μ-e conversion 探索実験

--- COMET ---

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「J-PARCハドロン物理の将来研究計画を考える」研究会

理化学研究所

2008/9/1-2

内容

- イントロダクション
- μ-e conversion 探索実験 @J-PARC --- COMET
  - パルス陽子
  - パイオン捕獲ソレノイド
  - カーブソレノイドスペクトロメータ
  - 実験感度
- mu2e@FNAL
- まとめ

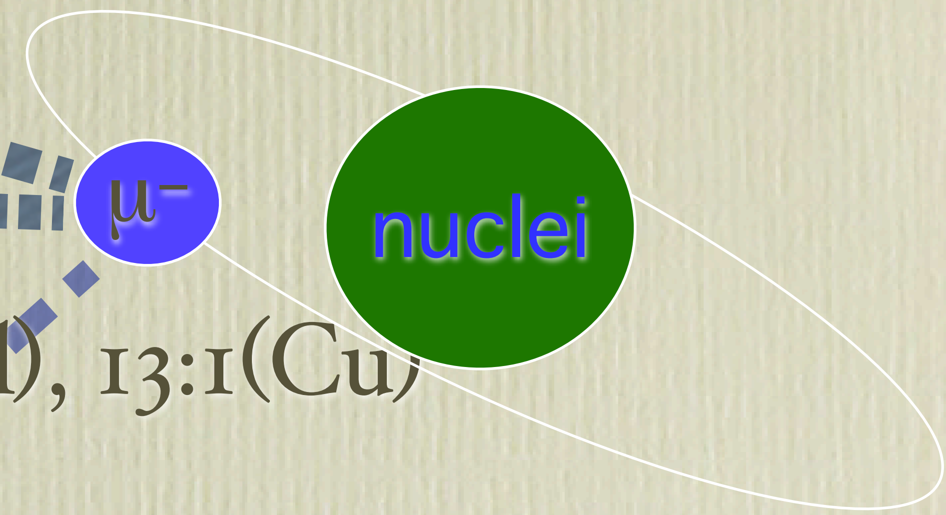
μ-e Conversion

- Muonic Atom (1S state)

Muon Capture(MC)

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

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



  - MC:MDO = 1:1000(H), 3:2(Al), 13:1(Cu)
  - τ(free-μ-) = 2.2 μs
  - τ(μ-;Al) = 0.88 μs

- μ-e Conversion

$$\mu^-(A,Z) \to e^- + (A,Z)$$ Coherent Process

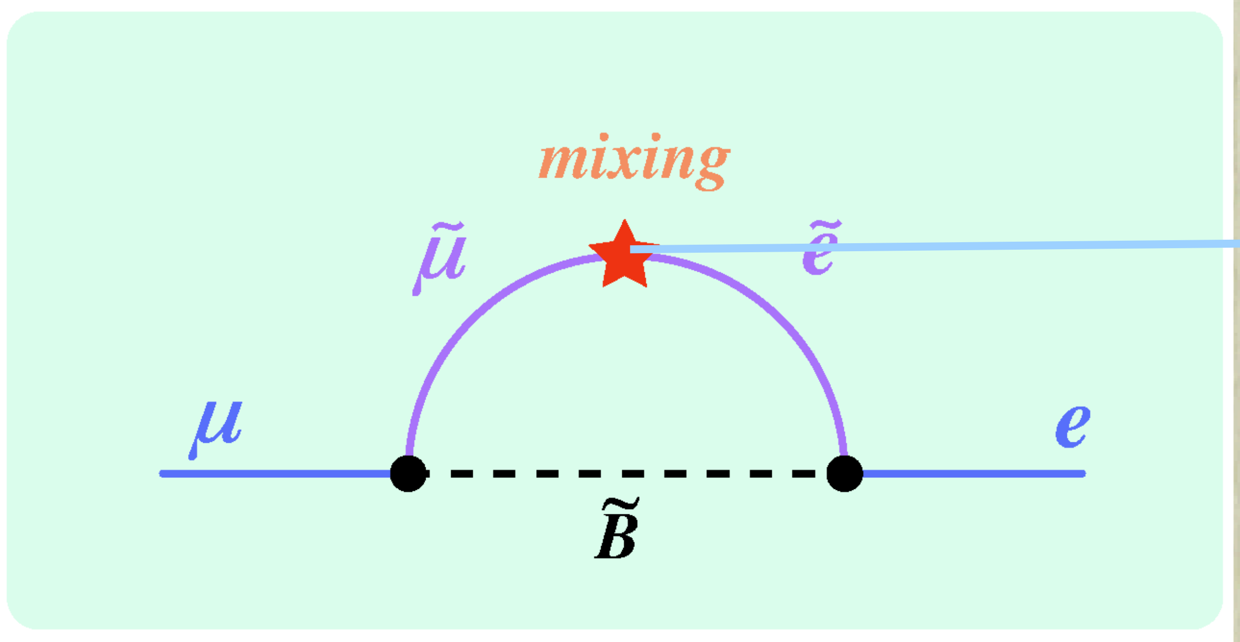
$$\mathrm{BR}[\mu^- + (A,Z) \to e^- + (A,Z)] \equiv \frac{\Gamma[\mu^- + (A,Z) \to e^- + (A,Z)]}{\Gamma[\mu^- + (A,Z) \to \nu_\mu + (A,Z-1)]}$$

- $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$
  - レプトン・フレーバー非保存過程：標準理論では禁止されている。
    - ニュートリノ混合による高次効果は非常に小さい
  - 標準理論を越える物理に敏感

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

A. de Gouvea

超対称性理論

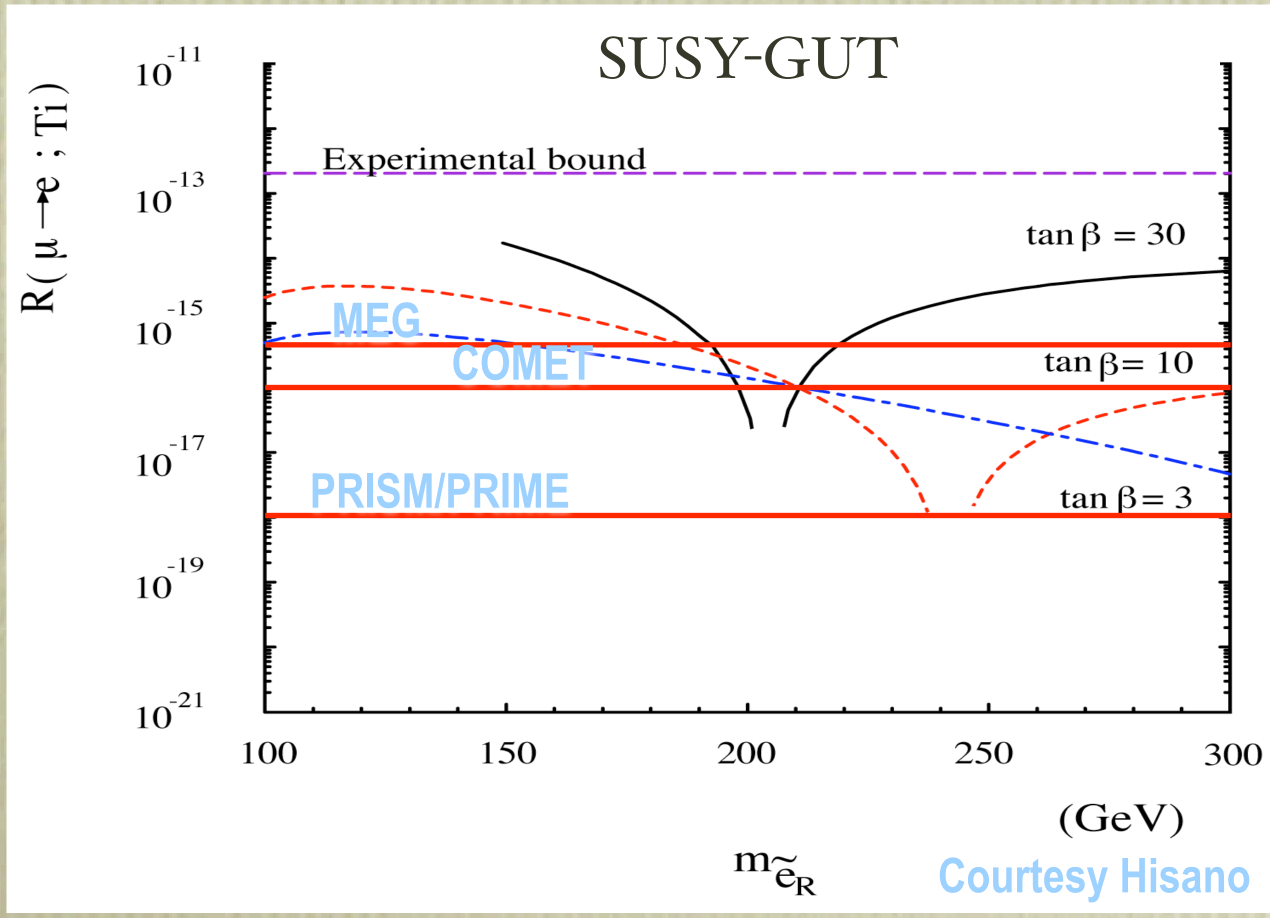


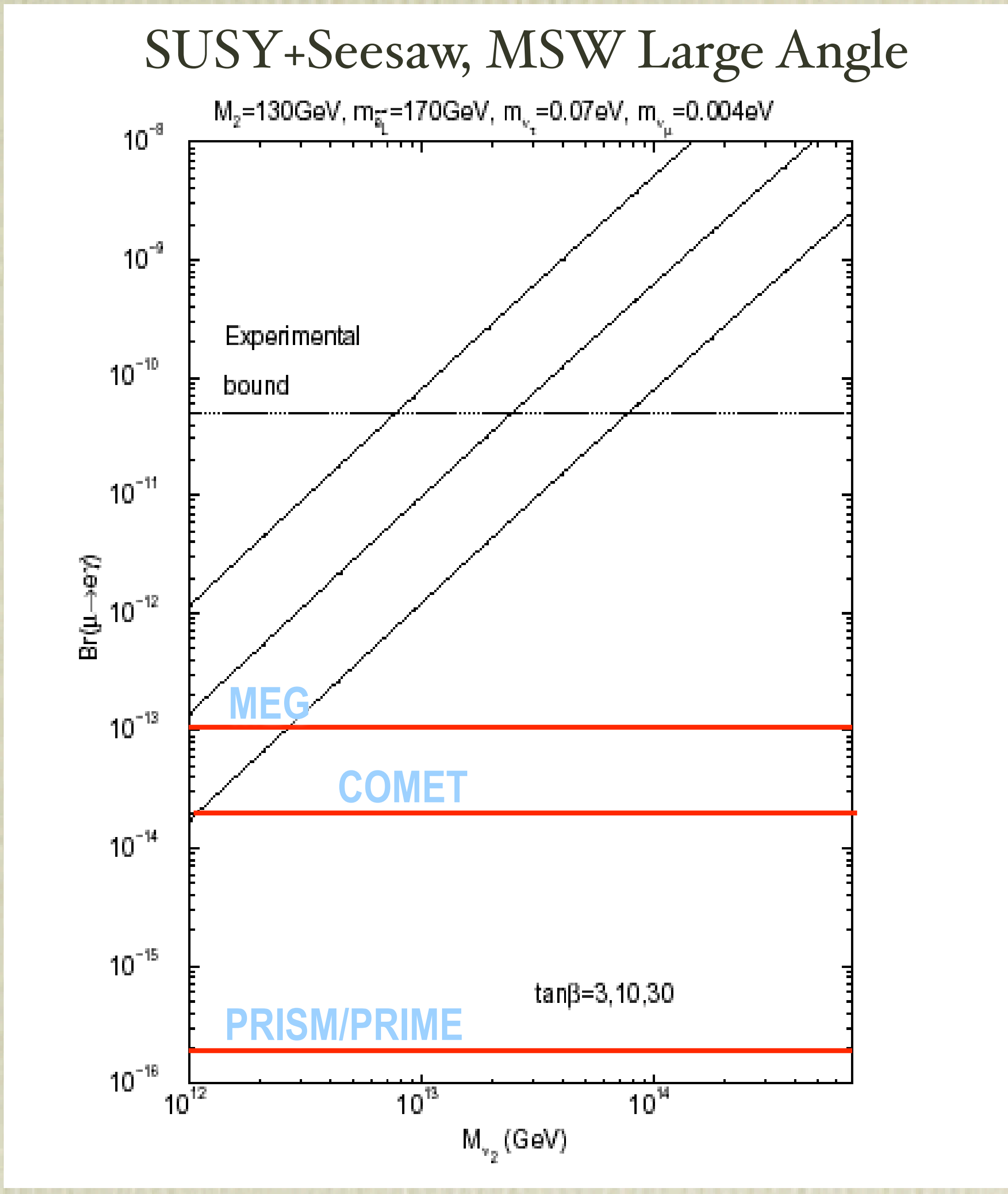
$$\begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} &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

slepton 質量行列の物理

理論的予想

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

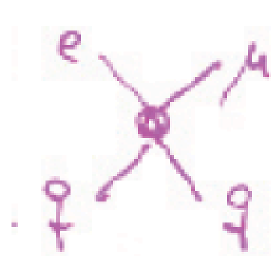


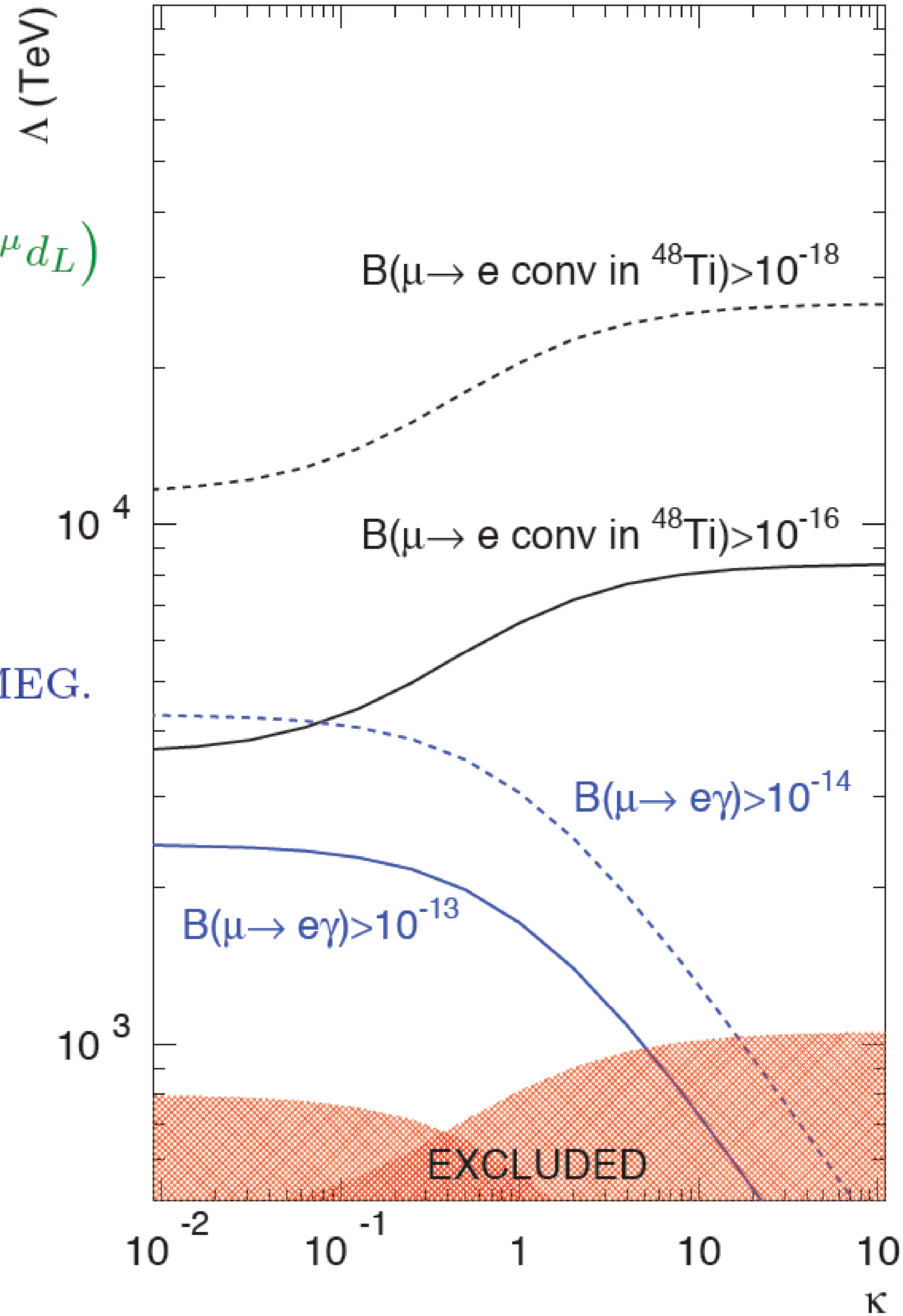


Model Independent Analysis

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

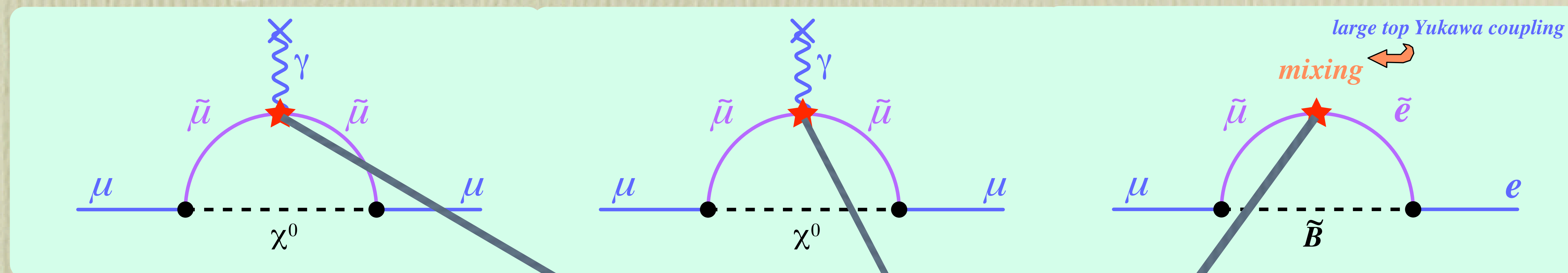
- $\mu\to e$-conv at 10^{-17} "guaranteed" deeper probe than $\mu\to e\gamma$ at 10^{-14}.
- We don't think we can do $\mu\to e\gamma$ better than 10^{-14}. $\mu\to e$-conv "only" way forward after MEG.
- If the LHC does not discover new states $\mu\to e$-conv among very few process that can access 1000+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





Golden Trio

g-2 | EDM | c-LFV



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

Physics Capabilities

J-PARC PAC report

The PAC is impressed with the physics capabilities of the proposed COMET experiment and believes that this experiment could become one of the flagship experiments in the J-PARC program.

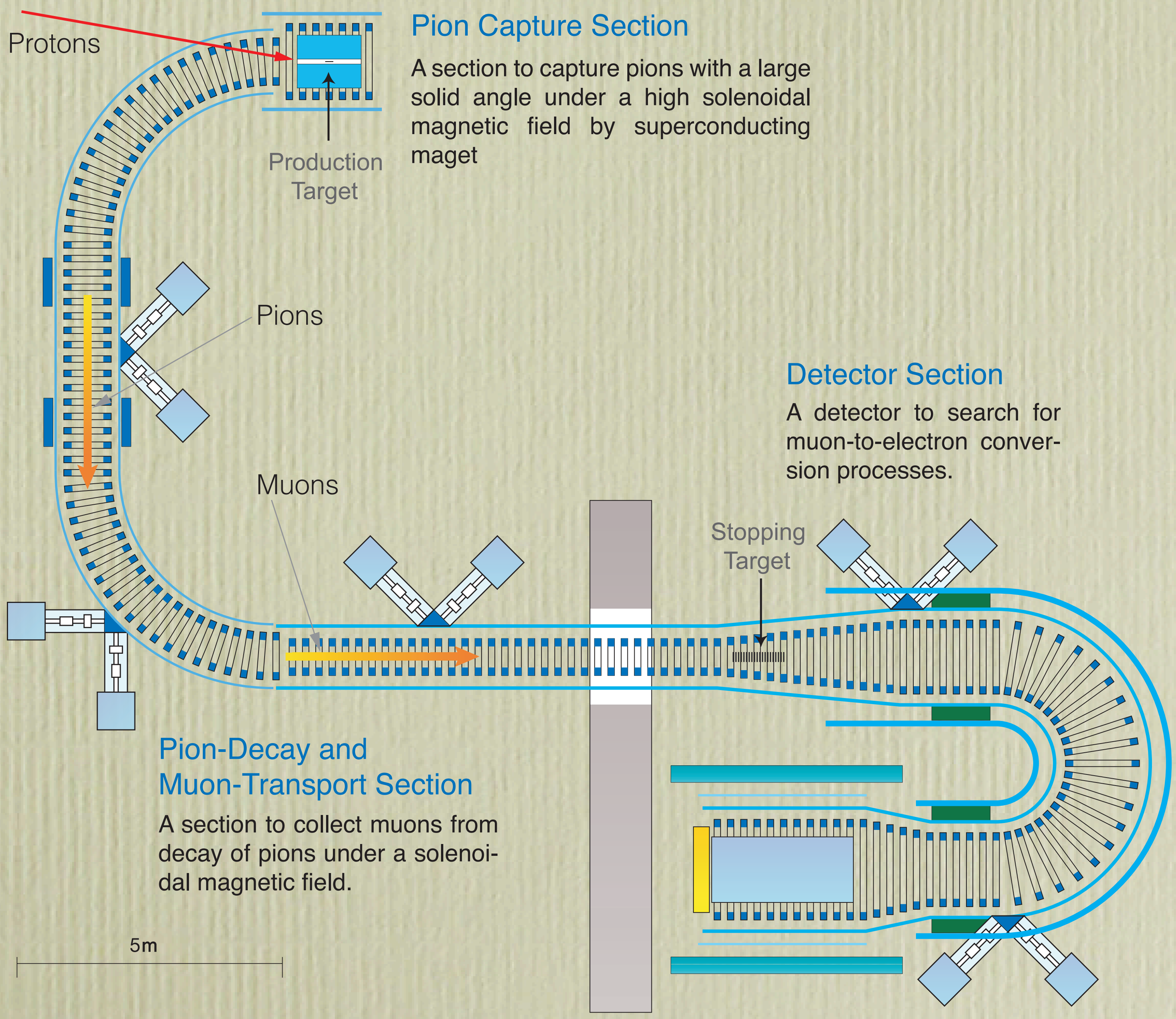
US P5 Report

US Particle Physics:
Scientific Opportunities
A Strategic Plan
for the Next Ten Years

Report of the Particle
Physics Project
Prioritization Panel

The panel recommends pursuing the muon-to-electron conversion experiment, subject to approval by the Fermilab PAC, under all budget scenarios considered by the panel. The intermediate budget

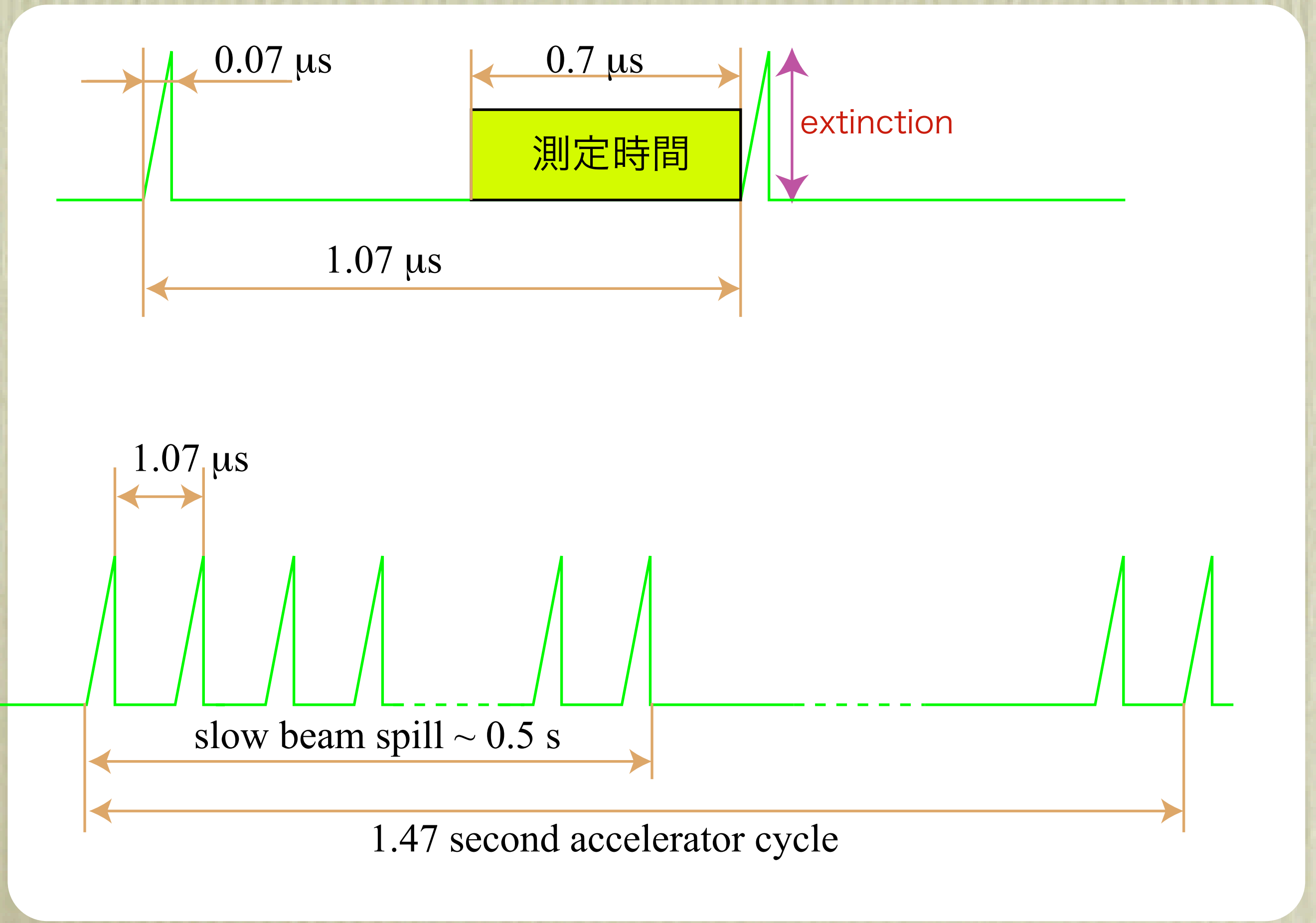
COMET Overview



- Pulsed Proton Beam
  - π-b.g. suppression
  - J-PARC/MR
- 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)
- Curved-solenoid detector
  - Lower detector rate
- Upgradability to PRISM
  - add Phase-Rotator-Ring

パルス陽子ビーム

- バックグランド
  - $\pi^- + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$,　$\gamma \rightarrow e^+ e^-$　：一次陽子ビームに同期
  - μ^- decay-in-flight, e^- scattering, neutron streaming
- 信号
  - $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$：遅延 (~1μs)



$N_{bg} = N_P \times R_{ext} \times Y_{\pi/P} \times A_\pi \times P_\gamma \times A$

N_P : total # of protons (~10^{21})

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

$Y_{\pi/P}$: 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)

$BR = 10^{-16}$, $N_{bg} < 0.12$

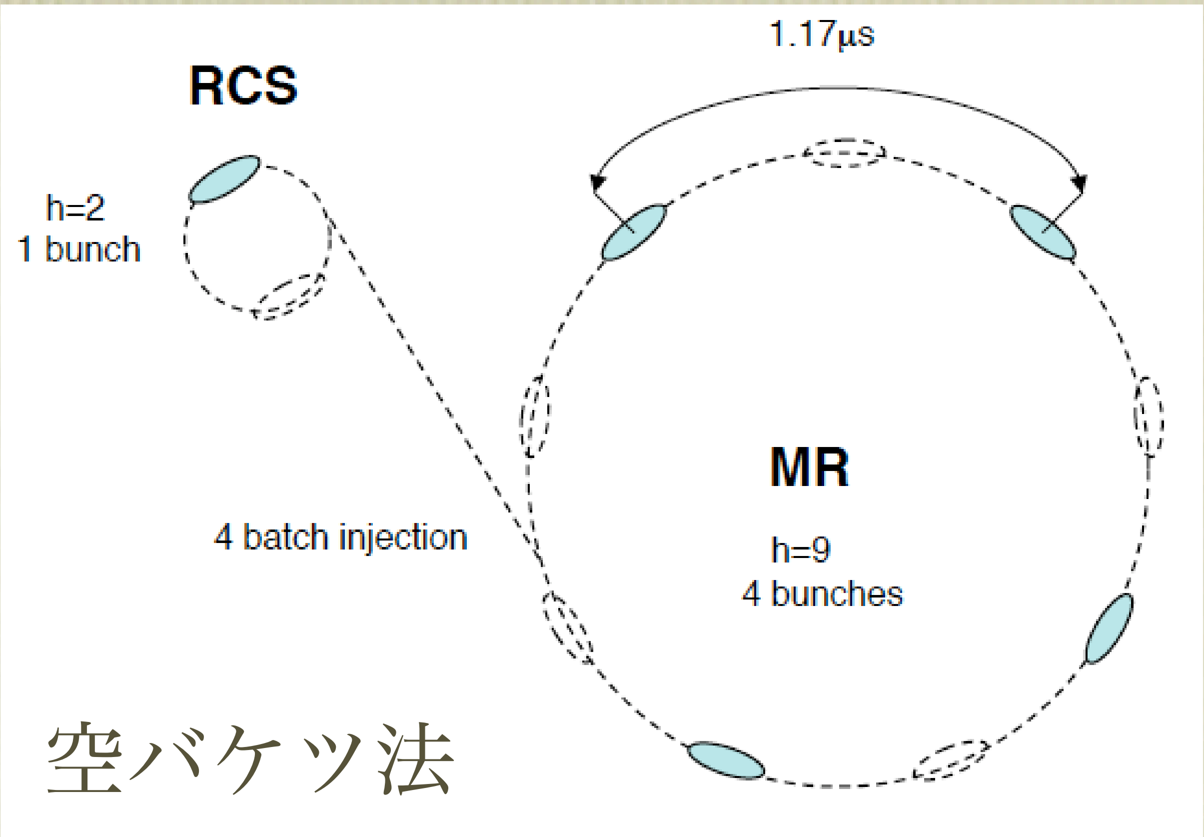
⇔ Extinction < 10^{-9}

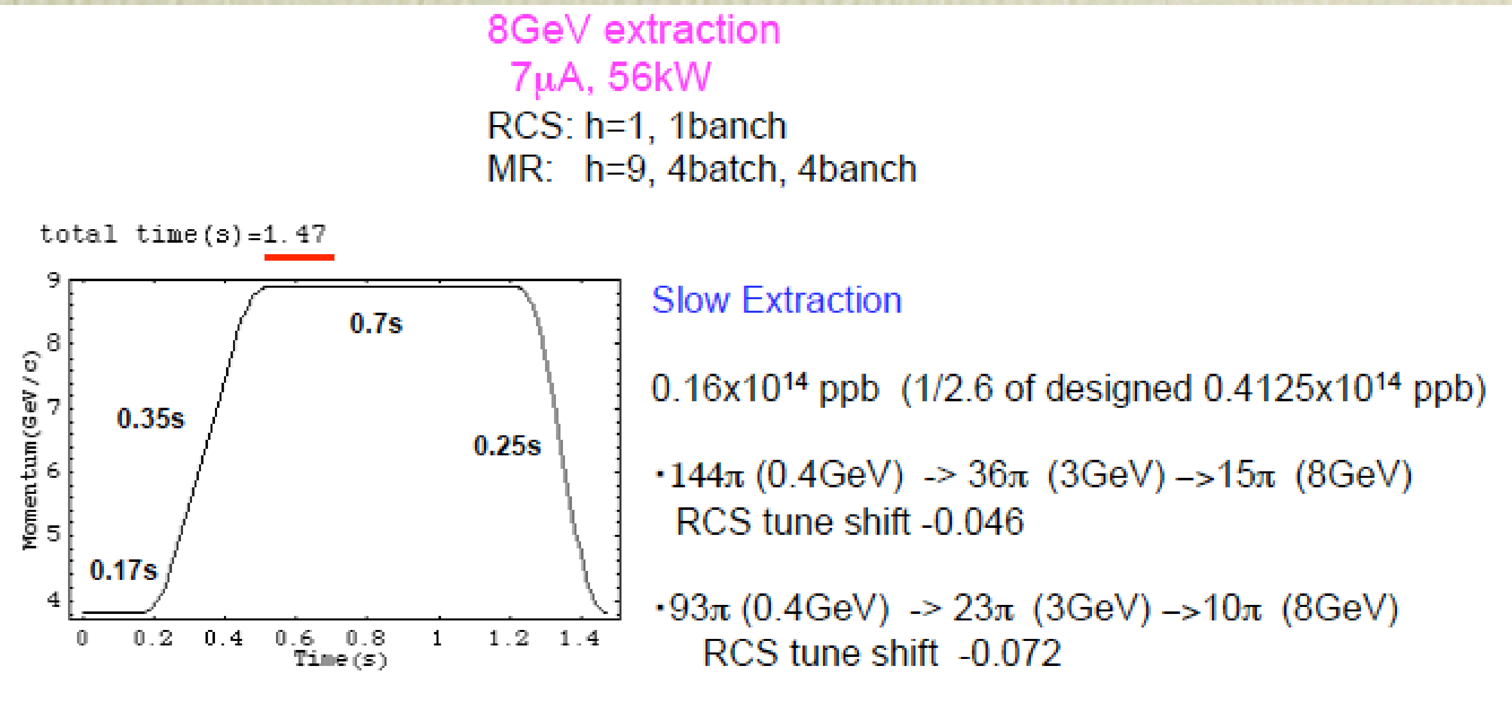
パルス陽子 from J-PARC/MR

Tomizawa Scheme

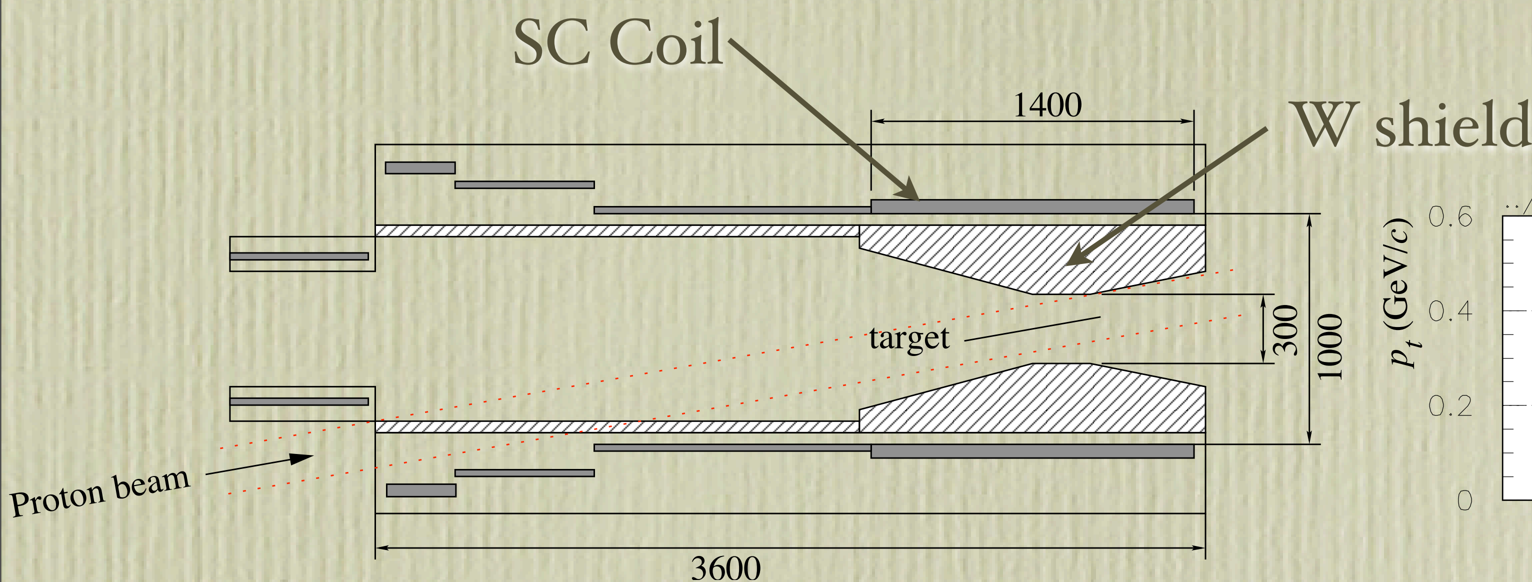
- 8 GeV, 7 μA
- Beam Pulsing
  - Empty bucket Scheme
  - Bunched Slow Extraction
- Beam Emittance
  - V: Reduce RCS painting area
  - Reduce N_P in a bunch: small space charge effect
  - H: SX < 5π mm.mrad
- Proton Yield
  - High Repetition Rate

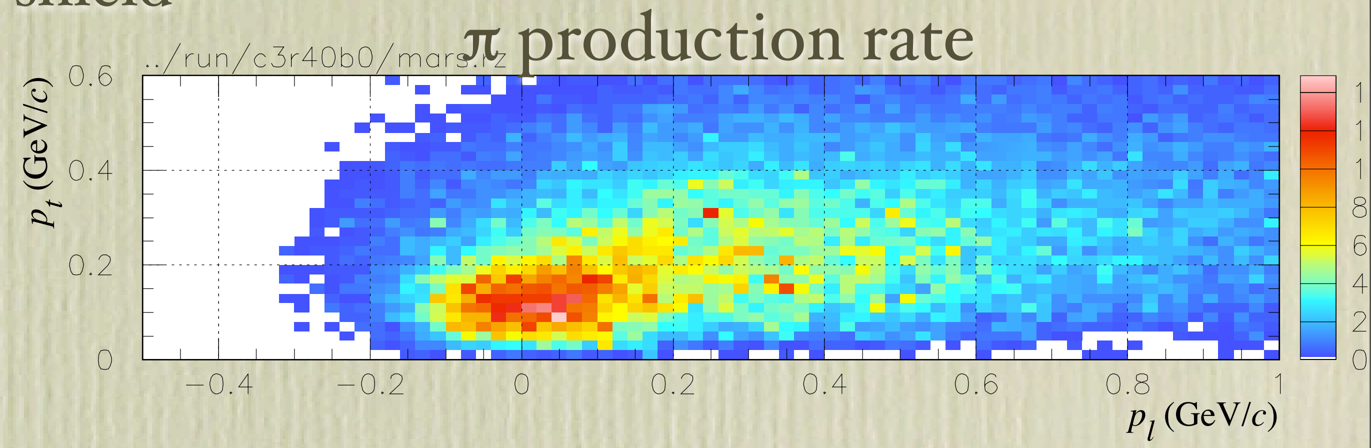
Extinction: < 10^{-9}
Power: 60 kW (4×10^{13} pps@8 GeV)

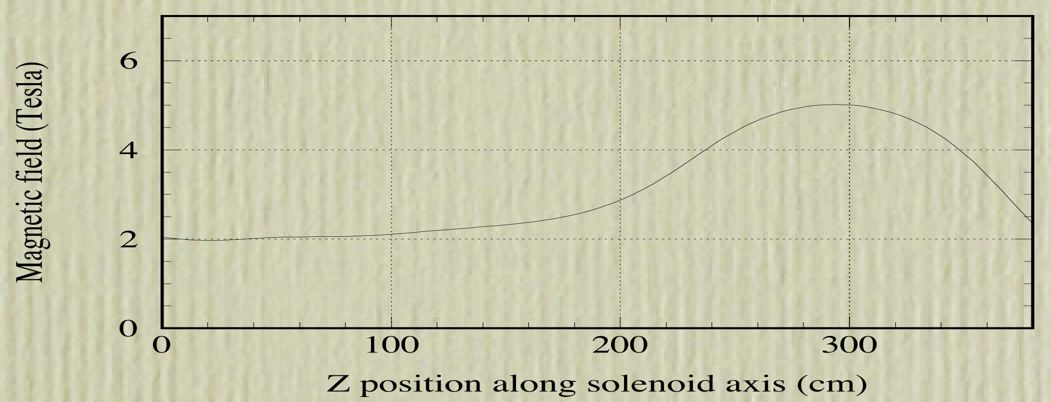


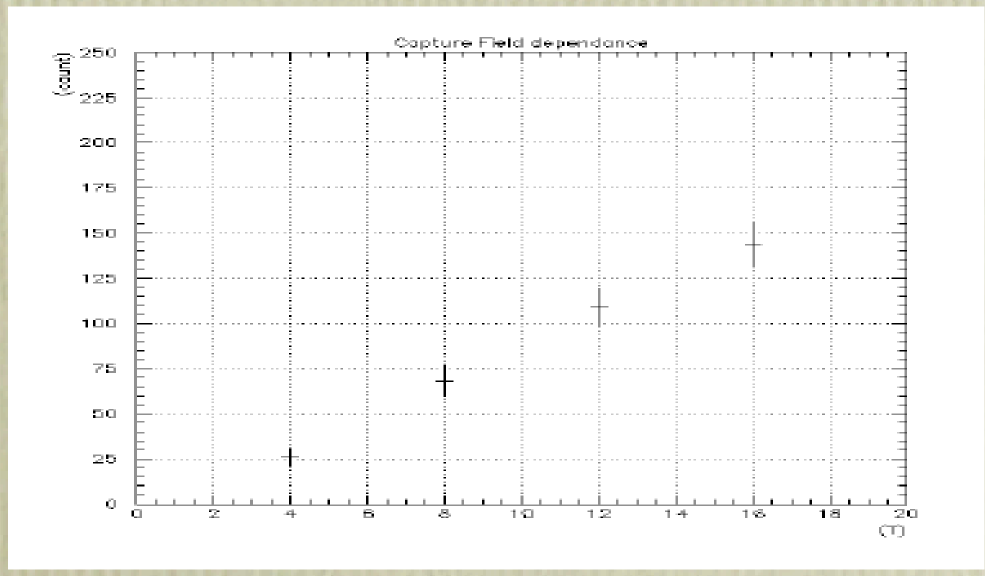


Pion Capture









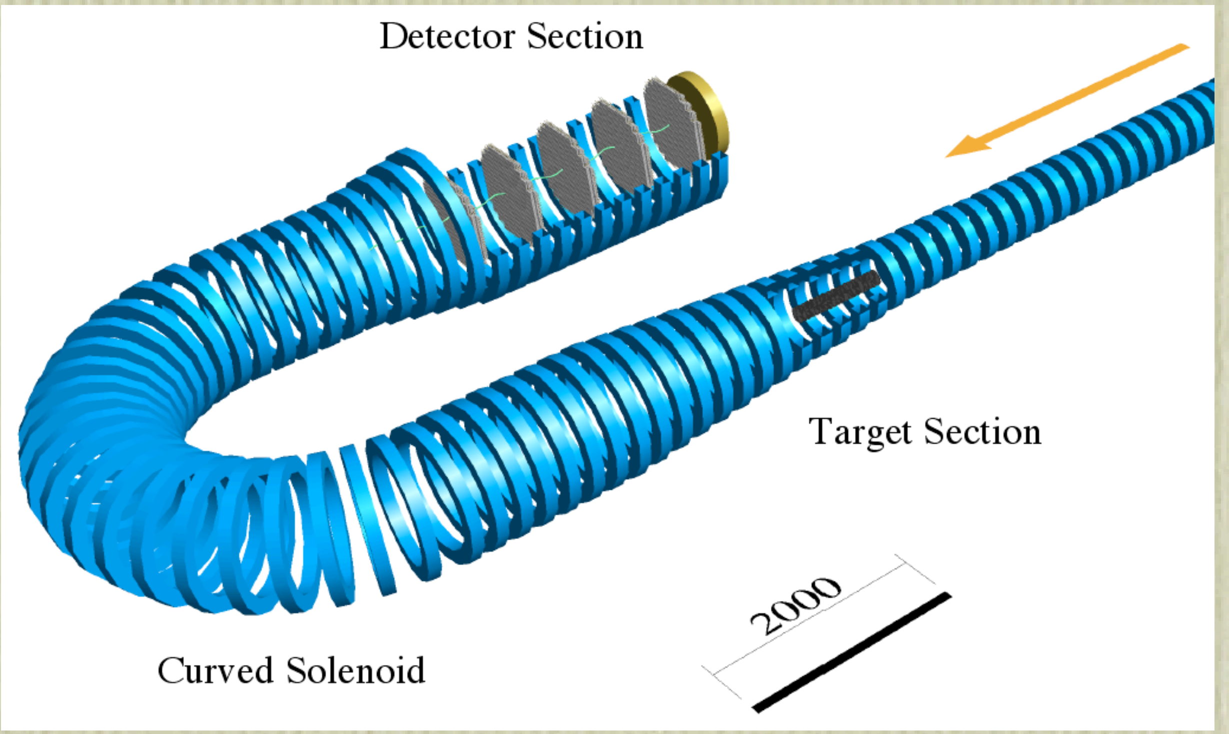
μ-yield vs. B_{max}

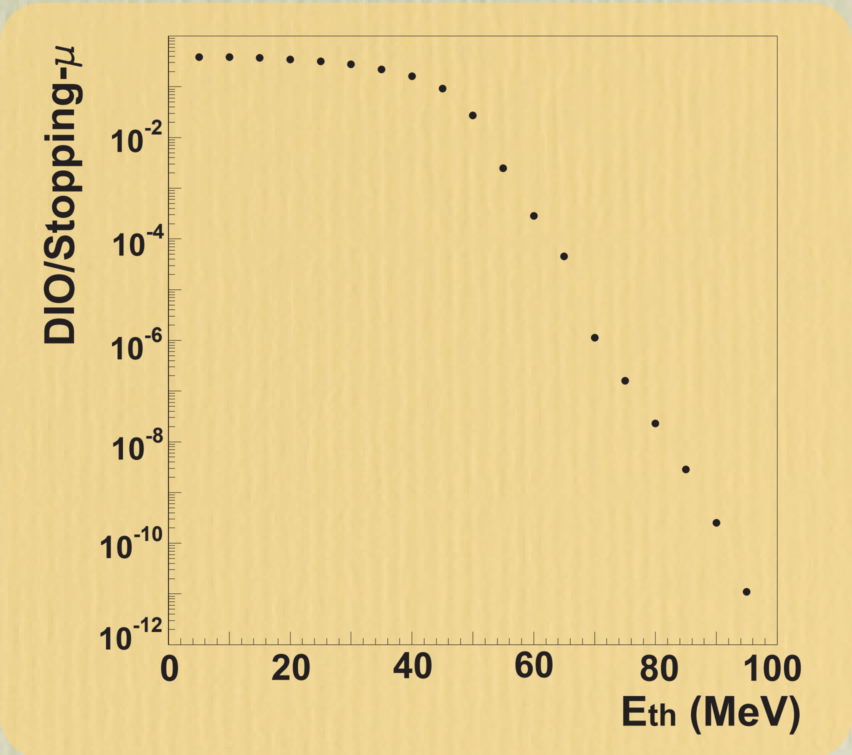
- Tungsten Target
  - 16cm × 0.8cm$^\phi$
  - water or radiation cooling
- ΔE@Target: 3-4 kW
- yields

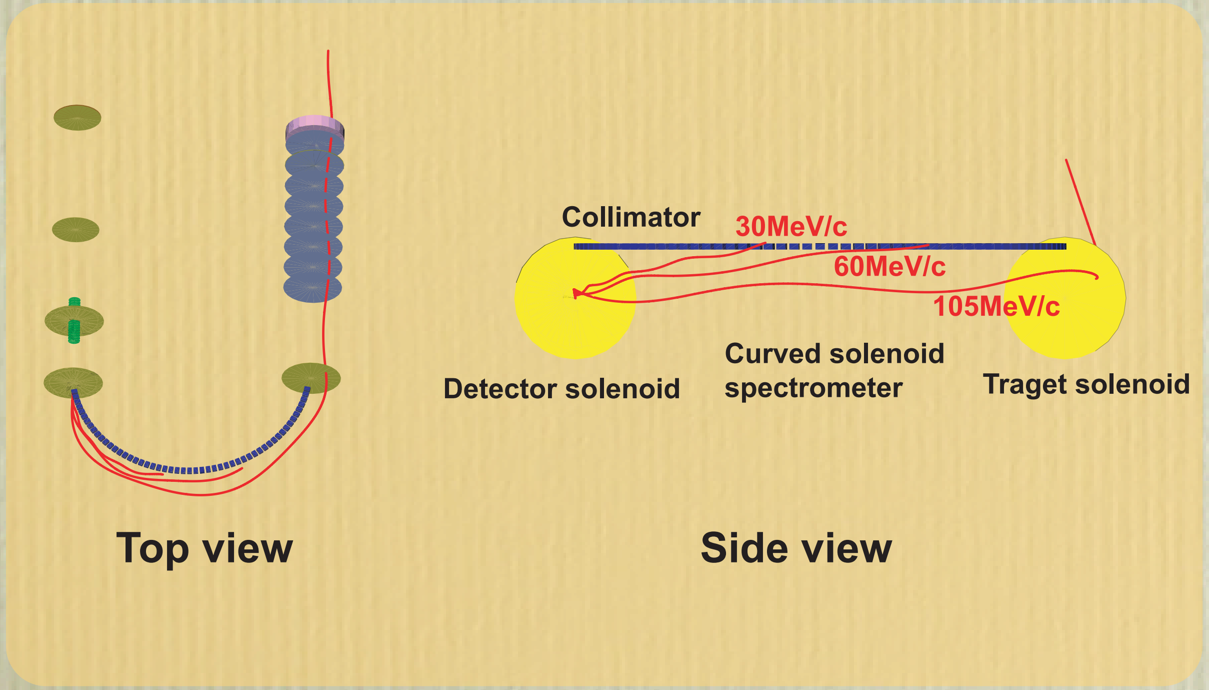
  0.002 stopping-μ^-/proton

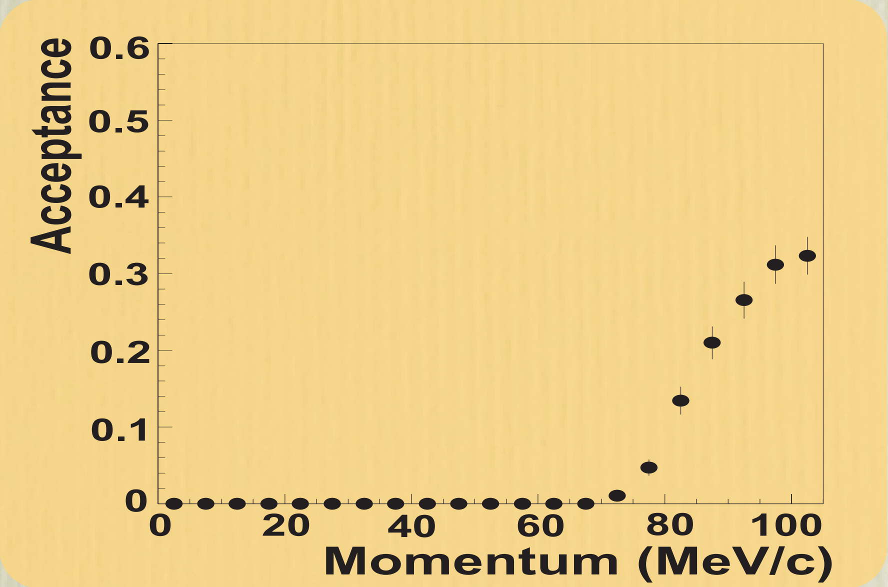
(M. Yoshida)

Curved Solenoid Spectrometer







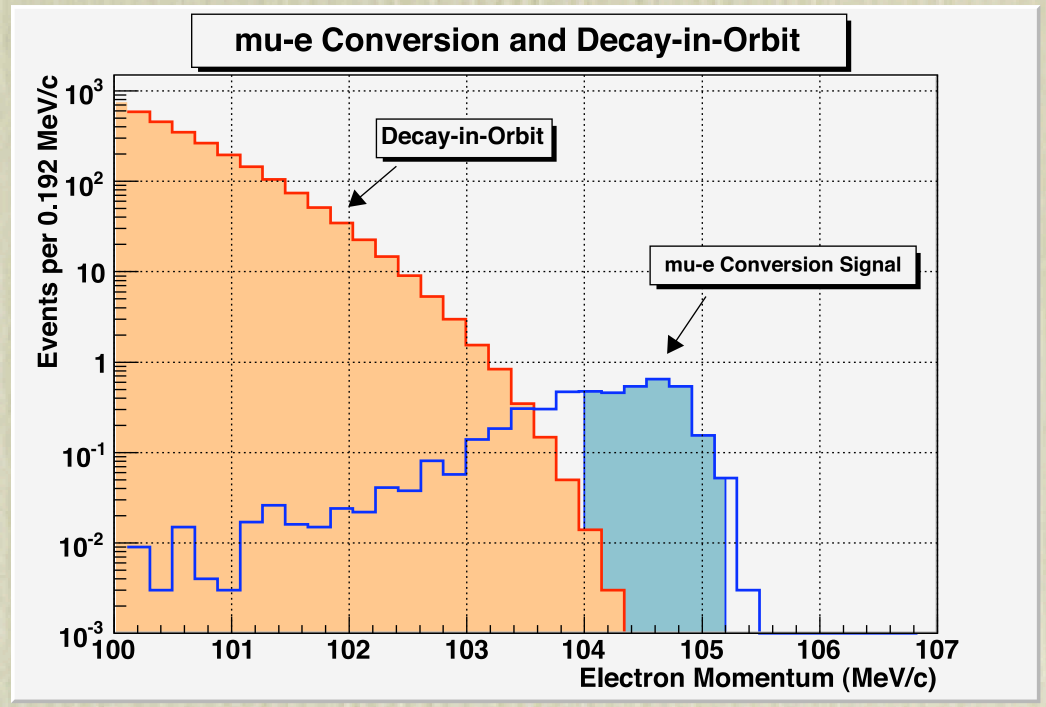


Transmission efficiency

Detector Acceptance & Signal Sensitivity

	Acceptance
Geometrical Acc.	0.73
Electron Transport	0.44
$p_t > 52$ MeV/c	0.67
χ^2 Cut ($\chi^2 < 9$)	0.86
Energy Selection	0.56
Timing cut	0.38
Total	0.04

Proton Intensity	4×10^{13} Hz
Running Time	2×10^{7} sec
μ's yields per proton	0.007
μ-stopping efficiency	0.26
Total	1.5×10^{18} stopped μ's

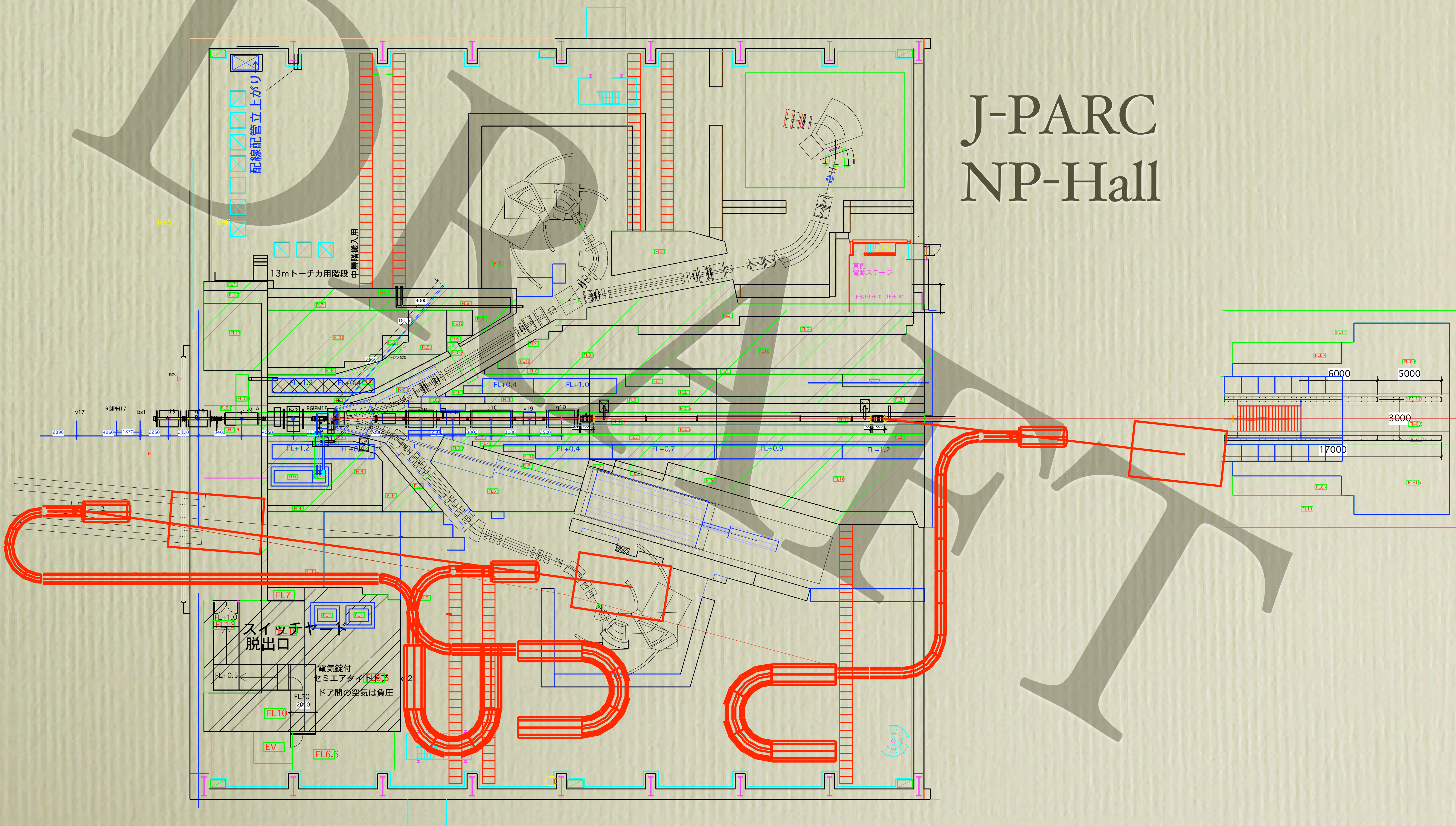


$$B(\mu^- + Al \to e^- + Al) = \frac{1}{N_\mu \cdot f_{\mathrm{cap}} \cdot A_e}$$

- $N_\mu = 1.5 \times 10^{18}$
- $f_{cap} = 0.6$ for Aluminum
- $A_e = 0.04$
- $B(\mu^- + \mathrm{Al} \to e^- + \mathrm{Al}) = 2.8 \times 10^{-17}$
  $< \underline{5 \times 10^{-17}\ (90\%\ \mathrm{C.L.})}$

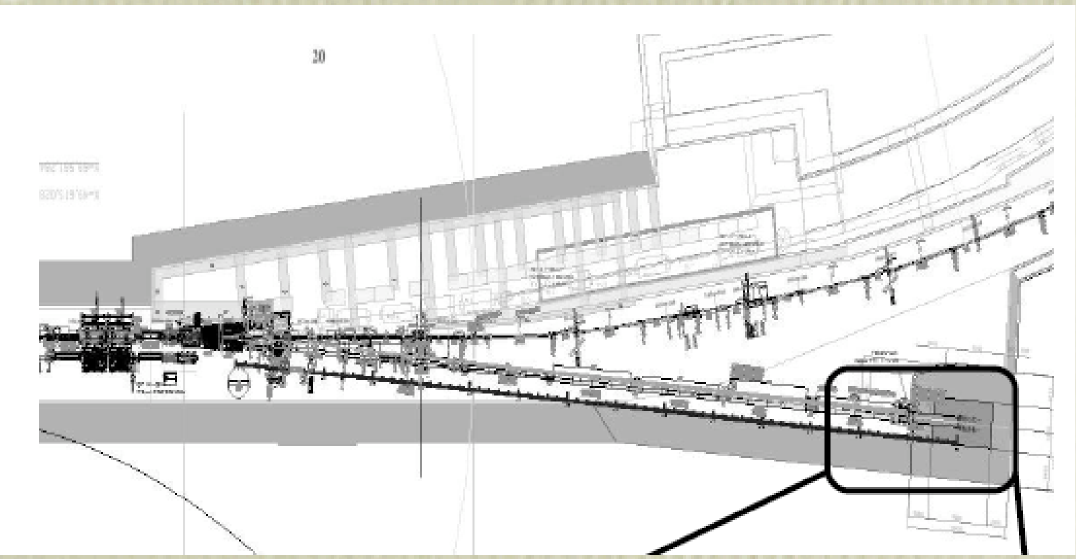
(Still) Straw-man's Layouts

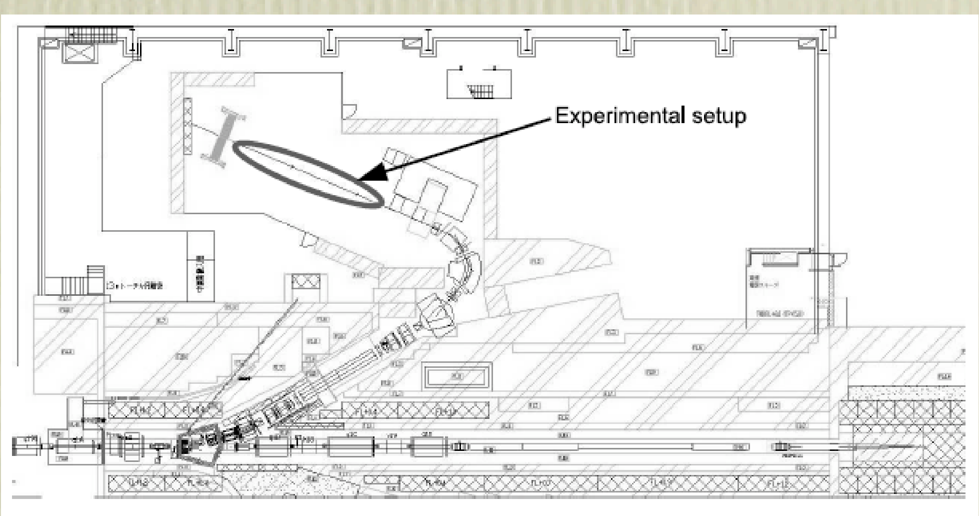
J-PARC
NP-Hall



Recent Activities

- muon task force (chaired by S. Mihara)
  - to address charges given by PAC
- J-PARC/MR extinction study
  - pulsed FX measurement: MR abort line
  - pulsed SX measurement: K1.8BR

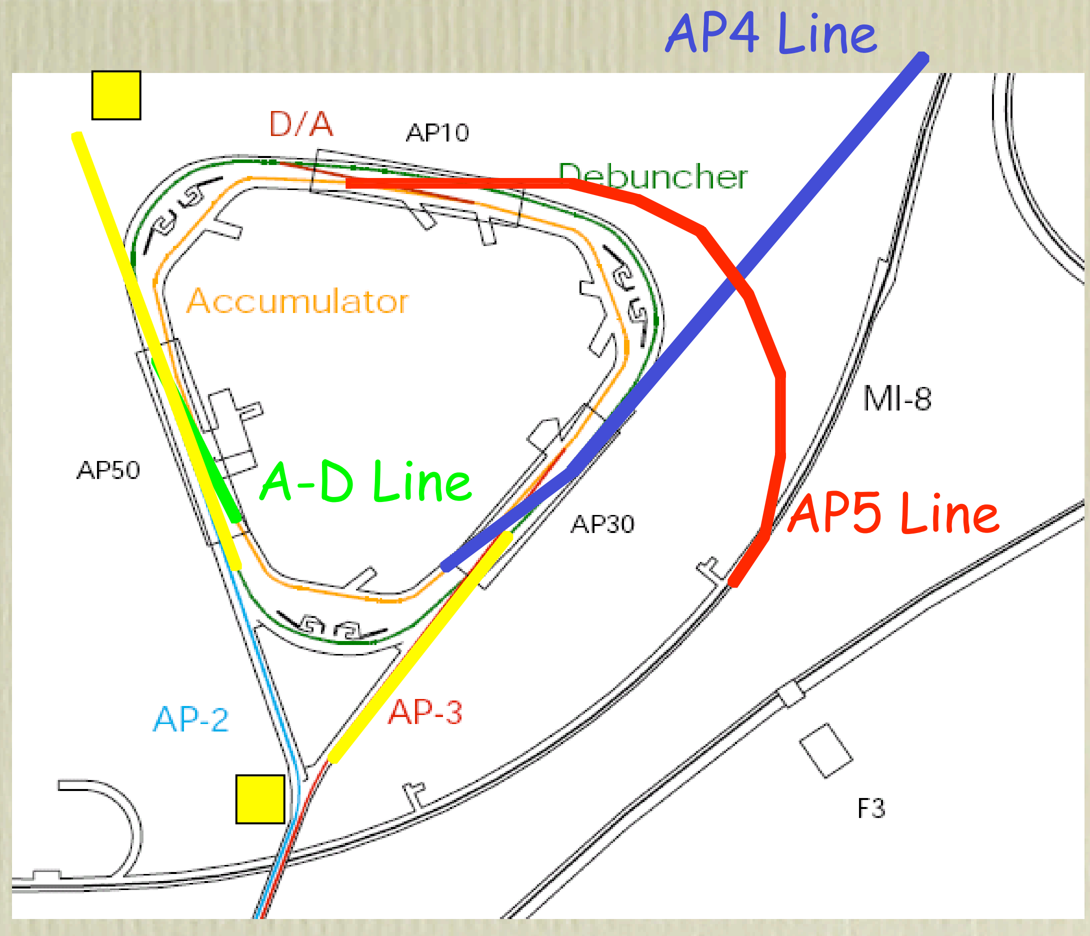


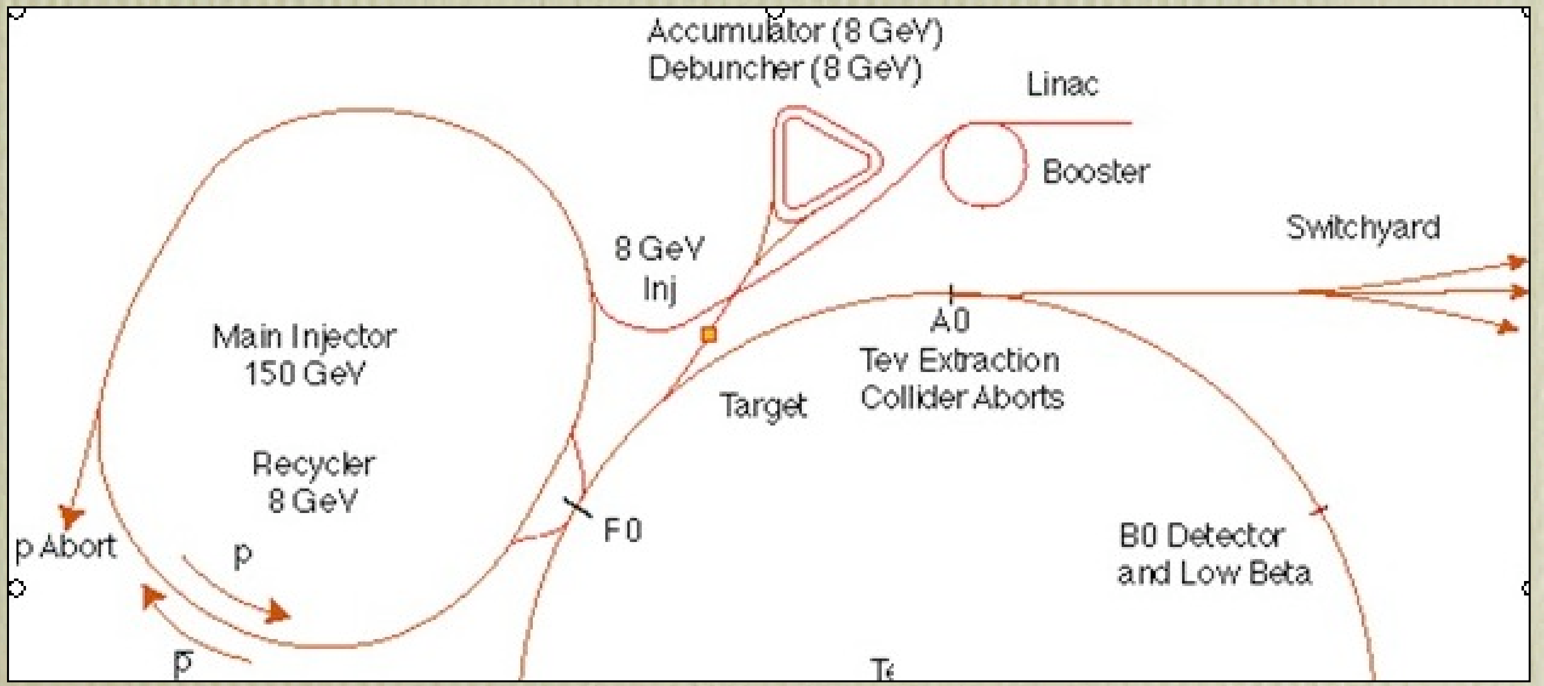


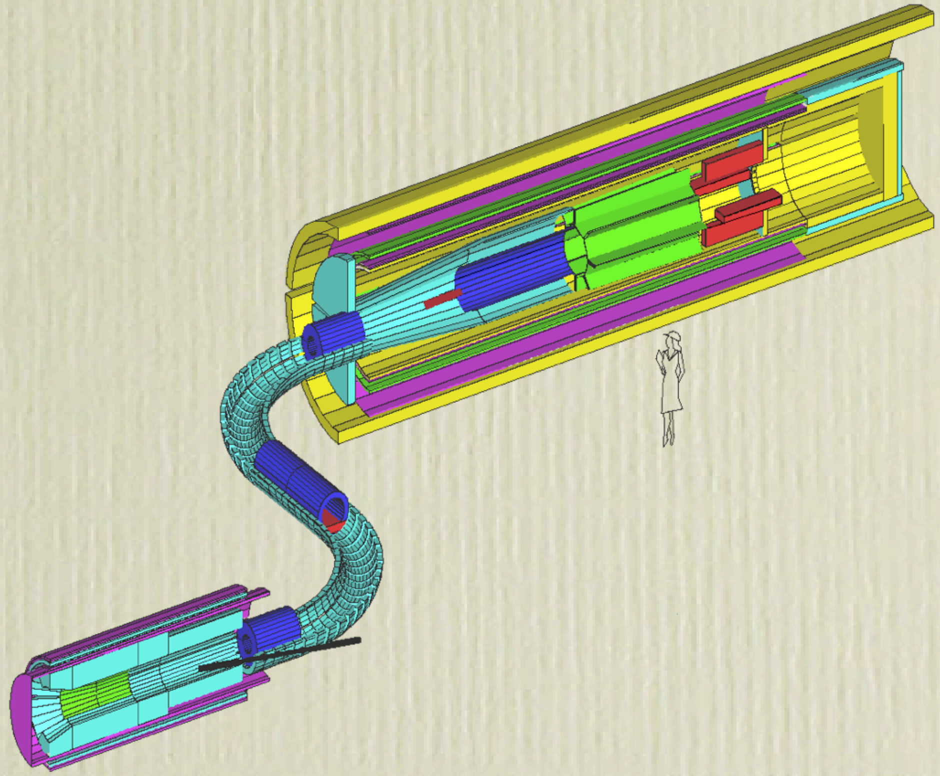
- COMET location study

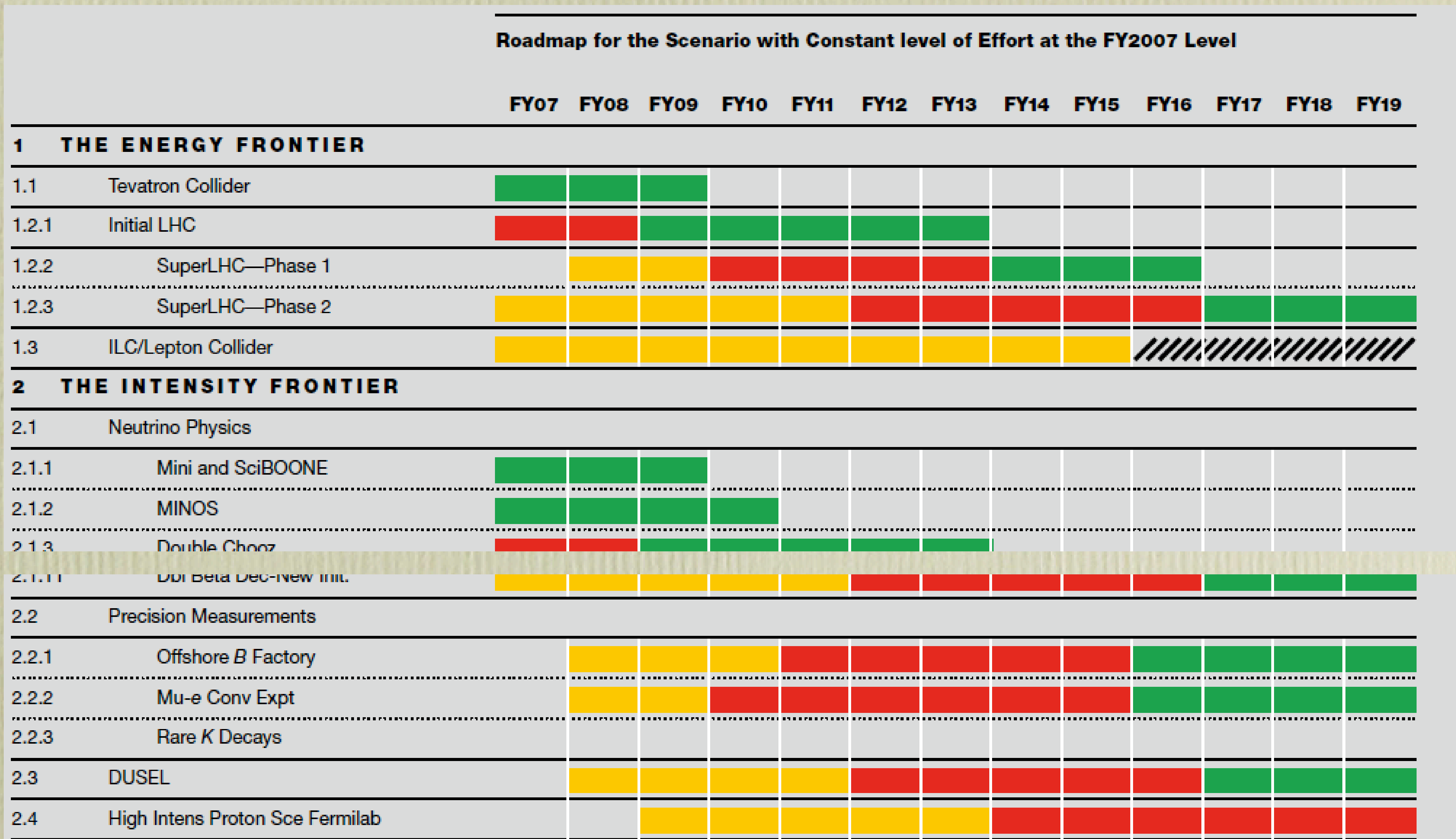
mu2e @Fermilab

- mu2e(FNAL + xMECO)
  - Revive of MECO
  - After the shutdown of Tevatron
  - Parasite on SNuMI-2
    - 2012 ~
  - Renovate a Debuncher ring for beam bunching
- Single Event Sensitivity: 2×10^{-17}








Roadmap for the Scenario with Constant level of Effort at the FY2007 Level
FY07 FY08 FY09 FY10 FY11 FY12 FY13 FY14 FY15 FY16 FY17 FY18 FY19
1 THE ENERGY FRONTIER
1.1 Tevatron Collider
1.2.1 Initial LHC
1.2.2 SuperLHC—Phase 1
1.2.3 SuperLHC—Phase 2
1.3 ILC/Lepton Collider
2 THE INTENSITY FRONTIER
2.1 Neutrino Physics
2.1.1 Mini and SciBOONE
2.1.2 MINOS
2.1.3 Double Chooz
2.2 Precision Measurements
2.2.1 Offshore B Factory
2.2.2 Mu-e Conv Expt
2.2.3 Rare K Decays
2.3 DUSEL
2.4 High Intens Proton Sce Fermilab

まとめ

- μ-e電子転換過程は標準理論を越えたc-LFV過程の一つであり、TeVスケールの物理を研究する為の重要な手段を提供する。
- 10^{-16}まで探索すればイベントが見つかるかもしれない。
- MEG(μ→eγ 探索@ PSI)とは相補的である。
- COMET
  - BR=10^{-16} で μN→eN を探索する実験
  - J-PARC/MRとハドロンホールを活用
- Fermilab/mu2eとCOMETの競争
- muon-TF (chaired by S. Mihara)
  - extinction study
  - location study

End of Slides