The Muon g-2/EDM Experiment at J-PARC

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for the J-PARC E34 Collaboration

The 26th International Workshop on
Weak Interaction and Neutrinos

20th June 2017

The J-PARC g-2/EDM Collaboration

- Institutions
  - 9 countries
    - Canada, China, Czech, France, Japan, Korea, Russia, UK, US
  - 49 institutions

- Collaborators
  - 72 in Proposal (2009)
  - 92 in Conceptual Design Report (2011)
  - 137 in Technical Design Report (2015)
  - 144 in Technical Design Report rev. (2016)

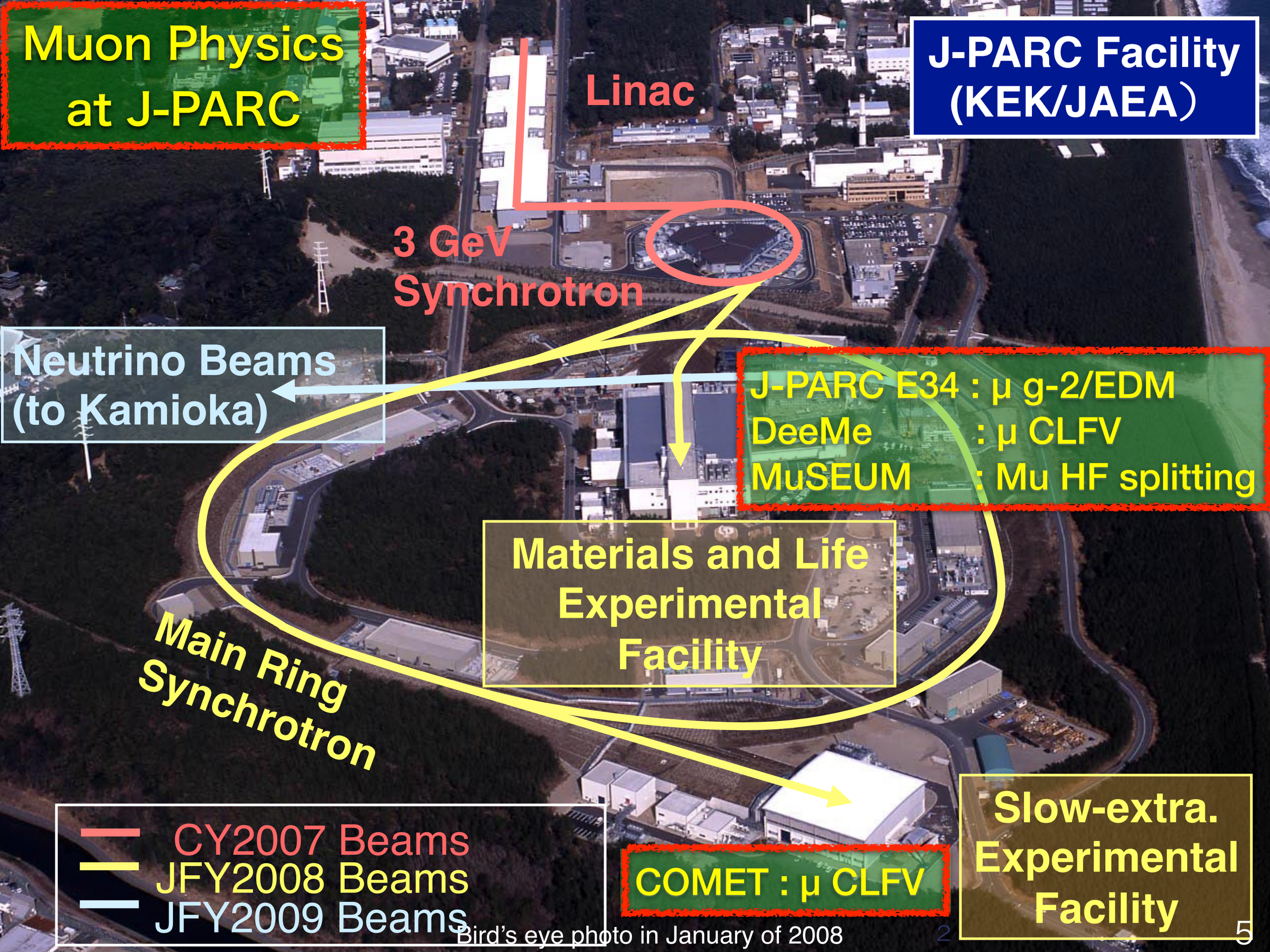

The 14th collaboration meeting on muon g-2/EDM at J-PARC
June 7 – 9, 2017

Brief History

Date	Event
Jul 2009	**Letter of Intent** submitted to PAC8
Jan 2010	**Proposal** submitted to PAC9
Jan 2012	**Conceptual Design Report** submitted to PAC13 Milestones defined
Jul 2012	Stage-1 status recommended by PAC15 **Stage-1granted by the KEK IPNS director**
May 2015	**Technical Design Report** submitted to PAC and
Oct 2016	**Revised TDR** submitted to PAC and FRC
Nov 2016	**Focused review in the revised TDR**

Next step : Revised TDR and request for Stage-2 status

Muon Physics at J-PARC



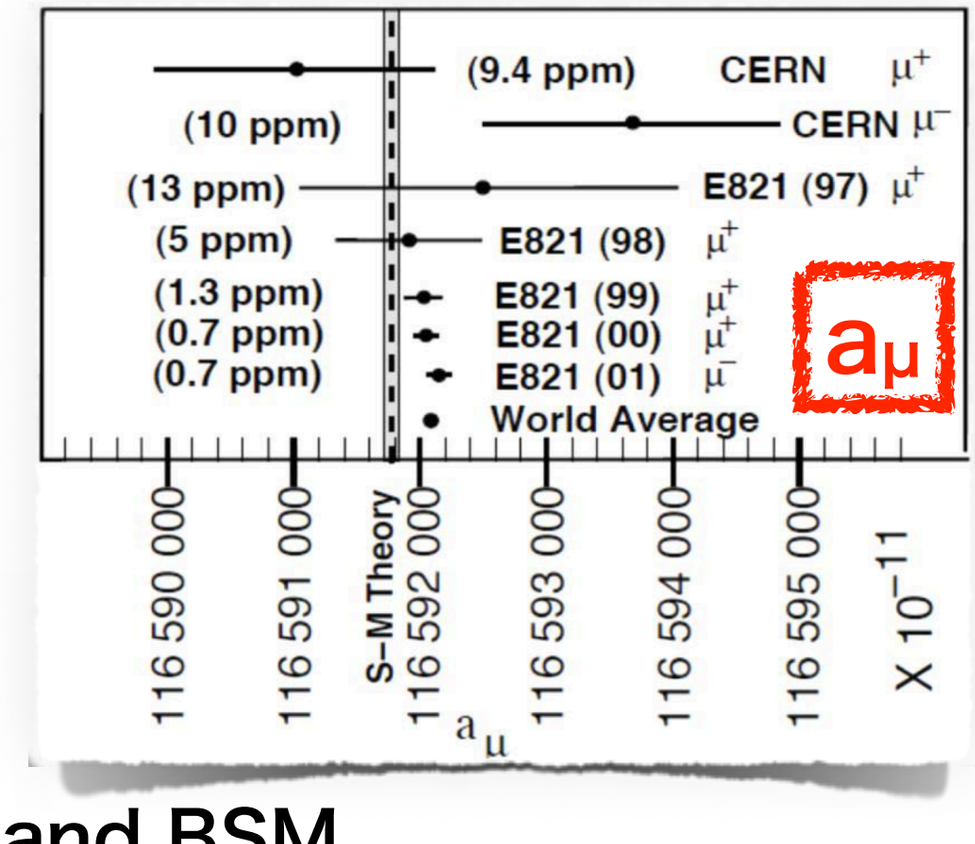
Bird's eye photo in January of 2008

Muon Dipole Moment

- **Anomalous magnetic moment a_μ**

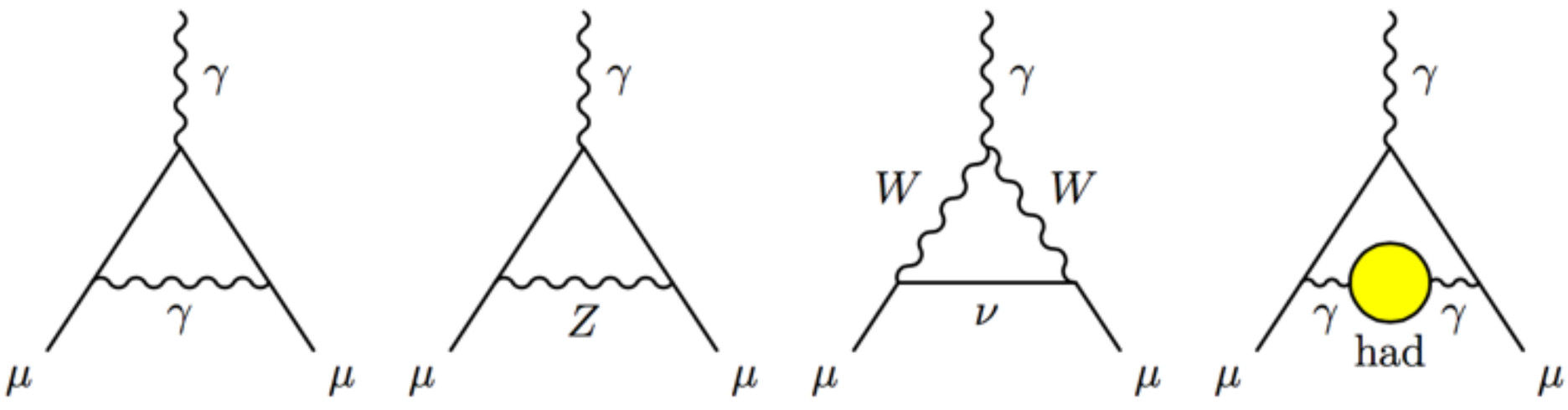
$$\vec{\mu} = g\left(\frac{e}{2m}\right)\vec{s}$$

$$a_\mu = \frac{g-2}{2}$$



- **CP-even**
- **Contributions from QED, EW, QCD and BSM**

QED **EW** **QCD (Had. Vac. Pol.)**



+ BSM

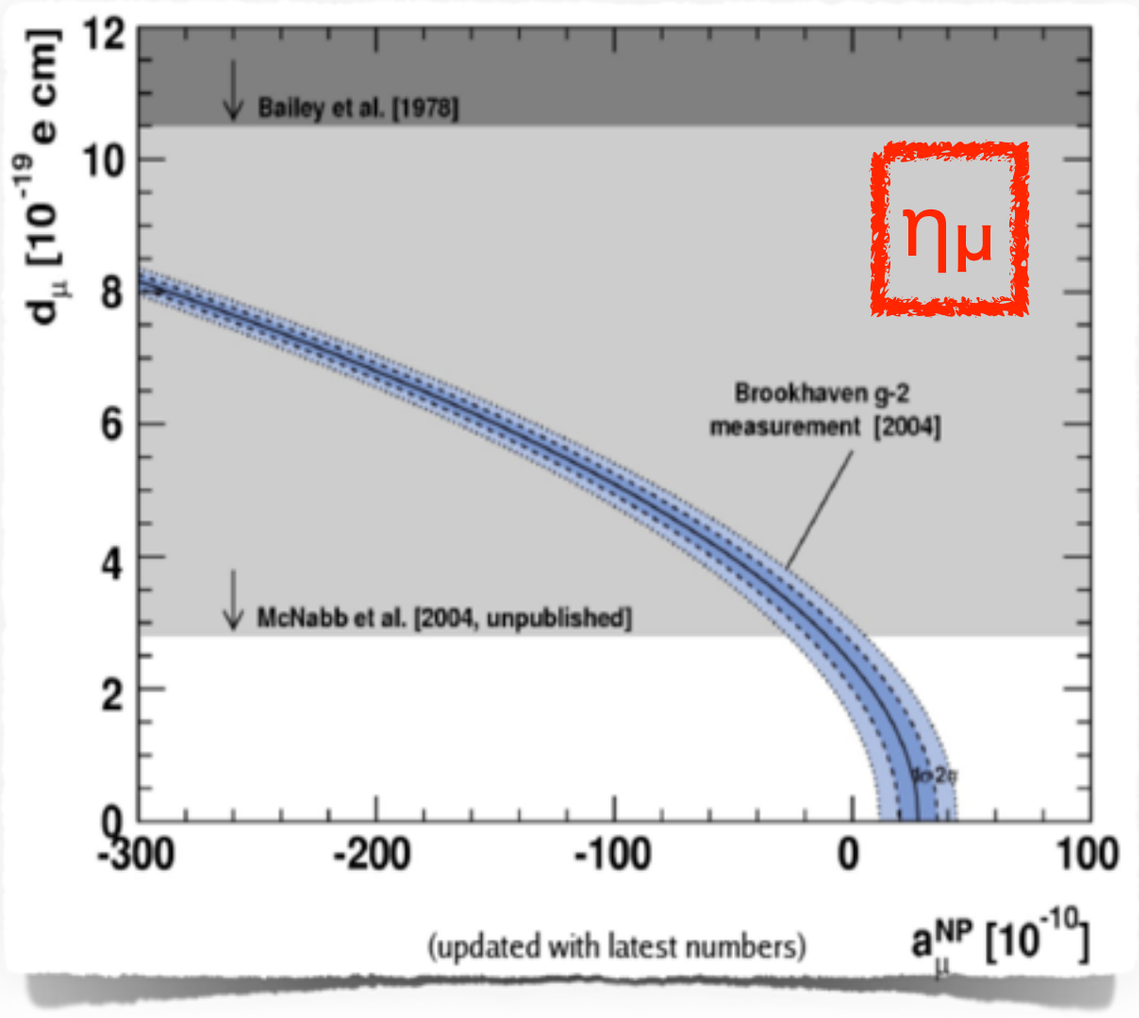
SM LO diagrams

Muon Dipole Moment

- **Electric dipole moment (EDM) η_μ**

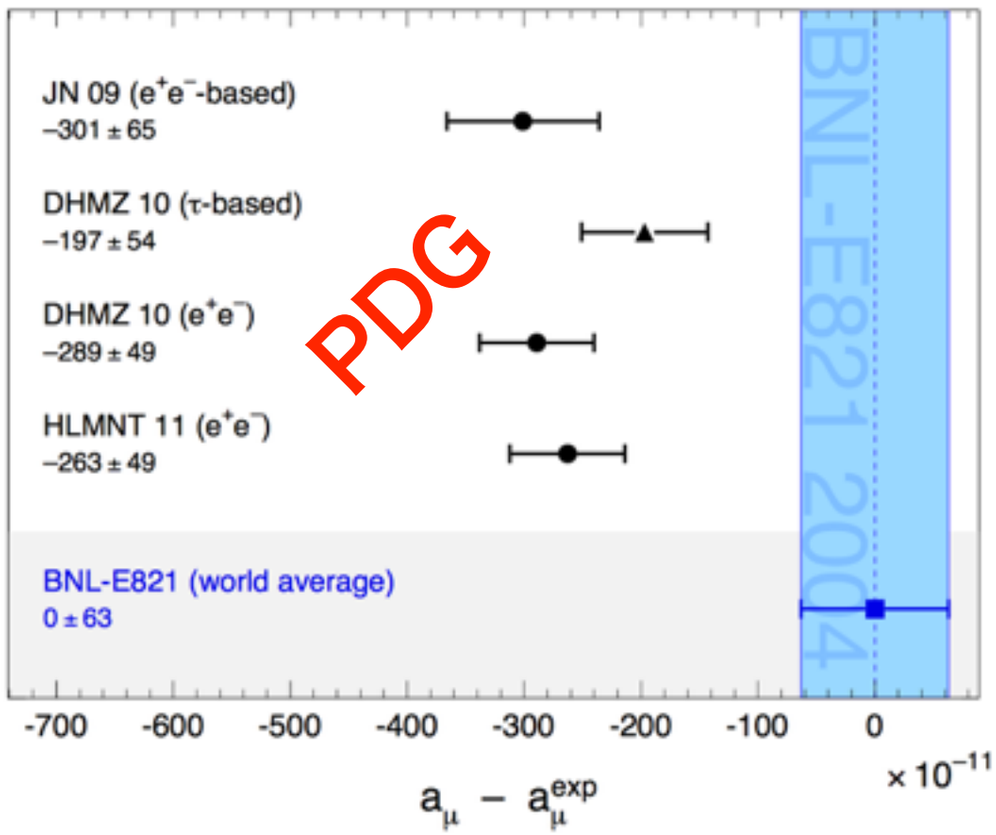
$$\vec{d} = \eta_\mu \left(\frac{e}{2mc} \right) \vec{s}$$

- CP-odd (T-odd)
  - Assuming the CTP invariance
- CP violation in the lepton sector



Muon Dipole Moment

- The results by BNL E821 is at the frontier now.
  - g-2 : 0.54 ppm, a famous 3.3σ deviation from the SM
    - Can be a window to BSM, Tension in global analyses
  - EDM : < 10^{-19} e • cm
    - Needs much better precision



Results | KNT17 update

KNT17 a_μ^{SM} update

	2011		2017	*to be discussed
QED	11658471.81 (0.02)	→	11658471.90 (0.01)	[Phys. Rev. Lett. 109 (2012) 111808]
EW	15.40 (0.20)	→	15.36 (0.10)	[Phys. Rev. D 88 (2013) 053005]
LO HLbL	10.50 (2.60)	→	10.80 (2.60)	[EPJ Web Conf. 118 (2016) 01016]*
NLO HLbL			0.30 (0.20)	[Phys. Lett. B 735 (2014) 90]*
	HLMNT11		**KNT17**	
LO HVP	694.91 (4.27)	→	692.23 (2.54)	this work*
NLO HVP	-9.84 (0.07)	→	-9.83 (0.04)	this work*
NNLO HVP			1.24 (0.01)	[Phys. Lett. B 734 (2014) 144] *
Theory total	11659182.20 (4.94)	→	11659181.00 (3.62)	this work
Experiment			11659209.10 (6.33)	world avg
Exp - Theory	26.1 (8.0)	→	28.1 (7.3)	this work
Δa_μ	3.3σ	→	3.9σ	this work

Recent update

Alex Keshavarzi (UoL) | KNT17: $a_\mu^{had,VP}$ update | 3rd June 2017 | 22 / 23

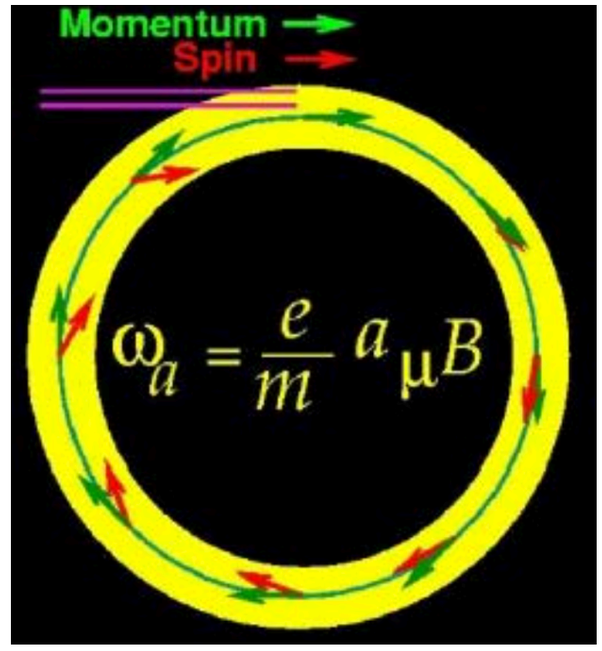
The 1st WS of the muon g-2 theory initiative

- The next generation experiments with new technologies have been hoped for and proposed.

Measurement Principle

- Spin precession in a uniform B-field

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$



- Two alternative methods
  - Magic momentum : BNL E821 and FNAL E989
    - Eliminate the 2nd term by setting p=3.09 GeV/c (γ=29.3)
    - Can use E-field for beam focusing

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

  - Zero E-field : J-PARC E34
    - Separation of a_μ and η_μ
    - A new technology is necessary.
      - Muon beam w/o E-focusing

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$

⇨ Ultra-cold muon beam

New Muon g-2/EDM Experiment at J-PARC with Ultra-Cold Muon Beam

3 GeV proton beam
(333 uA)

Graphite/SiC target
(20 mm)

Surface muon beam
(28 MeV/c, $3x10^8$ /s)

Muonium Production
(300 K ~ 25 meV ⇒ 2.3 keV/c)

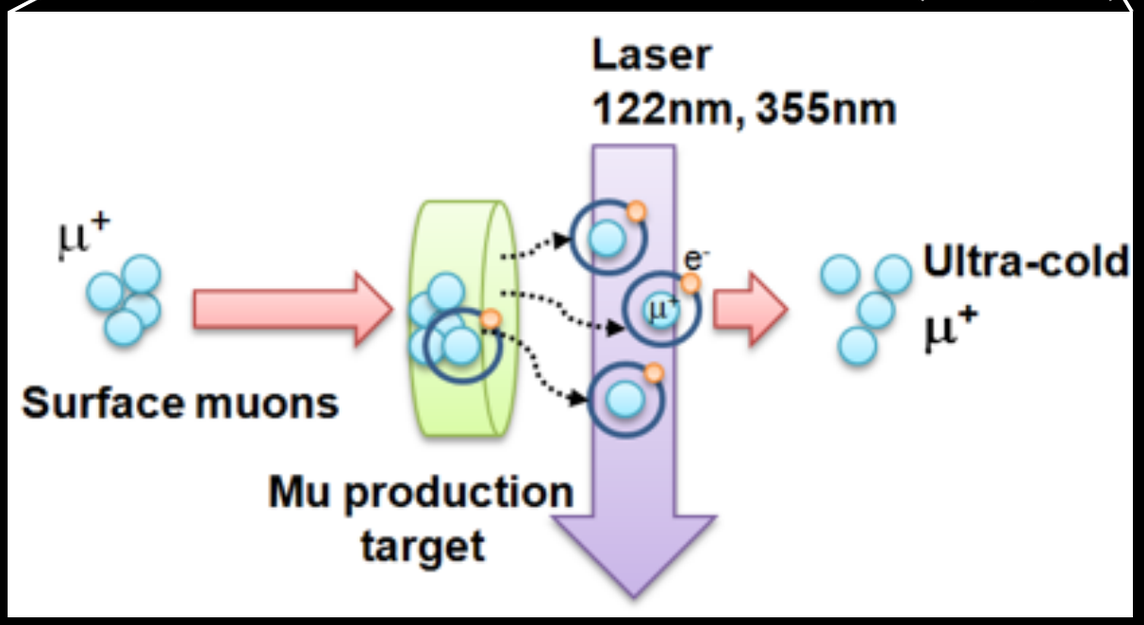
Surface muon

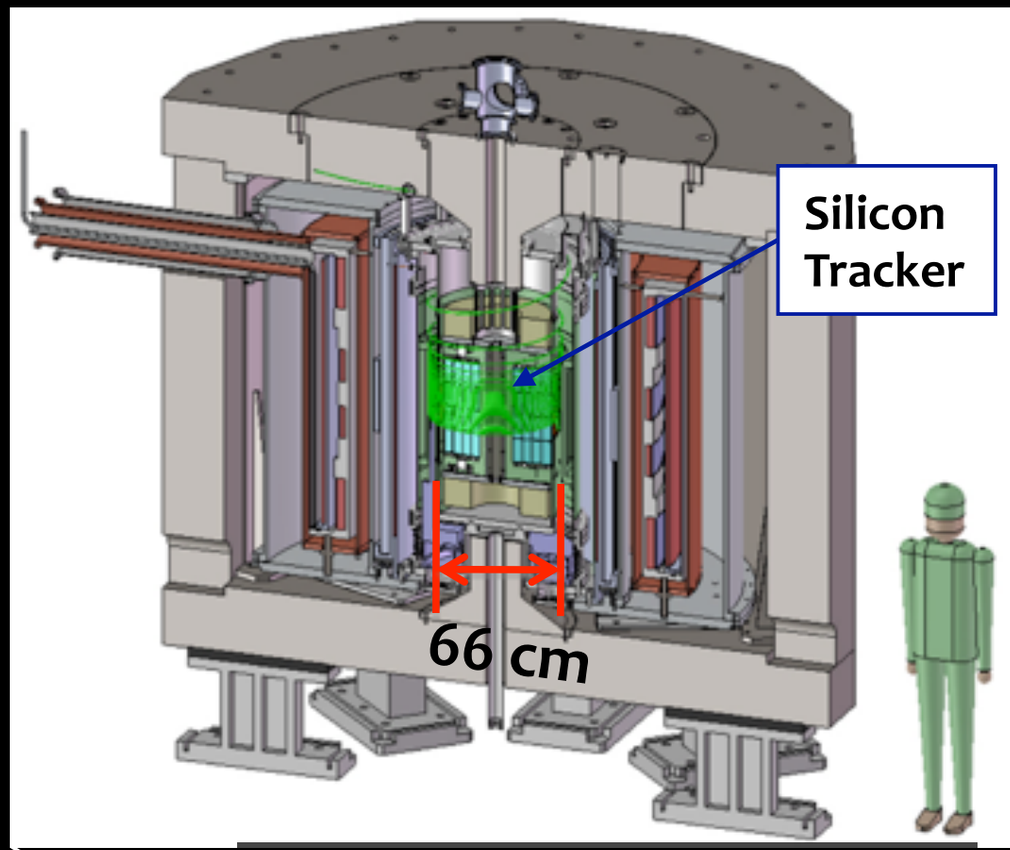
Ultra Cold μ+ Source

Muon LINAC (300 MeV/c)

Muon storage

Resonant Laser Ionization of Muonium (~10^6 μ^+/s)





Super Precision Storage Magnet
(3 T, ~1 ppm local precision)

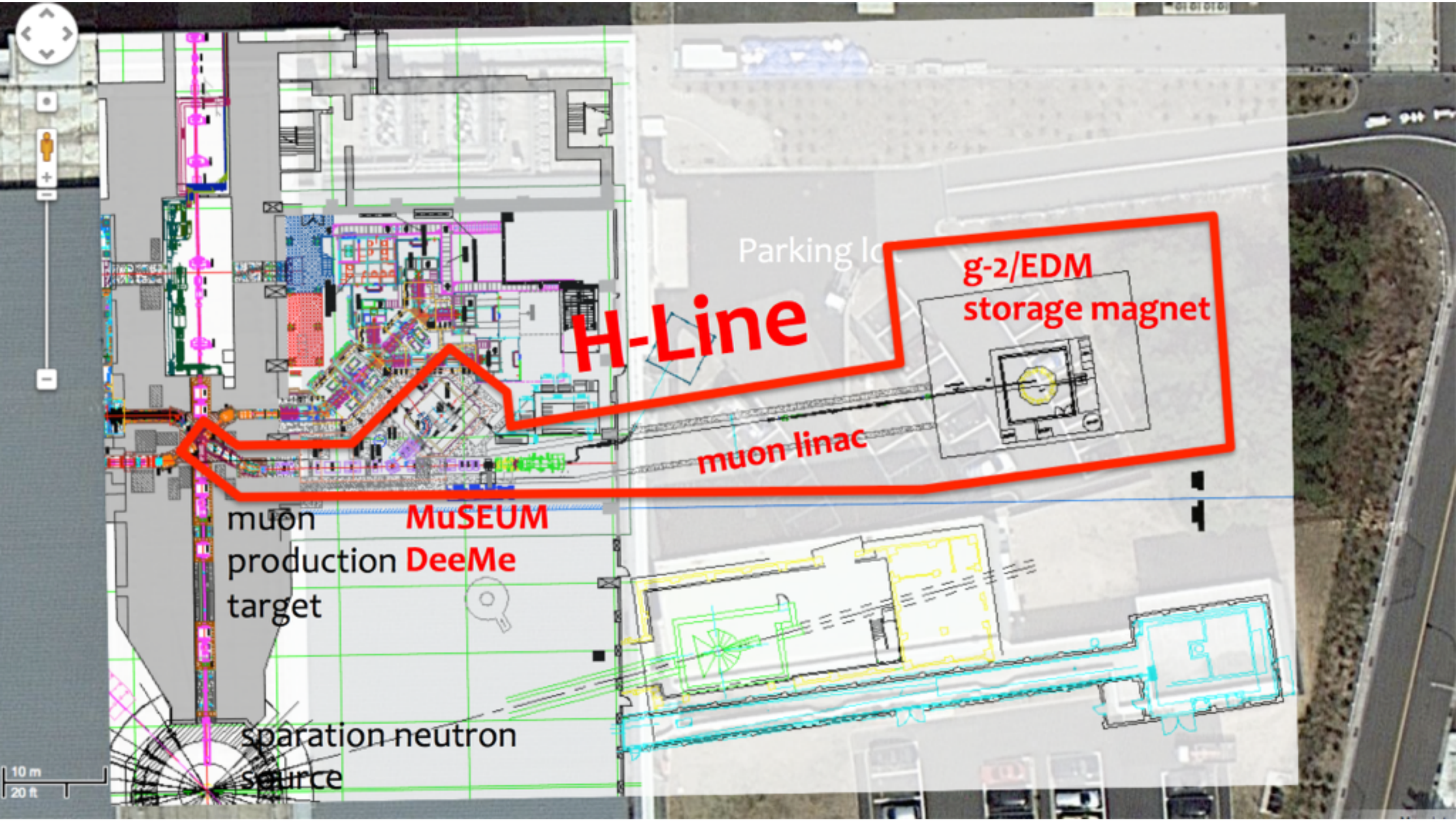
Goal

g-2 : 0.1 ppm

EDM : ~10^{-21} e・cm

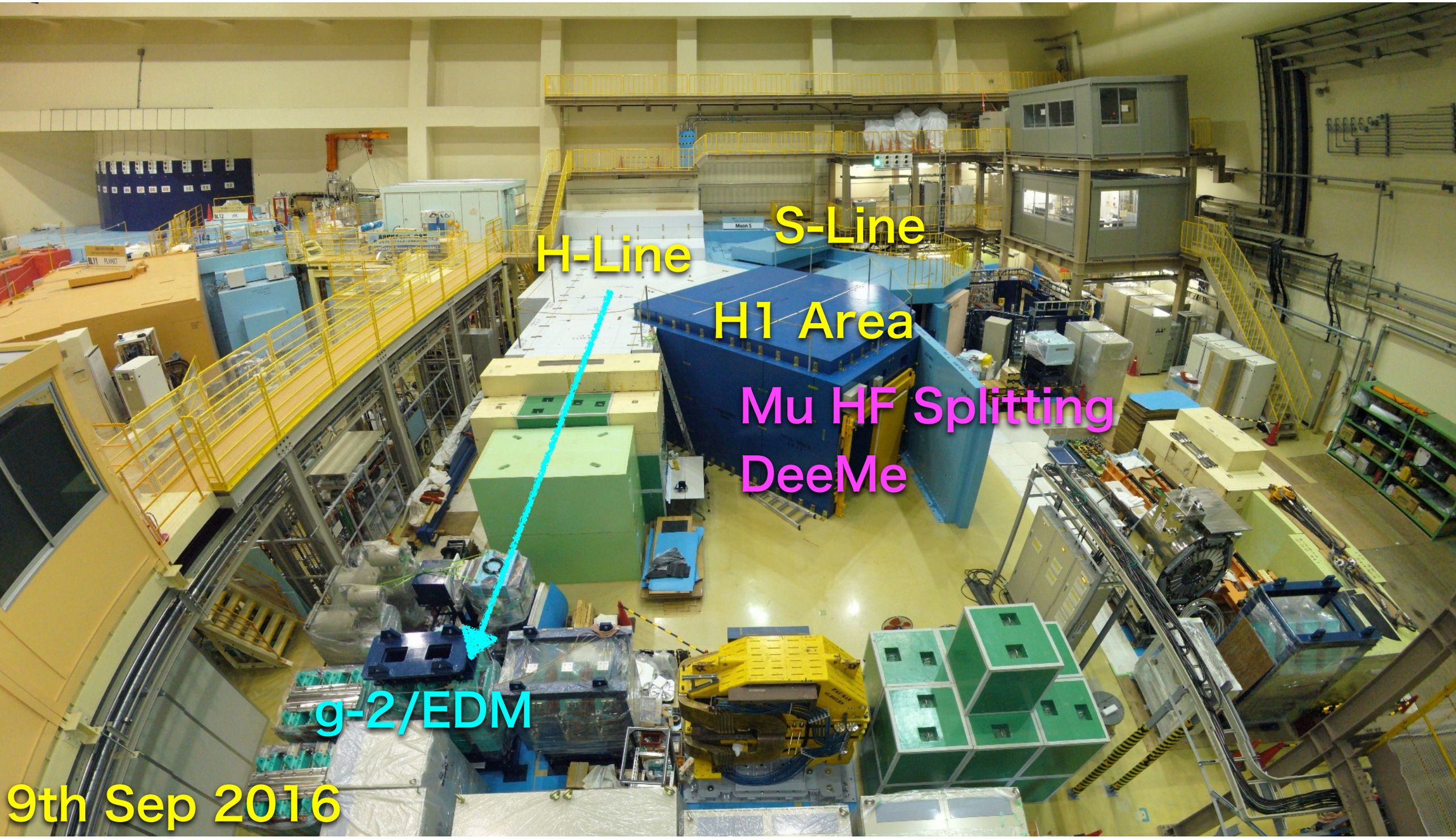
Proposed Site at J-PARC

MLF (Material and Life Science Facility)



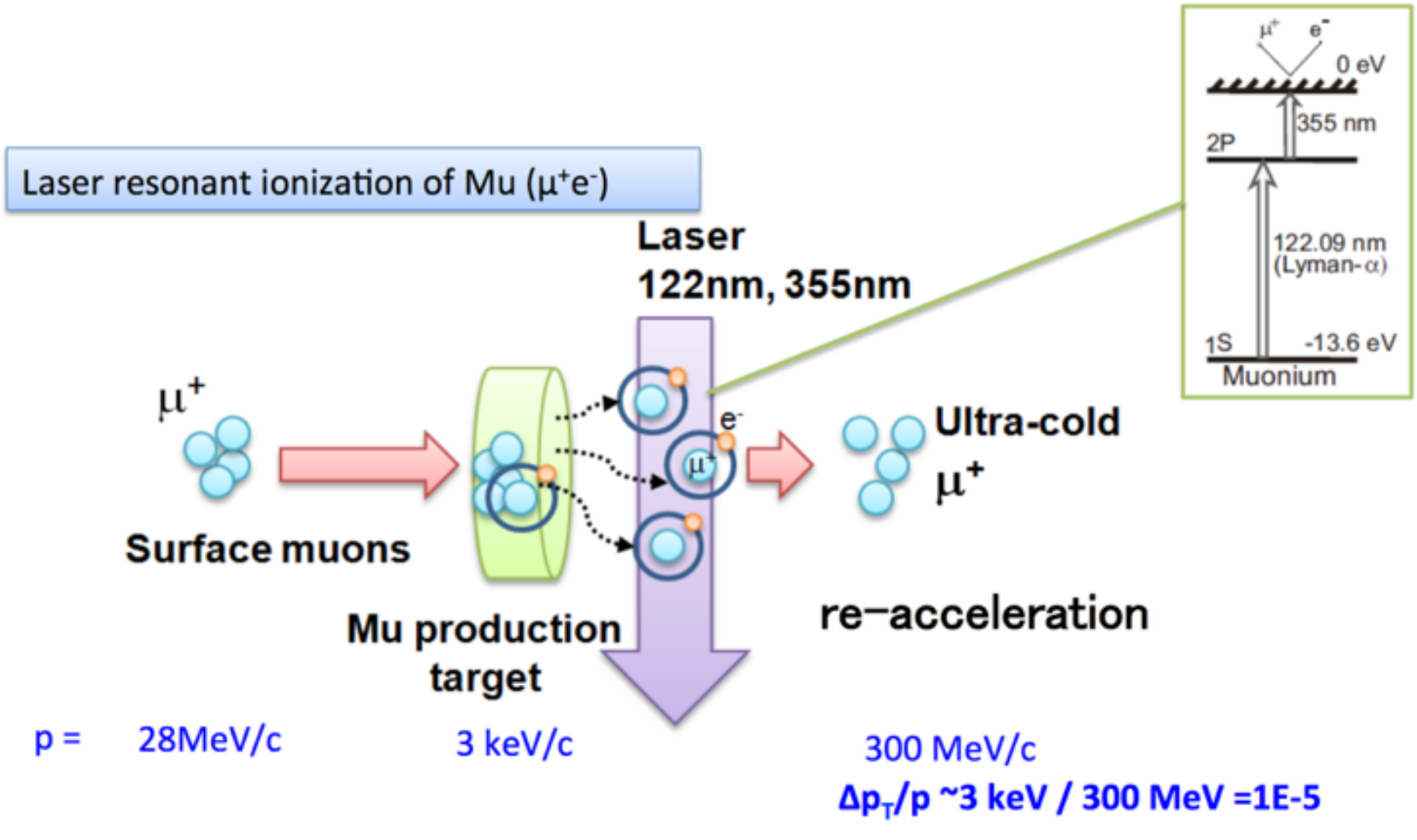
H-Line Construction

Completion of the shielding blocks

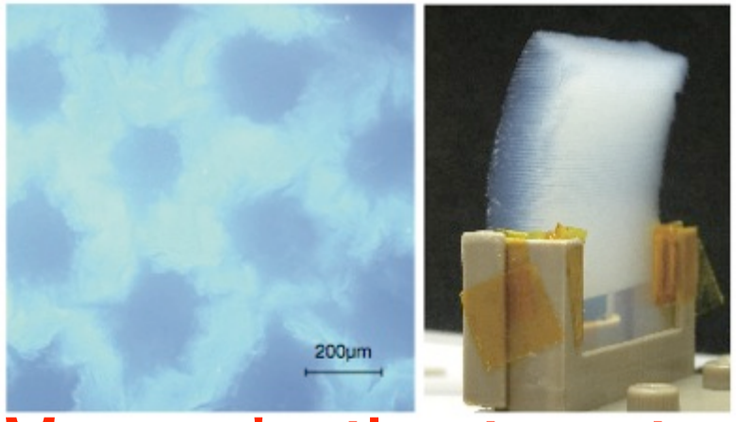


Ultra-Cold Muons

- Ultra-cold muon is one of the most important technology to establish J-PARC E34.
  - Ultra-small transverse dispersion : $\Delta p_T/p_T < 10^{-5}$
  - Cooling with muonium production and laser ionization



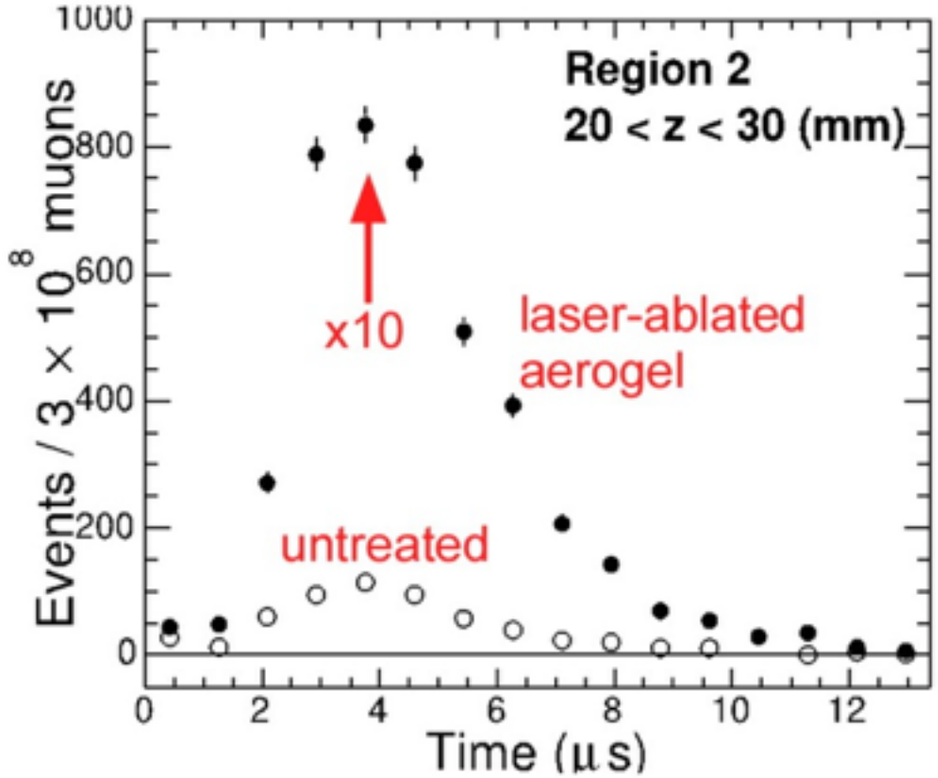
Ultra-Cold Muons

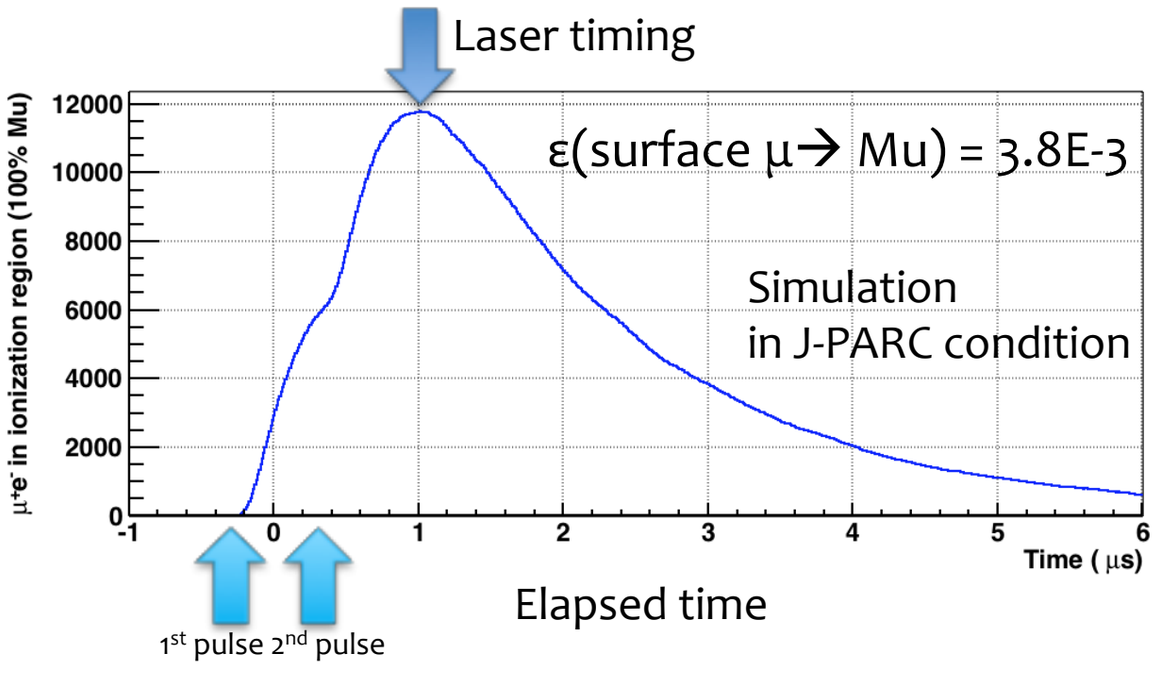


Mu production target

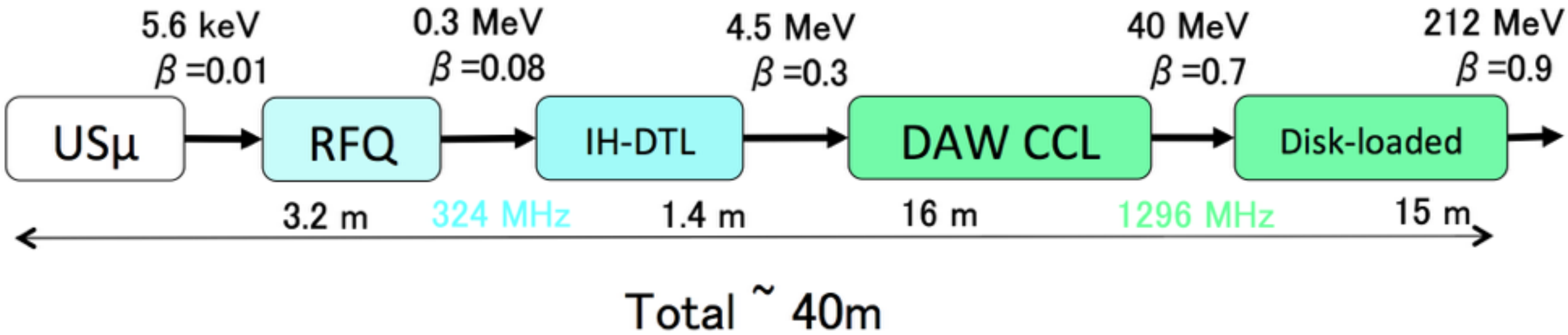
(Laser-ablated silica aerogel)

Further Improvement is expected with new target samples.





Muon Acceleration Development

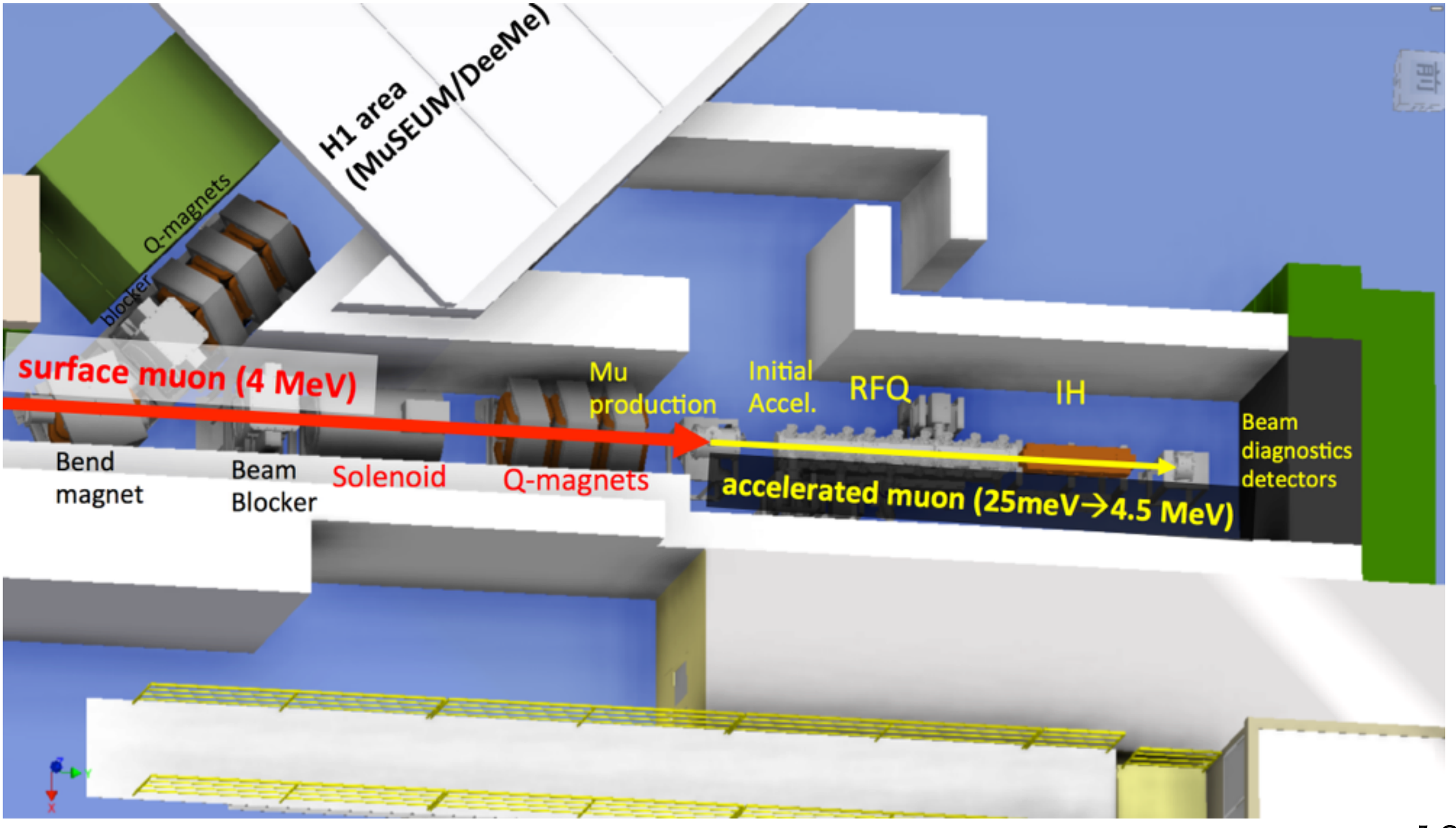


- Multiple-structures
  - Covering a wide range of β

- Low current & low duty
  - Intensity : 10^6 μ/sec
  - Repetition : 25 Hz
  - Pulse length : 10 sec

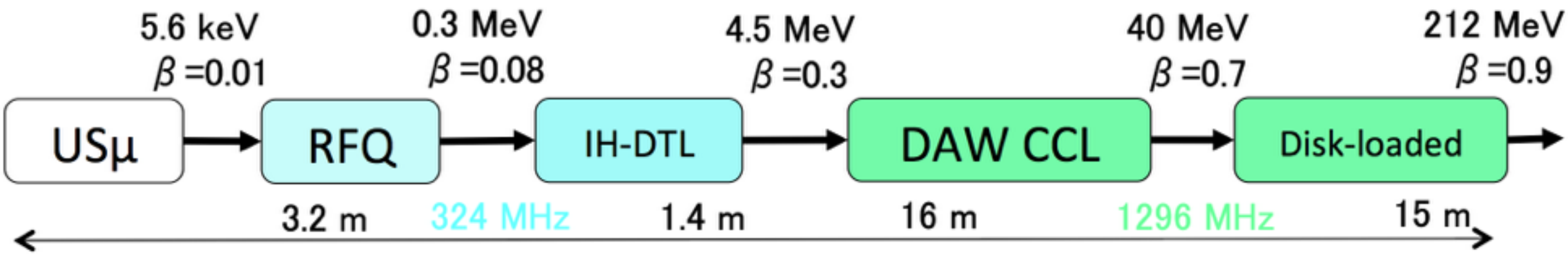
- Fast acceleration
  - Minimize the decay loss

Muon Acceleration Development

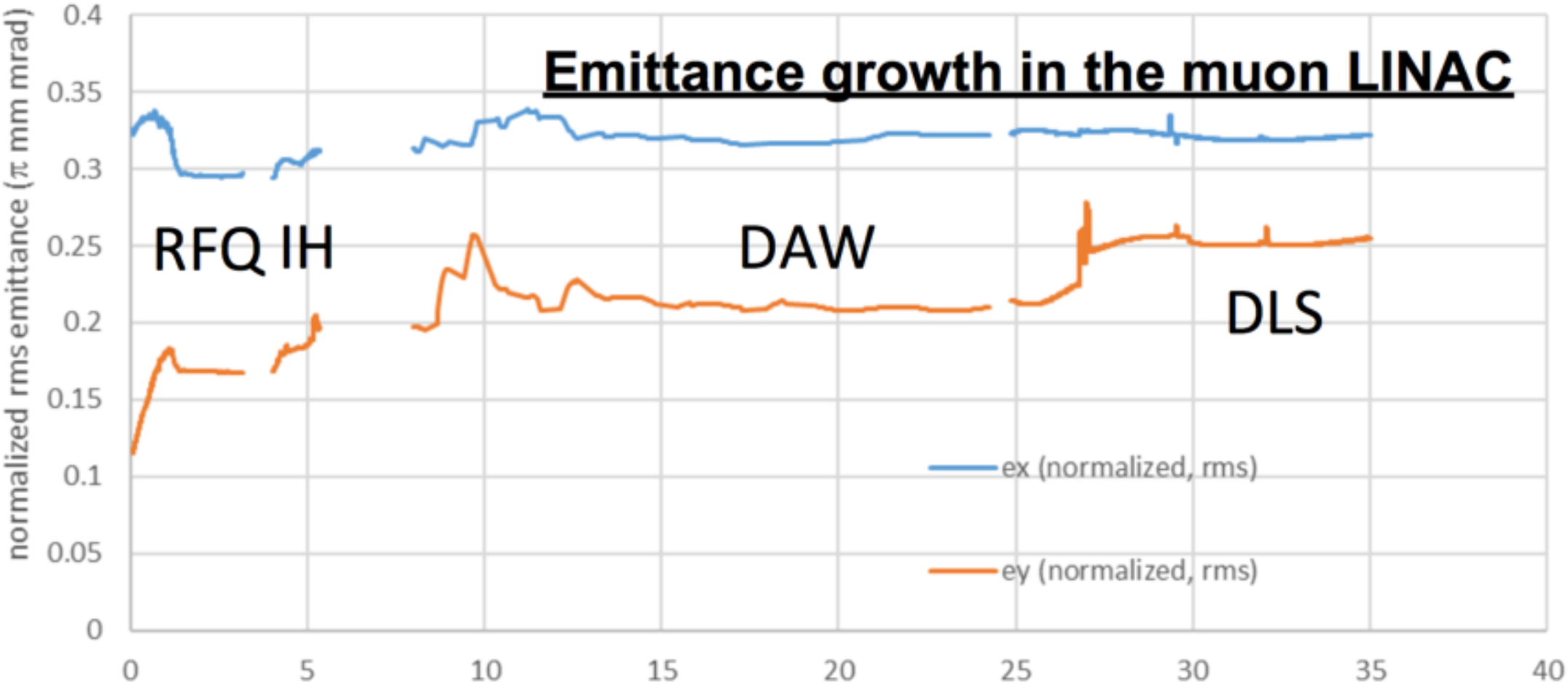


Muon Acceleration Development

Emittance Growth Simulation



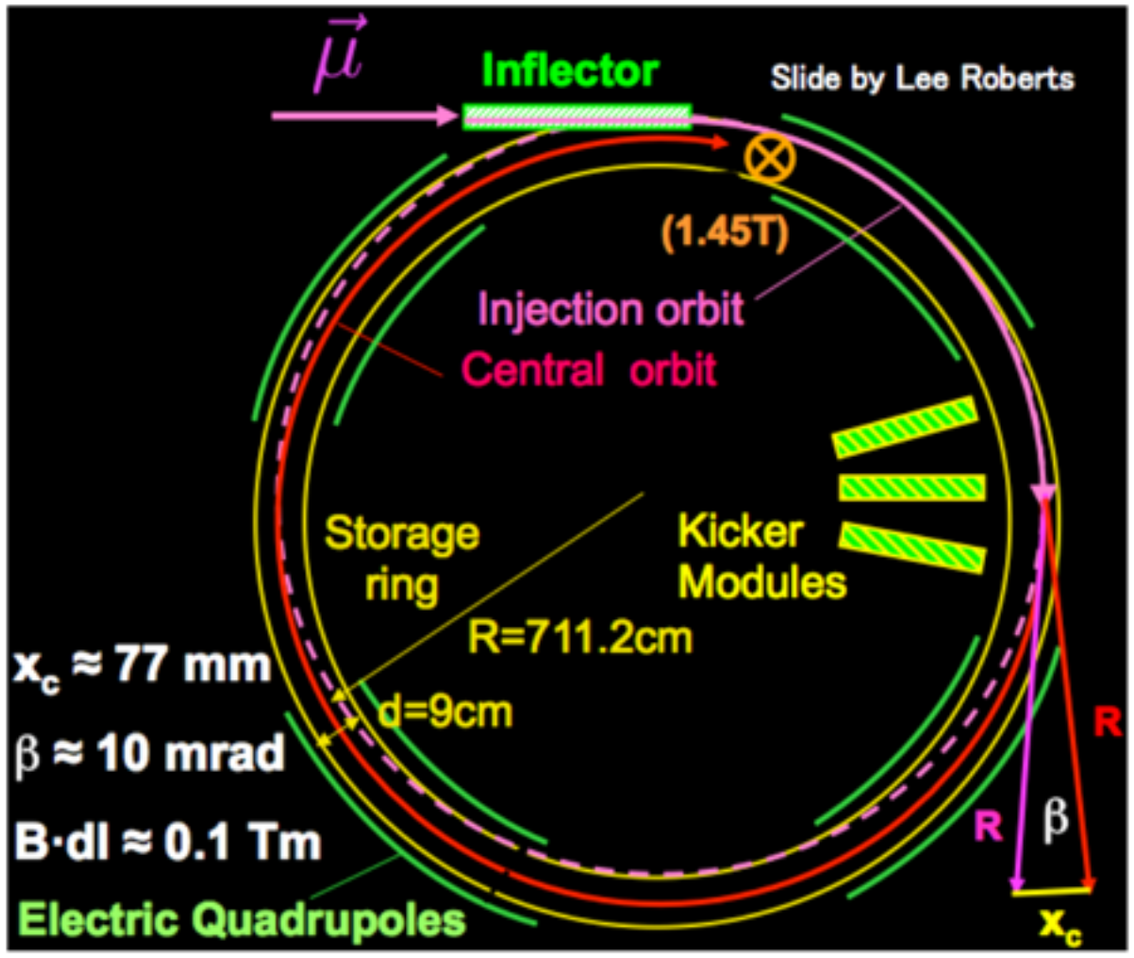
Total ~ 40m



Matching btw DAW and DLS leads to a better emittance.

Muon Beam Injection and Storage

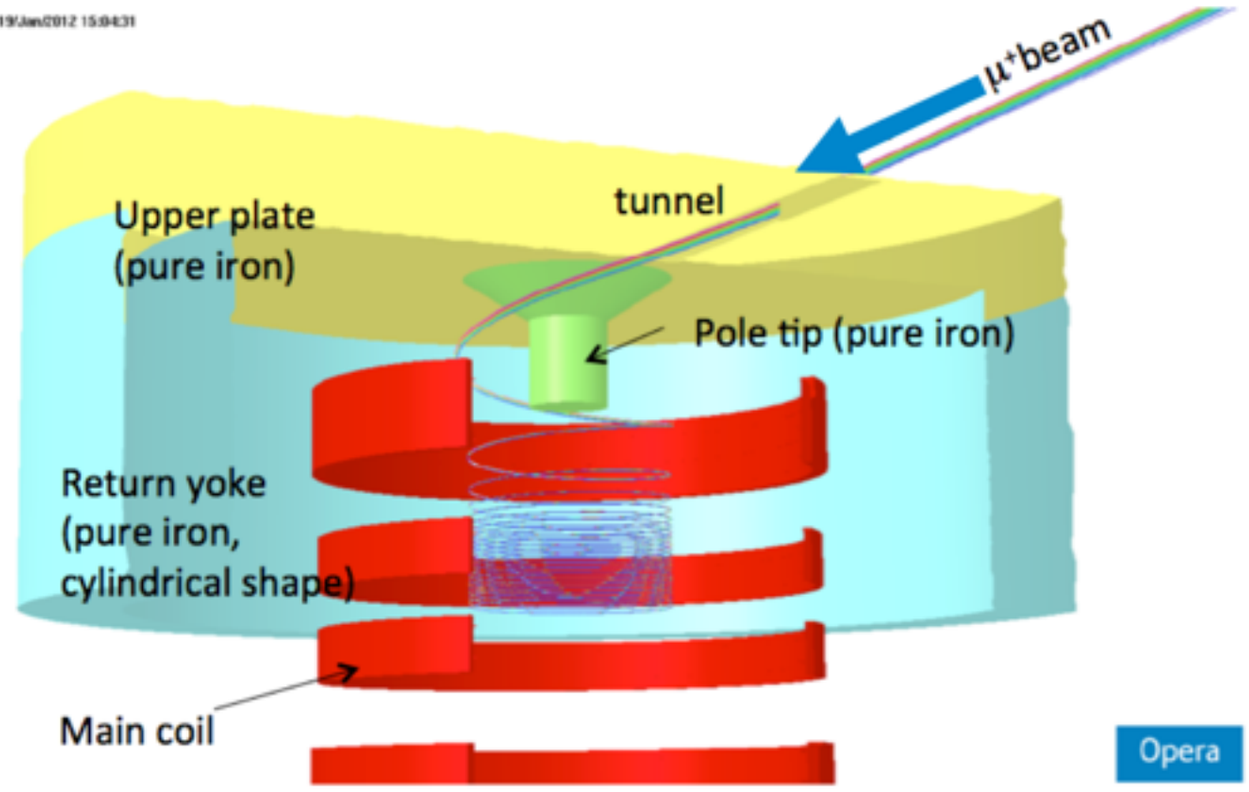
Horizontal injection + kicker (BNL E821, FNAL E989)



Injection efficiency : 3-5%(*)

(*) PRD73,072003 (2006)

3D spiral injection + kicker (J-PARC E34)

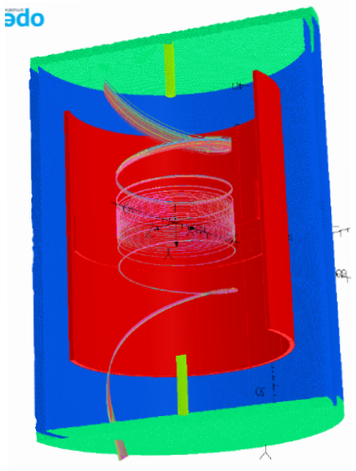


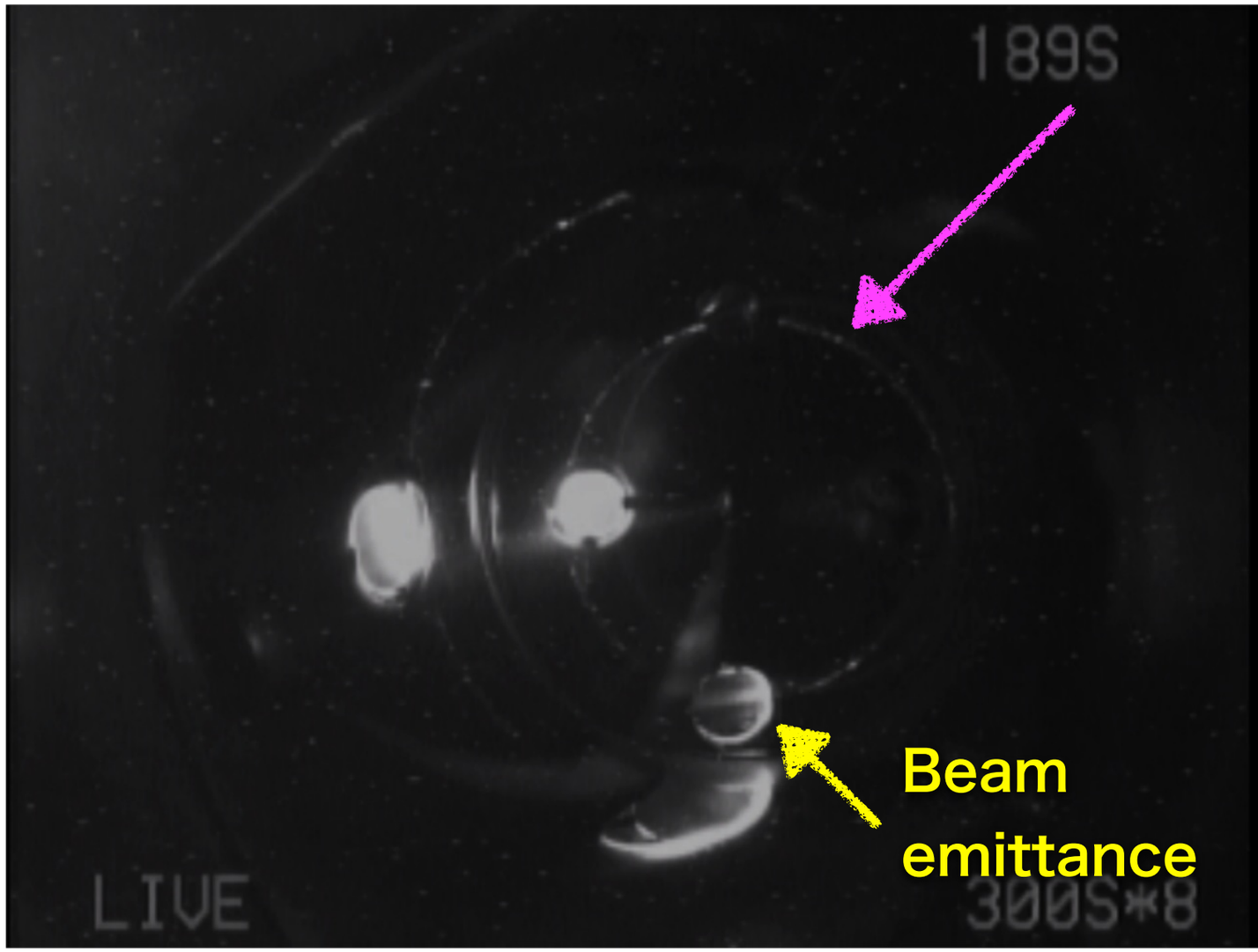
Injection efficiency : ~90%

NIM A 832, 51 (2016) by H. Iinuma et al.

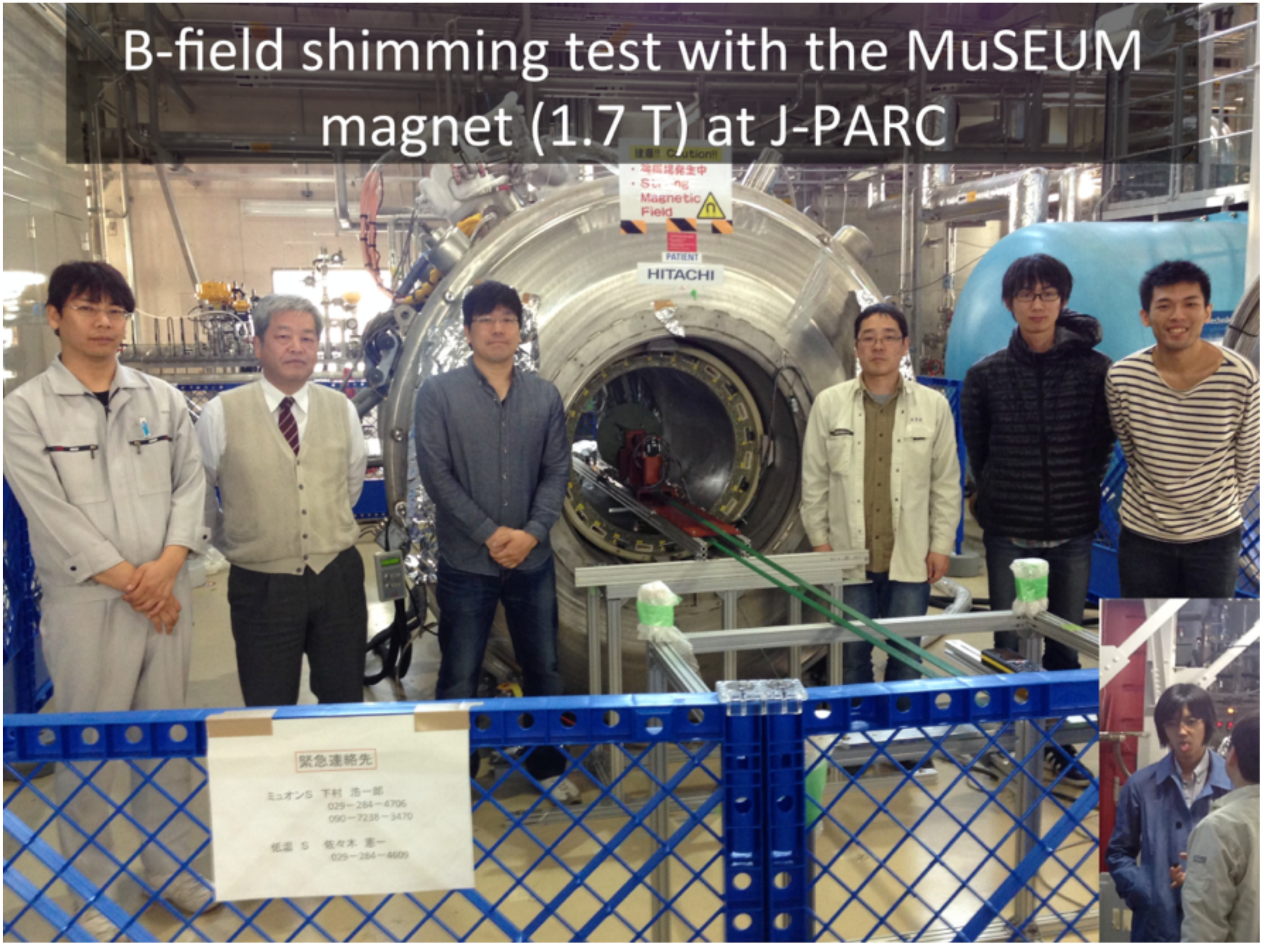
Spiral Injection Test

- Proof-of-principle injection test using electrons.
- Successfully observed a spiral track



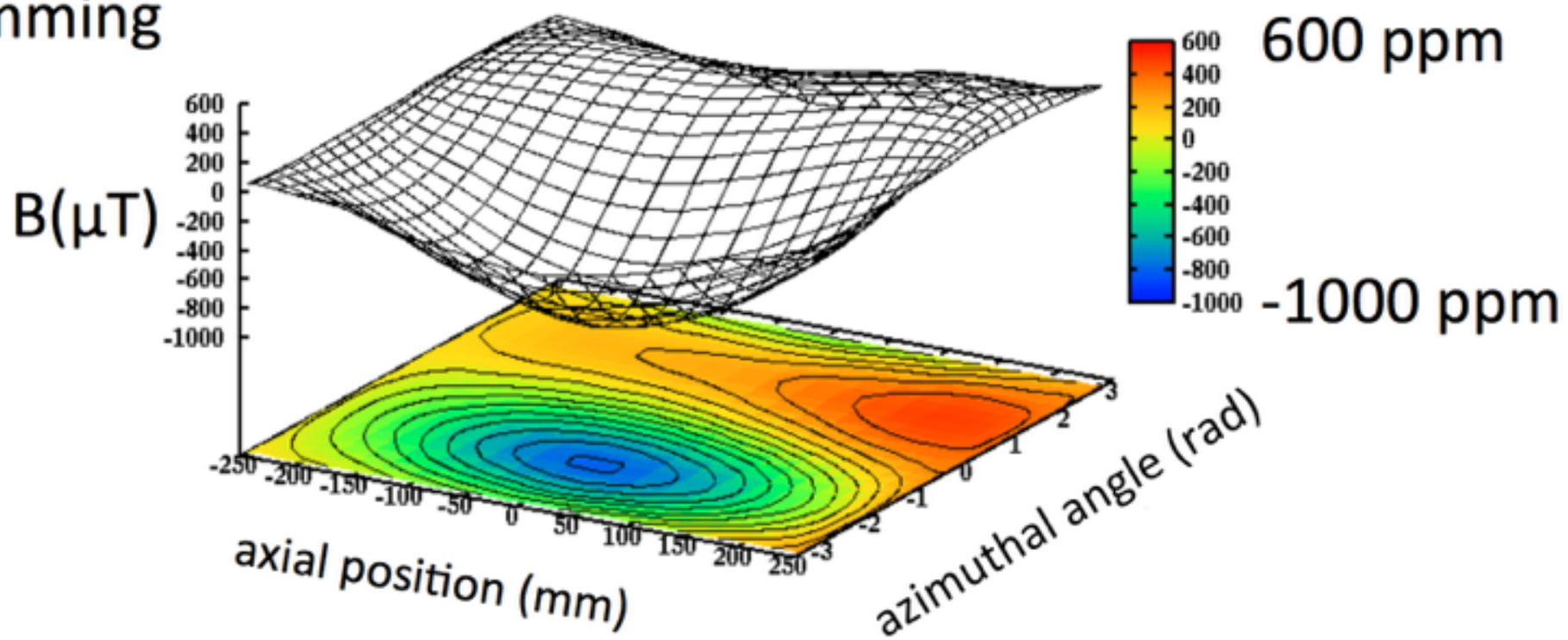


B-Field Shimming

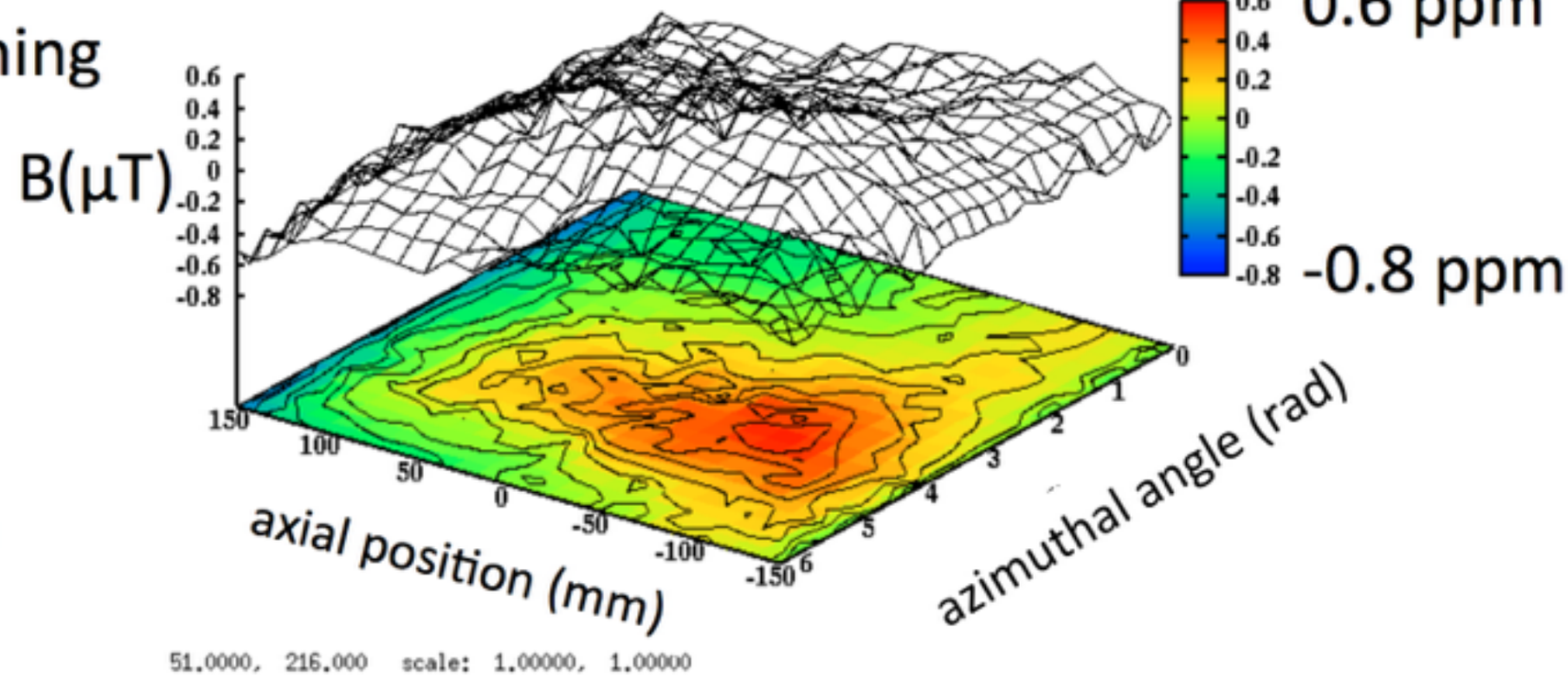


B-Field Shimming

Before shimming

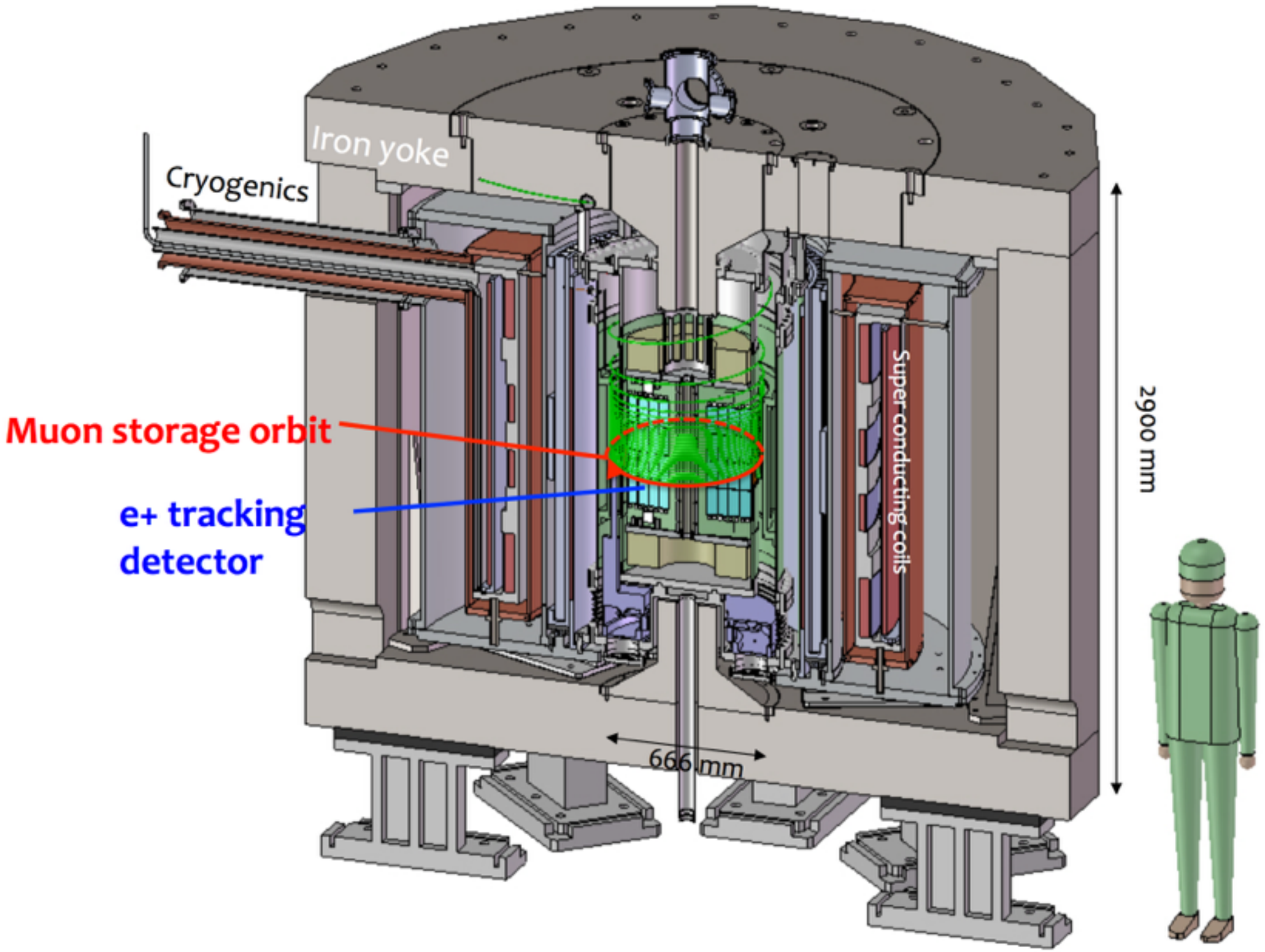


After shimming

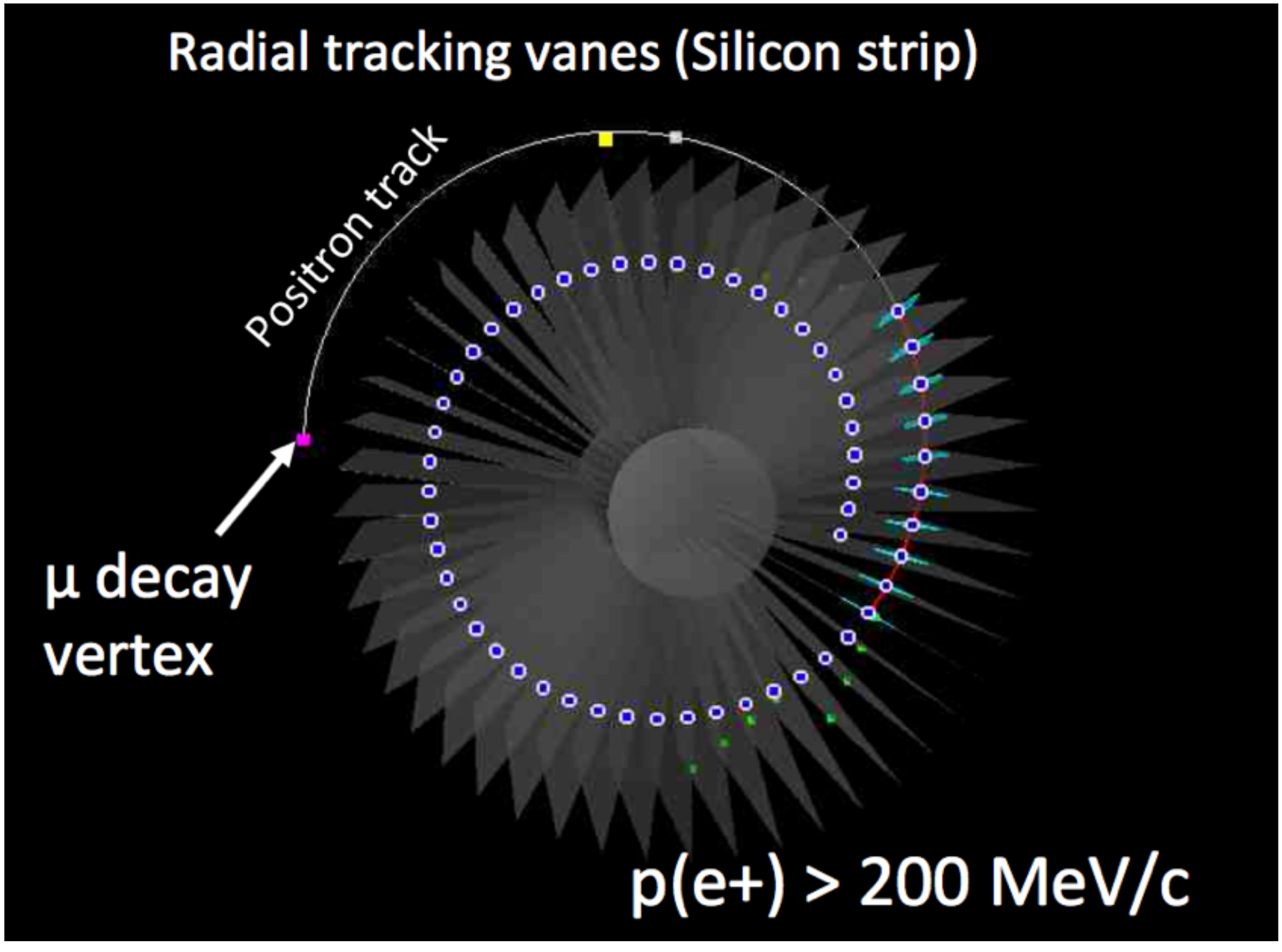


r = 140 mm

Muon Storage Magnet and Detector

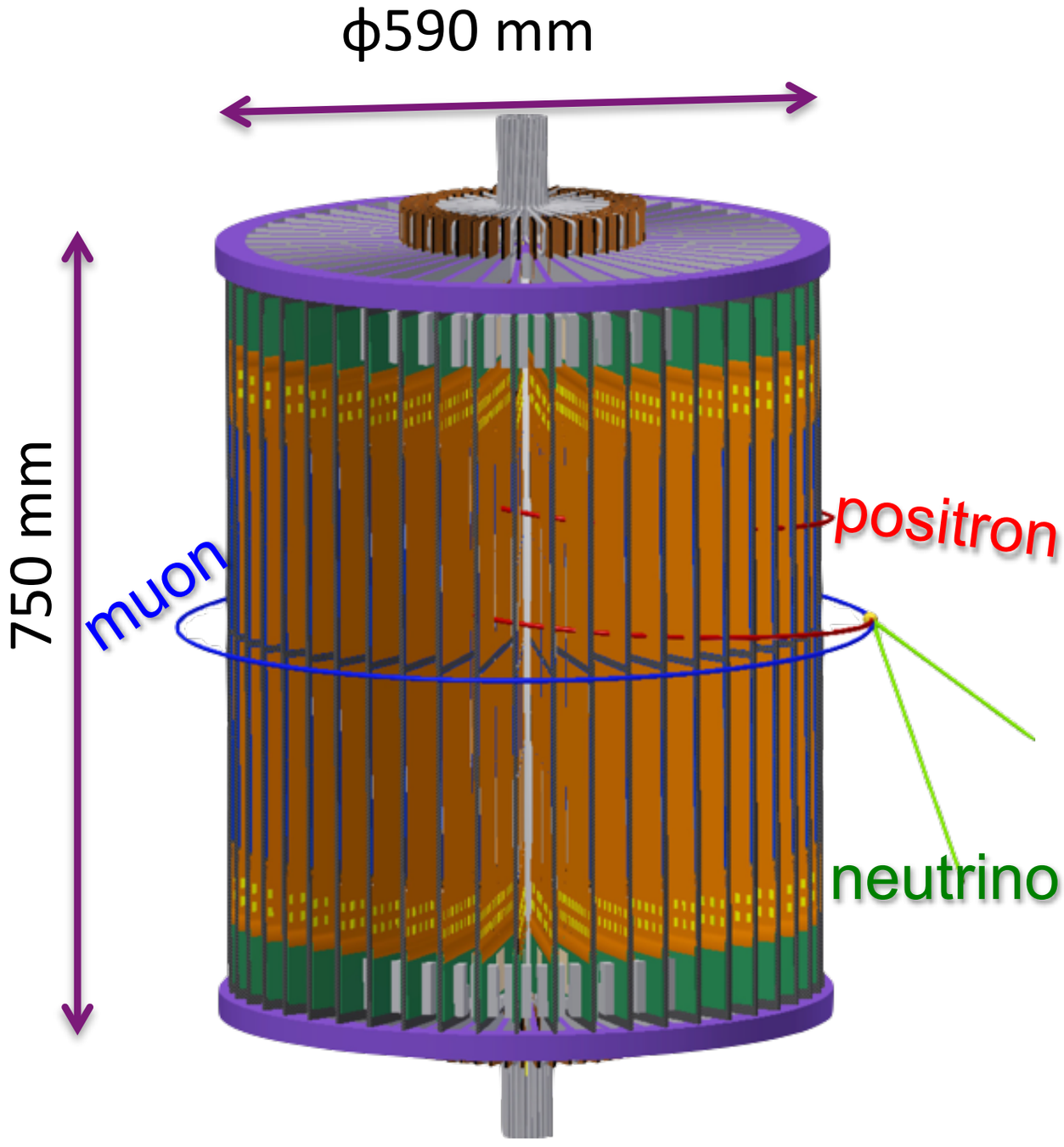


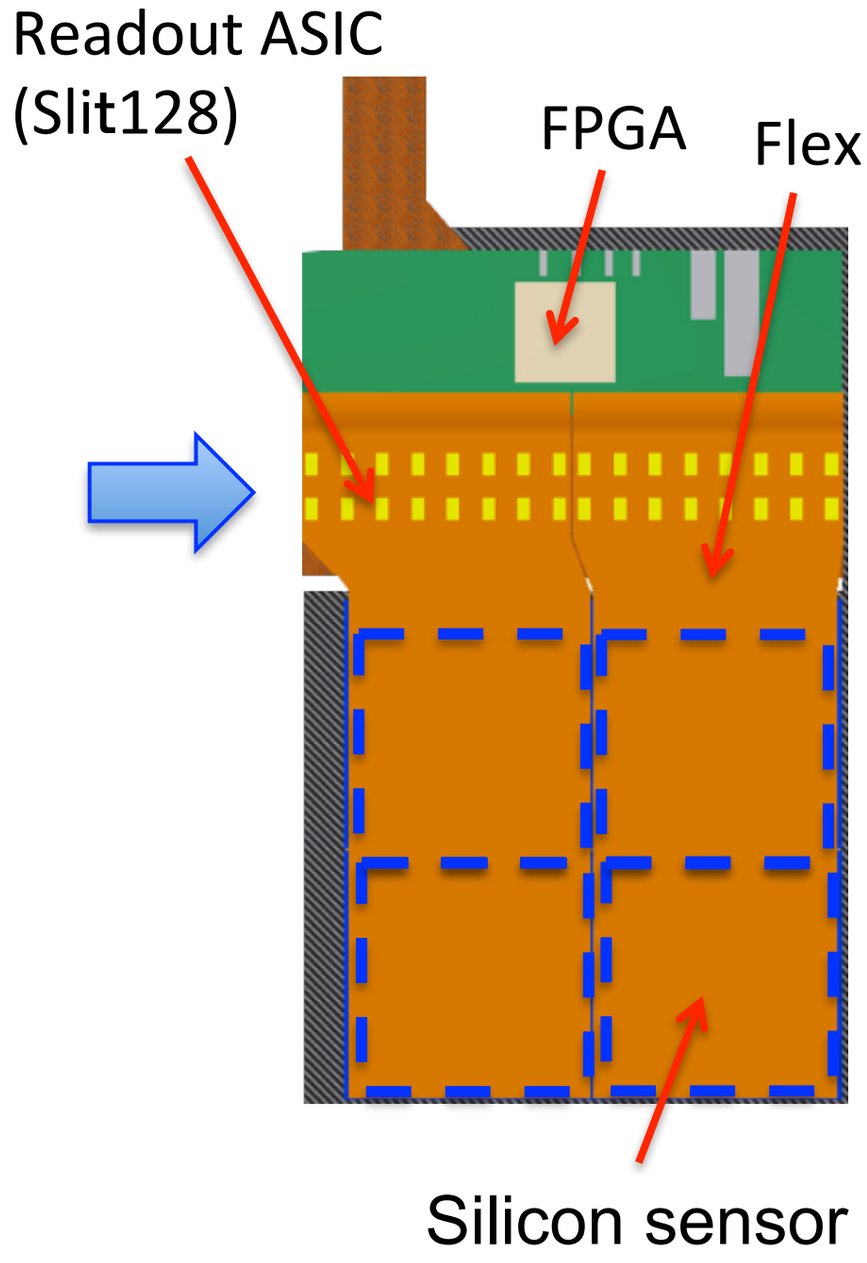
Positron Tracking Detector



Detector

- Silicon strip tracker with a “vane” structure

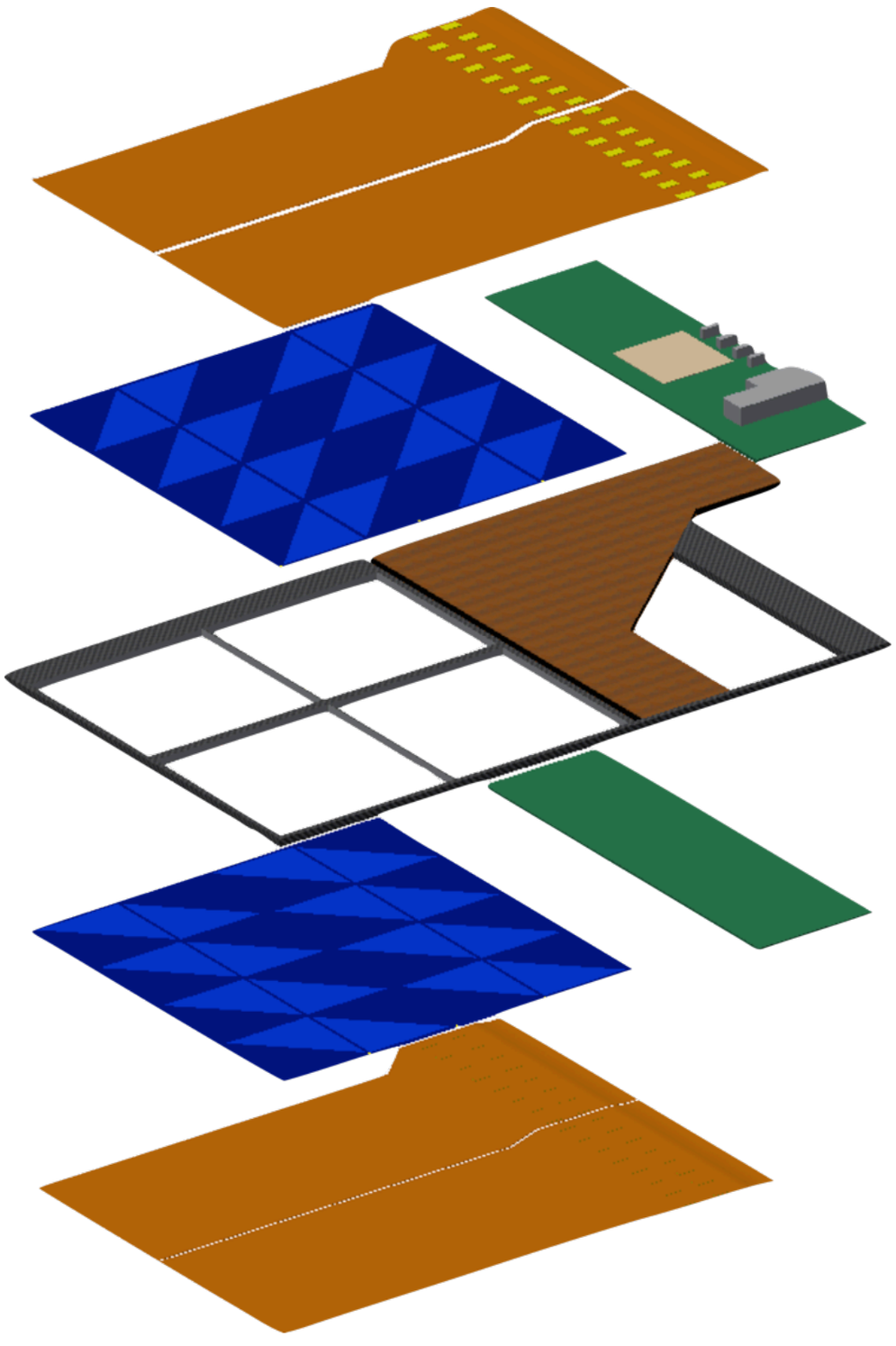




Detector

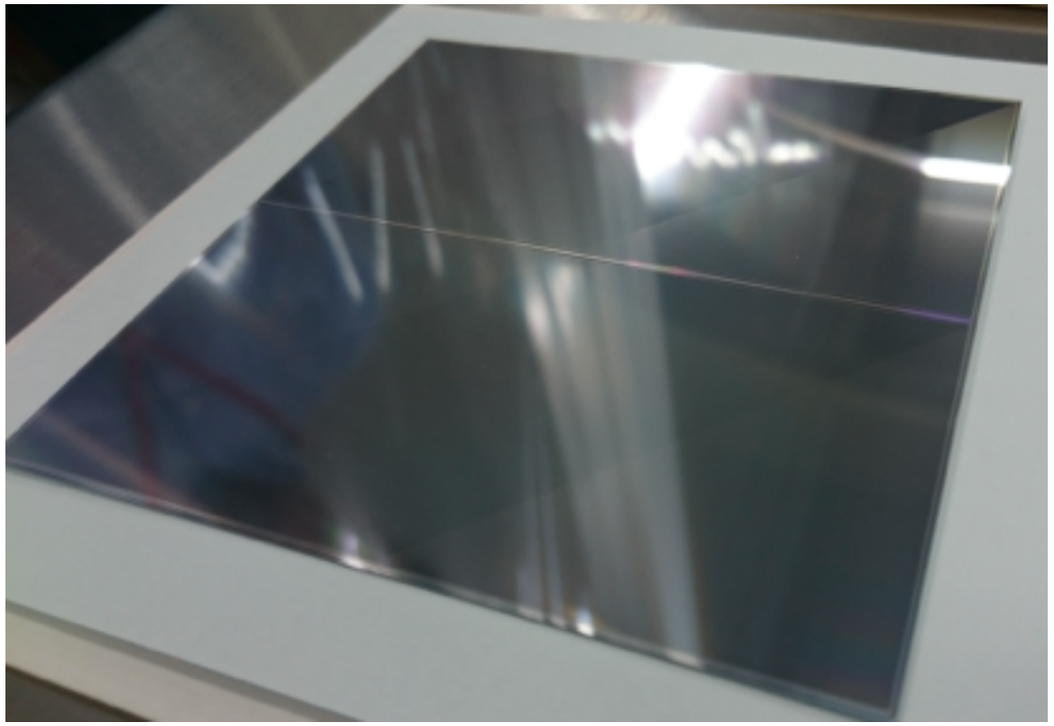
- Vane
  - Two single-sided p-on-n sensors
    - Axial/radial strips
    - 190 μm strip pitch
    - 1,024 strips/sensor
  - ASIC readout outside the tracking volume
    - Binary readout with ToT
- The entire detector
  - 768 sensors
  - 786,432 channels

Half vane

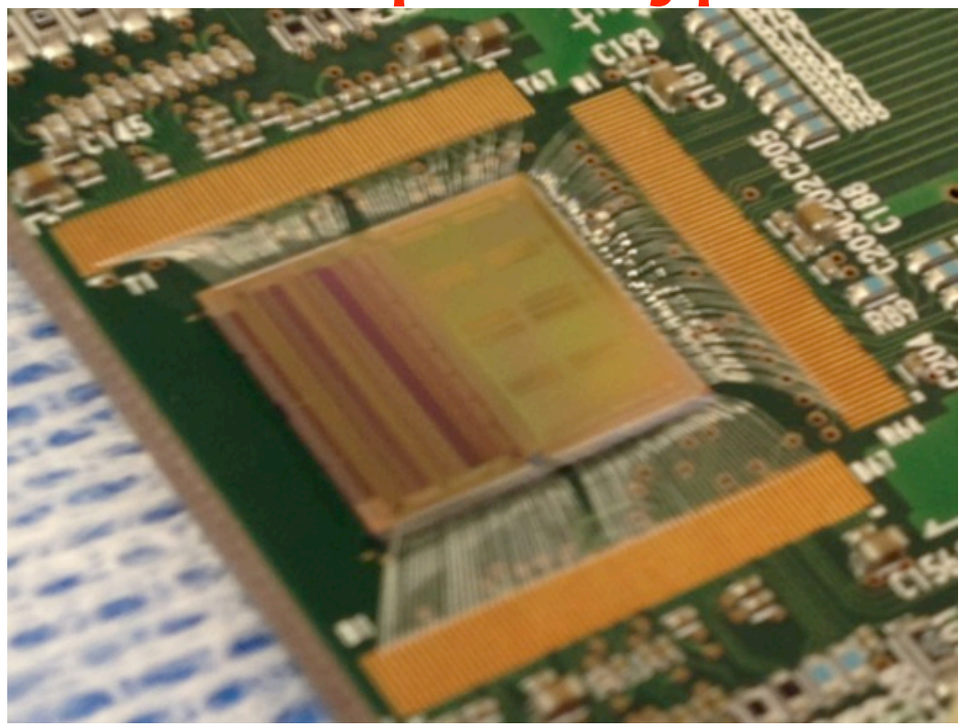


Detector Development

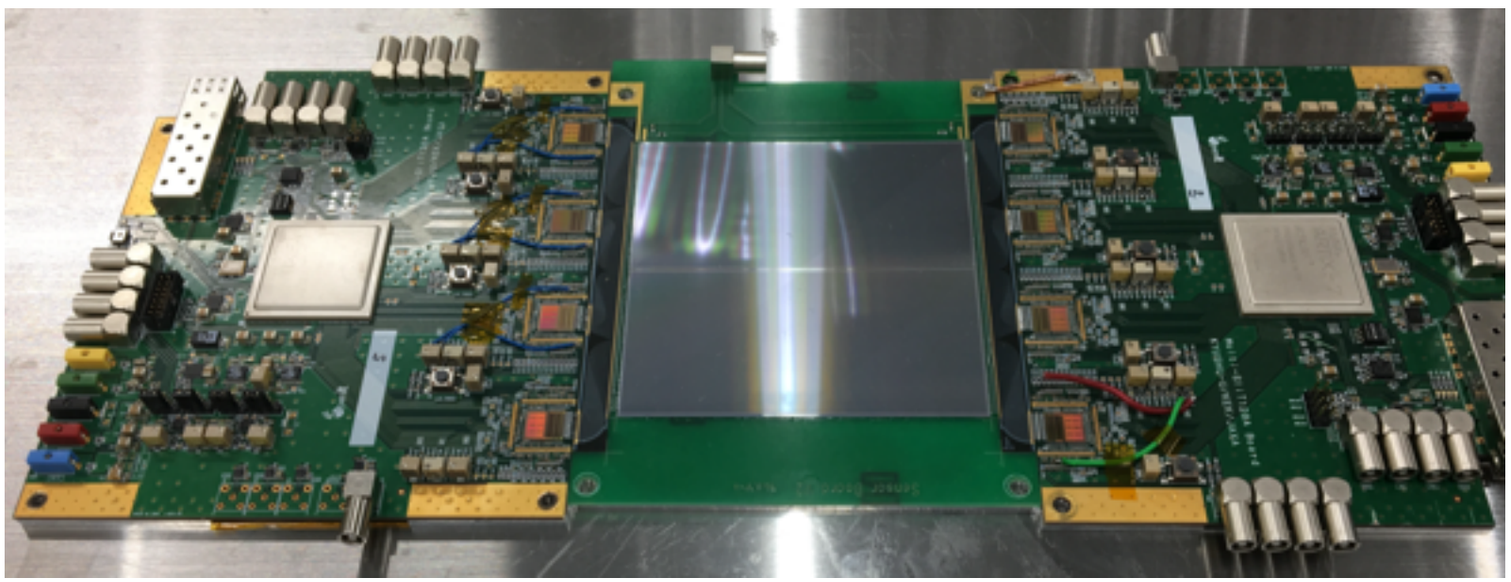
Full-scale sensor



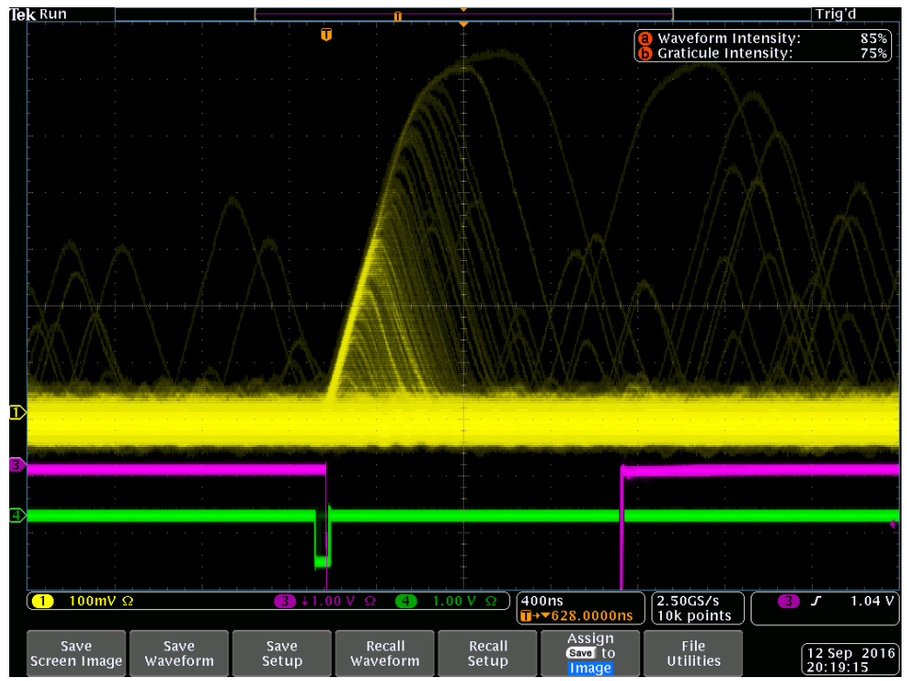
ASIC prototype



Prototype development

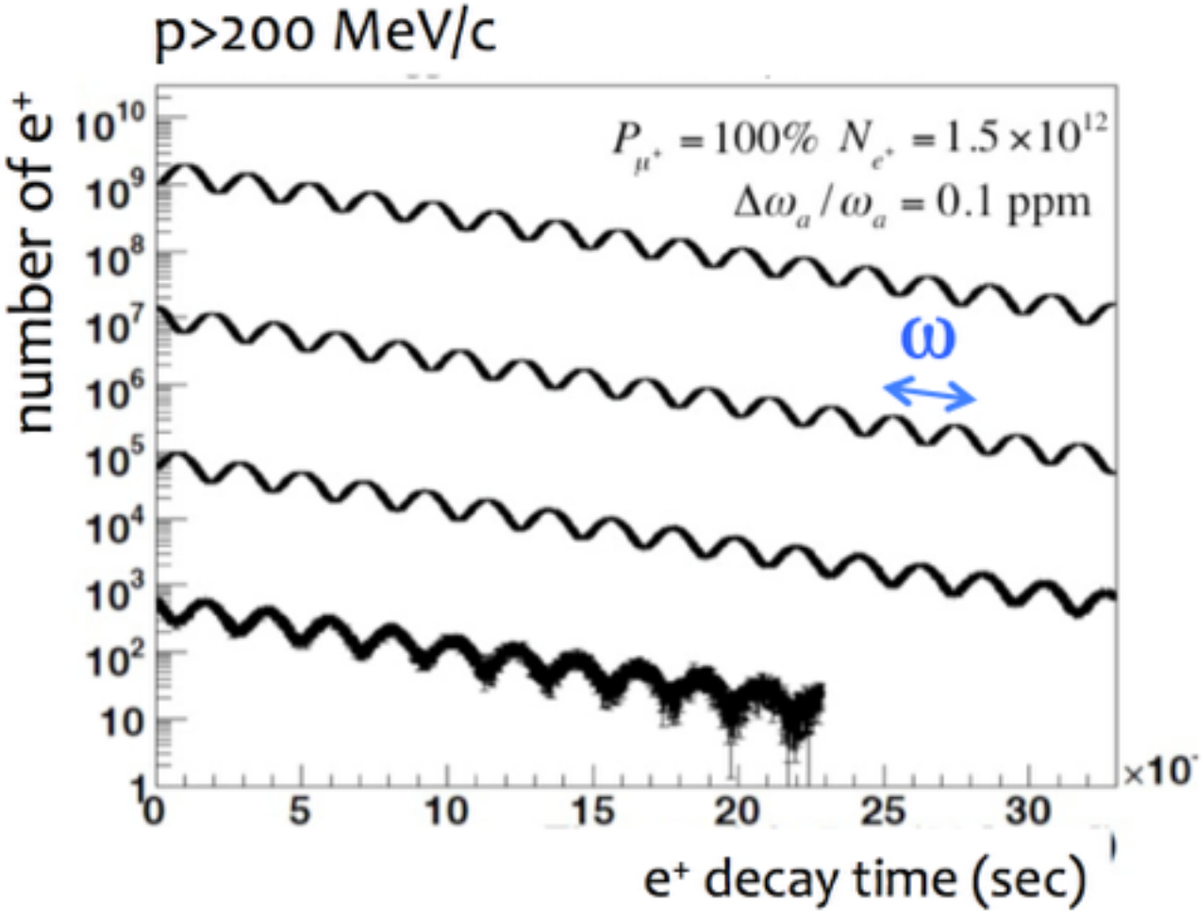


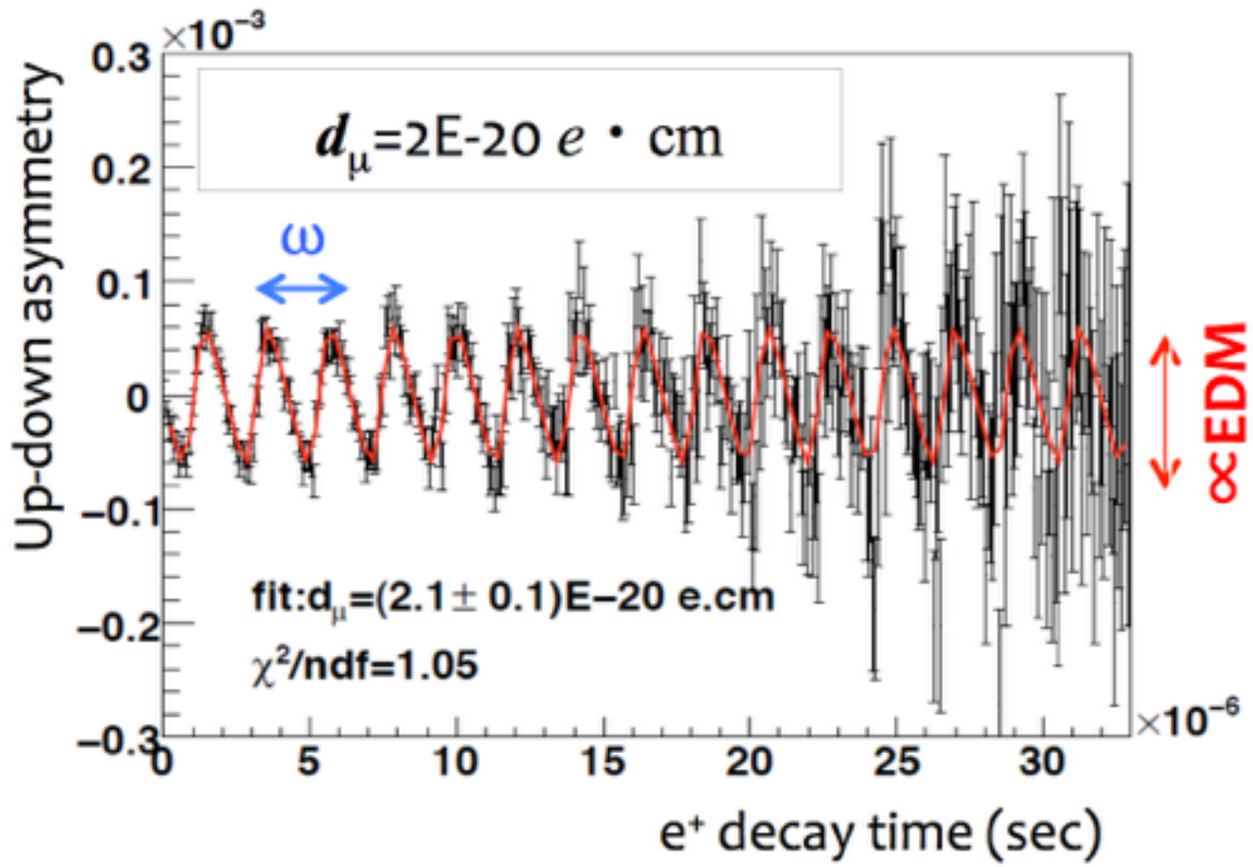
Evaluation



Expected g-2/EDM Measurement

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$





- Separation of g-2 and EDM
- Simultaneous measurements of both g-2 and EDM

Summary

- The muon g-2/EDM experiment at J-PARC uses a ultra-cold muon beam to establish a new principle of the measurement with E=0.

- The targeted goal
  - g-2　: 0.37 ppm in Phase-1, 0.1 ppm at Phase-2
  - EDM : 1.3×10^{-21} e・cm

- The R&Ds in all the area are progressing very well towards the readiness for the construction.

- The independent measurement of g-2 together with EDM could contribute to opening a window to new physics.