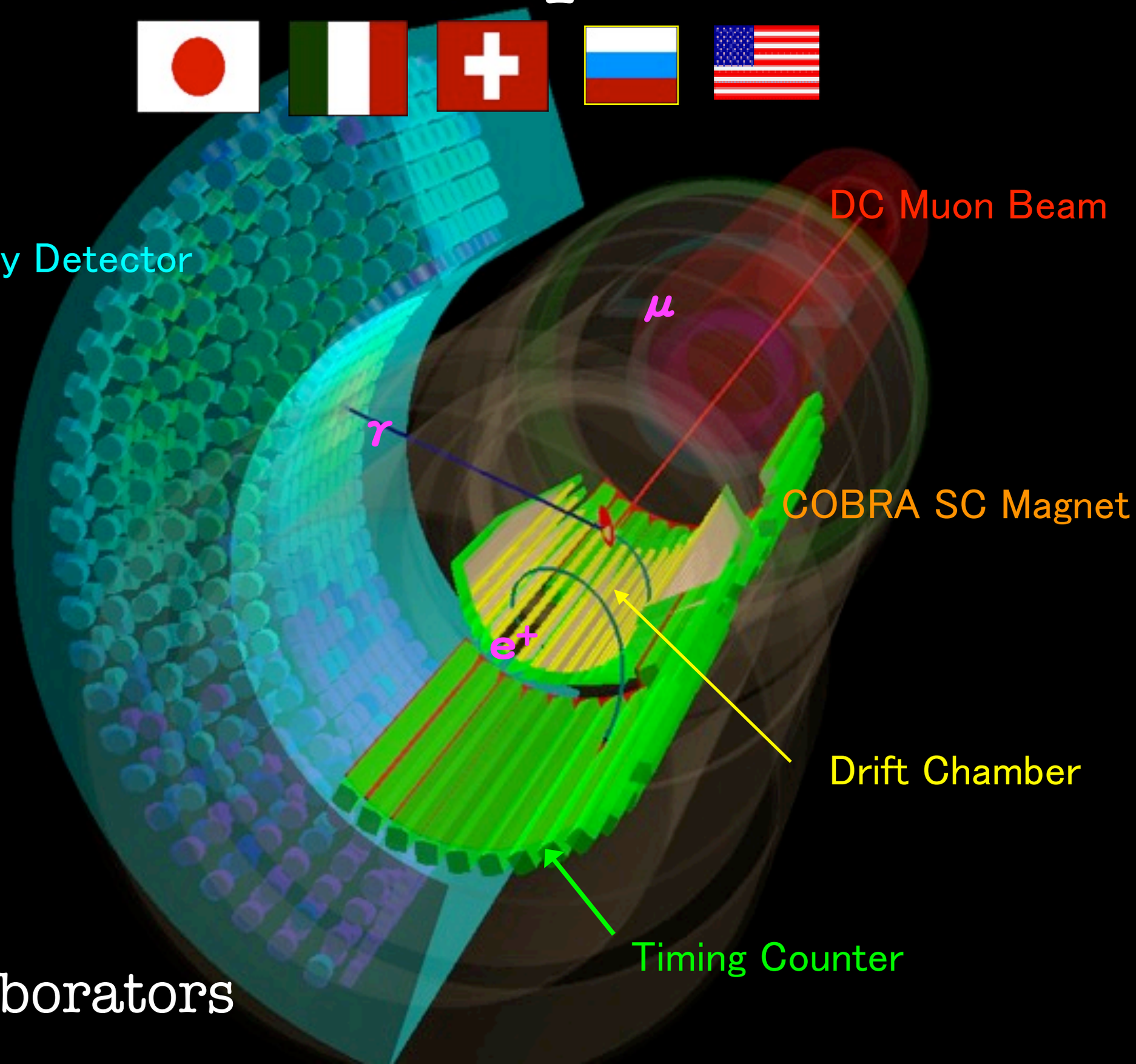
The MEG Experiment

T. Mori

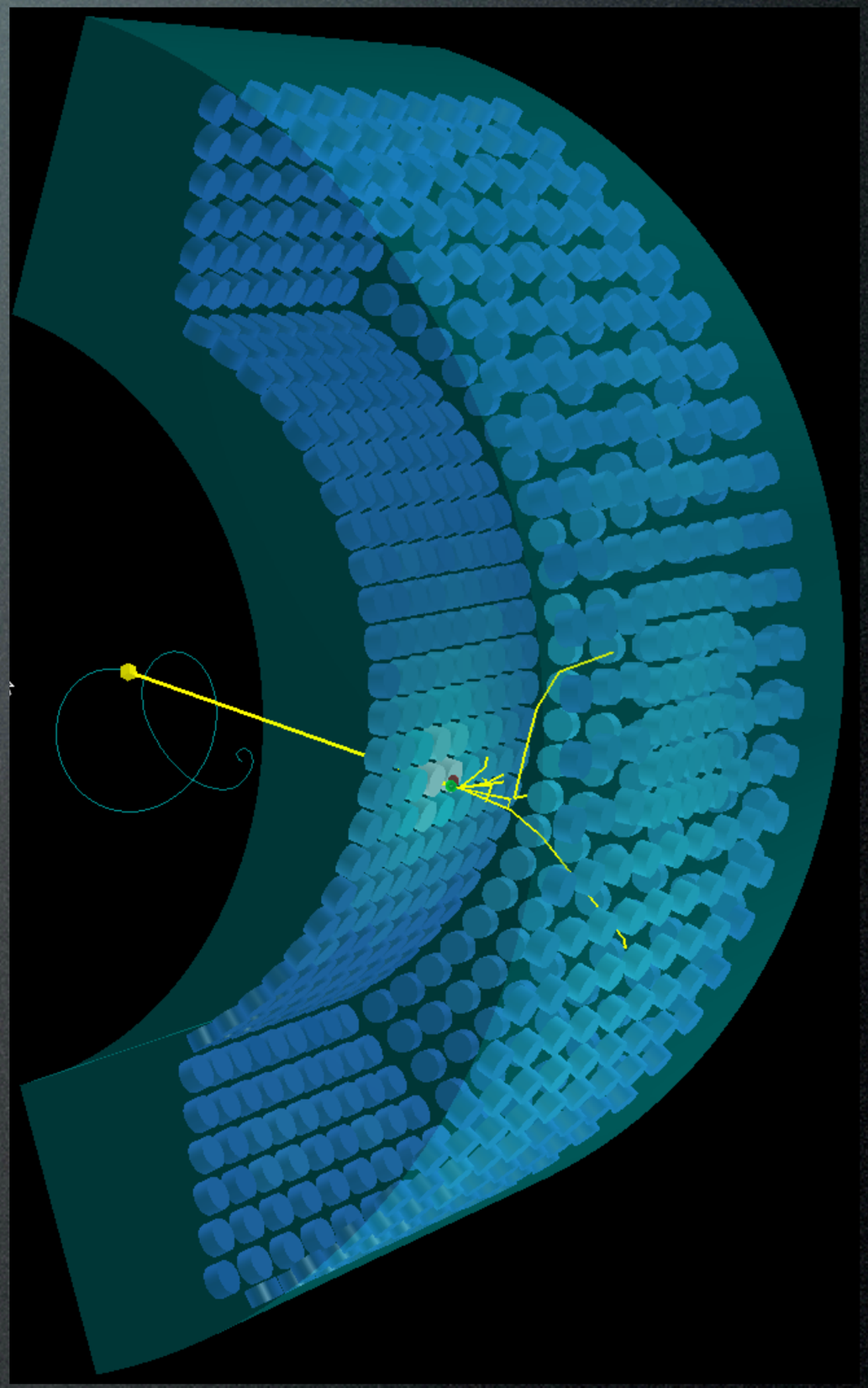
The MEG Experiment



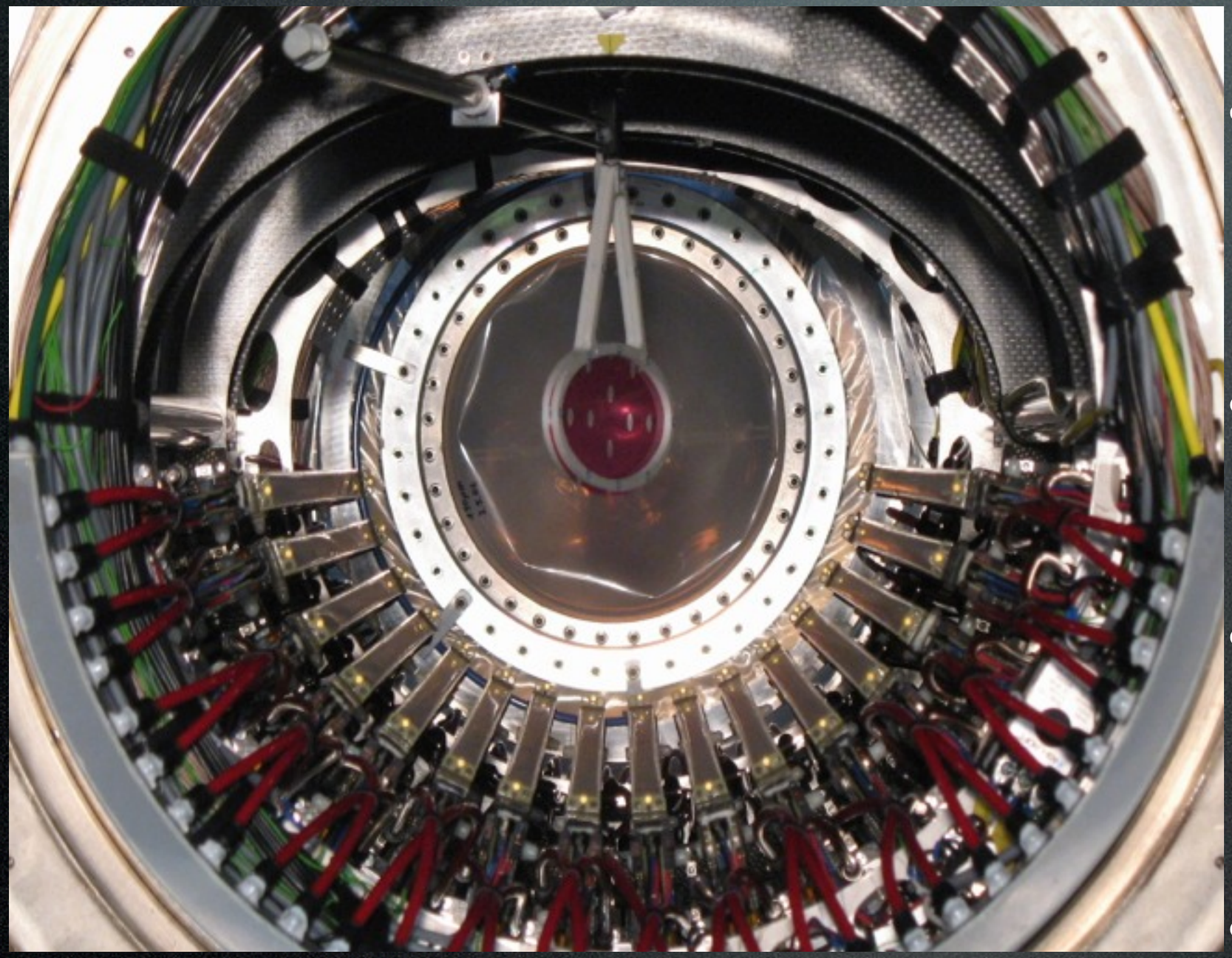
~55 collaborators

2.7t Liquid Xenon Photon Detector

- Scintillation light from 900 liter liquid xenon is detected by 846 PMTs mounted on all surfaces and submerged in the xenon
- fast response & high light yield provide good resolutions of E, time, position
- kept at 165K by 200W pulse-tube refrigerator
- gas/liquid circulation system to purify xenon to remove contaminants



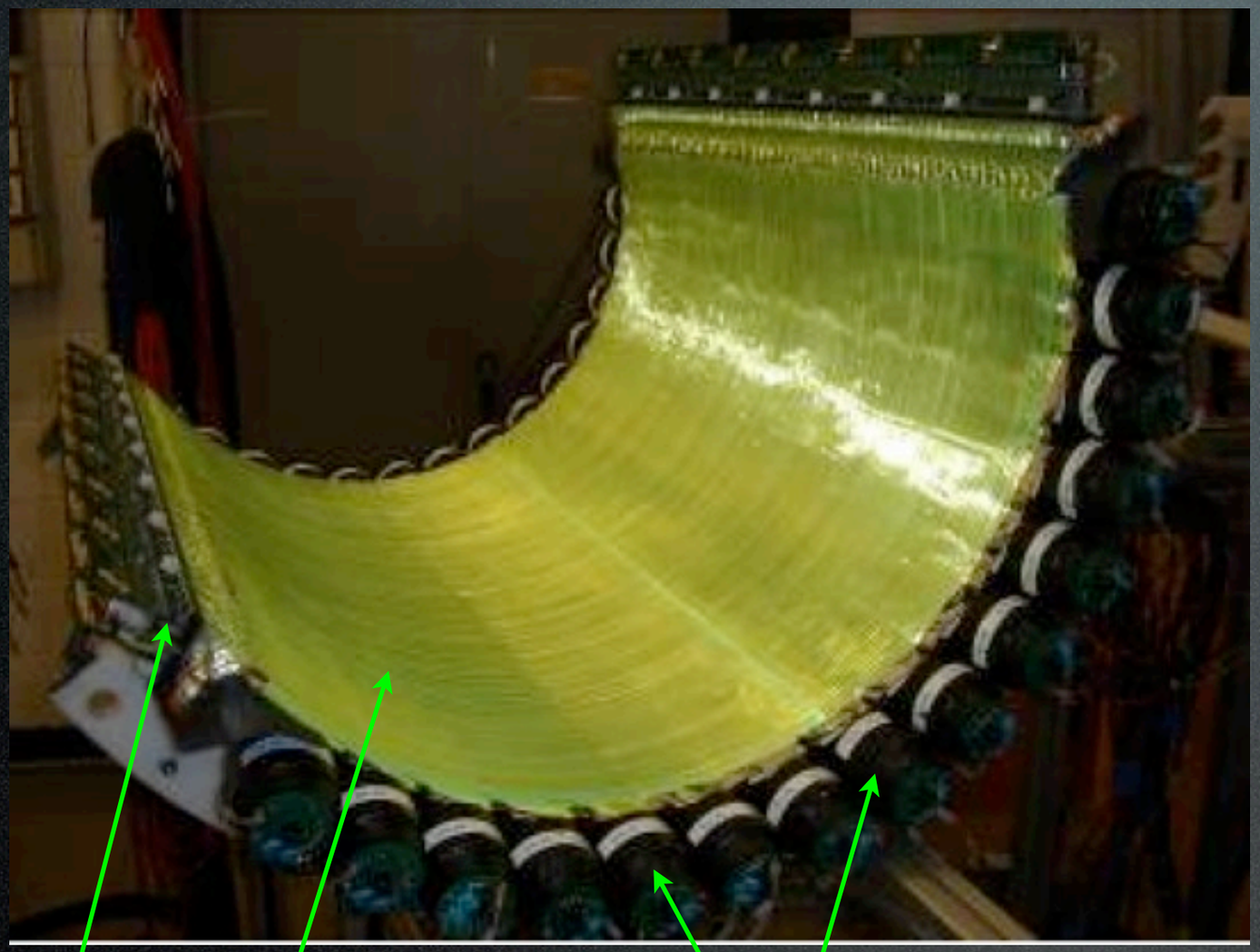
Drift Chambers



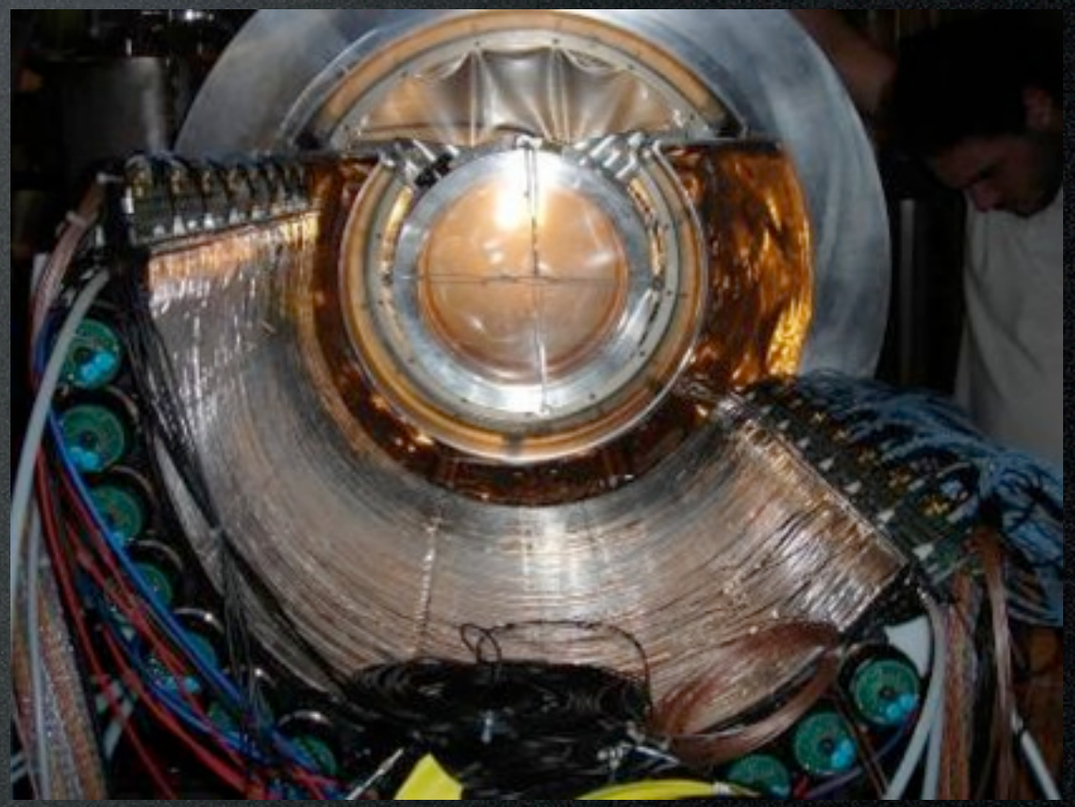
filled with He inside COBRA

- 16 radially aligned modules, each consists of two staggered layers of wire planes
- 12.5um thick cathode foils with a Vernier pattern structure
- He:ethane = 50:50 differential pressure control to COBRA He environment
- ~2.0×10^{-3} X_0 along the positron trajectory

Timing Counters



- Scintillator arrays placed at each end of the spectrometer
- Measures the impact point of the positron to obtain precise timing

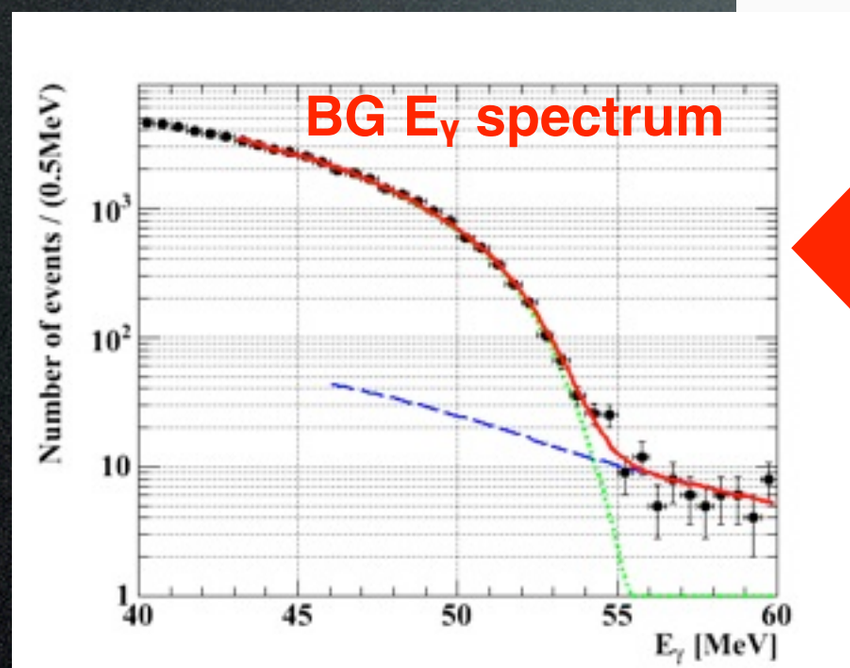


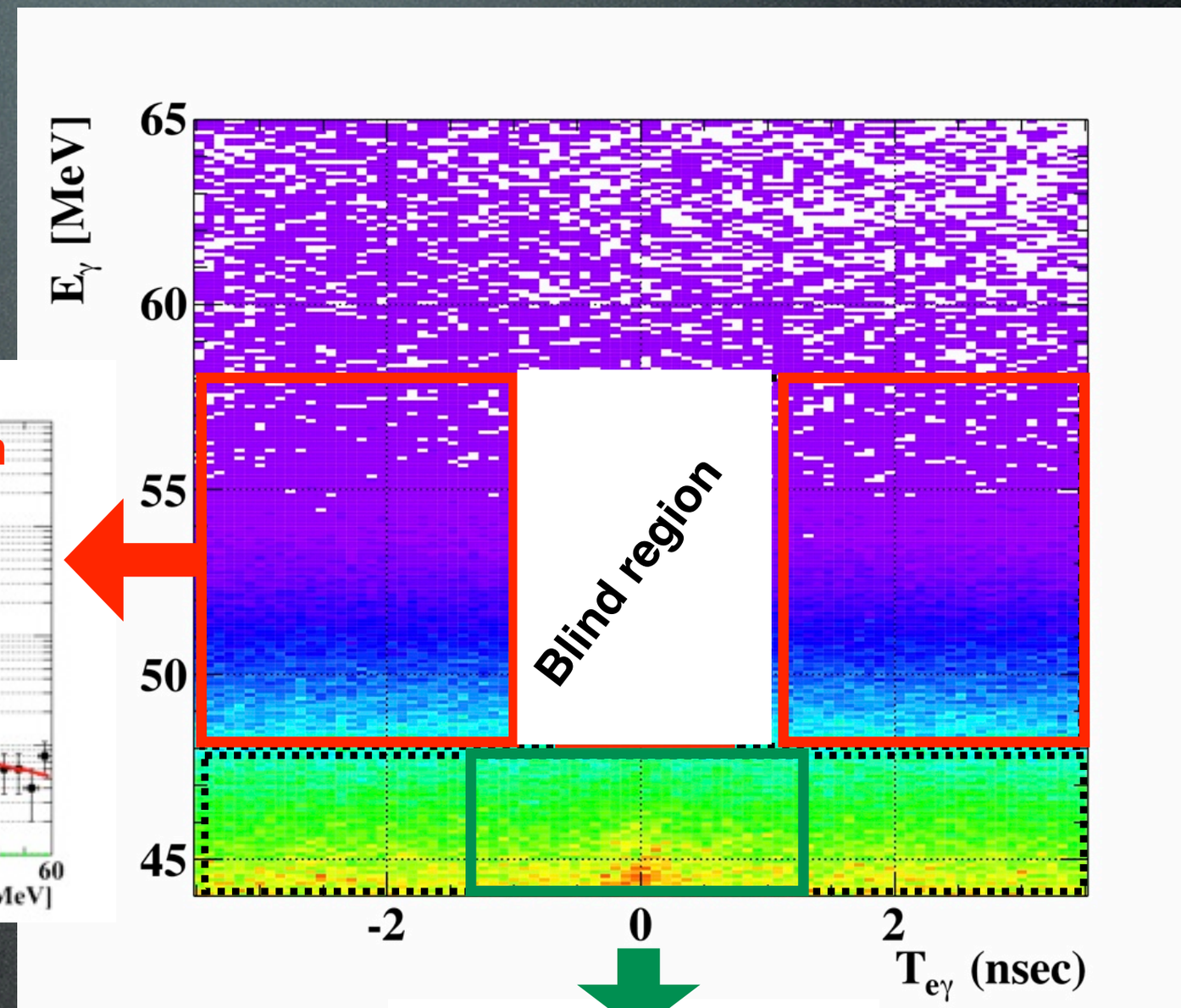
installing inside COBRA

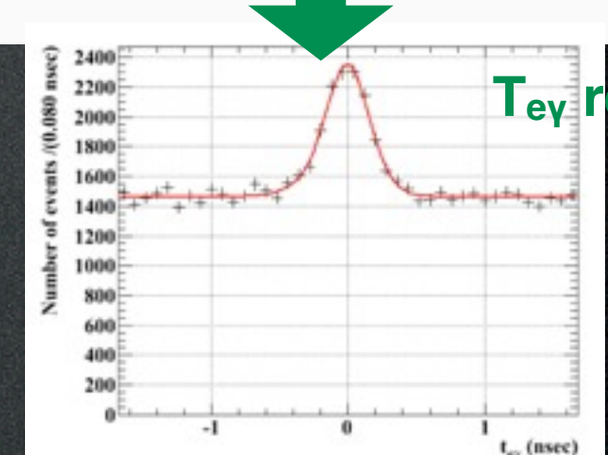
Blind & Likelihood Analysis

$(E_\gamma, E_e, T_{e\gamma}, \theta_{e\gamma}, \phi_{e\gamma})$

→ signal, acc BG, RD BG







PDFs mostly from data

accidental BG: side bands

signal: measured resolution

radiative BG: theory + resolution

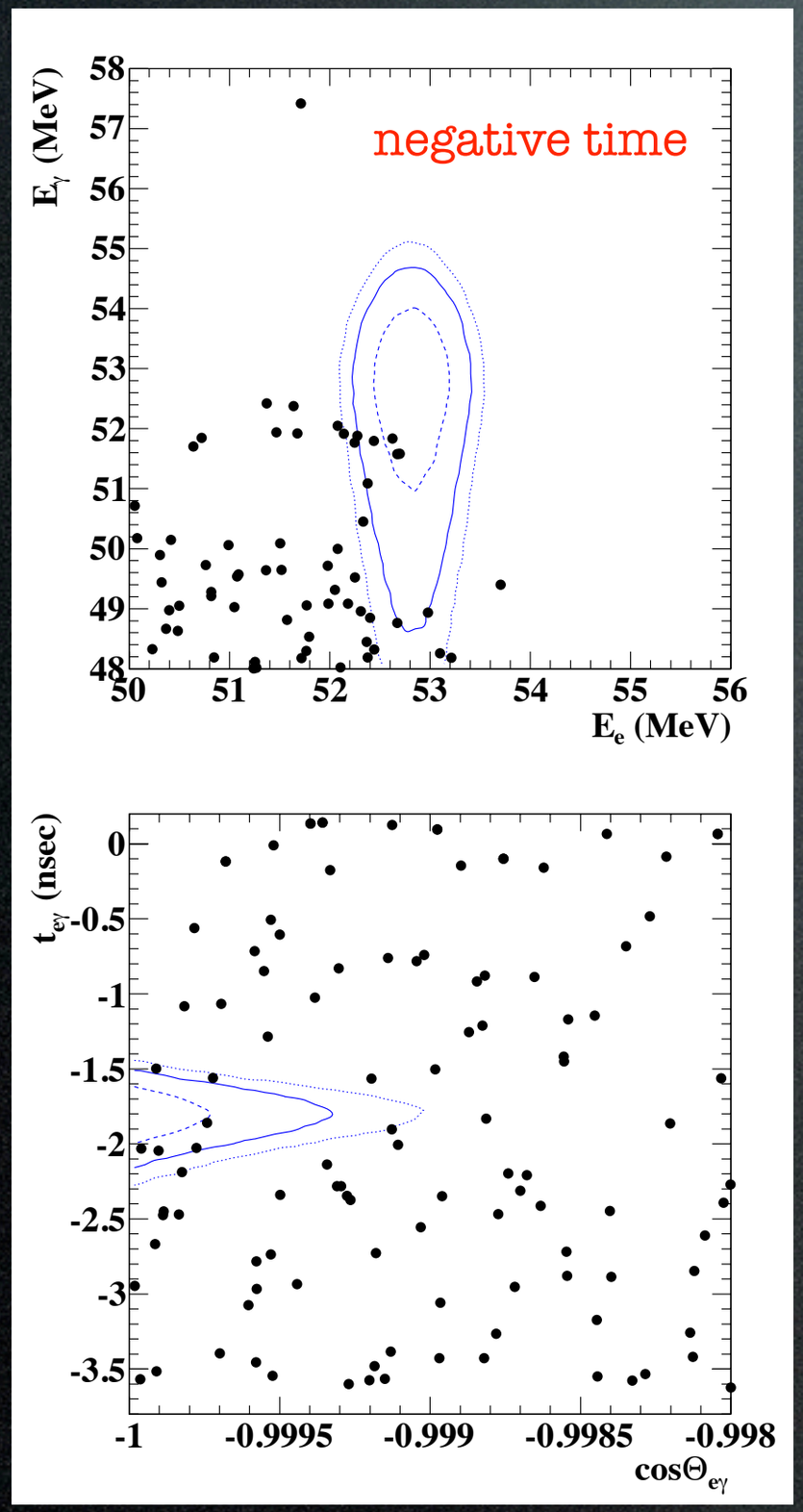
Likelihood Fit

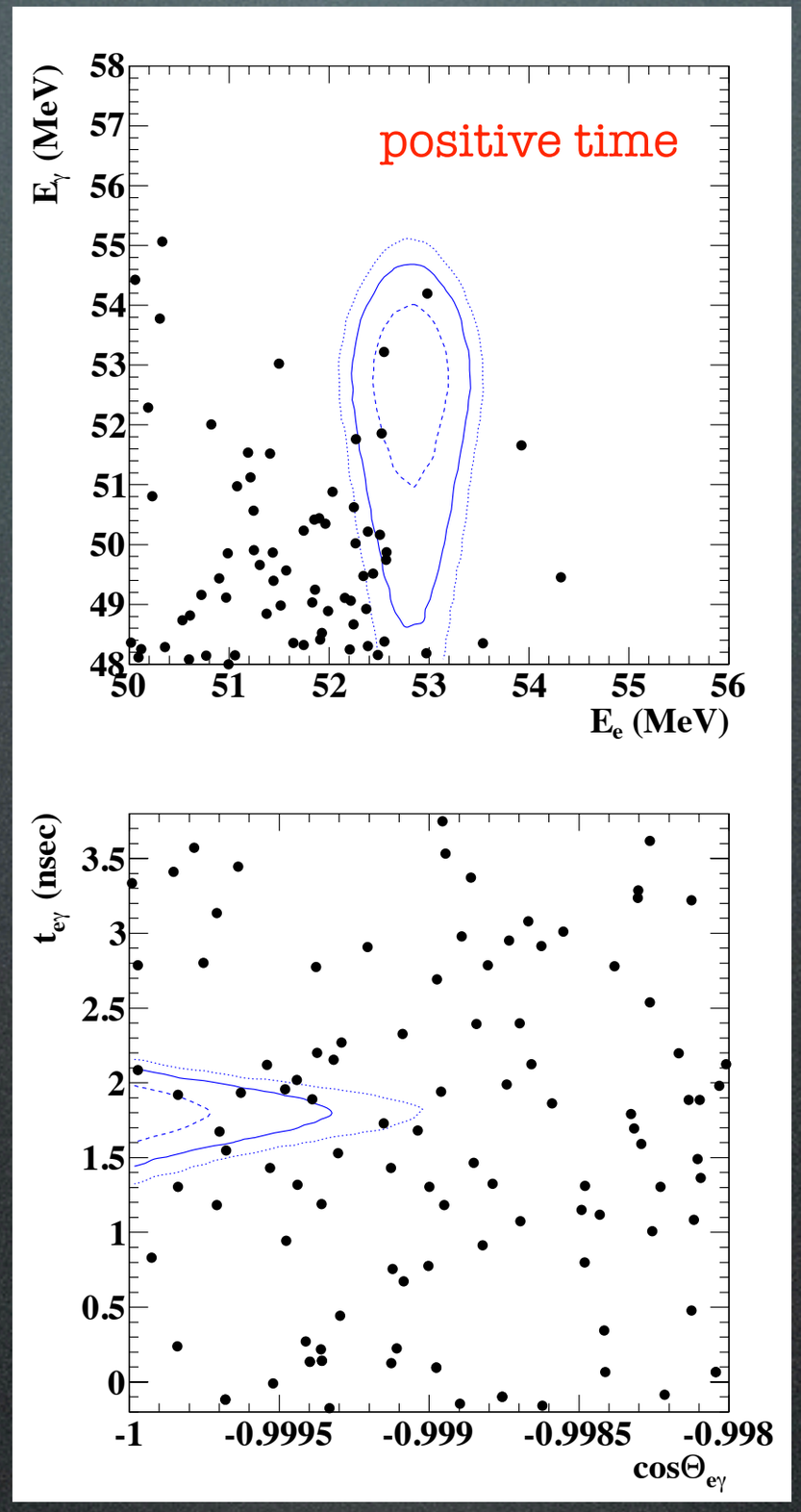
- fully frequentist approach (Feldman & Cousins) with profile likelihood ratio ordering

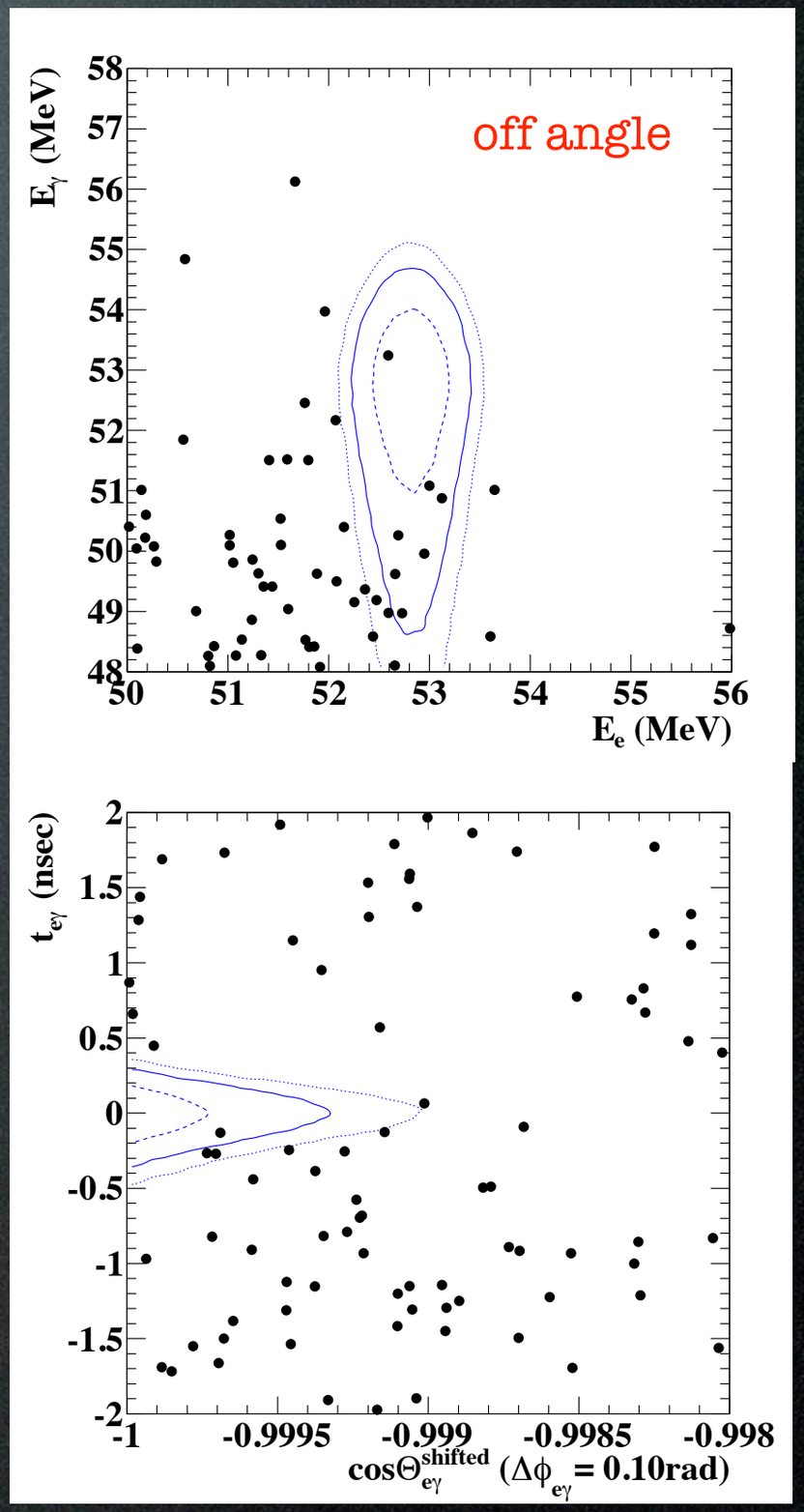
$$\mathcal{L}\left(N_{\rm sig}, N_{\rm RMD}, N_{\rm BG}\right) = \frac{e^{-N}}{N_{\rm obs}!} e^{-\frac{1}{2}\frac{(N_{\rm BG}-\langle N_{\rm BG}\rangle)^2}{\sigma^2_{\rm BG}}} e^{-\frac{1}{2}\frac{(N_{\rm RMD}-\langle N_{\rm RMD}\rangle)^2}{\sigma^2_{\rm RMD}}} \times \prod_{i=1}^{N_{\rm obs}} \left(N_{\rm sig} S(\vec{x}_i) + N_{\rm RMD} R(\vec{x}_i) + N_{\rm BG} B(\vec{x}_i)\right),$$

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

Side band data

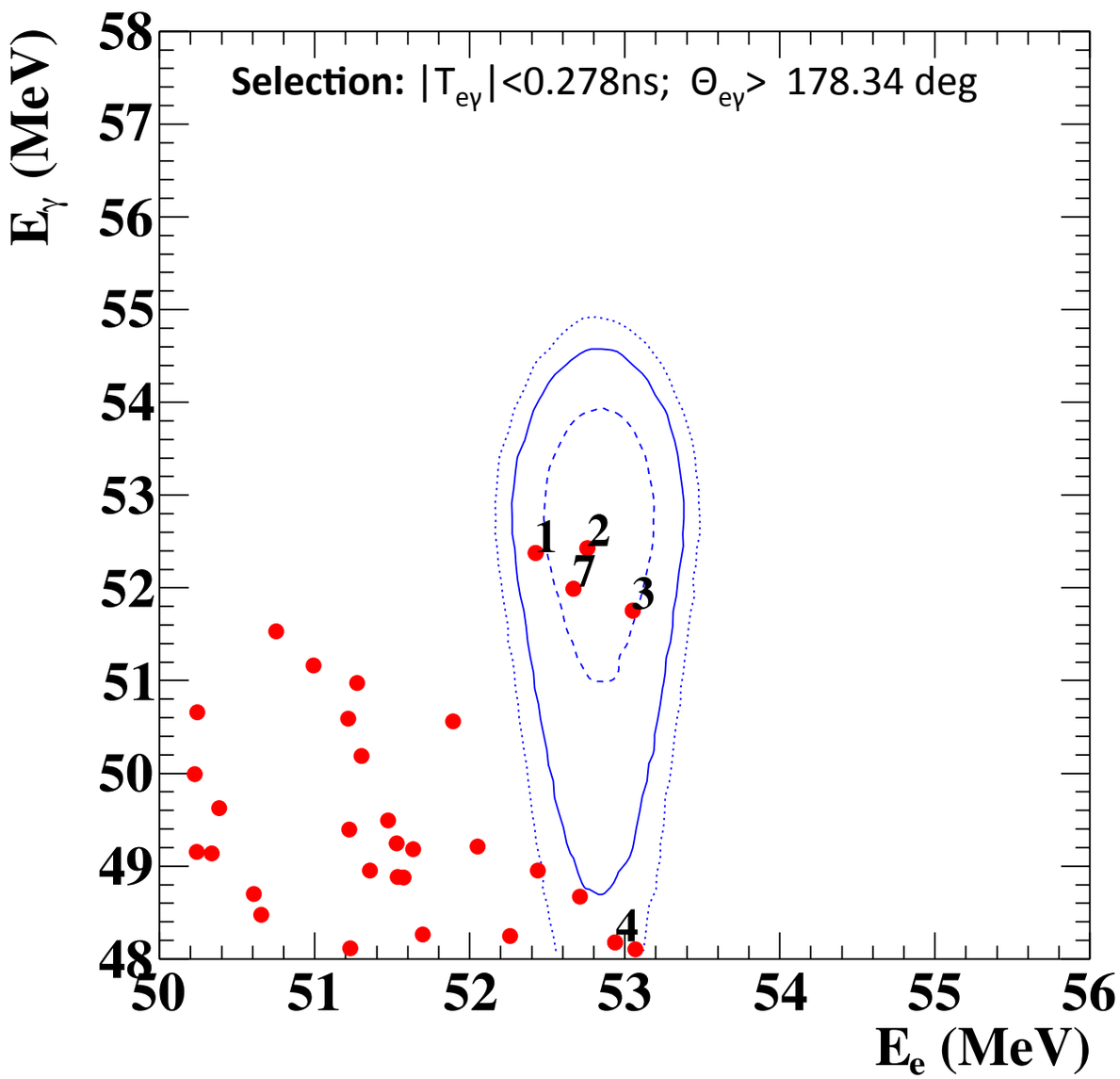


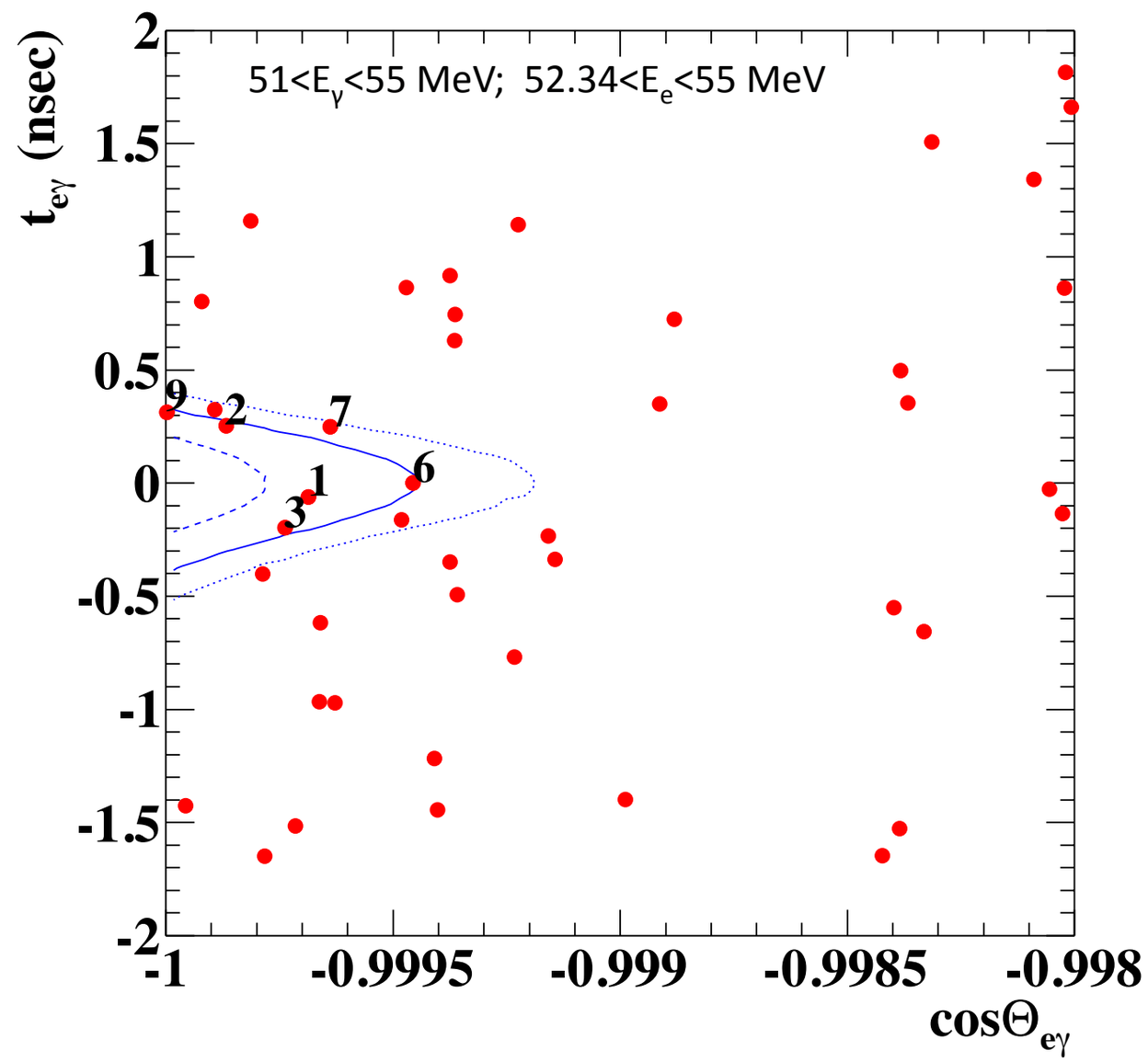




expected sensitivity for 2010 data = 2.2×10^{-12} @90% C.L.

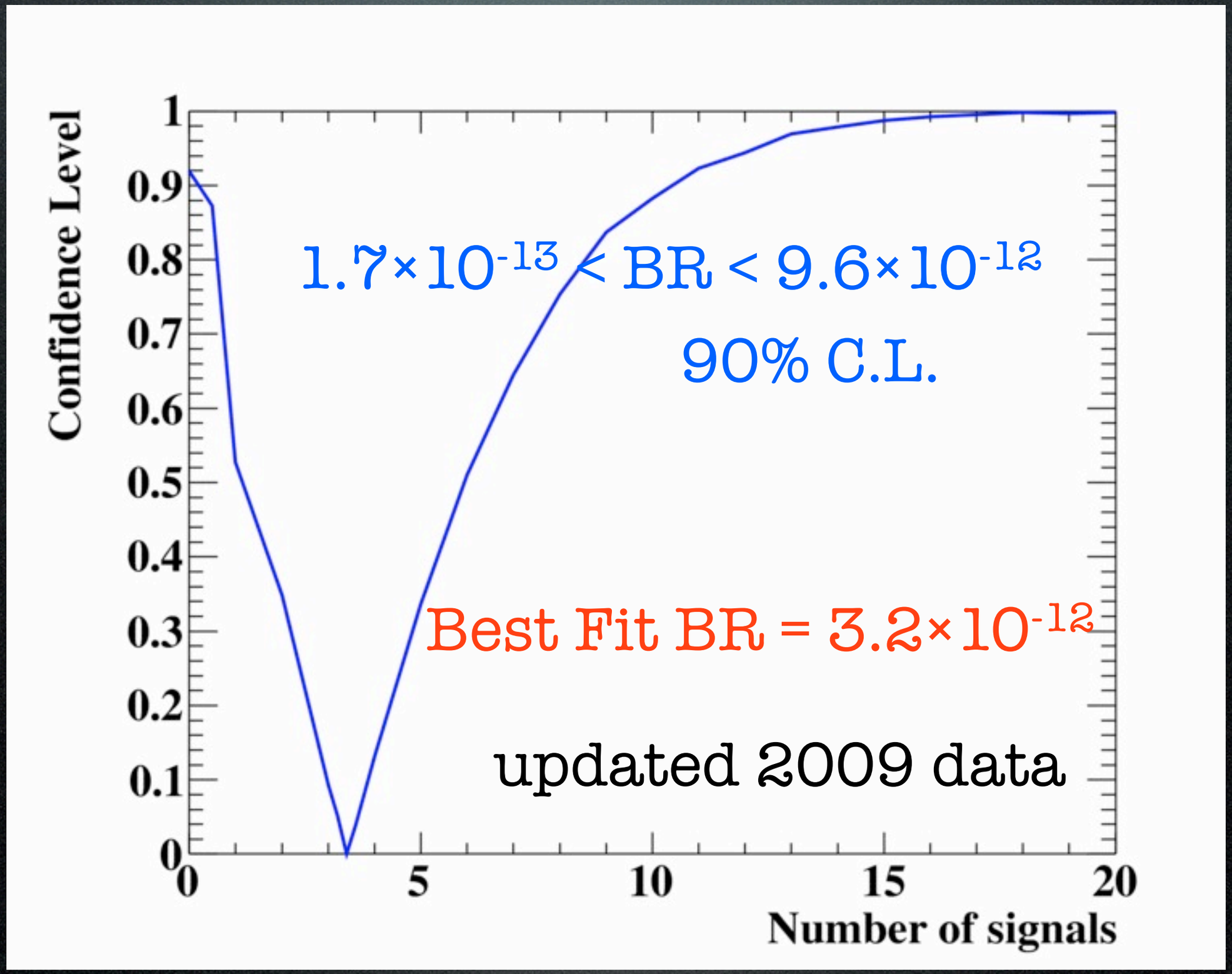
2009 data update



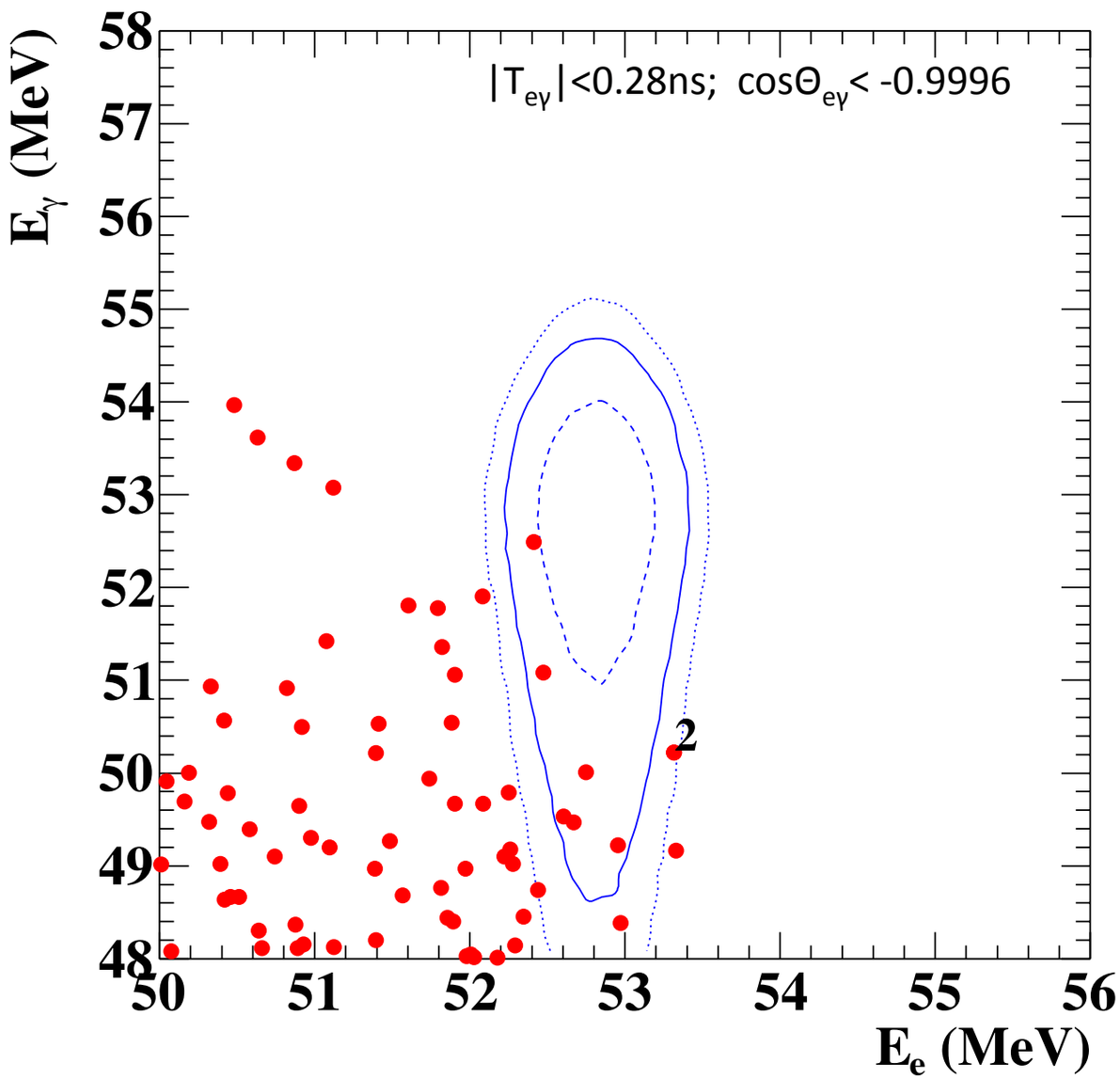


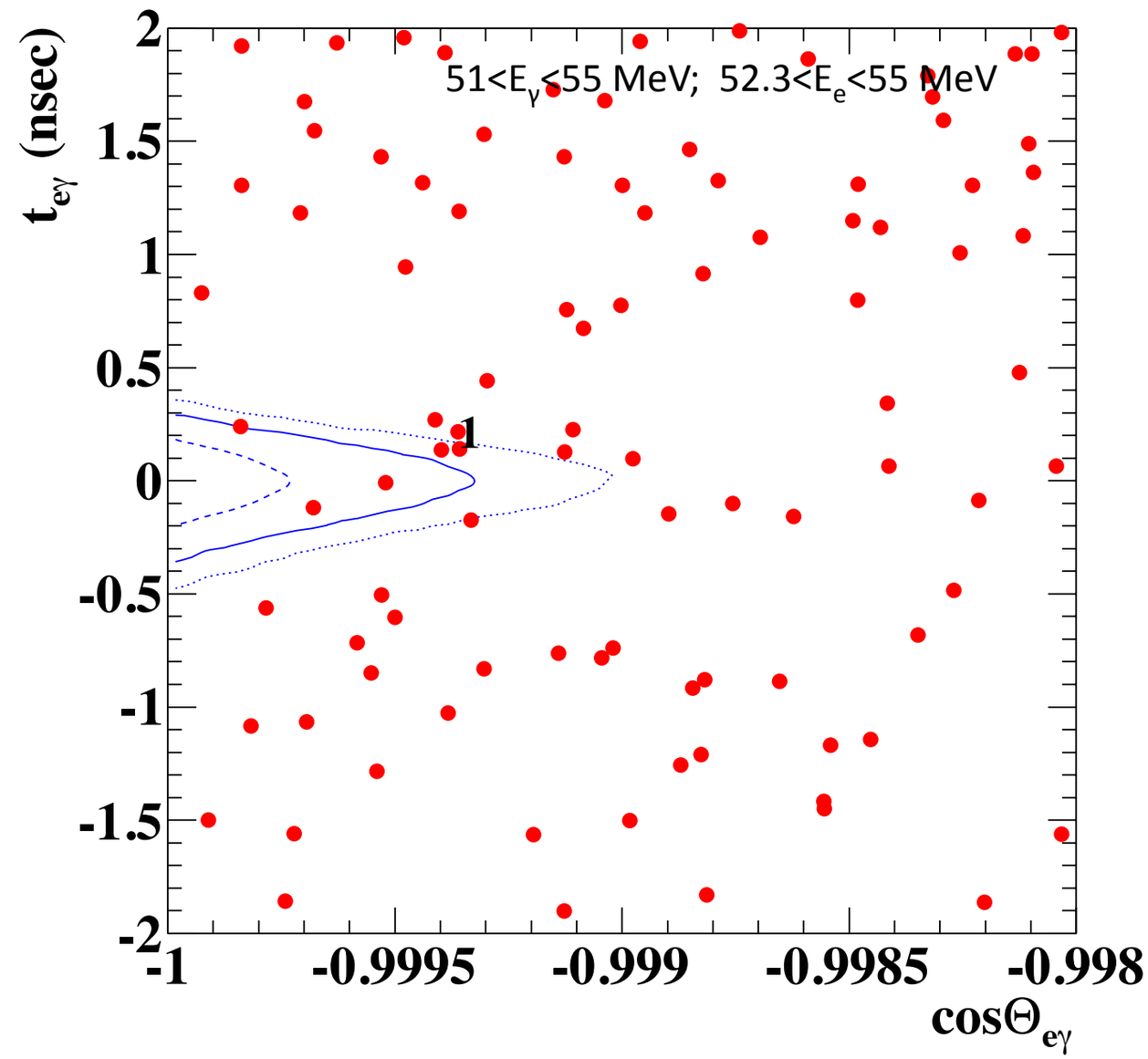
... presented at last year's BVR

Likelihood Analysis

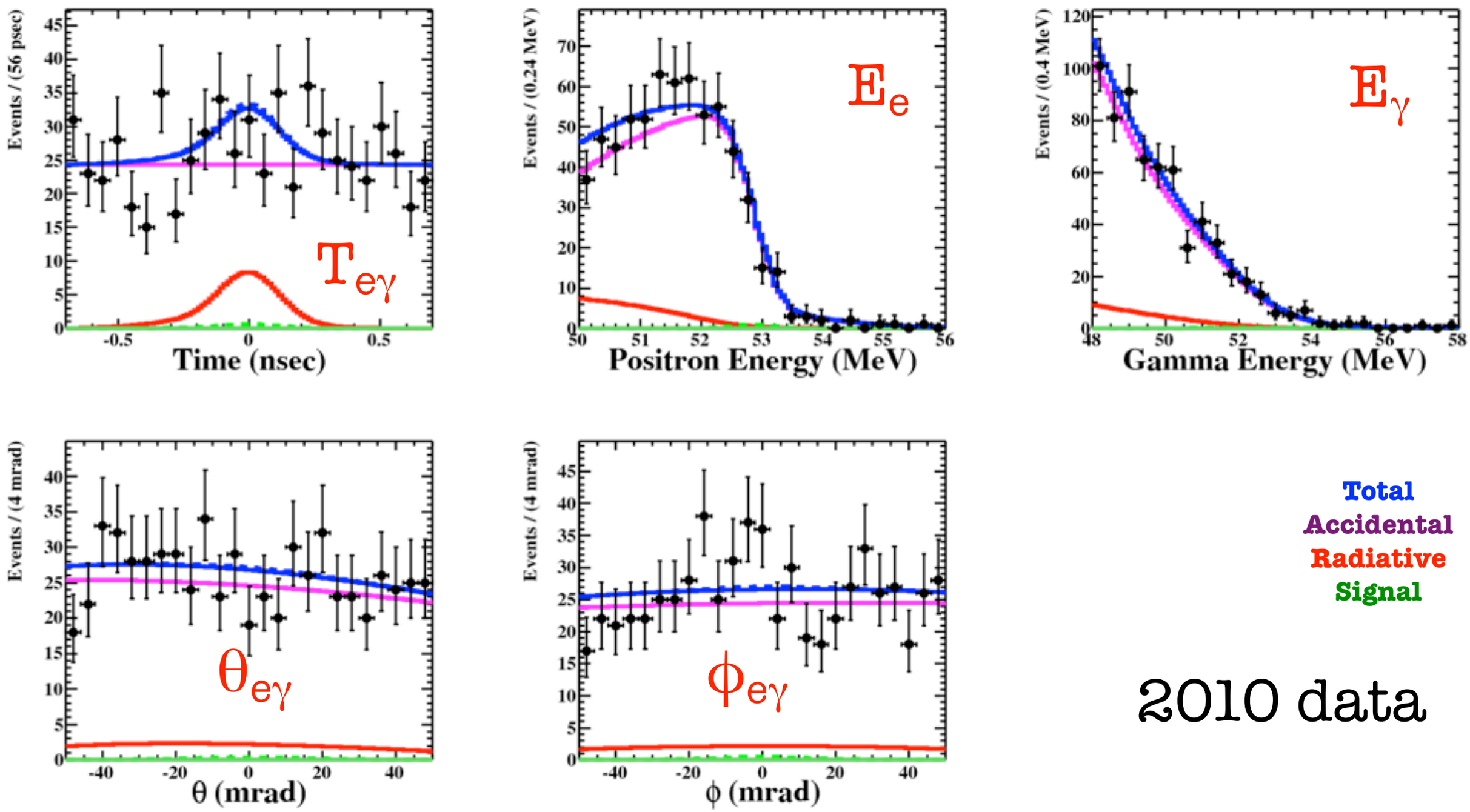


2010 data unblinded on July 5th, 2011

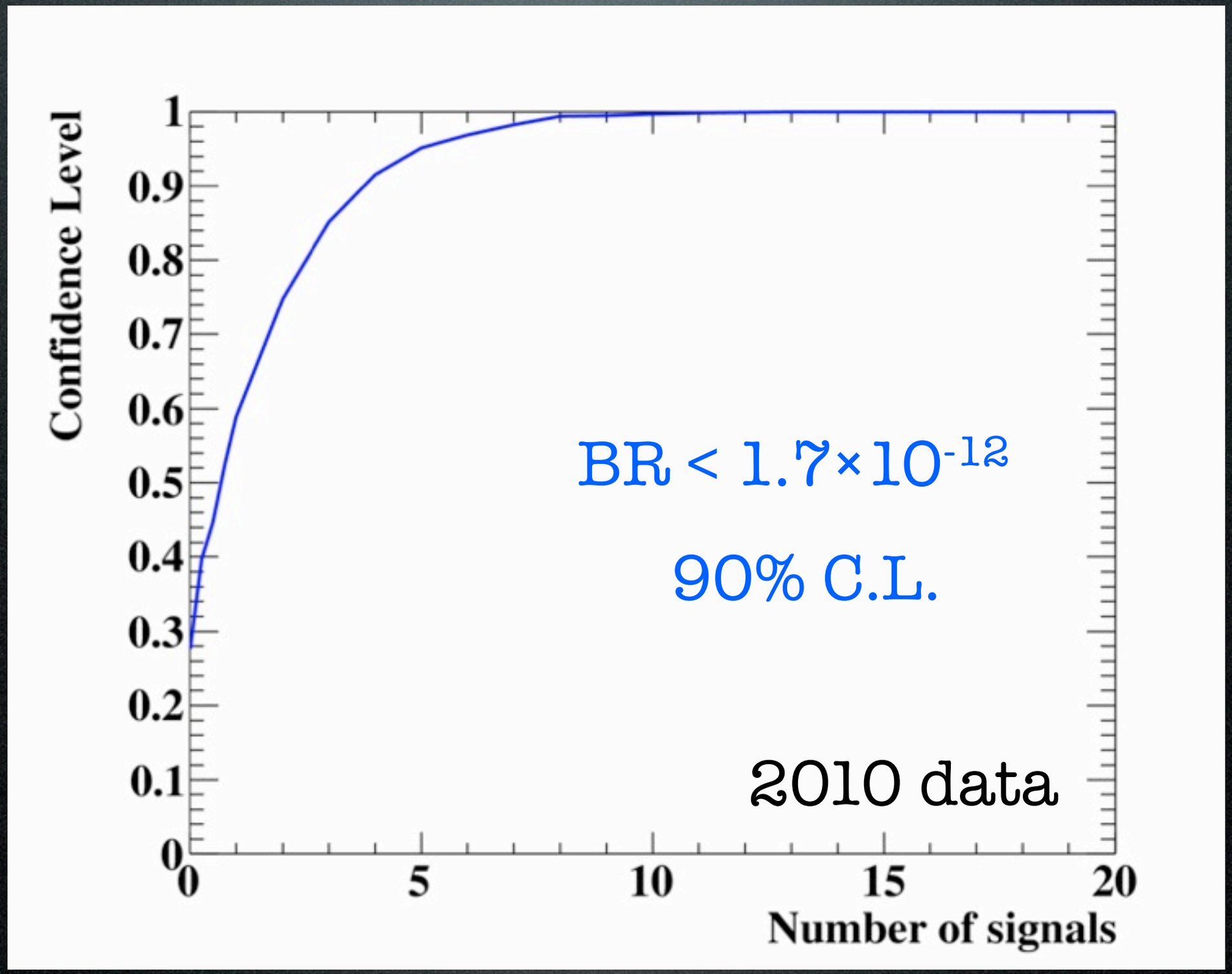


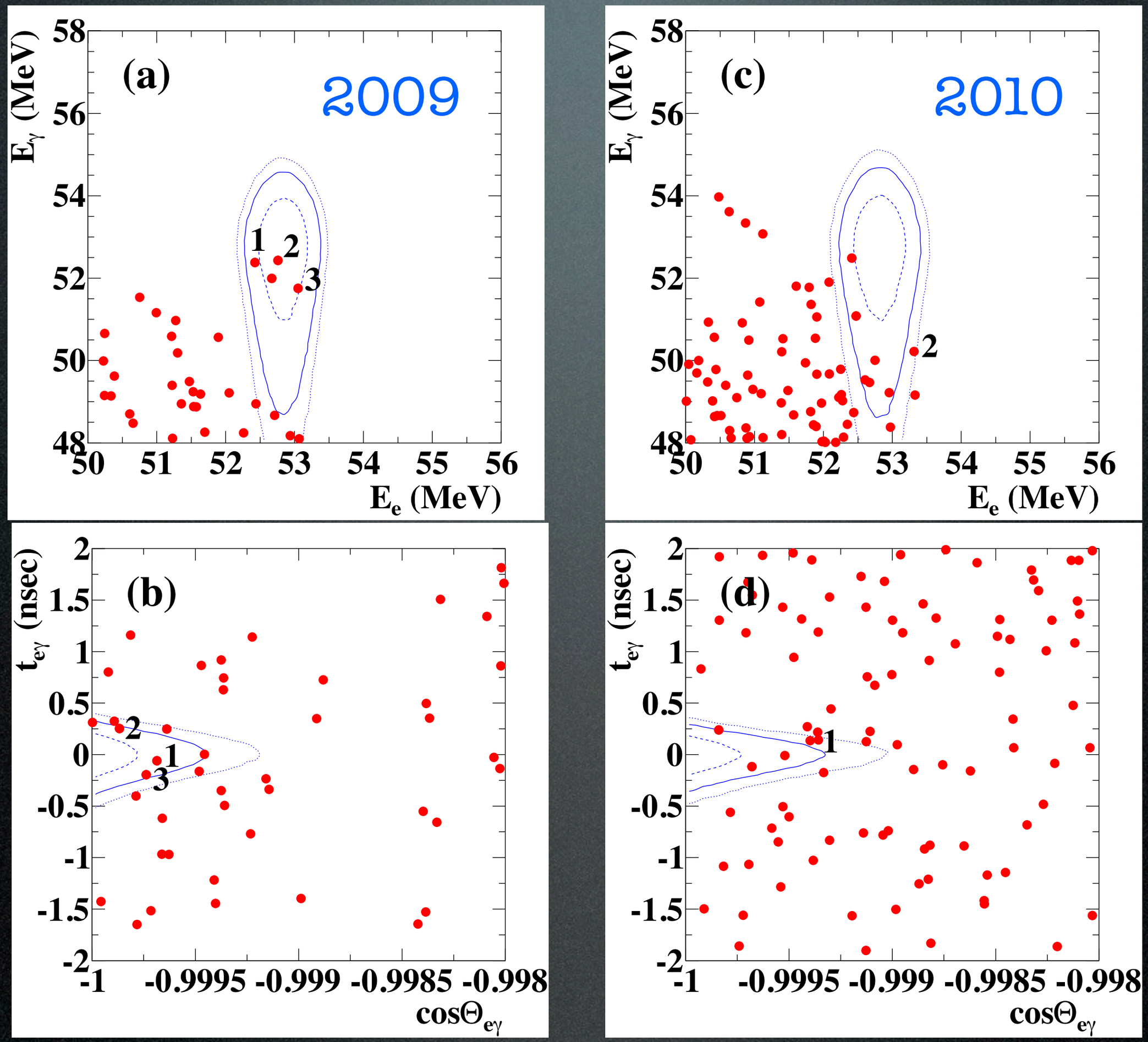


Likelihood Fit - 2010 Data



Likelihood Analysis




(a)
2009
(b)
(c)
2010
(d)
E_γ (MeV)
E_e (MeV)
$t_{e\gamma}$ (nsec)
$\cos\Theta_{e\gamma}$
1
2
3

Likelihood Analysis Results

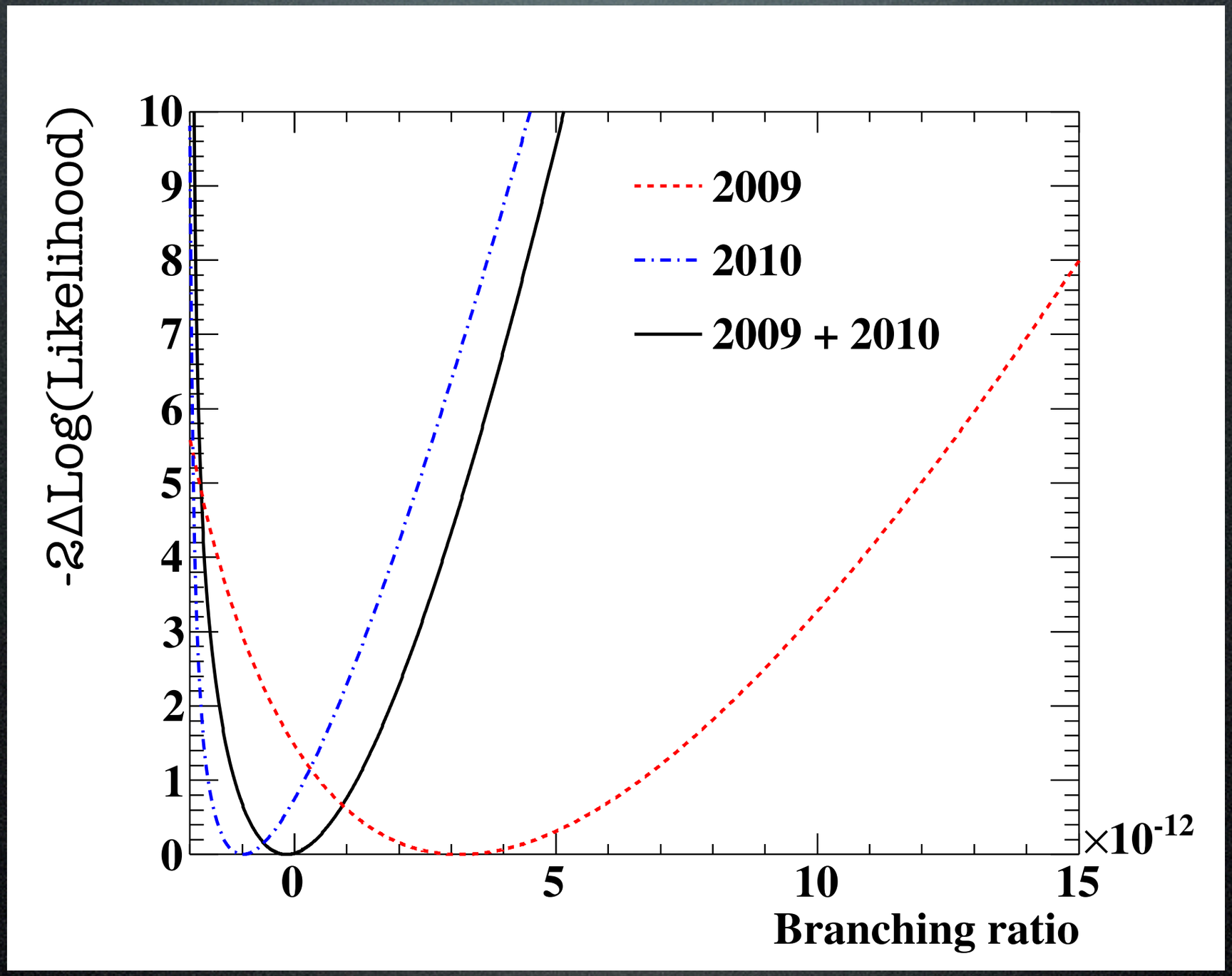
	BR(fit)	LL 90%	UL 90%
2009	3.2×10^{-12}	1.7×10^{-13}	9.6×10^{-12}
2010	-9.9×10^{-13}	--	1.7×10^{-12}
2009+2010	-1.5×10^{-13}	--	$\underline{2.4\times10^{-12}}$

combined result

(2009+2010expected UL = 1.6×10^{-12})

Published in Phys. Rev. Lett. 107, 171801 (2011)

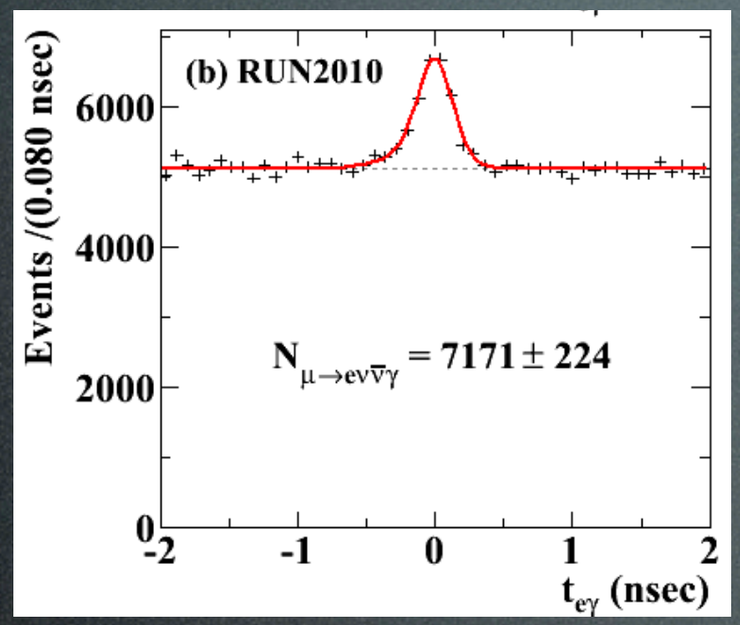
Profile Likelihood Curves



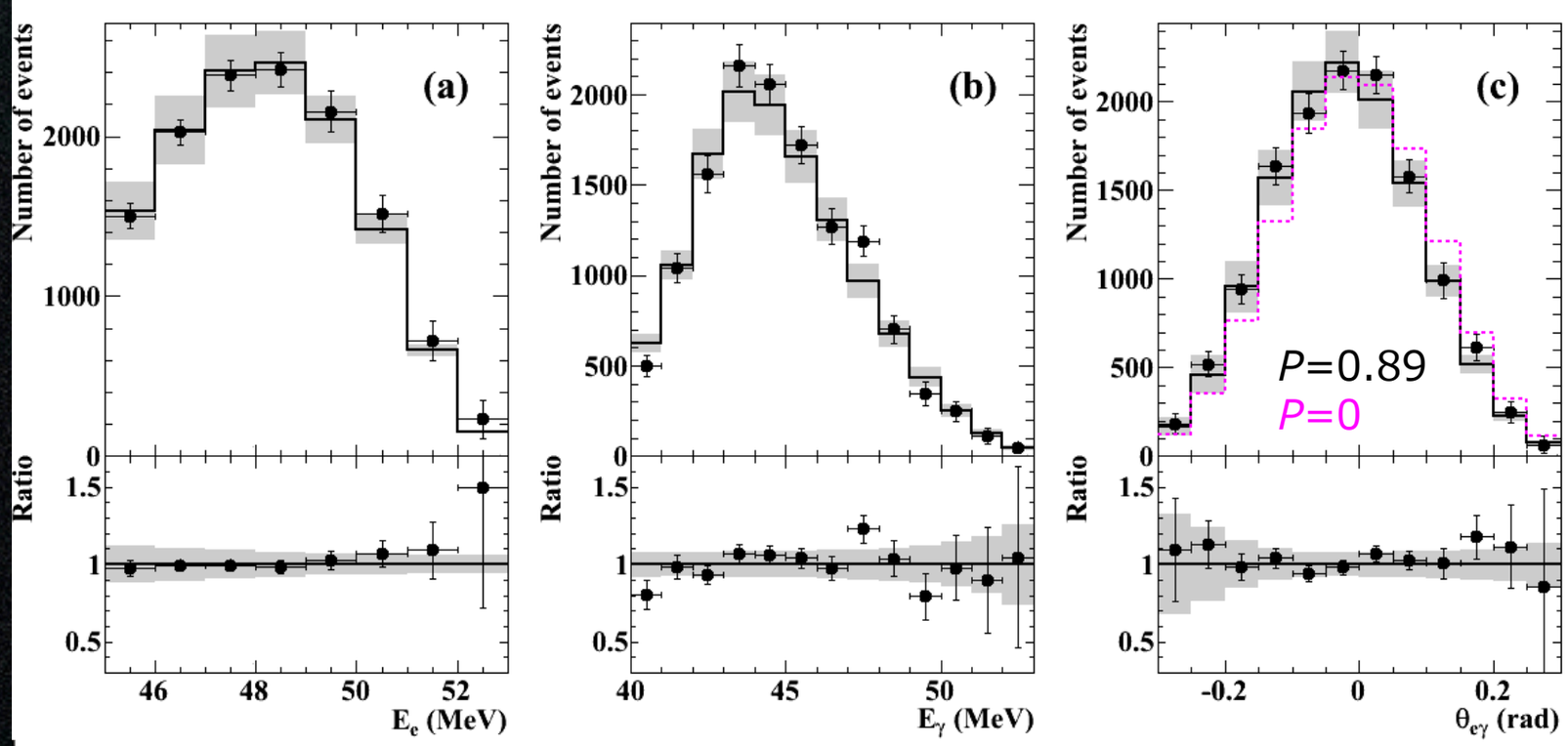
Note these curves are not directly used to derive the U.L. which are obtained in a frequentist approach.

Other physics results

Radiative Muon Decays



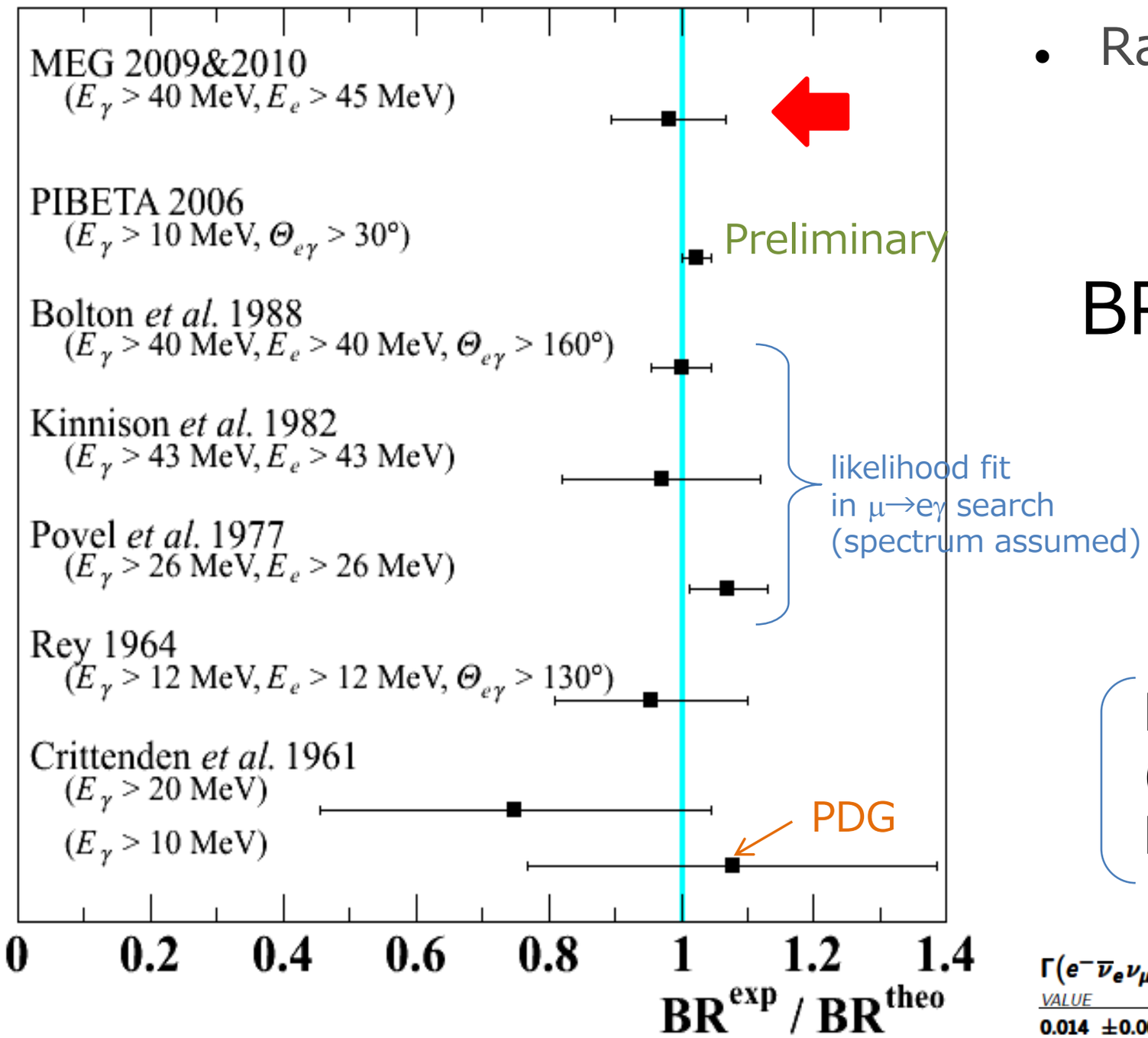
- 2009+2010



- Important check of $\mu\to e\gamma$ analysis
  - BG, calibration, normalization
- Close to kinematical edge w/ polarization ~89%
  - sensitive to BSM
  - determine Michel parameters: $\bar{\eta}$, $\varkappa$

to be published soon

Comparisons



- Ratio to theory (SM)

$$\mathcal{B}^{\mathrm{SM}}(\mu^+ \to e^+\nu_e\bar{\nu}_\mu\gamma) = 6.15 \times 10^{-8}$$

BR^{exp}/BR^{theo}

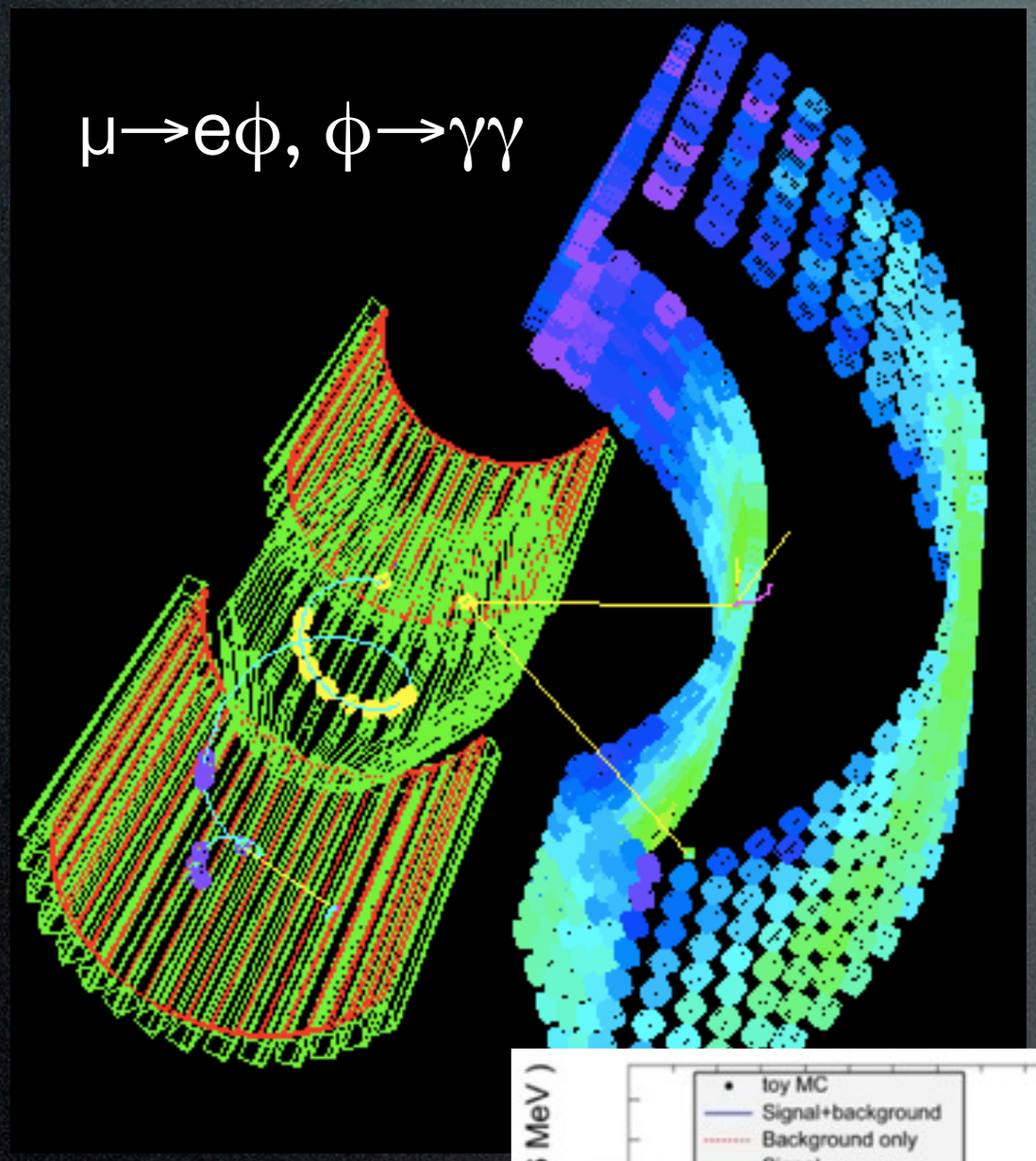
$= 0.98 \pm 0.09$

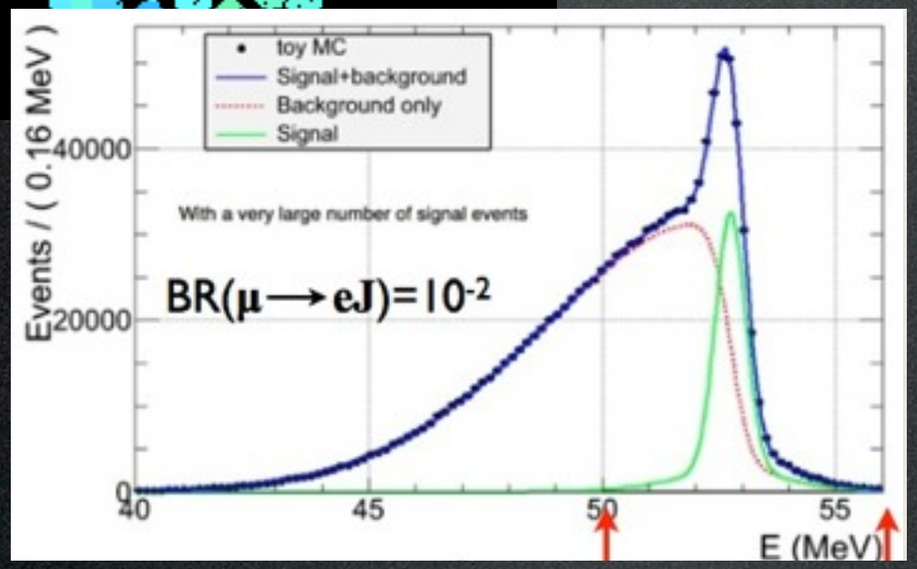
No definition of 'total' BR
(infrared divergent)
BR in limited phase space

$\Gamma(e^-\overline{\nu}_e\nu_\mu\gamma)/\Gamma_{total}$ Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.014 ±0.004		CRITTENDEN	61	CNTR	γ KE > 10 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	862	BOGART	67	CNTR	γ KE > 14.5 MeV
0.0033±0.0013		CRITTENDEN	61	CNTR	γ KE > 20 MeV
	27	ASHKIN	59	CNTR	

Exotics



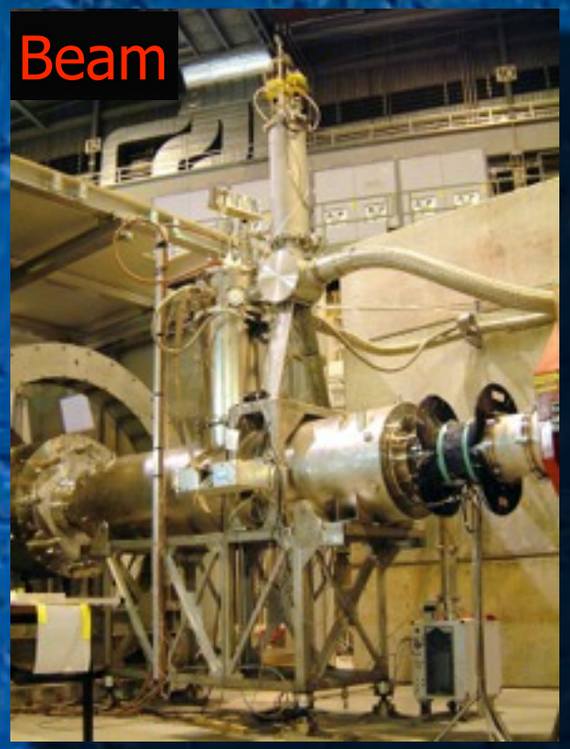


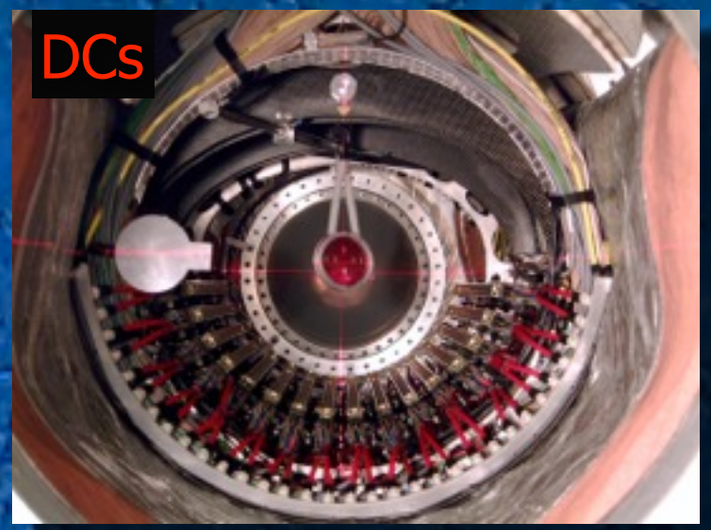
- μ→eϕ, ϕ→γγ
  - light, long-lived pseudo scalar
  - first search
  - expected 90% UL 10^{-11}–10^{-10} for 2009+2010 data
- μ→eJ (Majoron)
  - TWIST result (not published) $< 6.7\times10^{-5}$

2011 Run
& Data Analysis

MEG 2011 Overview

VERY Successful Physics Run : Doubled 2009+2010 Statistics!!!



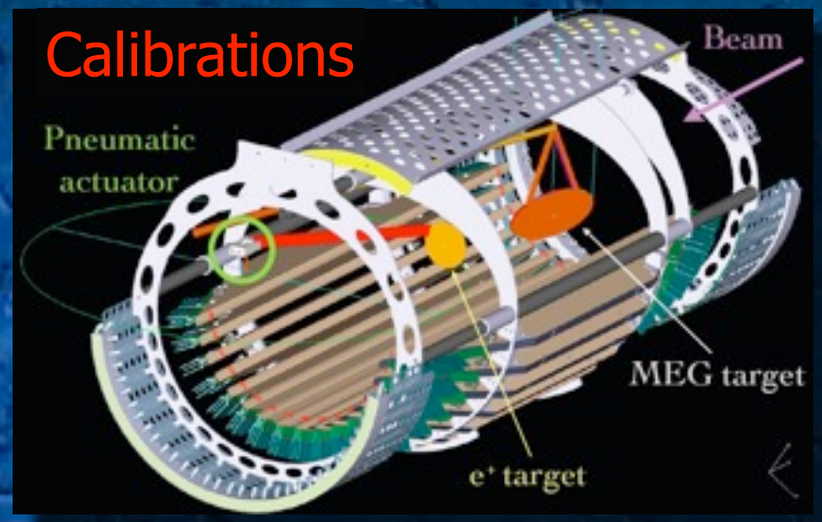


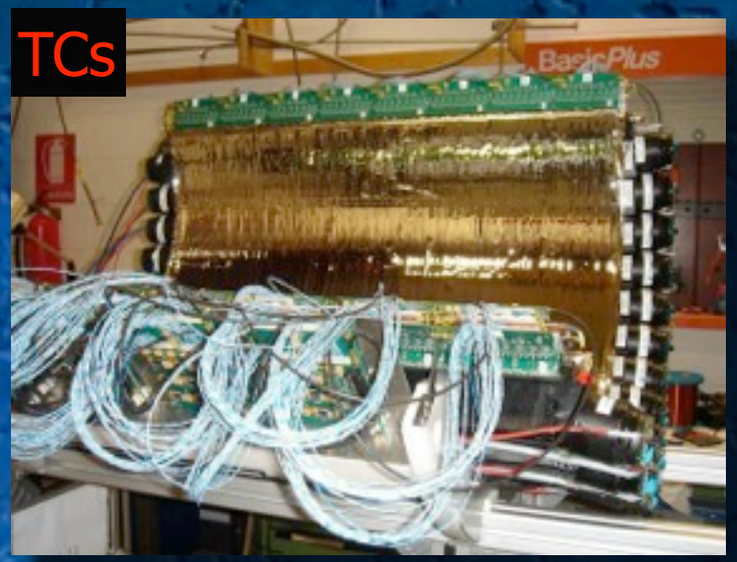
- BTS major repair & safety modifications (end 2010 + Spring 2011) – proved to be successful
  Ran contiuously for 212 D
- Beam-rate Optimization low, Normal, High & Intermediate intensities for 2011 detector intensity tests

- New DC HV-system successfully introduced to reduce noise – though effect on resolutions was counter-balanced by gain-degradation suspected to be due to aging effects
- New DC alignment system laser-tracker + prismatic corner-cube reflectors
- Gas + beam intensity studies undertaken
  Shows may be also possible to work at "Intermediate intensity"

- BGO array replaces NaI array in CEX
  - finer granularity,
  - 30% improved $\sigma E/E$ at 55 MeV,
  - improved position resolution,
  - 30% increase in LT to 97%
  - factor 2.1 > in efficiency
  REDUCES π^0 calibration time by 2

MEG 2011 Overview Cont.





- **Stable operation of calorimeter**
  - slow 4% LY-loss (well monitored & compensated)
  - PMT gain-loss at 2010 level 0.1%/D
  - improved energy resolution
  - beam intensity studies show pile-up rejection works well even at $R_\mu \sim 1 \cdot 10^8$ Hz

  Shows could work at increased beam rate 2012!

- **Mott scattering e^+ Beam**
  - study of cloud muon contamination 50 & 53 MeV/c
  - RF introduced 1st time
  - Mott & MEG target data taken

  RF-selection gives good monochromatic line
  $\sigma_E \sim 450$ keV (8‰ σ_E /E)

- **Neutron generator** with 9 MeV Ni gamma-line used as standard calibration tool

- **Dedicated Cosmic Alignment** data runs taken throughout run period

- **TC bar performance**
  - stable operation
  - performance comparable 2010

- **TC Fibre performance**
  - US-side 10% noisy channels excluded (influence on DC)
  - performance not sufficient for online trigger inclusion
  - used for "offline" analysis

MEG 2011 Overview Cont.

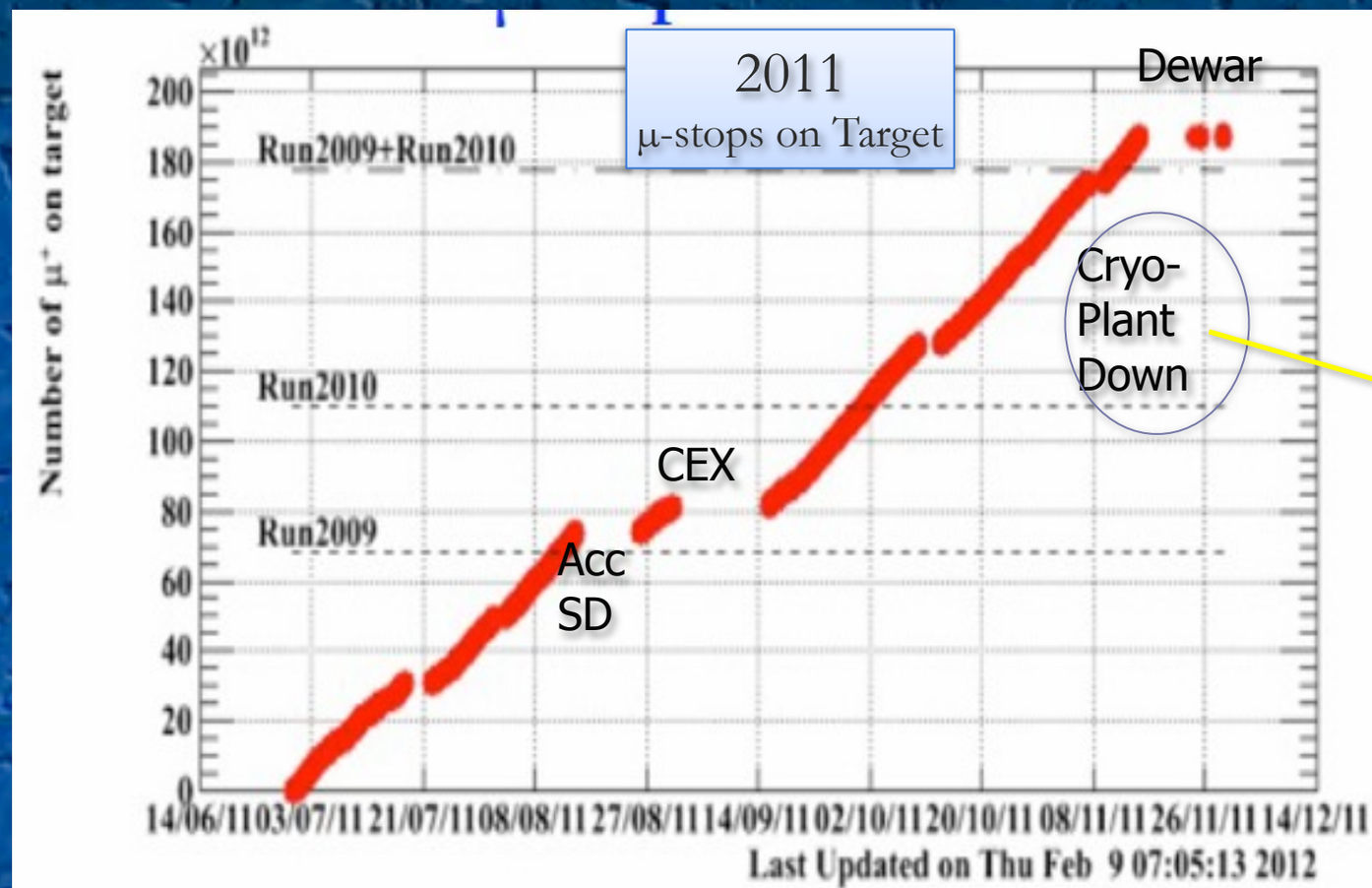
- **Trigger/DAQ Performance**
  - Multi-buffering used as standard
  - LT increases to > 99%
  - MEG trigger rate 5→11 Hz
  - direction-match LUT relaxed without loss of efficiency
  - UCN spill compensation for LXe PMT-gain change (<1% effect) in trigger BUT! available UCN-signal needs optimizing

- **Remote Shift Scheme introduced**
  - during Physics Run Part-II
  - full set of "remote tools" to run experiment over Internet
  - added monitoring & surveillance tools
  - added electronic control room aids

- **Power Outage**
  - kills Cryo-plant 4 down till next year
  - setup for BTS dewar operation once another source LHe ready
  - 10D beam loss to MEG
  - successful dewar operations all tests could be finished

2011 in Numbers

Statistical – MEG's most Significant Physics Run



10 Day Beam-loss due to unexpected power-outage & loss of cryo-plant 4

- 2011 **Double** the Statistics of **2009 + 2010**
  (based on Normalization)

  2011 →$1.9 \cdot 10^{14}$ μ-stops compared with
  2009+2010 →$1.75 \cdot 10^{14}$ μ-stops

- 113 Physics Days/81.3 DAQ Days
- 62.4 M Triggers (MEG) – 30998 Runs @ 2k events
- Total of 1213 shifts & remote shifts

Performance Summary for Run 2011 (Preliminary)

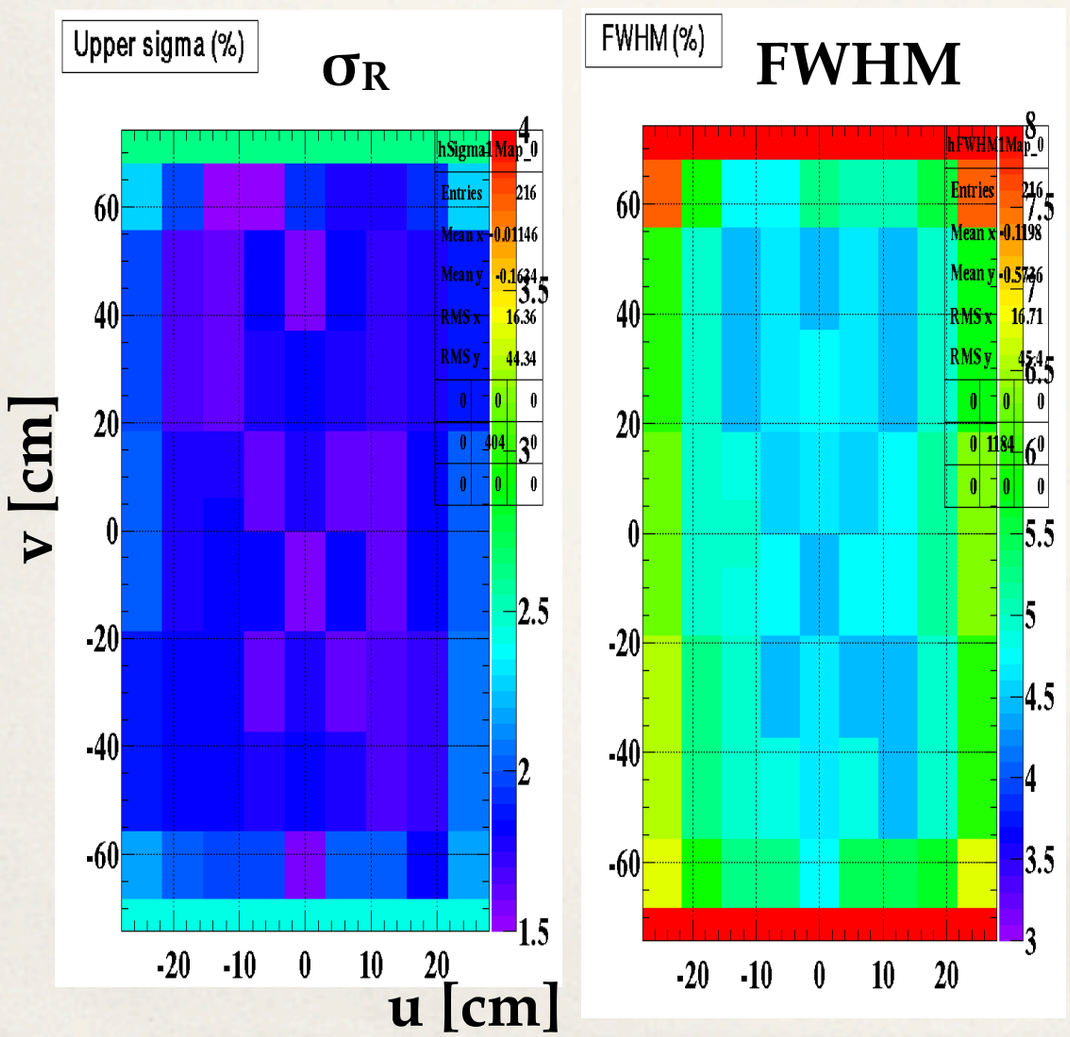
- Data reprocess of data 2011 with new calibrations (Jan2012-reprocess) is in progress.
- Preliminary studies on new reprocessed data show performance comparable to previous years.

	2009	2010	2011(preliminary)
Gamma energy (%)	1.9% (w>2cm)	1.9% (w>2cm)	1.7% (w>2cm)
Gamma position (mm)	5 (u,v) / 6 (w)	5 (u,v) / 6 (w)	←
Positron momentum (%)	0.59 (core 80%)	0.61 (core 79%)	0.61 (core 86%)
Positron angle (mrad)	6.7 (Φ,core), 9.4 (θ)	7.2 (Φ,core), 11.0 (θ)	6.5 (Φ,core), 10.8 (θ)
Vertex position (mm)	1.5 (Z), 1.1(Y)	2.0 (Z), 1.1(Y)	1.9 (Z), 1.0(Y)
Gamma-positron timing (ps)	146 (core)	126 (core)	133
Gamma efficiency (%)	58	59	←
Trigger efficiency (%)	91	92	95
Data statistics (k-factor)	1.1×10^{12}	2.1×10^{12}	3.4×10^{12}

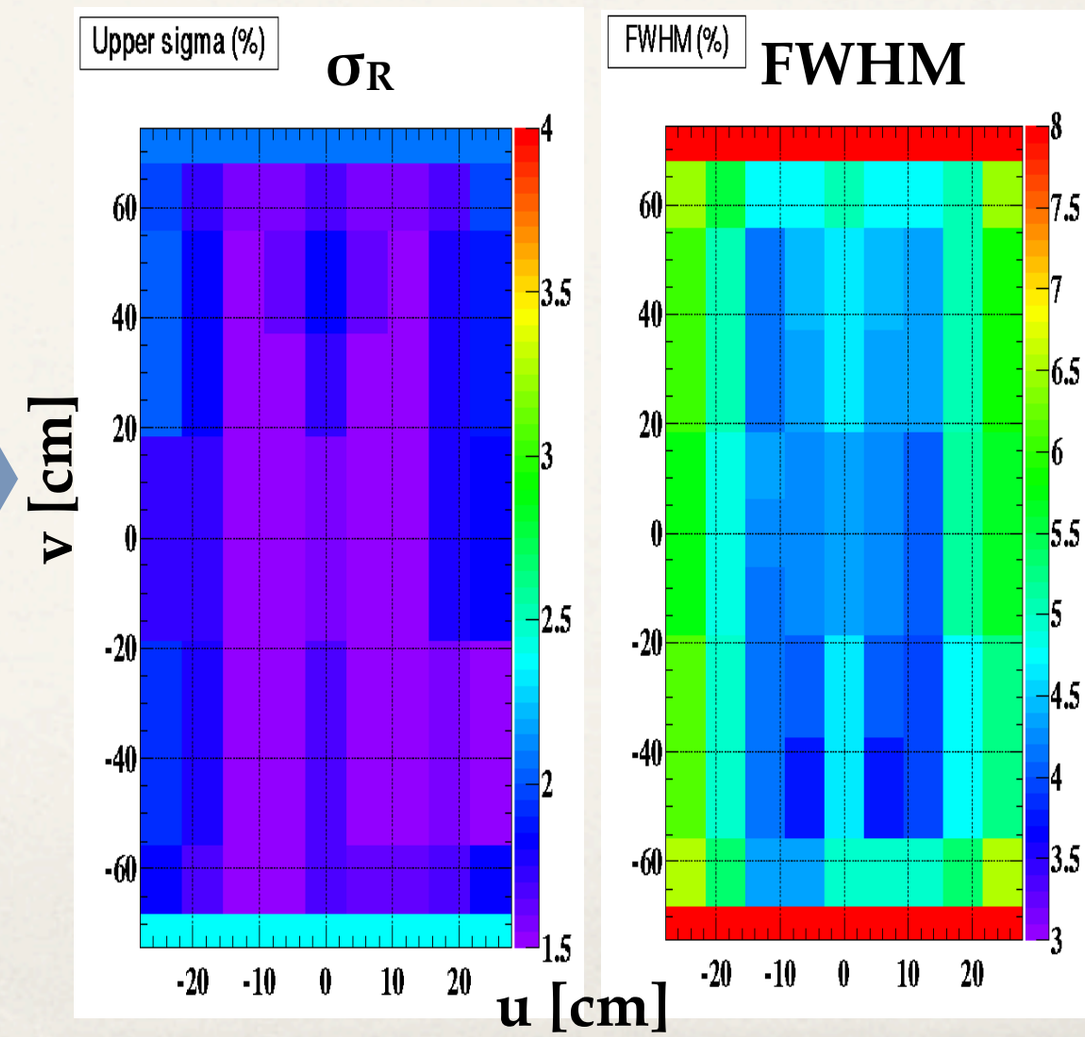
Energy Resolution

- Obtained slightly better energy resolutions for 2011
  - 1.9% (2010) →1.7% (2011) @w(depth) > 2cm

2010



2011



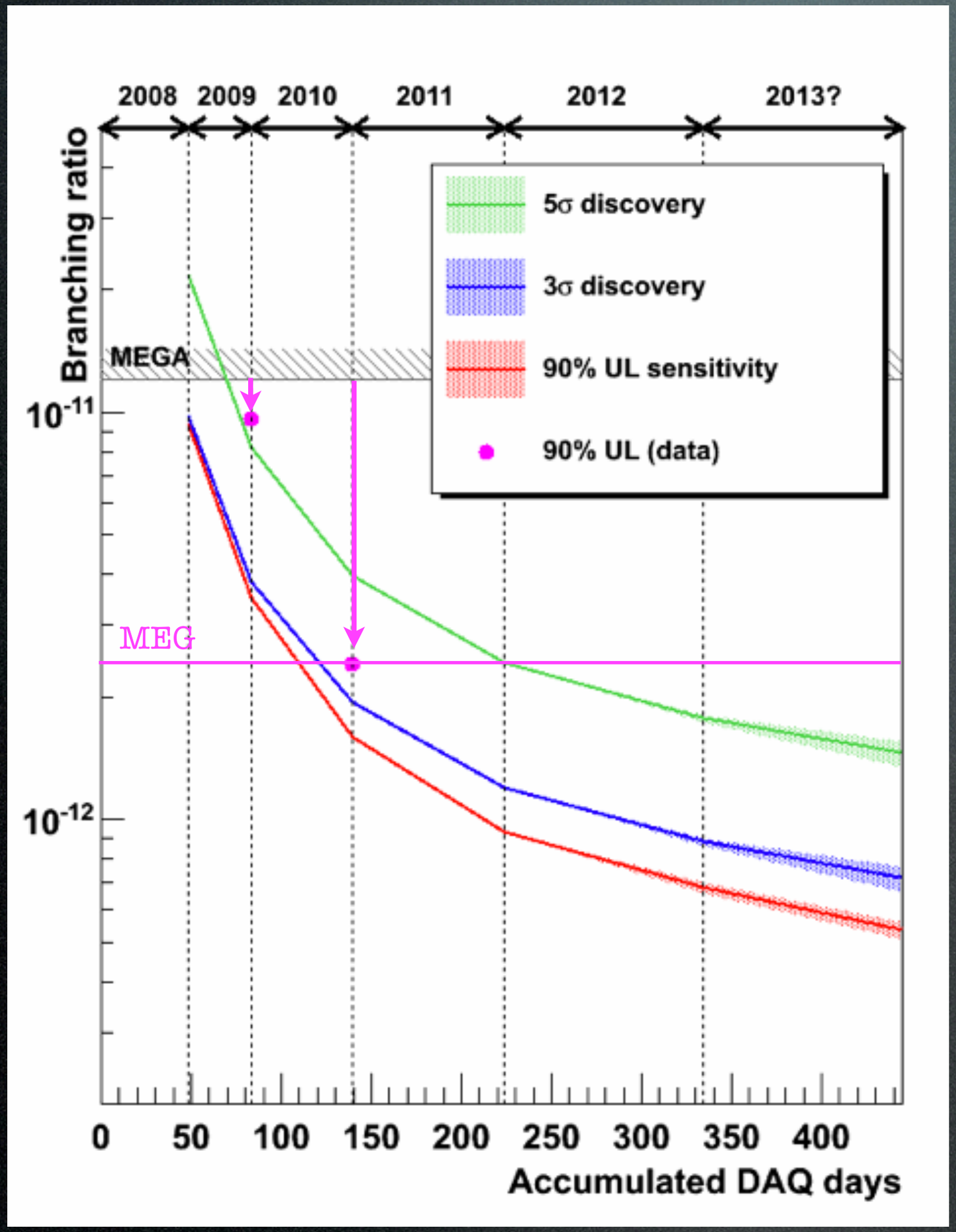
Next Steps for Data 2011 Analysis

- Studies with full statistics from new reprocessing
  - BG study
  - Construction of PDFs
  - Sensitivity estimate
- Further refinement of calibrations and reconstructions.
- We will need at least one more reprocessing with final calibrations.
- Check fulfillment in task list before unblinding
- We will hopefully be ready for unblinding in few months.

Task List before Unblinding

- Check list for reconstruction and calibration
- Nominal DC alignment scheme definition and evaluation of sys. error
- B-field type
- Selection algorithm
- Evaluation of photon energy and scale
- Evaluation of relative timing resolution
- Evaluation of positron momentum resolution and scale
- Evaluation of angular resolutions
- Evaluation of normalization factor
- Evaluation of correlations in positron variables
- Sensitivity evaluation (toy MC)
- Sensitivity evaluation (side-band fit)
- Systematics uncertainties

All should be straightforward once we finish final data reprocess.

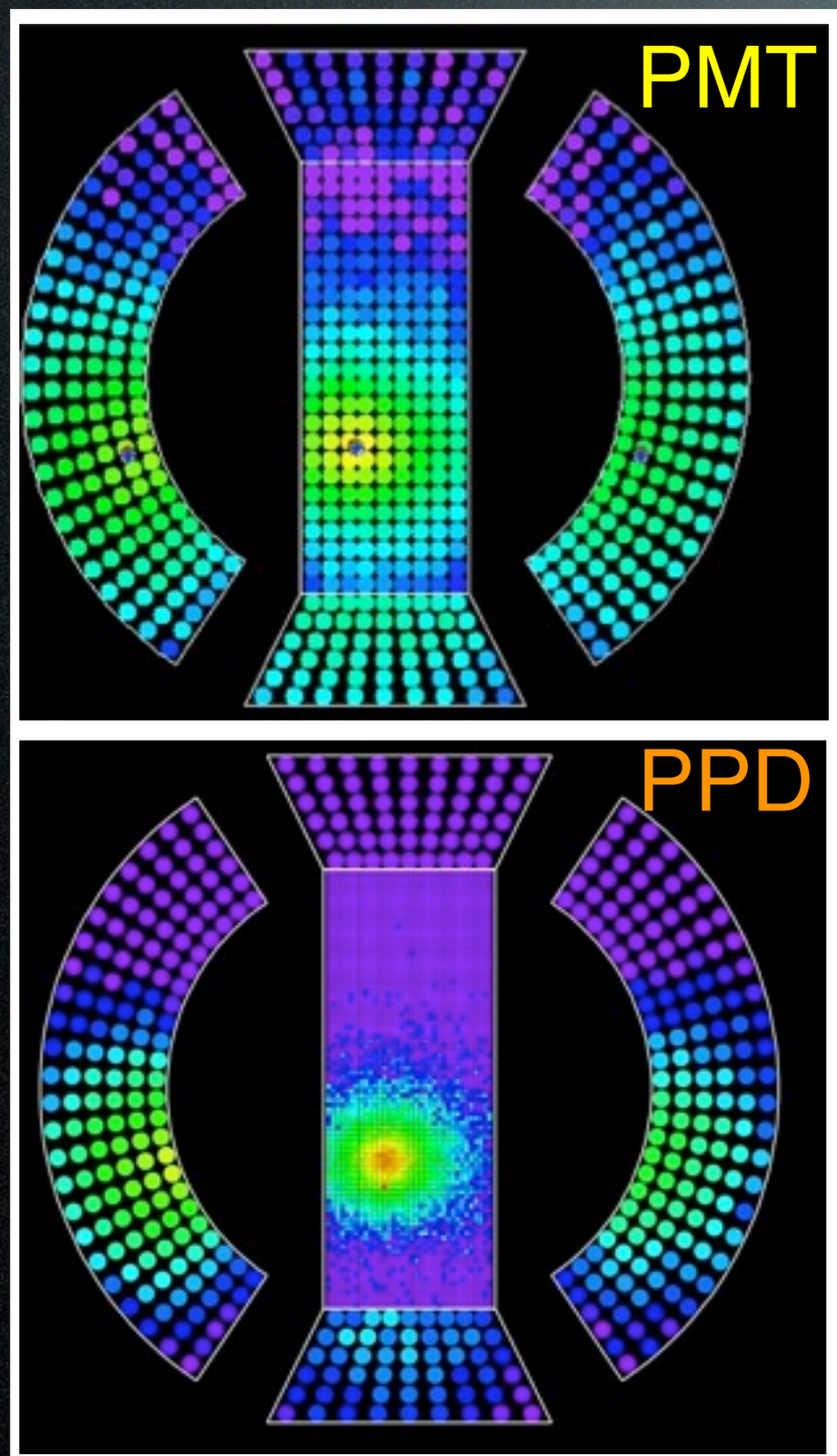


Prospects

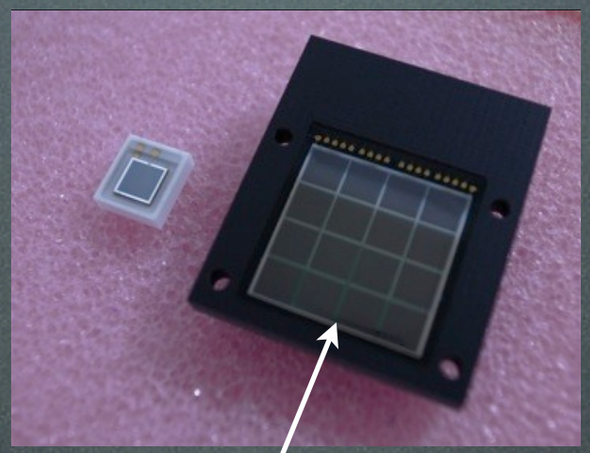
- With 2011+2012 data we will go below 10^{-12}
- Improvement gets slower after 2012
  - statistics, BG
- Time to consider upgrading the experiment!
  - "MEG phase-II"

upgrade ideas

Small photo-sensors for LXe

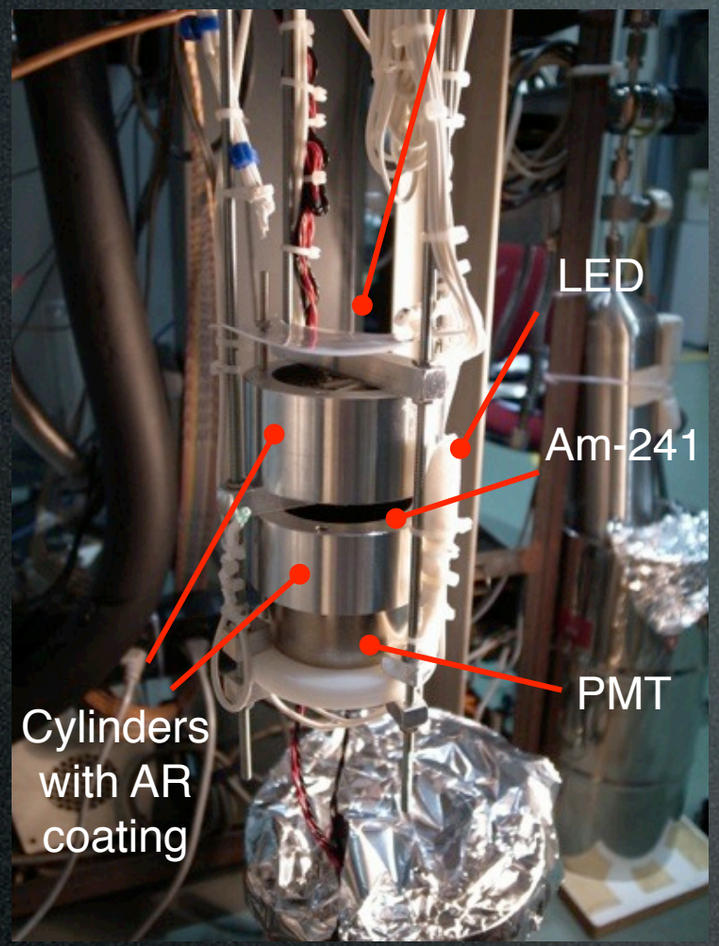


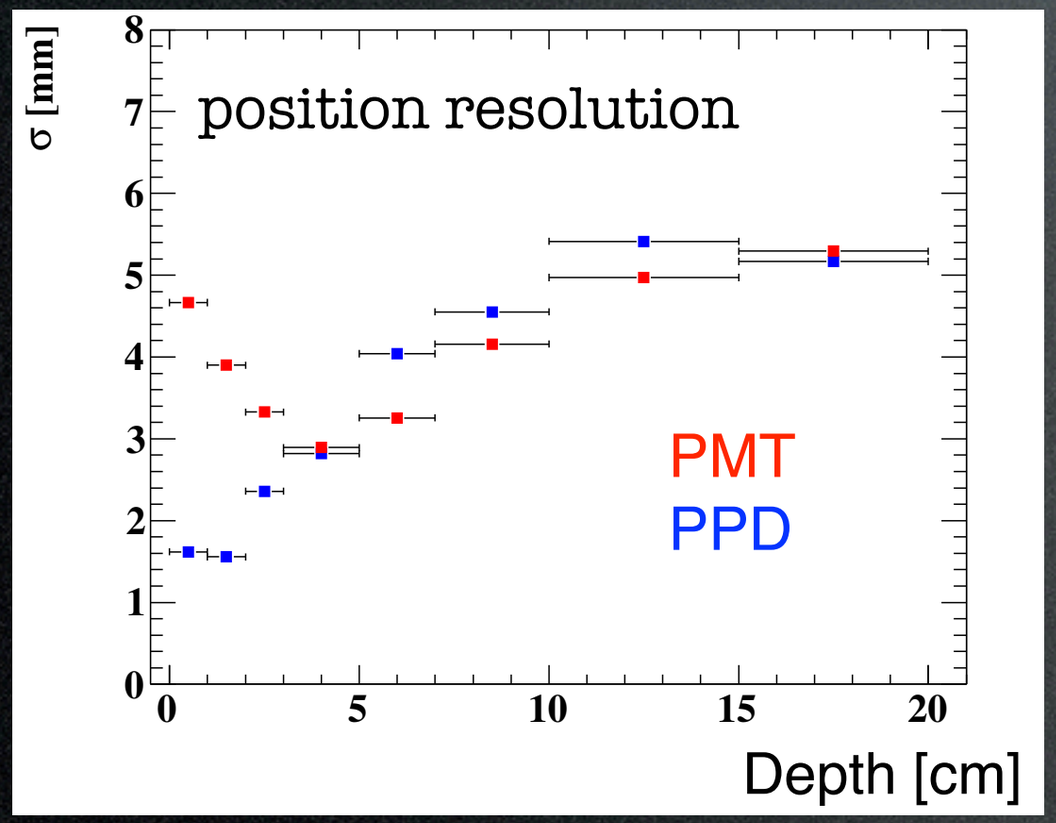
SiPM (MPPC)



monolithic array
16 × 3×3 mm²

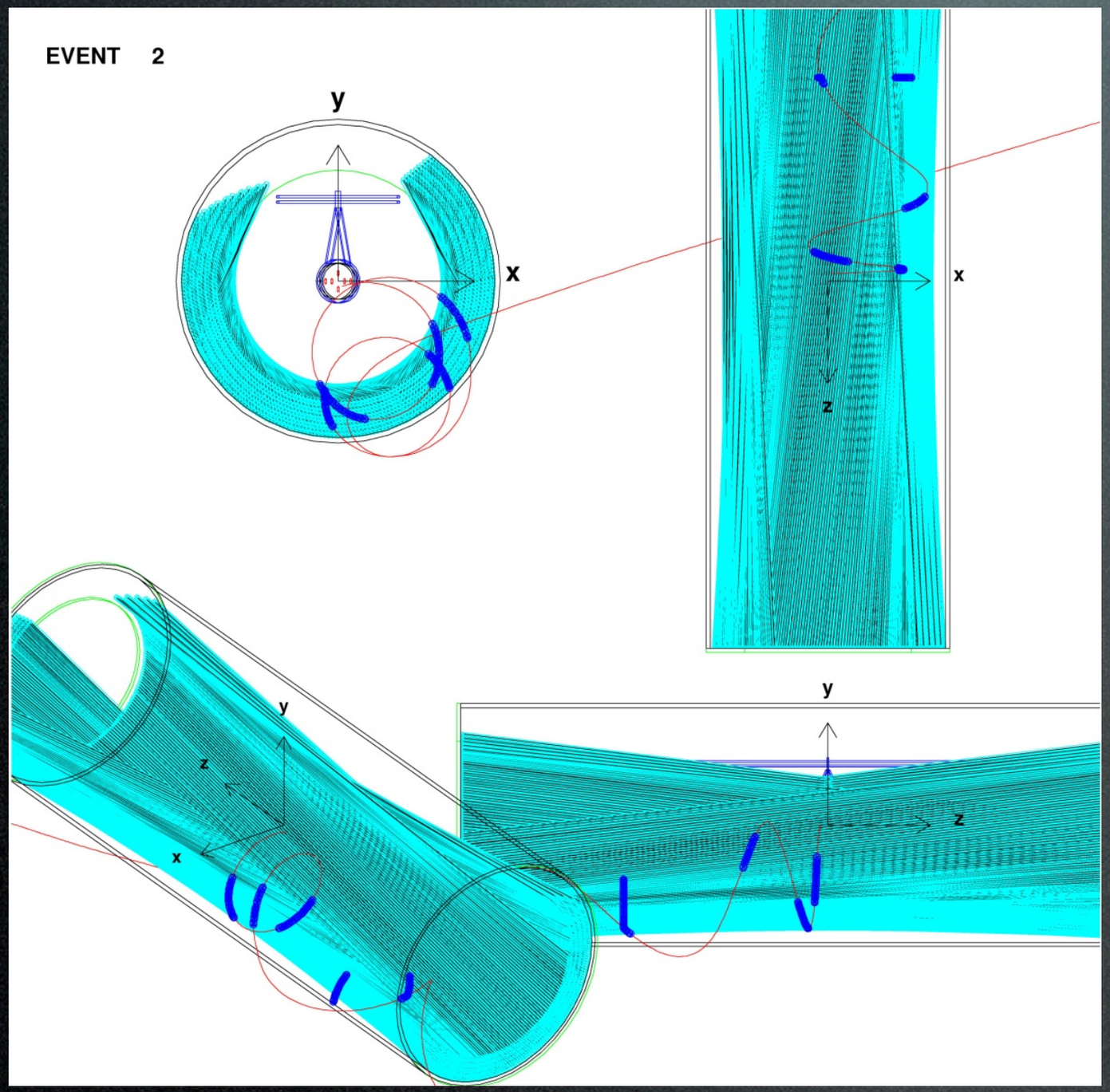
- PPD (SiPM) for the front wall
- lower material
  → better efficiency
- higher granularity & uniformity
  → better resolutions
  → pile-up rejection
- operation in B field, low power, etc



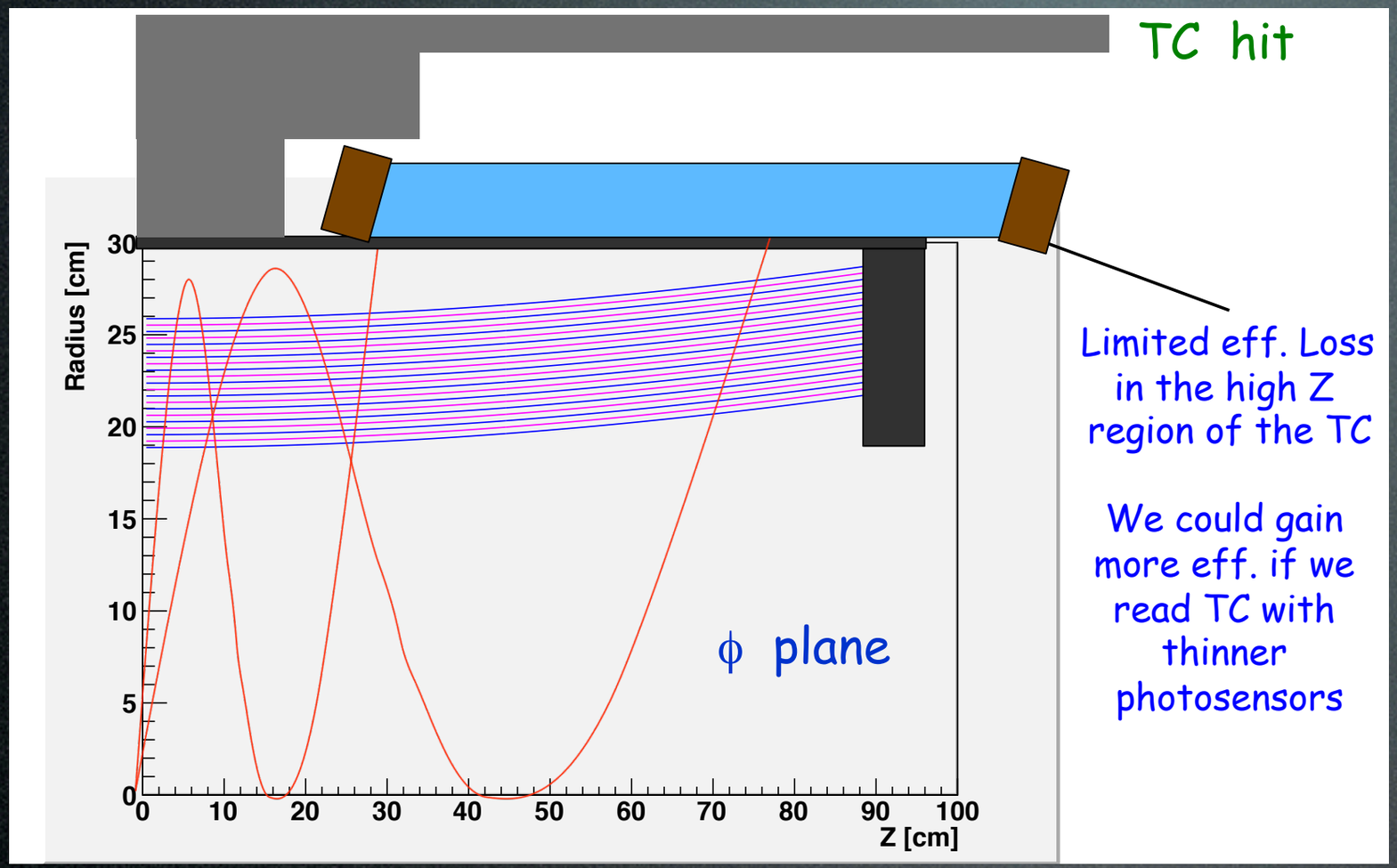


- VUV sensitive?
  - already achieved PDE~10% no protection layer, thinner p++ layer, anti-reflection
- dark counts
  - no problem at LXe temp.
- cross-talk, after-pulsing
  - simulation studies underway
- foresee Prototype w/ ~500 PPDs to test in 2012-2013 if successful developments

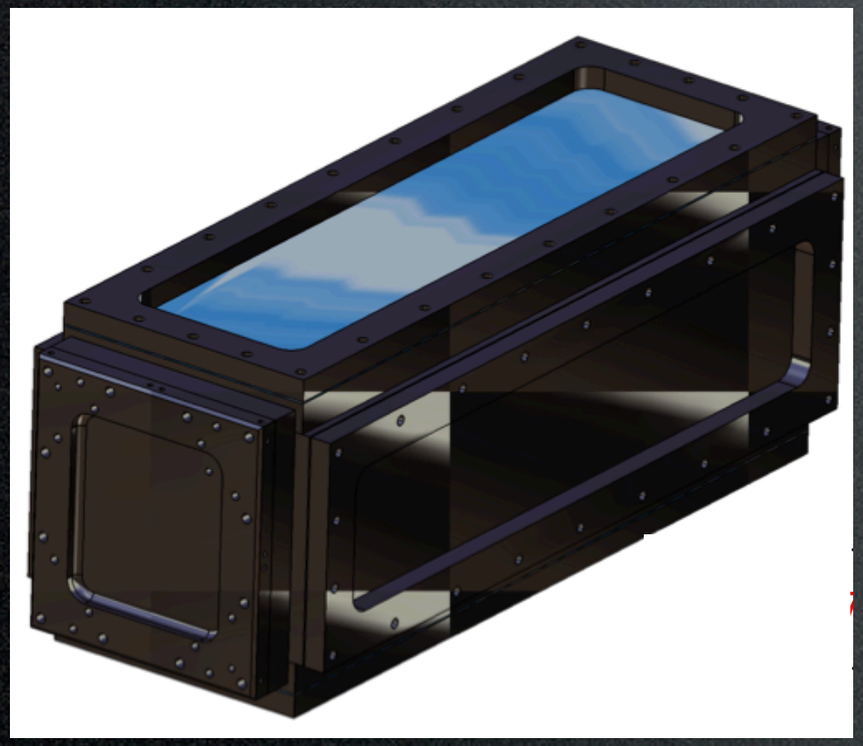
New Drift Chamber



- Single volume DC with small cells & stereo angles
- fast GHz readout
  - cluster timing, high band width
    → better resolutions
- He/iC_2H_4 = 90/10
  - keep $<1.7\times10^{-3}X_0$ for e+ full turn
- stable operation at 10^8
- transparent to TC

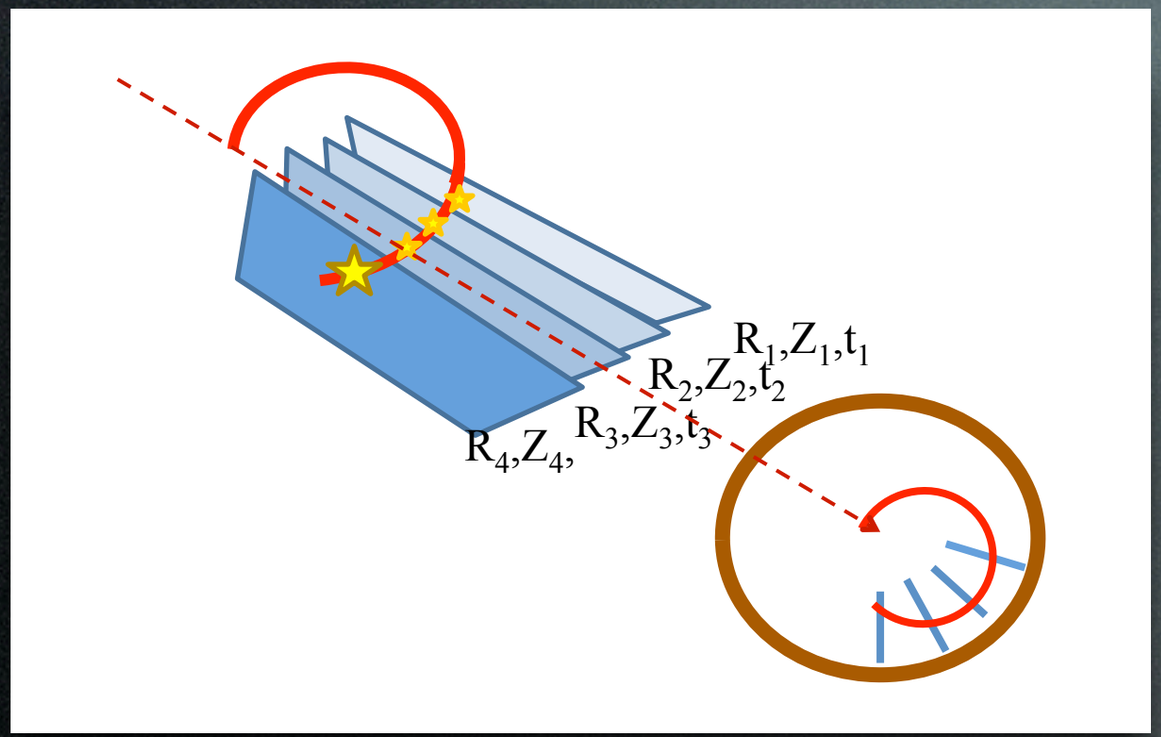


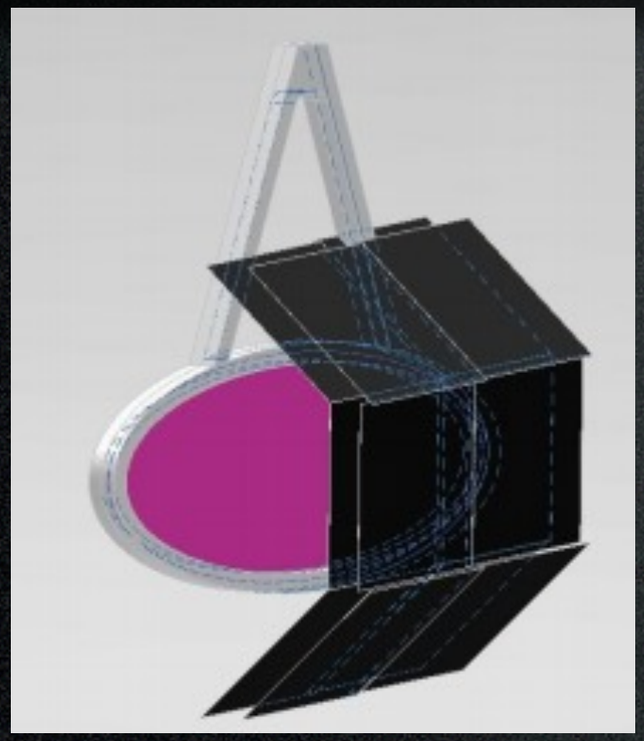
- Various studies ongoing
- Prototype under construction
  - tests this year
- Ageing tests
- TDR by end 2012

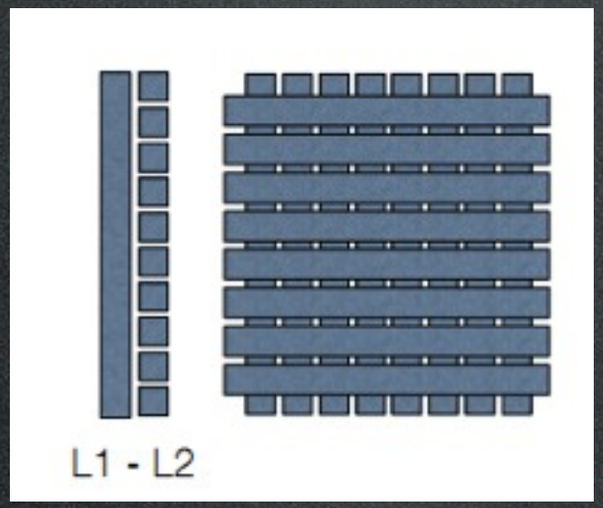


Joint INFN-PSI European Research Council Advanced grant request (submitted Feb. 16 2012)

other ideas...







- tracker + timing using thin (100-200μm) scintillator foils read by SiPM
- thin (50μm) Si vertex detector to aid angle/ vertex measurement
- active target (250μm) using scintillating fibers read by SiPM
- and others...

Conclusion

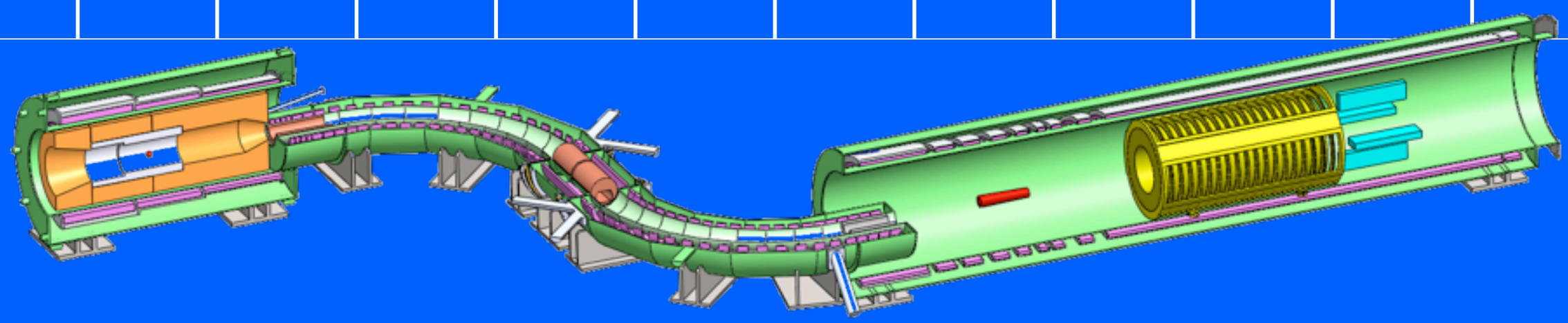
- We published the result of 2009+2010 data & constrained new physics by 5× tighter UL: BR < 2.4×10^{-12} @90% C.L.
- Successful 2011 run doubled the data sample
- We look forward to running the full 2012 beam time to go below 10^{-12} sensitivity
- We have started R&D to upgrade detectors
  - R&D and construction budget (next 3 years) already approved in Japan
  - Scientific approval in Italy
- We will present our proposal for the following years at next BVR in 2013

back up sllides

μ → e conversion at 5×10^{-17}

~1/390 × $\mu^+ \to e^+\gamma$ (Al)

year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022



mu2e	CD1	CD2/ 3a	CD3b	solenoid/ detector fabrication	solenoid/ detector installation	engi neer ing run	physics running				

COMET @J-PARC ~similar schedule