J-PARC Kaon and Muon Program

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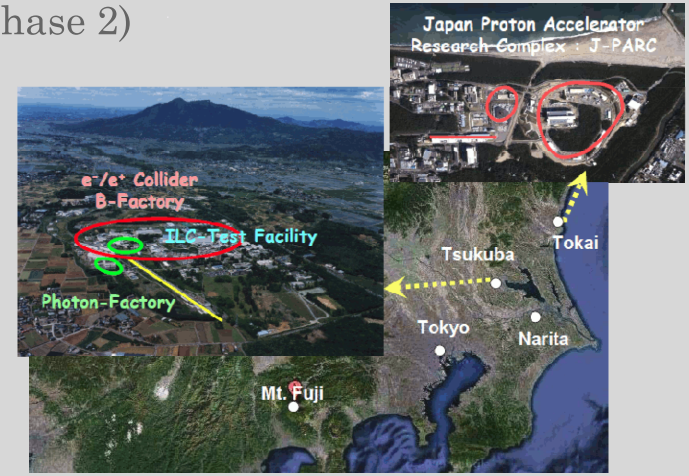
Outline

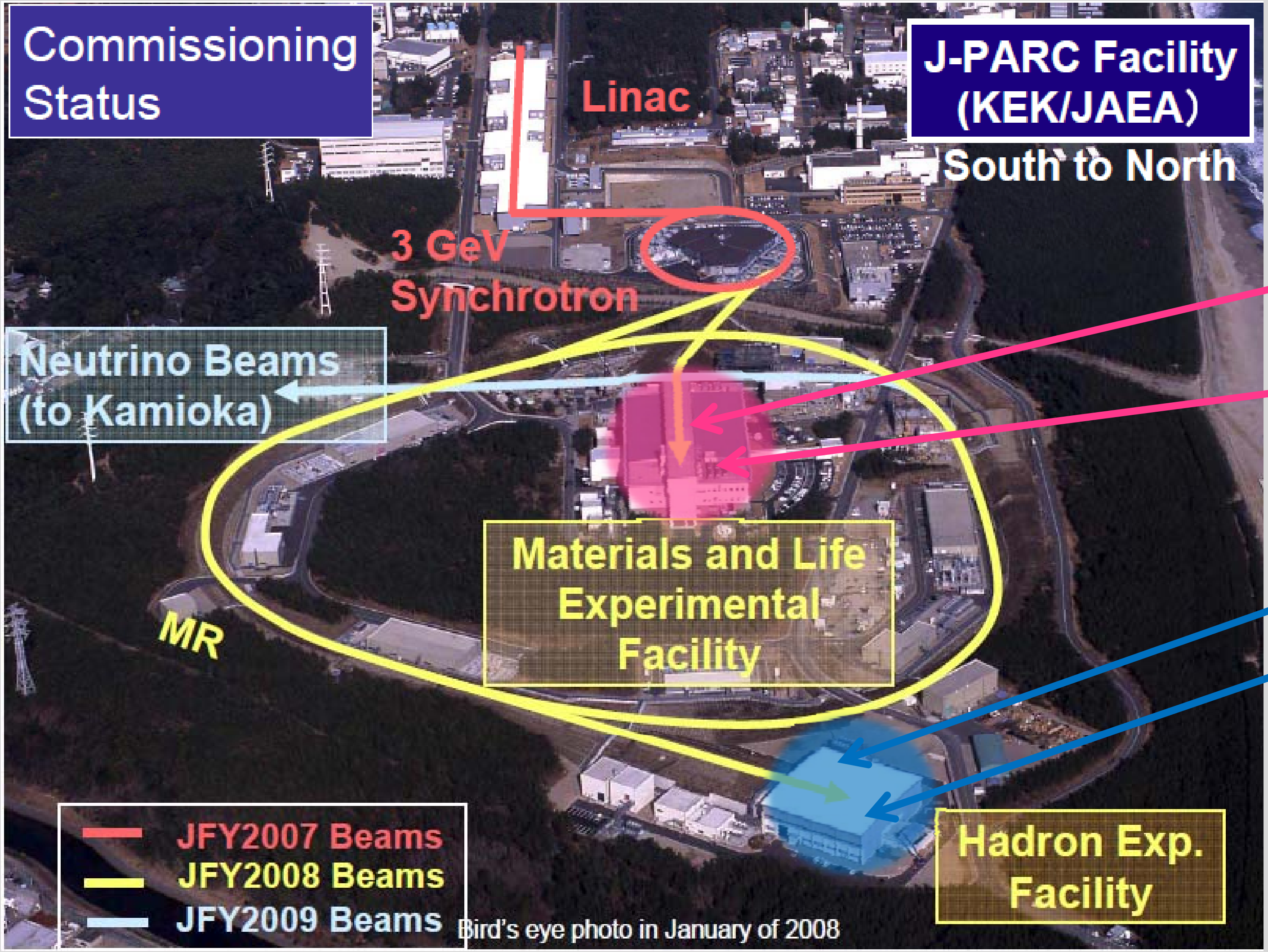
- Introduction
- J-PARC Accelerator Status
- Kaon Program
- Muon Program
- Summary

Introduction

- What is J-PARC (Japan Proton Acceleration Research Complex)?
  - Joint project between JAEA and KEK
  - **New and exciting accelerator research facility**, using MW-class high power proton beams at both 3 GeV and 30 GeV.
  - Various secondary particle beams
    - neutrons, muons, kaons, neutrinos, etc. produced in proton-nucleus reactions
  - Three major scientific goals using these secondary beams
    - Particle and Nuclear physics
    - Materials and life sciences
    - R&D for nuclear transformation (in Phase 2)
  - The anticipated goal is 1 MW



J-PARC Accelerator



Bird's eye photo in January of 2008

3GeV proton

Muon

Neutron

< 30GeV proton

Muon

Kaon

Status of Accelerator

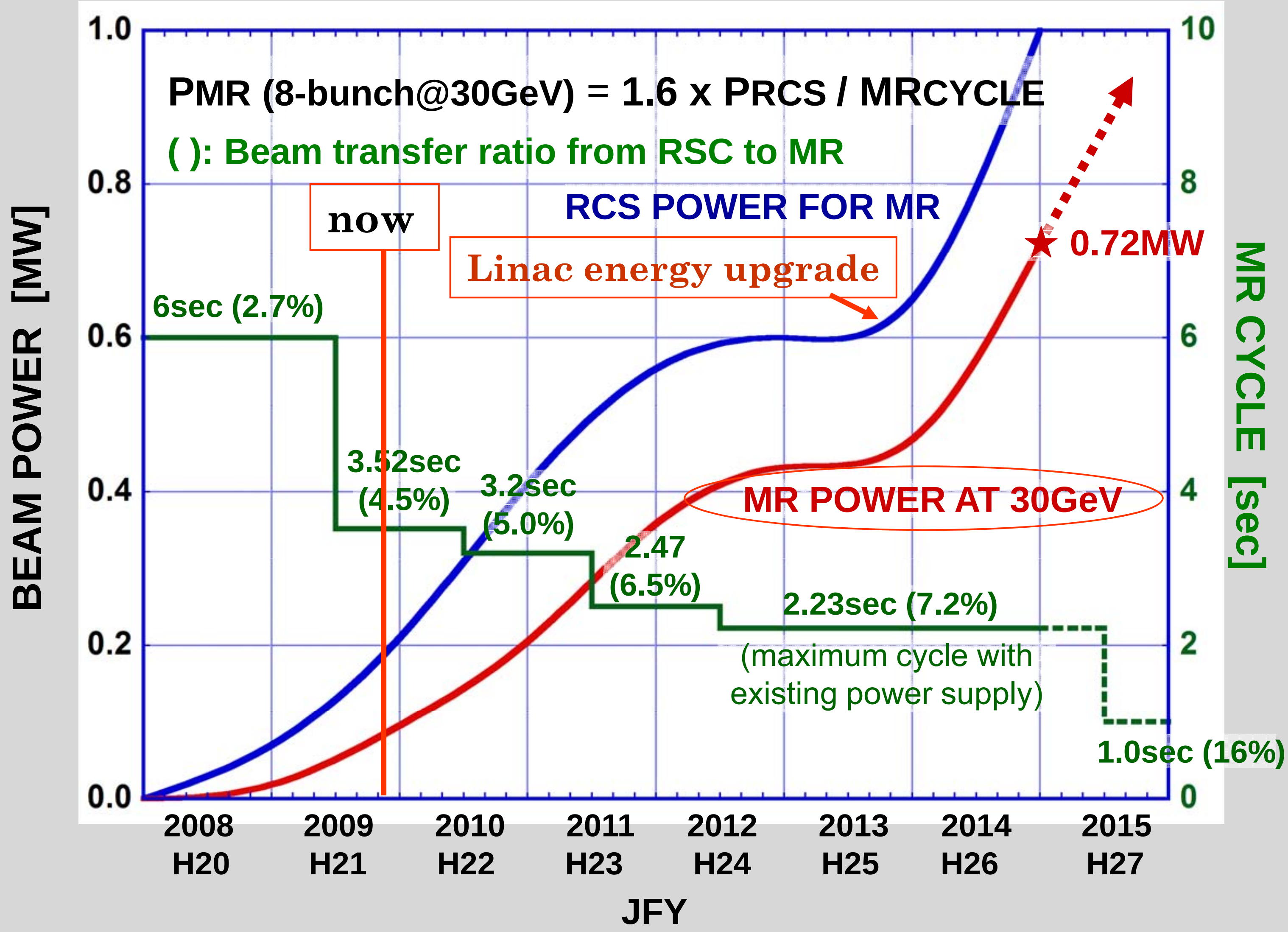
- From 2008 four secondary beams have been obtained exactly on schedule;
  - neutron beams (May, 2008)
  - muon beams (September, 2008)
  - kaon beams (February, 2009)
  - neutrino beams (April, 2009)

$\Big\}$ @ 3GeV RCS

$\Big\}$ @ 30GeV MR

- Linac 181MeV
  - Upgrade to 400MeV in 2013
  - nEDM measurement proposal
- RCS 3GeV
  - 120-300 kW operation for Material Life Science Facility
  - Particle physics experiments using muon (this talk)
- MR 30 GeV
  - 50-100 kW operation with fast extraction for T2K (previous talk)
  - 1.6kW operation with slow extraction for 2ndary beam expts (this talk)

An Expected Beam Power Curves

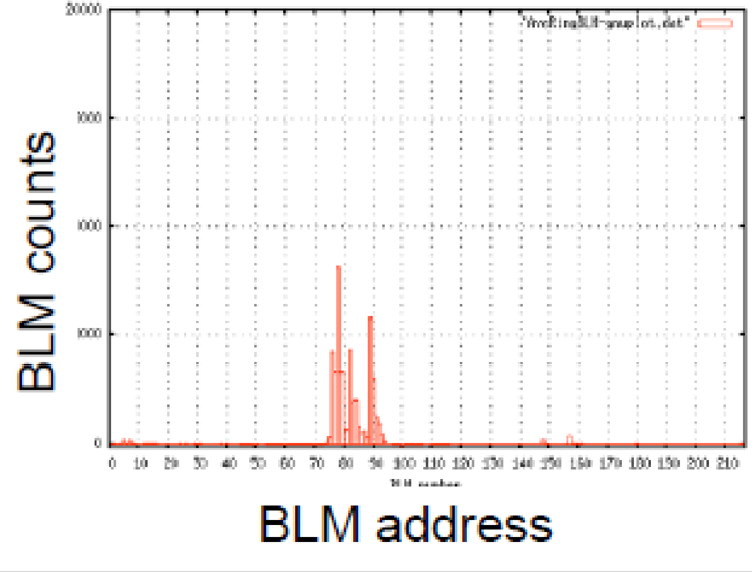


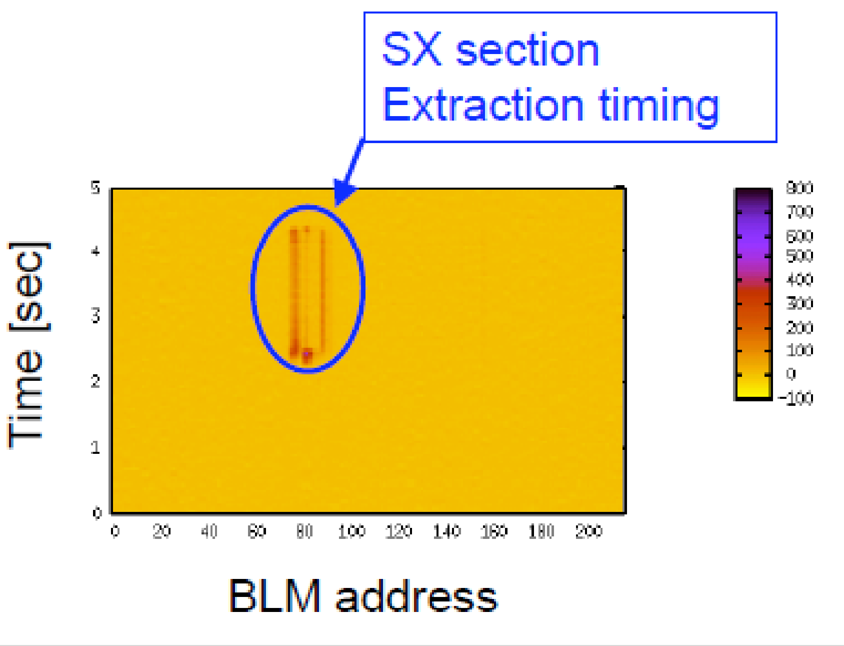
MR Proton Beam Extraction

- Fast extraction **50-100kW**
  - Beam extraction using kickers and septum magnets for the neutrino program
- Slow extraction **1.6kW**
  - Beam extraction using electro-static septum and septum magnets for particle and nuclear physics experiments
- Bunched slow extraction **Starting**
  - Slow extraction with keeping the beam bunch structure for the mu-e conversion experiment

Slow Extraction Efficiency

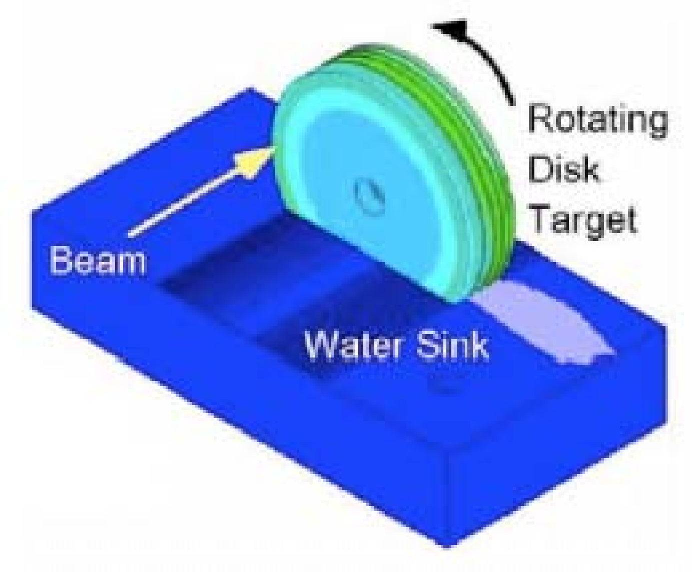
- **Bump orbit tuning in the SX section**
- **Position adjusting of ESS1, ESS2 and SMS1**

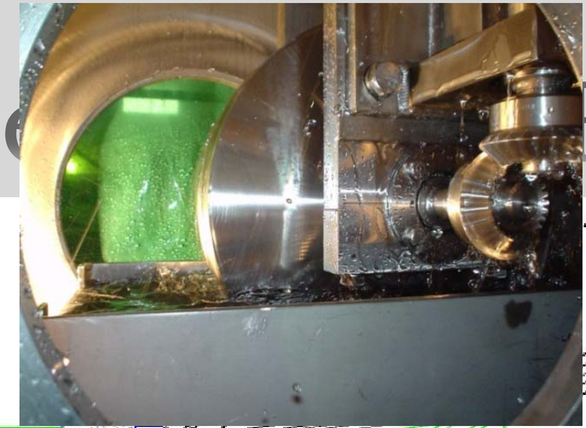


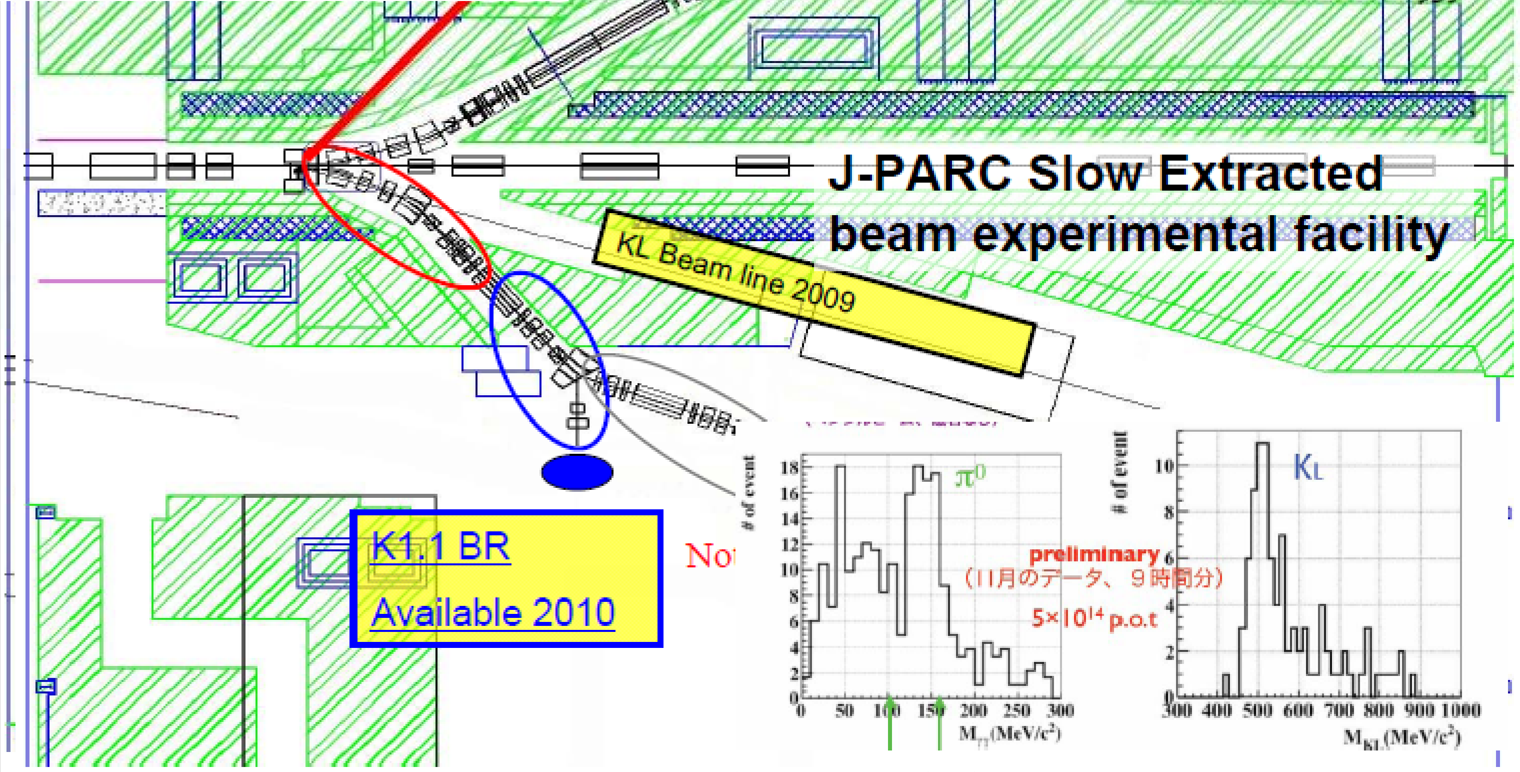

SX section
Extraction timing

Ext. efficiency: ~ 98.5 %

Se Beam







J-PARC Slow Extracted beam experimental facility

KL Beam line 2009

K1.1 BR
Available 2010

KAON PROGRAM

J-PARC Kaon Program

- **T-violating Muon P_T Measurement in $K^+ \rightarrow \pi^0 \mu^+ \nu$ Decays**
  - **TREK**
- **Study on $K_L \rightarrow \pi^0 \bar{\nu} \nu$**
  - KOTO

TREK

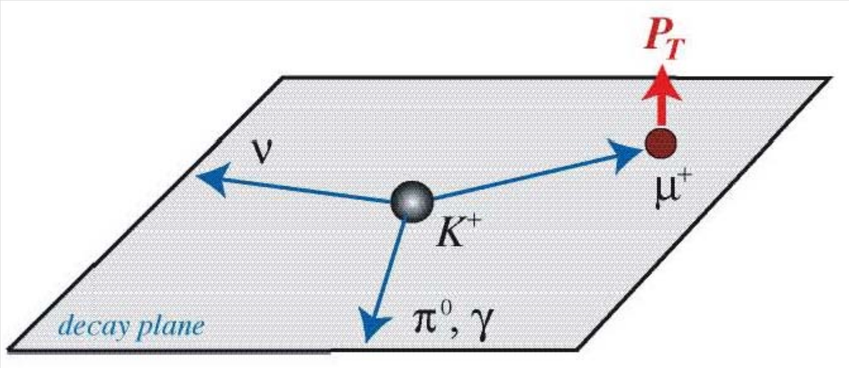
Time
Reversal violation
Experiment with
Kaons

Picture of the E246 detector

Transverse μ^+ polarization in $K_{\mu 3}$

$K^+ \to \pi^0 \mu^+ \nu$ decay

$$P_T = \frac{\sigma_\mu \cdot (p_{\pi^0,\gamma} \times p_{\mu^+})}{|(p_{\pi^0,\gamma} \times p_{\mu^+})|}$$



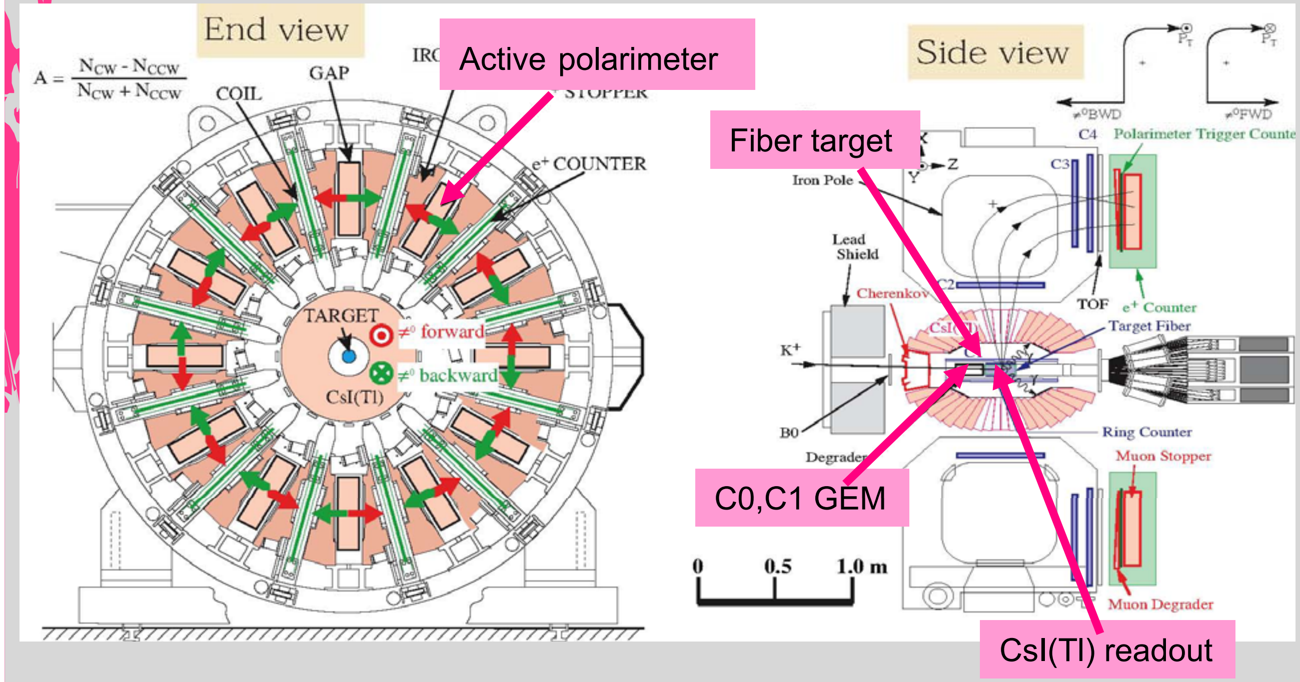
- P_T is T-odd, and spurious effects from final state interaction are small : P_T(FSI)<10^{-5}
  - Non-zero P_T is a signature of T violation
- Standard Model contribution to P_T: P_T(SM)<10^{-7}
  - P_T in the region 10^{-3}~10^{-4} is a sensitive probe of CP violation beyond SM
- Typical models with scaler interactions allowing a sizable P_T
  - Multi-Higgs doublet model
  - SUSY with R-parity violation or large squark mixing

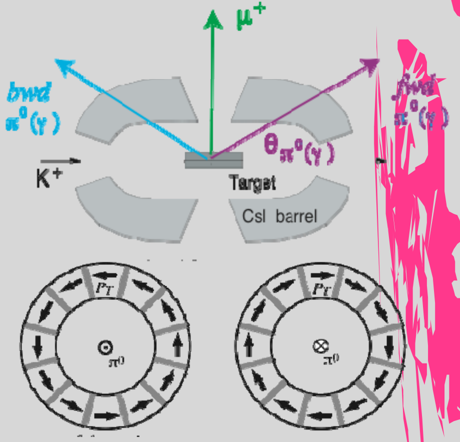
TREK experiment aims for a sensitivity of 10^{-4}

T Violation

TREK-Stopped Beam Method to Measure P_T

$K^+ \to \pi^0 \mu^+ \nu$





bwd $-\pi^0$ (γ) *fwd* $-\pi^0$ (γ)

Double ratio experiment

$A_T = (A^{fwd} - A^{bwd}) / 2$

$$A^{fwd(bwd)} = \frac{N_{cw} - N_{ccw}}{N_{cw} + N_{ccw}}$$

$P_T = A_T / \{\alpha <\cos\theta_T>\}$

α : analyzing power

$<\cos\theta_T>$: attenuation factor

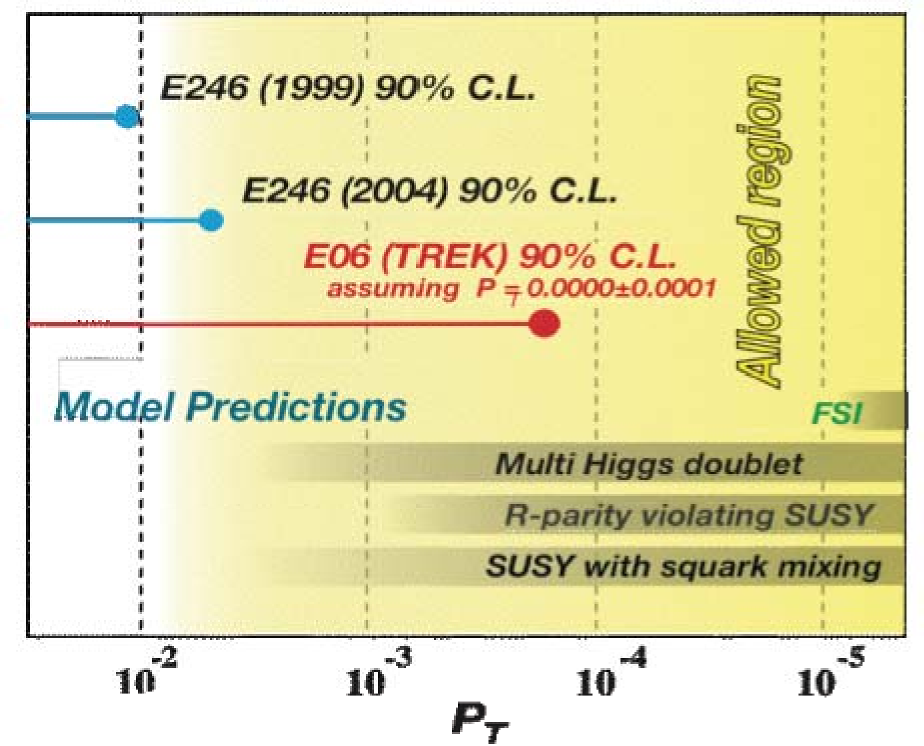
$\mathrm{Im}\xi = P_T / KF$:

KF : kinematic factor

- P_T is measured as the azimuthal asymmetry A_{e^+} of the μ^+ decay positrons

TREK Schedule

- **2006** : Proposal and Stage-1 approval
- **2007-2010** : Detector R&D,
  - Construction of Active polarimeter
- **2009** : Budget request for detector
- **2009-2010** : Construction of the K0.8 beamline
- **2010-2012** : Detector construction
- **2012-2013 (?)** : Run
- **More than 100 kW of beam power is necessary**



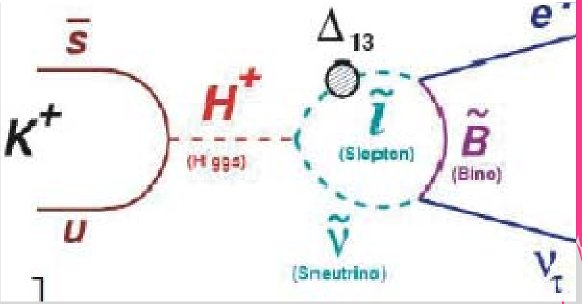
Lepton Universality in $K_{e2}/K_{\mu 2}$

- Standard Model

$$R_K^{SM} = \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)} = \frac{m_e^2}{m_\mu^2}\left[\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right](1+\delta_r) = (2.472 \pm 0.001) \times 10^{-5}$$

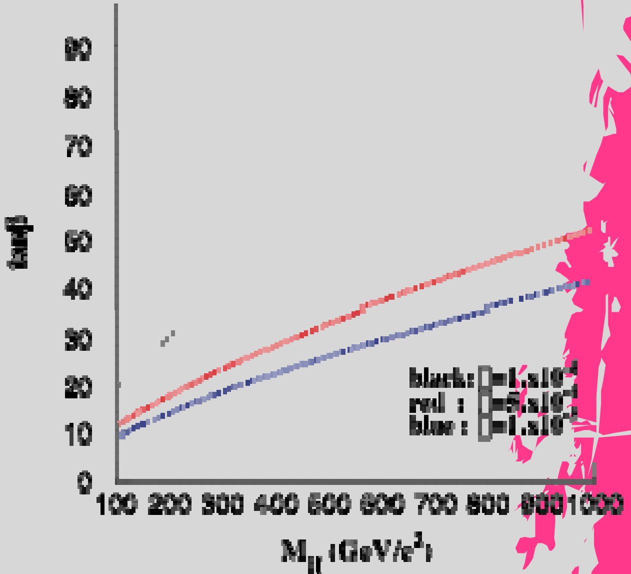
- SUSY

$$R_K^{LFV} = R_K^{SM}[1 + \frac{m_K^4}{M_{H+}^4}\frac{m_\tau^2}{m_e^2}\Delta_{13}^2 \tan^6\beta],$$



Deviation from SM can be 1.3%

- More sensitive than $\pi_{e2}/\pi_{\mu 2}$
- NA48/2; NA62
- R_K=(2.500±0.016) ×10^{-5} ; 0.7% →0.5%
- KLOE
- R_K=(2.493±0.031) ×10^{-5} ; 1.5%
- J-PARC@30 kW x 50 days
- 250 k events →$\Delta R_K/R_K$ = 0.2%



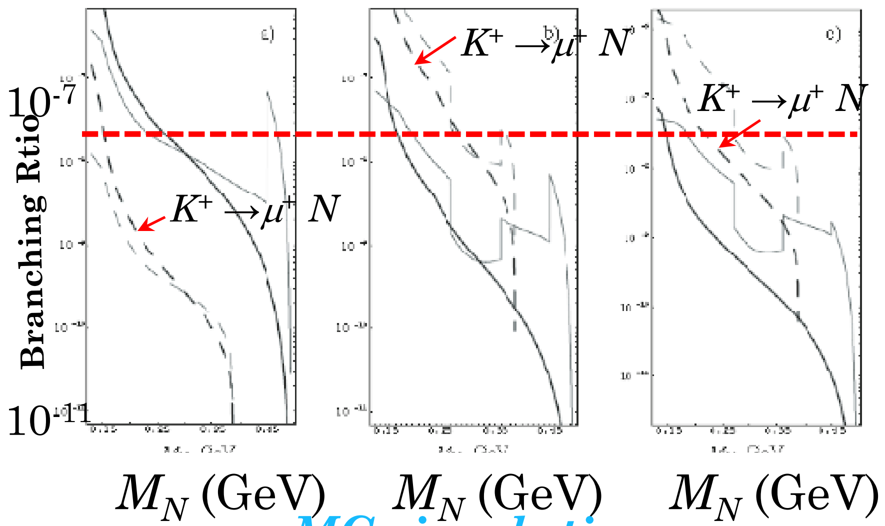
Heavy neutrino search in $K^+ \rightarrow \mu^+ N$

- ν Minimal Standard Model
  - (νMSM) : (Shaposhnikov *et al.*)
    - Explanation of DM and BAU
    - Possibility of $M_N \leqq M_K$
- monochromatic peak in $K^+ \rightarrow \mu^+ N$
  - Gorbunov and Shposhnikov (2007)
- μ^+ polarization : opposite to $K_{\mu 2}$ muon

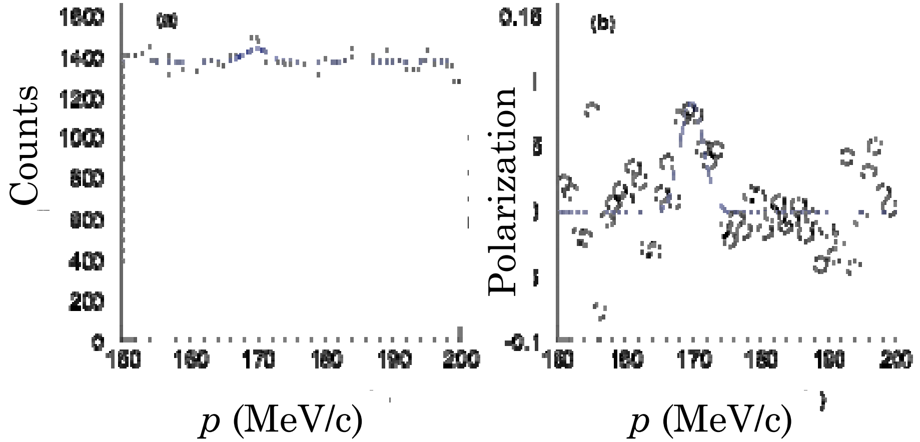
J-PARC@30kW, 50 days

Sensitivity of:
BR($K^+ \rightarrow \mu^+ N$) = 1x10^{-8}

different models

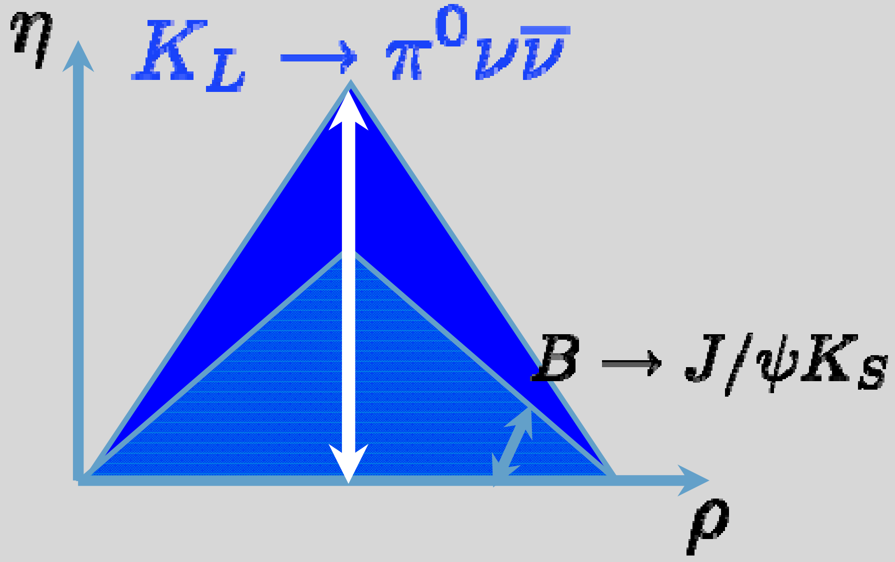


MC simulation



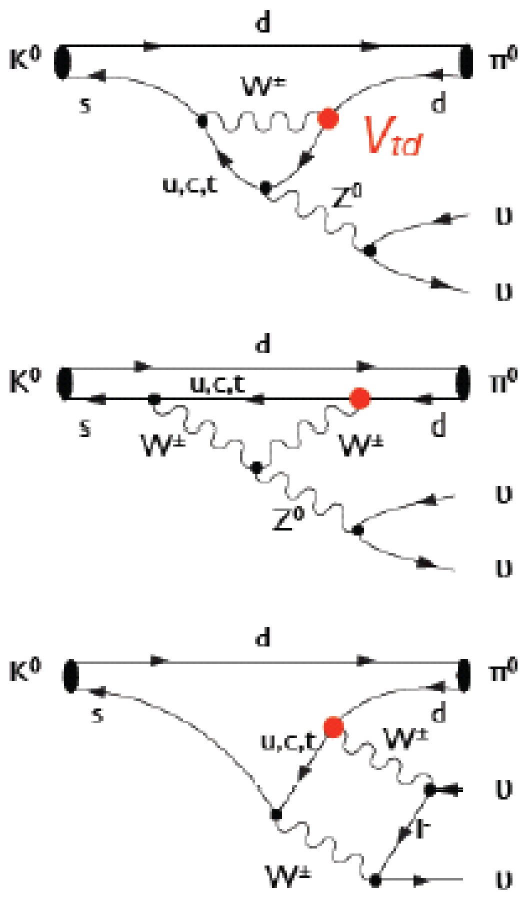
KOTO

- Study on $K_L \rightarrow \pi^0 \bar{\nu}\nu$ decay



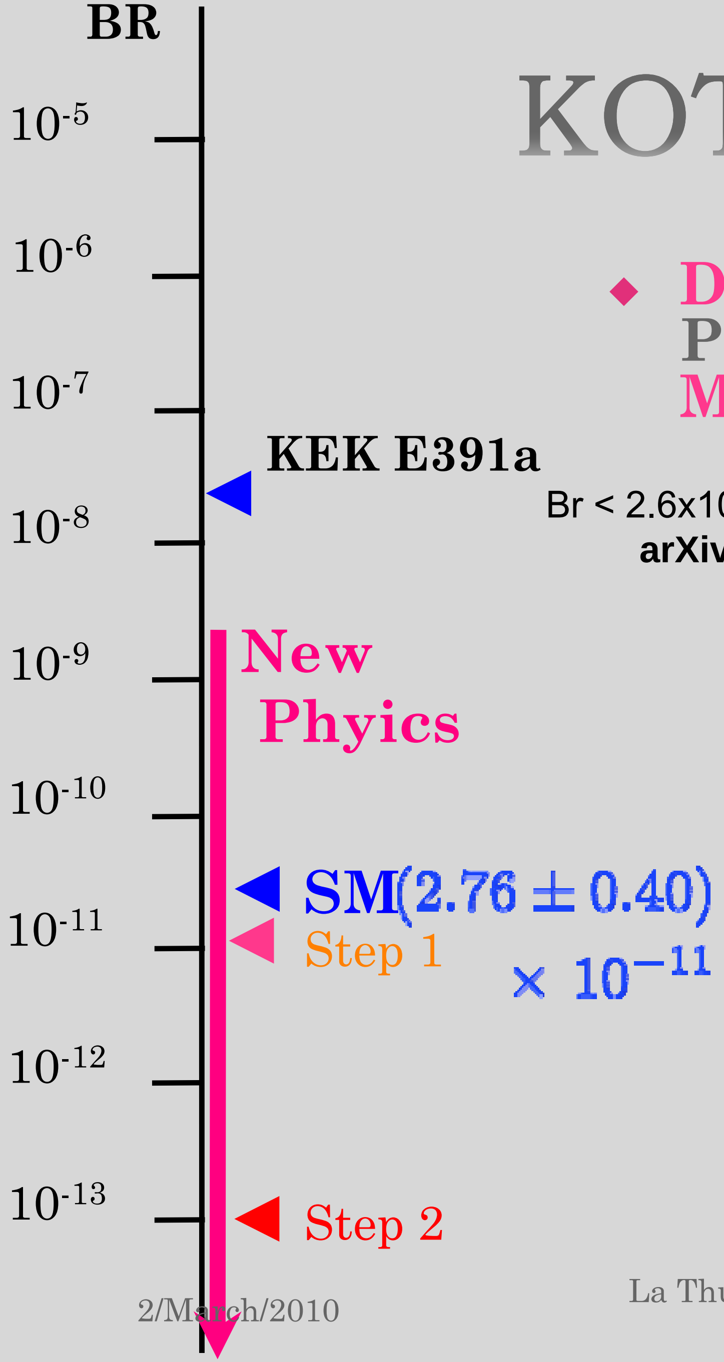
KOTO – K0 at TOkai

- Study on $K_L \rightarrow \pi^0 \overline{\nu}\nu$ decay
  - CP-Violating, FCNC process
    - Top-quark loop dominates in SM
    - Non-SM particle can contribute
  - Branching ratio proportional to $|\eta|^2$
    - K_0-$\overline{K}_0$ supurposition extracts imaginary pa of amplitude : $\mathrm{Im}(V_{td})$
  - Small theoretical uncertainty
    - $\mathrm{Br}(K_L \rightarrow \pi^0 \overline{\nu}\nu) = (2.8+/-0.4)\mathrm{x}10^{-11}$
    - Error dominated by SM parameters (intrinsic theoretical uncertainty is small)



KOTO - Goal

- **Direct CP-violating** rare decay for Physics **beyond the Standard Model**



KEK E391a

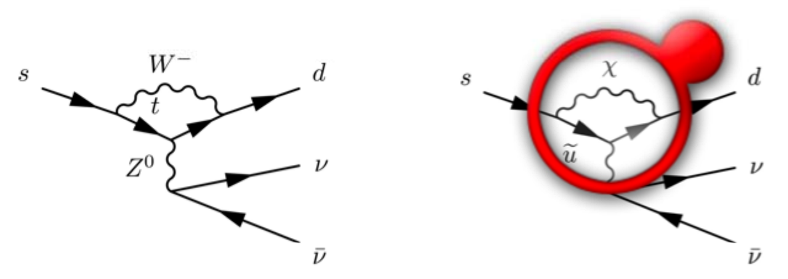
Br < 2.6x10^{-8} (90%CL)
arXiv:0911.4789

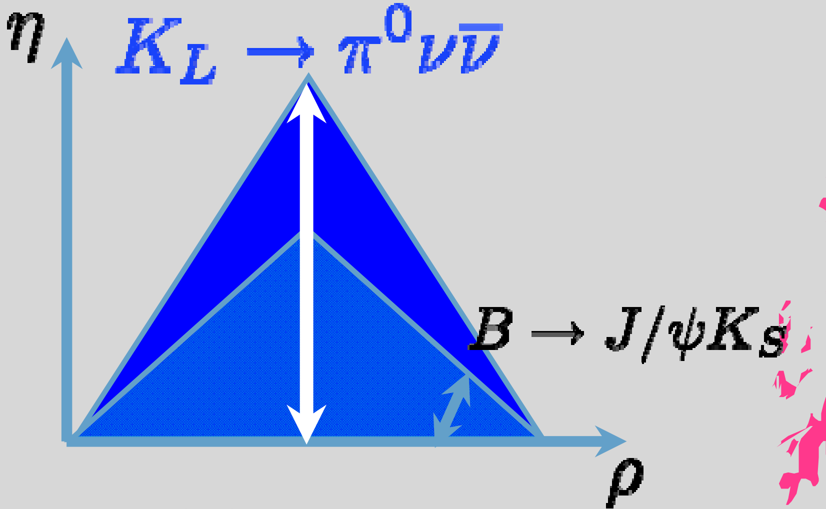
New Phyics

SM$(2.76 \pm 0.40) \times 10^{-11}$

Step 1

Step 2

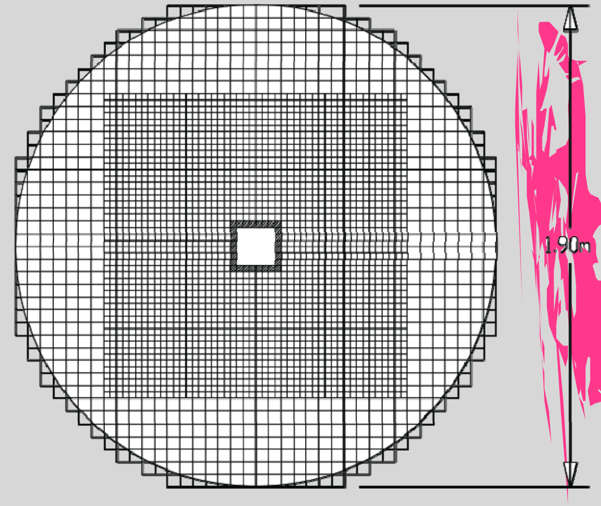


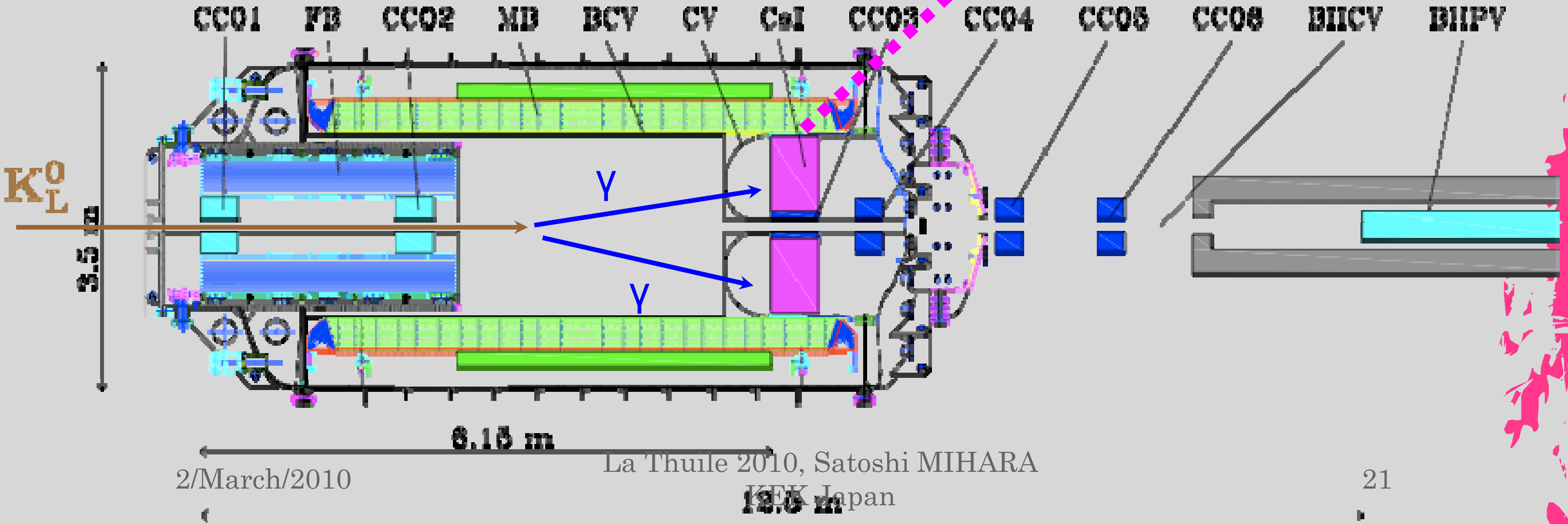


a long Japanese musical instrument(zither) with thirteen strings

KOTO Detector

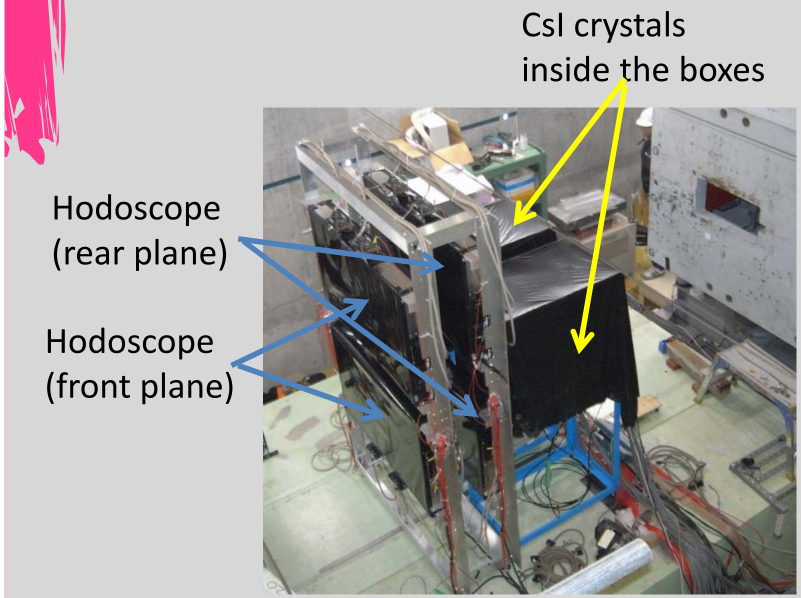
- New beamline
- Move and modify E391a detector
    - **CsI calorimeter (KTeV crystals)**
    - **Readout: waveform digitization**
    - Photon veto in the beam

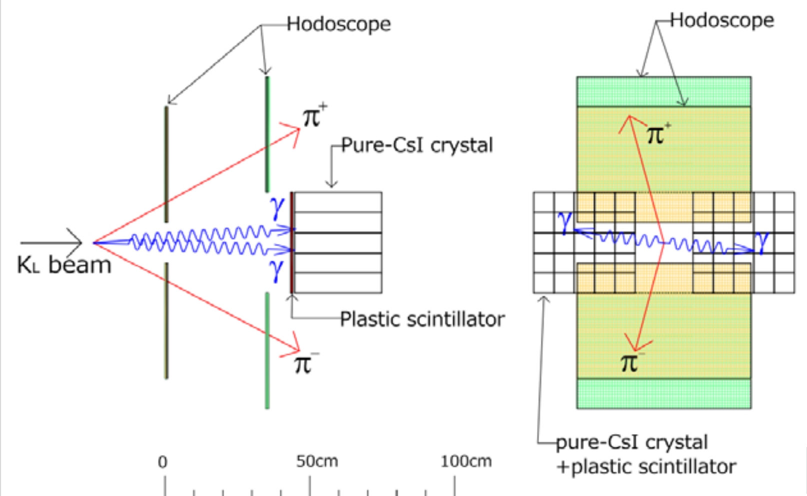




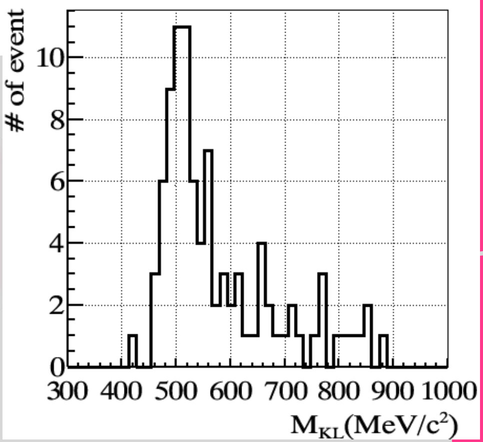
KOTO Status

- Beam survey using $K_L \rightarrow \pi^+\pi^-\pi^0$ decay (13%), 1kw slow extraction



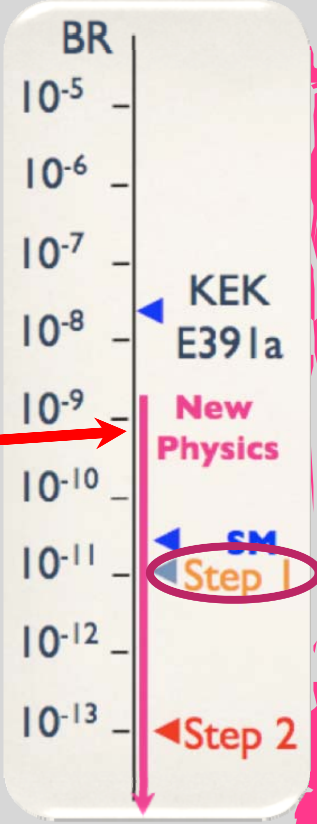


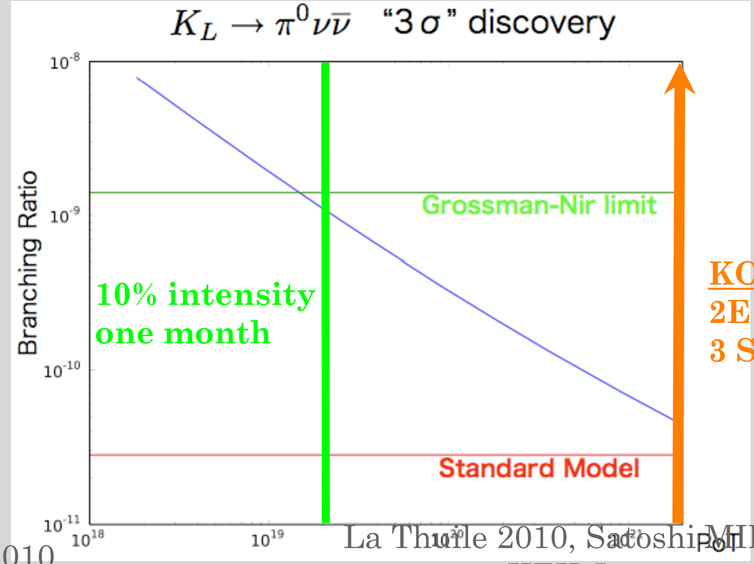
running in a few hours, $5\text{x } 10^{14}$ protons on tgt



Milestones of KOTO

- 2009: beamline construction
  - Beam survey (KL flux)
- 2010: CsI calorimeter construction
  - engineering run
  - beam properties with calorimeter
- 2011: detector installation
  - full engineering run, start physics run
  - **10% intensity(30kW) one month**





KOTO goal
2E14 pps
3 Snowmass years

MUON PROGRAM

J-PARC Muon Program

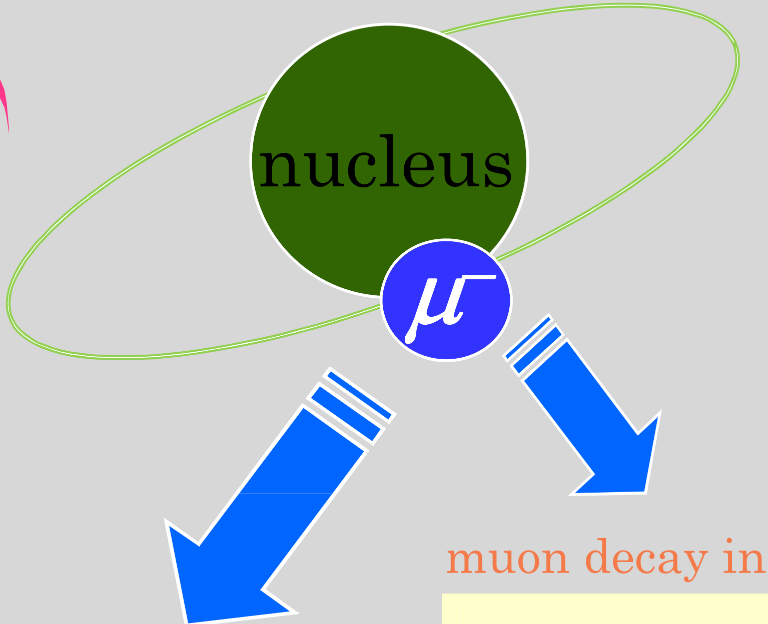
- m-e conversion search experiments
  - COMET
  - DeeMe
- Muon g-2/EDM measurement

COMET

- MEG ($\mu \rightarrow e\gamma$ search at PSI) is expected to reach and go beyond the current limit pretty soon → G. Piredda's presentation
- Need other experiment(s) to confirm it !
  - Using "different" physics process (with better sensitivity)!
- COMET (COherent Muon Electron Transition)
  - Submitted a proposal to J-PARC in 2008 and a CDR in 2009,and obtained Stage-1 approval in July 2009
  - Target sensitivity : 10^{-16}
  - cf Mu2E at FNAL

What is a μ-e Conversion ?

1s state in a muonic atom



muon decay in orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

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

Neutrino-less muon nuclear capture (=μ-e conversion)

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

lepton flavors changes by one unit

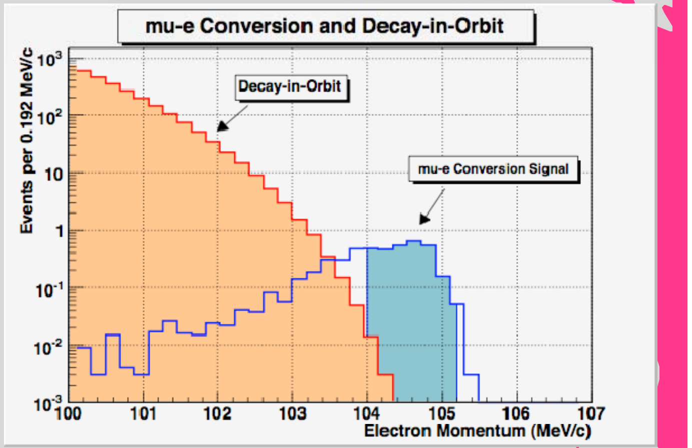
$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

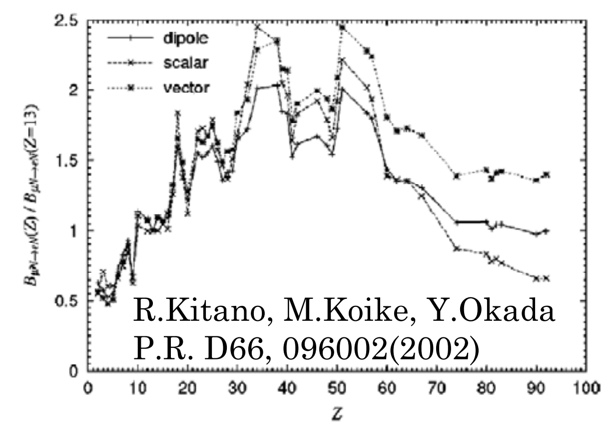
μ-e conversion Signal

- $E_{\mu e} \sim m_\mu - B_\mu$
  - B_μ: binding energy of the 1s muonic atom
- Comparison with μ→eγ (and μ→3e) from the view point of experimental technique

	Background	Challenge
μ→eγ and μ→3e	Accidental	Detector performance resolution, high rate
μ-e conversion	Beam	Beam background

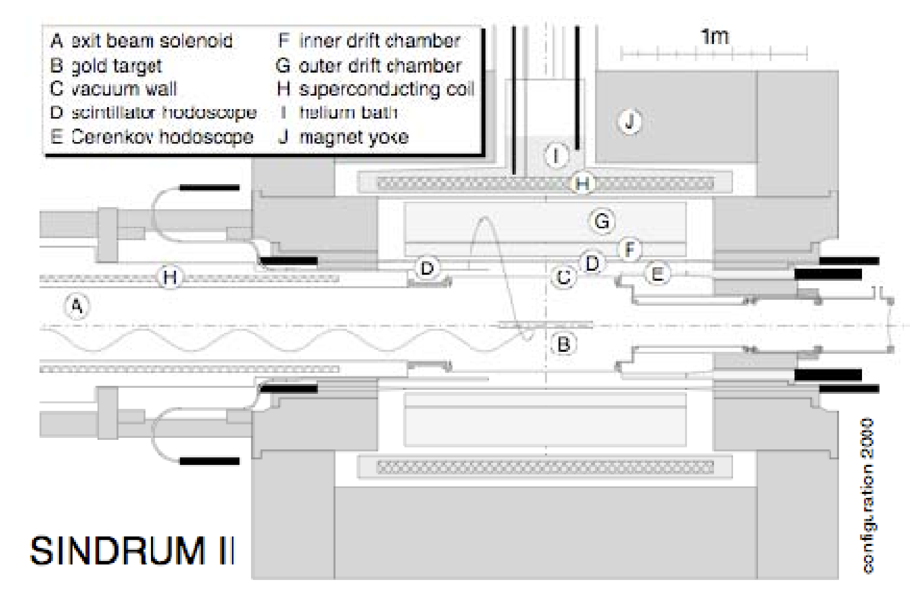
- Improvement of a muon beam is possible, both in purity (no pions) and in intensity (***thanks to muon collider R&D***). A higher beam intensity can be taken because of no accidentals.
- Potential to discriminate different models through studying the Z dependence





R.Kitano, M.Koike, Y.Okada
P.R. D66, 096002(2002)

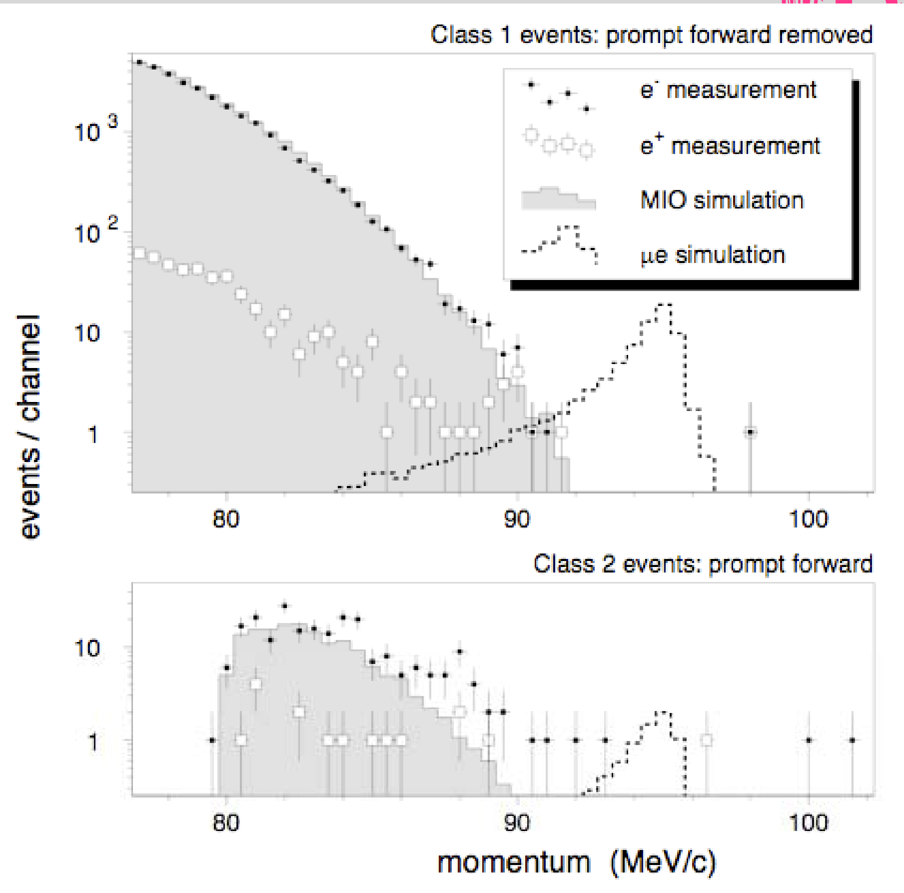
The SINDRUM-II Experiment (at PSI)



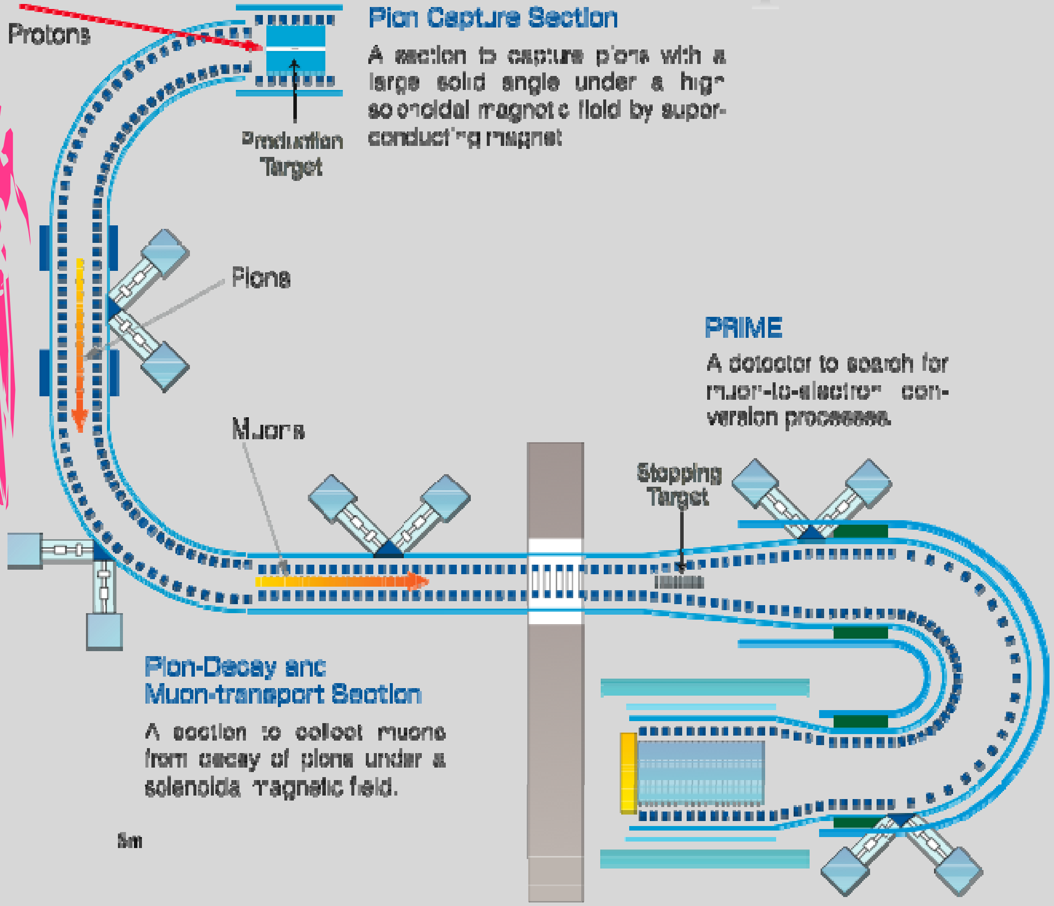
SINDRUM-II used a continuous muon beam from the PSI cyclotron. To eliminate beam related background from a beam, a beam veto counter was placed.

Published Results

$$B(\mu^- + Au \to e^- + Au) < 7 \times 10^{-13}$$



Overview of the COMET Experiment



Pion Capture Section

A section to capture pions with a large solid angle under a high solenoidal magnetic field by superconducting magnet

PRIME

A detector to search for muon-to-electron conversion processes.

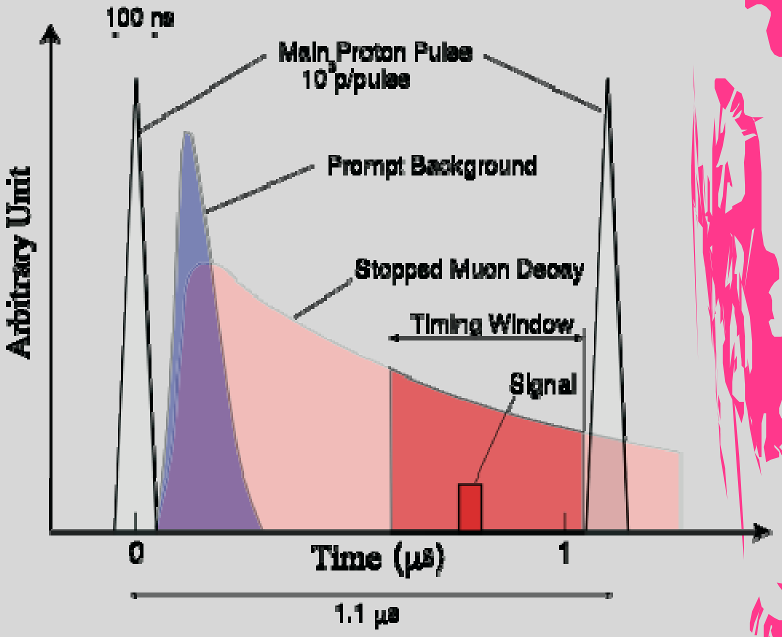
Pion-Decay and Muon-transport Section

A section to collect muons from decay of pions under a solenoidal magnetic field.

- **Proton Beam**
  - $p \to \pi \to \mu$
- **The Muon Source**
  - Proton Target
  - Pion Capture
  - Muon Transport
- **The Detector**
  - Muon Stopping Target
  - Electron Transport
  - Electron Detection

Requirements for the Muon Beam

- Backgrounds
  - Beam Pion Capture
    - π^-+(A,Z) → (A,Z-1)* → γ + (A,Z-1)
      γ → e^+ e^-
    - ***Prompt timing → good Extinction!***
  - μ^- decay-in-flight, e^- scattering, neutron streaming
- Requirements from the experiment
  - Pulsed
  - High purity
  - Intense and high repetition rate



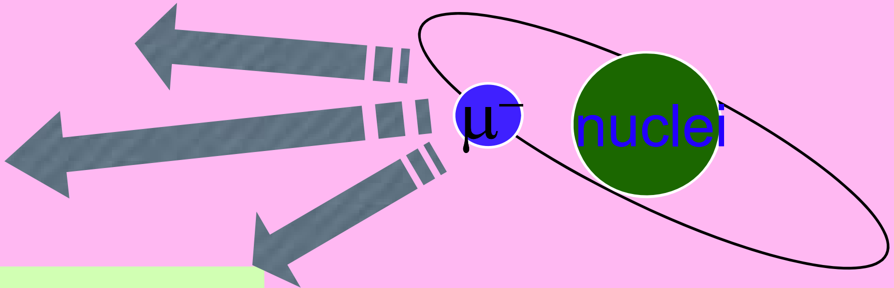
Muon Capture(MC)

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

Muon Decay in Orbit (MDO)

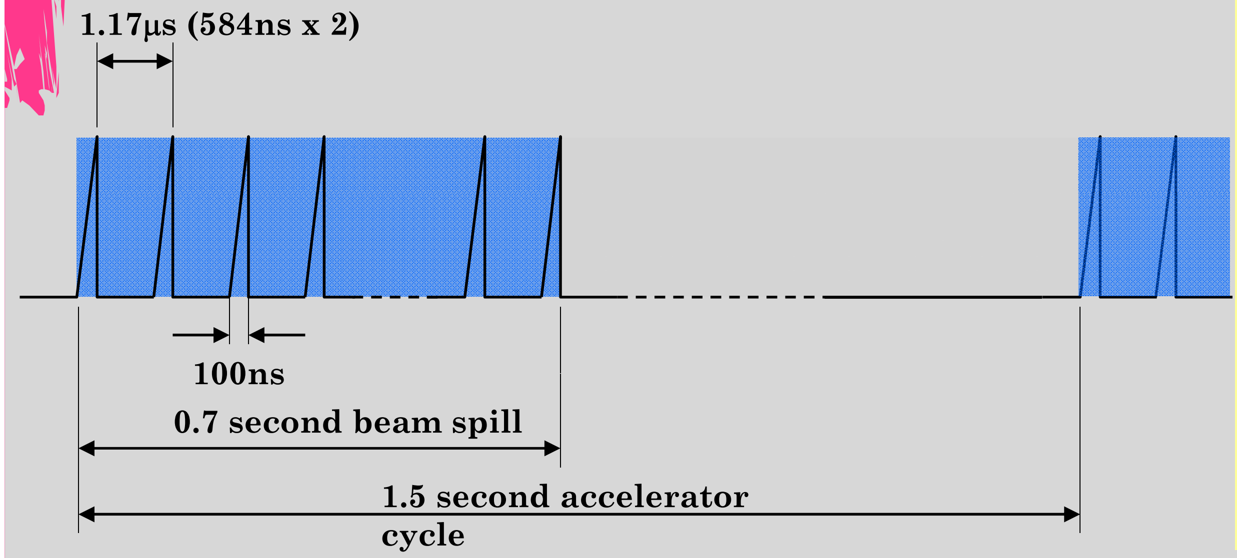
$$\mu^- \rightarrow e^- \nu \overline{\nu}$$

SIGNAL $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$



Requirements for the Proton Beam

- Proton beam structure for the mu-e conversion search
  - 100nsec bunch width, 1.1μsec bunch-bunch spacing
  - 8GeV to suppress anti-proton background
  - $< 10^{11}$ proton/bunch, limited by the detector performance
  - Repetition rate as high as possible within tolerable CR background
- Extinction
  - Residual protons in between the pulses should be $< 10^{-9}$



$N_{bg} =$

$NP \times R_{ext} \times Y_\pi/P \times A_\pi \times P_\gamma \times A$

NP : total # of protons ($\sim 10^{21}$)

R_{ext} : Extinction Ratio (10^{-9})

Y_π/P : π yield per proton (0.015)

A_π : π acceptance (1.5×10^{-6})

P_γ : Probability of γ from π (3.5×10^{-5})

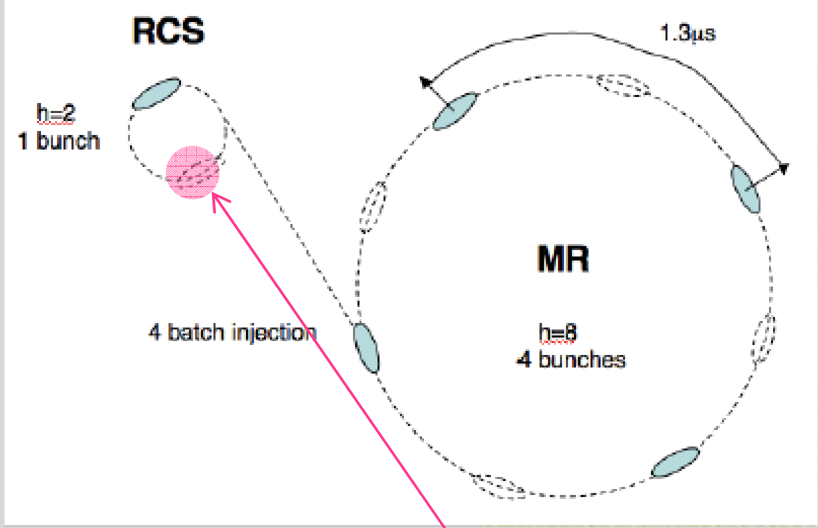
A : detector acceptance (0.18)

$BR=10^{-16}$, $N_{bg}=O(0.1)$ →

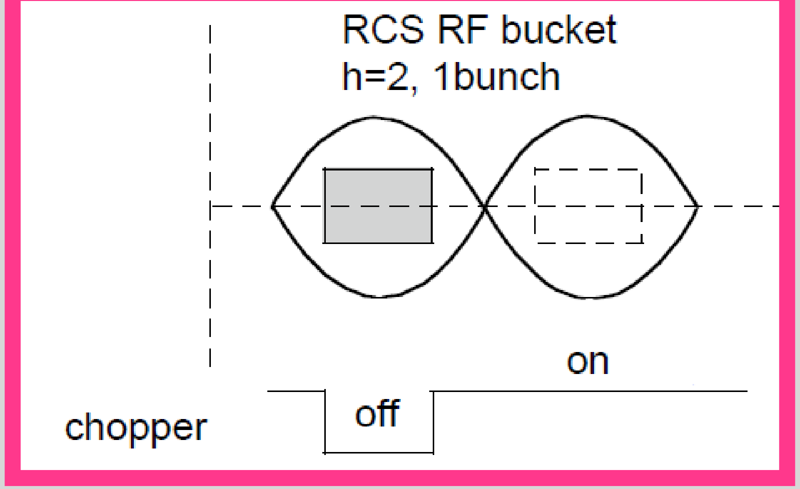
Extinction < 10^{-9}

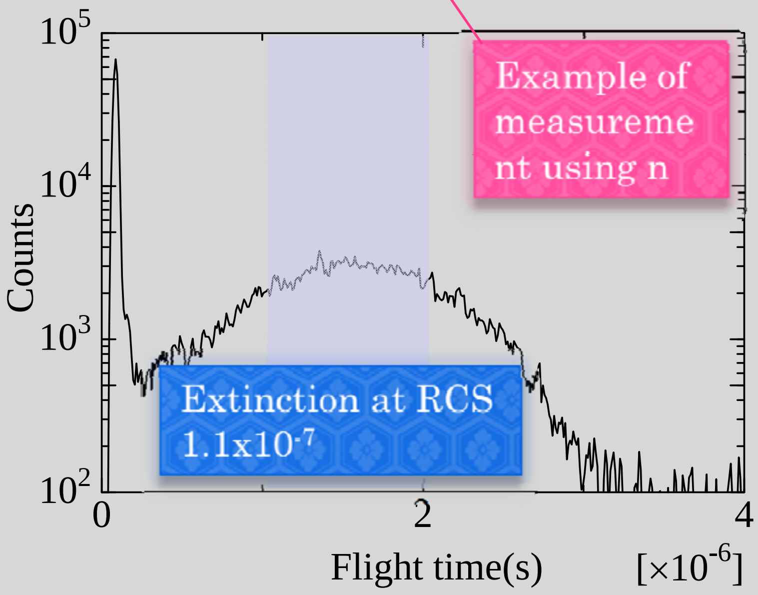
Proton Acceleration for COMET

- RCS: h=2 with one empty bucket
- MR:h=8(9) with 4(3) empty buckets
- Bunched slow extraction
  - Slow extraction with RF cavity ON



Realization of an empty bucket in RCS by using the chopper in Linac





Example of measurement using n

Extinction at RCS $1.1\text{x}10^{-7}$

Signal Sensitivity

2x10^7 sec running

- Single event sensitivity

$$B(\mu^- + Al \to e^- + Al) \sim \frac{1}{N_\mu \cdot f_{cap} \cdot A_e},$$

  - N_μ is a number of stopping muons in the muon stopping target. It is 2.0x10^{18} muons.
  - f_{cap} is a fraction of muon capture, which is 0.6 for aluminum.
  - A_e is the detector acceptance, which is 0.031.

total protons	8.5x10^{20}
muon yield per proton	0.0035
muon stopping efficiency	0.66
# of stopped muons	2.0x10^{18}

Single event sensitivity 2.6 x 10^{-17}

90% C.L. upper limit 6.0 x 10^{-17}

Potential Background Events

- Background rejection is the most important in searches for rare decays.
- Types of backgrounds for $\mu^- + N \rightarrow e^- + N$ are,

Intrinsic backgrounds	originate from muons stopping in the muon stopping target.	muon decay in orbit radiative muon capture muon capture with particle emission
Beam-related backgrounds	caused by beam particles, such as electrons, pions, muons, and anti-protons in a beam	radiative pion capture muon decay in flight pion decay in flight beam electrons neutron induced antiproton induced
Other backgrounds	caused by cosmic rays	cosmic-ray induced (pattern recognition error)

Background Estimation Summary

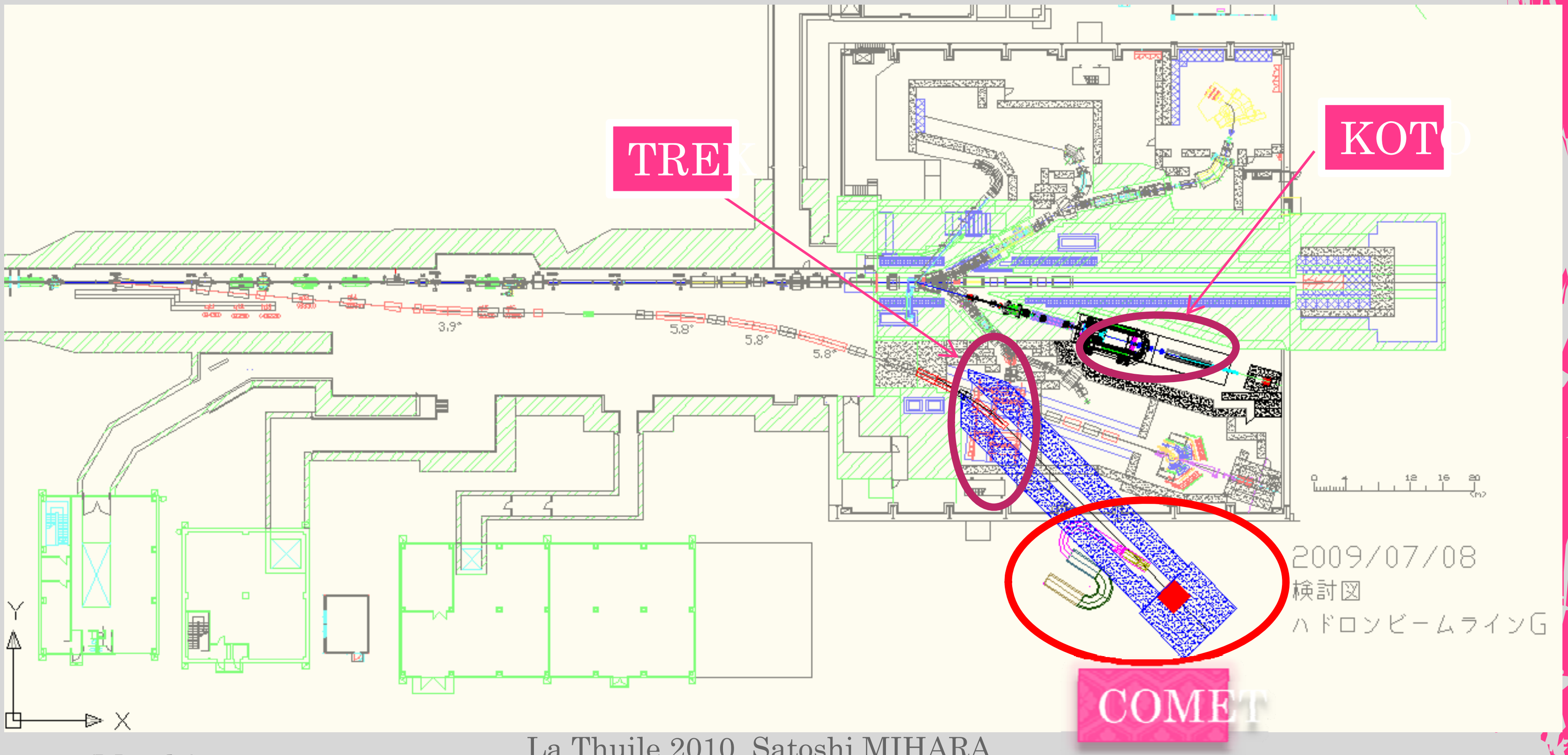
Background	Events	Comments
Radiative Pion Capture	0.05	
Beam Electrons	<0.1	MC stat limited
Muon Decay in Flight	<0.0002	
Pion Decay in Flight	<0.0001	
Neutron Induced	0.024	For high E n
Delayed-Pion Radiative Capture	0.002	
Anti-proton Induced	0.007	For 8 GeV p
Muon Decay in Orbit	0.15	
Radiative Muon Capture	<0.001	
Muon Capture with n Emission	<0.001	
Muon Capture with Charged Part. Emission	<0.001	
Cosmic-Ray Muons	0.002	
Electrons from Cosmic-Ray Muons	0.002	
Total	0.34	

Assuming proton beam extinction < 10^{-9}

Experimental Space

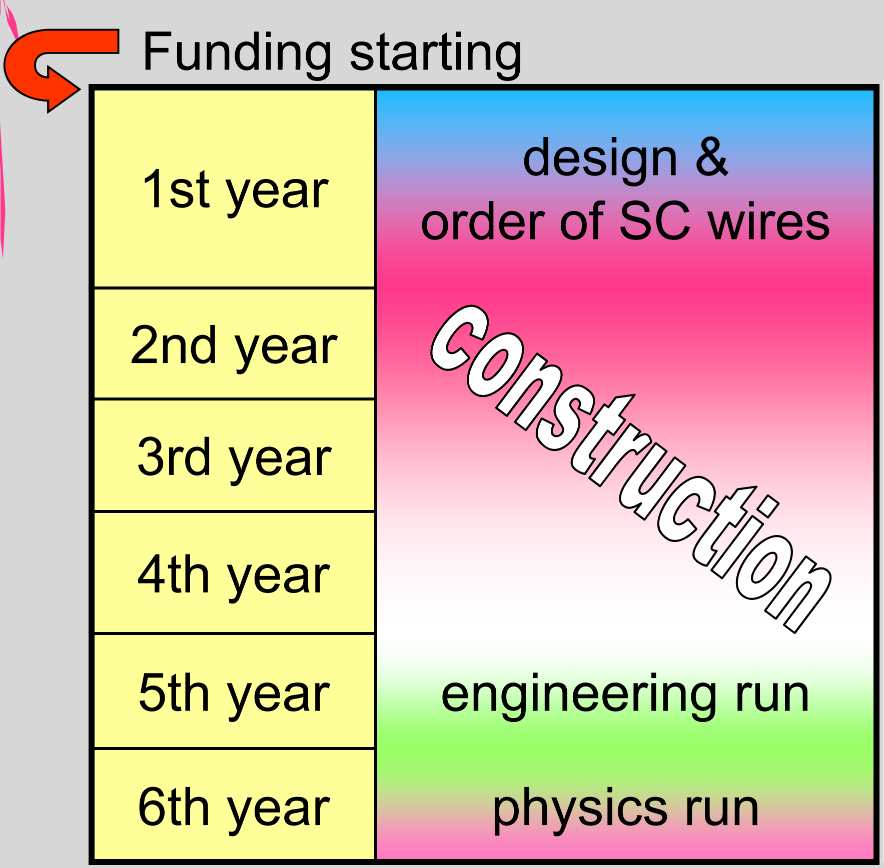
A possible layout

- Target and beam dump outside the hall
- Share the upstream proton transport line with the high p beam line
- External extinction device in the switch yard



Toward Starting Experiment

- R&D work in progress
  - Detector, SC magnet, Proton extinction



Funding starting

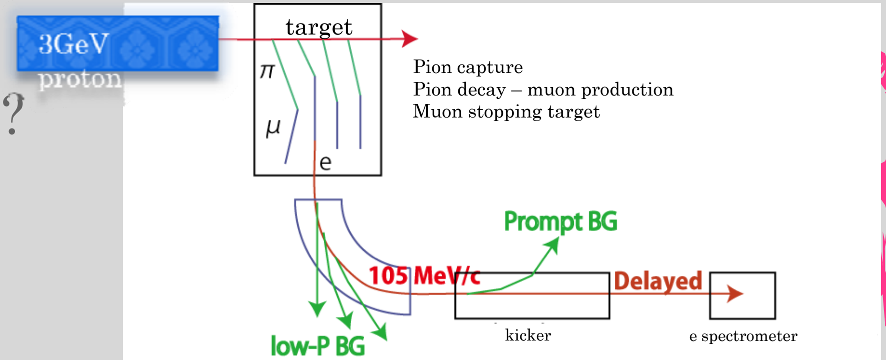
1st year	design & order of SC wires
2nd year	construction
3rd year	
4th year	
5th year	engineering run
6th year	physics run

Item	Cost (Oku JPY)
Proton beam line	
Proton beam line magnets	17
Proton beam dump	2
Radiation shielding for a proton beam line	3
Superconducting Solenoid	35.7
Detector	
Electron tracker	2.1
Electron calorimeter	2.3
Cosmic ray shield	3
DAQ system	0.5
Infrastructure	
Refrigeration	4.7
Pion production system and tungsten shielding	2.3
Civil construction	
Extension of the NP experimental hall	3
Total	75
Total (with 20% contingency)	90

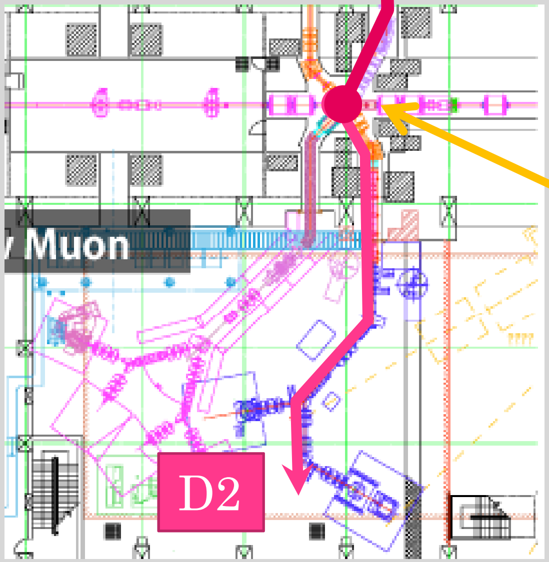
DeeMe

Another m-e conversion search at J-PARC

- Mu-e conversion electron directly comes from the target?
- 10^{10} muon stops/sec/MW
- Transport 105MeV/c delayed electrons
- Expected reach (crude)
  - D2 beam line (40msr)
    - 8×10^{-13} for C (10^7 sec)
    - $2X10^{-13}$ for Al (10^7 sec)
  - New beam line (150msr)
    - 10^{-14} for Al (2×10^7 sec)
  - cf SINDRUM II limit: 7×10^{-13}



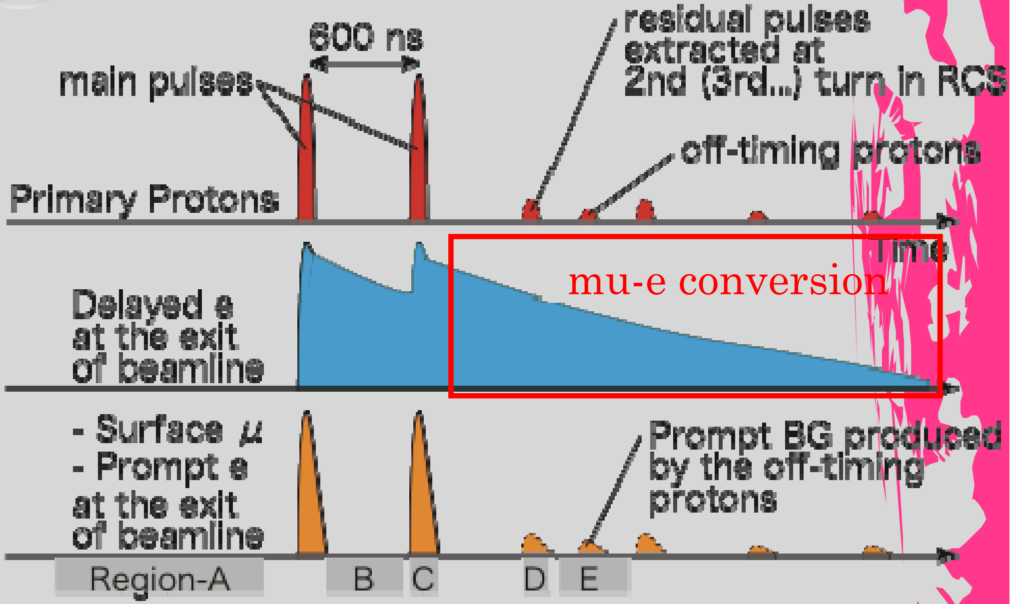
New μ beam line



Graphite target with water cooling

Background

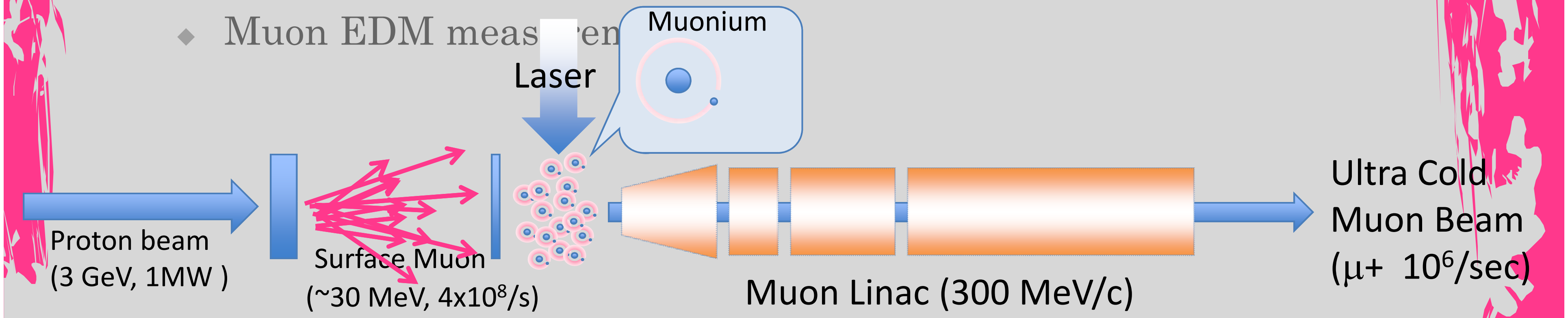
- Event signature
  - $P_e = 105$ MeV/c
  - $T_e > \sim\mu$sec

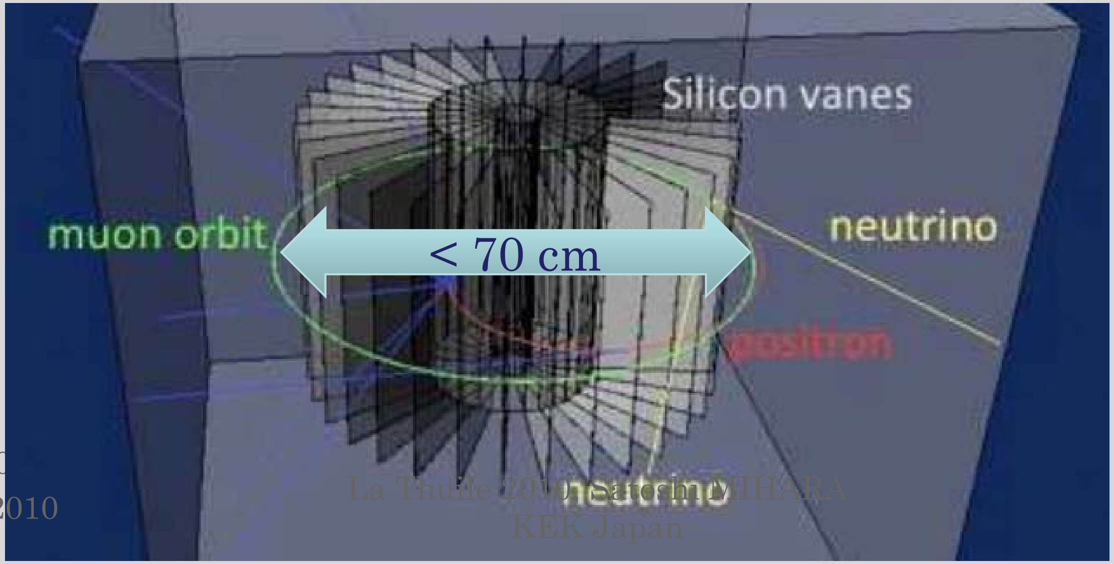


- Any particle production 1μsec later than the prompt proton timing?
  - Only decay product of μ
    - Michel electron P_e<55MeV/c
- If any off-timing proton exists, that can be BG
  - Extinction < 10^{-14}

g-2/EDM Measurement

- Use very cold muons and precisely controlled magnetic field
  - Smaller size detector for lower muon momentum than the "magic" momentum
  - Muon EDM meas en





Injection !

Muon Spin precession

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

$$a_\mu - \frac{1}{\gamma^2 - 1} = 0$$

$$\gamma_{\text{magic}} = 29.3$$

$$p_{\text{magic}} = 3.09 \text{ GeV}/c$$

$\eta: \; d_\mu = \frac{\eta}{2}\left(\frac{e}{2m} \right)$ Electric Dipole Moment

$$d_e = (6.9 \pm 7.4) \times 10^{-28} e \cdot \text{cm}$$

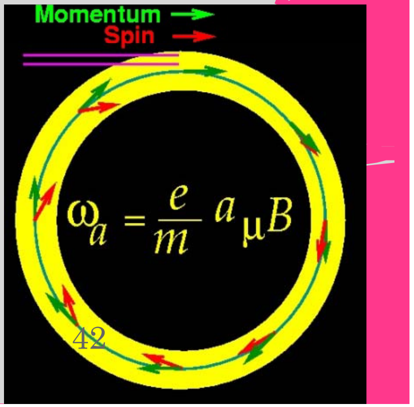
Expected to be

$$d_\mu < (1.5 \pm 1.4) \times 10^{-25} e \cdot \text{cm}$$

Measured to be

$$d_\mu = (3.7 \pm 3.4) \times 10^{-19} e \cdot \text{cm}$$

$$\vec{\omega}_a = -\frac{e}{m} a_\mu \vec{B}$$

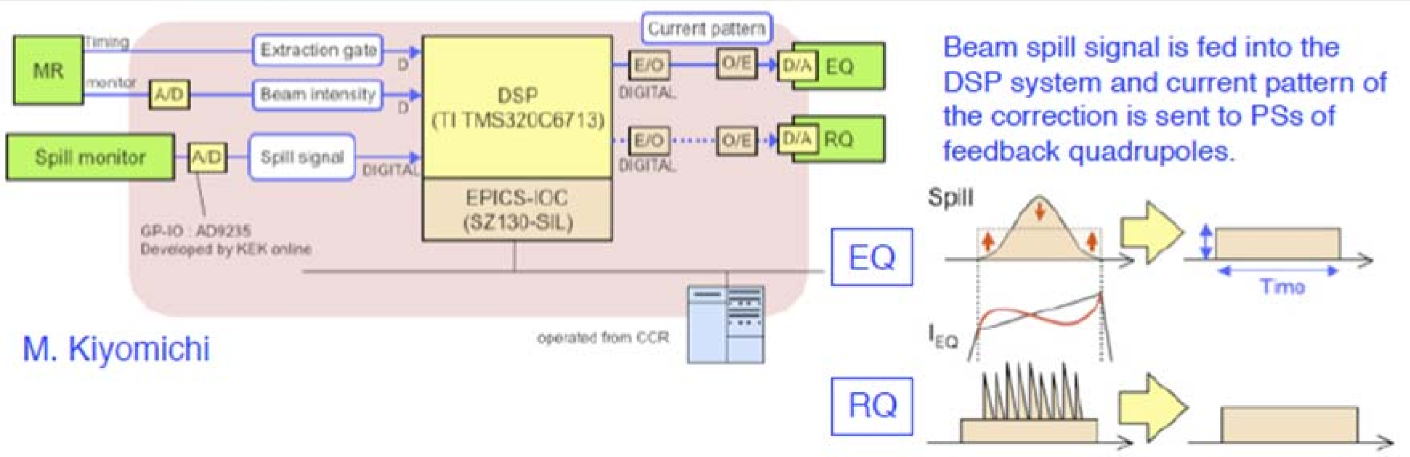


Summary

- J-PARC accelerator conditioning to reach the planned beam power is in progress
  - Understanding beam properties
  - Linac Upgrade
- Particle (and nuclear) physics experiments are starting
  - Kaon program: TREK, KOTO
  - Muon program: COMET, DeeMe, g-2/EDM

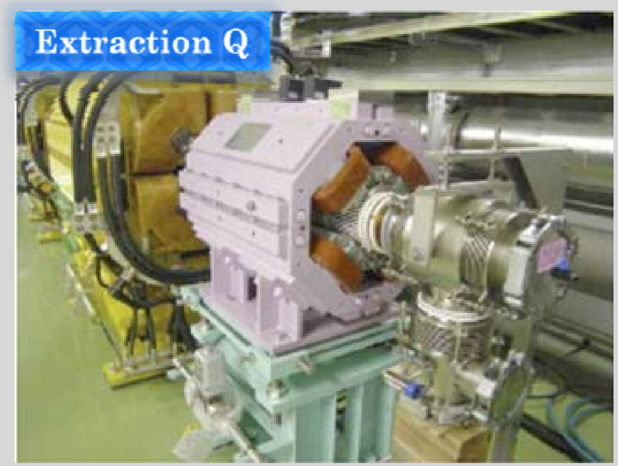
Spill Feedback System

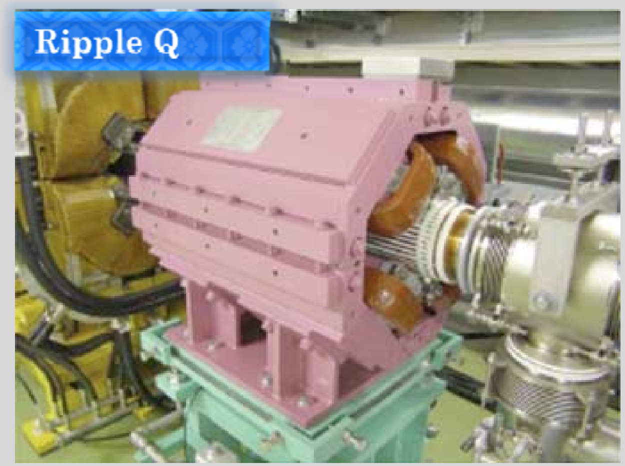
- Spill feedback using EQ, RQ and DSP system



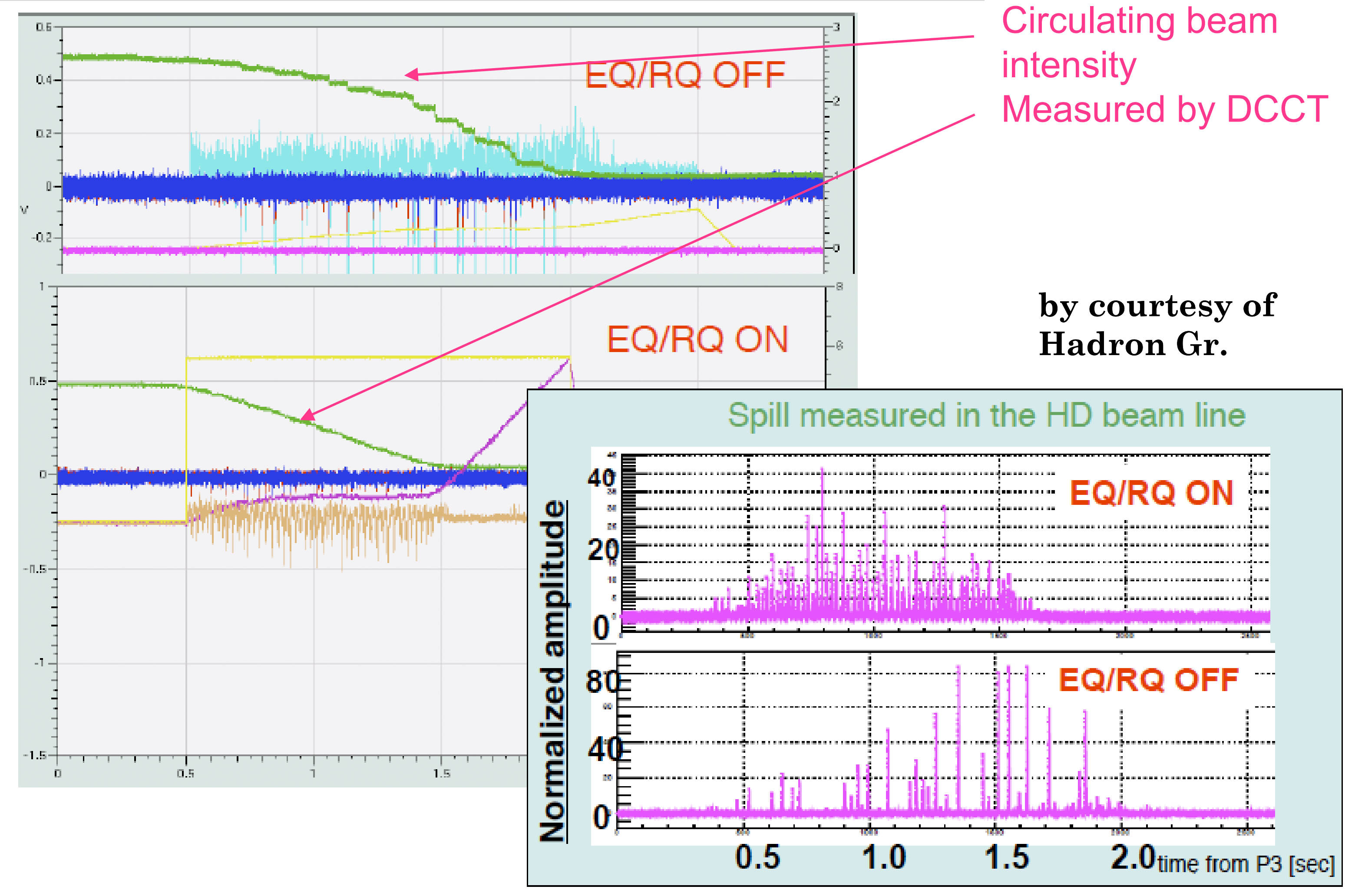
M. Kiyomichi

Beam spill signal is fed into the DSP system and current pattern of the correction is sent to PSs of feedback quadrupoles.





Slow Ext Beam Commissioning with Spill Feedback System



Circulating beam intensity
Measured by DCCT

by courtesy of Hadron Gr.

Noise canceling headphones

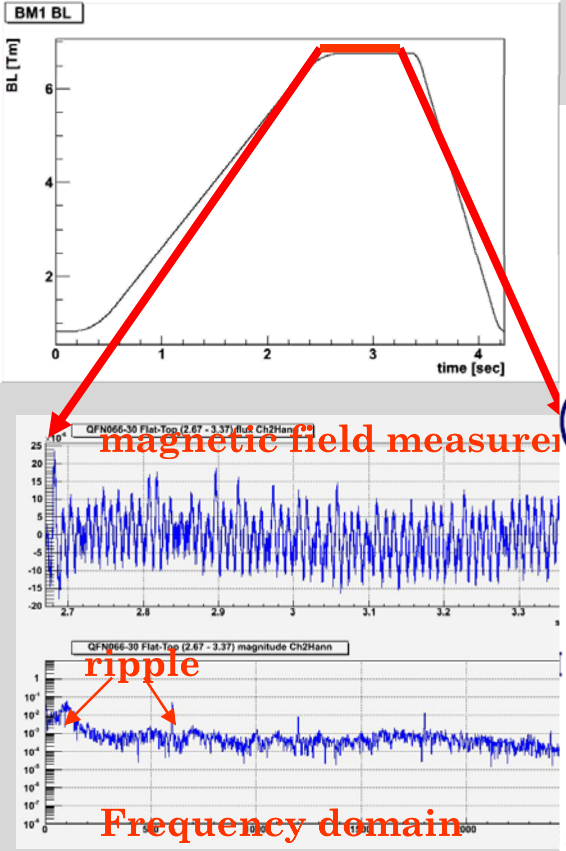
Ripple Cancellation of MR Magnetic Field using a Trim Coil

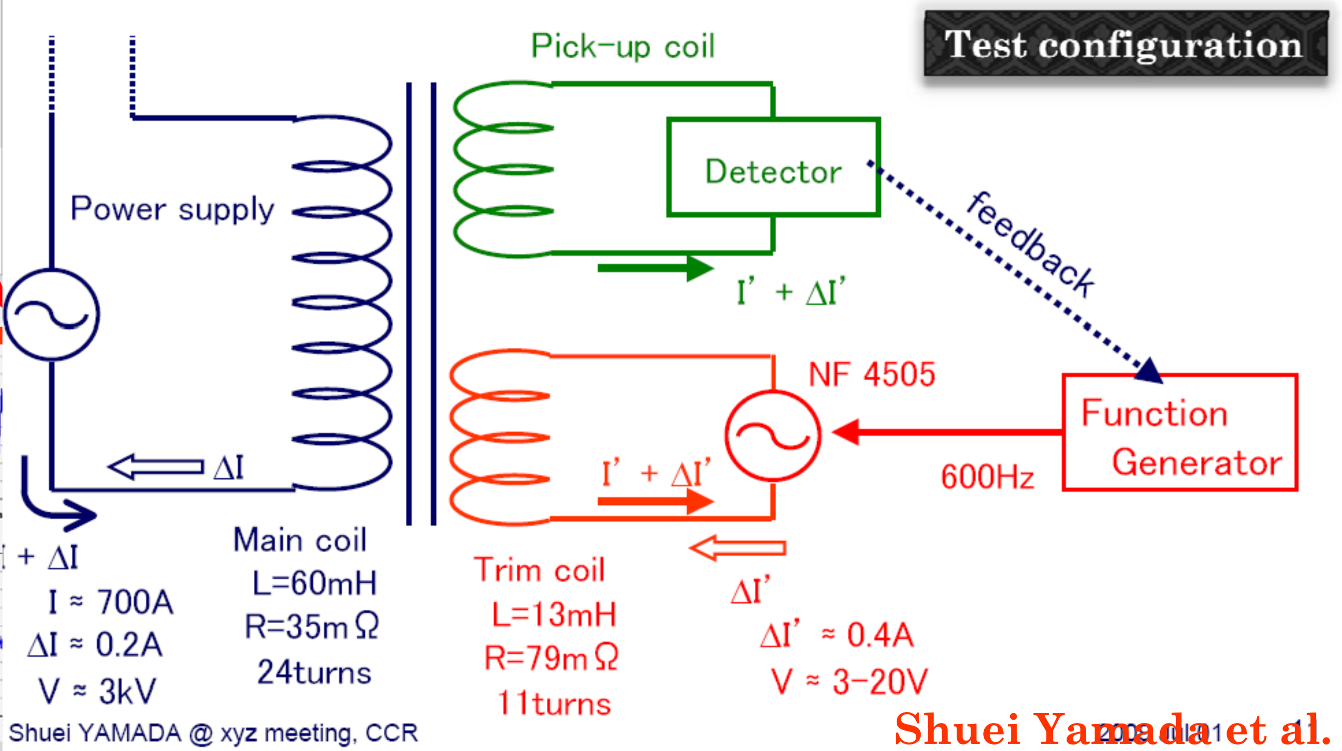
- Pick-up mag. Field
- Feedback to magnet ~20kHz

Early stage of R&D
→encouraging results

Spill control
☐Power supply improvement
☐SX power cable configuration
☐Feedback Q
  - **➢Extraction Q (EQ)**
  - **➢Ripple compensation Q (RQ)**

☐Cancellation with trim coil



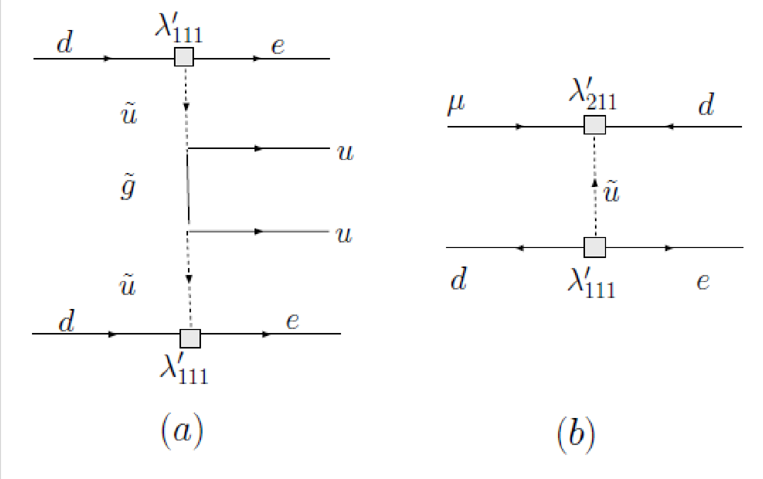


Shuei Yamada et al.

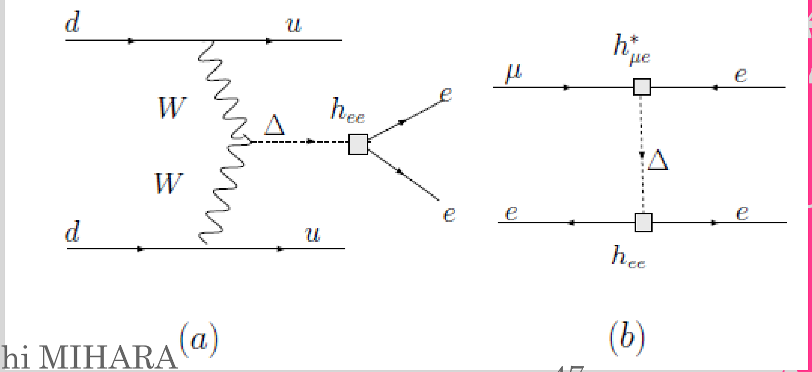
0νββ and μ-e conversion

- V. Cirigliano et al. PRL 93, 231802 (04)
- R=$B(\mu\rightarrow e)/B(\mu\rightarrow e\gamma)$
- RPV-SUSY
  - R >> 10^{-2}
- LRSM (Left-Right Symmetric Model)
  - R~O(1)
- Important to measure R to extract $m_{0\nu\beta\beta}$ from $\Gamma_{0\nu\gamma\gamma}$

RPV-SUSY



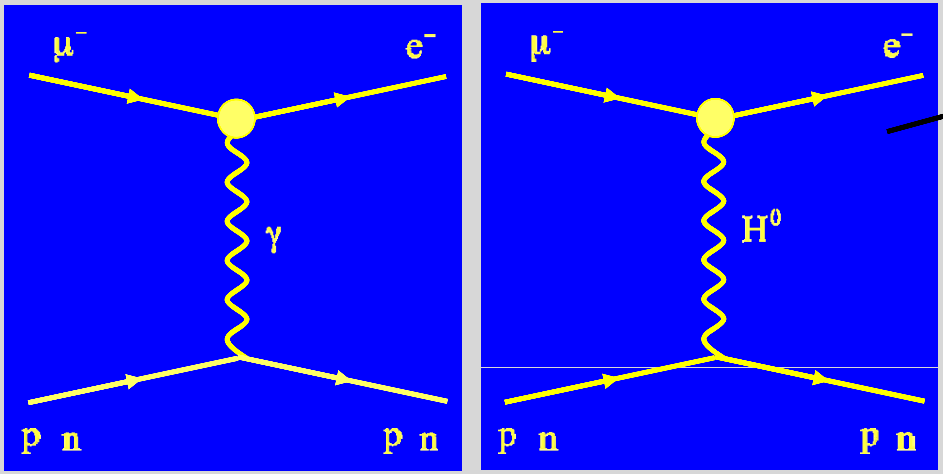
LRSM



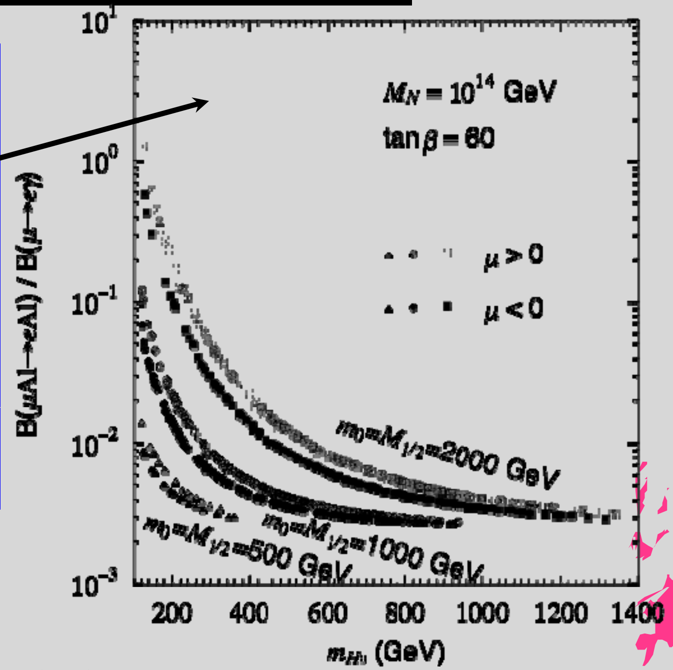
Comparison between
μ→eγ and μ-e Conversion (Physics Sensitivity)

- Photonic and non-photonic (SUSY) diagrams

	photonic	non-photonic
• μ→eγ	yes (on-shell)	no
• μ-e conversion	yes (off-shell)	yes



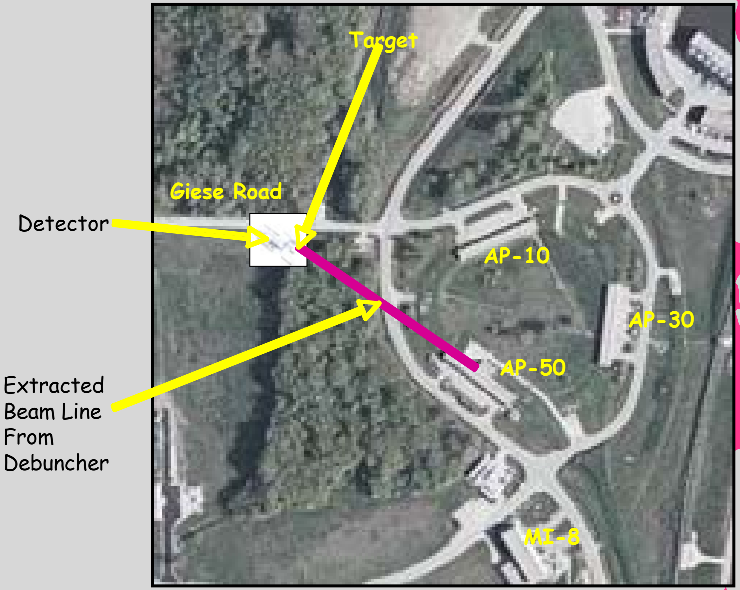
$$\frac{B(\mu N \rightarrow eN)}{B(\mu \rightarrow e\gamma)} \sim \frac{1}{100}$$

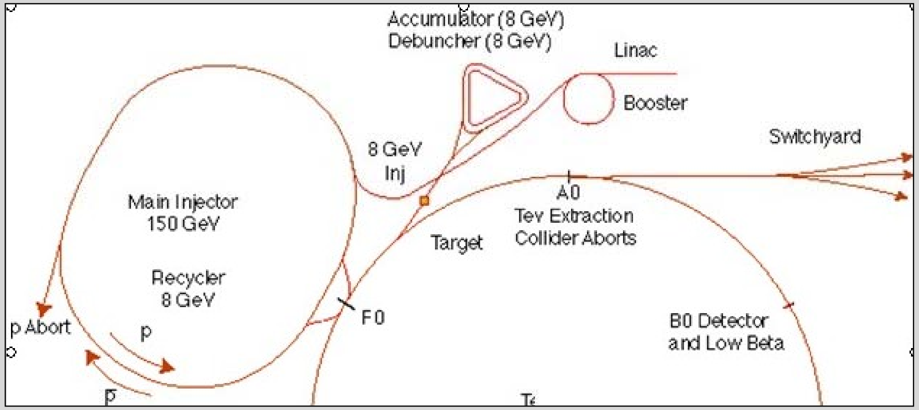


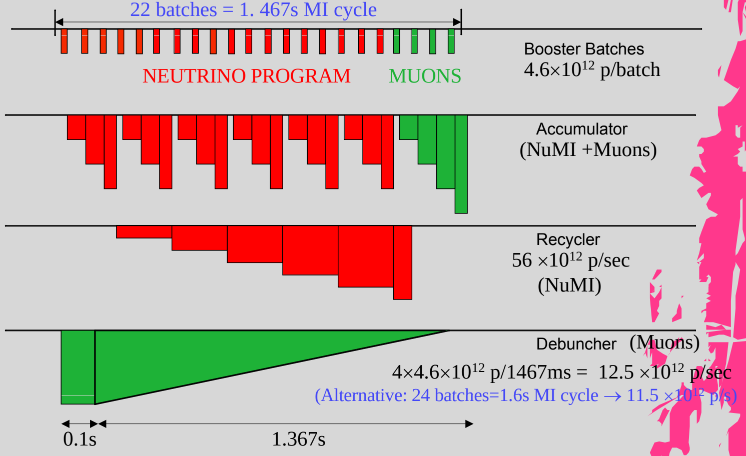
Mu2E @ Fermilab

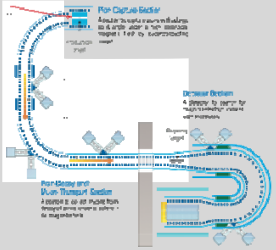
- The mu2e Experiment at Fermilab.
  - Proposal has been submitted.
    - CD-0
  - After the Tevatron shut-down
    - uses the antiproton accumulator ring
    - the debuncher ring to manipulate proton beam bunches

Fermilab Accelerators



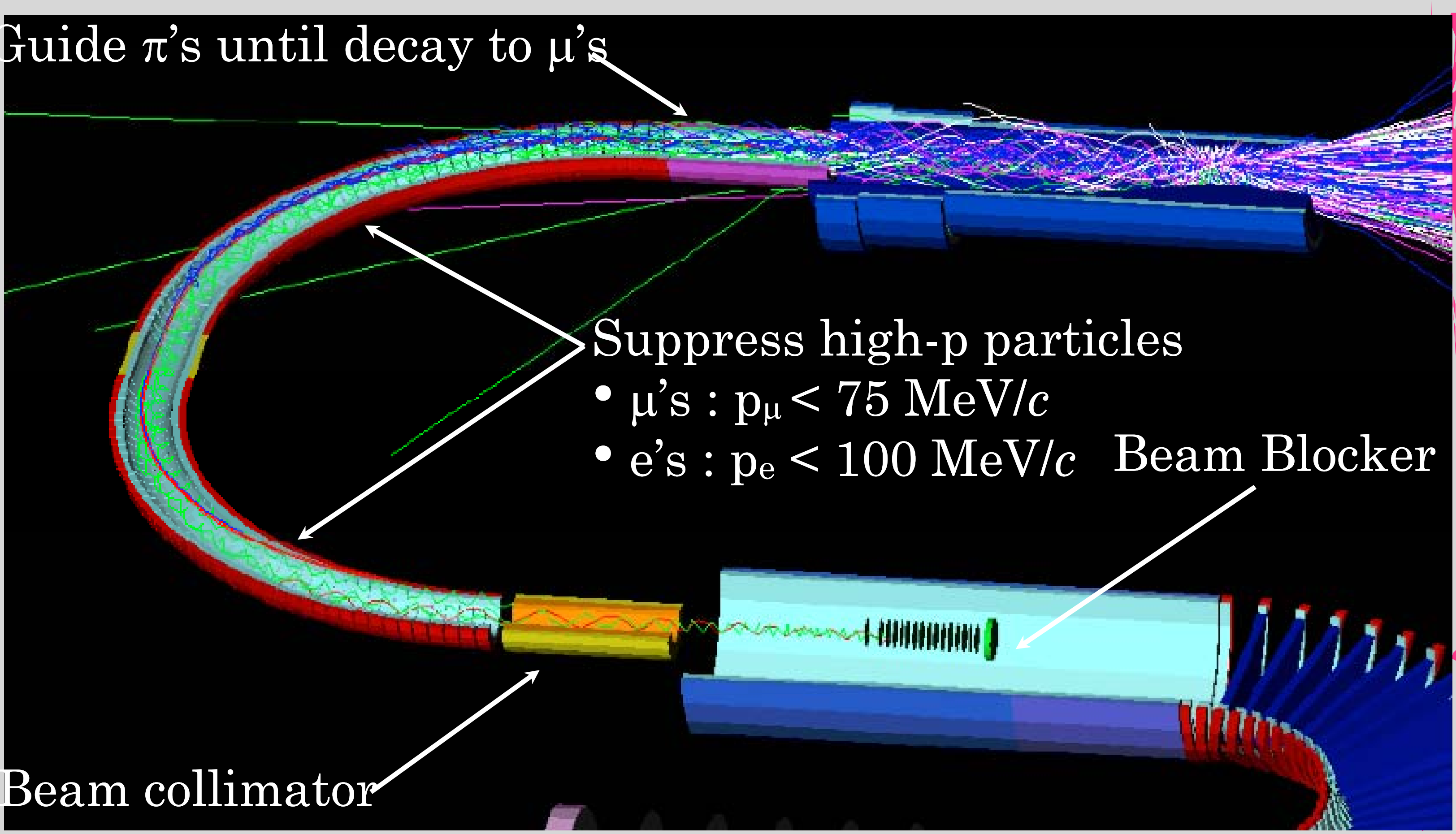






Why Curved Solenoid?

Muon Transport



Guide π's until decay to μ's

Suppress high-p particles
- μ's : $p_\mu < 75$ MeV/*c*
- e's : $p_e < 100$ MeV/*c*

Beam Blocker

Beam collimator

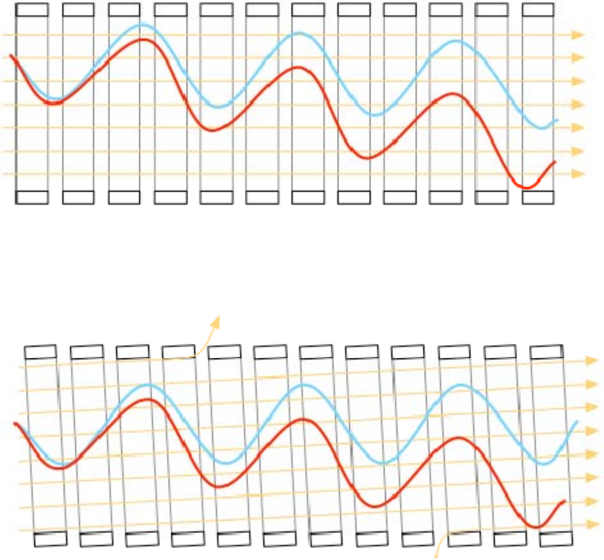
High-p Suppression

- A center of helical trajectory of charged particles in a curved solenoidal field is drifted by

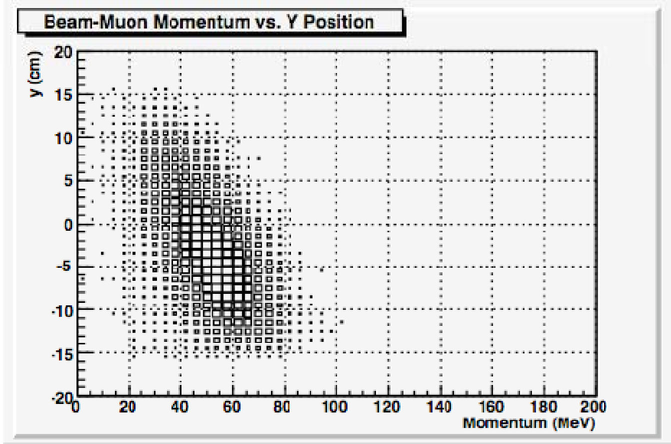
$$D[m] = \frac{1}{0.3 \times B[T]} \times \frac{s}{R} \times \frac{p_l^2 + \frac{1}{2}p_t^2}{p_l}$$

  - This effect can be used for charge and momentum selection.

- This drift can be compensated by an auxiliary field parallel to the drift direction



See "Classical Electrodynamics", J.D.Jackson Ch.12-Sec.4



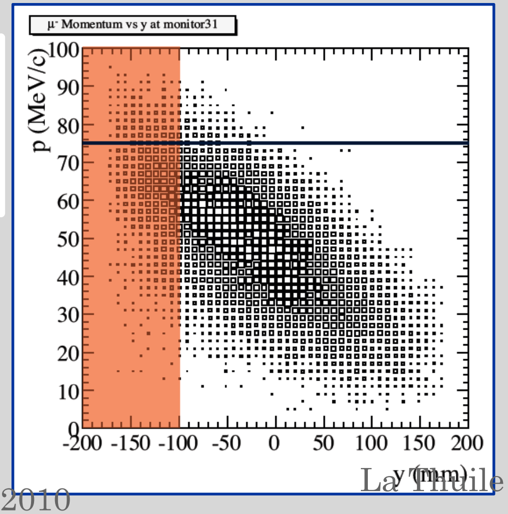
δp/δx = 1 MeV/c/cm

Spectra at the End of the Muon Transport

- Preliminary beamline design
  - main magnetic field
  - compensation field
  - Inner radius of transport magnet cryostat (175 mm)
- Transport Efficiency

# of μ /proton	0.0071
# of stopped muons/proton	0.0035
# of muons with p>75MeV/c / proton	10^{-5}

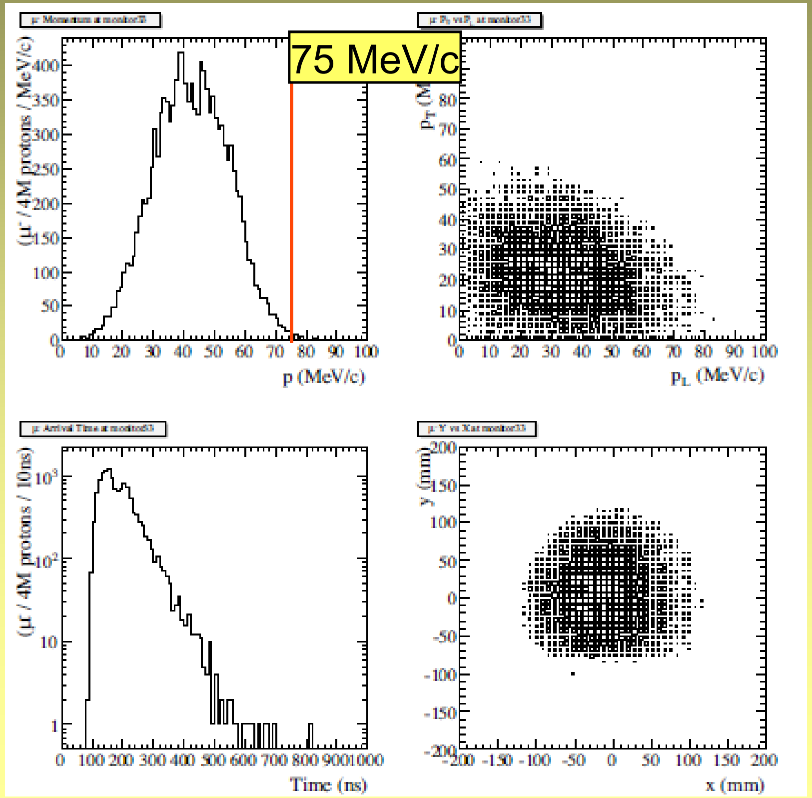
Dispersion on the muon beam just before the collimator.



Spectra at the end of the beamline

(top left) total momentum
(top right)pt vs pL
(bottom left) time of flight
(bottom right) beam profile

.



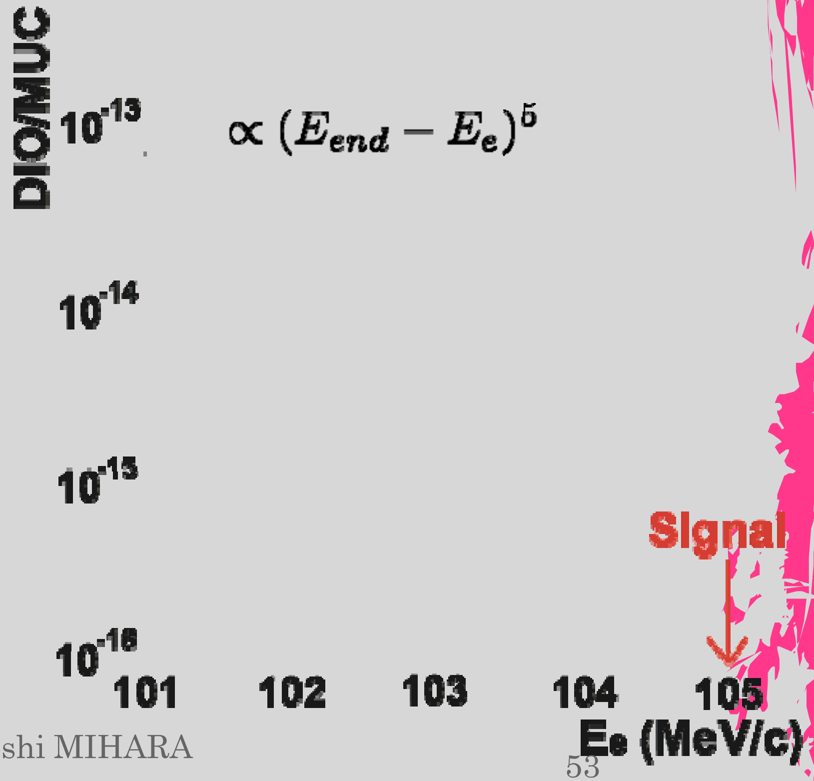
Intrinsic Background (from muons)

- Muon Decay in Orbit
  - Electron spectrum from muon decay in orbit
  - Response function of the spectrometer included.
  - 0.05 events in the signal region of 104.0 - 105.2 MeV (uncorrected).
- Radiative Muon Capture with Photon Conversion

$$\mu^- + Al \to \nu_\mu + Mg + \gamma$$

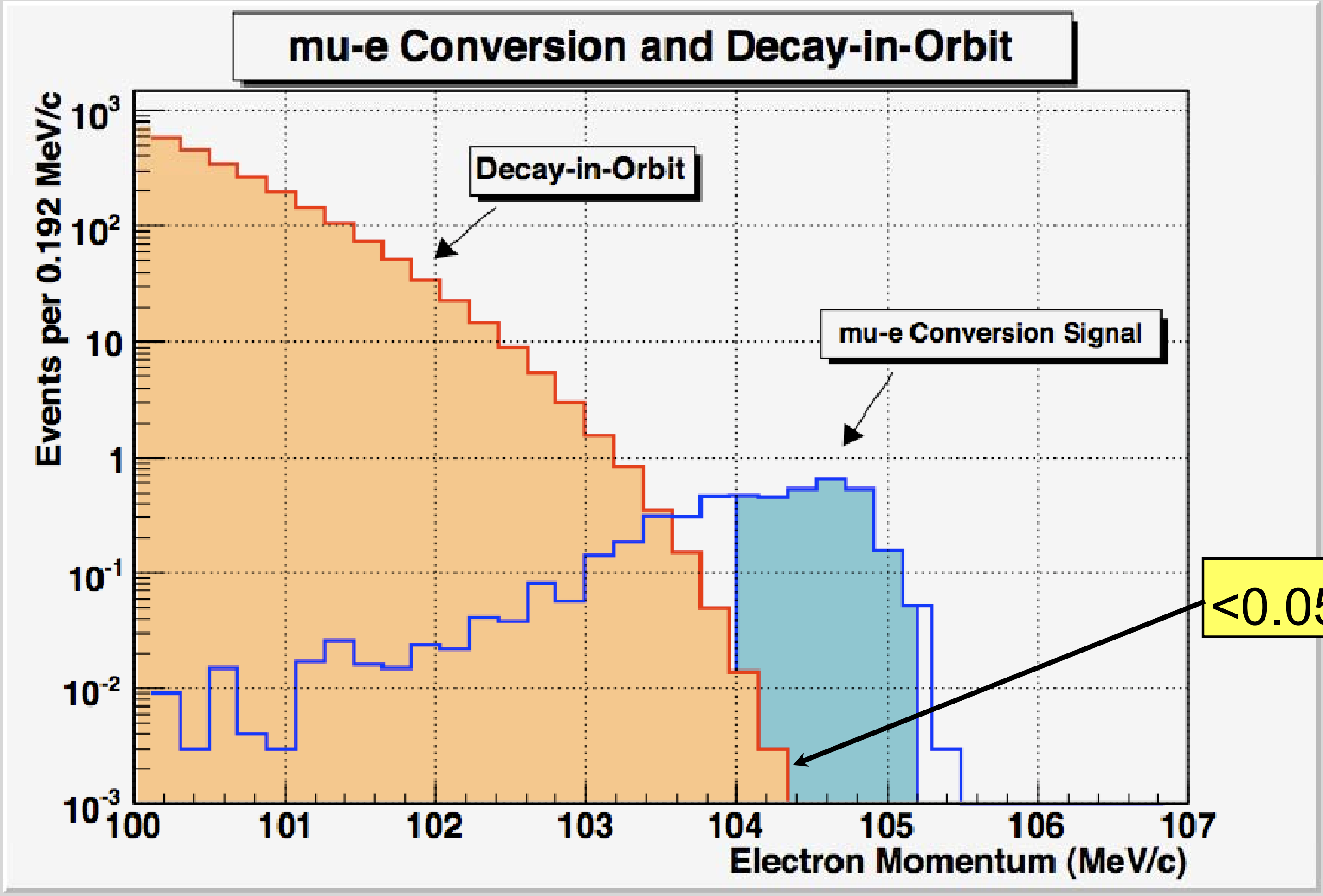
  - Max photon energy 102.5 MeV
  - < 0.001 events
- Muon Capture with Neutron Emission
- Muon Capture with Charged Particle Emission
  - <0.001 events for both.

Energy spectrum of electrons from decays in orbit in a muonic atom of aluminum, as a function of electron energy. The vertical axis shows the effective branching ratio of μ-e conversion.



DIO Background

a number of events for 1.1×10^{18} stopped muons.



<0.05 events

Beam Related Background Rejection

Rejection of beam related (prompt) backgrounds can be done by a combination of the following components.

Momentum Selection at the Muon Transport
(p_μ < 75 MeV/c)

Electron Energy Cut
(104.0 - 105.2 MeV uncorrected)

Electron Transverse Momentum Cut
(p_T> 52 MeV/c)

Timing Cut and Beam Extinction
(10^{-9})

Beam Channel Length
(pion decay)

Beam Related Backgrounds (and CR)

- Radiative Pion Capture
  - pion prod. rate : 1x10^{-5}
  - pion survival : 2x10^{-3}
  - E_e>104 MeV with conversion : 6.3x10^{-6}
  - beam extinction : 10^{-9}
  - 0.12 events at 10^{-16}.
- Muon Decay in Flight
  - p_μ>77 MeV/c : 2x10^{-4}/proton
  - muon decay prob. : 3x10^{-2}
  - E_e>104 MeV & p_t> 52MeV/c : <10^{-8}
  - beam extinction : 10^{-9}
  - total is 0.02 events at 10^{-16}.
- Pion Decay in Flight
  - $\pi \rightarrow e\nu$ branching ratio : 10^{-4}
  - p_π>60MeV/c to make E_e>104MeV:5x10^{-6} /proton
  - E_e>104 MeV & p_t> 52MeV/c : 5x10^{-6}
  - beam extinction : 10^{-9}
  - <0.001 events at 10^{-16}
- Beam Electrons
  - p_e>100 MeV/c : 10^{-8}/proton
  - scat. prob. : 10^{-5}
  - beam extinction : 10^{-9}
  - 0.08 events at 10^{-16}

8x10^{20} protons

- Neutron induced
  - neutrons through beamline.
  - E_n>100 MeV : 3x10^{-7}/proton
  - E_e>100 MeV : 10^{-7}
  - beam extinction : 10^{-9}
  - 0.024 events at 10^{-16}.
- Antiproton induced
  - eliminate high-energy antiprotons by curved solenoid.
  - absorb low-energy antiprotons by 120 μm beryllium foil placed in the middle of beamline.
  - eliminate backgrounds from antiproton annihilation above.
  - 0.007 events at 10^{-16}.

- Cosmic ray Background
  - eliminate by passive and active shields.
  - 10^{-4} veto inefficiency assumed.
  - 0.04 events for 2x10^7 sec (a duty factor 0.2)