MEG実験2013と
アップグレード計画の現状

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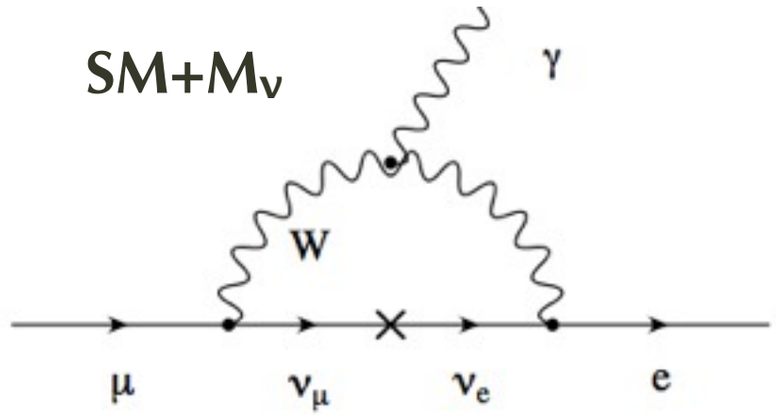
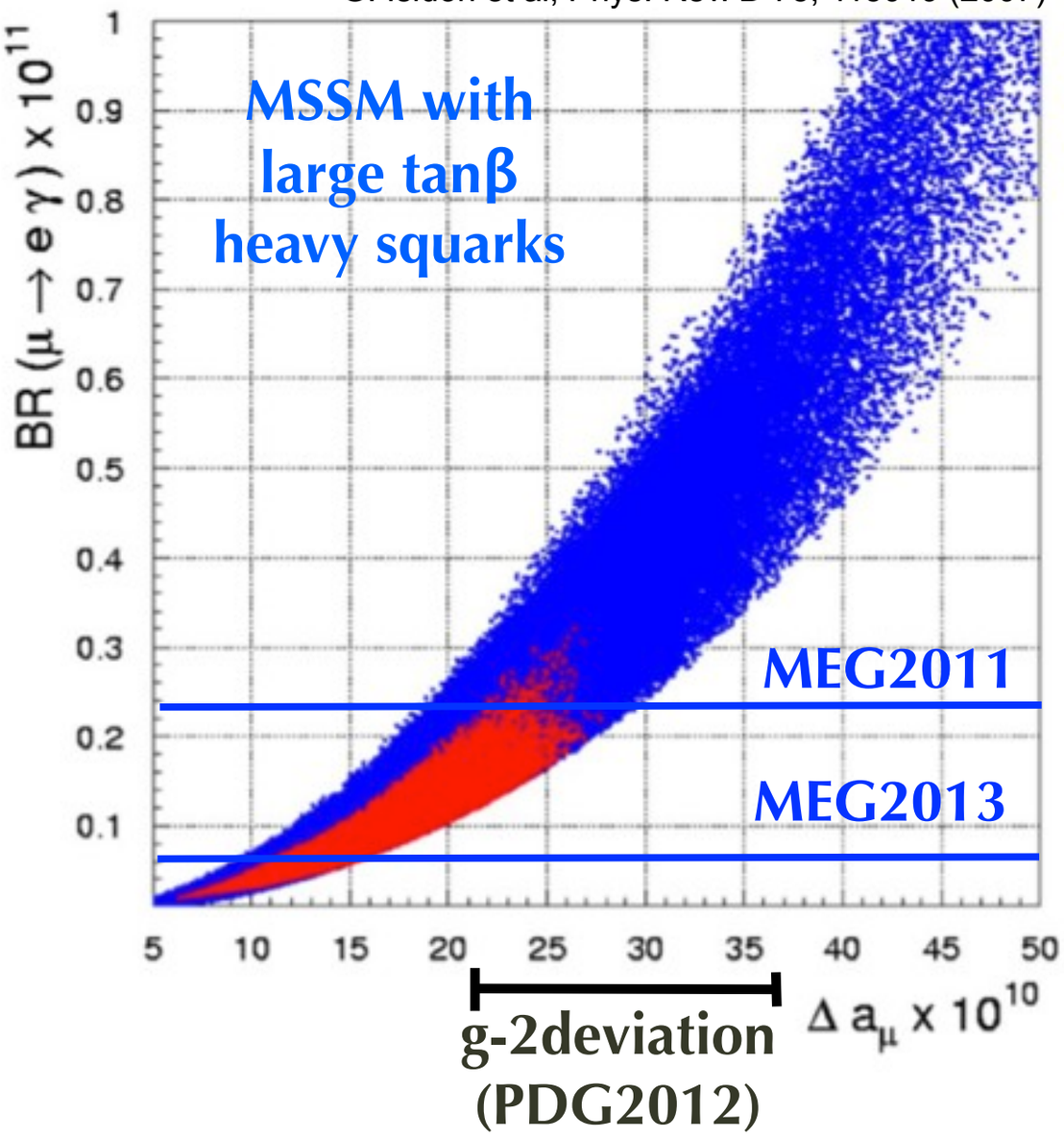
日本物理学会2013年秋季大会　高知大学　朝倉キャンパス

Physics Motivation of lepton flavor violation search

- Quark mixing is well described by CKM matrix in Standard Model.
- Neutrino oscillation is the first observed lepton flavor violating process
- No LFV is found yet in charged lepton
- SM + neutrino mass ⇒ tiny BR((μ→eγ)
- New physics like SUSY-GUT, SUSY-seesaw, Extra Dimensions etc. predict large BR
- If muon g-2 discrepancy is really evidence for new physics, searches for μ -> eγ reveal that the “amount” of flavor violation in the new physics sector



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

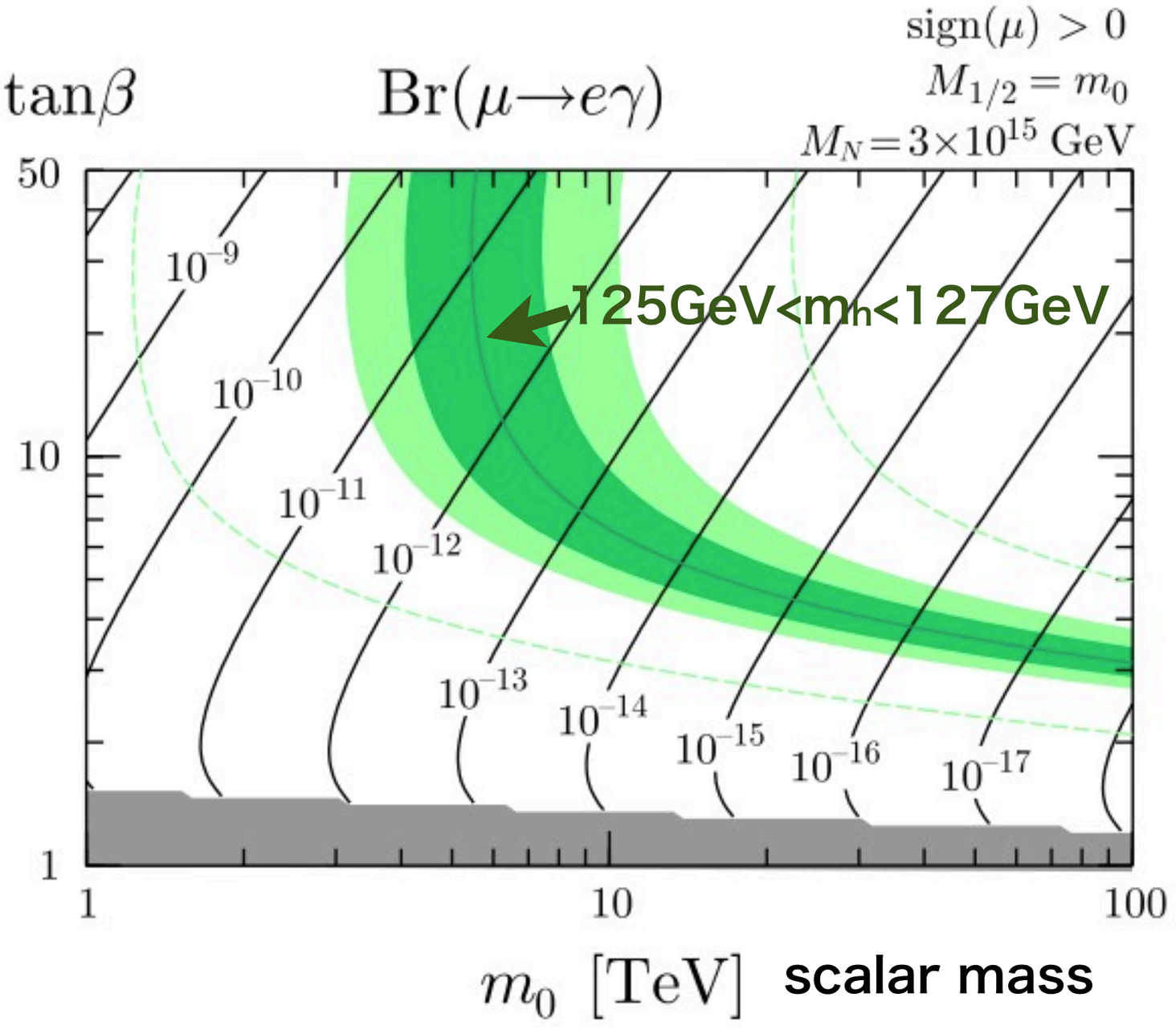


Anomalous magnetic moment

The current situation of LFV

- Higgs boson ~ 126GeV
- Non observation of SUSY particles
- Even if slepton masses O(10TeV), large LFV may occur by renormalization group effects
- Complementary with direct search of new physics

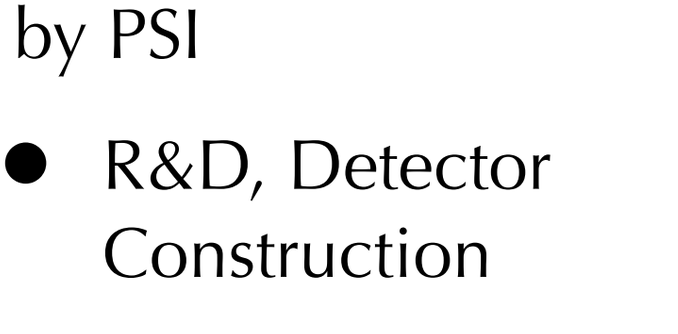
High-scale SUSY with right handed neutrino



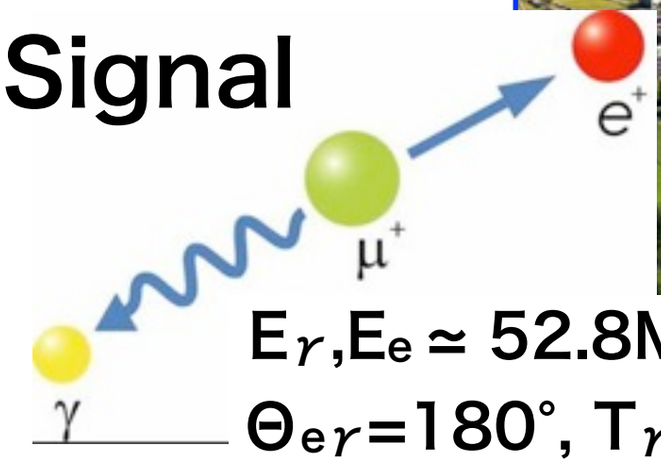
Moroi et. al., arXiv:1305.7357[hep-ph]

MEG実験

- 1999 Proposal accepted by PSI
  - R&D, Detector Construction
- 2008 Physics run started
- International collaboration
  - Japan, Italy, Switzerland, Russia, and USA
  - ~60 physicists

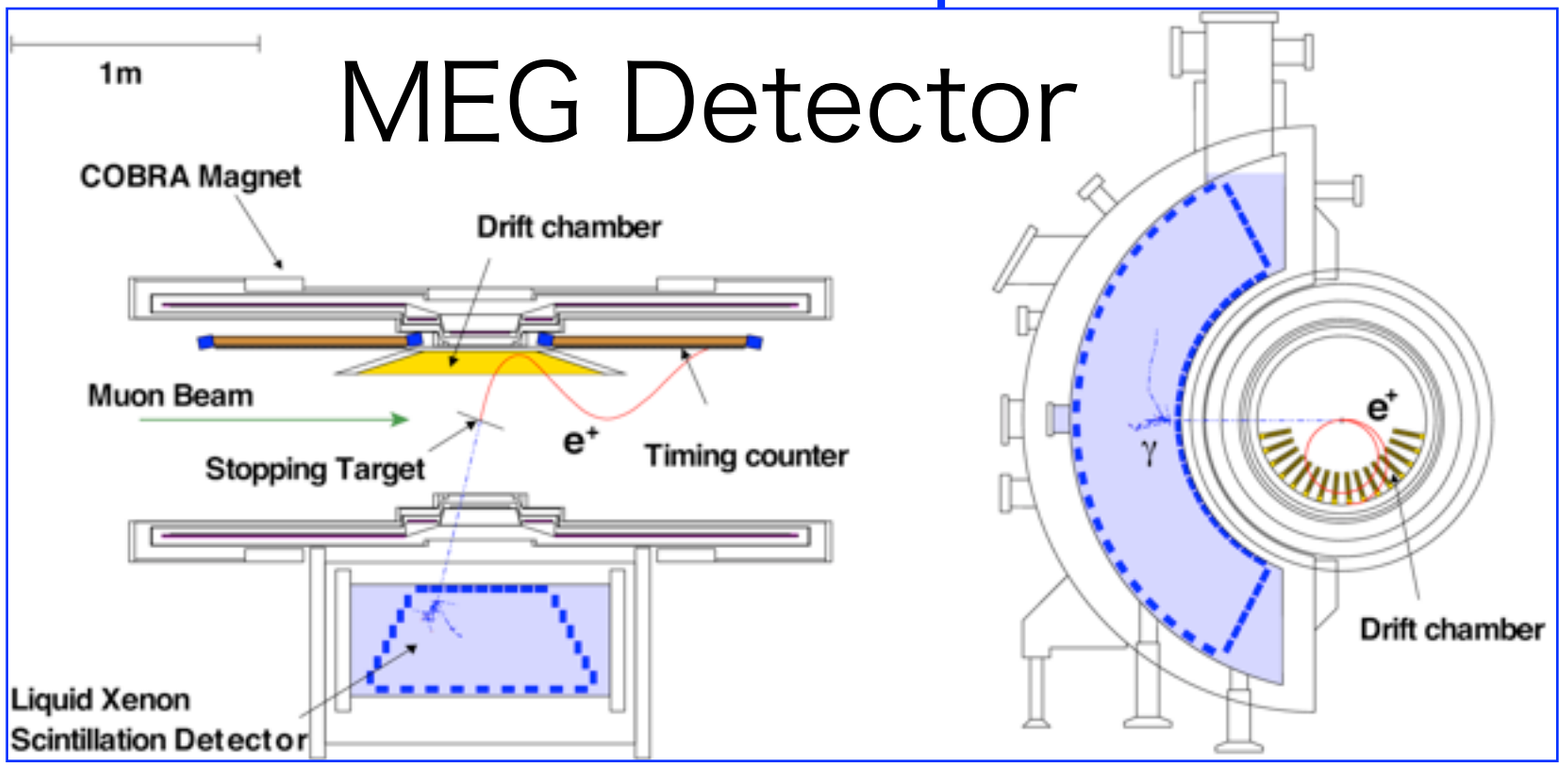


Signal



$E_\gamma, E_e \simeq 52.8\text{MeV}$

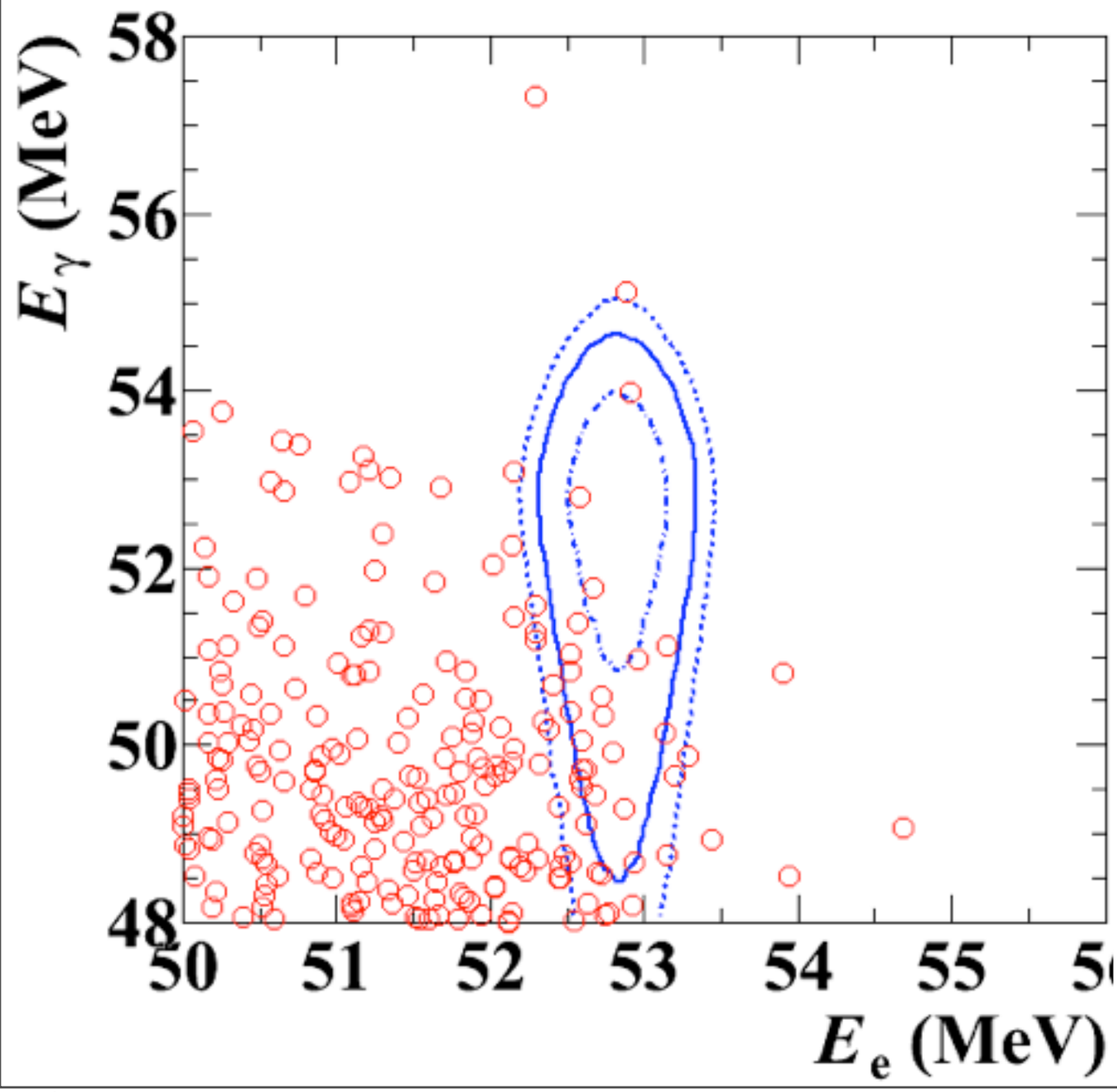
$\Theta_{e\gamma}=180^\circ,\ T_\gamma=T_e$

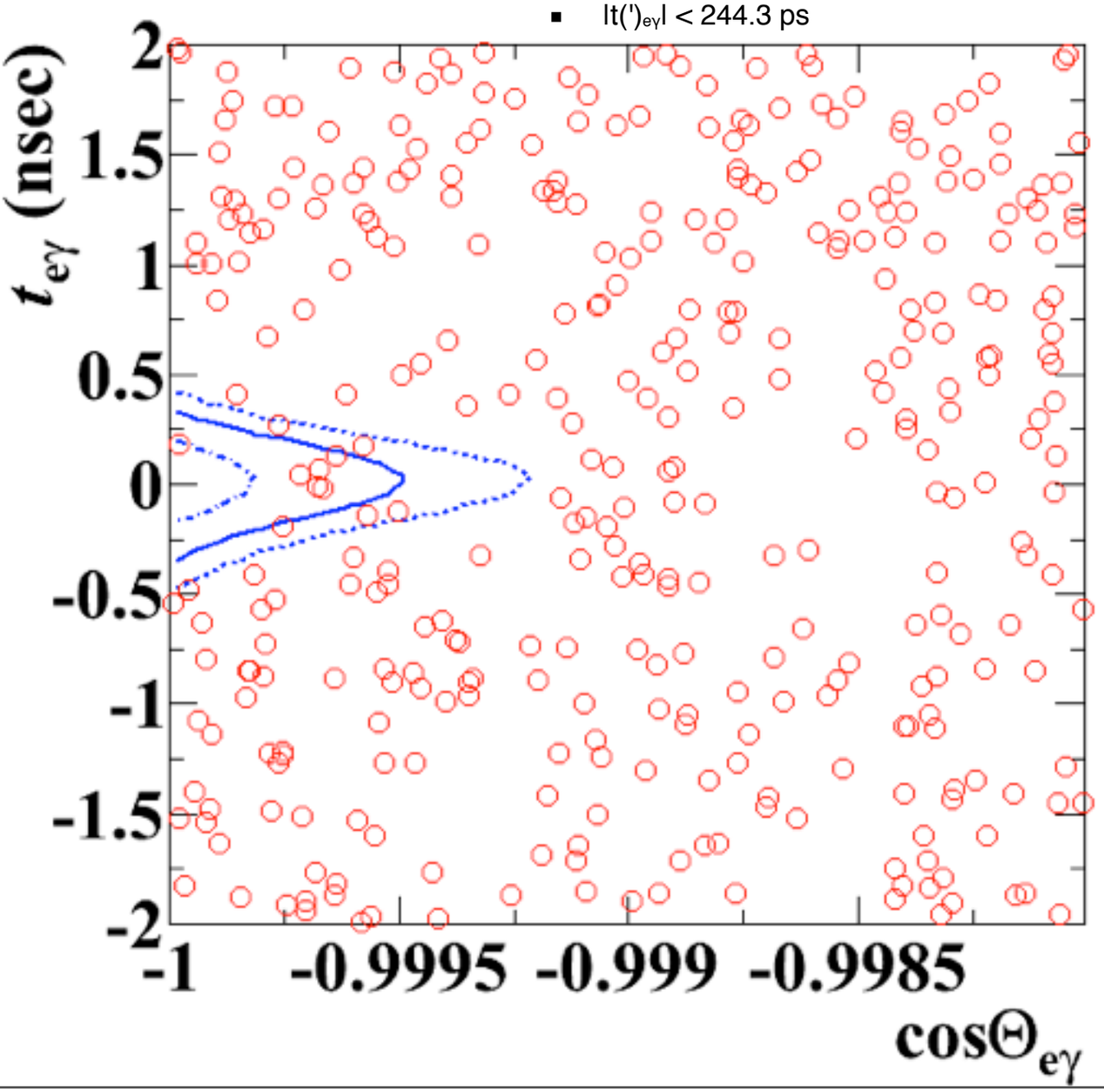


Latest result

- 2009-2011 likelihood analysis
  - **BR < 5.7x10^{-13} @ 90% C.L., PRL110, 201801(2013)**
  - **4x** improved upper limit than previous MEG result (2.4x10^{-12}), **20x** improved than previous experiment MEGA (1.2x10^{-11})

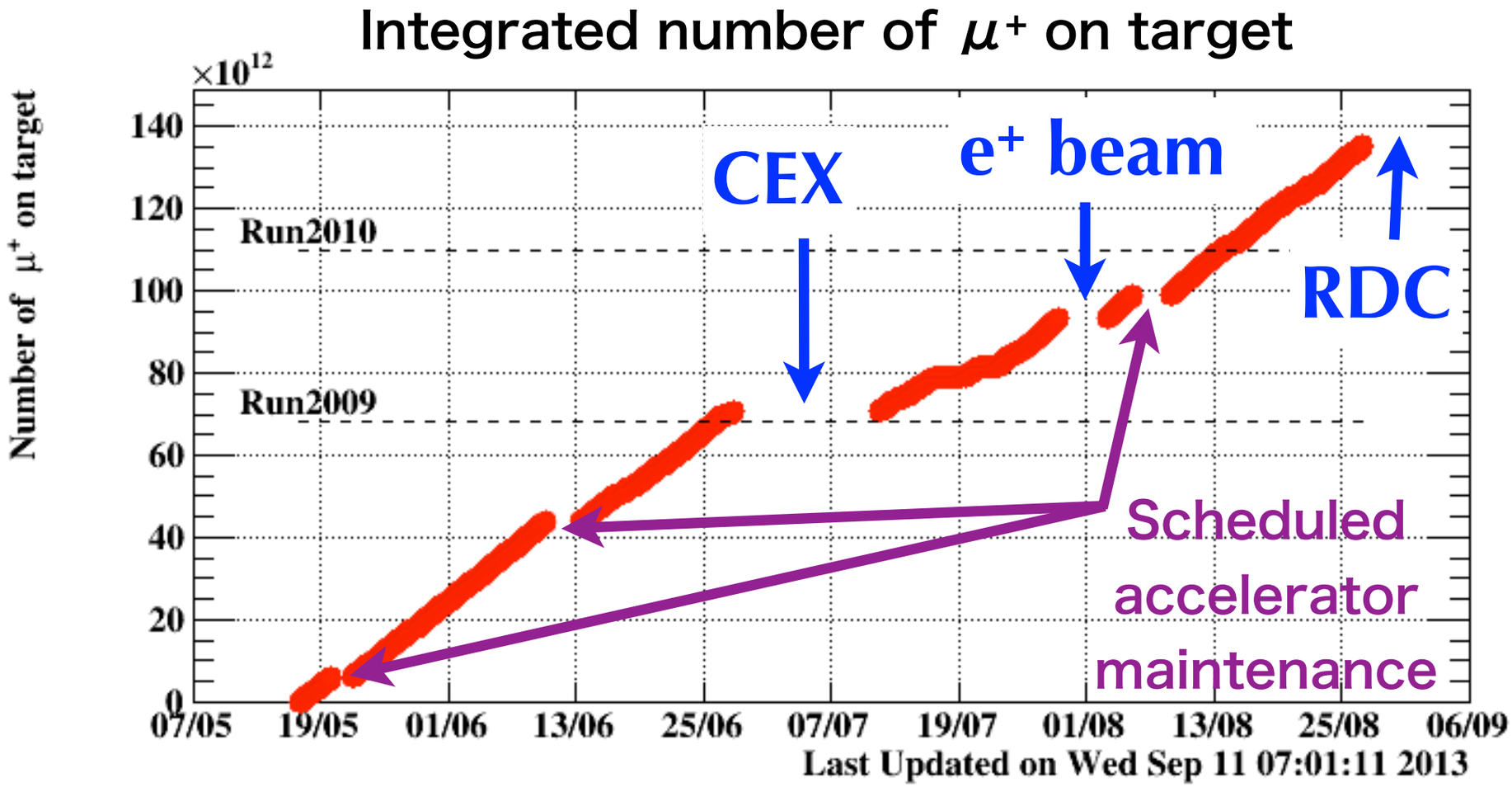
- 51 < EGamma < 55.5 MeV
- 52.385 < EPositron(') < 55 MeV
- π - Θ(')$_{e\gamma}$ < 27.2 mrad (cosΘ$_{e\gamma}$ < -0.99963)
- |t(')$_{e\gamma}$| < 244.3 ps





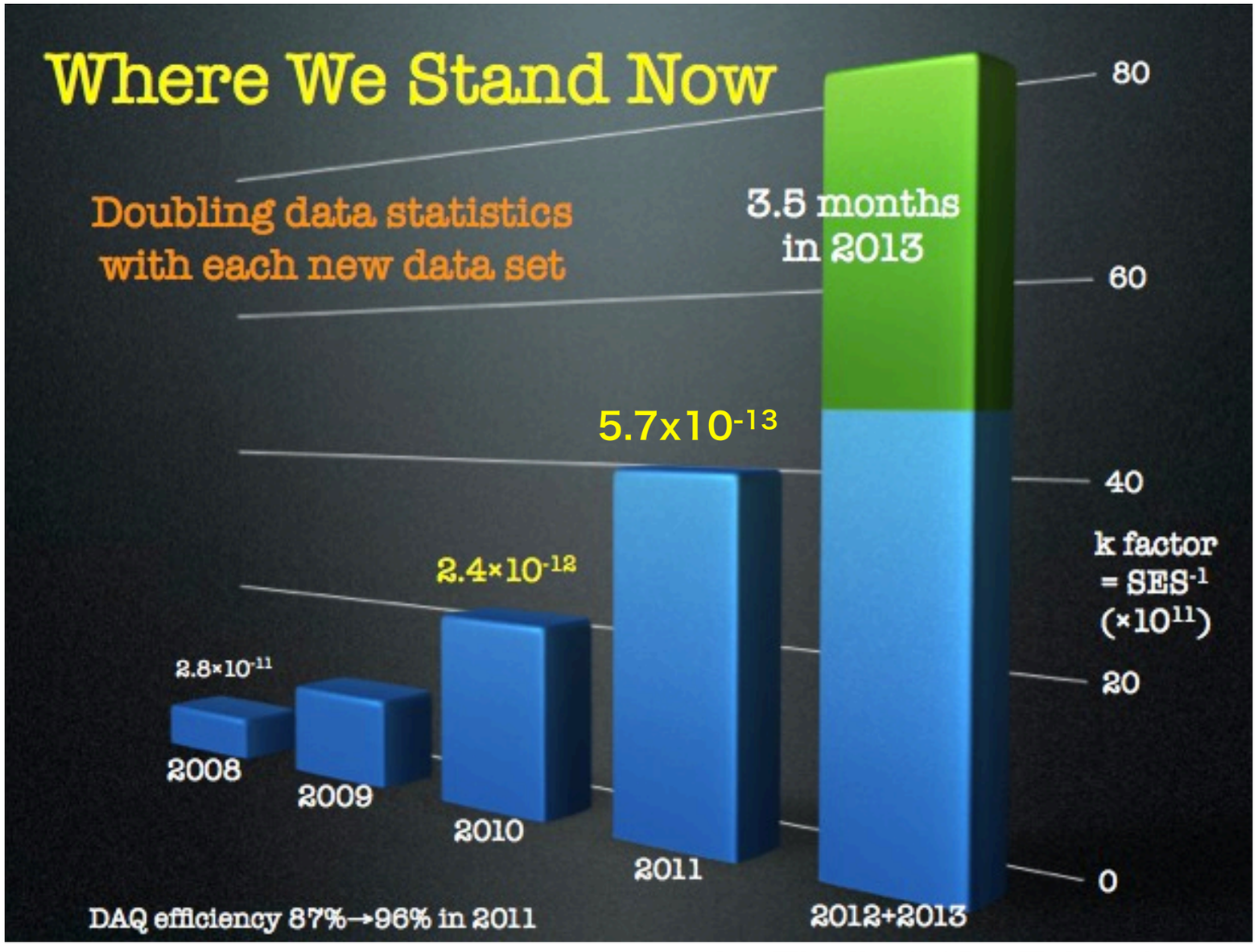
MEG2013

- Smooth physics run for 3.5 months
  - 6 DC modules are replaced, LXe purification for light yield recovery after MEG2012
- Calibrations: **CEX** by LXe 55MeV γ-ray for 10 days, **e^+ beam** for 1 week
- Beam tests for upgrade (**RDC**) for 5 days
- **MEG physics run finished successfully in Aug. 2013!**



MEG analysis status

- An analysis of 2012+2013 data is going on.
- Data statistics will be doubled.
- The final result will be published next year. Stay tuned.
- Next -> **Upgrade**

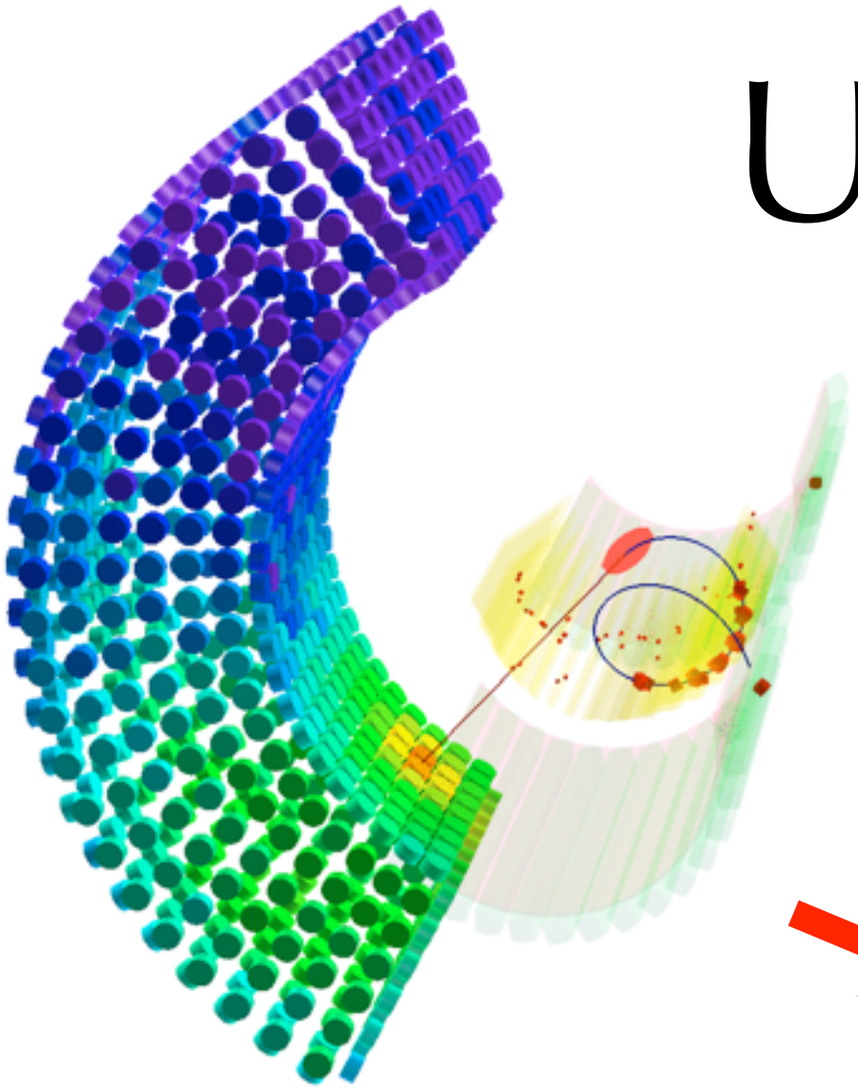


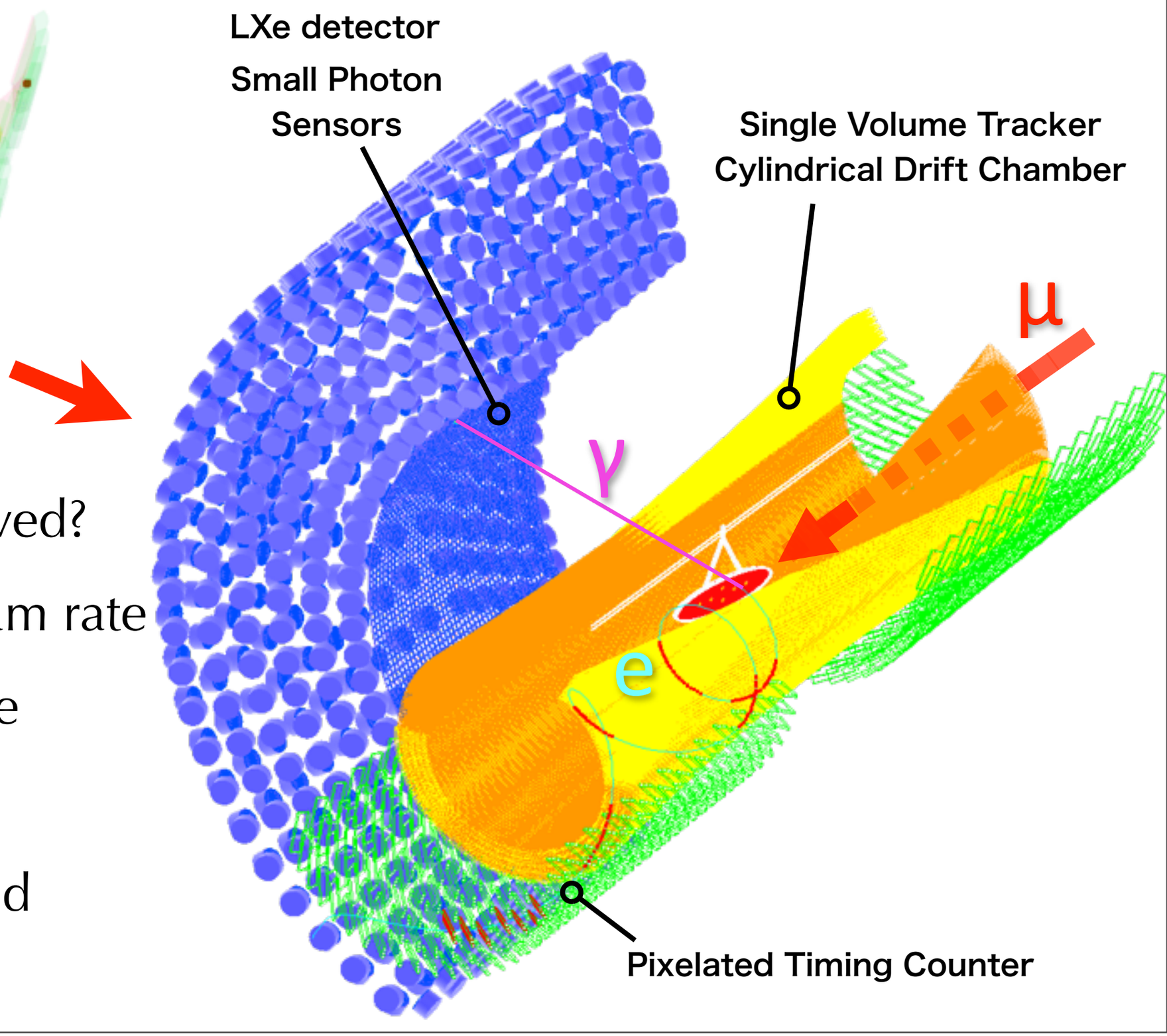
La Thuile 2013 T. Mori

Upgrade Status

- 2013/Jan- Upgrade proposal presented, and accepted by PSI (arXiv:1301.7225)
- 2013-2015 Design & Construction
- 2015- Engineering run
- 2016 - 2018 Physics run

Upgrade Concept



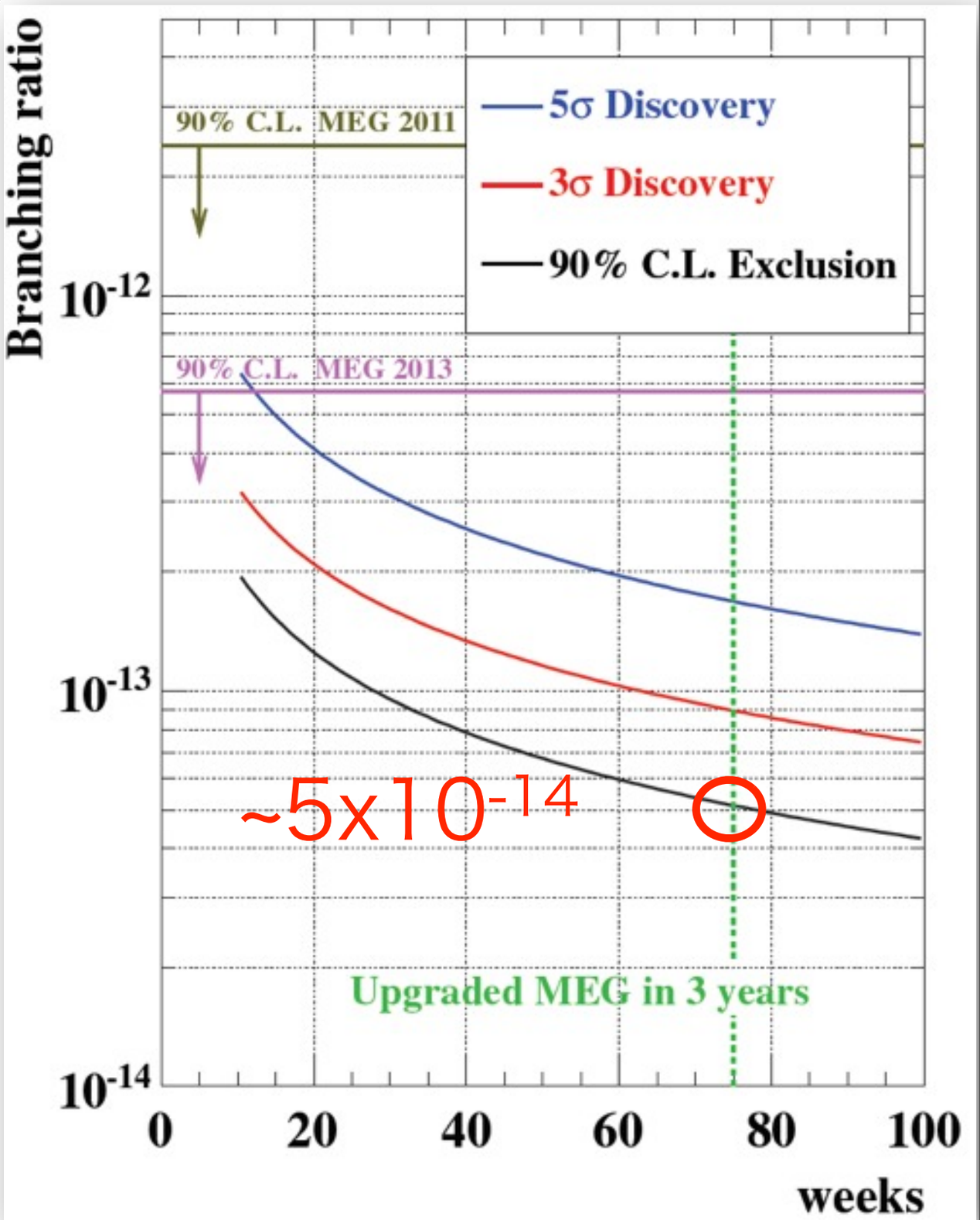


- What can be improved?
  - Higher muon beam rate
  - Larger acceptance
  - Better resolutions
  - Active background suppression

Expected Detector performance & Sensitivity

TABLE XI: Resolution (Gaussian σ) and efficiencies for MEG upgrade

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

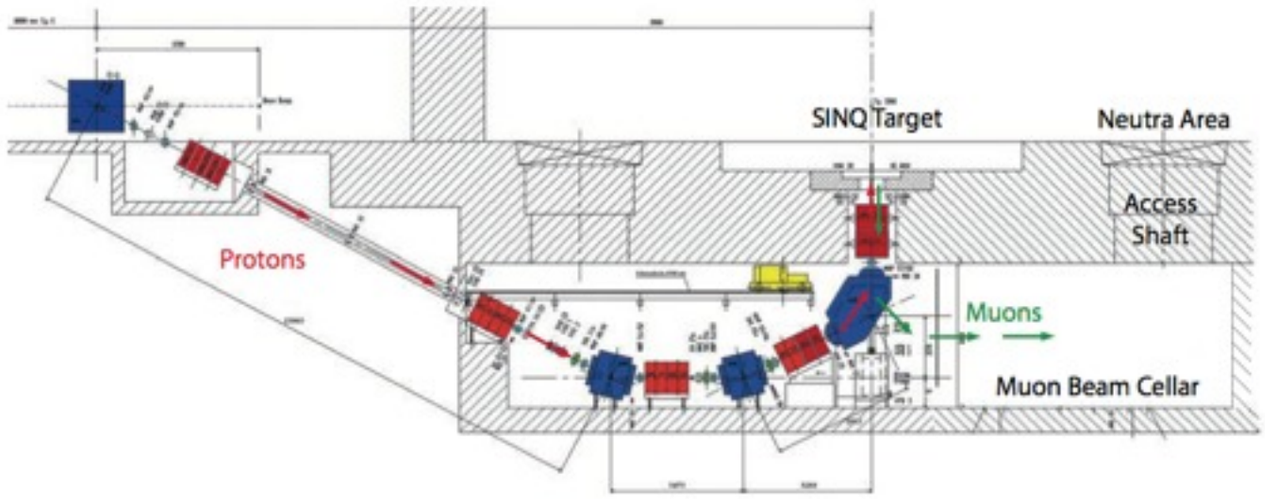


PSI Accelerator (muon beam rate)

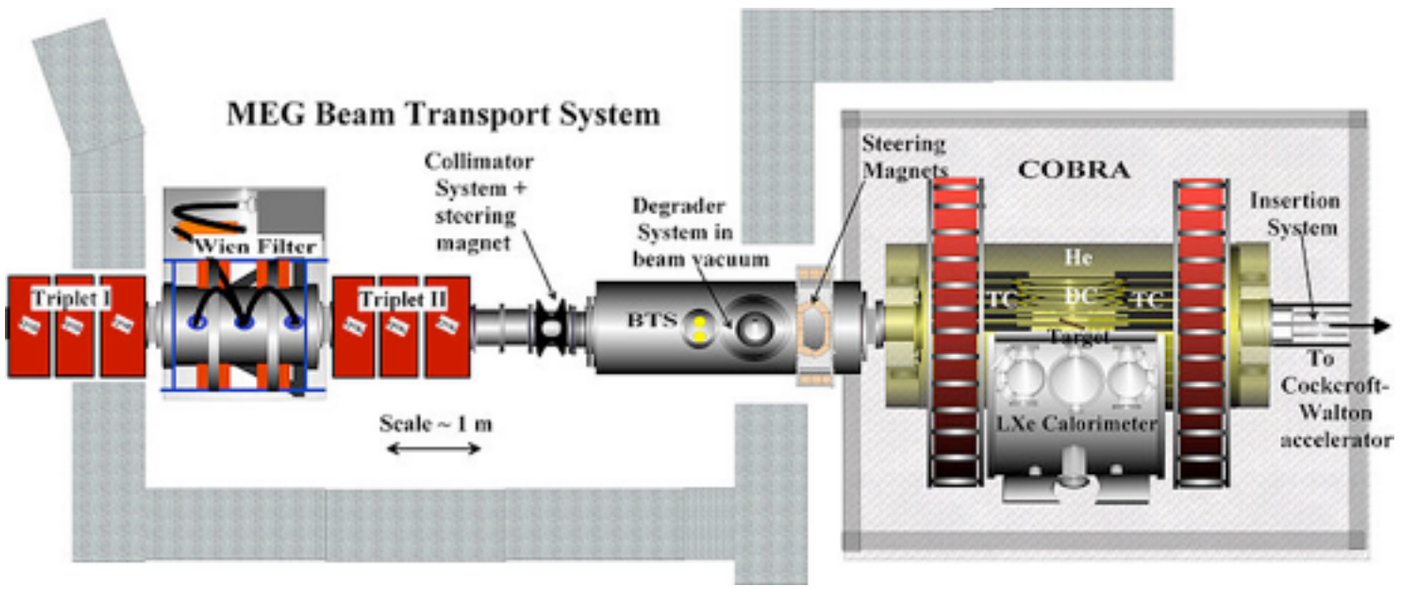
- PSI also has a plan to upgrade the accelerator
  - Mainly for Mu3e experiment
- MEG experiment doesn't require the accelerator upgrade
  - We can quickly start whenever the detector upgrade finishes
  - $3.0 \times 10^7 \Rightarrow 7.0 \times 10^7$ μ/s

    stopped at the target are possible now

High Intensity Muon Beam (HIMB) projects



3×10^{10}/s, >2017

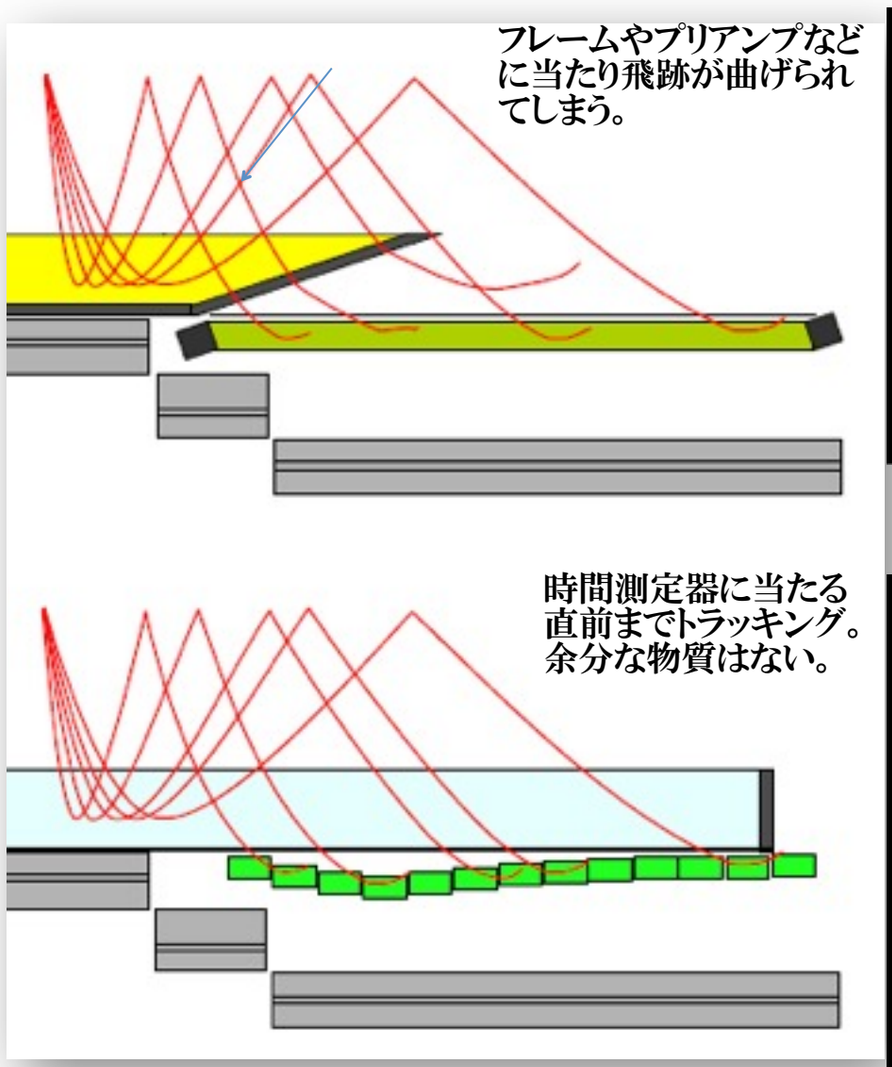


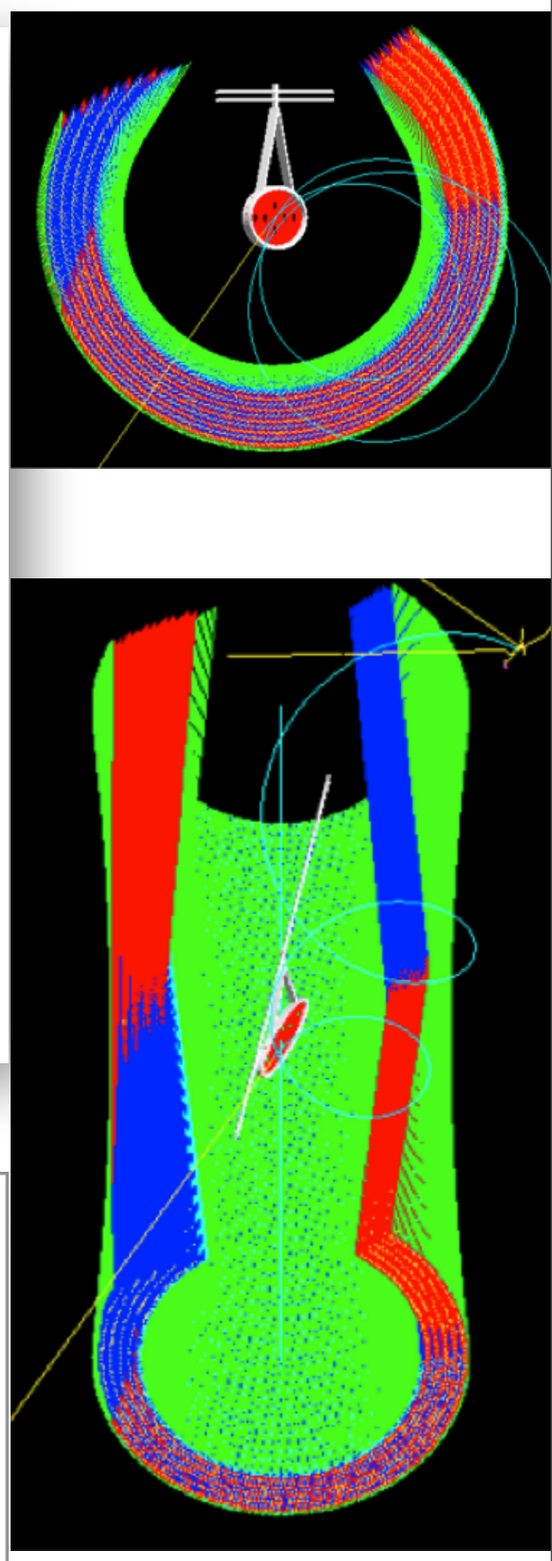
Drift chamber

- Single volume gaseous detector
- Stereo wires along z
- Finer granularity, better resolution
- Larger acceptance DC + TC

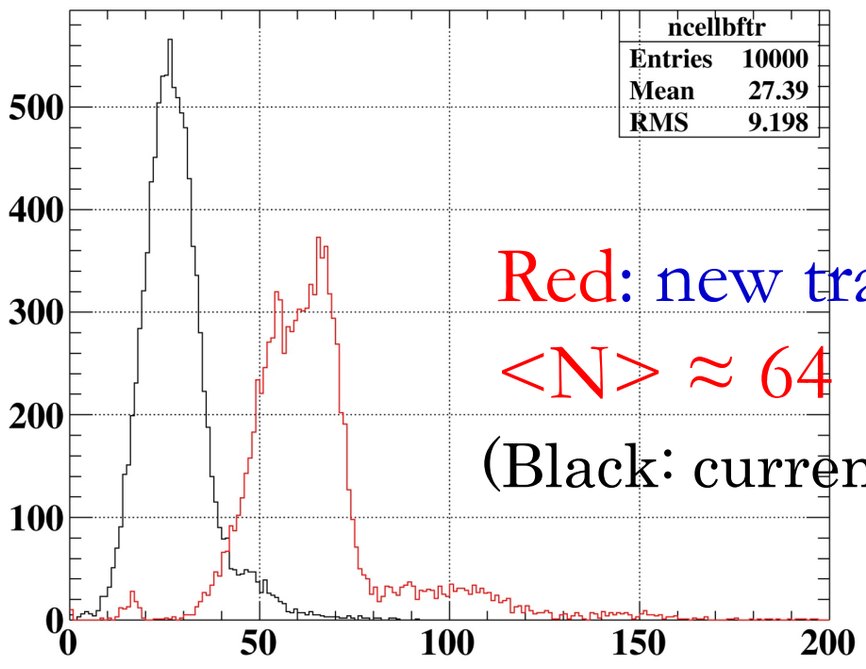
Challenging

Long wires : ~200cm
High rate environment





Large number of hits



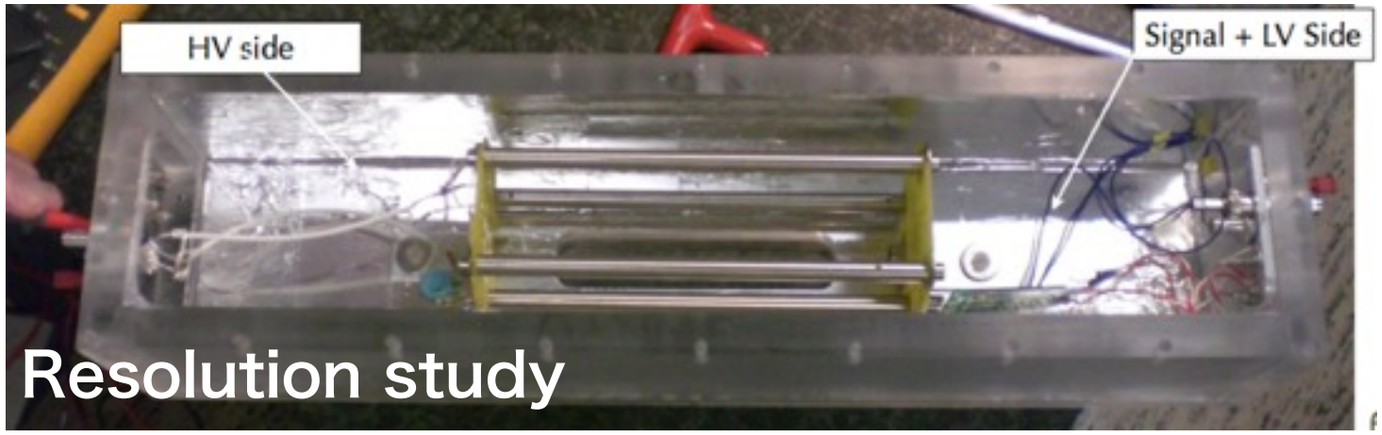
Red: new tracker
<N> ≈ 64
(Black: current one)

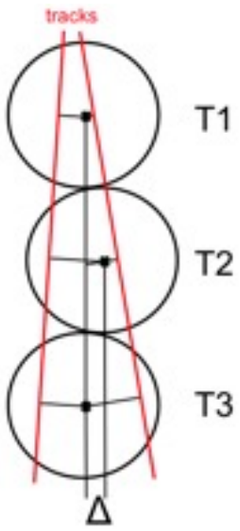
Expected Performance

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%)

DC R&D Status

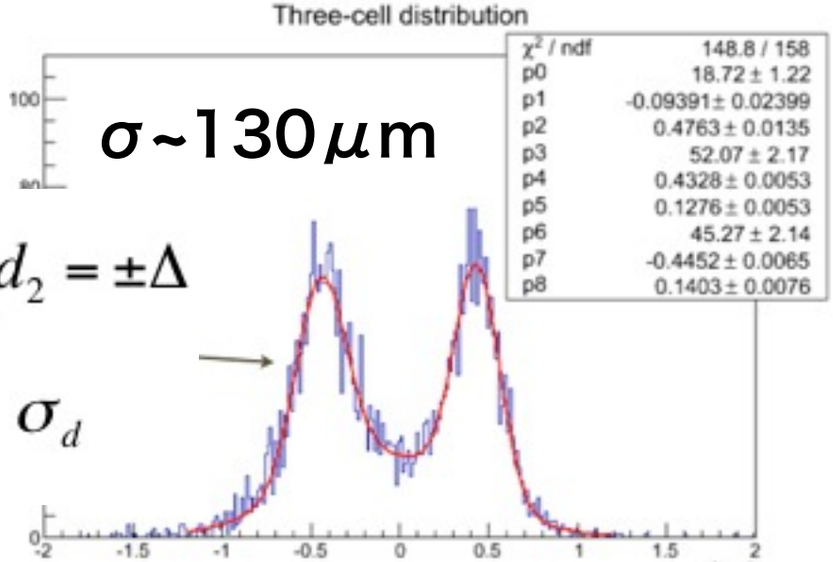
- Many prototypes
  - Single hit resolution
  - Aging
  - Mechanical design & optimize the length etc.

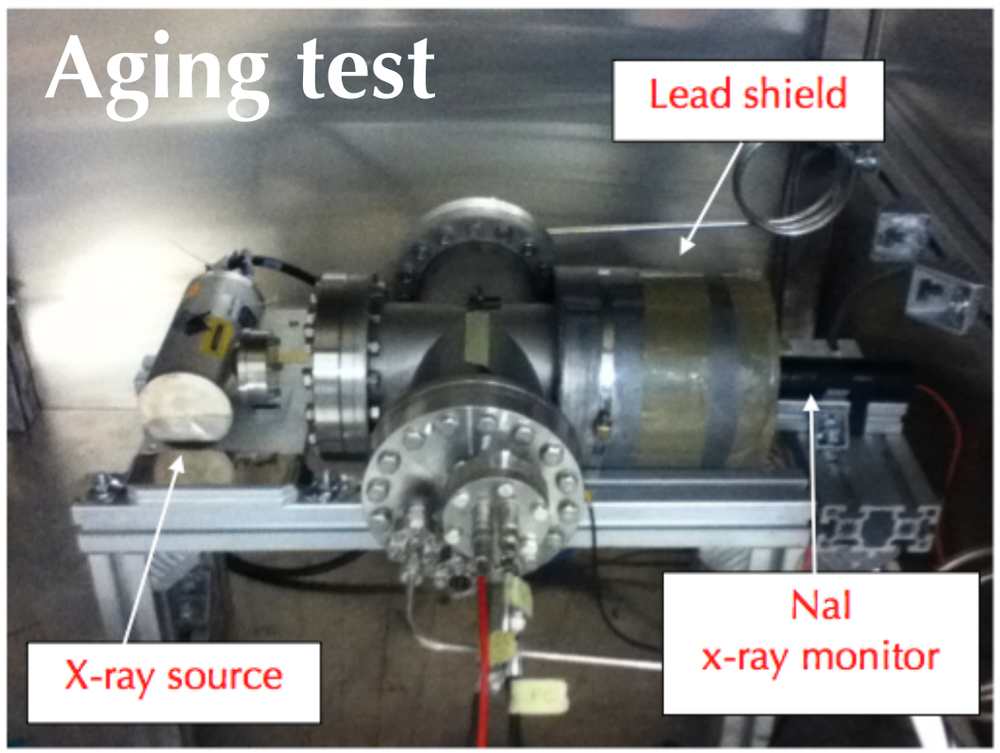




$$\frac{d_1 + d_3}{2} - d_2 = \pm\Delta$$

$$\sigma_\Delta \cong \sqrt{\frac{3}{2}}\,\sigma_d$$

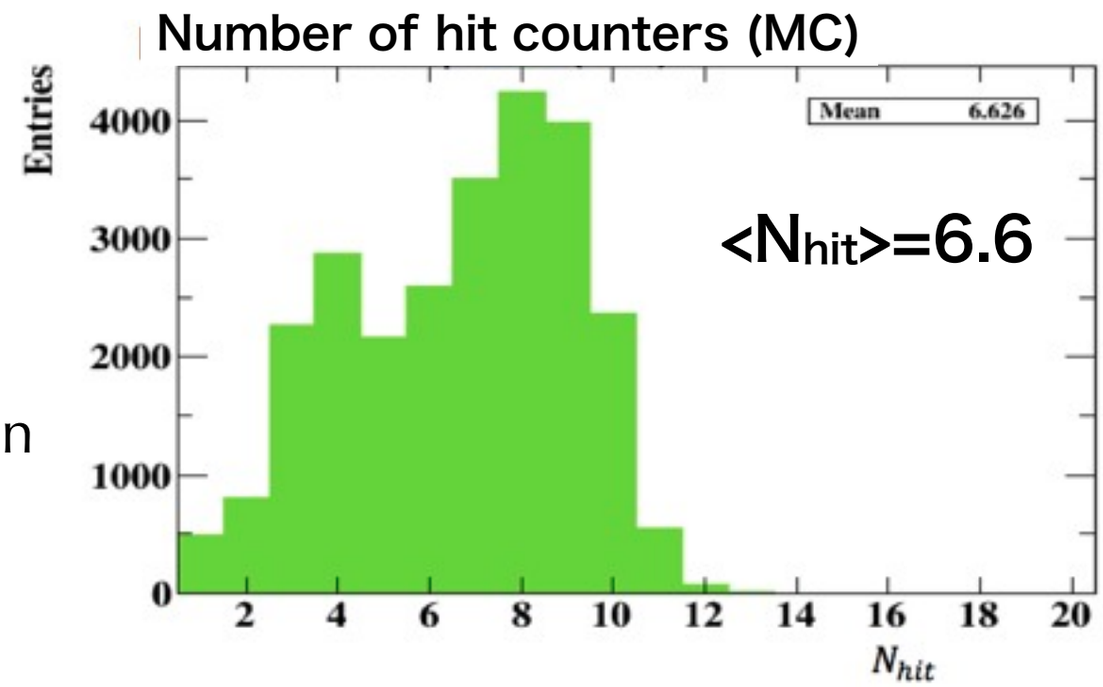


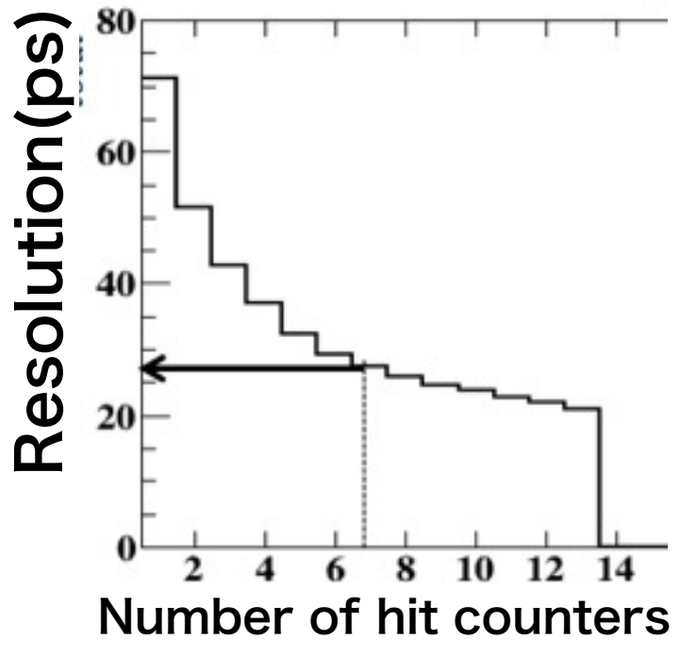


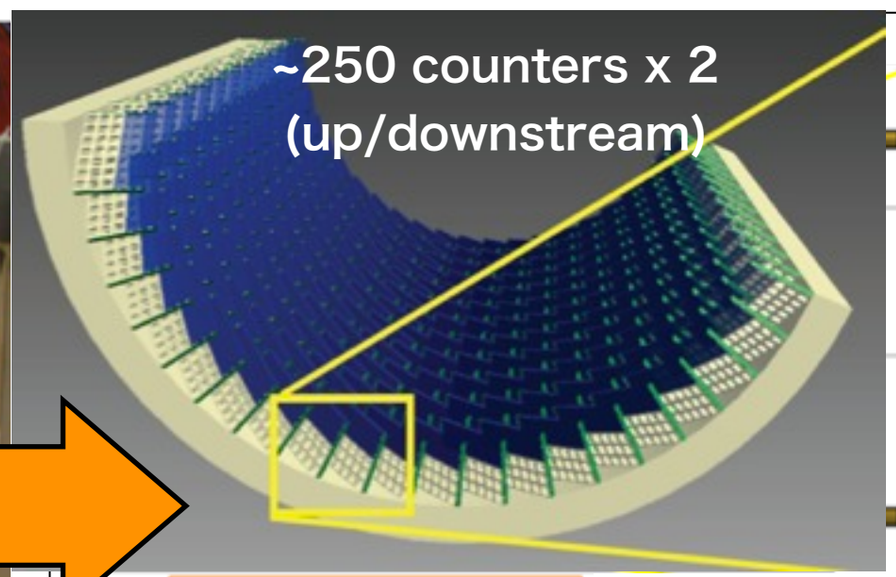
New Pixelated Timing Counter

20pSL1 内山雄祐

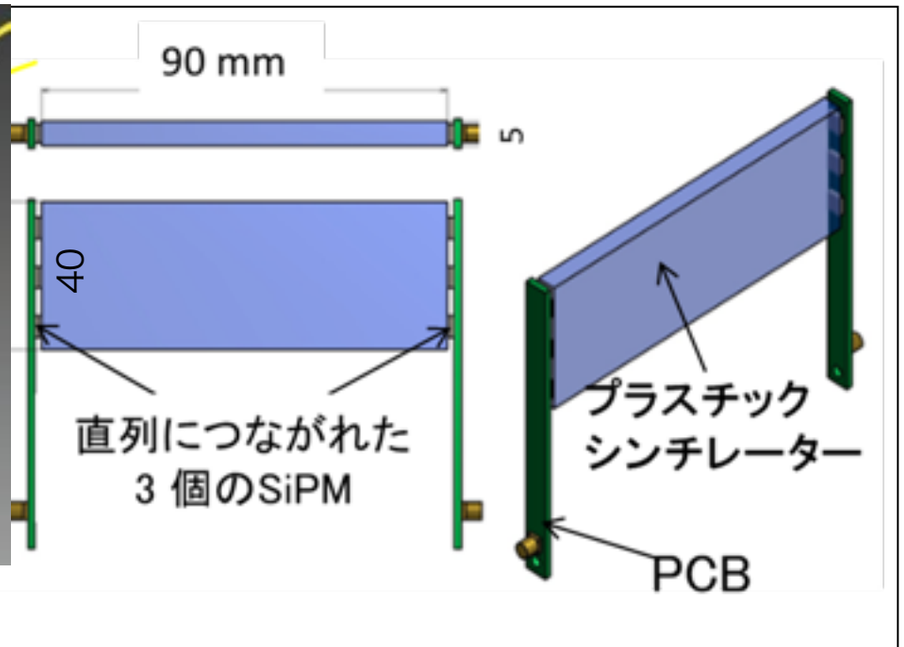
- Array of ultra-fast plastic scintillator counters
- SiPM readout
- high resolution with multiple counter hits
- Expected resolution 30-35ps





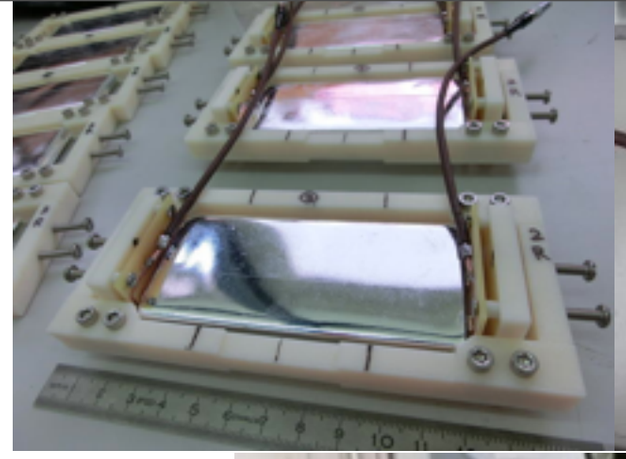


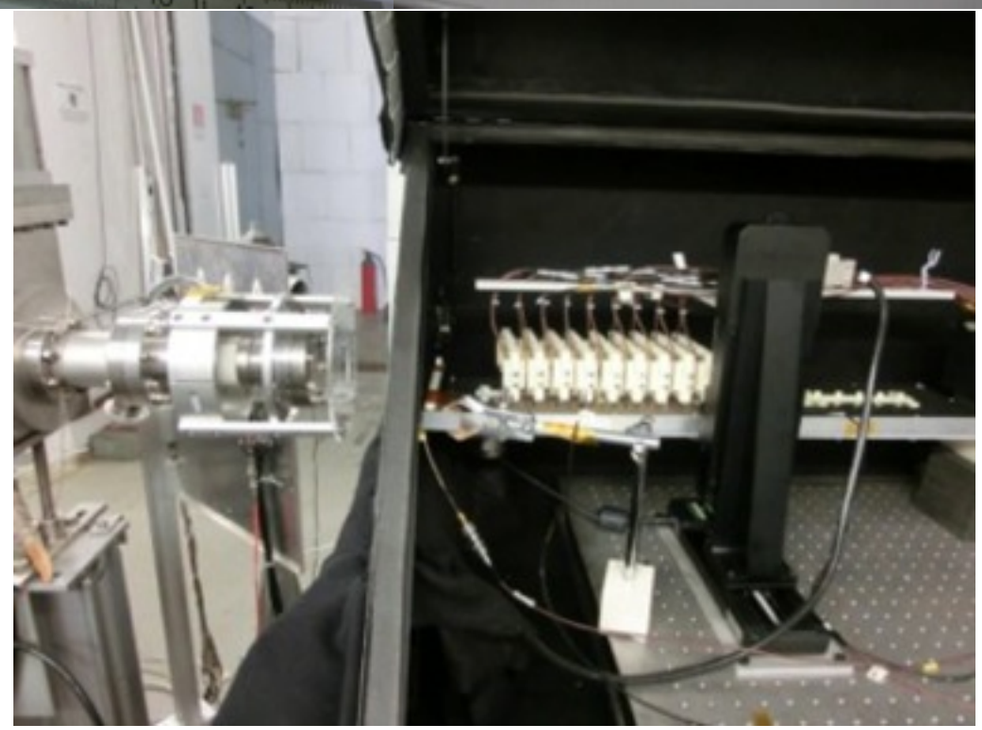
アップグレード



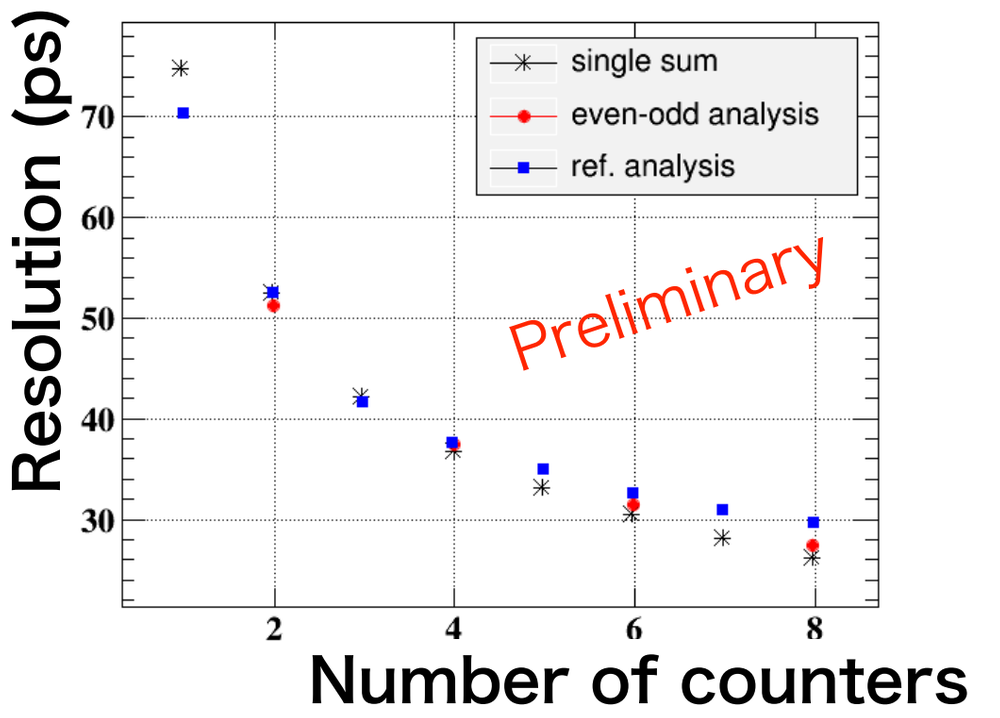
Beam tests @ Frascati

20pSL2 西村美紀



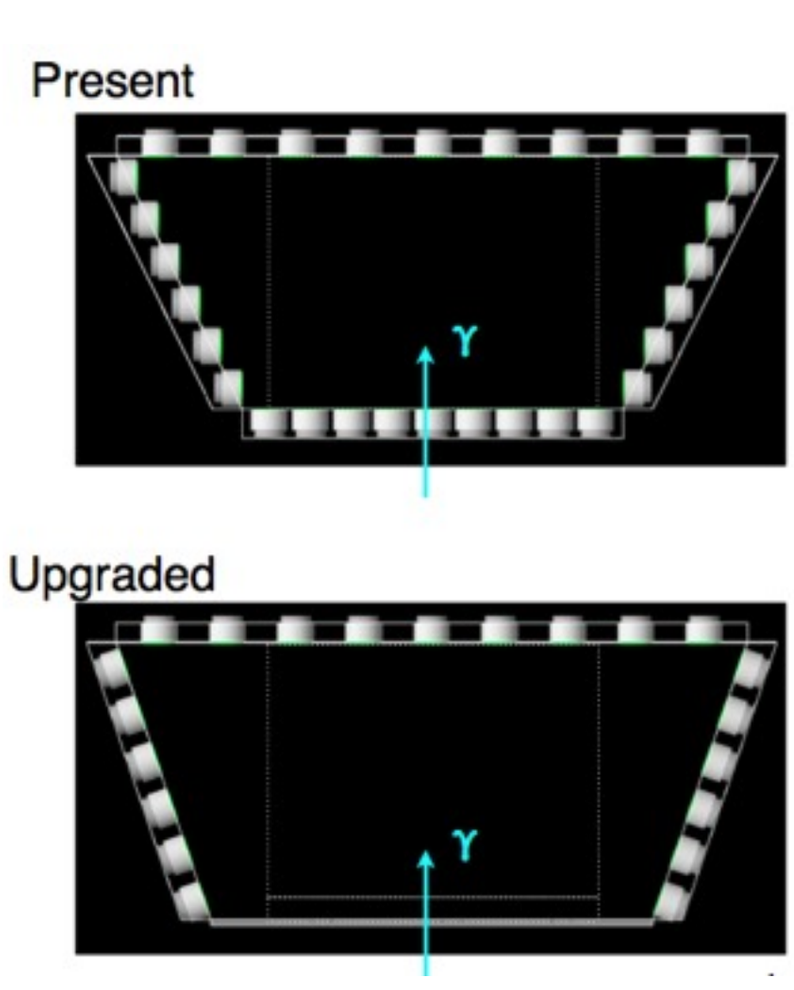


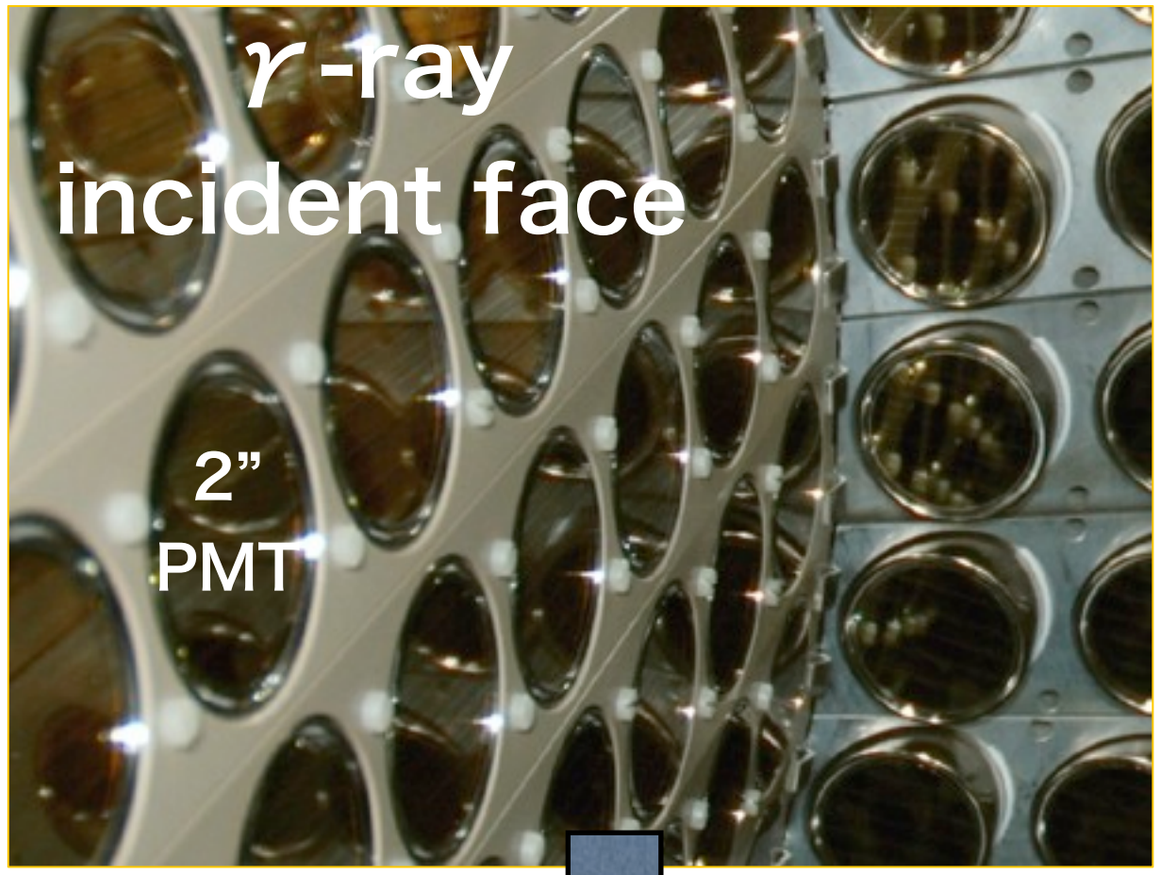
- Single counter resolution ~70ps
  (90x40x5mm^3, BC418)
- Ultimate resolution with multi-counter hit
  - Reduce electronics, calibration contribution, and counter resolution
  - Eight counters(90x40x5mm^3, BC418) with MPPC and six counters with AdvanSiD are prepared (still to be optimized)
- Beam test condition @ Frascati
  - repetition rate : 50Hz
  - Bunch width : 10ns
  - Positron 48MeV
- Resolution improvement as a function of number of counters is confirmed!
  - Measured resolution 30~35ps

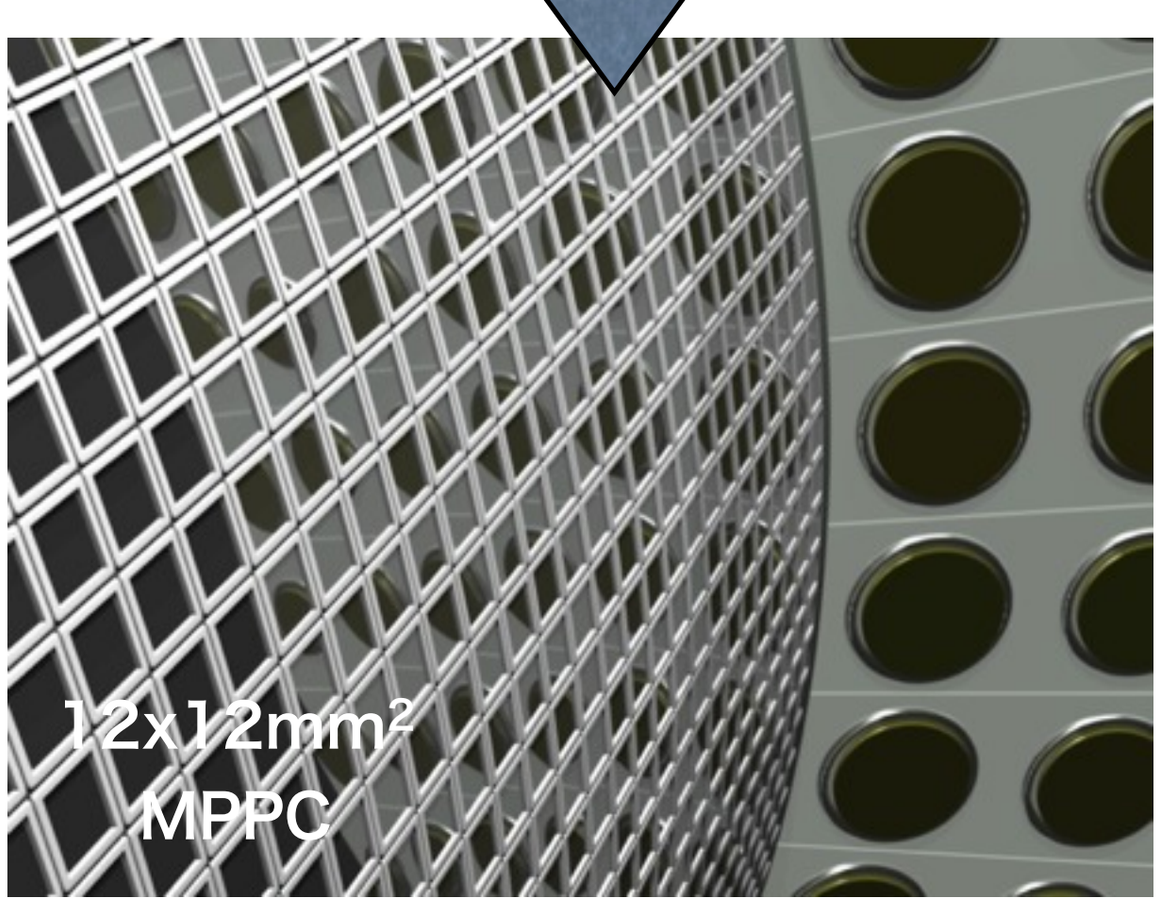


LXe γ-ray detector

- Small photon sensors (12x12mm^2 MPPC) at γ-ray incident face
  - ~4000ch MPPCs instead of 216 PMTs
  - Better position, energy resolutions at shallow events
  - Better identification of pile-up events
- Wider incident face, Change PMT angle at lateral face
  - To reduce shower leakage, better uniformity



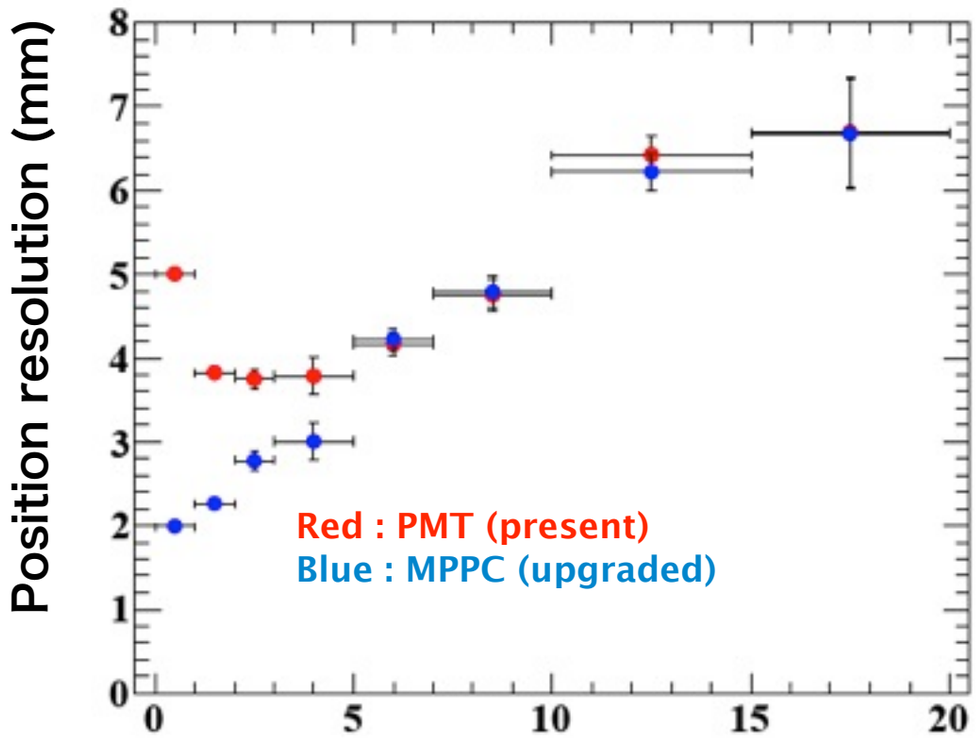




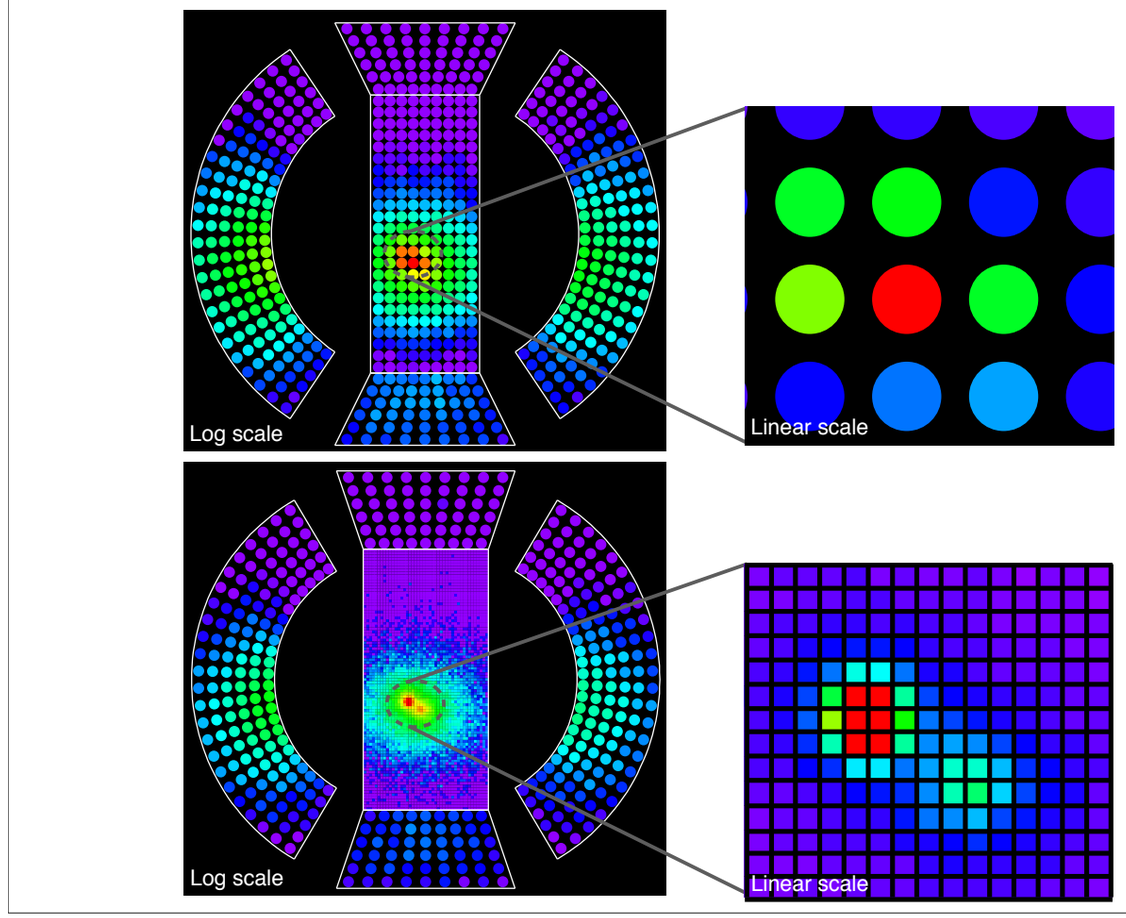
Computer Graphic

Possible improvements

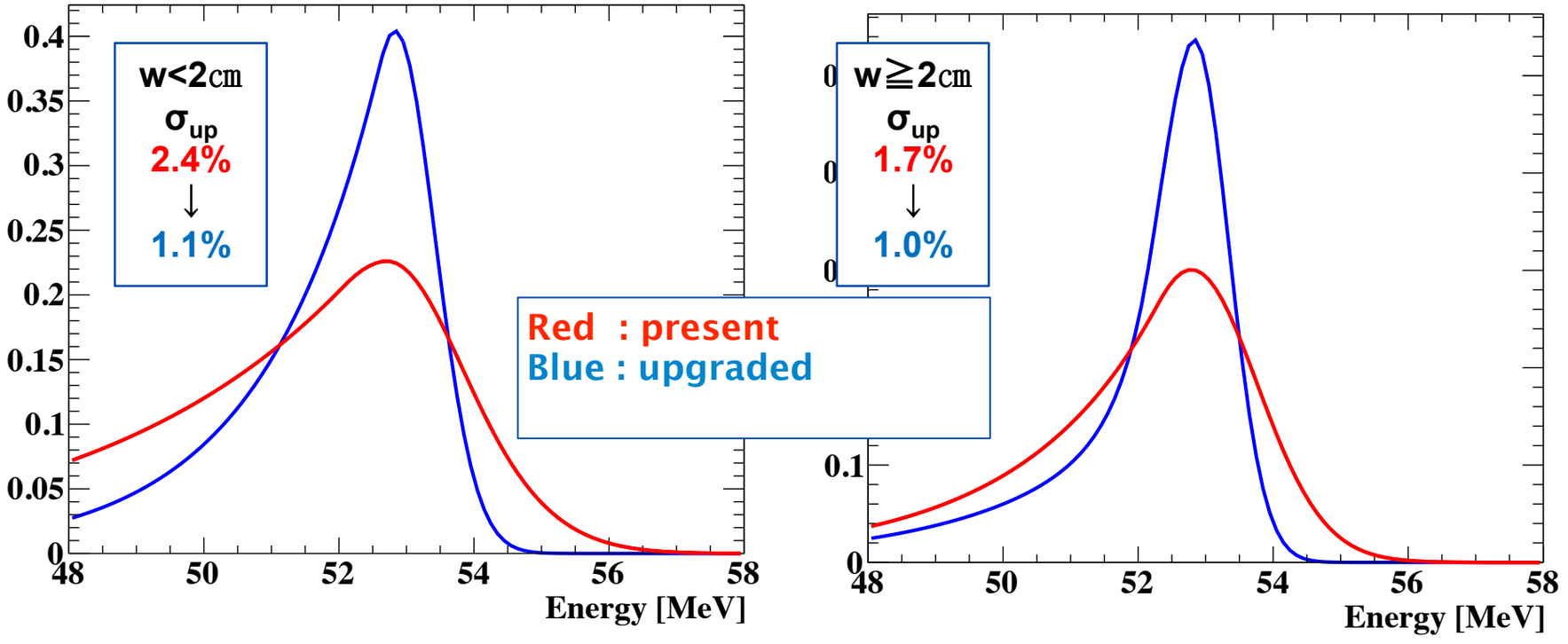
Position Resolution



Pileup identification

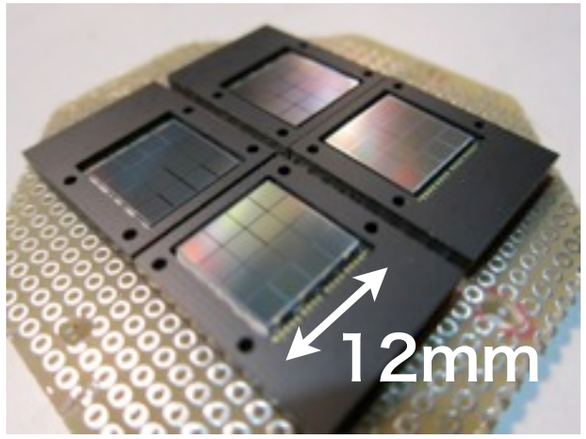


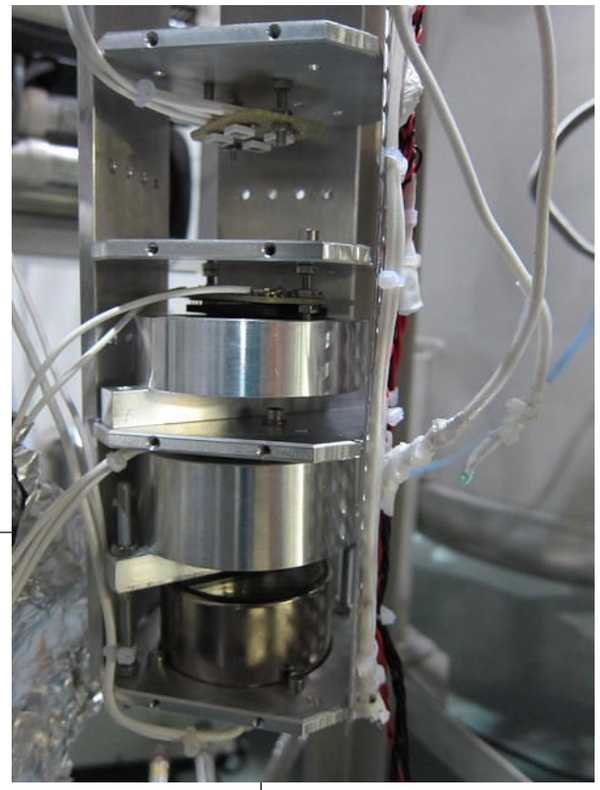
Energy resolution



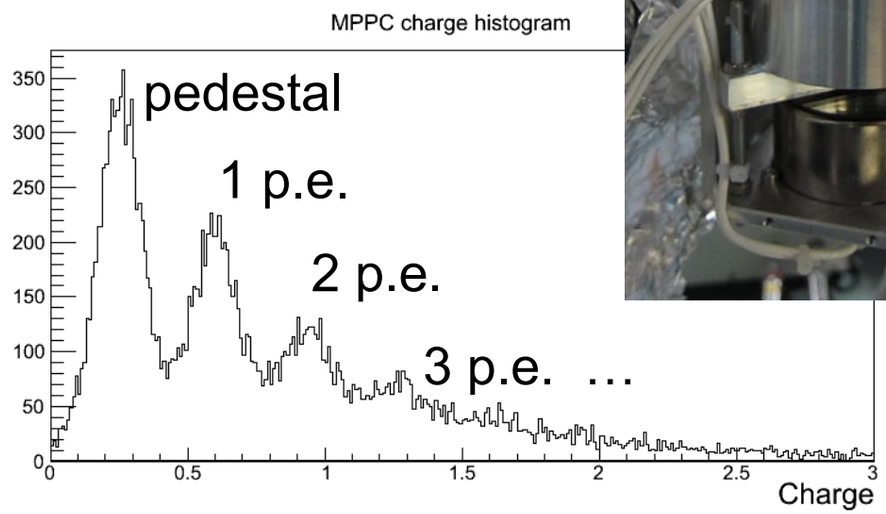
MPPC R&D Status

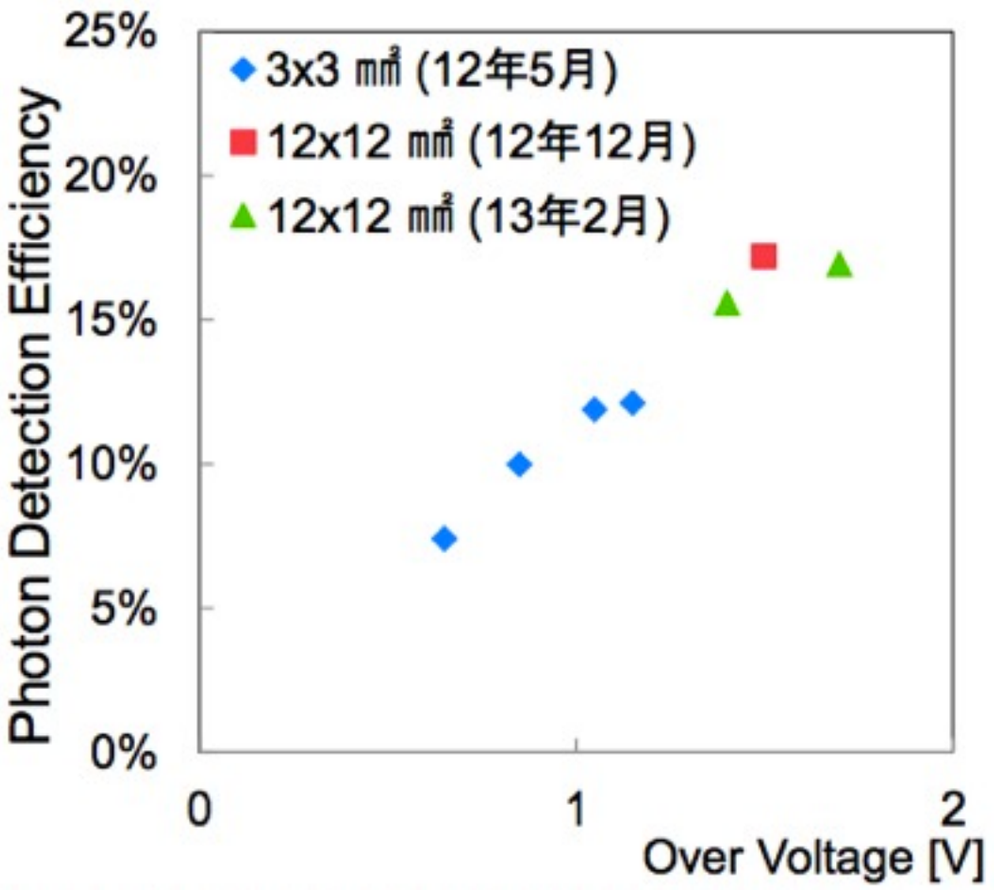
20pSL4 金子大輔





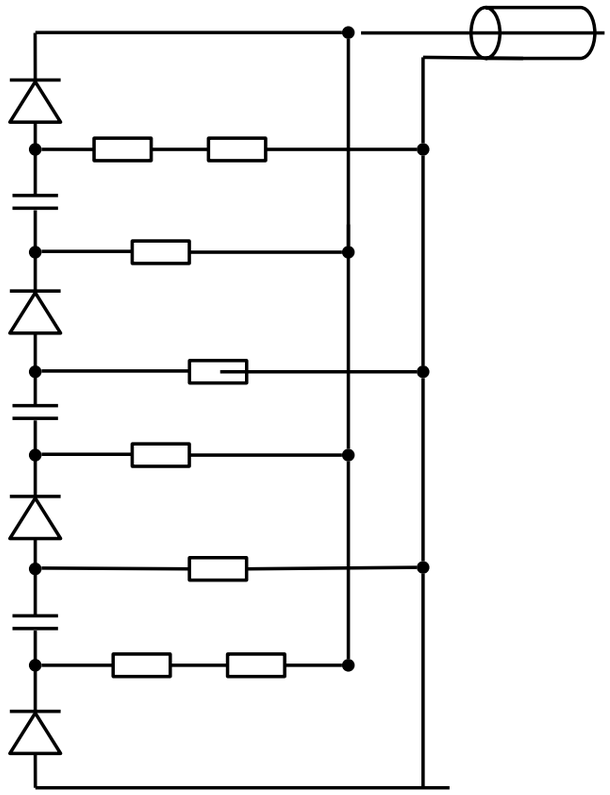
- MPPC development in cooperation with Hamamatsu
- Achieved
  - UV(~175nm) sensitivity: PDE >15%
  - Large area (12x12mm^2), single photoelectron peak resolved
- Remaining issues
  - To reduce long tail (~200ns)

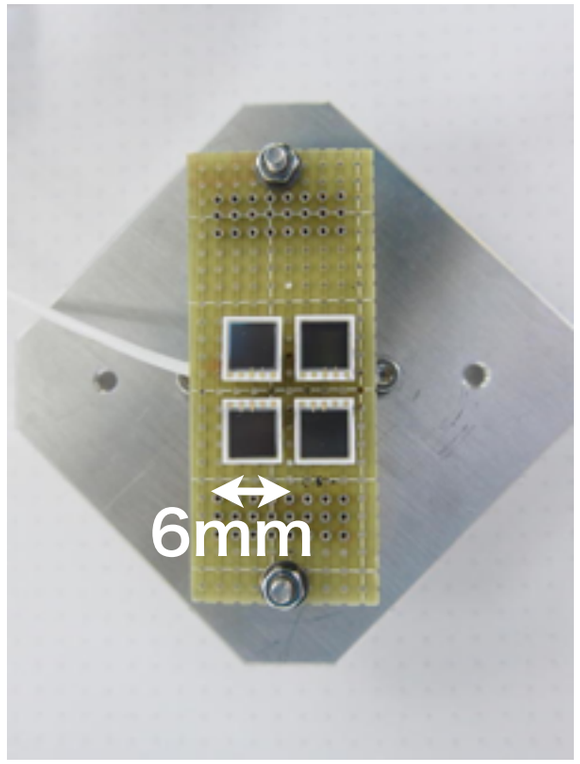


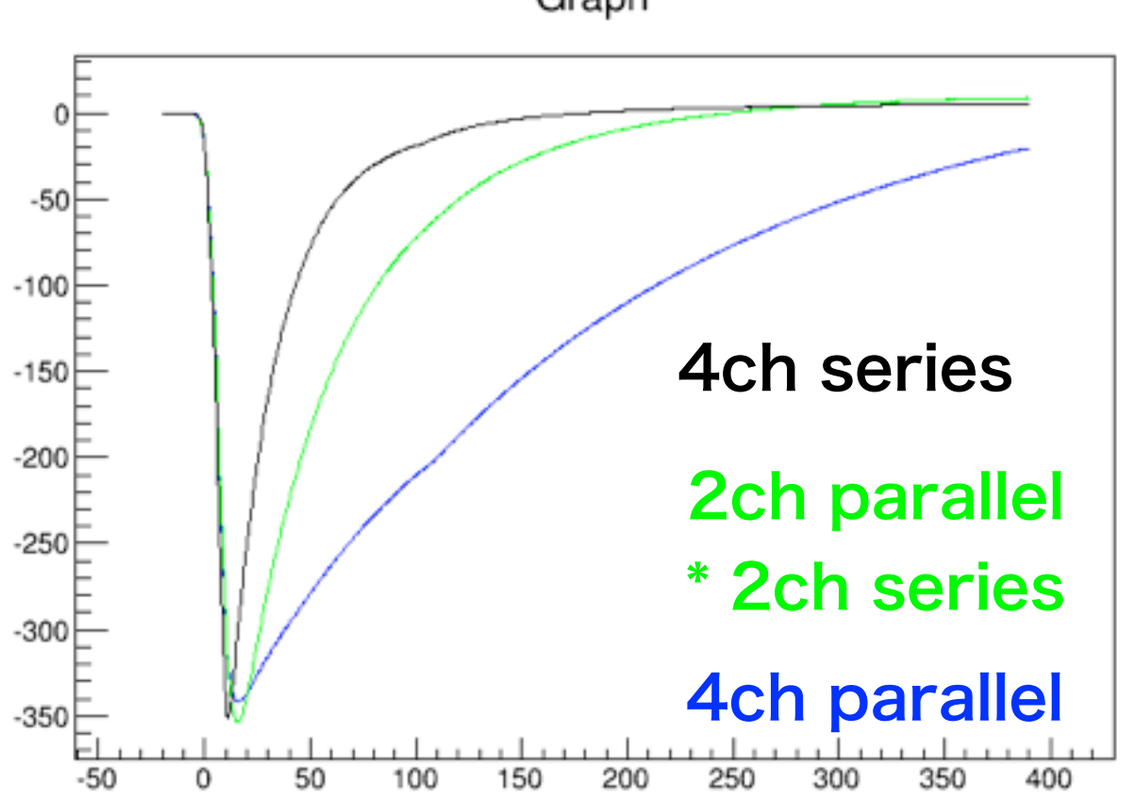


Series or Parallel connection?

- Original plan was a single sensor with 12x12mm^2 large area, but it had a long tail ~ 200ns
- To reduce a sensor capacitance, one sensor can be segmented into sectors, which will be connected in series.
- To simulate the concept works or not, 4 independent 6x6mm^2 samples are connected differently, and the waveforms are compared.
- Succeeded in obtaining shorter tail (30-50ns)!

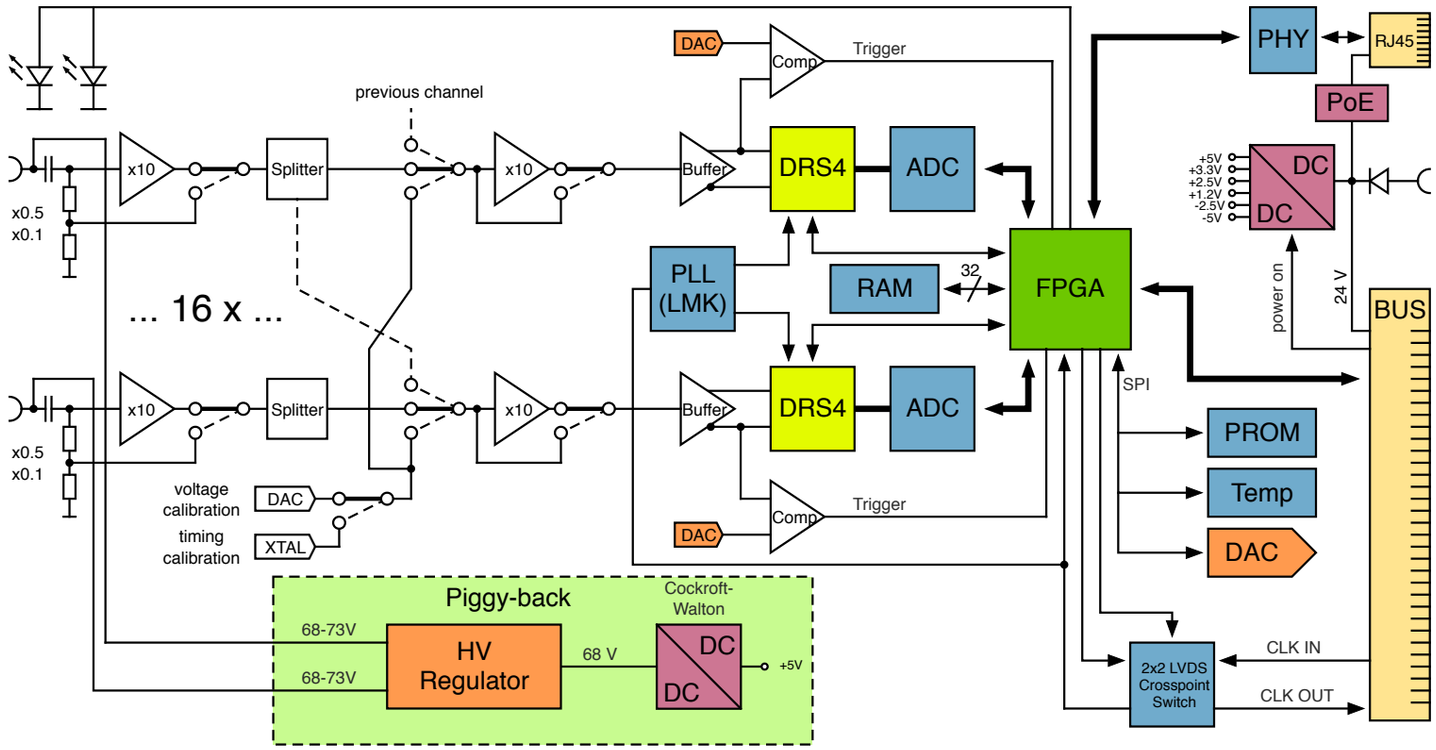


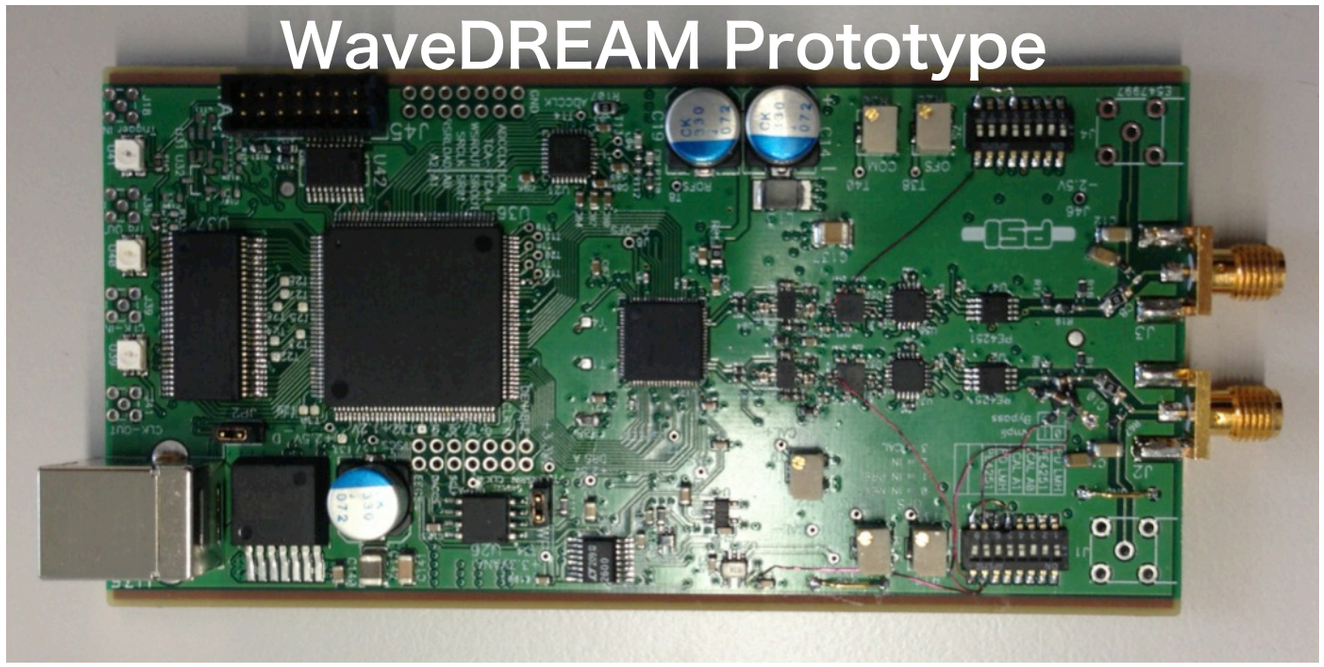




DAQ/Trigger

- More channels, higher rate
  - XEC MPPC (inner face) : ~4000
  - XEC PMT (other faces) : 630
  - pTC MPPC : ~1200
  - DC : 2760 (1GHz bandwidth)
- WaveDREAM
  - Higher density, compact
  - Waveform digitizer(DRS) +bias voltage supply +amplifier+simple trigger

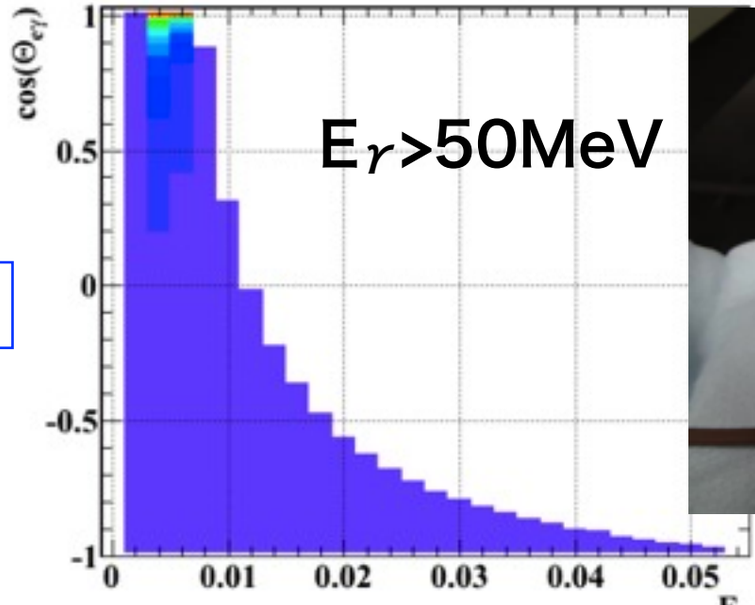


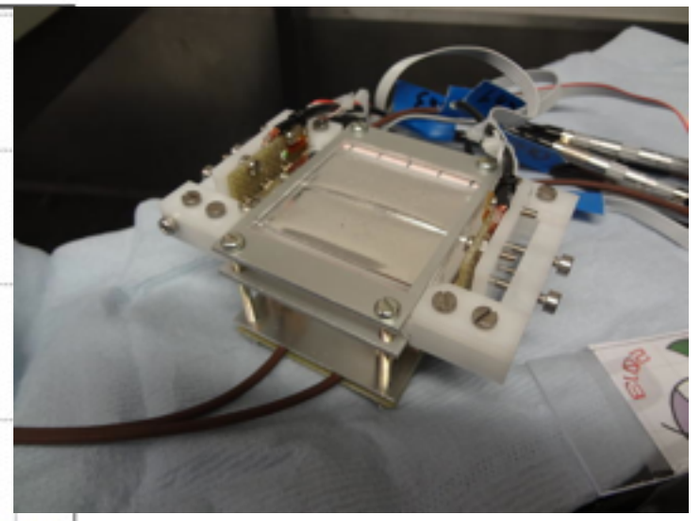


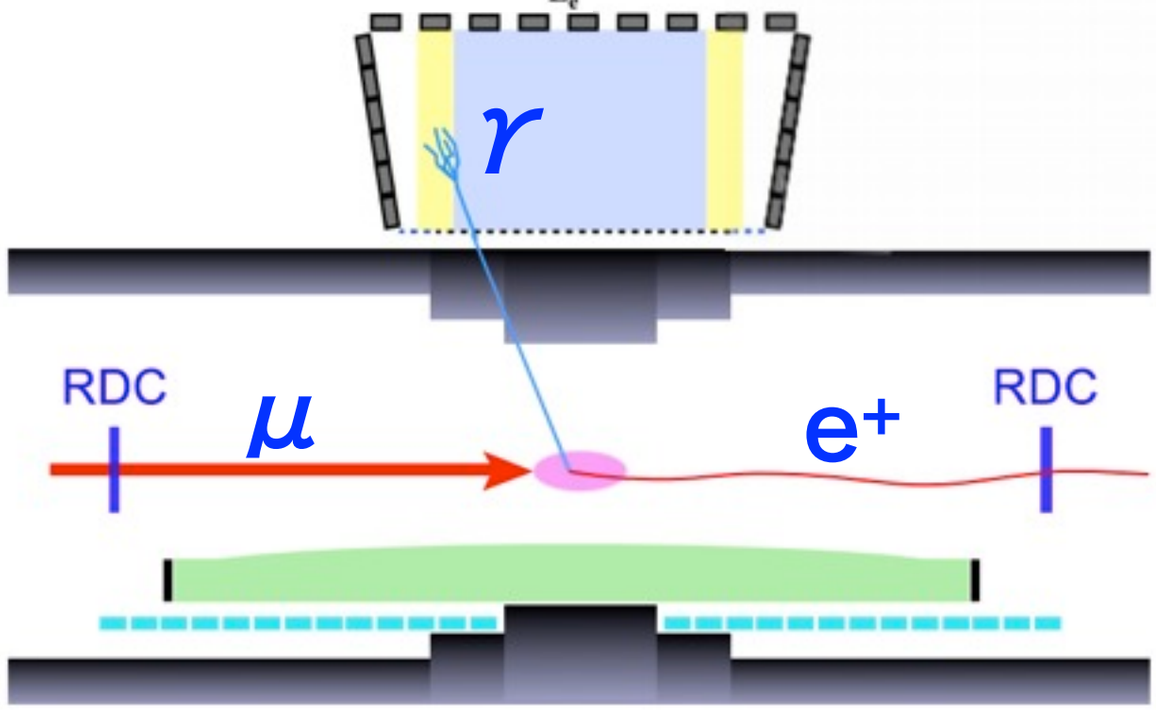
Background tagging detectors

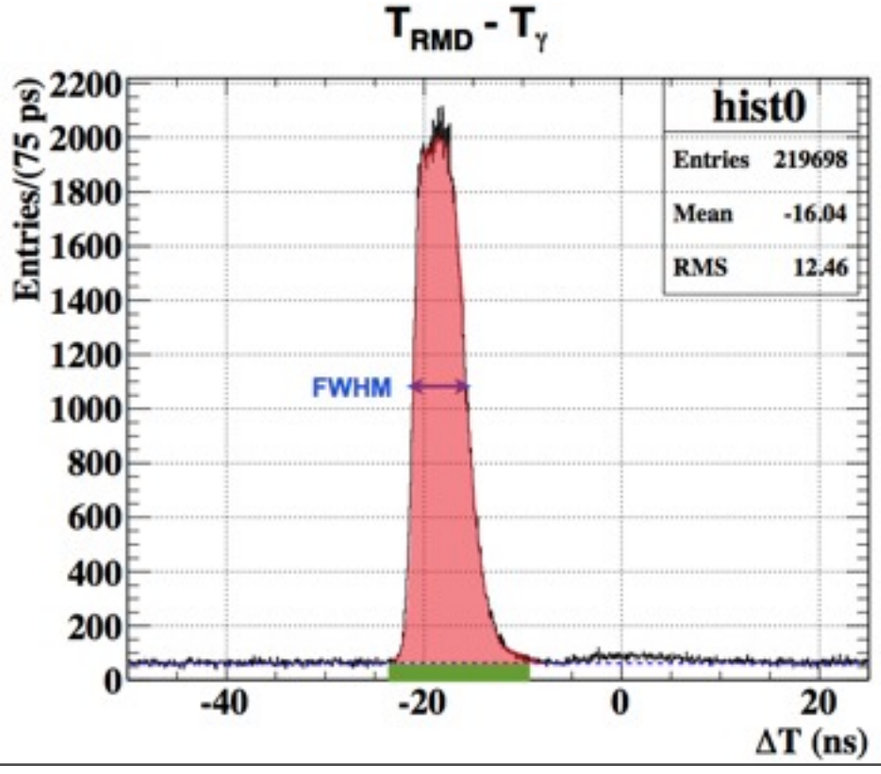
20pSL3 藤井祐樹

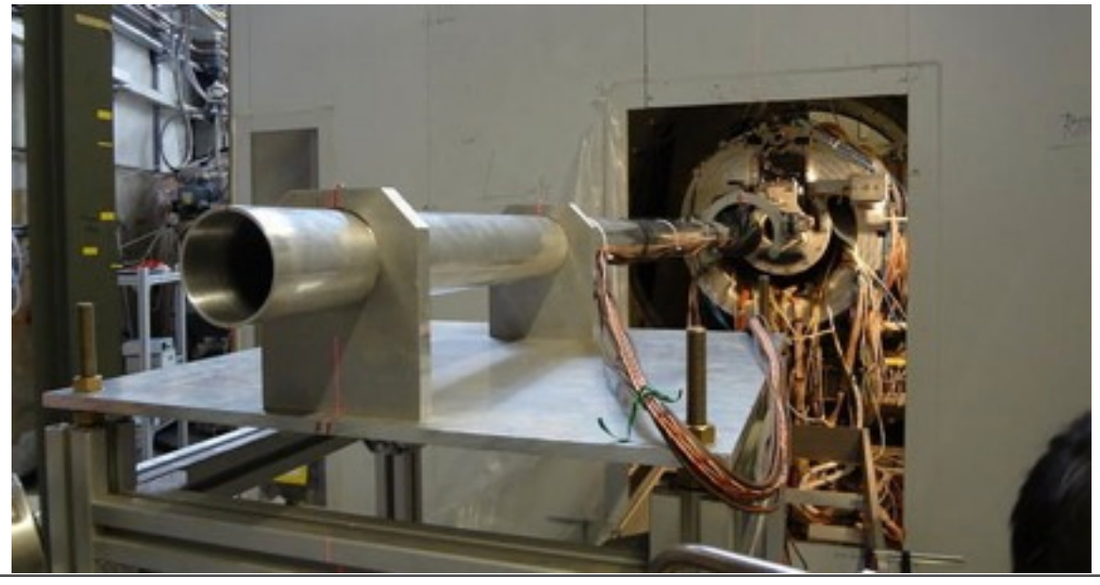
- Tagging radiative muon decay events with ~50MeV γ (low energy e^+ is emitted ~ 4MeV)
- Plastic scintillator + crystal with MPPC readout
- Beam test was performed at the end of MEG beam time in August with prototype









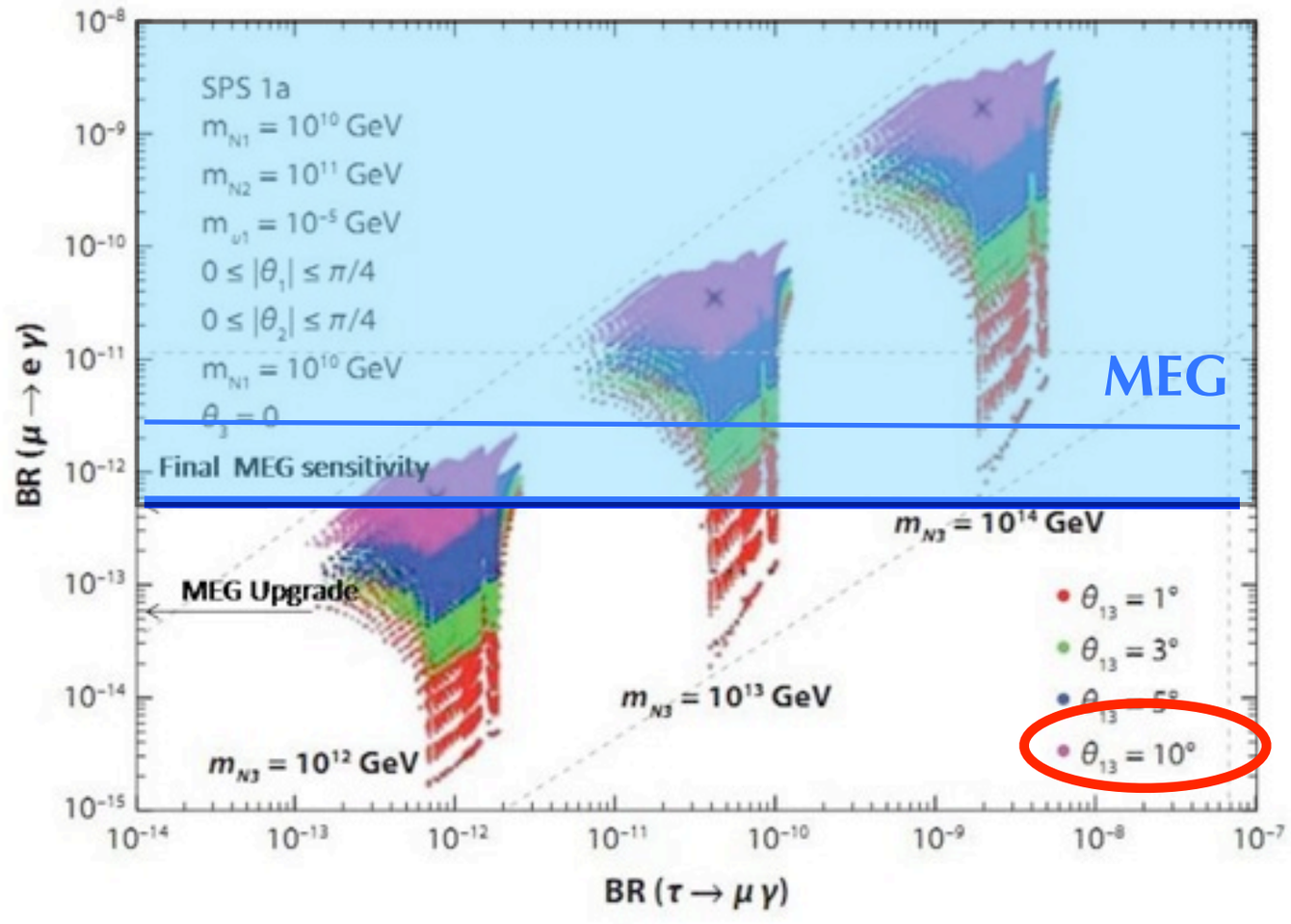


Summary

- The MEG experiment improved the BR(μ→eγ) upper limit this year, 5.7×10^{-13} at 90% C.L.
- MEG physics run finished in Aug. 2013.
- The statistics will be doubled by adding 2012-2013 data, and the analysis is ongoing. The final result will be published next year. Stay tuned.

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

SUSY-Seesaw



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

Likelihood analysis

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

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

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

New DC parameters

- 90% He + 10% Iso-Butane (iC_4H_{10})
- Spatial resolution estimate ~130μm
- Momentum resolution ~ 130keV
- Angular resolution ~5mrad
- DC-TC matching eff. ~ 90%
- 10layers, square projective cells of 0.7cm, stereo angle of ~8 deg with respect to Z (z resolution ~ 7 times the transverse resolution)
- 25 and 40μm anode and field wires
- Total length 180-190cm, outer radium 29.2cm, 1380 anode/7500 field wires
- Positron hit rate density by MC simulation
  - Michel e+ generated over 4π at $1x10^8$ μstop/s, max rate 45kHz/cm2
  - At $1x10^5$ gain and $7x10^7$ μstop/s, the maximum current is 6nA/cm(innermost wire), 3years of running, the maximum integrated charge is 0.4C/cm
  - Free radical polymerization is regarded as the dominating mechanism of wire chamber aging
- Pisa aging up to 0.5C/cm

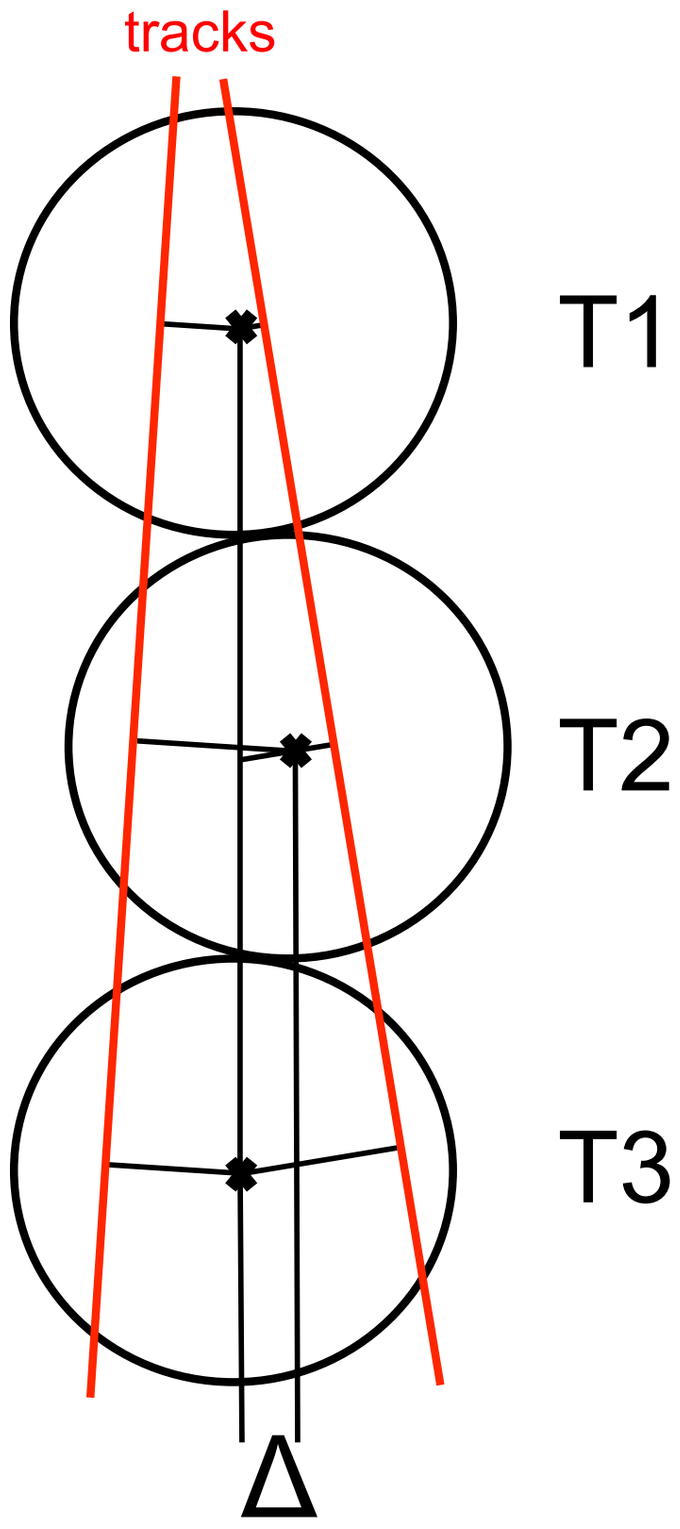
Hit resolution estimate

- Arrange 3 cells with the central one displaced by Δ
- Measure t_i drift times, compute d_i drift distances

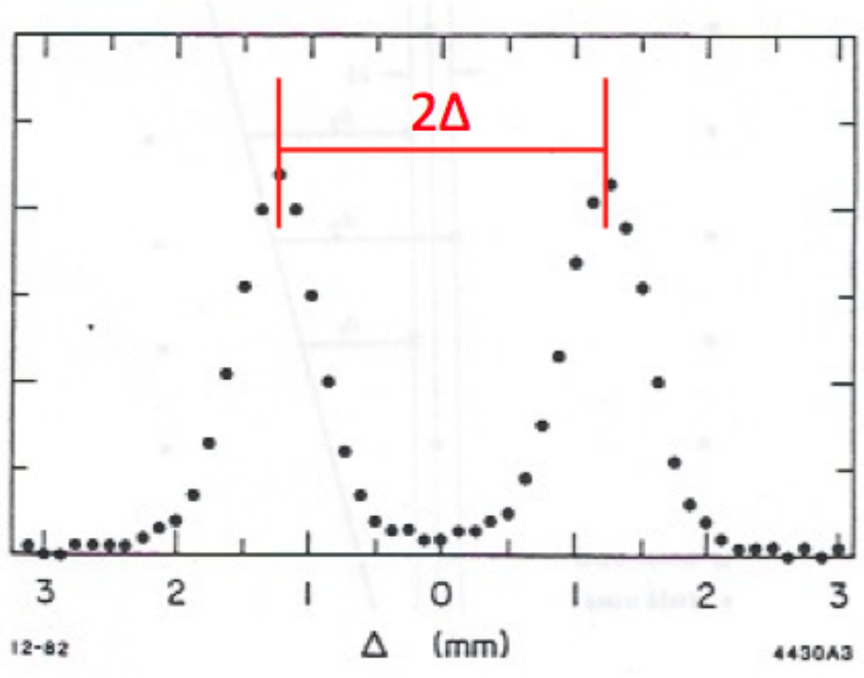
- For straight tracks it results independently of drift distance and angle (almost)

$$\frac{d_1 + d_3}{2} - d_2 = \pm\Delta$$

$$\sigma_\Delta \cong \sqrt{\frac{3}{2}}\ \sigma_d$$



- Measure single hit resolution averaged on all impact parameters and angles if $\sigma_\Delta << 2\Delta$



Scintillator Type

- Test BC418, 420, and 422 which is 90x40x5mm with 4MPPCs

Properties	BC-418	BC-420	BC-422
Light Output [% Anthracene]	67	64	55
Rise Time [ns]	0.5	0.5	0.35
Decay Time [ns]	1.4	1.5	1.6
Wavelength of Max. Emission [nm]	391	391	370
Bulk Light Attenuation Length [cm]	100	110	8

Properties of ultra-fast plastic scintillators from Saint-Gobain

Scintillator Type	Single Resolution (ps)
BC422	51.2
BC420	57.7
BC418	55.8

Calibration

MEG
Mu-E-Gamma Collaboration

- **Important item for actual operation**
- **Laser calibration**
  - **Light pulse from a laser system**
    - Hamamatsu PLP10-040
      - 70 ps width, 405 nm wavelength
  - **Distribute via optical fibers**
- **Michel (track-based)**
  - **in-situ calibration using data itself**
  - **Develop a technique similar to position alignment**
    - like Millipede or Linear-fit algorithms
    - to calibrate all channels simultaneously
- **Finally, with RMD**

Example I

"Accidental" and "real" AIF candidates in the same event: