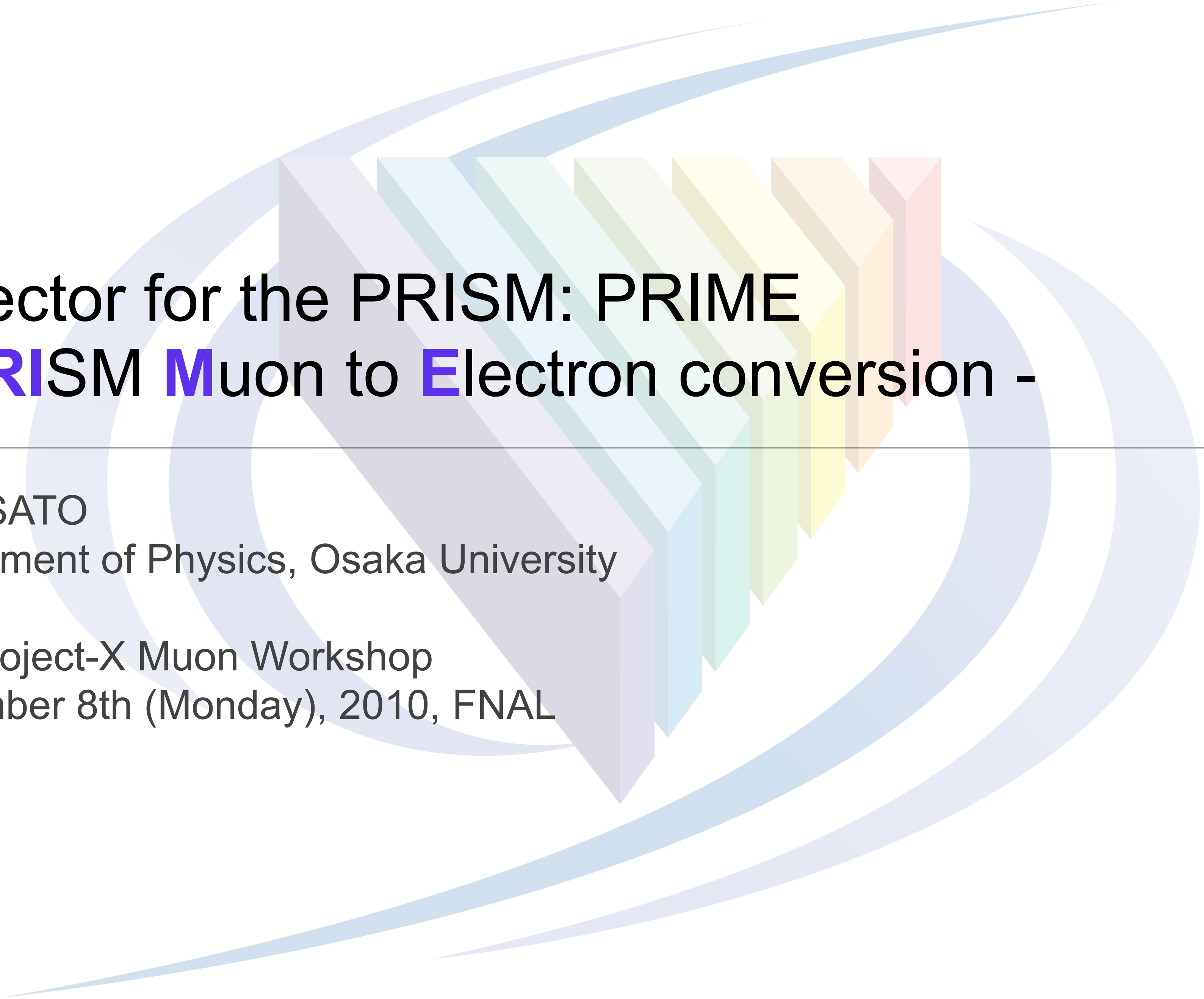
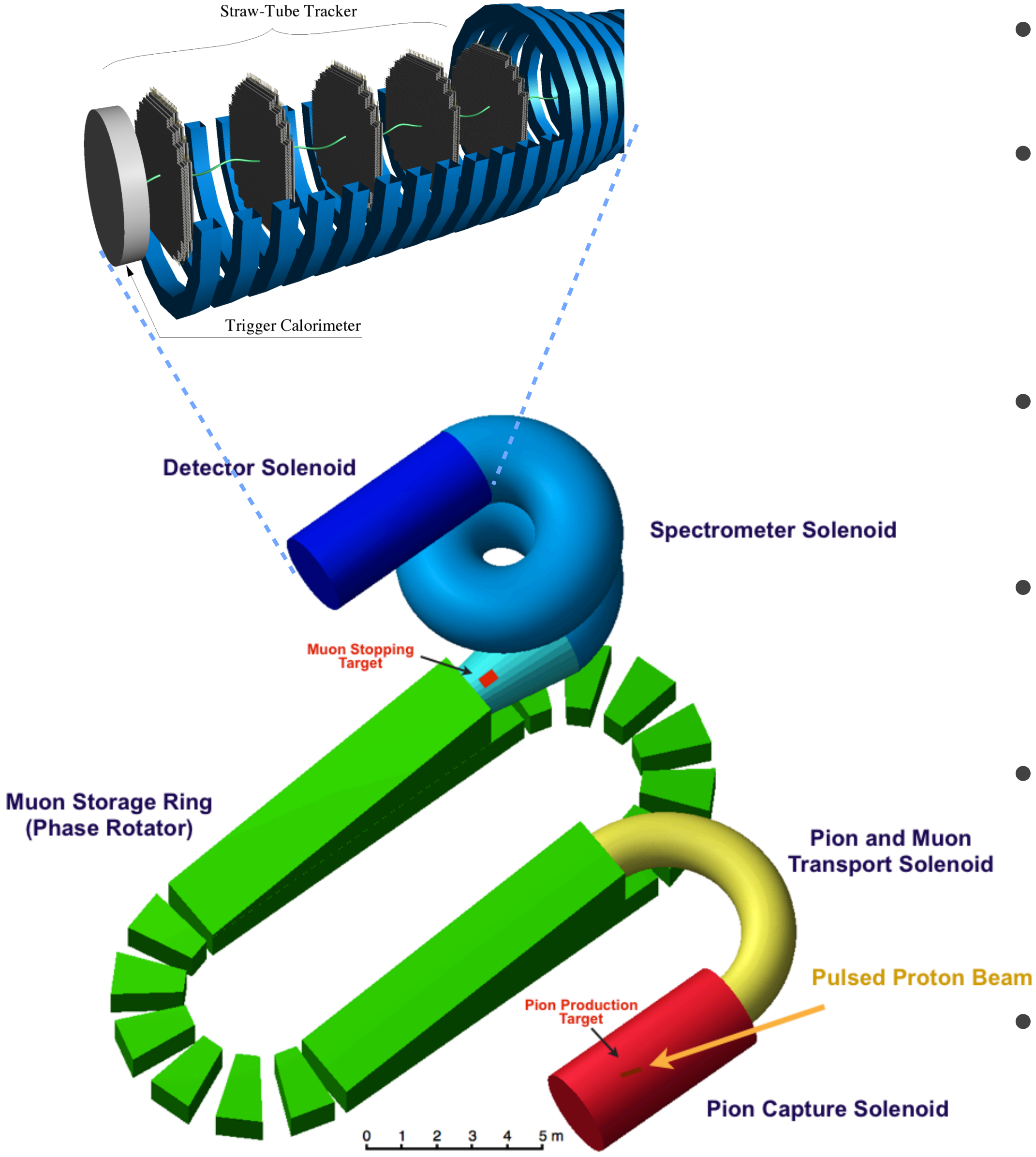


Detector for the PRISM: PRIME
- **PRI**SM **M**uon to **E**lectron conversion -

Akira SATO
Department of Physics, Osaka University

The Project-X Muon Workshop
November 8th (Monday), 2010, FNAL

PRIME: from stopping targets to detectors



- **Thin Stopping Targets**
  - due to mono-energetic muons
- **Graded Field at Muon Target Solenoid**
  - To maximize transmission efficiency of the curved solenoid.
- **Curved Solenoid**
  - To suppress low momentum electrons.
- **Low Mass Tracker**
  - to be transparent to γ's.
  - f < 1 MHz
- **Electron Calorimeter**
  - Trigger
  - Cosmic Muon suppression
  - f < 1 MHz
- **No Time Window**
  - pure muon beam
  - + curved solenoid

Introduction

- The parameters of muon beam for the PRISM would have many advantages.
  - ex). **Thinner stopping target** to get better electron energy resolution.
- but also would make a very high instantaneous detector hit rate R_{inst}.
- Rough estimation
  - R_{inst}
    - $= 2\times10^{12}\mu/s / 10^{3}pulse/s / 10^{-6}/s$
    - $=\sim10^{15}Hz$
  - Detector cannot work!
- We use a **Spiral Solenoid Spectrometer** to suppress the instantaneous rate.

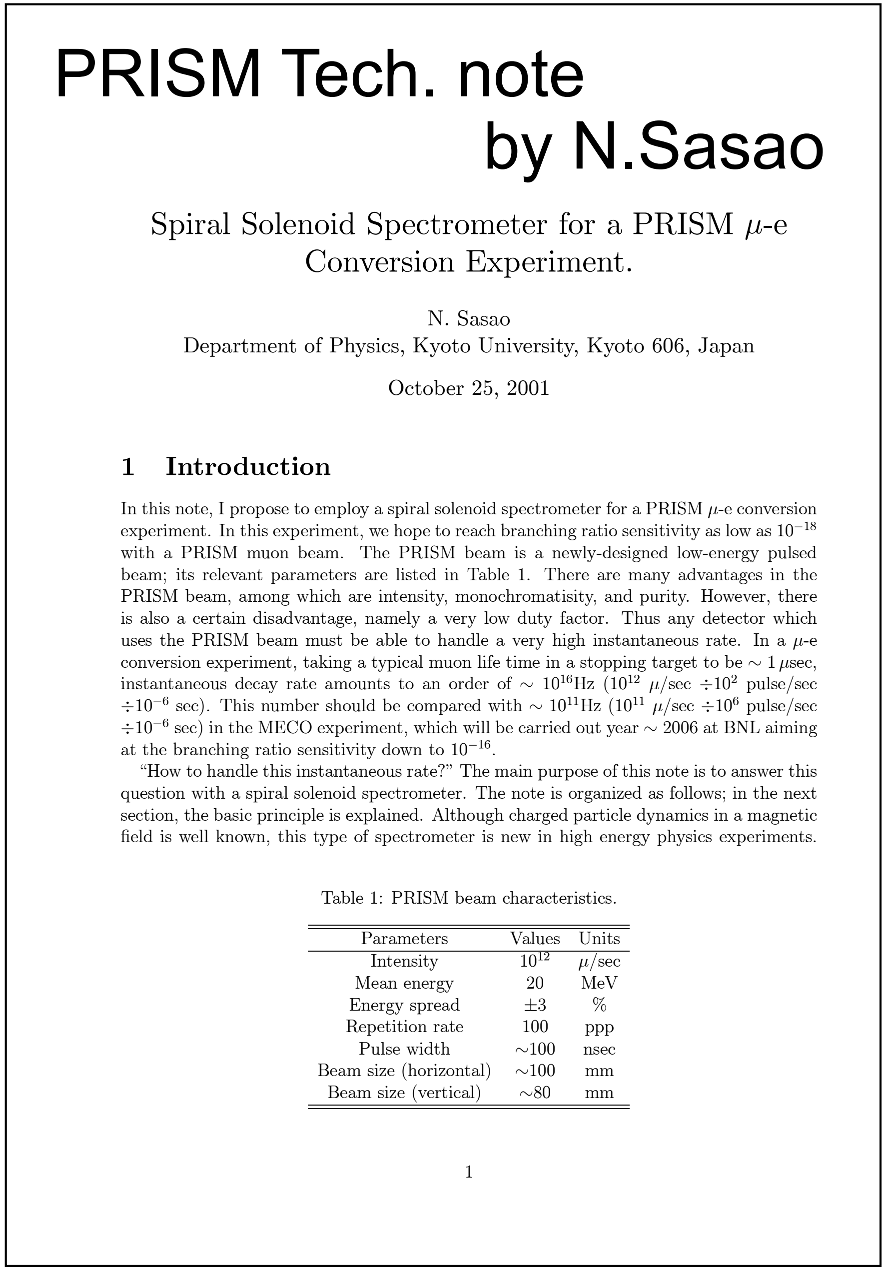
Muon beam param. in this study

Muon intensity	2×10^{12}	μ/sec
Mean momentum	68	MeV
Momentum spread	3	%
Rep. rate	1000	Hz
Pulse width	100	nsec
Beam size (H.)	~100	mm
Beam size (V.)	~80	mm

will be changed to 40MeV/c +- 3%

This talk shows a MC study for the stopping target and the spectrometer.

References of this talk



PRISM Tech. note
by N.Sasao

Spiral Solenoid Spectrometer for a PRISM μ-e Conversion Experiment.

N. Sasao
Department of Physics, Kyoto University, Kyoto 606, Japan

October 25, 2001

1 Introduction

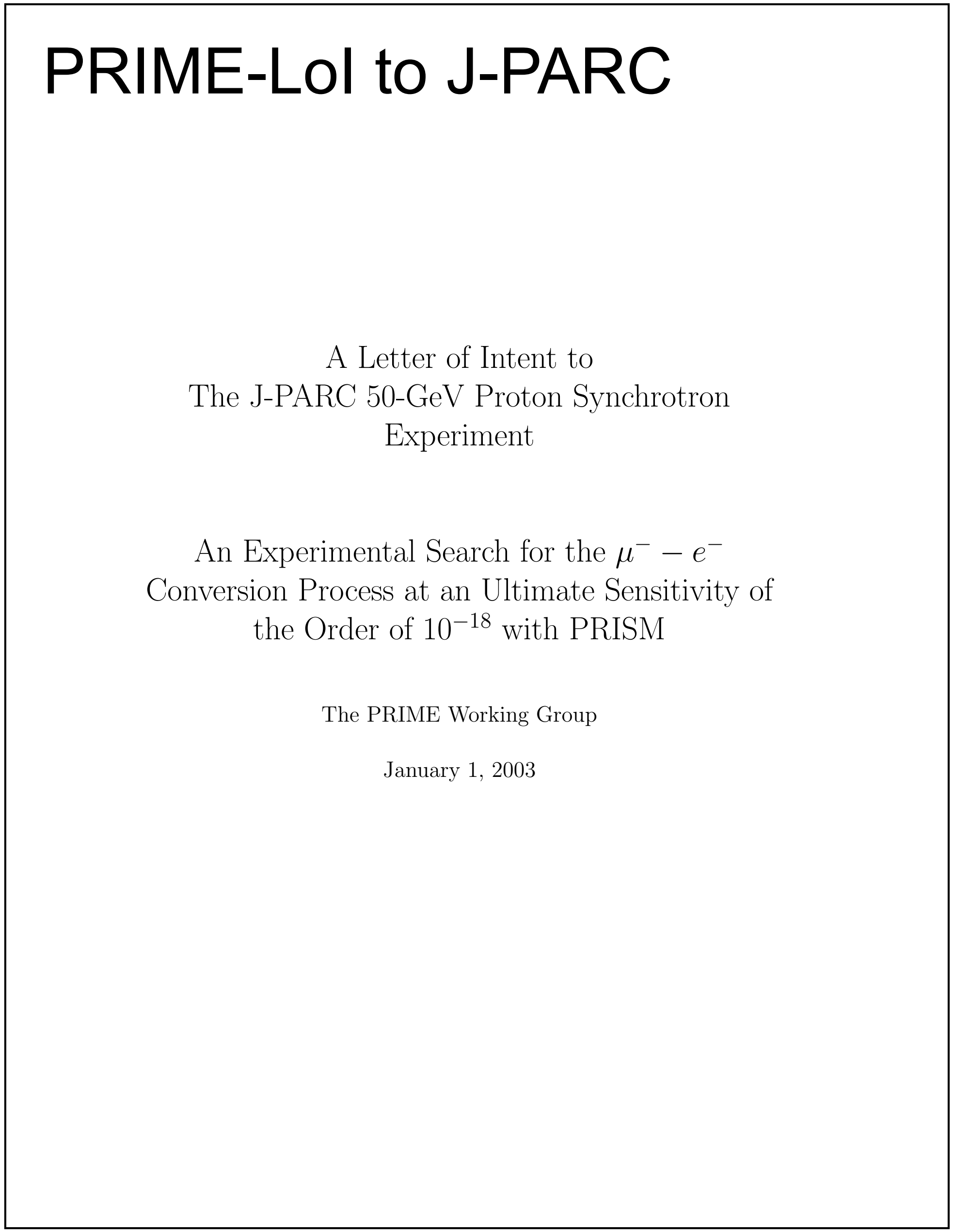
In this note, I propose to employ a spiral solenoid spectrometer for a PRISM μ-e conversion experiment. In this experiment, we hope to reach branching ratio sensitivity as low as 10^{-18} with a PRISM muon beam. The PRISM beam is a newly-designed low-energy pulsed beam; its relevant parameters are listed in Table 1. There are many advantages in the PRISM beam, among which are intensity, monochromatisity, and purity. However, there is also a certain disadvantage, namely a very low duty factor. Thus any detector which uses the PRISM beam must be able to handle a very high instantaneous rate. In a μ-e conversion experiment, taking a typical muon life time in a stopping target to be $\sim 1\,\mu$sec, instantaneous decay rate amounts to an order of $\sim 10^{16}$Hz (10^{12} μ/sec $\div 10^{2}$ pulse/sec $\div 10^{-6}$ sec). This number should be compared with $\sim 10^{11}$Hz (10^{11} μ/sec $\div 10^{6}$ pulse/sec $\div 10^{-6}$ sec) in the MECO experiment, which will be carried out year $\sim$ 2006 at BNL aiming at the branching ratio sensitivity down to 10^{-16}.

"How to handle this instantaneous rate?" The main purpose of this note is to answer this question with a spiral solenoid spectrometer. The note is organized as follows; in the next section, the basic principle is explained. Although charged particle dynamics in a magnetic field is well known, this type of spectrometer is new in high energy physics experiments.

Table 1: PRISM beam characteristics.

Parameters	Values	Units
Intensity	10^{12}	μ/sec
Mean energy	20	MeV
Energy spread	±3	%
Repetition rate	100	ppp
Pulse width	~100	nsec
Beam size (horizontal)	~100	mm
Beam size (vertical)	~80	mm

1



PRIME-LoI to J-PARC

A Letter of Intent to
The J-PARC 50-GeV Proton Synchrotron
Experiment

An Experimental Search for the $\mu^- - e^-$
Conversion Process at an Ultimate Sensitivity of
the Order of 10^{-18} with PRISM

The PRIME Working Group

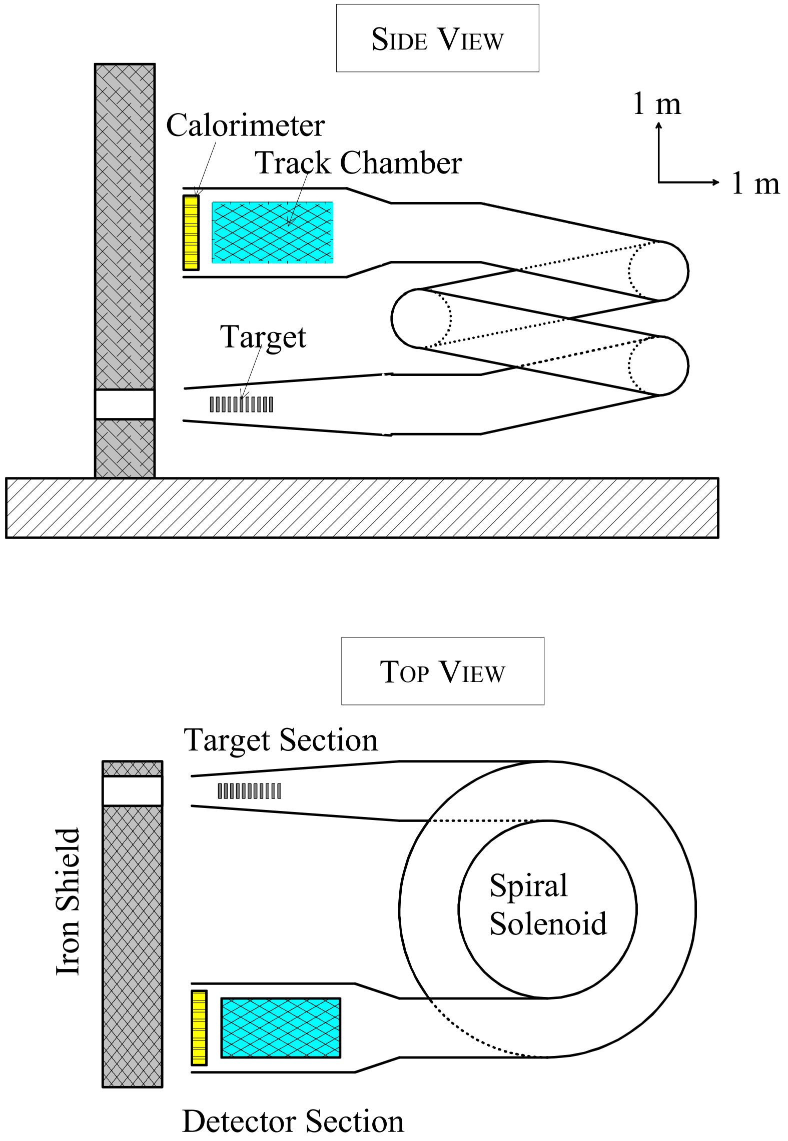
January 1, 2003

http://www-ps.kek.jp/jhf-np/LOIlist/pdf/L25.pdf

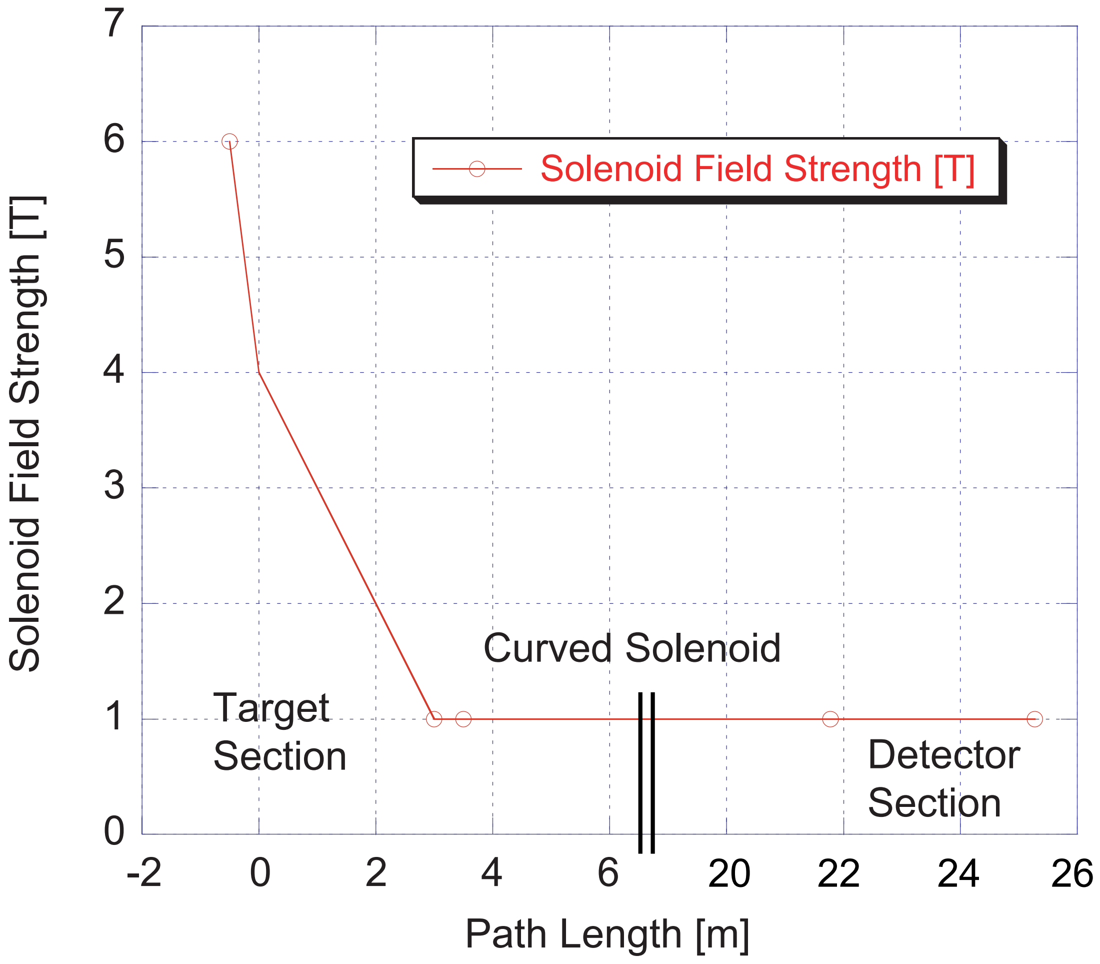
Layout and Magnetic Field in This Study

- 540 deg. spiral solenoid for the electron spectrometer.
  - cf. COMET has a 180 deg solenoid for the spectrometer.

Spiral Solenoid Spectrometer for PRISM



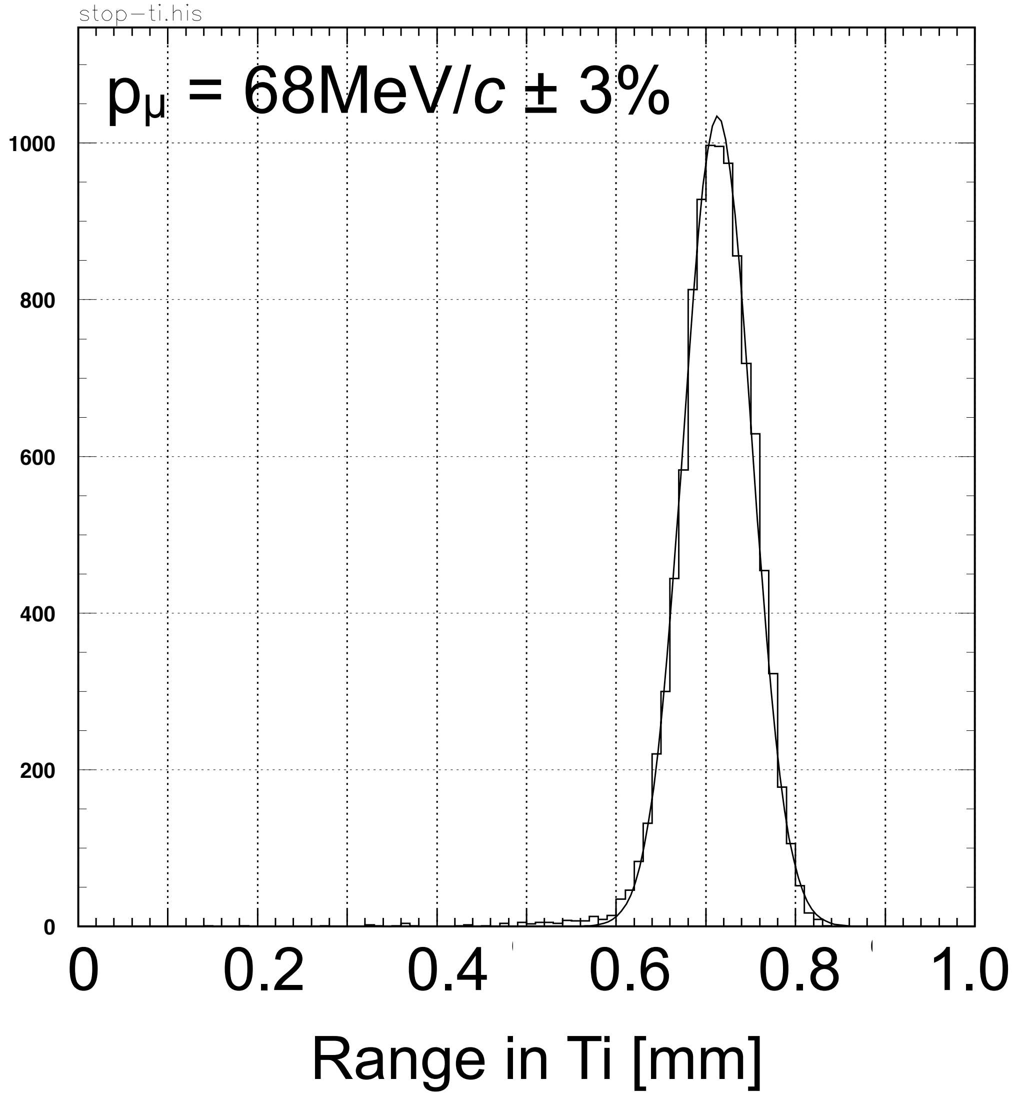
Magnetic Field Configuration



Muon Stopping Targets

for the narrow energy spread muon beam

Muon Stopping Target:

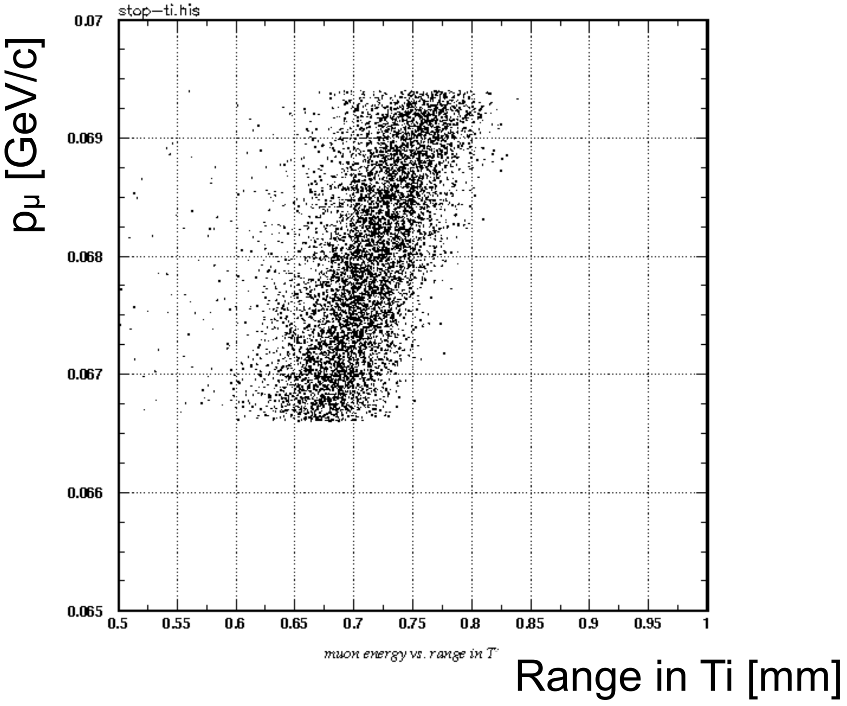


σ_{range}=38μm

It is dominated by momentum distribution.

Ti target of 1mm is enough to stop muons.

If the performance of phase rotation at PRISM gets better, there is still a room to get a muon-stopping target thinner by a factor of two at most (to about 500 μm full width).

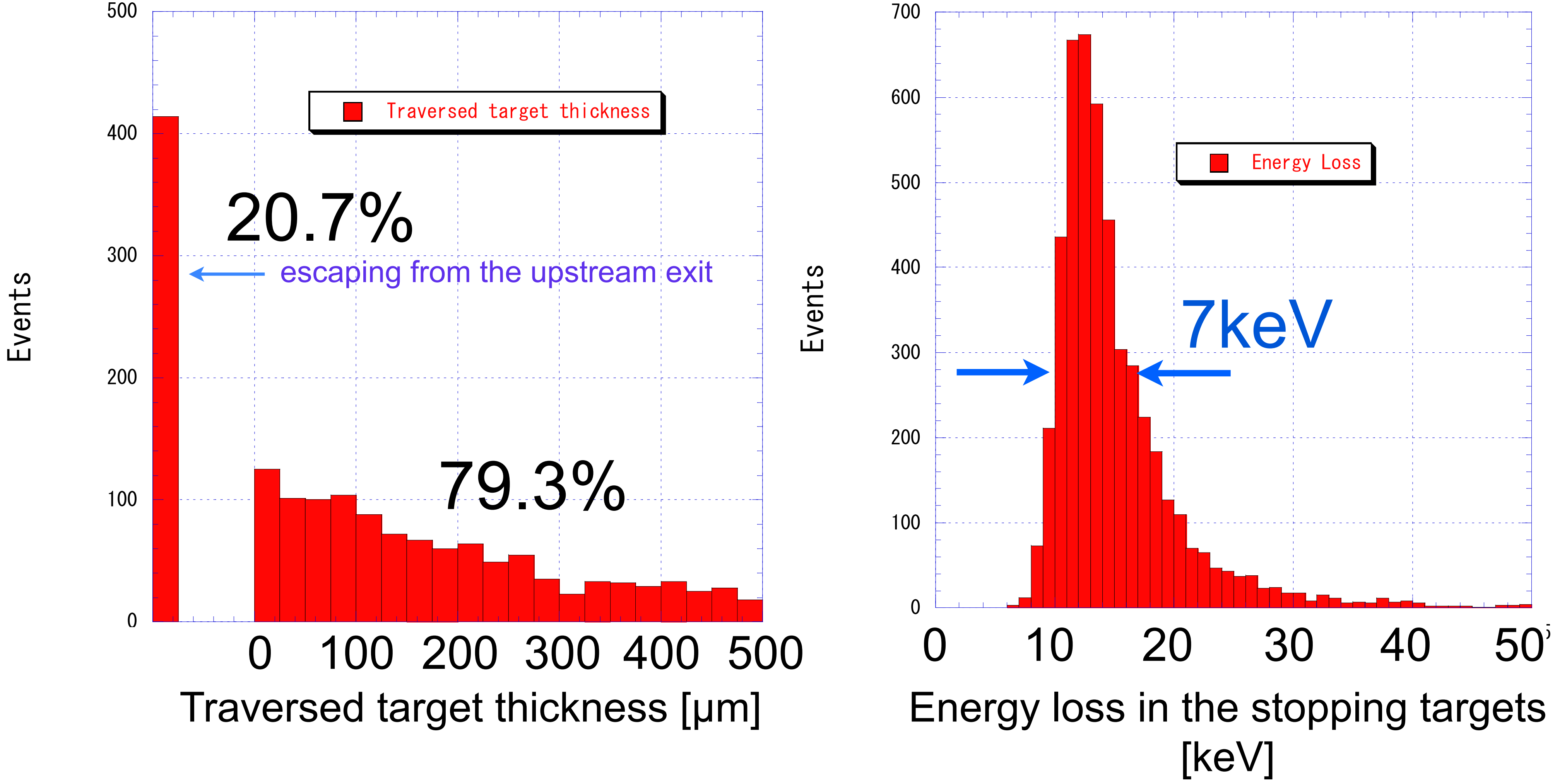


Parameters of Stopping Targets

In the following studies,

	PRISM	cf.COMET
Number of layers	20	17
Disk thickness	50µm	200µm
Disk diameter	5cm	10cm
Disk spacing	5cm	5cm
Material	Ti	Al

Energy Loss of Outgoing Electrons



20.7%

escaping from the upstream exit

79.3%

7keV

20 layers of 50μm Ti disks (D=5cm, 5cm separation)

cf. Energy Loss of Outgoing Electrons for COMET

from COMET-CDR

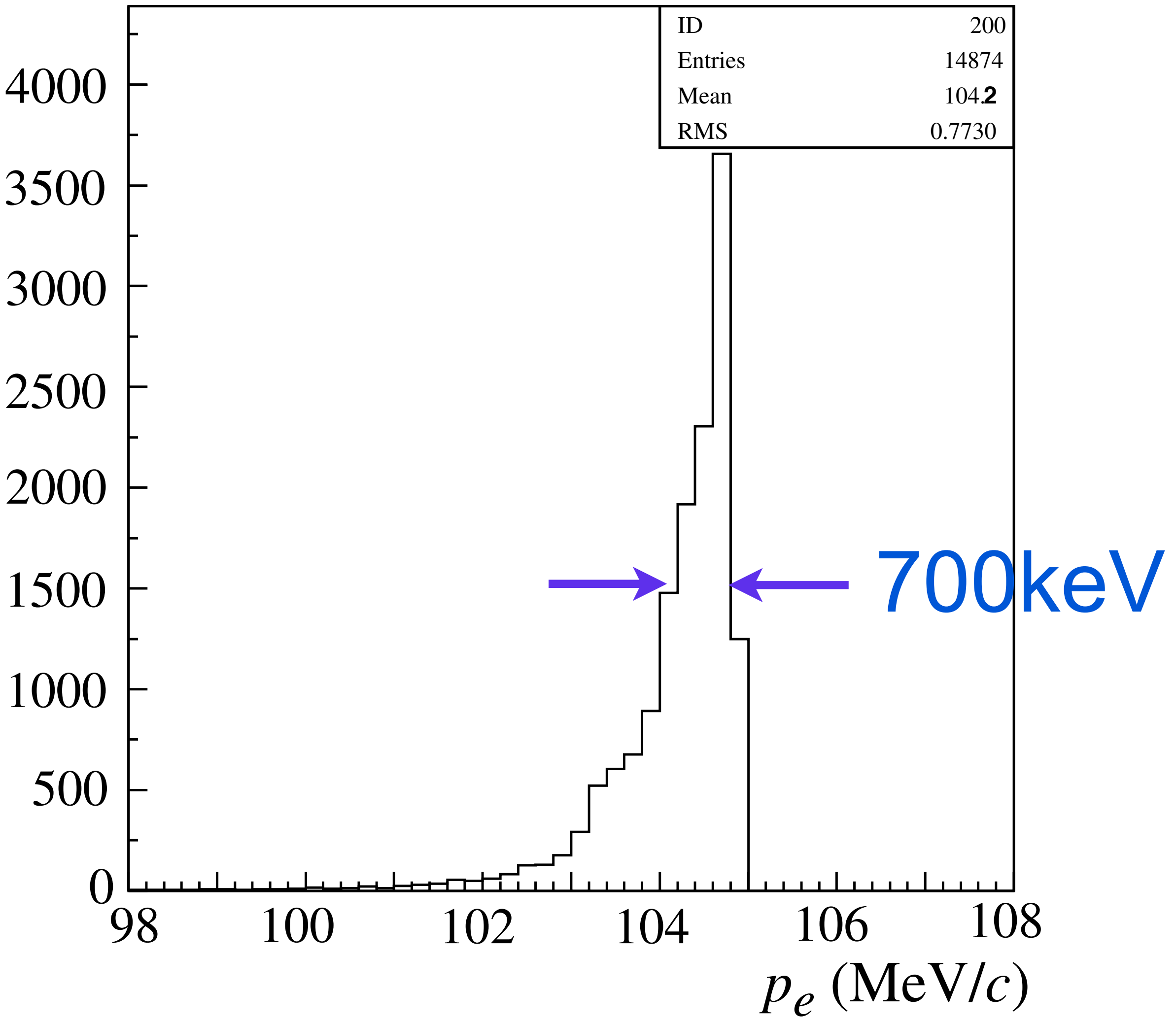


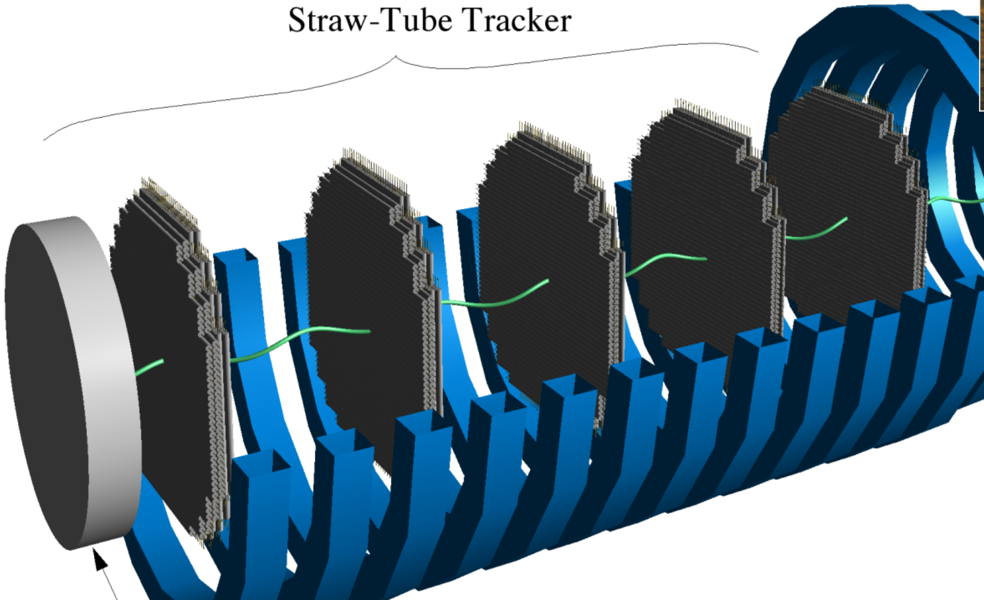
Figure 6.6: Momentum distribution of $\mu^-{-}e^-$ conversion signal electrons, including the effect of energy loss in the muon-stopping target.

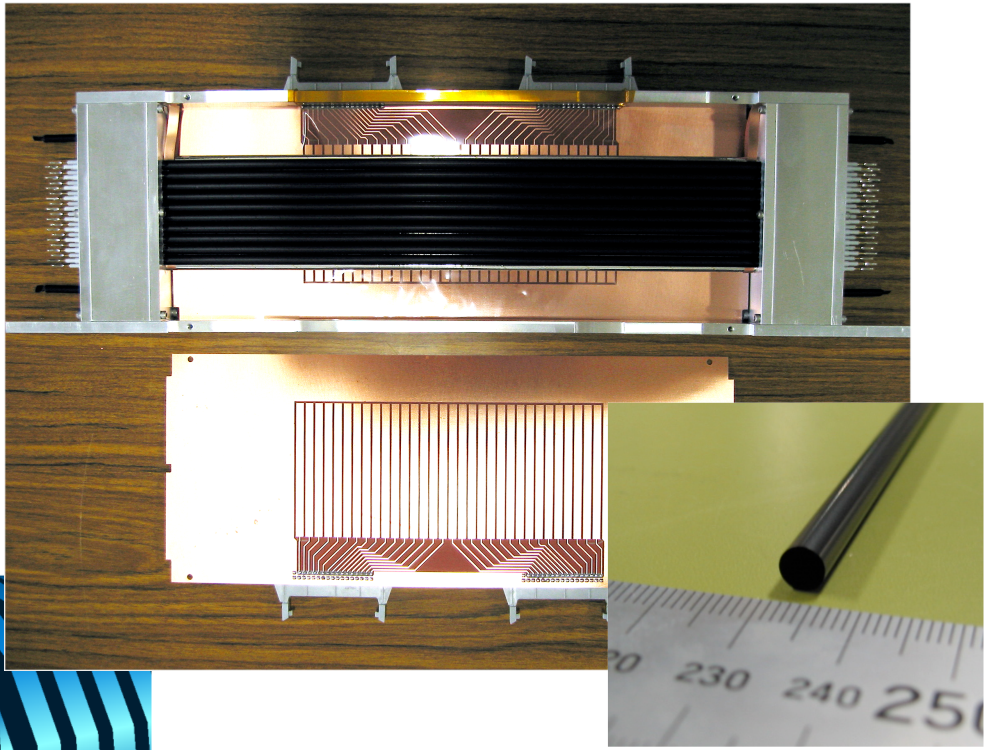
17 layers of 200μmTi disks (D=10cm, 5cm separation)

Tracking Detector

- Main detector to measure Ee
- Thickness should be about 0.01 radiation-length to suppress γ backgrounds.
- Spatial resolution < 0.5 mm
- Hit multiplicity ~ 1 per plane per event

- Straw tube tracker
  - 5mmΦ, 208 tubes per sub-layer
  - four layers per station
    - anode readout (X, X’, Y, Y’)
  - five stations, 48 cm apart





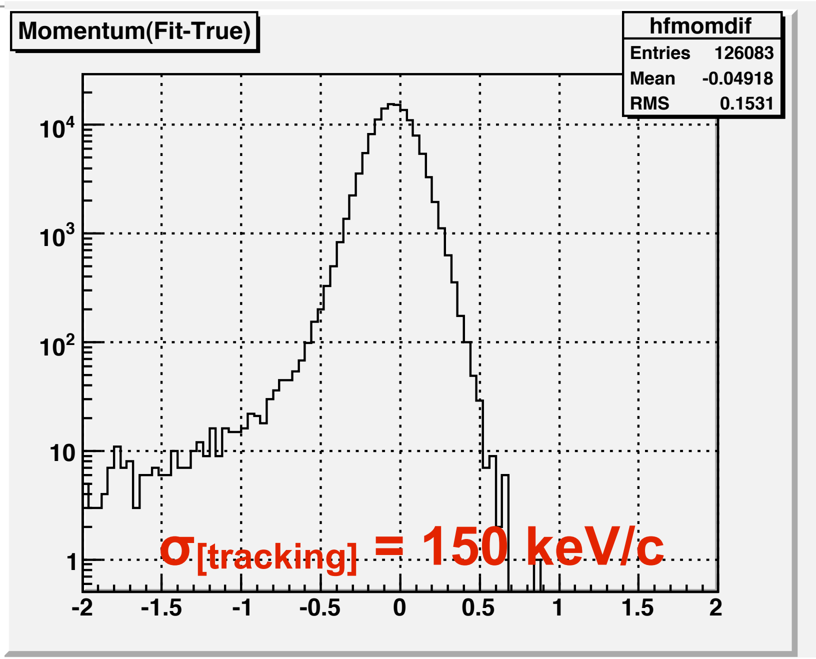
A Prototype chamber
tested by beam.
Anode position resolution of 112 μm.

Track Fitting Simulation

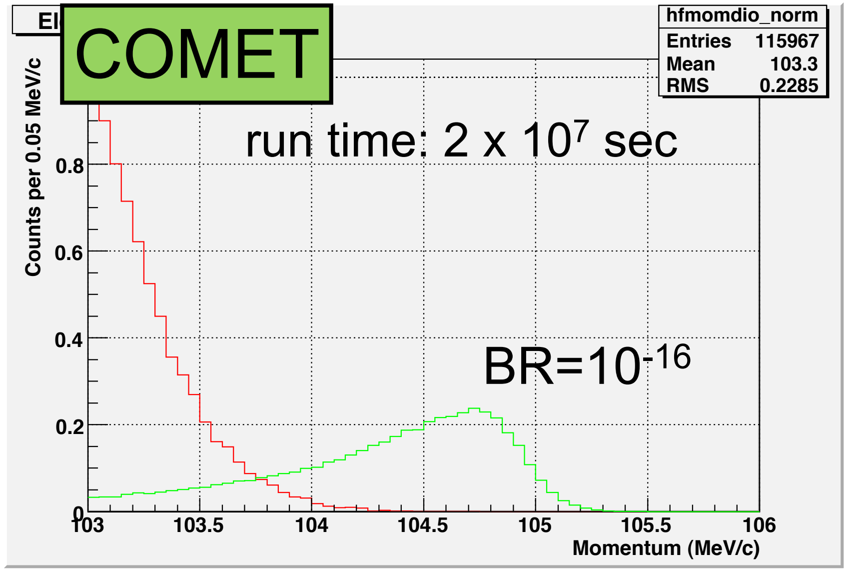
- 5 x-y Tracking Stations
  - 1-T uniform B
  - 480 mm spacing
  - Polyimide:160μm^t per plane
- Multiple Scattering by Break Point Method
- Require single hit for each plane

- $\sigma_{[\text{tracking}]}$ = 150 keV/c

- Momentum resolution
  - COMET: rms[total] = 770 keV/c
    - the energy loss uncertainly in the muon-stopping target is large.
  - **PRISM: rms[total] ⇒150 keV/c**



$p_{\text{fit}} - p_{\text{true}}$



Spiral Solenoid Spectrometer

Principle of Electron Transport Solenoid

Charged Particle Trajectory in Curved Solenoids

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

$$D = \frac{p}{qB}\theta_{bend}\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

D : *drift distance*
B : *Solenoid field*
θ_{bend} : *Bending angle of the solenoid channel*
p : *Momentum of the particle*
q : *Charge of the particle*
θ : *atan*(P_T/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 given by

$$B_{comp} = \frac{p}{qr}\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

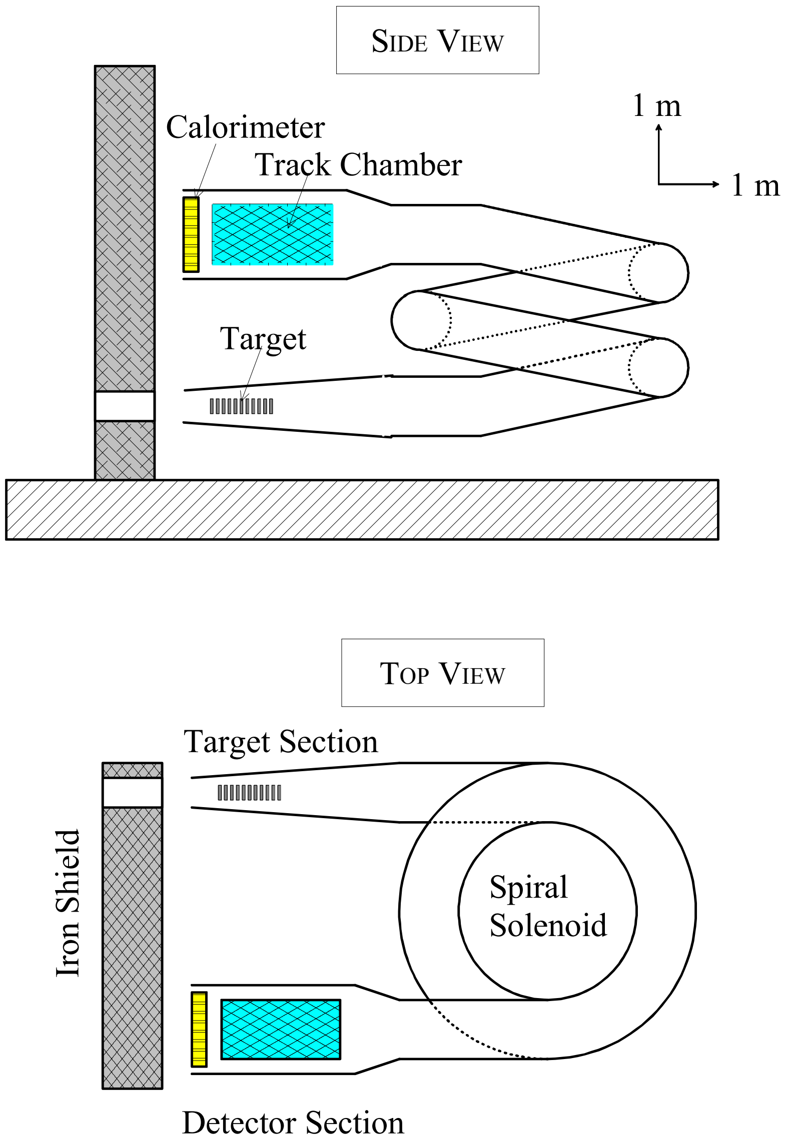
p : *Momentum of the particle*
q : *Charge of the particle*
r : *Major radius of the solenoid*
θ : *atan*(P_T/P_L)

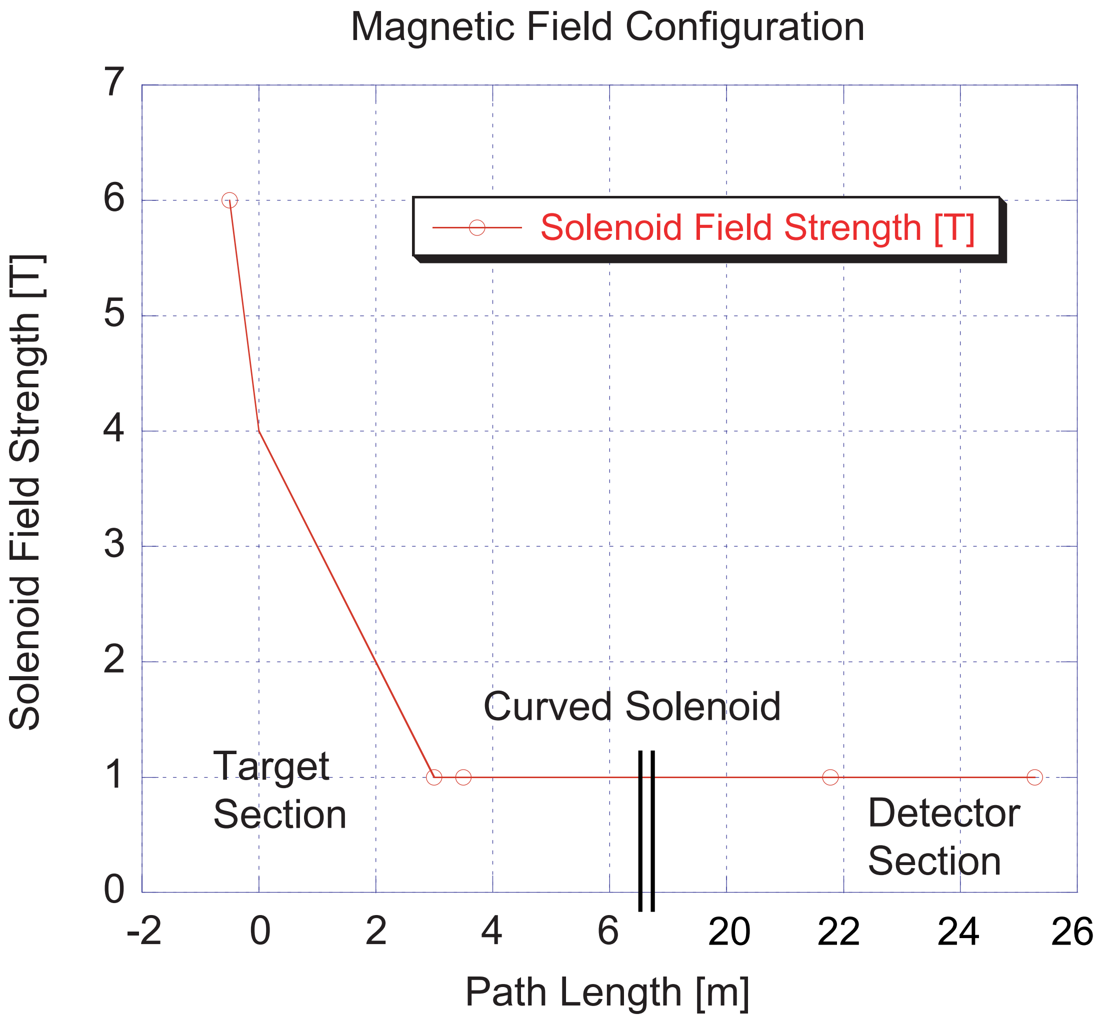
- Blockers in the curved solenoid improve the background suppression.

Layout and Magnetic Field in This Study

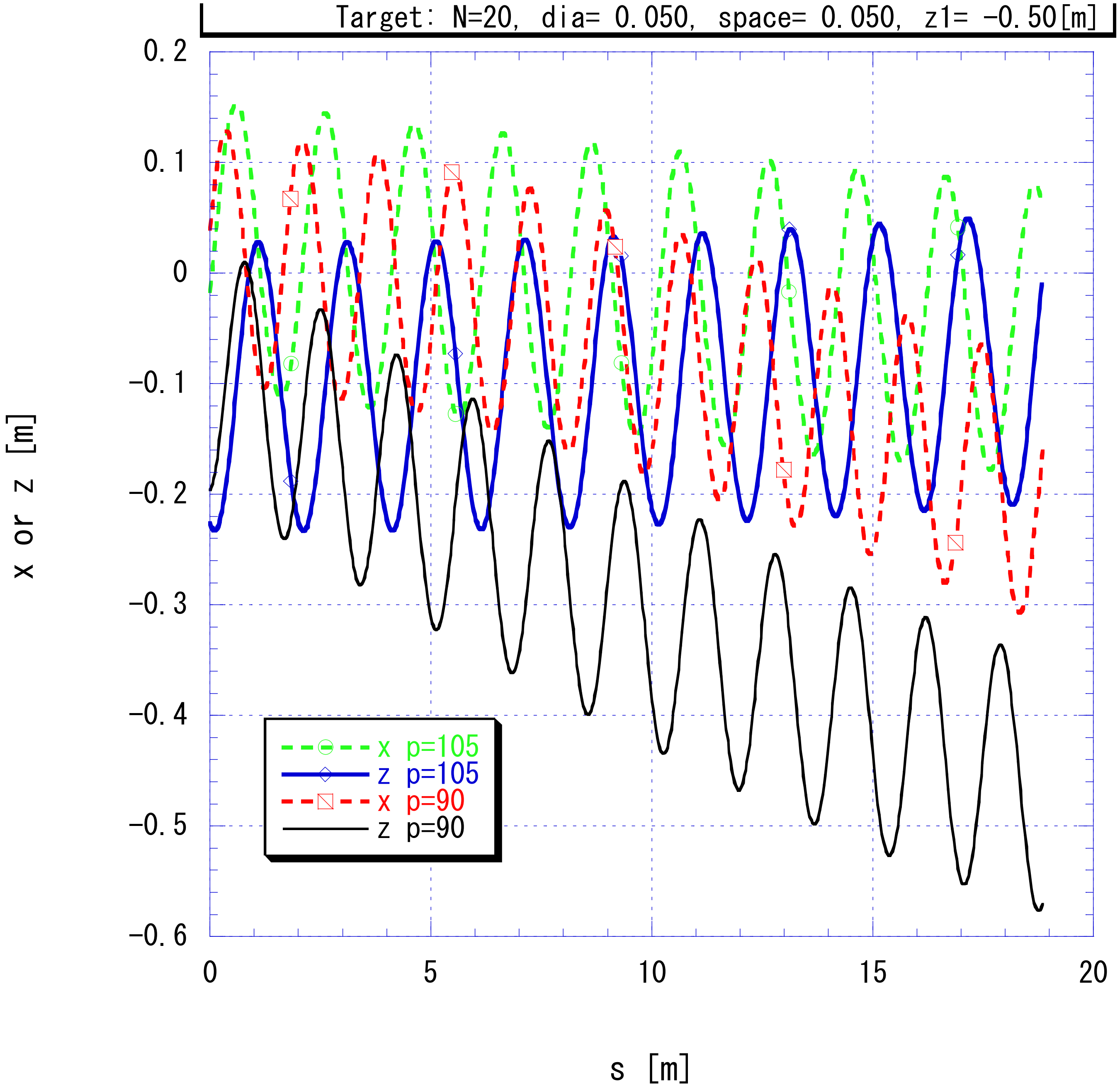
- The performance of the spectrometer was studied by MC simulation.

Spiral Solenoid Spectrometer for PRISM

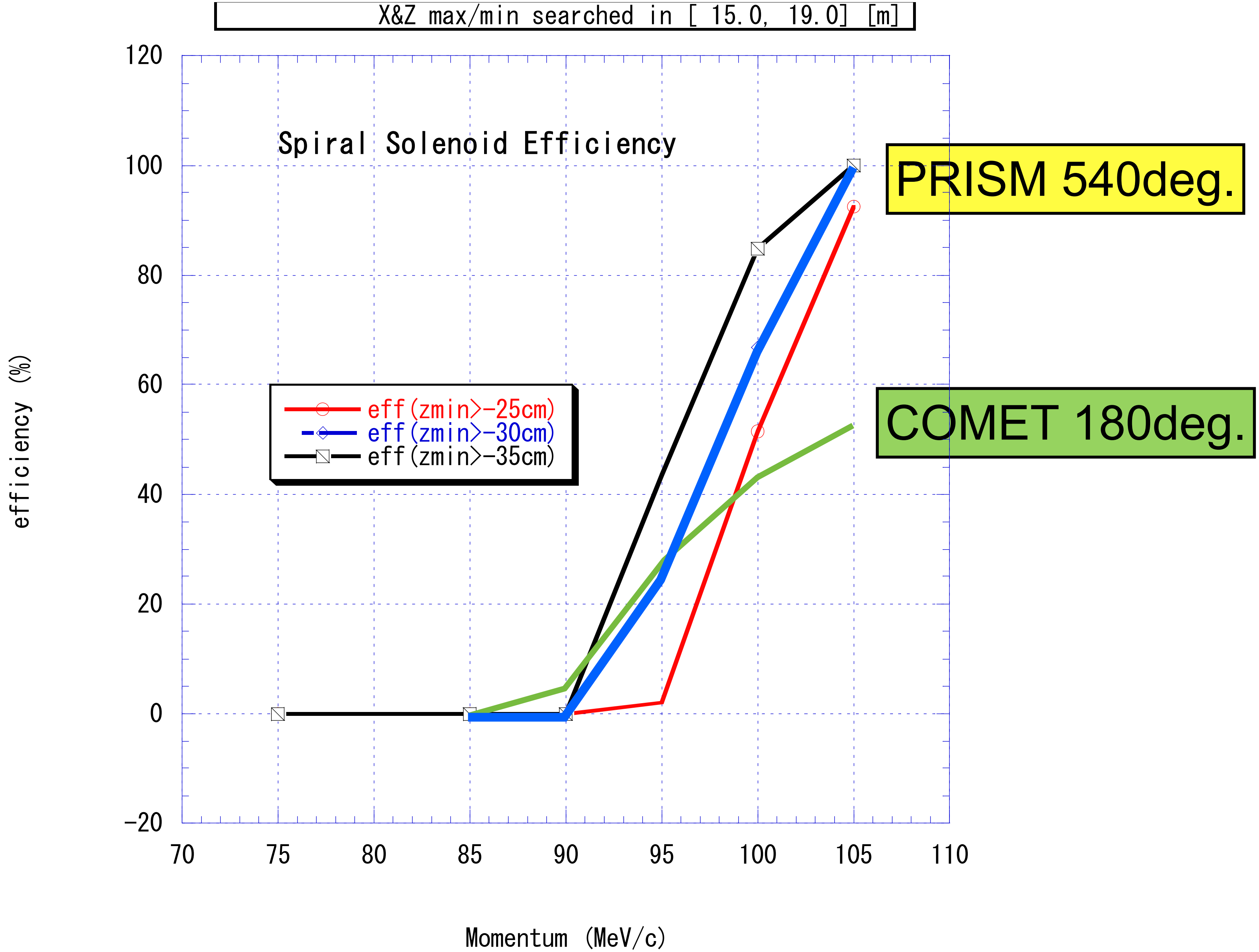




Trajectory in the spiral solenoid



Electron Transport Efficiency



Detector Rate

- Particles entering the detector are expected to be dominated by DIO electrons.
  - Positively charged particles and neutrals would be altered out, to a large extent, by the spiral solenoid section.
- We estimated the number of entering particles using the transport efficiency and the decay in orbit electron spectrum.

Cut conditions	No. of DIO particles per pulse	Signal efficiency
$z>-0.25[m]$; $x>-0.35[m]$.	< 0.1	92.4%
$z>-0.30[m]$; $x>-0.35[m]$.	< 0.4	100%
$z>-0.35[m]$; $x>-0.35[m]$.	< 0.8	100%

used for acc. estimation

Muon intensity	2×10^{12}	μ/sec
Mean momentum	68	MeV
Momentum spread	3	%
Rep. rate	1000	Hz
Pulse width	100	nsec

Acceptance of the spiral spectrometer

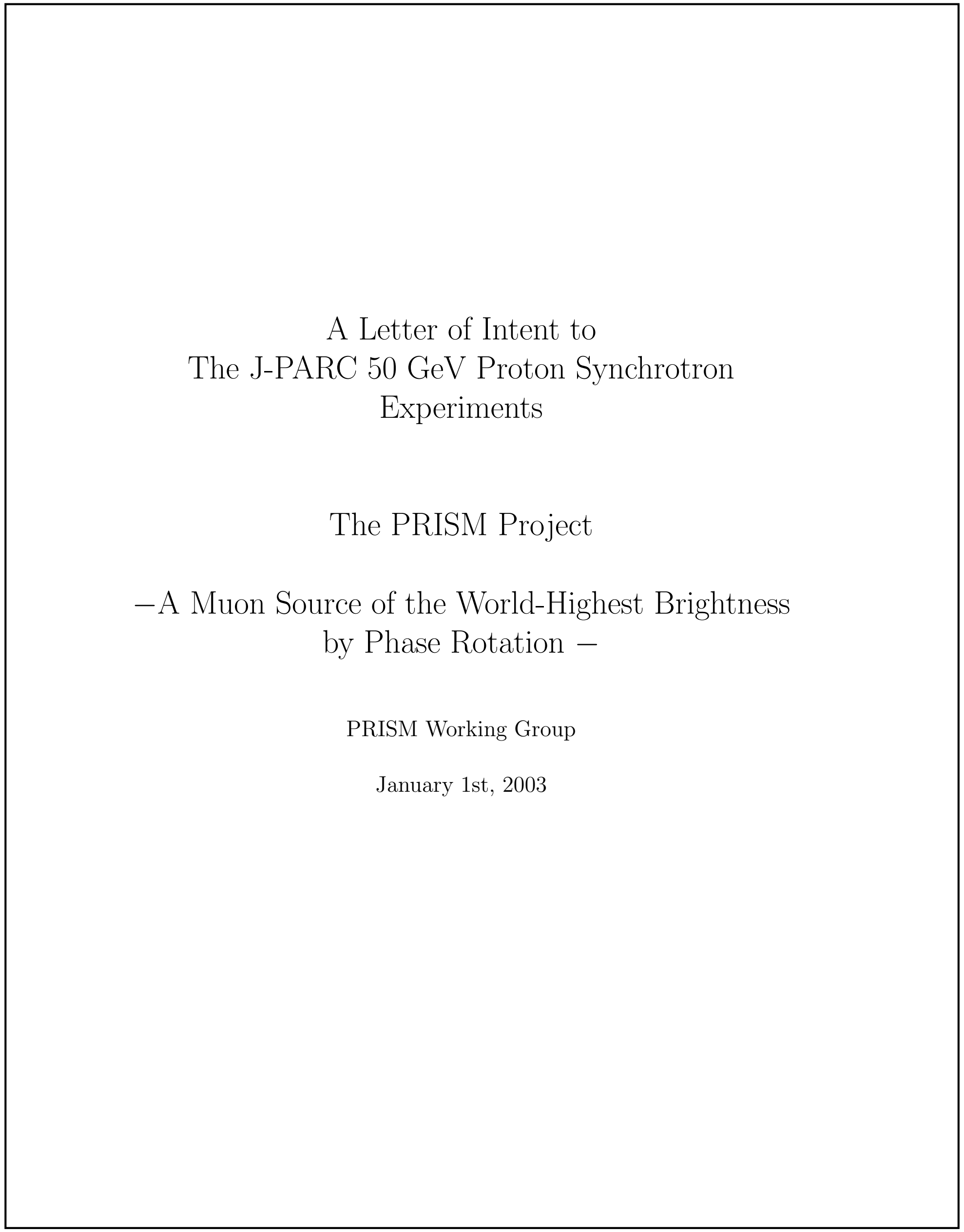
Label	Condition	Section	Fraction	Remark
C1	Target stopping rate	target	100%	assumed
C2	Forward direction.	target	79.3%	
C3	Blocker cut (vertical)	spiral solenoid	79.3%	Zmin>-0.30
C4	Blocker cut (horizontal)	spiral solenoid	79.3%	Xmin>-0.35
C5	$\sin\theta > 0.33$	detector	65.3%	
C6	$\Delta E < 150$ [keV]	target	41.2%	

Overall efficiency is 41%

Summary (Detector)

- Detecter system from the stopping target to the detectors for PRISM is studied.
    - Thin enough stopping target for the aimed energy resolution.
    - Spiral solenoid spectrometer
    - with DIO blocker to reduce detector rate
    - detector instantaneous hit rate is <0.4 / pulse (~1μs) = 4×10^5Hz
        - Straw chamber 200 straws/plane -> 2kHz/wire
        - Calorimeter 1000 segments -> 400Hz/segment
    - overall acceptance is 40%
  - They look very nice!
- We need to study and optimize the design for the new PRISM parameters.

Phase Rotator Linac in the PRISM-LoI



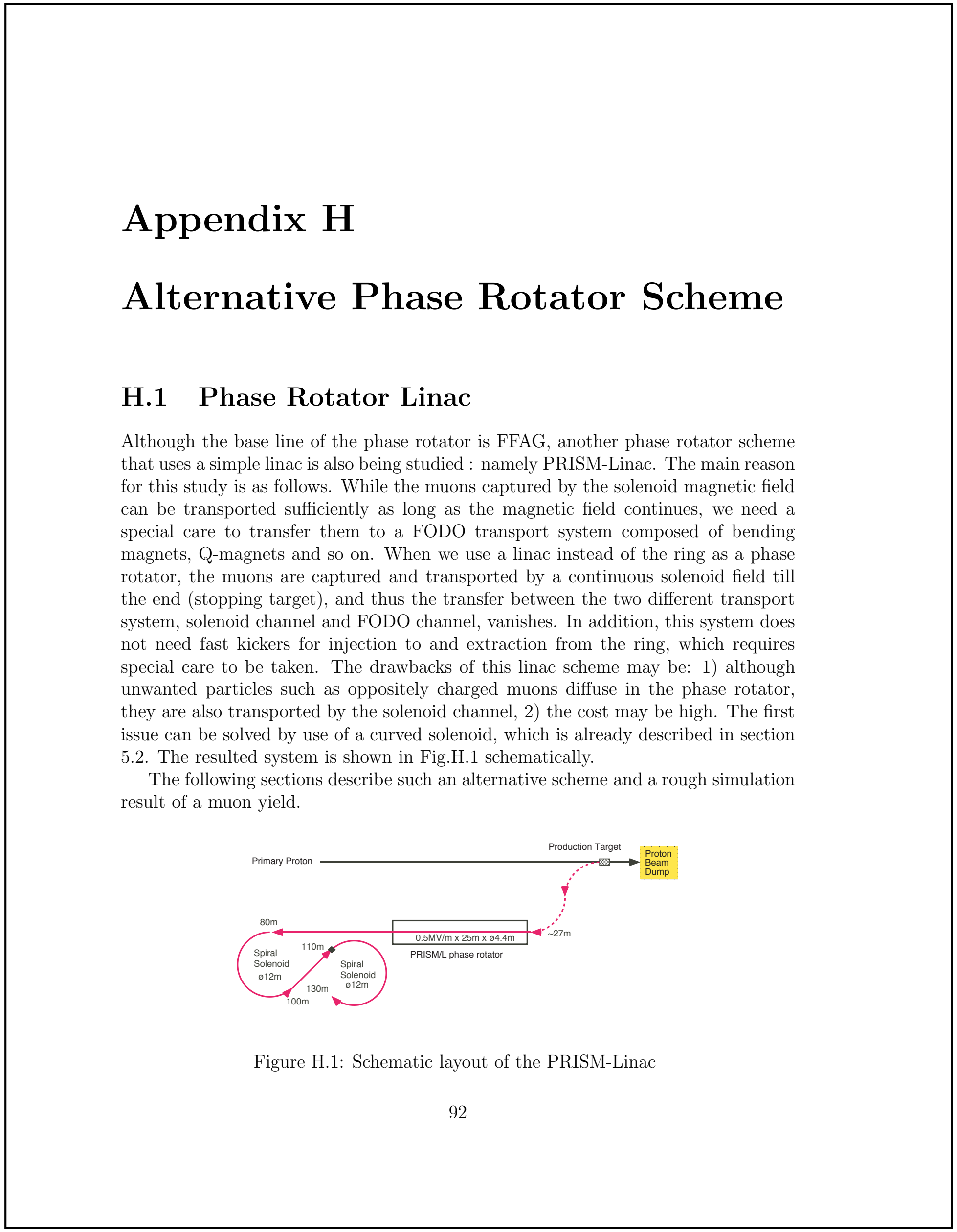
A Letter of Intent to
The J-PARC 50 GeV Proton Synchrotron
Experiments

The PRISM Project

—A Muon Source of the World-Highest Brightness
by Phase Rotation —

PRISM Working Group

January 1st, 2003



Appendix H

Alternative Phase Rotator Scheme

H.1 Phase Rotator Linac

Although the base line of the phase rotator is FFAG, another phase rotator scheme that uses a simple linac is also being studied : namely PRISM-Linac. The main reason for this study is as follows. While the muons captured by the solenoid magnetic field can be transported sufficiently as long as the magnetic field continues, we need a special care to transfer them to a FODO transport system composed of bending magnets, Q-magnets and so on. When we use a linac instead of the ring as a phase rotator, the muons are captured and transported by a continuous solenoid field till the end (stopping target), and thus the transfer between the two different transport system, solenoid channel and FODO channel, vanishes. In addition, this system does not need fast kickers for injection to and extraction from the ring, which requires special care to be taken. The drawbacks of this linac scheme may be: 1) although unwanted particles such as oppositely charged muons diffuse in the phase rotator, they are also transported by the solenoid channel, 2) the cost may be high. The first issue can be solved by use of a curved solenoid, which is already described in section 5.2. The resulted system is shown in Fig.H.1 schematically.

The following sections describe such an alternative scheme and a rough simulation result of a muon yield.

Figure H.1: Schematic layout of the PRISM-Linac

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http://www-ps.kek.jp/jhf-np/LOIlist/pdf/L24.pdf

Phase Rotator Linac in the PRISM-LoI

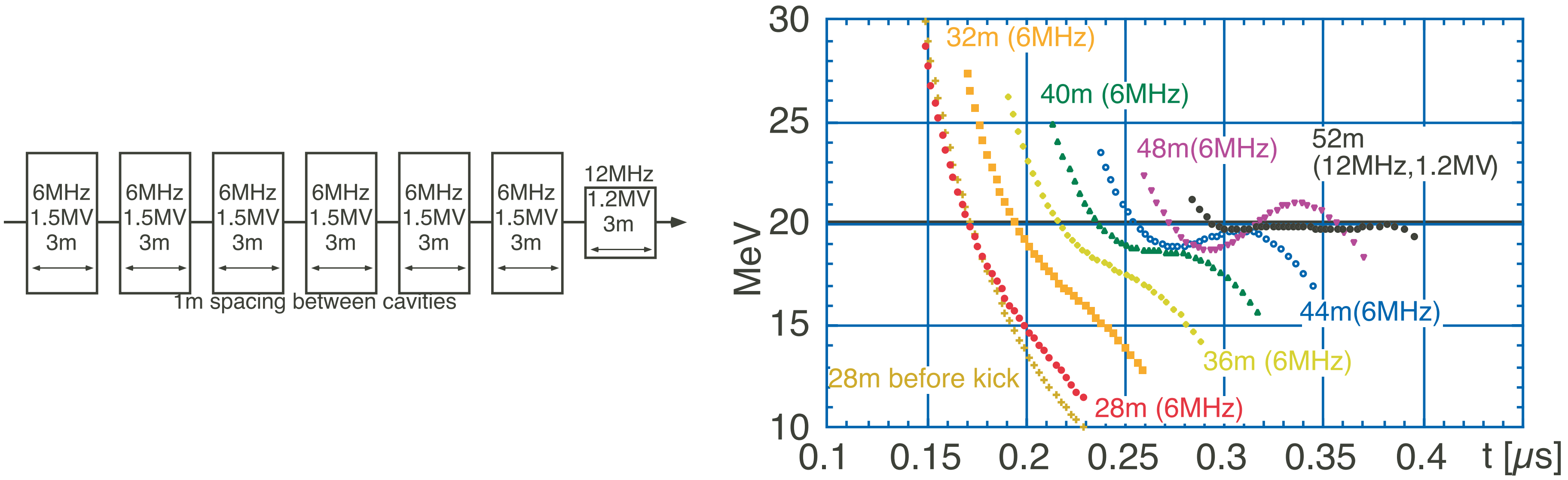

Figure H.3: Rough simulation shows how the phase rotation goes. Six 3m-cavities lined up with 1m spacing generate 9 MV in total. 12-MHz one is used to fit the waveform.