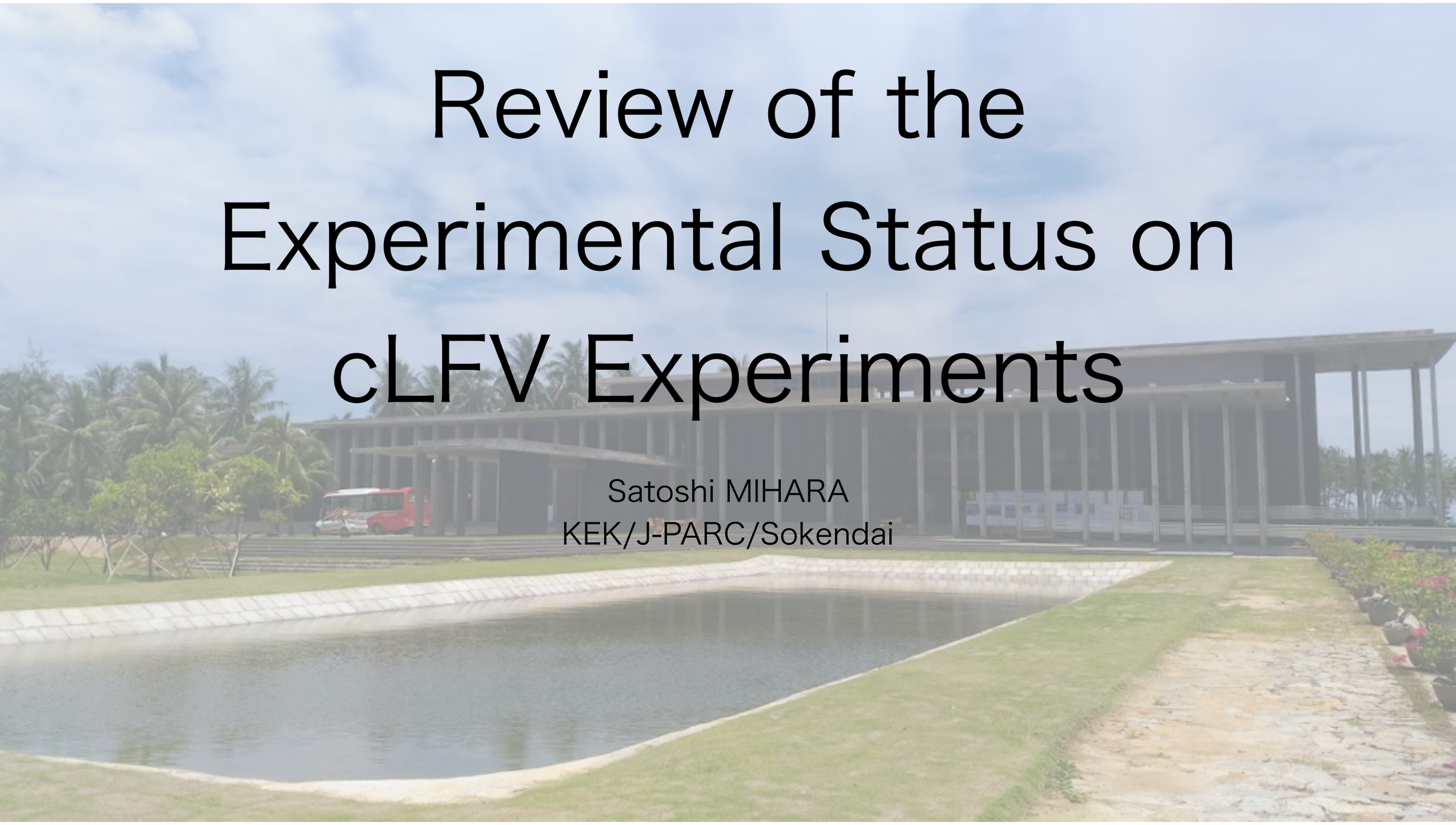
Review of the Experimental Status on cLFV Experiments



Satoshi MIHARA
KEK/J-PARC/Sokendai

KEK 大学共同利用機関法人 高エネルギー加速器研究機構

J-PARC

Outline

- Introduction
- CLFV experiments using muons
  - DC muon beam experiments
  - Pulsed muon beam experiments
- (CLFV experiments at higher energy machines)
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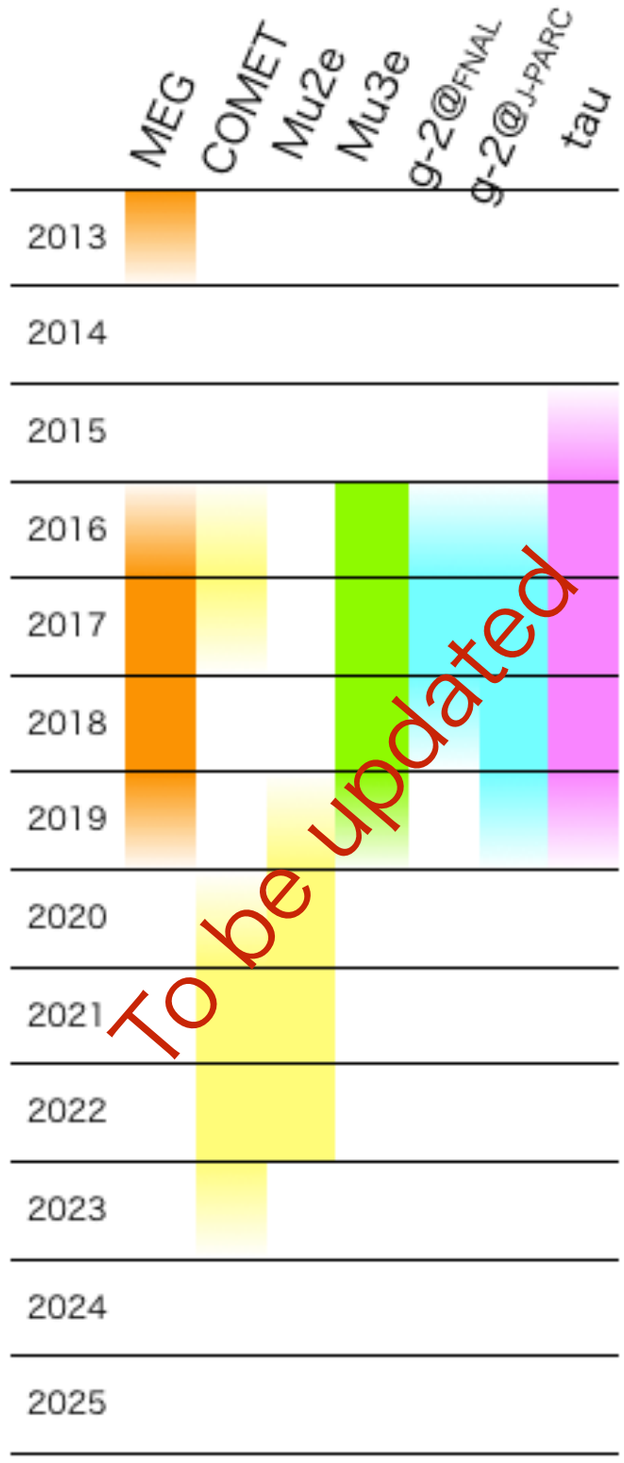
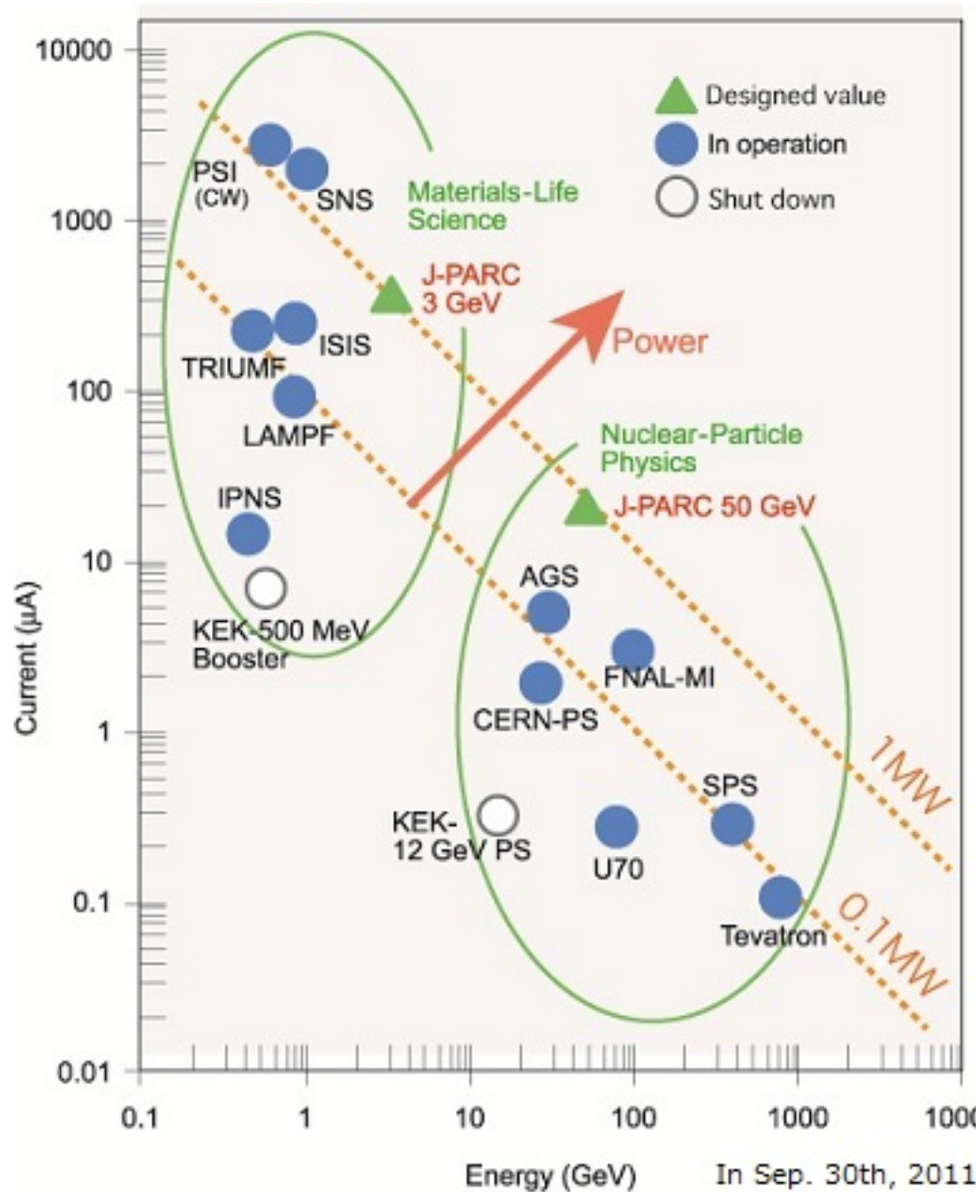


SM NuFACT2013 @ IHEP

cLFV Search Experiments

- No Standard Model background thanks to tiny neutrino mass
- Large amount of muons available thanks to current high-power proton machines
  - Lower energy machine preferred to perform searches using stopped muons in most cases
  - Normal muon decay modes well understood
  - taus at B factories (or future tau/charm factory)
- Many BSM models predict the existence
  - Previous talk



cLFV Experiments using Muons

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J-PARC

DC or Pulse?

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  - $\mu \rightarrow e\gamma$, $\mu \rightarrow e\ e\ e$

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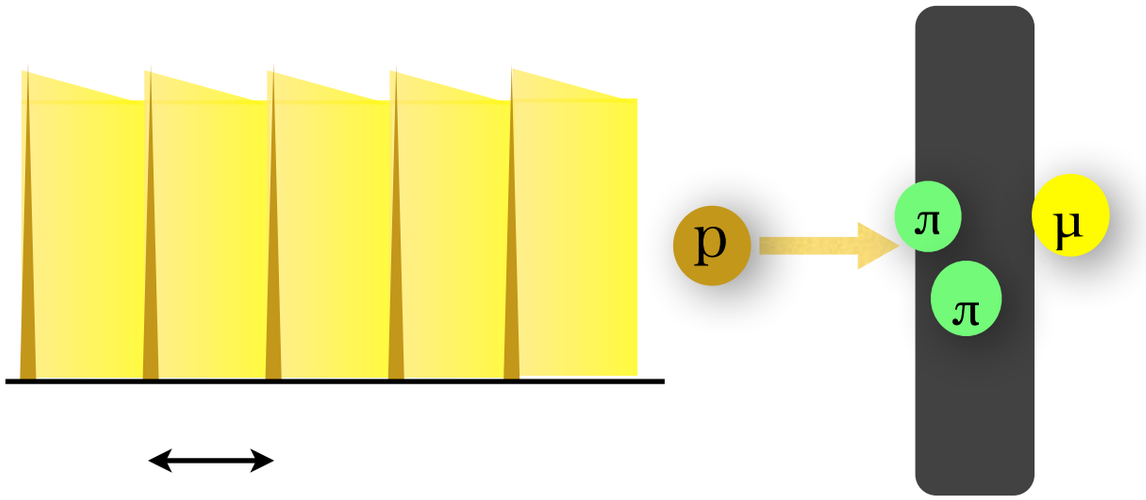

DC or Pulse?

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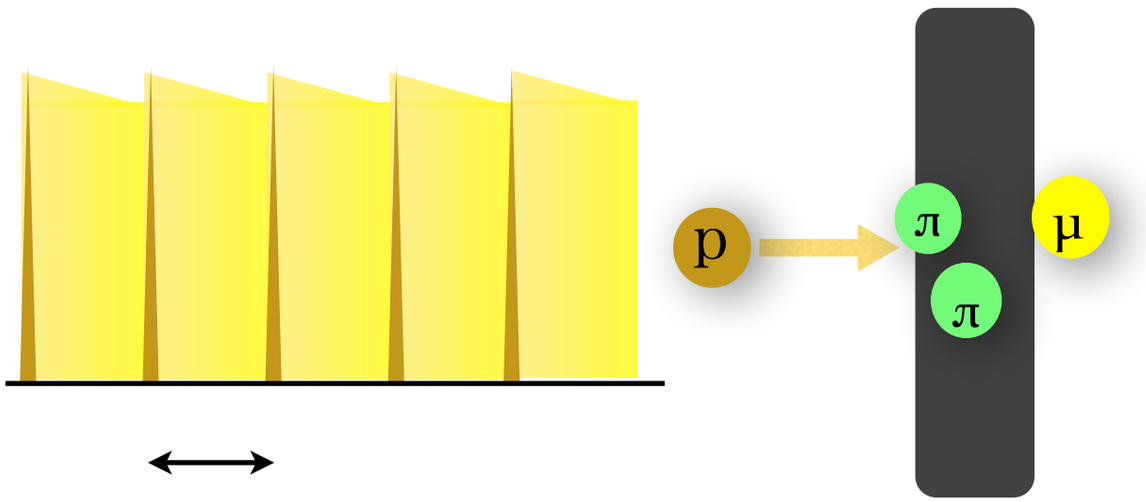

~20 ns

- Pulse beam for non-coincidence experiments
  - μ-e conversion

DC or Pulse?

- DC beam for coincidence experiments
  - $\mu \rightarrow e\gamma$, $\mu \rightarrow e\ e\ e$
- Pulse beam for non-coincidence experiments
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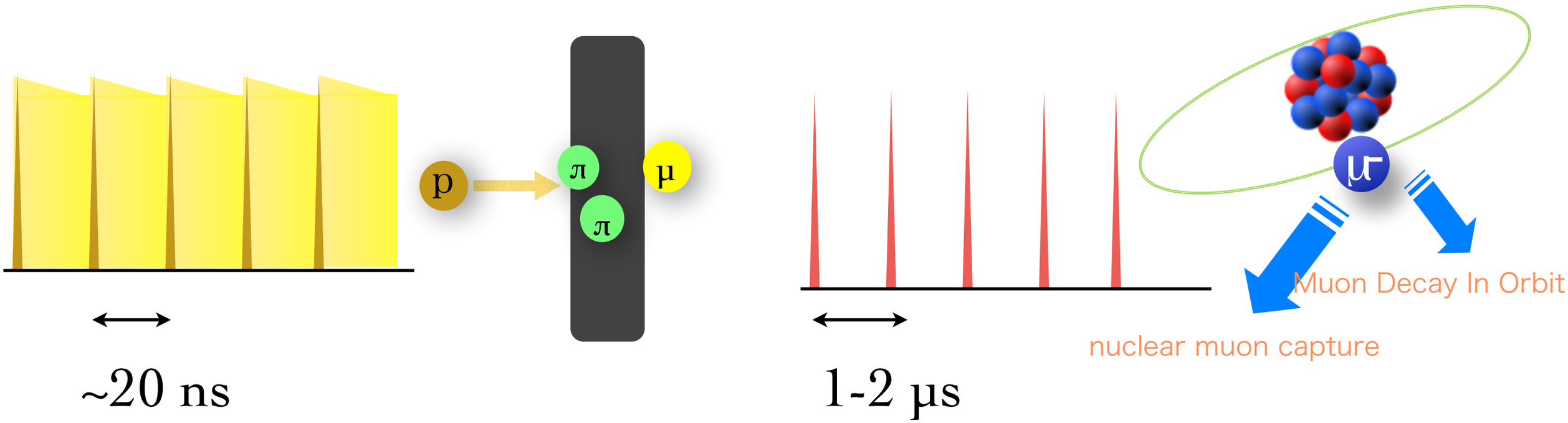
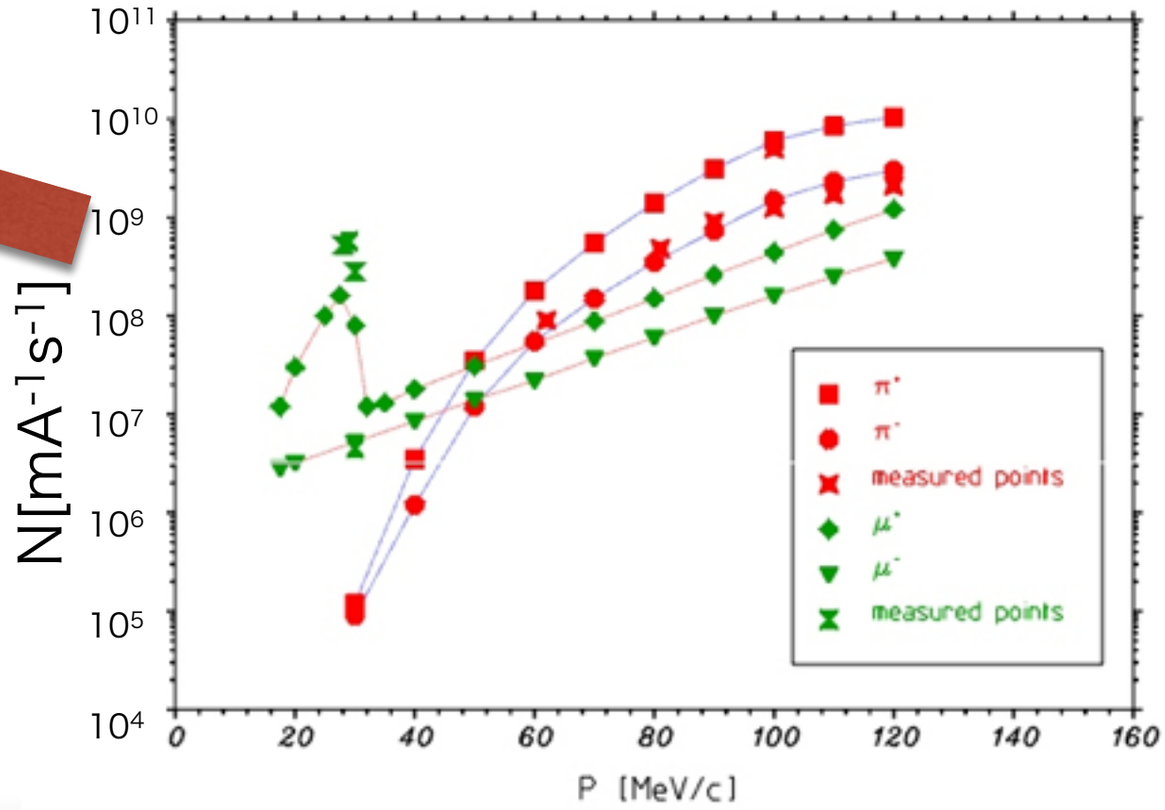


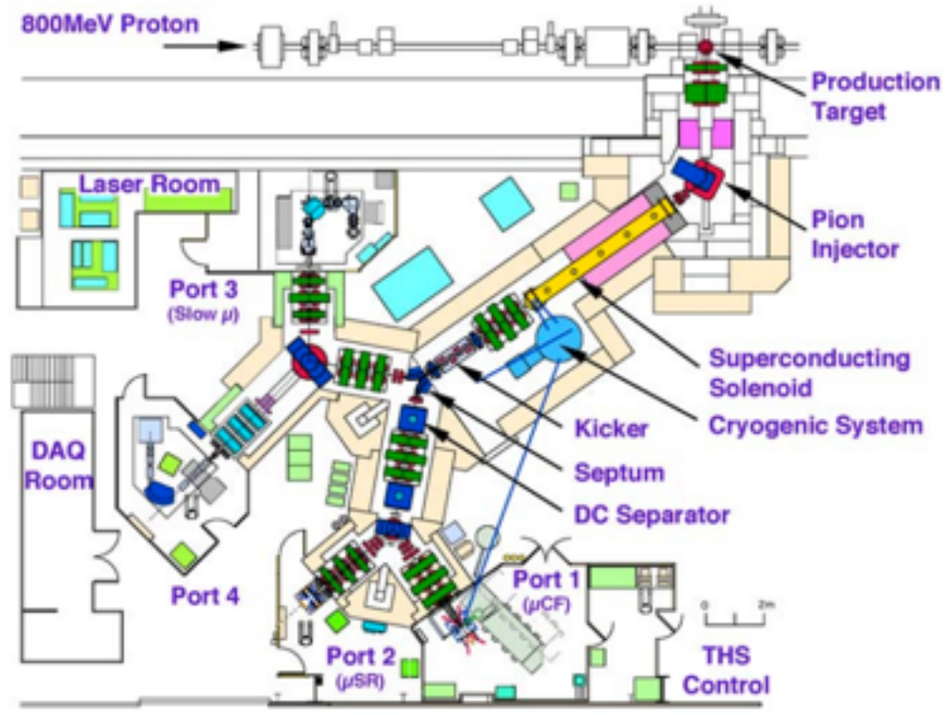
PSI DC Muon Beam

Injection Energy	72 MeV
Extraction Energy	590 MeV
Extraction Momentum	1.2 GeV/c
Energy spread (FWHM)	ca. 0.2 %
Beam Emittance	ca. 2π mm×mrad
Beam Current	2.2 mA DC
Accelerator Frequency	50.63 MHz
Time Between Pulses	19.75 ns
Bunch Width	ca. 0.3 ns
Extraction Losses	ca. 0.03%

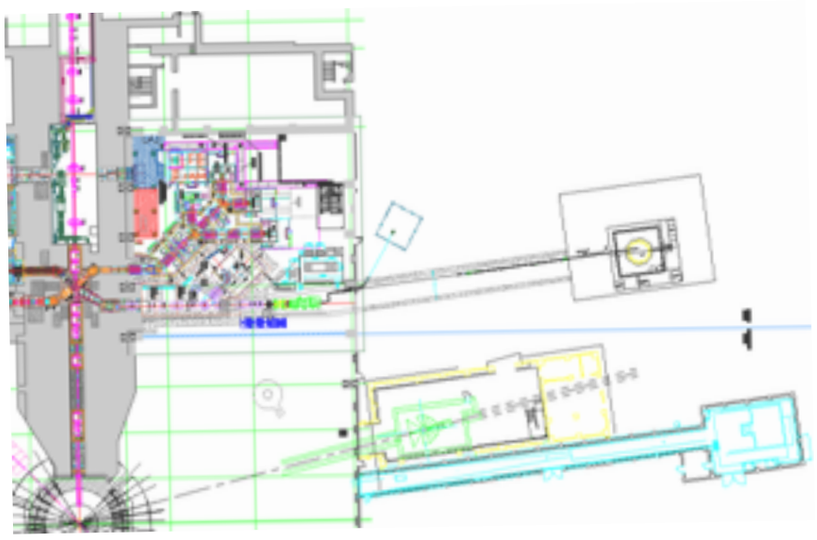


Pulsed Muon Beam Facility

- RIKEN-RAL muon facility
  - 800MeV-300μA, 50Hz
  - Surface mu: 1.5x10^6 /sec
- J-PARC MLF
  - 3GeV, 1MW (goal), 25Hz
  - Surface mu: > 3x10^7 /sec (as of 2016 Jan)
  - 3x10^8 /sec at H-Line (future)



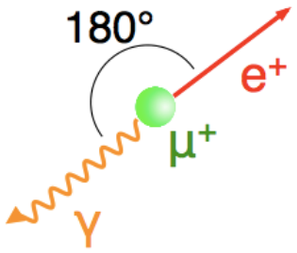
Layout of the RIKEN-RAL Muon Facilty



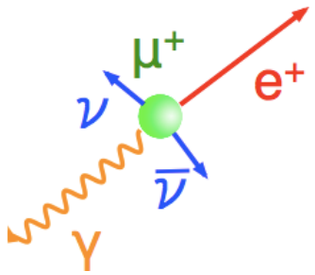
J-PARC MLF H-Line

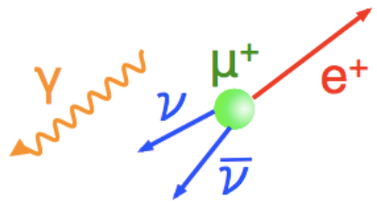
MEG & MEG II

Signal



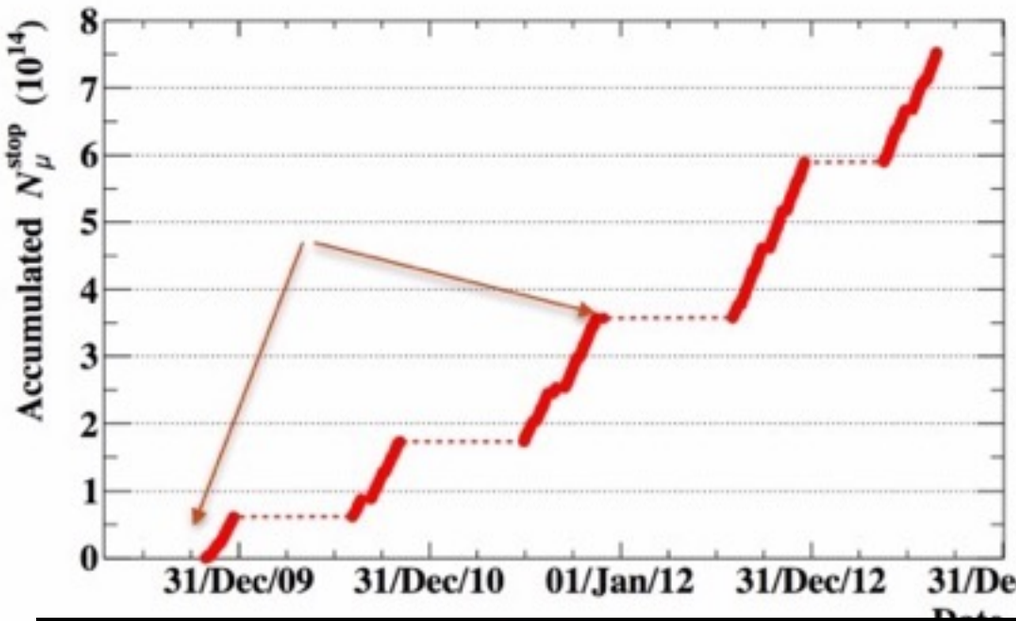
Background

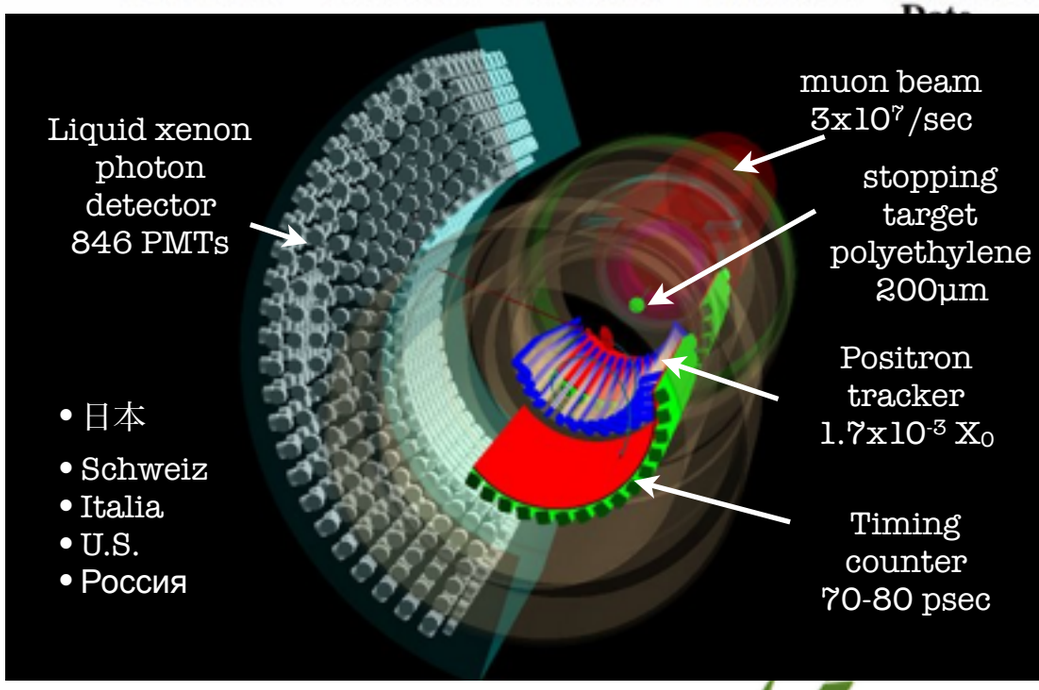




- MEG@PSI
  - Search for $\mu^+ \to e^+ \gamma$ using 3x10^{7}Hz muon beam
  - Liquid Xe photon detector & COBRA positron spectrometer
  - DAQ in 2008-2013
  - **Final upper limit result published: 4.2x10^{-13} @ 90% C.L.**
  - European Physical Journal C, 76(8), 1-30
- Detector upgrade to achieve 10 times better sensitivity : MEG II
- See presentation by Marco Venturing (WG4) for more details

MEG Muon Statistics



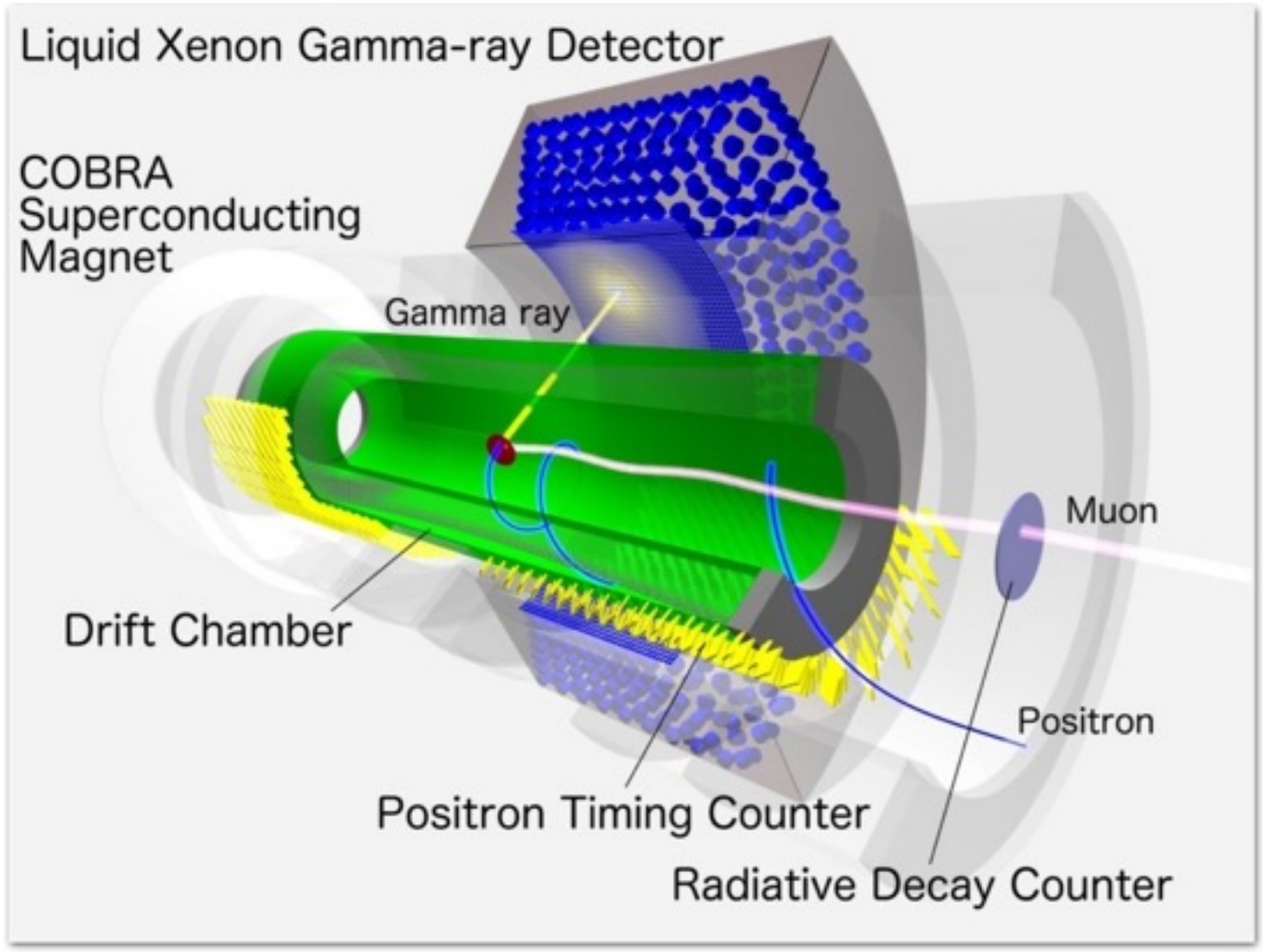


MEG II

- Improve resolutions by about factor 2 everywhere

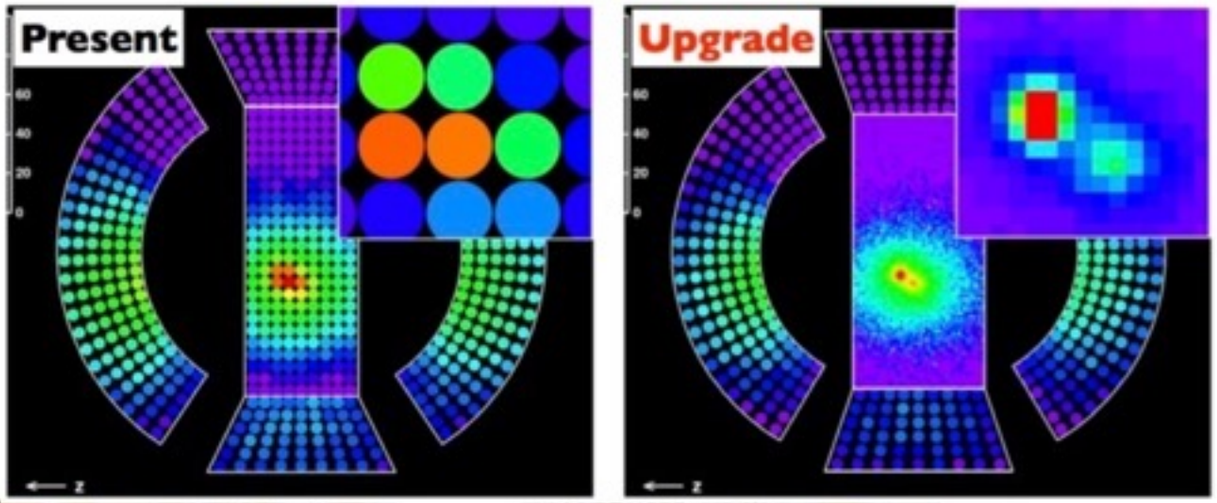
- μ beam rate of 7×10^7 Hz to reach the sensitivity of 4×10^{-14}

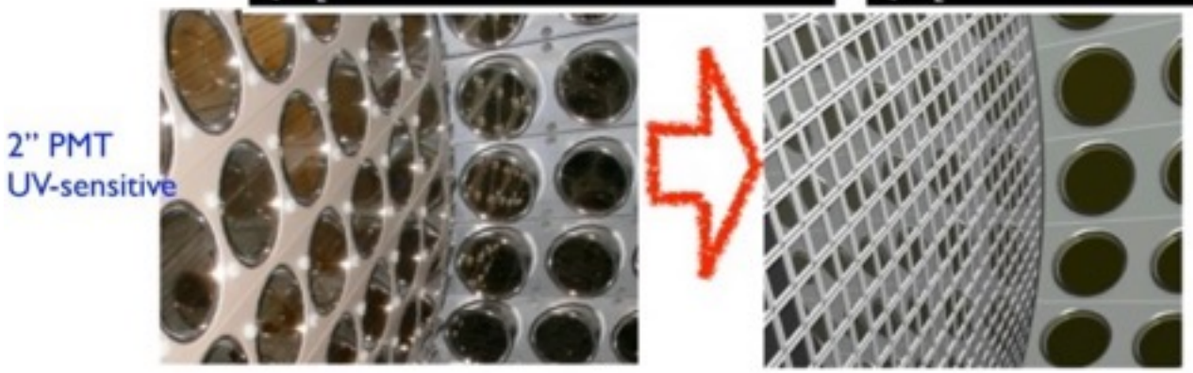
- Engineering run in 2016

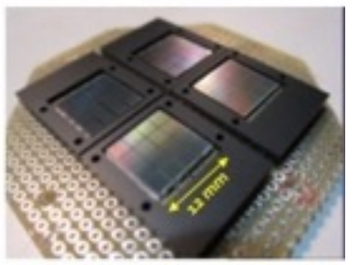


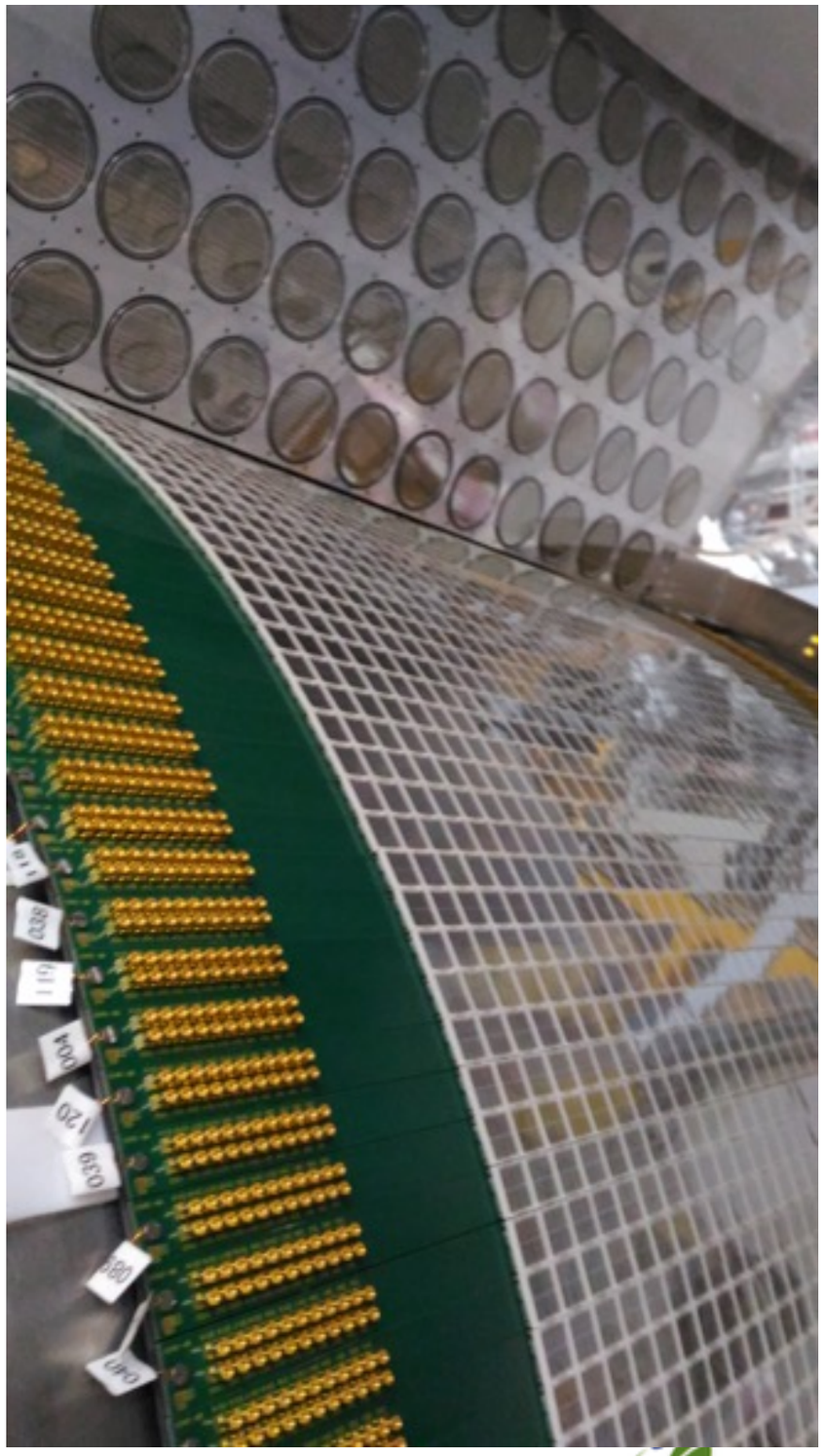
- See presentation by Angela Papa (WG4) for more details

MEG II LXe Upgrade





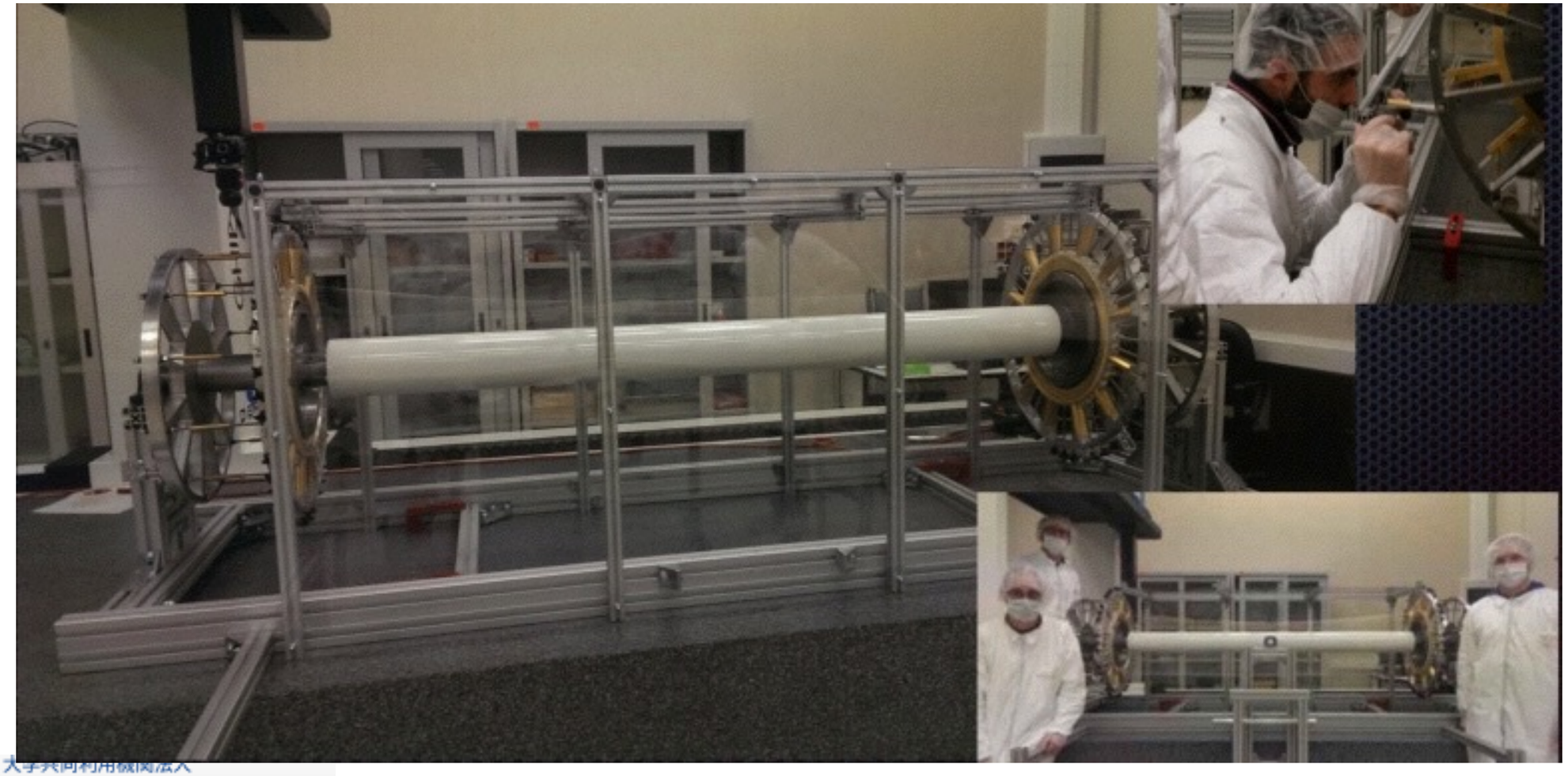




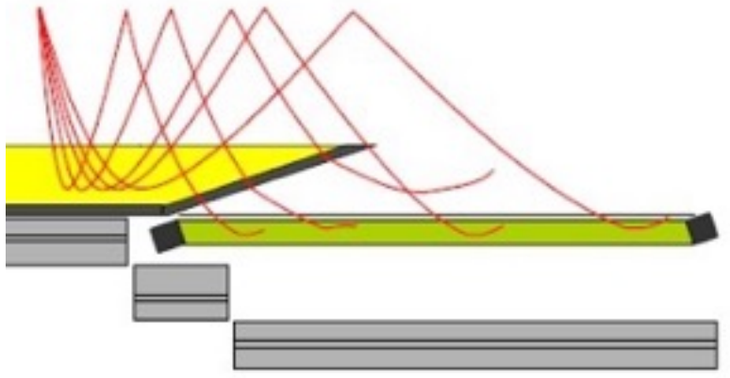
- Replace 2-inch PMTs with VUV-SiPM to cover the front face
- 4000 SiPM with minimum material
- Installation completed July/2016

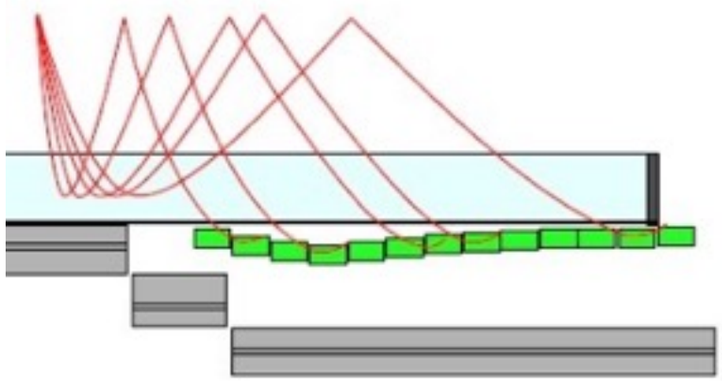
MEG II Drift Chamber

- Single volume, 2m long stereo wire & low mass
- More hits provides better resolutions
  - σ_{Ee} = 130keV, σ_{angles} = 5mrad

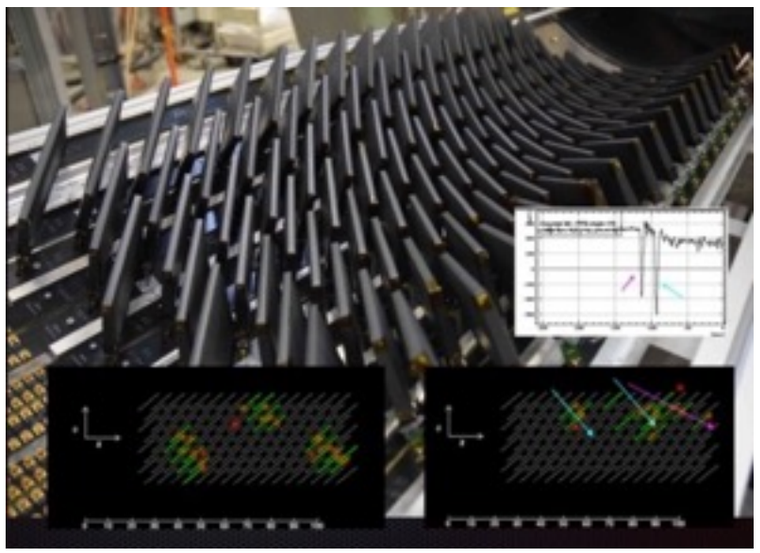


MEG II Timing Counter



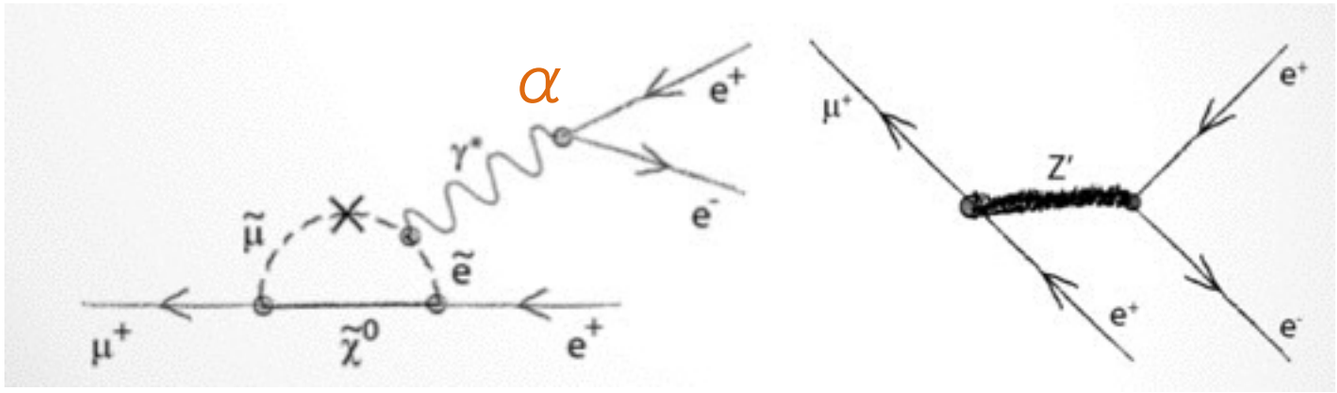


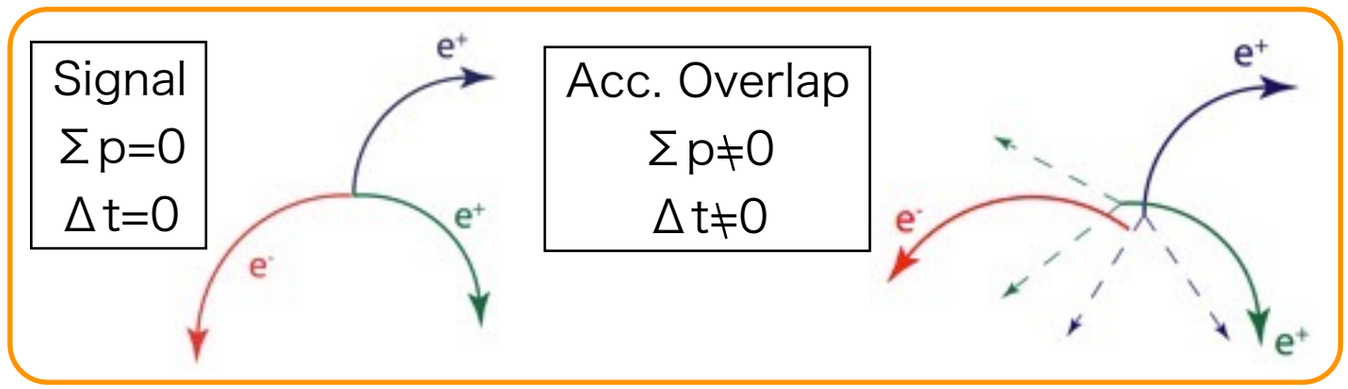
- Pixelated plastic scintillators read by SiPM
- Best resolutions σ~30psec anticipated for multiple counter hits events

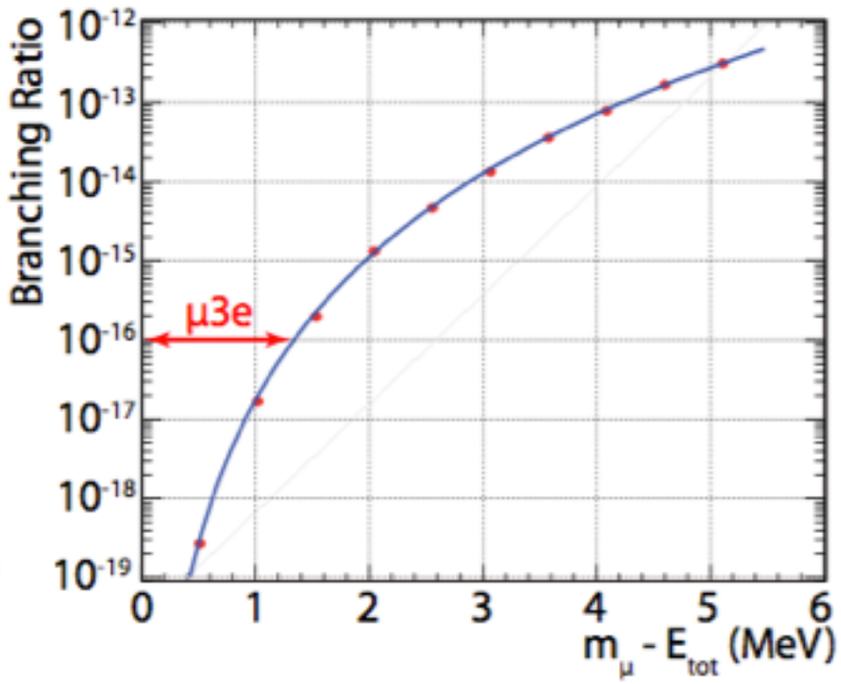


Mu3e: $\mu \rightarrow$eee Search using DC Muon Beam

- Another channel sensitive to cLFV with DC muon beam
  - 1.0×10^{-12} (90% C.L.) by SINDRUM
  - **Goal : 10^{-16} in 3 steps**
    - **Phase I in 2018-2020 Sensitivity:~10^{-15}**
- Measure all electron tracks precisely
- most severe BG —
  - $\mu^+ \rightarrow e^+ e^+ e^- \nu \nu$
- See presentation for more details by Angela Papa (WG4)

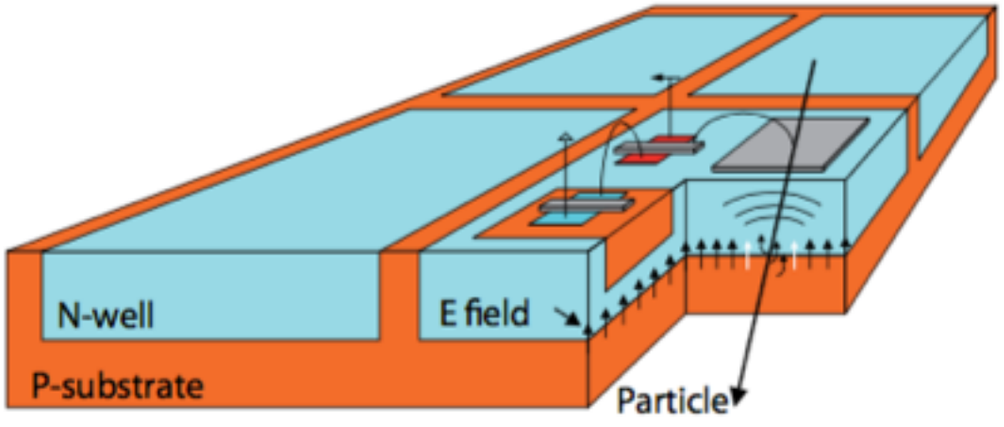






Suppress BG by more than **16 orders of magnitudes**

Mu3e: Detector Technology

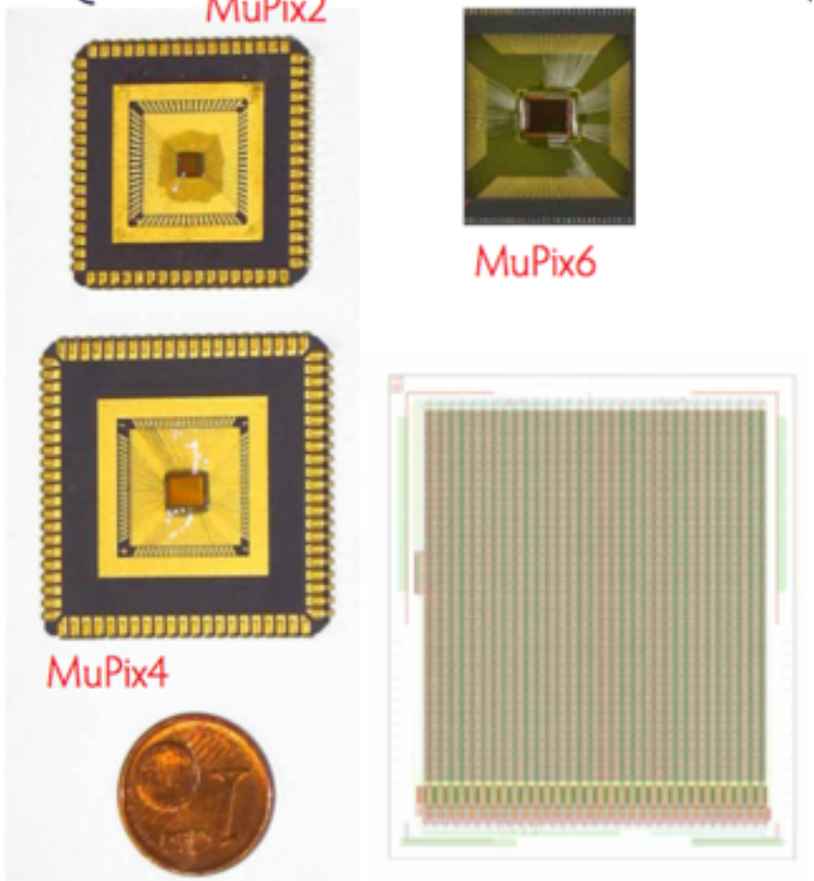


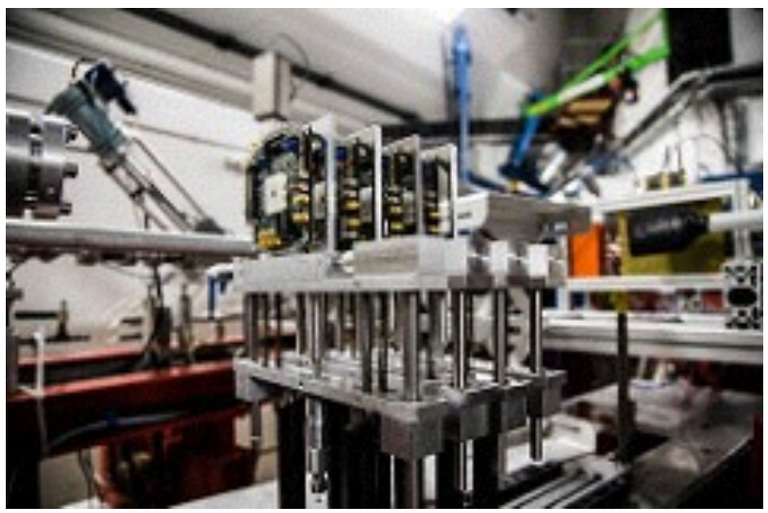
. NIM A 582 (2007) 876

High voltage monolithic active pixel sensors - Ivan Perić

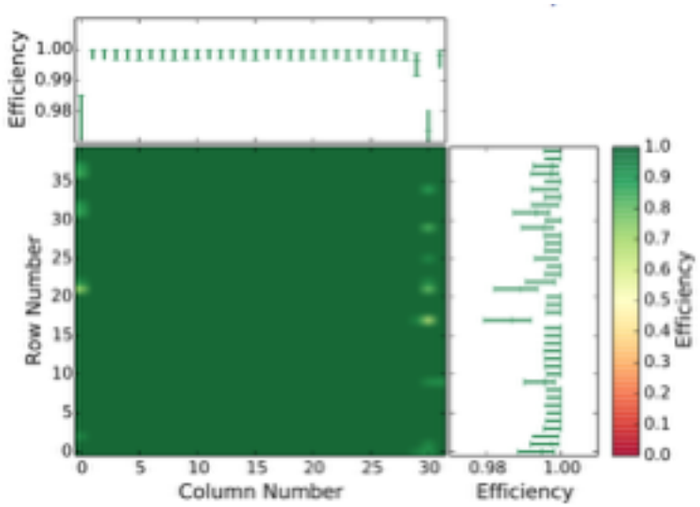
- thinned down to < 50 μm
- Logic on chip: Output zero suppressed hit addresses and timestamps

5 generations of prototypes, MuPix7 is current generation with all features of final sensors



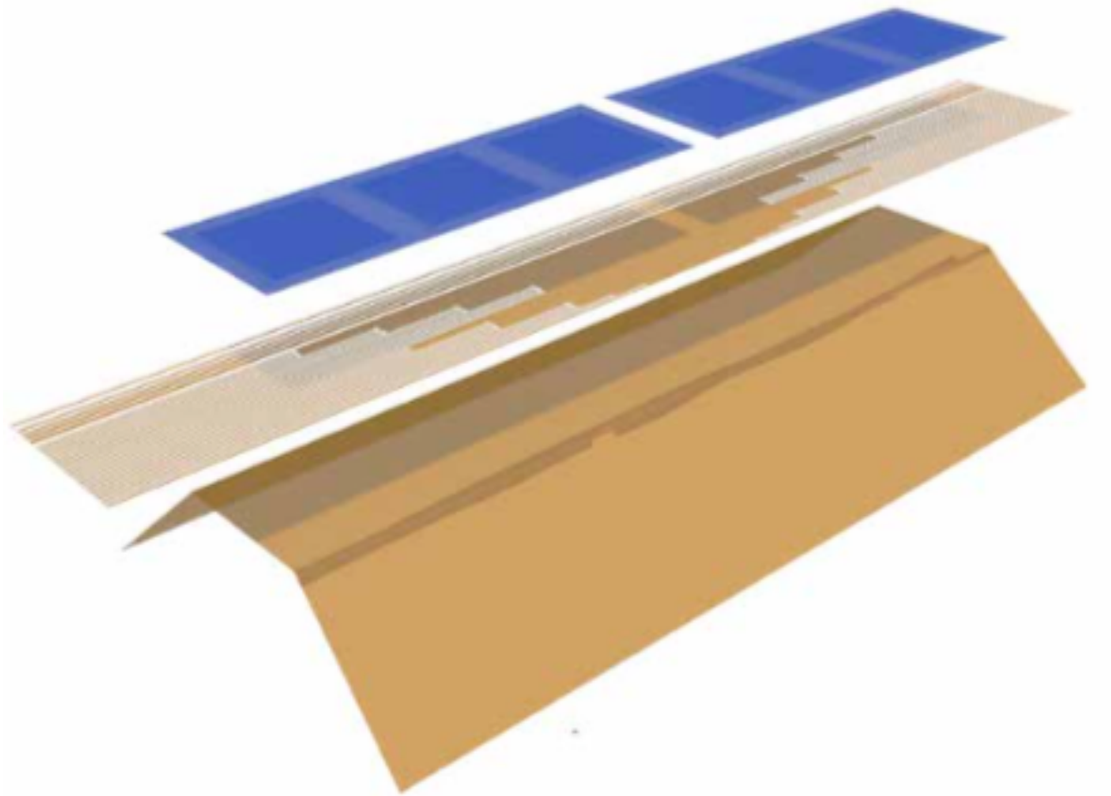


Mainz test beam in June 2016

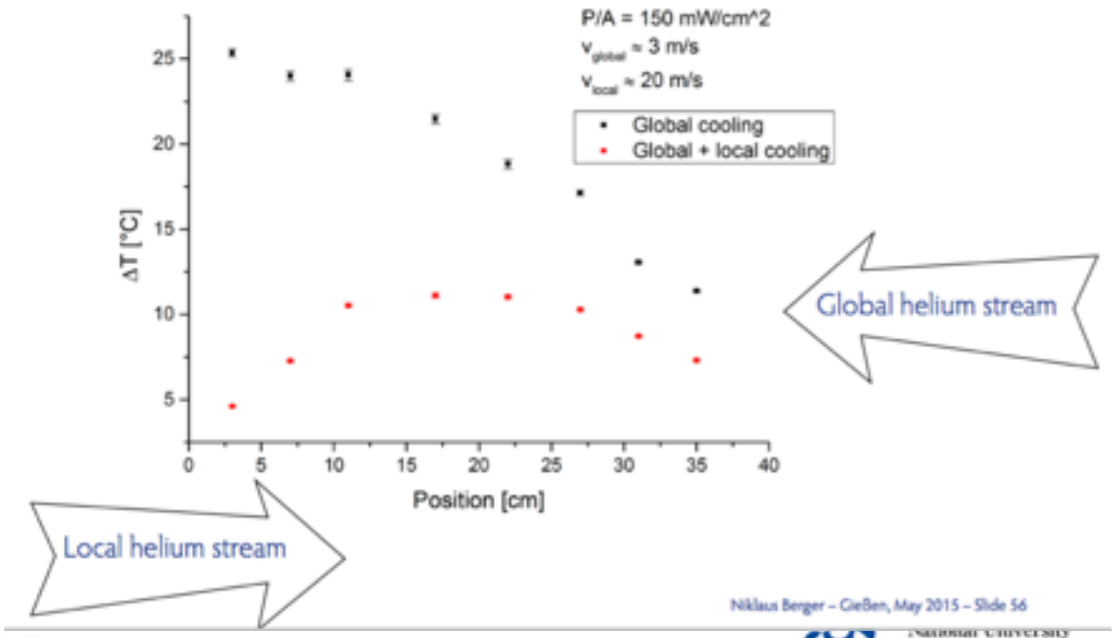


Efficiency above 99%

Mu3e: Detector Building

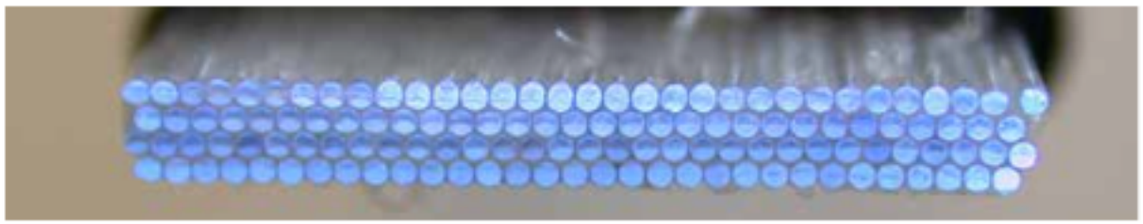


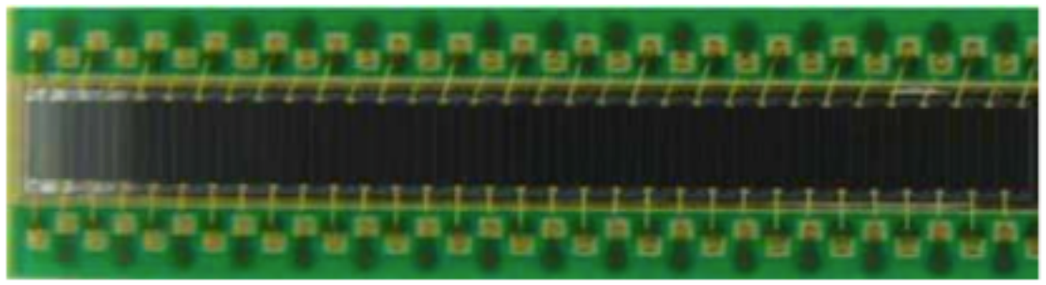
- 50 μm silicon
- 25 μm Kapton™ flexprint with Al traces
- 25 μm Kapton™ frame
- Less than 1% R.L. per layer
- He cooling for 2kW heat generation from the chips

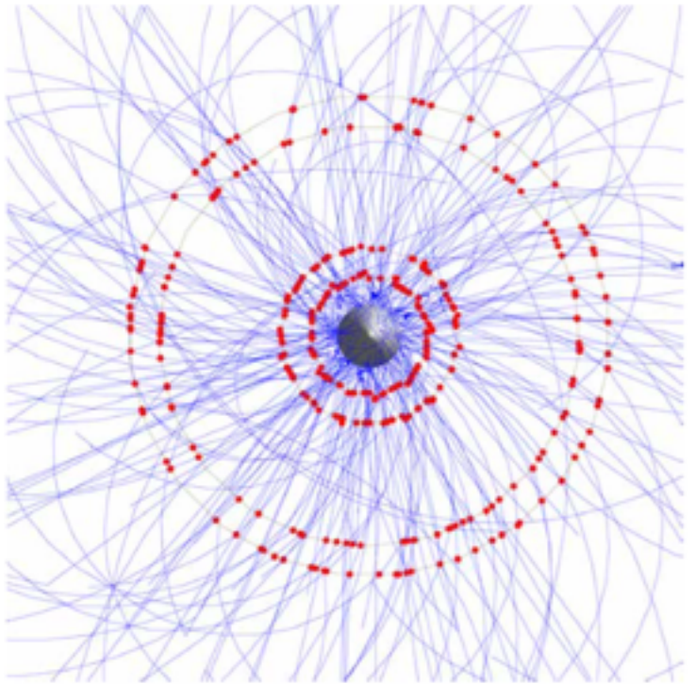


Mu3e: Timing Measurement

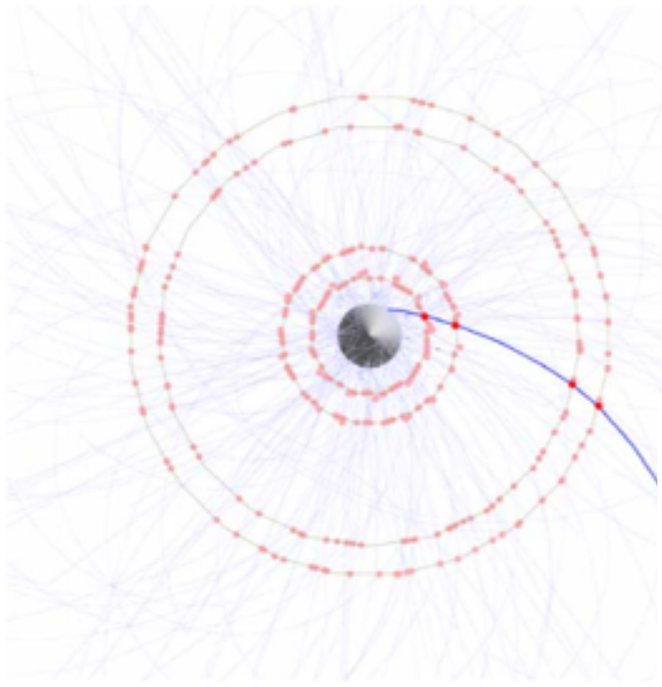
- Precise timing measurement is critical to reduce accidental BGs
  - Scintillating fibers O(1nsec)
  - Scintillating tiles O(100psec)



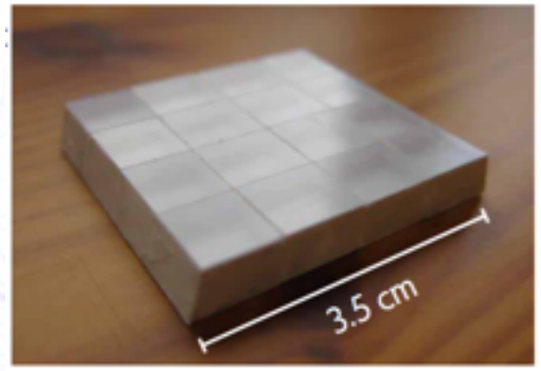


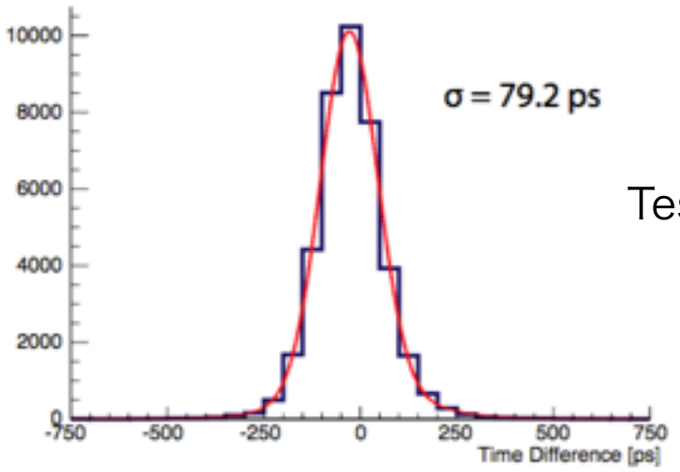


Pixels: O(50 ns)



Scintillating fibres O(1 ns);
Scintillating tiles O(100 ps)



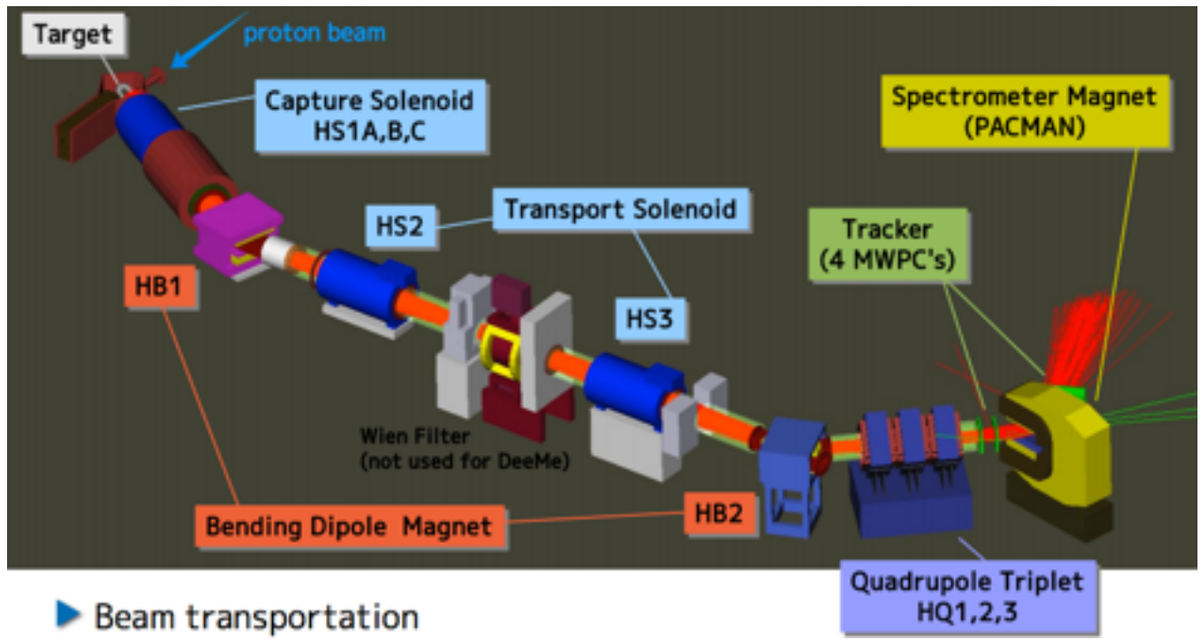


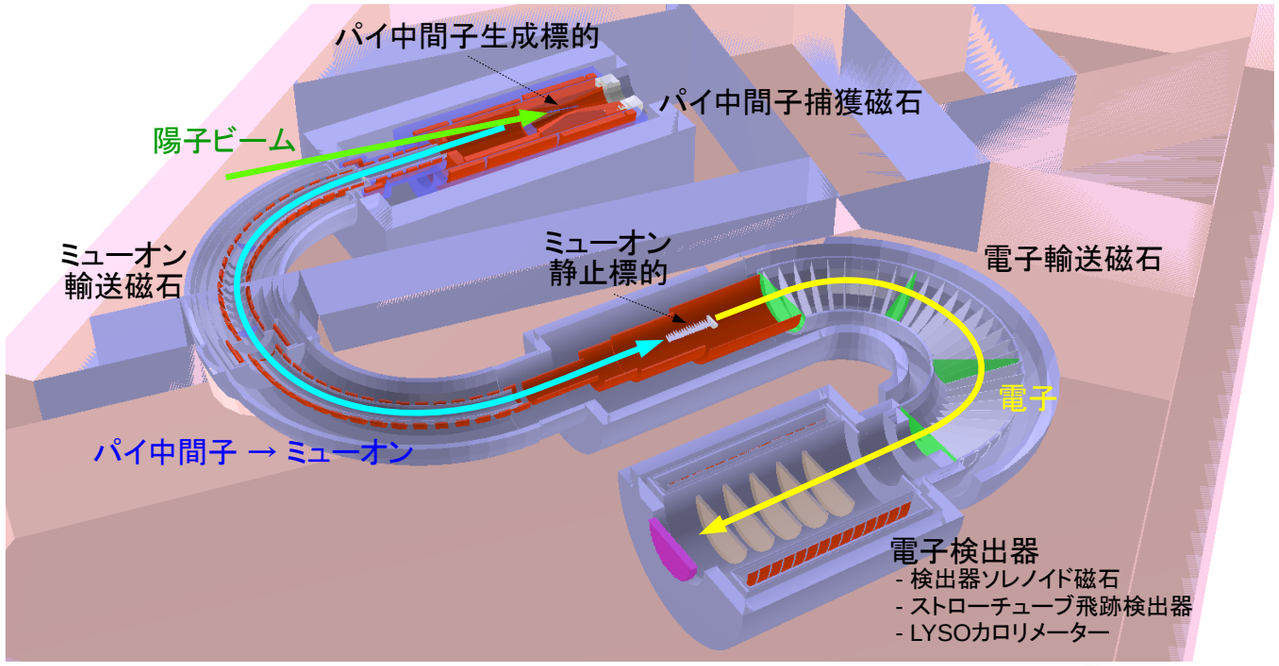
Test beam with Tiles
SiPM and ASIC

μ-e conversion searches

- J-PARC
  - DeeMe
    (D. Nagao WG4)
  - COMET Phase-I & II
    (Y. Yuan WG4)
- FNAL
  - Mu2e

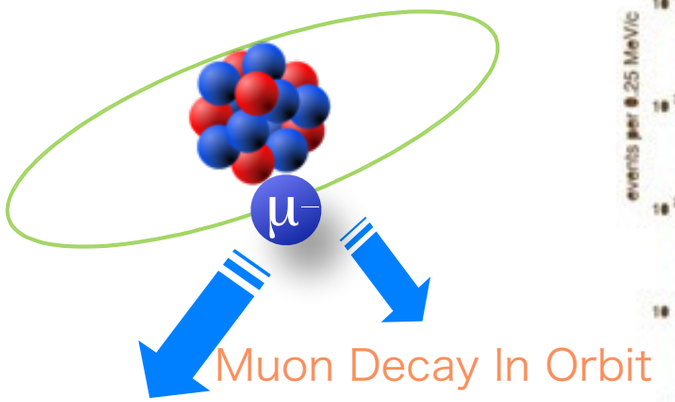
10^{-14} ~ 10^{-16} sensitivity



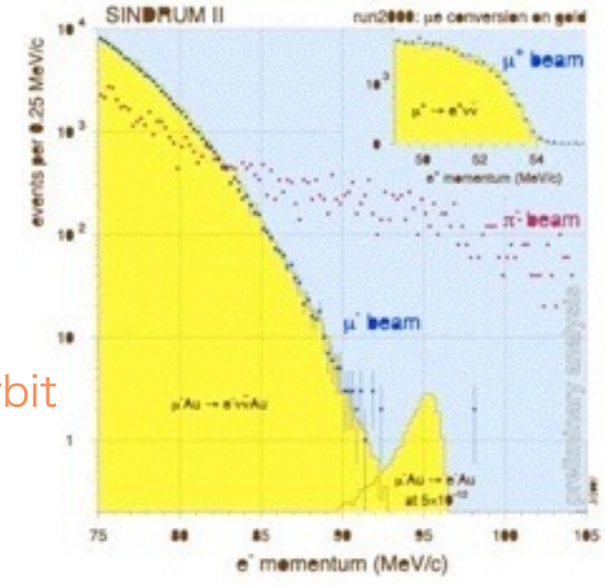


Experimental Techniques

- Process : μ^- +(A,Z) →e^- +(A,Z)
  - A single mono-energetic electron
    - $E_{\mu e}$ ~ m_μ-B_μ :105 MeV for Al
  - Delayed : ~1 μS
  - No accidental backgrounds

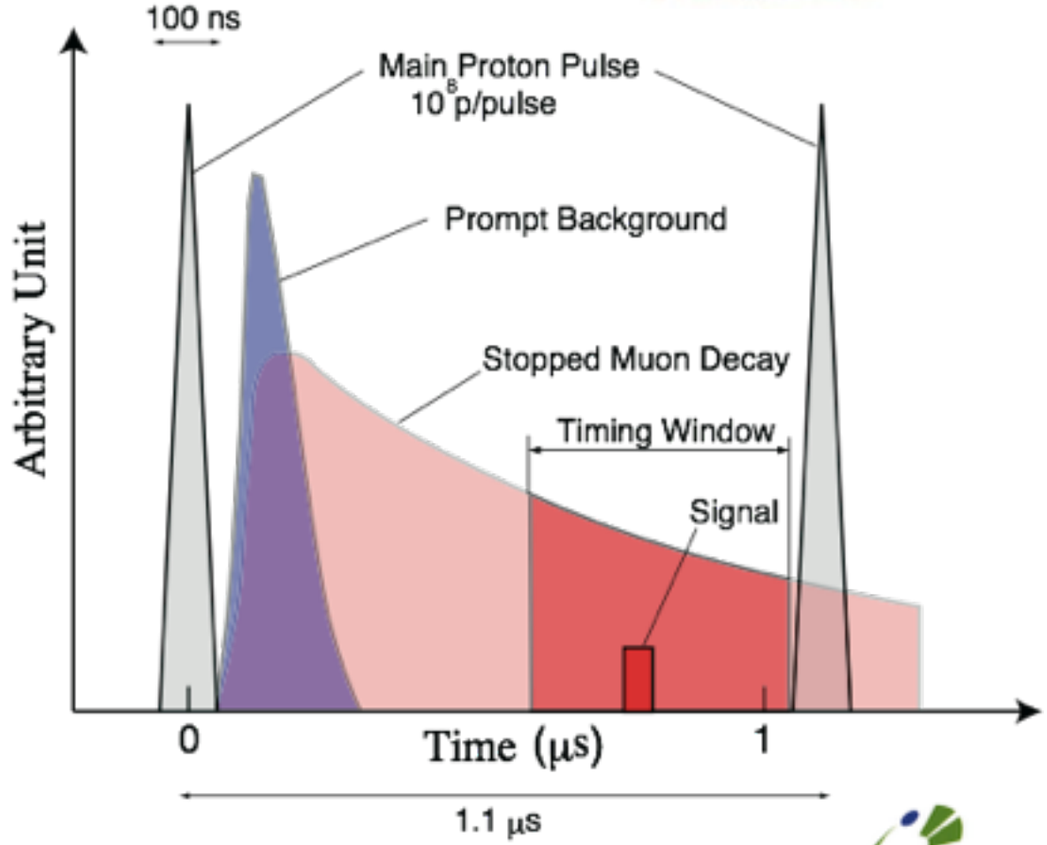


SINDRUM II



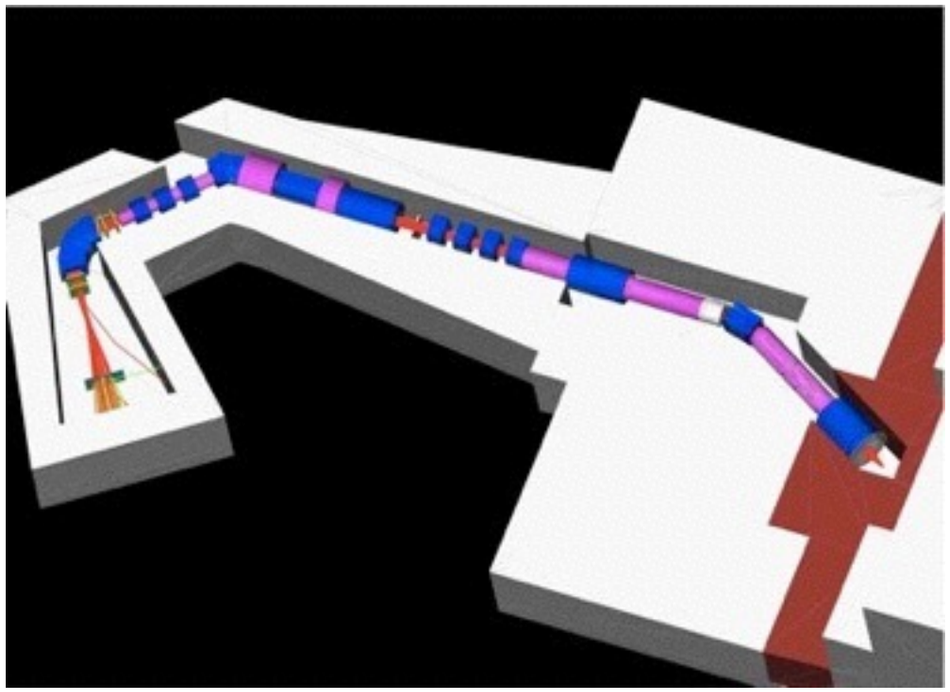
- Physics backgrounds
  - Muon Decay in Orbit (DIO)
    - E_e > 102.5 MeV (BR:10^{-14})
    - E_e > 103.5 MeV (BR:10^{-16})
  - Beam Pion Capture
  - π^-+(A,Z) → (A,Z-1)* → γ+(A,Z-1)
    γ → e^+ e^-

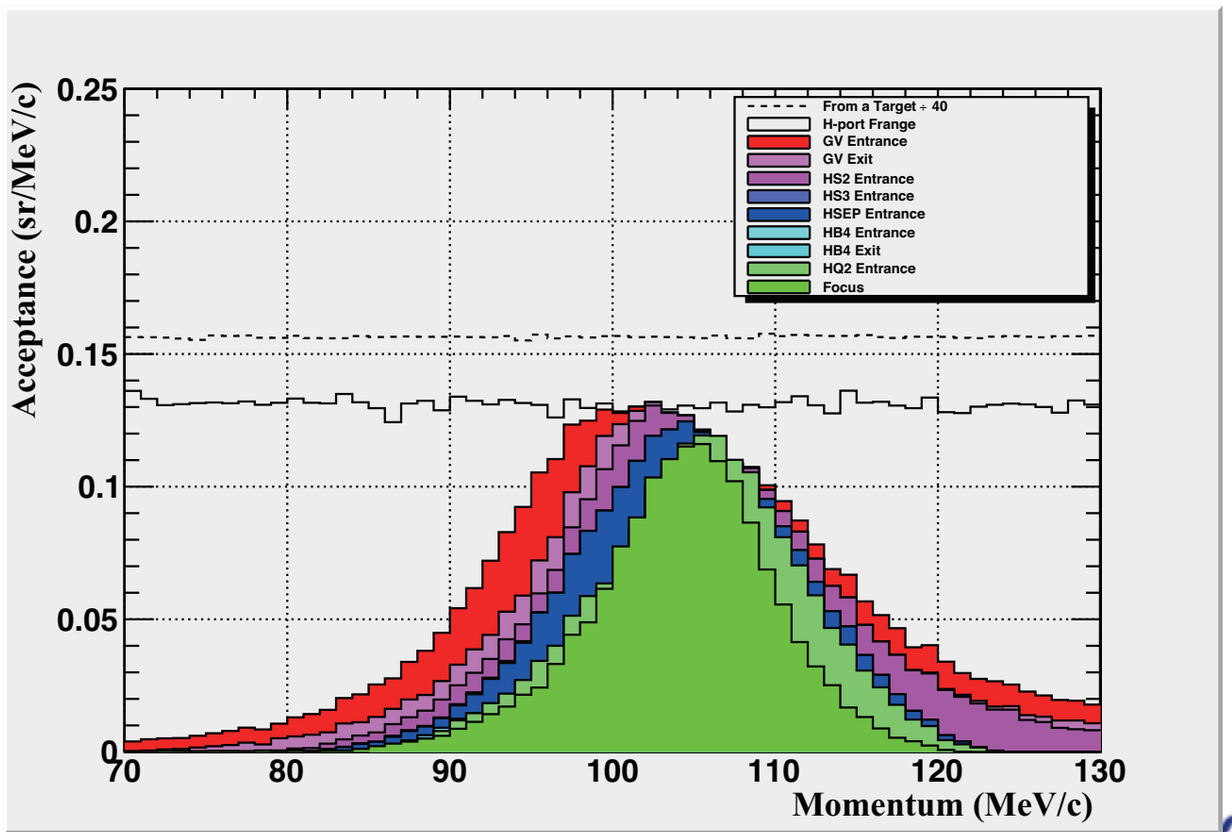
$$R_{ext} = \frac{\text{number of proton between pulses}}{\text{number of proton in a pulse}}$$



DeeMe at J-PARC

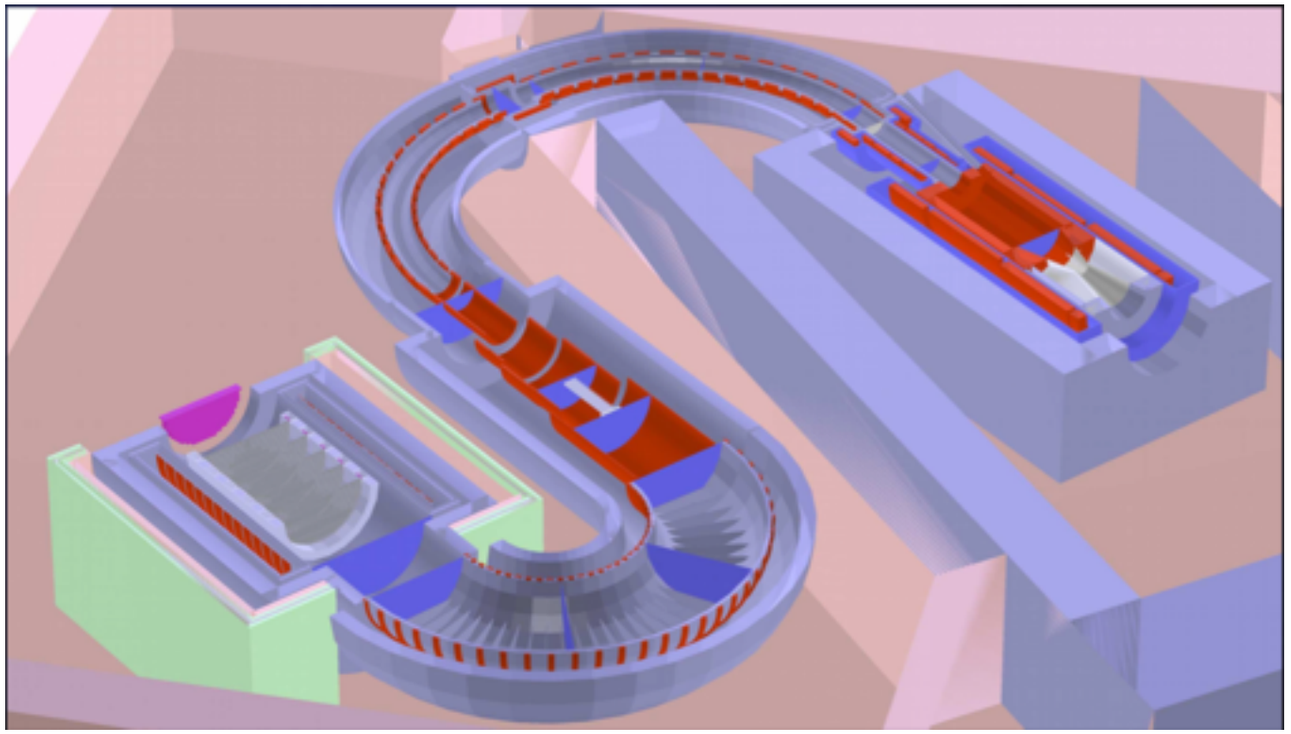
- **mu-e conversion search at J-PARC with a S.E.S. of 10^{-14}**
  - Primary proton beam from RCS
    - 3GeV, 1MW
  - Pion production target as a muon stopping target
  - Beam line as a spectrometer
    - Kicker magnets to remove prompt background
  - Multi-purpose beam line for DeeMe, HFS, g-2/EDM is under construction
- See presentation for more details by Daiki Nagao (WG4)

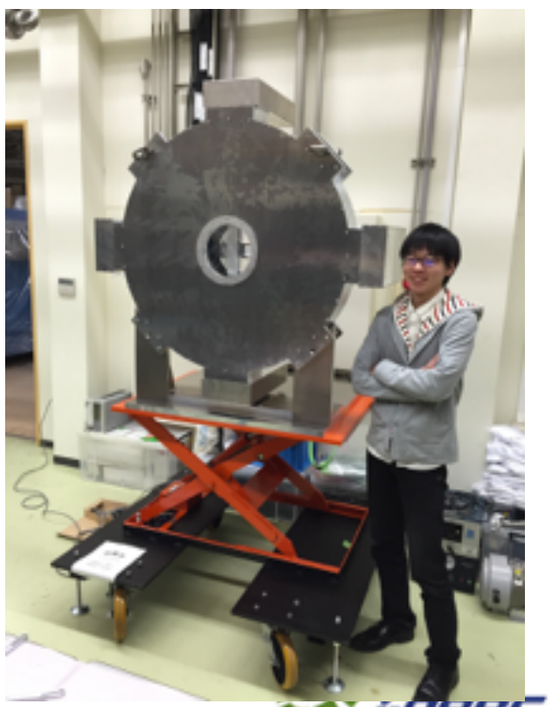




COMET at J-PARC

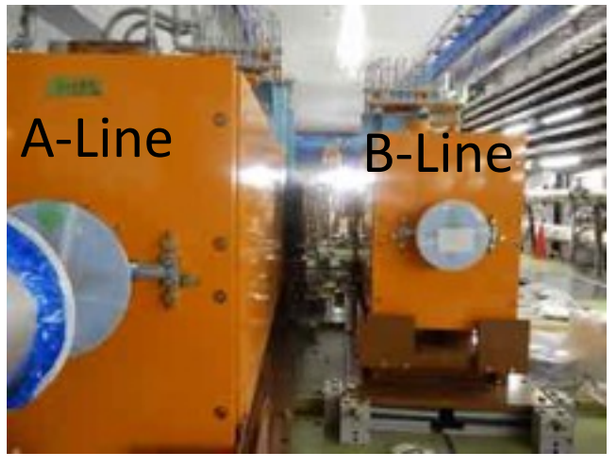
- **Target S.E.S. 2.6×10^{-17}**
- Pulsed proton beam at J-PARC
  - Insert empty buckets for necessary pulse-pulse width
  - bunched-slow extraction
- pion production target in a solenoid magnet
- Muon transport & electron momentum analysis using C-shape solenoids
  - smaller detector hit rate
  - need compensating vertical field
- Tracker and calorimeter to measure electrons
- Recently staging plan showed up. The collaboration is making an effort to start physics DAQ as early as possible under this.



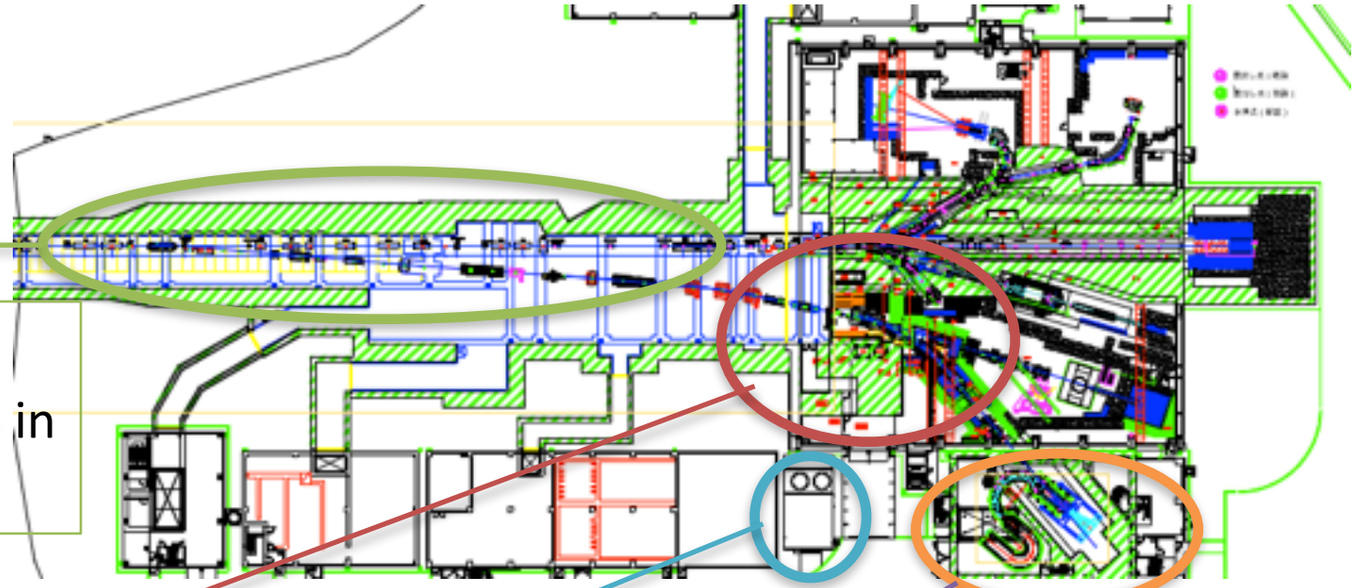


Status of COMET Experiment Facility

Switch Yard Beamline Elements



Beam line component installation in progress in SY since 2014



Beam transport line in HD hall

Significant construction work 2016 Summer to connect SY and Hall along the B-Line

He compressor used for E36 will be reused for COMET

90 deg. Transport Solenoid installed in Spring 2015

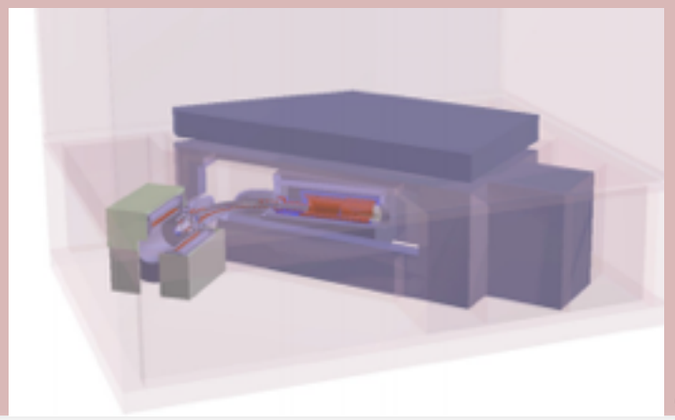
SC magnets

Hall construction

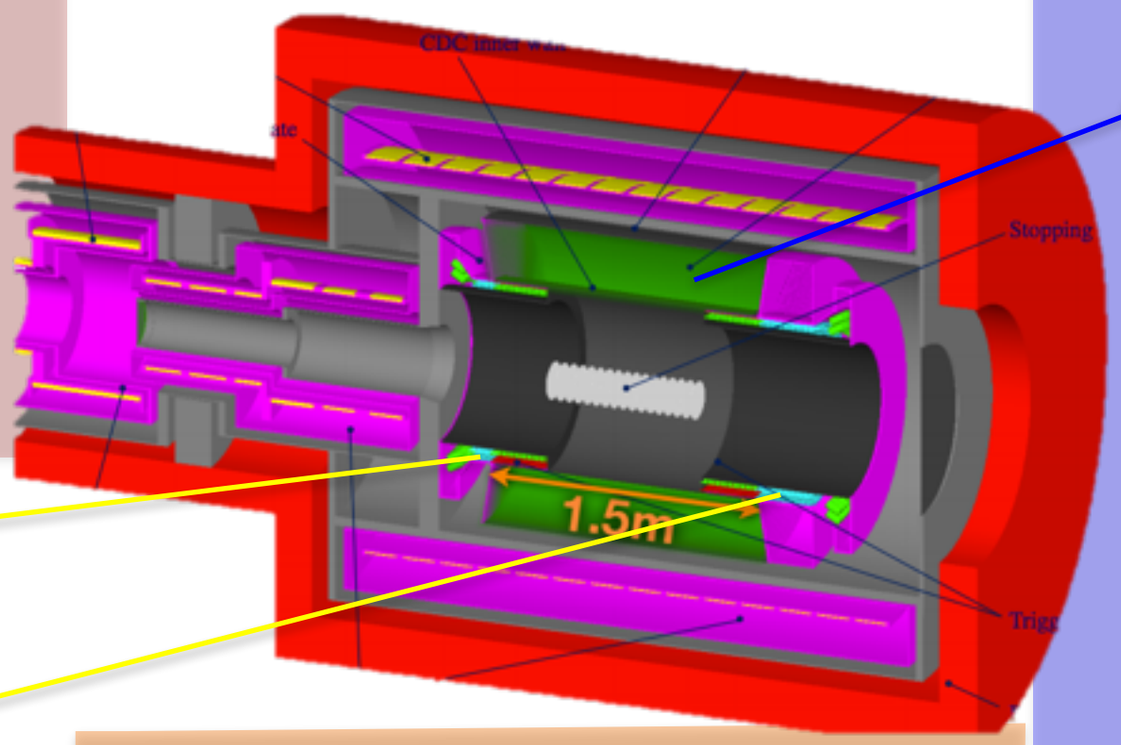
COMET Hall ready in Spring 2015

COMET:Status of Detector Preparation

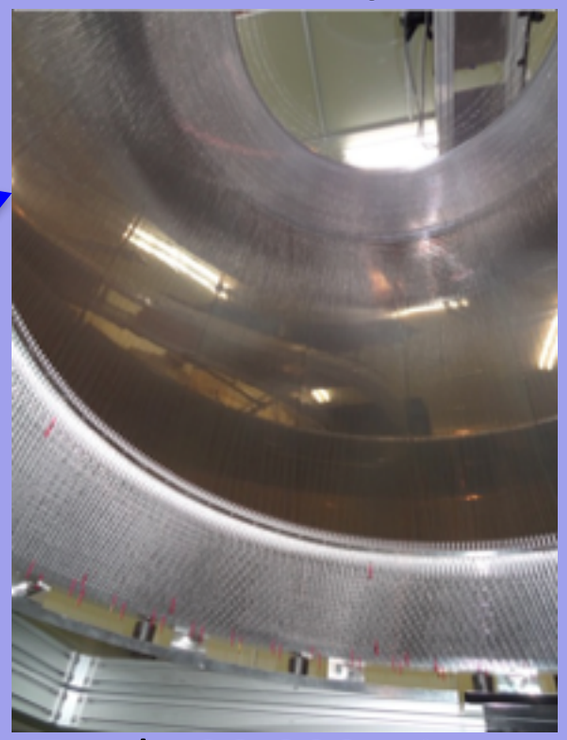
All geometry implemented in the full simulation: ICEDUST



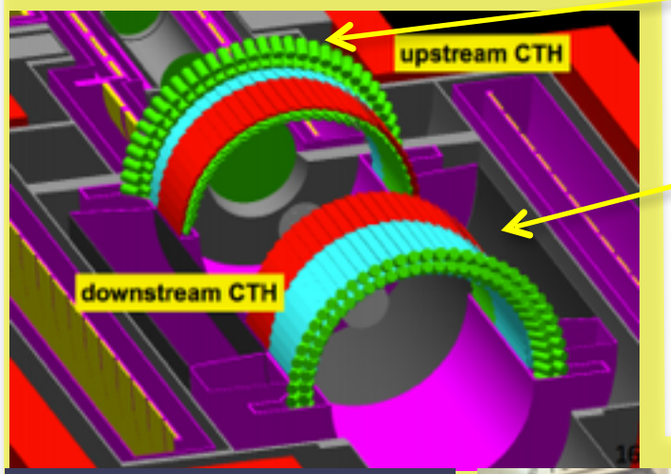
Detector for physics measurement in Phase I

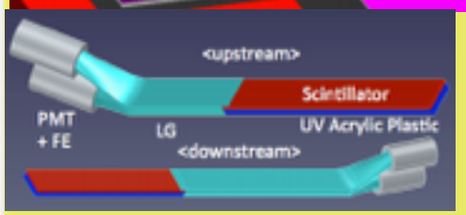


CDC : the main detector of COMET Phase-I Physics



Total ~20,000 wire stringing completed in Nov. 2015 at KEK

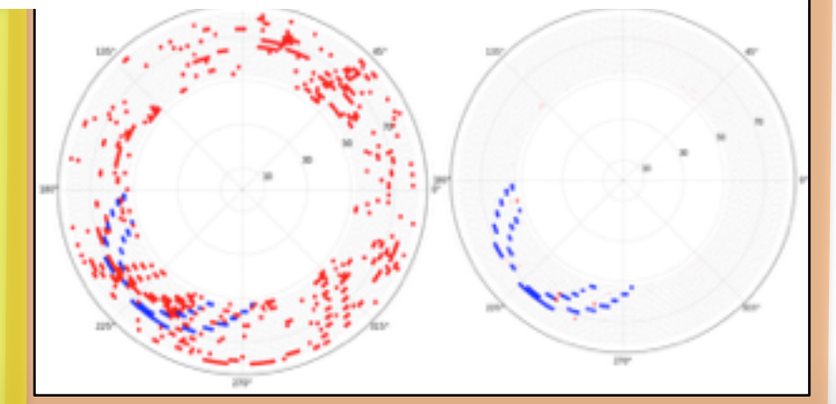




Beam test @ PSI 2015

Trigger Hodoscope Counter
Scintillator + Cerenkov

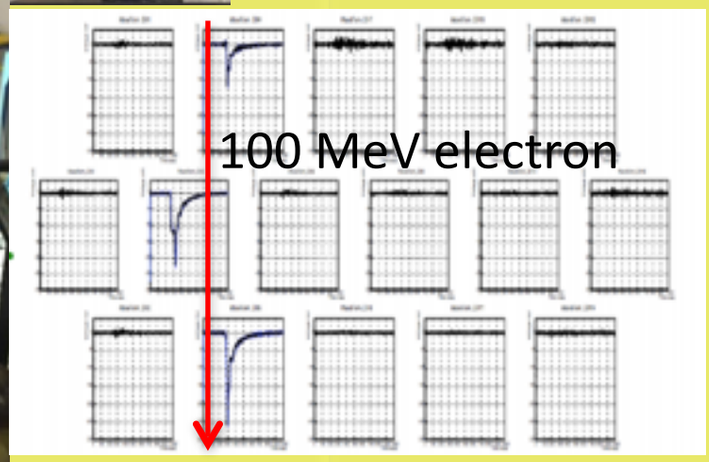
Analysis algorithm development in progress using simulation data.
ex) track finding in CyDET



CDC Read Out Electronics RECBE production at IHEP

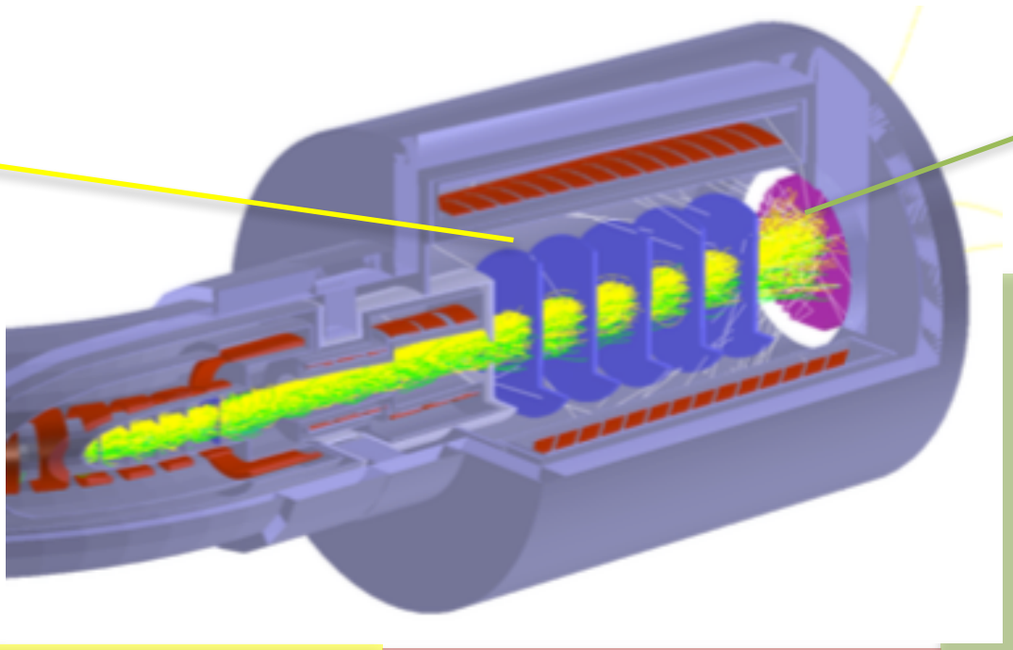
COMET: Detector Preparation Cont'd

Straw tracker (operational in vacuum) prototype

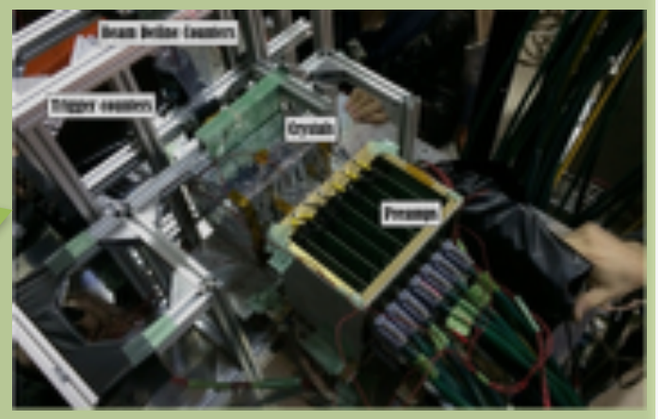


↑Wave form taken in the test
← Electron beam test at ELPH

Detector for beam BG measurement in Phase I and physics measurement in Phase II

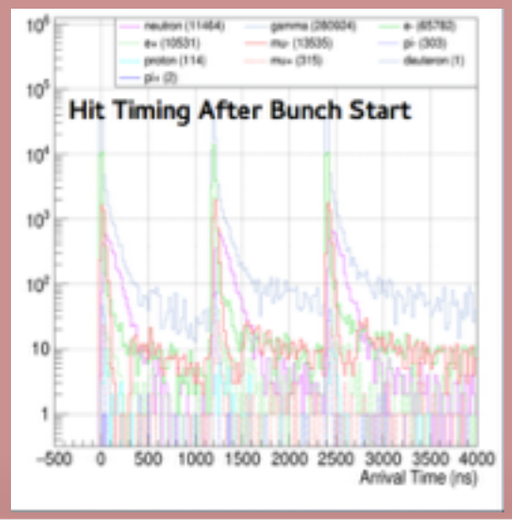


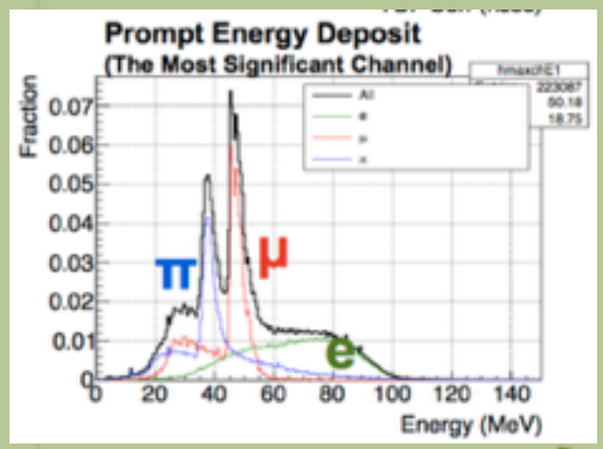
ECal (LYSO) R&D using prototypes



Crystal quality test bench at JINR

Ecal Pile-up study using simulation data





Ecal PID performance evaluation at PSI 2015

Mu2e at FNAL

- **Target S.E.S. 2×10^{-17}**

- uses the antiproton accumulator/debuncher rings to manipulate proton beam bunches

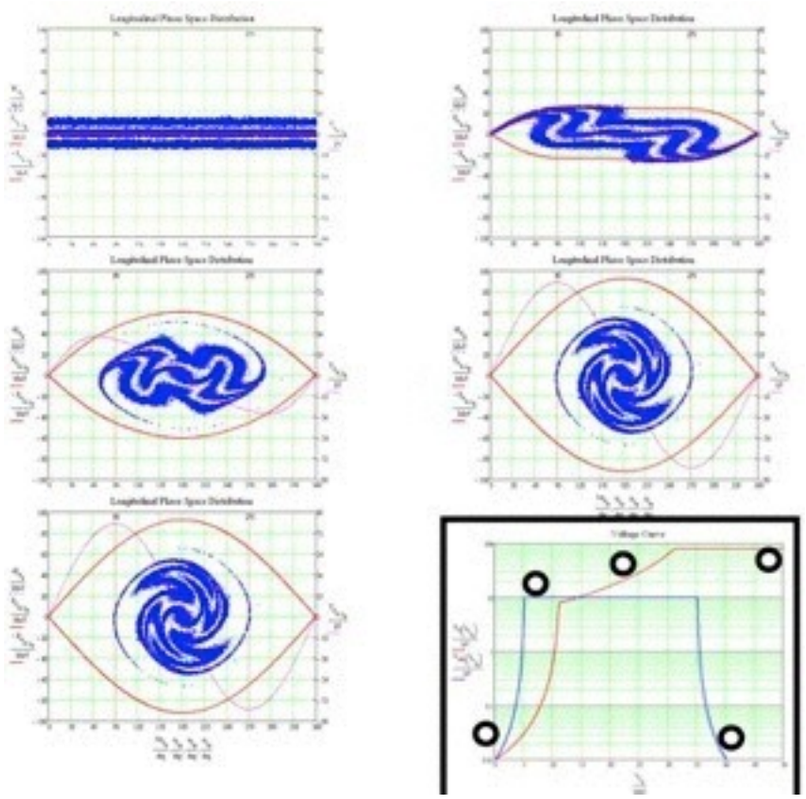
- No interference with NOvA experiment

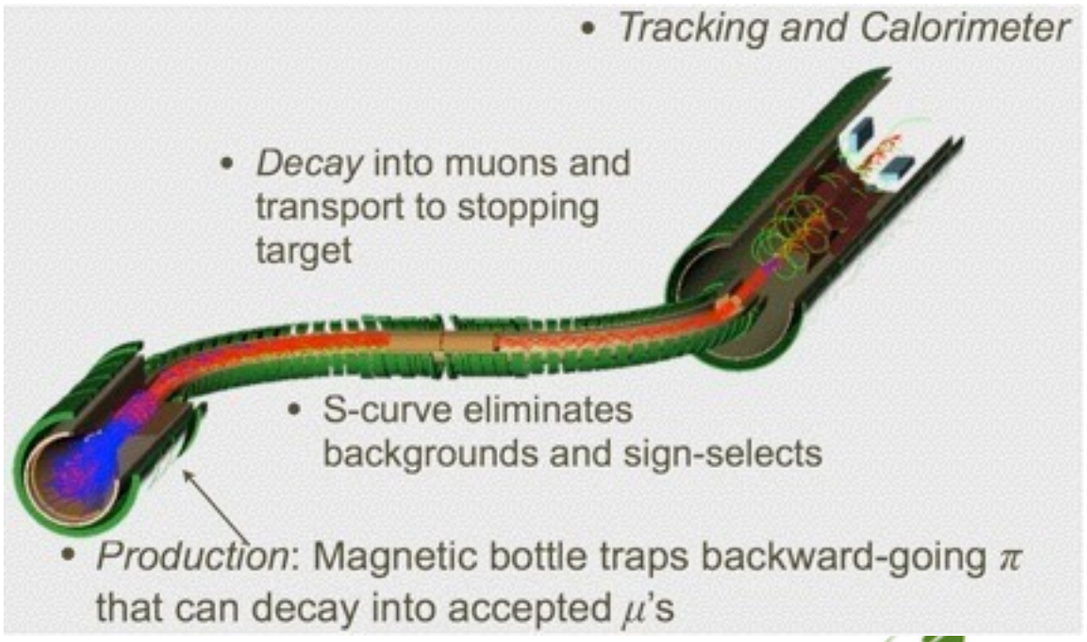
  - Mu2e uses beam NOvA can't

- pion production target in a solenoid magnet

- S-shape muon transport to eliminate BG and sign-select

- Tracker and calorimeter to measure electrons





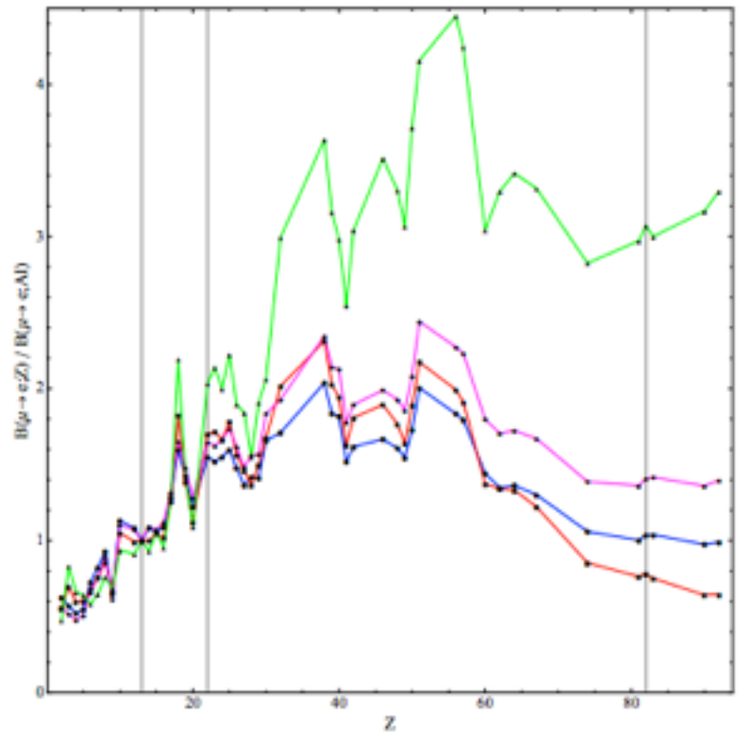
Muon Stopping Target Dependence

- DeeMe: C (& Si)

- COMET & Mu2e: Al (& Ti in future? & Pb in far future ??)

On the model discriminating power of $\mu \to e$ conversion in nuclei

Vincenzo Cirigliano[a], Ryuichiro Kitano[a,b], Yasuhiro Okada[c], Paula Tuzon[a,d]



	Al	Ti
lifetime	864 ns	330 ns
time window	0.3	0.2
signal	1	1.5
net	0.3	0.3

cLFV Searches at Collier Experiments

- Presentations in WG4 parallel session
  - cLFV searches at ATLAS, Marc Bret
  - cLFV searches at BES III, Ye Yuan
  - (Test of lepton flavor universality at LHCb, Federica Lionetto)
  - (Heavy neutrino and lepton number violation searches at CMS, Un-ki Yang)
  - (Kaon experiment at CERN, Giuseppina Anzivino)

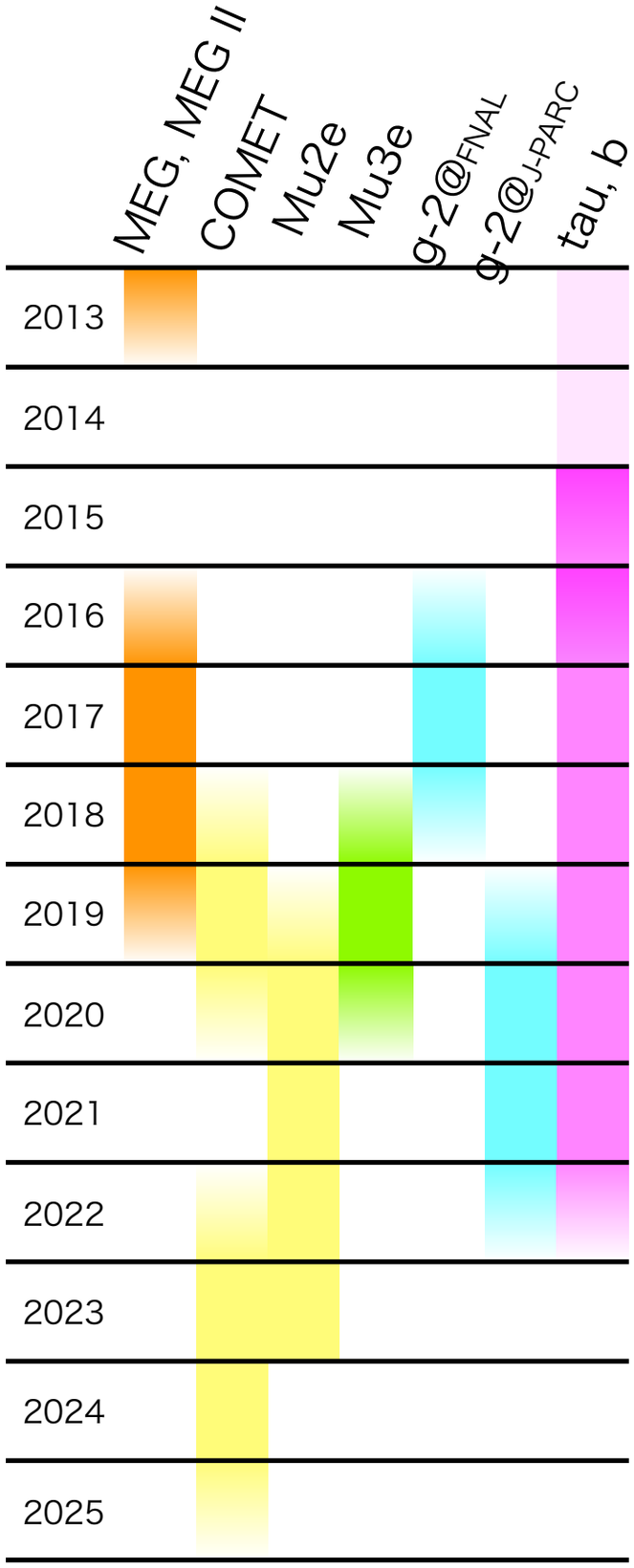
Tensions in B-Physics

- $B^0 \to D(*)\ \tau\ \nu_\tau / l\ \nu_l$ 3.9 σ : LHCb + BaBar + Belle
- $B^+ \to K^+ \mu\ \mu$ / ee 2.6 σ : LHCb
- Anomalies b → sll , esp. P'5 in $B \to K^* \mu\ \mu$ @ LHCb

More details in Federica's presentation

& arXiv:1604.08221

Summary



- cLFV experiments using muons
- MEG new result
  - Br($\mu \rightarrow e\gamma$) < 4.2x10^{-13} @ 90% C.L.
- MEG II, DeeMe, COMET, Mu2e, Mu3e in preparation
- New results from LHC experiments and BES III