Elisabetta Baracchini
ICEPP,The University of Tokyo
on behalf of the MEG Collaboration

MEG Experiment: past, present and future

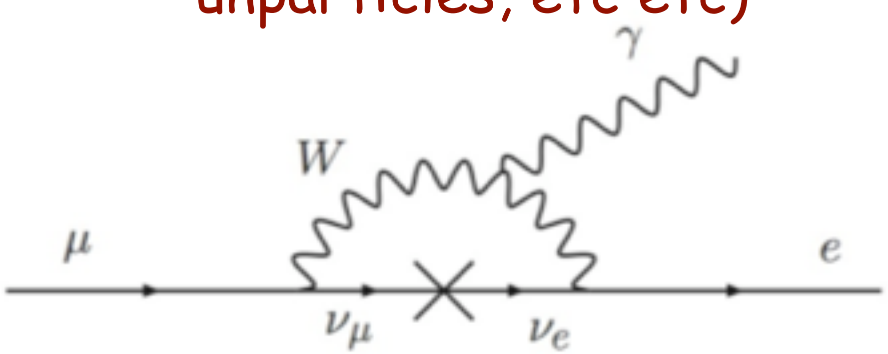
Recontres du Vietnam 2013
Windows on the Universe
International Center for Interdisciplinary Science Education, Quy Nhon, Vietnam

Lepton Flavour Violation

- Lepton Flavour Conservation is an accidental symmetry of SM:
  - Not related to the gauge structure of the theory
  - Naturally violated in SM extensions

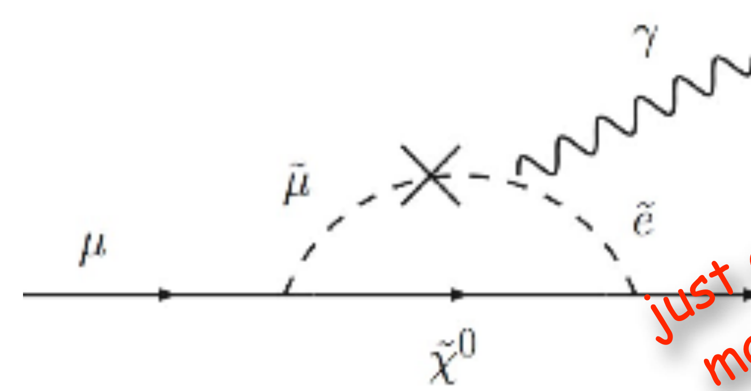
Observation of cLFV would be an unambiguous evidence of NP beyond SM

- LFV already observed in the neutral sector: neutrino oscillations
- LFV in charged sector could be mediated by
  - neutrino oscillation in SM extensions with massive neutrinos ---> unobservable
  - through RG evolution even if theory is LFC at high energy scales (SUSY, ED, unparticles, etc etc)



$$\Gamma(\mu \to e\gamma) \approx \underbrace{\frac{G_F^2 m_\mu^5}{192\pi^3}}_{\mu-\text{decay}} \underbrace{\left(\frac{\alpha}{2\pi}\right)}_{\gamma-\text{vertex}} \underbrace{\sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2}{M_W^2}\right)}_{\nu-\text{oscillation}}$$

BR (μ → e γ) ~ 10^{-54}



just one example of many possibilities

$$BR(\ell_i \to \ell_j \gamma) \propto \delta_{ij}^2 \tan^2 \beta$$

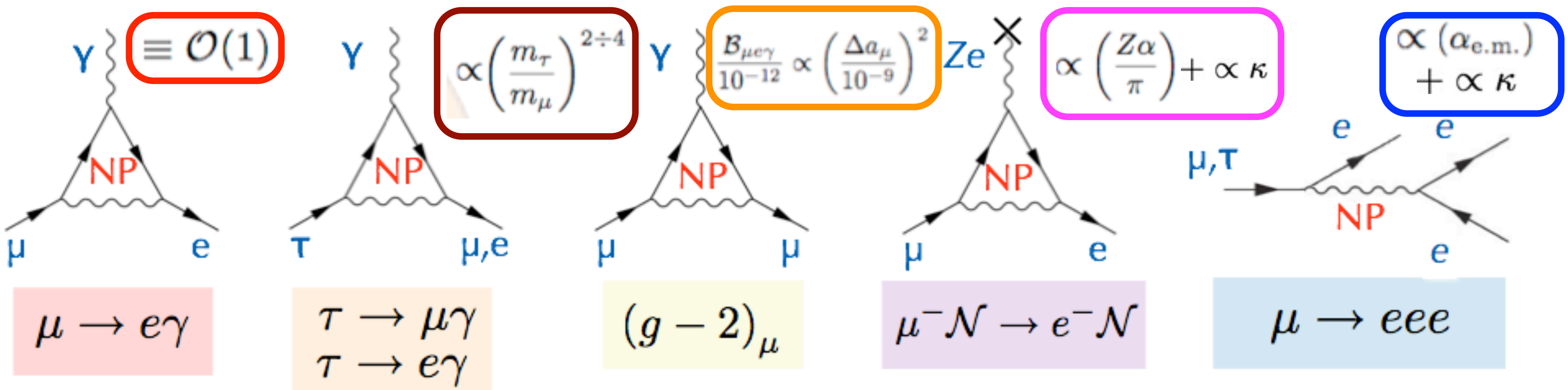
BR (μ → e γ) ~ 10^{-13} - 10^{-14}

Charged LFV processes

Model independent effective cLFV Lagrangian

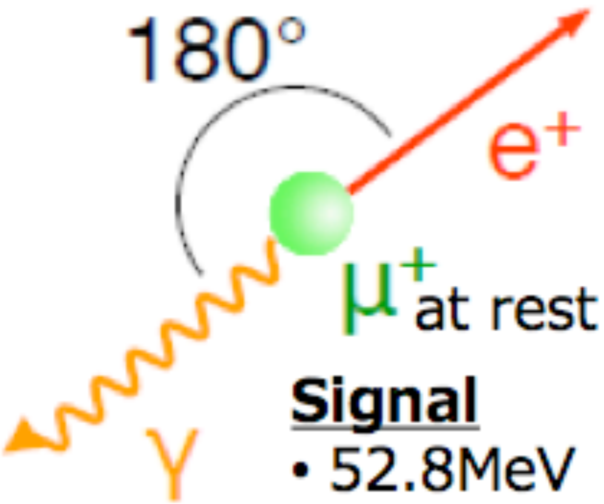
$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2}(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L)$$

new coupling (SUSY, heavy ν) — contact term (leptoquark, Z'…)

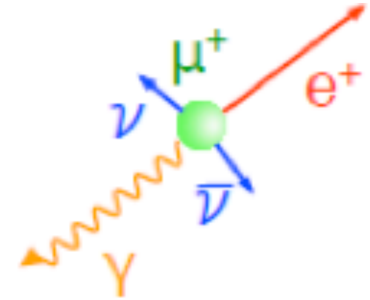


- cLFV processes are a wide field of research
  - LFV decays
  - Muon to electron conversion in matter
  - Anomalous magnetic moment

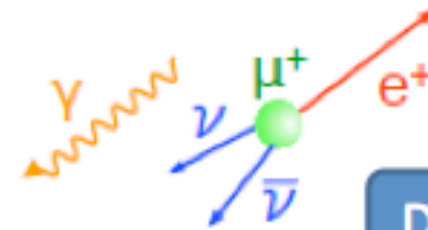
μ→eγ :experimental challenge!!



Signal
- 52.8MeV
- Back-to-back
- Time coincidence



Physics BG RMD
(radiative muon decay)
- <52.8MeV
- Any angle
- Time coincidence

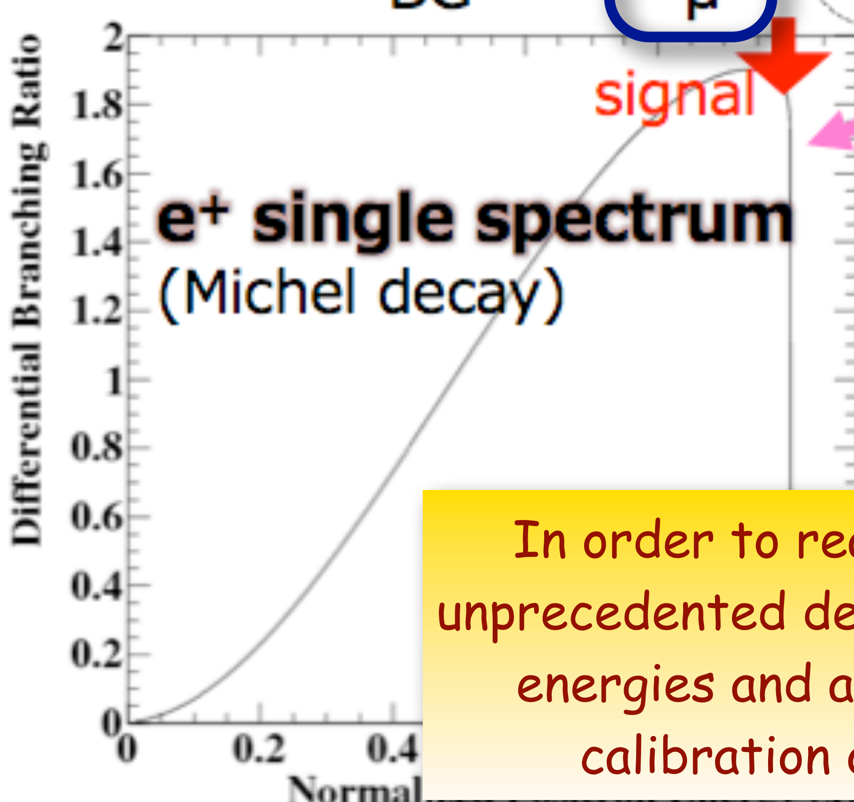


Dominant

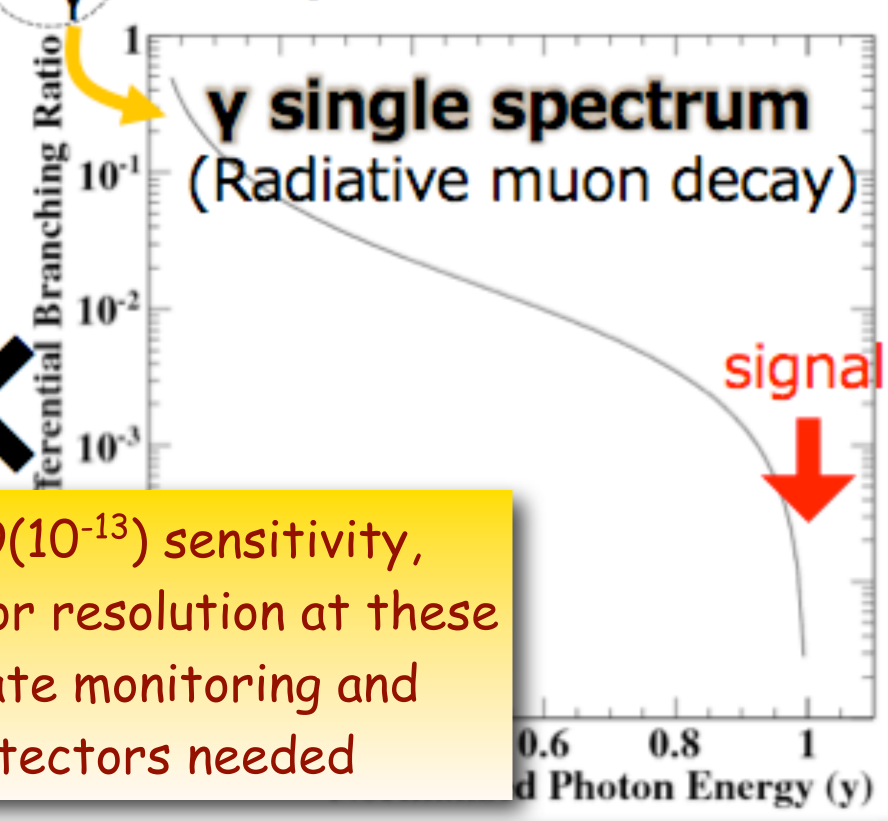
Accidental BG
- <52.8MeV
- Any angle
- Random

Accidental background is determined by the experimental resolutions

$$R_{BG} \propto R_\mu^2 \cdot f_e \cdot f_\gamma \cdot \delta\omega/4\pi \cdot \delta t$$



×



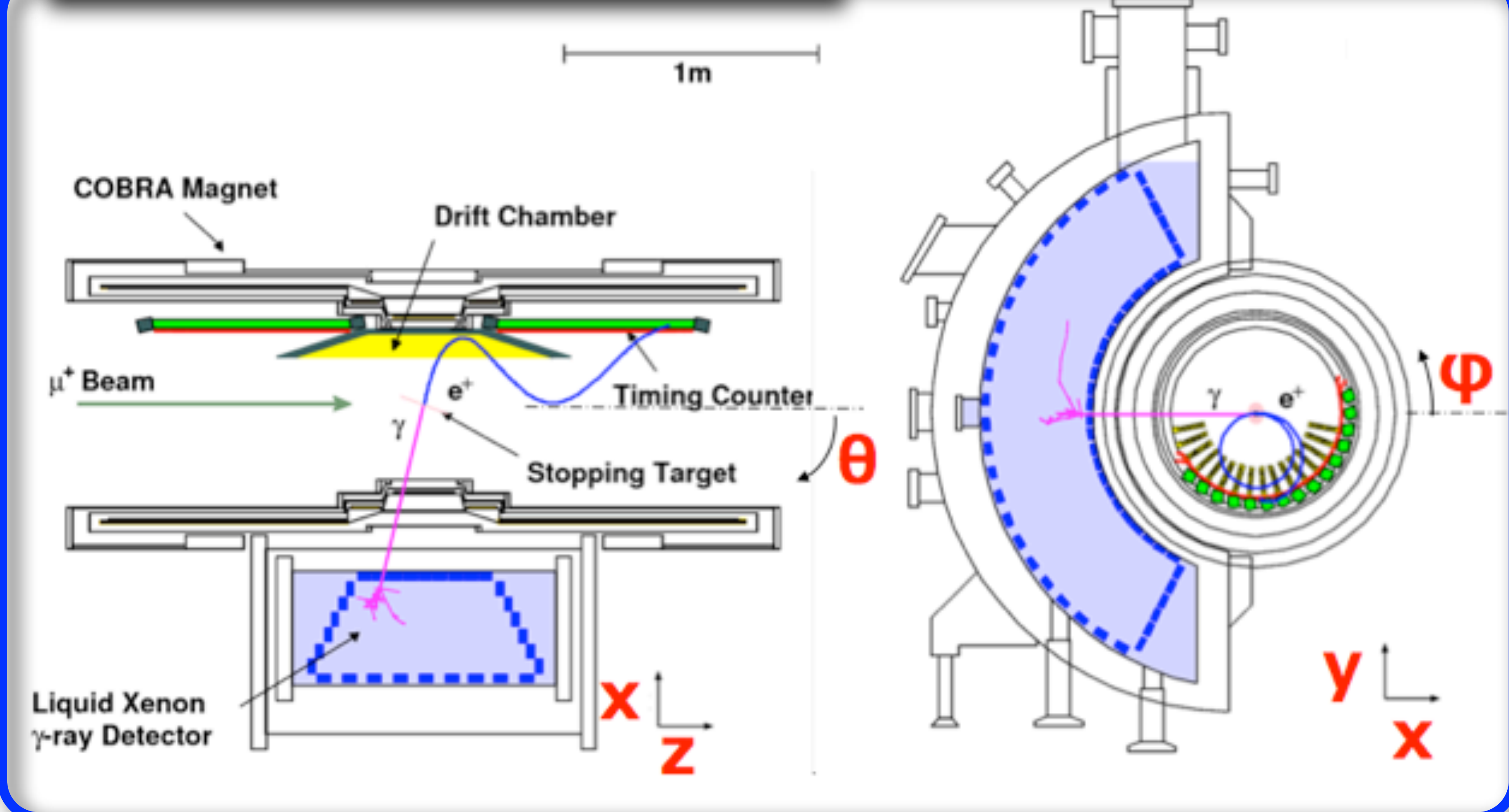
In order to reach O(10^{-13}) sensitivity, unprecedented detector resolution at these energies and accurate monitoring and calibration of detectors needed

A needle in a haystack

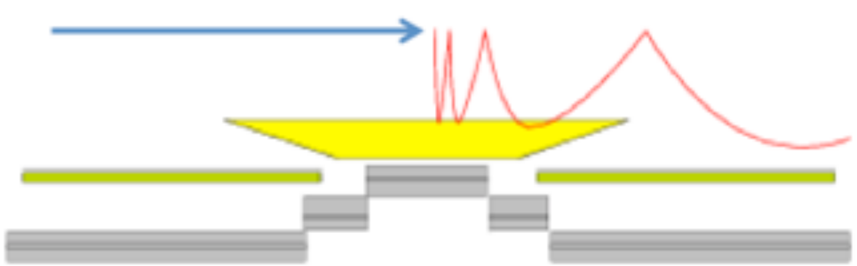
....only that our haystack is at least as big as 4 Cheops Pyramids.....

MEG in a nutshell

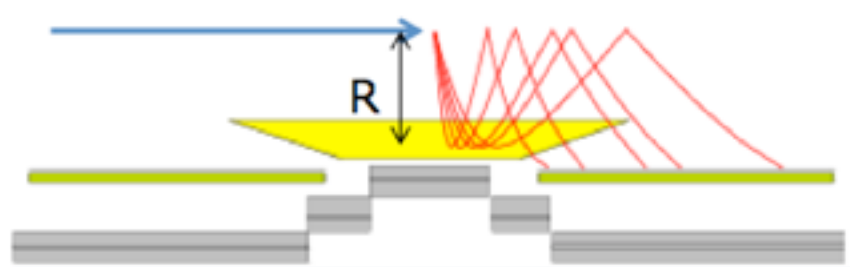
Eur. Phys. J. C 73 (2013) 2365



- Most intense DC muon beam of 3 x 10^7 muon/s at Paul Scherrer Institut, Switzerland
- Quasi-solenoidal spectrometer & low mass drift chamber for e^+ kinematic measurement
- Scintillator bars and fibers for e^+ timing read by PMT/APD
- Liquid Xenon calorimeter for photon detection read by PMT
- ~10^7 fully efficient trigger bkg suppression



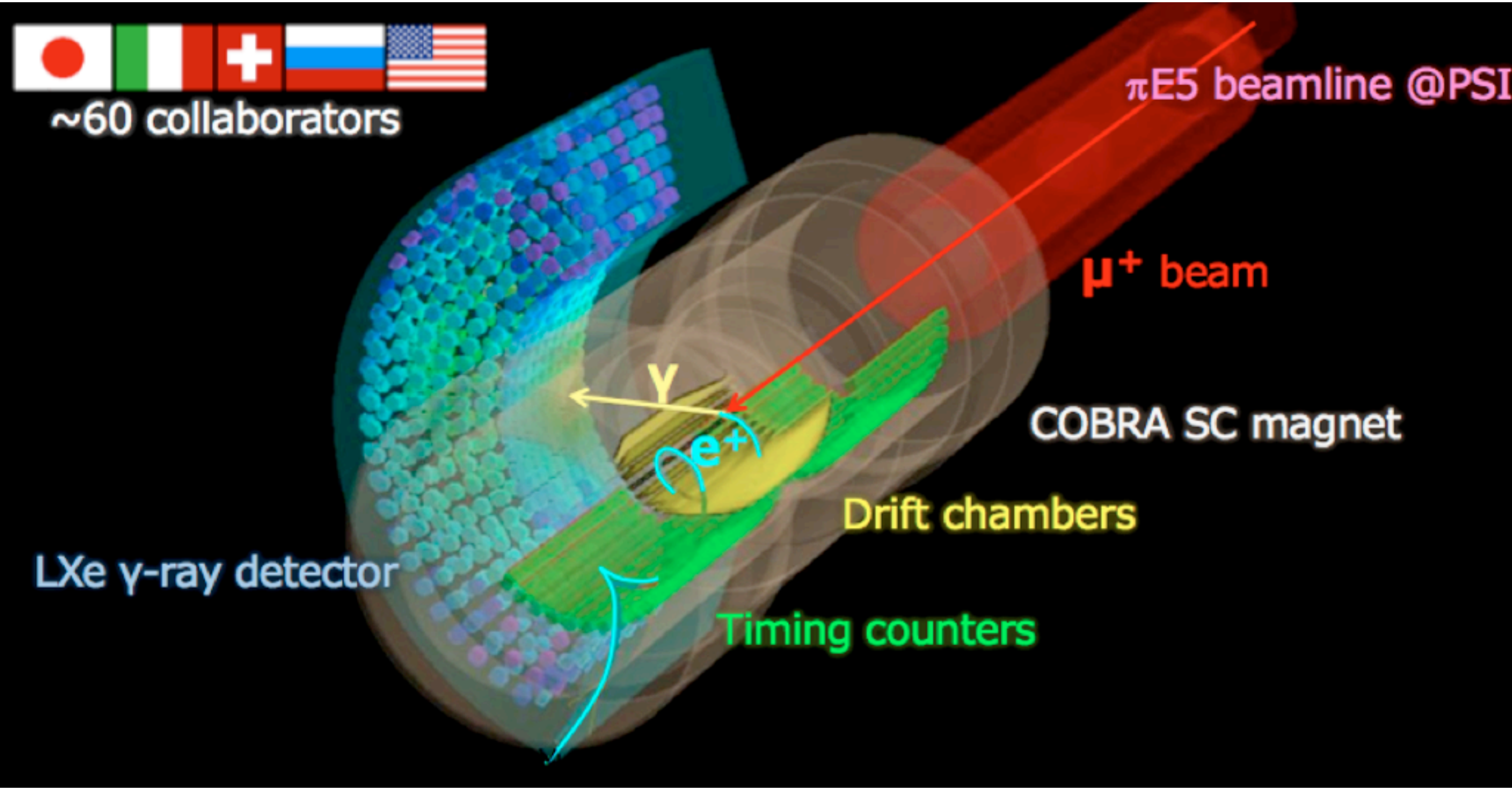
e^+ quickly swept out



Constant bending radius independent of emission angles

Gradient B field instead of uniform B field for good momentum resolution and high pile up rejection

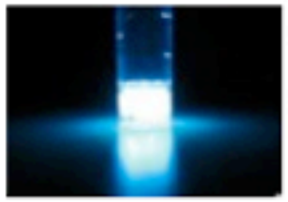
MEG Picture

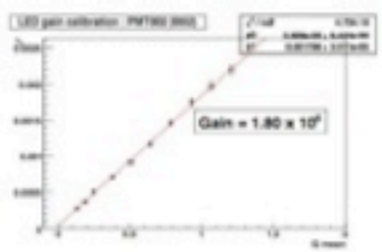

~60 collaborators
πE5 beamline @PSI
μ+ beam
γ
e+
COBRA SC magnet
Drift chambers
LXe γ-ray detector
Timing counters

Calibrations

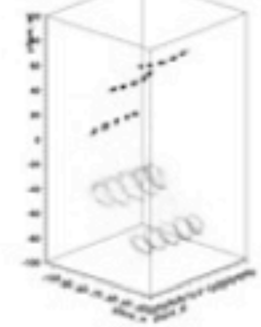
XENON CALIBRATION

LED
PMT gain

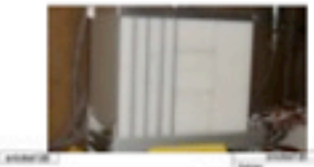


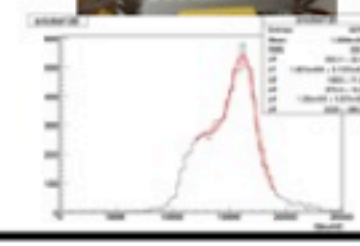


α source
PMT QE
Absorption length

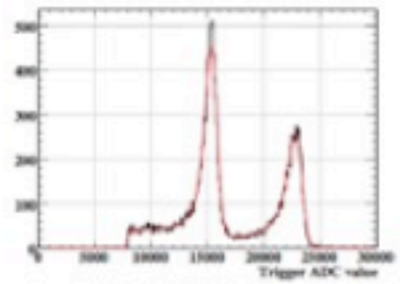


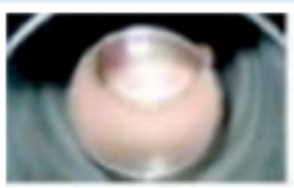
Ni γ generator
9 MeV γ-line
beam on/off calib.



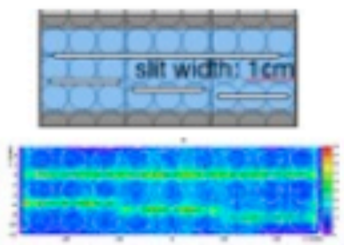


CEX
γ-resolutions:
- energy
- time
- impact point

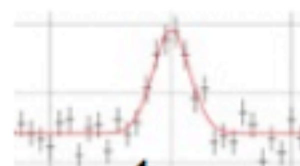




LH2 target

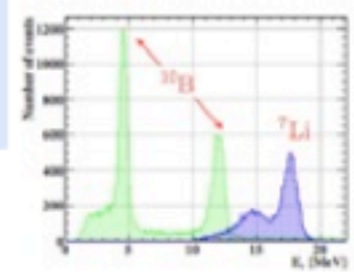


$\mu \to e\nu\bar{\nu}\gamma$

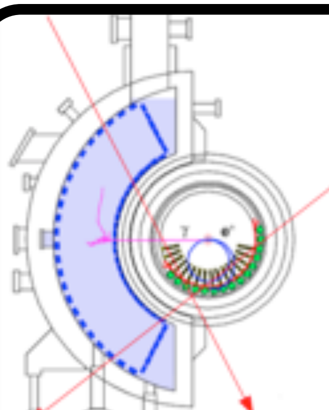


$t_{e\gamma}$

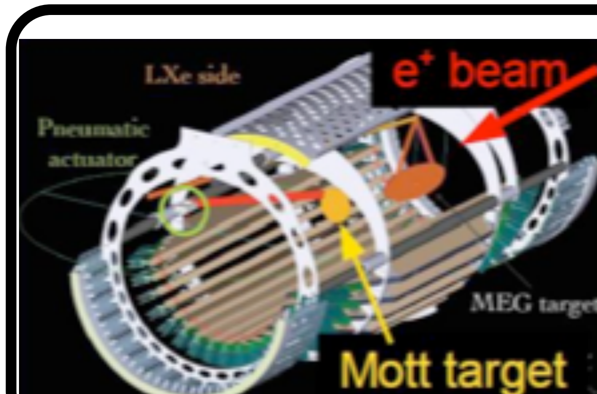
CW p-accel
Light Yield
LXe-TC t-calib



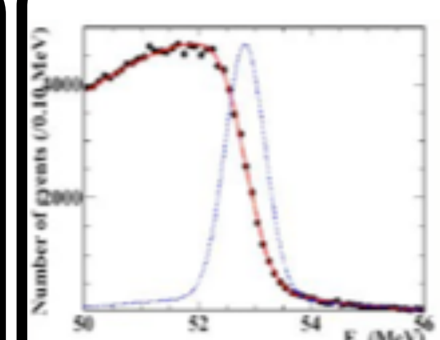
TRACKER CALIBRATION



Cosmic Ray
- DC alignment
- TC uniformity
- LXe monitoring



e+ Mott-scatter
- Monochromatic, tunable momentum beam



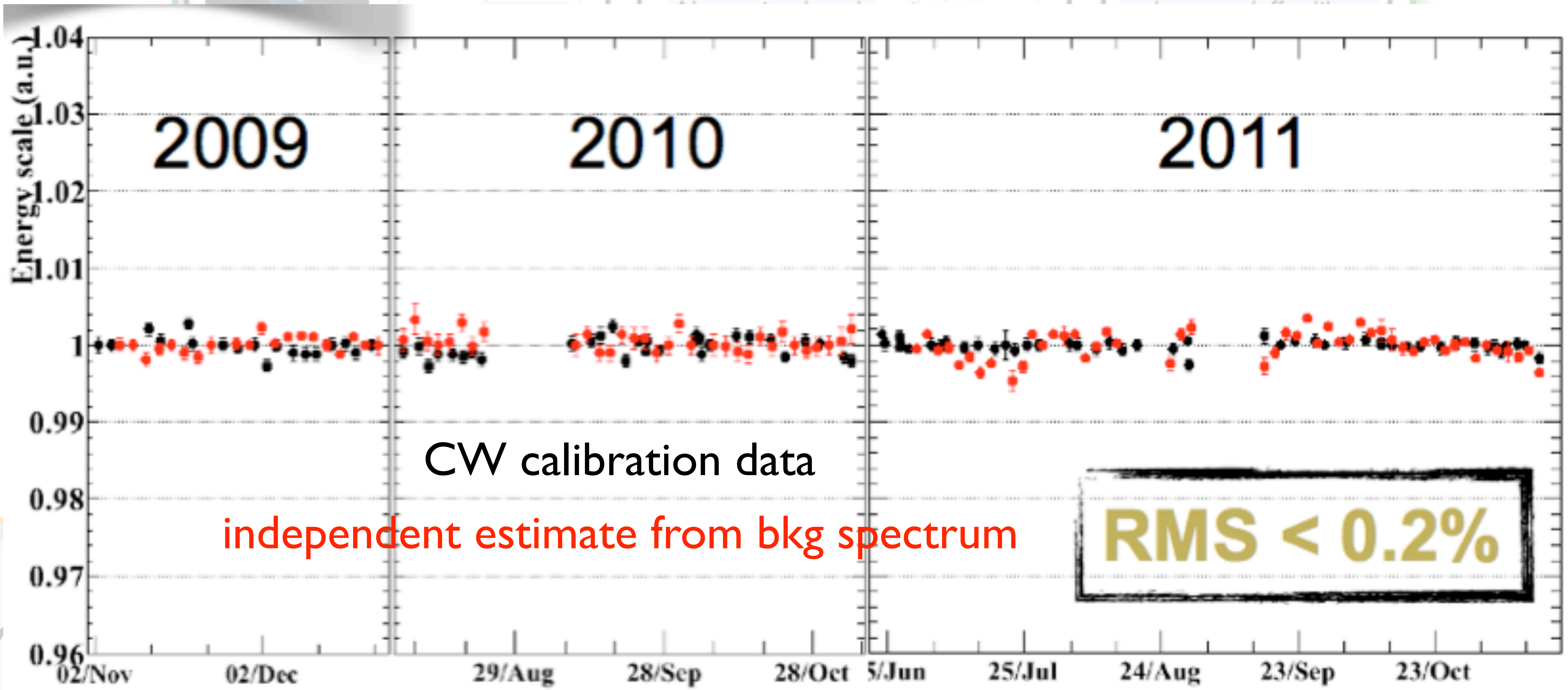
Michel decays
- μ→ e νν for momentum energy scale

Calibrations

LED
PMT gain

α source
PMT QE

Ni γ generator
9 MeV γ-line

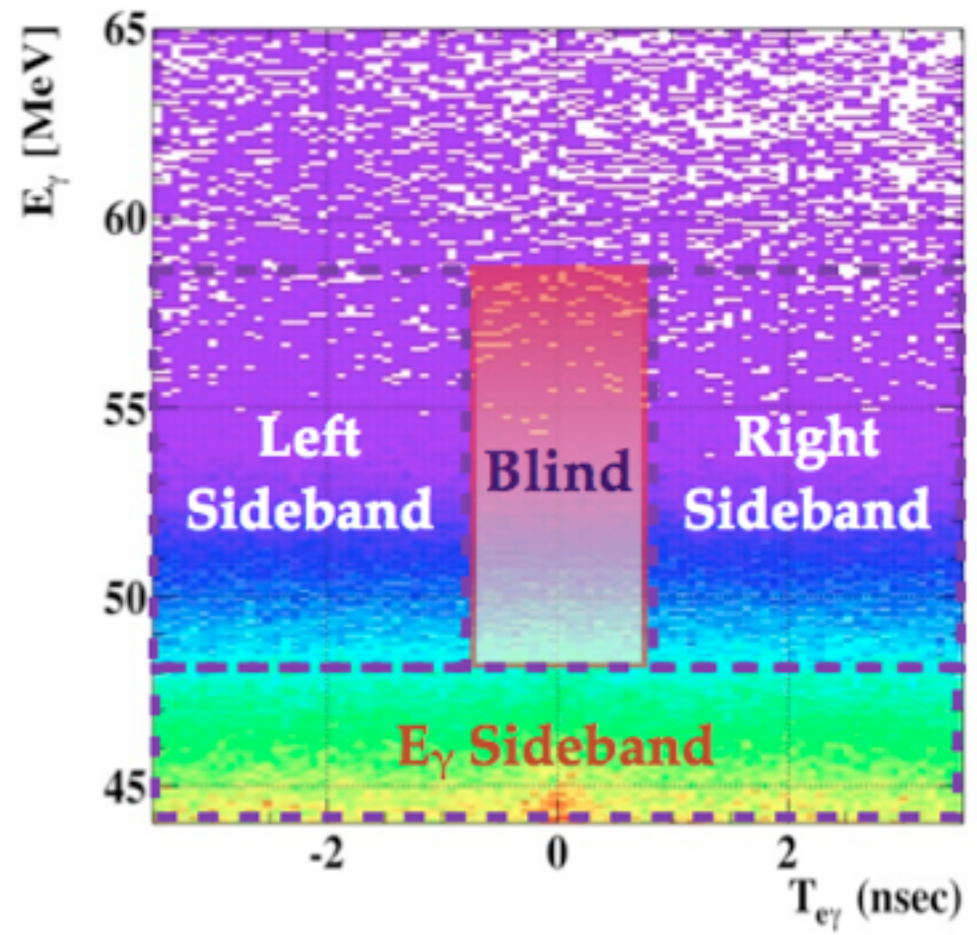


- DC alignment
-TC uniformity
-LXe monitoring

- Monochromatic, tunable momentum beam

- μ→ e νν for momentum energy scale

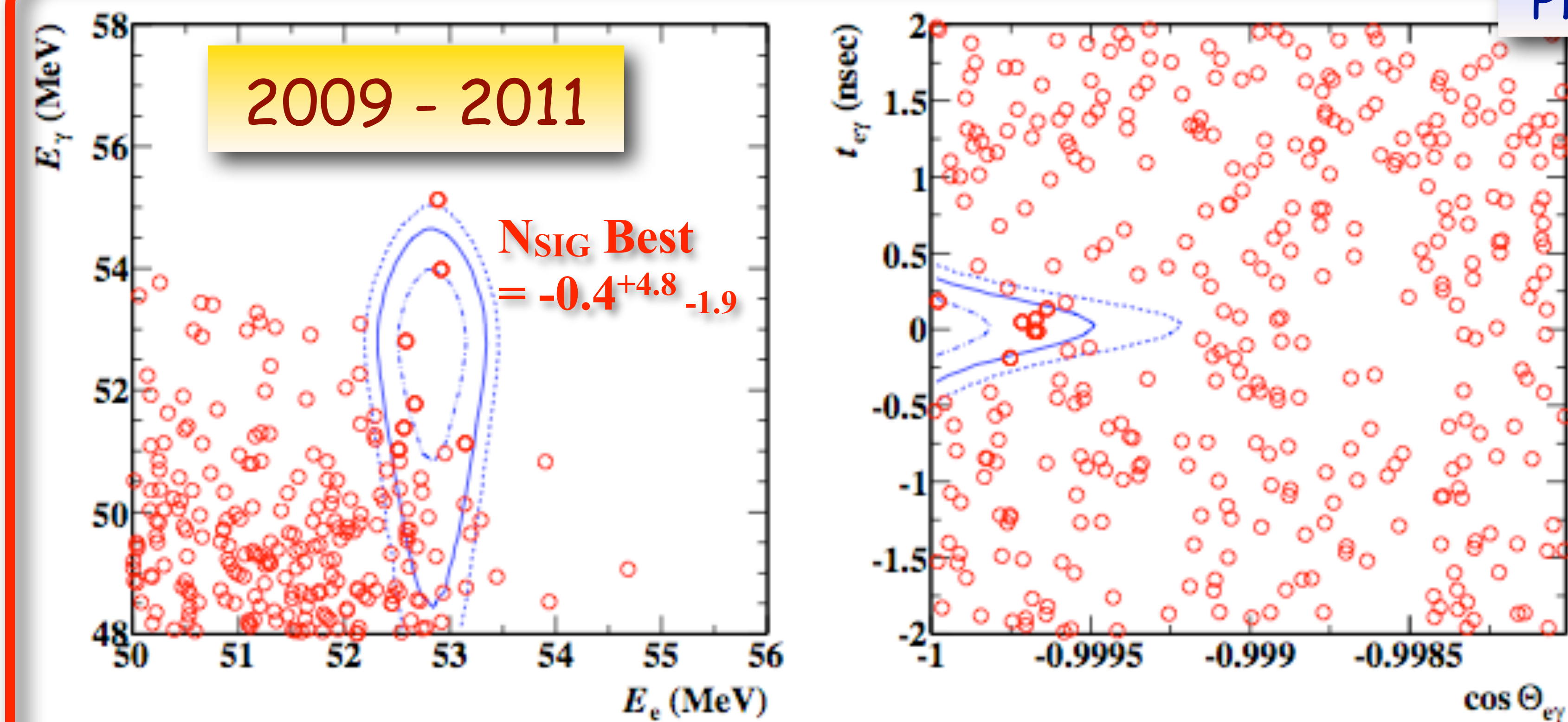
Analysis Technique



- Blind analysis technique adopted:
  - Events inside a signal region of E_γ and $t_{e\gamma}$ not used for analysis development
  - Background and signal characterization from sidebands:
    - accidental bkg fully defined from sidebands data
    - RMD from low energy E_γ sideband
- Extended unbinned ML fit of N_{sig}, N_{RMD} and N_{bkg}
  - Observables E_γ, E_e, $t_{e\gamma}$, $\theta_{e\gamma}$, $\varphi_{e\gamma}$,
- Number of muons stopped on target: 3.6×10^{14} (2009-2011)
  - Count unbiased Michel sample in physics data simultaneously with the signal
    - Count RMD sample in E_γ sideband (independent sample) for consistency check
  - Independent of instantaneous beam rate and insensitive to acceptance and efficiency

$$\mathrm{BR}(\mu^+ \to e^+\gamma) = \frac{N_{\mathrm{sig}}}{N_{e\nu\bar{\nu}}} \times \frac{f^E_{e\nu\bar{\nu}}}{P} \times \frac{\epsilon^{\mathrm{trig}}_{e\nu\bar{\nu}}}{\epsilon^{\mathrm{trig}}_{e\gamma}} \times \frac{A^{\mathrm{TC}}_{e\nu\bar{\nu}}}{A^{\mathrm{TC}}_{e\gamma}} \times \frac{\epsilon^{\mathrm{DCH}}_{e\nu\bar{\nu}}}{\epsilon^{\mathrm{DCH}}_{e\gamma}} \times \frac{1}{A^{\mathrm{g}}_{e\gamma}} \times \frac{1}{\epsilon_{e\gamma}},$$

2009-2011 Combined Result

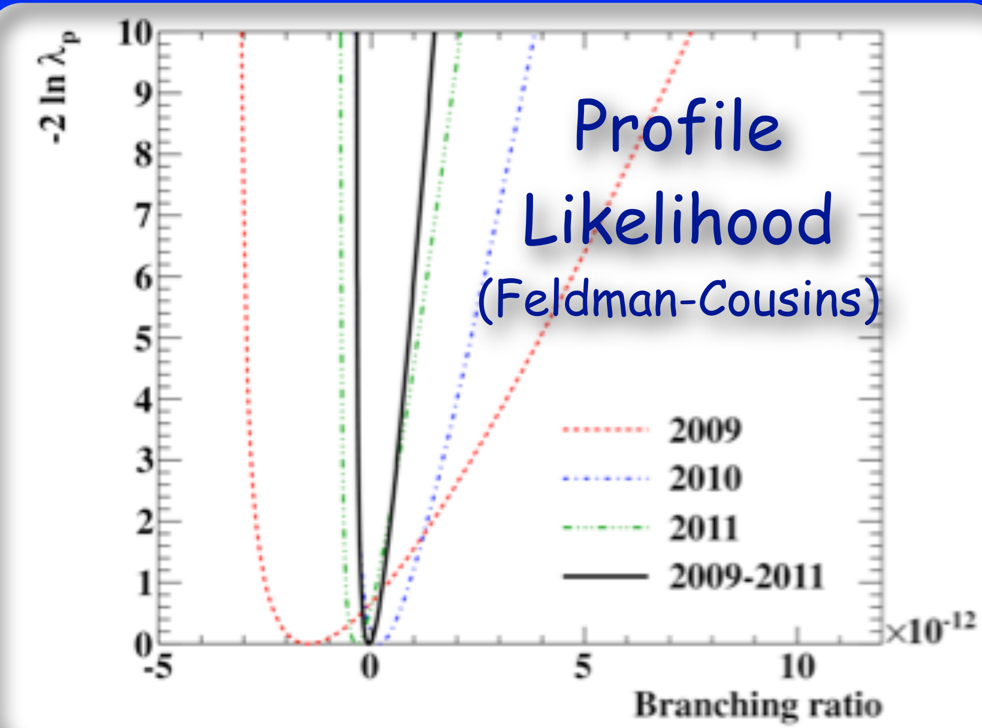


Phys. Rev. Lett. 110, 201801 (2013)

UL @ 90% C.L.

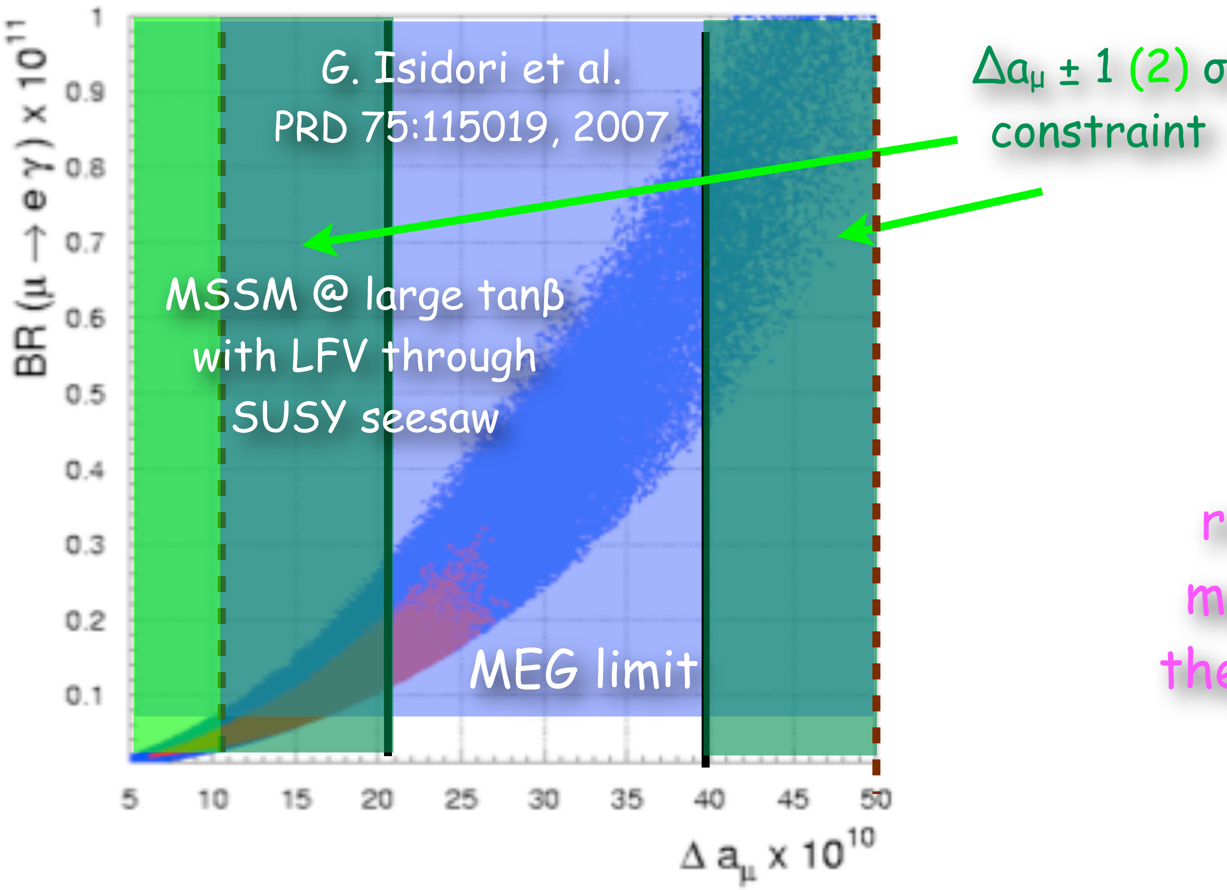
BR(μ→eγ) < 5.7×10^{-13}

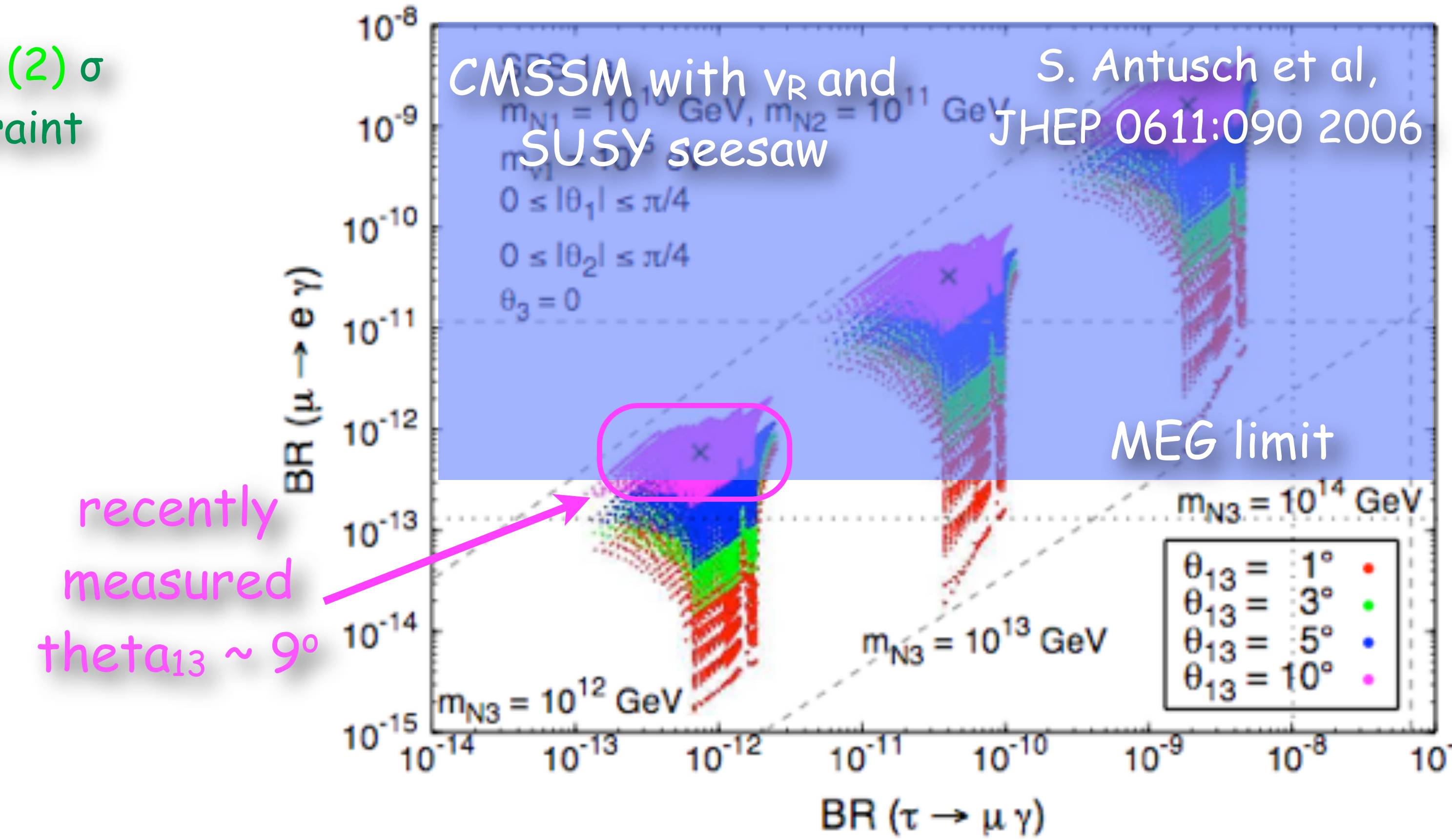
Dataset	$\mathcal{B}_{fit} \times 10^{12}$	$\mathcal{B}_{90} \times 10^{12}$	$\mathcal{S}_{90} \times 10^{12}$
2009–2010	0.09	1.3	1.3
2011	−0.35	0.67	1.1
2009–2011	−0.06	0.57	0.77



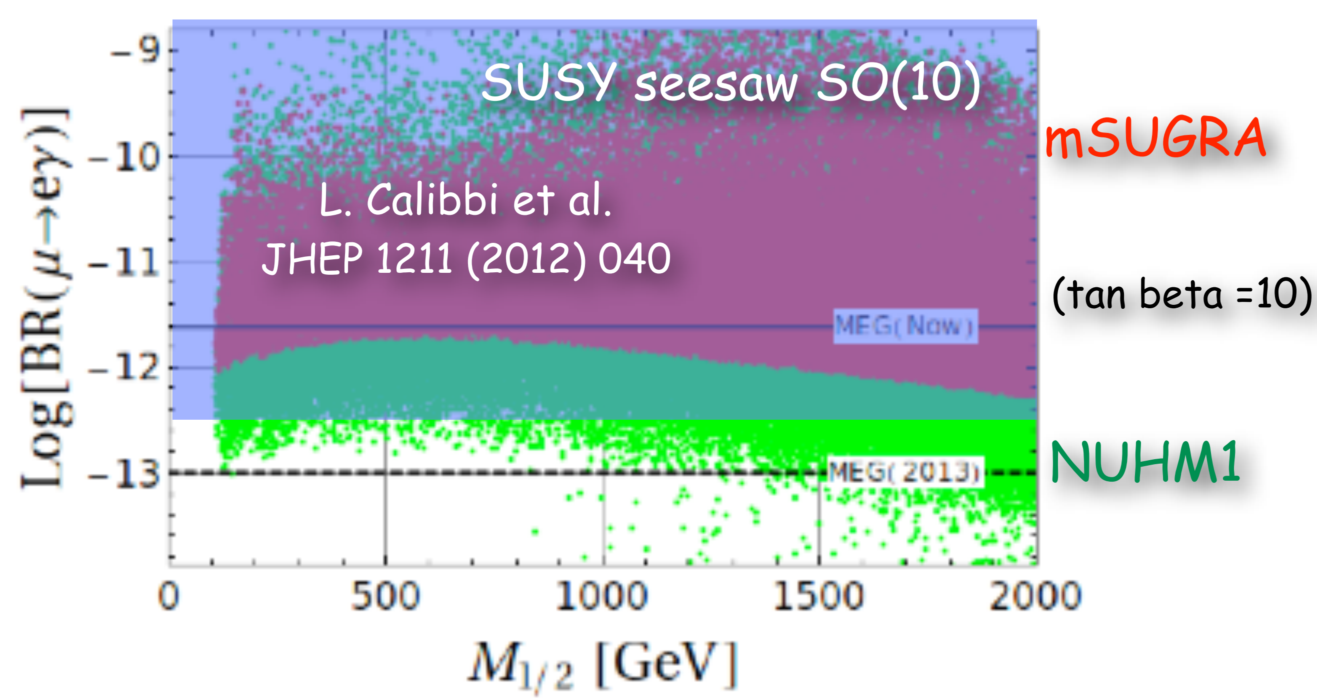
- 2011 data with improved DAQ efficiency > 96%
- 2009-2011 data analysis improvement
  - Event by event positron pdf and careful treatment of correlations + 10 %
  - Improved reconstruction
    - new photon pile-up rejection algorithm + 6%
    - new positron Kalman filter tracking algorithm +6%
    - positron WF offline noise reduction

Some Implications

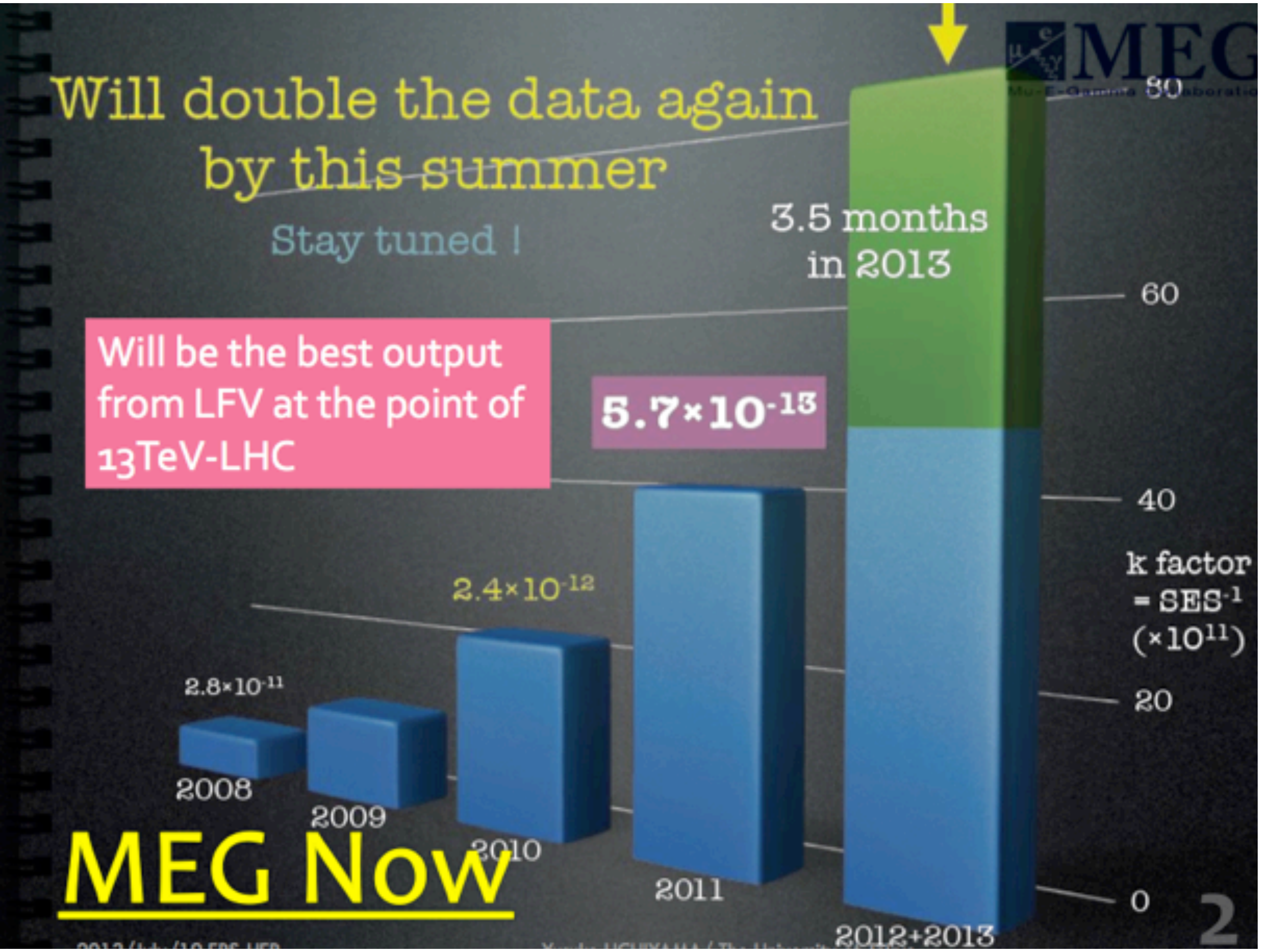


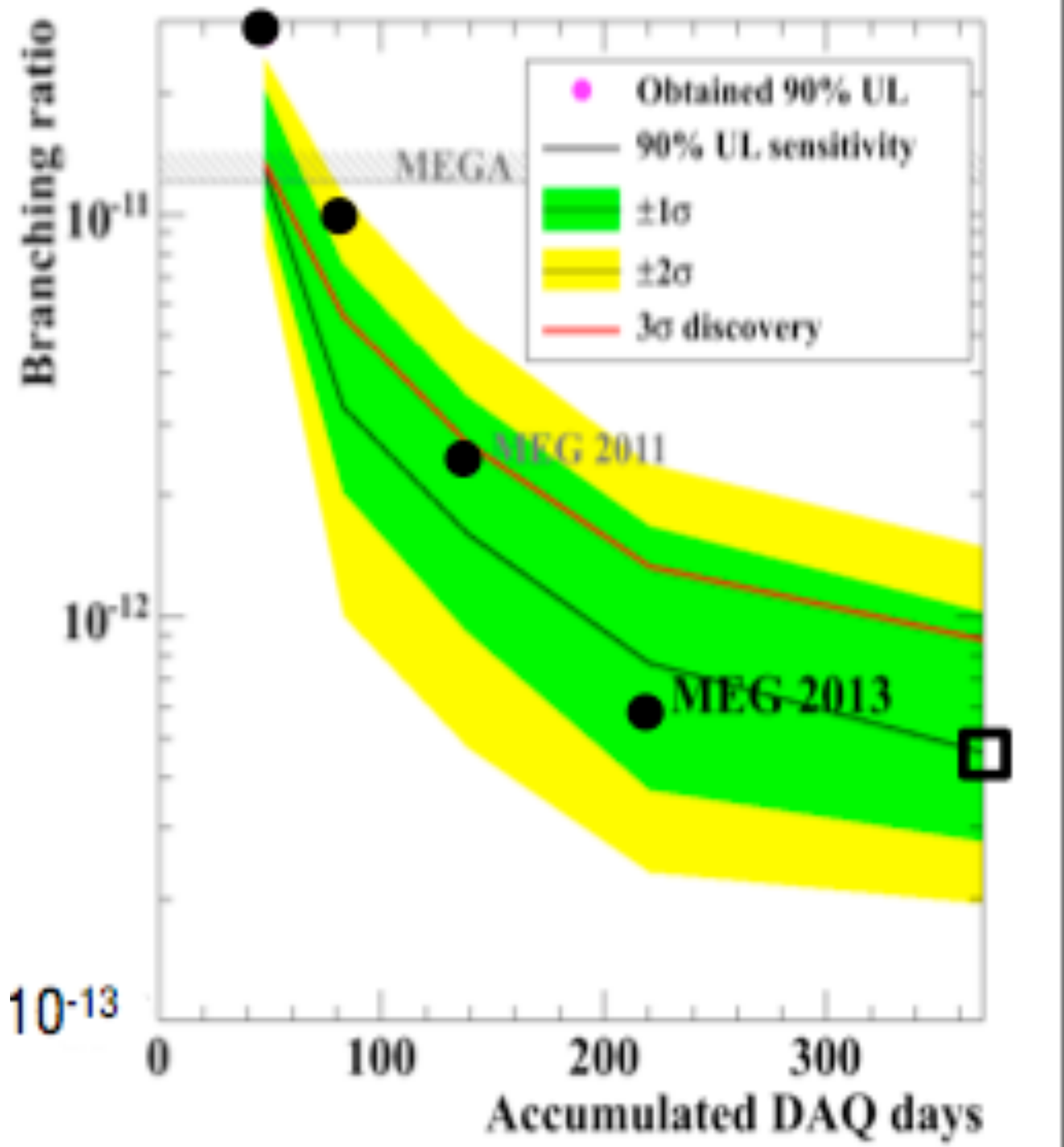


I am not a theorist and I apologize if I am not citing your favourite model....



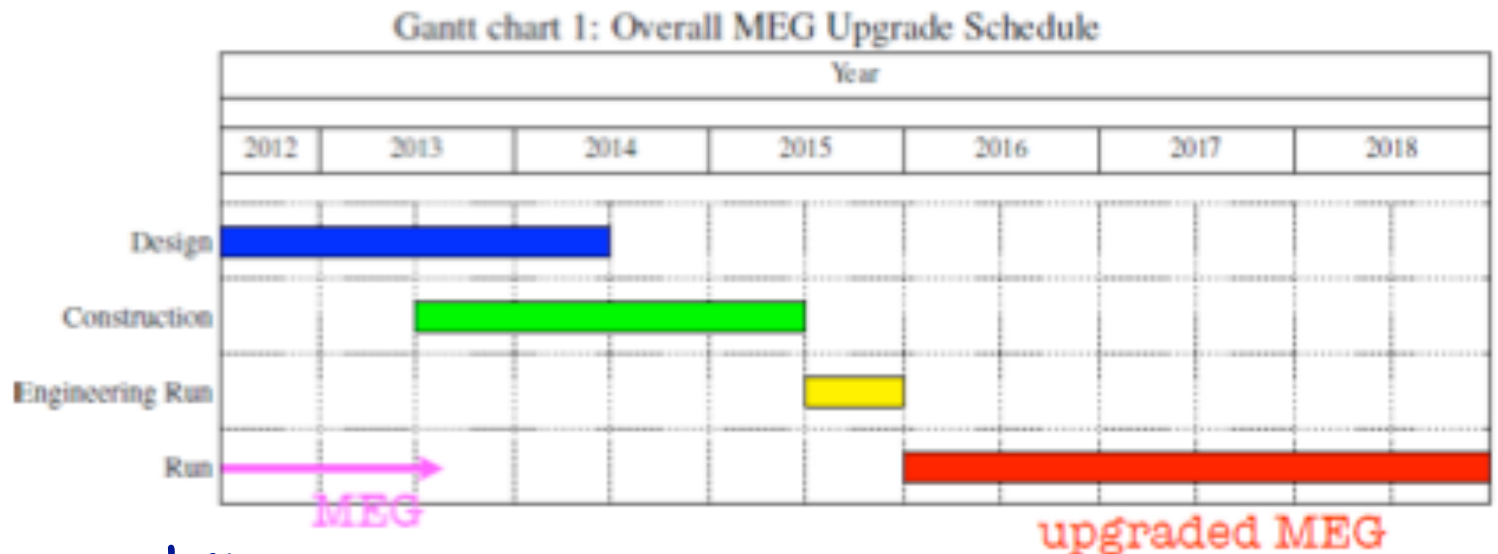
Present



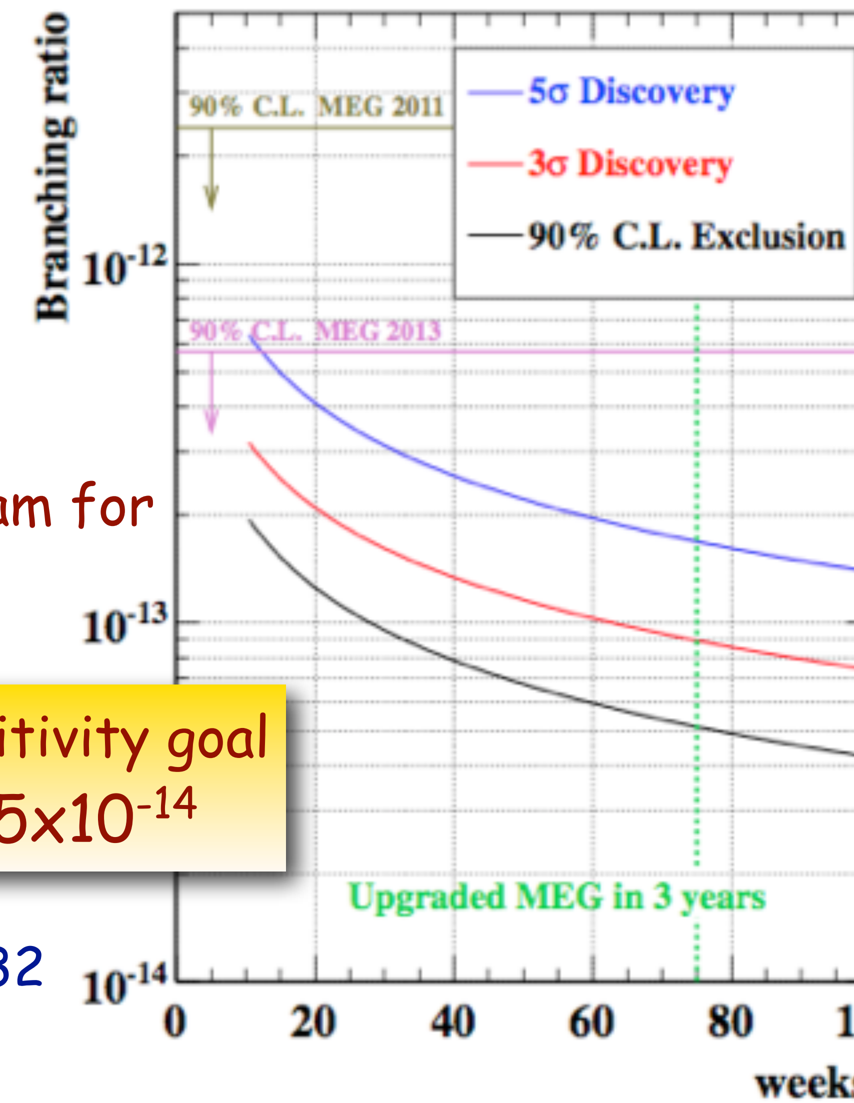


MEG will saturate its sensitivity
with the current run

MEG Upgrade



A. Baldini et al, arXiv:1301.7225

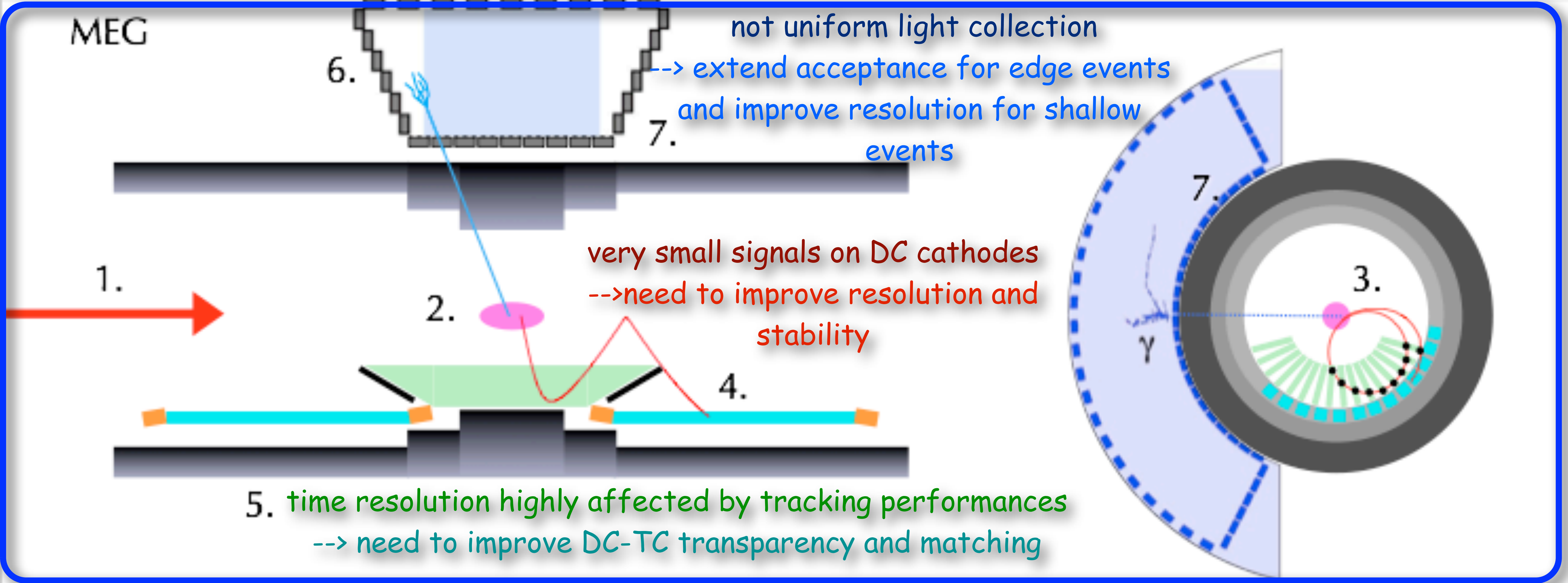


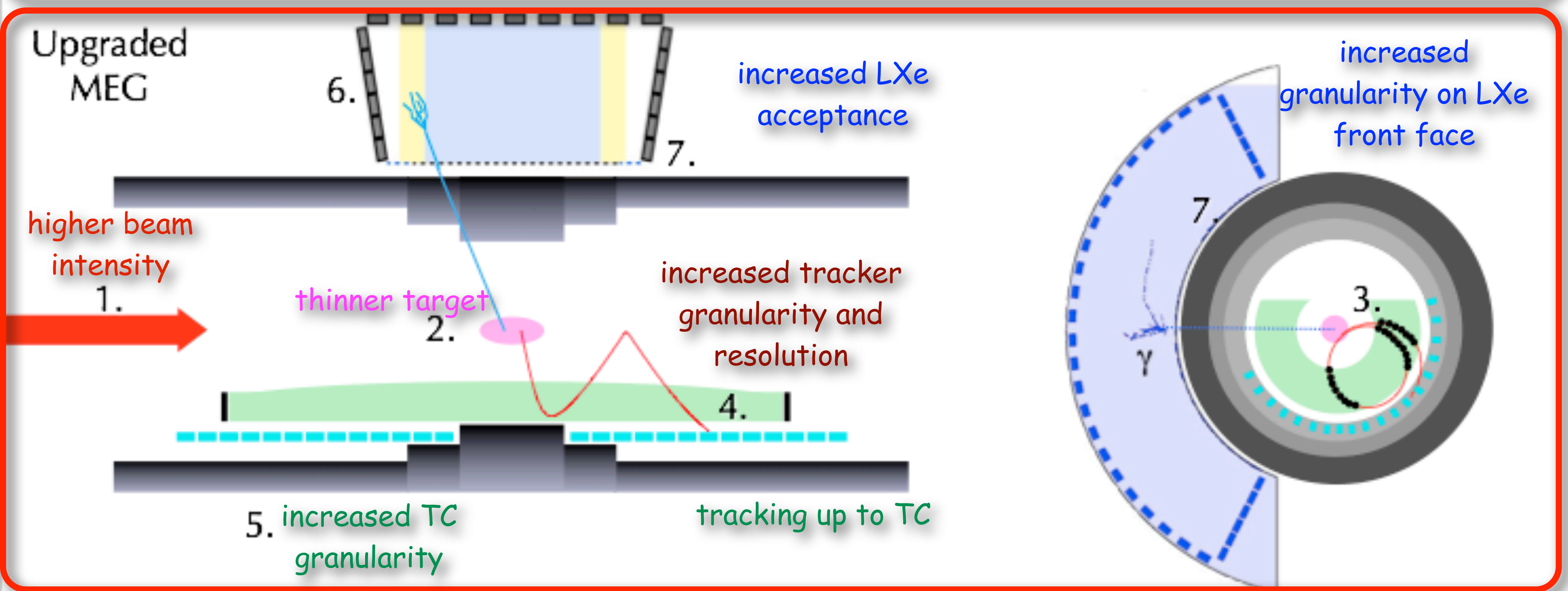
- Key elements:
  - Exploit existing apparatus and well established collaboration team for low costs and early realization (time scale ~5 years)
  - Increase beam intensity x2-3
  - Improve efficiency x2
  - Improve BG suppression x30 through:
    - resolutions: (e^+ mom x2)x(γ energy x2)x(angle x2)x(time x2) = 32
    - possibly identify positron from radiative decay to tag BG

sensitivity goal ~5×10^{-14}

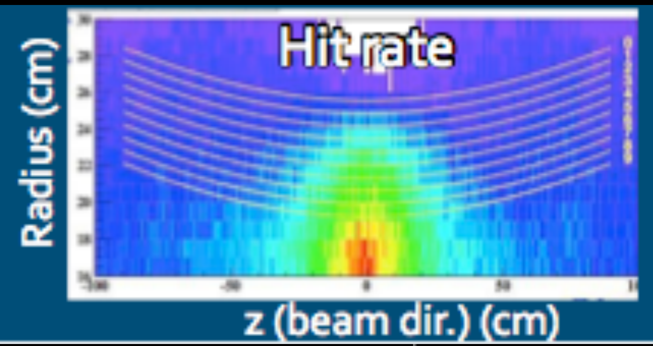
Fully approved by all funding agencies and given the highest priority from PSI

will ensure that PSI keeps its world leadership in the study of this process. The Committee approves the upgrade proposal and expects that, after the upgrade is successfully completed, MEG will be given the highest priority in πE5.

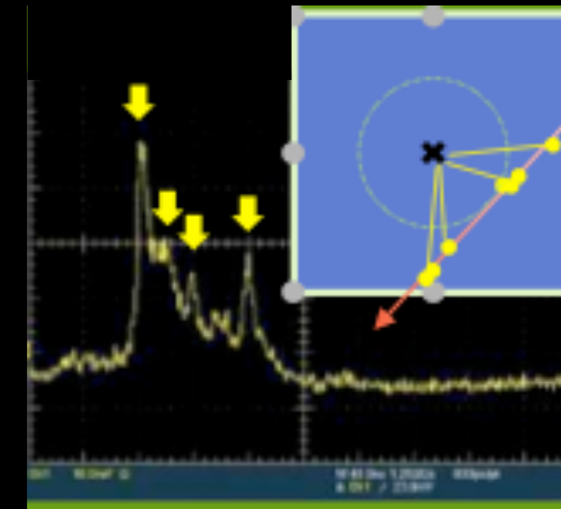

MEG
6.
7.
not uniform light collection
--> extend acceptance for edge events
and improve resolution for shallow
events
1.
2.
very small signals on DC cathodes
-->need to improve resolution and
stability
4.
3.
γ
5. time resolution highly affected by tracking performances
--> need to improve DC-TC transparency and matching


Upgraded
MEG
6.
7.
increased LXe
acceptance
increased
granularity on LXe
front face
higher beam
intensity
1.
thinner target
2.
increased tracker
granularity and
resolution
4.
3.
γ
5. increased TC
granularity
tracking up to TC

Positron Side



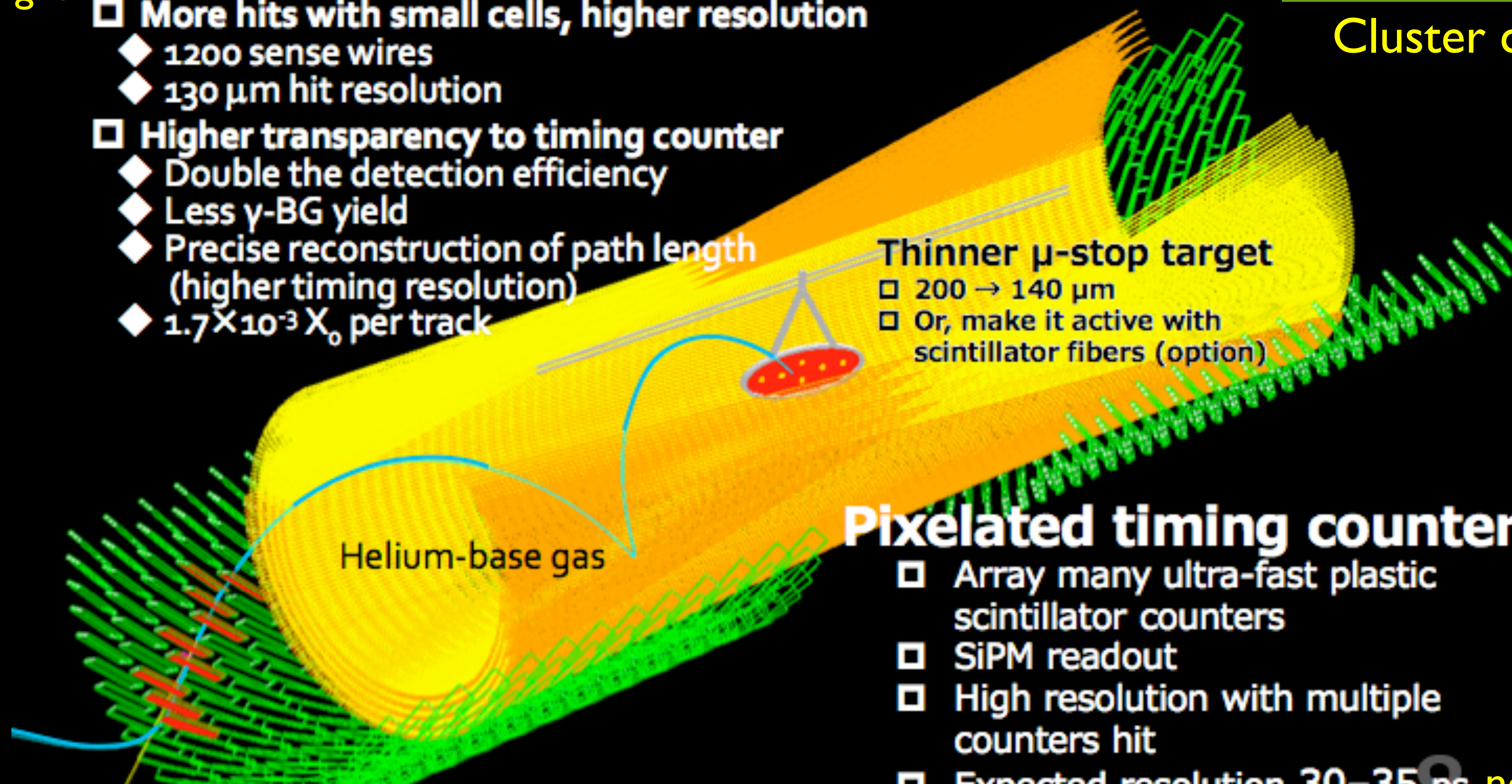
Maximum integrated charge for 3 year running is 0.32 C/cm



Cluster counting

Single-volume stereo-wire drift chamber

- High rate tolerable, long stability
- More hits with small cells, higher resolution
  - 1200 sense wires
  - 130 μm hit resolution
- Higher transparency to timing counter
  - Double the detection efficiency
  - Less γ-BG yield
  - Precise reconstruction of path length (higher timing resolution)
  - 1.7×10^{-3} X_0 per track



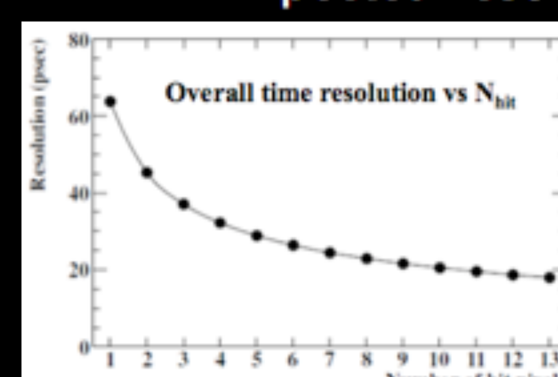
Thinner μ-stop target

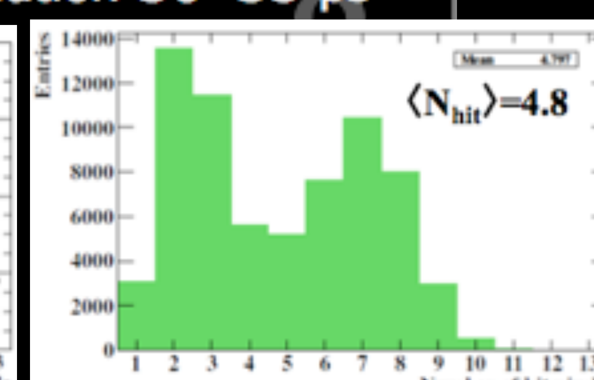
- 200 → 140 μm
- Or, make it active with scintillator fibers (option)

Pixelated timing counter

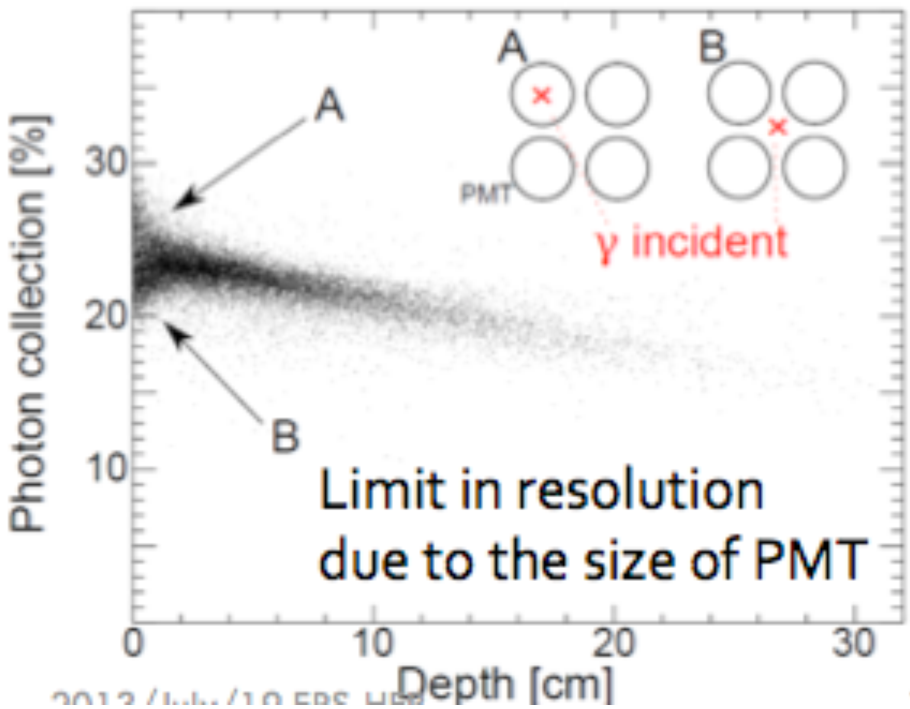
- Array many ultra-fast plastic scintillator counters
- SiPM readout
- High resolution with multiple counters hit
- Expected resolution 30–35 ps now 76 ps

	Present chamber	Expected
Momentum (keV)	350	~130
Angular (mrad)	9, 11	~5, ~5
Vertex (mm)	1.8, 1.1	1.2, 0.8
Efficiency to TC (%)	40	>80

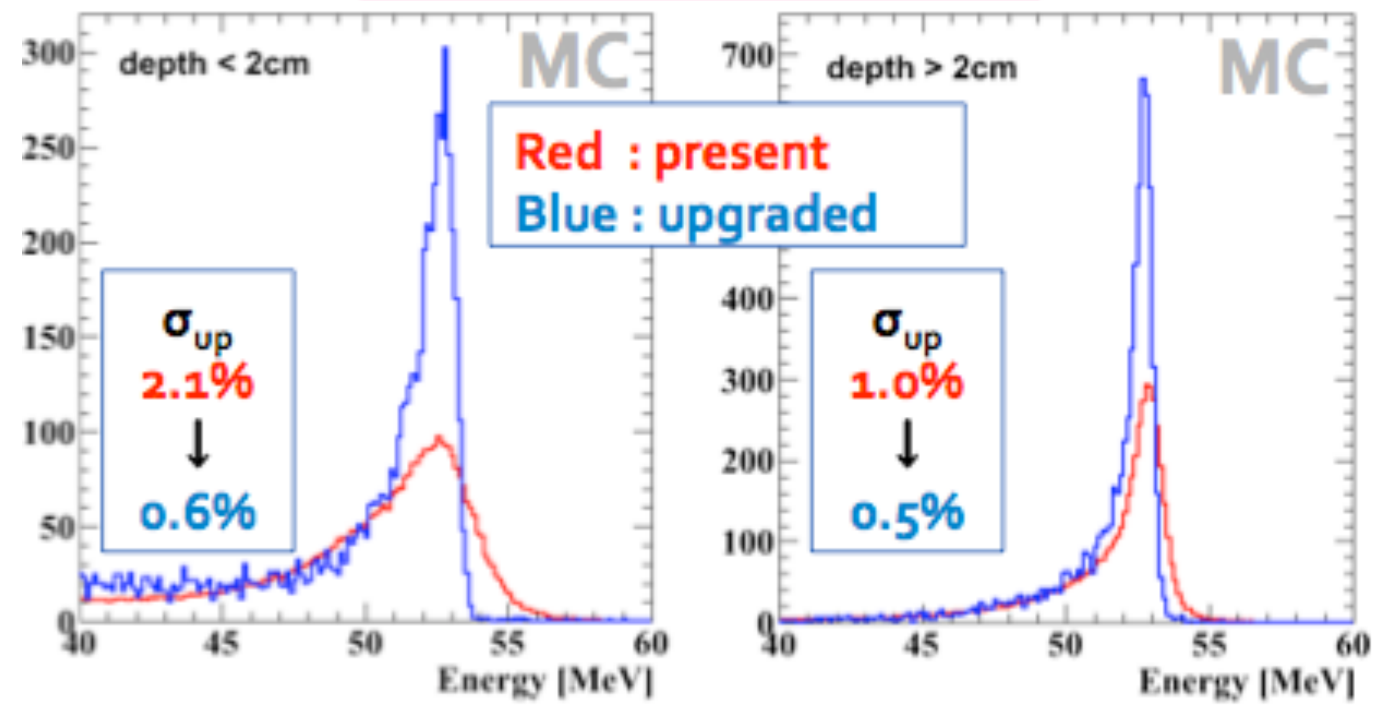




Photon Side

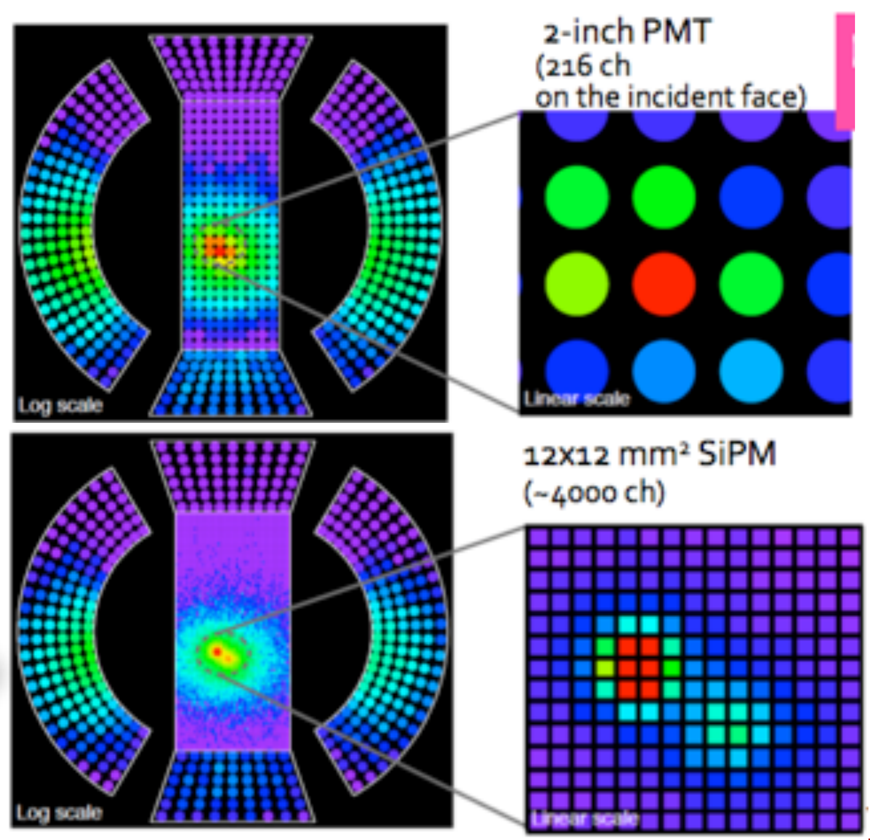


Energy Resolution

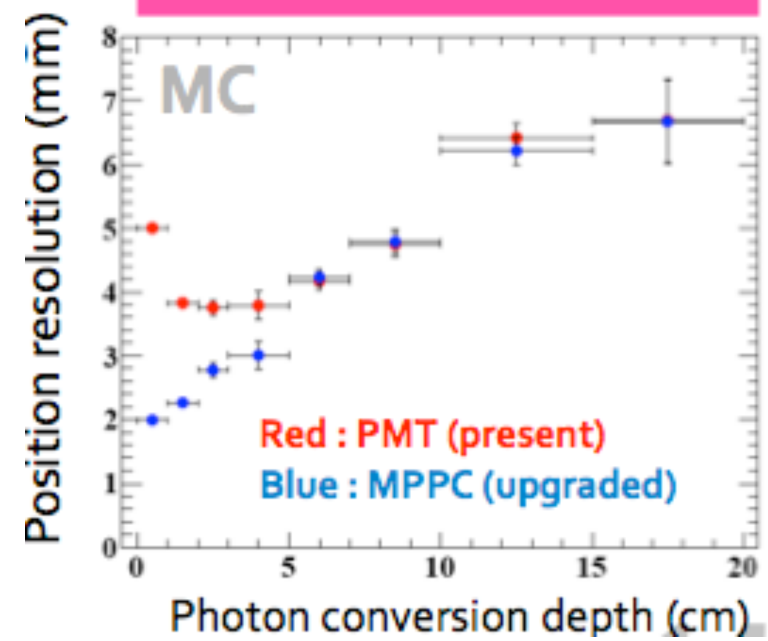


now

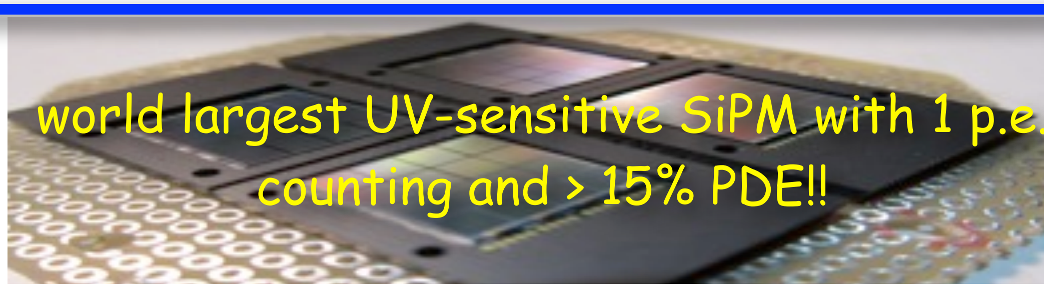
MEG^{UP}

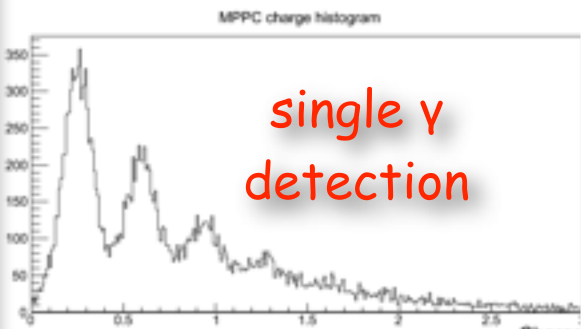


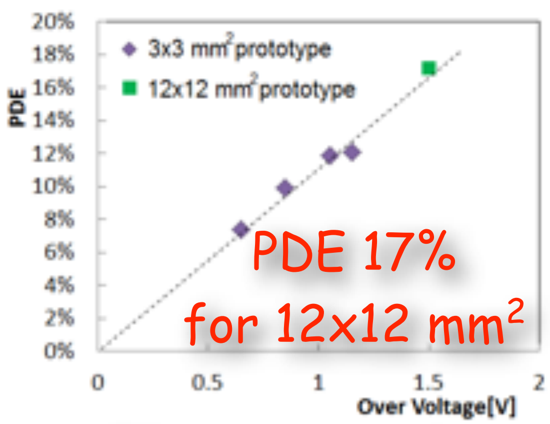
Position Resolution



Ongoing R&D Activities

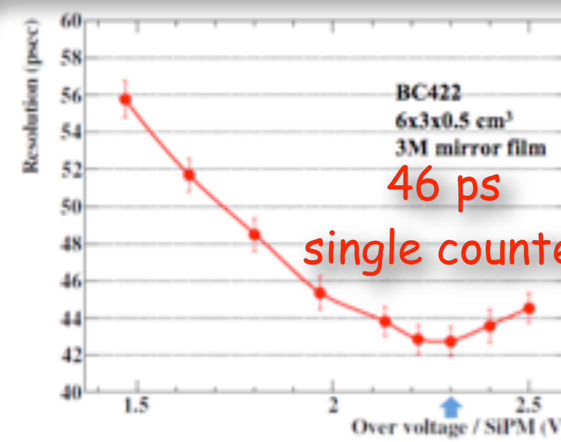


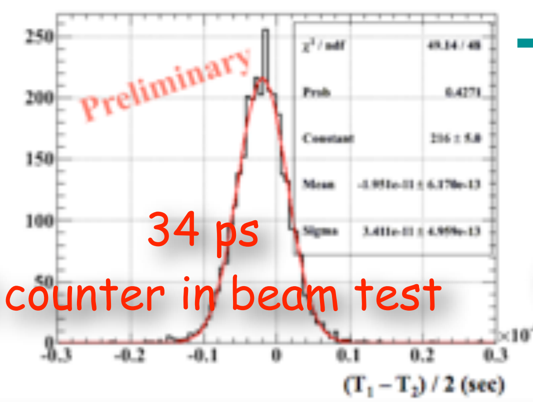


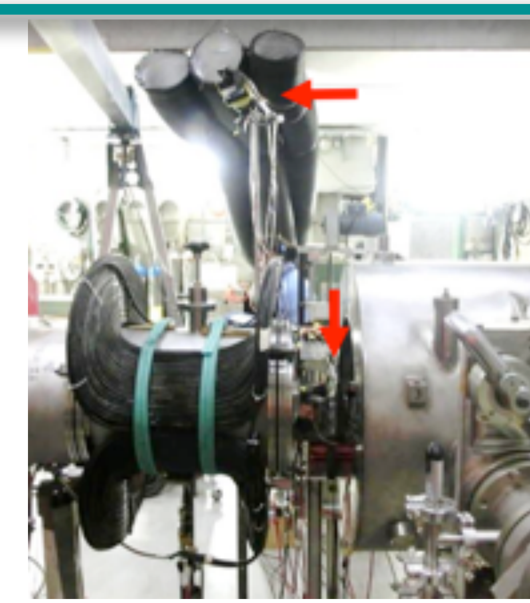


XEC

Development and test of large area UV-enhanced MPPC with Hamamatsu Photonics

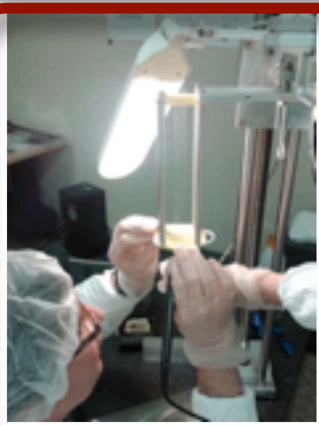


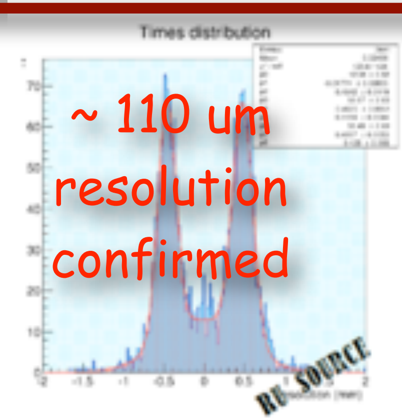




TIC

Single counter and prototype development and test of different SiPM types

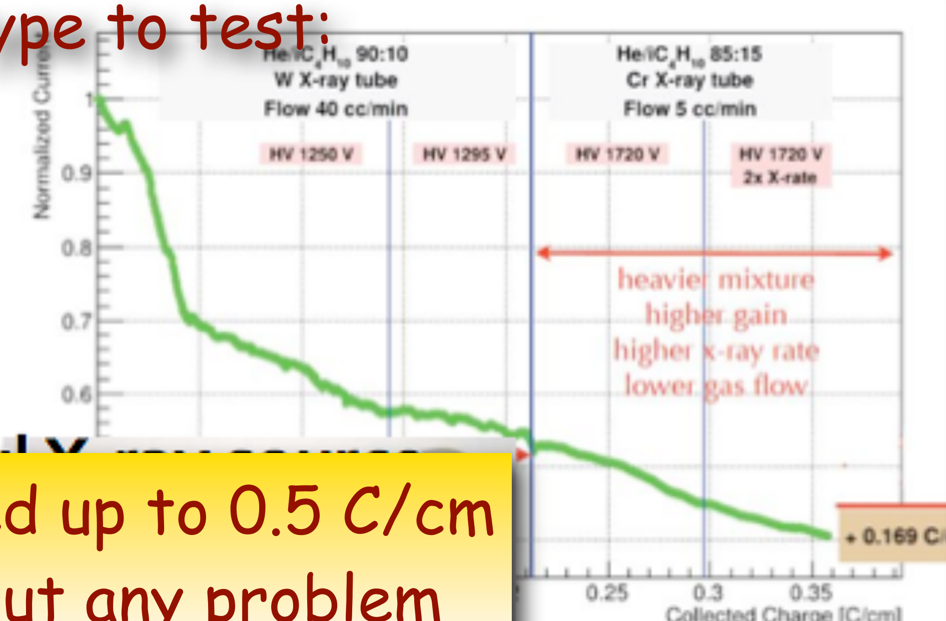




DC

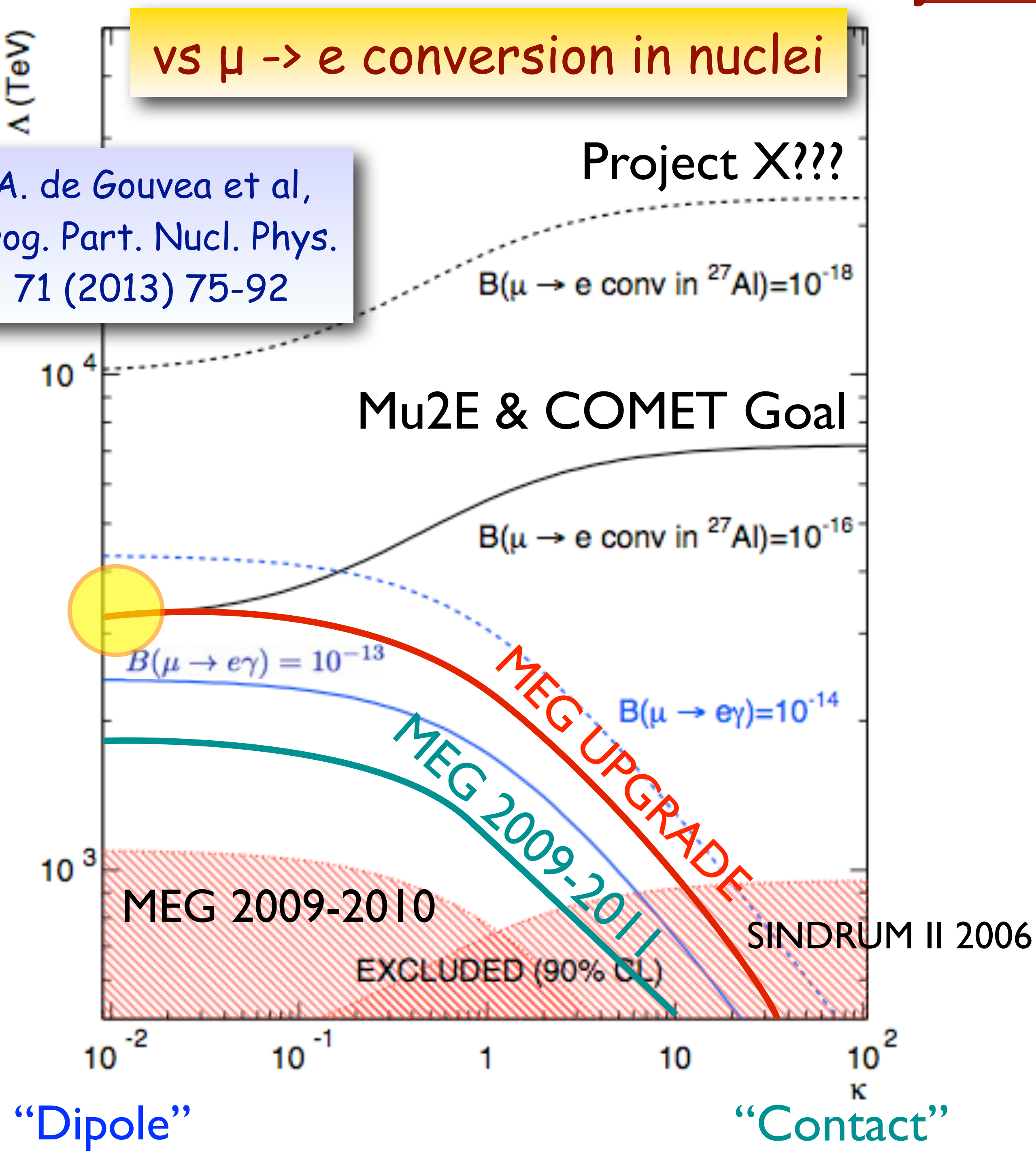
Several long and small prototype to test:

- single hit resolution
- ageing
- FE electronics
- mounting procedure
- wire type and cell stability
- charge division and timing

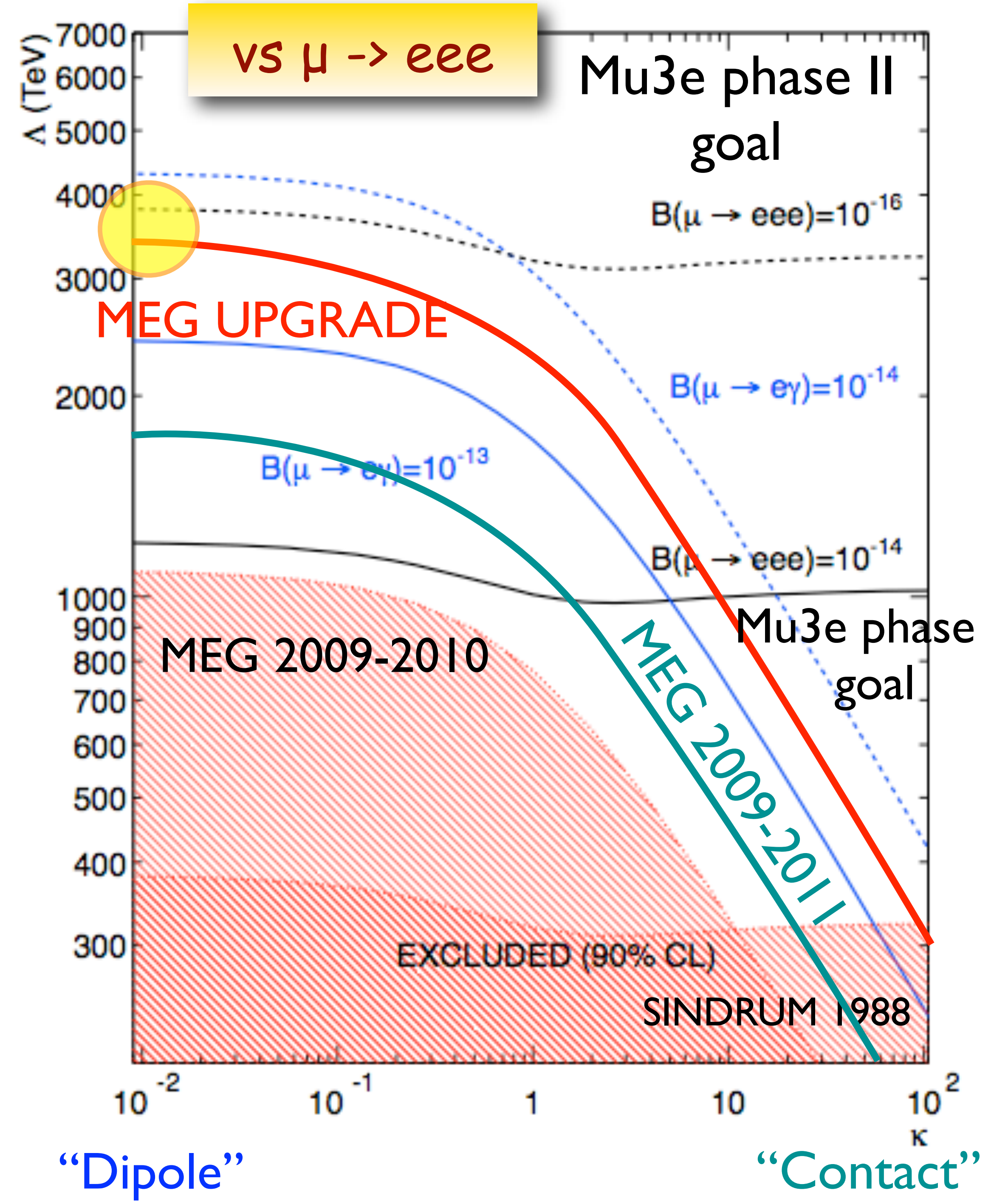


tested up to 0.5 C/cm w/out any problem

Sensitivity Comparison



A. de Gouvea et al, Prog. Part. Nucl. Phys. 71 (2013) 75-92



MEG upgrade goal is competitive with next generation experiments for "dipole-type" coupling !!!!

Conclusions & Prospects

- MEG latest result is the most stringent UL on cLFV process (improved by factor 4)

$BR(\mu^+ \rightarrow e^+ \gamma) < 5.7 \times 10^{-13}$ @ 90% CL

- MEG 2012-2013 dataset will double the statistic

Expected sensitivity with full dataset ~ 5×10^{-13}

- MEG upgrade for the improvement of one order of magnitude in sensitivity has been approved by all funding agencies and given the highest priority by PSI

- Several ongoing R&D activities, already showing very encouraging results

Upgrade proposal sensitivity ~ 5×10^{-14}
on a time scale of 5 years (end 2018)

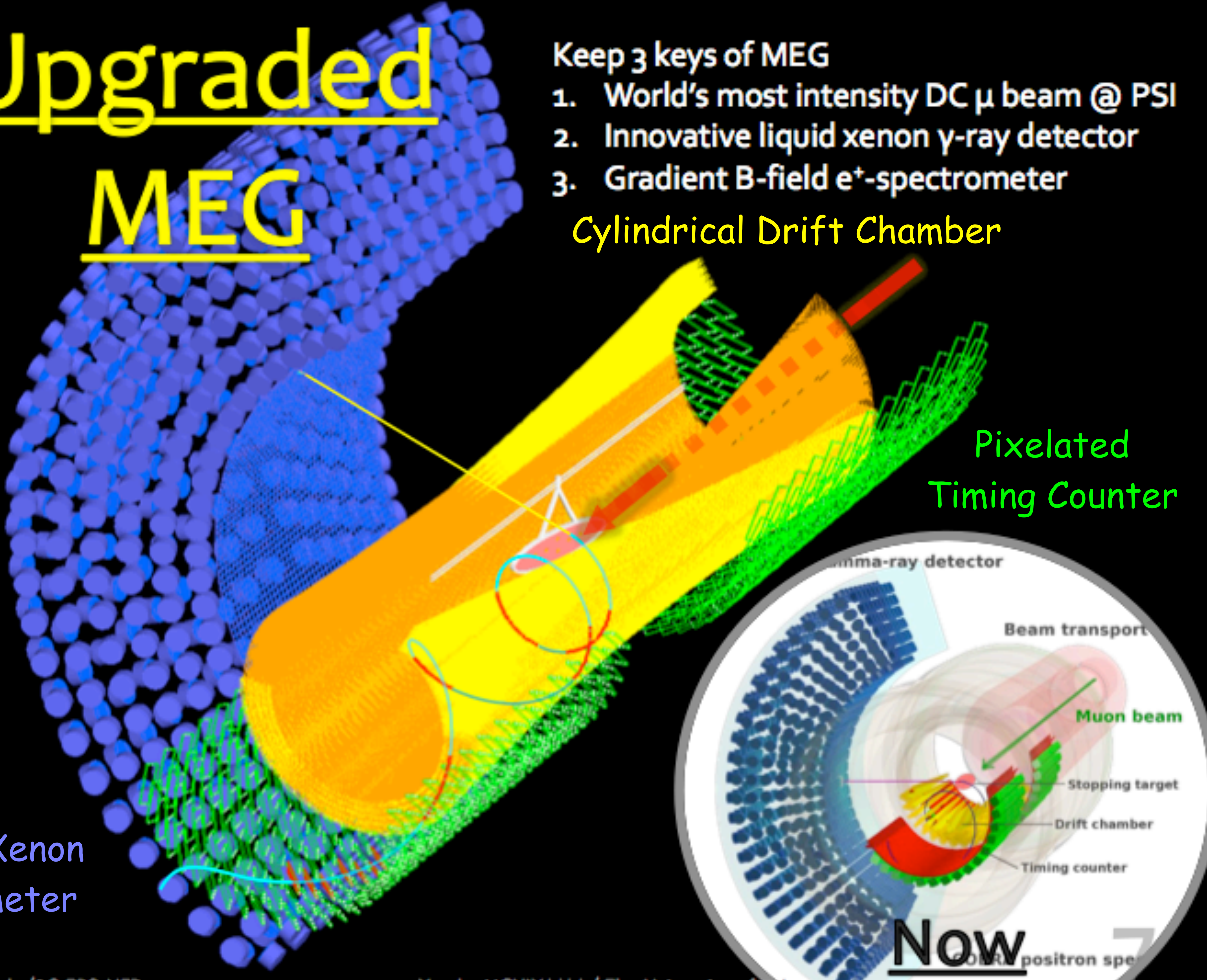

INFN Genova
INFN Lecce
INFN Pavia
INFN Pisa
INFN Roma
Tokyo University
KEK
Waseda University
UC Irvine
PSI
JINP Dubna
BINP Novosibirsk
~ 60 collaborators
MEG
experiment
Thank you !!
The MEG Collaboration

Backup slides

Upgraded MEG

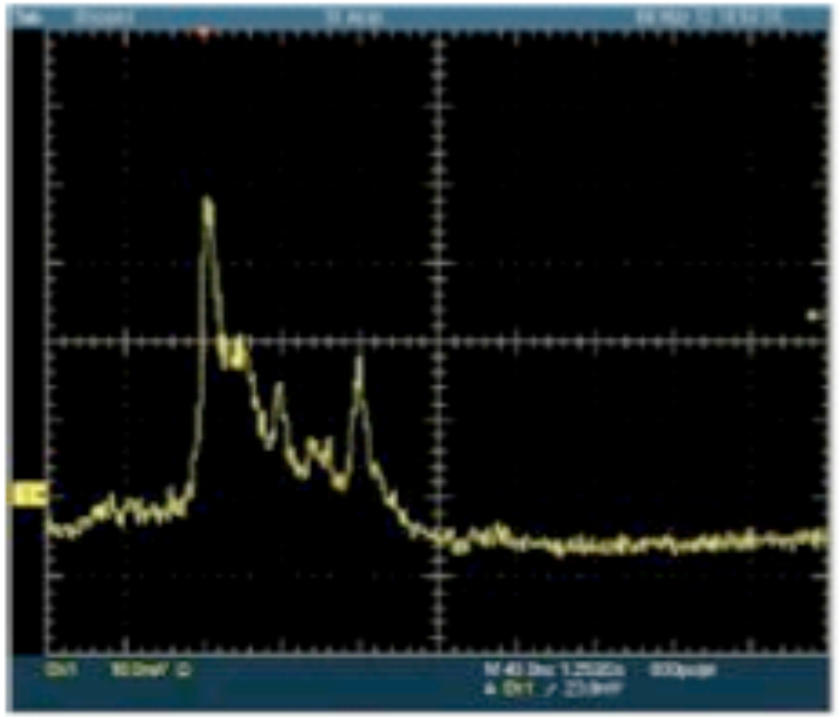
Keep 3 keys of MEG

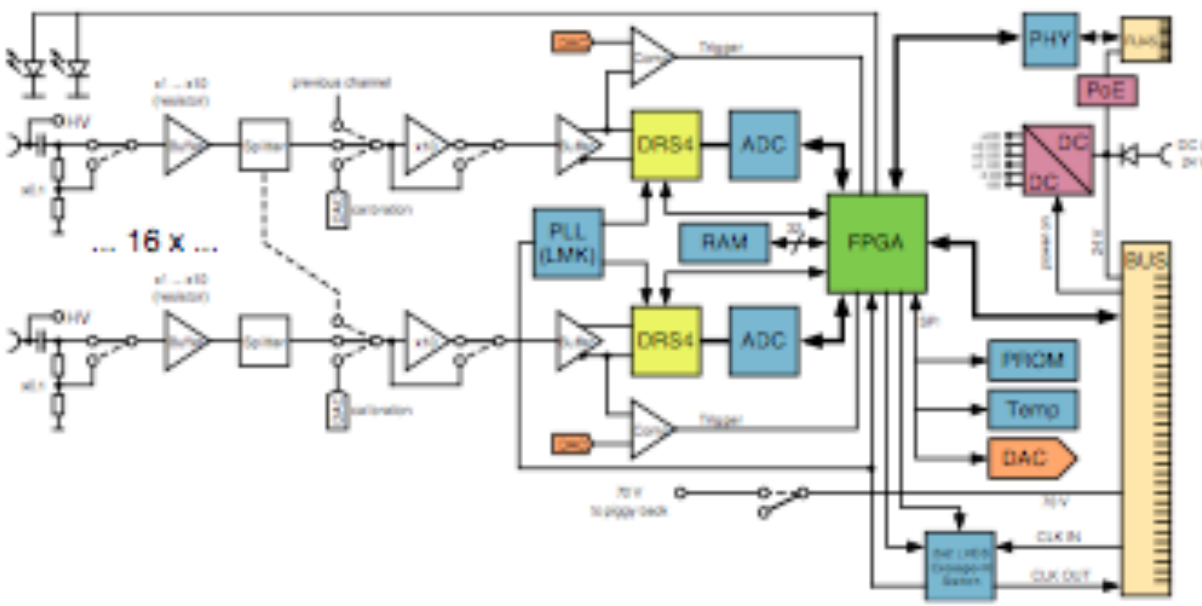
1. World's most intensity DC μ beam @ PSI
2. Innovative liquid xenon γ-ray detector
3. Gradient B-field e^+-spectrometer



Trigger & DAQ upgrade

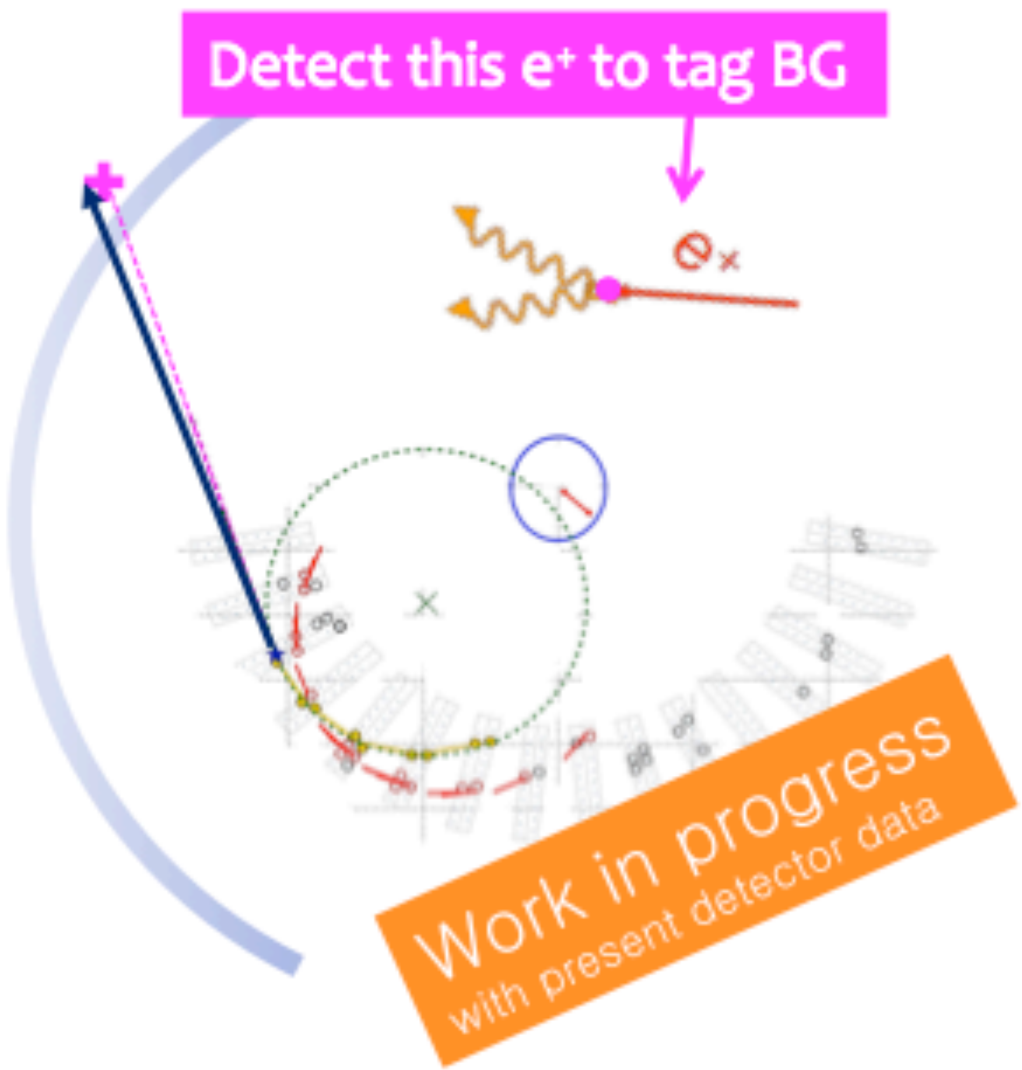
- **Increased number** of **channels** (DC +1000, LXe +3000, TC +200)
  - ***higher bandwidth*** *for timing, DC cluster recognition*
- **2 GHz waveform digitizer** for **all signals**
- **WaveDREAM board**
  - ***General purpose*** *board*
  - ***DRS4*** *waveform digitizing technology*
  - ***splitter + trigger***
  - *dedicated* ***fast comparator*** *for* ***self trigger*** *and* ***FPGA*** *for* ***complex algorithms***
  - ***improved*** *clock* ***synchronization*** *→* ***timing***

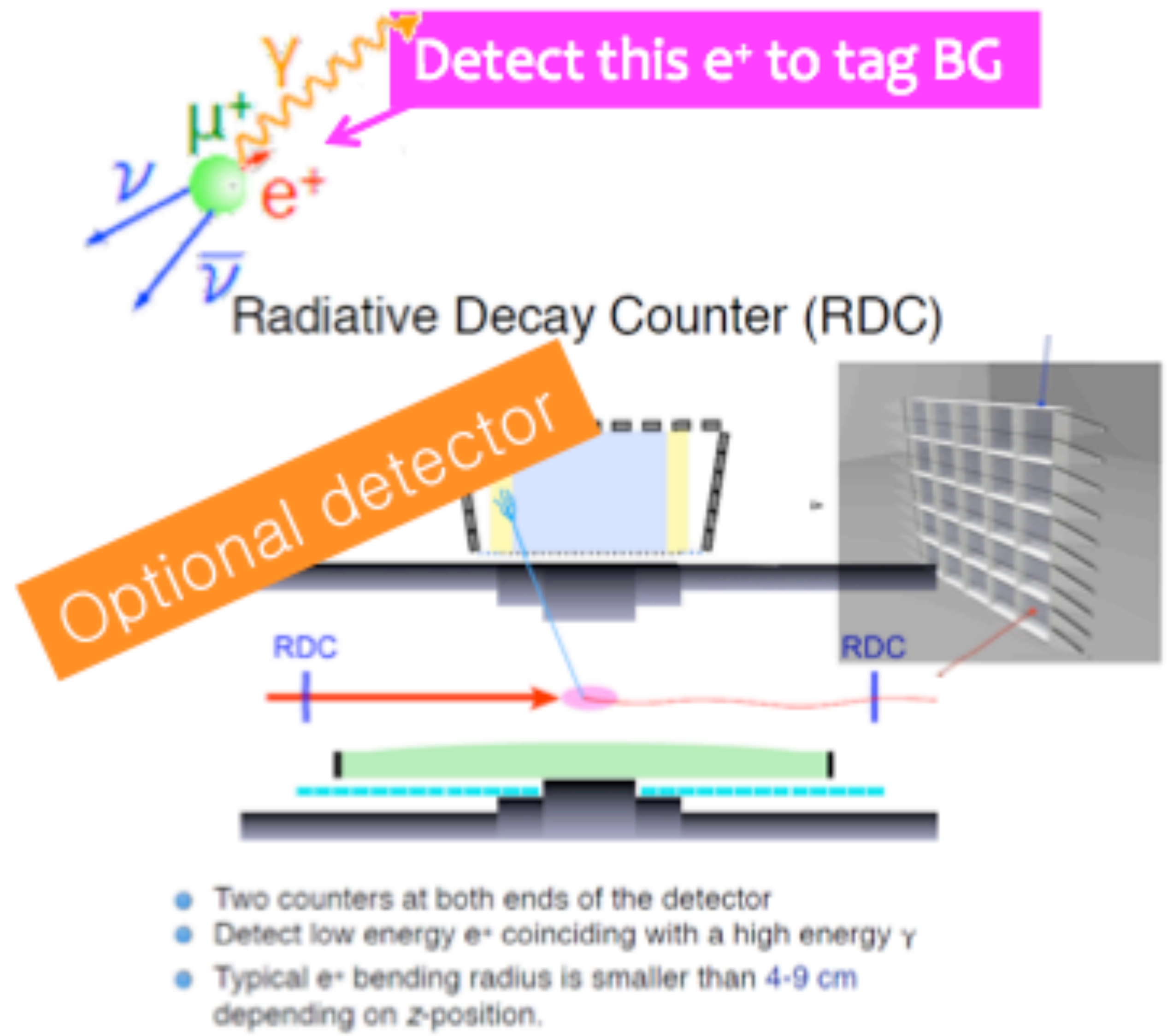




- **Trigger** algorithm **the same** as **MEG**

Additional possible bkg suppression

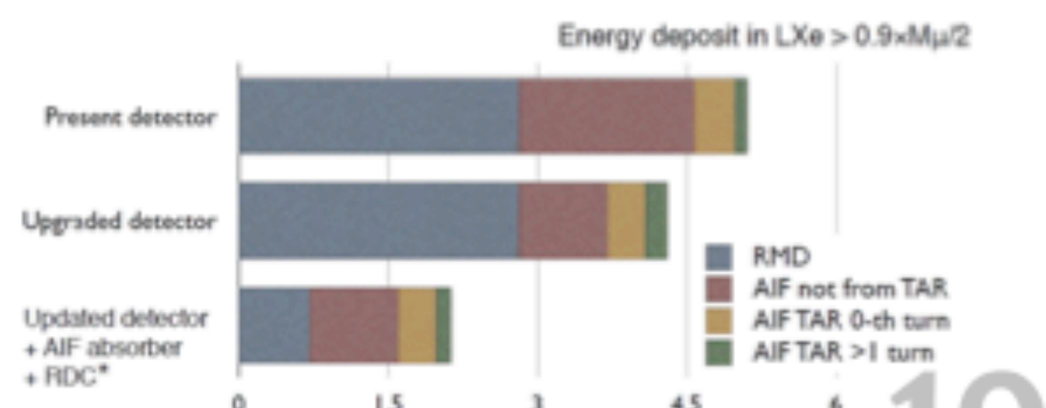




Identify AIF-BG by

1. Detect e^+ trajectory before annihilation
2. Test correlation with γ

This algorithm will work better with upgraded tracker



Resolutions & Costs

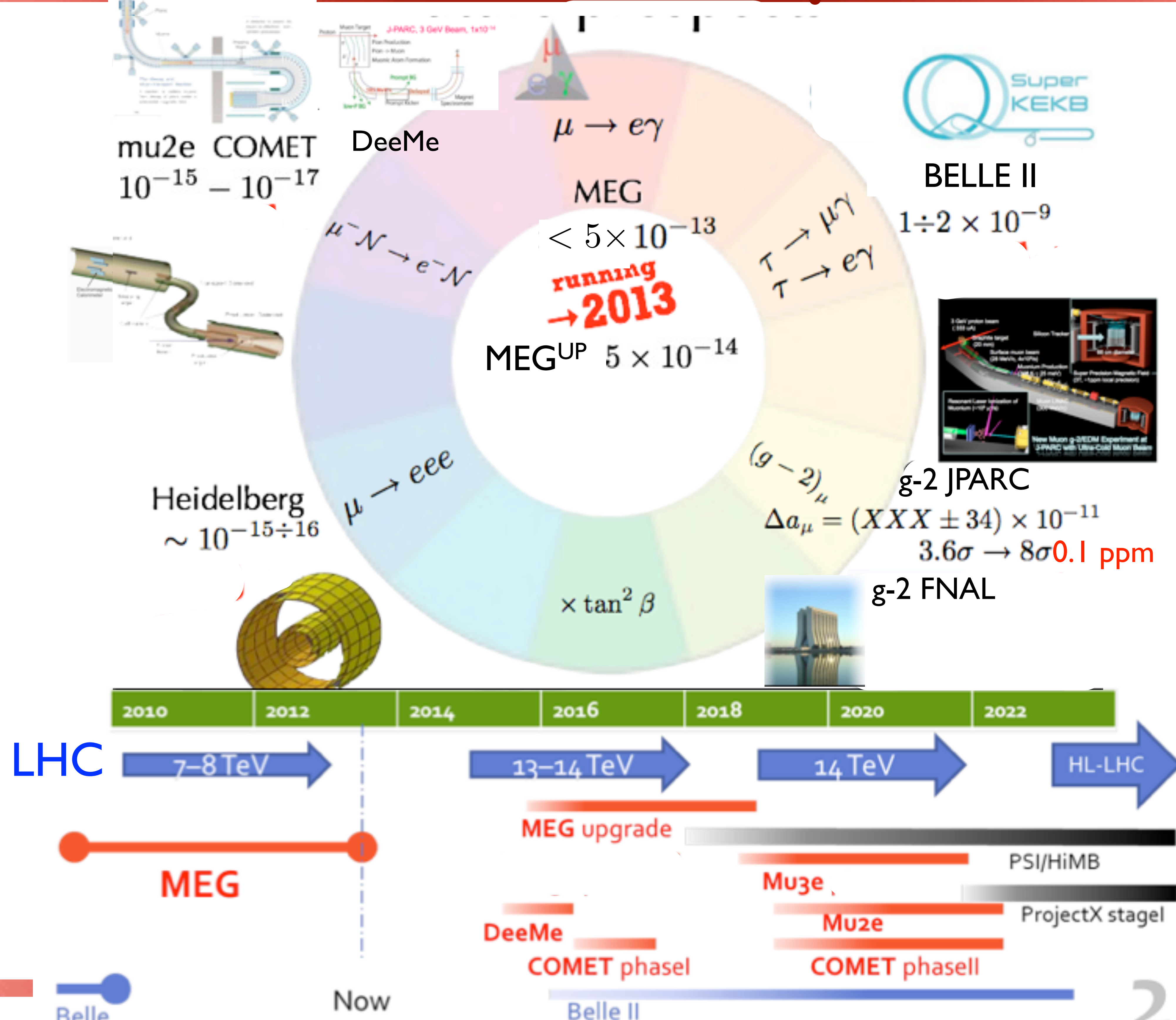
TABLE XI: Resolution (Gaussian σ) and efficiencies for MEG upgrade

PDF parameters	Present MEG	Upgrade scenario
e^+ energy (keV)	320	110-140
e^+ θ (mrad)	11	5-7
e^+ ϕ (mrad)	7.2	5-7
e^+ vertex Z/Y(core) (mm)	2.0/1.1	1.5/1.0
γ enegy (%) ($w > 2$ cm)	1.9	1.0
γ position (u, v, w) (mm)	5(u, v), 6(w)	2
γ-e^+ timing (ps)	122	75-90
Efficiency (%)		
trigger	≈ 99	≈ 99
γ reconstruction	59	59
e^+ reconstruction	40	85-90
event selection	80	85

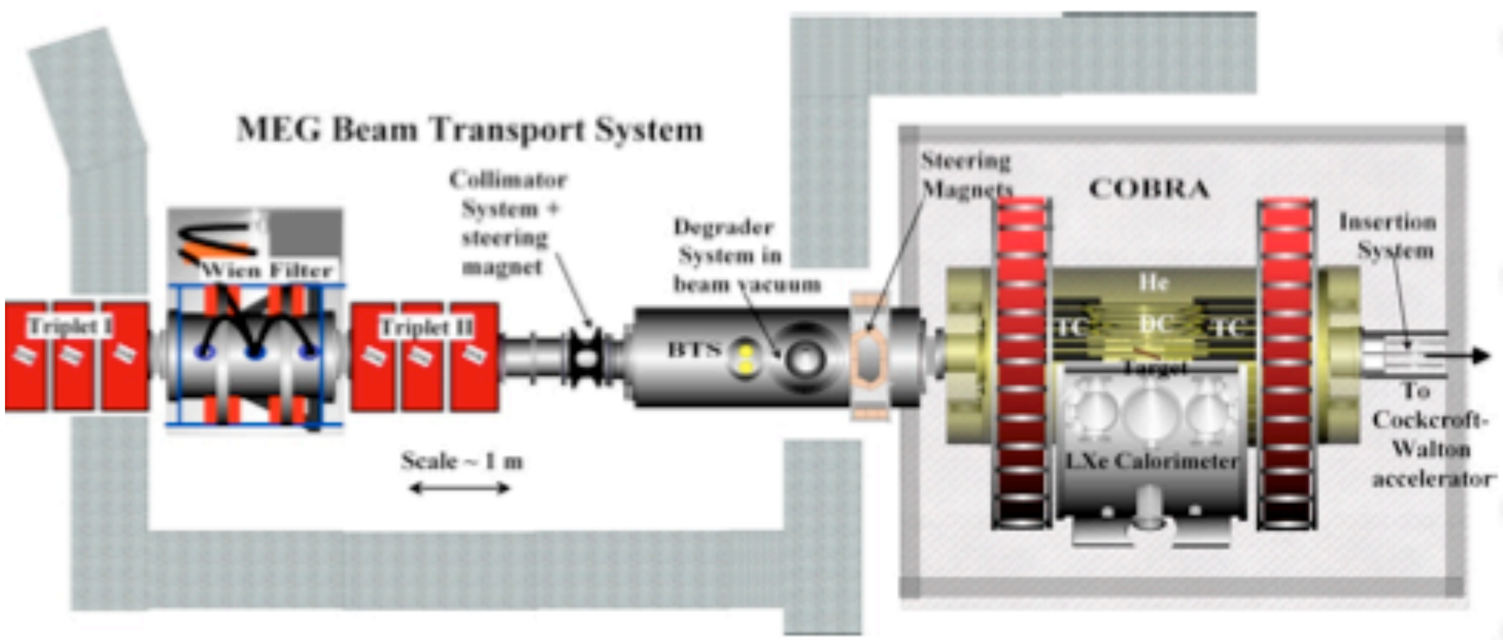
Item	cost (k euros)
calorimeter	1692
timing counter	206
DAQ	915
drift chamber	786
total	3600

~ 30% of original MEG budget

Future Prospects

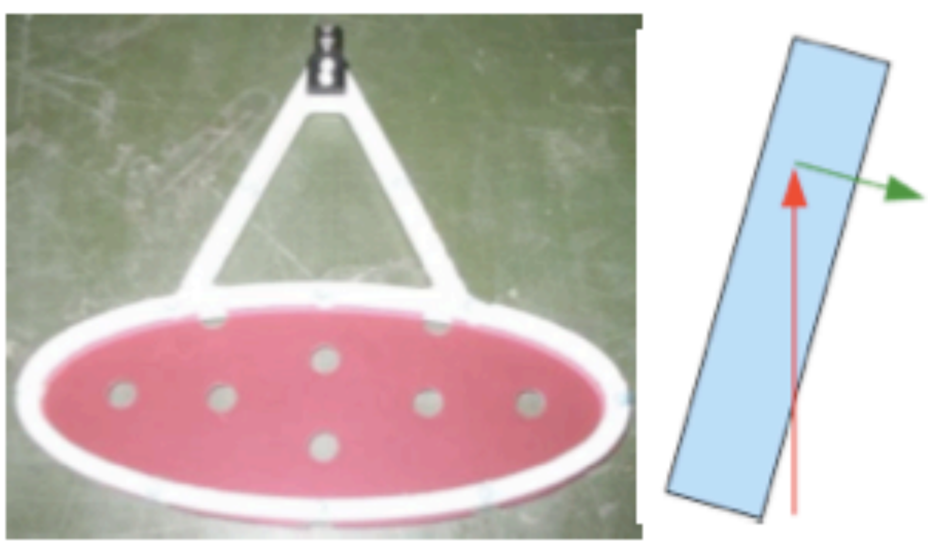


The PSI πE5 beam & target



- Most intense proton DC beam in the world : 2 mA @ 1.3 MW
- 28 MeV/c "surface muons" from decay of π at rest
- Wien filter for e/μ separation
- Solenoid to couple beam with the COBRA magnetic field

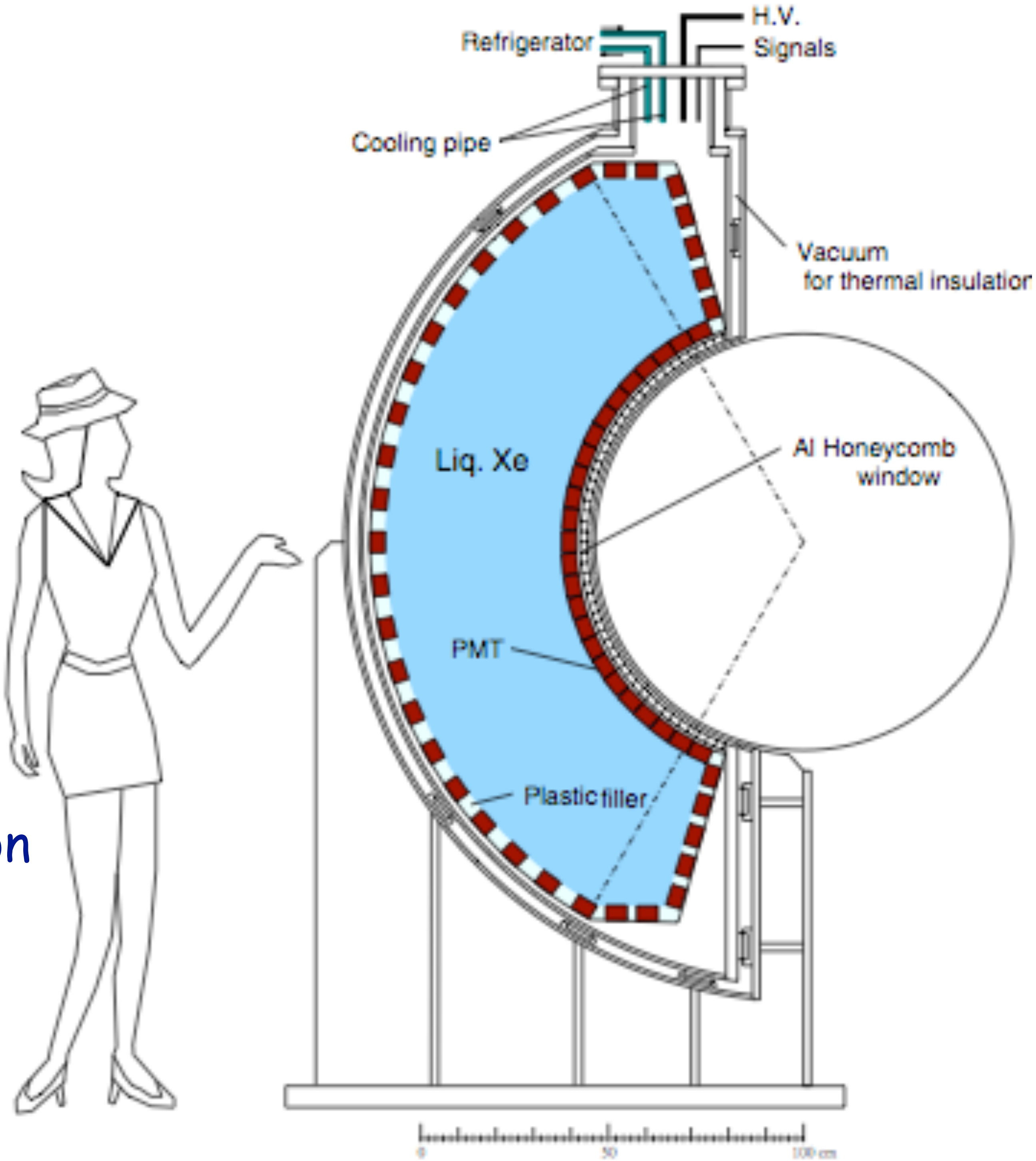
- Need enough material for stopping muons but low bremsstrahlung for signal positron:
  - degrader 200/300 μm + target 205 μm
  - 20.5° angle between beam and target
  - material with high radiation length X_0 (CH_2)



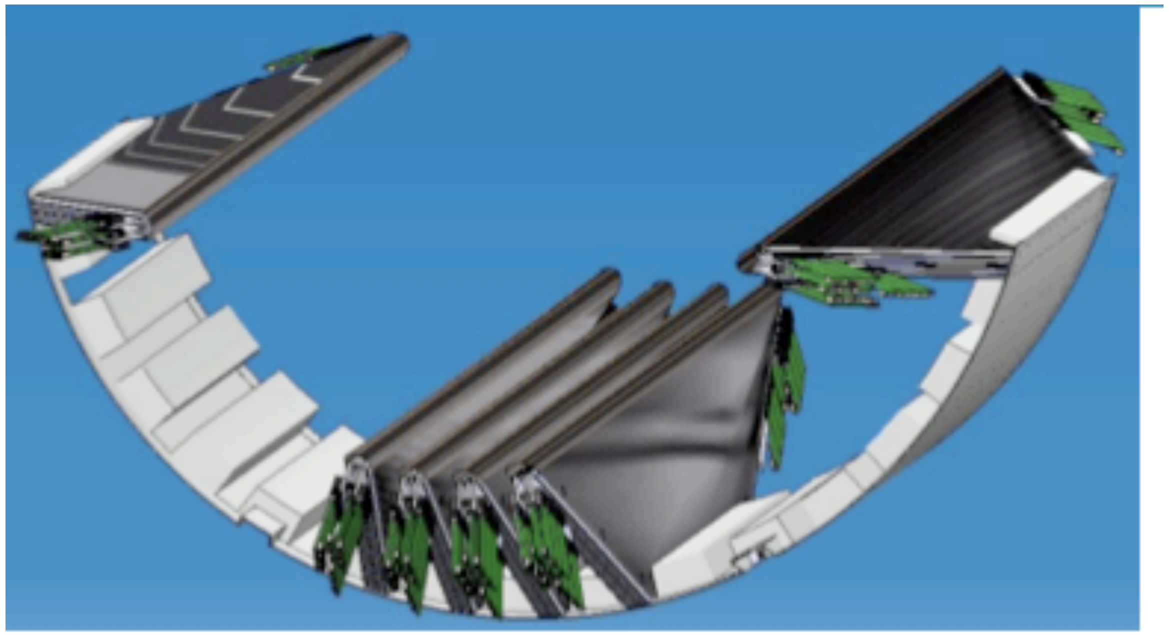
Liquid Xenon γ detector

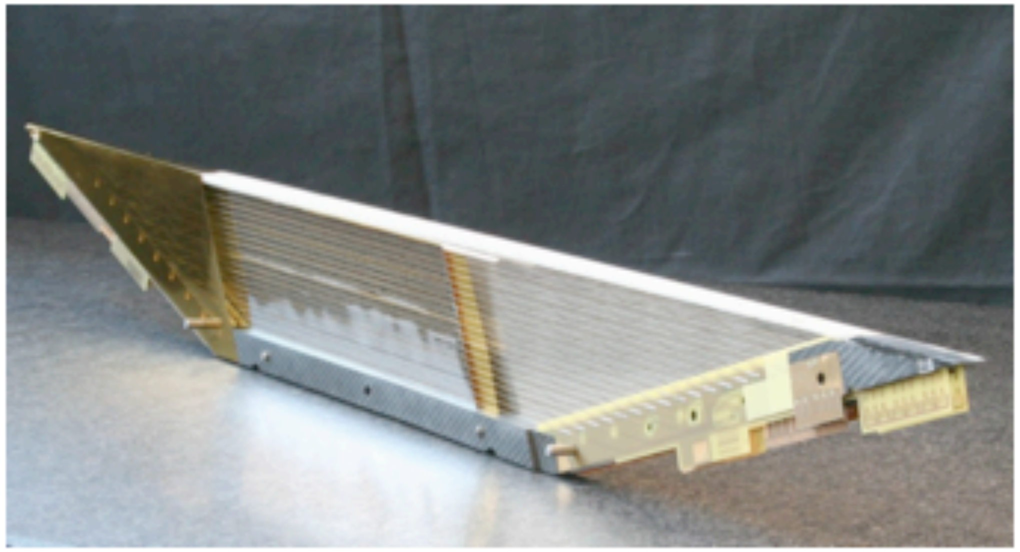
- First ton-scale (~ 900 L) LXe calorimeter in use in the world
- Pros
  - High light yield (~ 75% NaI)
  - Fast response (τ_{decay} = 45 ns)
  - High stopping power (X_0 = 2.8 cm)
  - No self absorption
  - Uniform, no segmentation, no aging
- Challenges
  - Vacuum ultra violet (178 nm)
  - Low temperature (165 K)
  - Need high purity
- Measure photon energy and time and position of conversion inside the LXe

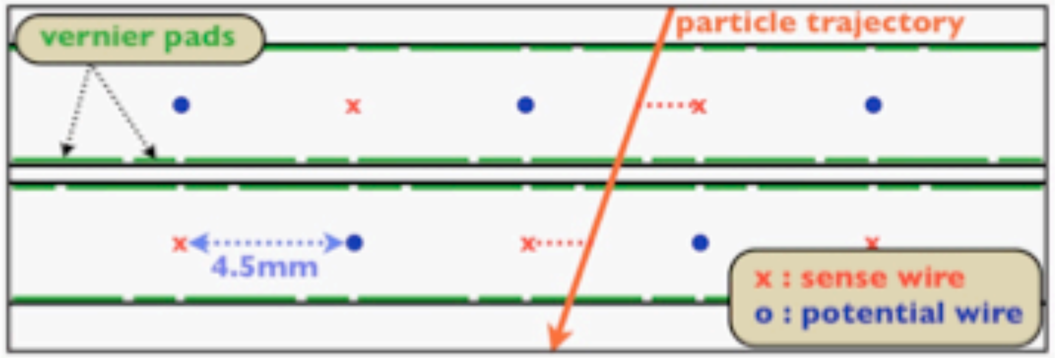
	proposal
σ_E/E < 2 % @ 52.8 MeV	1.2 %
σ_t = 67 ps	43 ps
σ_x = 5-6 mm	3.8-5.1 mm



Drift Chambers





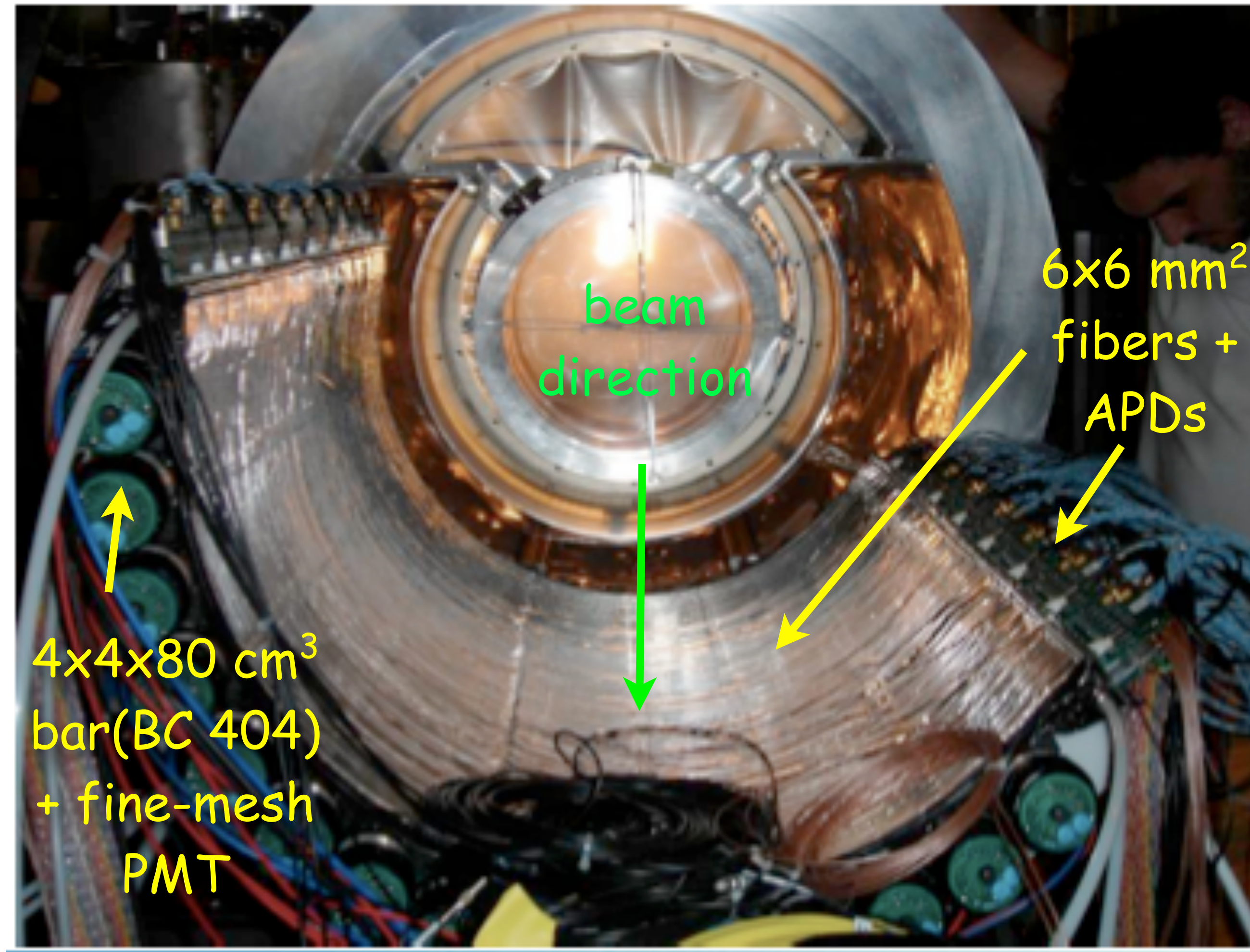


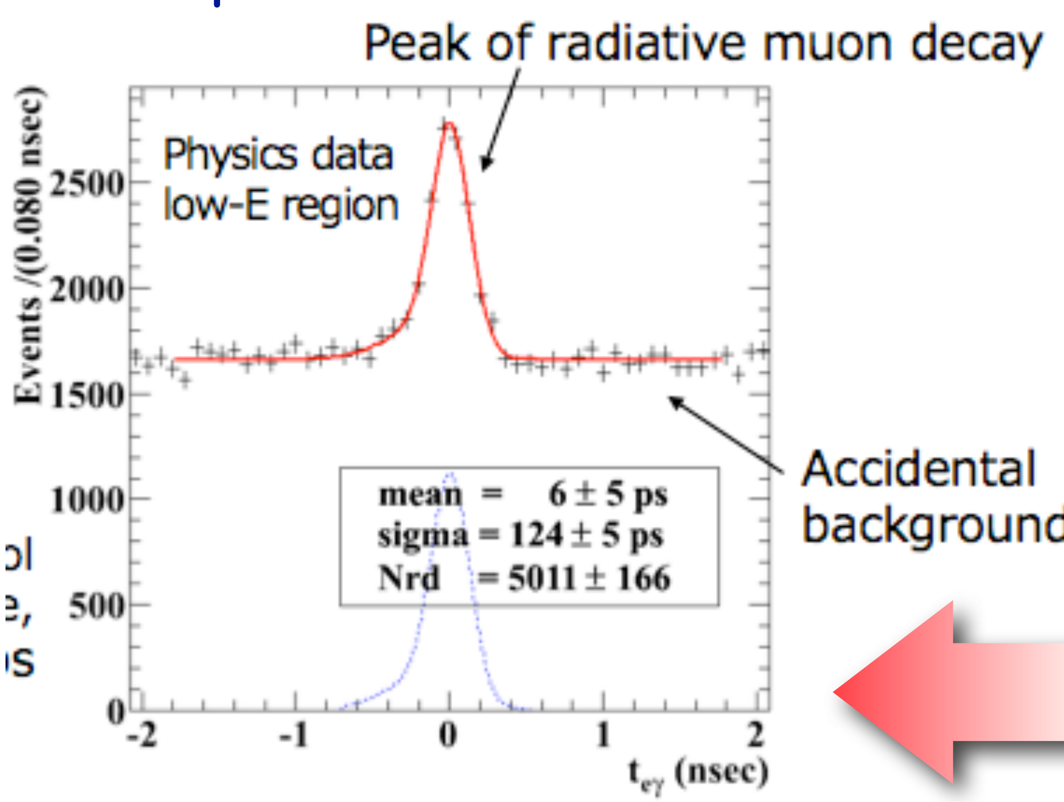
- 16 chamber sectors, 2 planes each
- Staggered array of drift cells
- Helium:Ethane 50/50 mixture
- Ultra low mass chamber to suppress MS that limits momentum and angular resolutions
  - 12.5 μm cathode foils with Vernier patter for Z hit position
  - ~ 0.2 % X_0 along e^+ trajectory
- Reconstruct e^+ momentum vector at target with Kalman filter technique

		proposal
-	σ_E/E ~ 0.6 %	0.3 %
-	σ_θ ~ 10 mrad	5 mrad
-	σ_φ ~ 7 mrad	5 mrad

Time Measurement

- Positron time measured by timing counter: 2 sections (upstream & downstream) of 15 bars each read by fine mesh PMTs
- Further z impact position measurement with scintillating fibers read by APDs
- Crucial for positron time measurement: intrinsic time resolution: current ~ 70 ps/ goal ~ 50 ps

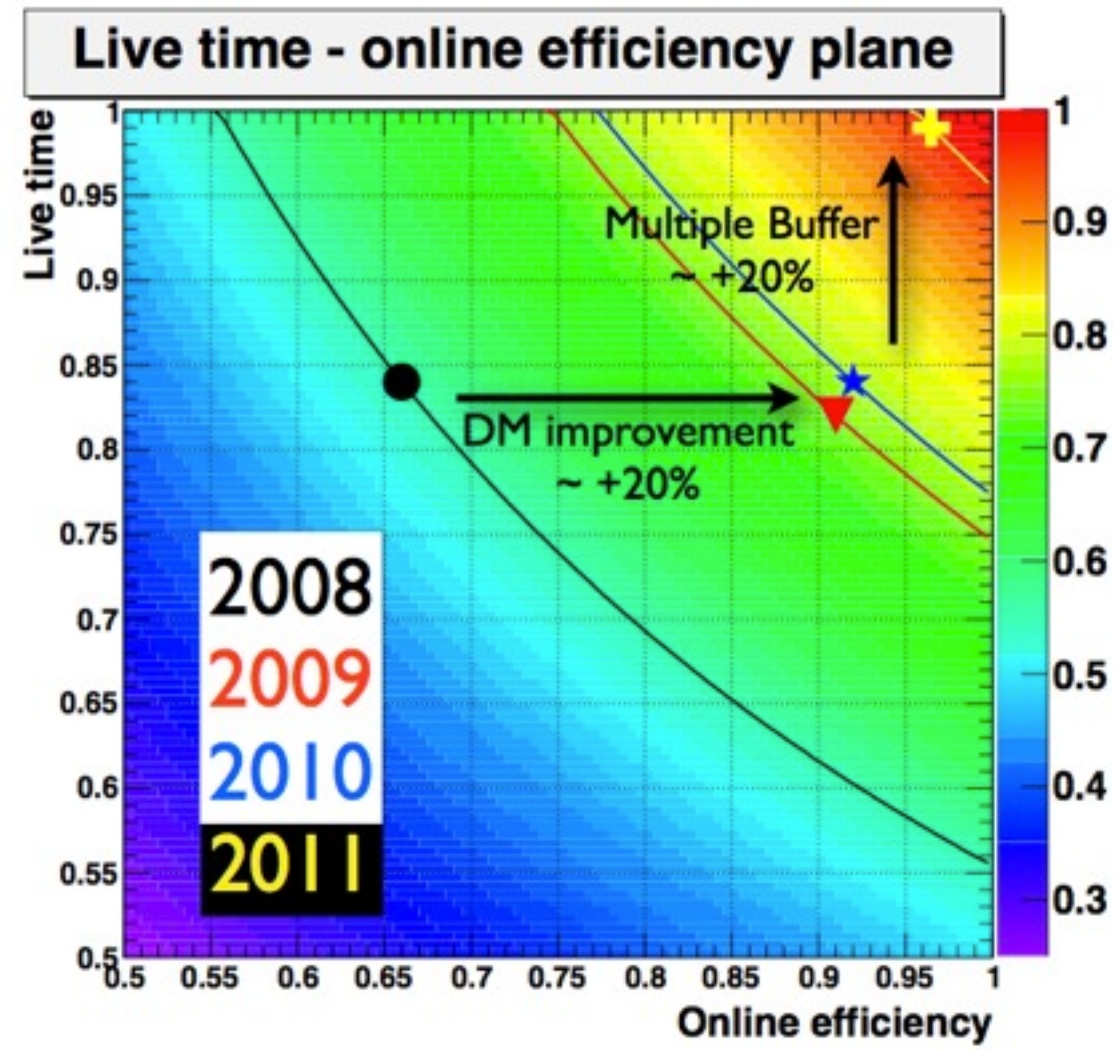




- Muon decay time:
  - TC hit time + e^+ flight length from DC
  - LXe hit time + γ flight lenght
  - $t_{e\gamma} = t_{e+} - t_\gamma$
- $\sigma_{te\gamma}$ = 124 ps from RMD

Trigger & DAQ

- DAQ
  - Custom WF digitizer DRS chip design at PSI
  - Sampling speed [800 MHz, 5 GHz]
  - Bandwidth 1 GHz
  - inter-chip synchronization < 30 ps
- Trigger experimental requirements
  - O (10^7) background suppression
  - > 95 % efficiency on signal
  - Maximum latency ~ 450 ns
  - Flexibility for physics analysis as well as calibrations
- MEG choices
  - 100 MHz digital conversion of input signals
  - Selection algorithms on FPGAs
  - Use of fast detector, LXe and TC:
    - E_γ > 45 MeV ---> rate 2 x 10^3 Hz
    - Δt between LXe and TC --> rate 100 Hz
    - Collinearity based on LUT tables --> 10 Hz



Trigger improvements through time thanks to improved online resolutions (DM improvement) and multiple buffer readout implementation (MB)

CW and CEX calibrations

$p + {}_{5}^{11}B \rightarrow {}_{6}^{12}C^{**} + \gamma$

4.4, 11.7, 16.1 MeV

$^{12}C^{**} \rightarrow {}^{12}C\,\gamma$

$\downarrow$

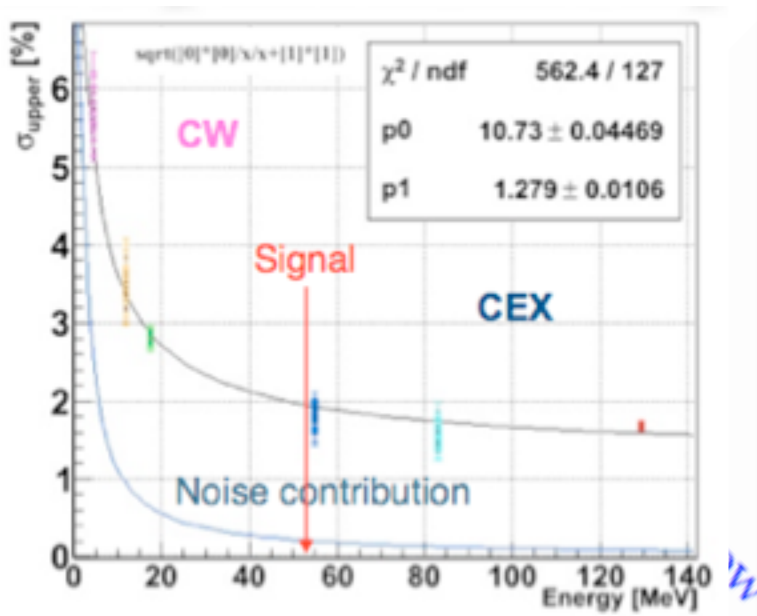
$^{12}C\,\gamma\,\gamma$

at the same time

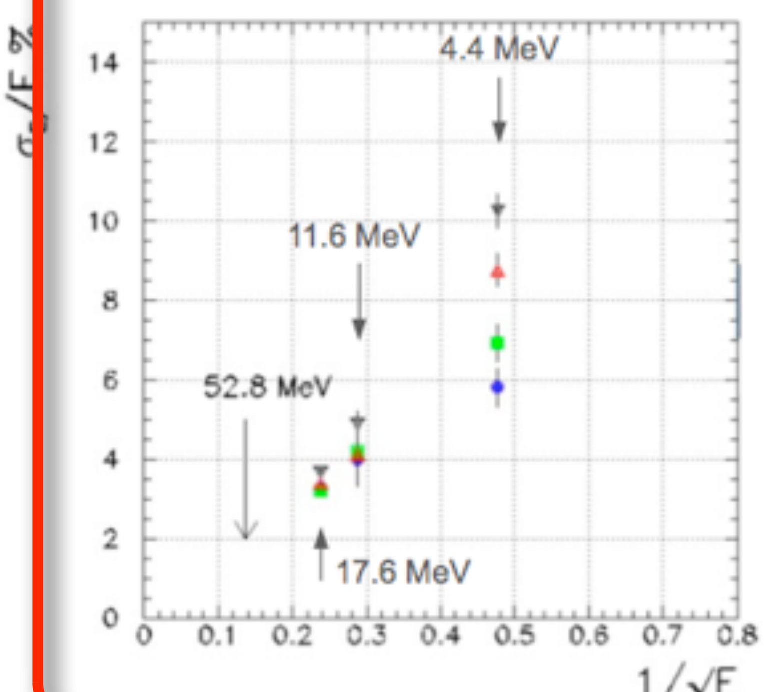
$p + {}_{3}^{7}Li \rightarrow {}_{4}^{8}Be + \gamma$

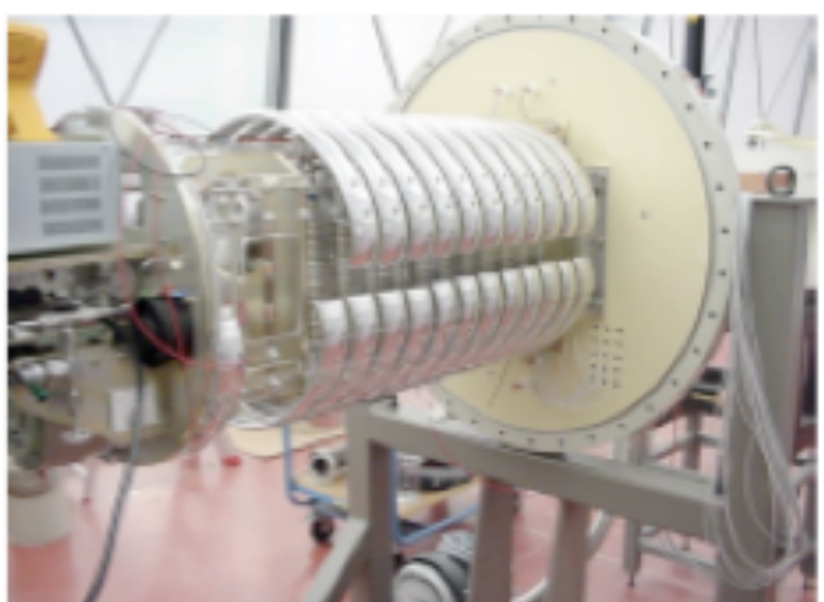
17.6, 14.6 MeV

Target of $Li_2B_4O_7$ allows both calibrations at same time



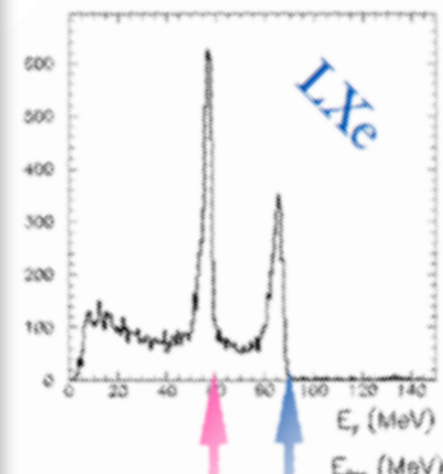
Cockcroft-Walton accelerator



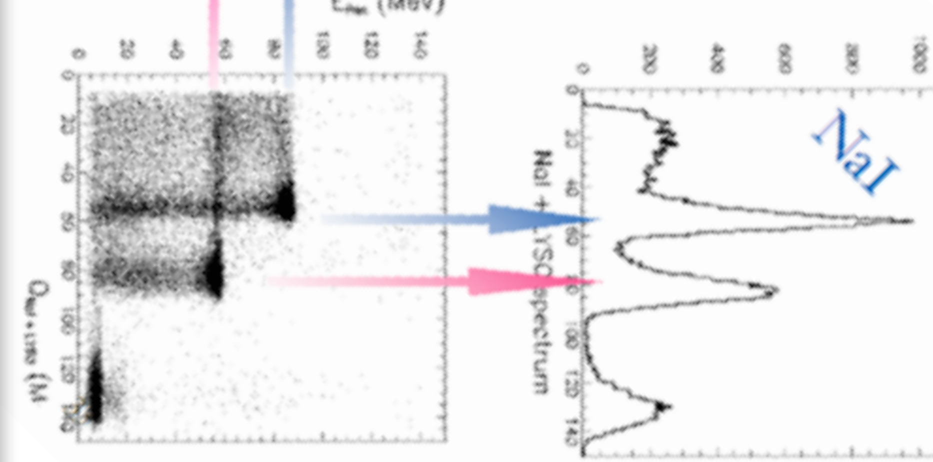


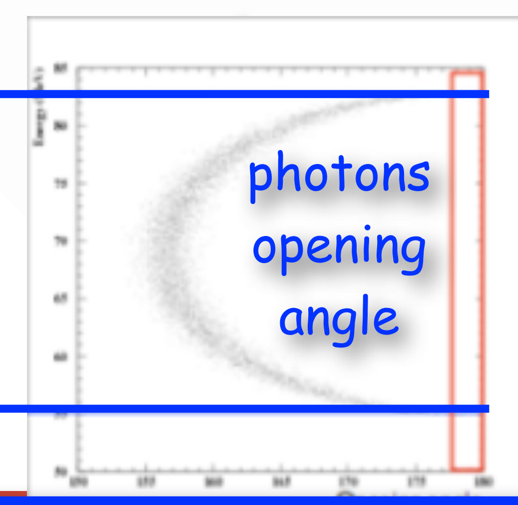
$\pi^- p \rightarrow \pi^0 n$

$\pi^0 \rightarrow \gamma\gamma$



Photons from π^- Charge EXchange reaction

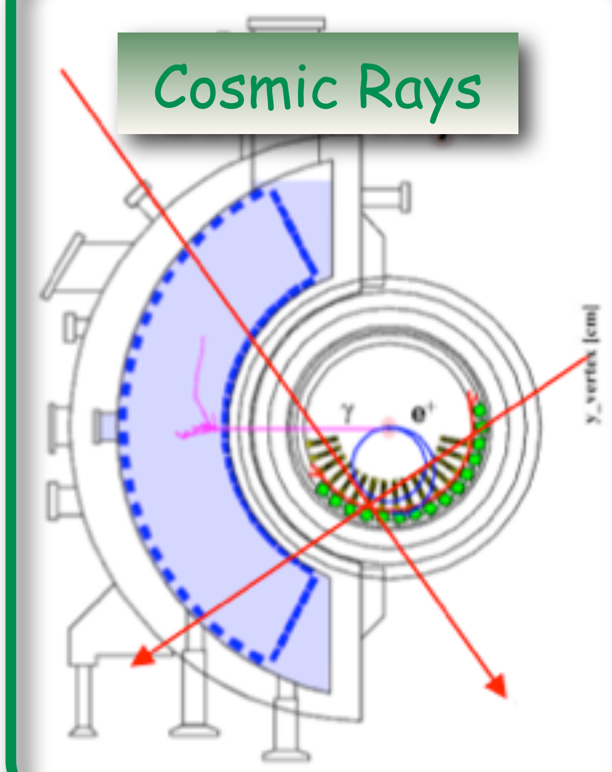




Alignment

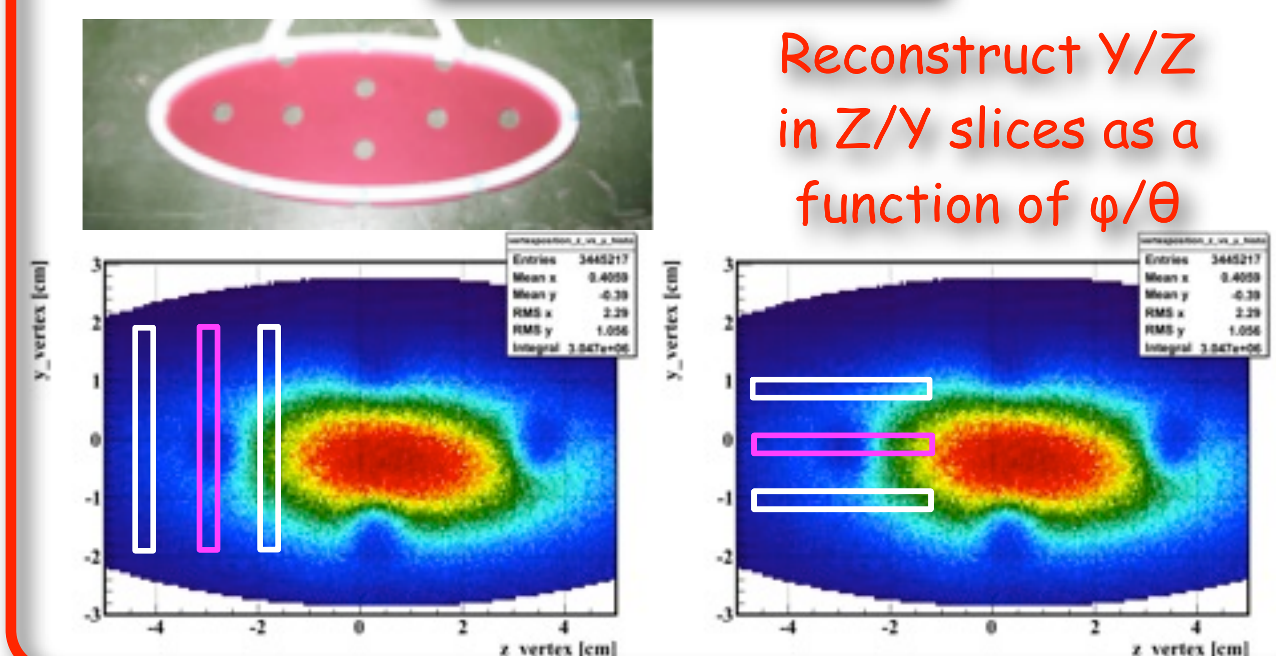
- Good alignment is crucial to reduce systematics on relative photon-positron angle
  - No back to back source for calibration
  - Nonetheless, we improved alignment inside and among detectors
    - DC - B field - target - LXe
- Tools:
  - Optical surveys
  - DC: Millipede (a la CMS) with cosmic rays + Michel e^+
  - Target holes
  - LXe: Pb collimators
  - B field: resolutions and correlations

Cosmic Rays

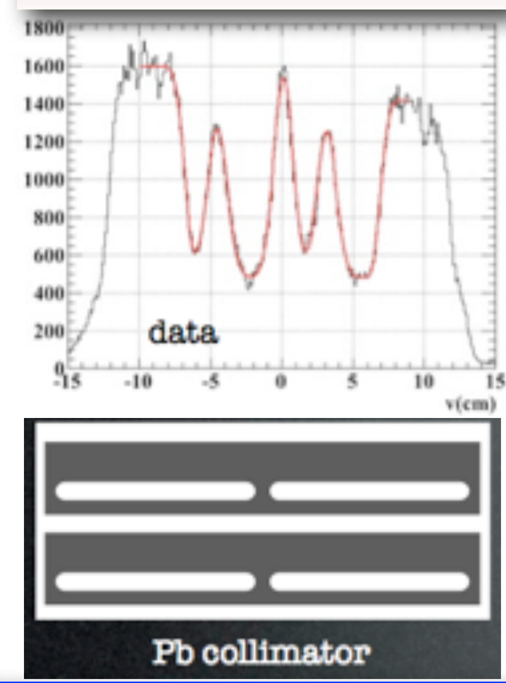


Target holes

Reconstruct Y/Z in Z/Y slices as a function of φ/θ



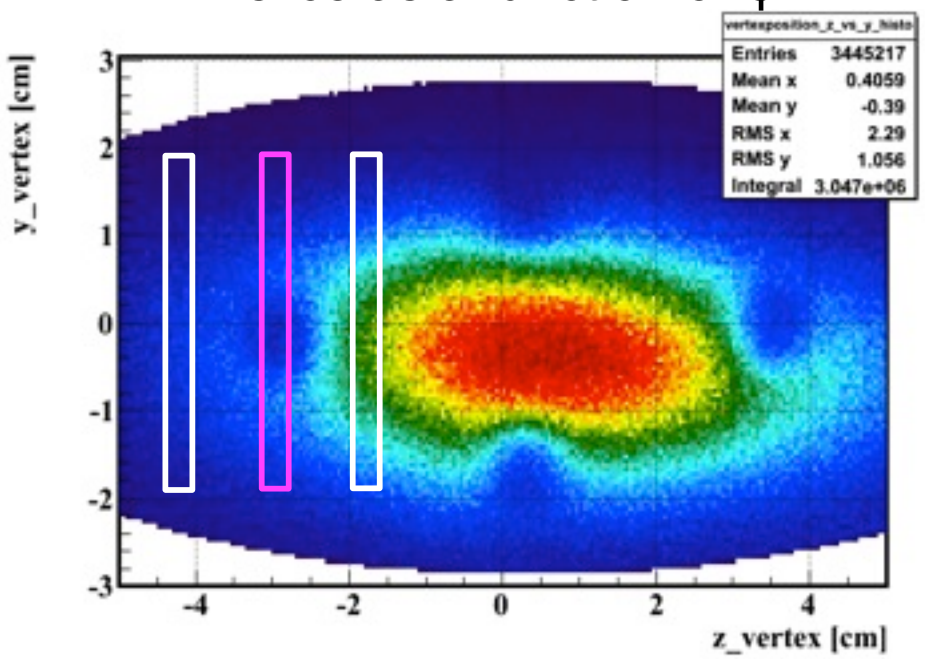
Pb collimators in CEX run

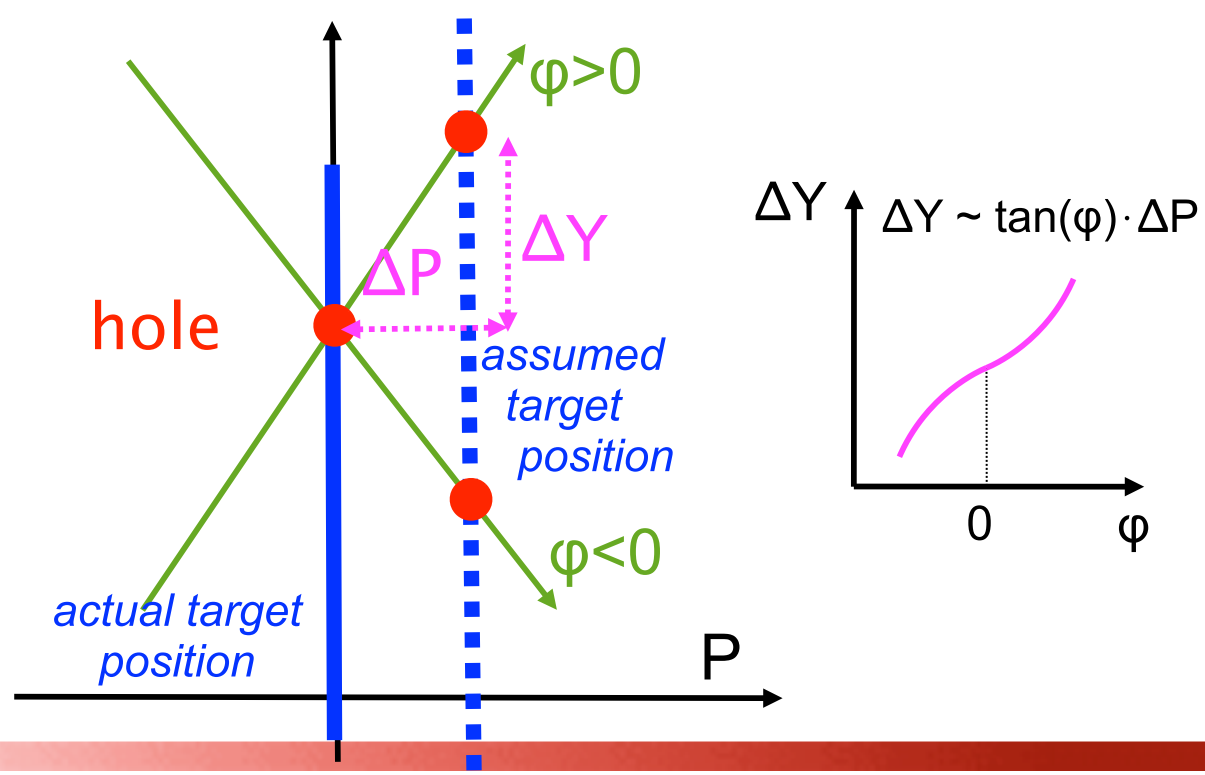


Target Holes

Method 1:

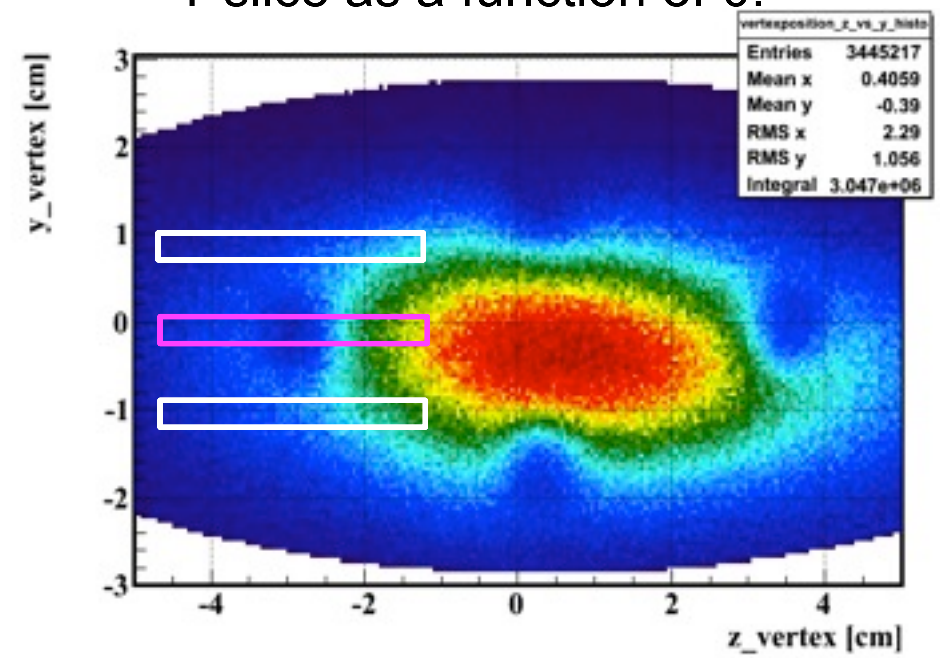
Reconstruct Y-coordinate in Z-slice as a function of φ:

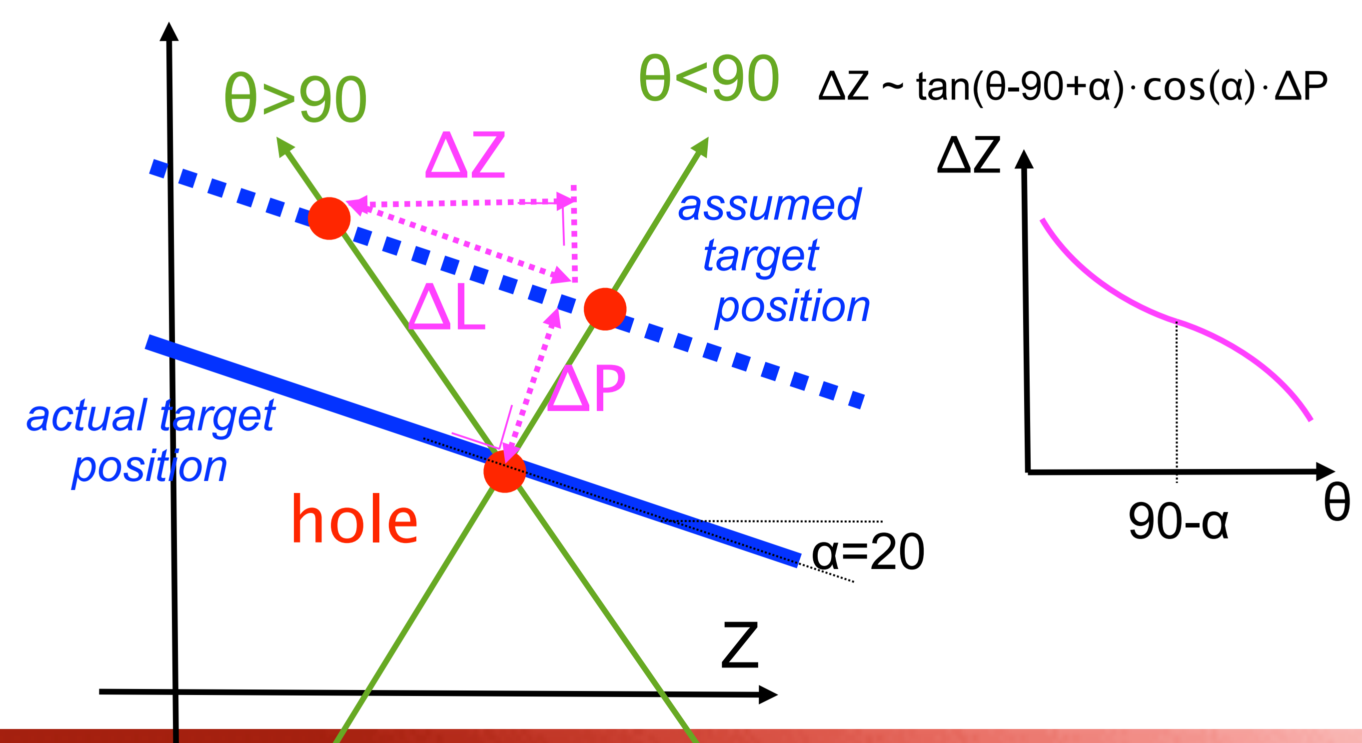




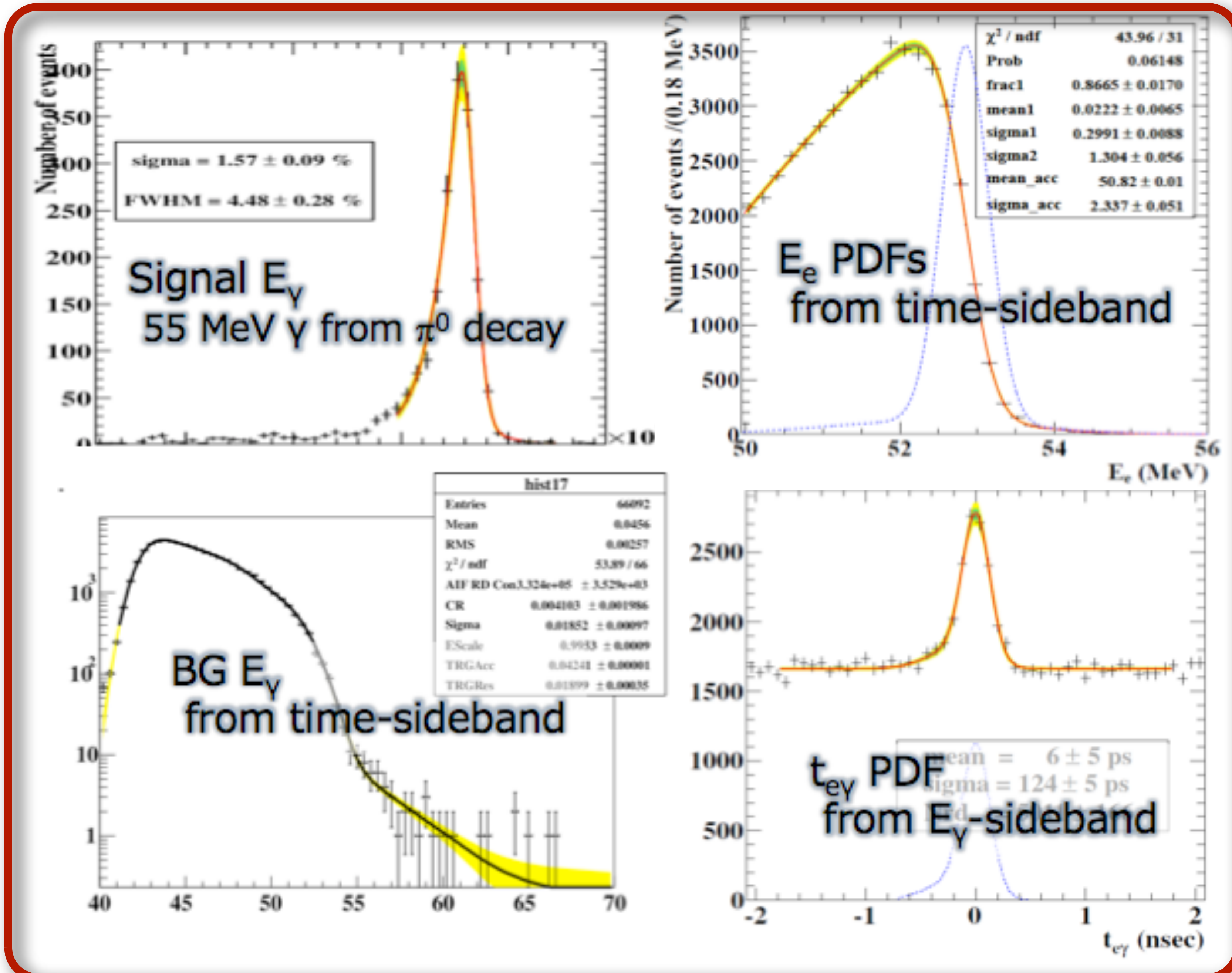
Method 2:

Reconstruct Z-coordinate in Y-slice as a function of θ:





PDFs

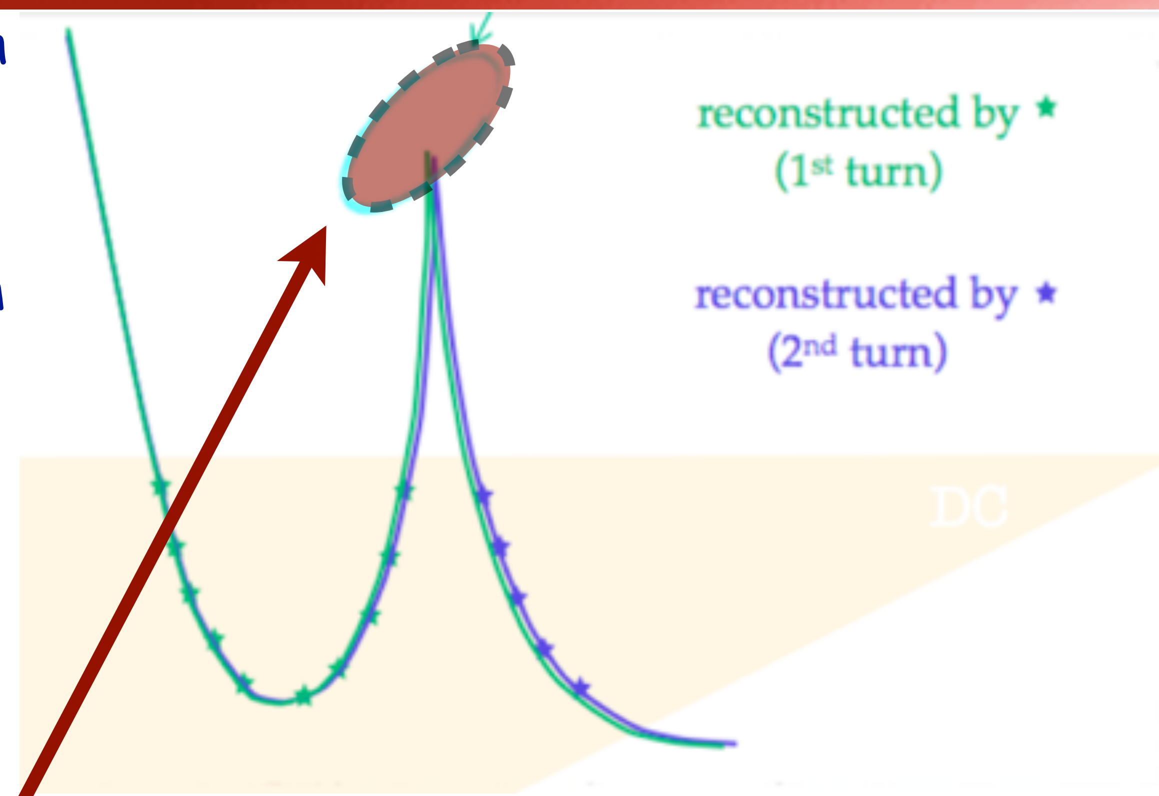


- Signal E_e PDF from fit to Michel edge data
- Signal angle PDFs measured on data from tracks which make two turns inside the spectrometer
- Background angle PDFs measured on time sideband
- RMD PDFs from theoretical distributions convoluted with measured resolutions

Fit variables: E_γ, E_e, $t_{e\gamma}$, $\theta_{e\gamma}$, $\varphi_{e\gamma}$

Signal Positron PDFs & Correlations

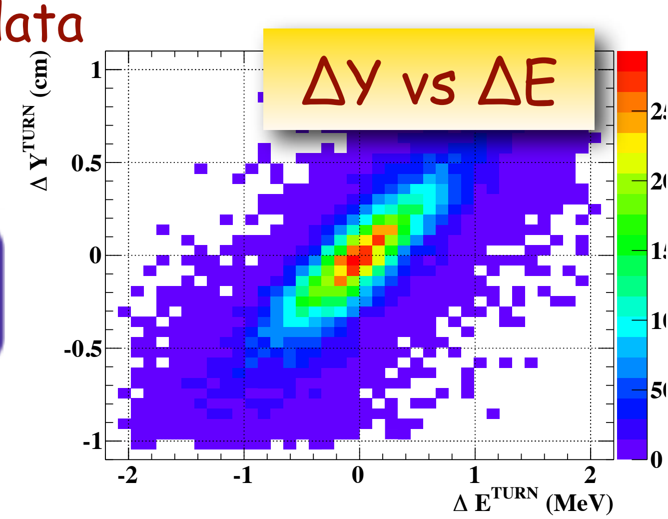
- Signal positron PDFs are evaluated from tracks which make 2 turns inside the spectrometer, treating each turn as an independent pseudo track
- Since all positrons must come from the target (~200 μm thick, fairly considered bidimensional in our analysis), this constraint removes one degree of freedom from the problem, introducing correlations among all positrons track parameters and resolutions
- This geometrical effect worsen resolutions, which can nevertheless be partially recovered taking correlations into account in the likelihood analysis
- Evaluating resolution at the 2-turn track turning point on a fictitious plane with same inclination as the target allows to extract correlations from data

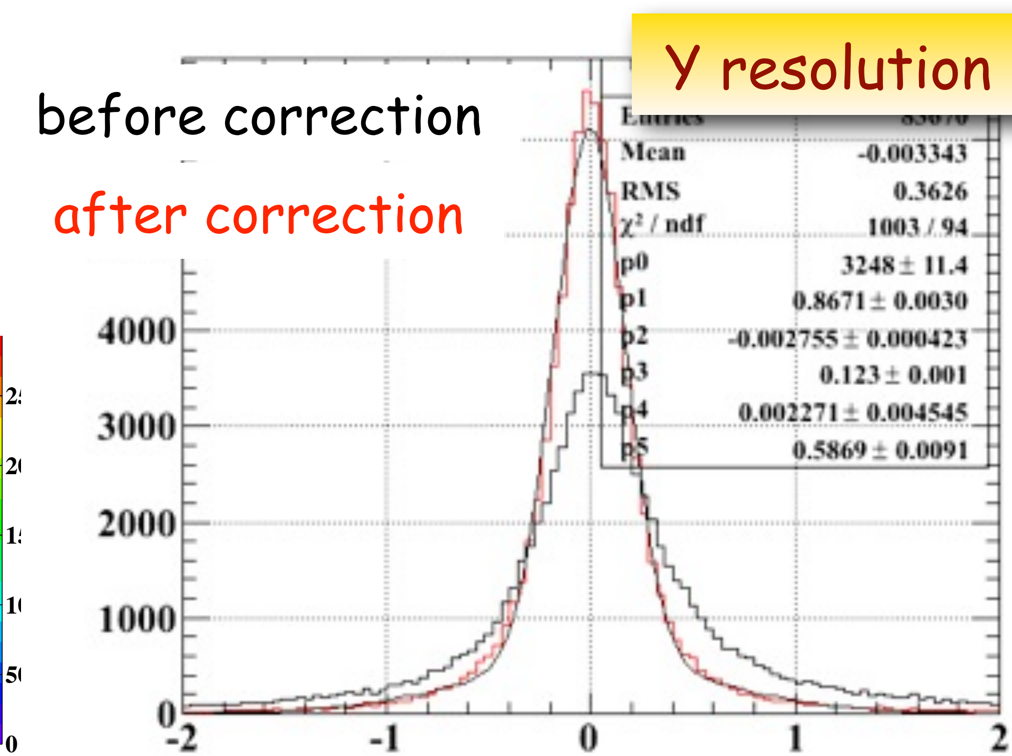


$$\delta\phi_e = -2\tan\phi_e \frac{\delta R}{R} = -2\tan\phi_e \frac{\delta E}{E}$$

$$\delta Y = 2\delta R\cos\phi_e + R\sin\phi_e\delta\phi_e = \frac{2R}{\cos\phi_e}\frac{\delta E}{E}$$

$$\delta Z = \frac{2R}{\sin^2\theta_e}\delta\theta_e - 2R\cot\theta_e\frac{\delta E}{E}$$





Performances

	2009	2010	2011
γ energy	1.9%(w> 2cm), 2.4%(w< 2cm)	1.9%(w> 2cm), 2.4%(w< 2cm)	1.7%(w> 2cm), 2.4%(w< 2cm)
γ timing	96 ps	67 ps	67 ps
γ position	5 mm (u,v), 6 mm(w)	5 mm (u,v), 6 mm(w)	5 mm (u,v), 6 mm(w)
γ efficiency	63%	63%	63%
e^+ timing	107 ps	107 ps	107 ps
e^+ energy	0.31 MeV (80% core)	0.32 MeV (79% core)	0.31 MeV (85% core)
e^+ angle (θ)	9.4 mrad	11.0 mrad	10.6 mrad
e^+ angle (φ)	6.7 mrad	7.2 mrad	7.5 mrad
e^+ vertex (Z/Y)	1.5 mm/1.1 mm(core)	2.0 mm/1.1 mm(core)	1.9 mm/1.3 mm(core)
e^+ efficiency	40%	34%	36%
e^+ - γ timing	156 ps	122 ps	127 ps
Trigger efficiency	91%	92%	97%
e^+ - γ angle (θ)	14.5 mrad	16.1 mrad	16.2 mrad
e^+ - γ angle (φ)	8.9 mrad	9.0 mrad	8.9 mrad
Stopping μ rate	2.9×10^7 s^{-1}	2.9×10^7 s^{-1}	3.0×10^7 s^{-1}
DAQ time/ Real time	35 days/43 days	56 days/67 days	81 days/113 days
Total stopped μ	6.5×10^{13}	1.1×10^{14}	1.85×10^{14}

Systematics

Table 16: Relative contributions of uncertainties to upper limit of $\mathcal{B}$.

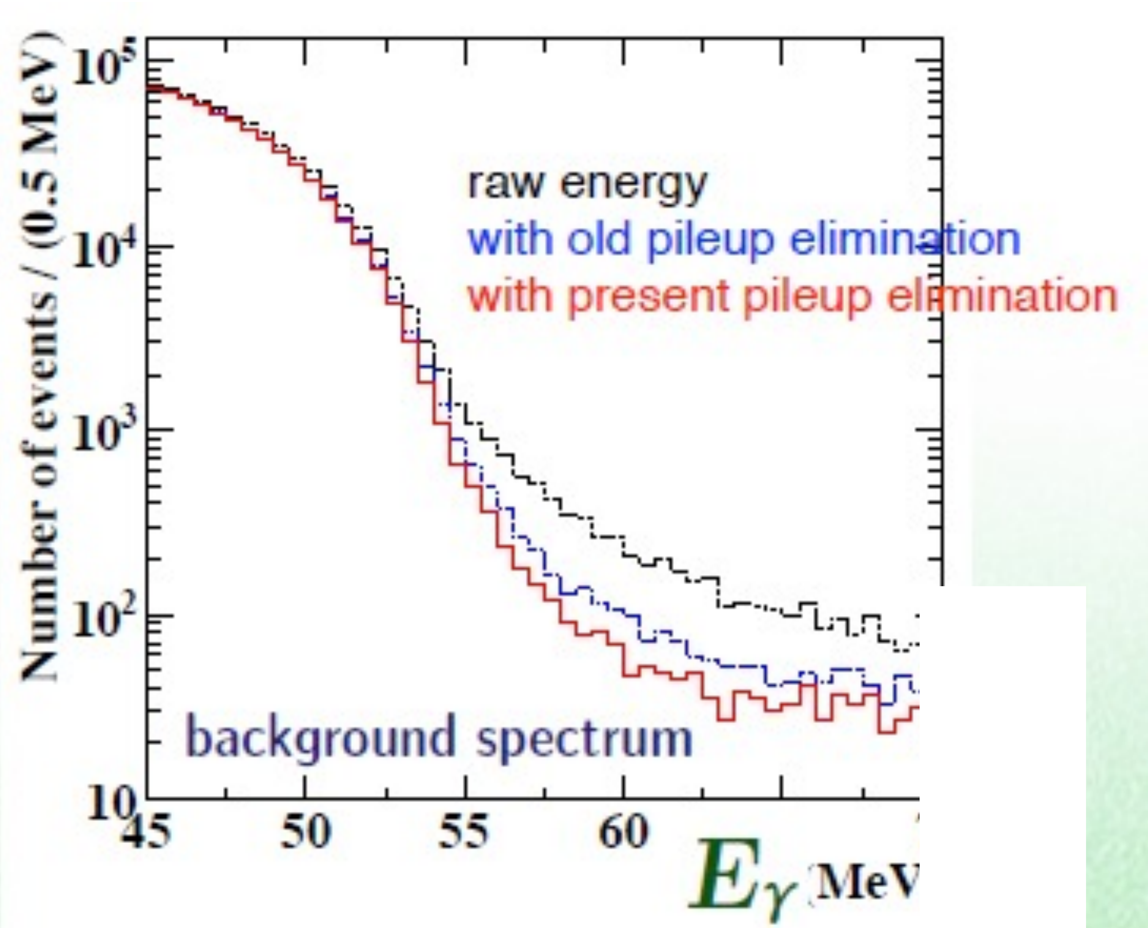
Center of $\theta_{e\gamma}$ and $\phi_{e\gamma}$	0.18
Positron correlations	0.11
E_γ scale	0.07
E_e bias	0.06
$t_{e\gamma}$ signal shape	0.06
$t_{e\gamma}$ center	0.05
Normalization	0.04
E_γ signal shape	0.03
E_γ BG shape	0.03
Positron angle resolutions (θ_e, ϕ_e, z_e, y_e)	0.03
γ angle resolution (u_γ, v_γ, w_γ)	0.03
E_e BG shape	0.01
E_e signal shape	0.01
Angle BG shape	0.00
Total	0.25

Reconstruction Improvements

γ-side:

improved pile-up rejection method:

- reduced high energy tail
- 7% higher signal efficiency



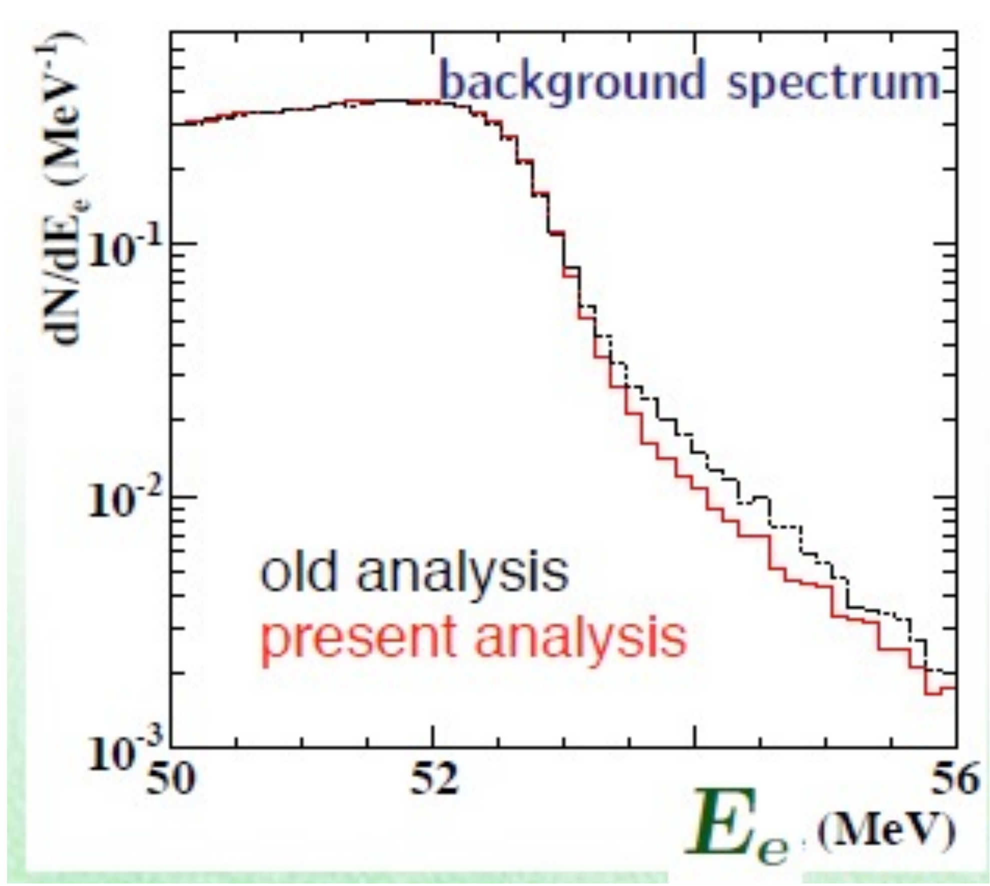
e⁺-side:

FFT offline noise reduction

- few % better angle resolution
- 6% higher signal efficiency

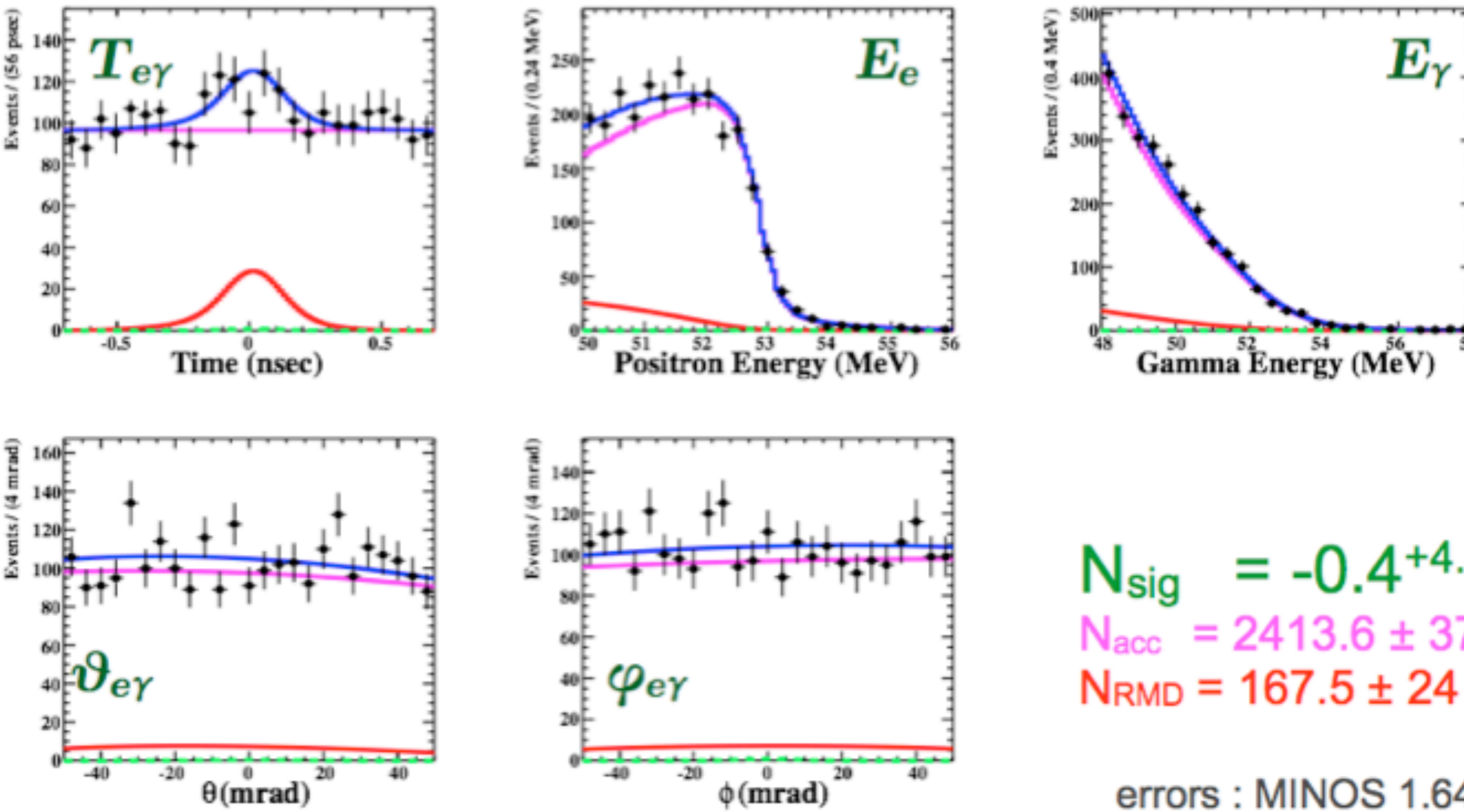
New track fitter (Kalman filter)

- reduced high energy tail
- 7% higher signal efficiency



New algorithms applied to: - reanalyze 2009-2010 sample;
- process data collected in 2011

Fit to 2009-2011 data



$N_{sig} = -0.4^{+4.8}_{-1.9}$

$N_{acc} = 2413.6 \pm 37$

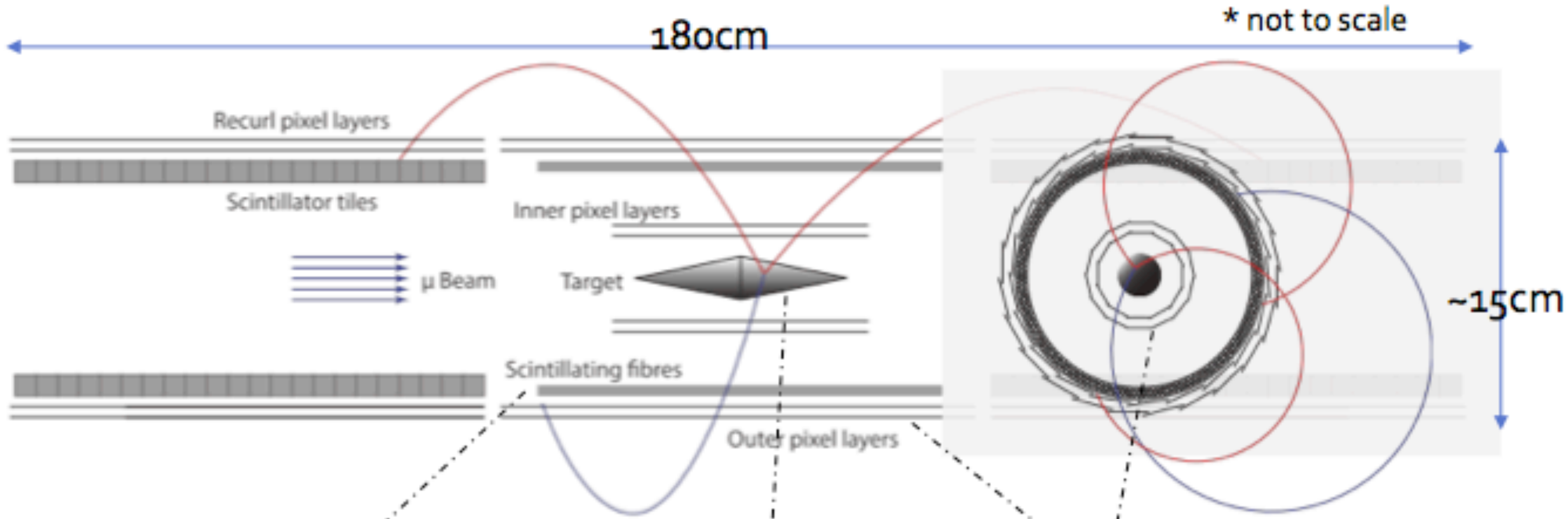
$N_{RMD} = 167.5 \pm 24$

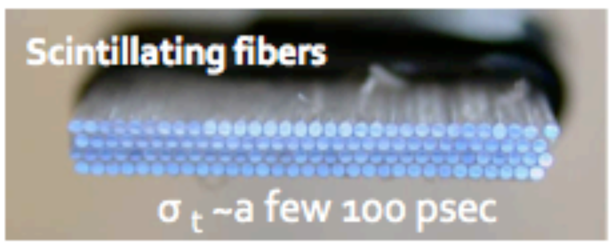
errors : MINOS 1.645σ

expected from sideband data:

N_{acc} = 2415 +/- 25 N_{RMD} = 169 +/- 17

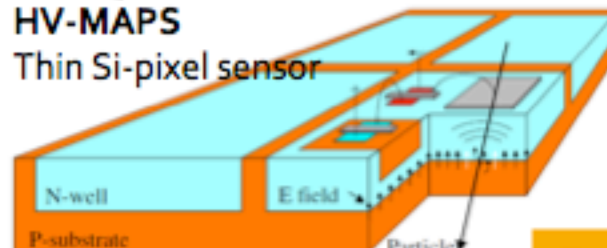
Mu3e @ PSI



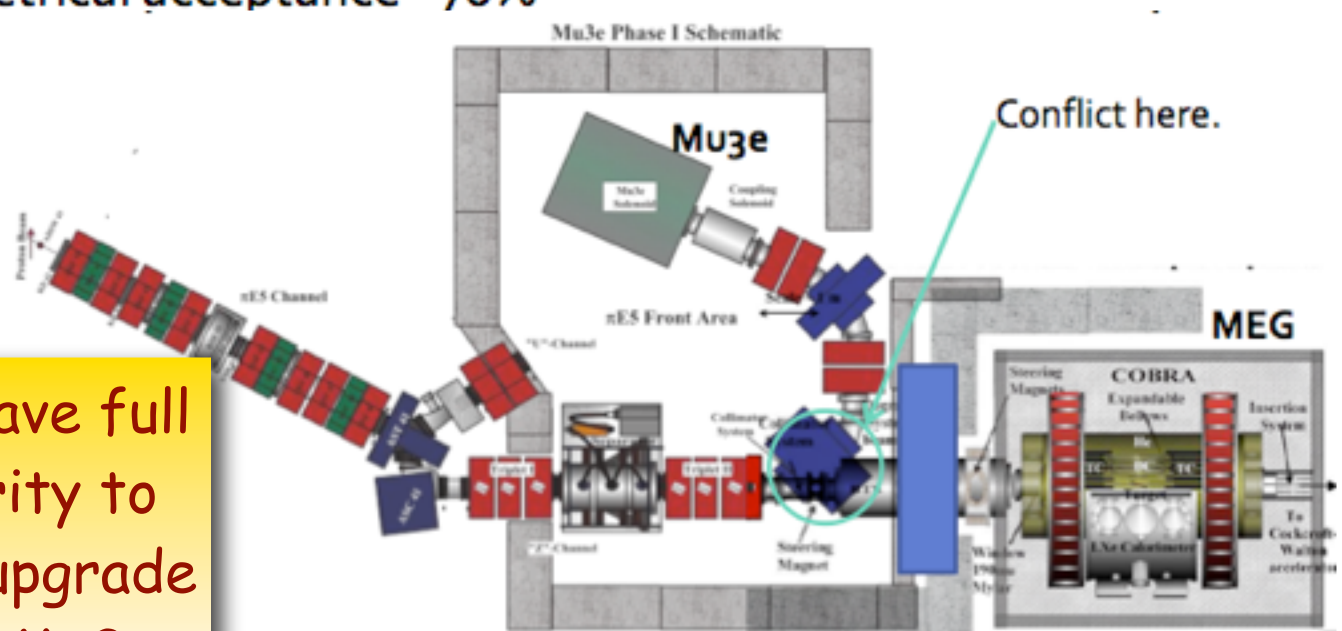


Double-cone shape target
Large surface area to disperse decay vertices

HV-MAPS
Thin Si-pixel sensor

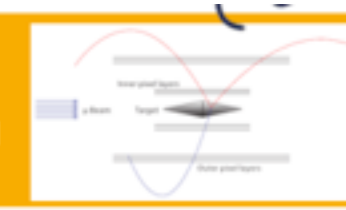


- Geometrical acceptance ~70%



PSI gave full priority to MEG upgrade over Mu3e

Early realization with central Si
- ≦10^7μ/s @πE5
- Experience for the new tech. Verify principal
- O(10^{-14})



Introduce 1st side-station & ToF
- ~10^8μ/s max. @πE5
- O(10^{-15})
  - ✓ Limited by statistics

Full configuration
- ~2×10^9μ/s @new beamline
- Goal O(10^{-16})