Study of Pion Capture Solenoids for PRISM

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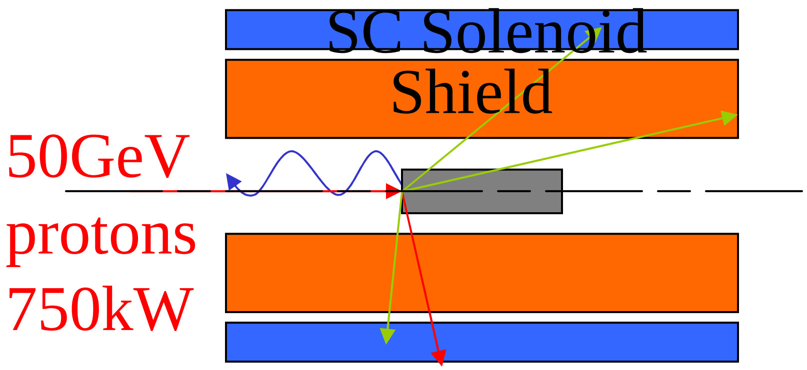
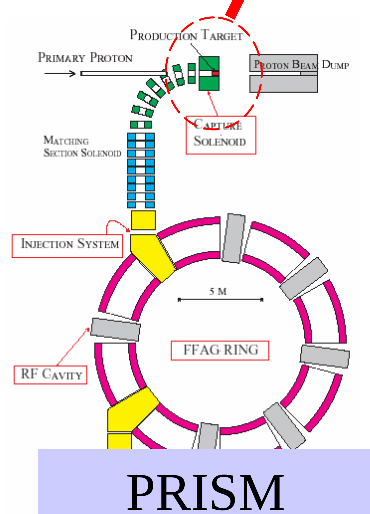
Outline

- Introduction
  - Pion capture solenoid for PRISM
- **A Model Experiment to Measure Radiation Heat Load**
  - Experimental set up
  - Measurement
  - Results
  - Comparison with simulation results (MARS)
- Further R&D plan
- Summary

Pion Capture Solenoid for PRISM



Pion capture solenoid



PRISM

- PRISM needs the SC solenoid required a high field (B_c = 6~12 T)
  - Keep the solenoid at low temperature
- The solenoid is heated by radiations from the target
- To reduce the radiation heat load, thick radiation shield is needed

- We estimate the radiation heat load with simulation code MARS, but the accuracy of simulation results have not been studied

→ We experimentally evaluate the accuracy of simulation results.

A Model Experiment to Measure Radiation Heat Load

- Radiation heating in a model solenoid (mockup) was precisely measured
- The experimental results were compared with the result obtained by MARS

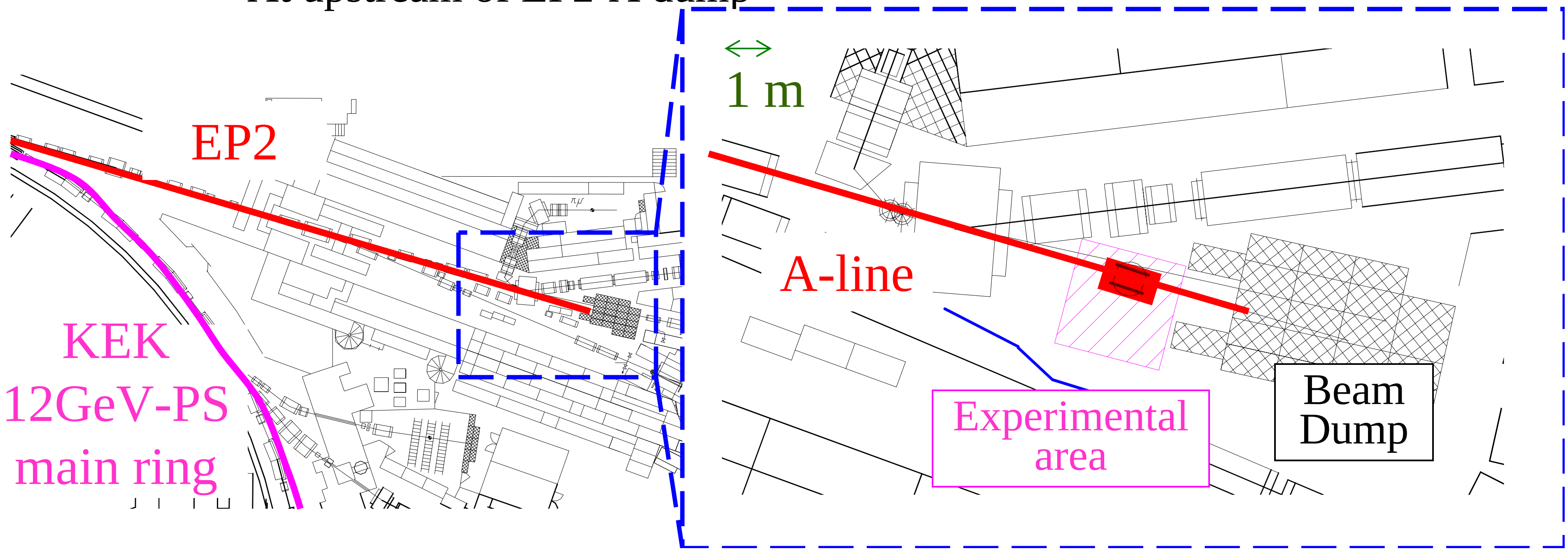
Experimental Conditions
(KEK 12GeV-PS)

Beam parameters

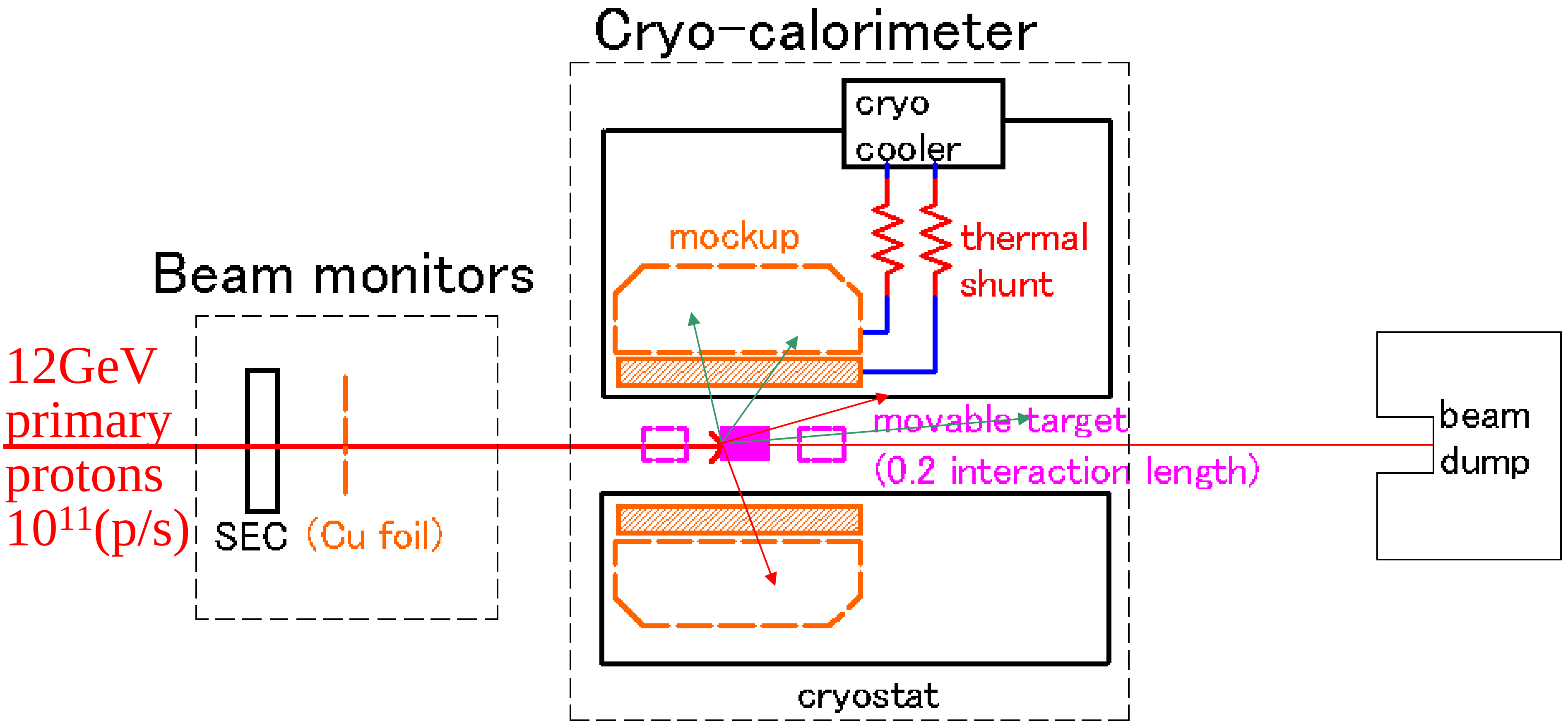
- 12 GeV proton
- Intensity ~10^{11} (protons/sec)
- Slow extraction

Experimental area

- At upstream of EP2-A dump



Experimental setup

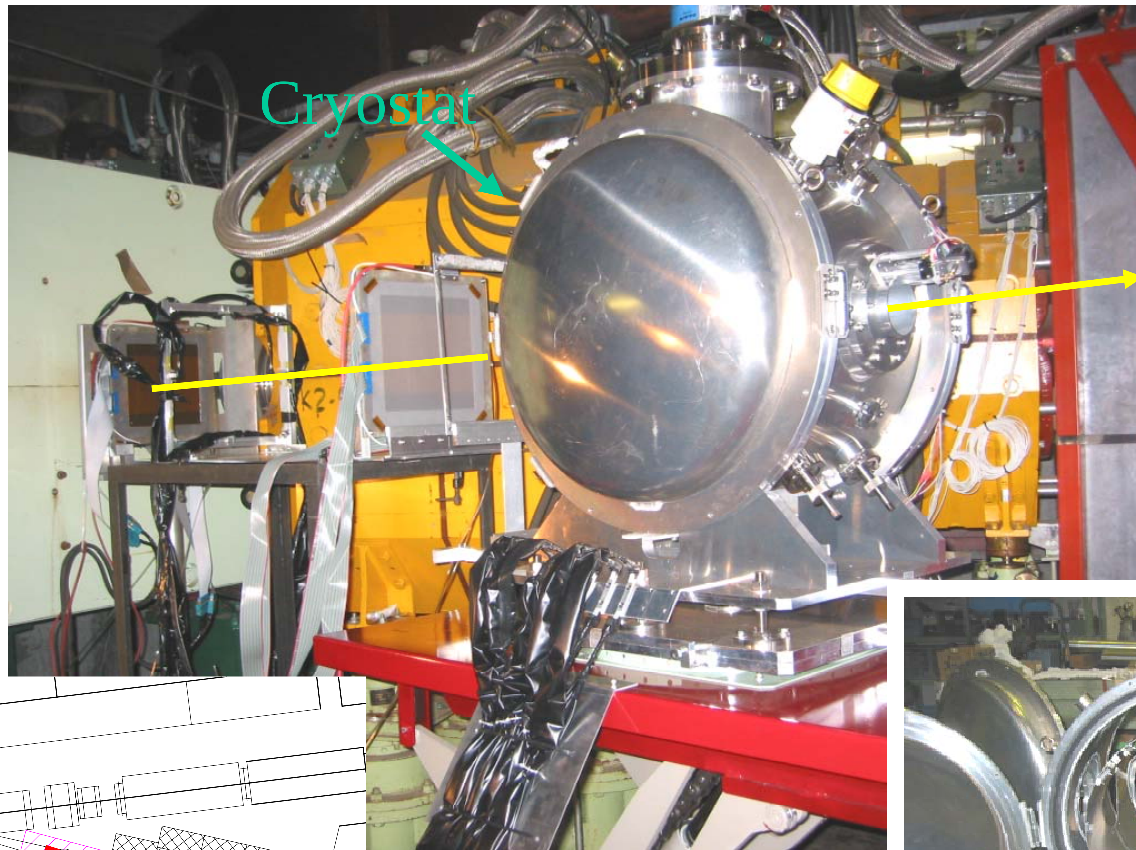


- Sensitive measurement of radiation heat load to the mockup with the cryo-calorimeter

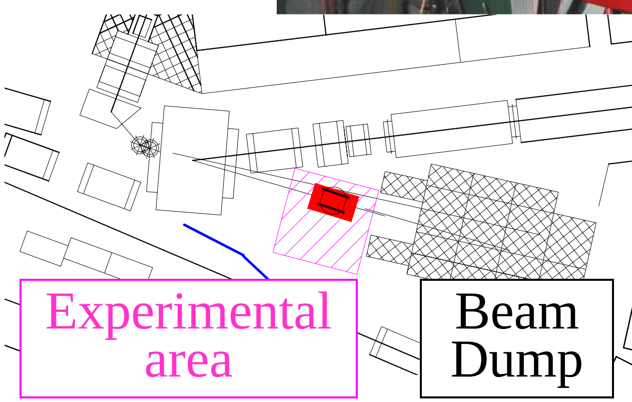
Experimental Installation

12GeVPS
primary protons

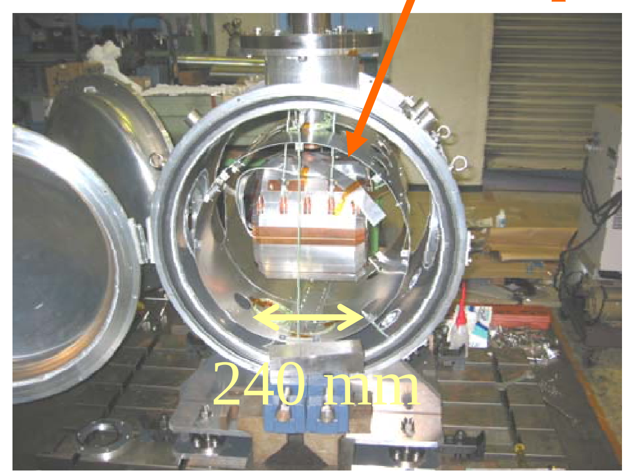
12GeV
$\sim 10^{11}$(p/s)



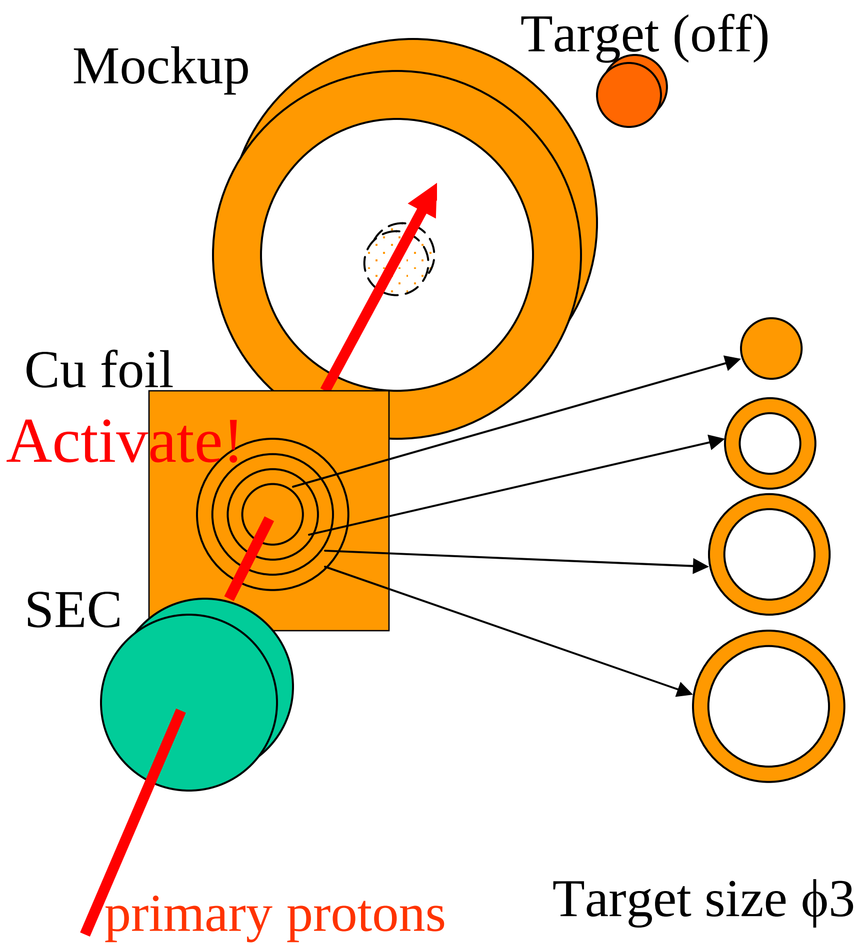
Beam dump



Mockup



Profile & Intensity of Primary Protons



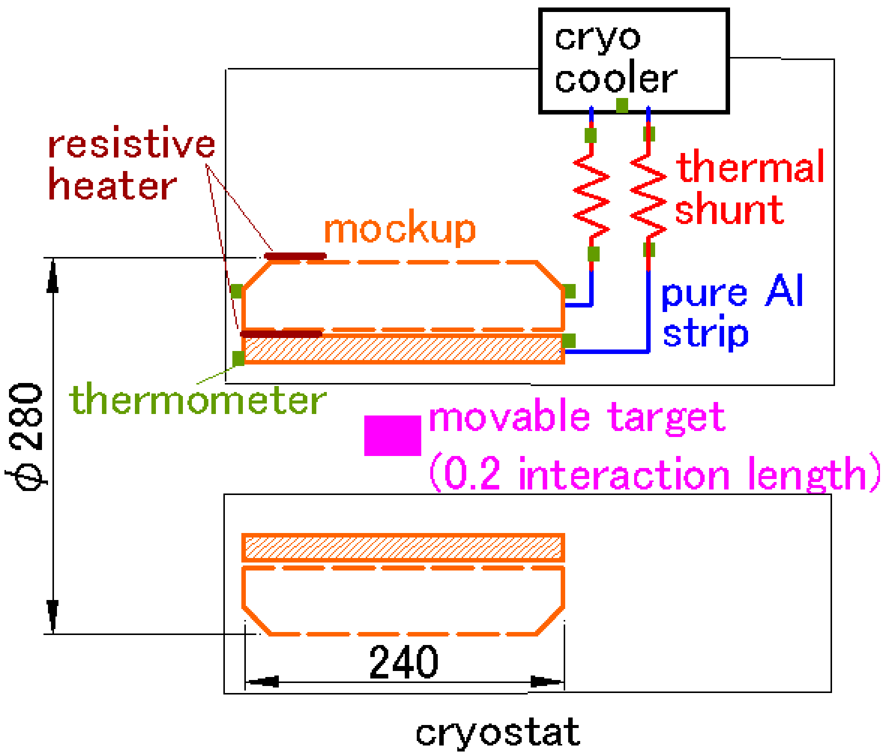
Profile of Primary Protons

Cu foil area (mm)	intensity (protons/sec)	fraction (%)
φ 20	6.70 (±0.45) × 10^{10}	99.92
φ 20_30	3.14 (±0.26) × 10^{7}	0.05
φ 30_40	1.19 (±0.09) × 10^{7}	0.02
φ 40_50	8.00 (±0.77) ×10^{6}	0.01

Target size φ30 → >99.9 % protons bombard the target

SEC count rate 23.16 (counts/sec)
Calibration result 2.89 ± 0.19 (10^{9} protons/count)

Cryo-calorimeter



Highly sensitive measurement by cooling the mockup (20 K)

- Highly sensitive thermometers (resolution < 20 mK)
- Quick response because of small specific heat

Mockup temperature rise up $\Delta T = Q \times K$ at thermal equilibrium state

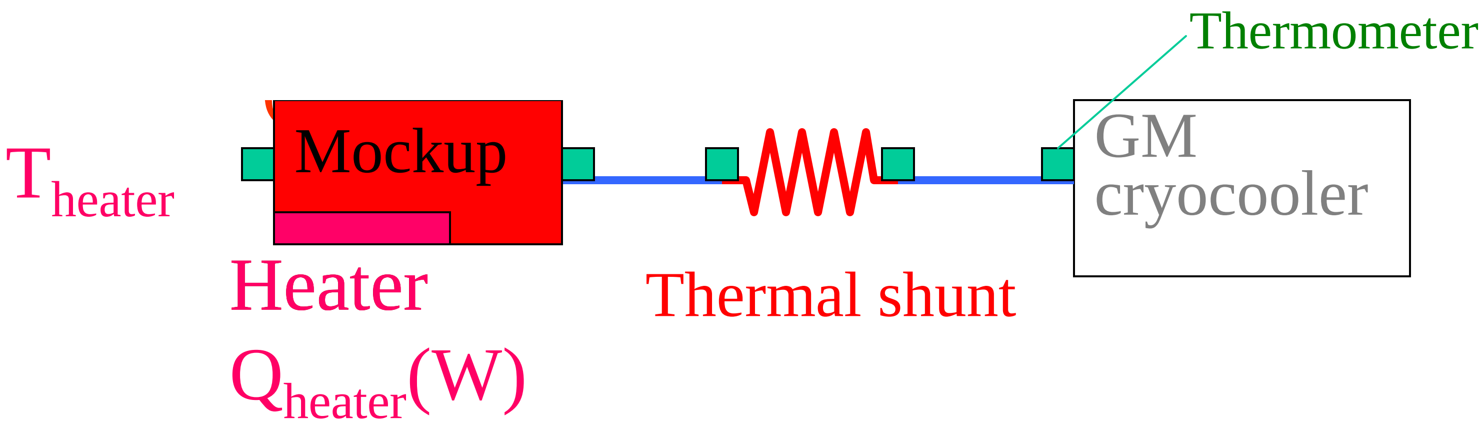
Q : Heat load

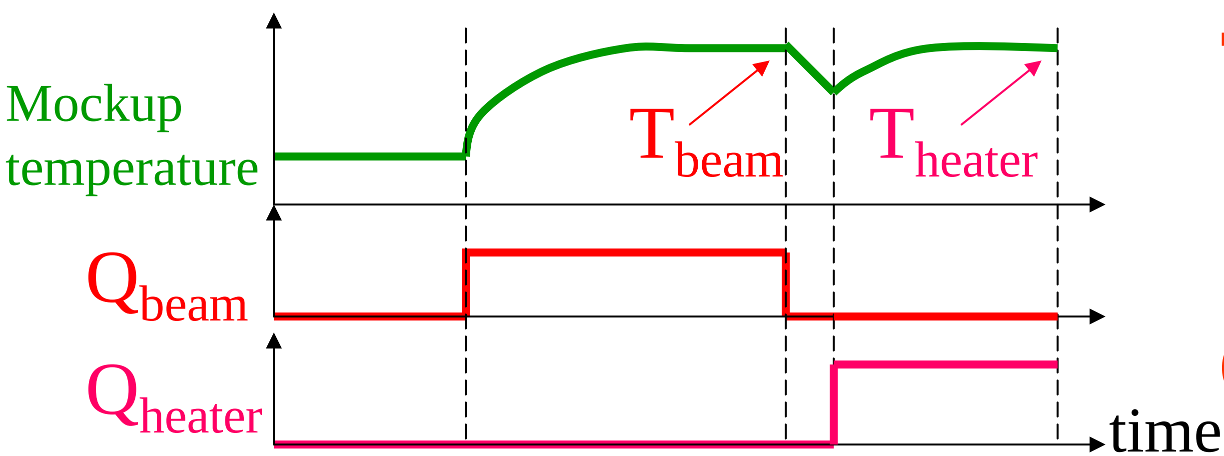
K : Thermal conductance determined by thermal shunt

→ Thermal shunt determines the relation between mockup temperature and heat load

How to Measure Radiation Heat Load

Thermal equilibrium state!

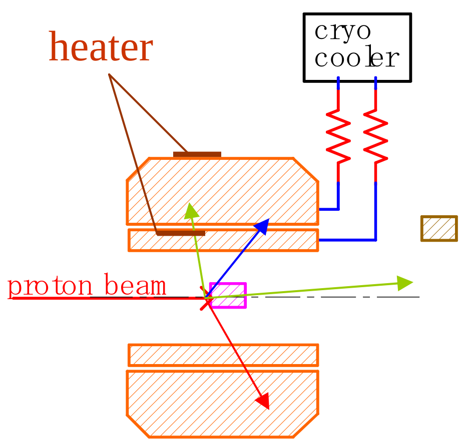


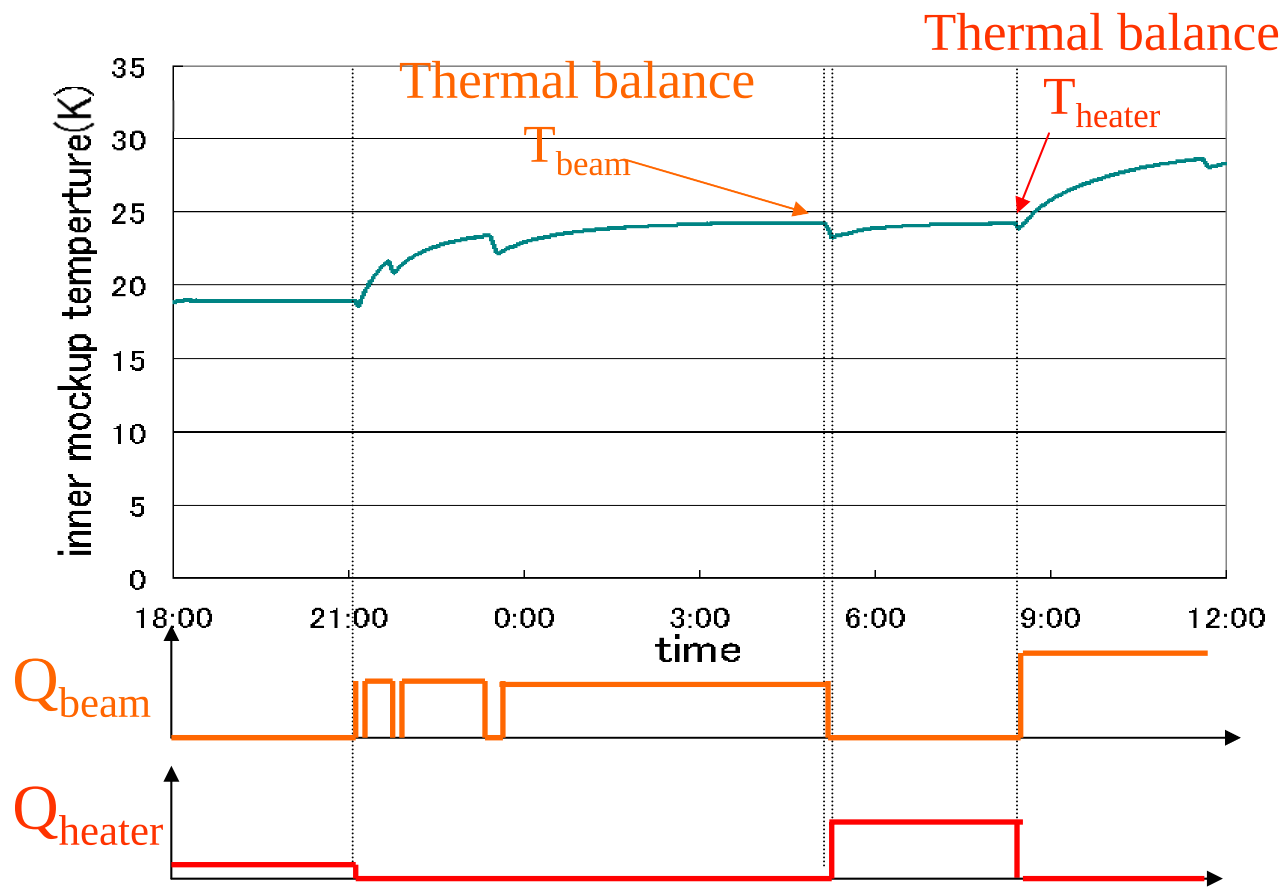


$$T_{beam} = T_{heater}$$

$$\mathbf{Q_{beam}} = Q_{heater}$$

Typical Experimental Data





Target on

Target off

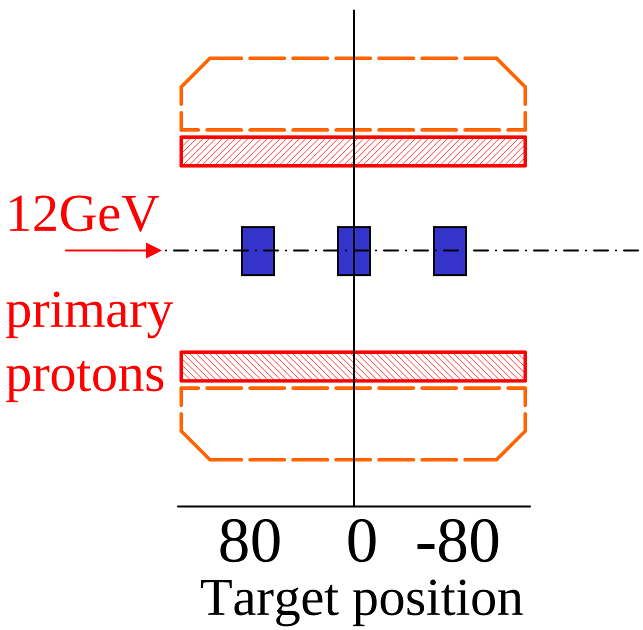
Heater on

Heater off

Target on

$$T_{beam} = T_{heater} \rightarrow Q_{beam} = Q_{heater}$$

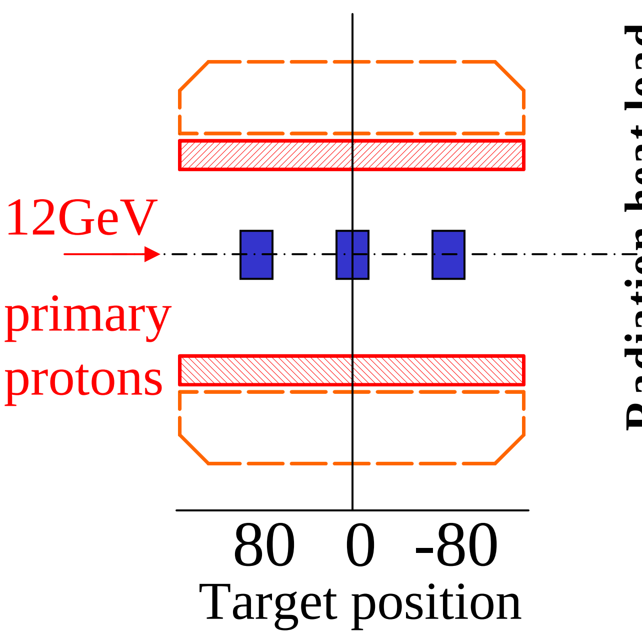
Experimental Results

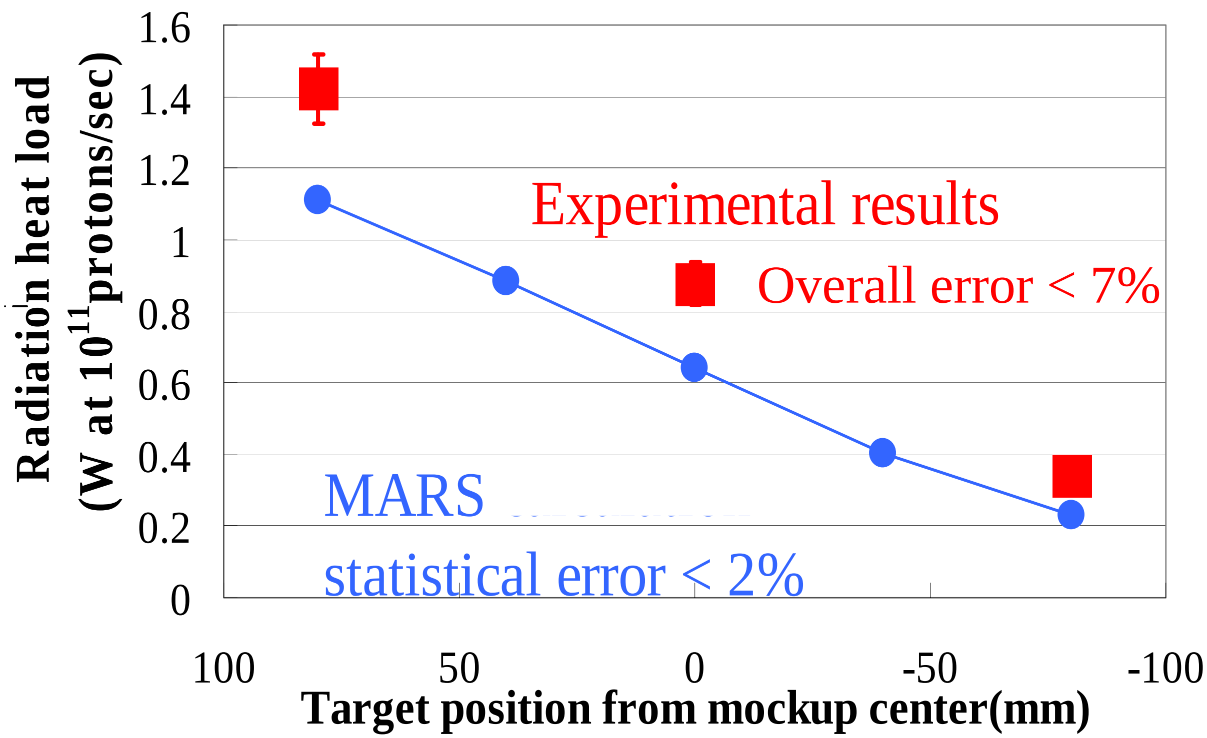


Target position (mm)	Radiation heat load (W at 10^{11} protons/sec)
-80	0.34 ± 0.02
0	0.88 ± 0.06
80	1.42 ± 0.10

Overall error is nearly equal to 7 %

Comparison with simulation results





Experimantal Summary

- We have performed direct measurement of radiation heat load.
- Experimental results are 20-30% higher than simulation results
- Experimental results show the consistent dependency with simulation.

Further R&D Plan for PRISM Capture Solenoid

Base-line Parameters for PRISM Capture Solenoid

- Boundary condition
  - The maximum transverse momentum

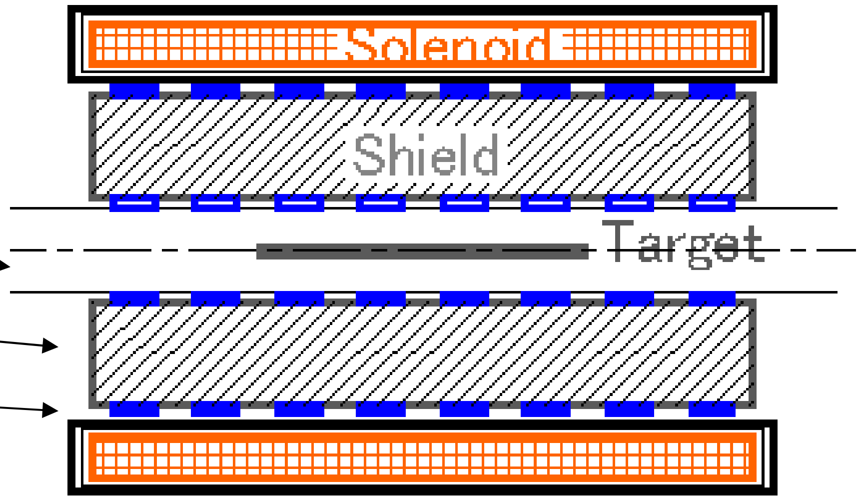
    $P_t = 300 \times B \times R/2 \quad = 90$ MeV/c
- Central field $\quad B_c = 6$ T

- Effective bore $\quad R = 0.1$ m

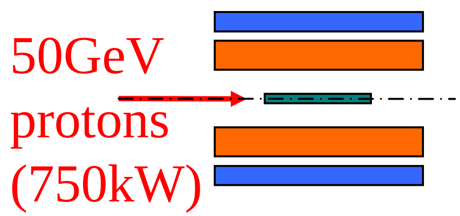
Solenoid Parameters

- Parameters
  - Central field 6 T
  - Coil length (× 2 target length) 1.6 m
  - Stored energy / solenoid mass ratio 10 kJ/kg
  - Solenoid inner radius x
  - Al stabilized NbTi cable

- Radial thickness
  - Beam pipe 0.1 m
  - Radiation shield f(x)
  - Vacuum insulation 0.05 m

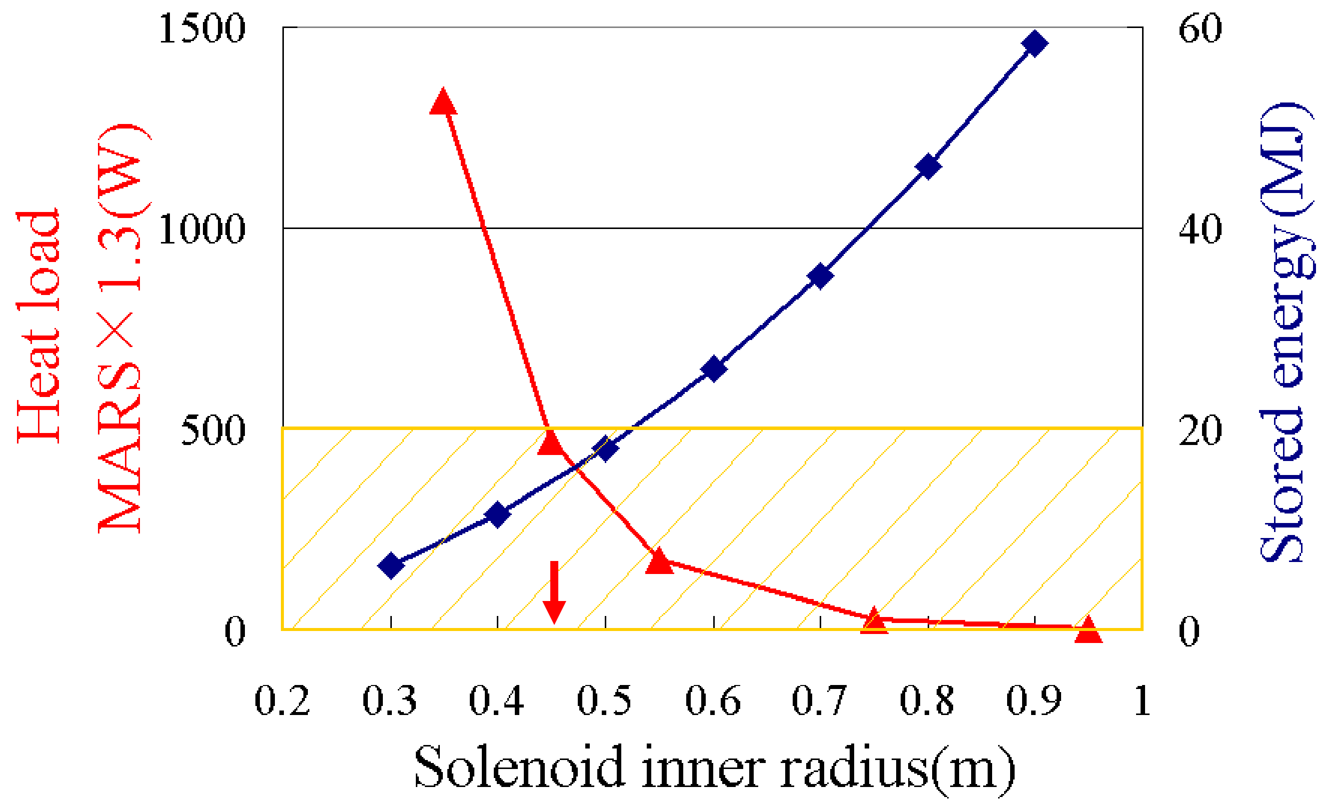


Radiation Heat Load & Stored energy <u>vs. Solenoid radius</u>

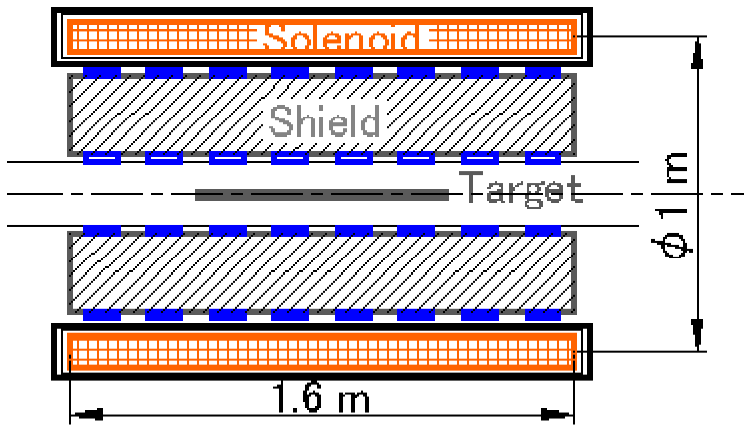


Materials

- Target C(graphite)
- Shield W
- Solenoid Al stabilized NbTi

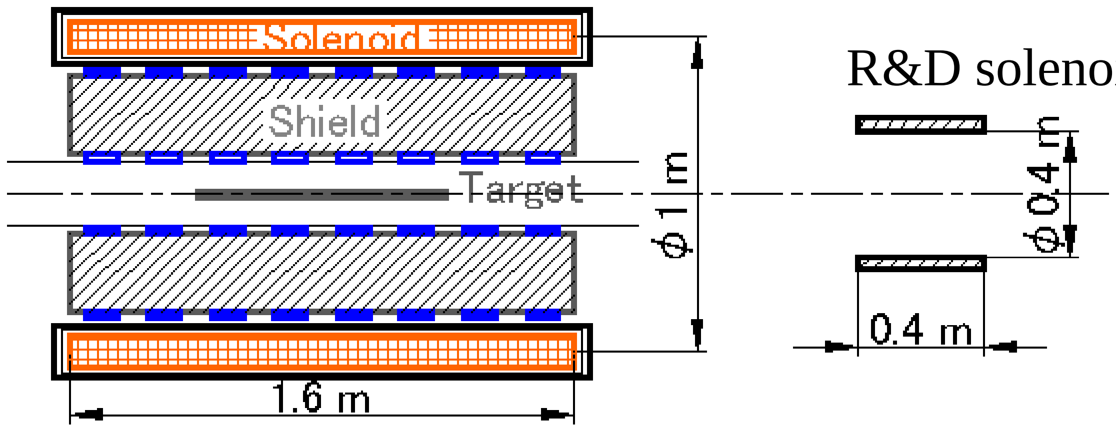


Preliminary design Parameters



	PRISM	
Central field(T)	6	
Shield thickness(m)	0.25	
Solenoid radius(m)	0.45~0.55	
Length(m)	1.6	
stored energy(MJ)	16	
Heat load(W)	470	

Small Size R&D Solenoid



	PRISM	R&D(1/2.5scale)
Central field(T)	6	3~6
Shield thickness(m)	0.25	-
Solenoid radius(m)	0.45~0.55	0.2~0.24
Length(m)	1.6	0.4~0.6
stored energy(MJ)	16	0.5~1
Heat load(W)	470	$470/(2.5)^3 = 30$

Summary

- We have performed direct measurement of radiation heat load
- Experimental results are 20-30% higher than simulation results
- Experimental results show the consistent dependency of target position with simulation
- We are planning R&D with a small size solenoid

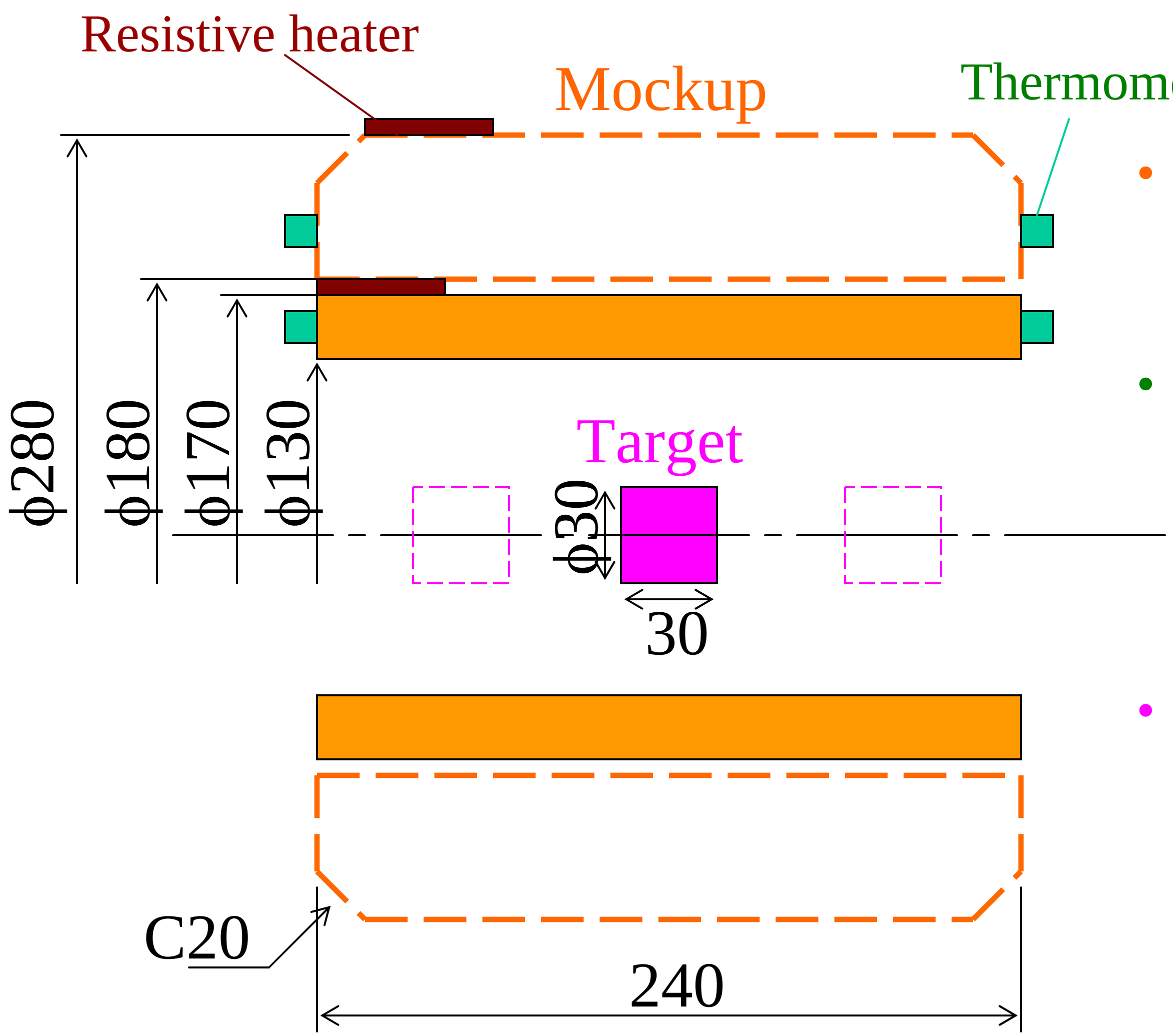
Error Breakdown

Target position (mm)	-80	0	80
*12GeV proton – Cu ^{24}Na production cross section	5.1	5.1	5.1
Ge detector efficiency	4.3	4.3	4.3
Fluctuation of beam intensity	2.1	0.8	1.3
Measurement of heat load	<1	<1	<1
Total error	7.0	6.8	6.8

(%)

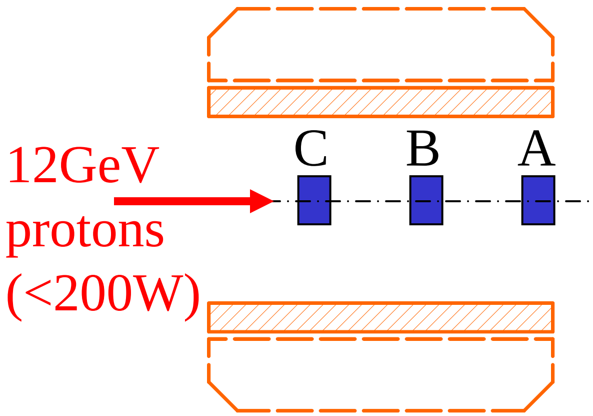
* T.Asano et al, 'Target dependence of charge distributions in spallation reactions of medium-mass nuclei with 12GeV protons' , Phys. Rev. C 28, 1718(1983)

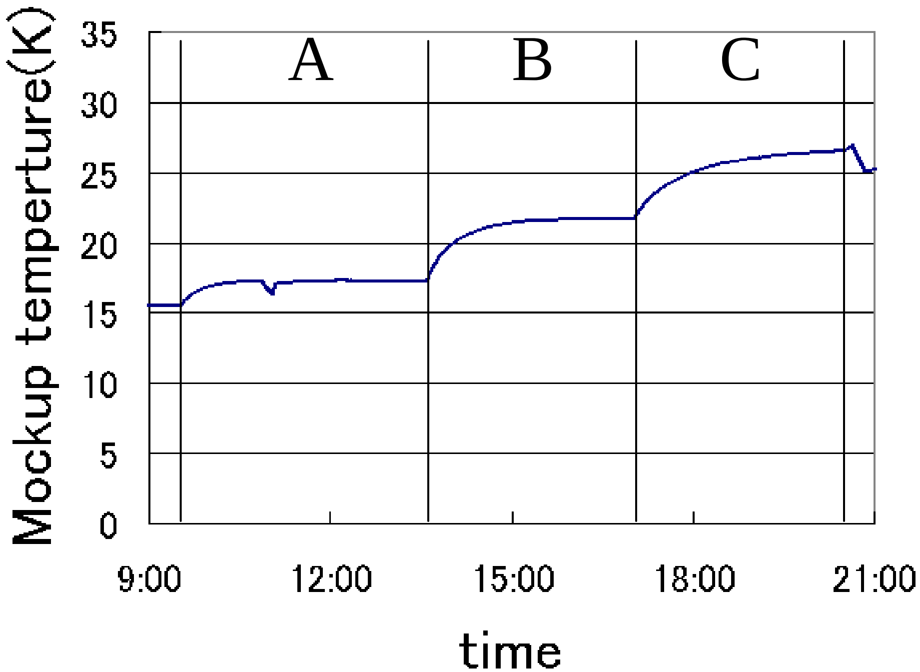
Mockup & Target



- Mockup
  - Made of copper
  - Set resistive heater
- Thermometer
  - High sensitivity at low temperature
  - Four terminal measurement
- Target
  - 0.2 interaction length
  - Movable
  - Made of copper

Typical Experimental Data





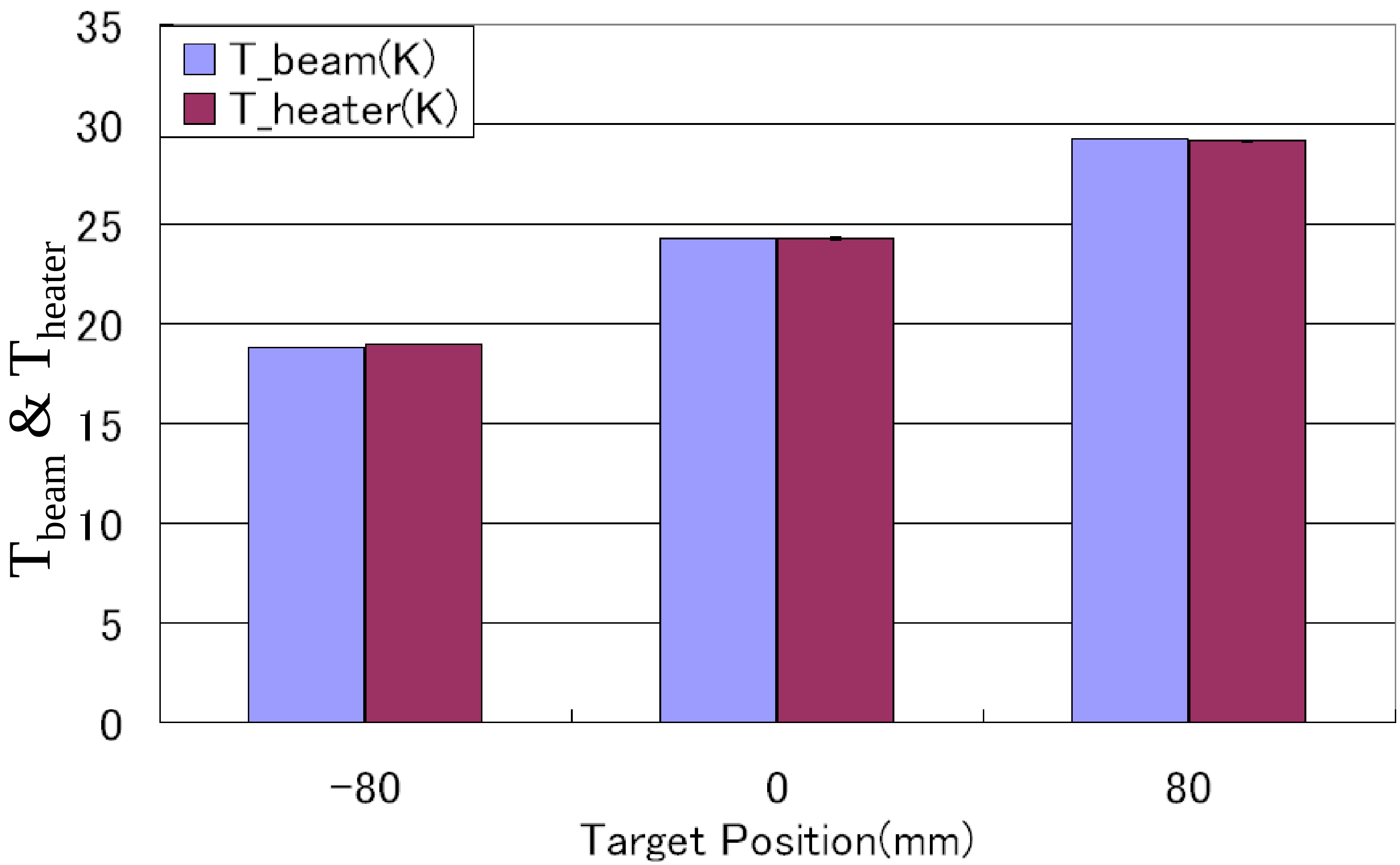
Heat load measurement has need to thermal equilibrium state

Target position move to up-stream

→ higher radiation heat load

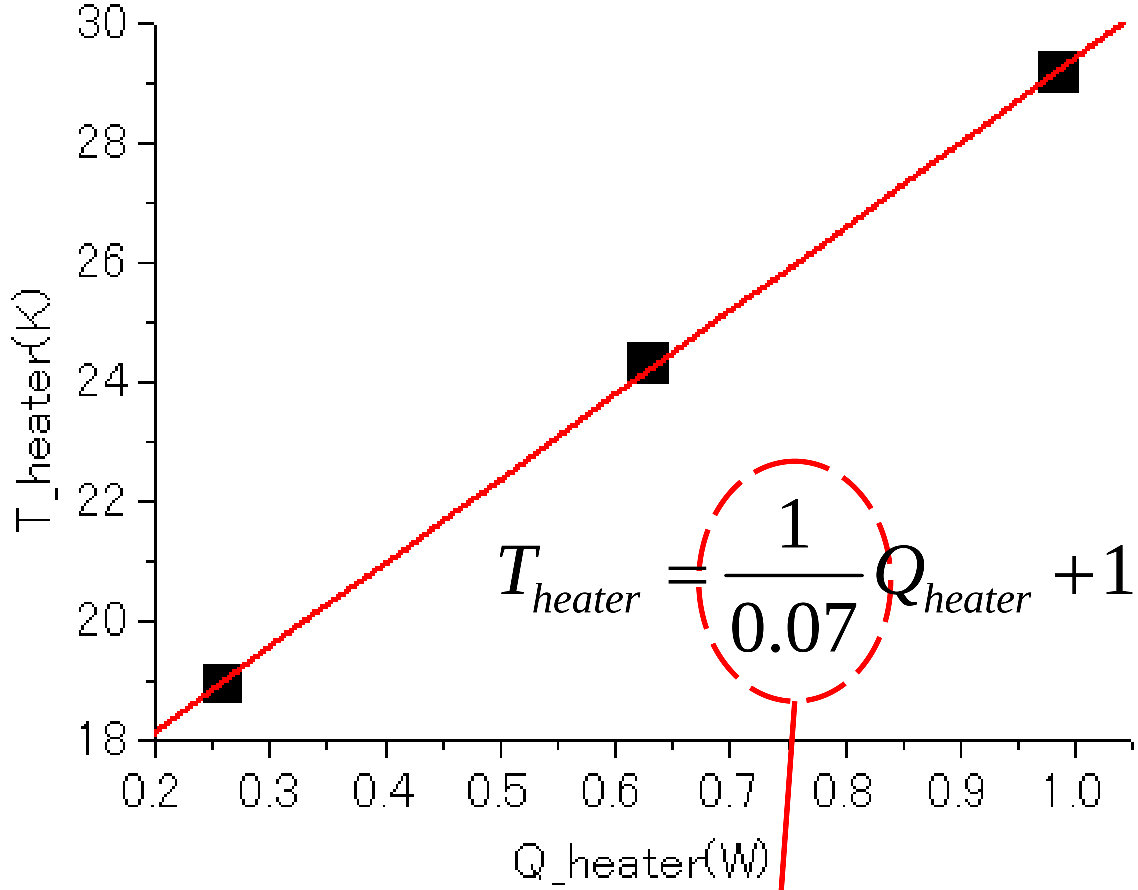
→ Many secondary particles fly out forward

Difference between T_{beam} and T_{heater}



Difference between T_{beam} and T_{heater} < 0.15K

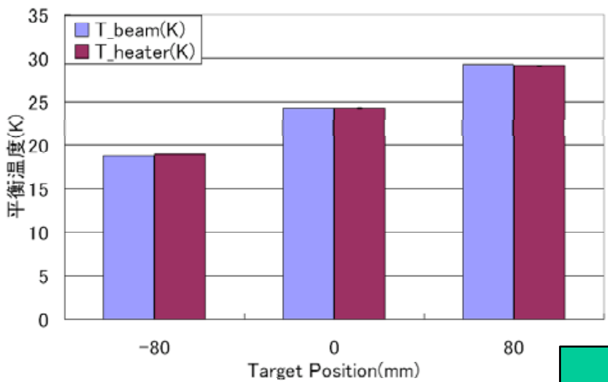
Plot Q_{heater} vs. T_{heater}

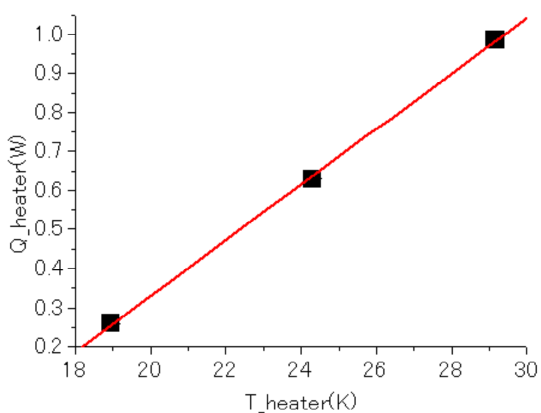


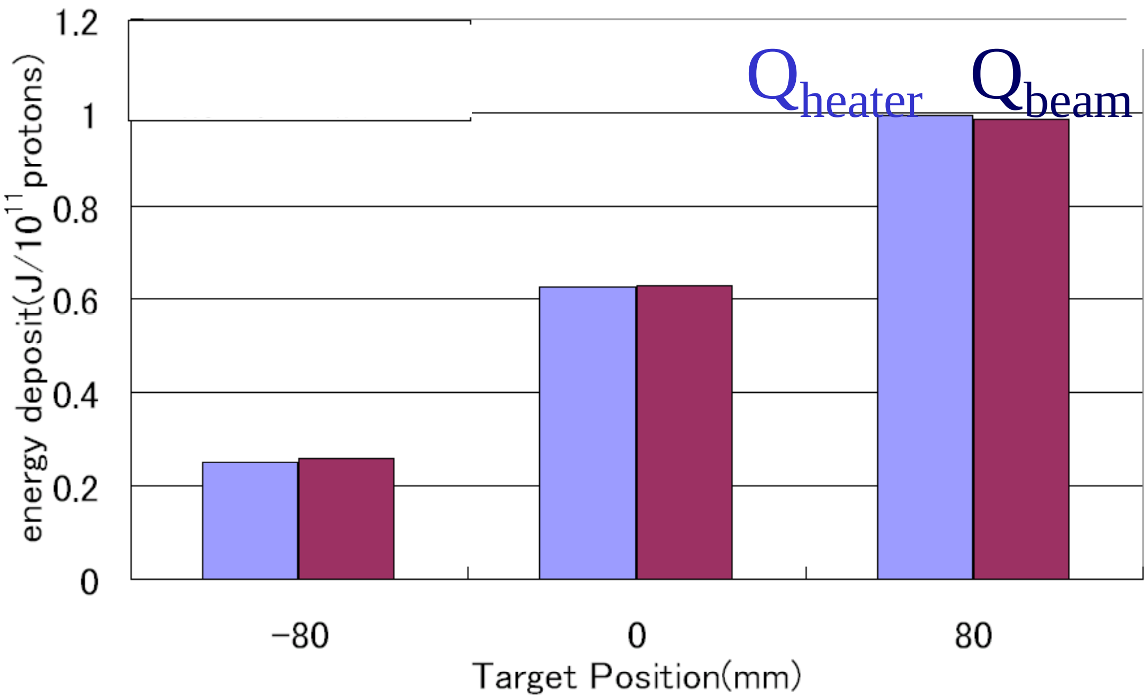
$$T_{heater} = \frac{1}{0.07} Q_{heater} + 15.35$$

$$\Delta T = Q \times K$$

Correcting Q_{beam} with difference between T_{beam} and T_{heater}

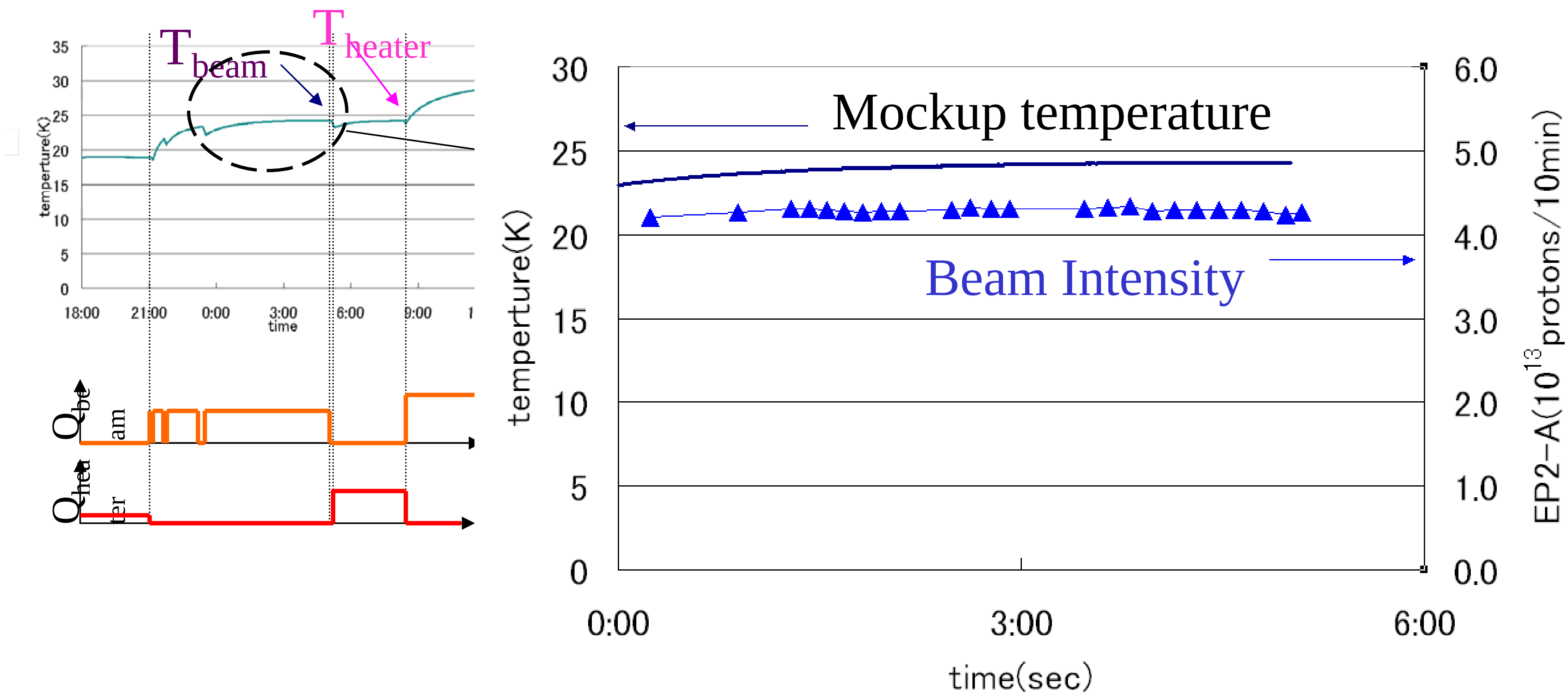






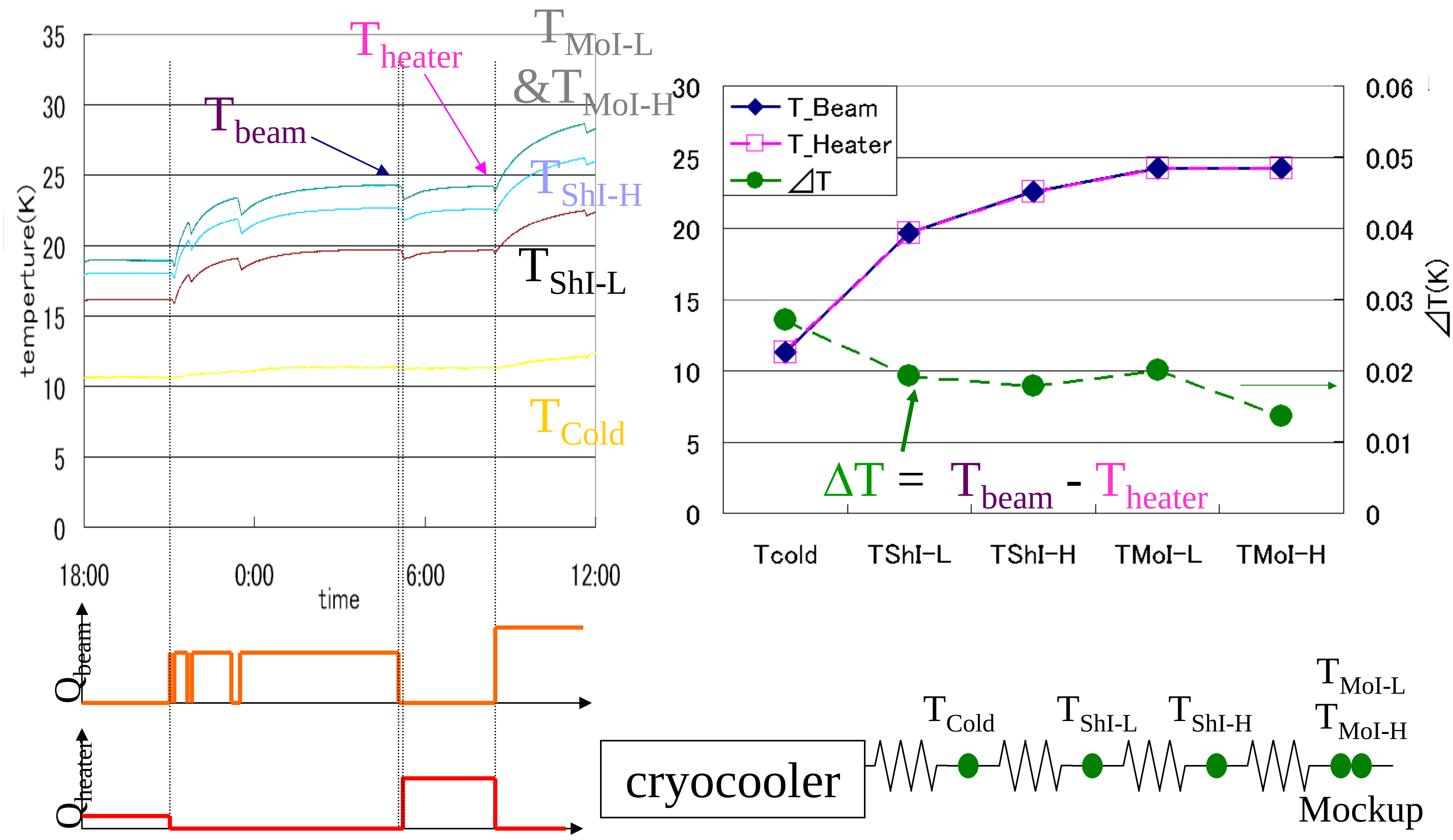
Effect of the difference between T_{beam} and T_{heater} < 1%

Fluctuation of Beam Intensity

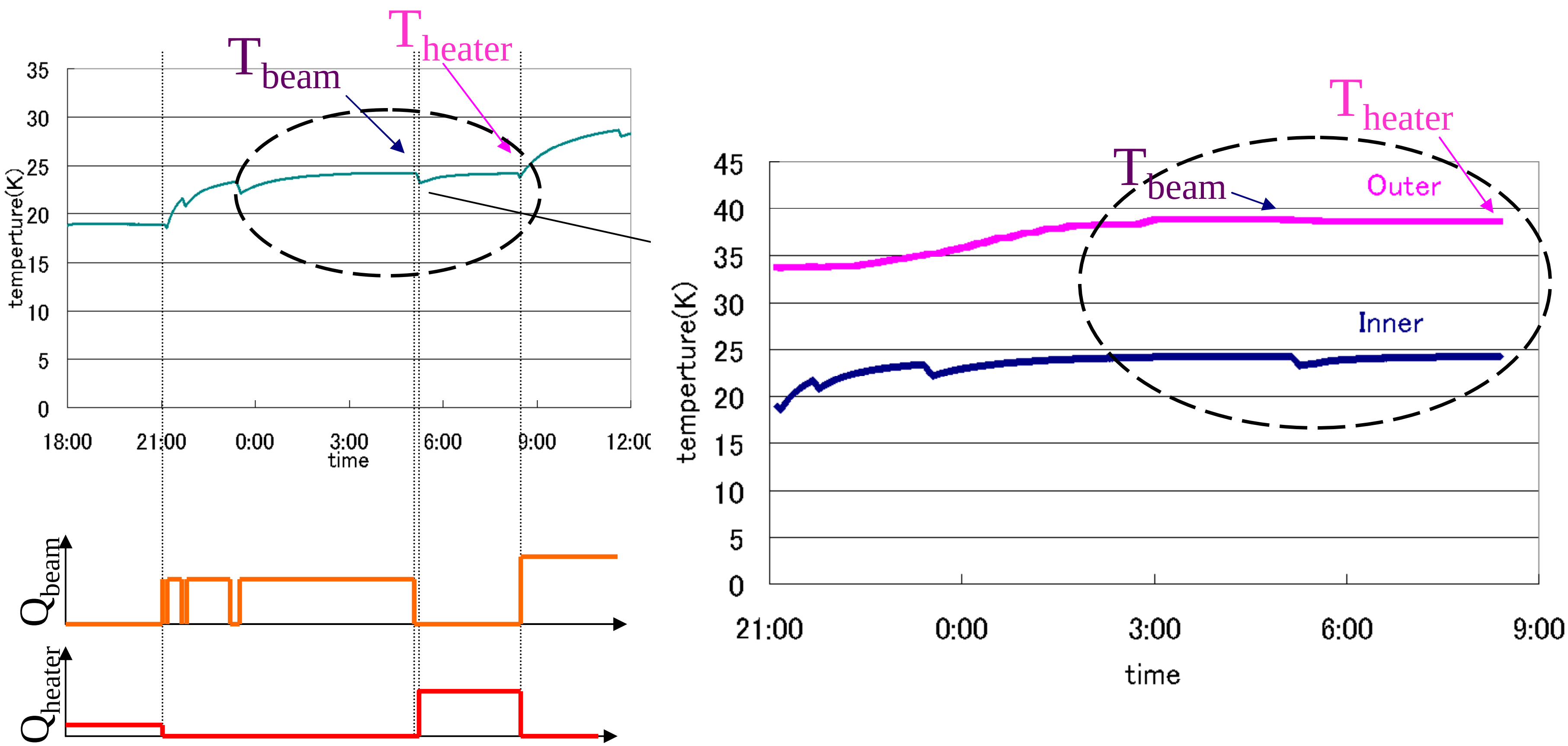


Fluctuation of beam intensity (protons/10min) < 3%

T_{beam} & T_{heater} at Various Thermometer



Effect of Outside Mockup



Temperature of outside mockup is nearly constant.

Effect of outside mockup to T_{beam} & T_{heater} hardly changed.