Recent results from the MEG experiment

Donato Nicolò
Università di Pisa & INFN
(on the behalf of MEG collaboration)

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Outlook

- The MEG experiment
  - The physics goal
  - Signal & background
  - Beam and detector layout
- The Run
  - Detector calibration & monitoring
  - Performances
  - Data summary
- Results
  - Analysis strategy
  - Review of results from Run 2009
  - Latest results from combined (2009+2010) data
- Perspectives for the future
  - Sensitivity plan
- Conclusions

The experiment

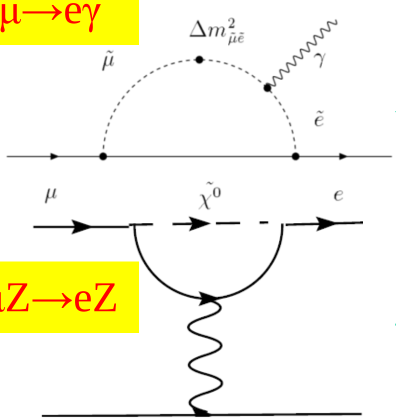
- Physics goal
- Signature & background
- Detector layout

LFV relation to EDM, g-2

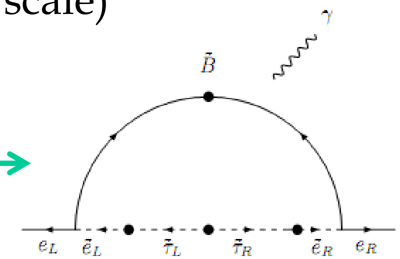
- Contribution to EDM, MDM of leptons (hadrons) from diagonal elements of the slepton (squark) mass matrix
- LFV processes induced by off-diagonal terms (depend on how SUSY breaking is generated and what kinds of LFV interactions exist at the GUT scale)

μ→eγ

μZ→eZ



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

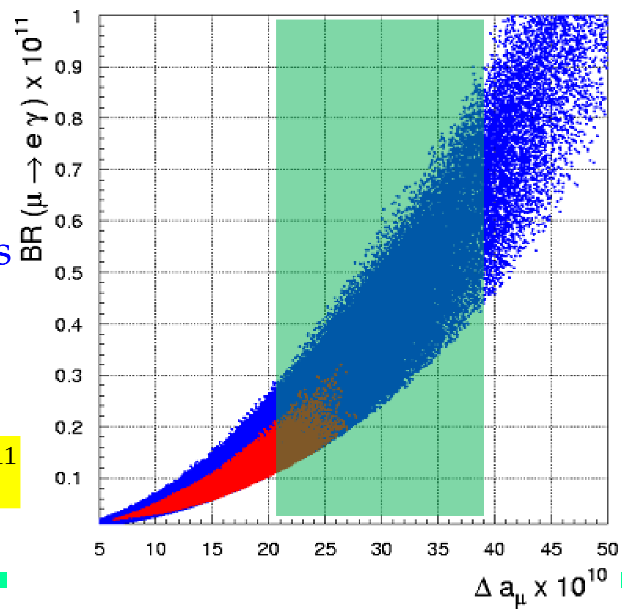


g-2	$\propto \Re(m^2_{\tilde\mu\tilde\mu})$
EDM	$\propto \Im(m^2_{\tilde\mu\tilde\mu})$

- SUSY effect on g-2 ➔ deviations from SM predictions
- an experimental clue: E821 results

$$\Delta a_\mu \equiv a_\mu^{exp} - a_\mu^{SM} = (297 \pm 79)\times 10^{-11}$$

Phys.Rev.Lett. 92(2004) 1618102



$\Delta a_\mu \neq 0$ associated with SUSY

➔ $BR(\mu \to e\gamma) \geq 10^{-12}$

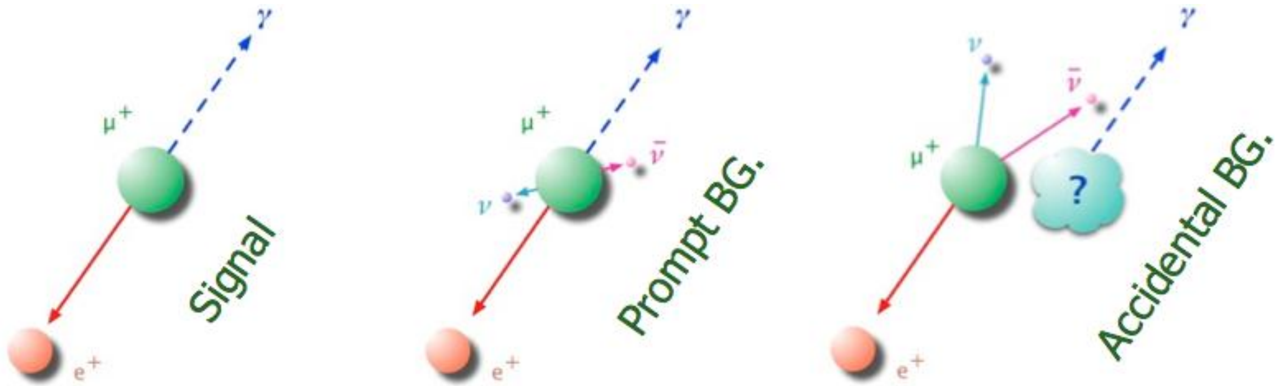
G.Isidori *et al.*

Phys. Rev. D75 (2007) 115019

➔ strong physics case

Latest results ...

Signal & background



$$E_e = E_\gamma = 52.8\,\text{MeV}$$

$$\Theta_{e\gamma} = 180^\circ$$

$$\delta t_{e\gamma} = 0$$

$$B_{pro} \approx 0.1 \times B_{acc}$$

$$B_{acc} \propto R_\mu \Delta E_\gamma^2 \Delta E_e \Delta \Theta_{e\gamma}^2 \Delta t_{e\gamma}$$

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

The layout

The beam

- The worldwide most intense DC beam (>10^8m/s)

of surface muons (28 MeV/c)

→ stopped on a thin (100 μm) target

- Currently $R_\mu = 3\text{x}10^7\ s^{-1}$ due to pile-up

The detector

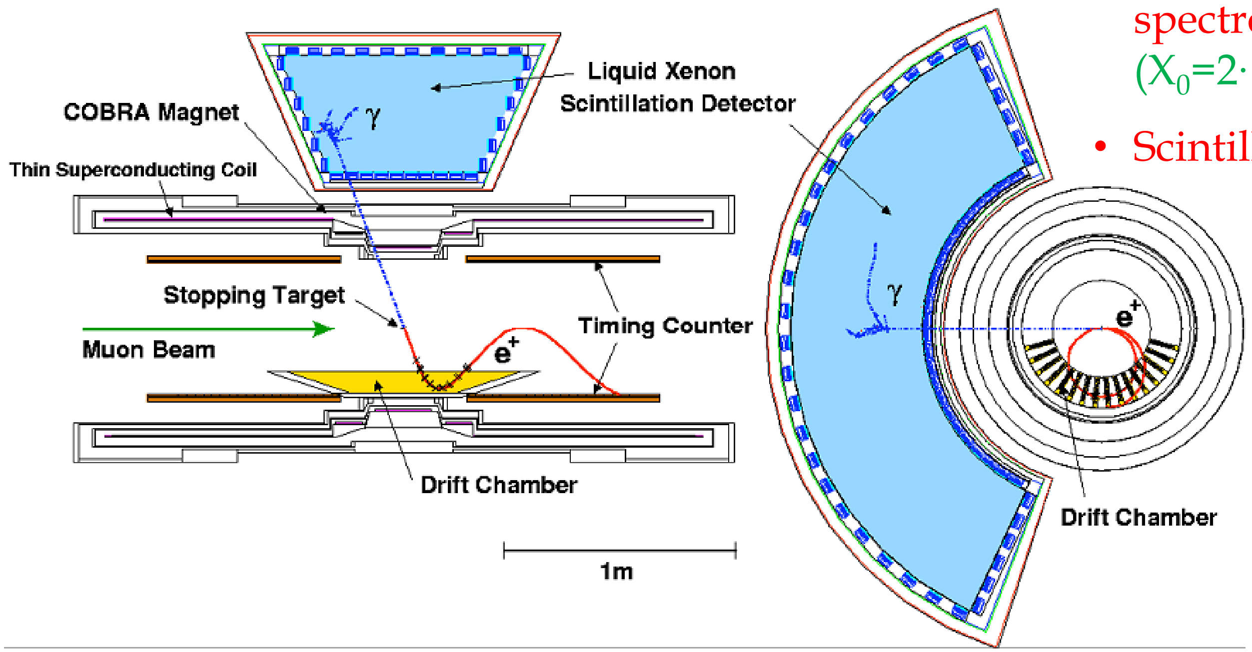
- Liquid Xenon calorimeter for γ detection (scintillation)

  - fast (τ ~ 20÷40 ns)

  - high light yield (70% NaI)

- Thin wall quasi-solenoidal spectrometer & drift chambers ($X_0=2\cdot10^{-3}$) for e^+ momentum

- Scintillation counters for e^+ timing

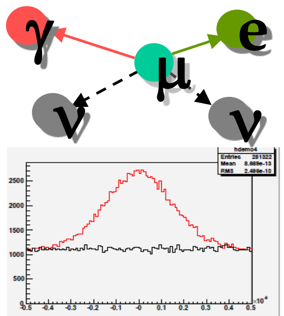


Matter effects must be minimized in order not to spoil the resolution

The Run

- Detector monitoring & calibration
- Performances
- Data summary

Calibration tools



Lower beam intensity < 10^7

Is necessary to reduce pile-ups

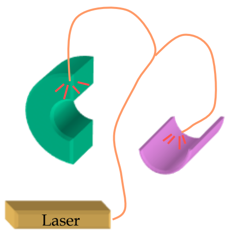
Better σ_t, makes it possible to take data with higher beam intensity

A few days ~ 1 week to get enough statistics

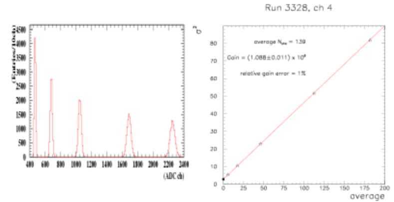
Laser

(rough) relative timing calib.

< 2~3 nsec



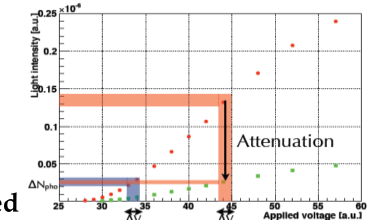
LED



PMT Gain

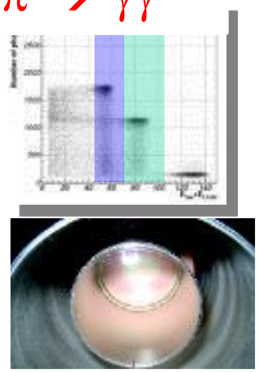
Higher V with light att.

Can be repeated frequently



MEG detector standard calibrations

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



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

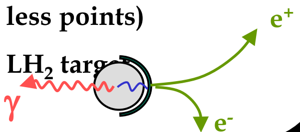
$\pi^0 \rightarrow \gamma\gamma$ (55MeV, 83MeV)

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

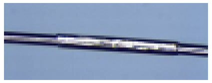
10 days to scan all volume precisely

(faster scan possible with less points)

LH_2 target



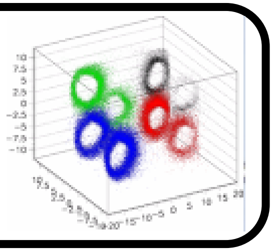
alpha



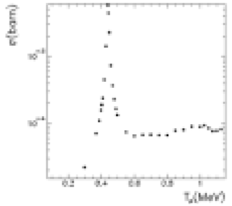
PMT QE & Att. L

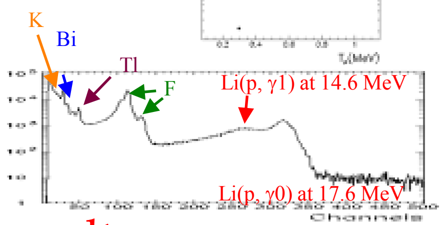
Cold GXe

LXe



(p, γ) reactions





Li(p,γ)Be

LiF target at COBRA center

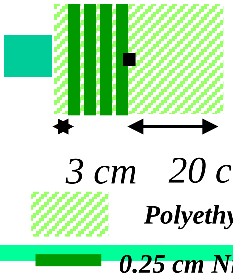
17.6MeV γ

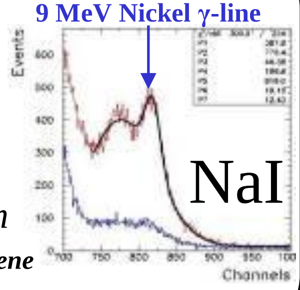
~daily calib.

Can be used also for initial setup

(n,γ) on Ni

Neutron pulsed generator to induce (n, γ)

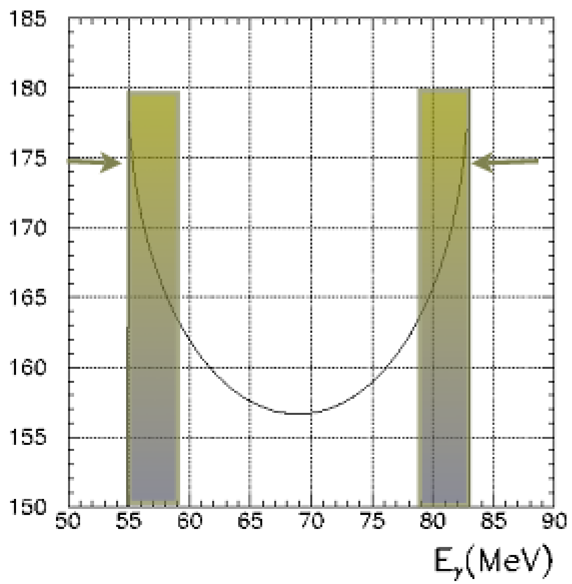


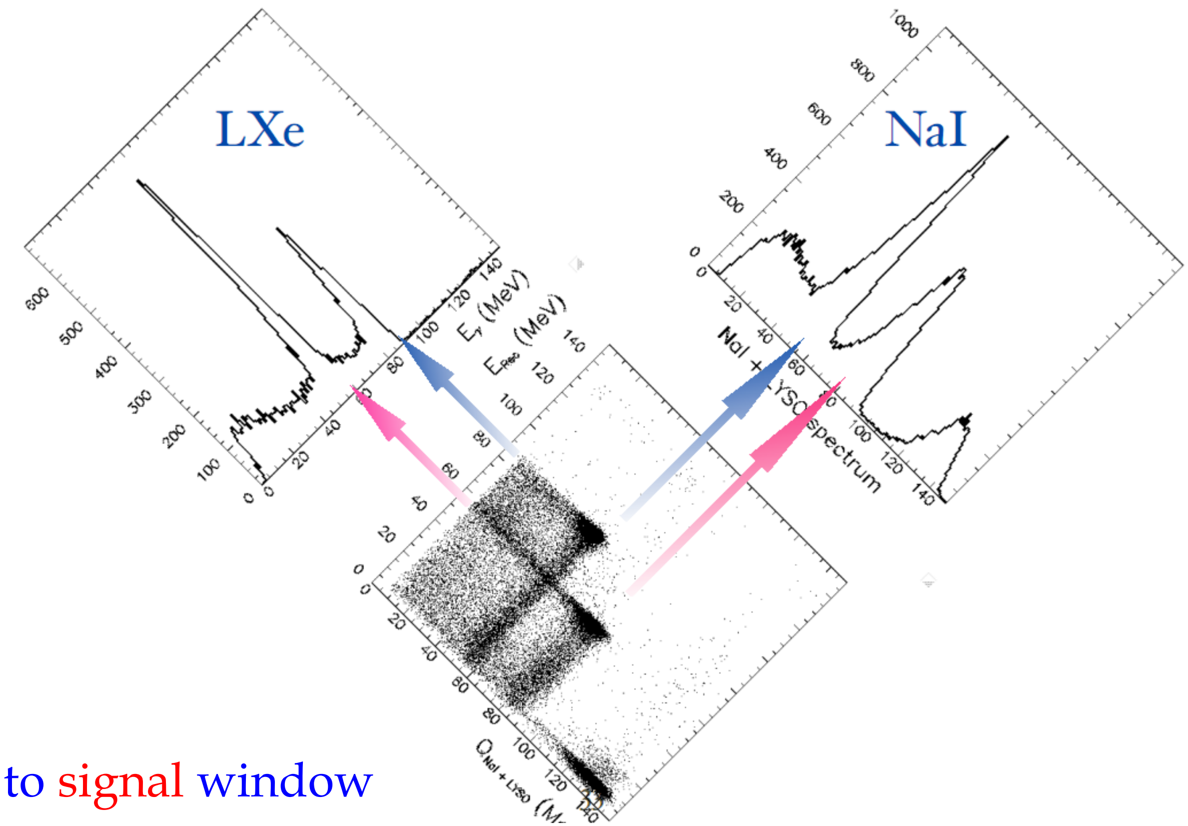


Latest results ...

γ from π-CEX

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

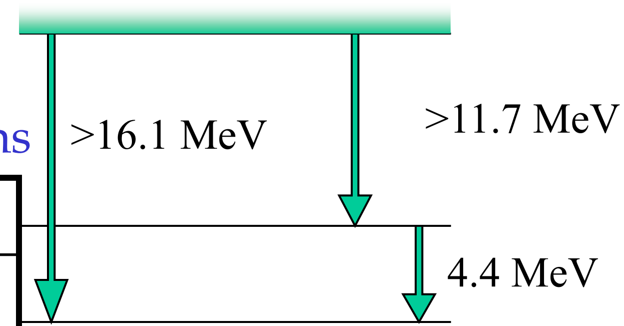




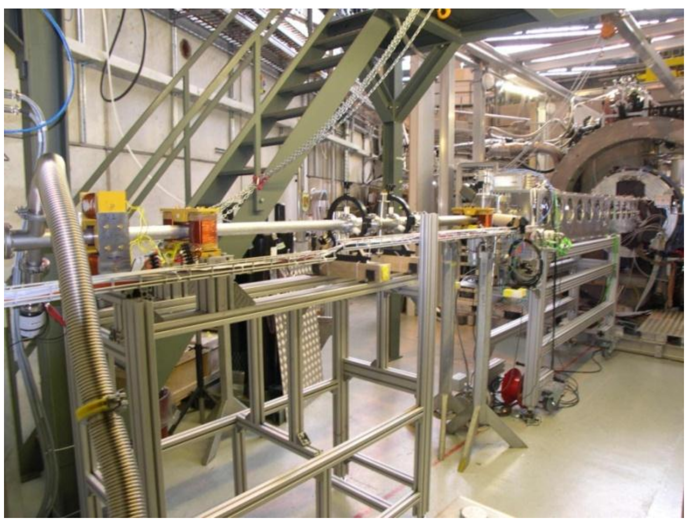
- E_γ = 55 (83) MeV ➔ close to signal window
- liquid H-target
- beam polarity and settings to be changed as well
  → to be used quite seldom (~ 1/year)

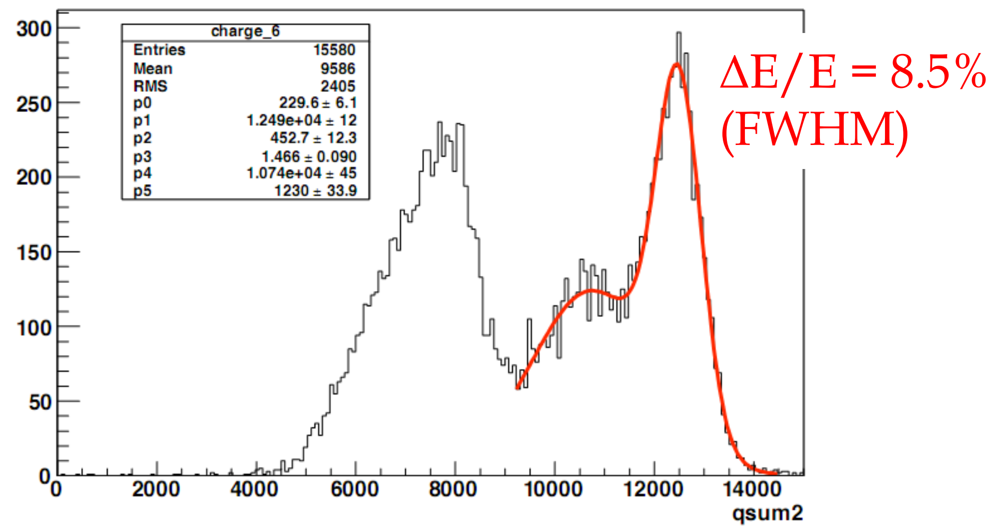
(p,γ) reactions

- Makes us of a Cockcroft-Walton accelerator to deliver tunable-energy protons to a $Li_2B_4O_7$ target
  - Li: high rate, higher energy photon
  - B: two (lower energy) time-coincident photons



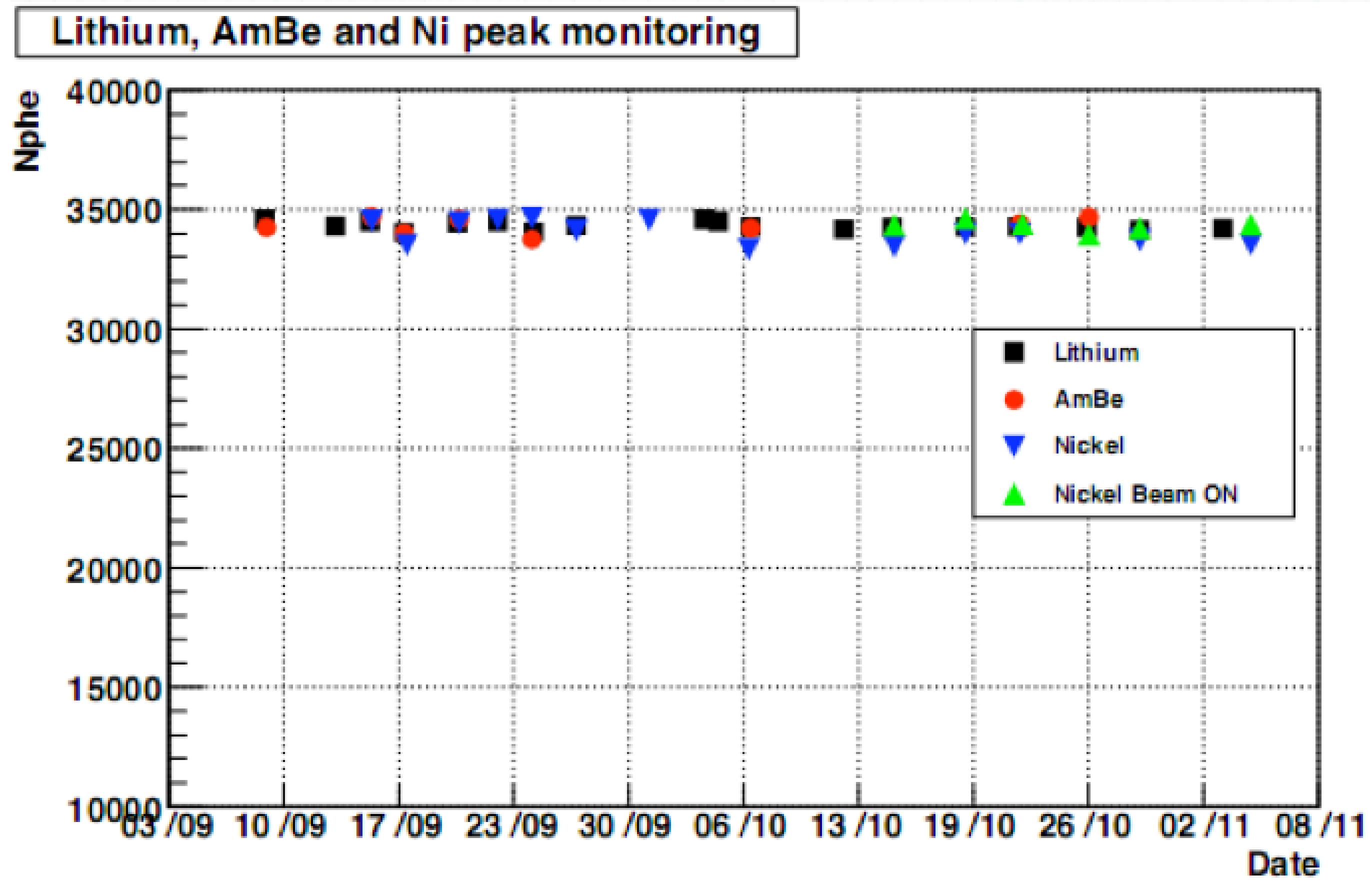
Reaction	E_{res}	σ_{res}	***γ-lines***
Li(p,γ)Be	440 keV	5 mb	(17.6, 14.6) MeV
B(p,γ)C	163 keV	$2\ 10^{-1}$ mb	(4.4, 11.7, 16.1) MeV



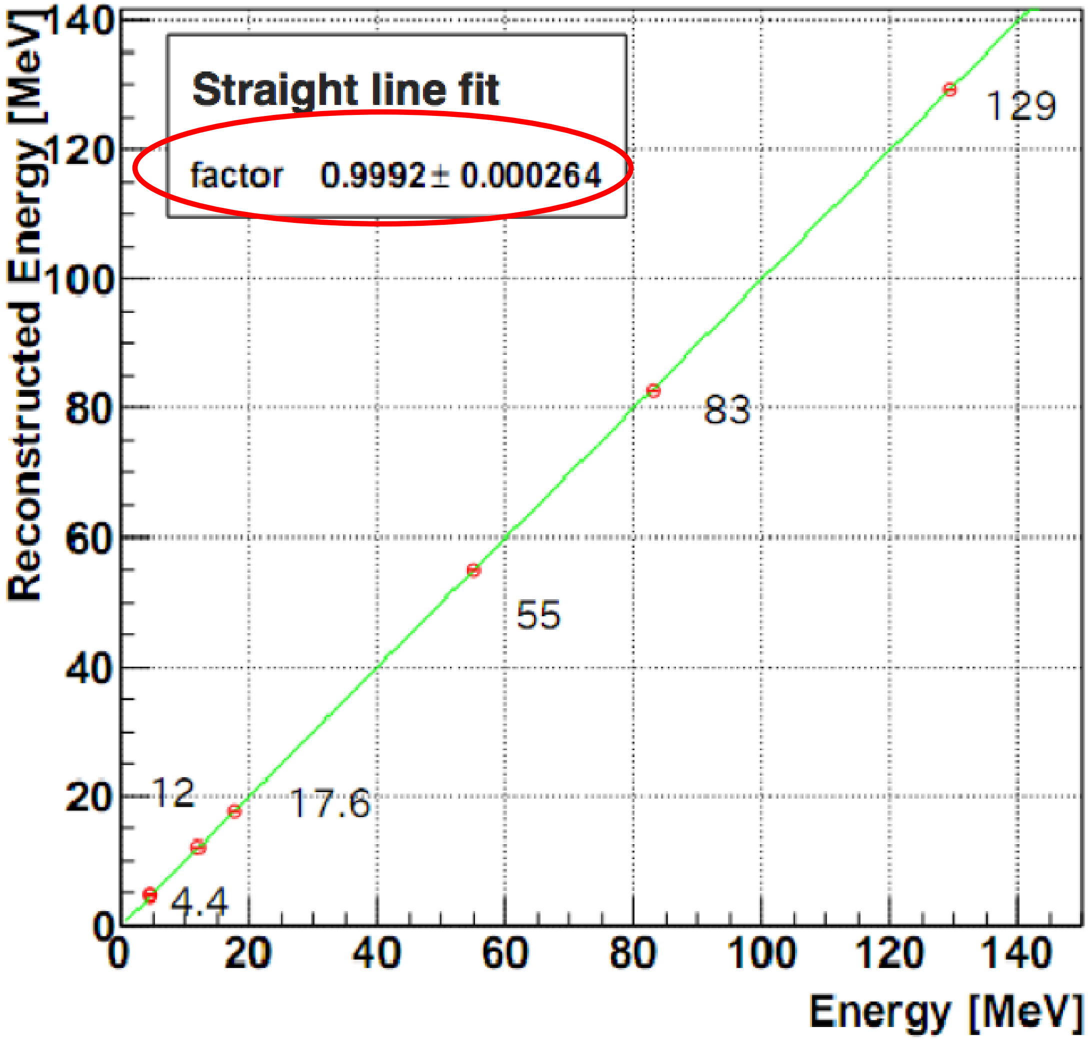


Monitoring

- All methods operational during Run 2010
- Confirm stability of the energy scale within 0.3%

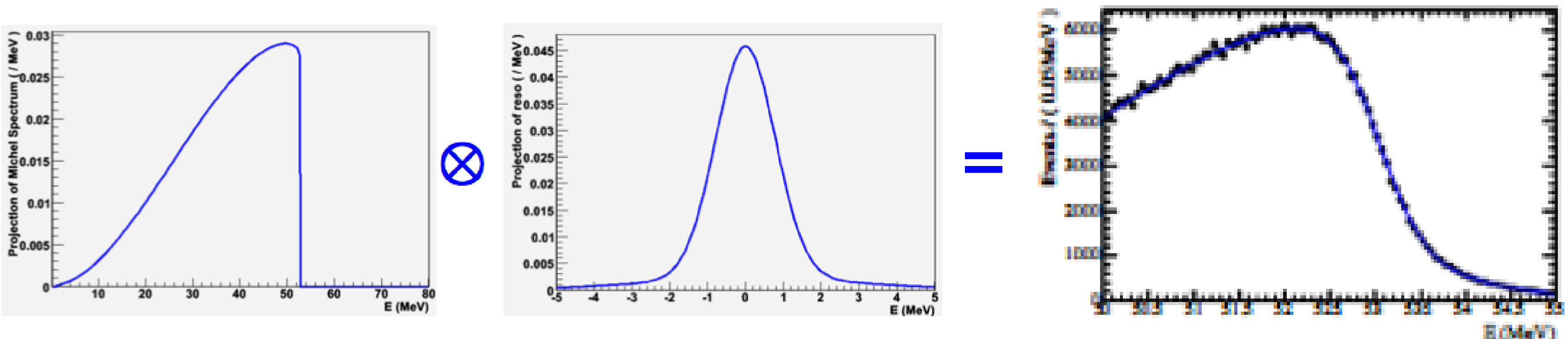


Energy-scale linearity

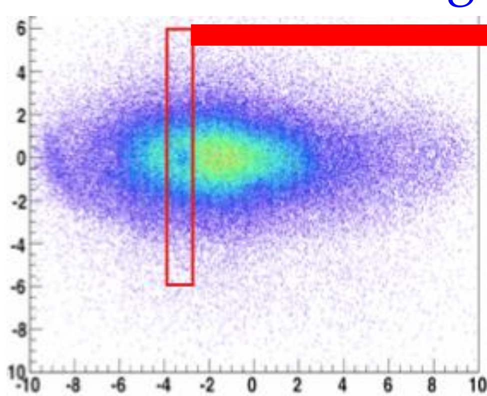


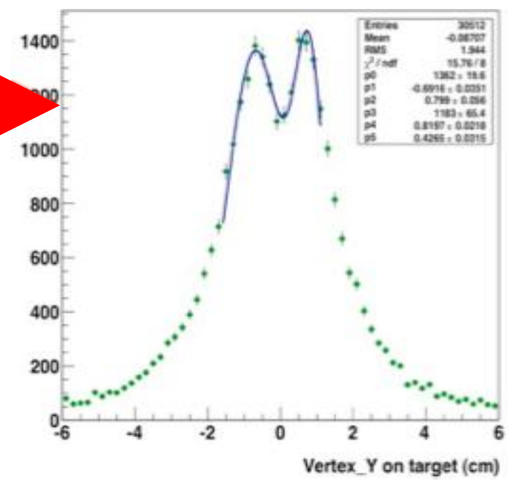
Tracker performance (1)

- No decay available to produce back-to-back particles at these energies (apart from $\mu \rightarrow e\gamma$ ... if any)
- positron momentum ➔ fit of Michel edge



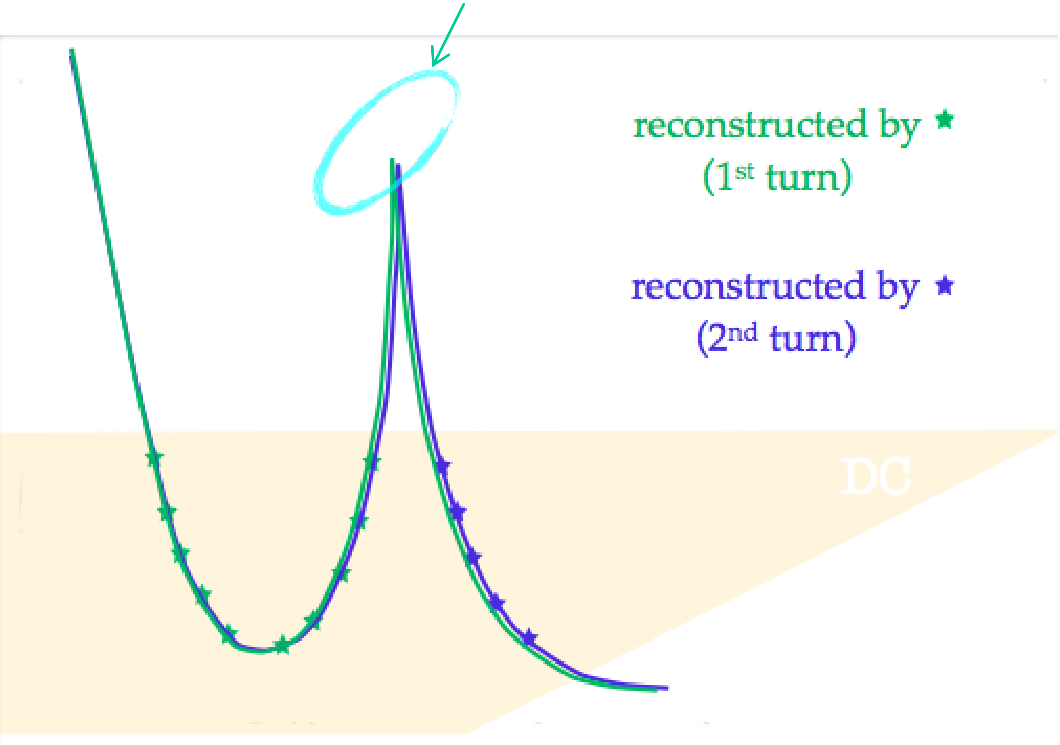
- muon decay vertex ➔ fit to target holes





Tracker performance (2)

- direction ➔ fit of double-turn positrons
  - track segments reconstructed as due to different particles
  - angular resolution obtained from the difference of the two reconstructions at the turning point



New features in 2010

- DC
  - calibrations with Mott-scattered positrons (dedicated beam+target, tunable momentum byte down to 1%)
  - cosmic rays data for relative DC alignment
  - newly reconstructed magnetic field (measurements on a lattice + symmetry + Maxwell equation constraints)
  - Michel events for target-DC alignment

- LXe
  - (n,γ) reactions induced by a pulsed neutron generator

- LXe-DC alignment
  - "radiography" based on Pb-cubes in known positions w.r.t. DC

Results

- The analysis strategy
- Review of results from Run 2009
- Combination of (2009+2010) data

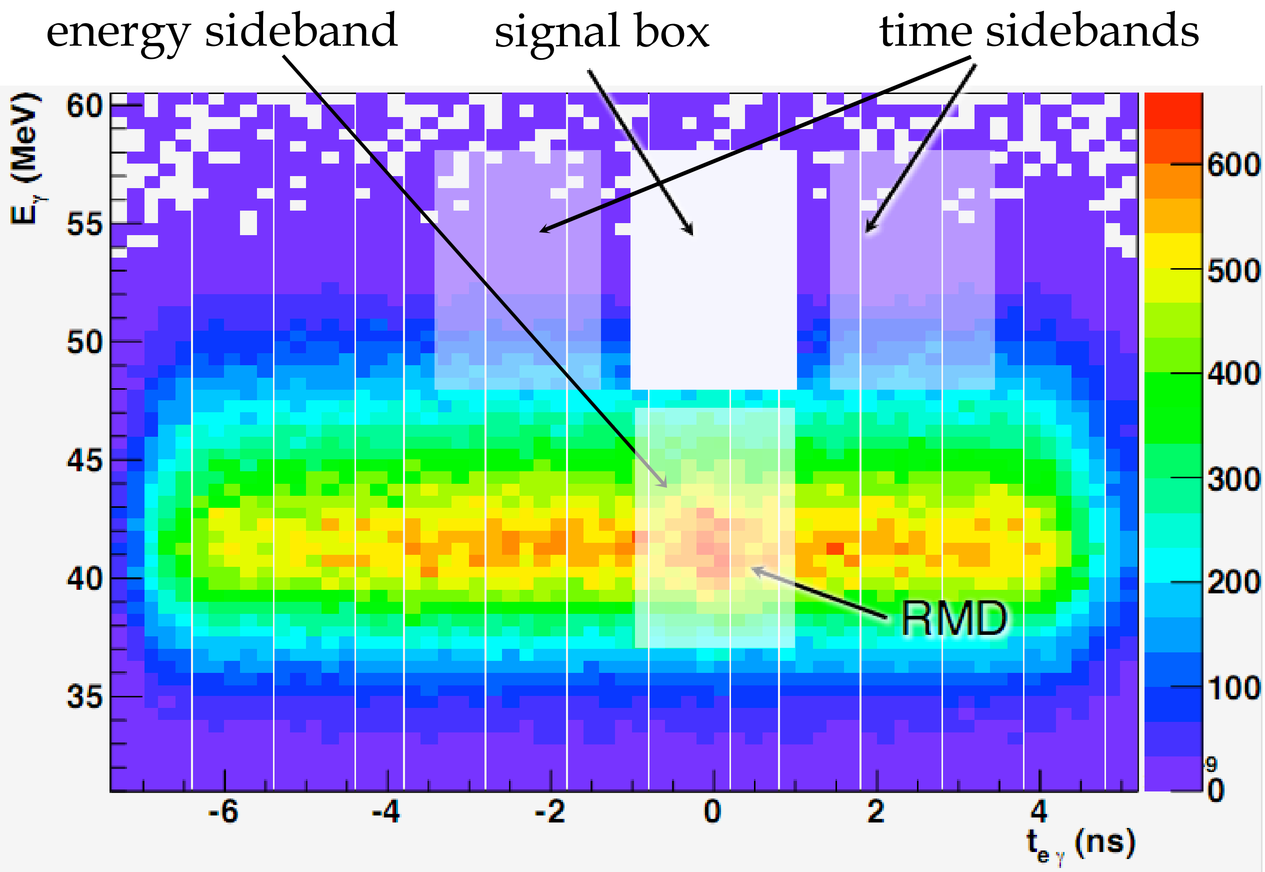
(see J.Adam et al. Arxiv:1107.5547)

Data summary

	2009	2010
Gamma E [σ_R, w>2cm – 63%]	1.9%	1.9%
Relative timing $T_{e\gamma}$ (RMD)	150ps	130ps
Positron E [Michel edge]	330 keV(82% core)	330 keV (79% core)
Positron θ	9.4 mrad	11.0 mrad
Positron ϕ [at zero]	6.7 mrad	7.2 mrad
Positron Z/Y	1.5/1.1(core) mm	2.0/1.1(core)mm
Gamma position	5(u,v)6(w) mm	5(u,v)6(w) mm
Trigger efficiency	91%	92%
Gamma efficiency	58%	59%
Positron efficiency	40%	34%
Muon stopping rate	2.9 10^7 s-1	2.9 10^7 s-1
DAQtime/real time	35/43 days	56/67 days
SES [analysis region]	0.92 10^{-12}	0.44 10^{-12}

Analysis strategy

- likelihood blind analysis strategy
  - blinding observables: E_γ and $\Delta t_{e\gamma}$



pdfs:

- signal: from detector response function
- accidental: from event distribution in data sidebands
- RD: from RD data distribution and trigger simulation (angular cut)

Likelihood fit

- Frequentist approach based on Feldman-Cousins prescriptions with profile likelihood ratio ordering

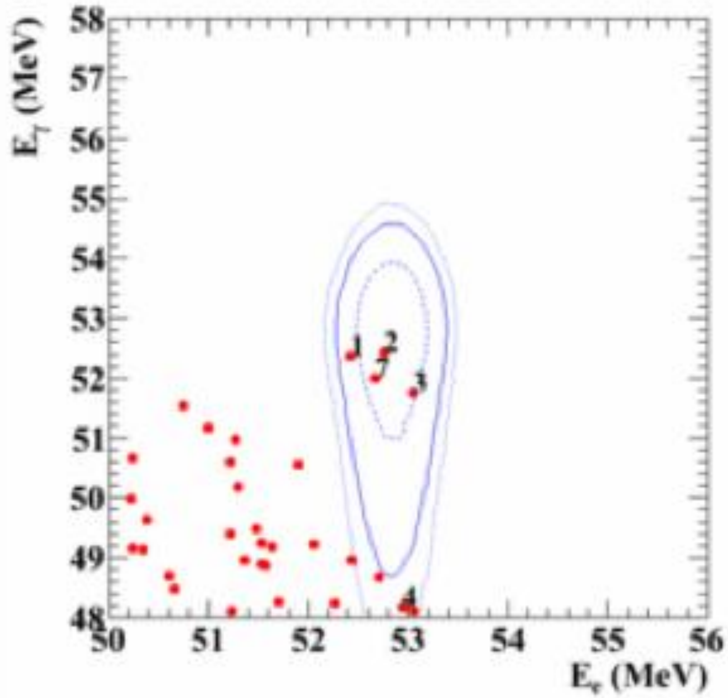
$$\mathcal{L}(\vec{x}_1, ..., \vec{x}_n, R_\diamond, A_\diamond |, \hat{S}, \hat{R}, \hat{A}) = \frac{e^{-\hat{N}}}{\hat{N}} e^{-\frac{1}{2}\frac{(A_\diamond - \hat{A})^2}{\sigma_A^2}} e^{-\frac{1}{2}\frac{(R_\diamond - \hat{R})^2}{\sigma_R^2}} \prod_{i=1}^{N} (\hat{S}s(\vec{x}_i) + \hat{R}r(\vec{x}_i) + \hat{A}a(\vec{x}_i))$$

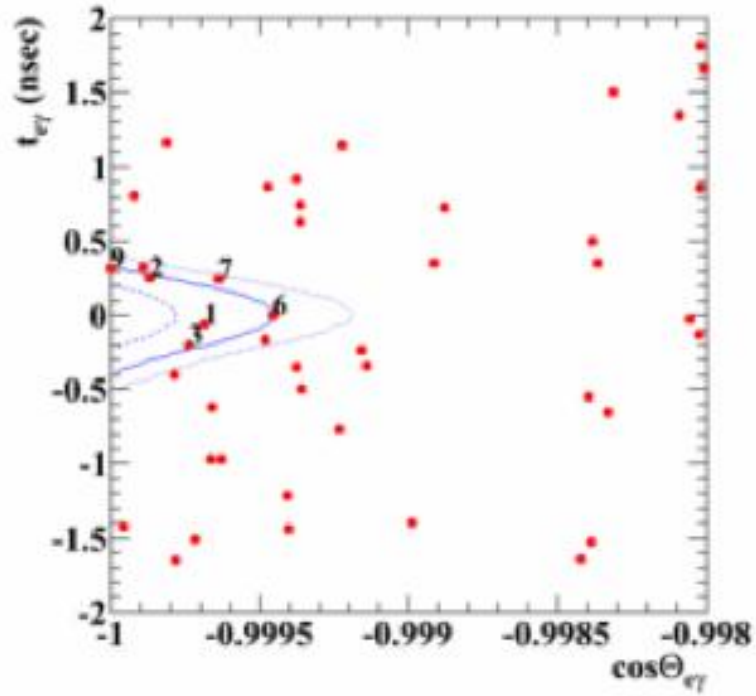
$$LR_p(N_{\text{sig}}) = \frac{\max_{N_{\text{BG}}, N_{\text{RMD}}} \mathcal{L}(N_{\text{sig}}, N_{\text{BG}}, N_{\text{RMD}})}{\max_{N_{\text{sig}}, N_{\text{BG}}, N_{\text{RMD}}} \mathcal{L}(N_{\text{sig}}, N_{\text{BG}}, N_{\text{RMD}})}.$$

- Observables
  - kinematics ($\vec{x}_i$)
  - event counts in the sidebands $R_\diamond$, $A_\diamond$
- Parameters
  - number of signal and background events
  - nuisance parameters added to take systematics into account

Update of 2009 analysis

Selection: $|T_{e\gamma}|<0.278$ns; $\cos\Theta_{e\gamma}<$ 0.9996 $51<E_\gamma<55$ MeV; $52.34<E_e<55$ MeV

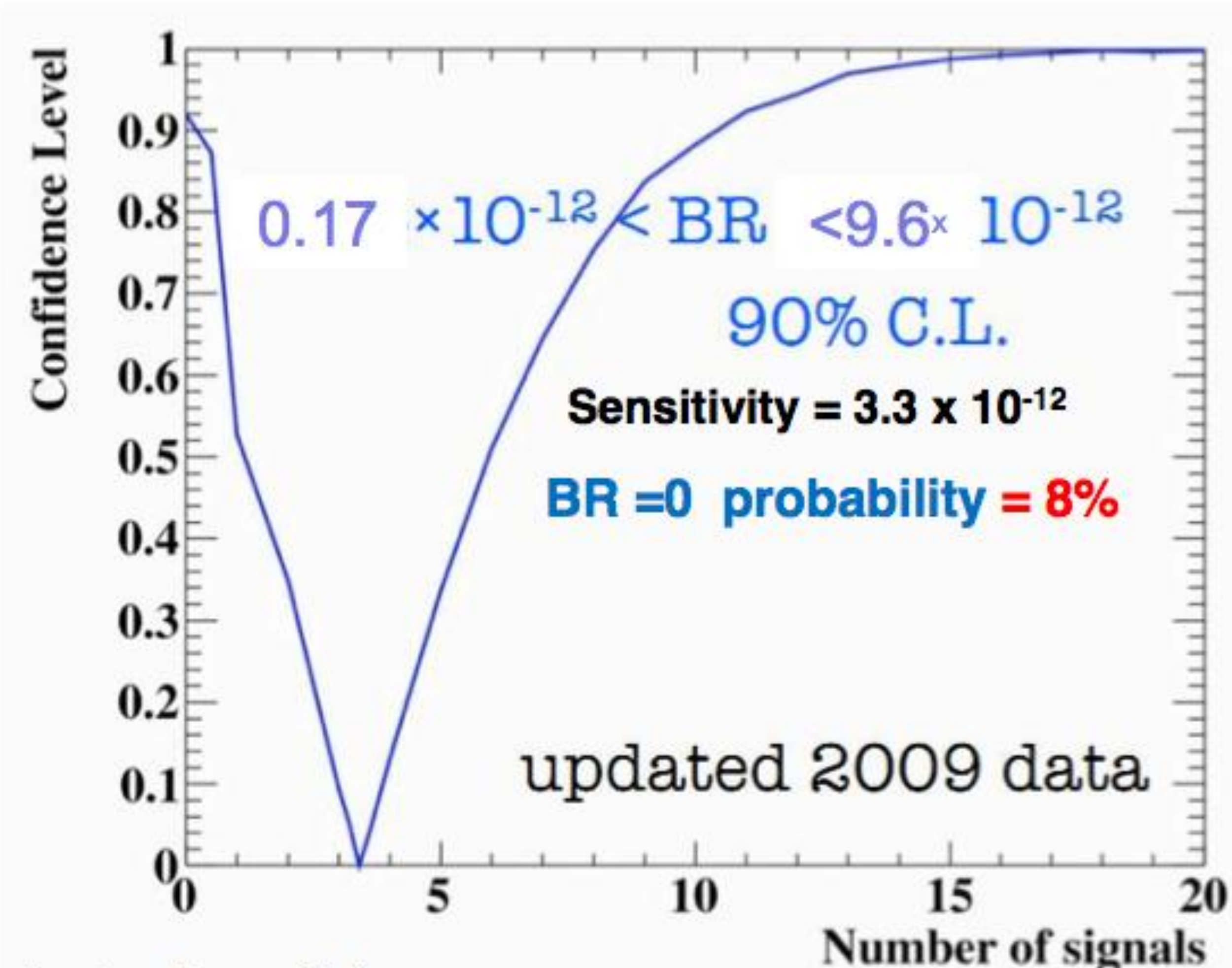




event ranking based on signal/background likelihood ratio

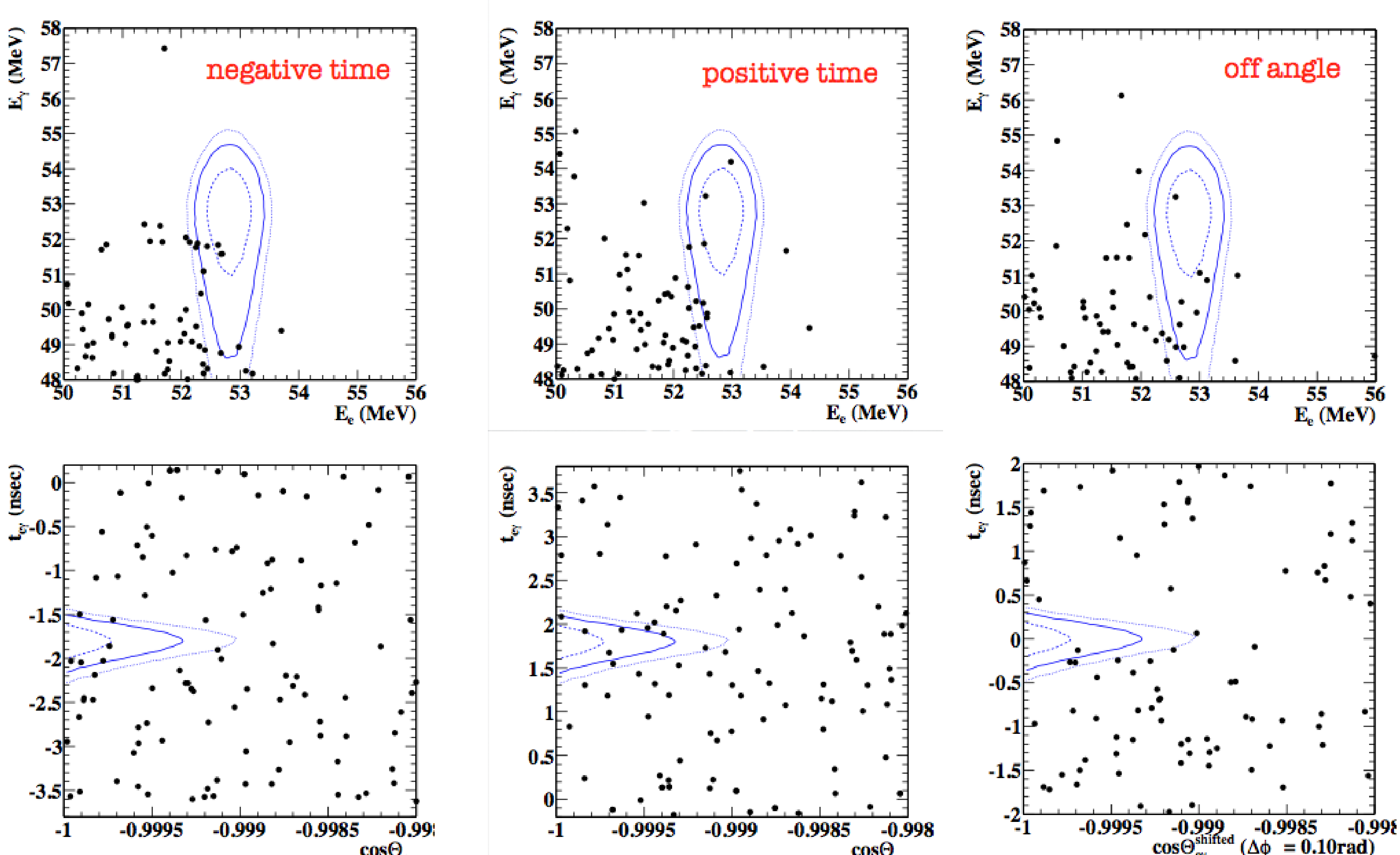
1, 1.64, 2 σ-contours

Likelihood 2009



Nsig best value = 3.4

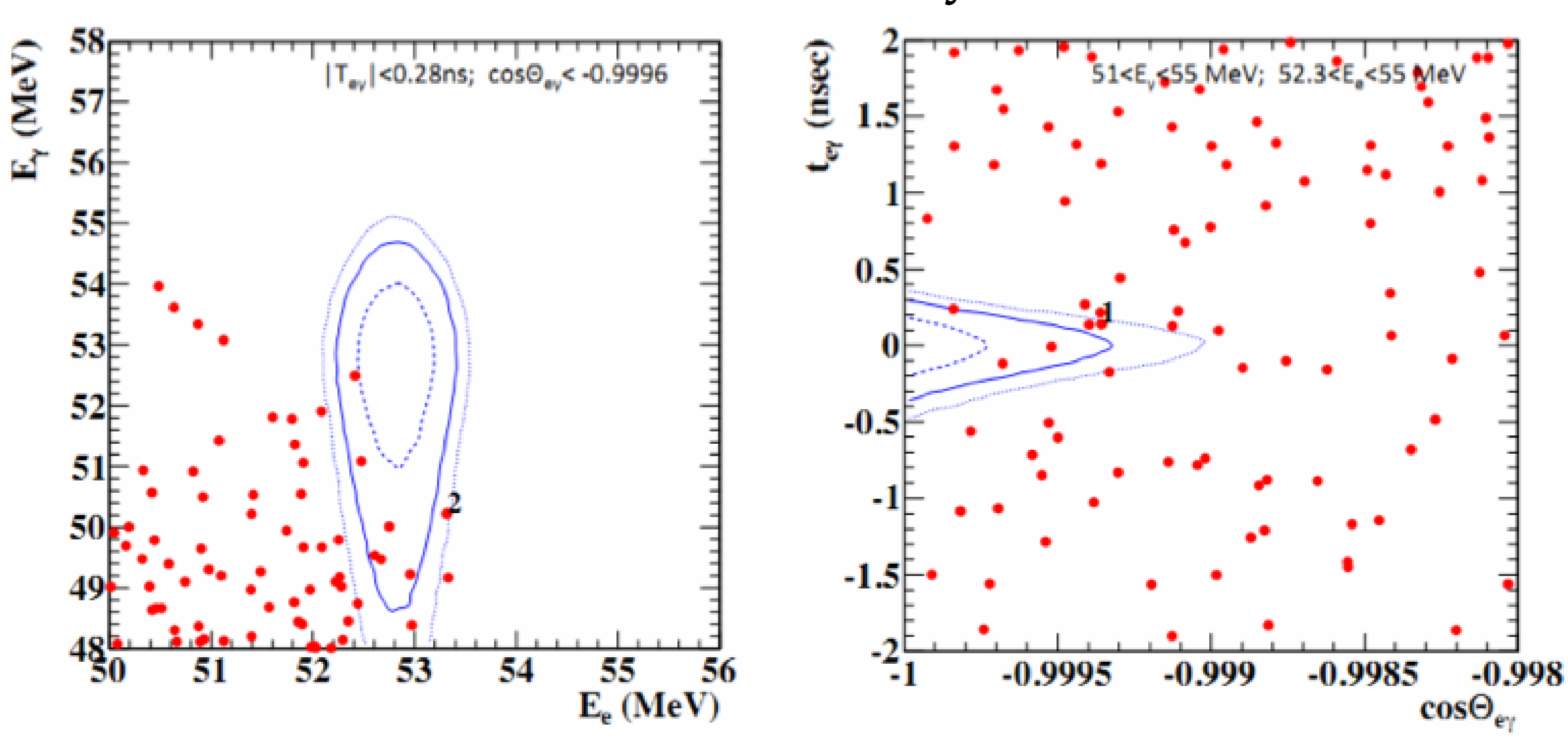
Data 2010, sidebands



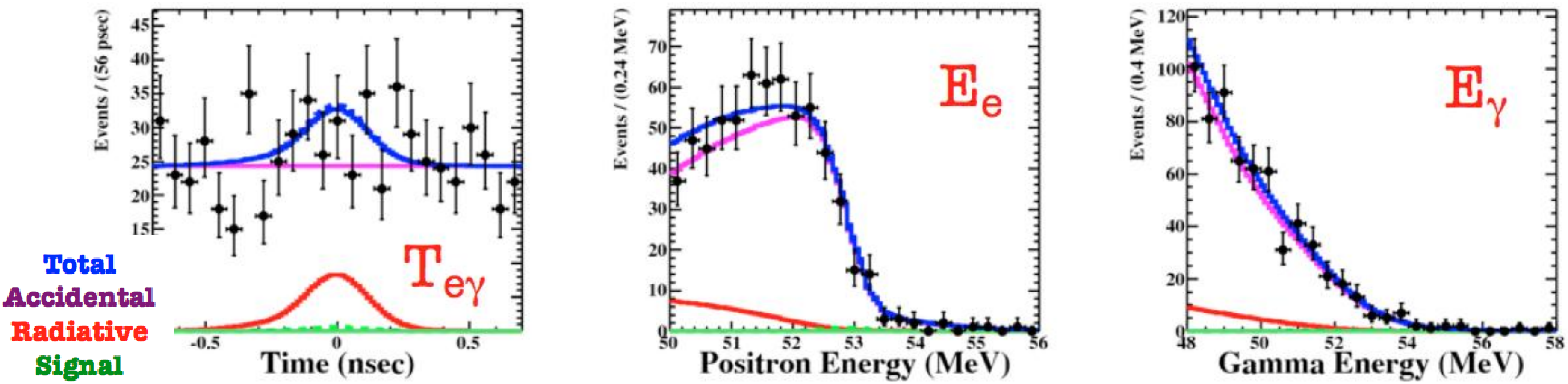
Expected sensitivity = 2.2×10^{-12} (90% CL)

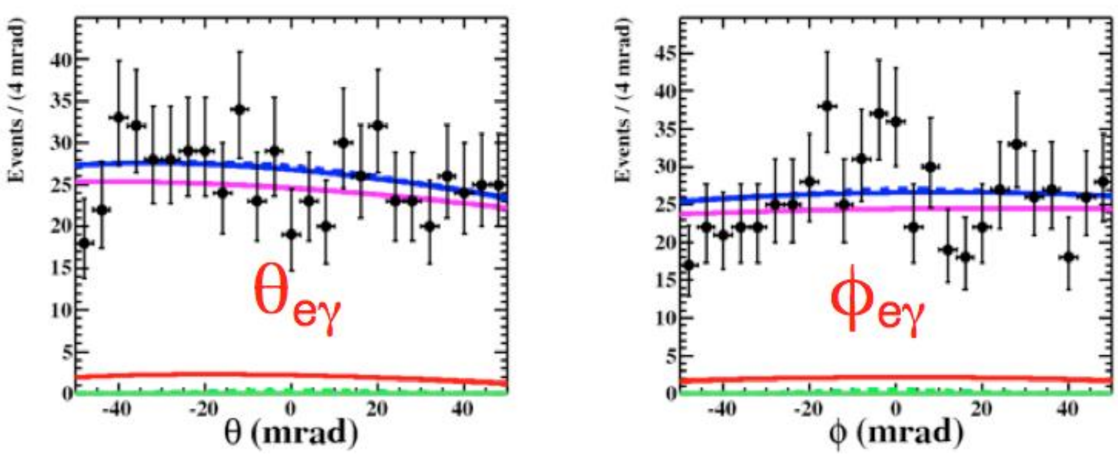
Data 2010, signal region

Data unblind on July the 5th



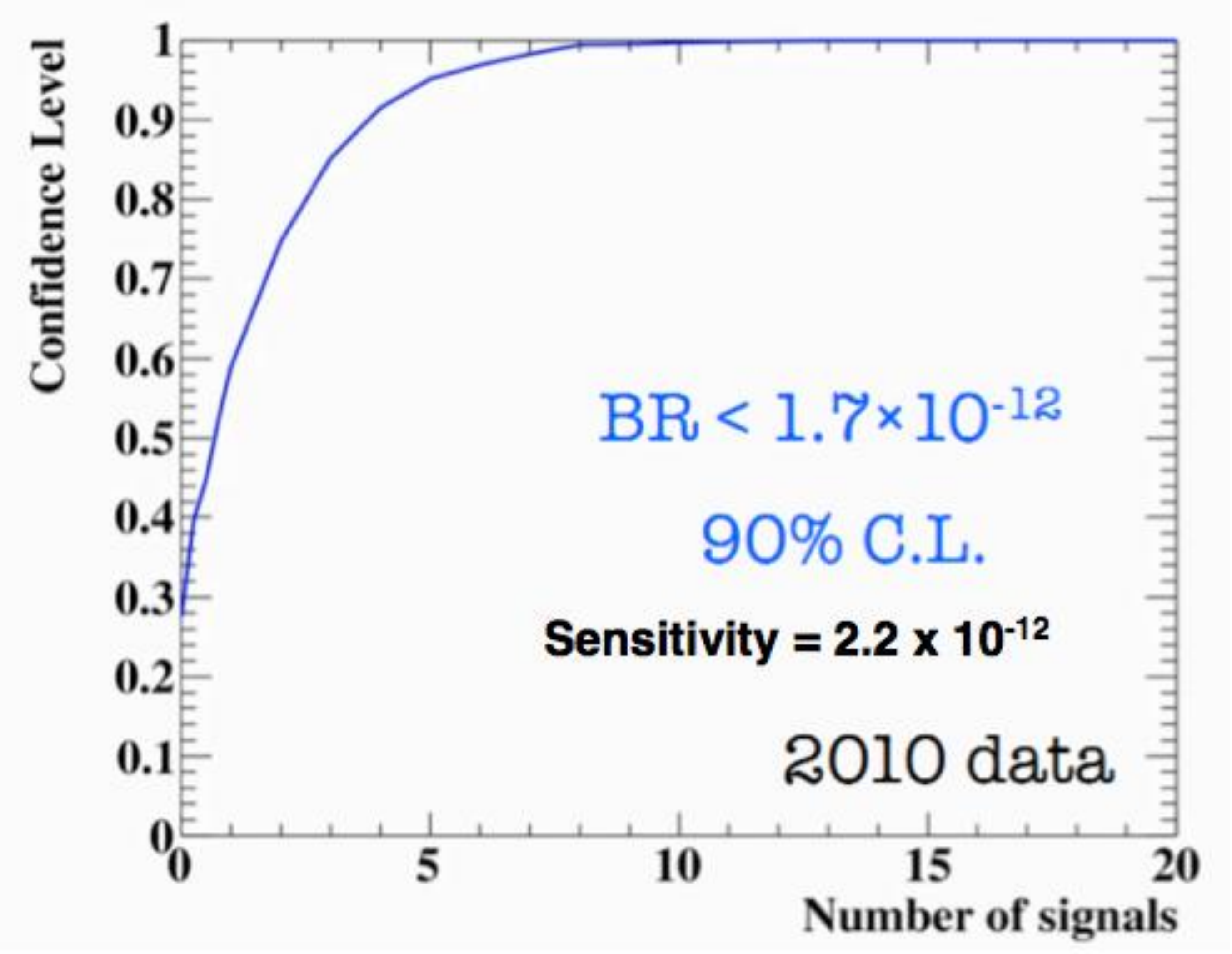
Likelihood fit to data 2010





Param	Best fit	MINOS [1.645σ]
NSIG	-2.2	+5.0 -1.9
NBG	609	+19 -19
NRMD	50.2	+9.2 - 9.2

Limits on 2010

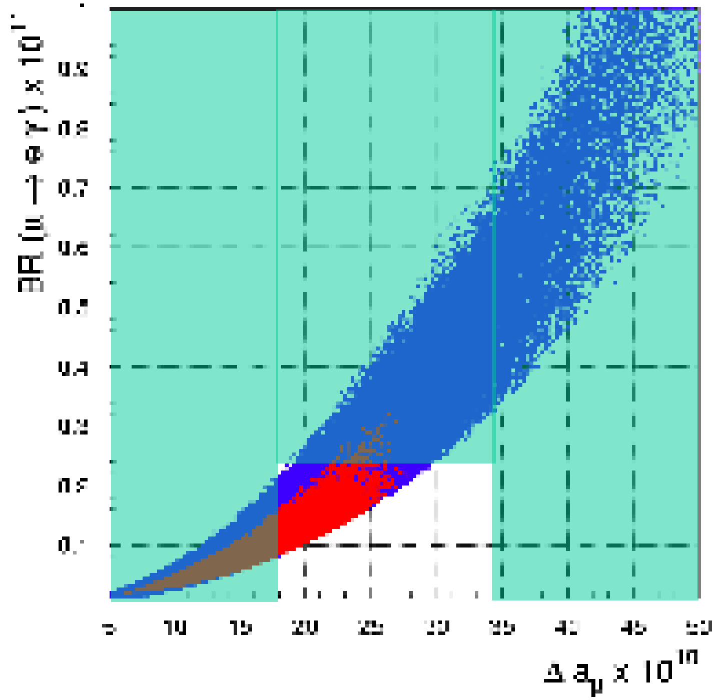


Combined results

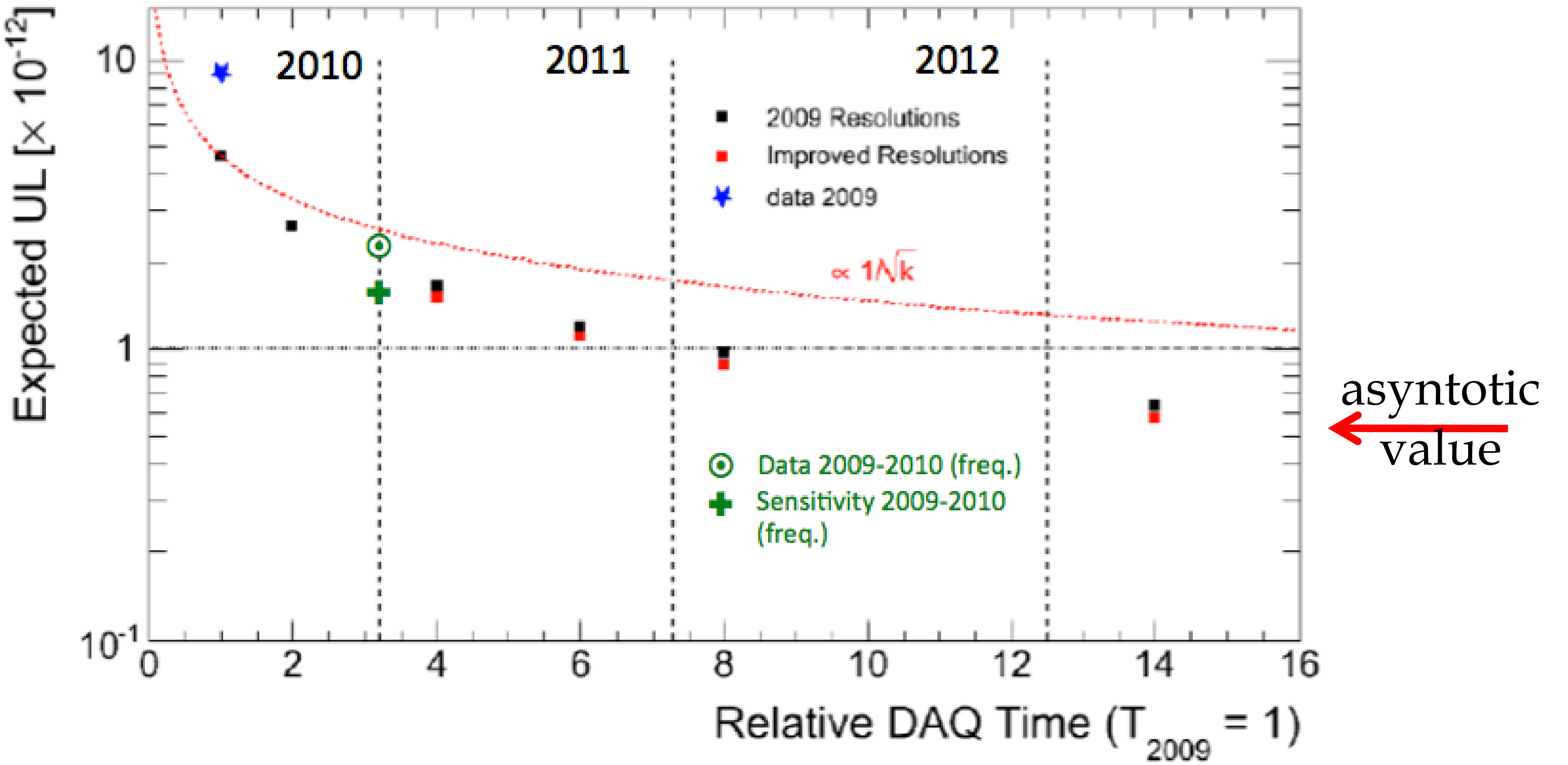
Data set	$\mathcal{B}_{\text{fit}}$	LL	UL
2009	3.2×10^{-12}	1.7×10^{-13}	$.96 \times 10^{-11}$
2010	-9.9×10^{-13}	–	1.7×10^{-12}
2009 + 2010	-1.5×10^{-13}	–	2.4×10^{-12} ← **MEG result**

Sensitivity = 1.6 x 10^{-12}

Systematic error included (2% effect on UL) due to correlation in positron reconstruction, γ-energy scale, normalization



Sensitivity projection



- MEG data taking will continue in 2011 and 2012
  - Sensitivity projection → 5×10^{-13} range

Conclusions

- Past (2009+2010)
  - Data analyzed, no evidence in favour of LFV
  - 90% UL set to 2.4×10^{-12} (factor 5 improvement wrt MEGA)
- Present (2011)
  - DAQ+ trigger, multiple-buffer read-out
    - ➔ trigger efficiency*livetime from 75 % (2010) to 98%
  - New DC HV system, lower noise, best performance ever
- Future
  - Still room for improvements to detector performance
    - $\sigma(E_\gamma) = 1.5\%$, $\sigma(p_e) = 290$ keV, $\sigma(\theta_{e\gamma}) = 8$ mrad
  - Run to continue on 2011 (>2 x 2010 statistics expected) and 2012
    - exclusive πE5 utilization
    - sensitivity projected down to a few times 10^{-13}

Backup slides

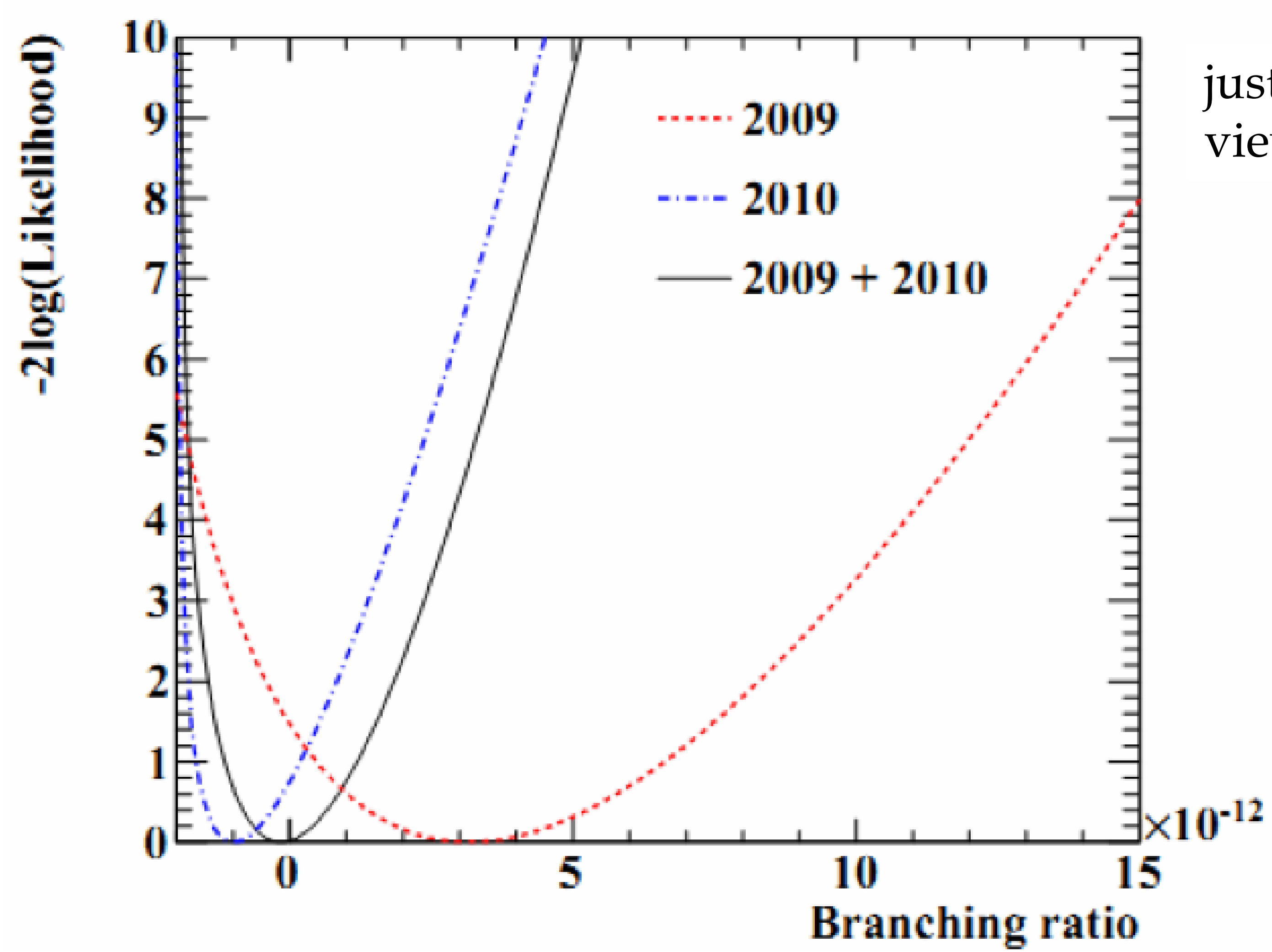
Systematics budget

	Uncertainty	Nsig RMS	UL RMS
$\theta_{e\gamma}$ center	$3.4 \oplus 2$ mrad	1.8	0.7
θ vs ϕ	25%	0.6	0.3
Ee bias for correlation	O(100 keV)	0.2	0.3
$\phi_{e\gamma}$ center	$3.4 \oplus 2$ mrad	0.4	0.3
$\delta\phi_{e\gamma}$ vs δE_e correlation anomaly	Betta	0.2	0.2
δz_e vs $\delta\theta_e$ corr	Beta/Francesco note	0.5	0.2
γ position resolution	0.3(UV), 0.7(W) mm	0.4	0.2
Time center	15 psec	0.5	0.2
E_γ BG shape	Fitting error	0.4	0.1
ϕ_e and vertex resolution	Beta/Francesco note	0.1	0.1
Time signal shape	Fitting error	0.1	0.1
θ_e and vertex resolution	Beta/Francesco note	0.2	0.1
Ee tail bias	250 keV	0	0.1
E_γ signal shape	Fitting error	0.1	0.1
$\delta\phi_{e\gamma}$ vs δE_e corr	Beta/Francesco note	0.1	0.1
$\sigma\phi_e$ vs ϕ_e	Beta/Francesco note	0.1	0.1
E_γ scale	0.31%	0.6	0
Ee Michel shape	Fitting error	0.1	0
Ee bias	25 keV	0	0
Ee signal shape	Fitting error	0	0
BG angle shape	Fitting error	0	0
All		**2.2**	**0.9**

Target geometry

B-field and alignment

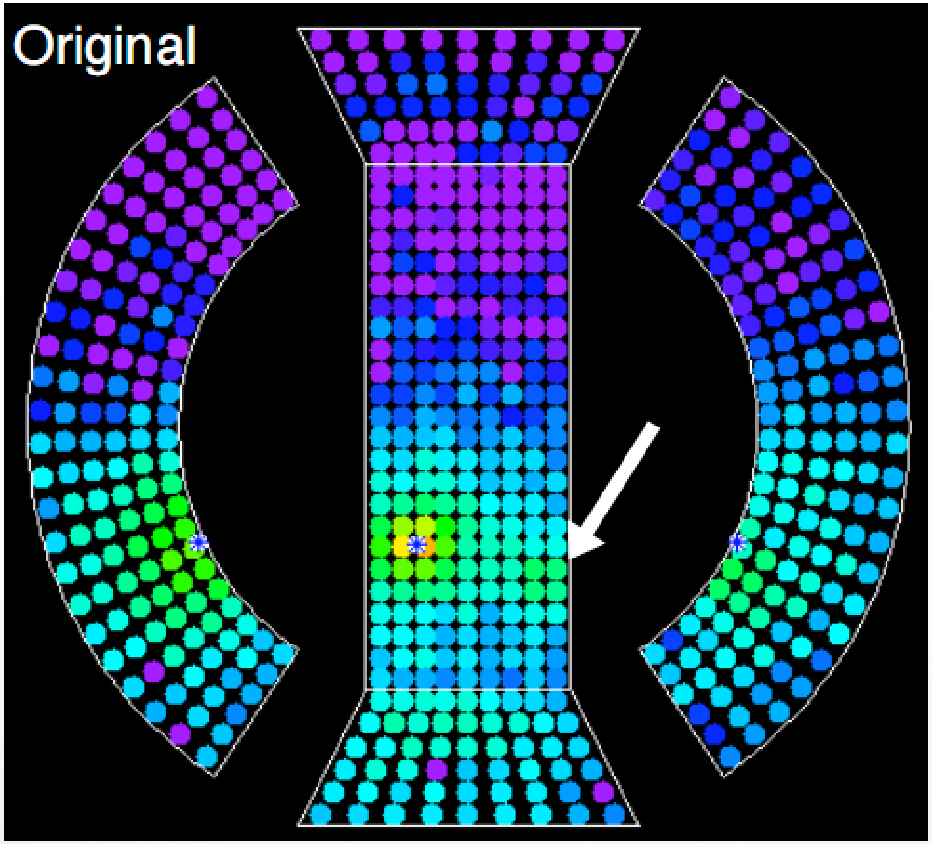
Likelihood vs BR

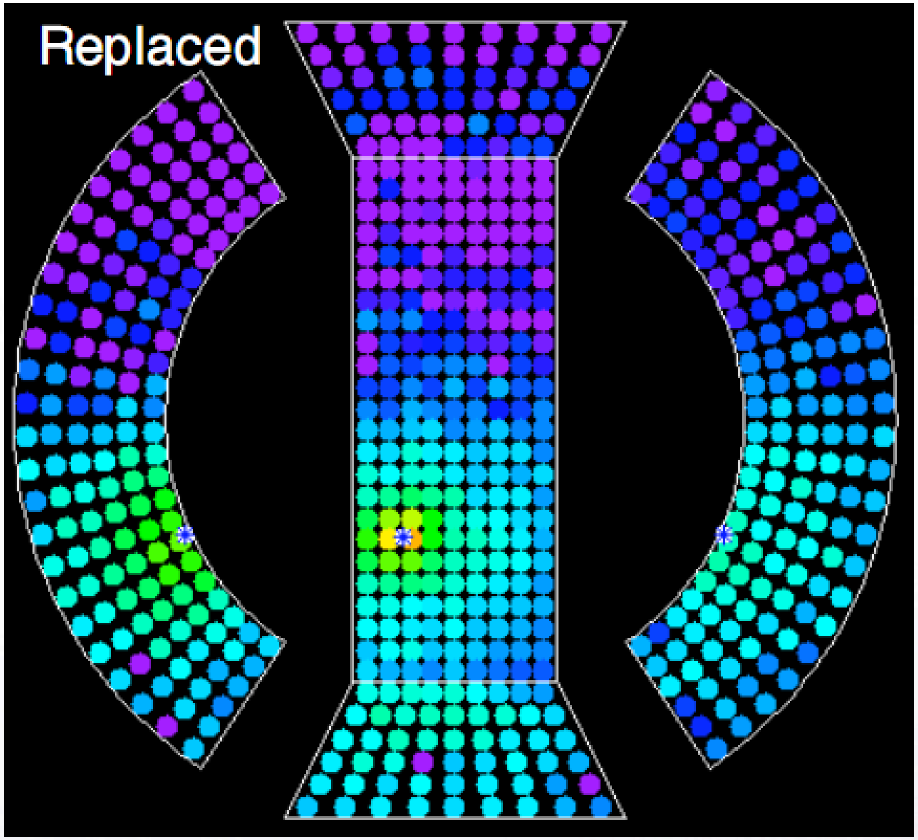


just a pictorial view

Pile-up rejection

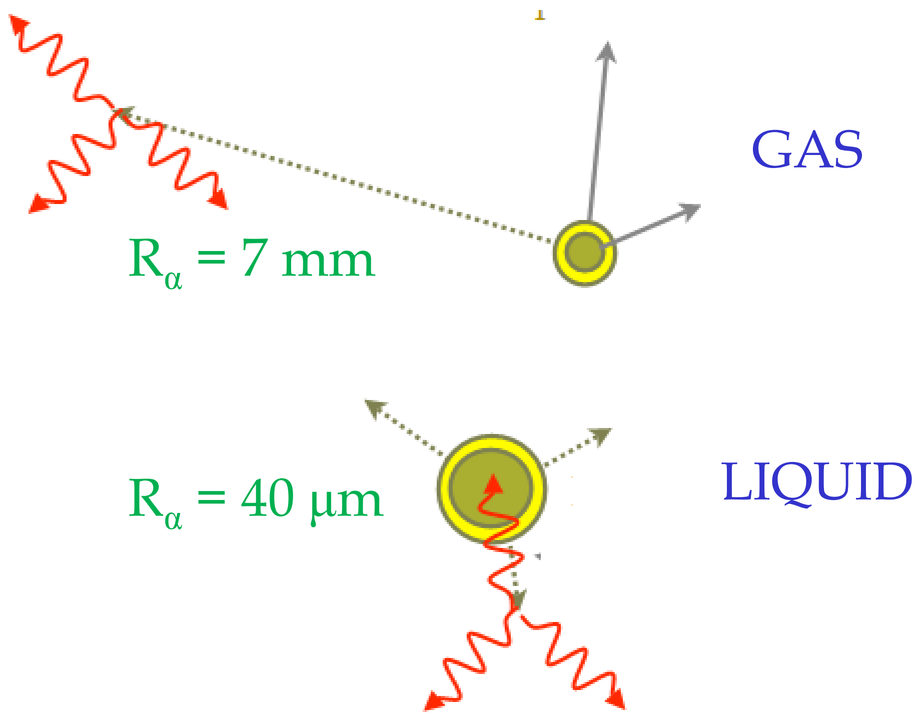
- reconstruction of the main cluster
- replacement of Npe for pile-up cluster with expected values

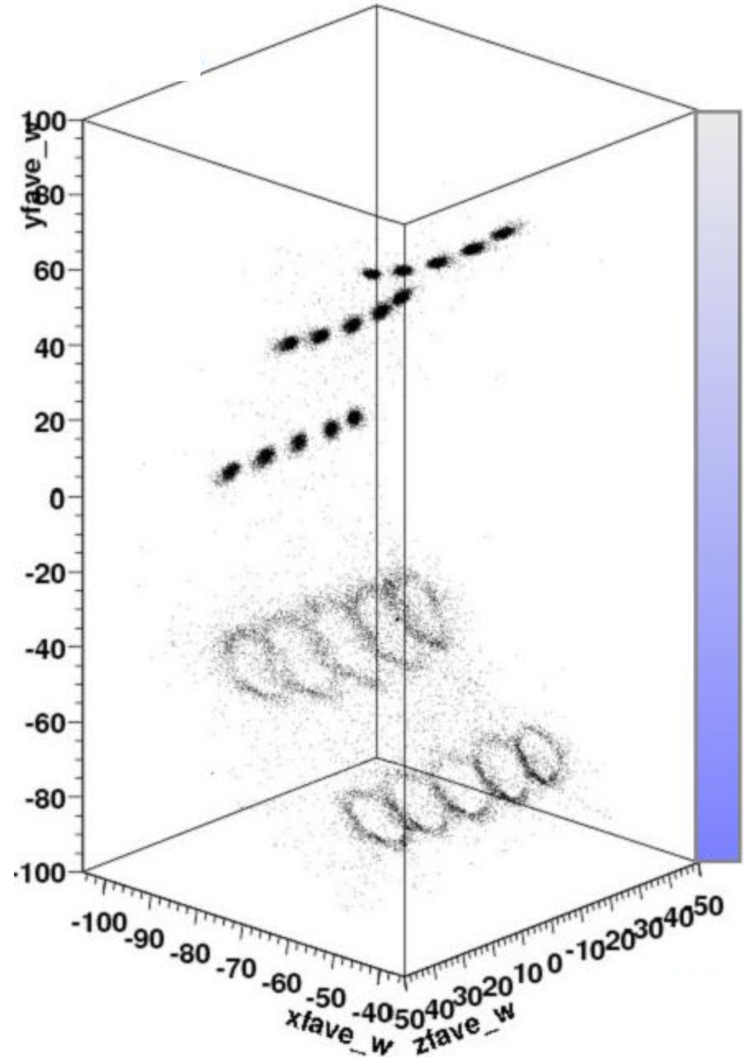




LXe PMT monitoring

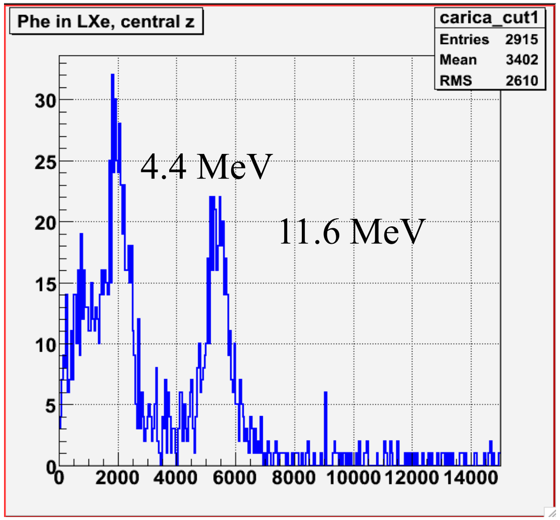
- ^{241}Am sources on ϕ=100μm wires to
  - –determine PMT QEs
  - –monitor absorption length

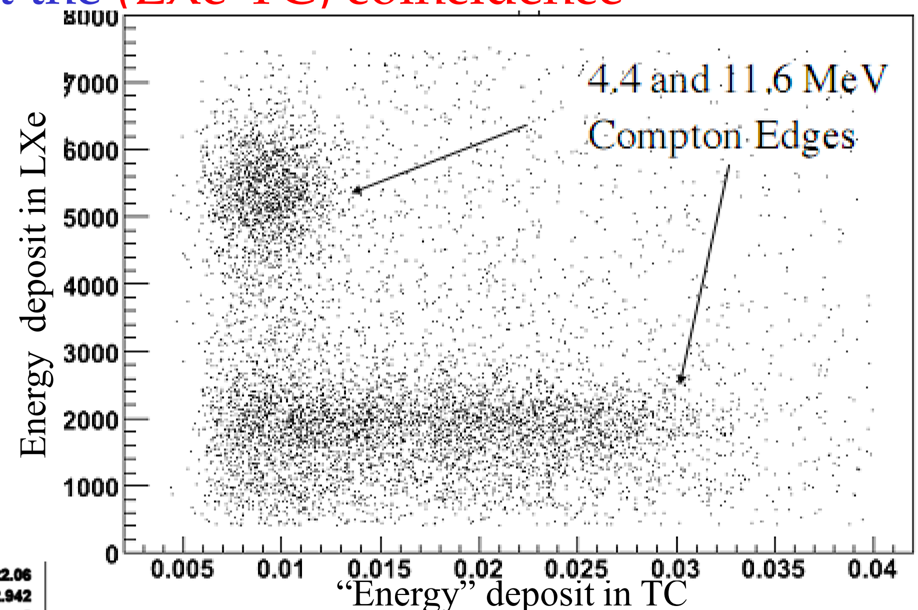


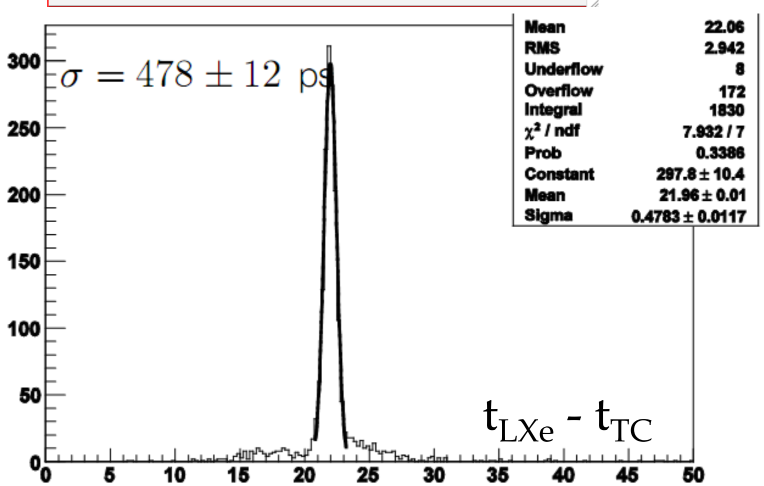


B(p,γ)C reaction

- 2 simultaneous lines to exploit the (LXe-TC) coincidence

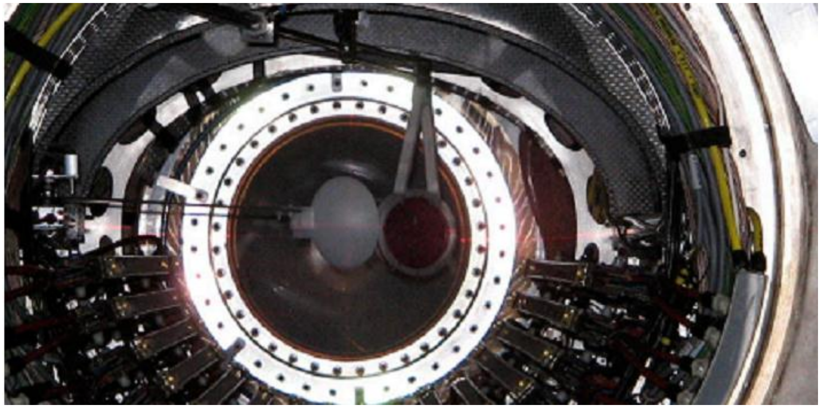






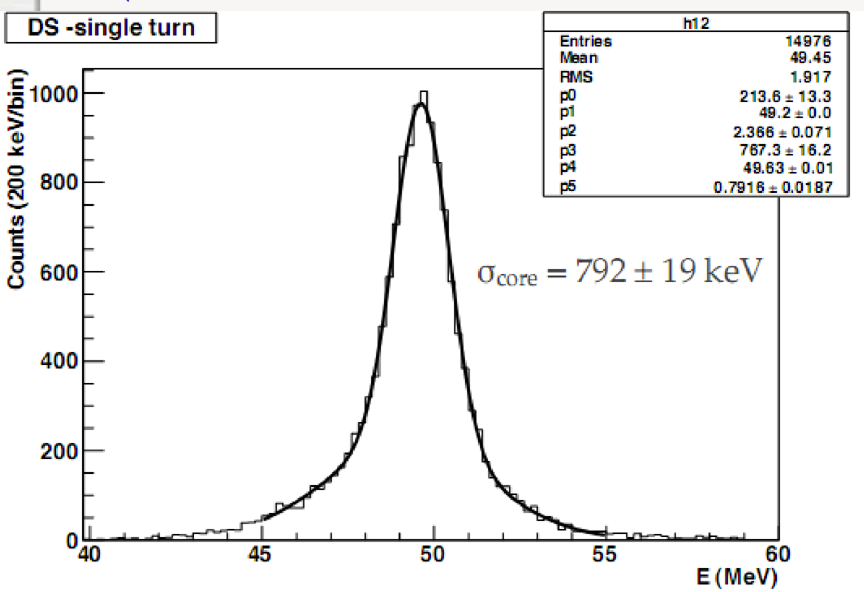
Mott positrons

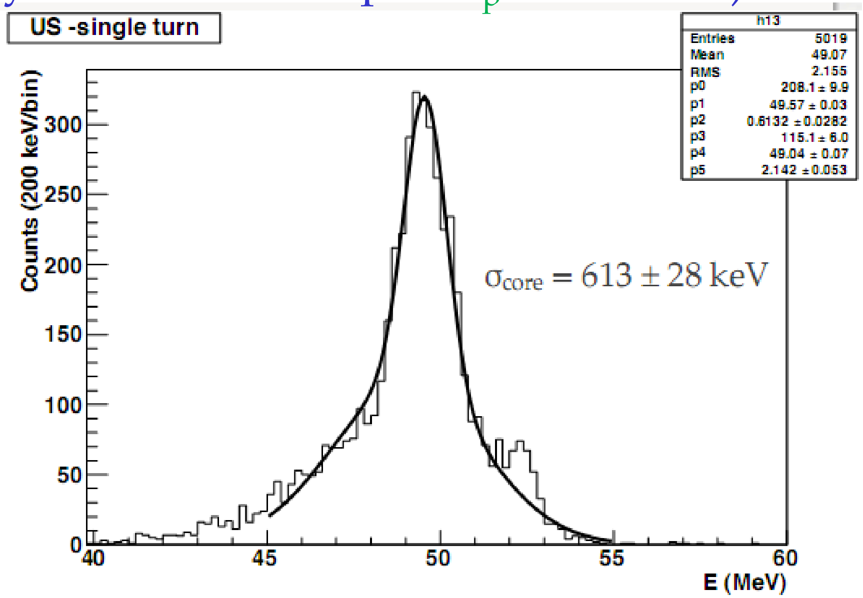
- monochromatic positrons delivered by πE5
  - Rate on target $8x10^8$ e^+/s @I_p = 2 mA e Δp/p ~ 7%
  - momentum spread tunable fino a Δp/p ~ 1% (at a cost of a rate reduction)
- Tunable momentun around 50 MeV (byte ~ 30 keV)
- Scattered by a 2 mm-thick ^{12}C target (known cross section)
  - absolute efficiency



Results e future objectives

- test done at the beginning of Run 2010 (7 h live time)
  - p = 40, 45, 50 MeV
- Non-optimal target-beam angle (= 45°)
- different resolution for US ($\theta > 90°$) e DS ($\theta < 90°$) positrons
  (in both cases the beam momentum byte contributes up to σ_p = 480 KeV)

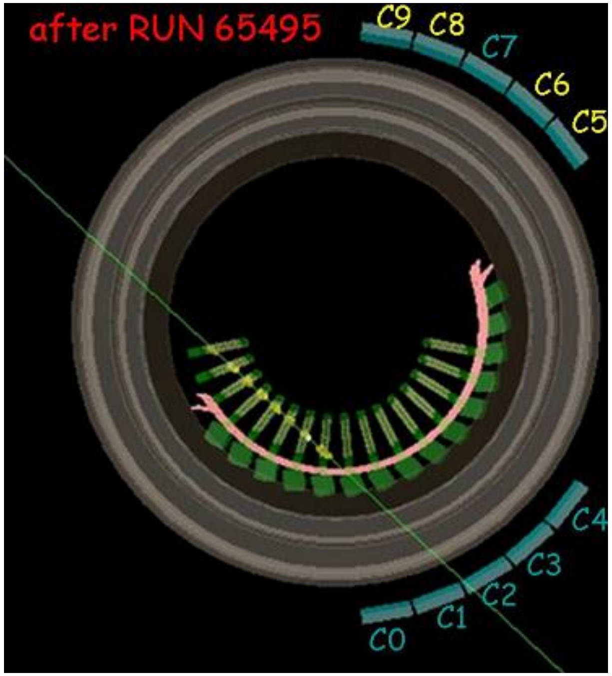




- New DAQ going on (angle = 35°) before Run 2011
- Further test: relative DC-COBRA alignment

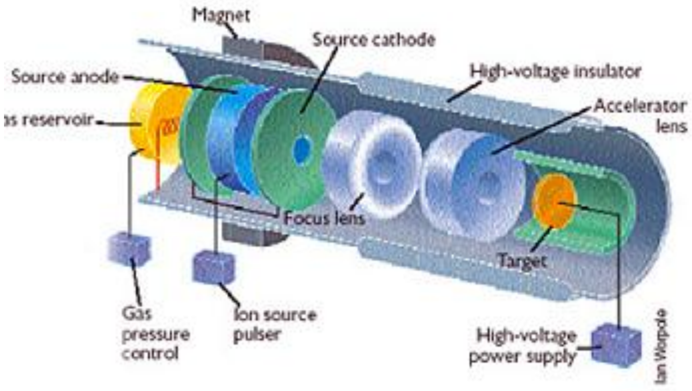
DC alignment with cosmics

- DC frame embedded in the absolute detector frame (=magnet frame) thanks to an optical survey (poor resolution ~ 1 mm)
- previous method based on hit-residual minimization of Michel positron tracks
- new procedure utilizing cosmic rays cosmici (field OFF)
  - → independent of the field and tracking algorithm
  - → pile-up free
  - → higher momentum tracks (p ~ O(1GeV)) ➔ fewer matter effects
- "analytical" χ^2 minimization as a function of alignment parameters (similar to Millipede algorithm used by CMS CMS note 2008/008)



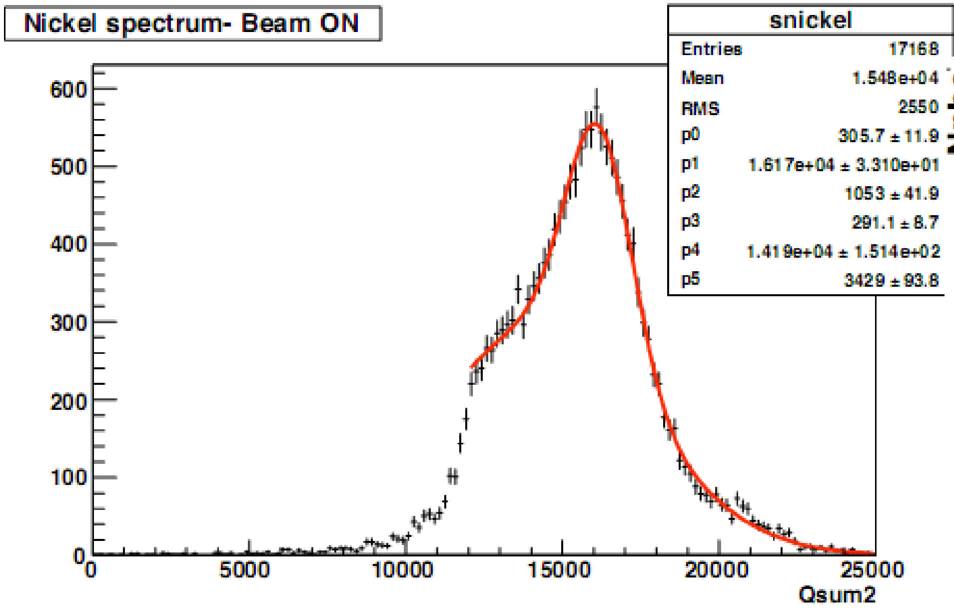
The neutron generator

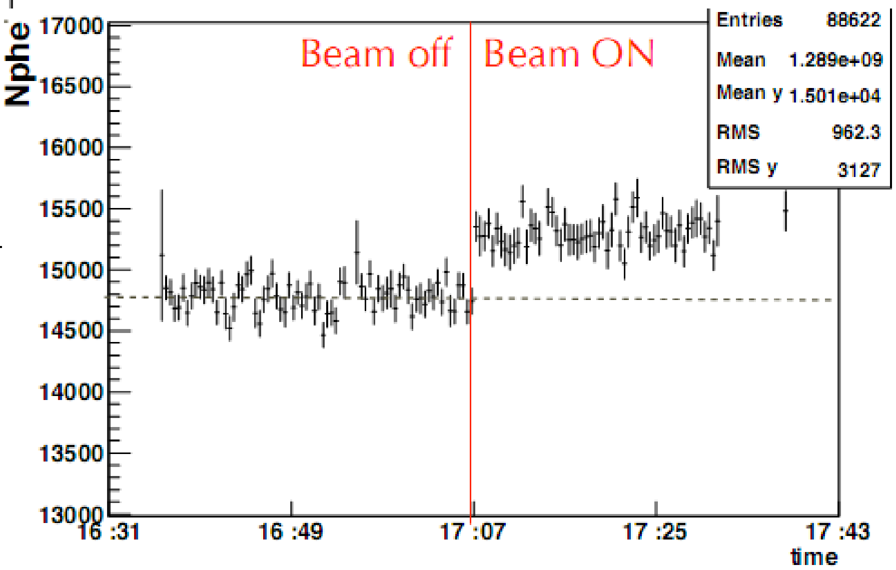
- LXe calibration
  - Need to monitor the calorimeter during normal run conditions
  - α-events already available
  - To be cross-checked with m.i.p.
- Pulsed generato installed
  - Thermofisher (based on D-D fusion)
  - 9 MeV γ-line from thermal neutron capture on Nickel
  - new trigger in coincidence ($\Delta T = 100\ \mu s$) with the plasma extraction pulse



Energy spectrum

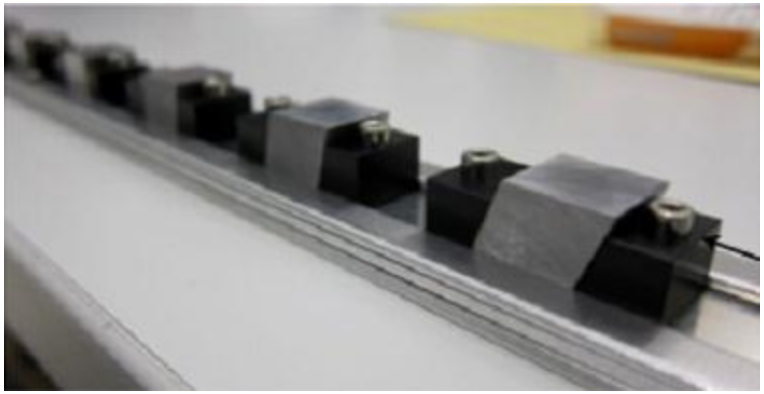
- Events acquired with a pre-scaled trigger
- Dominating over the beam-related γ-background
- Allows to take beam off/on effects (related to the different PMT working conditions under control)

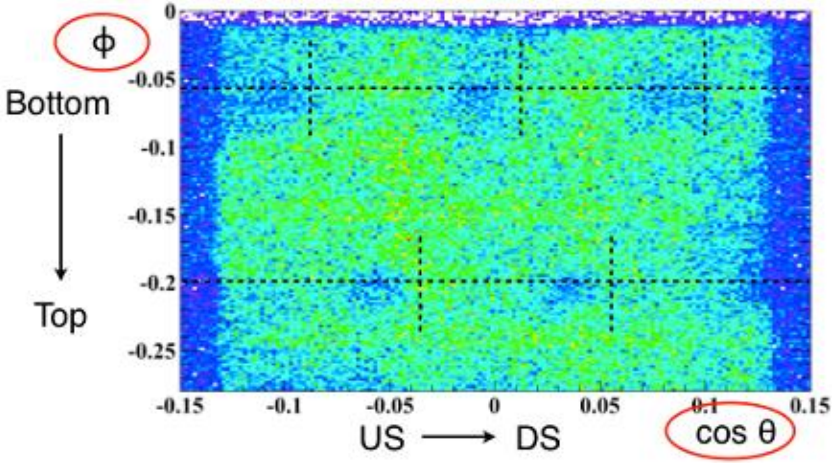




DC-LXe alignment

- crucial test of the back-to-back condition of the decay products
- implemented methods:
  - Cosmic rays
  - LXe-radiography by means of Pb-cubes in known positions in the absolute detector (COBRA) frame

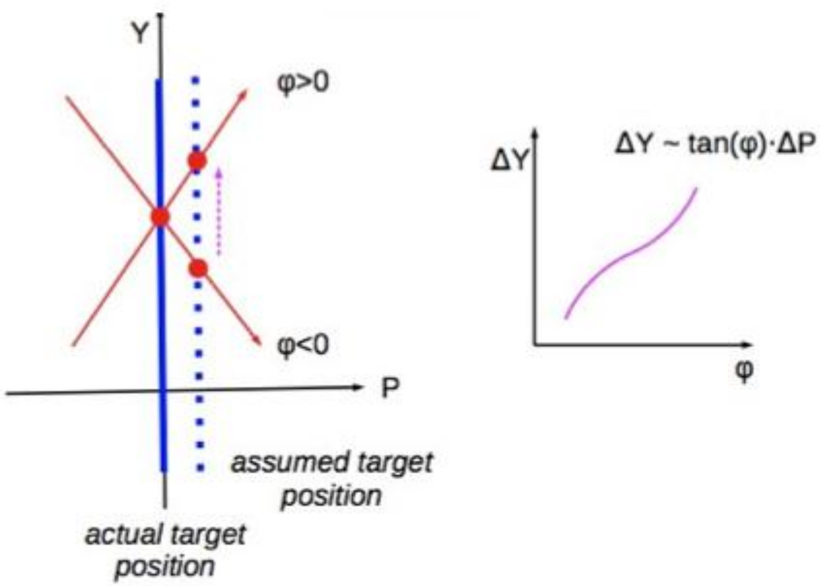


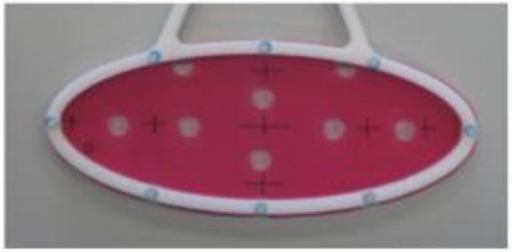


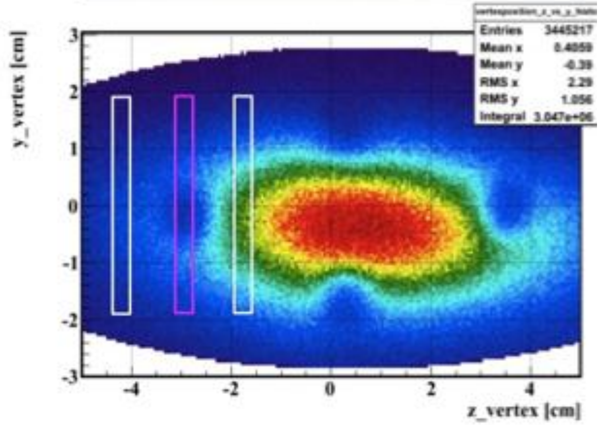
- new method being proposed:
  - makes use of RMD-events close to the end-point
  - already implemented in previous experiments
  - current limitations due to trigger biases and low statistics
  - need of dedicated run with low beam intensity and no direction match

Target-DC alignment

- The optical surevy provides a measurement of the target position
- That position can be cross-checked by comparing the expected vs reconstructed position of the holes







B-field corrections

- A further approach for the extraction of a *reconstructed B field*, based on measured B_z component + Maxwell equations + boundary conditions (at z = 0);

$\mathrm{div}\vec{B} = 0$

$$\frac{1}{r}\frac{\partial}{\partial r}(rB_r) + \frac{1}{r}\frac{\partial B_\phi}{\partial \phi} + \frac{\partial B_z}{\partial z} = 0 \Rightarrow$$

used to estimate **misalignment angle**

$\mathrm{rot}\vec{B} = 0$

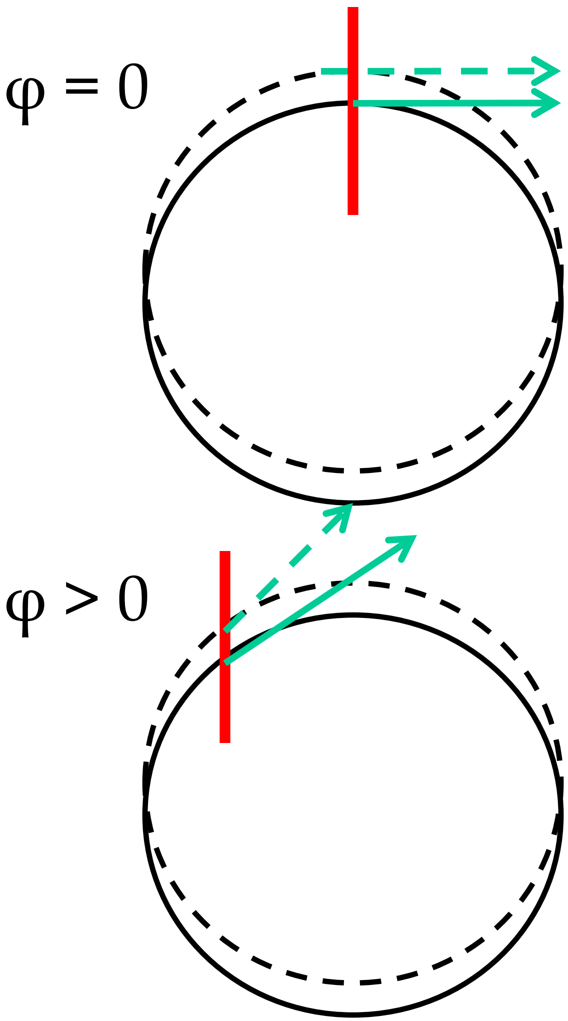
$$\frac{1}{r}\frac{\partial B_z}{\partial \phi} - \frac{\partial B_\phi}{\partial z} = 0 \Rightarrow \quad B_\phi(z,r,\phi) = B_\phi(z_0,r,\phi) + \frac{1}{r}\int_{z_0}^{z}\frac{\partial B_z}{\partial \phi}(z',r,\phi)dz'$$

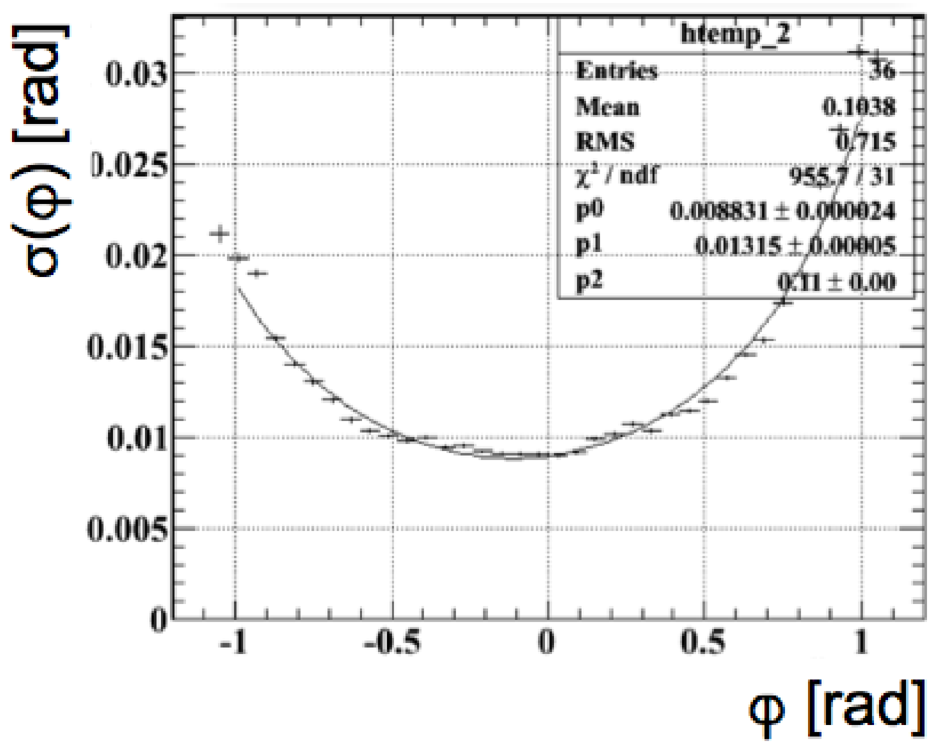
$$\frac{\partial B_r}{\partial z} - \frac{\partial B_z}{\partial r} = 0 \Rightarrow \quad B_r(z,r,\phi) = B_r(z_0,r,\phi) + \int_{z_0}^{z}\frac{\partial B_z}{\partial r}(z',r,\phi)dz'$$

$$\frac{\partial (rB_\phi)}{\partial r} - \frac{\partial B_r}{\partial \phi} = 0 \Rightarrow$$

used to estimate **misalignment angle**

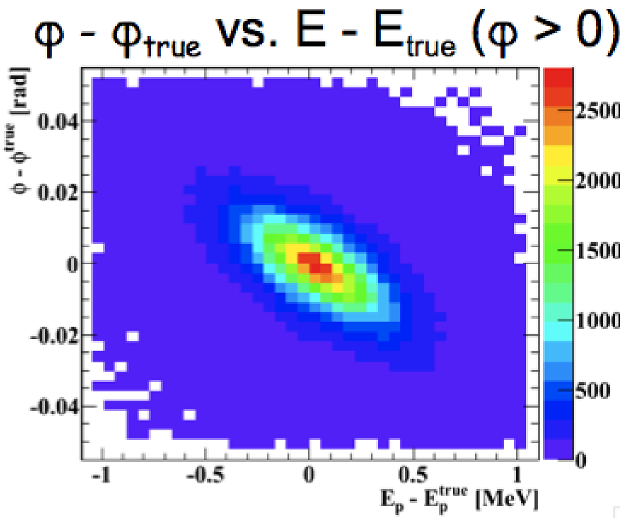
Correlation (1)



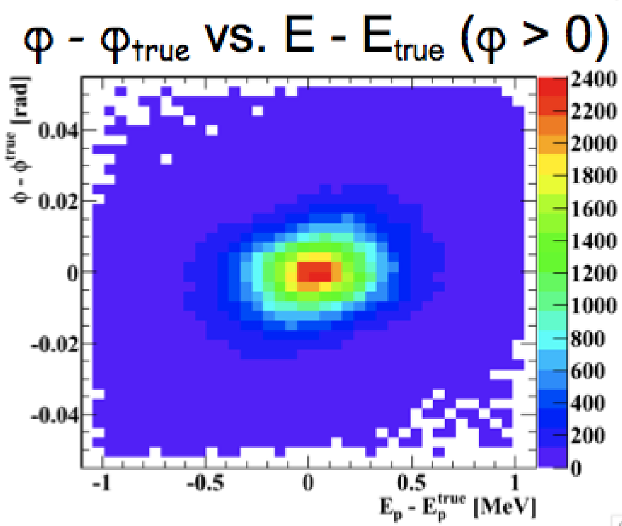


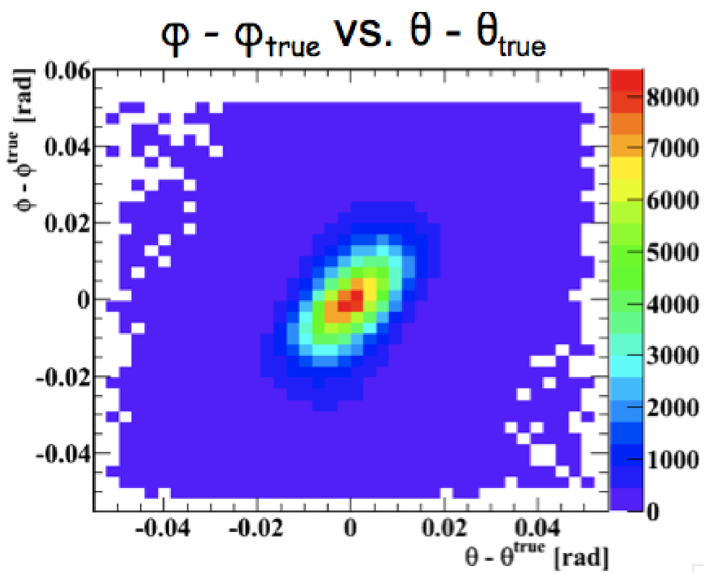
$$\sigma_\varphi(\varphi) = \sqrt{\sigma_0 + k^2 \tan^2 \varphi}$$

Correlations (2)

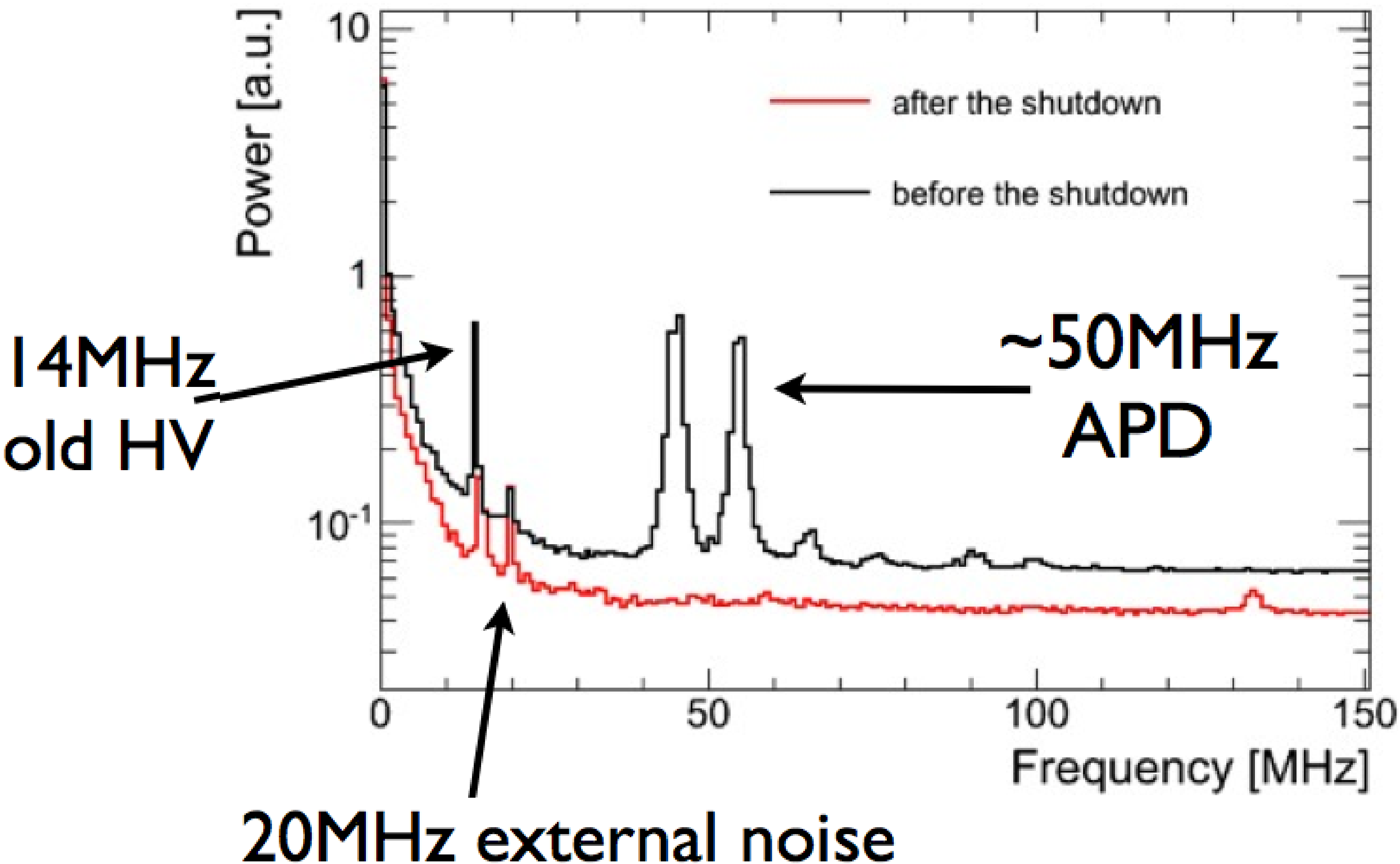


Correlation in positron observables comes out of the decay vertex reconstruction (defined as the intersection of fitted track with the target plane)





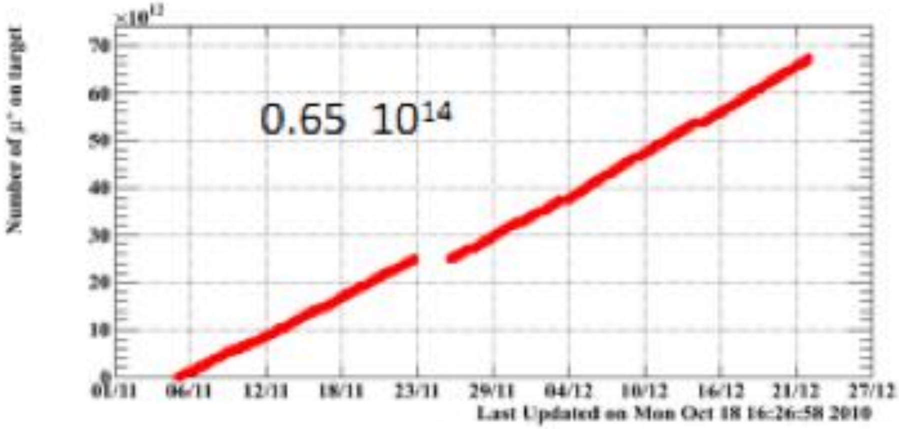
Noise figure in DC signals



Data summary

muons on target

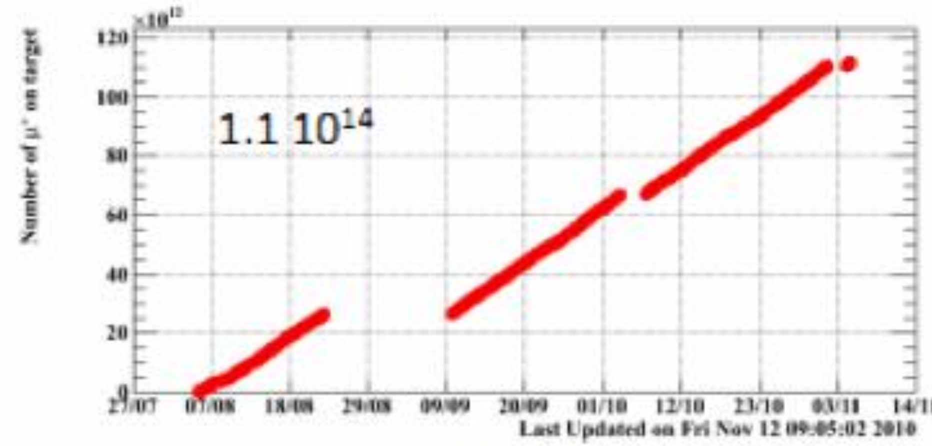
2009



DAQ time : 35 days

Fully efficient detector
Stable conditions (DCH, LXe light)

2010



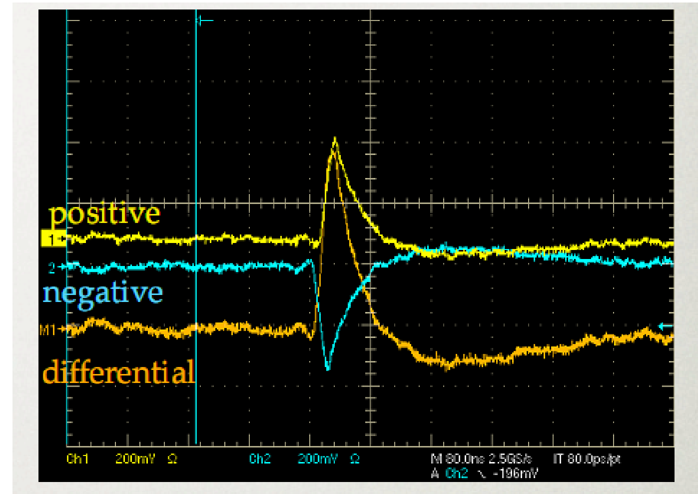
DAQ time : 56 days

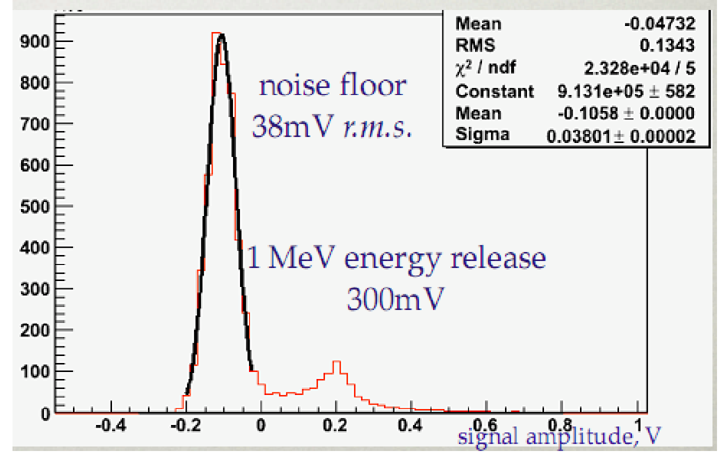
Optimized beam (degrader)
Improved electronics timing
Slightly worse DC noise
Conditions

Run 2010 prematurely ended due to a serious quench of the transport solenoid

TC status

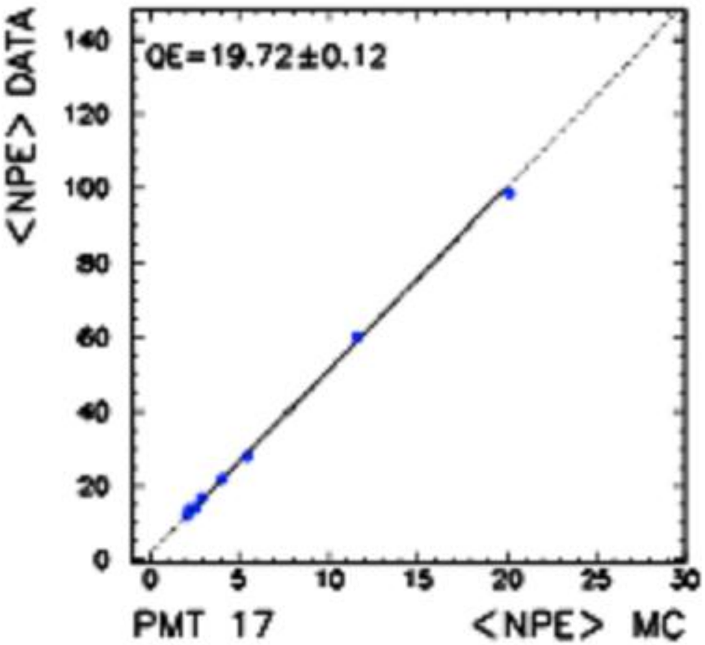
- New fast electronics for the shaping of fiber-coupled APDs
  - Stereo reconstruction of TC hit point
  - useful at both trigger and off-line stage
- Implementation of a Nd-laser
  - precise tool for LXe-TC timing

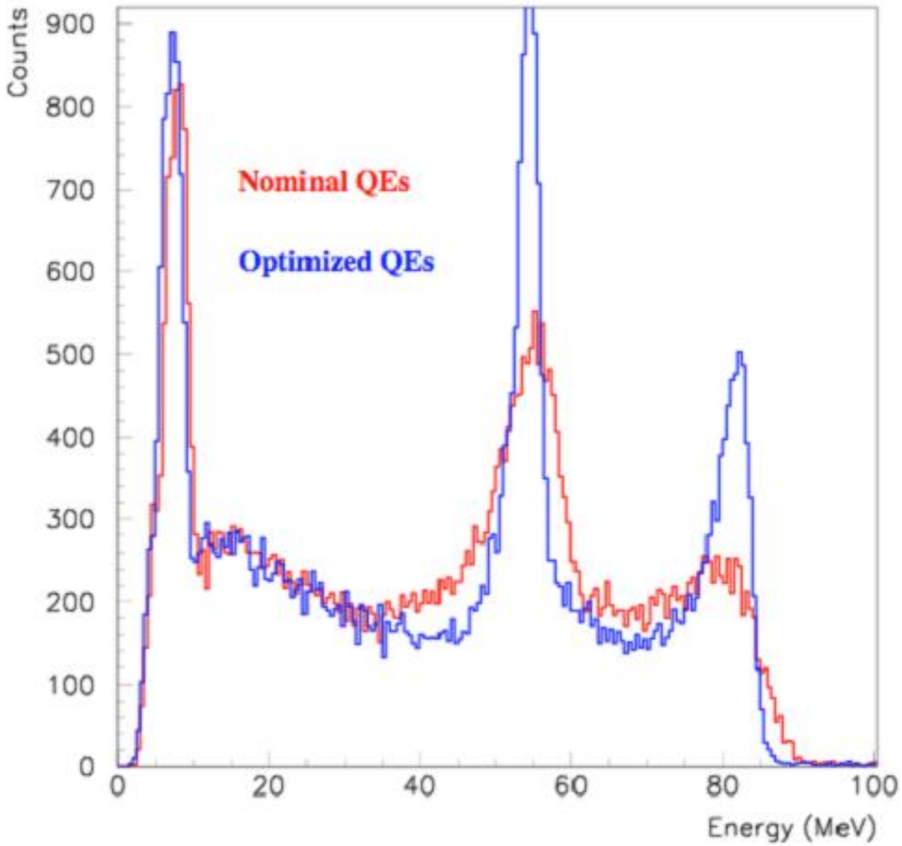




QE measurement

Obtained by comparison of measured vs. expected number of photoelectrons from each α-source





Additional quenching factors

- Ionization quenching

  e-capture by electro-negative impurities (namely O_2)

  (WARP collaboration, submitted to NIM A, and references therein)

- Non-radiative collitional reactions

  $\mathbf{Xe_2^* + N_2 \rightarrow 2\,Xe + N_2}$

  $1/t'_j = 1/\tau_j + k[N_2]$ (shorter decay-time)

  $A'_j = A_j/(1 + \tau_j k[N_2])$ (lower light intensity)

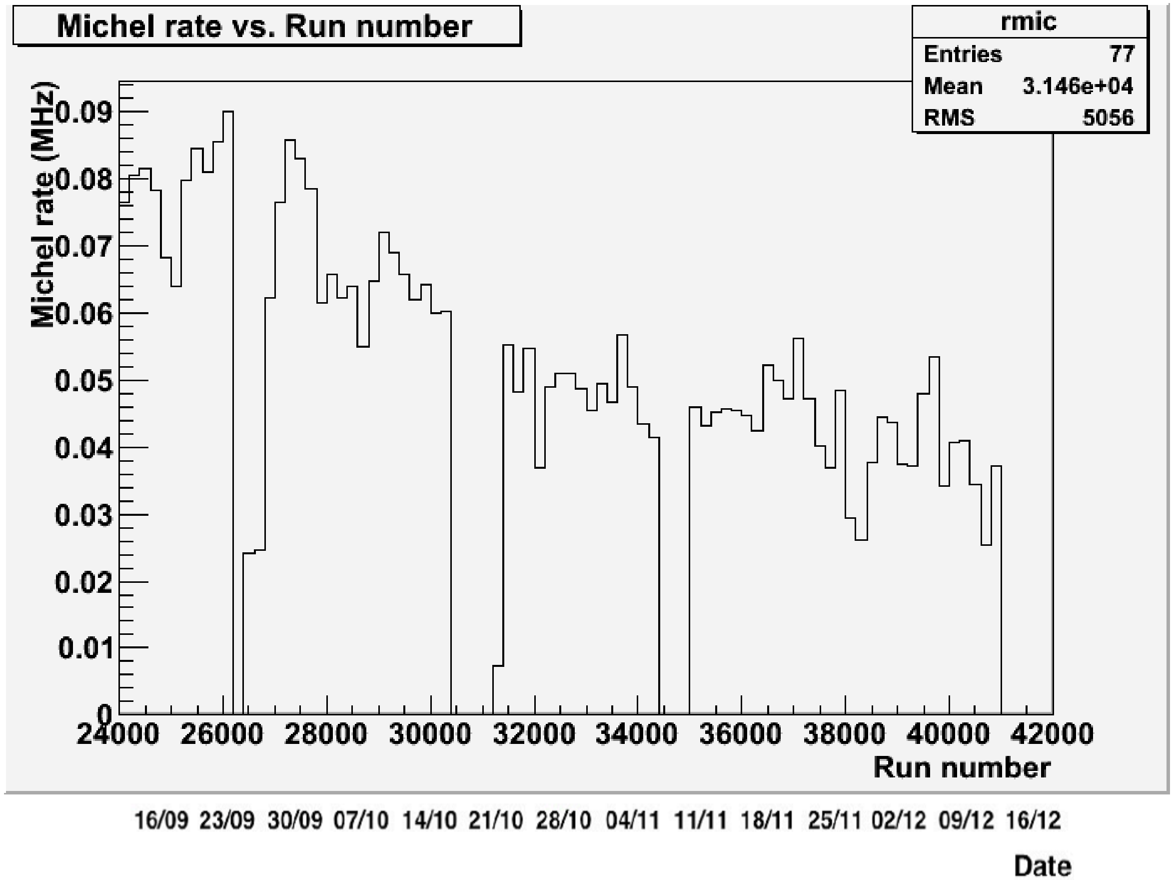
  used in LAr to shorten the long decay-time component

  (WARP collaboration, arXiv:0804.1217v1 [nucl-ex])

In both cases, quenching of scintillation light is expected,
More significant in the case of lightly ionizing particles

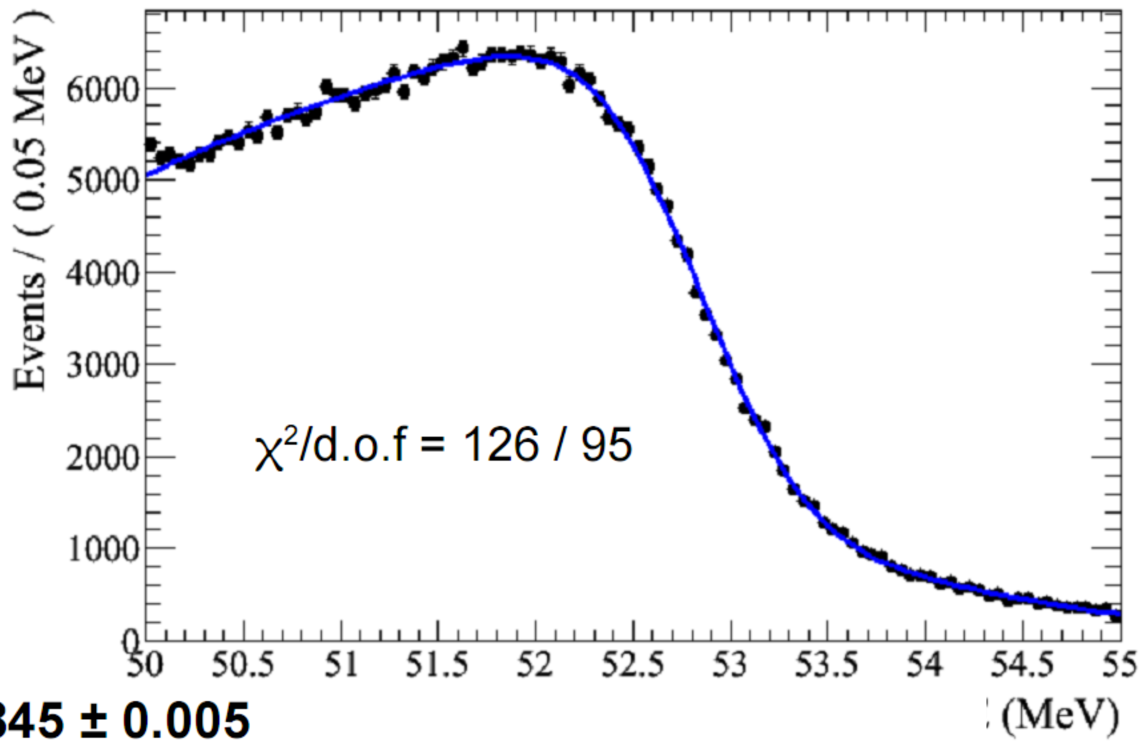
DC performance

The rate of events with a reconstructed track decreases with the Run going on ➔ absolute e+-efficiency getting lower and lower



e^+-momentum resolution

obtained from a fit of the edge of Michel spectrum
(with a slight dependence on the emission angle)



f_{core} = 0.845 ± 0.005

μ_{core} = 0 (fixed)

σ_{core} = 0.431 ± 0.007 MeV

μ_{tail} = -0.51 ± 0.05 MeV

σ_{tail} = 1.89 ± 0.06 MeV

twice worse than expected

pdfs

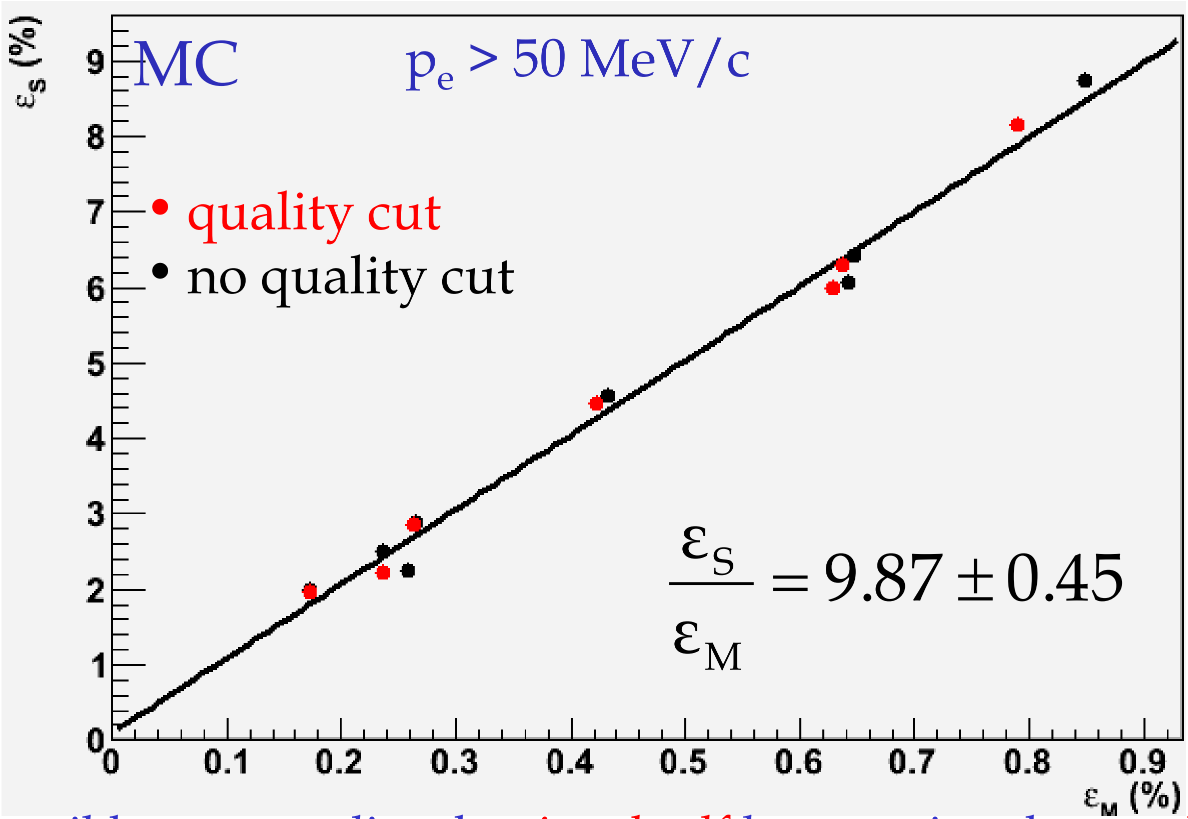
- Signal
  - E_γ from full signal simulation (response function tuned on the data)
  - E_e from 3-gaussian fit on data
  - $\theta_{e\gamma}$ from combined positron and gamma angular resolution (data fit)
  - $t_{e\gamma}$ from gaussian fit to RD data spectrum

- RD
  - E_e, E_γ, $\theta_{e\gamma}$ 3d-histo pdf from toy MC (including resolution and acceptance smearing)
  - $t_{e\gamma}$ gaussian fit to RD data spectrum (as in the case of signal)

- accidentals
  - E_γ, $\theta_{e\gamma}$ from fit to the sidebands
  - E_e from the data
  - $t_{e\gamma}$ flat distribution

DC relative efficiency

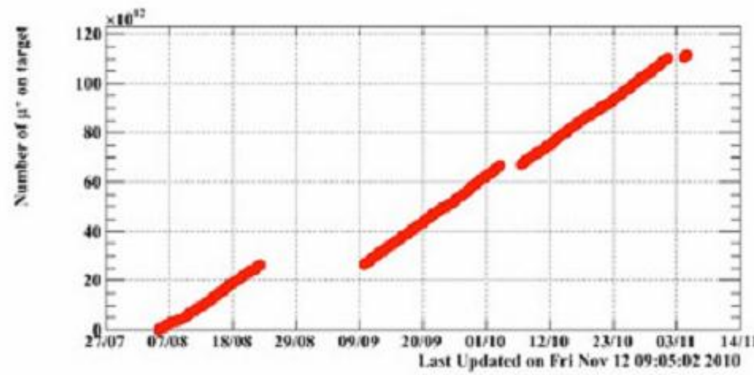
• Relative efficiency (i.e. fraction of signal/Michel events) is almost constant during the run (in spite of DC deterioration)
• average ratio agrees with the expected fraction of e^+ with p>50 MeV



➔ it is possible to normalize the signal pdf by counting the number of Michel

Il Run 2010

Summary of Run 2010



- Aug-Oct, 2009 (DAQ time: **56 days**)
- μ-stop rate: **2.9×10^{7} s^{-1}**
- Total μ-stop in target: **1.1×10^{14}**

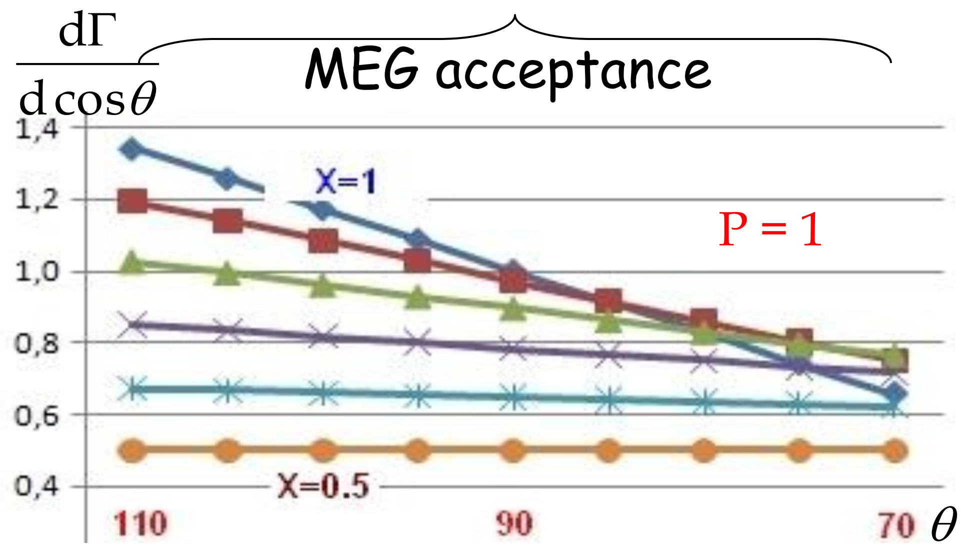
- Optimized μ-stop distribution in target
- Improved electronics timing accuracy (DRS4)
- Smooth and efficient DAQ had to be stopped on Nov. 5th due to the problem of the BTS.
  - Resultant data statistics: ×**1.9 higher** w.r.t. run 2009
  - Normalization factor: k = **2.1×10^{12} (preliminary)**
- Calibration and optimization of the analysis are still in progress.

Delayed start: DCHs construction, MEG target accidentally broken
Premature end: BTS solenoid magnet problem on beginning of november

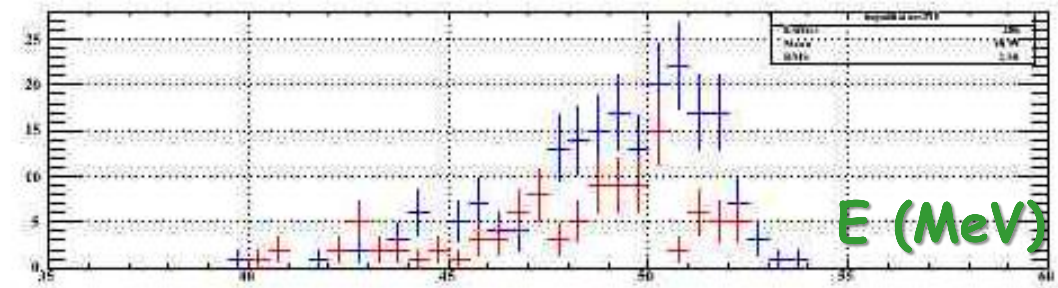
Polarizzazione dei muoni

- Fascio costituito da "surface muons" ➔ P = 1
- Possibili effetti di depolarizzazione
  - contaminazione da "cluod muons"
    (i.e. muoni da decadimenti di pioni non a riposo) ➔ ΔP = 4%
  - rotazione di spin ➔ ΔP < 0.7%
  - multiplo scattering nel bersaglio ➔ ΔP < 0.3%
  - divergenza del fascio ➔ ΔP = 4%
  - ➔ $\langle P_z \rangle = 0.92 \pm 0.03$
- Misura della polarizzazione
  - distribuzione angolare
    dei decadimenti di Michel

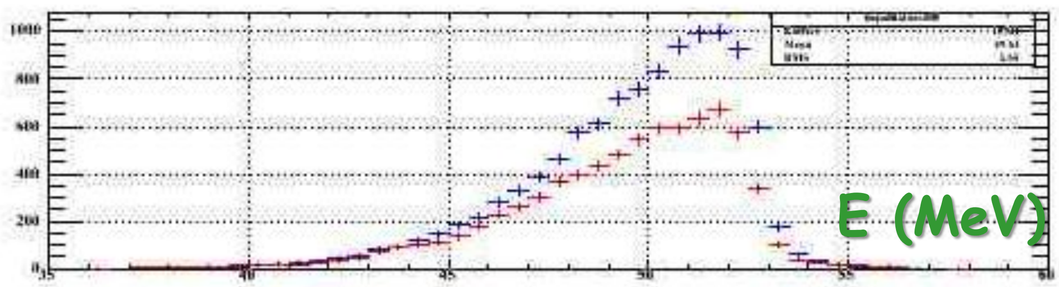
    (tanto più asimmetrica
    all'end-point)



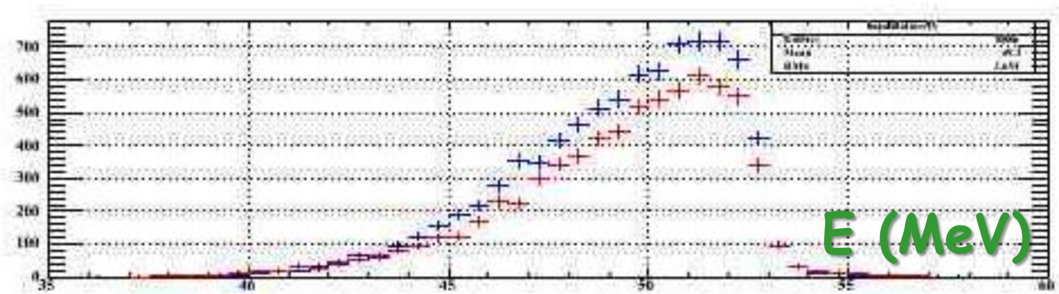
Dati 2009



$$\vartheta_1 = 20 \quad \vartheta_2 = 30$$



$$\vartheta_1 = 10 \quad \vartheta_2 = 20$$



$$\vartheta_1 = 0 \quad \vartheta_2 = 10$$

Blue: US

Red: DS

US

$$\int_{90+\vartheta_1}^{90+\vartheta_2} \frac{dN}{dE\,d\cos\vartheta}\, d\cos\vartheta$$

DS

$$\int_{90-\vartheta_2}^{90-\vartheta_1} \frac{dN}{dE\,d\cos\vartheta}\, d\cos\vartheta$$

$\langle P \rangle = 0.89 \pm 0.04$
(only statistical error)

Radiative decays

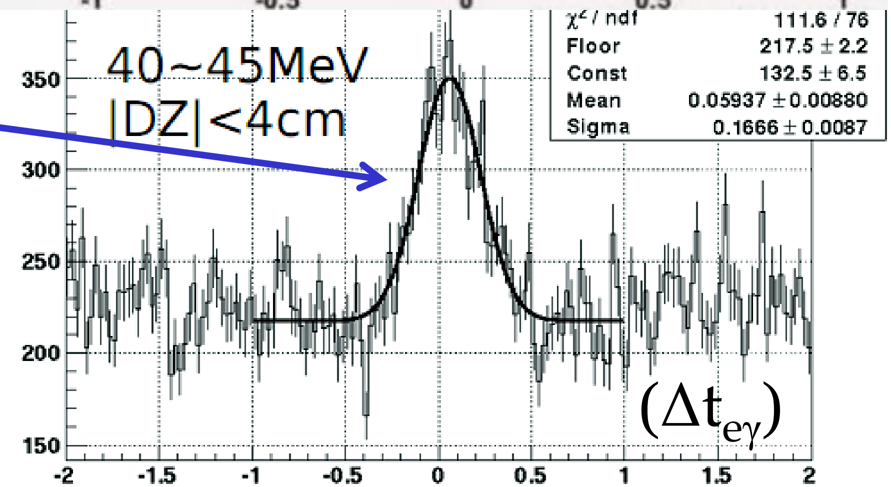
- The number of observed events is compatible with estimated efficiencies
- also the angular distribution agrees with expectations

- also seen in normal data (with kinematical cuts applied)

  $\sigma(\Delta t_{e\gamma})$ = (159±9) ps

  (extrapolated to 143 ps @52.8 MeV)
- contribution from tracking

  ➔ e^+ time-of-flight uncertainty



α-sources, a closer view