The Latest result of the MEG Experiment

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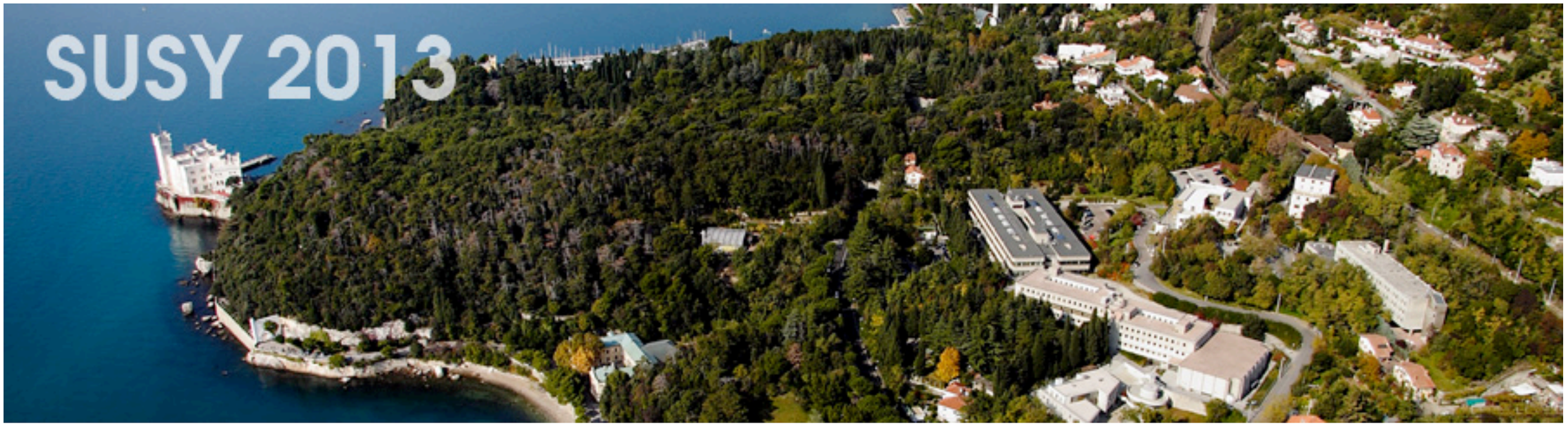
on behalf of MEG Collaboration

ICEPP, the University of Tokyo

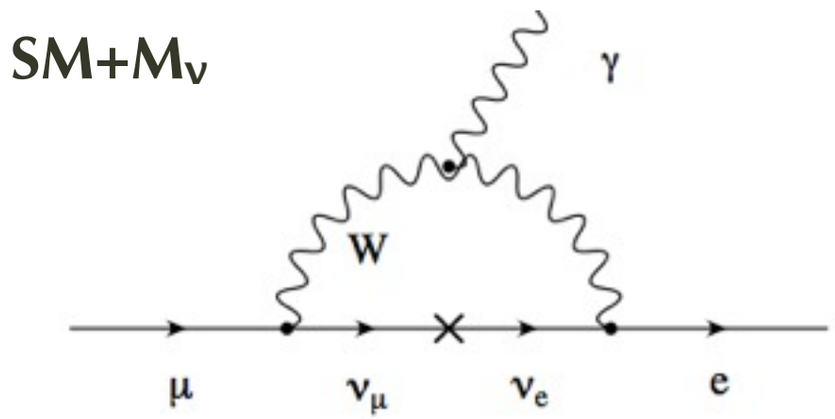


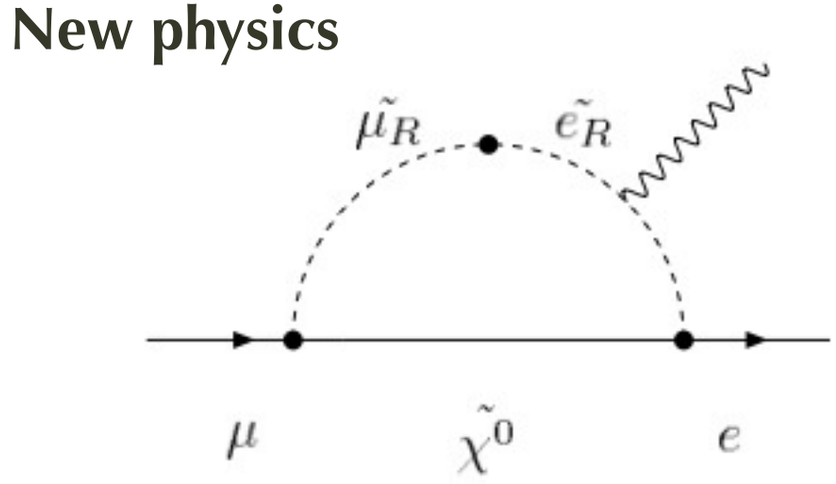
21st International Conference on Supersymmetry and Unification of Fundamental Interactions
The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy
26-31 August 2013

Lepton Flavor Violation (LFV)

- Quark mixing : CKM matrix
  - established in Standard Model

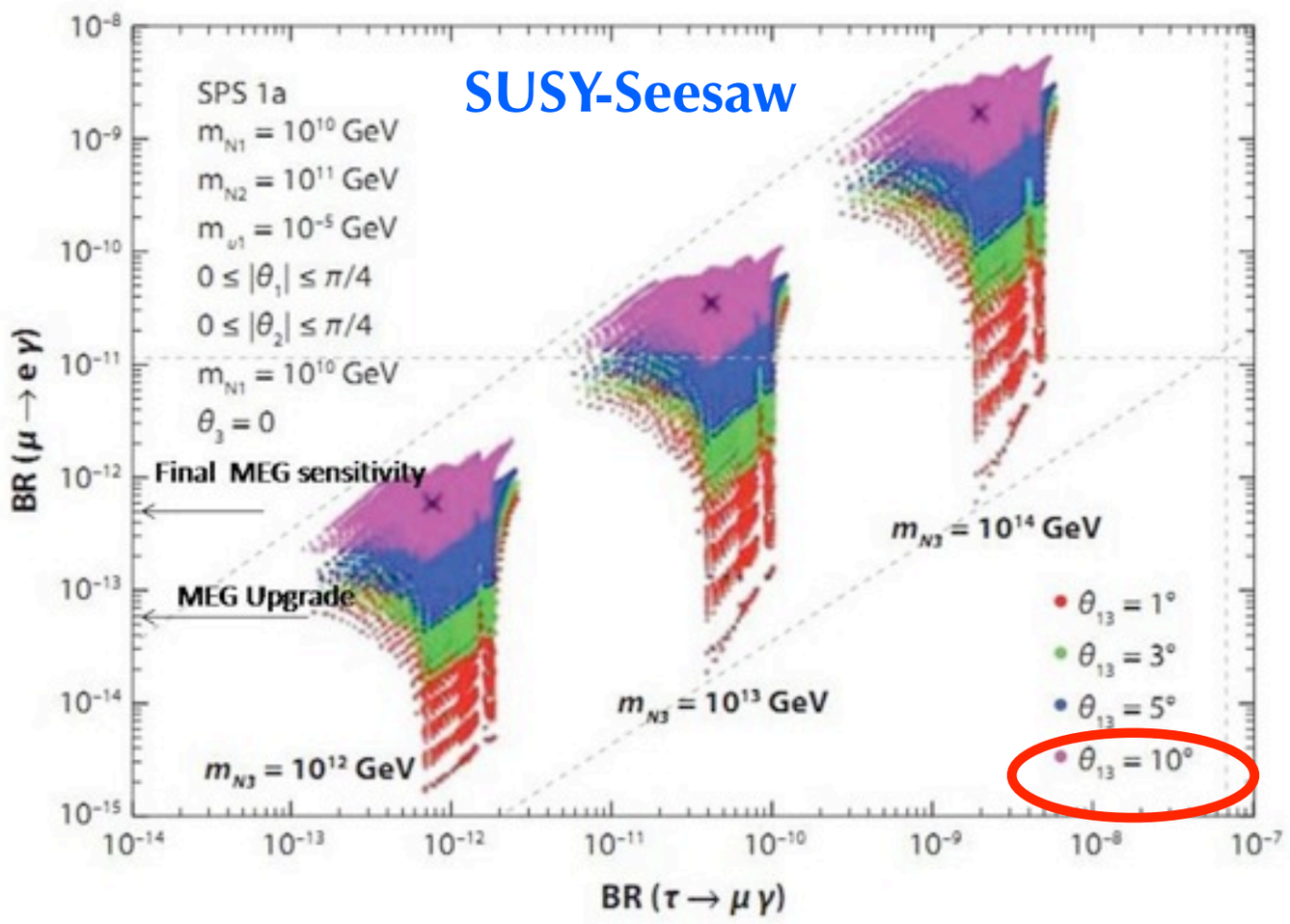
- Lepton :
  - Neutrino : Neutrino oscillation
    - New hint for new physics
  - Charged lepton : No LFV is found yet
    - SM + neutrino mass ⟹ BR(μ→eγ)<10^{-40}
    - Observation of μ→eγ will be a clear sign of new physics
    - New physics like SUSY-GUT, SUSY-seesaw, Extra Dimensions etc. predict large BR (μ→eγ)





LFV from New Physics

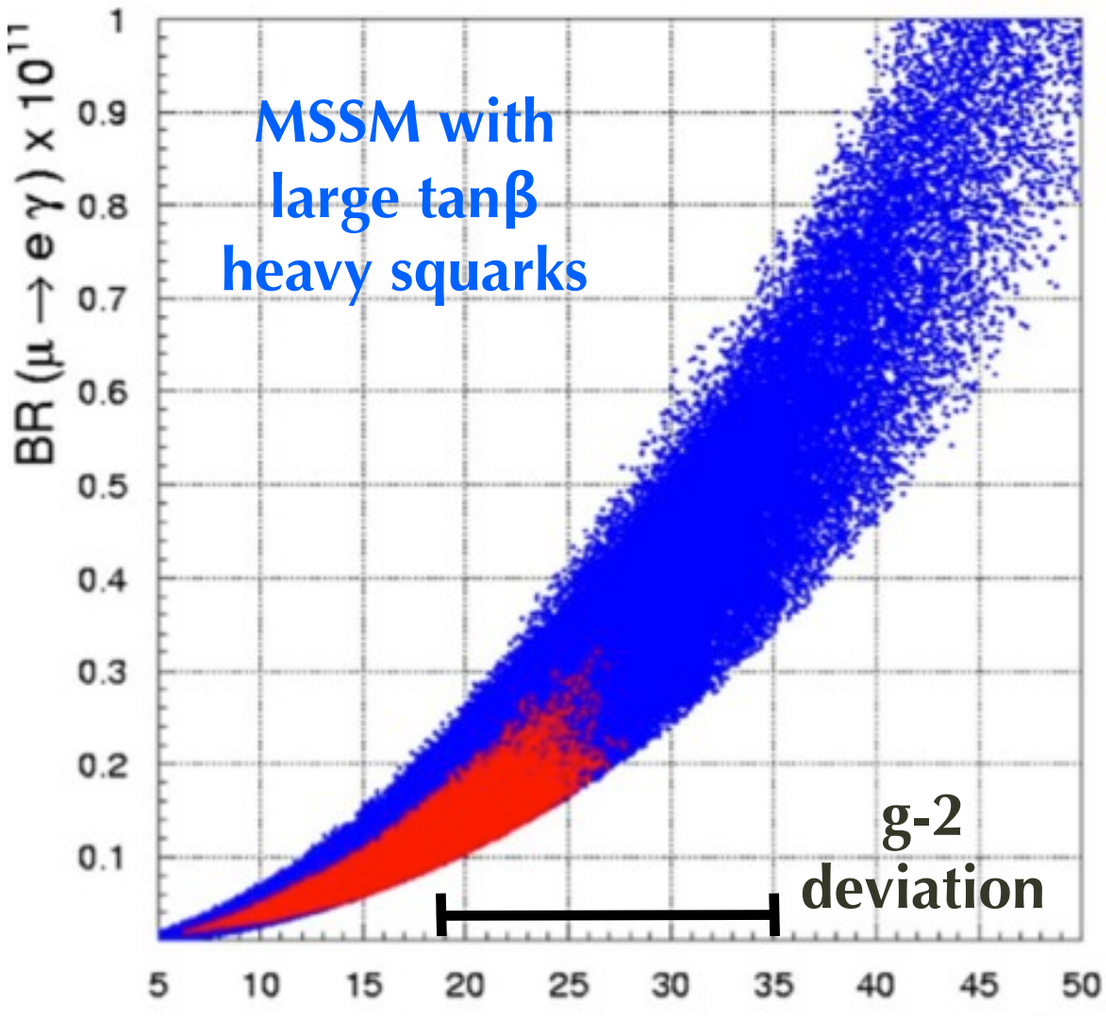
S. Antusch et al, JHEP 0611:090(2006)



- Discovery of large θ_{13}

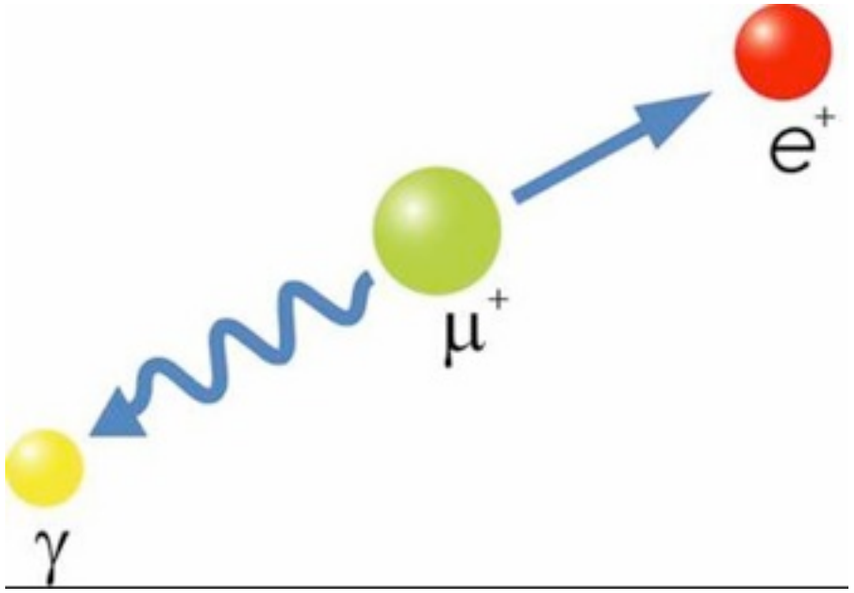
  →Large BR (μ→eγ)

G. Isidori et al, Phys. Rev. D 75, 115019 (2007)

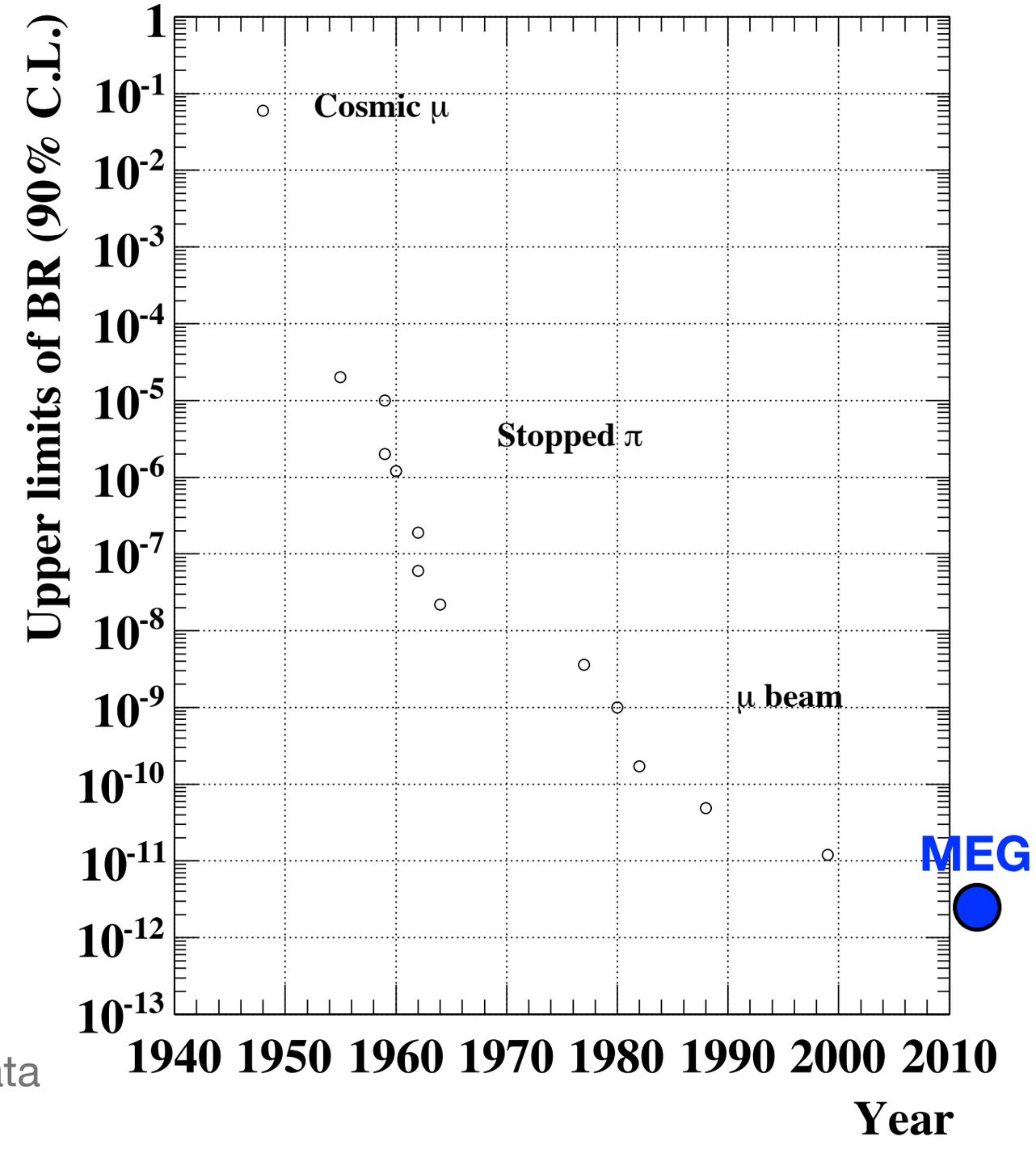


- If muon g-2 discrepancy is really evidence for new physics, searches for μ→eγ reveal the “amount” of flavor violation in the new physics sector

μ -> e γ search (Experimental situation)

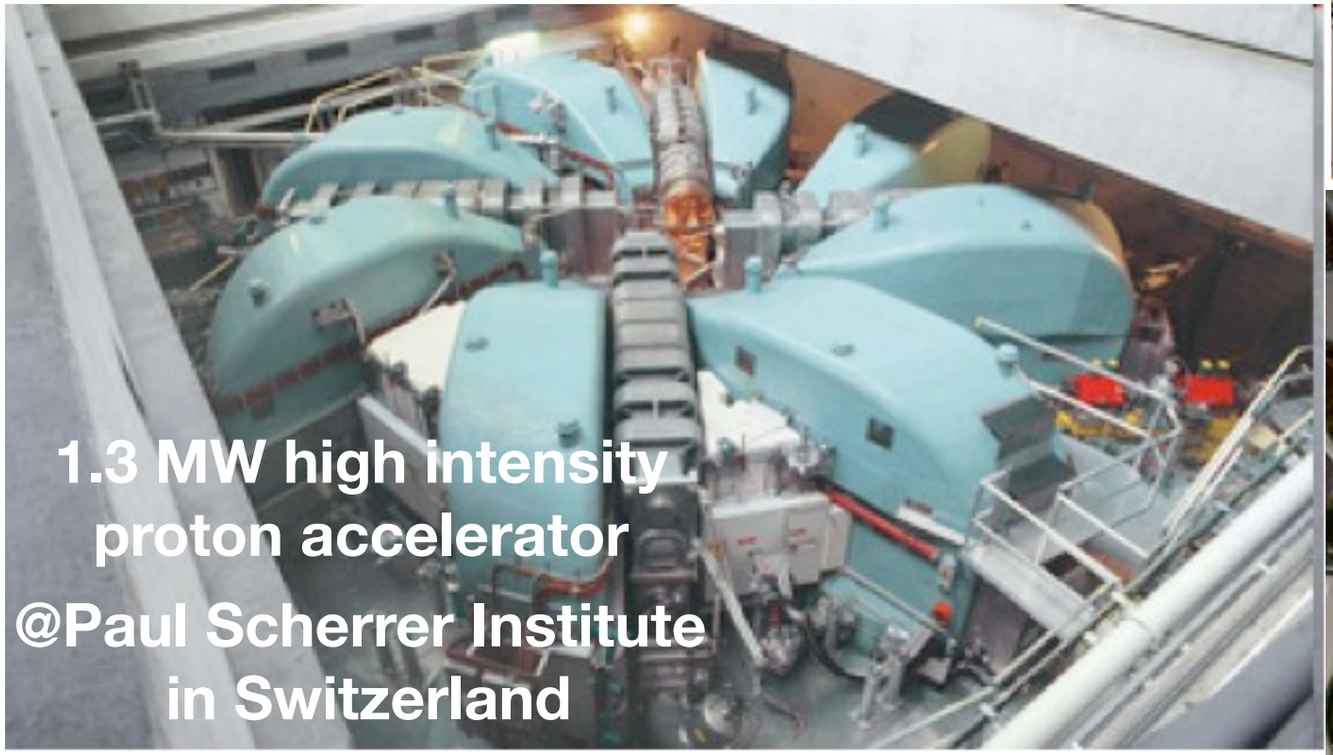


- Simple kinematics
  - $E_e = E_\gamma = 52.8\text{MeV}$
  - $T_e = T_\gamma$
  - $\theta_{e\gamma} = 180°$
- Long history since 1940s
- Previous best limit : MEGA 1.2×10^{-11}
- 2011 MEG result : 2.4×10^{-12} at 90%C.L (x5 improvement) based on 2009+2010 data



MEG Experiment

- **Key elements**
  - World most intense DC μ^+ beam
  - e^+ tracking in high rate environment
  - Innovative liquid xenon γ-ray calorimeter



- Proposal : 1999
- Physics data taking start : 2008
- Japan, Italy, Switzerland, Russia, USA
  ~ 60 Collaborators

MEG Detector

COBRA Positron spectrometer

SC magnet
special gradient magnetic field
(1.27T-0.5T)

Drift chamber (DC)
16 segmented modules
low material budget
($1.7\times10^{-3}X_0$)

Timing counter (TC)
σ: 70-80 ps

Stopping target
polyethylene
200μm

LXe γ-ray
calorimeter
846 PMTs
2.7ton LXe

e^+

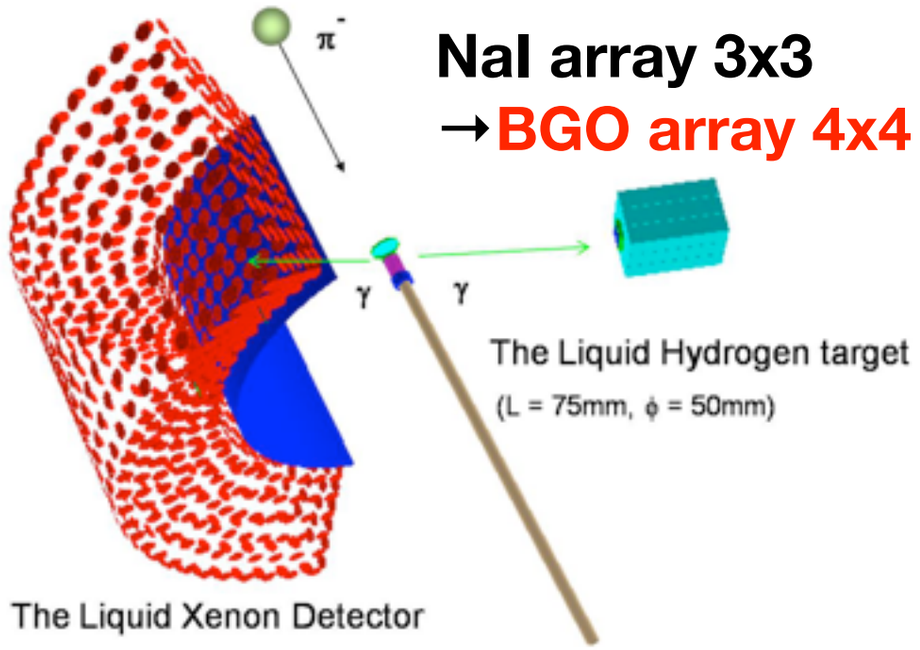
γ

μ^+ **beam**
3×10^7/s

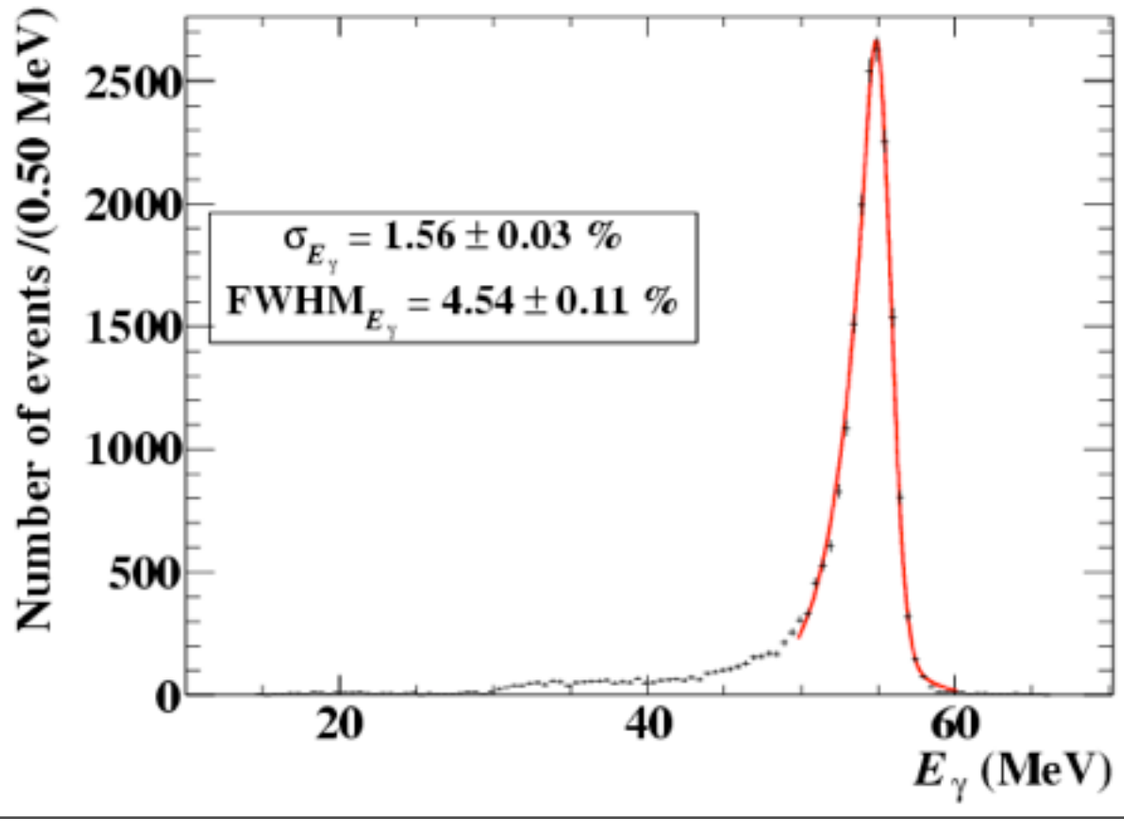
Update since last publication

- Statistics
  - Statistics is doubled (2011 = 2009+2010), 3.6×10^{14} stopped μ^+ on target
  - DAQ efficiency is improved from 72% to 96% (double buffer readout)
- Hardware improvements
  - Higher resolution BGO array detector in LXe calibration with CEX reaction ($\pi^- p \rightarrow \pi^0 n$, $\pi^0 \rightarrow 2\gamma$)
    - better performance evaluation
  - New optical survey technique with laser tracker for drift chamber
    - better precision of alignment

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

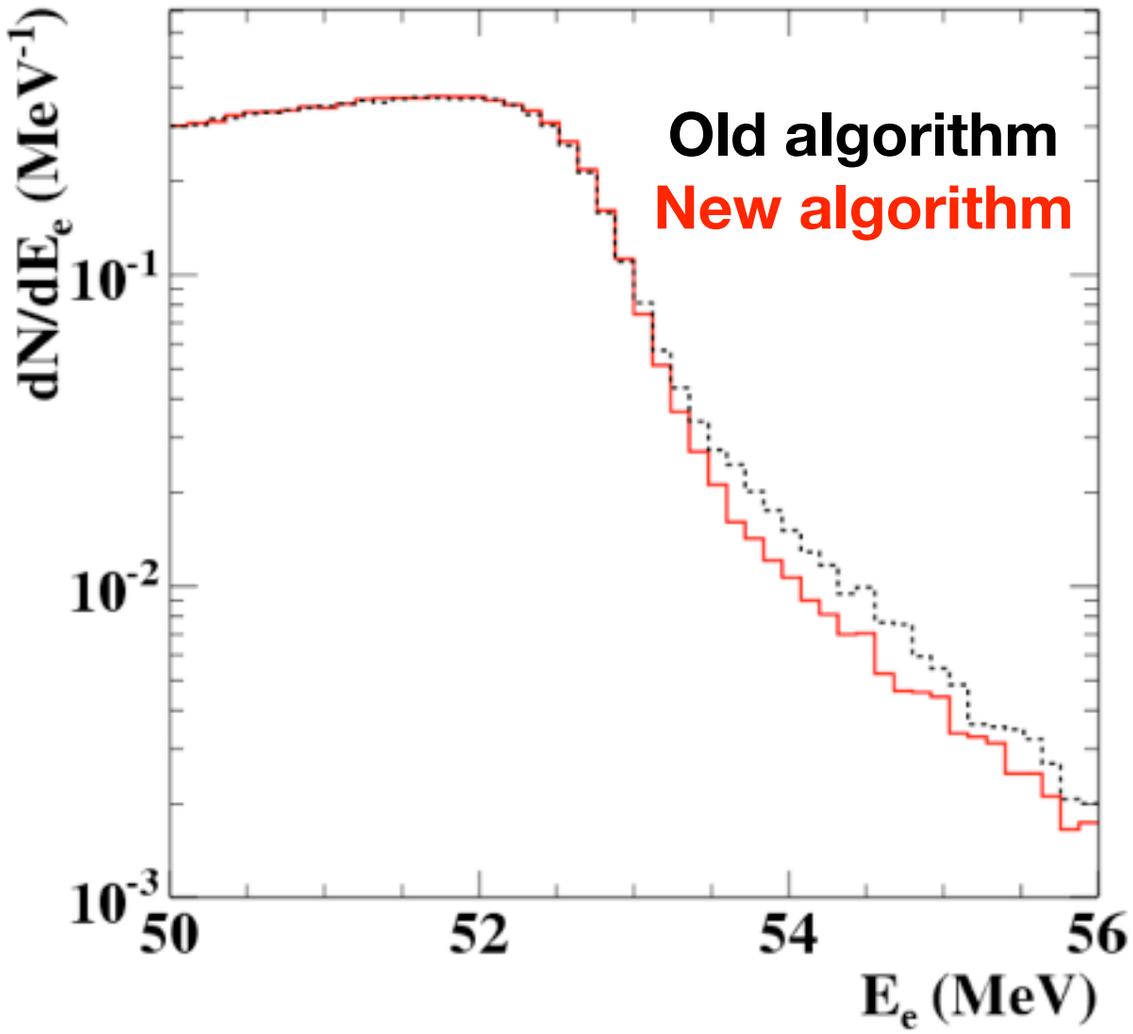


Absolute E_γ (55MeV) calibration



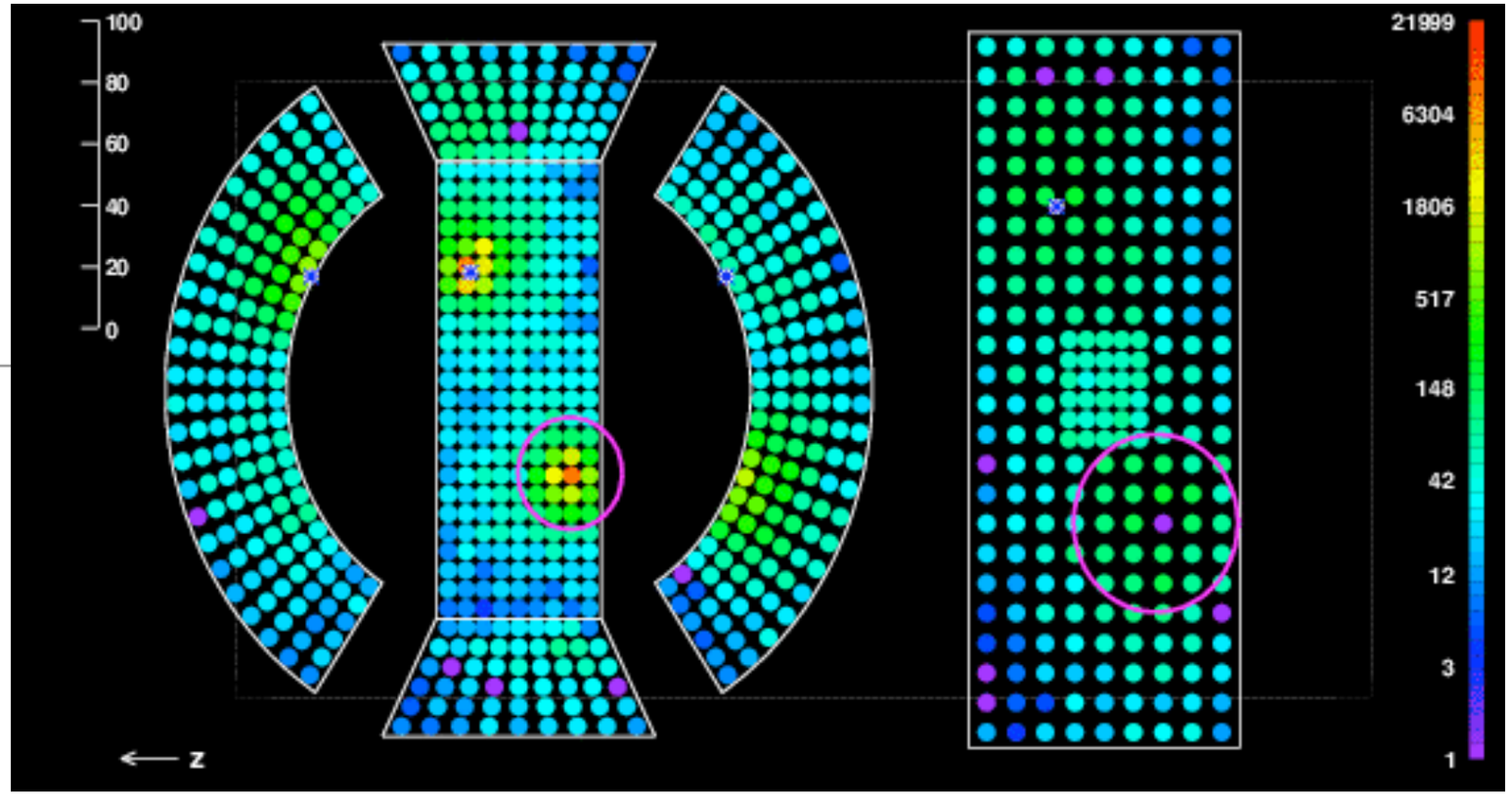
Update since last publication (analysis on e^+ side)

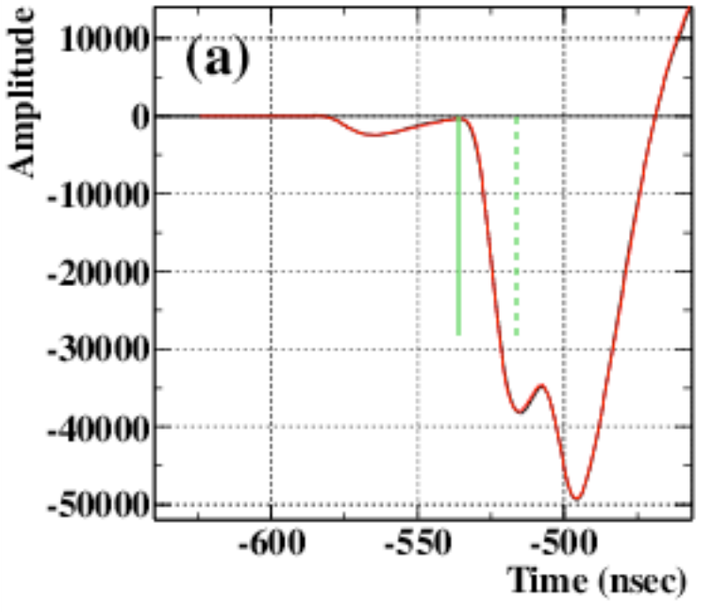
- FFT offline noise reduction for DC
  - better angle resolution and 6% higher signal efficiency
- New track fitter (Kalman filter)
  - reduced high energy tail
  - 7% higher signal efficiency
- Per-event error matrix
  - provided by Kalman filter is incorporated in likelihood analysis
  - Sensitivity is improved by ~10%

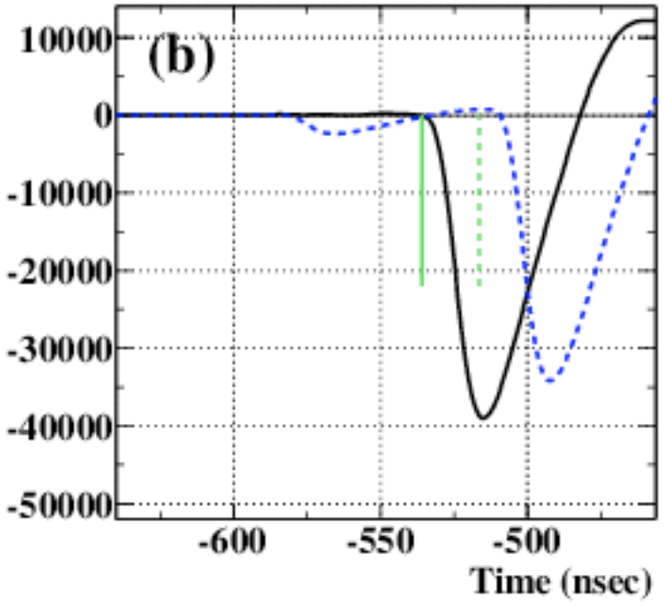


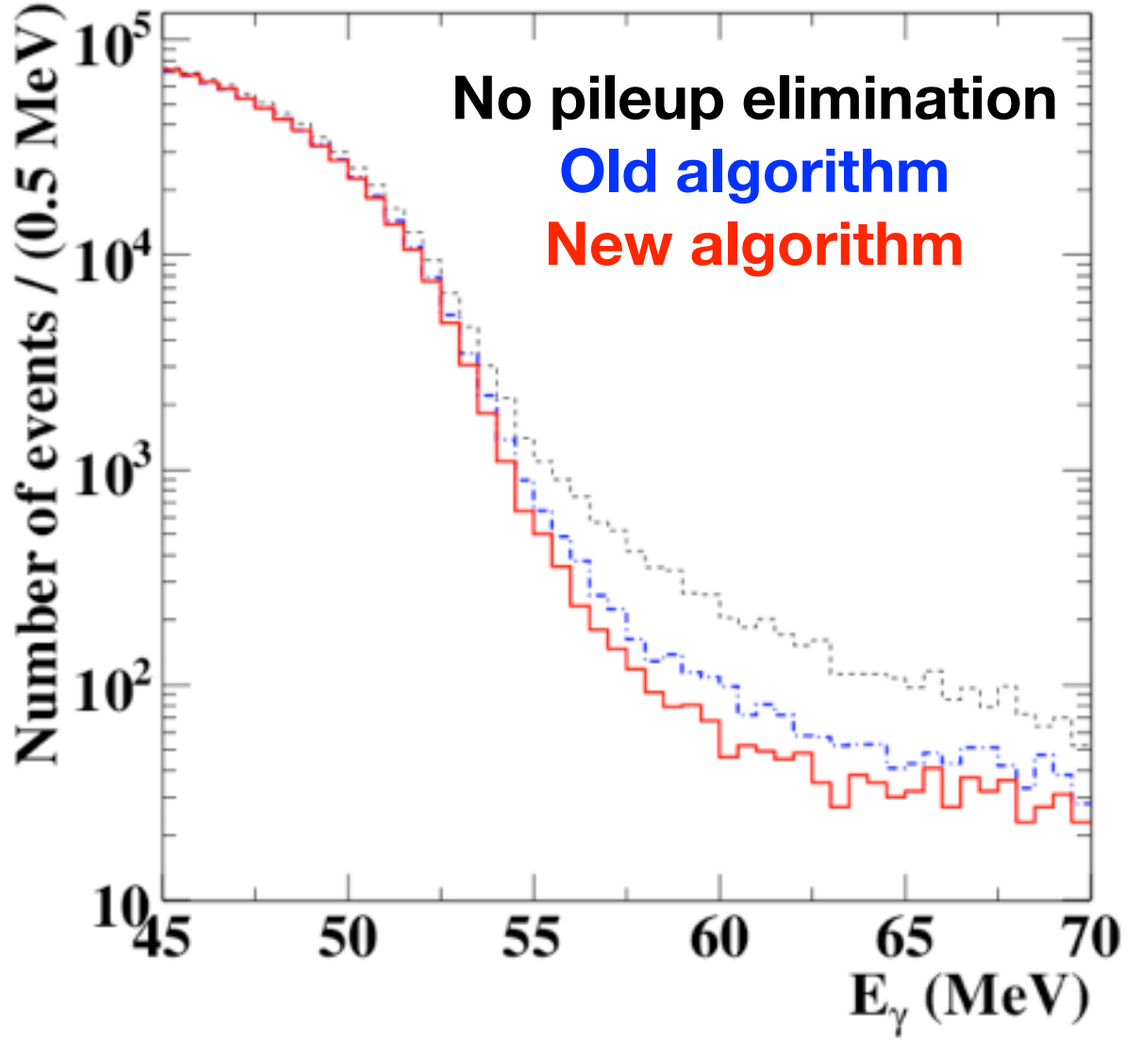
Update since last publication (analysis on γ side)

- γ side
  - At 3x10^{7}μ$^+$/s beam rate, 15% of triggered events suffer from pile-up
  - improved pile-up rejection using PMT waveform with template fit
  - 7% higher signal efficiency



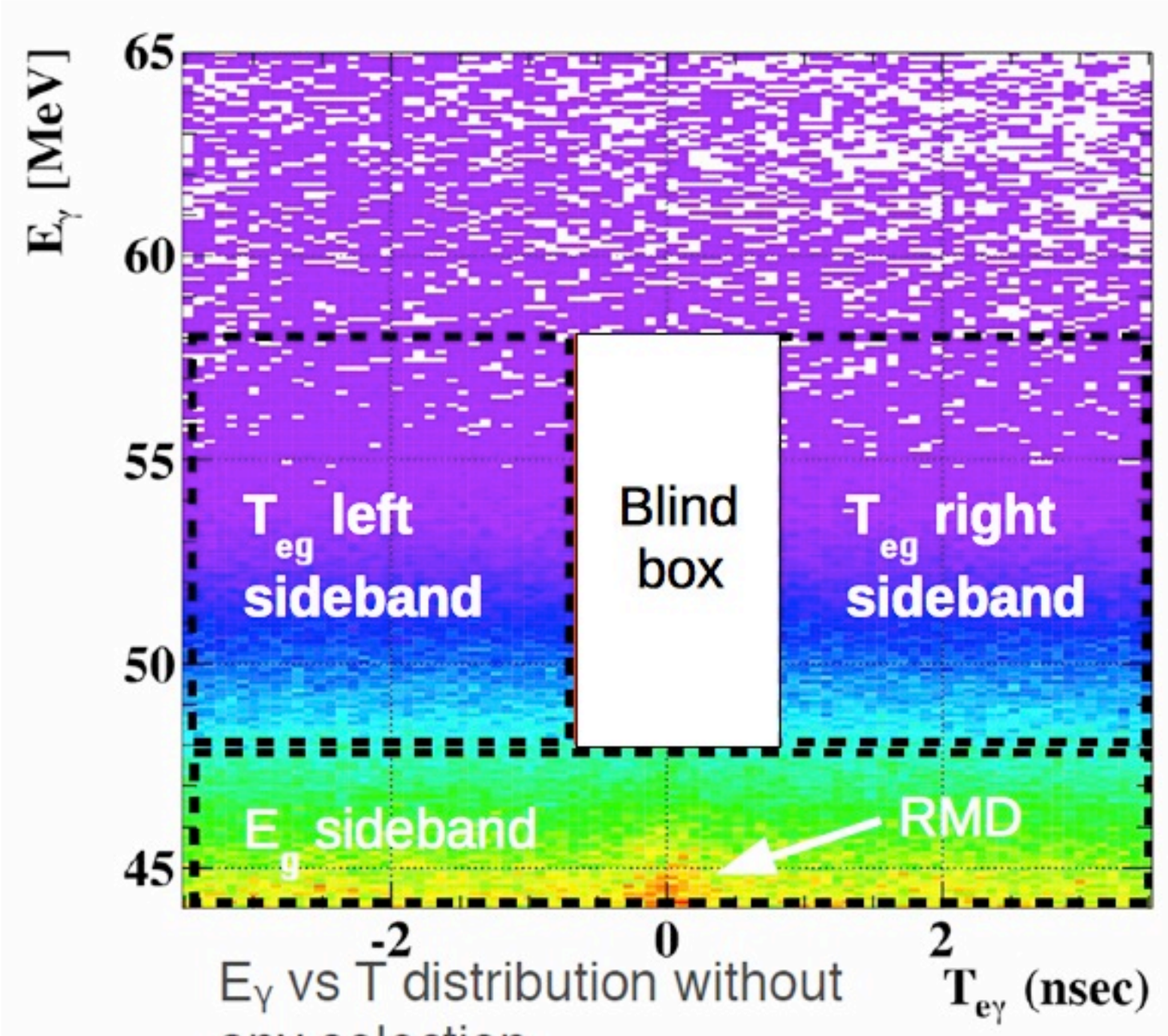






Analysis

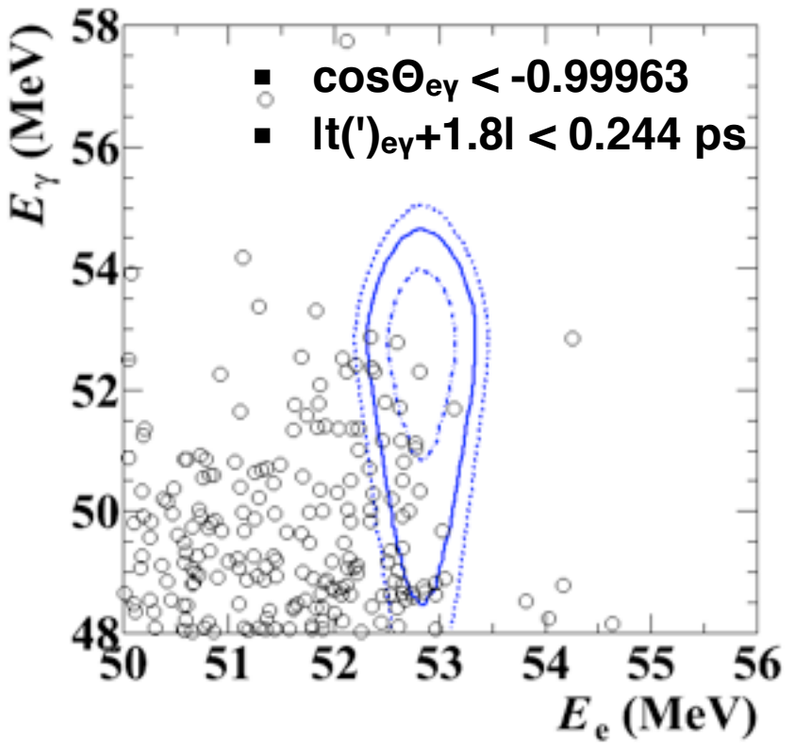
- Maximum likelihood analysis to extract Nsignal
- Observables : E_γ, E_e, $T_{e\gamma}$, $\theta_{e\gamma}$, $\phi_{e\gamma}$
- PDF
  - Background : measured in sideband data
  - RMD : theoretical spectrum convolved with detector response
  - Signal : measured detector response function
- Blind analysis
  - applied to new data in 2011

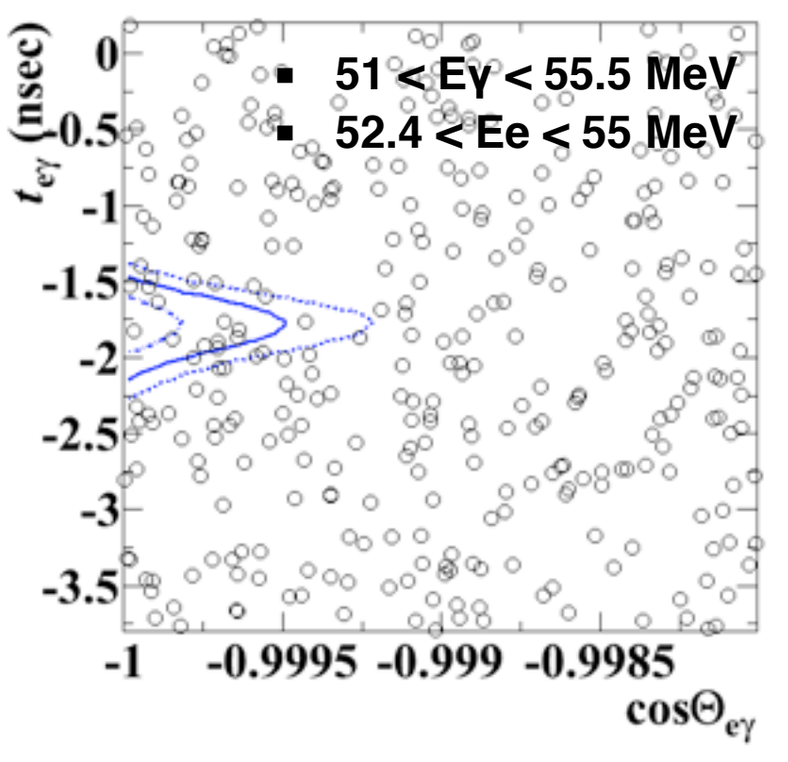


E_γ vs T distribution without any selection.

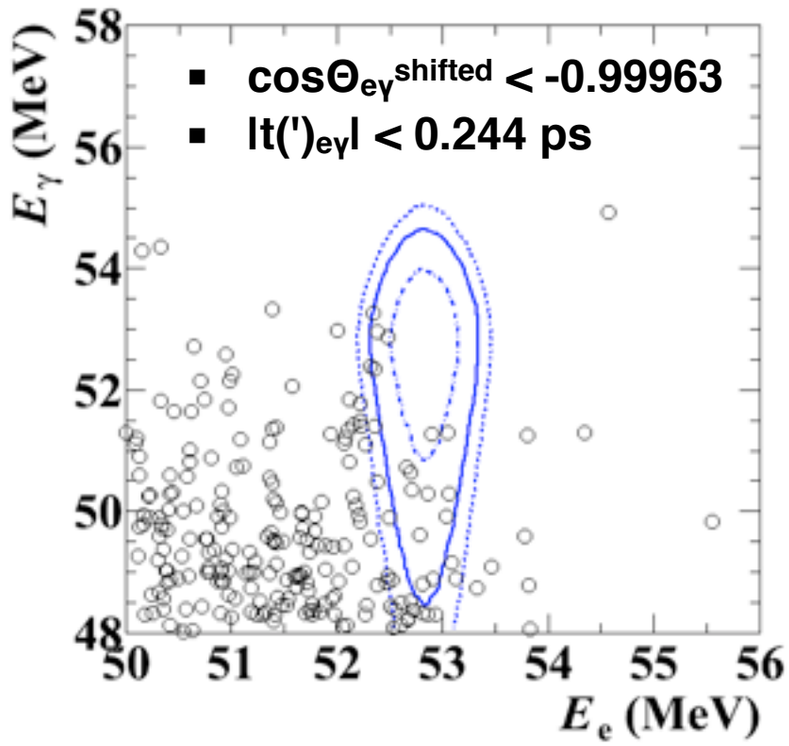
Sideband data (2009-2011)

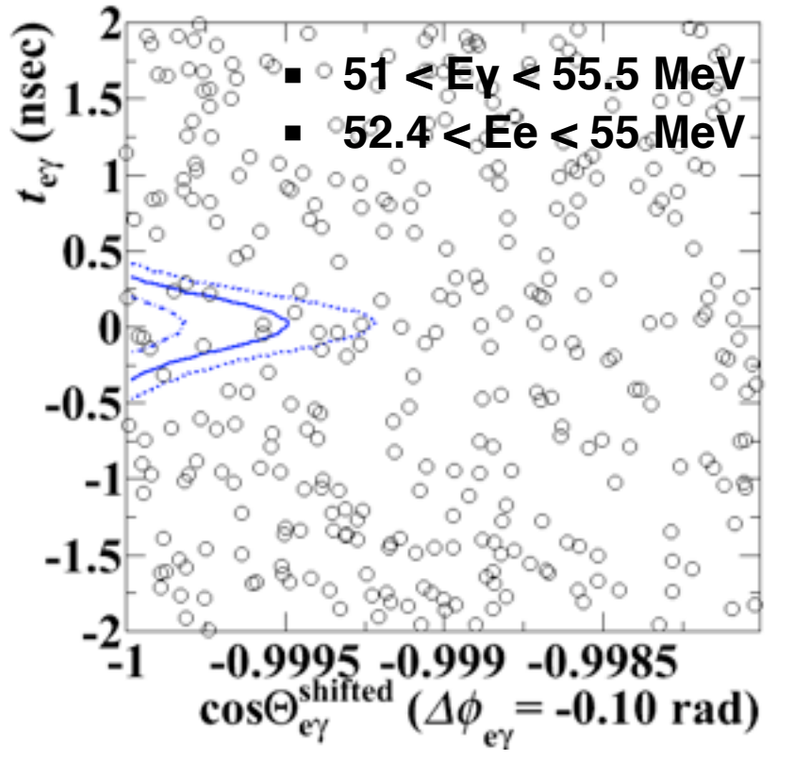
Negative time sideband





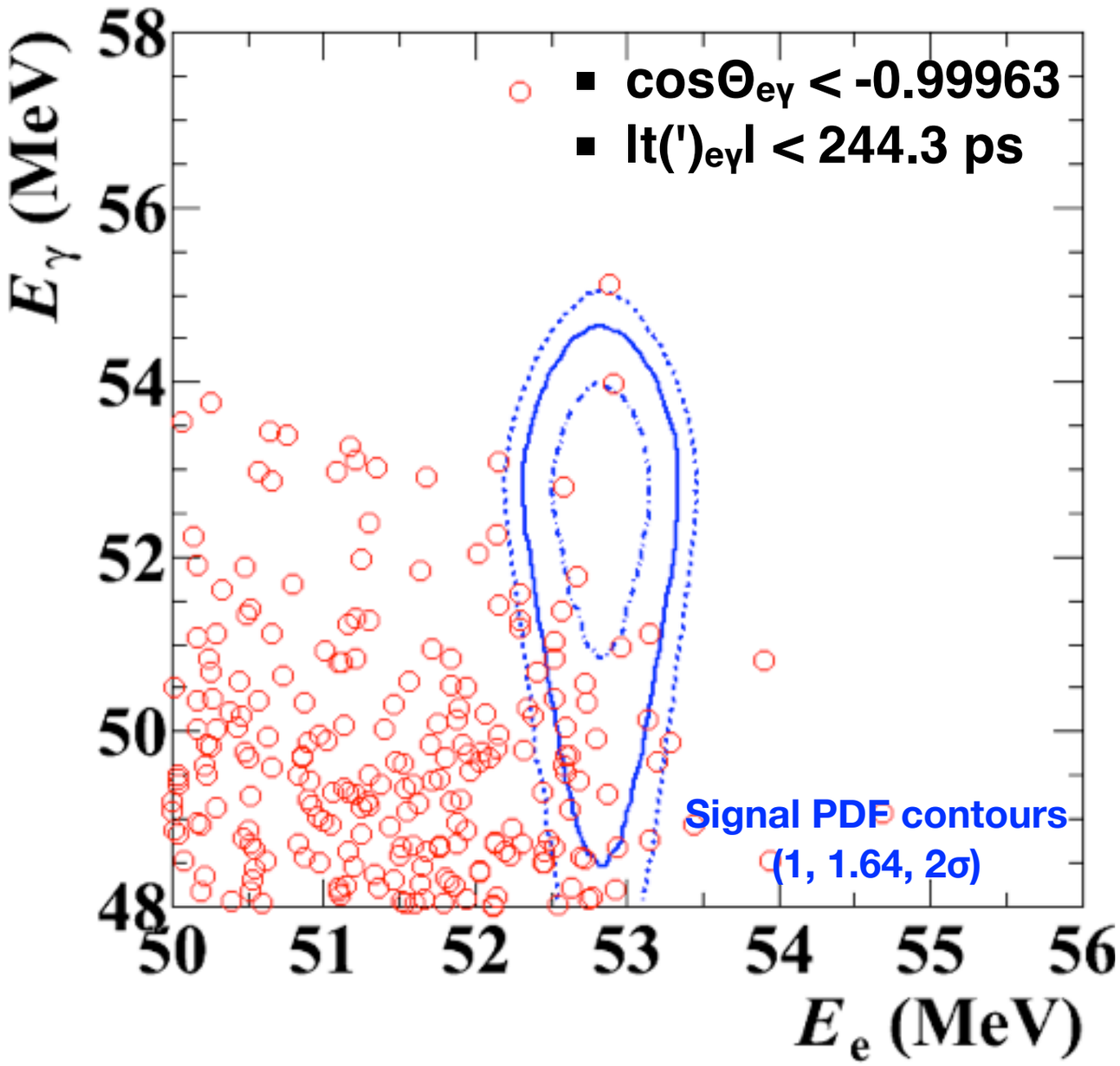
off angle sideband

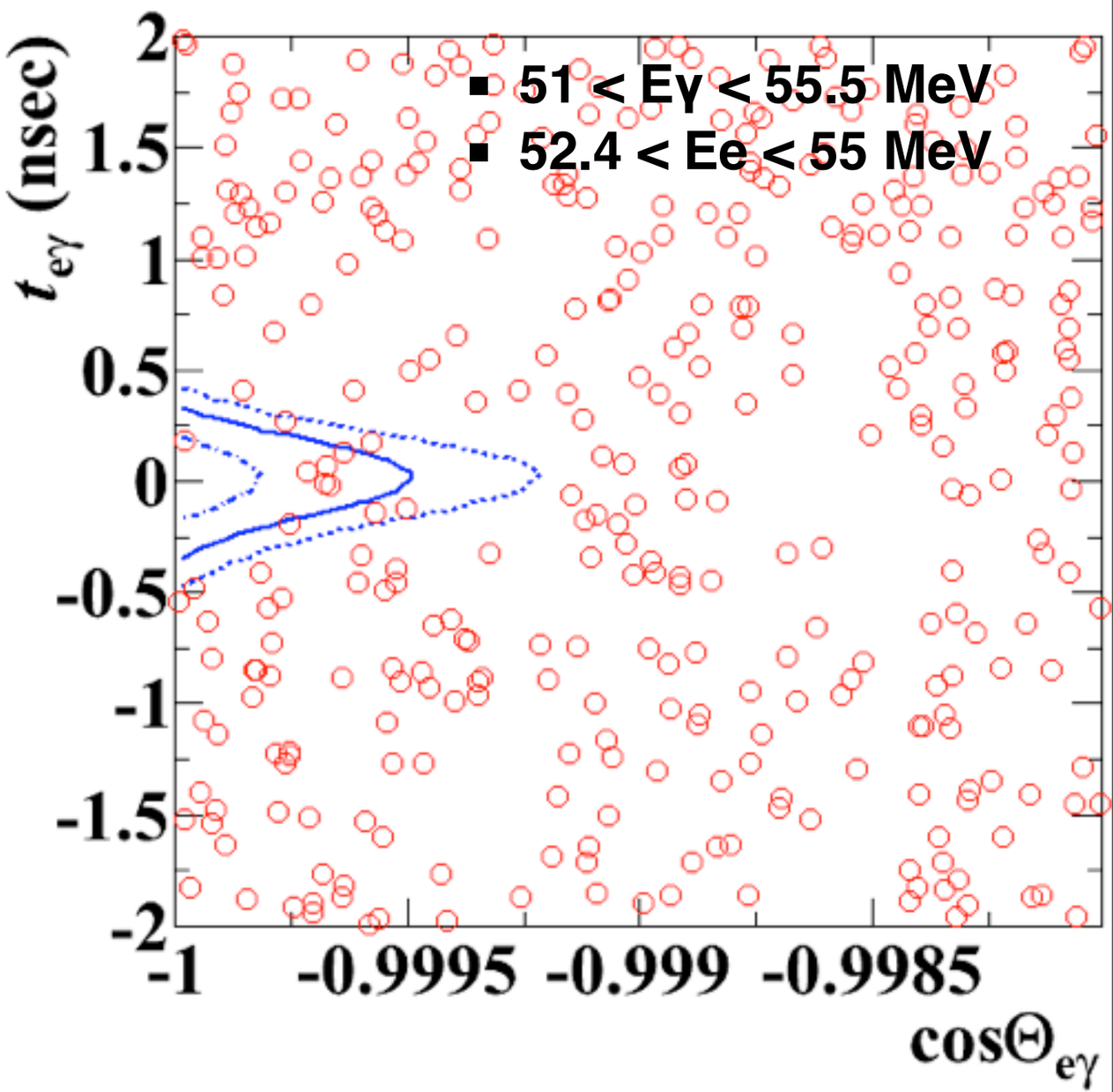




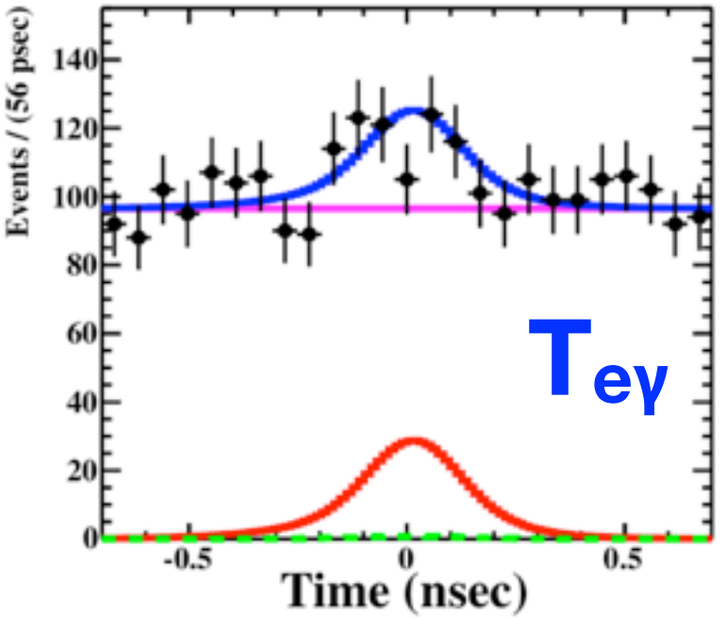
- Sideband BG data are consistent with sensitivity for 2009-2011 data (7.7×10^{-13} @ 90% C.L.)

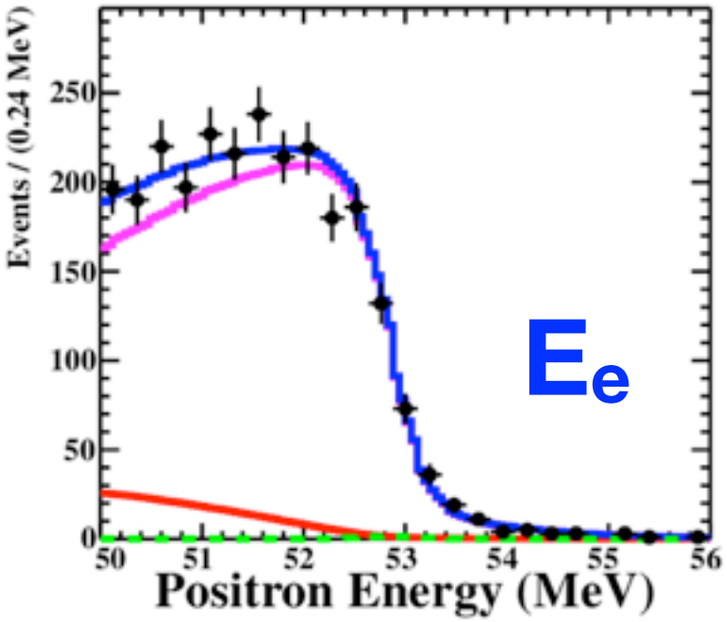
Event distribution after unblinding (2009-2011)

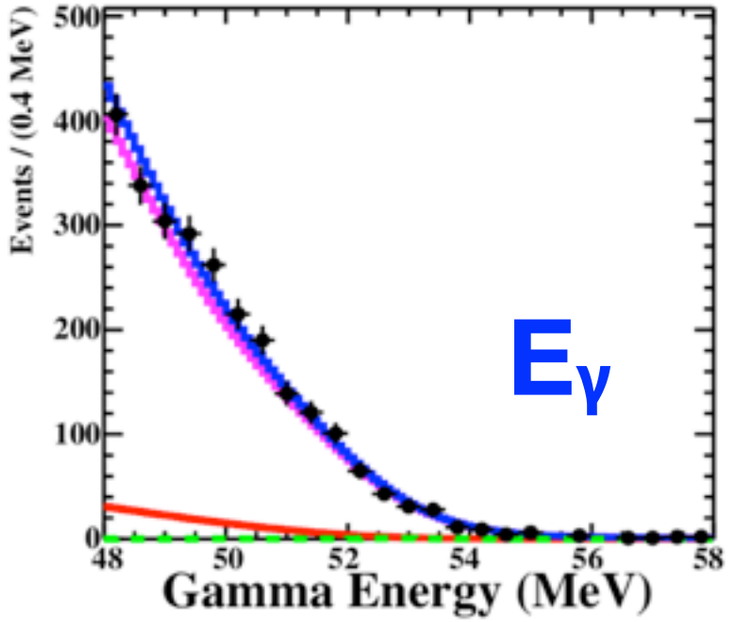


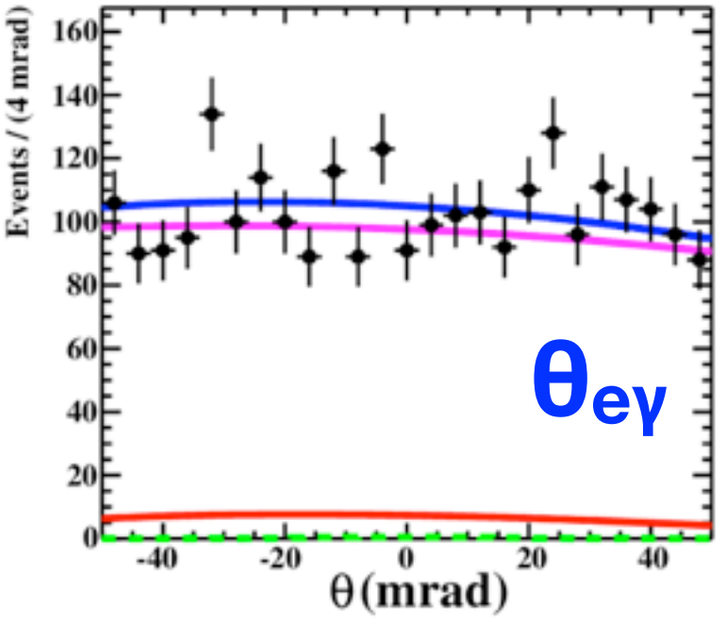


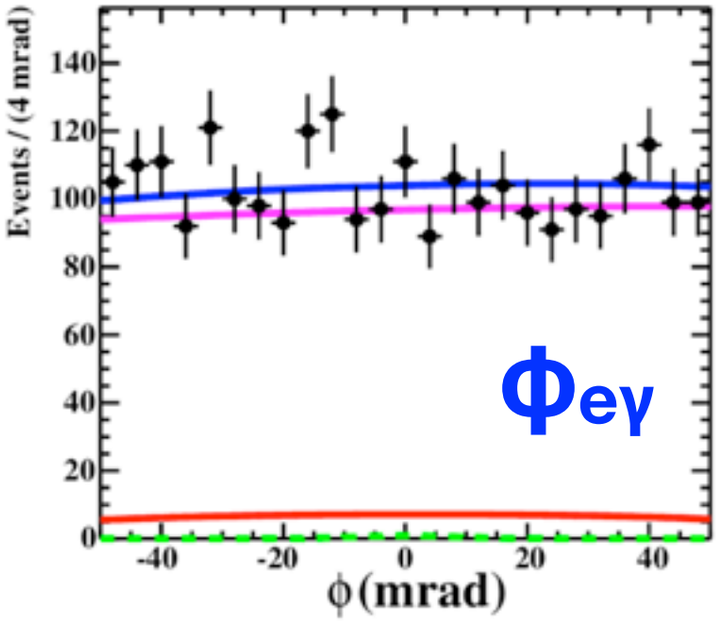
Likelihood fit







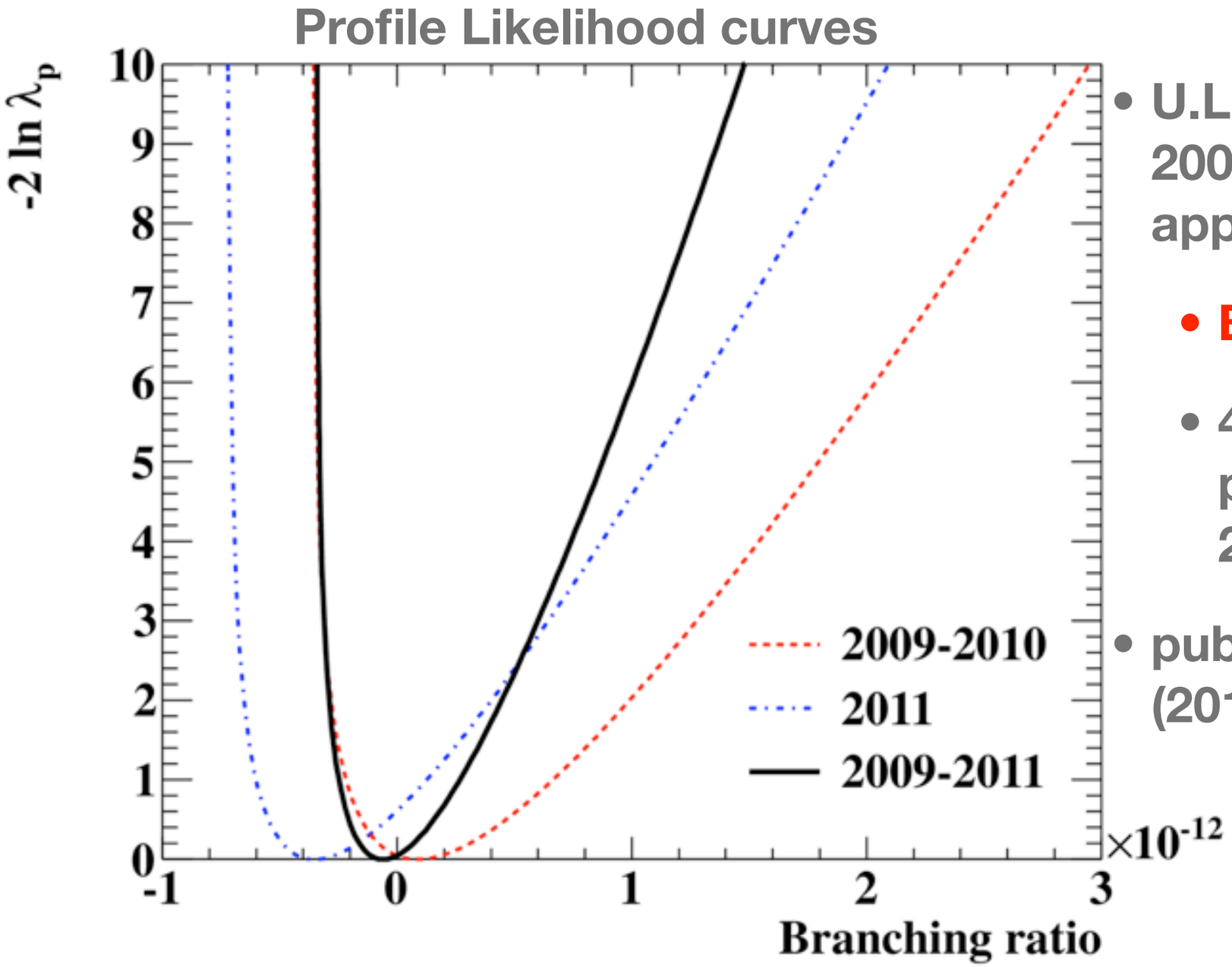




Total	
Accidental	2413.6
Radiative	167.5
Signal	-0.4

Consistent with null signal

Latest result

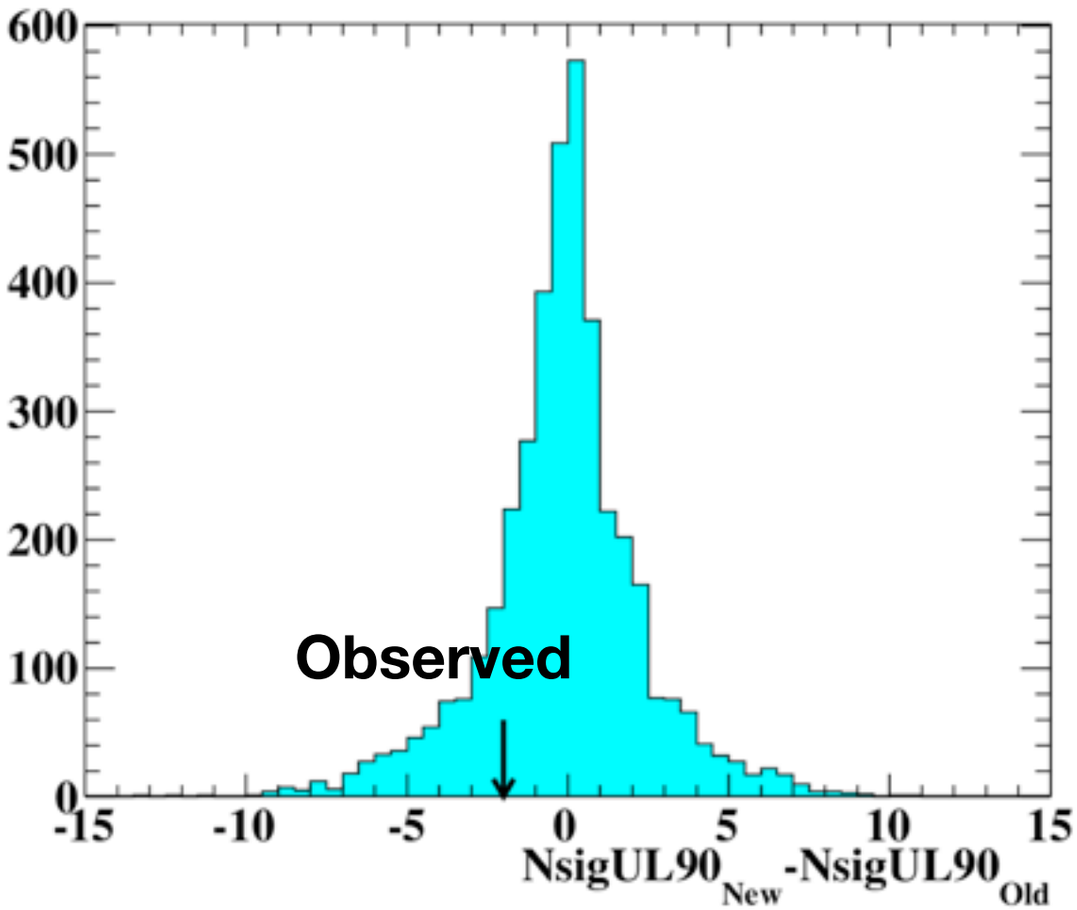


- U.L. are obtained with 2009-2011 data in a frequentist approach
  - BR < 5.7×10^{-13} @ 90% C.L.
  - 4x improved upper limit than previous MEG result 2.4×10^{-12}
- published in PRL110, 201801 (2013)

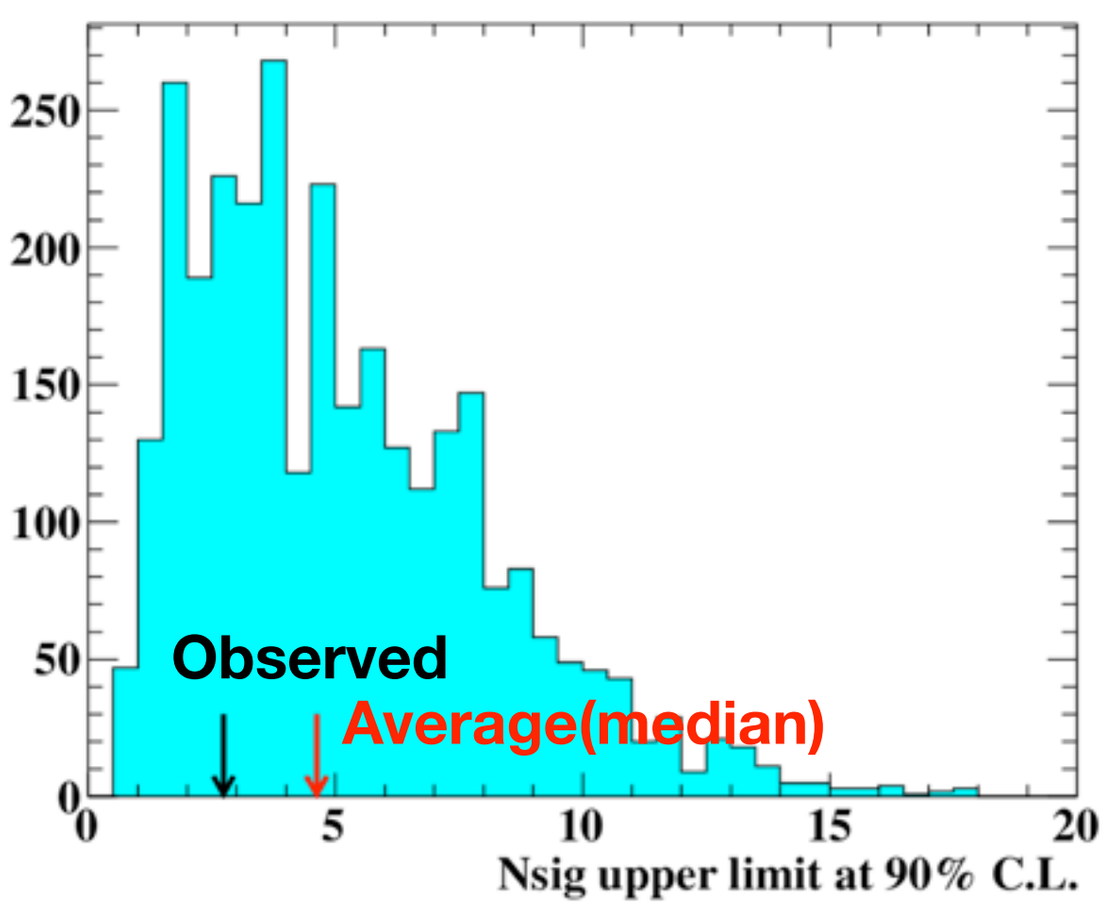
- Note these curves are not directly used to derive the U.L.

Compatibility test

- Compatibility test for 2009-2010 data between the results with the new and old analyses : **31%**

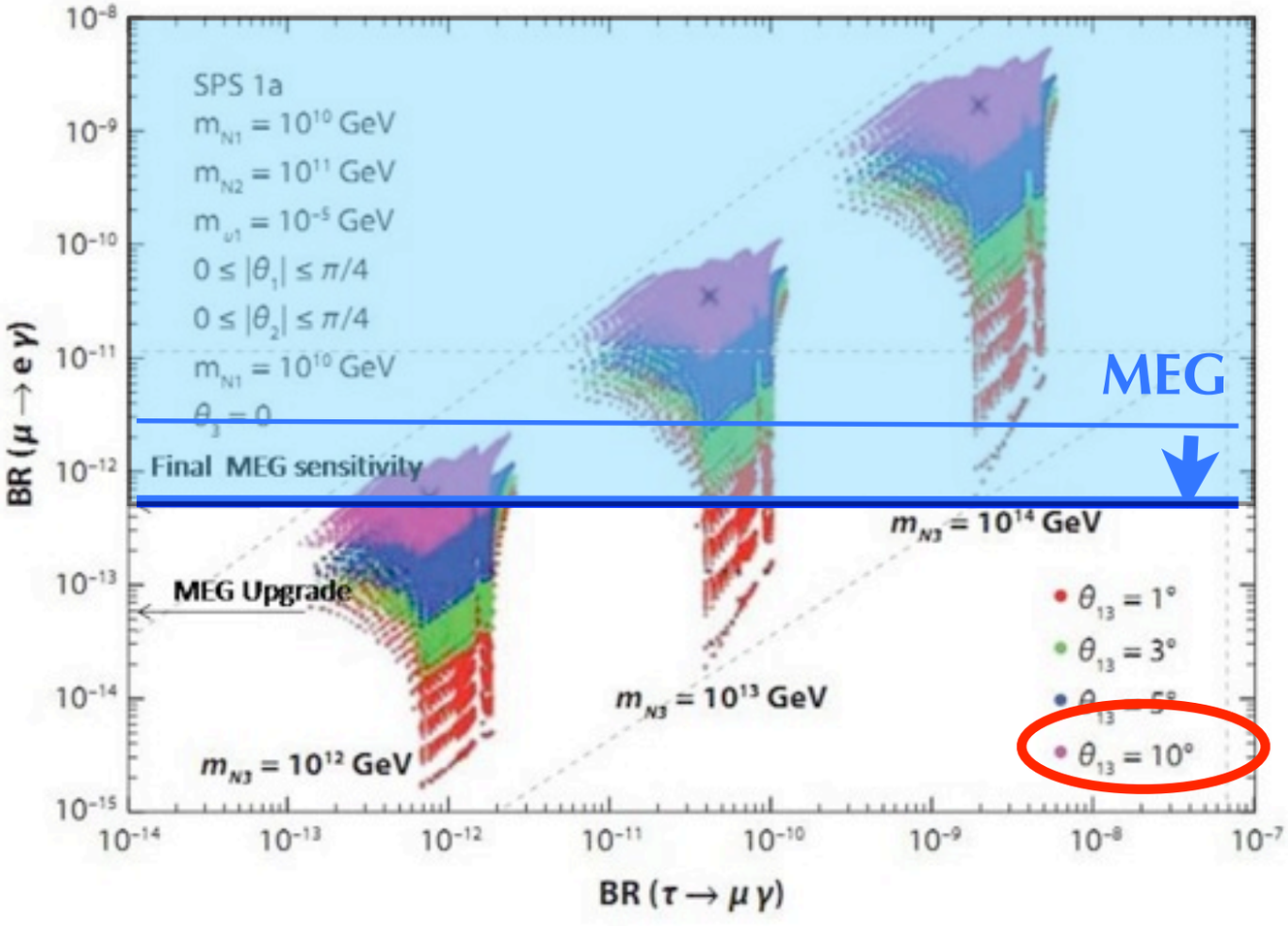


- Compatibility test for 2011 data between the results with toyMC sensitivity and observed 90%UL : **24%**

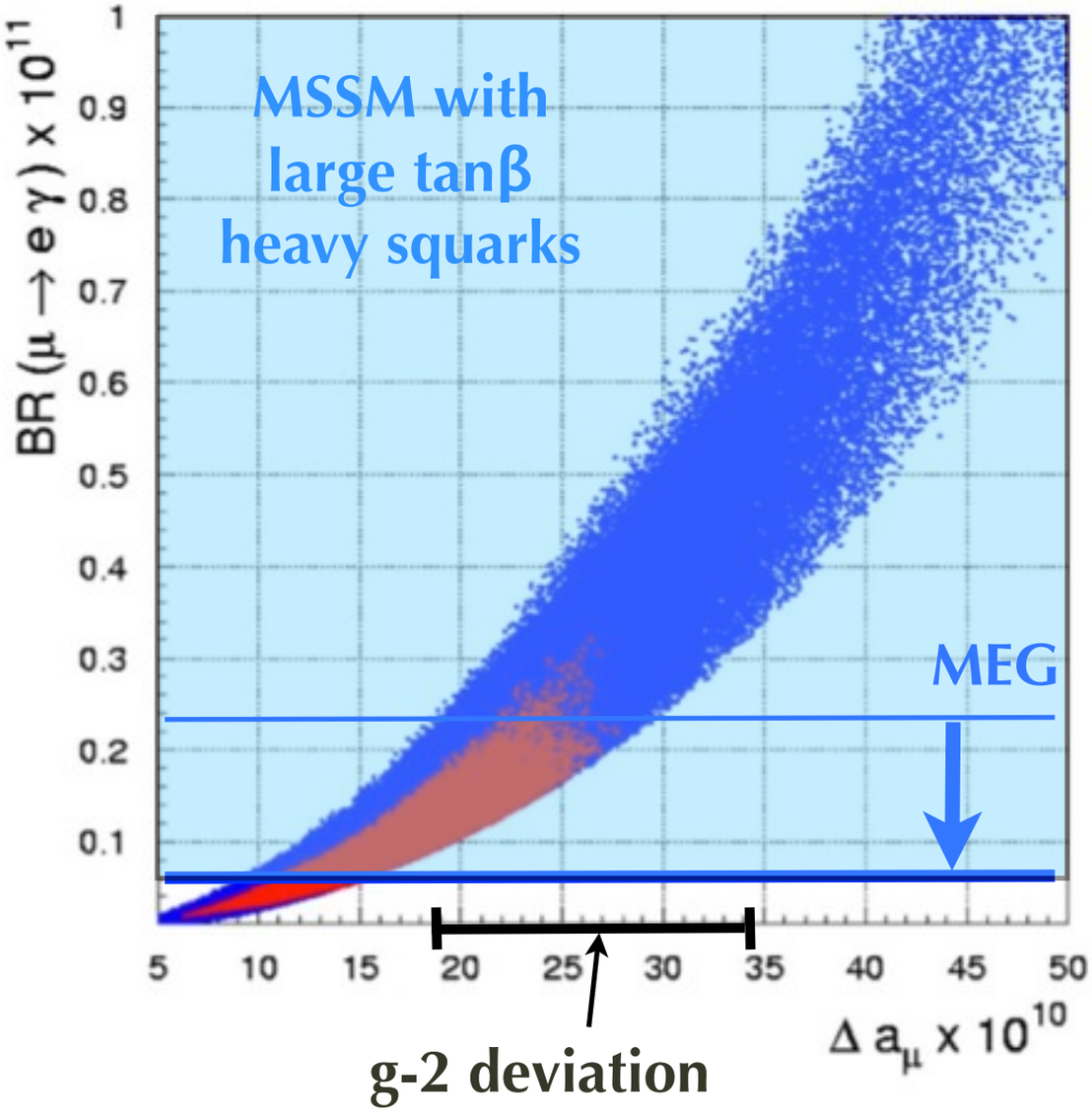


Constraint on new physics

SUSY-Seesaw



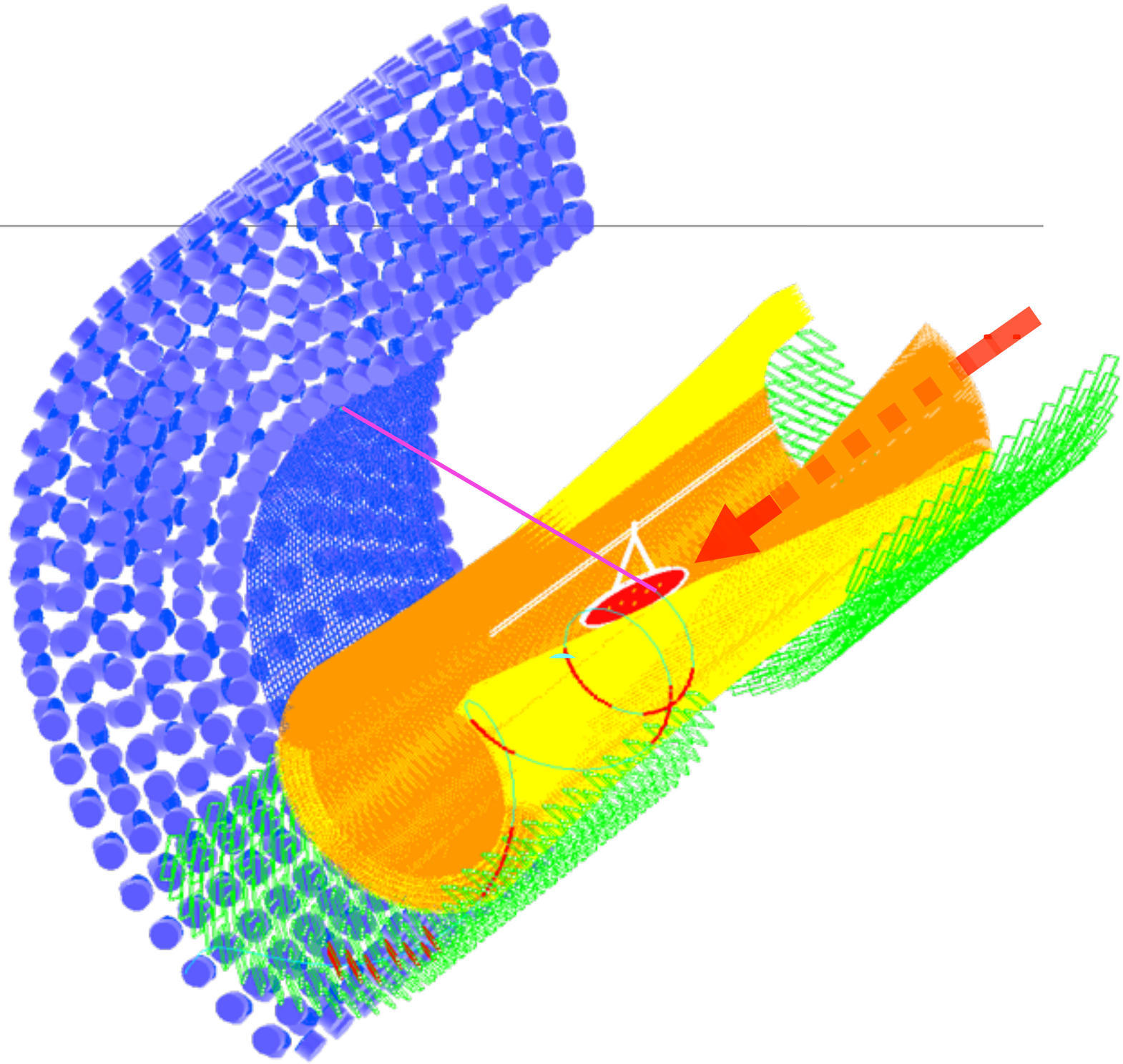
S. Antusch et al, JHEP 0611:090(2006)



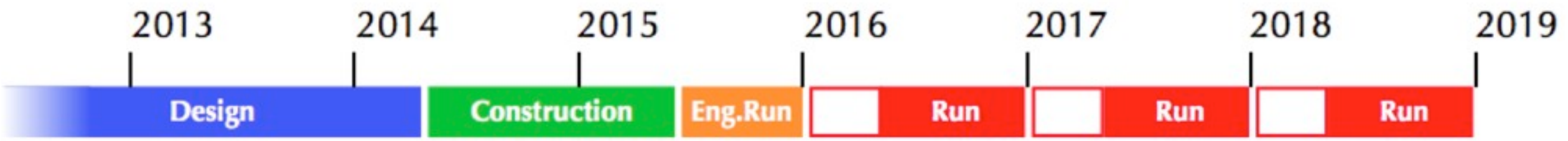
G. Isidori et al, Phys. Rev. D 75, 115019 (2007)

Upgrade plan

- MEG-I
  - Physics data taking finished on 26th/Aug/2013! Now we are making a beam test for upgrade study.
  - Statistics will be doubled with 2012-2013 data since the latest result. Analysis is ongoing. Stay tuned!

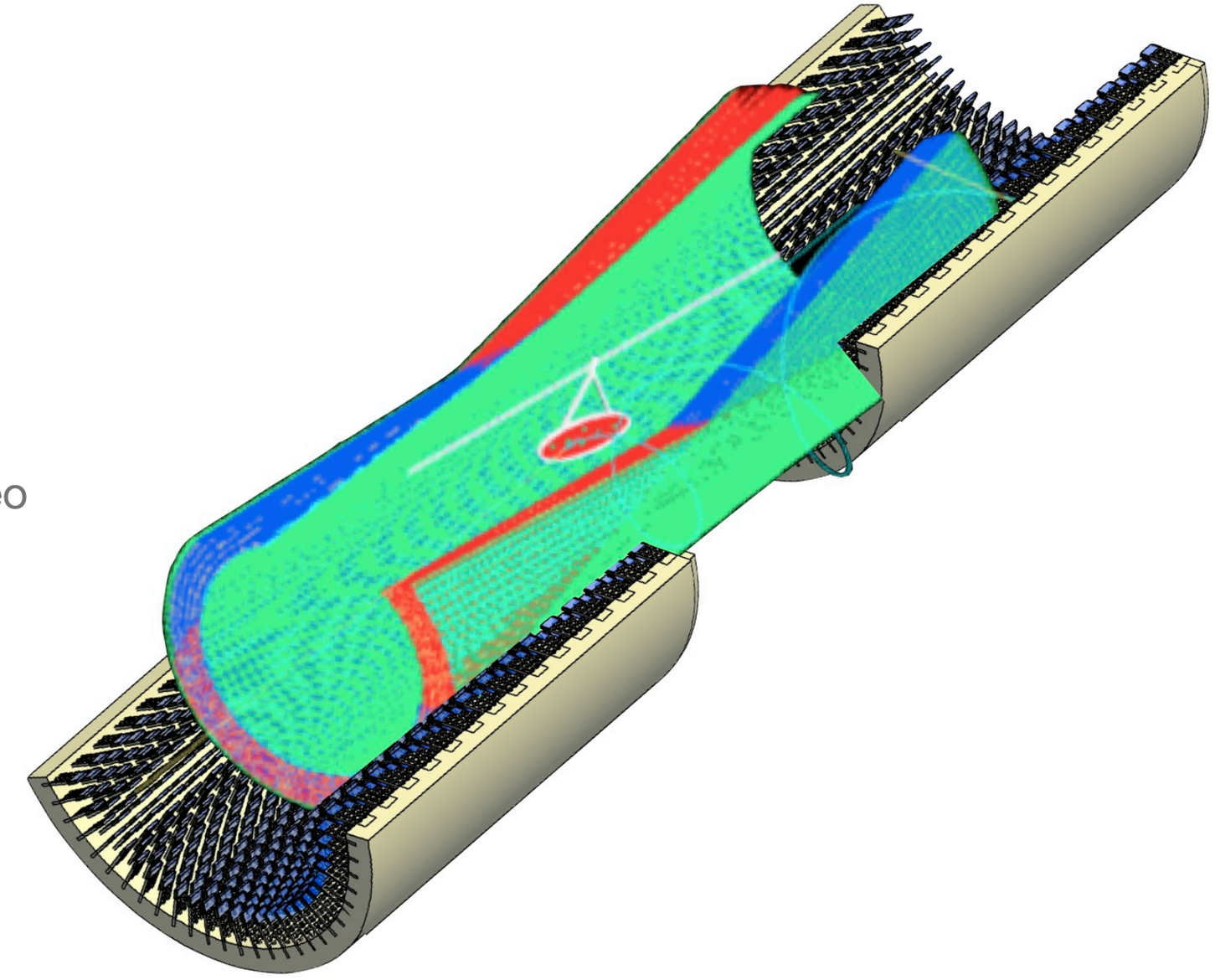


- MEG-II
  - MEG upgrade proposal approved at PSI in Jan. 2013
  - Detector upgrade
  - Use PSI full beam intensity
  - Target sensitivity : 5×10^{-14}

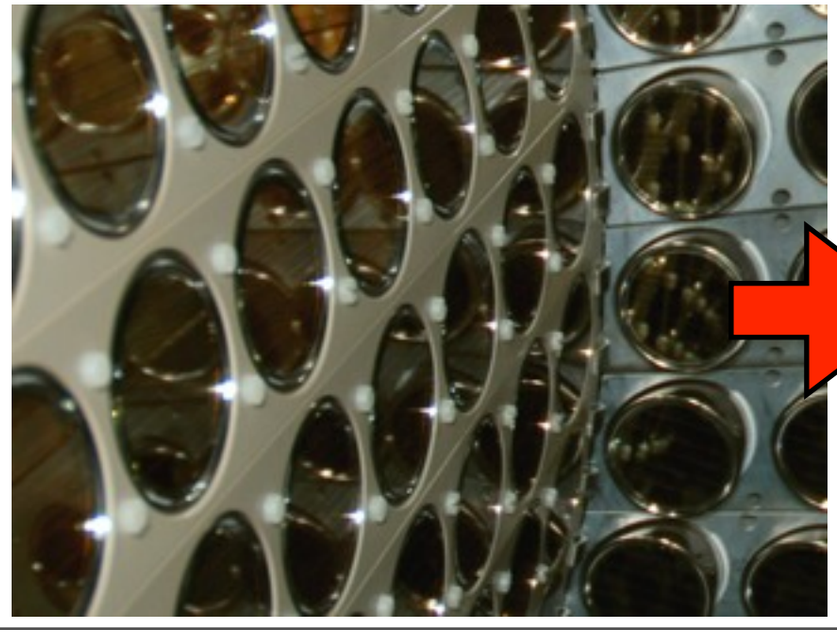


Detector Upgrade

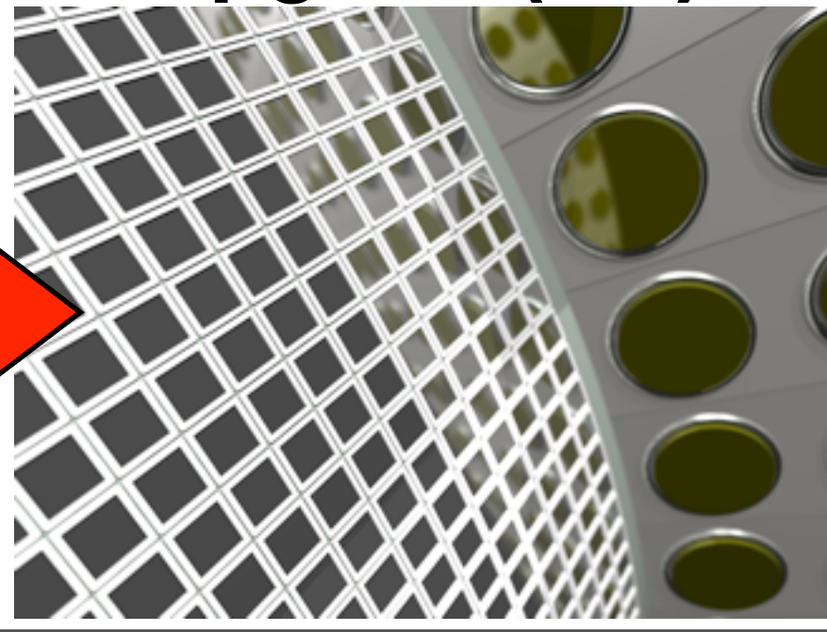
- Drift chamber
  - Single volume drift chamber with stereo angle wire configuration
  - Finer granularity & better resolution
  - Larger DC+TC acceptance
- Timing counter
  - Excellent resolution with pixelated scintillators with SiPM readout
- Gamma-ray detector
  - Smaller photon sensors at entrance face
  - Better uniformity, better efficiency
- Thinner target
  - 200 → 140μm



Current

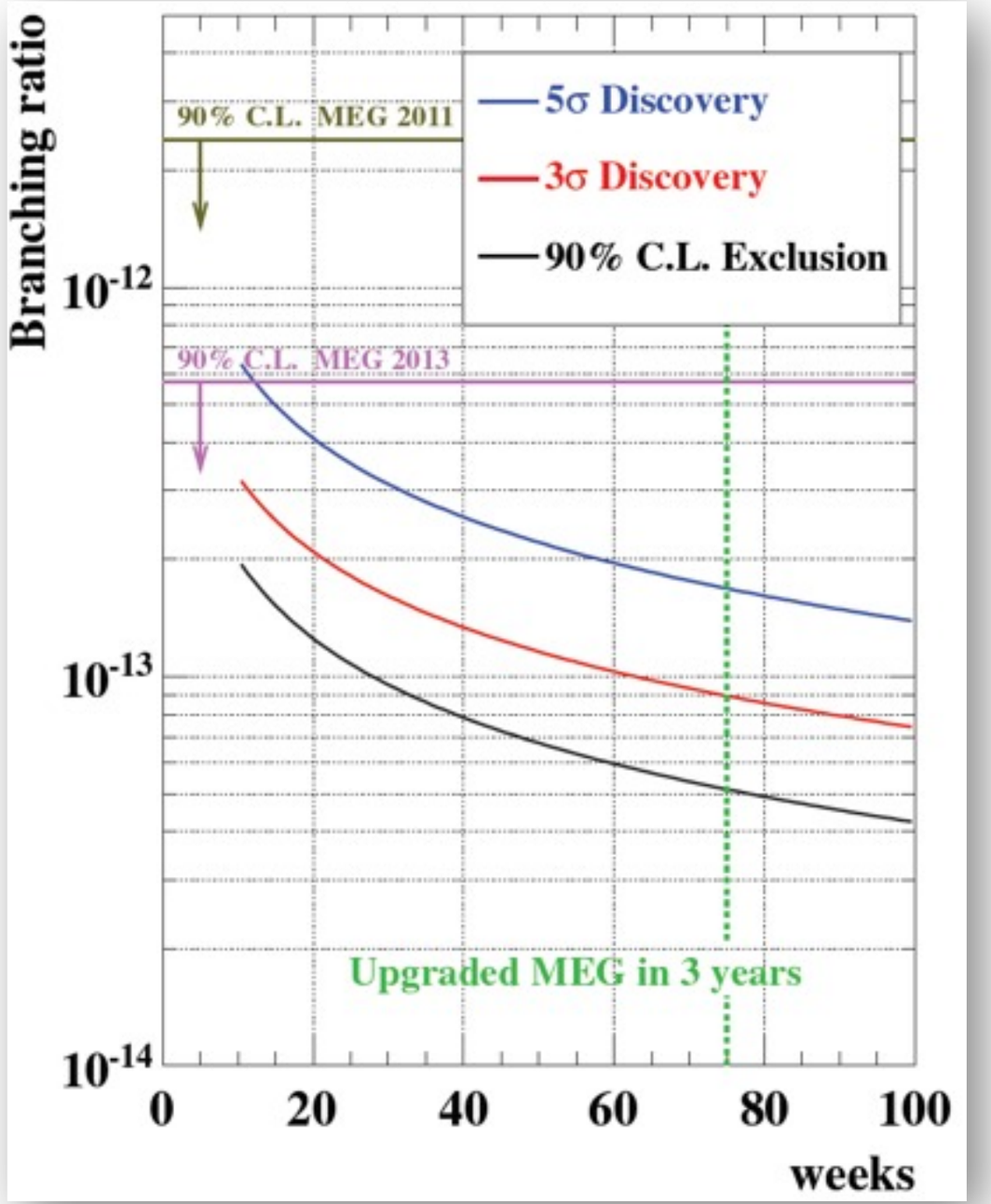


Upgrade(CG)



Sensitivity of Upgraded MEG Experiment

PDF parameters	Present MEG	Upgrade scenario
e^+ energy (keV)	306 (core)	130
e^+ θ (mrad)	9.4	5.3
e^+ ϕ (mrad)	8.7	3.7
e^+ vertex (mm) Z/Y(core)	2.4 / 1.2	1.6 / 0.7
γ energy (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
γ position (mm) $u/v/w$	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	≈ 99	≈ 99
γ	63	69
e^+	40	88



Target: 5×10^{-14} in three years data taking

Summary

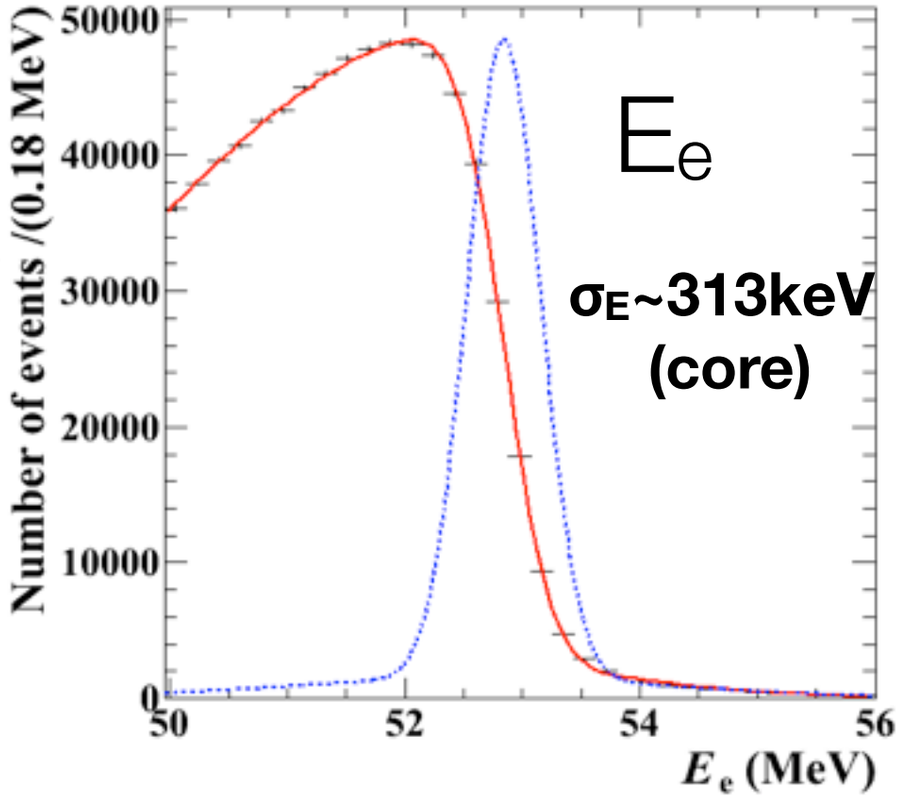
- The MEG experiment improved the BR(μ→eγ) upper limit this year, 5.7×10^{-13} at 90% C.L.
- MEG-I data taking finished 26th/Aug/2013.
- The statistics will be doubled by adding 2012-2013 data, and the analysis is ongoing. Stay tuned.

- MEG upgrade proposal is approved by PSI in 2013. R&D for detector upgrade is on-going.
- The target sensitivity is 5×10^{-14}, and data taking for three years starting from 2016.

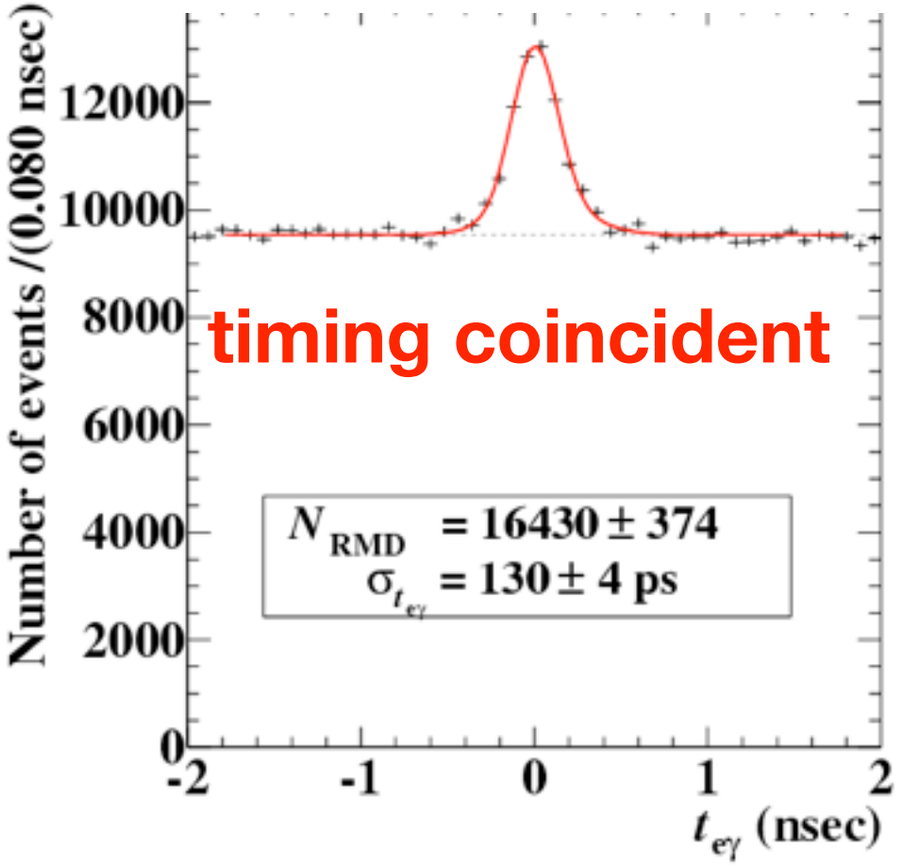
Calibration, cont.

- can be evaluated by physics data (background spectra), too.

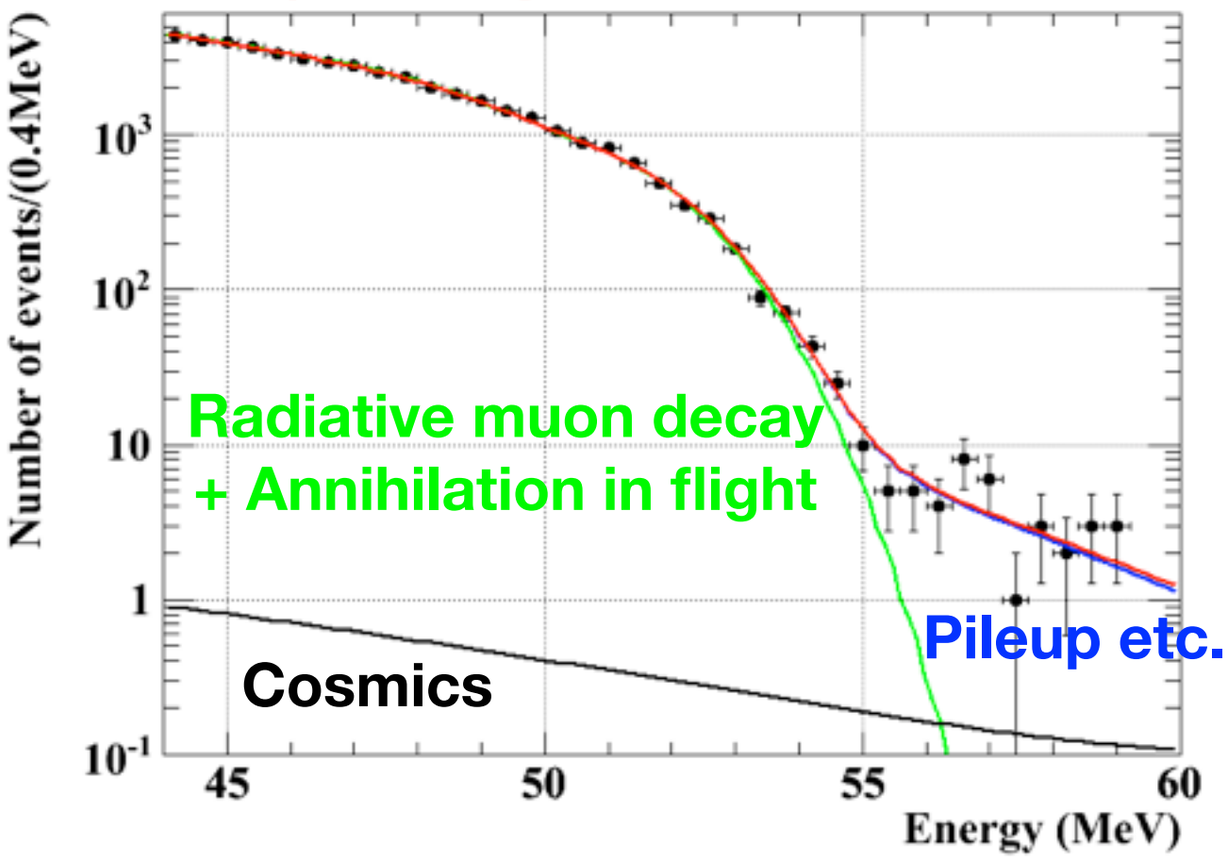
Michel spectrum



Radiative muon decay (μ→eγνν)

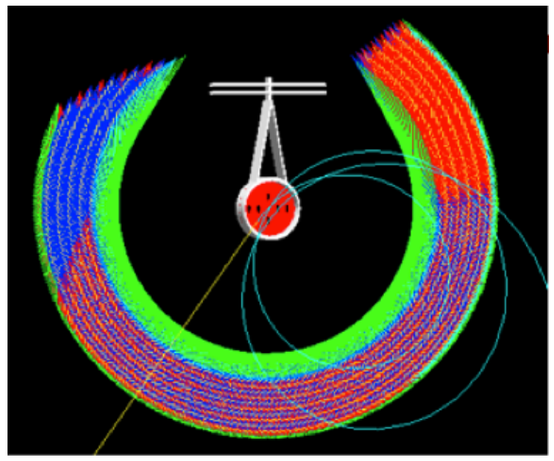


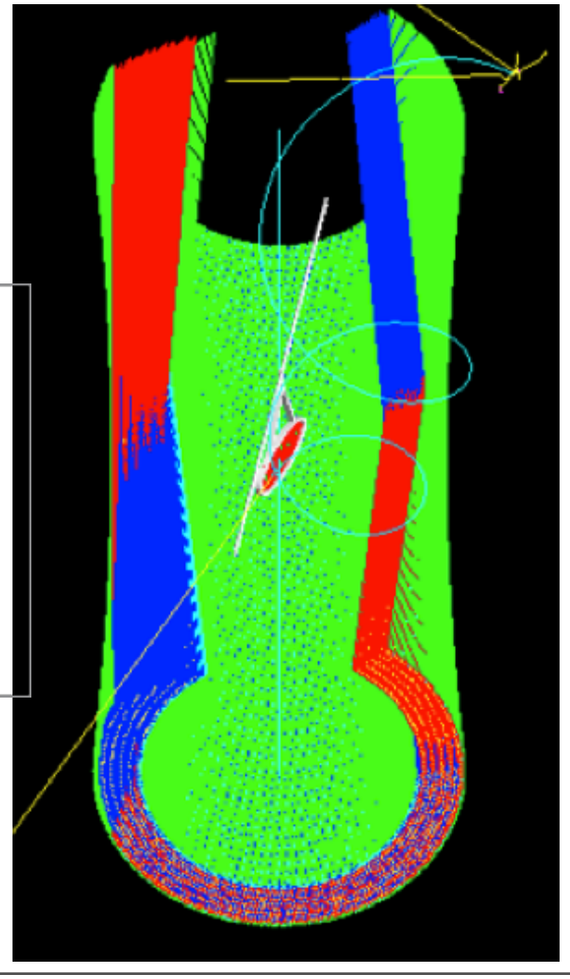
E_γ background spectrum

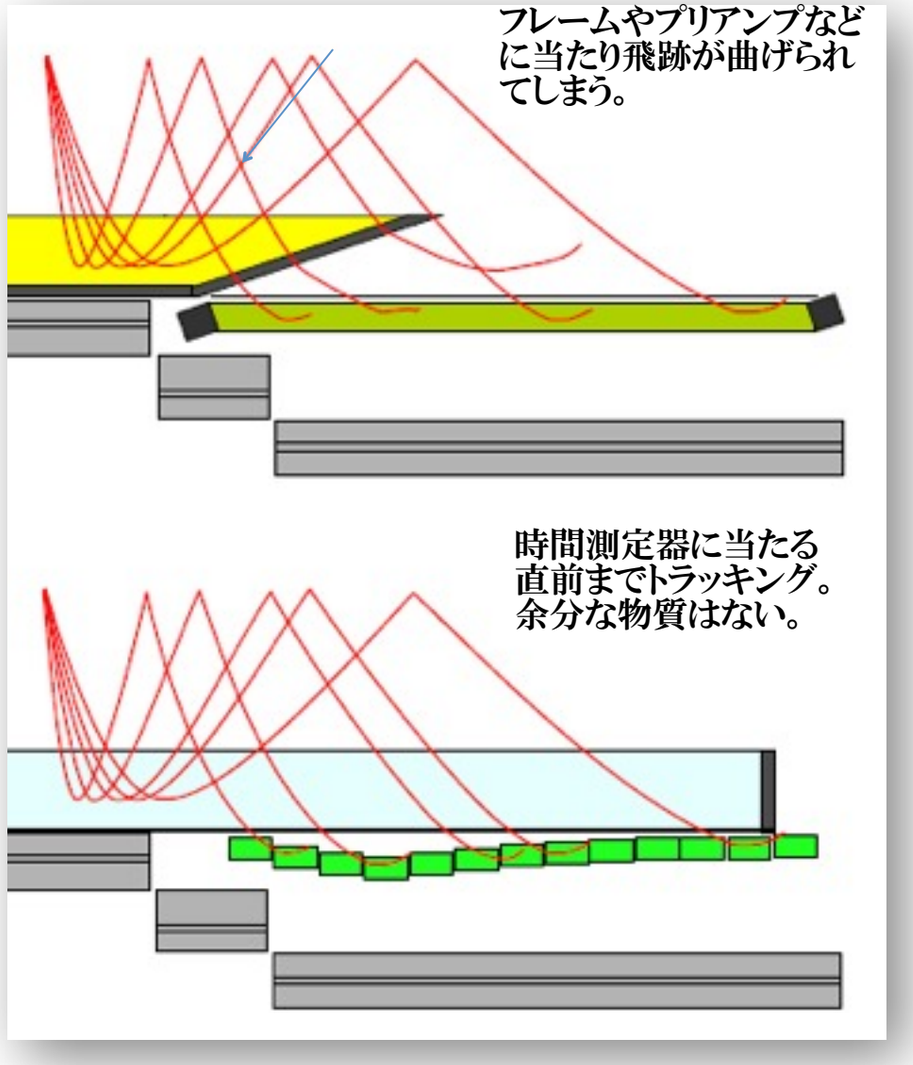


Drift chamber

- Single volume gaseous detector
- Cylindrical shape with longitudinal wires
- U-V stereo for hit position along z



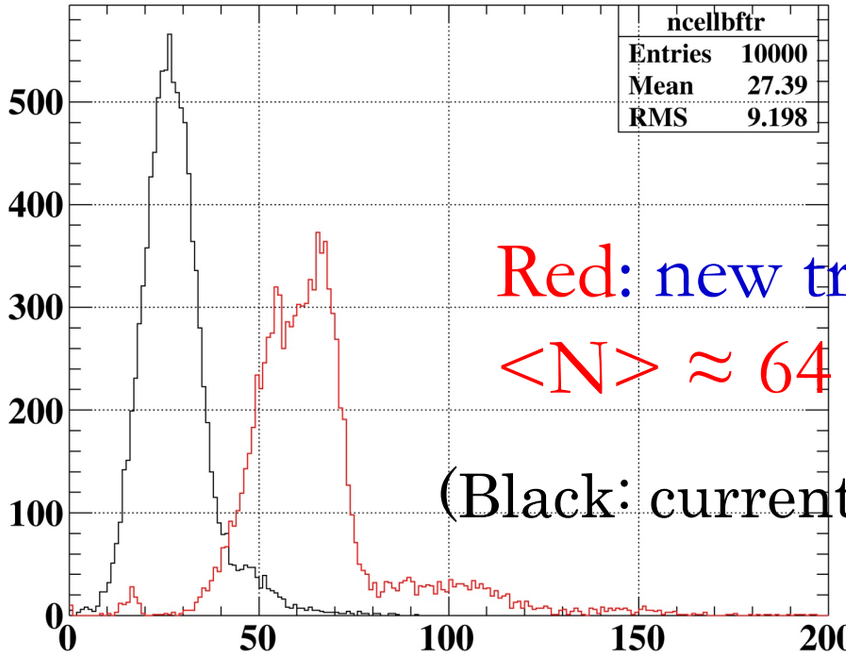




Expected Performance

Momentum ~130 keV (350 keV)
Angular ~5 mrad ; ~5mrad
(9mrad ; 11mrad)
Vertex ~1.2 mm ; ~0.7 mm
(1.8 mm ; 1.1 mm)
DC-TC matching eff. ~ 90 % (41%)

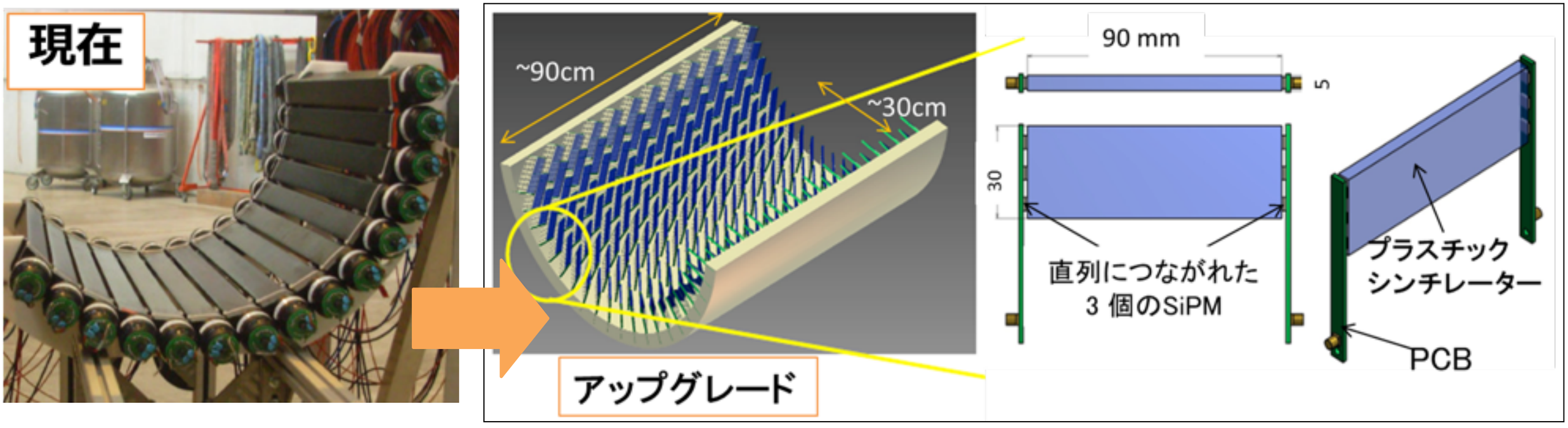
Large number of hits



Red: new tracker
<N> ≈ 64
(Black: current one)

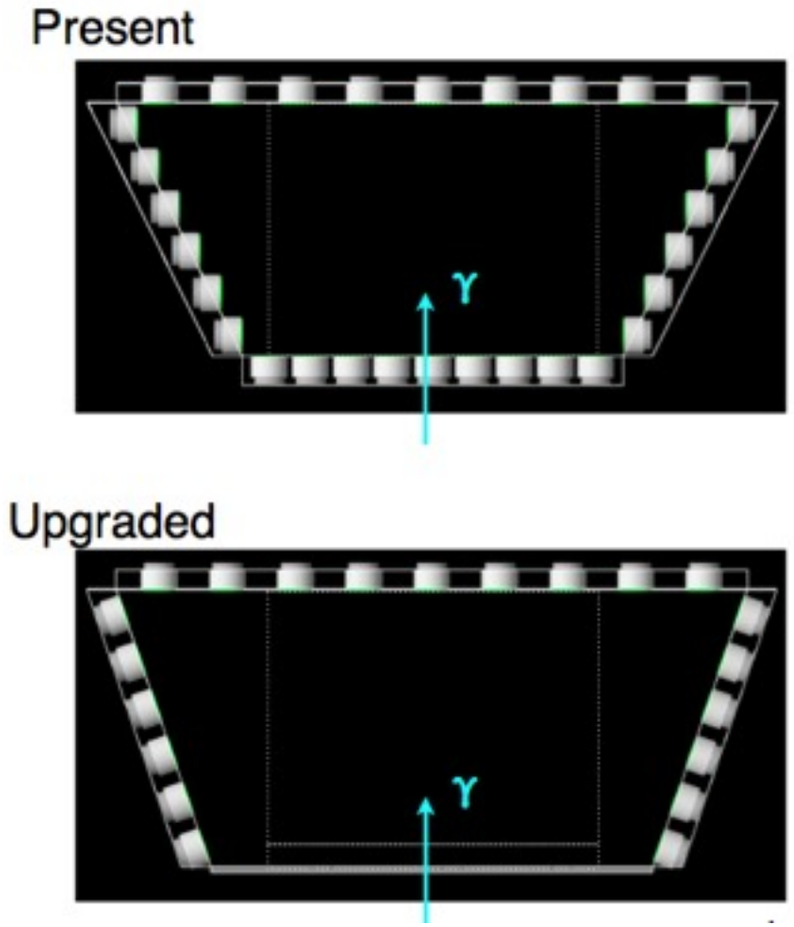
New Pixelated Timing Counter

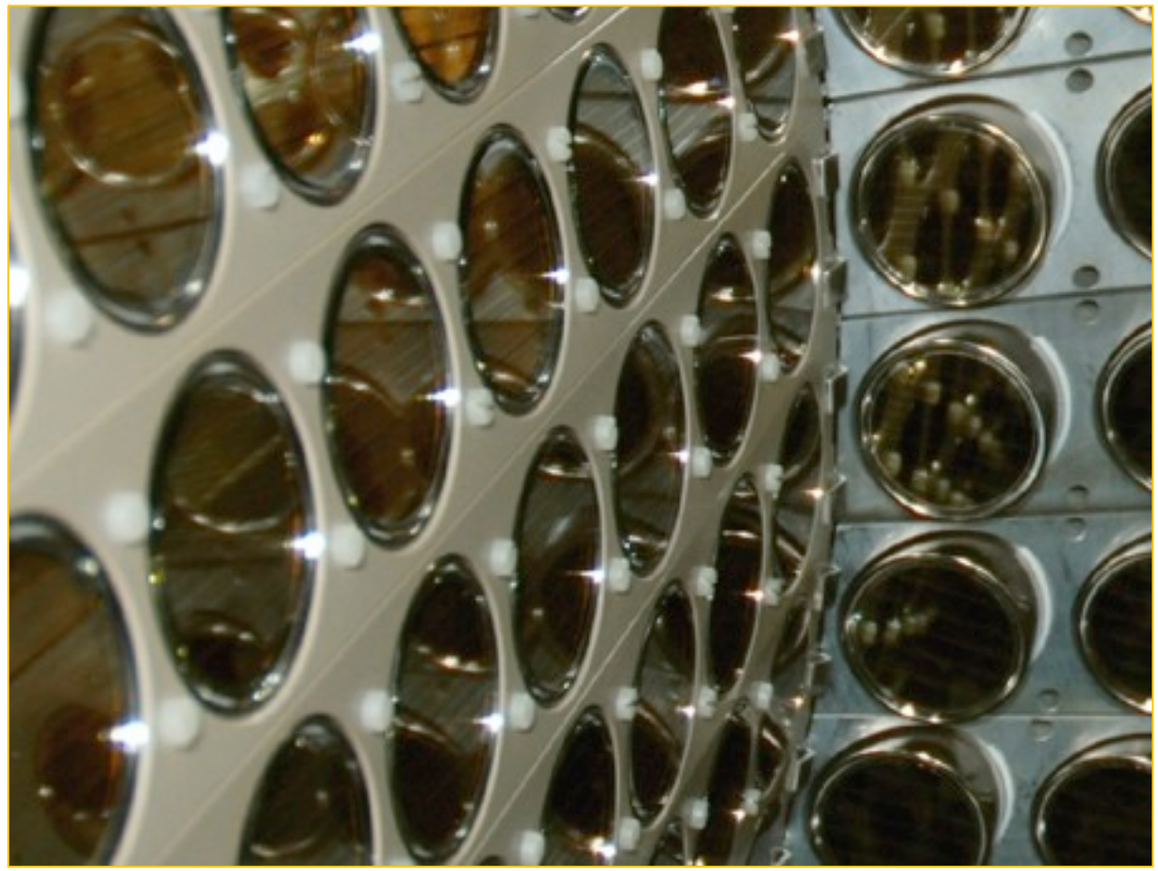
- Array of ultra-fast plastic scintillator counters
- SiPM readout
- high resolution with multiple counter hits
- Expected resolution 30-35ps

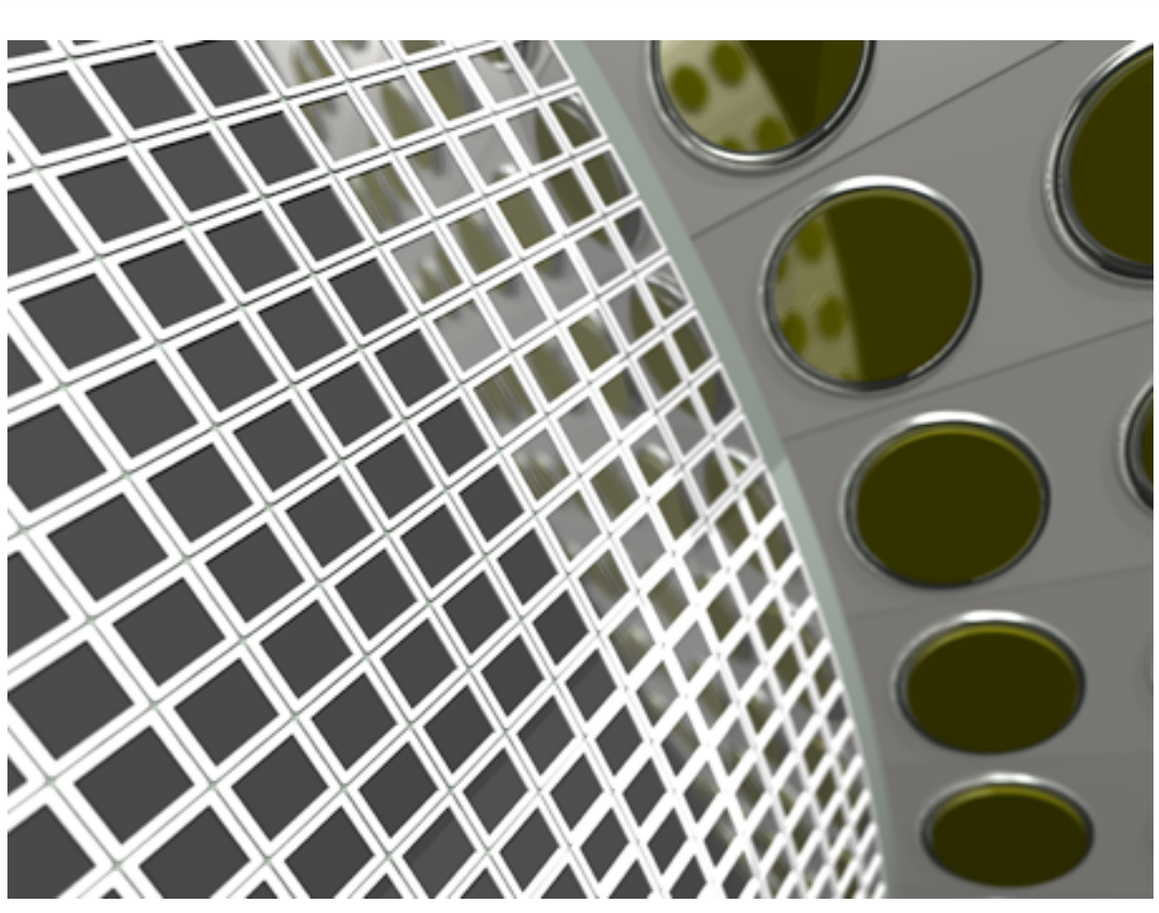


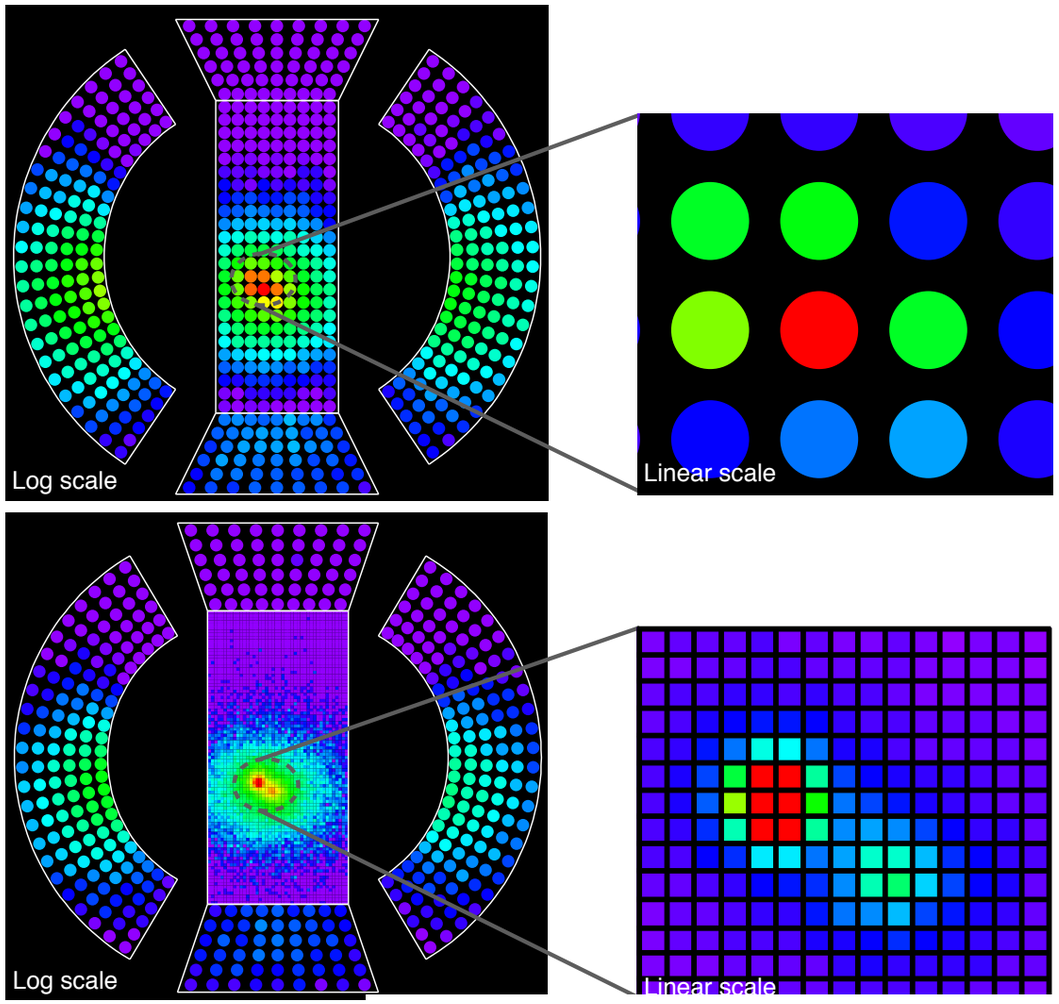
LXe

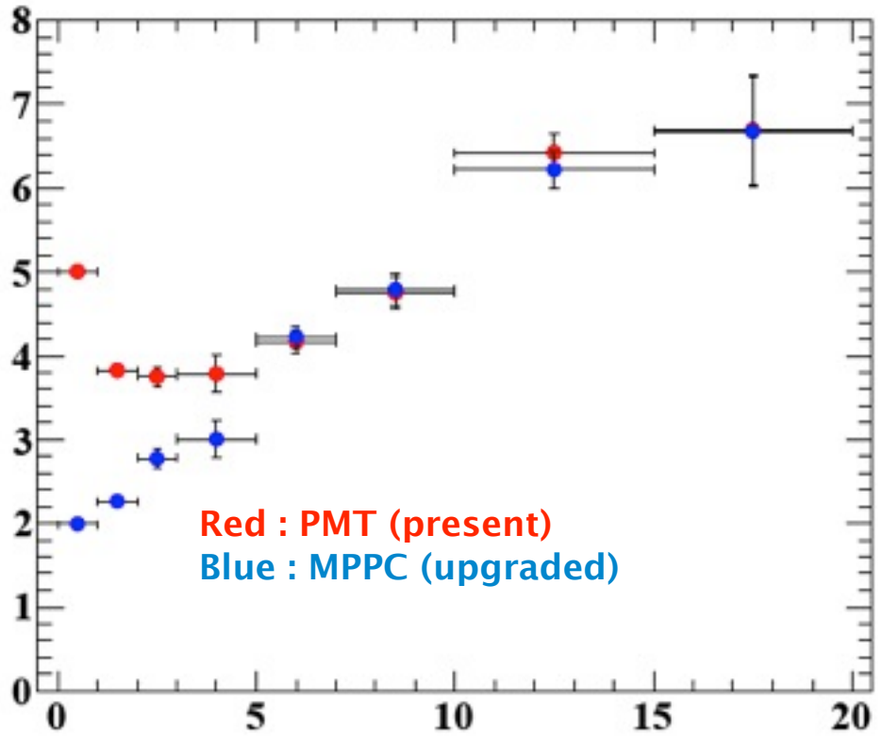
- Small photon sensors (MPPC) at gamma-ray incident face
- wider incident face
- change PMT angle at lateral face

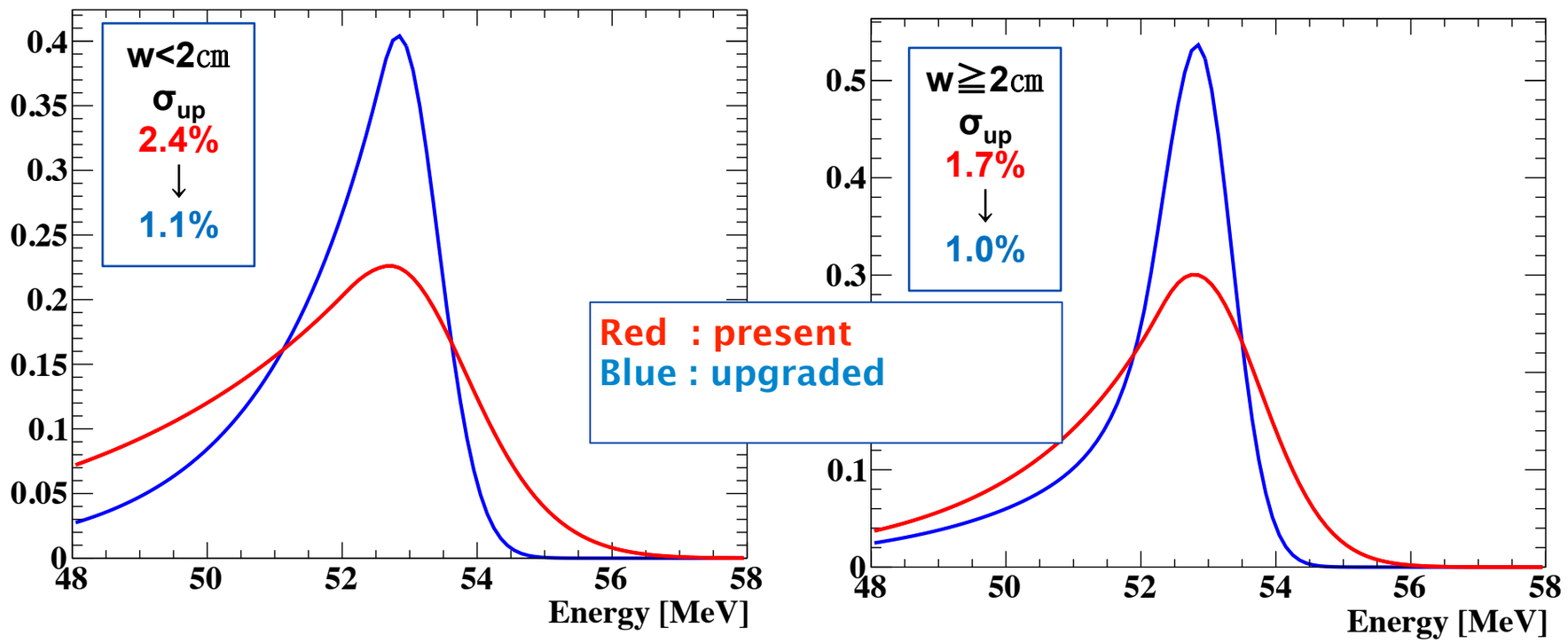




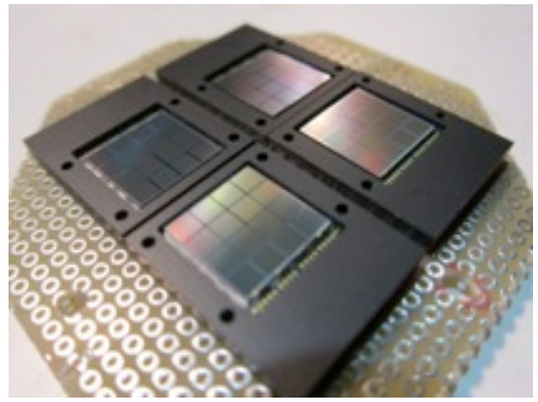



Log scale
Linear scale
Log scale
Linear scale

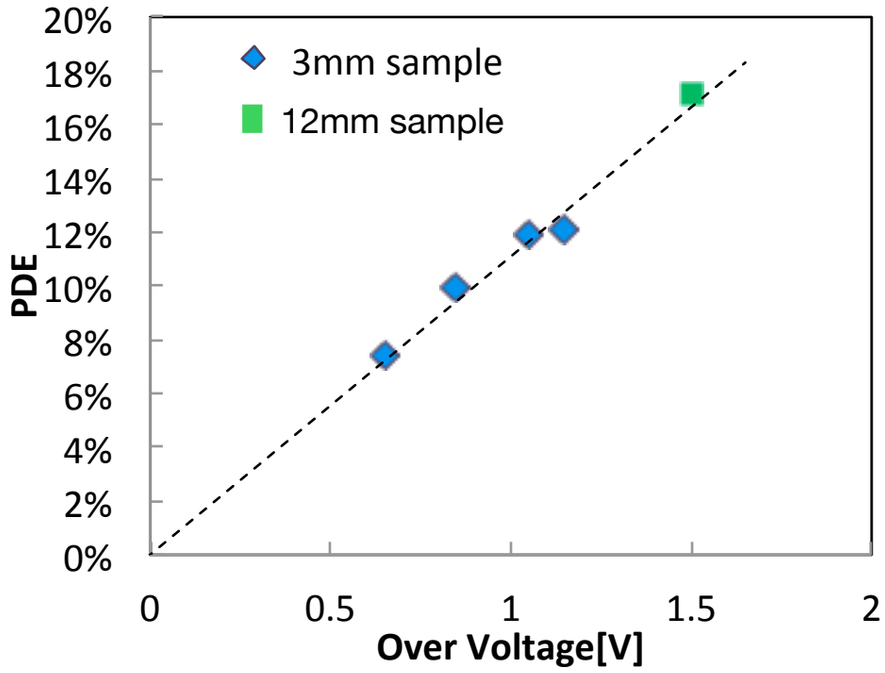

Red : PMT (present)
Blue : MPPC (upgraded)

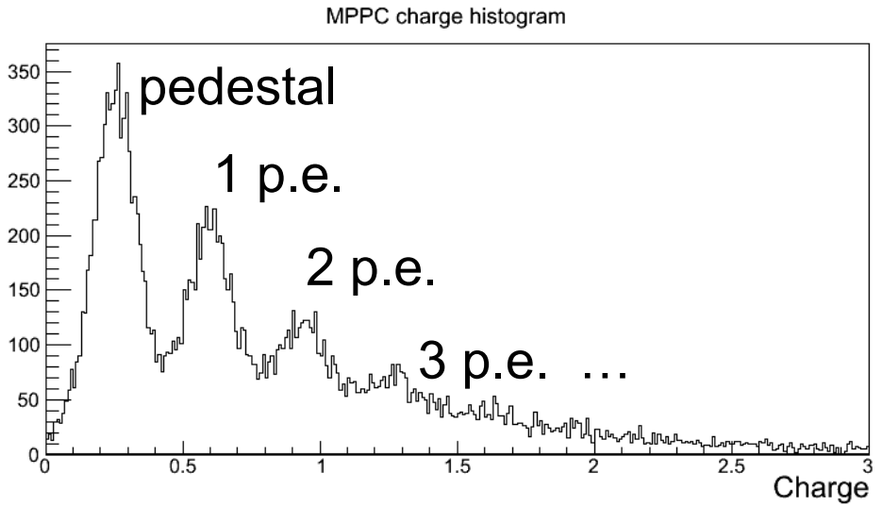

w<2cm
σup
2.4%
↓
1.1%
w≧2cm
σup
1.7%
↓
1.0%
Red : present
Blue : upgraded
Energy [MeV]
Energy [MeV]

MPPC R&D Status



- MPPC development in cooperation with Hamamatsu
- Achieved
  - UV(~175nm) sensitivity ~17%
  - Large area (12x12mm^2), single photoelectron peak resolved
- Remaining issues
  - Can we make shorter waveform?
  - Should cross talk be suppressed in our application?





Likelihood analysis

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

$$\mathcal{L}(N_{\rm sig}, N_{\rm RMD}, N_{\rm BG}) = \frac{e^{-N}}{N_{\rm obs}!} e^{-[(N_{\rm RMD}-\langle N_{\rm RMD}\rangle)^2/2\sigma^2_{\rm RMD}]}$$
$$\times e^{-[(N_{\rm BG}-\langle N_{\rm BG}\rangle)^2/2\sigma^2_{\rm BG}]} \prod_{i=1}^{N_{\rm obs}} [N_{\rm sig} S(\vec{x}_i)$$
$$+ N_{\rm RMD} R(\vec{x}_i) + N_{\rm BG} B(\vec{x}_i)], \qquad \vec{x}_i = \{E_\gamma, E_e, t_{e\gamma}, \theta_{e\gamma}, \phi_{e\gamma}\}$$

$$\lambda_p(N_{\rm sig}) = \frac{\mathcal{L}(N_{\rm sig}, \hat{\hat{N}}_{\rm RMD}(N_{\rm sig}), \hat{\hat{N}}_{\rm BG}(N_{\rm sig}))}{\mathcal{L}(\hat{N}_{\rm sig}, \hat{N}_{\rm RMD}, \hat{N}_{\rm BG})},$$