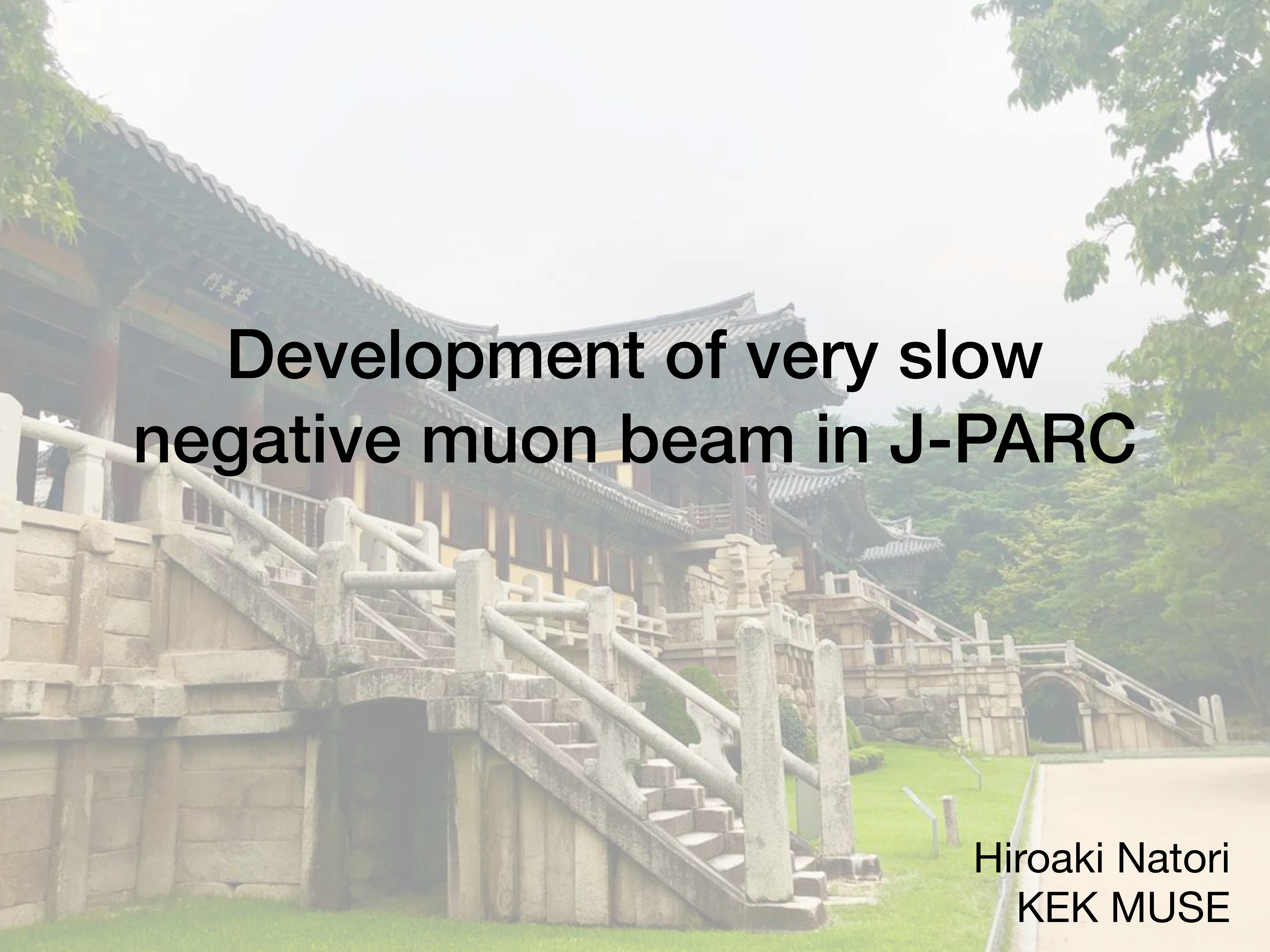
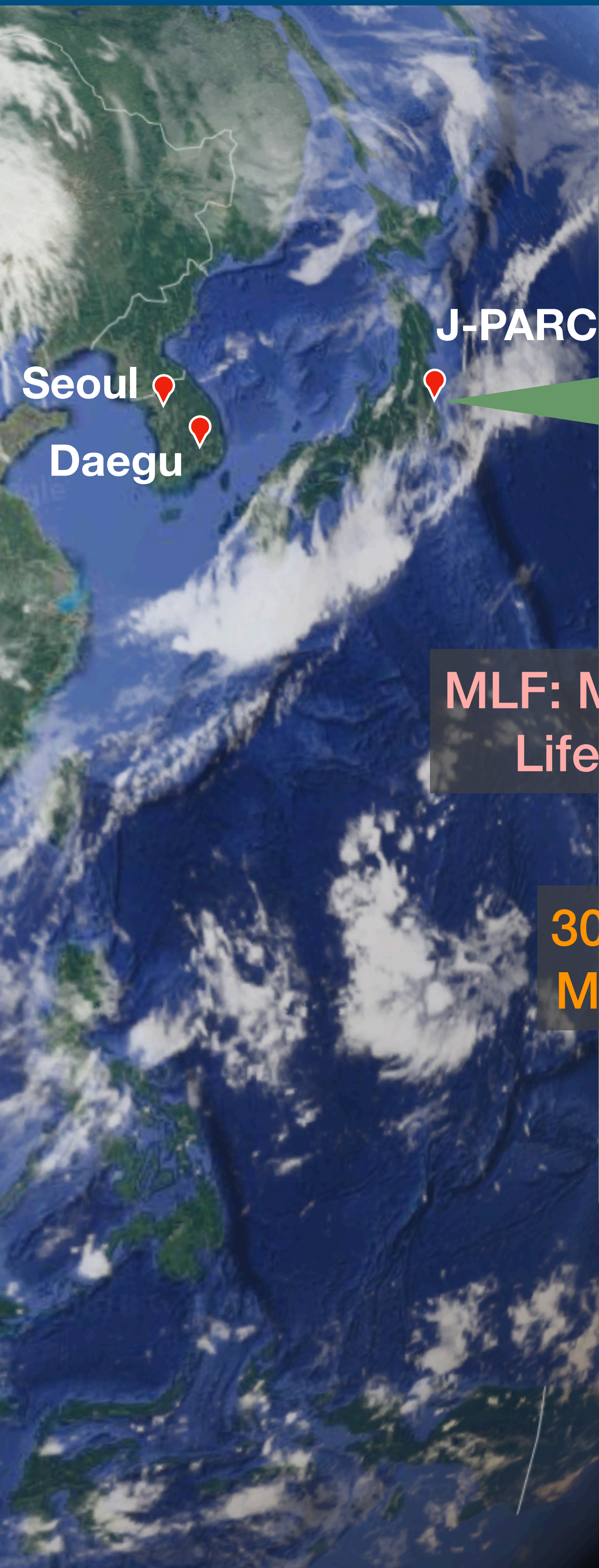
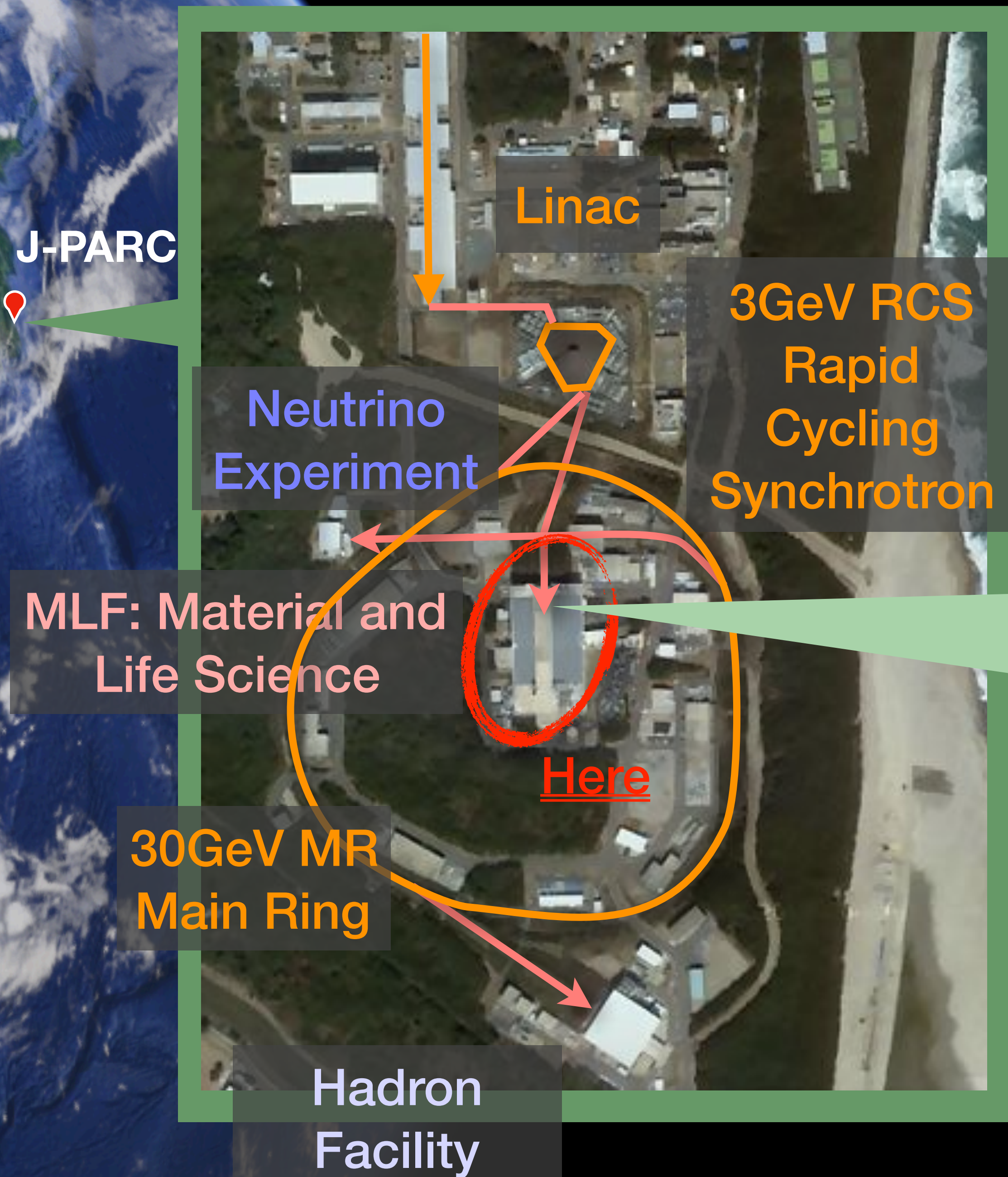


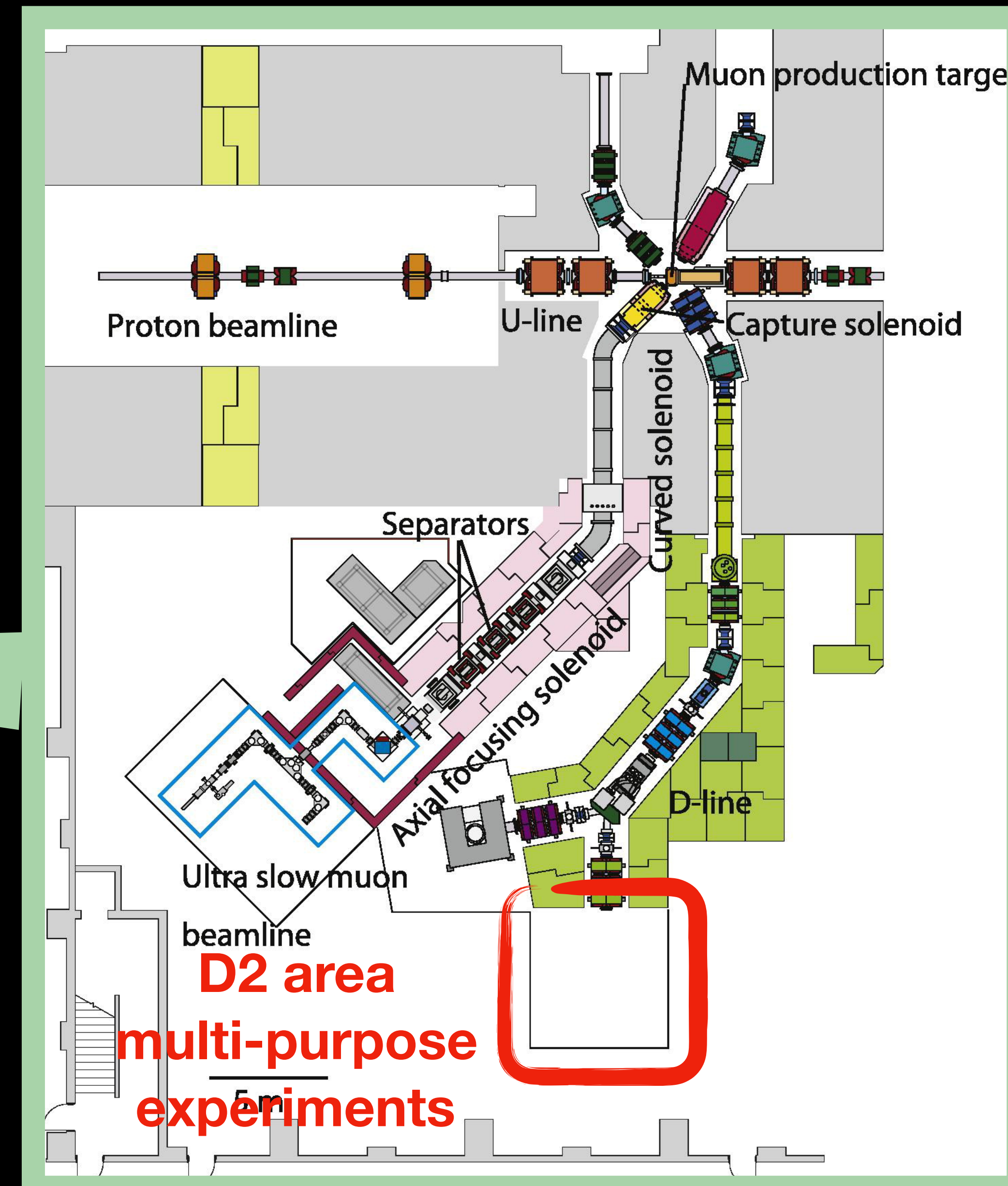
Development of very slow negative muon beam in J-PARC

Hiroaki Natori
KEK MUSE

Introduction: J-PARC MLF



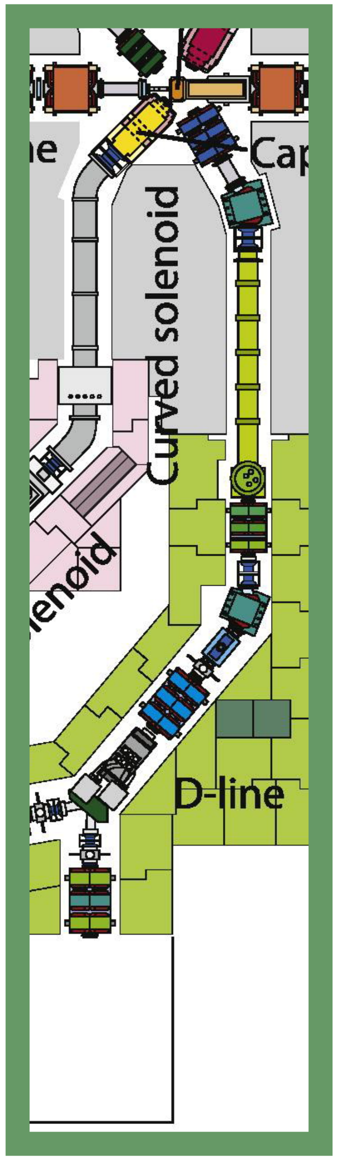




Utilize powerful pulsed proton beam from J-PARC
Extract secondary muon beam

I will focus on one of the beam development,
Slow negative muon beam

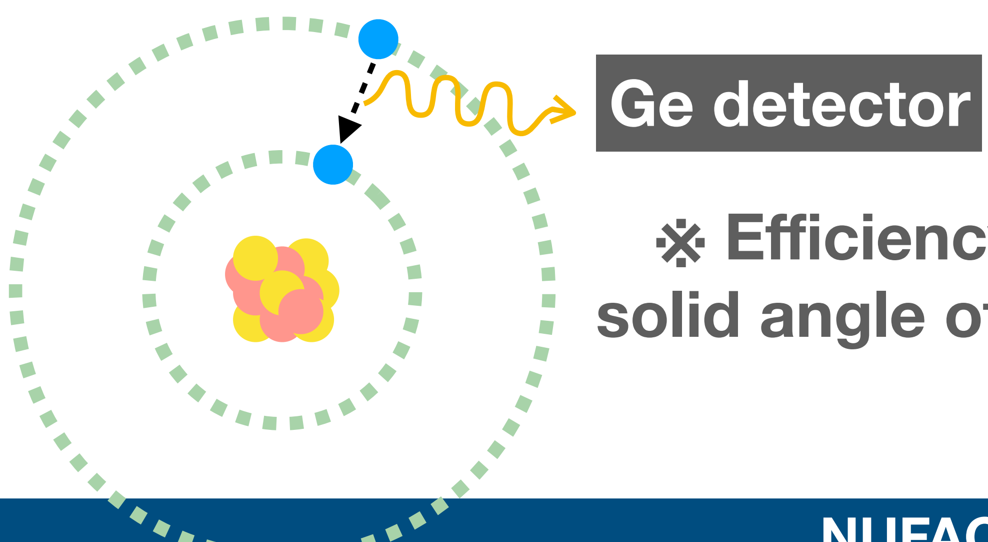
Slow negative muon in D2 area



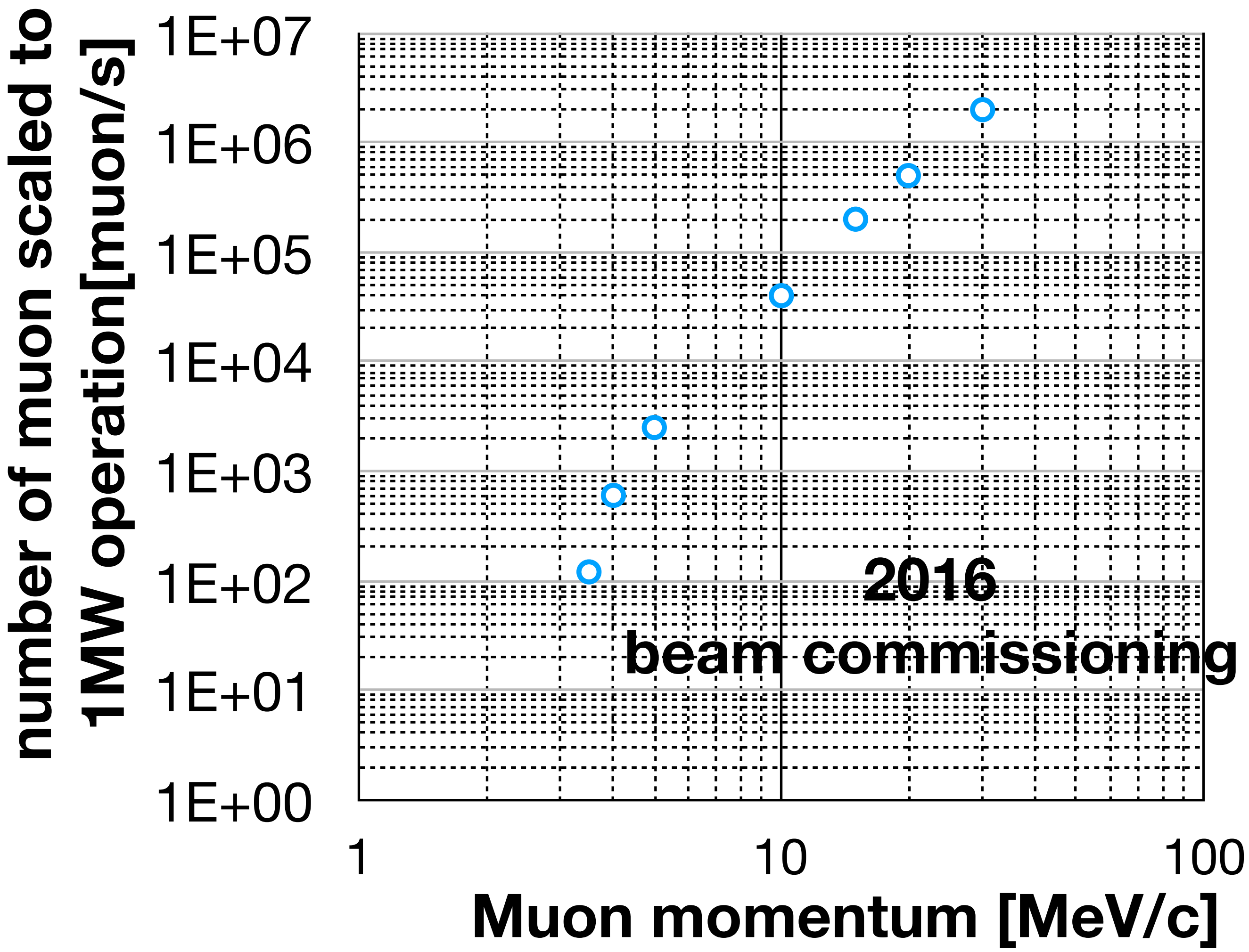
J-PARC MLF employs
warm bore
no heat shielding window
along the beam line

Slow muon can be extracted

muonic atom
characteristic X-ray

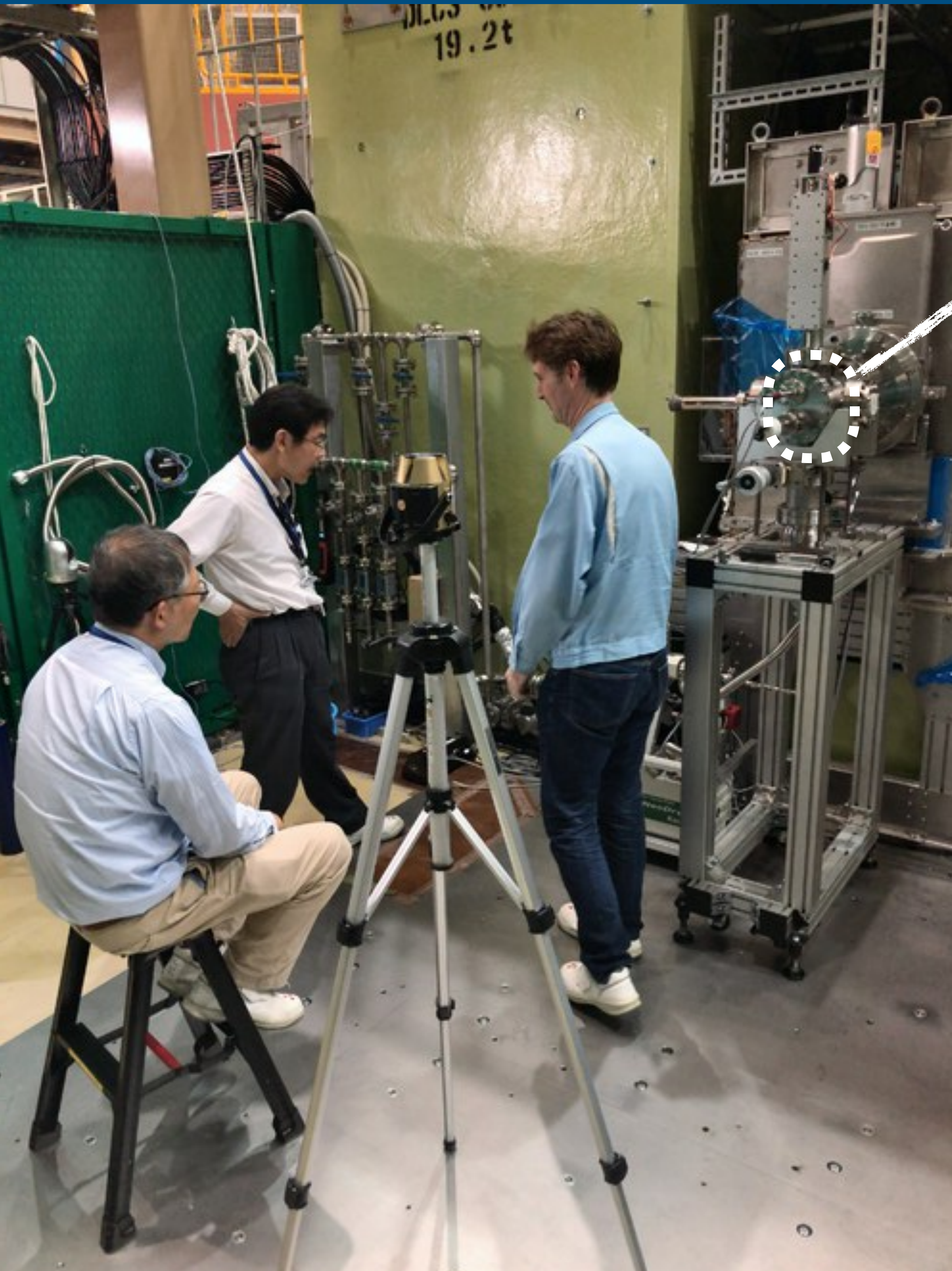


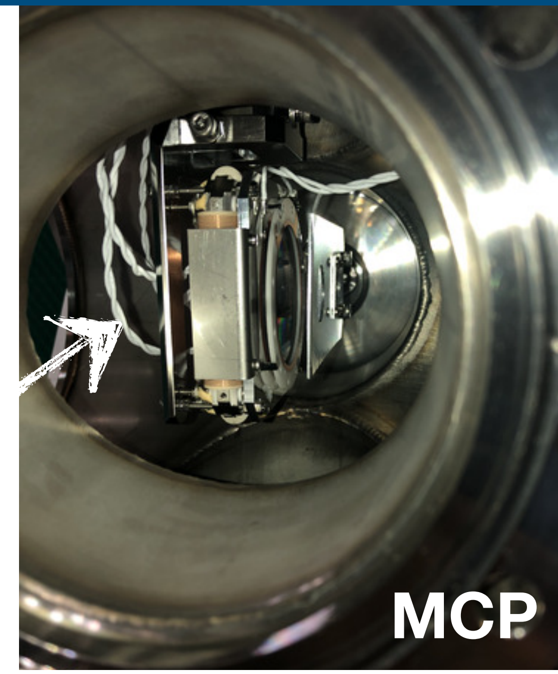
※ Efficiency limited by
solid angle of the detector



3.5 MeV/c in 2016

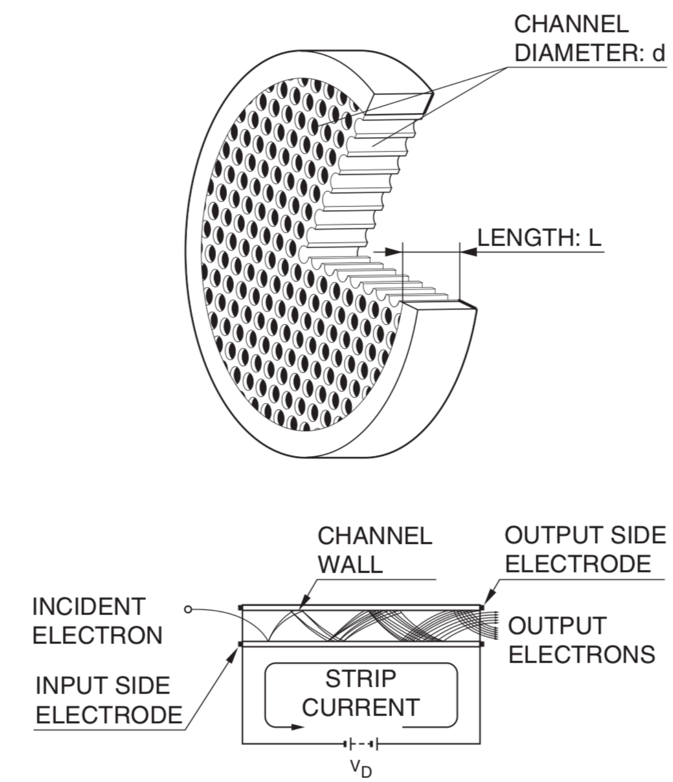
Update in slow negative muon in J-PARC





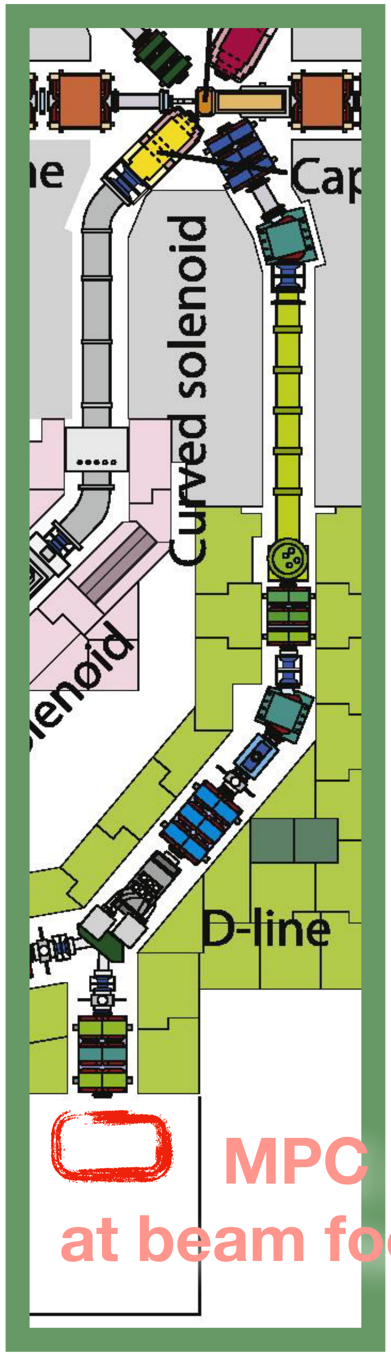
Direct muon detection with MCP
Getting rid of loss of efficiency due to solid angle

Schematic structure of MCP

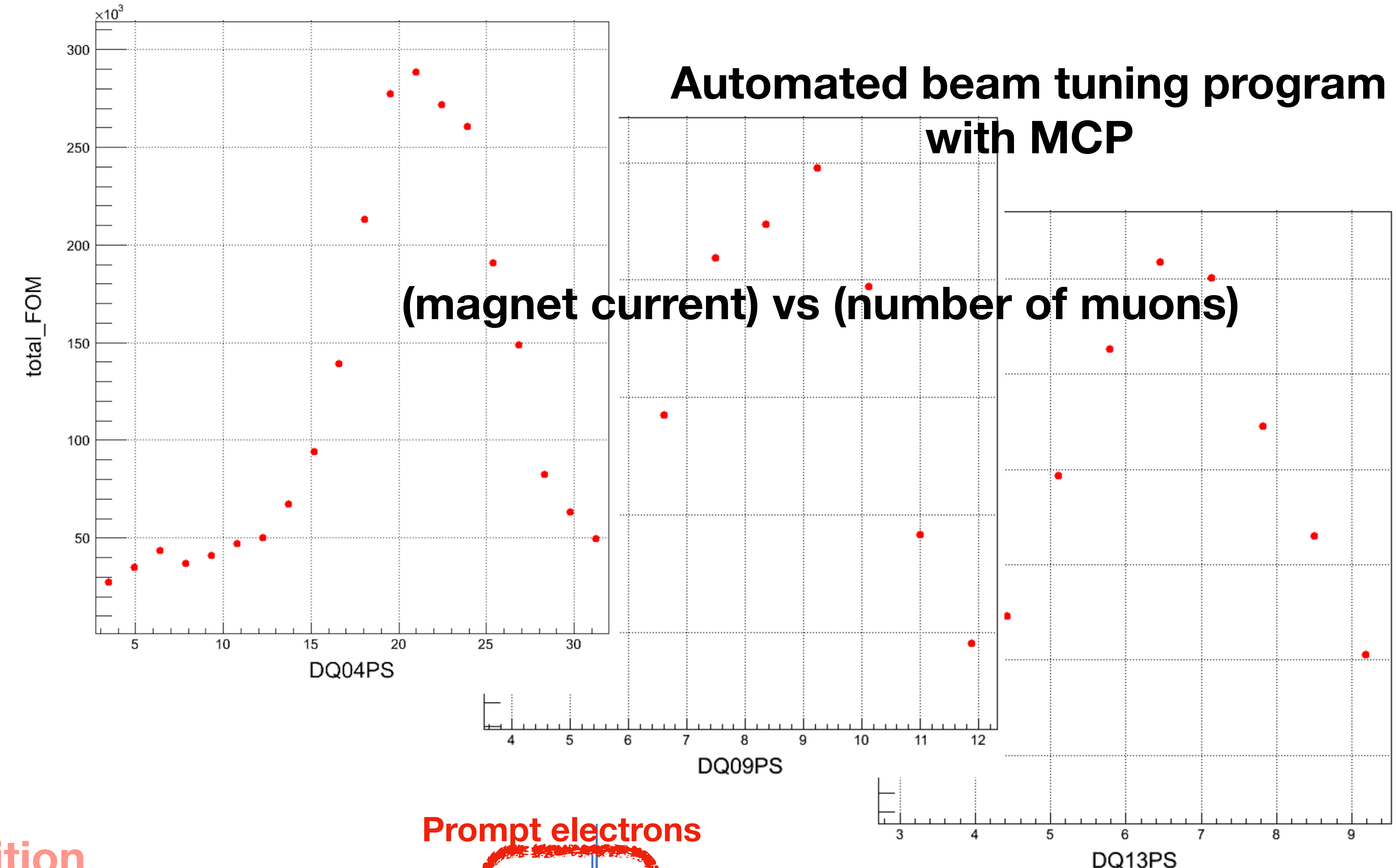


※ Quantum efficiency for slow muon and its energy dependence are not well known

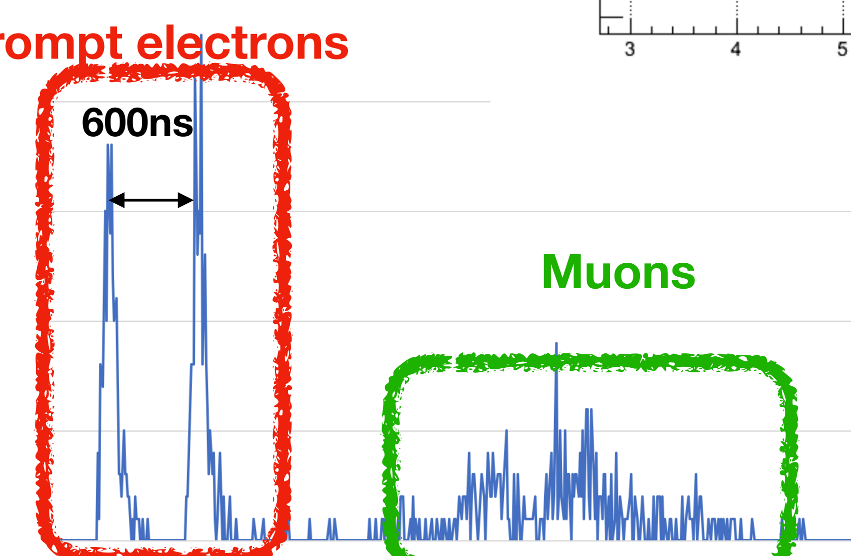
Update in slow negative muon in J-PARC



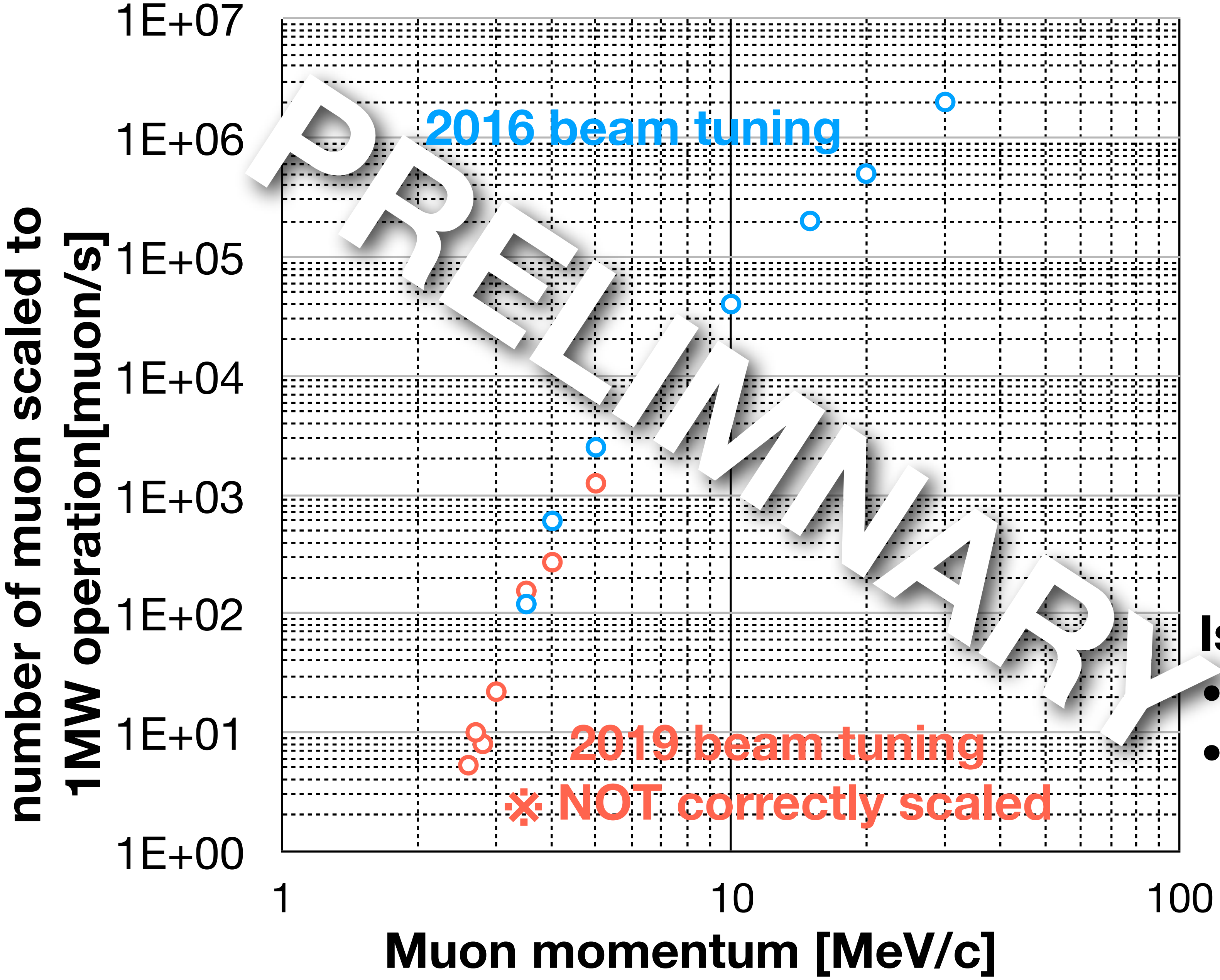
MPC placed
at beam focus position



Direct measurement of incoming muon enables efficient beam tuning.
Primary electron elimination by TOF



Update in slow negative muon in J-PARC



2.6 MeV/c muon extracted

Issues

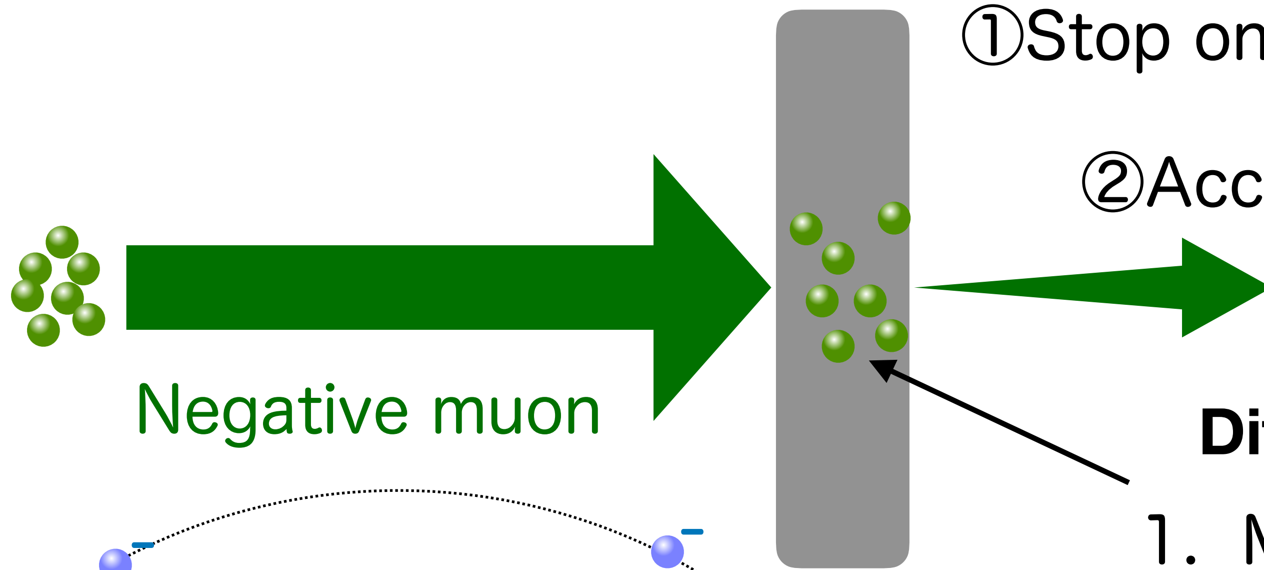
- **Quantum efficiency for slow muon**
- **Reproducibility?**
  - **Stability of power supply in low current? Hysteresis?**

-> Continue to work to solve them

Future plan

Sophisticated procedure to make very slow negative muon

How can we make ultra slow negative muon?



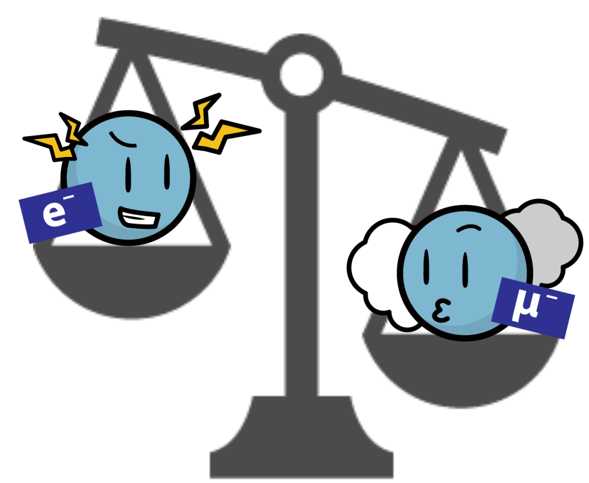
①Stop on a material

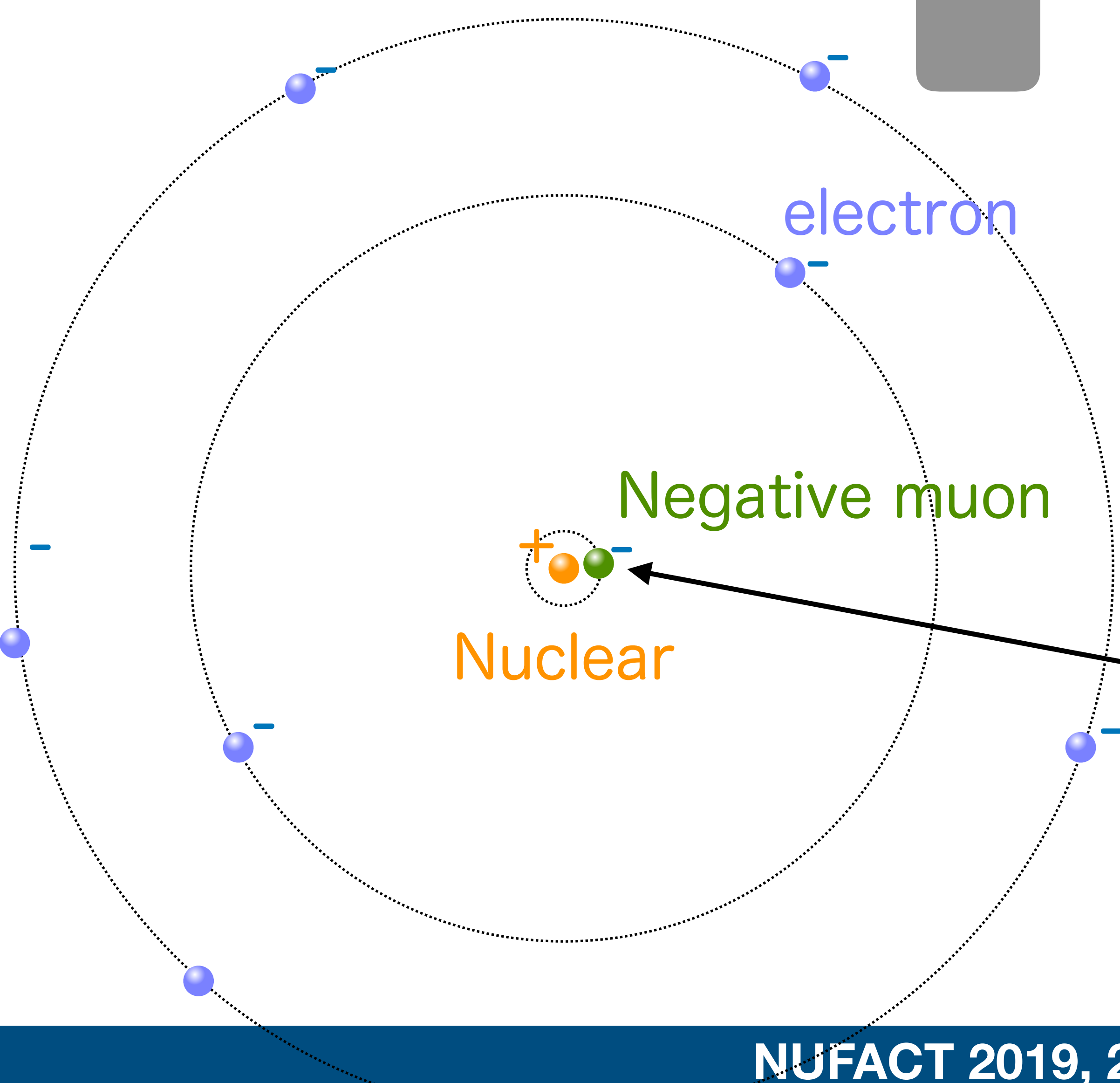
②Accelerate

If it is possible, it's ok but …

Difficult issues for μ-

1. Muons stop deep inside





2. Muon is 200 times heavier than electron

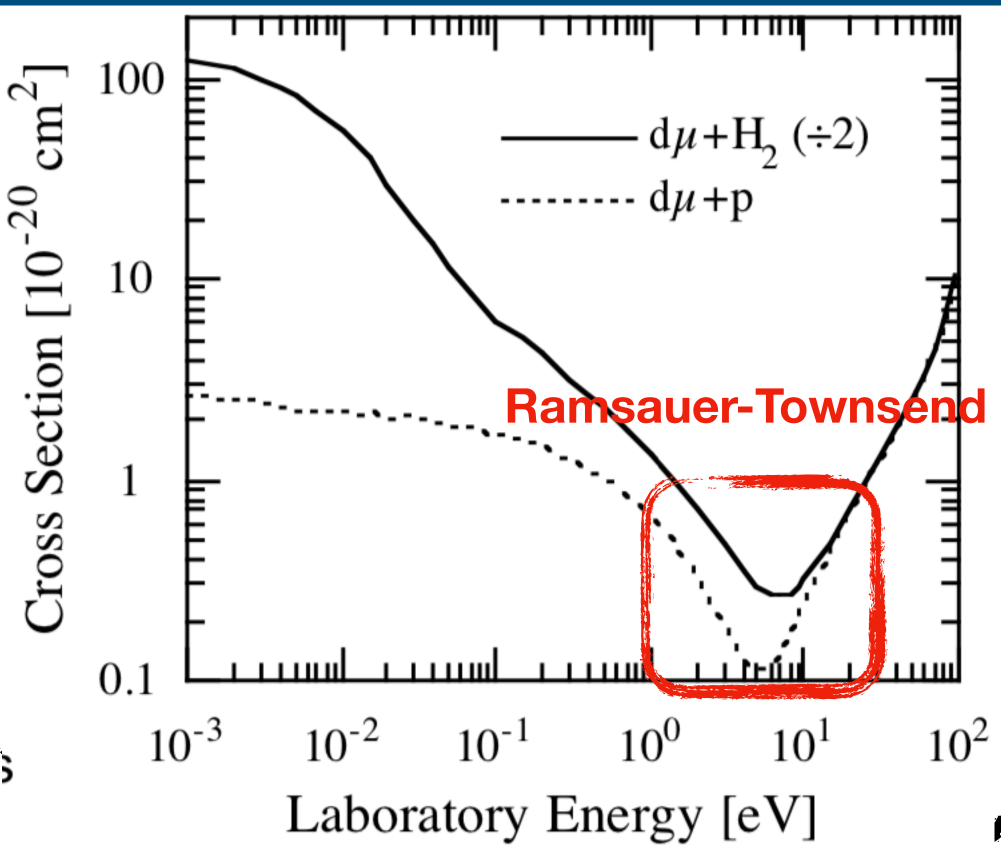
Go deeply inside nuclear

Then,

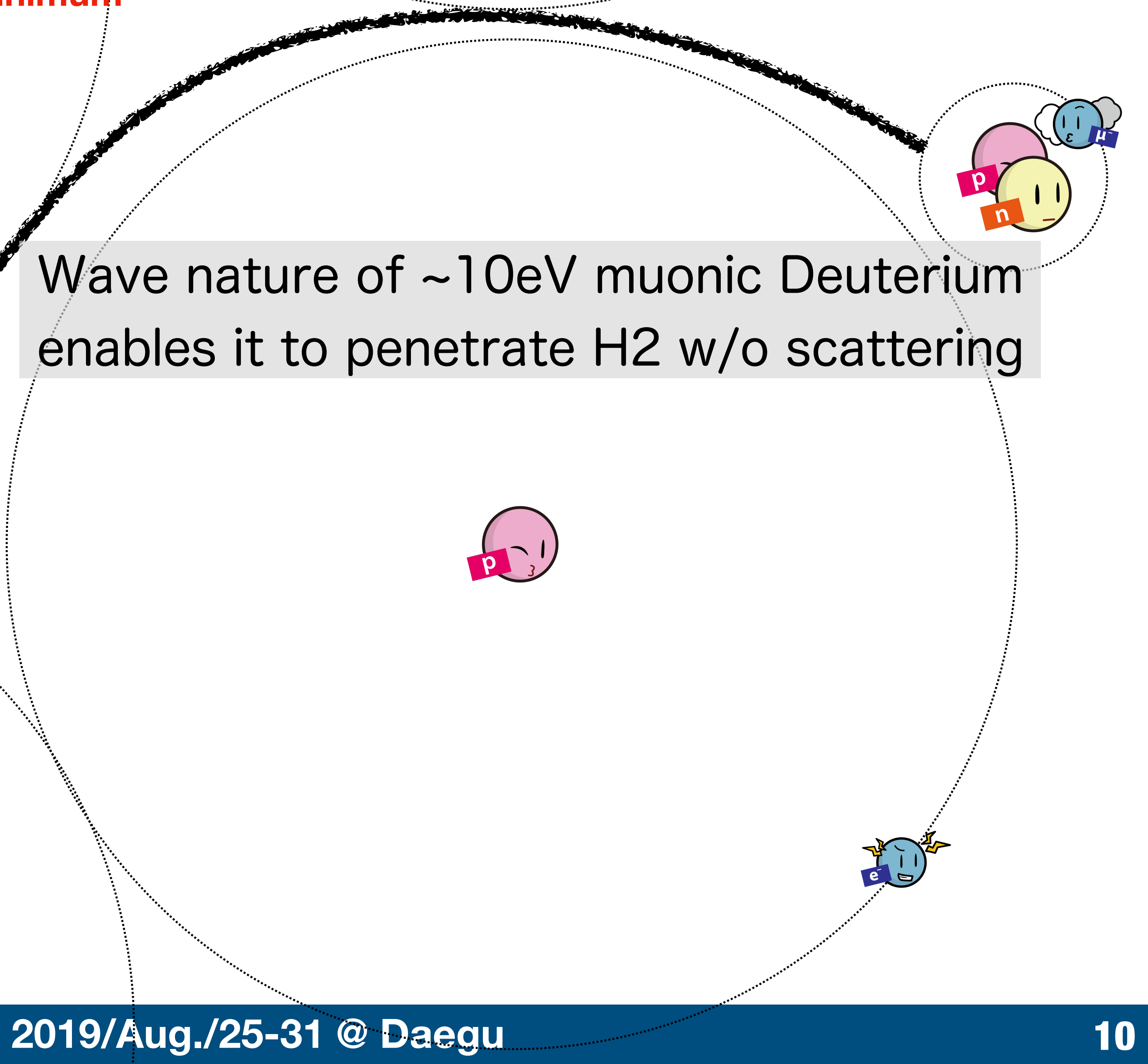
We plan to utilize

- **Ramsauer-Townsend effect**
- **Muon catalyzed fusion**

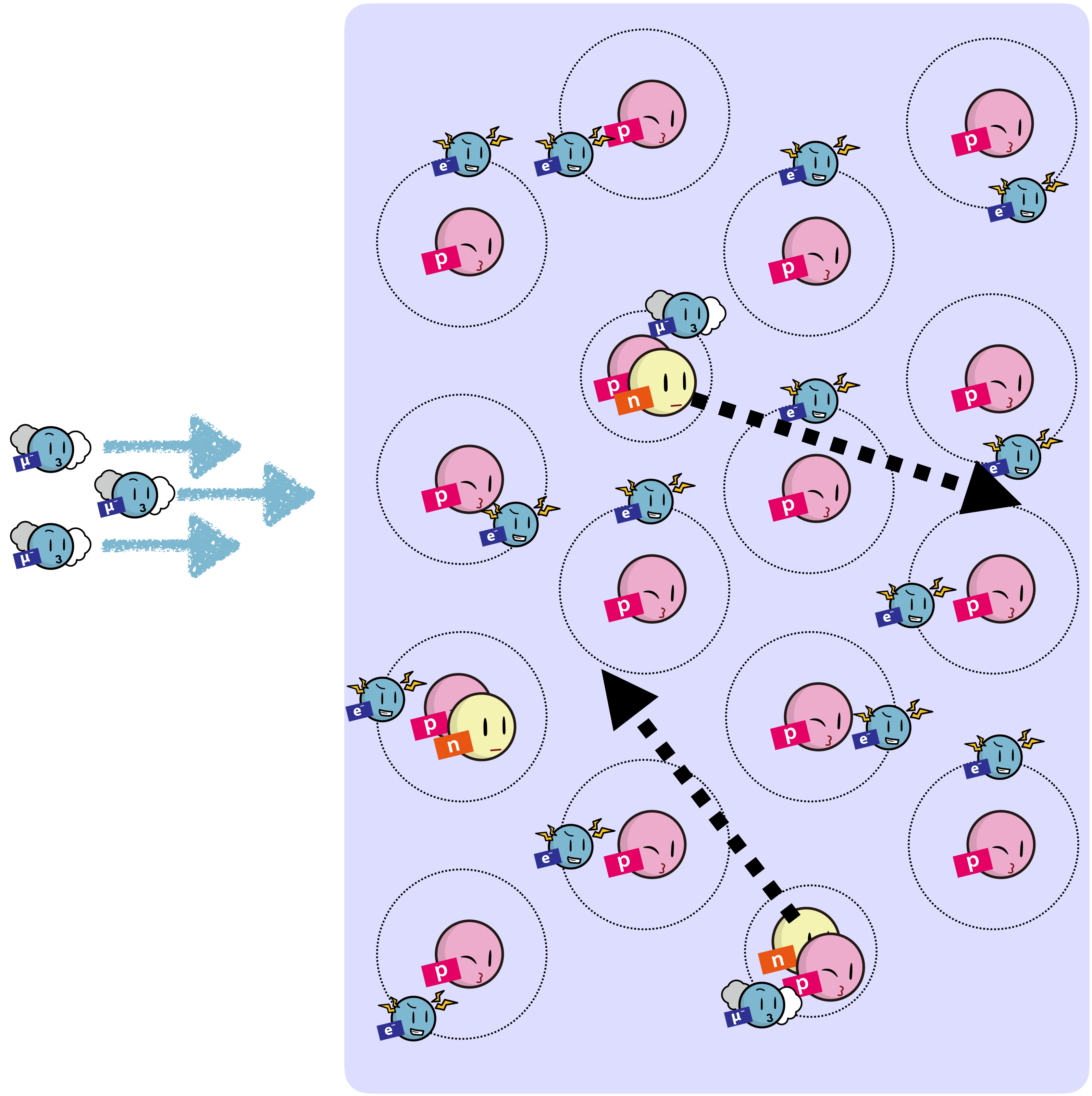
Ramsauer-Townsend effect



[C.Chiccoli et al., Muon Catal. Fusion 7(1992) 87]
[A. Adamczak et al., Atomic Data and Nuclear Data Tables 62 (1996) 255]



Wave nature of ~10eV muonic Deuterium enables it to penetrate H2 w/o scattering



Stopping μ- on solid H/D,
Muon transfer:

$p\mu + d \rightarrow d\mu(\sim 45eV) + p$

then some dμ moves to the surface

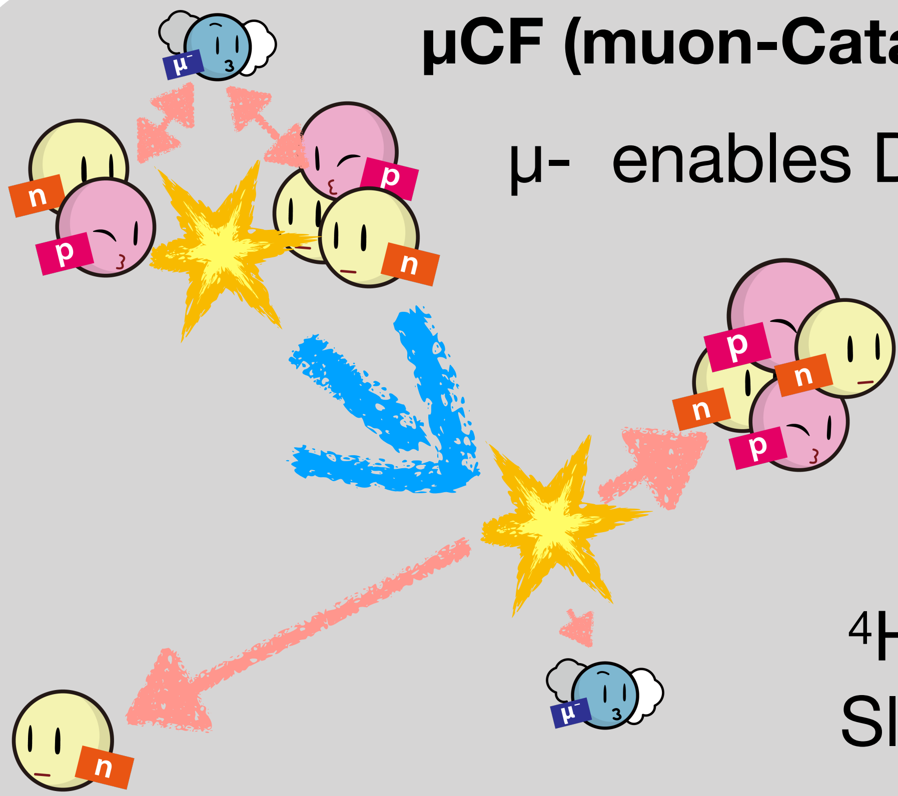
According to [Forster et al., Hyp. Int. 65 (1990) 1007-1014], 0.1% D concentration is optimum

Mean free path ~ 0.5mm

(# of transportation to surface) / (# of Incident muon) ~ 10^{-2} [Forster 1990, Marshall 2001]

Next: drag μ- away from D

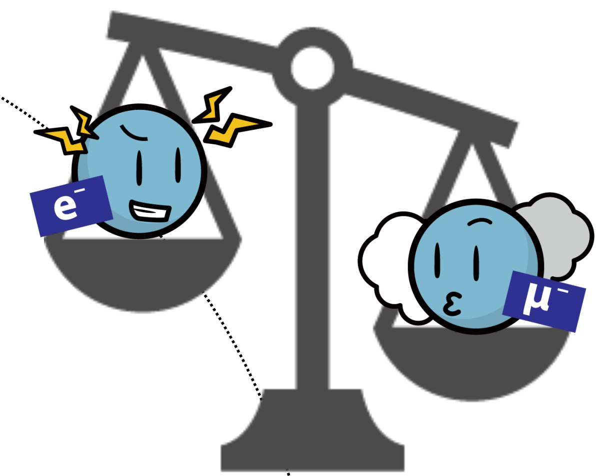
Muon-Catalyzed Fusion

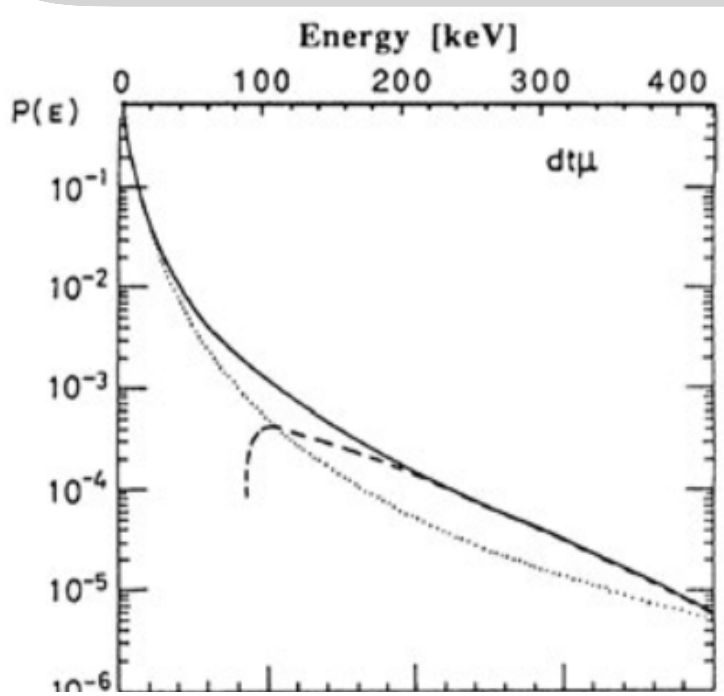


μCF (muon-Catalyzed Fusion)

μ- enables D and T come close enough to make D-T reaction

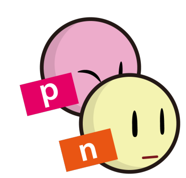
^{4}He and n are emitted by μCF
Slow μ$^-$ (~10keV) is left behind



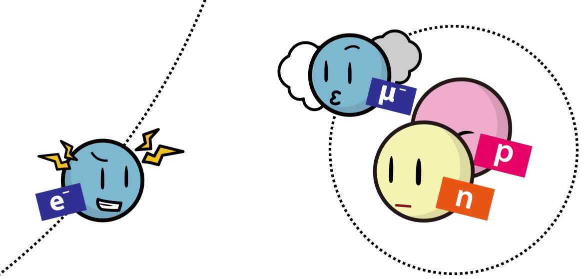


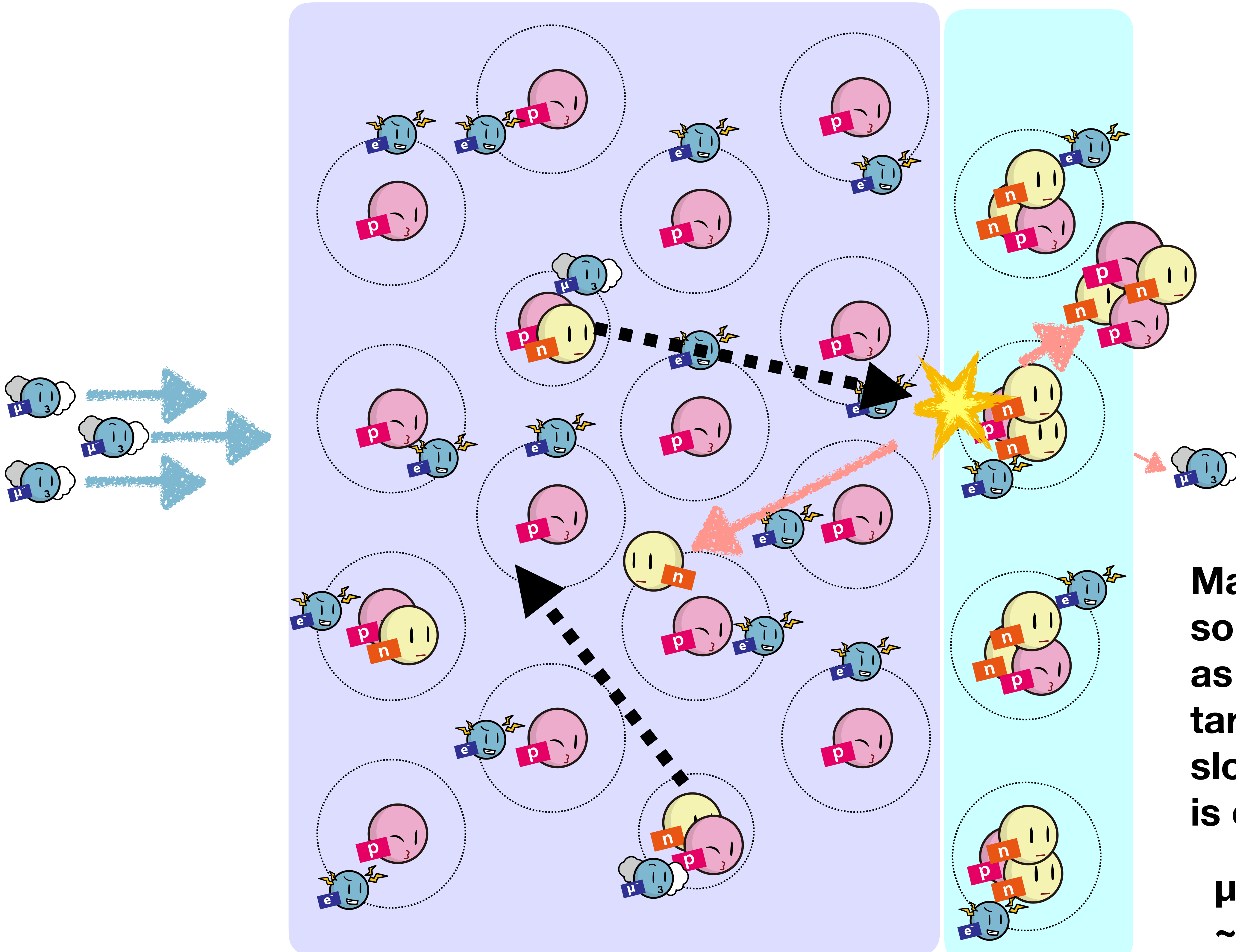
μ- energy after μCF (calculation)

B. Müller et al., Phys. Rev. 40A (1989) 2839



Mμ ~ 200 x Me
Orbital radius ~1/200

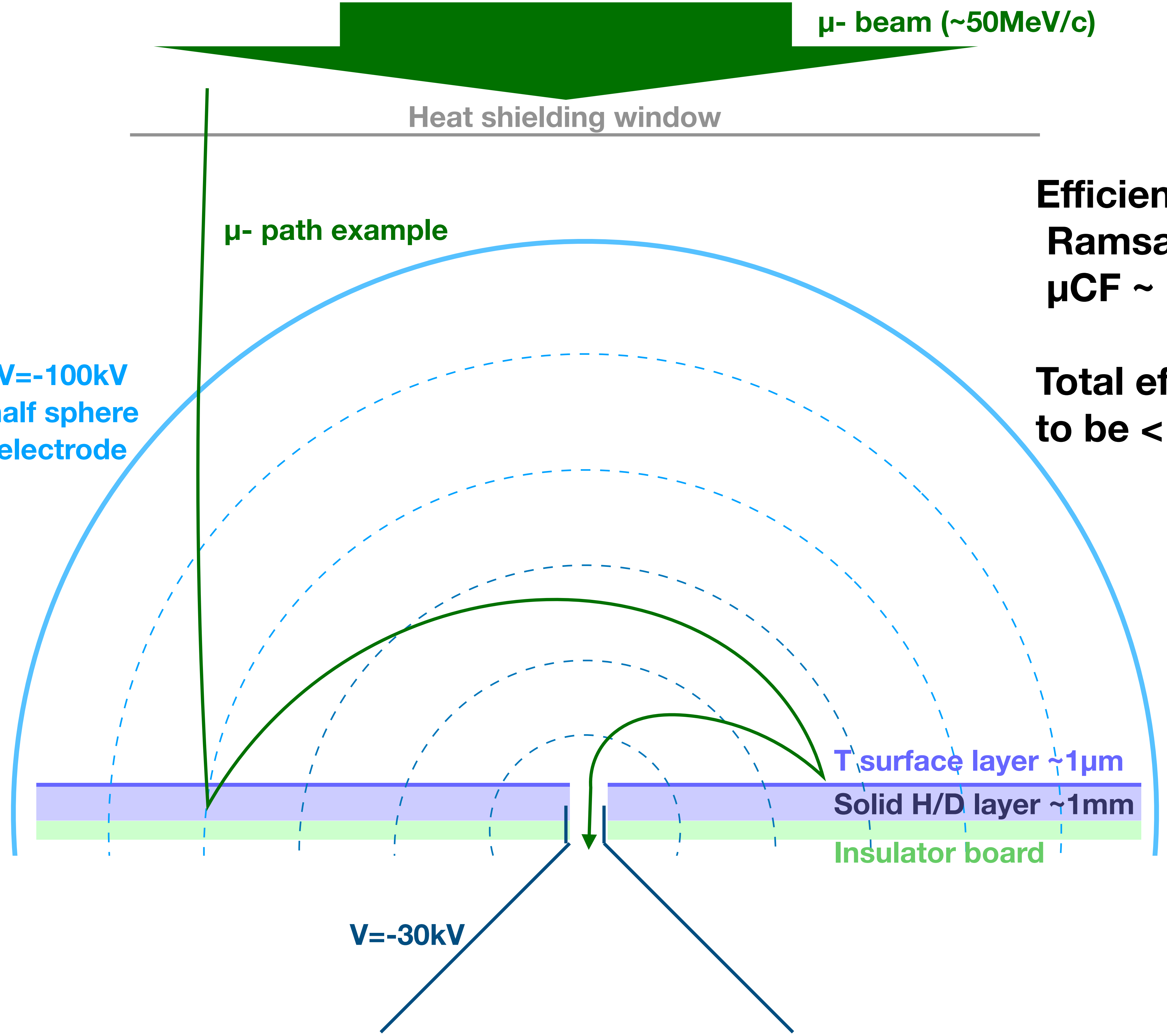




Make thin T layer on solid H/D mixture as muon stopping target, and slow muon in vacuum is obtained

µCF efficiency
~ a few 10 %

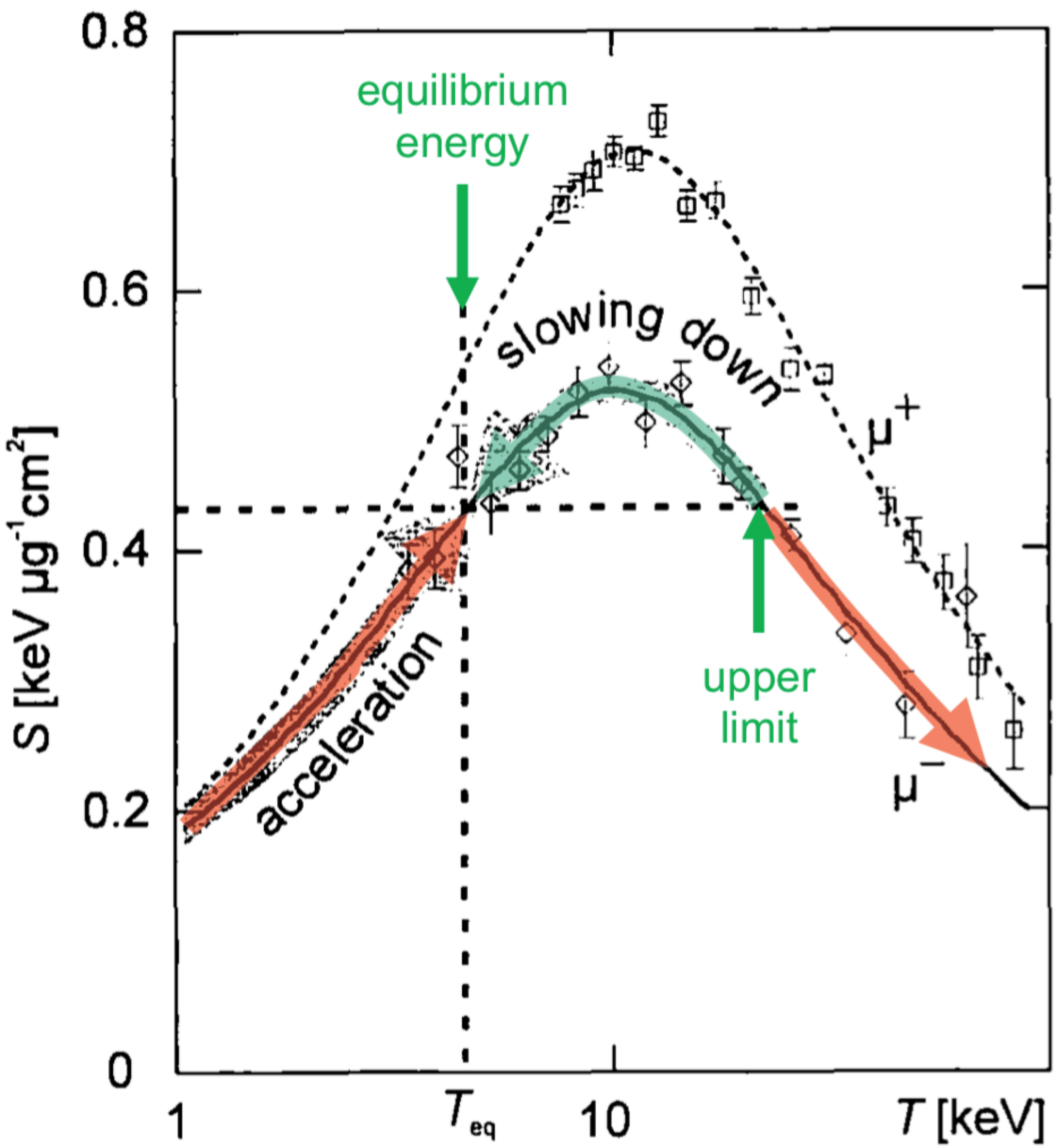
Collection of μ from μCF



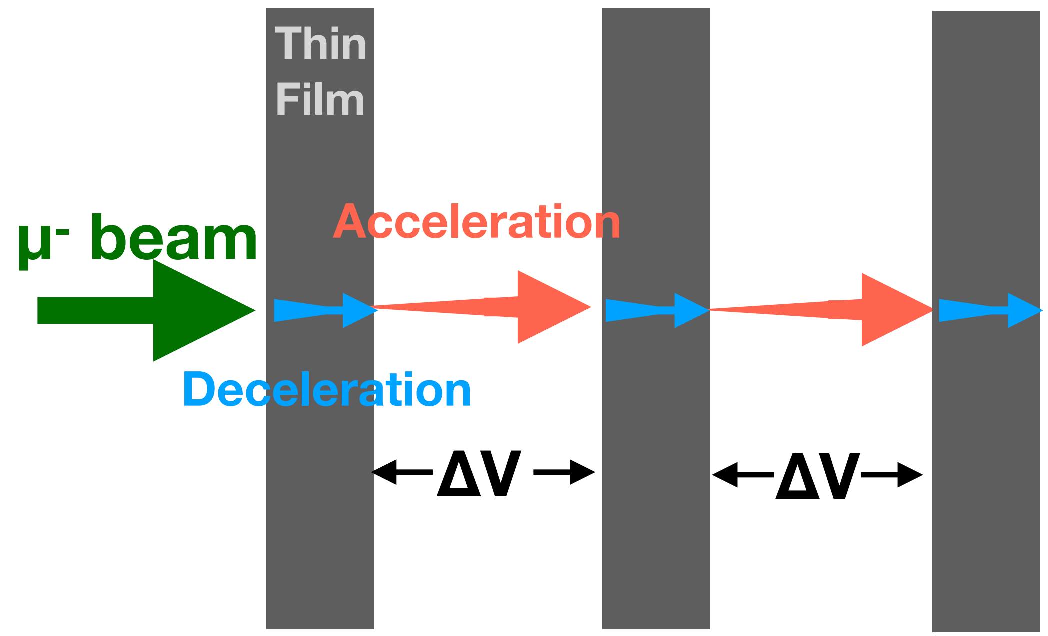
Efficiency of
Ramsauer-Townsend ~ 10^{-2}
μCF ~ $O(10^{-1})$

Total efficiency is expected to be < 10^{-3}

Frictional cooling



M. Mühlbauer et al., Hyp. Int. 101 (1996) 607



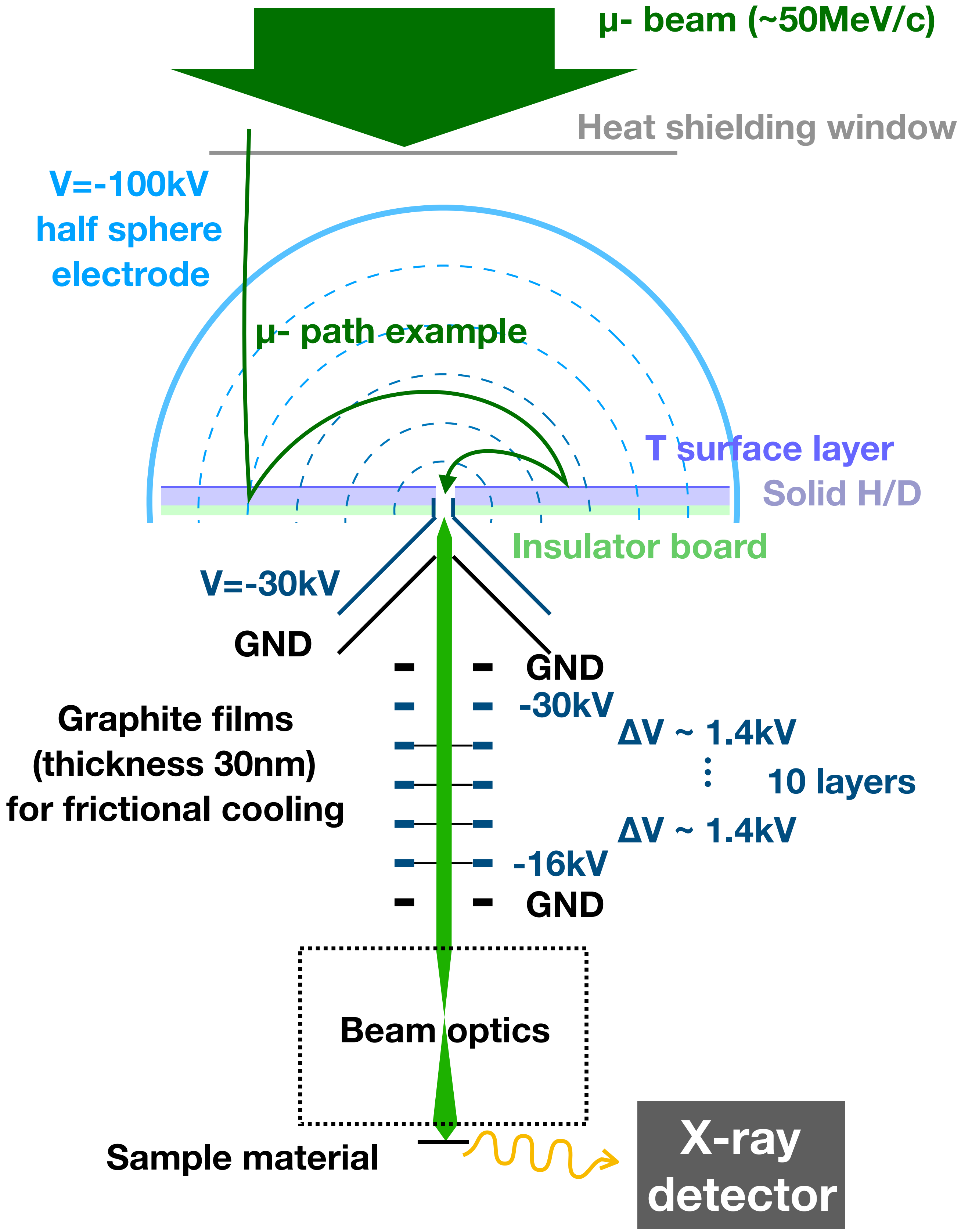
Repeating

- **Slowing down with thin film**
- **Acceleration with ΔV**

to cool down muon

10 films and
E = a few keV, ΔE ~ 100eV
is expected

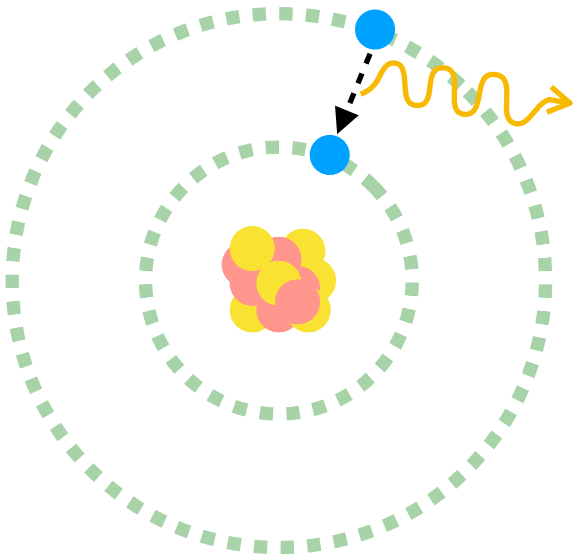
Scanning muon microscope

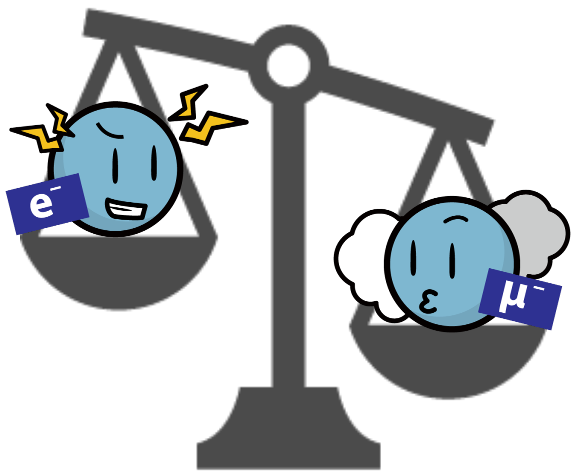


1) **Injection of μ- from accelerator ~50 MeV**
2) **Stop μ- on Solid Hydrogen and Deuterium (thickness = 1mm)**
3) **Transportation to the surface by Ramsauer-Townsend effect**
4) **μCF D-T reaction**
   μ^- is left aside with ~10 keV
5) **Collect μ^- by electrical field**
6) **Extracting muon**
   distribute around a few keV
7) **Frictional cooling**
   ΔE ~ 100 eV
8) **Extraction to beam optics**
   E ~ 16 keV
9) **Correct chromatic aberration by Achromatic lens**
10) **Focus ~ 10um, Scan the sample**

-> Scanning muon microscope

μ^- as a tool for non destructive inspection





Mμ ~ 200 x Me

-> Characteristic X-ray has x200 energy,
Transparent to thick sample material

Electron injection can identify atoms heavier than Na,
μ^- can identify Li

Efficiency of characteristic x-ray
Electron injection case < 10^{-4}
Negative muon injection ~ 100%

Current target is non-destructive inspection of nuclear distribution in a sample material but,

Your ideas for application to particle physics are welcome

Summary

- Updated lowest momentum of μ- delivery from 3.5 MeV/c to 2.6 MeV/c by tuning magnets using MCP
  - Study for stabilization of the beam for low momentum will be done
- Brand new way to make very slow negative muon beam is planned
  - Stop muon on solid H/D
  - Transport muon to surface by Ramsauer-Townsend effect of dμ
  - μCF of D-T reaction and ~10keV bare μ- in vacuum obtained
  - Give frictional cooling
  - Total efficiency $< 10^{-3}$ expected