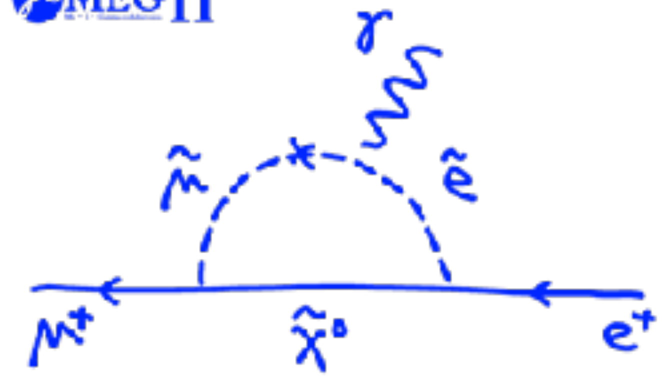
東京大学
THE UNIVERSITY OF TOKYO

東京大学
素粒子物理国際研究センター
International Center for Elementary Particle Physics
The University of Tokyo

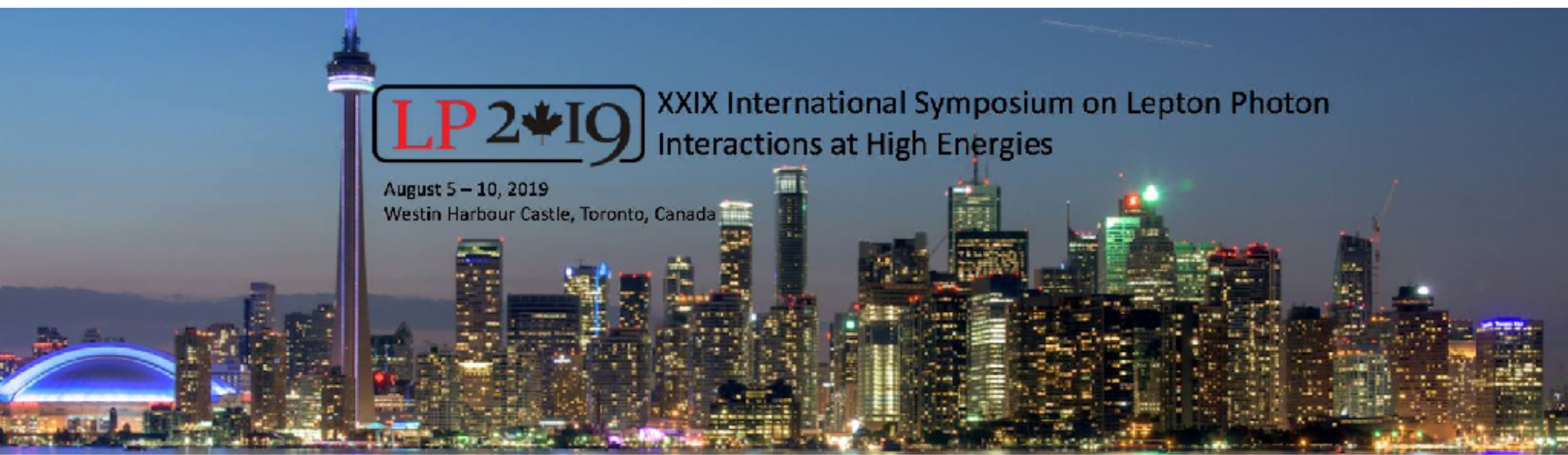
JSPS Core-to-Core Program

MEG II



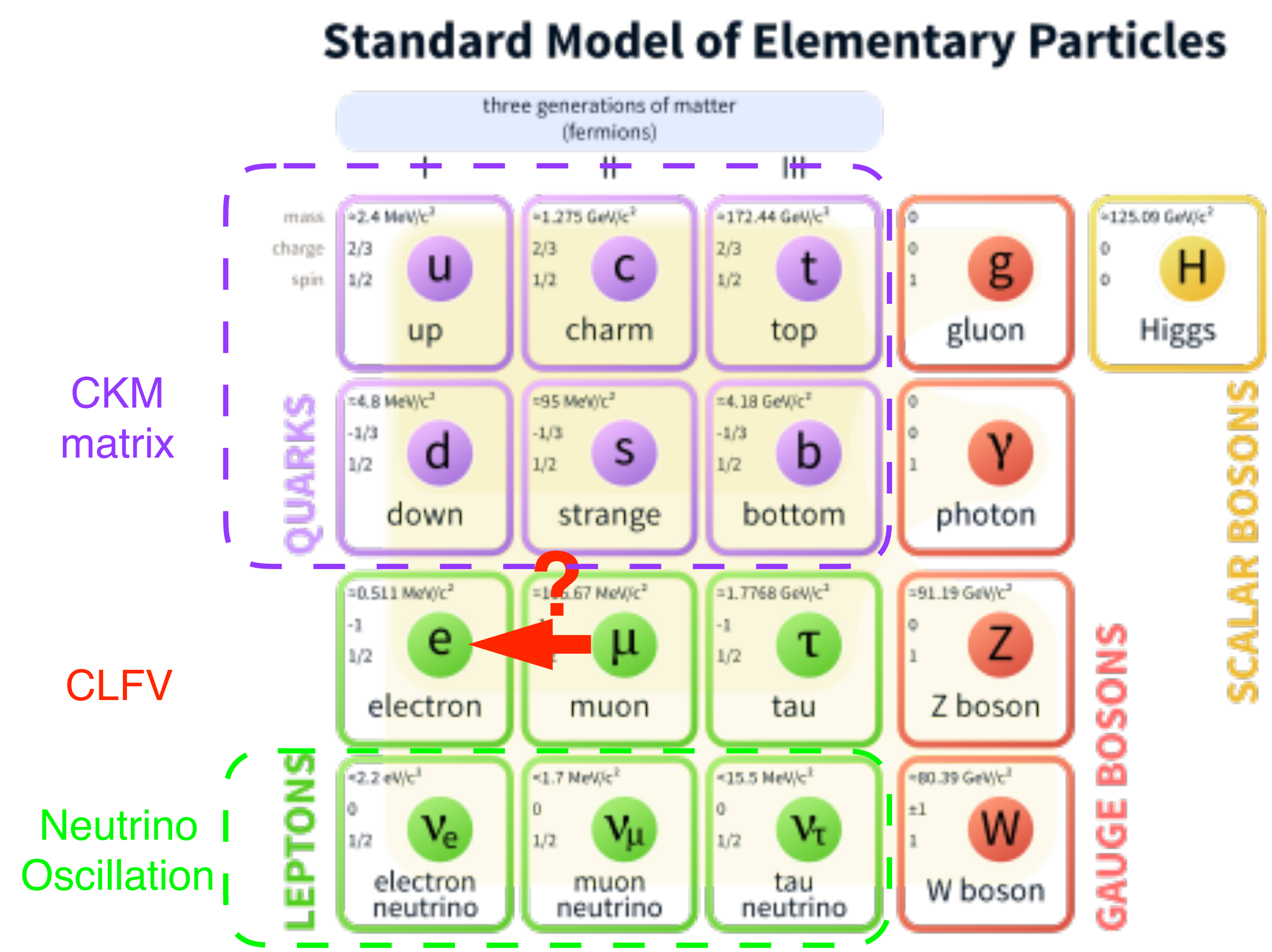
Searches for charged lepton flavor violating muon decay, MEG/MEG II experiment

Toshiyuki Iwamoto on behalf of the MEG II Collaboration
ICEPP, the University of Tokyo
8 August 2019

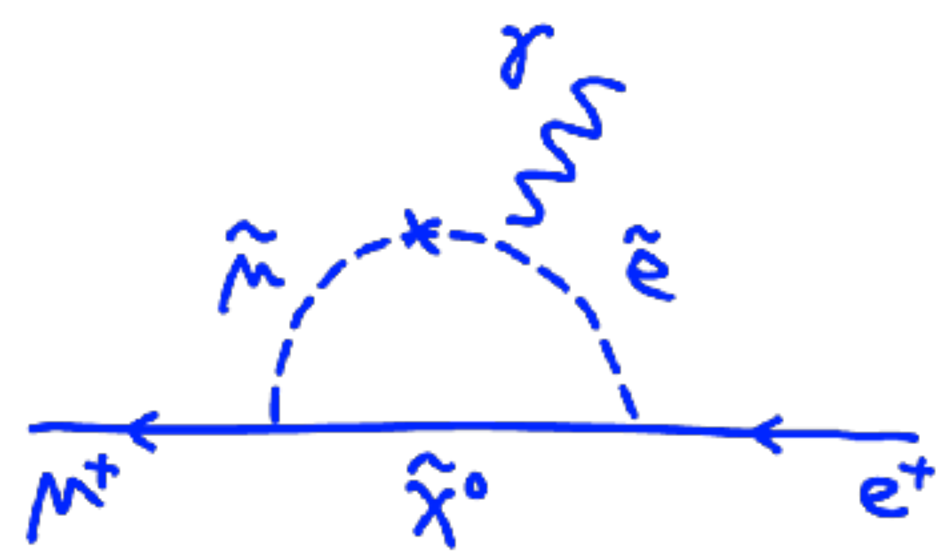


Introduction

- Charged Lepton Flavor Violation
  - FV happens in quarks, neutral lepton (neutrinos)
  - Why has charged lepton flavor violation never been observed yet?
- μ→eγ
  - Long search history since the muon has been discovered.
  - In SM + neutrino oscillation, Br(μ→eγ)~10^{-50}
  - Many new physics scenarios (SUSY-GUT, SUSY-seesaw etc.) predict large Br(μ→eγ) through new particles in a loop diagram

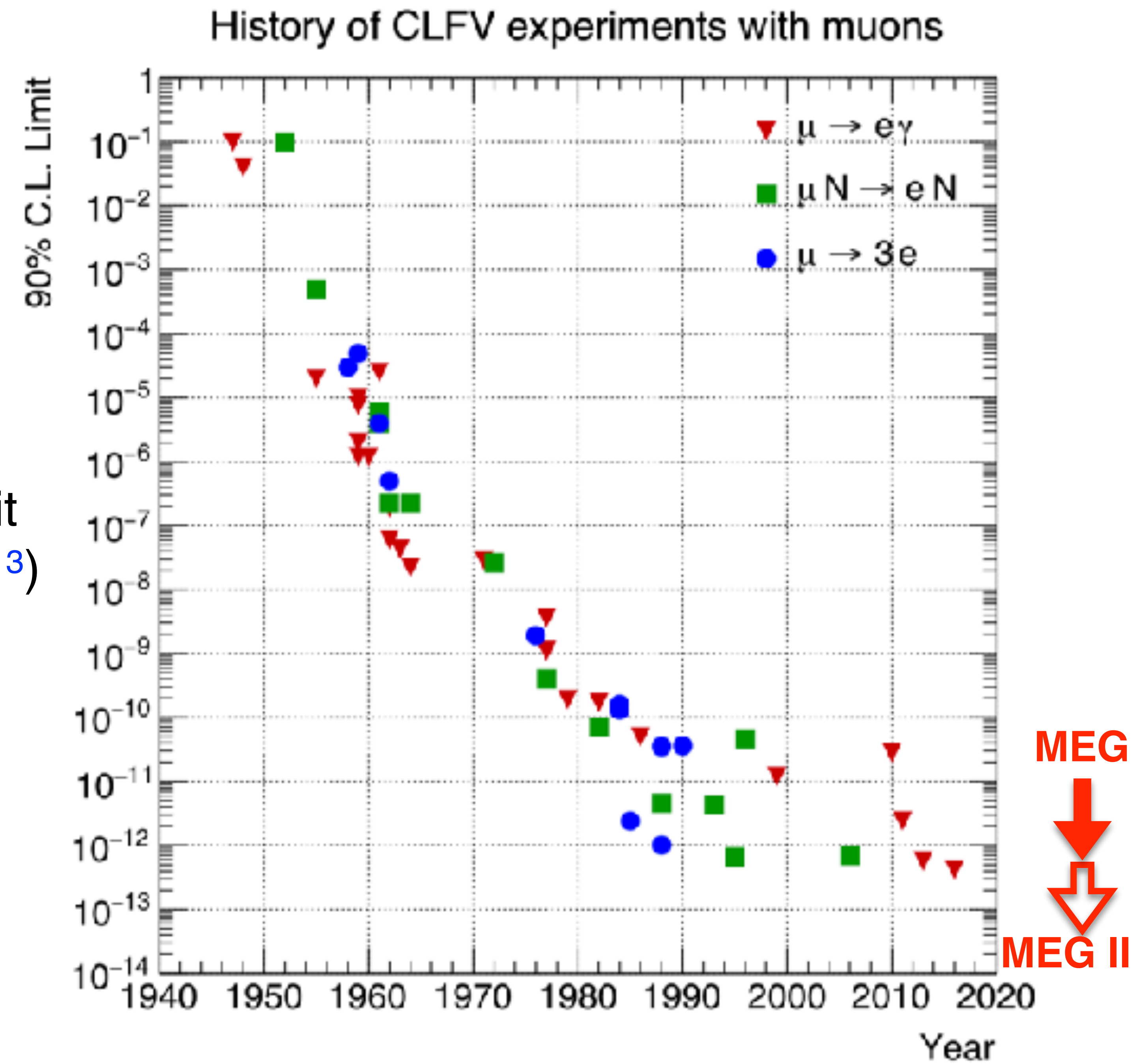


From Wikipedia



MEG/MEG II Experiment

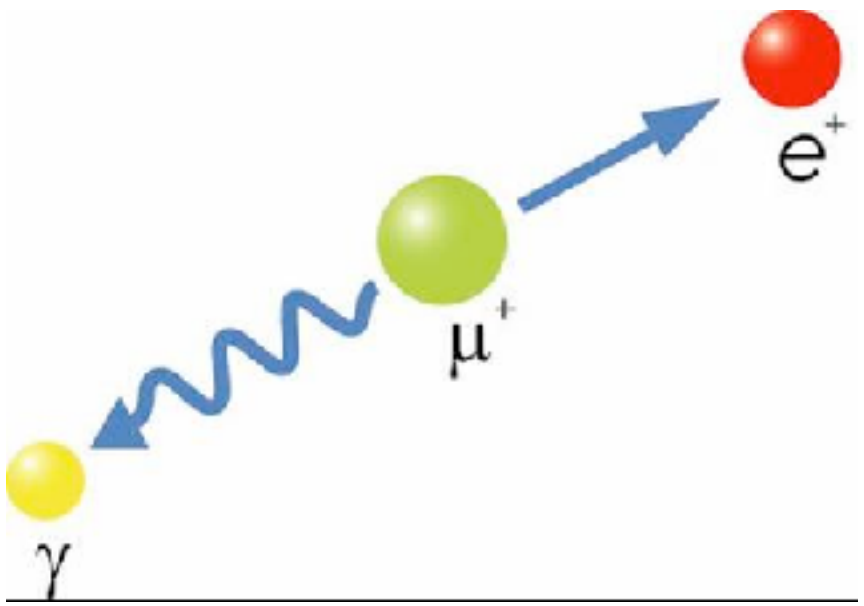
- MEG experiment
  - MEG was designed to search for such regions where new physics like SUSY-GUT, SUSY-seesaw predict
  - Real chance to discover new physics
  - Data taking during 2009-2013
  - MEG final results : Br($\mu \rightarrow e\gamma$) upper limit 4.2×10^{-13} @90%CL (sensitivity 5.3×10^{-13}) (Eur. Phys. J. C 76(8),434(2016))
- MEG II experiment
  - An order of magnitude better sensitivity with three years data taking than MEG
  - Target sensitivity : 6×10^{-14}
- CLFV experiments
  - μ-e conversion(DeeMe, COMET, Mu2e), $\mu \rightarrow 3e$ (Mu3e) experiments etc. will also come soon



Eur. Phys. J. C (2018)78:380

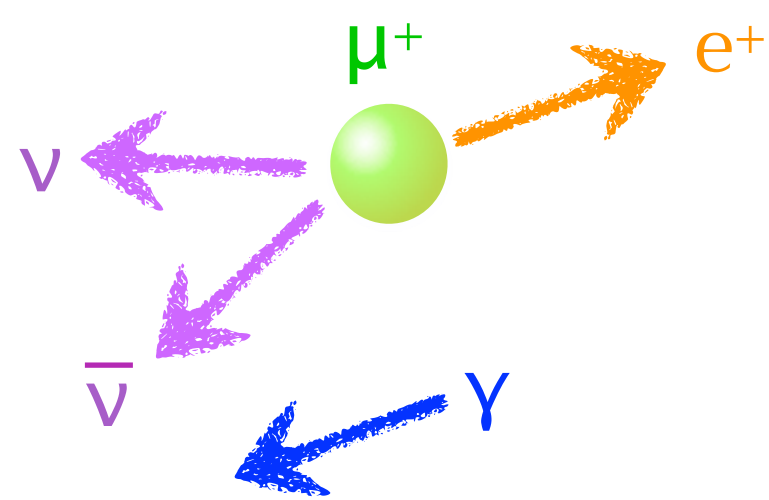
$\mu \to e\gamma$ signal and background

Signal



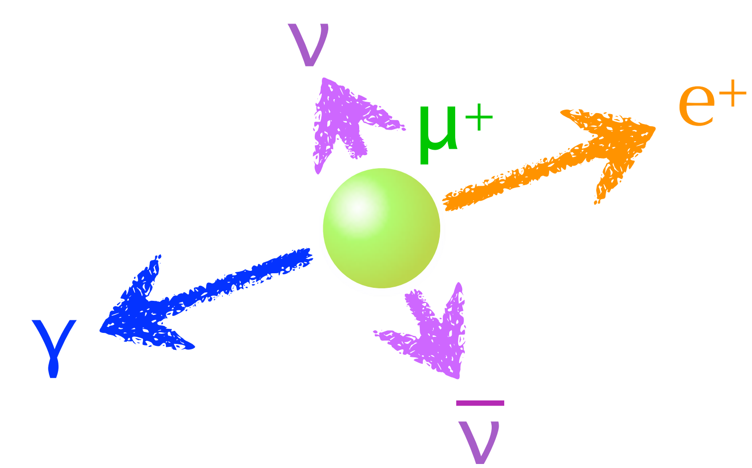
$E_\gamma, E_e \simeq$ 52.8MeV
$\Theta_{e\gamma}$=180°, $T_\gamma = T_e$

Accidental Background



- Dominant BG
- Michel e^+ + random γ from RMD/Annihilation in flight (AIF)

Radiative Muon Decay (RMD) Background



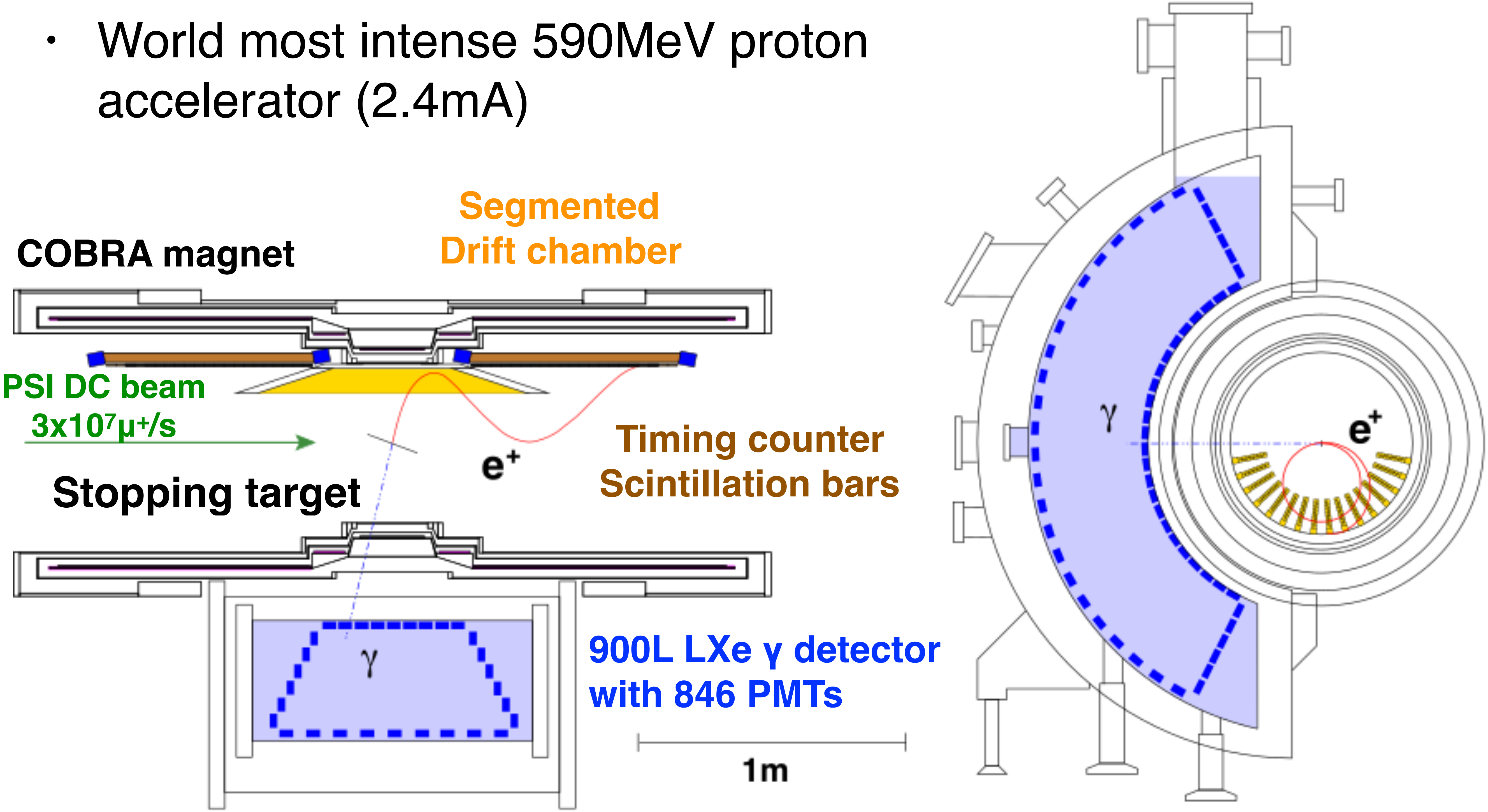
- e^+-γ timing coincident
- Good for timing calib.

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

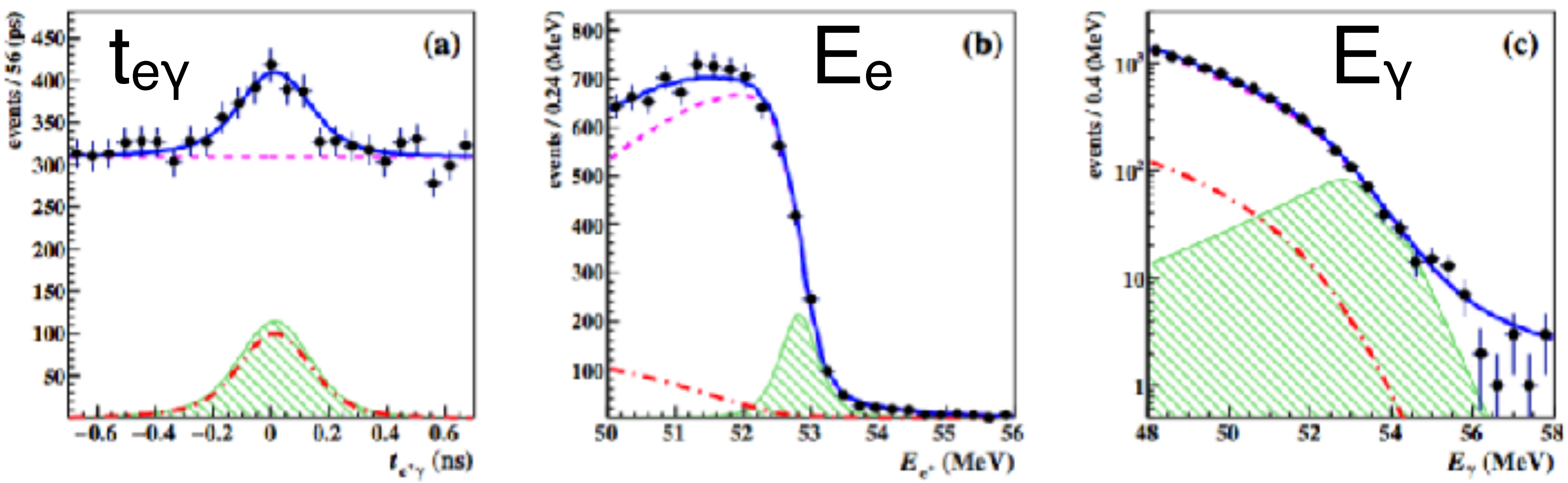
- Lower instantaneous muon beam rate (DC muon beam)
- Better detector resolutions

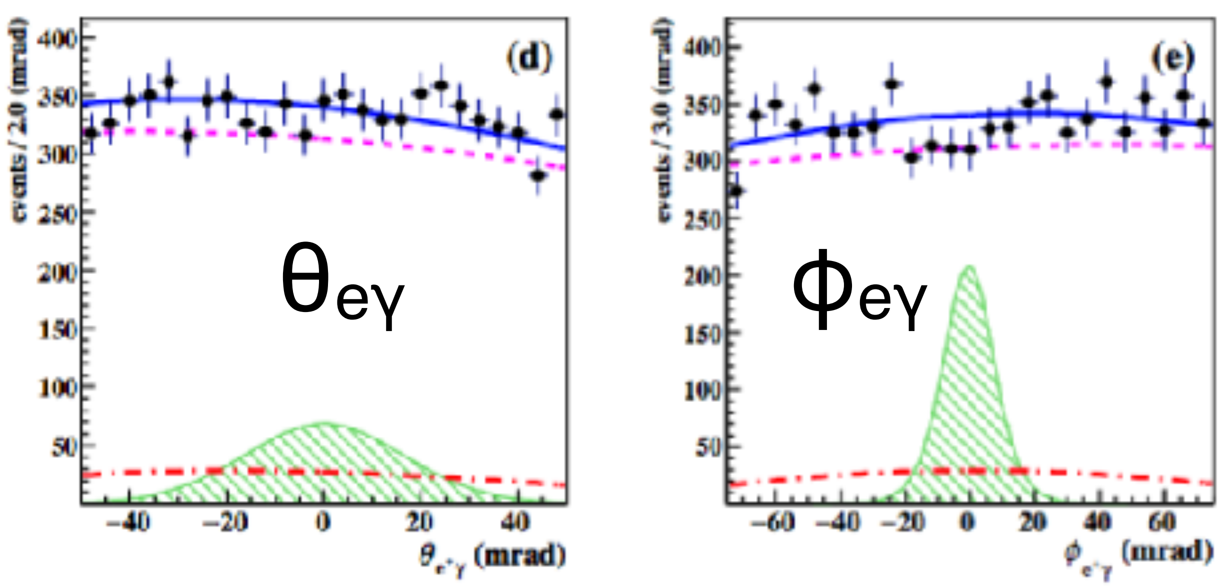
MEG experiment

- Paul Scherrer Institute in Switzerland
- World most intense 590MeV proton accelerator (2.4mA)



MEG results



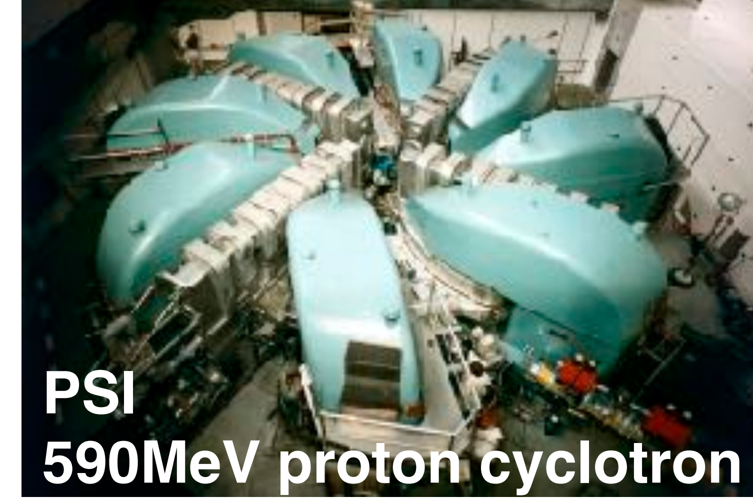


- N_{ACC} = 7684 ± 103
- N_{RMD} = 663 ± 59
- Signal PDF enhanced

- Full dataset : 7.5×10^{14} μ^+ stopped on the target
- Blind analysis in (E_γ, $t_{e\gamma}$) plane
- Five observables $E_\gamma, E_e, t_{e\gamma}, \theta_{e\gamma}, \phi_{e\gamma}$
- Maximum likelihood analysis
- All PDFs well consistent with data
- The fit result was consistent with no signal

- **$Br(\mu^+\rightarrow e^+\gamma) < 4.2\times10^{-13}$ @ 90% C.L.**

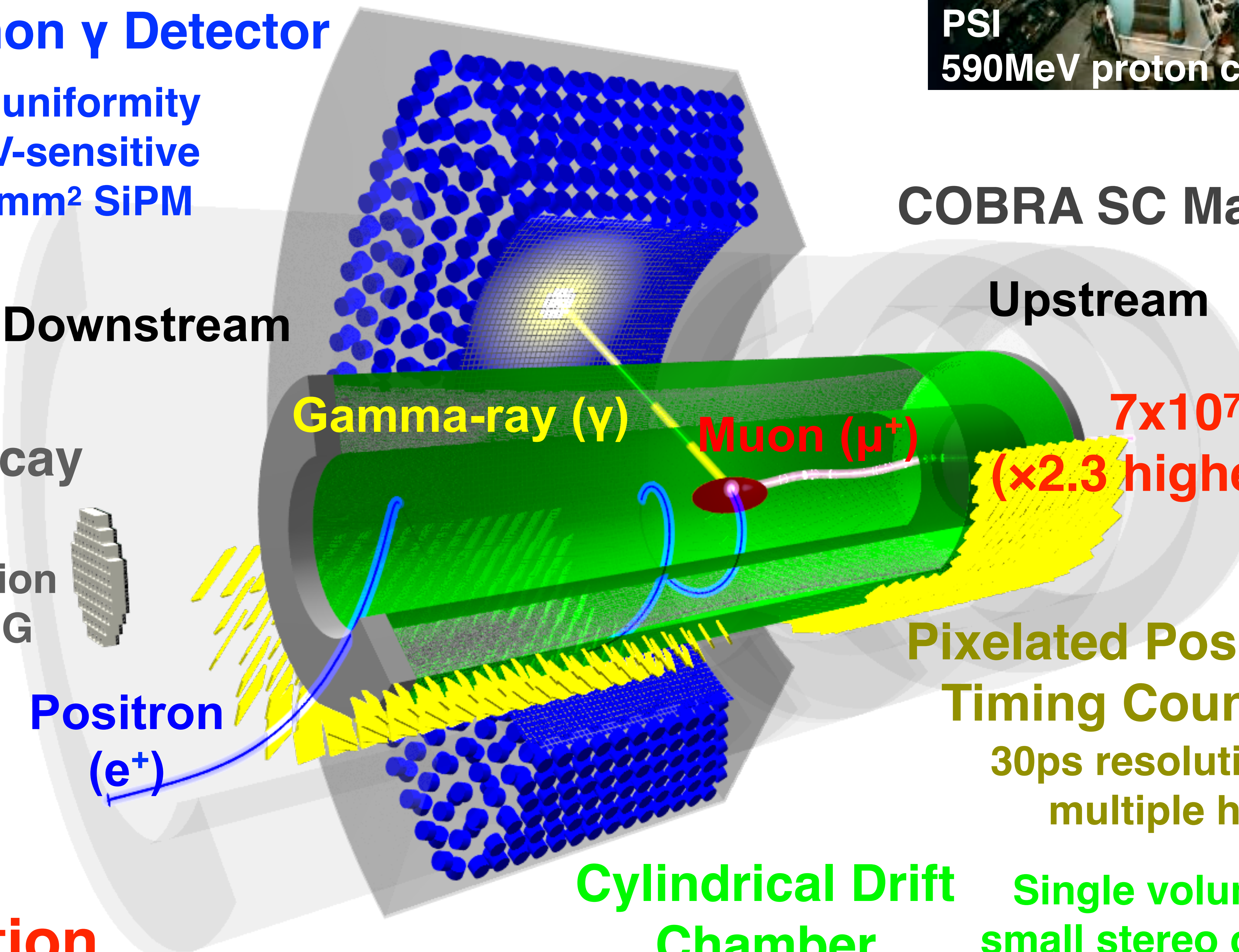
MEG II Experiment



Liquid Xenon γ Detector

Better uniformity
w/ VUV-sensitive
12x12mm² SiPM

COBRA SC Magnet



Radiative Decay Counter

Further reduction
of radiative BG

Pixelated Positron Timing Counter

30ps resolution w/
multiple hits

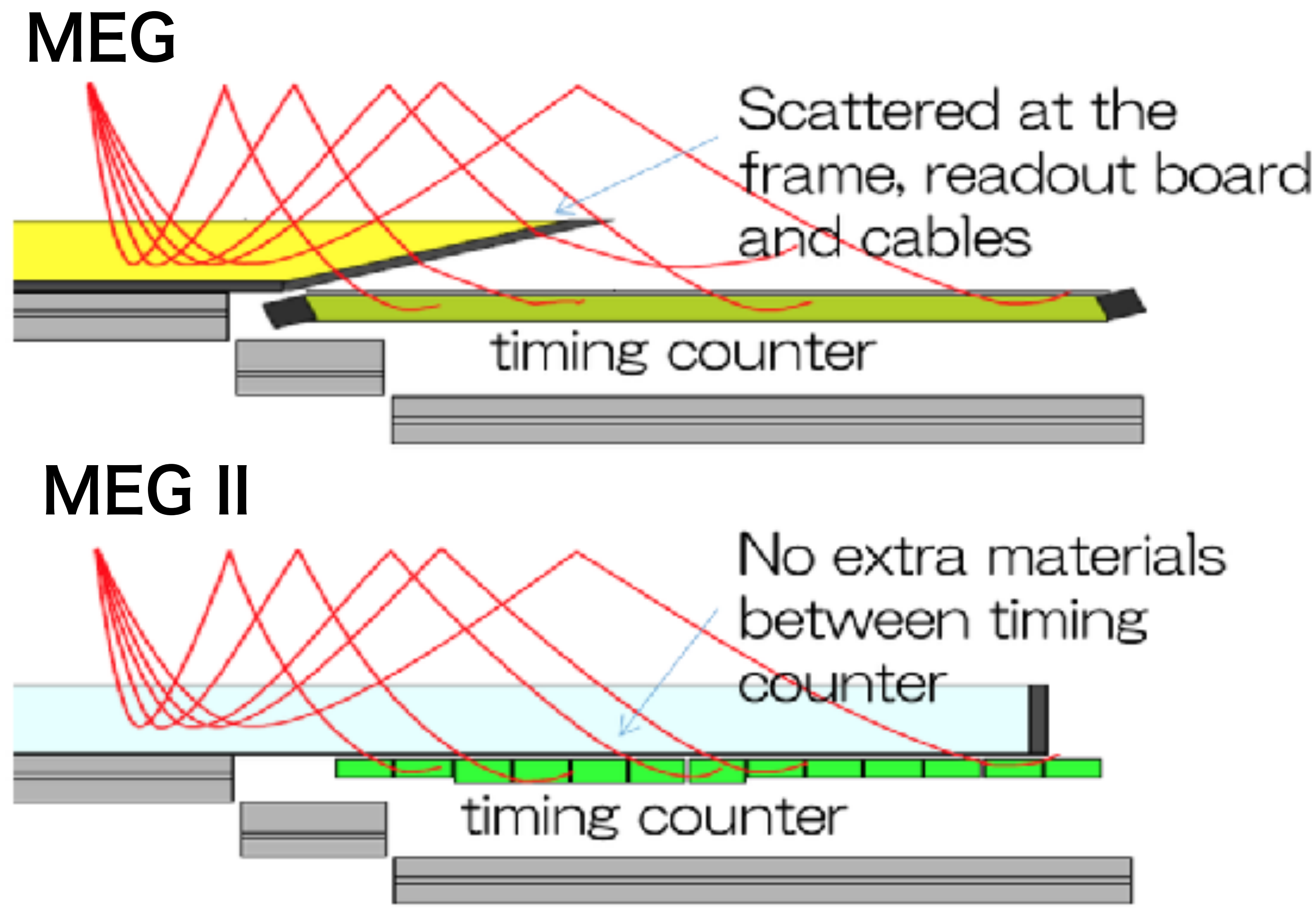
Cylindrical Drift Chamber

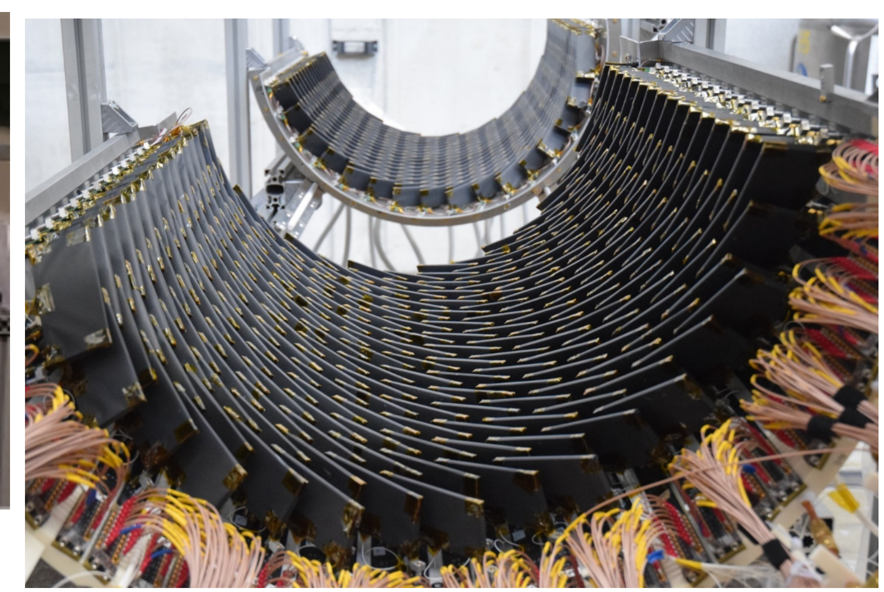
Single volume
small stereo cells
more hits

×2 resolution everywhere

MEG II positron spectrometer

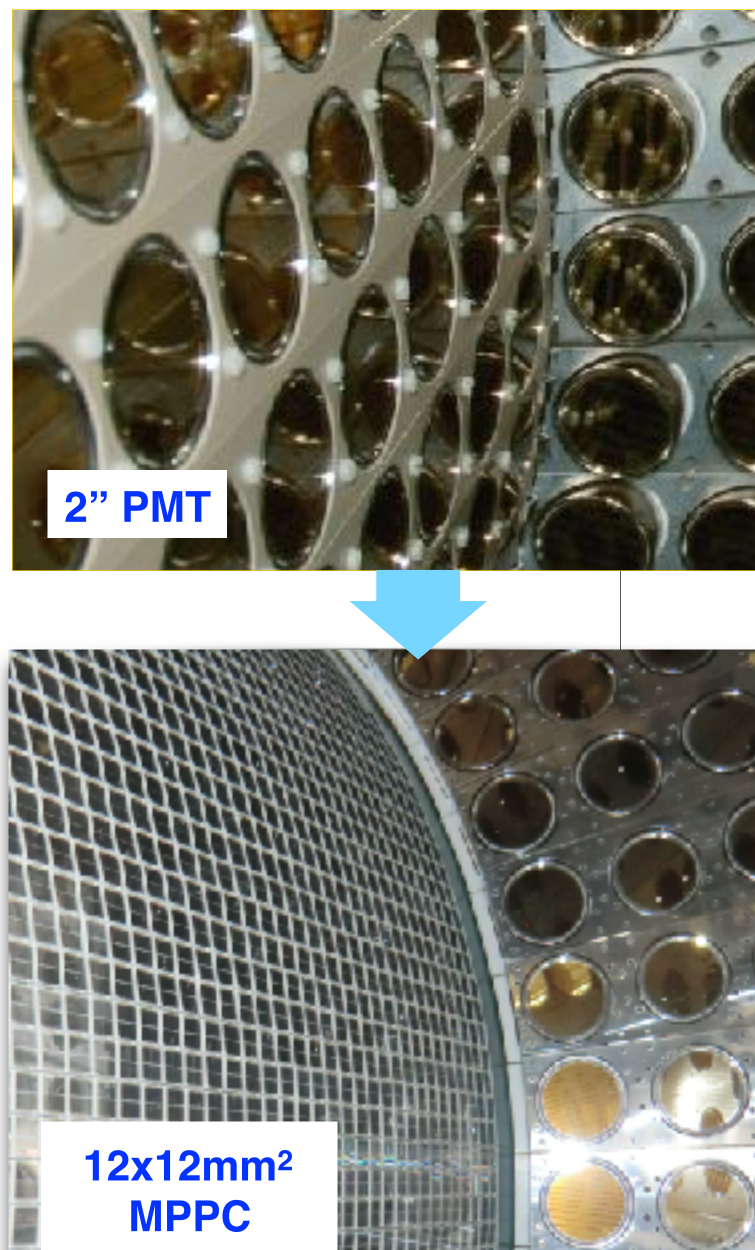
- Cylindrical Drift Chamber
  - Tracking 52.8MeV e^+ to reconstruct vertex, angle, and momentum
  - Single volume wire drift chamber with 1280 anode wires with less material
  - Higher granularity, increased number of hits per track → better angle/momentum resolution
  - High transparency towards TC → Higher positron detection efficiency
- Pixelated Timing Counter
  - Time measurement of 52.8MeV e^+
  - 15 scintillator bars → 256 scintillator plates
    - multi-counter hits → better timing resolution down to ~30ps

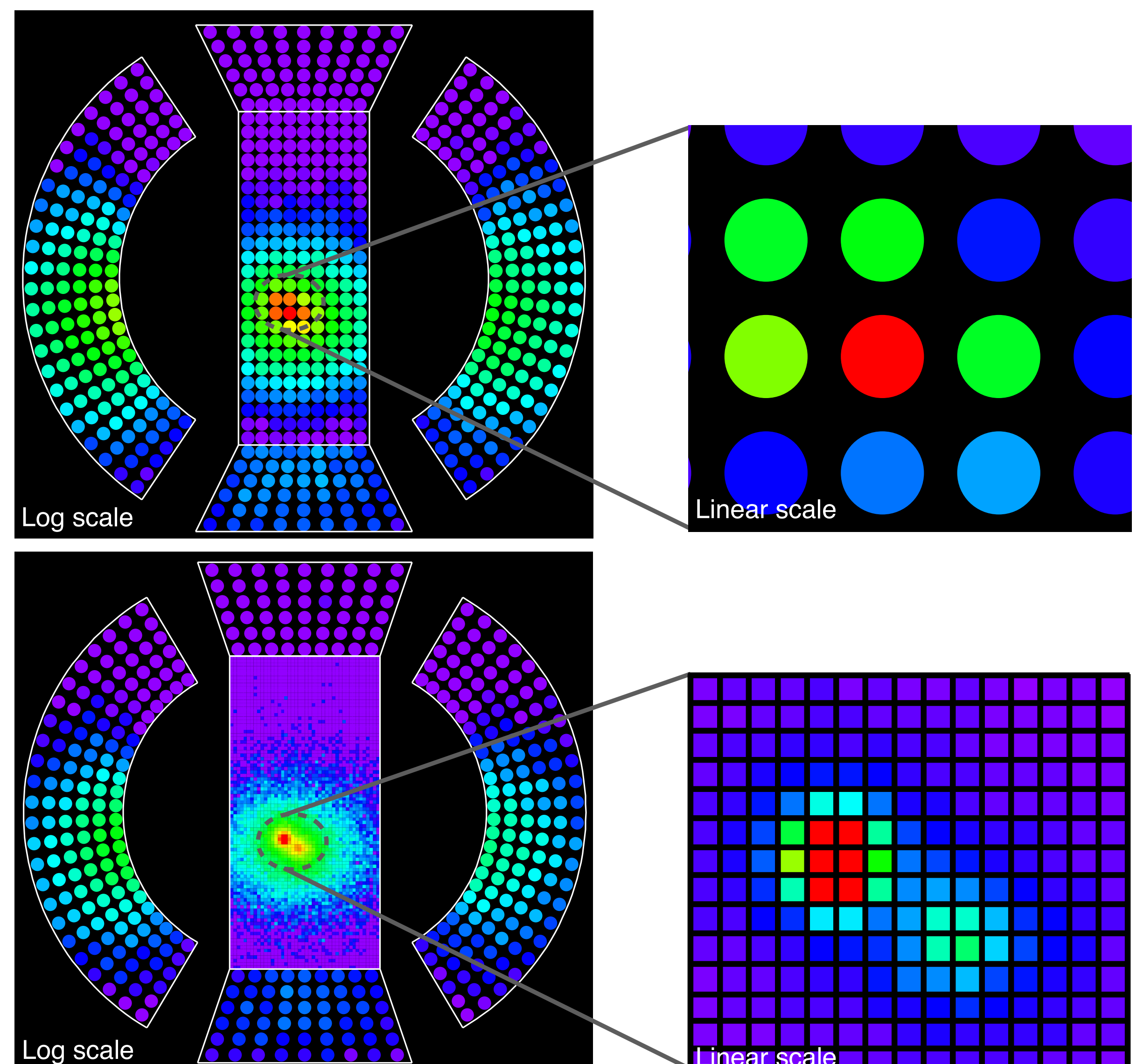




MEG II liquid xenon γ detector

- Energy, position, time measurement of 52.8MeV γ from μ→eγ decay
- Inner 216 PMTs → 4092 MPPCs (VUV-sensitive large area MPPCs)
- Better granularity, better uniformity→Better energy, position resolution

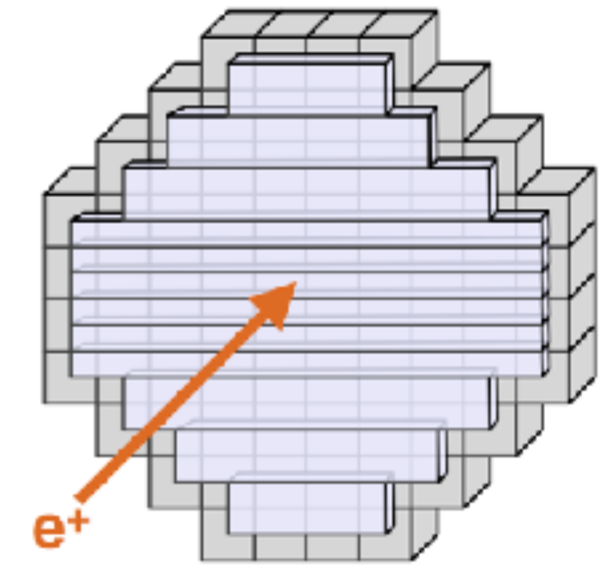




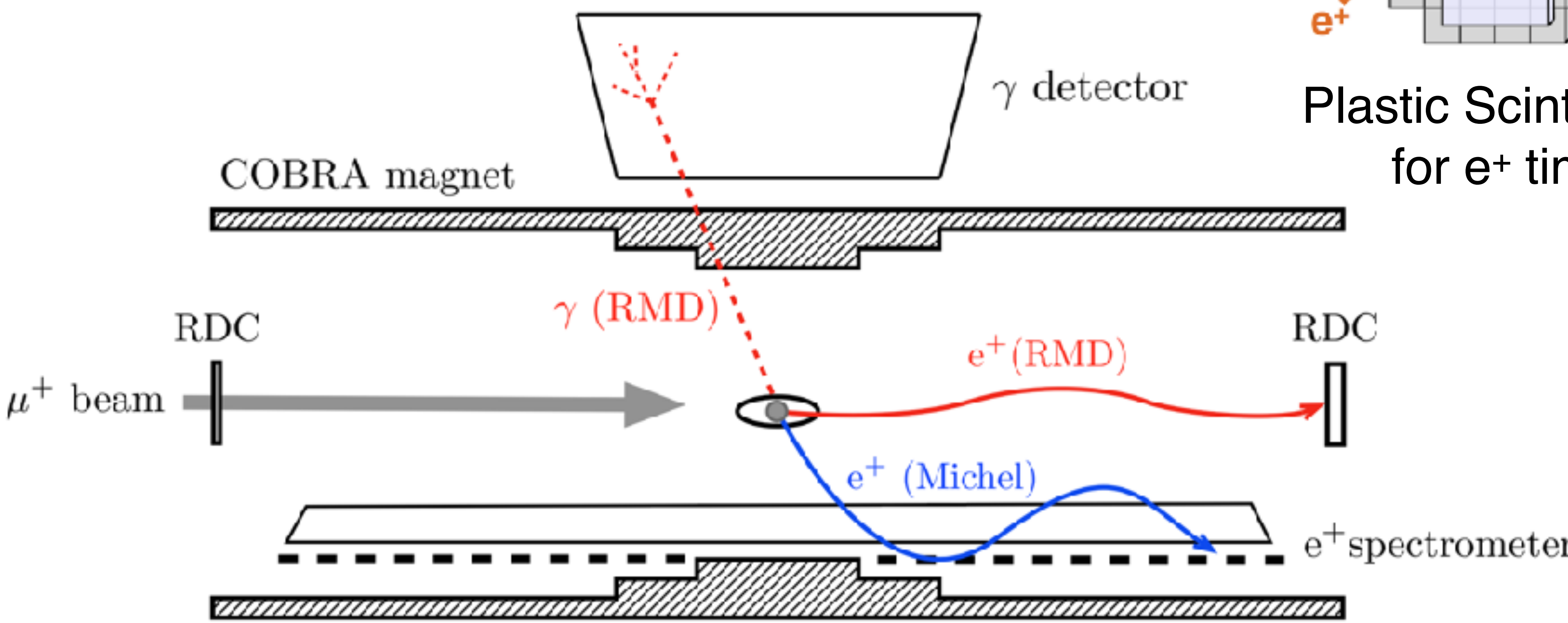
Radiative Decay Counter

- New device for MEG II
  - To tag high energy γ background from radiative muon decay by detecting low momentum e^+
- Downstream detector ready, upstream detector under development
  - μ^+ beam goes through US RDC

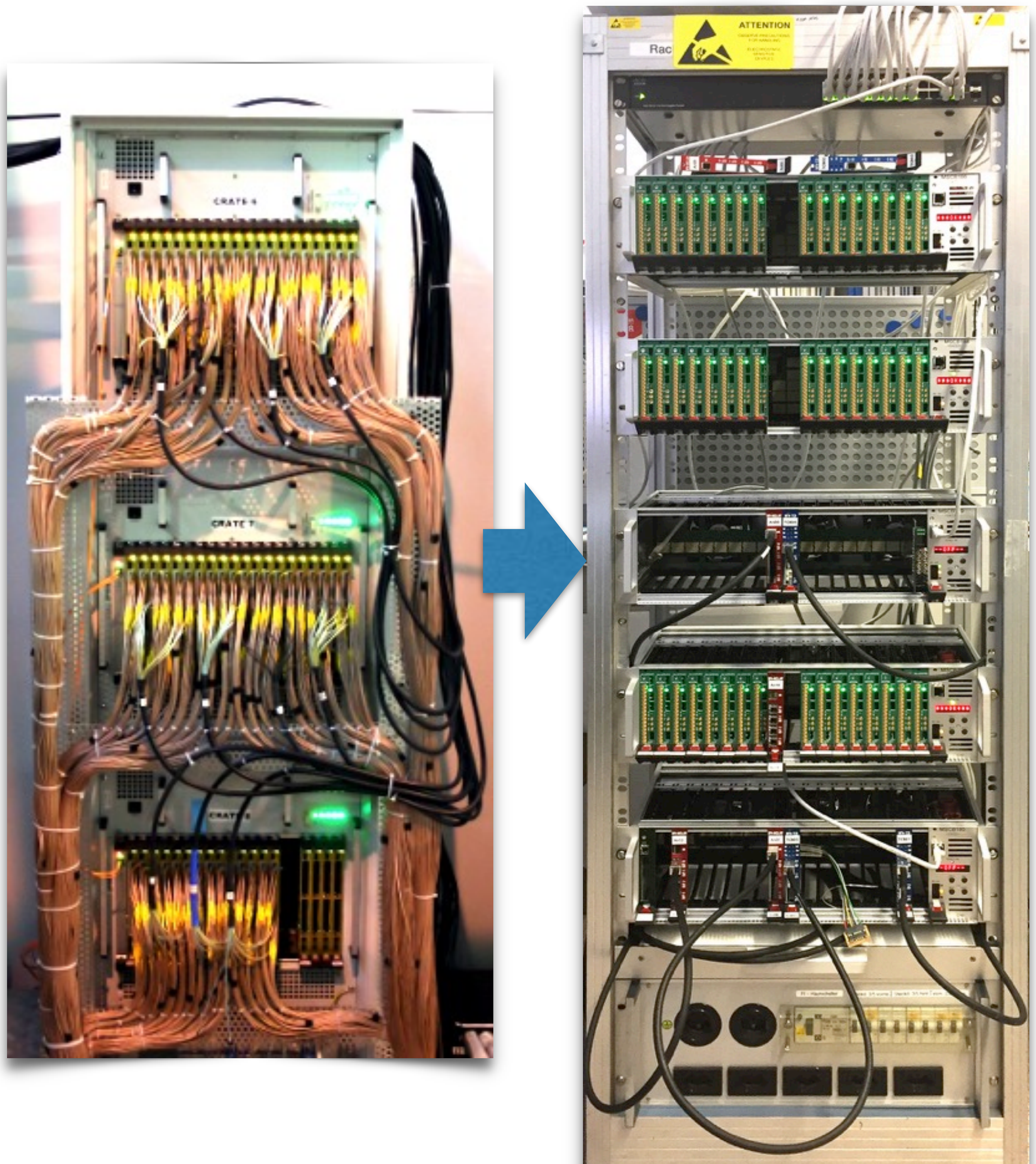
LYSO 2×2×2 cm³+SiPM for e^+ energy



Plastic Scinti.+SiPM for e^+ timing



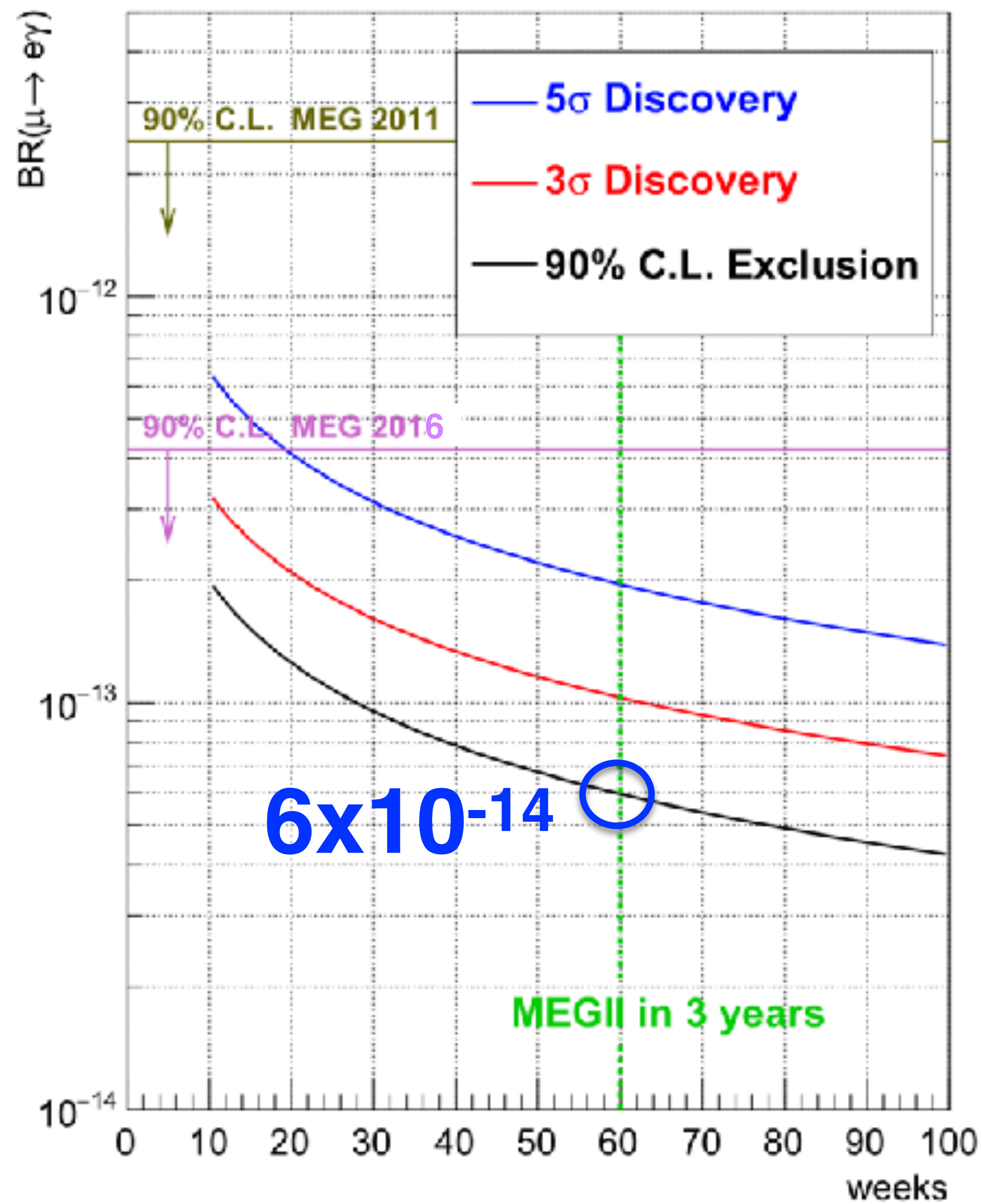
Readout Electronics



- Waveform data crucial for high rate environment
- Number of channels increased
  - For finer granularity
  - More compact boards necessary
- WaveDREAM developed by PSI
  - Waveform digitizer(DRS4) , simple trigger, amplifier and bias voltage supply (~200V) are integrated in a board, suitable for SiPM
- Online trigger important to manage high event rate and background suppression.
  - FPGA based trigger system prepared

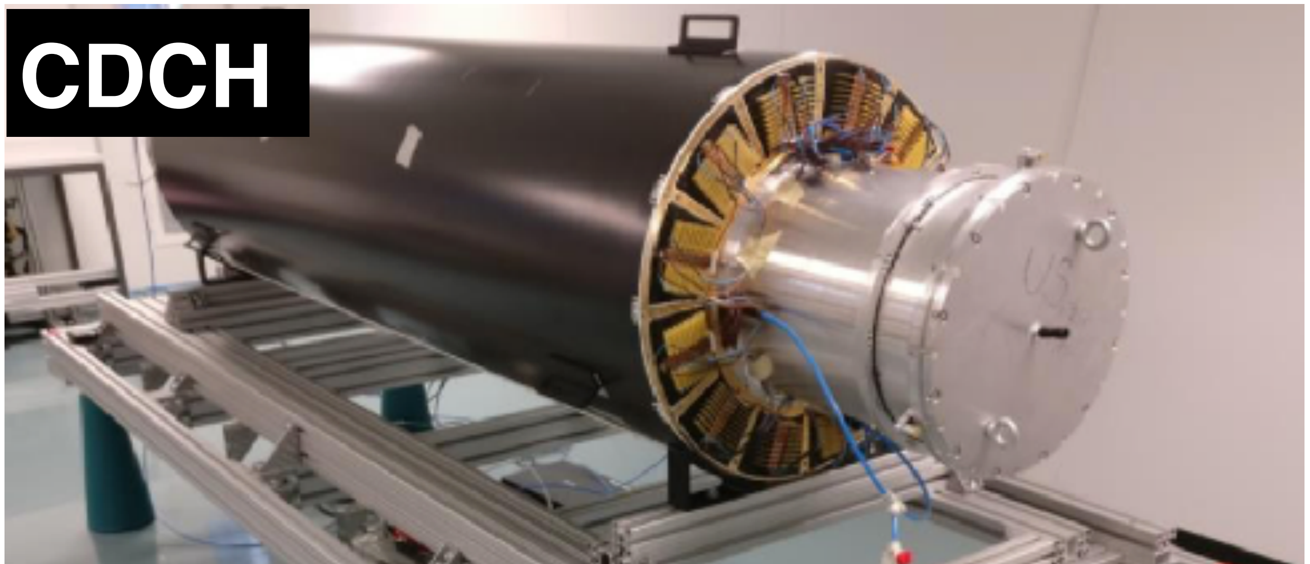
Sensitivity

Resolution	MEG	MEG II
E_{e+} (keV)	380	130
θ_{e+} (mrad)	9.4	5.3
ϕ_{e+} (mrad)	8.7	3.7
z_{e+}/y_{e+} (mm) core	2.4/1.2	1.6/0.7
E_γ(%) (w>2cm/<2cm)	1.7/2.4	1.0/1.1
u_γ, v_γ, w_γ (mm)	5/5/6	2.6/2.2/5
$t_{e\gamma}$ (ps)	122	84
Efficiency (%)		
Trigger	99	99
γ	63	69
e^+ (tracking × matching)	30	70

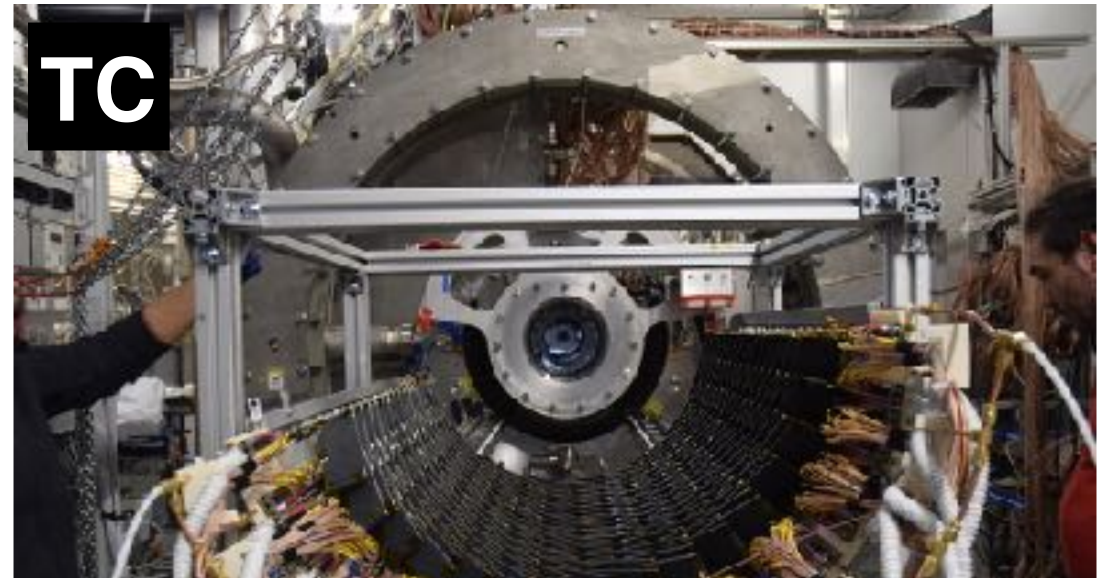


- Data for a few months exceed the current limit, and reach 6×10^{-14} in three years

Current status

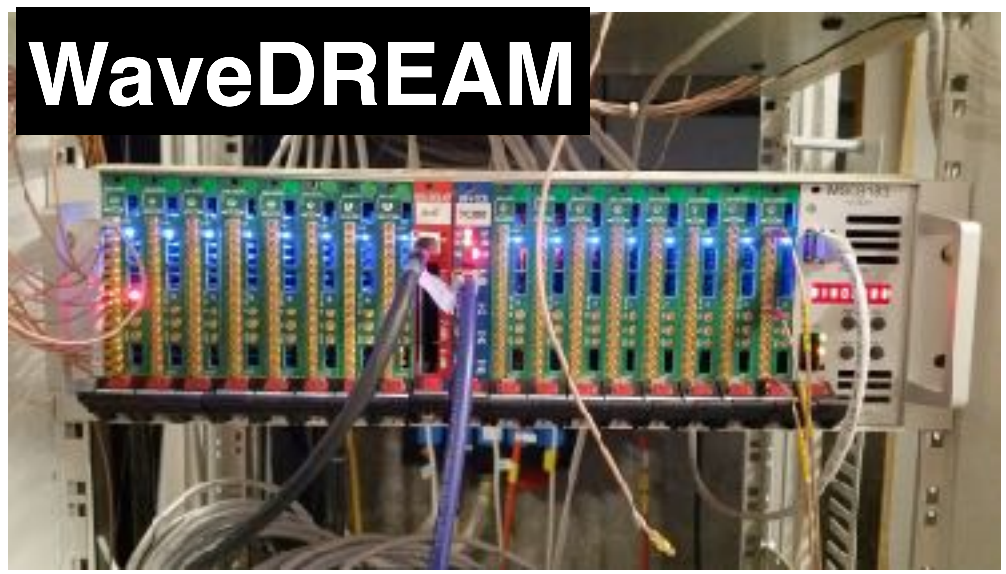


Construction finished in 2018. Detector commissioning after small modification will be restarted this fall.



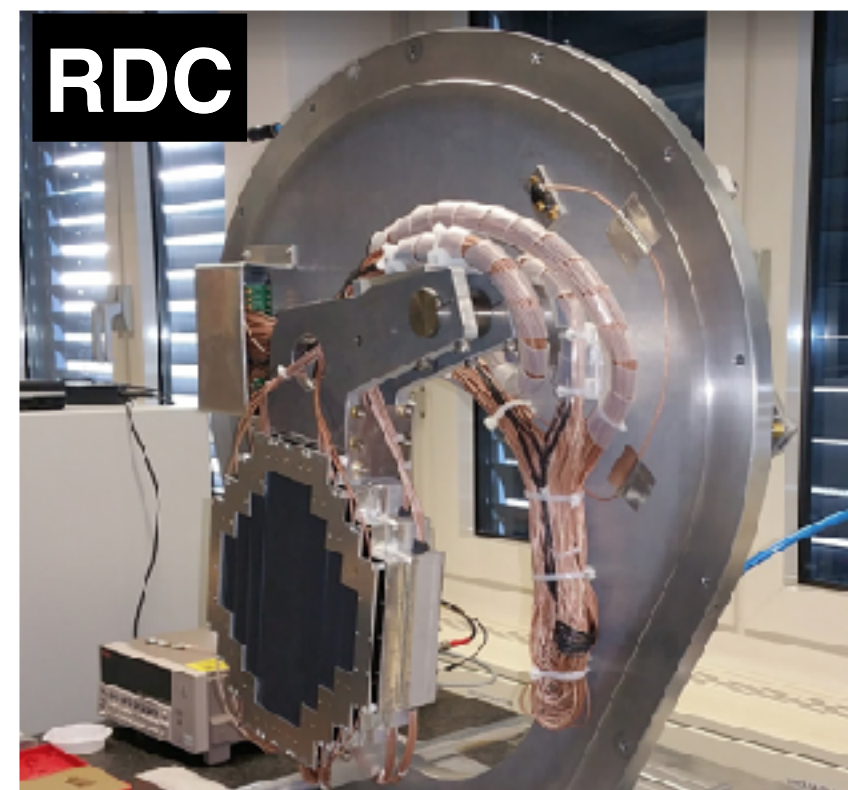
Construction finished in 2017. Basic performance test with muon beam finished

Construction finished in 2017. Performance check ongoing.



Tests of Prototype WaveDREAM with 6 crates (~1500ch.) and final version with 2 crates will be carried out this fall

Mass production next year



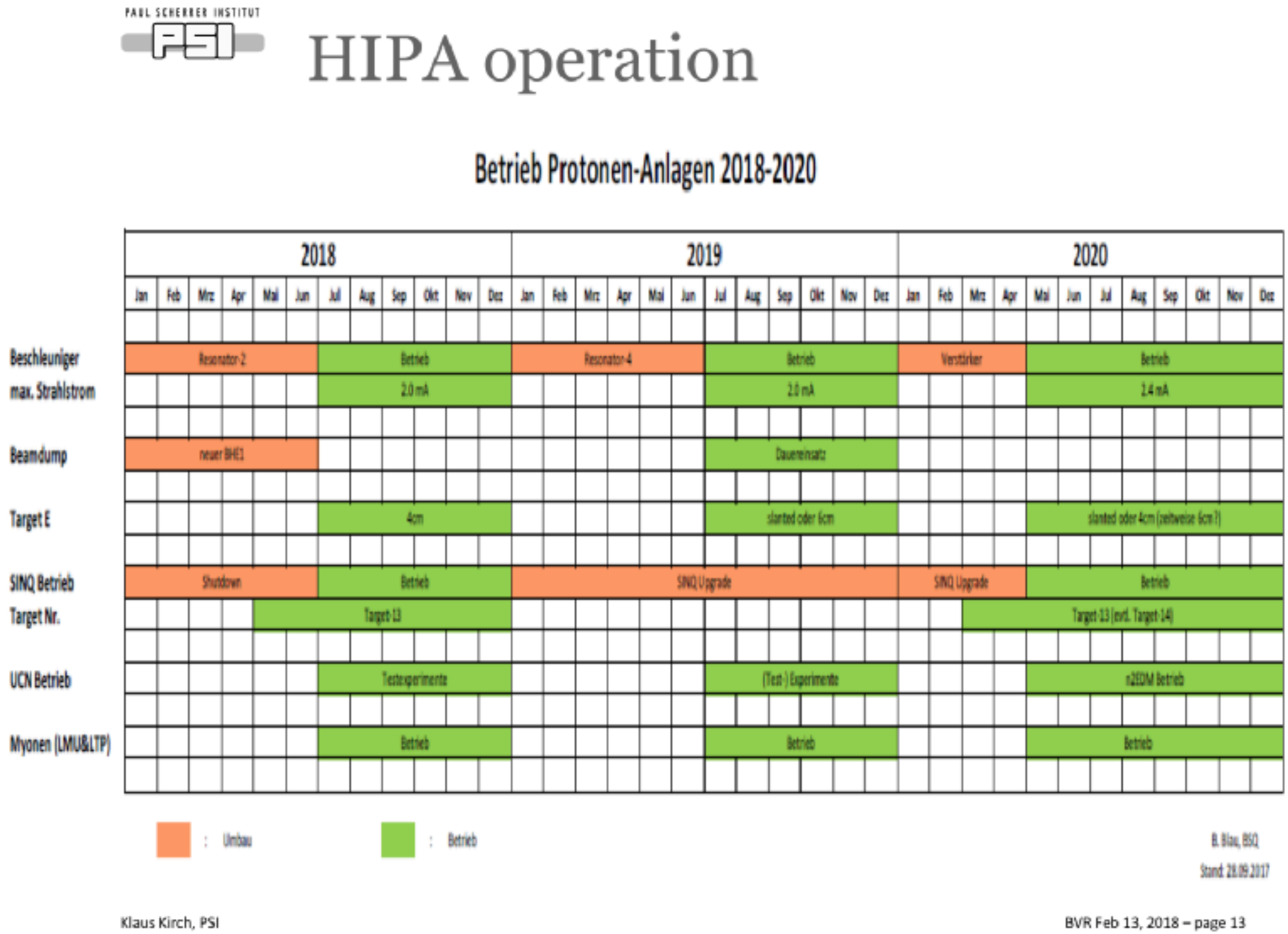
Downstream detector constructed in 2017, and performance test with muon beam finished.

Prospects & Summary

- MEG II Detector integration in August 2019, and muon beam time from September to December with limited no. of electronics

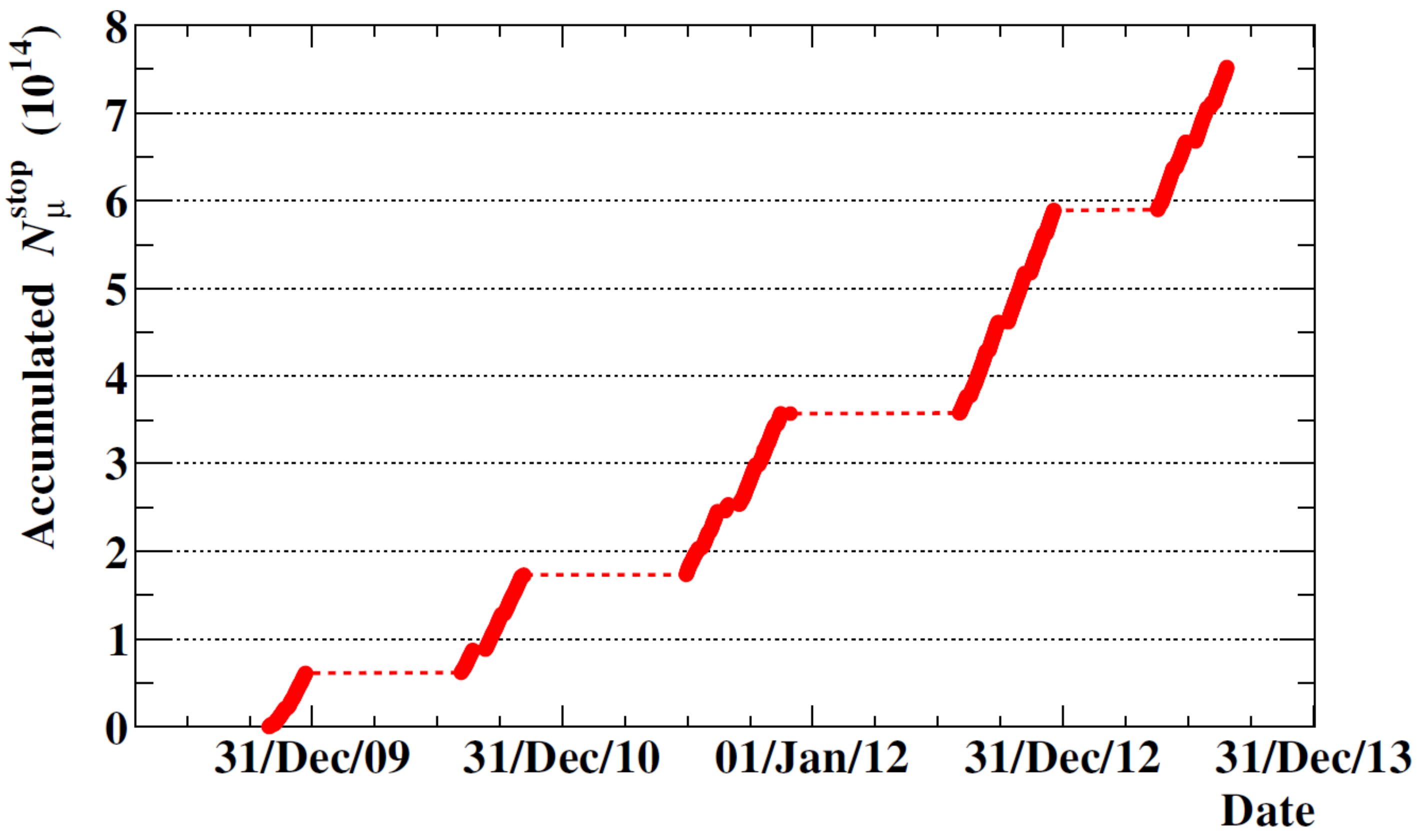
- Mass production of the readout electronics happens next year.
- Engineering run and physics run will follow.
- The sensitivity of the MEG II experiment will exceed the current limit with a few month data statistics, and will be improved by one order of magnitude with three years data.

HIPA operation in 2018-2020



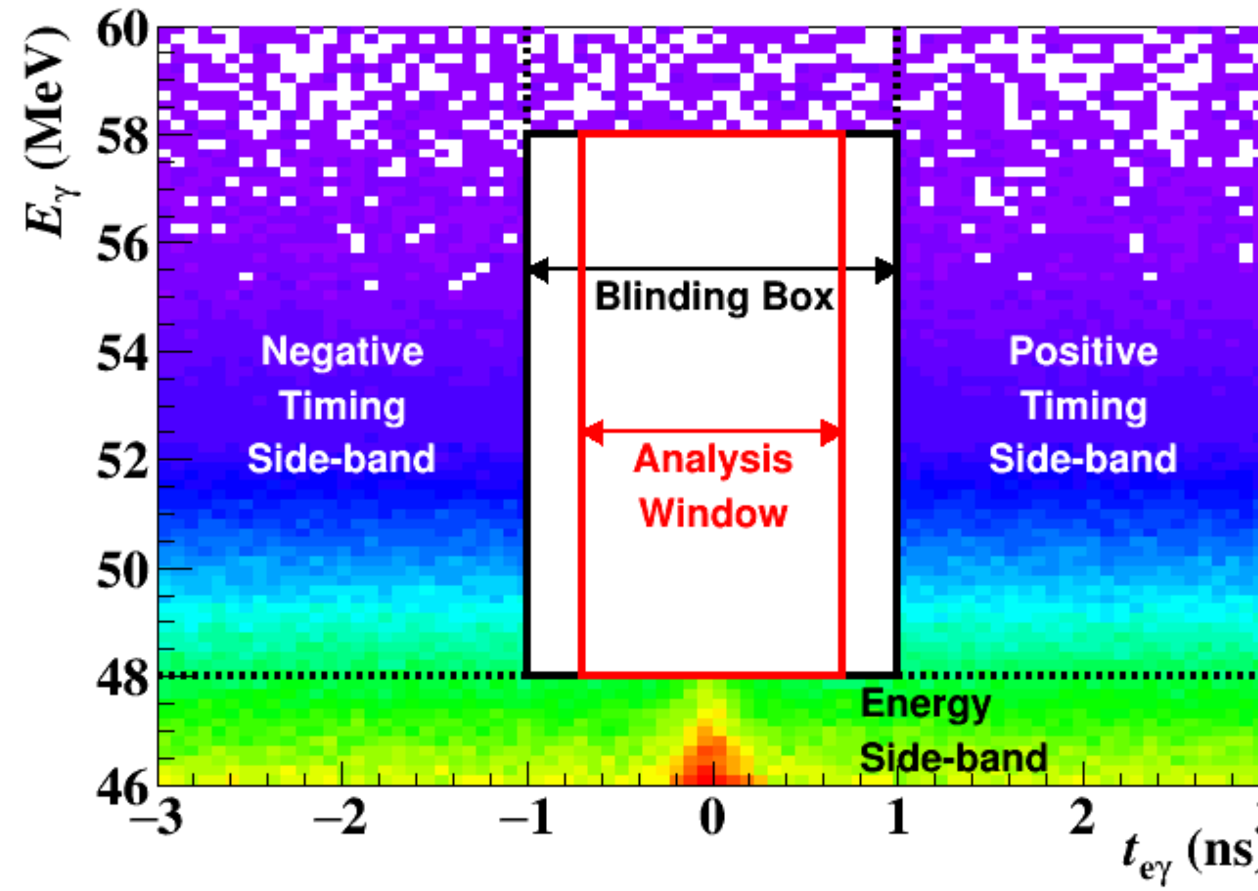
Final MEG dataset / Analysis

- Accumulated number of muons stopped on the target as a function of time



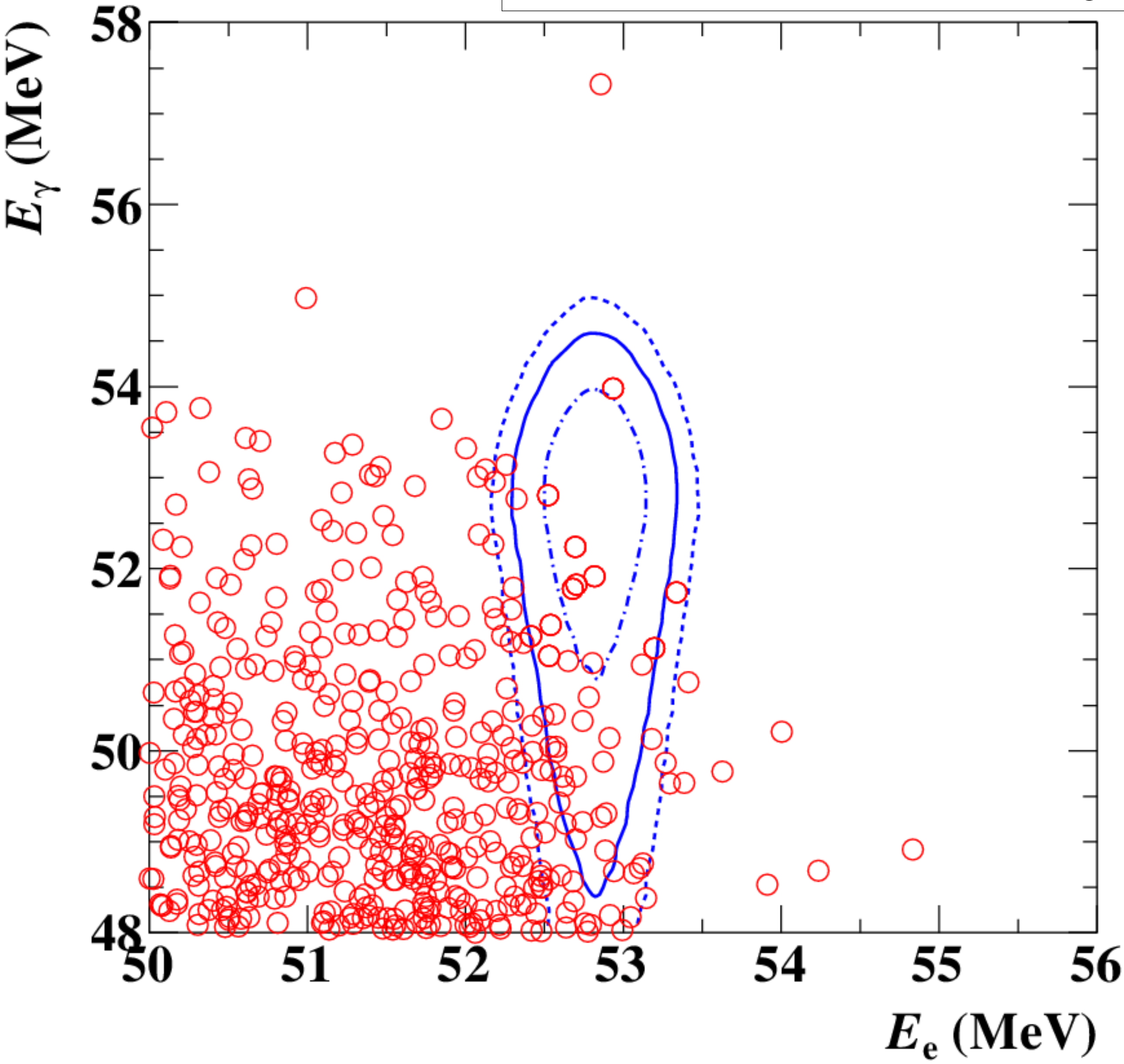
- Full dataset : 7.5×10^{14} μ^+ stopped on the target

- Blind analysis in (E_γ, $t_{e\gamma}$) plane
- Five observables $E_\gamma, E_e, t_{e\gamma}, \theta_{e\gamma}, \phi_{e\gamma}$
- Maximum likelihood analysis

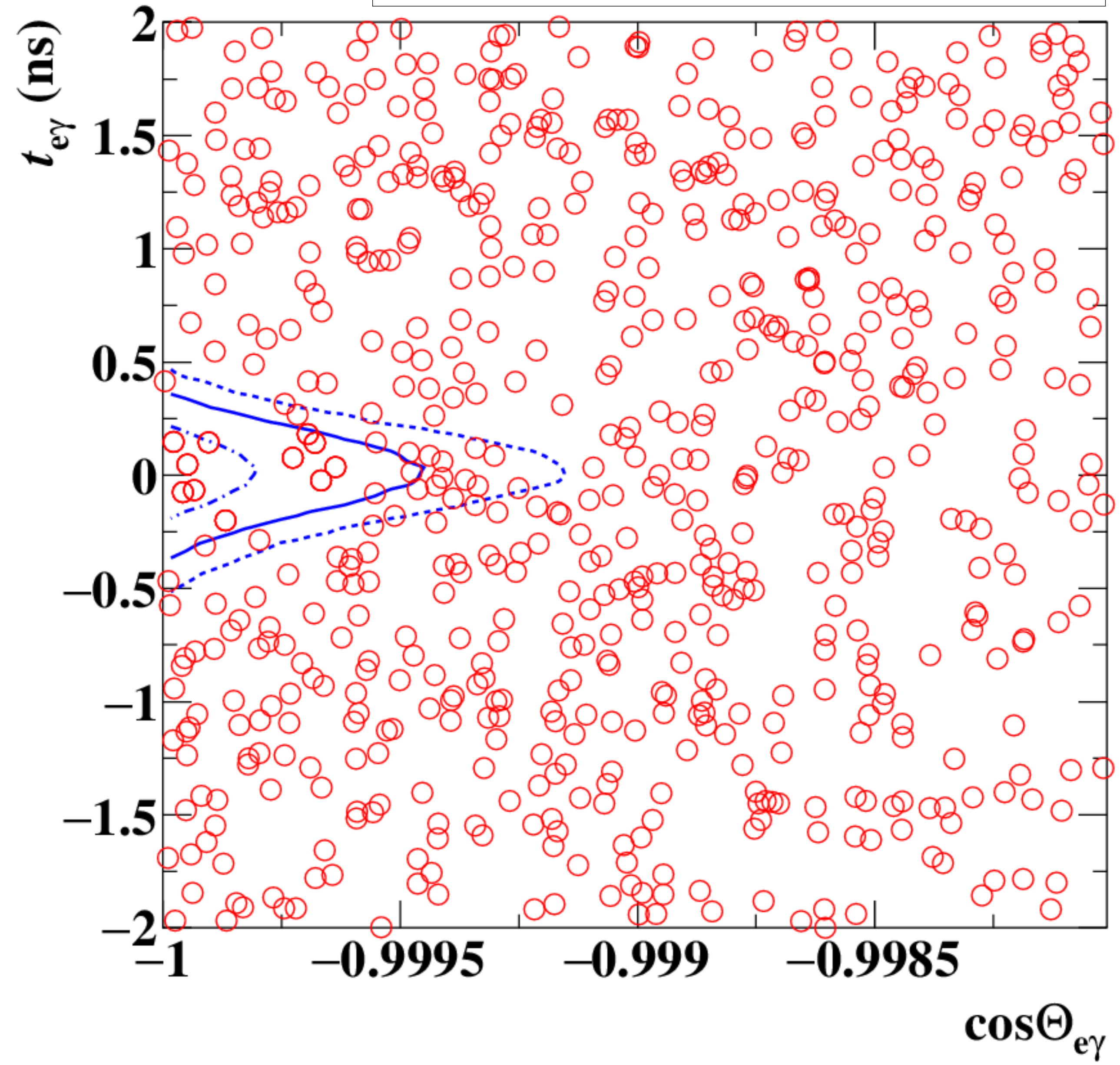


Event distribution

cosΘ<-0.99963 (90% ε_{signal})
$|t_{e\gamma}|$<0.2443ns (90% ε_{signal})



51<Eγ<55.5MeV (74% ε_{signal})
52.385<E_e<55MeV (90% ε_{signal})

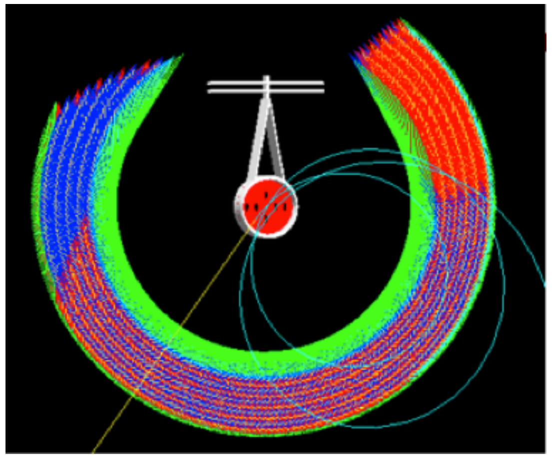


2009-2013 data

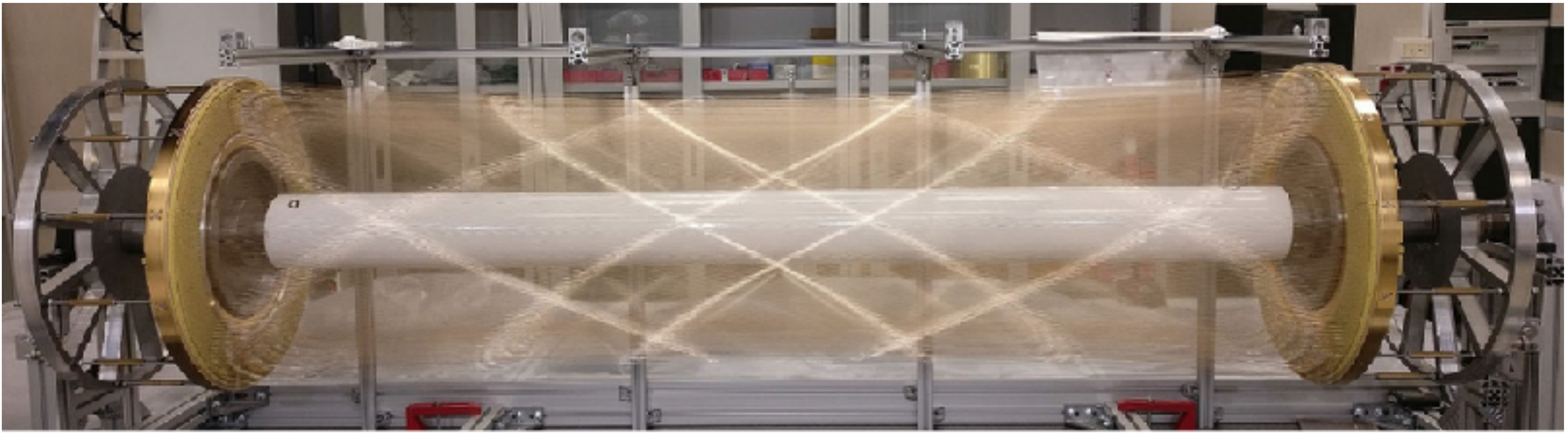
Signal PDF contour (1σ, 1.64σ, 2σ)

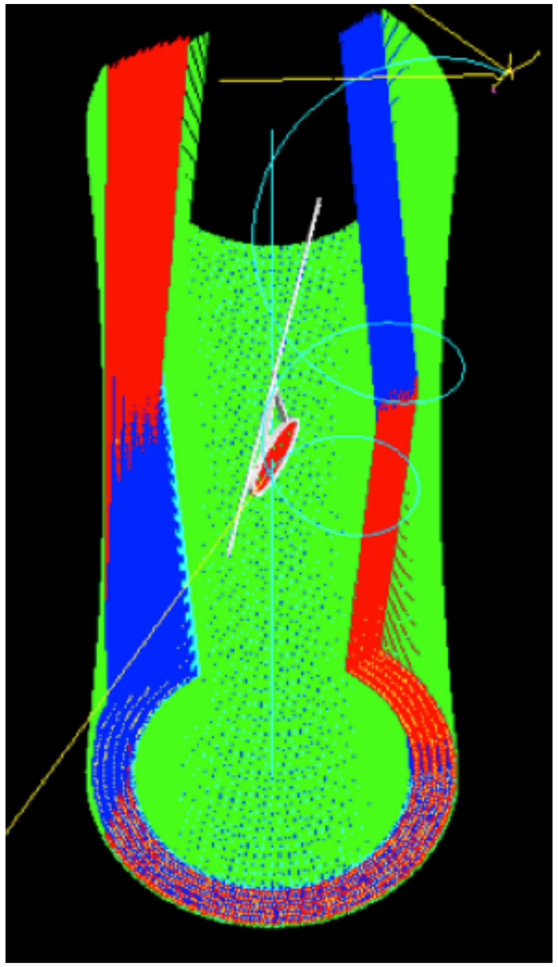
Cylindrical Drift Chamber

- Tracking 52.8MeV e^+ to reconstruct vertex, angle, and momentum
- Single volume wire drift chamber with 1280 anode wires
- Higher granularity, increased number of hits per track



MEG DCH	MEG II CDCH
16 modules	single volume
288 drift cells	1280 drift cells
40-80cm	2m long, stereo angle
$He:C_2H_6$=50:50	$He:iC_4H_{10}$=85:15

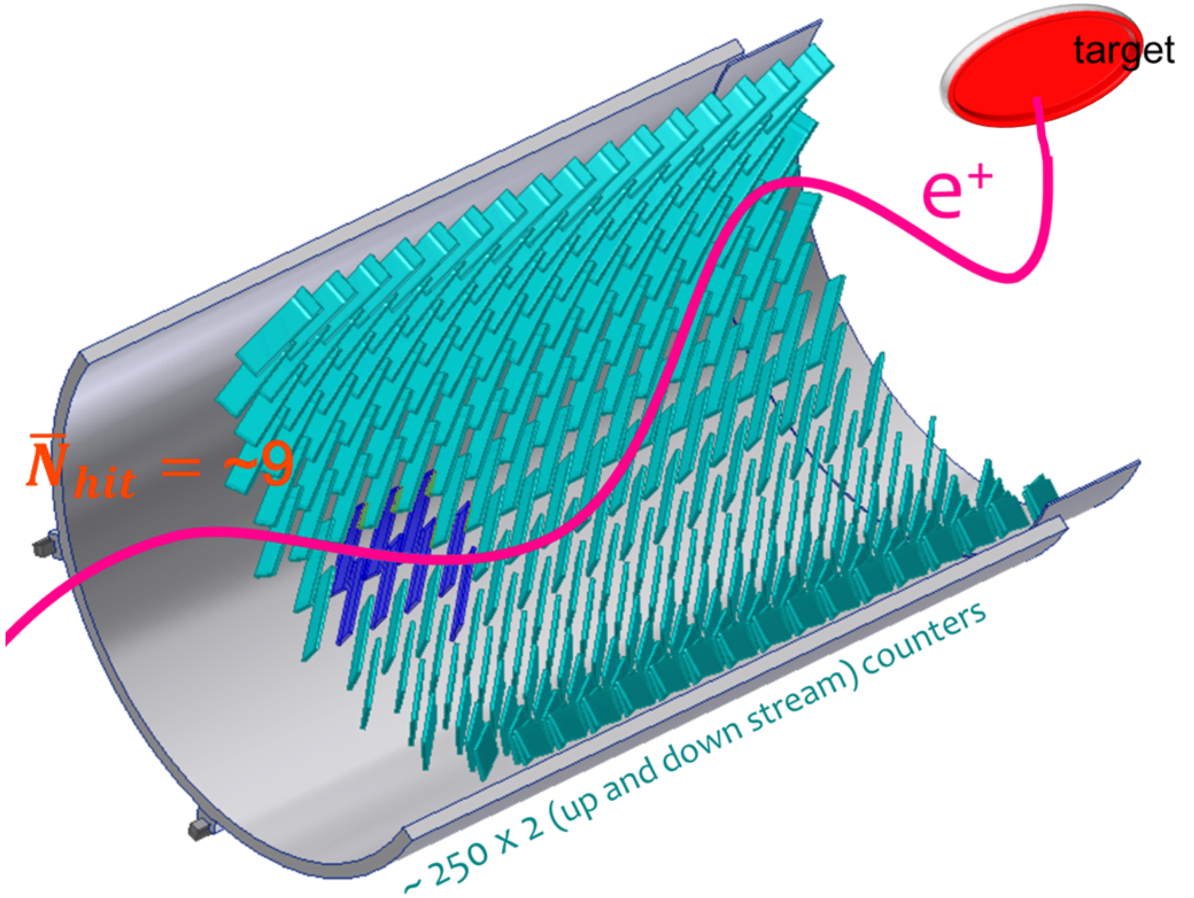


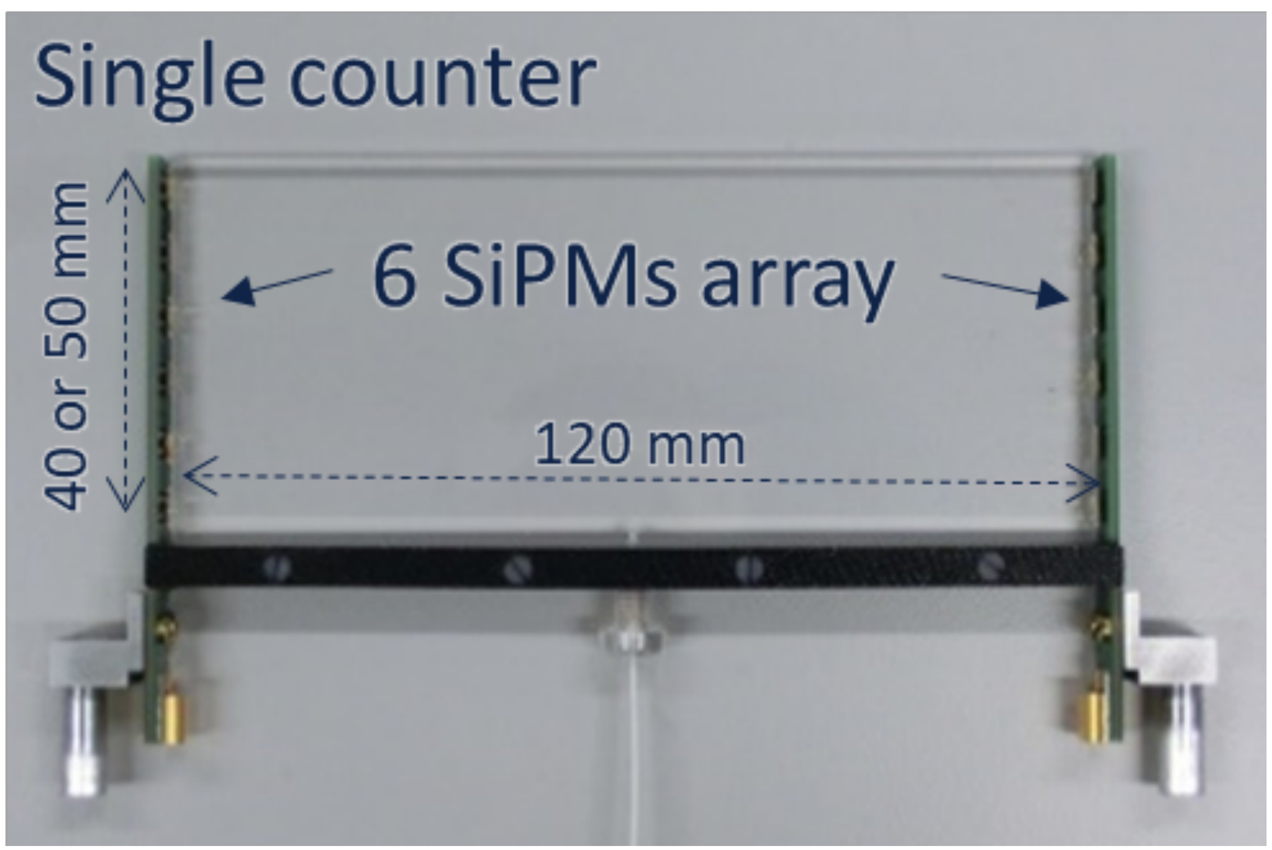


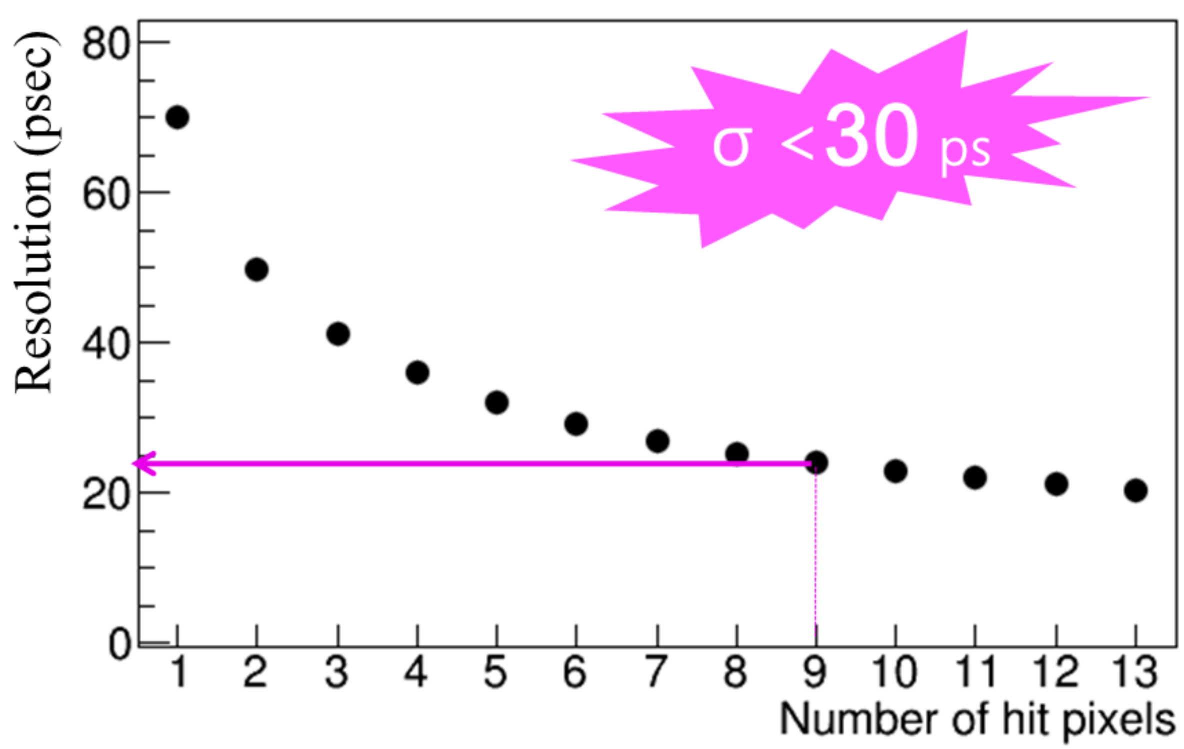
MEG II timing counter

- Time measurement of 52.8MeV e^+

MEG TC	MEG II TC
15 scintillating bars x 2	256 scintillator plates x 2
$4 \times 4 \times 80$ cm^3	$12 \times (4 or 5) \times 0.5$ cm^3
Readout by PMTs	Readout by SiPM
Single bar hit	Multiple counter hits

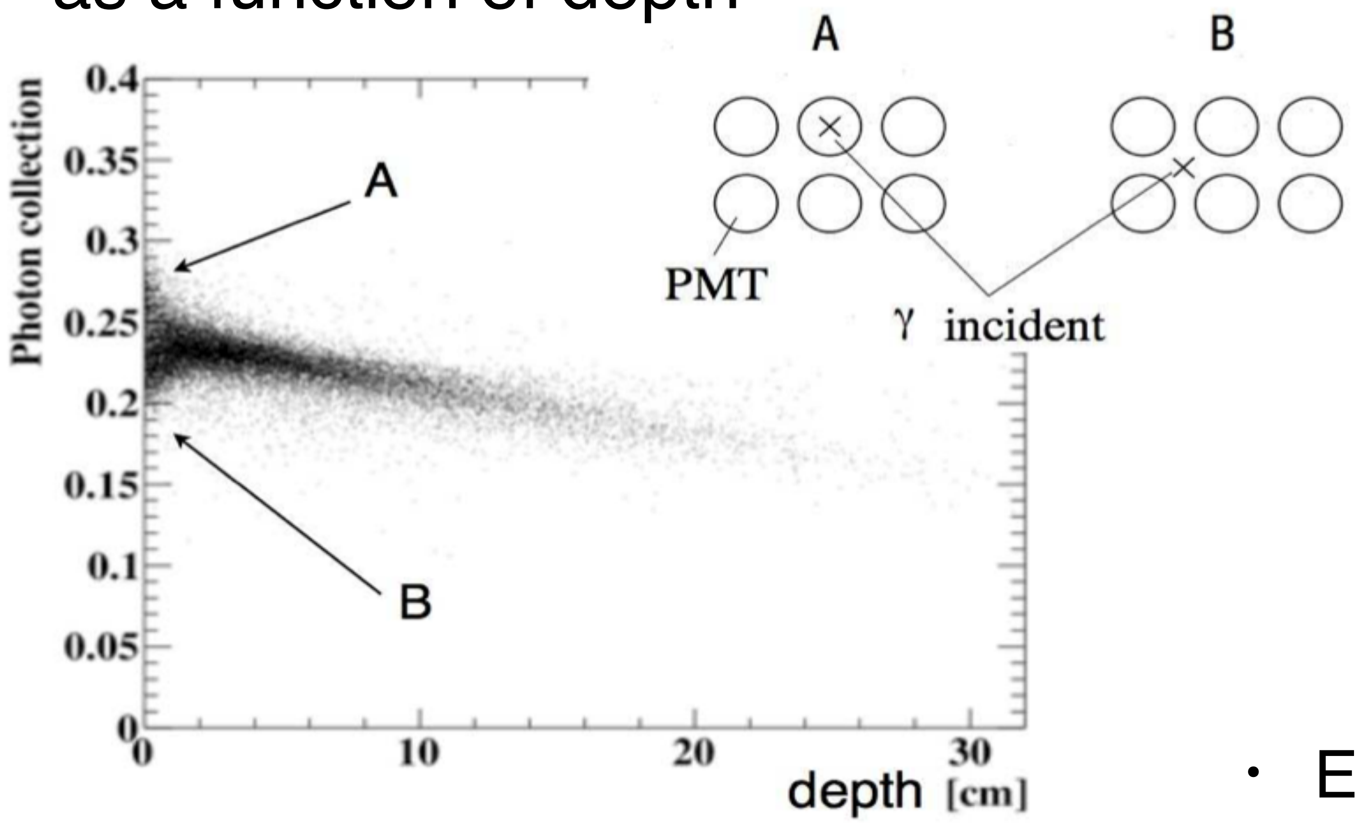


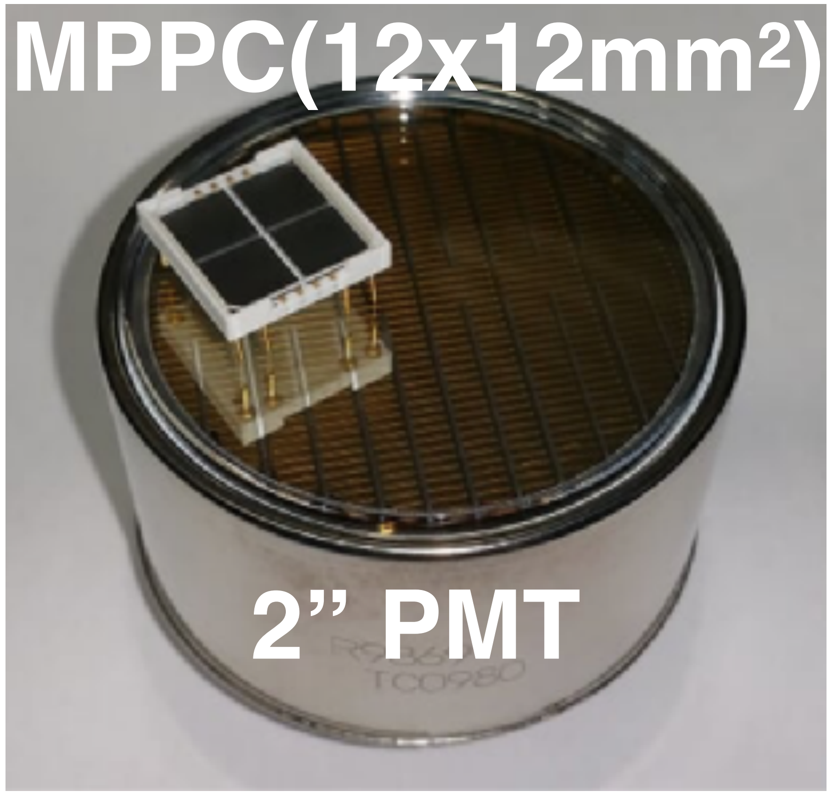




MEG II liquid xenon γ detector

of photons collected by PMTs
as a function of depth





- Energy, position, time measurement of 52.8MeV γ from μ→eγ decay

MEG LXe	MEG II LXe
900L LXe	900L LXe
216 2"PMTs (γ entrance)	4092 12x12mm^2 MPPCs
630 PMTs (other faces)	668 PMTs

- Non uniform response for shallow events
- Replace inner PMTs with MPPCs
- Better granularity, better uniformity →Better energy, position resolution