An Experimental Search for Muon-Electron Conversion in Nuclear Field at Sensitivity of 10^{-14} with Pulsed Proton Beam --- DeeMe ---

Masaharu Aoki, Osaka University
on behalf of DeeMe Collaboration

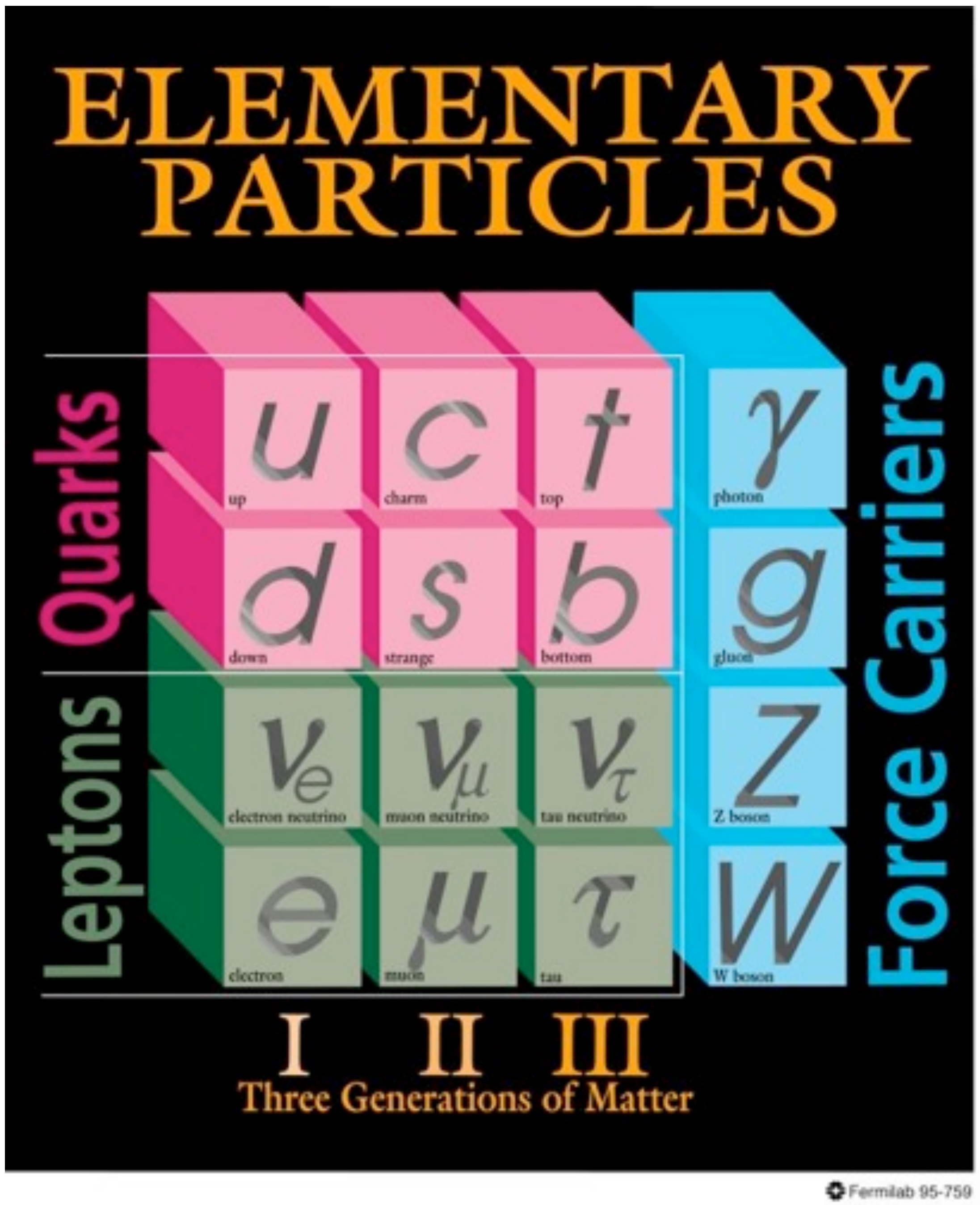
11th Oct. 2011 at BNL

Contents

- Introduction
- Experimental Method
- Test Measurement of Muonic-Atom's Yield
- Design of DeeMe
- Research & Developments for DeeMe
- Summary

Introduction

Muon in the Standard Model of Particle Physics

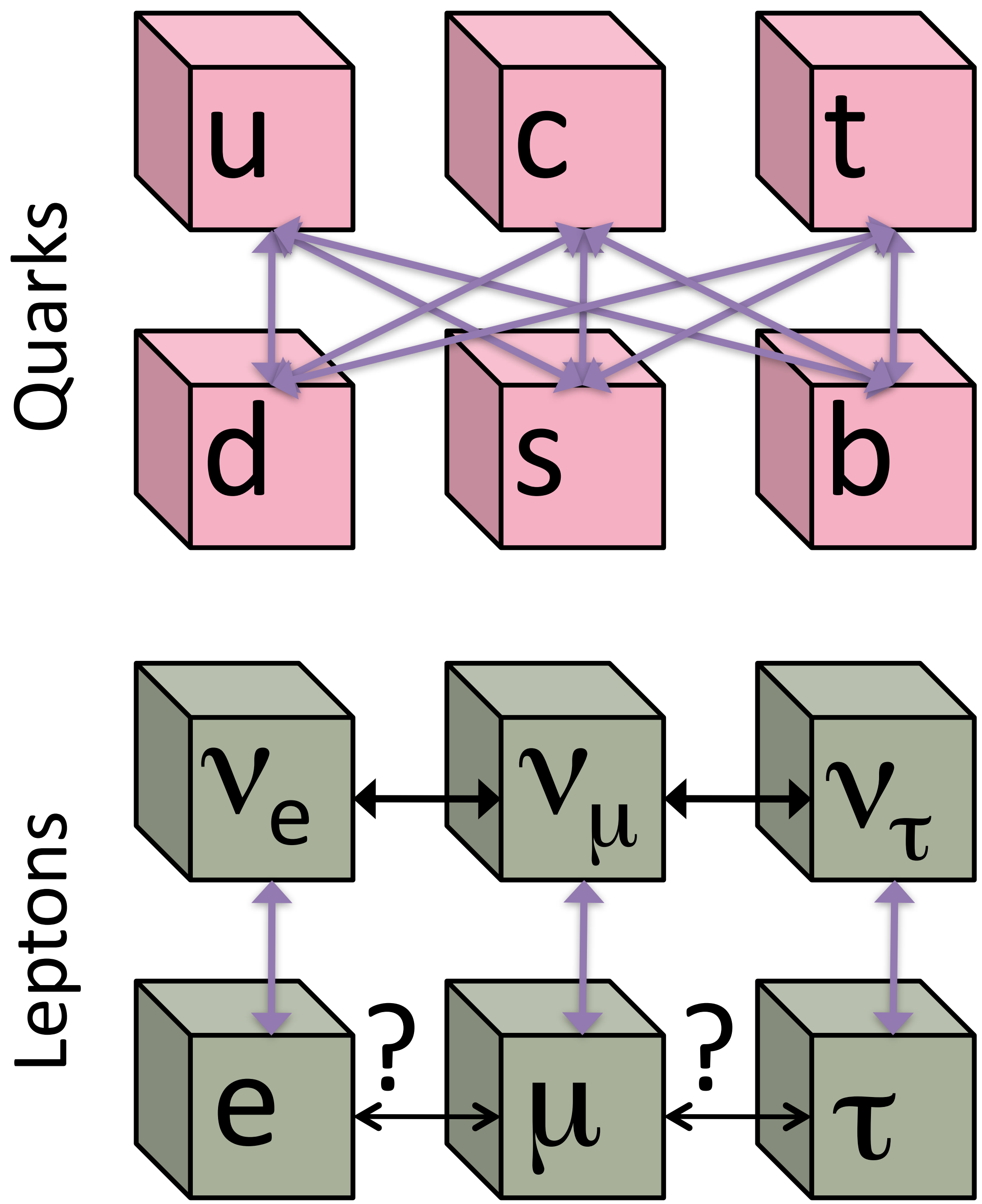


- There are three generations (flavors) of Quarks and Leptons.
- Muon was found at 1936.
  - I.I. Rabi said "Who ordered that?"
- Is the muon excited state of electron?
  - The world-first search for muon rare process: $\mu \to e \gamma$ @1947
  - Null Result → a hint of generation
- $BR_{theory}(\mu \to e\gamma) \sim 10^{-4}$ @ 1958
  - But exp. already gave $BR_{exp.} < 2 \times 10^{-5}$

    → Two neutrinos model
- $\nu_e \neq \nu_\mu$ @1962 BNL
  - Toward the establishment of the concept of "generation/flavor".
- $(g-2)_\mu$@BNL hints physics beyond the Standard Model

Muon played very important role in the development of particle physics.

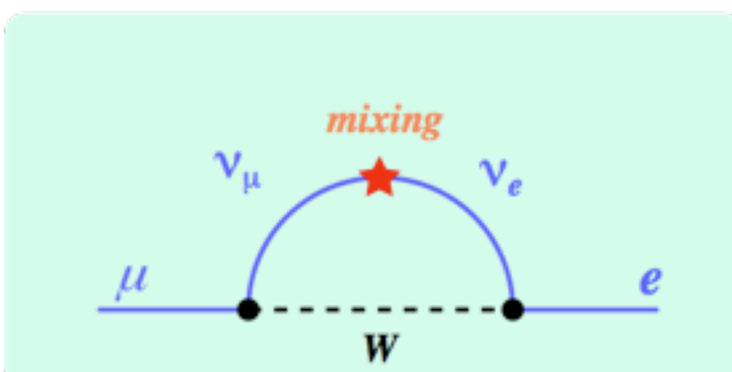
Flavor Physics



- Quark Mixing
  - Cabbibo-Kobayashi-Maskawa (CKM) Matrix
  - Established --- Novel Prize@2008
- Neutrino Mixing
  - Pontecorvo-Maki-Nakagawa-Sakata (PMNS) Matrix
  - Homestake, Kamiokande, SNO etc.
  - Observed and Established.
- Charged Lepton Flavor Violation (CLFV)
  - No observation yet at all.
  - Implemented to the Standard Model of Particle Physics as <u>"forbidden"</u>.

Charge Lepton Flavor Violation

- Charged Lepton Flavor Violation (CLFV)
  - Forbidden in the Standard Model of particle physics.
  - $\mu^- + A \rightarrow e^- + A$, $\mu \rightarrow e\gamma$, $\mu \rightarrow eee$, $\tau \rightarrow e(\mu)\gamma$, $\tau \rightarrow e(\mu)h$ ...
- Neutron Oscillation may induce the effective CLFV, but it is very small due to the combination of GIM-like mechanism and smallness of the neutrino masses.

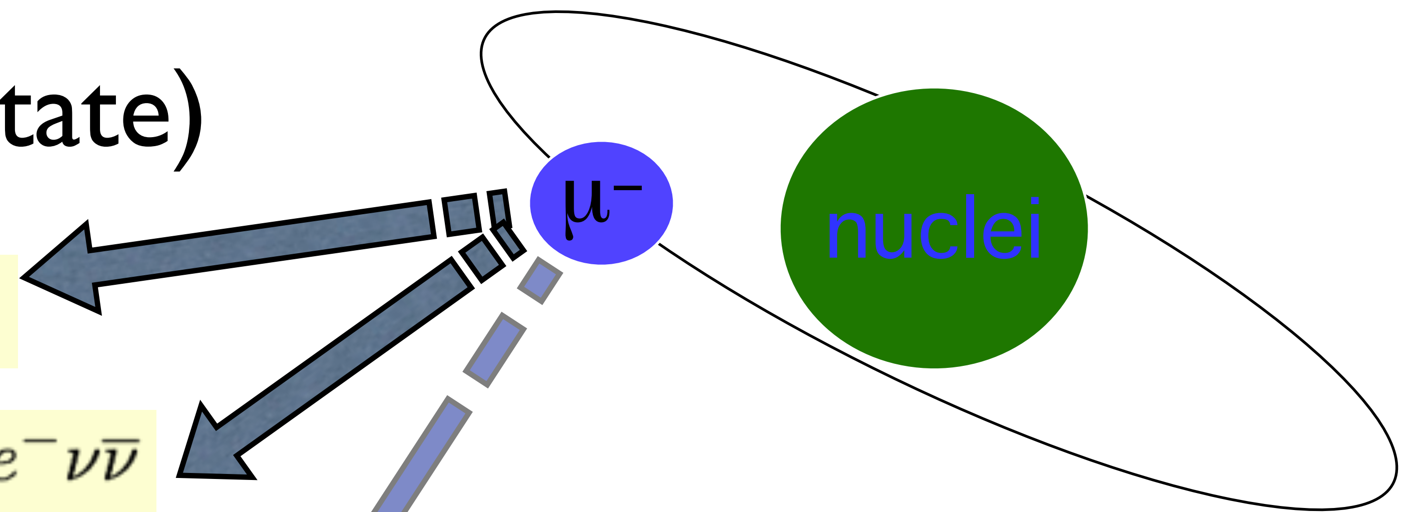


$$B(\mu \rightarrow e\gamma) = \frac{3\alpha}{32\pi} \sum_i \left| U_{\mu i} U^*_{ei} \frac{m^2_{\nu_i}}{M^2_W} \right|^2 \simeq 10^{-60} \left(\frac{m_\nu}{10^{-2}\,\mathrm{eV}} \right)^4$$

A. de Gouvea

- CLFV →
  Clear evidence of the physics beyond the Standard Model with neutrino-oscillation extension.

Muon-Electron Conversion



- Muonic Atom (1S state)

  Muon Capture(MC)

  $\mu^- + (A,Z) \rightarrow \nu_\mu + (A, Z-1)$

  Muon Decay in Orbit (MDO) $\mu^- \rightarrow e^- \nu \overline{\nu}$

  - MC:MDO = 1:1000(H), 2:1(Si), 13:1(Cu)
  - τ(free μ-) = 2.2 μs
  - $\tau(\mu^-;Si)$ = 0.76 μs

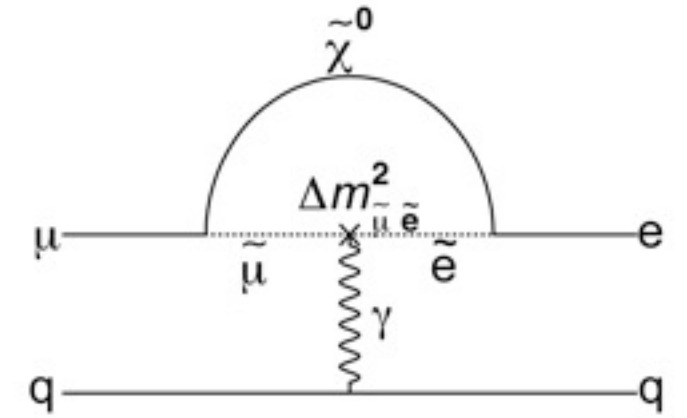
- μ-e Conversion

  $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$ Charged Lepton Flavor Violation (CLFV)

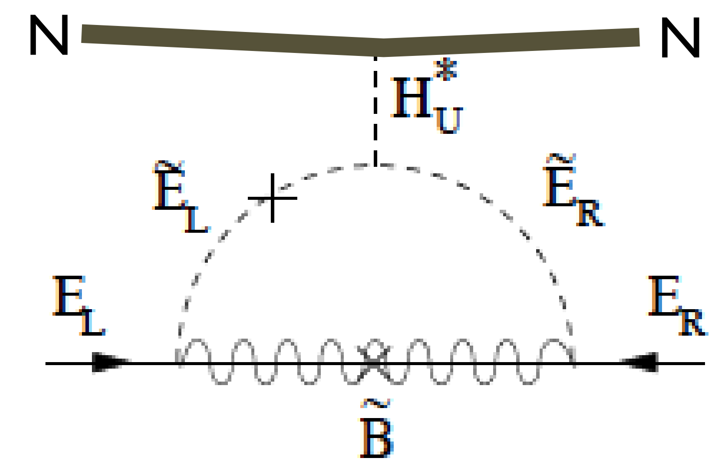
$$\mathrm{BR}[\mu^- + (A,Z) \rightarrow e^- + (A,Z)] \equiv \frac{\Gamma[\mu^- + (A,Z) \rightarrow e^- + (A,Z)]}{\Gamma[\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)]}$$

Physics of μ-e Conversion

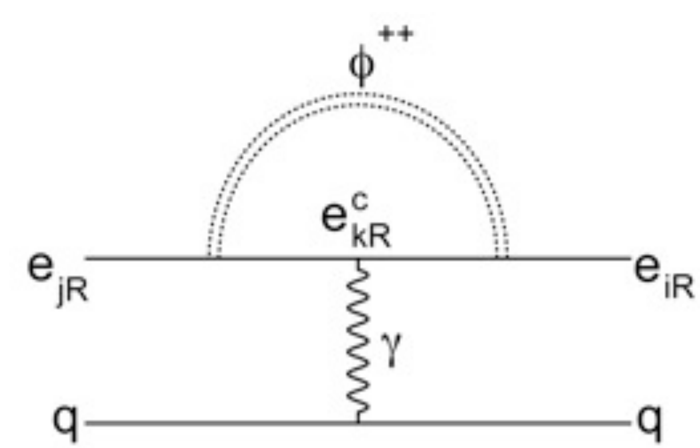
- SUSY-GUT, SUSY-seesaw (Gauge Mediated process)
  - BR = 10^{-15} = BR(μ→eγ) × O(α)
  - τ→lγ



- SUSY-seesaw (Higgs Mediated process)
  - BR = 10^{-12}~10^{-15}
  - τ→lη



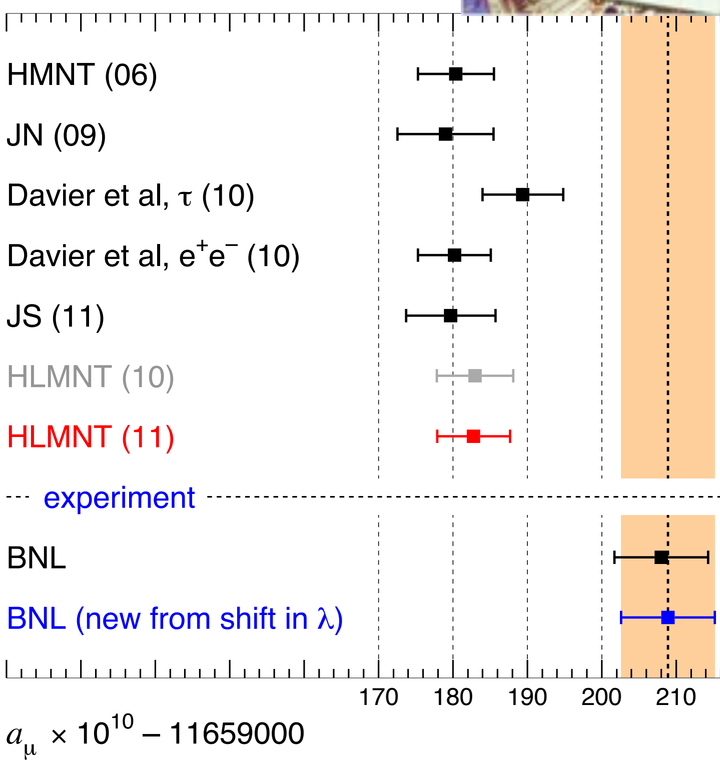
- Doubly Charged Higgs Boson (LRS *etc.*)
  - Logarithmic enhancement in a loop diagram for $\mu^-N \rightarrow e^-N$, not for μ→e γ
    - M. Raidal and A. Santamaria, PLB 421 (1998) 250

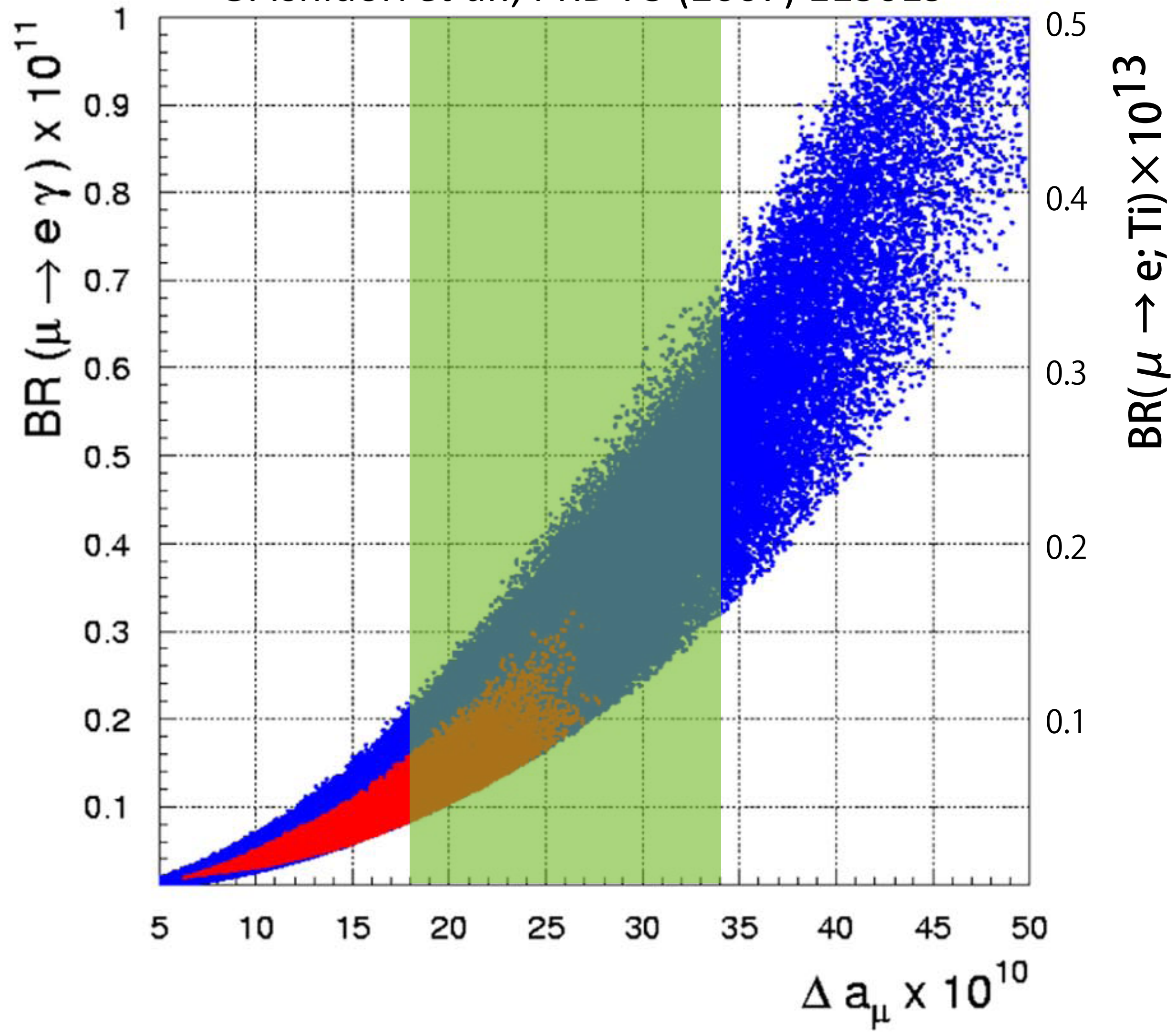


- Little Higgs Models
- Randall-Sundrum Models
- SUSY with R-parity Violation
- Leptquarks
- Heavy Z'
- Multi-Higgs Models

Relations with other observables

- B asymmetries (see the red dots in the plot below).
- muon g-2
  - Δa_μ: off by 3.3σ



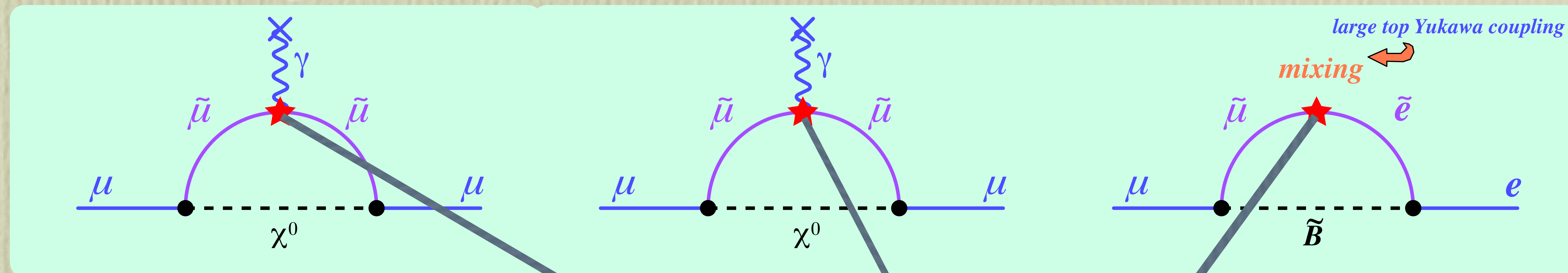


- μ → e γ (MEG)
  - 2009-2010
    BR < 2.4×10^{-12} (90%C.L.)

Recent Upper Limits
SINDRUM-II: BR[μ^- + Au → e^- + Au] < 7×10^{-13}
SINDRUM-II: BR[μ^- + Ti → e^- + Ti] < 4.3×10^{-12}
TRIUMF: BR[μ^- + Ti → e^- + Ti] < 4.6×10^{-12}

Physics of slepton mass matrix

μ g-2 μ EDM CLFV



Real Imaginary

slepton mass matrix
$$\begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$

τ-LFV

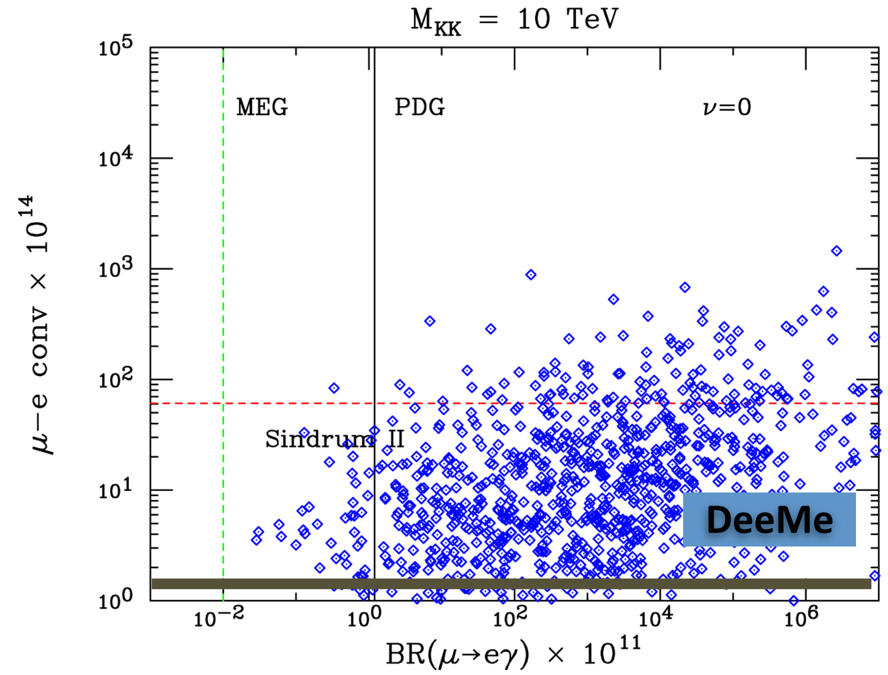
A transparency of J. Hisano at IFMF WS 2010 (DeeMe lines added by M. Aoki)

Non-SUSY models at TEVs

Many proposed TeV-scale models have new particles, which have lepton-flavor numbers or have lepton-flavor violating interactions.

SM on Randall&Sundrum BG

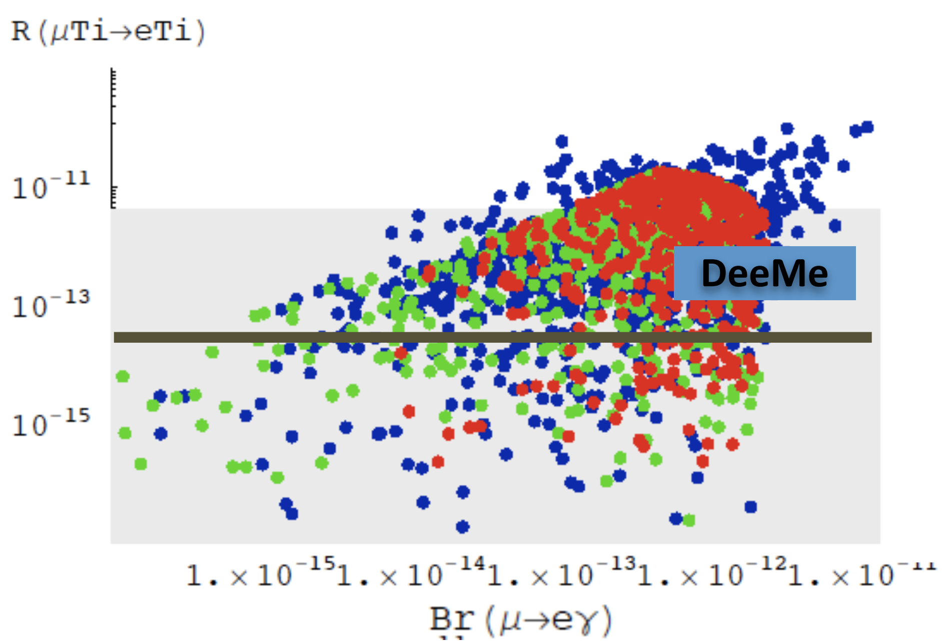
- SM particles propagate over curved 5th dim. space.
- Overlapping of wave functions of quark/lepton and Higgs explains hierarchical structure.
- Kaluza-Klain particles have large flavor-violating interactions.



(Agache et al)

Littlest-Higgs model with T parity

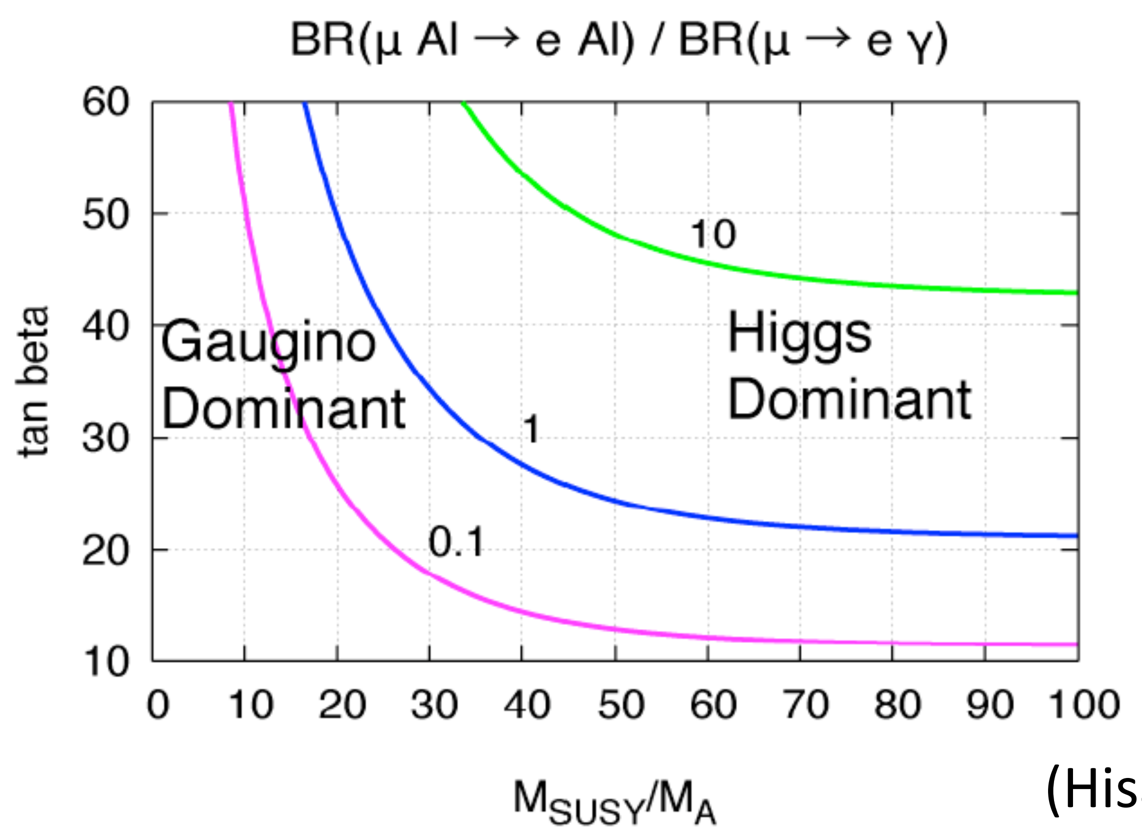
- SM Higgs is pseude NG boson.
- T parity is imposed to escape from EW precision test and also to introduce the DM candidate.
- T-odd mirror leptons/quarks have flavor-violating interactions.



11年10月11日火曜日

What is the BSM if cLFV is found?

In SUSY SM, the Higgs mediation contribution is sizable when SUSY particle masses are larger O(1-10) TeV. Ratio between μ-e conversion rate and Br(μ-eγ) is modified.



(Hisano et al, 10)

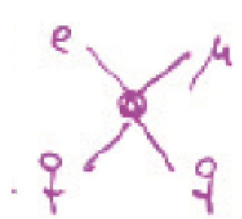
(Hisano IFMFS2010)

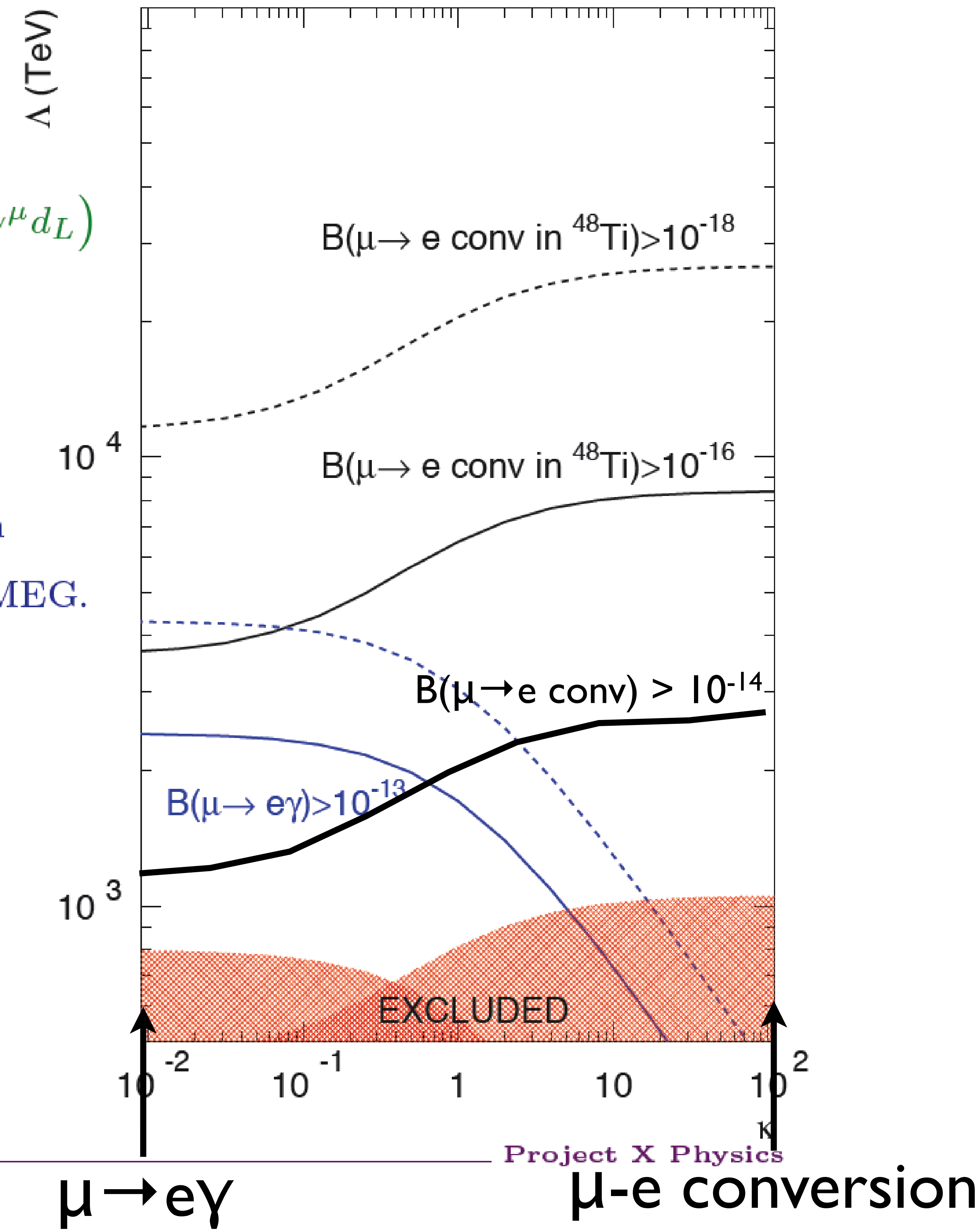
μ→eγ vs. μ-e conversion

Model Independent Analysis

$$L_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L\right)$$

- $\mu \to e$-conv at 10^{-17} "guaranteed" deeper probe than $\mu \to e\gamma$ at 10^{-14}.
- We don't think we can do $\mu \to e\gamma$ better than 10^{-14}. $\mu \to e$-conv "only" way forward after MEG.
- If the LHC does not discover new states $\mu \to e$-conv among very few process that can access 1000+ TeV new physics scale: tree-level new physics: $\kappa \gg 1$, $\frac{1}{\Lambda^2} \sim \frac{g^2\theta_{e\mu}}{M^2_{\rm new}}$.



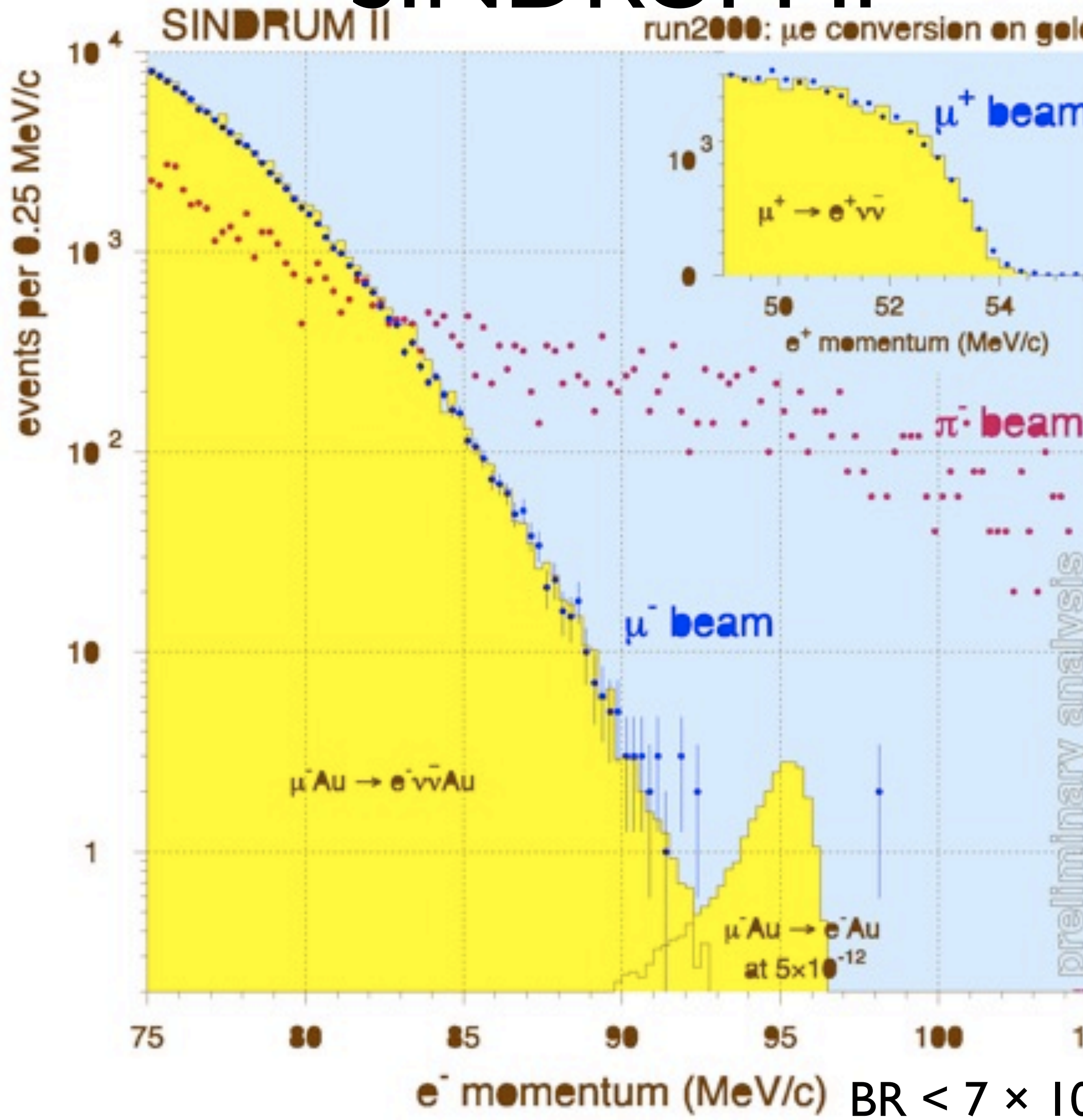


Experimental Method

Principle of μ-e Search

- Signal : μ- +(A,Z) → e- +(A,Z)
  - Mono-energetic, single, delayed electron
    - Mono-energetic: 105 MeV
    - Delayed: ~1μS
    - No accidental Background
- Major Backgrounds
  - Muon Decay in Orbit (MDO)
    - Ee < 102.5 MeV (BR:10^{-14})
    - Ee < 103.5 MeV (BR:10^{-16})
  - Beam Pion Capture
    - π-+(A,Z) → (A,Z-1)* → γ+(A,Z-1)
      γ → e+ e-
    - Prompt Timing
- Discriminating signal from backgrounds
  - T_e > 300 ns
  - E_e > 102.5 MeV

SINDRUM II



BR < 7 × 10^{-13}

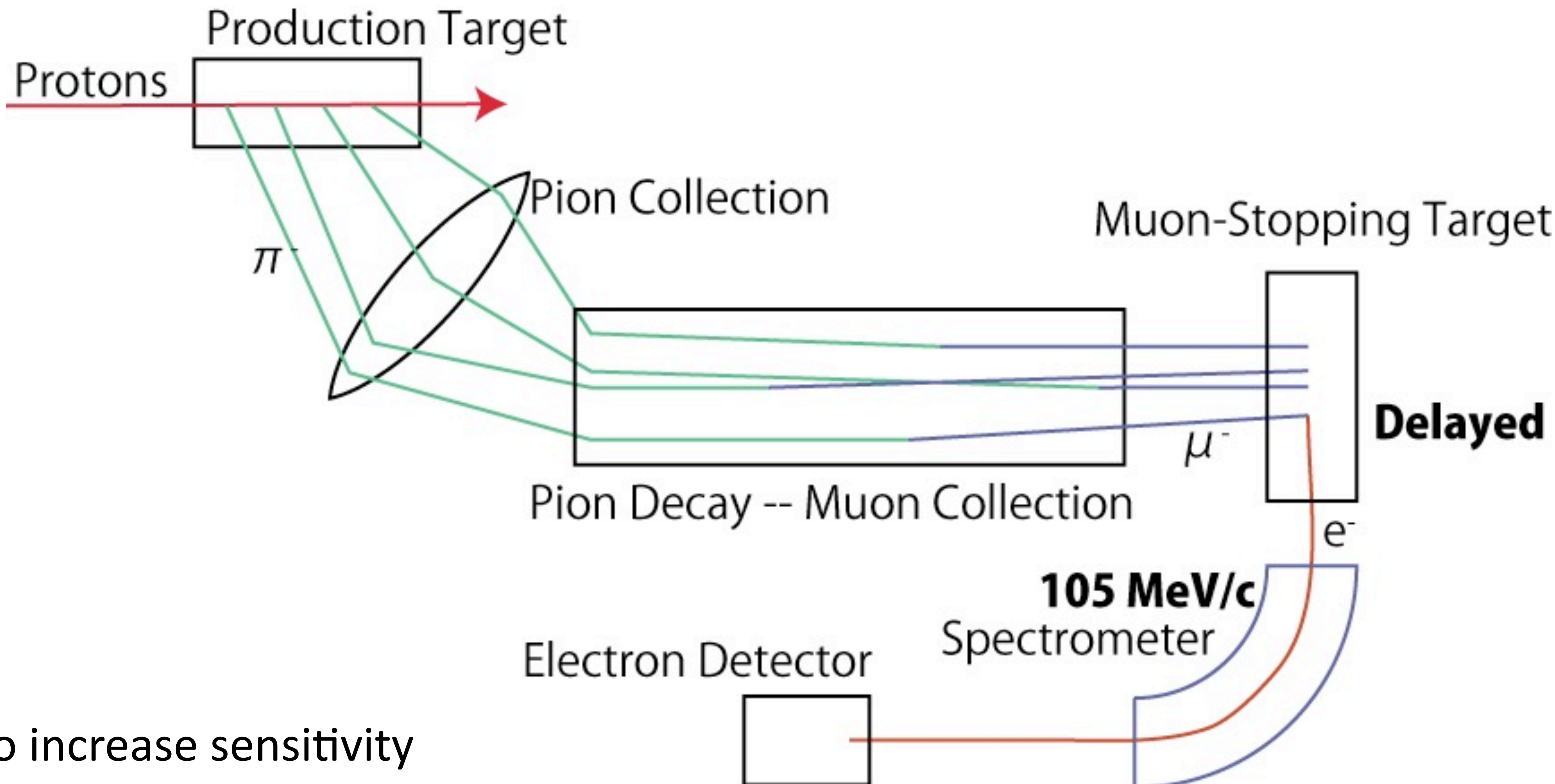
Recent Upper Limits

SINDRUM-II: BR[μ^- + Au → e^- + Au] < 7 × 10^{-13}

SINDRUM-II: BR[μ^- + Ti → e^- + Ti] < 4.3 × 10^{-12}

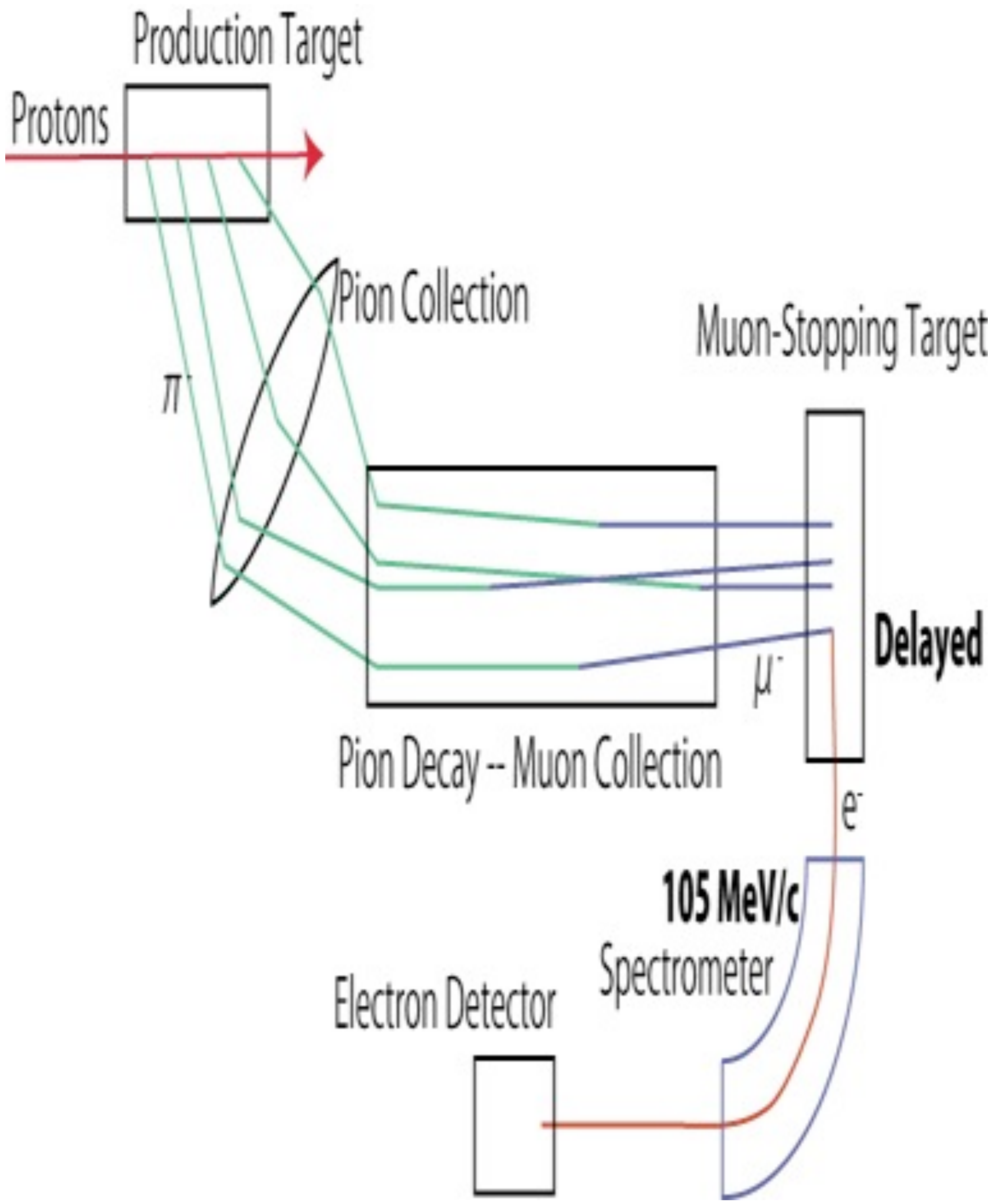
TRIUMF: BR[μ^- + Ti → e^- + Ti] < 4.6 × 10^{-12}

Generic Scheme of the Measurement

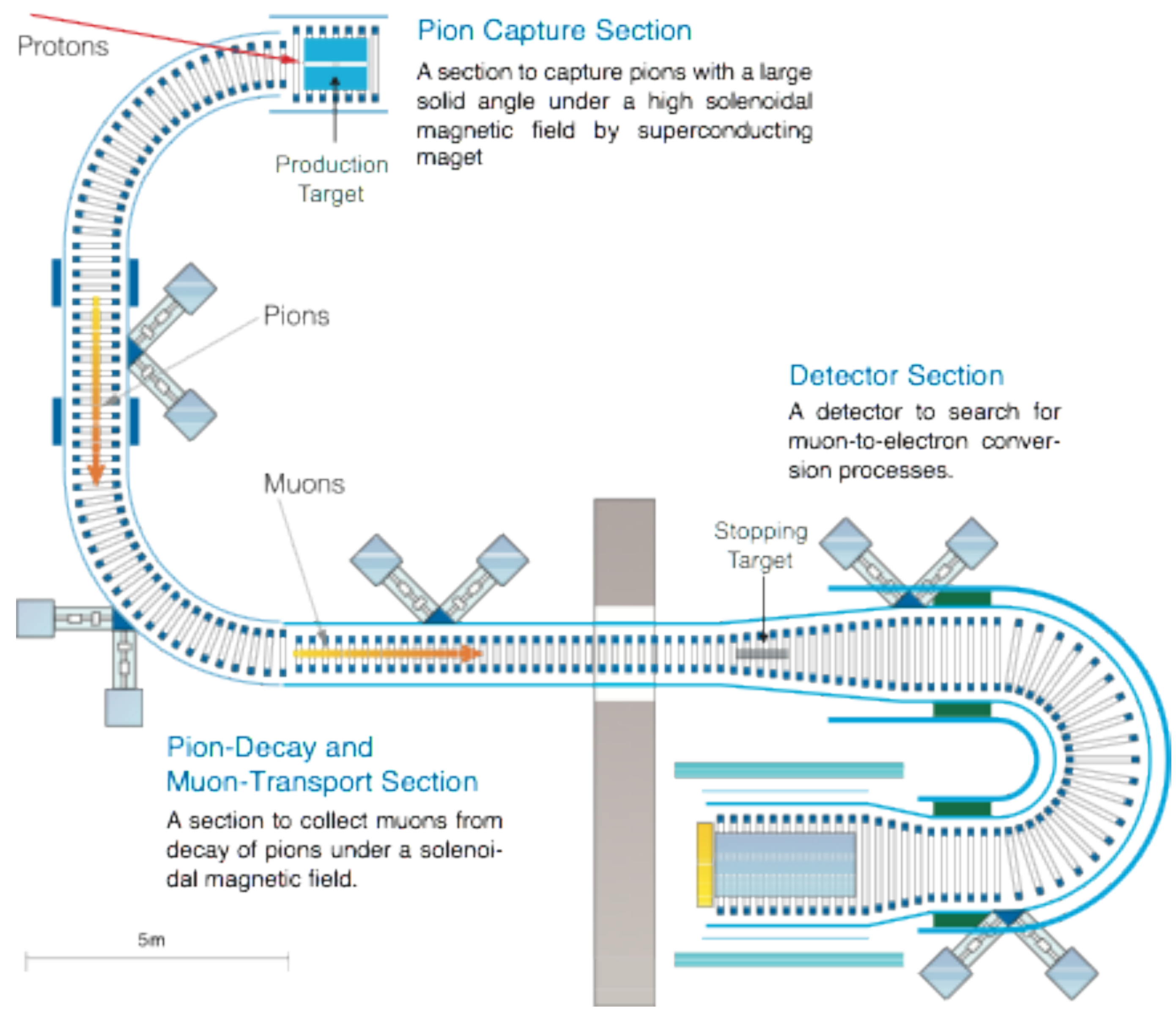


- To increase sensitivity
  - Collect μ^- as much as possible
- Suppress Backgrounds
  - Pulsed Proton Beam
  - Good momentum resolution.

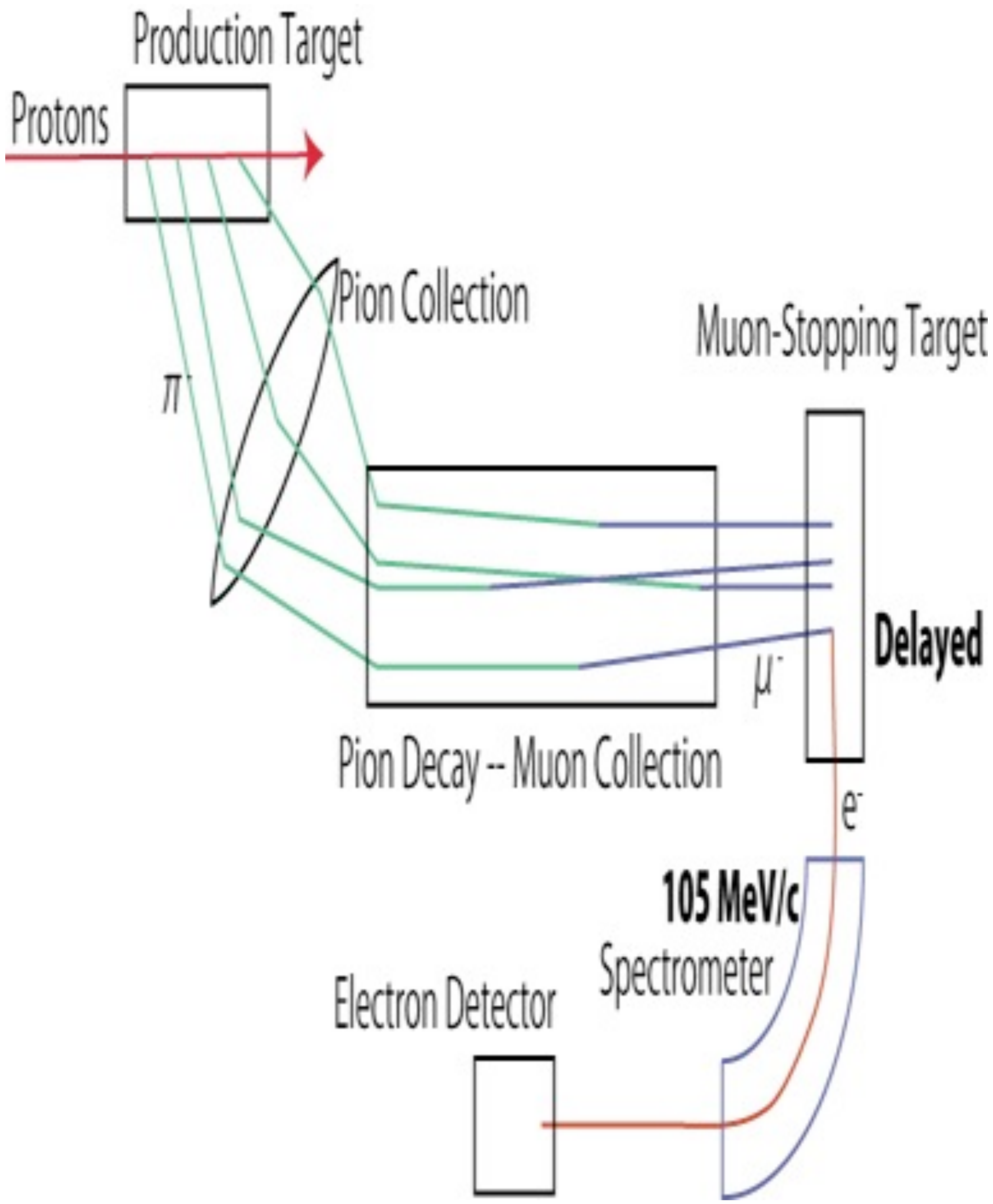
COMET @ J-PARC/MR

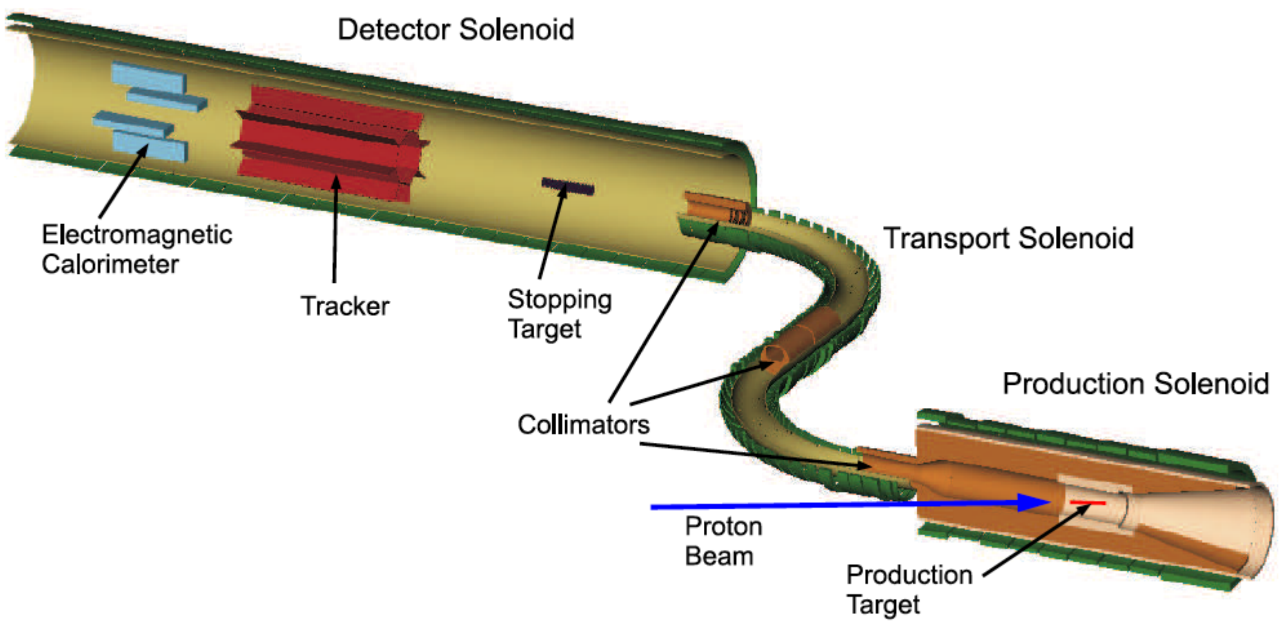


COMET: BR[Al] < 10^{-16}



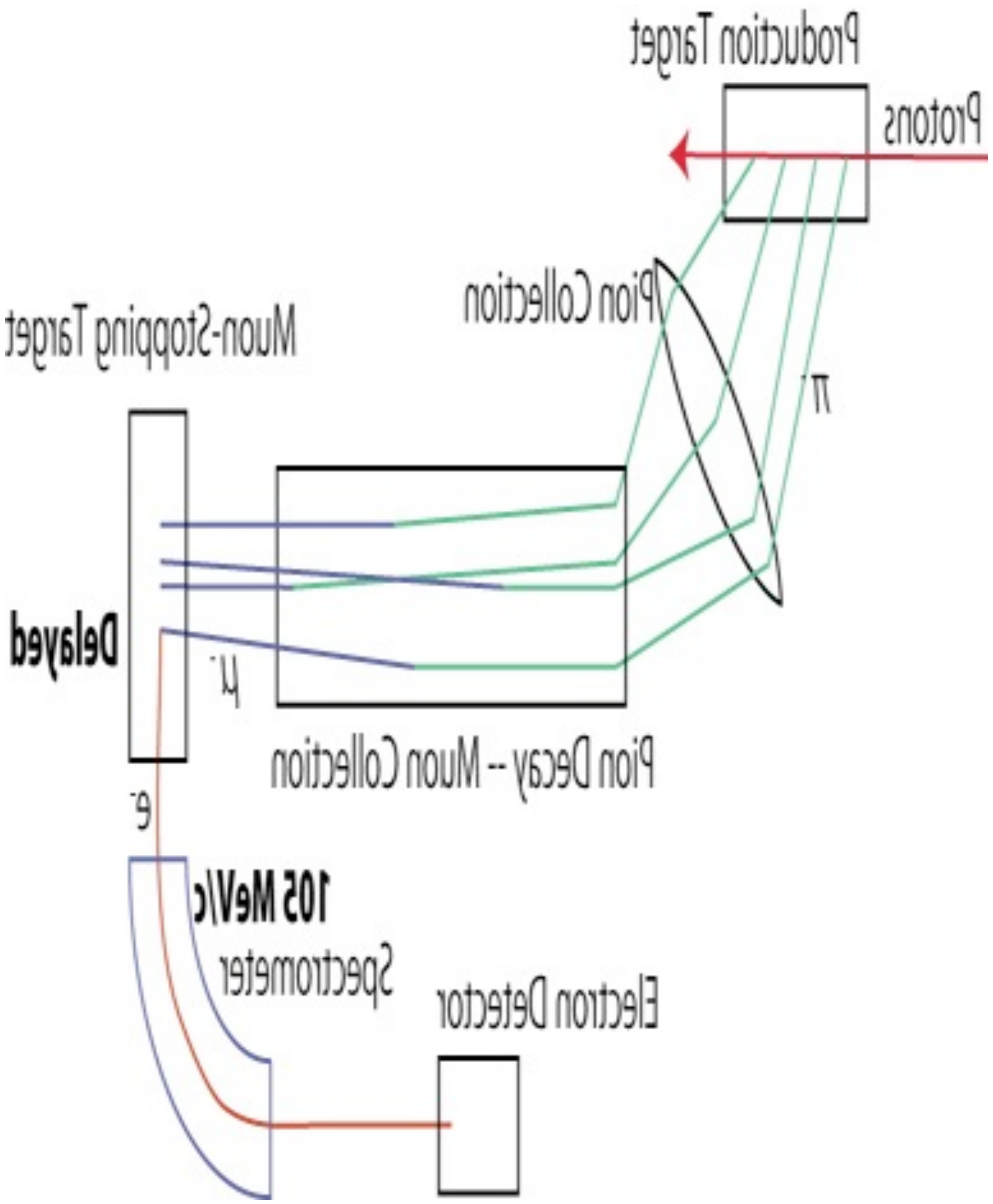
Mu2E @ Fermi Lab

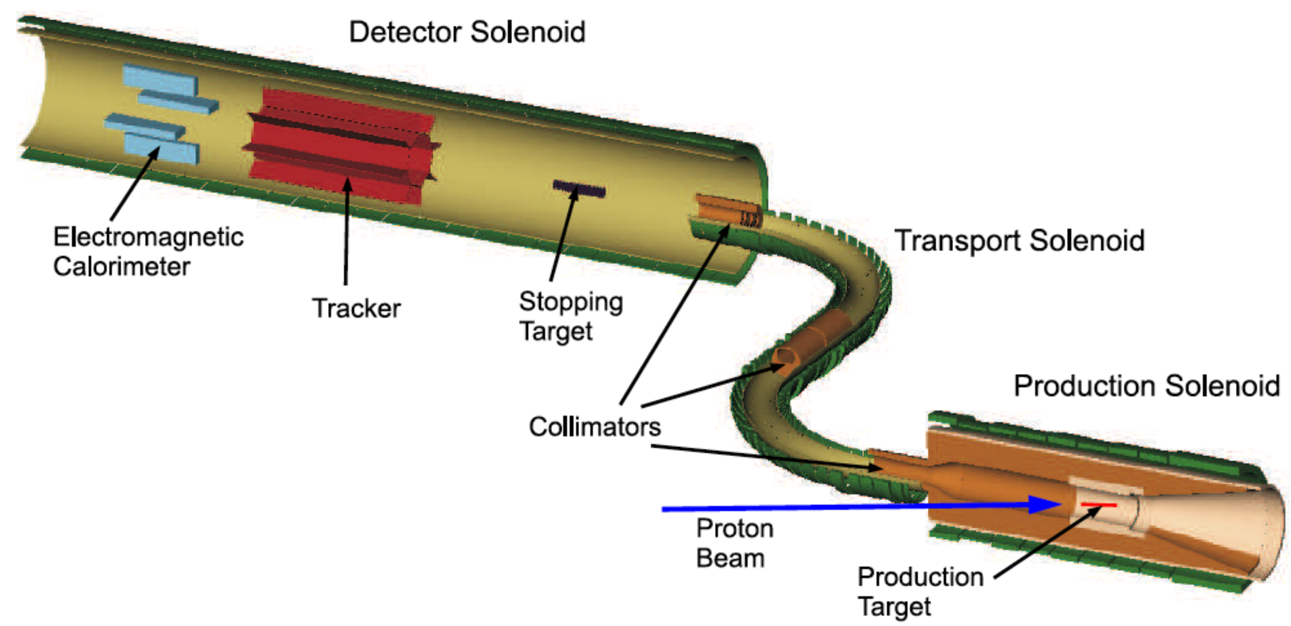




Mu2E: BR[Al] < 10^{-16}

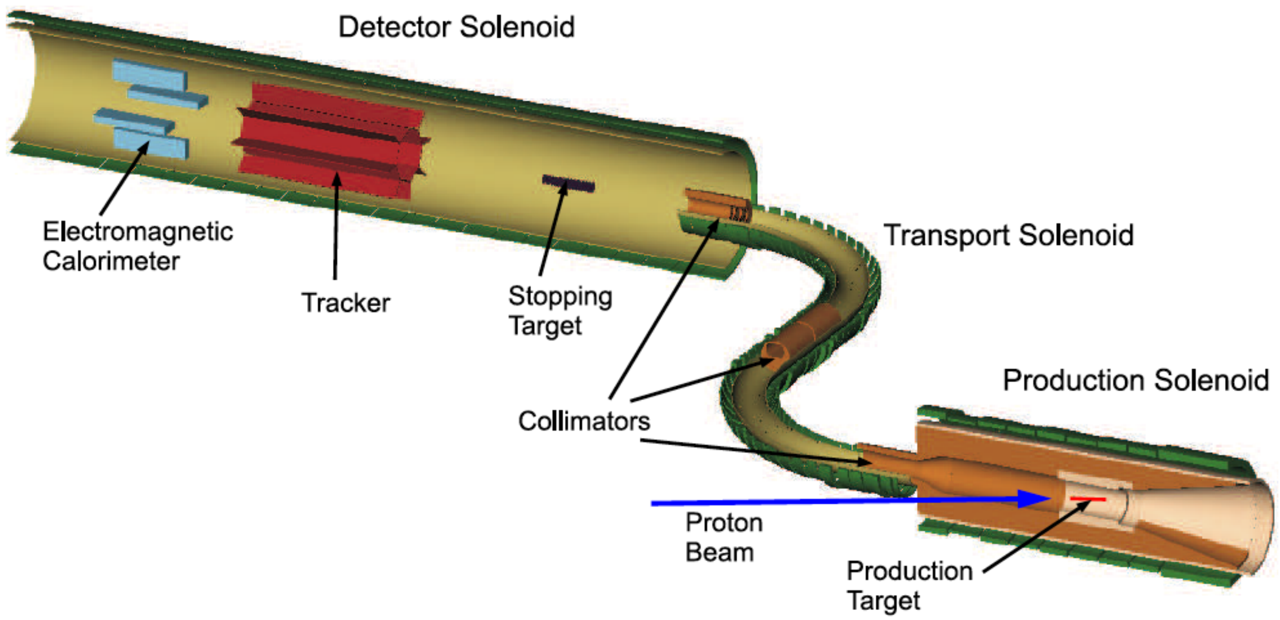
Mu2E @ Fermi Lab

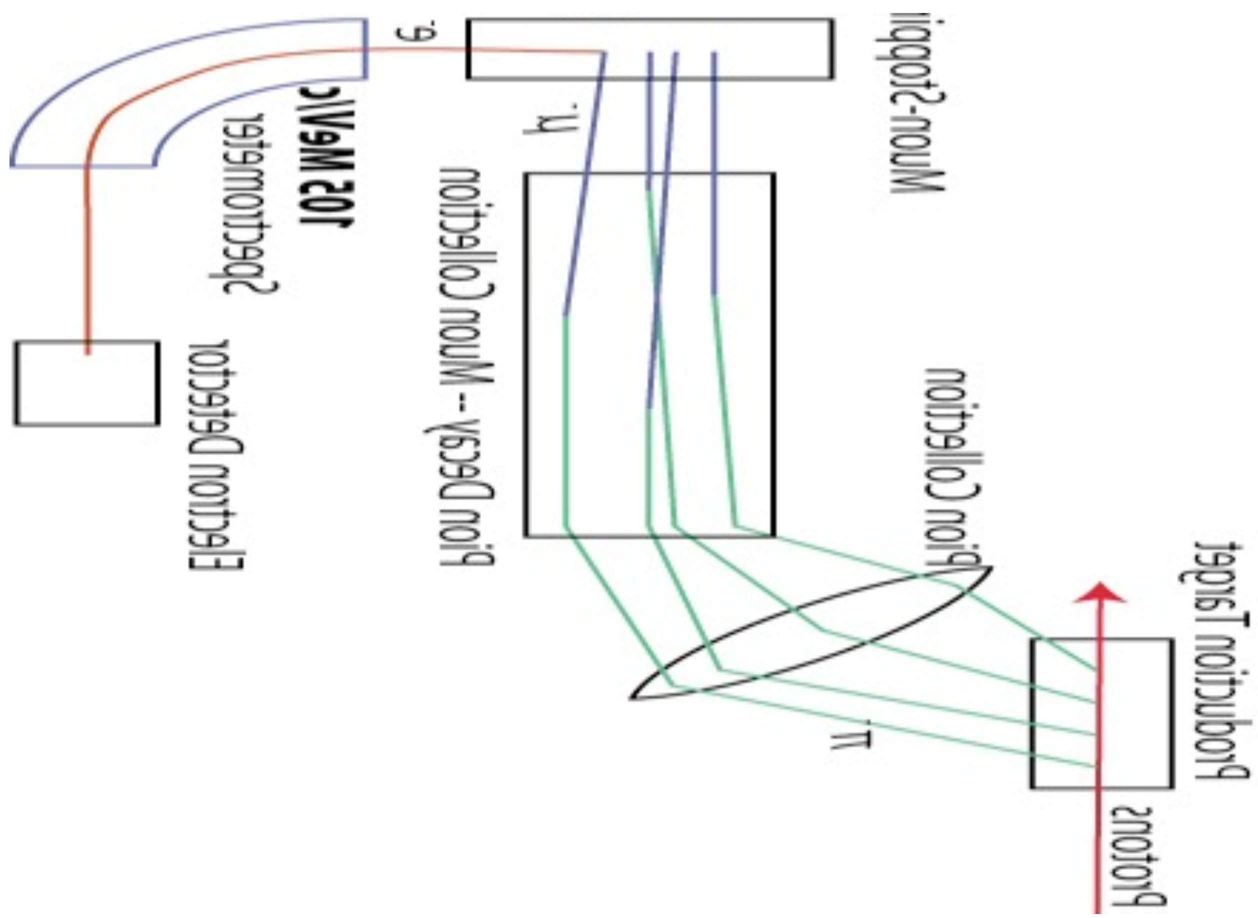




Mu2E: BR[Al] < 10^{-16}

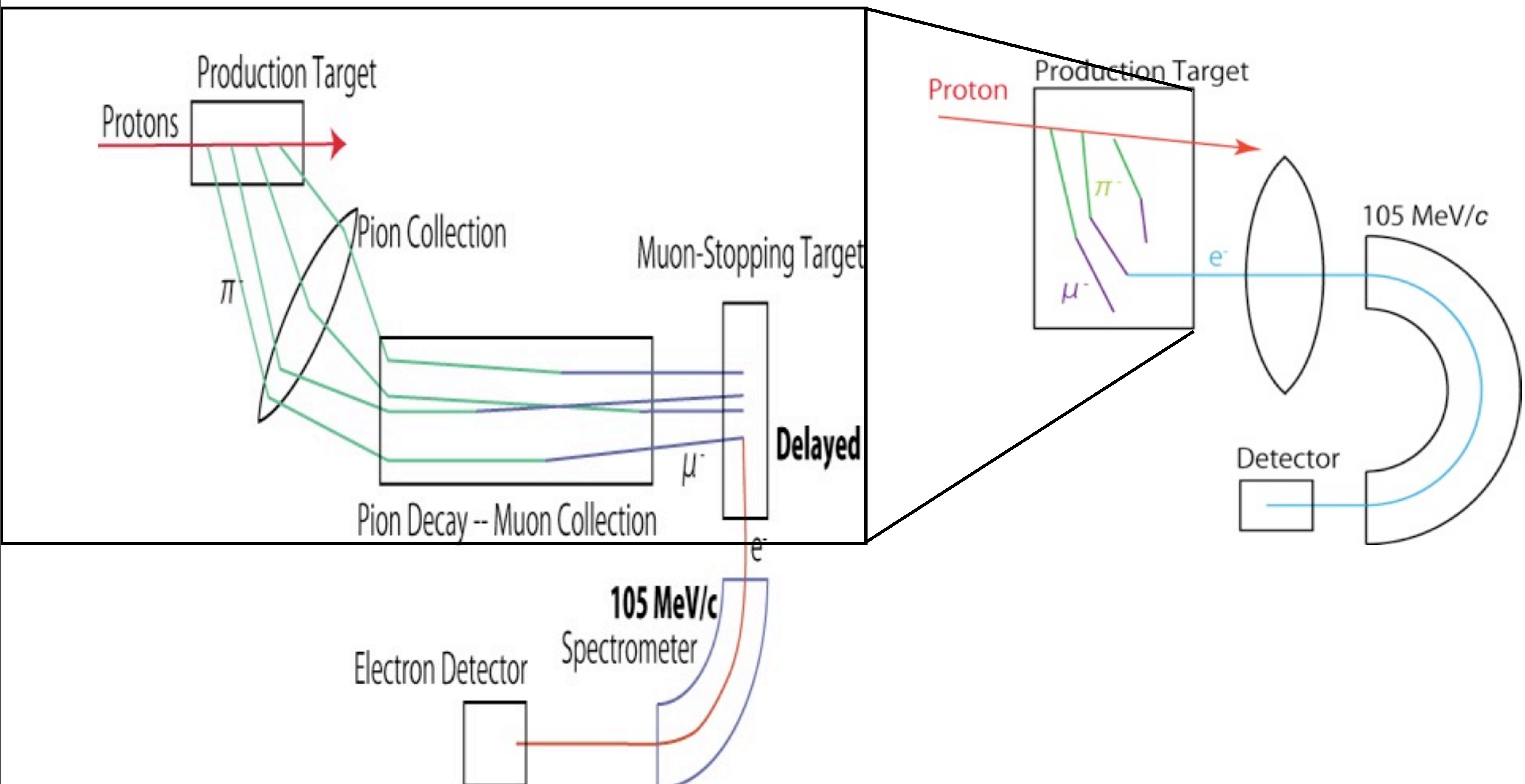
Mu2E @ Fermi Lab





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

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



an electron analogue of the surface muon.

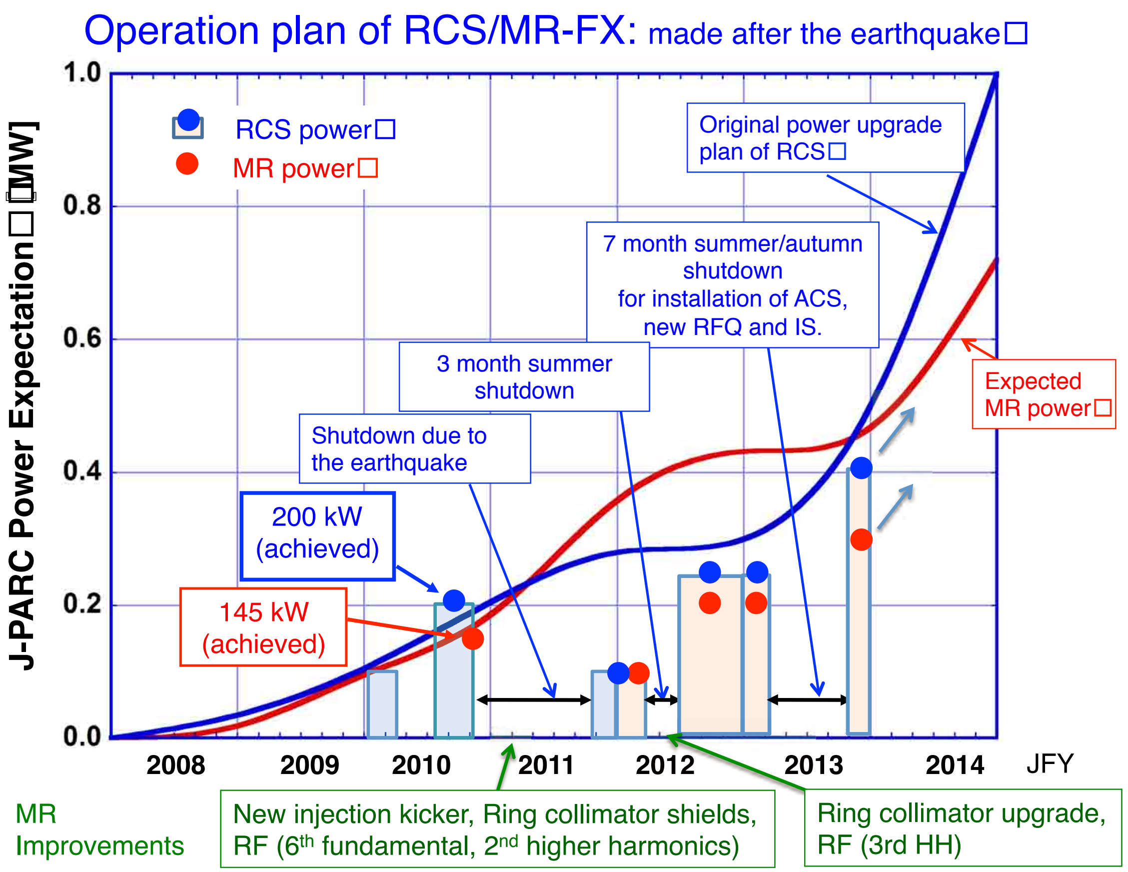
Experiment could be very simple, quick and low-cost.

Test Measurement

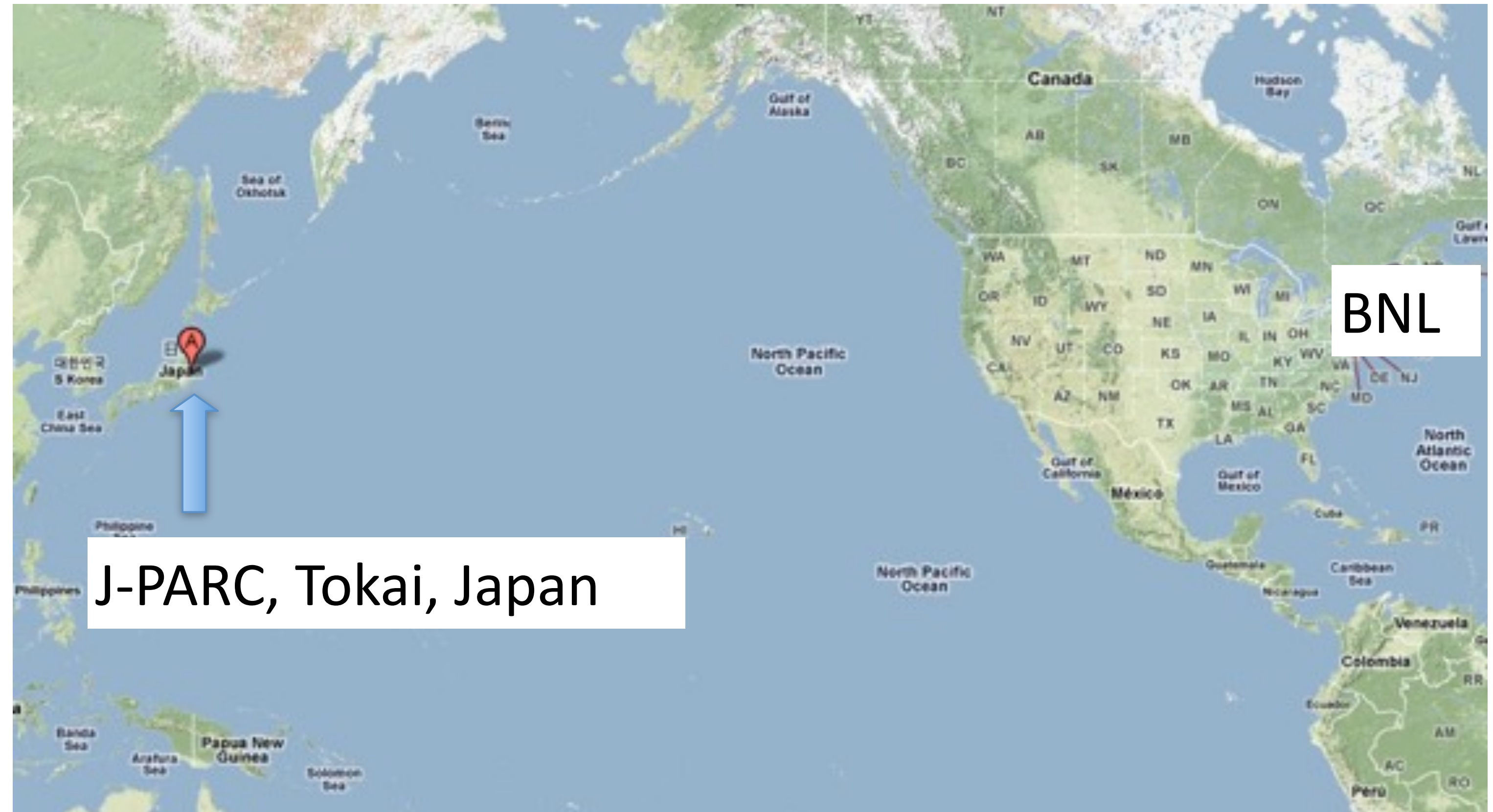
How many μ^- are actually stopping in the production target?

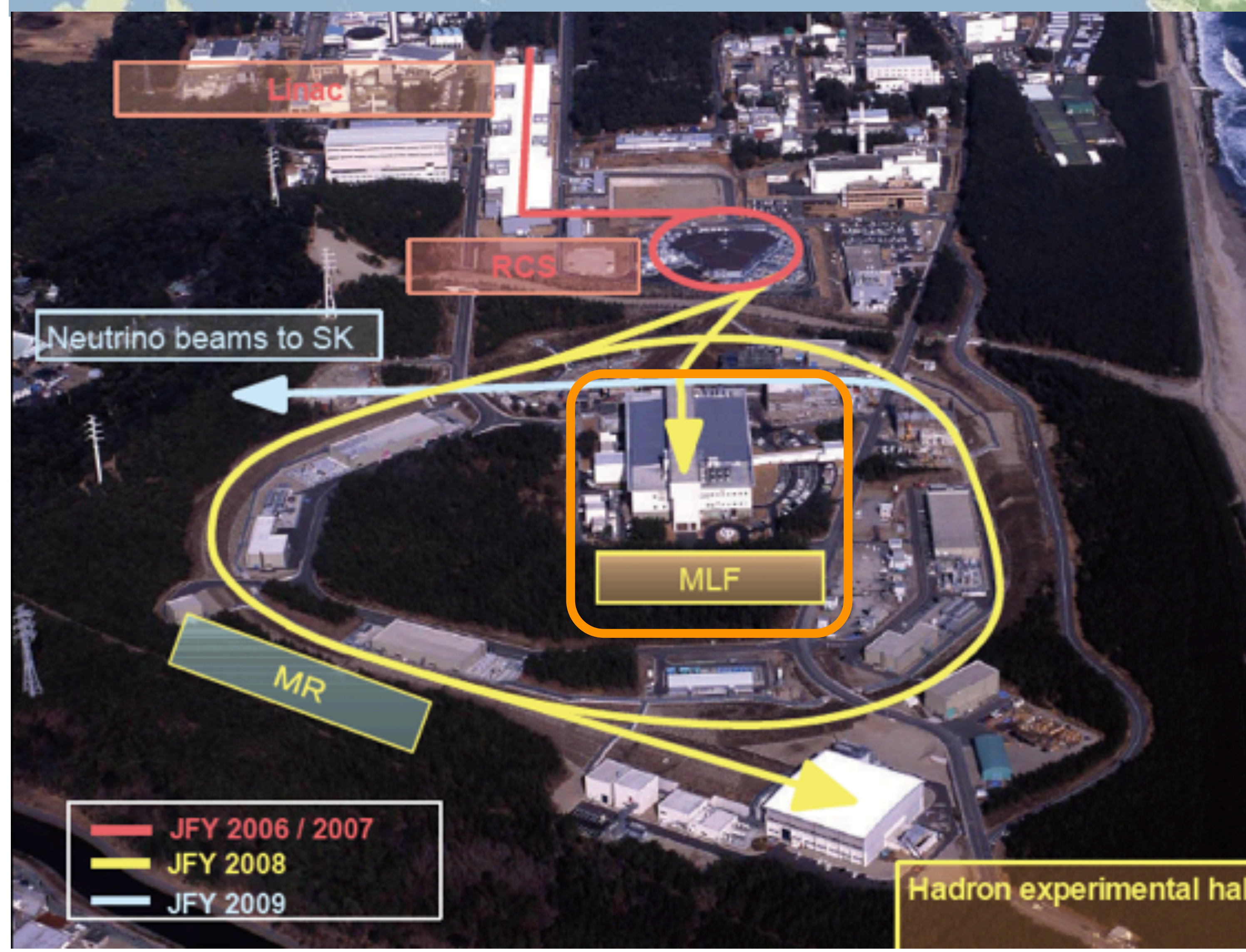
J-PARC

- LINAC
  - H^-, 400 MeV, 50 mA
  - 50 Hz
- RCS
  - 3 GeV, 333 μA, 1MW
  - 25 Hz, Fast Extraction
  - Material and Life-science Facility (MLF)
- MR
  - 30 GeV, 15 μA
  - Fast and Slow EX

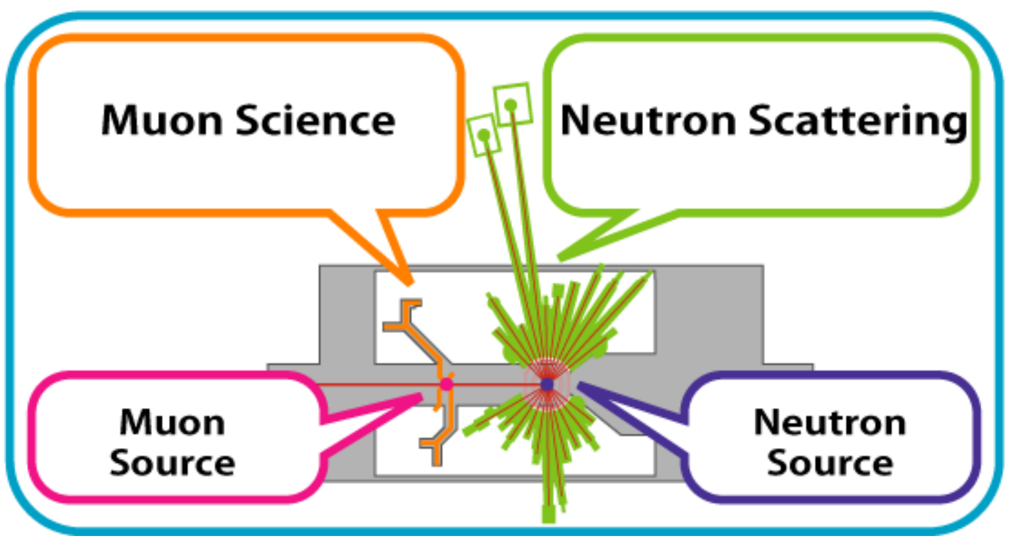


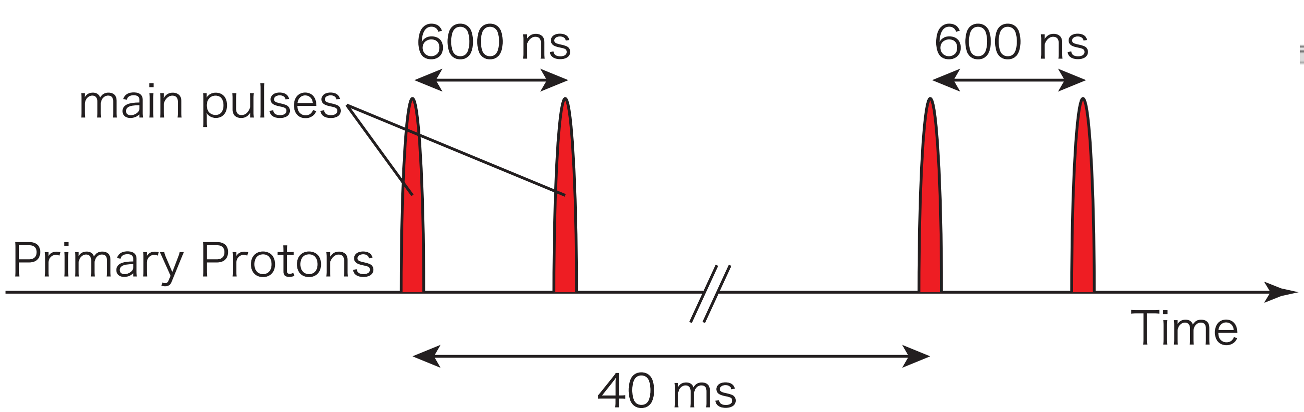
T. Koseki @J-PARC PAC presentation

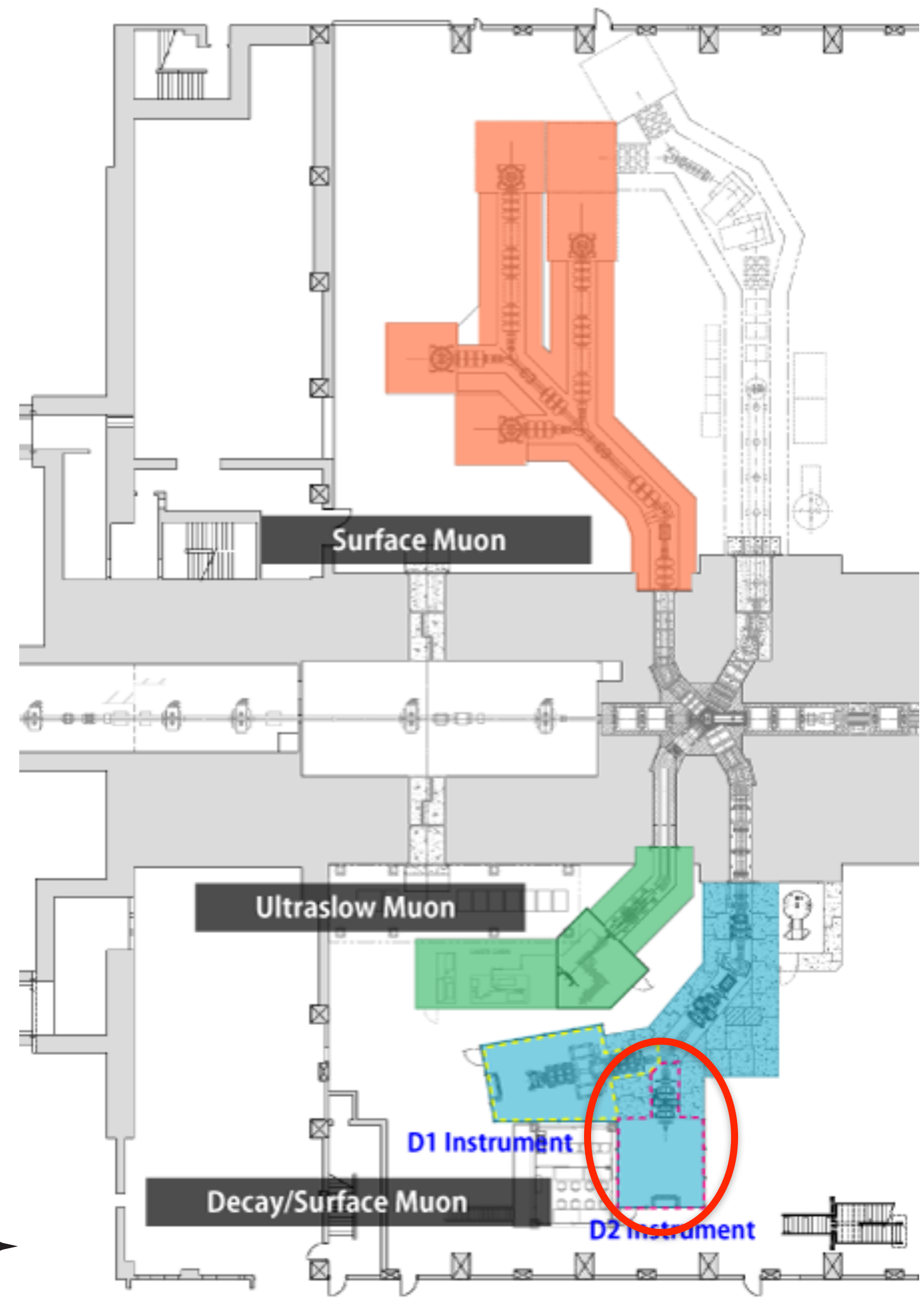




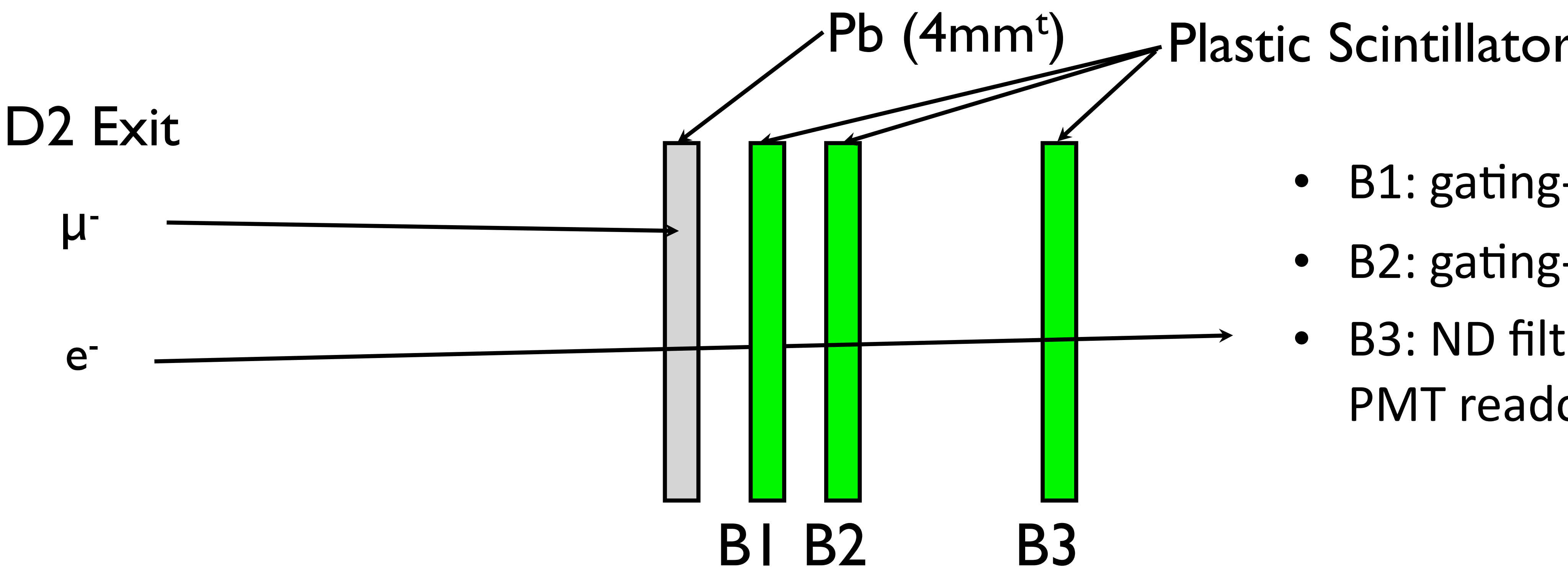
J-PARC MLF Muon Facility







Counters at the exit of D-Line



- B1: gating-PMT readout
- B2: gating-PMT readout
- B3: ND filter (1/1000), normal PMT readout

•Count only after the prompt beam-burst (>10^4/pulse).

•Can't close a beam slit to reduce the beam rate. Otherwise, it takes forever to accumulate the enough number of events.

➡use gating-PMTs that can be turned-off during the prompt beam-burst.

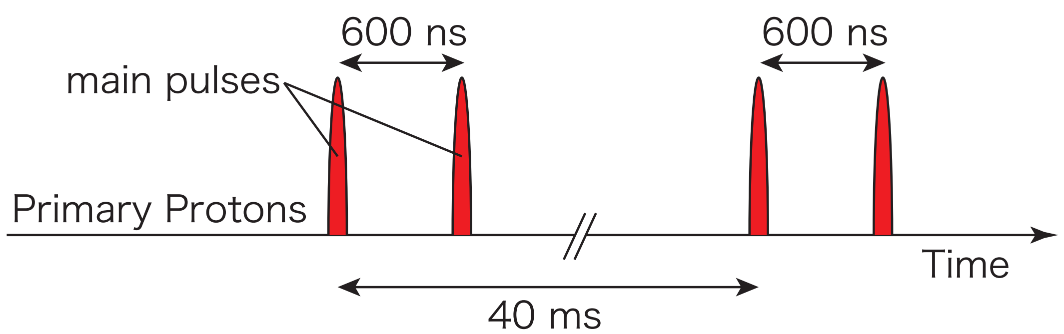
•Beam μ$^-$ will produce delayed hits if they stop in the plastic scintillator.

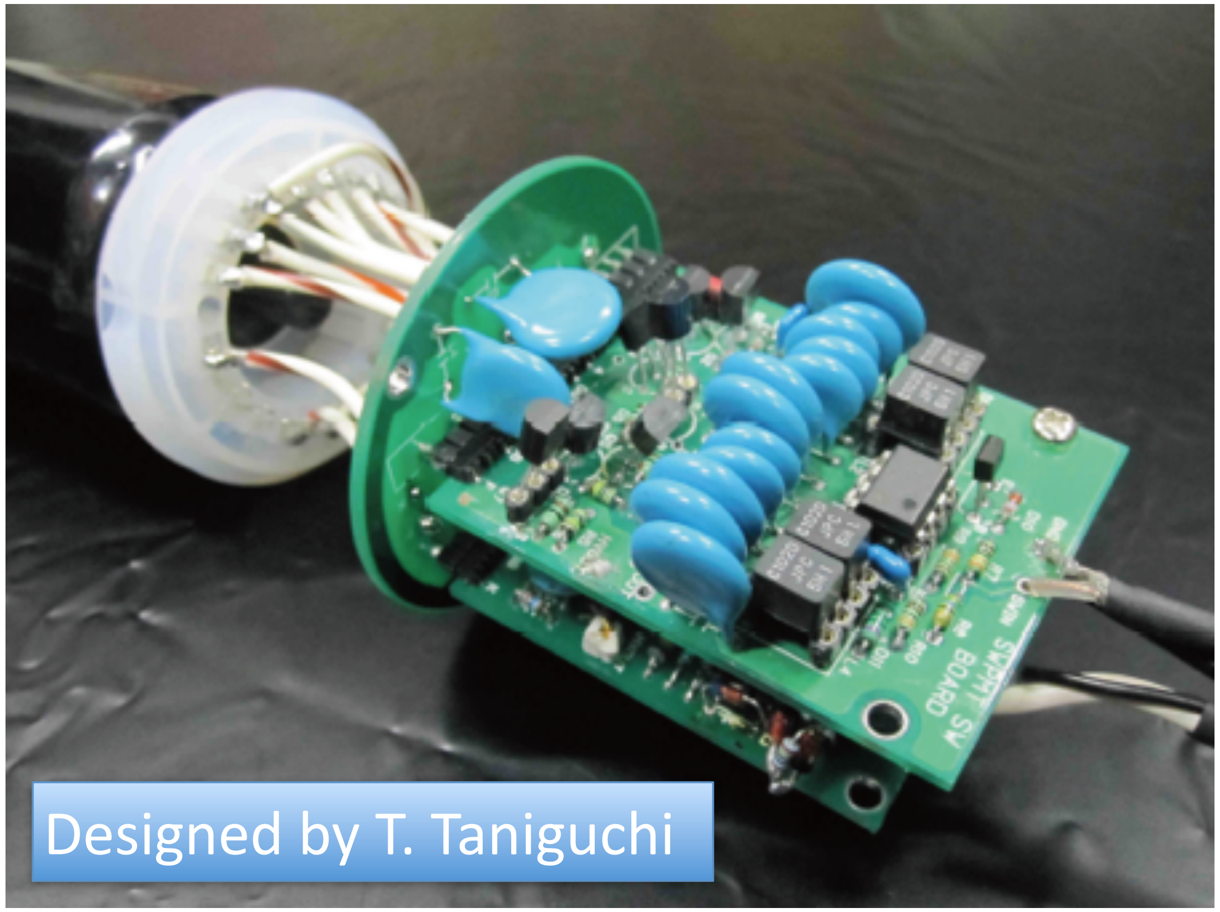
➡Pb plate to absorb μ$^-$

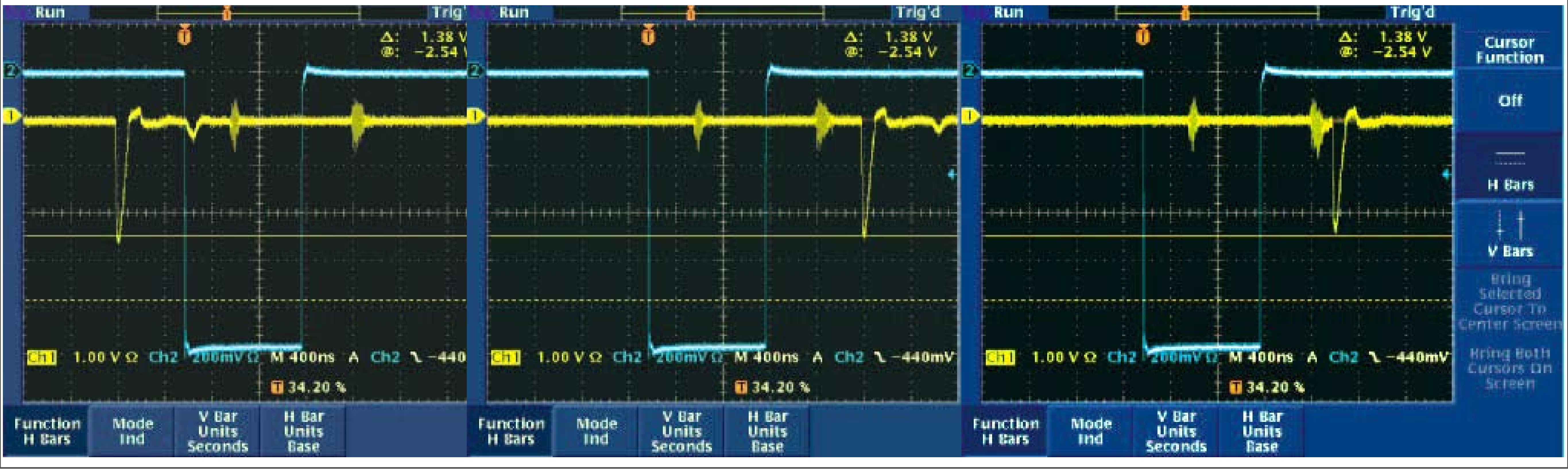
➡Electron detection efficiency ~ 50% @ 40 MeV/c

gating PMT

- No. of prompt burst: ~1e4
- Standard PMT will be blinded.
- a gating-PMT developed for COMET
  - off/on gain ratio = 1e-6

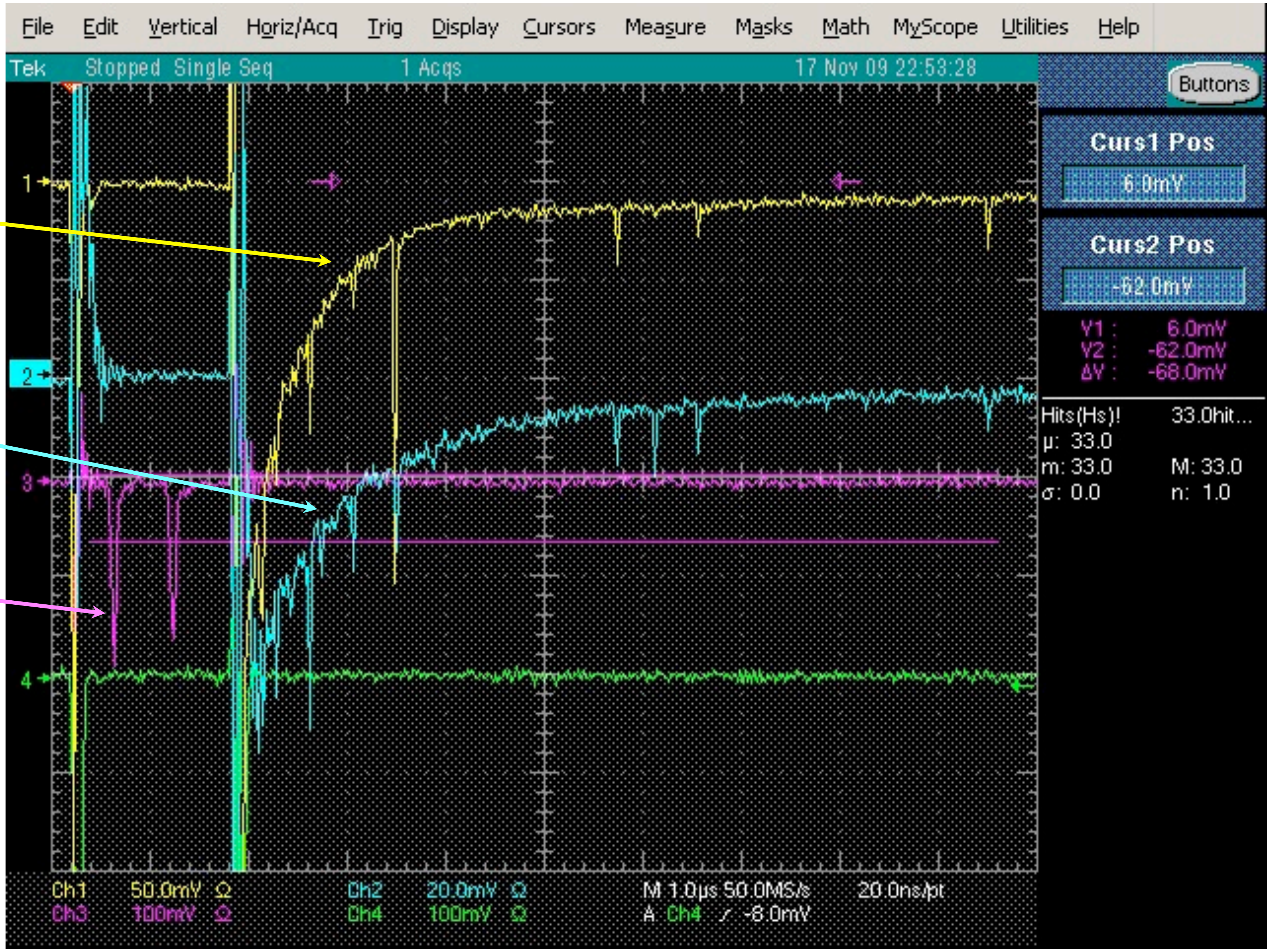






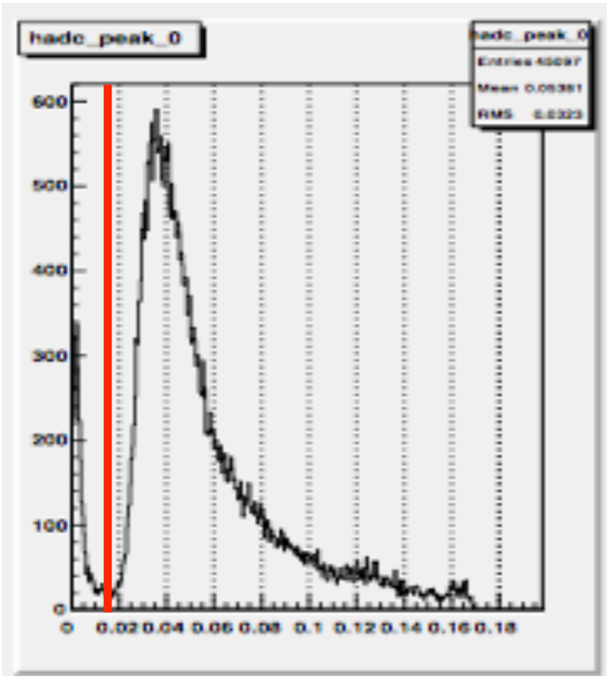
Signals taken by gating-PMT

- B1
- Plas. Scinti.
- gating
- B2
- Plas. Scinti.
- gating
- B3
- Plas. Scinti.
- normal PMT
- ND filtered

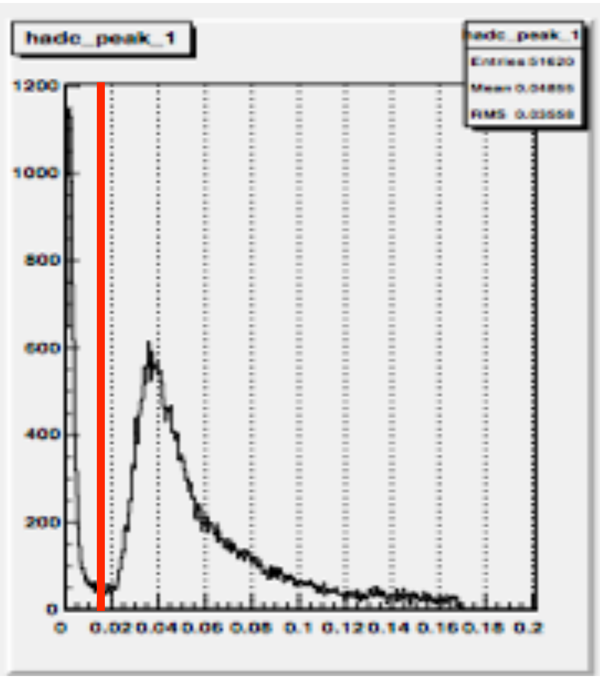


The baseline of the signal is not flat owing to the delayed fluorescence background, but individual hits are clearly observed as spikes on the baseline.

Analysis

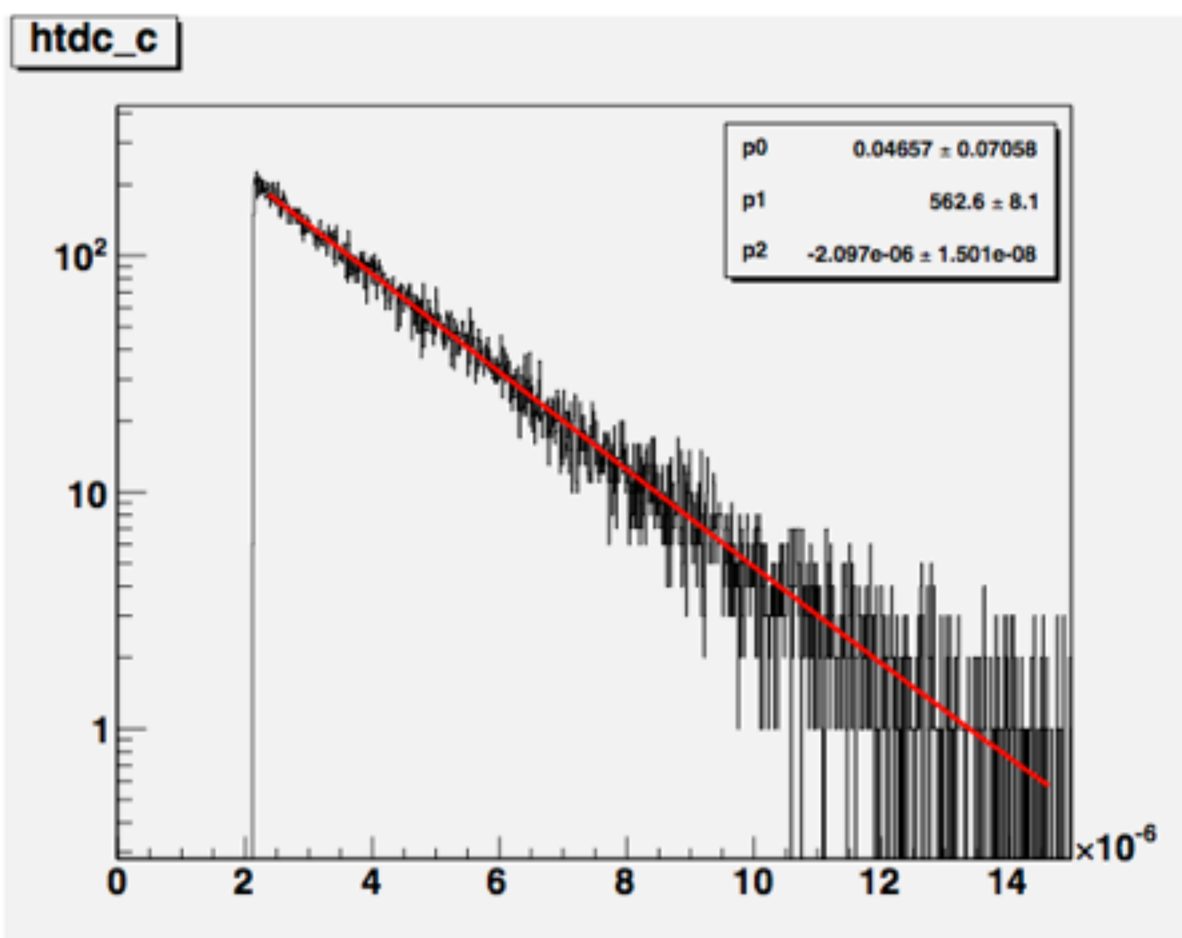


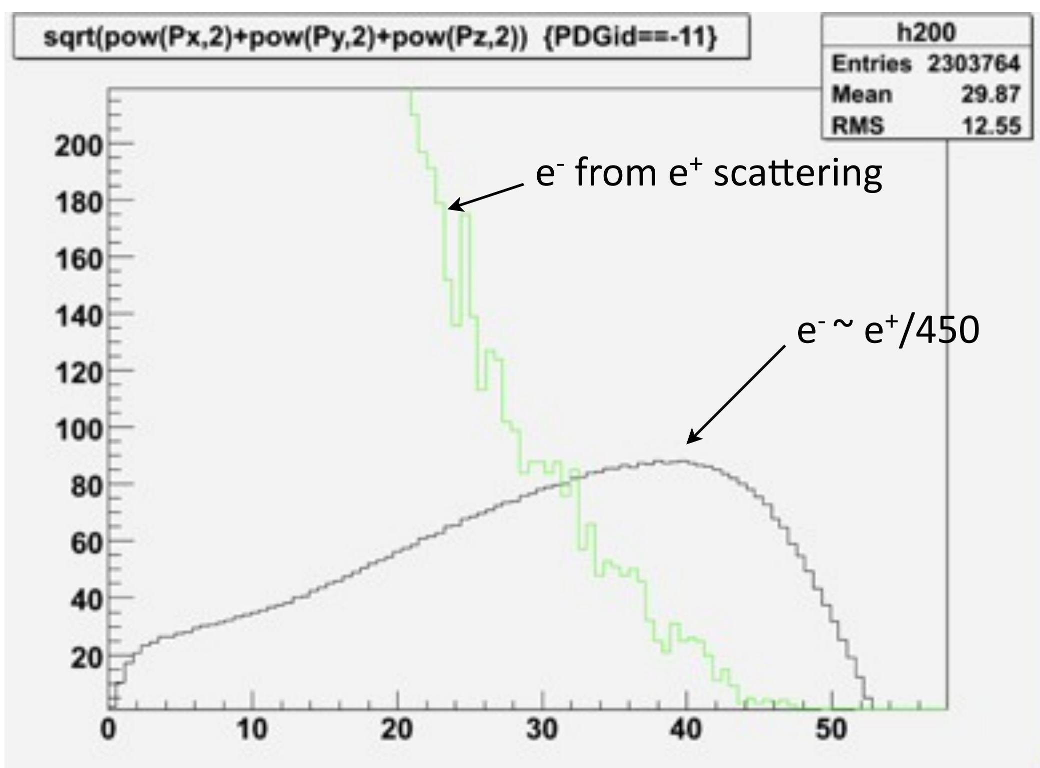
B1 pulse height
(B2 tagged)



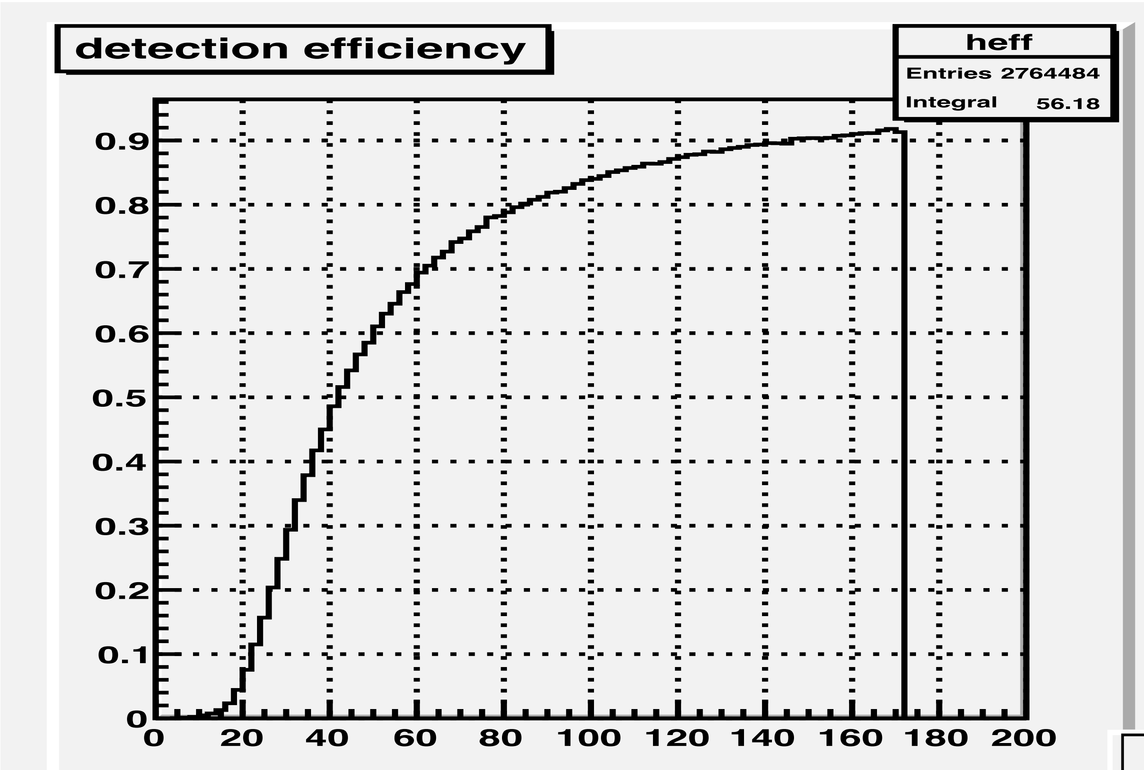
B2 pulse height
(B1 tagged)

- Record PMT signals by using500MHz FADC like E787/949.
- Subtract a baseline template from the recorded waveform.
- Maximum hight of the pulse tagged by the other counter shows clear valley between pedestal and signal.
  - The detection efficiency is sufficient.
- Real hits by the beam particles = B1*B2
  - τ = 2.10±0.02 μs
  - Combination of τ_{μ^+}(2.2μs) and $\tau_{\mu^- - C}$(2.0μs). There is a contamination coming from e^- produced by e^+ scattering where the e^+ is from Michel decay of μ^+ in the target. The number of stopped μ^+ is 450 times more than that of μ^-.

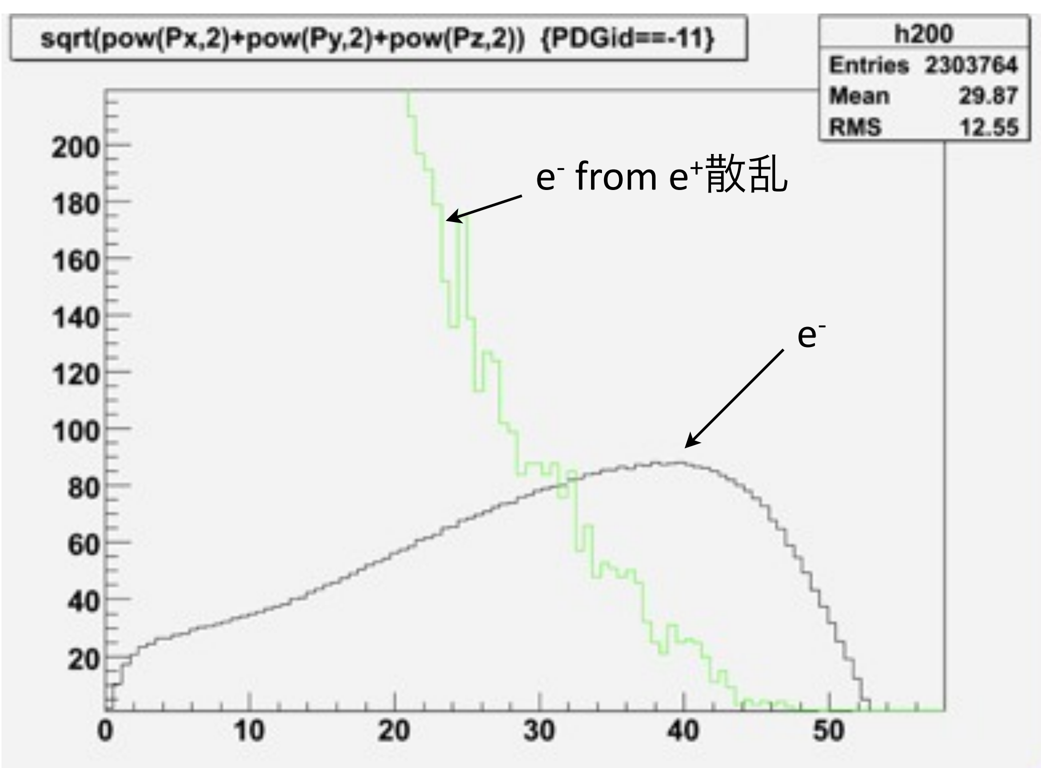


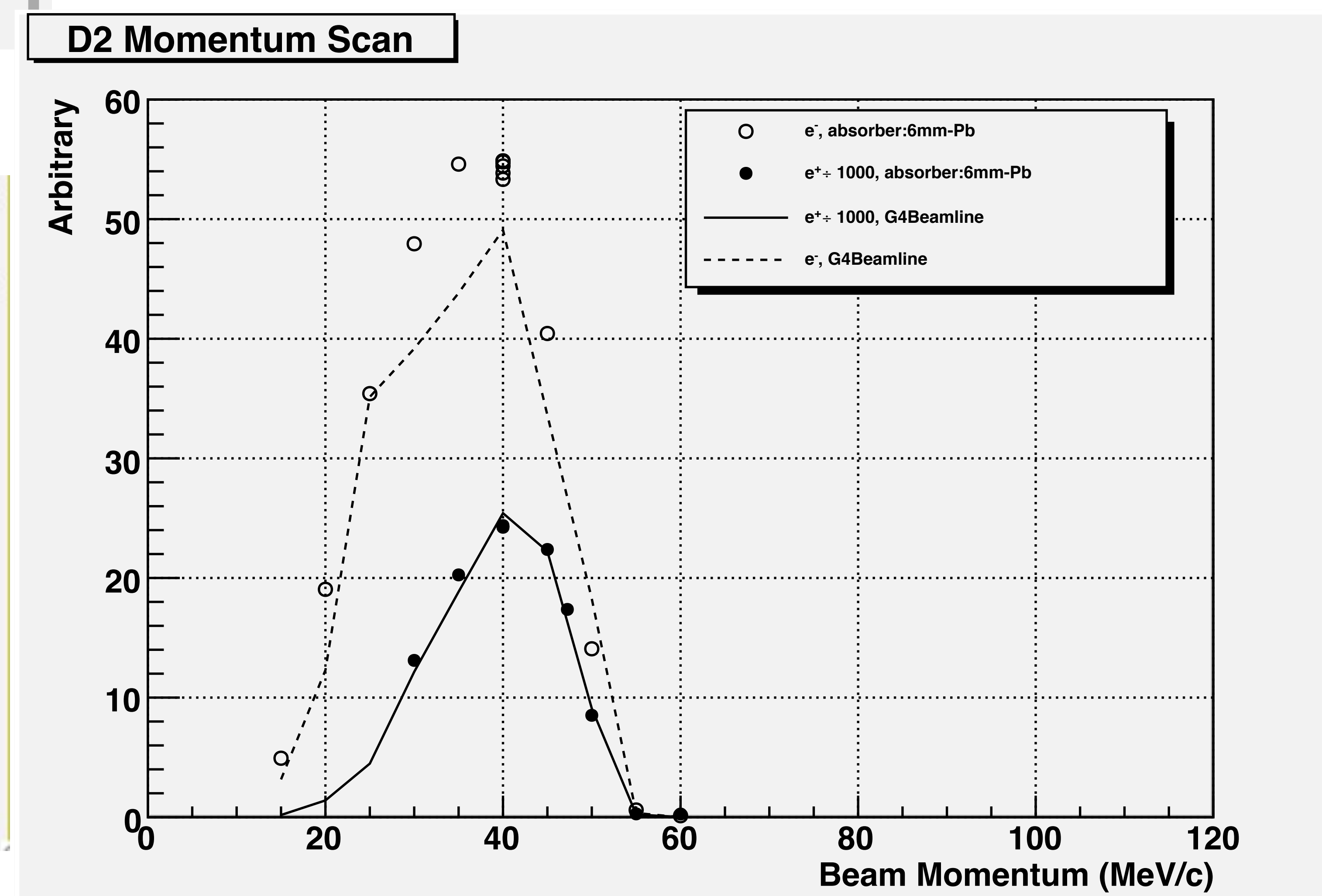


Analysis (cont.)

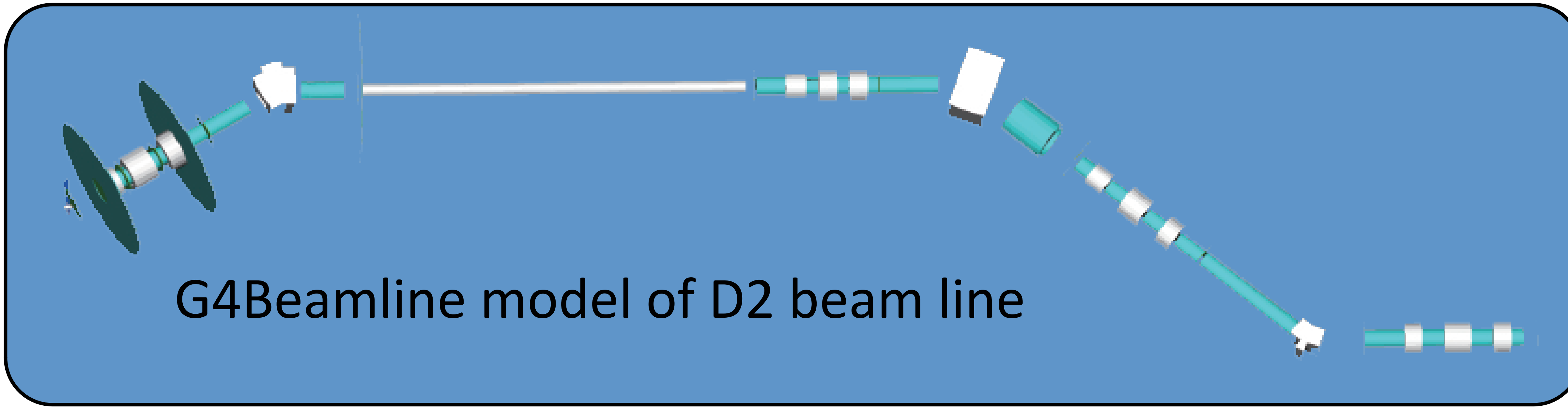


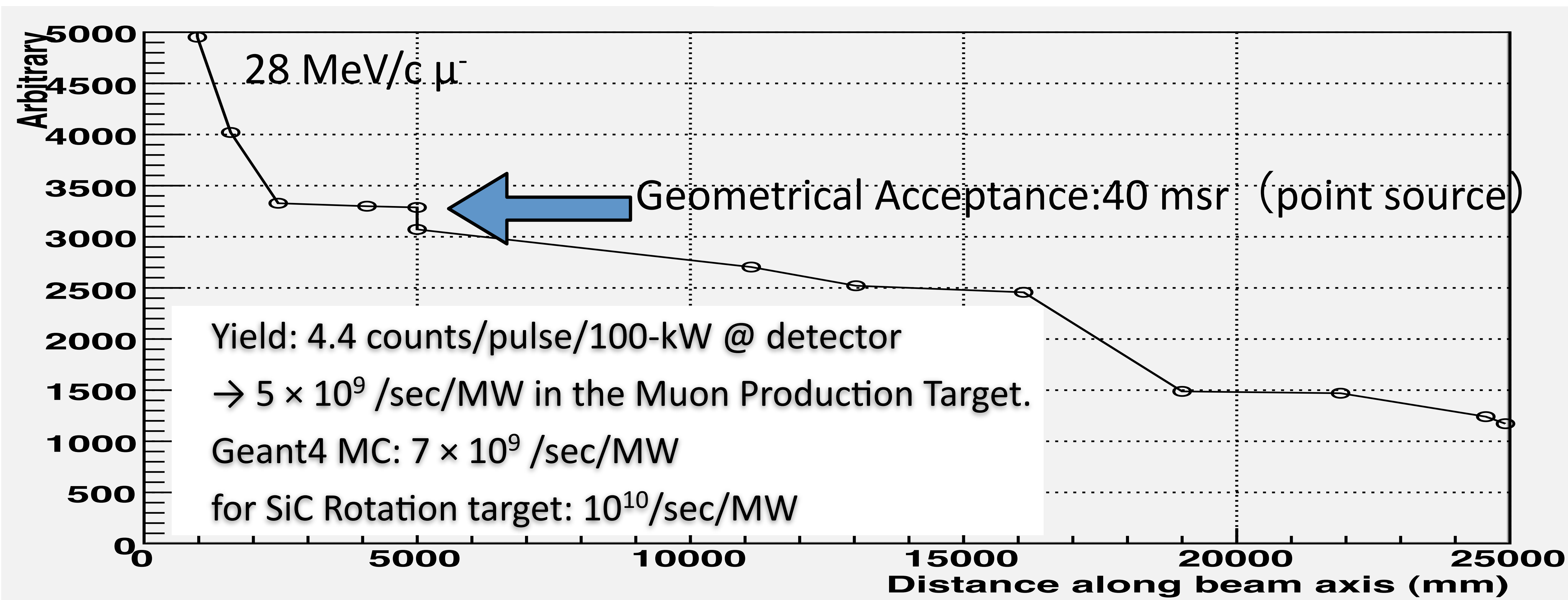
- Detection efficiency is not flat due to the Pb absorber.
- p_e > 40 MeV/c: dominated by e^- from μ^- decay.
- p_e ~ 50 MeV/c: The edge is certainly from the Michel Edge. Not from the e^+-scattered e^-.
- p_e < 30 MeV/c: dominated by e^- from μ^+ decay.





G4Beamline Estimation





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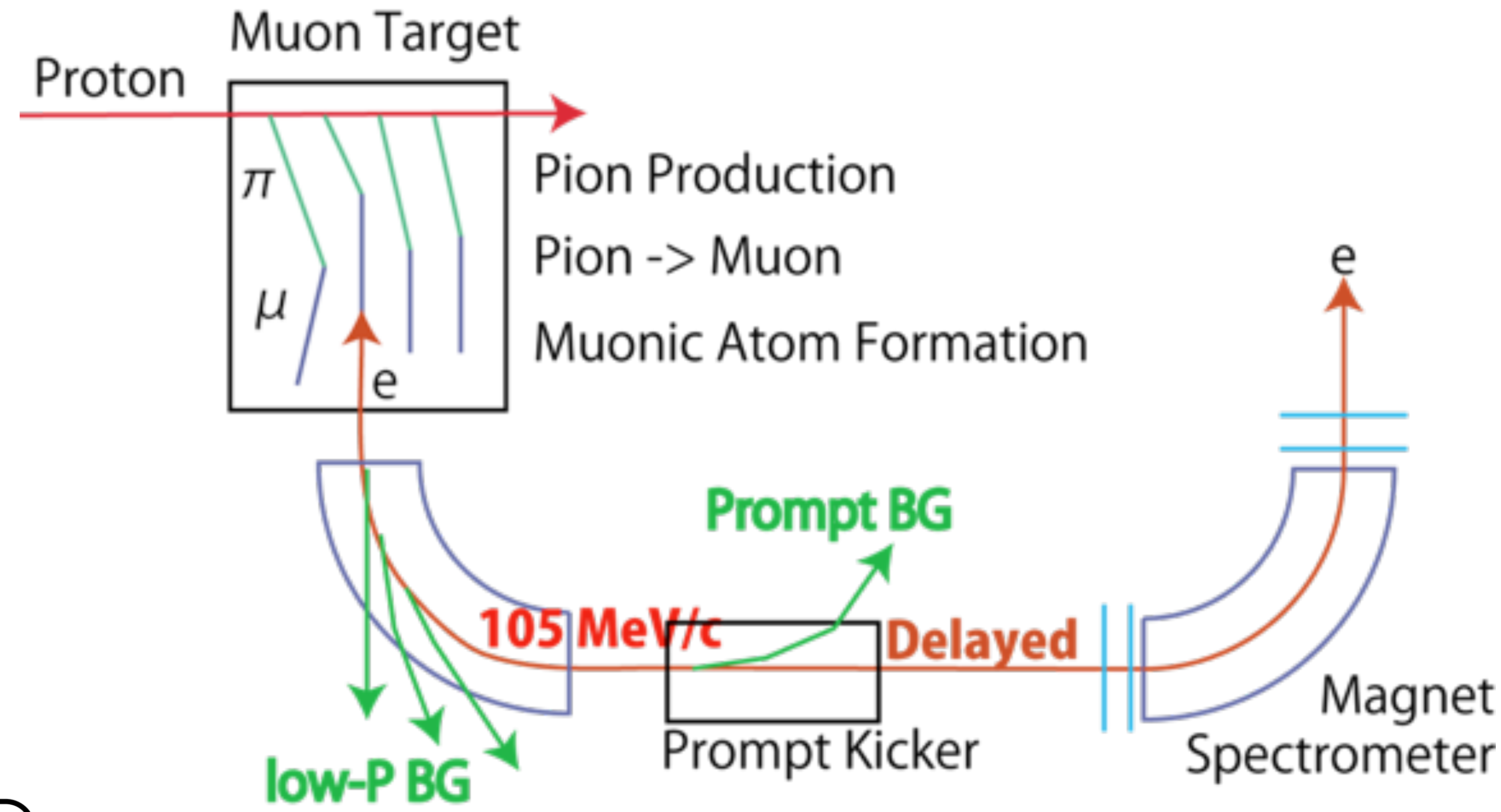
Design of DeeMe

DeeMe Collaboration

- Osaka U.
  - M. Aoki
- KEK
  - MUSE: Y. Miyake, K. Shimomura, N. Kawamura, P. Strasser
  - Accelerator: M. Kinsho, K. Yamamoto, P.K. Saha, H. Kobayashi, H. Matsumoto, C. Ohomori, M. Ikegami, M. Yoshii
  - IPNS: S. Mihara, H. Nishiguchi, K. Yoshimura, N. Saito, T. Mibe
- UBC
  - D. Bryman
- TRIUMF
  - T. Numao

DeeMe



- 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 (Δp < 0.3%)
- Main pulse:
  Kicker to reduce the detector rate.
- after-protons:
  Suppressed owing to the extremely small after-protons from J-PARC/RCS: $R_{AP} < 10^{-17}$.

Design Policy of DeeMe

- Beamline
  - In order to achieve the maximum sensitivity, we need a large-acceptance beamline. Construct a new large-acceptance beamline at H-port of MLF Muon facility.
  - This H-Line can be shared with other experiments such as muon g-2, muonium hyper fine splitting measurement and so on. It is actually “a multi purpose beamline”, and the cost performance is very high.
- SiC rotation target
  - The physics sensitivity of carbon is not high.
  - Replace the current carbon rotation target with Silicon Carbide.
- Schedule
  - Better to obtain the physics result before COMET and Mu2E. Aiming to get it around 2015. Utilize the fast-pace policy for impressing the funding agency.

Physics Sensitivity

- Single Event Sensitivity: S

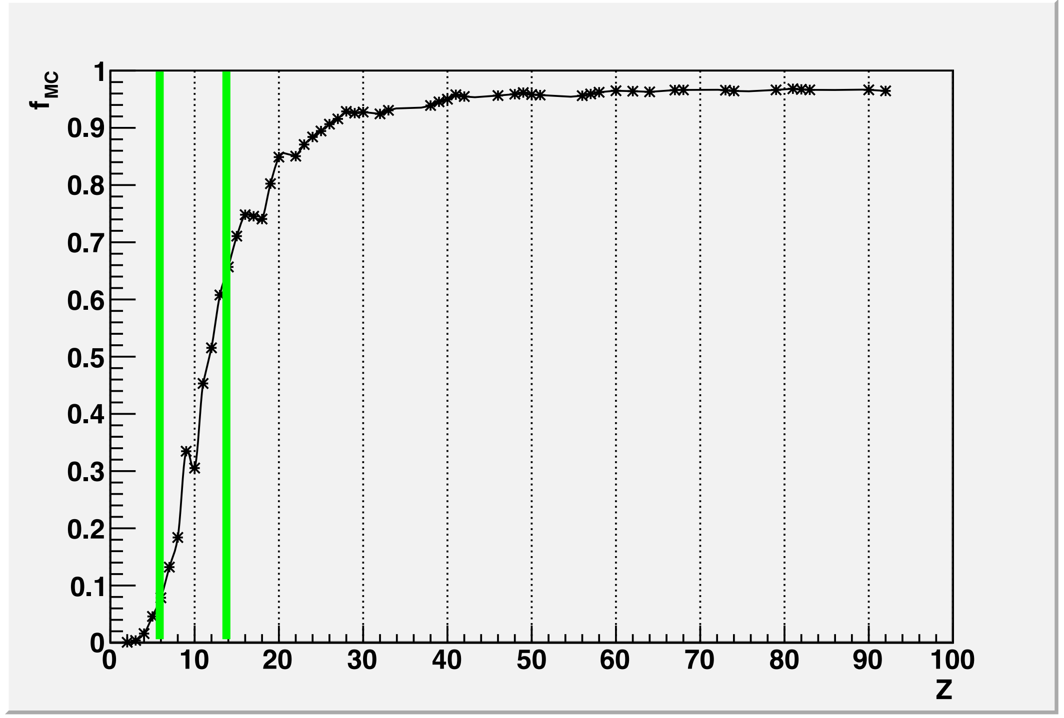
$$S = \frac{1}{N^{\mu}_{\rm obs}}$$

$$N^{\mu}_{\rm obs} = R_{\mu-{\rm stop}} \times f_{\rm C} \times f_{\rm MC} \times A_{\mu-e} \times T$$

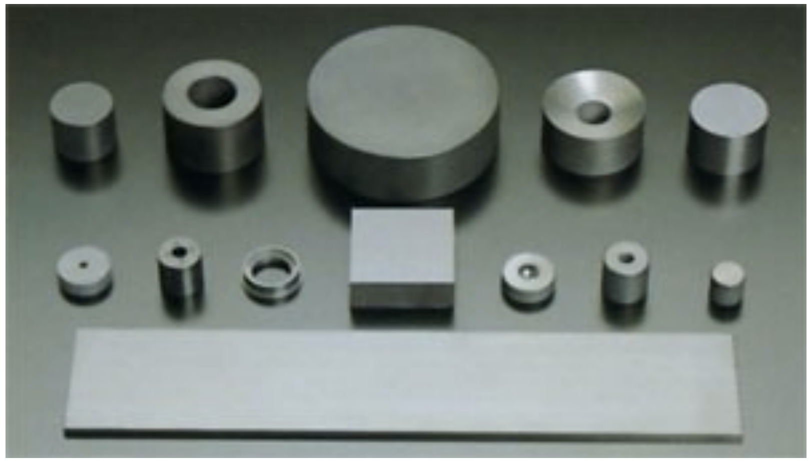
- $R_{\mu\text{-stop}}$: Rate of the muonic atom production -- target shape and size.
- f_C: Fraction of the μ^- atomic-captured by Si (not C). -- choice of target material.
- f_{MC}: Fraction of muonic nuclear-capture rate -- choice of target material.
- $A_{\mu\text{-e}}$: Acceptance to the 105-MeV/c electron from muon-electron conversion. -- beamline
- T: time of measurement
  - 2×10^7 sec
  - Running time of MLF facility is 2×10^7 sec/year.
  - Can run with other muon programs at the same time: 4 beamlines looking at the same target.

Target Material

- f_{MC}: muonic nuclear-capture rate
  - $(1-f_{MC})=f_{DIO}$ --- useless muons: as large f_{MC} is better, larger Z is preferred.
- On the other hand, τ_{μ^-} > 300 nsec (light Z) to avoid the prompt background.
- Target hit by primary protons: cannot use metal.



- Silicon-Carbide (SiC):
  - good thermal shock resistance: ΔT=450°C
  - high melting point: >1450°C
  - good radiation resistance
    - 10 dpa @ 1000°C or more



Silicon Carbide
- CERASIC

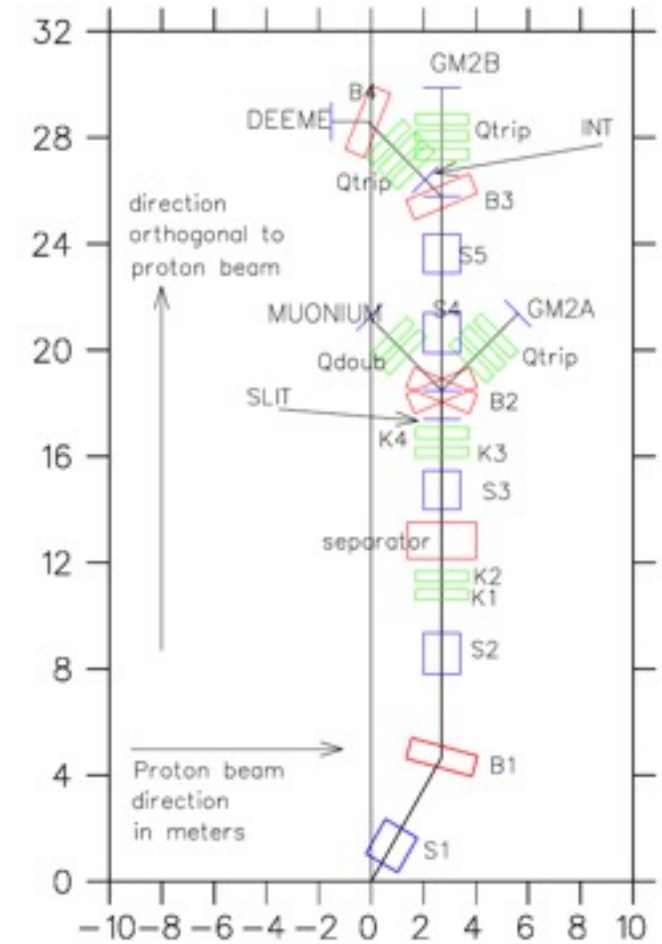
- f_C: Fraction of the atomic capture of muon to the atom of interest: proportional to Z (Fermi-Teller Z law)
  - Single-element material: $f_c = 1$
  - Silicon-Carbide --- Si:C = 7:3

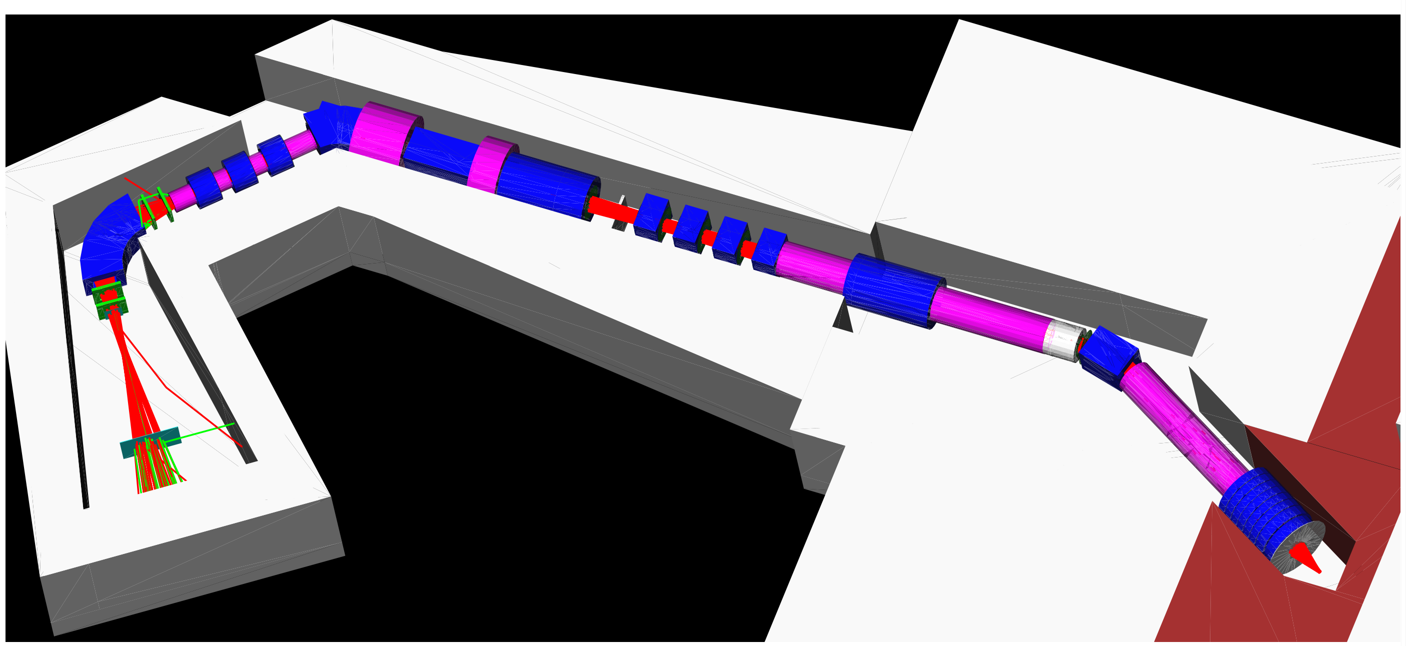
target material	$f_C \times f_{MC}$
Graphite	0.08
Silica-carbide (SiC)	0.46

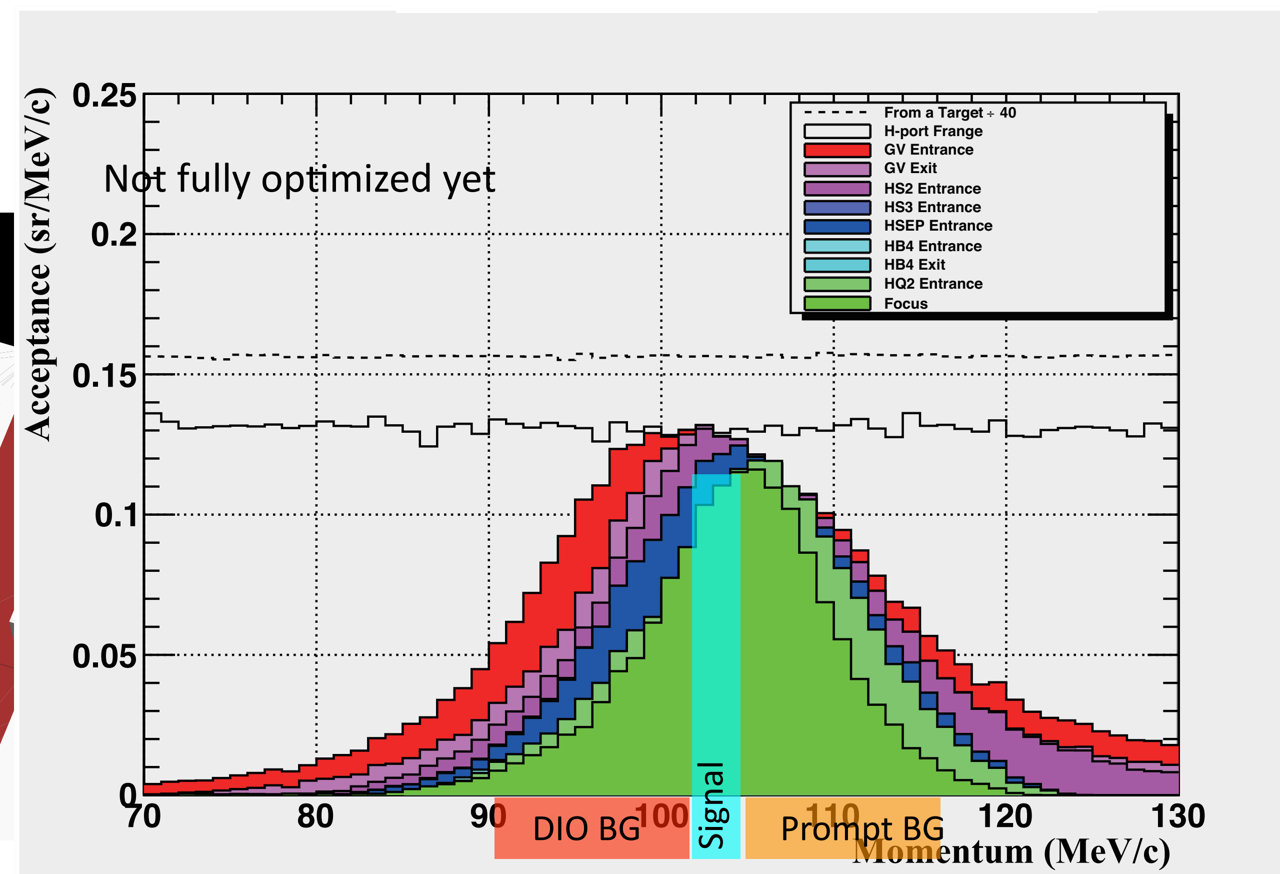
SiC Muon Target: 6 times higher physics sensitivity than Graphite.

Beamline: H-line

- the 1st concept by Jaap Doornbos (TRIUMF)
  - multi purpose beamline
    - DeeMe + g-2 + muonium-HFS
  - large acceptance by using solenoid focus
    - > 110 msr
  - long straight section for kickers and a separator.
  - moderate Δp so that the BG's can be monitored simultaneously.
    - DIO backgrounds (p < 102.5 MeV/c)
    - Prompt backgrounds (p > 105.0 MeV/c)
- Detailed design is ongoing by MUSE/IMSS/J-PARC.







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Physics Sensitivities

	H-Line SiC Target	H-Line C Target	D-Line SiC Target	D-Line C Target
$R_{\mu\text{-stop}}$	15×10^9	15×10^9	15×10^9	15×10^9
Target Material	SiC	C	SiC	C
$f_C \times f_{MC}$	0.46	0.08	0.46	0.08
A[beamline]	0.25%	0.25%	0.025%	0.025%
A[detector]	79%	79%	79%	78%
E_e threshold	102.5 MeV/c	102.0 MeV/c	102.0 MeV/c	101.0 MeV/c
A[E_e cut]	52%	60%	60%	63%
A[time window]	0.49	0.75	0.49	0.75
Running Time	2×10^7 sec	2×10^7 sec	2×10^7 sec	2×10^7 sec
S.E.S	2×10^{-14}	6×10^{-14}	7×10^{-14}	3×10^{-13}

MLF beam time ~ 2×10^7 sec/year

Current Upper Limits (SINDRUM II)

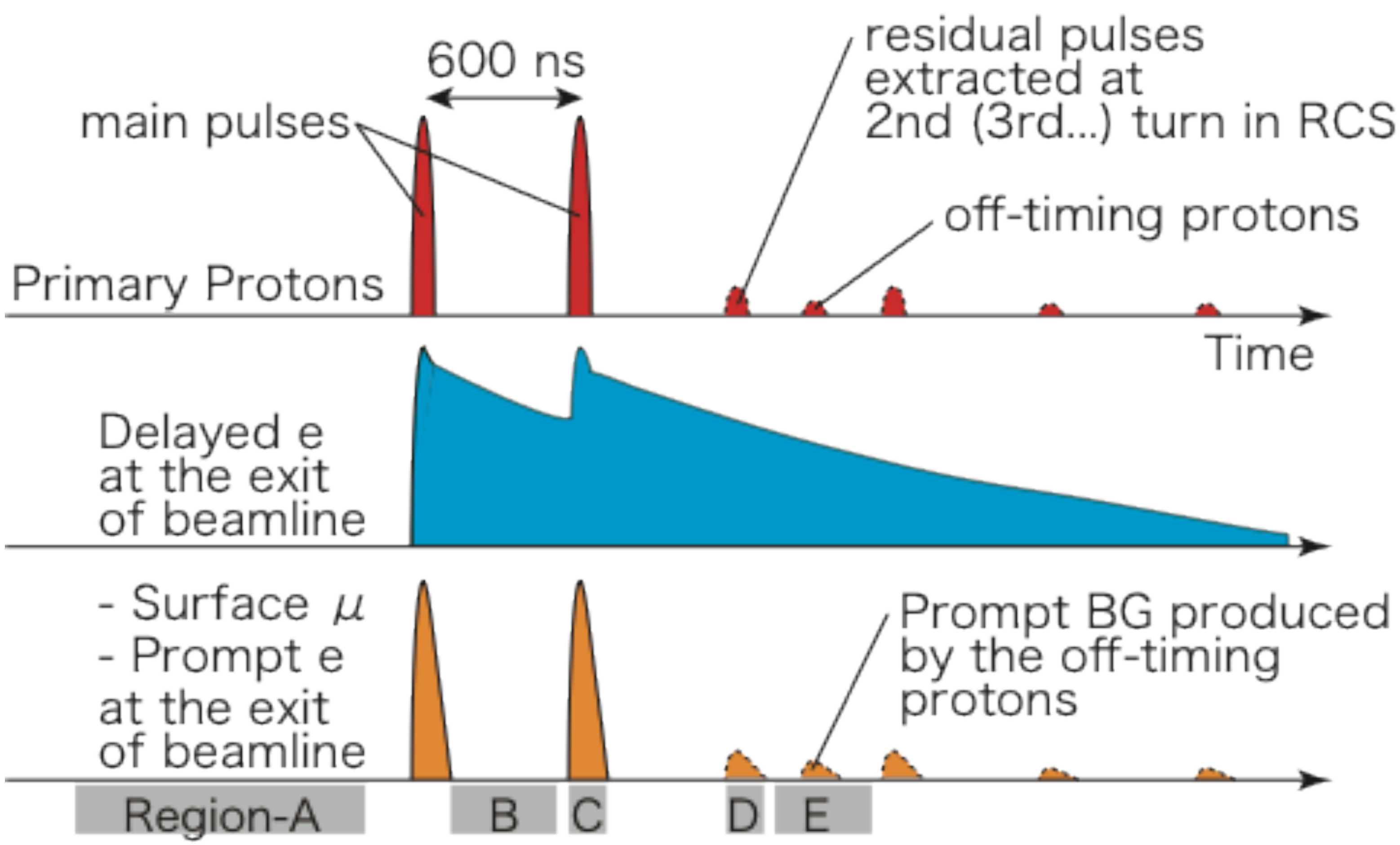
$BR[\mu^- + Au \rightarrow e^- + Au] < 7 \times 10^{-13}$

$BR[\mu^- + Ti \rightarrow e^- + Ti] < 4.3 \times 10^{-12}$

Backgrounds

- Signal: μ-e Electron: P_e = 105 MeV/*c* and Delayed

- Muon Decay in Orbit : mostly $E_e < 55$ MeV
  - $N_{DIO} < 10^{-14}$: $E_e > 102.5$ MeV
- After Protons : any off-timing protons could become potential background.
  - Pulsed proton technique
  - 6M/pulse x 50 pulses/sec x 4 x 10^7 sec x (5/10) = $(10^{-16})^{-1}$ --- After-proton ratio ~ 10^{-17}

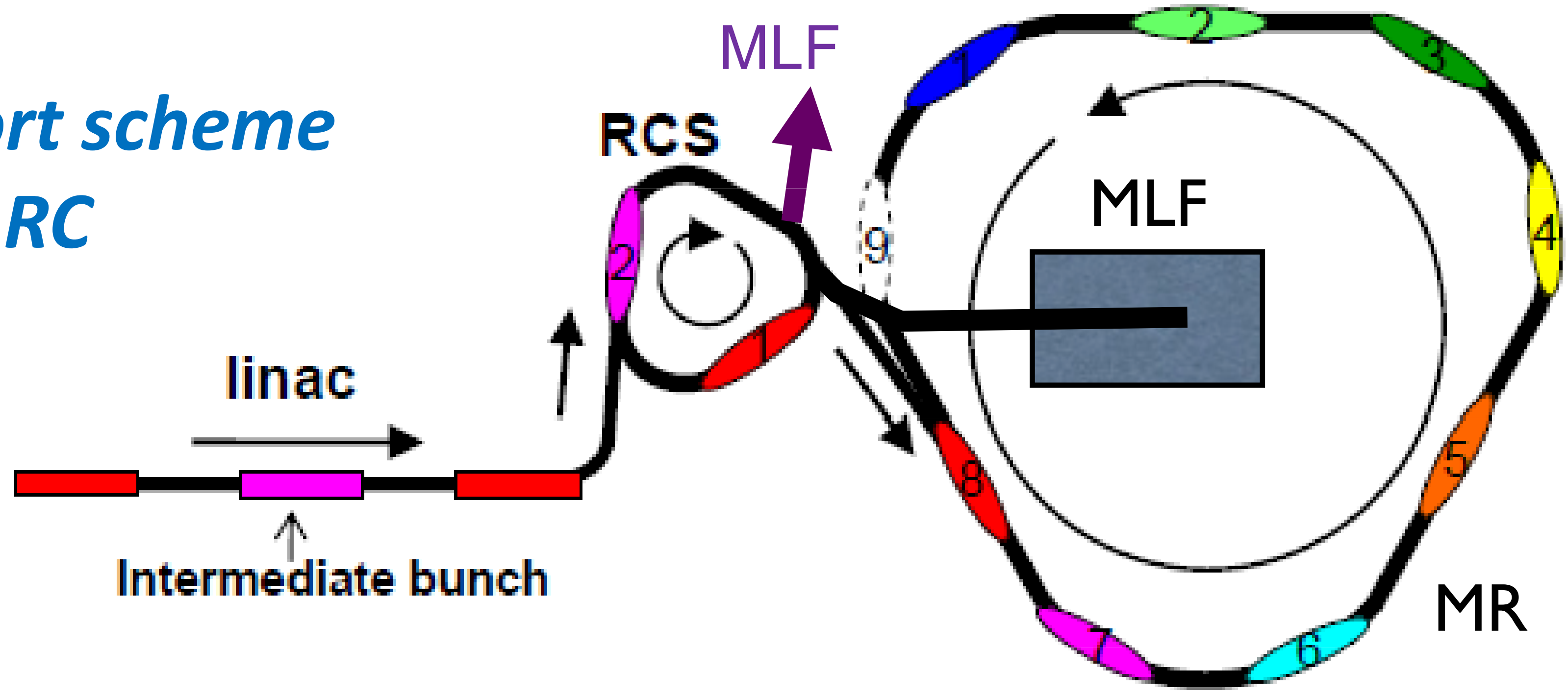


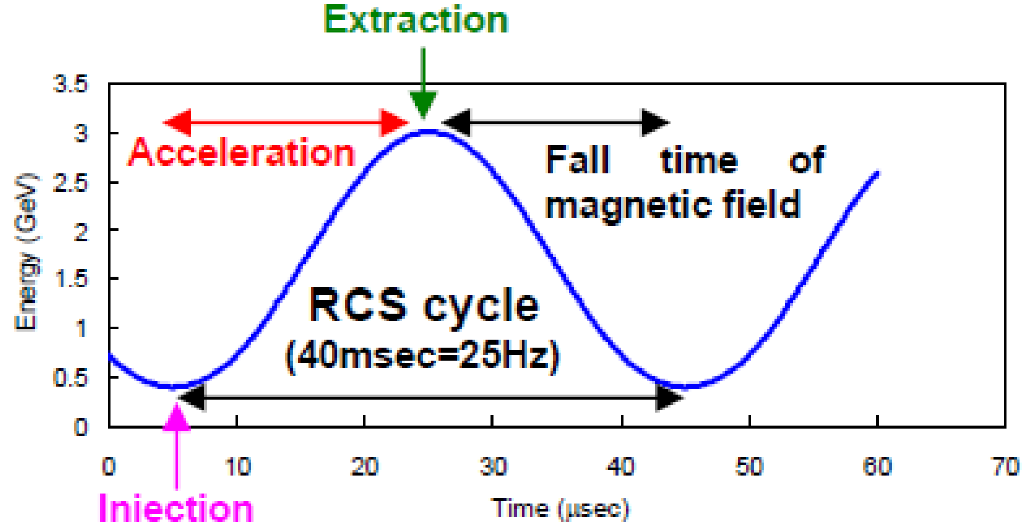
How much easy/difficult to achieve ~10^{-17}

- Fast Extraction (not the slow ex.)
  - No scattering by septum during the slow-ex.
  - no effect from inter-bunch protons.

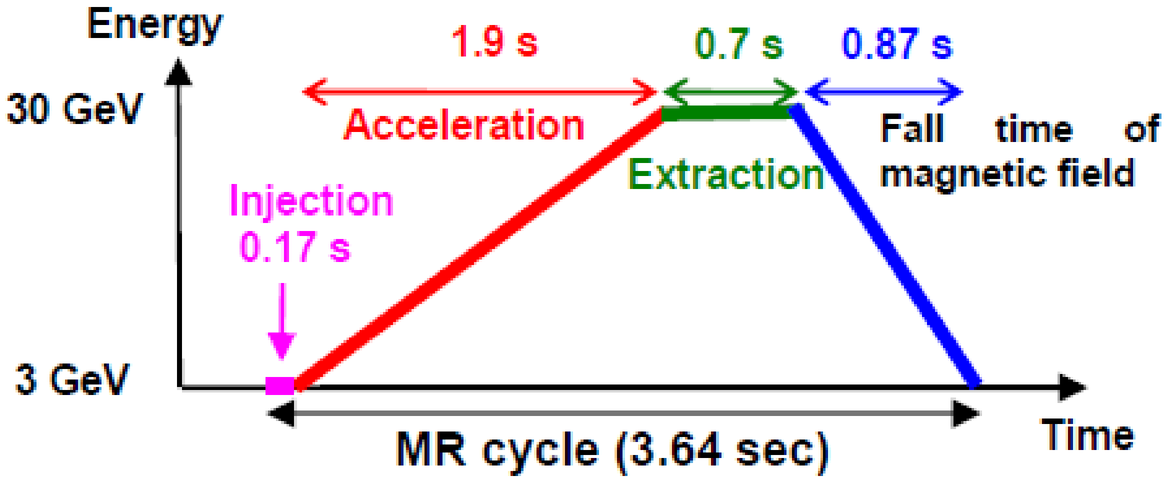
→ pulsed-proton from RCS @ MLF

Beam transport scheme of J-PARC





Time diagram of an RCS cycle



Time diagram of a MR cycle

■Intermediate bunches are injected into the 2 RF buckets of RCS for duration of macro pulse width.

■ RCS accelerates the beam to 3GeV in 20msec in a sinusoidal curve as shown in figure.

■ In MR cycle of 3.64 sec, 8 RCS bunches are injected into 8 out of 9 MR buckets.

■In the latest operation, MR cycle is 3.04 sec. Then the total pulse number is 3.4/0.04=76

Itemize

✓MR:4 pulse

✓Brank:2 pulse

(Due to fall time of the pulsed bending magnet for 3-N and 3-50 BT)

✓MLF:70 pulse

What is 3GeV-RCS in J-PARC

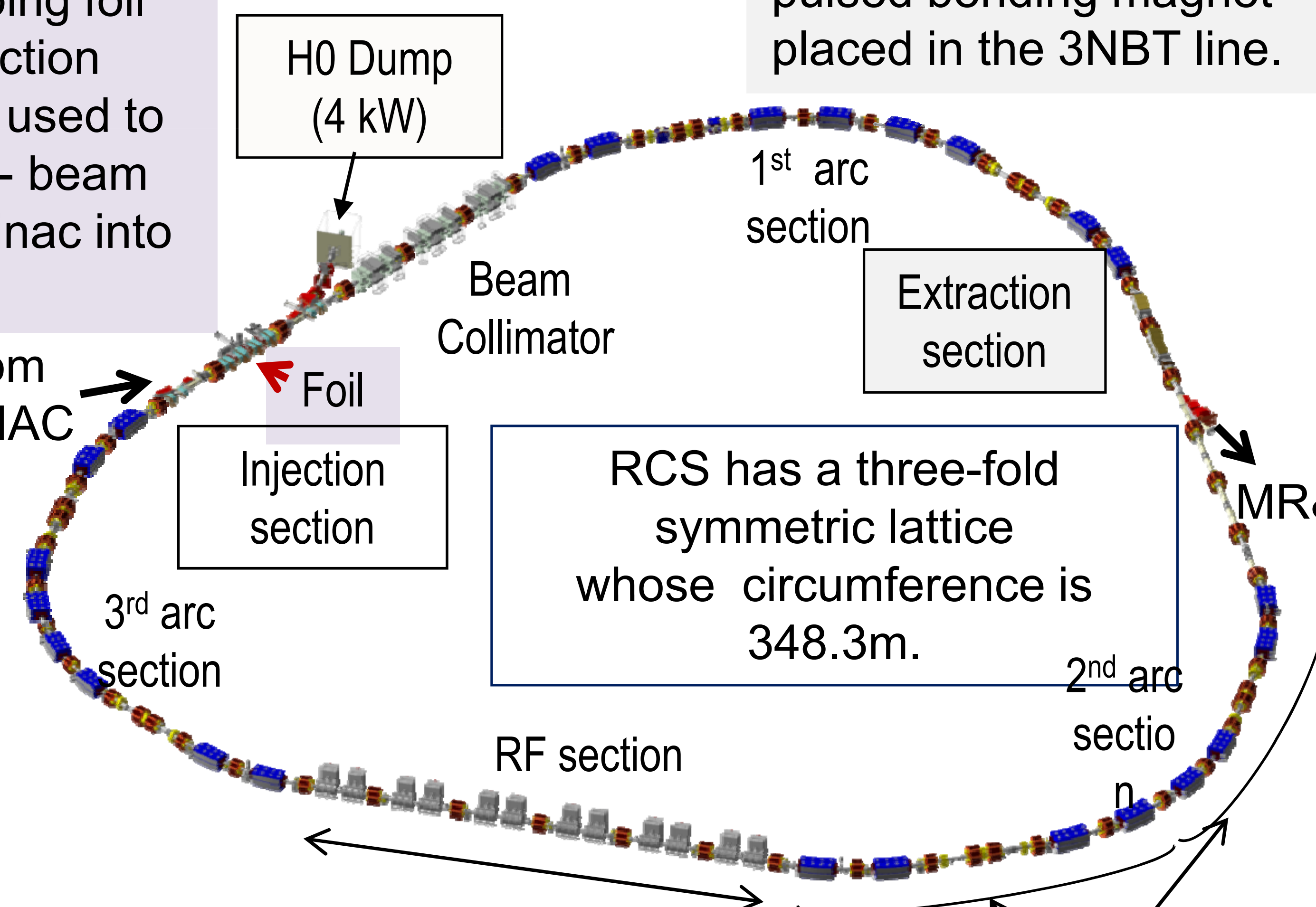
Design parameters

Circumference	348.333 m
Superperiodicity	3
Harmonic number	2
No of bunch	2
Injection energy	181 MeV (400 MeV)
Extraction energy	3 GeV
Repetition rate	25 Hz
Particles per pulse	1.7e13 – 2.5e13 (8.3e13 with 1 MW)
Output beam power	0.2- 0.3 MW (1 MW)
Transition gamma	9.14
Number of dipoles	24
quadrupoles	60 (7 families)
sextupoles	18 (3 families)
steerings	52
RF cavities	12 (11 at present)

The H0 dump is used to dump unstripped beams at the stripping foil. The capacity is 4kW.

The beams are extracted by kicker magnets and DC septum magnets at the extraction section and then transported either to MLF or to MR with a pulsed bending magnet placed in the 3NBT line.

The stripping foil in the injection section is used to convert H- beam from the linac into protons.

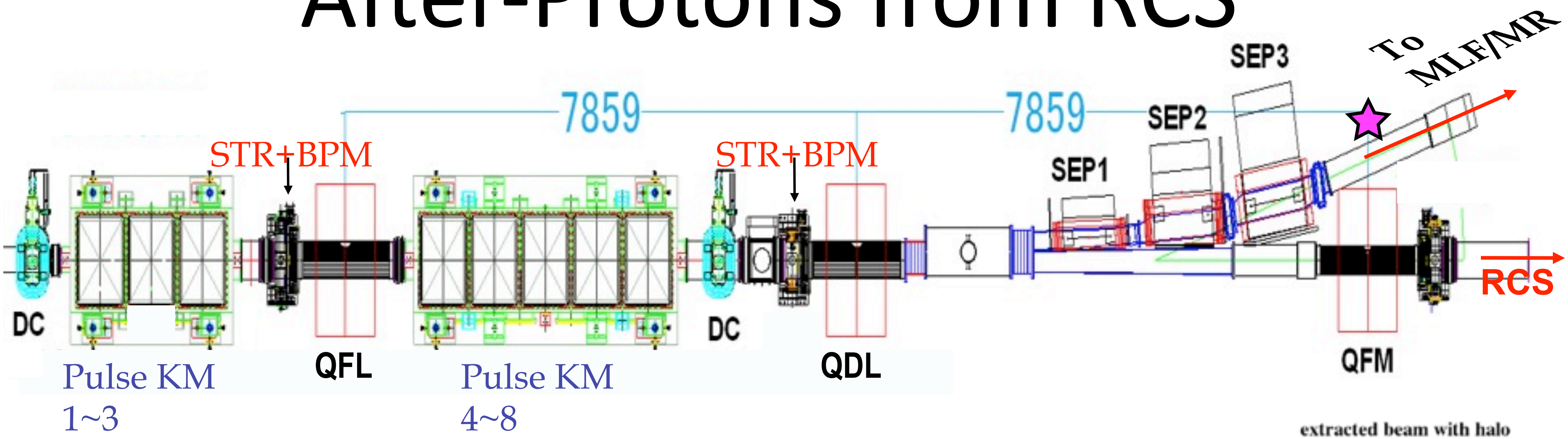


RCS has a three-fold symmetric lattice whose circumference is 348.3m.

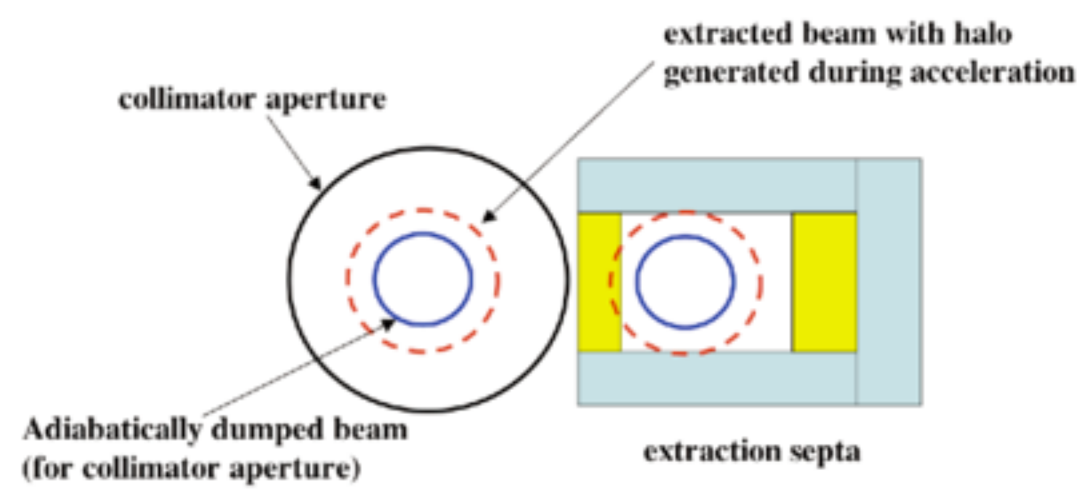
One of the three-fold symmetric lattice comprises two arc modules and a long straight insertion.

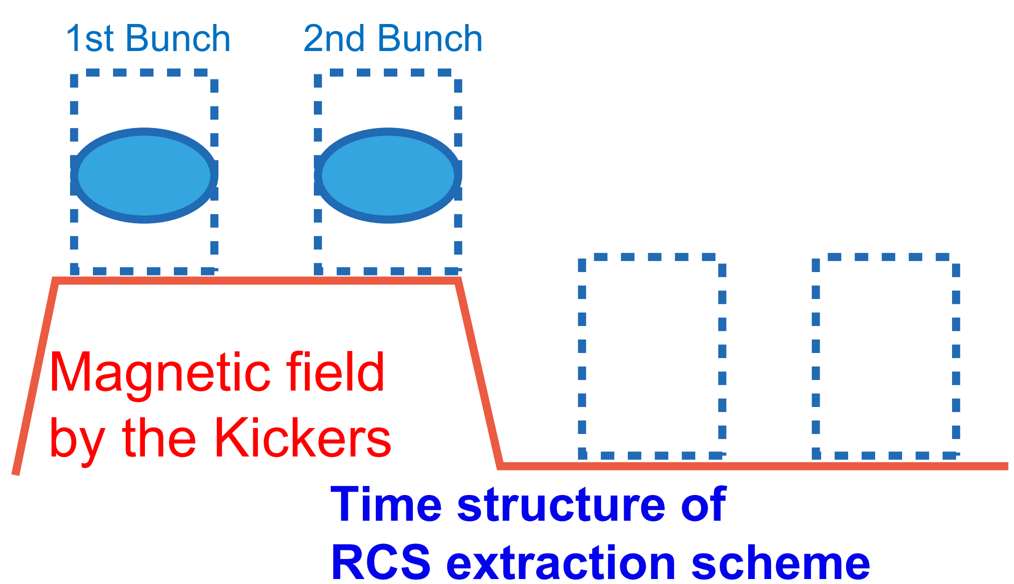
Each arc module has a missing-bend cell.

After-Protons from RCS

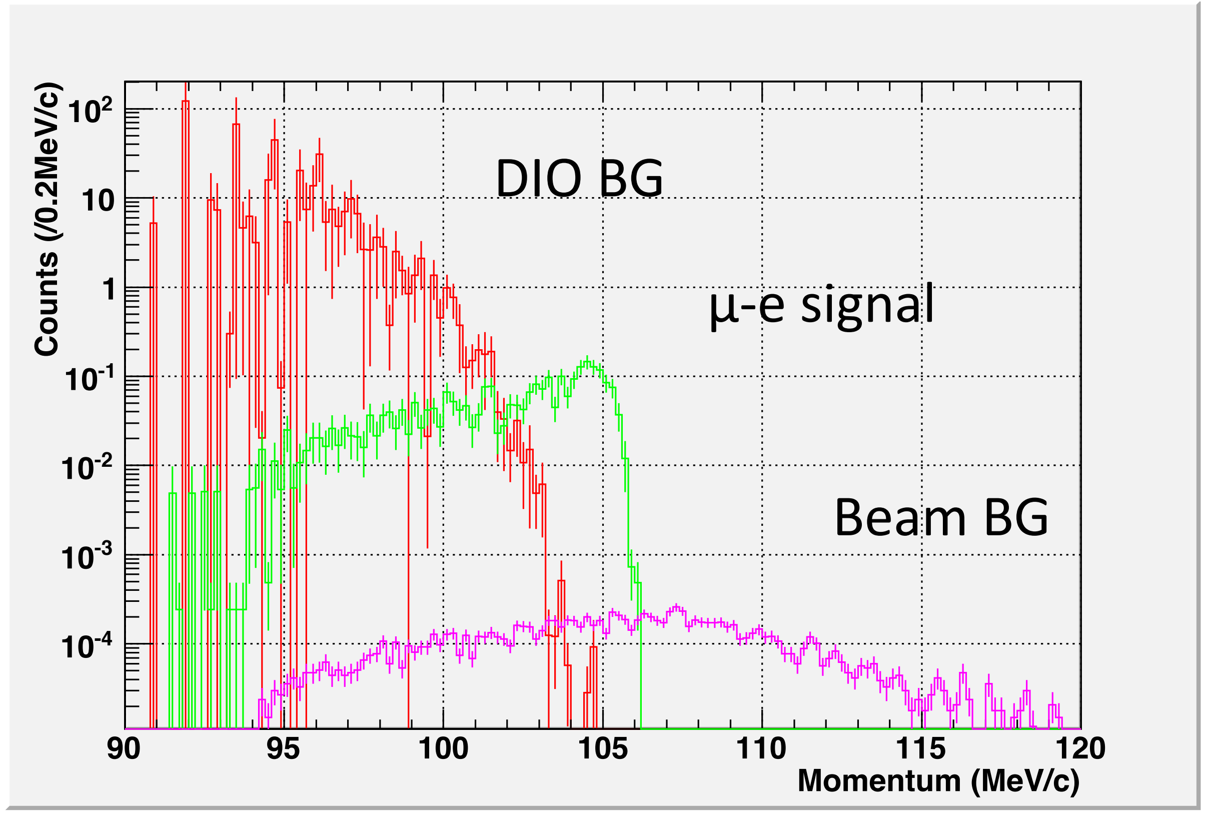


- Excellent design of RCS transverse acceptance
  - RCS ring aperture = 486π mm.mrad
    ring collimator aperture = 350π mm.mrad
  - Extraction Beamline aperture = 324π mm.mrad
  - Total kick angle = 17 mrad --- > 2000π mm.mrad
- Fast Extraction Scheme (not a slow extraction)
- Preliminary measurement of a beam-loss monitor showed promising result: R_{AP} could be $< 10^{-19}$.
- Improved measurement will be performed in next February, 2012.





Sensitivity and Backgrounds



Signal Region: 102.0 -- 105.6 MeV/*c*

- Signal Sensitivity
  - S.E.S.: 2×10^{-14} (for 2×10^{7}sec of run)
- Backgrounds
  - Assuming $R_{AP}=10^{-19}$ (based on the recent R&D)
  - Detector live-time Duty = 1/20000

DIO Background	0.09
Beam-related Background	< 0.01
Cosmic-Muon Induced Electron Background	0.018 or much less
Cosmic-Muon Induced Muon Background	< 0.001

- If we could extend the running-time up to 8×10^{7} sec
  - Standard Cut: S.E.S.= 0.5×10^{-14} (N_{BG}=0.48)
  - Tighter Cut: S.E.S.= 0.6×10^{-14} (N_{BG}<0.02)

In-situ Monitoring of Backgrounds

Moderate Δp of H-line makes it possible to monitor backgrounds in situ.

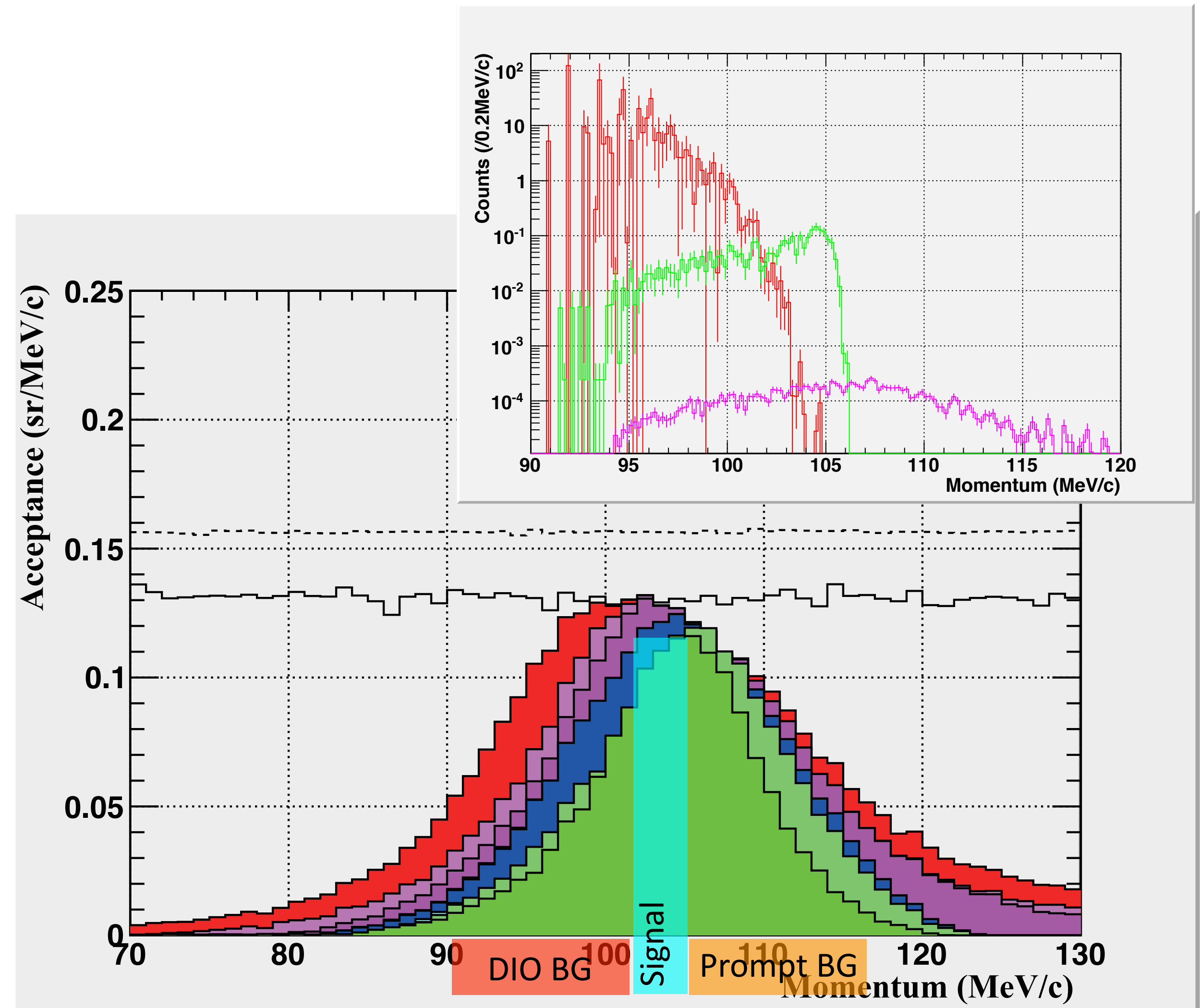
- DIO backgrounds ($p < 102.0$ MeV/c)
- Prompt backgrounds ($p > 105.6$ MeV/c)

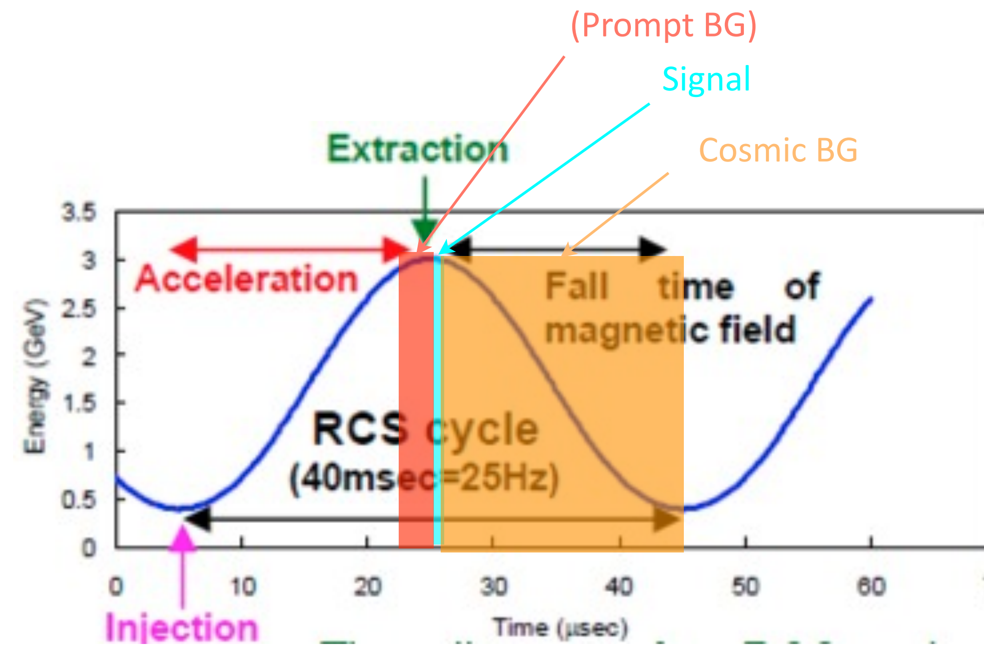
Signal Sensitivity Calibration

- Calibrated by using number of DIO electrons.
- N_{DIO}=300 (2e7 sec)

Background Monitoring

- DIO electrons
  - shape
  - yield
- Prompt Backgrounds
  - p>105.0 MeV/c (direct upper limit)
  - Beam-loss counters in RCS
- Cosmic-induced Backgrounds
  - Beam-on: 50μsec/sec
  - Beam-off: >500msec/sec





DeeMe Status

- KEK/IMSS Muon PAC: Stage-1 approved.
- J-PARC PAC: Examination is ongoing.
  - Scientific merit is recognized.
  - Encouraged for further R&D.

    The PAC strongly encourages the proponents to continue the R&D studies for all aspects of the experiment and the extinction study in particular.
  - Strongly encouraged H-line construction.

    The PAC also encourages KEK, JAEA and the collaborating institutions associated with these three experimental proposals to work together toward funding and the timely completion of the H-beamline, which has the potential to substantially broaden the J-PARC research program.
- A muon group in J-PARC/IMSS already started the procurement of magnets in the tunnel of H-line.
- Preliminary measurement of the after-protons were performed with very promising result. An improved measurement will be performed in February, 2012.

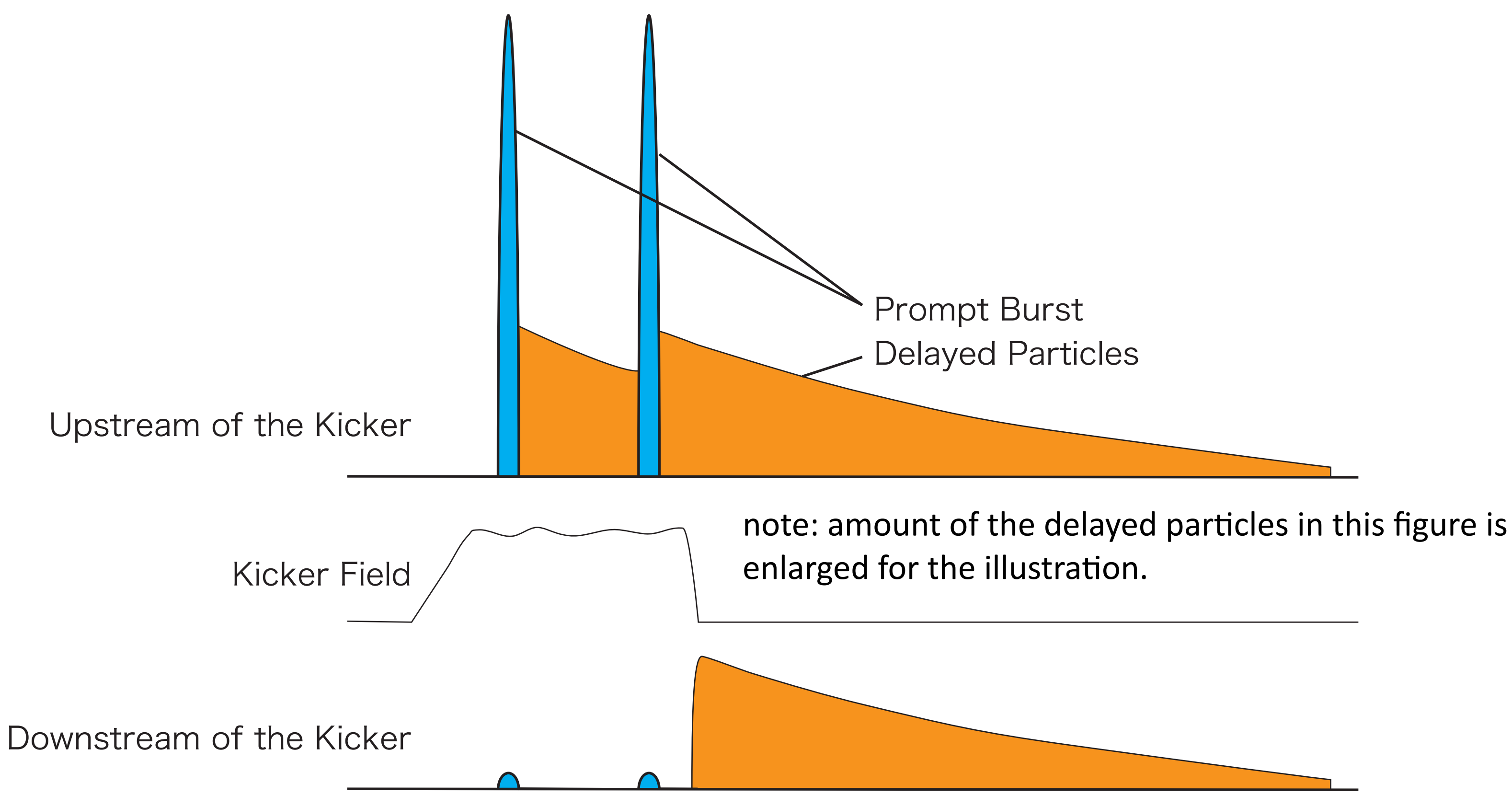
DeeMe R&D

R&D Items

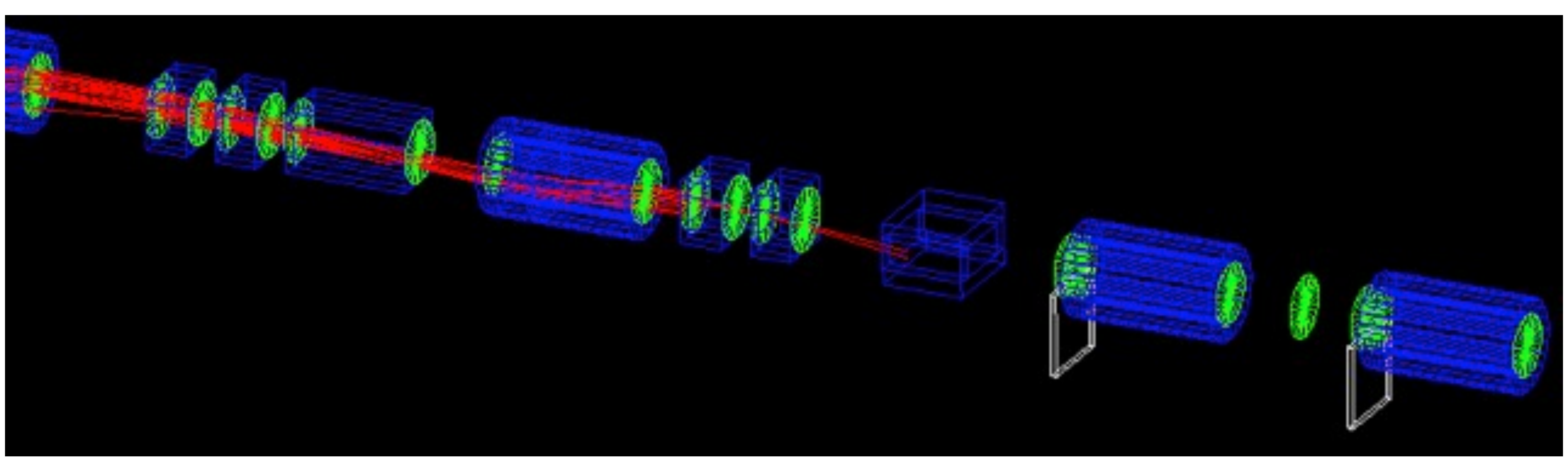
- H-Line
  - Large Acceptance (> 110 msr)
- Prompt Kicker
  - Large Aperture (320-mm × 320-mm)
  - High Magnetic Field > 385 G
  - Fast Fall Time < 300 ns
- SiC Rotation Target
  - Proton beam loss
  - Radiation Shielding
- Detector
  - Fast operation to tolerate prompt beam burst.
- After Protons
  - To suppress the beam related background.

Secondary-Beamline Kicker

- prompt burst: coincide with the primary proton pulse from RCS.
  - 50M particles/pulse (based on the test measurement at 2009)
    - detector (counter and wire chamber) will be blind for while.
- Reduce the prompt burst by kicker <1/1000
  - detector rate will be 33k particles/pulse, and it is acceptable.

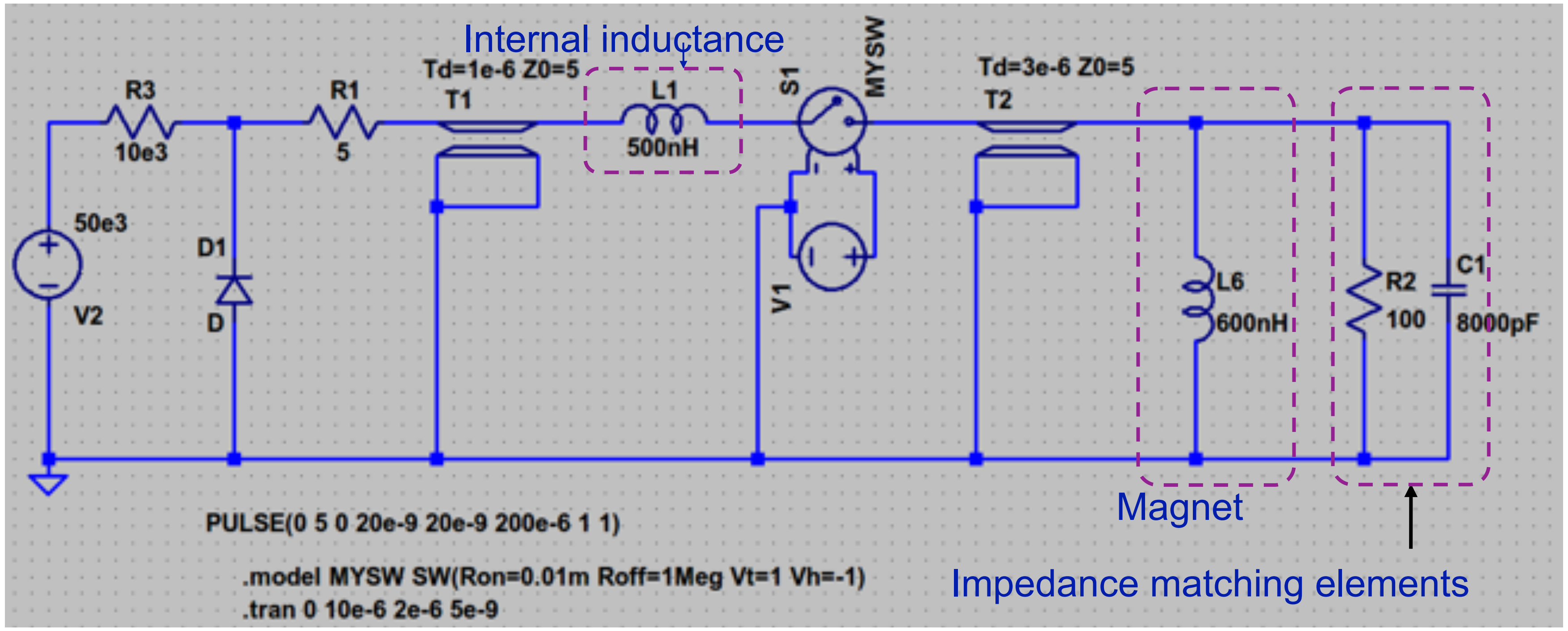


Mag. Field	> 385 Gauss
Gap	320 mm
Width	320 mm
Length	400 mm
No.	4
Fall Time	< 300 nsec
Rep. Rate	25Hz

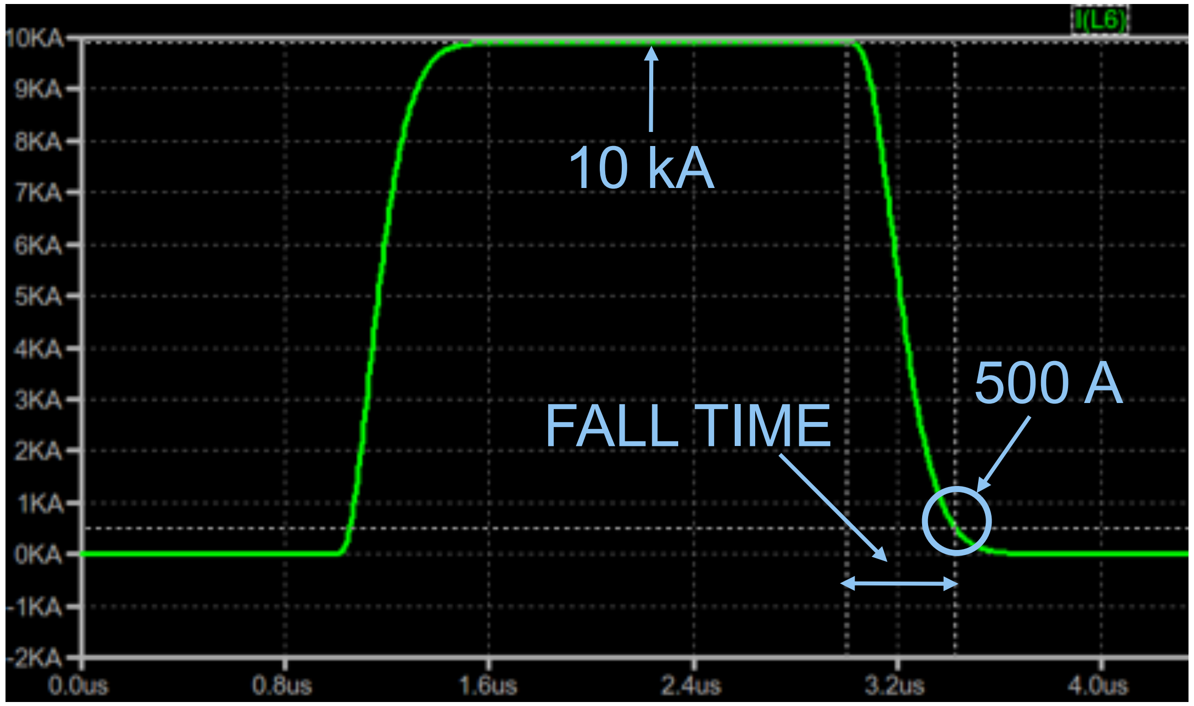


Conceptual Design

By H. Matsumoto (KEK)



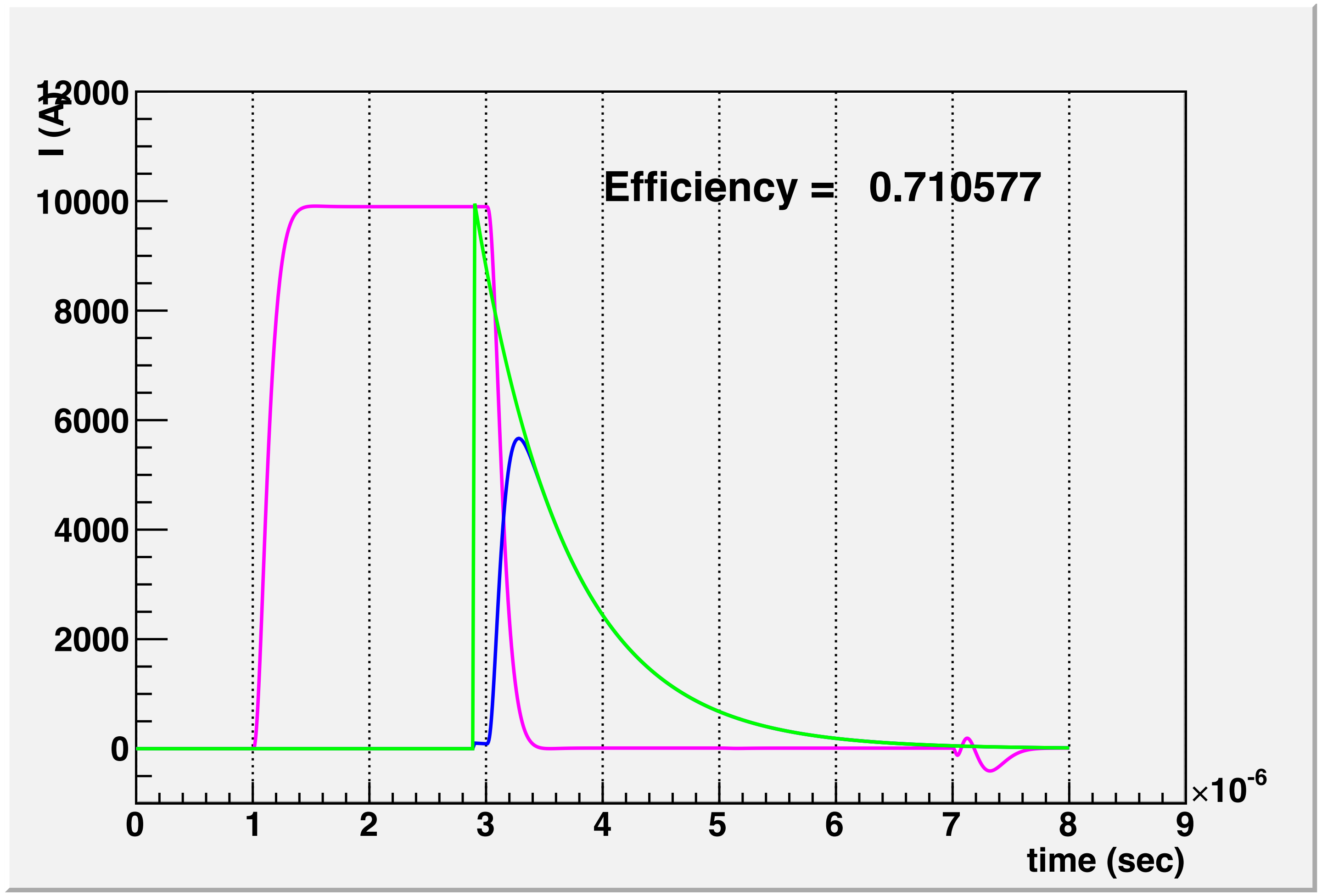
INTERNAL INDUCTANCE	FALL TIME @ 500 A
100 nH	307 nsec
300 nH	361 nsec
500 nH	430 nsec



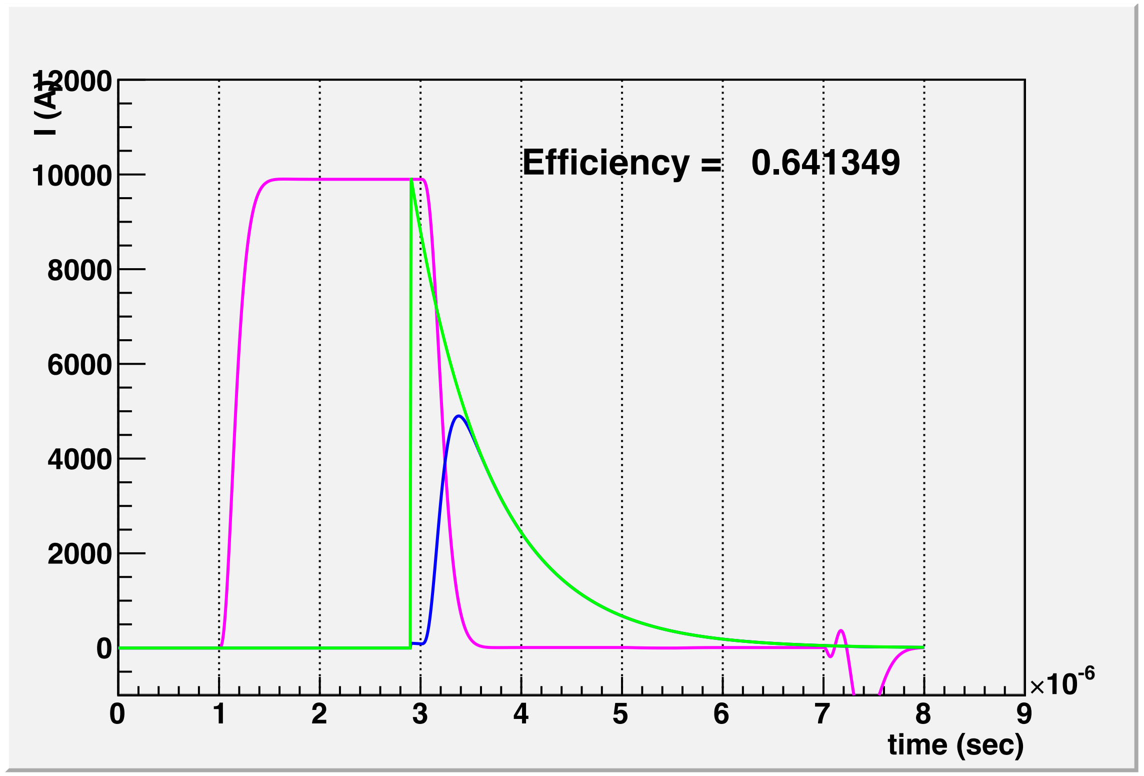
MAGNET COIL CURRENT [A]

1) MAGNET INDUCTANCE: 600 nH
2) IMOEDABCE MATICHING ELEMENT: 8000 pH, 100 Ohm
3) MAGNET COIL CURRENT: 10 kA
4) PFL IMPEDANCE: 5 Ohm

Transmission Efficiency



Internal Inductance = 100 nH
Magenta: kicker current
Green: mu-e signal strength @ birth
Blue: mu-e signal @ detector

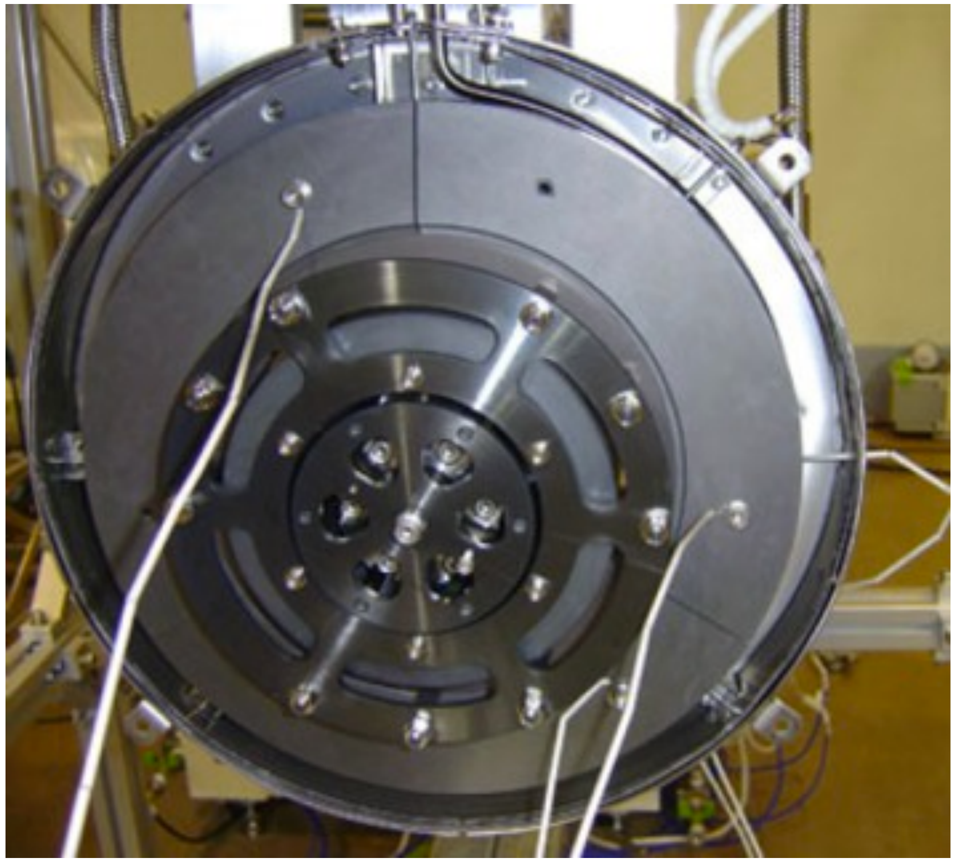


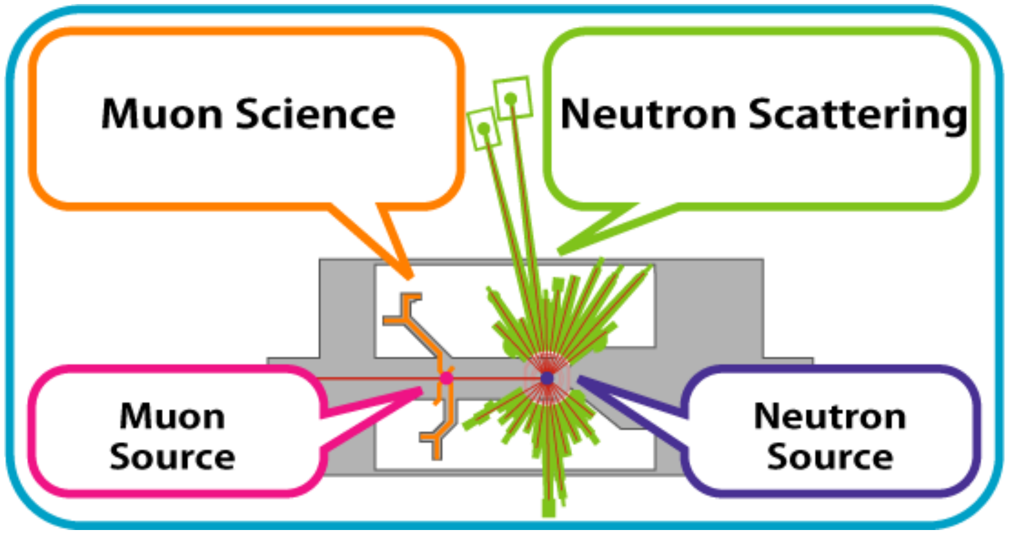
Internal Inductance = 500 nH
-10% --- acceptable

SiC Rotation Target

- A bench-test of a Graphite Rotation Target is ongoing.
- Replacing the Graphite plate with SiC one is easy.
- The issue is the political negotiation with a neutron target users since they may loss 10% of protons.

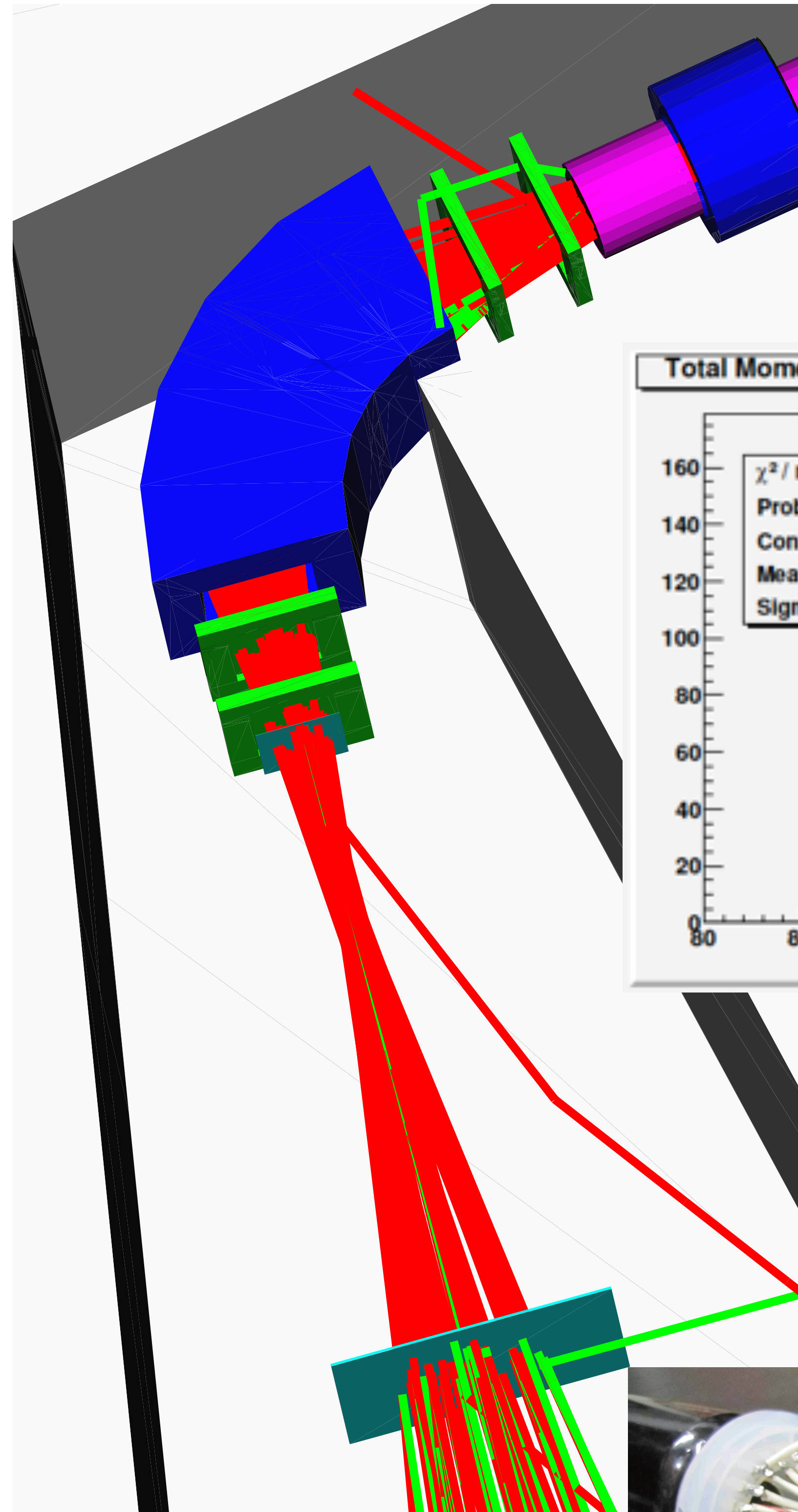
Carbon Rotation Target on a test bench

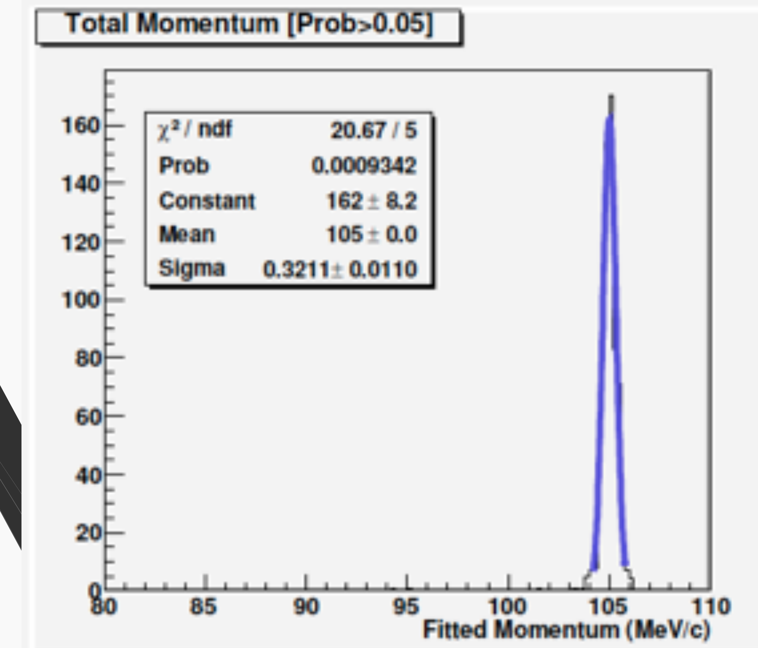


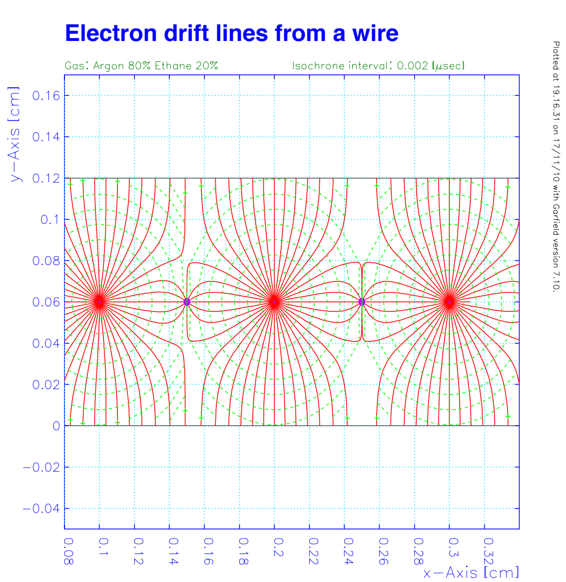


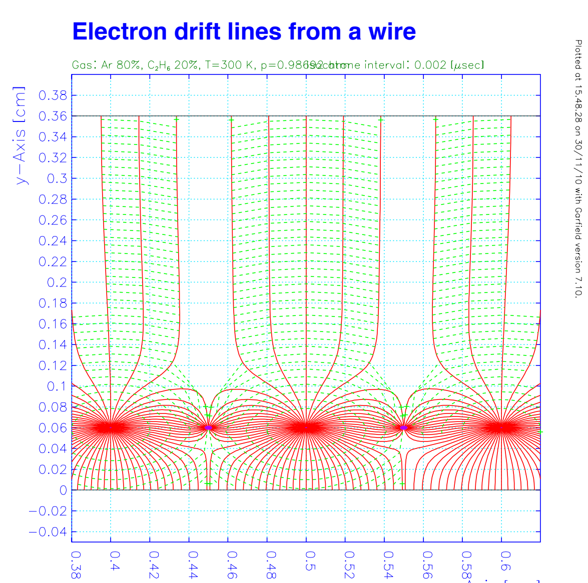
Detector

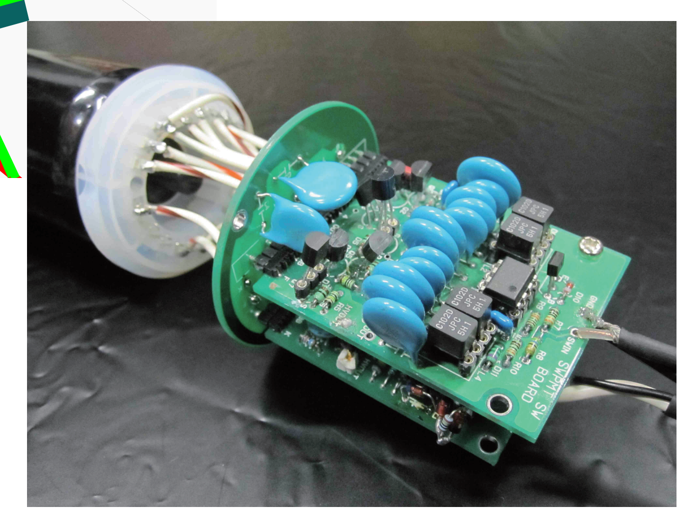
- prompt burst = 33k per pulse even after suppressed by the kicker.
- BH1,2: hodoscope
  - gating PMT
  - Designed by T. Taniguchi, but he passed away.
  - Development is suspended.
- WC1-4: wire chamber
  - micro-cell or asymmetric-cell
  - Doable, but may need further R&D
- Amp. and readout FADC system.
- $\sigma < 0.5$ MeV/c











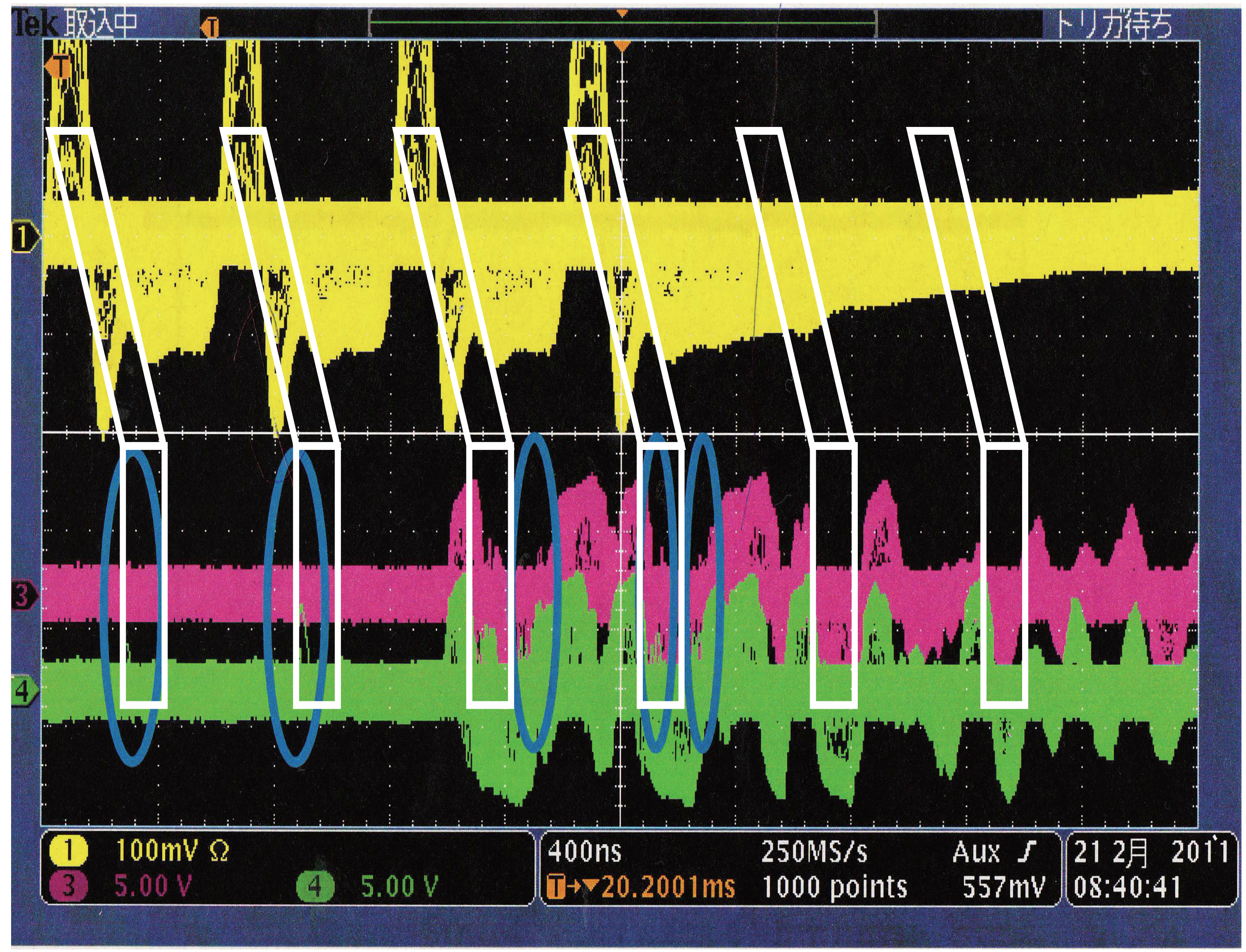
After-Protons

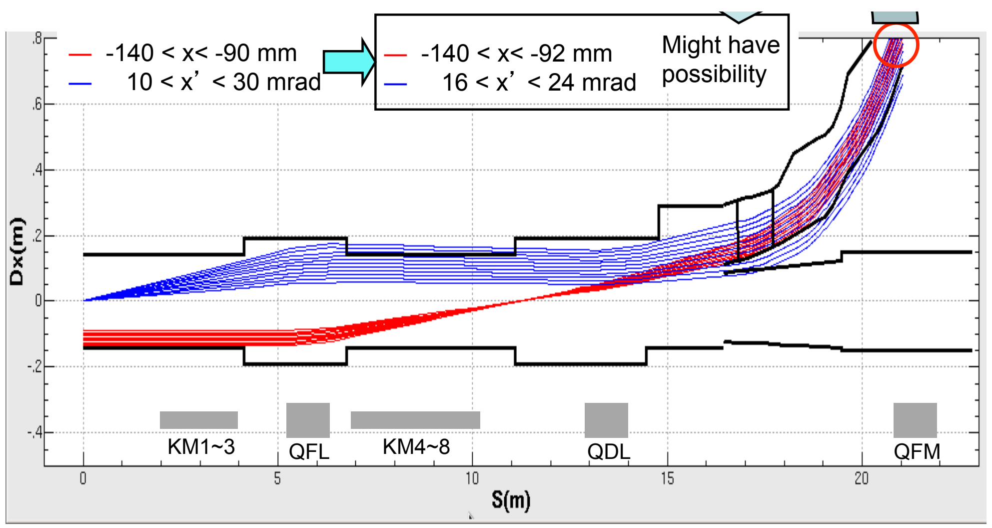
- Preliminary Measurement was performed by K. Yamamoto at J-PARC RCS group.
  - $N_{AP} < \sim 10^{-19}$
- Beam dynamics study is ongoing (in collaboration with RCS group)
  - (hardly) possible scenario of the after-proton production.
- A plan for further studies (in collaboration with RCS group)
  - developing into an in-situ monitor system of the after-protons in physics runs.

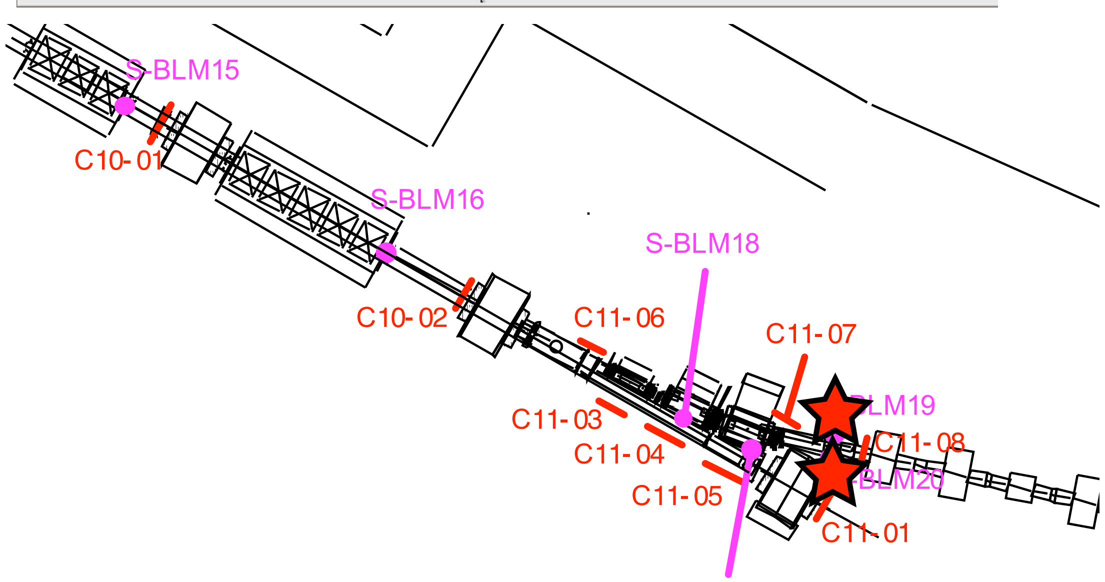
Preliminary Measurement

- after-protons involve scattered protons.
- beam-loss counters can observe it.
- 258 hours of measurement

by Kazami Yamamoto @ JAEA







- No evidence of the after-protons so far. Measurement is limited by event statistics and the electrical noise from the RCS kickers.
- The above snapshot: R_{AP} could be < $\sim 10^{-19}$
  - It is required to be < 10^{-17}

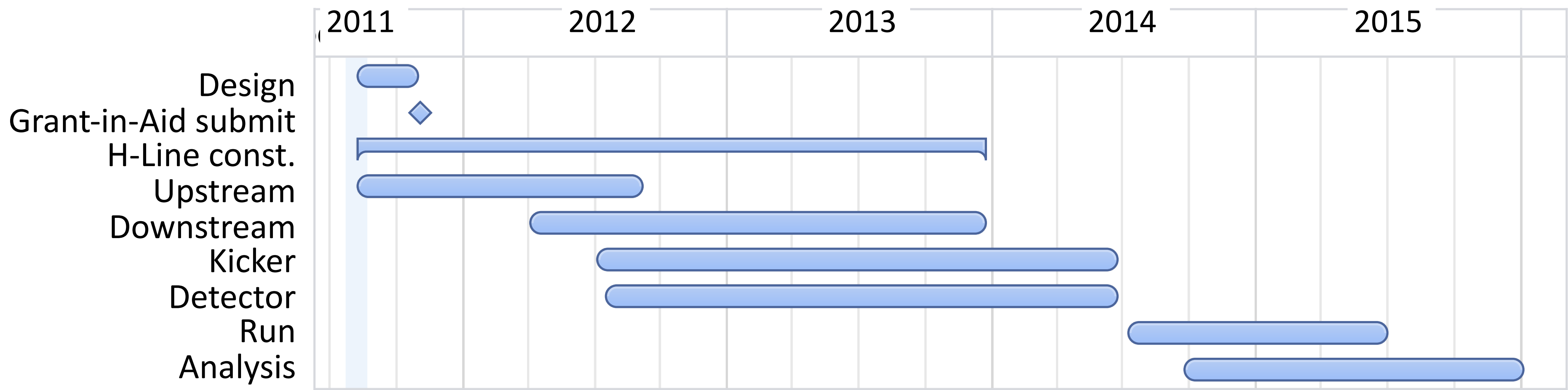
Plan of R&D

- Principle
  - Aiming to obtain the first physics result around 2015.
  - Aiming to achieve the sensitivity 10^{-14}.
- Overview
  - A base policy is to build H-line for maximum sensitivity.
  - Push forward the RCS after-protons measurement.
  - Apply for the Grant-in-Aid for Scientific Research in Japan to cover the detector construction.
  - Push KEK administration to move forward with building H-Line.
  - If something get wrong, as a backup plan, start the measurement at D-Line. But, we have to move to H-Line eventually.
  - Any way, aim to have the physics result in timely manner.

Cost and Schedule

Item		Cost (kJPY)	sub total	Note
Detector			103,000	(73,000)
	Spectrometer Magnet	30,000		
	Hodoscope	10,000		gating-grid type
	WC R&D	3,000		
	WC Construction	50,000		
	Readout Electronics	10,000		
Target			30,000	
	SiC Target	30,000		
H-Line Construction				Facility
Prompt Kicker			220,000	
	Magnet	60,000		
	Power Supply	160,000		
PostDoc (3)		15,000/y	75,000	
Total			428,000	

Multi-purpose beamline: Can be used for other experiments



A bit aggressive plan of Schedule

Summary

- There is a competitive merit of physics in searching for μ-e conversion at sensitivity of 10^{-14} in timely manner.
- Needless to say that the result should be obtained before the result from COMET and/or Mu2e. But who knows when they get the result...
- It will maximize the potential of major discovery at J-PARC.
- It is necessary to build a large-acceptance beamline (H-line) for the best result. The H-line can be time-shared with other experiments, such as g-2. The bidding of two magnets in a tunnel was already called.
- A preliminary measurement of after-protons revealed that it is very likely to be small enough.
- The size of cost (except for the multi-purpose H-line and the kicker system) is within the range of the Grant-in-Aid for Scientific Research of Japan.
- We are aiming to get the first physics result around 2015.

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