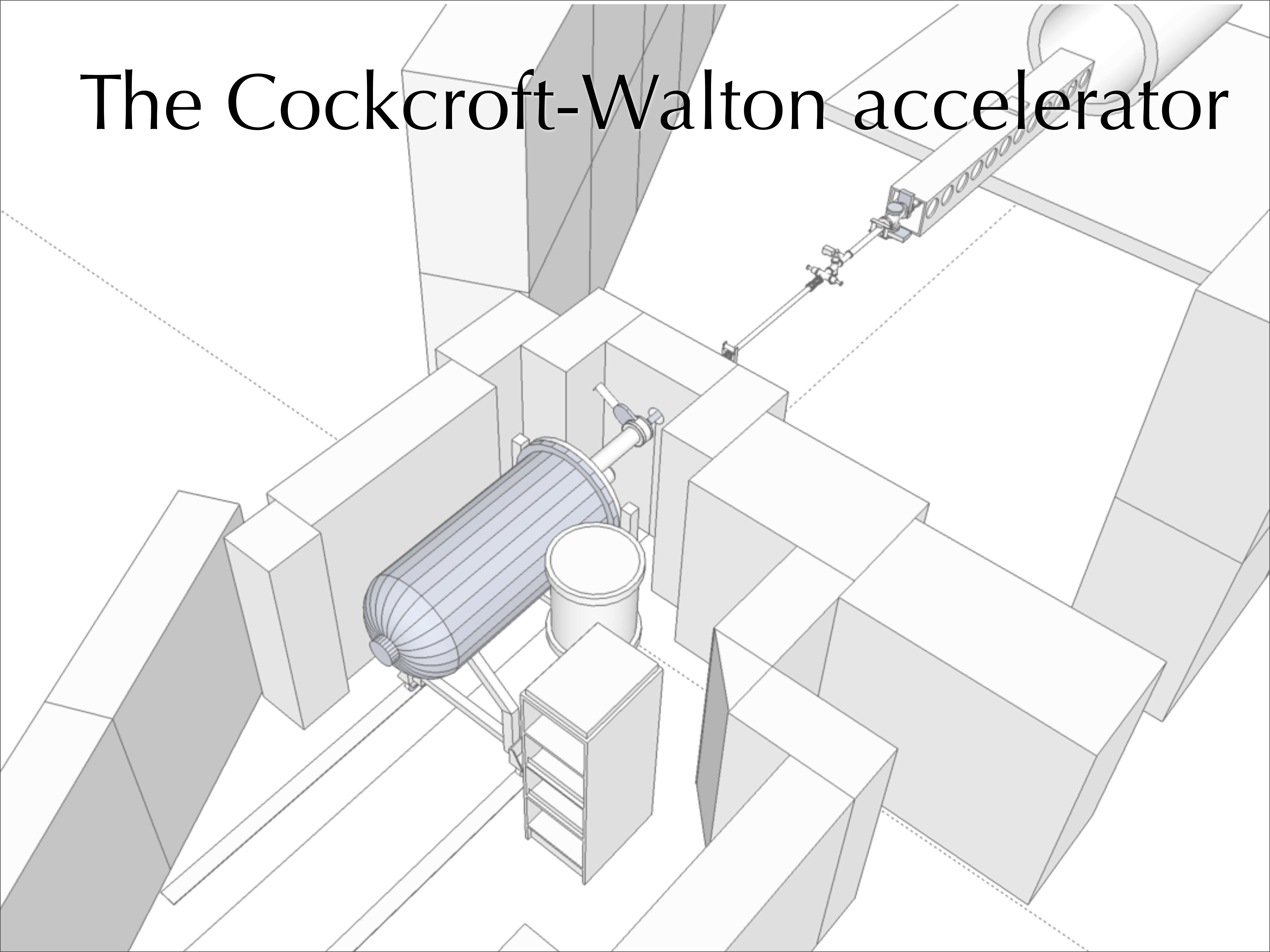
- The precise knowledge of the calorimeter energy scale is crucial for the experiment
- constant check of Xe light yield and purity
  - trigger threshold
  - systematic error on energy scale
- Different calibrations have different time-scales



Process		Energy	Frequency
Charge exchange	$\pi^- p \rightarrow \pi^0 n$ $\pi^0 \rightarrow \gamma\gamma$	55, 83, 129 MeV	year - month
Proton accelerator	$^7\mathrm{Li}(p,\gamma_{17.6})^8\mathrm{Be}$	14.8, 17.6 MeV	week
Nuclear reaction	$^{58}\mathrm{Ni}(n,\gamma_9)^{59}\mathrm{Ni}$	9 MeV	daily
Radioactive source	$^{60}\mathrm{Co}$, AmBe	1.1 -4.4 MeV	daily



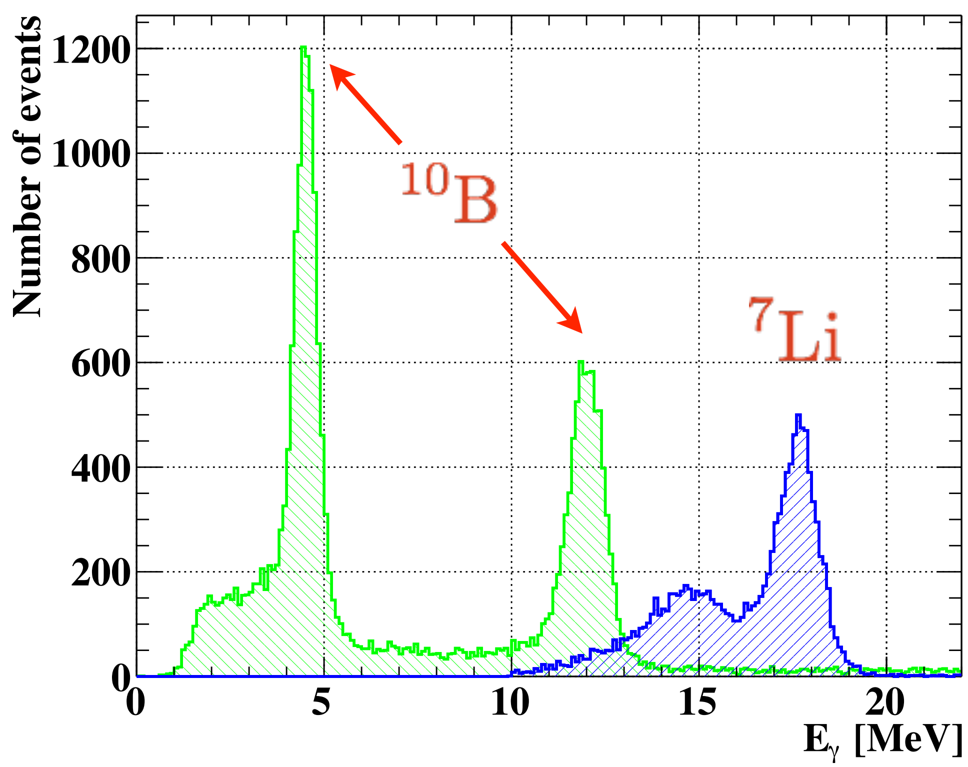
The Cockcroft-Walton accelerator

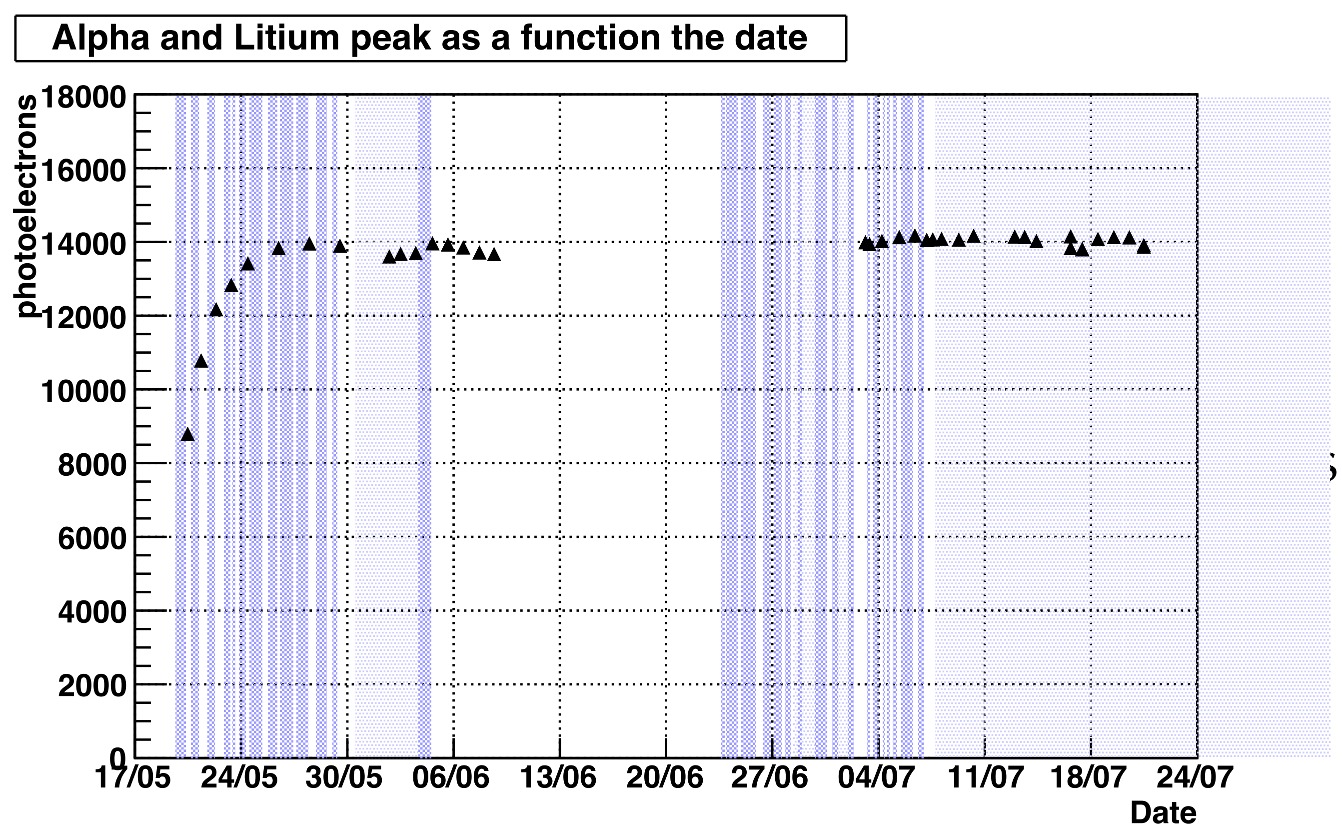


CW - daily calibration

- 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

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





liquid phase purification

gas phase purification

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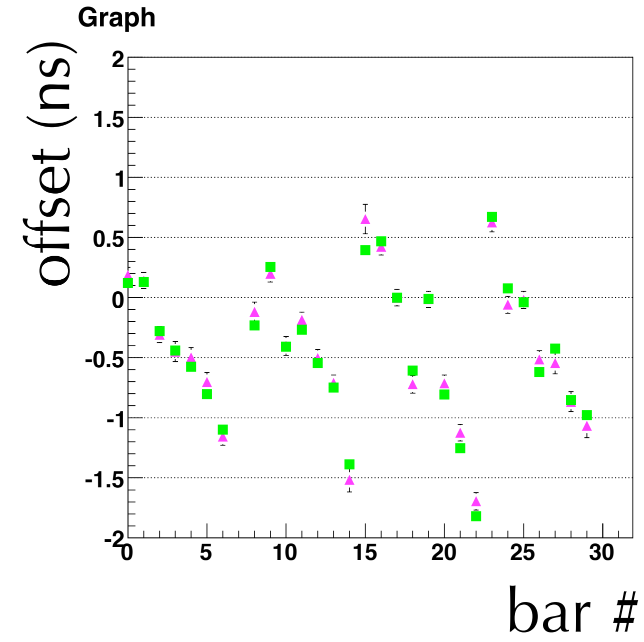

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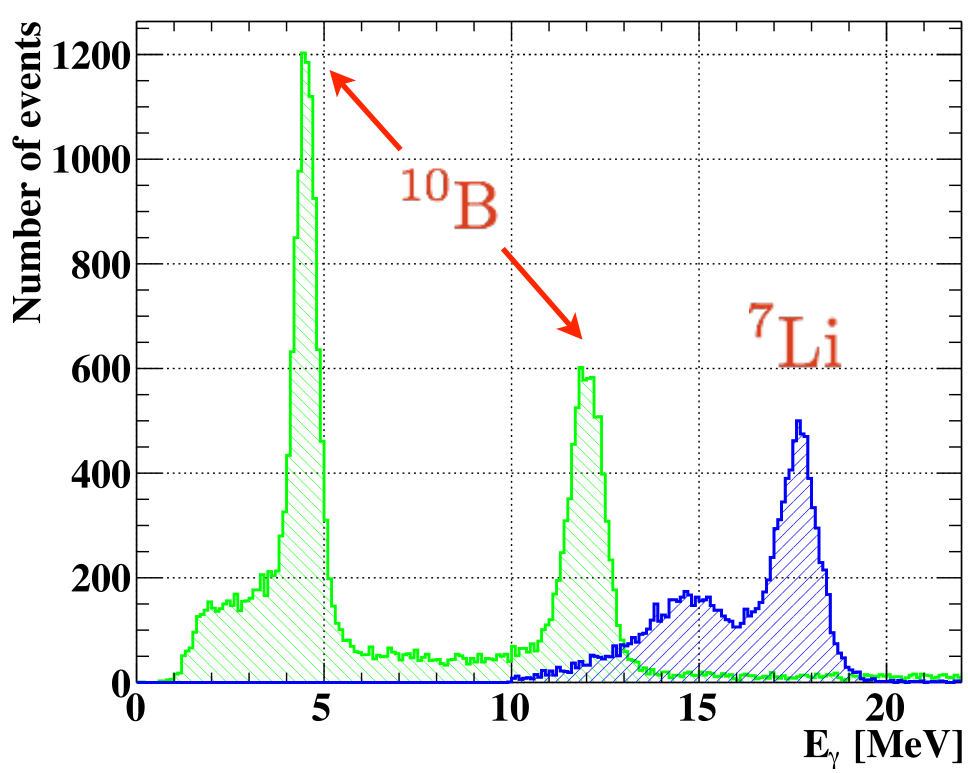

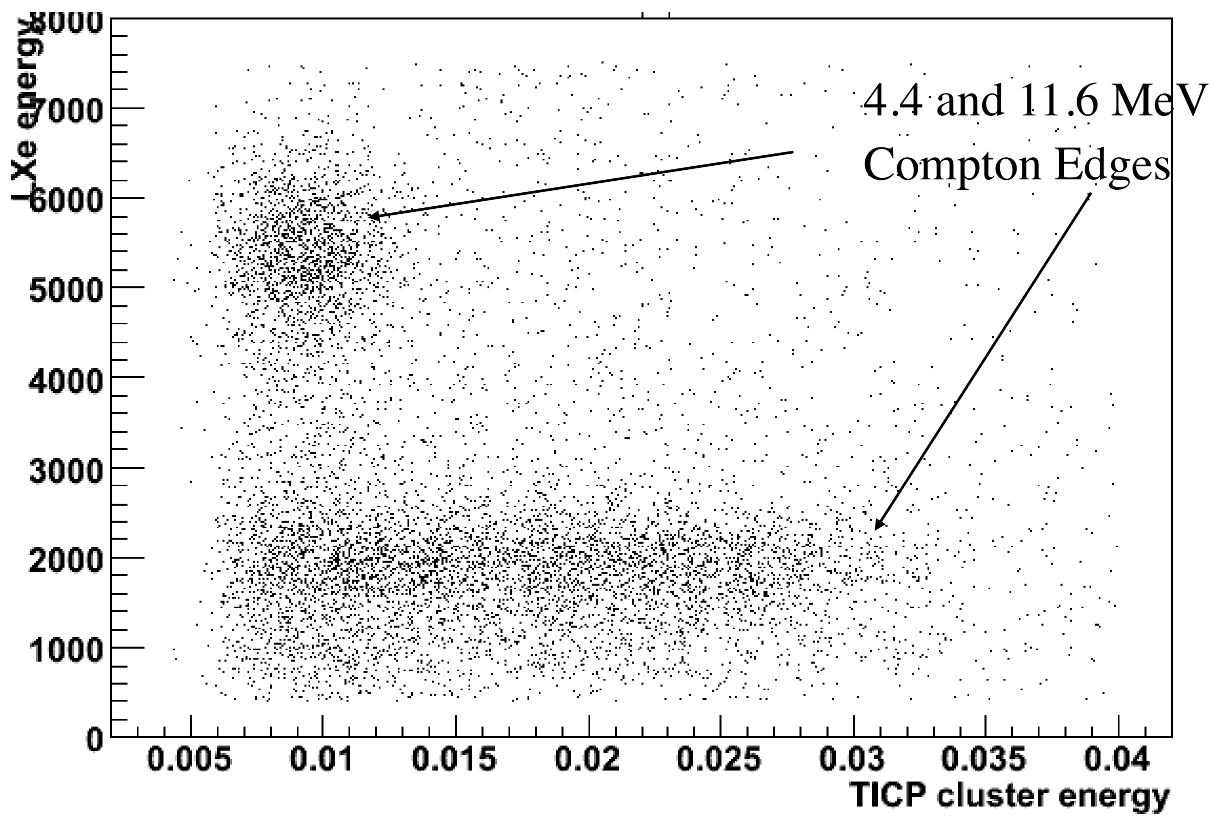

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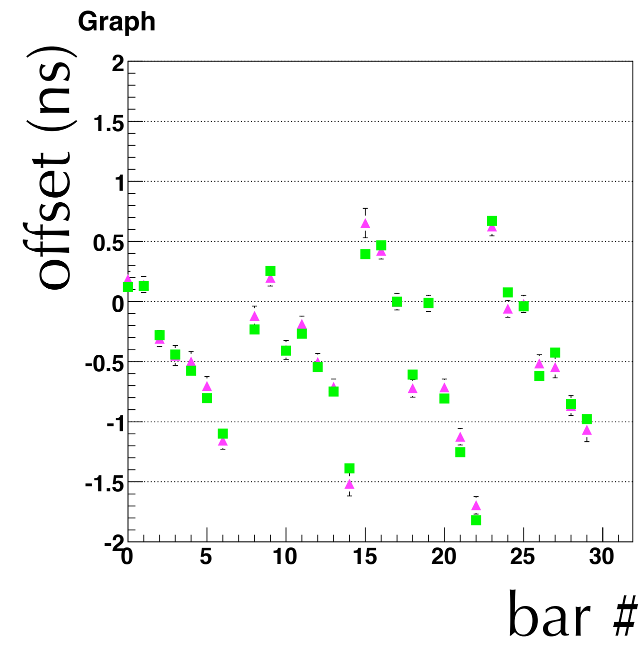

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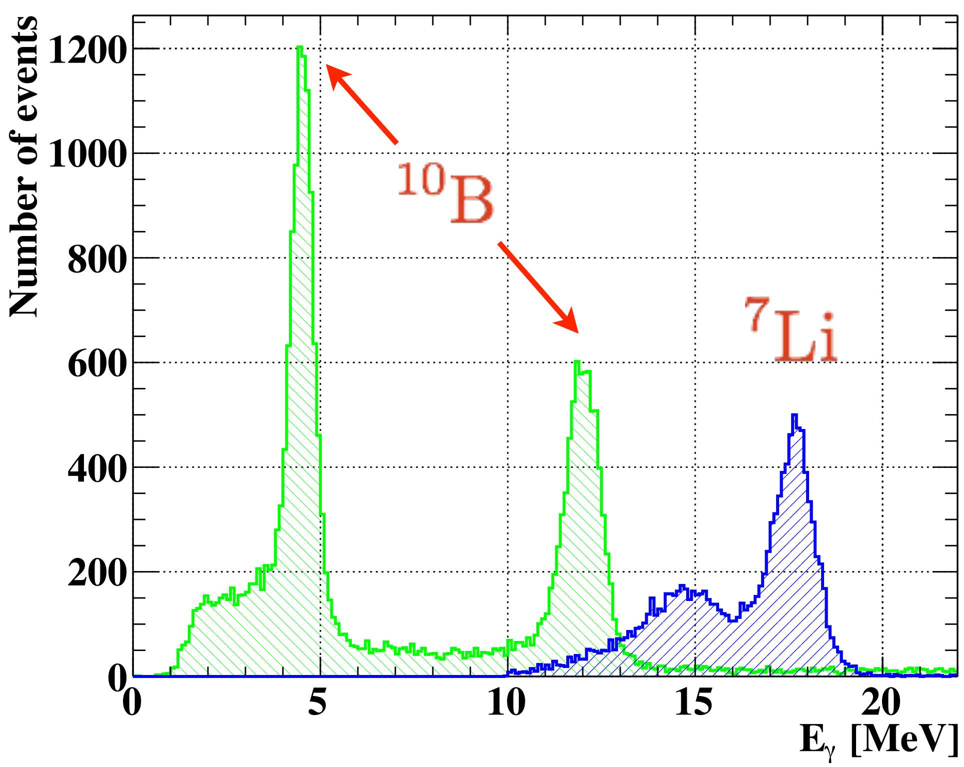
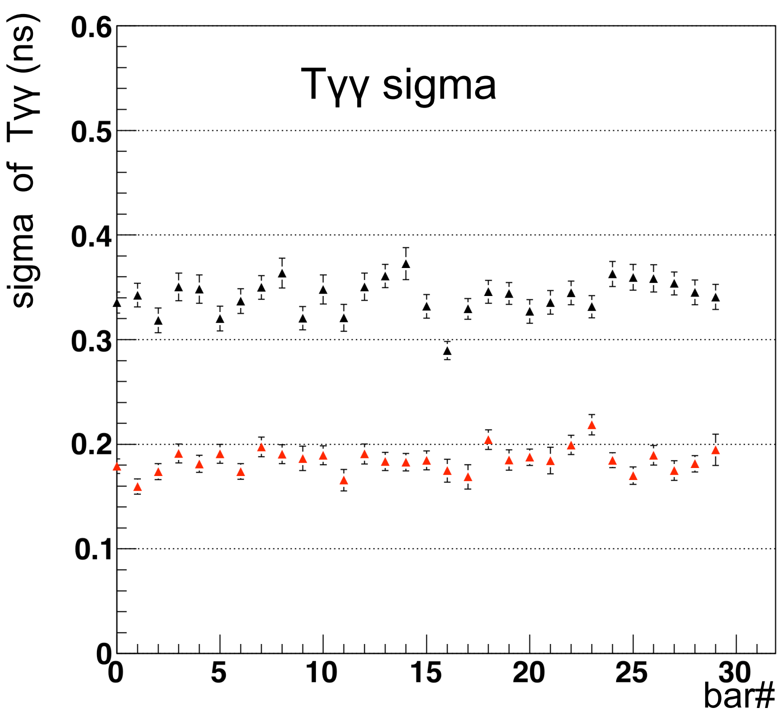




2009: efficient physics run

- 2008 run BR<2.8 x 10^{-11}
Nucl. Phys. B834, 1–12 (Apr. 2010)

January - October

- detector dismantling
- improvement (after run 2008)
  - -DCH
  - -Electronic
- re – installation
- LXe purification
- CW calibration
- another experiment in the area had "exciting results" (μp)

October

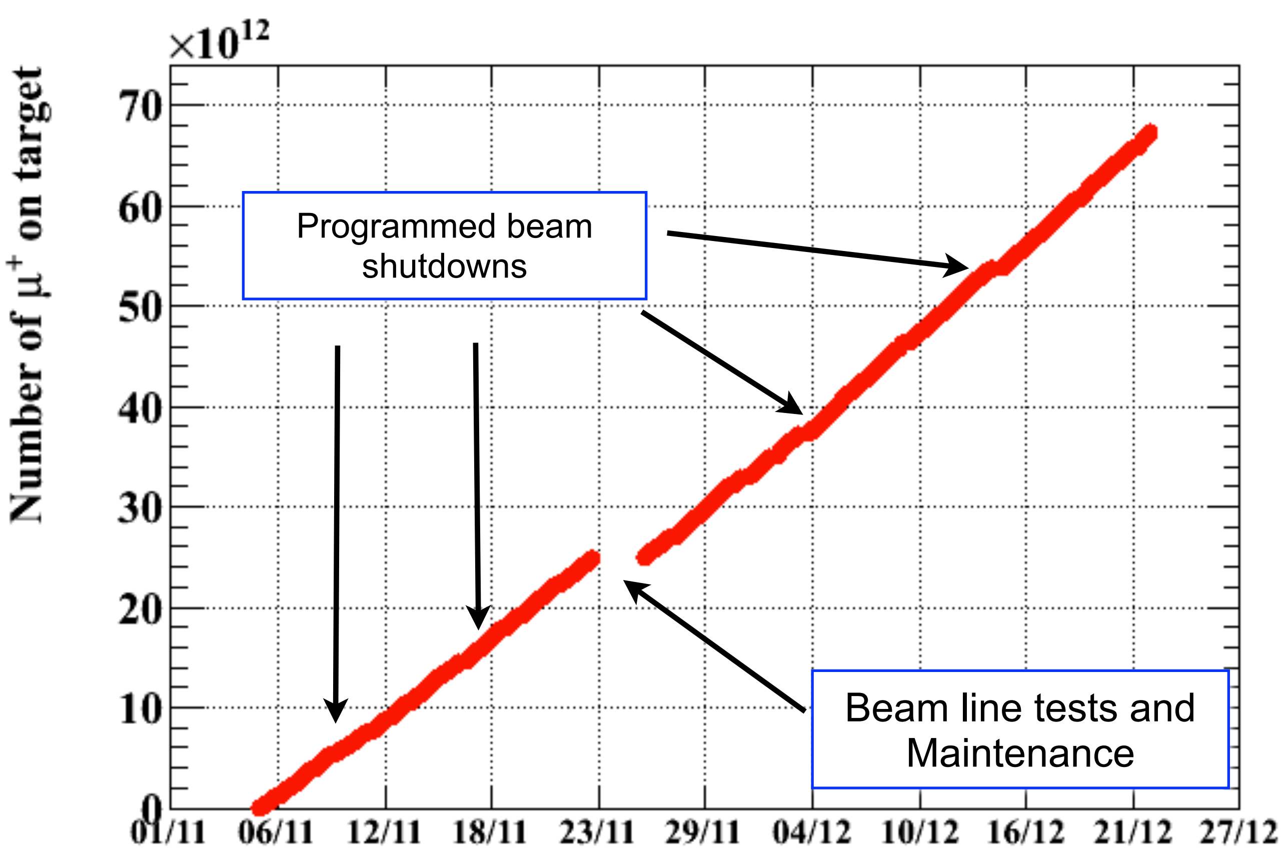
- π^o calibration

November – December

- MEG run

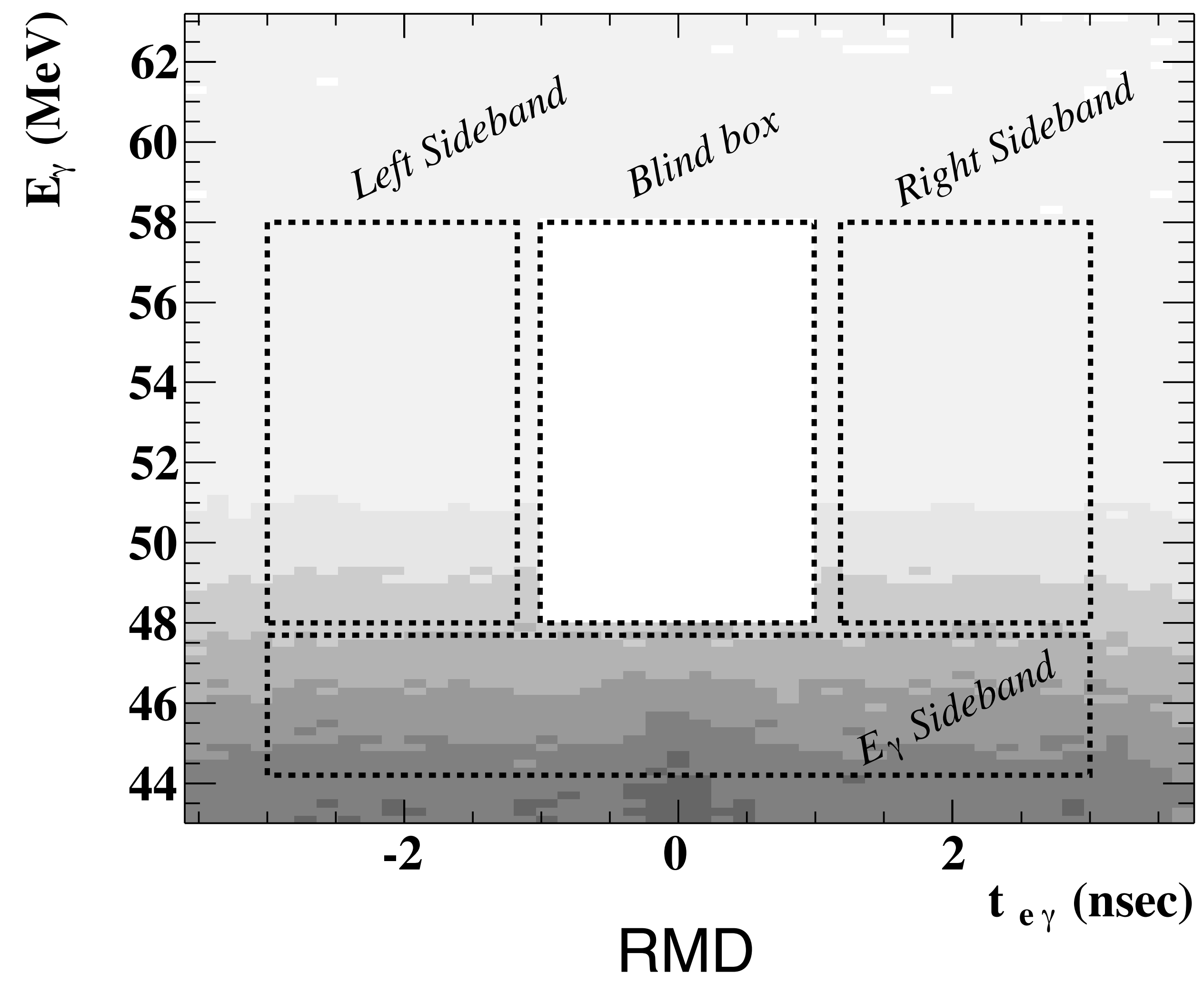
Running conditions
MEG run period

- Live time ~84% of total time
- Total time ~ 7 weeks
- μ stop rate: 3×10^7 μ/s
- Trigger rate 6.5 ev/s ;
- Total data taken: 93 TB



Analysis principle

- We decided to adopt a blind-box likelihood analysis strategy
- The blinding variables are E_γ and $t_{e\gamma}$
  - Hidden until analysis is fixed
- Three independent analyses
  - different *pdf* implementation
  - Fit or input N_{RMD}, N_{BG}
  - Different statistical treatment (Freq. or Bayes)
- Use of the sidebands
  - our main background comes from accidental coincidences
  - RMD can be studied in the low E_γ sideband



Analysis principle

- A μ→eγ event is described by 5 kinematical variables

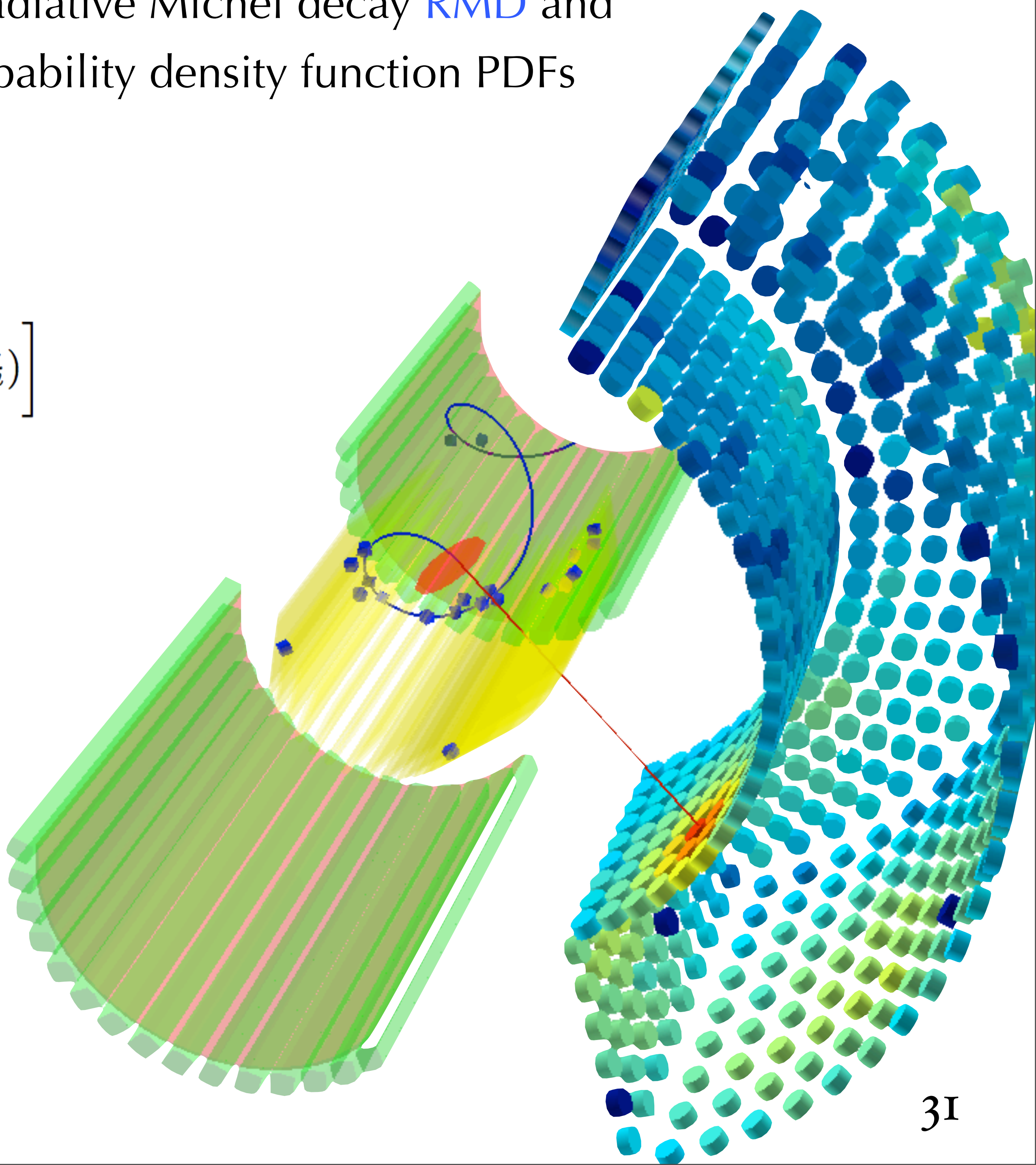
$$\vec{x_i} = (E_\gamma, E_e, t_{e\gamma}, \theta_{e\gamma}, \phi_{e\gamma})$$

- Likelihood function is built in terms of Signal, radiative Michel decay RMD and background BG number of events and their probability density function PDFs

$$
\begin{aligned}
& -\ln \mathcal{L}\left(N_{\mathrm{sig}}, N_{\mathrm{RMD}}, N_{\mathrm{BG}}\right) \\
& \;= \; N_{\mathrm{exp}} - N_{\mathrm{obs}} \ln\left(N_{\mathrm{exp}}\right) \\
& \quad - \sum_{i=1}^{N_{\mathrm{obs}}} \ln\left[\frac{N_{\mathrm{sig}}}{N_{\mathrm{exp}}} S(\vec{x_i}) + \frac{N_{\mathrm{RMD}}}{N_{\mathrm{exp}}} R(\vec{x_i}) + \frac{N_{\mathrm{BG}}}{N_{\mathrm{exp}}} B(\vec{x_i})\right]
\end{aligned}
$$

- Extended unbinned likelihood fit
  - fit (N_{sig}, N_{RMD}, N_{BG}) in a wide region
- PDFs taken from
  - data
  - MC tuned on data

• $48 \le E_\gamma \le 58$ MeV
• $50 \le E_e \le 56$ MeV
• $|T_{e\gamma}| \le 0.7$ ns
• $|\phi_{e\gamma}|, |\theta_{e\gamma}| \le 50$ mrad



Probability Density Functions

- SIGNAL

  E_γ: from full signal MC (or from fit to endpoint)
  E_e: 3-gaussian fit on data
  $\theta_{e\gamma}$: combination of e and gamma angular resolution from data
  $t_{e\gamma}$: single gaussian from MEG trigger Radiative Decay (no cut on Eg)

- RADIATIVE

  $E_e, E_\gamma, \theta_{e\gamma}$: 3D histo PDF from toy MC that smears and weighs Kuno-Okada distribution taking into account resolution and acceptance
  $t_{e\gamma}$: single gaussian with same resolution as signal

- ACCIDENTAL

  E_γ: from fit to $t_{e\gamma}$ sideband
  E_e: from data
  $\theta_{e\gamma}$: from fit to $t_{e\gamma}$ sideband
  $t_{e\gamma}$: flat

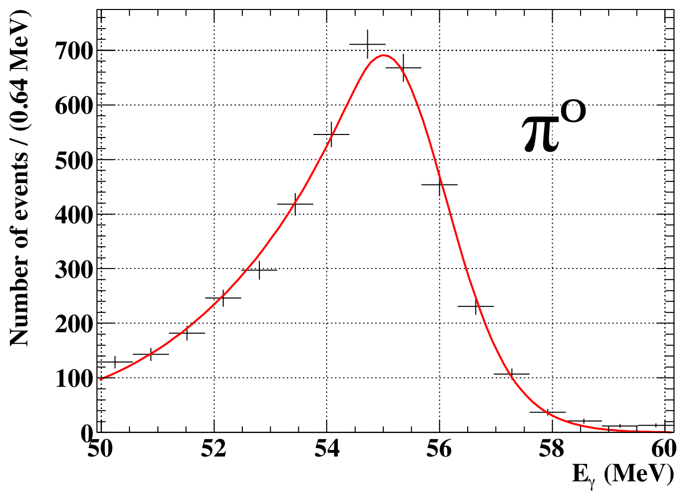
Alternative observables definition

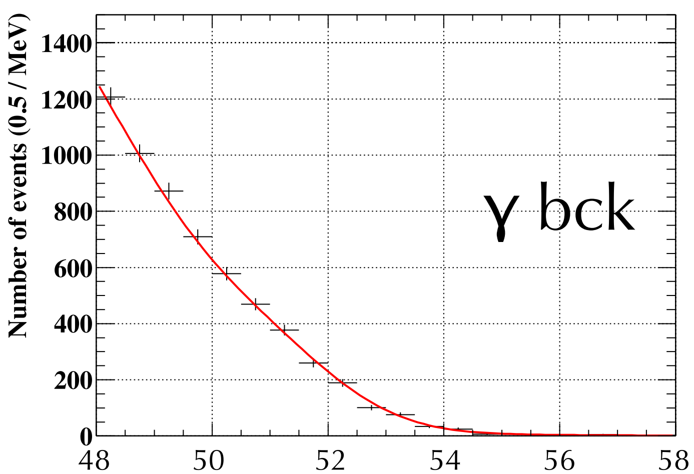
1) different algorithm for LXe Timing

2) Trigger LXe waveform digitizing electronics (E_γ)

Pdfs and resolutions

E_γ

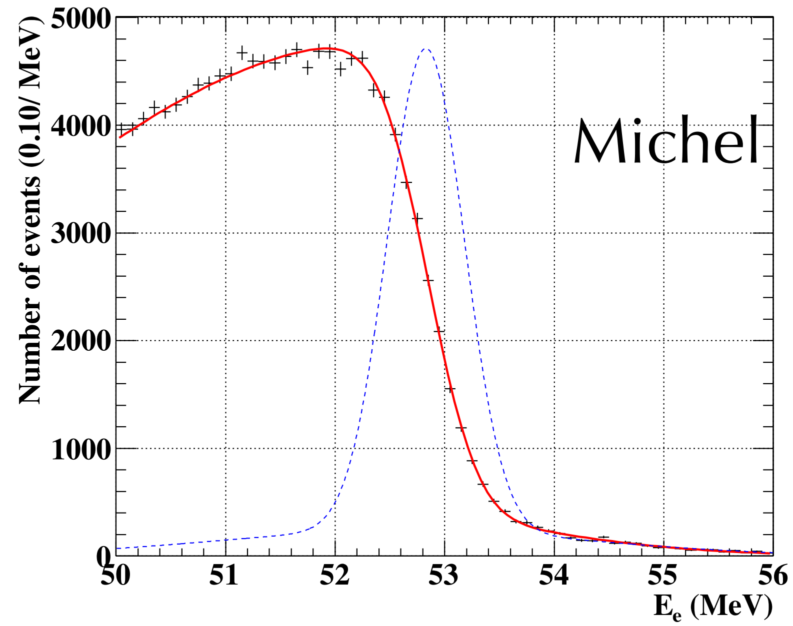




- Average upper tail for deep conversions
  - σ_R = (2.1 ± 0.15) %
- Systematic uncertainty on energy scale < 0.6%

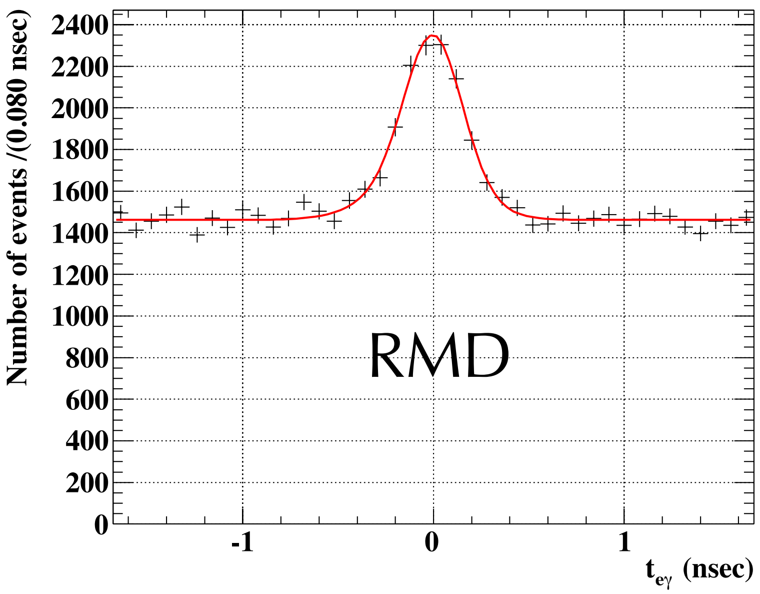
E_{e^+}

- Resolution functions of core and tail components
  - core = 390 keV (0.74%)
- Positron angle resolution measured using multi-loop tracks
  - $\sigma(\varphi)$ = 7.1 mrad (core)
  - $\sigma(\vartheta)$ = 11.2 mrad



- Overall angular resolution combining
  - XEC+DCH+target
    - $\sigma(\varphi)$ = 12.7 mrad (core)
    - $\sigma(\vartheta)$ = 14.7 mrad

$t_{e\gamma}$



- 40 MeV < E_γ < 48 MeV
- σ_t is corrected for a small energy-dependence
  - (142 ± 15) ps
  - stable within 15 ps along the run
- MEGA had on RMD
  - 700 ps resolution

Normalization

- The normalization factor is obtained from the number of observed Michel positrons taken simultaneously (pre-scaled) with the μ→eγ trigger
- Cancel at first order
  - Absolute e+ efficiency and DCH instability
  - Instantaneous beam rate variations

O(1)

$$\frac{\mathcal{B}(\mu^+ \to e^+\gamma)}{\mathcal{B}(\mu^+ \to e^+\nu\bar{\nu})} = \frac{N_{\rm sig}}{N_{e\nu\bar{\nu}}} \times \frac{f^e_{e\nu\bar{\nu}}}{P \cdot \epsilon_{\rm pu}} \times \frac{\epsilon^{\rm trig}_{e\nu\bar{\nu}}}{\epsilon^{\rm trig}_{e\gamma}} \times \frac{\epsilon^{\rm DC}_{e\nu\bar{\nu}}}{\epsilon^{\rm DC}_{e\gamma}} \times \frac{1}{A^{\rm geo}_{e\gamma}} \times \frac{1}{\epsilon_{e\gamma}}$$

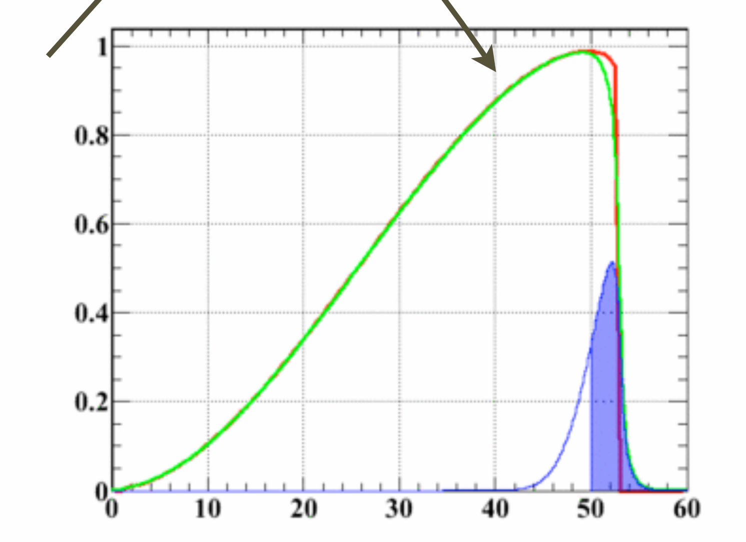
~18k

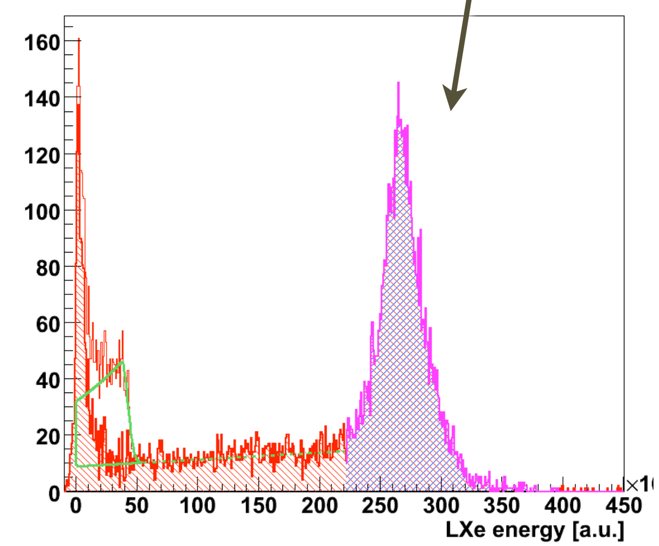
10^7

theory

resolution

acceptance

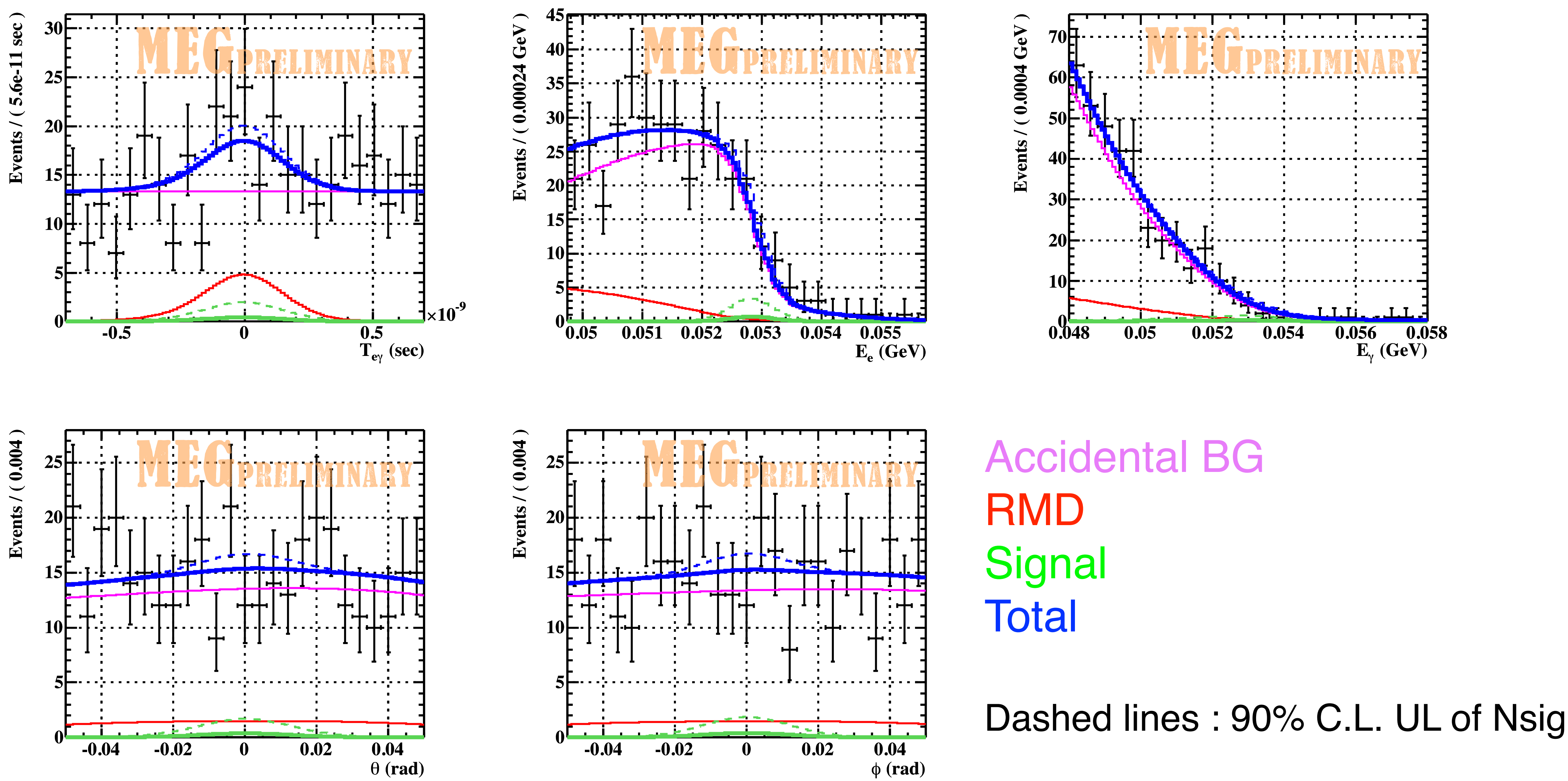




B.R. = $N_{\rm sig}$ x (1.01 ± 0.08) × 10^{-12}

Likelihood fit result

- N_{sig} < 14.5 @ 90% C.L., N_{sig} best–fit value = 3.0
- N_{sig} = 0 is in 90% confidence region
  - C.L @0: 40÷60% depending on the statistical approach



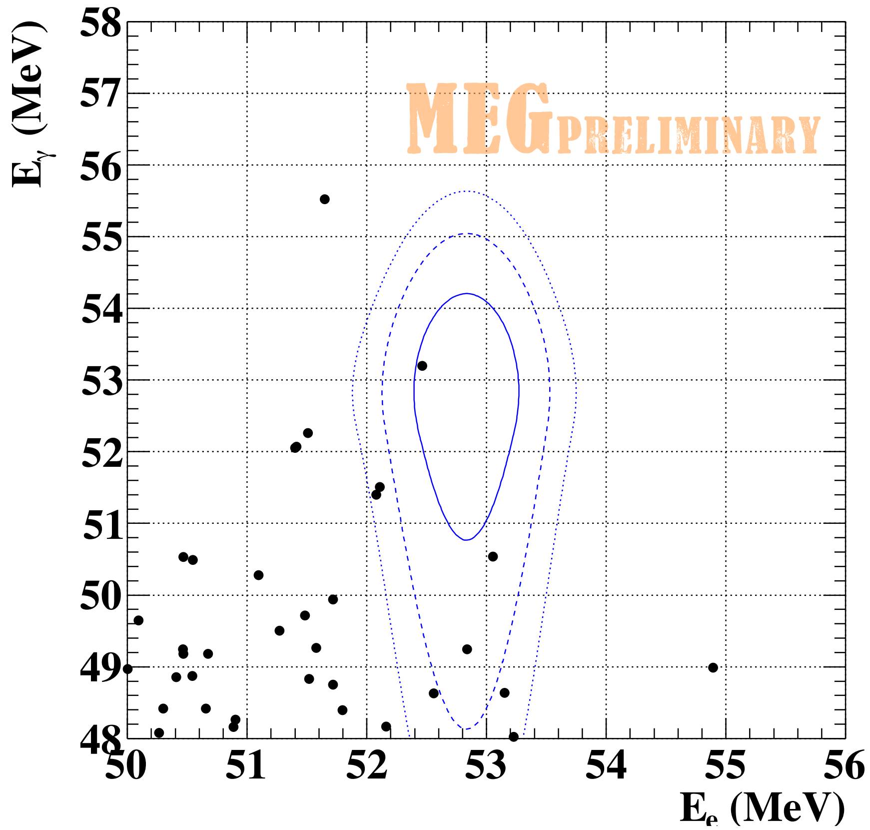
Fitting was done by three groups with different parametrization, analysis window and statistical approaches, and confirmed to be consistent (Nsig best fit = 3.0-4.5, UL = 1.2-1.5×10^{-11})

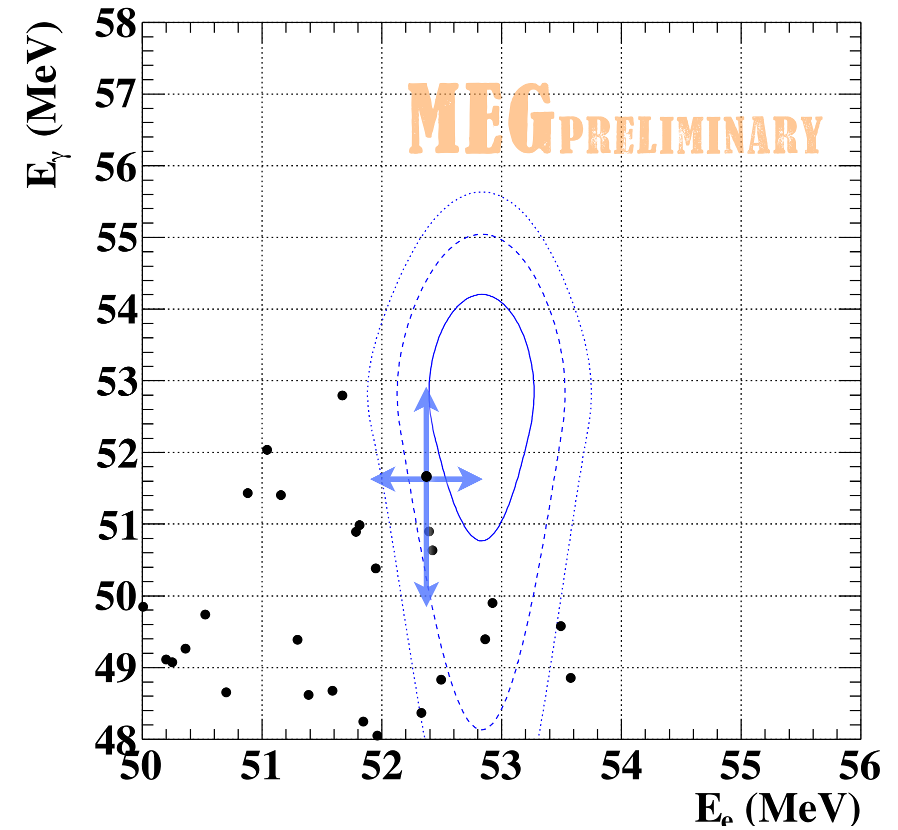
Sensitivity

- Computed as the average 90% upper limit on toy experiments
  - no signal assumption
  - 6.1×10^{-12}

- Consistent with the likelihood analysis performed on the sidebands
  - $t_{e\gamma} = \pm 1.7$ ns
  - BR < $(4 \div 6) \times 10^{-12}$

Sidebands





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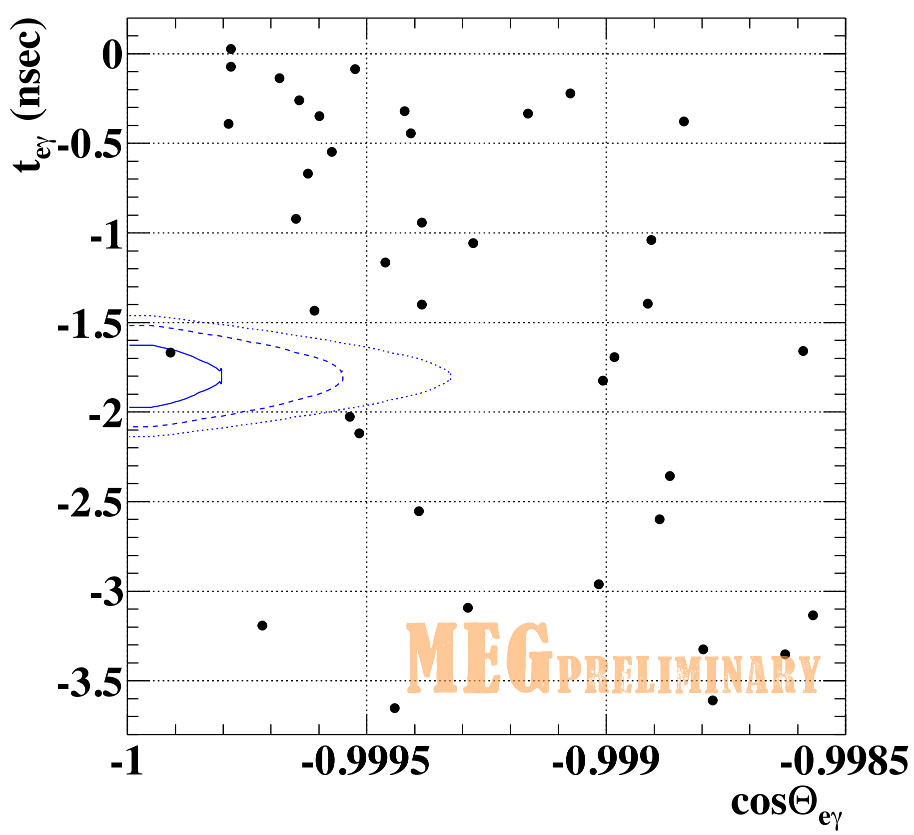
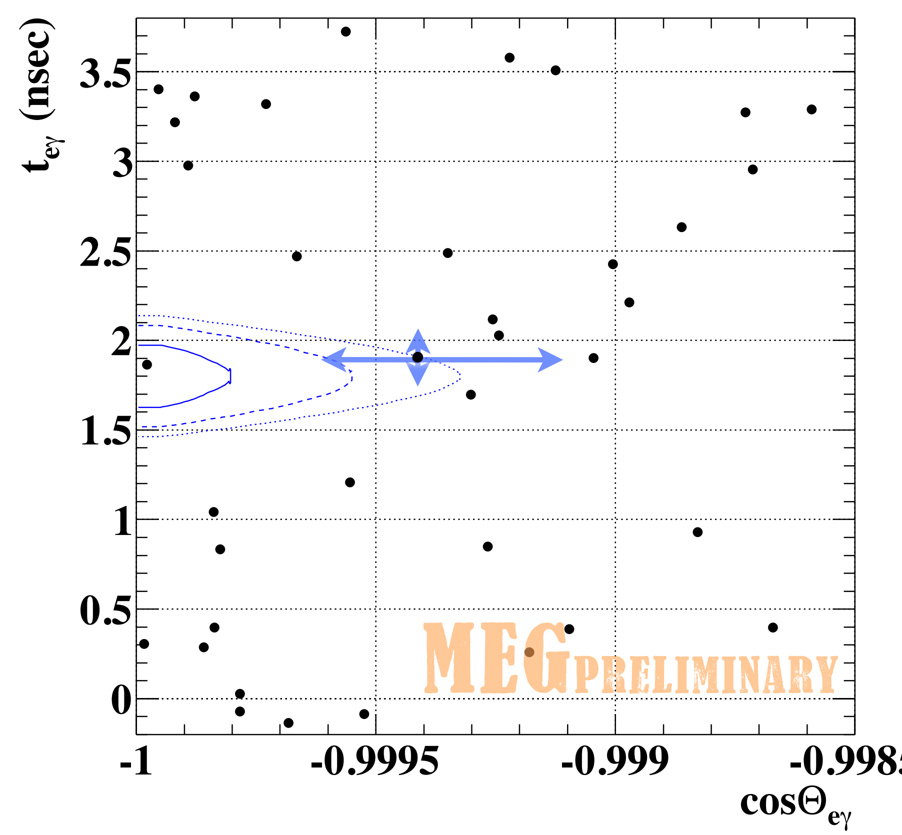
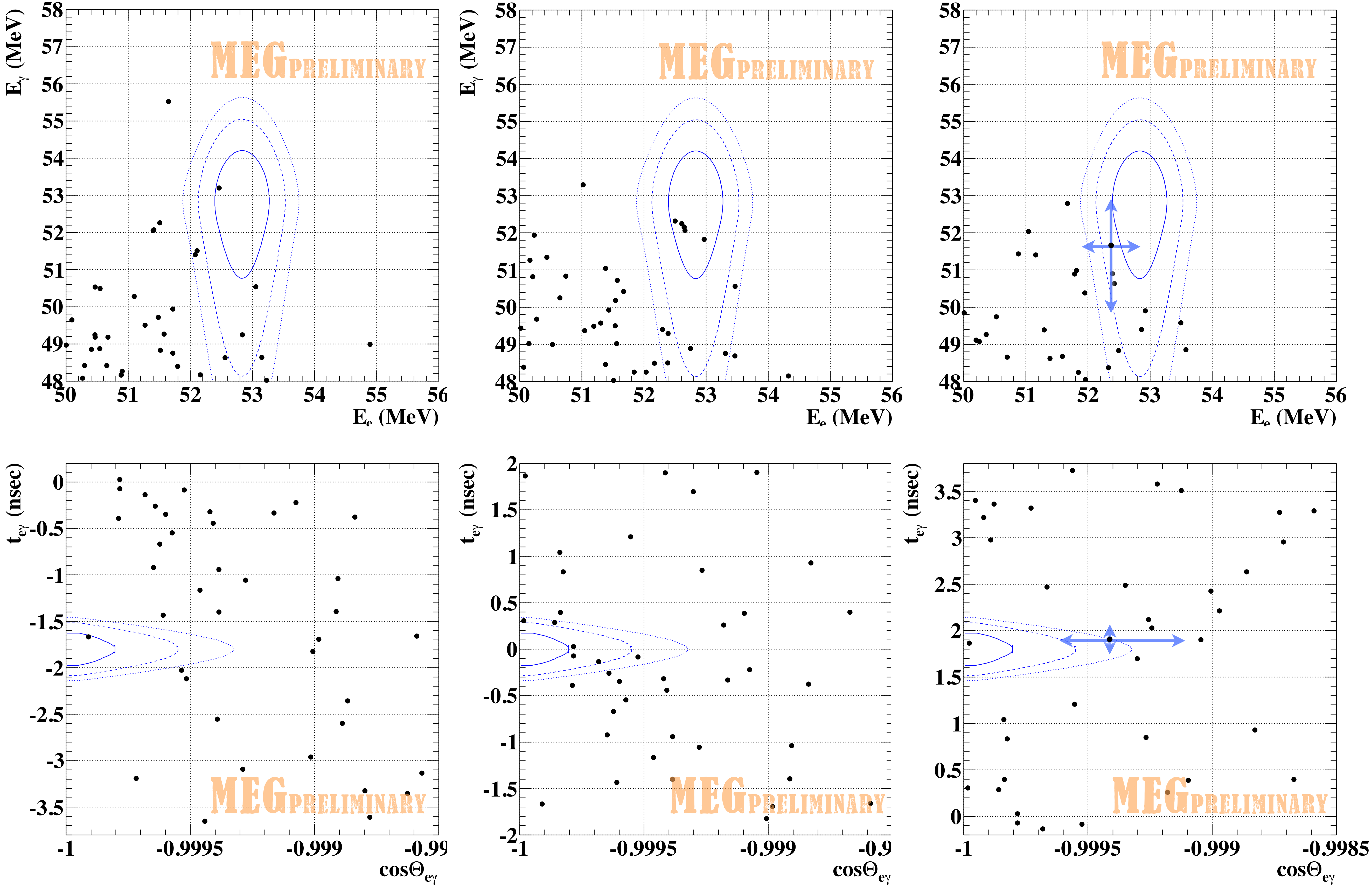




- Consistent with the likelihood analysis performed on the sidebands
  - $t_{e\gamma} = \pm 1.7$ ns
  - $BR < (4 \div 6) \times 10^{-12}$

Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.
For each plot, cut on other variables for roughly 90% window is applied.

Open blind box



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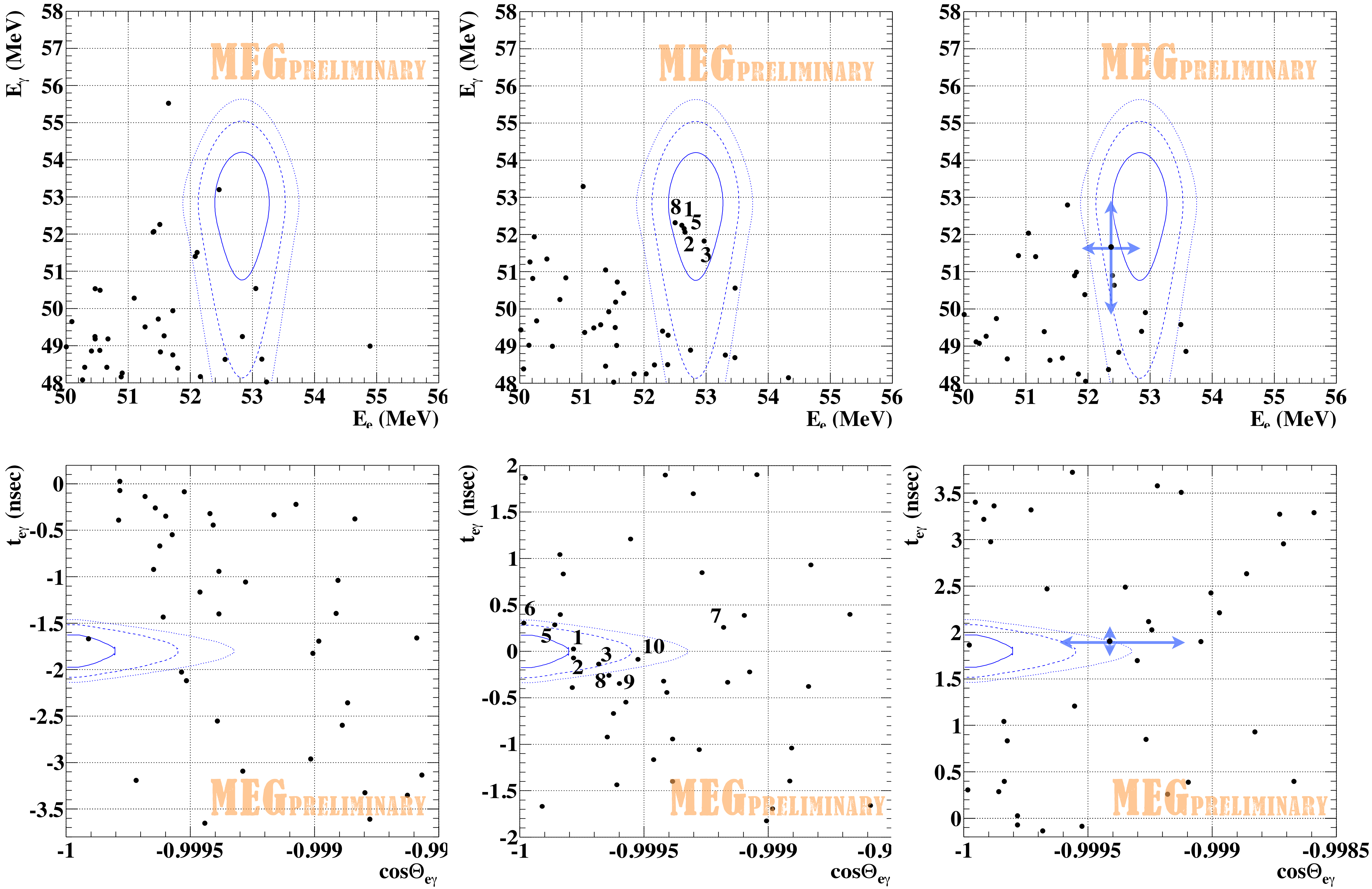

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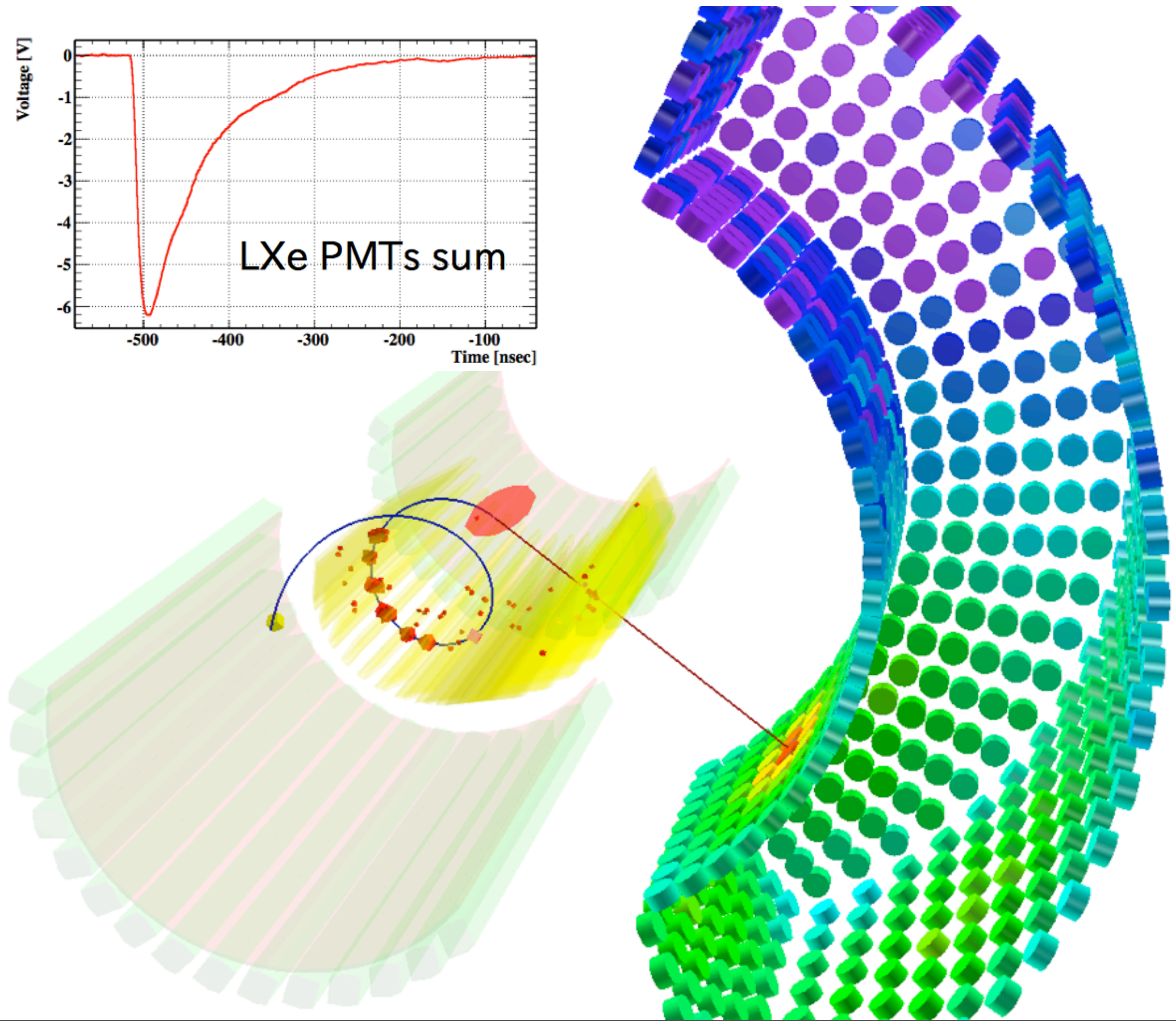
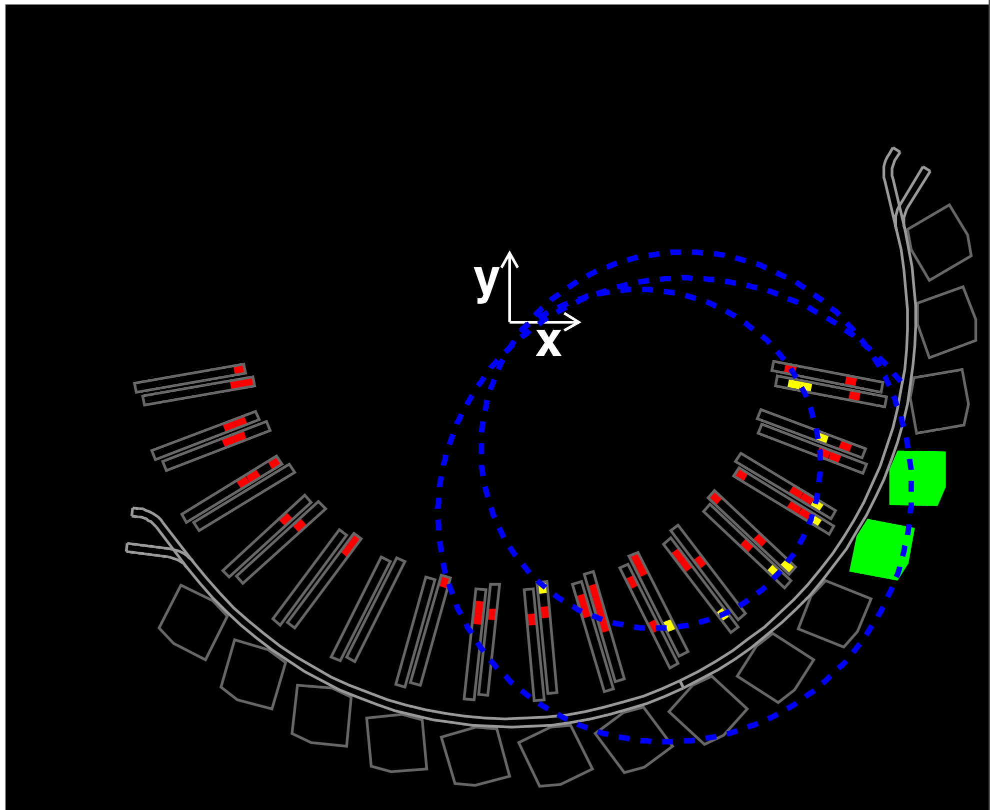
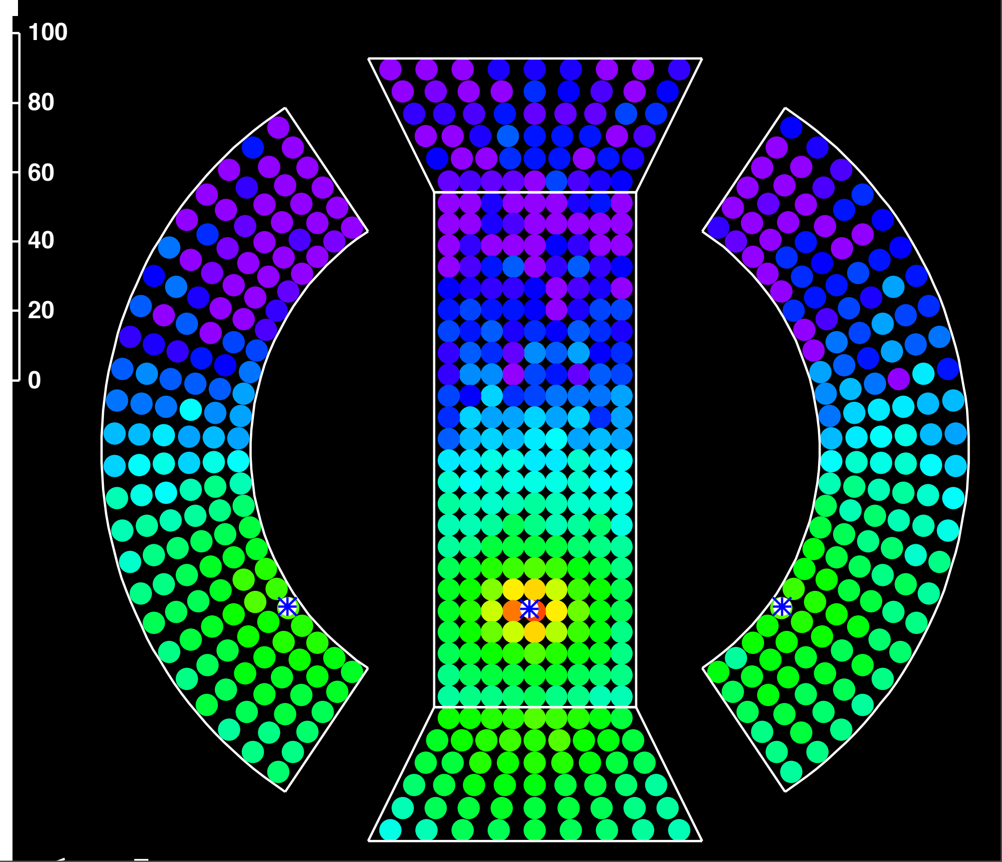
For each plot, cut on other variables for roughly 90% window is applied.

Event display

- Events in the signal region were checked carefully
- An event in the signal region







Systematic uncertainties

- The effect of systematics is taken into account in the calculation of the confidence region by fluctuating the *pdfs* according to the uncertainty values

	Uncertainty	
Normalization	8%	P_{e+} ε_γ ε_{TRG}
E_γ scale	0.4%	Light yield stability, gain shift
E_γ resolution	7%	
E_e scale	50 keV	from Michel edge
E_e resolution	15%	
$t_{e\gamma}$ center	15 ps	
$t_{e\gamma}$ resolution	10%	RMD peak
Angle	7.5 mrad	Tracking + LXe position
Angular resolution	10%	
E_e–φ_e correlation	50%	MC evaluation

- overall effect of systematics: $\Delta N_{sig} \sim 1$

Upper limit

- From the analysis of the 2009 data our limit on the BR is the following:

Preliminary

$$\frac{\mathcal{B}(\mu^+ \to e^+\gamma)}{\mathcal{B}(\mu^+ \to e^+\nu\bar{\nu})} < 1.5 \times 10^{-11}$$

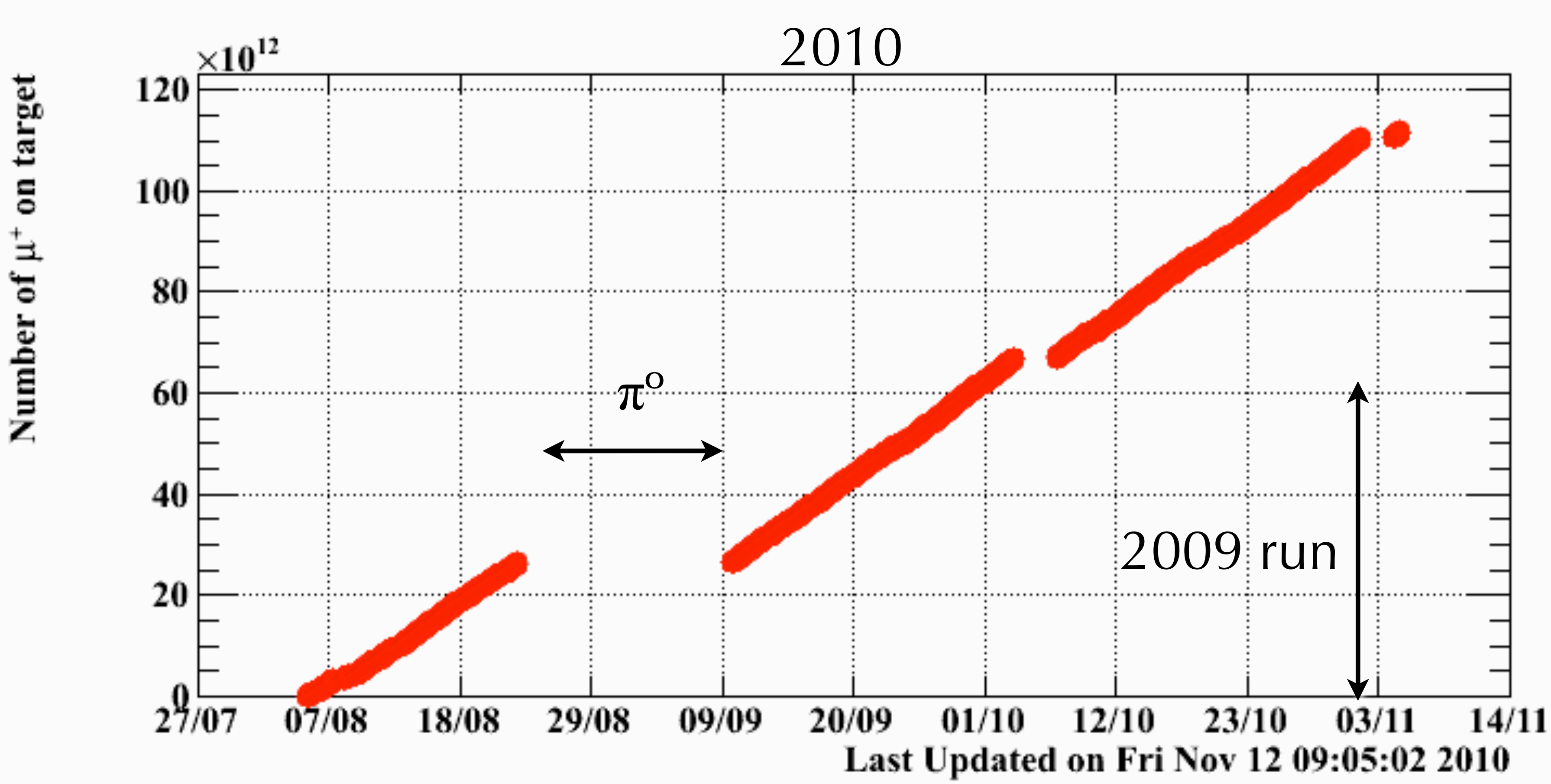
at 90% C.L.

MEG PRELIMINARY

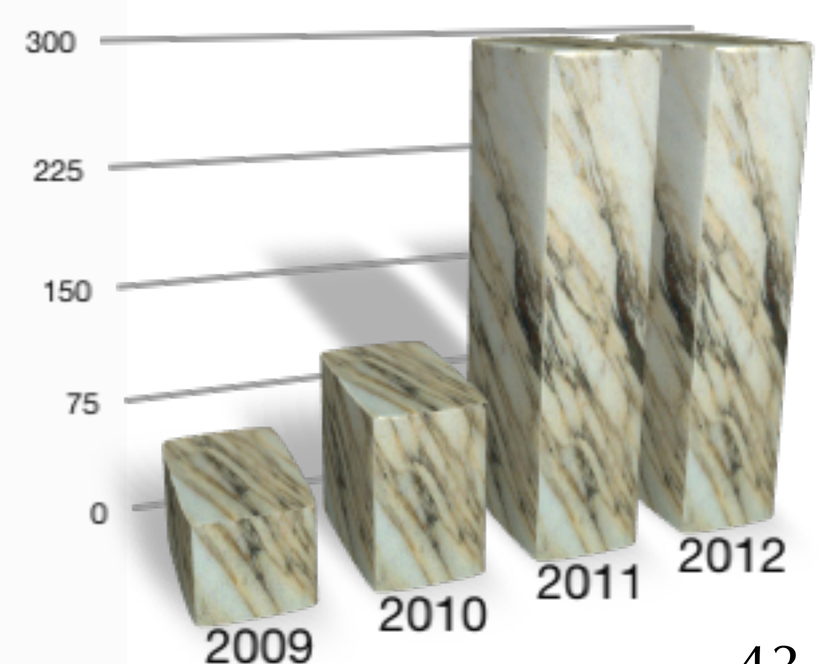
- cfr. MEGA limit BR < 1.2 x 10^{-11} @ 90% C.L.

What’s next?

- Data taking was restarted from Aug. 5 to Nov. 6 2010
  - π^o calibration from 23/8 to 9/9
  - accident to the beam transport solenoid on Nov. 6
  - ~ 2 x 2009 statistics
- An accident on Nov. 6 put a premature end to the 2010 run
- Analysis ongoing
  - 2009 & 2010 data together
- Run 2011 soon starting
  - physics data taking from June to December



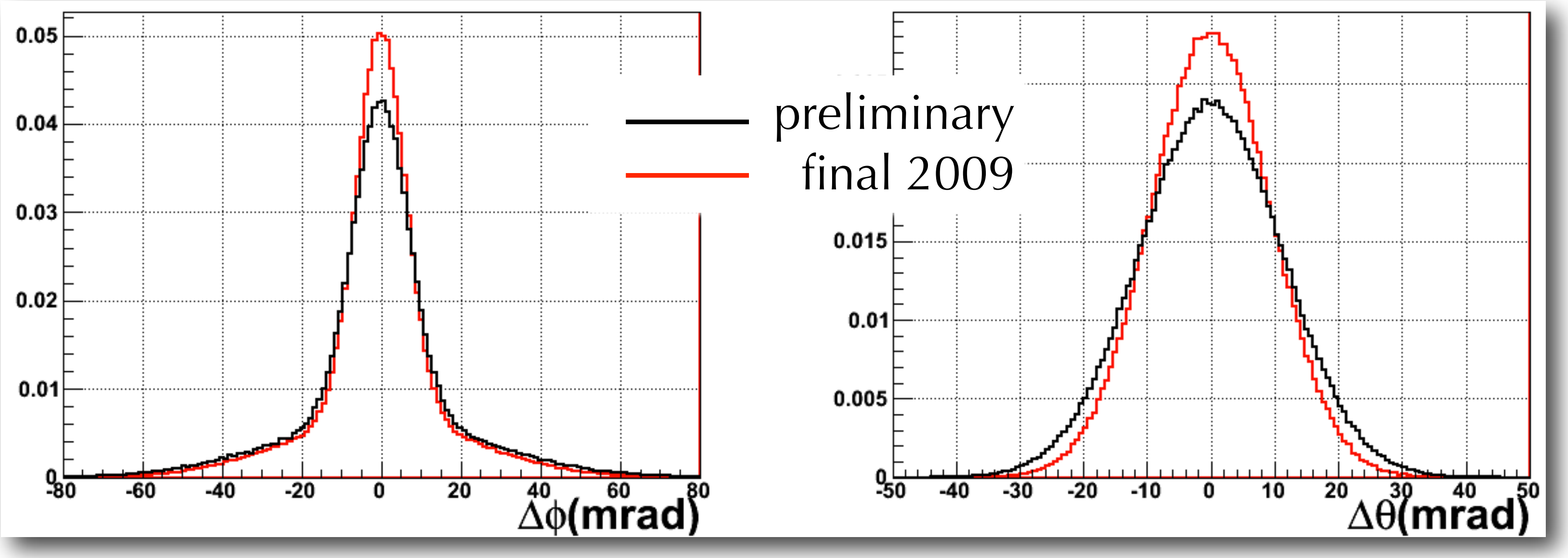
μ on target



What's next

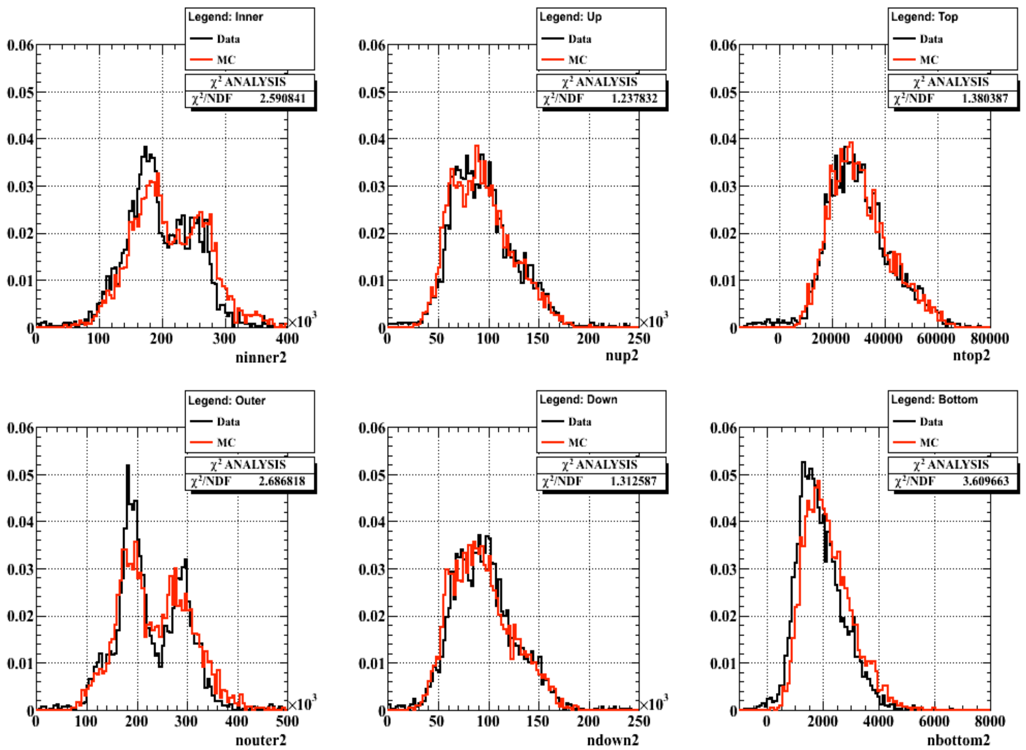
- Analysis of 2009 data finalized
  - Better understanding of spectrometer and B field
    - improvement of positron resolutions
  - Reduction of the systematics in the back-to-back alignment
    - usage of cosmics
  - Better usage of the information from the sidebands
    - we are interested in a limit on N_{SIG}
- Include 2010 analysis

σ_p/p	0.74 %	→	0.61%
σ_φ	7.4 mrad	→	6.1 mrad
σ_ϑ	11.2 mrad	→	9.4 mrad

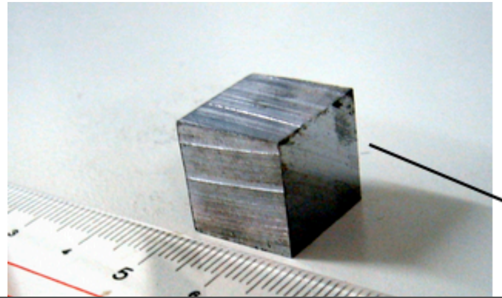


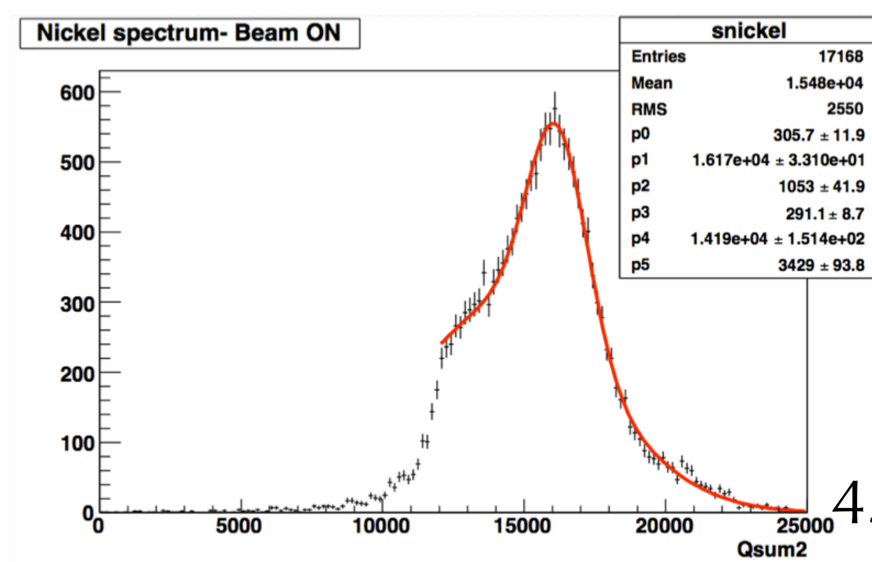
not only statistics

- XEC
  - MC description of the detector
    - better implementation of materials
    - treatment of polarization during reflection
    - affects
      - uniformity correction (response)
      - PMT Q.E. determinations
    - usage of new algorithms for XEC reconstruction
      - "Linear-fit" method



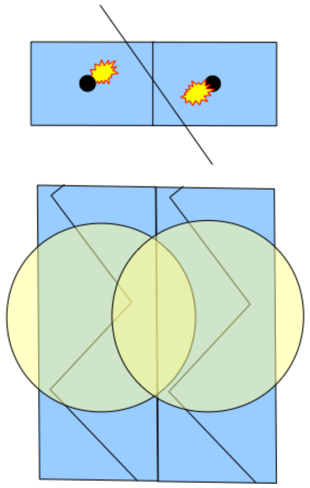
- Nickel/n–generator
  - allows the presence of a physical signal during different beam conditions
  - resolution from RMD edge seems better that what is estimated from π^o
- Alignment
  - more dedicated XEC–DCH coincidence
  - usage of lead dices to improve knowledge XEC position

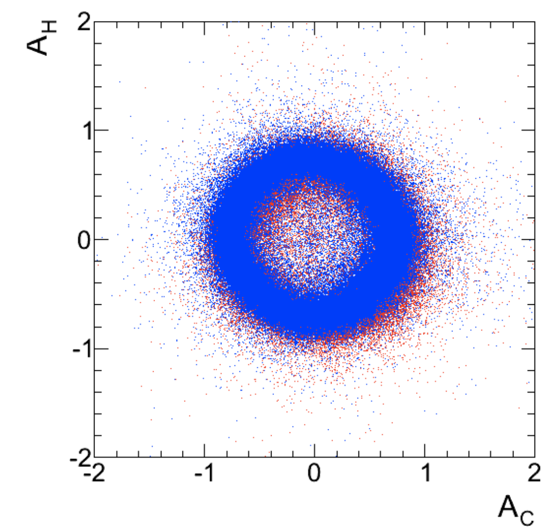


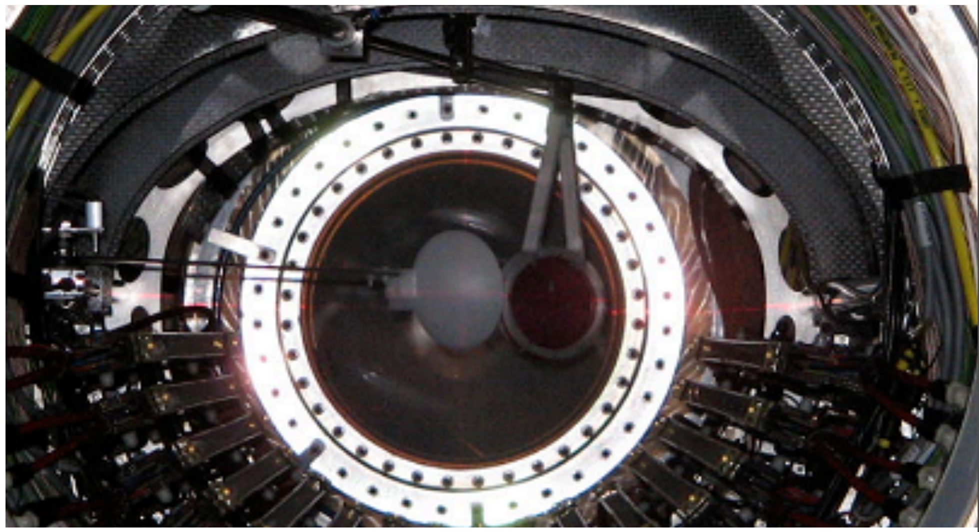


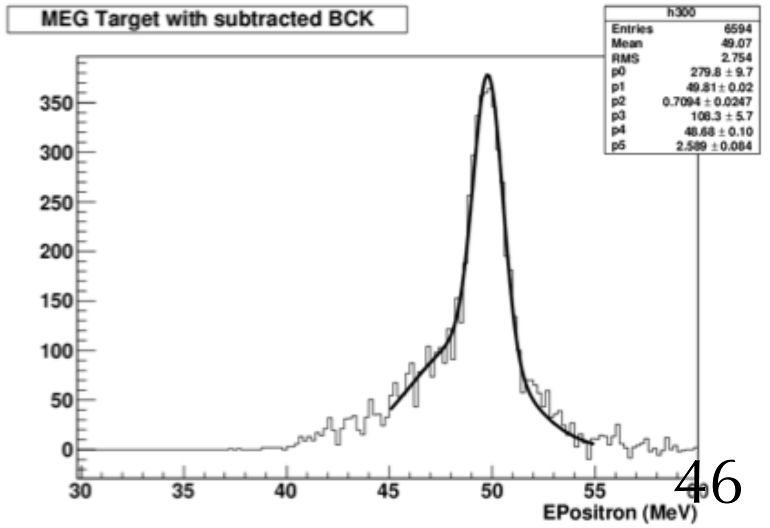
not only statistics

- DCH
  - hardware improvement
    - lower resistivity cathode foils for larger charge/smaller noise
    - new HV power supply with reduced noise
  - Mott scattering positron calibration
    - monochromatic variable energy positron
  - tracking improvement
    - better treatment of rapidly varying magnetic field
    - cross talk between adjacent Vernier pads
    - shadow effect from the anode wires on the Vernier pads
- TC
  - fiber detector operational
    - improved DCH/TC matching
    - absolute positioning of TC bars, improvement of t_{e+}
- DAQ/TRIGGER
  - DRS hardware fine tuning → reduced contribution to σ_t
  - multiple buffer read out
    - dead-time free operation (ε= 84% → 99%)
- ANALYSIS
  - Inclusion of information from the sidebands in the likelihood









Expected performance

	2008	2009	2010 (preliminary)	2011 (preliminary)	2012 (preliminary)
Gamma Energy (%)	2.0(w>2cm)	←	1.5(w>2cm)	←	←
Gamma Timing (psec)	80	>67	←	←	←
Gamma Position (mm)	5(u,v)/6(w)	←	←	←	←
Gamma Efficiency (%)	63	58	60	←	←
e^+ Timing (psec)	<125	←	←	←	←
e^+ Momentum (%)	1.6	0.61(core)	←	0.55(core)	←
e^+ Angle (mrad)	$10(\phi)/18(\theta)$	6.2(core)/9.4	←	6.2(core)/7	←
e^+ Efficiency (%)	14	40	←	←	(50)
e^+-gamma timing (psec)	148	151(core)	130	120	←
Muon Decay Point (mm)	3.2(Y)/4.5(Z)	3.3(Y)/3.3(Z)	←	2.8(Y)/3.0(Z)	←
Trigger efficiency (%)	66	91	92	95	95
Stopping Muon Rate (sec^{-1})	3×10^7	2.9×10^7 (300 μm)	2.9×10^7	←	←
DAQ time/ Real time (days)	48/78	35/43	56/67	135/161	←

Conclusion

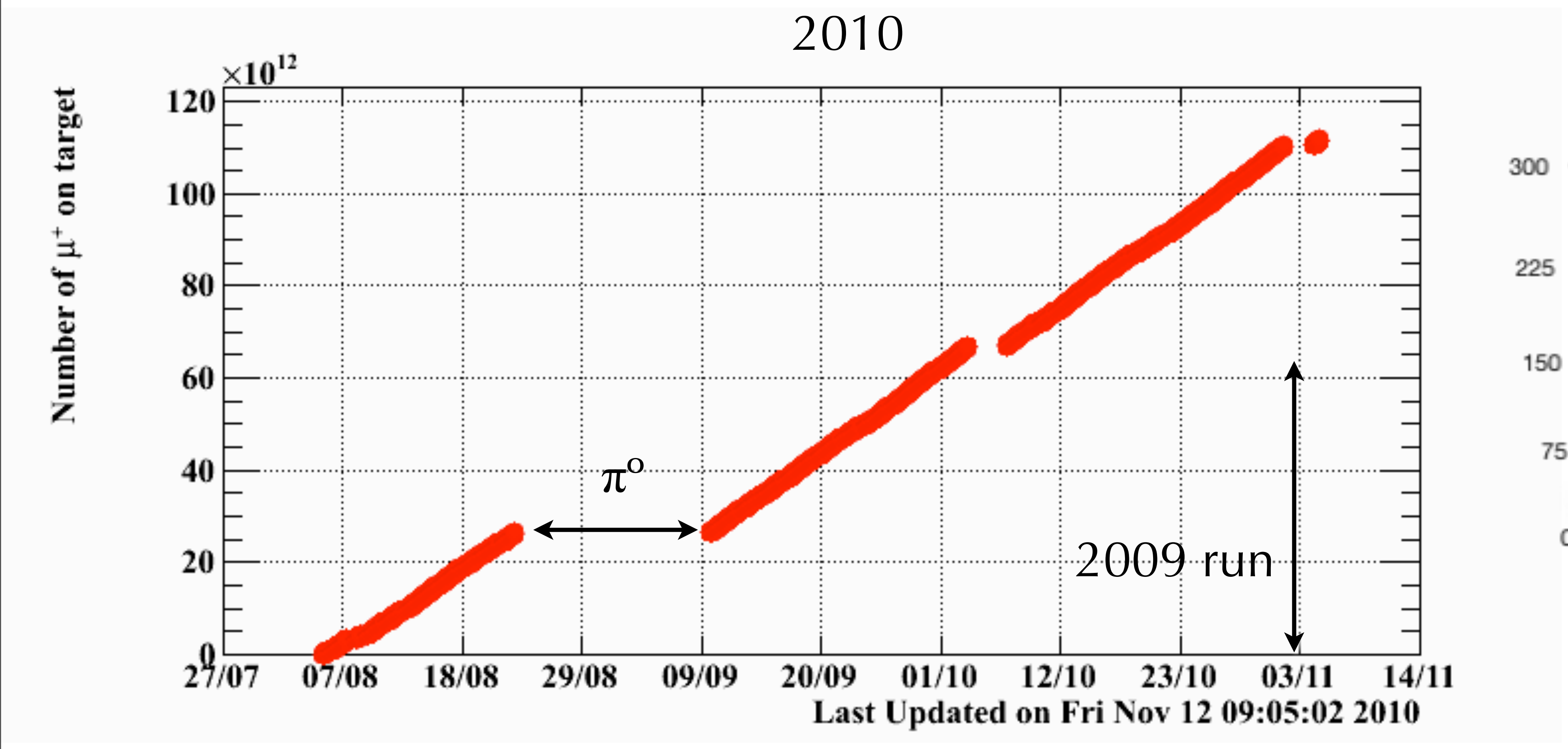
- Data from the two months of stable data taking of the MEG experiment in 2009 give a result competitive with the previous limit
- Preliminary result
  - Sensitivity: 6.1×10^{-12}
  - 90% C.L. Upper limit: 1.5×10^{-11}
- New data taken from August 2010 to 6 November
  - we will clarify the result with 2x more statistics
  - new calibration tools
  - improved analysis algorithms
- Continue running for the next two years towards the final target sensitivity of a few $\times 10^{-13}$

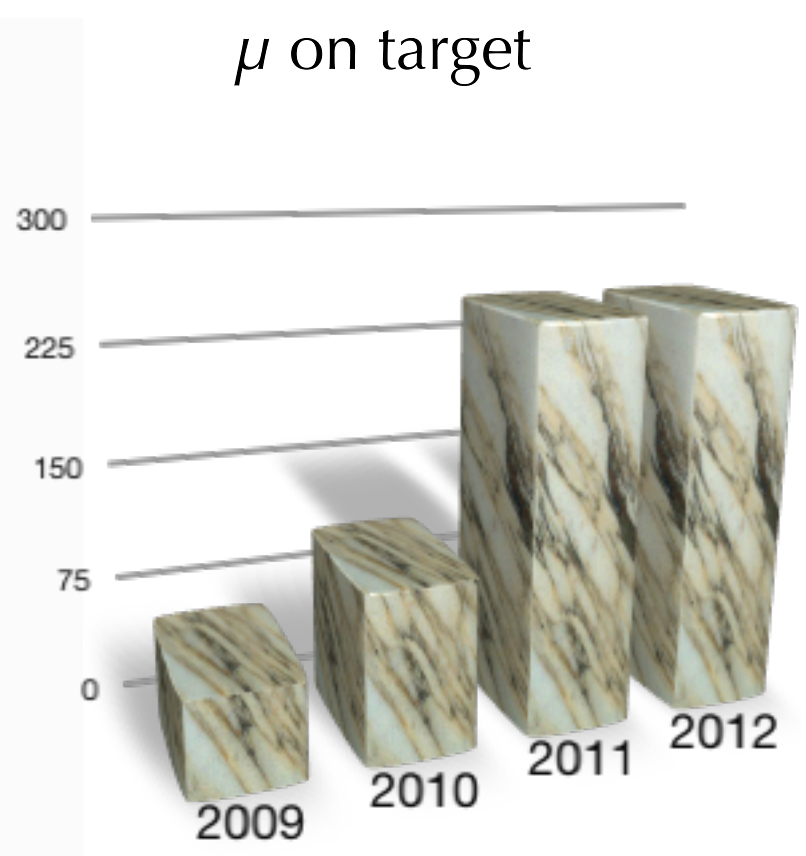
Thank you

Back-up slides

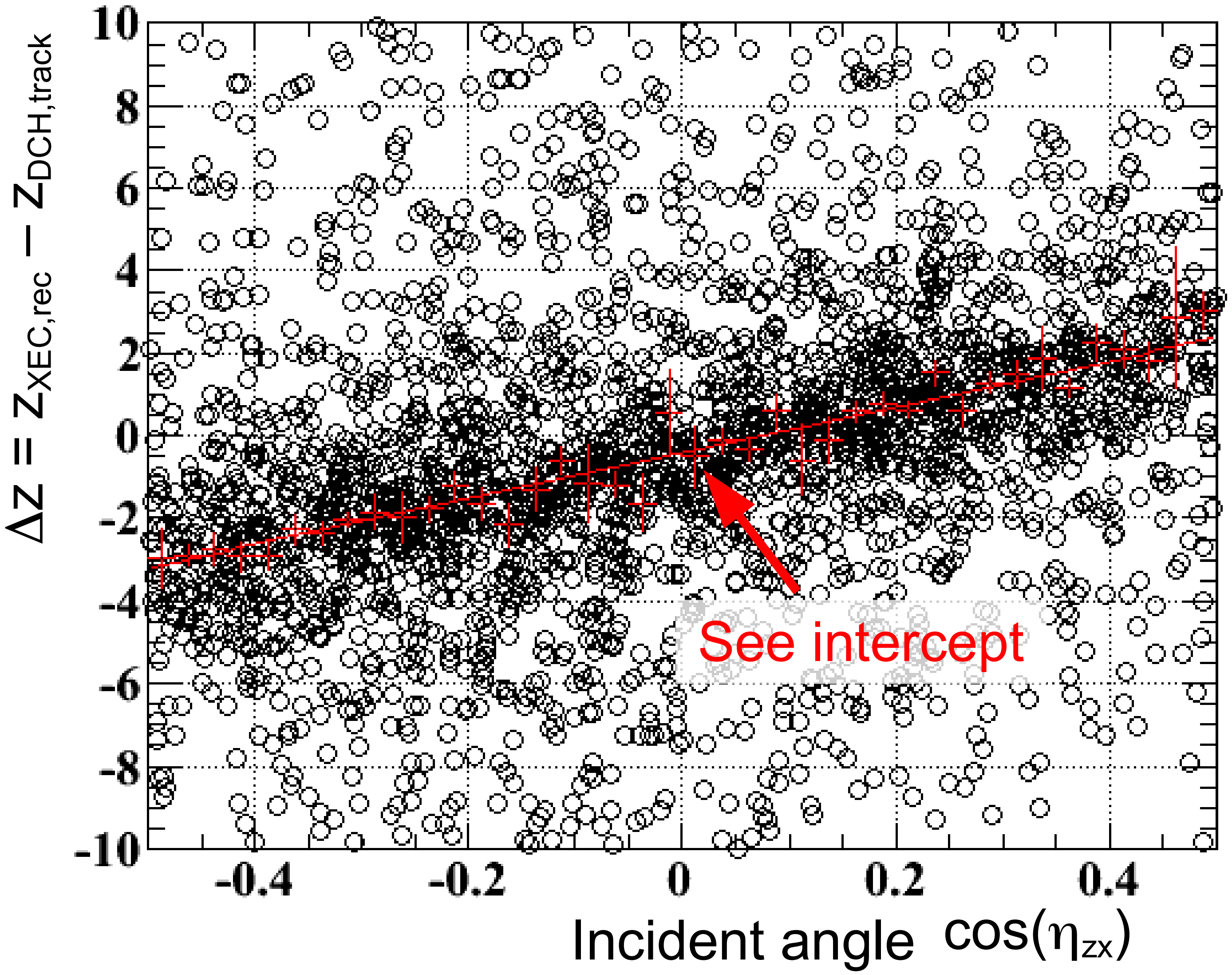
What’s next?

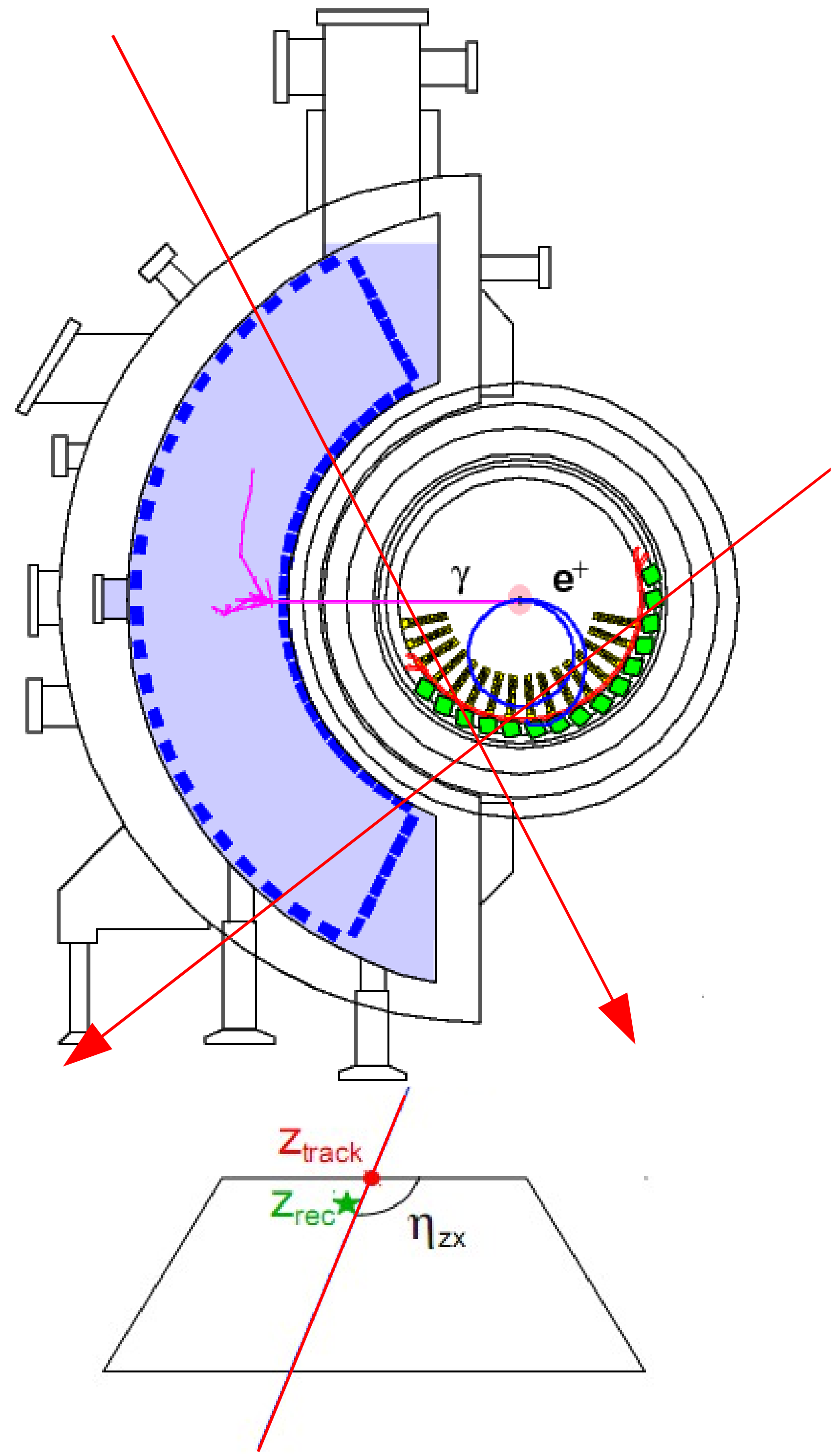
- Data taking was restarted from Aug. 5 to Nov. 6
  - π^o calibration from 23/8 to 9/9
  - accident to the beam transport solenoid on Nov. 6
  - ~ 2 x 2009 statistics
- An accident on Nov. 6 put a premature end to the 2010 run
- We will have two more years of stable data taking (until the end of 2012)
  - statistical power





- Alignment of detectors
  - Relative alignment b/w XEC and spectrometer
    - Took CR w/o magnetic field June & November 2010

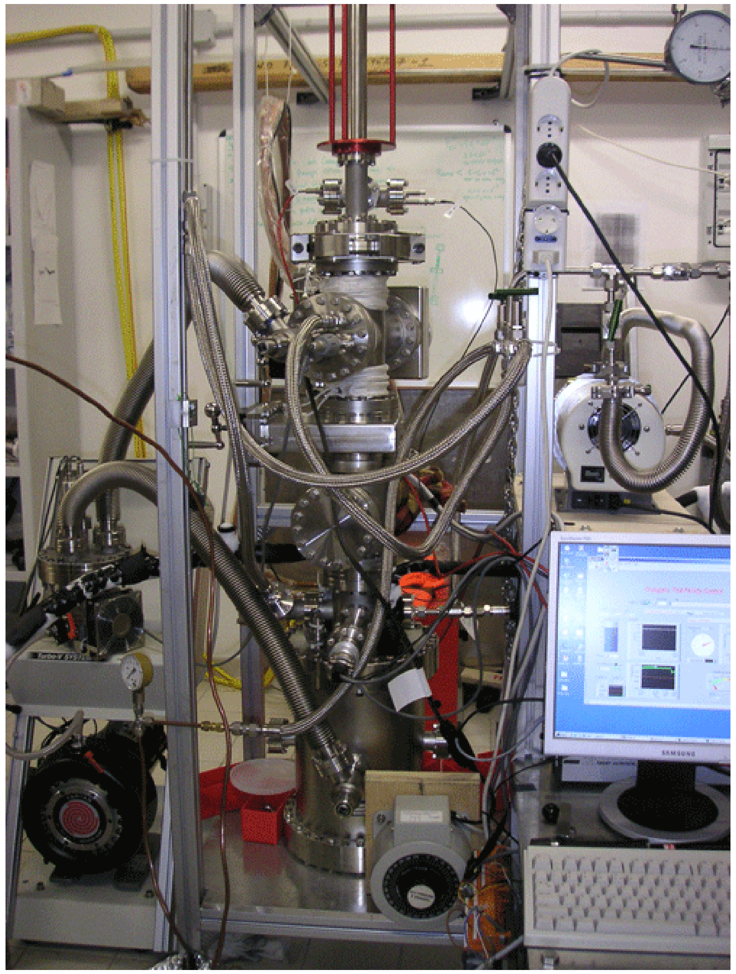


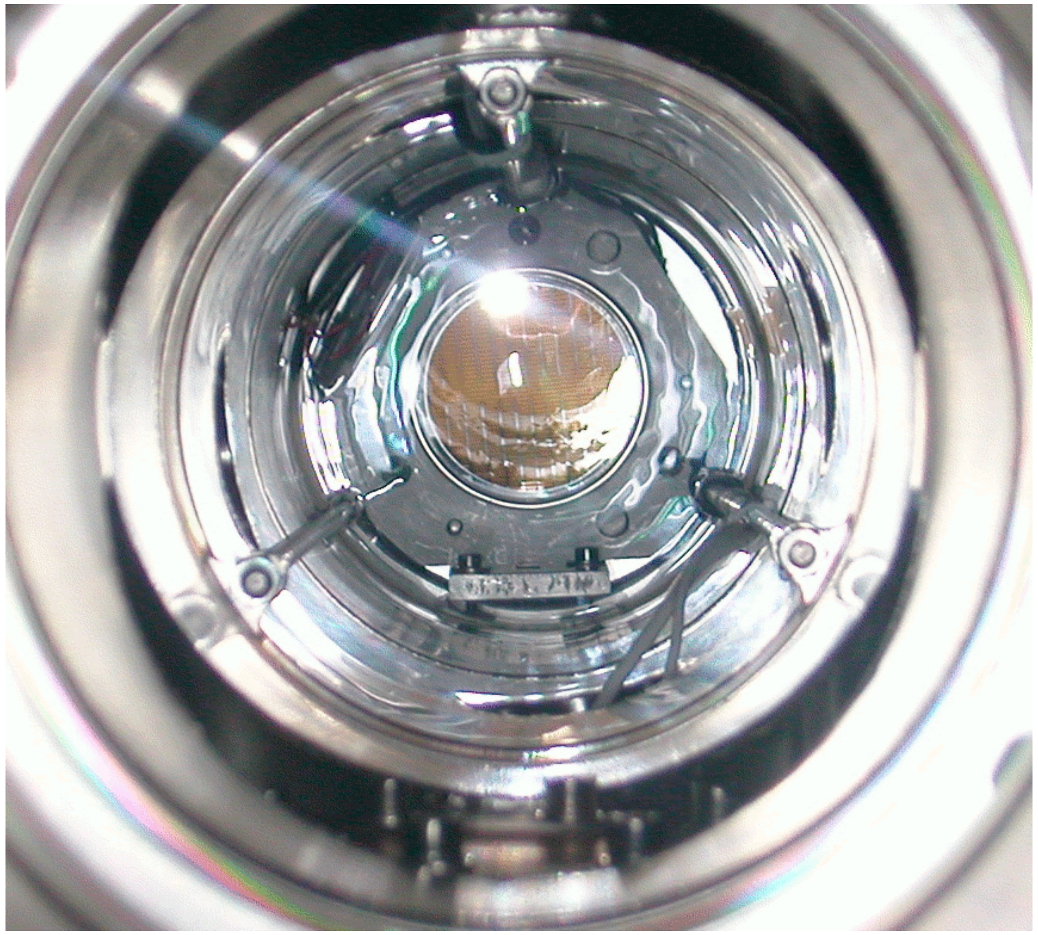


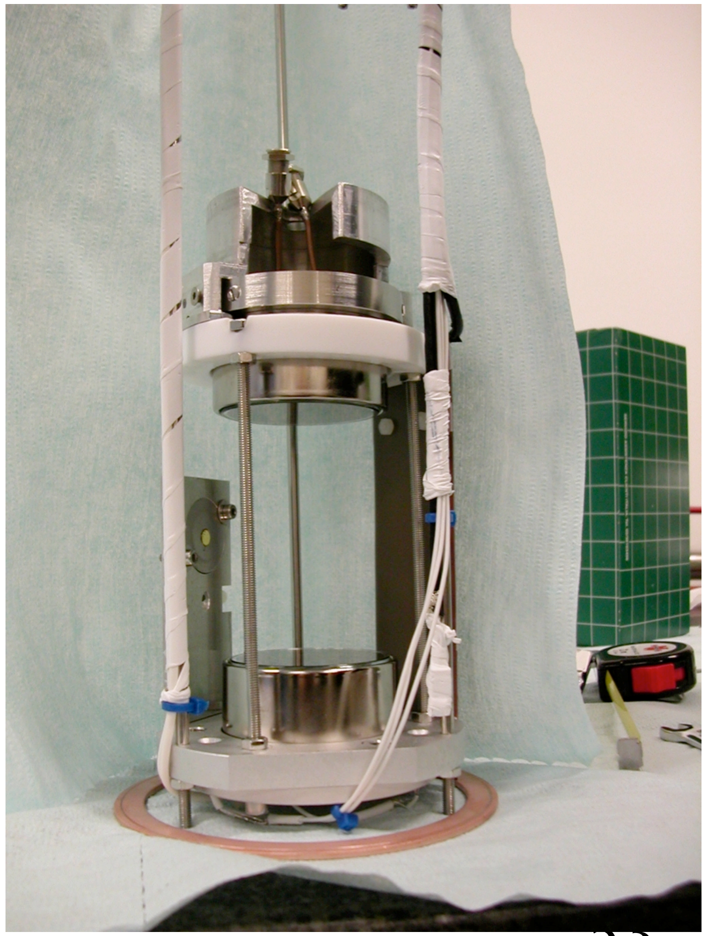
$\Delta z = z_{rec} - z_{track} = -4.3 \pm 0.6$ mm

LXe PMT test facility

- Tests of 900 PMTs for the final calorimeter Pisa / Tokyo
  - more than 400 PMTs tested individually in the same experimental contitions
    - immersed in LXe
    - high rate environment
    - relative Q.E. determination







Trigger rates

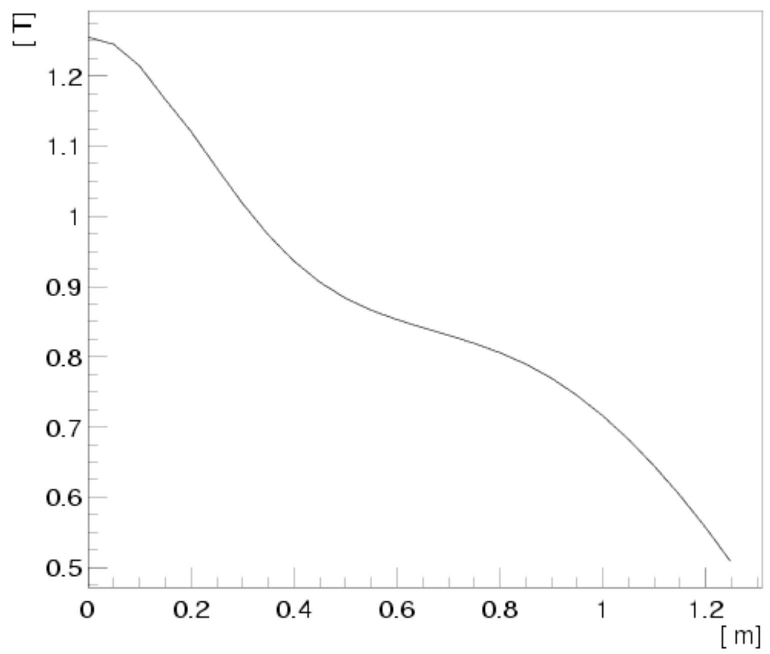
TRGDAQRateMeter

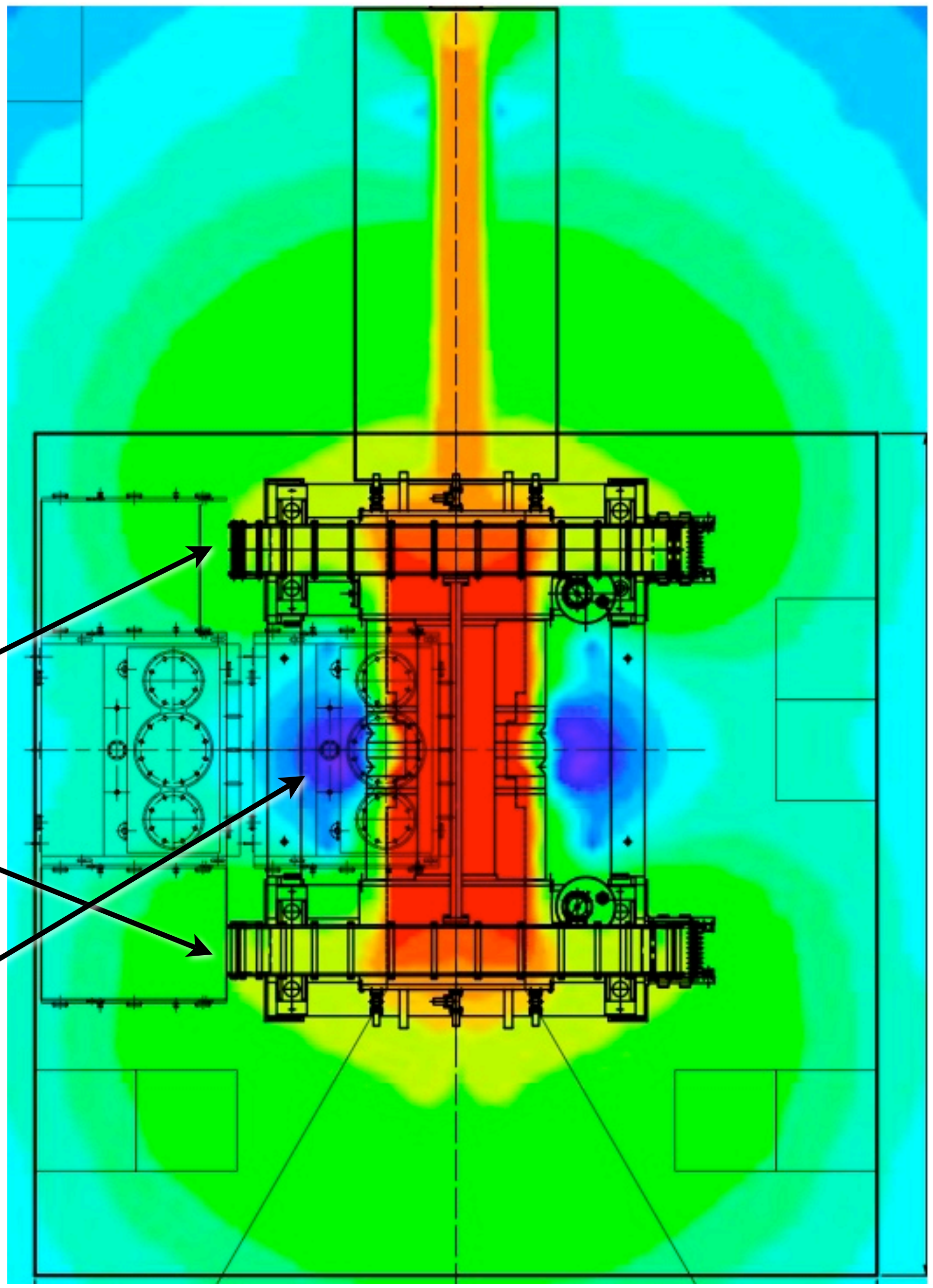
Proton Current	Total trigger rate	Live Time	Total Time	Live Time (%)
2195.0 μ Amp	5.017 Hz	257.419 sec	305.751 sec	84.192

	#Ev(#DAQ)	EvRate(DAQ Rate,%)		#Ev(#DAQ)	EvRate(DAQ Rate,%)
Id0 MuEGamma	1.6e+03 (1.3e+03)	5.16Hz(4.4Hz,87.0)	Id16 Michel	1.6e+08 (0)	5.33e+05Hz(0.0Hz,0.0)
Id1 MEG LowQ	3.2e+03 (20)	10.53Hz(0.1Hz,1.3)	Id17 DC Trackout	2.8e+08 (0)	9.05e+05Hz(0.0Hz,0.0)
Id2 MEG WidAng	7.2e+03 (8)	23.41Hz(0.0Hz,0.5)	Id18 DC Track	4.0e+08 (21)	1.31e+06Hz(0.1Hz,1.4)
Id3 MEG WidTime	2.9e+03 (4)	9.38Hz(0.0Hz,0.3)	Id19 DC Cosm	0 (0)	0.00Hz(0.0Hz,0.0)
Id4 Rad NarTime	1.3e+04 (8)	42.49Hz(0.0Hz,0.5)	Id20 DC single	6.7e+08 (0)	2.20e+06Hz(0.0Hz,0.0)
Id5 Rad WidTime	2.3e+04 (0)	76.09Hz(0.0Hz,0.0)	Id21 Cosm Alone	0 (0)	0.00Hz(0.0Hz,0.0)
Id6 Pi0	0 (0)	0.00Hz(0.0Hz,0.0)	Id22 TC Alone	4.0e+08 (36)	1.32e+06Hz(0.1Hz,2.3)
Id7 Pi0 NPrSh	0 (0)	0.00Hz(0.0Hz,0.0)	Id23 CR Coinc	0 (0)	0.00Hz(0.0Hz,0.0)
Id8 NaI	0 (0)	0.00Hz(0.0Hz,0.0)	Id24 TC Pair	3.6e+07 (0)	1.16e+05Hz(0.0Hz,0.0)
Id9 LXe HighQ	3.8e+05 (13)	1.23e+03Hz(0.0Hz,0.8)	Id25 NaI Cosmic	0 (0)	0.00Hz(0.0Hz,0.0)
Id10 LXe LowQ	7.6e+05 (0)	2.49e+03Hz(0.0Hz,0.0)	Id26 APD Single	2.6e+08 (0)	8.66e+05Hz(0.0Hz,0.0)
Id11 CW Bo	2.0e+05 (0)	652.46Hz(0.0Hz,0.0)	Id27 LXe Cosmic	5.0e+04 (0)	164.77Hz(0.0Hz,0.0)
Id12 Alpha	7.5e+05 (27)	2.46e+03Hz(0.1Hz,1.8)	Id28 NaI PrSh	0 (0)	0.00Hz(0.0Hz,0.0)
Id13 Laser	0 (0)	0.00Hz(0.0Hz,0.0)	Id29 !NeutronNi	7.6e+05 (0)	2.49e+03Hz(0.0Hz,0.0)
Id14 LED	315 (48)	1.03Hz(0.2Hz,3.1)	UNUSED	0 (0)	0.00Hz(0.0Hz,0.0)
Id15 NeutronNi	0 (0)	0.00Hz(0.0Hz,0.0)	Id31 Pedestal	3.1e+05 (14)	9.99e+02Hz(0.0Hz,0.9)

COBRA spectrometer

Non uniform magnetic field decreasing from the center to the periphery

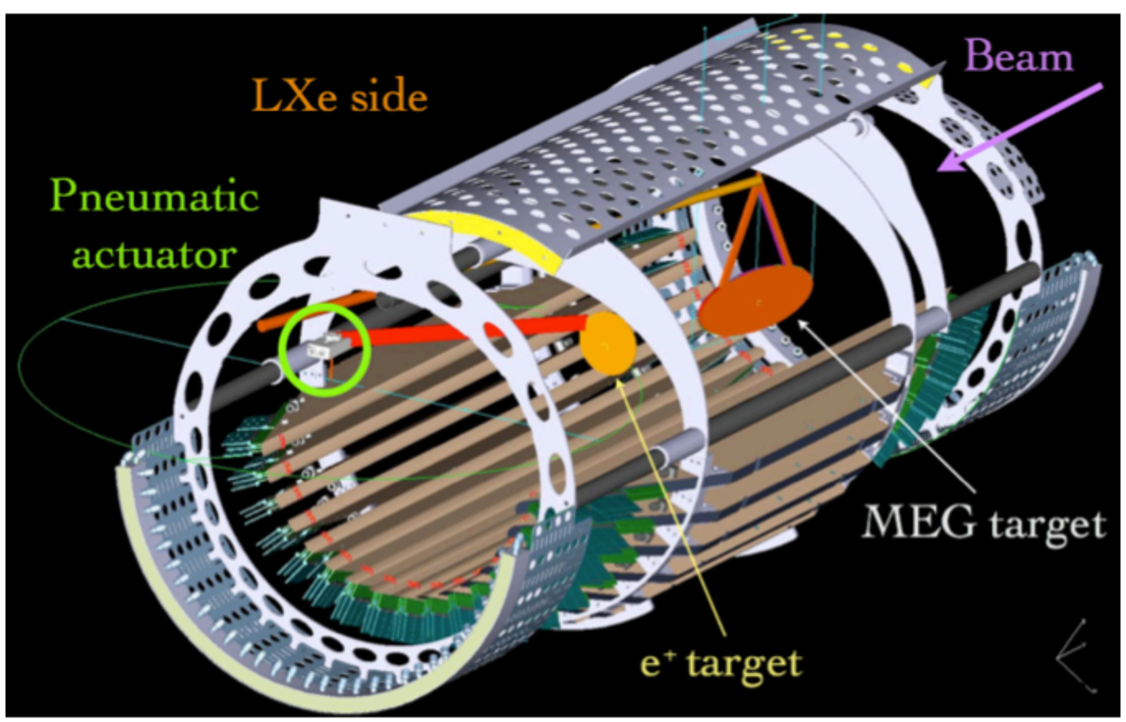


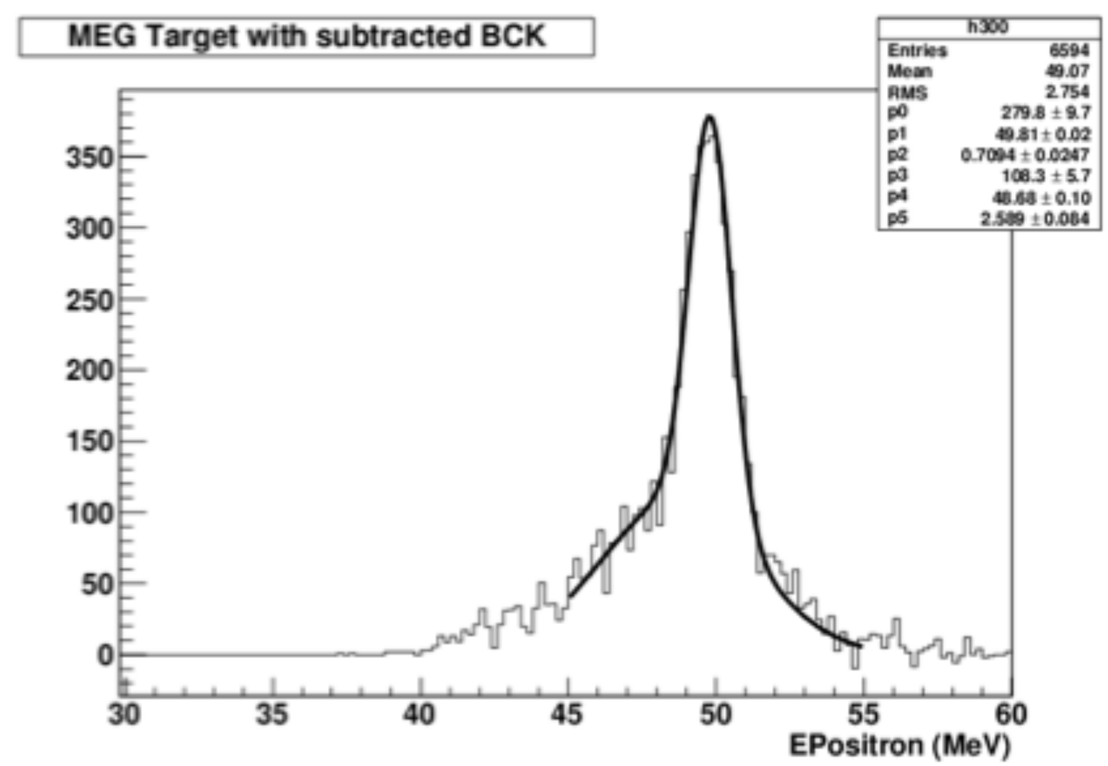


- The superconducting magnet is very thin (0.2 X_0)
- Can be kept at 4 K with GM refrigerators (no usage of liquid helium)

Mott

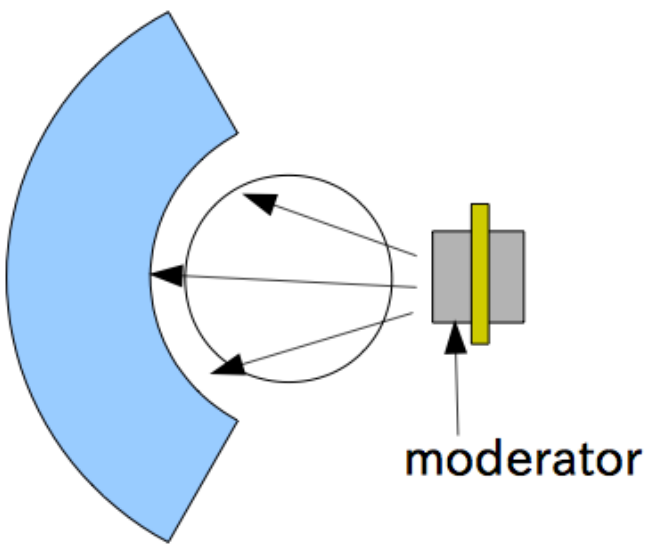
- Tunable monochromatic positron beam
  - Coherent elastic scattering of e+ on carbon
  - momentum resolution 50 keV

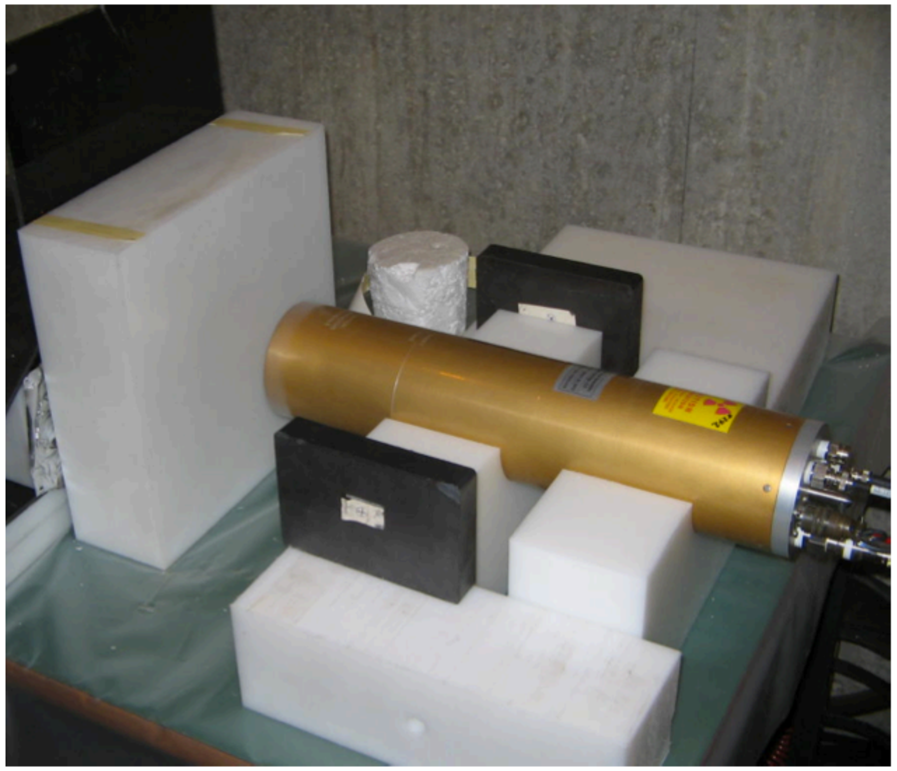




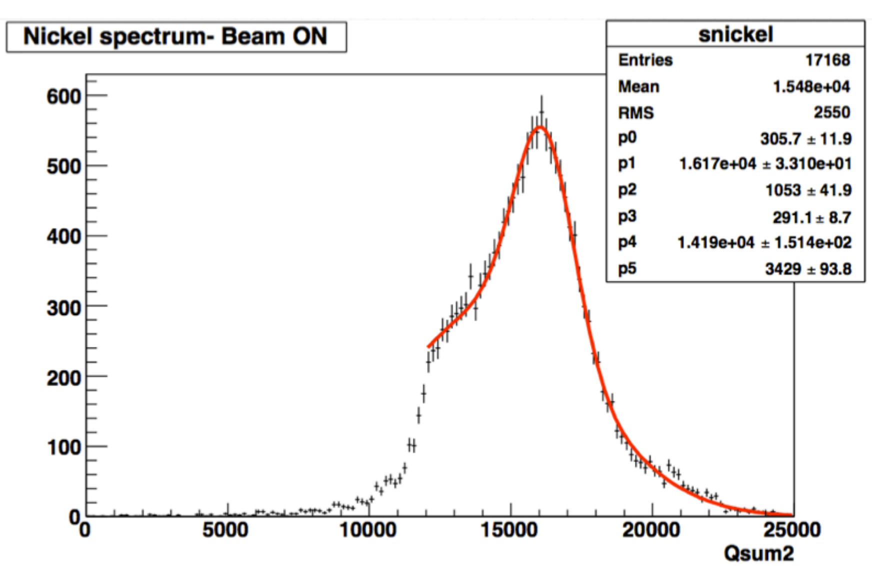
nNickel

- 9 MeV γ-ray from nNi reaction
  - thermal capture on Nickel
  - pulsed D-D generator
    - unique possibility to calibrate XEC with a line during beam ON

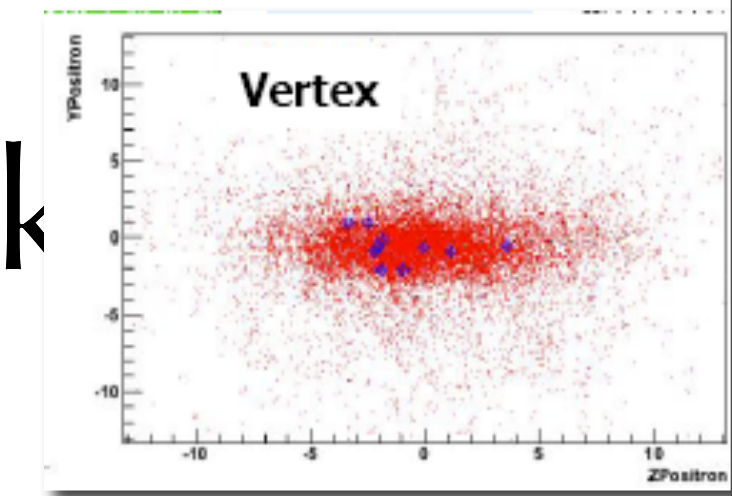


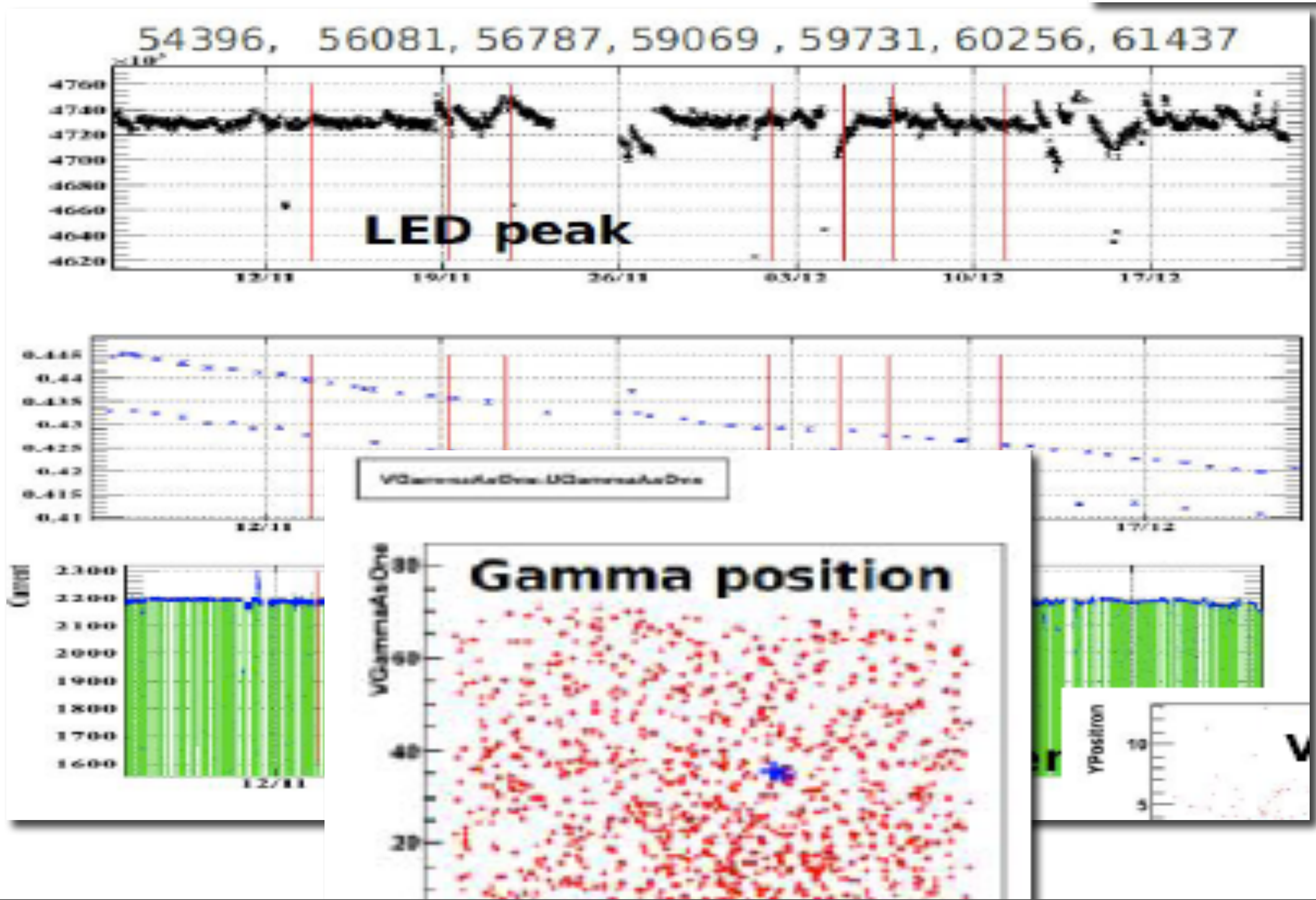


Specifiche tecniche	
Tipo di Generatore	D-D ($Q = 3.27$ MeV, $E_n = 2.45$ MeV)
Neutroni per impulso	$2.5 \cdot 10^4$
Neutroni al secondo	$2.5 \cdot 10^6$(@ 100 Hz)
Vita media del tubo	> 500 h
Frequenza	10-100 Hz, singolo impulso
Larghezza dell'impulso	$\sim 10\mu$s

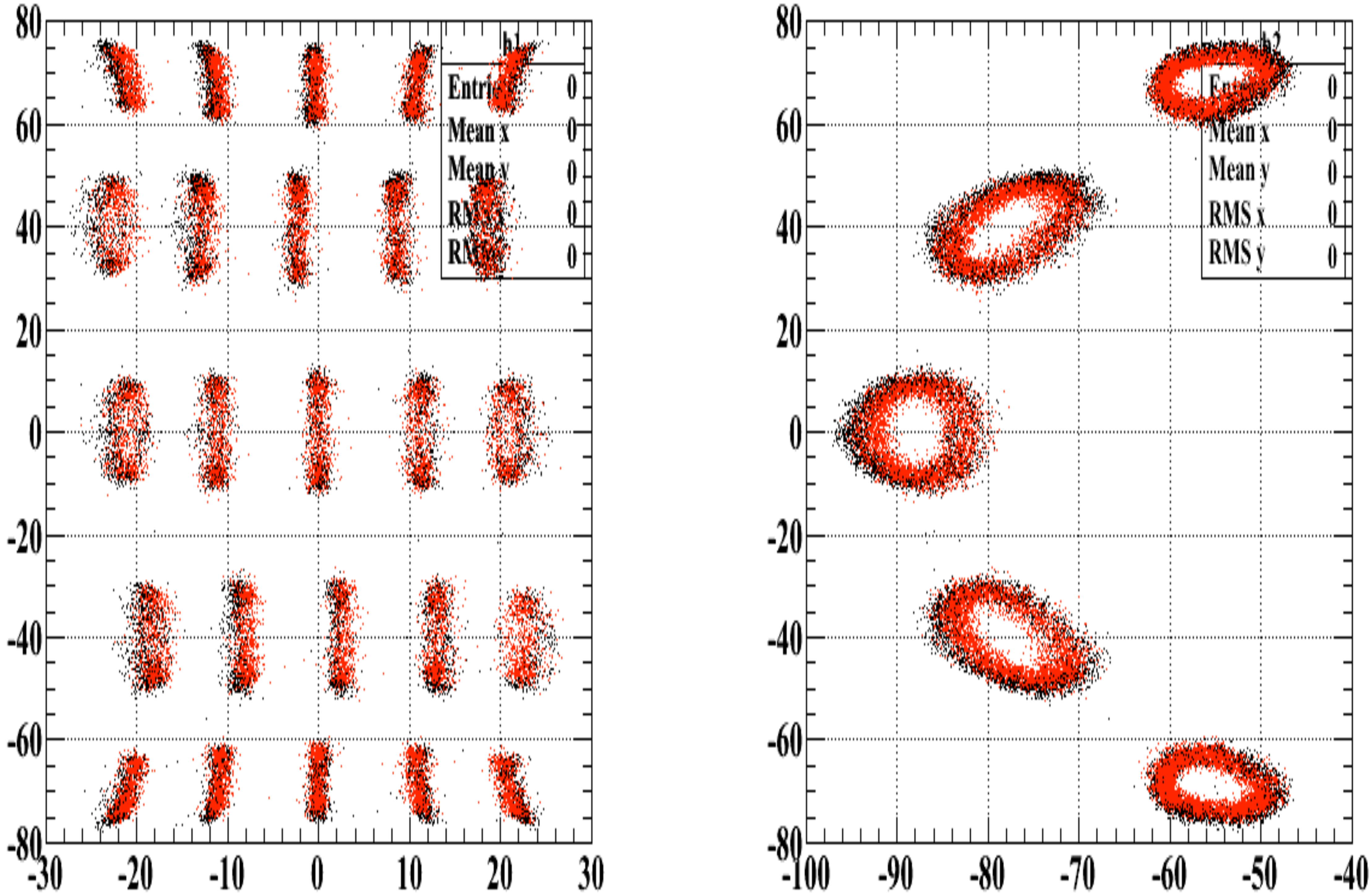


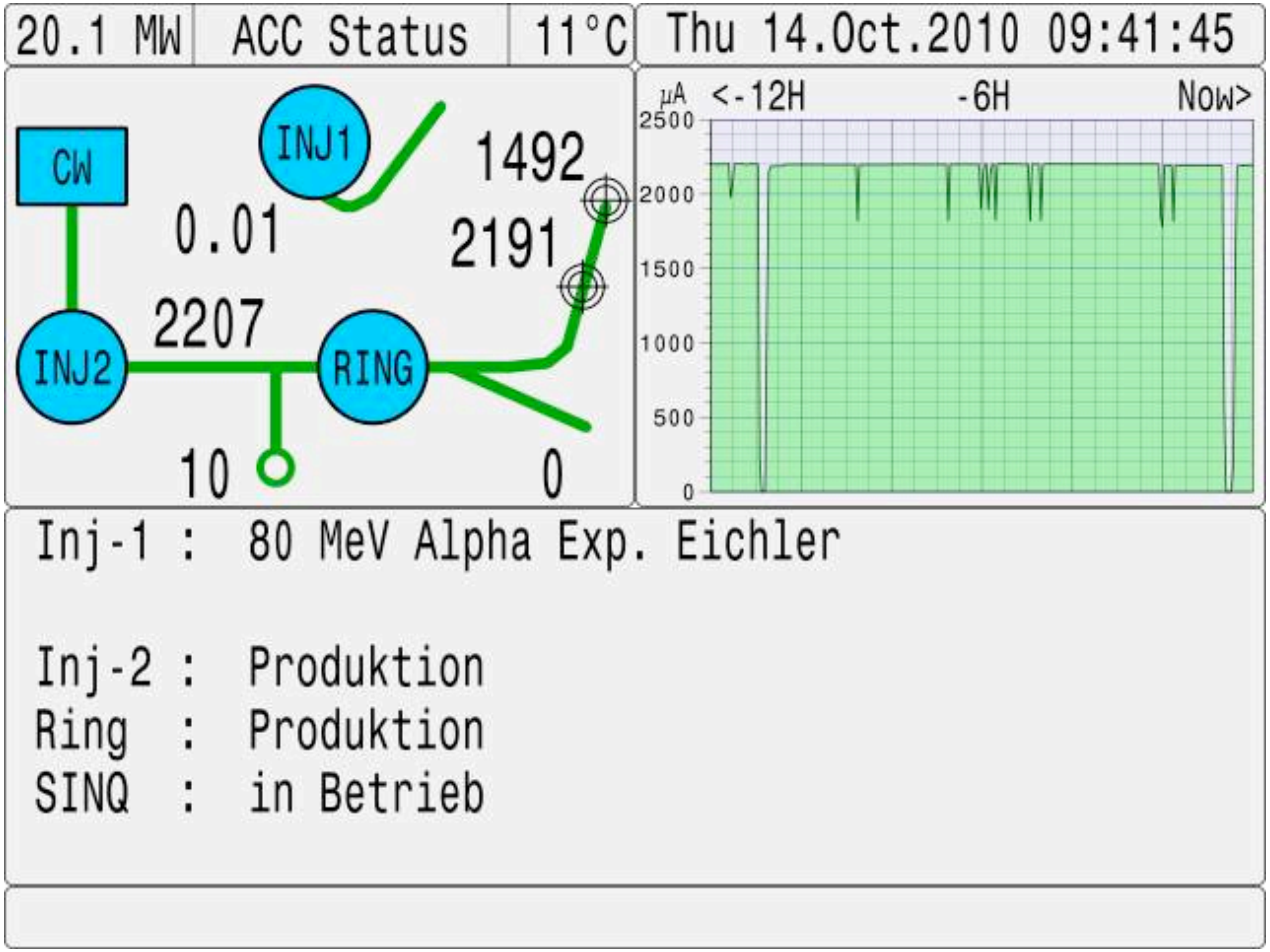
Event quality check





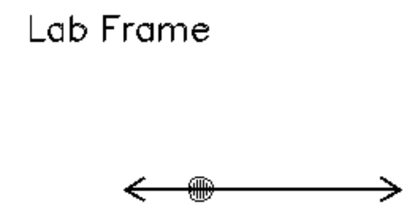
α:data vs new MC

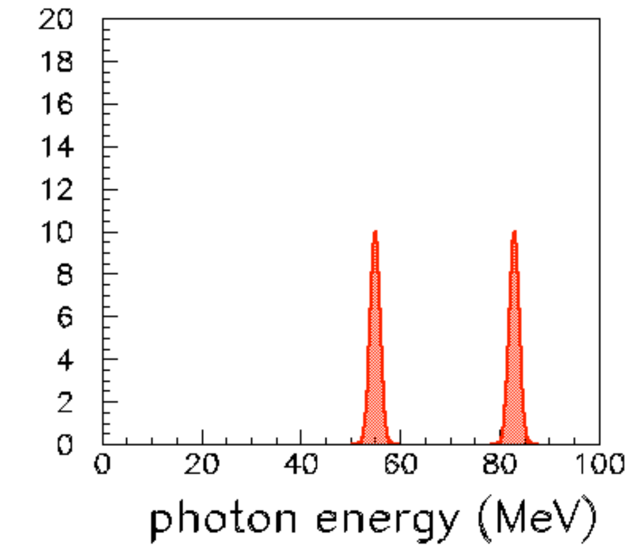



20.1 MW
ACC Status
11°C
Thu 14.Oct.2010 09:41:45
CW
INJ1
INJ2
RING
0.01
1492
2191
2207
10
0
µA
<-12H
-6H
Now>
2500
2000
1500
1000
500
0
Inj-1 : 80 MeV Alpha Exp. Eichler
Inj-2 : Produktion
Ring : Produktion
SINQ : in Betrieb

CEX measurement

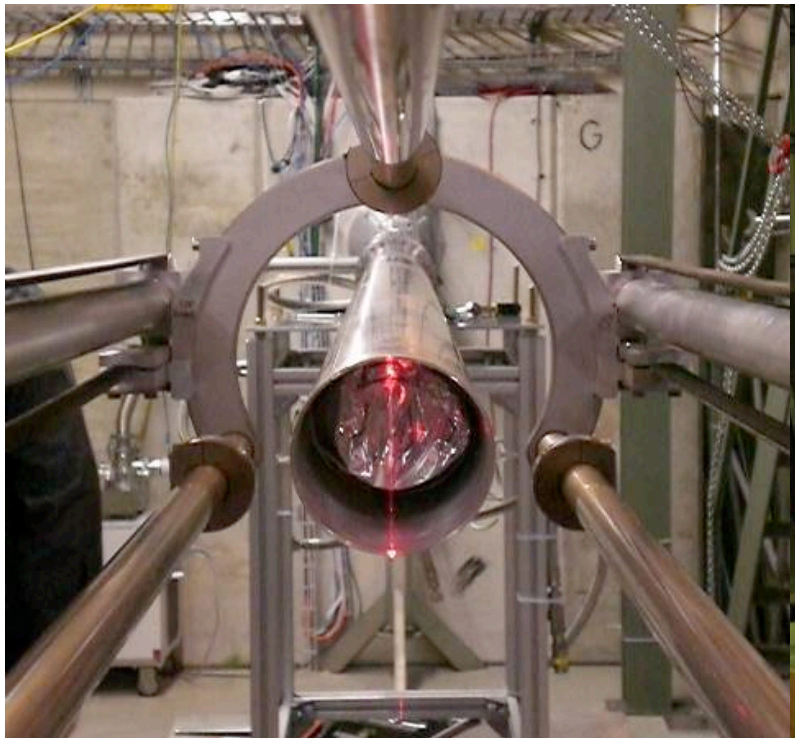
$$\pi^- p \to \pi^0 n$$
$$\pi^0 \to \gamma\gamma$$



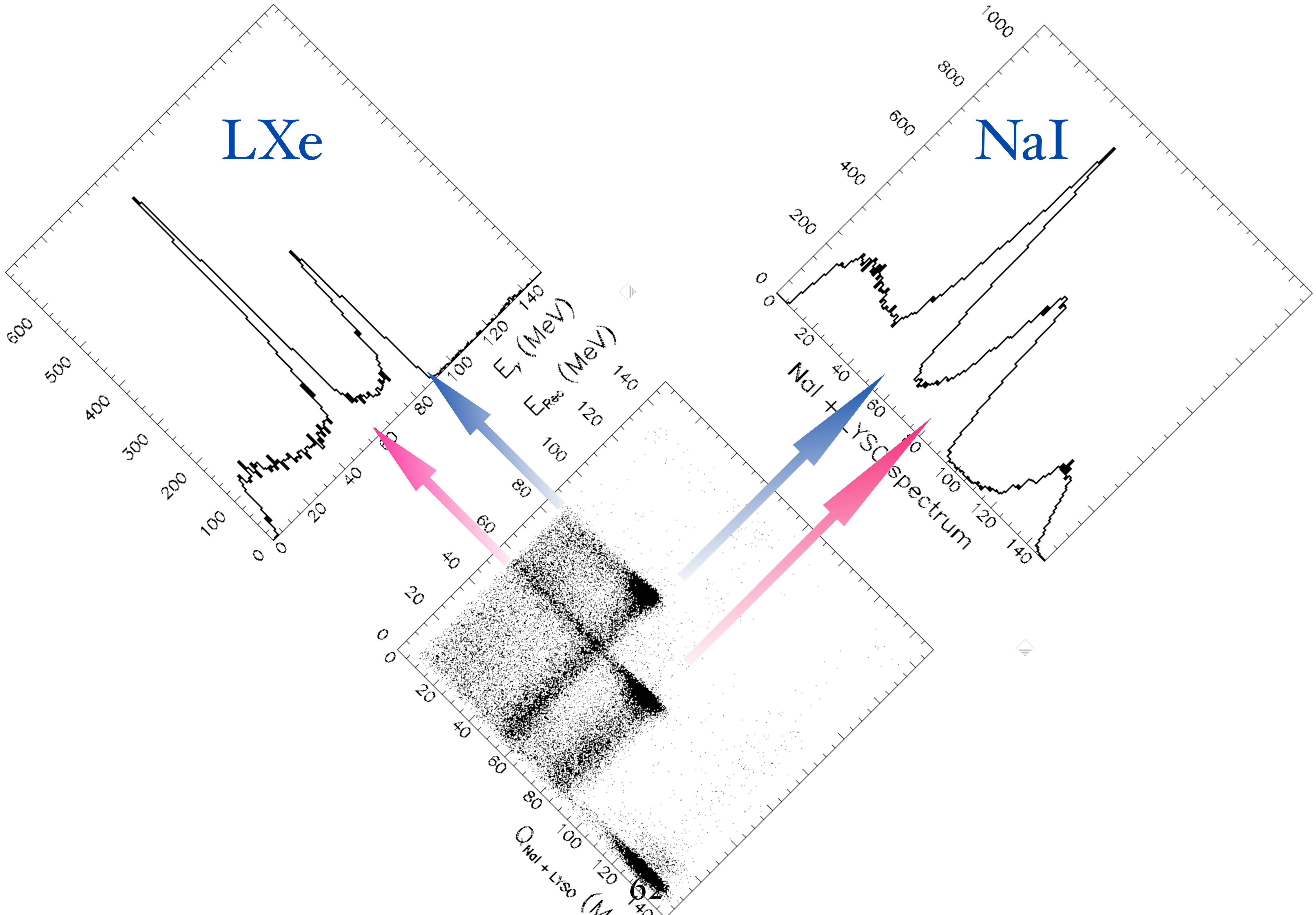


- The monochromatic spectrum in the pi-zero rest frame becomes flat in the Lab
- In the back-to-back configuration the energies are 55 MeV and 83 MeV

- Even a modest collimation guarantees a sufficient monochromaticity
- Liquid hydrogen target to maximize photon flux
- An "opposite side detector" is needed (NaI array)



- In the back-to-back raw spectrum we see the correlation
  - 83 MeV ⇔ 55 MeV
  - The 129 MeV line is visible in the NaI because Xe is sensitive to neutrons (9 MeV)



Example: α-sources in Xe

- Specially developed Am sources:
  - 5 dot-sources on thin (100 μm) tungsten wires
  - SORAD Ltd. (Czech Republic)