MEG II 実験の現状とその展望

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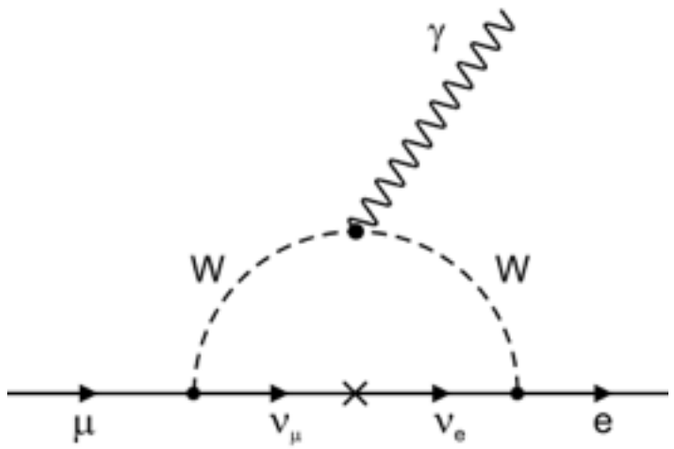
Lepton Flavor Violation

- The Standard Model is completed after the discovery of the Higgs boson.
- However, many parameters and issues remain in the SM.
- Is there new physics beyond the SM?
- No discovery of new physics from the LHC results (yet).
- Lepton flavor violation
  - Neutrino : Neutrino oscillation is a lepton flavor violating process.
  - Charged lepton : No LFV has been observed yet. Why?

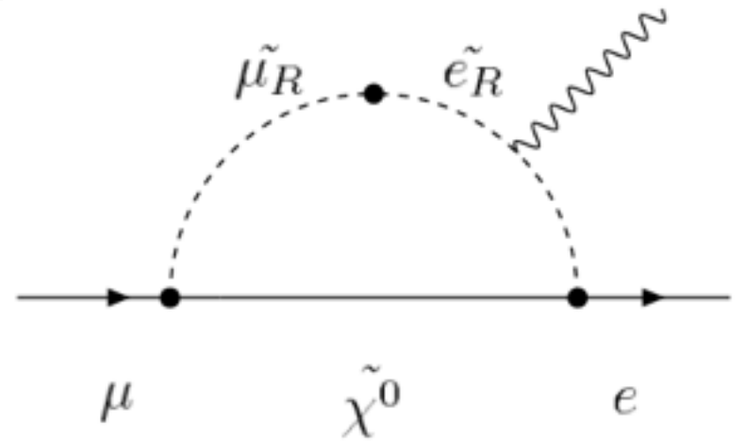
SM+M_ν



In SM with neutrino mass, BR(μ→eγ)~10^{-54}
(No background from SM!)

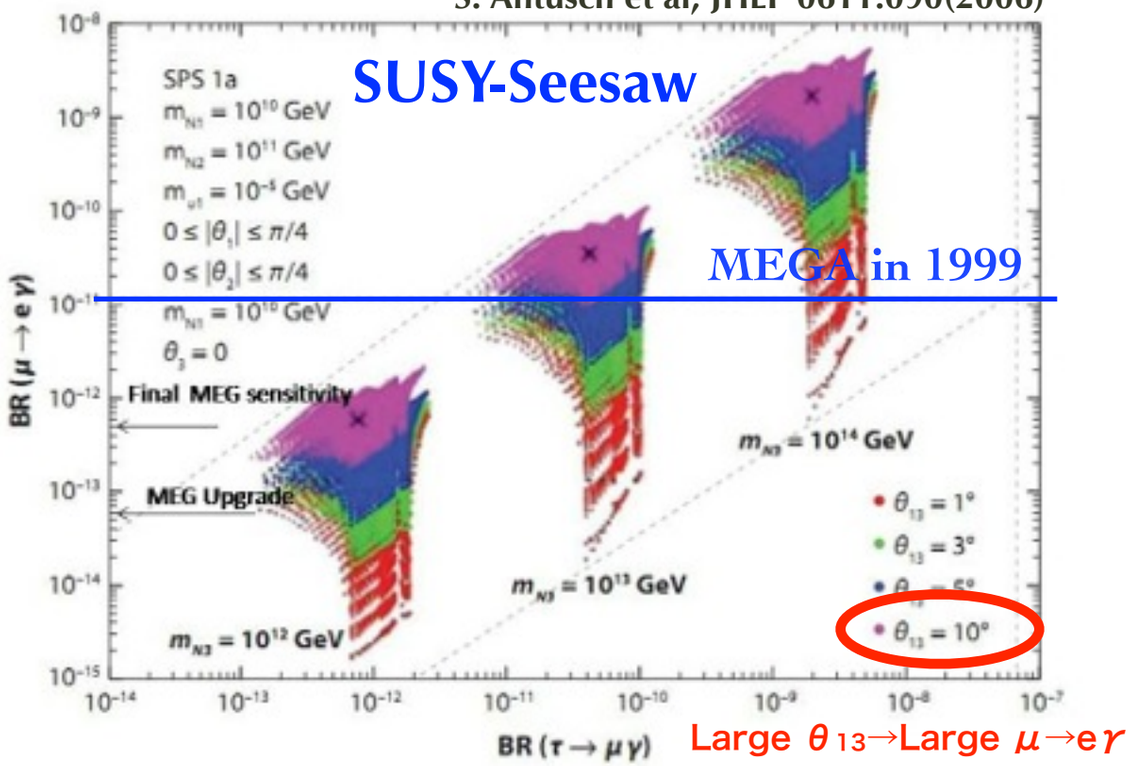
Observation of μ→eγ decay is a clear sign of new physics beyond SM

New physics



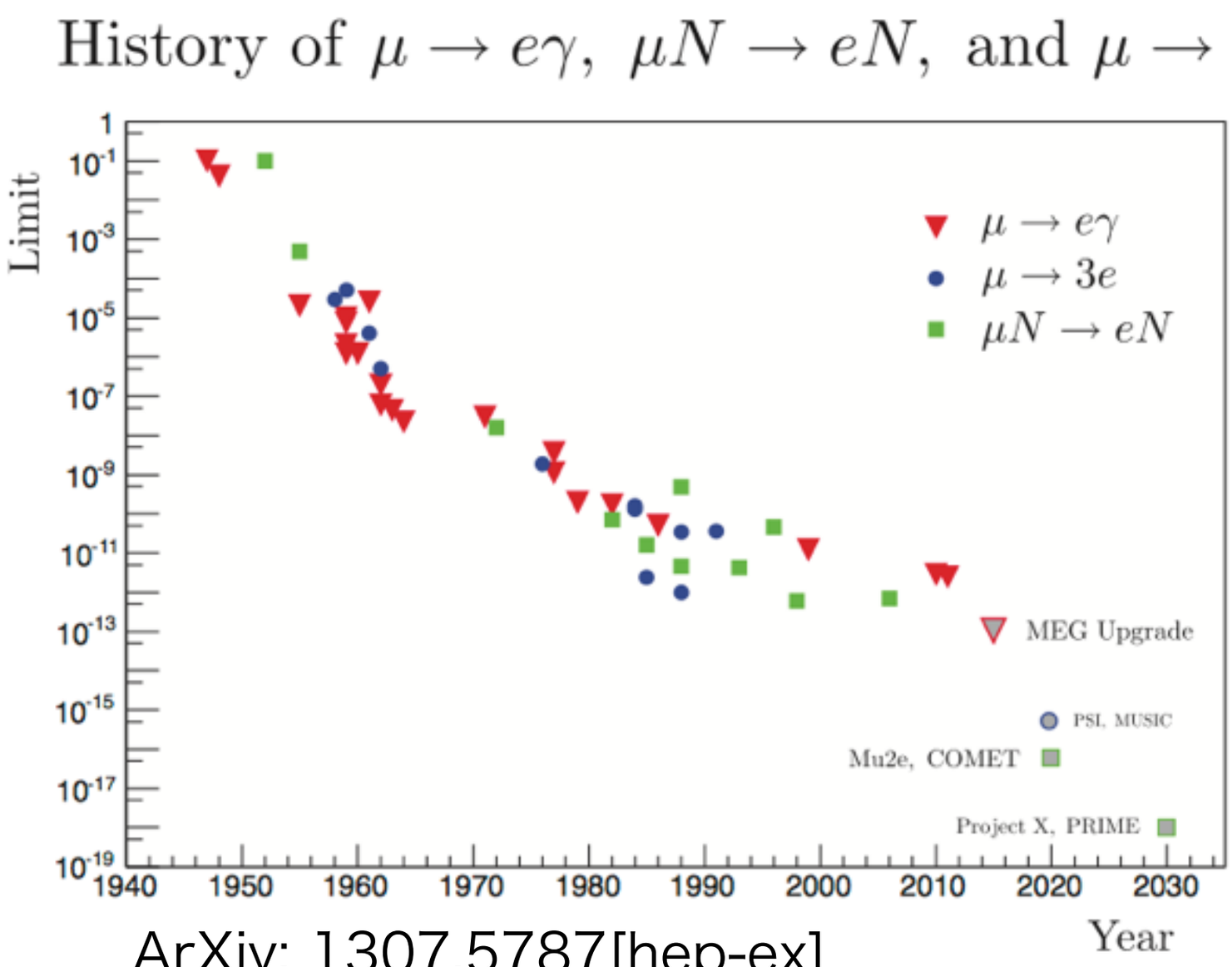
Many new physics such as SUSY-GUT, SUSY-seesaw, Extra Dimensions etc. predict large BR(μ→eγ)

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



Search for new physics with ultimate sensitivity and with not very large experiment quickly!

Muon LFV



ArXiv: 1307.5787[hep-ex]

金子大輔　18pSJ4

- μ→eγ
  - 5.7x10-13 @90% CL upper limit from 2009-2011 data
  - analysis ongoing with full statistics
  - MEG II
  - Ultimate μ→eγ experiment?

内山雄祐　18pSJ3

- μ→e conversion
  - COMET, DeeMe in Japan
  - Mu2e in USA

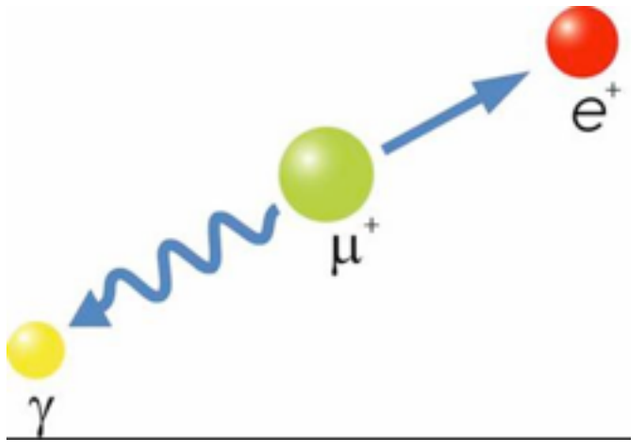
- μ→3e
  - at PSI

- Many experiments will start soon.

- Once LFV process is discovered, other inputs will also be important to know new physics

μ→eγ signal & background

Signal

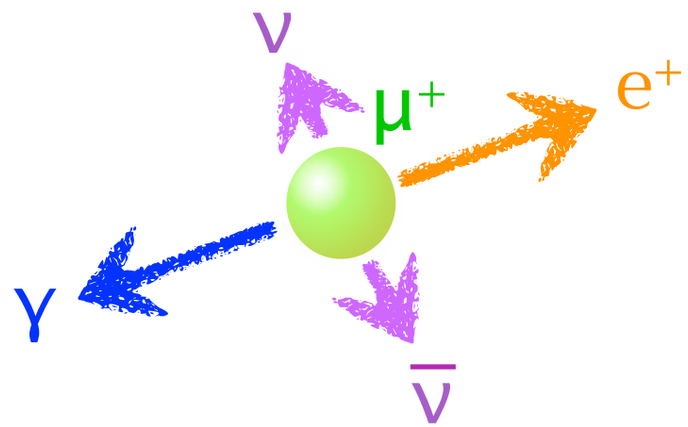


- Simple two body decay

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

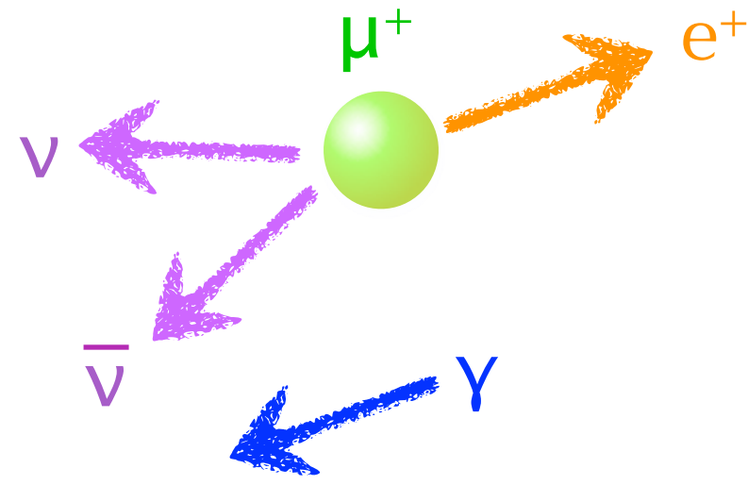
$\Theta_{e\gamma}=180^\circ,\ T_\gamma=T_e$

Radiative muon decay background



- if two neutrinos have low energy and e+ and γ are emitted back-to-back
- timing coincident, can be used for timing calibration

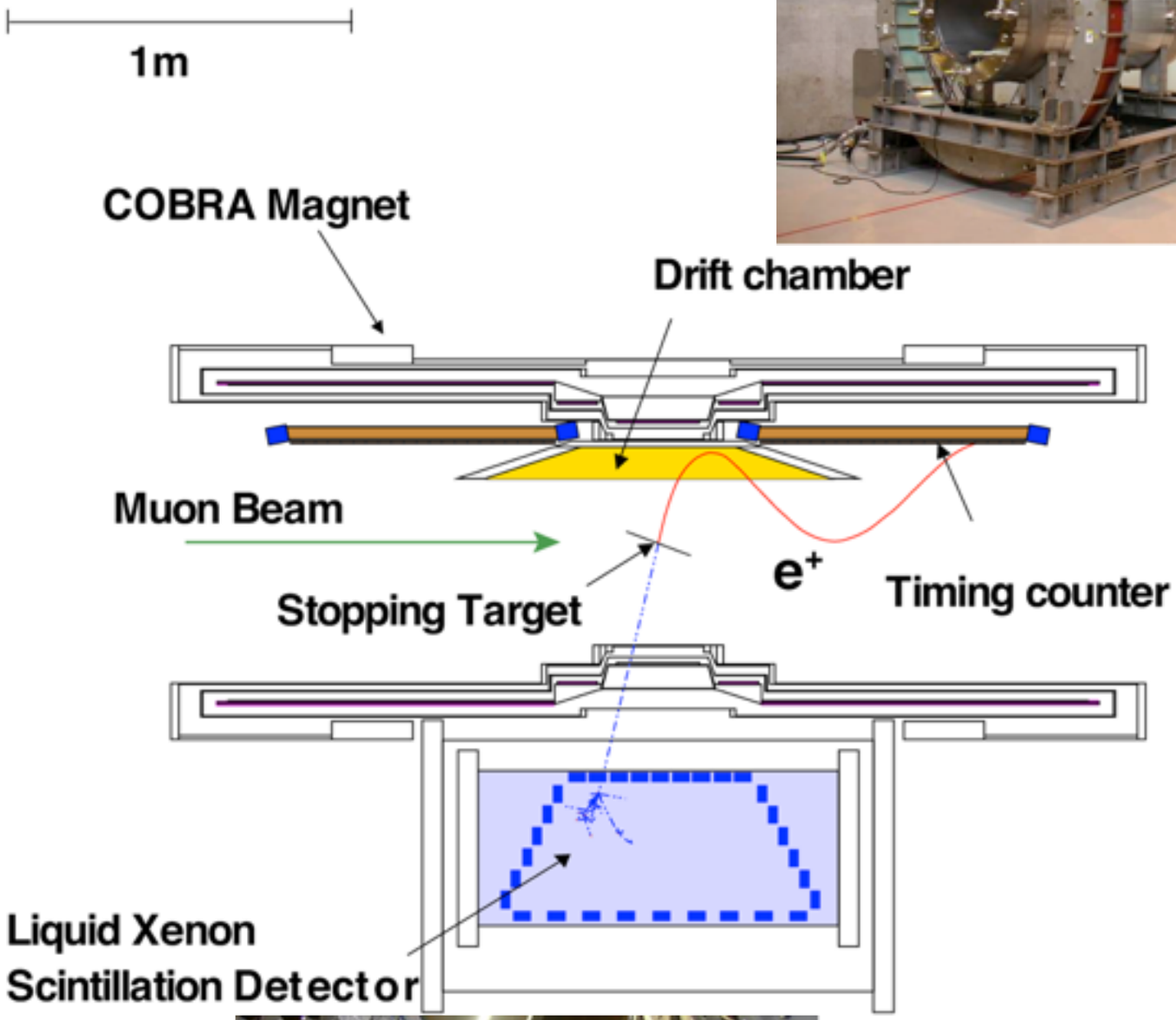
Accidental background

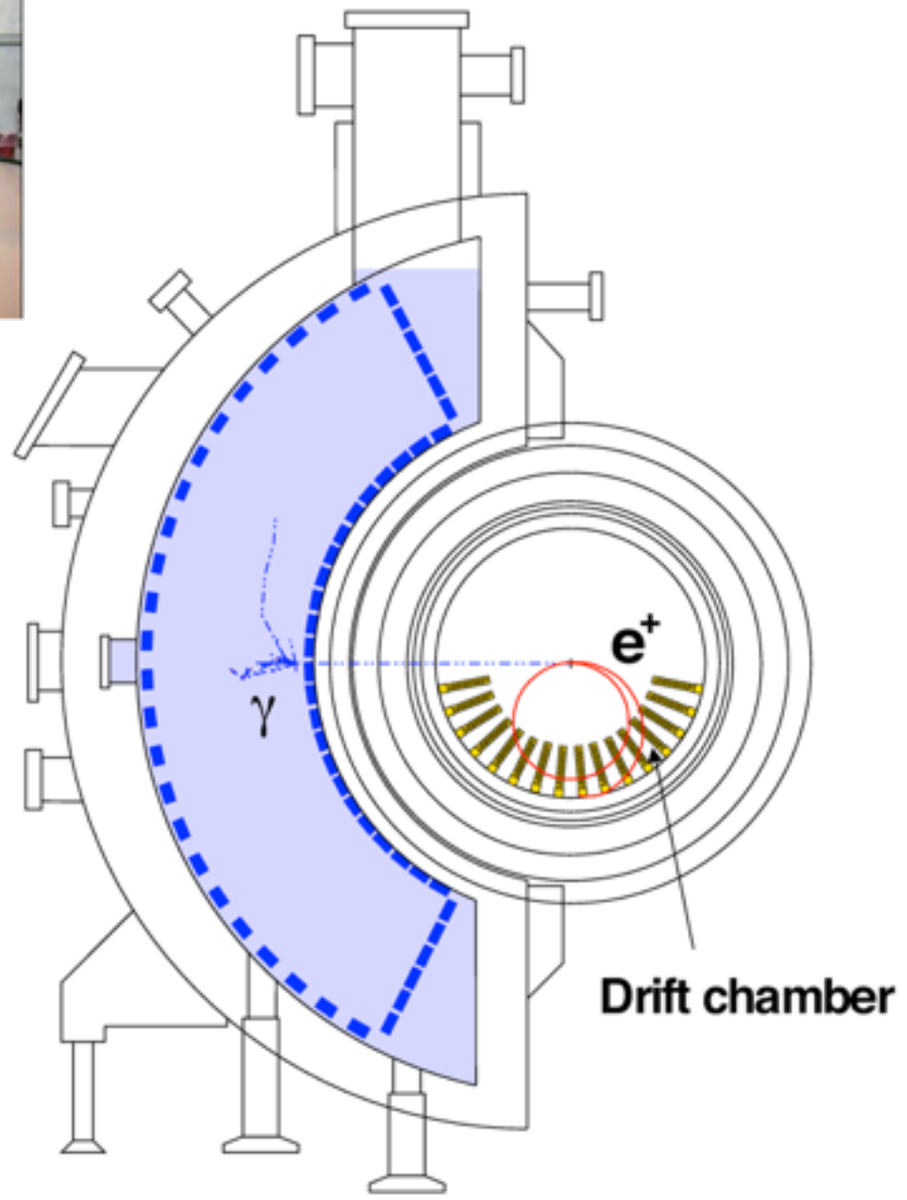


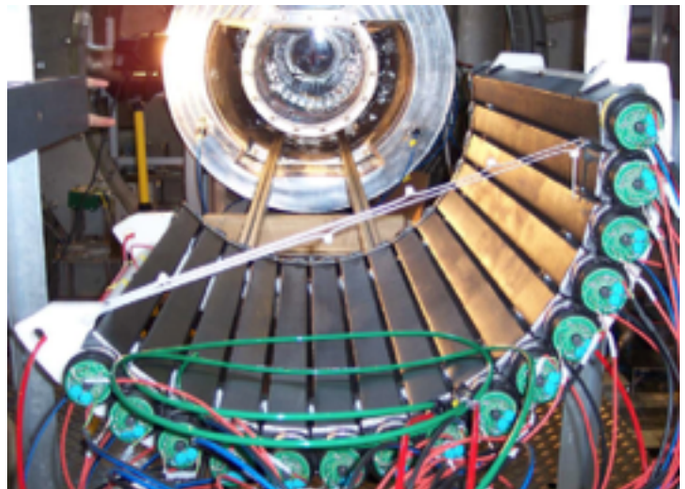
- Usual muon decay Michel e^+ + random γ from RMD/ Annihilation in flight (AIF)
- dominant for us
- To get good sensitivity, all the resolutions should be good!

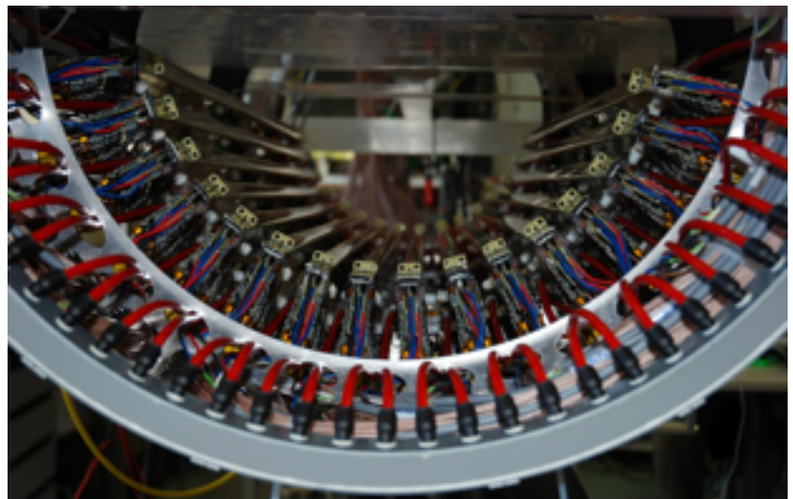
$N_{acc} \propto R_\mu^2 \times \Delta E_\gamma^2 \times \Delta E_e \times \Delta \Theta_{e\gamma}^2 \times \Delta t_{e\gamma} \times T$

MEG experiment

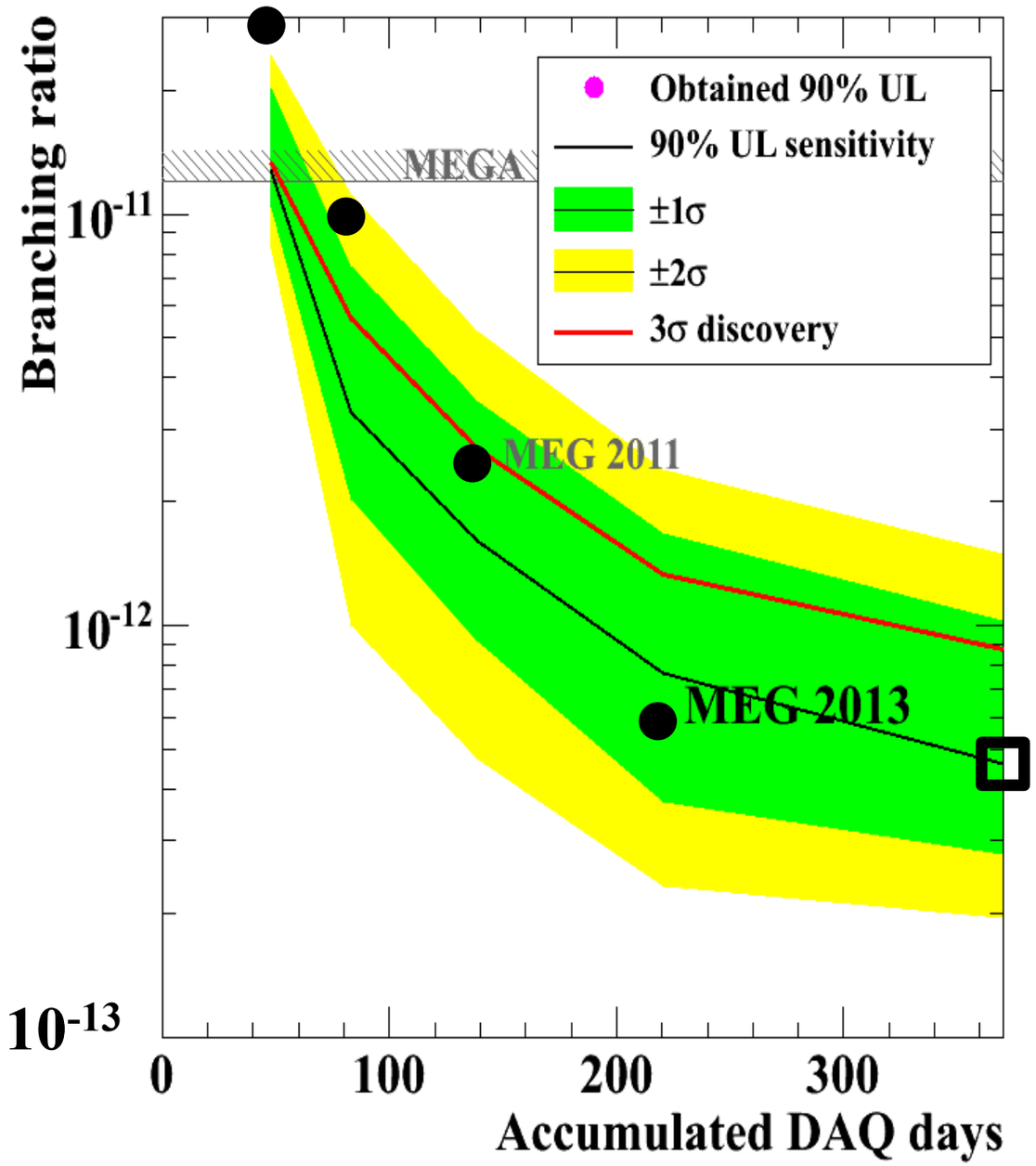






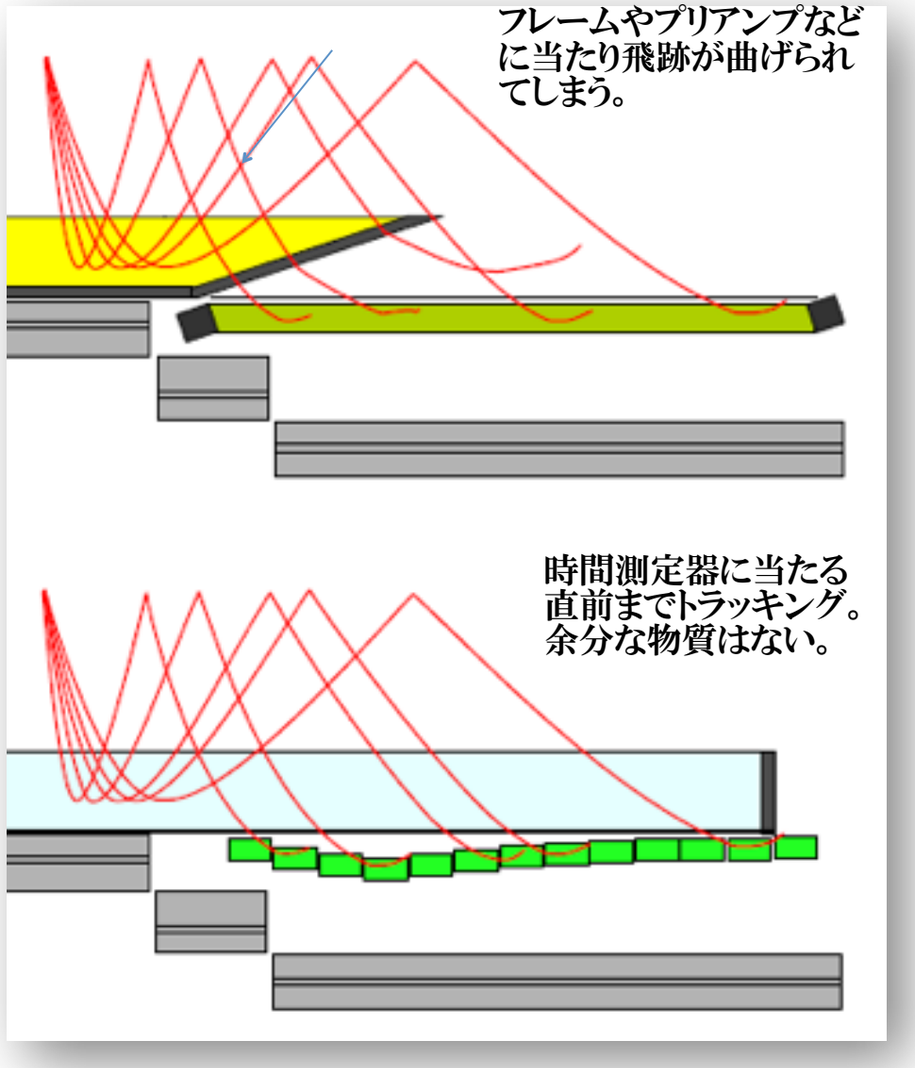


MEG Limitation

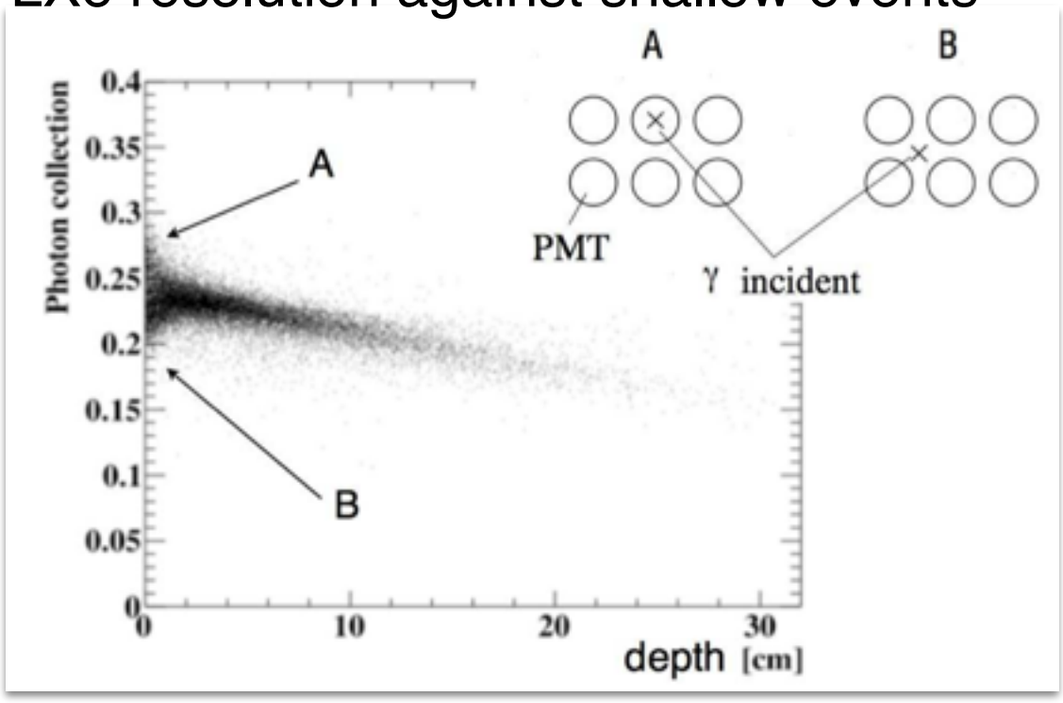


- MEG detector worked fine, and improved the previous best limit.
- However, sensitivity improvement is being limited by accidental background

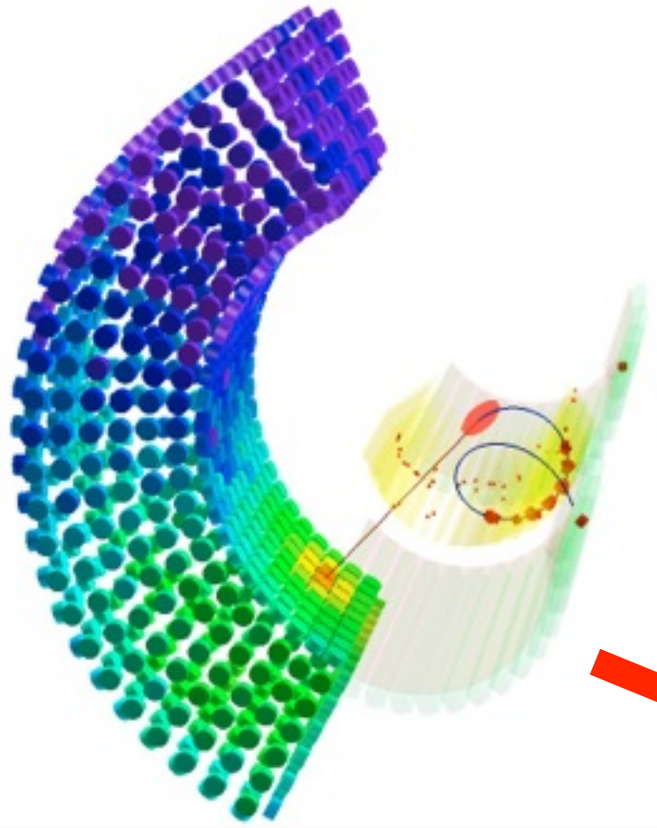
Positron detection efficiency



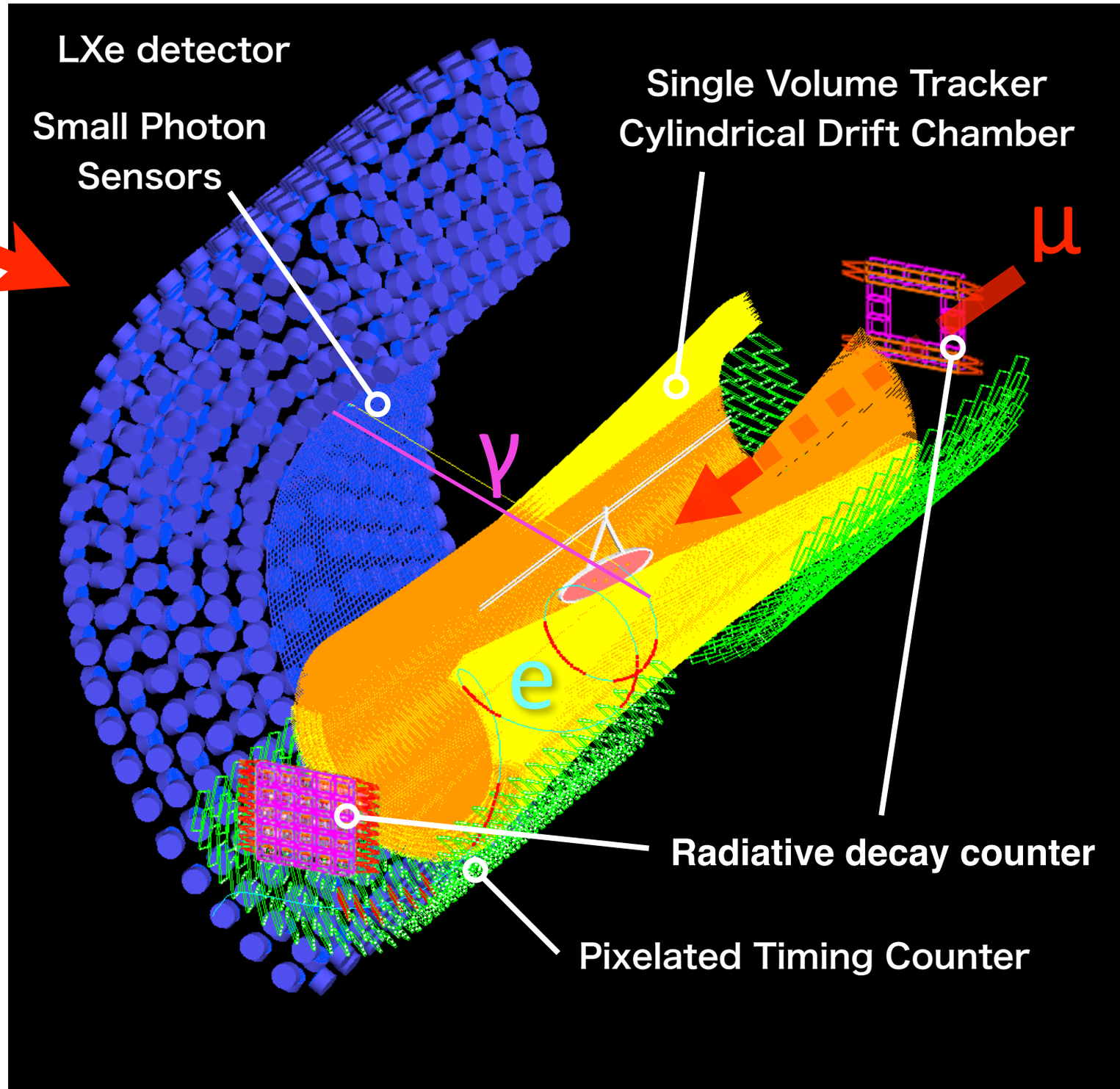
LXe resolution against shallow events



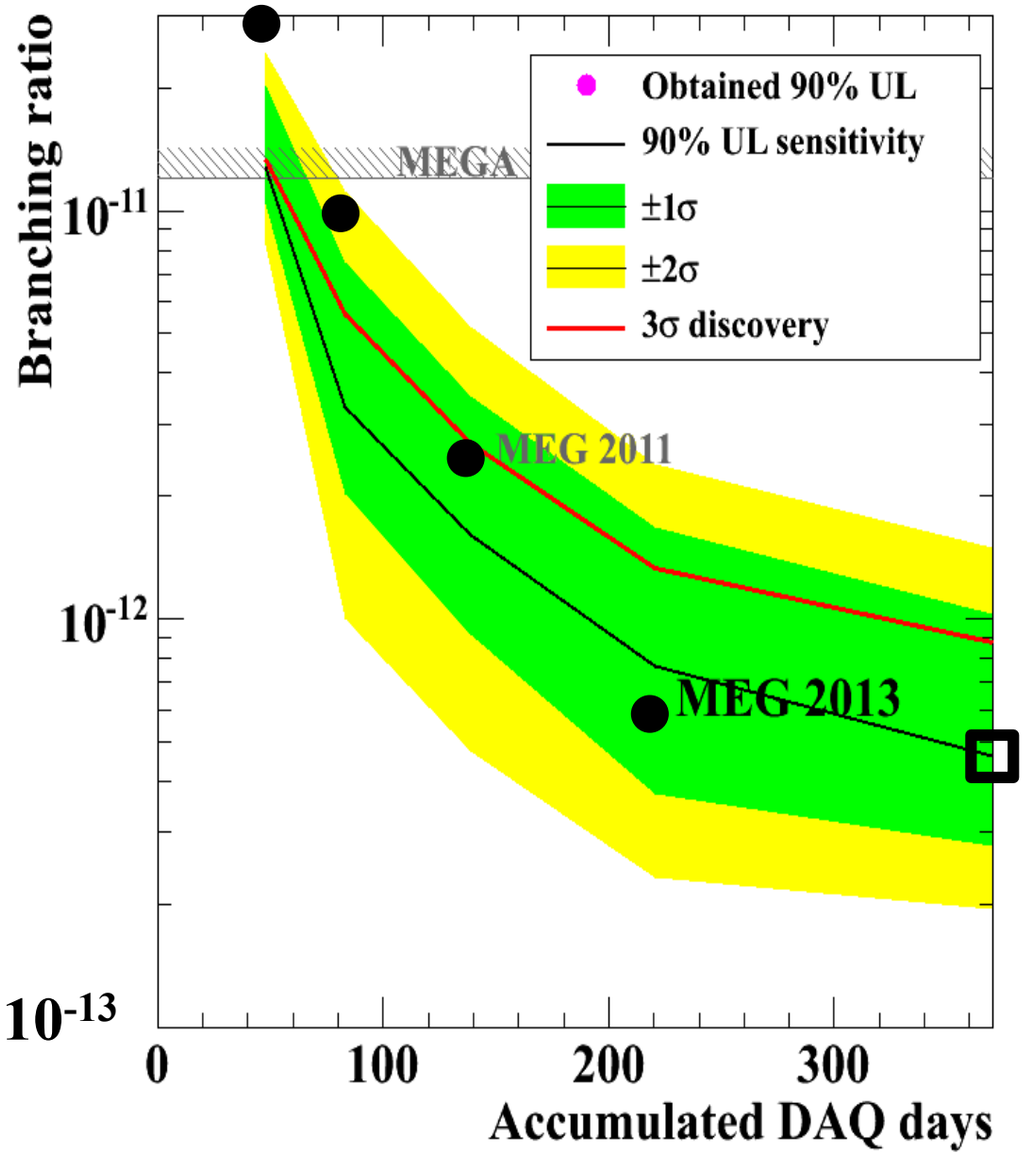
Upgrade idea

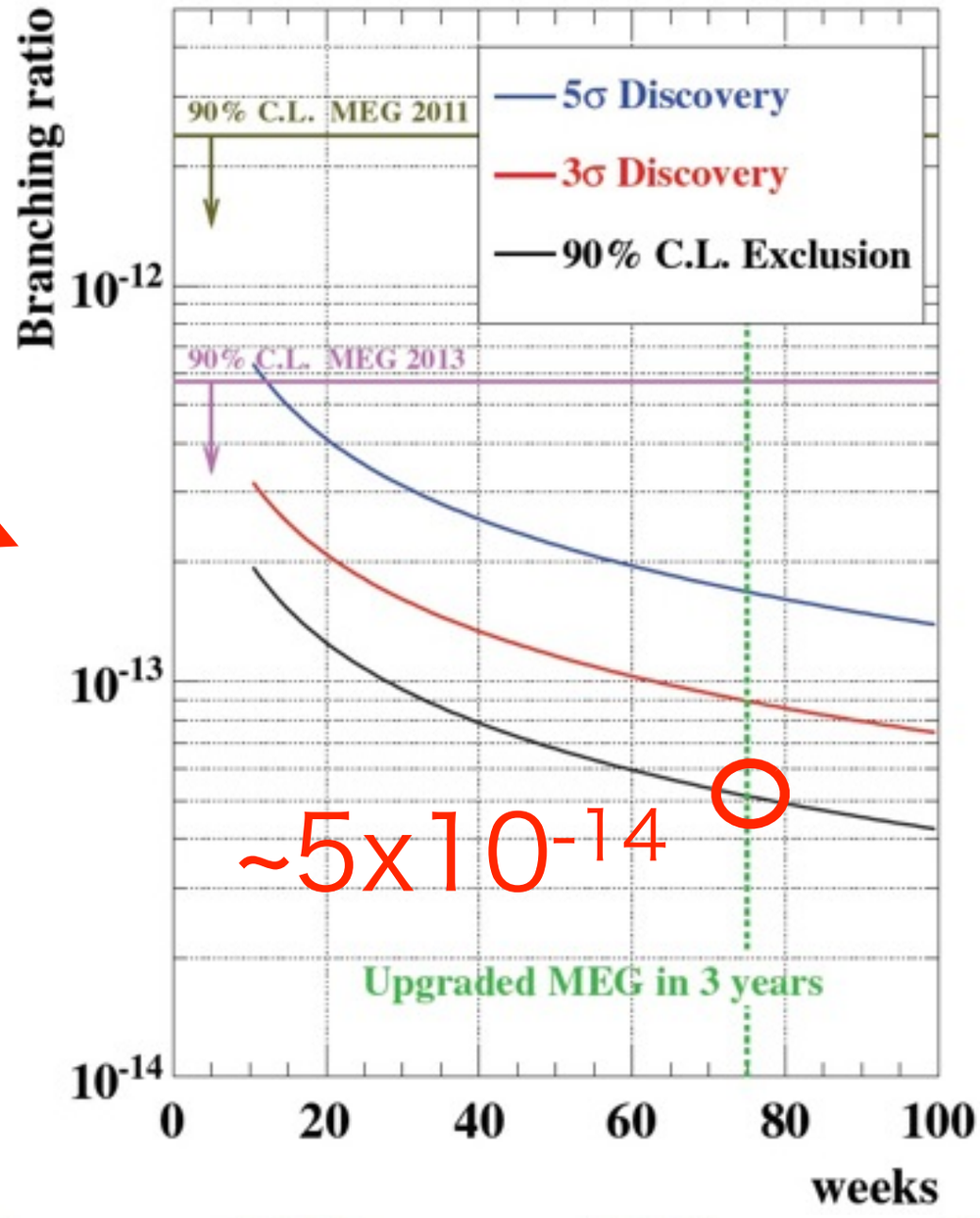


- We know possible improvement items
  - PSI beam rate can be increased up to 7x107μ+/s
  - Important to improve detector performance!
  - Segmented DC -> homogeneous DC with long wires to get more # hits and to reduce material
  - XEC inner face 2″ PMTs -> smaller photo sensors (MPPCs)
  - TC -> pixelated scintillation counters
  - Additional radiative muon decay tagging
- These can be quickly upgraded within reasonable time with our experience



MEG II Sensitivity

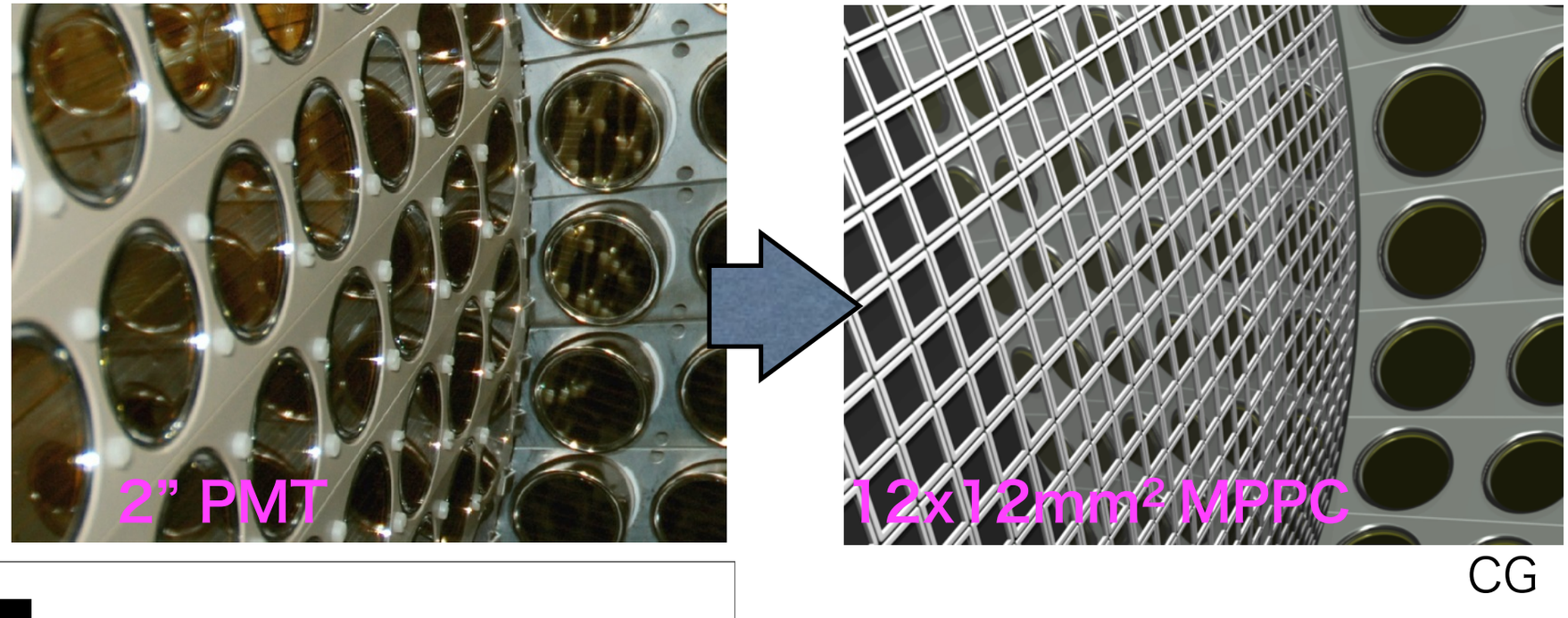




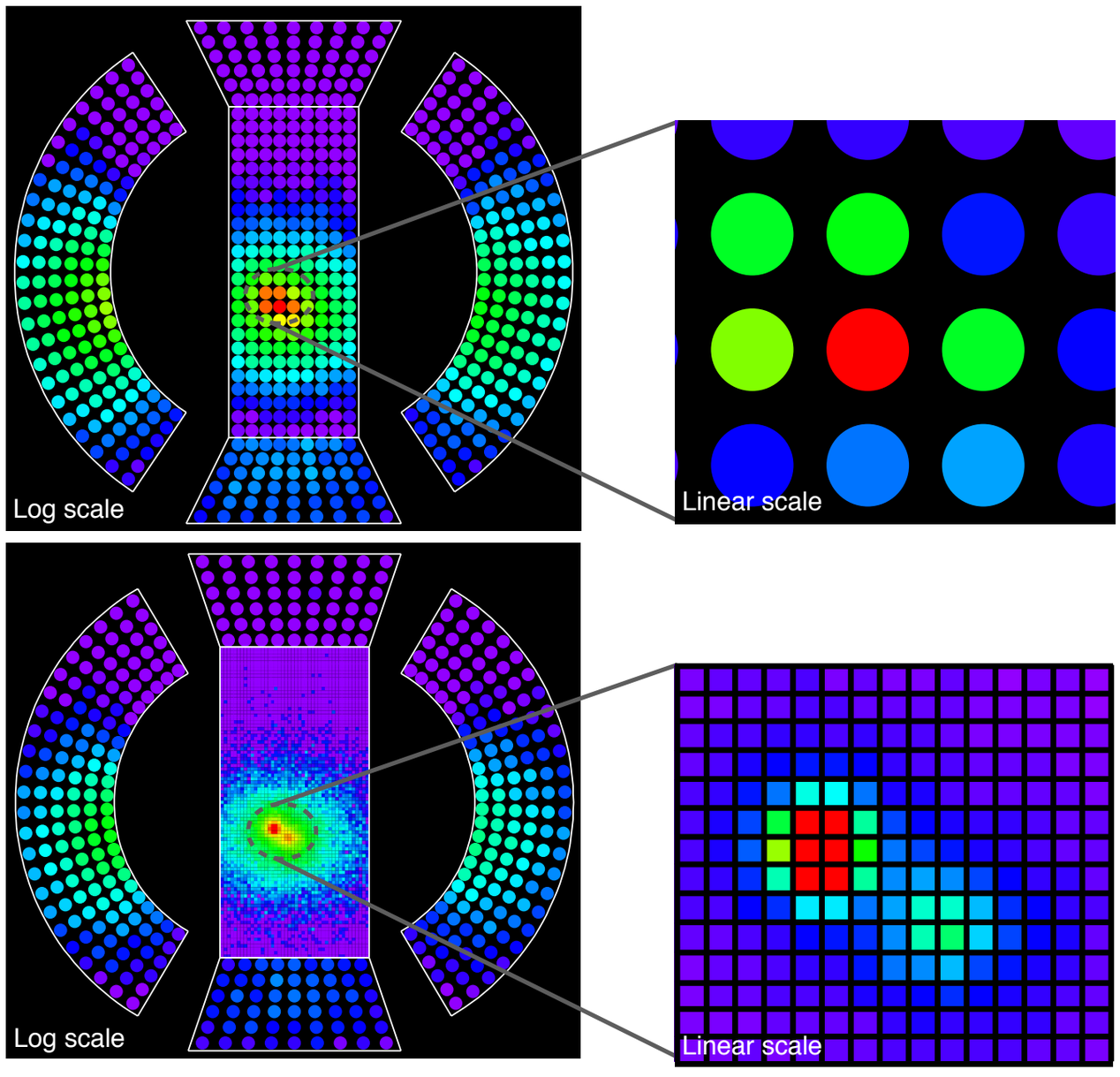
-14

- MEG II target sensitivity ~ 5x10
- Interested region can be explored with a short time scale.
- Still big chance to discover!

Liquid Xenon Detector

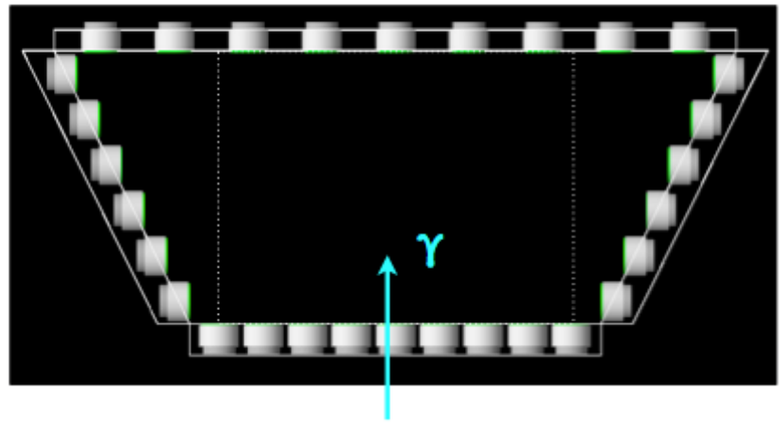


CG

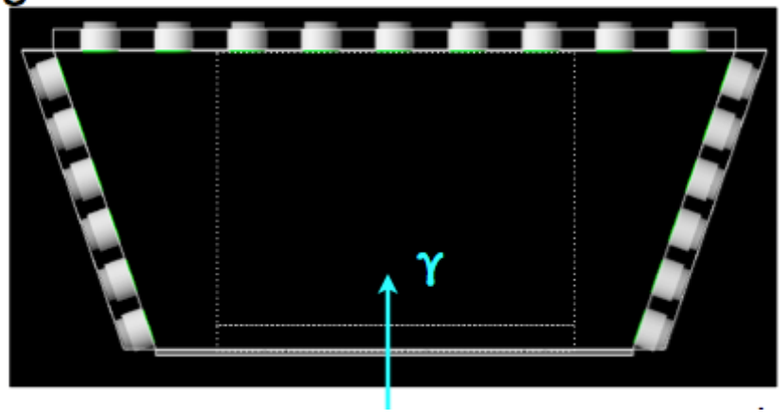


Wider incident face,
different PMT angle at lateral face

Present



Upgraded



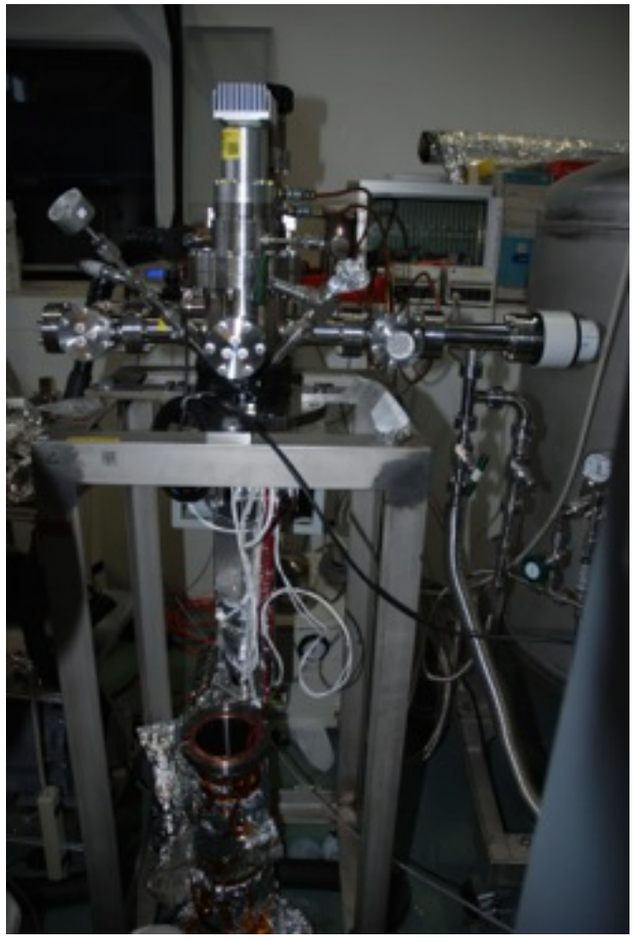
Liquid Xenon Detector

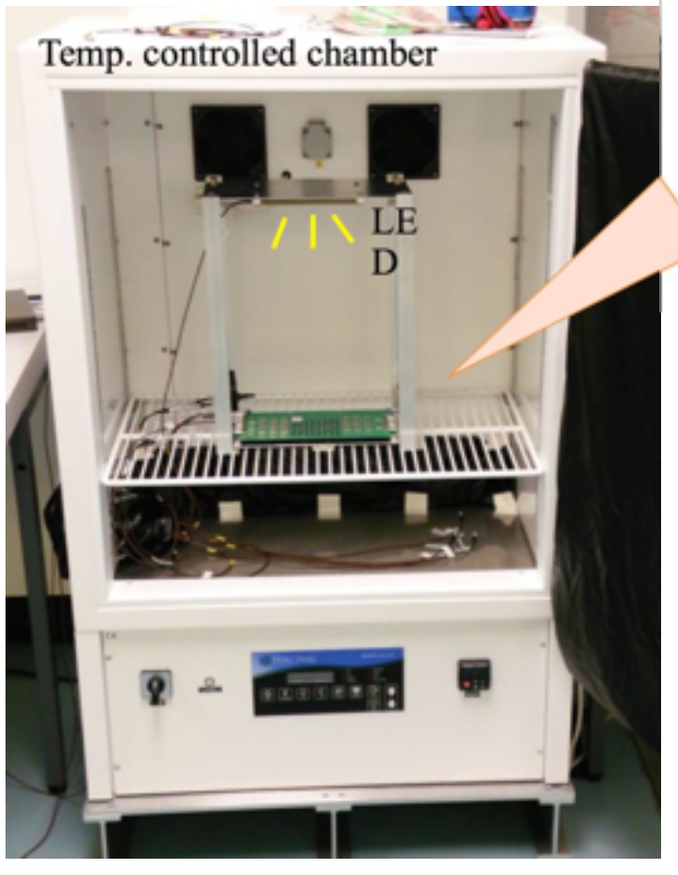
2

- 600 large area (12x12mm) VUV sensitive MPPCs delivered
- Basic characteristic measurements at room T finished!
- Several MPPCs tested at LXe T.,
  and all MPPCs will be tested at LXe T. with prototype
- Cross talk suppress technique will be applied to our MPPCs
  this year. Mass production for the final detector will follow.
- Detector construction next year.

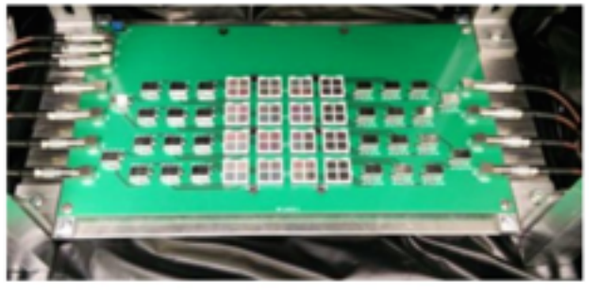
家城佳 19pSG2

小川真治 19pSG3



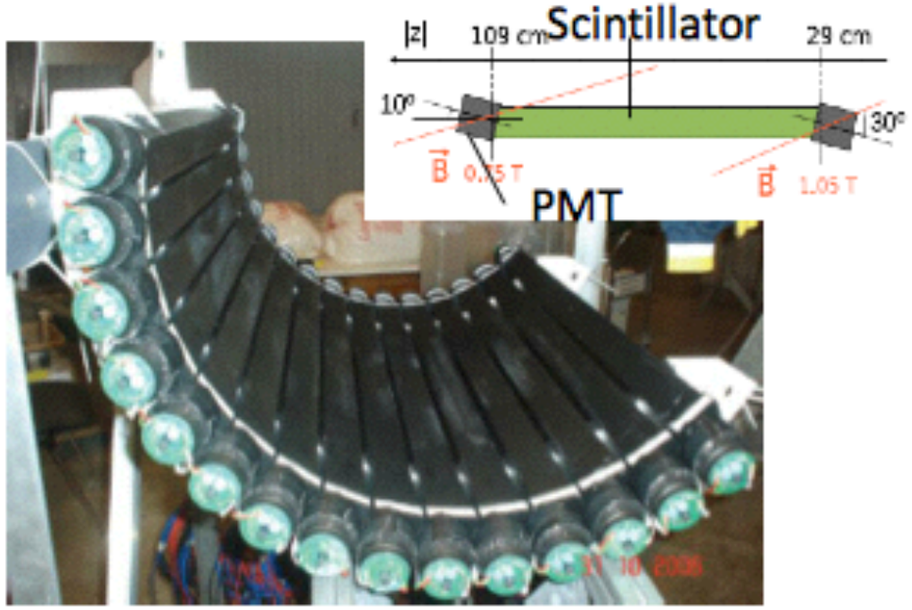


PCB and 16 MPPCs (64 chips)

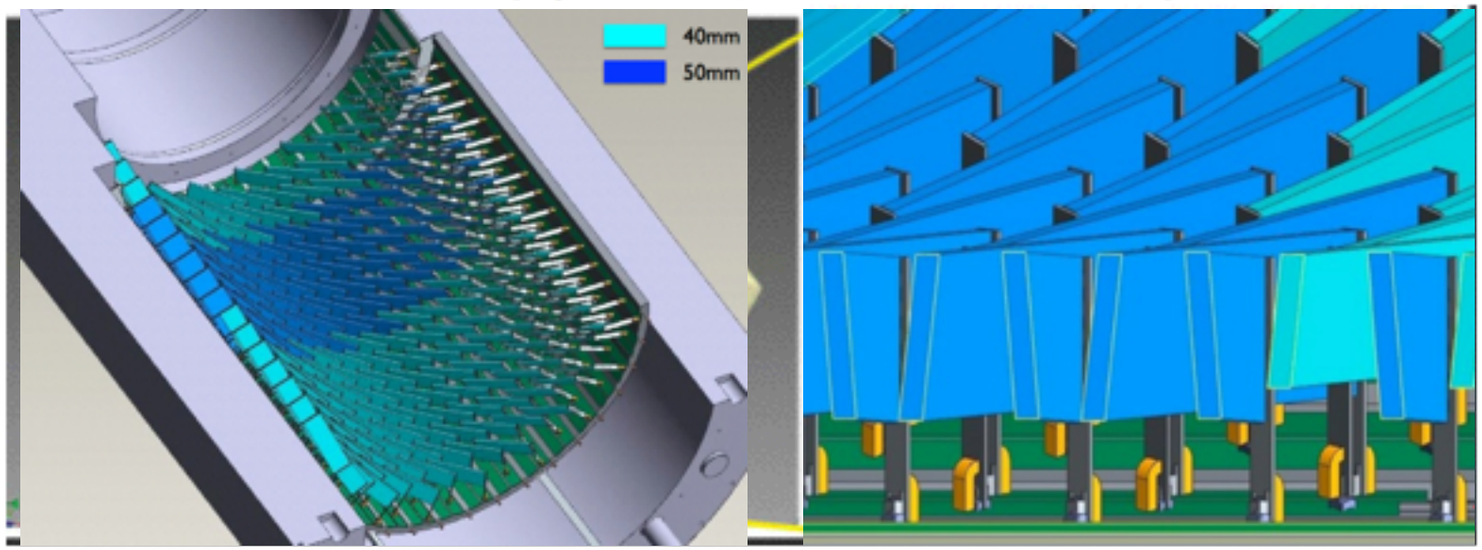


8 readout ch.×8 relay settings = 64

pixelated Timing Counter



~300 counters × 2 (upstream, downstream side)



present

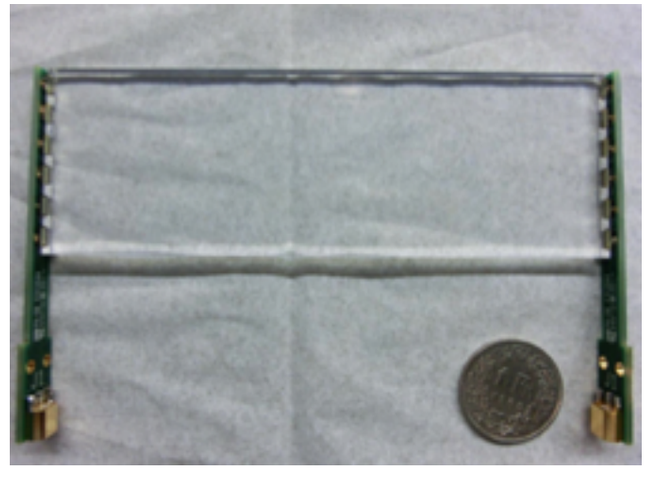
- 2x array of 15 scintillating bars readout by PMTs
- 40x40x800mm^3 scintillator
- Mean resolution ~ 65ps

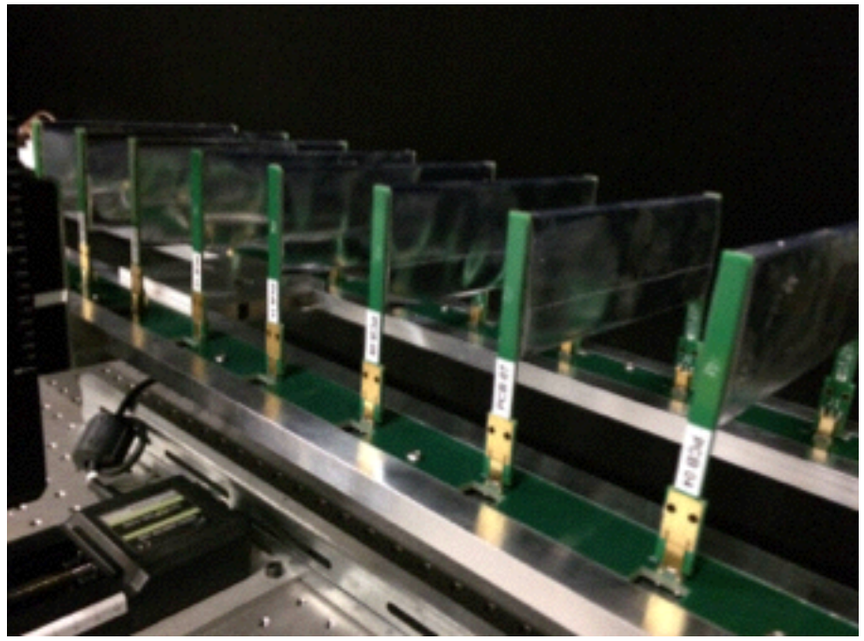
upgrade

- Higher granularity 2x256 of small scintillator plates(90x(40-50)x5mm^3) readout by SiPM
- Resolution down to 30ps
  - High single pixel resolution
  - Further improvement with multi-counter hits
- Thin scintillator for less multiple scattering
- Less pile-up also with higher beam intensity

pTC Schedule

- July 2014 at Frascati
  - AdvanSiD SiPM (unfortunately this time bad timing resolution of these SiPMs. Will be fixed for Oct. 2014 beam test)
  - 12cm scintillator
  - 6 SiPMs in series connection
  - PCBs used as structure 吉田昂平 19pSG5
- Oct.-Nov. 2014 at PSI
  - SiPM final configuration (6500 SiPMs are already ordered to AdvanSiD)
  - WaveDREAM readout
  - High rate environment test
- Study on calibration methods 西村美紀 19pSG4
- Start counter construction, and ready in 2015



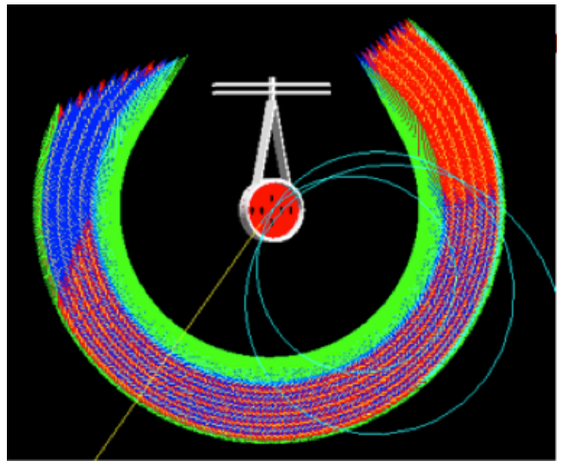


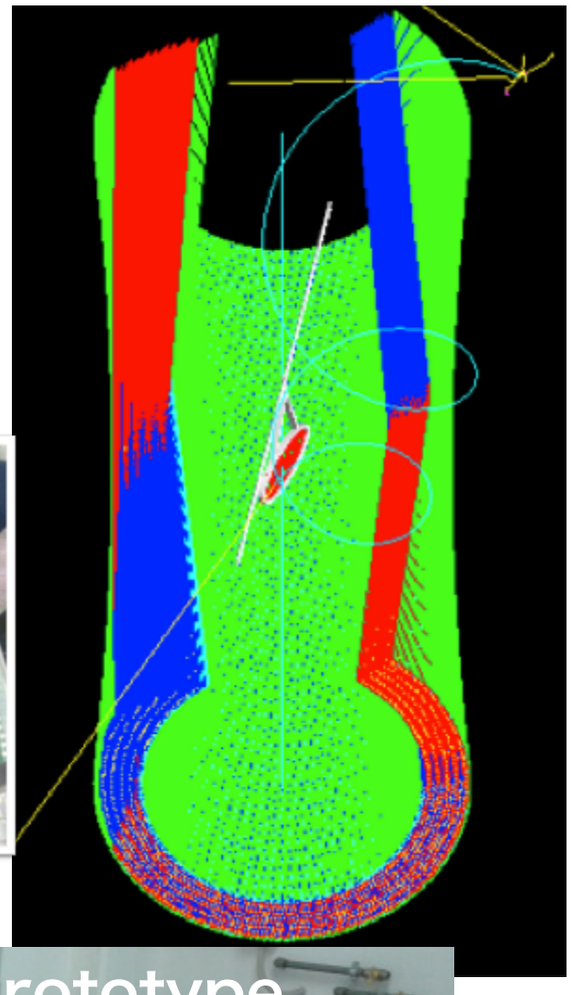
Cylindrical Drift Chamber

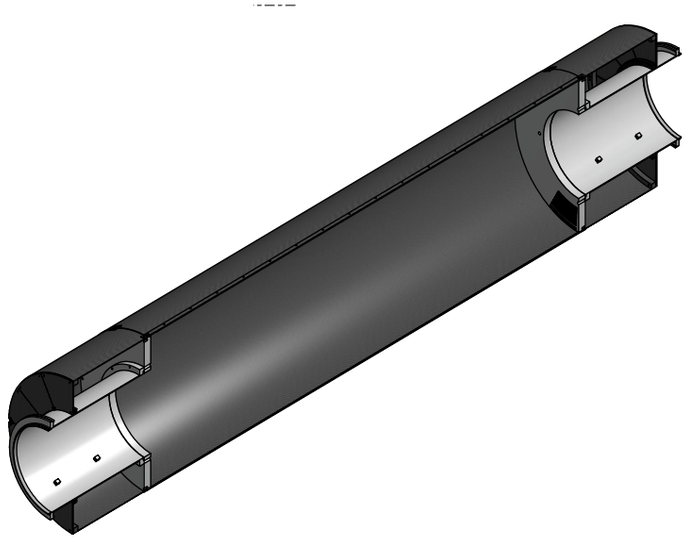
- Single volume gaseous detector
- Stereo wires along z
- Finer granularity, better resolution
- Larger acceptance DC + TC
- Resolution check, aging test performed, detector construction by 2015 summer

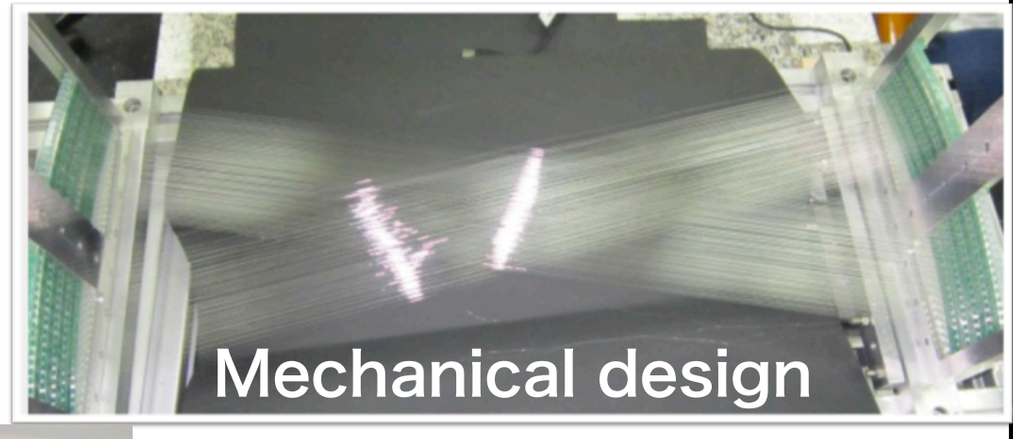
Expected Performance

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%)



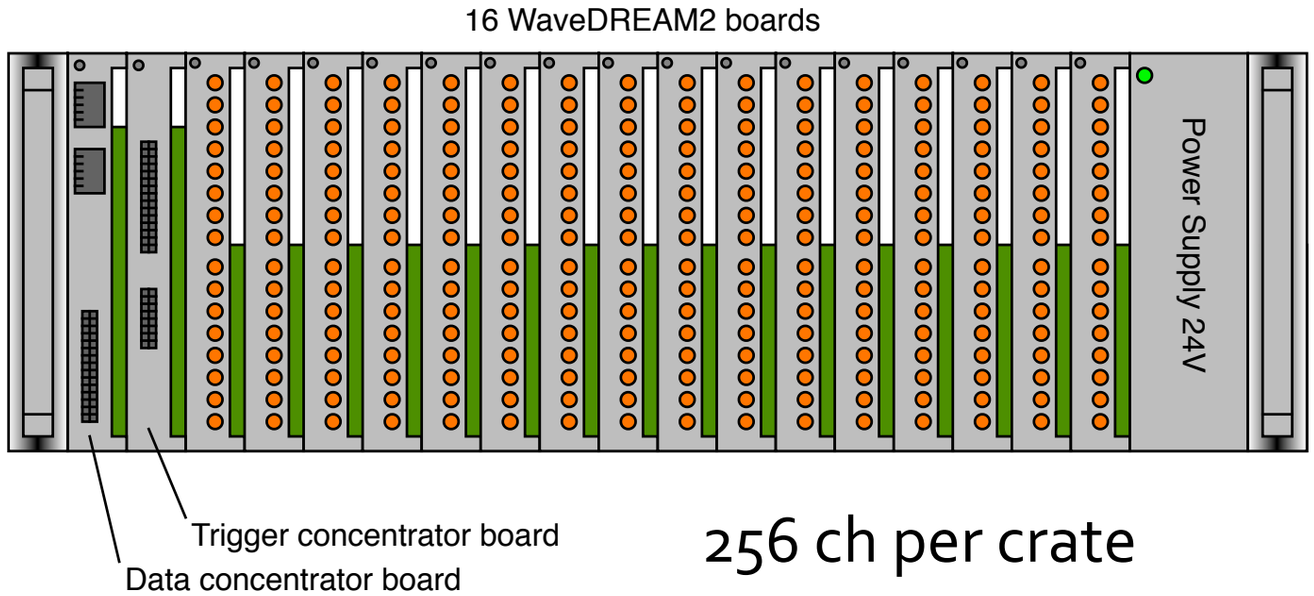






Electronics

- higher granularity -> more # channels
  - LXe 846 -> 4722
  - DC 1730 -> 2760
  - pTC 60 -> ~1000
- DRS4 VME board-> WaveDREAM
  - waveform digitizer
  - higher density
  - bias voltage supply, amplifier for SiPM, and simple trigger are integrated
- Test boards will be ready soon, and will be used in pTC beam test this November
- Mass production in next year

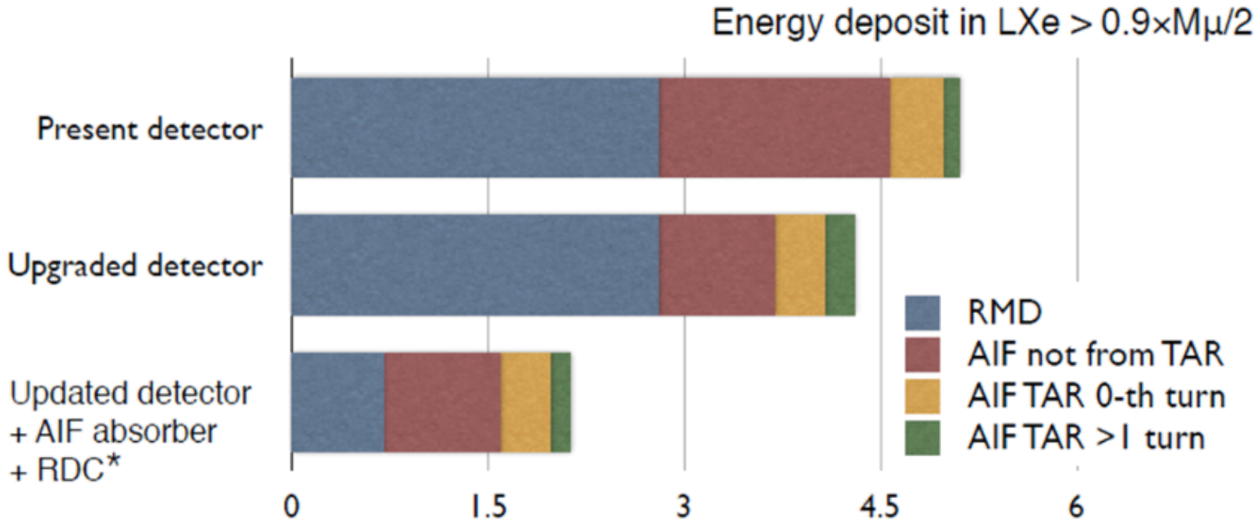


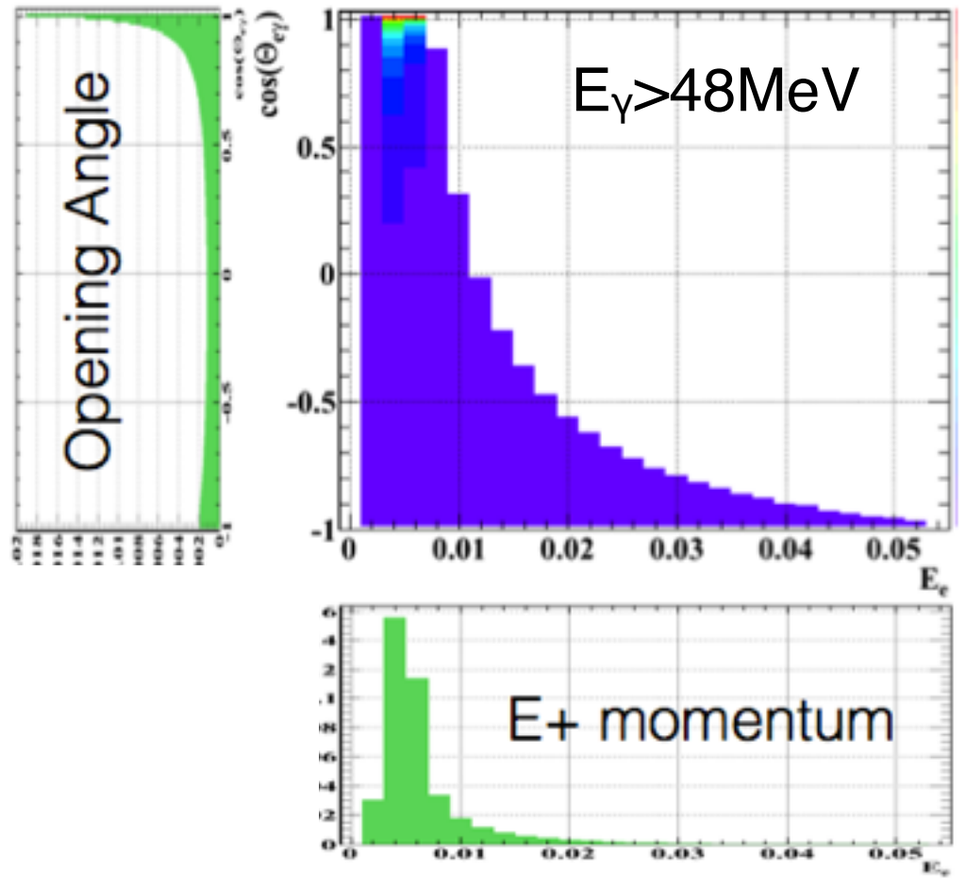
256 ch per crate

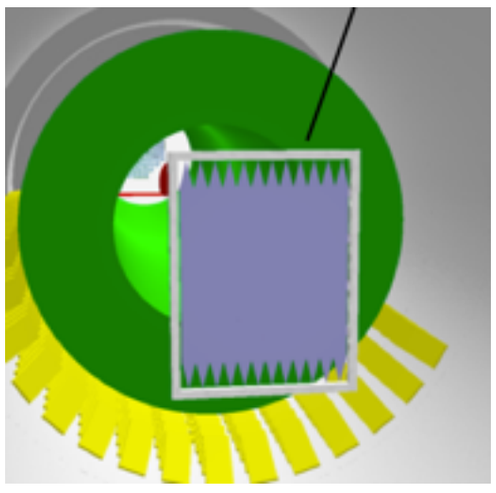
Radiative Decay Counter

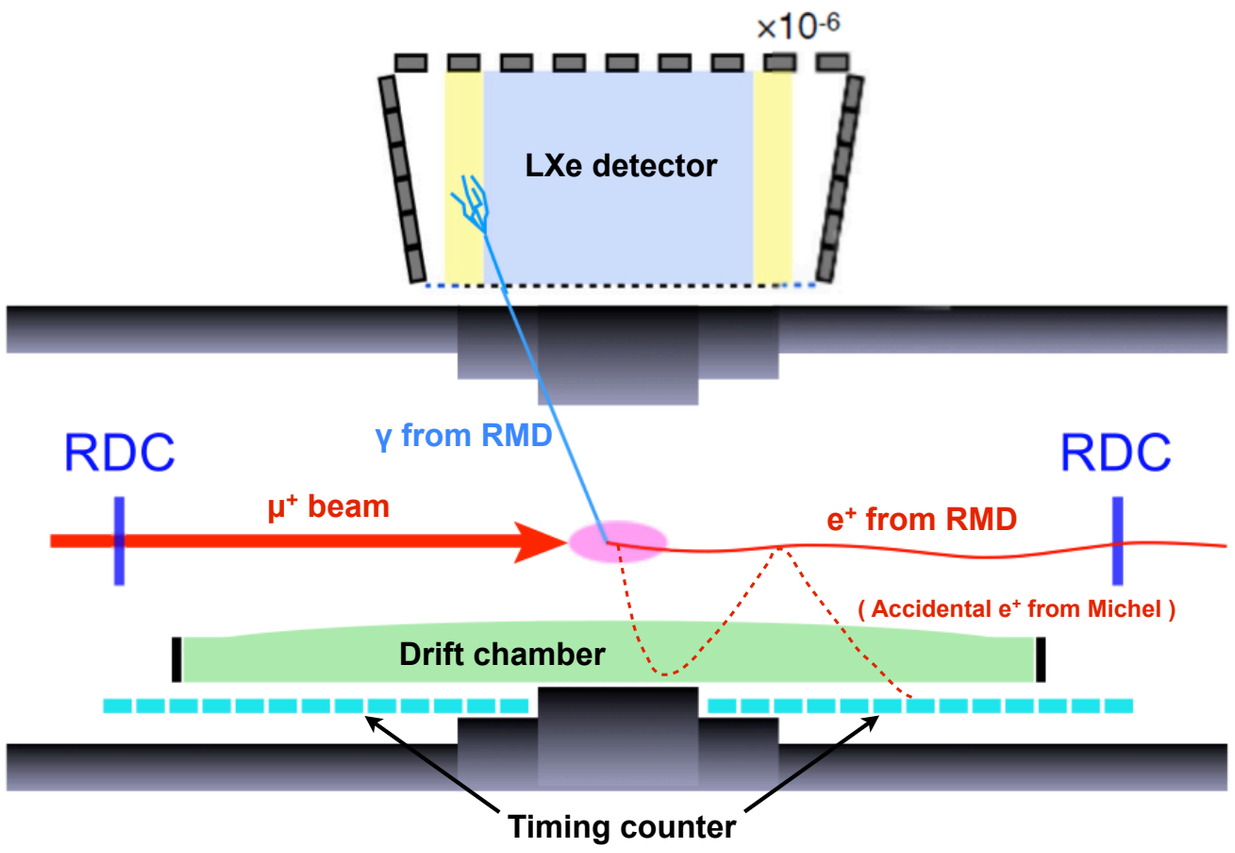
中浦正太 19pSG1

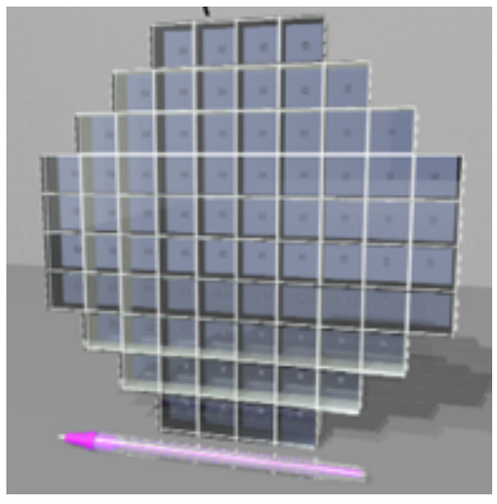
- Tagging radiative muon decay events with ~50MeV γ (low energy e⁺ is emitted ~ 4MeV)
- Plastic scintillator + crystal with MPPC readout





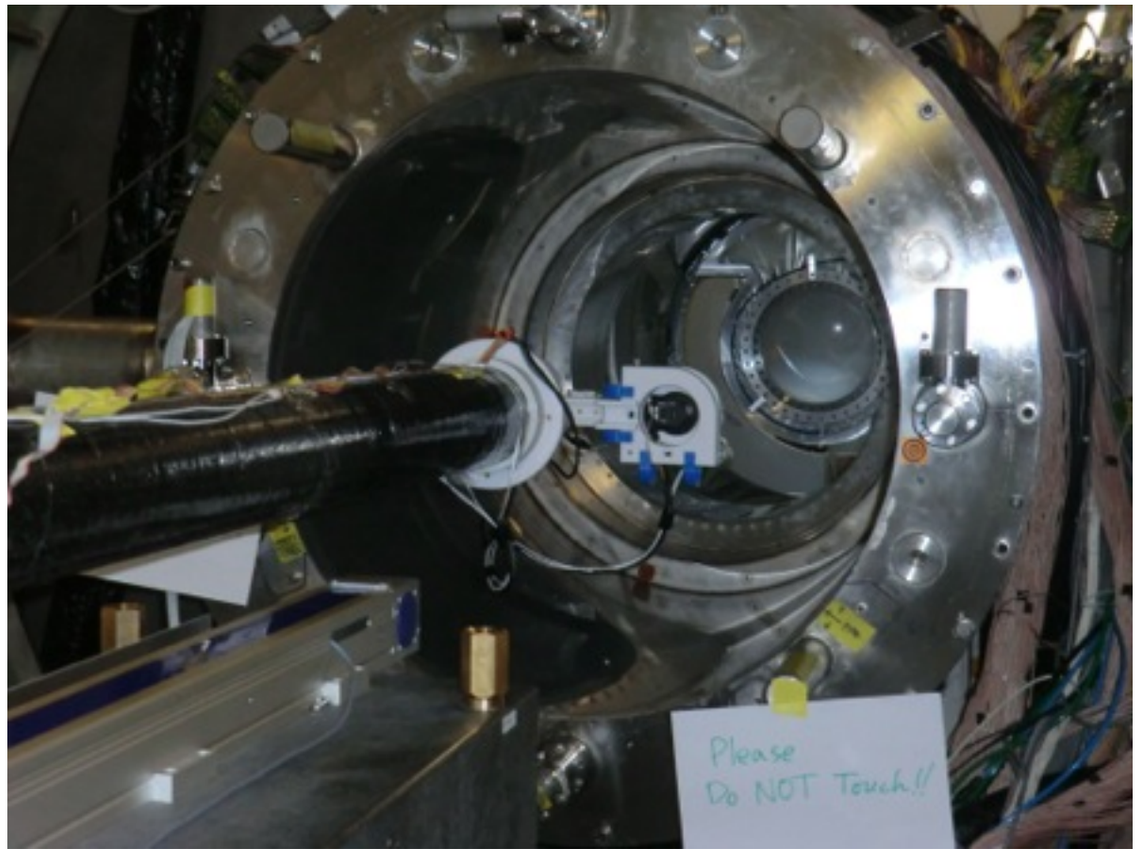


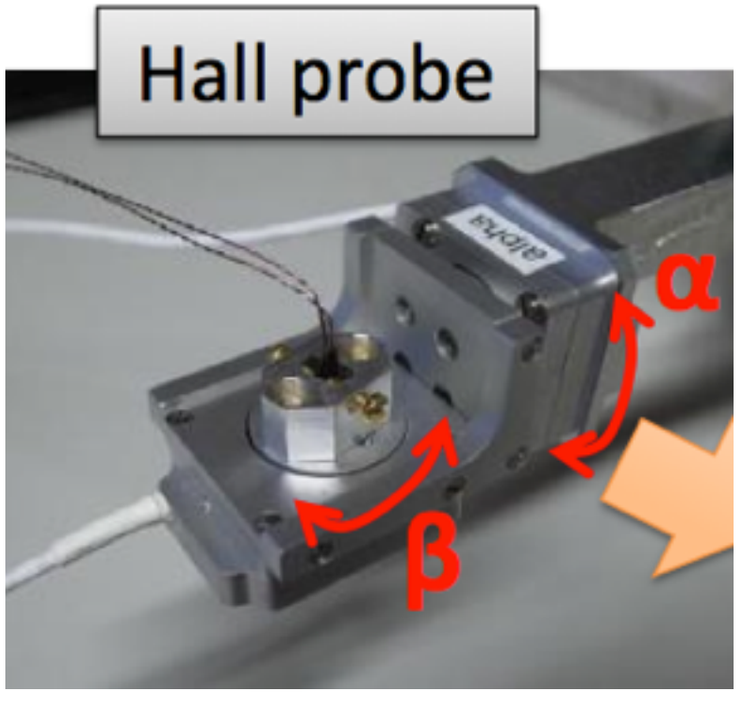


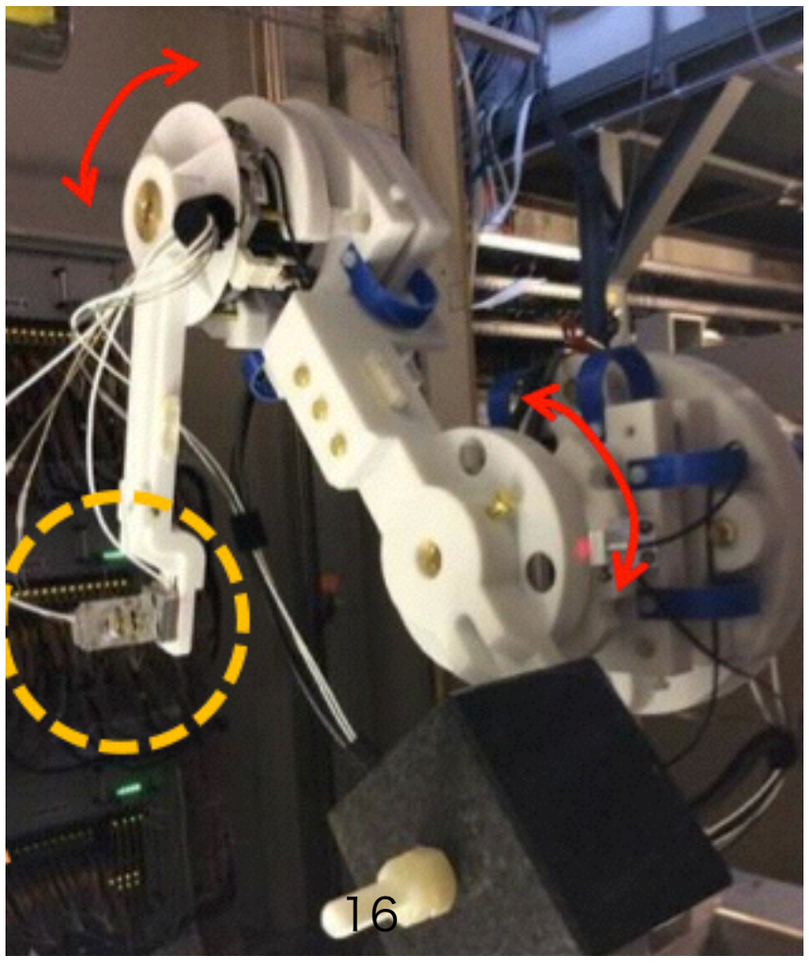


Magnetic field measurement

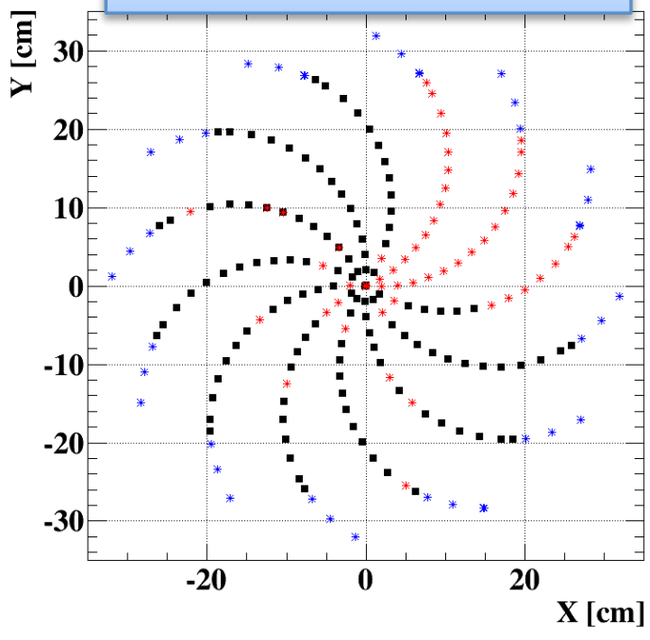
- 2006 magnetic field was measured with 0.2% precision (sensor position calibration ~800μm) ~ 150keV momentum resolution
- Momentum resolution in MEG II ~ 130keV, need to reduce the uncertainty of the magnetic field
- In July and August 2014, magnetic field measurements were performed with a new measurement machine which sensor position is more precisely calibrated (<300μm). If this new field map improves the momentum resolution of the current MEG data, this will be applied to them, too.





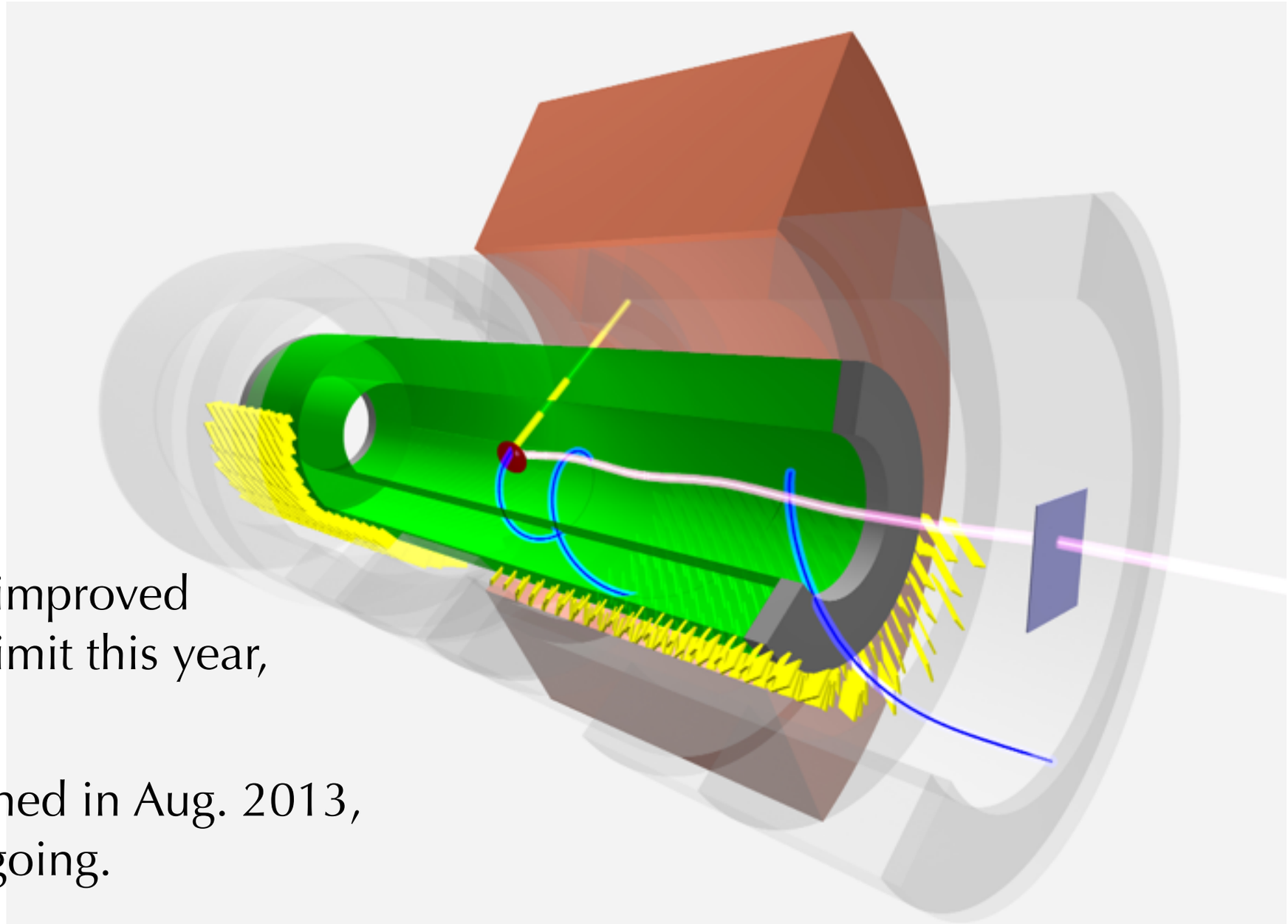


new measurement



Z: ~4 mm step
R: 20 mm step
ϕ: 30 deg step

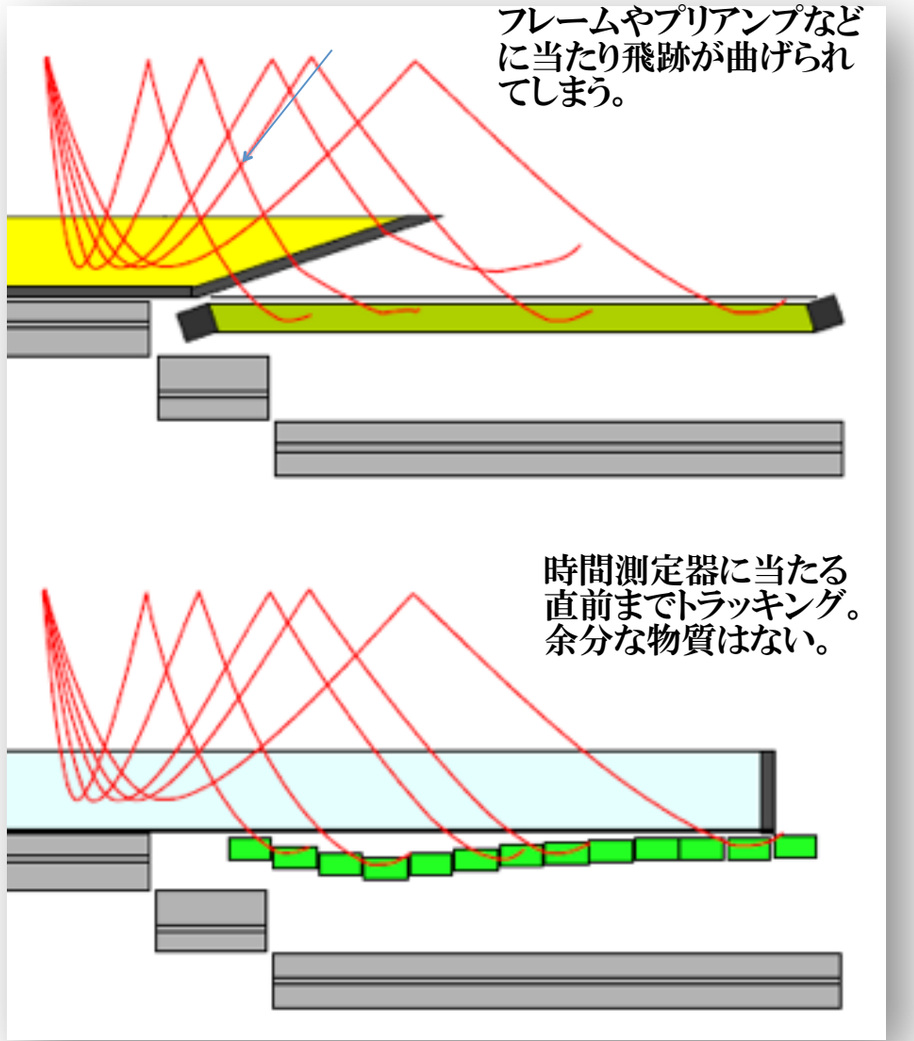
Summary

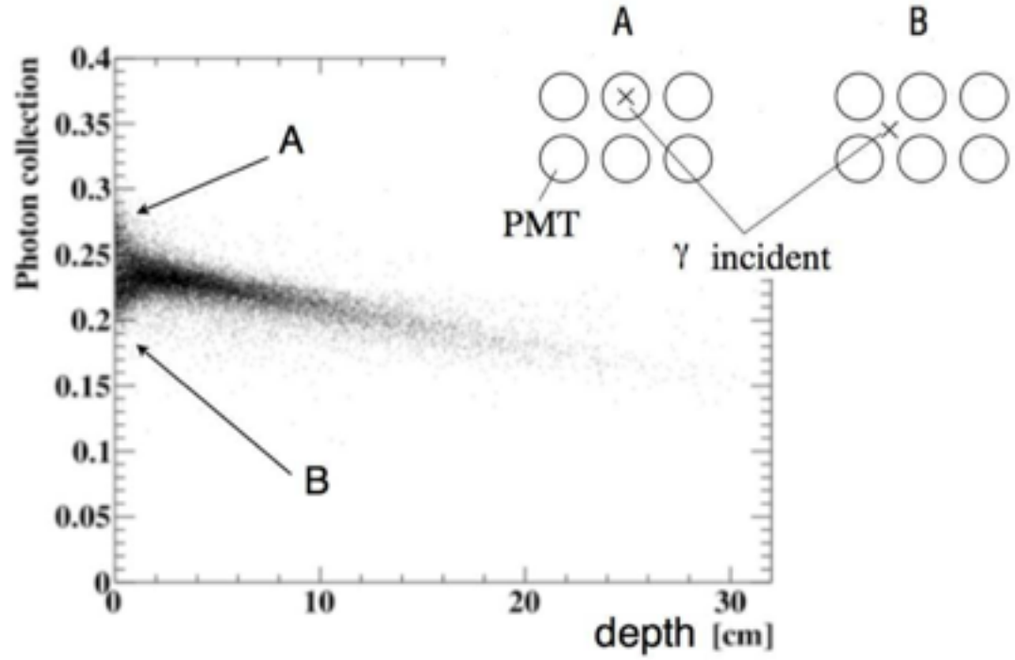


- The MEG experiment improved the BR($\mu \to e\gamma$) upper limit this year, 5.7×10^{-13} at 90% C.L.
- MEG physics run finished in Aug. 2013, and the analysis is ongoing.

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

MEG limitation





MEG Experiment

- 1999 Proposal to PSI
- 2008–2013 Physics run
- The latest result based on 2009–2011 data set upper limit of $BR(\mu \to e\gamma) < 5.7 \times 10^{-13}$ @90%CL
- 2012–2013 data will double the statistics, and the new result with our full statistics would be published at winter conferences
- MEG Collaborator ~ 60 physicists from Japan, Italy, Switzerland, Russia, and USA

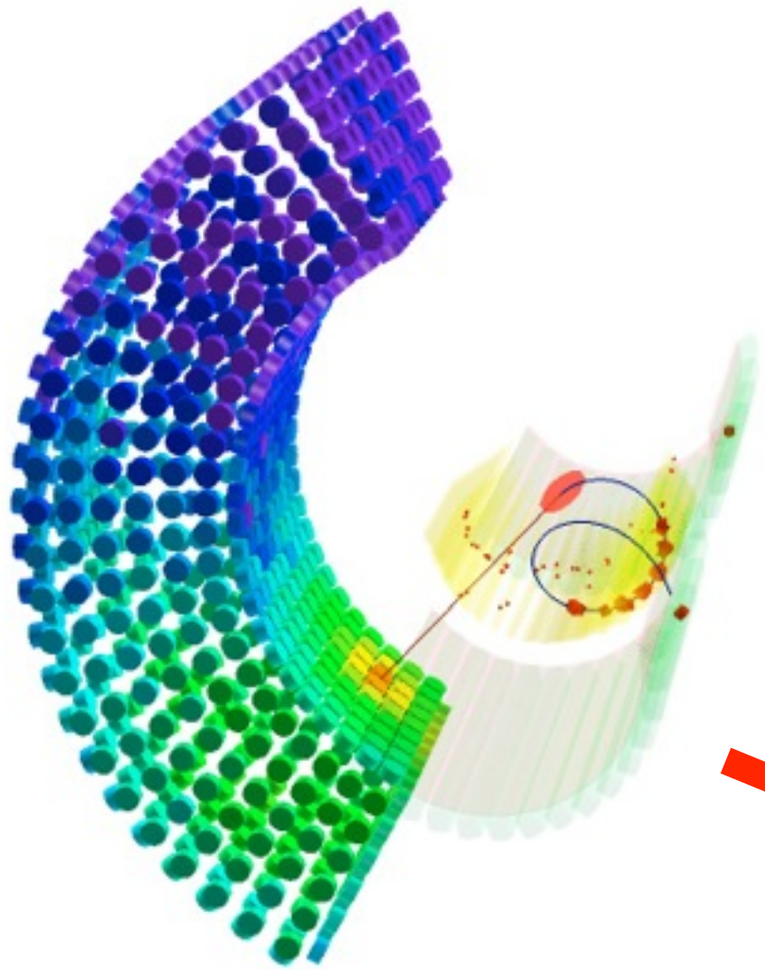
1.3MW high intensity proton accelerator
World most intense DC μ^+ beam
$>1 \times 10^8$ μ^+/s

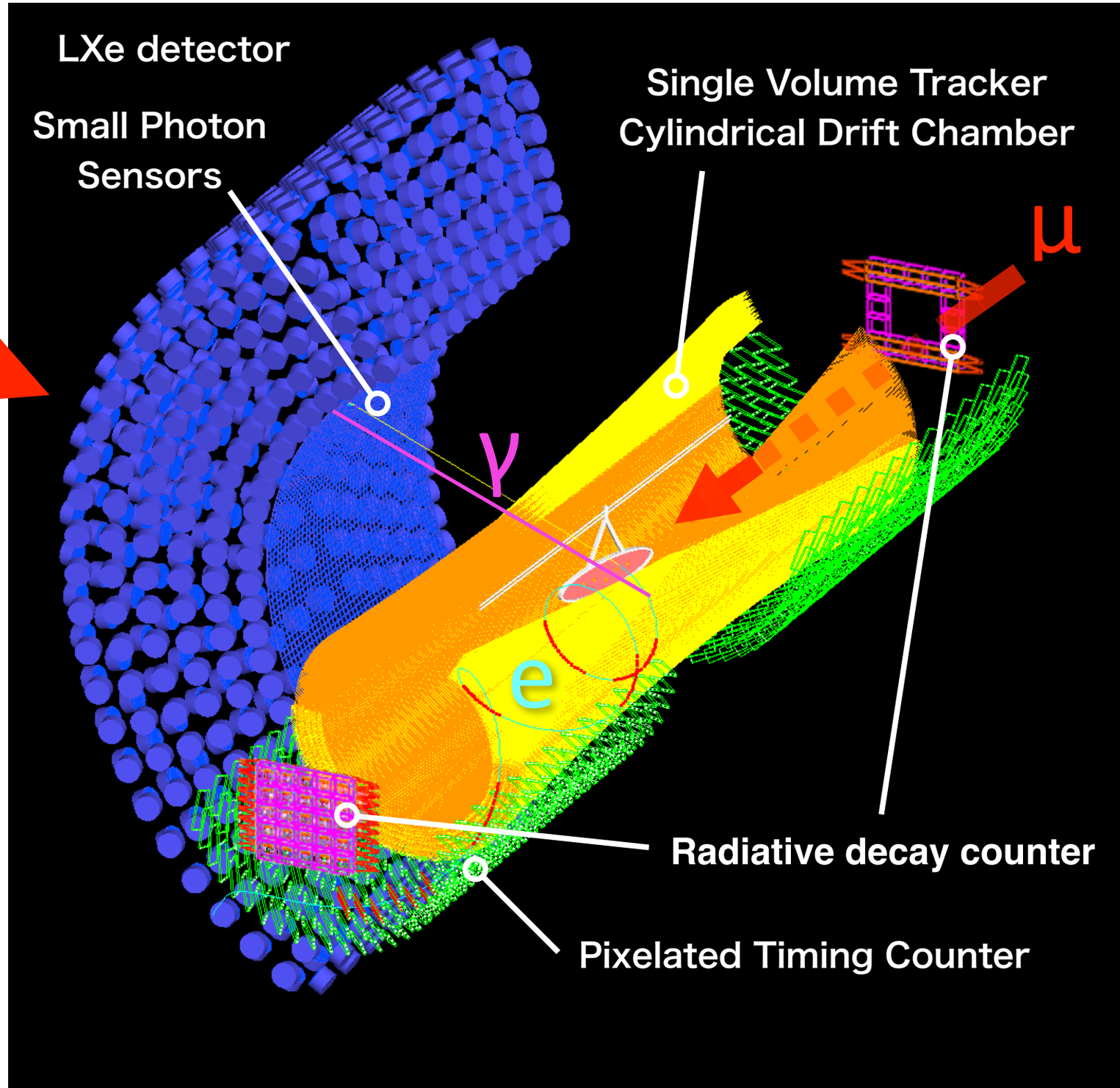
MEG II Status

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

PDF parameters	Present MEG	Upgrade MEG II
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<2cm)/ (w>2cm)	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

Upgrade Concept





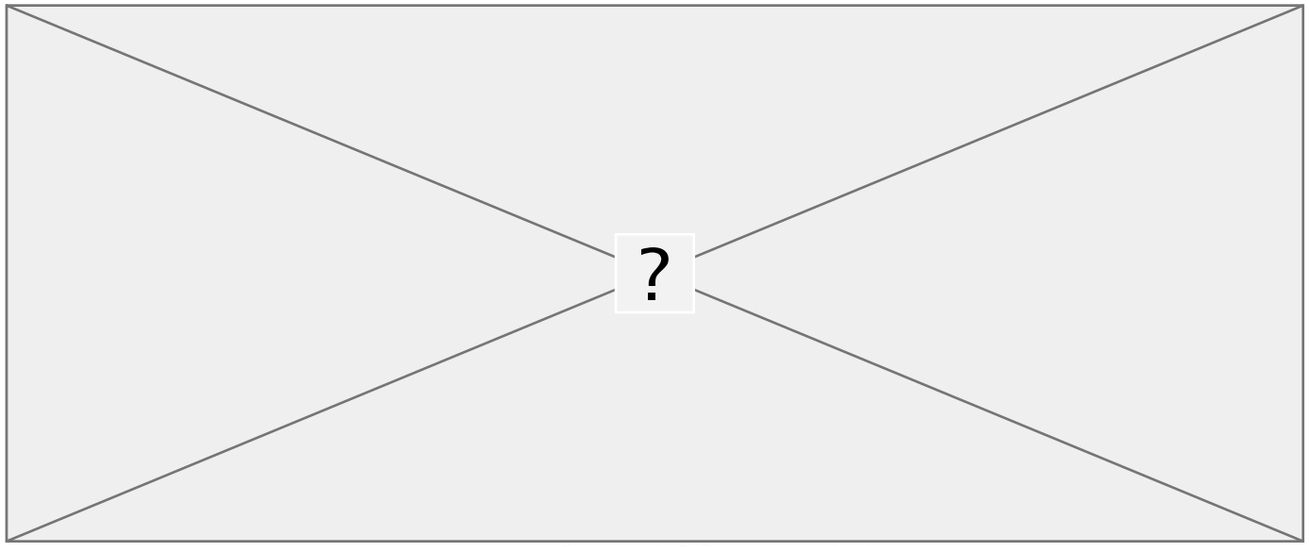
- What can be improved?
  - Higher muon beam rate
    - 3->7x10^{7} μ^{+}/s
  - Larger acceptance
  - Better resolutions
  - Active background suppression
    - Radiative muon decay tagging detector

PSI Accelerator (muon beam rate)

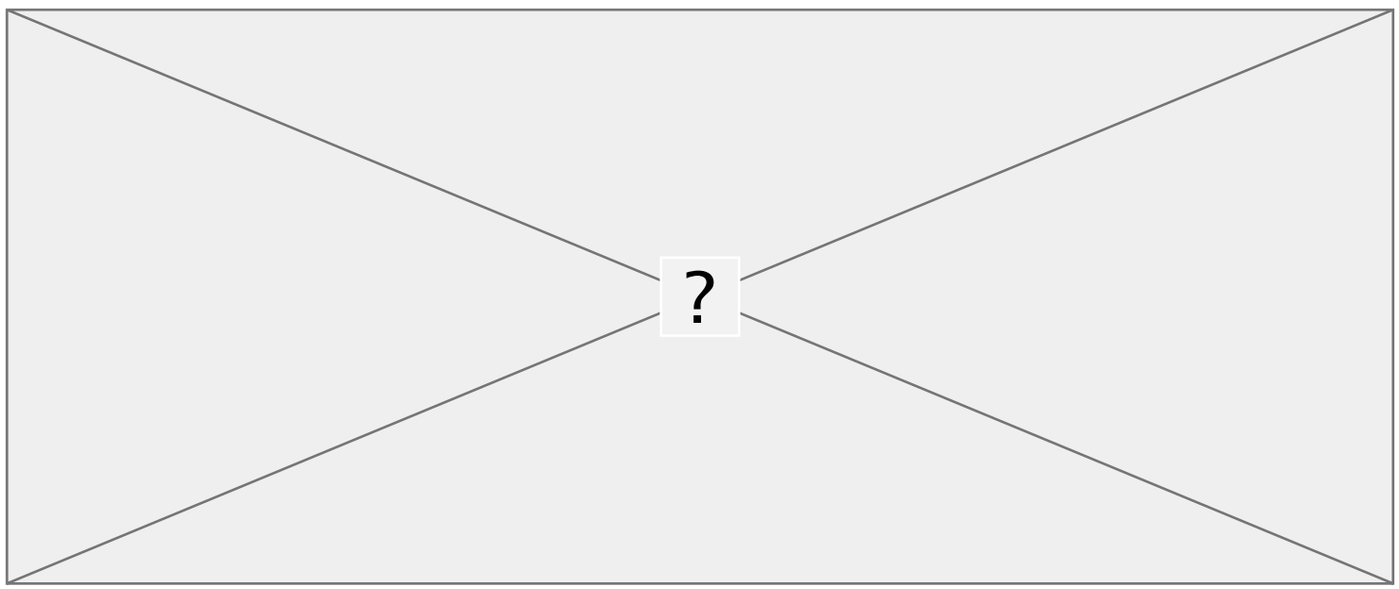
- PSI also has a plan to upgrade the accelerator
  - Mainly for Mu3e experiment
- MEG experiment doesn't require the accelerator upgrade
  - We can quickly start whenever the detector upgrade finishes
  - $3.0 \times 10^{7} \Rightarrow 7.0 \times 10^{7}$ μ/s

    stopped at the target are possible now

High Intensity Muon Beam (HIMB) projects



3×10^{10}/s, >2017

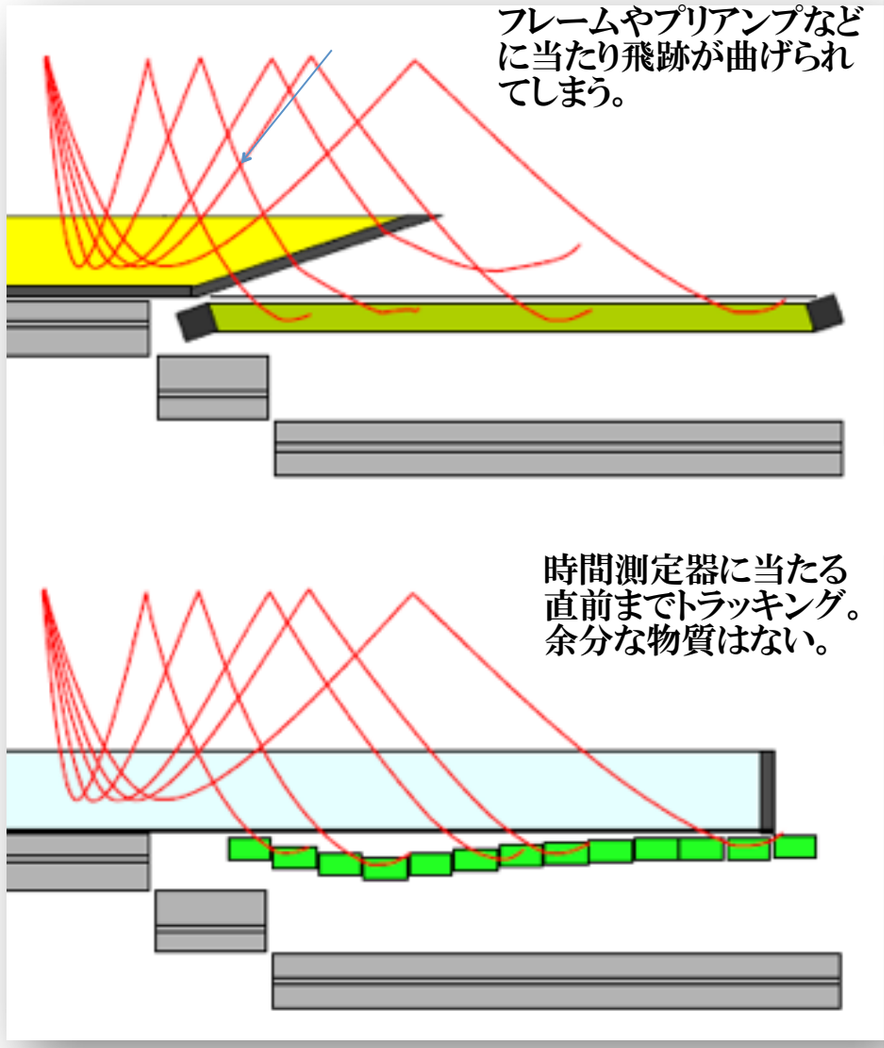


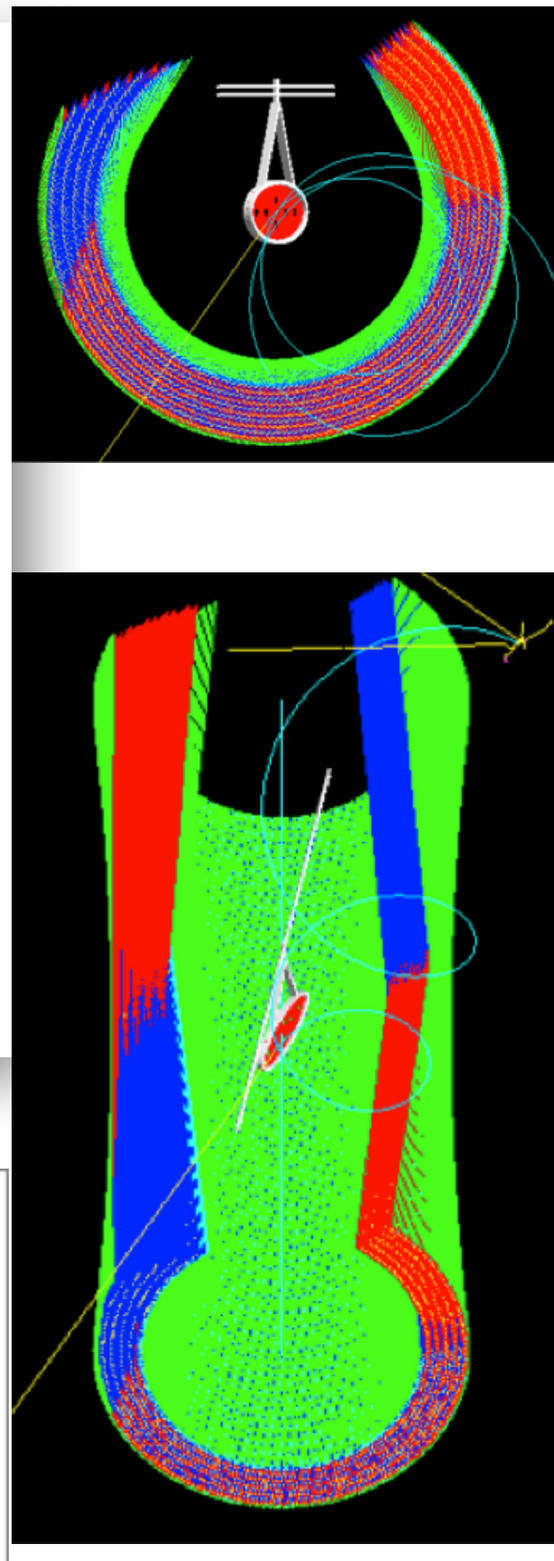
Drift chamber

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

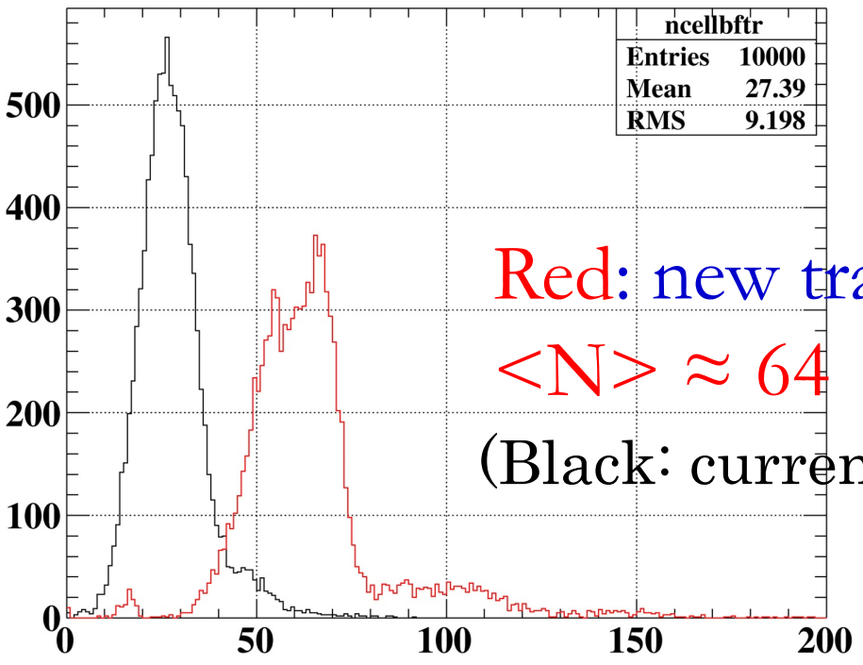
Challenging

Long wires : ~200cm
High rate environment





Large number of hits



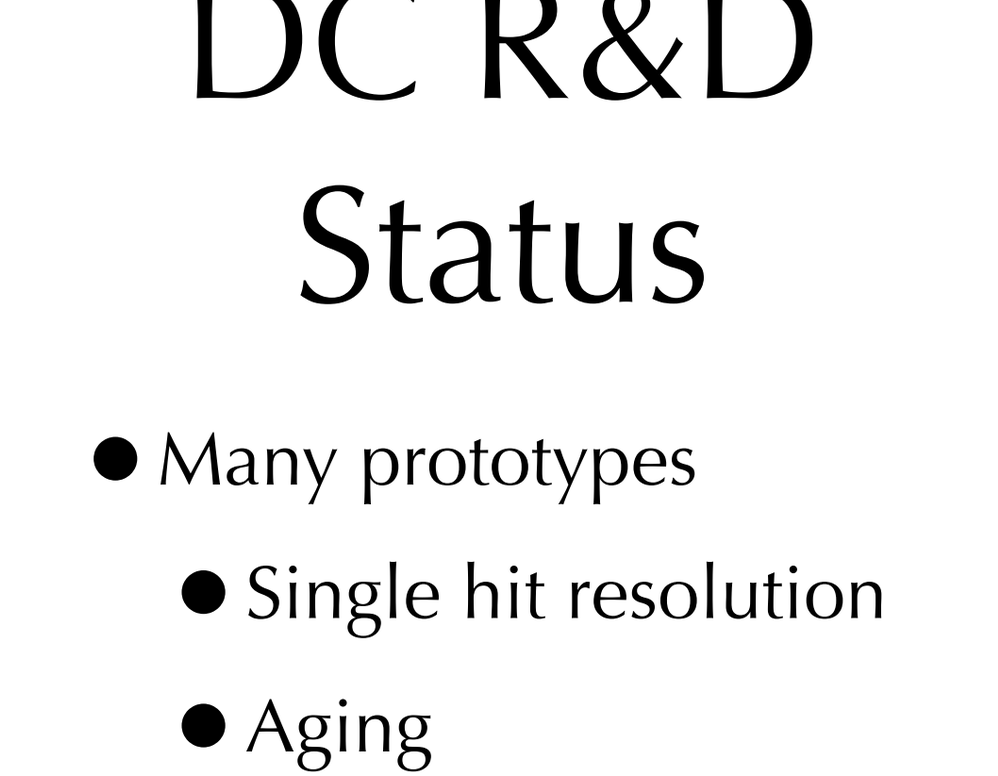
Red: new tracker
<N> ≈ 64
(Black: current one)

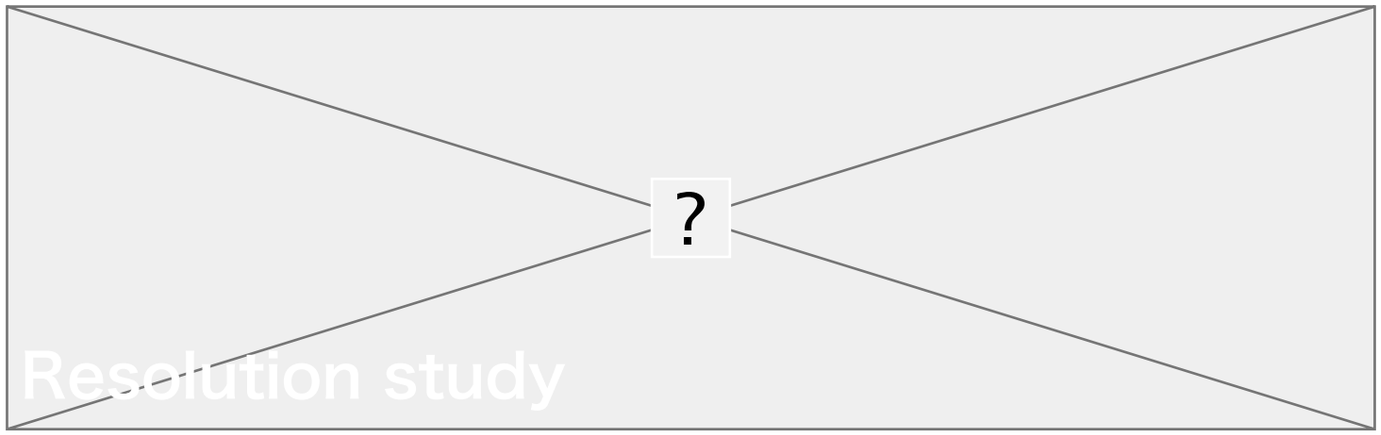
Expected Performance

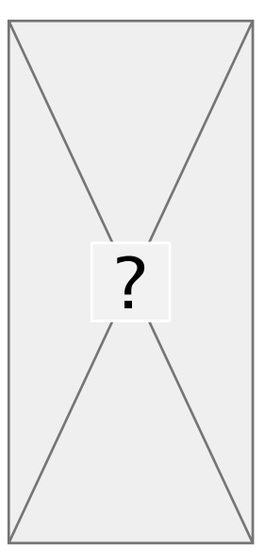
Momentum ~130 keV (350 keV)
Angular ~5 mrad ; ~5mrad
(9mrad ; 11mrad)
Vertex ~1.2 mm ; ~0.7 mm
(1.8 mm ; 1.1 mm)
DC-TC matching eff. ~ 90 % (41%)

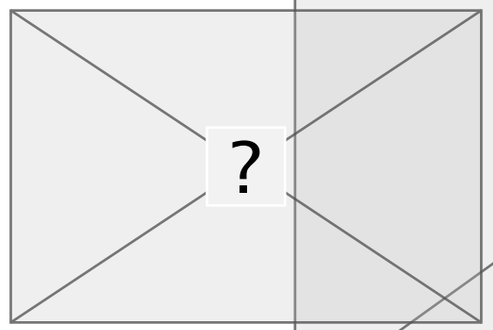
DC R&D Status

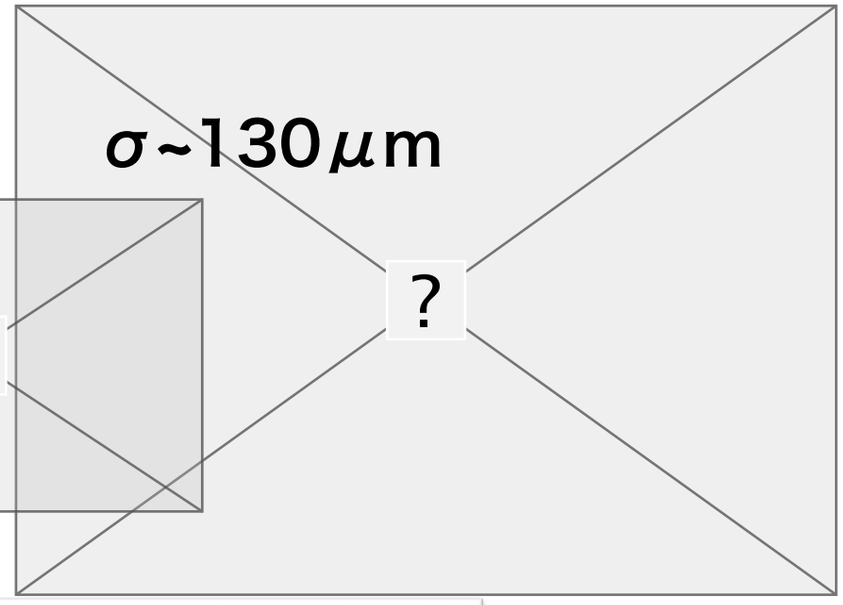
- Many prototypes
  - Single hit resolution
  - Aging
  - Mechanical design & optimize the length etc.





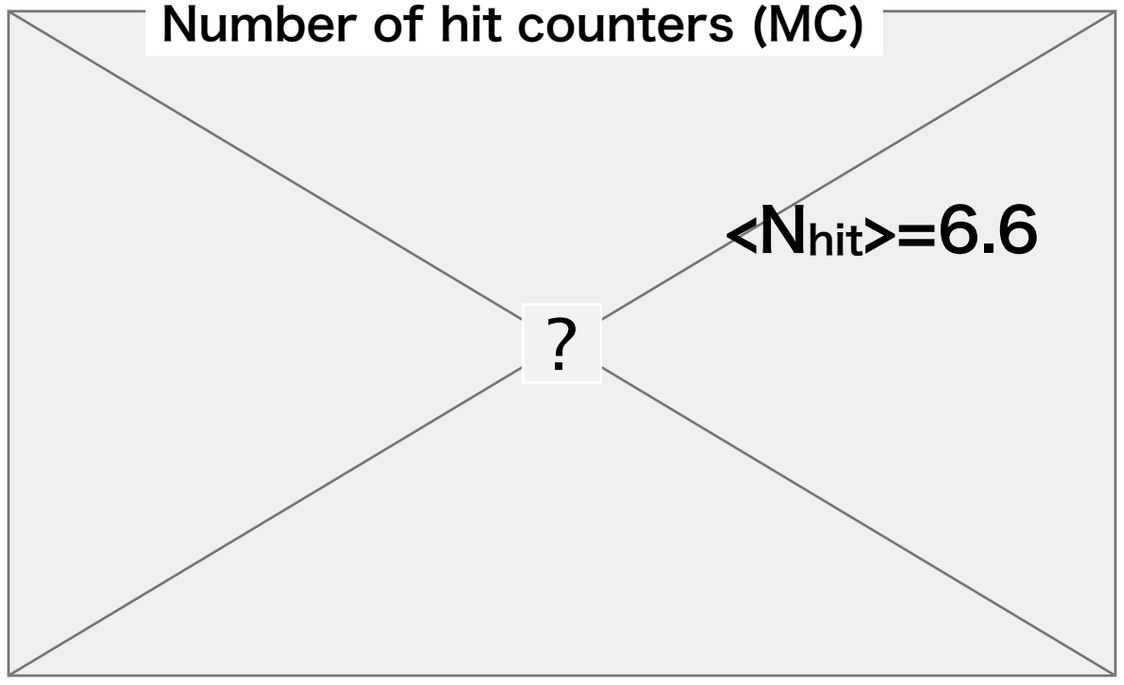


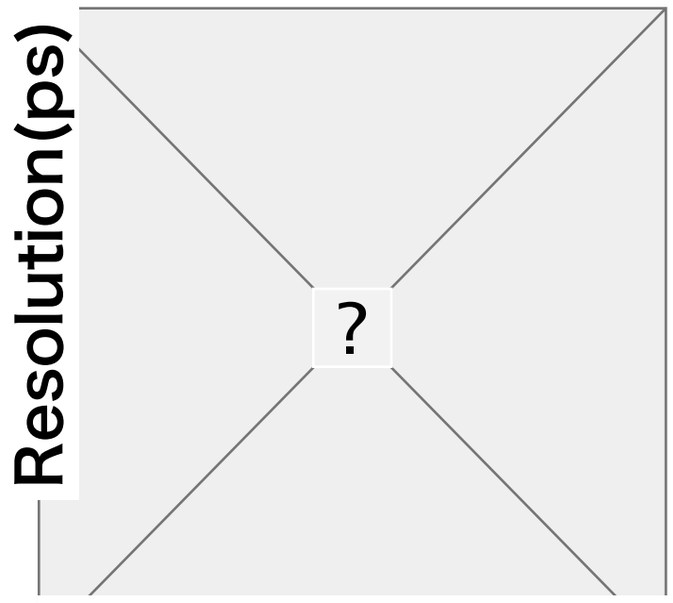


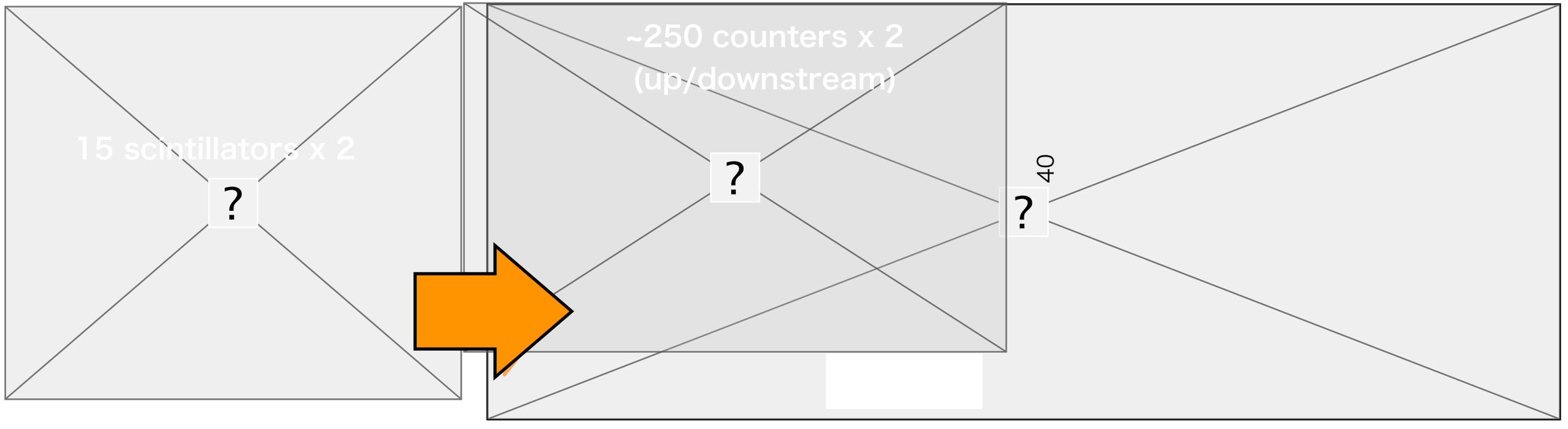


New Pixelated Timing Counter

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

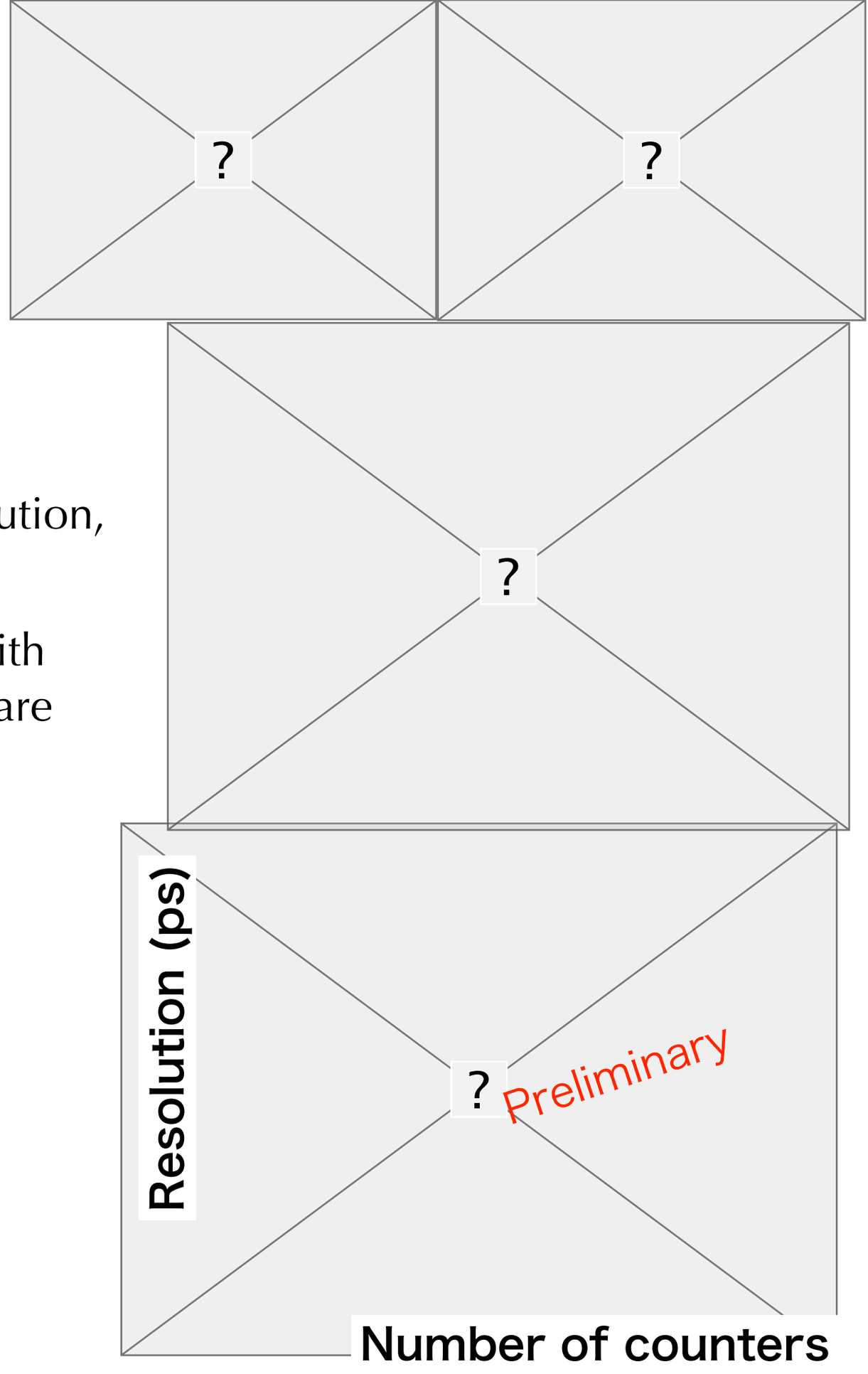






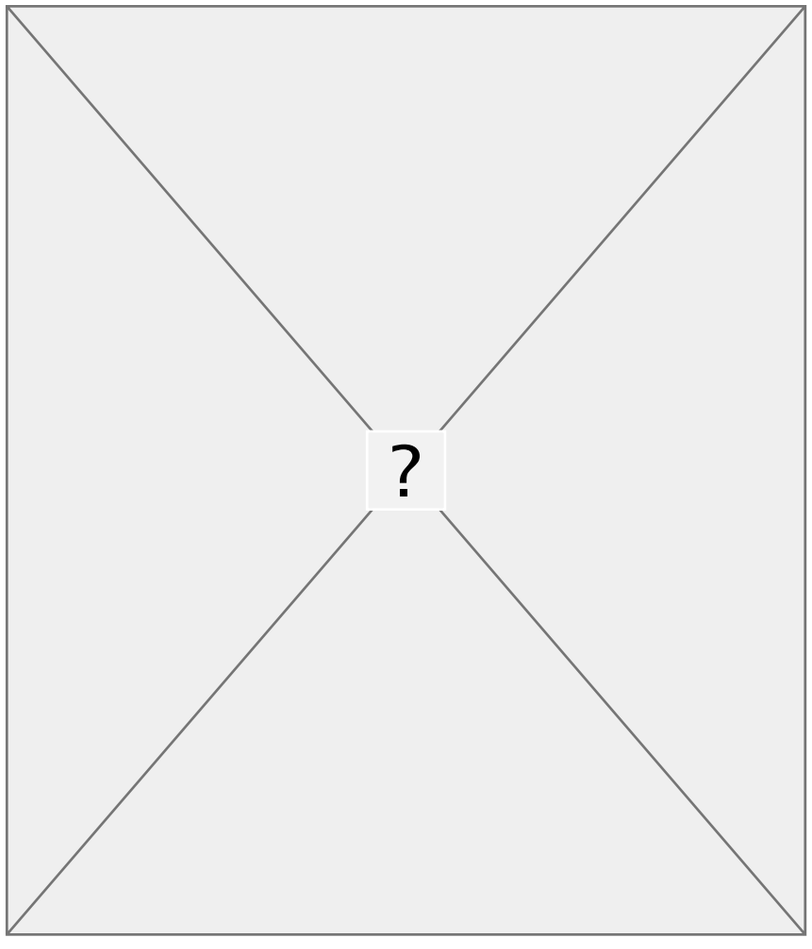
Beam tests @ Frascati

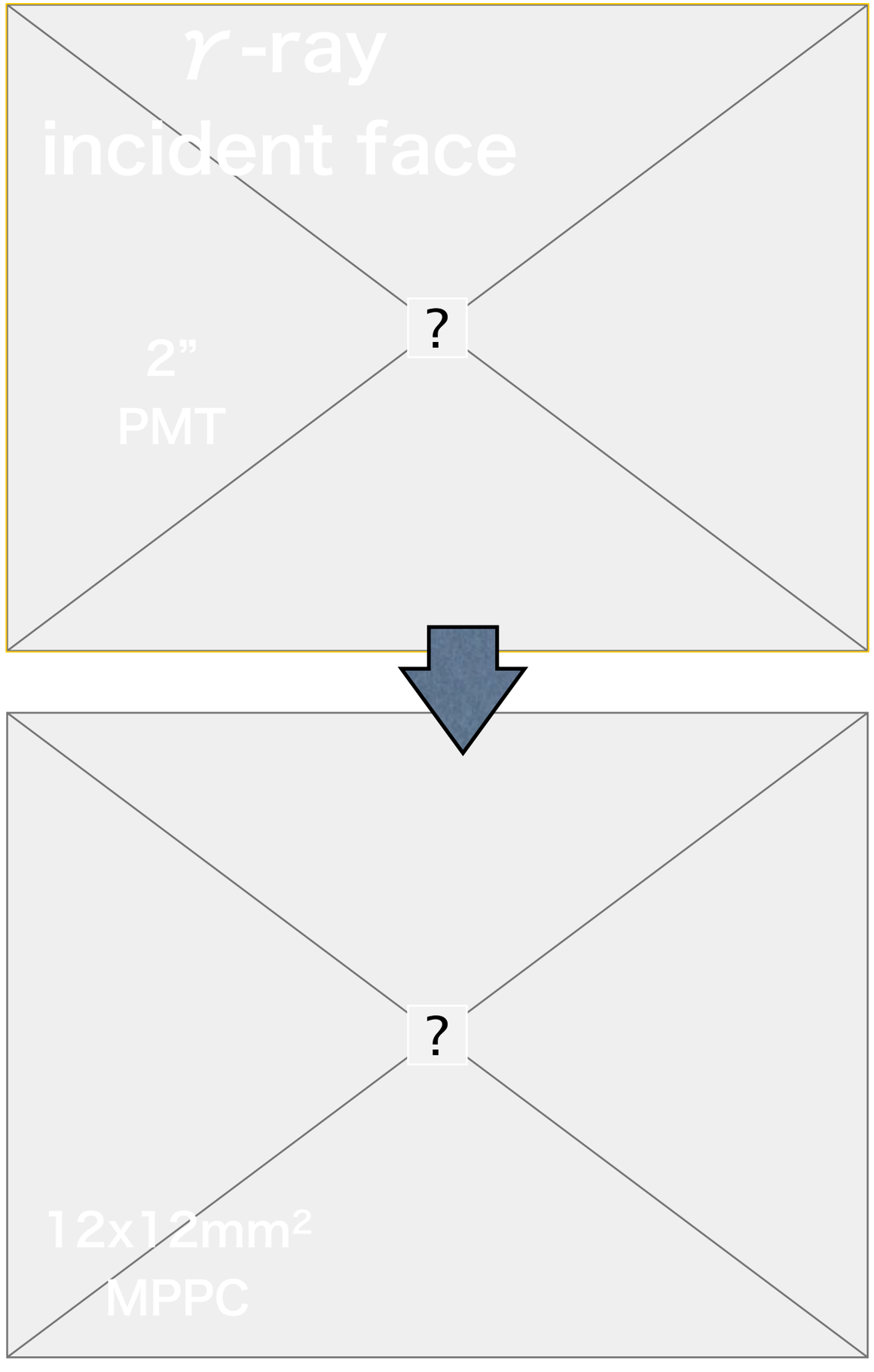
- Single counter resolution ~70ps (3 (90x40x5mm , BC418)
- Ultimate resolution with multi-counter hit
  - Reduce electronics, calibration contribution, and counter resolution
  - Eight counters(90x40x5mm^3, BC418) with MPPC and six counters with AdvanSiD are prepared (still to be optimized)
- Beam test 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

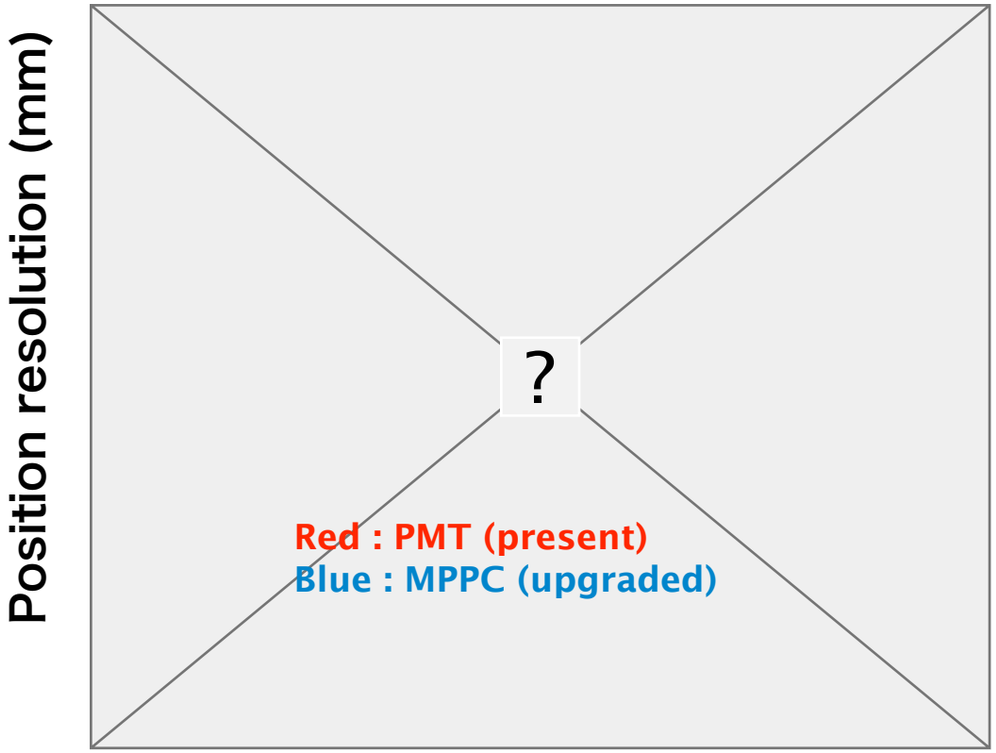




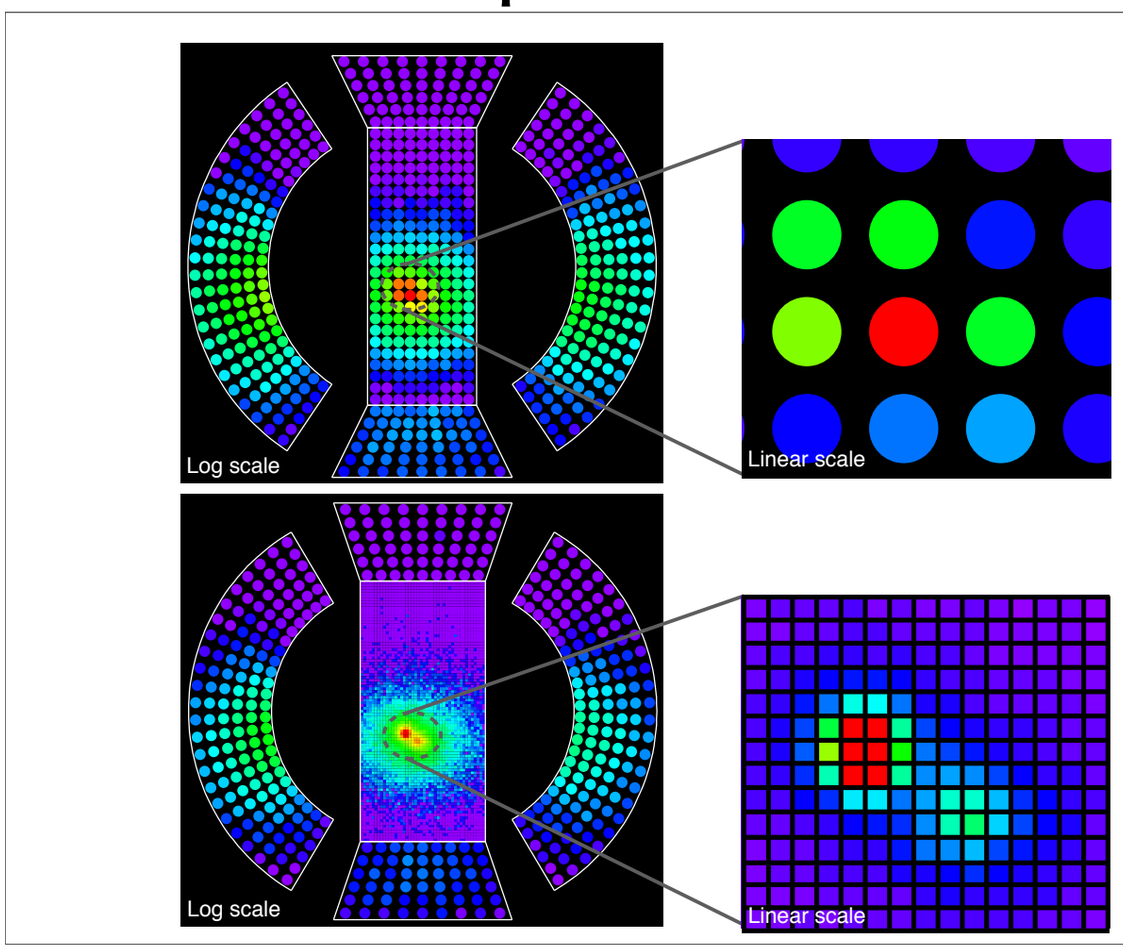
Computer Graphic

Possible improvements

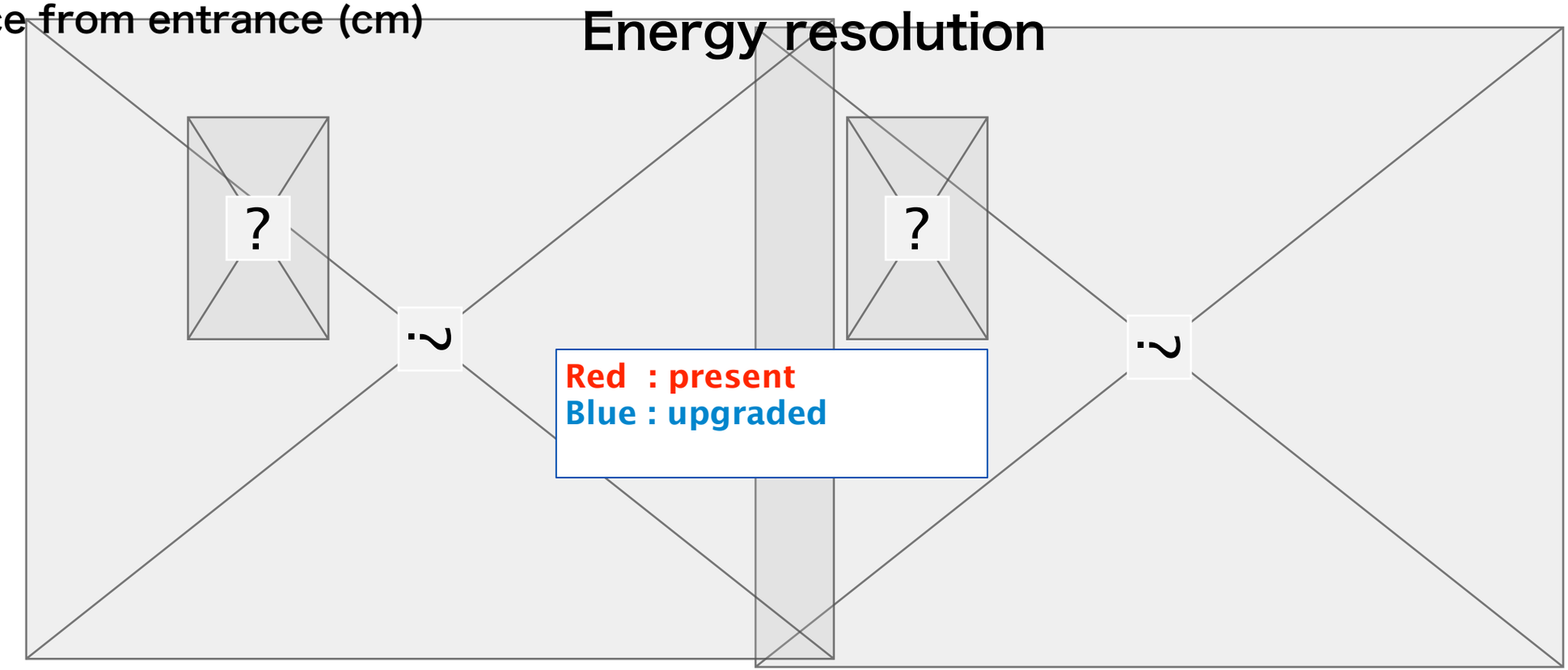
Position Resolution



Pileup identification

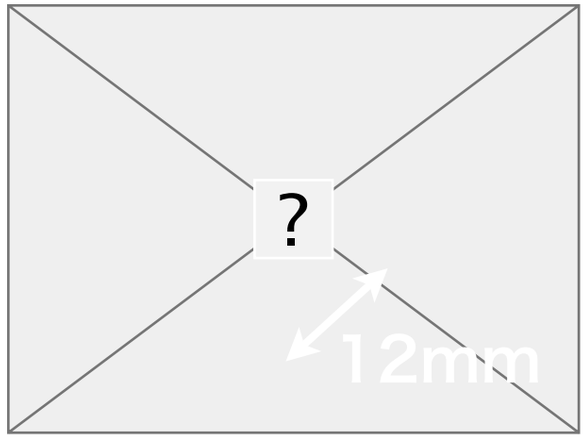


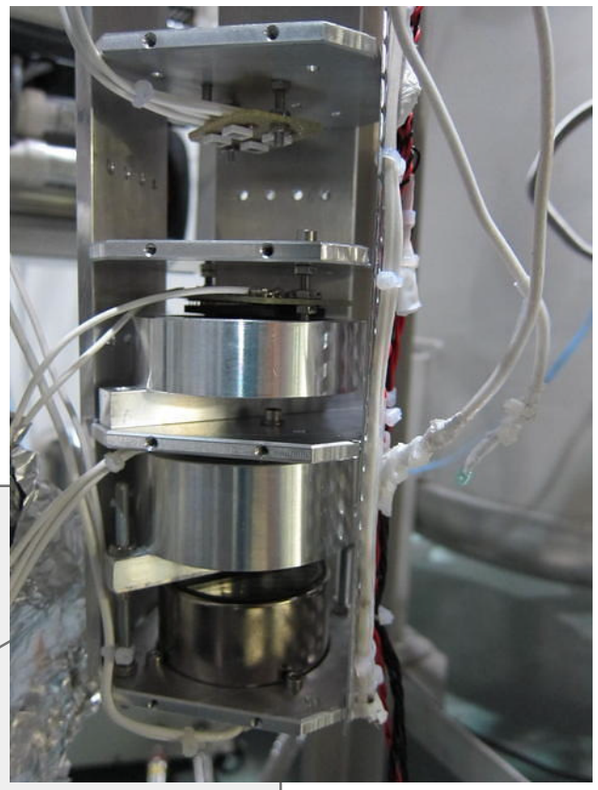
Energy resolution

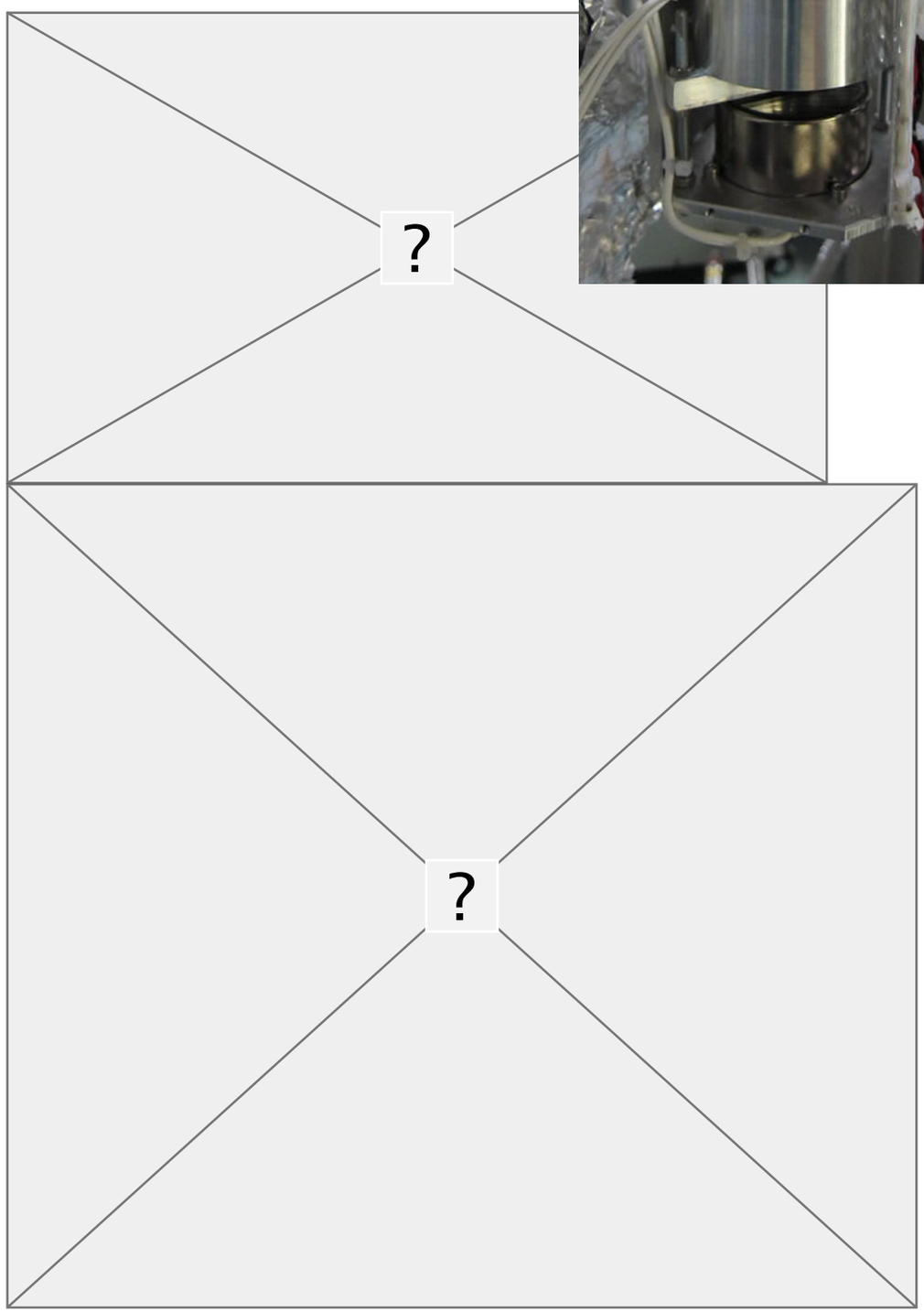


MPPC R&D Status

- 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)

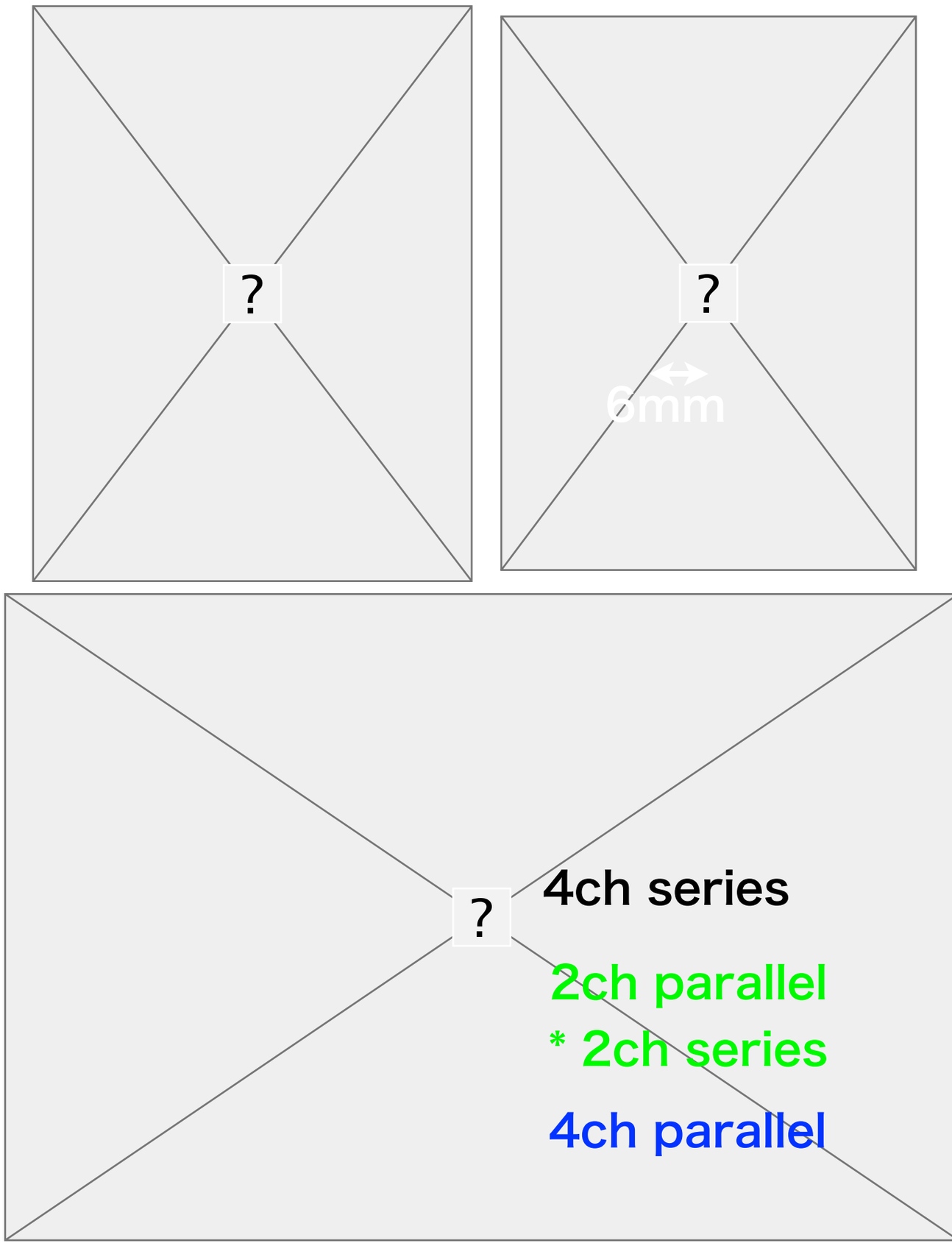






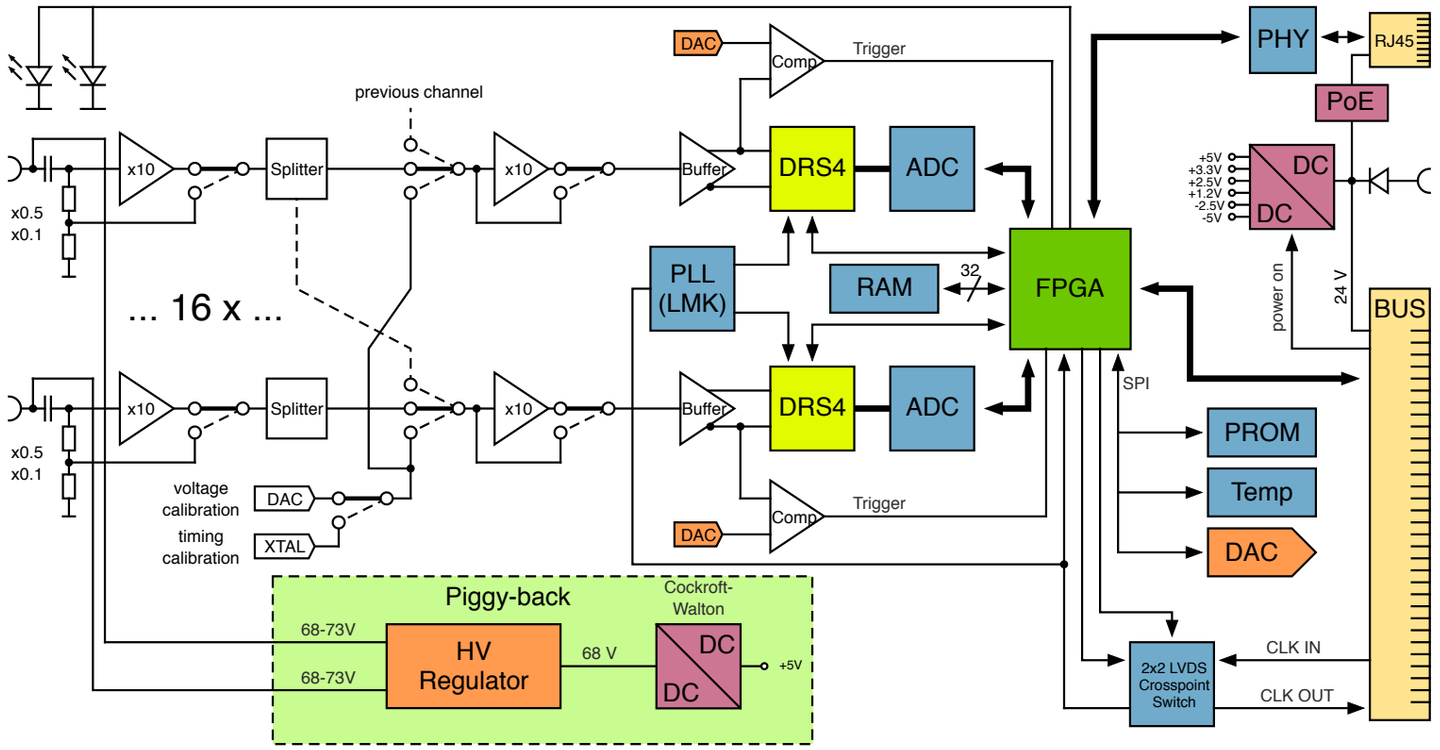
Series or Parallel connection?

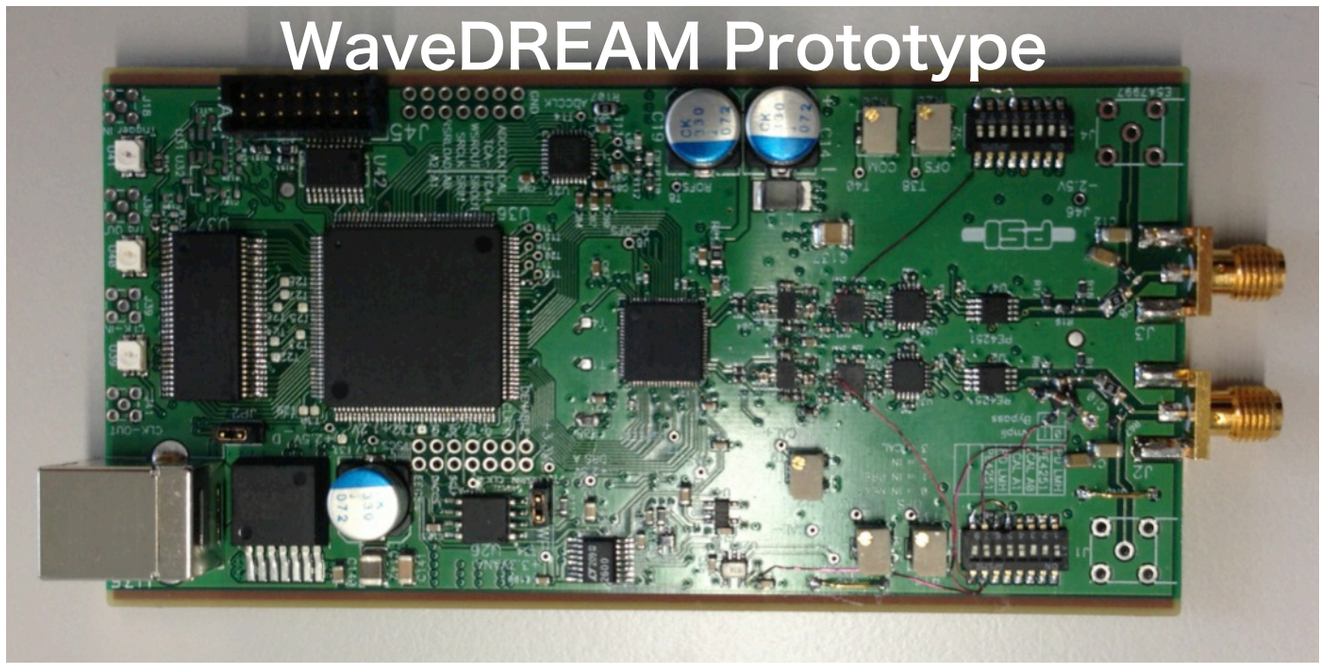
- Original plan was a single sensor with 12x12mm^2 large area, but it had a long tail ~ 200ns
- To reduce a sensor capacitance, one sensor can be segmented into sectors, which will be connected in series.
- To simulate the concept works or not, 4 independent 6x6mm^2 samples are connected differently,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



DAQ/Trigger

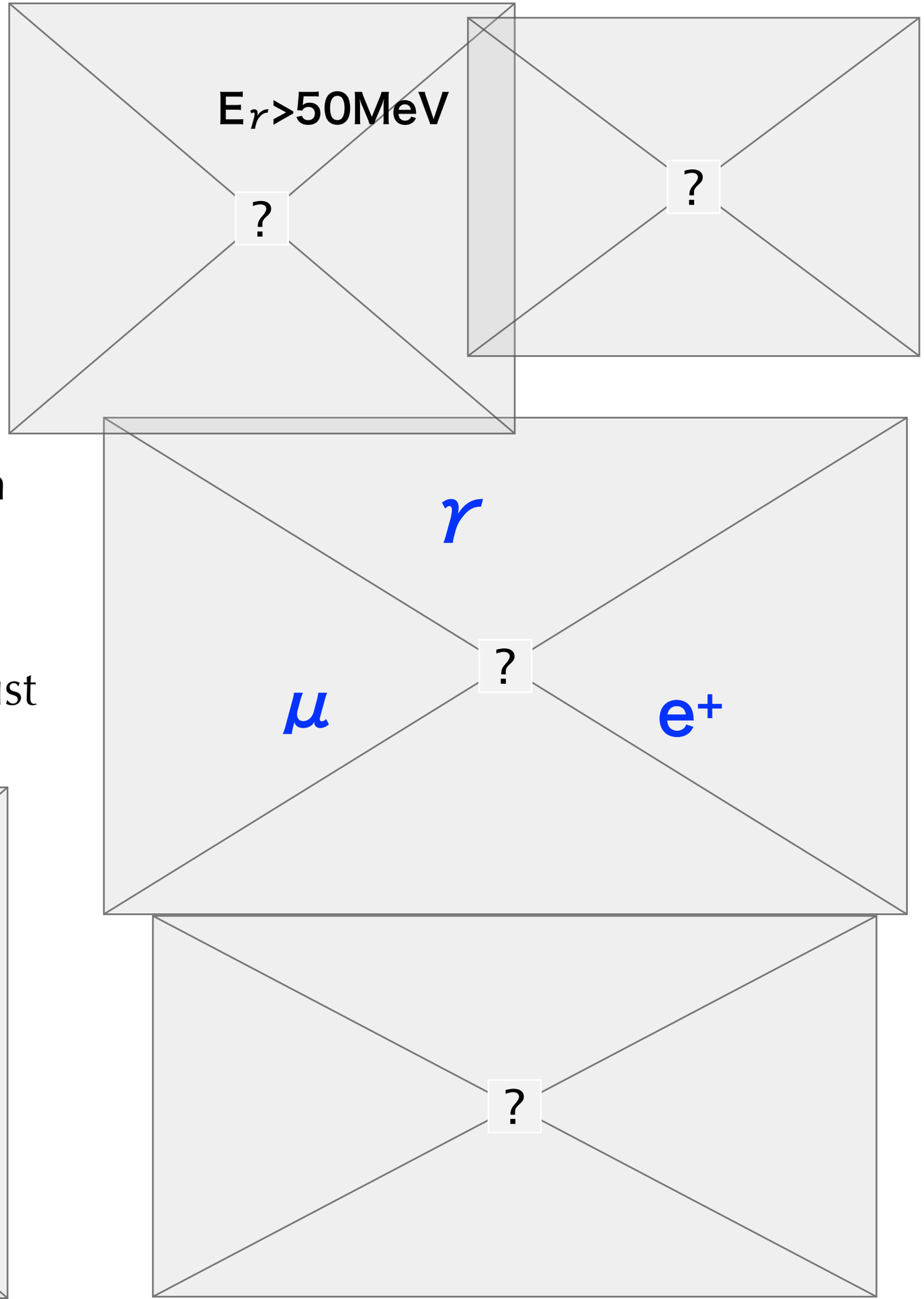
- More channels, higher rate
  - XEC MPPC (inner face) : ~4000
  - XEC PMT (other faces) : 630
  - pTC MPPC : ~1200
  - DC : 2760 (1GHz bandwidth)
- WaveDREAM
  - Higher density, compact
  - Waveform digitizer(DRS) +bias voltage supply +amplifier+simple trigger

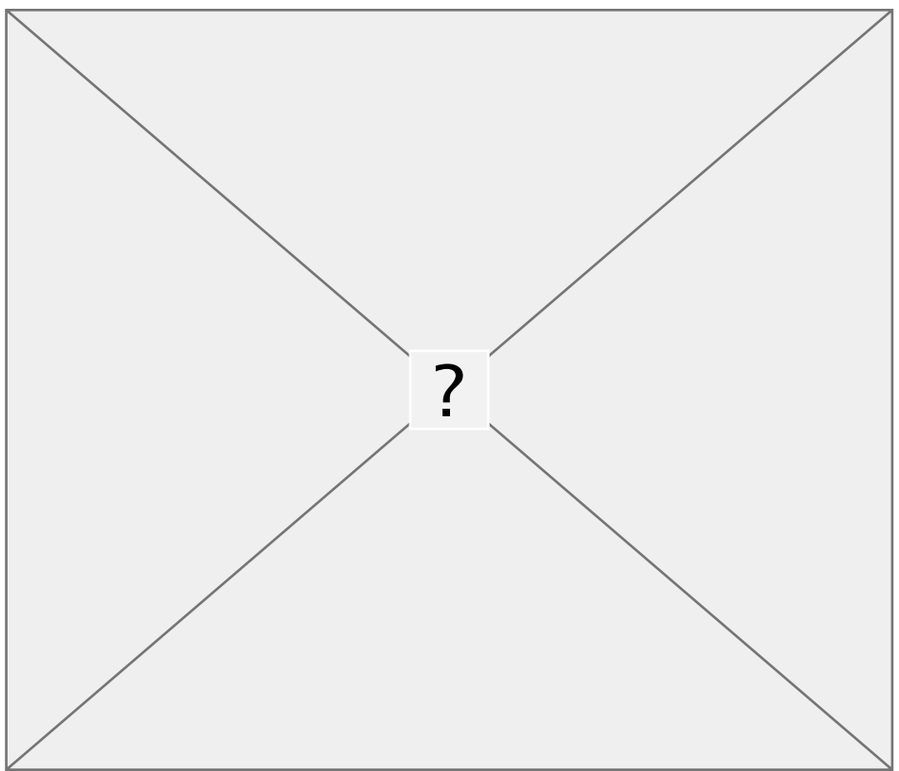


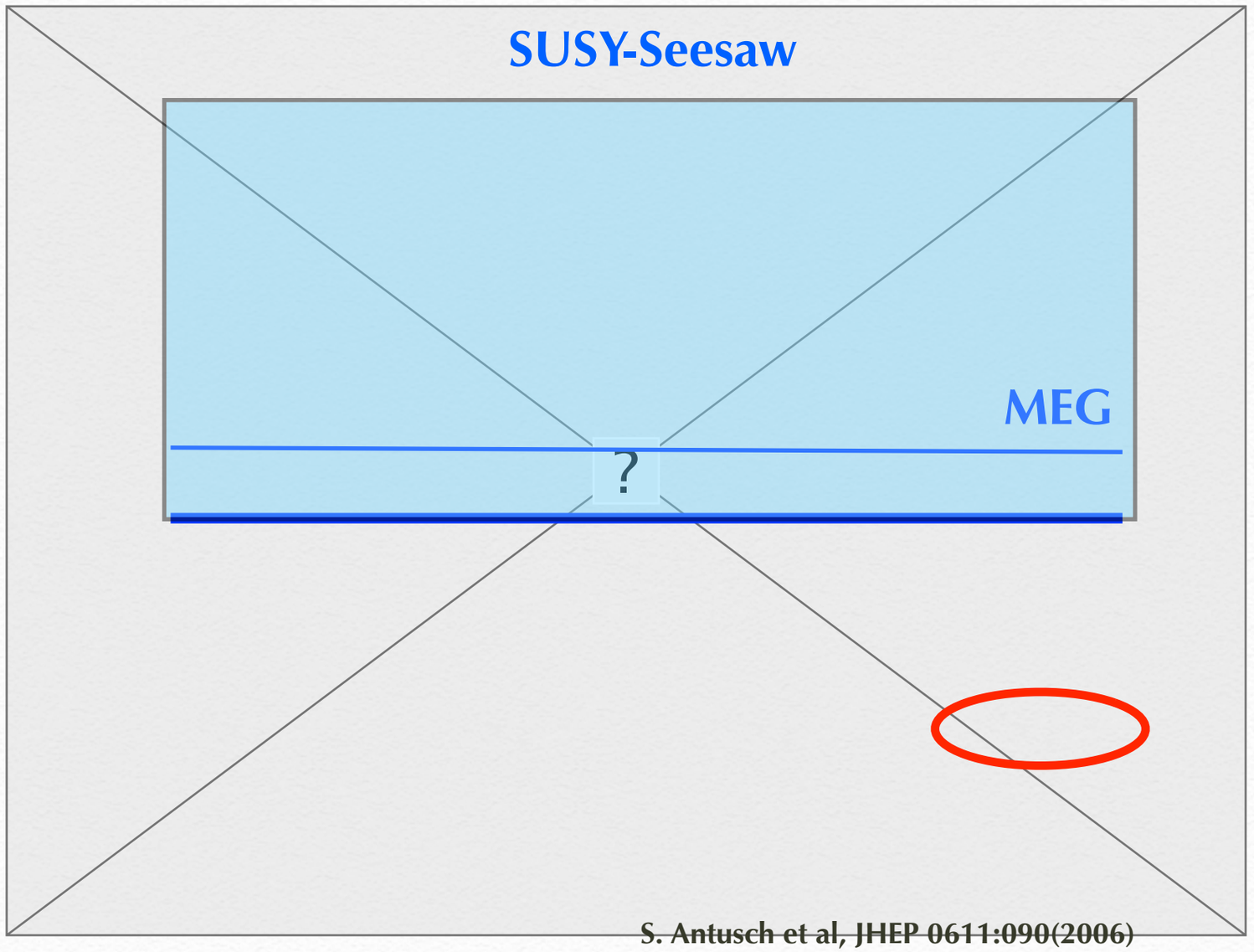


Background tagging detectors

- 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



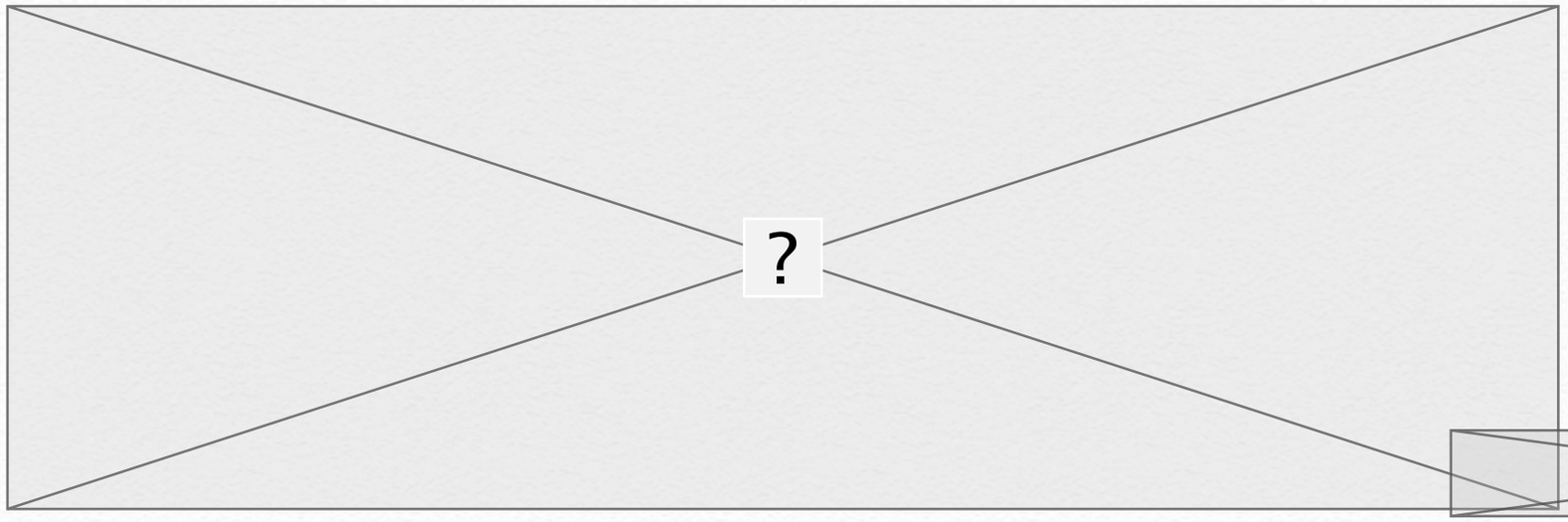


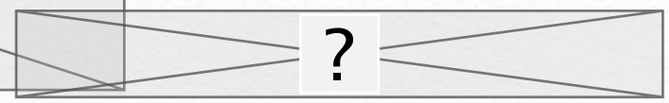


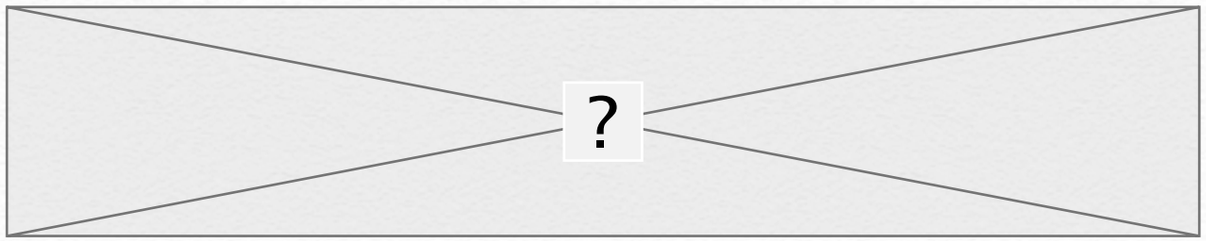
S. Antusch et al, JHEP 0611:090(2006)

Likelihood analysis

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

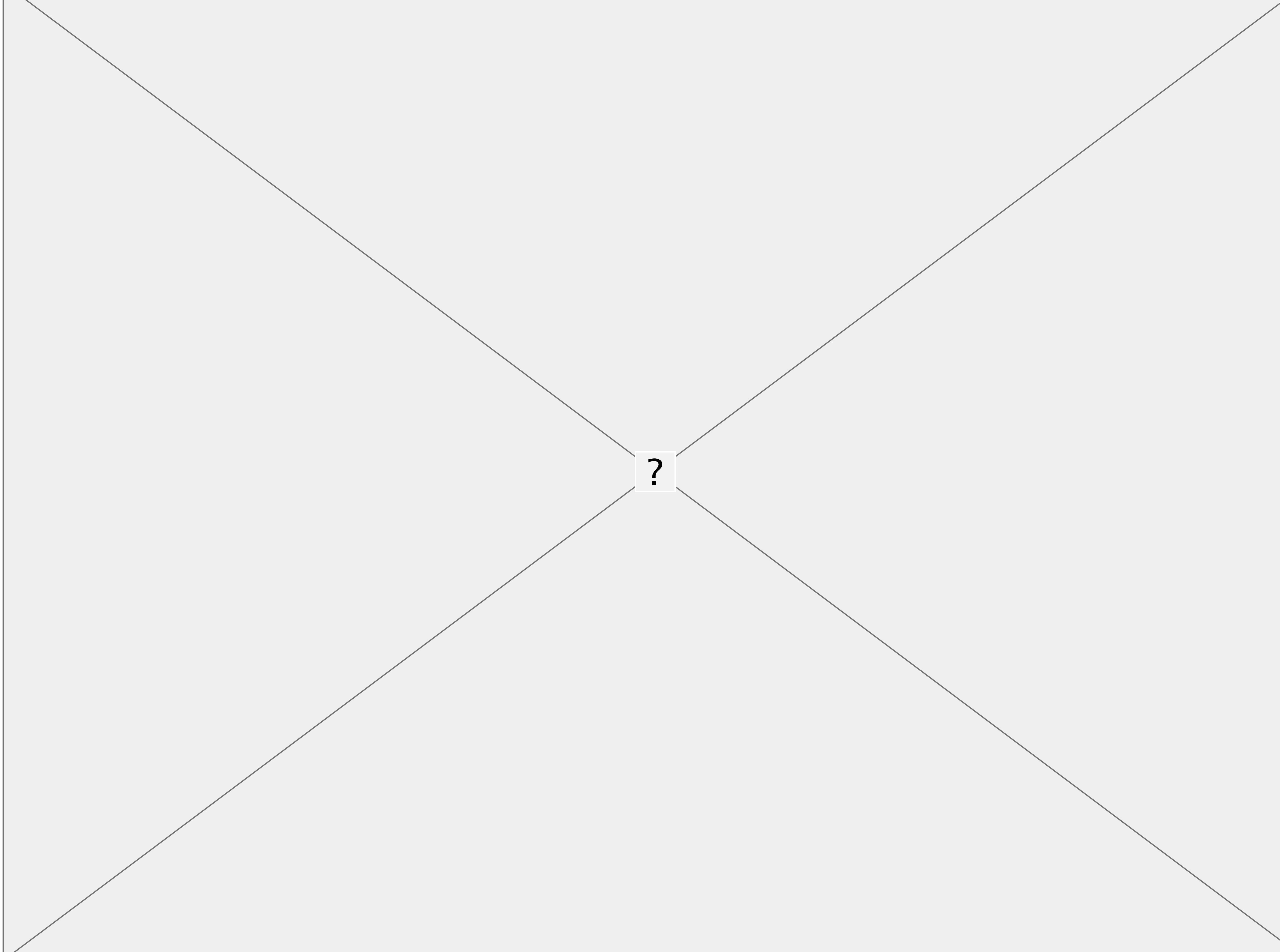






New DC parameters

- 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 1×10^5 μstop/s, max rate 45kHz/cm2
  - At 1×10^7 gain and 7×10^8 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



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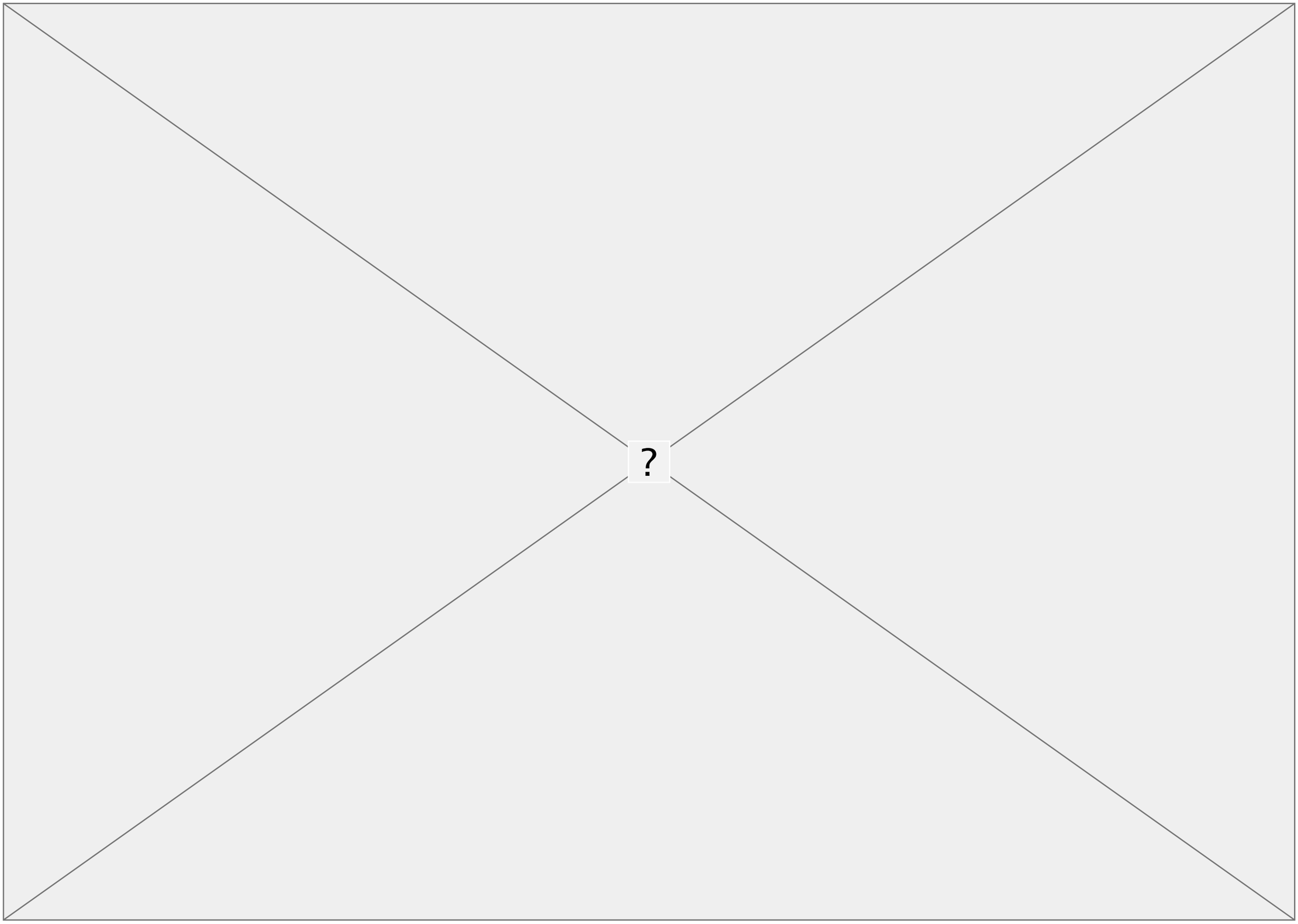

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