Emulsion Production and Scanning

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1. Emulsion production at Nagoya University
2. Scanning and track reconstruction
3. Non standard film (and applications)

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Hadron WS @ Nagoya university

Two technologies for particle physics

- Emulsion production facility have been constructed at Nagoya University in 2010.

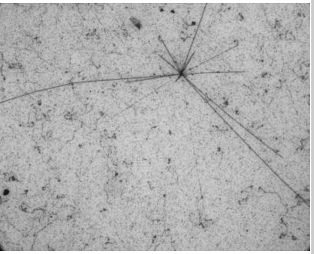
  Emulsion properties can be tuned by user-selves.

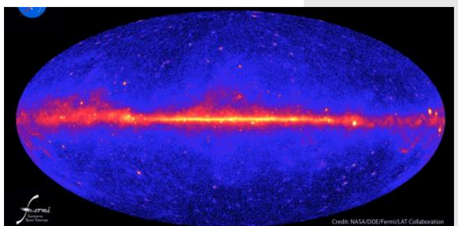
  “hand made” emulsions suit for experiments.

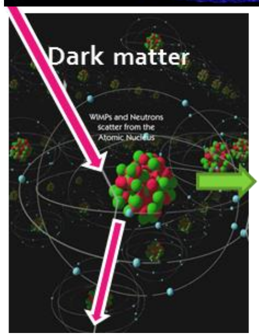
- Automatic scanning system was proposed 1974.
- Continuous development since 1980s and systematically employed in large scale experiment since 1994.

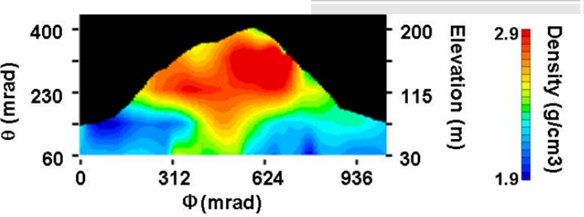
Projects with “hand made” emulsion

Project	Physics	Requirement	Technique
T60	Neutrino Oscillations, interaction processes study	High mass & high spatial resolution	Emulsion Cloud Chamber
GRAINE	Gamma ray telescope	Large area & fine angular resolution	Angle measurement in a short range
NEWS	Dark Matter search	Very short range <<1um tracking	Fine grain emulsion Detection of track
	Muon radiography	Large area & long term exposure	Long life emulsion



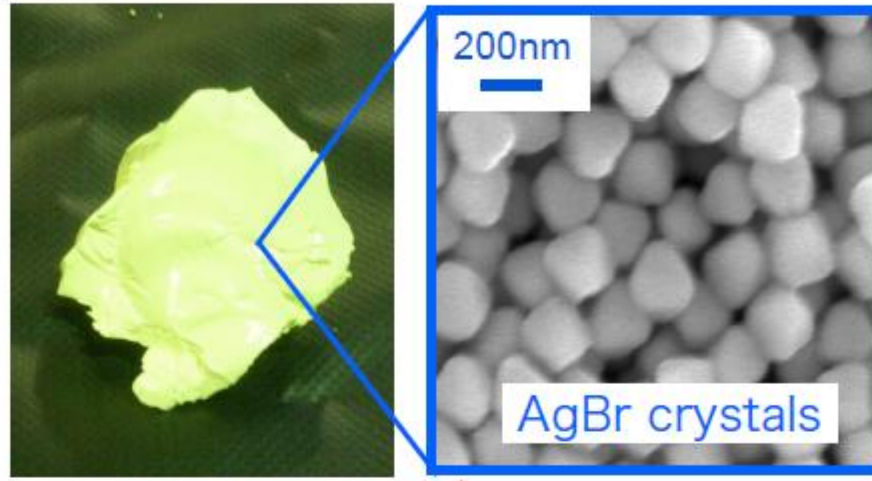


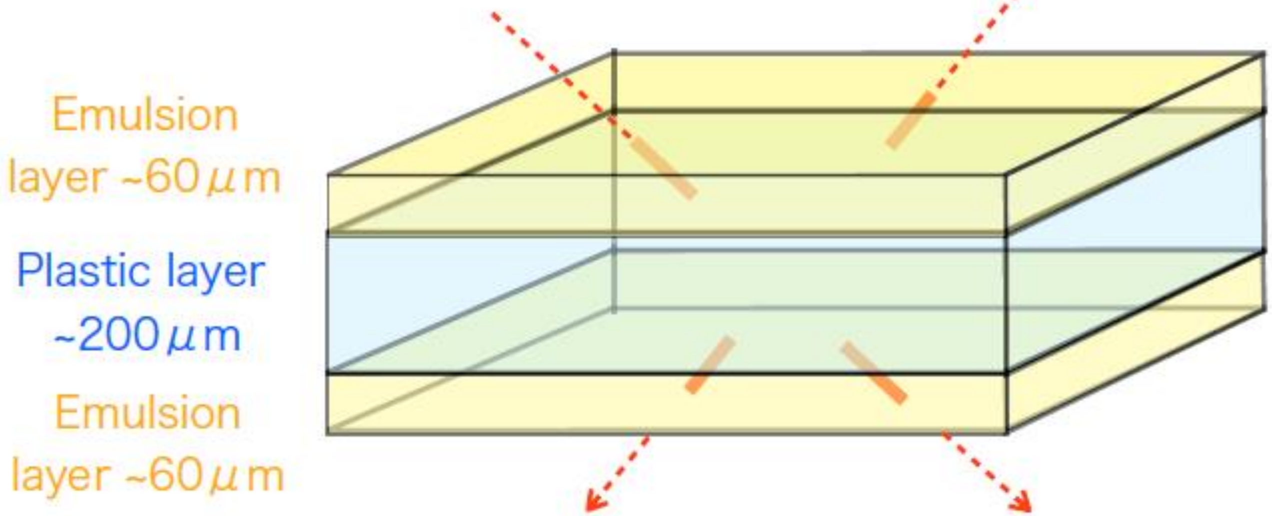




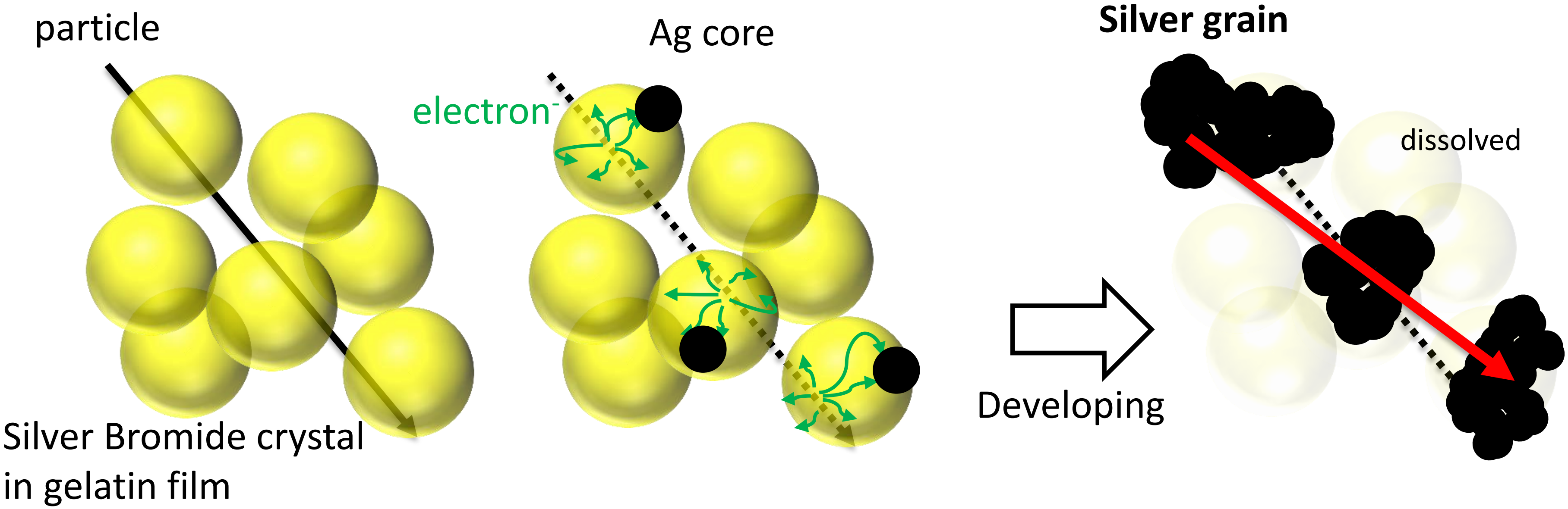
Production of Nuclear Emulsion

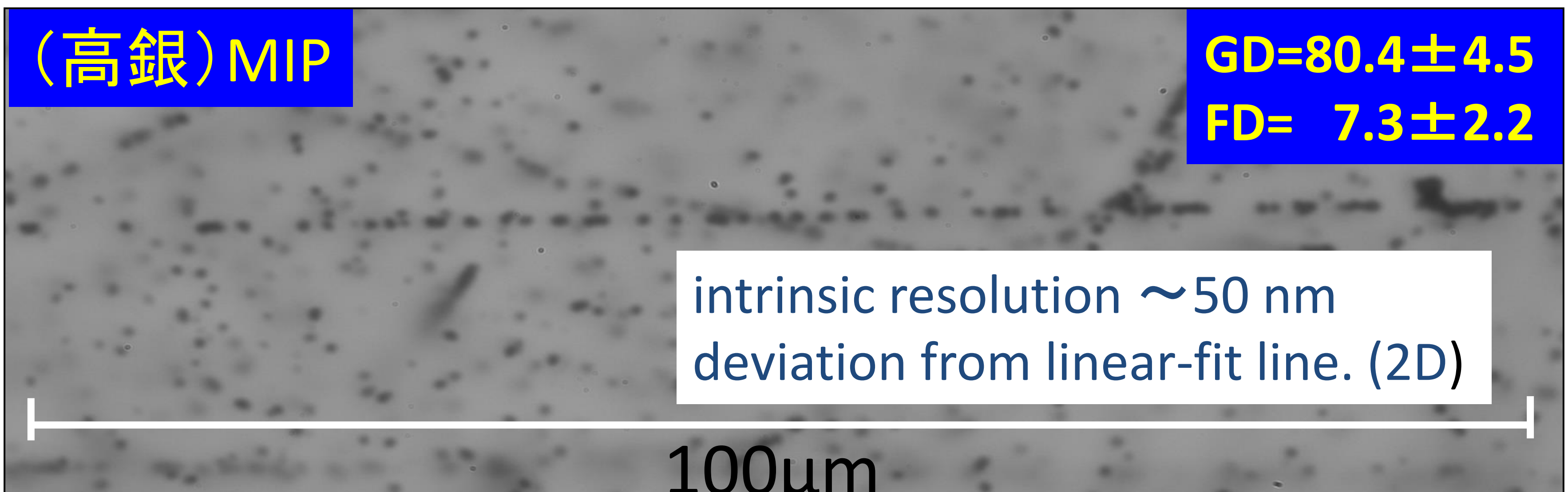
1. Gel Production
2. Plastic Base Preparation
3. Pouring
   (Forming film)



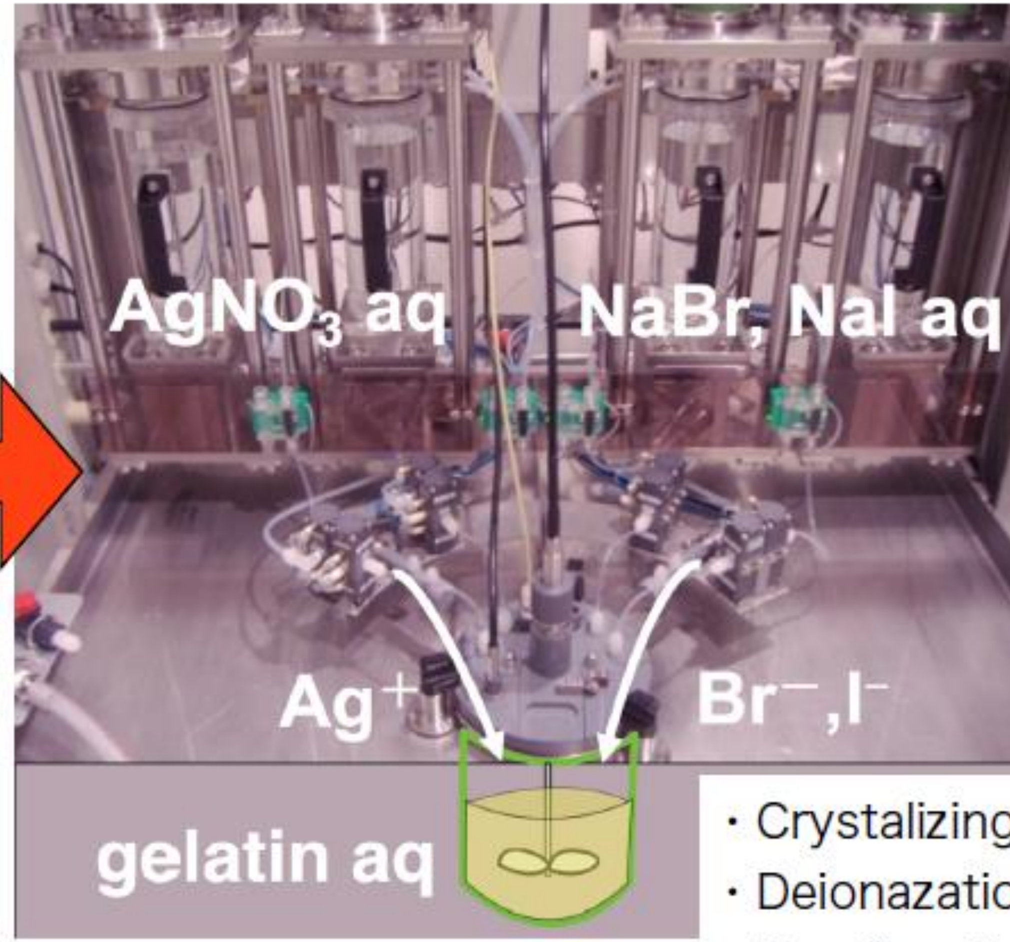


High Resolution Detector : Nuclear Emulsion





1. Gel Production

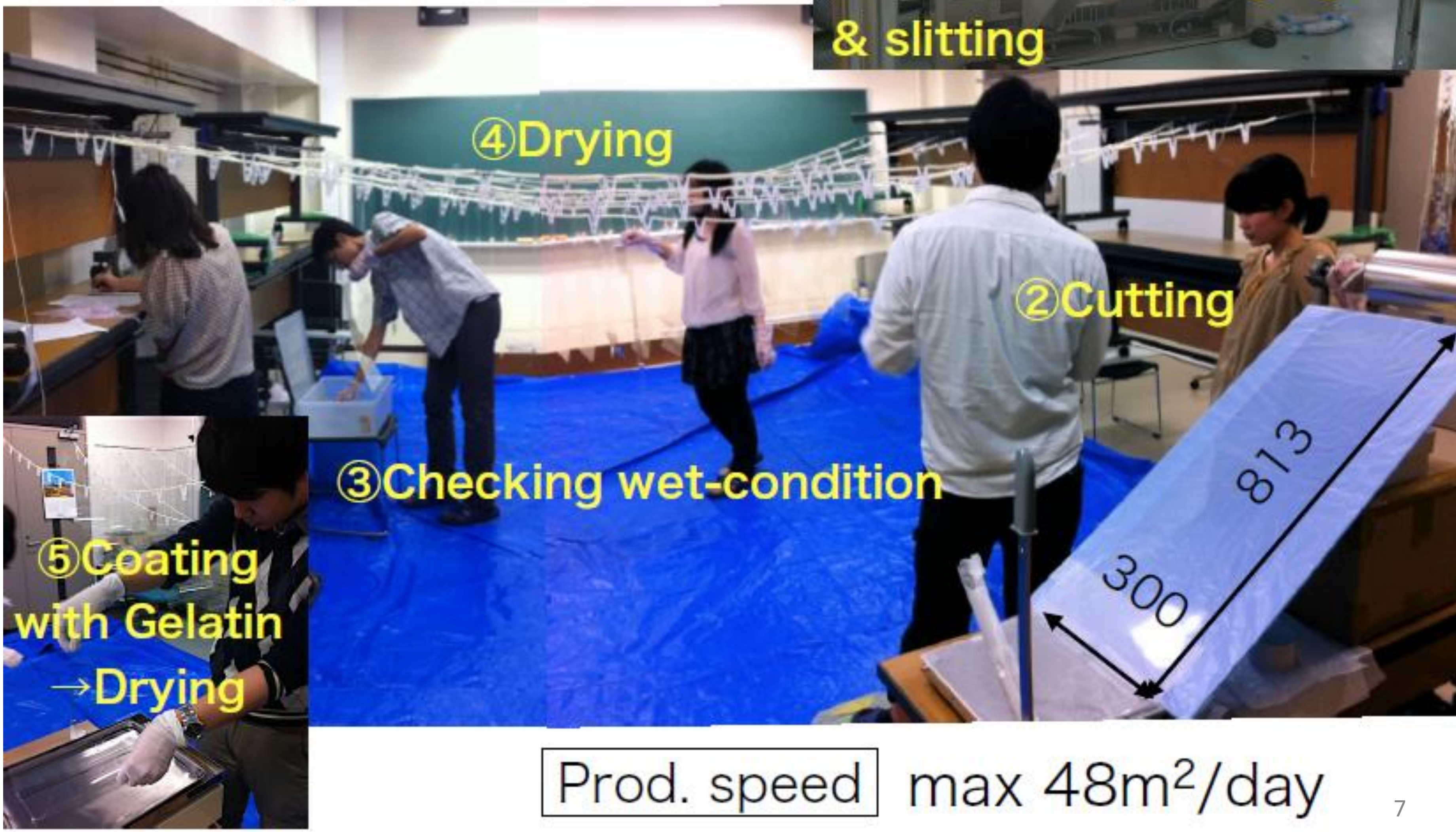


- Crystalizing
- Deionazation
- Sensitazation

~5 hours

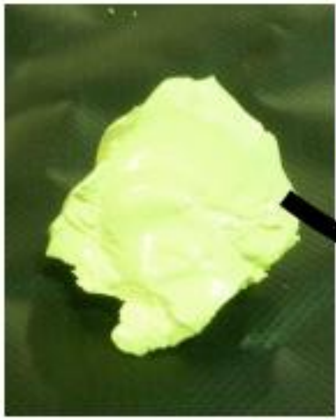
Prod. speed	2 kg (≒0.6m²)/day (-2014) → 6 kg (≒1.8m²)/day (current)

2. Plastic Base Preparation

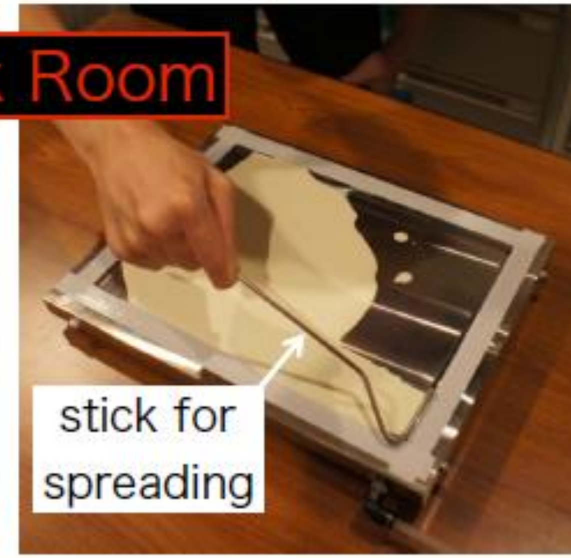


Prod. speed max $48 m^2$/day

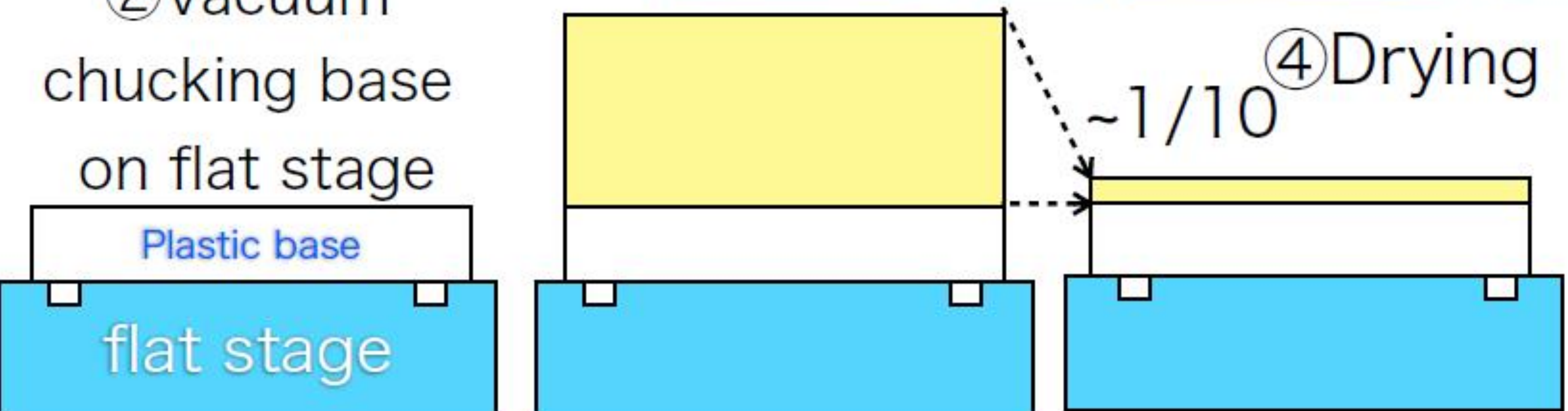
3. Pouring (Forming film)



①Melting gel @40℃



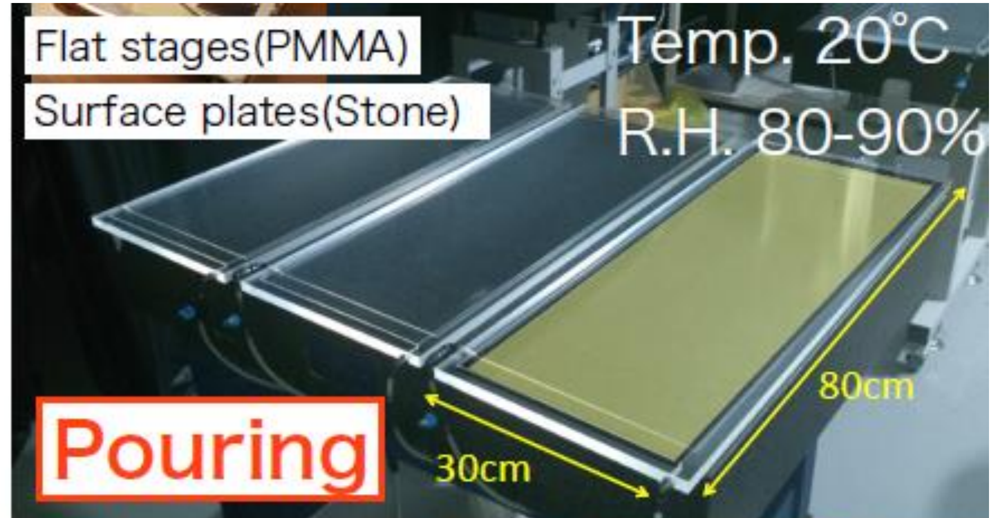
②Vacuum chucking base on flat stage

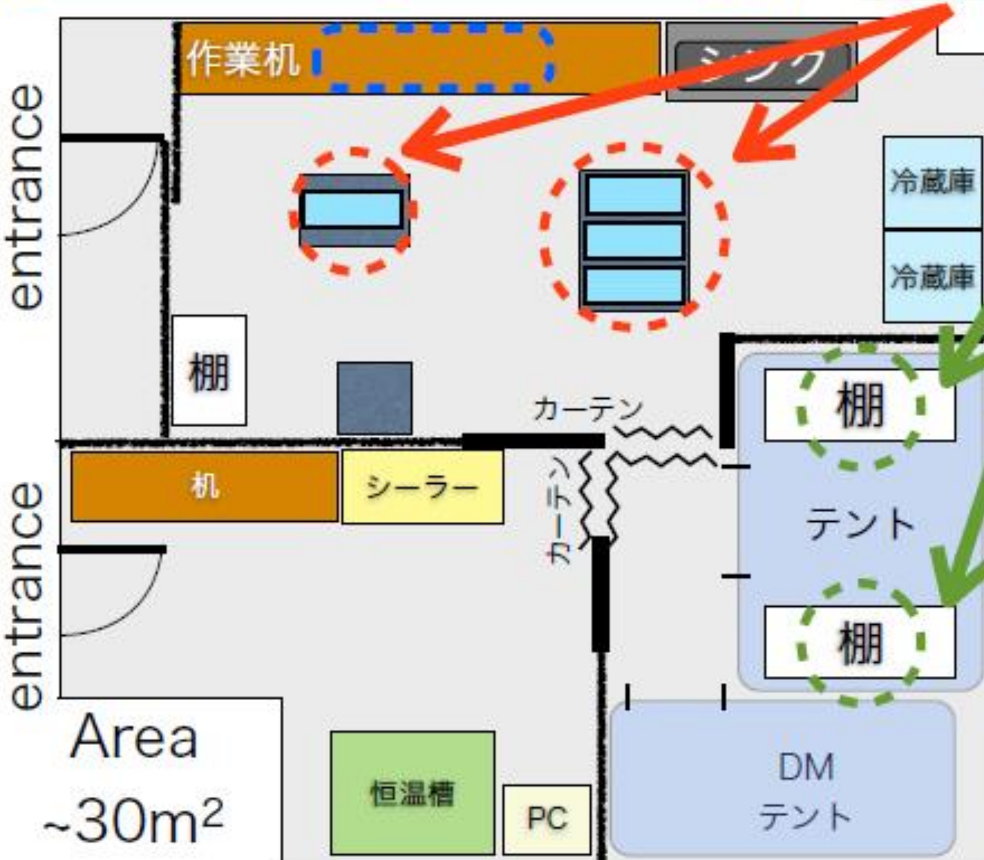


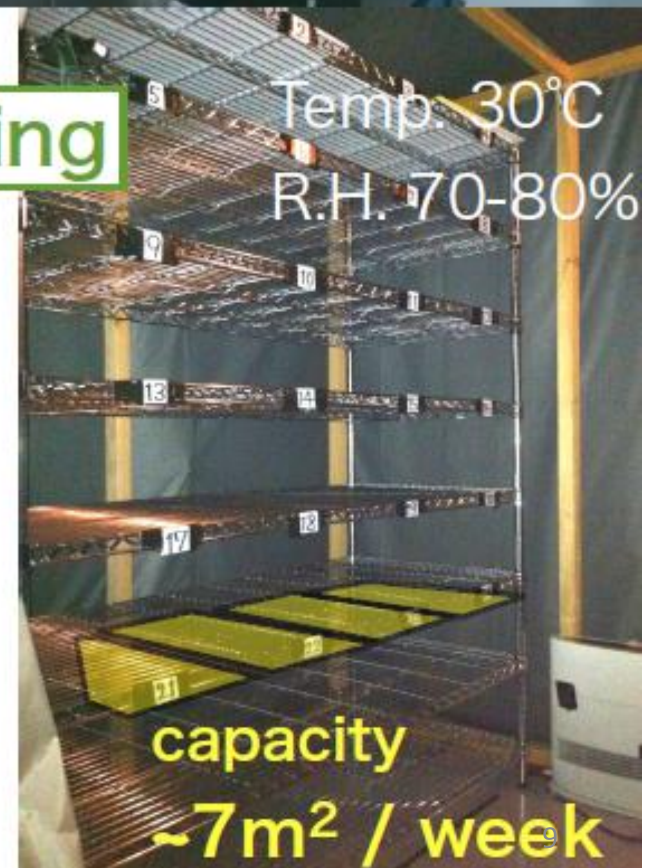
→Repeating for another side

Pouring Room

Measuring&Melting







Past performance of mass production (case of GRAINE-2015 experiment)

2014 Jan. Feb. Mar. Apr. May. Jun. Jul. Aug. Sep. Oct. Nov. Dec. 2015 Jan. Feb. Mar.

Gel

154 operations(x1)

51 operations(x1)

40 operations(x3)

subtotal 245 operations (194.7 kg)

Base

subtotal ~150m^2 (~600 cuts)

Discharging (30cm x 1260m=)387 m^2 → a half of area with good quality

Pouring

test run 1week

3 weeks

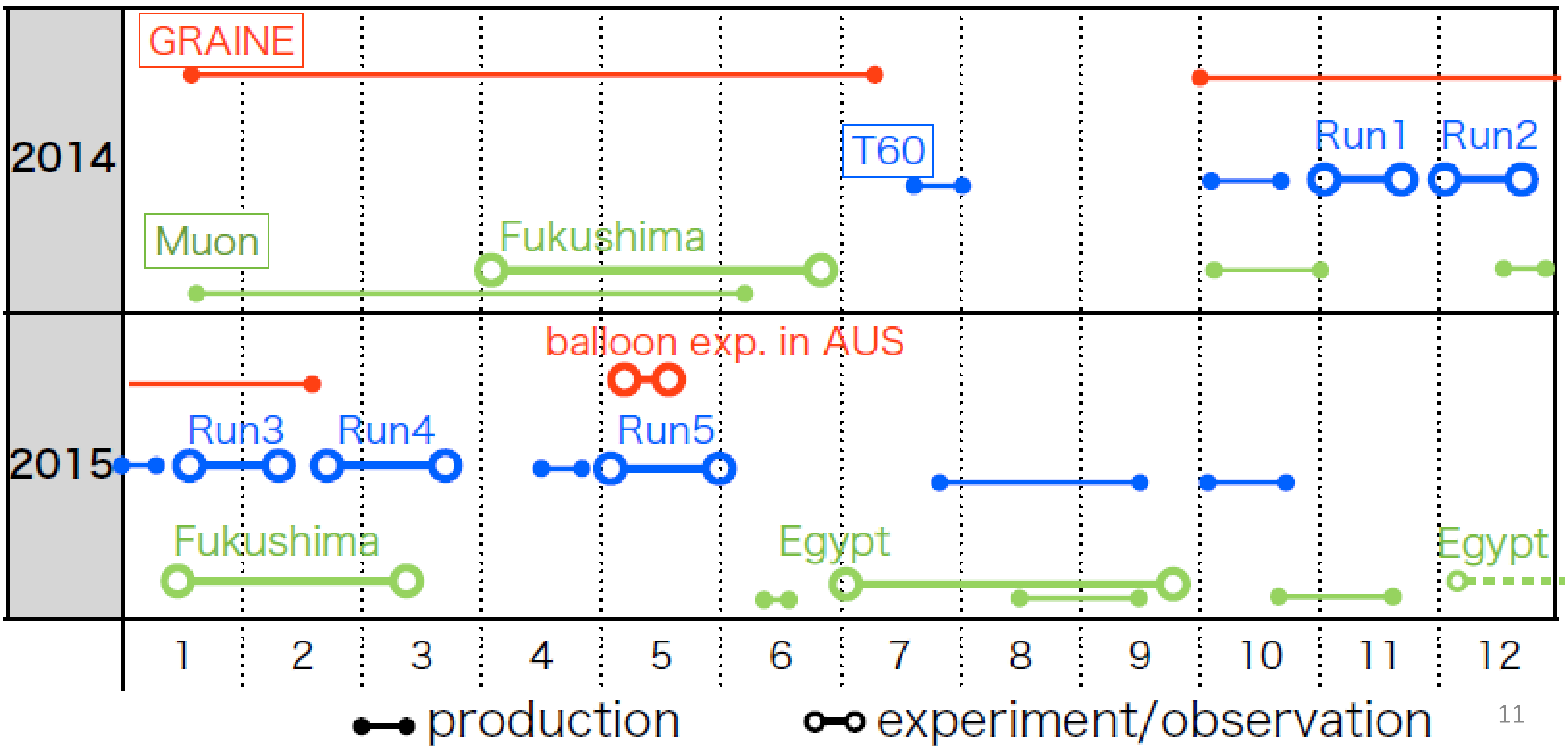
8 weeks

total 66.83 m^2 (gel 143.9 kg)

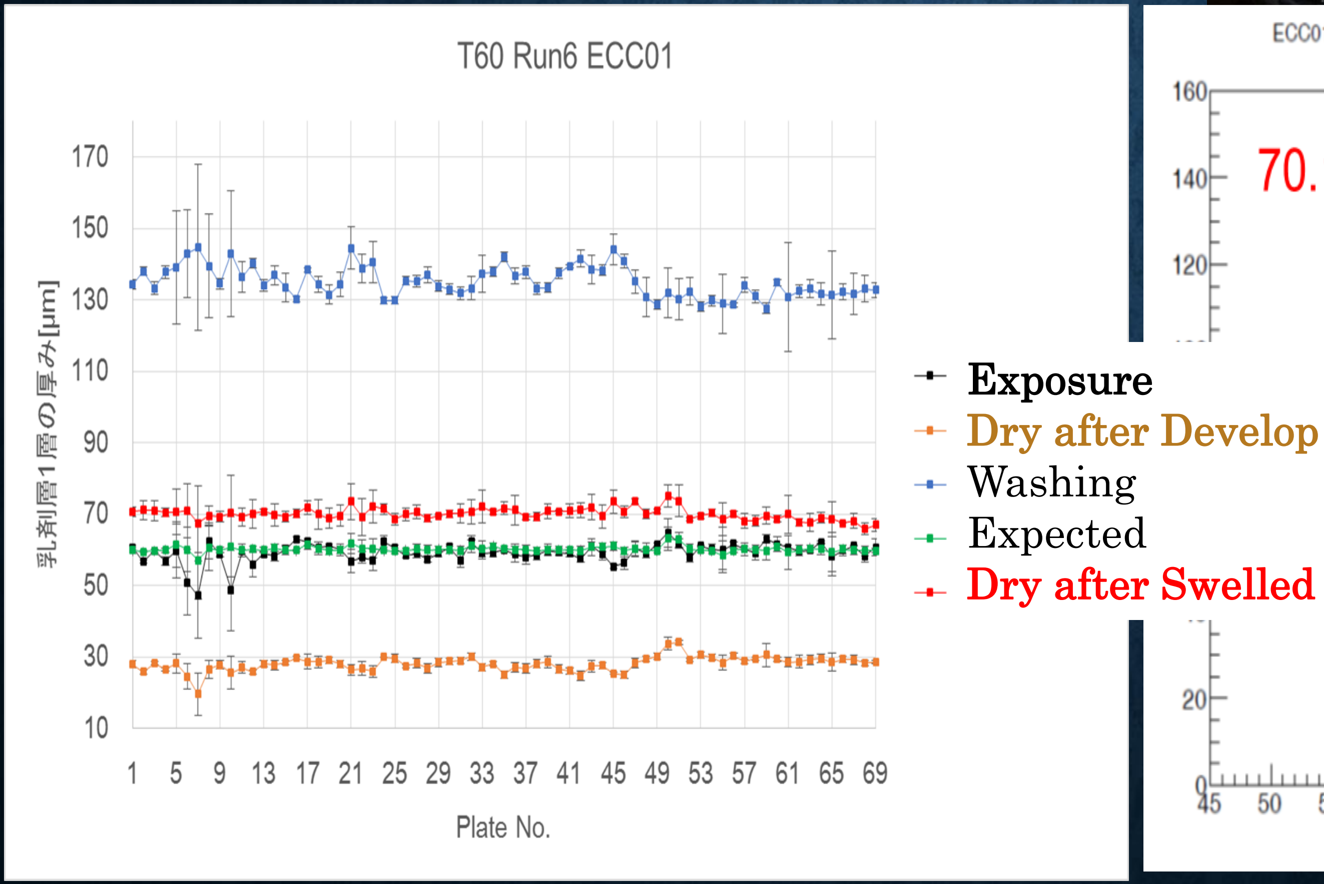
with 11 members

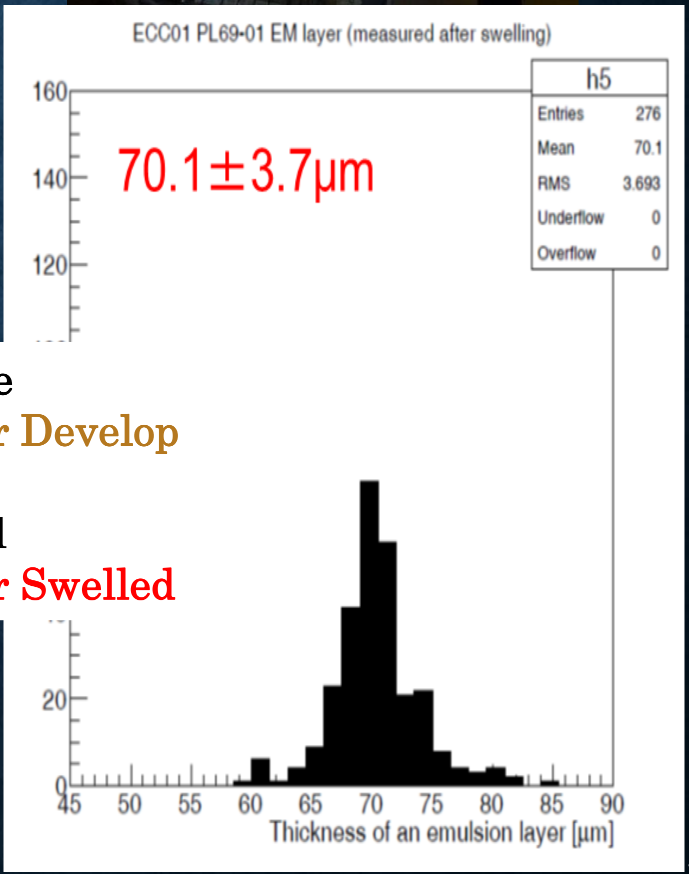
Productions & Experiments in 2014-15

	gel production	film production
GRAINE	200 kg	67 m^2
JPARC-T60	67 kg	30 m^2
μ-radiography	40 kg	20 m^2



After development treatment

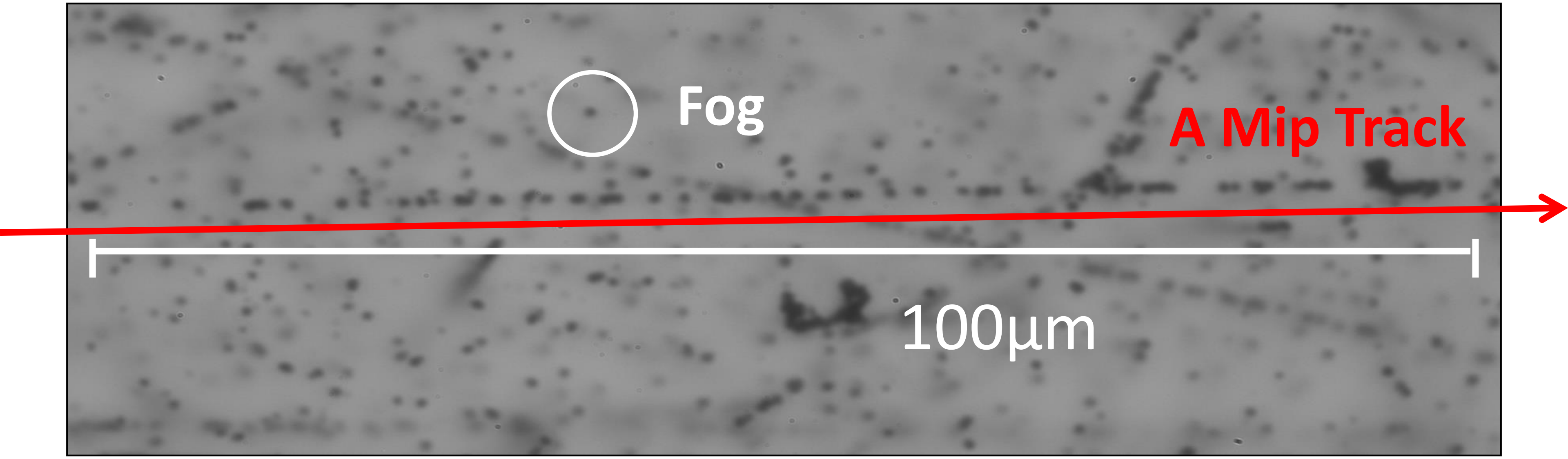




Basic characteristics of emulsion

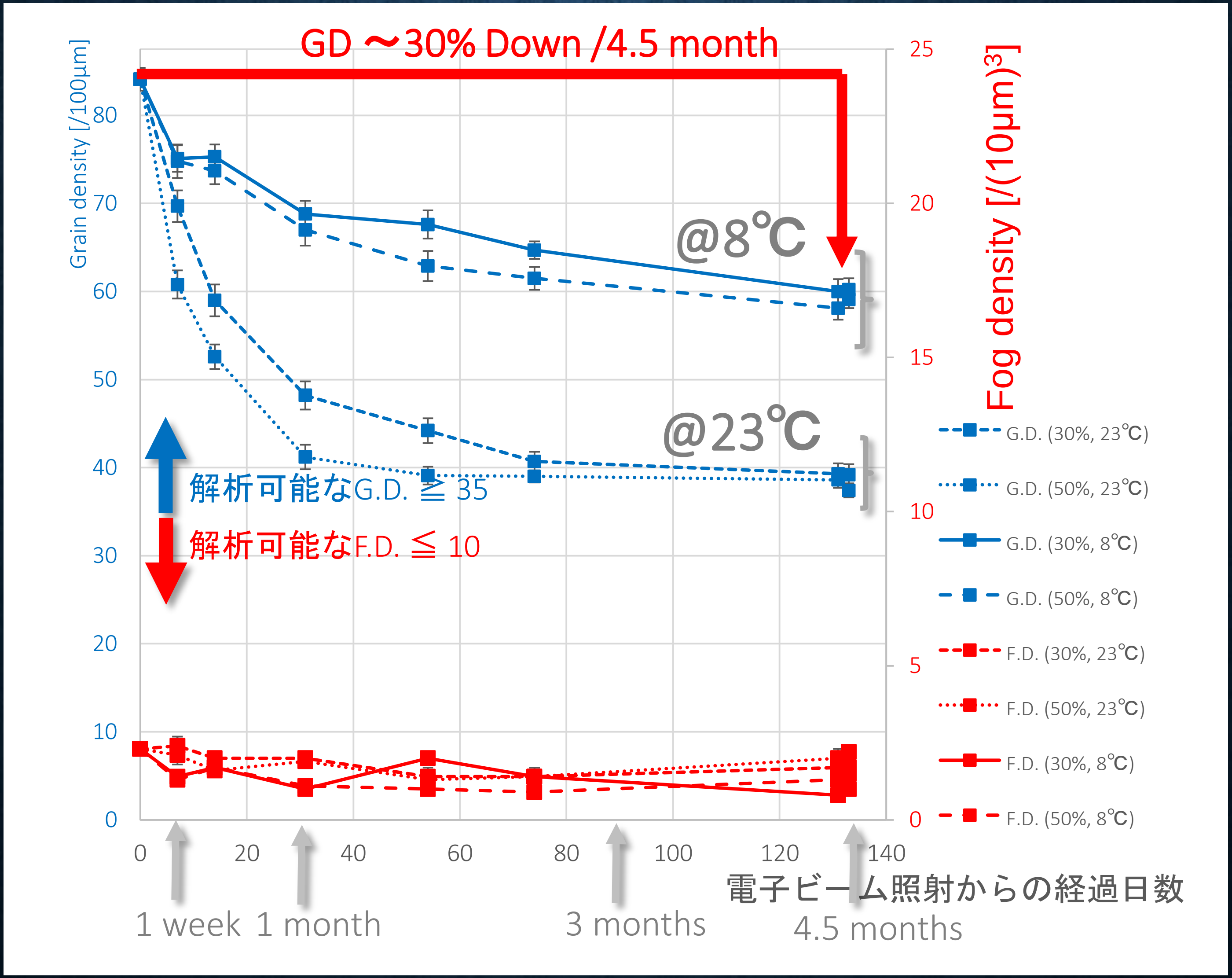
- Grain Density (GD) : Number of silver grains in 100 um mip track length
- Fog Density (FD) : Number of silver grains in a volume (10um)3

- Higher GD (>30 or so) and lower FD(<10 or so) is a good emulsion.



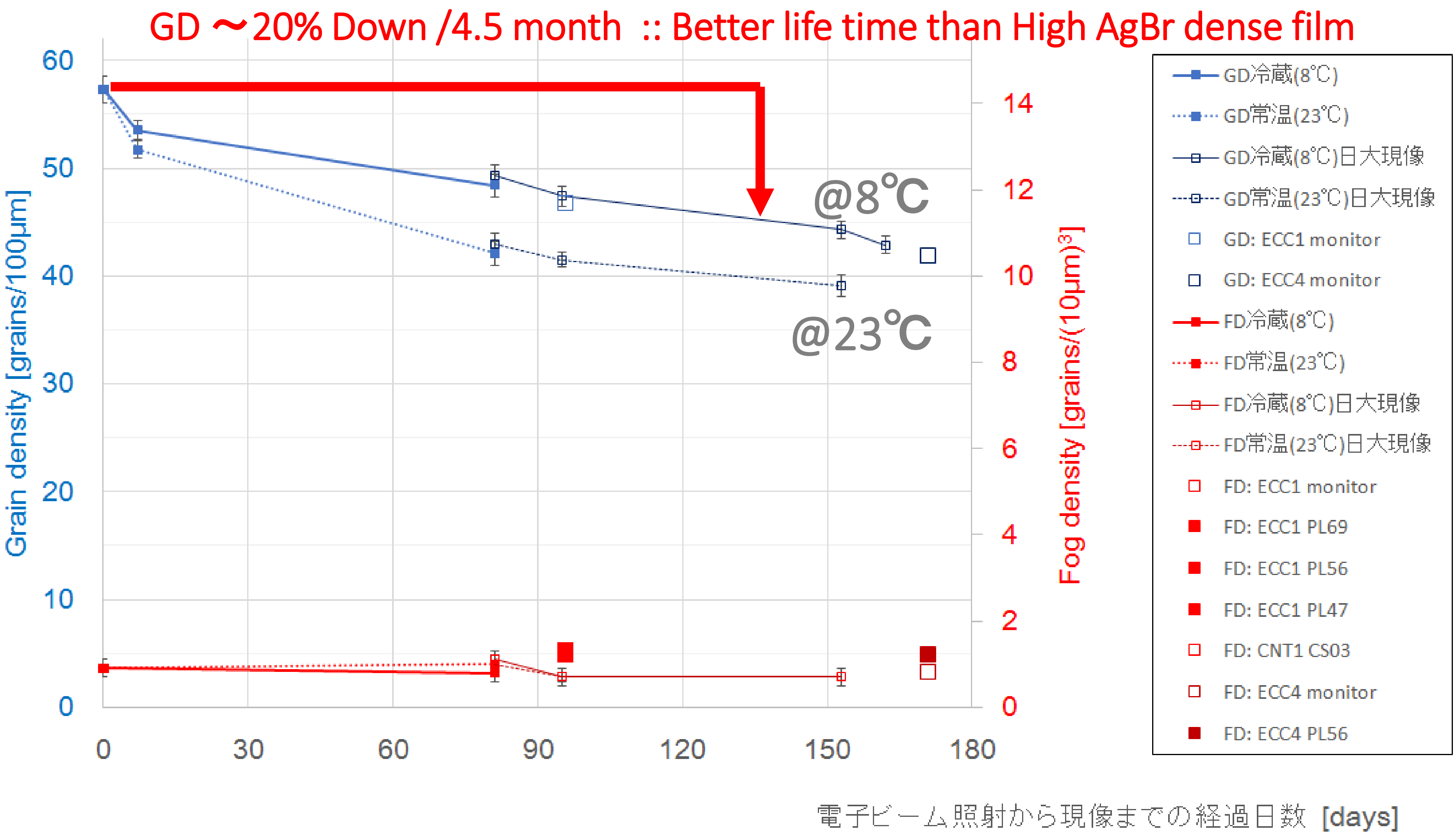
GD and FD long term stability

High AgBr dense composition film (55%v 高銀)



GD and FD long term stability

Middle AgBr dense composition film (45%v 中銀)

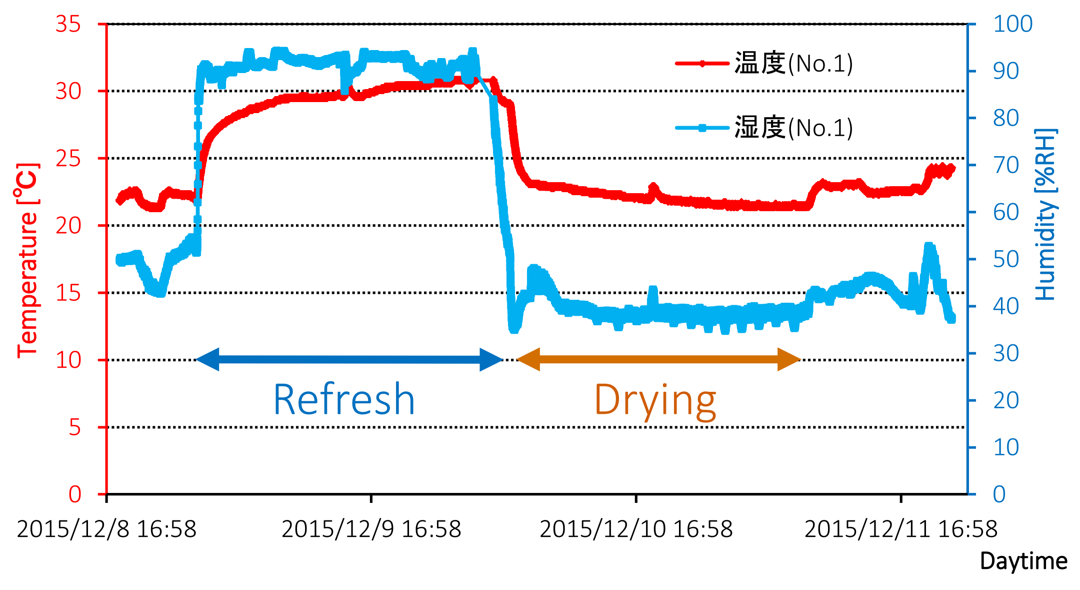


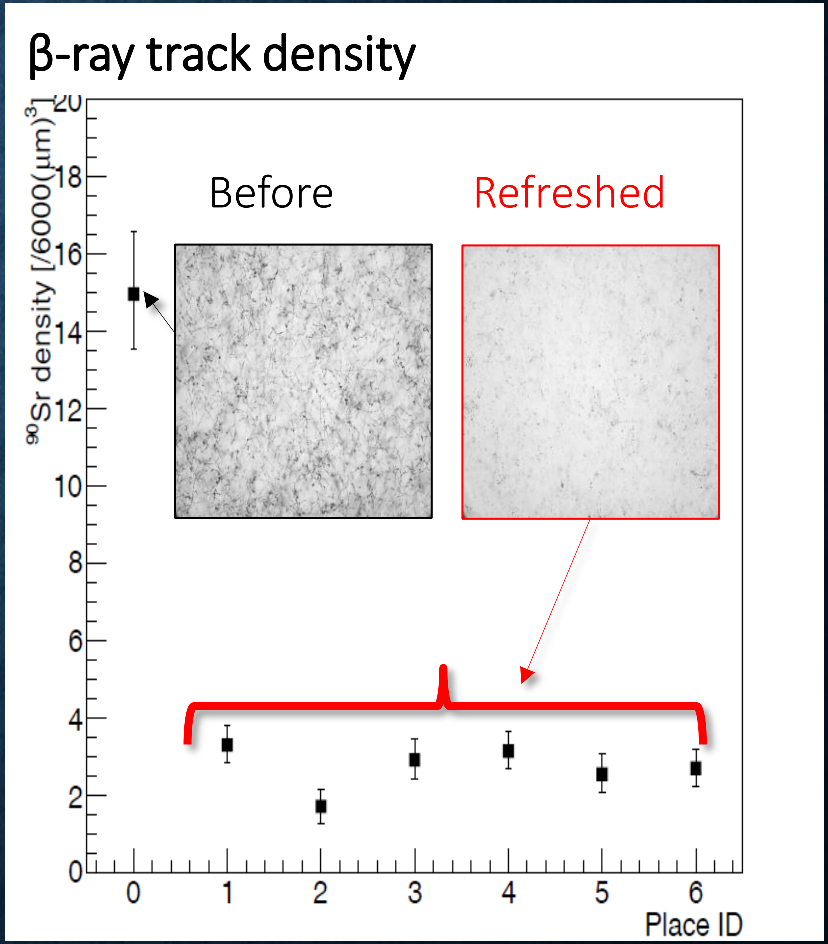
Refresh treatment

Film can be "Refreshed".

Before in use,
"Erasing" accumulated tracks by
high temperature and high humidity.

$Ag_4 + 2H_2O + O_2 \rightarrow 4Ag^+ + 4OH^-$





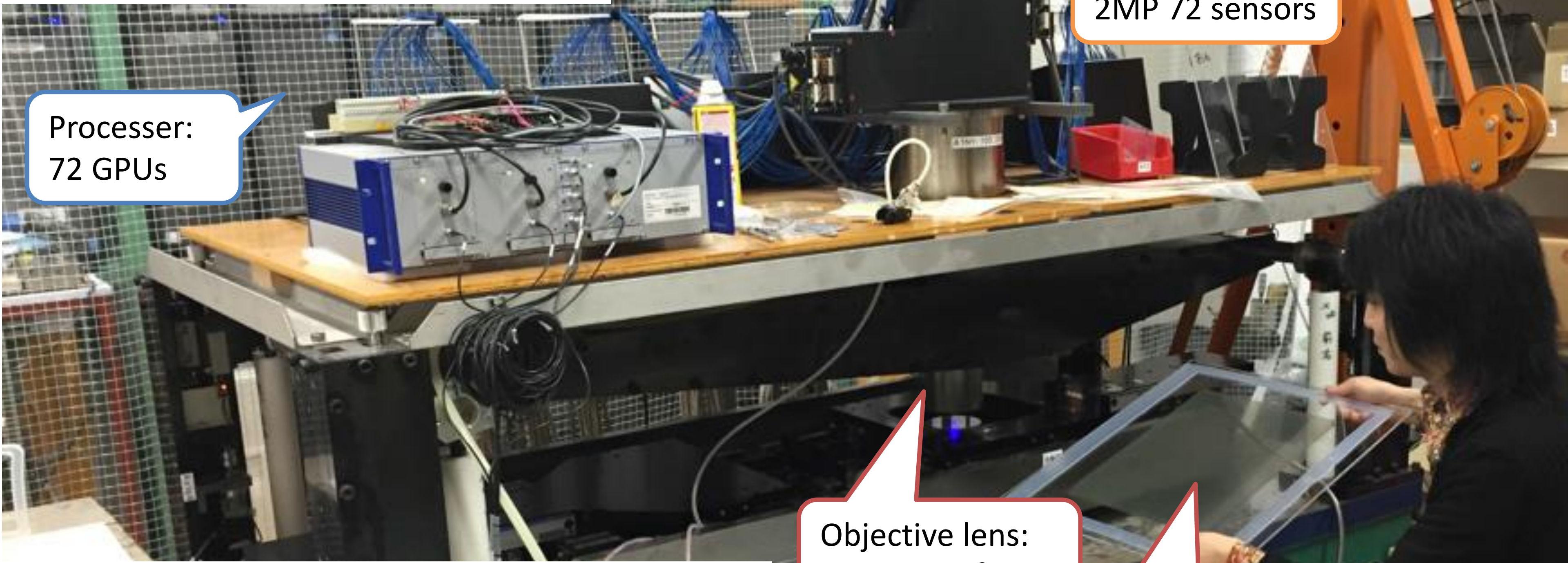
Emulsion amount

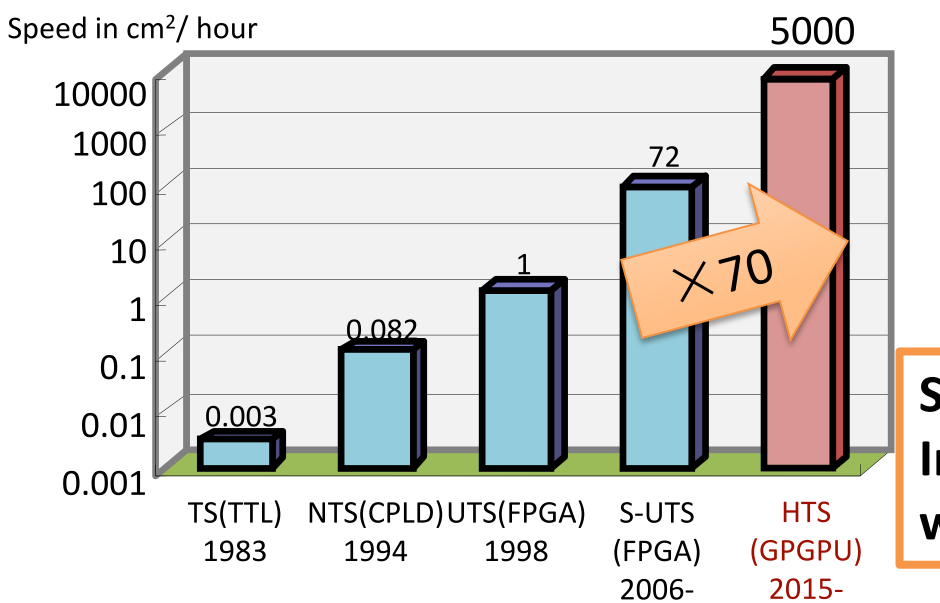
ECC **Chamber** structure depends on physics, specific conditions.
Sandwich with target material (plates) or only emulsion films ECC
Water, Fe, Pb, C etc.

Required emulsion amount can be estimated
① If fixing **tracking sampling rate** (material and film ratio) is fixed.
② If accumulating **track density** is fixed .
③ If exposure **period** (and **temperature** condition) is fixed

Remark
Direct contact by some metals (Al, non stainless Fe) make damage to Emulsion
Maximum track density can be analyzed in emulsion films $<10^{6}$ / cm^{2}
(keep $< 10^{4\text{-}5}$ /cm^2 is safer)

Hyper Track Selector

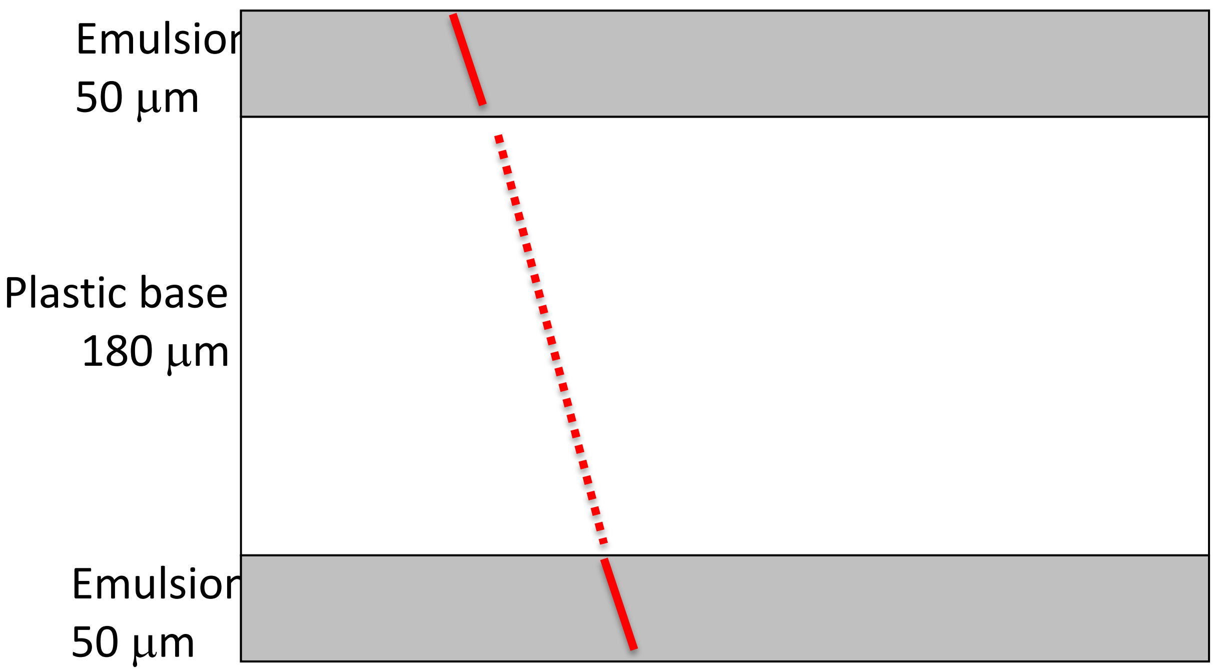


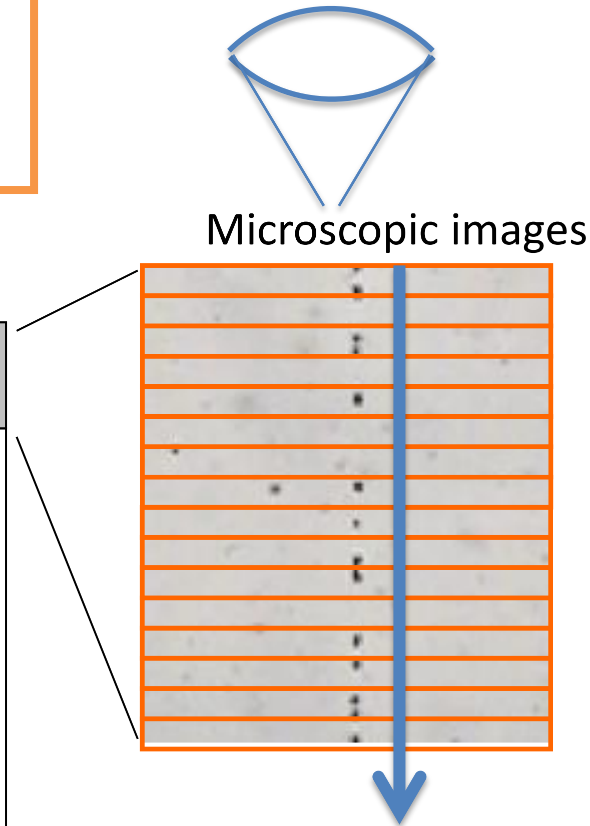


Scanning time is shared by projects.
In total about 100 m^2 film area (>1000 films) were scanned in recent 12 months

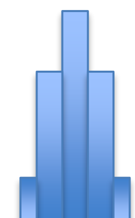
Track recognition by automatic scanning system

Cross section of a nuclear emulsion film





Summing up 16 layers



Out put of Automatic scanning system :
Angle(AX,AY),position(X,Y,Z),track darkness(PH)

Not a projection detector

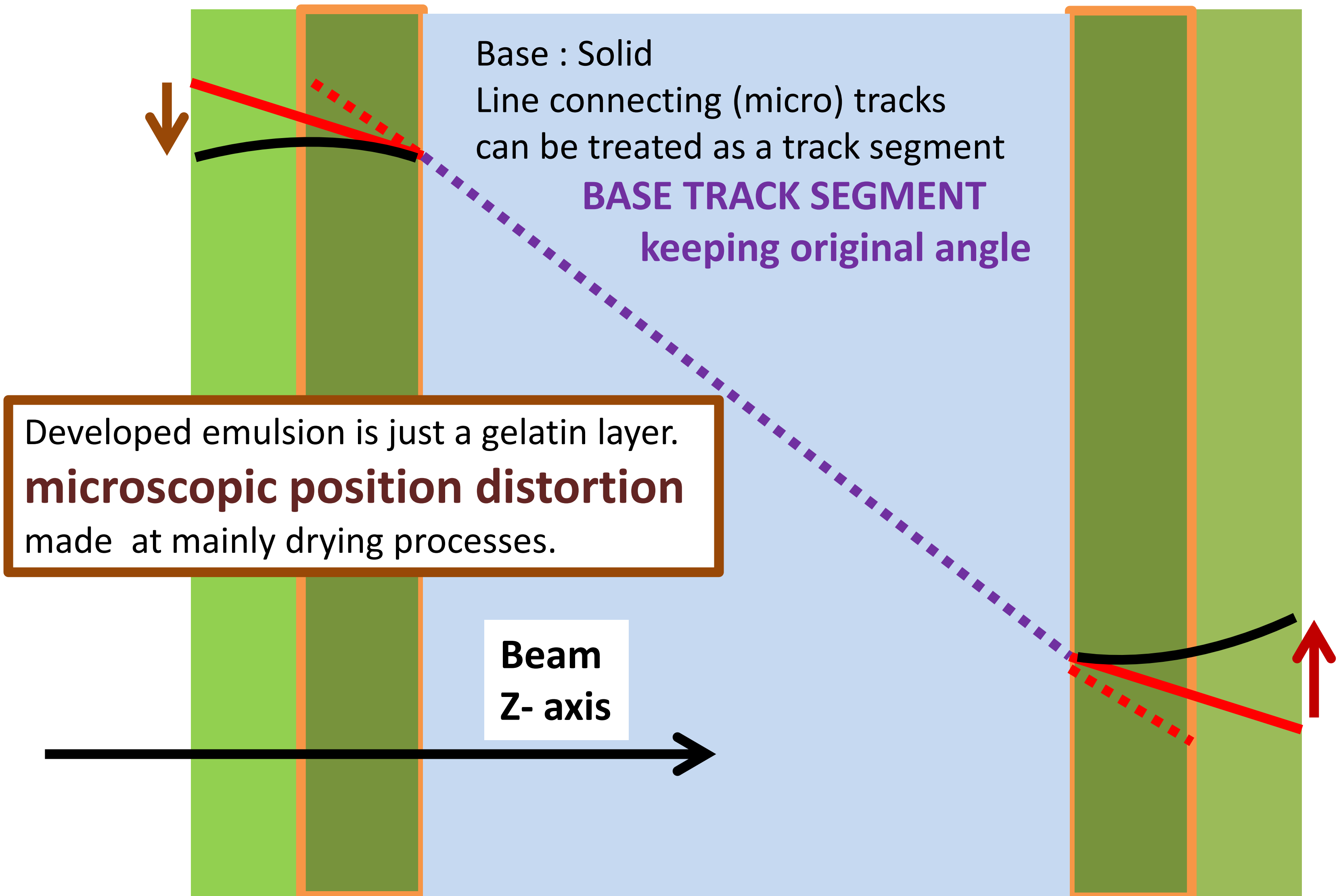
but a **vector** (6-dim) detector !

Sum of HIT pixels

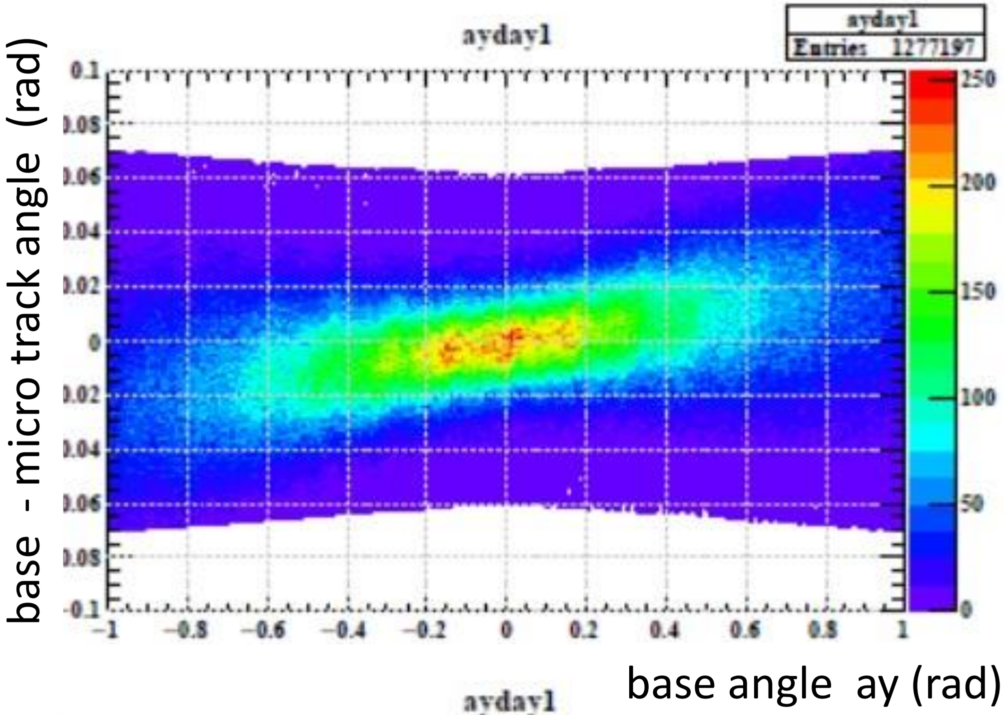
Proportional to dE/dX

Shrinkage and **distortion**

Emulsion is shrink or swelling after development treatment.
So angle is not conserved at exposure time and to be corrected .
Shrinkage factor :: Emulsion thickness ratio at exposure time and scanning

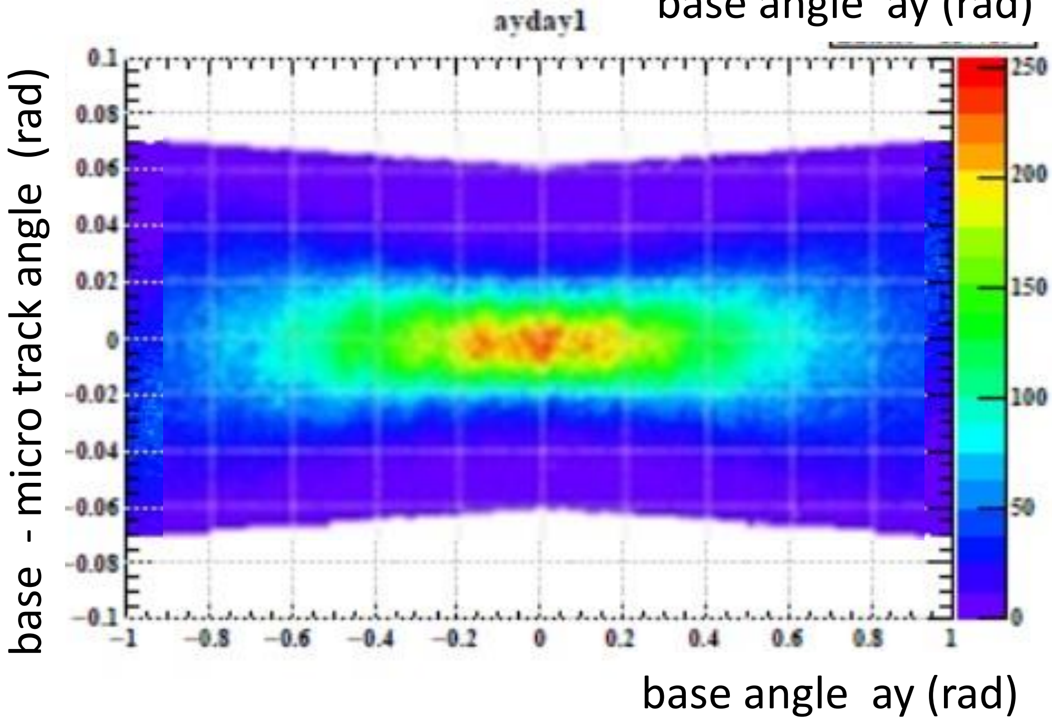


Shrinkage correction



Insufficient
Shrinkage correction

Angle difference have
Angular dependence

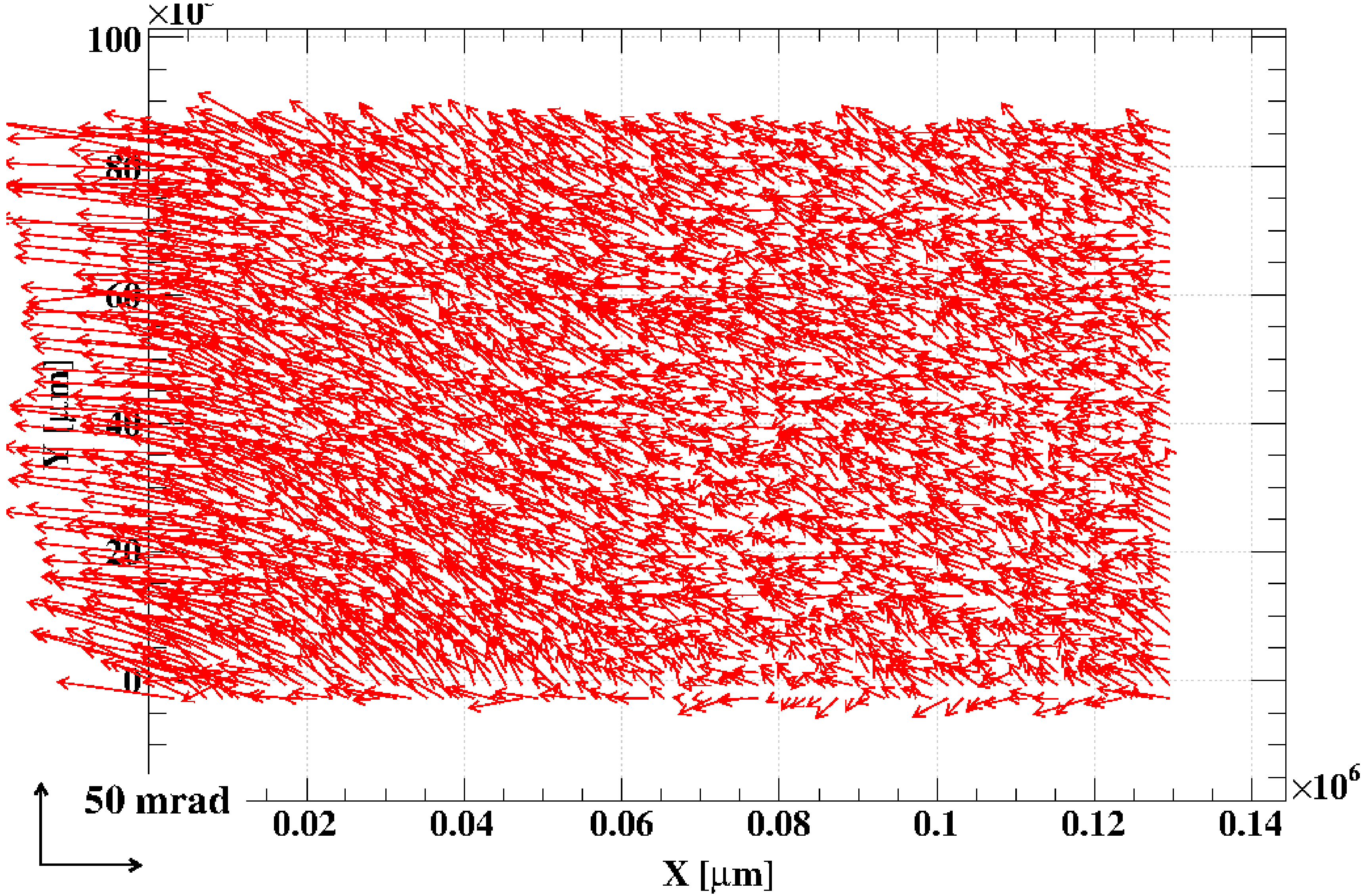


Shrinkage corrected !

Angle difference have
no angular dependence

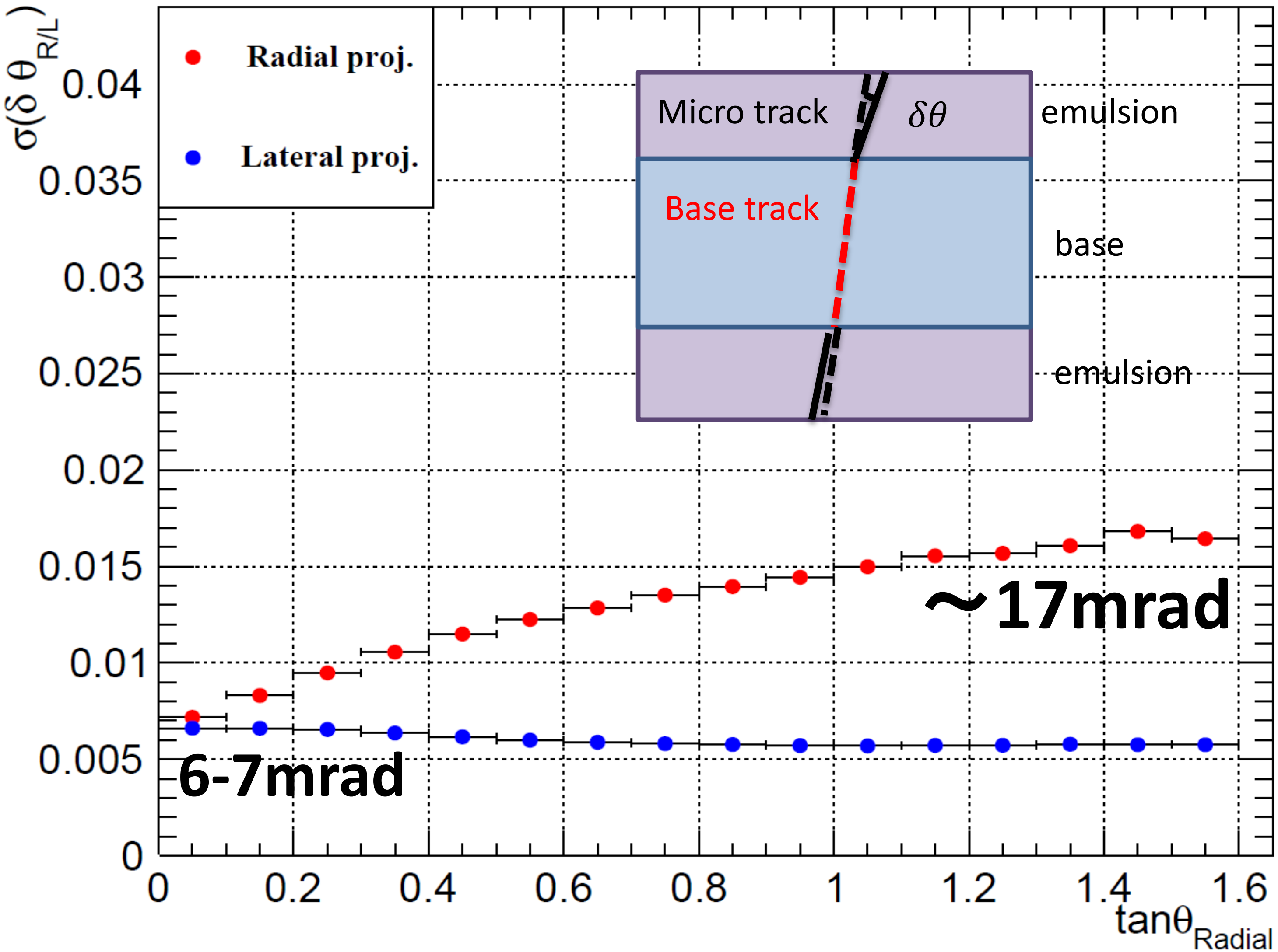
An example of distortion map (T60 PlotDc_dc-45.lst.ps)

Typically distortion is similar around a few mm area.
So the distortion correction is done by each several mm area box.
With shrinkage(film thickness) correction micro track angle is aligned to base track



Micro track angular resolution

(angle difference between base track and micro track)

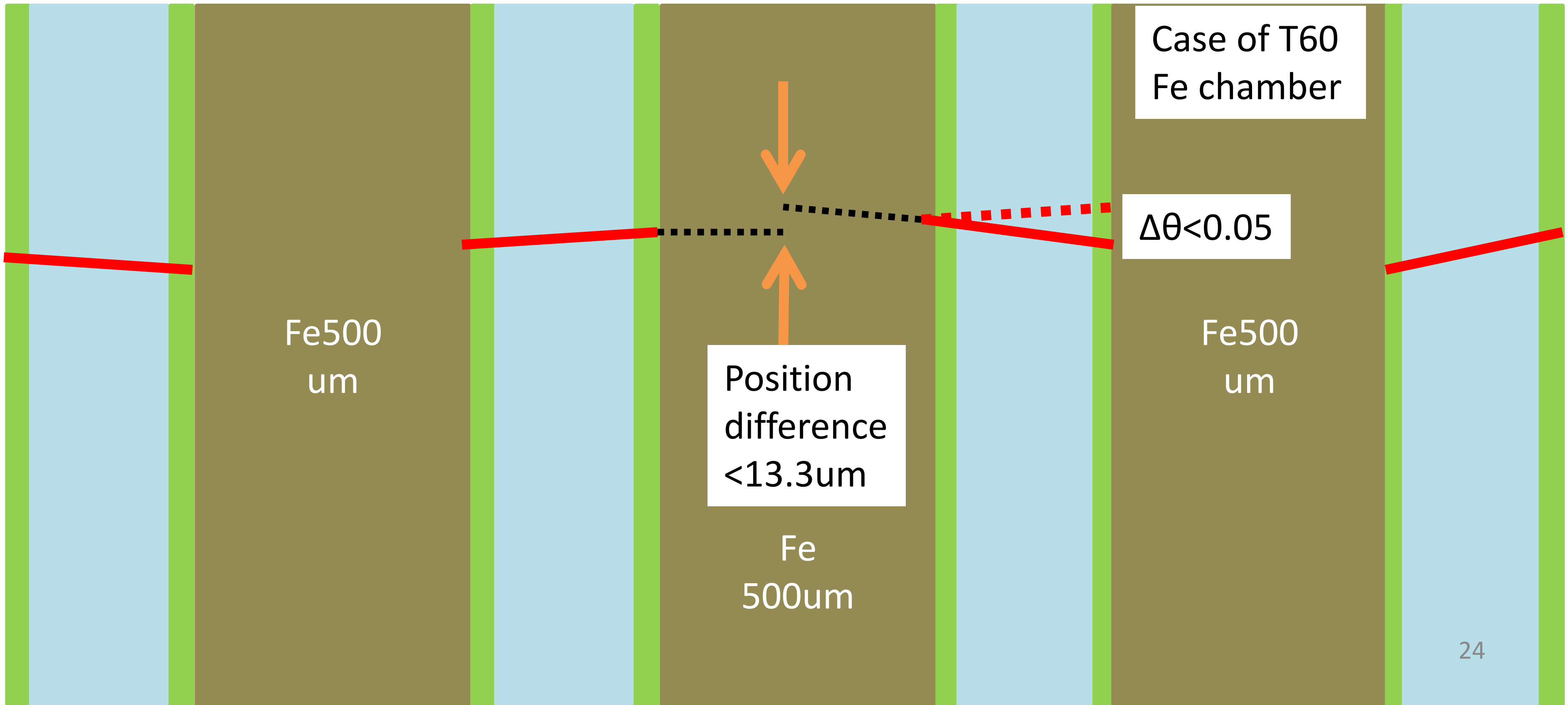


PH VOLの高い飛跡を残す

Track reconstruction

- Two base track segments are tried to be connected assuming cut off momentum.
- They are connected if the position and angular difference within the allowance .
  - Position difference between two segments extrapolating at middle place.
  - Angular difference

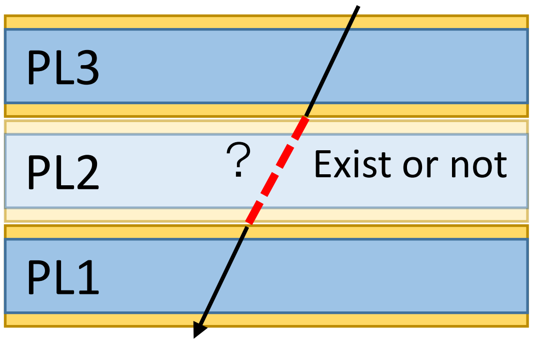
Continue to all possible combination of two tracks → all tracks are reconstructed.

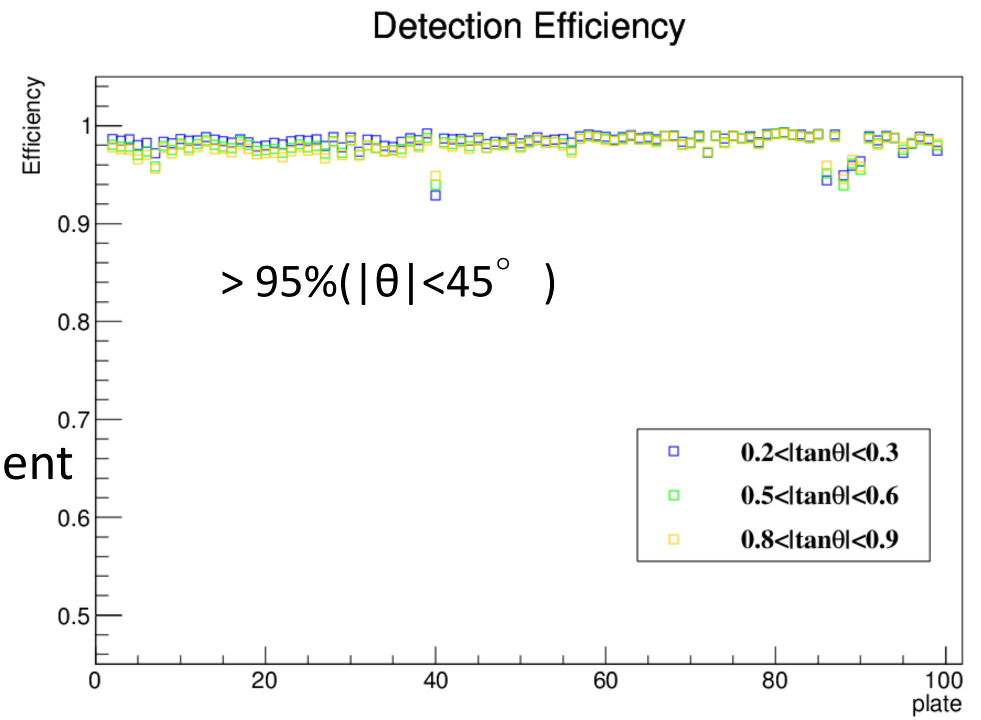


HTS performance

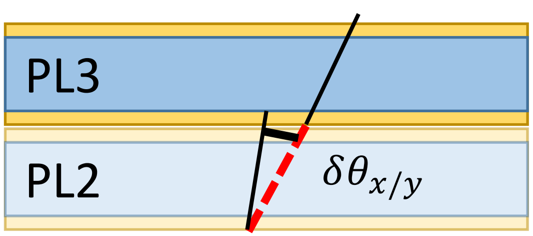
- GRAINE2015 films

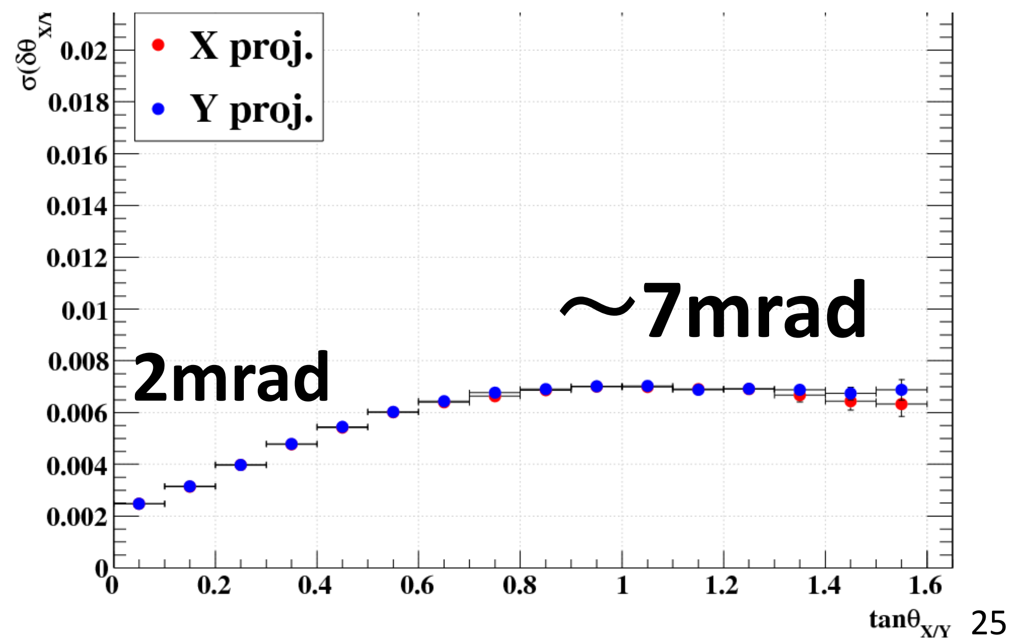
Tracking efficiency of base track segment





Base track angular resolution

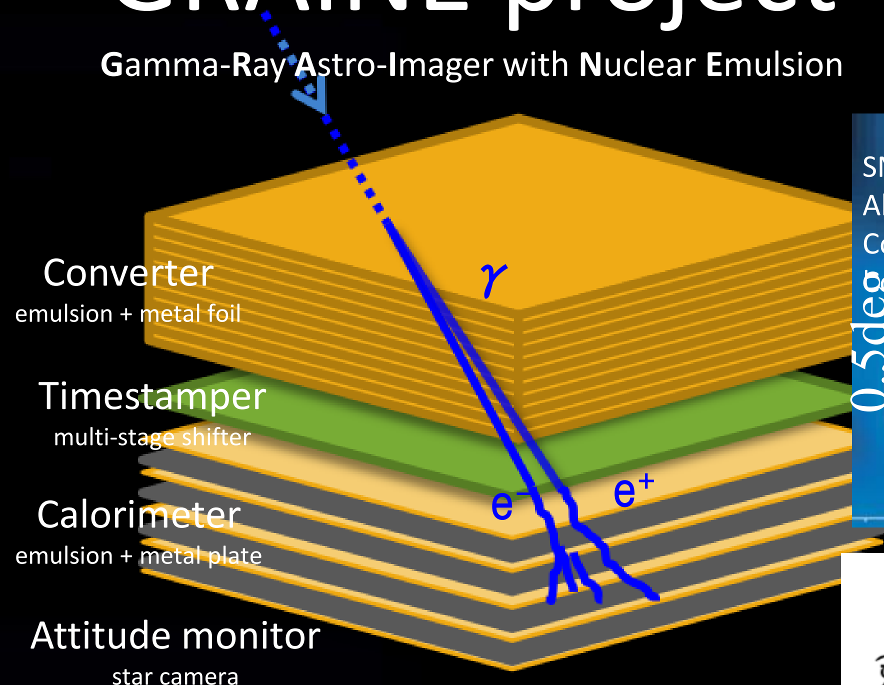




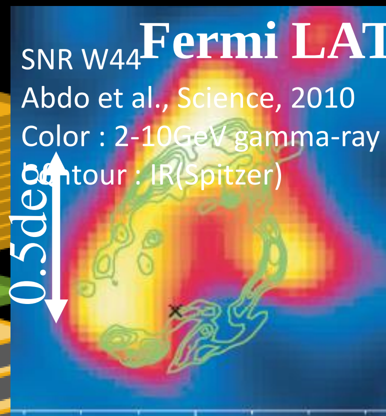
GRAINE project

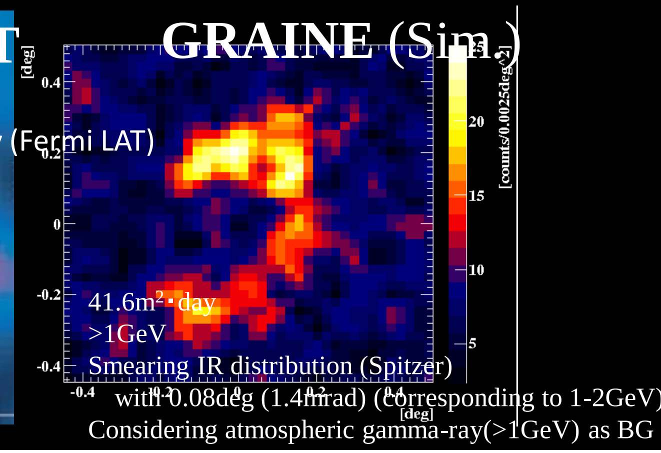
Gamma-**R**ay **A**stro-**I**mager with **N**uclear **E**mulsion

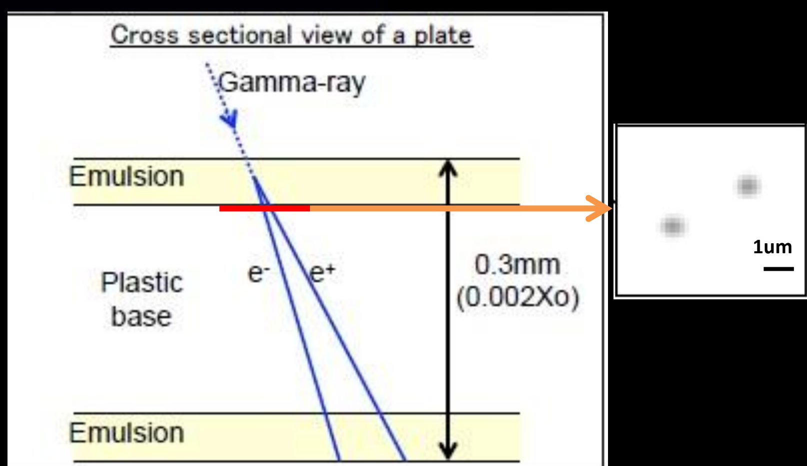
33 collaborators, 6 institutes, PI : S.Aoki (Kobe Univ.)
Aichi University of education, ISAS/JAXA, Kobe University, Nagoya University, Okayama University of science, Utsunomiya University

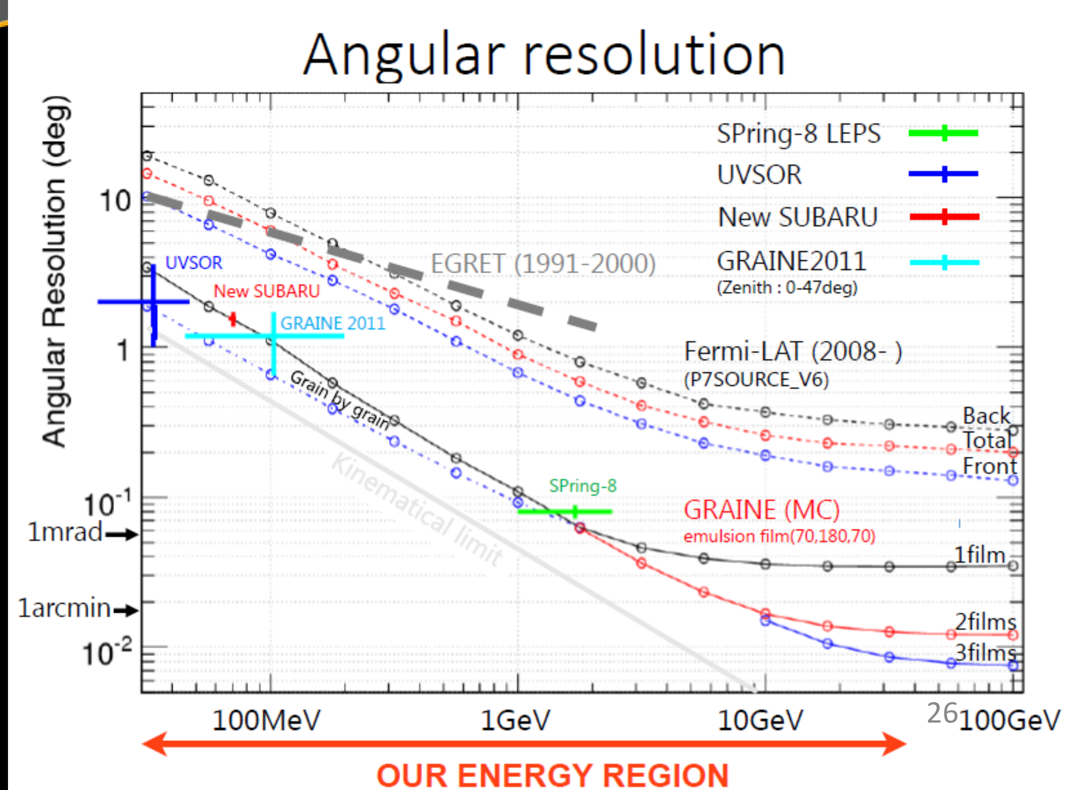


$10m^2$ x 7days x 5flights
(~ Fermi-LAT 1year ($1m^2$ x 365days))





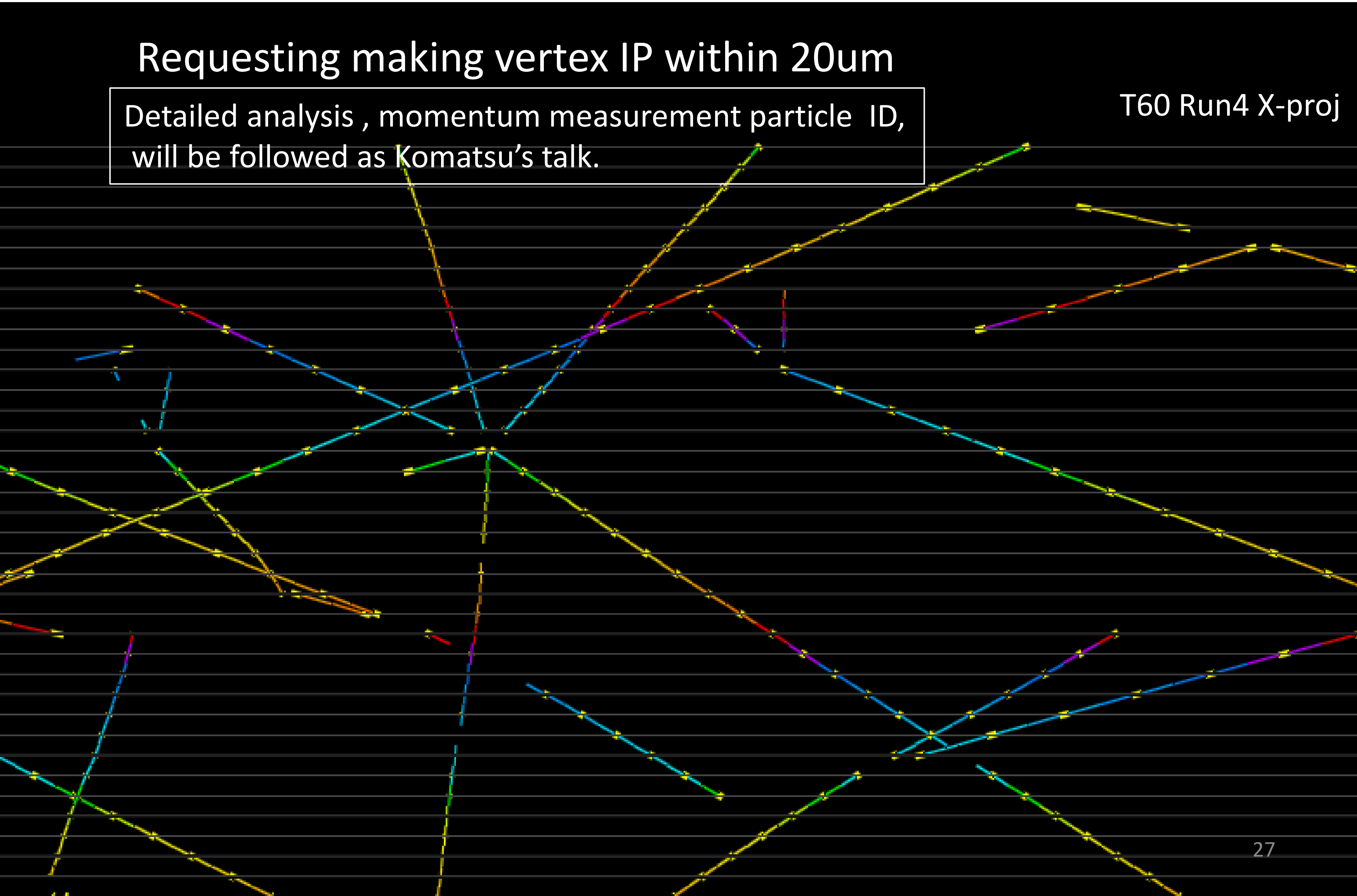




Event analysis example

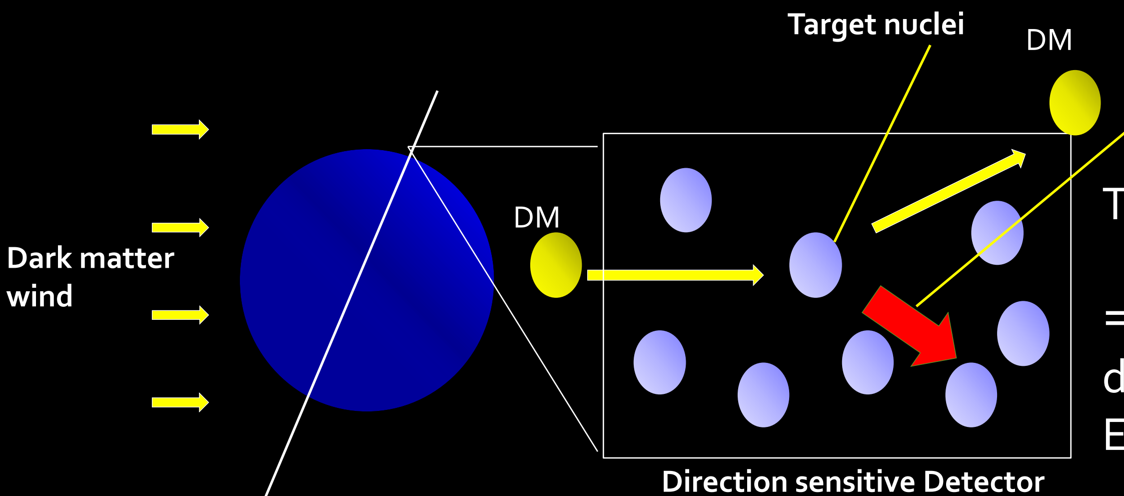
Requesting making vertex IP within 20um

Detailed analysis , momentum measurement particle ID,
will be followed as Komatsu's talk.



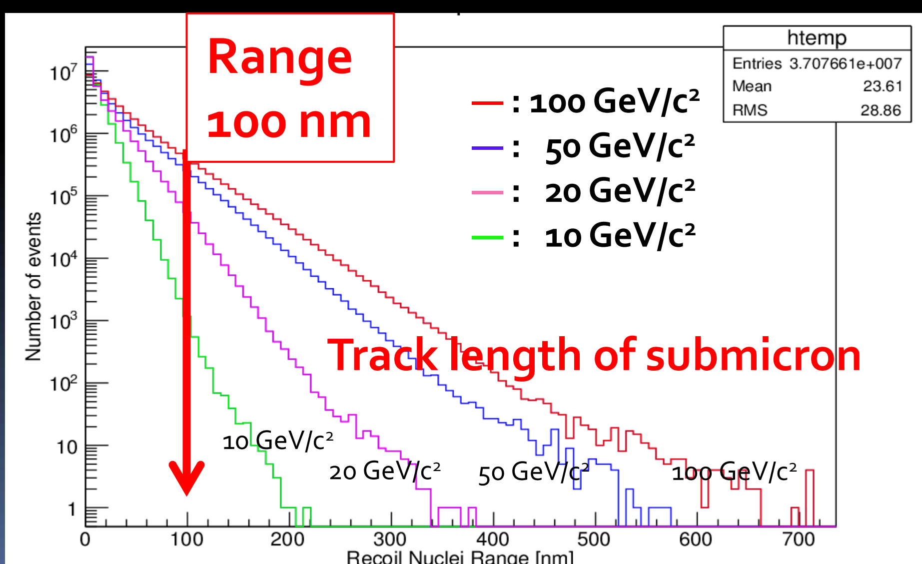
Use of non standard film, AgBr Crystal control film

Directional Dark Matter Search with very high resolution nuclear emulsion



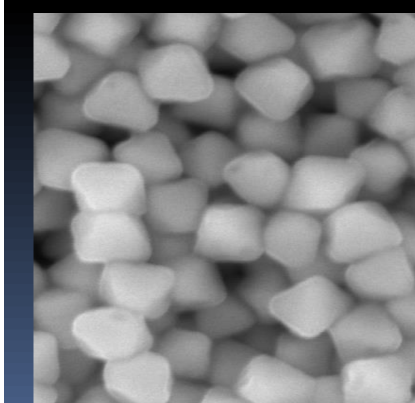
Detection of recoiled nuclei as tracks

Target Nuclei :
C (N,O) and Ag, Br
⇒ Sensitivity of C (N,O) recoil is dominant for tracking because tracking Energy threshold and form factor value.

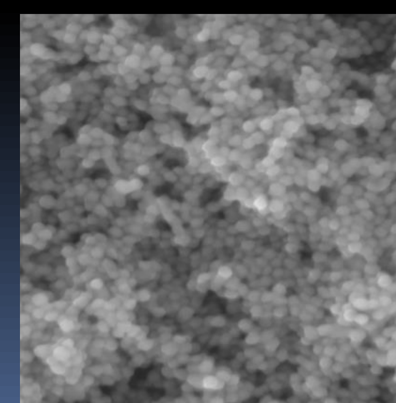


Track length [nm]

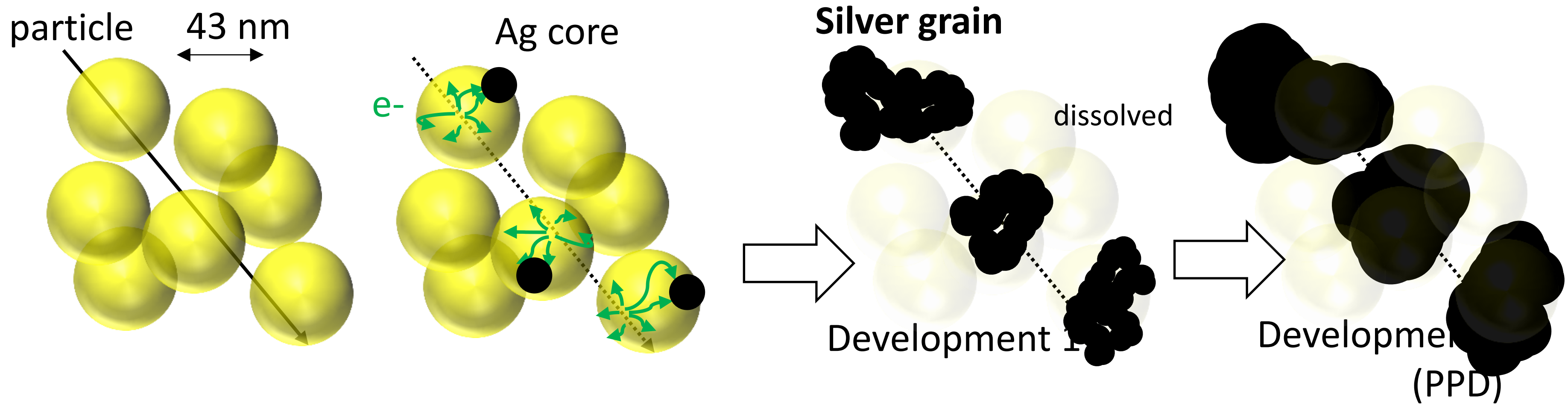
Standard
200 nm AgBr



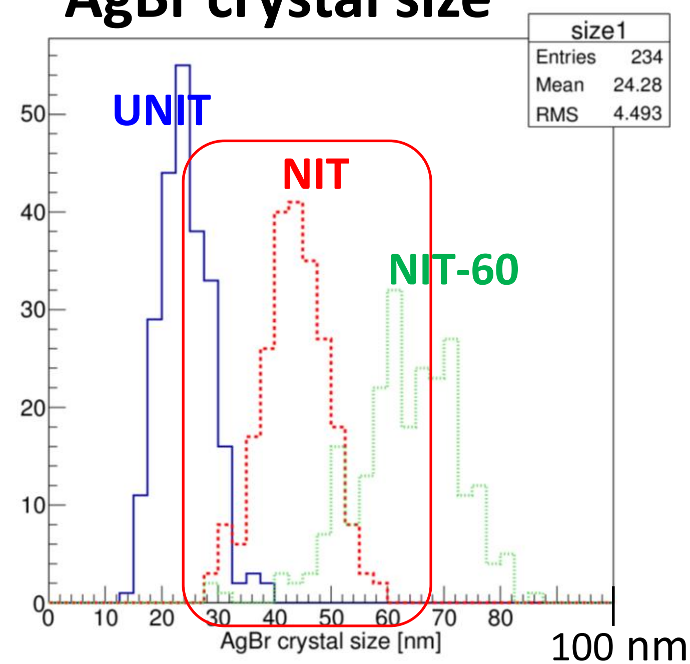
Nano Imaging Tracker
40nm AgBr



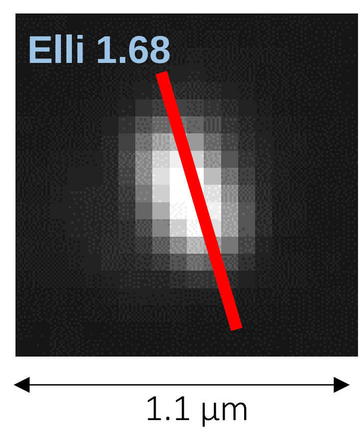
detector : nuclear emulsion (NIT)



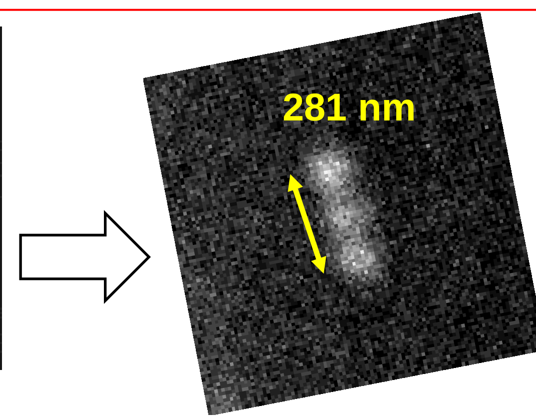
AgBr crystal size



Angular resolution ~ 350 mrad.



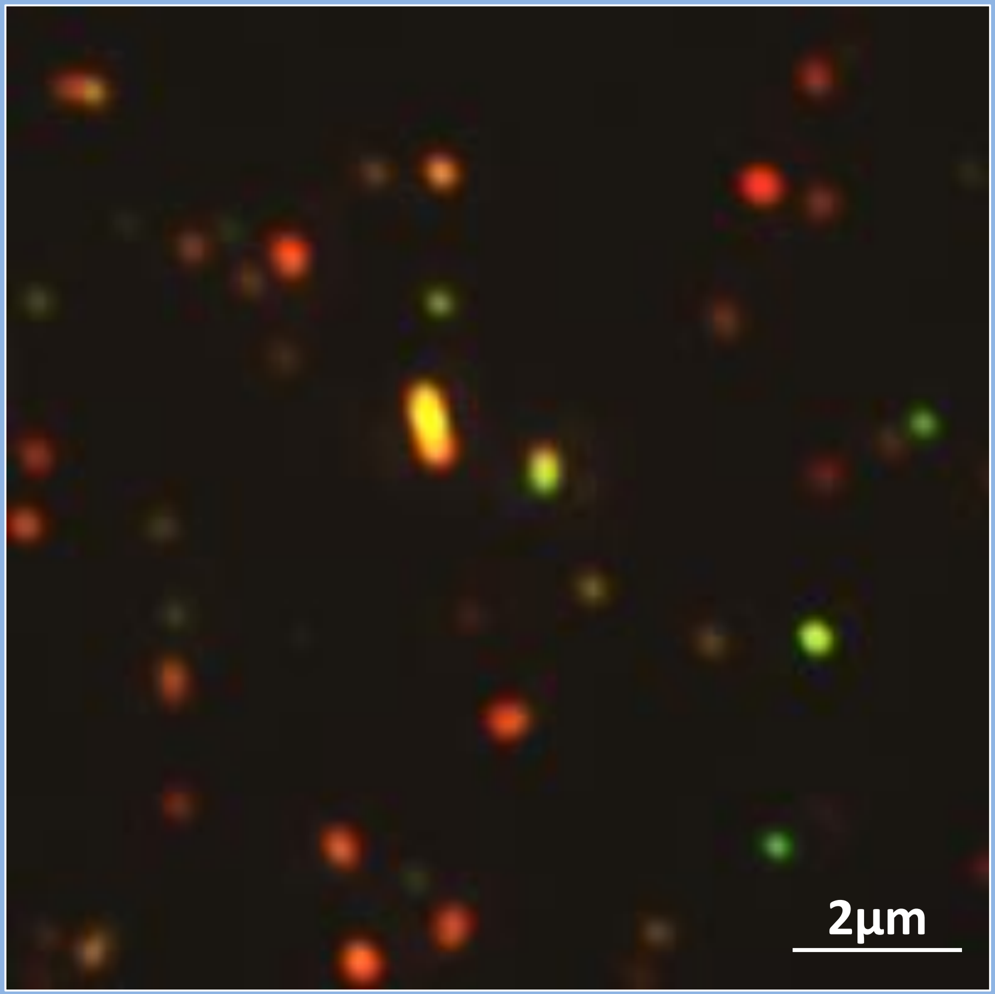
Optical micro scope
Readout image



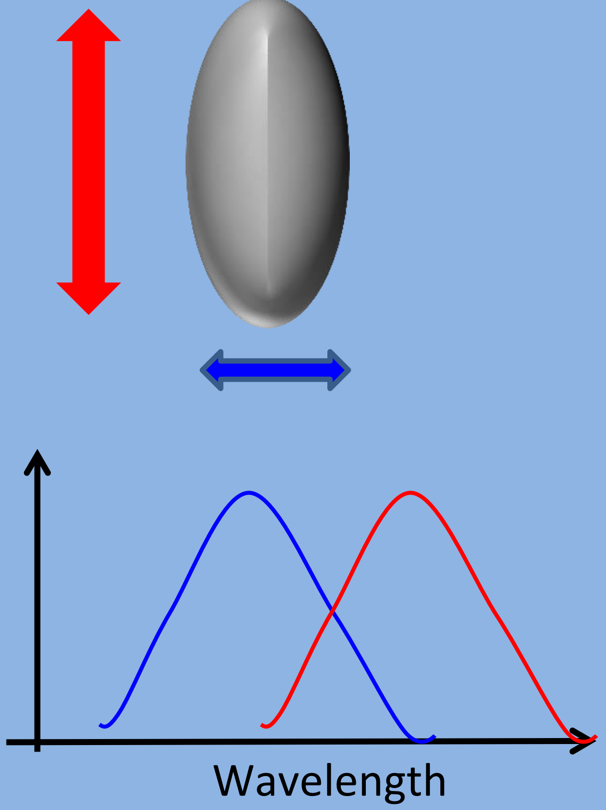
Xray micro scope
Readout image
(for confirmation)

Plasmon resonance in emulsion

Using optical microscope , can see tracks are colorful!!



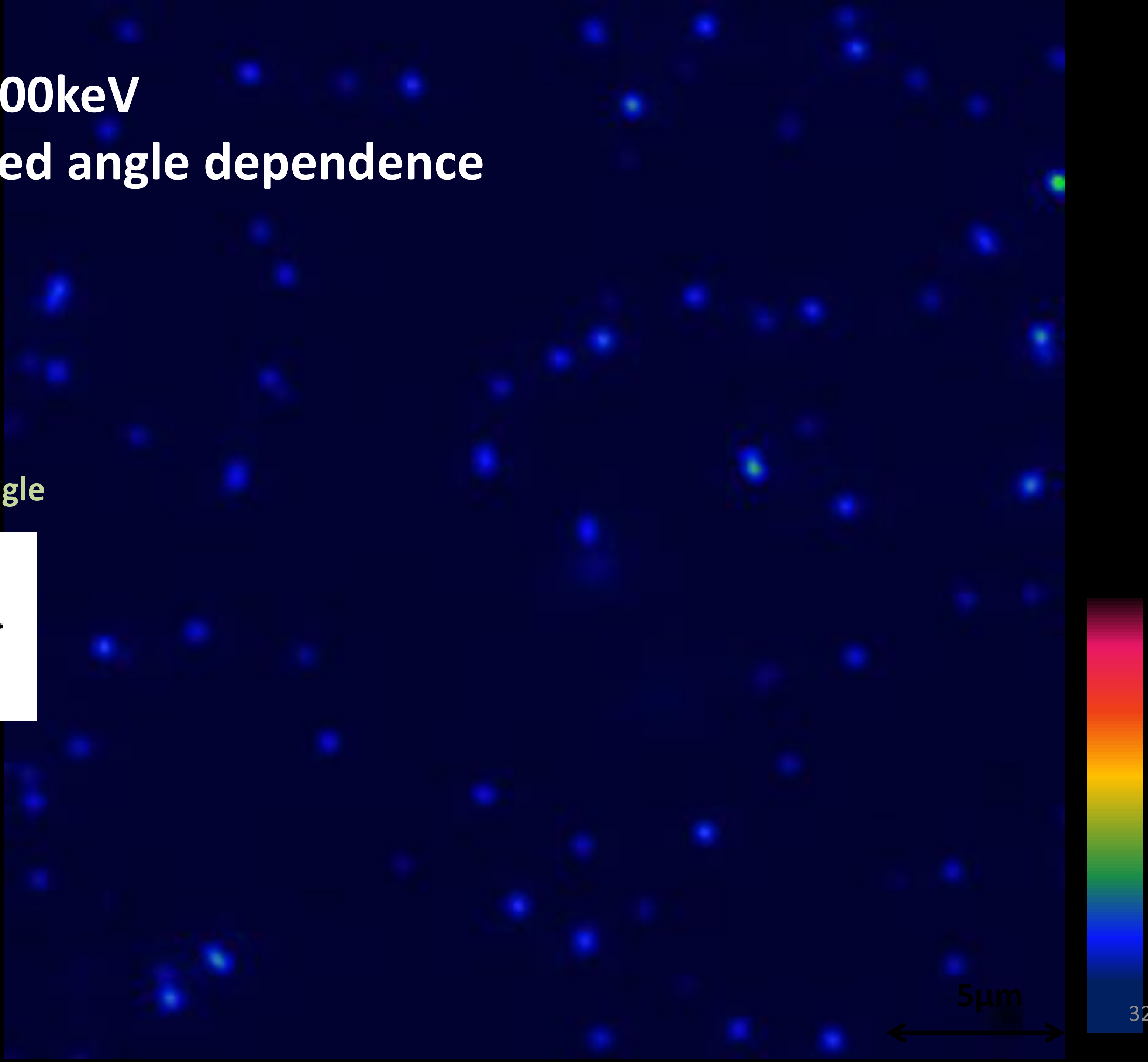
Polarized dependence



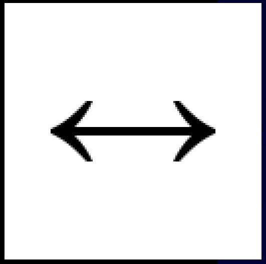
Carbon ion track after developing process

Taken by color camera (Halogen lamp λ = 300~3000nm)

C ion 100keV
Polarized angle dependence



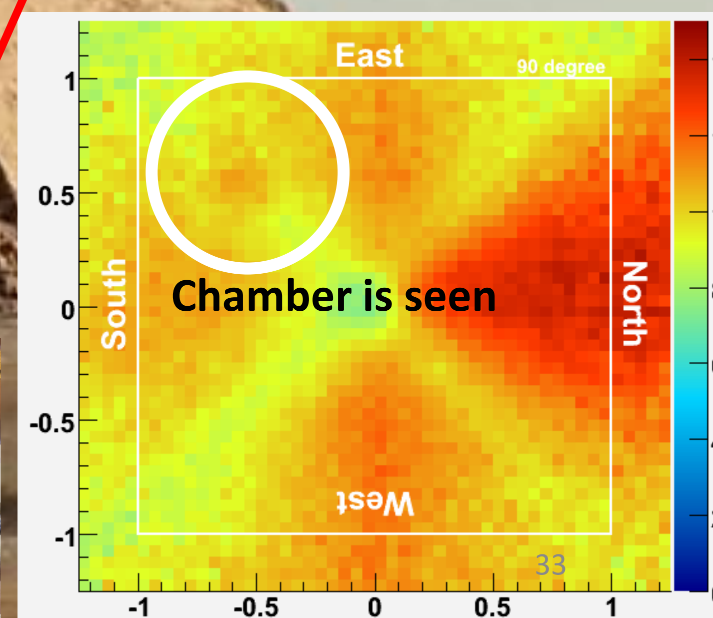
Polarizer angle



Muon radiography

100m

Arrived muon density as a function of angle
(40 films = $3m^2$ 40 days)



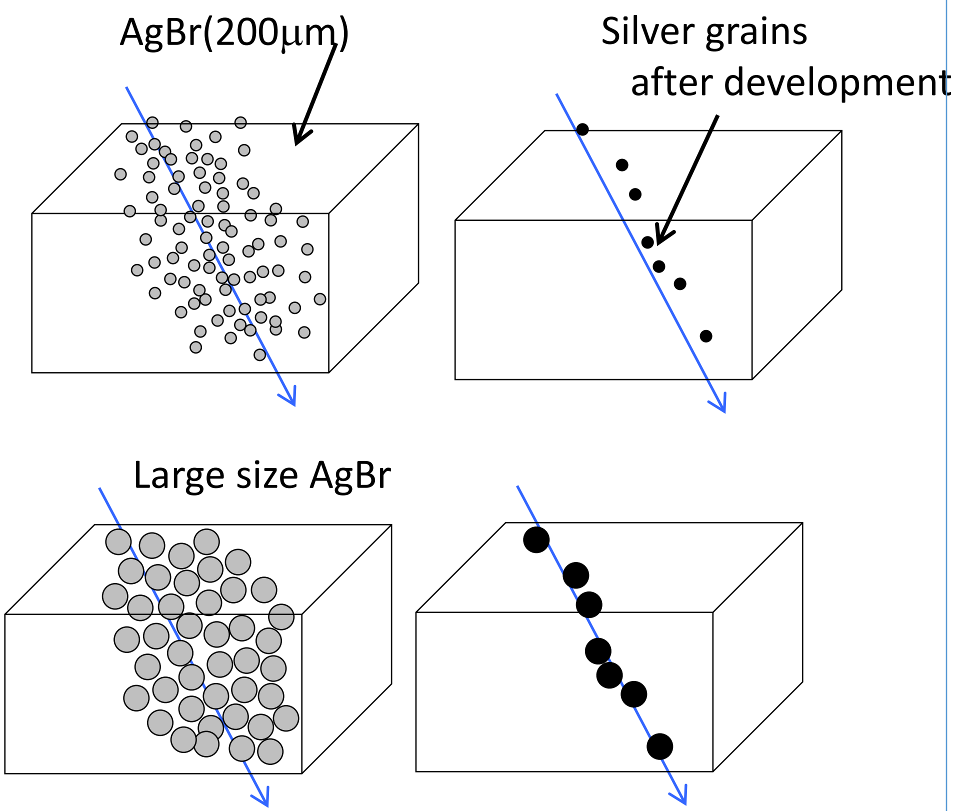
Counting penetrating muons
as a function of arrived angle (ax,ay)

<u>Long term</u> vs <u>Large film area</u>

<u>Temperature not under control</u>

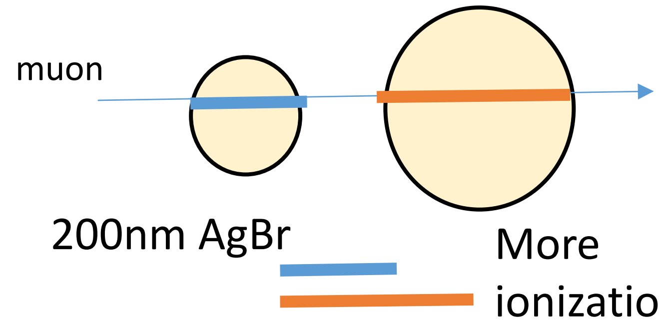
R&D for
Enlarging the AgBr crystal size

Schematic view of the concept



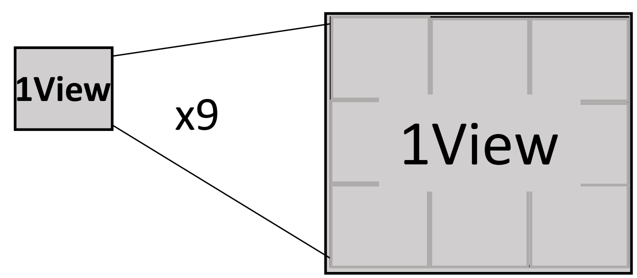
Pupose

1. Anti-Fading



→Loger term obs.

2. Larger film area

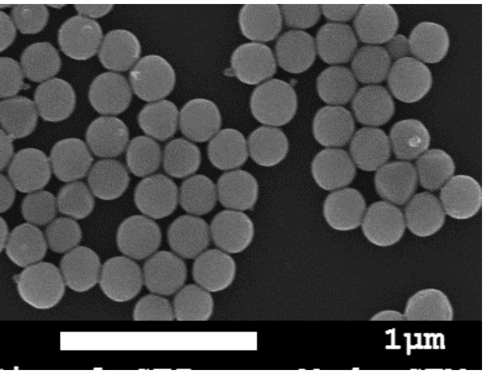


→ higher contrast of image

Read by lower magnification

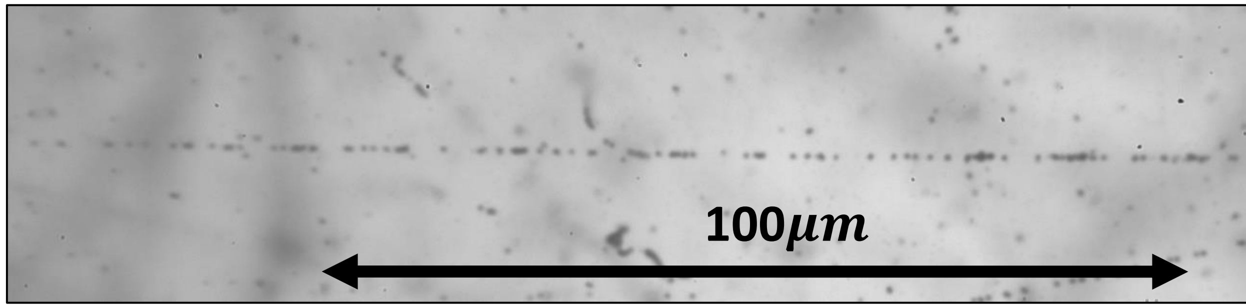
Prototype large crystal film comparison with standard film

200nm

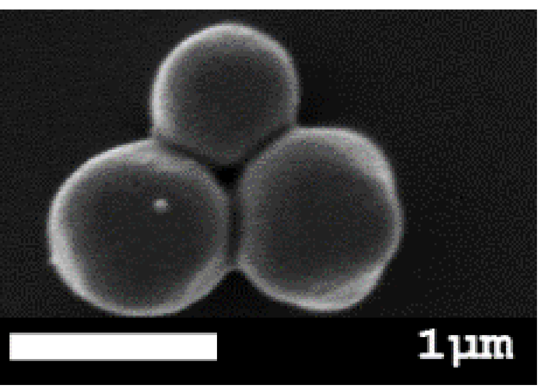


Standard film

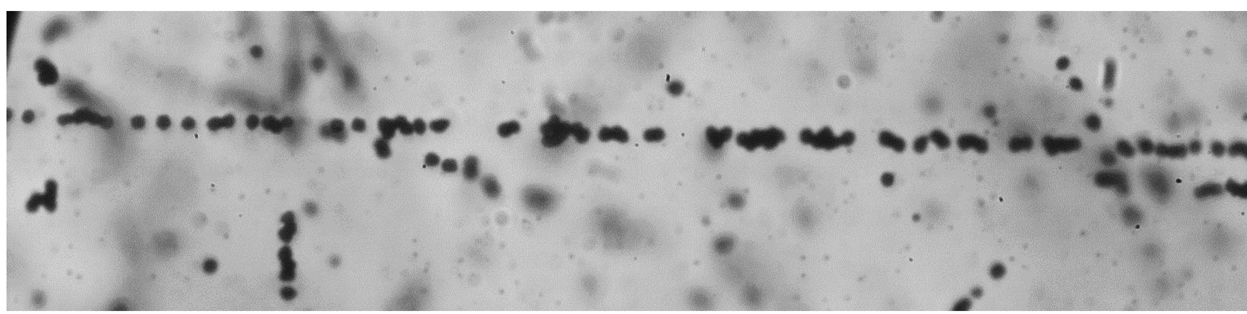
GD 35.7±0.9
FD 0.49±0.04



800nm



Prototype film **very high contract !**



GD 38.0±1.4
FD 0.47±0.17

Summary

- The emulsion production in Nagoya university started from 2010.
- Several types of emulsion, AgBr crystal size 20nm -800 nm , sensitize control, are developed being to use.
- 6-7 m^2 emulsion production and making films in one month.

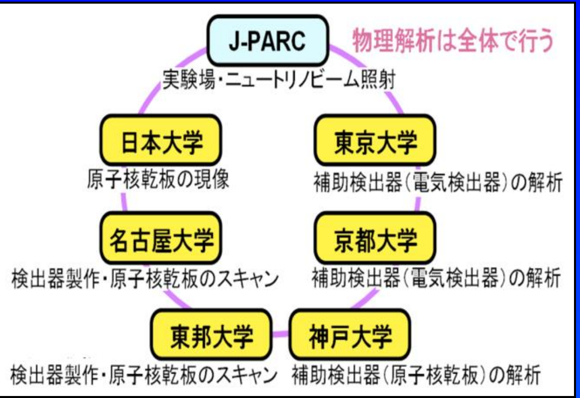
- Track readout system developed since 1980s and scanning speed is increasing x100 every 10 years.
- Current scanning speed is 5000 m^2 / year readout.
- Month scale for readout a 10 m^2.
- Tracking and reconstruction program is keep developing to follow the scanning speed.

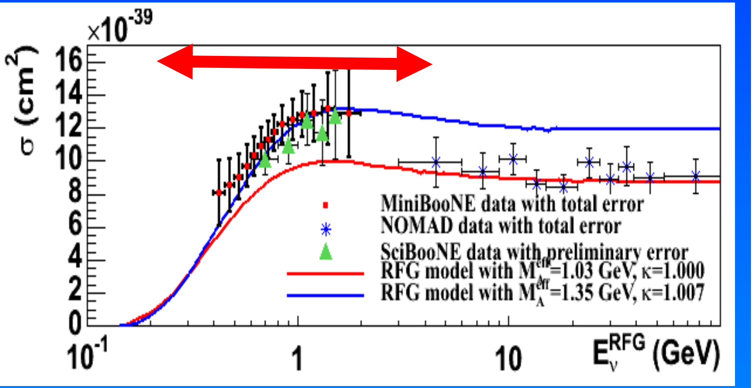
Back up

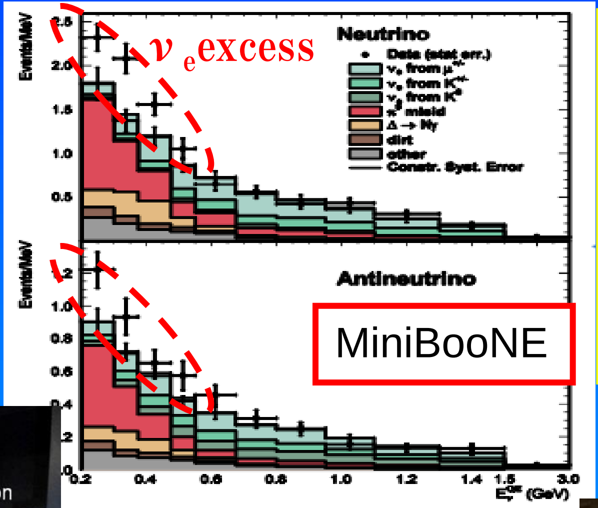
J-PARC T60 experiment

- 将来のニュートリノセクターにおけるCP対称性の破れの検証を目指し、ニュートリノー原子核反応断面積の超精密測定を行う。
- 20年近く正体がわかっていないステライル(不活性)ニュートリノ存在の検証を行う
- チャームペンタクウォークやチャーム原子核といったエキゾチックな粒子の探索・測定を行う。

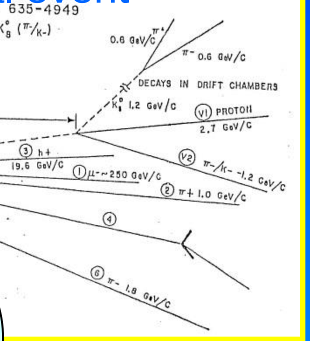
T60 Collaboration

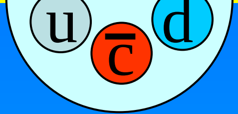




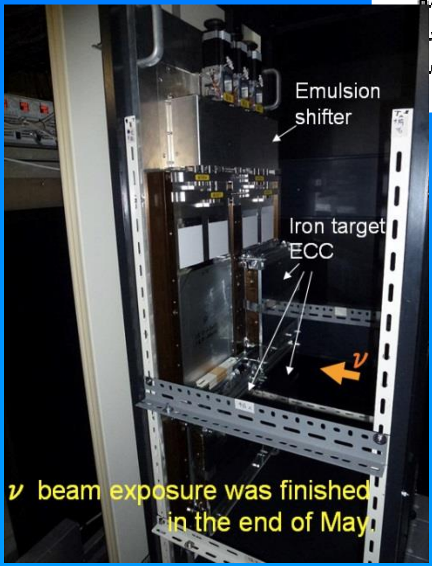


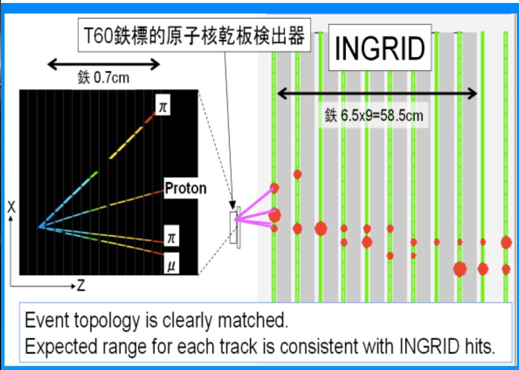
E531 special event

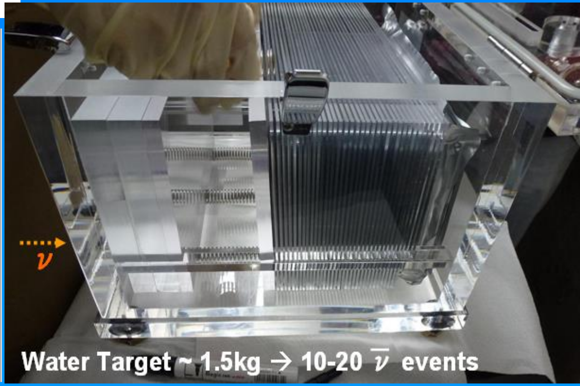




Θ_c^0

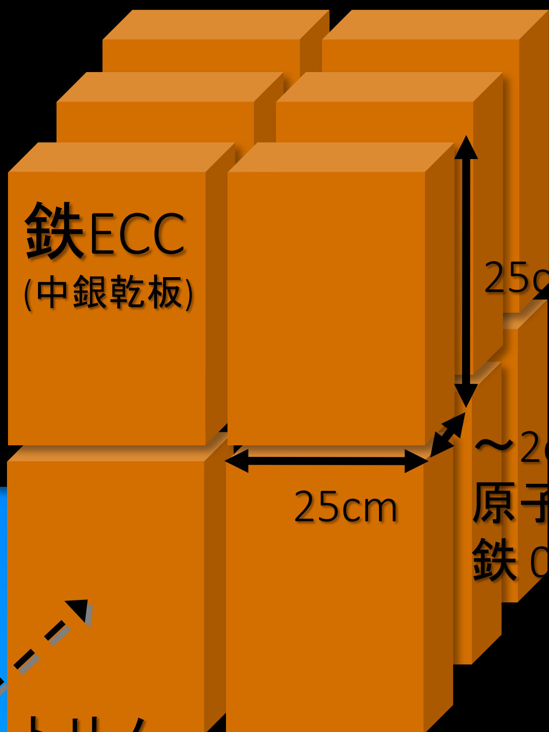






始まったばかりの実験なので、参加者募集中！！

T60 extensionの検出[redacted]

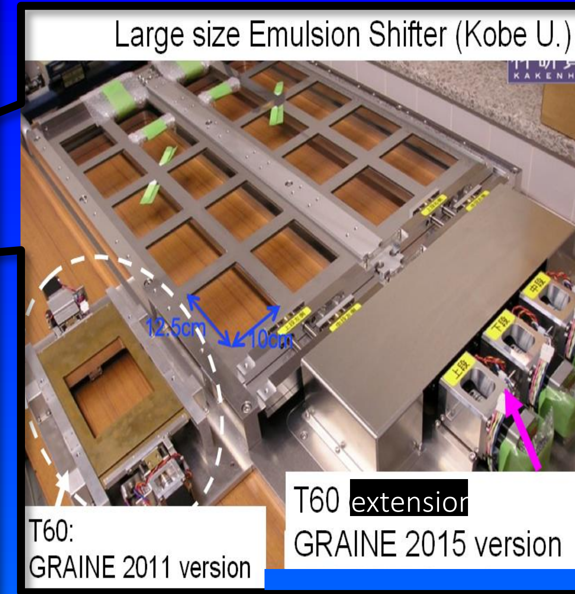


[redacted]

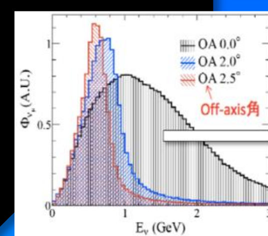
原子[redacted]板 × 23枚
鉄 0[redacted] × 22枚

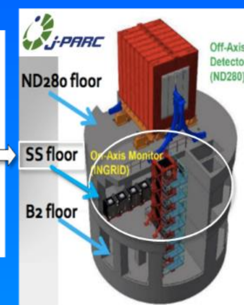
ニュートリノ

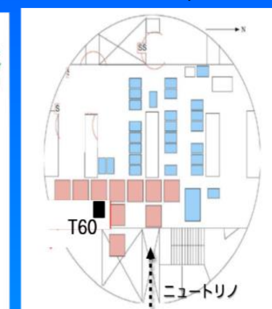
冷蔵シェルター(〜10℃)



シフター詳細: 19pAH-2 山





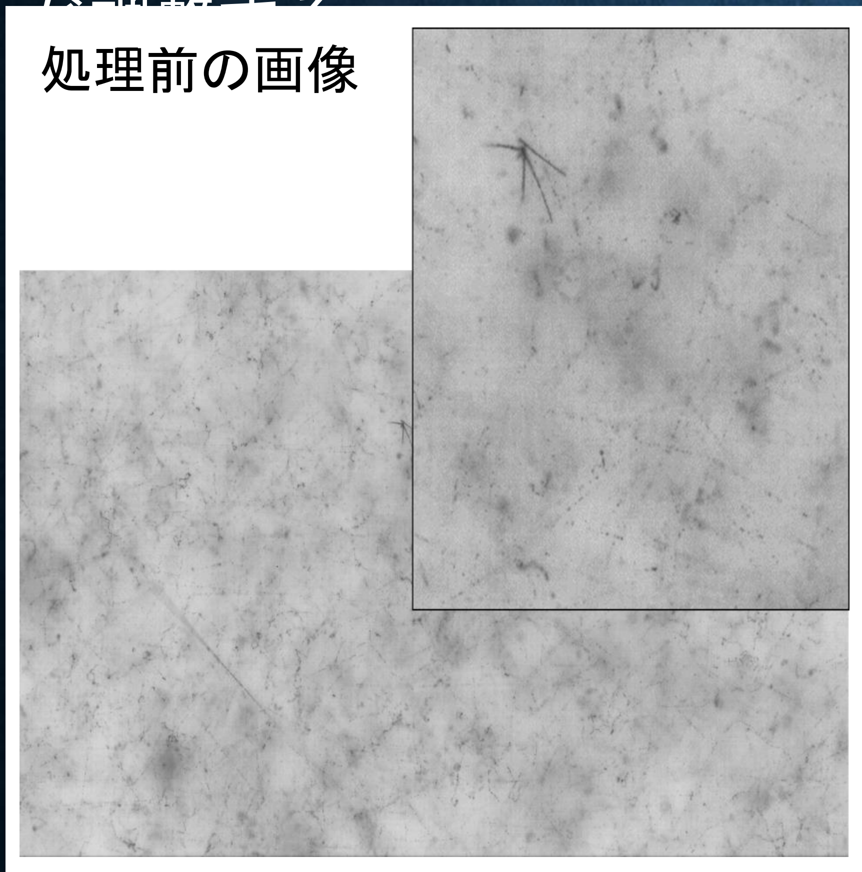


全318枚の原子核乾板を用いて、

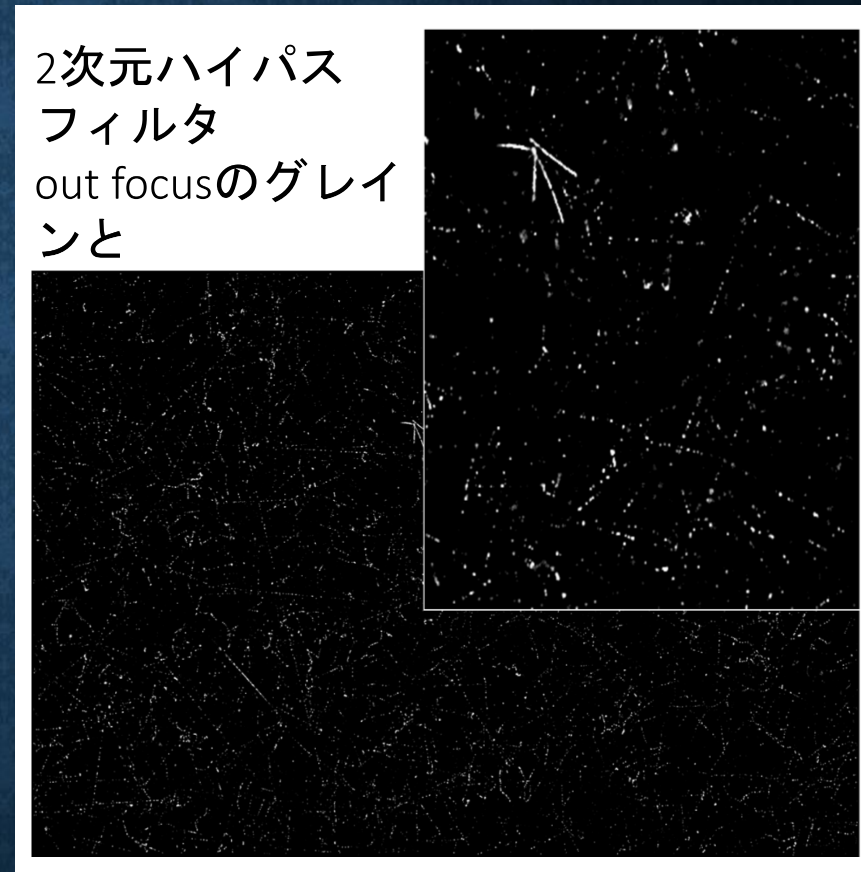
ニュートリノビーム照射@SSフロア
2016年1月末 〜 4月 or 5月
鉄ターゲット (total 〜 60kg, 500µm間隔)

スキャンパラメータの調整

画像処理パラメータ: フィルムや実験に応じてユーザが調整する



吉本雅浩 修士論文 名古屋大学 (2013年度)

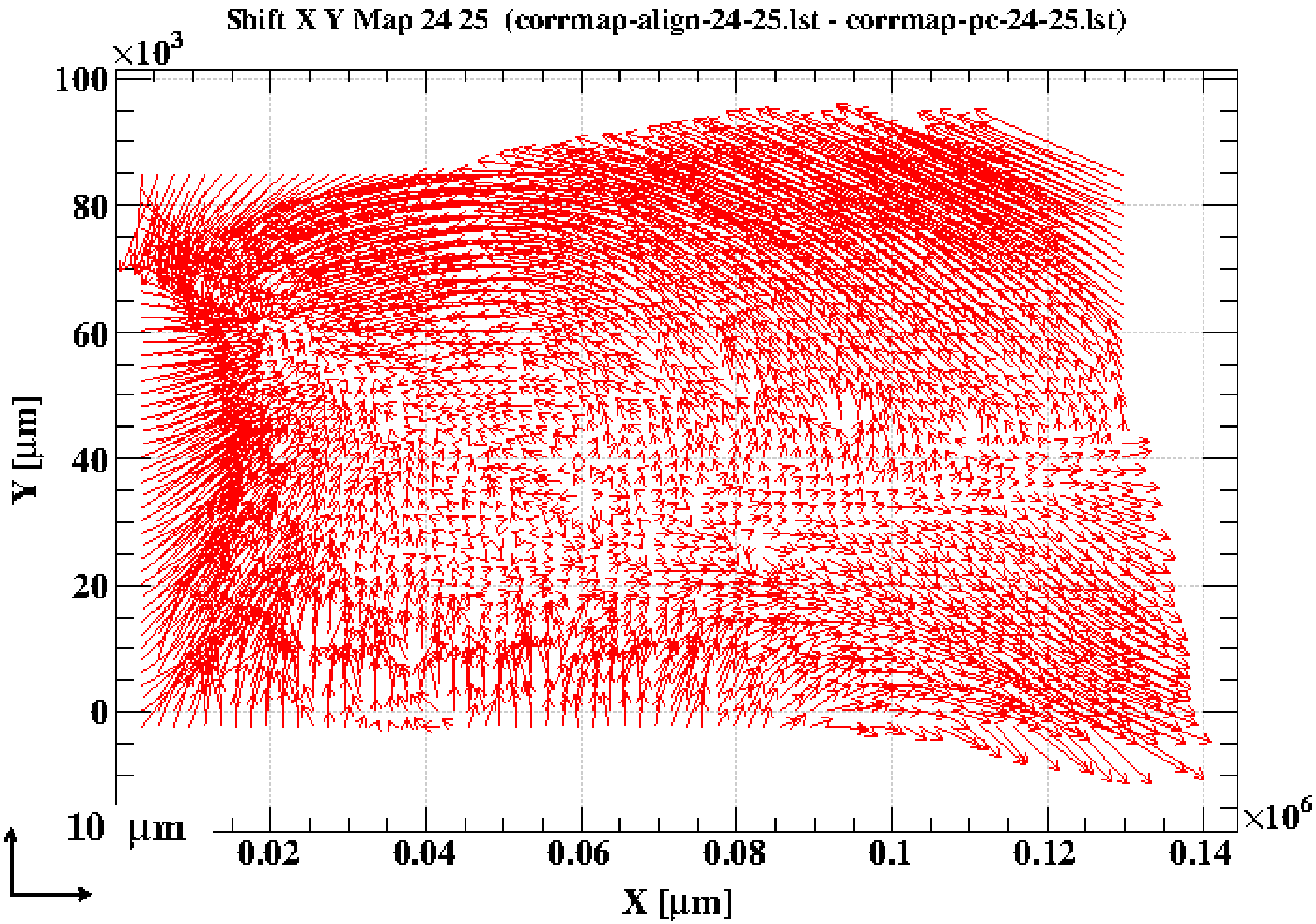


吉本雅浩 修士論文 名古屋大学 (2013年度)

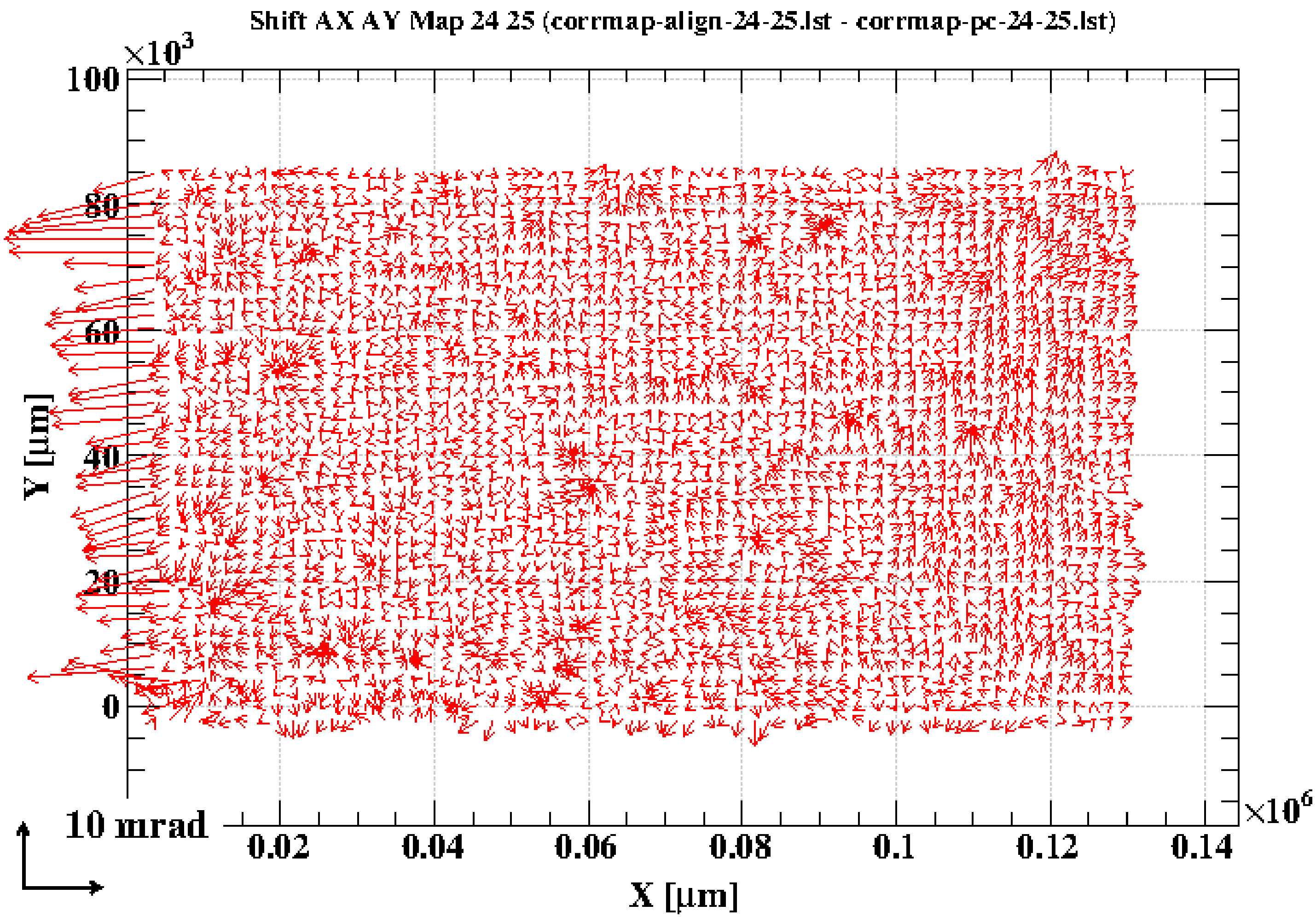
- 二値化のTh.
- ハイパスフィルタの周波数

飛跡検出効率 (Tracking efficiency) が良くなるように調整

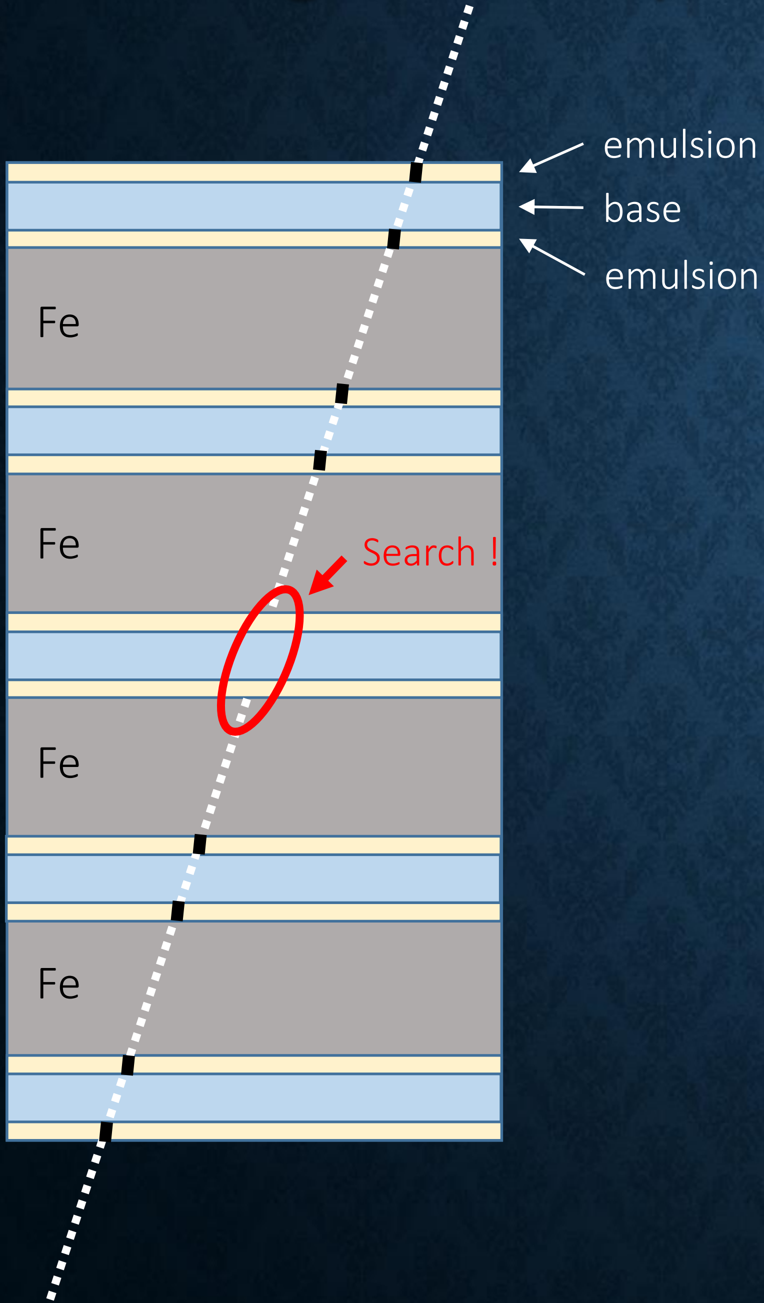
CORRMAP POSITION

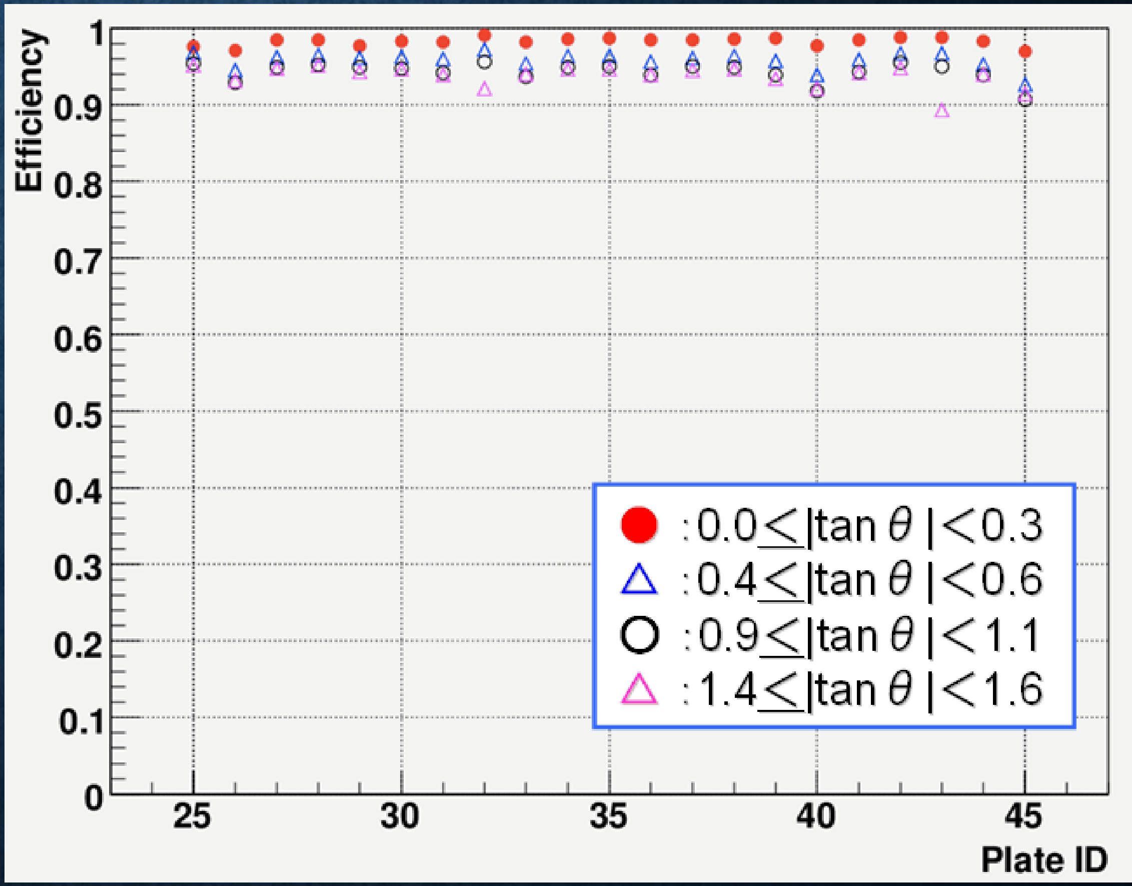


CORRMAP ANGLE



Tracking efficiency at each base track segment



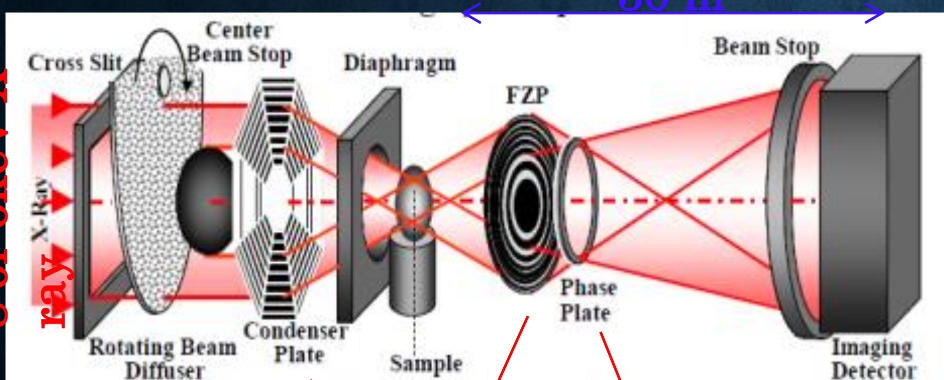


HARD X-RAY MICROSCOPE

SPring-8 @ Japan

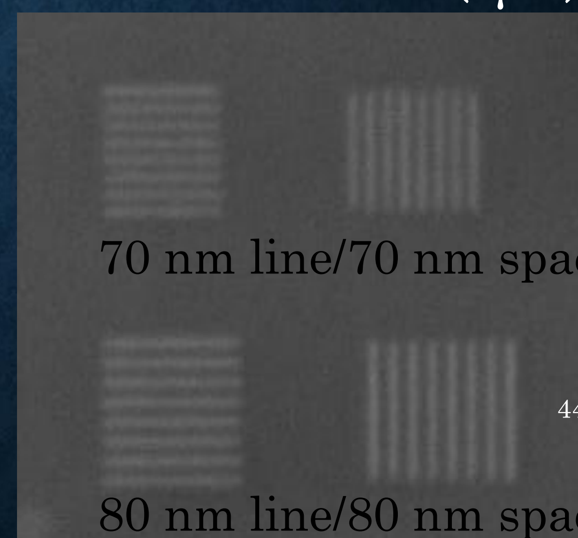
30 m

8 or 6keV X-ray



Zone plate Zernike phase plate
(outer most zone width of 50 nm)

Ta 100 nm thickness pertarn on SiN membrane (2μm)

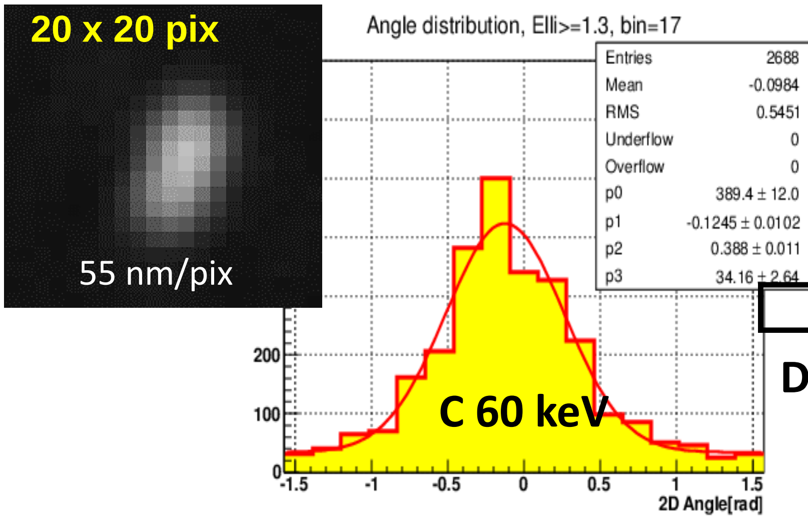


70 nm line/70 nm space

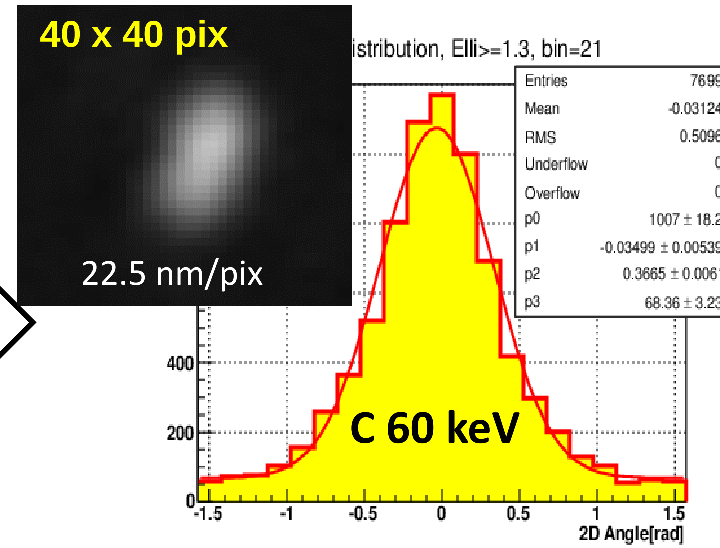
80 nm line/80 nm space

事象選別の高度化

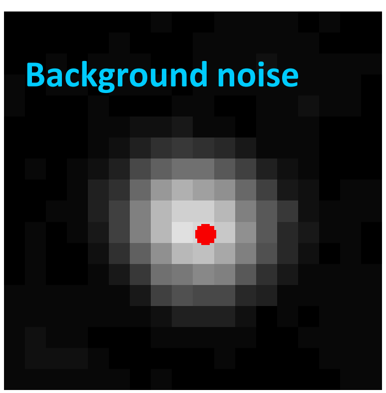
1. Pixelの高解像度化

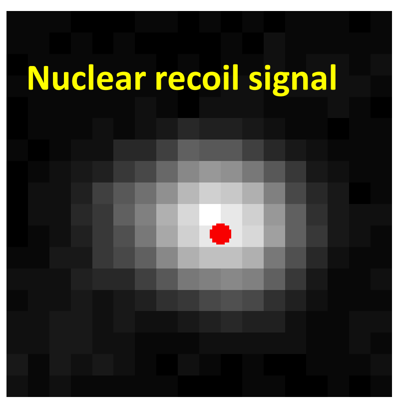


Detection eff.
30 % ⇒ 65 %



2. プラズモン共鳴効果解析



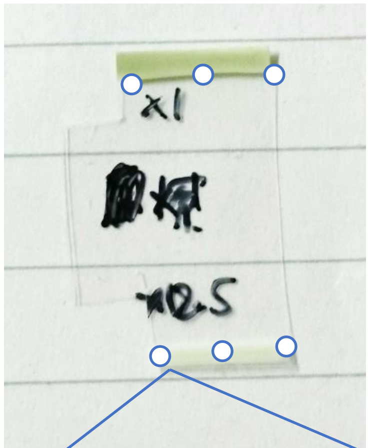


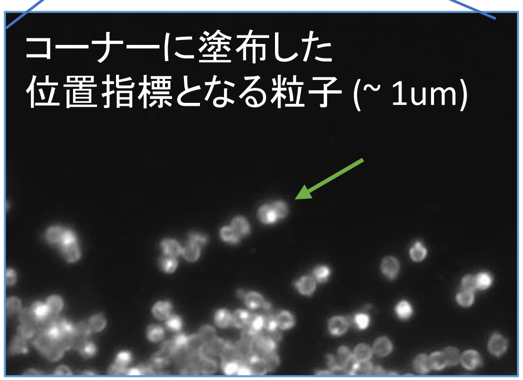
- 現像銀のnmスケール構造
⇒ シグナル-ノイズ同定、dE/dx情報 (PID)
- 構造を反映した特殊な光学応答
⇒局在プラズモン共鳴効果

実装可能なハード・ソフトの設計・構築 （2016年の課題)

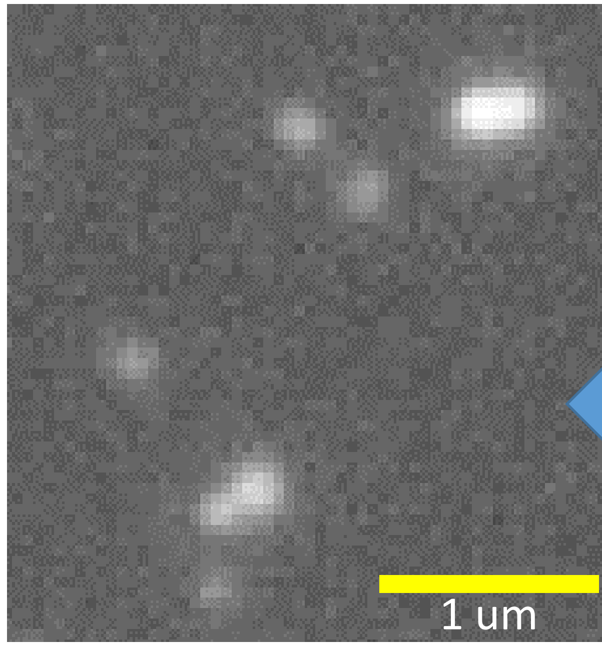
偏光特性を用いることで10nmの分解能を達成！

光学顕微鏡⇔SEMの対応付測定

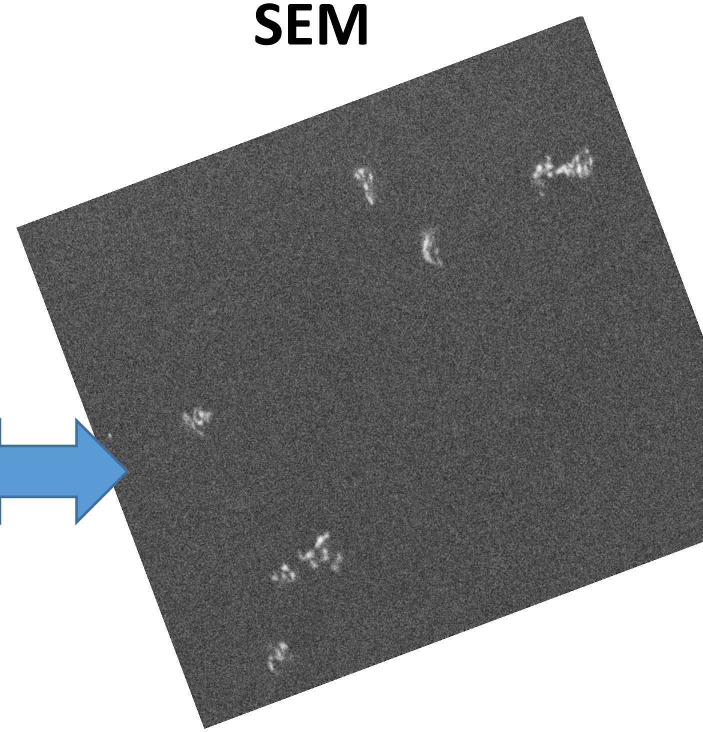




光学顕微鏡



SEM

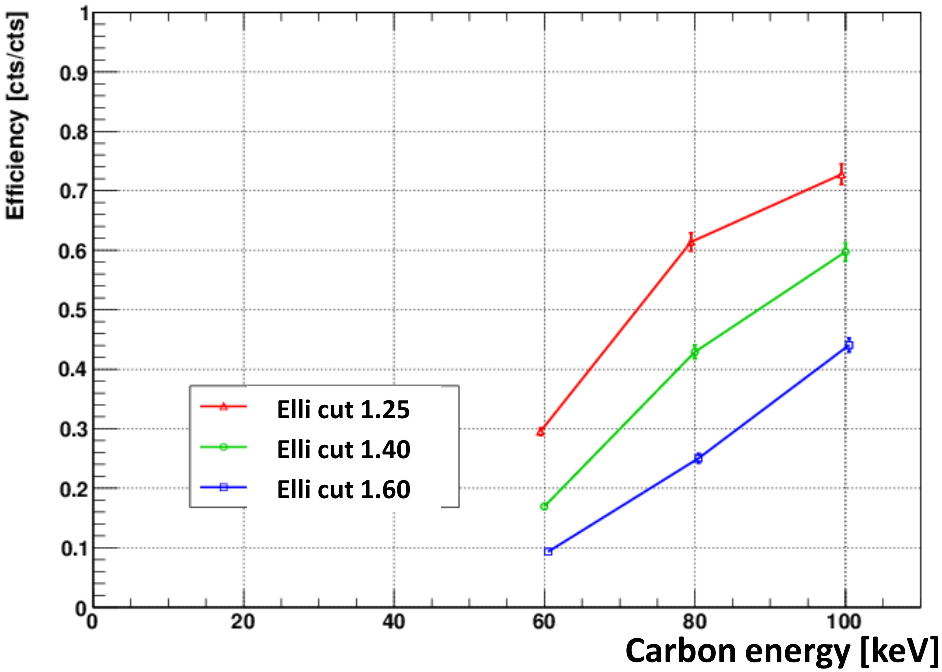


電子の散乱は深さによるが20~40 nm程度
ピクセルサイズ 5nm/pix

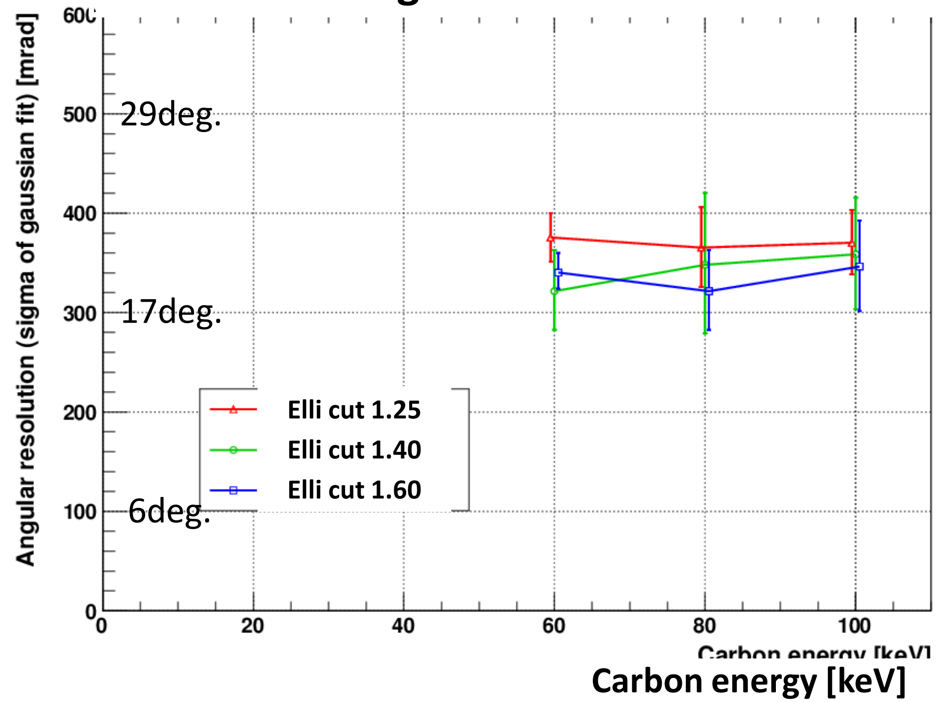
今回 ~2umの精度(≒ステージ移動精度)で光学顕微鏡⇔SEMの位置対応付を行う手法を確立
光学顕微鏡で撮像したイベントと初めて1対1対応させたSEM解析を行なった

Result of performance [60 – 100 keV] [Ion-implant system]

Absolute efficiency with direction sensitivity



“Angular resolution”



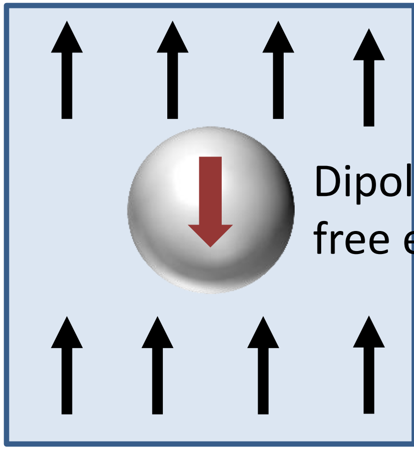
Energy	Elli>1.4	Elli>1.25
100 keV	59.7 $\pm$ 1.5(stat) %	72.8 $\pm$ 1.7(stat) %
80 keV	42.9 $\pm$ 1.2(stat) %	61.4 $\pm$ 1.5(stat) %
60keV	16.9 $\pm$ 0.4(stat) %	29.5 $\pm$ 0.6(stat) %

Systematic uncertainties have several % .

Angular resolution ~ 350 mrad.

Angular resolution is top value to another directional DM detector.

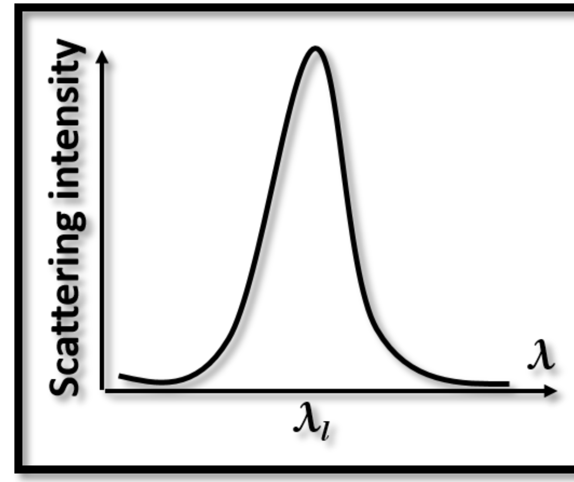
Plasmon resonance in nano-metaric particle



Dipole moment p for free electrons

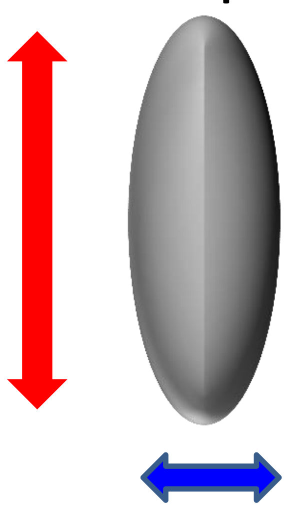
$$p = 4\pi\varepsilon_m a^3 \frac{\varepsilon_1(\lambda) - \varepsilon_m(\lambda)}{\varepsilon_1(\lambda) + 2\varepsilon_m(\lambda)} E_0$$

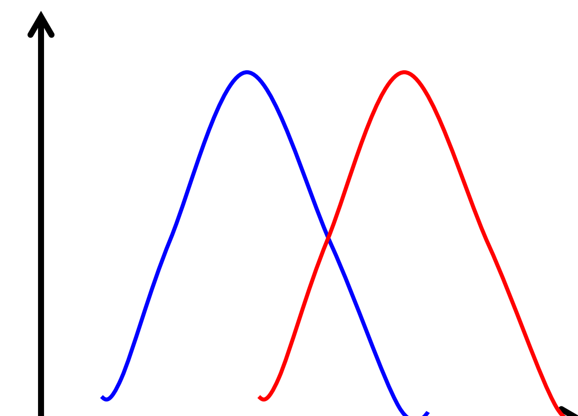
$$\varepsilon_1(\lambda_l) + 2\varepsilon_m(\lambda_l) \approx 0$$



λ_l has visible wave length for 40 – 100 nm Ag nano particle

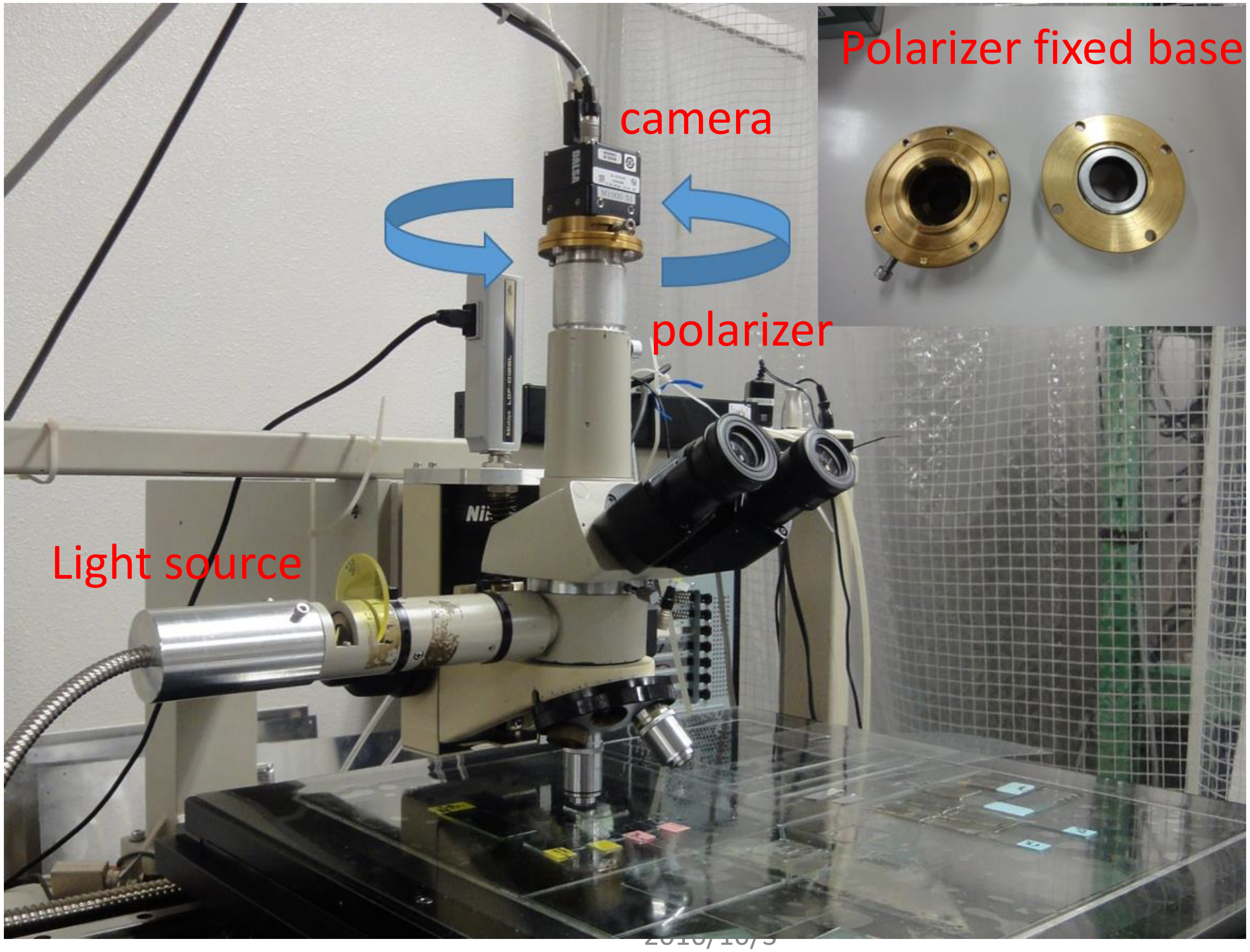
Polarized dependence





Polarization analysis

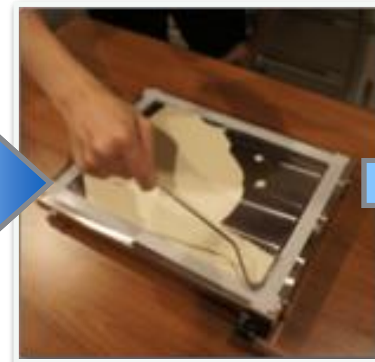
- develop the optical microscope that can do polarization analysis
- set a polarizer under the camera and rotate it



手動塗布による原子核乾板製造

乳剤

溶かす



塗布

セット/乾燥過程

ベース貼り	15分
塗布	15分
セット	30分
移動	10分
乾燥	1~2日

製造可能量

$0.15m^2$x5枚/1サイクル x 6回 x 4日
＝ $9m^2$/week

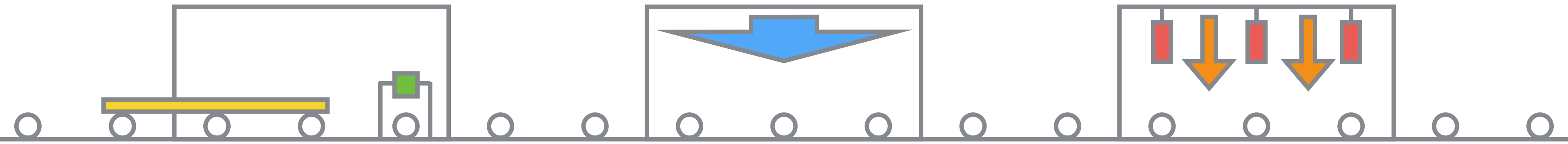
乳剤層
ベース
乳剤層

原子核乾板

原子核乾板塗布装置の開発

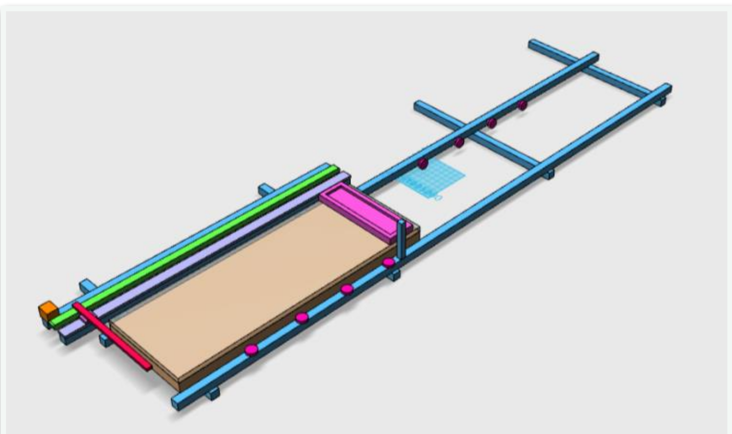
※1サイクル = 10min

自動塗布ゾーン（1min）　セットゾーン（2min）　乾燥ゾーン（7min）



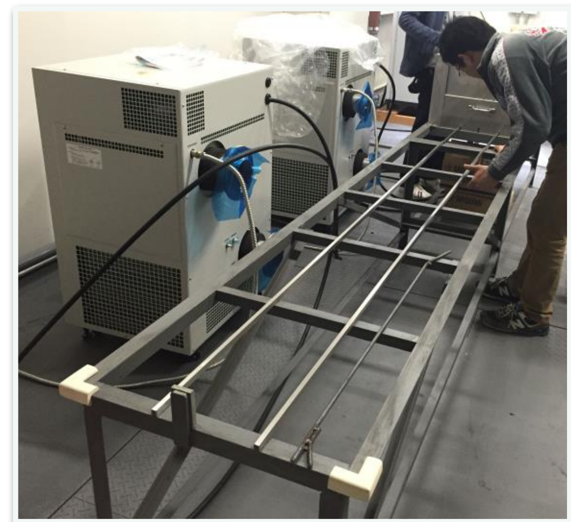
0.225m²/1サイクルを8時間稼働で5m²/day → 20m²/week → 1000m²/year

※製造量は両面塗布面積



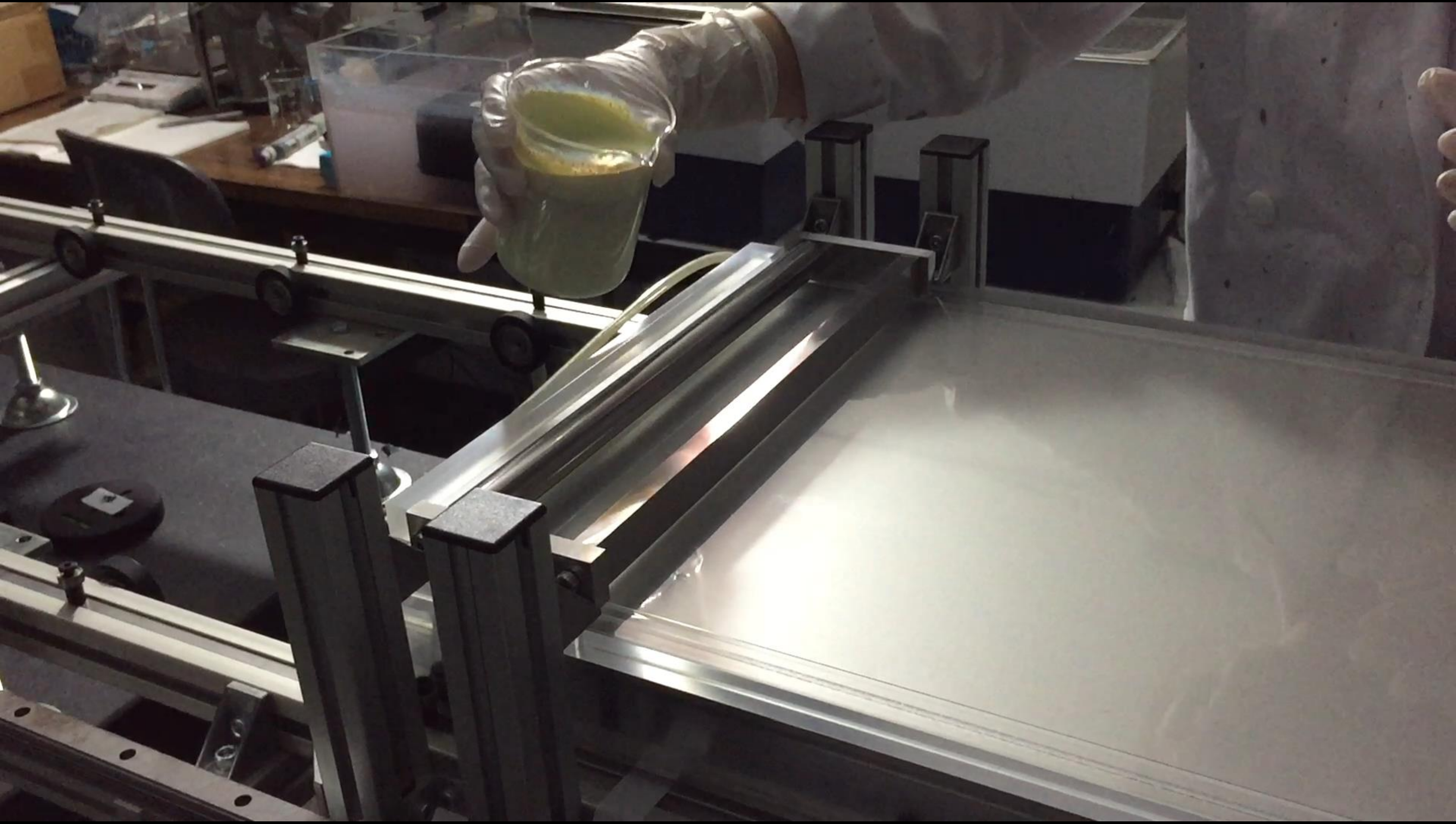
自動塗布装置

セット/乾燥BOX

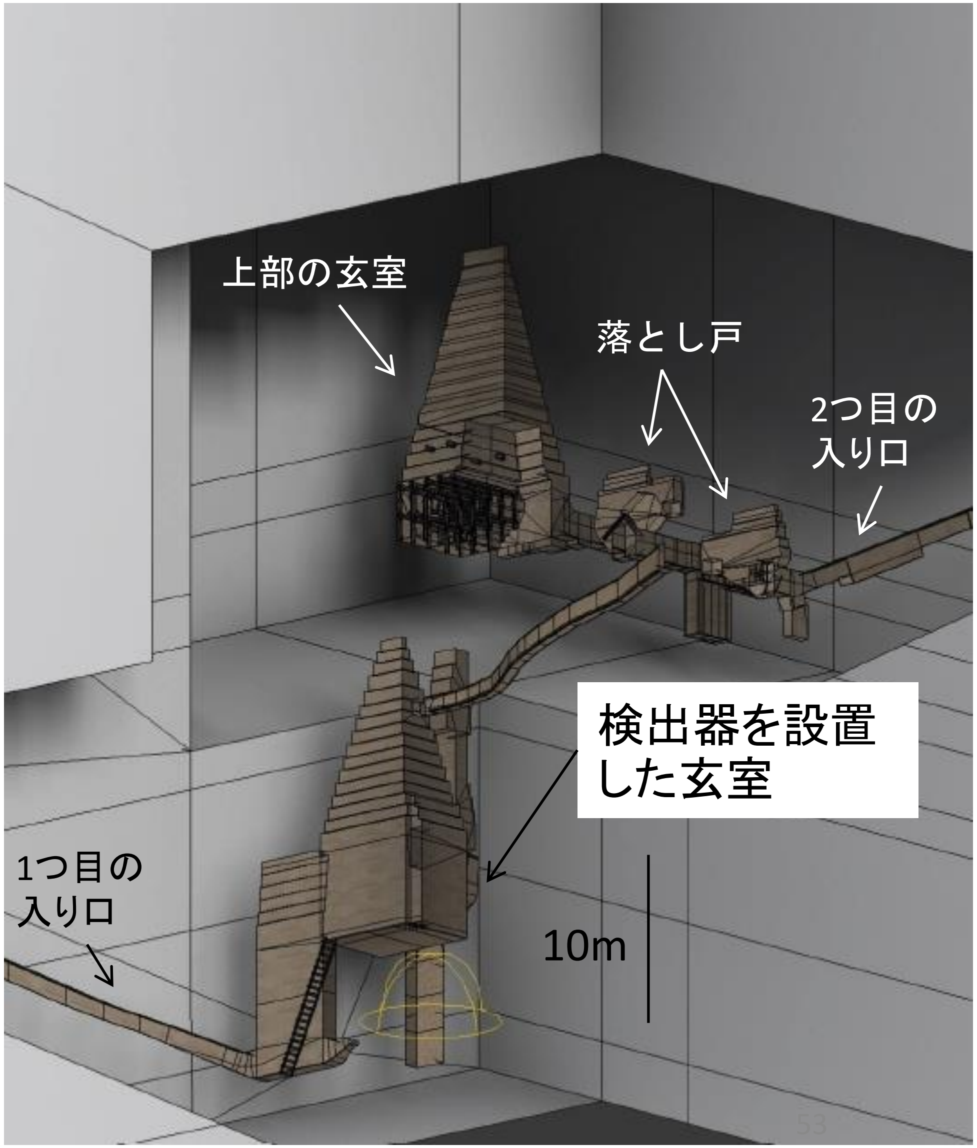


空調設備/レール

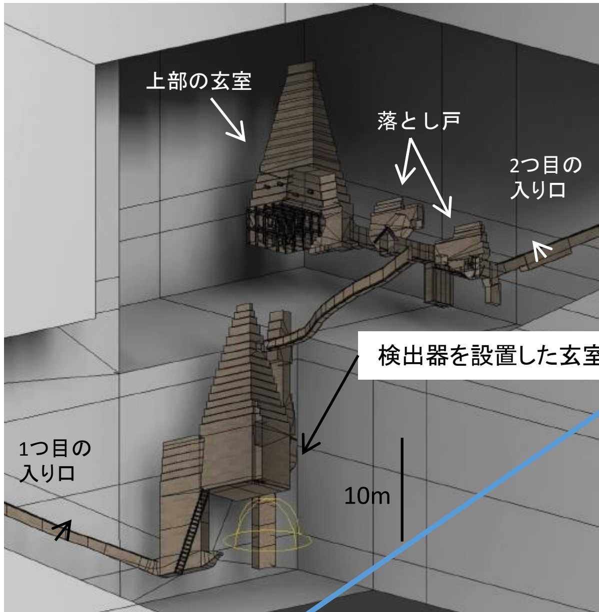
自動アプリケータ塗布

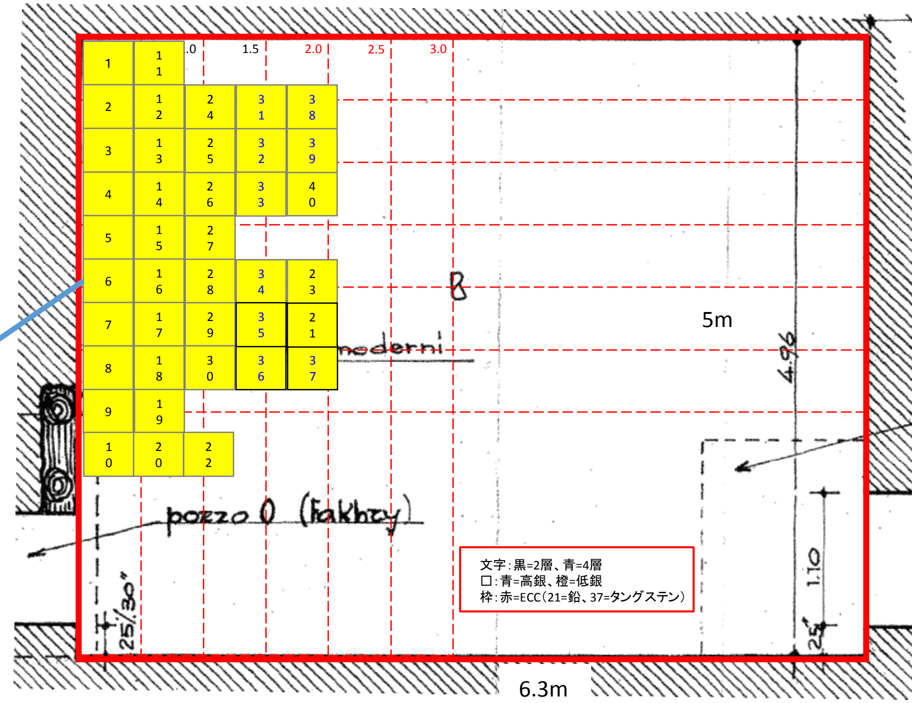


屈折ピラミッドの観測概要

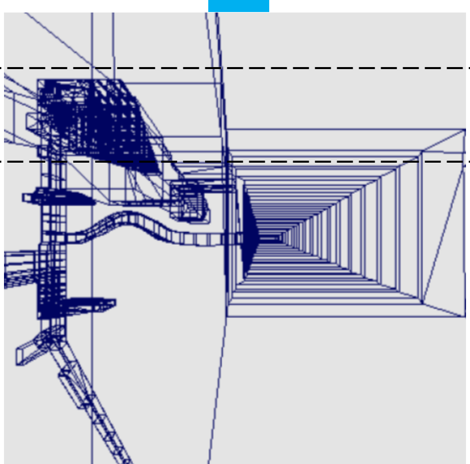


観測結果との比較(40枚)

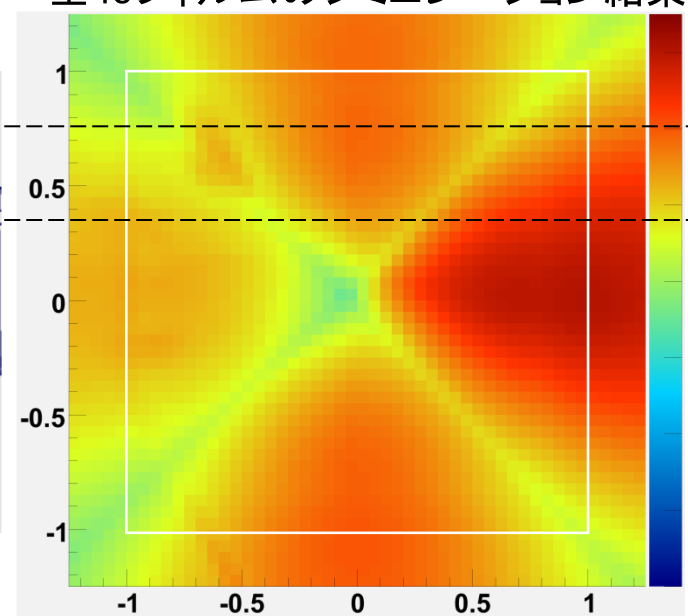




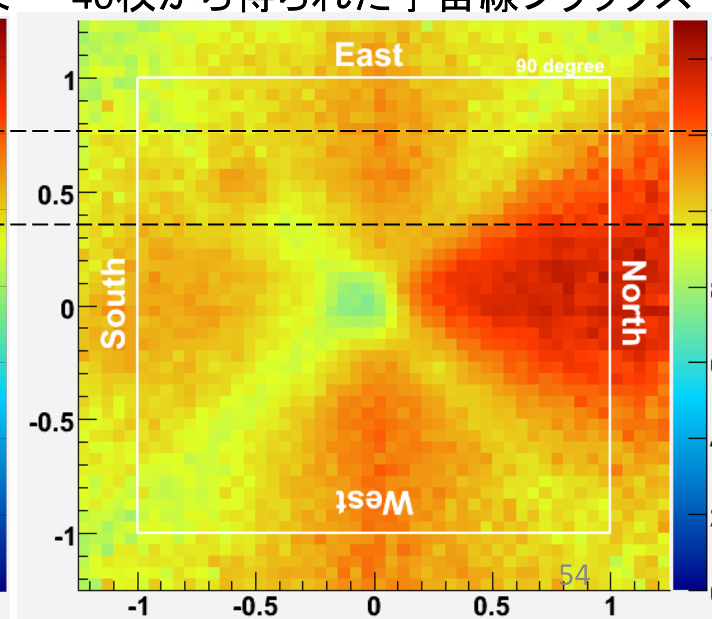
6



全40フィルムのシミュレーション結果



40枚から得られた宇宙線フラックス



200nm結晶 350nm結晶 800nm結晶