Experimental search for $\mu^+ \to e^+\gamma$ present and future

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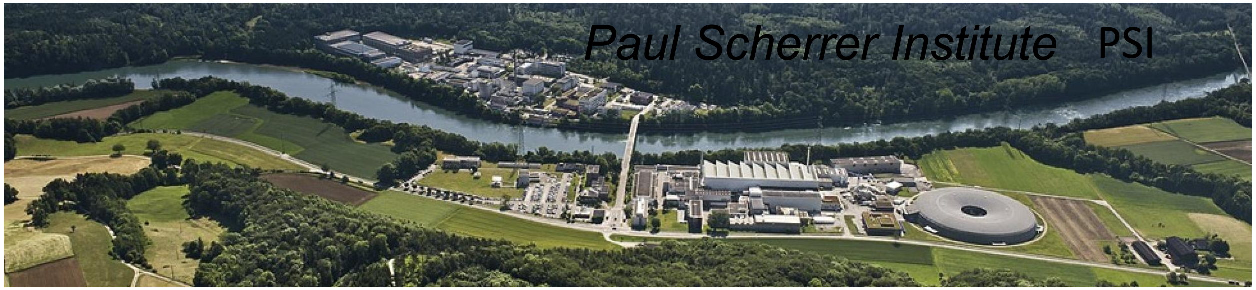
On behalf of MEG and MEG-2 collaborations

RENCONTRES DU VIETNAM
Quy Nhon, 31.07.2014

MEG HOME



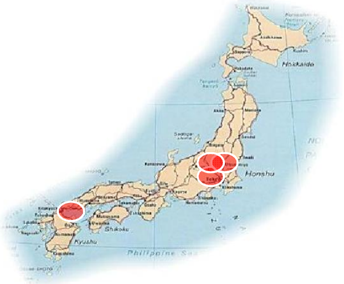
Switzerland
PSI, ETH-Z

Russia
BINP, Novosibirsk,
JiNR, Dubna

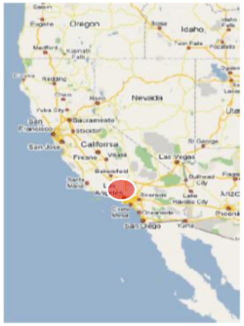
MEG Collaboration
some 65 Physicists
5 Countries, 14 Institutes

Italy
INFN + Univ. :
Pisa, Genova,
Pavia, Roma I
& Lecce

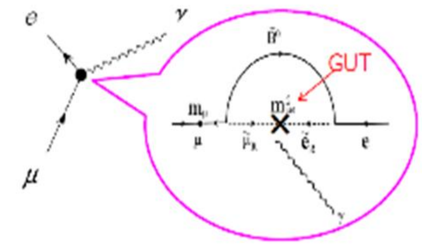
Japan
Univ.Tokyo, KEK
Waseda Univ.,
Kyushu Univ.



USA
University of
California Irvine
UCI



Why $\mu^+ \rightarrow e^+\gamma$



- CLFV Forbidden in SM (background: $Br(\mu^+ \rightarrow e^+\gamma) < 10^{-45}$)
- So far, no CLFV signal has been observed.
- Many new physics beyond SM (e.g. SUSY, Extra dimensions etc.) predict observable Br (10^{-14} — 10^{-11})
- Discovery will be an unambiguous evidence of new physics.

- Complementary search of new physics,
  - LHC Run 2
  - New experiments to search for other muon channels ($\mu \rightarrow e$ convertion, $\mu \rightarrow eee$)

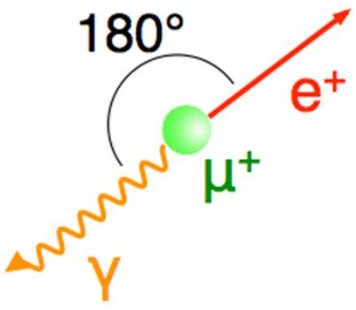
Signal and backgrounds

Signal μ+ decay at rest

52.8 MeV (half of M_μ) (E_γ,E_e)

Back-to-back ($\theta_{e\gamma}$,$\varphi_{e\gamma}$)

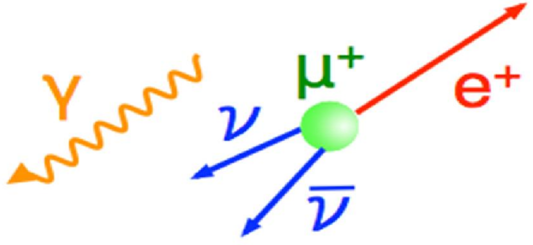
Timing coincidence ($T_{e\gamma}$)



Accidental background (dominant)

Michel decay e^+ + random γ

Random timing, angle, E < 52.8MeV

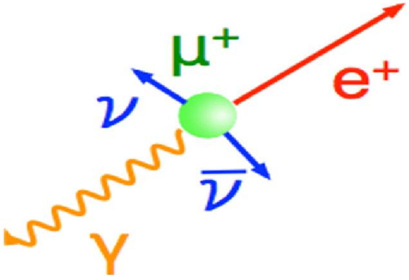


Radiative muon decay

$\mu^+ \rightarrow e^+\nu\nu\gamma$

Timing coincident, not back-to back,

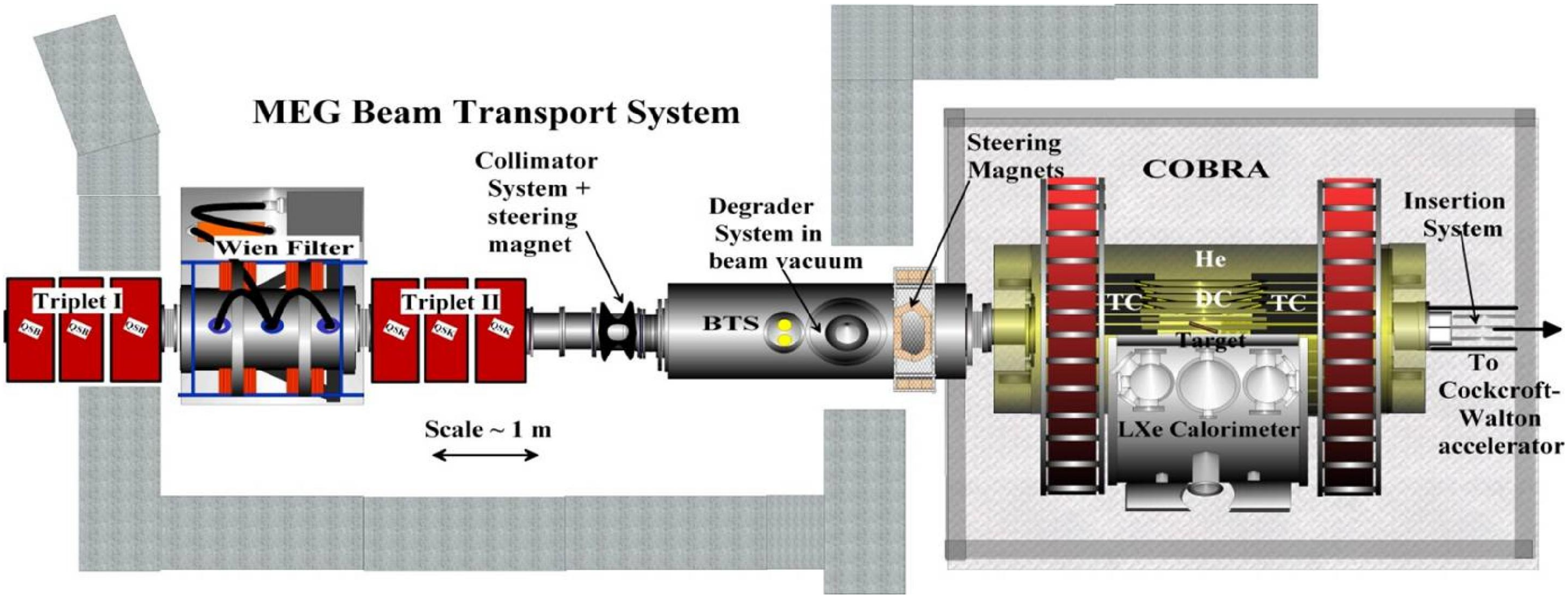
E <52.8MeV



Key points of the experiment

- high quality & rate stopped μ-beam ⇨ surface muon beam (10^8/s), $(\bar{E} \times \bar{B})$ Wien filter, SC-solenoid+degrador
- e^+ magnetic spectrometer with excellent tracking & timing capabilities ⇨ COBRA magnet, DCs & TCs
- photon detector with excellent spatial, tming & energy resolutions ⇨ 900 litre LXe detector (largest in world)
- Stable and well monitored & calibrated detector ⇨ Arsenal of calibration & monitoring tools

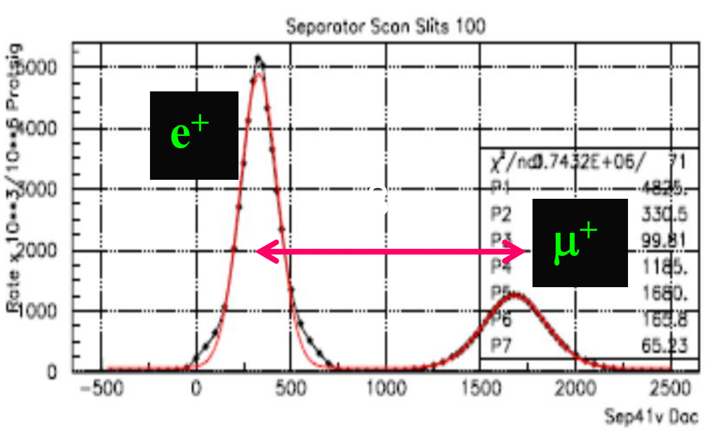
Layout of the experiment



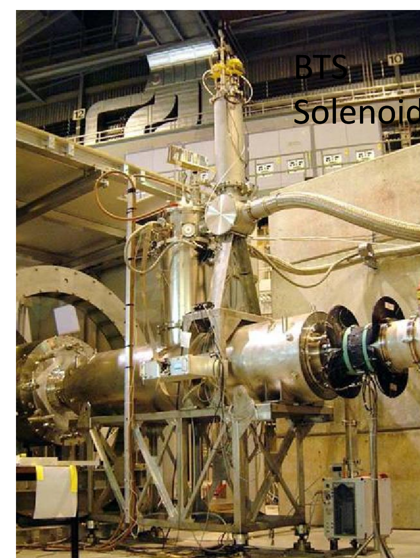
Beam line

- High-intensity DC surface muon beam - πE5+MEG
  ⇨ capable of > 10^8 μ^+/s at 28 MeV/c + ~10^9 ~beam e^+/s
- "pure" muon beam - Wien filter + Collimator system
- ⇨ μ-e separation at collimator >7.5σ (12 cm)
- Small beam-spot + high transmission – BTS
  ⇨ focus enhancement, beam σ~10 mm at target
  ⇨ focus at centre BTS – degrader
- Thin stopping target + minimal scattering – end-caps
  ⇨ 18 mg/cm^2 CH_2 target + He COBRA environment
  + remote Target & End-cap insertion system

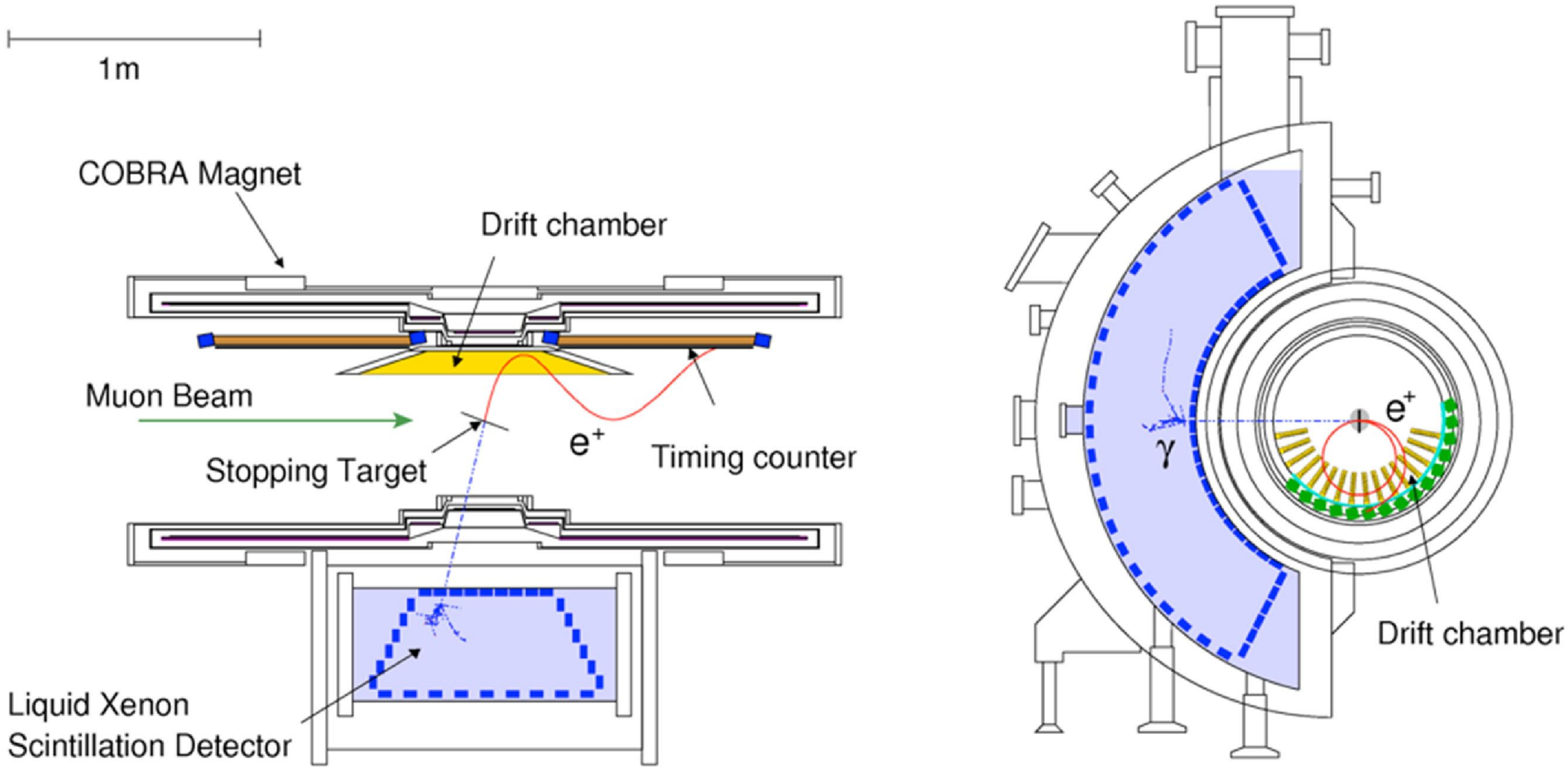
collimator



Target



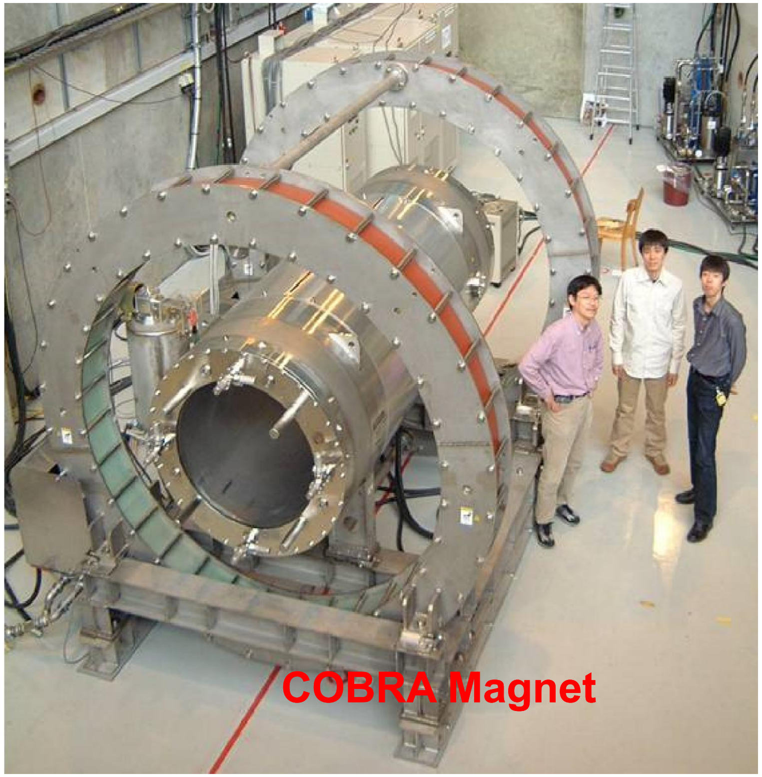
Layout of the detector



The important part – gradient field COBRA magnet:
tracks radius is independent on incident angle at 52.8 MeV/c

Positron spectrometer

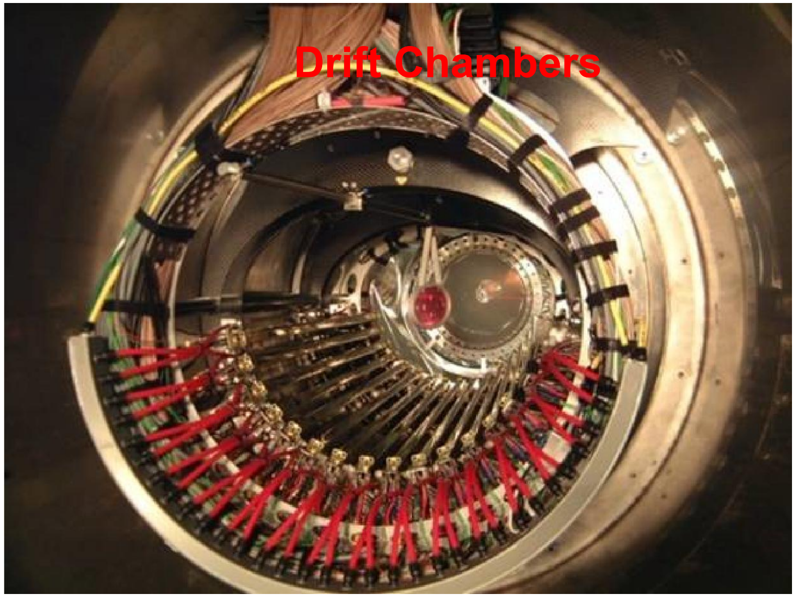
- **SC COBRA Magnet**
- Gradient Bfield (1.27-0.5) T
  CΟnstant Bending RAdius
- 0.2 X_0 fiducial thickness
  γ-transparency 95%
- NC Compensations coils
  reduce Bfield at Calorimeter
  < 5mT at PMT positions



Positron spectrometer

- **Drift Chambers**

- 16 radial, staggered double-layered DCs
- each 9 cells with "Vernier" cathodes
- 50:50 He/C_2H_6
- Ultra-thin $2 \cdot 10^{-3} X_0$ along e^+ path



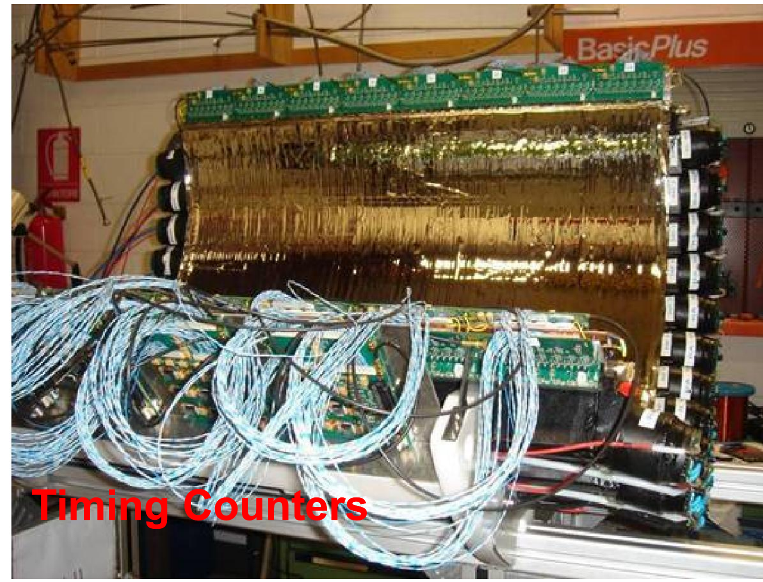
Momentum resolution $<\sigma p/p)$ 6‰
Angular resolution (e^+) ϕ ~7 mr
θ~ 10 mr

Positron spectrometer

- **Timing Counter Arrays**

- 2 arrays of each –
  15 axial scintillator bars
  BC404 e^+ impact point + timing
  intrinsic $\sigma_t \approx$ 70ps over 90 cm

- 256 orthogonal radial
  scintillating fibres
  BCF-20 + APDs
  triggering (angular matching)



Calorimeter

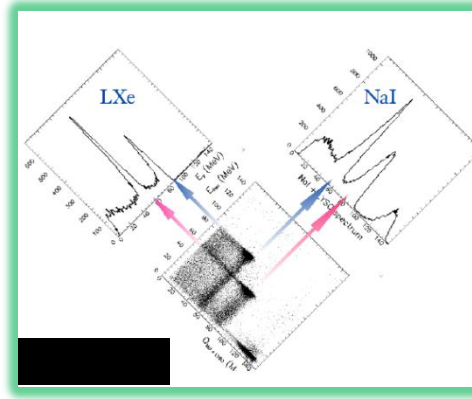
- Largest LXe calorimeter in the world 900 litres $\Delta\Omega/4\pi = 10\%$
- Fast response (4, 22 ns) - minimize “pileup”
- Large light-yield ~80% NaI
- high density, short X_0
- Homogeneous medium uniform response,
- no segmentation needed
- Sensitive to impurities at sub –ppm level (mainly H_2O, O_2, N_2)
- Scintillation light used for shower reconstruction λ= 175 nm
- 846 PMTs wall-mounted inside LXe-volume
  signals digitized @ 1.6 GHz

Energy resolution $<\sigma E/E>$ < 2% at 52.8 MeV
Timing resolution = 67 ps
Position resolution (X,Y) 5 mm, (depth) 6 mm
γ-efficiency 59% (ε_{Detect} x ε_{Anal})

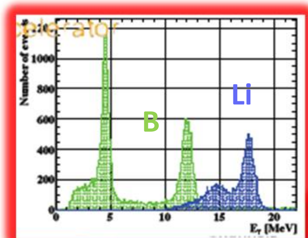
Calibration and Monitoring

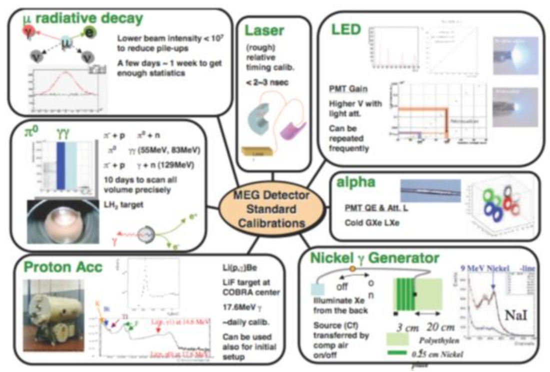
Crockcroft-Walton

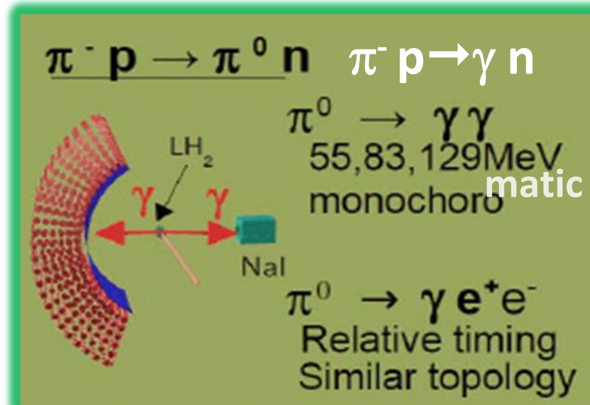
PMT: Gain, QE,
LXe: Light-yield , Attenuation-length
Calorimeter: Energy-scale
Calo.+TC: Relative detector timing, Alignment
e.g. αs, LED, $\pi^- p \rightarrow \pi^0 n$ or γn, "Dalitz-decay,
RMD, protons from C-W accelerator on $Li_2B_4O_7$,
n-generator+ Ni, cosmics, Mott e^+ beam



Pion CEX on LH_2

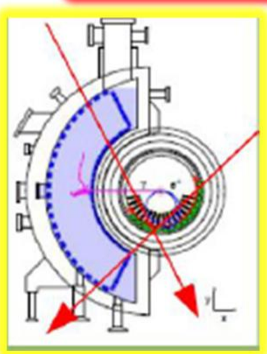




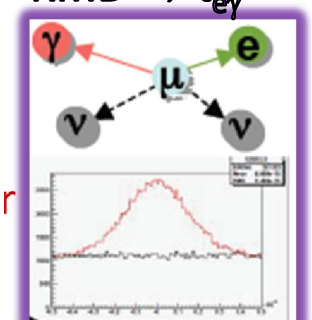


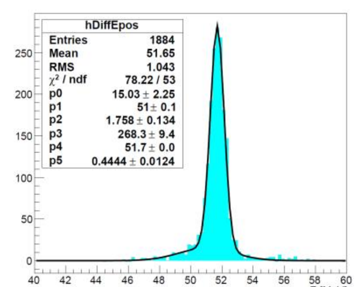
Radiative Muon Decay
RMD $\rightarrow t_{e\gamma}$

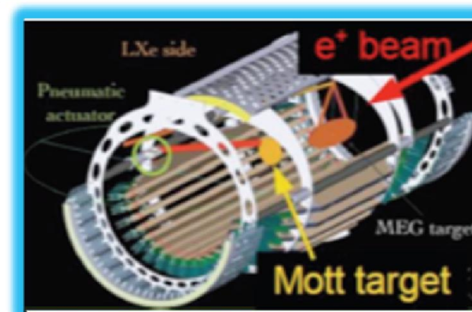
Mott mono.
e+ scattering



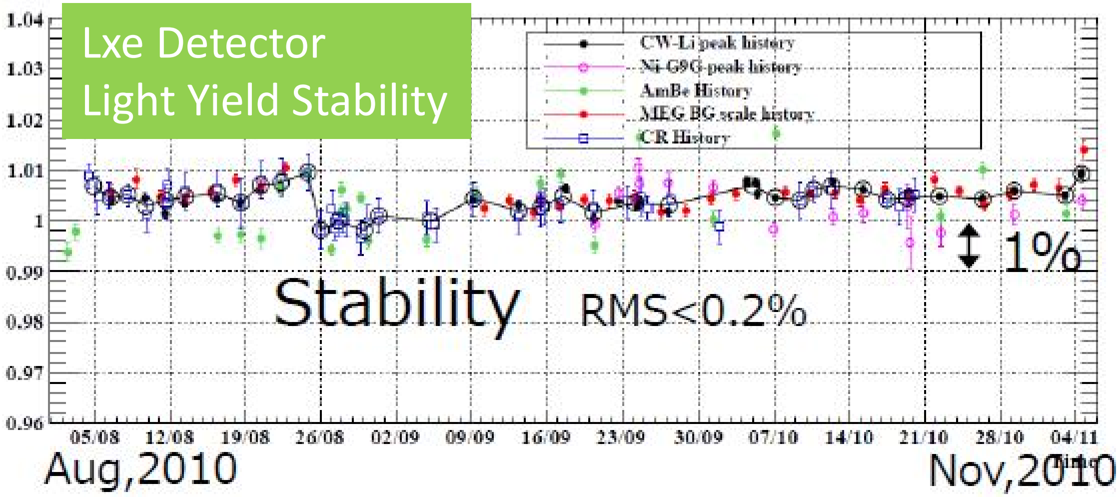
Cosmic rel.
alignment LXe
+ spectrometer

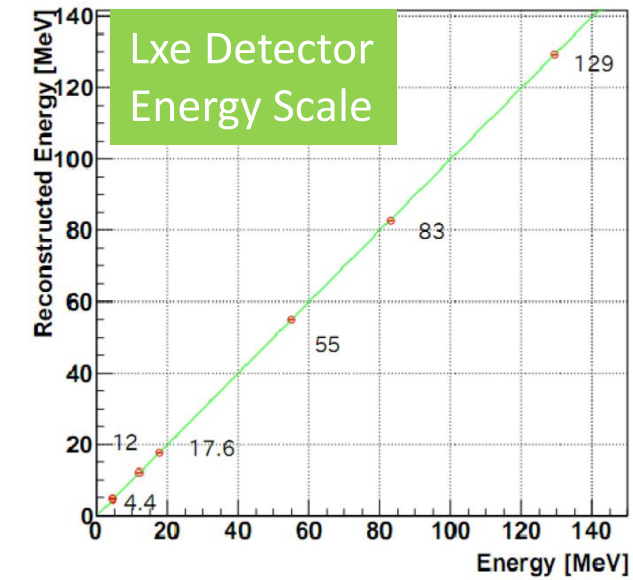


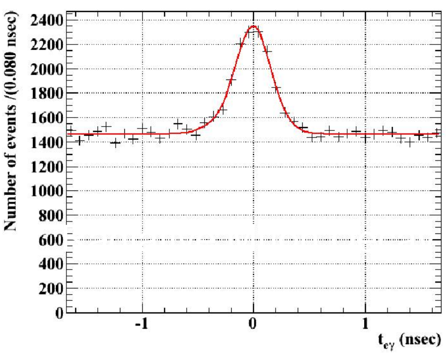




Detector Stability







<u>Detector Stability permanently monitored</u>

- Light Yield stable to < 1% rms < 2‰
- Photon energy-scale cross-checked using BG-spectrum from LXe side-bands
- Timing stability checked using radiative muon decay events (RMD) taken simultaneously during run (multi-trigger)

$T_{e\gamma}$ stable ~ 15 ps over whole run

Analysis Principle

Blind likelihood Analysis:

Data Sample defined by 5 Observables:

E_{e^+}, E_γ, $\theta_{e\gamma}$, $\phi_{e\gamma}$, $T_{e\gamma}$

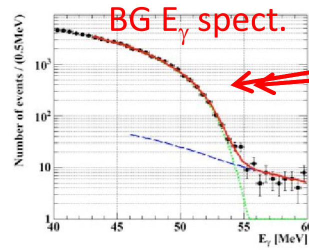
Analysis-box for Likelihood fit
Defined in 5D-space as:

Analysis Box vs 5 Observables

(~10σ wide windows cf. res.)

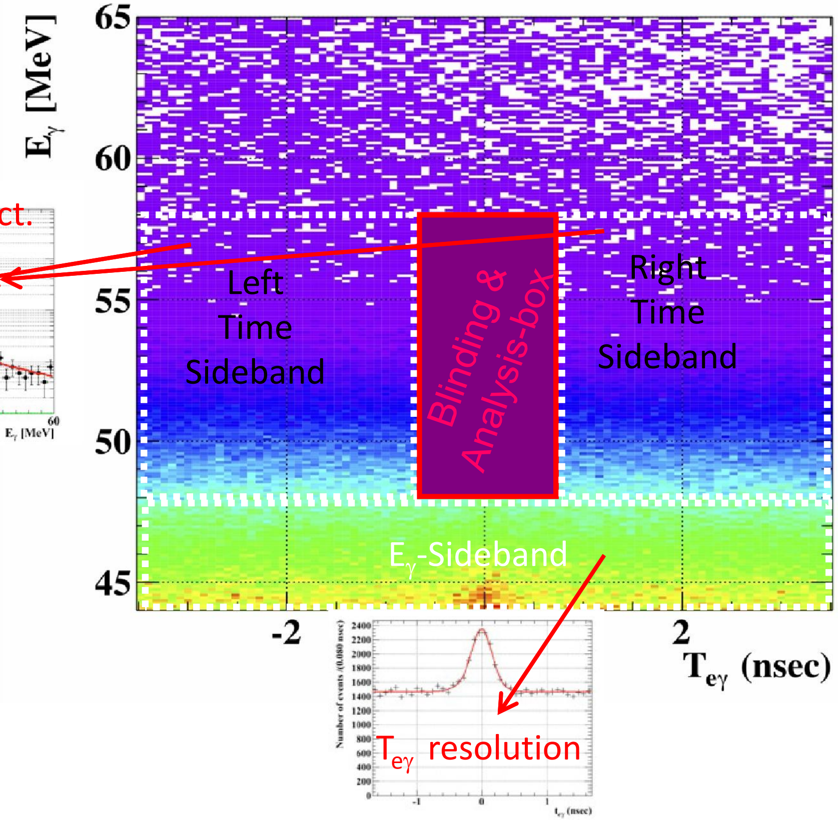
- $48 \leq E_\gamma \leq 58$ MeV
- $50 \leq E_e \leq 56$ MeV
- $|T_{e\gamma}| \leq 0.7$ ns
- $|\phi_{e\gamma}|$, $|\theta_{e\gamma}| \leq 50$ mrad

(angles between e^+ & flipped γ vec.)



Analysis box
"Blinded" in the
E_γ vs $T_{e\gamma}$ plane
during calibration
and
optimization of
physics analysis

Analysis Region shown in 2D
(No Selection)



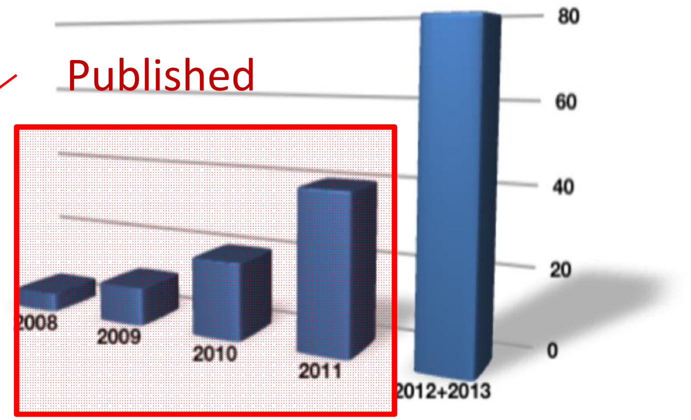
!!! Time and E_γ sidebands Important Ingredient to Analysis also angular sidebands introduced

⇨ Since our background is dominated by "accidentals" the side bands can be used to estimate the background in the signal region, check of experimental sensitivity & measure the timing resolution using RMD in the E_γ-sideband

Results

Phy. Rev. Lett. 110, 201801 (2013)

Data taking finished at 31.08.2013
Statistics is doubled compare to published



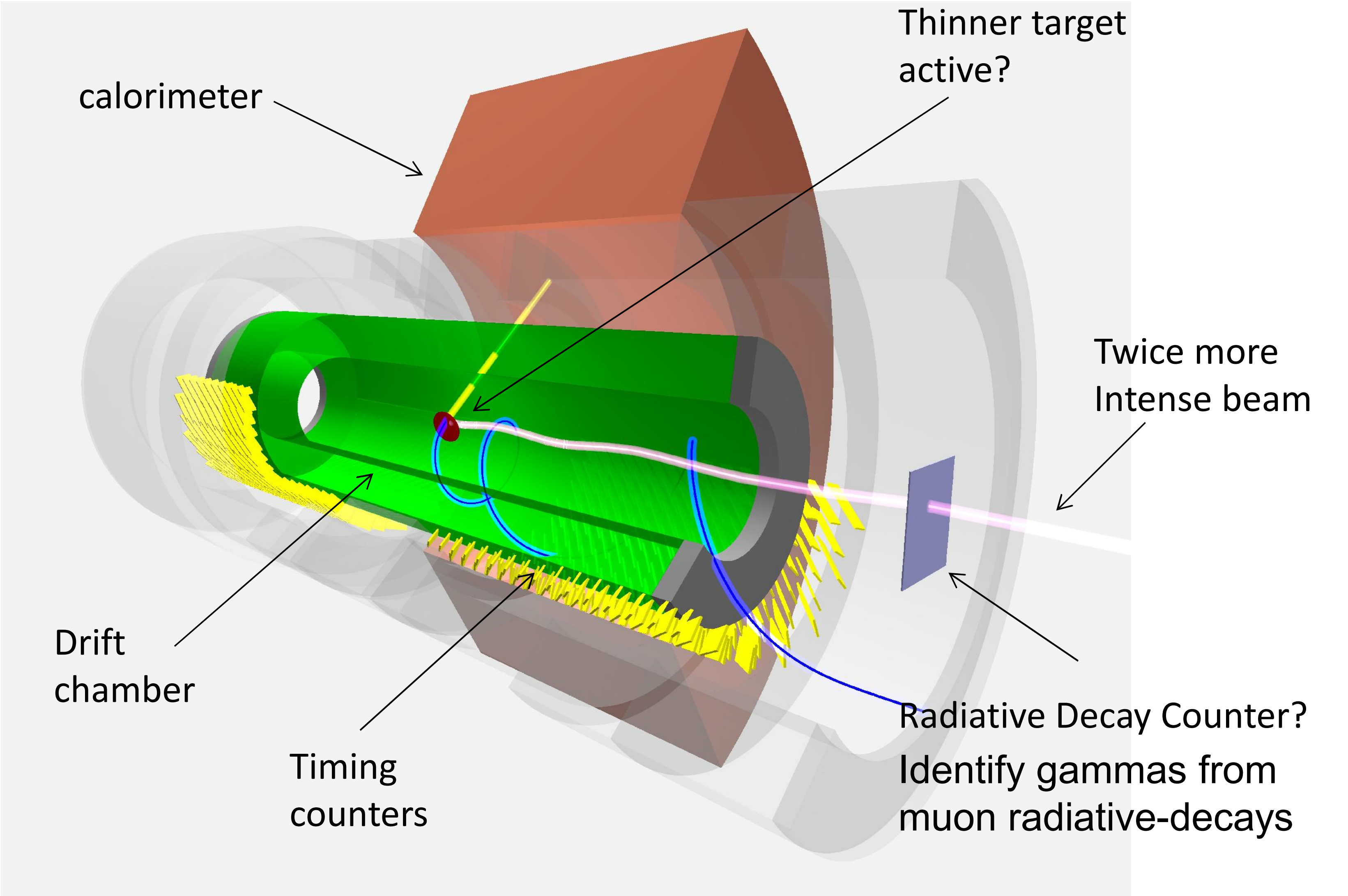
year	Nstop μ, $x10^{13}$	Sensitivity, $x10^{-13}$	Br, Upper limit (CL 90%), $x10^{-13}$
2009+2010	17.5	13	13
2011	18.5	11	6,7
2009+2010+2011	36.0	7.7	**5.7** (20 times better
All data (expected)	~80	~5	than MEGA)

Final result of analysis is expected by the end of 2014

MEG-2

- **Goal to reach sensitivity in order of magnitude better than MEG:**
  - **More statistics (double beam rate)**
  - **Improve efficiency ~2 and background rejection ~30 (*upgrade of LXe calorimeter, new cylindrical Drift Chamber, new Timing counters*).**

Layout of MEG-2 detector



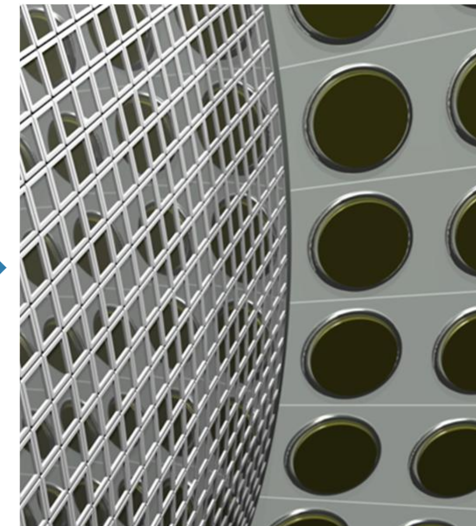
Calorimeter upgrade

- Improved layout of PMTs
- Replace 2" PMTs on inner face with newly developed VUV-sensitive SiPMS

Present

2 inch PMT
216 ch

Upgraded



computer graphics

12×12 mm2 MPPC
~ 4000 ch

	Present	**Upgraded**
Energy resolution [%]	2.4 / 1.7	1.1 / 1.0
Position resolution [mm]	5 / 5	2.6 / 2.2
Detection Efficiency	63%	69%

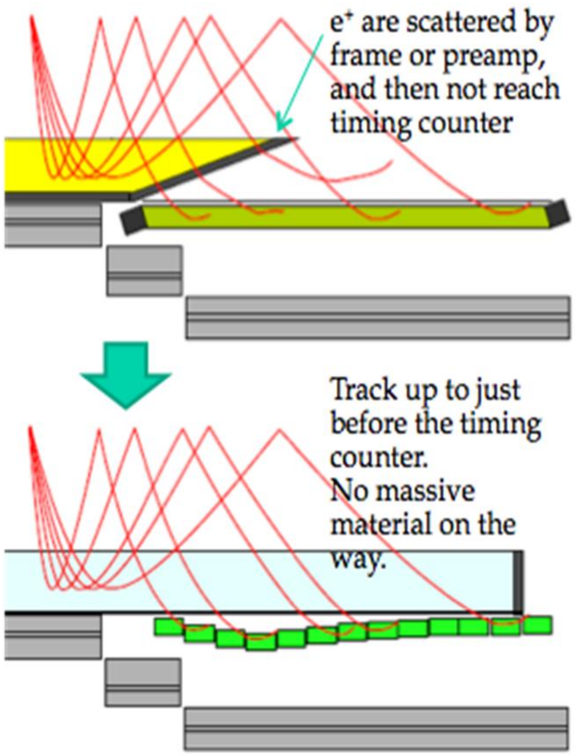
Energy resolution: shallow / deep events (d = 2cm)

Position resolution: horizontal / vertical

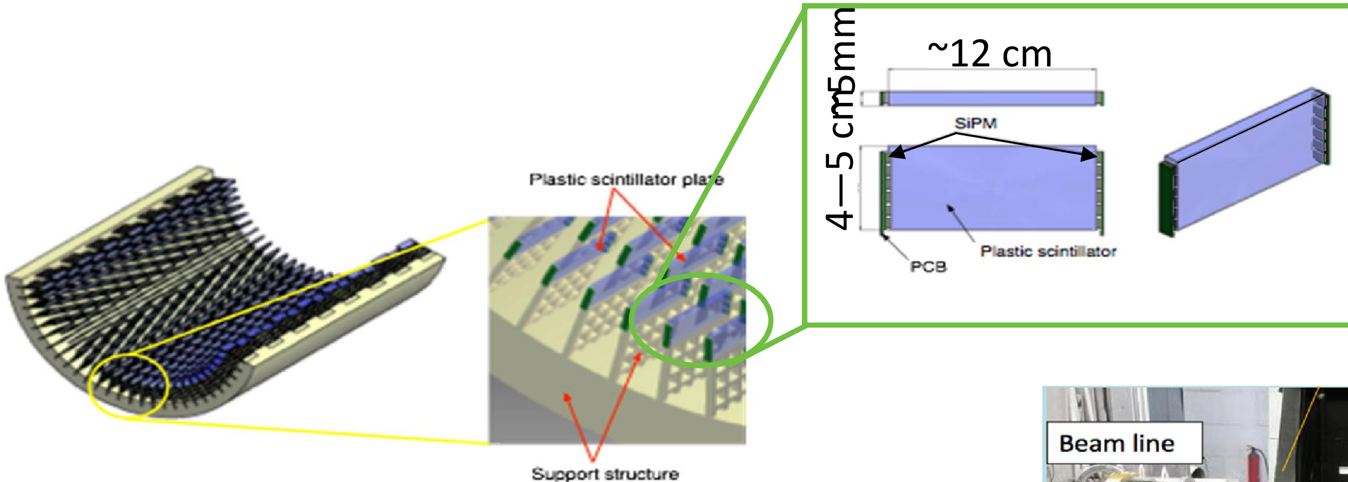
Factor 2 better energy and position resolutions
10% higher efficiency

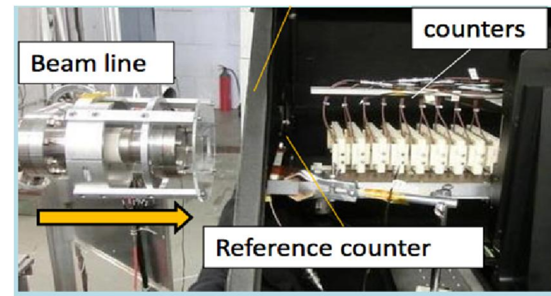
New drift chamber

- Gas volume
  - Lower Z gas mixture (85% He + 15% iso-butane)
  - Unique 2m-long chamber-gas volume, improved transparency to timing-counters.
    - Double the detection efficiency
    - Improve the Time-Of-Flight error down to 10 psec
- Wire configuration
  - Stereo-angle configuration for longitudinal position
  - Finer granularity (7 mm cell) and higher multiplicity (15 → 60 hits per track)
  - Single hit spacial resolution of 120~μm

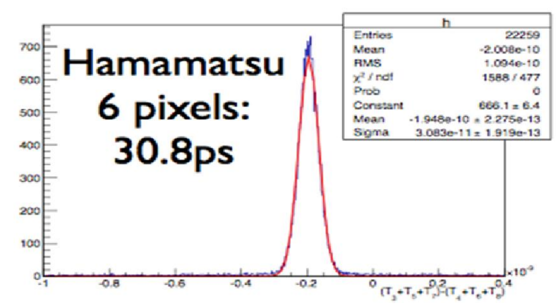


New timing counters





- Many small plastic counters.
- Six SiPMs are directly attached on both sides for high light-collection efficiency.
  - SiPMs on the same side are attached in series to read with a single channel.
- In average, ~8 counters hit by a signal positron.
  - 30 psec time resolution by averaging the hit-times

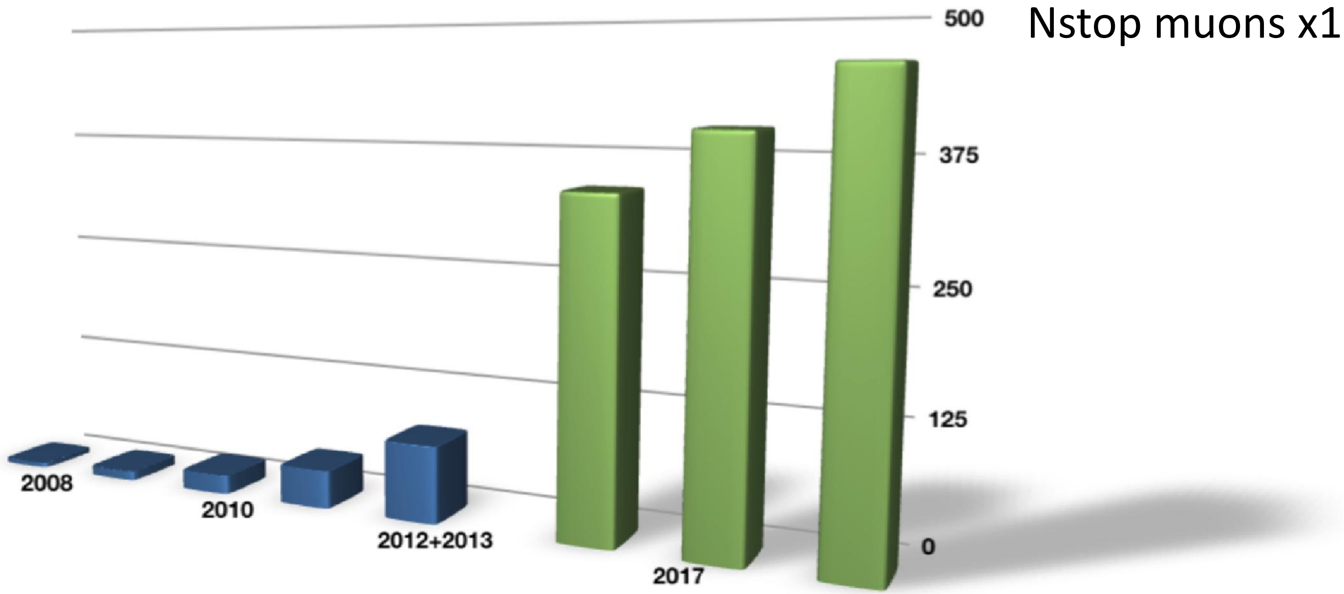


Current status

- Xenon calorimeter
  - Development of LXe MPPC is finished. PDE of 15% is achieved for LXE light. Production of 600 MPPCs for a prototype is done.
  - Mass test of MPPCs and the performance study of the calorimeter will be done with a prototype detector.
- Drift chamber
  - Geometrical parameters have been fixed.
  - Prototype R&D on-going (aging, resolution).
  - Good (~110 μm) spacial resolution for cosmic-rays was confirmed
- Timing counters
  - Prototype R&D on-going. 30 ps resolution is achieved at test beam.

GOAL- start physical run at 2016

Near future



Nstop muons $x10^{13}$

Conclusion

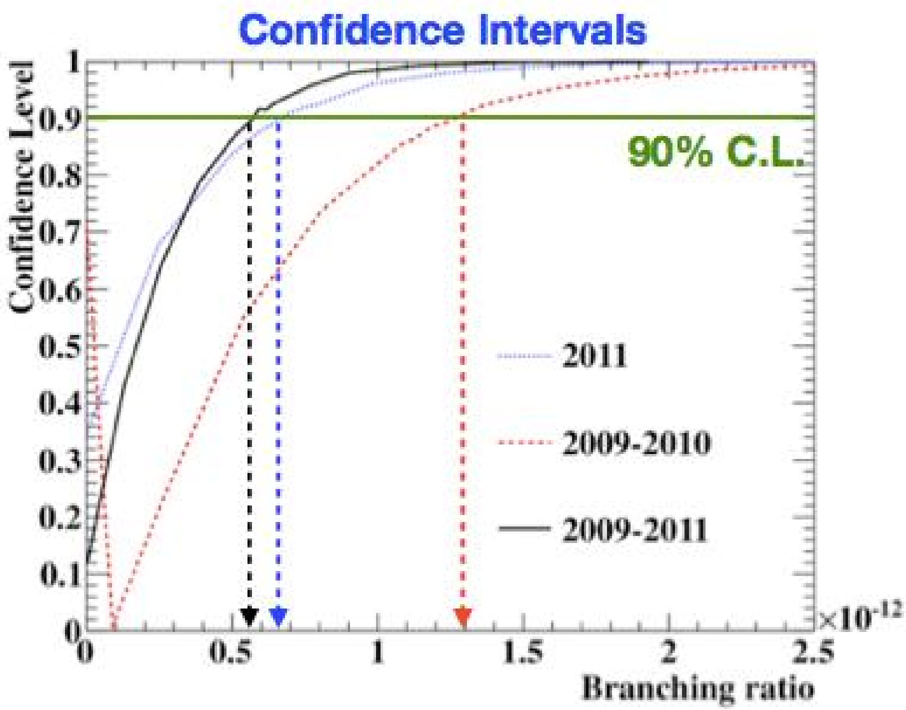
- MEG experiment successfully finished data taking 31.08.2013.
- The statistics is double compare to published result. The data analysis will be finished at 2014.
- Expected improvement of sensitivity from 7.7×10^{-13} to $\sim 5 \times 10^{-13}$.
- Preparation of MEG-2 is in good shape.
- Expected MEG-2 sensitivity after data taking in 2016-2018 is $\sim 5 \times 10^{-14}$.

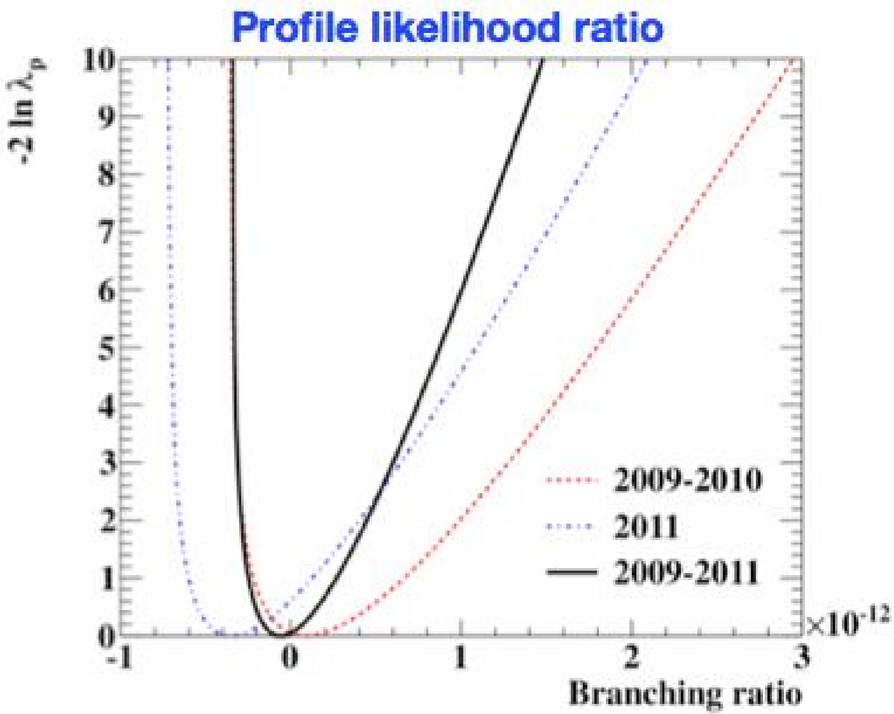
Thanks for your attention!

Backup

Confidence Interval

- Confidence interval calculated with Feldman-Cousins method + profile likelihood ratio ordering





Consistent with null-signal hypotesis