Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

NAGOYA UNIVERSITY

EcoTopia Science Institute
NAGOYA UNIVERSITY

# Development of muon radiography system with nuclear emulsion


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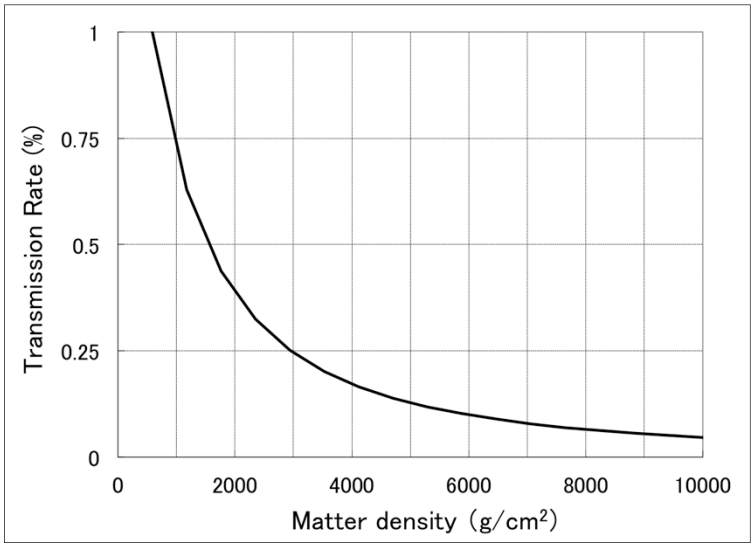
EcoTopia Science Institute

Kobayashi-Masukawa Institute for the Origin of Particle and the Universe

Nagoya University

# Principle of cosmic ray muon radiography



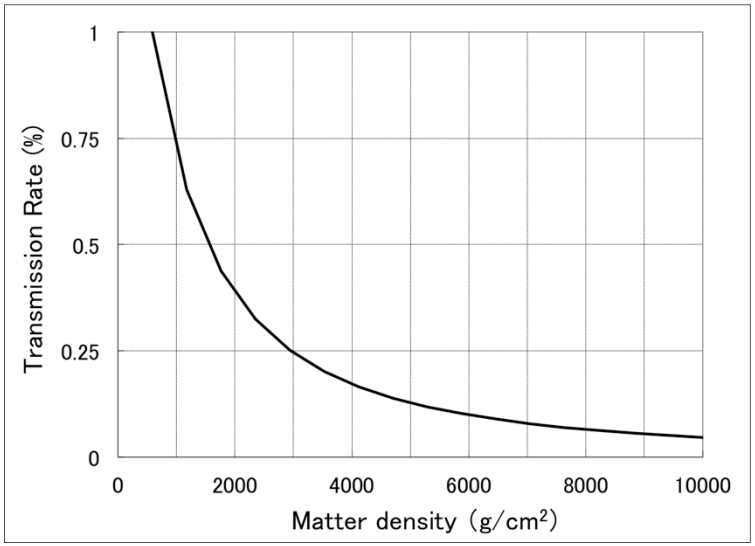

Angular distribution of muon flux at the detector position

Cosmic ray muons

detector

Large structure object

# Principle of cosmic ray muon radiography




Angular distribution of muon flux at the detector position

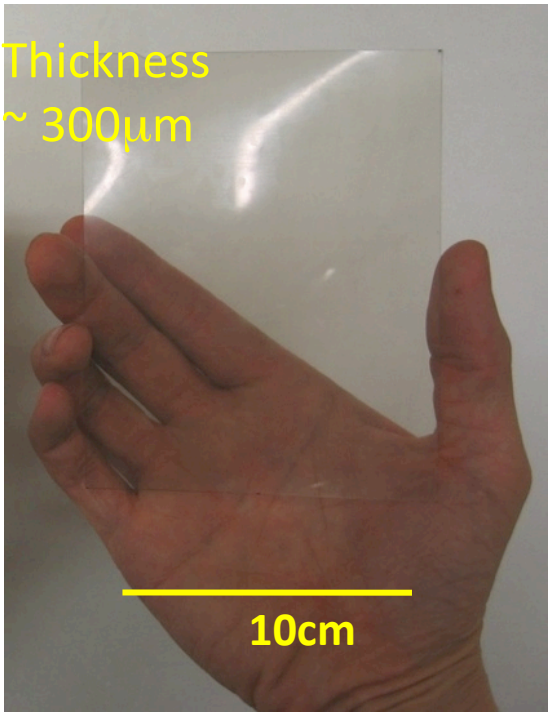
Tomography

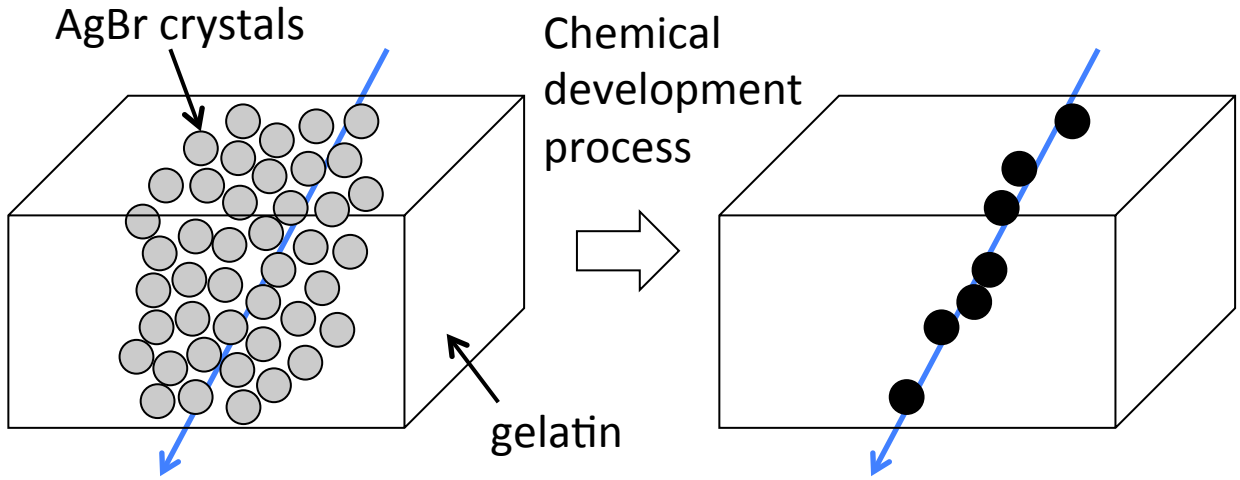
Cosmic ray muons

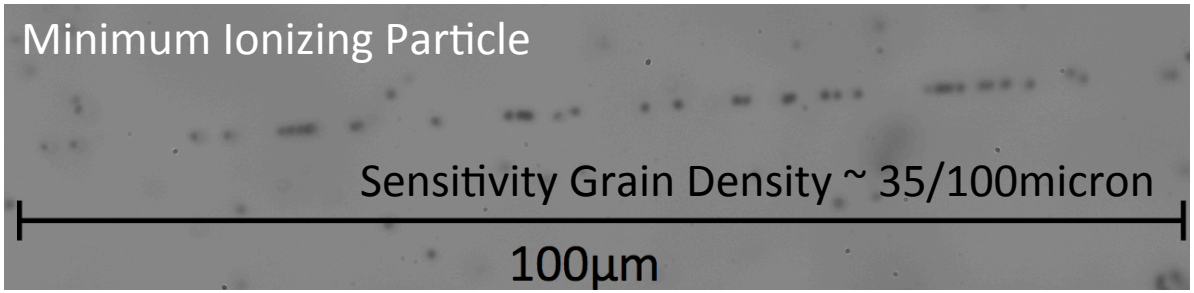
detector

Large structure object

# Nuclear Emulsion




- 3 dimensional tracking detector
- High spatial resolution ( < silver grain size )
- Solid state detector, No power supply
- flexible shape and size($1cm^2$-$100m^2$), light weight ($300g/m^2$)

These properties have advantage in field observation



# Targets of muon radiography


# Overview of Muon Radiography System

Development of technologies (Emulsion, Scanning, Analysis)
and establish methodology

- A detector design suitable for observation target and its environment around the observation point

- Production of emulsion
- Pouring of emulsion
- Construction of the emulsion detector

- A methodology of installation and exposure in observation point.

- Chemical development

- Scanning

- Reconstruction of muon tracks
- Calculation of muon flux
- Calculation of matter density

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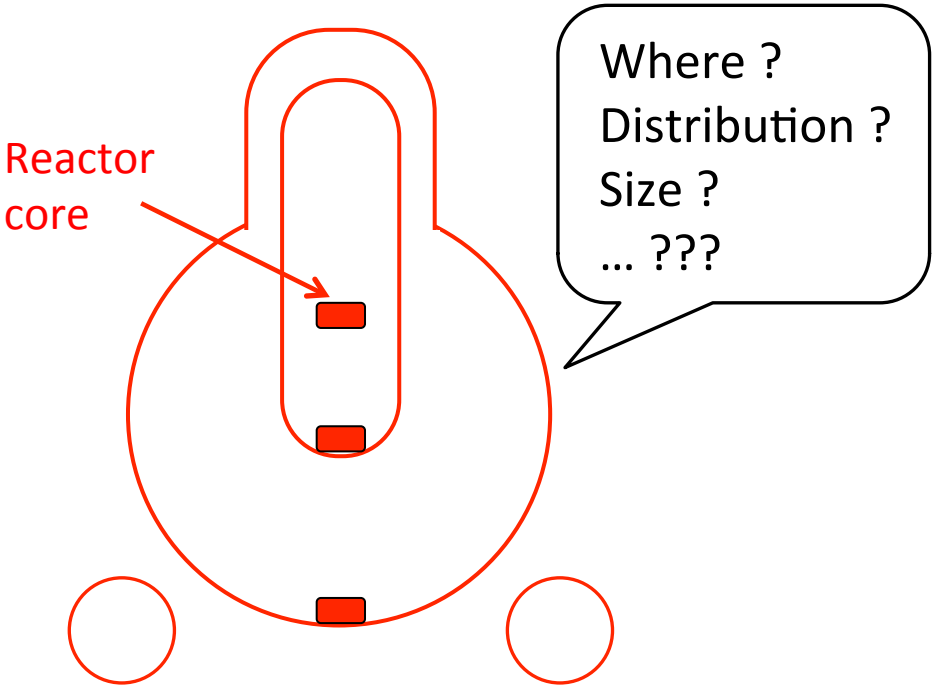
Muon radiography of Reactor core

# The present situation expected in Fukushima Daiichi nuclear power plant



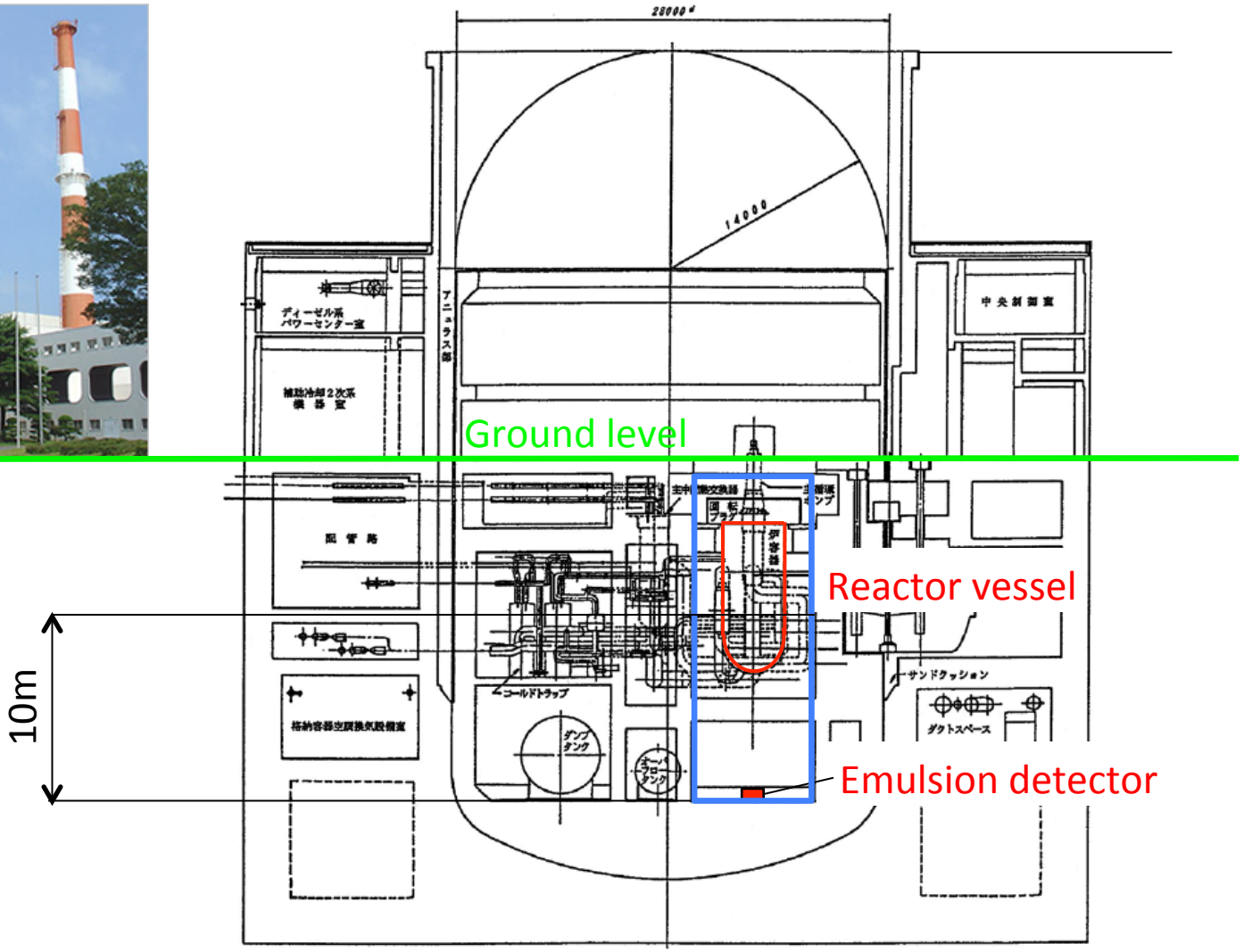

- High radioactivity → shielding material

- Lack of power supply
- Lack of free space

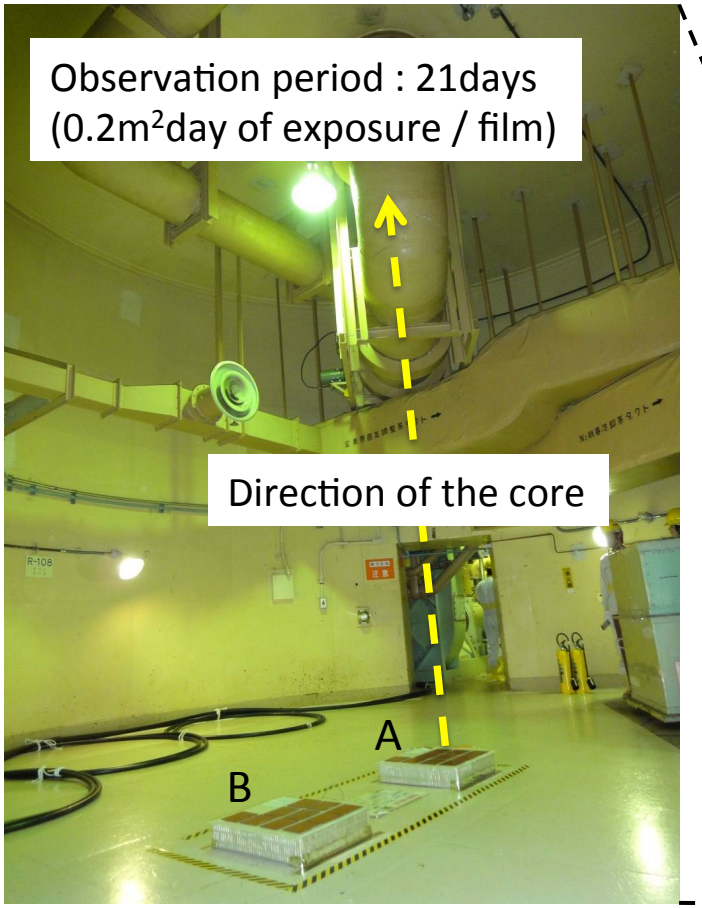
Advantages of nuclear emulsion as muon detector

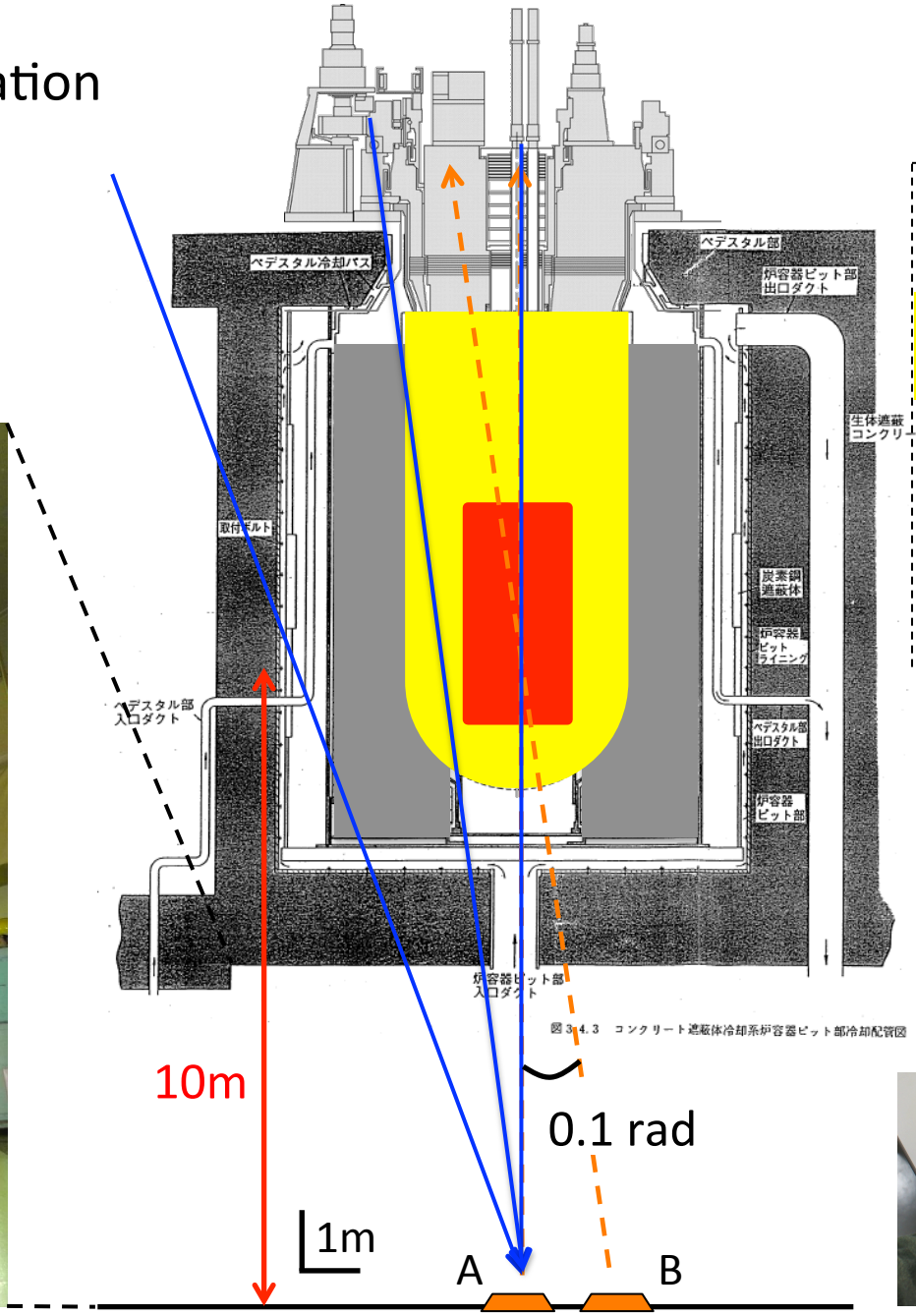
- Compact, light weight
- No need of power supply
- High spatial resolution

# Test experiment :
# Using experimental fast reactor Joyo



# Cross-sectional view of Reactor vessel and installation position of the detectors



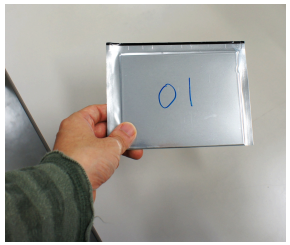

Reactor Vessel
（radius 2m）

Liquid sodium
（0.9g/cm3）

Core structure
Pultonium,
Uranium,
Stenress Steel
(5.9g/cm2)

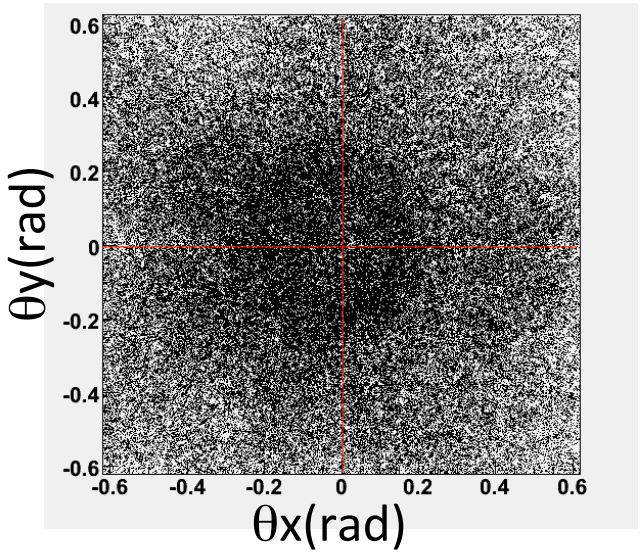
Carbon
（2.2g/cm3）

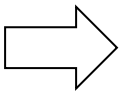
Concrete
（2.3g/cm3）

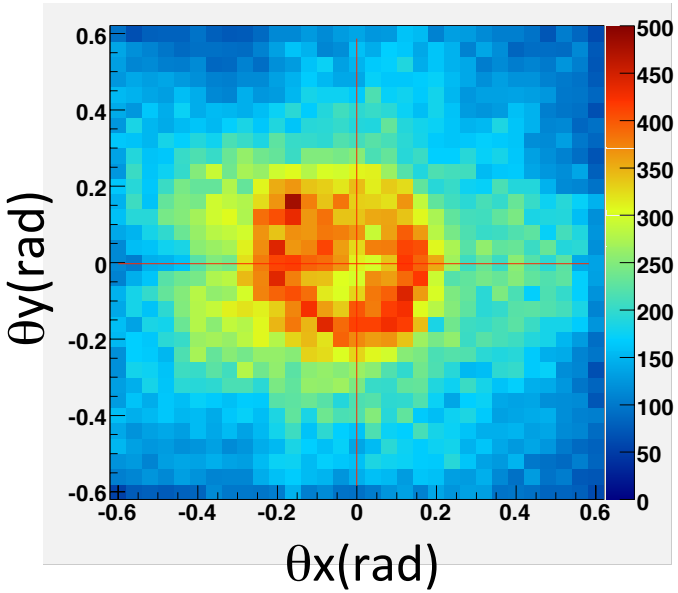


# Angular distribution of muon tracks

Position A

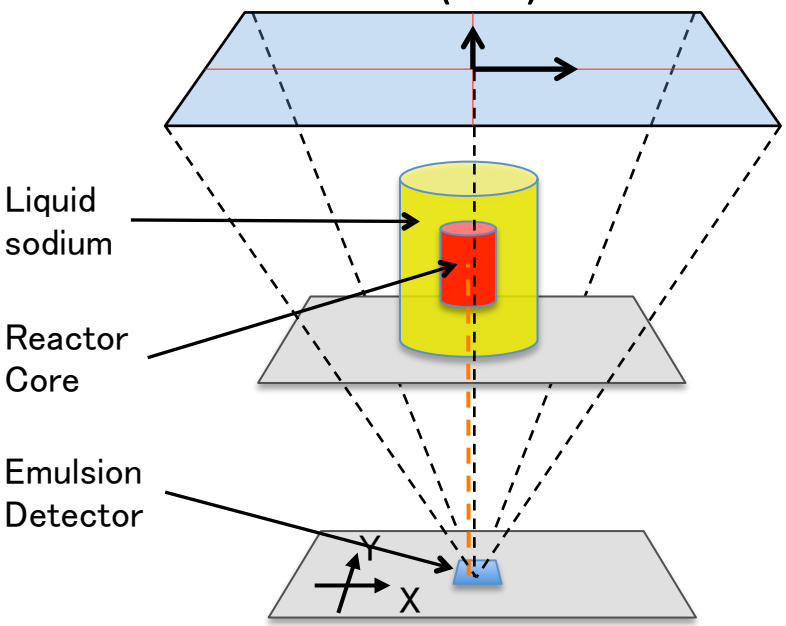





(muons/cm2/sr)

1bin : 40mrad x 40mrad



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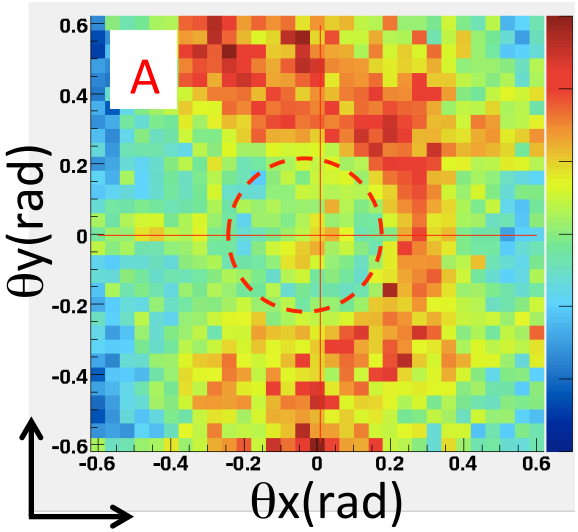
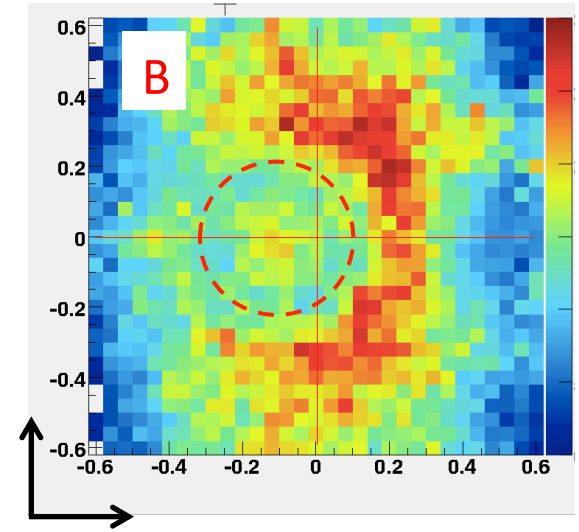
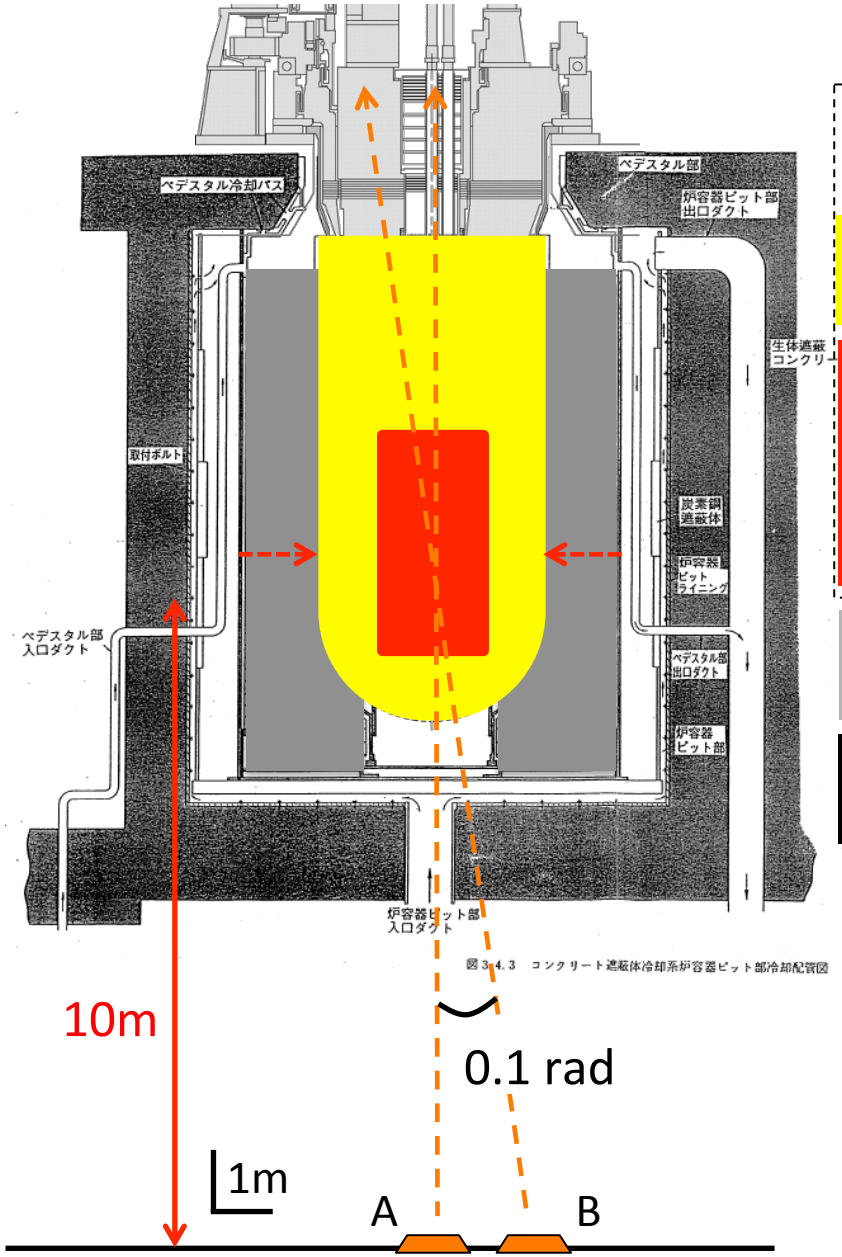
## Results

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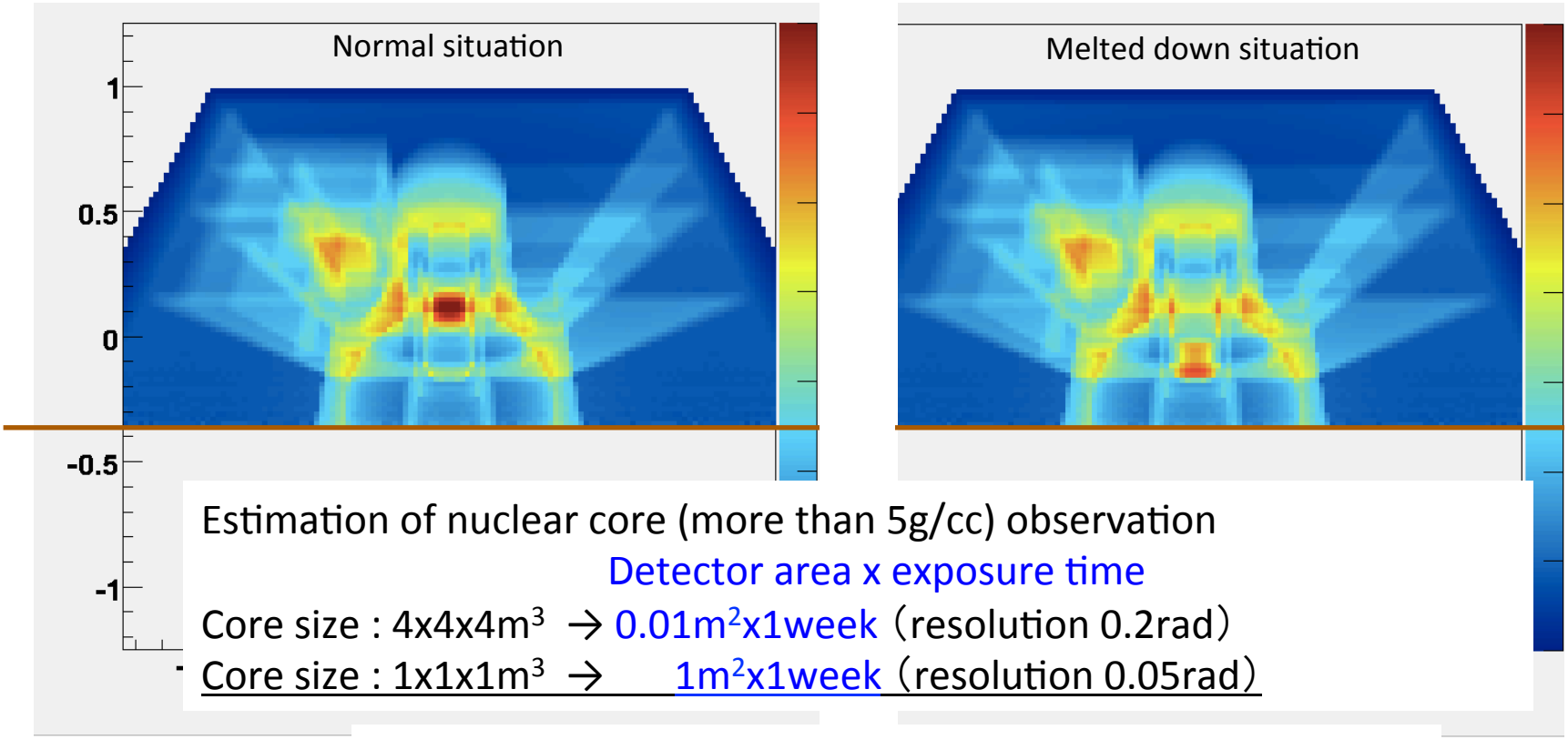
Concrete
（2.3g/cm$^3$）

# Application: Examination to The Fukushima Daiichi Nuclear Power Plant Accident

Density distribution




Estimation of nuclear core (more than 5g/cc) observation

Detector area x exposure time

Core size : 4x4x4$m^3$ → 0.01$m^2$x1week（resolution 0.2rad）

Core size : 1x1x1$m^3$ → 1$m^2$x1week（resolution 0.05rad）

Several 10 $m^2$ Films needed for this application

# Overview of Muon Radiography System

Development of technologies (Emulsion, Scanning, Analysis)
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- Pouring of emulsion
- Construction of the emulsion detector

Development items
- Emulsion gel production technology
- Emulsion gel pouring technology
- Production speed

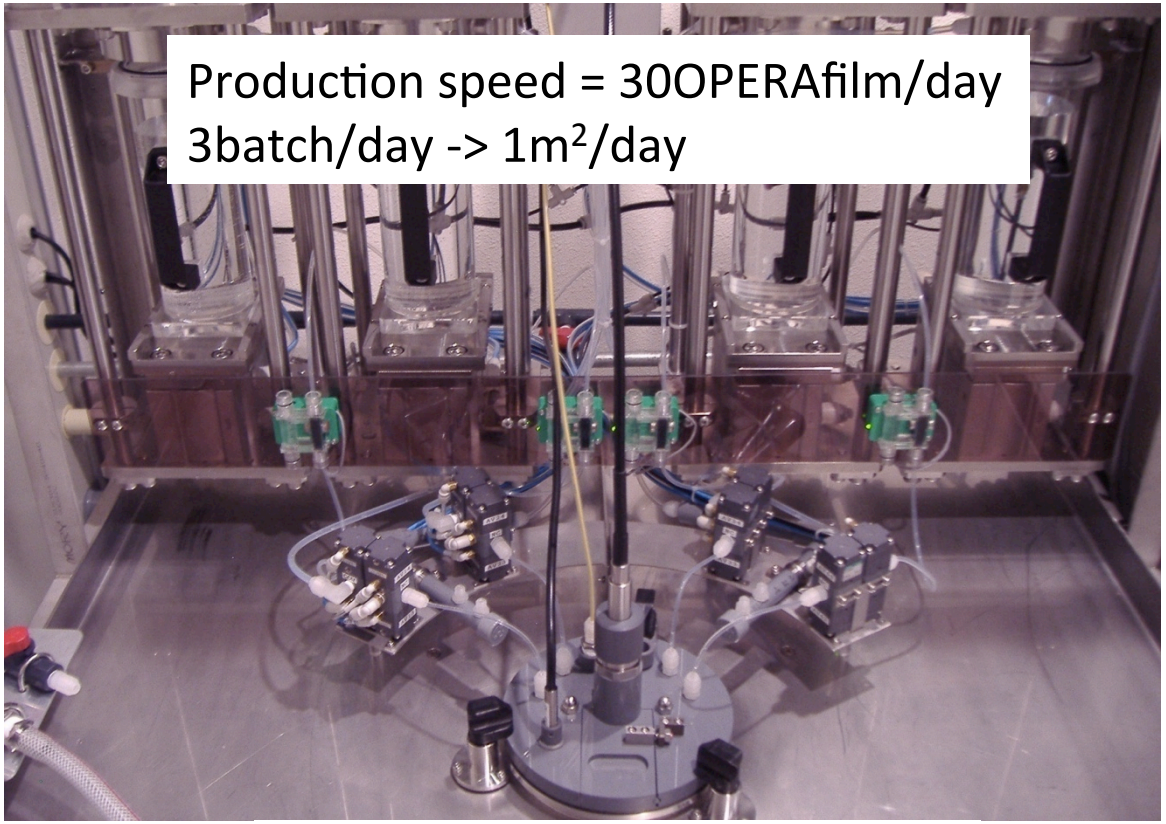
- A methodology of installation and exposure in observation point.

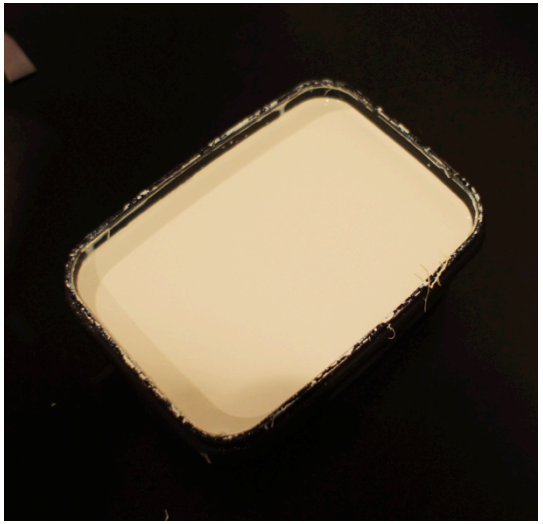
- Chemical development

- Scanning

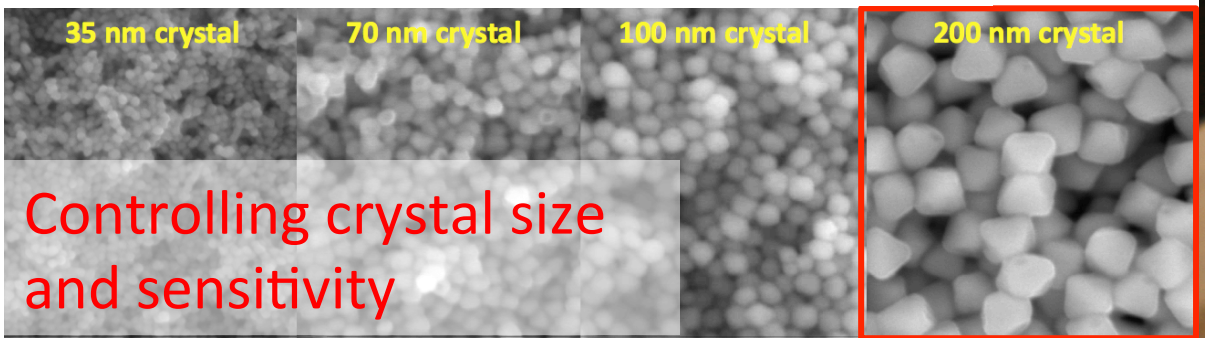
- Reconstruction of muon tracks
- Calculation of muon flux
- Calculation of matter density

# Gel Production Machine

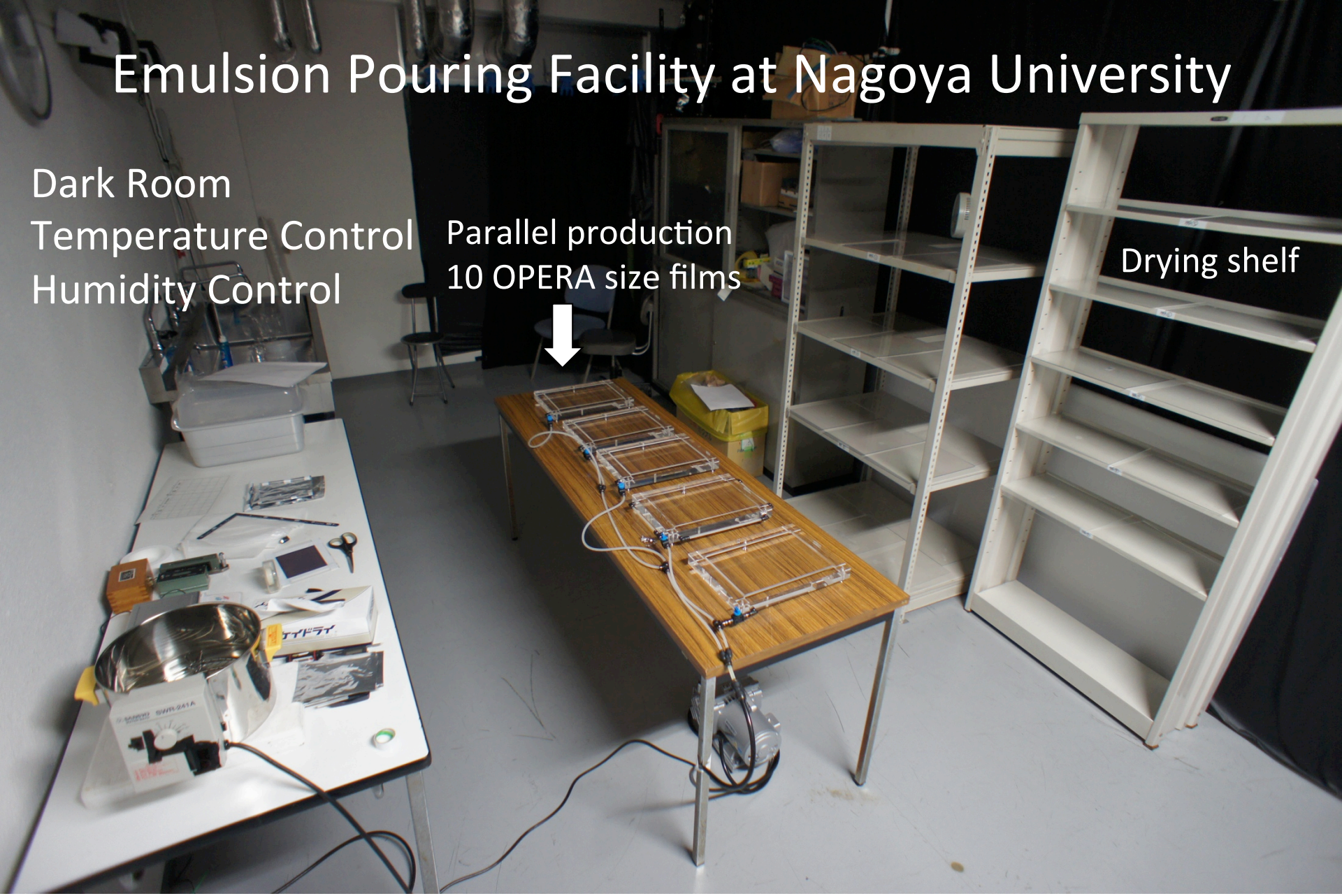


$AgNO_3 + KBr \rightarrow AgBr\downarrow + KNO_3$



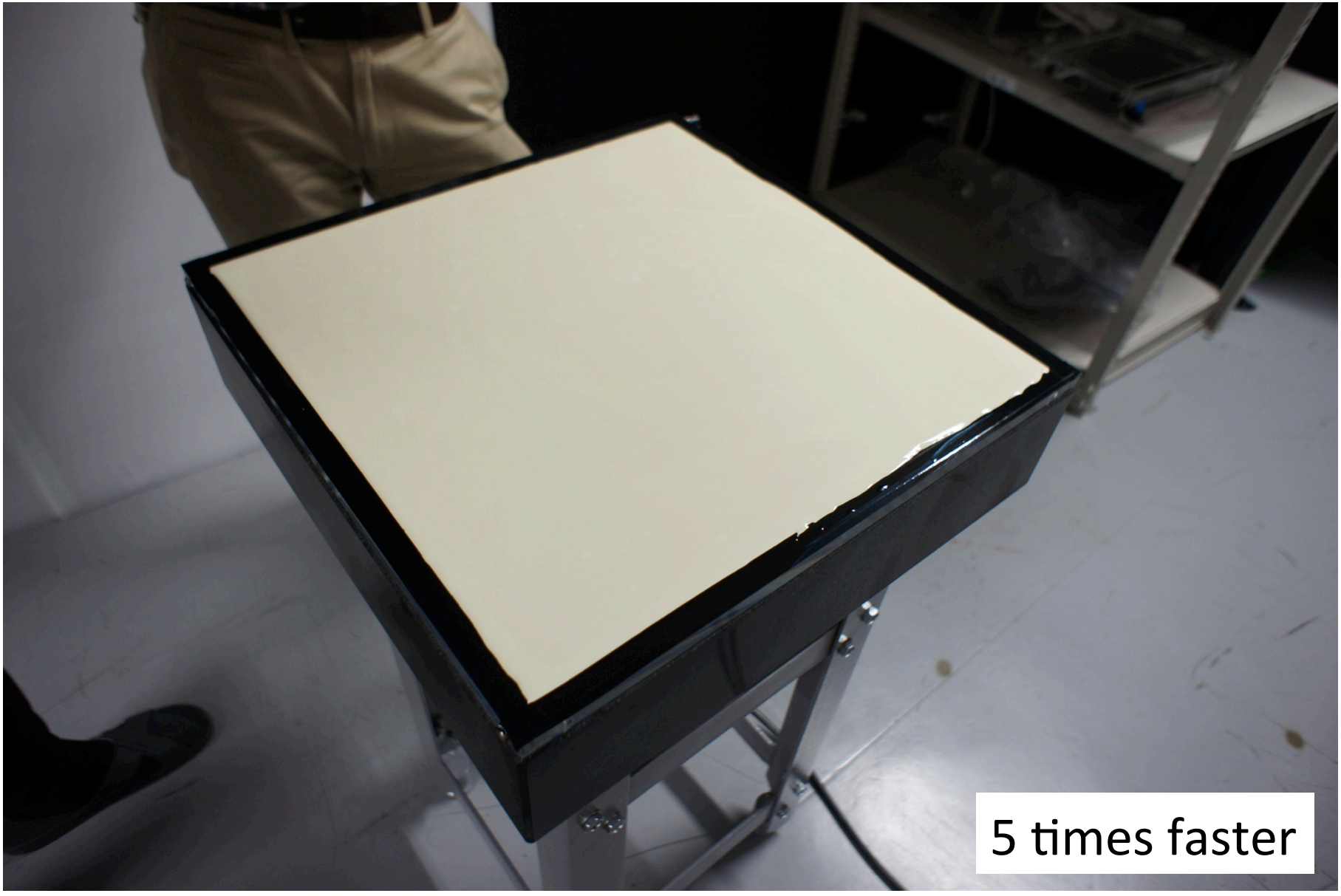

# Emulsion Pouring Facility at Nagoya University



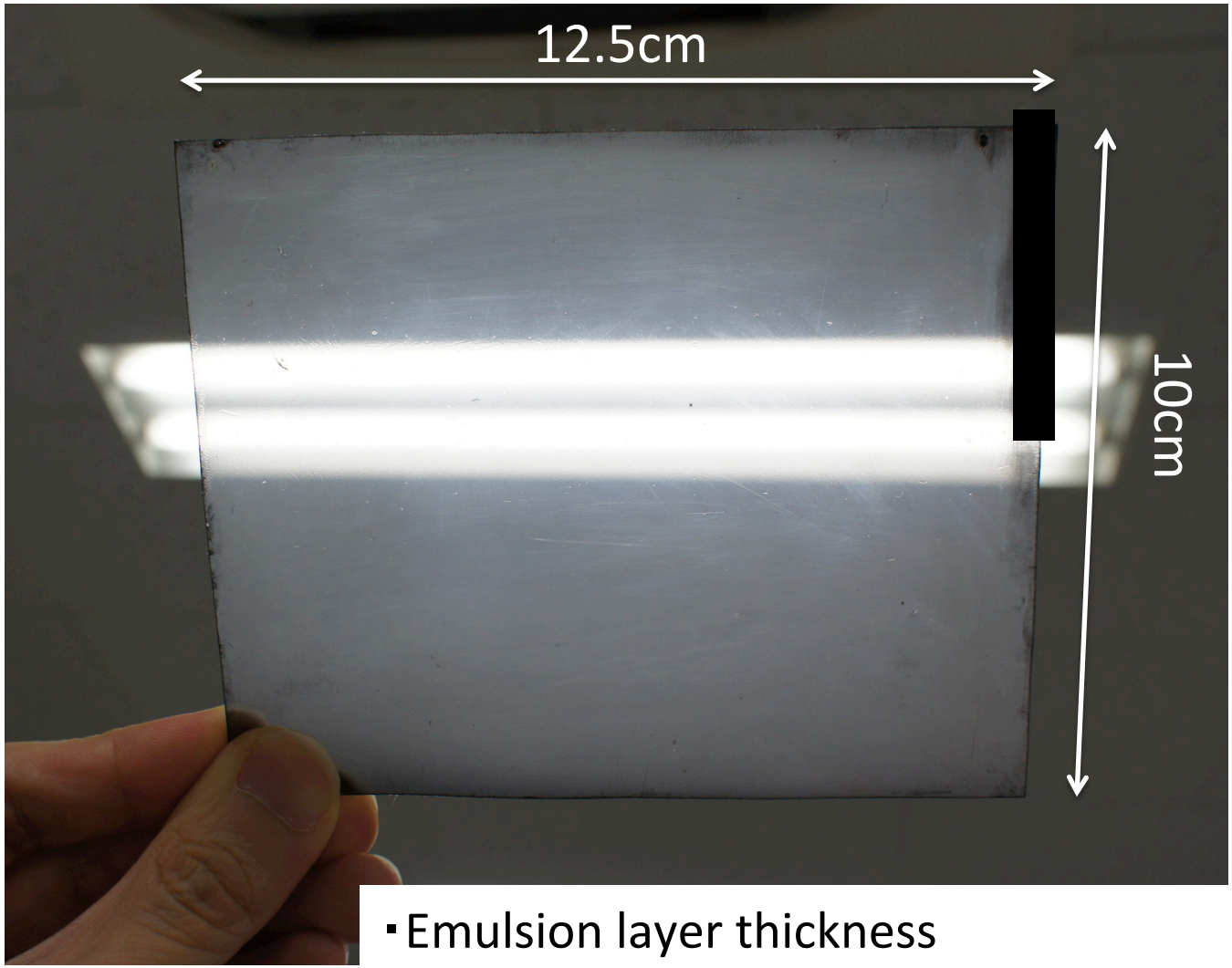

Production speed : 1m$^2$/4days

We are planning to increase the speed of 1m$^2$/day

# Enlarging pouring stage (50cm x 50cm)

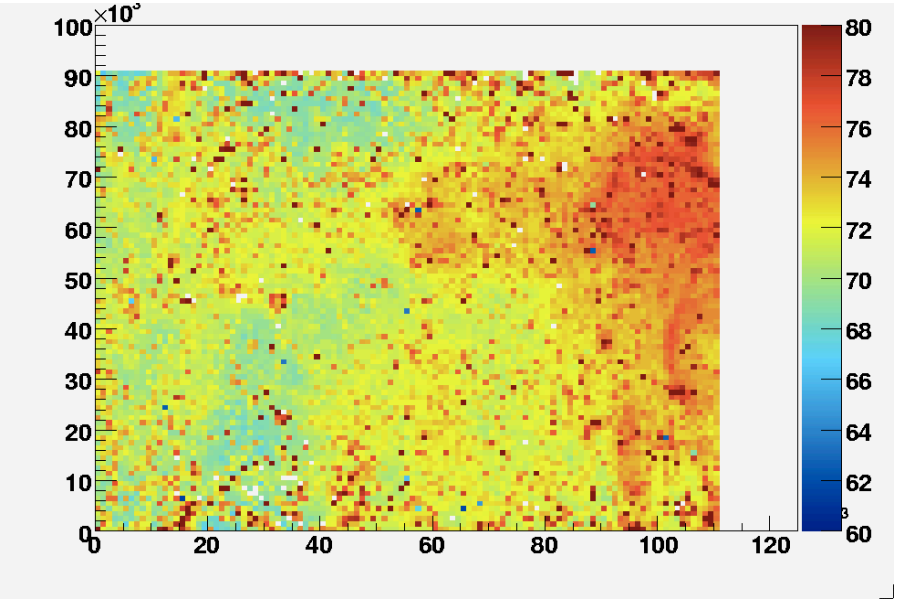


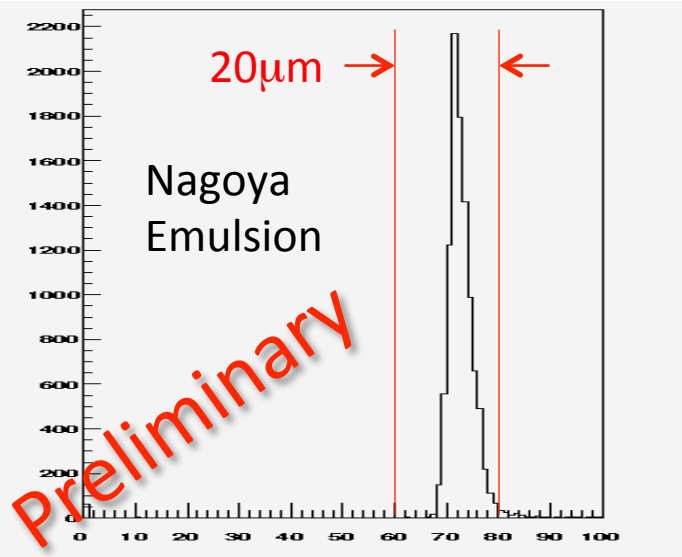
# Nagoya Emulsion (OPERA film size)



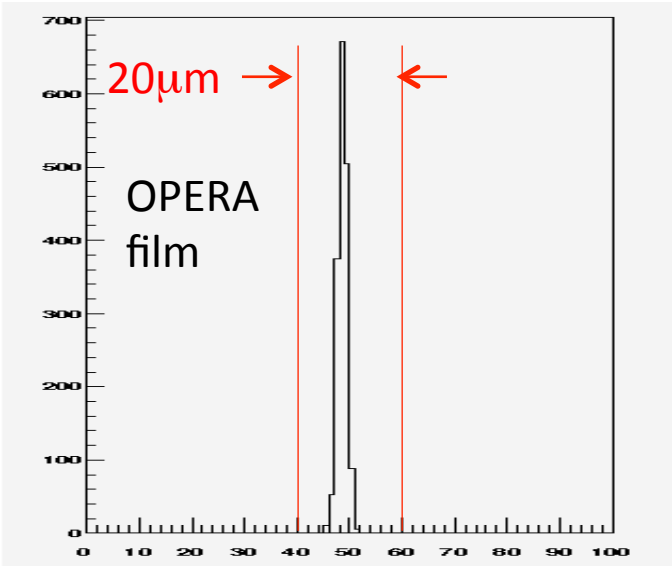

- Emulsion layer thickness
- Emulsion distortion
- Improvement of sensitivity and signal noise ratio

# Thickness Distribution of Emulsion Layer



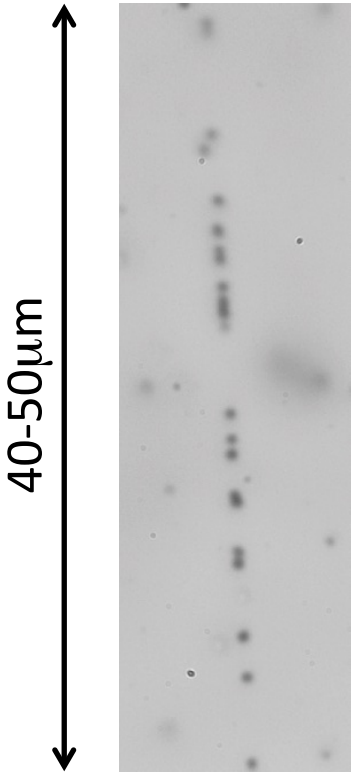




The un-uniformity of the thickness of 10μm per 10mm is 1mrad

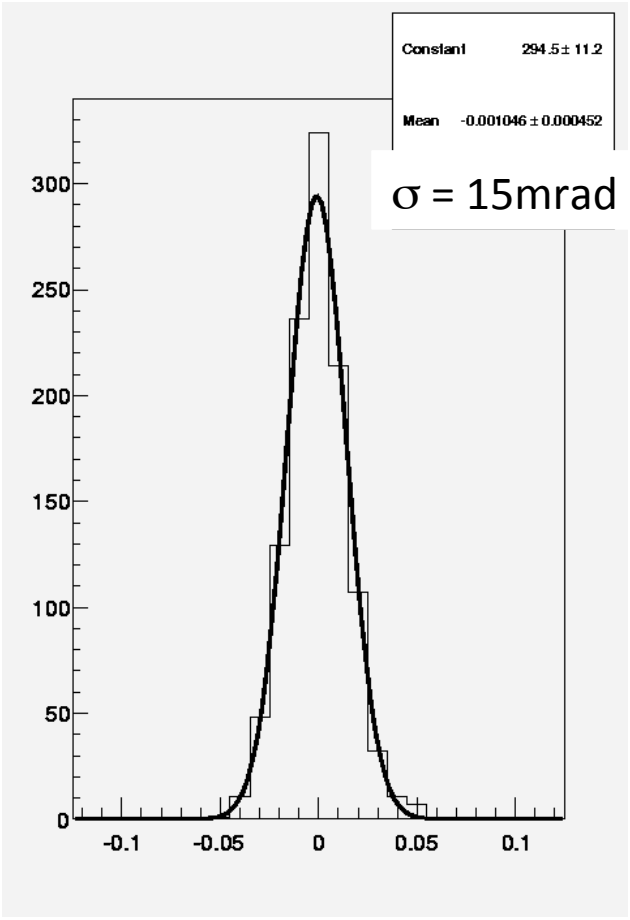



Enough performance for muon tomography

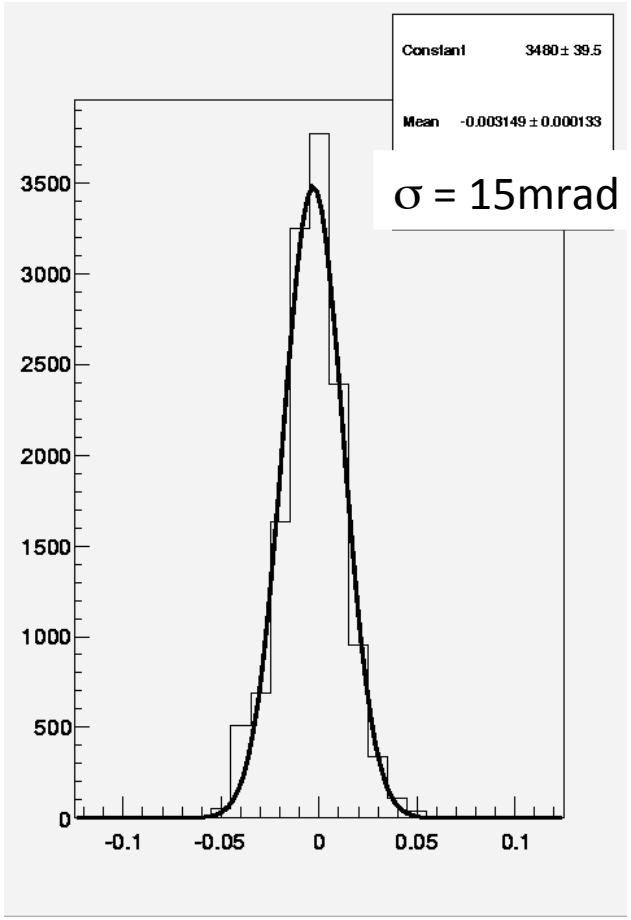
# Track measurement accuracy in emulsion layer




OPERA film



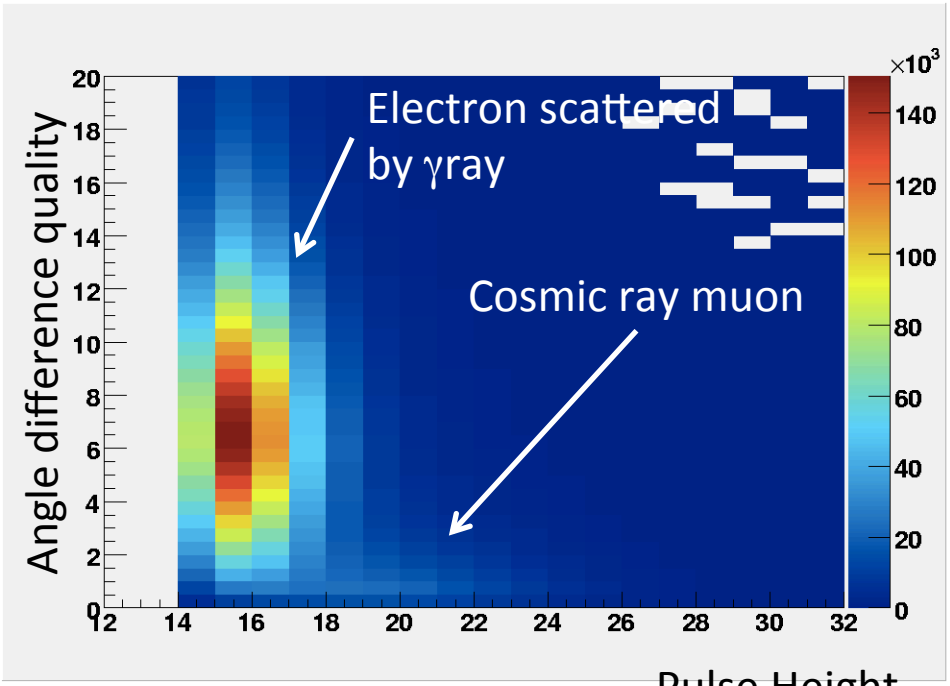

Nagoya Emulsion



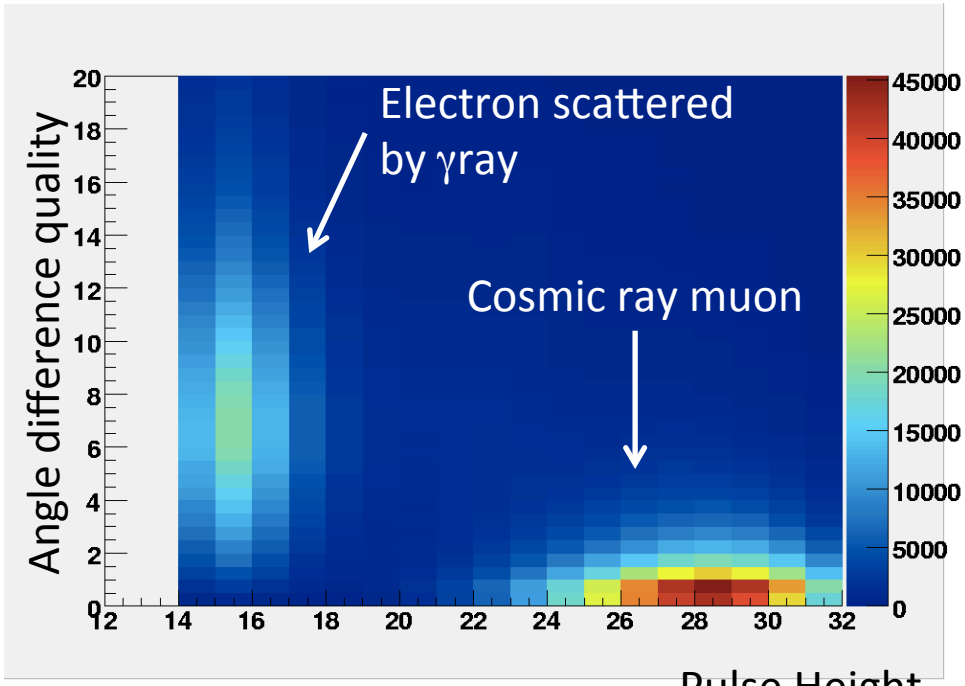

New Emulsion distortion is equivalent value to OPERA film

# Performance of discrimination of gamma ray tracks

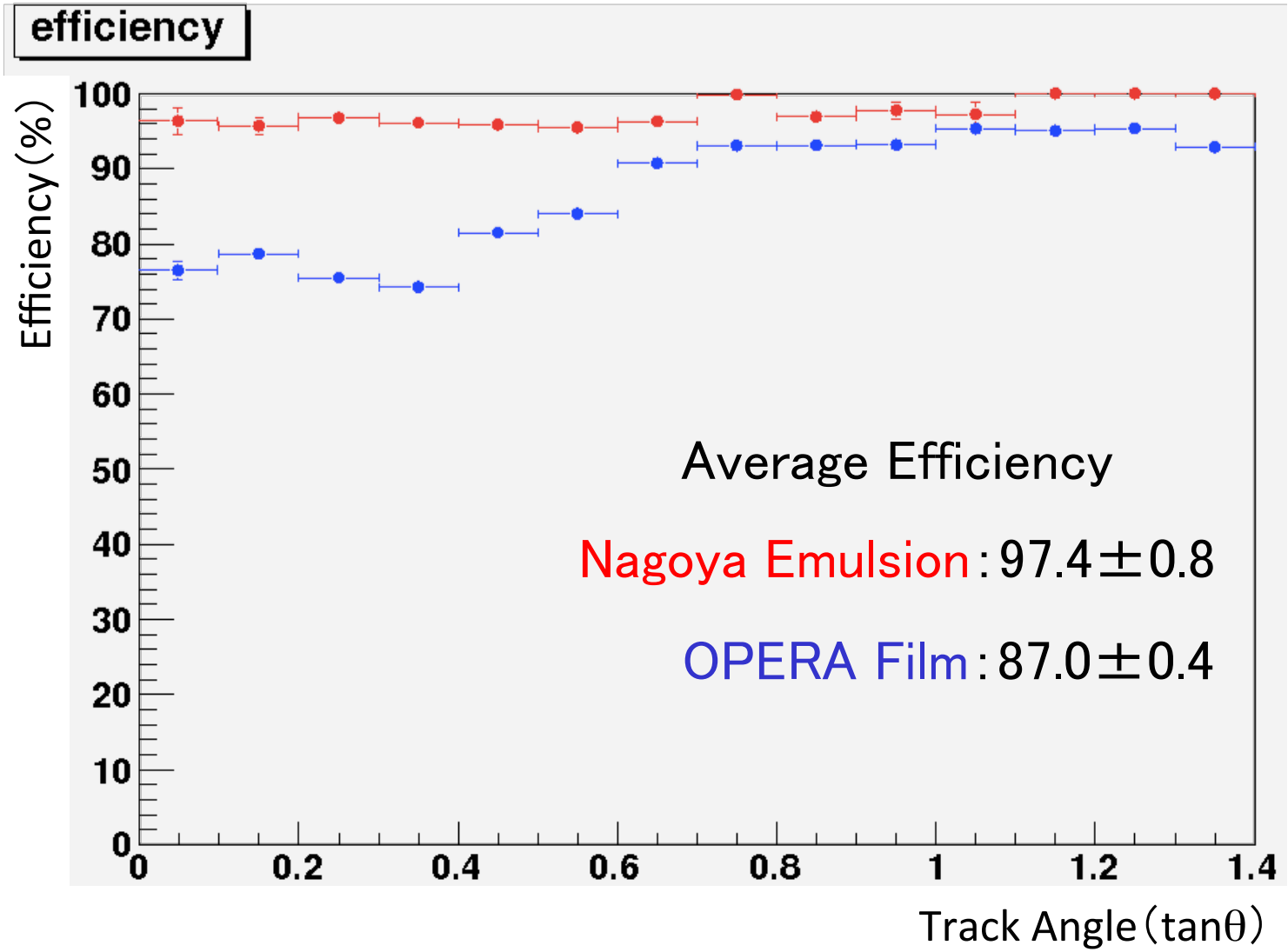
OPERA film




Nagoya Emulsion

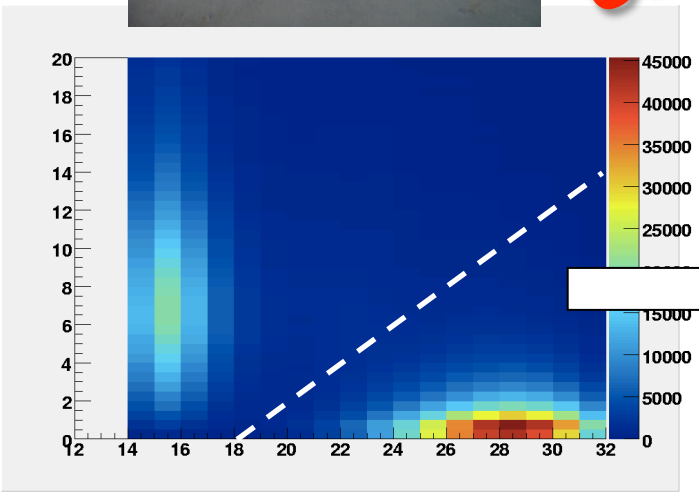


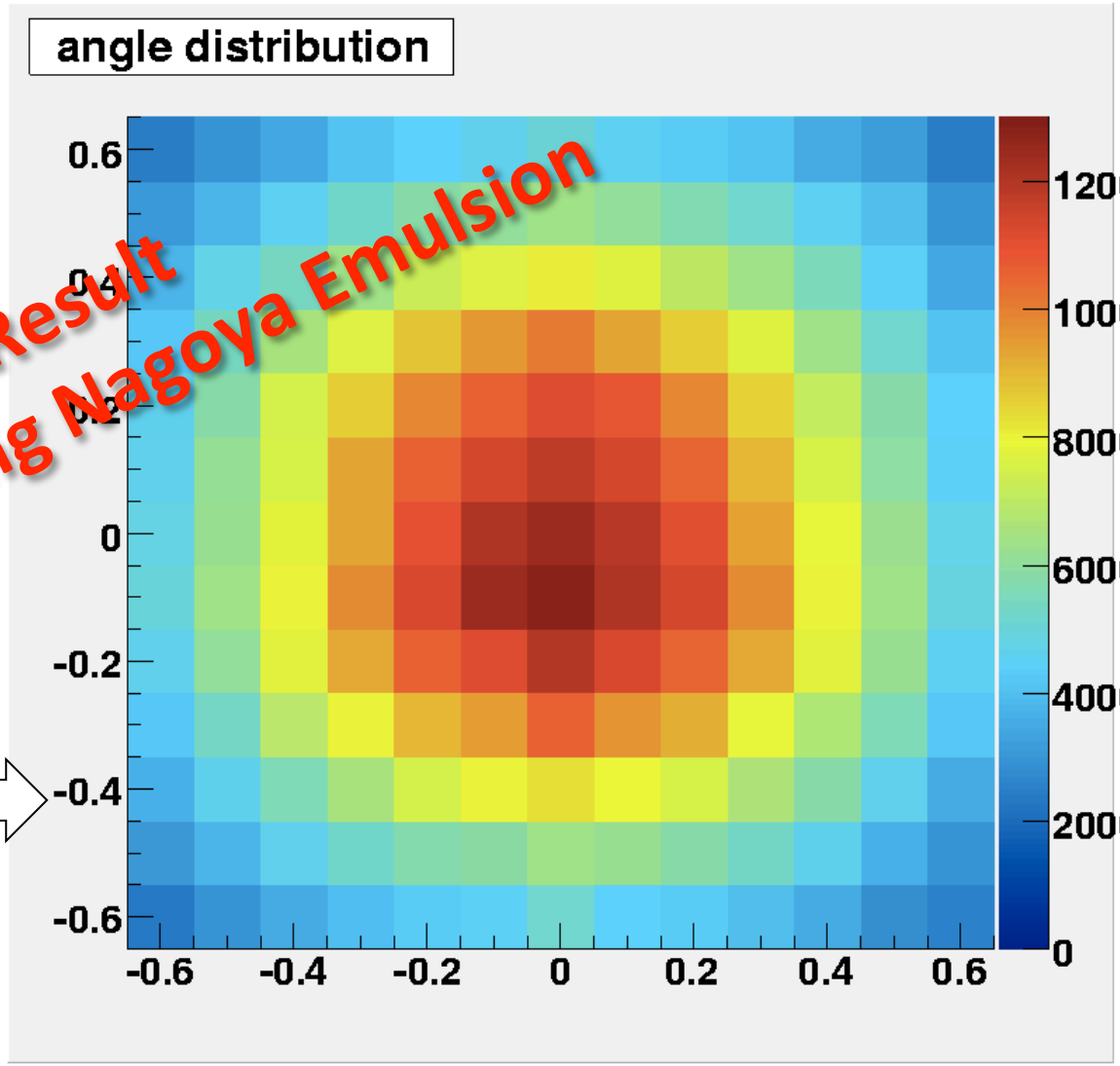
# Detection Efficiency by Track Selector



# Cosmic ray muon angular distribution achieved by using one new emulsion plate

Measured on the rooftop of the building at Nagoya University

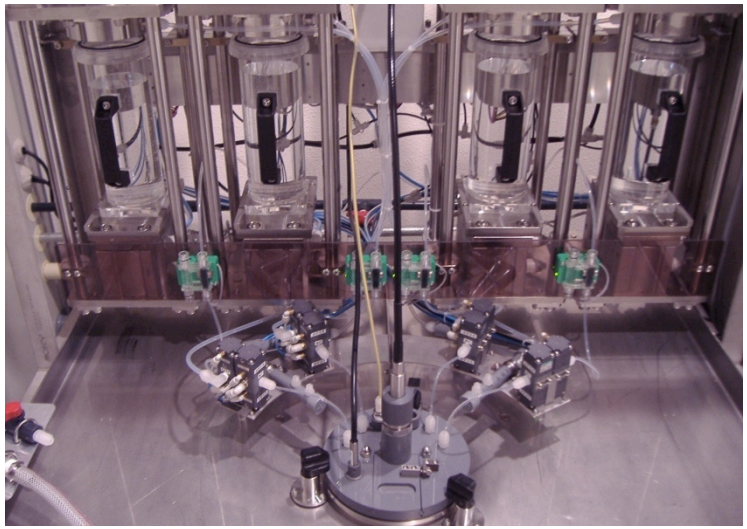



First Result
Using Nagoya Emulsion

# Future prospects of production speed

## Emulsion gel production



Threefold scale emulsion gel production machine

- design was fixed
- operation test will be started December, 2013

Speed ~ 1m$^2$/batch

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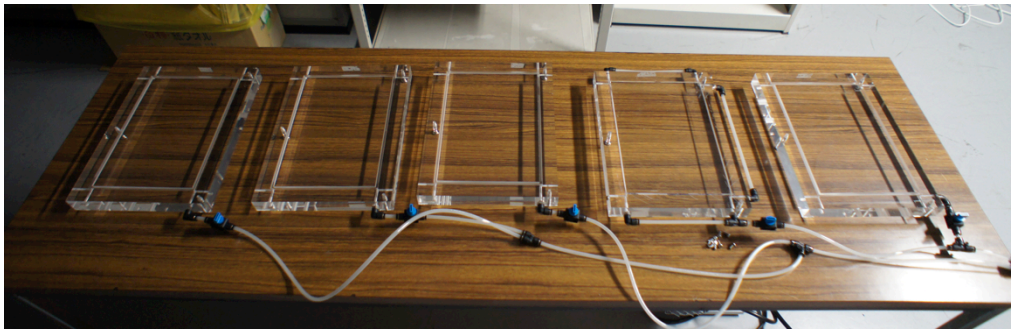
## Emulsion pouring



Automated emulsion pouring machine

- under designing

Speed ~ 10m$^2$/day

# Conclusions

- Several 10m$^2$ nuclear emulsion area detector is needed for muon tomography
- We are proposing to measure the inner structure of Fukushima Daiichi Nuclear Power Plant. We have validated the methodology by measurement of JOYO plant.
- We are developing nuclear emulsion production techniques
  - Gel production
  - Gel Pouring
- We achieved enough performance (flatness, distortion) and higher performance (noise discrimination) for cosmic ray muon tomography at the production speed of 1m$^2$/week
- We can start 1m$^2$ area detector experiment with high sensitive Nagoya Emulsion soon !
- We are planning to apply to ancient tomb, volcano, fault, concrete structure, …