mu-e conversion search experiment
COMET at J-PARC

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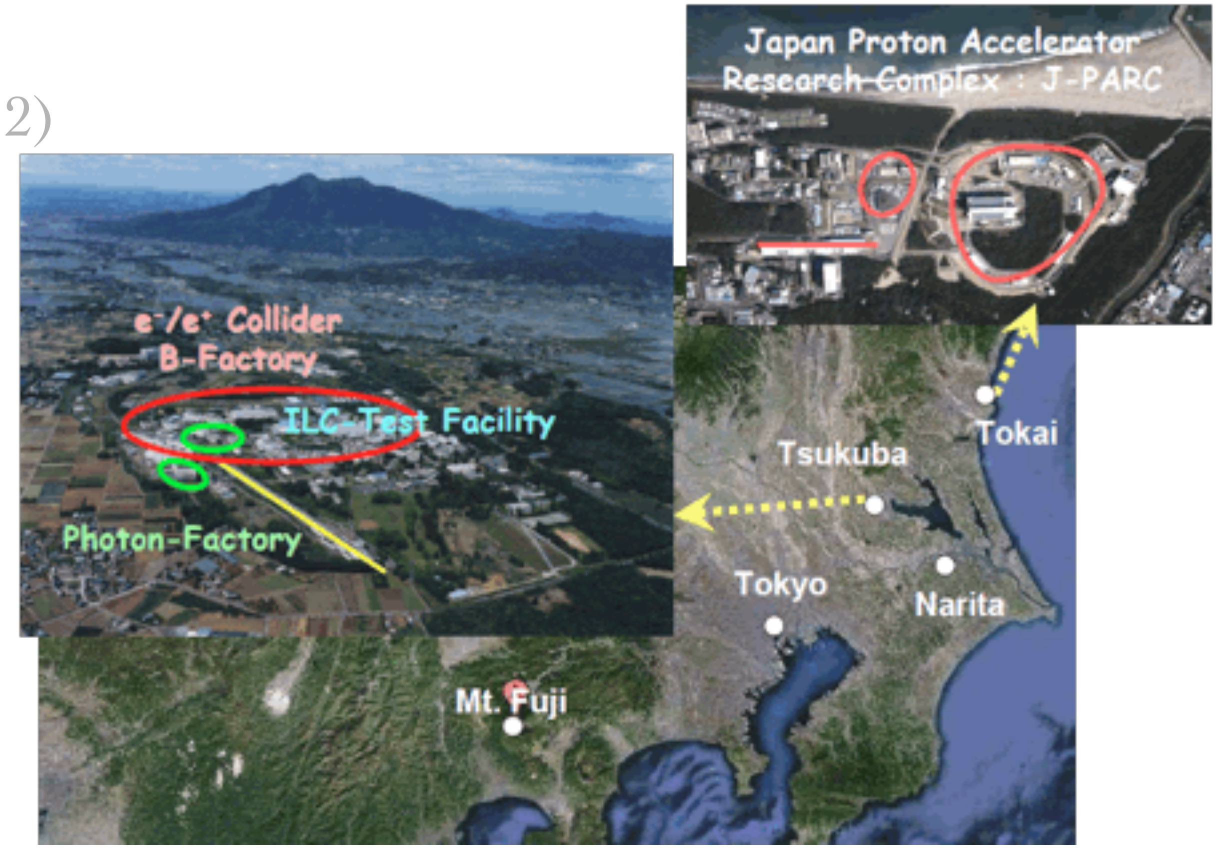
Outline

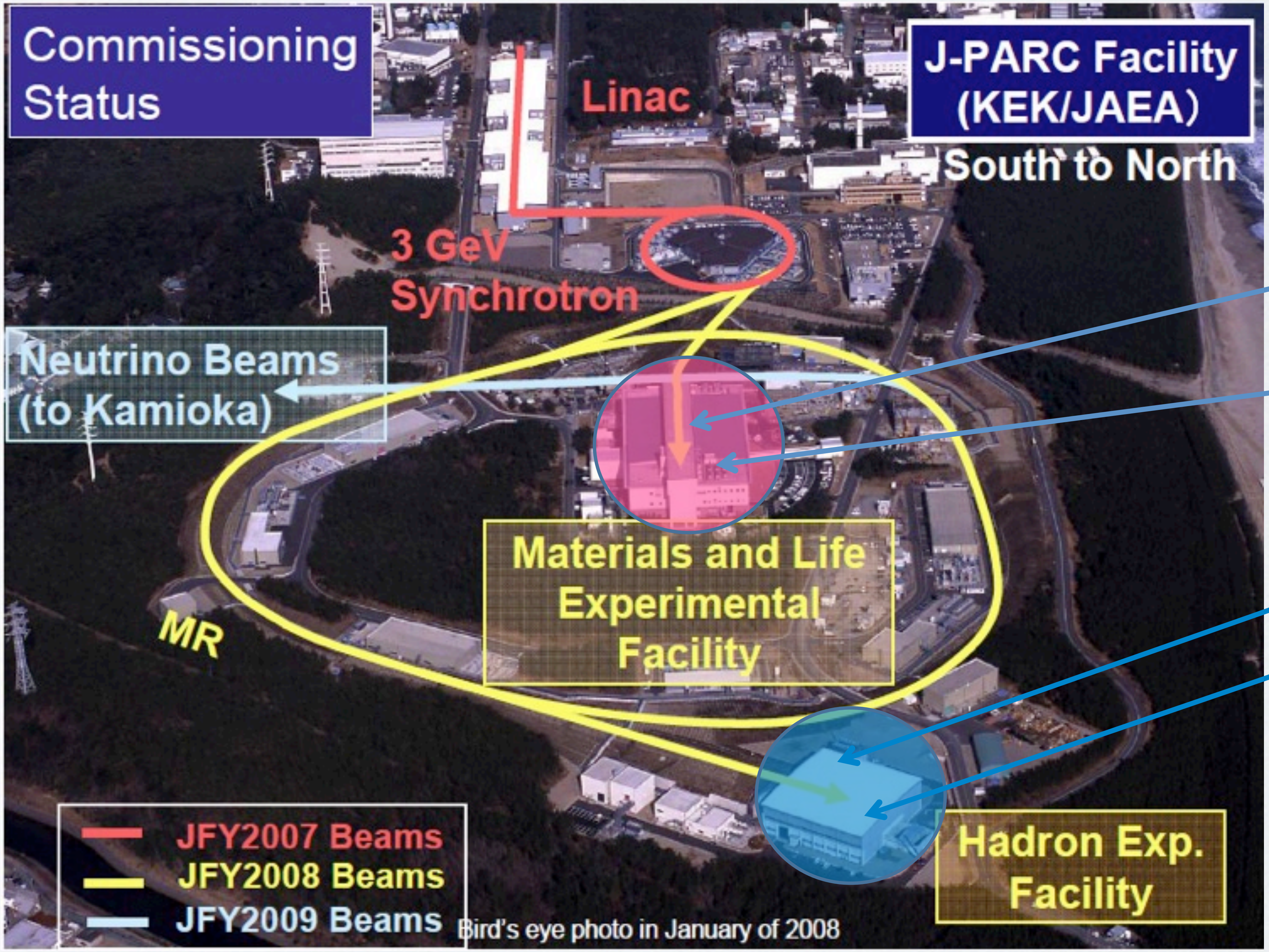
- J-PARC Introduction
- COMET at J-PARC
  - Proton/Muon beam at J-PARC
  - Detector
  - Sensitivity and Background
  - (R&D Status)
  - Schedule and Cost
- Summary

J-PARC 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



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)

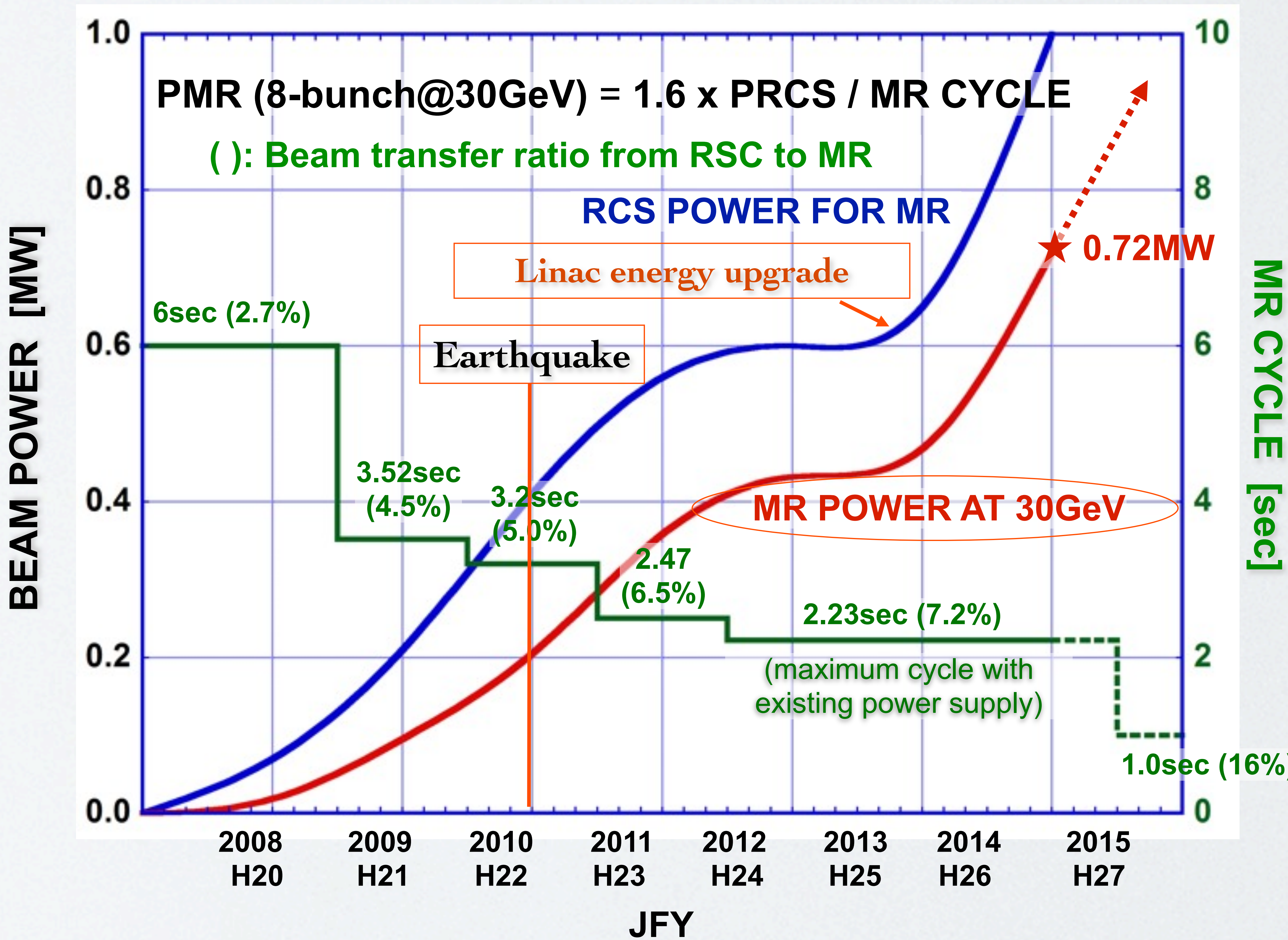
} @ 3GeV RCS

} @ 30GeV MR

- Linac 181MeV
  - Upgrade to 400MeV in 2013
  - nEDM measurement proposal
- RCS (booster) 3GeV
  - 120-300 kW operation for Material Life Science Facility
  - Particle physics experiments using muon
- MR (Main Ring) 30 GeV
  - 100-150 kW operation with fast extraction for T2K
  - 10kW operation with slow extraction for 2ndary beam expts

An Expected Beam Power Curves

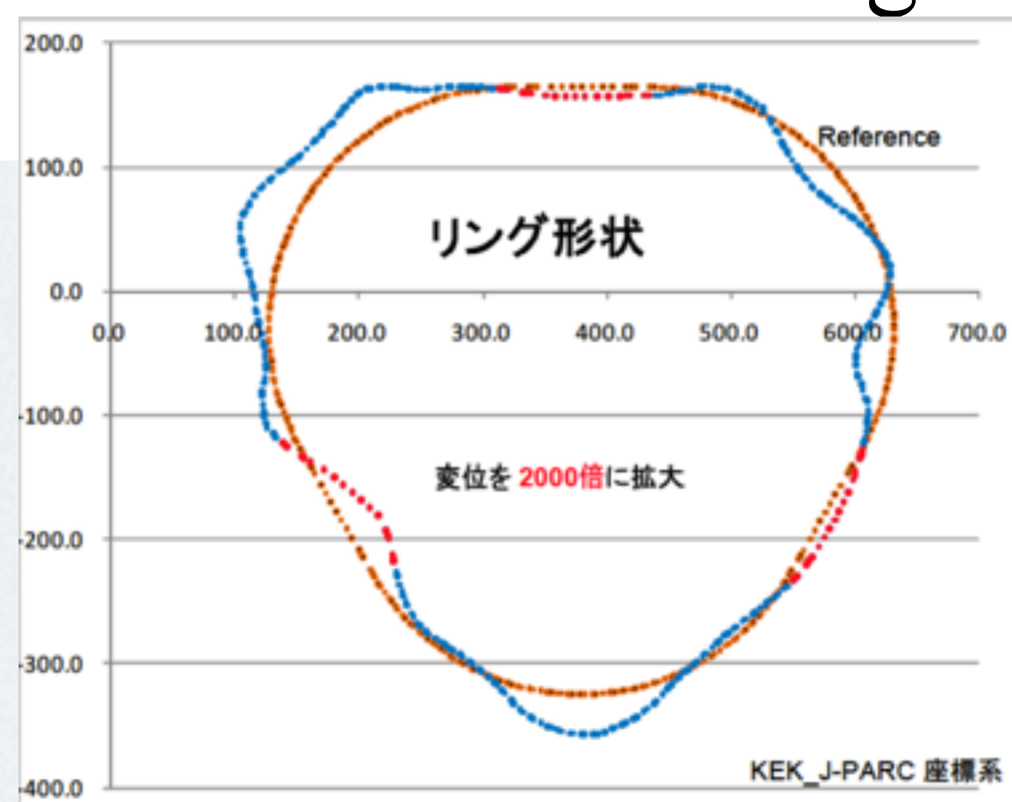
defined before the earthquake



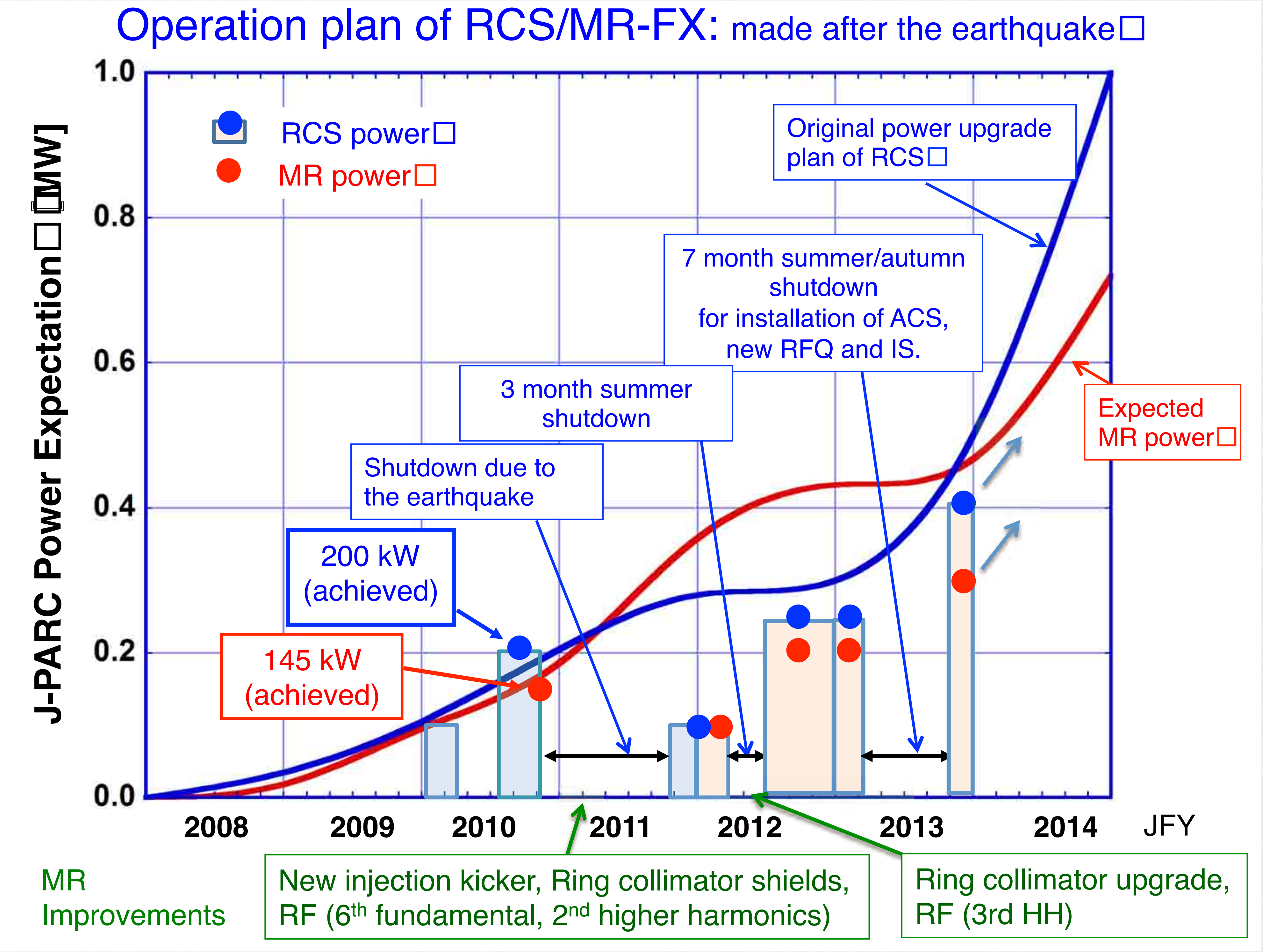
J-PARC Damage by Earthquakes

- No damage by Tsunami
- All equipments are standing at where they should be but...
  - Needed to align again
- LINAC/T2K near detector floors were covered by underground water
  - quickly removed when the electricity was recovered
- Many cracks on the wall in tunnels
- Inspection and recovery are in progress
- Plan to provide beam for experiments at the end of this JFY
  - **Acceleration test in Dec. 2011!**

Power Receiving



Revised Beam Power Curves



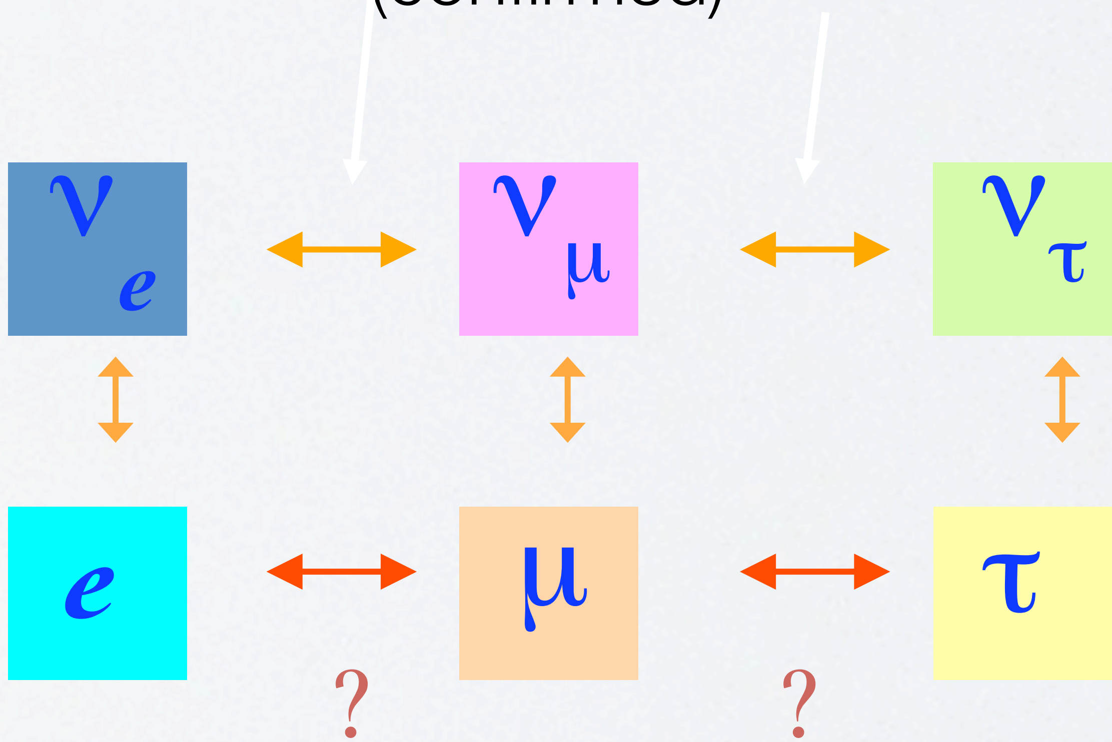
mu-e conversion physics

Introduction

Introduction

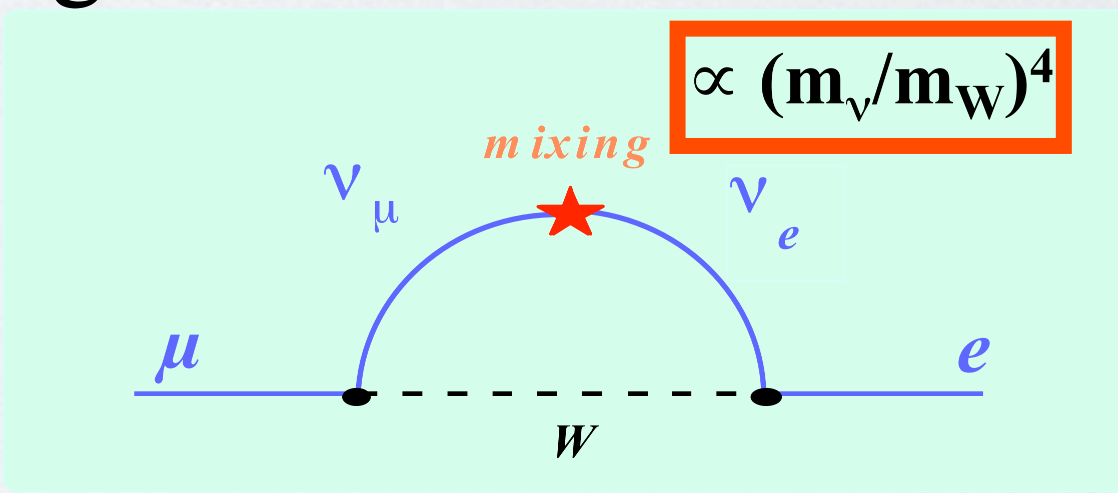
Lepton Flavour Violation of Charged Leptons

Neutrino Mixing
(confirmed)



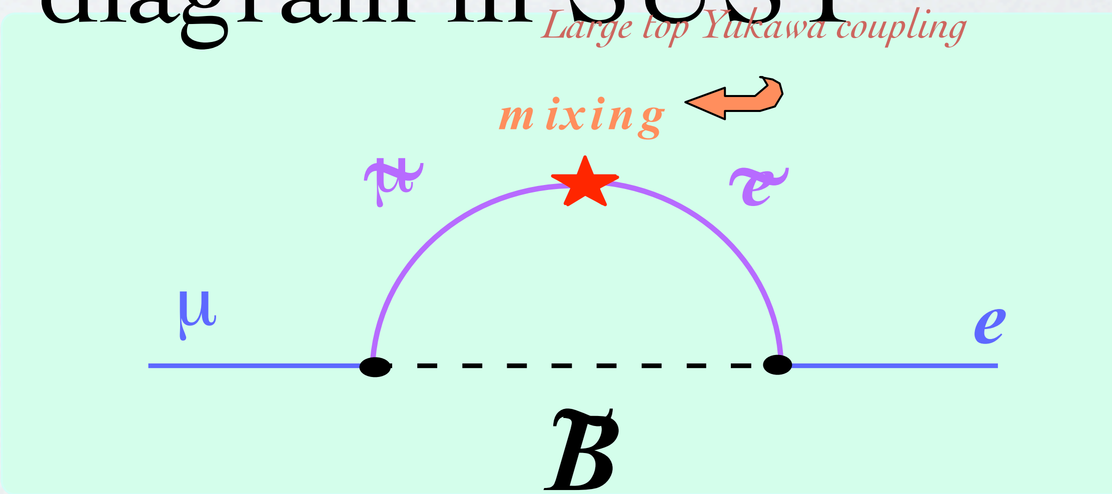
Charged Lepton Mixing
(not observed yet)

LFV diagram in Standard Model



Very Small (10^{-52})

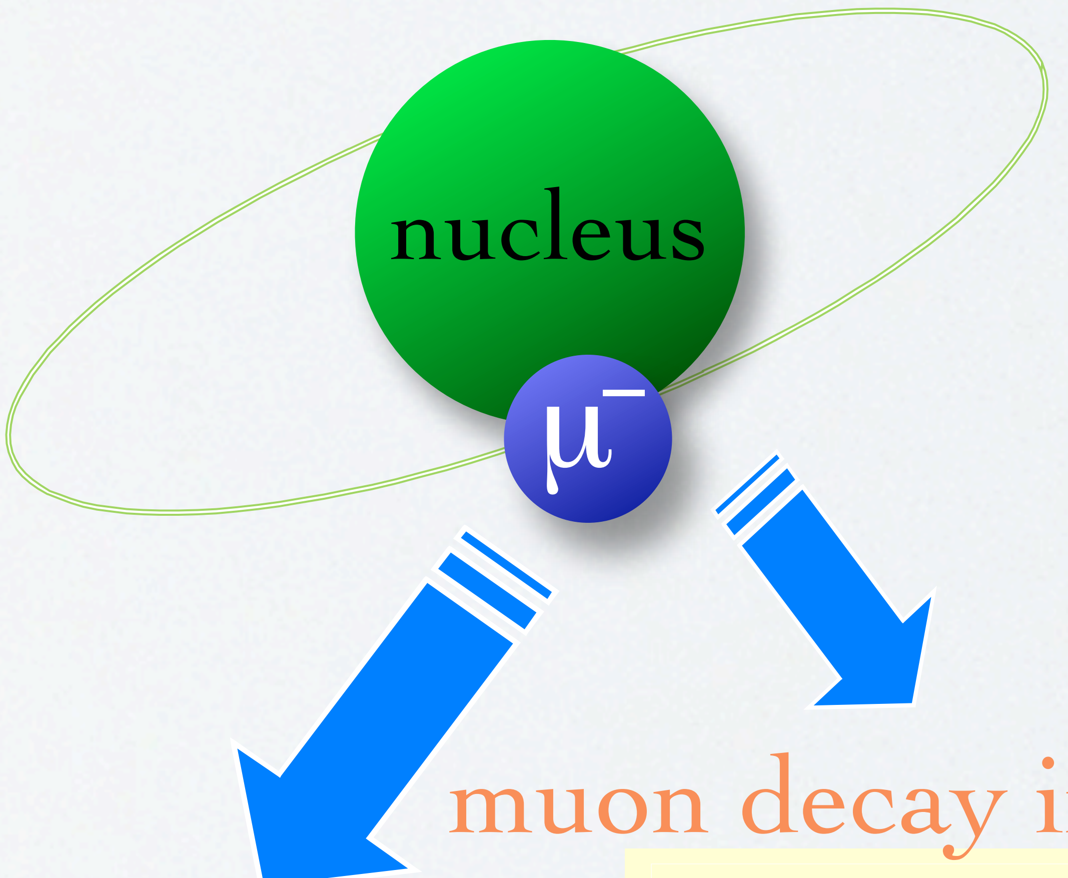
LFV diagram in SUSY



Sensitive to new Physics beyond the Standard Model

What is 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

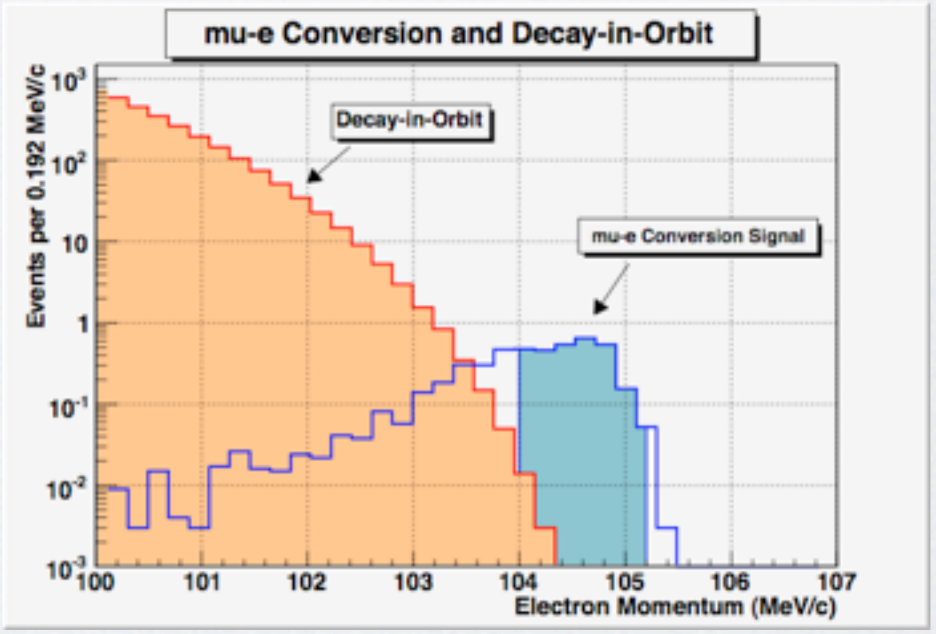
- $E_{\mu e} \sim m_\mu - B_\mu$
  - B_μ: binding energy of the 1s muonic atom

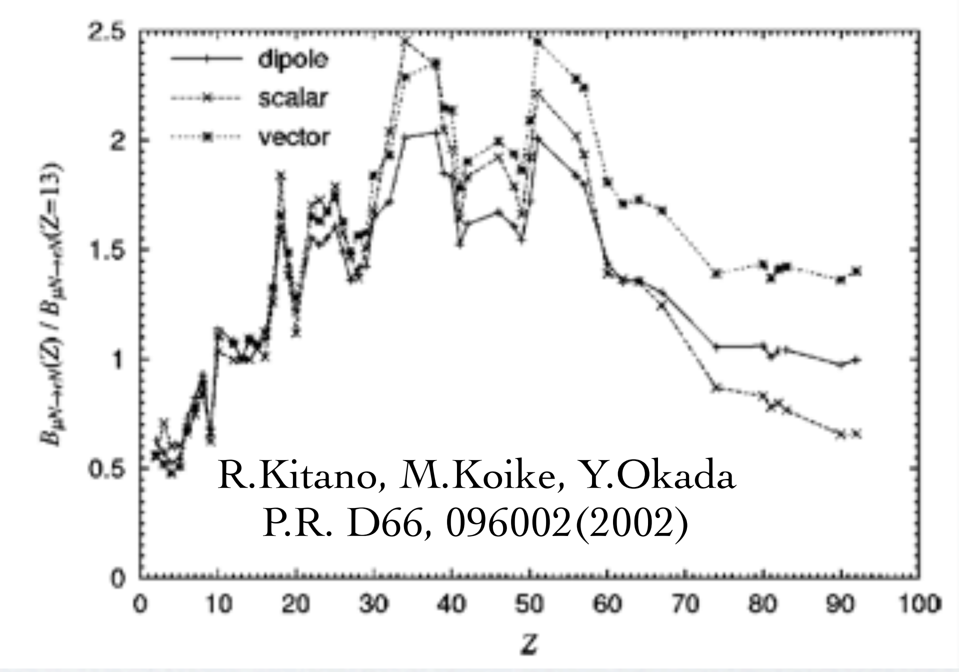
- Comparison with $\mu \to e\gamma$ (and $\mu \to 3e$) from the view point of experimental technique

	Background	Challenge
$\mu \to e\gamma$ and $\mu \to 3e$	Accidental	Detector performance resolution, high rate
μ-e conversion	Beam Cosmic	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.

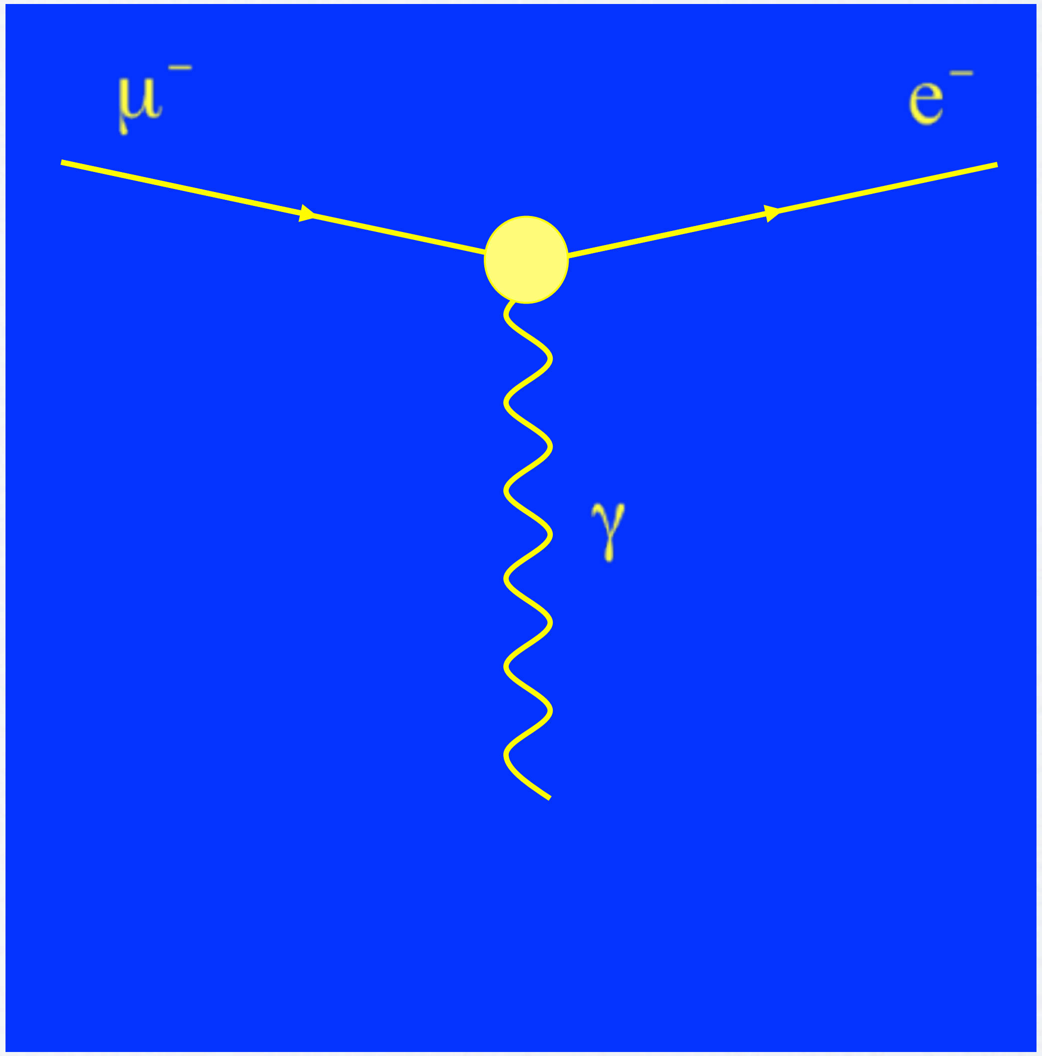
- Potential to discriminate different models through studying the Z dependence





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

μ→eγ and μ-e conversion



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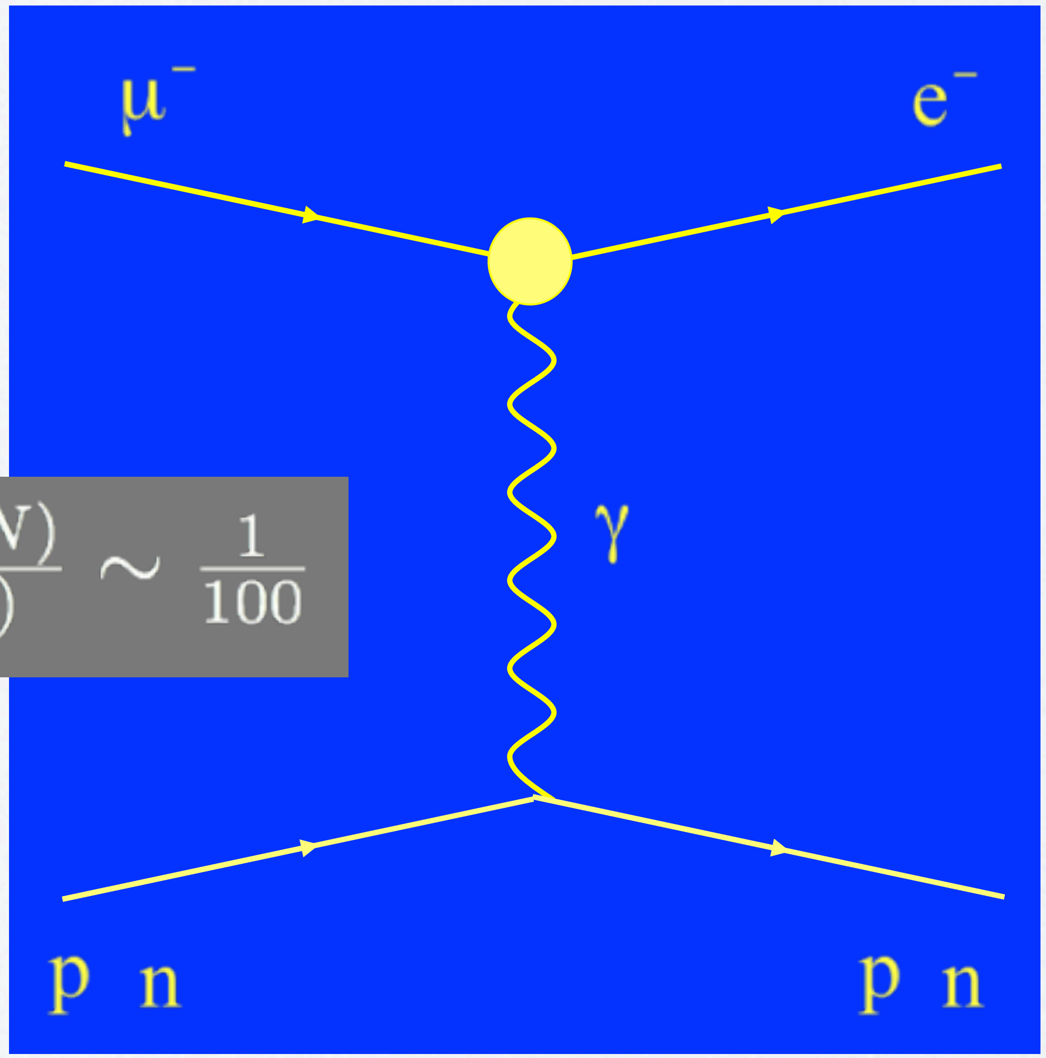
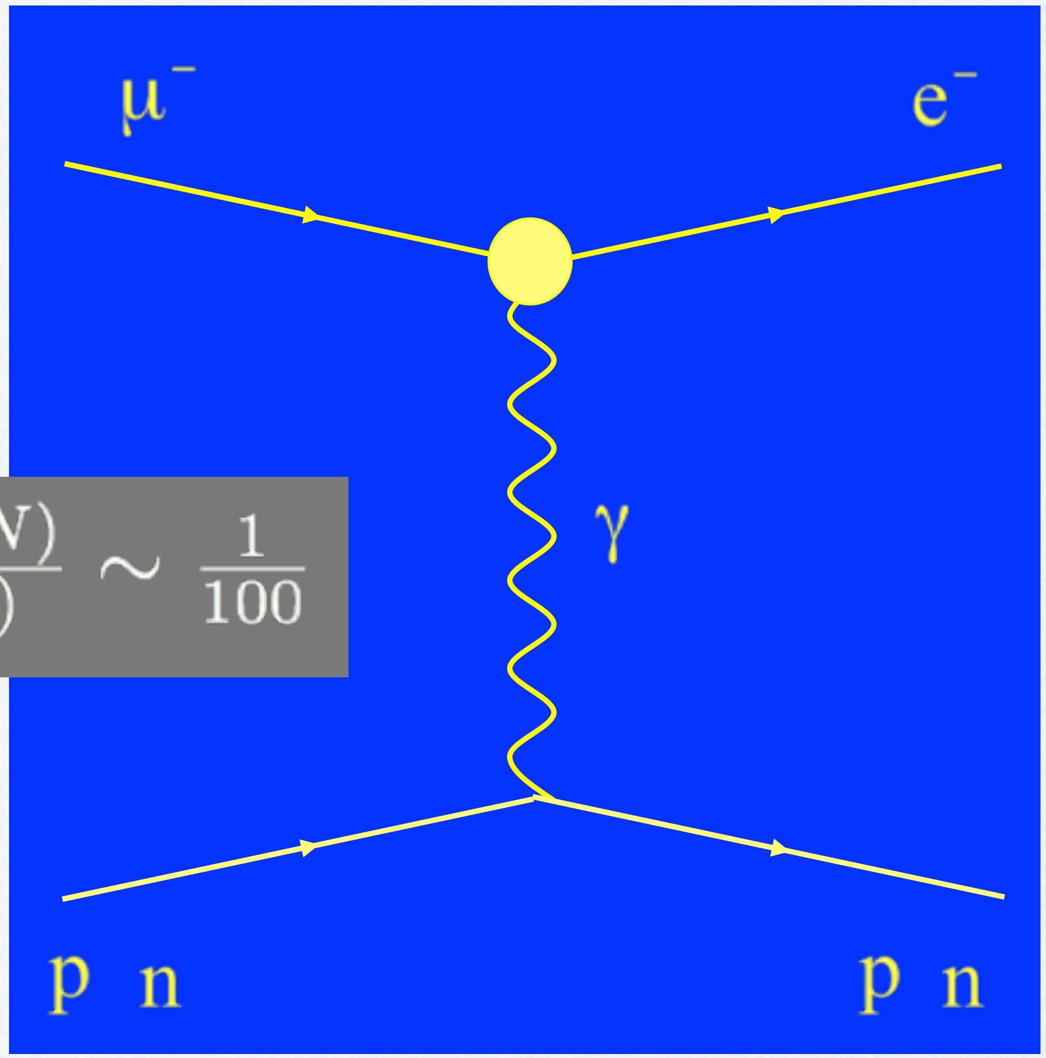


$$\frac{B(\mu N \to eN)}{B(\mu \to e\gamma)} \sim \frac{1}{100}$$

- If μ→eγ exits, μ-e conv must be

μ→eγ and μ-e conversion



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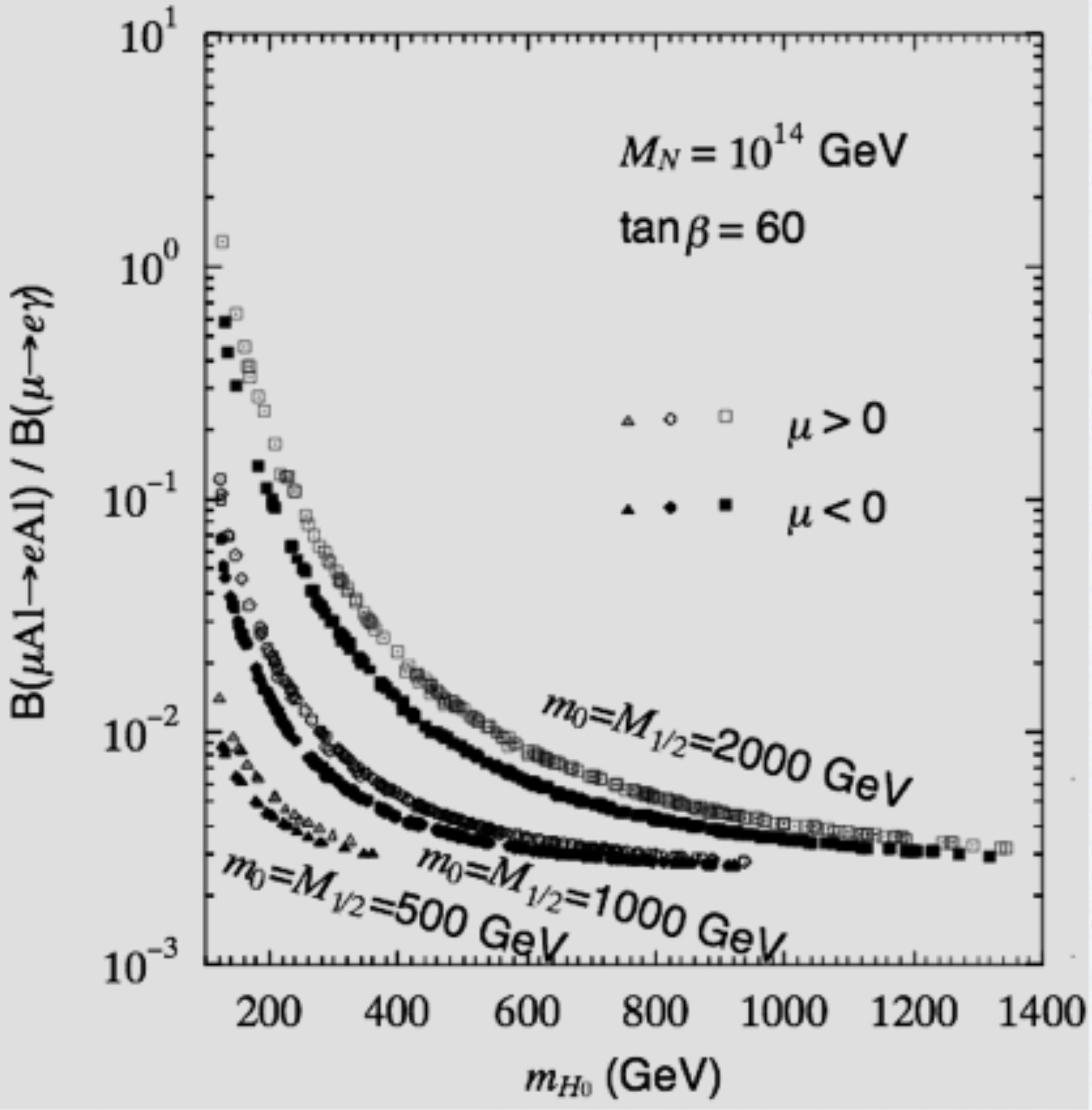
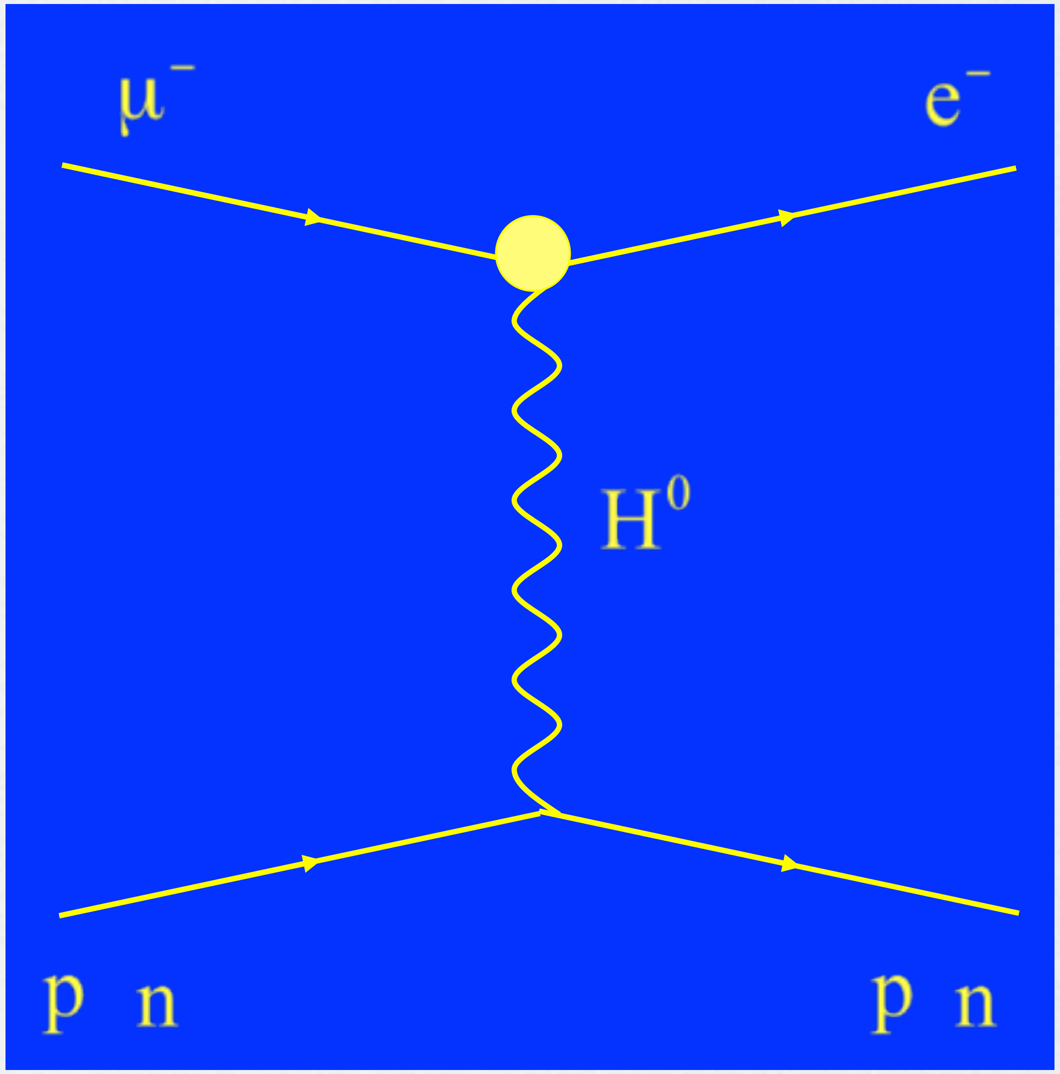
- Even if μ→eγ is not observed, μ-e conv may be
  - Loop vs Tree
  - Searches at LHC

μ→eγ and μ-e conversion





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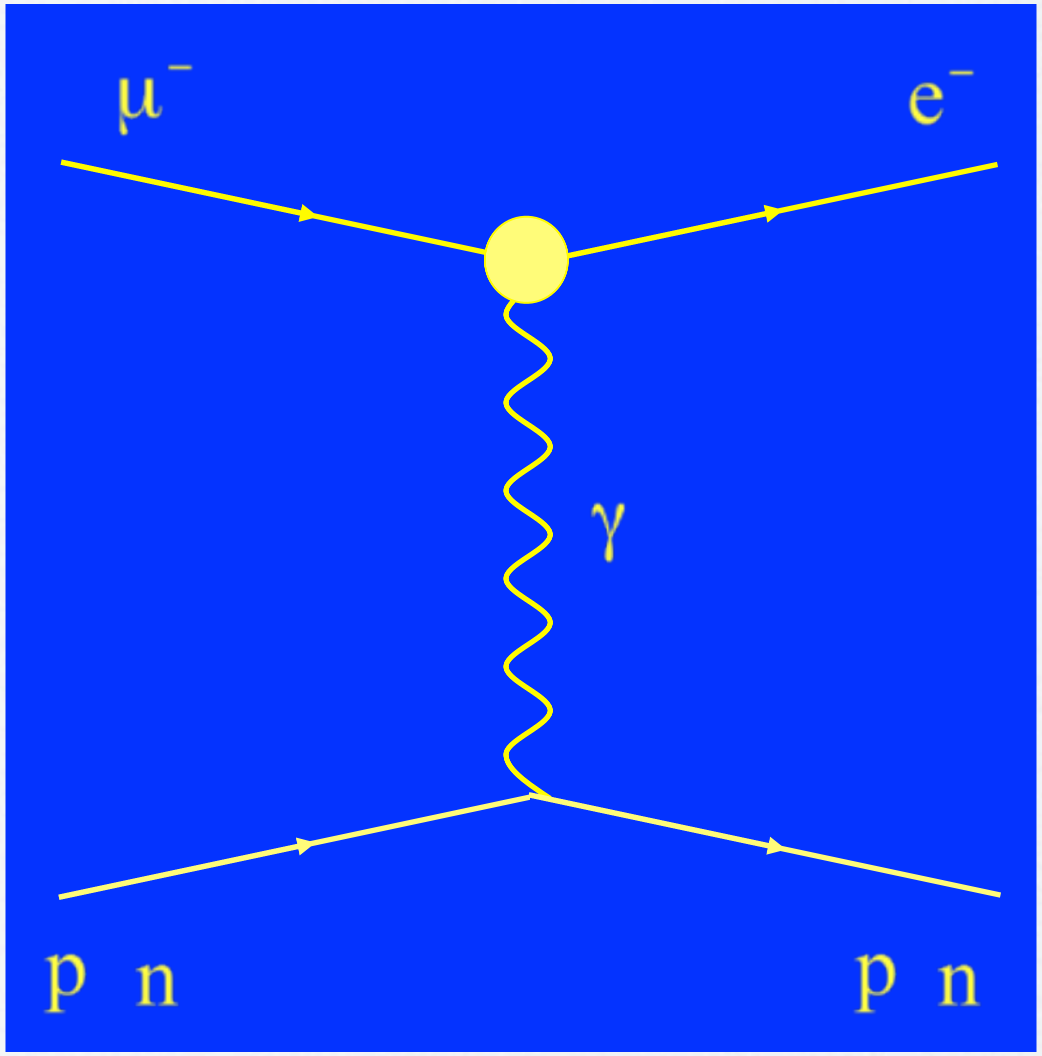

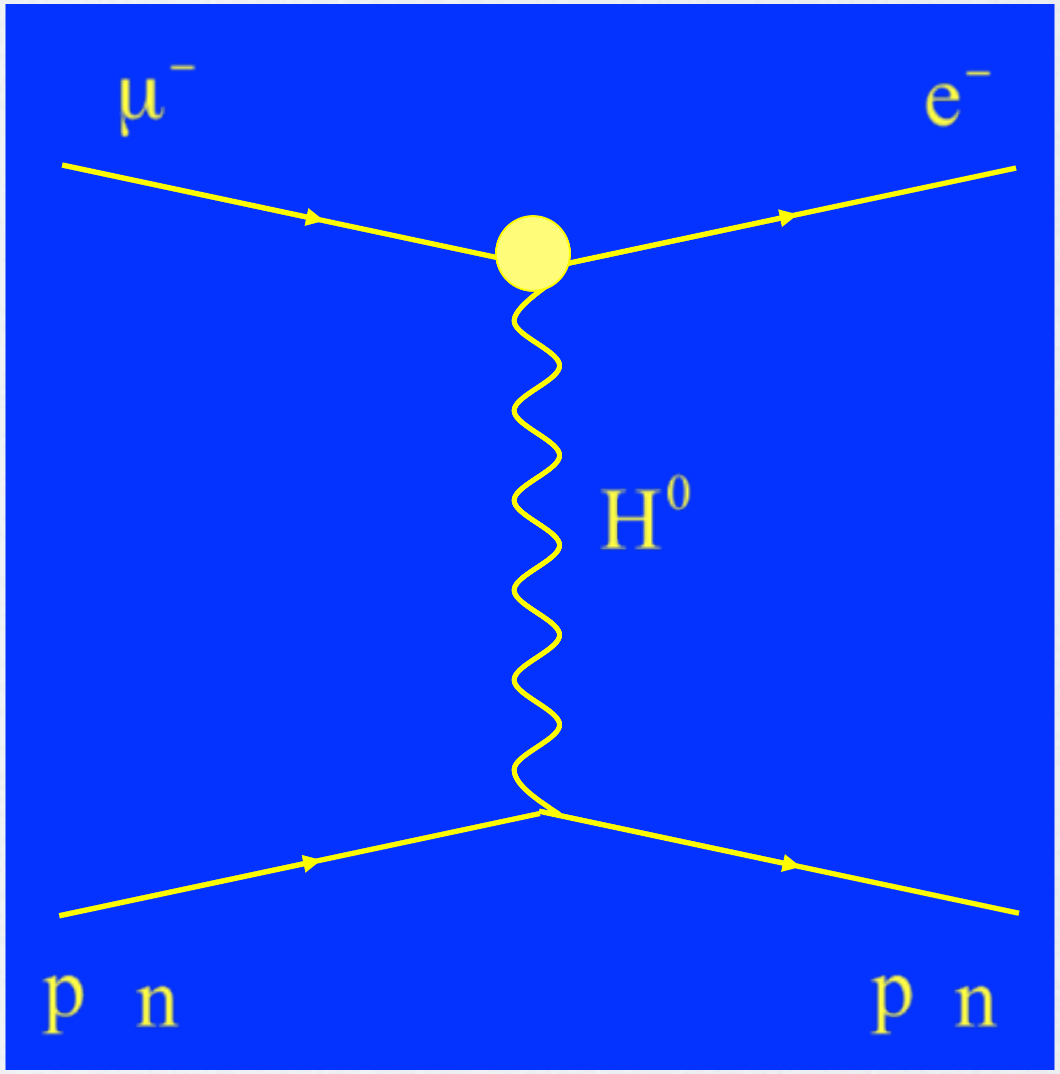

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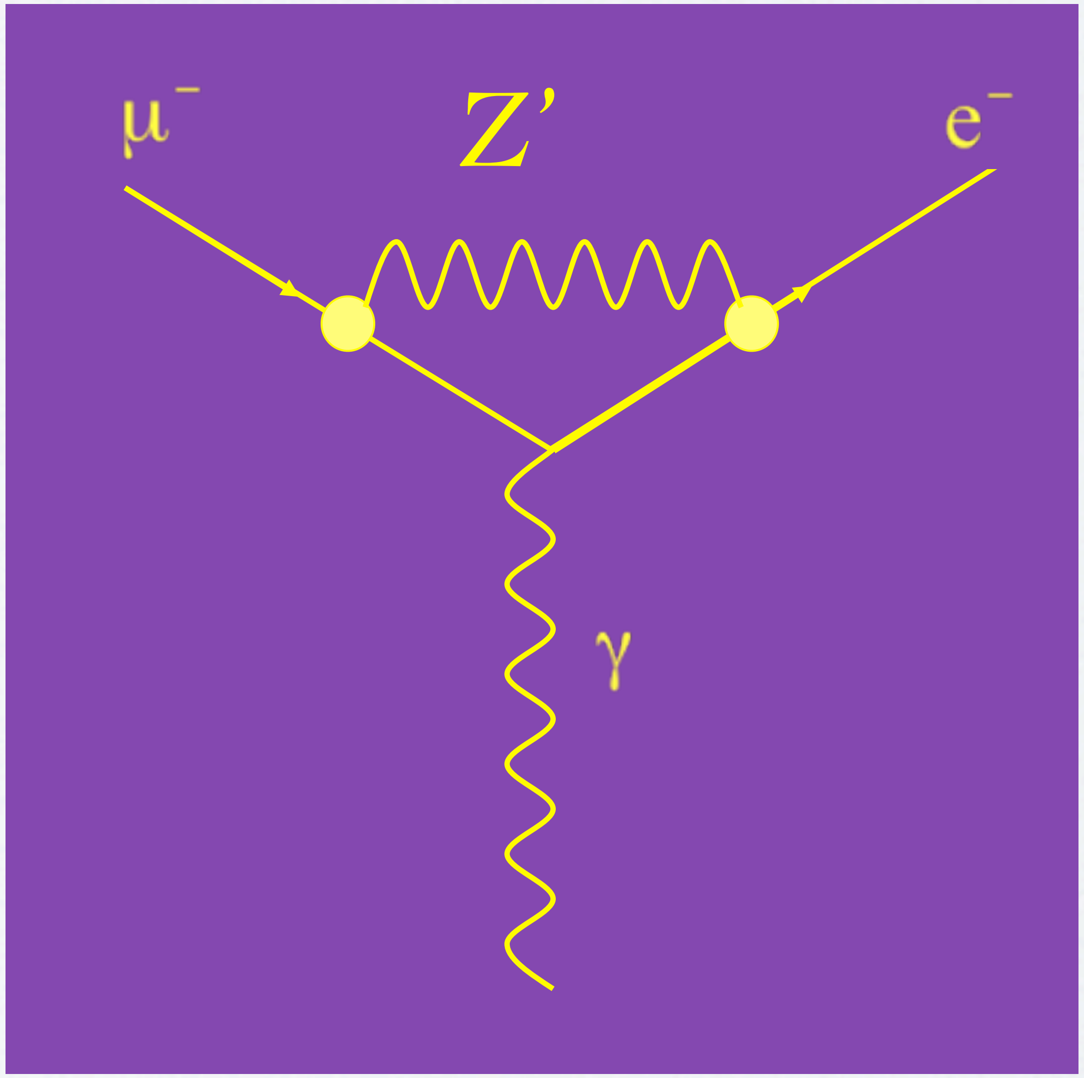

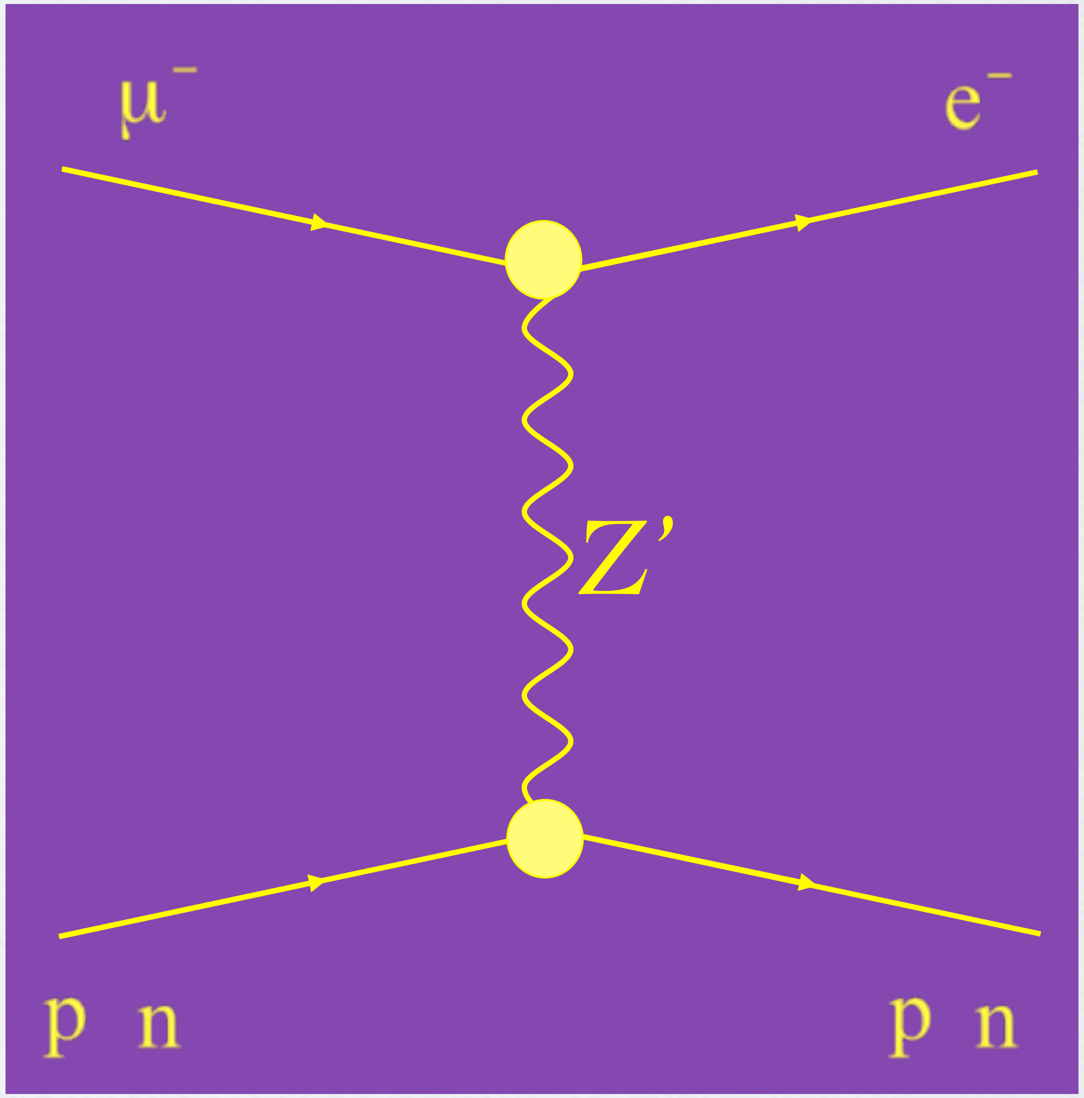

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  - Loop vs Tree
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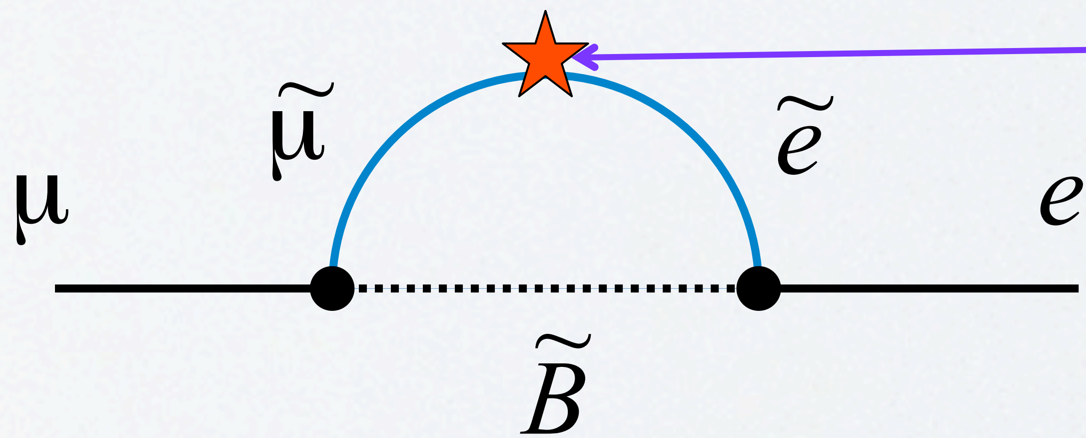
What can we learn from cLFV search?

- Mass matrix information of SUSY sleptons



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

- Off-diagonal components
  - –How SUSY is breaking?
  - –What kind of LFV interactions at GUT scale?

SUSY-GUT and Seesaw

$$(m^2_{\tilde{l}})_{ij} = m_0^2 \delta_{ij}$$

@ Planck mass scale

SUSY-GUT

Yukawa interaction

SUSY Seesaw Model

Neutrino Yukawa interaction

$$(\Delta m^2_{\tilde{l}})_{ij} \neq 0$$

$$\left(m^2_{\tilde{L}}\right)_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h_t^2 V_{td}^* V_{ts} \ln \frac{M_{GUT}}{M_{R_s}}$$

CKM matrix

LFV

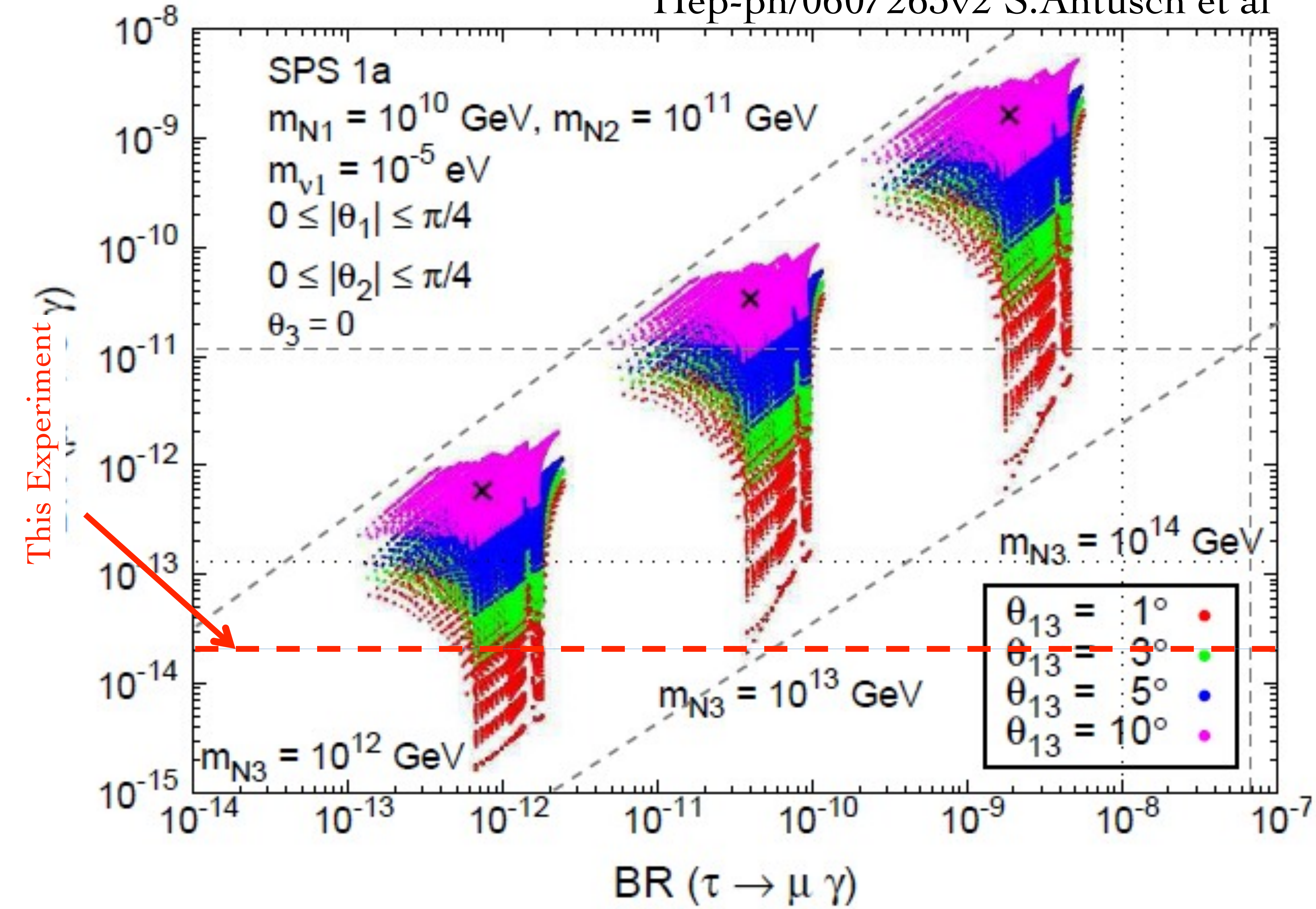
$$\left(m^2_{\tilde{L}}\right)_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h_i^2 U_{i1}^* U_{i2} \ln \frac{M_{GUT}}{M_{R_s}}$$

Neutrino oscillation

L.J.Hall, V.Kostelecky, S.Raby, 1986; A.Masiero, F.Borzumati, 1986

cLFV Search and ν oscillation, g-2

Hep-ph/0607263v2 S.Antusch et al



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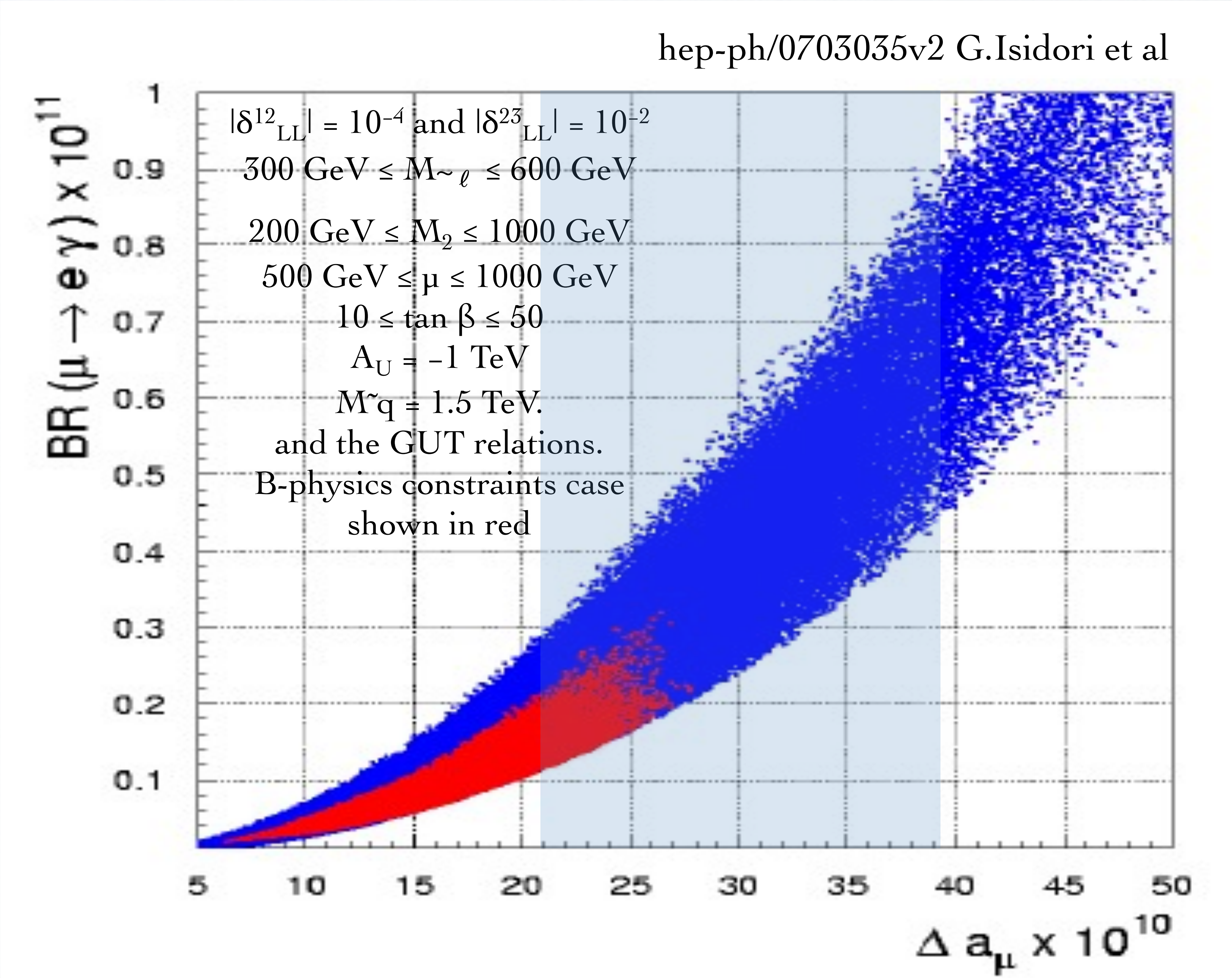

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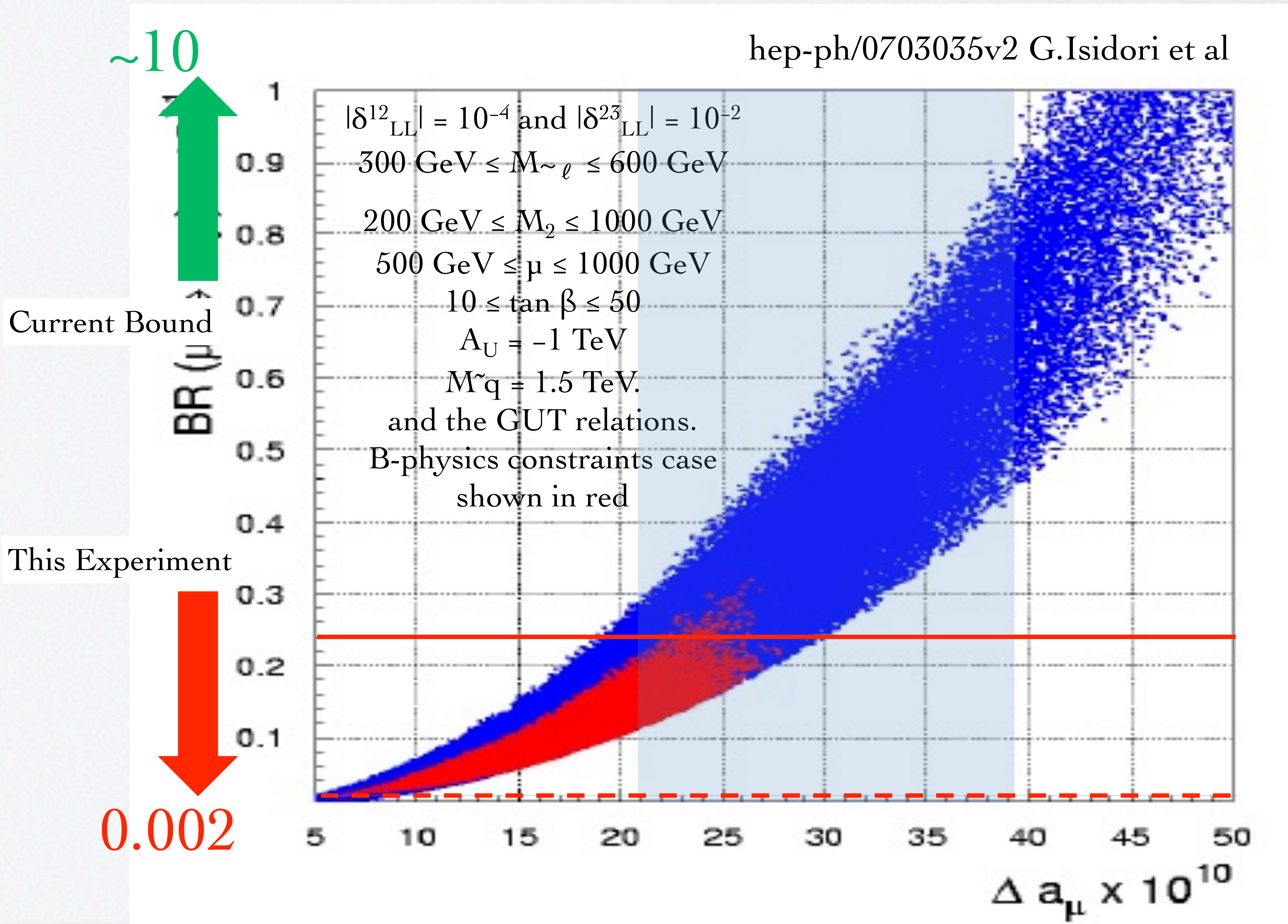
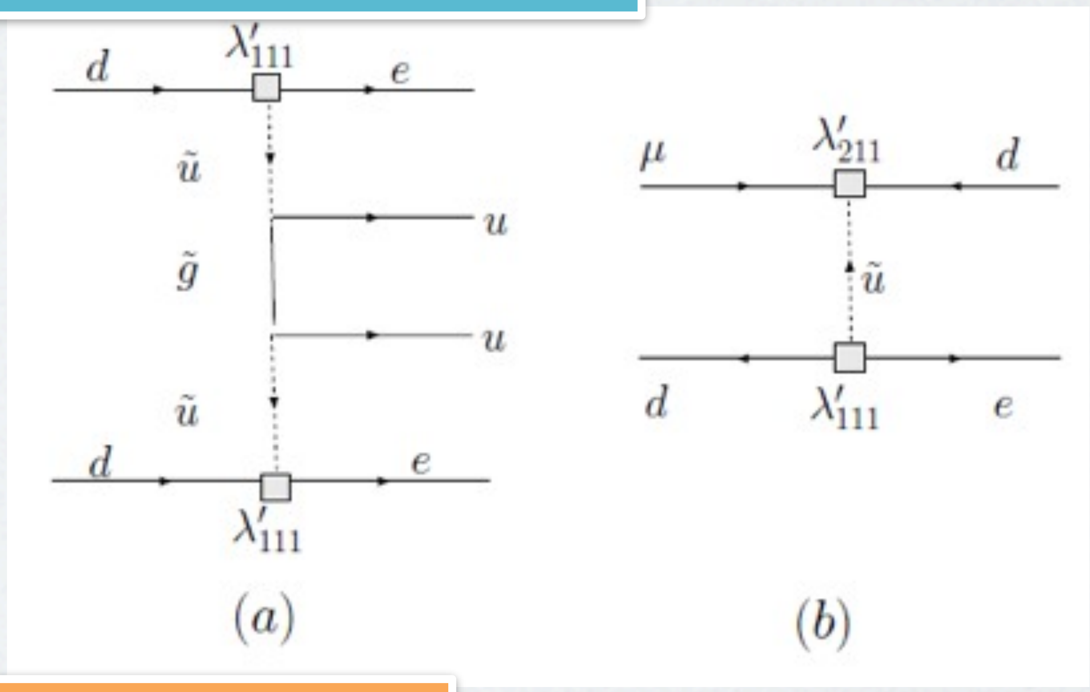


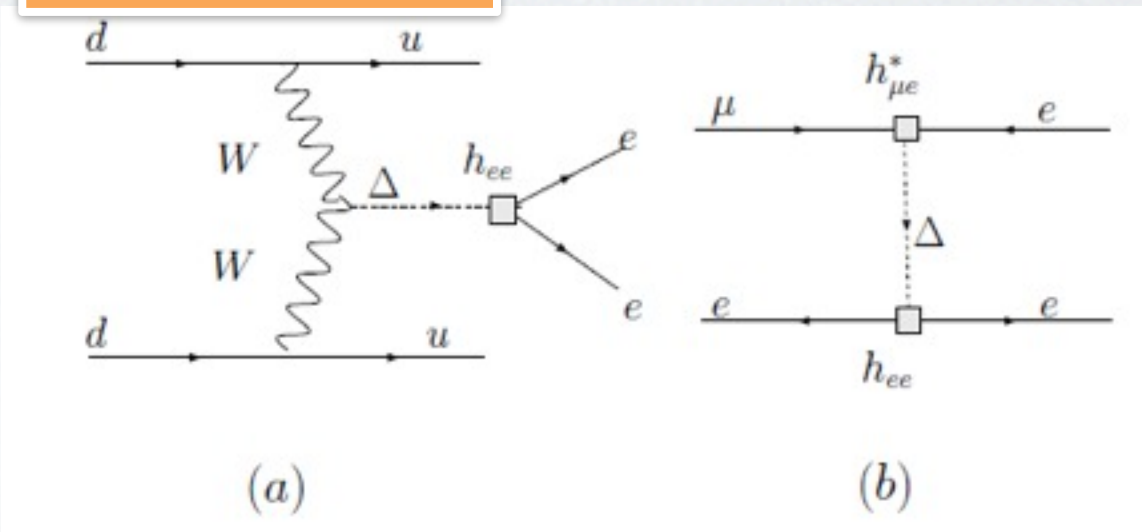
$0\nu\beta\beta$ and μ-e conversion

- 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

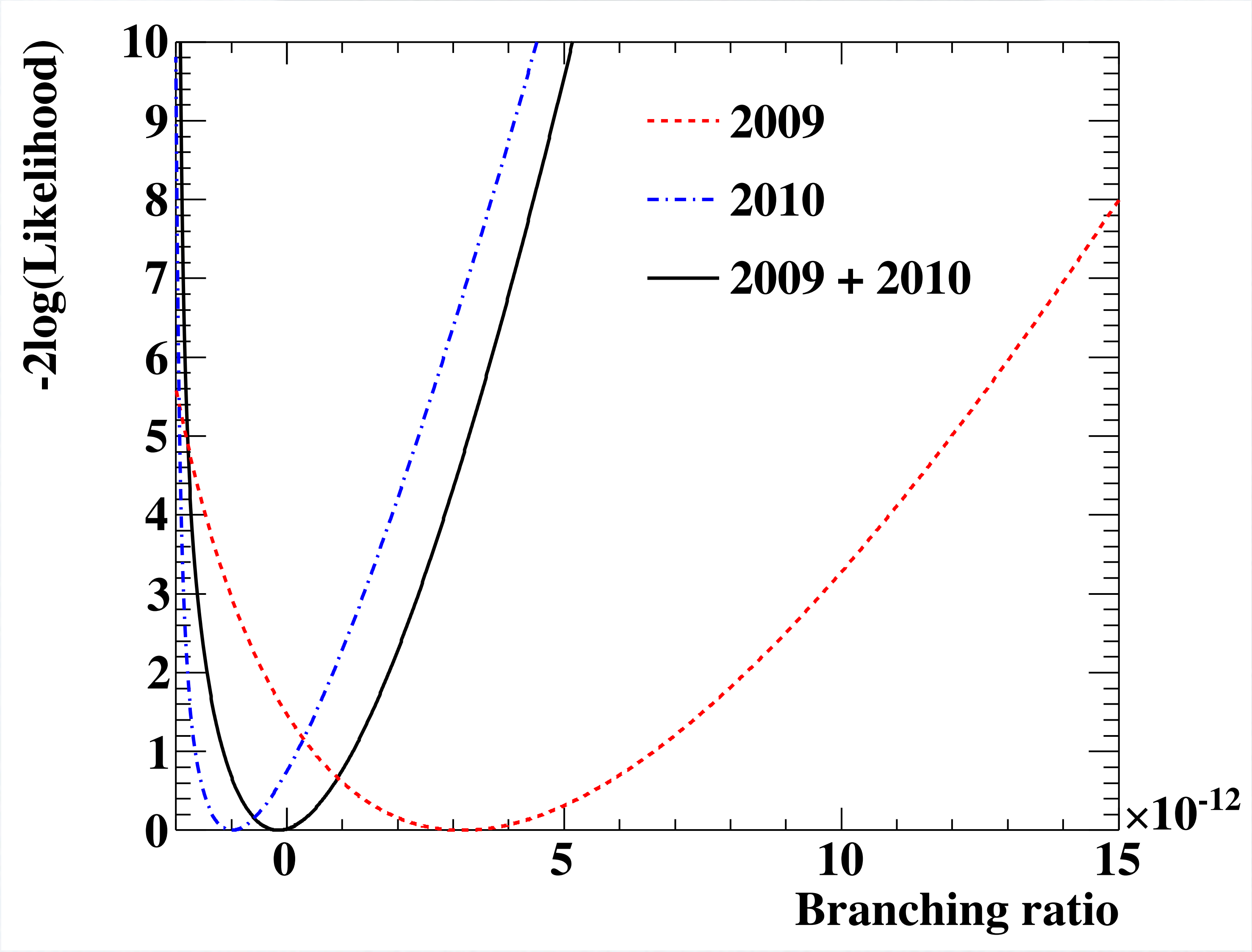


LRSM

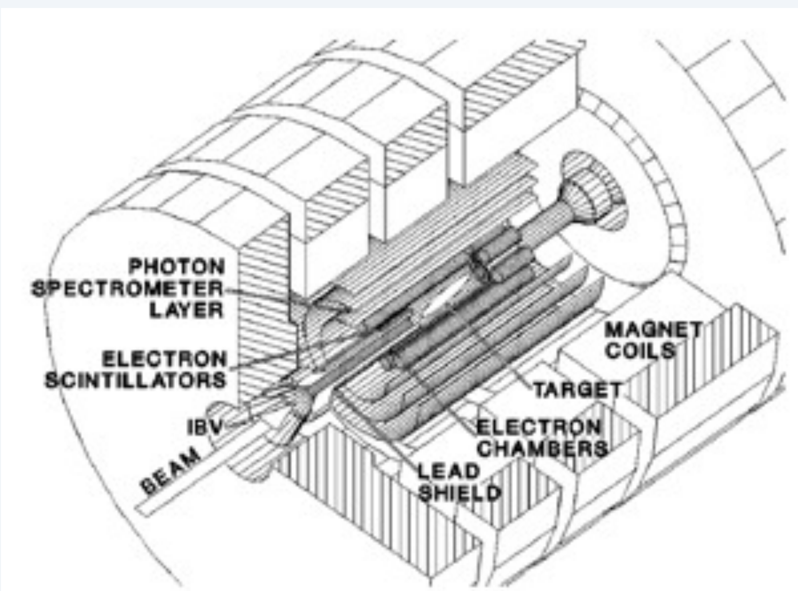
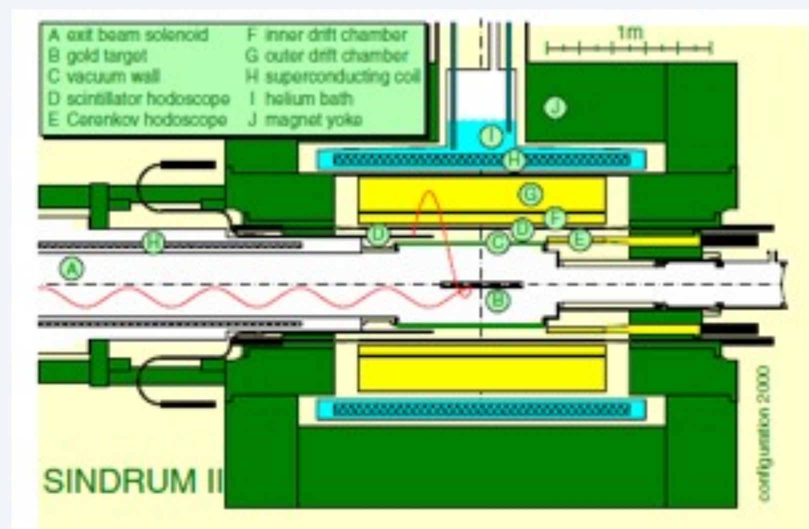
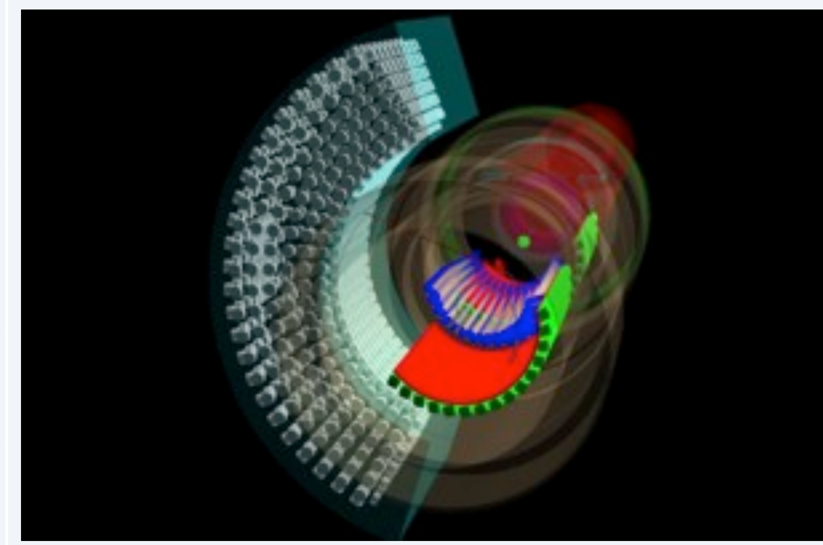


MEG at PSI Status

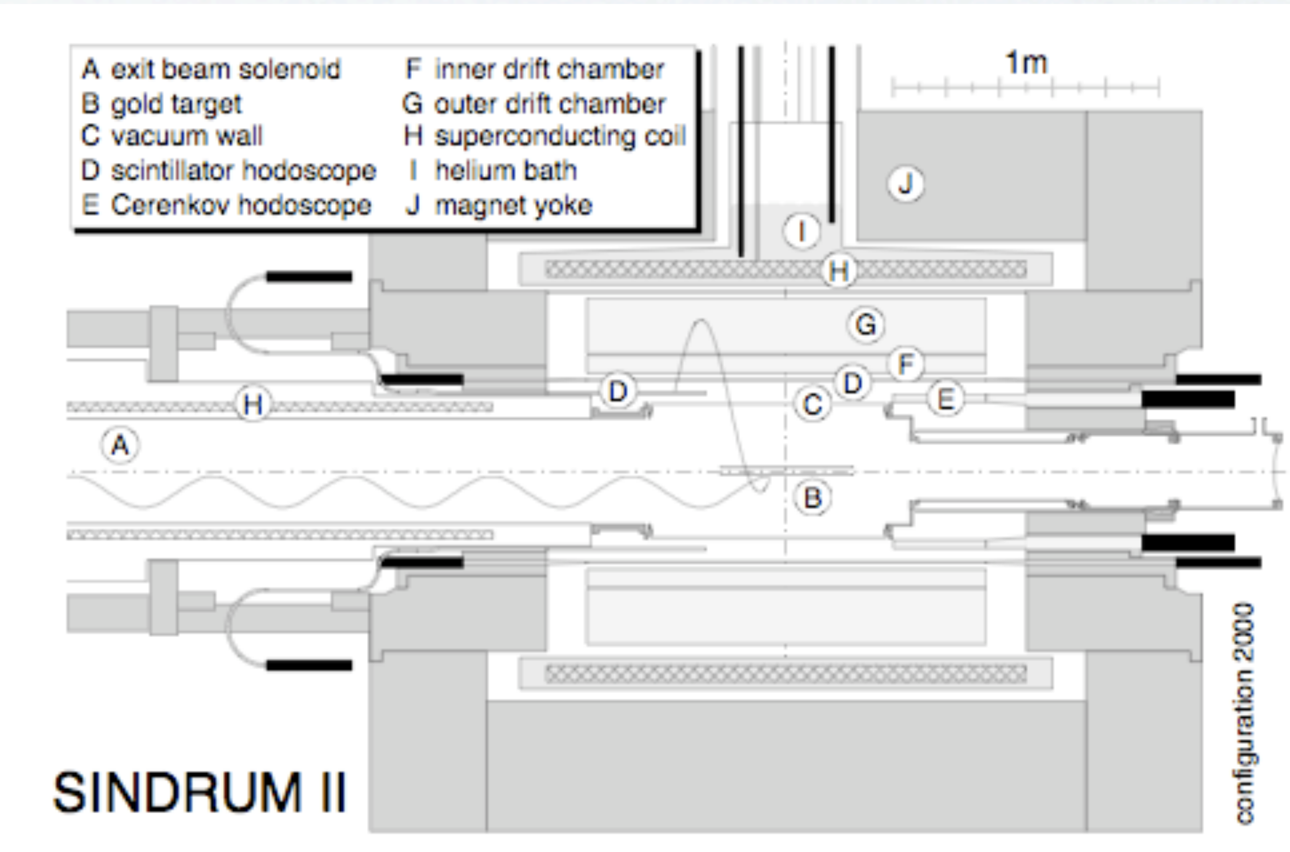
- Physics data production started in 2008
- Current published limit Br(μ→eγ)<2.4x10^{-12} (at 90% C.L.) using 2009 and 2010 data
- Further data statistic; 2011 DAQ finished this morning!
- Detector upgrade is under discussion to further sensitivity improvement



Status of Muon cLFV

MEGA	SINDRUM II	MEG
Los Alamos $\mu \rightarrow e\gamma$	PSI μ-e conversion	PSI $\mu \rightarrow e\gamma$
		
Pulsed μ beam (28MeV/c) 4×10^{7} s^{-1}	(Cont.)μ beam (52MeV/c) $\sim 10^{7}$ s^{-1}	Cont. μ beam (28MeV/c) 3×10^{7} s^{-1}
DAQ completed in 1995 PRD 65, 112002 UL 1.2×10^{-11}	DAQ completed EPJ C47 337-346 (2006) UL (Au) 7×10^{-13}	DAQ in progress PRL 107 (2011) 171801 UL 2.4×10^{-12}

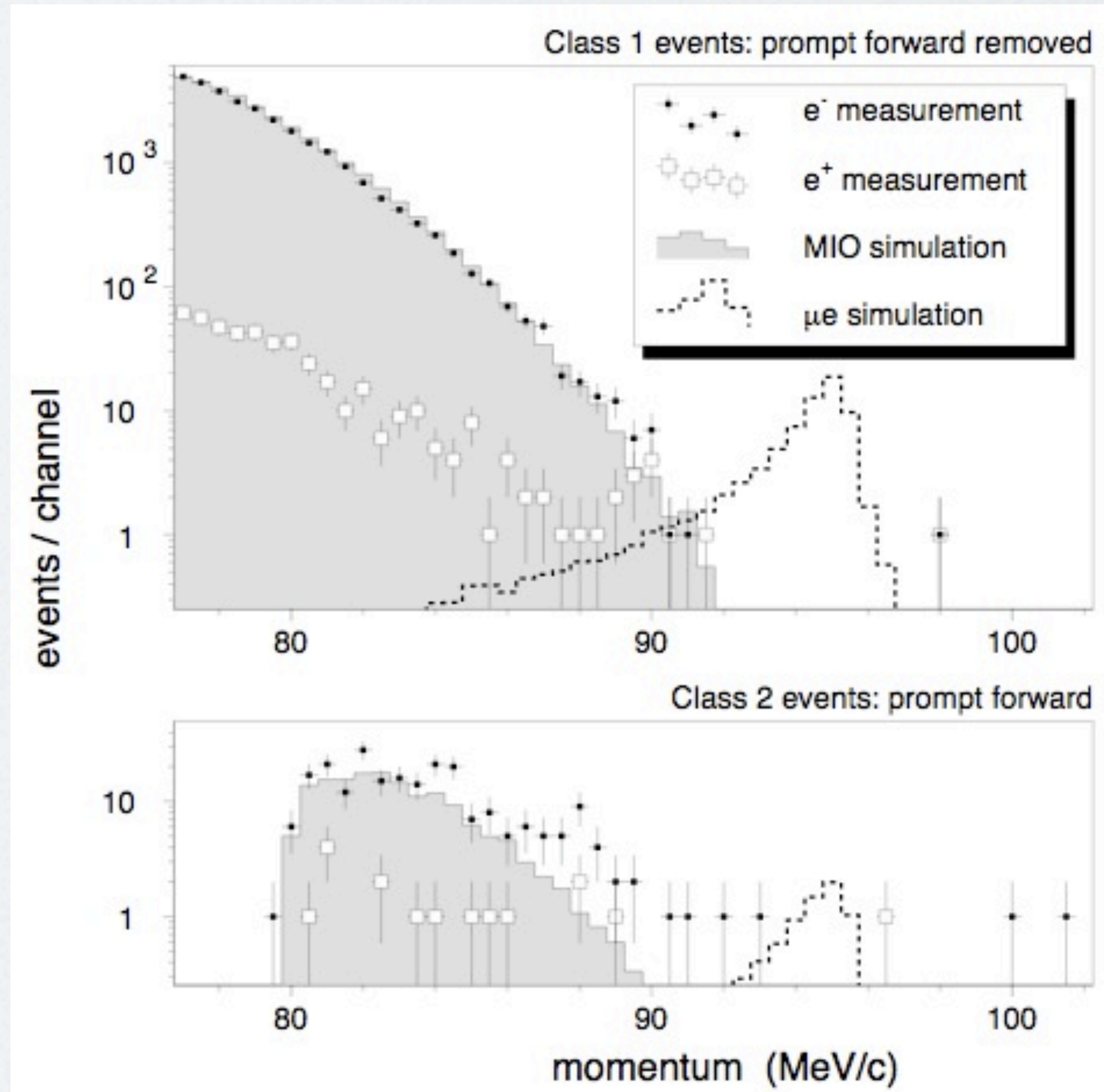
The SINDRUM-II Experiment (at PSI)



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.

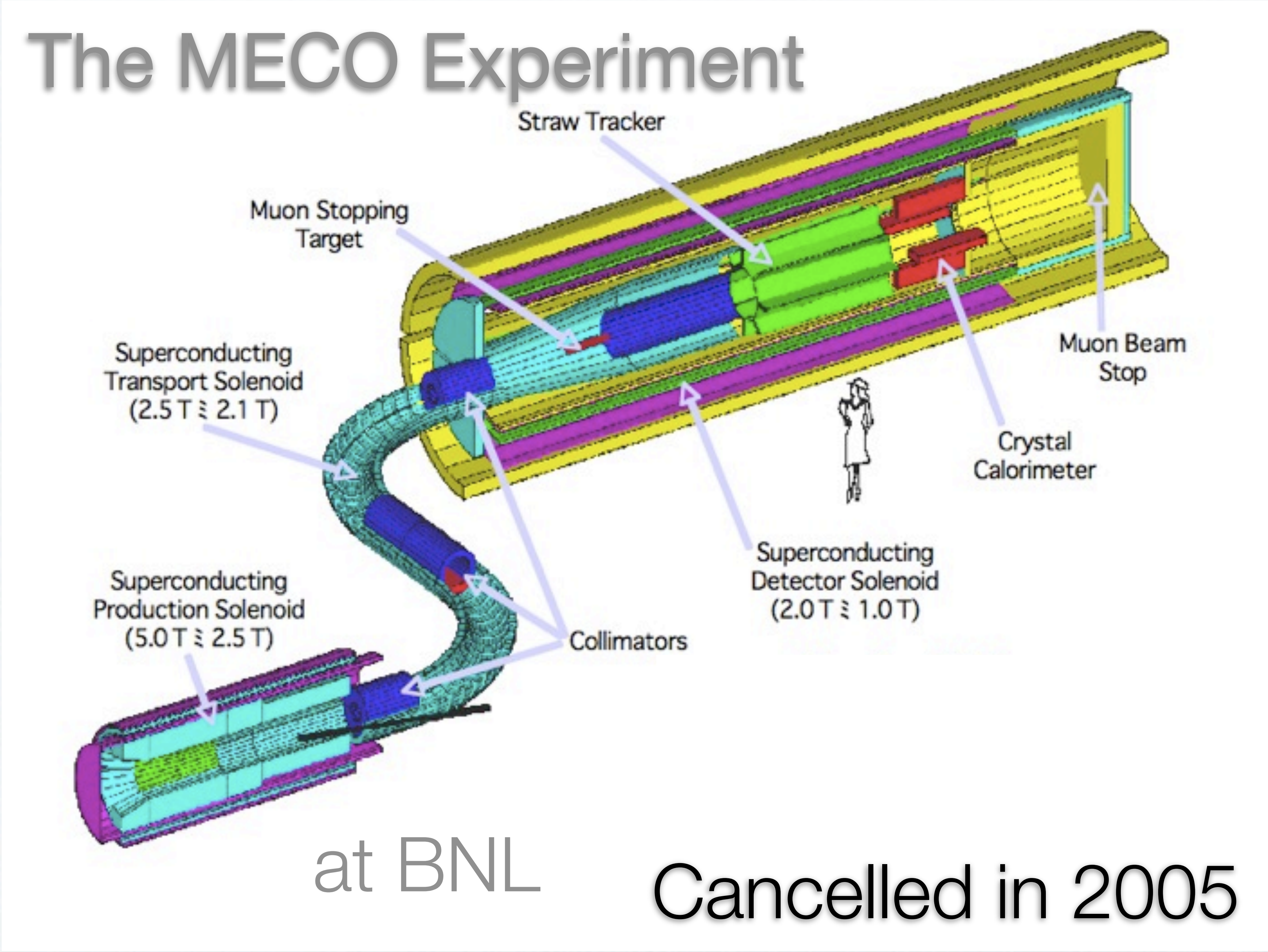
Published Results

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



The MELC and MECO Proposals

- MELC (Russia) and then MECO (the US)
- To eliminate beam related background, beam pulsing was adopted (with delayed measurement)
- To increase a number of muons available, pion capture with a high solenoidal field was adopted
- For momentum selection, curved solenoid was adopted



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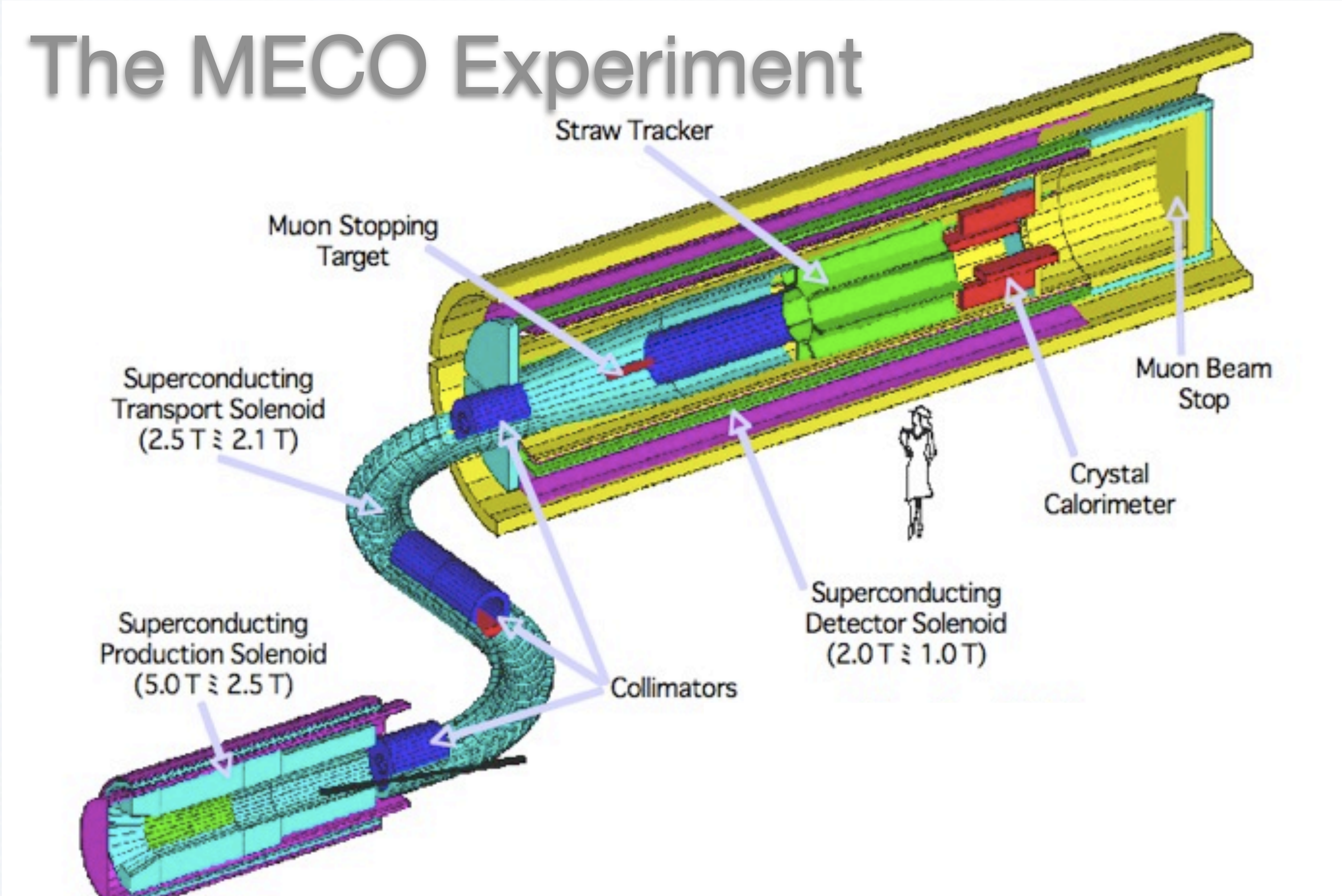


at BNL

Cancelled in 2005

→ mu2e @ Fermilab

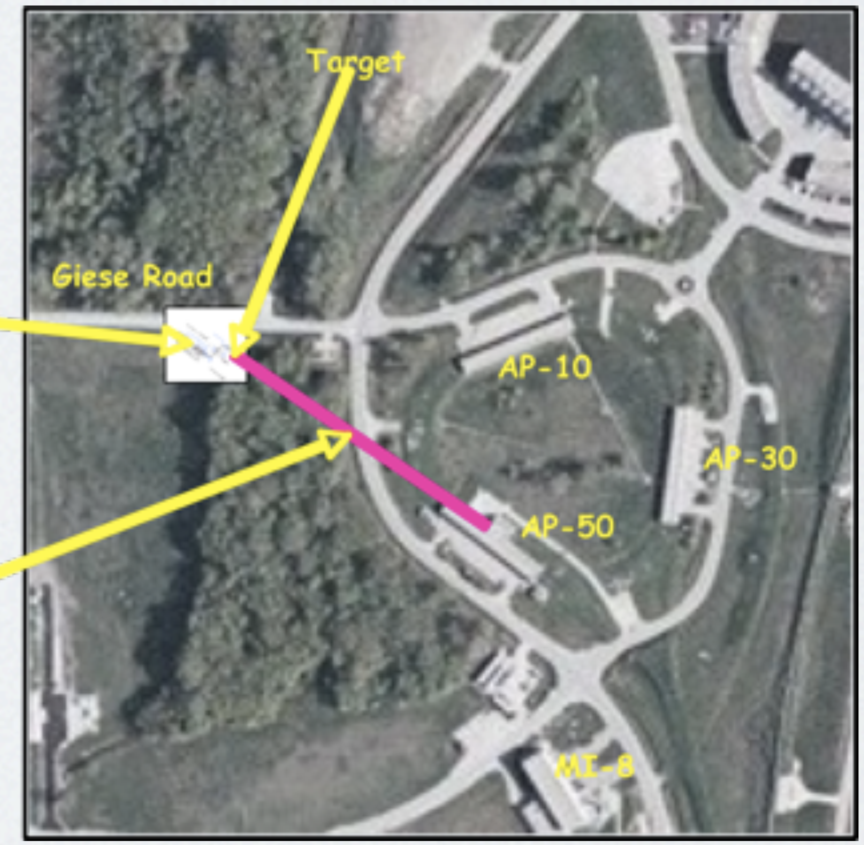
Mu2E @ Fermilab

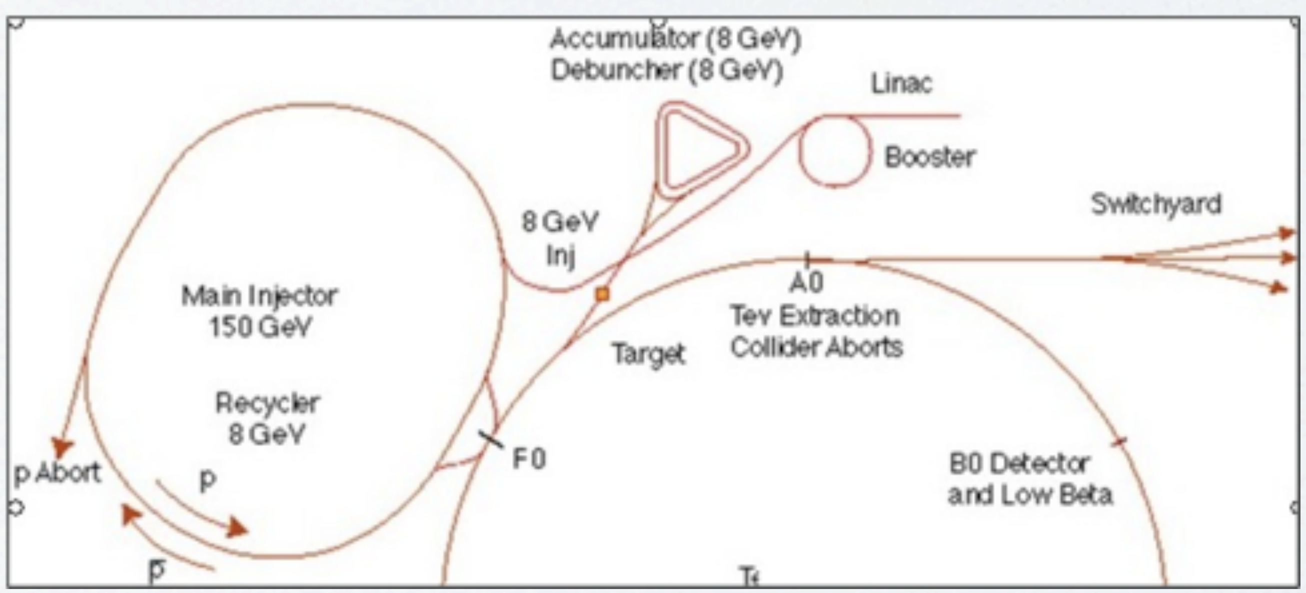
- The mu2e Experiment at Fermilab.
  - Proposal has been submitted.
    - CD-1 in Spring 2012
  - After the Tevatron shut-down
    - uses the antiproton accumulator ring
    - the debuncher ring to manipulate proton beam bunches

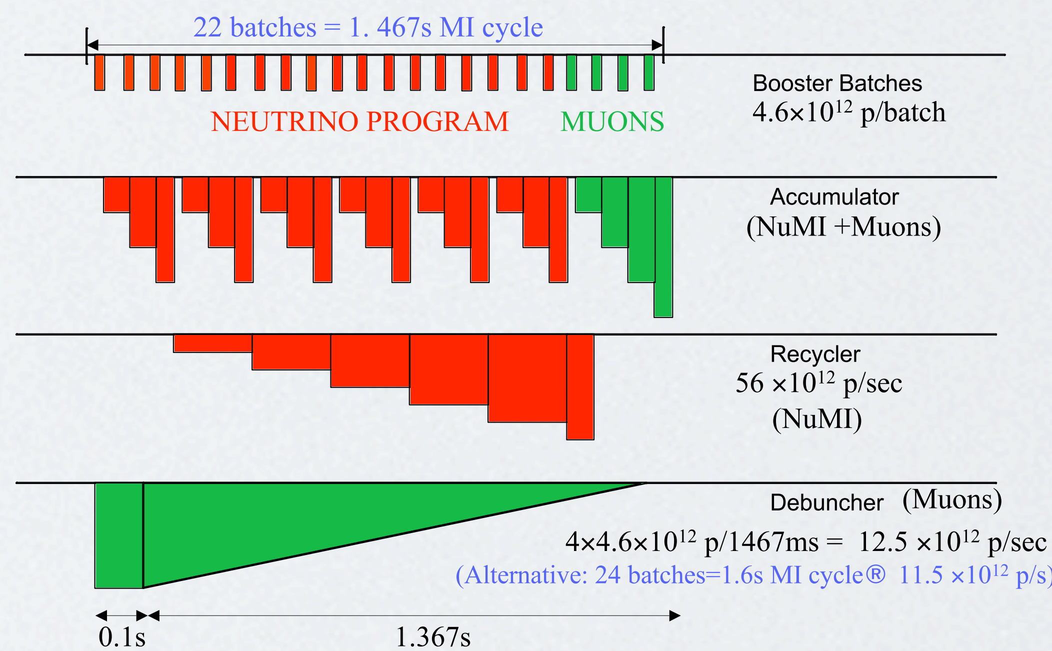
Fermilab Accelerators

Detector

Extracted Beam Line From Debuncher



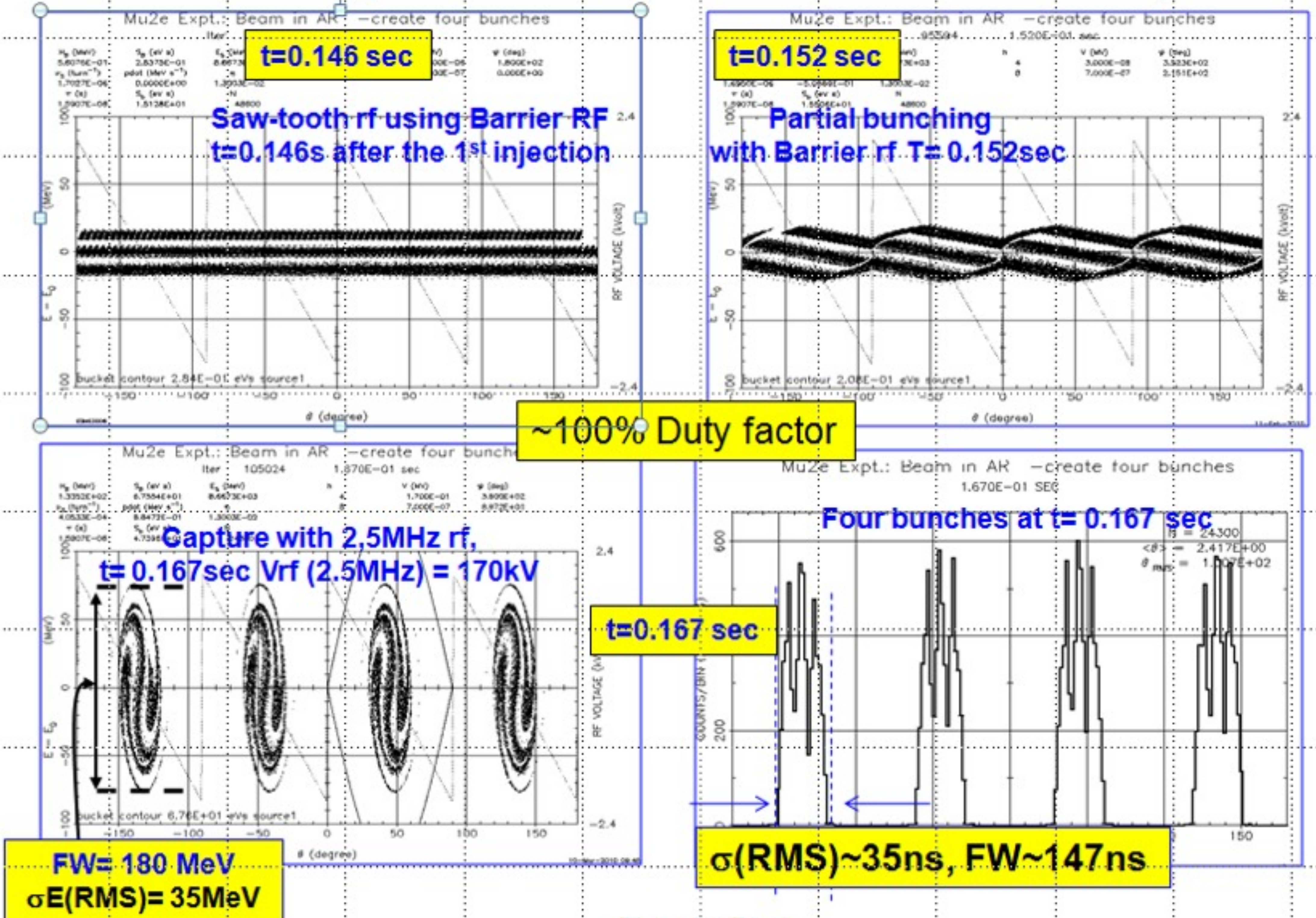




ESME Simulations – Scenaroi-I

Bunching using Barrier saw-tooth rf and 2.5 MHz rf.

Beam is ready for the Mu2e experiment in ≈33 ms after the 3rd injection



9

Chandra Bhat

cLFV Search Experiment

cLFV Search Experiment

- cLFV search is as important as high-energy frontier experiments (and ν oscillation measurements) to find a clue to understand
  - SUSY-GUT
  - Neutrino See-saw

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  - Using “different” physics process (with better sensitivity if possible)!

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- MEG is running first and will improve the sensitivity more in future
- Need other experiment(s) to confirm it
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- COMET (<u>CO</u>herent <u>M</u>uon <u>E</u>lectron <u>T</u>ransition)
  - Submitted a proposal to J-PARC in 2008 and a CDR in 2009,
  - and obtained Stage-1 approval in July 2009
  - TDR in preparation, will be published in 2011

An Experimental Search For Lepton Flavor Violating

$\mu^- - e^-$ Conversion at Sensitivity of $\mathbf{10^{-16}}$

http://comet.phys.sci.osaka-u.ac.jp:8080/comet

COMET

COMET Collaboration List

70 people from 19 institutes (December 2010)

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E. Hungerford, K. Lau

Tbilisi State University
Nika Tsverava

Institute for Nuclear Science and Technology
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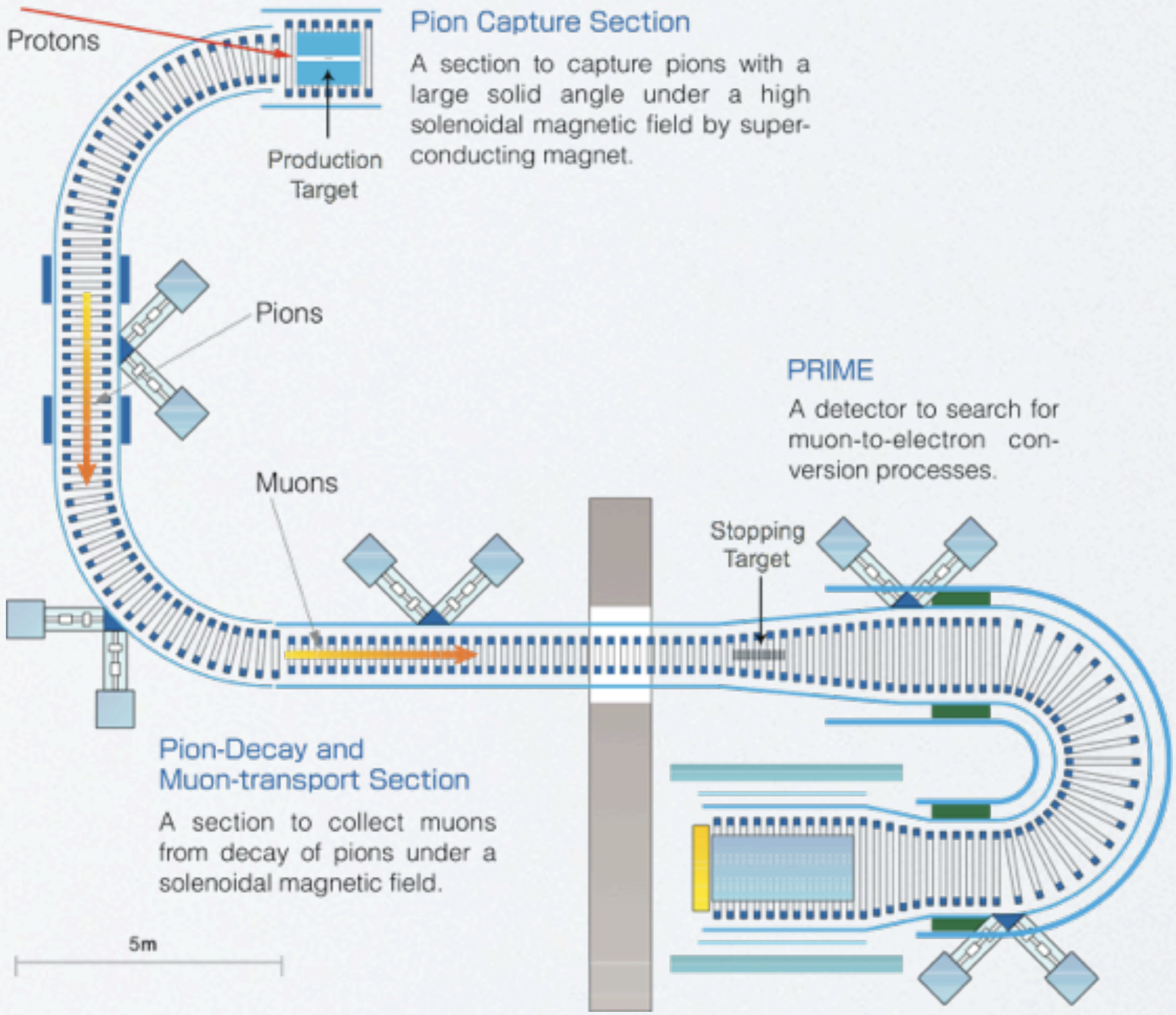
Overview of the COMET Experiment

Overview of the COMET Experiment

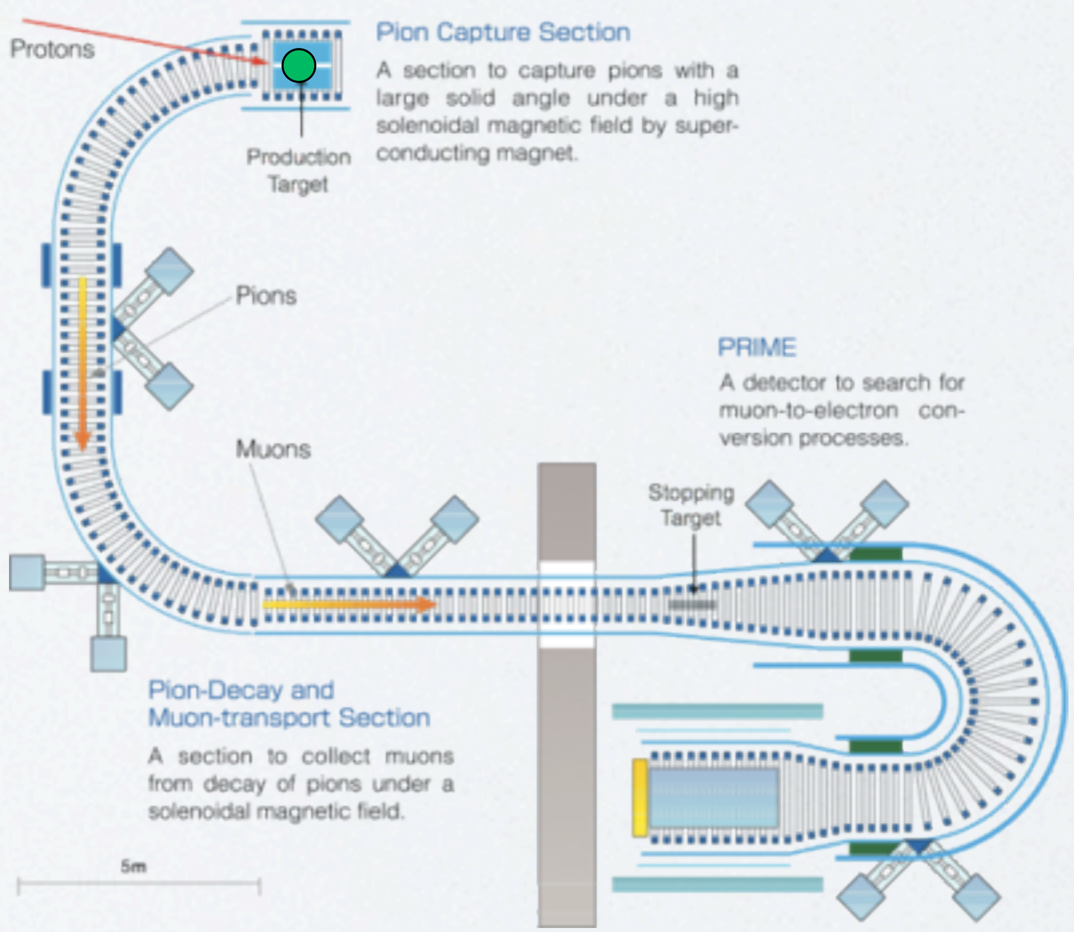


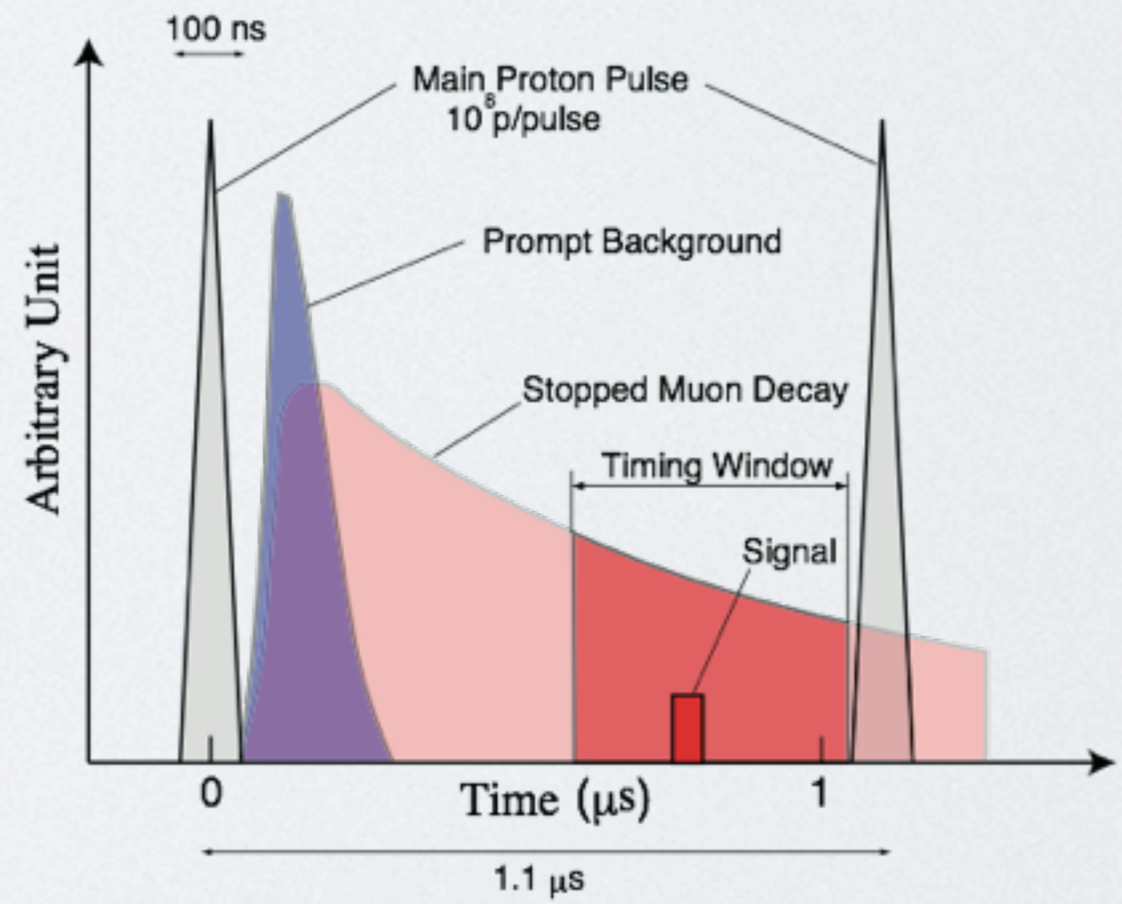
- ✦ Proton Beam
  - ✦ p→π→μ
  - ✦ 8GeV, ~7μA
- ✦ The Muon Source
  - ✦ Proton Target
  - ✦ Pion Capture
  - ✦ Muon Transport
- ✦ The Detector
  - ✦ Muon Stopping Target
  - ✦ Electron Transport
  - ✦ Electron Detection

Proton BEAM

Requirements for the Beam

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





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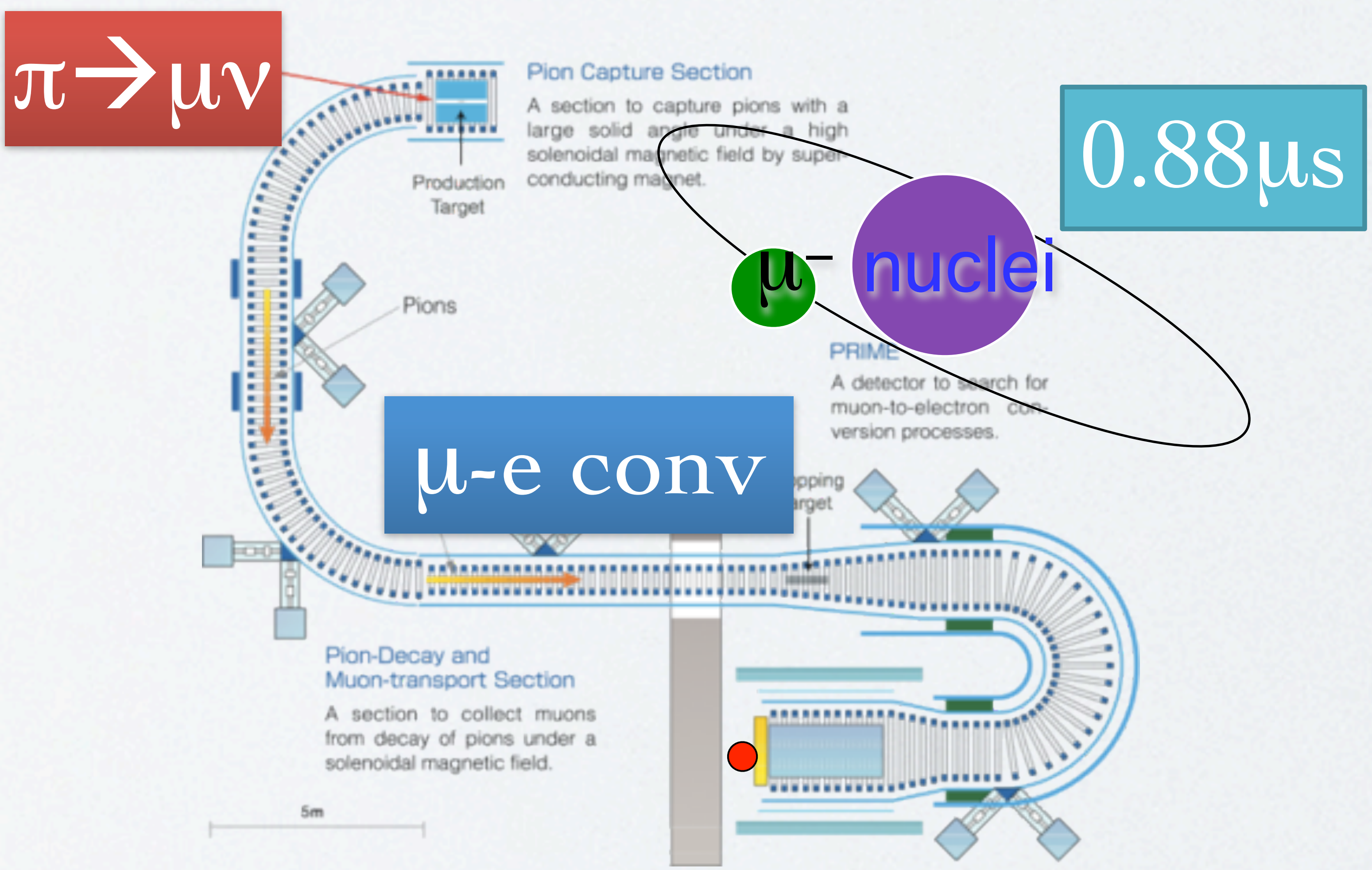

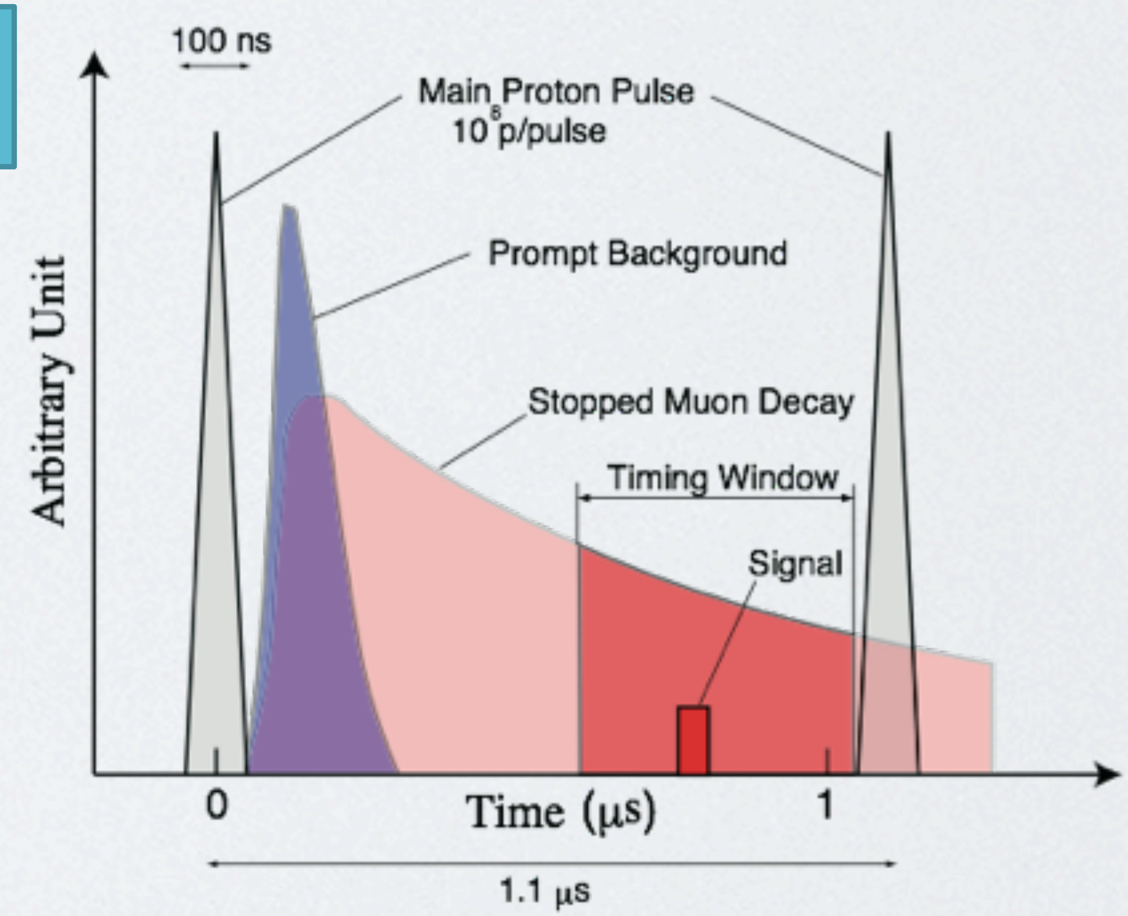

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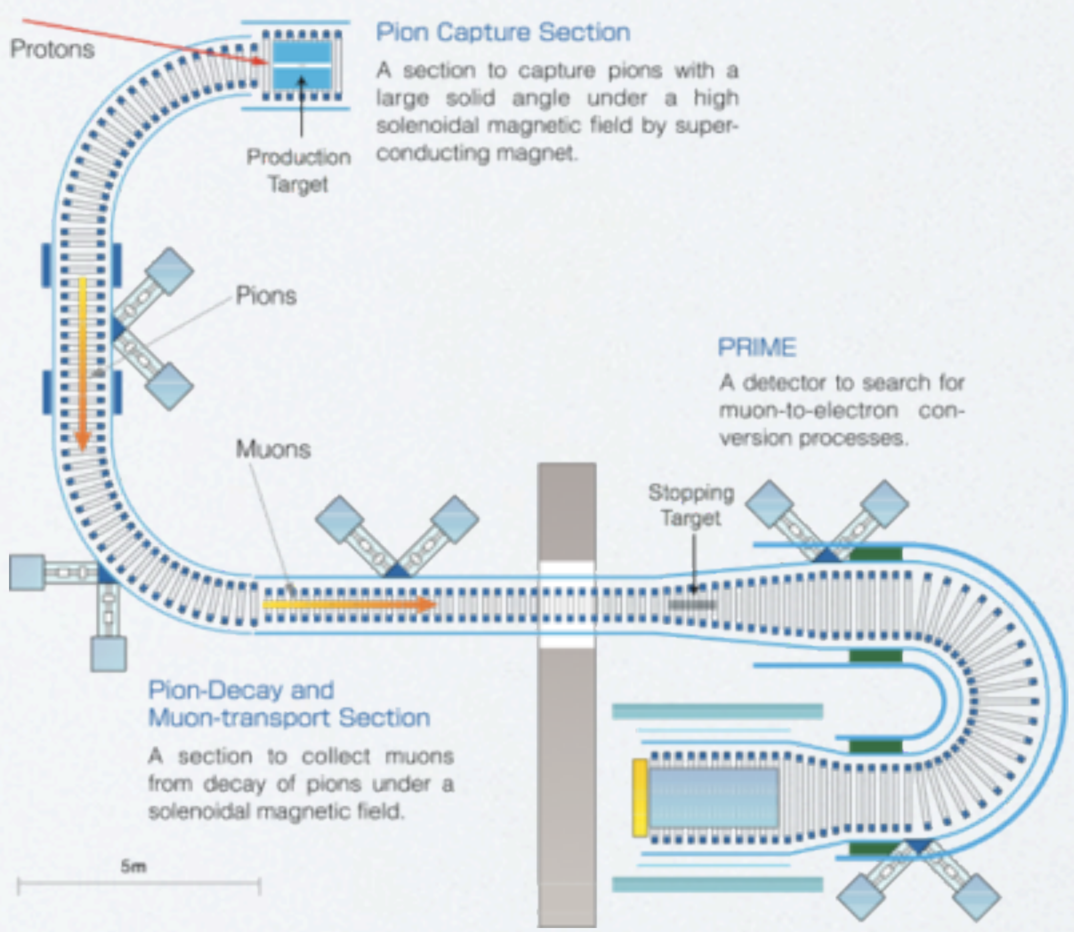

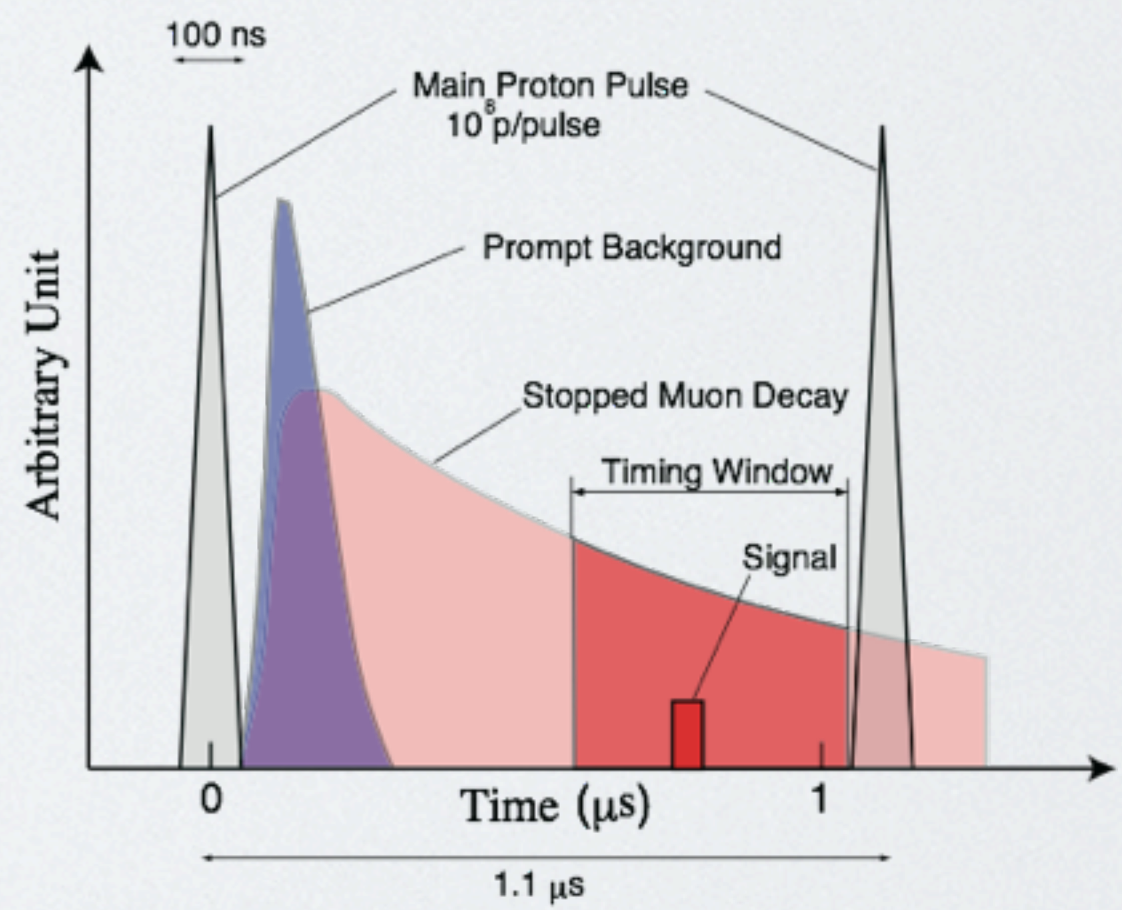

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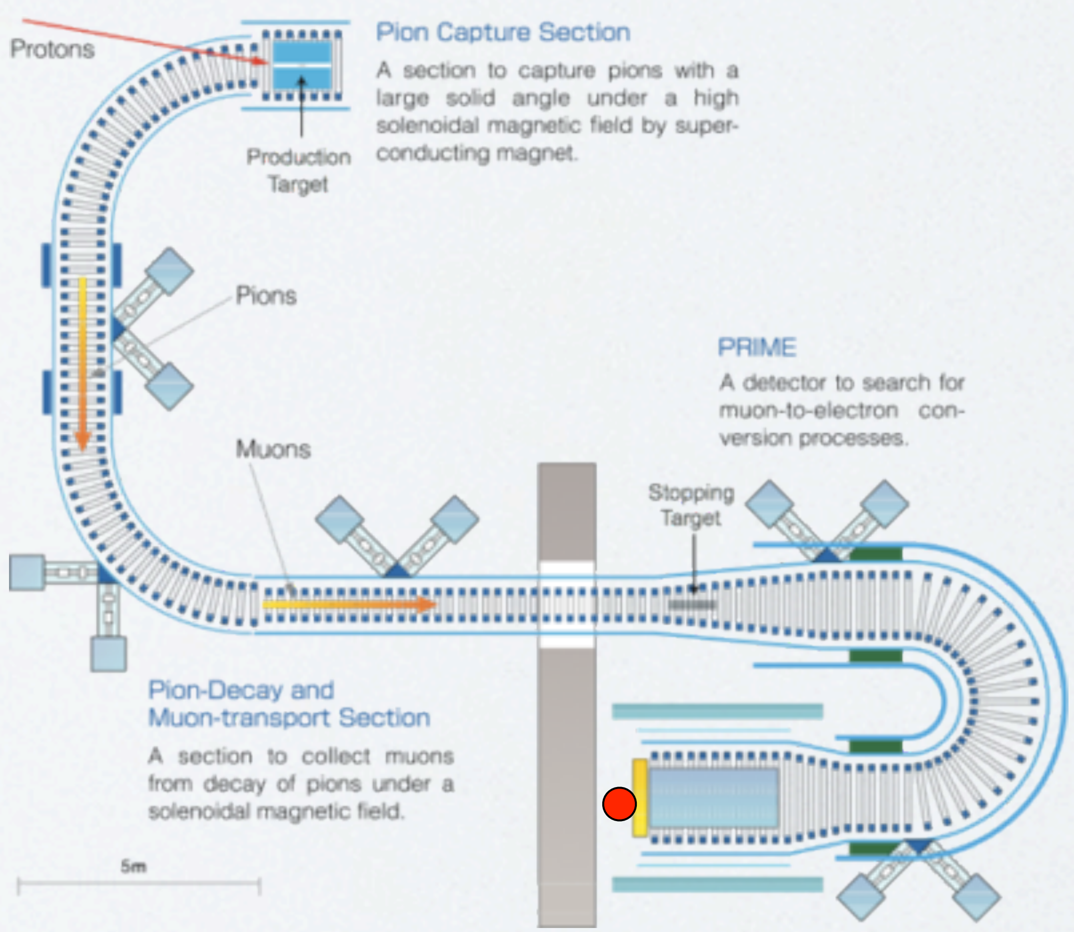
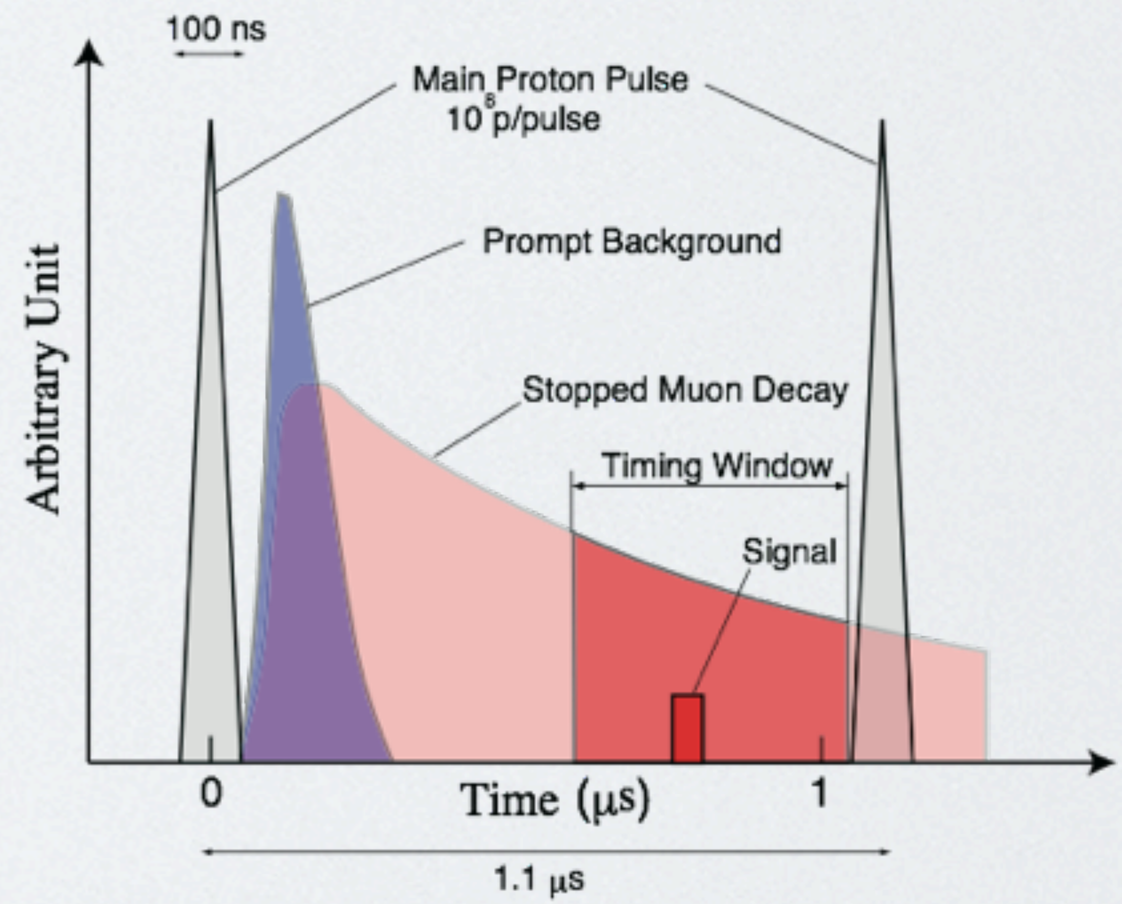
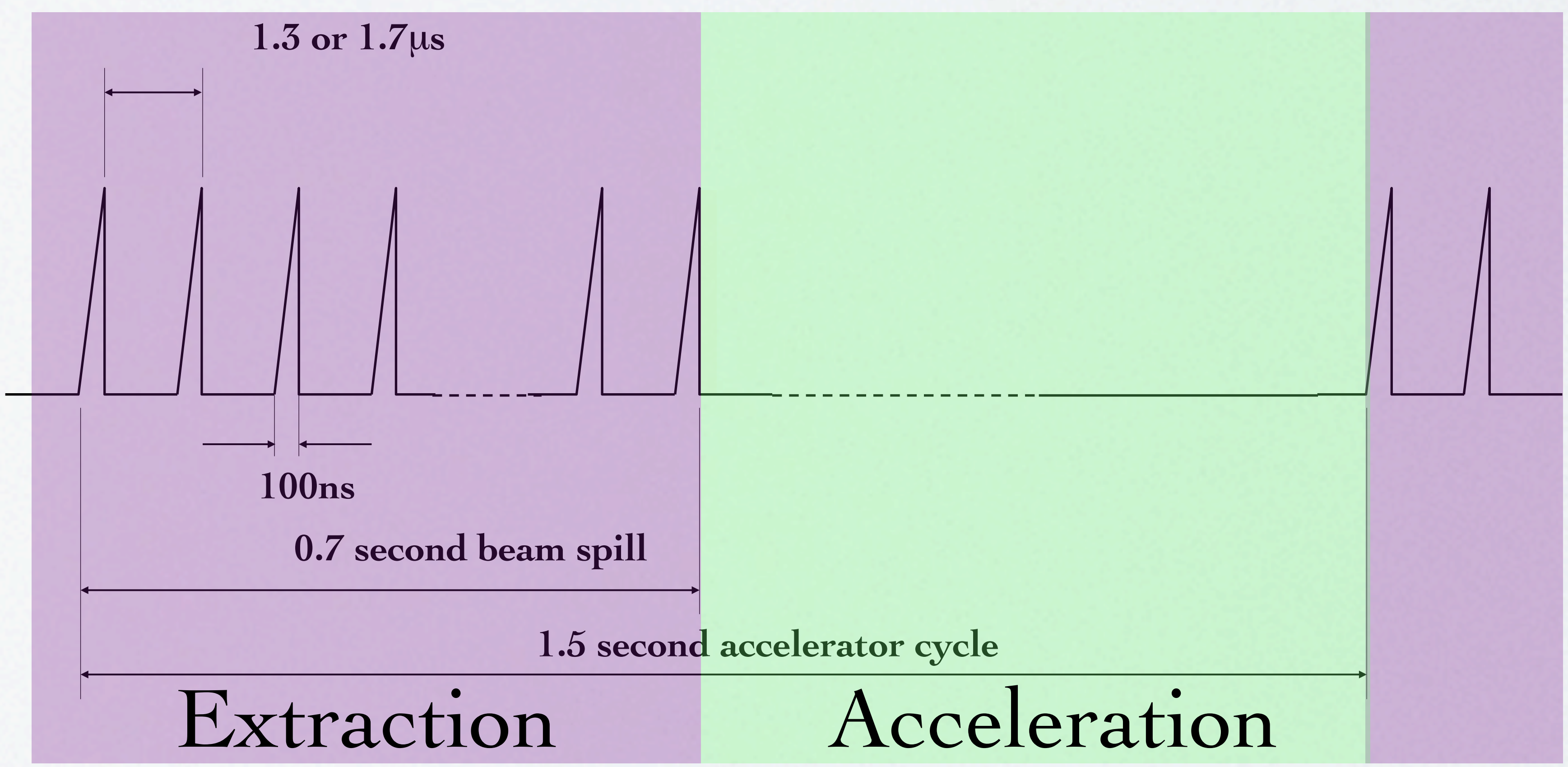




Requirements for the Proton Beam

- Proton beam structure for the mu-e conversion search
  - 100nsec bunch width, 1.3 (or 1.7) μsec 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}



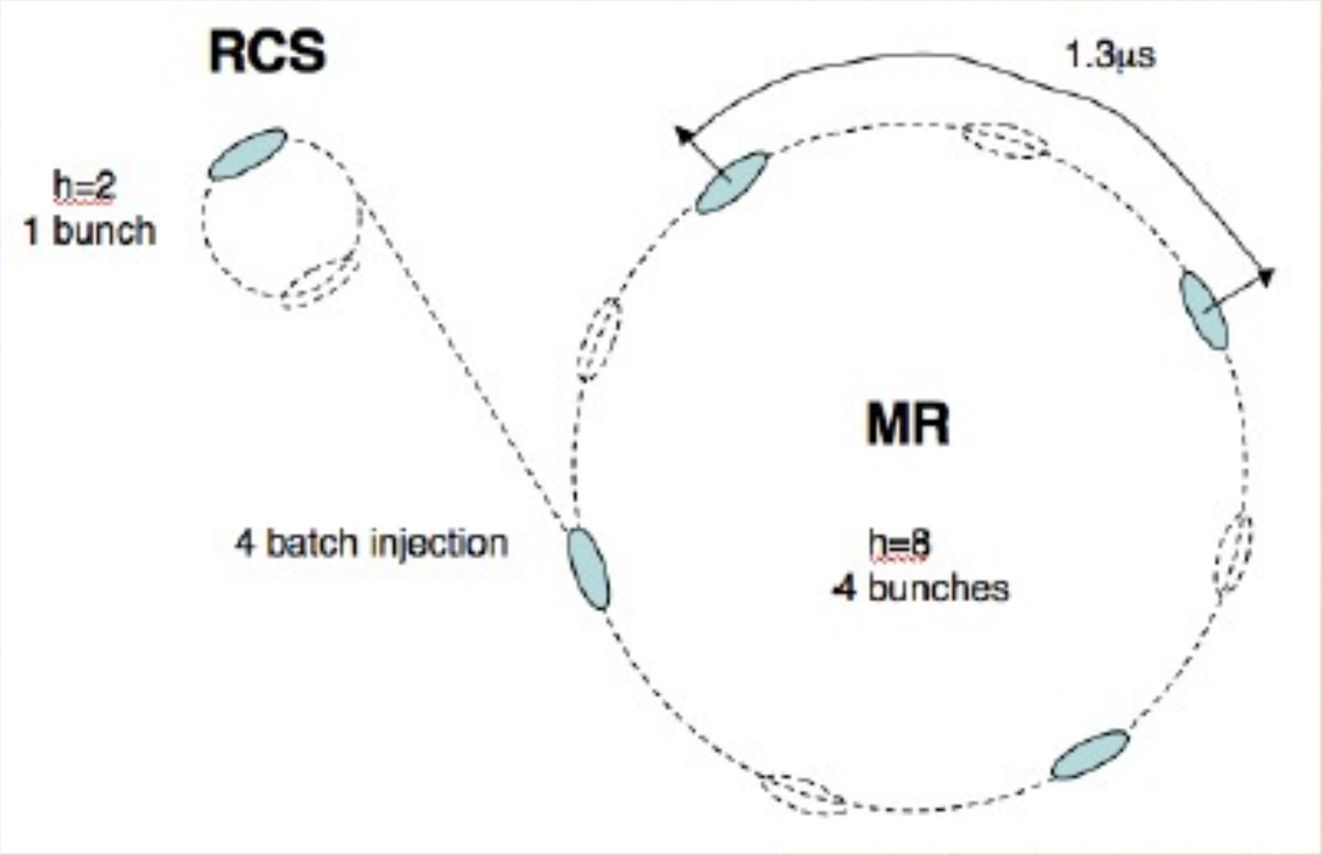
N_{bg} = NP x R_{ext} x Y_π/P x A_π x P_γ x A

NP : total # of protons (~10^{21})
R_{ext} : Extinction Ratio (10^{-9})
Y_π/P : π yield per proton (0.015)
A_π : π acceptance (1.5 x 10^{-6})
P_γ : Probability of γ from π (3.5x10^{-5})
A : detector acceptance (0.18)

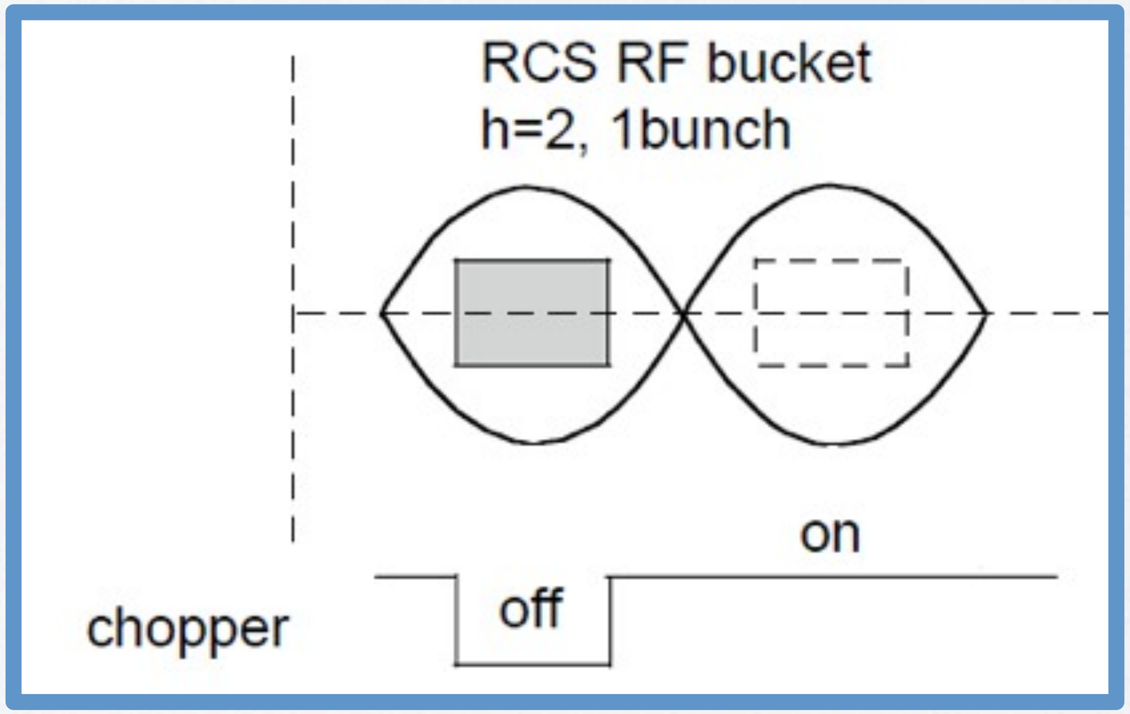
BR=10^{-16}, N_{bg} ~ 0.1 →
Extinction < 10^{-9}

J-PARC 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



- Simple solution
- No need of hardware modification
- Heavier heat load in the scraper
- Possible leakage of chopped beam in empty buckets

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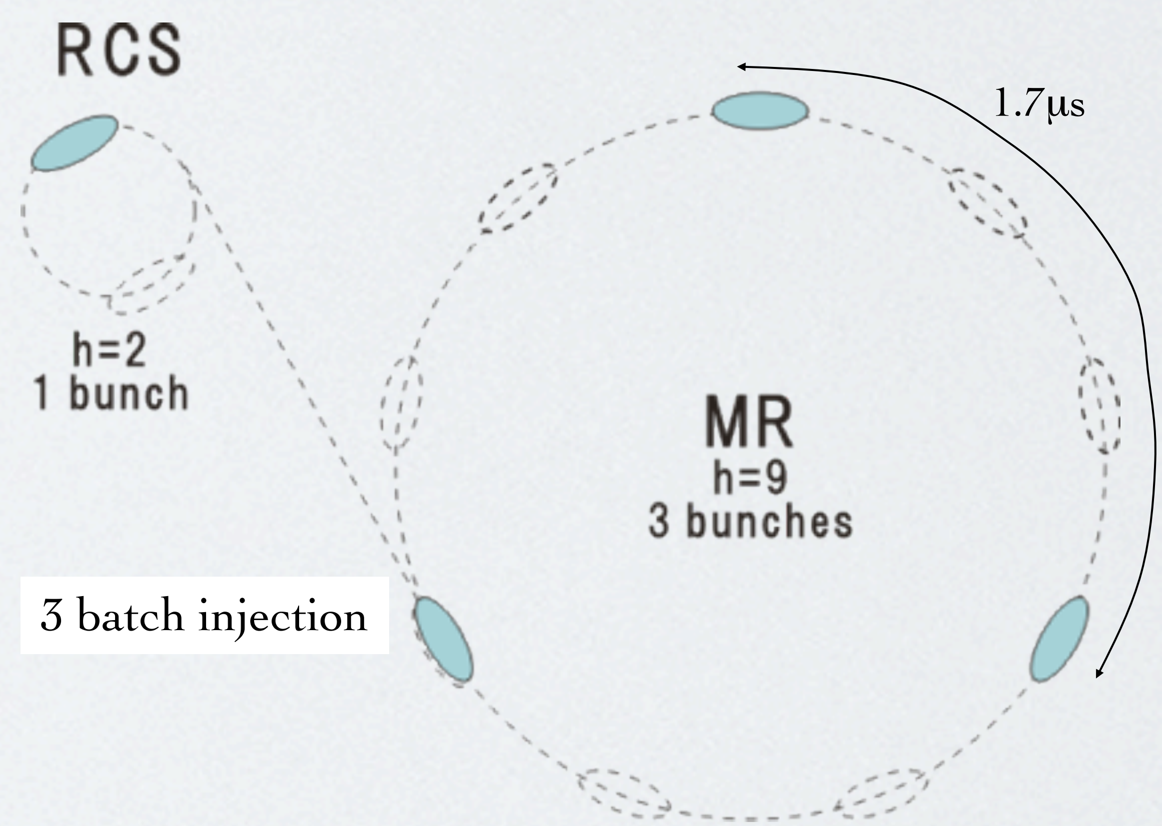

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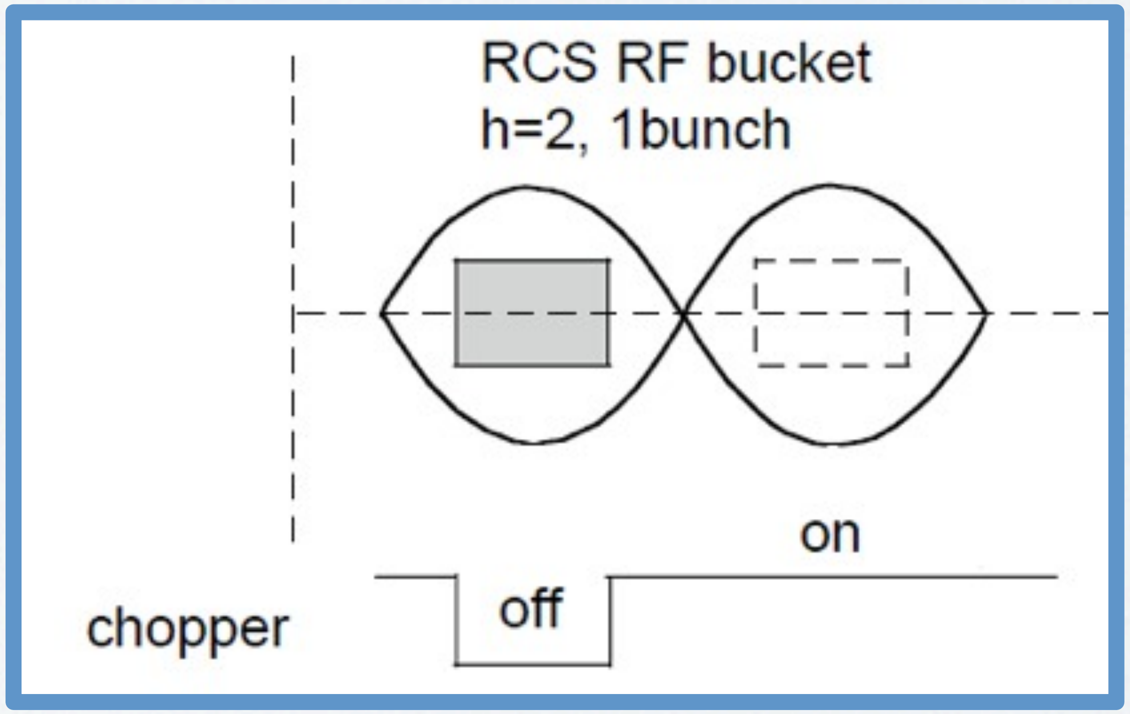
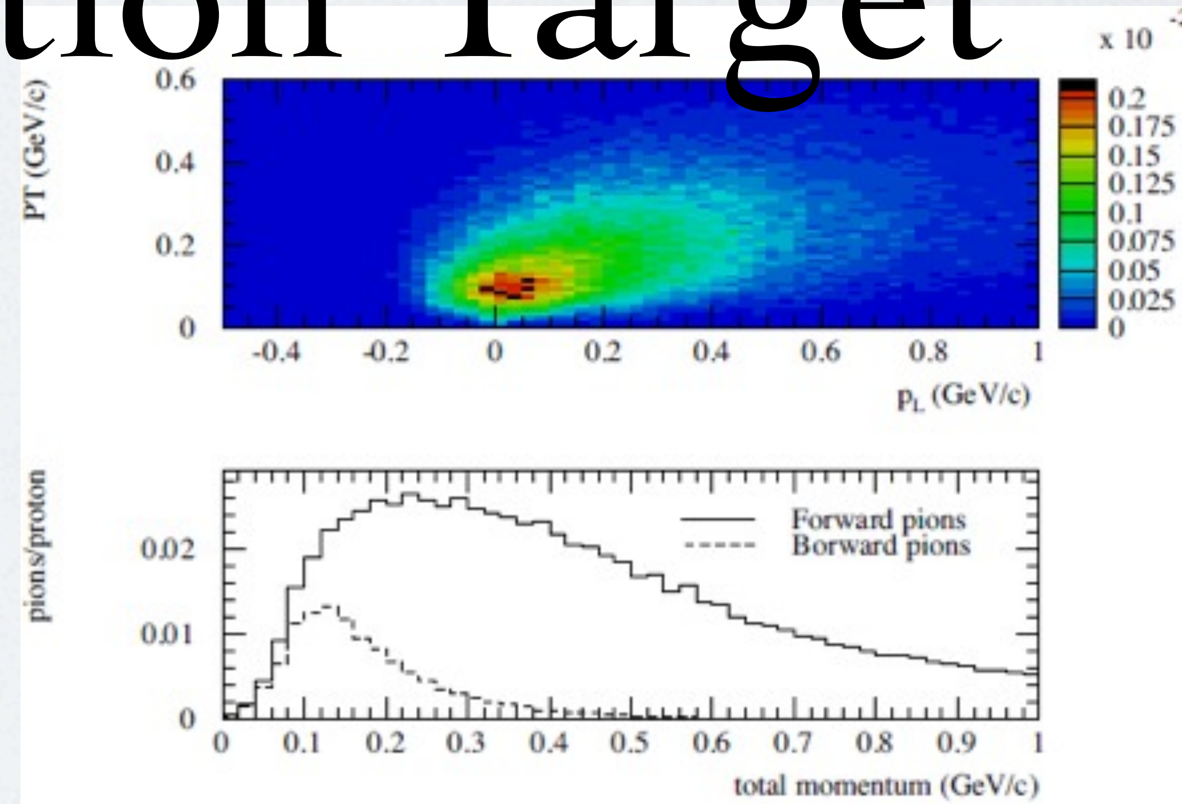


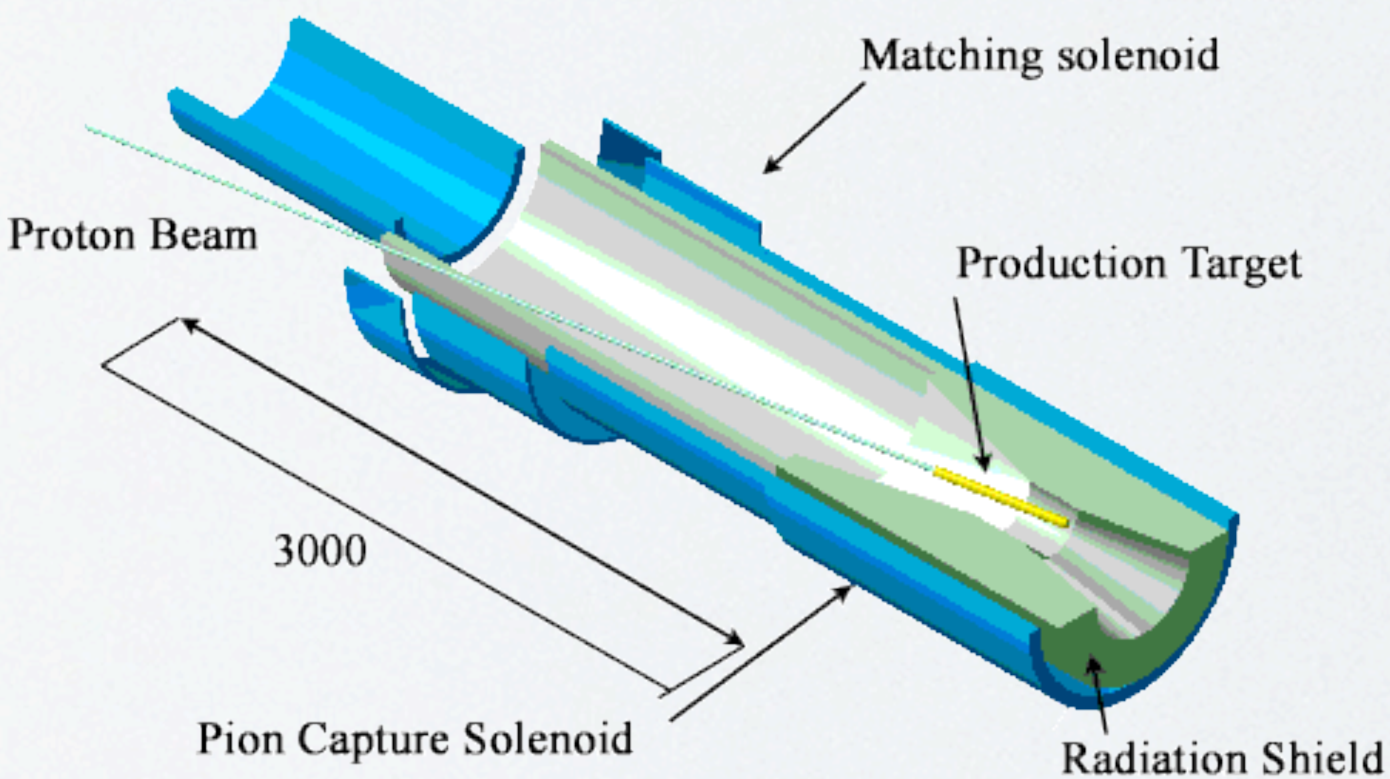
- Simple solution
- No need of hardware modification
- Heavier heat load in the scraper
- Possible leakage of chopped beam in empty buckets

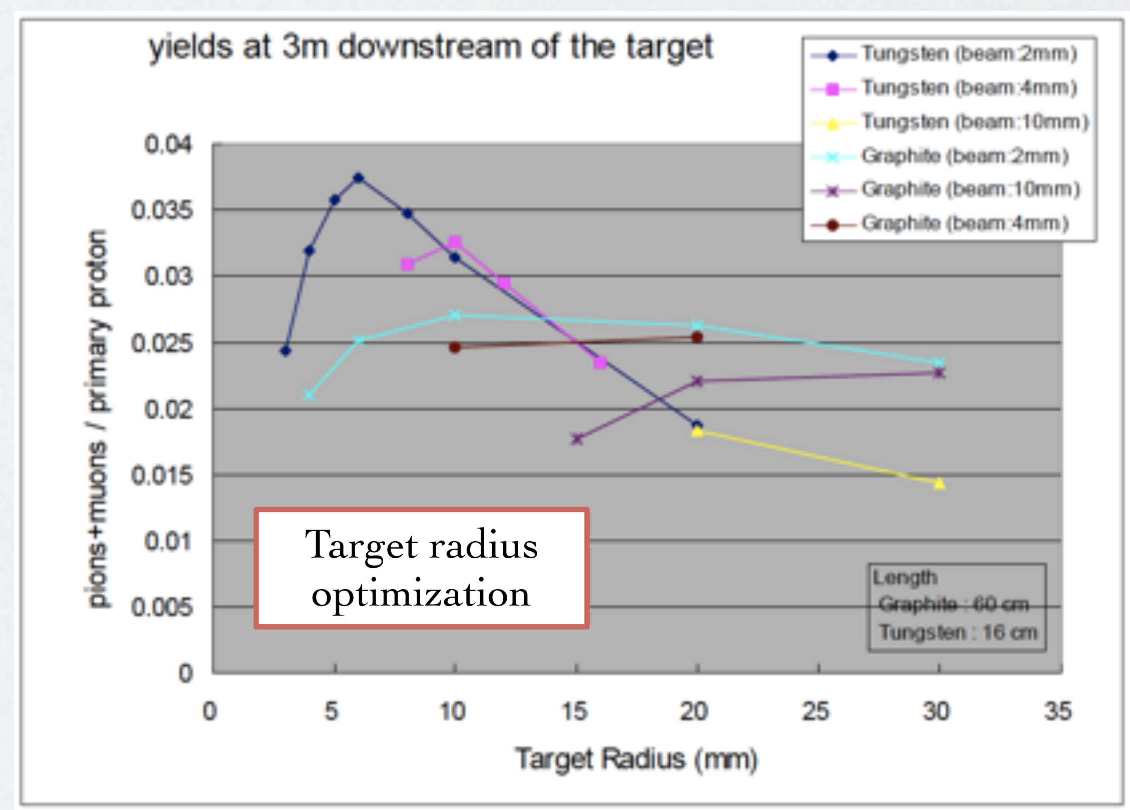
Muon/pion production

Pion Production Target

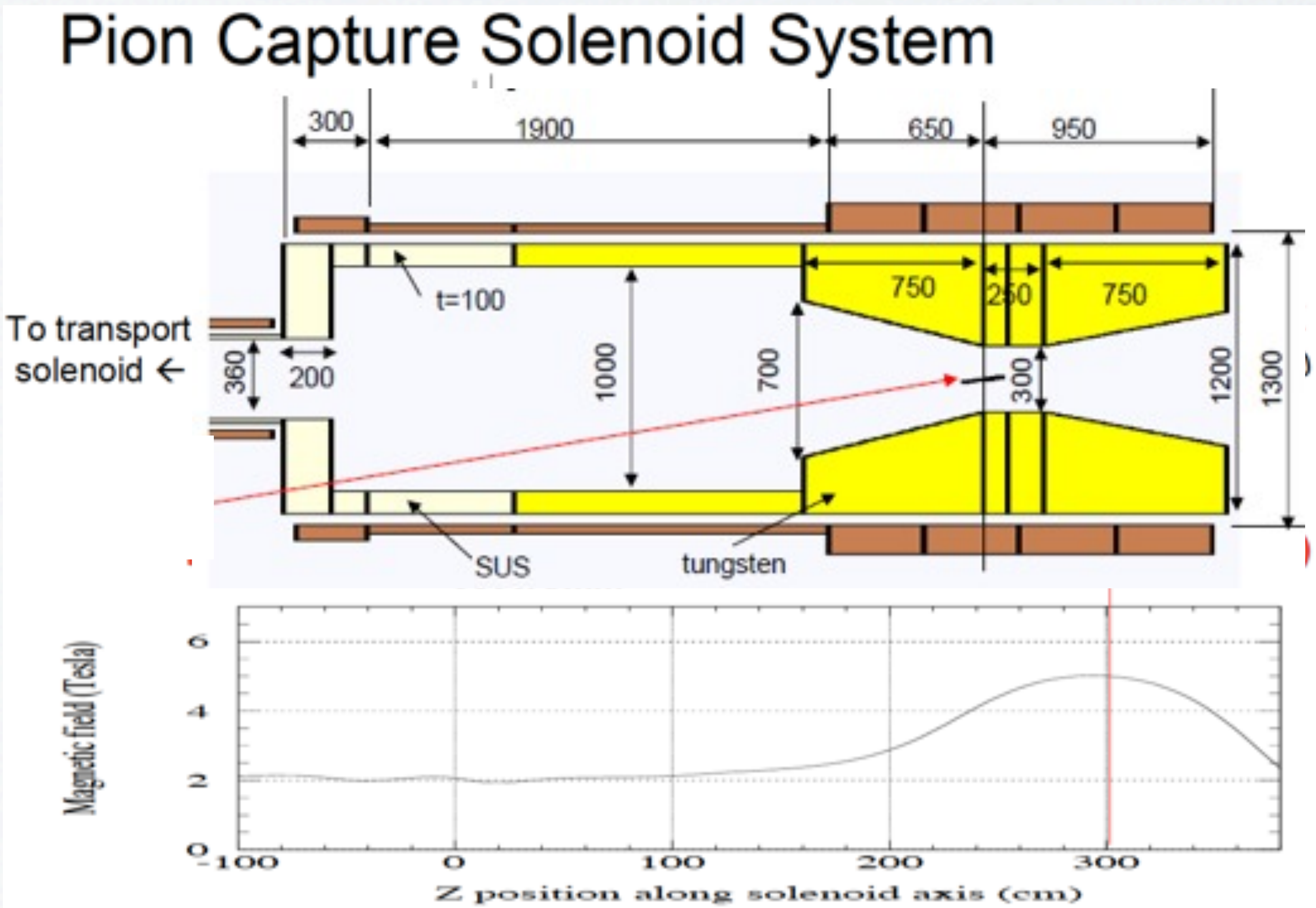
- low-E pions
  - for low-E muons to stop
  - Backward extraction
- pion yield is proportional to T_{proton}
  - pion yld is proportional to Beam Power
- Target material
  - High-Z Metal Rod like tungsten or gold
    - Water cooling
  - Graphite
    - Helium gas cooling



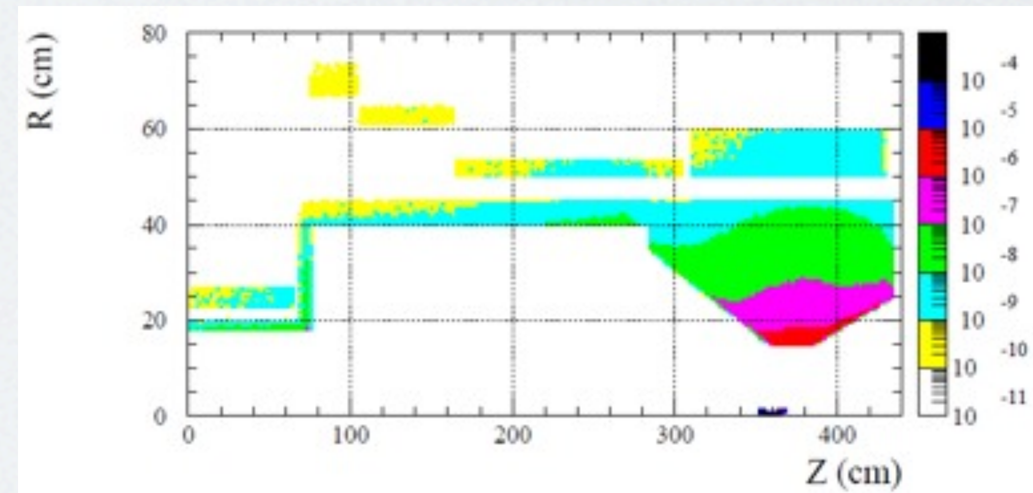


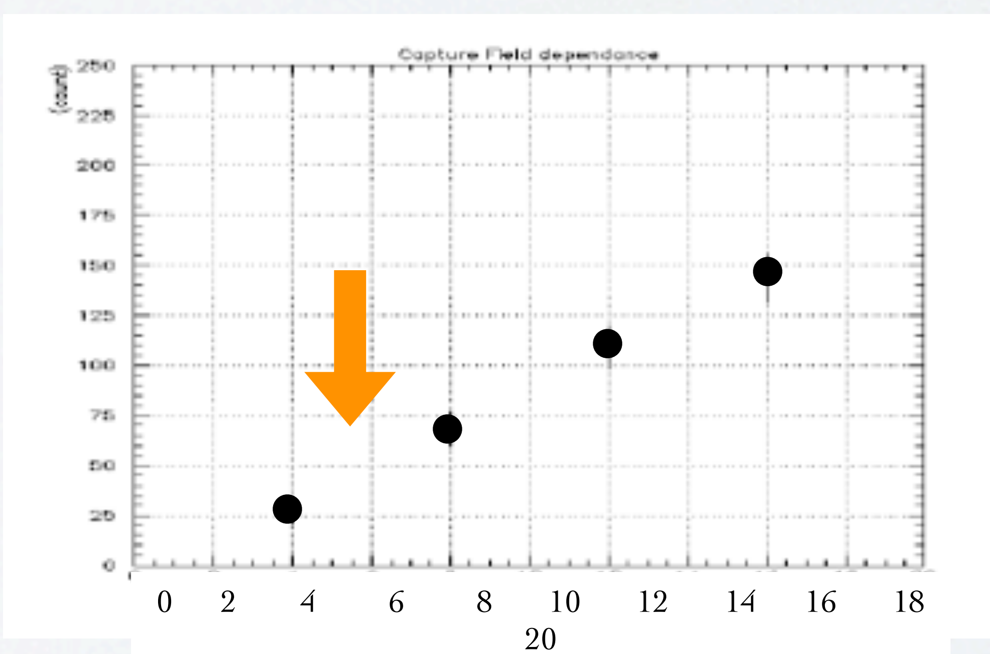


Pion Capture



MARS simulation



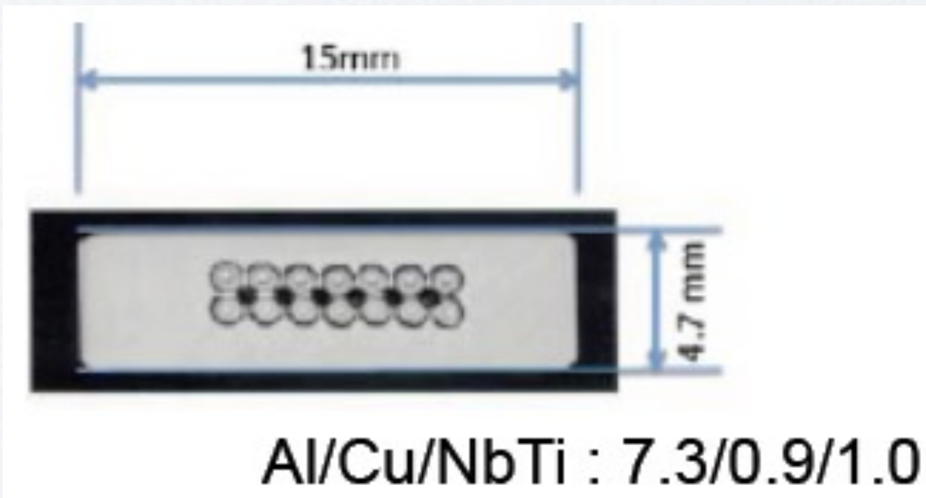


μ-yield vs. B_{max}

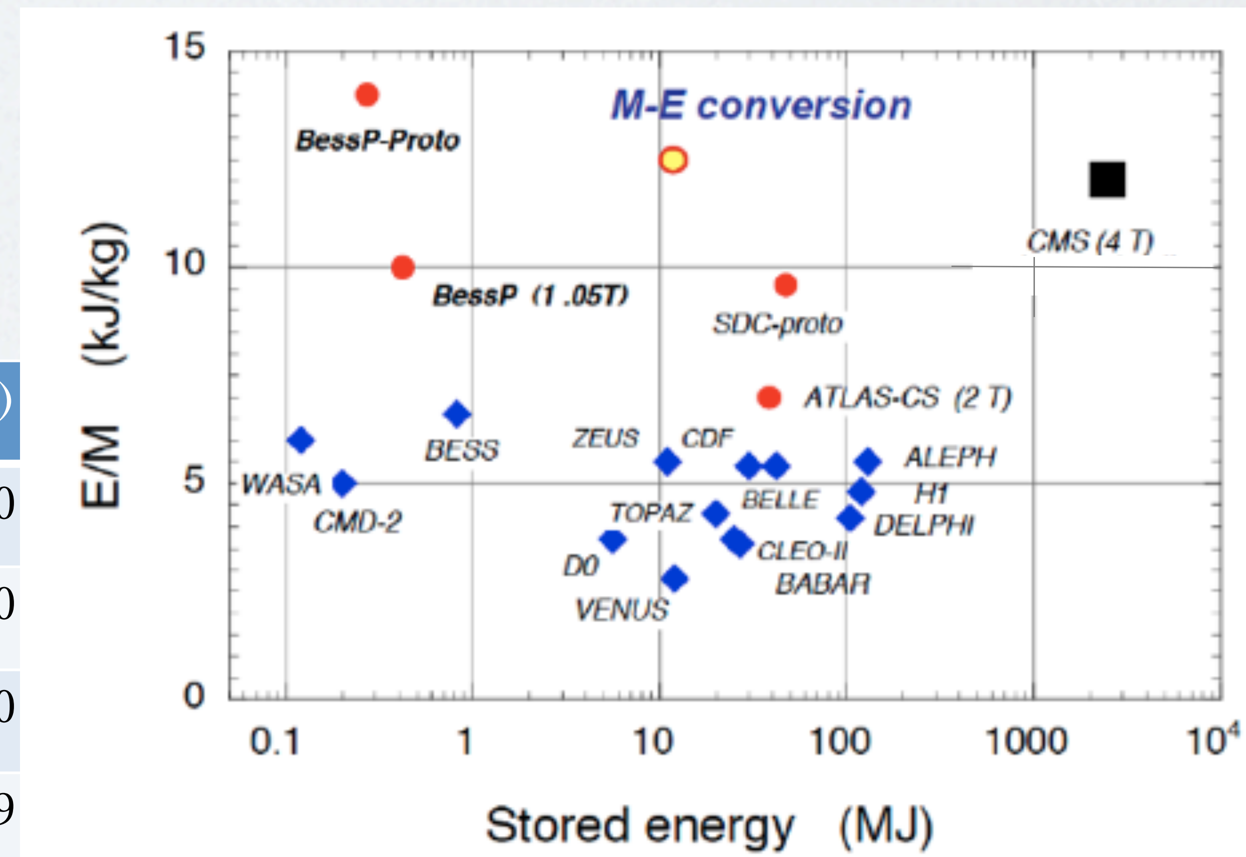
- > 5 T at the target position
  - capture p_t < 120 MeV/c
- Radiation Shield
  < 100 W on SC coil
  - 3-4 kW @ target
  - 35 kW @ W Shield
  - 2×10^{-5} W/g @ coil
- Yields
  - $0.05(\pi+\mu)$/8-GeV-proton

π-Capture Solenoid

- Heat-load density : 2 x 10^{-5} W/g behind W shield
- Utilize Al stabilized SC cable to reduce a heat load to the cold mass.
  - Cable dimension: 15mm x 4.7mm



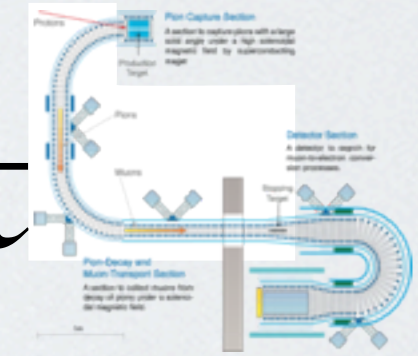
	Length(mm)	Thickness (mm)	$\rho_{Current}$ (A/mm2)
Coil 1	1200	90 (6 layers)	53.0
Coil 2	1400	30 (2 layers)	53.0
Coil 3	600	30 (2 layers)	53.0
Coil 4	300	60 (4 layers)	62.9

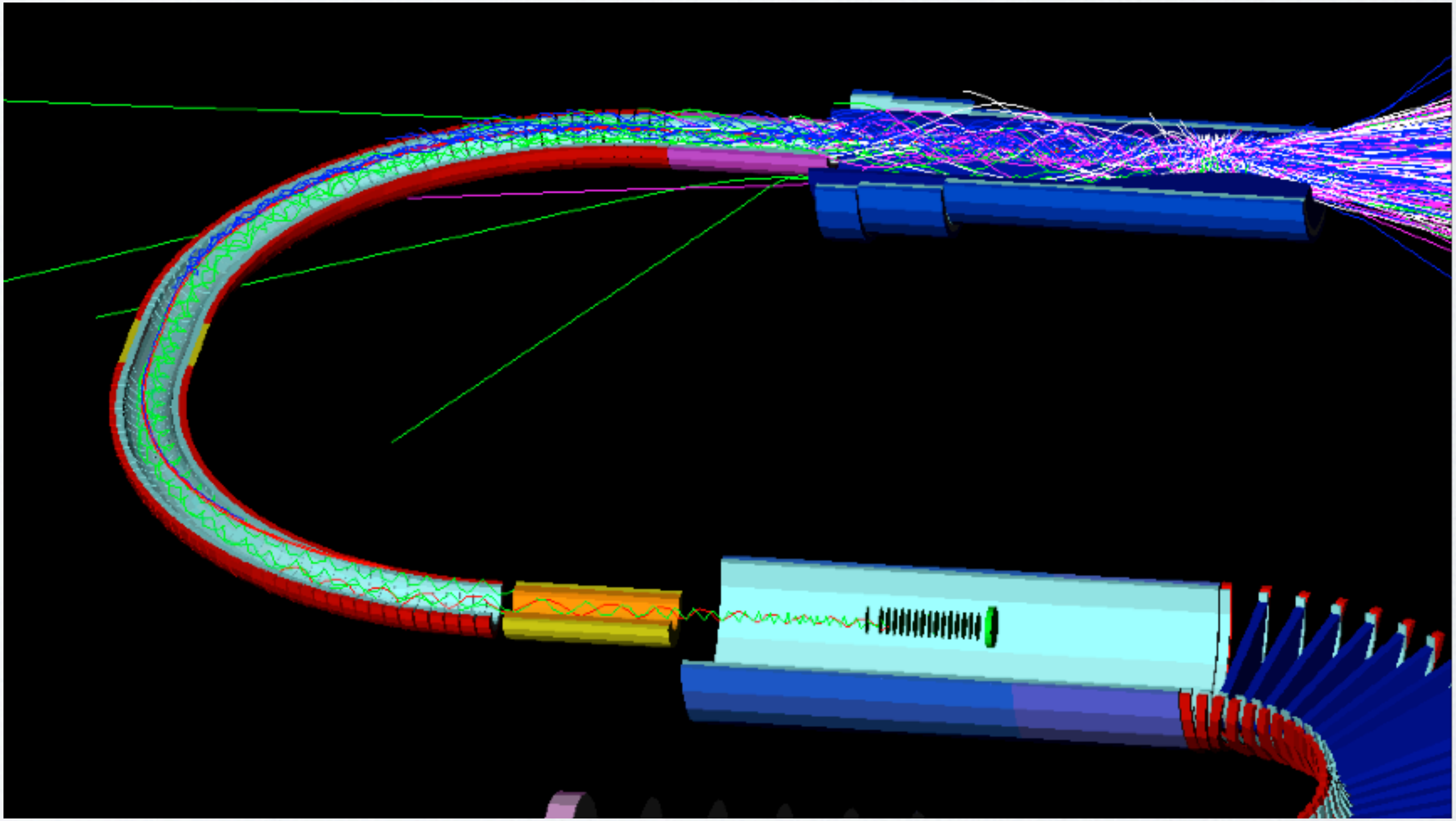


Al-SC: one of world leading expertise of KEK

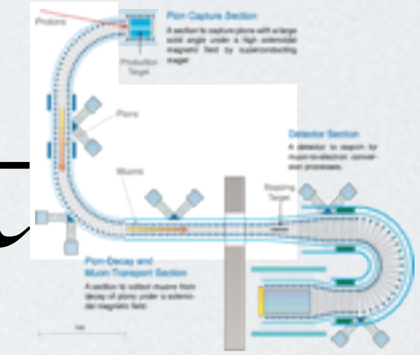
Muon transport

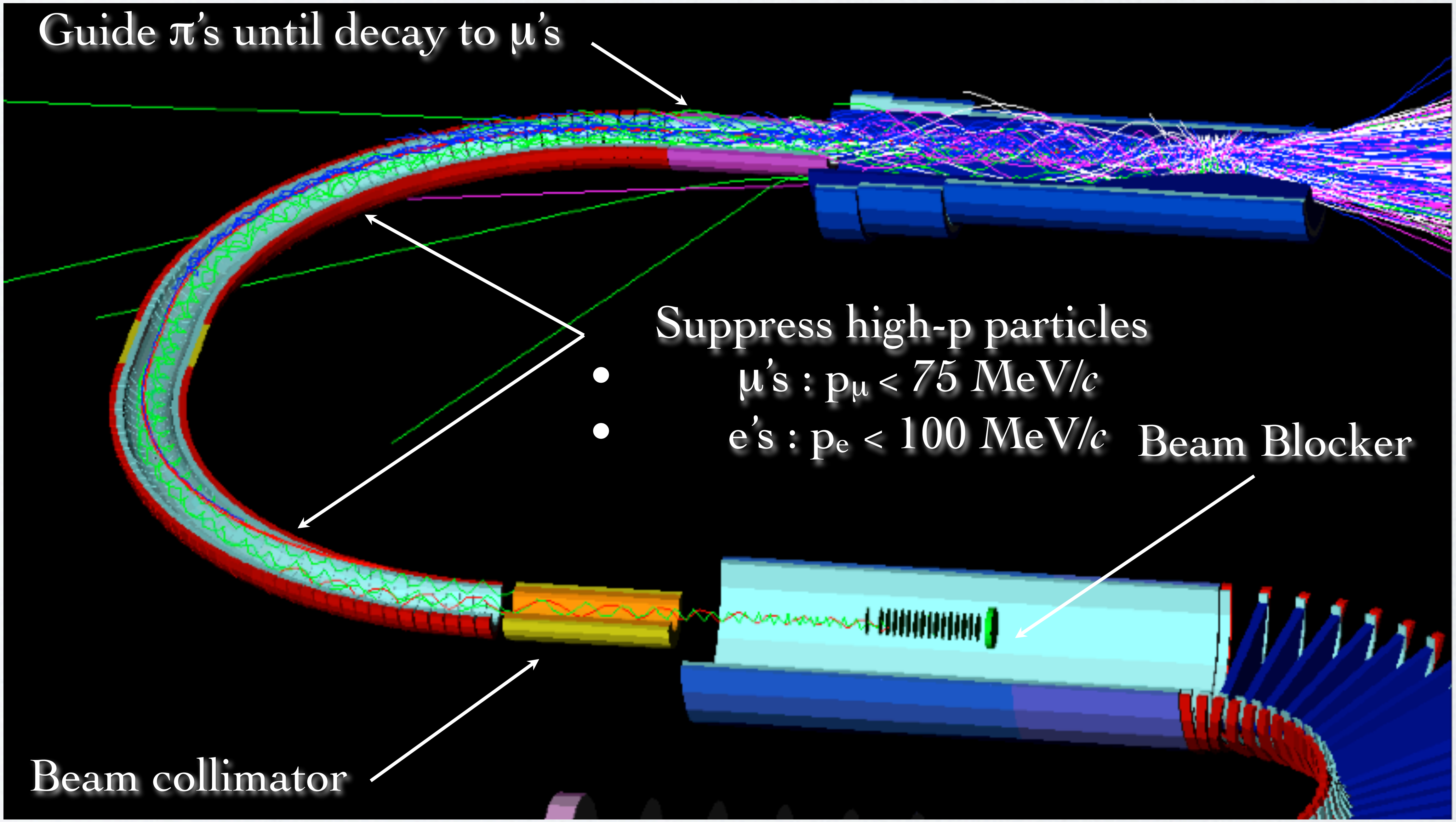
Muon Transport





Muon Transport





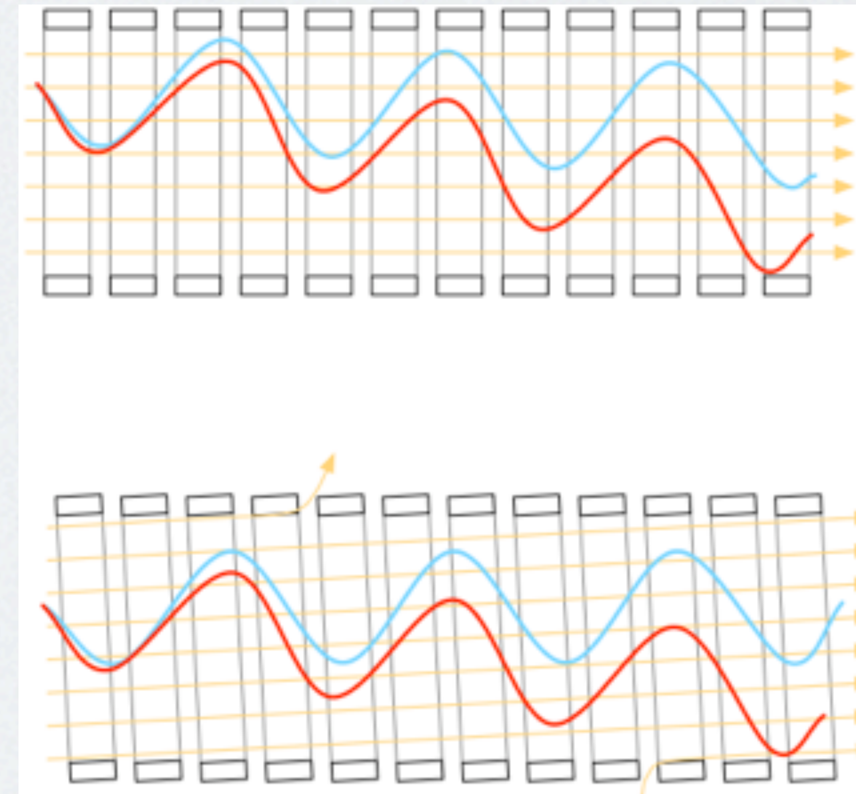
High-p Suppression

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

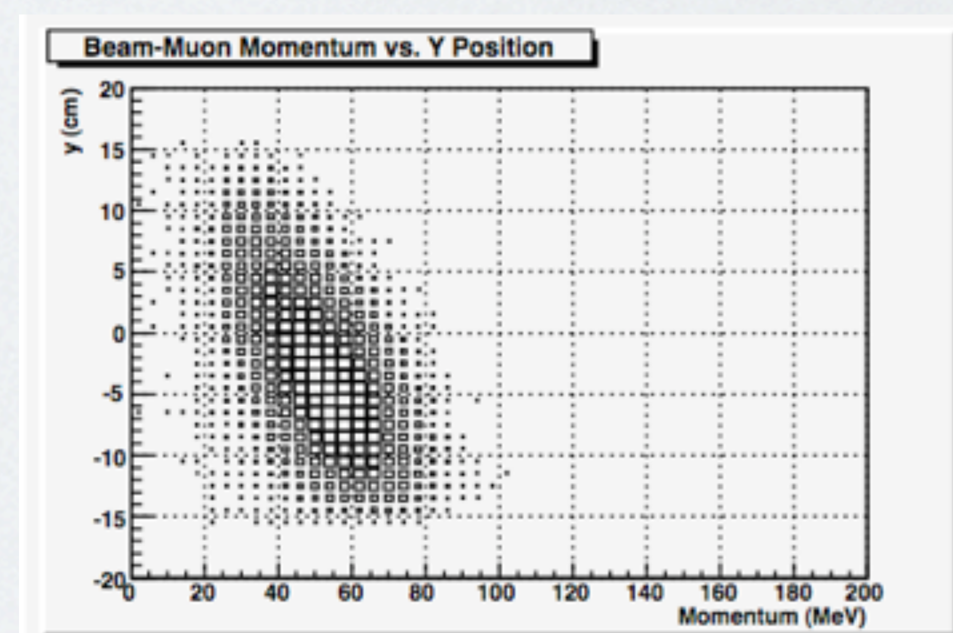
$$D[m] = \frac{1}{0.3 \times B[T]} \times \frac{s}{R} \times \frac{p_l^2 + \frac{1}{2}p_t^2}{p_l}$$

  – 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



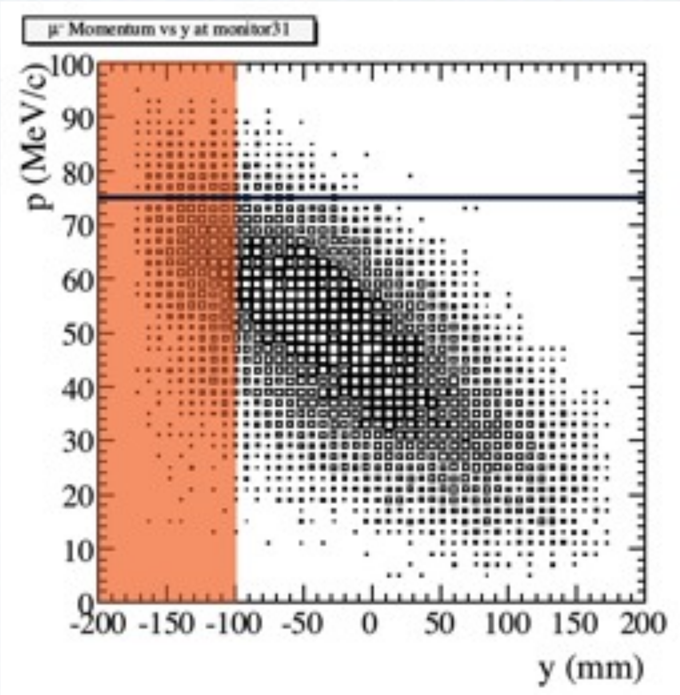
$\delta p/\delta x$ = 1 MeV/c/cm

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

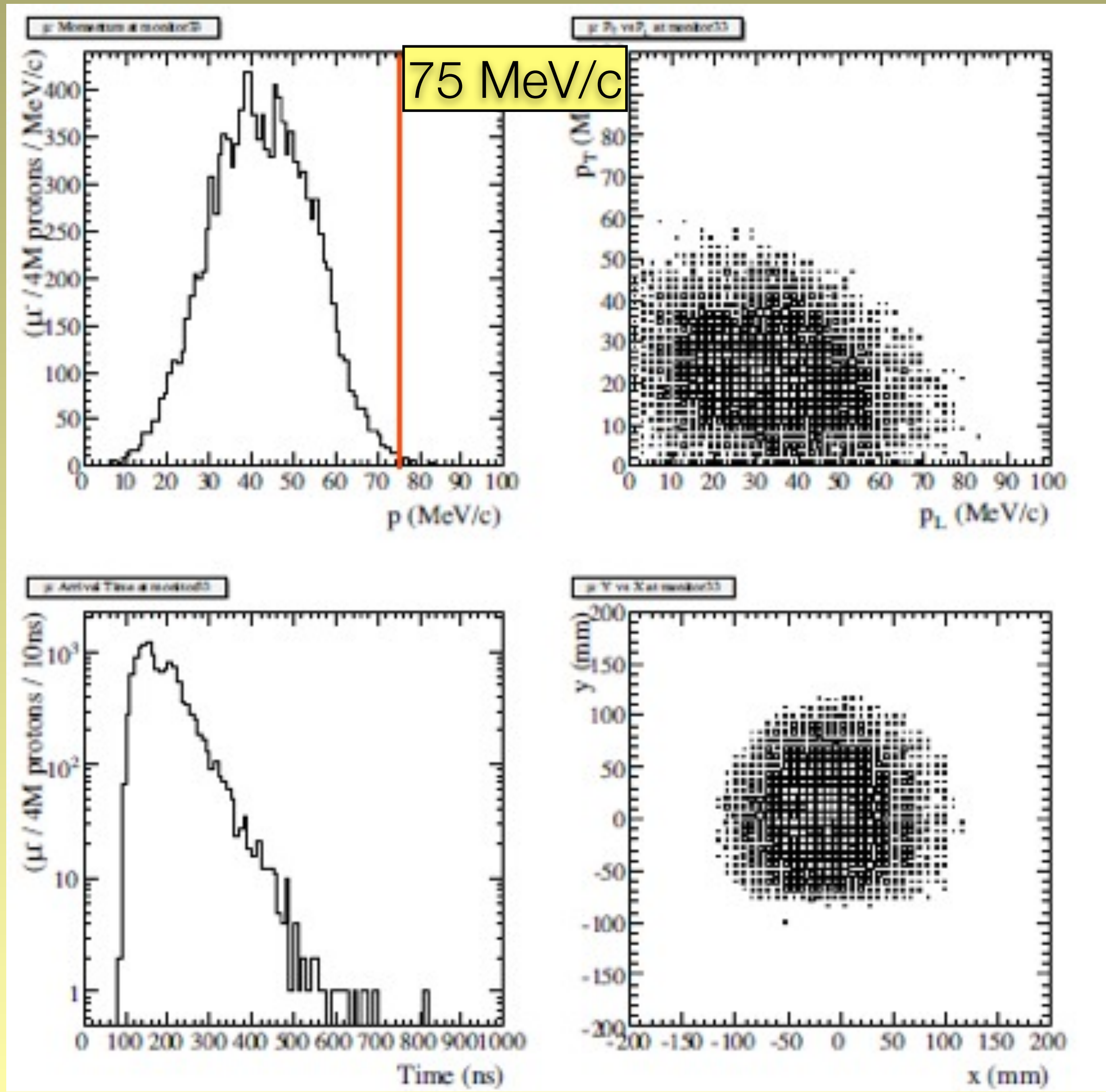
(top left) total momentum

(top right)pt vs pL

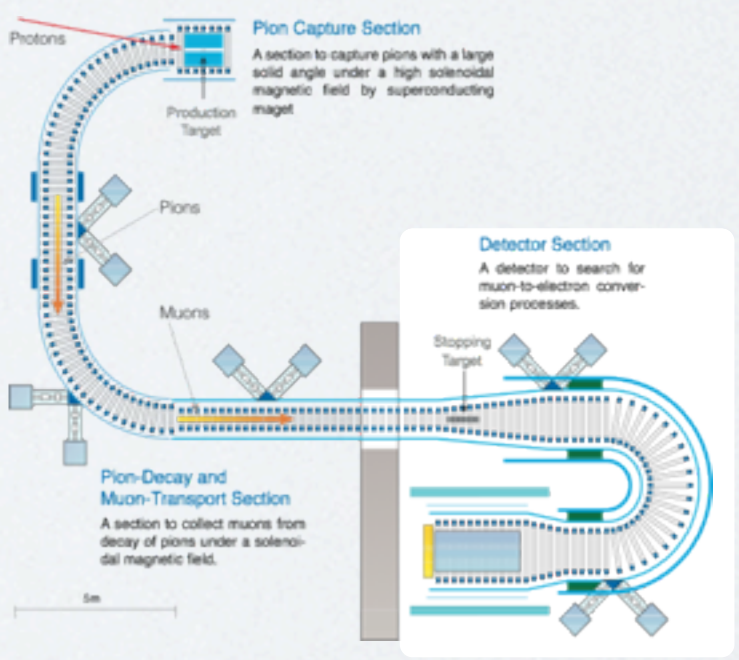
(bottom left) time of flight

(bottom right) beam profile

.



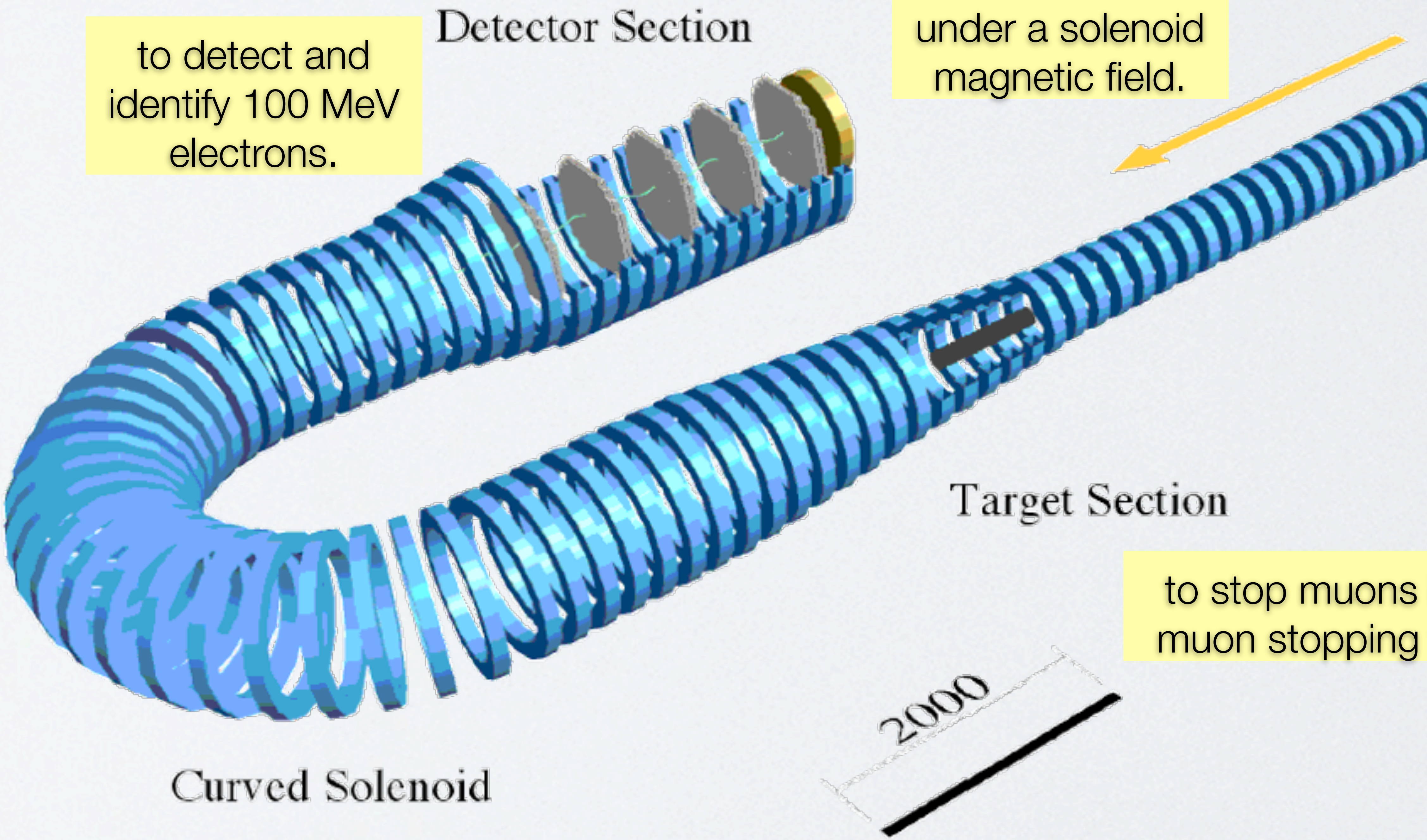
The COMET Detector



The COMET Detector

to detect and identify 100 MeV electrons.

under a solenoid magnetic field.

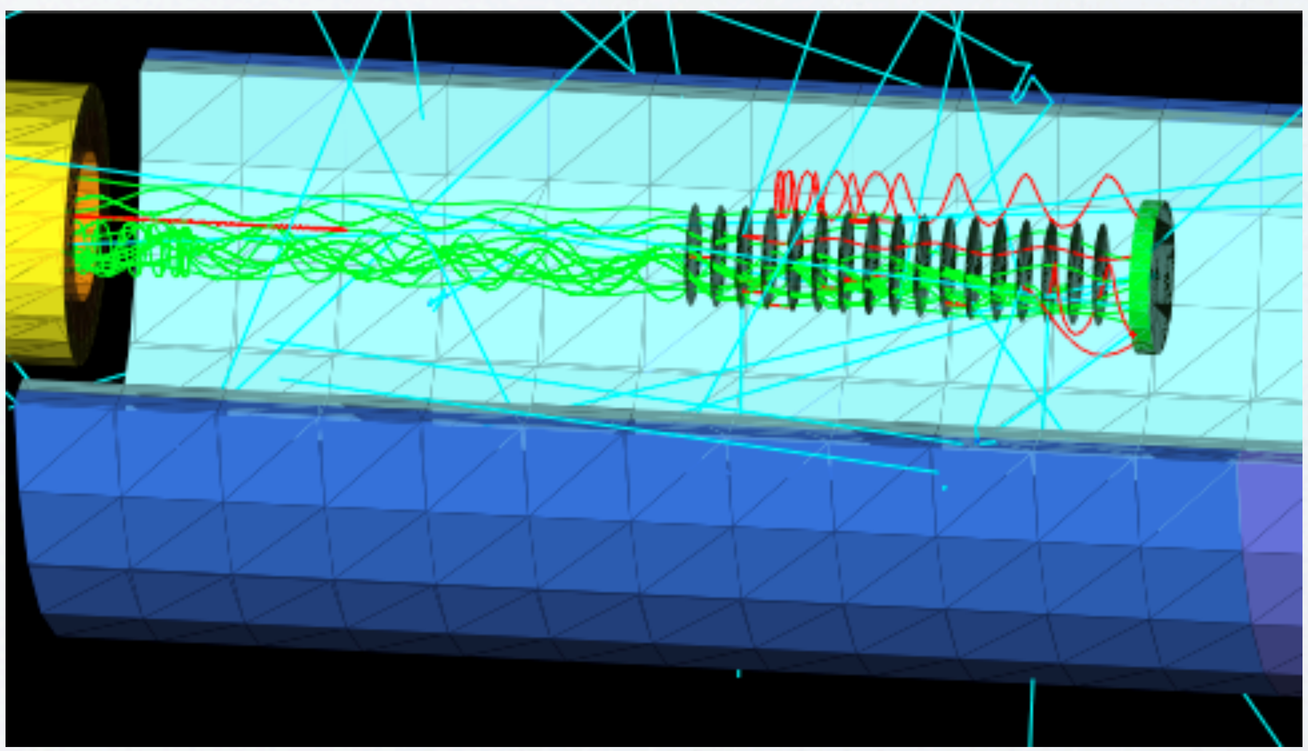


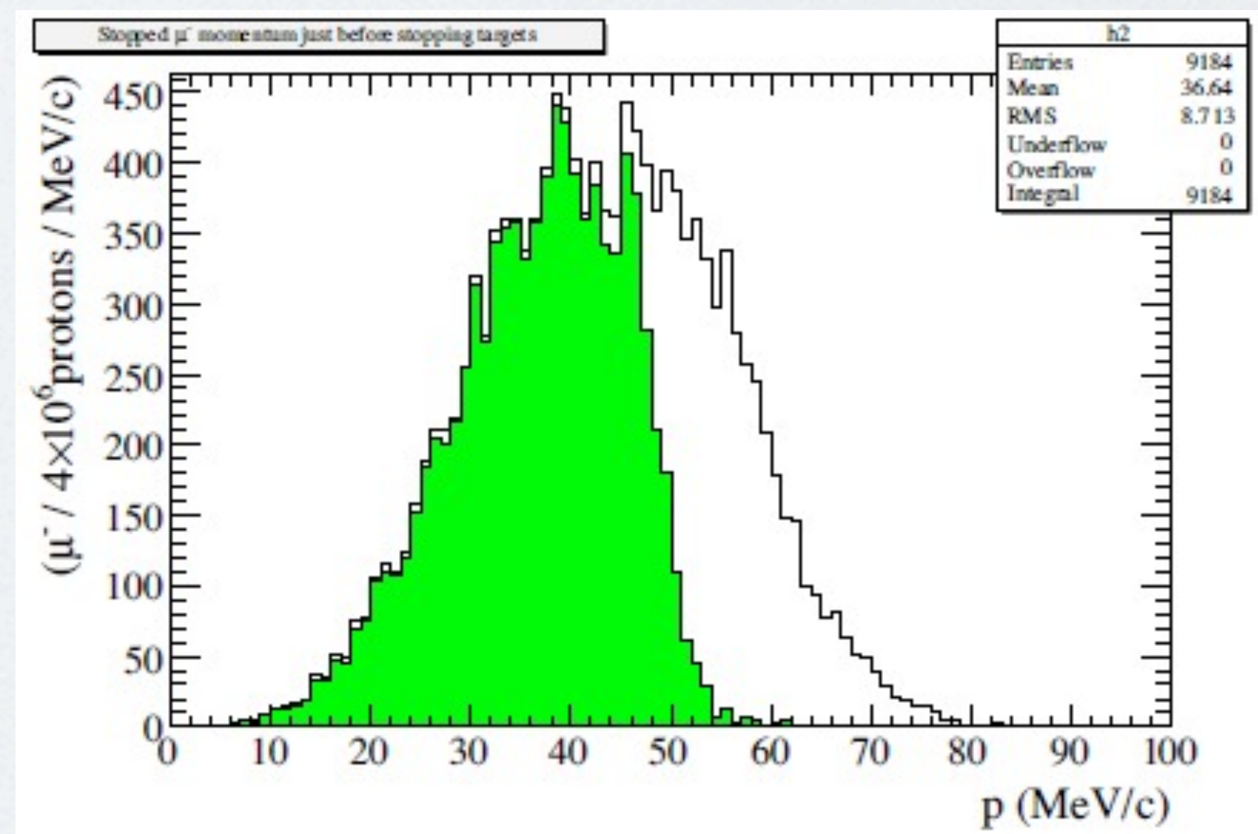
to stop muons in the muon stopping target

to eliminate low-energy beam particles and to transport only ~100 MeV electrons.

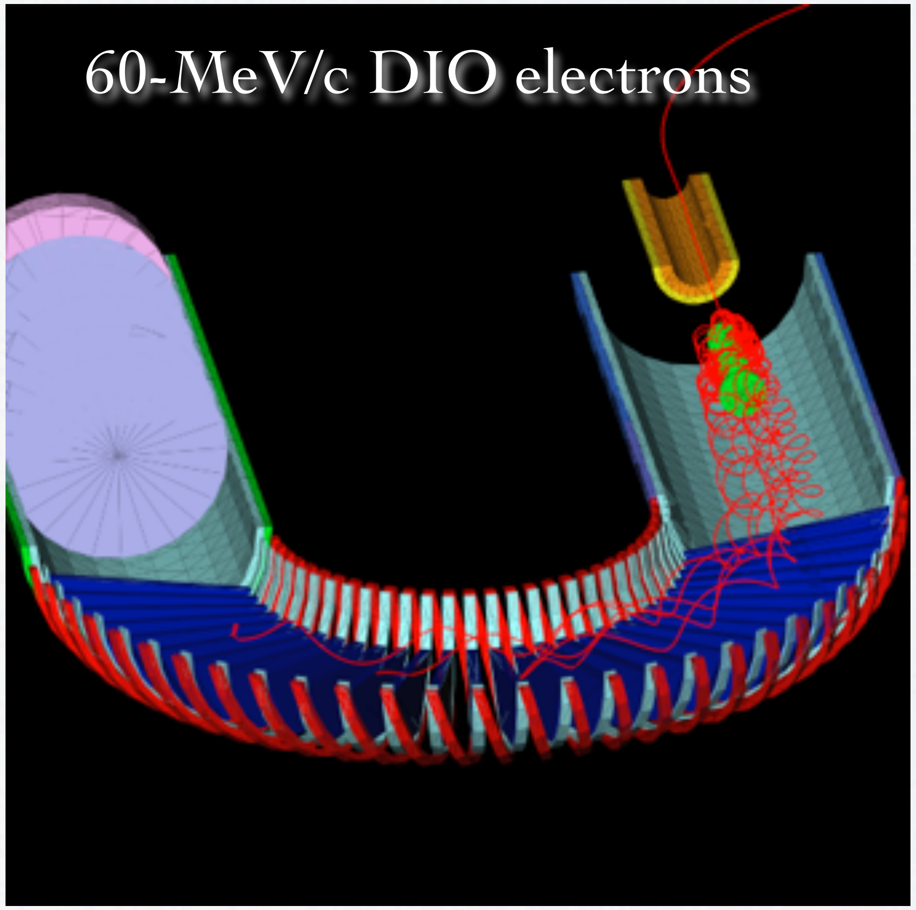
Muon Stopping Target

- Light material for delayed measurement (1st choice)
  - Aluminum : τ_{μ^-} = 0.88 μs
- Thin disks to minimize electron energy loss in the target
  - R = 100 mm, 200μm^t, 17 disks, 50 mm spacing
- Graded B field for a good transmission in the downstream curved section.
- Good μ-Stopping efficiency: ε=0.66
  - Muon rate 1.5×10^{11}/sec
  - stopped-muon yields:~0.0023 μ's/proton





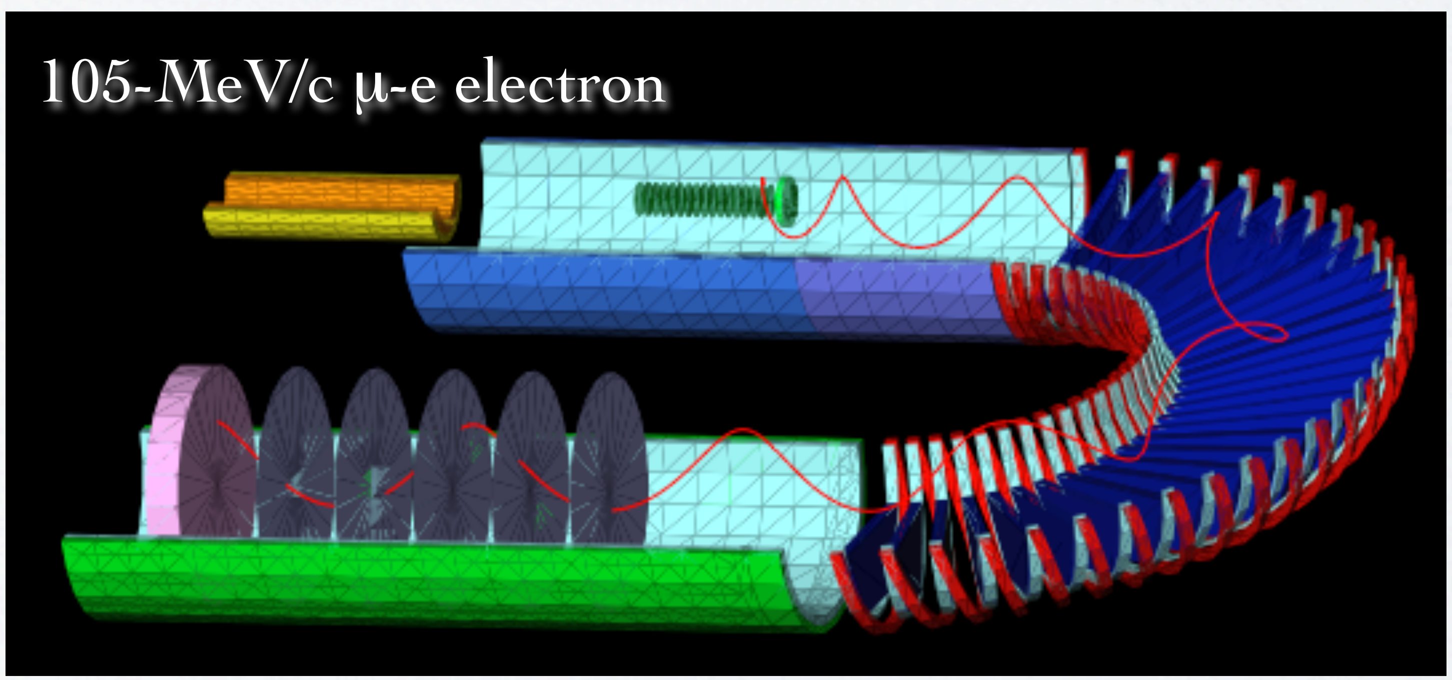
Curved Solenoid Spectrometer

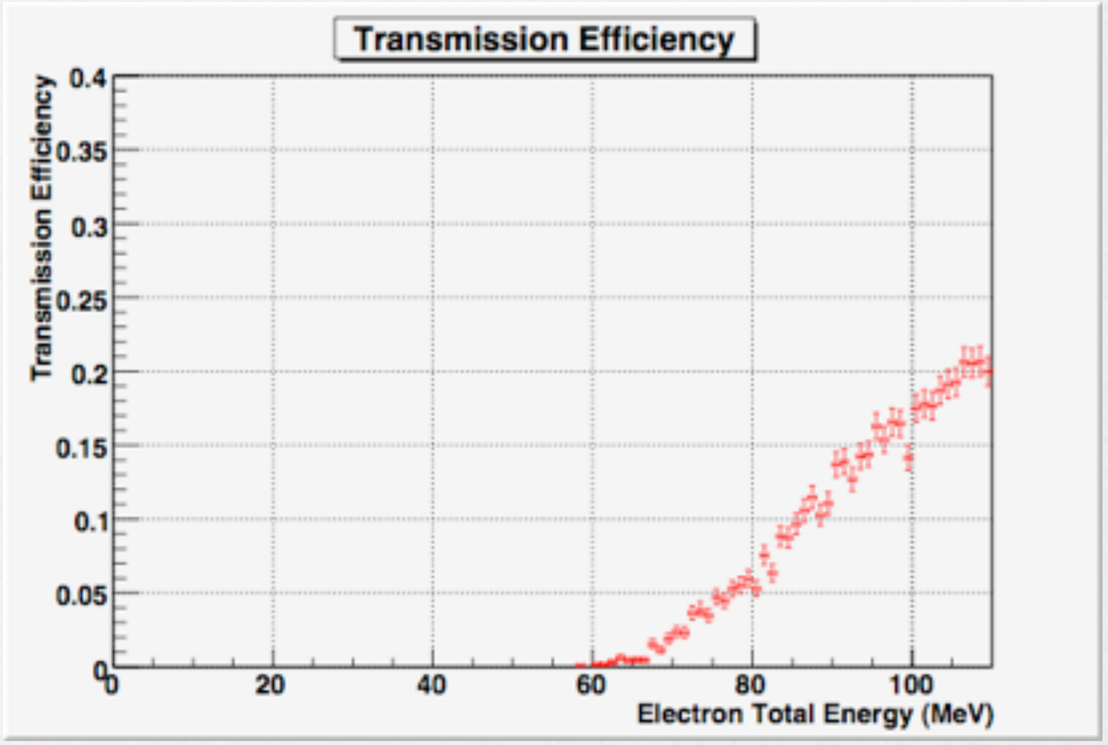


- Torus drift for rejecting low energy DIO electrons.

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

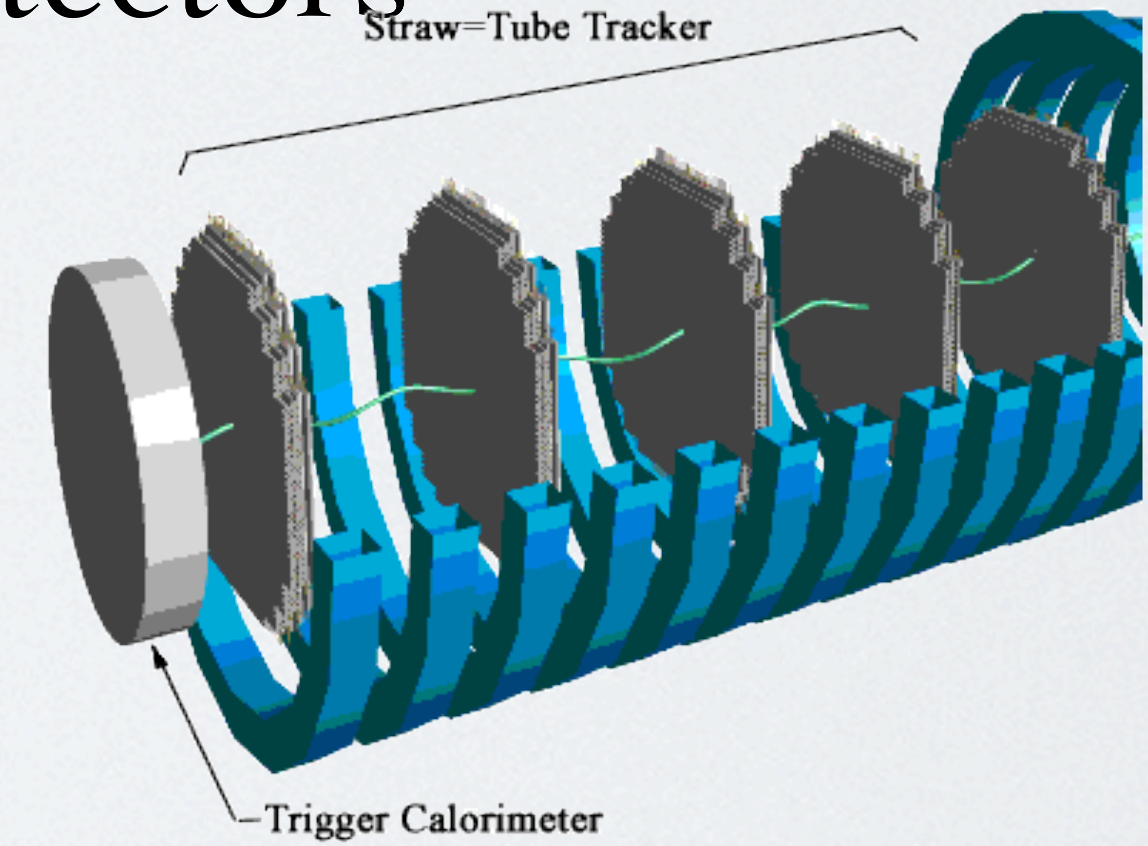
  - rejection ~10^{-6}: < 10kHz
- Good acceptance for signal electrons (w/o including event selection and trigger acceptance)
  - 20%

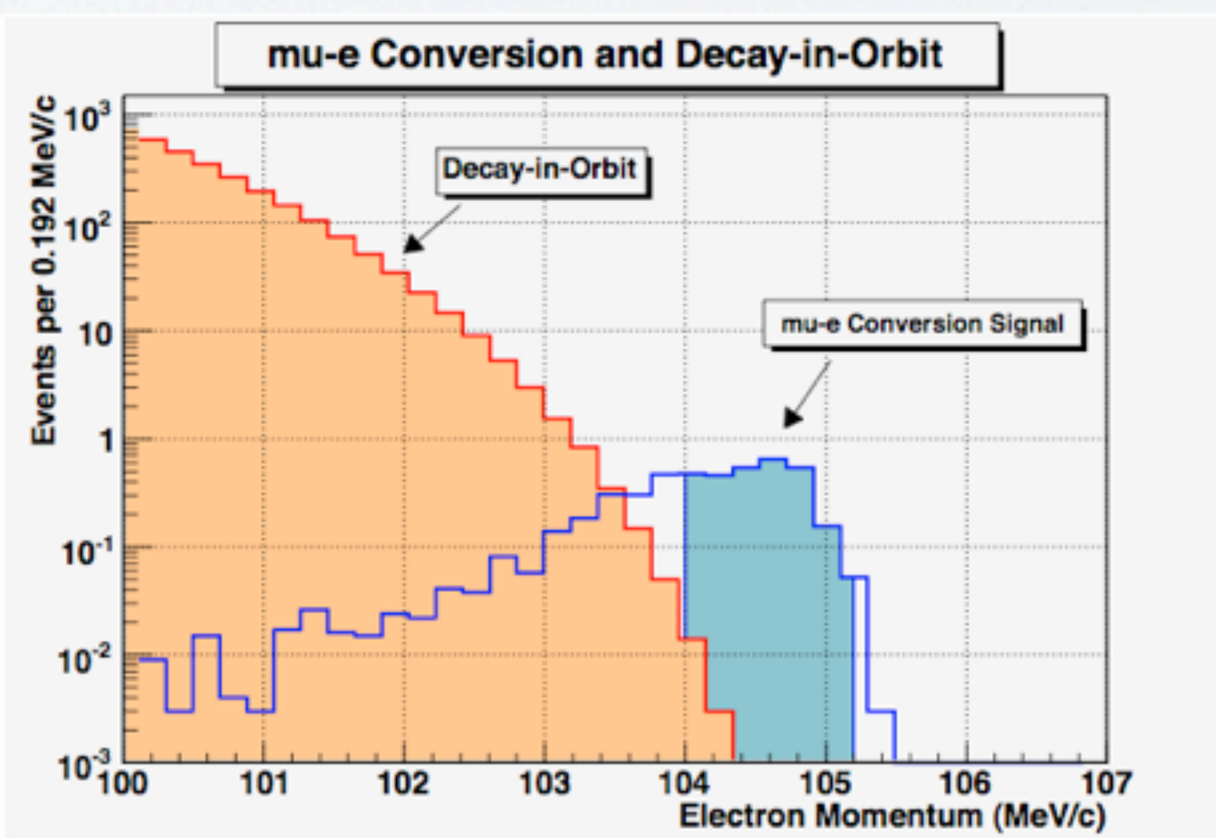


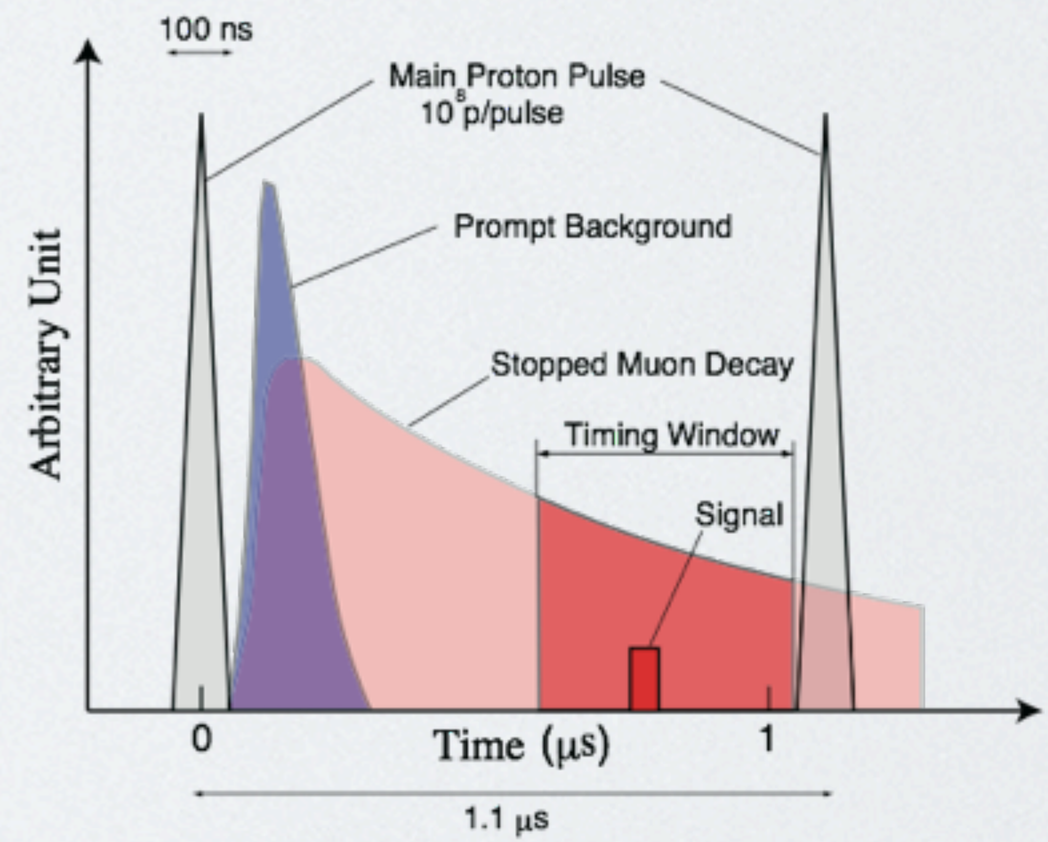


Electron Detectors

- Rate < 800 kHz
- Straw-tube tracker to measure electron momentum
  - 5 Planes with 48cm distance, σ_p = 230 keV/c
    - One plane has 2 views (x and y) with 2 layers per view.
    - A straw tube has 25mm thick, 5 mm diameter.
  - should work in vacuum and under a magnetic field.
  - <500μm position resolution.
- Crystal calorimeter for Trigger
  - GSO, PWO, LYSO, or new crystals …

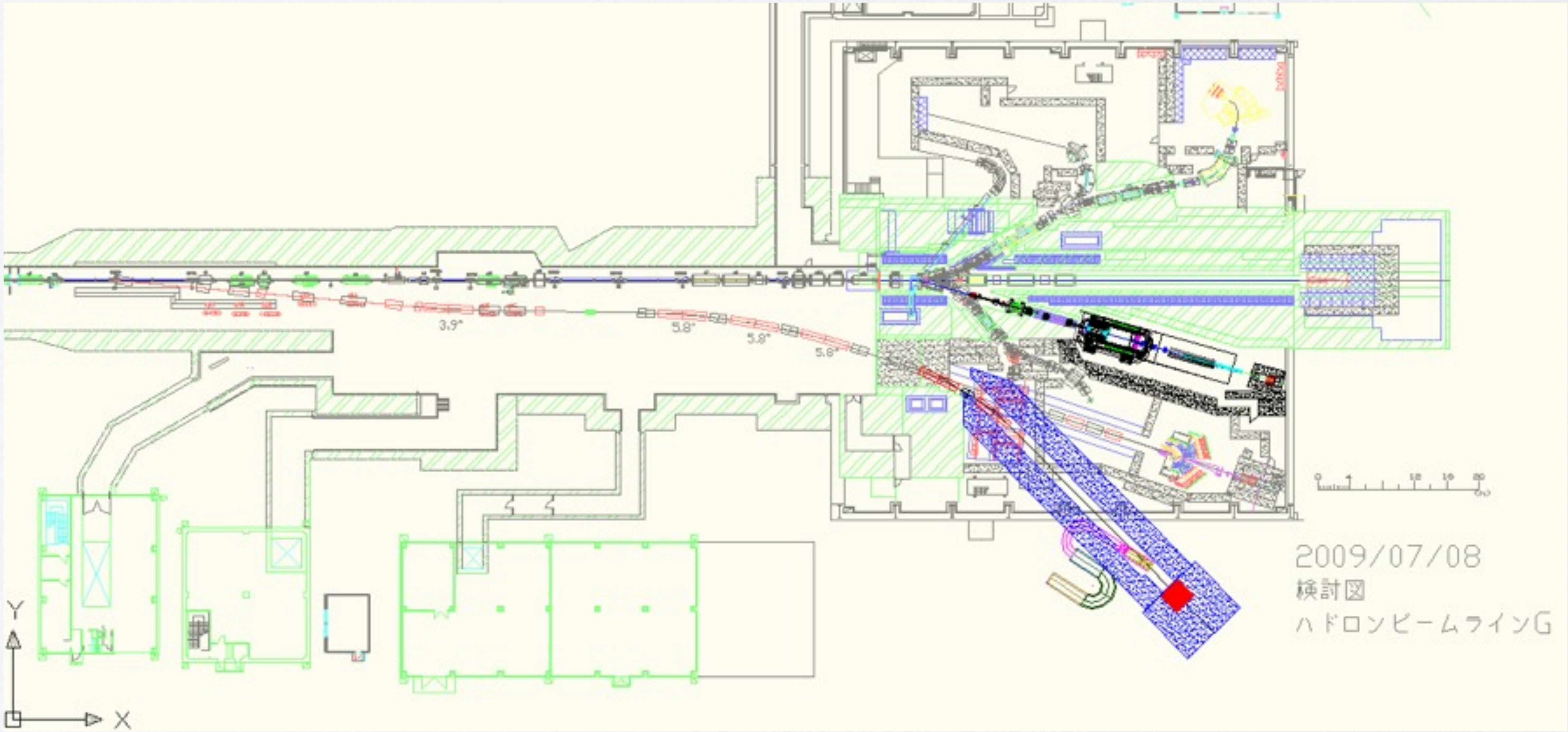






Experimental Space
A possible layout

- Discussion in the task force
  - 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



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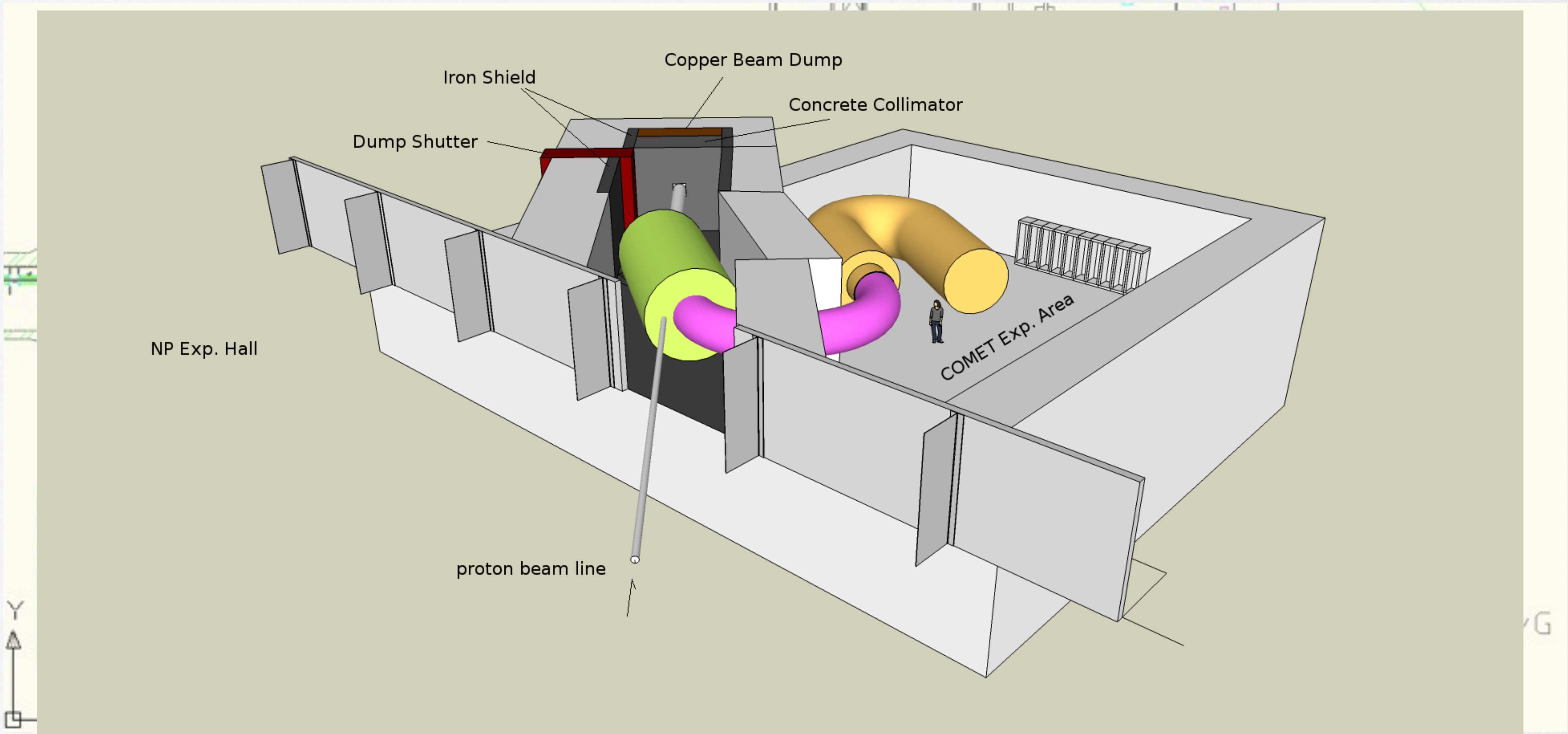


Signal Sensitivity

$2x10^7$ 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
2.6×10^{-17}

90% C.L. upper limit
6.0×10^{-17}

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}

R&D Status

R&D Status

- Straw-tube tracker
  - Done by Osaka group for MECO
  - being continued at KEK

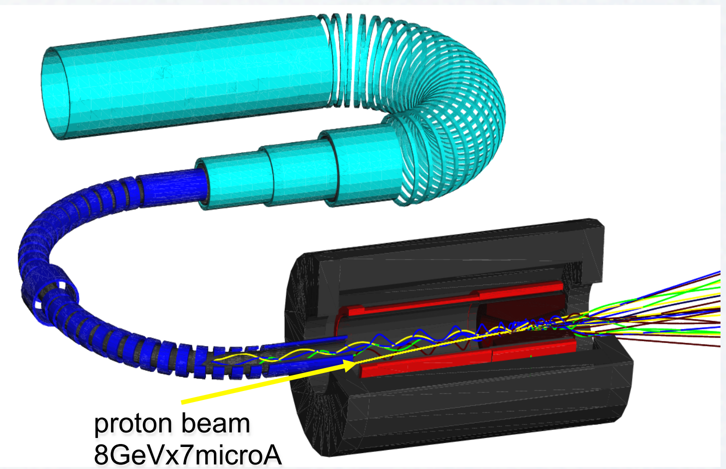
- Crystal calorimeter

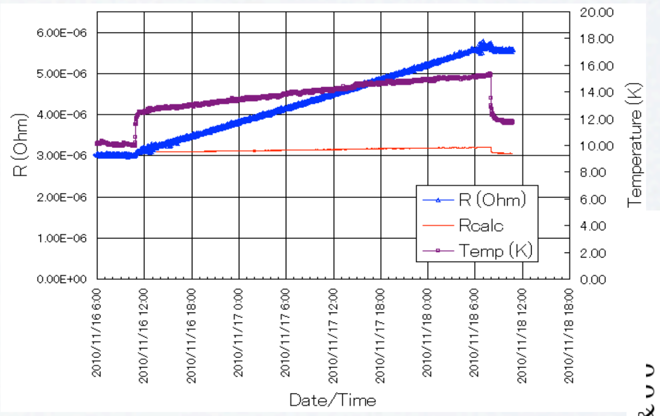
- Transport Solenoid

- Extinction Measurement
  - Device R&D
    - Gas Cherenkov + Gated PMT
  - Extinction measurement at J-PARC MR

R&D Status

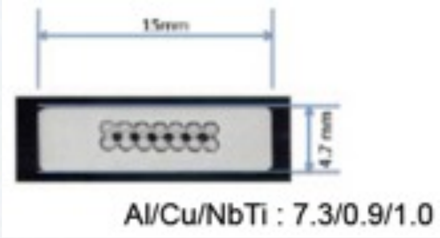
SC Magnet & Detector

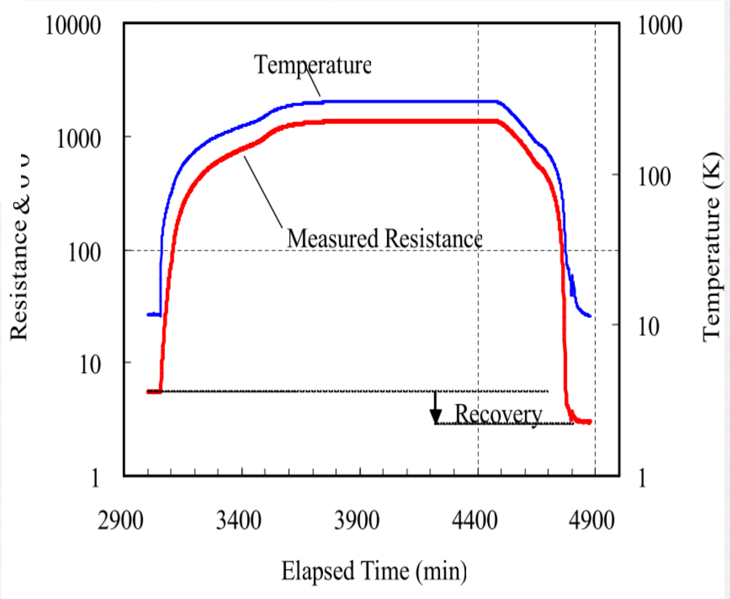




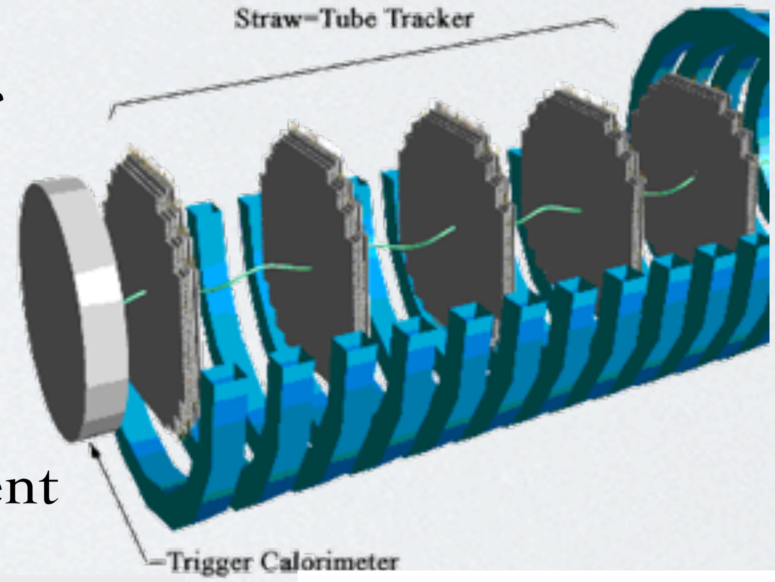
Neutron irradiation
at a research reactor

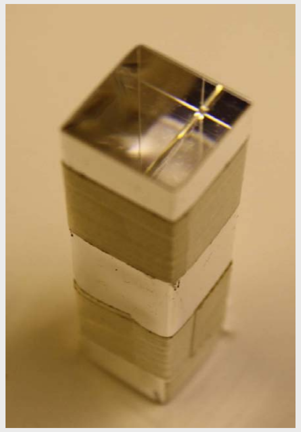
Al stabilized
conductor





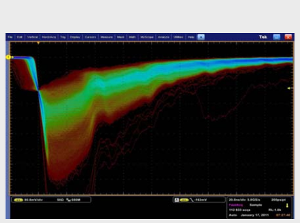
Crystal development



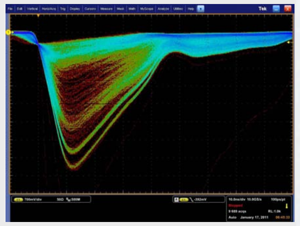


LYSO crystals

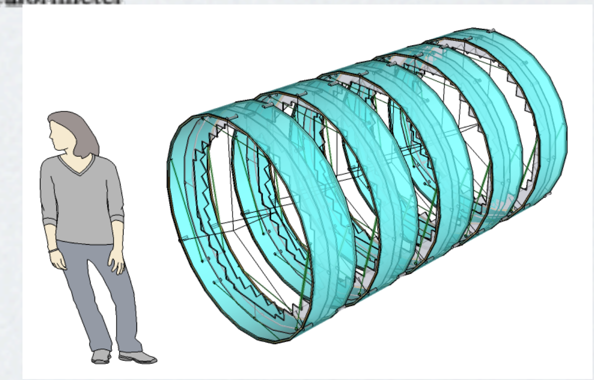
LaBr3 (5% Ce doping)

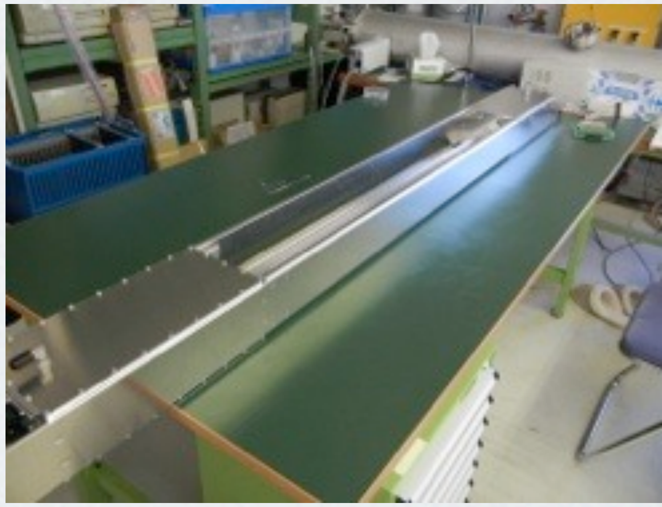


Pulse height of LYSO
crystal with ^{137}Ce



Pulse height of $LaBr_3$
crystal with ^{137}Ce

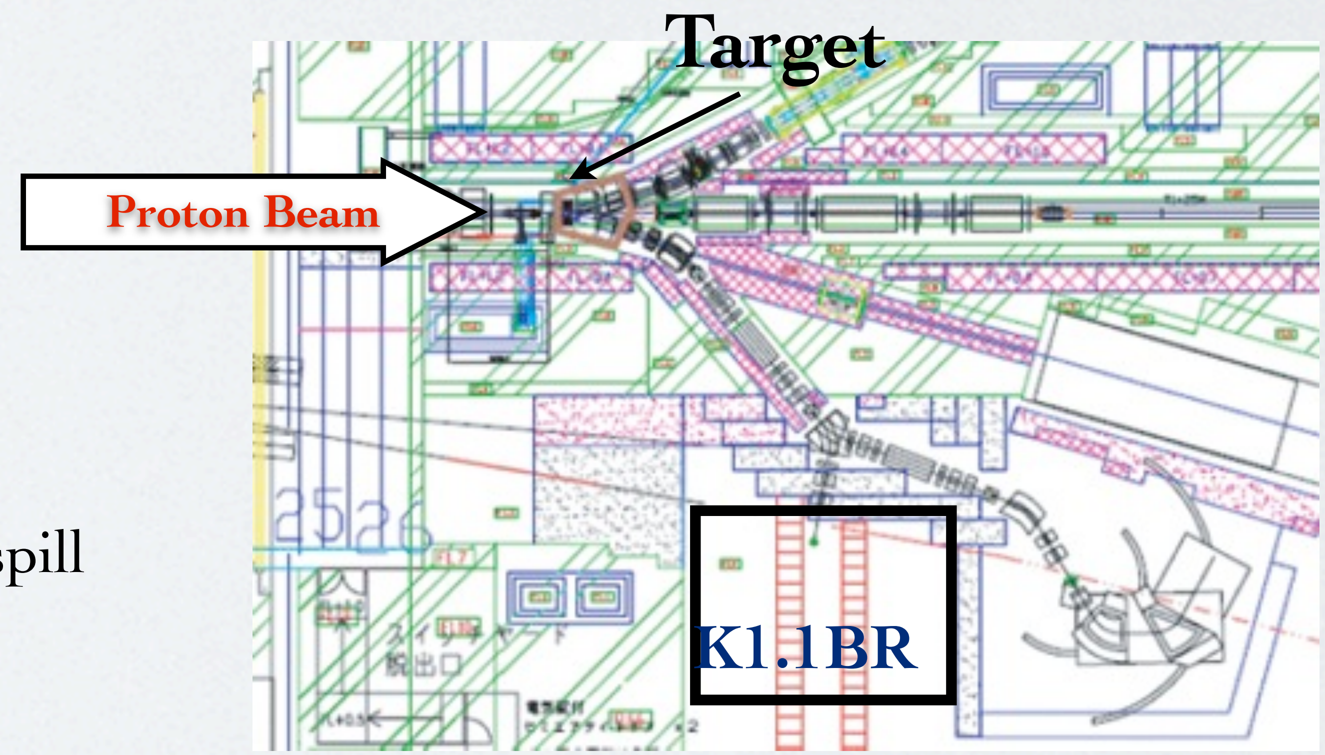




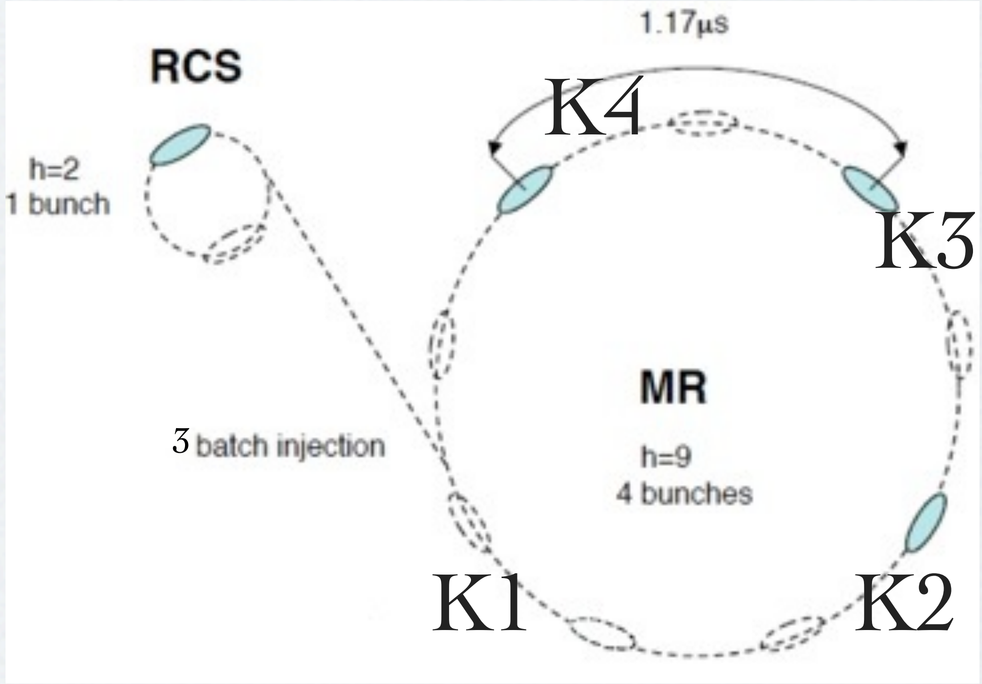
Straw-tube tracker

Slow Extraction R&D

- Measure the time structure of the primary proton beam
  - Secondary beam at K1.1BR
  - 800MeV/c, pion dominant, 200k/spill
  - Primary Beam Condition
    - h=9, 3 filled and 6 empty
    - 30GeV
    - Bunched Slow Extraction
  - Bunch ID using MR Flat Top and RF signals
  - Read out
    - Measure secondary beam (~100k sample/spill) for tens of minutes and get 10^8 samples

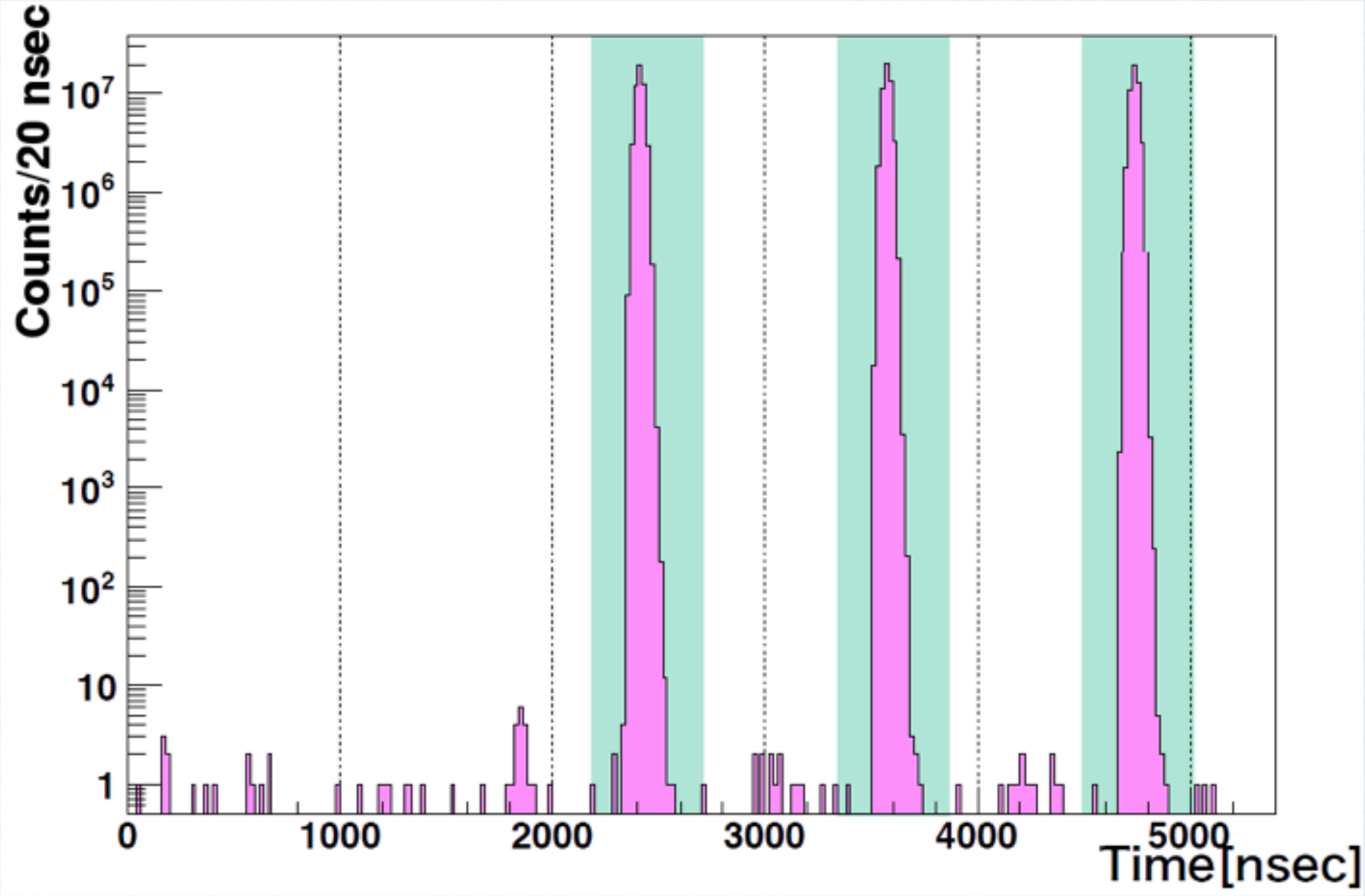


K1.1BR Layout



Extinction Measurement Result

- Normal beam injection to MR
- Integration over 20 minutes
- Extinction level at $(5.4 \pm 0.6) \times 10^{-7}$



Schedule and Construction Cost

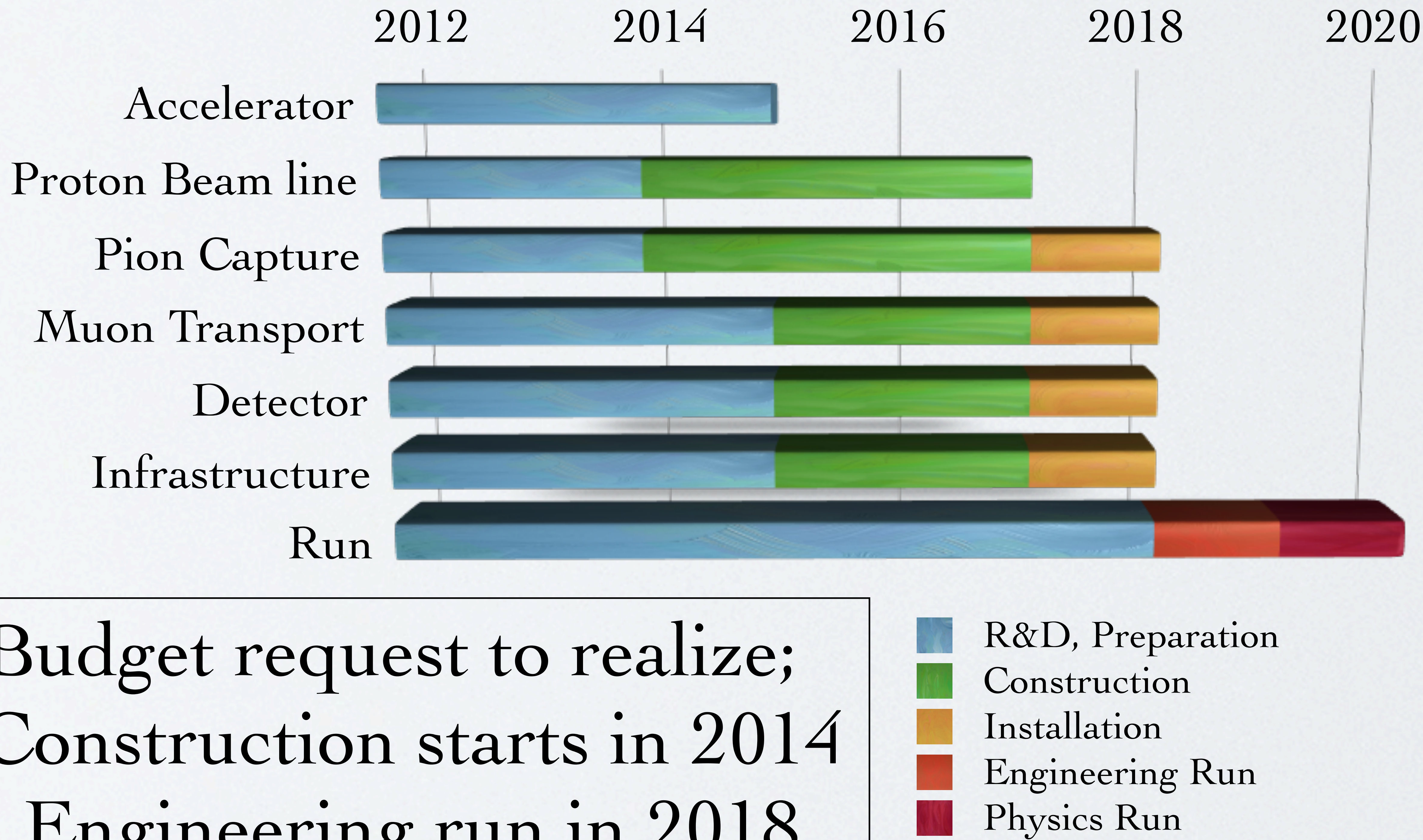
Funding starting

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)	$\boxed{90}$

1 Oku JPY ~ 0.953 M Euro

Schedule



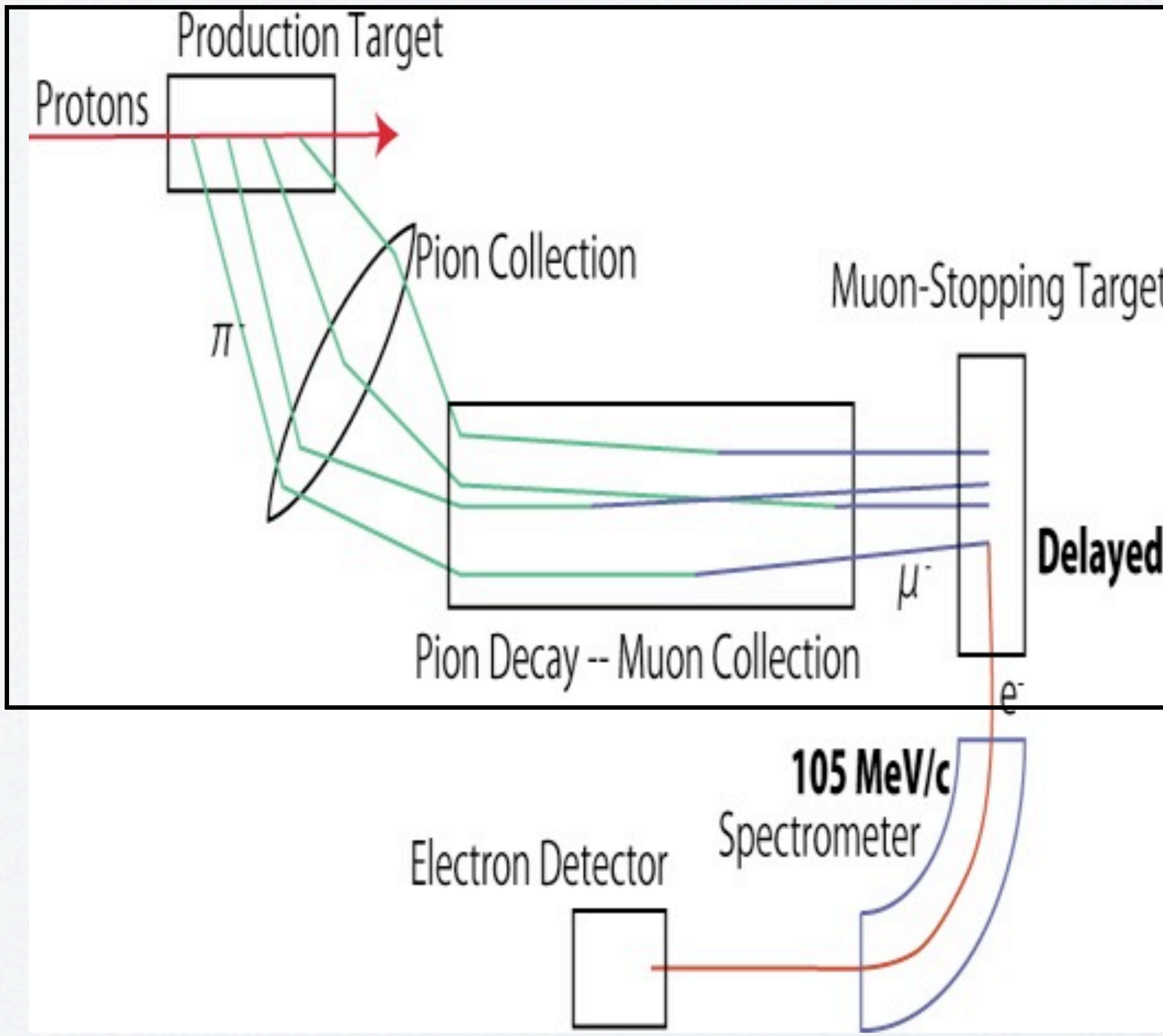
Budget request to realize;
Construction starts in 2014
Engineering run in 2018

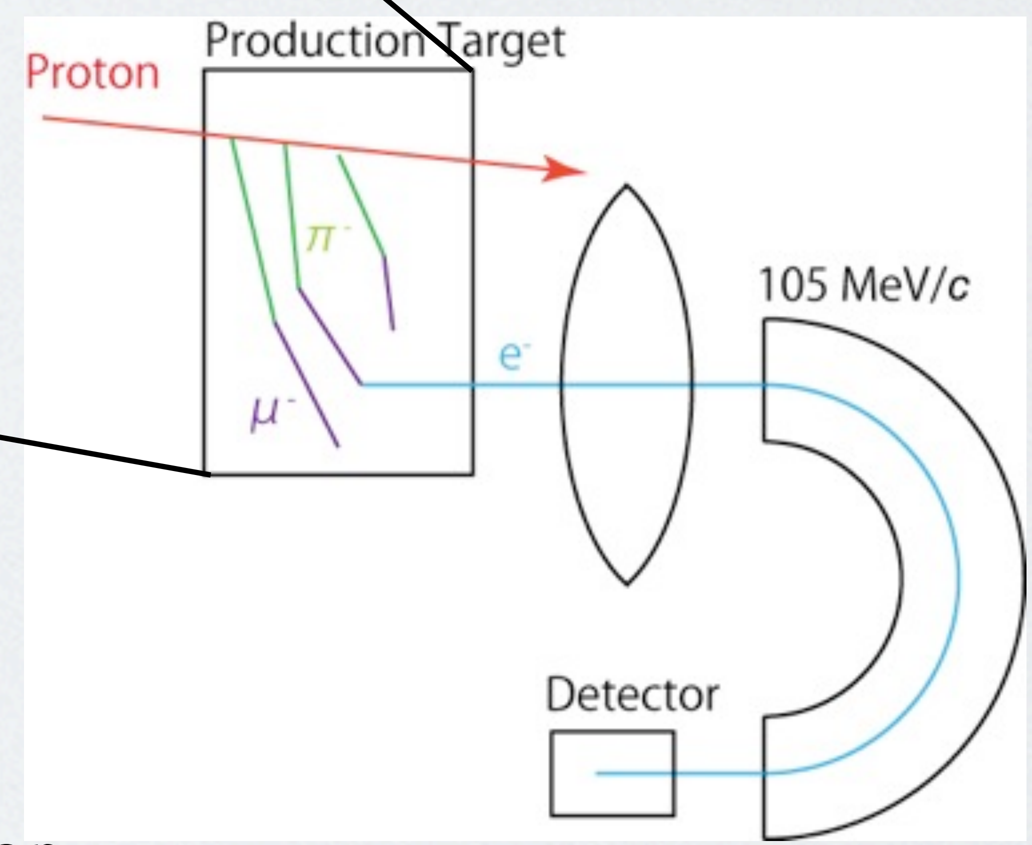
Yet Another Mu-e conversion Search at J-PARC

DeeMe

µ-e electrons may directly coming from a production target

→ DeeMe

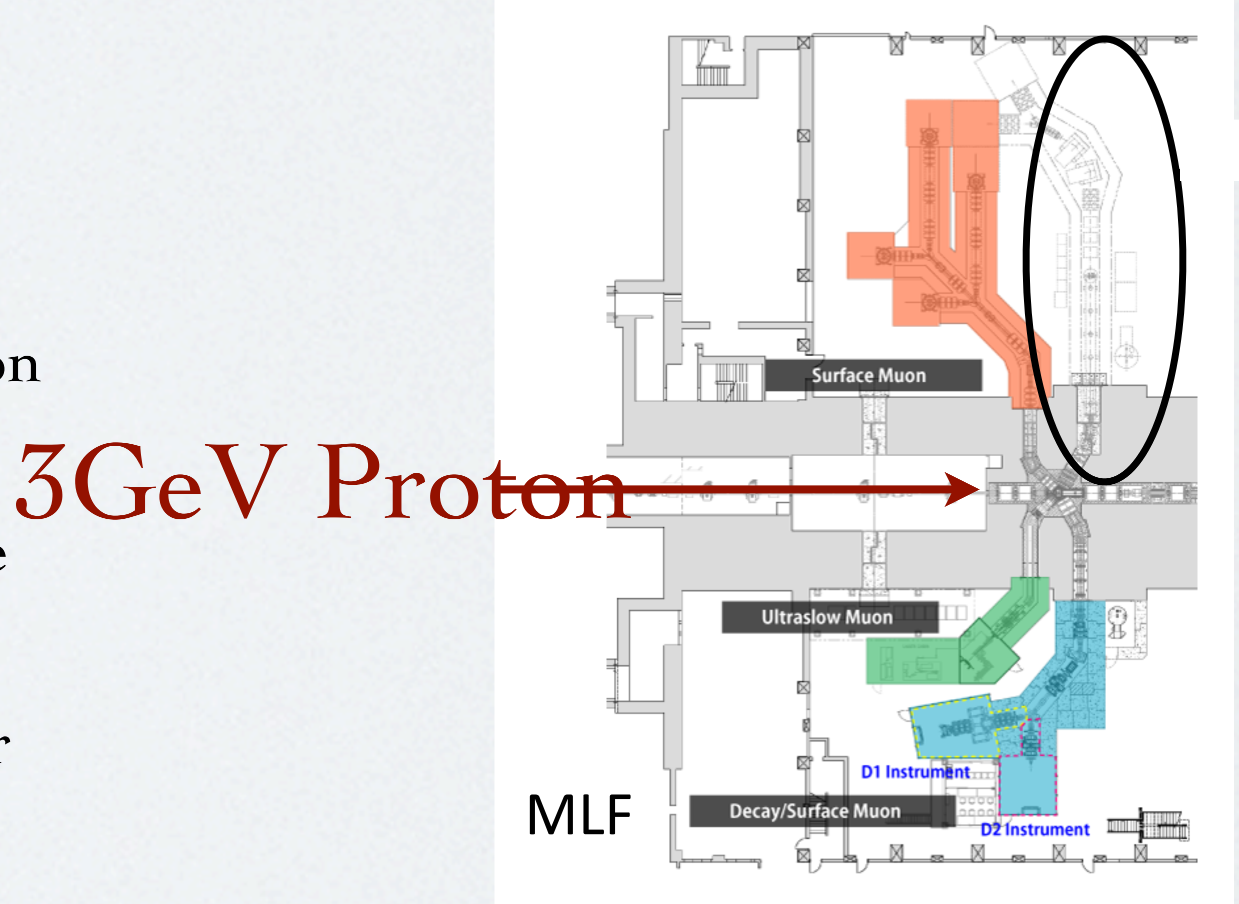


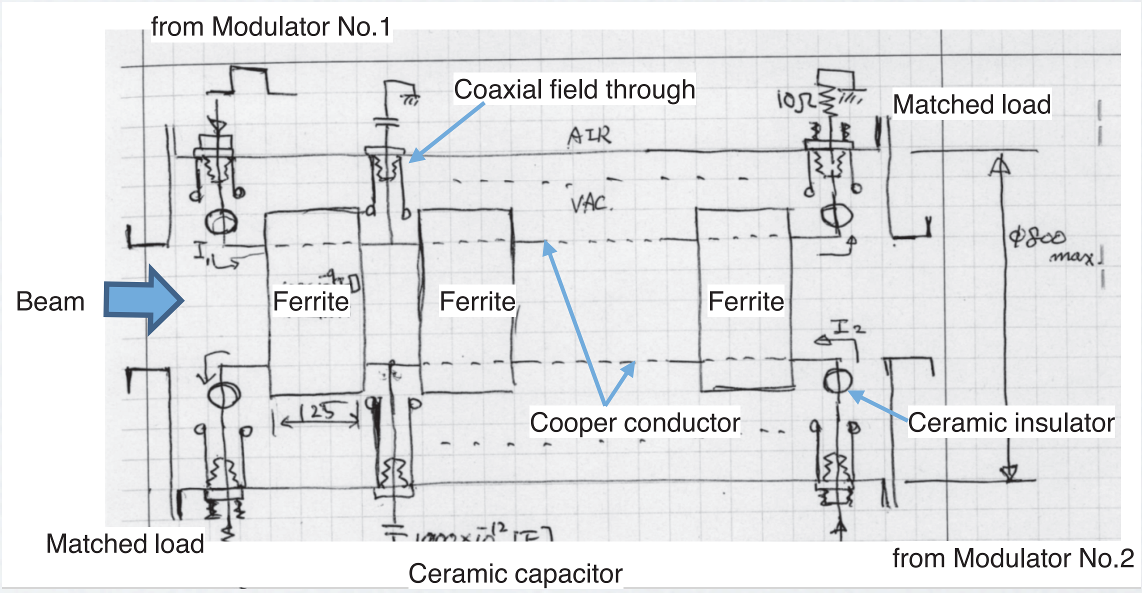


- An electron analogue of the surface muon.
- Experiment could be very simple, quick and low-cost.

DeeMe Overview

- Proton beam from RCS
- Pion production target as a muon stopping target
    - Replace the current graphite target with a SiC target
    - Si has larger muonic-nuclear capture rate
- Beam line as an electron spectrometer
    - Secondary beam-line kicker to remove prompt BG
    - Only delayed electrons enter the spectrometer
- S.E.S. 1.5×10^{-14} for 2×10^{7} sec DAQ





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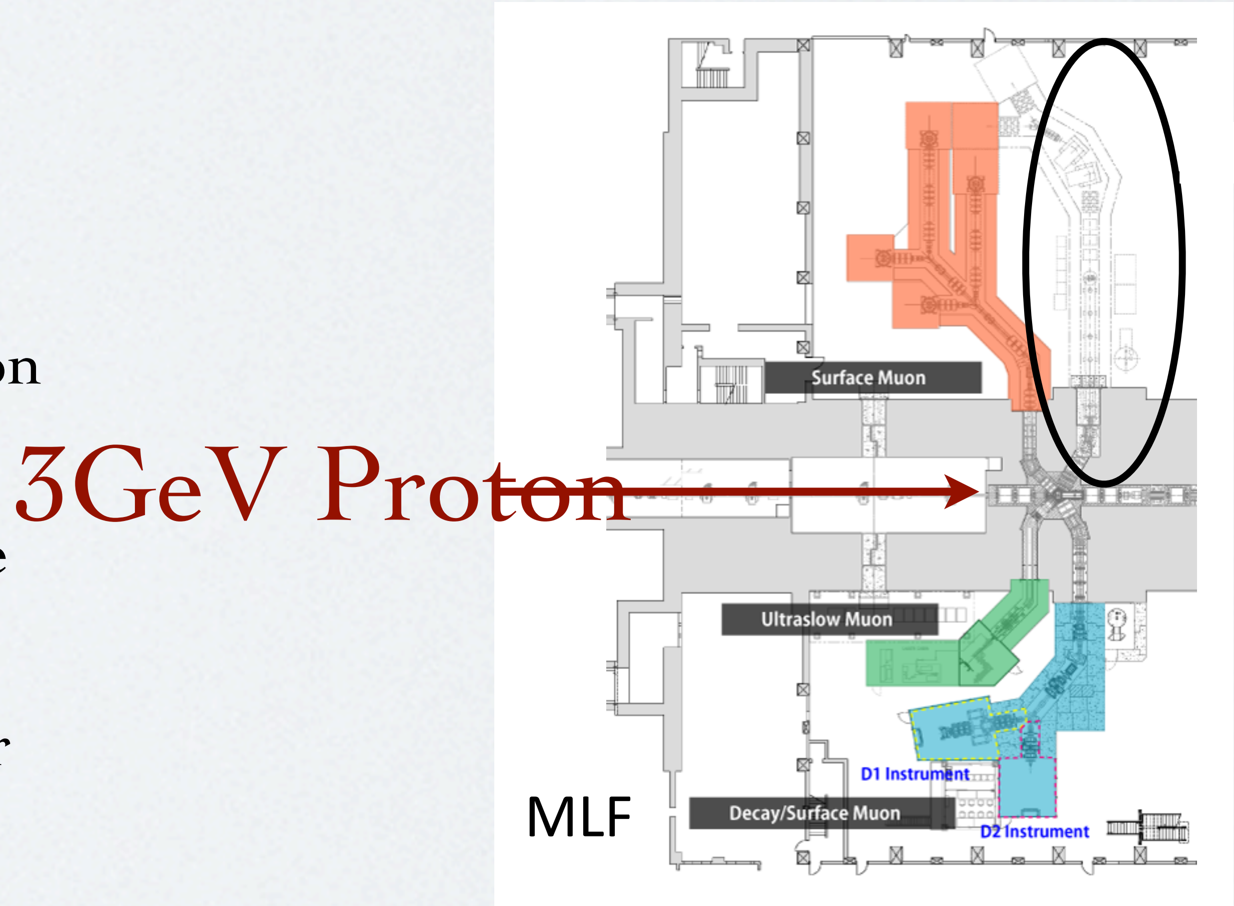
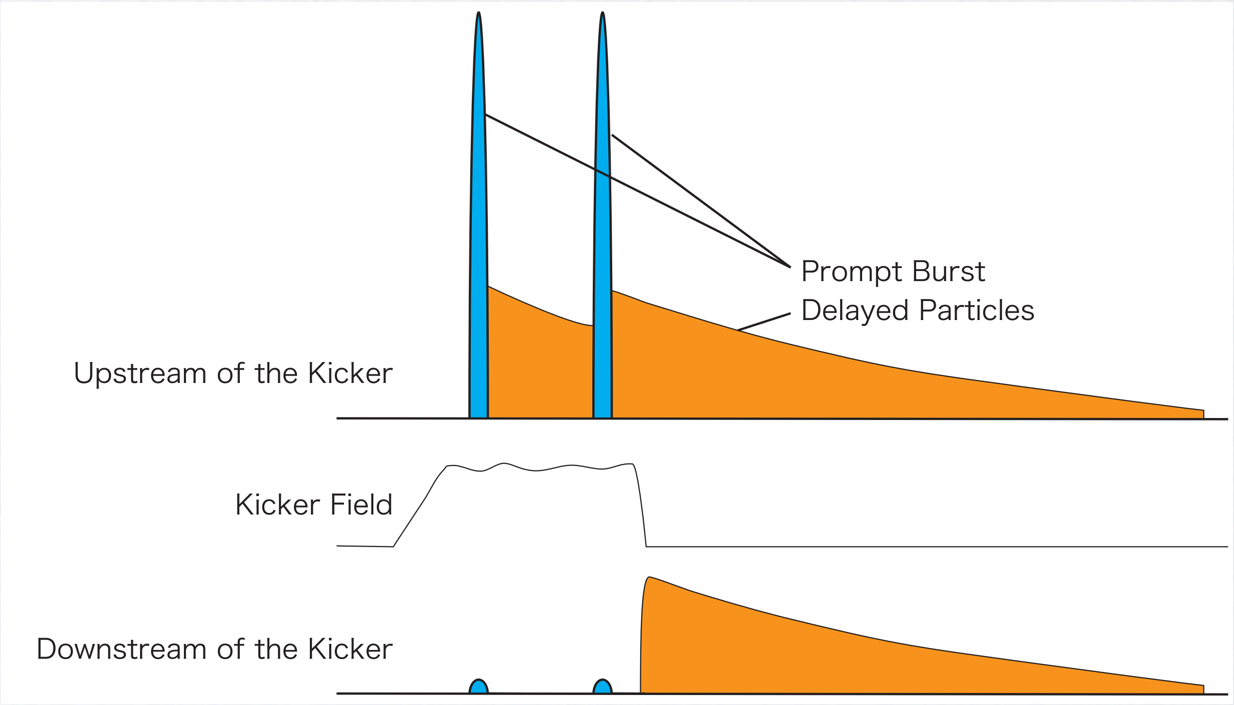




Summary

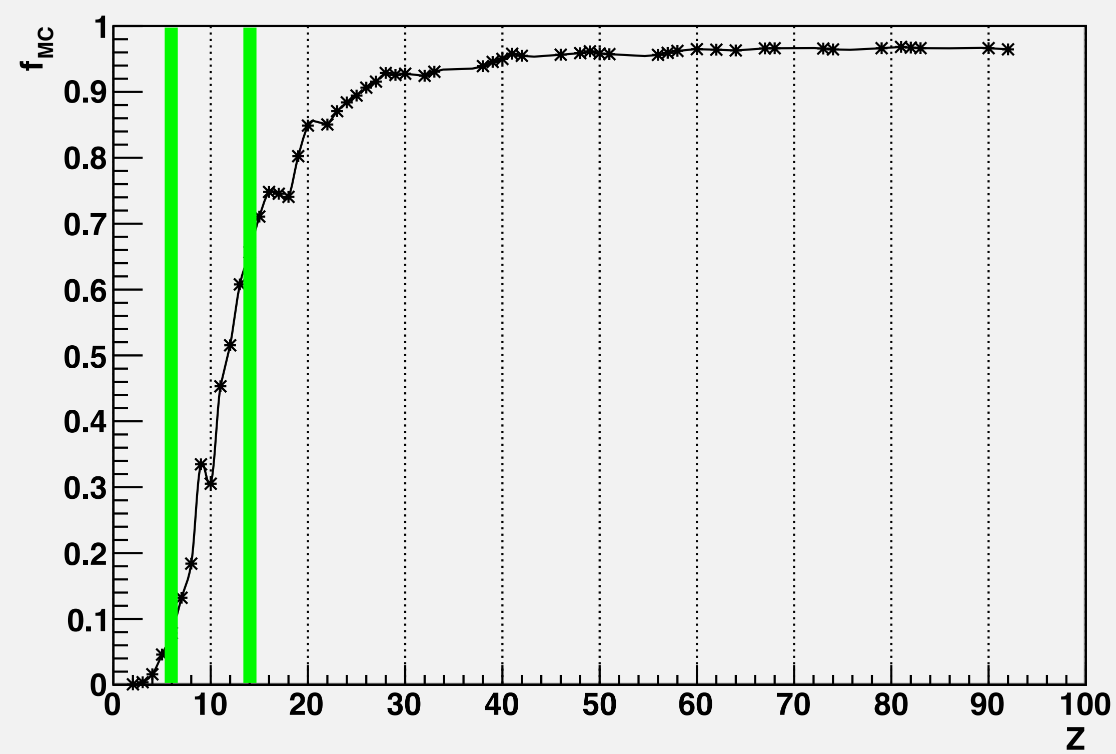
- New experiment (COMET) to search for mu-e conversion at J-PARC
- COMET aims at achieving a sensitivity of 10^{-16}
  - High-intensity, high-purity pulsed proton beam at J-PARC
  - Curved solenoid muon transport/spectrometer to suppress backgrounds efficiently
- R&D work in progress
  - Detector
  - Magnet
  - Proton beam
    - Beam structure
    - Extinction

Backup

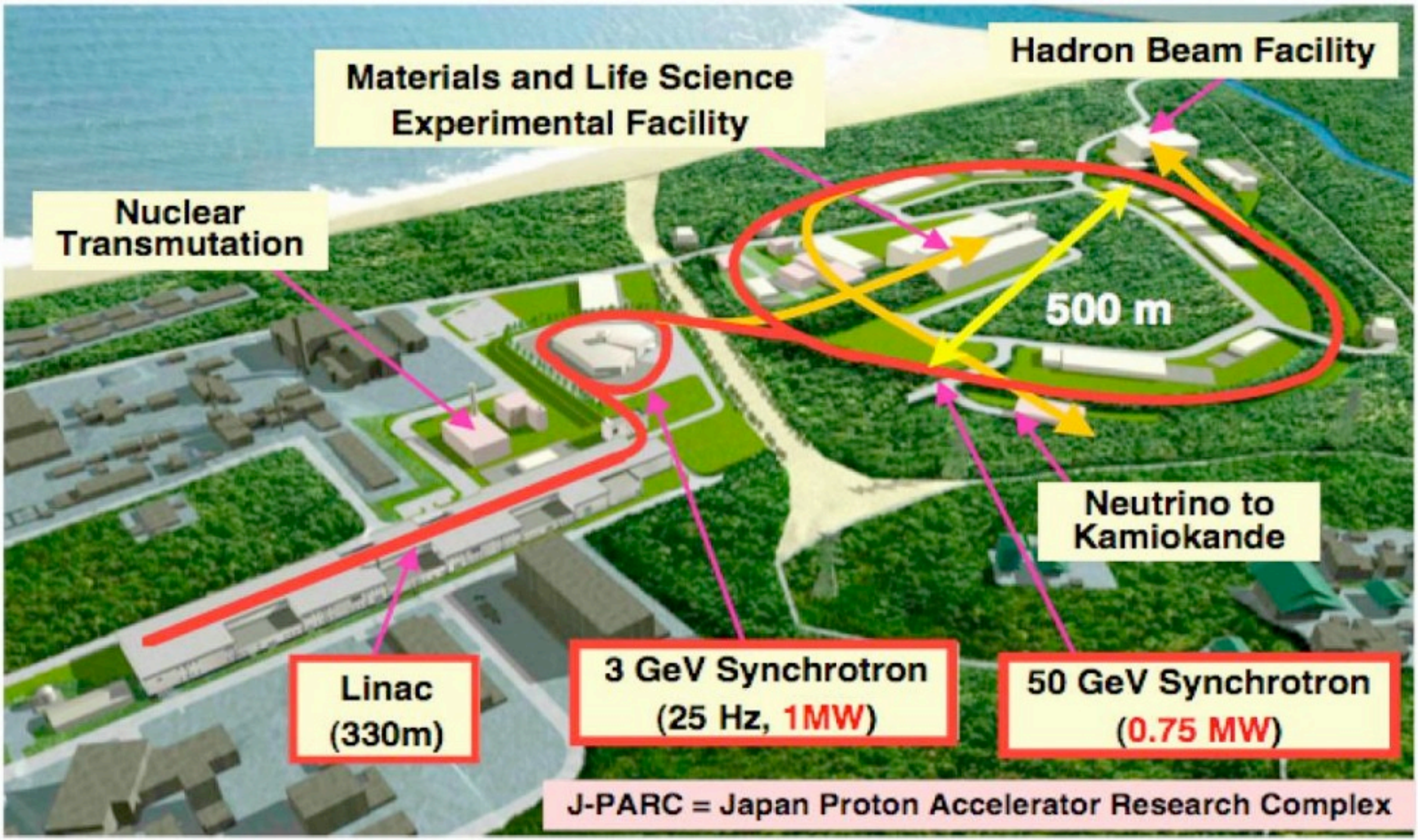
Target Material

- fc:Fraction of the atomic capture of muon to the atom of interest
  - single−element material: fc = 1
  - composite material:proportional to Z (Fermi-Teller Z law)
    - Silica−carbide Si:C=7:3
- f_{MC}: muonic nuclear−capture rate
  - $(1-f_{MC})=f_{free-decay}$−−−useless muons: large f_{MC} is better
- On the other hand, τ_{μ^-}>300 nsec (light Z) to avoid the prompt background
- Engineering point of view:
  - good thermal shock resistance
  - high melting point
  - good radiation resistance

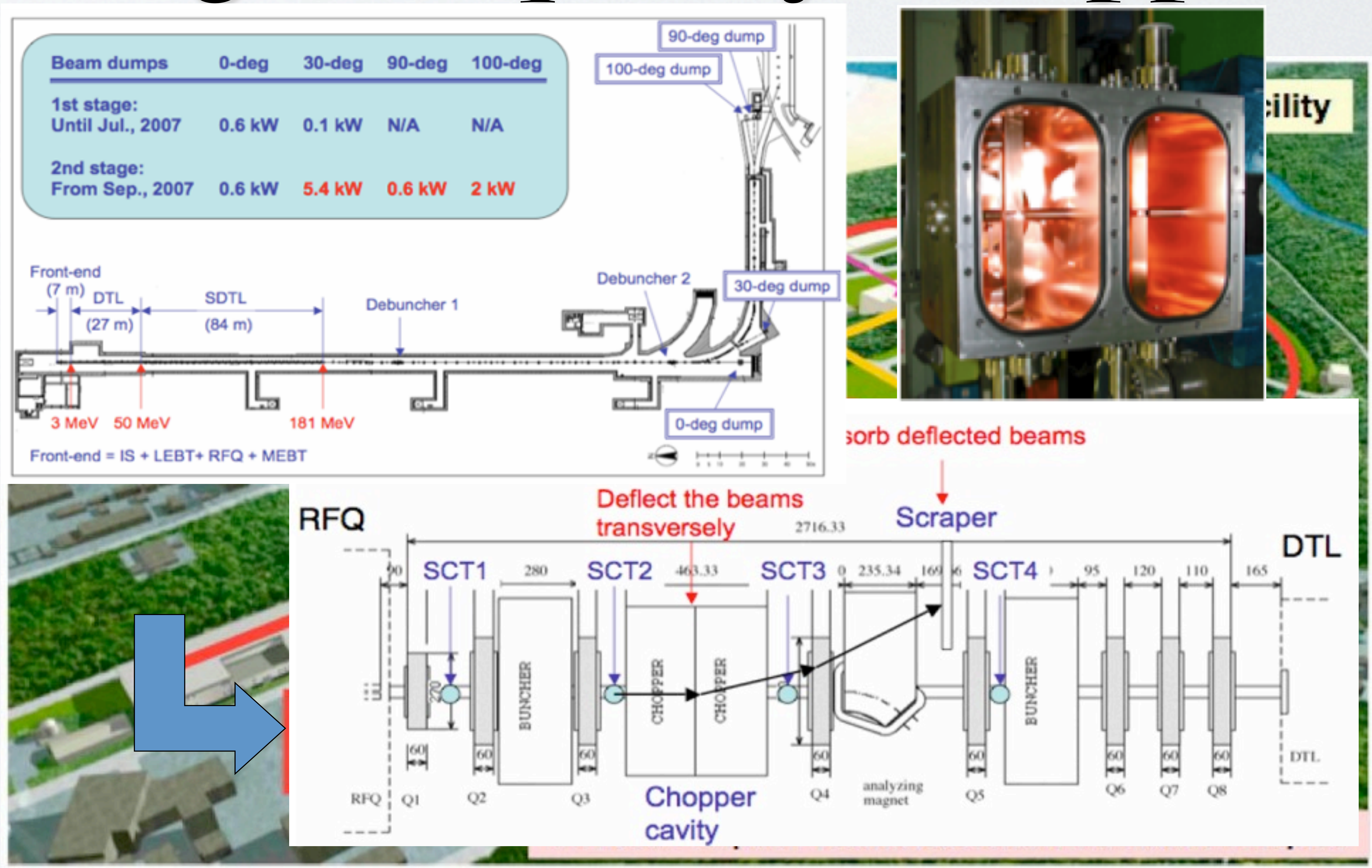
target material	$f_C \times f_{MC}$
Graphite	0.08
Silica-carbide (SiC)	0.46



High-frequency Chopper

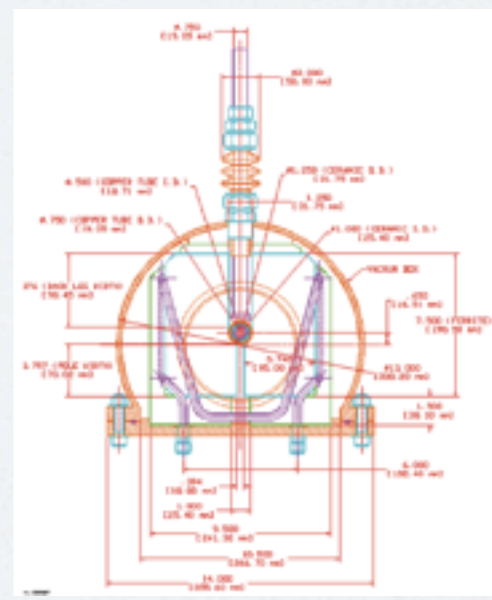


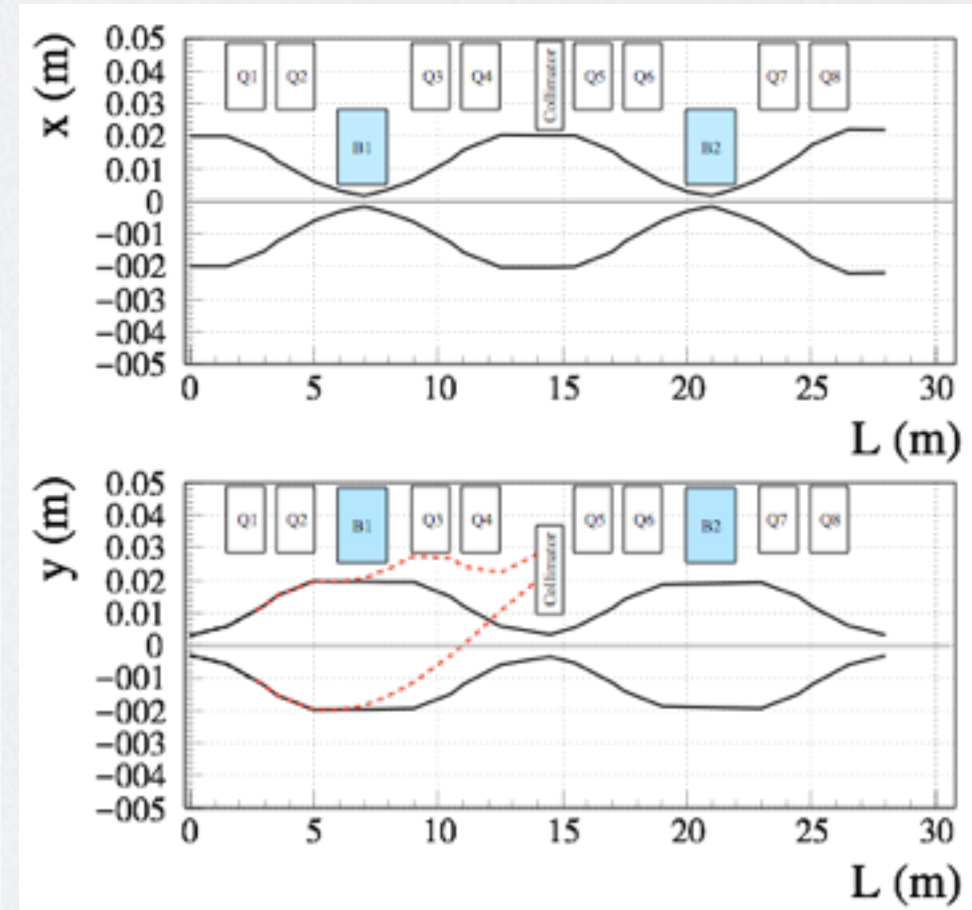
High-frequency Chopper



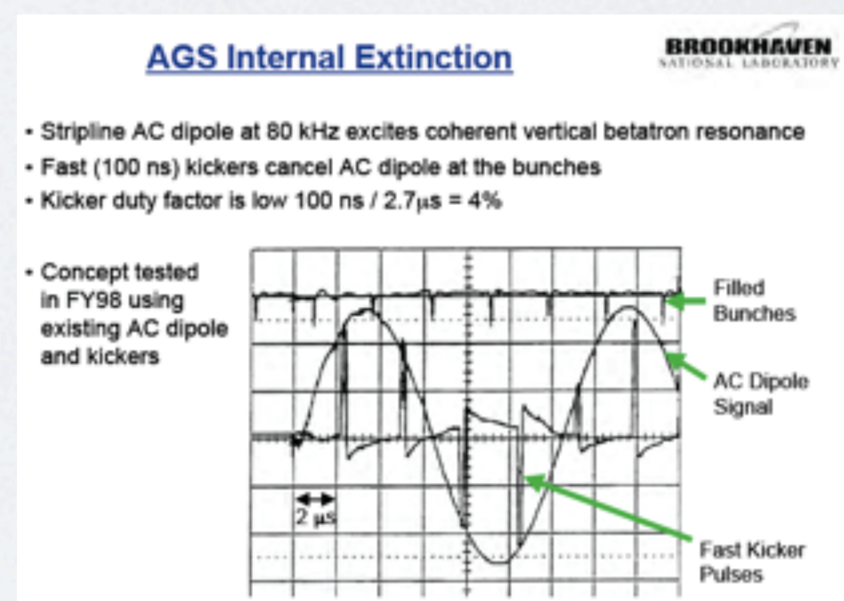
Additional Extinction Means

- AC-dipole
- @ primary beamline
- $f_{extinction} \sim 1/100$
- collaboration with mu2e



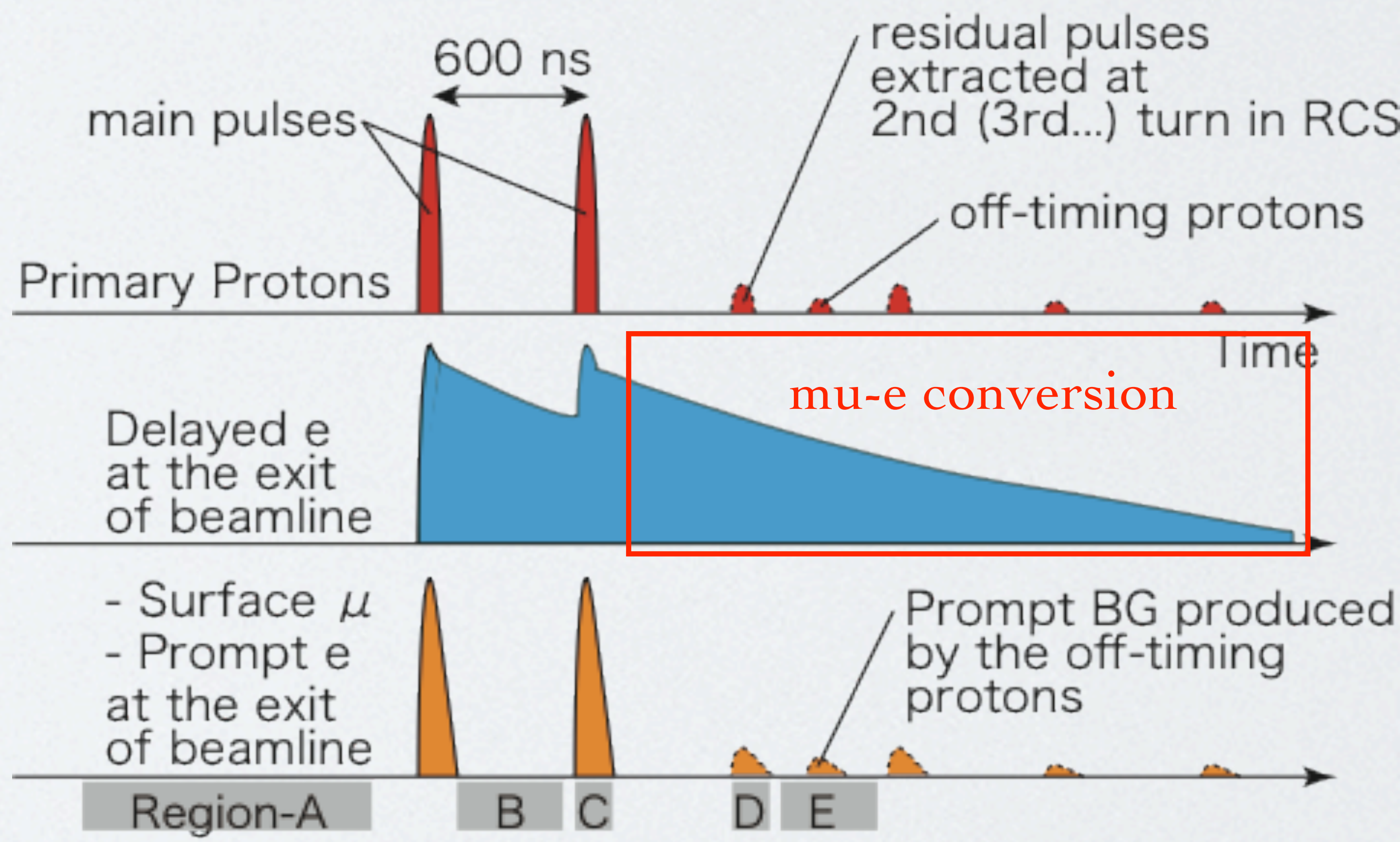


- Bunch Cleaner
  - in MR
  - tested at AGS for MECO



Background

- Event signature
  - P_e = 105 MeV/*c*
  - T_e > ~μsec



- 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}