Introduction of μ-e Conversion Experiment and Superconducting Magnet System at J-PARC

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Physics Motivation
charge Lepton Flavor Violation

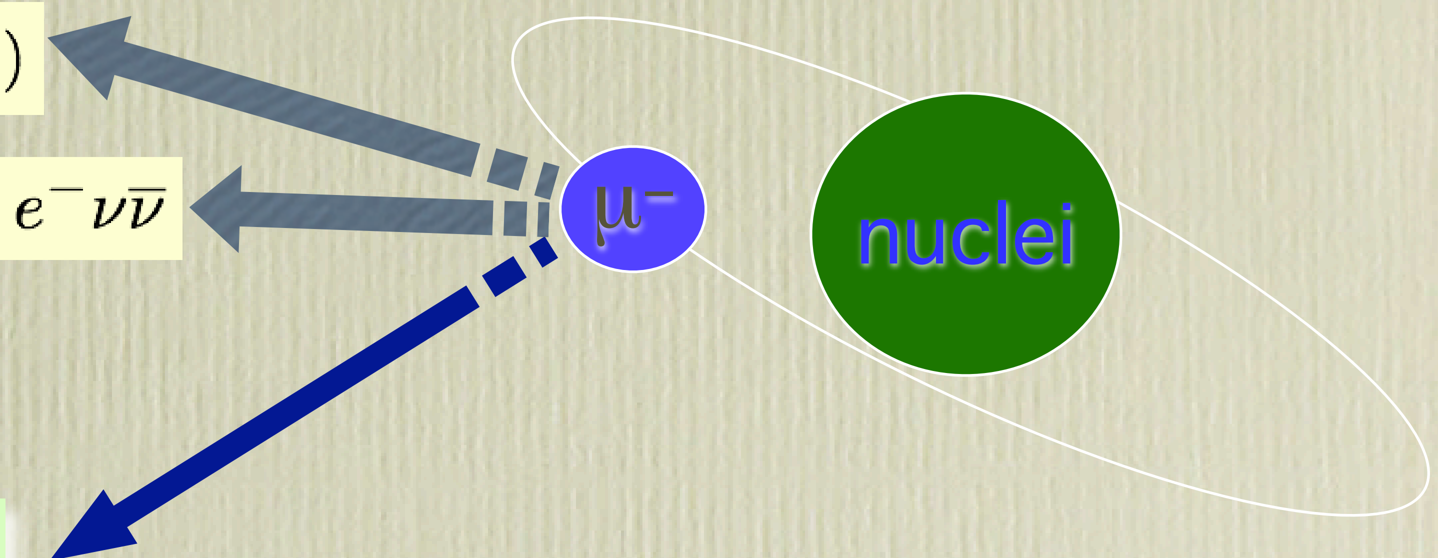
μ-e Conversion Process

- Muonic Atom (1S state)

Muon Capture

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

Muon Decay in Orbit $\mu^- \rightarrow e^- \nu \bar{\nu}$



- μ-e Conversion

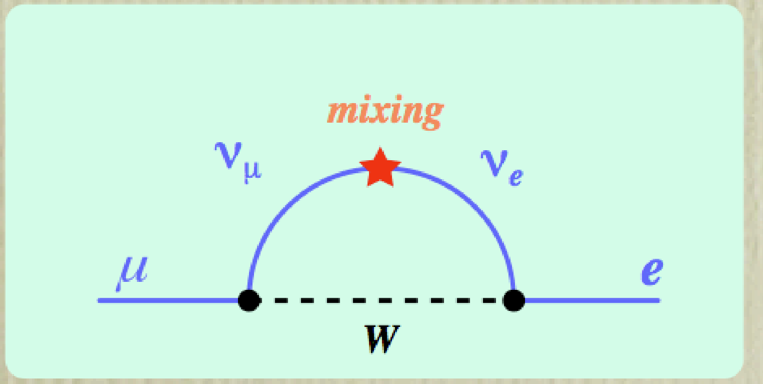
$$\mu^-(A,Z) \rightarrow e^- + (A,Z)$$

Coherent Process

  - Lepton Flavor is violated: LFV
    - Forbiden in Standard Model
  - Physics of chared Lepton Flavor Mixing

Lepton Flavor Mixing

- Quark Mixing : Kobayashi-Maskawa Matrix
- Neutrino Mixing : Maki-Nakagawa-Sakata Matrix
- charged Lepton Mixing : not-yet-observed
    - charged Lepton Flavor Violation (c-LFV)
    - Neutrino-mixing predicts very small amount of c-LFV via higher order diagram; it is as small as practically impossible to observe in forseeable future.



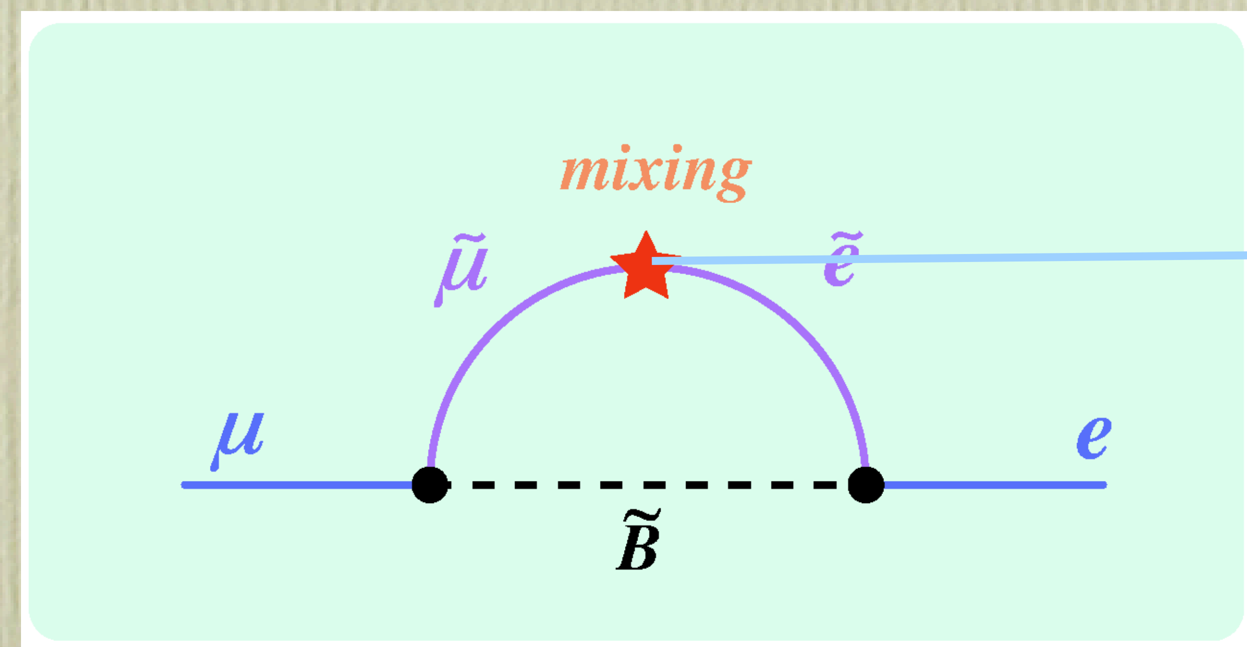
$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \sum_i \left| U_{\mu i} U_{ei}^{*} \frac{m_{\nu_i}^2}{M_W^2} \right|^2 \simeq 10^{-60} \left(\frac{m_\nu}{10^{-2}\,\mathrm{eV}} \right)^4$$

- c-LFV = Physics beyond SM

charge Lepton Flavor Violation (c-LFV)

c-LFV ⟷ slepton mixing

SUSY

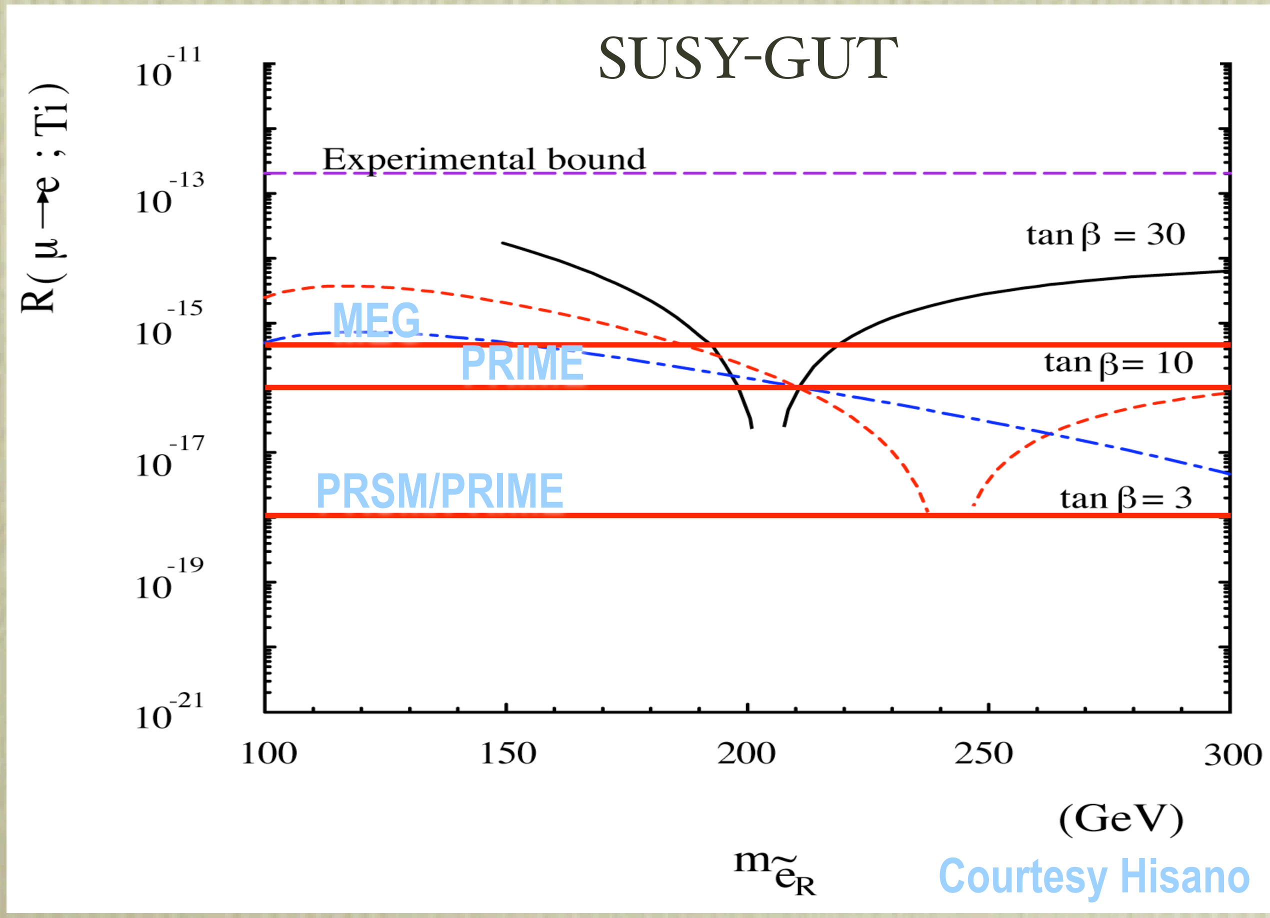


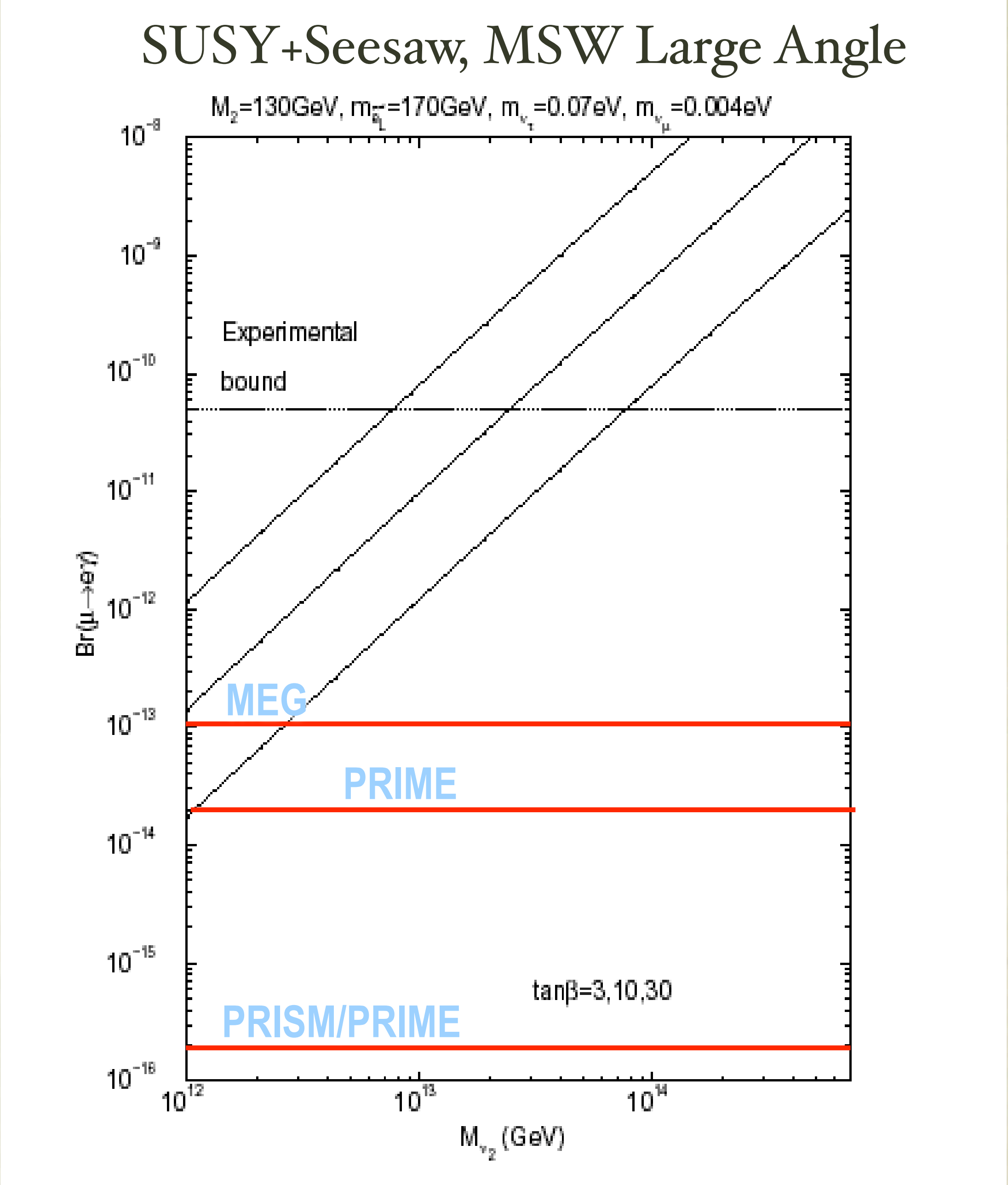
$$\begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} &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

Physics of slepton mass matrix

Theoretical Predictions

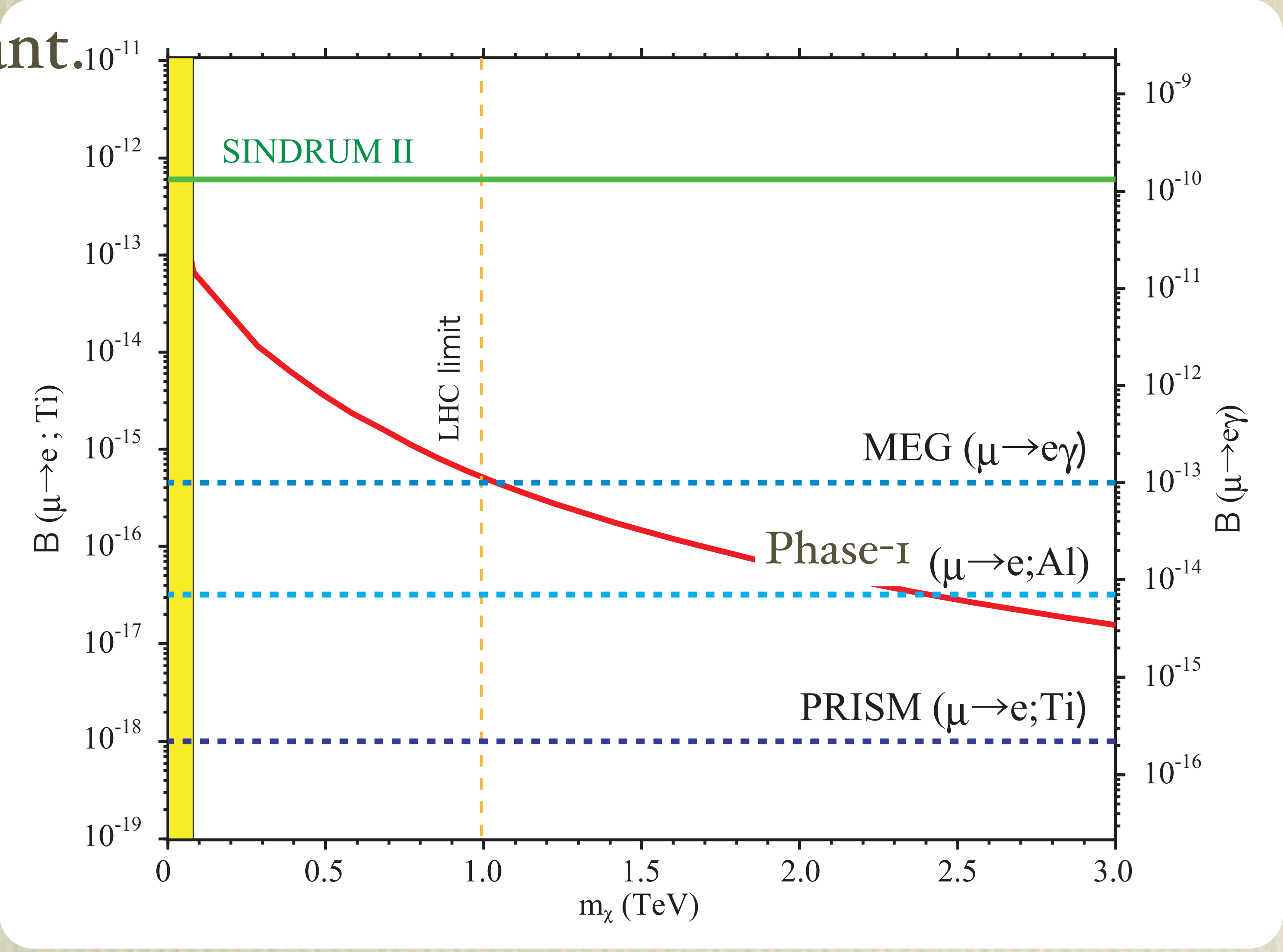
Process	Current Limit	SUSY-GUT level	Future
$\mu N \to e N$	10^{-13}	10^{-16}	$10^{-16}, 10^{-18}$
$\mu \to e \gamma$	10^{-11}	10^{-14}	10^{-13}
$\tau \to \mu \gamma$	10^{-6}	10^{-9}	10^{-8}





LHC and c-LFV

- if LHC finds SUSY particle
  - Physics of slepton mass matrix will be strengthened.
  - Further exploration of SUSY structure (SUSY-GUT, SUSY-Seesaw) will become more important.
- if LHC does not find SUSY particle
  - high-intensity exp. comes forefront.

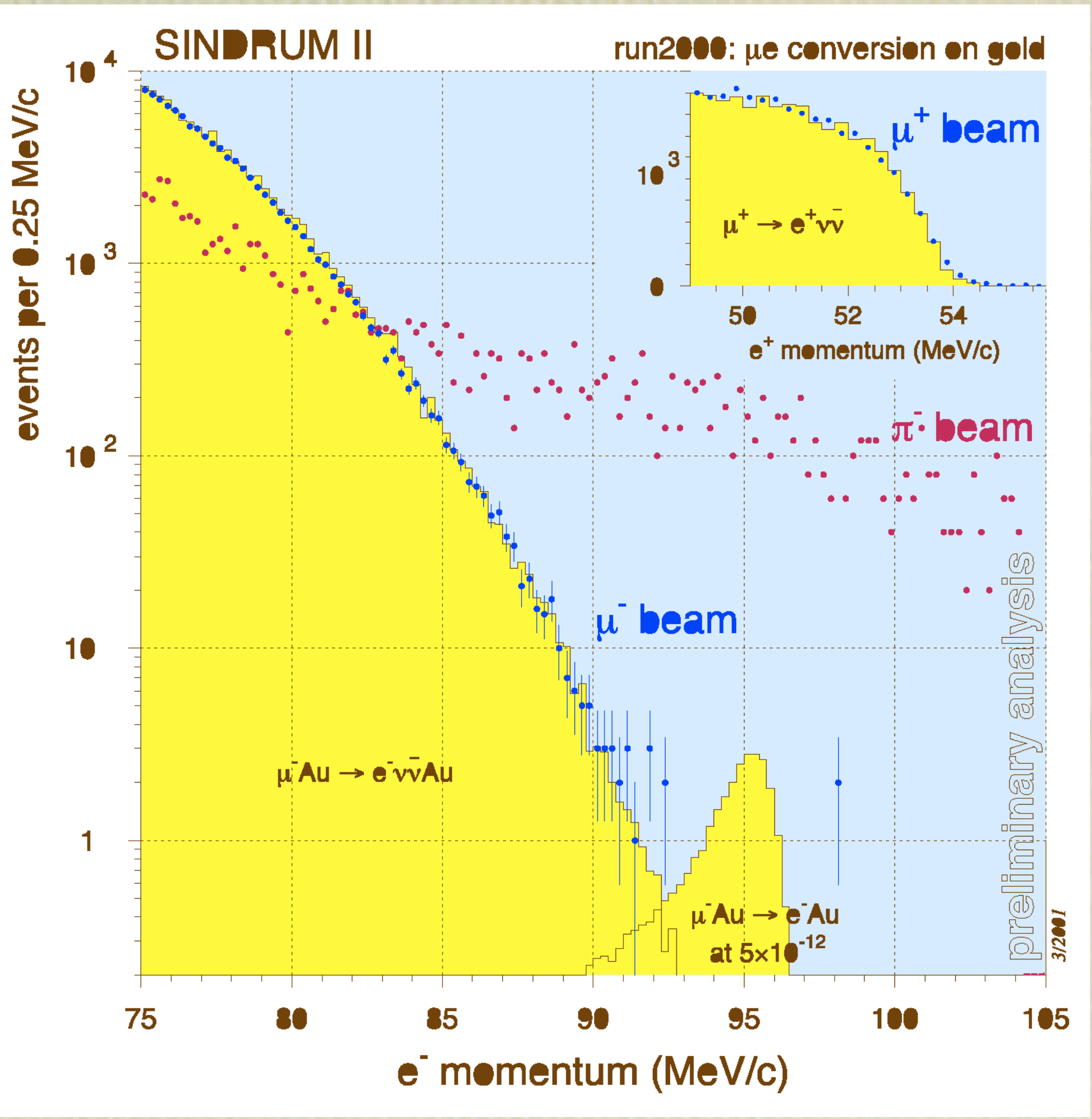


μ^--e Conversion Experiment

Principal of Experiment

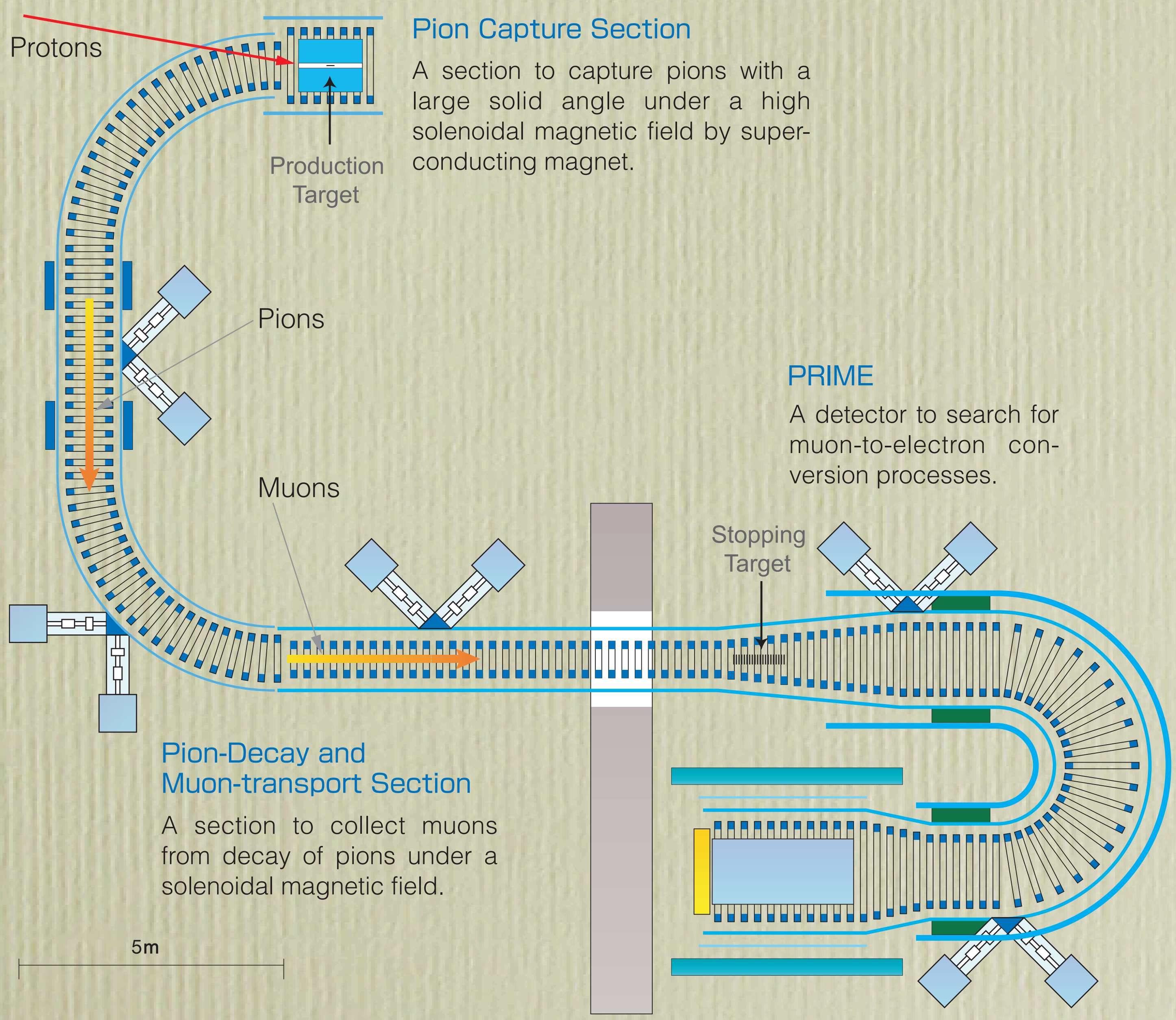
- Signal : $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$
  - A single mono-energetic electron
    - 100 MeV
    - Delayed : ~1μS
- No accidental backgrounds
- Physics backgrounds
  - Muon Decay in Orbit (MDO)
    - ΔE_e=350 keV (BR:10^{-16})
  - Beam Pion Capture
    - $\pi^- + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$
      $\gamma \rightarrow e^+ e^-$
    - Prompt timing
      or/and
    - Pure muon beam
- **High intensity μ beam**

PSI SINDRUM II



BR < 7×10^{-13}

Phase-1 Overview

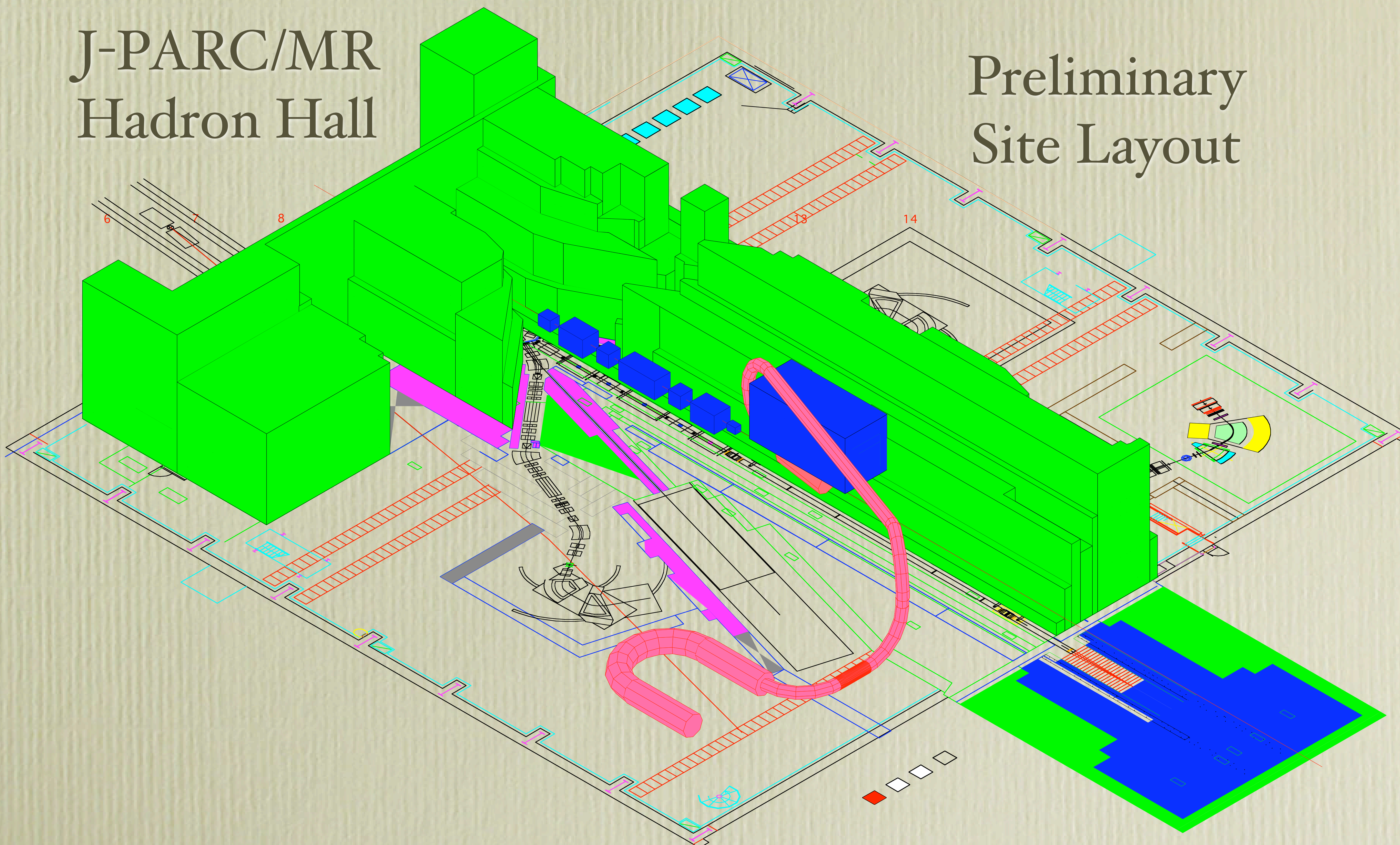


- Large μ yields
  - J-PARC/MR only 60 kW out of 450kW
  - π-capture SC-solenoid
  - 10^{11} μ/s (PSI:10^8 μ/s)
- Pulsed Proton Beam
  - π-b.g. suppression
- PRIME detector
  - Curved SC-solenoid
- Upgradability to PRISM
  - add Phase-Rotator-Ring

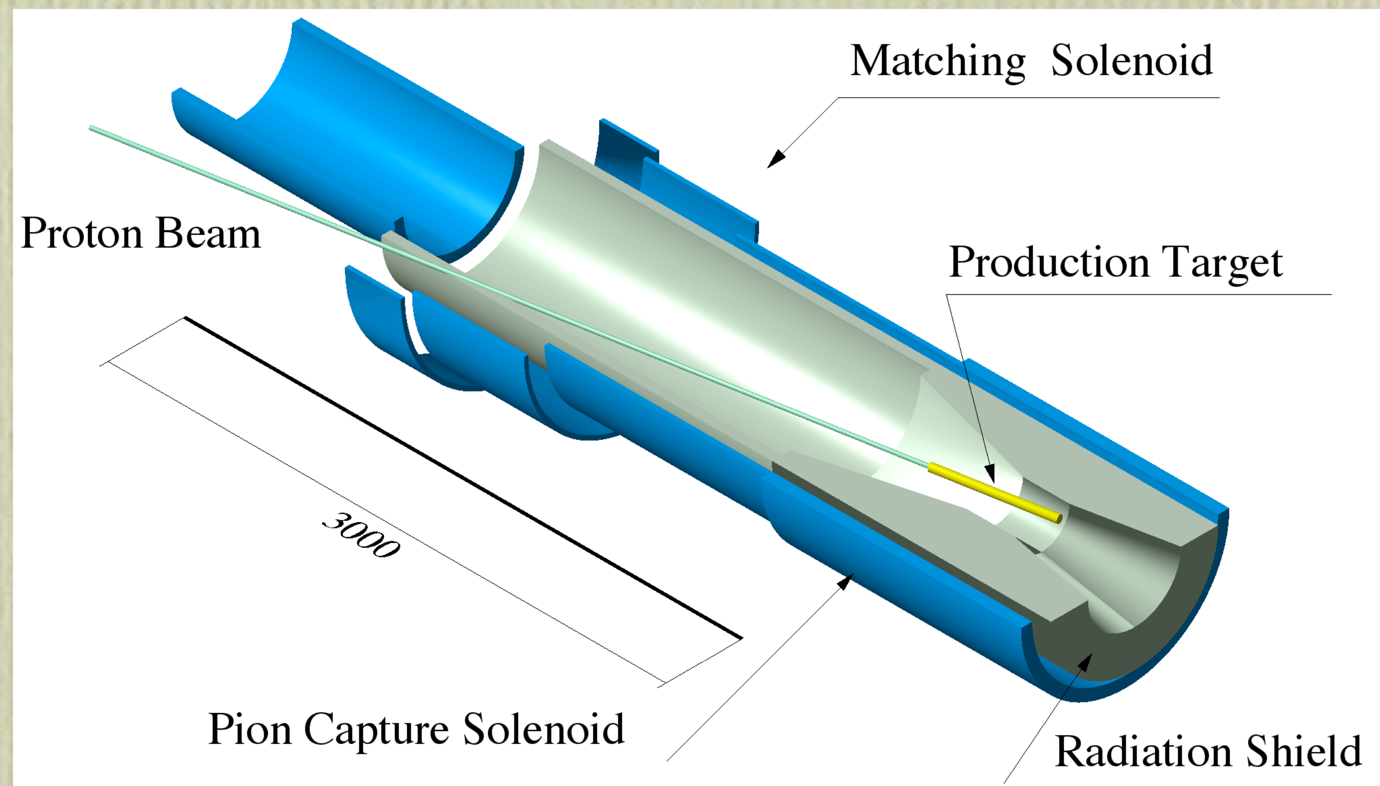
Experimental Site

J-PARC/MR
Hadron Hall

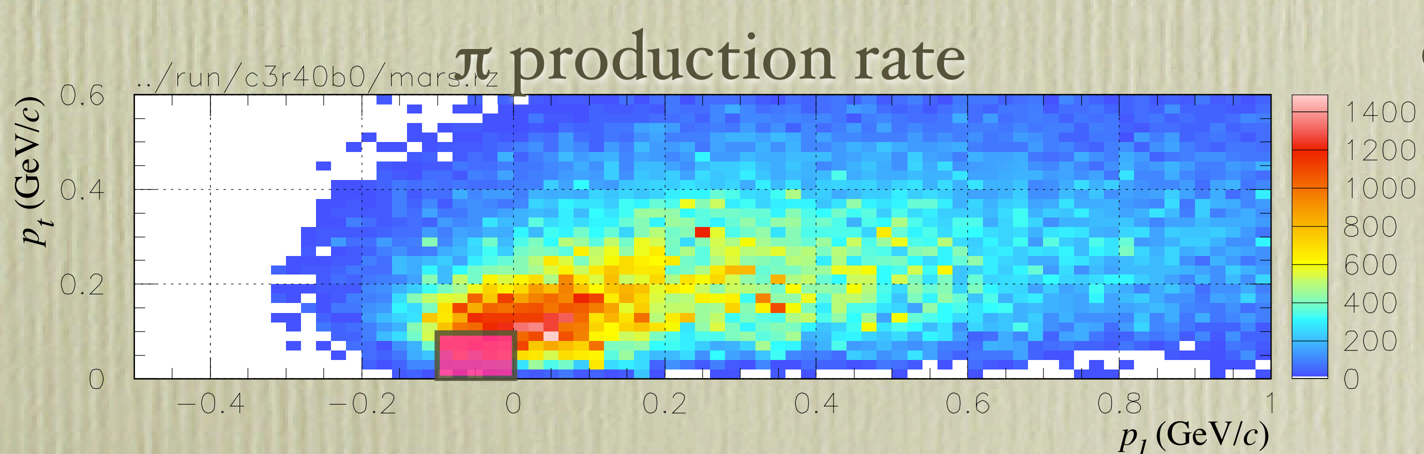
Preliminary
Site Layout



Pion Production



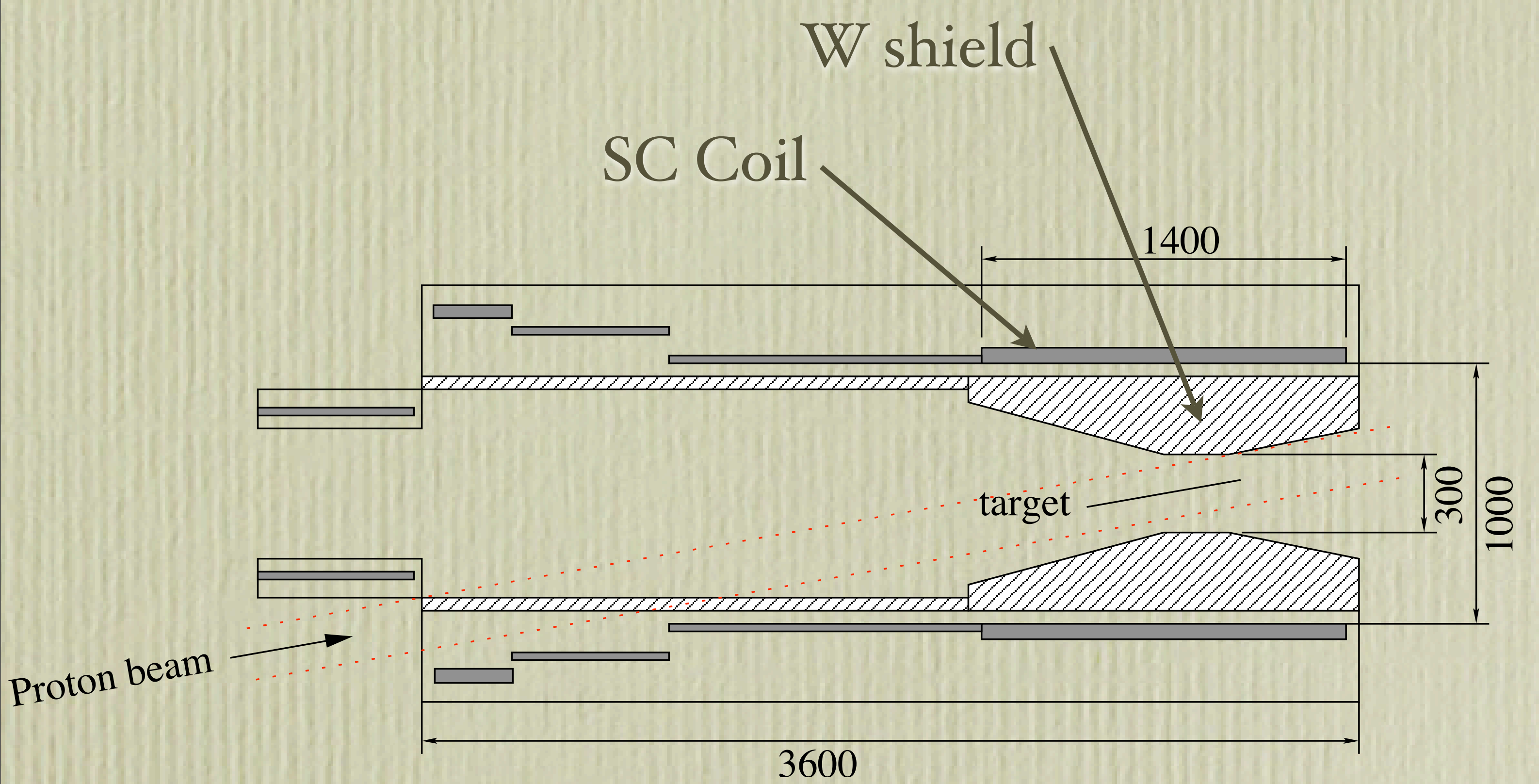
- Pion Production Target
  - Graphite : $60cm^{L}$, $4cm^{\phi}$
  - 2 kW energy dissipation for 56 kW
  - He or water cool

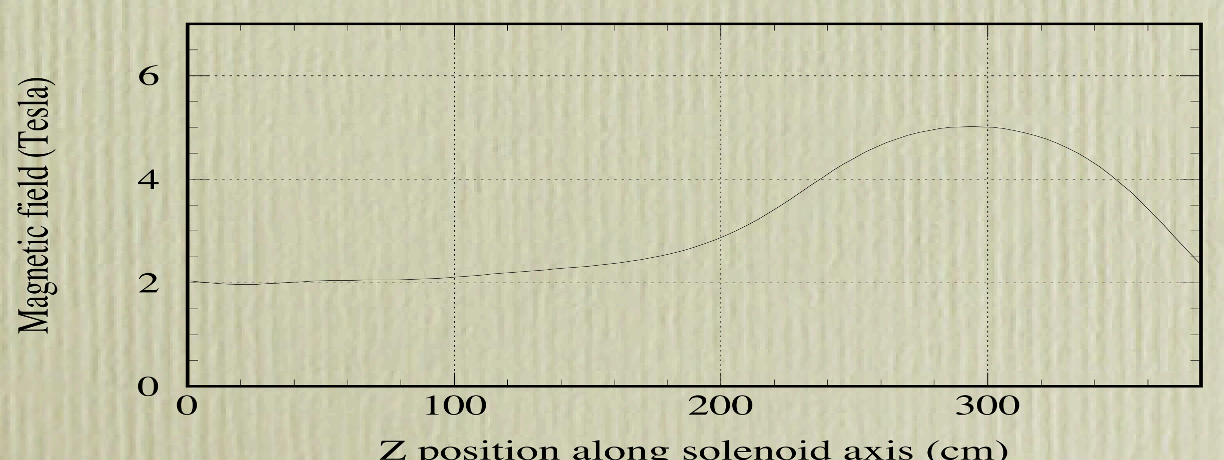


MELC, MECO idea

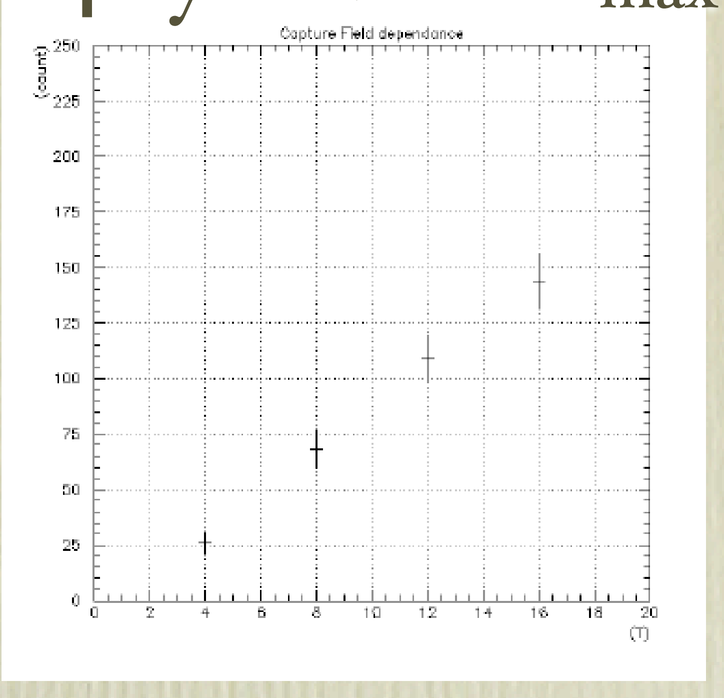
- Backward Extraction
  - Reduce high-p π-b.g.
  - Reduce heat-load to solenoids

Pion Capture



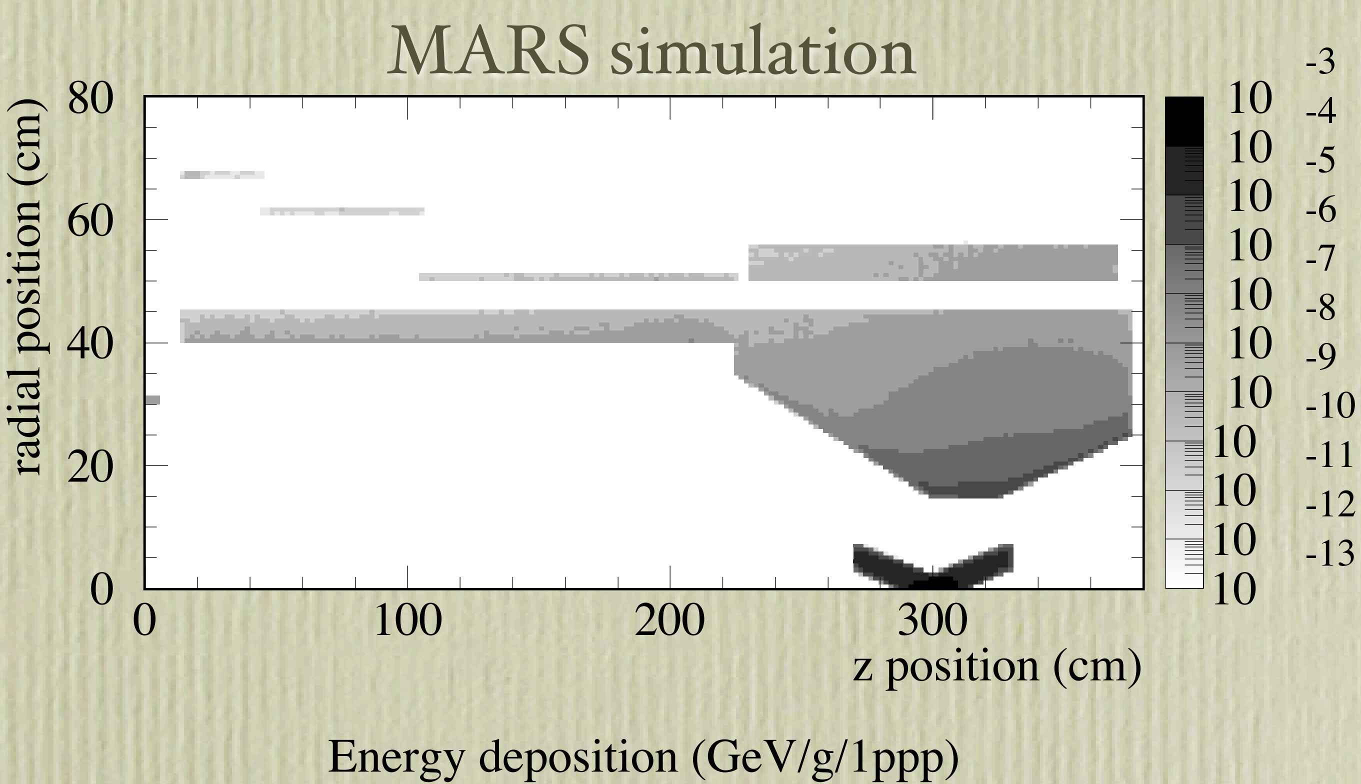


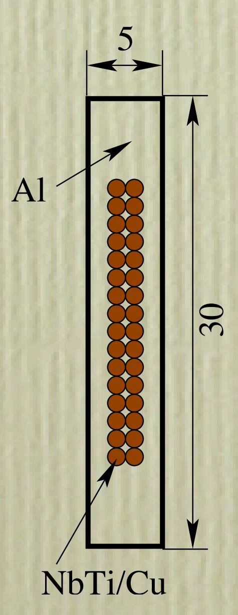
μ-yield vs. B_{max}



- $p_t \rightarrow p_l$
  - Parallel beam for p selection downstream
- yields : 0.05 (π+μ)/proton

Heat Load





30 mm × 5 mm
NbTi
1.28 mm diameter
32 strands
NbTi: Cu: Al = 19%: 34%: 46%
density: 4.0 g/cm^3

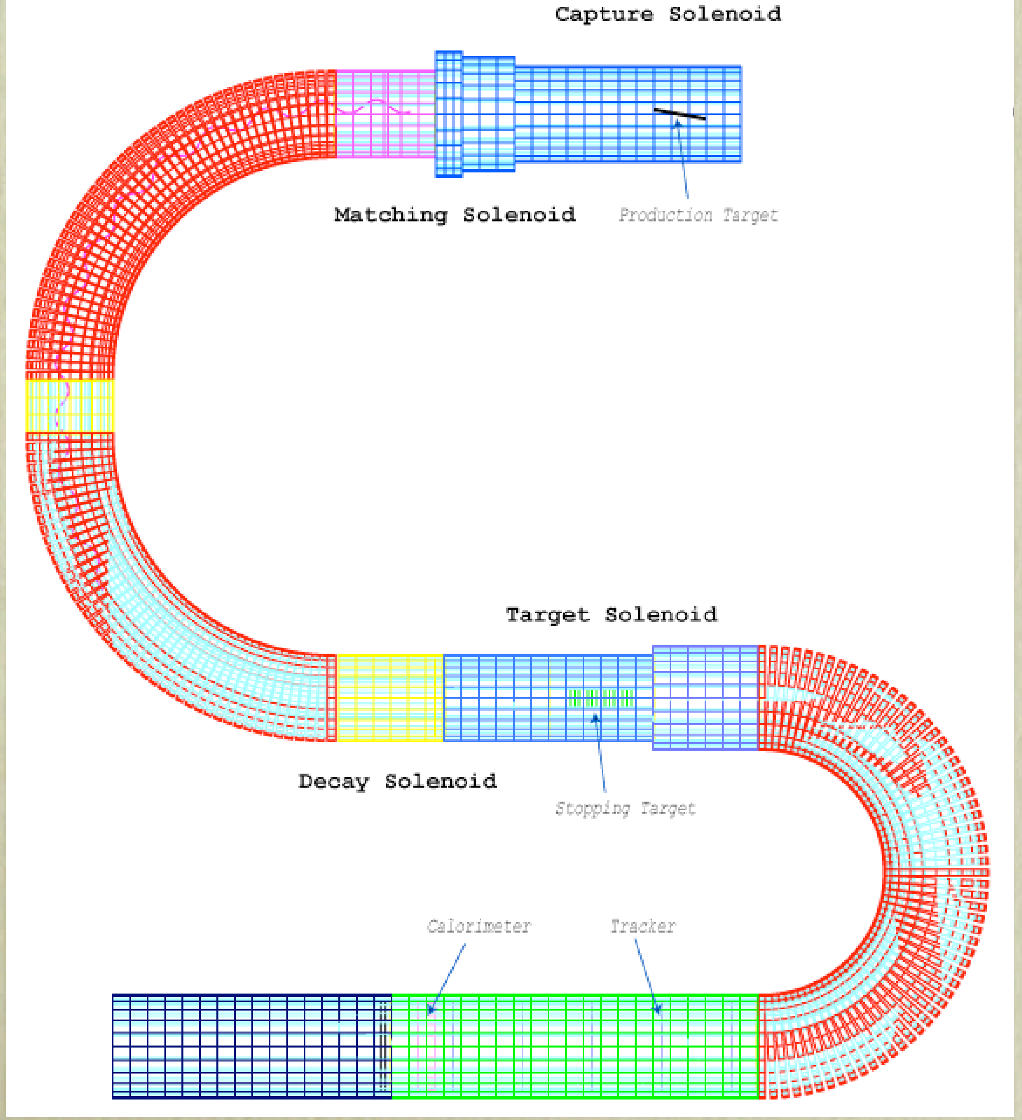
- Heat Load
  - 2 kW @ target
  - 35 kW @ W Shield
- ΔE density : 2×10^{-5} W/g behind W shield
  - 20cm-Cu SC coil : 1 kW MECO design
- Design goal < 100 W
  - 2 × 3cm-Al SC coil : 10 W
    - B = 5T, D = 300mm
    - 12.3 MJ, 12.5 kJ/kg
    - $B_{critical}$ = 8.4 T

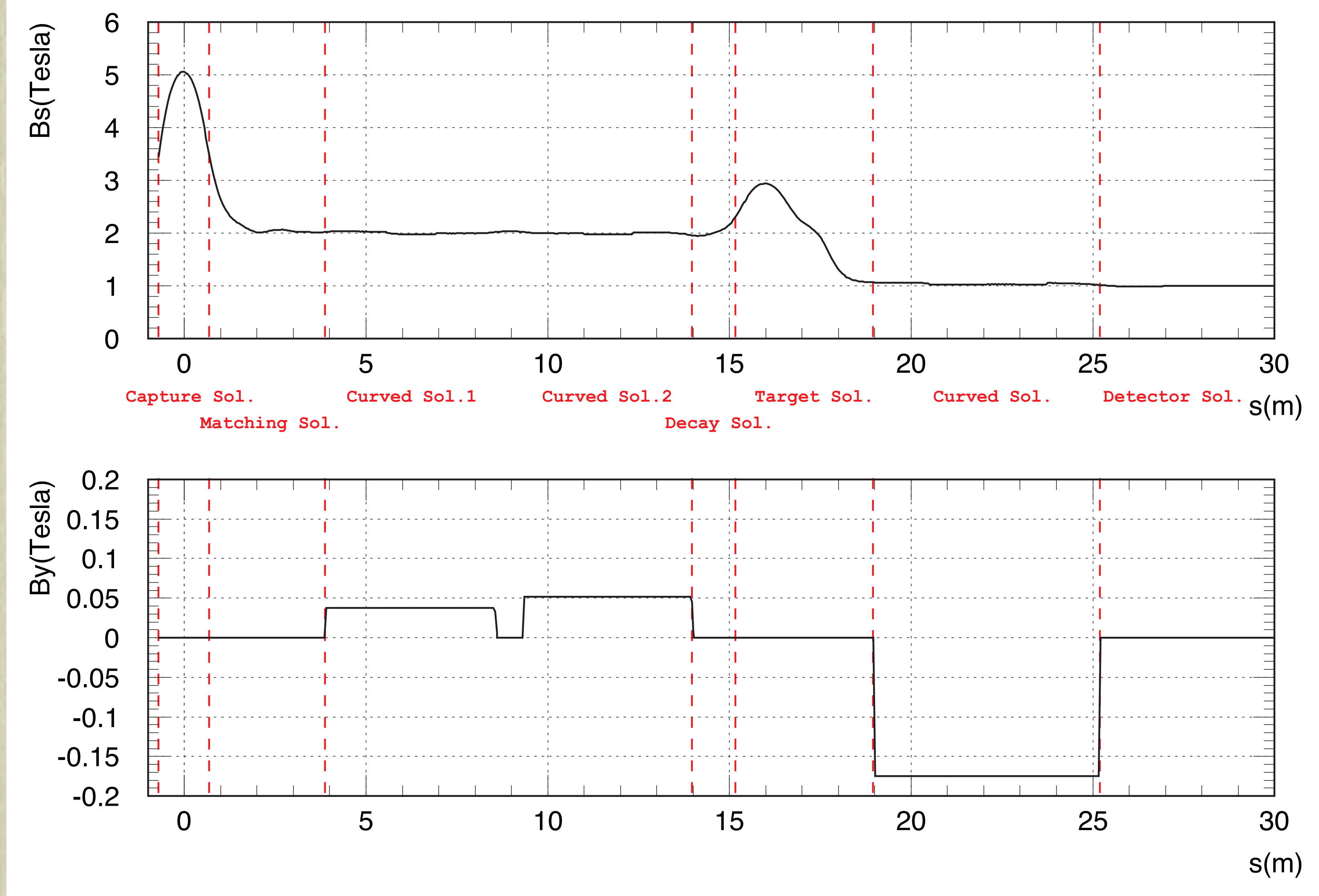
Muon Beamline

- Guide π's until decay to μ's
- Suppress unwanted particles
  - μ's : $p_\mu < 75$ MeV/*c*
  - e's : $p_e < 100$ MeV/*c*

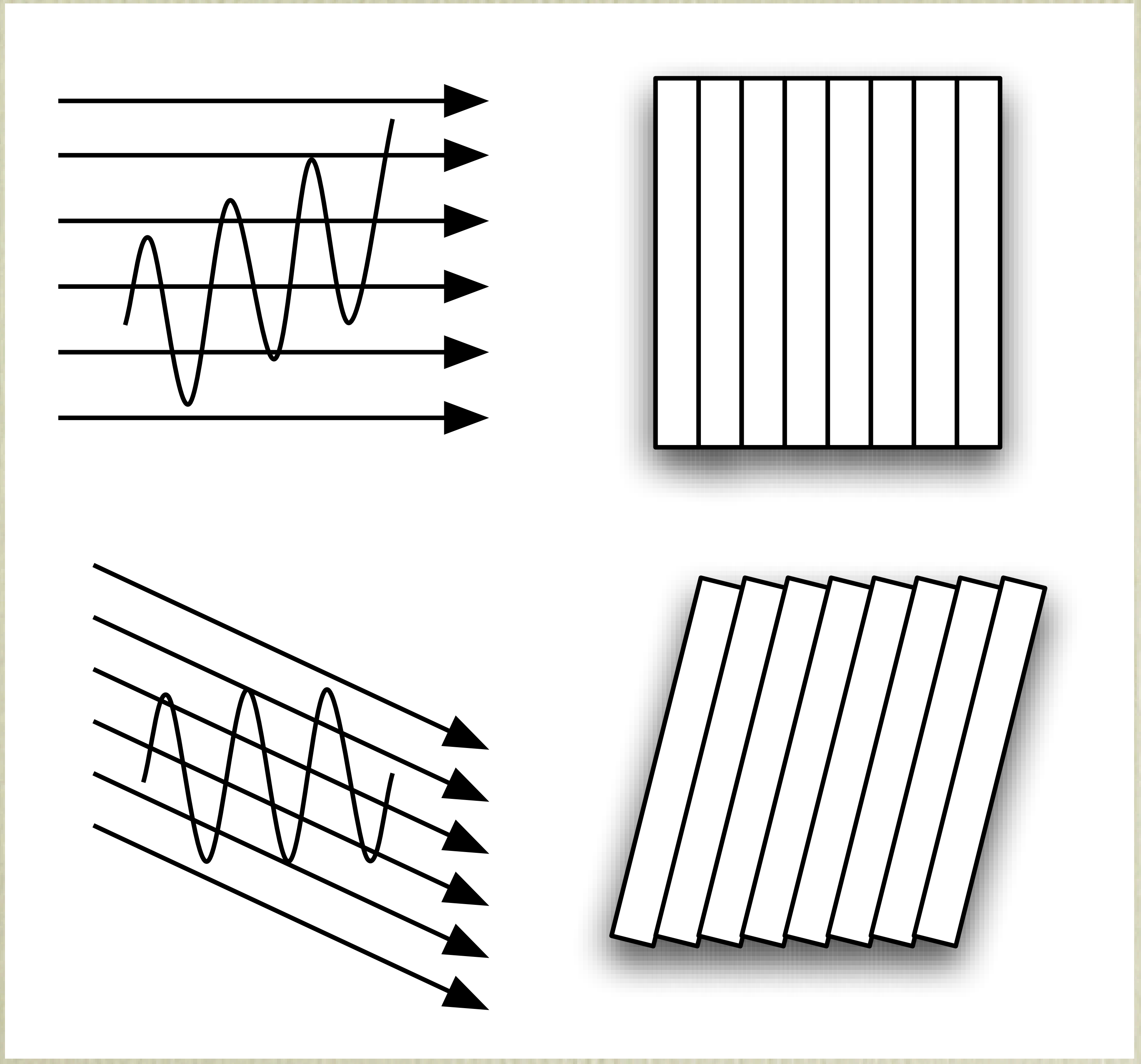
Vertical Drift in Torus

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



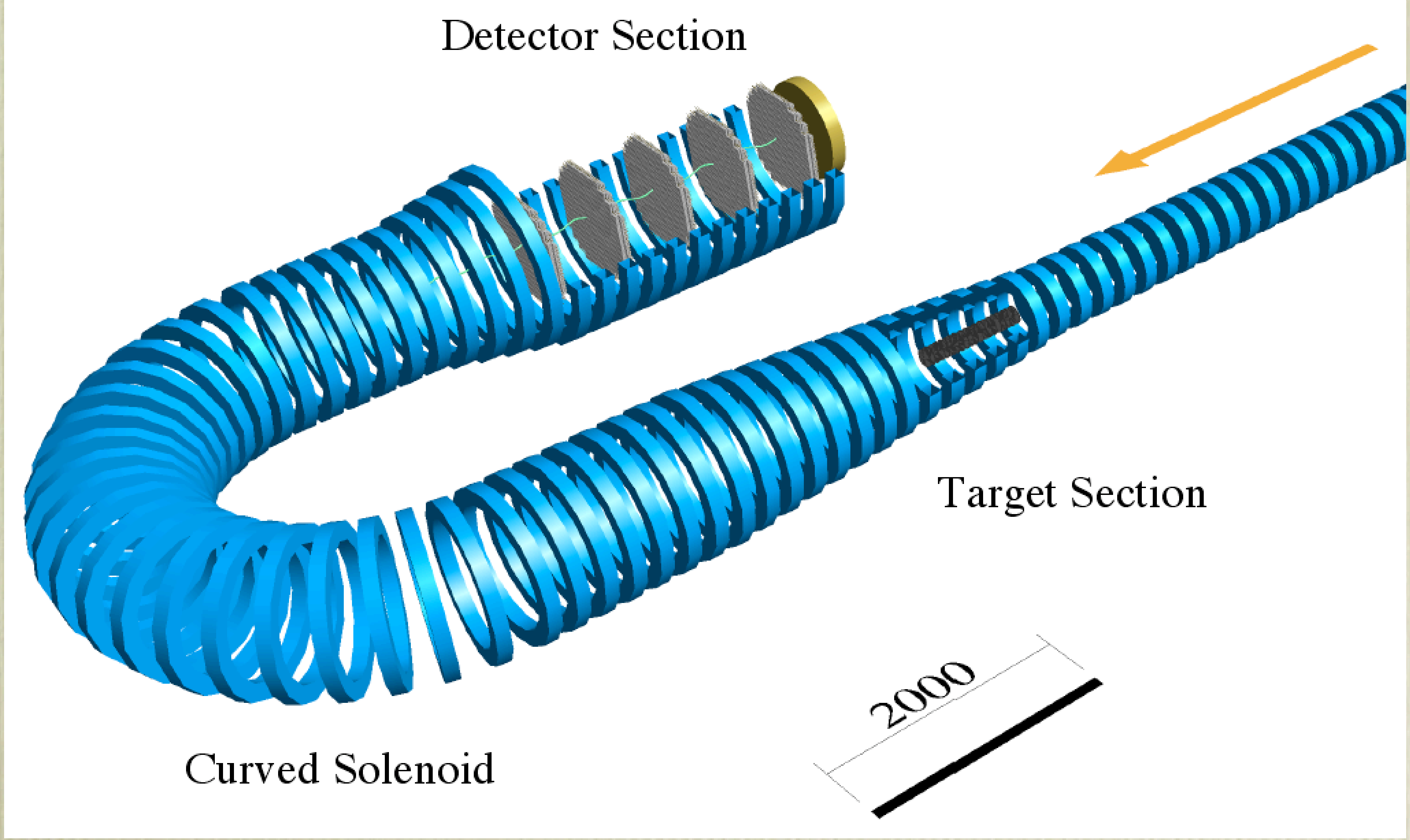


Compensative Vertical B



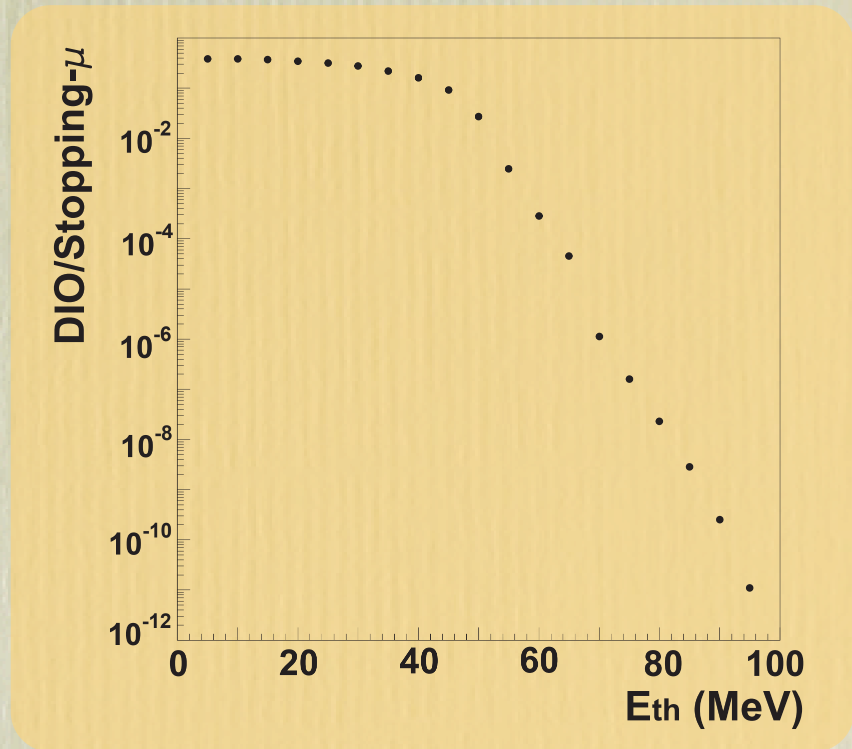
PRIME Overview

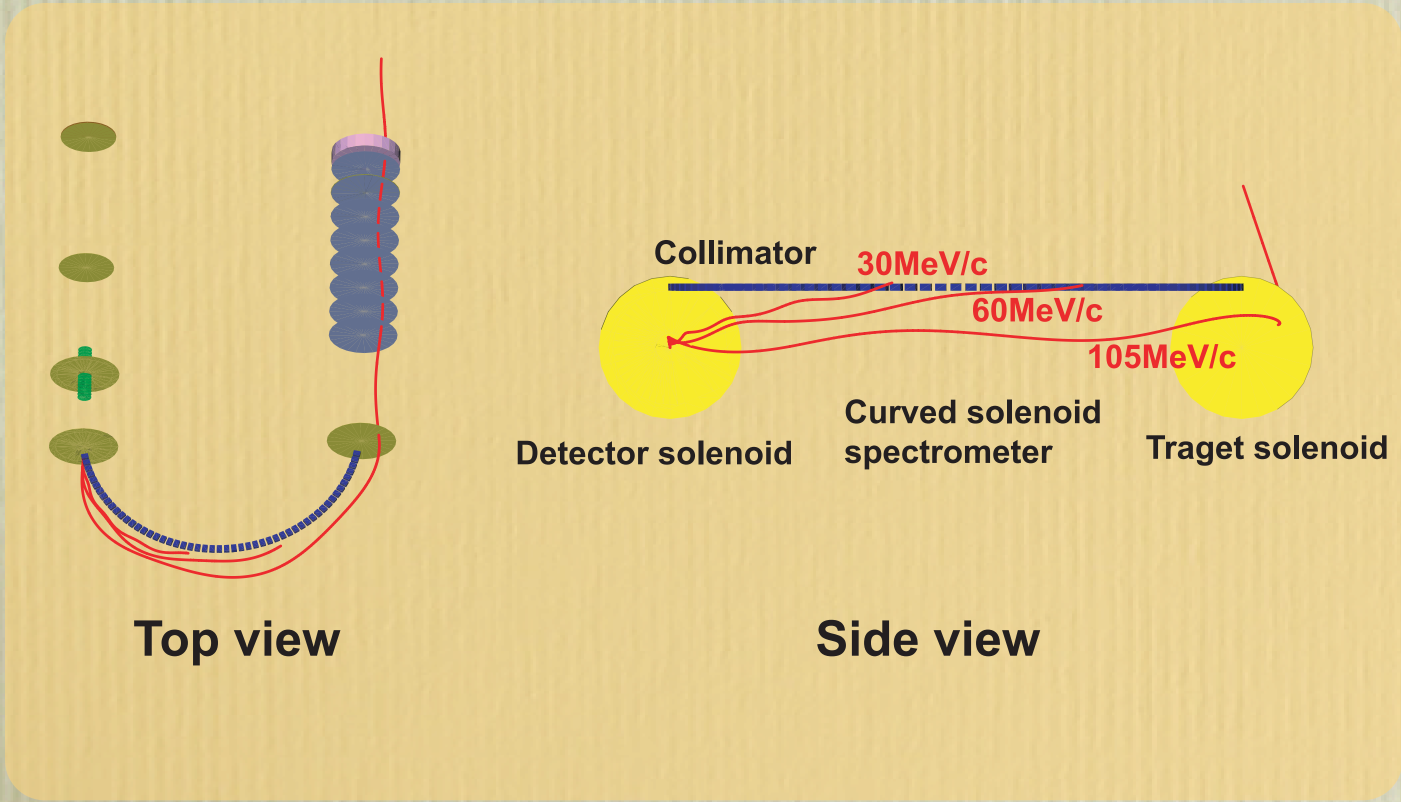
- Curved solenoid
  - Cut the low momentum charged particle backgrounds.
  - Cut the neutral particle backgrounds.



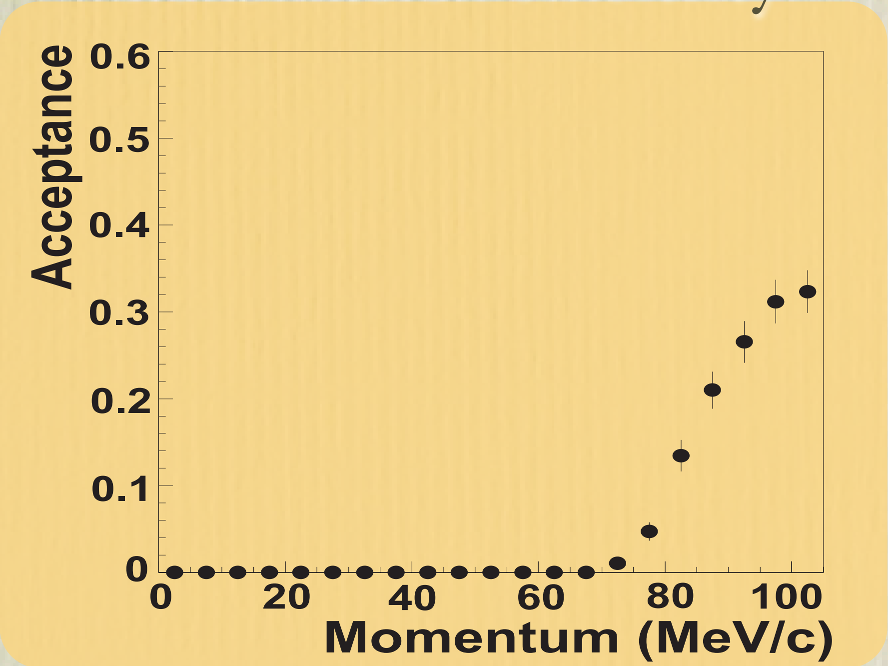
Electron Transmission

- Use torus drift for rejecting low energy DIO electrons.
  - rejection : 10^{-7}-10^{-8}, < 1kHz
- Good acceptance for signal e's
  - 30-40%



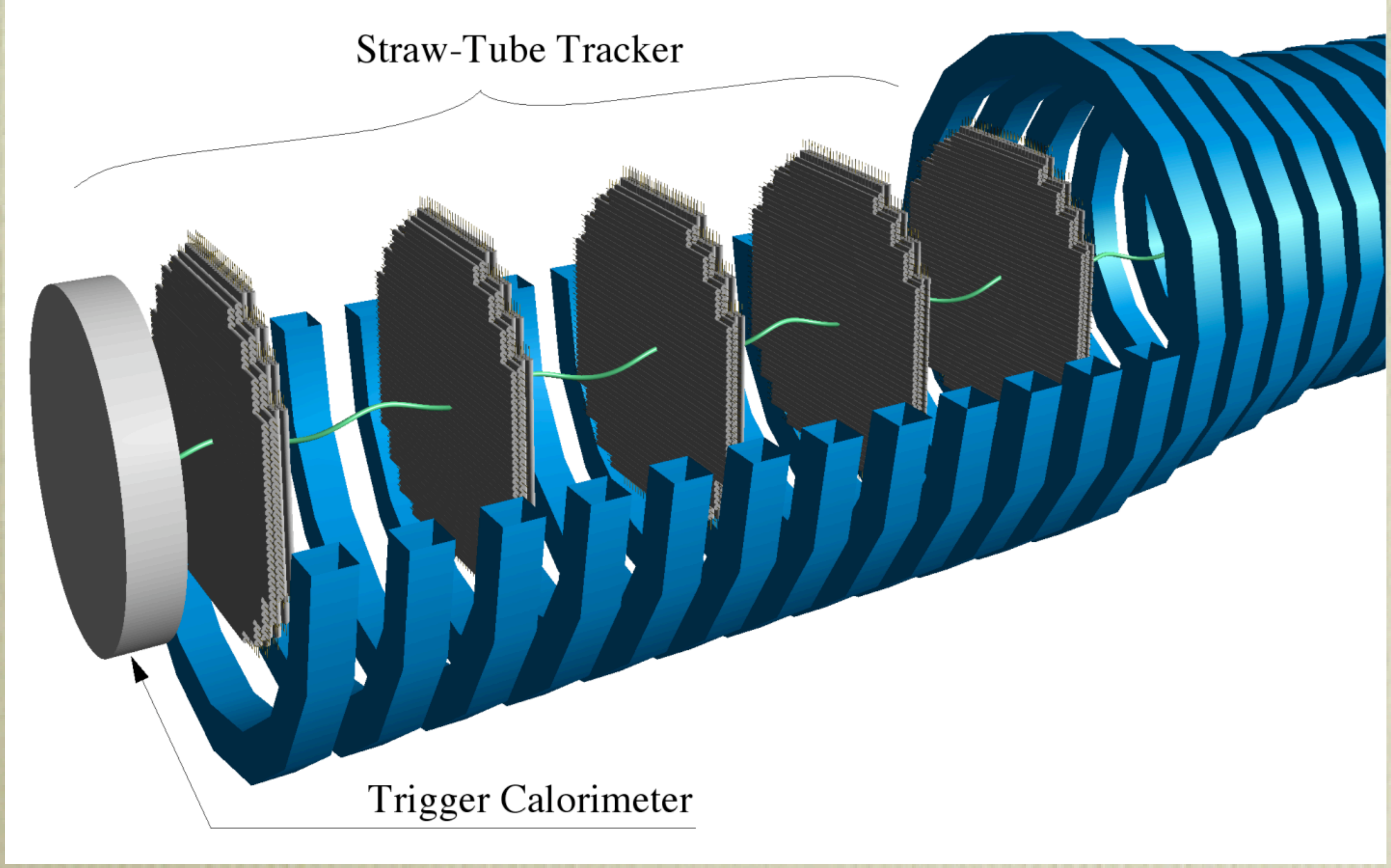


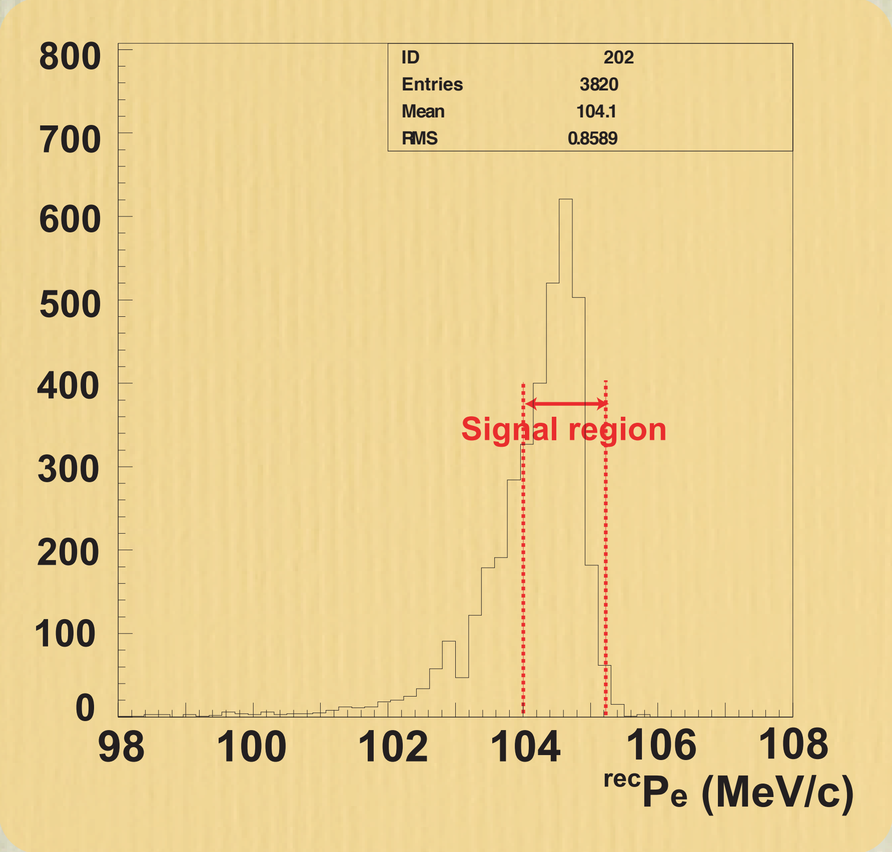
Transmission efficiency



Electron Detector

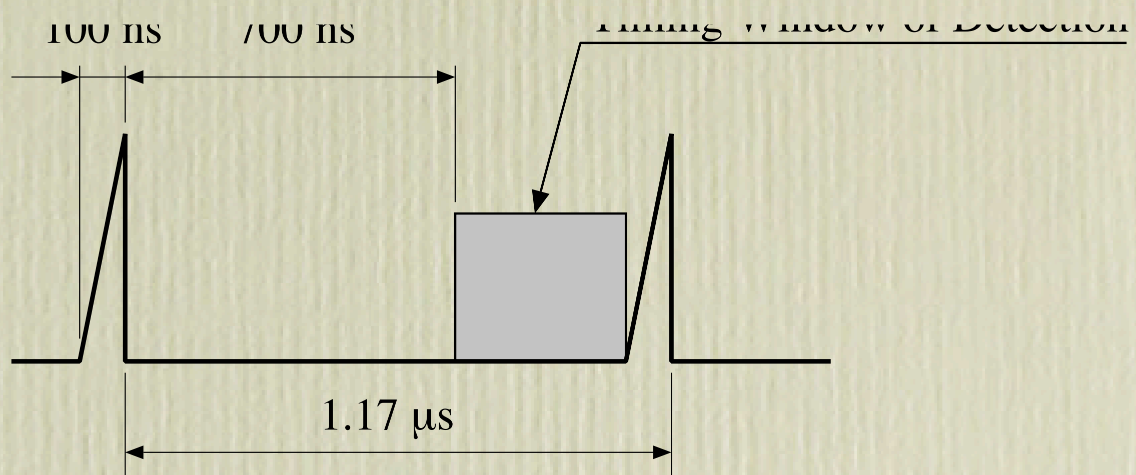
- Rate < 1 kHz
- Straw-tube tracker layers
  - σp = 230 keV/c
- Trigger calorimeter





Detector Acceptance & Signal Sensitivity

	Acceptance
Geometrical Acc.	0.73
Electron Transport	0.44
Energy Selection	0.68
$p_t > 90$ MeV/c	0.82
Timing cut	0.38
Total	0.07



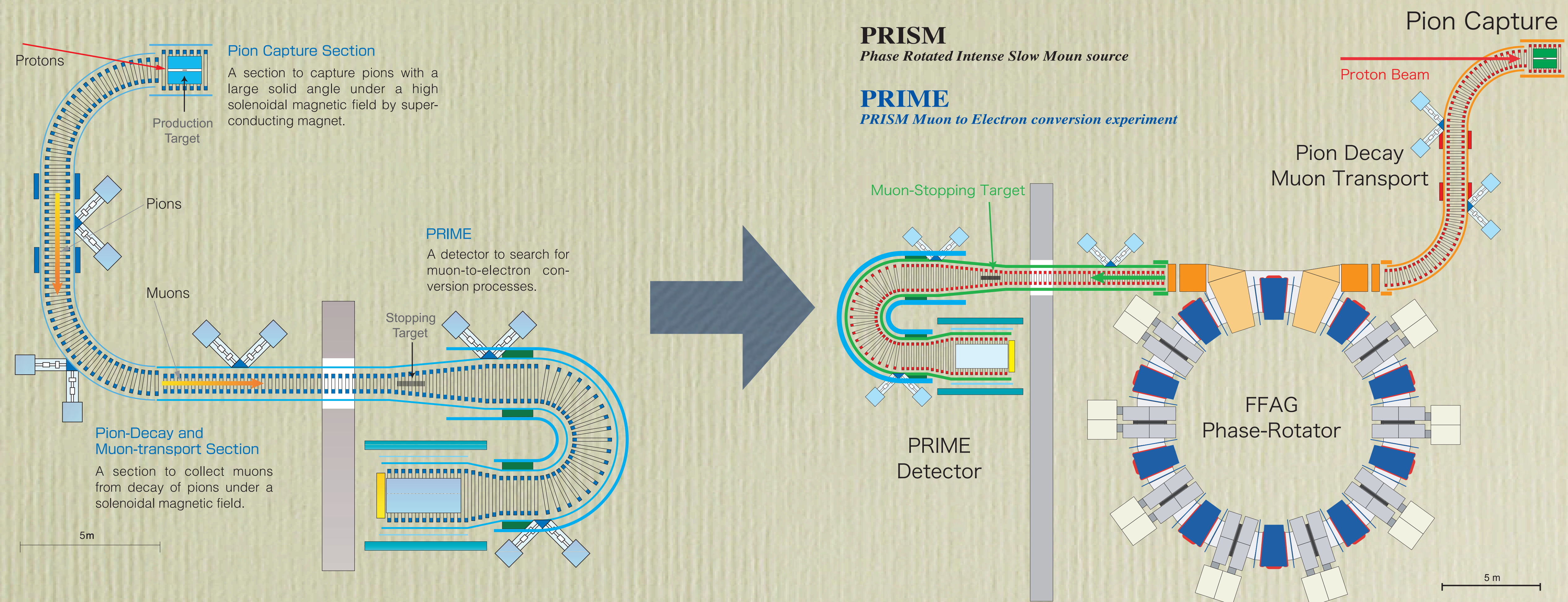
$$B(\mu^- + Al \rightarrow e^- + Al) = \frac{1}{N_\mu \cdot f_{\mathrm{cap}} \cdot A_e}$$

Proton Intensity	4×10^{13} Hz
Running Time	2×10^{7} sec
μ's yields per proton	0.0024
μ-stopping efficiency	0.29
Total	5.6×10^{17} stopped μ's

- $N_\mu = 5.6 \times 10^{17}$
- $f_{cap} = 0.6$ for Aluminum
- $A_e = 0.07$
- $B(\mu^- + Al \rightarrow e^- + Al) = 4 \times 10^{-17}$

  $< 10^{-16}$ (90% C.L.)

Toward full PRISM



Phase-1: $R<10^{-16}$ Full PRISM: $R<10^{-18}$

- Same Beamline, Detector (PRIME)
- Add FFAG Phase -Rotator
- Fast-Extracted Proton Pulse