J-PARC P21 Report
An Experimental Search for Lepton Flavor Violating mu-e conversion at Sensitivity of 10^{-16} with a Slow Extracted Bunched Proton Beam

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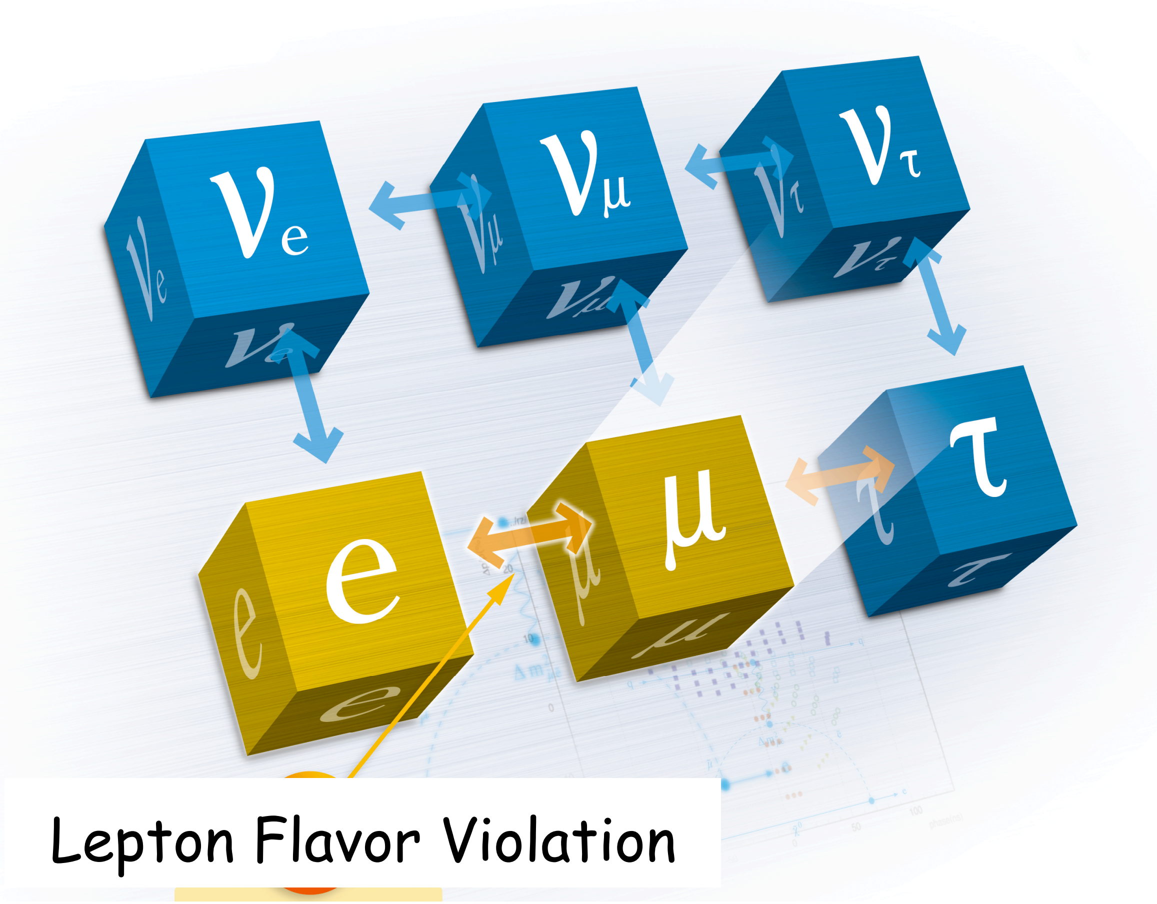
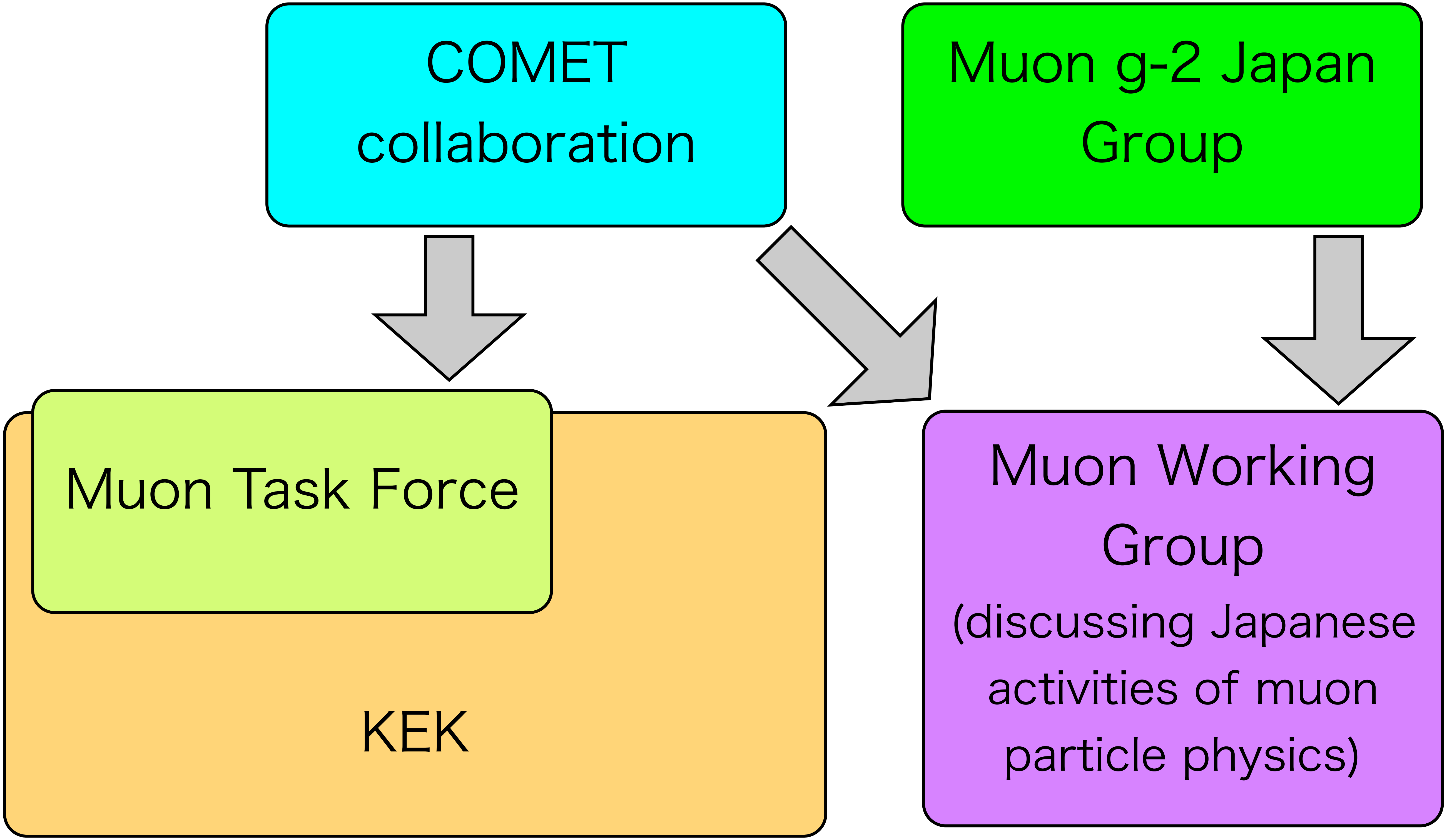
KEK, Tsukuba, Japan
J-PARC PAC
November 16th, 2008



Muon Task Force, Muon Working Group and the COMET collaboration

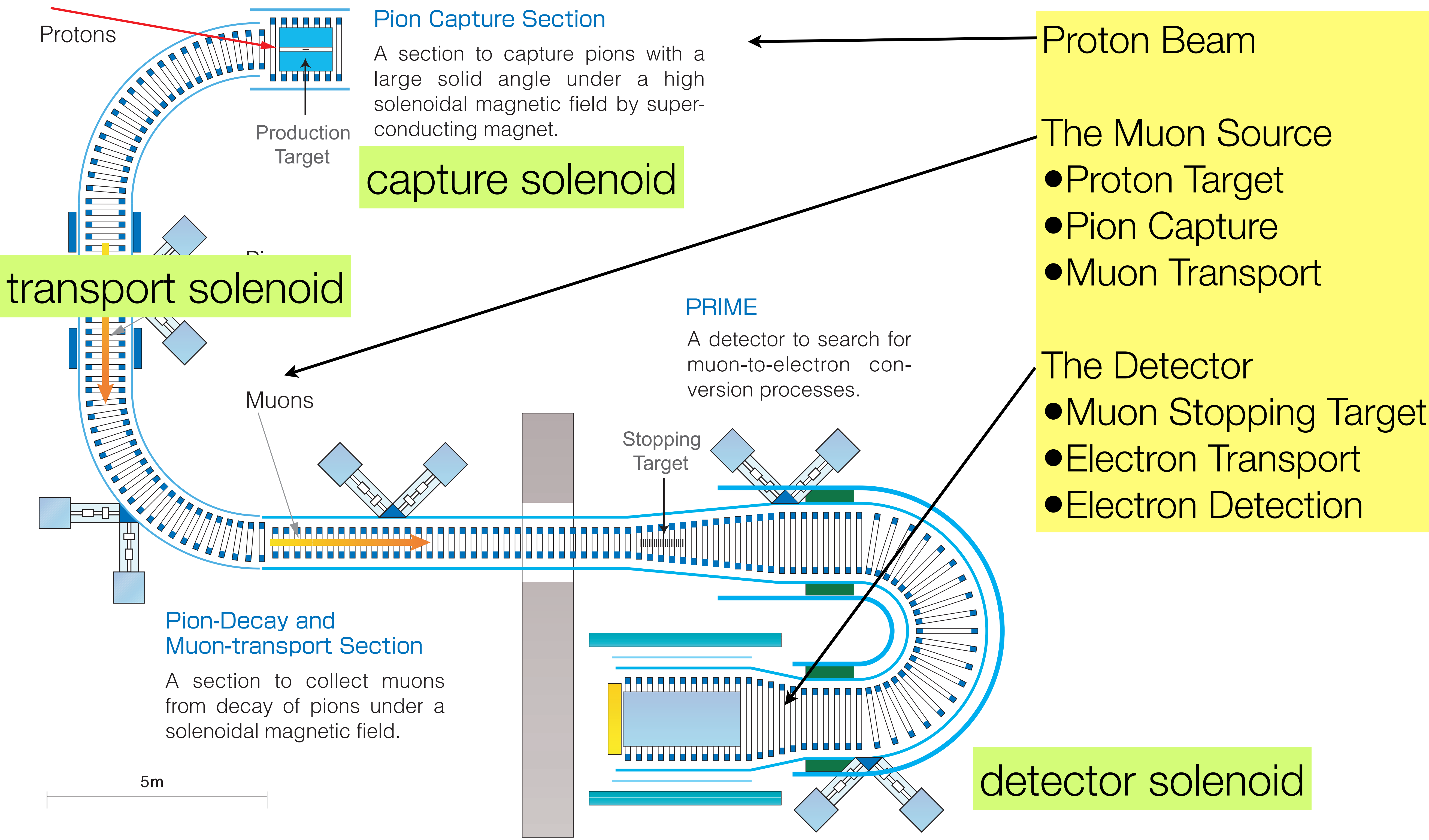


Outline

- P21 Status Report
  - CDR
  - COMET Collaboration
  - Communications to the Mu2E collaboration
- R&S Status Report
  - Proton Extinction Monitor R&D
  - Superconducting Magnet R&D
  - Calorimeter R&D
  - Simulation
- R&D Plan (response to the PAC report)
- Conclusion

P21 Status Report

Overview of the COMET Experiment (COherent Muon to Electron Transition)



COMET Conceptual Design Report

> required beam structure, energy, and intensity. Reports from these committees should be made to the PAC in upcoming meetings. The collaboration also needs to develop a Conceptual Design Report for the complete experiment in order to allow realistic assessments of the feasibility, cost, and schedule.
>
> (from J-PARC PAC report, Jan. 2008)

- The conceptual design report is planned be submitted to the PAC in spring, 2009.
- It would contain a more detailed design, simulation, capability, cost and schedule.
- Stay tuned ...

COMET Collaboration

4) The collaboration appears to be small for the scale of the experiment. A resource loaded schedule showing how the experiment can be designed, engineered, constructed, and commissioned is needed to show if the plans are realistic. (from J-PARC PAC report, Jan. 2008)

- The COMET collaboration is making efforts to increase collaborators, in particular outside Japan.

The COMET Collaboration (as of October 16, 2008)

D. Bryman

Department of physics and astronomy, University of British Columbia, Vancouver, Canada,

R. Palmer

Department of Physics, Brookhaven National Laboratory, USA,

E. Hungerford

Department of Physics, University of Houston, USA

Y. Iwashita,

Institute for Chemical Research, Kyoto University, Kyoto, Japan

V. Kalinnikov, A. Moiseenko, D. Mzhavia, J. Pontecorvo, B. Sabirov, Z. Tsamaiaidze, and P. Evtukhouvich

JINR, Dubna, Russia

M. Aoki, Y. Arimoto, Md.I. Hossain, T. Itahashi, Y. Kuno, A. Sato, and M. Yoshida

Department of Physics, Osaka University, Japan

J. Sato, M. Yamanaka

Department of Physics, Saitama University, Japan

Y, Takubo,

Department of Physics, Tohoku University, Japan

Y. Igarashi, S. Ishimoto, S. Mihara, H. Nishiguchi, T. Ogitsu, M. Tomizawa, A. Yamamoto, and K. Yoshimura

High Energy Accelerator Research Organization (KEK), Japan

T. Numao

TRIUMF, Canada

new in red

The (quasi) COMET Collaborators

(not sign in yet but participate in the meetings and even do simulation works.)

A. Kurup, (and Y. Uchida)
The Blakett Laboratory, Imperial College London, UK
T. Ito
Los Alamos National Laboratory, USA,

The COMET collaboration is approaching to ....

for the UK,

Oxford University, University College London, Glasgow University and other UK Universities.

and is planning a LFV workshop in the UK in November

for France,

Orsay and Saclay....

and is planning a seminar trip in French institutes in November

for Switzerland,

ETH Zurich and PSI

and is attending a Swiss Workshop in November

for Italy, Germany and Spain

not yet....

Communications with the Mu2E Collaboration

- A collaborative work on proton extinction studies has been initiated via the US-Japan program since 2007.
  - proton extinction monitor (JP) and AC dipole magnet design (US)
  - The MOU on this collaborative work has been made and signed between Fermilab and KEK.
- Communications between the two collaborations has started.
  - YK in the COMET collaboration was invited to the Mu2E collaboration meeting in September, 2008.
  - PI in the Mu2E collaboration will be invited to the COMET collaboration meeting in December, 2008.
  - The joint workshop between the COMET and Mu2E collaborations is scheduled to be held, in January, 2009.

R&D Status

R&D on Superconducting Magnets

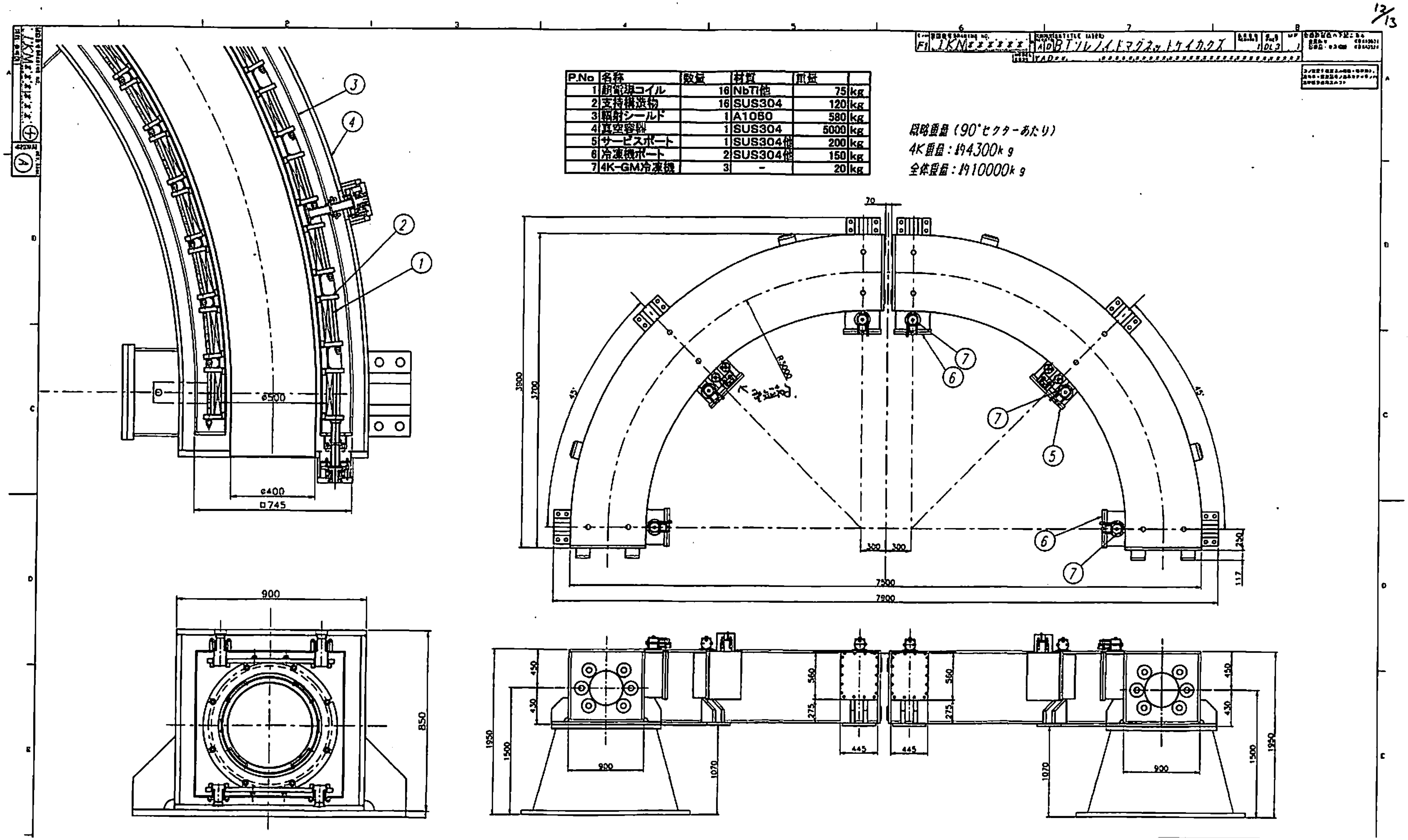
R&D on Superconducting (SC) Solenoid

5) A realistic schedule for developing the superconducting beamline solenoid should be worked out including a prototyping program.

(from J-PARC PAC report, Jan. 2008)

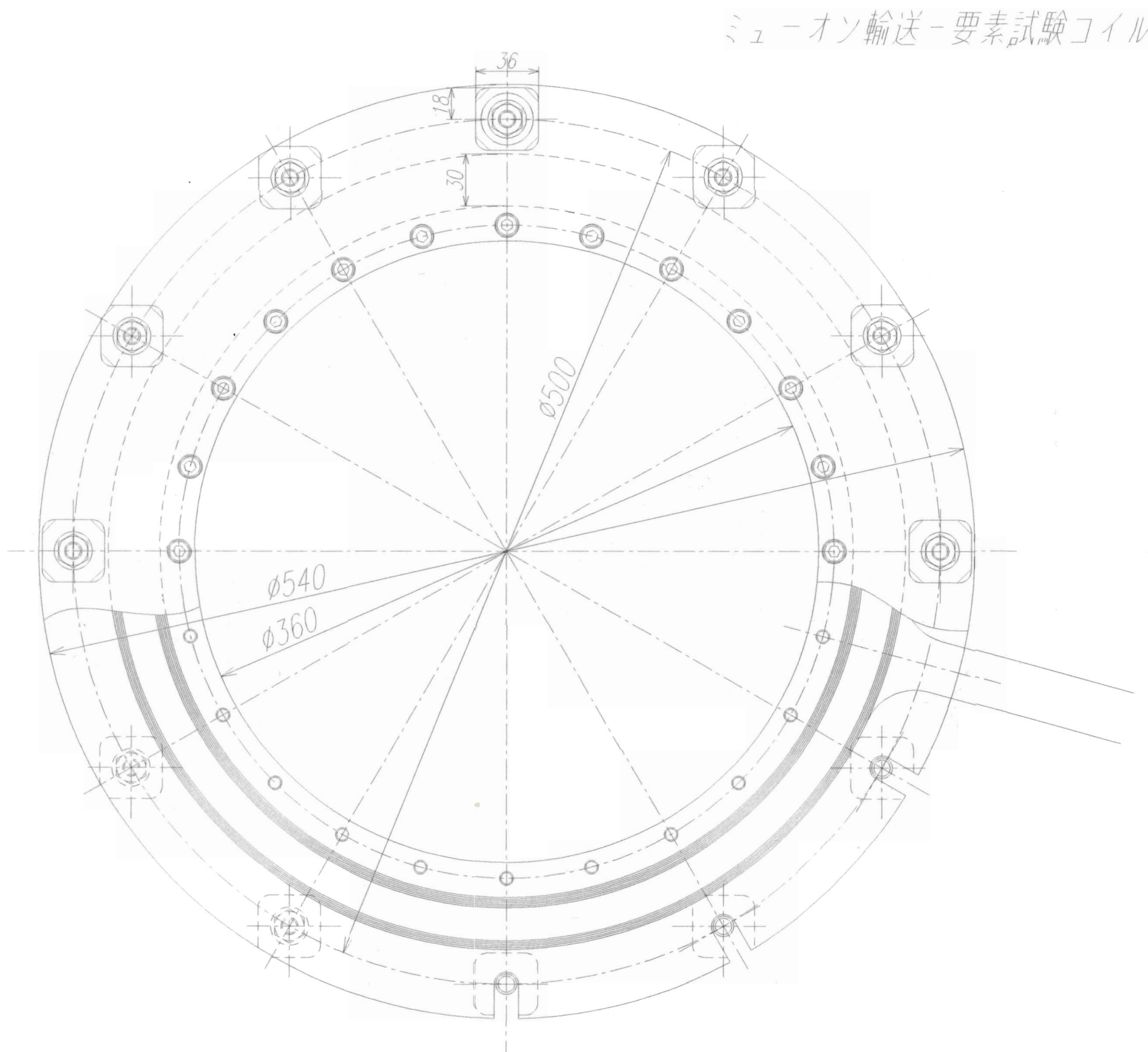
- Schematic designs of the capture and transport solenoids were being made since the previous J-PARC PAC.
- Prototyping of some of the transport solenoids is undertaken.

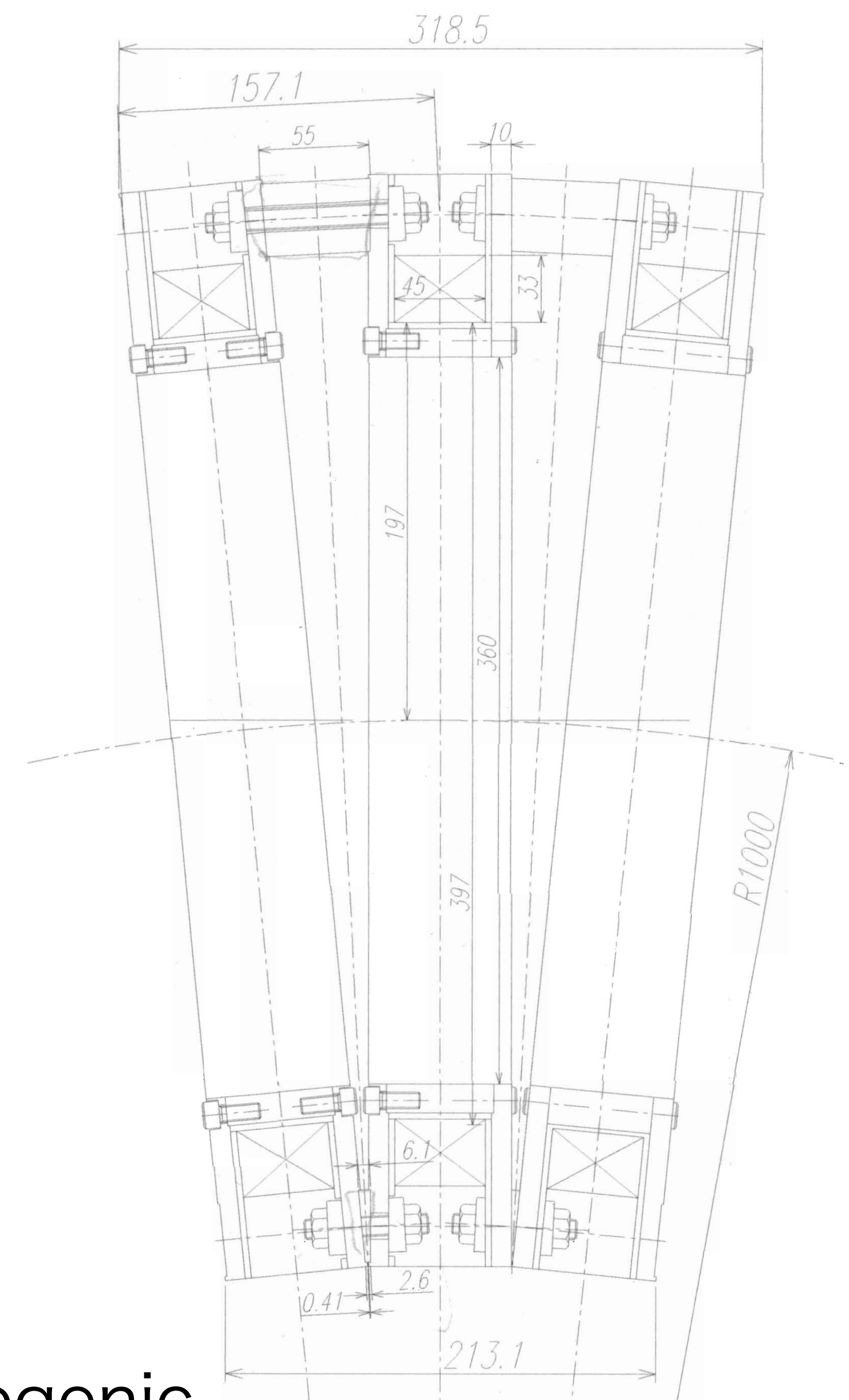
Transport Solenoid Design



P.No	名称	数量	材質	重量	
1	超電導コイル	16	NbTi他	75	kg
2	支持構造物	16	SUS304	120	kg
3	輻射シールド	1	A1050	580	kg
4	真空容器	1	SUS304	5000	kg
5	サービスポート	1	SUS304他	200	kg
6	冷凍機ポート	2	SUS304他	150	kg
7	4K-GM冷凍機	3	-	20	kg

Prototyping of the Muon Beam Transport Solenoid Magnets





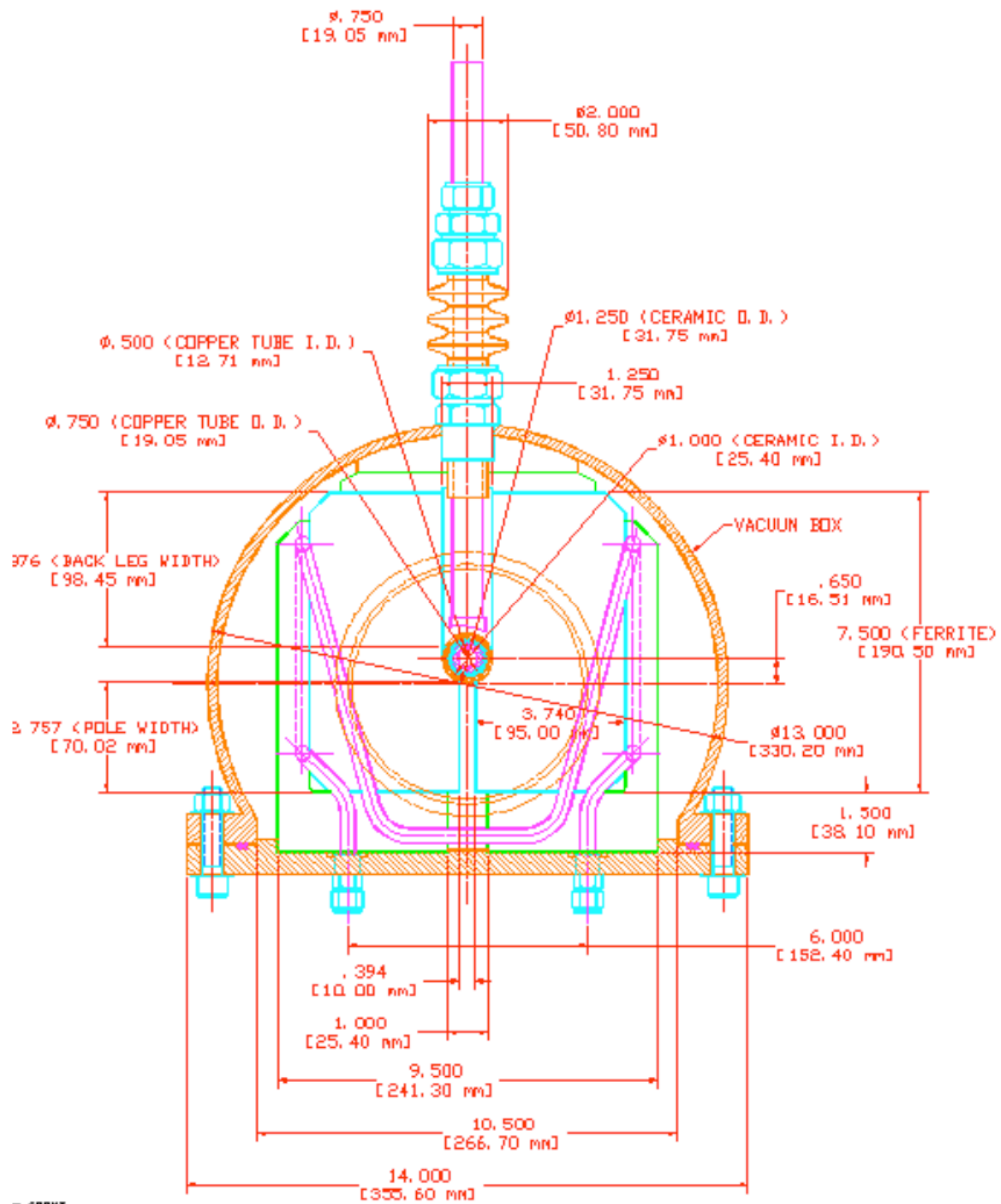
3 magnets (by COMET, muon MLF, KEK cryogenic science center) will be constructed by March, 2009.

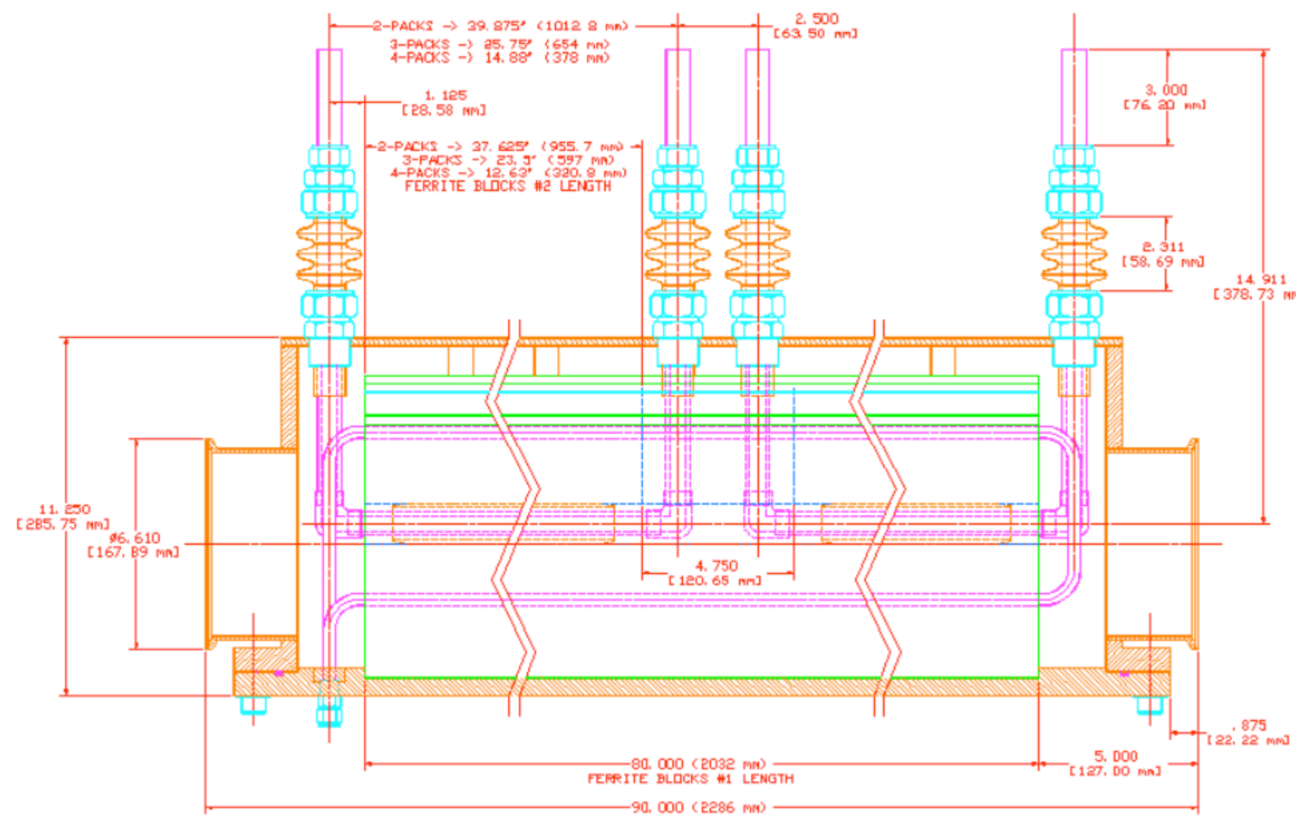
Prototyping of SC coils for Beam Transport Solenoid

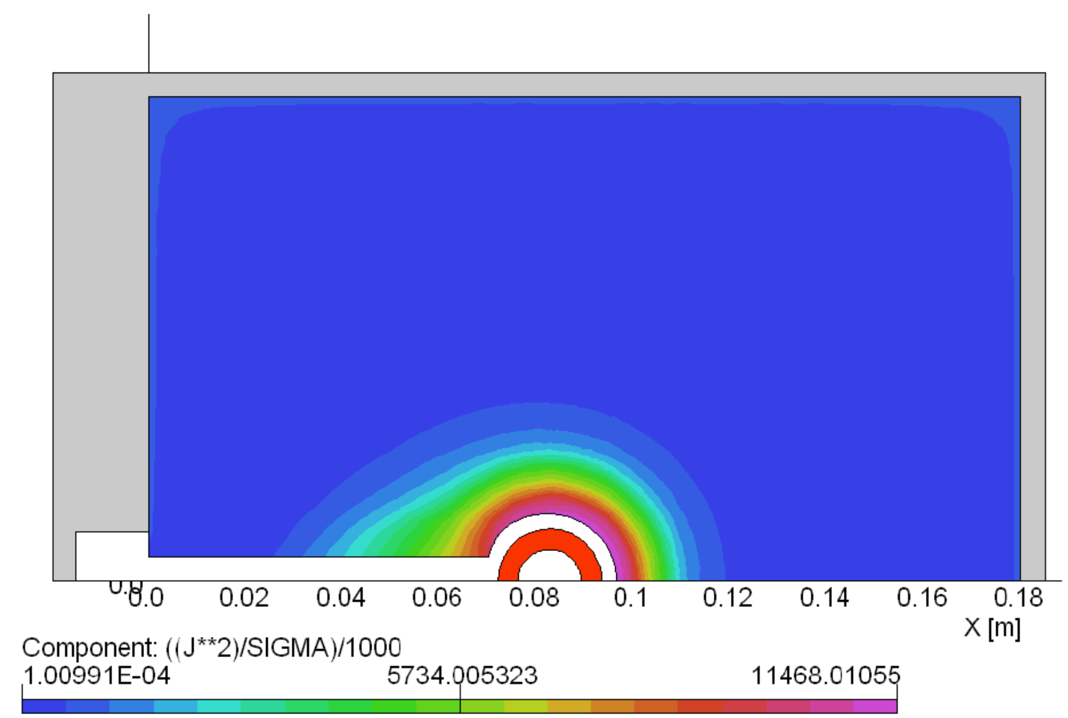
- 3 pancake coils will be constructed by March, 2009. (Toshiba Co)
  - Ready to make purchase order.
  - Based on that the configuration of 16 coils for 90 degrees
  - cooled by cryo-coolers.
- Mechanical tests and quench tests.
  - quench back system
    - closed loop (Al sheets) for induced currents
    - resistive coil frame for induced currents
- Different wedge supports to test different bending angles.
- A new high-Tc superconductor, MgB_2, will be used for one of the coils for the first time.
  - advantage on low cooling power needed
- A large cryostat to put 3 of them together is available at KEK.

R&D on Proton Extinction
- Monitors and AC dipole magnets -

Design of AC Dipole Magnet for an extra extinction device





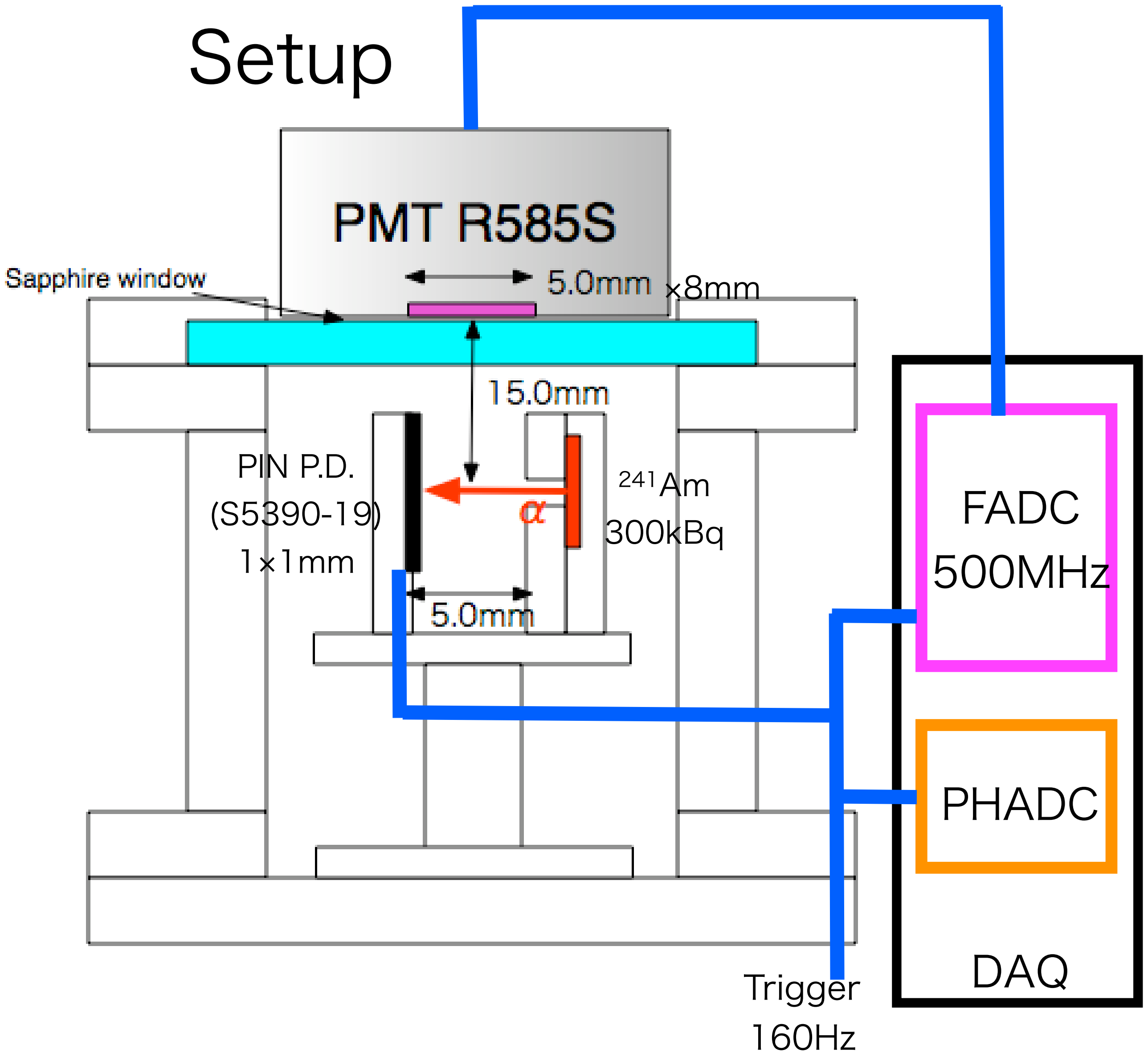


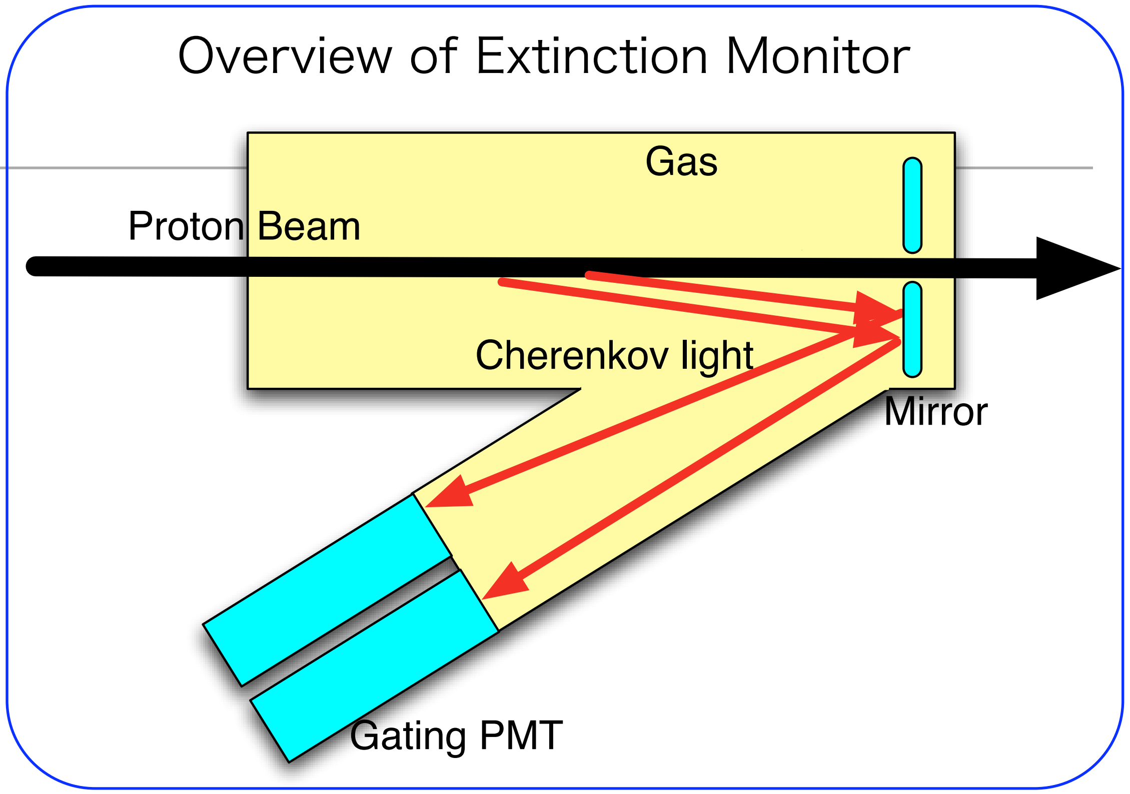
in collaboration with Mu2E (via. the US-Japan program)

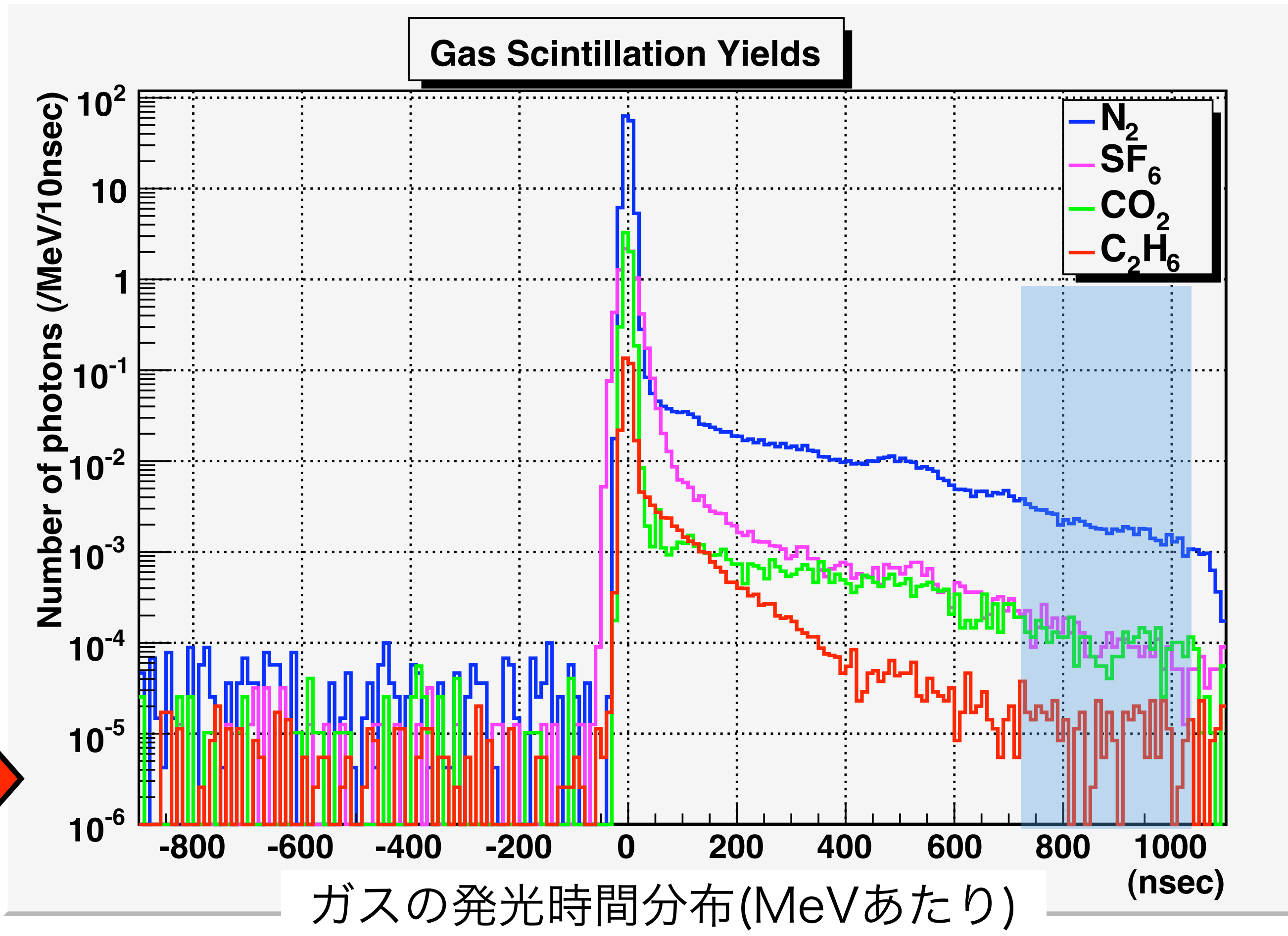
Beam Extinction Monitor and Veto

- Suppose proton extinction is 10^{-8}, what do we do ?
  - one out of 10 bunches has protons between bunches.
  - veto ? only 10% loss acceptance with keeping the same sensitivity.
- The Osaka U. group is working to develop a proton extinction monitor in an event-by-event base.
  - Gas Cherenkov counter with gating PMT (8 GeV protons)
  - veto a proton bunch if proton(s) are measured between bunches.
  - R&D on selection of gas, and a circuit for gating PMT
- As a crazy idea, it can be considered to put a muon veto system in the muon beam line.
  - plastic scintillator will not work for radiation damage.
  - liquid scintillator with thin window or radiation-hard scintillator
    - any decrease on muon yields ? How much materials are allowed ?

Gas Cherenkov Counter for Proton Monitor



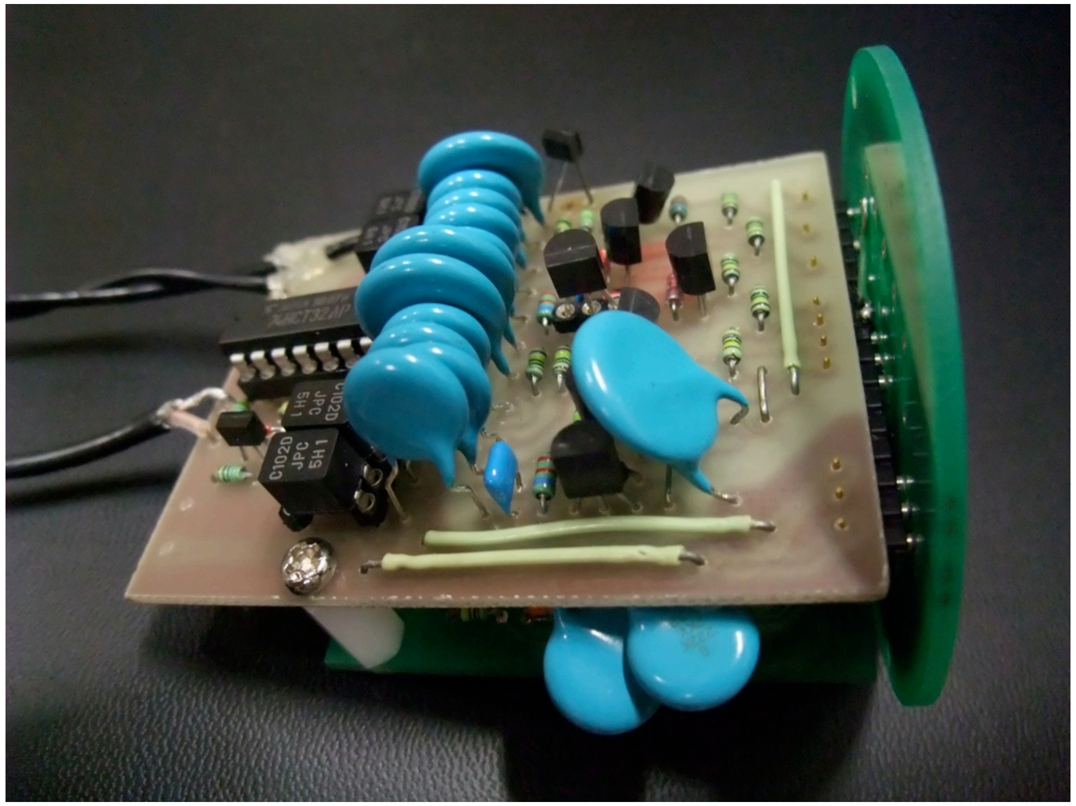




C_2H_6 residual scintillating photons :
$(1.11\pm0.09)\times10^{-6}$ photon/MeV/nsec
(at 700 ~1000 nsec after prompt)

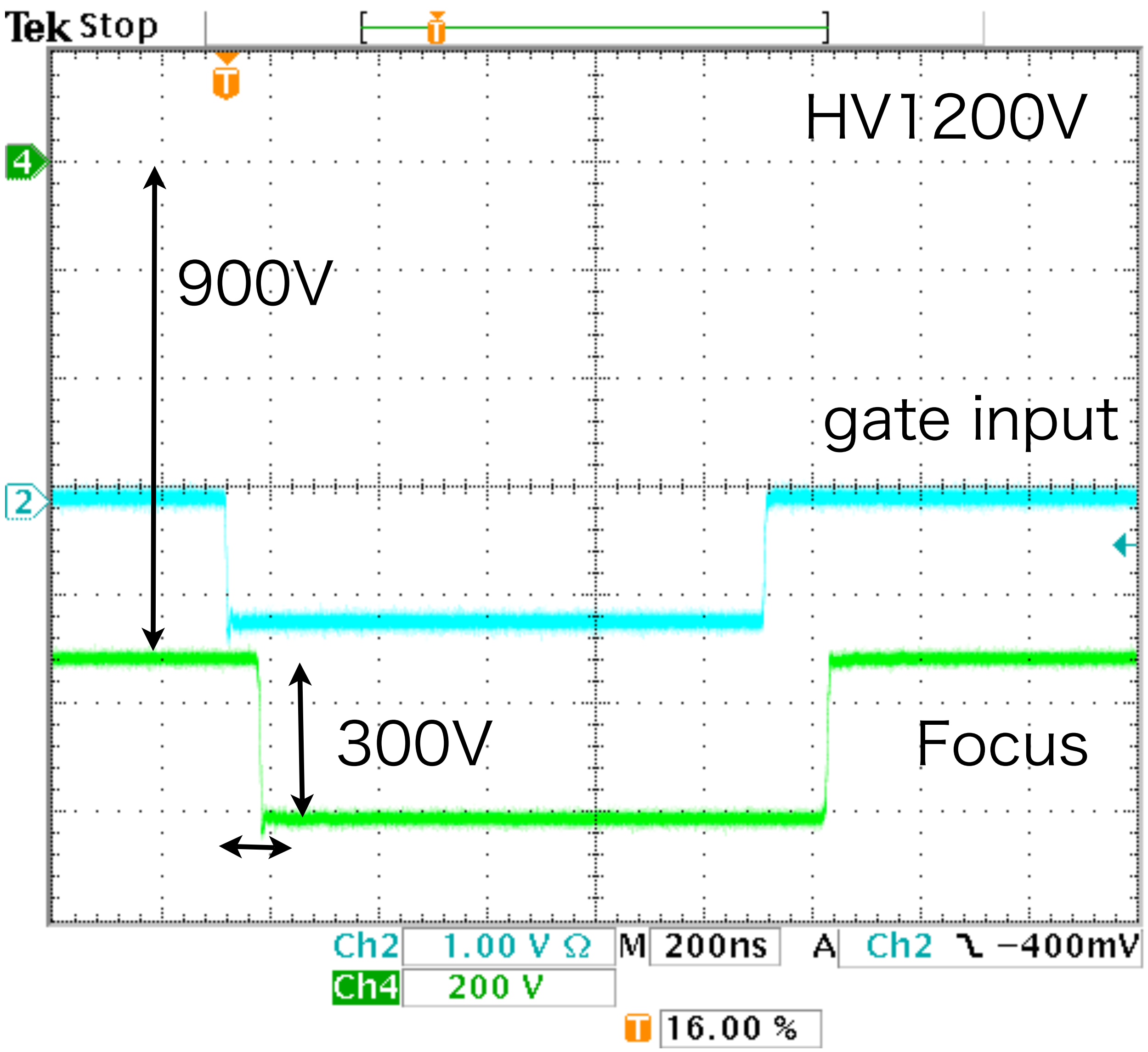
R&D on Gating PMT

- Requirements
  - about 1 MHz switching
  - a ratio of on/off < 10^{-6}



Divider Circuit Ver.2

operation at 100kHz by changing HVs
of the focus dinode and Dy3.



rise and fall times ～10nsec

circuit only, not
connected to PMT

R&D on Electron Calorimeter

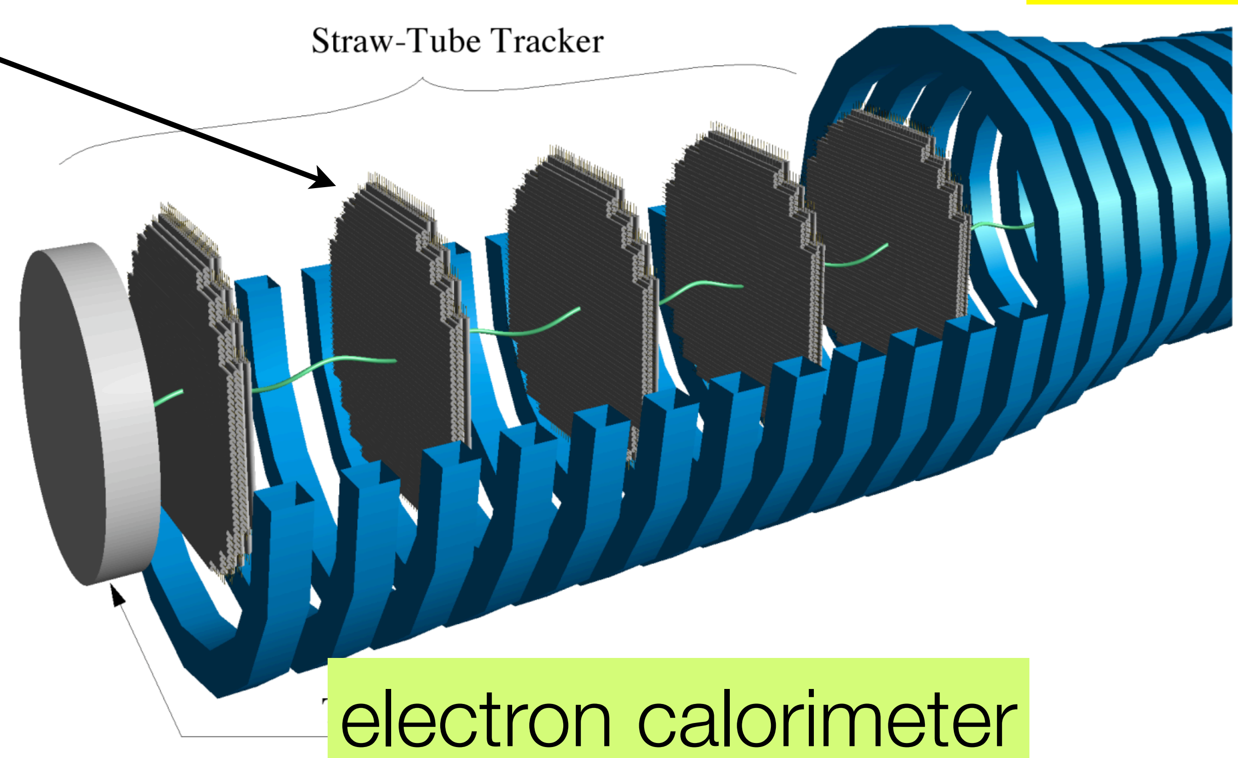
Electron Calorimeter (1)

- A scintillator array at the end of solenoid channel (size Φ1m, $11X_0$)
- Requirements
  - Energy resolution : σ < 10% at 100 MeV
  - Trigger Rate (energy selection) : < 5-10 kHz
  - Spacial resolution : < 1.5 cm
  - Fast response : < 100 nsec
  - Operate in a vacuum with a 1 Tesla magnetic field

Under a solenoidal magnetic field of 1 Tesla.

In vacuum to reduce multiple scattering.

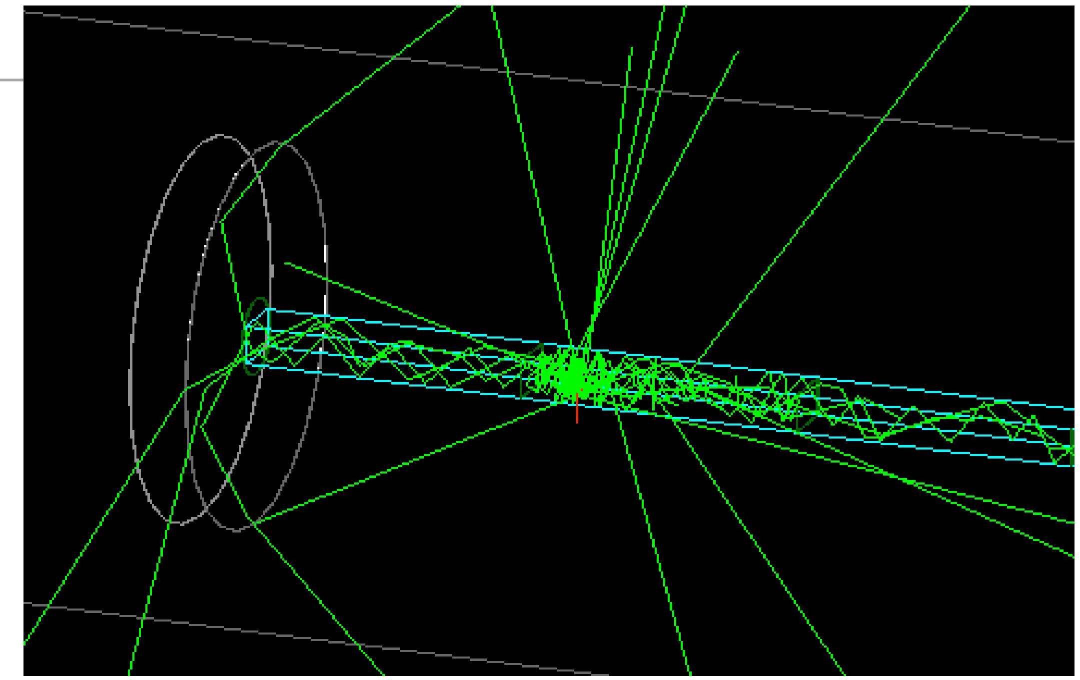
Straw-tube Trackers to measure electron momentum.
- should work in vacuum and under a magnetic field.
- A straw tube has 25μm thick, 5 mm diameter.
- One plane has 2 views (x and y) with 2 layers per view.
- Five planes are placed with 48 cm distance.
- 250μm position resolution.



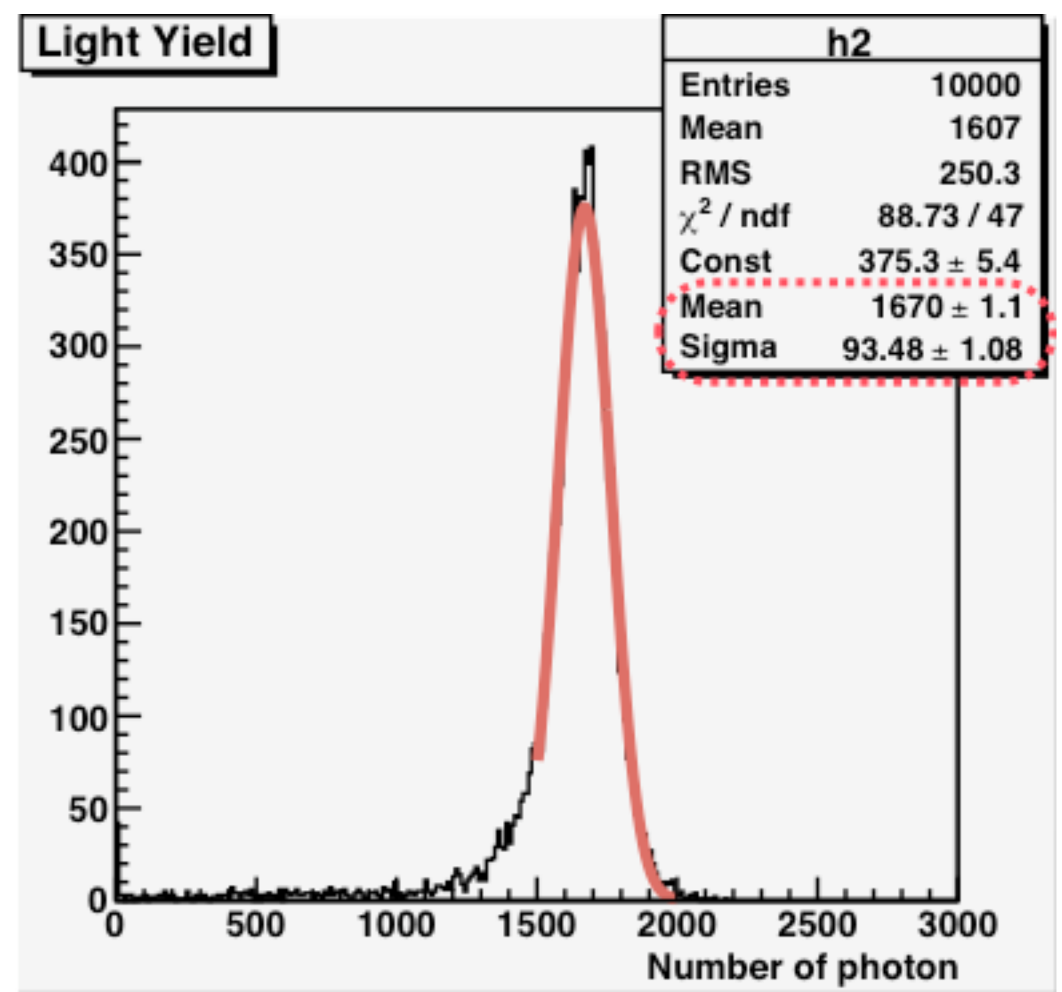
Electron Calorimeter (2)

- Candidates of scintillating crystals
  - GSO(Ce) : has enough light yield and fast response, but relatively expensive. difficult to get lager crystals.
  - PWO : less expensive, faster response. Large crystal is available. But, poor light yield. Needs cooling to increase light yield.
  - New R&D on scintillators will be held with the JINR group.
- Candidates of photon detectors
  - MPPC : high gain. Needs more R&D.
  - APD : established technology but with lower gain.

Simulation Study on Electron Energy Resolution



- Ray tracing in crystals using Geant4
  - Optimization of crystals and photon detectors.
  - Estimate the energy resolution and its components.



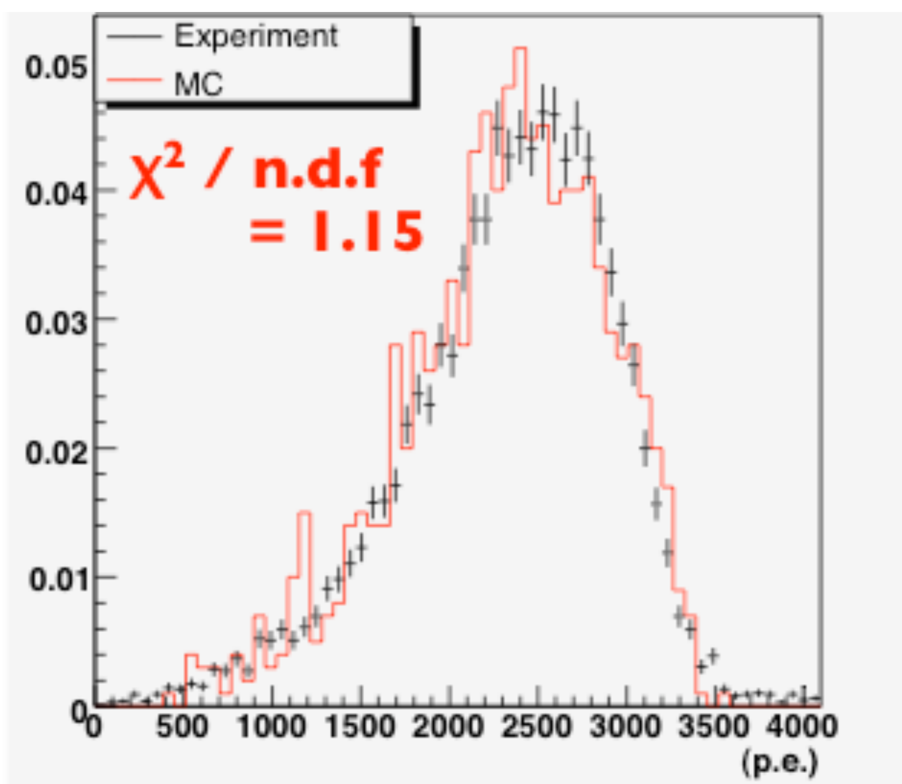
Expected energy resolution

	Stacked GSO(Ce)	Bulk PWO
with 10x10 mm^2 P.D.	8.4%	10.6%
with 30x30 mm^2 P.D.	5.3%	2.7%

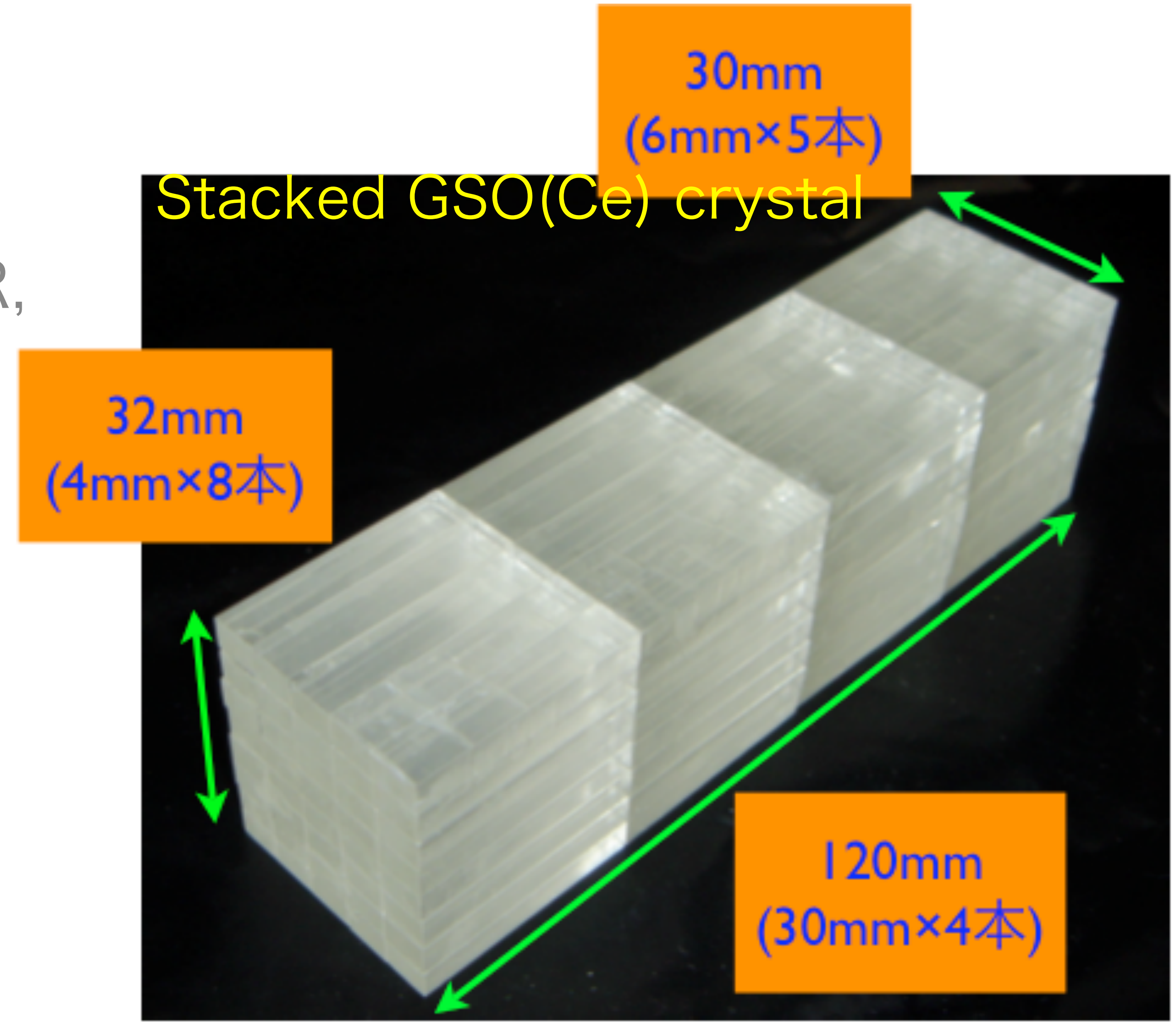
segment size :
32x30x120 mm^2

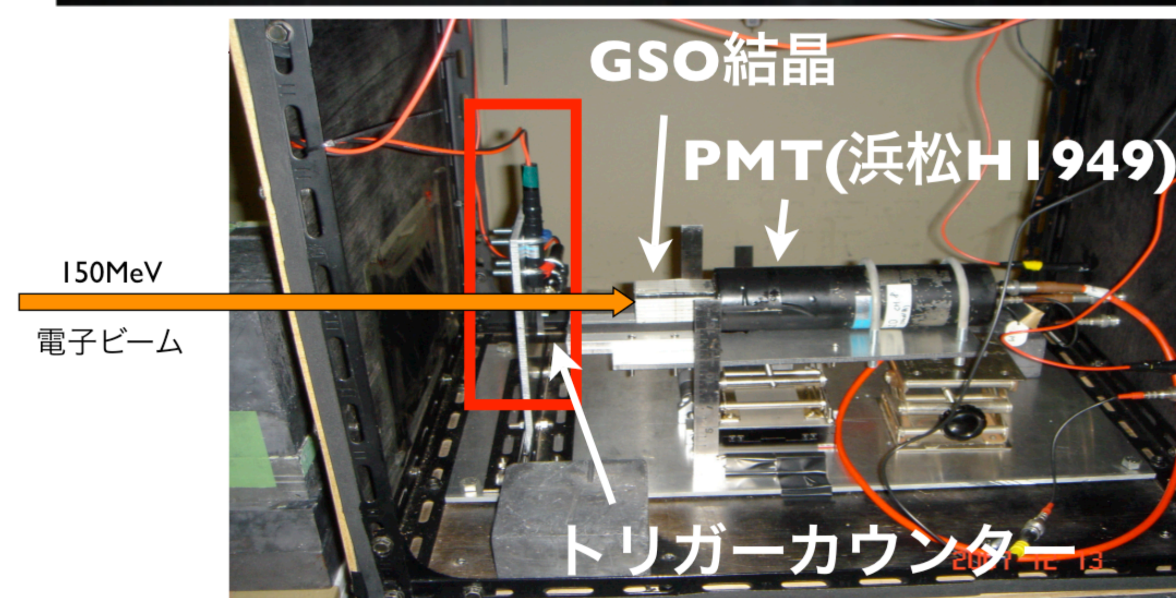
Beam Tests with GSO(Ce) crystals

- GSO(Ce) with PMTs
  - a 150 MeV e- beam from REFER, Hiroshima-University
  - good agreements with the simulation results

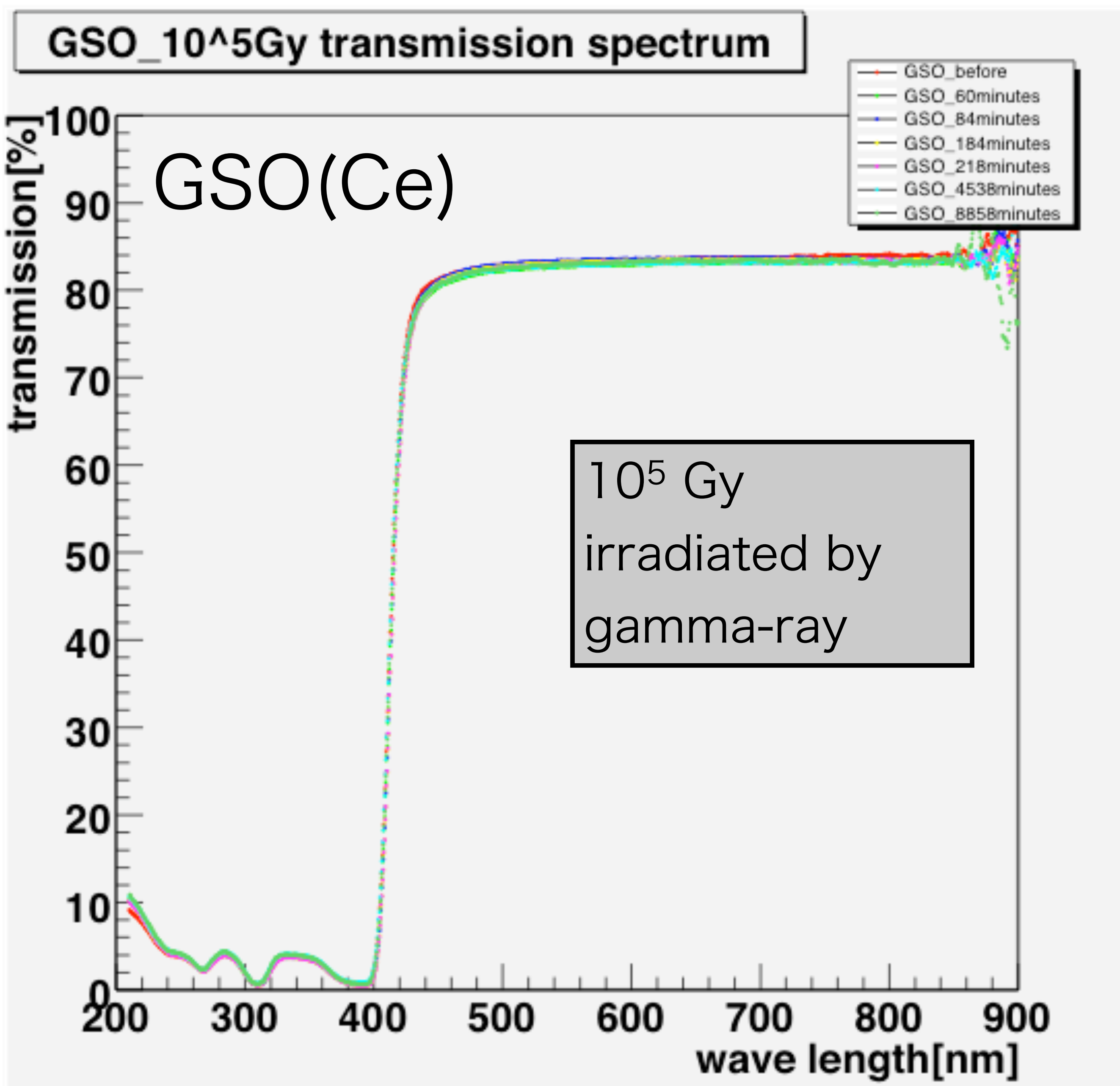


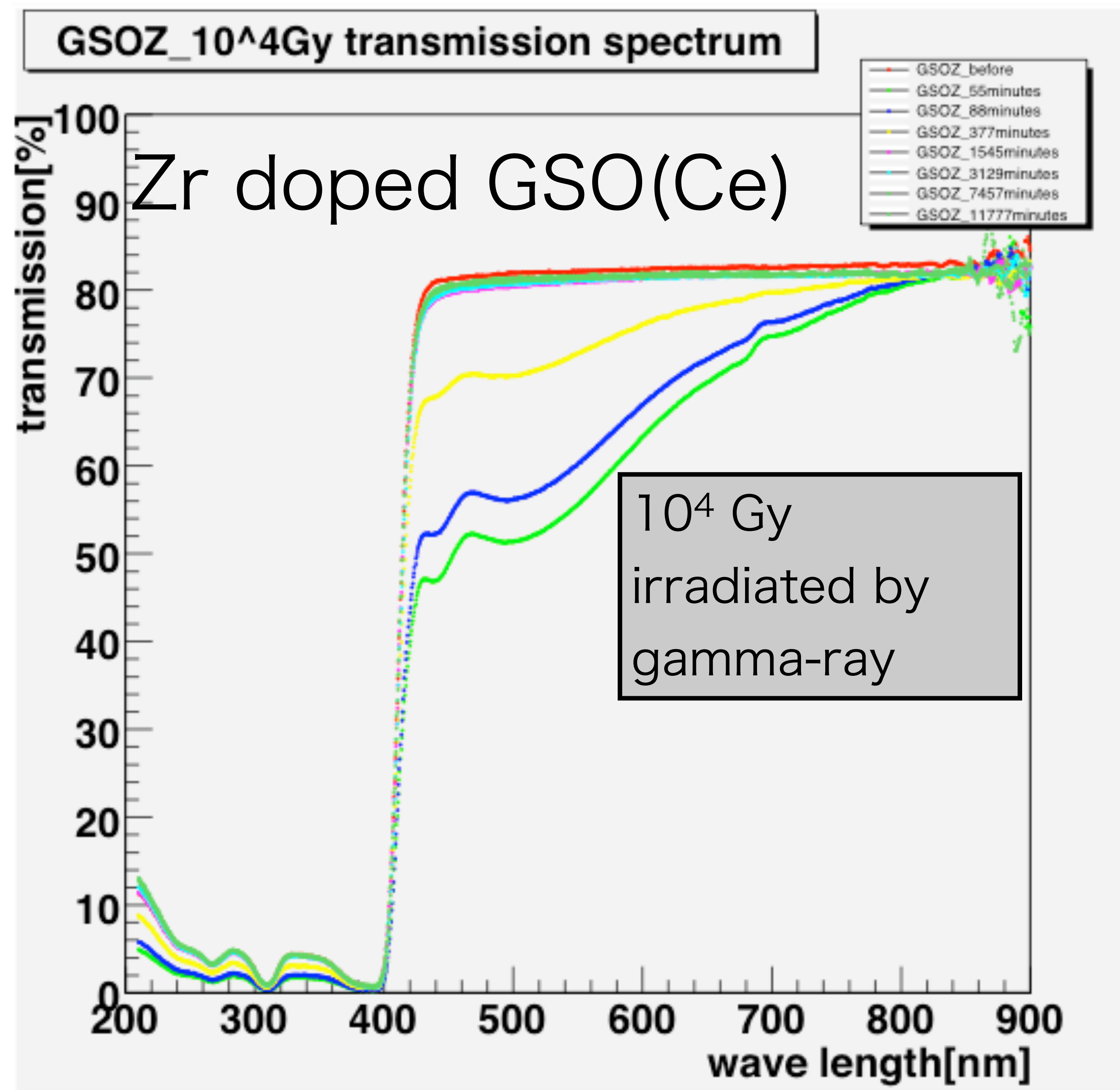
- Another test with APD readout will be done in November, 2008.





Radiation Hardness of GSO(Ce) and Zr-GSO(Ce)





- GSO(Ce) has high radiation hardness as expected.
- Zr doped GSO(Ce), which has higher light yield, has less hardness.

Simulations

Charged Particle Trajectory in Curved Solenoids

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

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

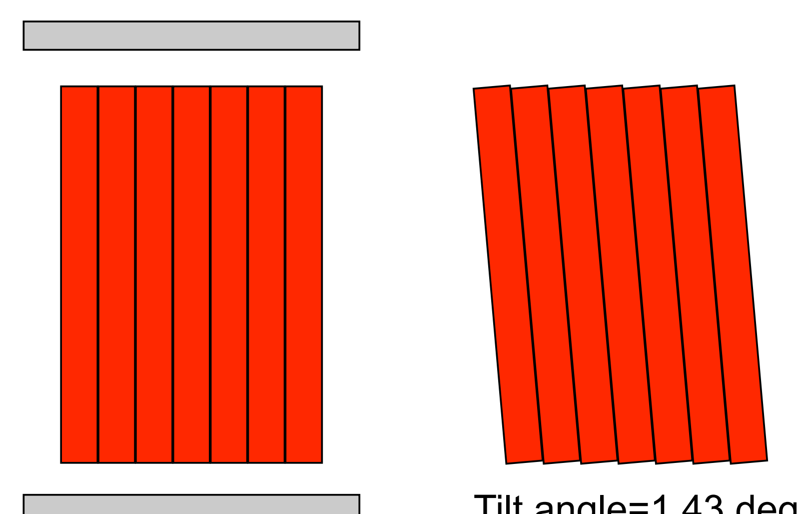
D : drift distance
B : Solenoid field
θ_{bend} *: Bending angle of the solenoid channel*
p : Momentum of the particle
q : Charge of the particle
θ *: atan*(P_T/P_L)

  - This 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)

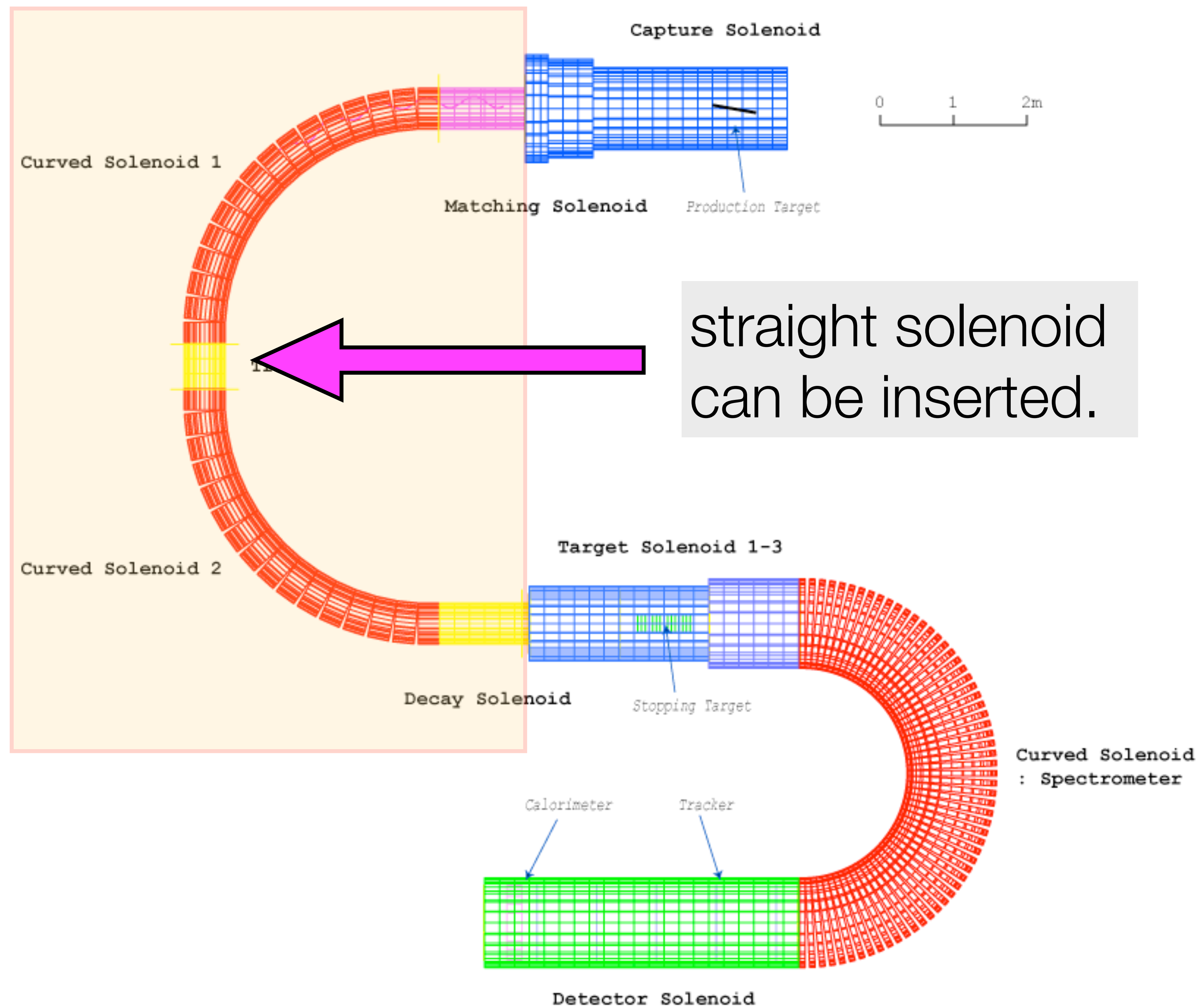


Requirements for Muon Beam-line

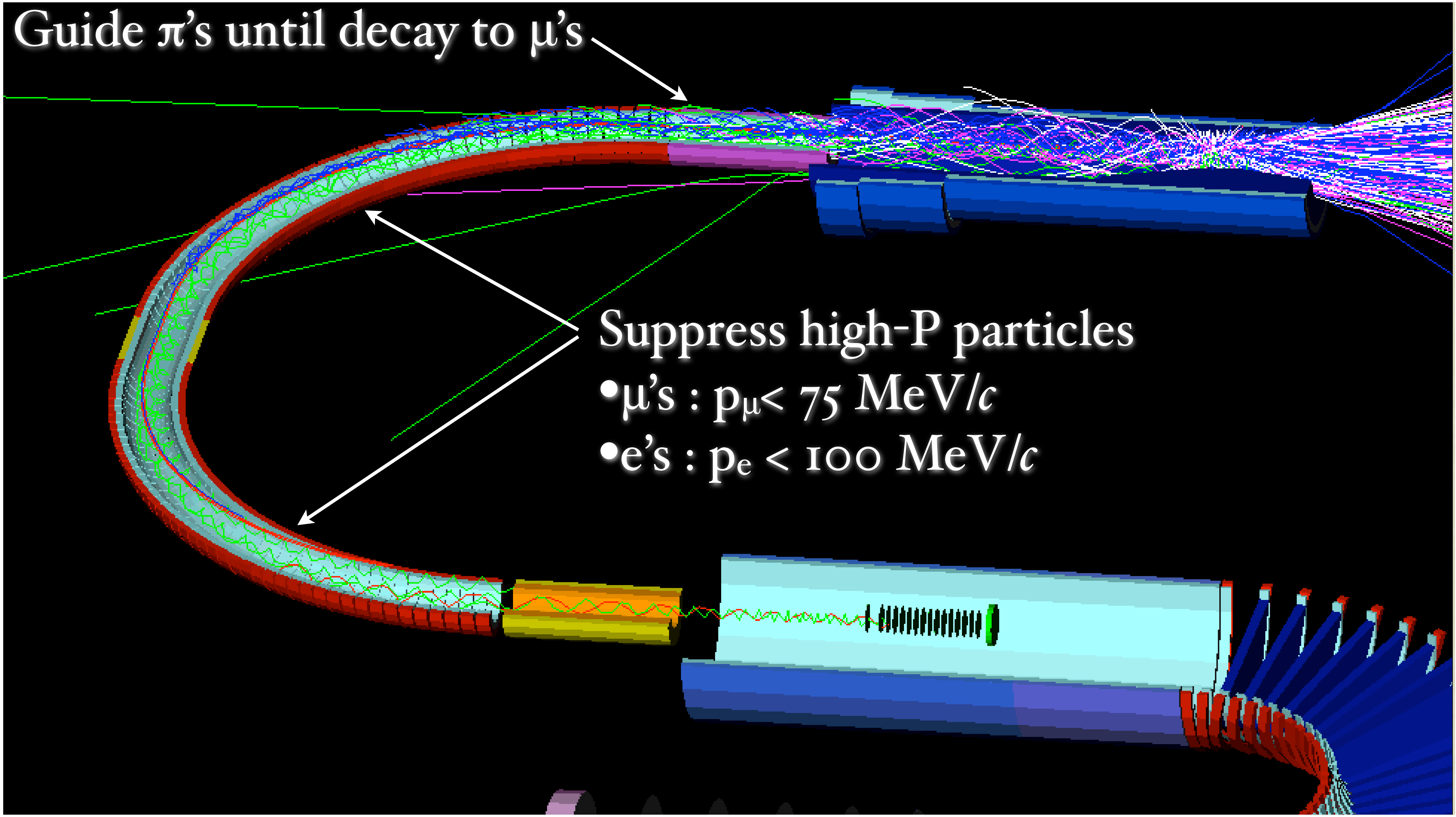
- Requirements :
  - long enough for pions to decay to muons (> 20 meters ≈ 2×10^{-3}).
  - high transport efficiency ($P_\mu \sim 40$ MeV/c)
  - negative charge selection
  - low momentum selection and elimination of high-momentum muons ($P_\mu < 75$ MeV/c to avoid muon decay in flight).

Muon Transport Solenoid Beam-line for COMET

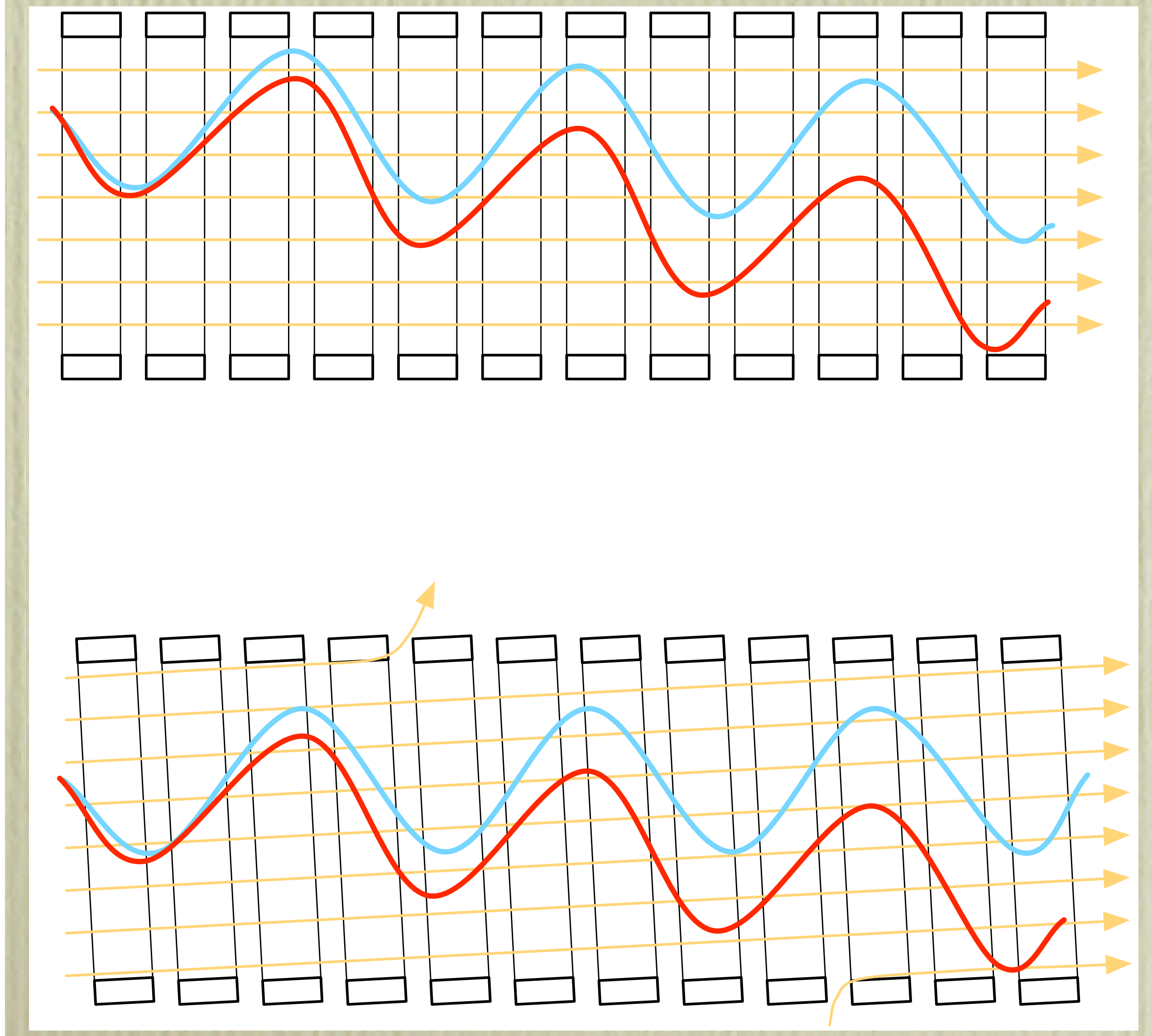
- C-shape beam line :
  - better beam momentum separation
  - collimators can be placed anywhere.
- Radius of curvature is about 3 meters.
- A straight solenoid section can be inserted between the two toroids.
- Reference momentum is 35 MeV/c for 1st bend and 47 MeV/c for 2nd bend.

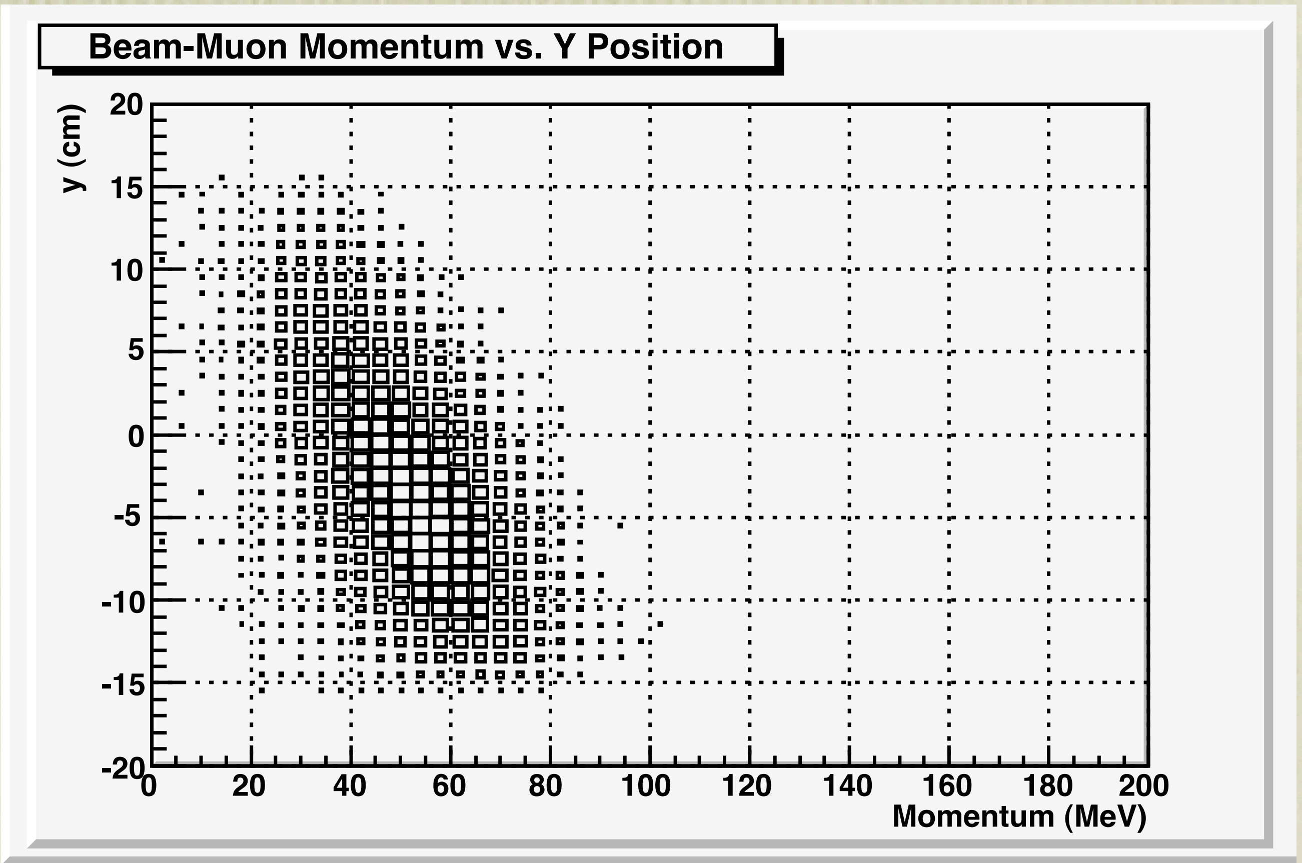


G4beamline Simulation for COMET



Muon Beam Dispersion at Muon Stopping Target



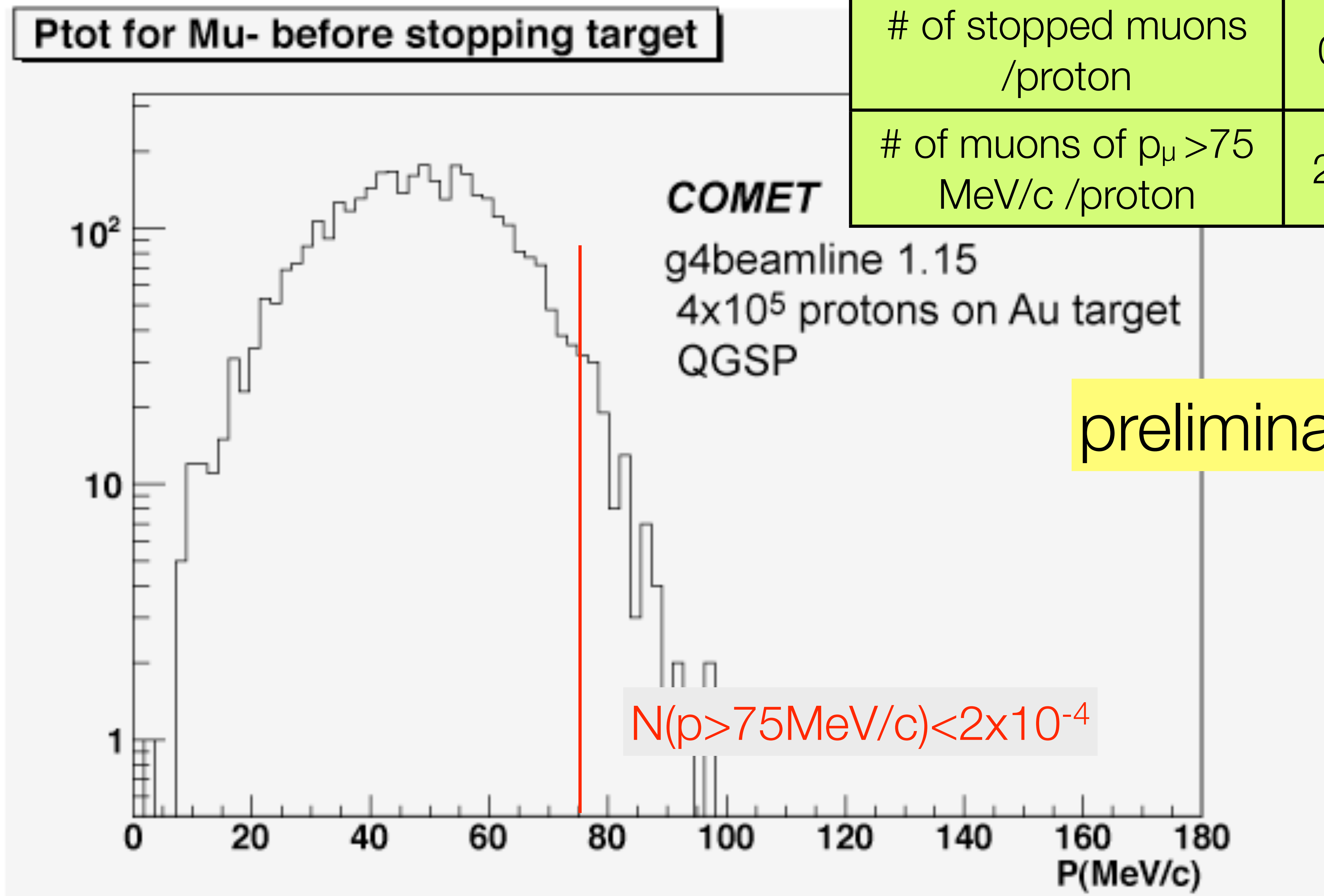


$\delta P/\delta x$ = 1 MeV/c/cm

How can we make use of this dispersion ?

Muon Momentum Spectrum at the End of the Transport Beam Line

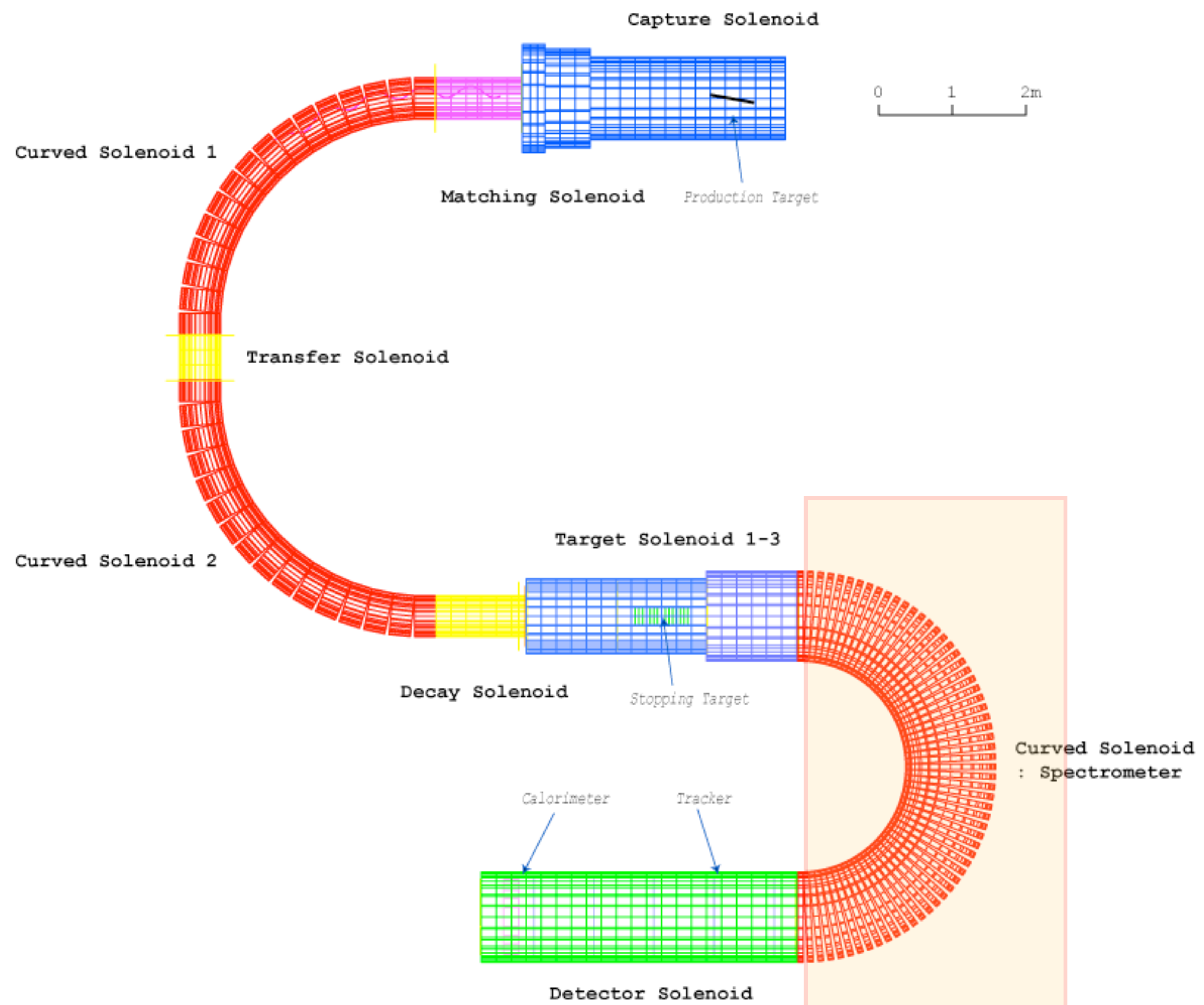
# of muons /proton	0.009
# of stopped muons /proton	0.003
# of muons of p_μ >75 MeV/c /proton	$2x10^{-4}$



preliminary

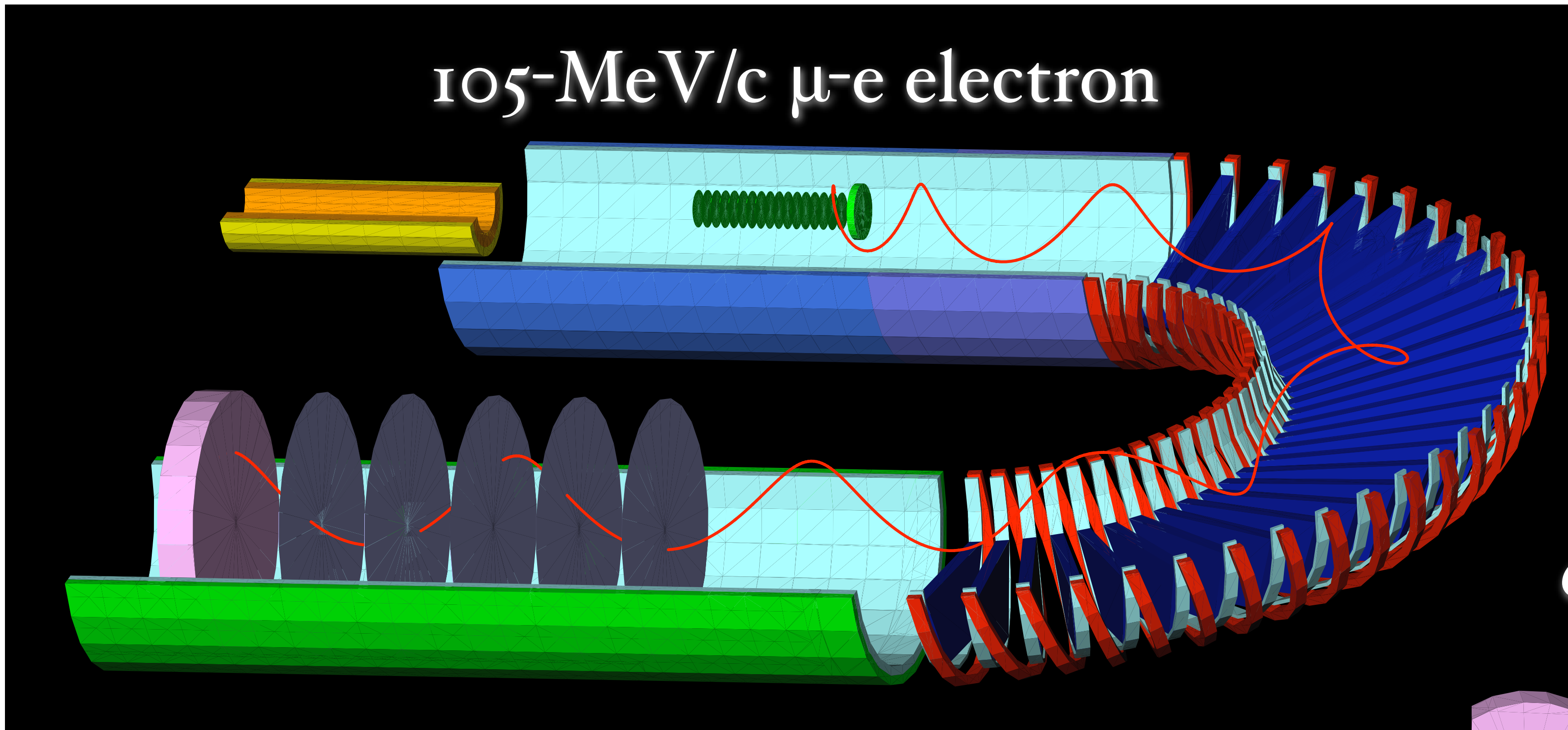
Curved Solenoid Spectrometer for COMET

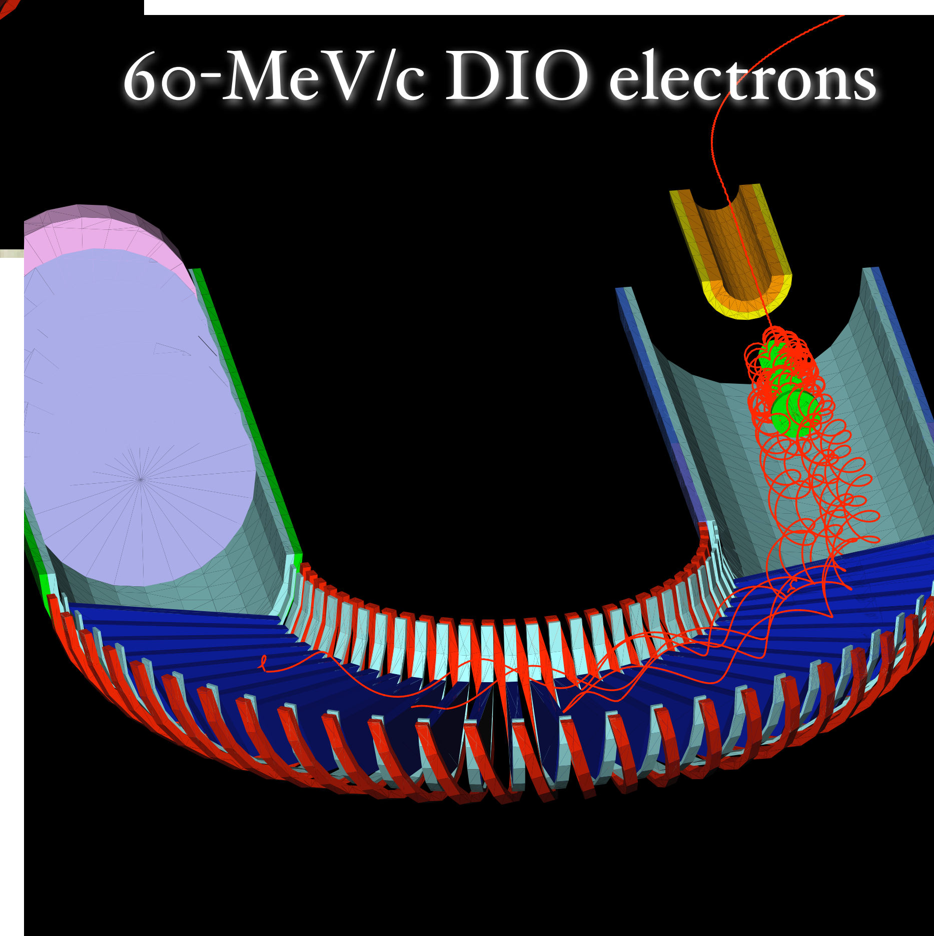
- 180 degree curved
  - Bore radius : 50 cm
  - Magnetic field : 1T
  - Bending angle : 180 degrees
- reference momentum ~ 104 MeV/c
- elimination of particles less than 80 MeV/c for rate issues
- a straight solenoid where detectors are put follows.



schematic

Event Displays for Curved Solenoid Spectrometer



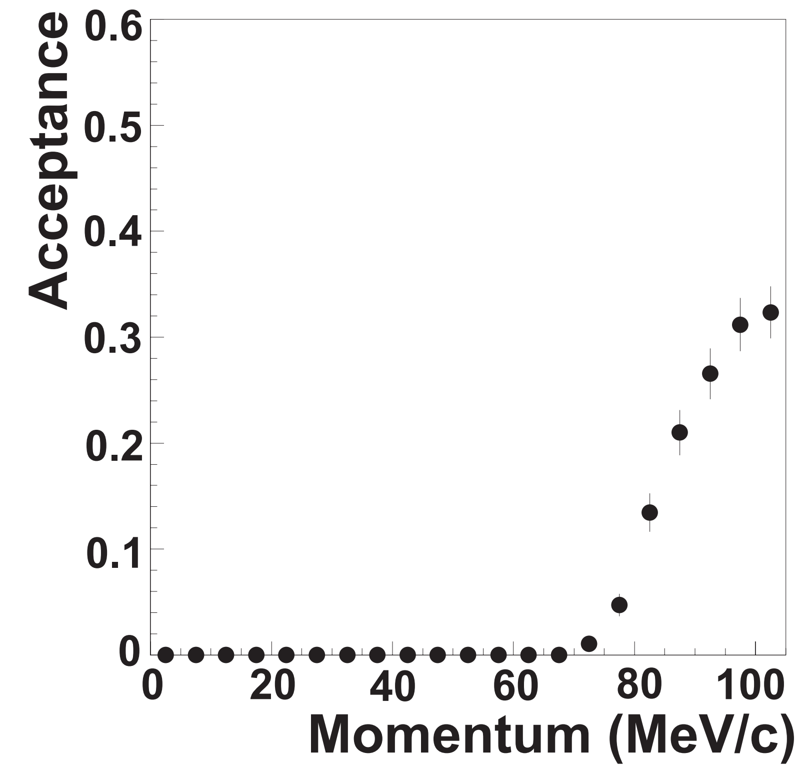


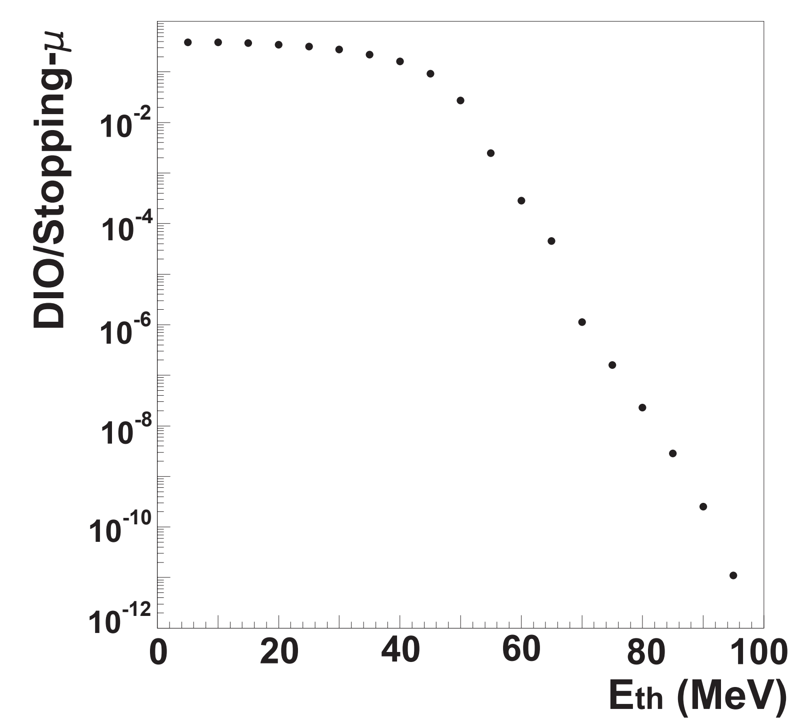
Suppression of DIO electrons

preliminary

- collimators inside the bore
- suppression of electrons from decay in orbit (DIO).
  - about 10^{-8} suppression for DIO electrons
  - about 1-10 k tracks/sec for 10^{11} stopping muons
- protons
- suppression of neutrons and photons
  - the curved solenoid eliminates (the detector do not see directly the muon stopping target.)

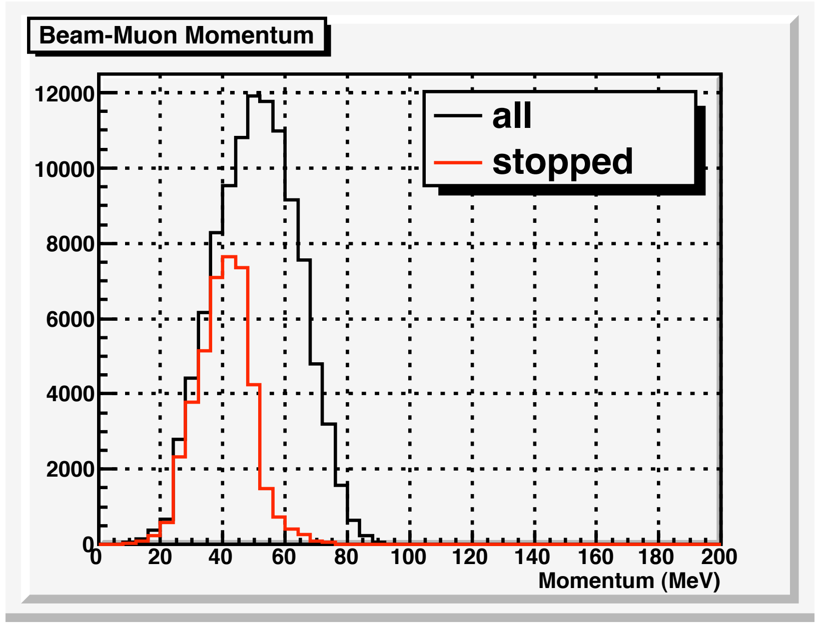
Ratio of a number of electrons reaching the end of transport to all electrons emitted in 4π.

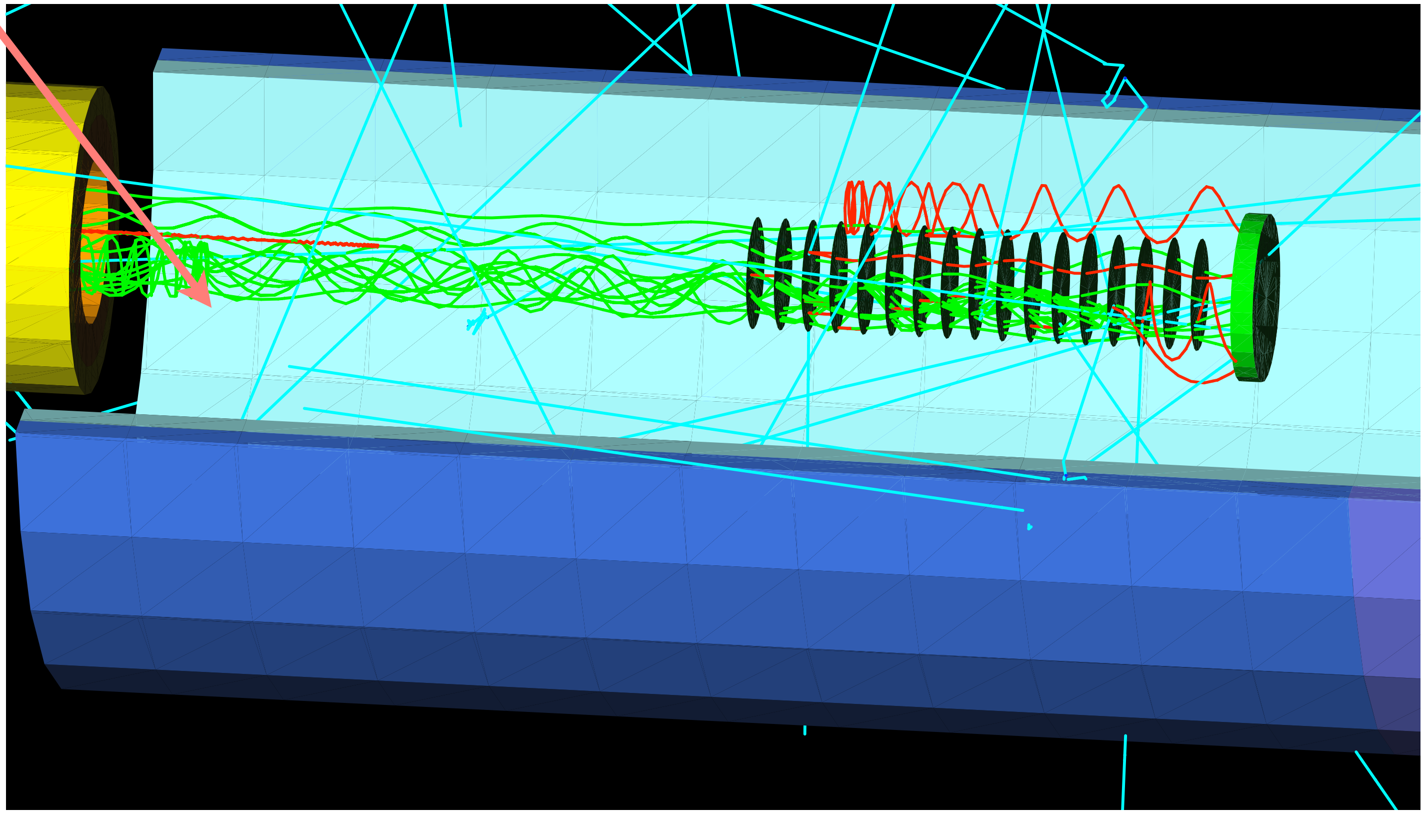




Beam Flash

- Muon beam stop is planned
  - Muon stopping efficiency ~ 30 %
  - Rate due to beam flash is being studied.
  - Special collimators
- Adjustment of the muon stopping target will be made (how many disks, degrader).
- Preliminary simulation studies are done. More studies will be made.





R&D Plan

Request from the J-PARC PAC (June, 2008)

The PAC thus would like to hear the following reports at the next PAC meeting: 1) A report from the muon task force on the study of the accelerator and muon source and 2) A R&D plan with milestones developed by the collaboration in conjunction with the laboratory for the experiment. A notable element of these reports is the

- A preliminary R&D plan is being made.

category	current R&D (as described)	next major R&D steps	comments
accelerator	extinction measurement	addressed by the muon task force (next time)	
experimental hall	extinction measurement		
extinction	monitor R&D AC dipole design	AC dipole construction & test (a few year)	via. US-Japan program ?
SC solenoids	prototype of transport solenoids	design of detector solenoids prototype of capture solenoids	with the KEK cryo, science center
detector	crystal / readout R&D	calorimeter prototype (JINR)	with JINR group
simulation	construction of full simulation code	BG & rate studies Muon beam studies	whole collaboration

category	next major R&D steps	Estimated Costs	Estimated additional FTE needed
accelerator	addressed by the muon task force (next time)		
experimental hall			
extinction	AC dipole construction & test (a few year)	10 M yen	1.5 FTE
SC solenoids	design of detector solenoids prototype of capture solenoids	1 M yen 50 M yen	0.5 FTE
detector	calorimeter prototype (JINR)	5 M yen	from collaboration
simulation	BG & rate studies Muon beam studies		from collaboration

Summary

- R&D for P21 are in progress. The areas are
  - superconducting magnet (with the KEK cryogenics research center)
  - proton extinction monitor and AC dipole magnets (via the US-Japan)
  - detector (calorimeter and trackers)
  - simulation studies
- CDR for P21 is under preparation. Will be submitted in spring, 2009.
- We collaborate with the Muon task force at KEK.
- After the muon task force report and CDR, the COMET collaboration like to know milestone for the stage-1 approval.

Backups