The MEG experiment: status and upgrade.

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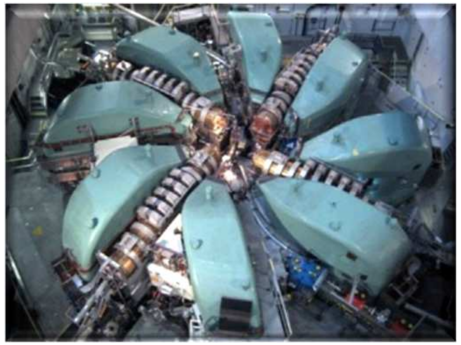
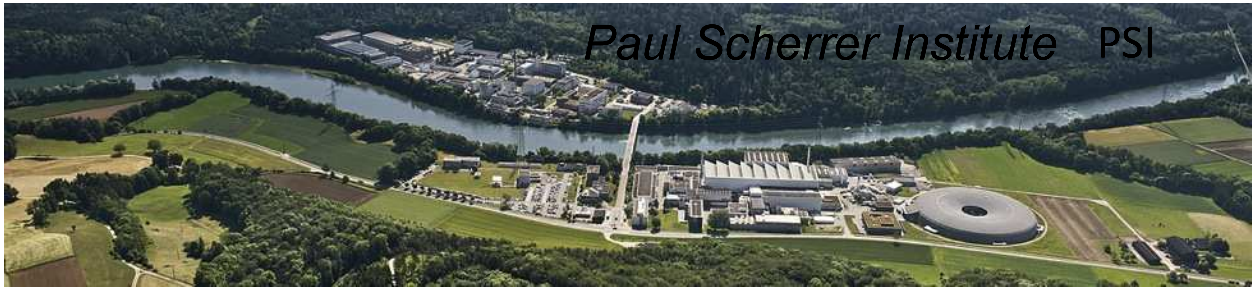
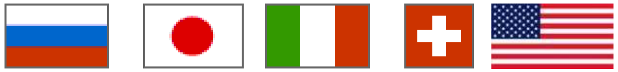
On behalf of MEG and MEG-2 collaborations

European Physical Society Conference
on High Energy Physics (EPS-HEP 2015)
Vienna, 24/07/2015

MEG HOME





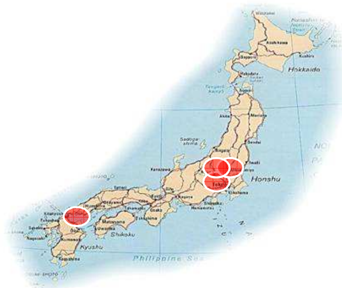


Switzerland
PSI, ETH-Z

Russia
BINP, Novosibirsk,
JINR, Dubna

MEG Collaboration
some 65 Physicists
5 Countries, 14 Institutes

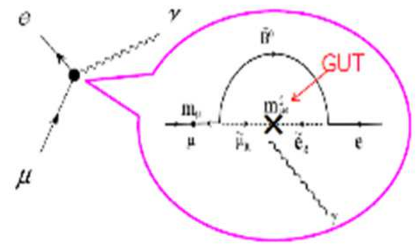
Japan
Univ.Tokyo, KEK
Waseda Univ.,
Kyushu Univ.



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

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, $\mu \rightarrow eee$)

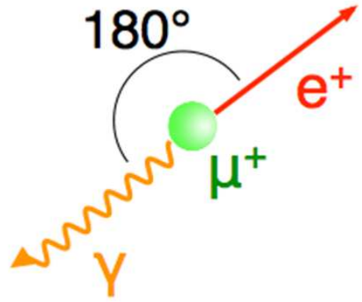
Signal and backgrounds

Signal μ^+ decay at rest

52.8 MeV (half of M_μ) (E_γ,E_e)

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

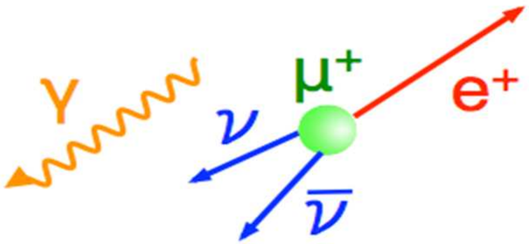
Timing coincidence ($T_{e\gamma}$)



Accidental background (dominant)

Michel decay e^+ + random γ

Random timing, angle, E < 52.8MeV

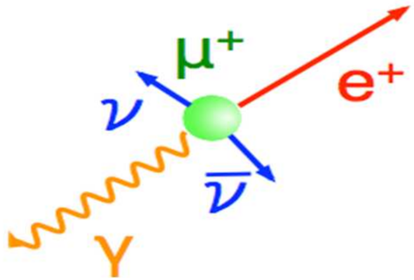


Radiative muon decay

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

Timing coincident, not back-to back,

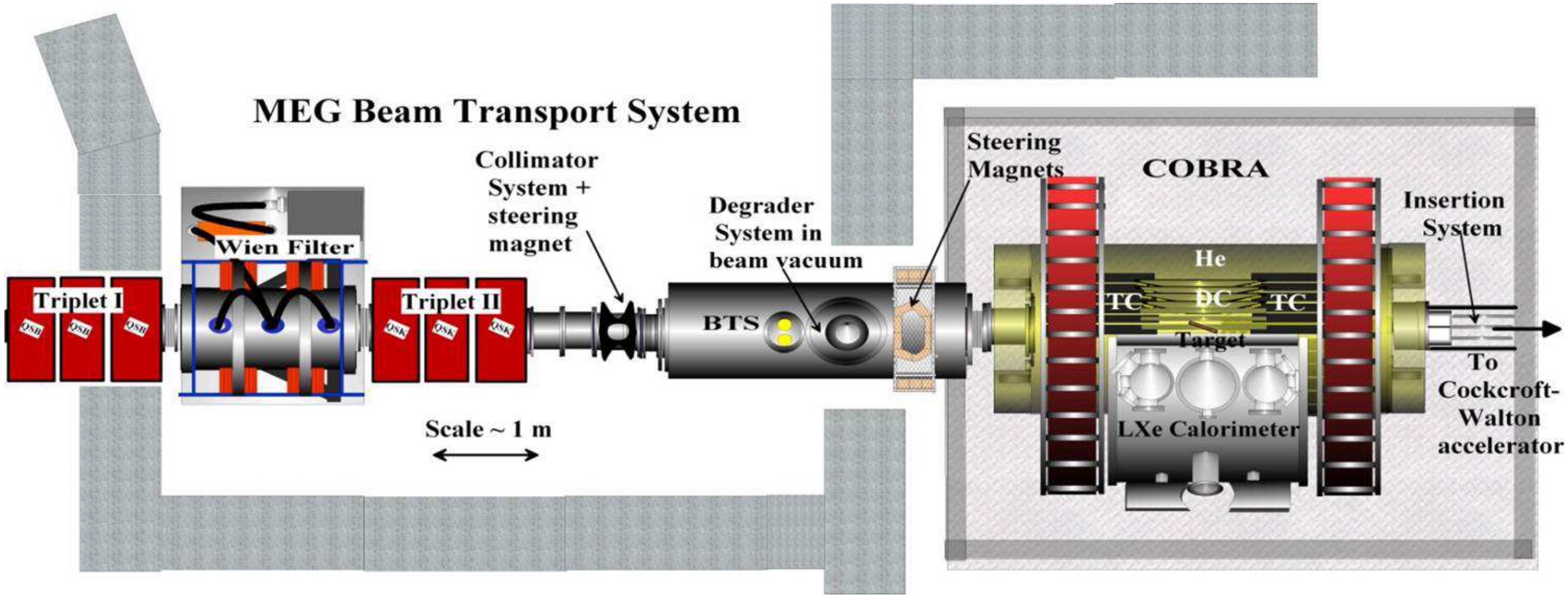
E <52.8MeV



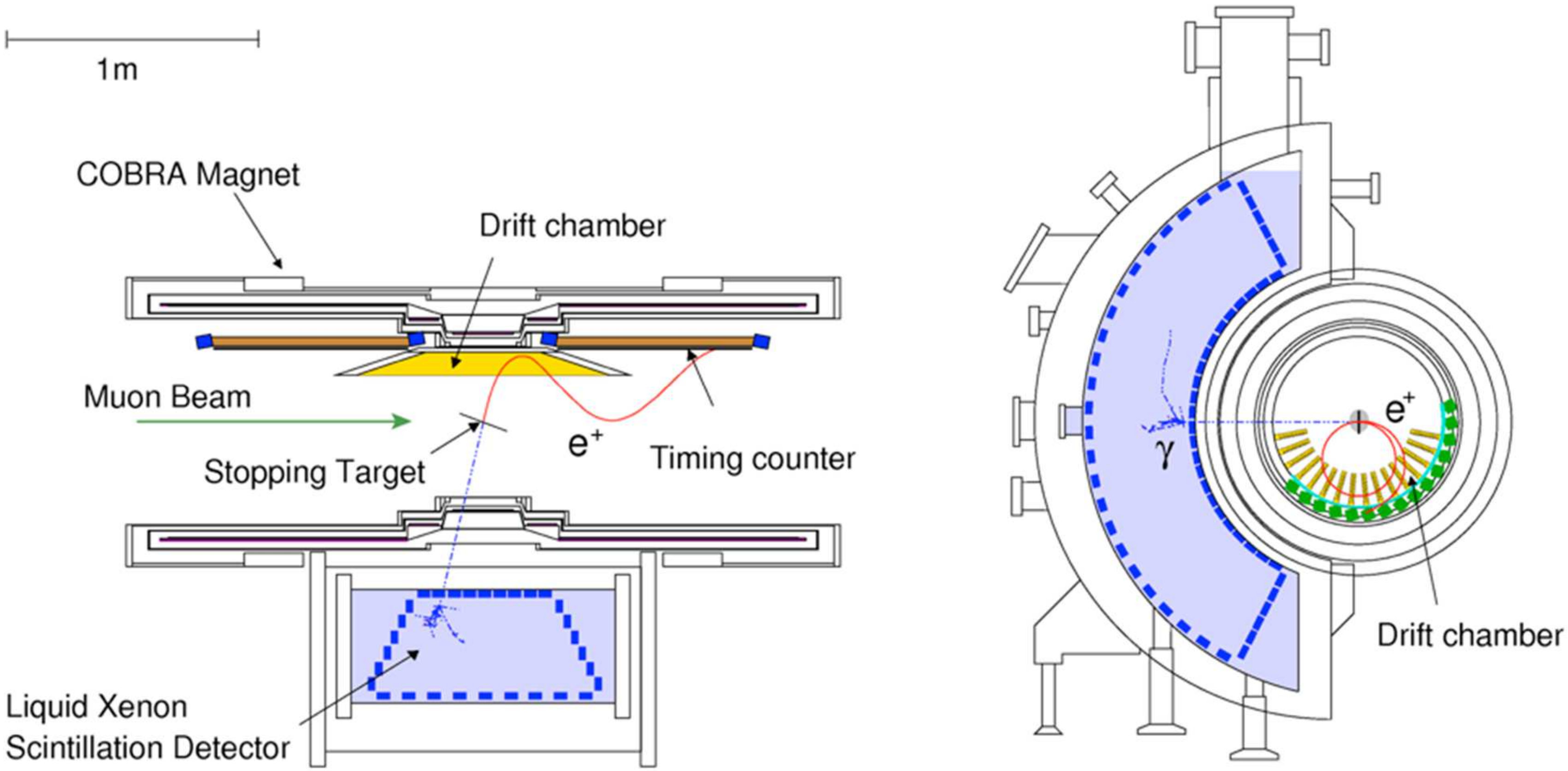
Key points of the experiment

- 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, timing & energy resolutions ⇨ 900 litre LXe detector (largest in world)
- Stable and well monitored & calibrated detector ⇨ Arsenal of calibration & monitoring tools

Layout of the experiment



Layout of the detector

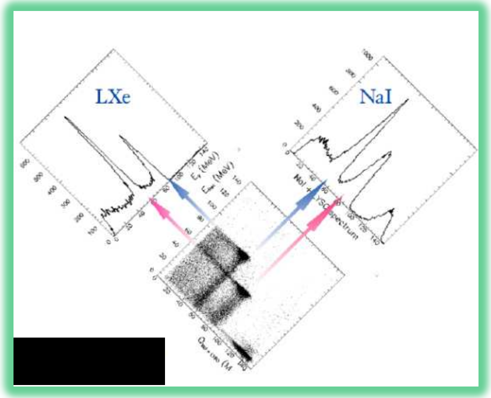


The important part – gradient field COBRA magnet:
tracks radius is independent on incident angle at 52.8 MeV/c

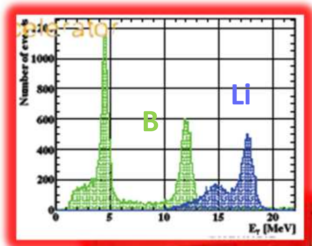
Calibration and Monitoring

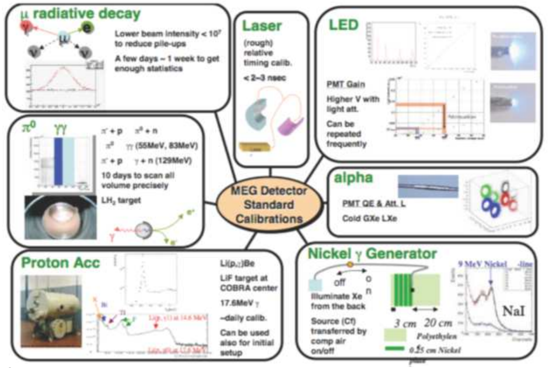
Crockcroft-Walton generator

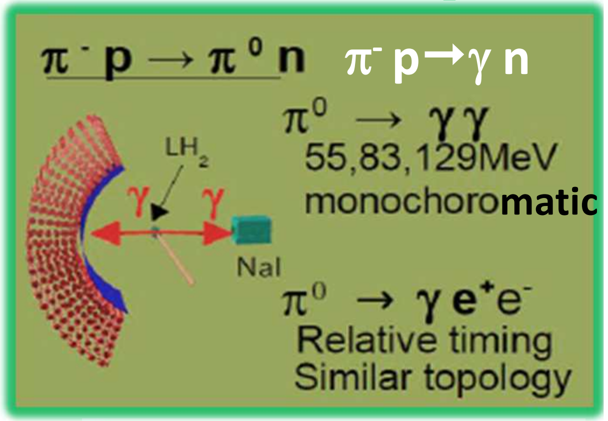
<u>PMT</u>: Gain, QE,
<u>LXe</u>: Light-yield , Attenuation-length
<u>Calorimeter</u>: Energy-scale
<u>Calo.+TC</u>: Relative detector timing, Alignment
e.g. αs, LED, $\pi^- p \rightarrow \pi^0 n$ or γn, “Dalitz-decay,
RMD, protons from C-W accelerator on $Li_2B_4O_7$,
n-generator+ Ni, cosmics, Mott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



Pion CEX on LH_2

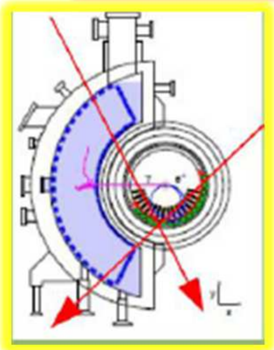




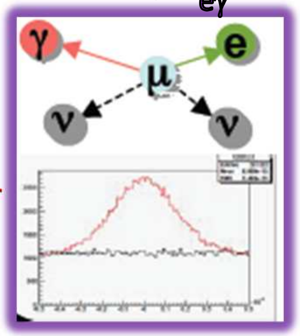


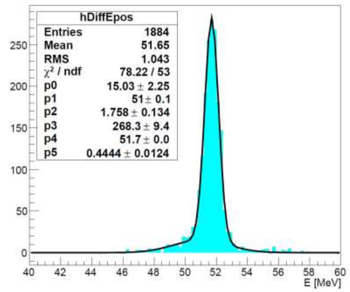
Radiative Muon Decay
RMD $\rightarrow t_{e\gamma}$

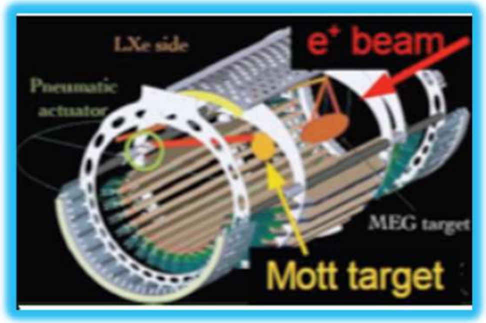
Mott mono.
e+ scattering



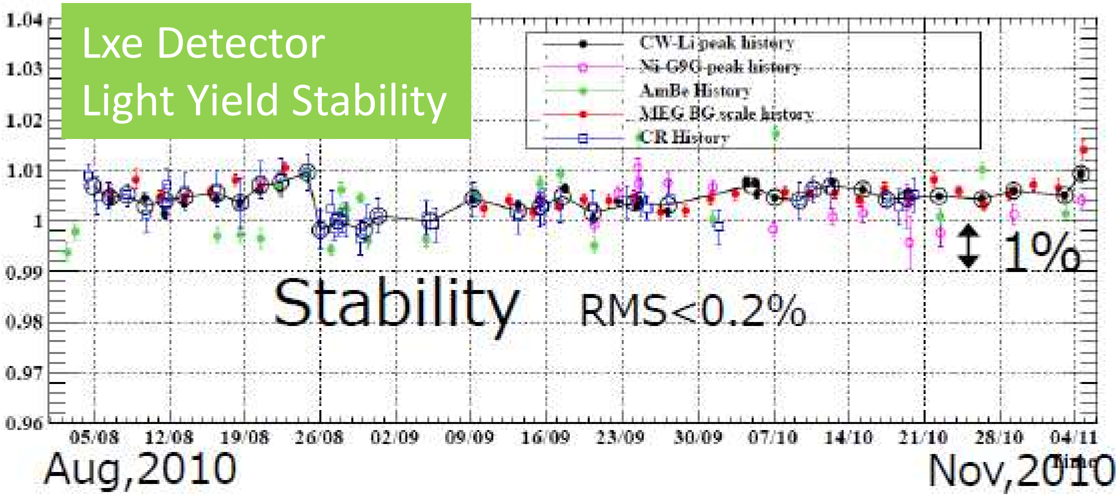
Cosmic rel.
alignment LXe
+ spectrometer

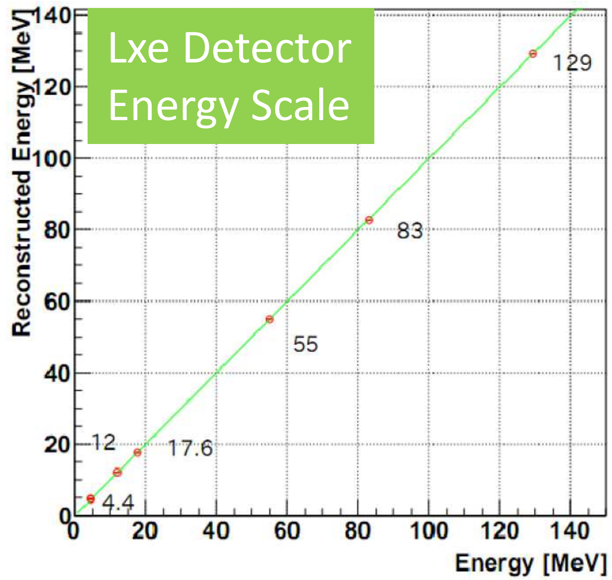


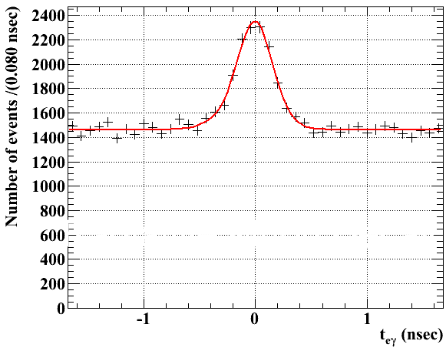




Detector Stability







<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.)

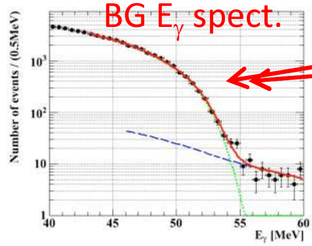
$48 \le E_\gamma \le 58$ MeV

$50 \le E_e \le 56$ MeV

$| T_{e\gamma} | \le 0.7$ ns

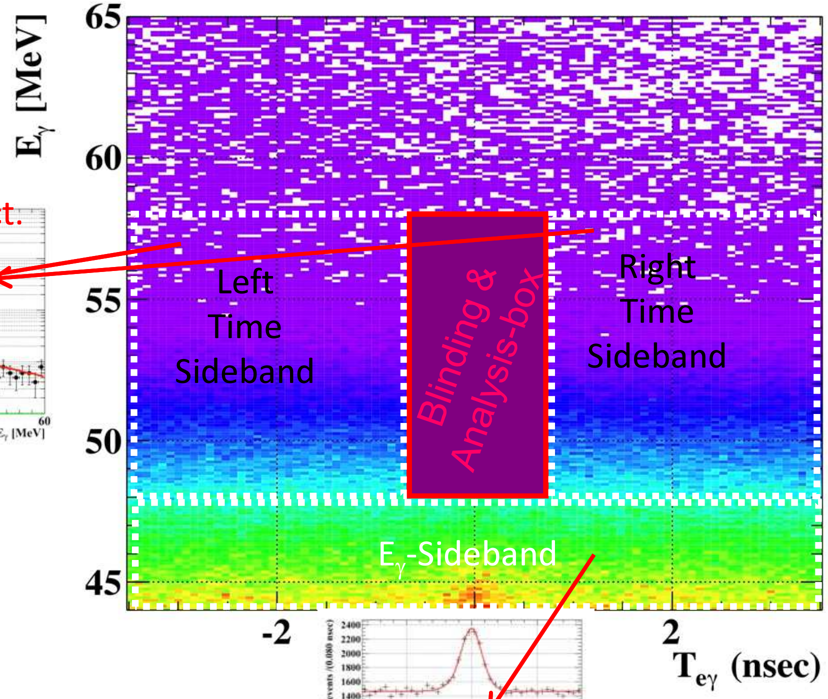
$| \phi_{e\gamma} |$, $| \theta_{e\gamma} | \le 50$ mrad

(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 2015 with the improved analysis. The data are reprocessed now.

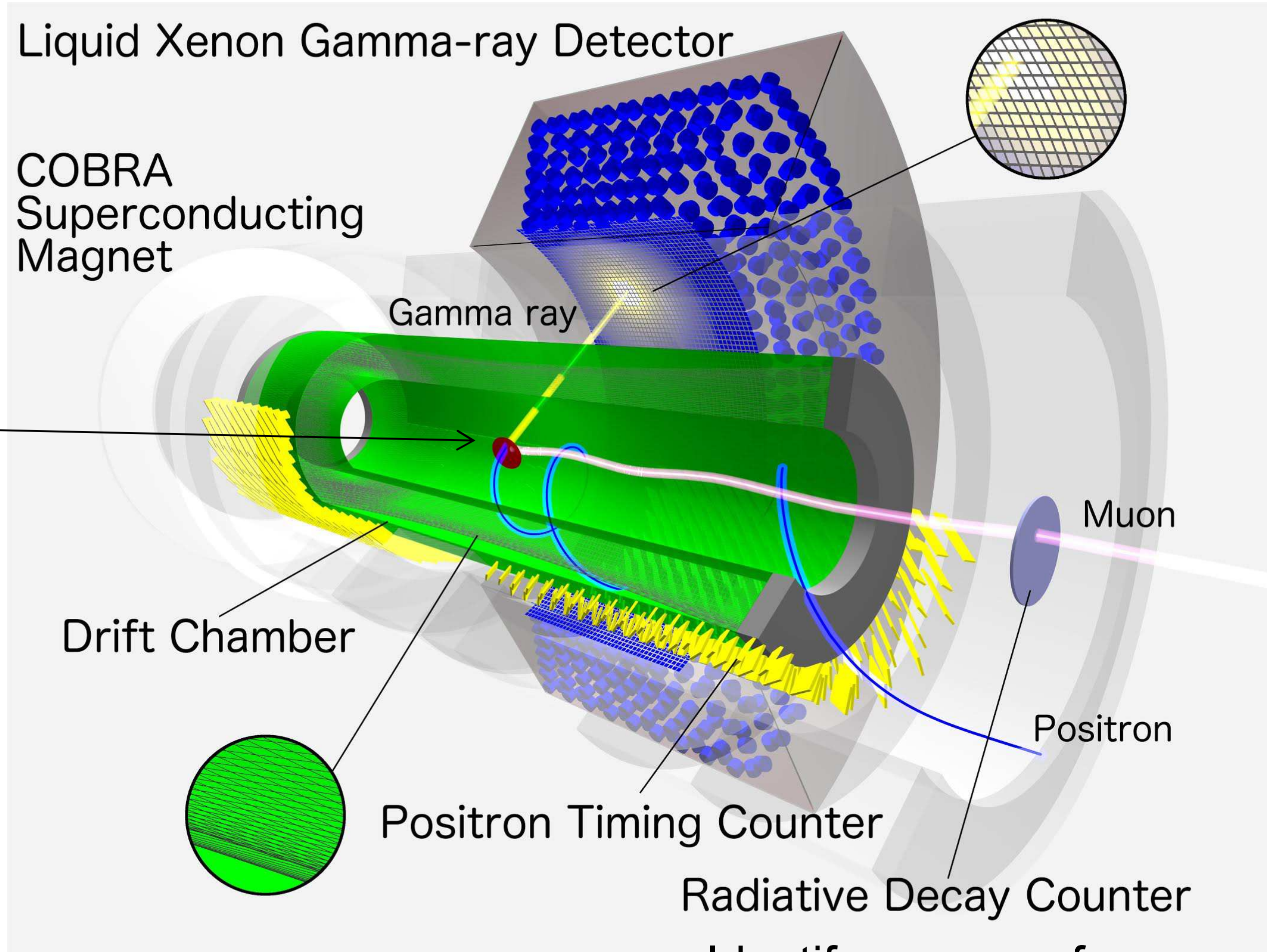
Improvement of the analysis

- Event reconstruction algorithm.
- Calibration procedures.
- Background rejection techniques.
  - recover positron tracks which cross the target twice (missing turn analysis)
  - Identify background γ-rays generated when a positron annihilates with an electron on some detector material (annihilation-in-flight (AIF) analysis)
  - refine the alignment procedure of the target and drift chamber system.

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



Thinner target active?

Identify gammas from muon radiative-decays

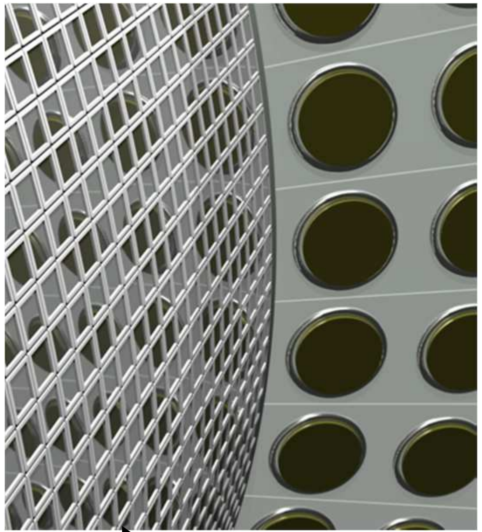
Calorimeter upgrade

- 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%

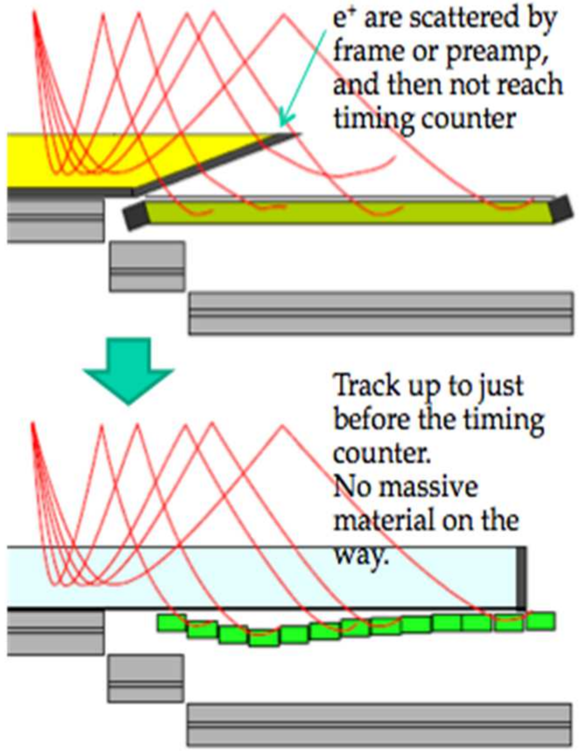
shallow / deep events
(d = 2cm)

horizontal / vertical

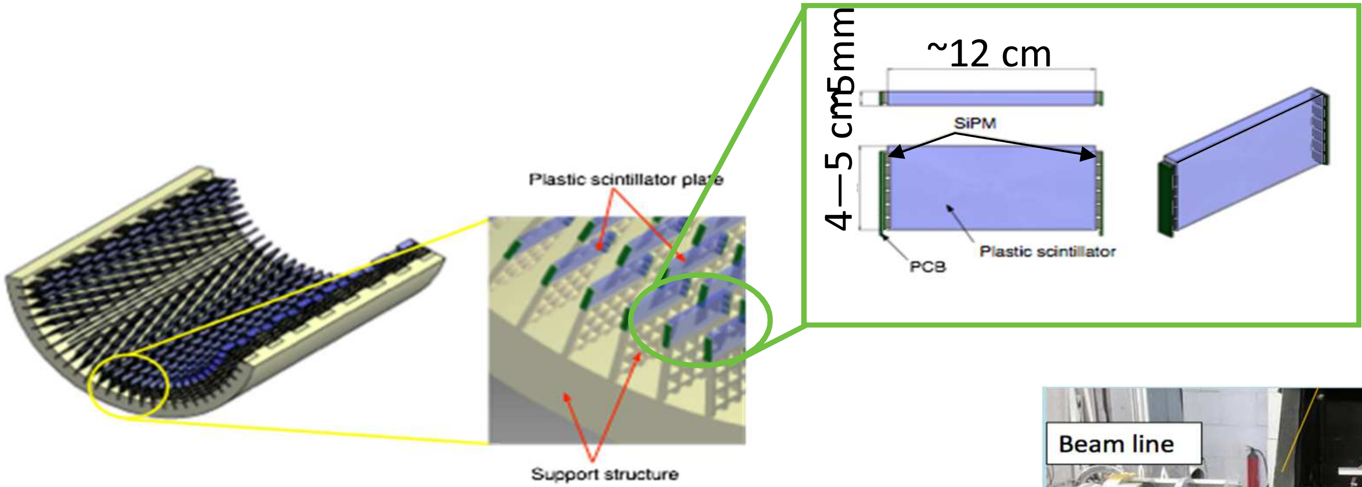
Factor 2 better energy and position resolutions and 10% higher efficiency

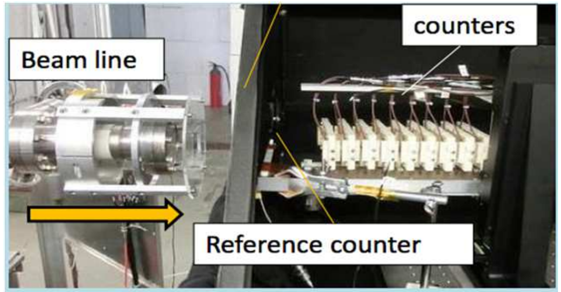
New drift chamber

- 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.

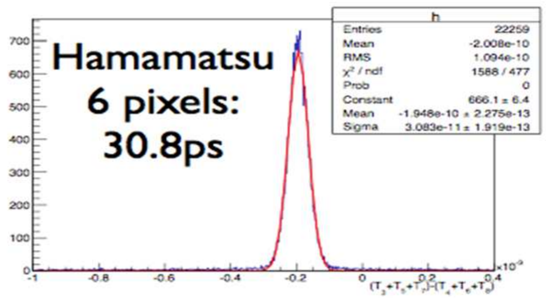


New timing counters





- 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

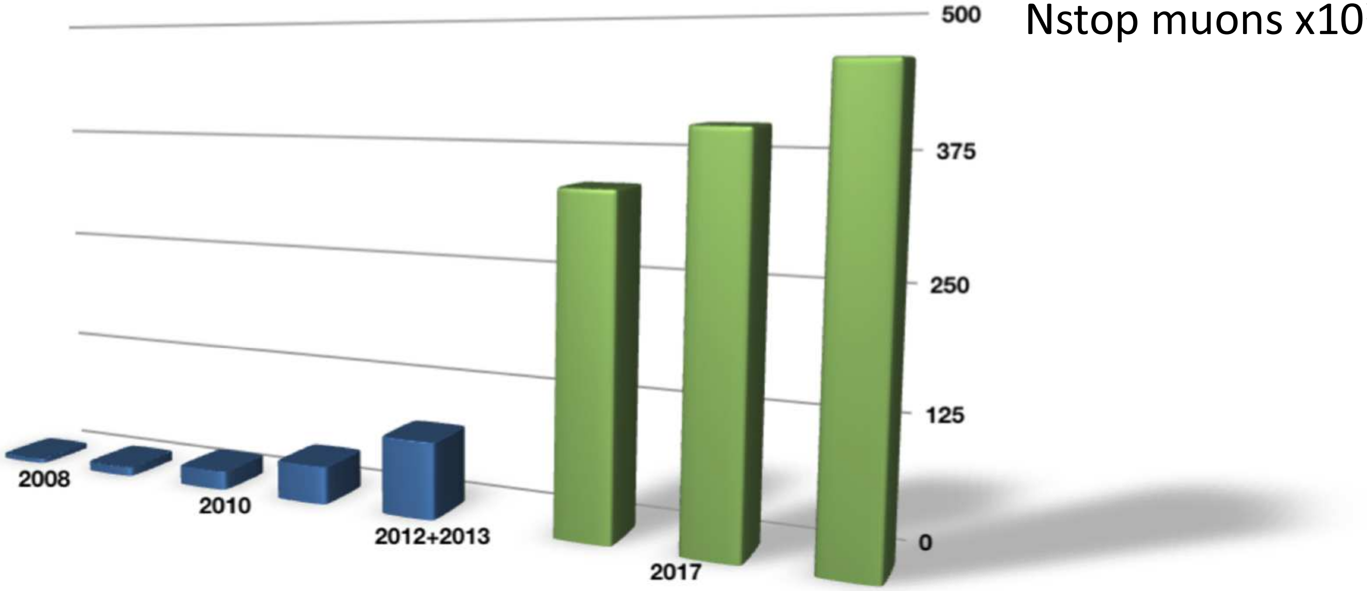


Current status

- Xenon calorimeter
  - Development of LXe MPPC is finished. PDE of 15% is achieved for LXe light. Production of 600 MPPCs is done. 568 MPPCs has been succesfully tested at LXe temperature with large prototype. 4000 MPPCs will be delivered by August to have the full set.
  - The PCBs for MPPC mounting has been designed and tested.
- Drift chamber
  - The Mock-up chamber will be ready soon.
  - The fully automatic wiring machine is operational.
  - The production of chamber is almost ready to start.
- Timing counters
  - All SiPMs and about 50% of scintillator plates are in hand.

GOAL: to have pre-engineering run at the end of 2015 and to 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 2015.
- Expected improvement of sensitivity from 7.7×10^{-13} to $\sim 5 \times 10^{-13}$.
- Preparation of MEG-2 is in good shape. The pre-engineering run is planed at the end of 2015.
- Expected MEG-2 sensitivity after data taking in 2016-2018 is $\sim 5 \times 10^{-14}$.

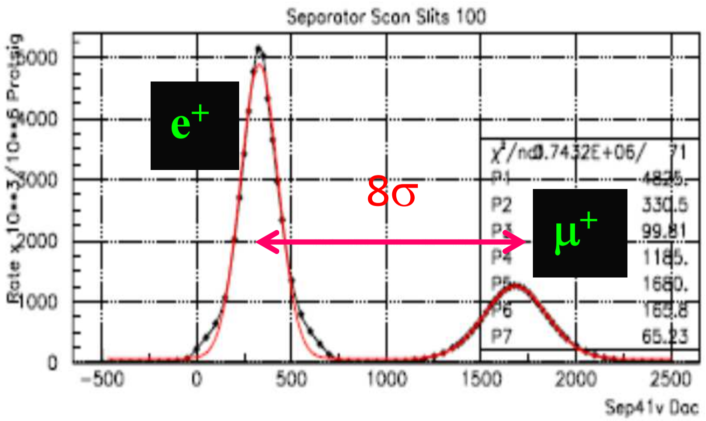
Thanks for your attention!

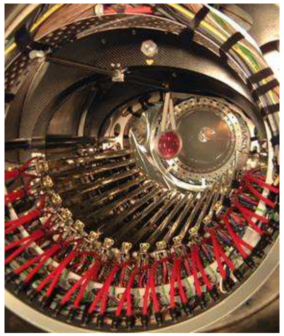
Backup

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

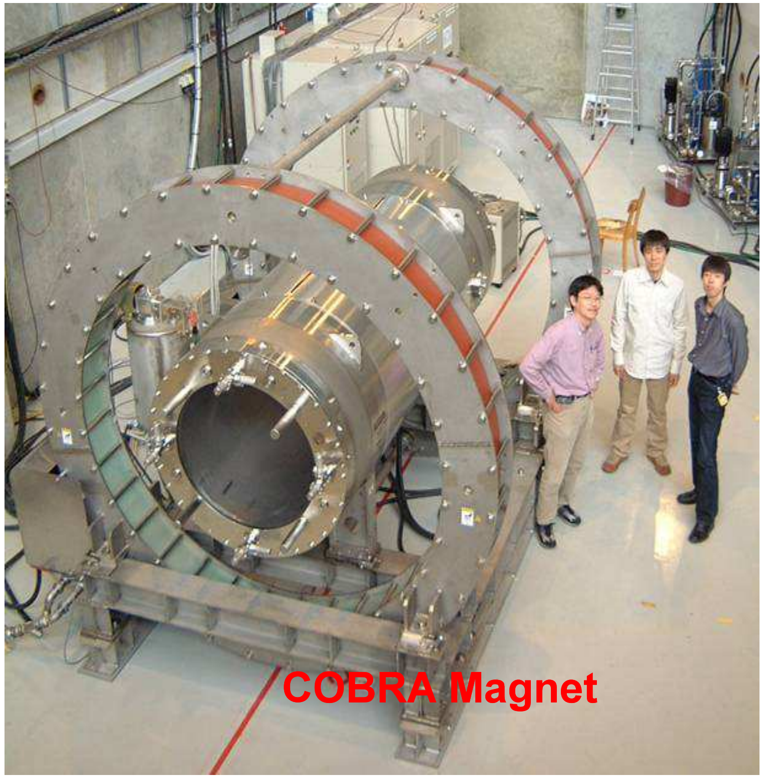




Target

Positron spectrometer

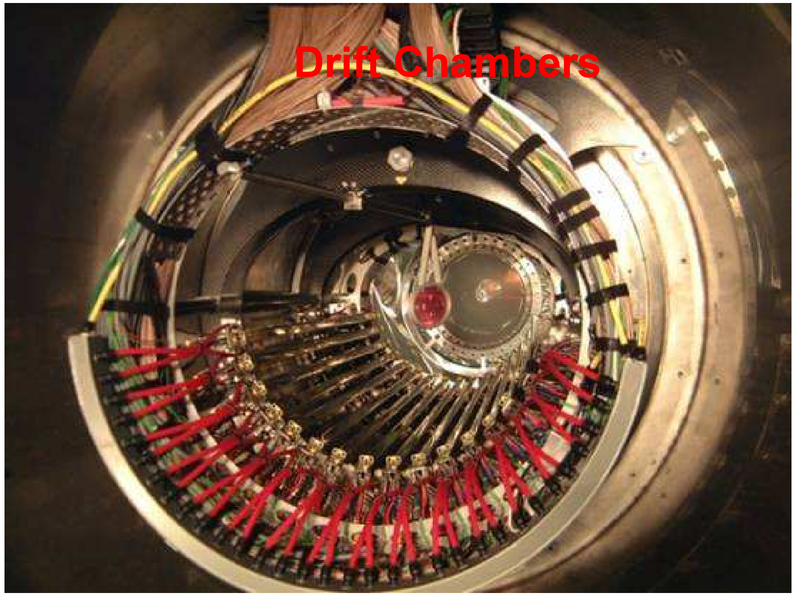
- **SC COBRA Magnet**
- Gradient Bfield (1.27-0.5) T
  COnstant Bending RAdius
- 0.2 X_0 fiducial thickness
  γ-transparency 95%
- NC Compensations coils
  reduce Bfield at Calorimeter
  < 5mT at PMT positions



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

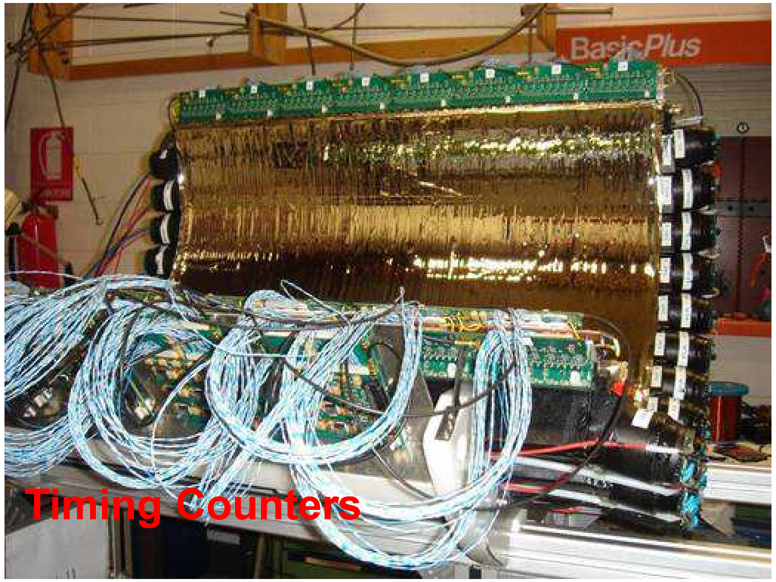
θ~ 10 mr

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)



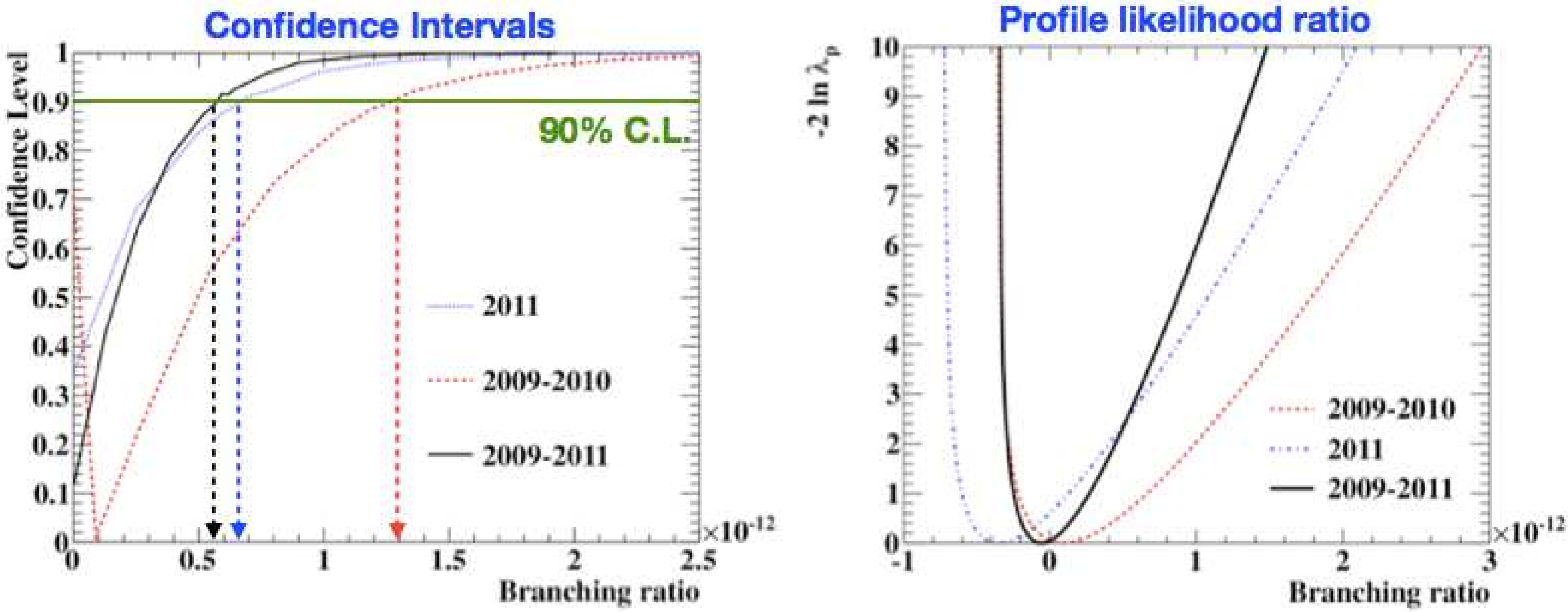
Calorimeter

- 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})

Confidence Interval

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



Consistent with null-signal hypotesis