Fundamental Particle Physics Lab.
Division of Particle and Astrophysical Sciences
School of Science of Nagoya University

Nuclear Emulsion for Directional Dark Matter Search

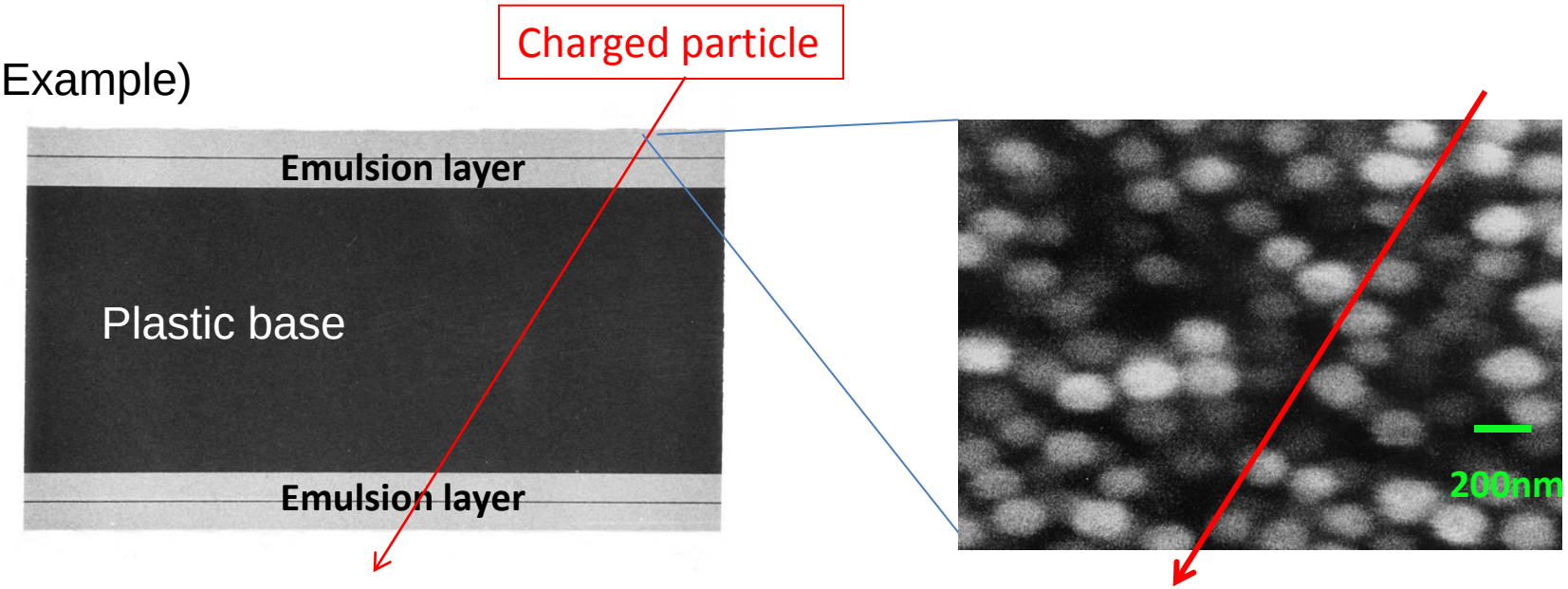
Tatsuhiro Naka
Nagoya University,Japan

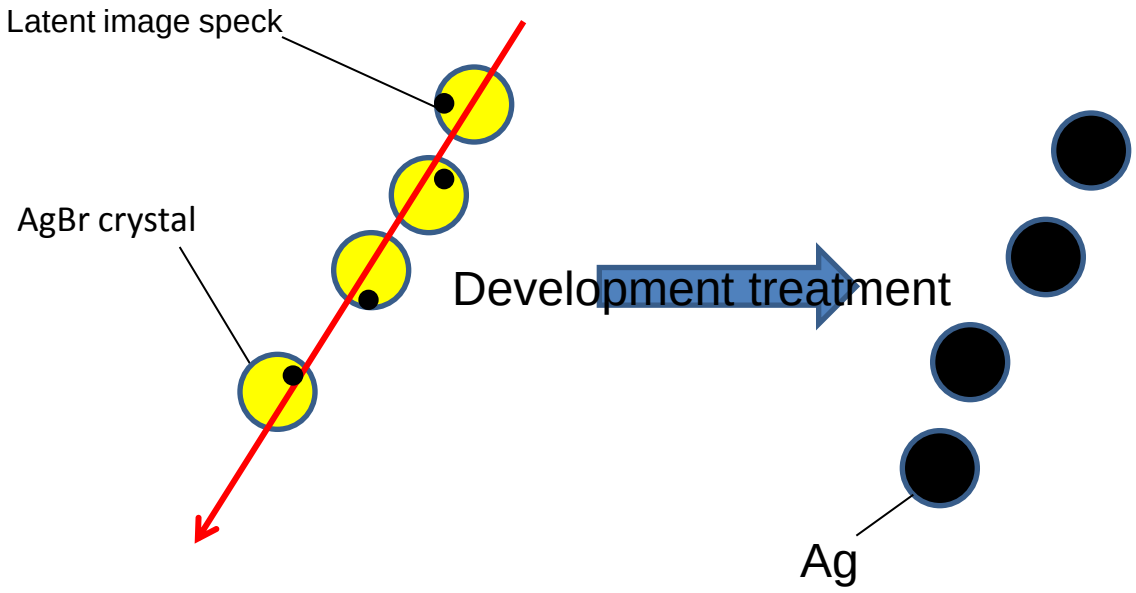
M.Nakamura,T.Nakano,O.sato, Y.Tawara @Nagoya Univ.
M.Kimura @ Toho Univ.
Y.Suzuki @ Spring-8
K.Kuge @Chiba Univ.

IDM2010 @ Monpellier, France 2010.7.27

Nuclear Emulsion

Example)

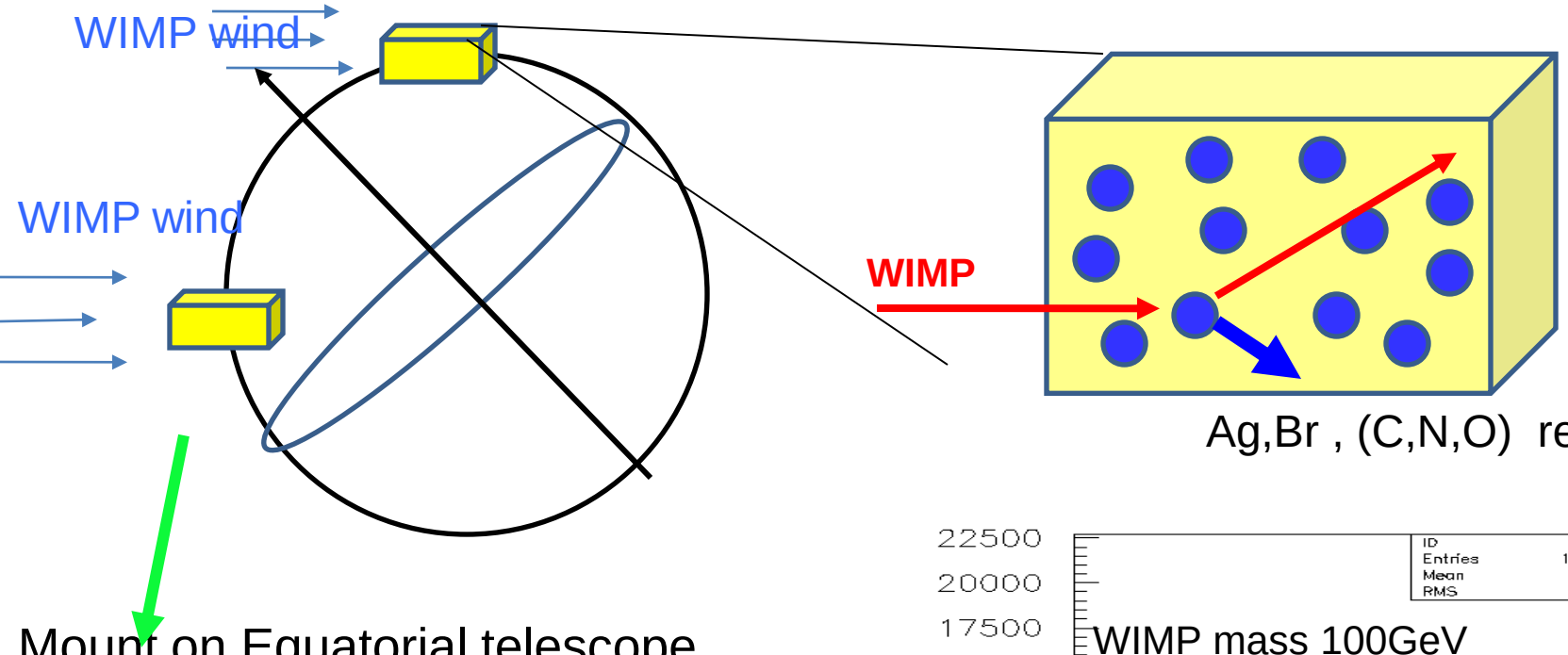




Resolution of nuclear emulsion depends on the number of AgBr crystal per length.
⇒crystal size and density.

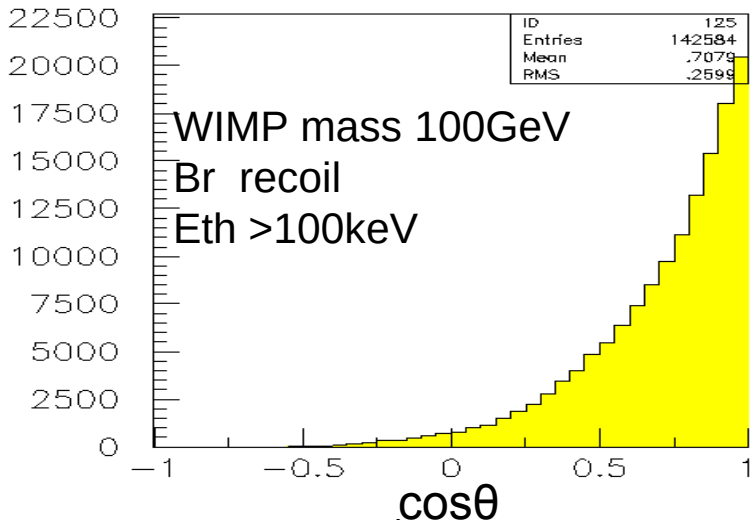
Concept of Directional detection by Nuclear Emulsion.

It is a solid detector that is possible to do the directional DM search.



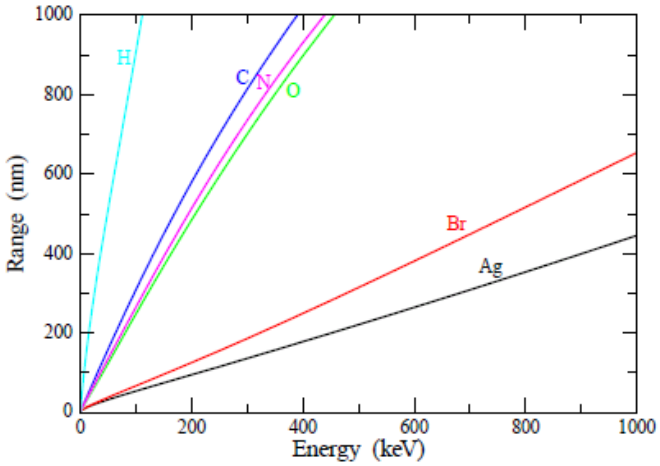
Mount on Equatorial telescope

⇒keep the detector direction to the WIMP wind.



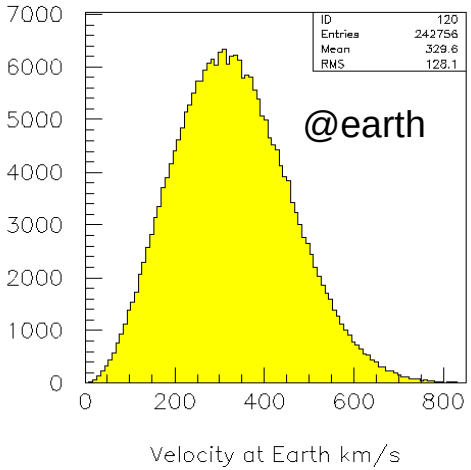
New Nuclear Emulsion for directional dark matter detection

Simulation by SRIM

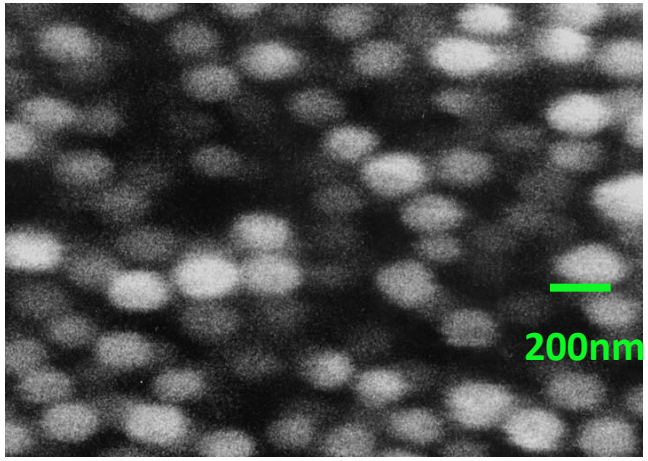


Nuclear Emulsion density : 3g/cm^3
⇒solid detector

Required resolution < 400nm
from escape velocity of DM



Usual Nuclear emulsion



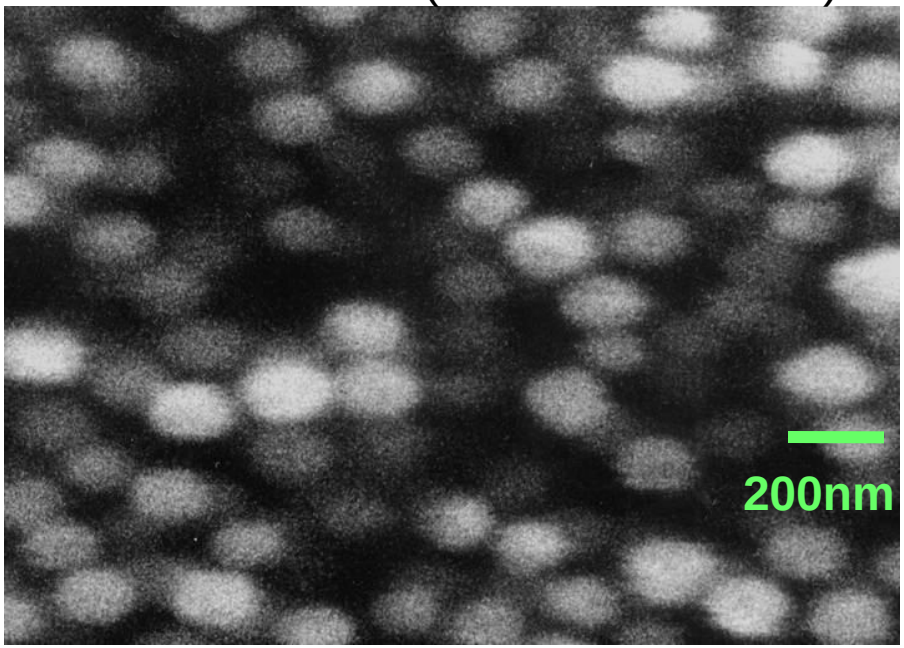
Usual Nuclear Emulsion
⇒AgBr crystal size : 200nm

Resolution ~ 2.3 AgBr crystal/μm

Low resolution for directional DM search!

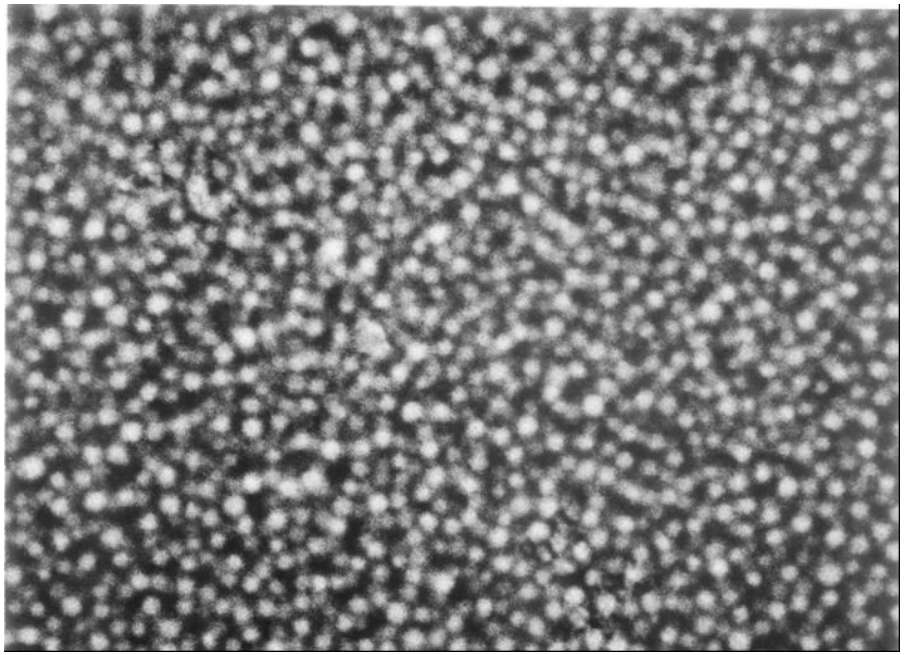
High resolution emulsion
(Nano Imaging Tracker:NIT)

normal emulsion(OPERA emulsion)



size 200±16 nm
density 2.8g/cc →V_{AgBr} : V_{gel} = 3 : 7
↓
2.3 grains/μm

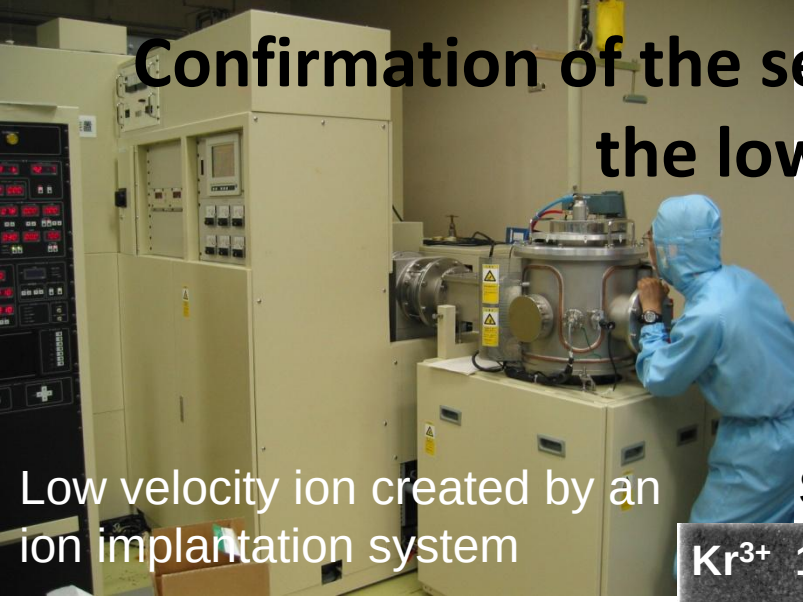
NIT



size 40±9 nm
density 2.8g/cc →V_{AgBr} : V_{gel} = 3 : 7
↓
11 grains/μm

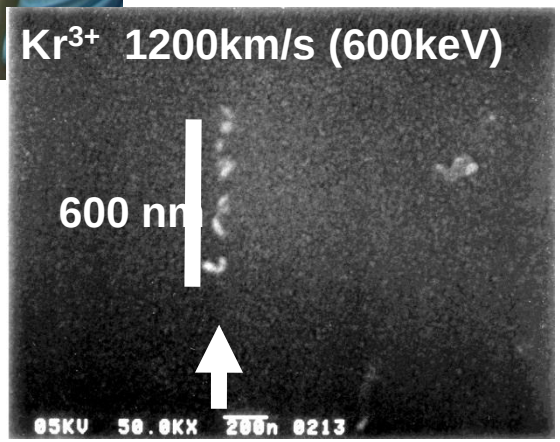
5-times higher resolution

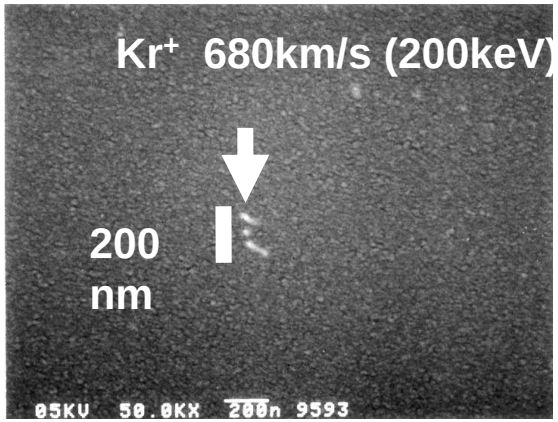
Confirmation of the sensitivity of nuclear emulsion to the low velocity Kr ion.

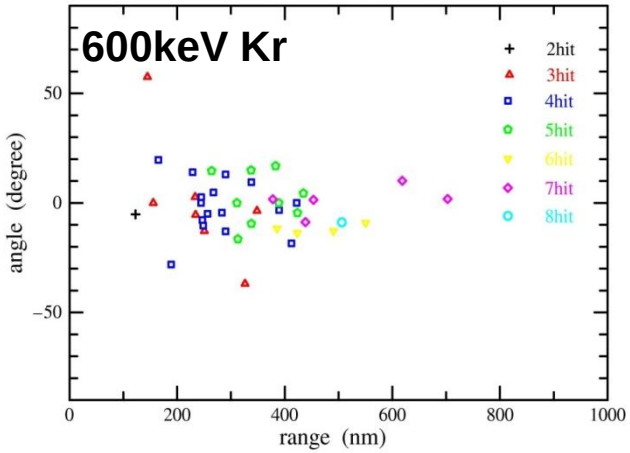


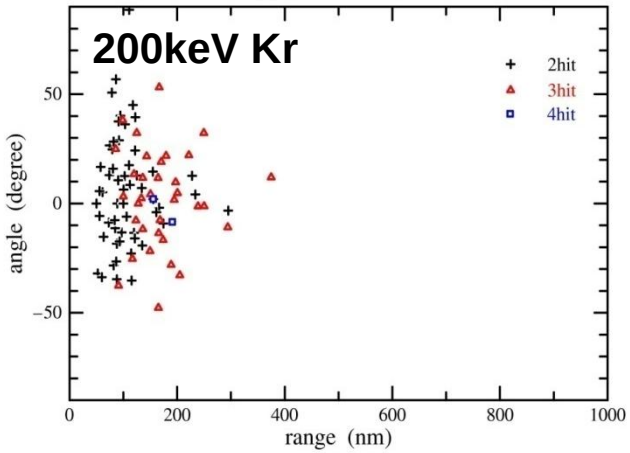
Low velocity ion created by an ion implantation system

SEM Image





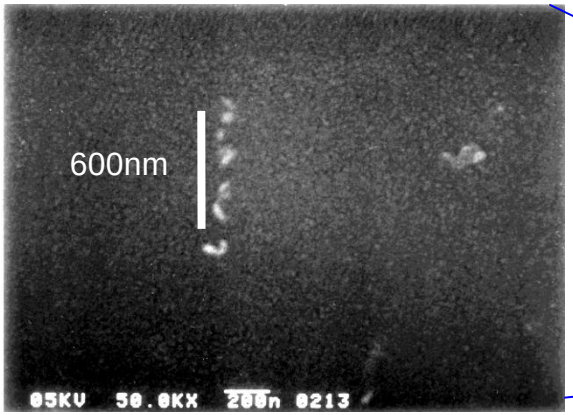


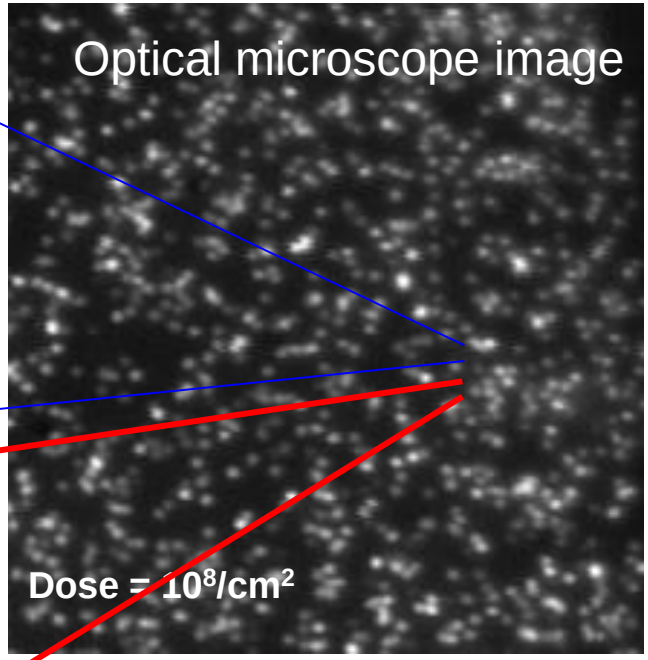


-NIT can detect the tracks with >100nm
-More than 60% tracking @ >200keV Kr (Br ion)

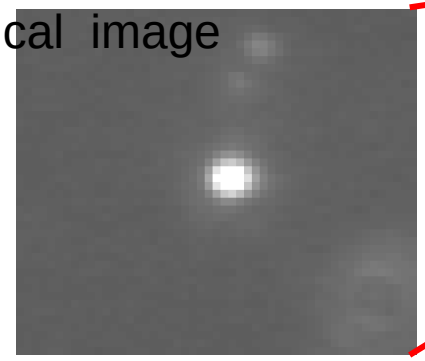
Optical image of nuclear recoil tracks without any treatment (~100nm track)

SEM image





Optical image



~100nm track can't be recognized as a track with optical microscope,because optical resolution is about ~μm

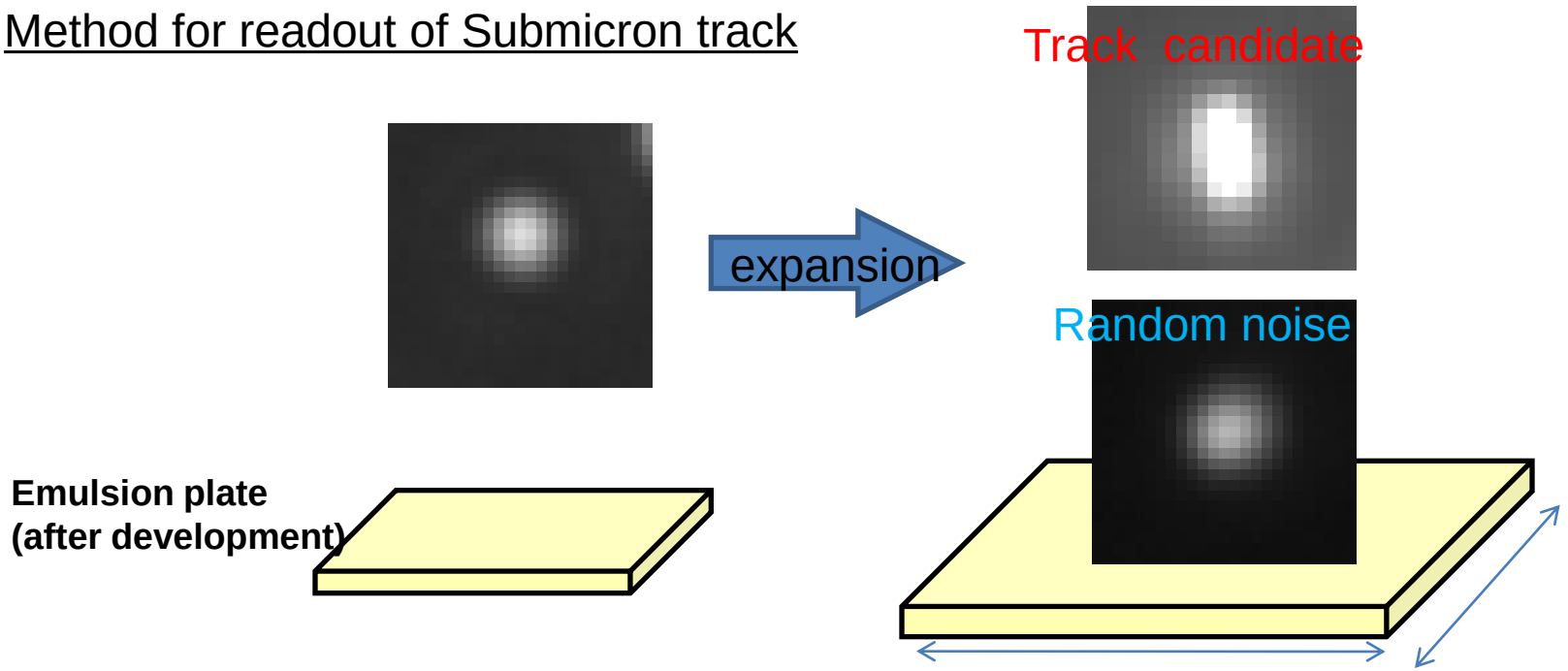
<u>Optical scanning is essential for large volume events searching.</u>

Concept of Readout system

Readout by expansion technique

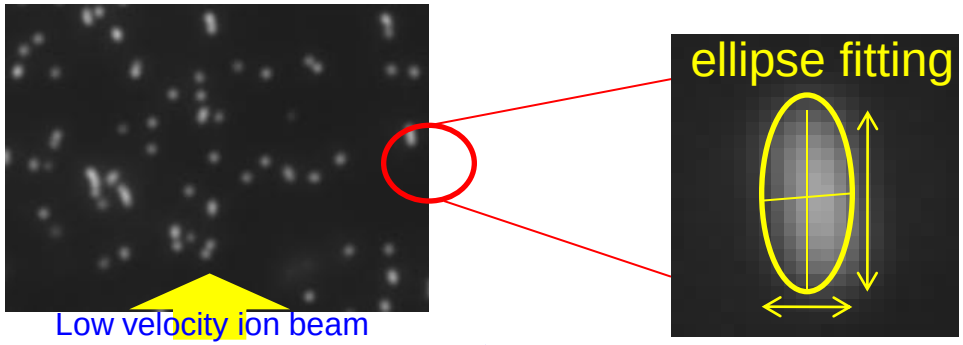
- Ideal optical microscope resolution ⊿R=0.61*λ/NA ~200nm
-By approx. 2 times expansion of the emulsion plate, Ag track becomes noticeably clear .
⇒detect elongated tracks by optical microscope.

Method for readout of Submicron track

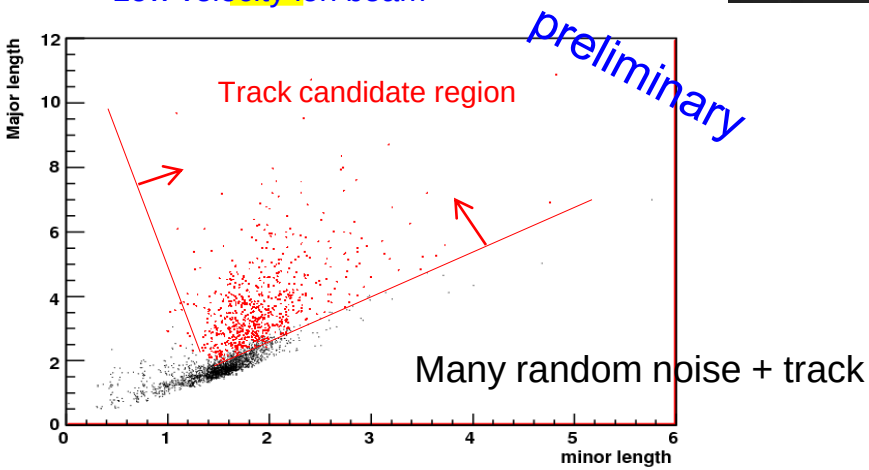


－expansion only X-Y direction (Z direction is ignored)
－use the swell characteristic of gelatin
⇒stable (uncertainty of angle~20mrad)

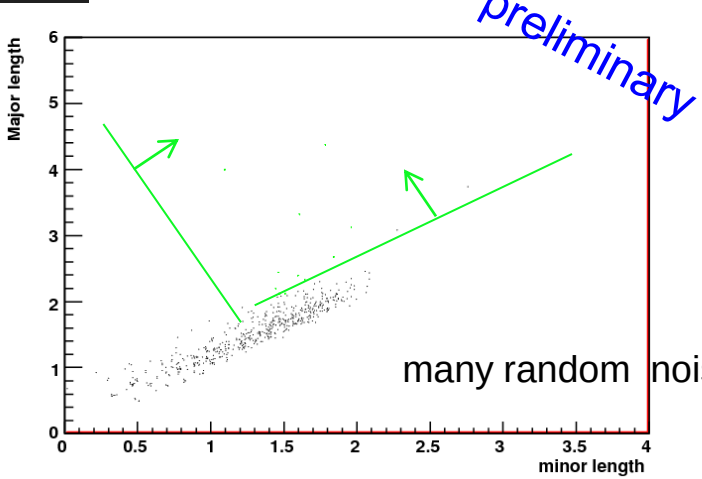
Concept of data taking for track selection



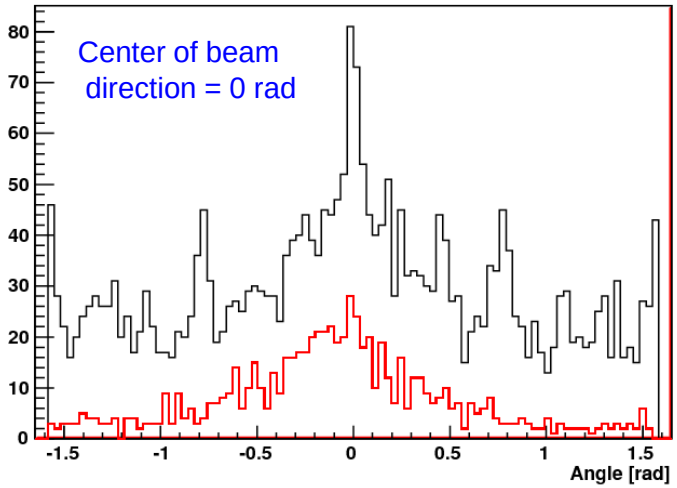
Tracks are selected by image processing.

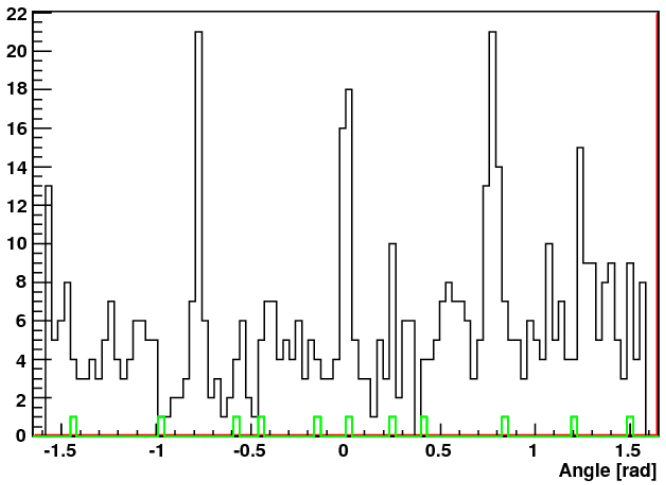


Many random noise + track

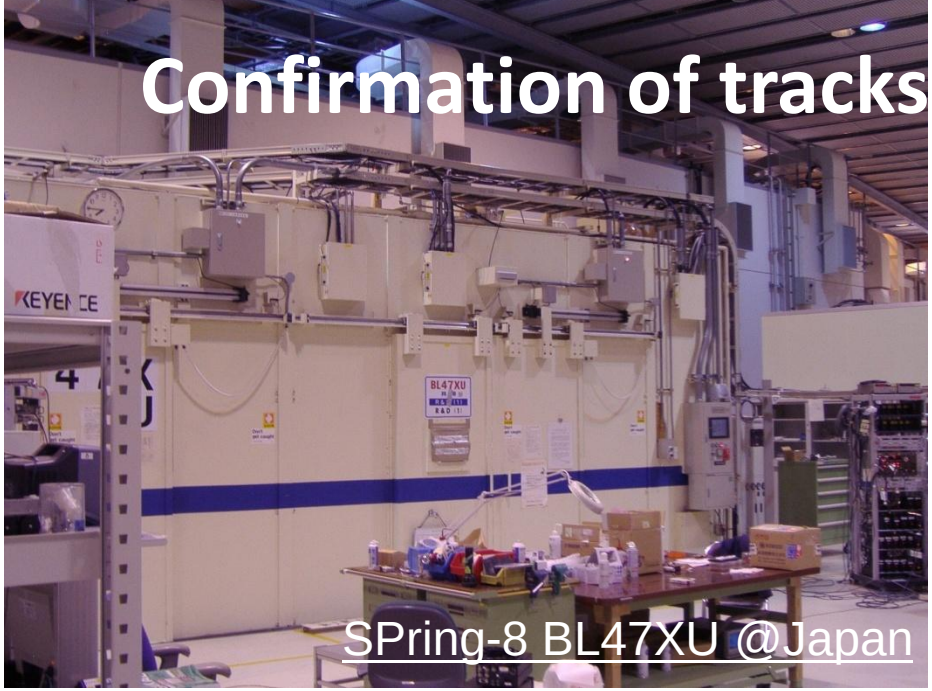


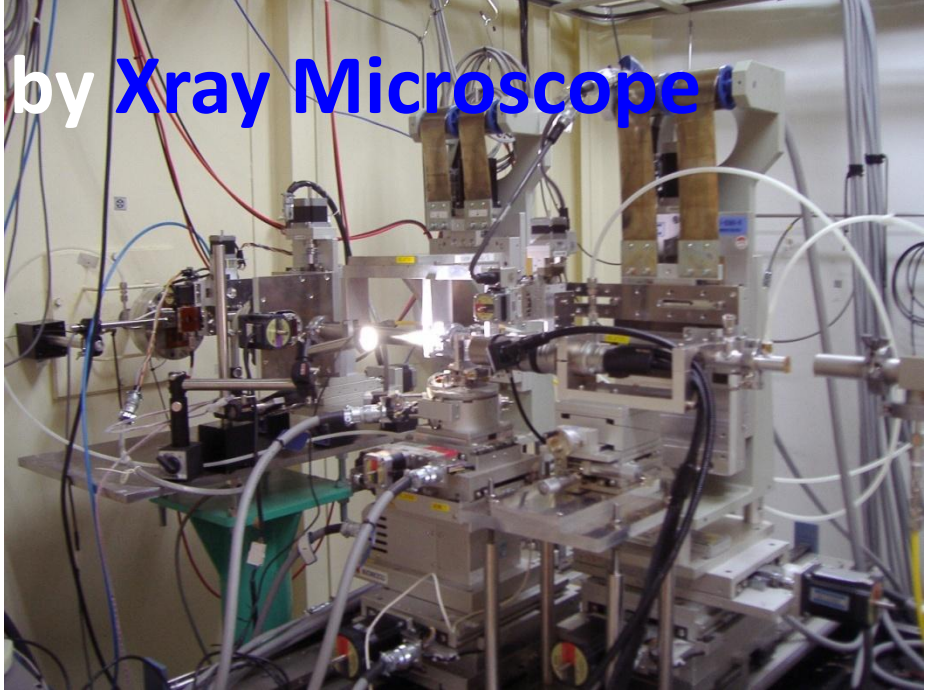
many random noise





Confirmation of tracks by Xray Microscope

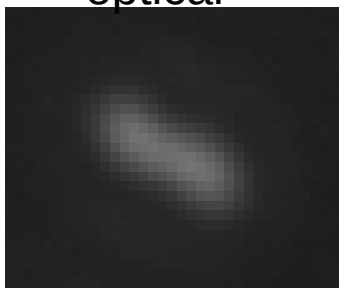


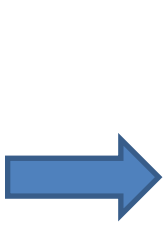


Selected tracks by optical microscope

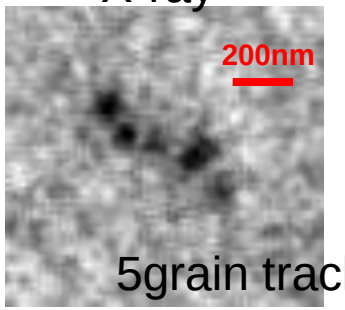
X-ray microscope measurement
- track length
- better directional determination

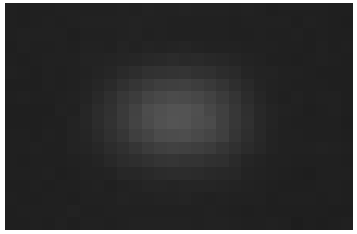
optical

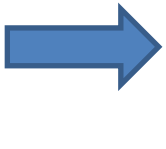


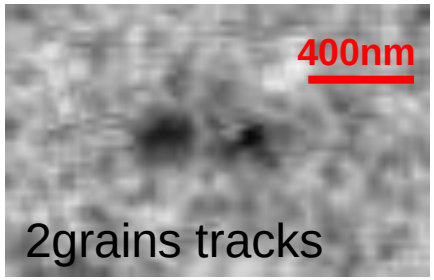


X-ray



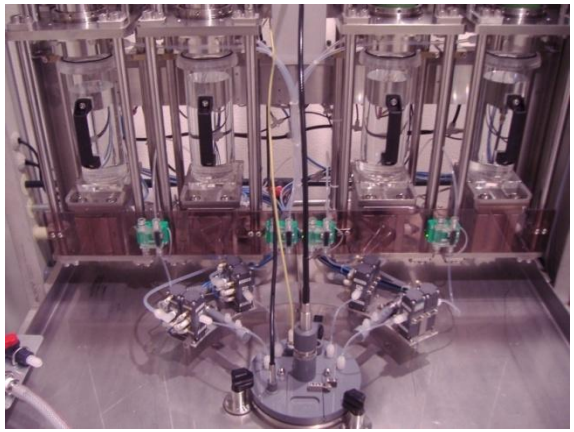




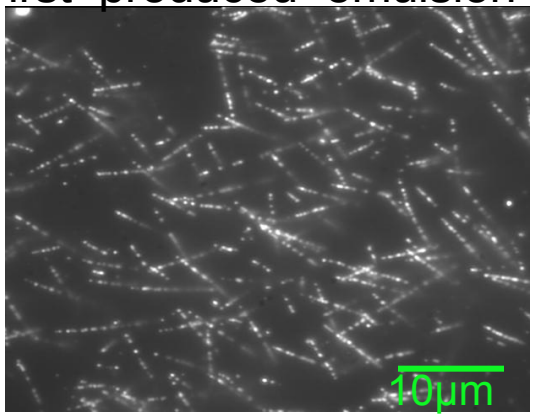


Nuclear Emulsion Production

We started to produce nuclear emulsion in laboratory with retired engineer of Fuji Film . ⇒ He produced the NIT emulsion and other emulsion for neutrino experiment .



First produced emulsion



We could detect alpha tracks.

Motivation

-Stable production of the nuclear emulsion for DM search
-the environment for a rapid development
-R&D of Low background emulsion
-R&D of finer grain emulsion (low energy threshold)
-First test toward underground production

Conclusion

- Confirmed the method for readout of <1μm tracks (This was the most challenging for this experiment)

⇒expansion readout by optical MS →X-ray MS

- Emulsion production facility was complete, and started the emulsion production.

⇒R&D, rapid production of emulsion, cost-down

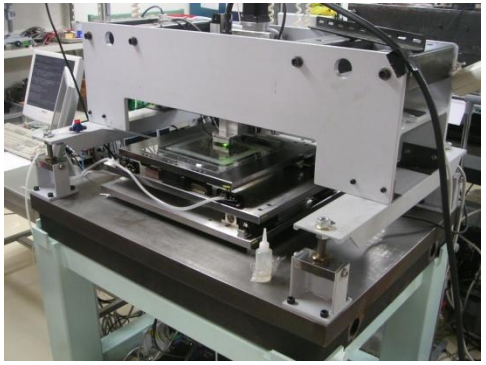
We are almost ready for first test run by above technique.

Planning in near future（this and next year)

2010-2011

- Tuning of Image processing scheme

- Development of automatic optical scanning microscope⇒improvement of the current scanning stage



- Production of good quality NIT.

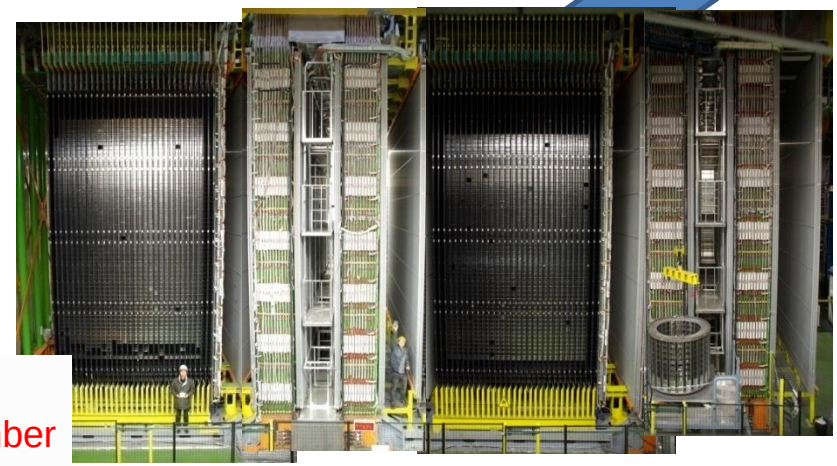
2011-2012

Start of the neutron and background run.

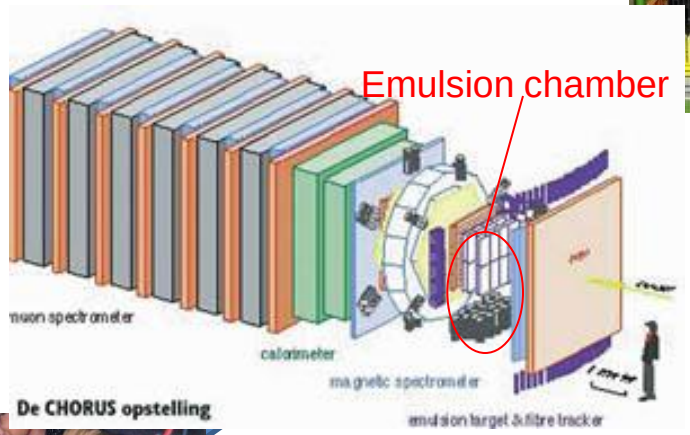
Make the prototype detector and facility.

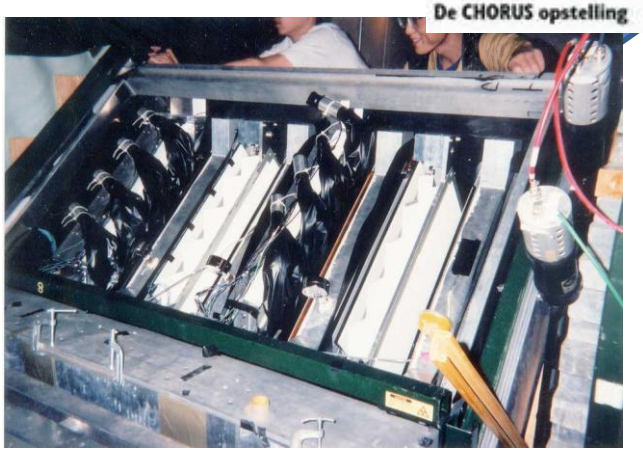
Back up

Nuclear Emulsion Experiment



OPERA experiment : 30000kg emulsion(10% volume of detector)

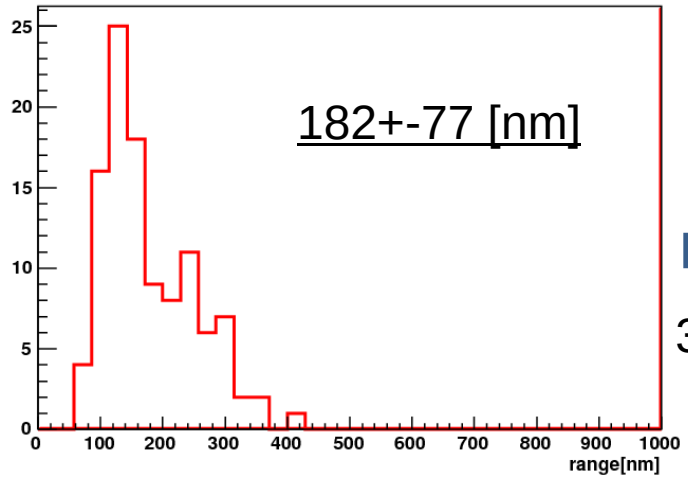




CHORUS :
780kg(140x140x3 cm^3) emulsion

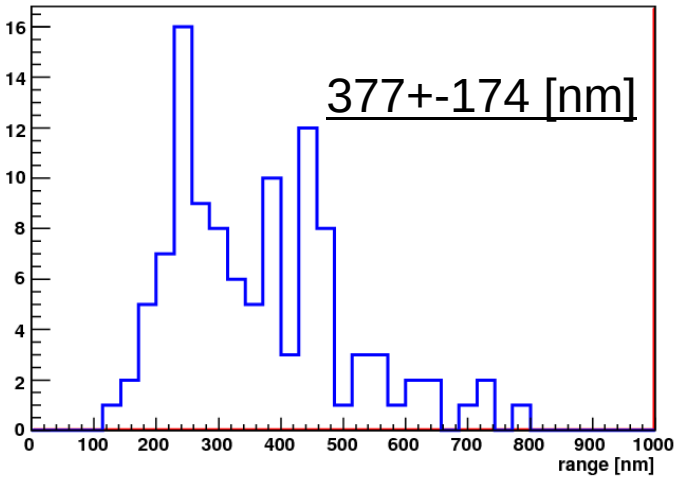
100-1000kg detector is easy to make!

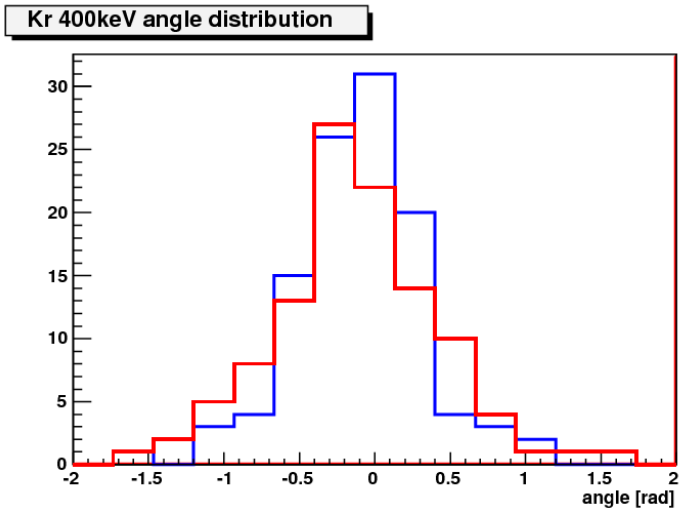
DONUT: 120kg emulsion (10% volume of this detector)

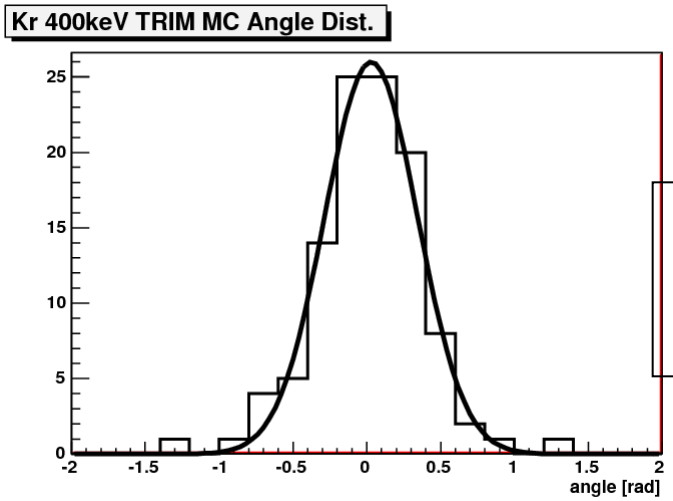


swell

377/182=2.07



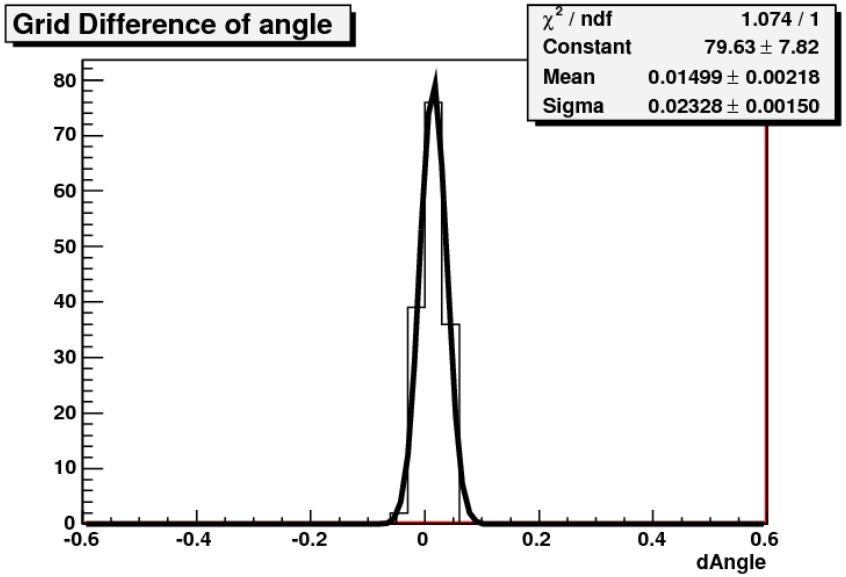




—: swell track
—: original track

σ_{swell} :0.34+-0.03
$\sigma_{original}$:0.51+-0.05
σ_{MC}: 0.32+-0.03

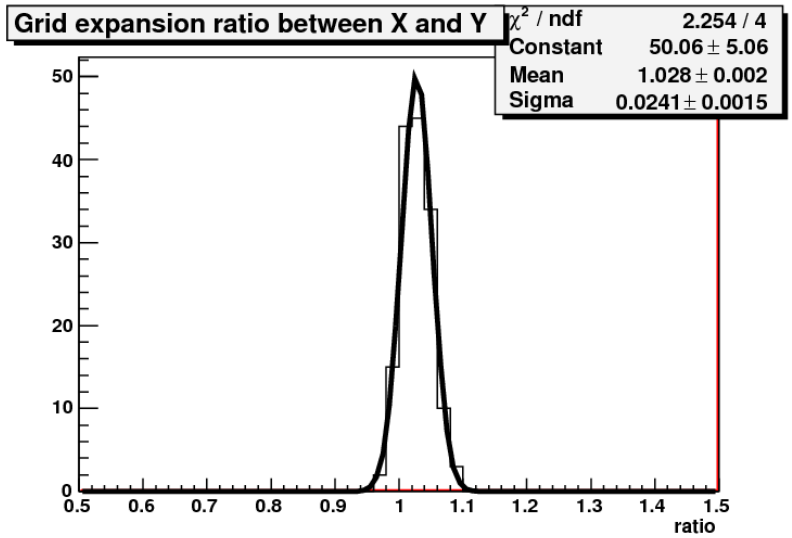
The accuracy for expansion



Grid angle of Mask (no Expansion)
= 1.572+-0.014 [rad]

Distribution of difference of expanded grid angle from mean original angle
=0.015+-0.023 [rad]

Angular accuracy=√0.014^2+0.015^2
= **0.021rad (1.2 degree)**



X/Y Ratio for expansion to original **=1.03+-0.02**

Expansion is isotropic!

WIMP sensitivity

WIMPs event rate　1 counts/（1000kg year）limit

Range threshold

200nm

100nm

50nm