Muon Linac
for the J-PARC Muon g-2/EDM Experiment

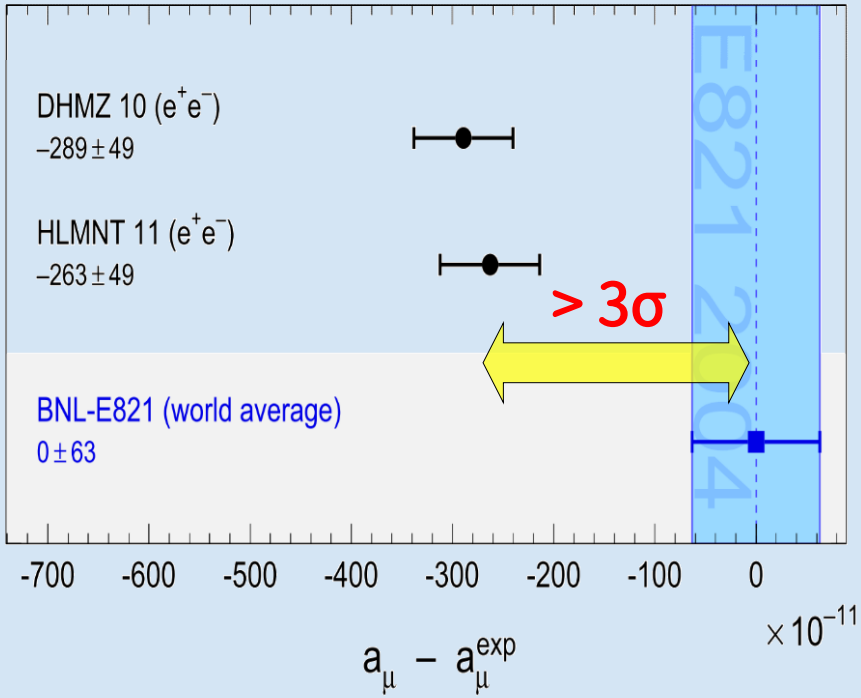
M. Otani (KEK)
for J-PARC E34

Hints to Beyond SM

- Higgs
  - very unique features and precision measurements of Higgs properties will open the door towards deeper understanding of EW symmetry breaking.
- Dark Matter
- Neutrino
- Flavour measurement in B etc.
- …
- Muon anomalous magnetic moment (g-2)

Muon g-2

- More than 3σ tension reported by BNL has not been understood more than 10 years.
- To solve it, precise measurement with different approach is necessary.



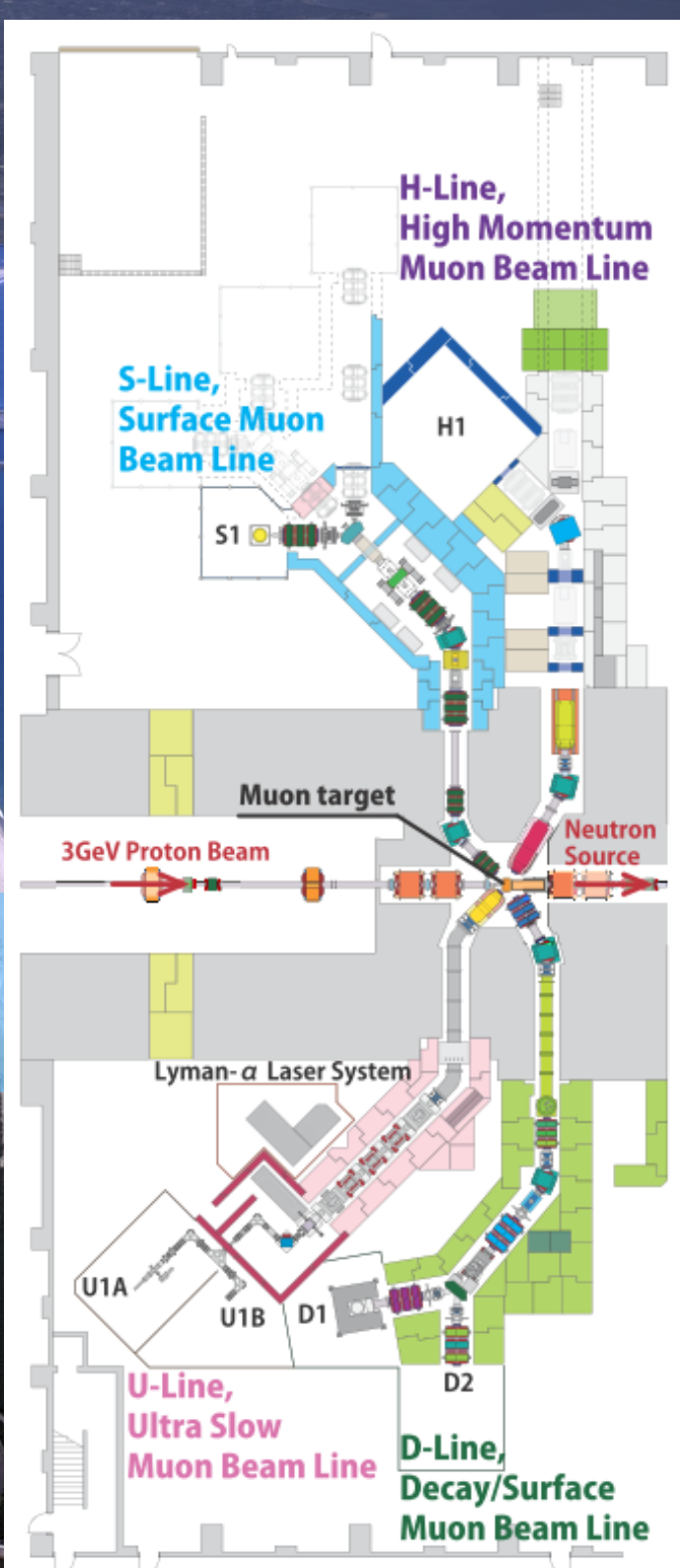
Systematics @BNL

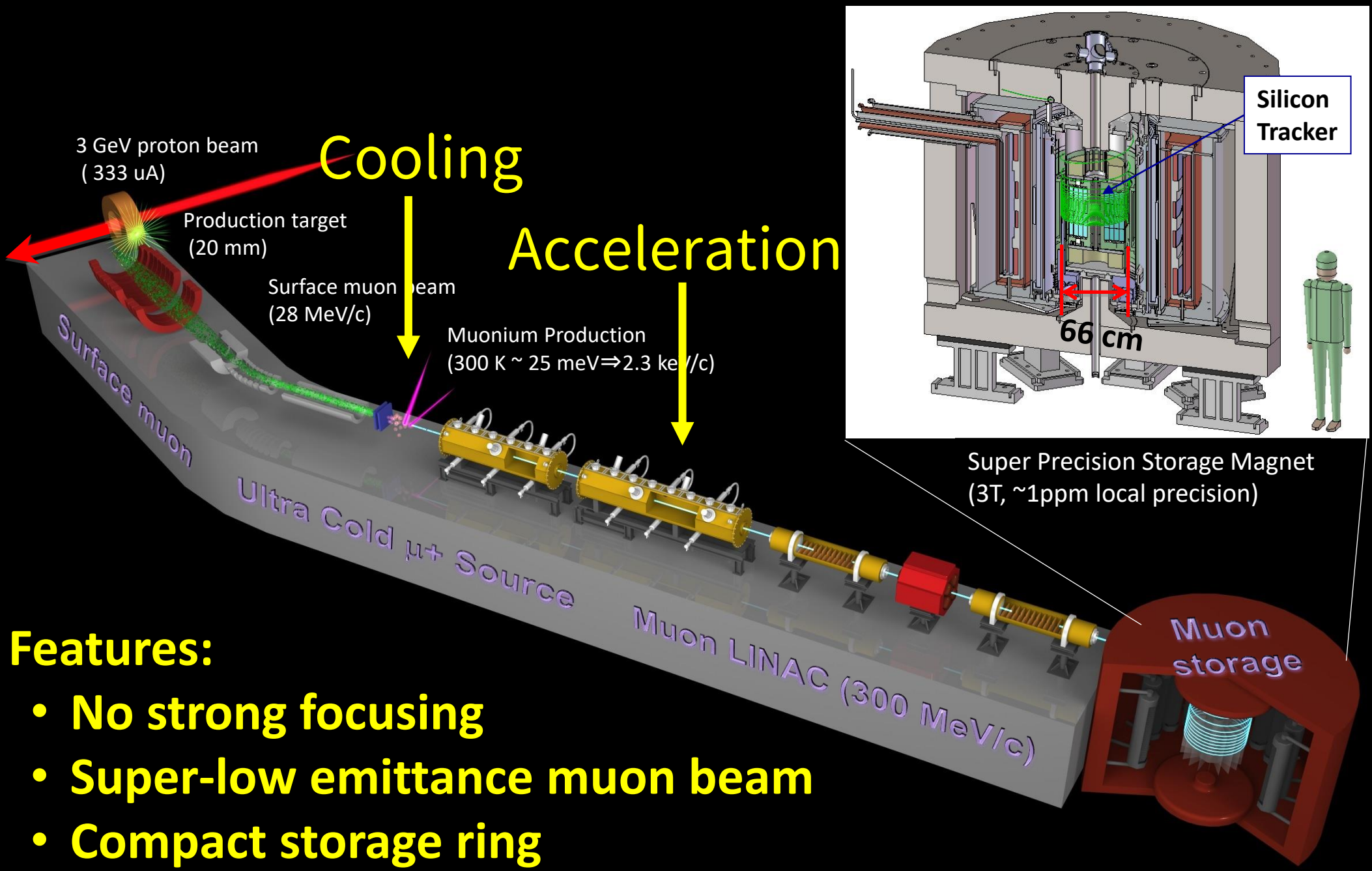
Systematic [ppb]	
B field	170
Lost muons	90
CBO	70
E and pitch	50
Gain changes	120
Pileup	80

Related to beam emittance

Low emittance muon beam offers precise and new measurement

J-PARC MLF


H-Line,
High Momentum
Muon Beam Line
S-Line,
Surface Muon
Beam Line
H1
S1
Muon target
3GeV Proton Beam
Neutron
Source
Lyman-α Laser System
U1A
U1B
D1
D2
U-Line,
Ultra Slow
Muon Beam Line
D-Line,
Decay/Surface
Muon Beam Line

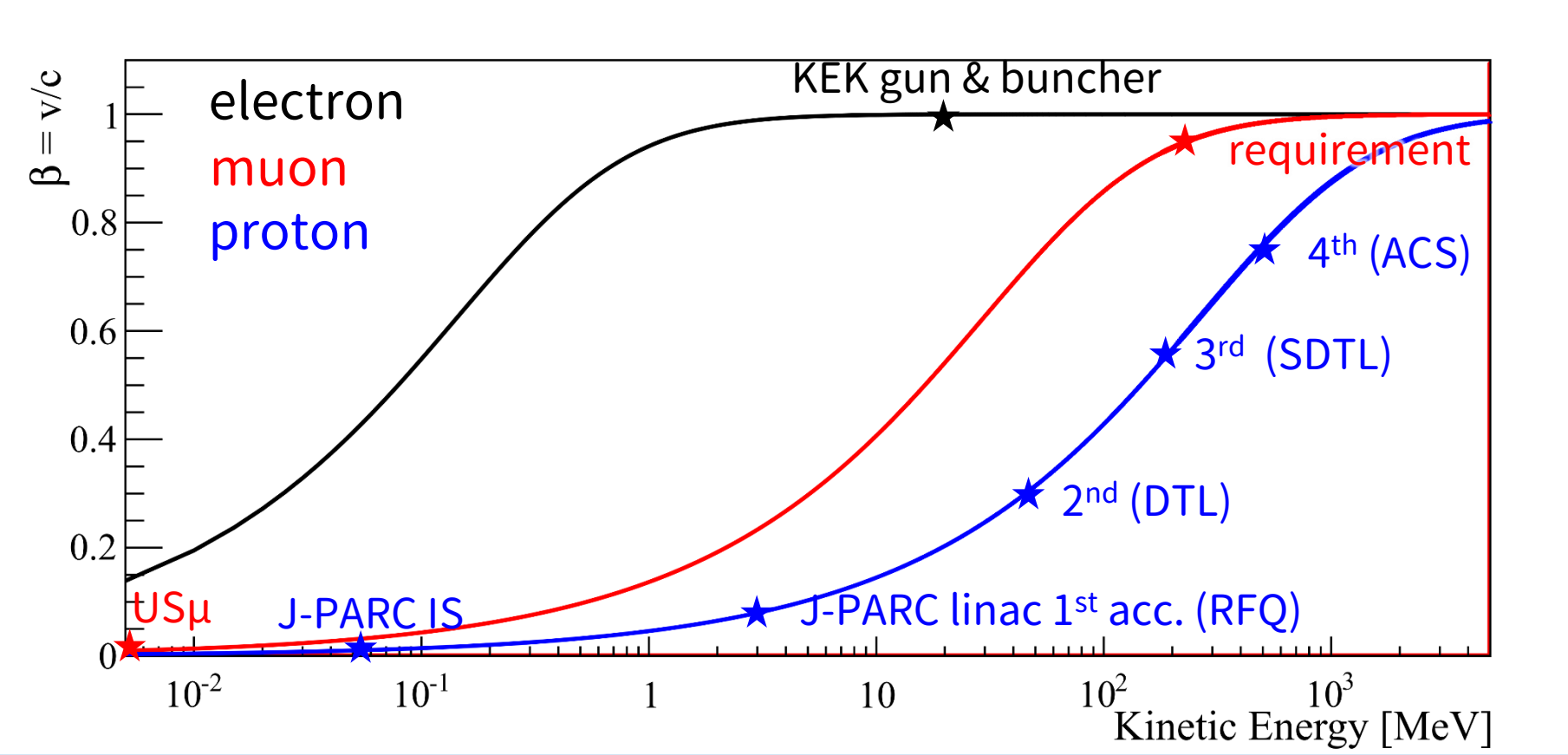


Features:

- **No strong focusing**
- **Super-low emittance muon beam**
- **Compact storage ring**
- **Full tracking detector**
- **Completely different from BNL/FNAL method**

Muon Acceleration

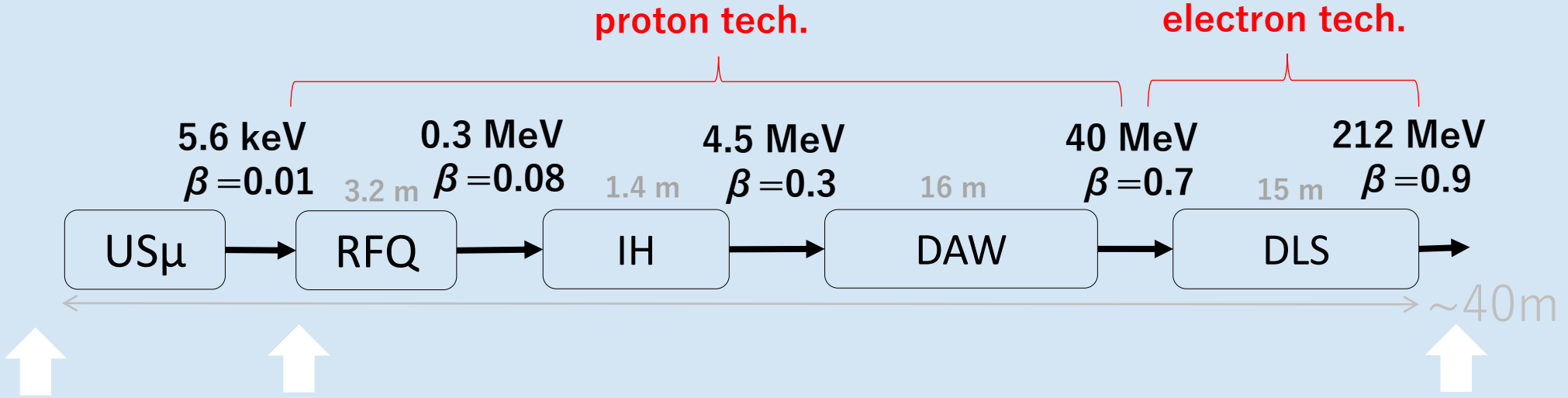
- Fast acceleration by linac is adopted to avoid decay loss.
- Velocity (β=v/c) is important for linac design (to be synchronized between flight length and acceleration gap)



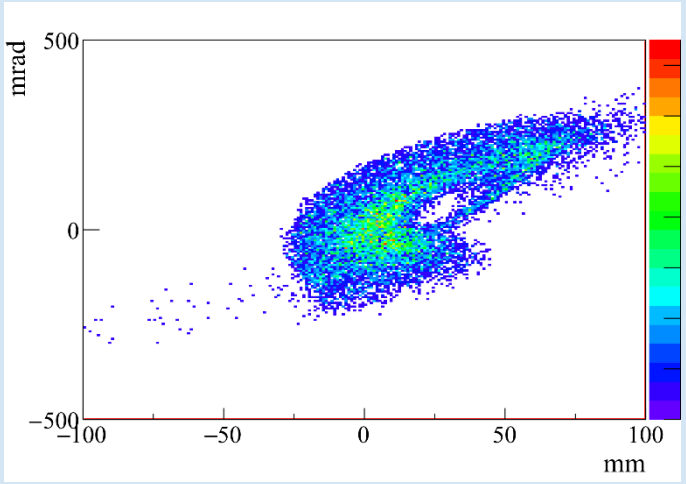
- Velocity is rapidly increased compared to proton, but not reach β~1 like electron.

Muon Linac

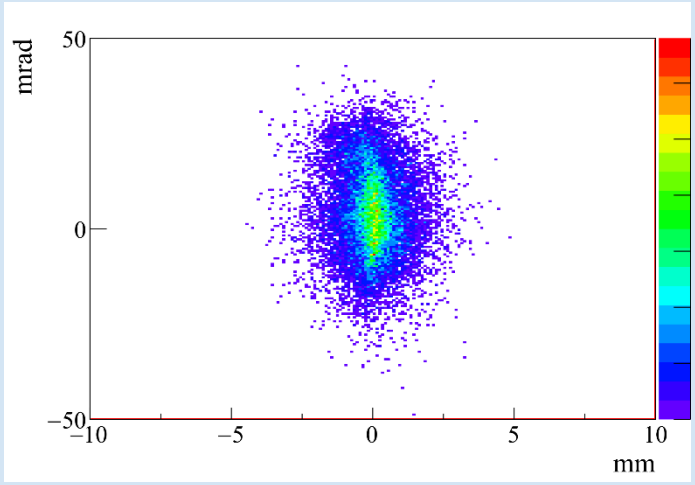
- Muon dedicated linac by hybrid proton- and electron-acceleration techniques.



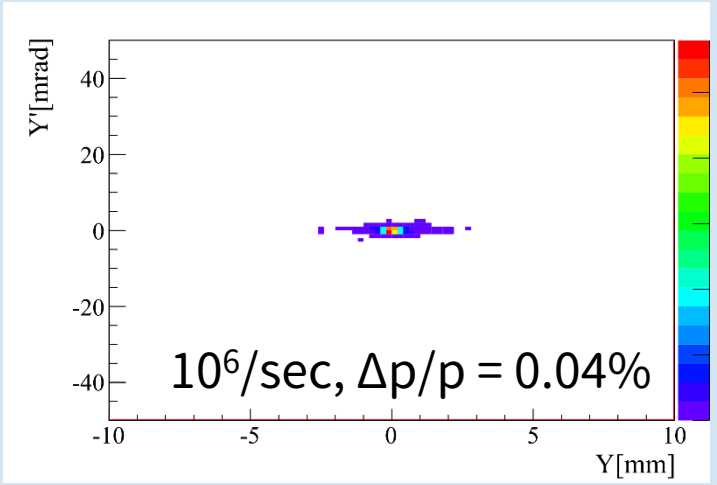
Before USμ



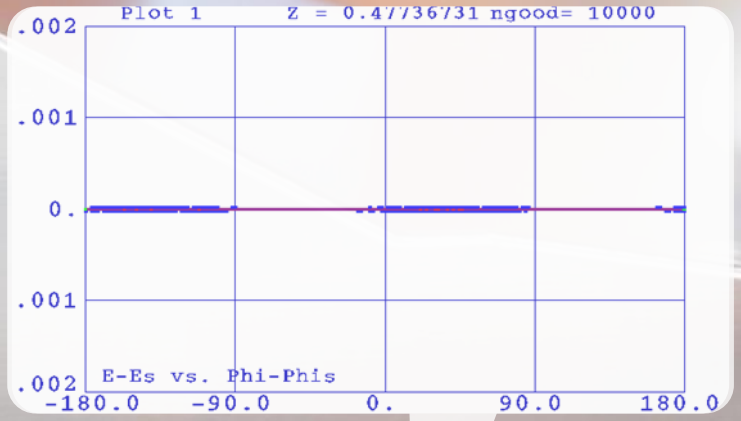
Before RFQ

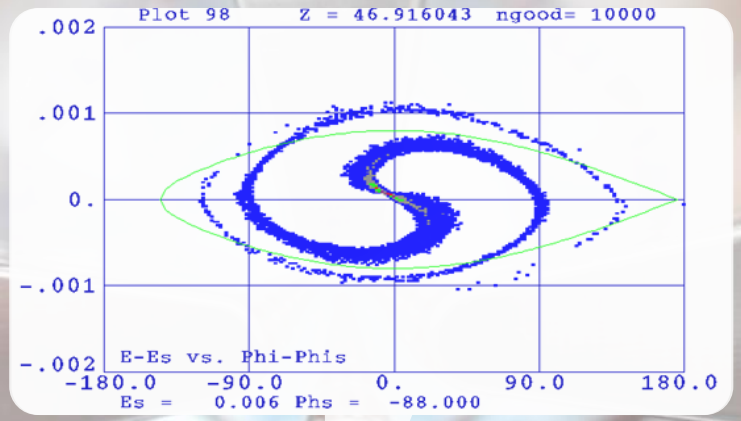


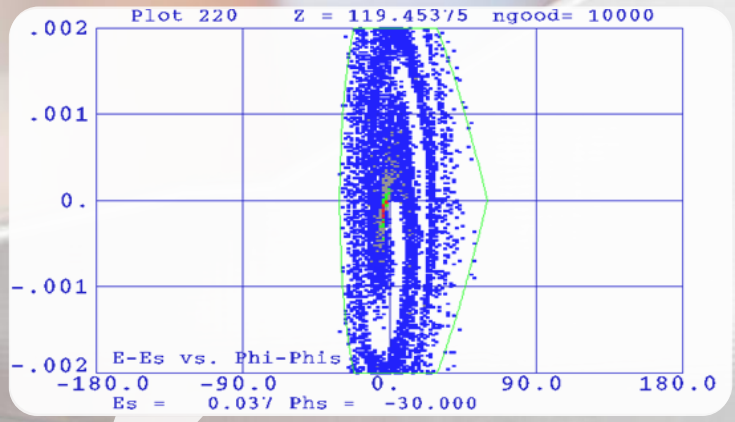
After linac

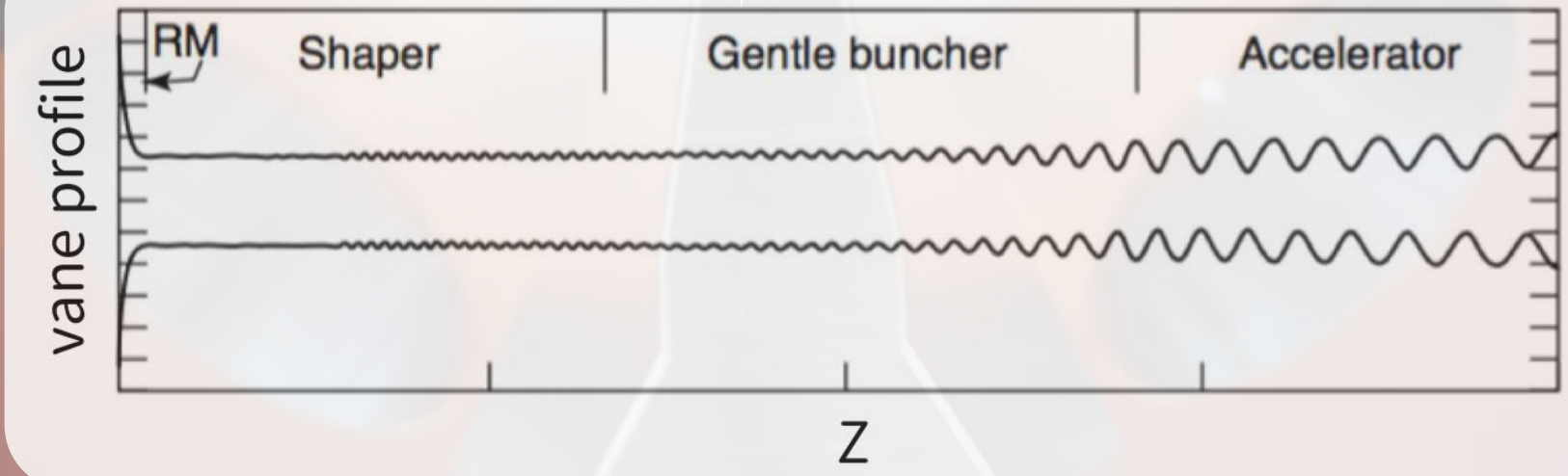


RFQ (Radio Frequency Quadrupole Linac)



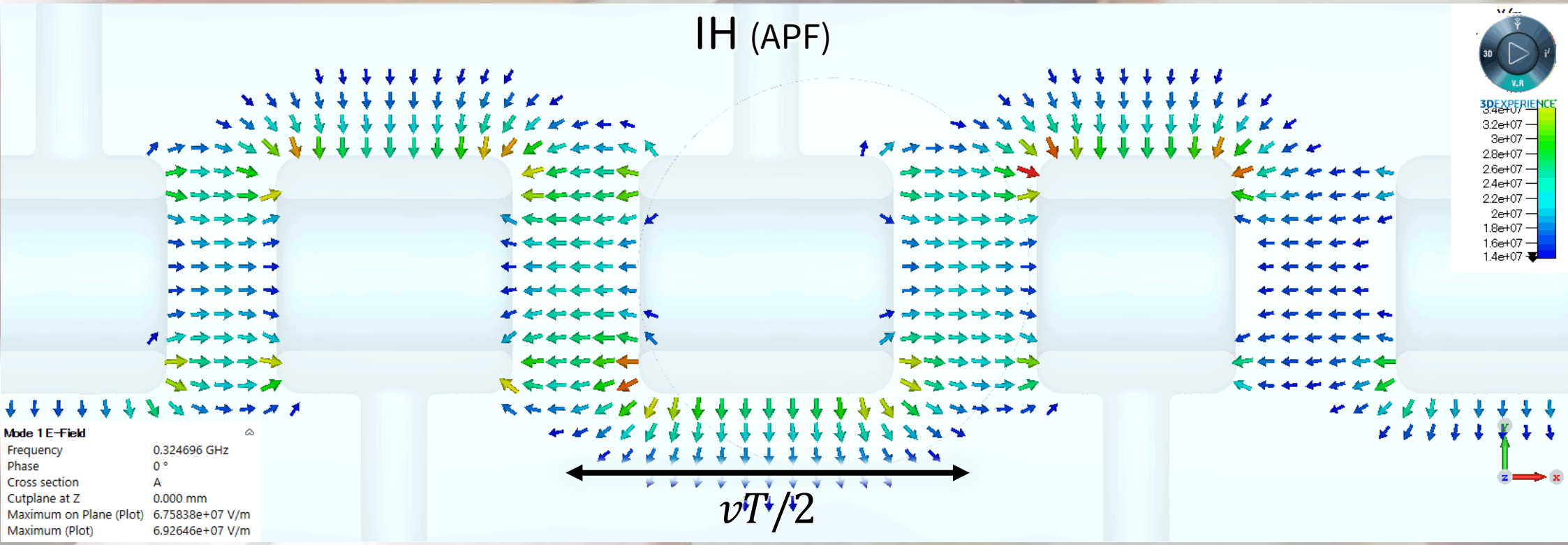






IH (Inter-digital H-mode Linac)

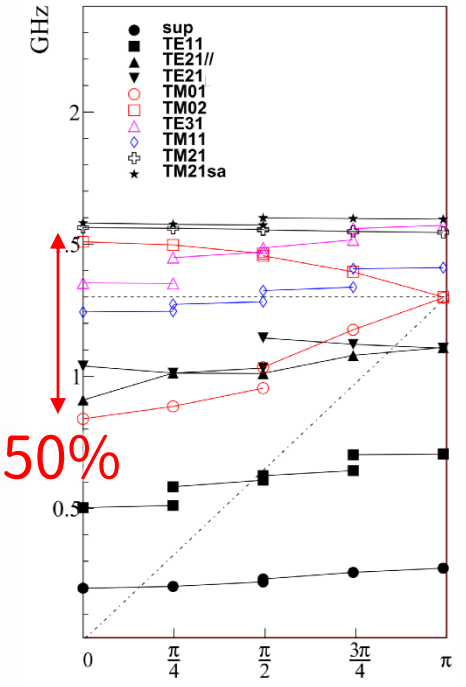
DTL Type	Alvaretz	IH (APF)
gap scaping	vT (βλ)	$vT/2$ (βλ/2)
Focusing	extra-magnet	only RF field



DAW (Disk And Washer CCL)

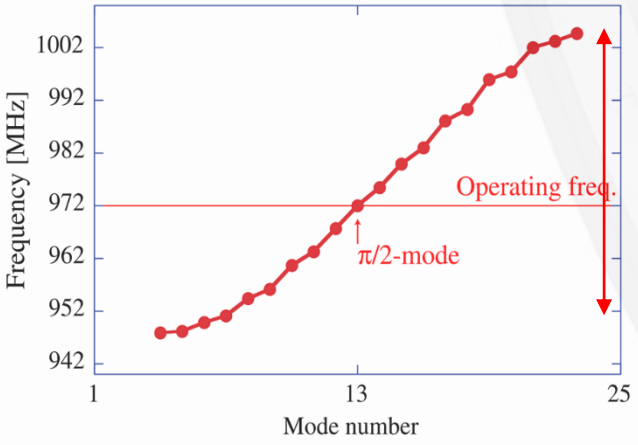
- One of Coupled Cell Linacs.
  - βλ/2 (π-mode) acceleration with coupling cell.
- Large coupling compared to other CCLs, which will reduce fabrication costs.

μ DAW



~50%

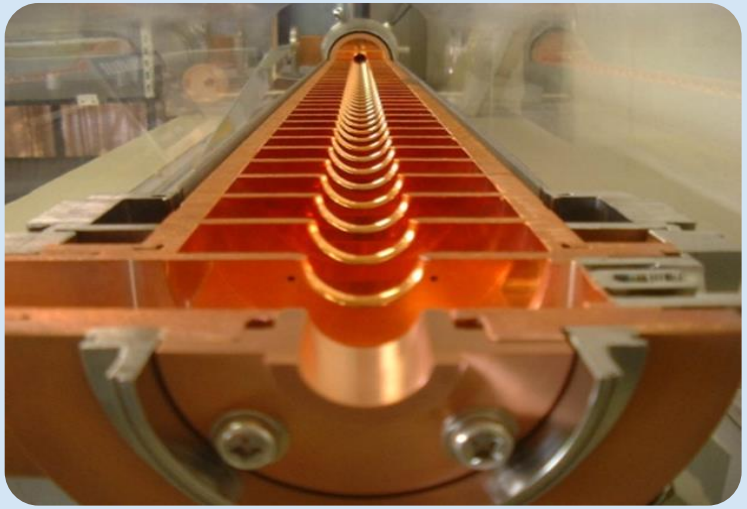
J-PARC ACS



coupling ~ 6%

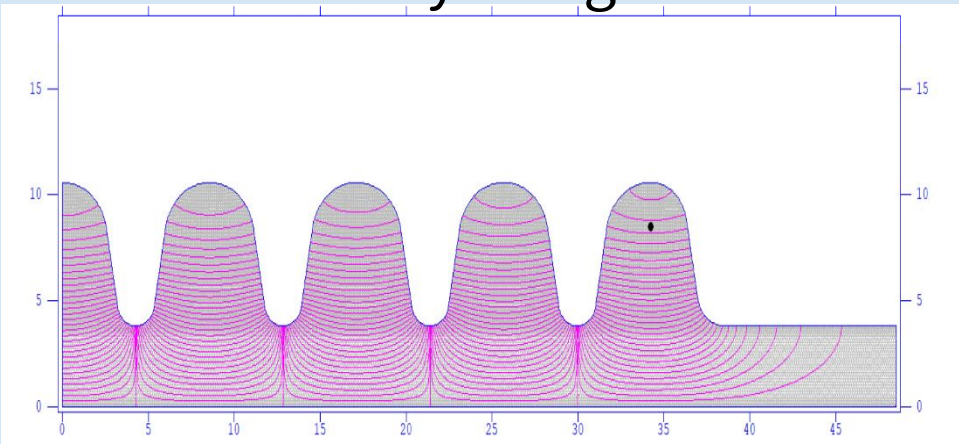
DLS (Disk Loaded Structure) and Synergy to ILC

- Base line design with DLS
  - has been used in e-linac and can be operated in high gradient (20 MV/m in our design)

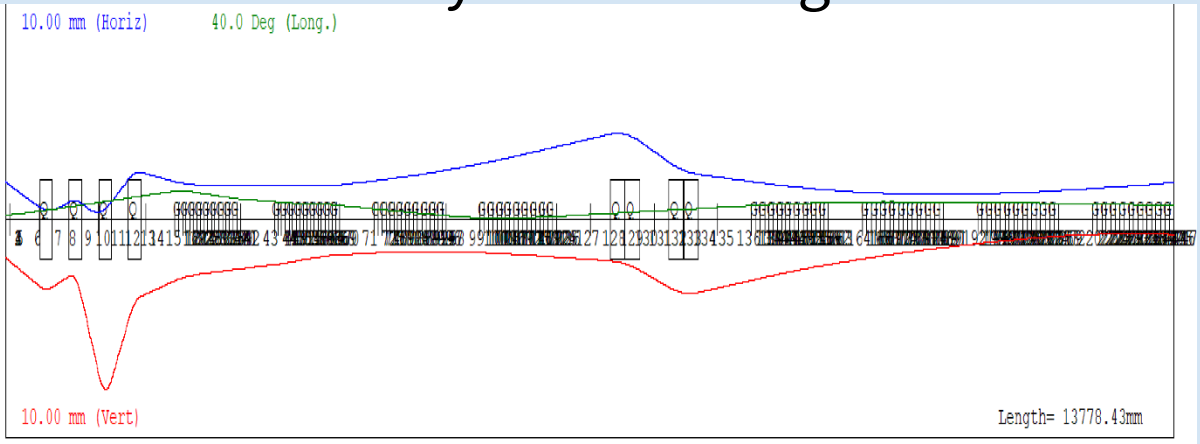


- Alternative solution with ILC-type SRF cavity.
  - can be operated in high gradient also.
  - comparable performance can be achieved [M. Otani, PASJ2019].

cavity design



beam dynamics design

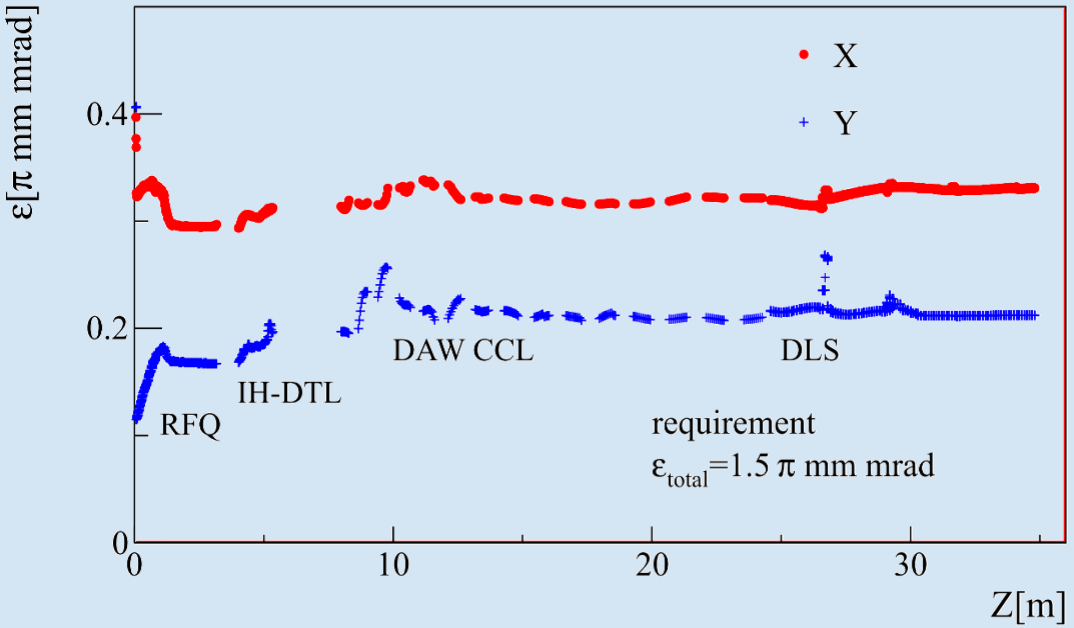


welcome to good collaboration

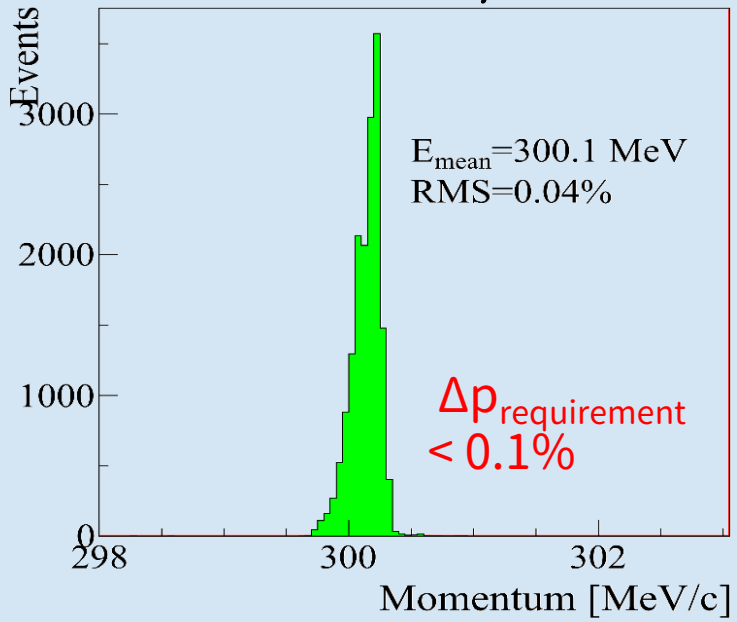
End to end design

- Completed basic design.
  - Phys. Rev. AB, 19, 040101 (2016)
  - J. Phys. :Conf. Ser. 875, 012054 (2017)
  - J. Phys. :Conf. Ser. 1350, 012097 (2019)... etc.

Emittance evolution



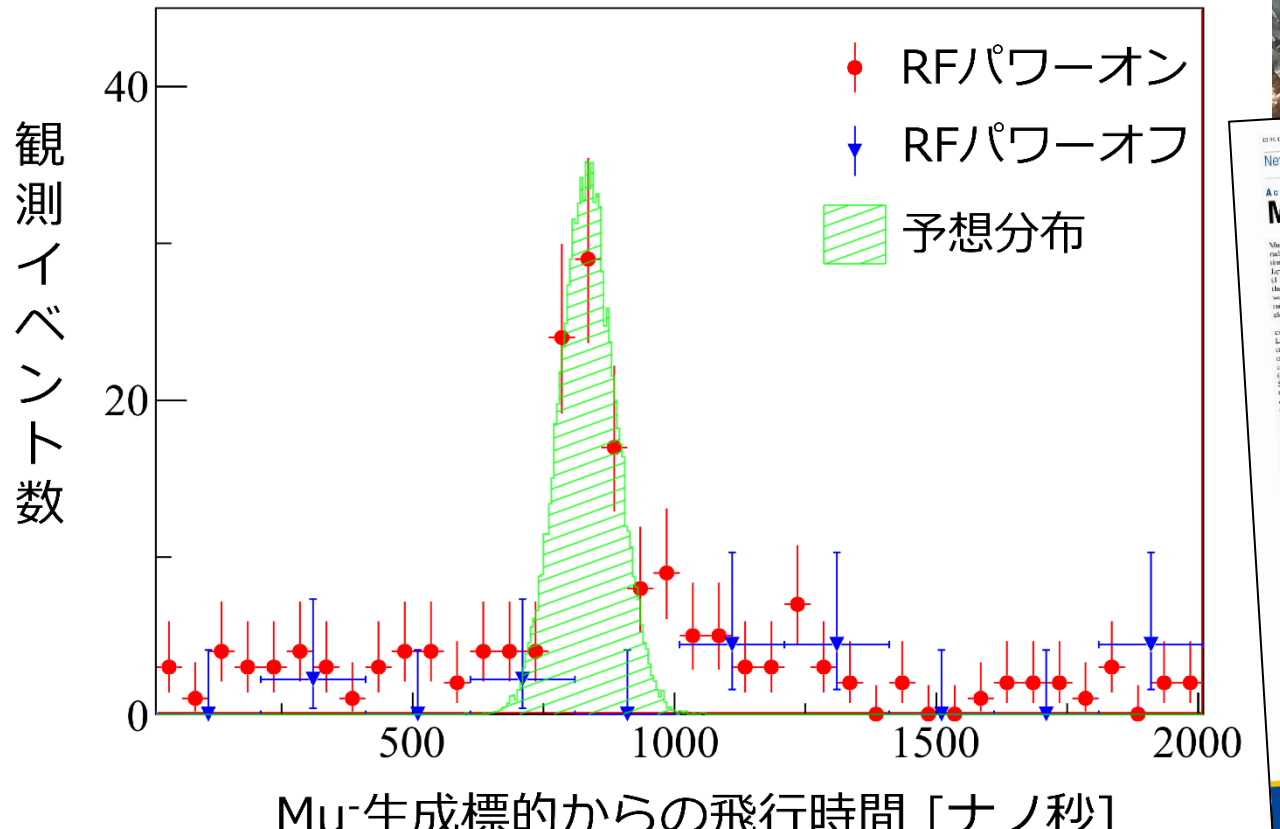
Momentum spread



	Init.	RFQ	IH	DAW	DLS
Decay survival [%]	83	81	98	96	99
Transmission [%]	87	95	99.9	99.5	99.9

Satisfy the requirement.

Demonstration of Muon Acceleration (Oct. 24th – 30th , 2017)



「加速器」Vol. 15, No. 2, 2018 (60–68)

話 題

線型加速器によるミューオン加速

大谷 将士*1・近藤 恭弘*2

Muon Acceleration Using a Linac

Masashi OTANI*1 and Yasuhiro KONDO*2

News

Muons accelerated in Japan

Higgs centre opens for business

Jefferson Lab inaugurates upgraded CEBAF

CERN COURIER

Volume 58 Number 6 July/August 2018

最近の研究から

ミュオン $g-2$/EDM の精密測定を実現する

ミュオン高周波加速

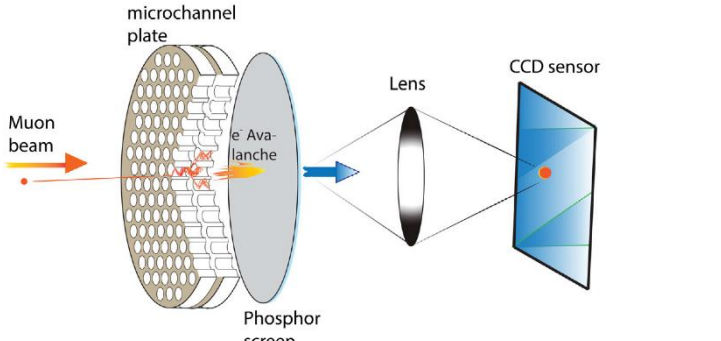
大谷将士 近藤恭弘 三部 勉

Next Step

- Acceleration by IH and DAW following RFQ.
- Prototypes had been fabricated and tested.
- Beam monitor was developed and observed accelerated muon (Mu^-)
  - Phys. Rev. AB, 23, 022804 (2020)
  - Nucl. Inst. Meth. Phys. Res. Sec. A. 899, 11, 22-27, 2018.

Development of a microchannel plate based beam profile monitor for a re-accelerated muon beam

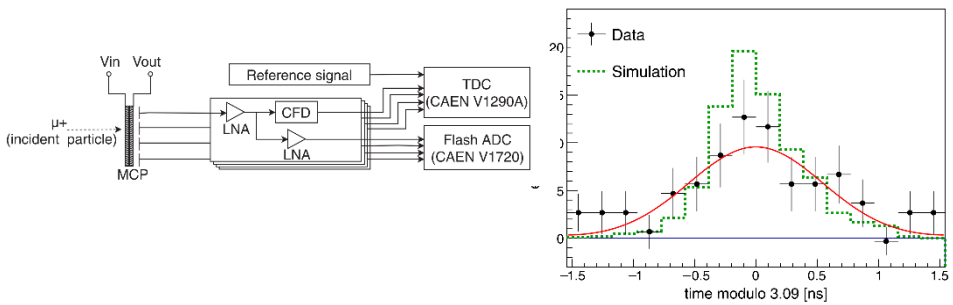
Bongho Kim [a,b], Sunghan Bae [a,b,*], Hyunsuk Choi [a,b], Seonho Choi [a,b], Naritoshi Kawamura [h,i], Ryo Kitamura [c], Ho San Ko [a,b], Yasuhiro Kondo [k], Tsutomu Mibe [d], Masashi Otani [d], Georgiy P. Razuvaev [e,f,g], Eunil Won [j]



Development of a bunch-width monitor for low-intensity muon beam below a few MeV

Yuki Sue [1,*], Mai Yotsuzuka [1], Kenta Futatsukawa [2], Kazuo Hasegawa [3], Toru Iijima [1,4], Hiromi Iinuma [5], Kenji Inami [1], Katsuhiro Ishida [6], Naritoshi Kawamura [2], Ryo Kitamura [3], Yasuhiro Kondo [3,5], Tsutomu Mibe [2], Yasuhiro Miyake [2], Takatoshi Morishita [3], Yuga Nakazawa [5], Masashi Otani [2], Naohito Saito [7], Koichiro Shimomura [2], Yusuke Takeuchi [8], Takahiro Ushizawa [9], Takayuki Yamazaki [2], and Hiromasa Yasuda [10]

[1] *Graduate School of Science, Nagoya University, Nagoya, Aichi 464-8602, Japan*
[2] *High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*
[3] *Japan Atomic Energy Agency (JAEA), Tokai, Naka, Ibaraki 319-1195, Japan*
[4] *Kobayashi-Maskawa Institute (KMI), Nagoya University, Nagoya, Aichi 464-8602, Japan*
[5] *Graduate School of Science and Engineering, Ibaraki University, Mito, Ibaraki 310-8512, Japan*
[6] *Riken, Wako, Saitama 351-0198, Japan*
[7] *J-PARC Center, Tokai, Naka, Ibaraki 319-1195, Japan*
[8] *Graduate School of Science, Kyushu University, Fukuoka 819-0395, Japan*
[9] *SOKENDAI (The Graduate University for Advanced Studies), Hayama, Kanagawa 240-0193, Japan*
[10] *Graduate School of Science, University of Tokyo, Hongo, Tokyo 171-8501, Japan*



Ready to fabricate real one

Led by Young Scientists

PD D2

茨城大学 Ibaraki University D1 Y. Nakazawa

M2 M. Yotsuzuka

D3 H. Yasuda

九州大学 KYUSHU UNIVERSITY D2 Y. Takeuchi

KEK

Collaboration Status

- Complete Technical Design.
  - PTEP2019, 053C02.
- Approvals by J-PARC and KEK-IMSS PAC.
- High priority in KEK PIP
  - Next to upgrading J-PARC for Hyper-K, HL-LHC.
- KEK SAC 2019 supports the PIP decisions.
- Budget requesting from KEK to MEXT.
- 科研費特別推進研究 [2020 – 2025, PI:T. Mibe]
  - as for accelerator, fabricate real IH & DAW.

Moving construction stage.

Summary

- Muon linac in the J-PARC muon g-2/EDM experiment was reviewed. First muon acceleration was demonstrated and following accelerator is being fabricated.
- The experiment is moving to realization.
- Postdoctoral fellow to play a central role in the experiment is open.
  - Contact: T. Mibe (mibe@post.kek.jp), who will present other experimental components on 25th

Backup