MEG将来計画

東京大学素粒子物理国際研究センター

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日本物理学会　2012年秋季大会　京都産業大学

東京大学
THE UNIVERSITY OF TOKYO

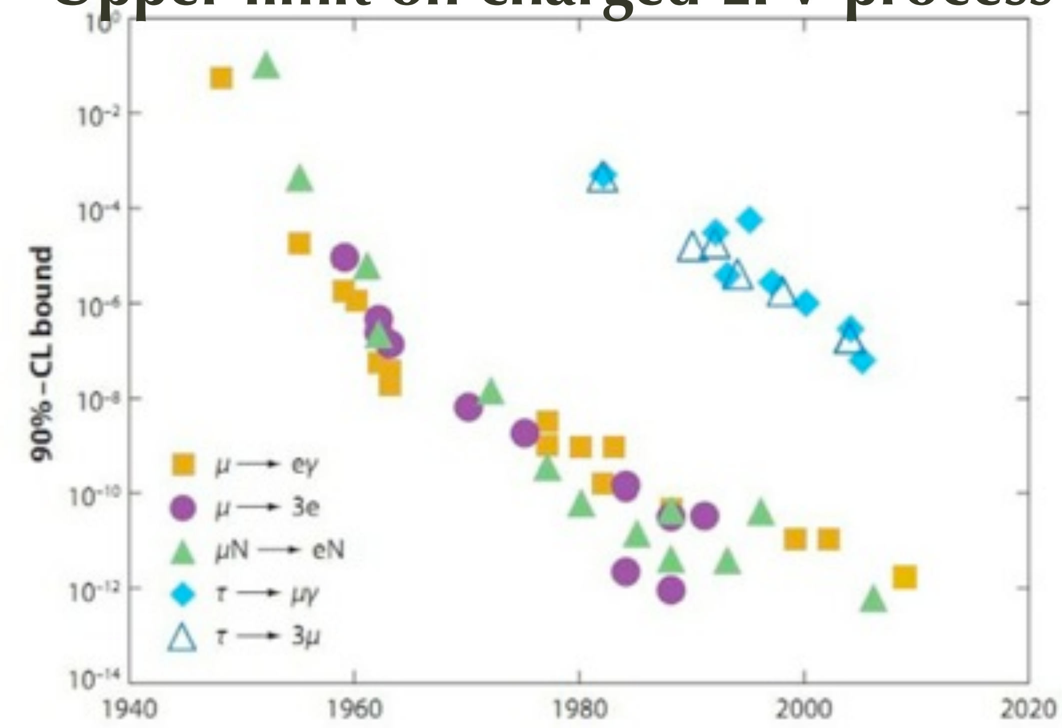
Outline

- Introduction & Status of the MEG experiment
- MEG upgrade design
- Improvements or redundancy with optional detectors

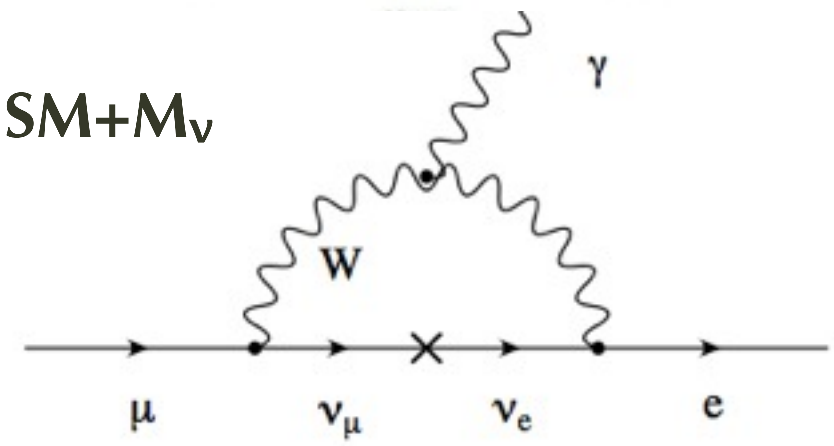
Lepton Flavor Violation

- MEG experiment is searching for Lepton Flavor Violating μ →eγ decay
  - Neutrino oscillation in neutrino sector, but no LFV observation yet in charged lepton sector
  - The SM with neutrino masses ~ B(μ →eγ) < 10^{-50}
  - Clean search for possible new physics beyond the SM
  - Well motivated new physics like SUSY-GUT, SUSY-seesaw models etc. predict large BR.

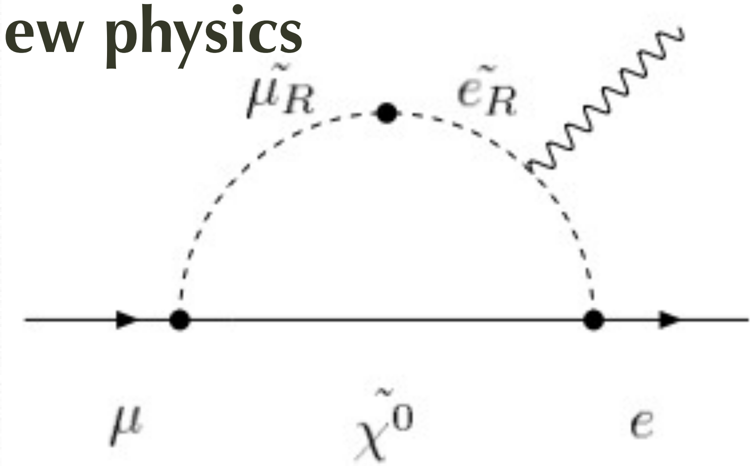
Upper limit on charged LFV process



SM+Mν

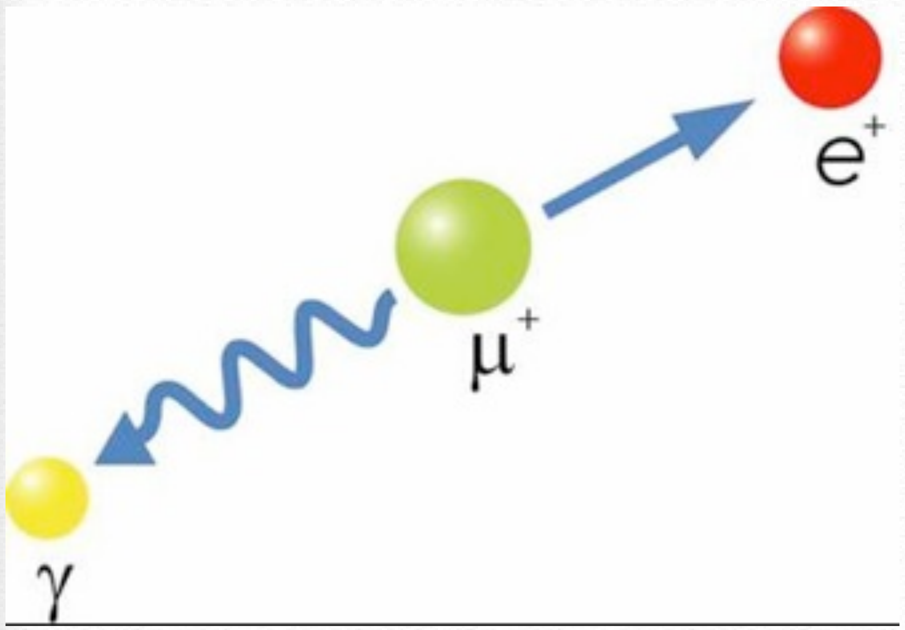


New physics



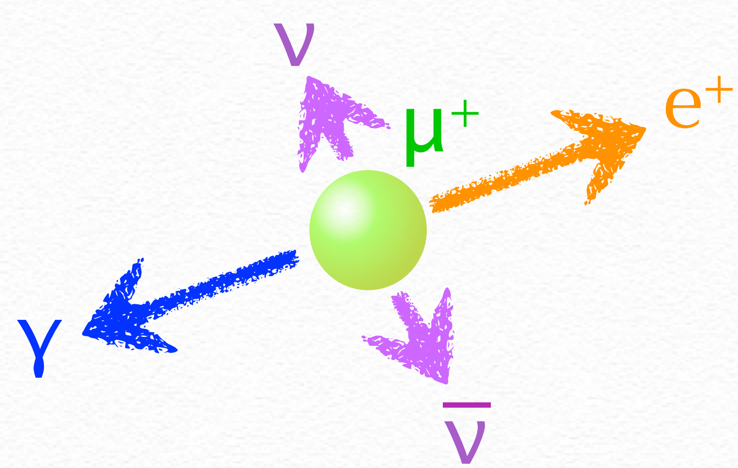
Signal & Background

Signal



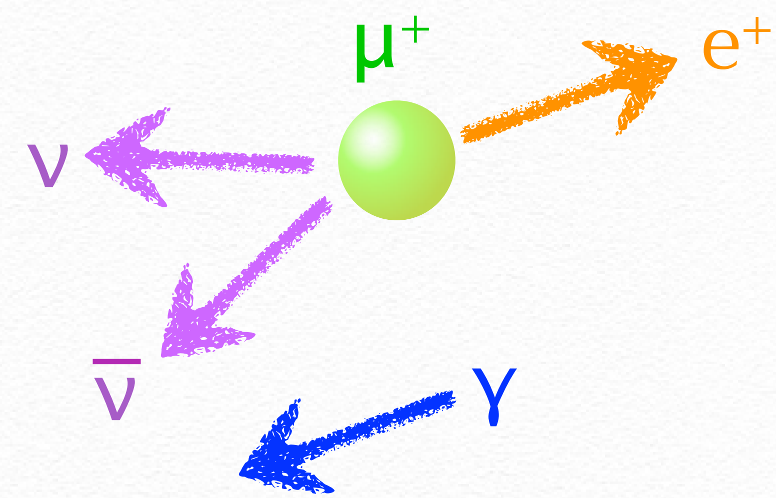
- μ^+ decay at rest
- Simple two body decay in final state
- **E_e, E_γ** = 52.8MeV
- **$T_e = T_\gamma$**
- back-to-back(**$\theta_{e\gamma}$**=180°)

Radiative muon decay background



- timing coincident

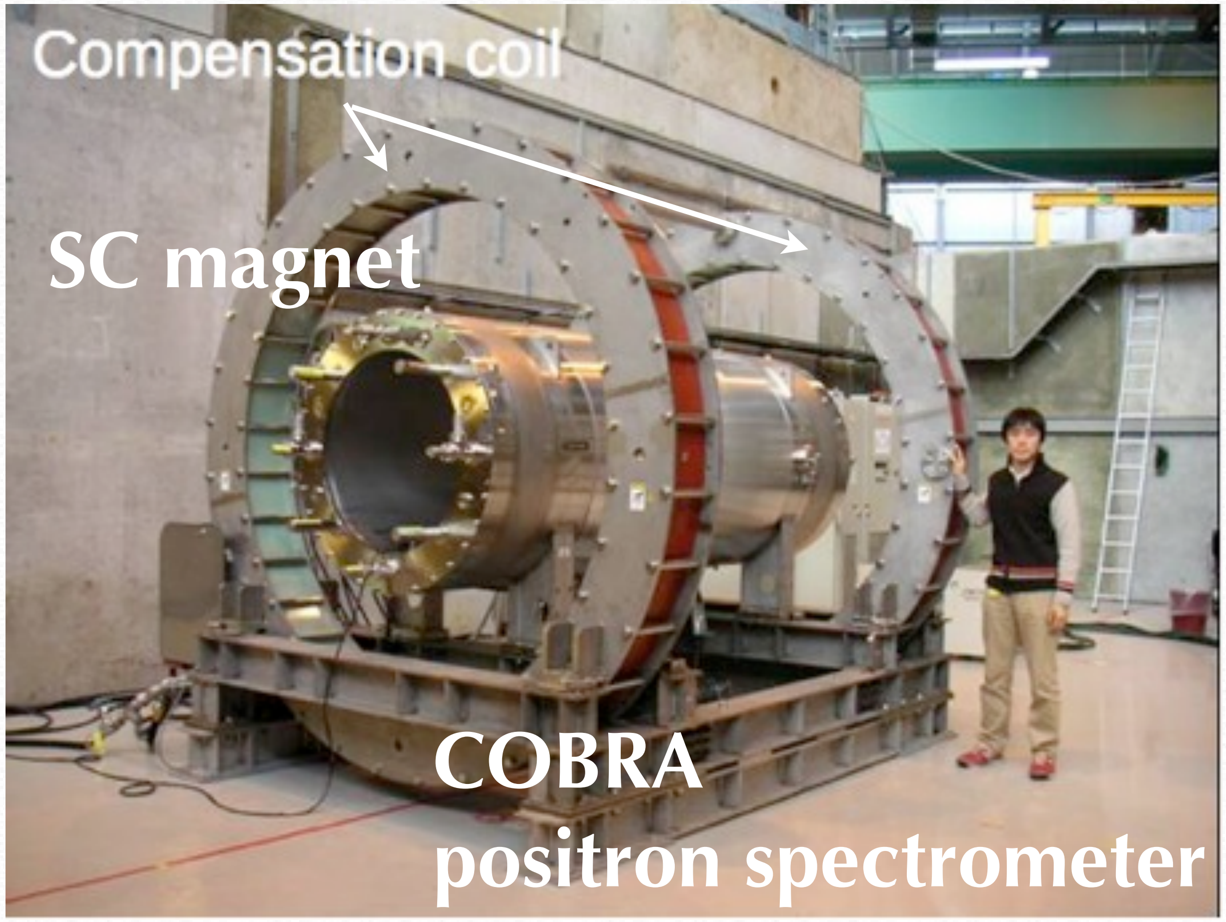
Accidental background



- dominant for us
- Michel e^+ + random γ from RMD/Annihilation in flight (AIF)

Key components

- Requirements
  - Intense μ^+ beam
  - e^+ tracking in high rate environment
  - Good energy, position, and timing resolutions



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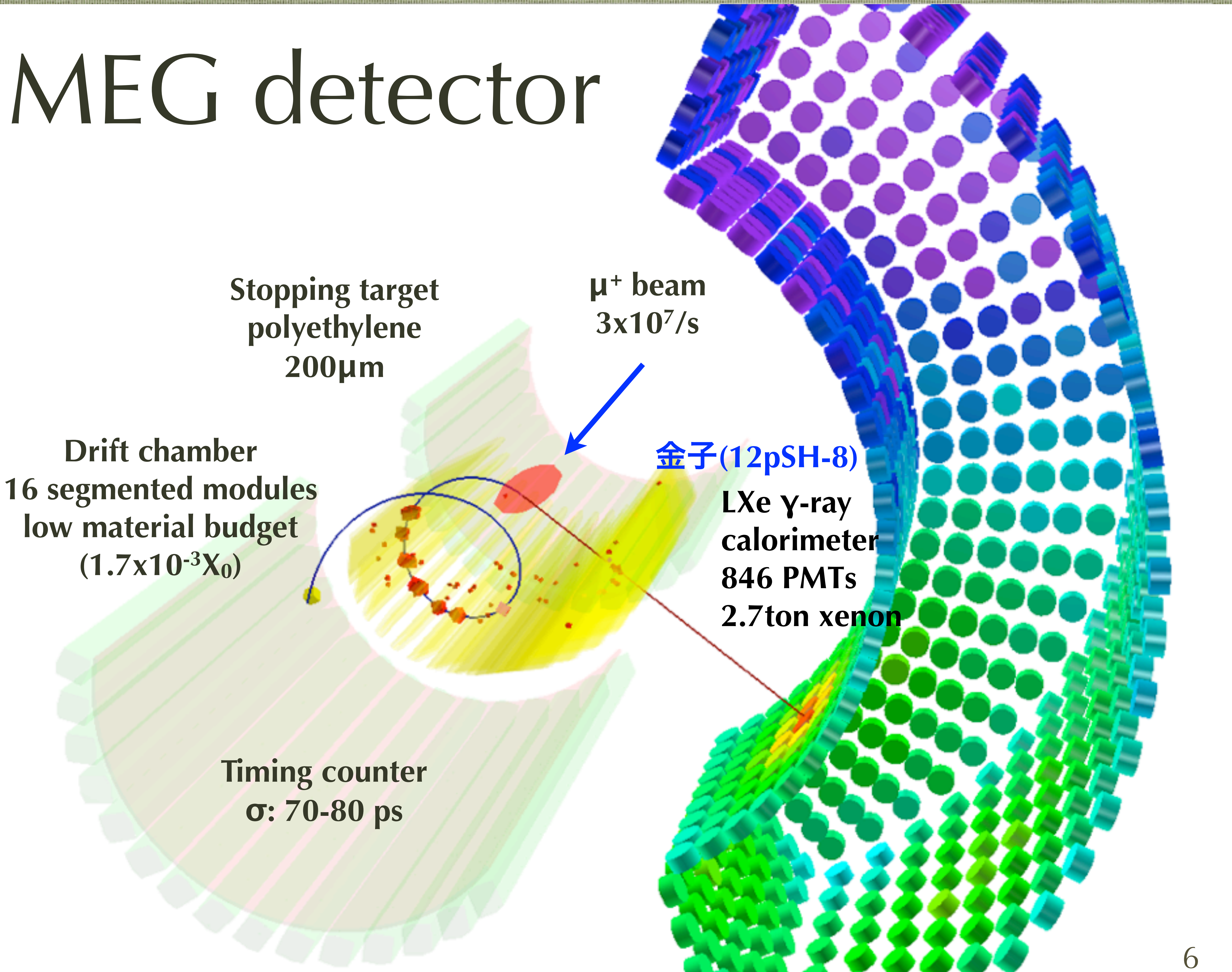
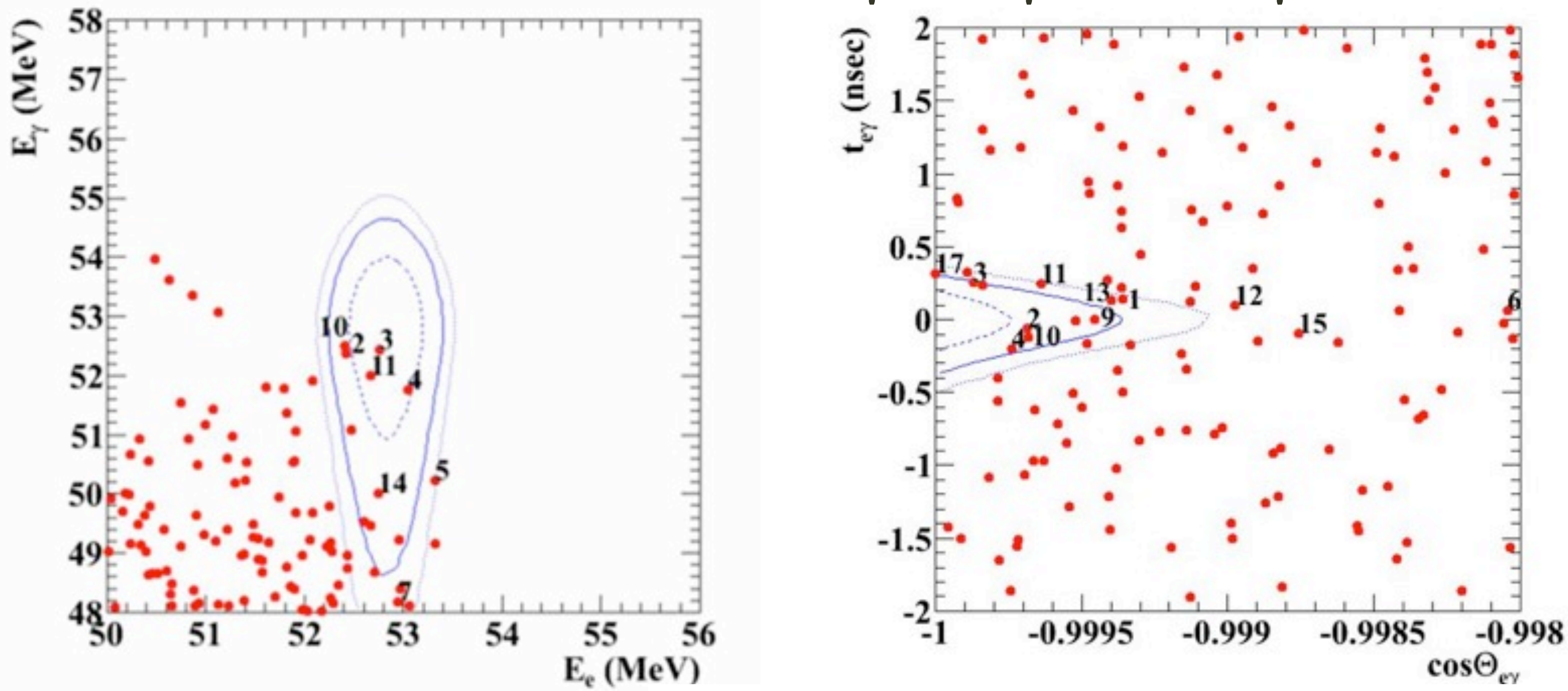
MEG detector



MEG result

Event distribution in E_e vs E_γ and $t_{e\gamma}$ and $\cos\Theta_{e\gamma}$



Combined analysis (2009 + 2010) result showed 90%CL Upper limit :

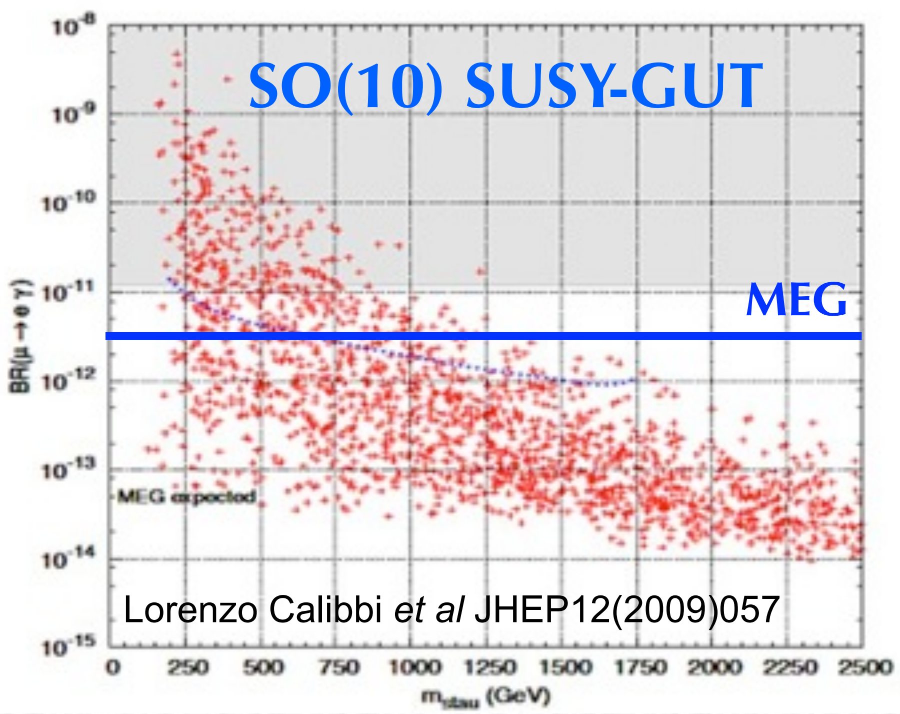
Br(μ->eγ)<2.4x10^{-12} (2009+2010 Sensitivity : 1.6x10^{-12})

Published in Phys. Rev. Lett. 107, 171801 (2011)

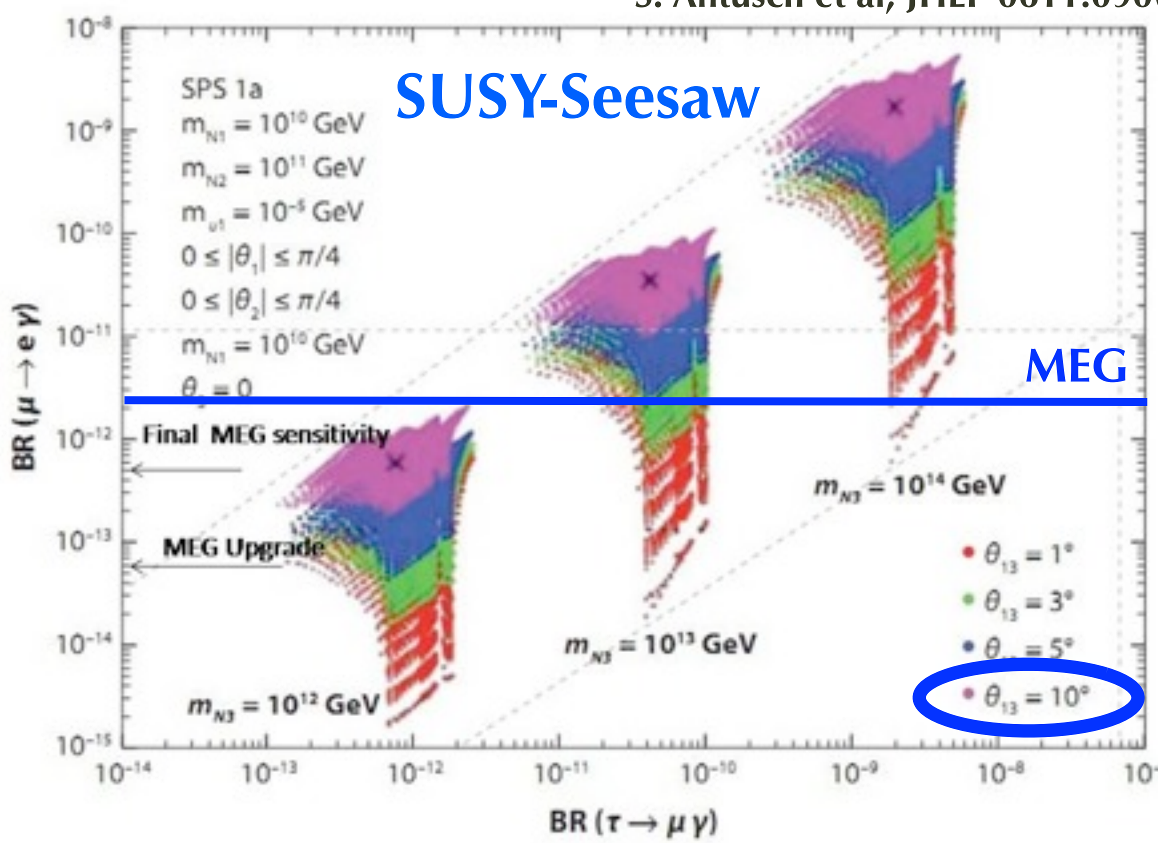
μ^- DECAY MODES			Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$e^-\bar{\nu}_e\nu_\mu$			$\approx$ 100%			53
$e^-\bar{\nu}_e\nu_\mu\gamma$		[d]	(1.4±0.4) %			53
$e^-\bar{\nu}_e\nu_\mu e^+e^-$		[e]	(3.4±0.4) × 10^{-5}			53
Lepton Family number (*LF*) violating modes						
$e^-\nu_e\bar{\nu}_\mu$	*LF*	[f]	< 1.2	%	90%	53
$e^-\gamma$	*LF*		< 2.4	× 10^{-12}	90%	53
$e^-e^+e^-$	*LF*		< 1.0	× 10^{-12}	90%	53
$e^-2\gamma$	*LF*		< 7.2	× 10^{-11}	90%	53

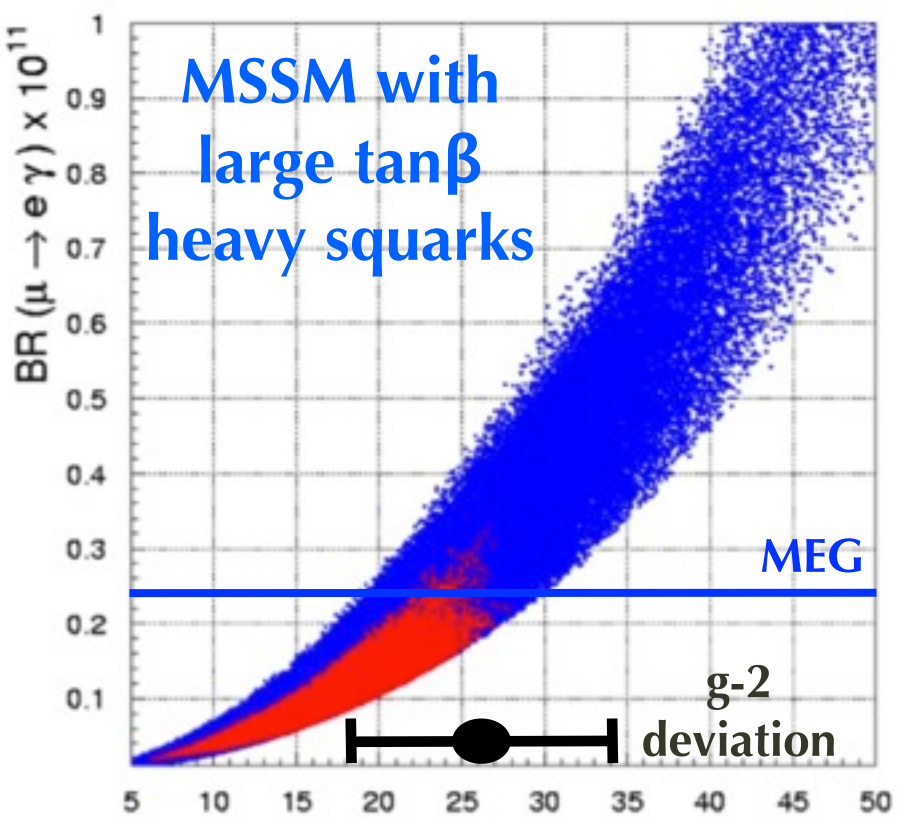
J. Beringer *et al.* (Particle Data Group), J. Phys. D**86**, 010001 (2012)

Impact on physics



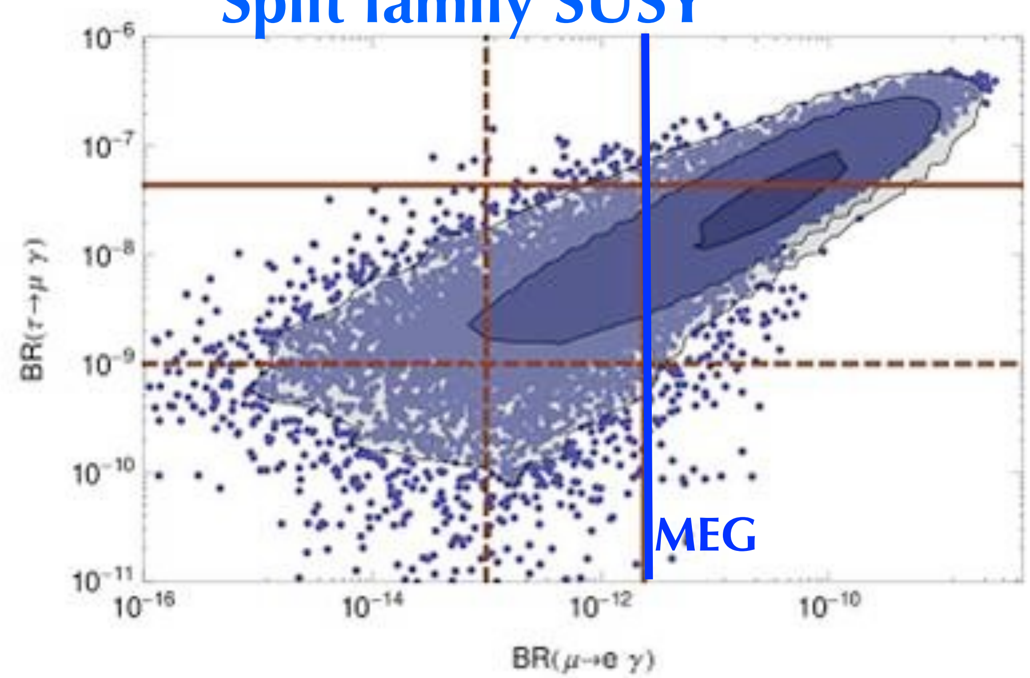
S. Antusch et al, JHEP 0611:090(2006)





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

Split family SUSY

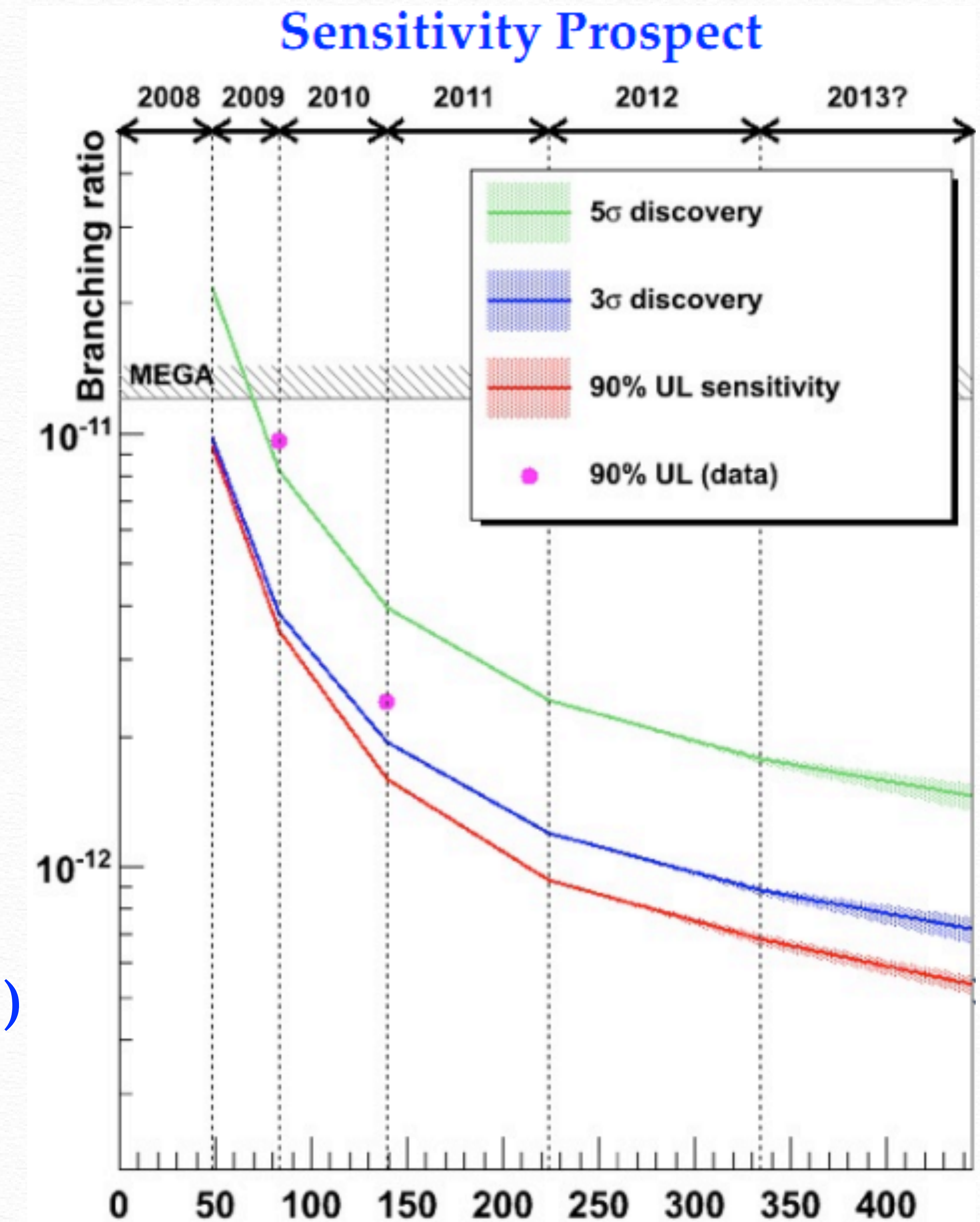


G. Blankenburg et al, arXiv:1204.0688, 2012

12年9月14日金曜日

MEG prospects

- Run2012 is ongoing
- Run2009+2010+2011 analysis result will be published soon (double the statistics, $<1\times10^{-12}$)
- MEG experiment will finish in 2013 when the sensitivity reaches $\sim6\times10^{-13}$ (Slower improvements after that)
- Time to consider MEG upgrade (MEG phase-II)



内山(13aSH-9)

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MEG upgrade design

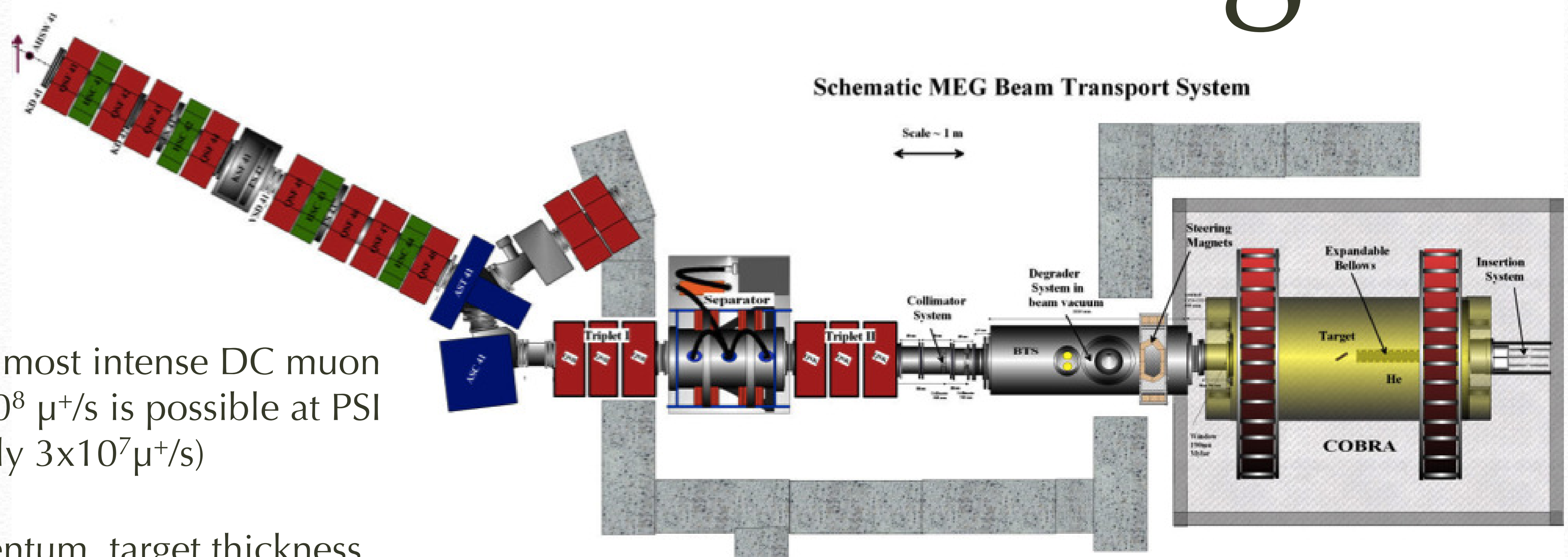
Concept

- Improvement of the MEG sensitivity to the μ->eγ decay in a reasonably short construction(~2years) and running time(3-4years)
- High statistics
  - higher muon stopping rate
  - improved detectors efficiencies
- Background reduction
  - Improvement of the experimental resolutions
  - Less detector material to reduce γ background generation
  - Actively tag and veto specific backgrounds
- Schedule
  - MEG upgrade proposal to PSI in Jan. 2013
  - Aims at BR(μ->eγ) ~ 5×10^{-14} with two years R&D and three years DAQ

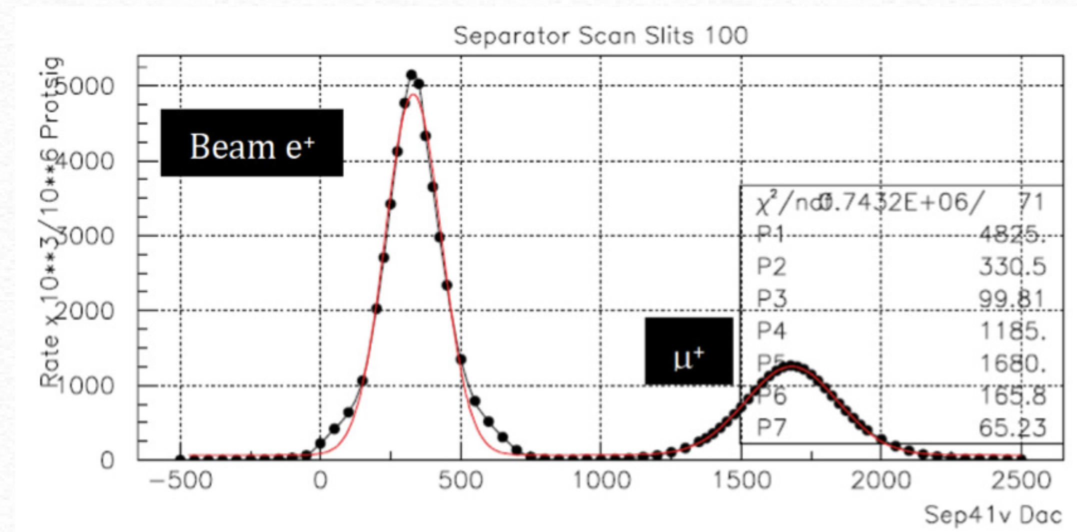
Performance of MEG detector to be improved

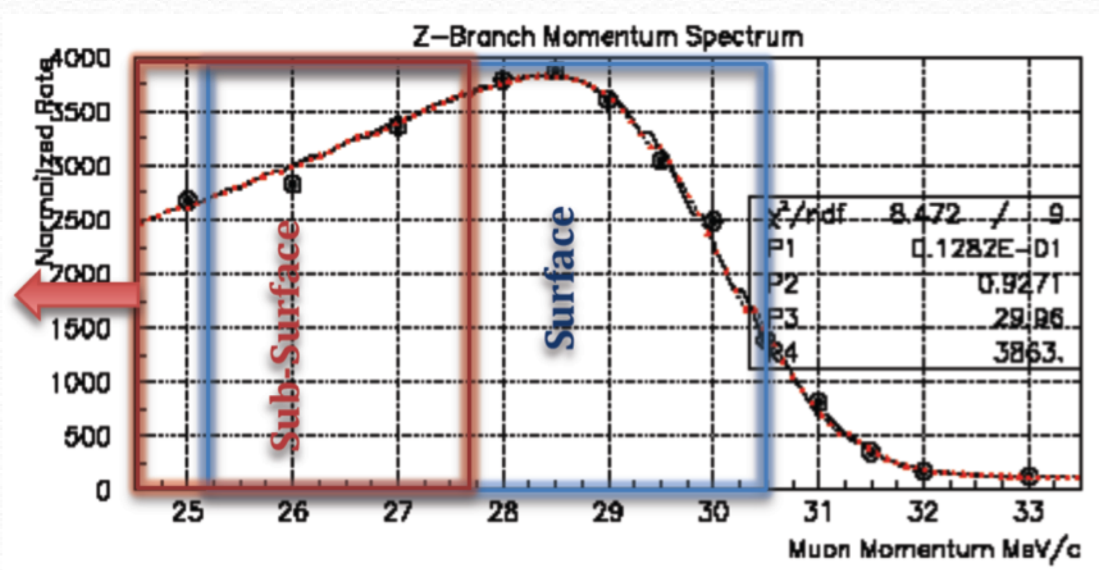
Variable	Obtained
ΔE_γ	1.6 (w>3cm), 2.0(0.8<w<3cm), 2.7(0<w<0.8cm)
Δt_γ	67
γ position (mm)	5(u,v), 6(w)
γ efficiency(%)	63
ΔP_e (keV)	330
e^+ angle (mrad)	11(φ_e),9(θ_e)
Δt_{e+} (psec)	107
e^+ efficiency(%)	40
$\Delta t_{e\gamma}$ (ps)	120

Beam line and target



- World's most intense DC muon beam 10^8 μ^+/s is possible at PSI (currently $3\text{x}10^7 \mu^+$/s)
- μ momentum, target thickness, target angle etc. can be optimized
- Current setting : 28MeV/c, 205μm thickness, 20.5deg angle ~ 82% stopping efficiency

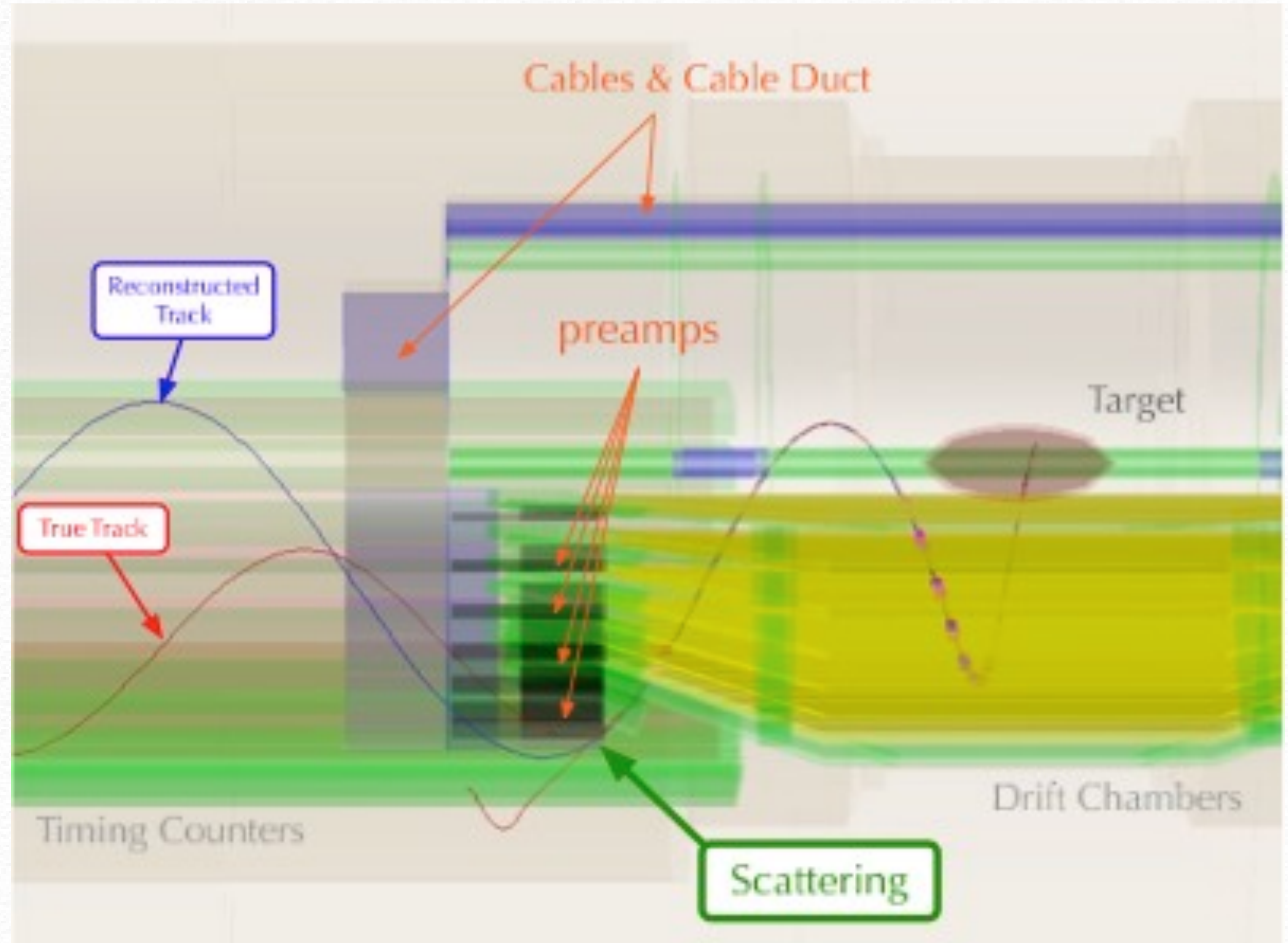


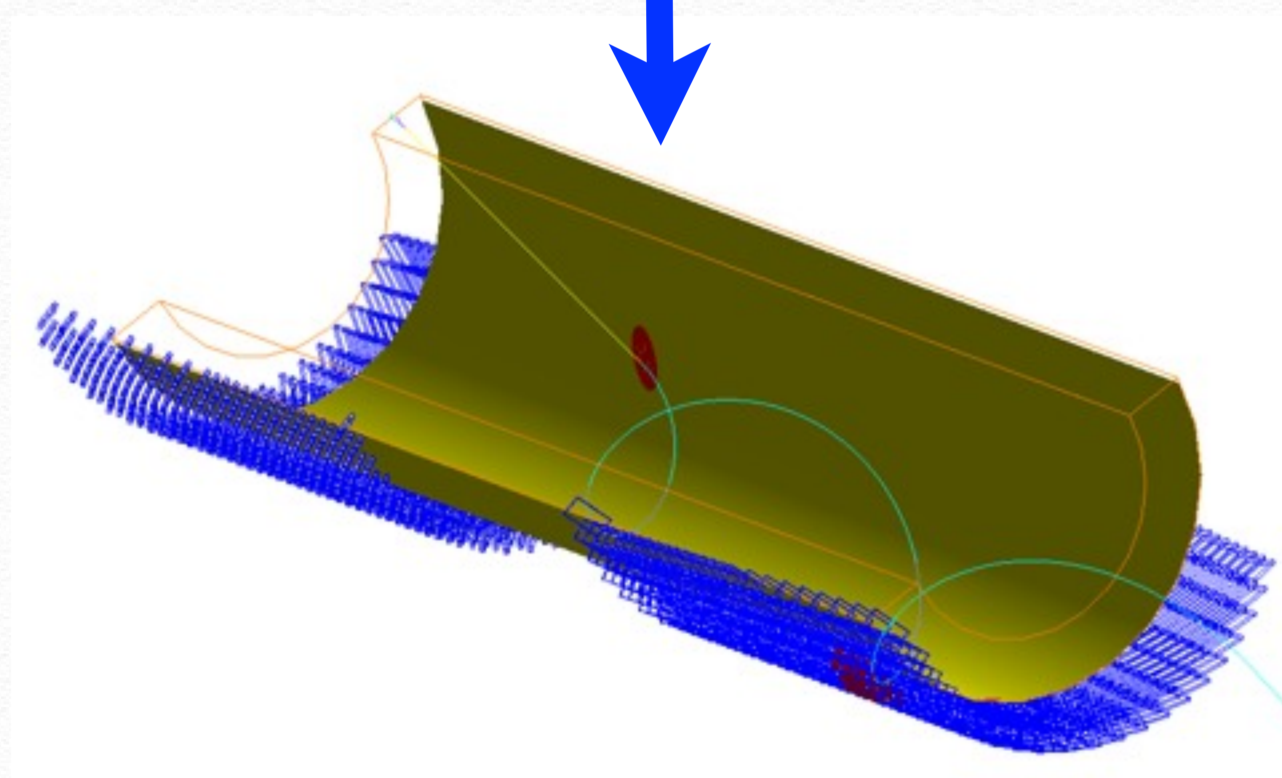


Upgrade plan:
Surface beam, 140μm thickness, placed at 15deg, ~$7.5\text{x}10^7$ Hz stop rate is obtained

Positron spectrometer

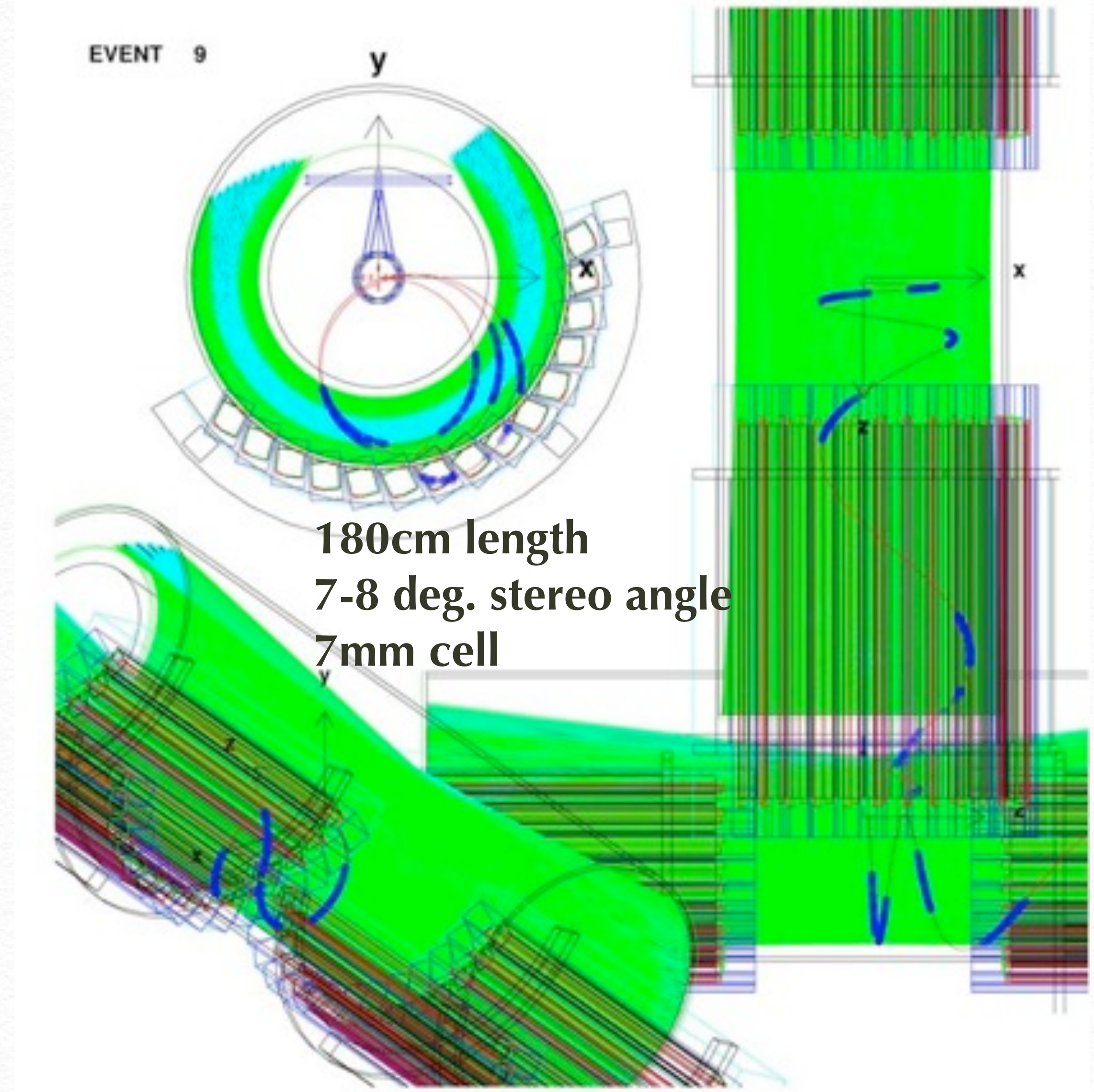
- Higher detection efficiency
  - need to minimize material along the positrons path to timing counter (40% -> ?)
- Minimize the contribution of the track length uncertainty
  - σ_{Te+} = 107ps = 76ps (TC) $\oplus$ 75ps (track)
- Good angle, momentum resolutions
- COBRA magnet will be re-used
- **Unique volume tracker !**

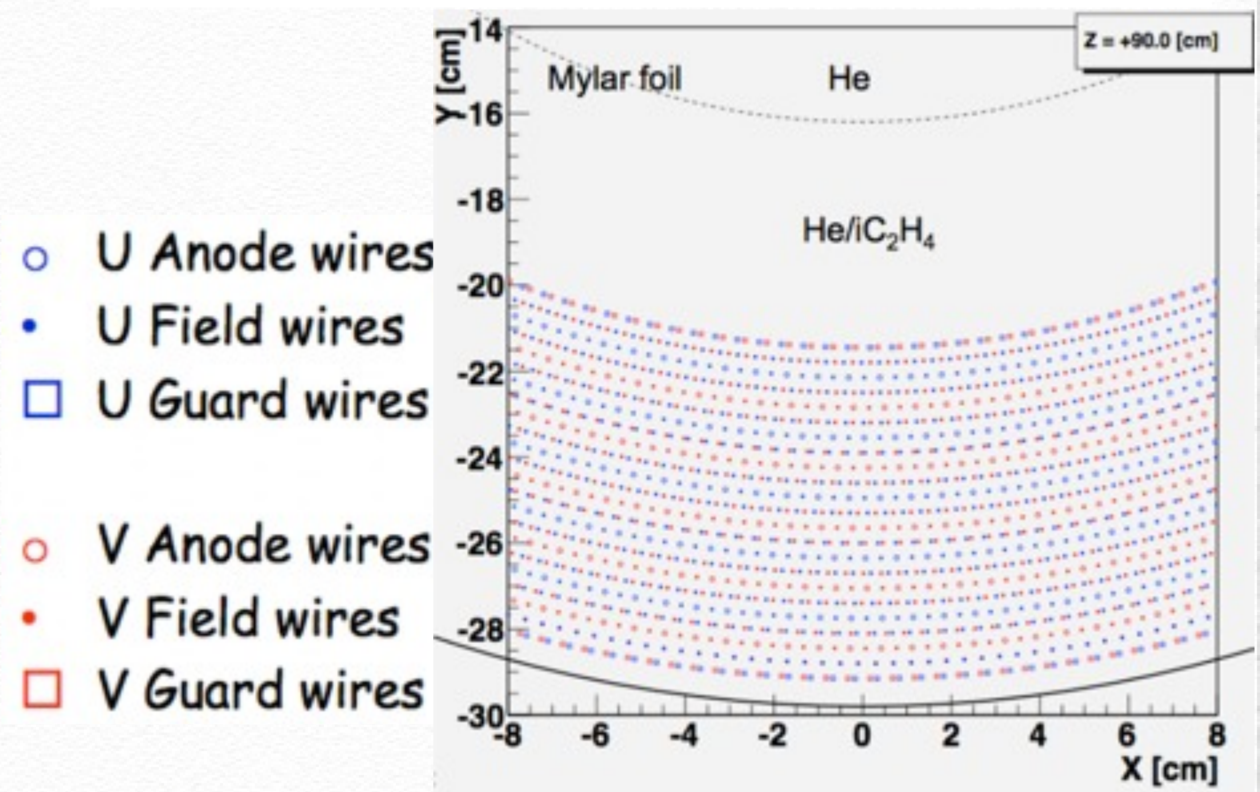




Positron tracker

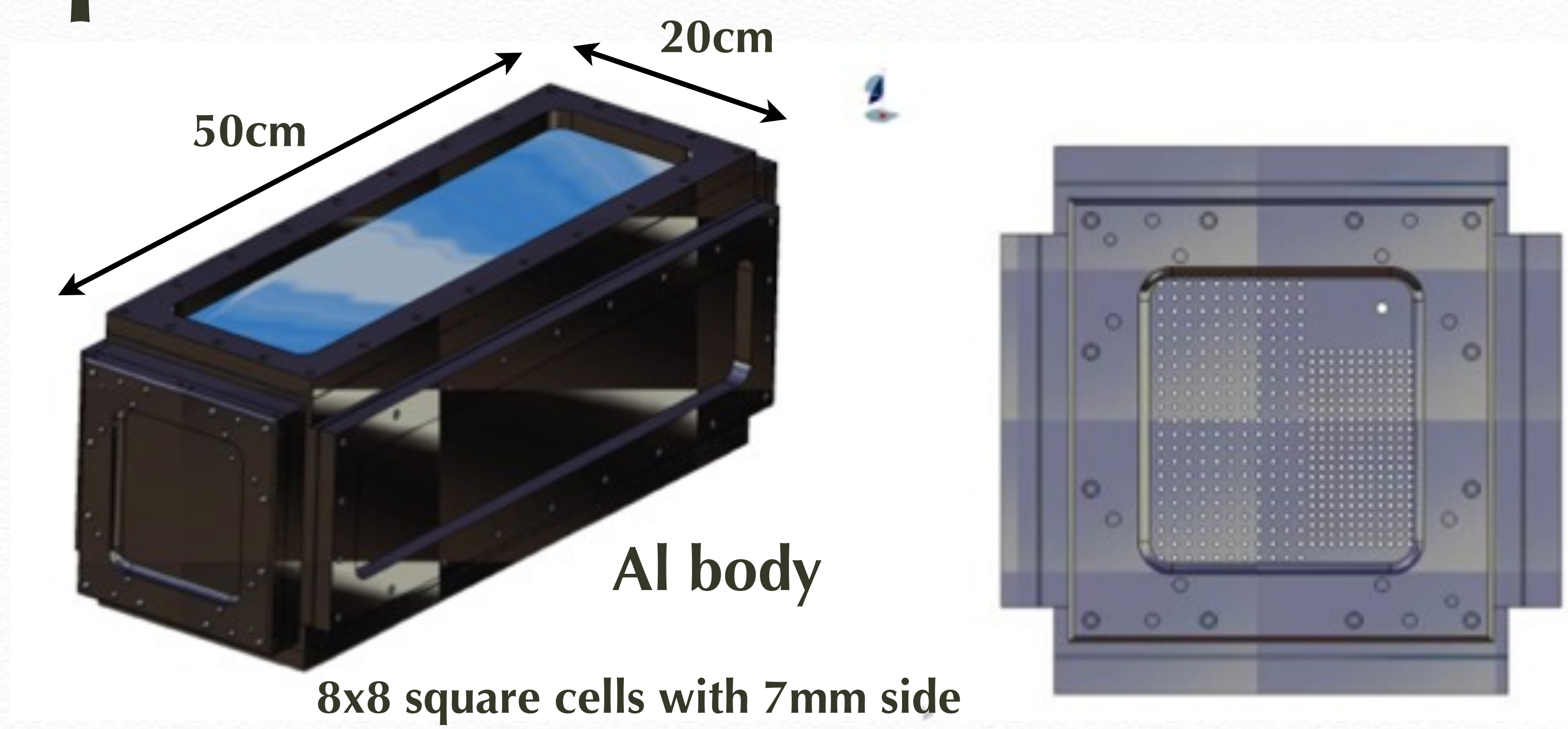
- Stereo wire type of drift chamber
- Unique volume, cylindrical DC
  - number of hits ~ 60 (3x more than now)
  - low material budget ($1.7\text{x}10^{-3}$-> $1.1\text{x}10^{-3}$ X_0)
  - cluster timing technique to minimize a bias of impact parameter meas.
- Expected performance
  - ε_e : > **85%** (40% now)
  - σ_p : **110-130keV** (330keV)
  - $\sigma_{\theta\phi}$: **5-6mrad** (9,11mrad)



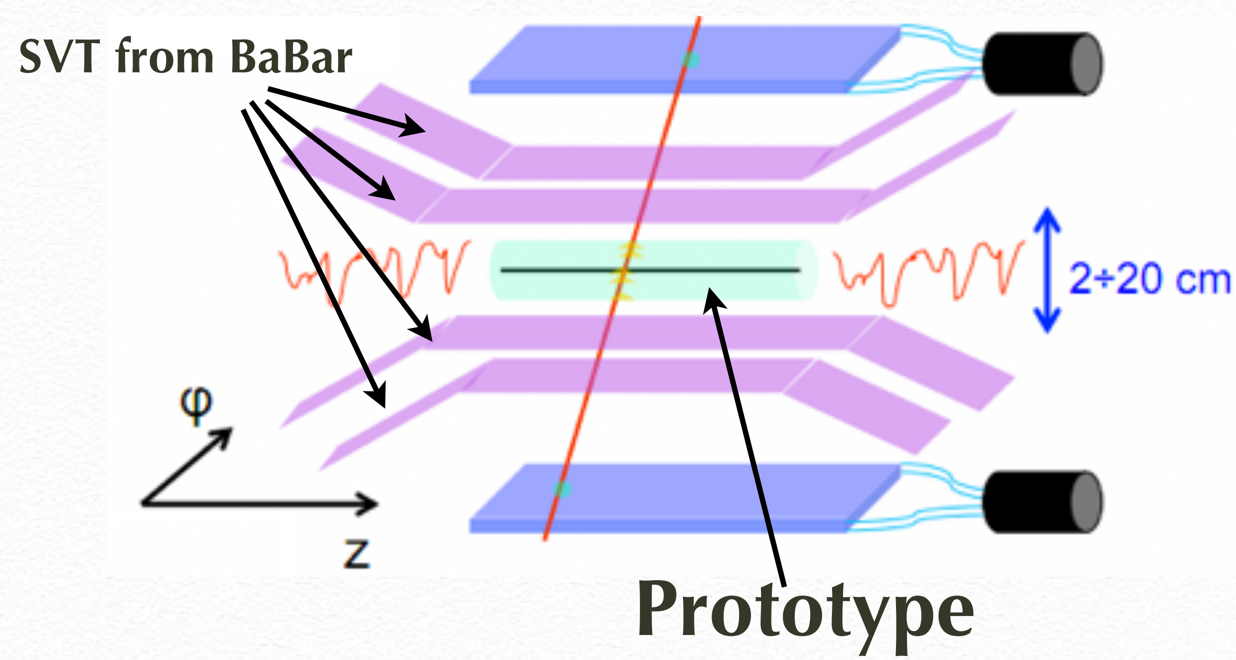


Tests for positron tracker

- Small prototype for resolution studies
    - measure radial resolution (σ_r~50-100μm)
- Telescope for cosmic rays
    - accuracy ~10μm (enough for prototype test)

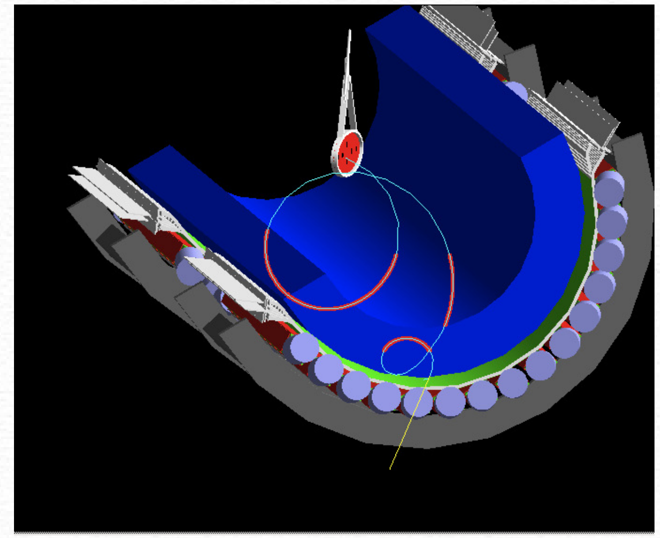


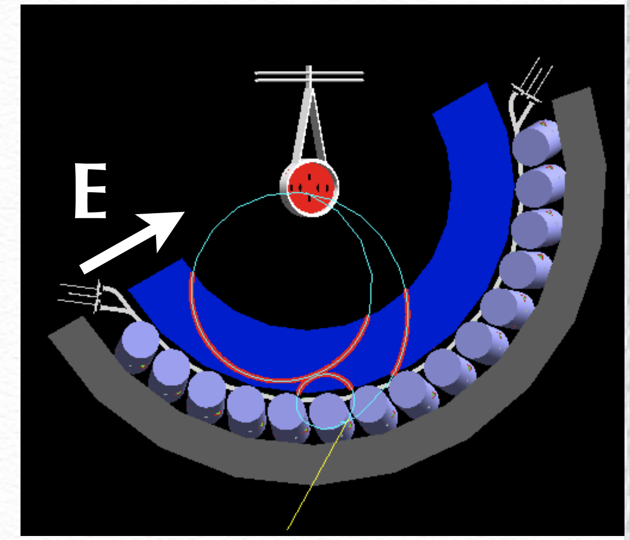
8x8 square cells with 7mm side
25μm gold plated tungsten sense-wire
and eight 50μm Cu-Be field-wires

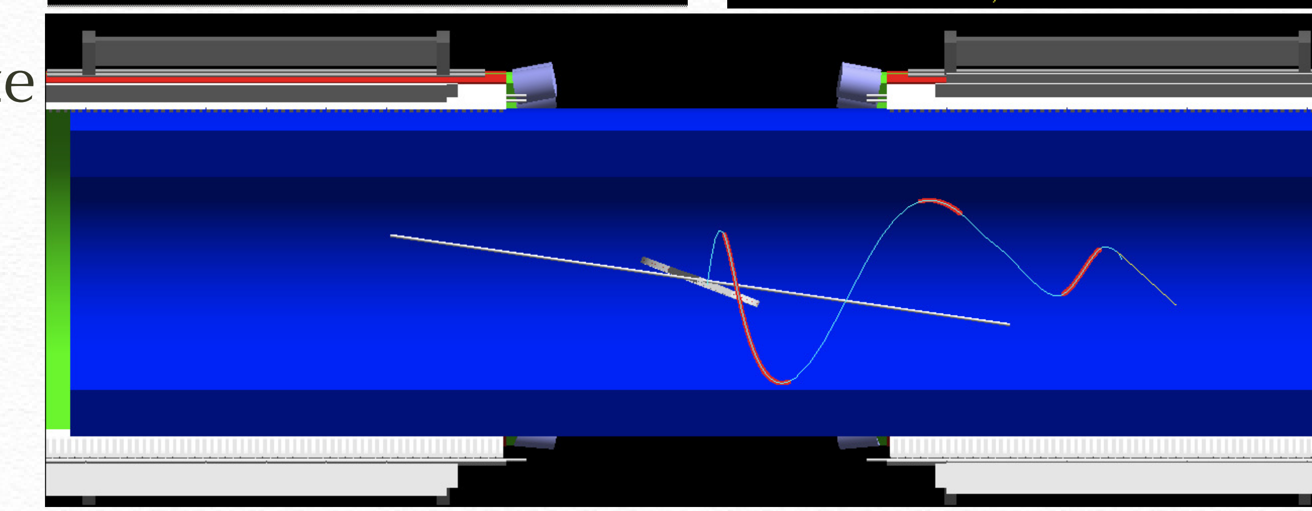


Alternative for positron tracker, TPC

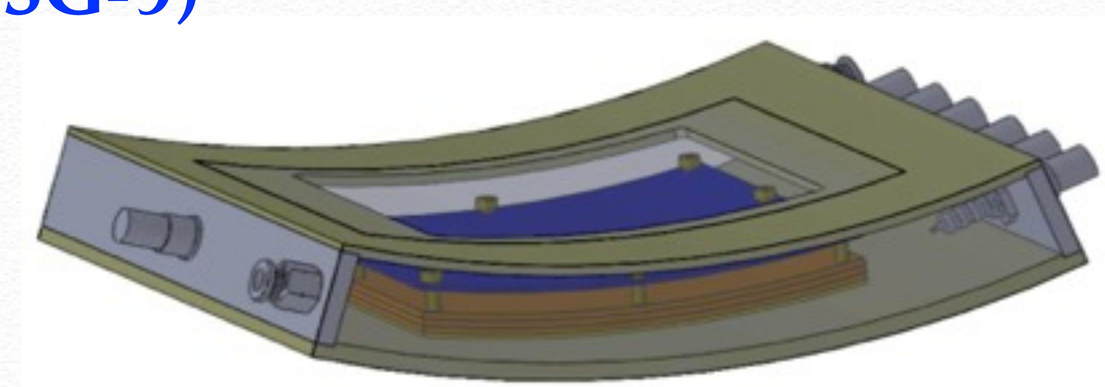
- Time projection chamber (TPC)
- Unique gas volume, Radial TPC
- Electrodes should be radial, electron detection device (GEM) cylindrically curved
- Helium-base gas mixture to minimize multiple scattering effect
- Number of hits >60 (depends on readout design)
- Expected performance
  - σ_p : **80-100keV/c**
  - $\sigma_{\theta\varphi}$: **4-6mrad**
  - ε_e : **~80%**
- First step : Cylindrical GEM prototype







藤井(13pSG-9)

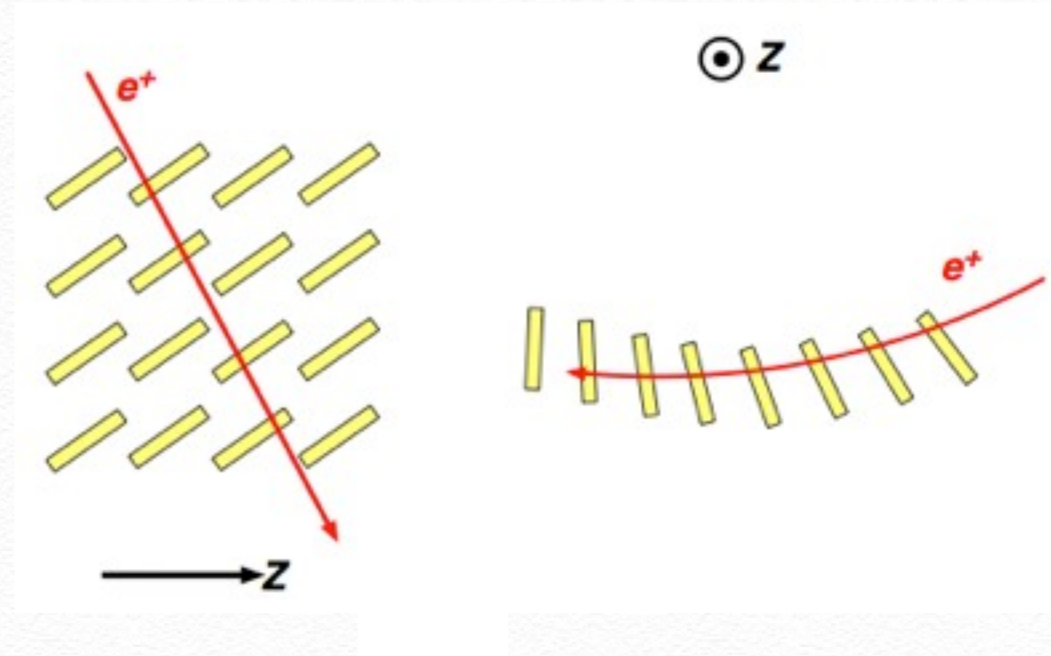


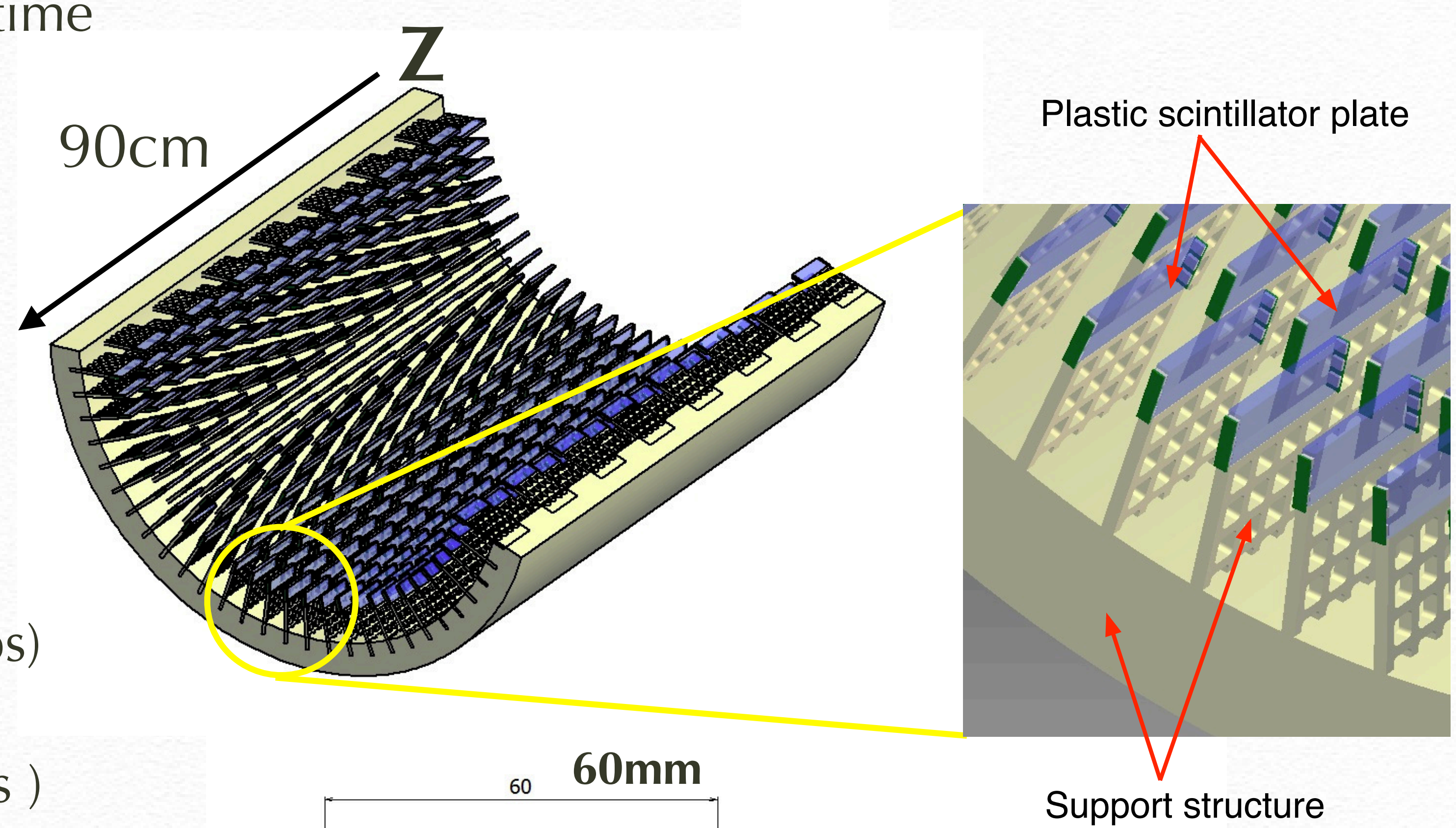
10x10cm^2 GEM foil

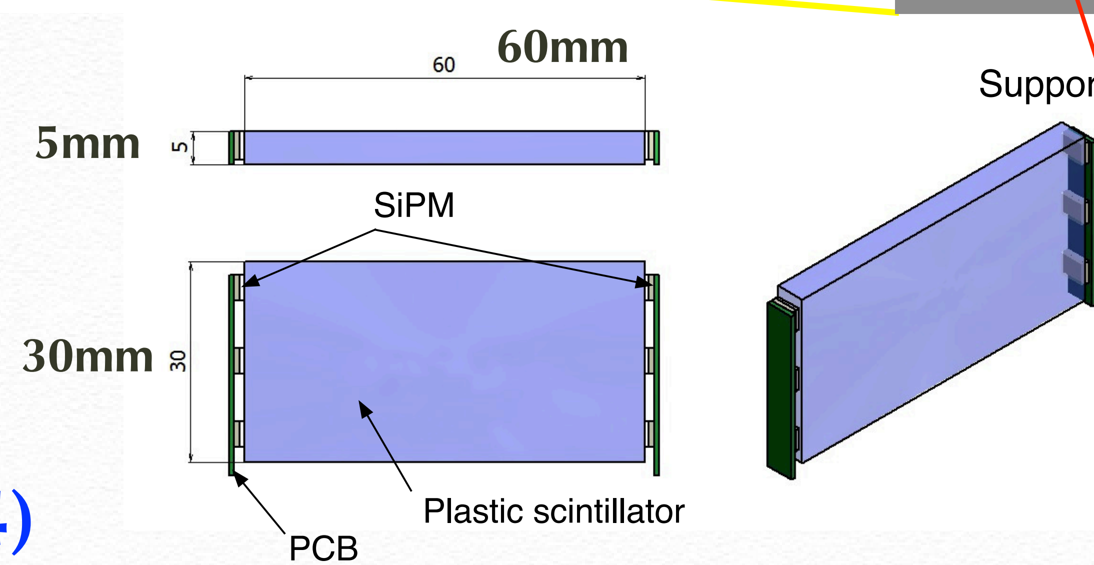
Pixelated timing counter

- New pixelated timing counter design : $60 \times 30 \times 5 mm^3$ scinti. (~800) and SiPM readout (~5000)
- A good timing resolution of single pixel. Further improvement using multiple hit time
- Higher level of segmentation, works at $1 \times 10^8 \mu/s$ (each pixel has ~1kHz hits, current TC PMT ~1MHz)
- High timing performance
    - σ_T < **38ps** (current TC ~76ps)
    - $\sigma_{e\gamma}$ = **80ps** (current ~ 120ps)
        - track length uncertainty 75ps -> **11ps**
        - σ_γ = 67ps

西村(14pSK-4)

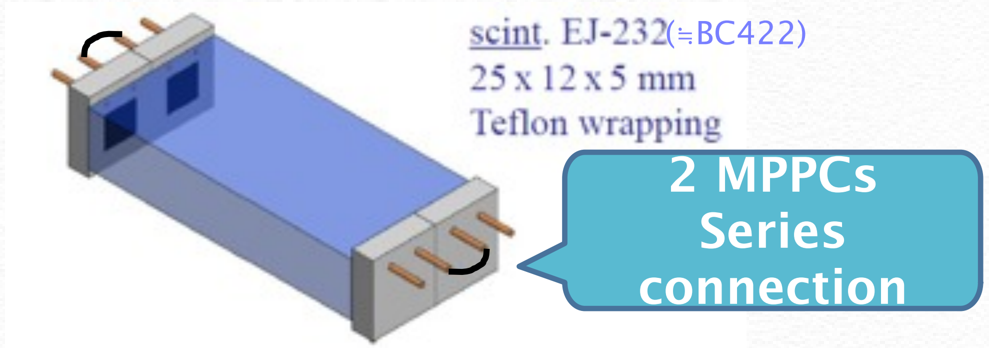




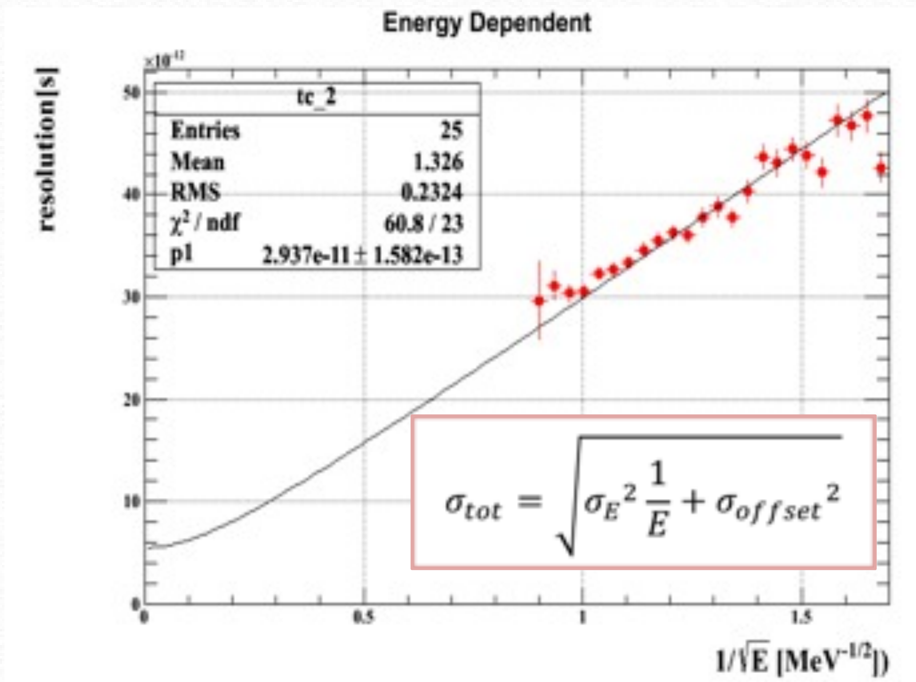


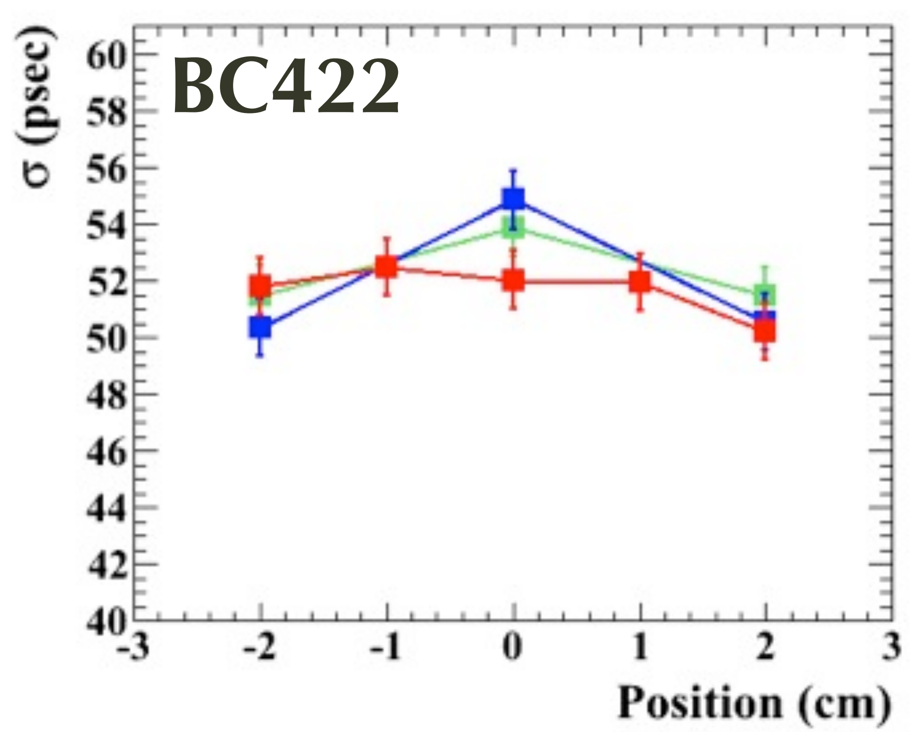
Tests for pixelated timing counter

- Resolution of single pixel counter 25x12x5mm^3 is measured by μSR
    - $\sigma(k \cdot E)^{0.5}$=23ps · MeV$^{0.5}$
- We confirmed the timing resolution,
    - $\sigma(k \cdot E)^{0.5}$=15ps · MeV$^{0.5}$
    - with waveform digitizer, the good timing resolution is obtained
- A larger counter is suitable to reduce # of pixels
    - 30x60x4.5mm^3 is tested, σ~50ps
- Series and parallel connections of SiPM to further reduce # of ch.



A. Stoykov et al. NDIP 2011





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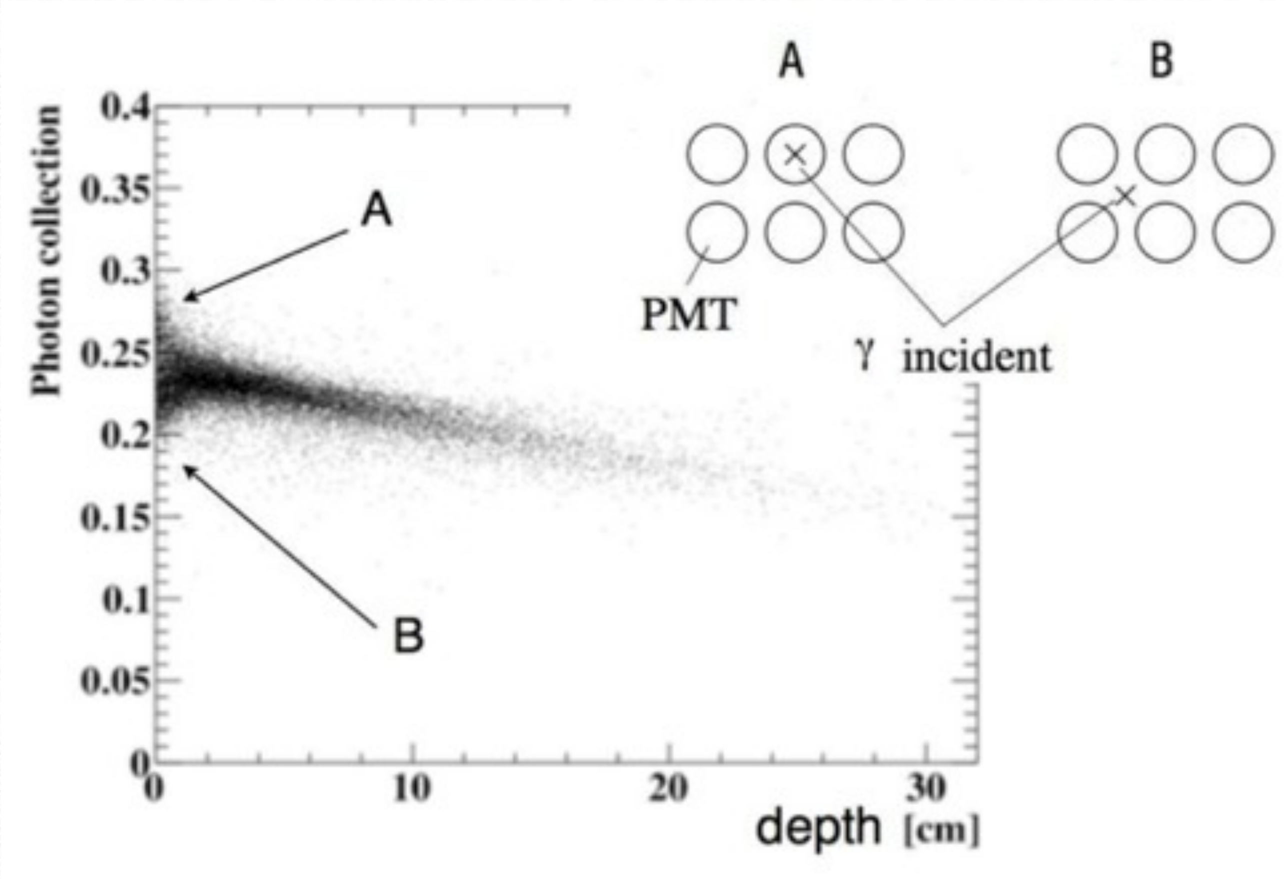
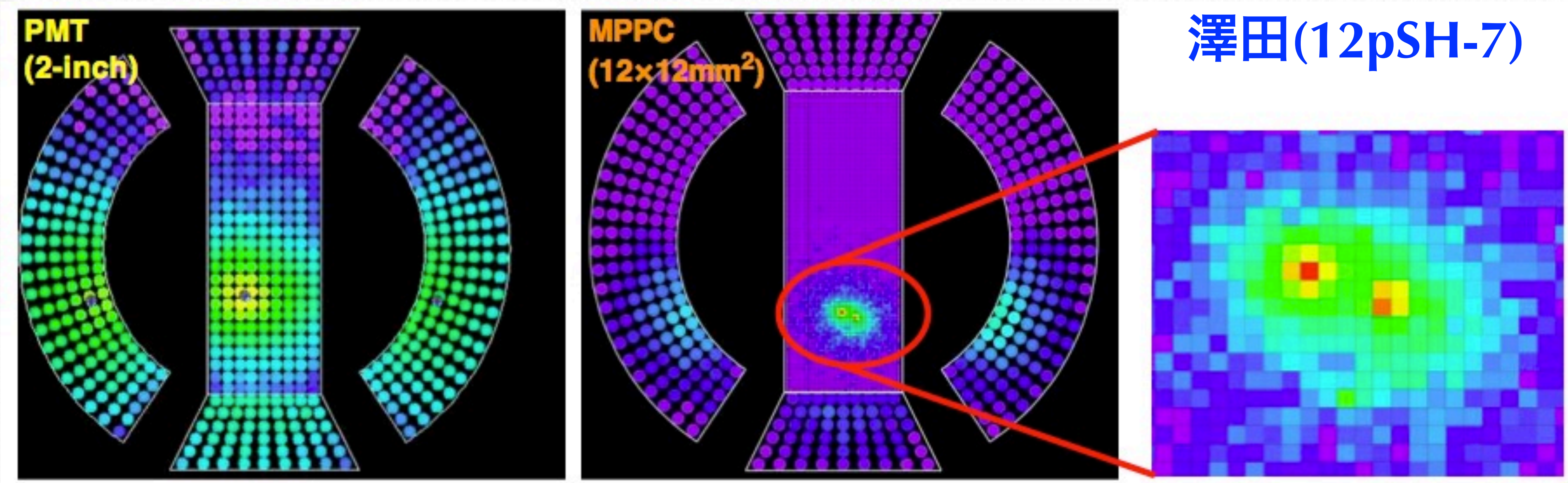
γ-ray detector

- There is non-uniform response at shallow events with 2″ PMT on inner face
- Small photo sensors for inner face
  - better position, energy resolution at shallow events
  - high detection efficiency
  - 216 2″PMT -> 4000 12x12mm^2 MPPC

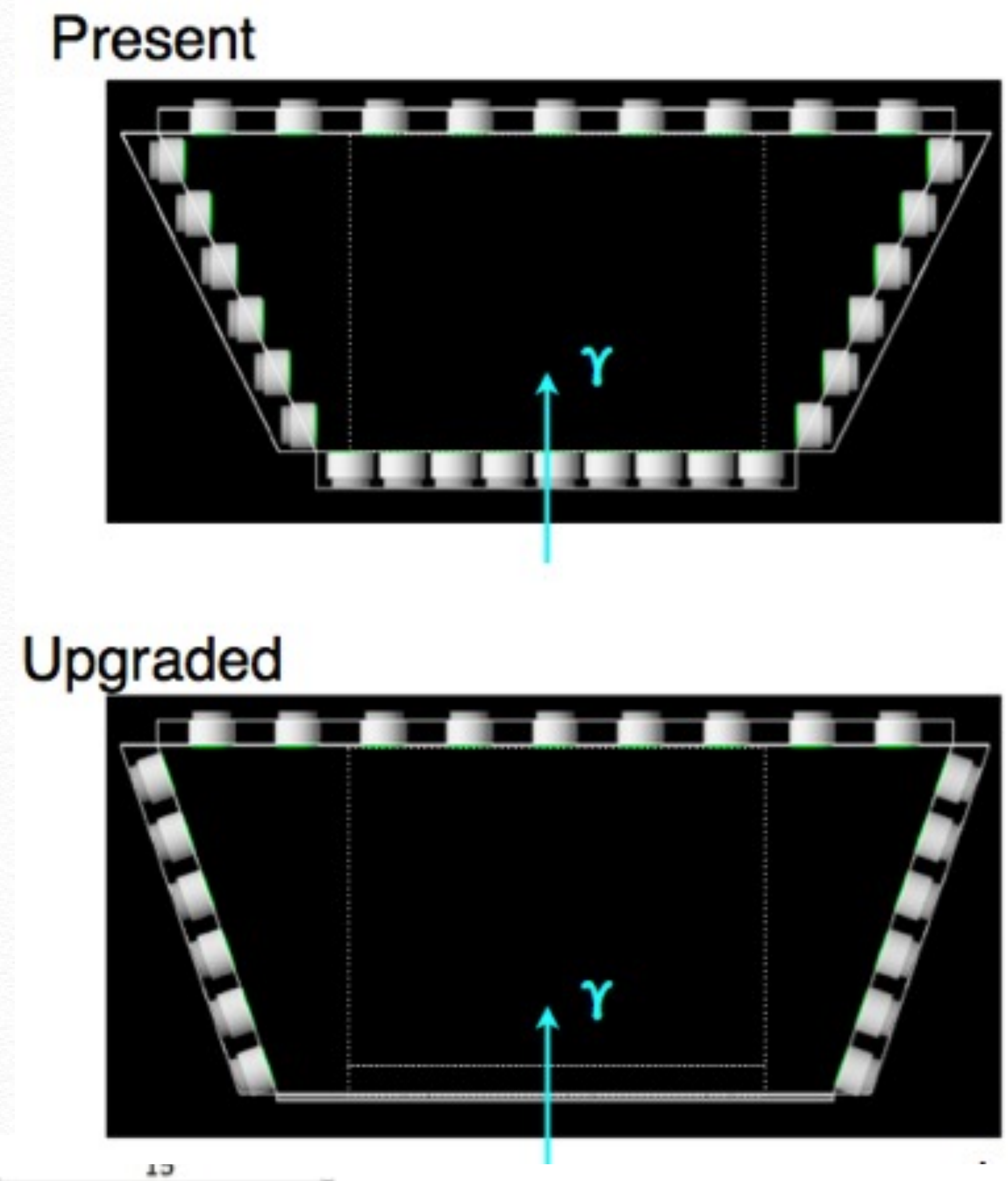


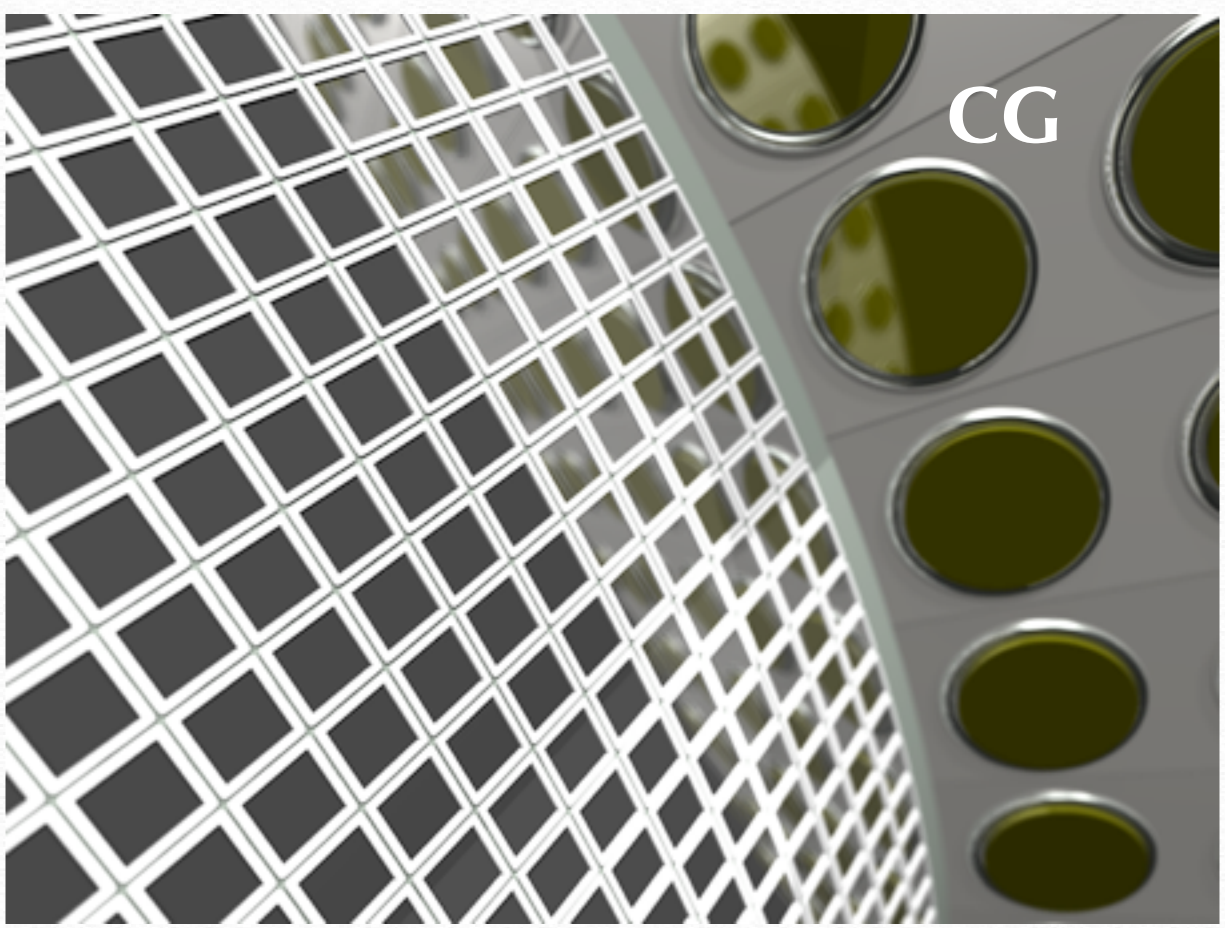


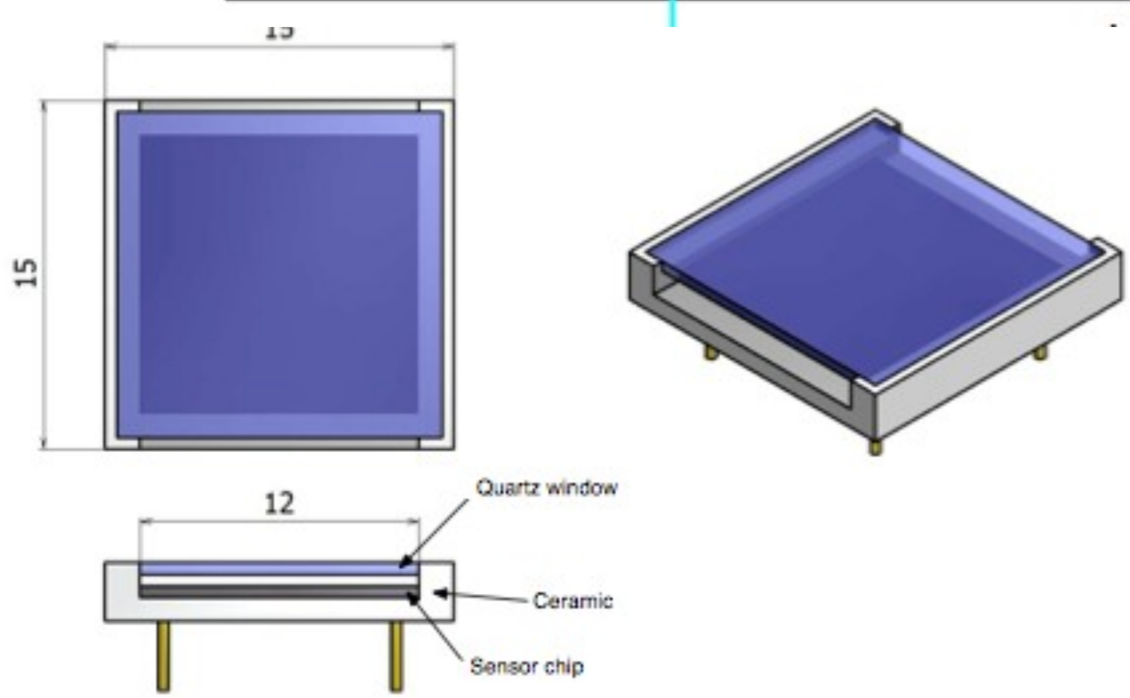
澤田(12pSH-7)

γ-ray detector

- Slant angle of lateral PMTs
  - better uniformity
- Wider inner face
  - reduce energy leakage

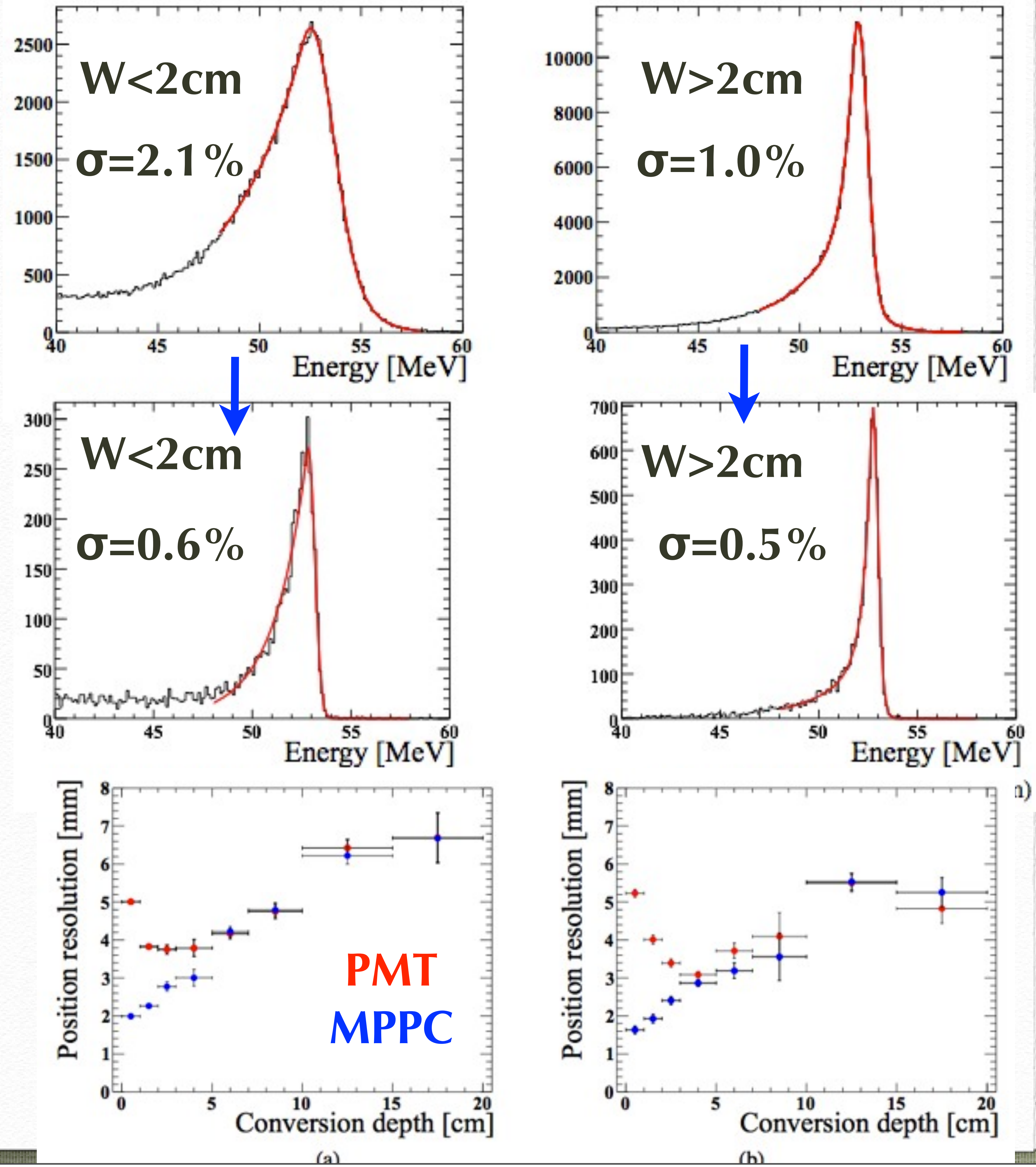




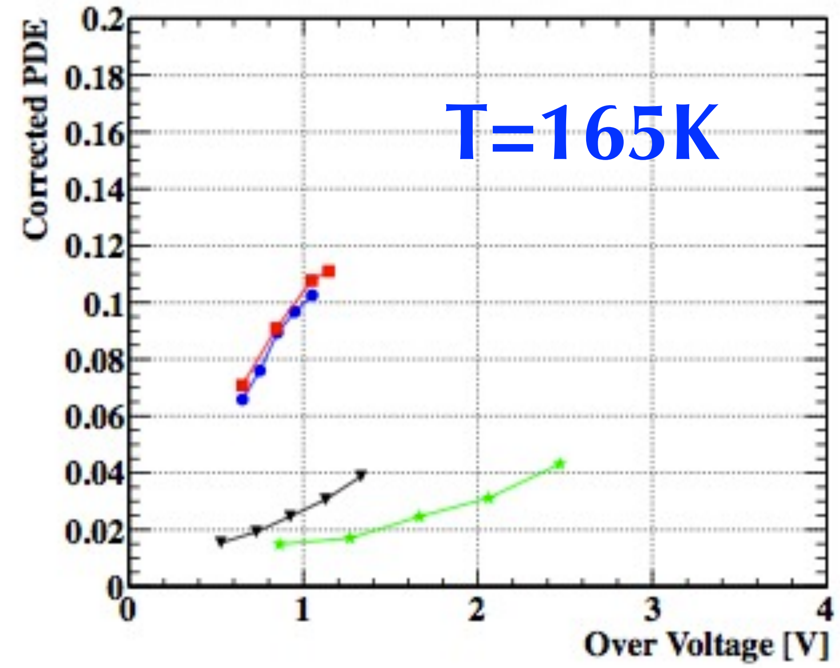


Improvements

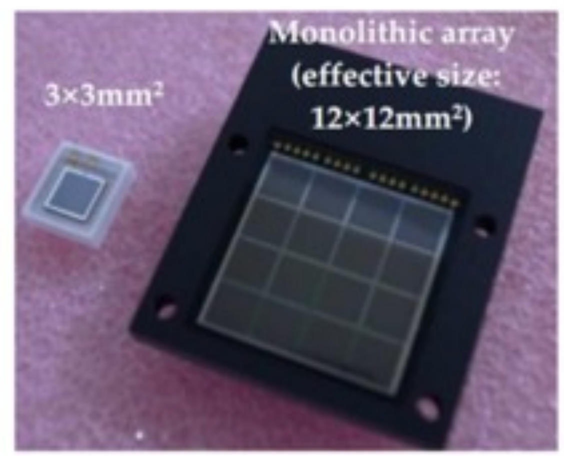
- Energy resolution
- Position resolution
- 10% higher detection efficiency

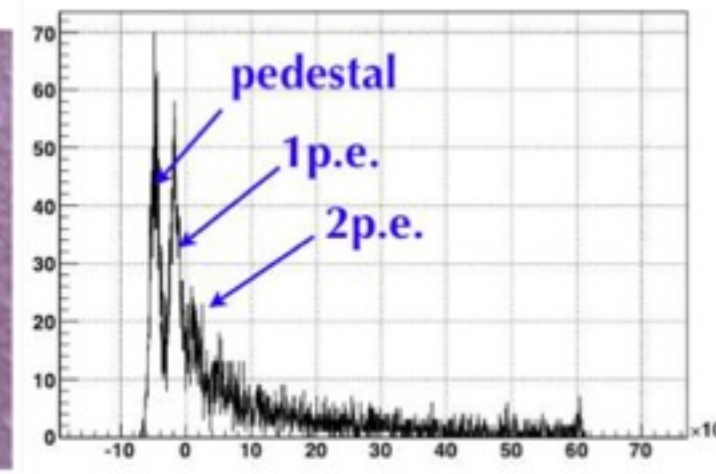


R&D for LXe detector

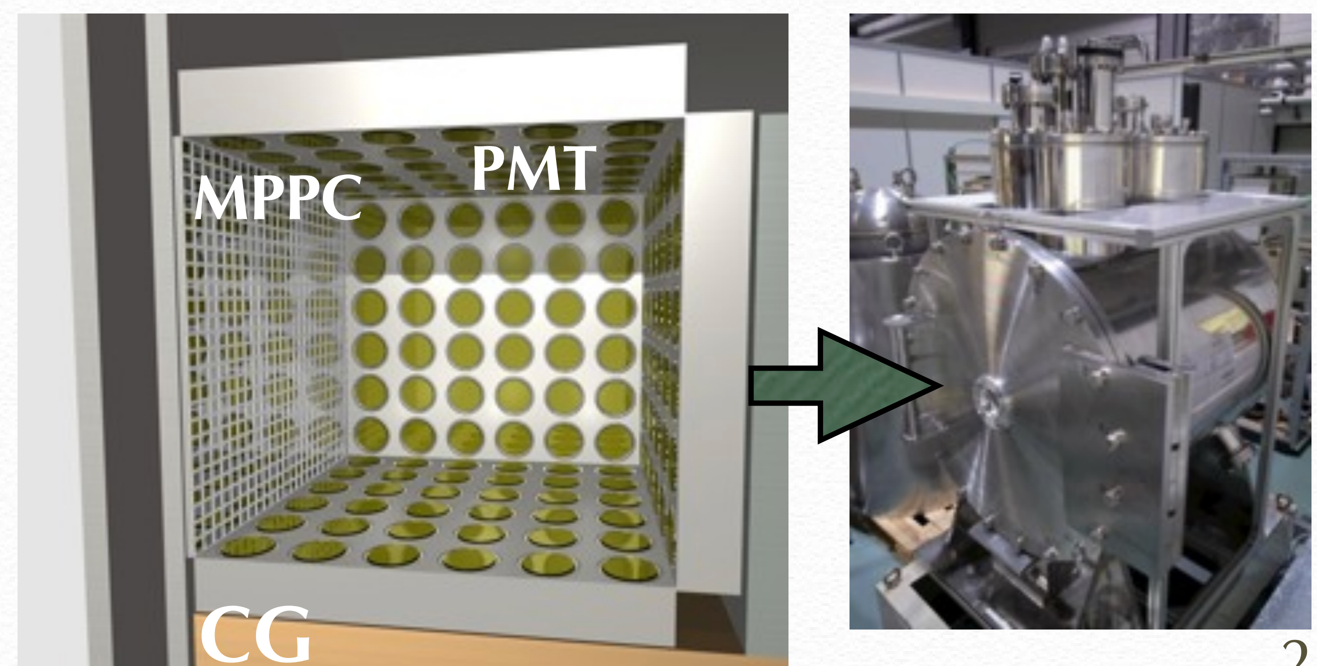


- Development of VUV (LXe scintillation ~175nm) sensitive MPPCs with Hamamatsu
    - PDE ~ 10% achieved
- 4x4 Monolithic array MPPC signals are connected in parallel, and 1p.e. is observed in LXe.



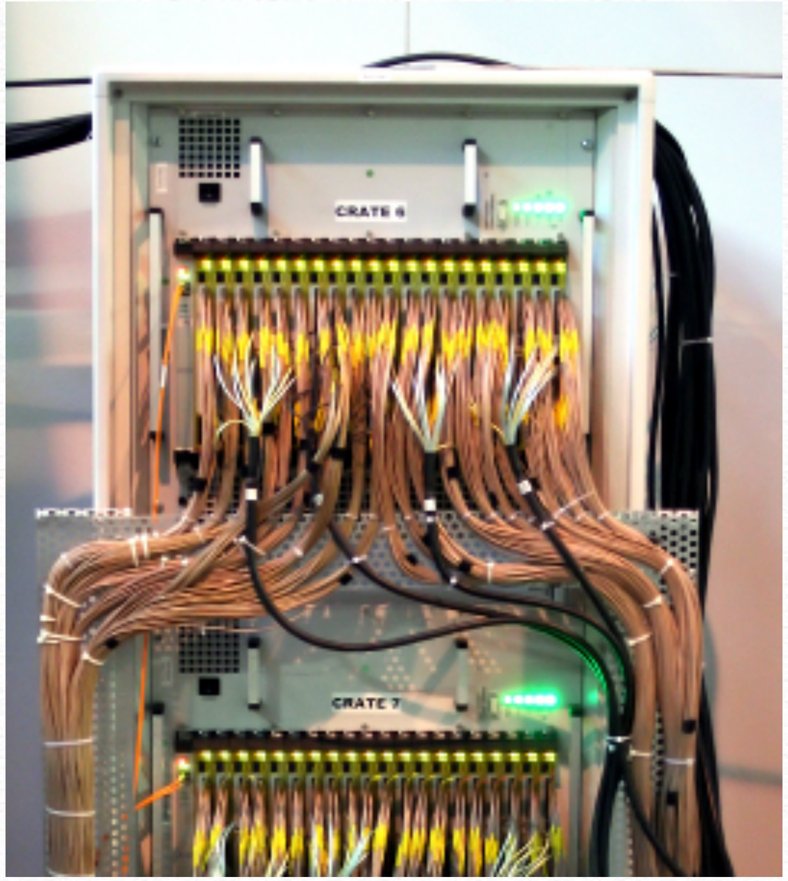


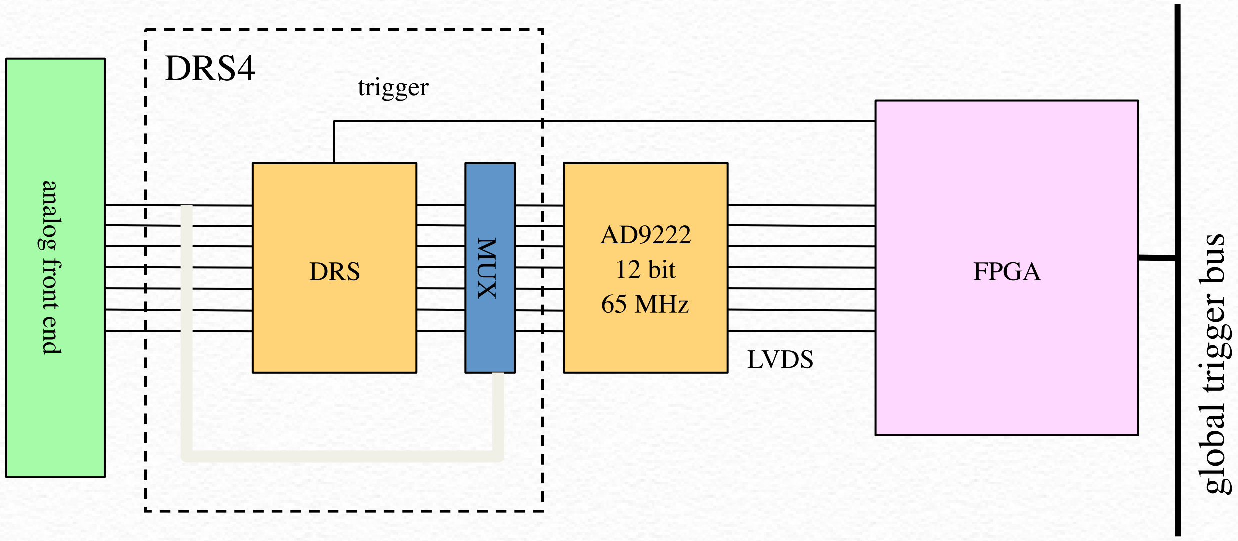
- Next step is to make large-area MPPC with >10x10mm^2 (this month)
- Prototype detector
    - 70L LXe, 576 MPPCs on gamma entrance face and 180 PMTs on the other faces
    - performance demonstration



Trigger and DAQ

- Integrate DRS and trigger on same board
  - Much increased number of channels
- Higher bandwidth
  - Bandwidth of 200MHz -> above 700MHz to recognize individual clusters originating from the primary ionization for drift chamber
  - Dedicated comparator for each channel : rate counter or trigger
- Improve timing resolution from electronics (40ps->?)
- Switchable gain amplifiers
- MPPC biasing integrated





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Performance

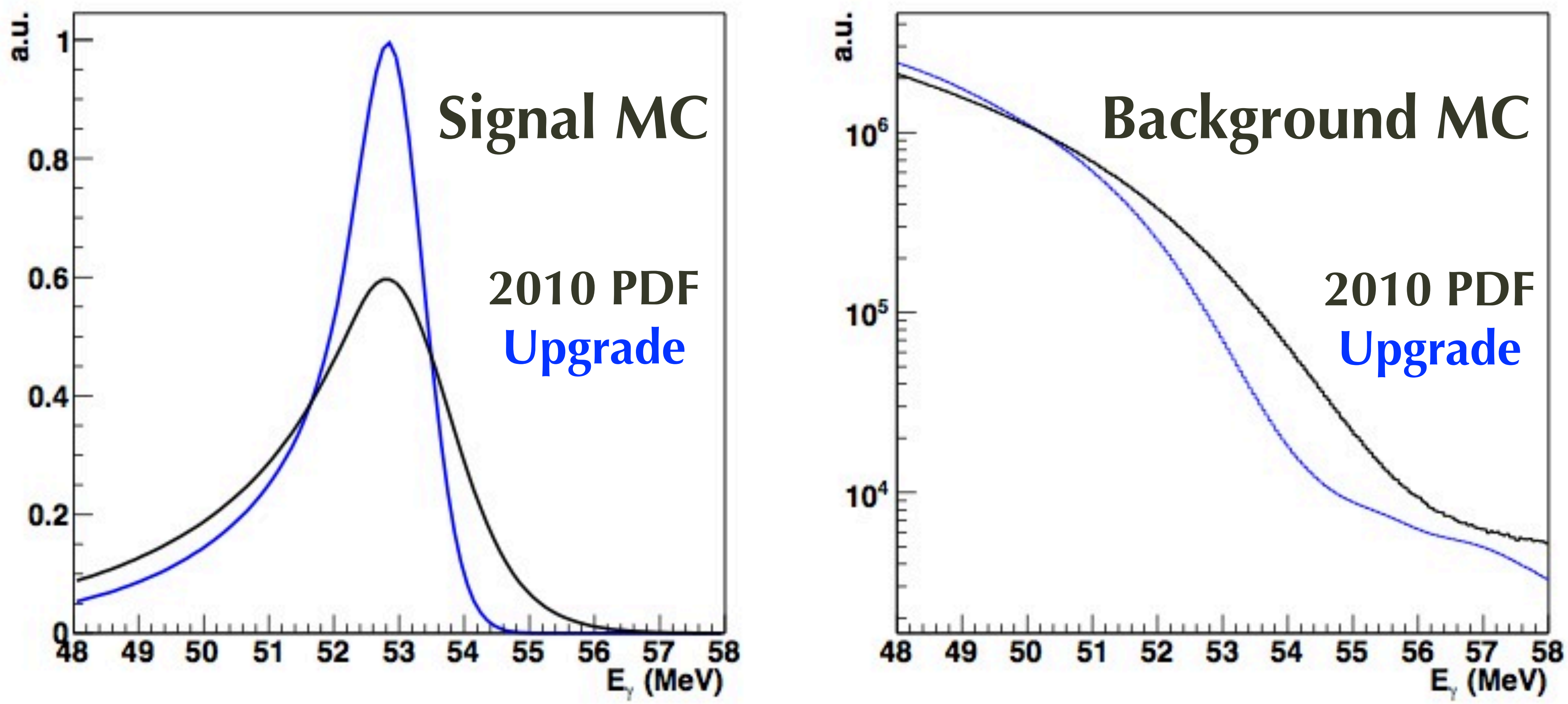
Variable	Obtained	Upgrade
ΔE_γ	1.6 (w>3cm), 2.0(0.8<w<3cm), 2.7(0<w<0.8cm)	0.5 (w>2cm) 0.6 (w<2cm)
Δt_γ	67	67
γ position (mm)	5(u,v), 6(w)	3
γ efficiency(%)	63	69
ΔP_e (keV)	330	110-130
e^+ angle (mrad)	$11(\varphi_e),9(\theta_e)$	5-6
Δt_{e+} (psec)	107	50
e^+ efficiency(%)	40	>85
$\Delta t_{e\gamma}$ (ps)	120	80

Preliminary

Background Reduction

- Resolution improvements
- Low material budget of positron spectrometer (AIF)
- Tag of RMD using RDC (later)
- Tag of AIF using positron track with a gamma-ray

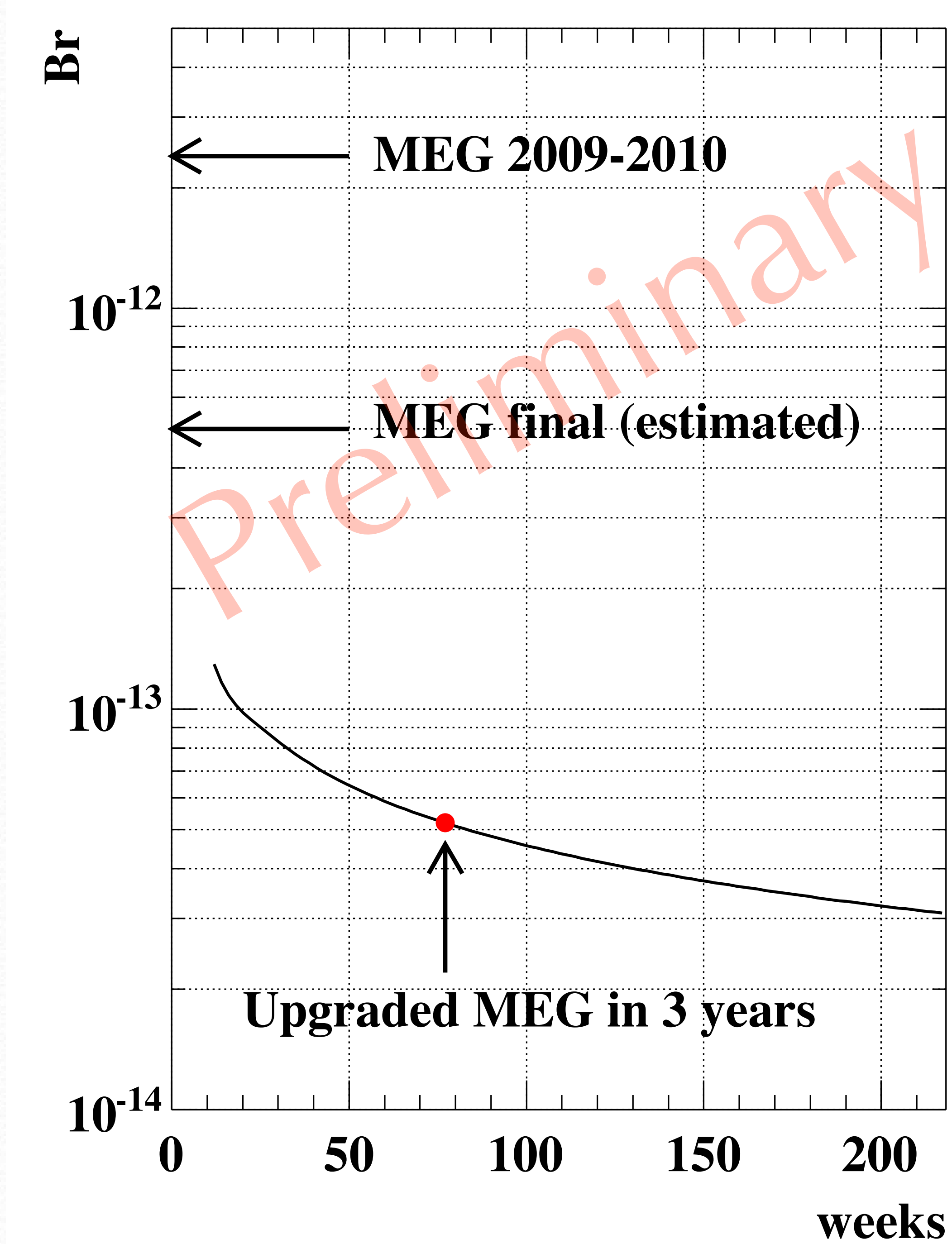
γ-ray detector response



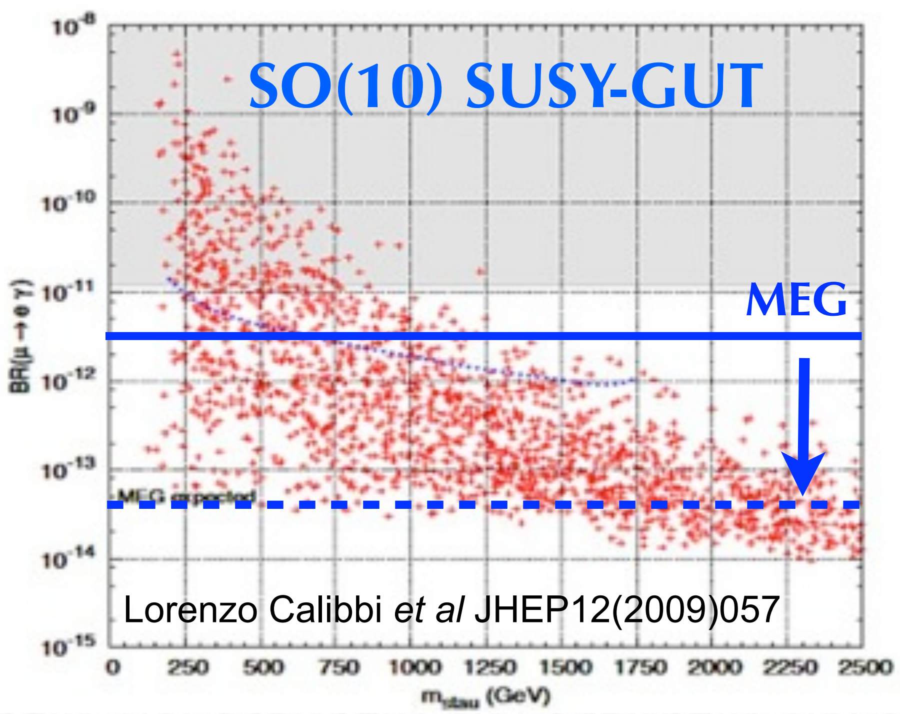
For shape comparison, these histograms are normalized by #events

Sensitivity

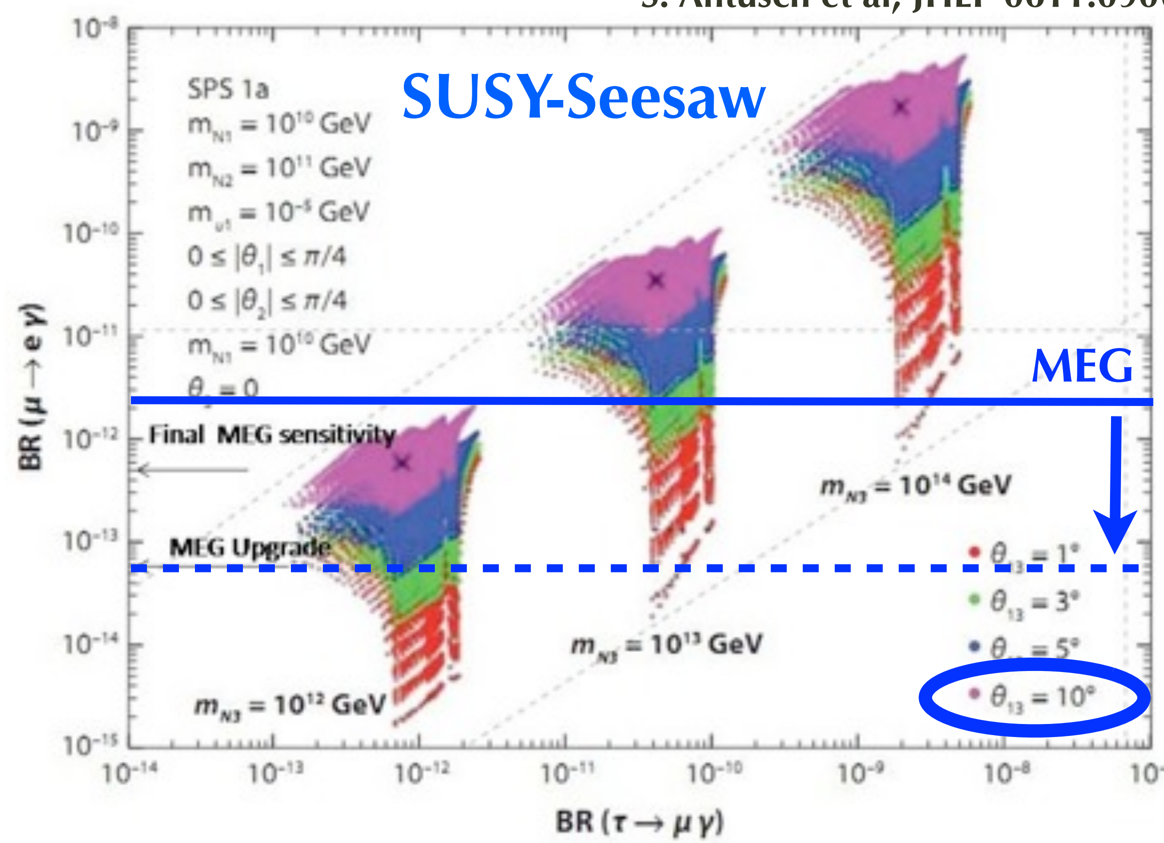
- Sensitivity of upgraded MEG as a function of the DAQ time in weeks
- Assuming 180 DAQ days per year
- UL on BR(μ->eγ) of ~5x10^{-14} in 3 years of running

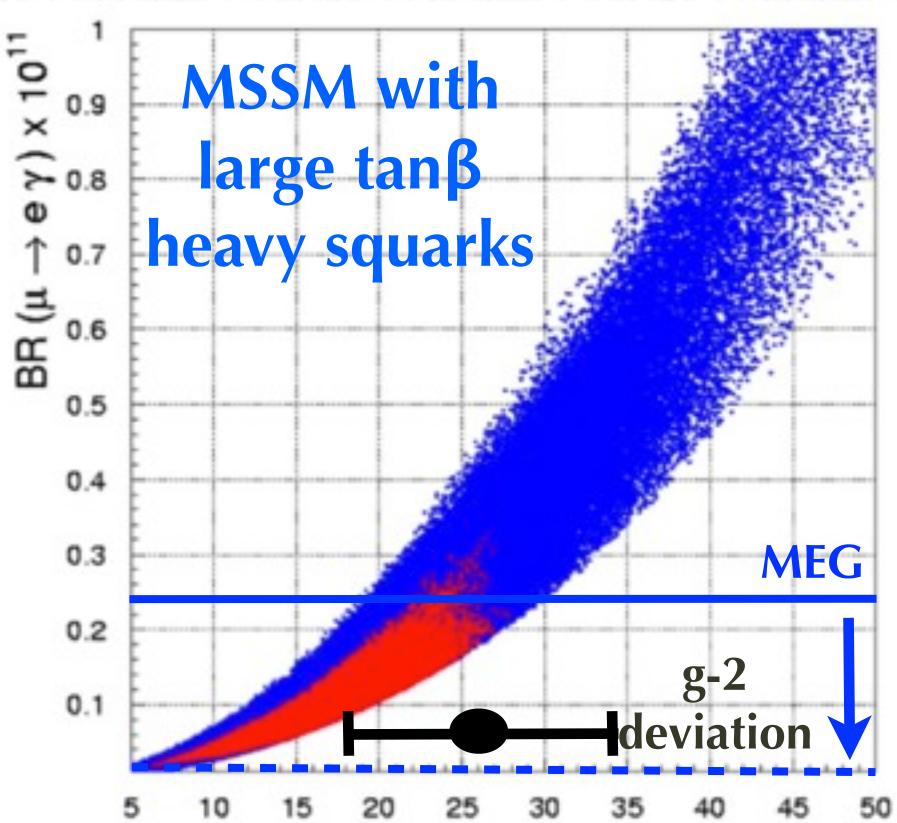


Impact on physics

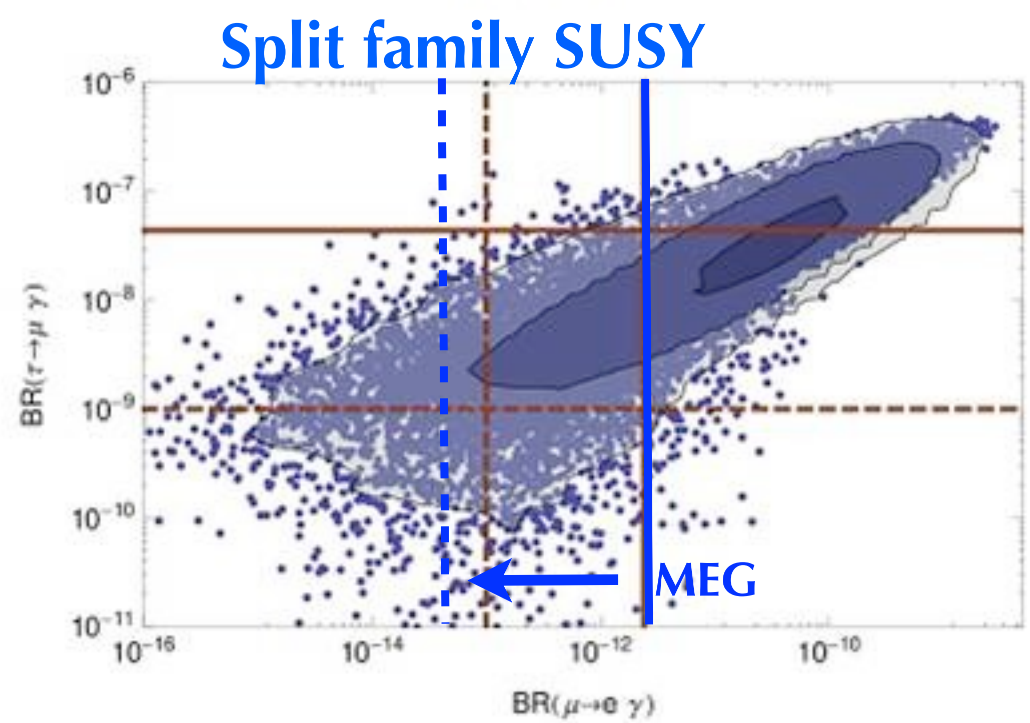


S. Antusch et al, JHEP 0611:090(2006)





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



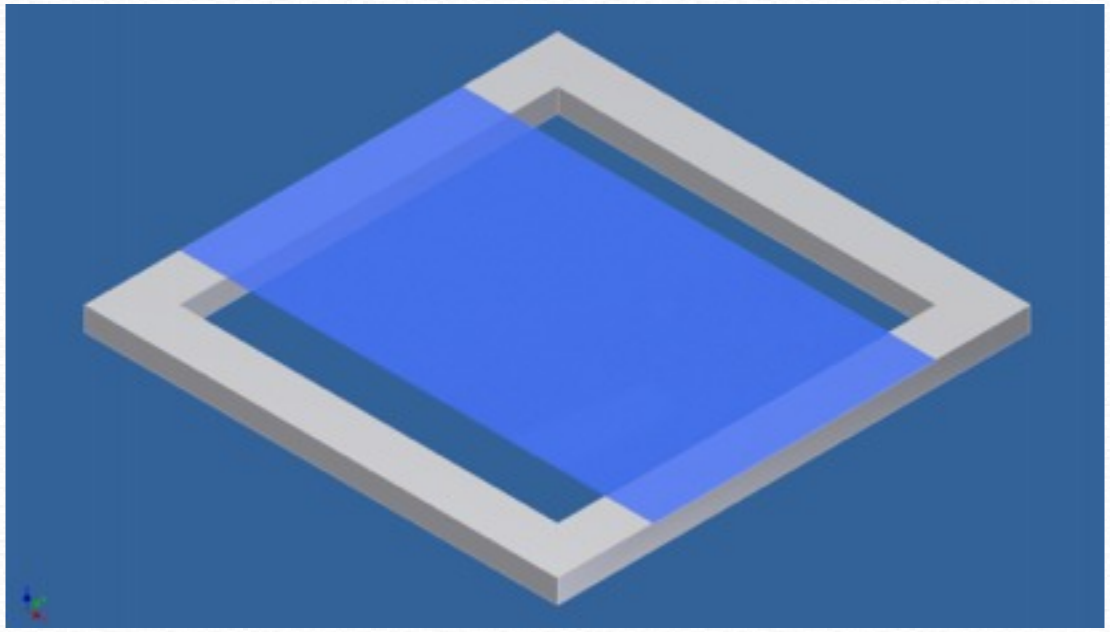
G. Blankenburg et al, arXiv:1204.0688, 2012

Improvements or redundancy with optional detectors

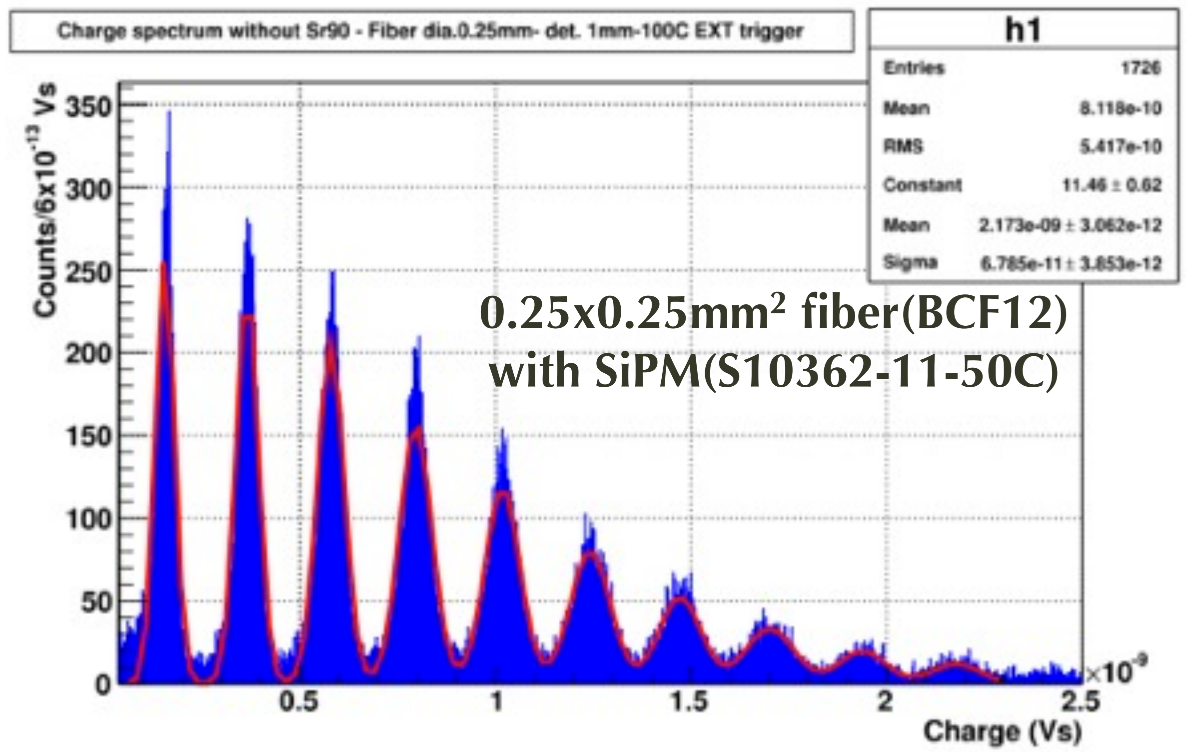
- Active Target
- Silicon Vertex Tracker
- Radiative Muon Decay veto Counter

Active Target

- Muon decay vertex measurement by detecting the positron from the stopped muon decay (Active target)
  - thin material to minimize positron multiple scattering and γ background from positron annihilation in flight(AIF)
- Thin scintillating fibers (250μm) coupled to SiPMs. One single layer of horizontally laid thin fibers (Y-coordinate measurement)
  - Improvements of σ_p and σ_φ.
  - Main challenge :
    - Detection efficiency > 80%, position resolution <100μm, timing resolution <500ps
    - R&D study is necessary



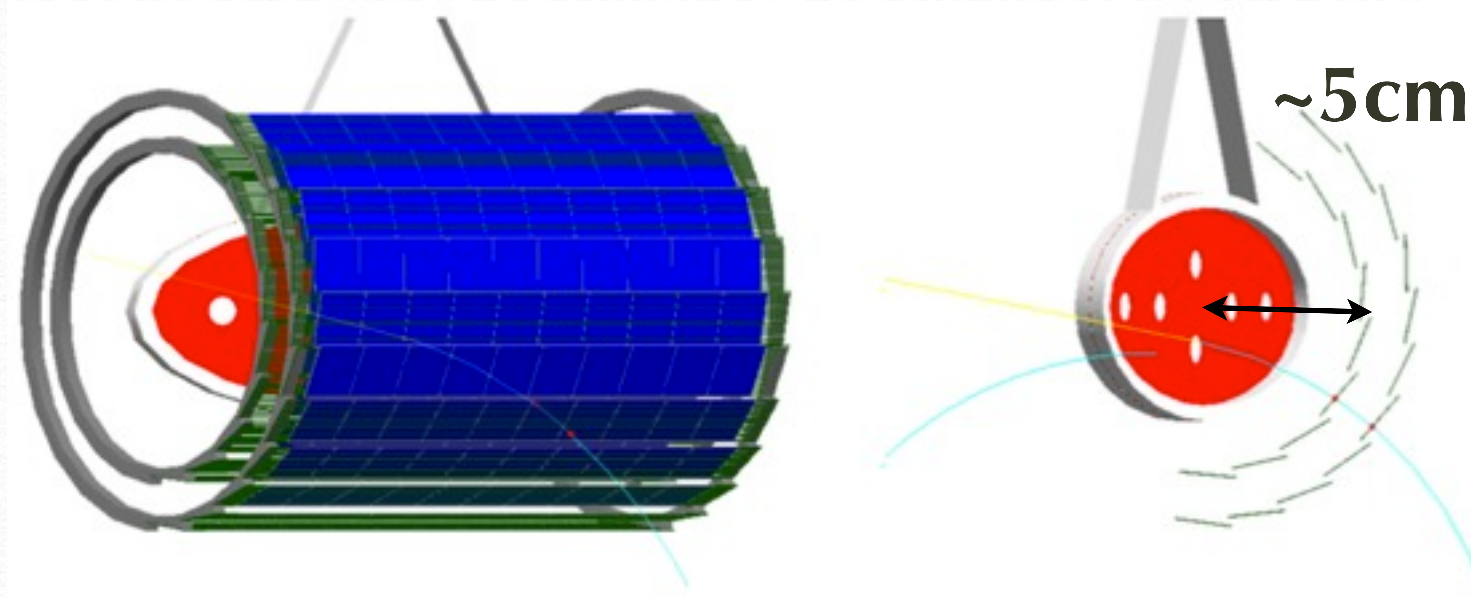
Target	thickness (μm)/ angle (deg)	σ_p/RMS (keV)	σ_ϕ/RMS (mrad)	σ_θ/RMS (mrad)	comment
Passive	140/ 15	125/270	5.8/8.0	5.0/6.2	baseline solution
Passive	205/ 20.5	120/240	7.0/9.6	5.6/6.5	present target
Active	250/ 20.5	100/210	5.0/6.6	5.7/6.6	ϵ_d = 100%

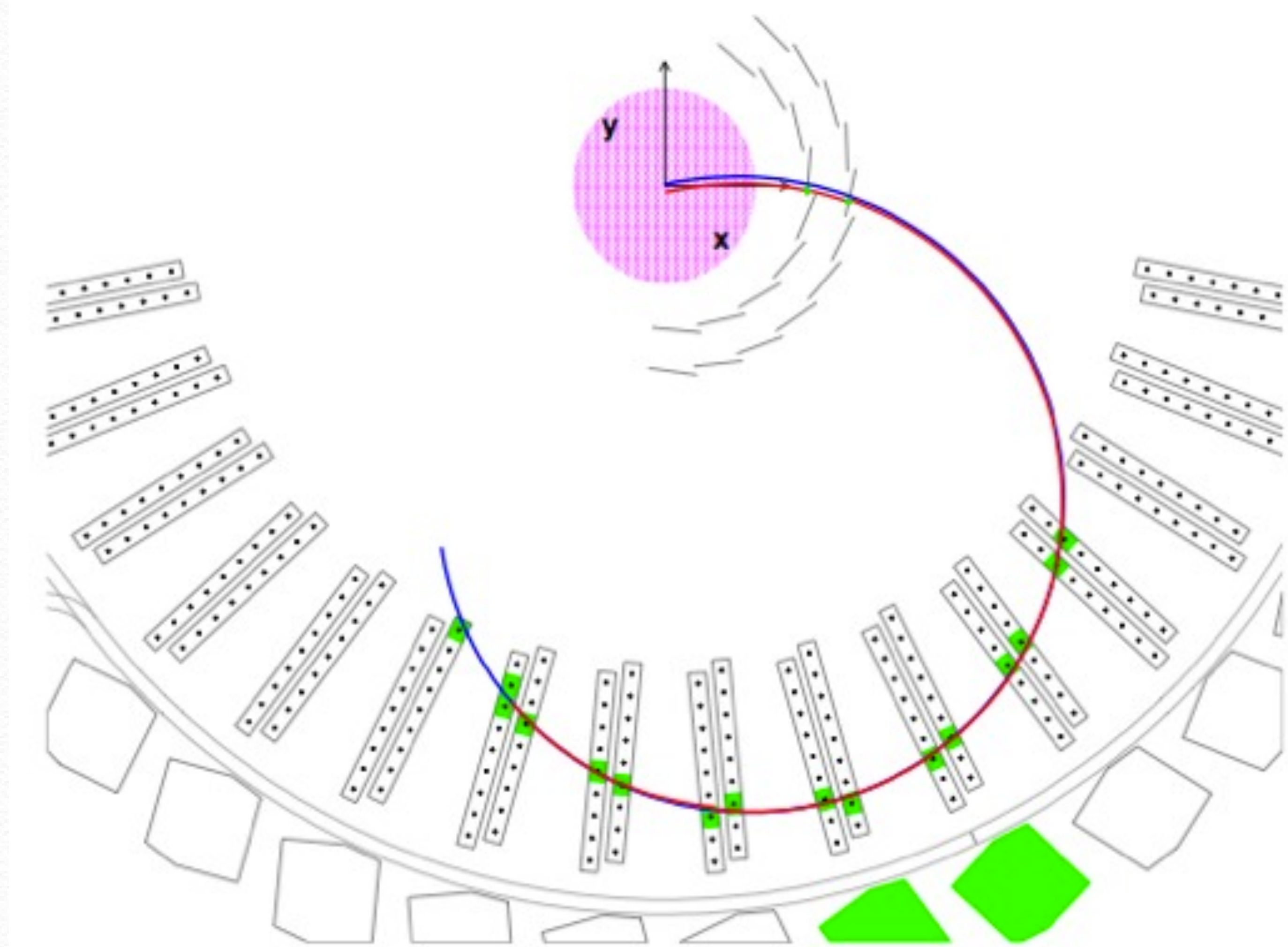


Charge spectrum of minimum ionizing electrons

Silicon vertex tracker : SVT

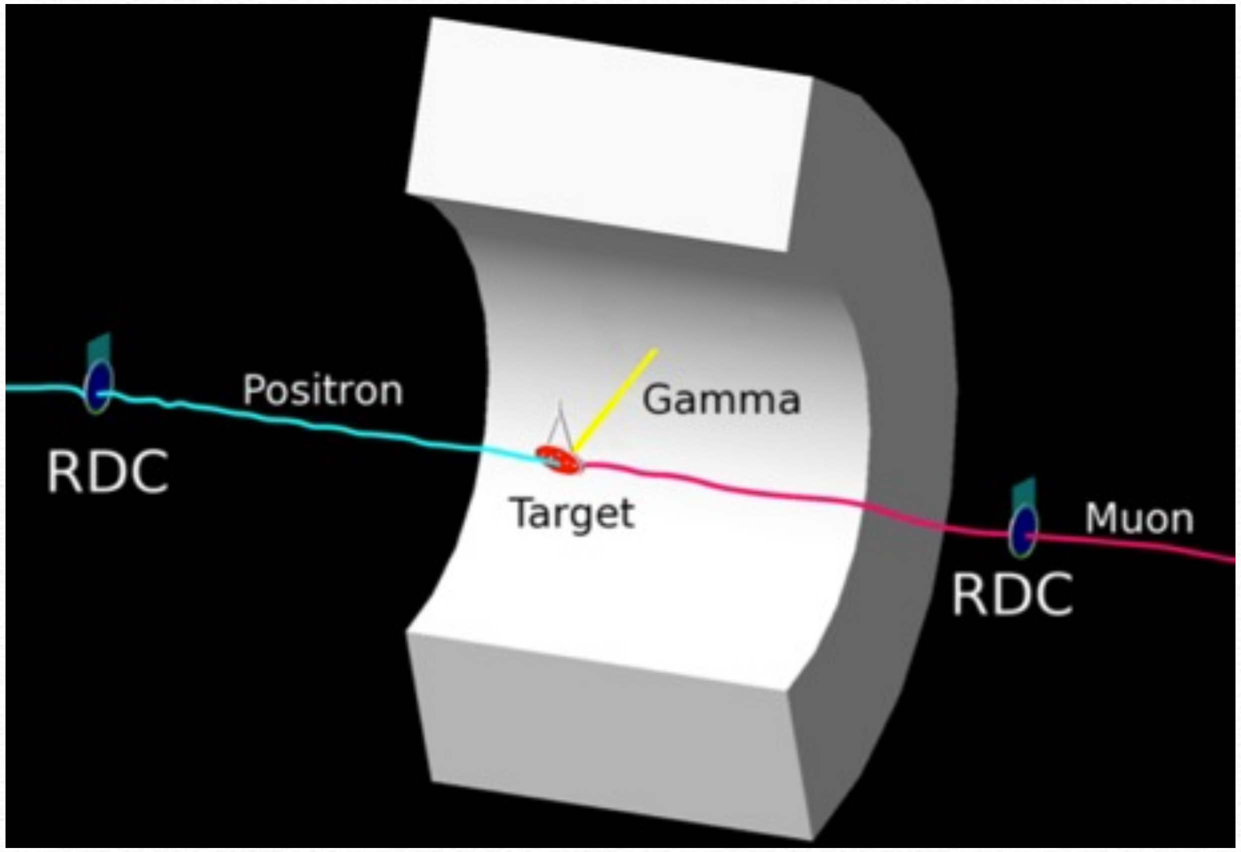
- Silicon pixel detectors
- Good stability of operation under high rate, low occupancy, high spatial resolution
- Material budget is crucial for low energy experiments (thin sensors like HV-MAPS for Mu3e etc., ~50μm thickness)
- Optional detector for precise measurements of muon decay vertices, of positron emission angles, and relaxing the requirements for the main tracker design

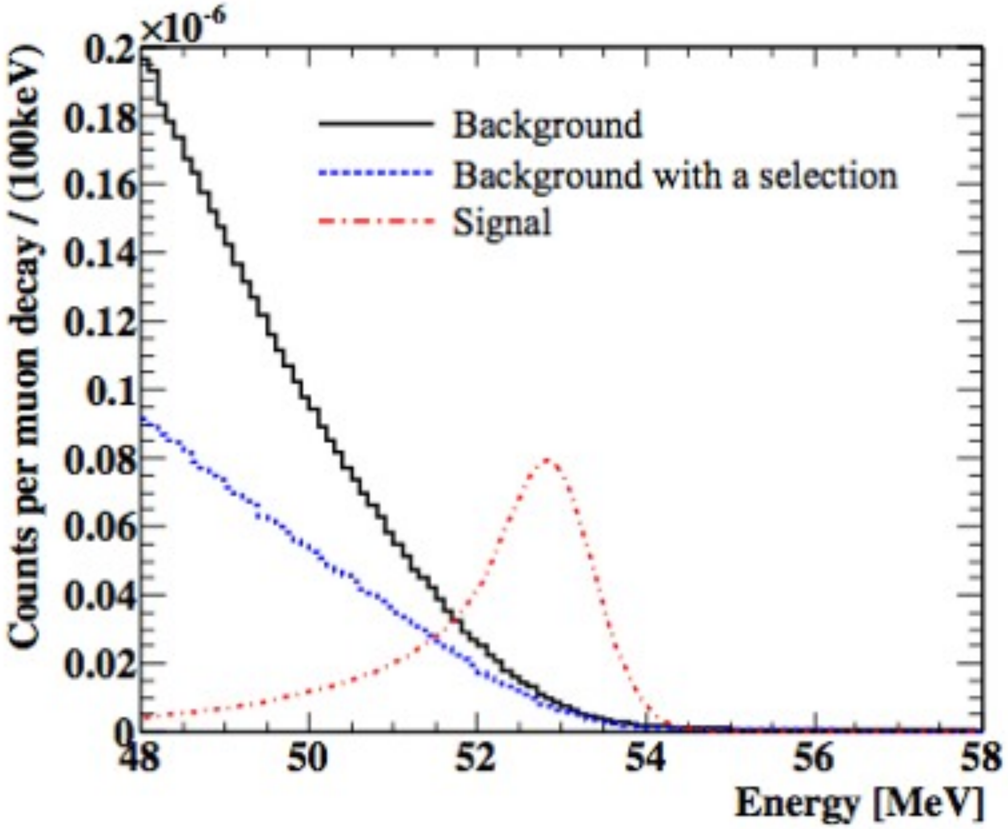




Radiative muon decay veto counter : RDC

- Contribution of RMD γ-rays in accidental background spectrum is dominant above 48MeV
- RMD with a high energy γ-ray has low momentum positron (typically <2MeV), and bending radii <4cm.
- Radiative muon decay veto counters (RDC) for both US and DS sides
    - Module : segmented plastic scintillation counters of 250μm thickness, optical fibers to transmit scintillation lights, and 1x1mm^2 SiPMs for readout
    - Tagging efficiency: 70% for events with γ-ray > 48MeV
    - Probability that a signal has accidentally a RDC hit is ~15%. Not to lose signal efficiency, the PDF of time difference between RDC hits and LXe timing can be used.





12年9月14日金曜日

Summary

- MEG is running now, and will finish in 2013 when the sensitivity reach ~$6x10^{-13}$ (Slower improvements after that).
- MEG Collaboration has started serious discussion for upgrade with higher μ beam intensity, with higher detection efficiency, with higher detector performance, and with lower background environment.
- Two positron trackers with a unique volume, cylindrical wire drift chamber, TPC, are being considered. Prototype study will be performed soon. Pixelated timing counter is considered for timing measurement. Significant improvements of resolutions and efficiency can be expected.
- Inner face of γ-ray detector will be modified by exchanging the current 2″ PMT to MPPCs to minimize non-uniform response.
- MEG upgrade proposal will be presented to PSI on January 2013.
- Target sensitivity is ~$5x10^{-14}$ with two years R&D and three years DAQ.

Backup

Cost estimate (rough)

- LXe : 1.6MEuro
- TC : 0.2MEuro
- DAQ : 0.7MEuro
- DC : 0.8MEuro

Responsibilities

TABLE XIII: Subdivision of the construction responsibilities

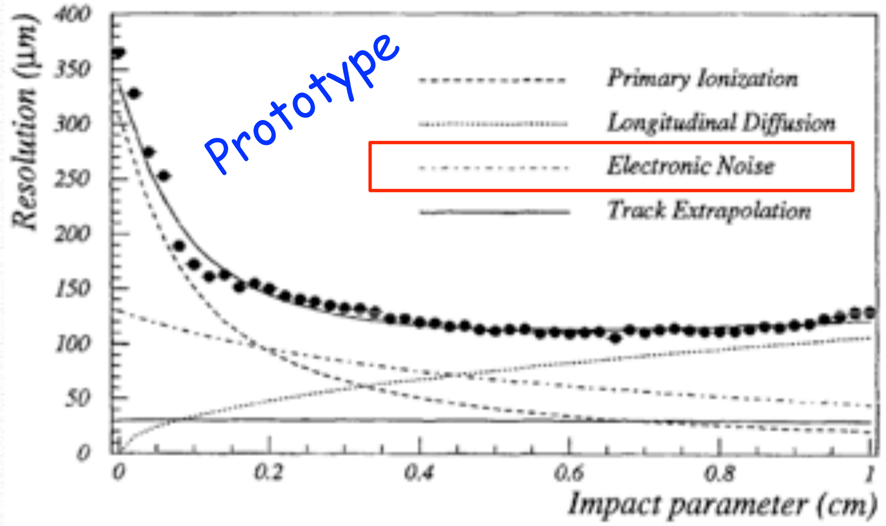
Item	Nation	Responsibility
Liquid xenon	Japan	SiPMs, LXe, Cryogenics
Drift Chamber	Italy	End-caps, Wiring, FE electronics, HV
	Switzerland	Gas-System
Timing counter	Italy	SiPMs, Support structure
	Japan	Scintillator, Laser system, Cables/Connectors
	UCI	
DAQ	Italy	Trigger boards
	Switzerland	WaveDREAM boards

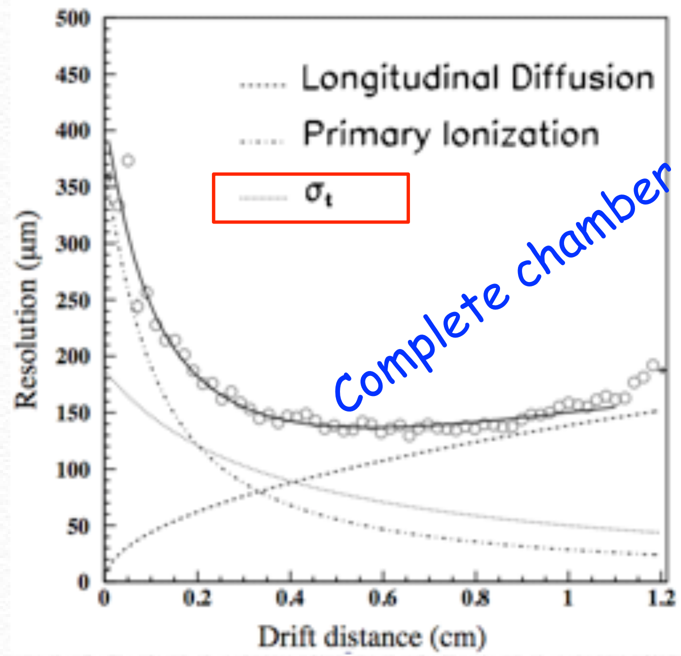
beam and target

Slit opening	Collimator position			COBRA center		
	R_μ (Hz) at 2mA	σ_x (mm)	σ_y (mm)	R_μ (Hz) at 2mA	σ_x (mm)	σ_y (mm)
250/280	$9 \cdot 10^7$	21.8	18.6	$7 \cdot 10^7$	9.6	10.1
115/115	$3.5 \cdot 10^7$	21.4	15.5	$2.9 \cdot 10^7$	8.9	8.8
70/70	$6.5 \cdot 10^6$	20.4	15.8	$5.8 \cdot 10^6$	8.4	8.3

Beam	Target Tickness (μ m)	Target Angle (deg)	US (%)	Tg+Supp (%)	Tg (%)	DS (%)	Stop Rate 2.3mA Whole Target x10^7Hz	Stopping Efficiency (%)	Stopping Quality Factor SQF	Measuring Time yrs
Surface	250	20.5	8.4	75.3	68.1	16.2	9.6	82.3	3.0	2.4
Surface	205	20.5	7.2	65.9	53.5	26.8	8.4	71.1	1.7	3.1
Surface	180	20.5	7.3	61.6	48.8	31.0	7.8	66.5	1.4	3.4
Surface	160	20.5	9.3	57.5	44.7	33.2	7.3	63.4	1.2	3.7
Surface	140	20.5	13.7	53.4	40.8	32.8	6.8	62.0	1.0	4.1
Surface	100	20.5	23.6	41.8	28.1	34.5	5.3	54.8	0.6	5.9
Surface	180	15.0	5.7	64.9	49.9	29.3	8.2	68.9	1.5	3.3
Surface	160	15.0	7.6	62.3	45.8	29.9	7.9	67.6	1.3	3.6
Surface	140	15.0	7.5	59.4	43.1	33.0	7.5	64.3	1.2	3.8
Surface	120	16.0	9.7	52.8	36.7	37.4	6.7	58.6	0.9	4.5
Sub-Surf	250	20.5	5.8	78.4	71.3	15.7	8.2	83.4	3.5	2.8
Sub-Surf	205	20.5	5.3	70.2	58.5	24.3	7.3	74.3	2.1	3.5
Sub-Surf	140	20.5	17.3	60.7	45.0	22.0	6.3	73.4	1.4	4.5
Sub-Surf	100	20.5	32.5	47.8	37.3	19.7	5.0	70.8	1.1	5.4
Sub-Surf	180	15.0	4.8	69.6	54.6	25.6	7.2	73.1	1.9	3.7
Sub-Surf	160	15.0	5.5	66.6	50.9	27.8	6.9	70.6	1.6	4.0
Sub-Surf	140	15.0	7.2	64.8	46.1	27.8	6.7	69.6	1.4	4.4
Sub-Surf	120	16.0	9.7	59.1	40.6	31.0	6.1	65.6	1.1	5.0

KLOE experience





Resolution on the impact parameter: 130 ÷ 300 μm

- He/iC_4H_{10} gas mixture
- 25 μm signal wires
- 500 and 10000 cells

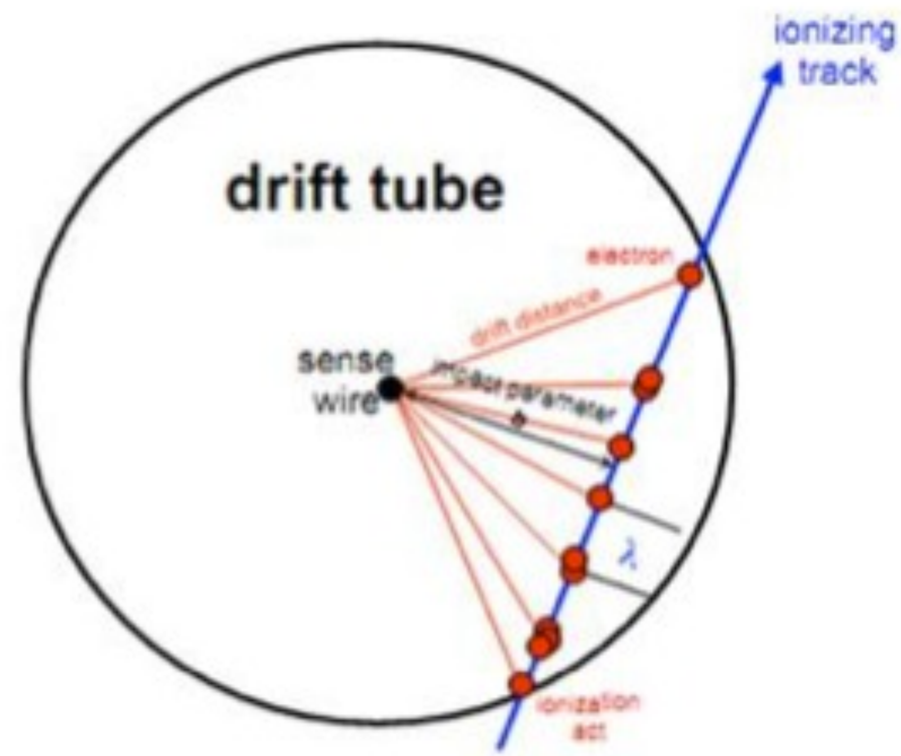
Limiting factors

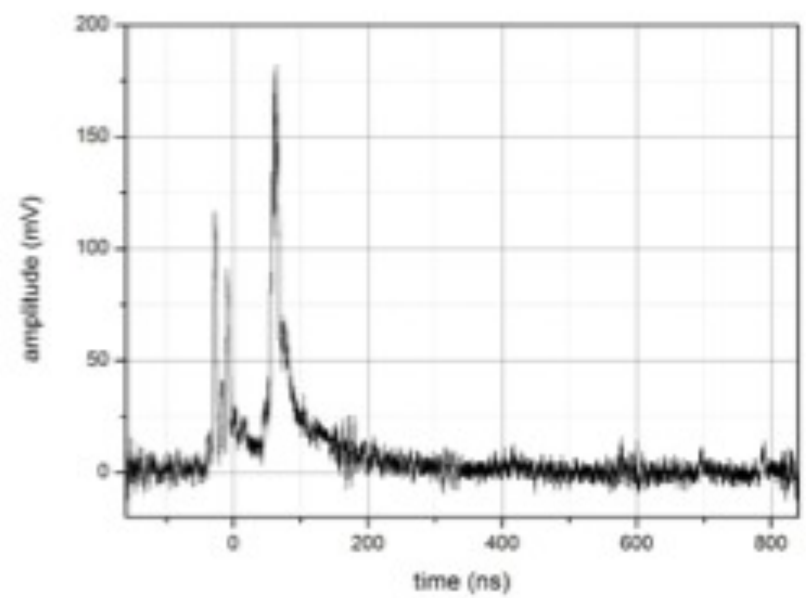
- Pre-amplifier bandwidth and TDC resolution
- Primary ionization density

Existing chamber

The 1 ns timing is possible which imply an average single hit resolution from ~ 150 μm (poor electronics)
to ~ 100 μm (fast electronics)

Cluster timing technique





Current DC

- σ_R(mm) = 250(core)
- σ_Z(mm) = 700(core)
- σ_p = 350keV
- σ_φ = 6.9mrad(at φ=0, 11mrad aver.)
- σ_θ = 10mrad
- σ_Y = 1.1mm
- σ_Z = 1.8mm
- DC-TC matching : 41%

Pixel TC

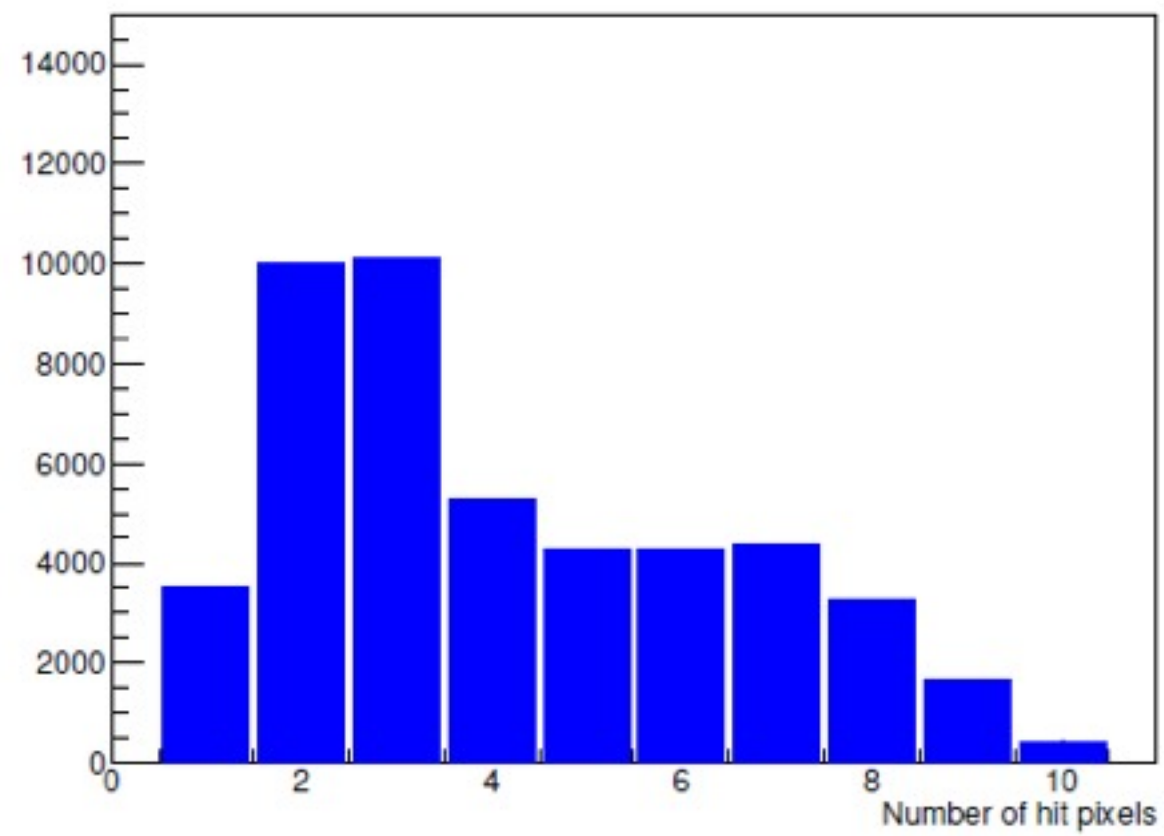
- Single pixel counter

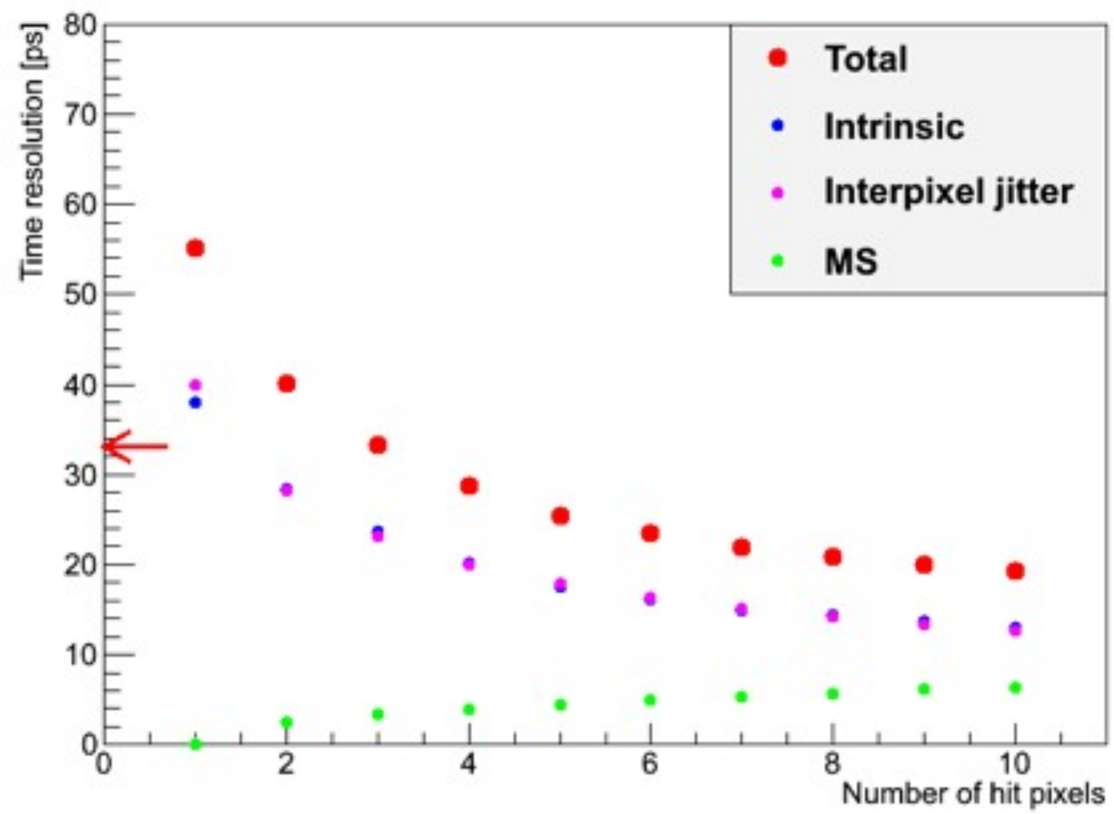
$$\sigma_{\text{single}} = \frac{19\,\text{ps}}{\sqrt{kE[\text{MeV}]}}$$

- Multiple hit

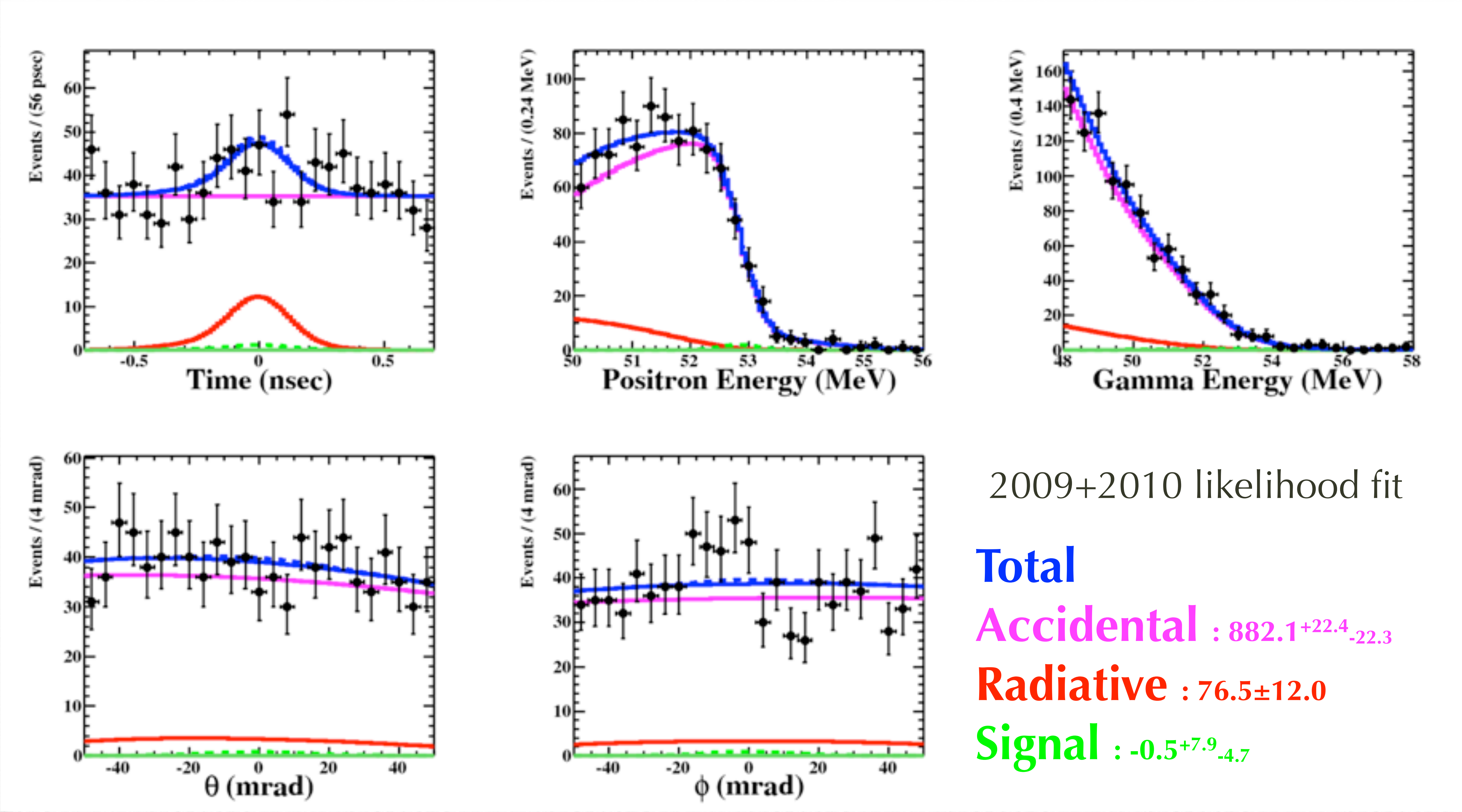
$$\sigma^2_{\text{overall}} = \frac{\sigma^2_{\text{single}}}{N_{\text{hit}}} + \frac{\sigma^2_{\text{inter-pixel}}}{N_{\text{hit}}} + \sigma^2_{\text{MS}}(N_{\text{hit}})$$

- $\sigma_{\text{inter-pixel}}$ ~ 30-40ps
- Effect of Multiple Scattering
  - angular resolution of new tracker ~ 5mrad
    - Time spread σ_{track} ~ 0.7ps
  - Angular spread due to multiple scattering ~ 35mrad for 5mm-thick pixel
    - Time spread σ_{MS} ~ 5ps for 30mm pixel spacing +45° incident angle
- Average time resolution 30-35 ps





Accidental Background



- Accidental background is our dominant background source.
- It is important to reduce background, improvements of all resolutions, less material budget, and if possible, to tag each background by using veto counters etc., and to remove those.

AIF background