Fundamental Physics Experiments @ RISP

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A muSR write-up meeting @ Fermilab

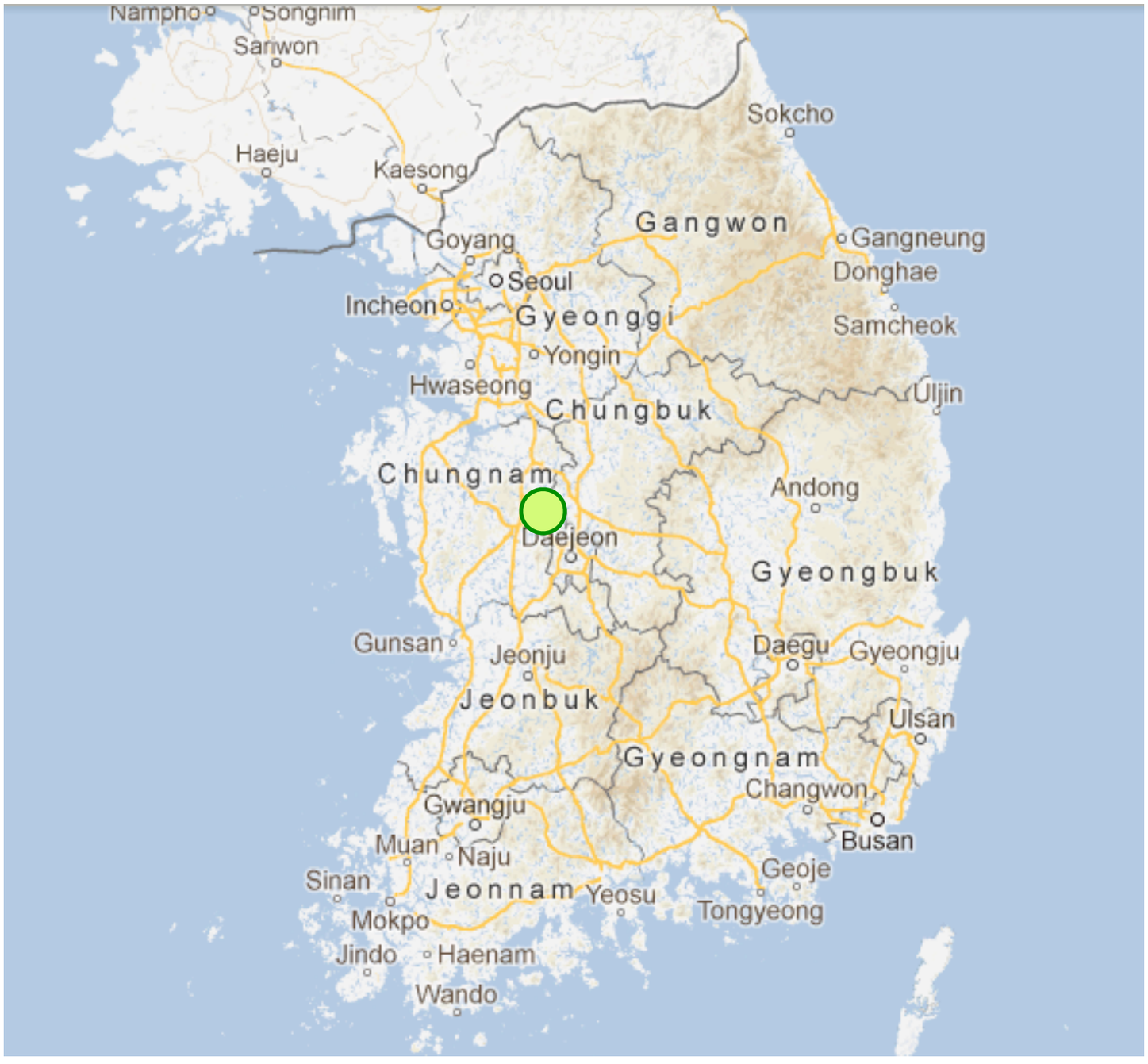
Fundamental physics with RISP/project-X/J-PARC

- Lepton flavor violation (LFV)
  - Muon-Atom to electron-Atom conversion (mu2e, COMET)
  - g-2/EDM of muons
  - mu to eee
  - muonium-antimuonium oscillation
  - (- muon+ lifetime measurement)
  - muonium-antimuon hyperfine splitting, Lamb shift

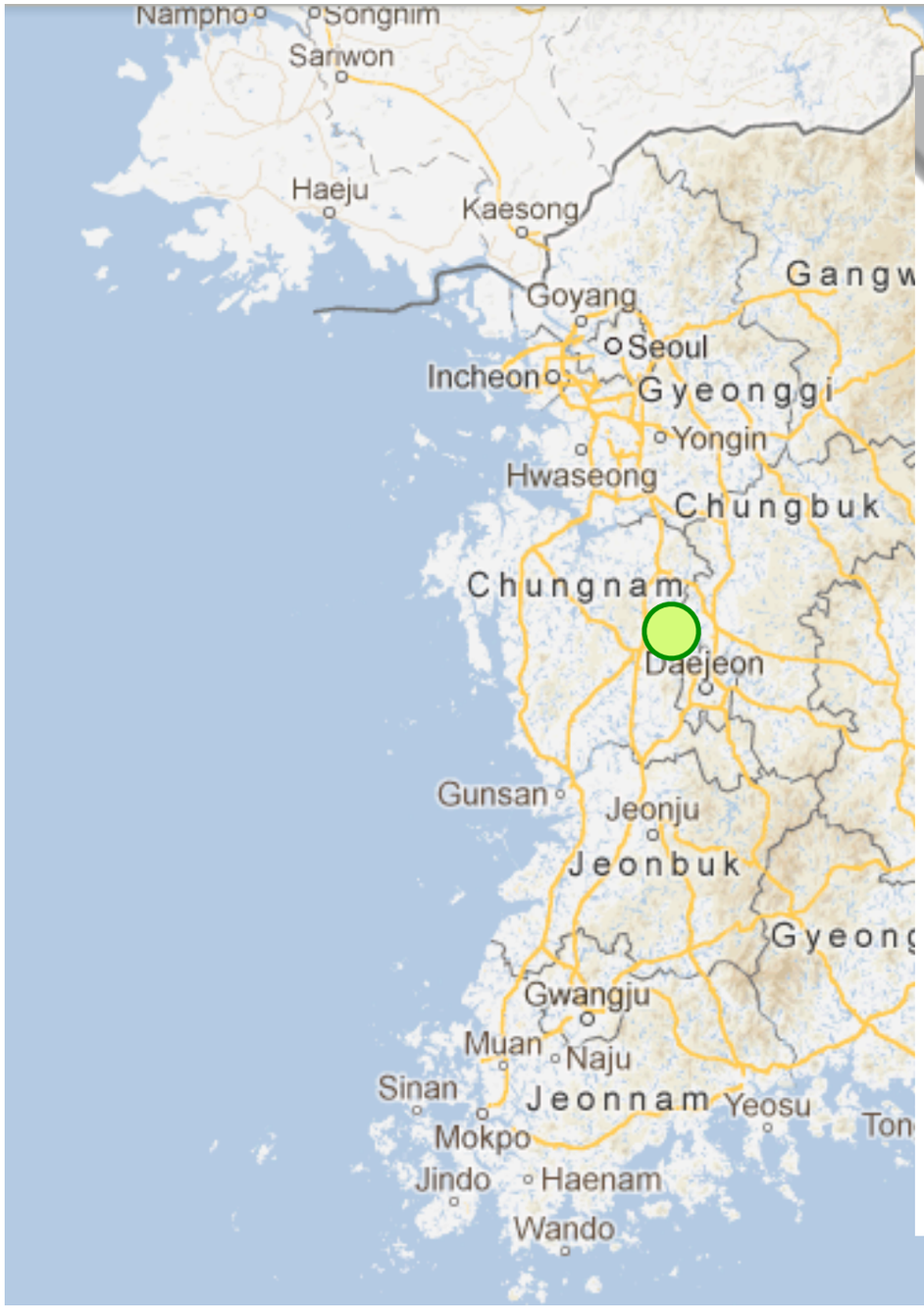
main focus today

- Atomic parity violation (not today, I think)

Location of RISP



Location of RISP



Bird's Eye View

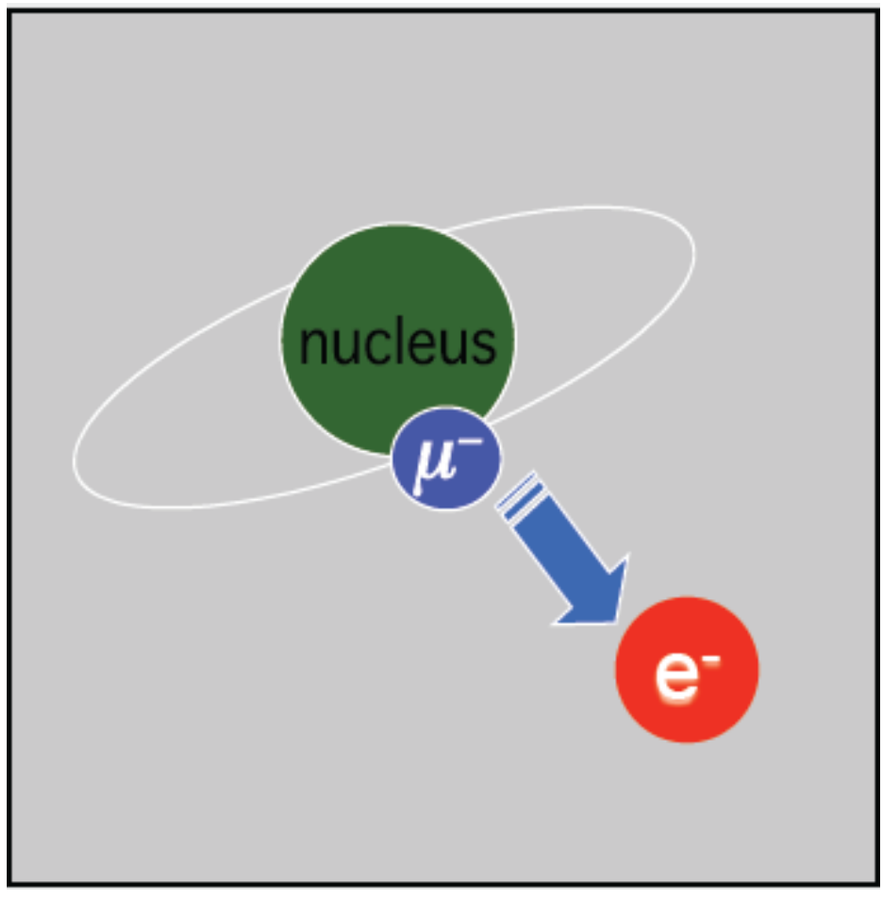
Mu to e conversion

Signature

Hyunsu Lee (Ewha Womans Univ)

$$\mu^- N \rightarrow e^- N$$

- Mono-energetic electron
  - 105MeV for Al target



Mu to e conversion

Fermilab program

- mu2e

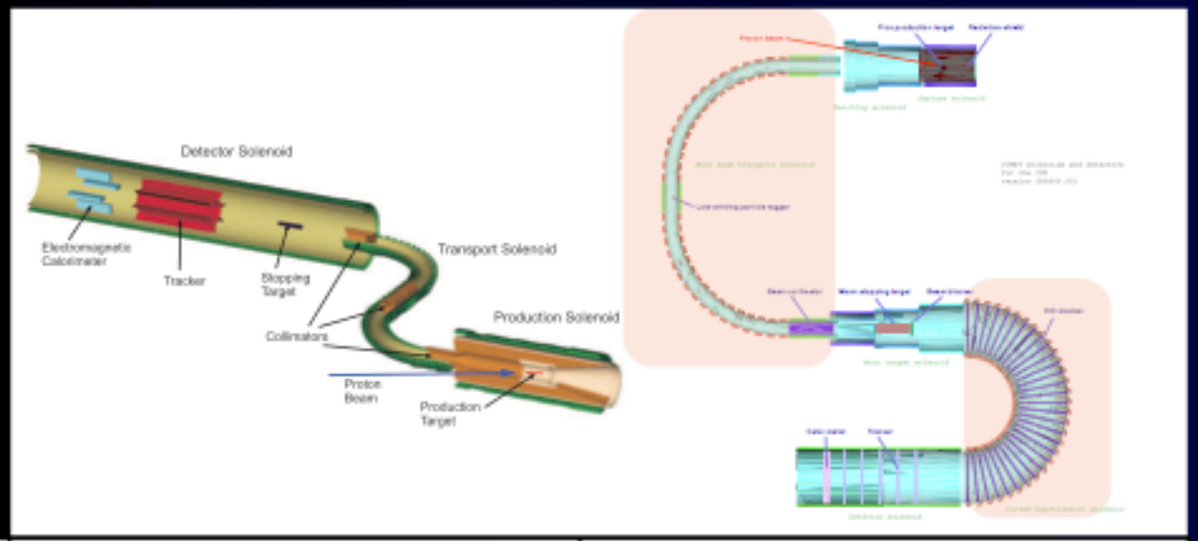
J-PARC program

- COMET, DeeMe

sensitivity of BR~10^{-14}
in a timely manner

Mu to e conversion

Comparison : COMET vs. Mu2e



Y. Kuno (Osaka U)

	Mu2e@FNAL	COMET@J-PARC
muon beam line	S-shape	C-shape
electron spectrometer	Straight solenoid	Curved solenoid

Selection of low momentum muons

eliminate background from muon decay in flight

Selection of 100 MeV electrons

eliminate protons from nuclear muon capture.

eliminate low energy events to make the detector quiet.

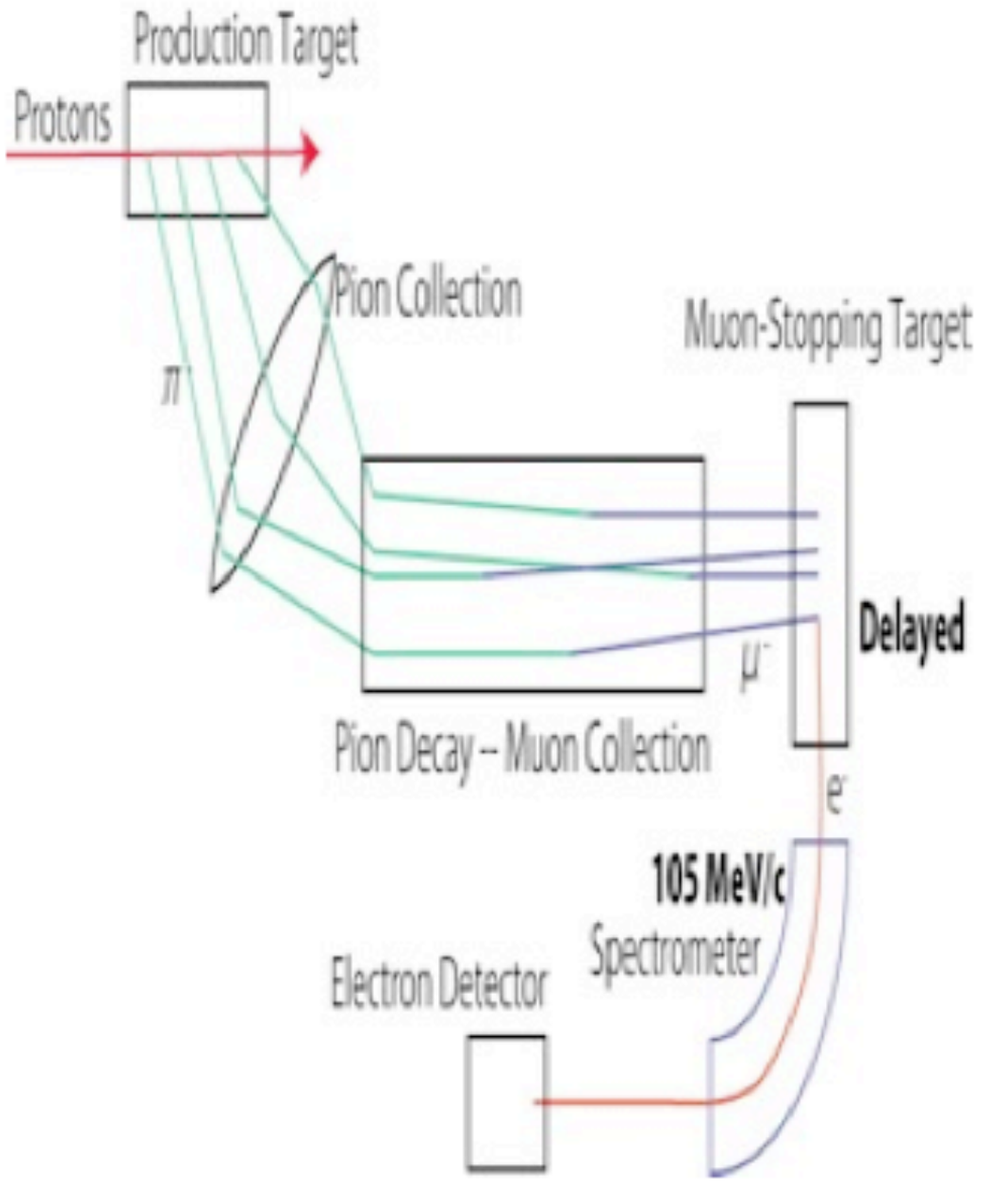
DeeMe

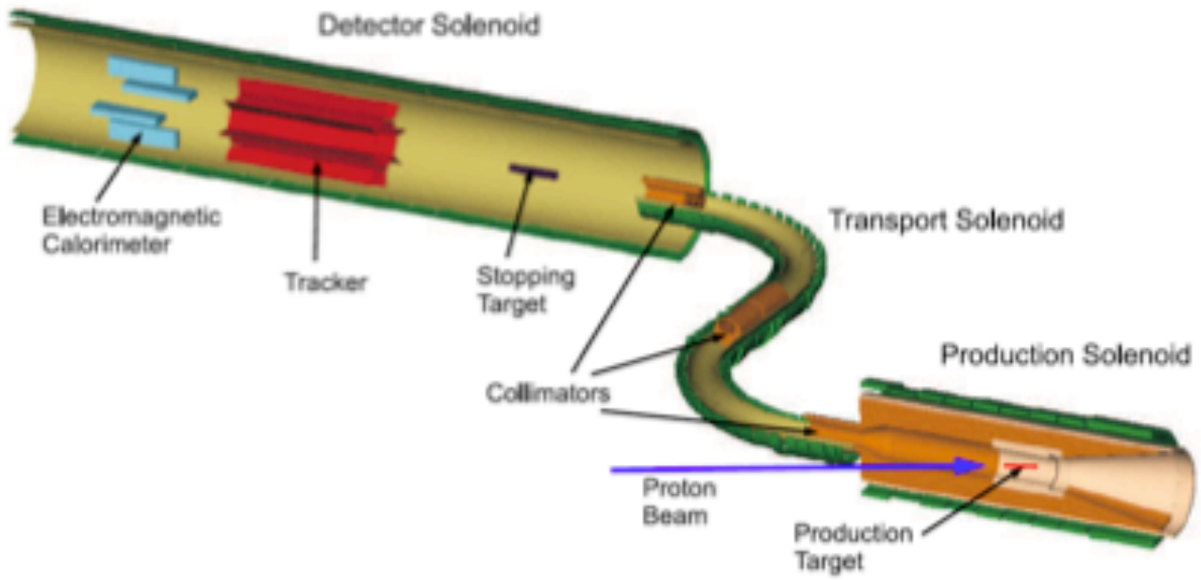
M. Aoki (Osaka Univ)

DeeMe

M. Aoki (Osaka Univ)

Mu2E @ Fermi Lab



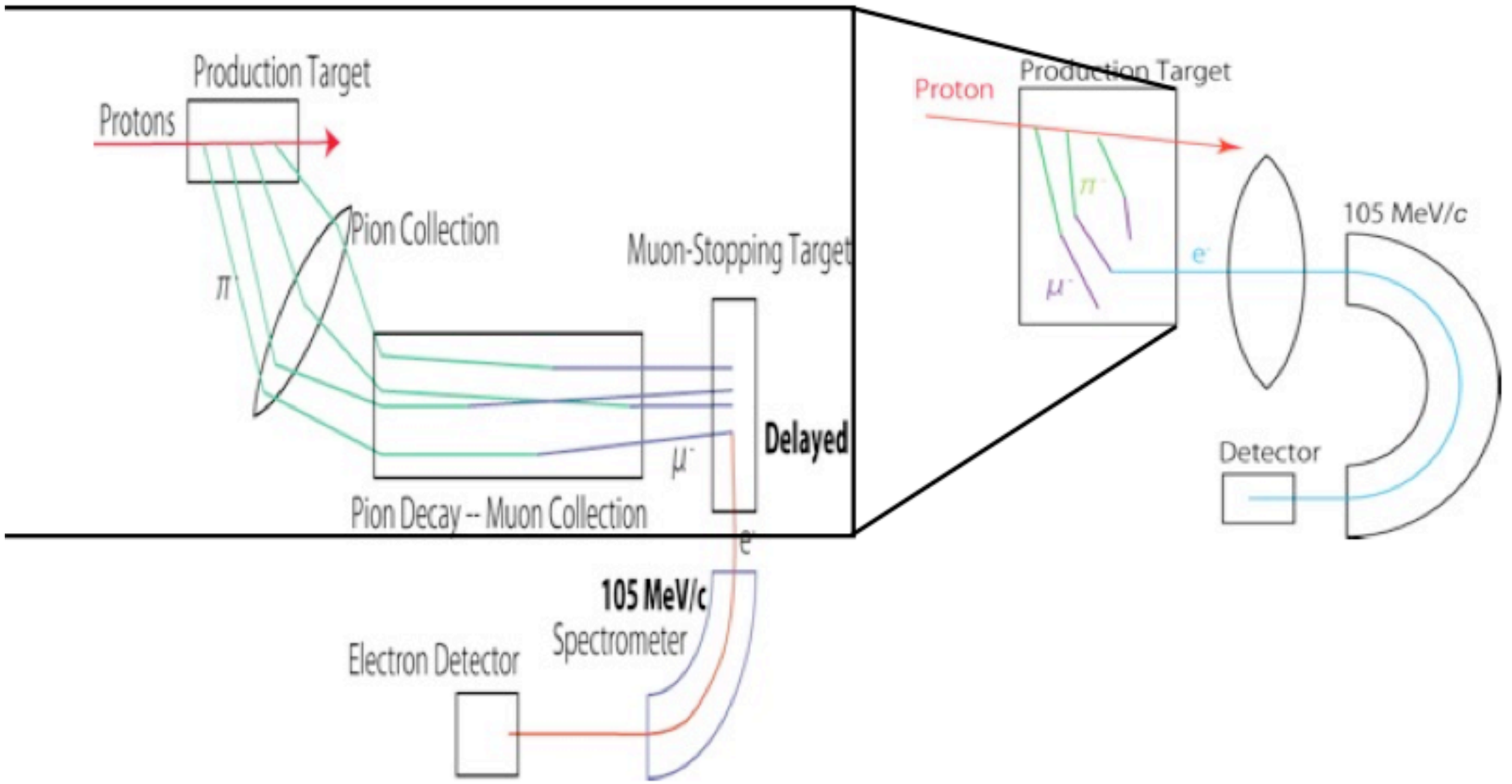


Mu2E: BR[Al] < 10^{-16}

DeeMe

M. Aoki (Osaka Univ)

μ-e electrons may directly coming from a production target.



an electron analogue of the surface muon.

Experiment could be very simple, quick and low-cost.

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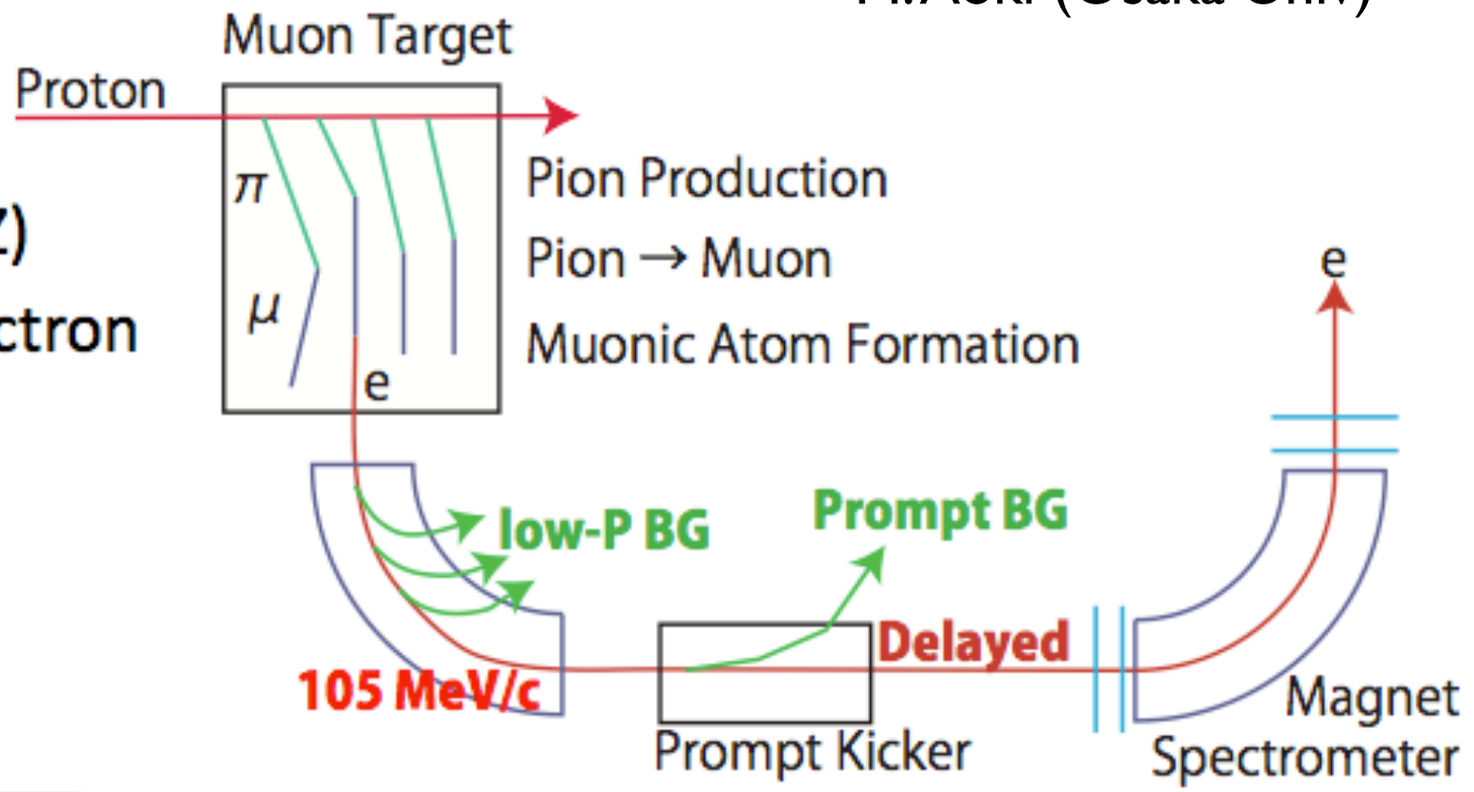
M. Aoki (Osaka Univ)

DeeMe(P41)

- Process : $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$
- A single mono-energetic electron
  - 105 MeV
  - Delayed : ~1μS
- No accidental backgrounds
- 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
    - $\pi^- + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$
      $\gamma \rightarrow e^+ e^-$
    - Prompt timing



- Low Energy main part: suppressed by the beamline.
- High Energy tail: Magnet Spectrometer ($\Delta p < 0.3\%$)
- Main pulse: Kicker to reduce the detector rate.
- after-protons: Suppressed owing to the extremely small after-protons from RCS -- $R_{AP} < 10^{-17}$.

g-2/EDM of muons

Fermilab program

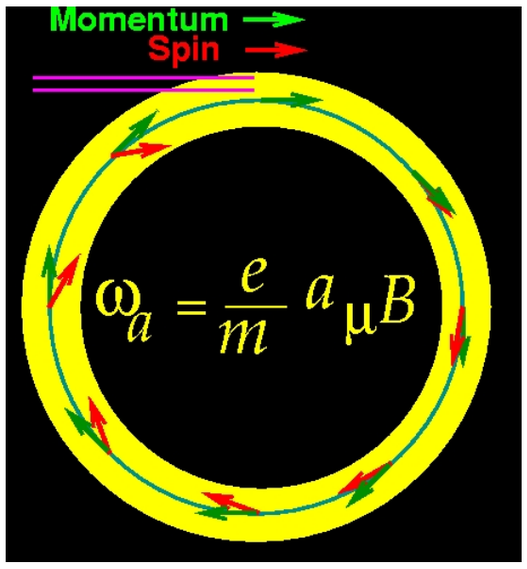
- g-2

J-PARC program

- g-2/EDM

muon g-2/EDM measurements

T. Mibe (KEK)



In uniform magnetic field, muon spin rotates ahead of momentum due to g-2 ≠ 0

a_μ (= (g-2)/2) is deduced from this residual rotation (precession). In general, spin also rotates due to $B_{eff} = \beta \times E$ and EDM.

general form of spin precession vector:

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

BNL E821 approach
γ=30 (P=3 GeV/c)

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

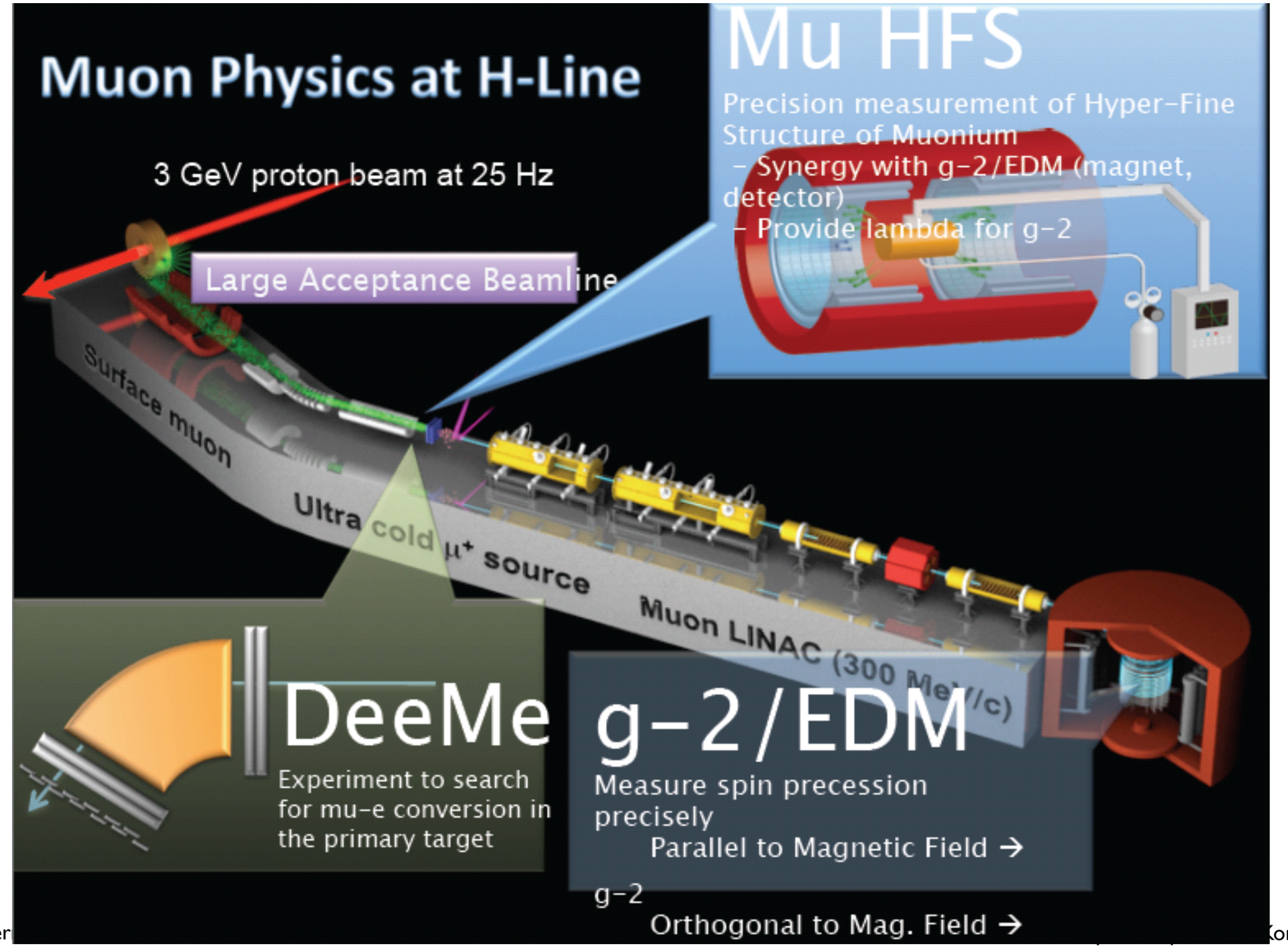
Continuation at FNAL with 0.1ppm precision

J-PARC approach
E = 0 at any γ

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

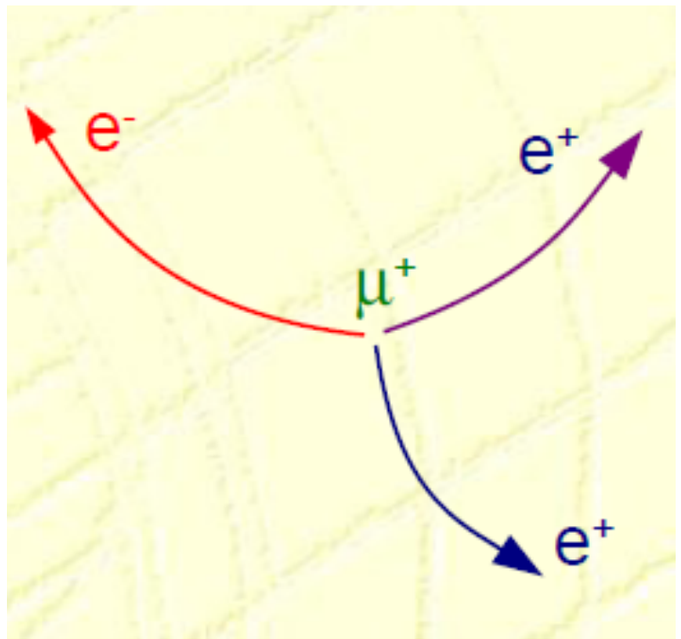
Proposed at J-PARC with 0.1ppm precision

J-PARC strategy



Mu->eee

Hyunsu Lee (Ewha Womans Univ)

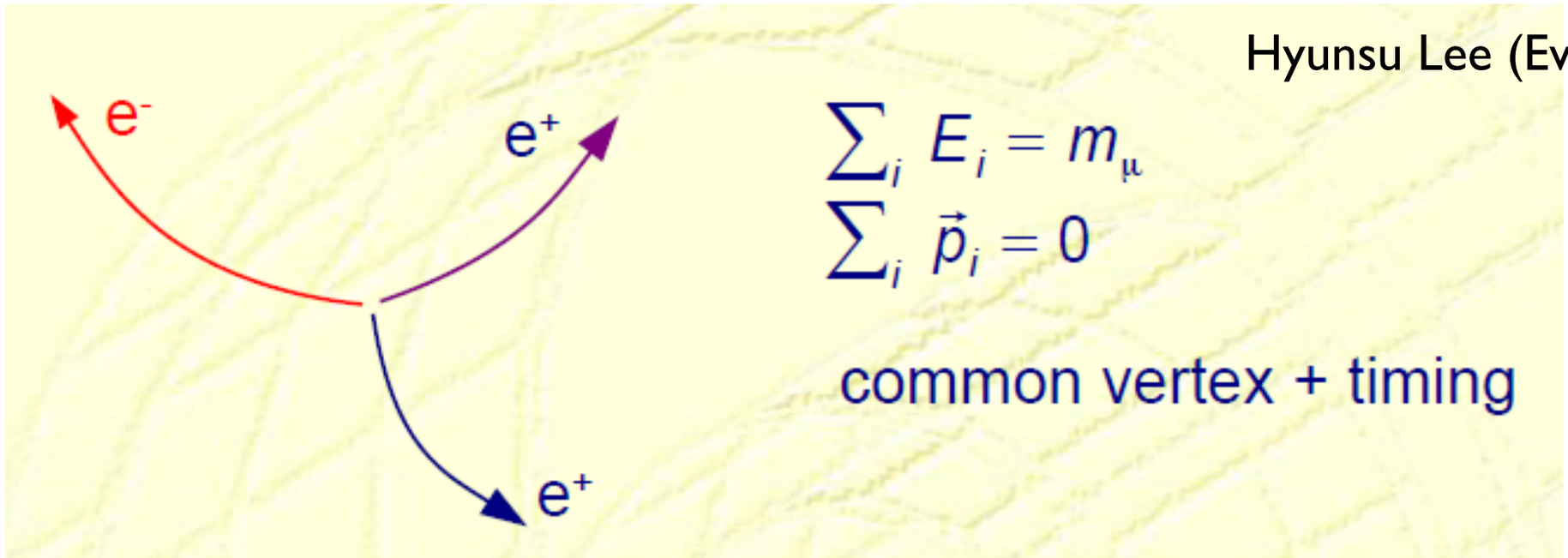


- Advances in detector technique
  - ❖ High rate/ high precision
- High muon rate (Plan to upgrade **PSI Beam** line)≥10^9 muon stops/s
- Less background compared with mu->e gamma
- Complement with the other LFV experiments

$$B(\mu^+ \rightarrow e^+e^+e^-) > 10^{-16}$$

Signal & background

Hyunsu Lee (Ewha Womans Univ)



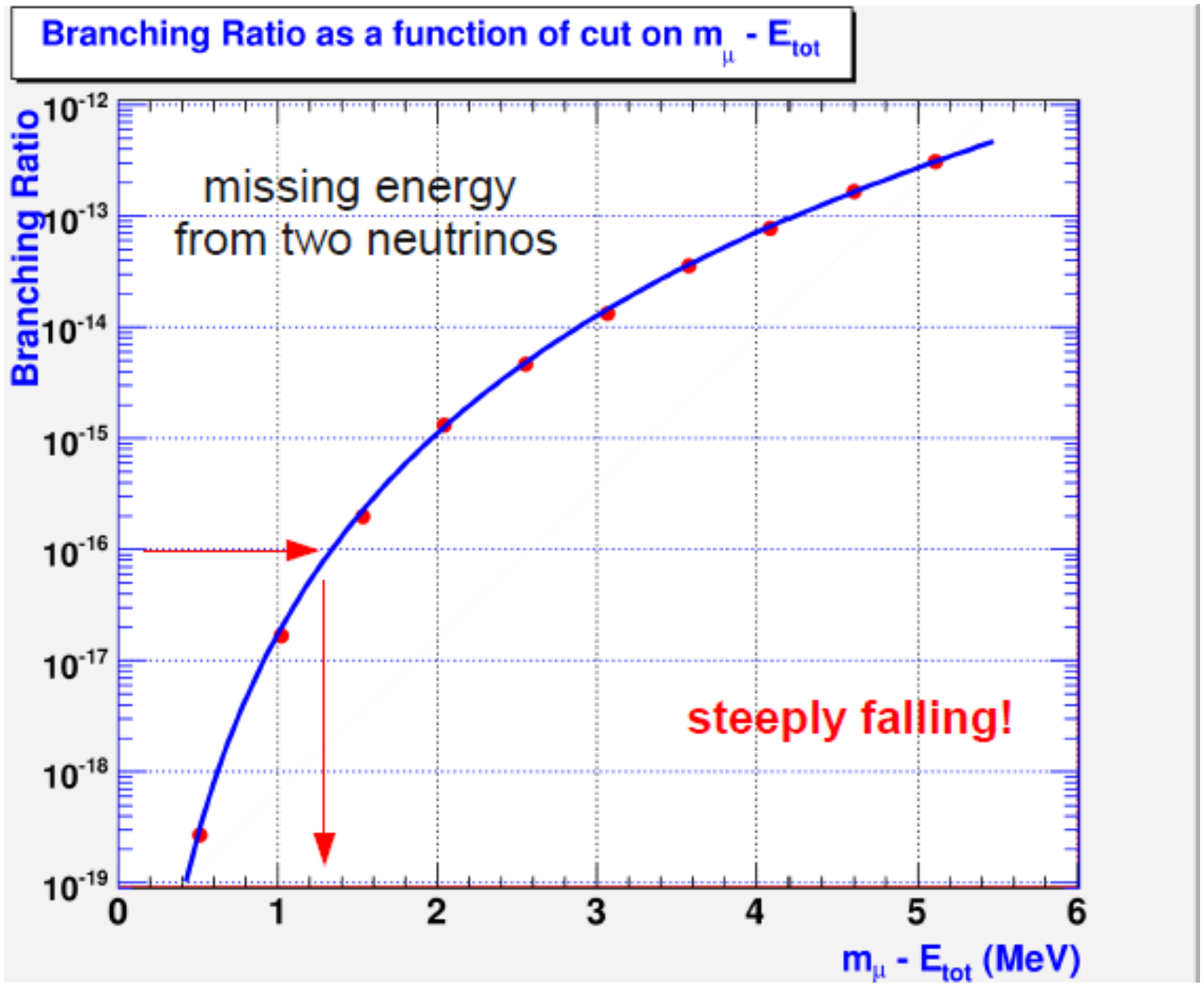
- Background
  - ❖ Irreducible

$$BR(\mu^+ \rightarrow e^+e^+e^- \nu\nu) = 3.4 \cdot 10^{-5}$$

    - ❑Well separated with signals (need good tracking & timing)
  - ❖ Accidental
    - ❑Electron charge from muon(+) should be positive
    - ❑So, relatively small contribution compared with mu->e gamma

Background

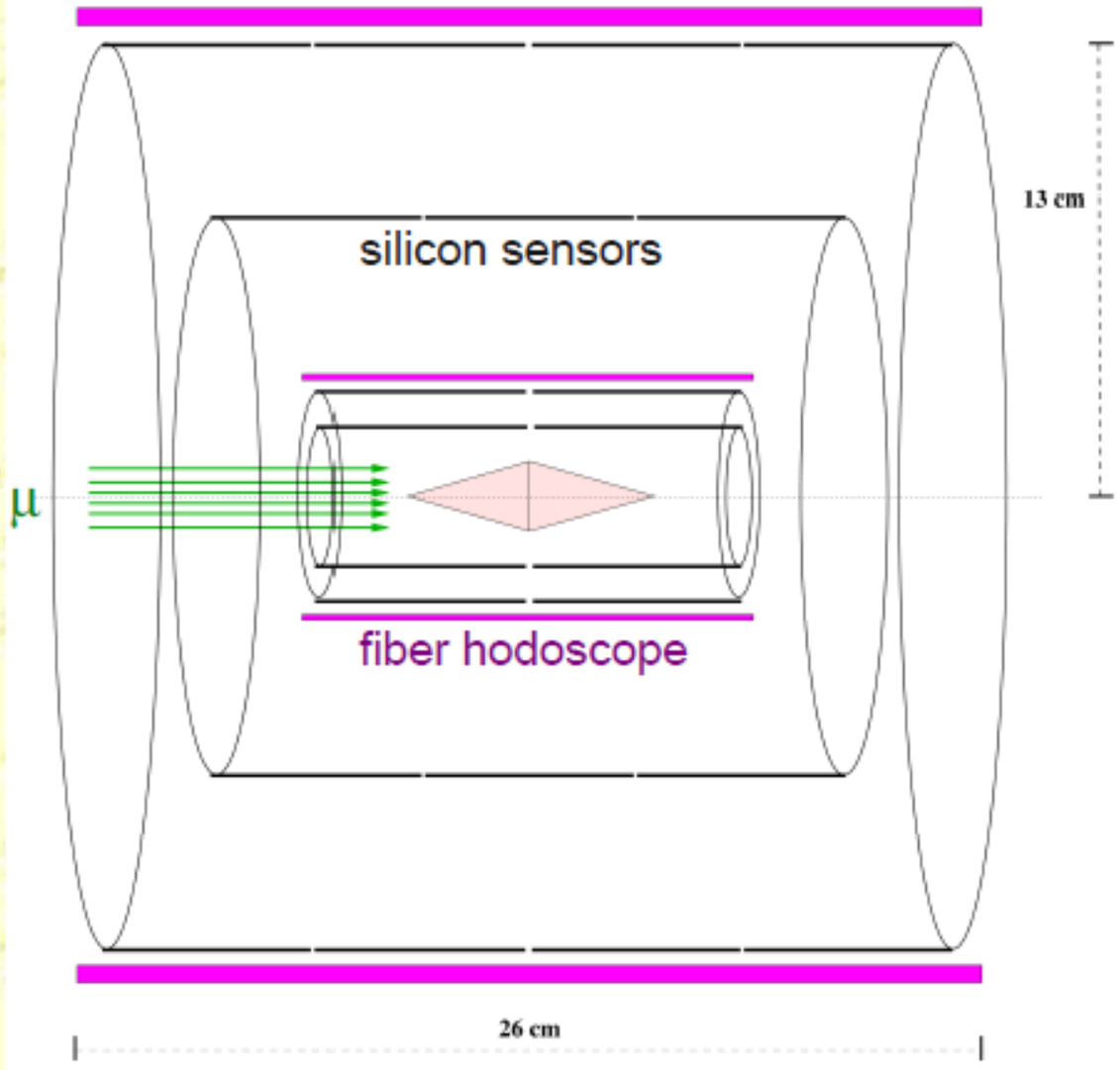
Hyunsu Lee (Ewha Womans Univ)



- Good energy (momentum) resolutions are essential

Conceptional Design

- **Magnet (B=1-2 Tesla)**
  solenoid, gradient field?
- **Hollow Double Cone Target**
  (Sindrum)
- **Silicon pixel detector for tracking**
  - high resolution
  - precise hit position **80 μm x 80 μm**
    (c.t. multiple scattering σ_{MS} ~ 150 μm)
- **Scintillating fiber hodoscope**
  - excellent timing **ΔT ≤ 100 ps**
  - good spatial resolution
  - vector tracking (particle direction)



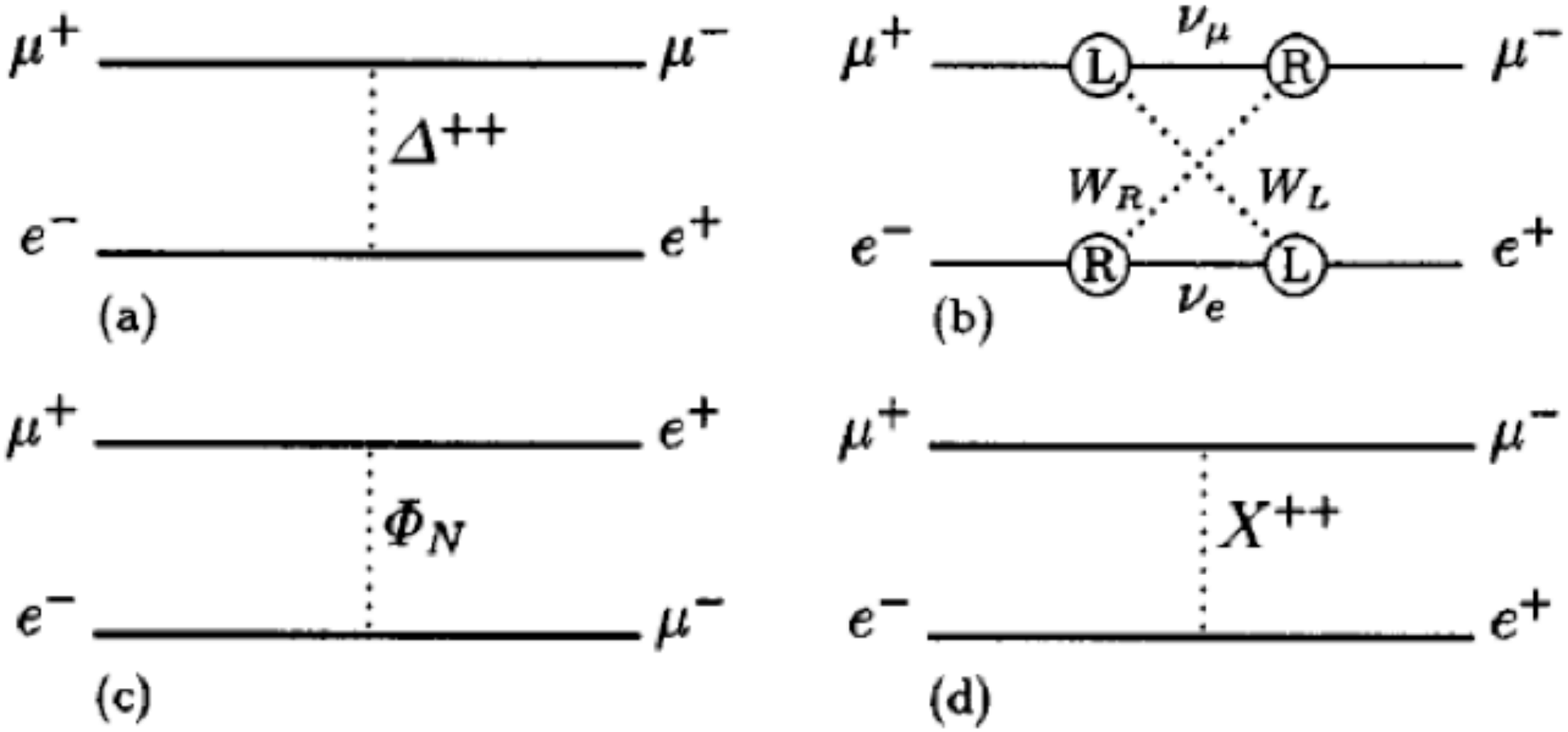
Estimated Cost

Task	Phase I Costs [kCHF]	Phase II Costs [kCHF]
Target + Infrastructure	50	50
Magnet	1000	0
Silicon Tracker	500	200
Fibre Hodoscope	400	200
Filter Farm	300	300
DAQ + Slow Control	500	500
Beamline	u.a.	u.a.

- Phase I use current PSI muon beam line (2014-2017)
  - $2*10^{8}$ muon stops/s
  - 1year operation ~ 10^{-15}
- Phase II need upgrade of PSI muon beam line (>2017)
  - 10^{9} muon stops/s
  - 1 year operation ~10^{-16}

Muonium-antimuonium oscillation

- ΔL=2, it is extremely forbidden from SM
- Different new physics with ΔL=1
- Lepton mixing & CP violation
- Double charge Higgs, Heavy neutrino ..



Best Experiment (1999) (MACS)

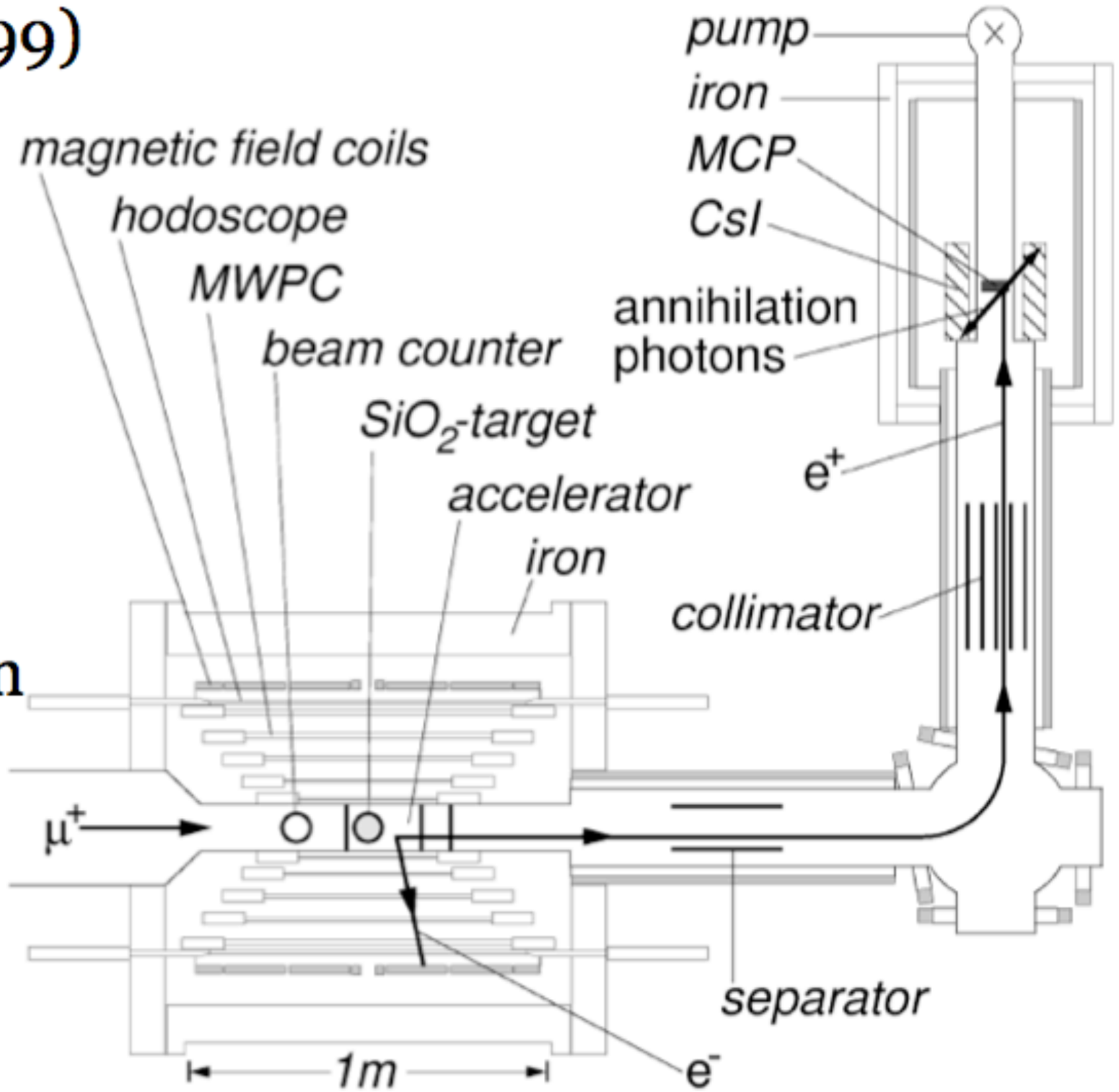
PRL 82, 49 (1999)

PSI surface muon

$p = 26\ \mathrm{MeV}/c$

$\Delta p/p = 5\%$

$8 \times 10^6\ \mu^+/\mathrm{s}$

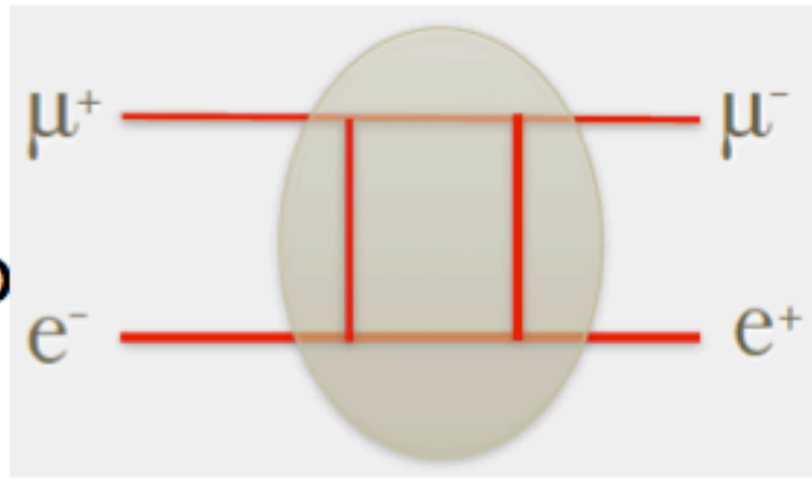


Signal & Background

- Energetic e^- from μ^- : Maximum 53MeV

$$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu}_e$$

- Low energy (1s state) positron 13.5 eV
  - ❖ Accelerating into 7keV and collected in MCP
- Should monitor muonium also (denominato
  - ❖ Monitoring was done every 5h
- Dominant background (Michel)



$$\mu \rightarrow e^+ e^+ e^- \nu_e \overline{\nu}_\mu$$

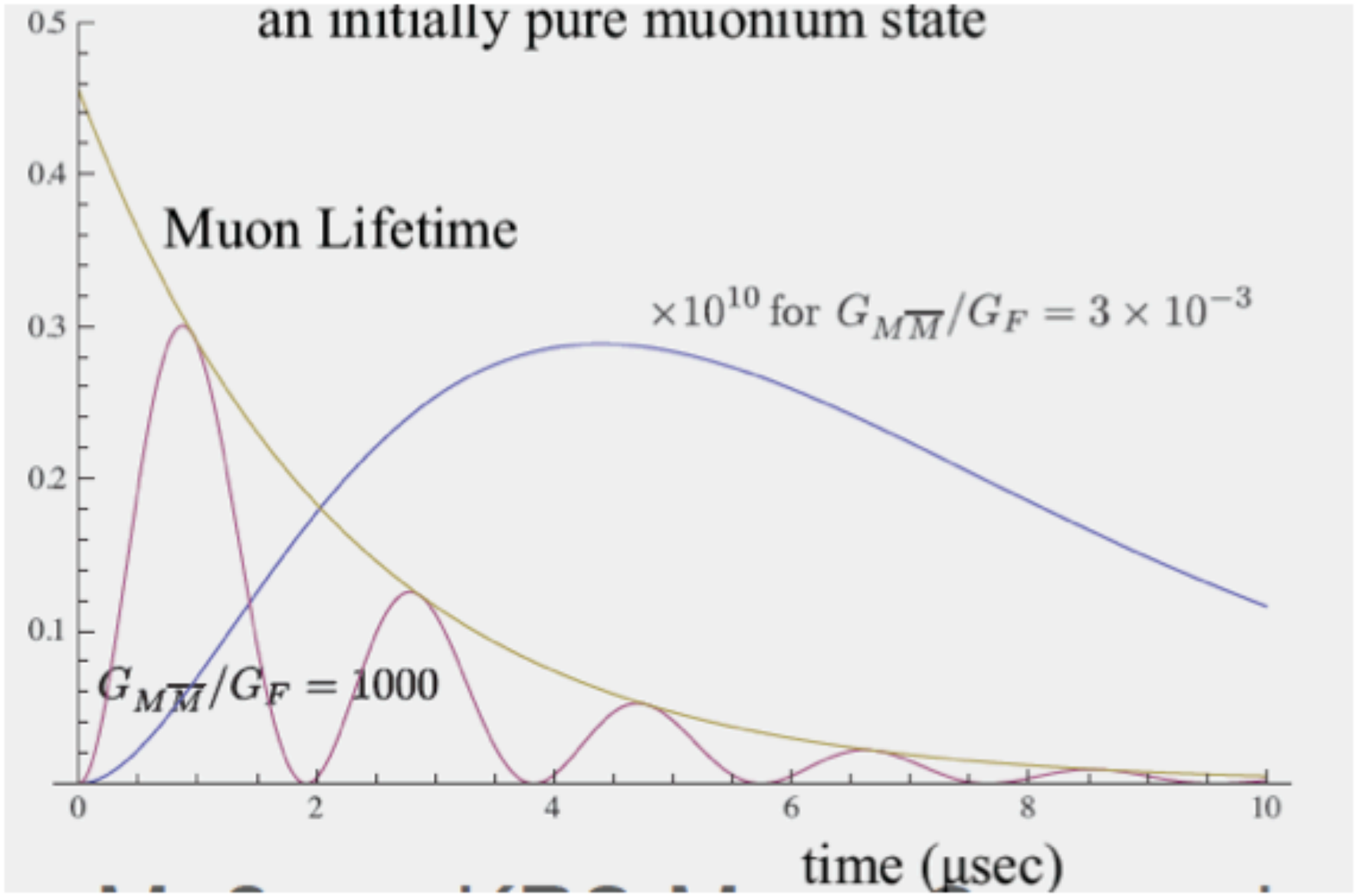
- ❖ Energetic electron and low energy positron (one positron missing)
- ❖ Branching ratio 3.4×10^{-5}

- Limit $P_{\mathrm{M\overline{M}}} \leq 8.3 \times 10^{-11}$ (90% C.L.)

$$G_{\mathrm{Mu\overline{Mu}}} < 3 \times 10^{-3} G_F$$

Pulsed beam ?

- Wait a couple of muon lifetime so then we can reduce the dominant background (Michel)
  - But, it might not be our option



Discussion Items

1) Plans on muSR in Korea

2) Fundamental physics experiments w/ muons at home or at foreign country

Domestic Program

- We think of a design that can be competitive to

$\mu \to eee$ or muonium oscillation experiments

We feel that g-2, mu2e, $\mu \to e\gamma$ might be tough.

Lamb shift/Hyperfine structure/muon+ lifetime are other potential considerations (?)

[22] arXiv:1301.6113 (cross-list from physics.ins-det) [pdf, other]

Research Proposal for an Experiment to Search for the Decay μ -> eee

A. Blondel, A. Bravar, M. Pohl, S. Bachmann, N. Berger, M. Kiehn, A. Schöning, D. Wiedner, B. Windelb
M. Hildebrandt, P.-R. Kettle, A. Papa, S. Ritt, A. Stoykov, G. Dissertori, C. Grab, R. Wallny, R. Gredig, F

Comments: Research proposal submitted to the Paul Scherrer Institute Research Committee for Particle Physics at the Ring C

Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex)

We may end up with similar beam line as for the muSR experiment

Muon Beamline Design for RISP

Suyong Choi (KU)

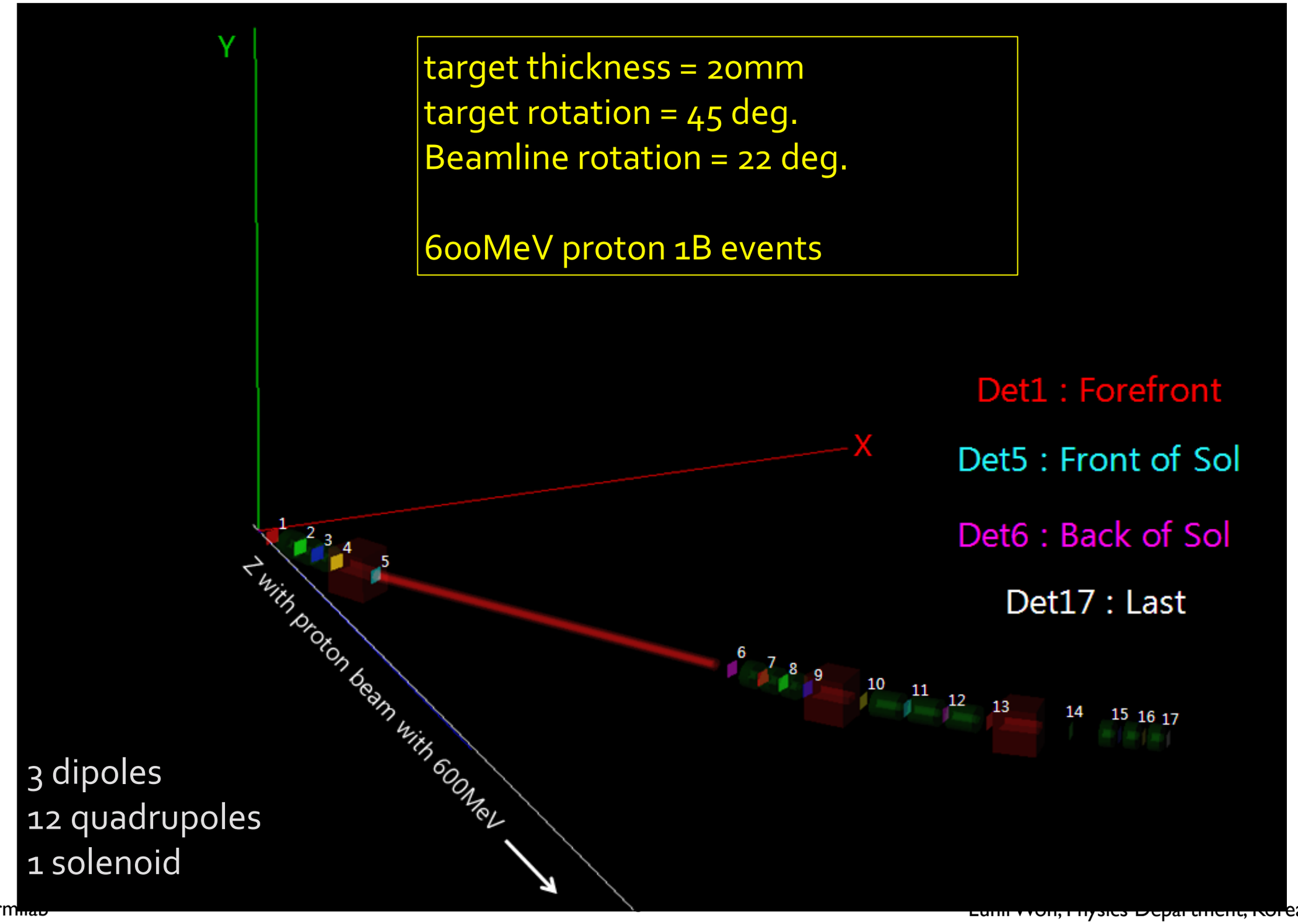
- Transport pion to long decay solenoid
  - p_0=200 MeV/c
- After the solenoid, transport muons <150 MeV/c
  - Small momentum overlap with π^+
  - High polarization
- Conventional design without restrictions for space
  - Sign selection achieved by reversing dipole polarity
  - Higher rate through thicker target

G4 Beamline Simulation Setup

Suyong Choi (KU)

target thickness = 20mm
target rotation = 45 deg.
Beamline rotation = 22 deg.

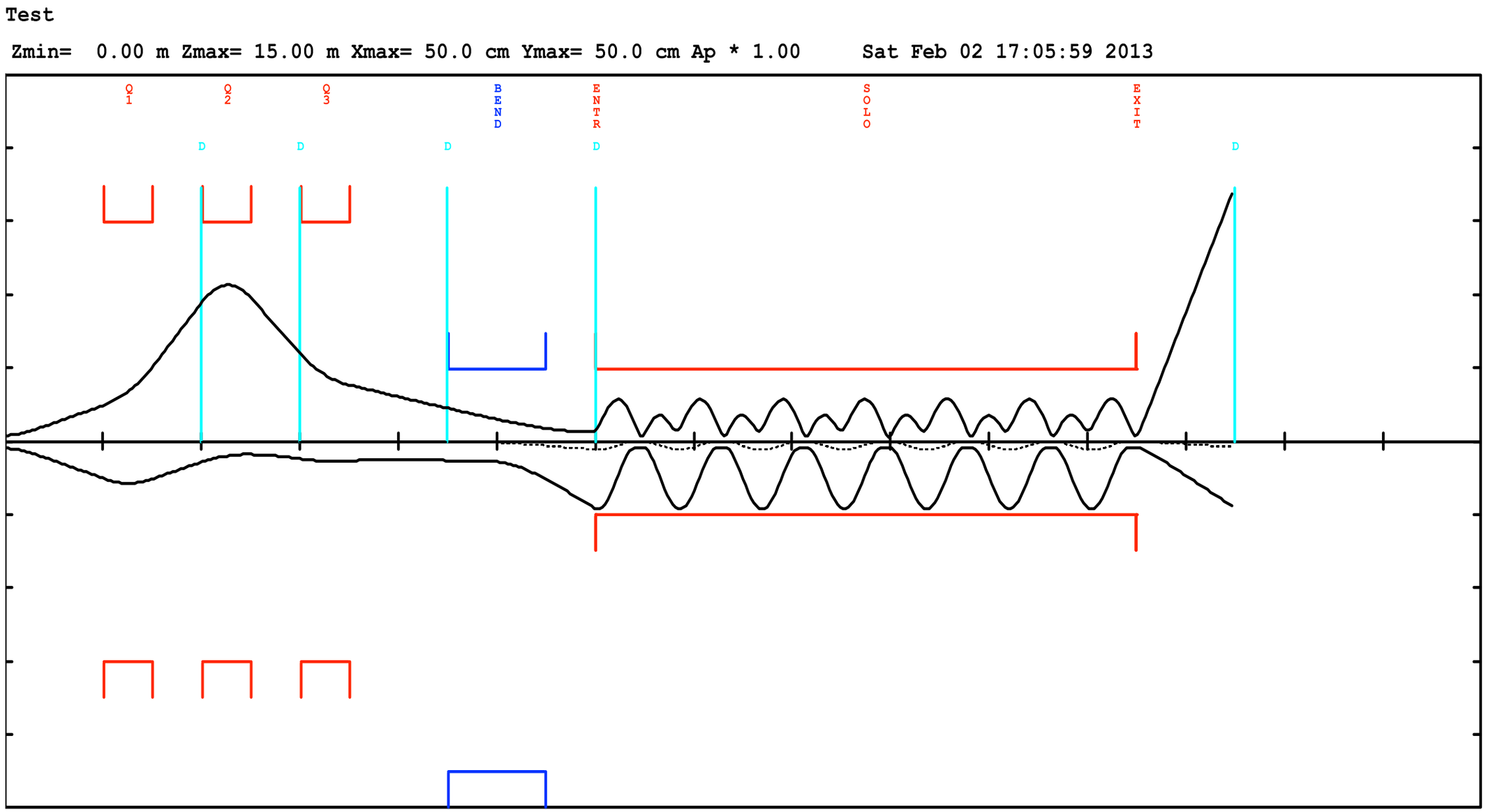
600MeV proton 1B events



3 dipoles
12 quadrupoles
1 solenoid

Pion transport line

Suyong Choi (KU)



Muon Rates

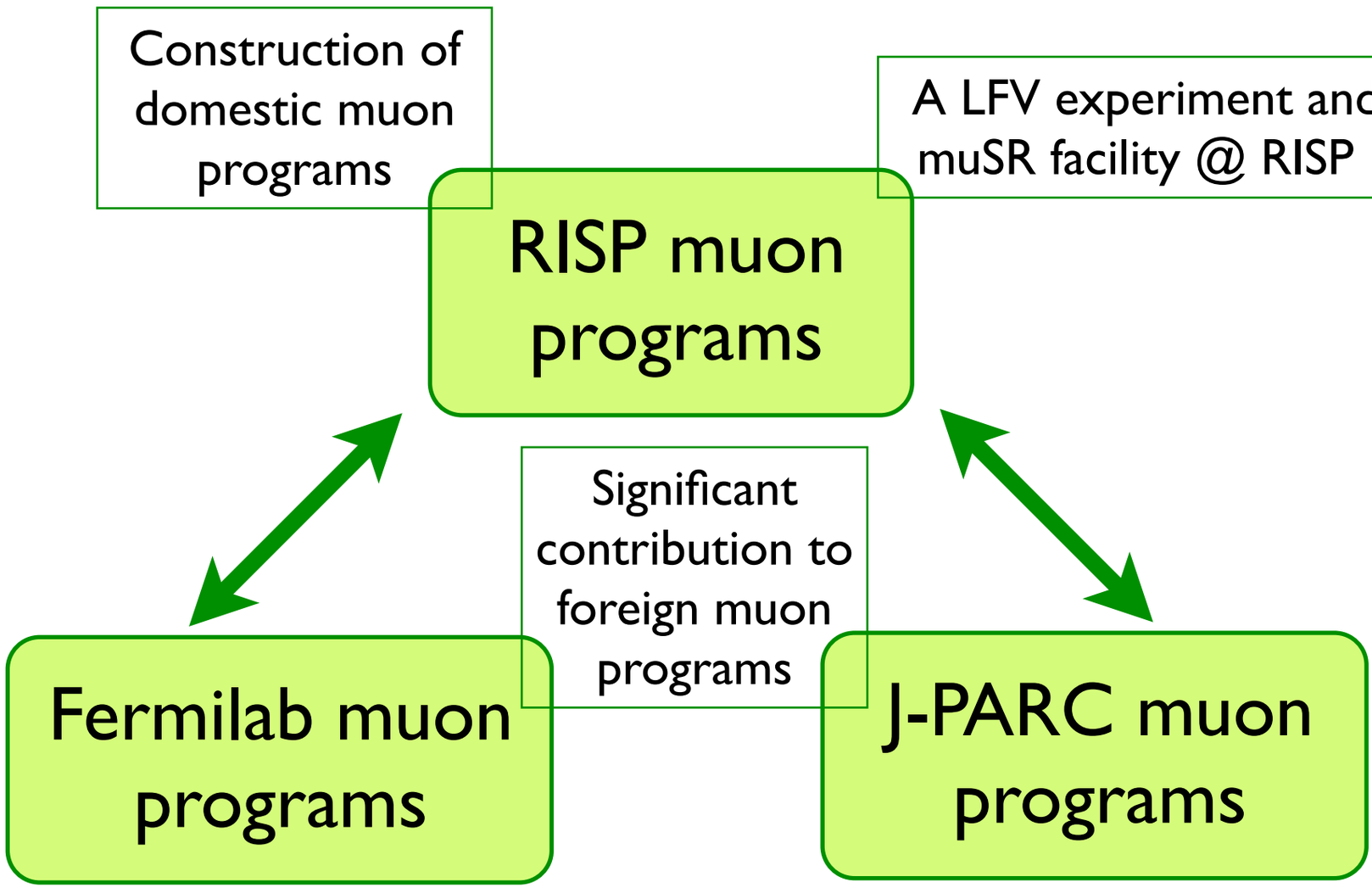
Suyong Choi (KU)

- 10^9 protons $\longrightarrow$ 100 muons
  - For 600μA beam, 4x10^8 μ^+/s, 10^7 μ^-/s
  - For 200 MeV/c muon transport (not optimal)
  - With optimized layout, higher rate achievable

Foreign Program?

My personal view

- Utilize the rare isotope accelerator (RISP) in Korea to carry out muon physics



Comments

- EW visited J-PARC on Jan. 30 2013
  Meeting w/ Yasuhiro Miyake (J-PARC MLF Muon section leader) and KEK folks

We discussed a possibility of a workshop
- Sometime in April/May(?) @ RISP/J-PARC?
- Will inform you in case you are interested in