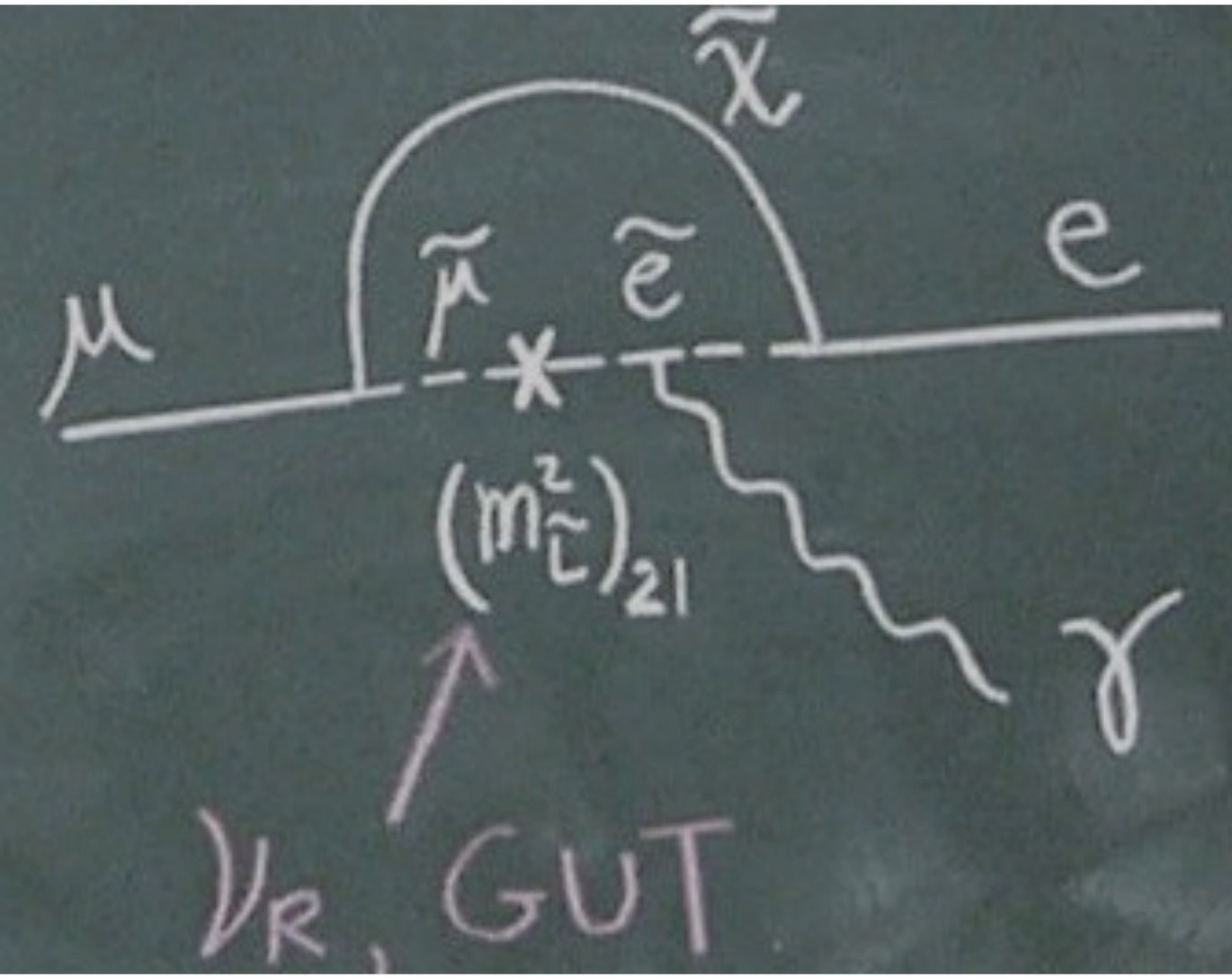
Latest Result from the MEG Experiment

MEG
Mu-E-Gamma project group

Hajime NISHIGUCHI, *KEK*
on behalf of the MEG Collaboration

PLANCK2011, 30.May-03.June 2011, Instituto Superior Técnico, Lisboa, Portugal



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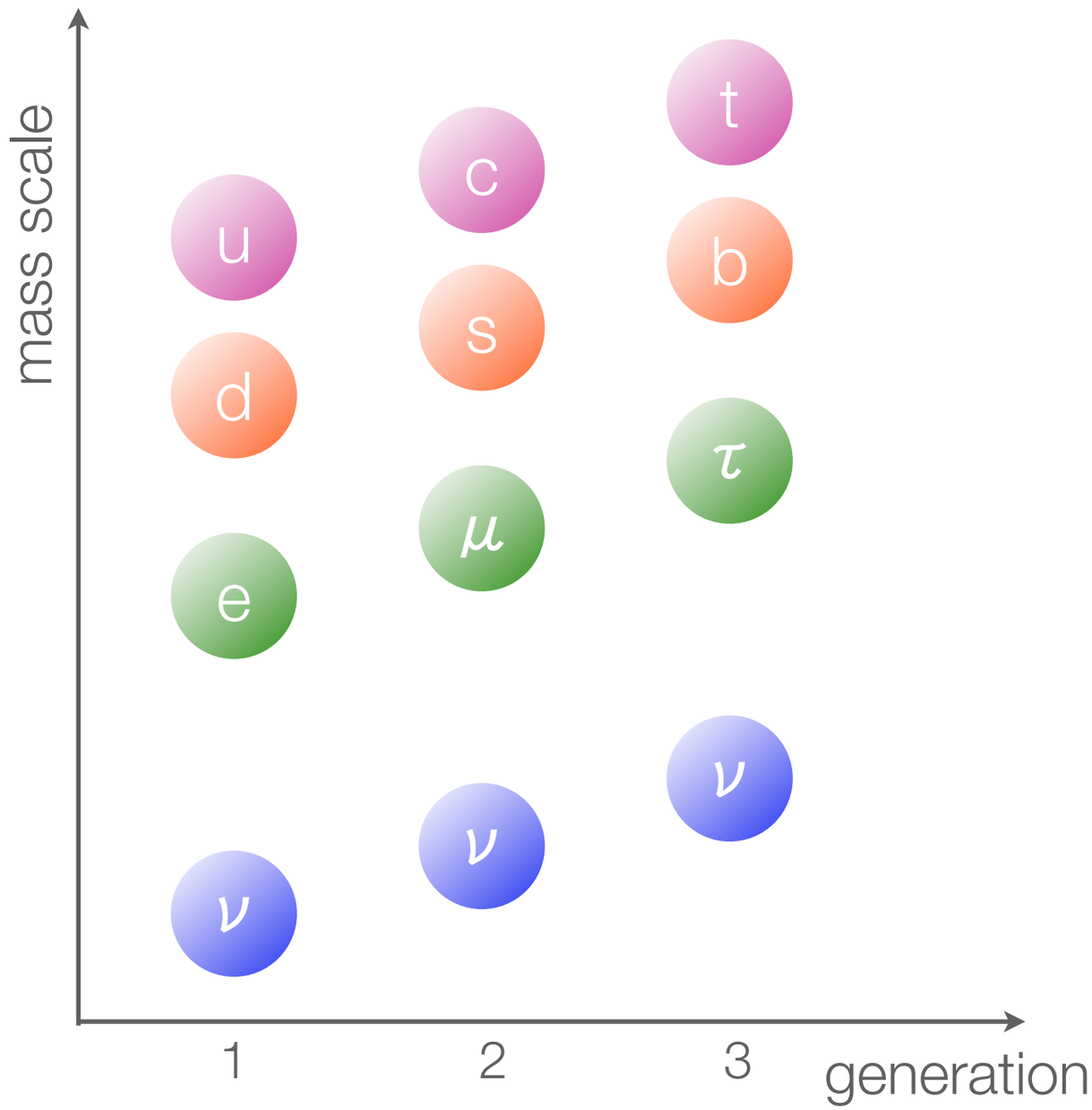
Flavour Violation



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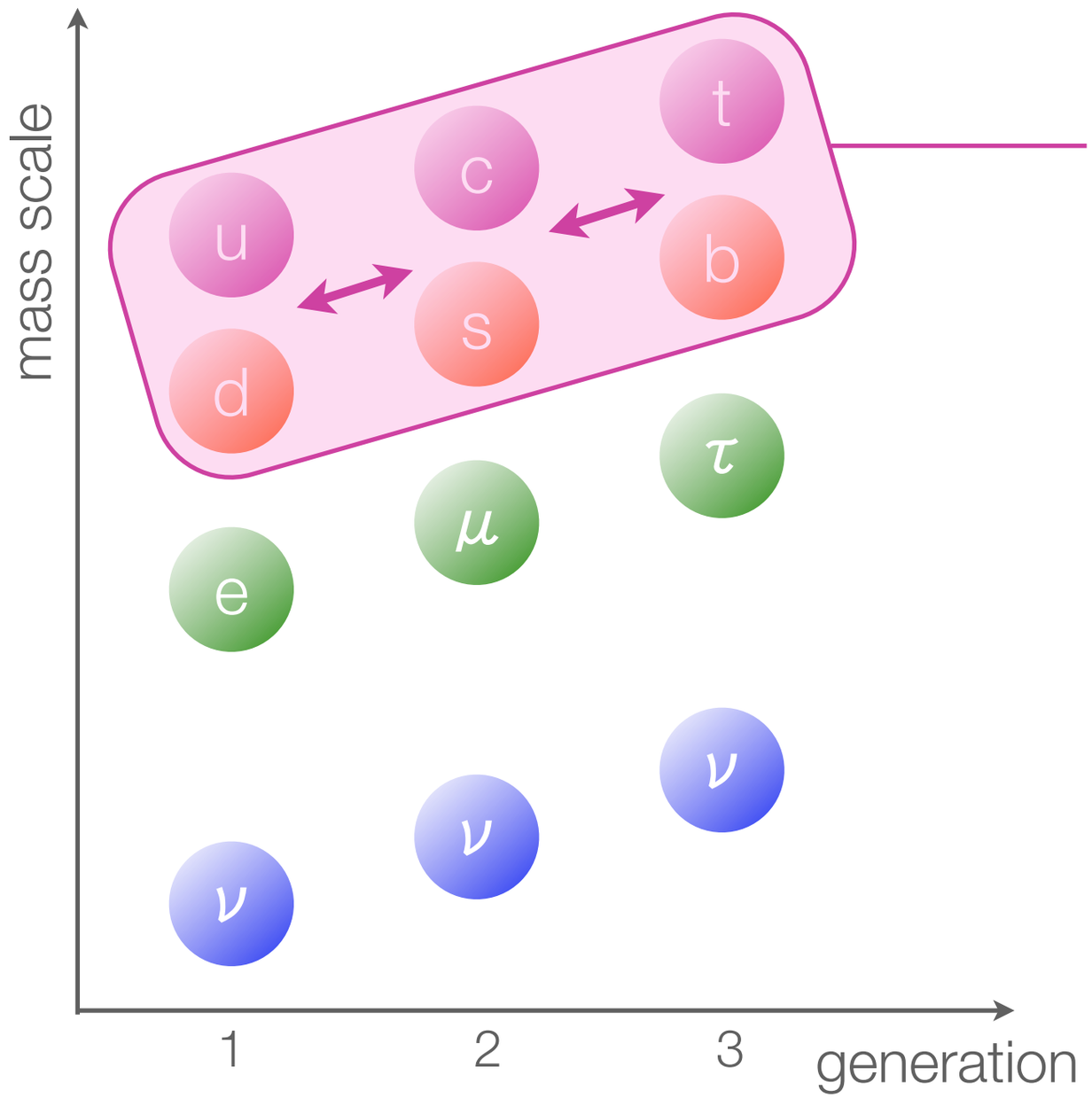

- Quark Sector
  - Mixed by CKM mechanism
  - Experimentally Verified
    - ➡ B factories

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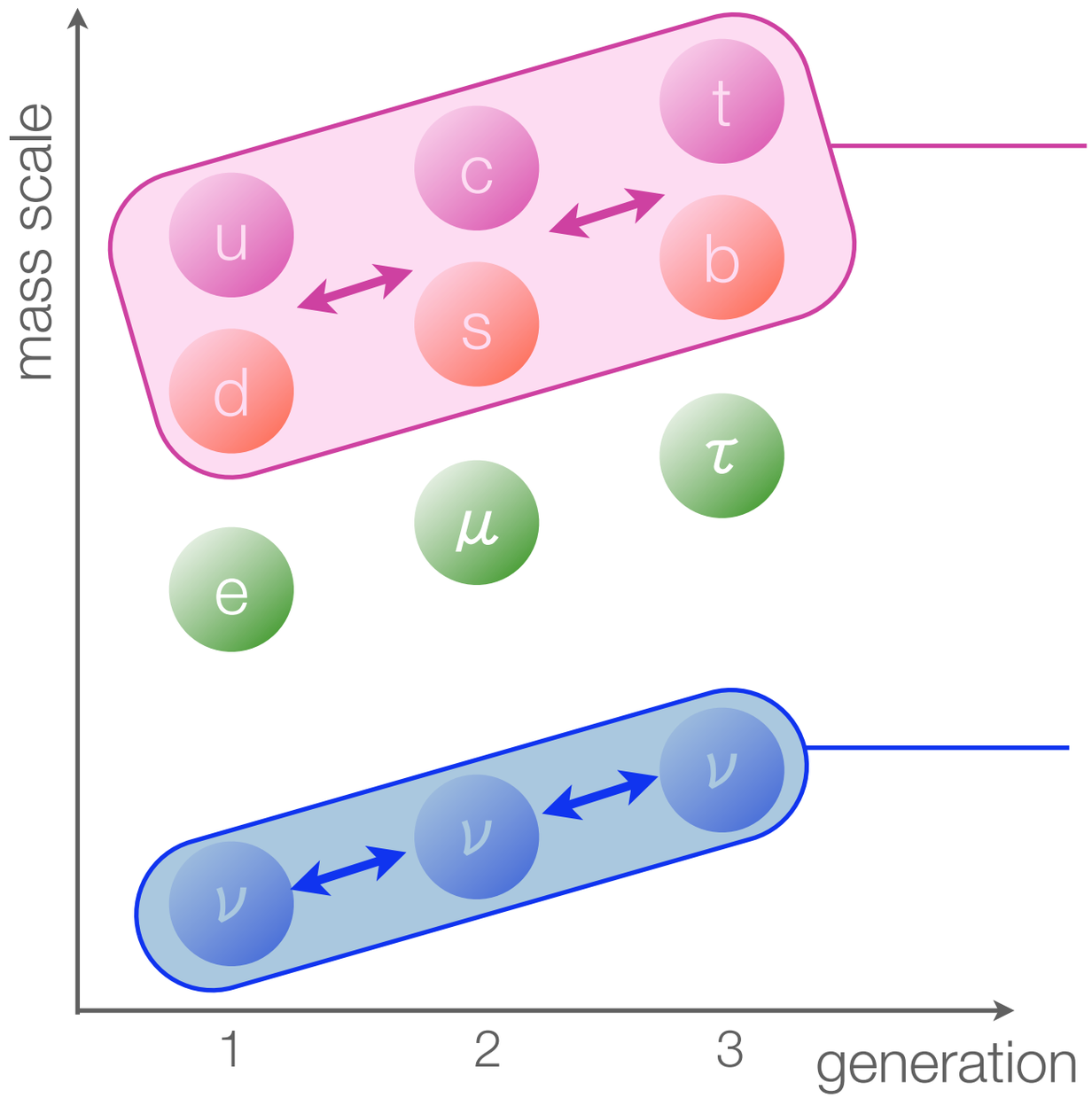

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- neutral Lepton Sector
  - Neutrino Oscillation
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    - ➡ SK, SNO, KamLAND, etc.

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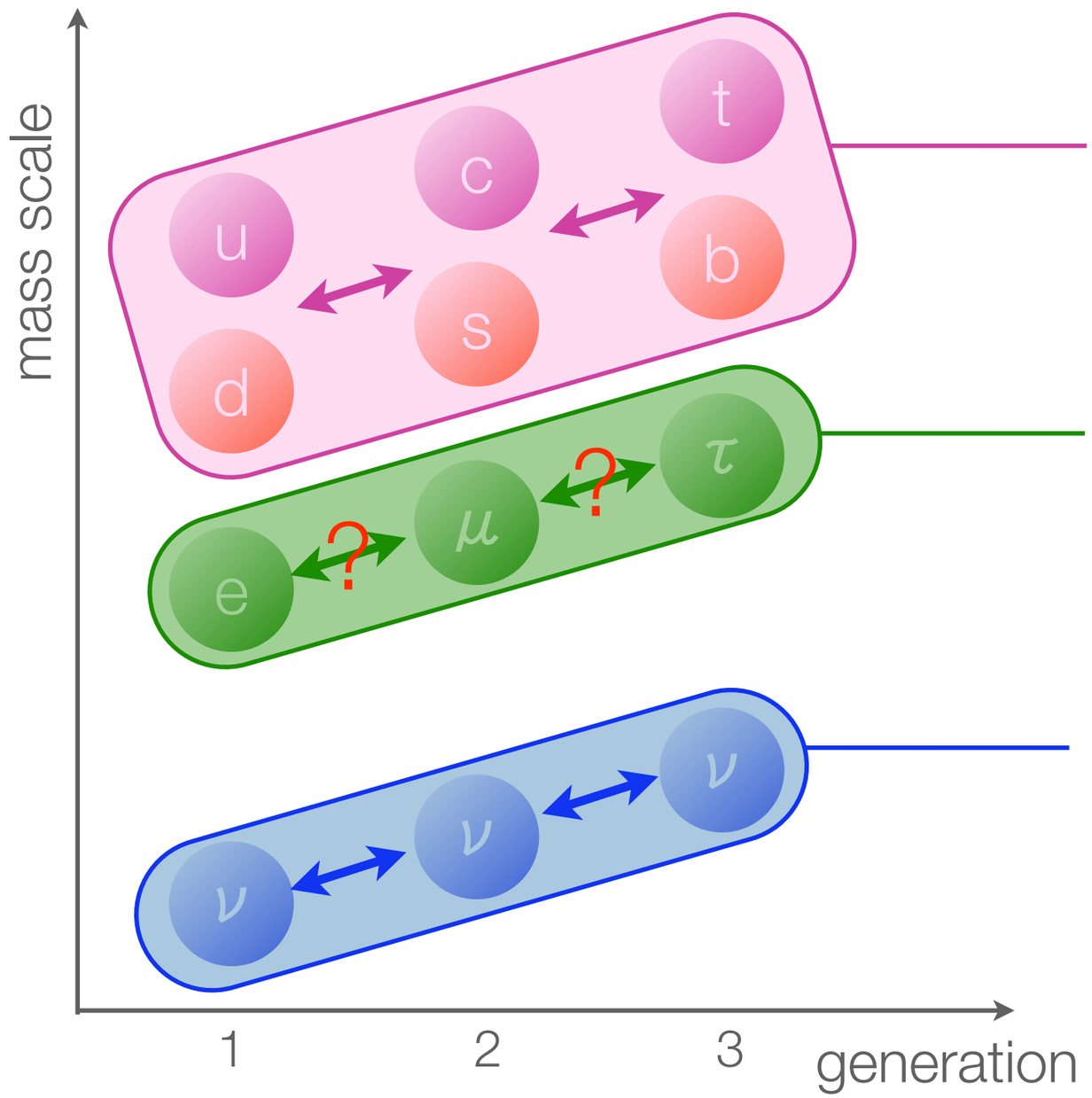


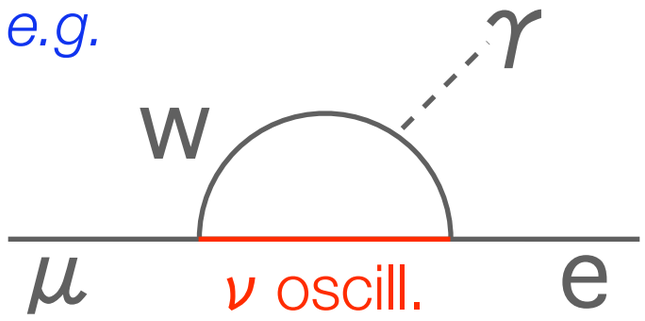
- Quark Sector
  - Mixed by CKM mechanism
  - Experimentally Verified
    - ➡ B factories
- charged Lepton Sector
  - never observed yet !!
  - source from beyond SM ??
- neutral Lepton Sector
  - Neutrino Oscillation
  - Experimentally Verified
    - ➡ SK, SNO, KamLAND, etc.

Why charged LFV has never been observed ?

SM + simple ν Oscillation

- charged LFV is possible

e.g.



- but extremely rare (small ν)

$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \sum_i \left| U^*_{\mu i} U_{ei} \frac{m^2_{\nu i}}{m^2_W} \right|^2$$

- $B(\mu \to e\gamma) = 10^{-50} \sim 10^{-40}$!!!

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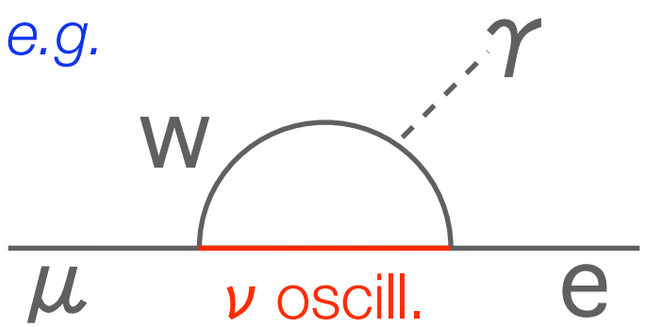

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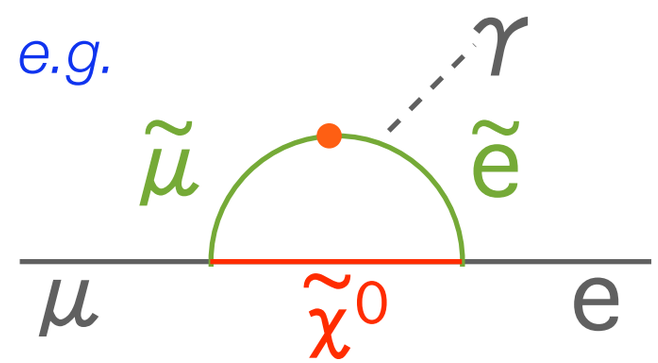
beyond SM (SUSY-GUT etc.)

- charged LFV is largely enhanced

e.g.



- still rare but observable level

$$\mathcal{B}(\mu \to e\gamma) \simeq \frac{\alpha^3 \pi \theta^2_{\tilde{e}\tilde{\mu}}}{G_F^2 \tilde{m}^4}$$

- B($\mu \to e\gamma$) = $10^{-15} \sim 10^{-11}$!!!

Why charged LFV is so Attractive ?

- Only charged LFV has never been observed.
- Neutrino Oscillation is possible by "SM + ν mass"
- Quark Mixing is generally contaminated by SM

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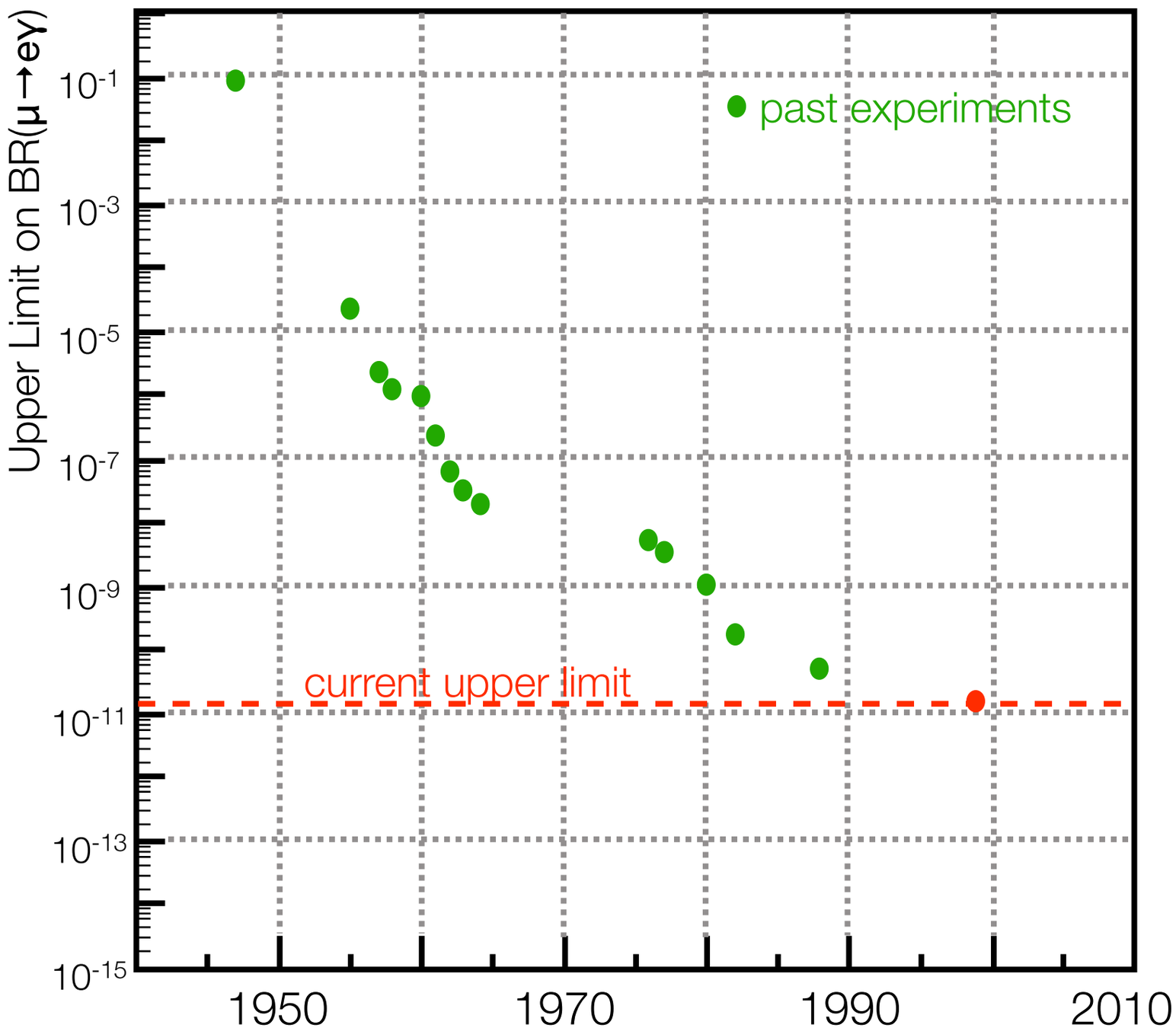
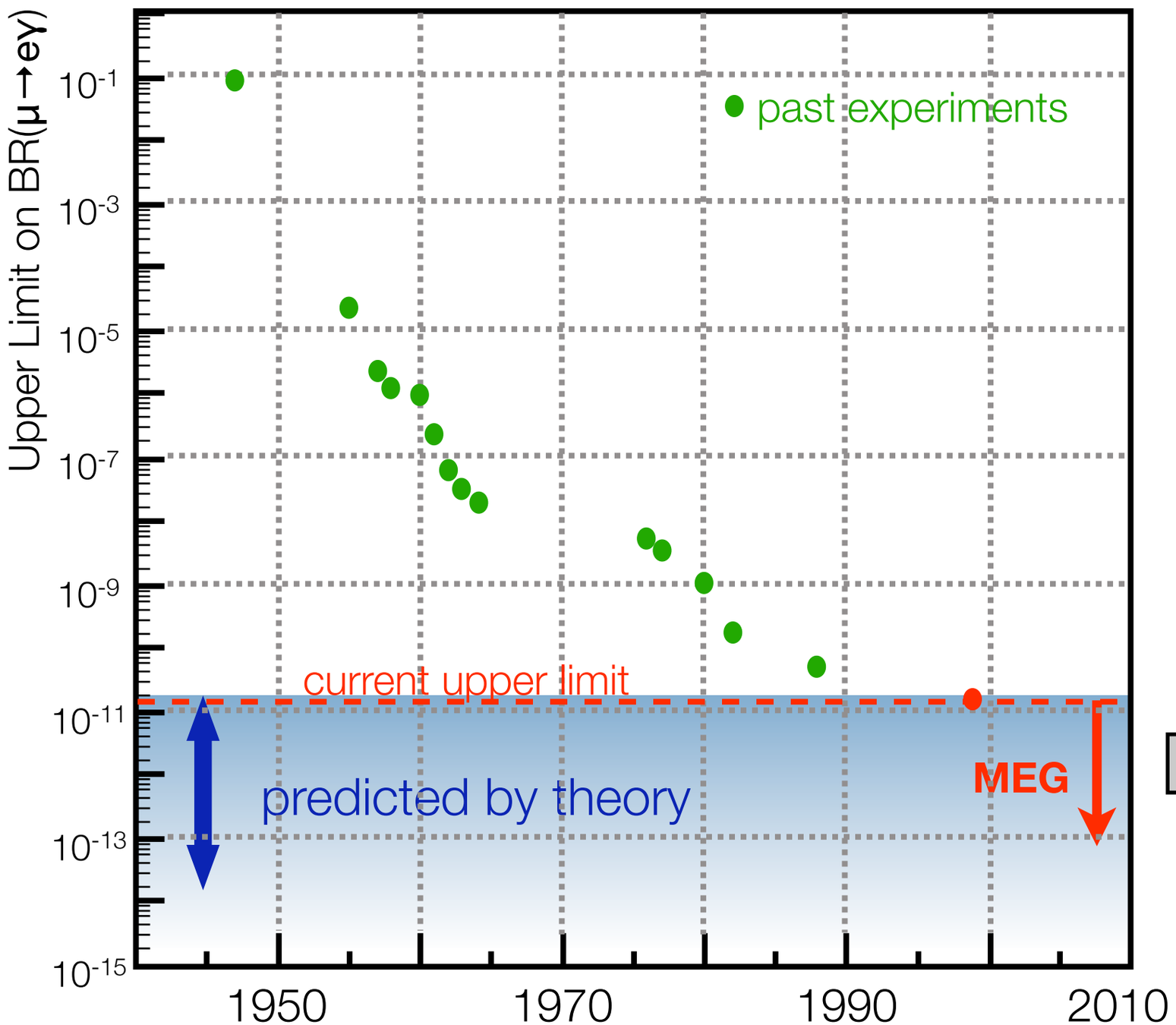
- Experimental Upper Limit is already sensitive to predicted region.
- *eg*. $\mu \rightarrow e\gamma$ is the most sensitive mode to search for charged LFV.
  - muon can be generated most easily.
  - Suitable for rare decay search experiment.

History of μ→eγ Search Experiment



- **μ→eγ** Search Experiment has started right after muon discovery.
  - Very Long Tradition
- Now we are approaching the predicted region

History of μ→eγ Search Experiment



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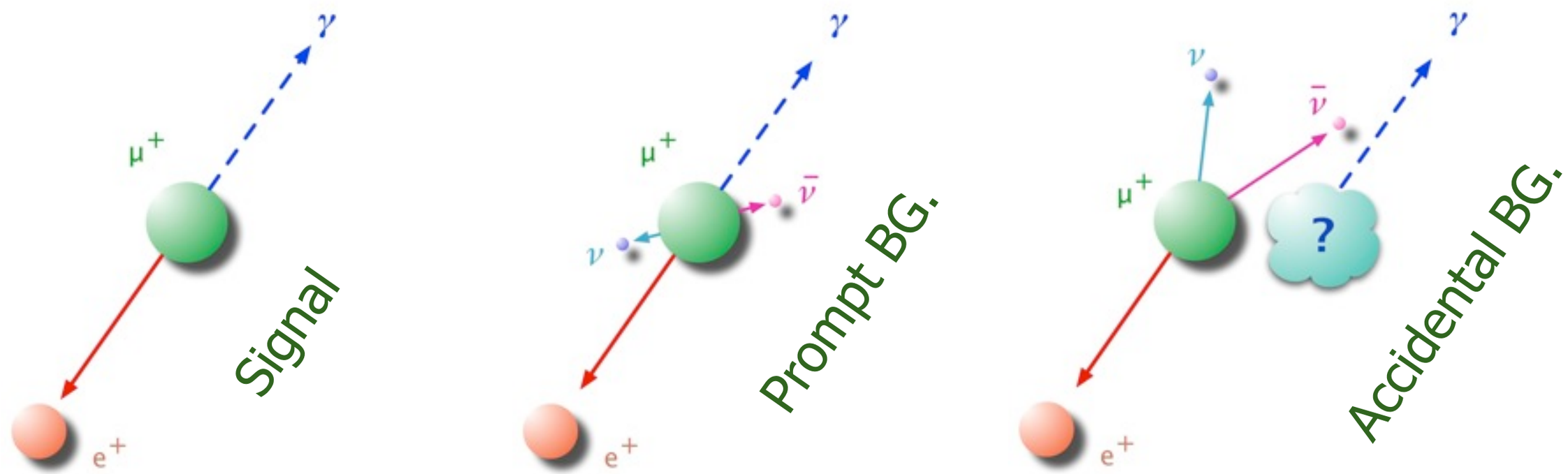
MEG Started !

(physics run from 2008)

Hunting for μ→eγ

- Signal and Backgrounds



- Clear 2-body kinematics (E_e=E_γ=52.8MeV, $\theta_{e\gamma}$=180°, Time Coincidence)
- Sensitivity is Limited by "Accidental Overlap"
  - **DC muon is the Best Solution**
  - **Good Resolution (Energy, Spacial and Timing) under Very High Rate**

Features of the MEG

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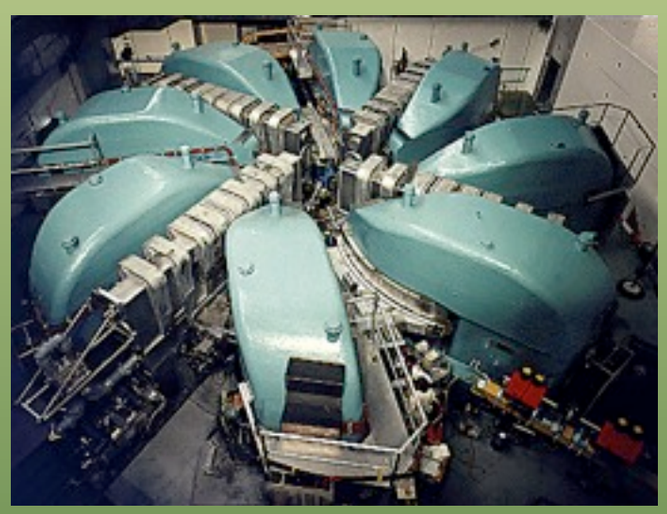

World Most Intense
DC Muon Beam at PSI
10^8 muon/sec

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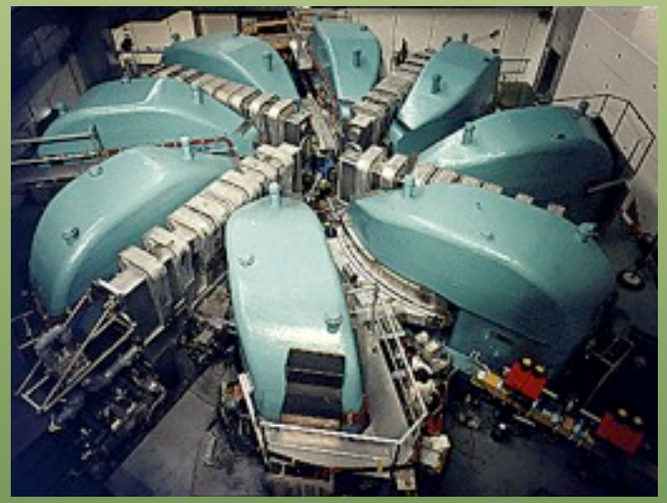

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Liquid Xenon
Scintillation Detector
(gamma)

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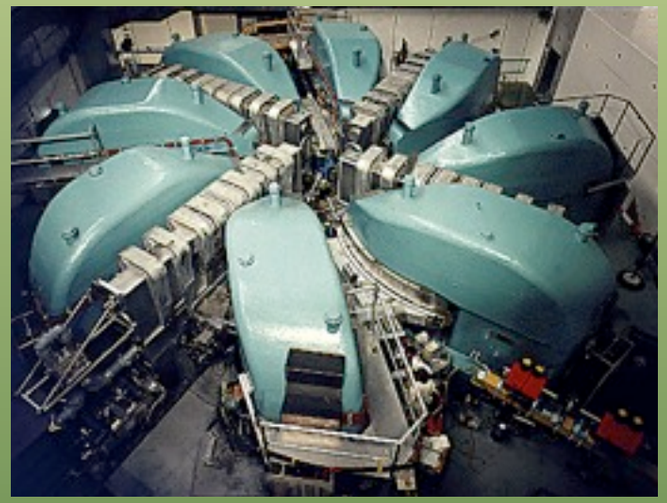

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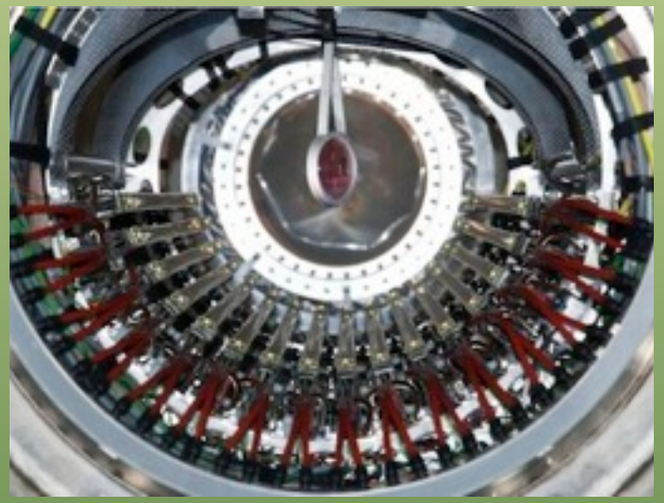

COBRA Spectrometer
(positron)

PSI and its Cyclotron Facility

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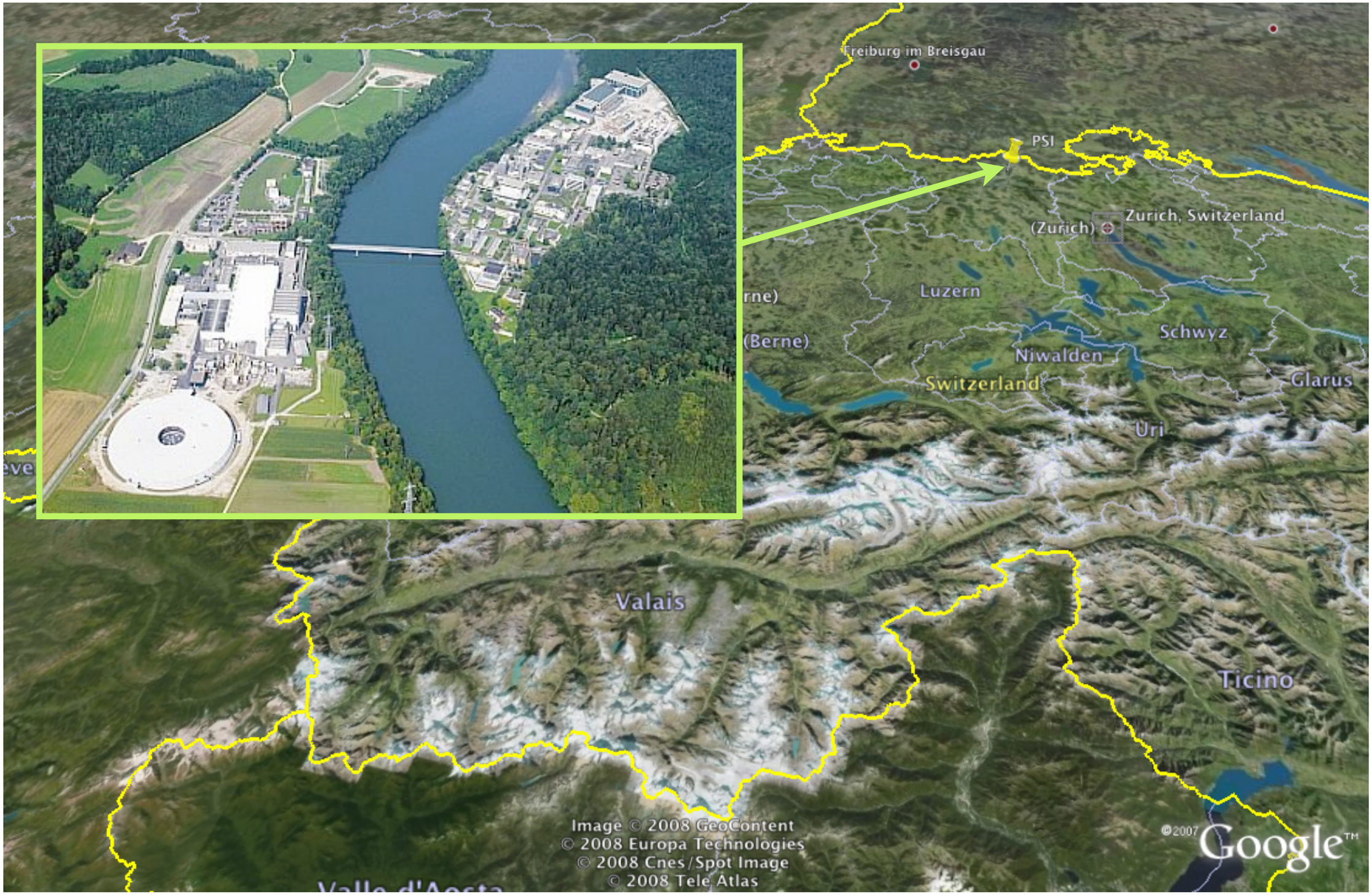

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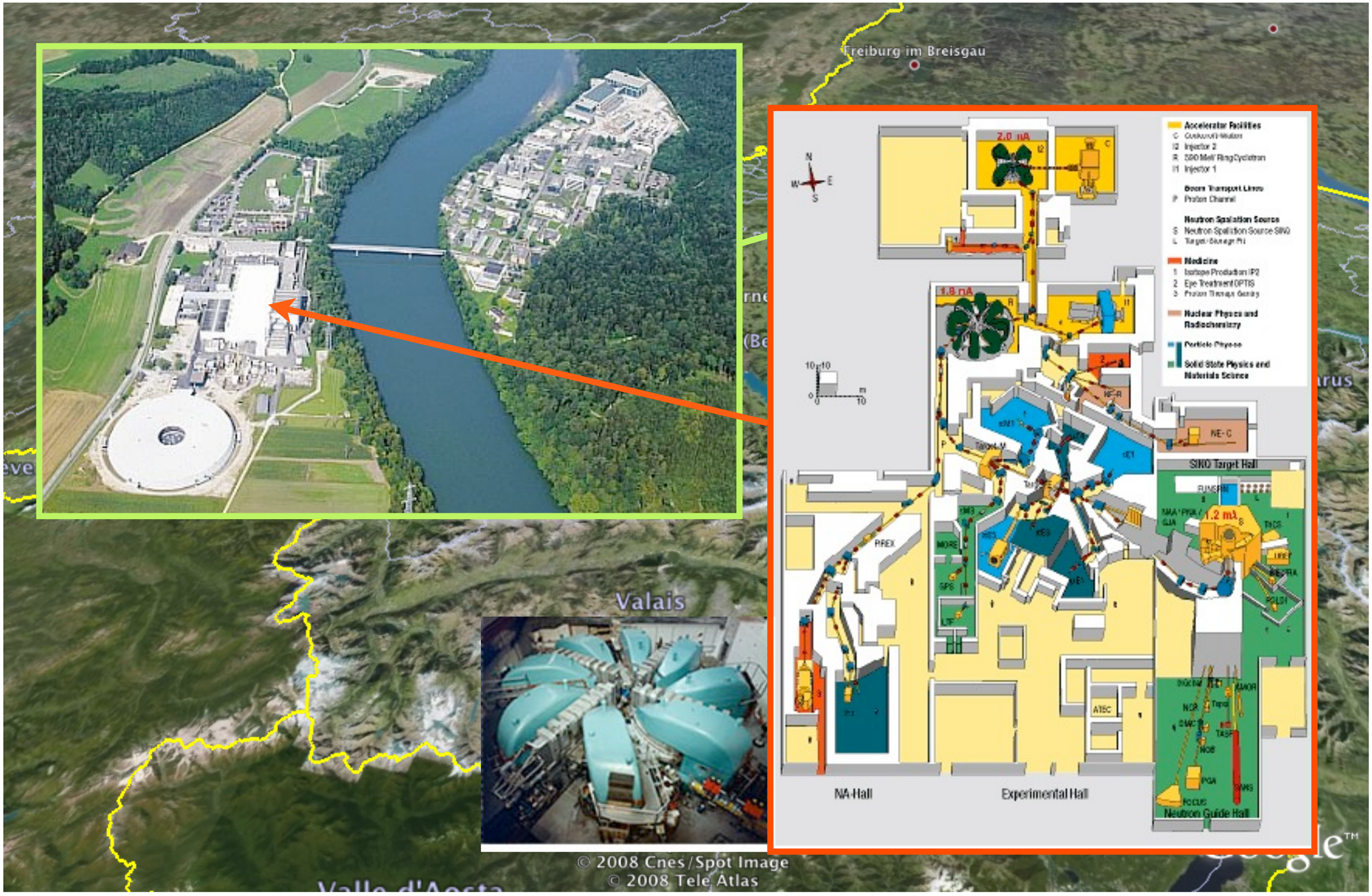
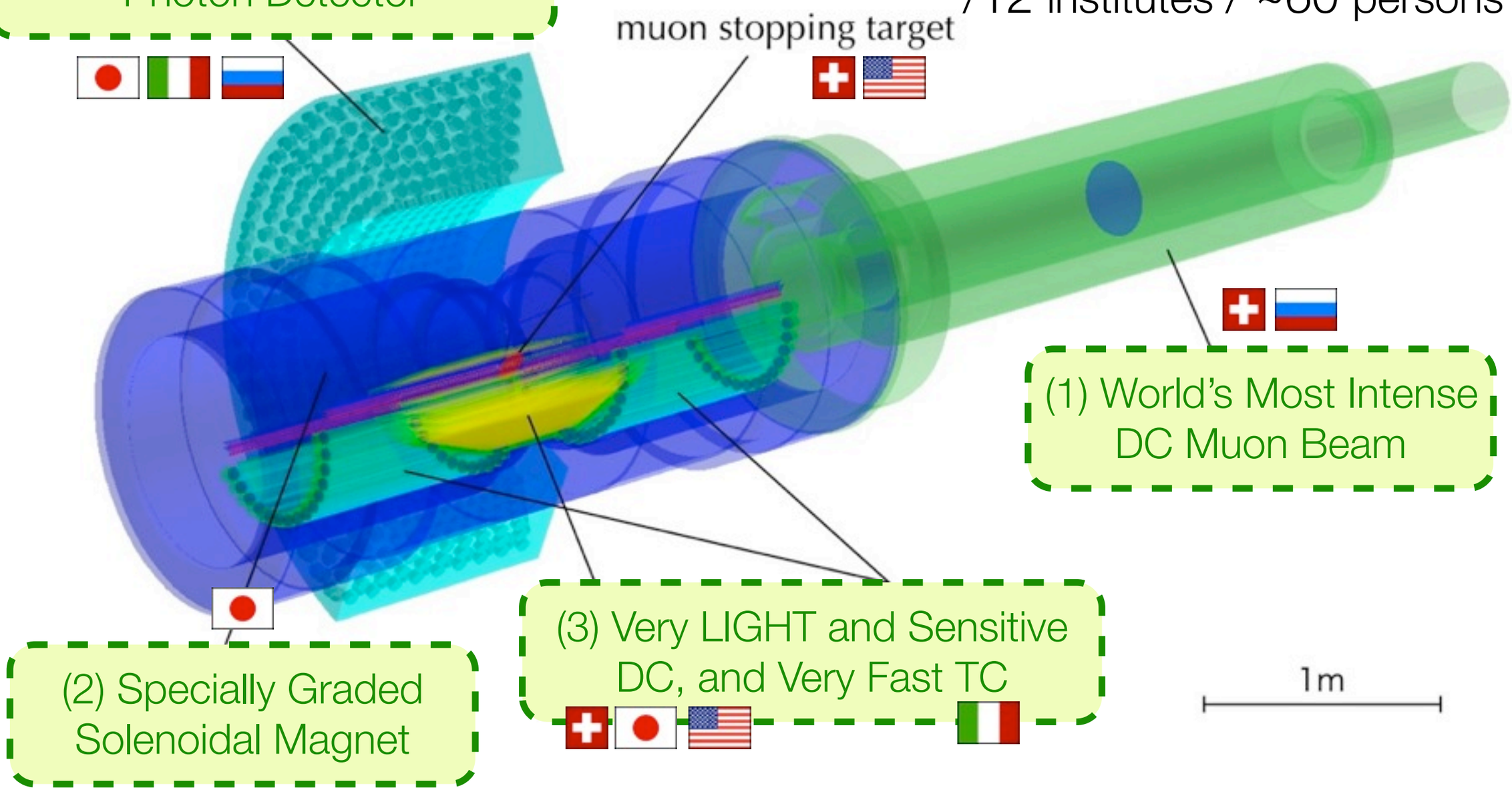


MEG Detector Apparatus

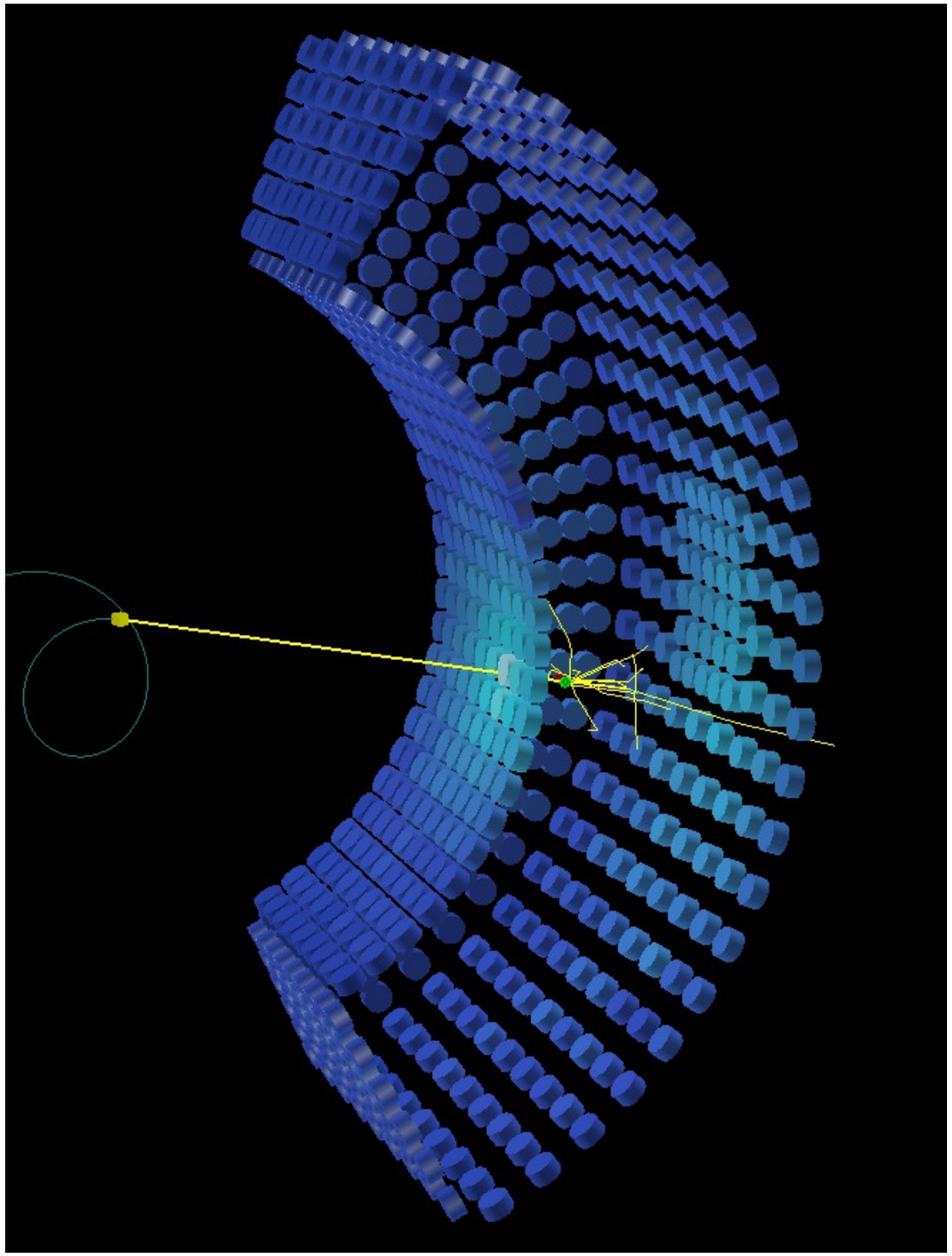
The MEG Collaboration

(5 countries , /12 institutes / ~60 persons)

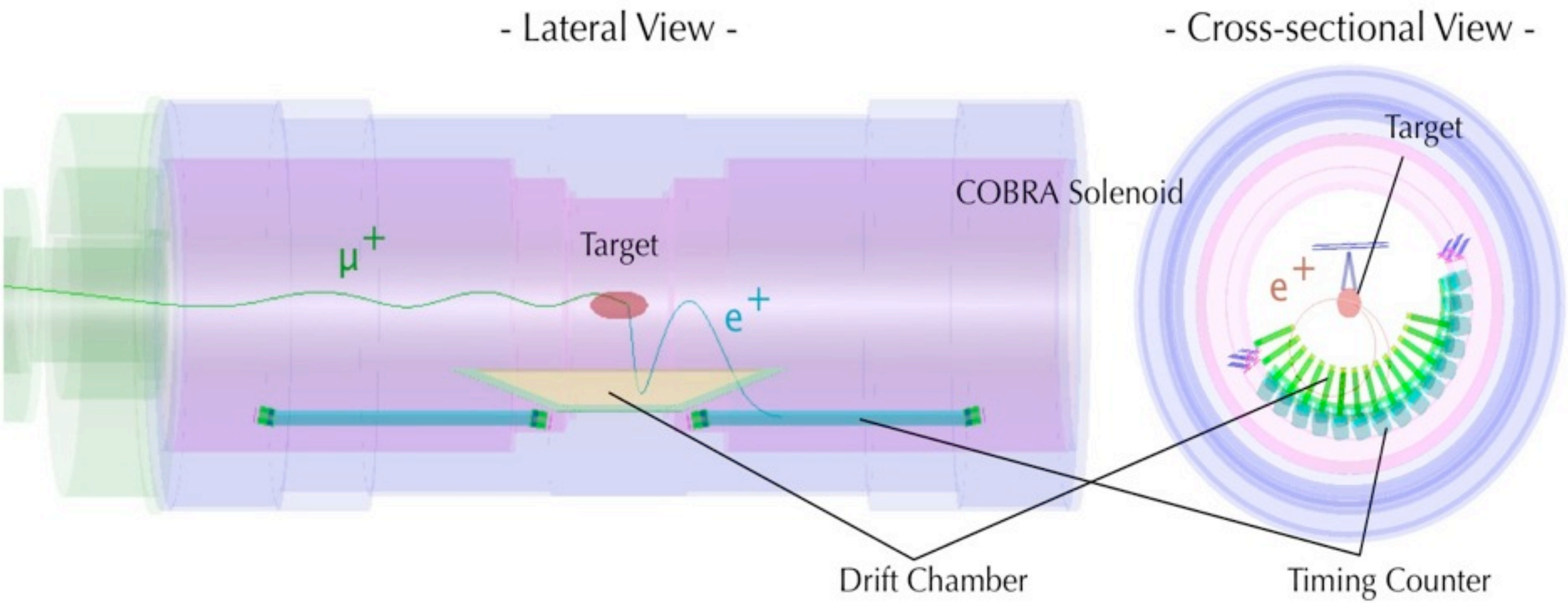


Liquid Xenon Scintillation γ Detector

- Homogeneous Volume (~800l) is surrounded by PMTs on all faces
- 846 PMTs submerged in the liquid
- Energy Measurement
  - All PMT outputs
  - σ_E/E ~ 2% (@52.8MeV)
- Position Measurement
  - PMTs on the inner face
  - σ_x = 5-6 mm (@52.8MeV)
- Timing Measurement
  - Averaging of signal arrival time of selected PMTs
  - σ_t ~ 70 ps (@52.8MeV)



COBRA Positron Spectrometer



Solenoid

superconducting solenoid
gradient B-field (0.5-1.7 T)
very thin conductor and
cryostat wall ($0.2X_0$)

Drift Chamber

segmented radially (16 sectors)
helium:ethane (50:50)
opened-frame
very thin cathode foil with pads

Timing Counter

2-layers of scintillators
- scintillator bars (outer)
- scintillator fibres (inner)

MEG History

1999
proposal submitted to PSI

1999~2006
prototyping, beamline study, construction

2007
construction completed, engineering run

calibration scheme established

2008
maintenances, 1st Physics Run (Sep.-Dec.)

very poor efficiency due to tracker discharge problem

Run2008 Result
preliminary

2009
fixed discharge, 2nd Physics Run (Oct.-Dec.)

fully operational !!

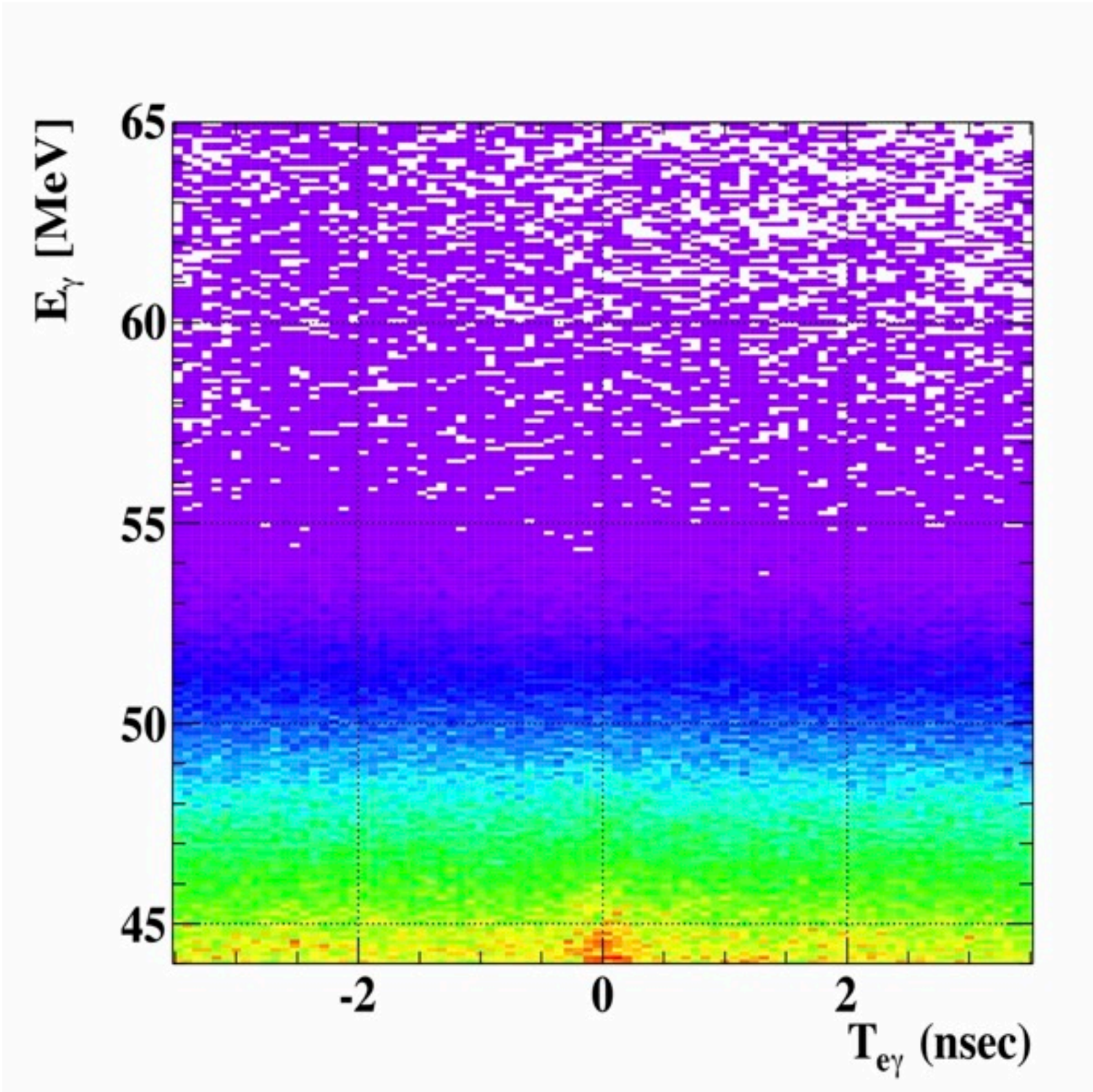
Run2009 Result
preliminary

2010
maintenances, 3rd Physics Run (Aug.-Nov.)

×2 statistics of 2009 data

Analysis Procedure

- **Blind Analysis**
  - Signal region was hidden until analysis fixed
  - Any study (calibration, BG estimation, performance evaluation) can be done with events outside the box
  - Hidden parameters (E_γ, $T_{e\gamma}$)
- **Sideband Data**
  - Accidental BG can be studied with off-timing sideband data
  - Radiative decay can be studied with low energy sideband data
- **Normalization**
  - Unbiased Michel data mixed in physics data
- **Wide Analysis Region**
  - for likelihood fitting



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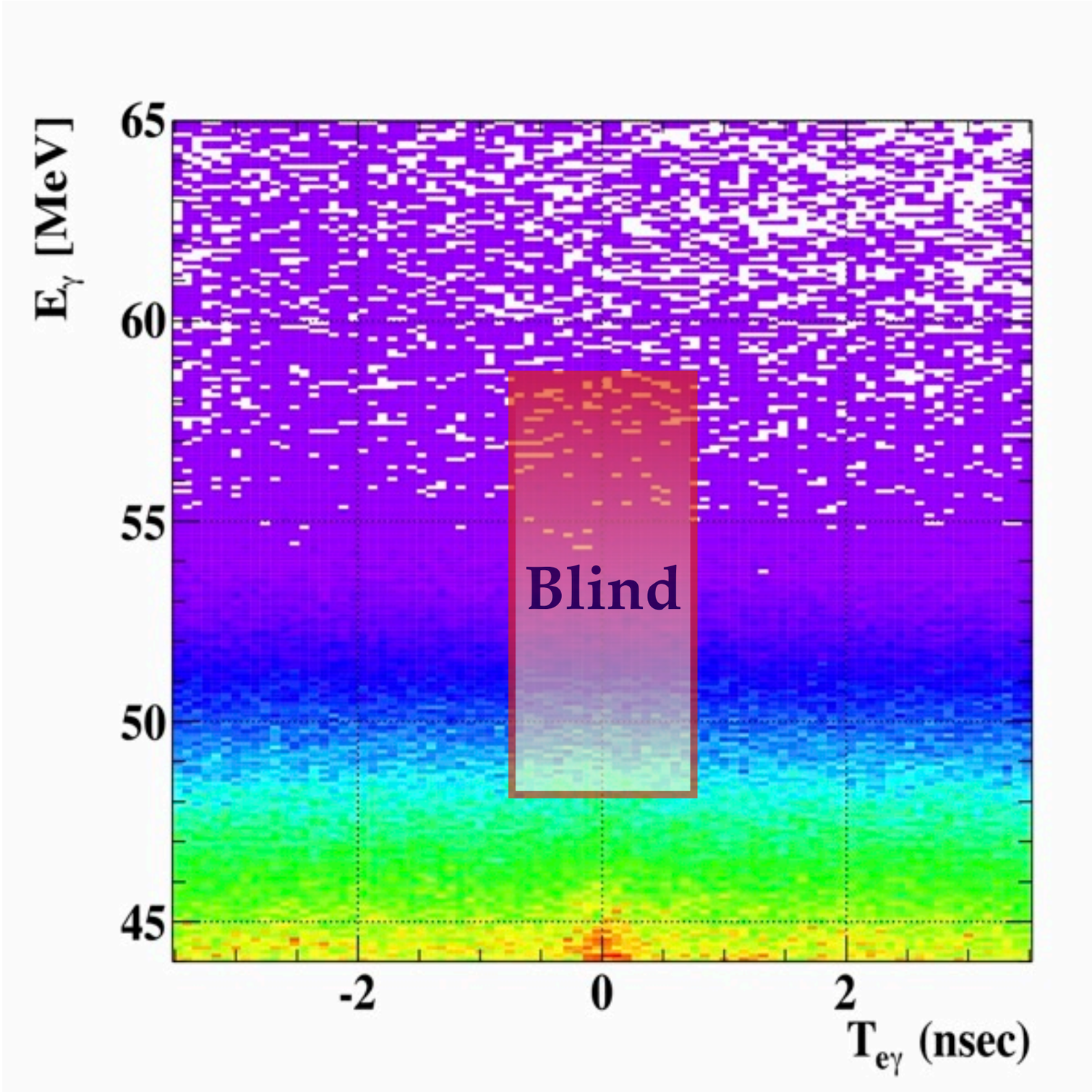

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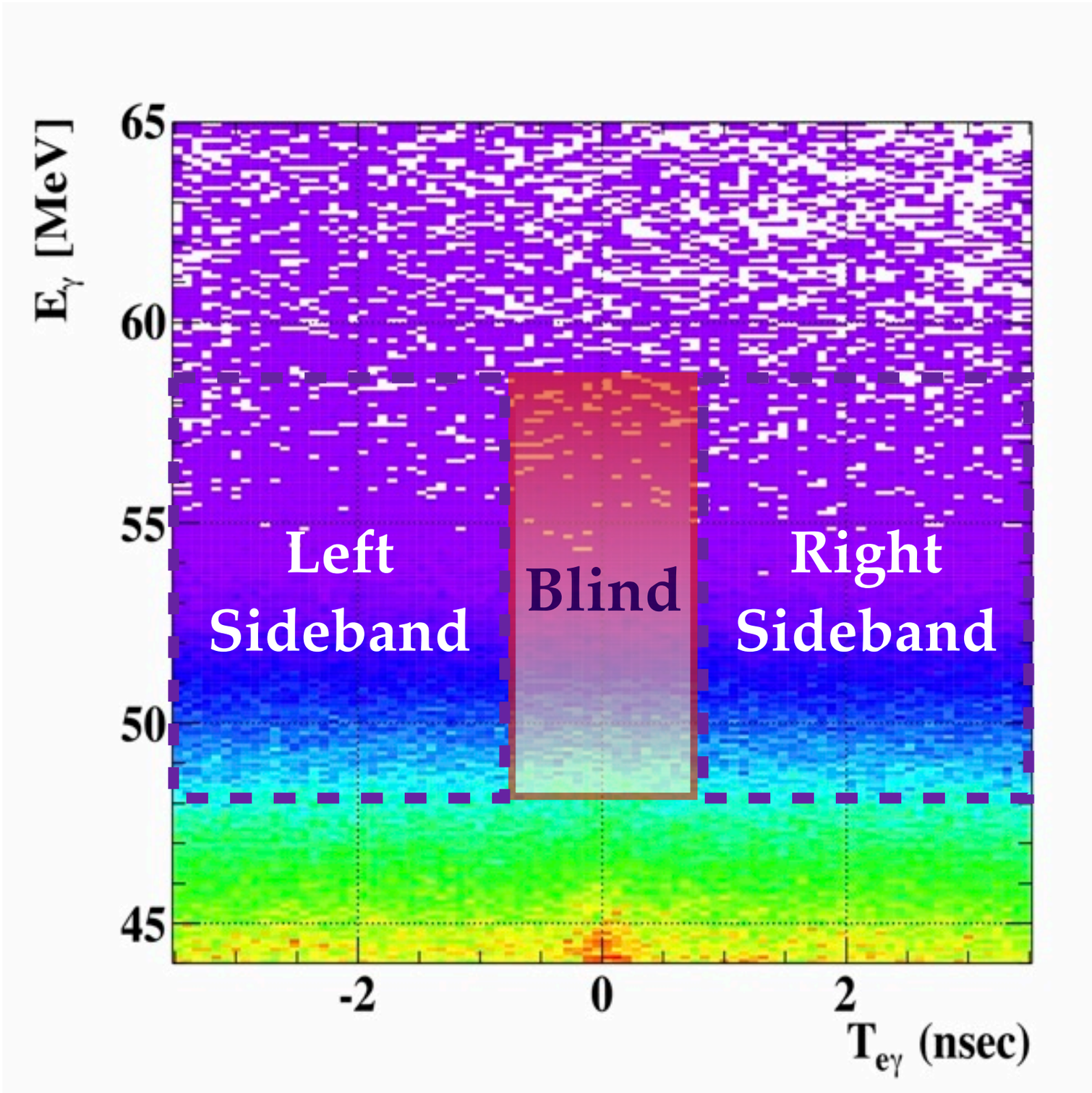

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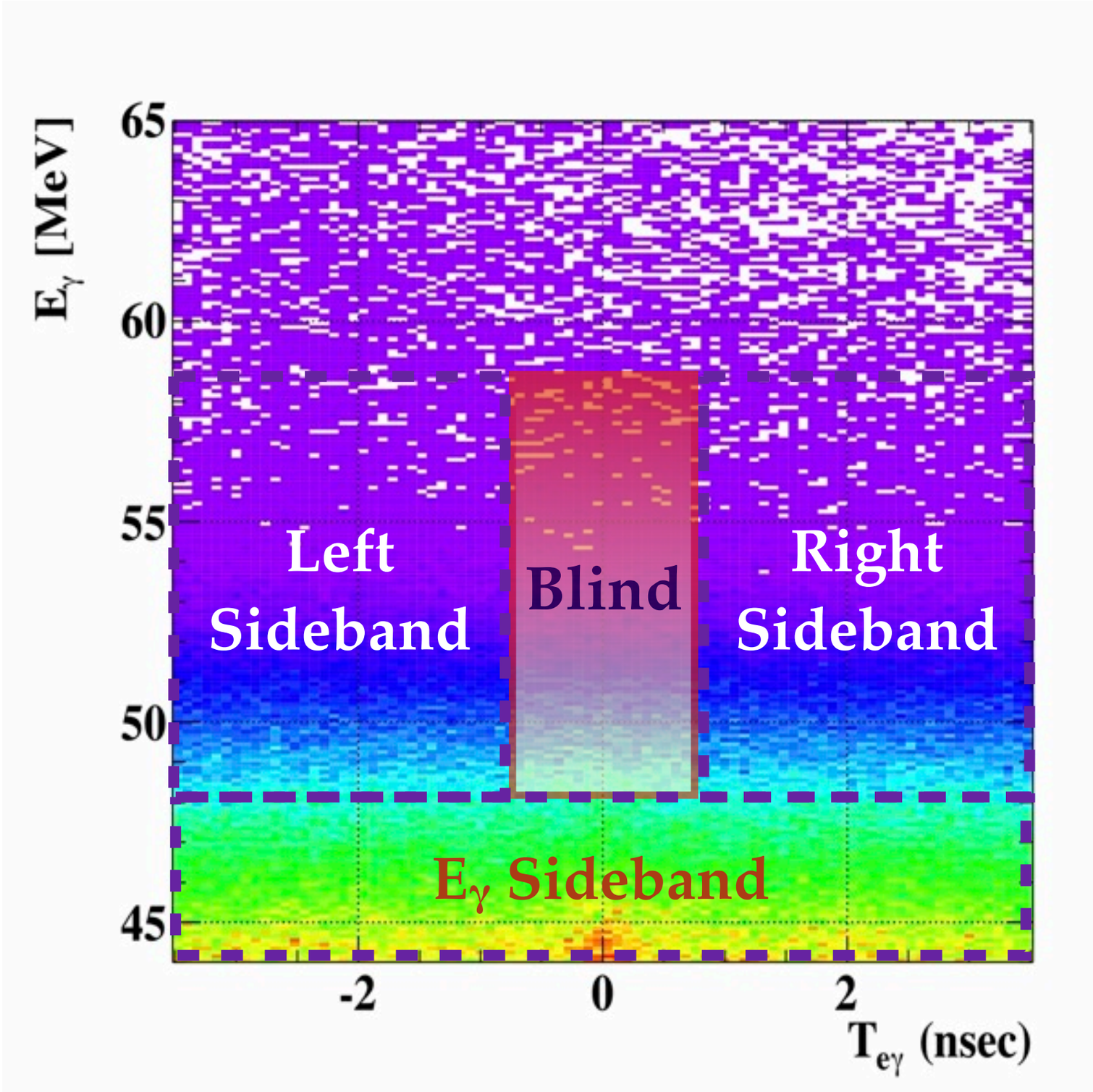


Likelihood Analysis

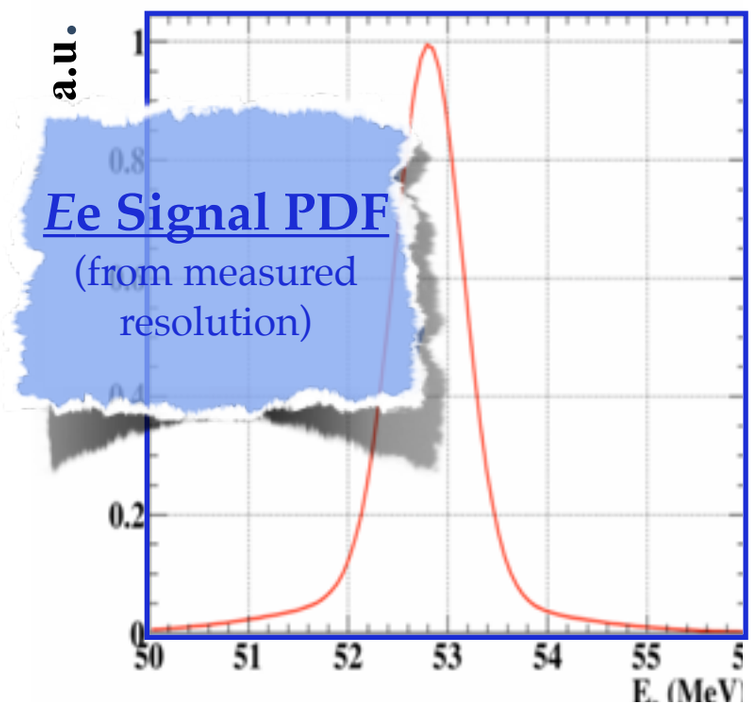
- Extended unbinned maximum likelihood analysis on number of events

$$\mathcal{L}(N_{sig}, N_{RD}, N_{BG}) = \frac{N^{N_{obs}} \mathrm{e}^{-N}}{N_{obs}} \prod_{i=i}^{N_{obs}} \left[\frac{N_{sig}}{N} S + \frac{N_{RD}}{N} R + \frac{N_{BG}}{N} B \right]$$

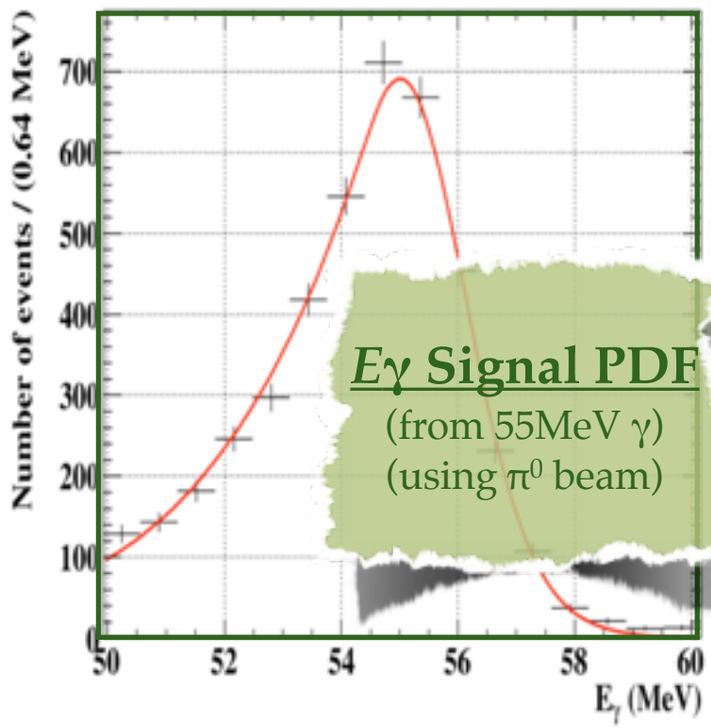
- Fit Parameters : # of events N_{sig}, N_{RD} and N_{BG} (N=N_{sig}+N_{RD}+N_{BG})
- Observables : Energy E_γ, E_e, Relative time $T_{e\gamma}$ and Opening angle $\theta_{e\gamma}$, $\phi_{e\gamma}$
- Probability Density Function for each event type (S, R, B)
  - PDFs are extracted from data
- Fit in Wide region (10σ)
  - Fit Signal and Background simultaneously
- Three Independent Analysis Tools

check, understanding
or find bug

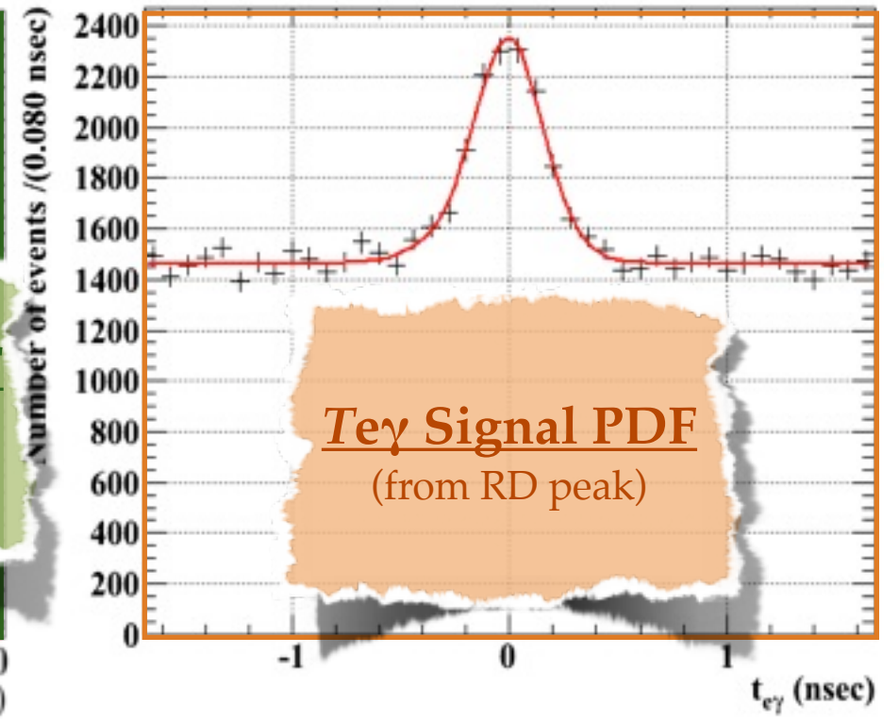
PDFs - Energies, Angles and Timing -



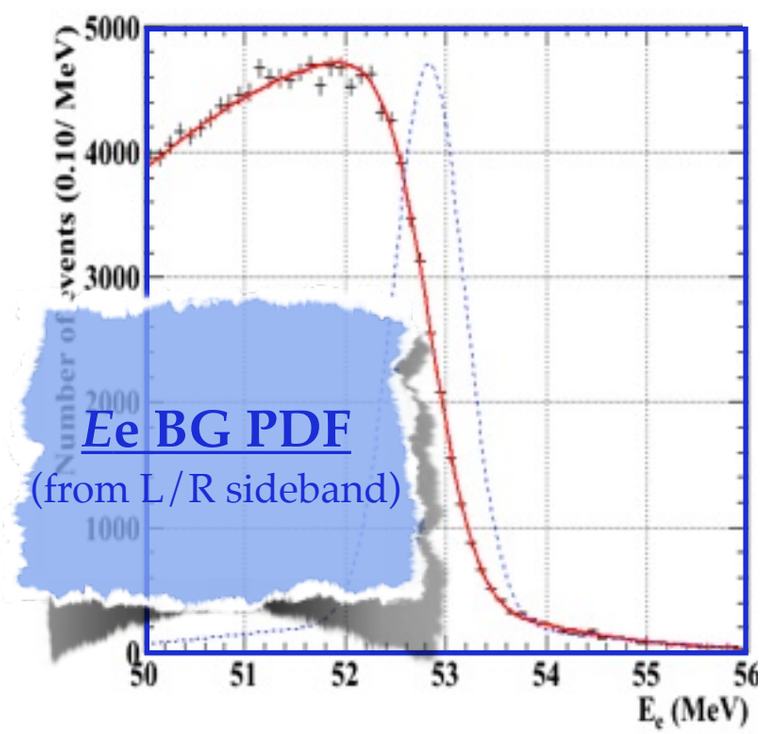
***Ee* Signal PDF**
(from measured resolution)



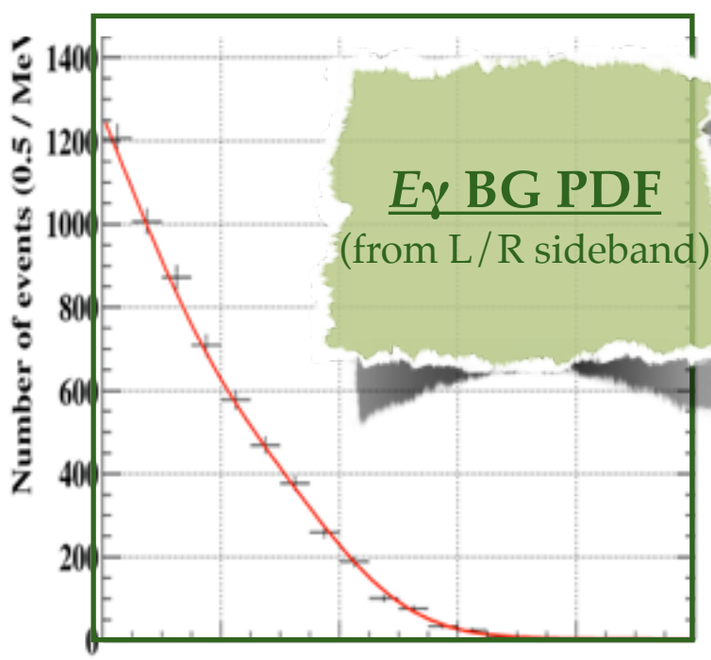
***Eγ* Signal PDF**
(from 55MeV γ)
(using π^0 beam)



***Teγ* Signal PDF**
(from RD peak)



***Ee* BG PDF**
(from L/R sideband)



***Eγ* BG PDF**
(from L/R sideband)

Relative Angle ($\theta_{e\gamma}$, $\phi_{e\gamma}$) PDF

Signal : from measured resolution

Background : from L/R sideband

Normalization - # of Muon Decay -

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

- # of Michel e^+ is counted during the physics run simultaneously by using the highly pre-scaled trigger.
- Advantage: Independent of beam-rate & in 1st-order insensitive to acceptances & efficiencies (ratios)
- Branching ratio is represented by obtained normalization factor "*k*" and the # of signal which will be obtained by the final analysis

$$\mathcal{B}(\mu^+ \to e^+\gamma) = \frac{k}{N_{sig}}$$

- Obtained normalization factor for 2009 data : **"*k*" = (1.0±0.1)×10^{12}**

Sensitivity (Preliminary at July-2010)

- Mean Upper Limit (90%C.L.) on ensemble of toy-MC experiments
  - Generate events with obtained PDFs assuming Null-Result Hypothesis
  - Repeat toy-MC experiments and calculate Upper Limit for each experiment in the same way as real data

Mean Sensitivity of Run2009 : 6.1×10^{-12} (90CL.)

(including no systematics)

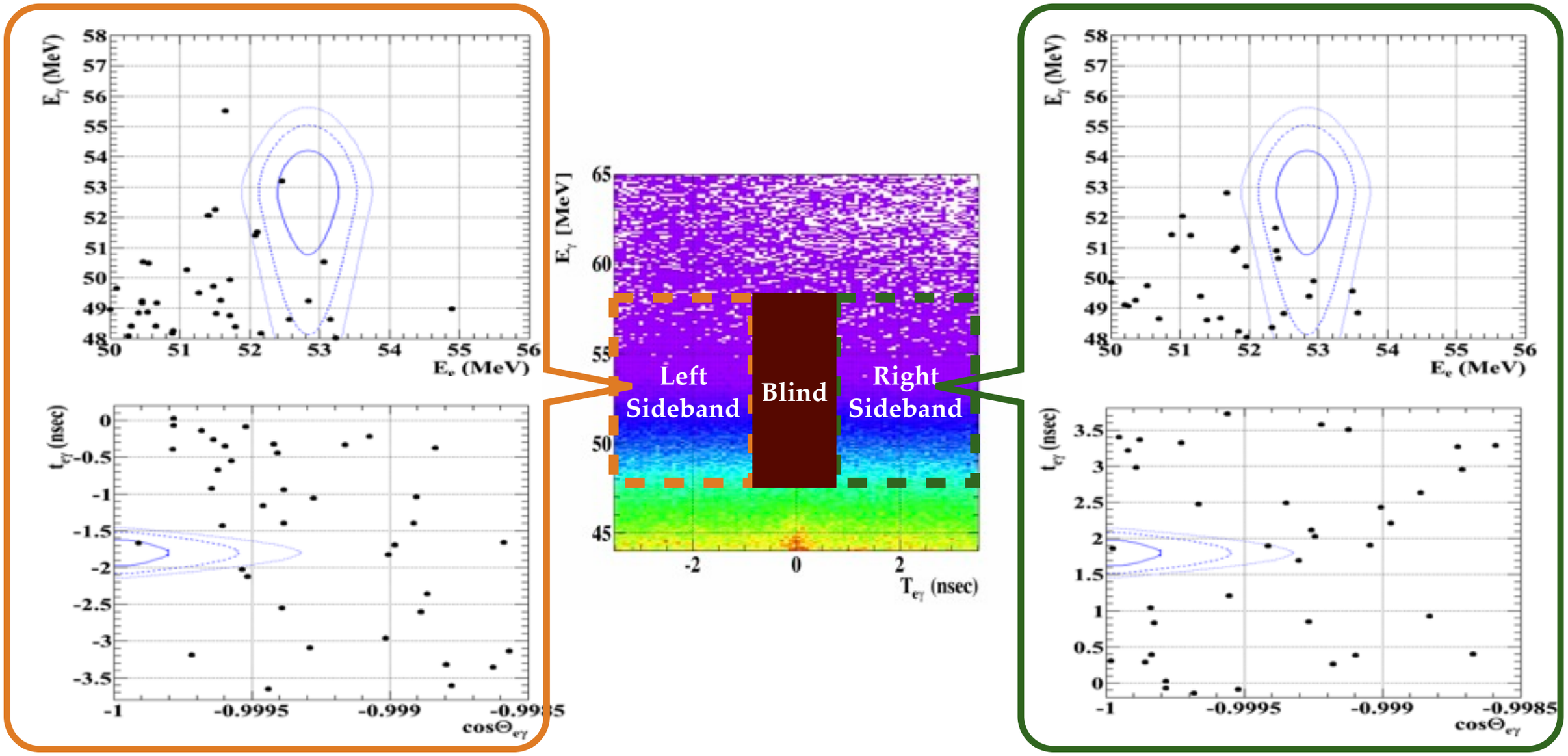
Sensitivity Run2008 : 1.3×10^{-11} (90CL.)

Present Upper Limit : 1.2×10^{-11} (90CL.)

- Signal-detection power of our likelihood analysis was also checked by dedicated toy-MC with mixed $\mu\rightarrow e\gamma$ signal events

Sideband Fits

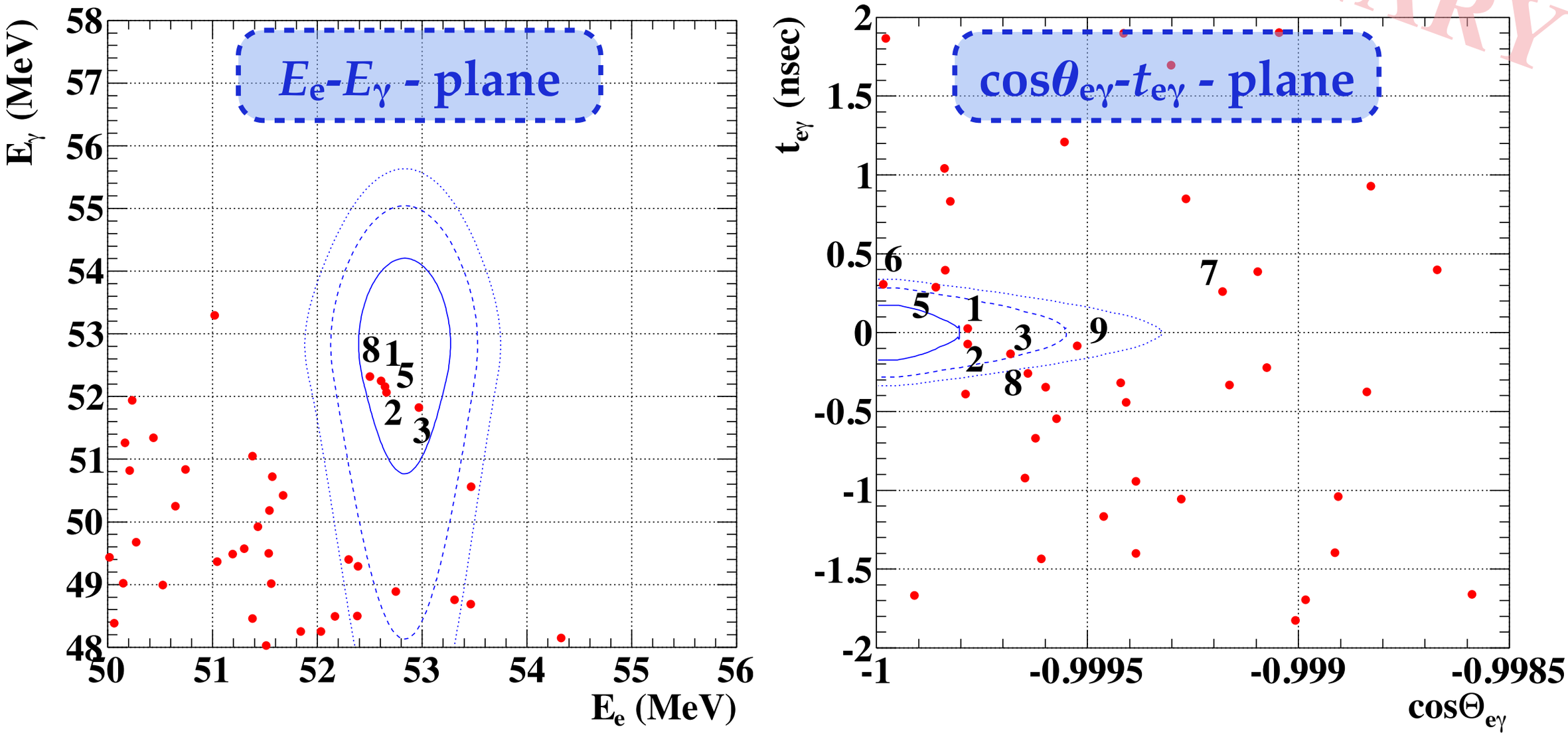
- To confirm the final analysis, Off-timing Sideband data is fitted



- Sideband-fit results : **BR UL Sensitivity < 4~6×10^{-12}**
- No Signal in Sideband /Sideband Fit is consistent with obtained Sensitivity

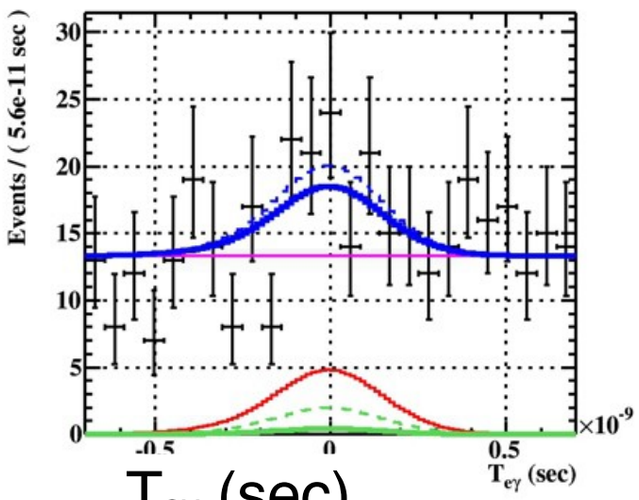
Event Distribution (after unblinding)

We opened the blind box on 06/July/2010

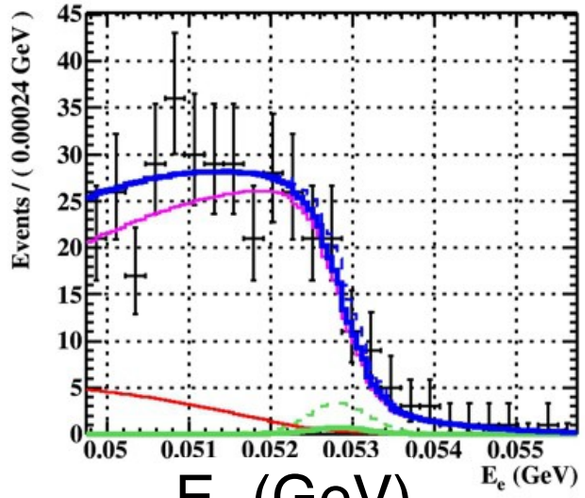


- Contours of the PDFs (**1σ, 1.64σ & 2σ**) are shown
- Same events in two plots are numbered correspondingly, by decreasing ranking in terms of relative signal likelihood ($S/(R+B)$)

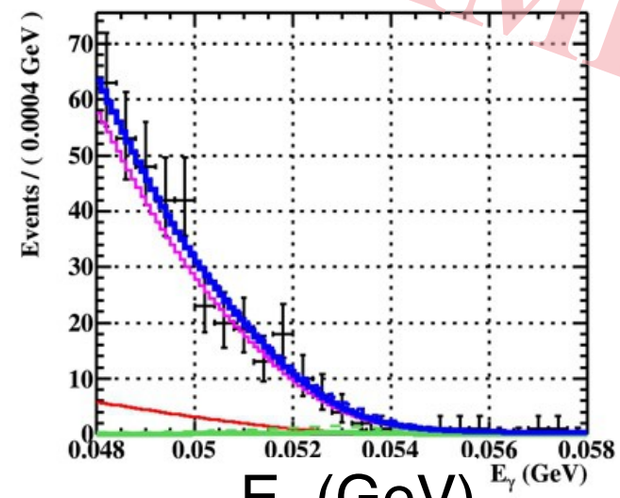
Likelihood-Fitting Preliminary Result



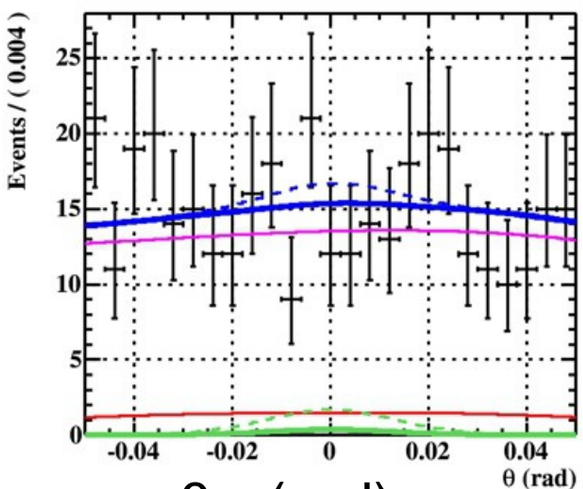
$T_{e\gamma}$ (sec)



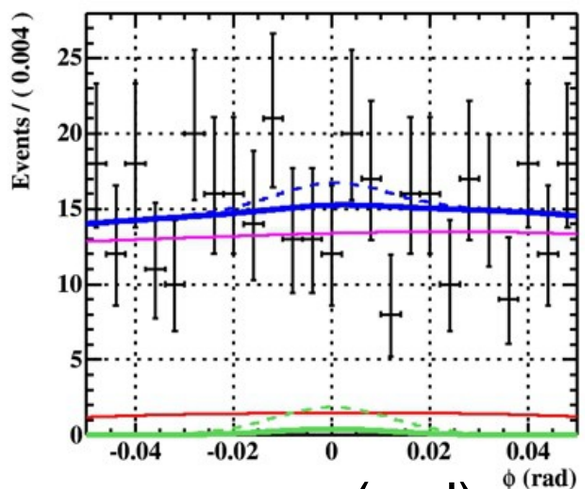
E_e (GeV)



E_γ (GeV)



$\theta_{e\gamma}$ (rad)



$\varphi_{e\gamma}$ (rad)

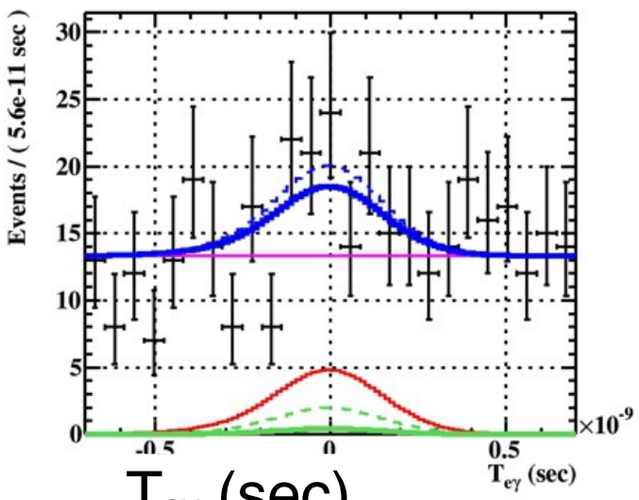
Accidental BG
RMD
Signal
Total

$N_{RMD} = 35\ (+24/-22)$
(Expected from sideband = 32±2)

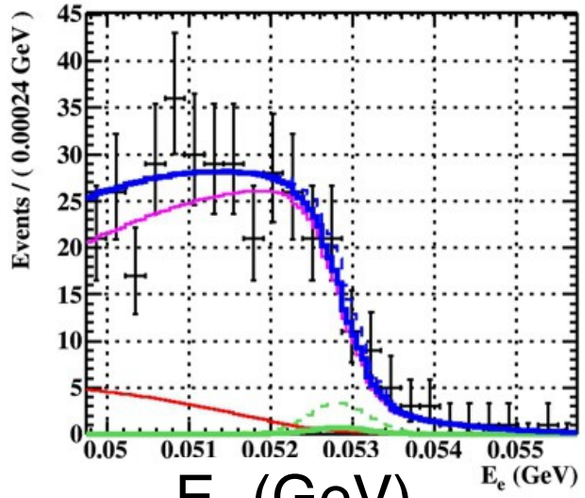
Dashed lines : UL(90CL.) of N_{sig}

N_{sig} best fit = 3.0

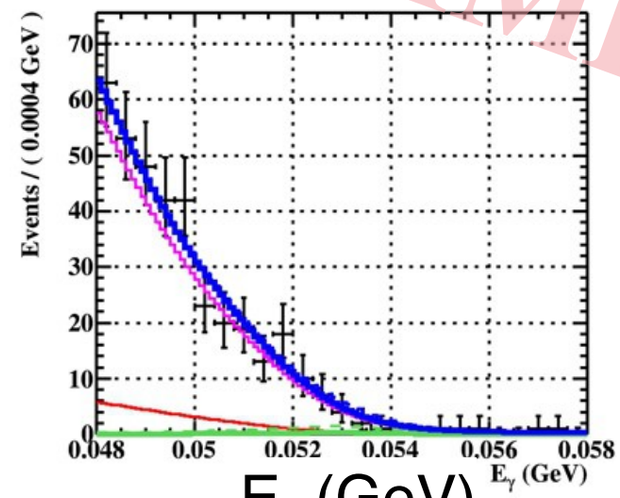
Likelihood-Fitting Preliminary Result



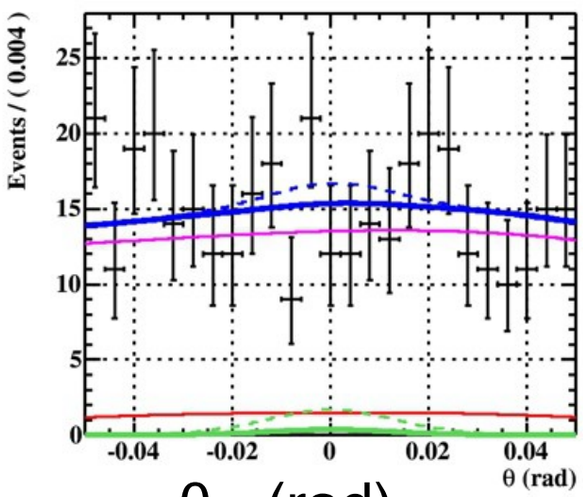
$T_{e\gamma}$ (sec)



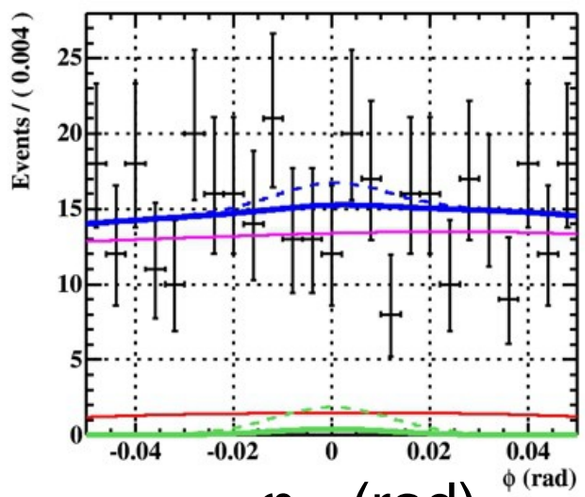
E_e (GeV)



E_γ (GeV)



$\theta_{e\gamma}$ (rad)



$\varphi_{e\gamma}$ (rad)

Accidental BG
RMD
Signal
Total

$N_{RMD} = 35\ (+24/-22)$
(Expected from sideband = 32±2)

Dashed lines : UL(90CL.) of N_{sig}

N_{sig} best fit = 3.0

- $N_{sig} < 14.5$ (90CL.) → $\mathcal{B}(\mu^+ \to e^+\gamma)^{2009} < 1.5\times10^{-11}$ **(90CL.)**
- **N_{sig}=0 is still in the 90% confidence region**
  - **Probability of this result due to a BG fluctuation is calculated to be 8 %**

Final Analysis of 2009 Run

- After the preliminary analysis was done, we obtained the further understanding of several sources of systematic uncertainties. Sensitivity becomes therefore better than the preliminary result.
- **Treatment of B-field**
  - Resulted in a better resolutions (e^+ momentum and angular resolution) and smaller systematic uncertainties
- **Relative alignment between photon and positron detectors**
  - Several measurements were carried out (Cosmic-ray alignment run / 17.6 MeV calibration gamma ray with putting small lead cubes in front of the photon detector / Am-Be source scan of front surface of photon detector)
  - Resulted in a **Smaller Uncertainty**
    - σ_p/p : 0.74 → 0.61 %
    - $\sigma_{\phi,\theta}$: 7.4, 11.2 → 6.1, 9.4 mrad

Analysis Updated, Improved.

Updated 2009 Result

Updated 2009 Result

- **All the Preliminary Results shown at ICHEP 2010 (Resolutions, Efficiencies, PDFs and Sensitivity, Upper Limit) are Updated.**

- **However, in view of the progress in ongoing 2010 data analysis, we decided not to publish the updated 2009 result alone but to <u>present the 2009 and 2010 results in a combined way in order to get a clearer picture of the origin</u> of what we observed in 2009.**

Prospects

- Run2010 finished in November 2010, **×1.9 times more data** statistics compared to 2009 run.
  - Better time resolution is expected thanks to digitizer upgrade
- Run2011 will be the first long term physics run
- Possible improvements:
  - Hardware
    - DAQ & Trig efficiency improvement w/ multiple event buffer
    - New HV modules to reduce noise
    - Positron detection efficiency improvement w/ thinner cables
  - Analysis
    - Software noise filtering on DC signal, Use scintillation fibre data, Calibration with monochromatic positron beam, Improvement of B-field systematics, Time reconstruction, Improvement of energy reconstruction algorithm on Photon detector.

Summary

- **Charged Lepton Flavour Violation** is very attractive to explore the new physics.
  - In particular, **μ→eγ** is the most sensitive probe and has the longest history.
- **MEG experiment** started in 2008 at PSI and is currently running in order to discover the first event of **μ→eγ**.
  - World Strongest DC Muon Source, Specially dedicated detectors.

- ***Preliminary*** results from Run2009,
  - Sensitivity : 6.1×10^{-12} / UL(90CL) : 1.5×10^{-11} (Null result is still within 90CL region.)

- 2009 Analysis is to be Updated due to analysis improvements.
- Run2010 is finished and currently being analyzed.
- Combined Result 2009+2010 (Sensitivity ~1.5×10^{-12}) will be published this summer.

- Run2011 (first long-term run) is now starting, wishing to have more statistics.