Development of High Position Resolution Neutron Detector Using Nuclear Emulsion

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High Position Resolution Ultra-cold Neutron Detector

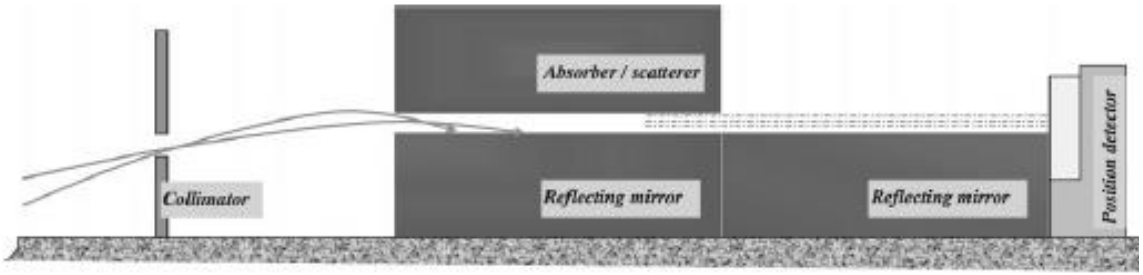


Fig. 3. General scheme of the experiment.

V.V. Nesvizhevsky et al. / Nuclear Instruments and Methods in Physics Research A 440 (2000) 754–759

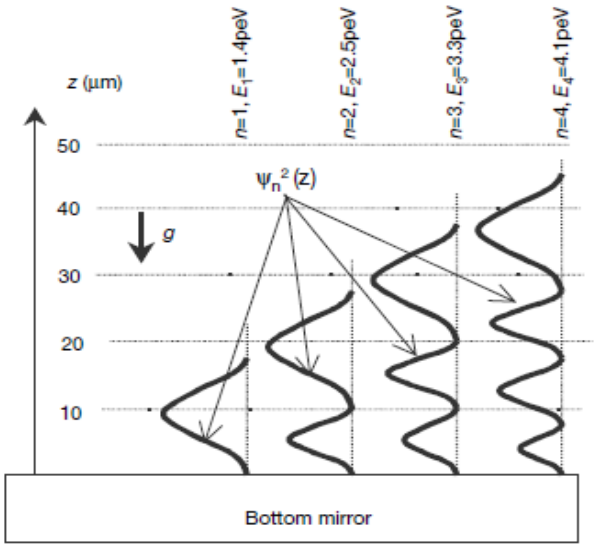


Figure 1 Wavefunctions of the quantum states of neutrons in the potential well formed by the Earth's gravitational field and the horizontal mirror. The probability of finding neutrons at height z, corresponding to the nth quantum state, is proportional to the square of the neutron wavefunction $\psi_n^2(z)$. The vertical axis z provides the length scale for this phenomenon. E_n is the energy of the nth quantum state.

Nesvizhevsky et al. Nature 415, 297 (2002)

$$V(r) = G\,\frac{m_1 m_2}{r}\,\left(1 + \alpha_G\, e^{-r/\lambda}\right)$$

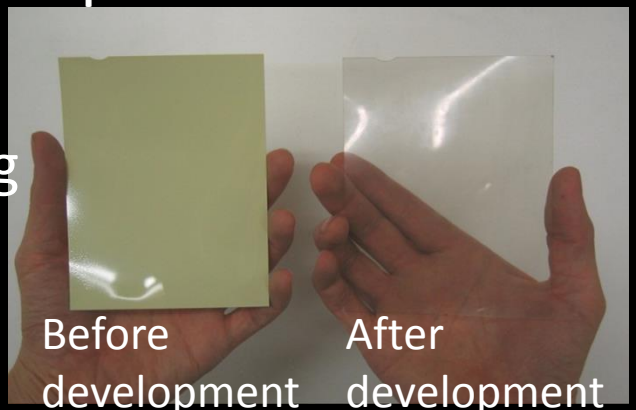
With nuclear emulsion, position resolution will be improved by 1~2 orders. (O(100)nm~O(10)nm).

Nuclear emulsion - a high position resolution tracking detector for ionizing particles.

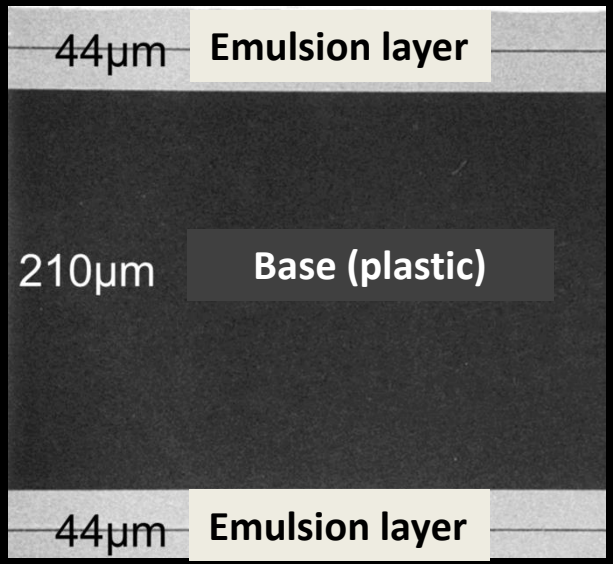
Emulsion gel（AgBr･I crystals dispersed in gelatin）

coating

emulsion film for OPERA experiment



Cross sectional view



Microscopic view (after development)

A track of minimum ionizing particle
: Grain Density (GD) ～30/100μm

10GeV π^-

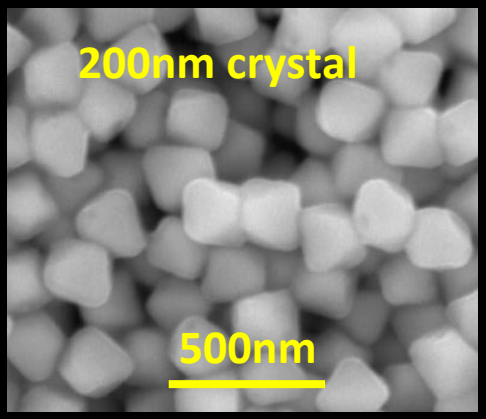
20μm

Fog (chemical noise)
Fog Density (FD)～3／(10μm)³

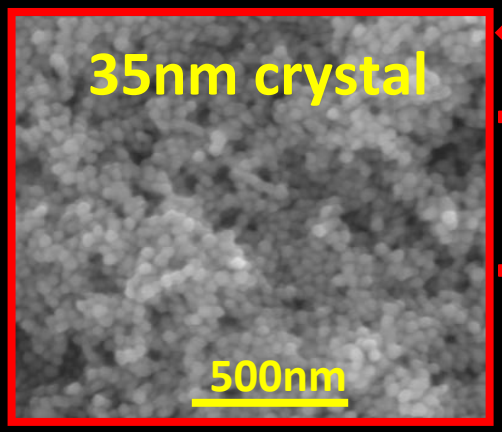
Fine grained nuclear emulsion produced at Nagoya University

(production since 2010)

Controled crystal growth of AgBr▪I in gelatin solution.

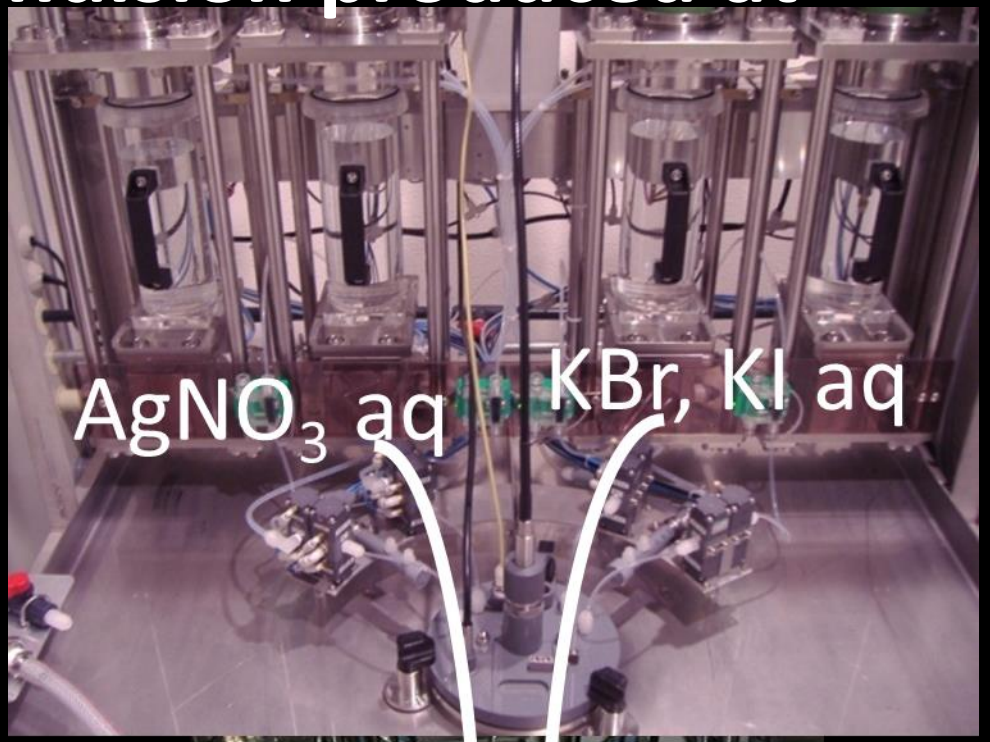


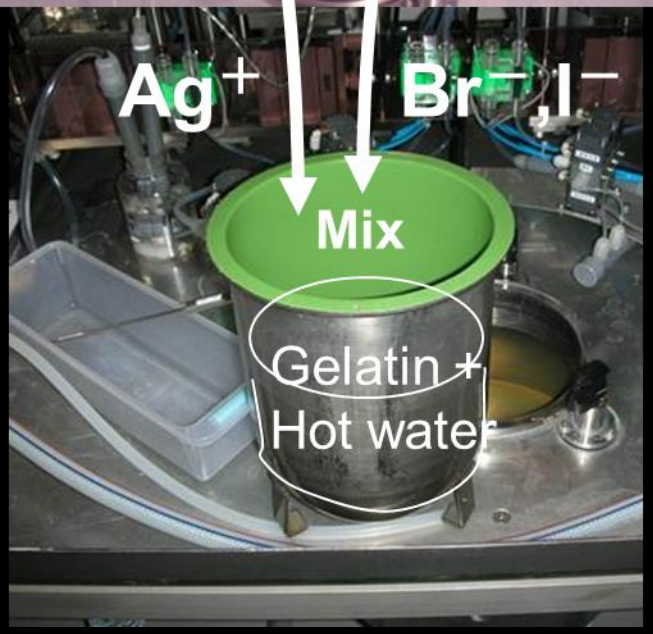
← Typical one for minimum ionizing particles.



← Fine-grained.

- **Crystals with 35nm of diameter.**
- **M.I.P.s and low E electrons are not detected. (strong to γ)**





Detection of neutrons by absorption

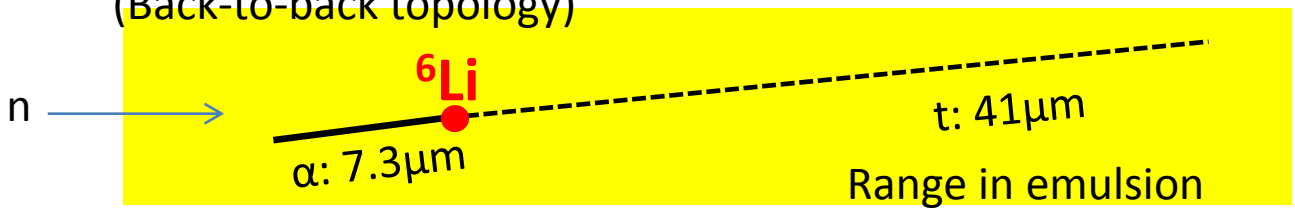
Suitable nuclides

- **Large absorption cross section.** → **^{6}Li, ^{10}B .**
- **Emitter of high dE/dx particles after absorption.**

^{6}Li(n,α) σ=940 barn (v_n=2200m/s), 4.14×10^{5} barn (v_n=5m/s)

$n + {}^{6}Li \rightarrow \alpha + t + 4.78MeV$

(Back-to-back topology)

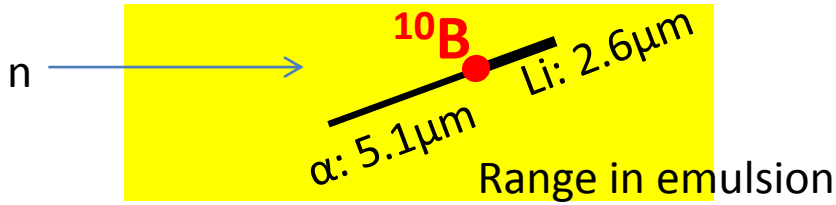


^{10}B(n,α) σ=3835 barn (v_n=2200m/s), 1.69×10^{6} barn (v_n=5m/s)

$n + {}^{10}B \rightarrow \alpha + {}^{7}Li$ (ground state) + 2.79MeV (6%)

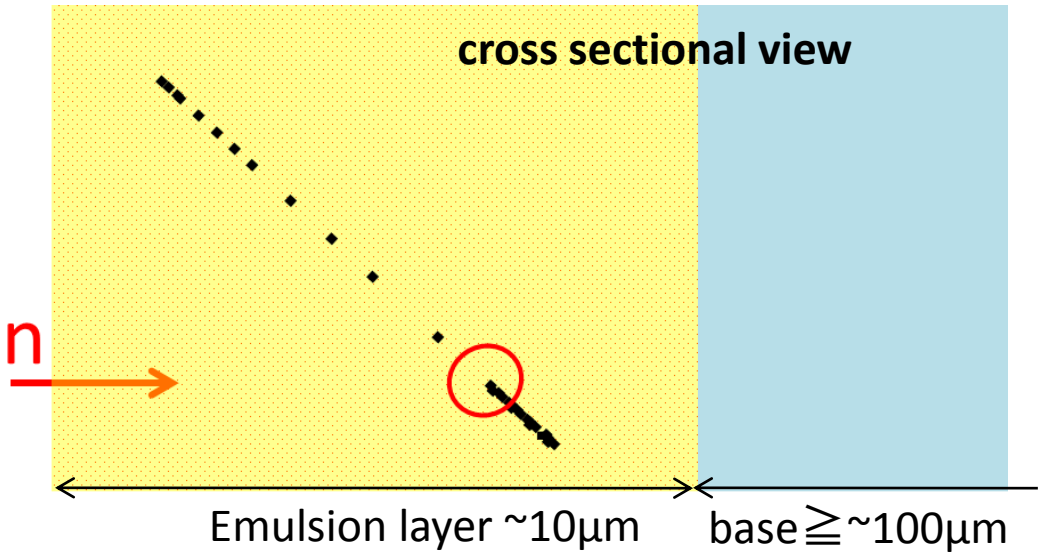
$\alpha + {}^{7}Li$ (1^{st} excitation state) + 2.31MeV (94%)

(Back-to-back topology)



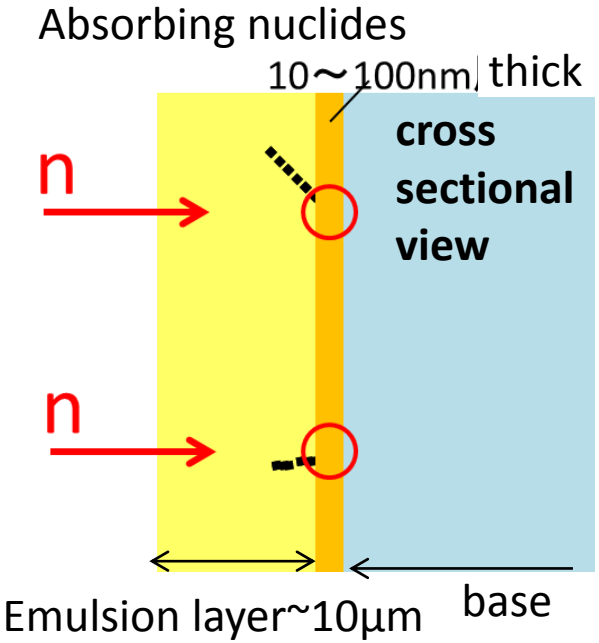
Possible structures of detectors

I) Doping type
Adding absorbing nuclides.
into emulsion gel layer.



Back to back topology of tracks
will be observed.

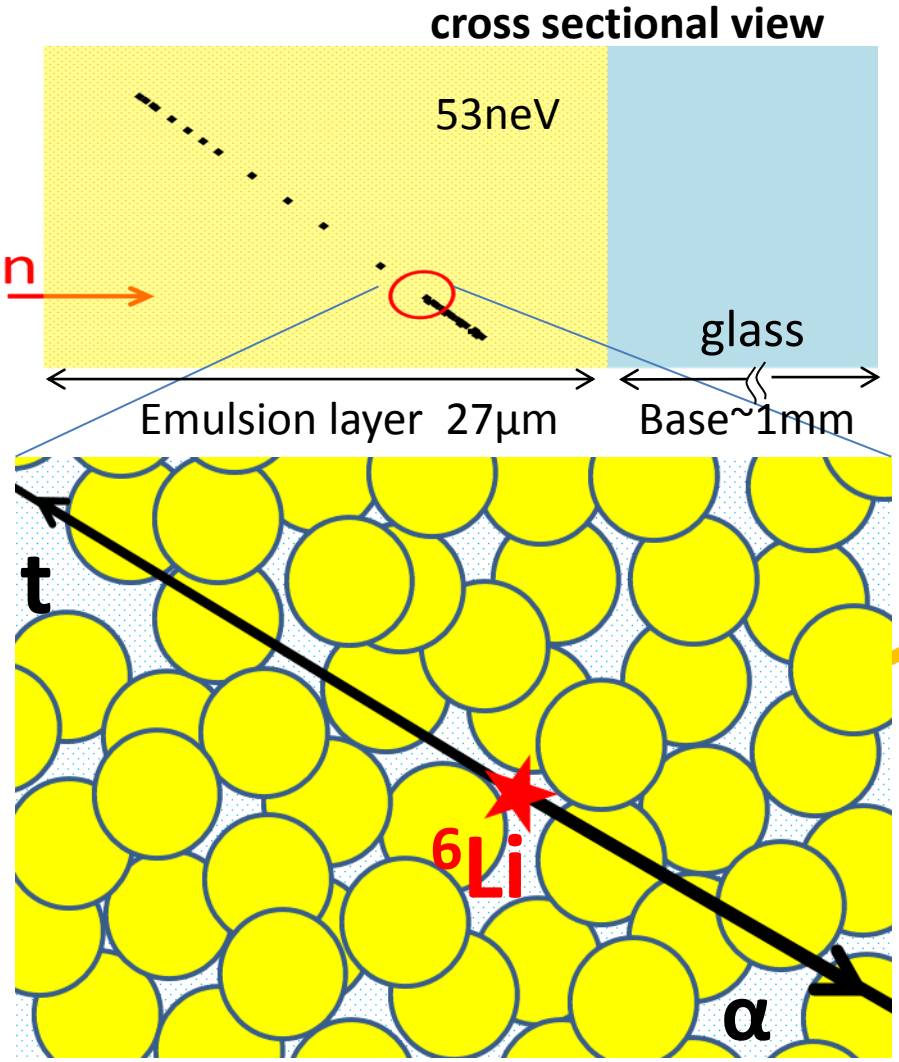
II) Thin layer type
Thin layer of absorbing nuclide
next to emulsion gel layer.



One of the tracks emitted
Is observed.

(I) Doping type

$LiNO_3$ solution (natural Li) mixed into emulsion gel before coating.



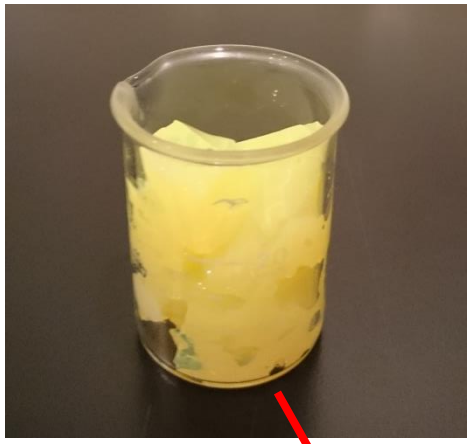
Amount of ^6Li in the gel is 0.096% in atomic ratio.
(5m/s UCN
→ absorption eff. : 8%)

AgBr･I crystal

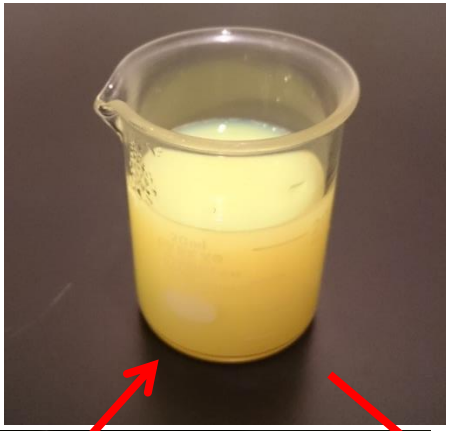
		Range (SRIM)
α	2.06 MeV	7.75 μm
t	2.73 MeV	43.48 μm

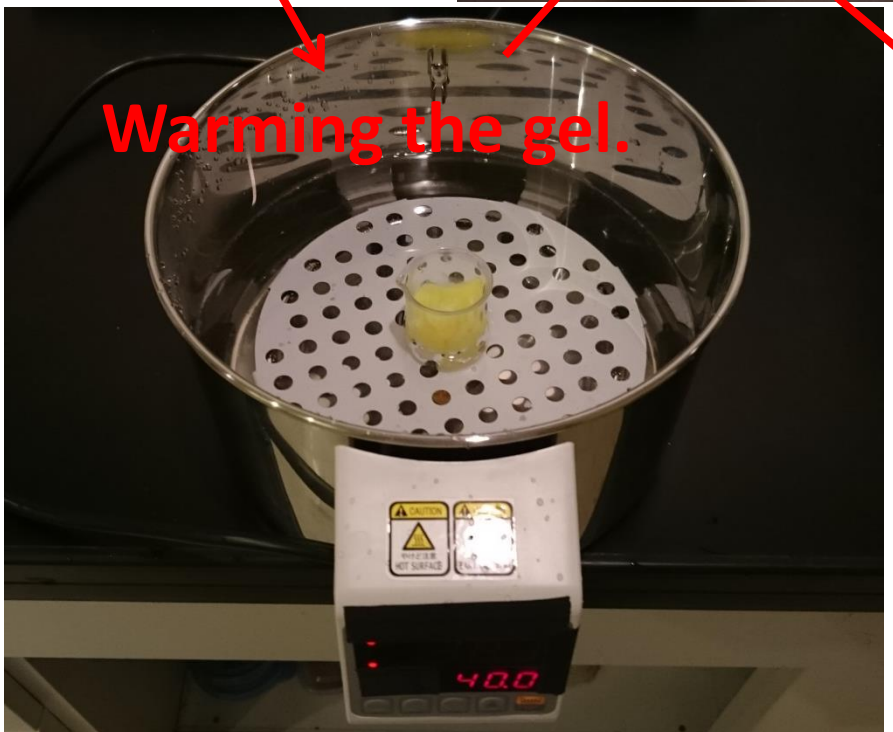
Doping method (must be done in darkroom)

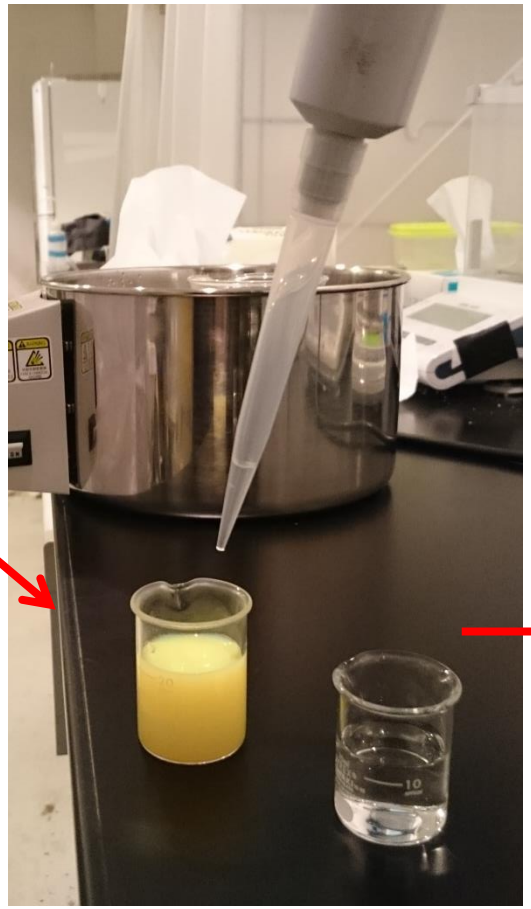
Pick up emulsion gel



Melted gel 20 mL





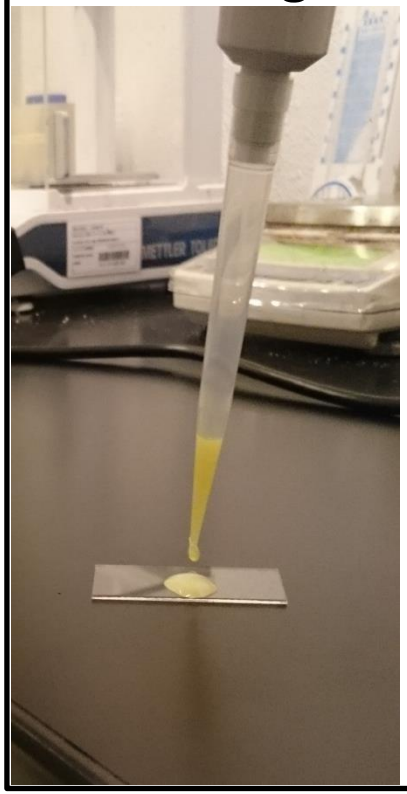


Add 0.4mL $LiNO_3$ solution with its mass concentration : 25g $LiNO_3$ in 100mL.

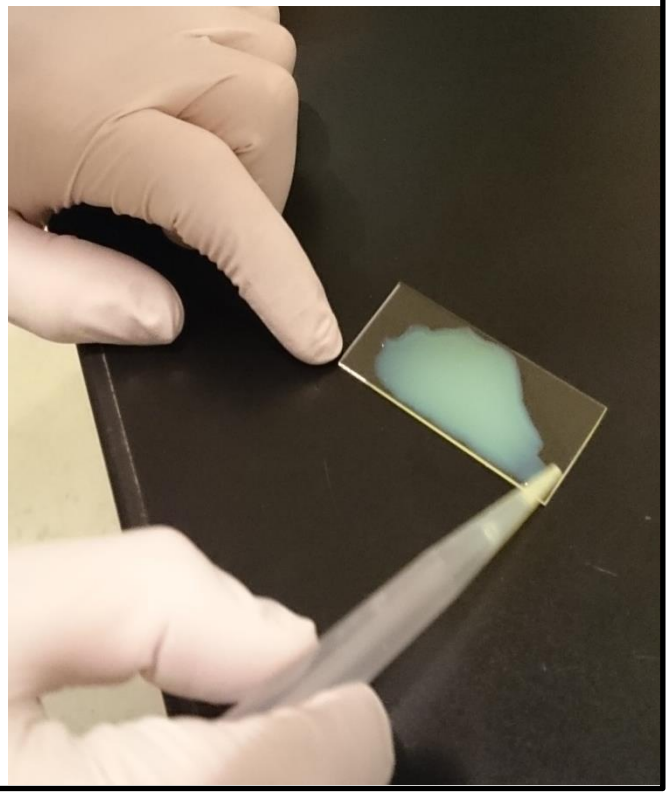
Mix for several minutes.

Coating

Dropping the gel on a slide glass.

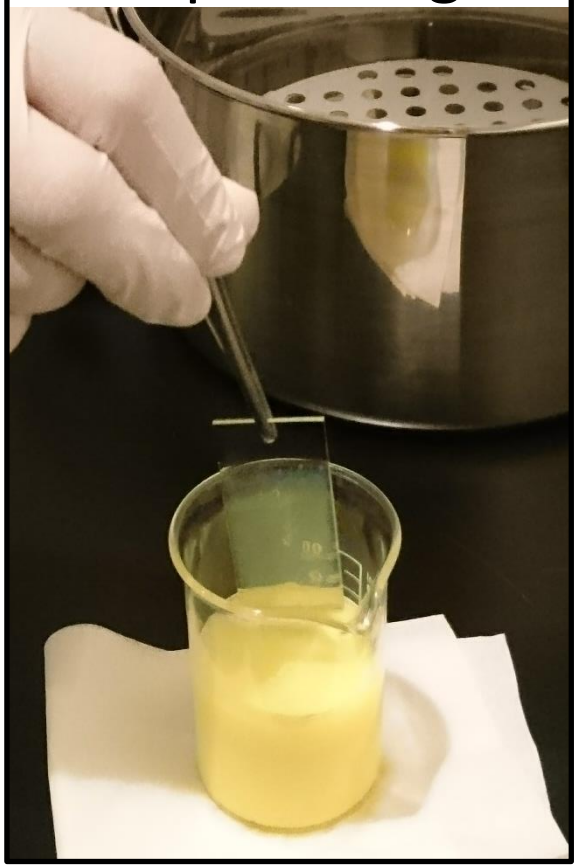


Coating



or

Dip coating

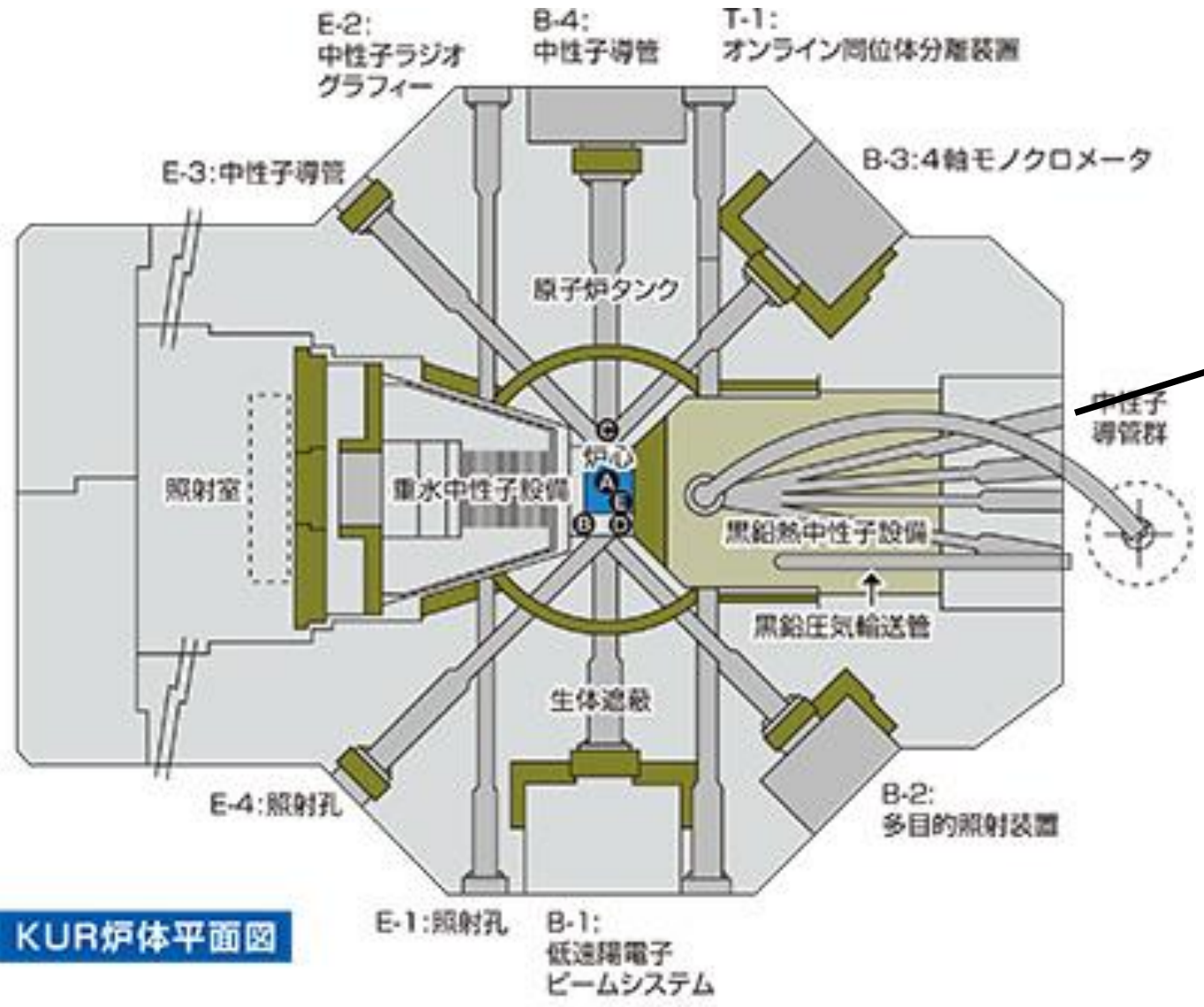


After dry, packing

Light tight, air tight package.

Inside …

Thermal neutron test exposure @Kyoto Univ. Reactor 2014

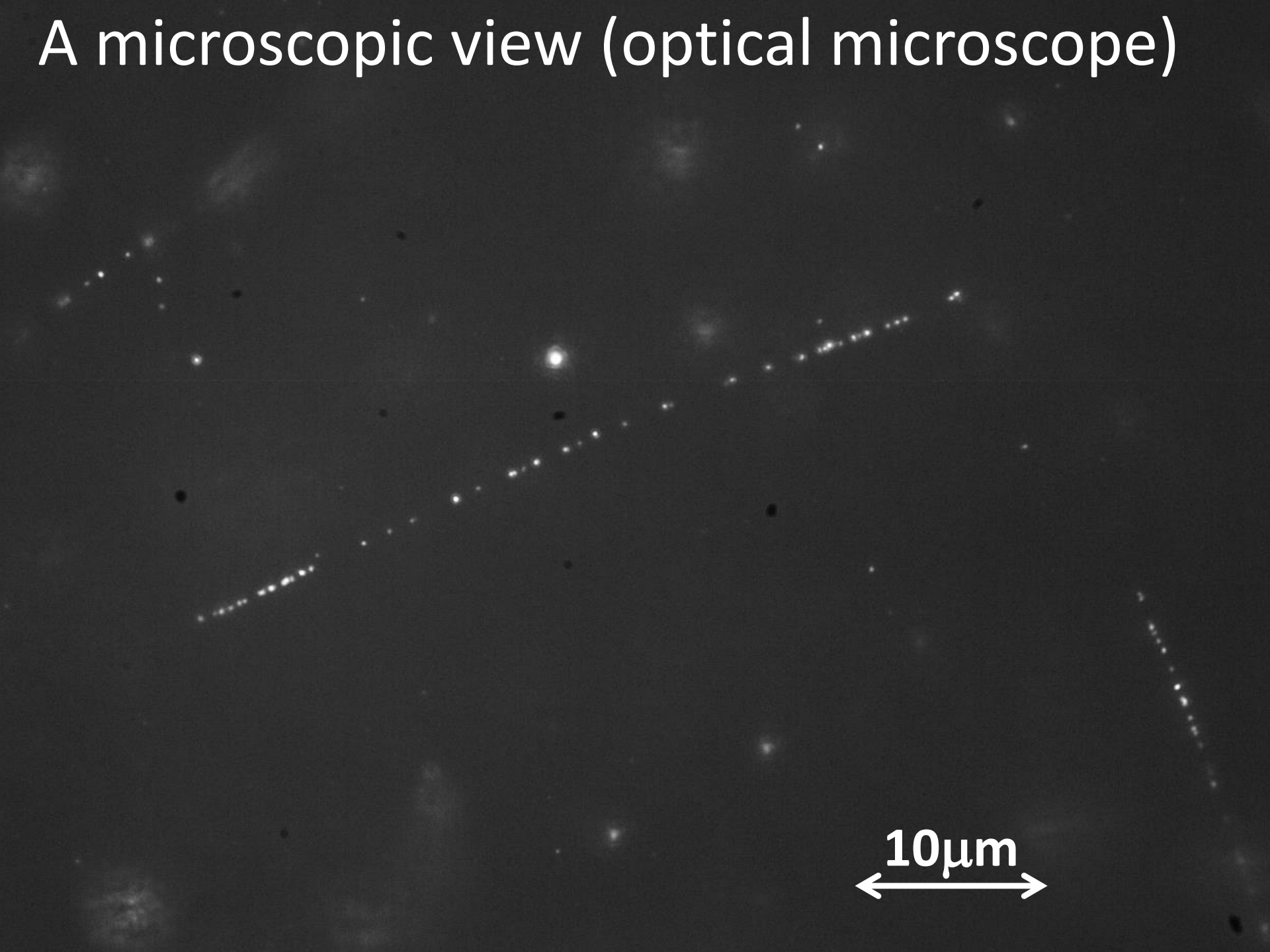


Emulsion sample

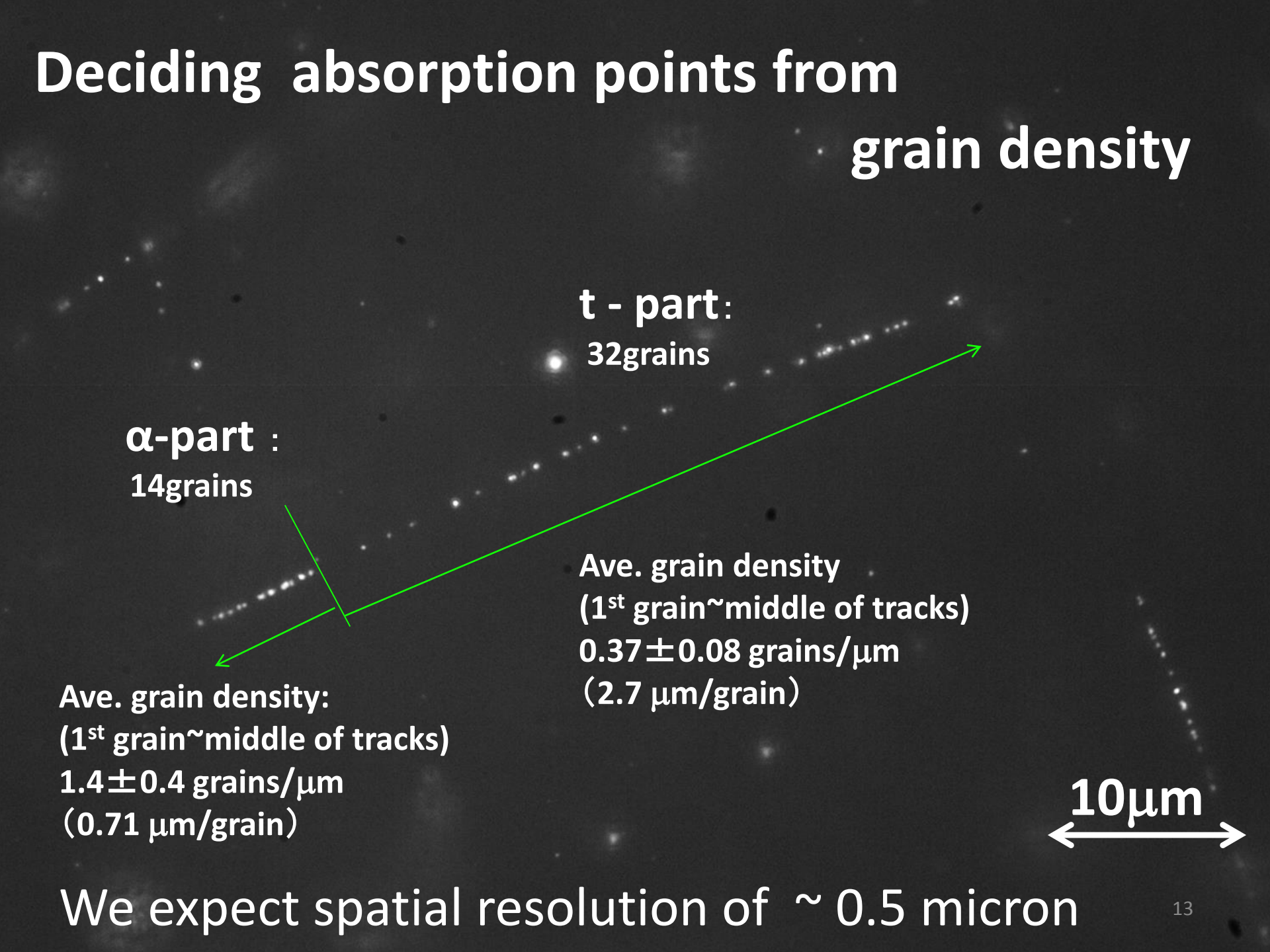
Downstream of an extraction pipe

～10^6 n/cm^2/s
×5min exposure

A microscopic view (optical microscope)

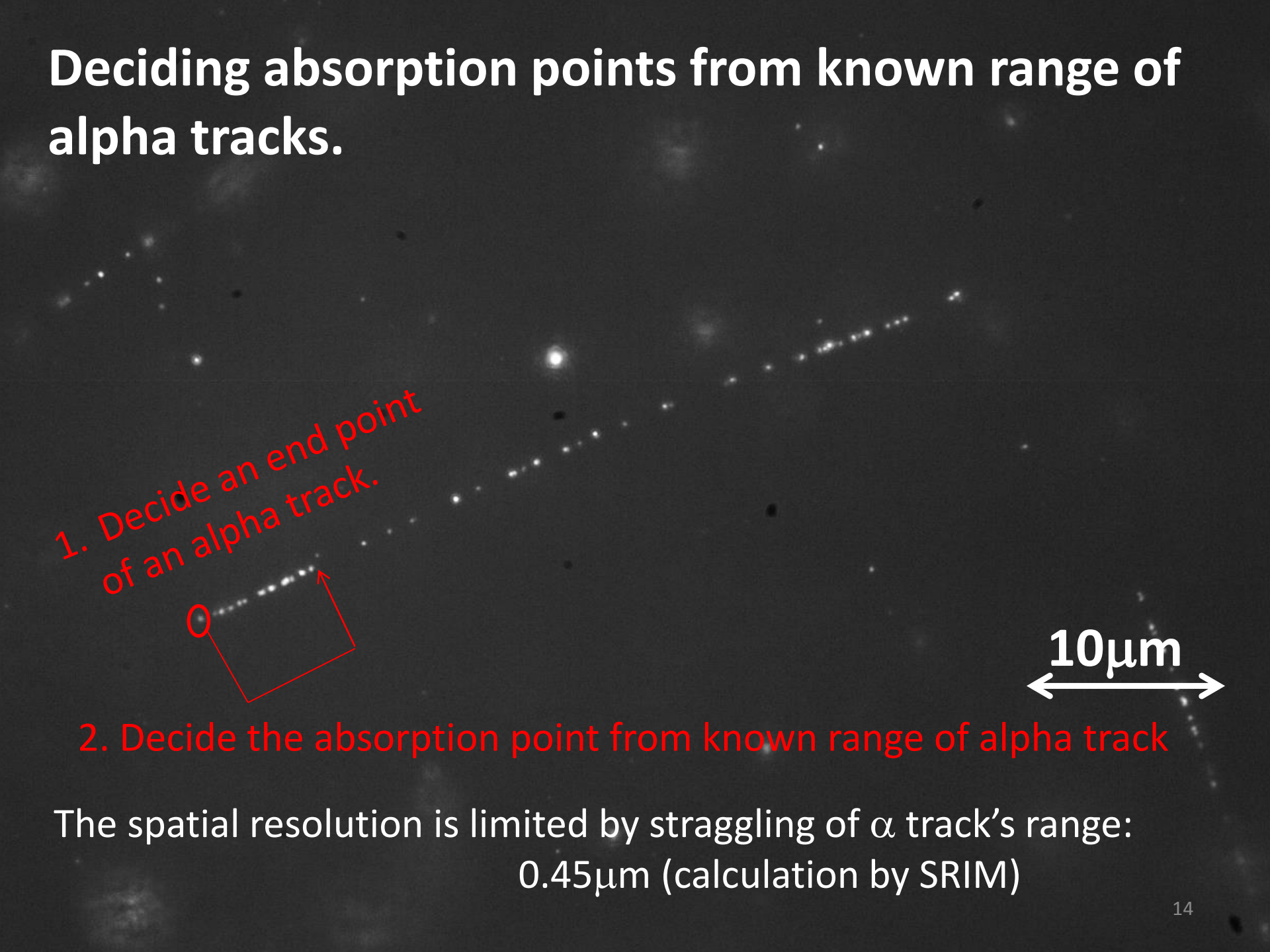


Deciding absorption points from grain density



We expect spatial resolution of ~ 0.5 micron

Deciding absorption points from known range of alpha tracks.

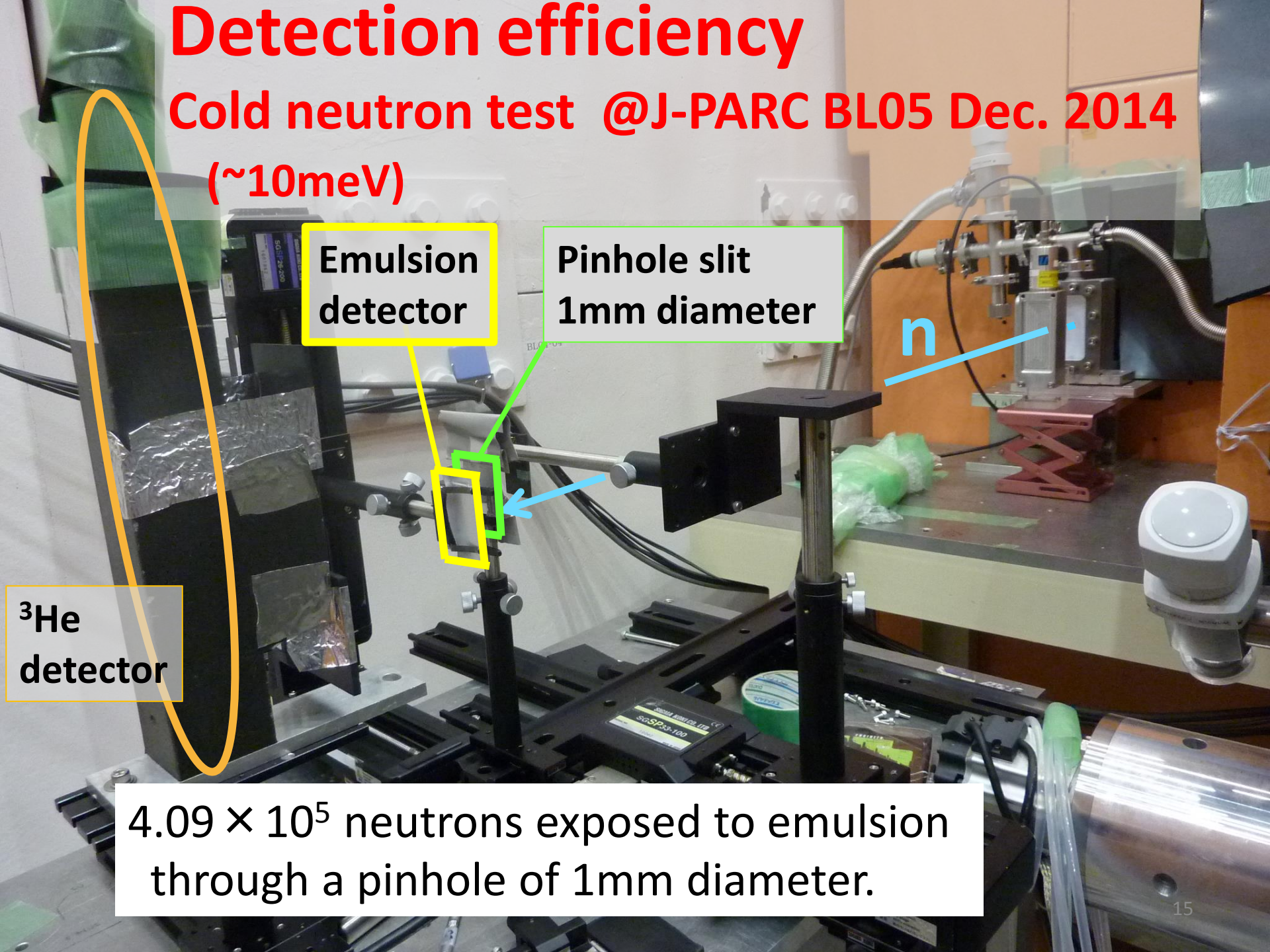


2. Decide the absorption point from known range of alpha track

The spatial resolution is limited by straggling of α track's range:
0.45μm (calculation by SRIM)

Detection efficiency

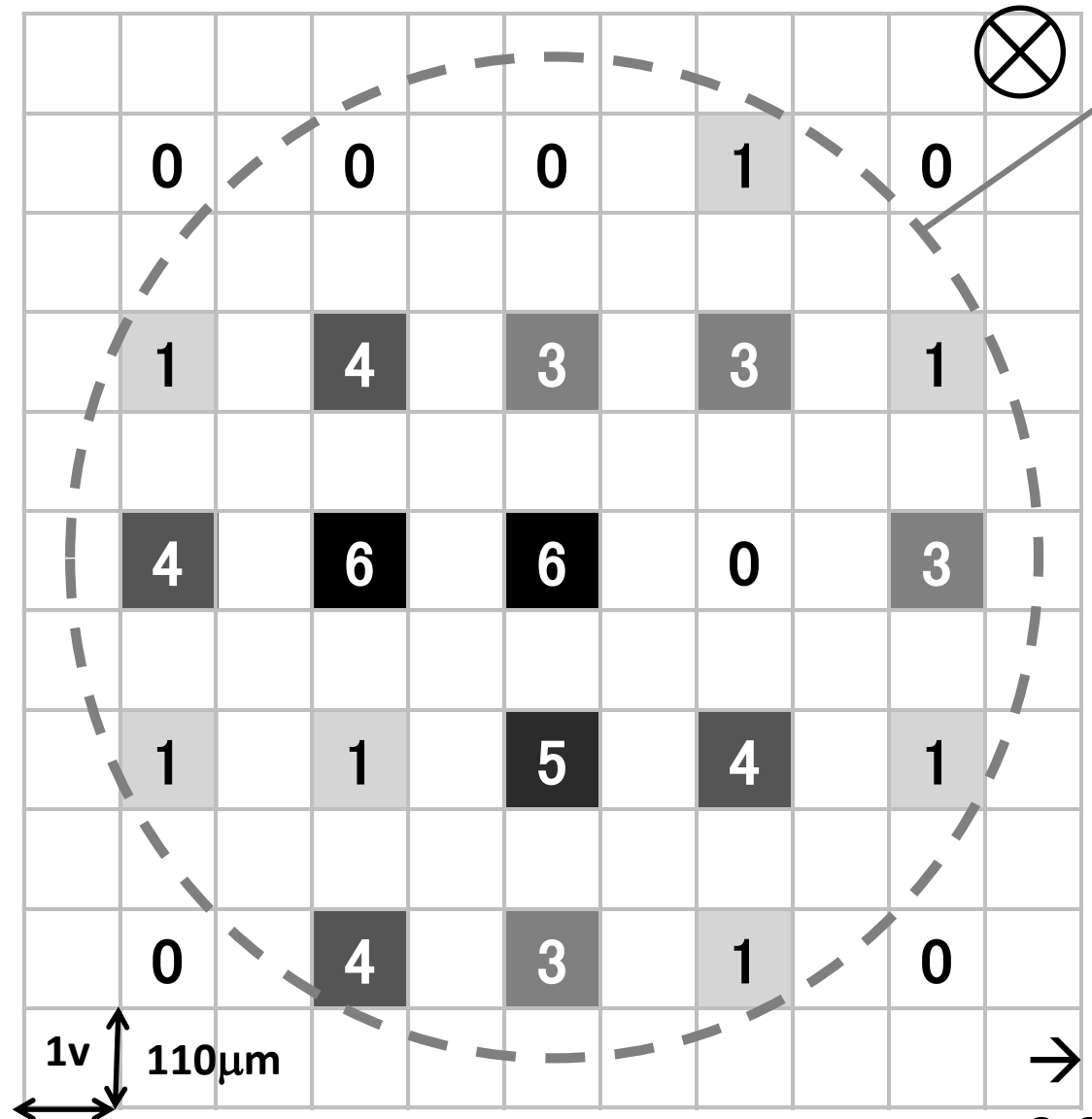
Cold neutron test @J-PARC BL05 Dec. 2014 (~10meV)



4.09×10^5 neutrons exposed to emulsion through a pinhole of 1mm diameter.

Result : Number of absorption observed in emulsion

Absorption events in 21 views（1view=(110μm)^2）are counted by human eyes.



Total observed:
52 events/21 views

(exposed n :
1.2×10^5 n/21views
→ Expected number of absorption events by $LiNO_3$ = 43 events/21views.)

Expected were detected.

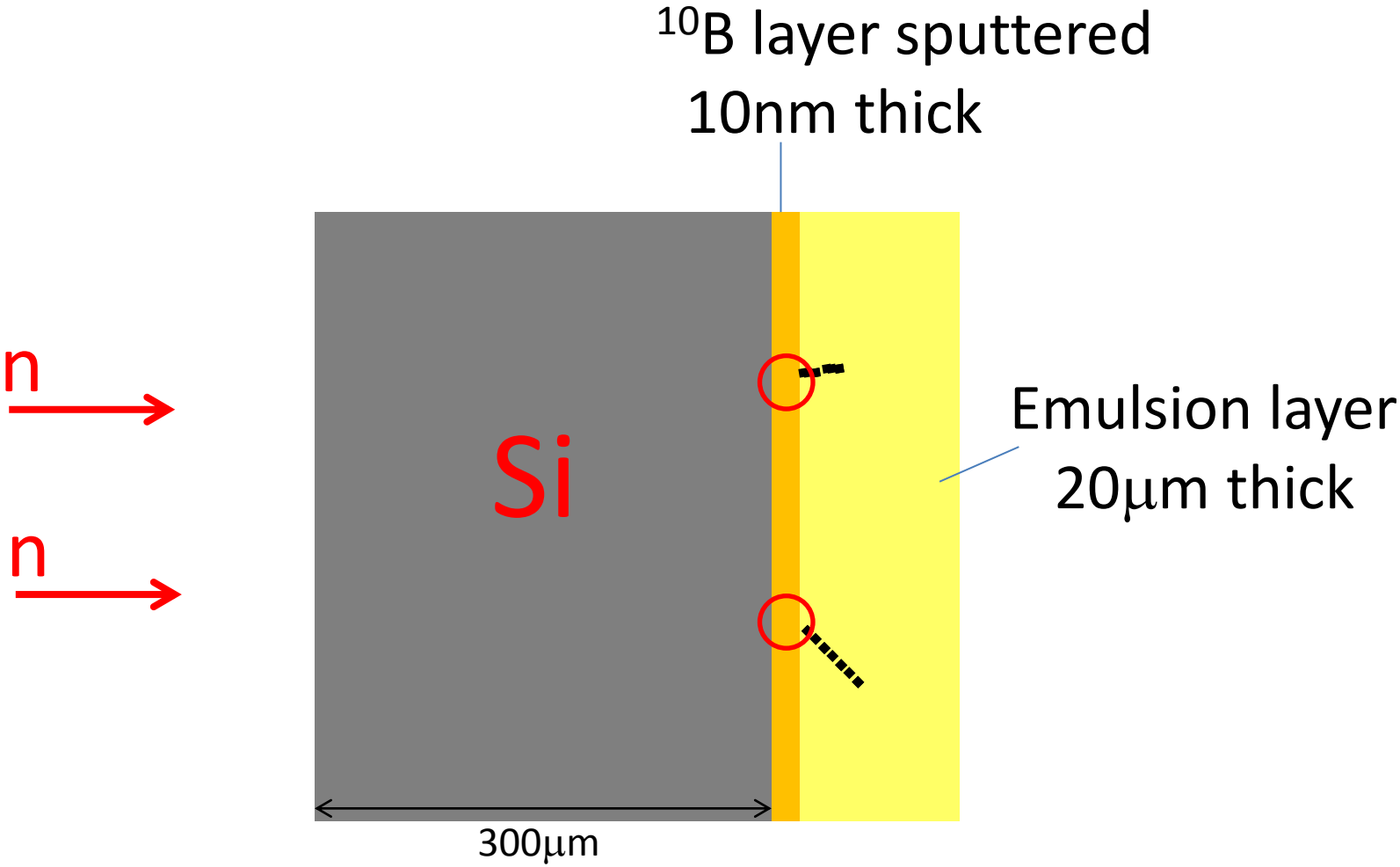
Detection efficiency:
4.4×10^{-4} events/n

→ Simple extrapolation,
0.086 events/n (for 5m/s UCN)

Tasks to be done

- Uniform doping of Li should be confirmed.
- Distortion of emulsion should be measured.
- Spatial resolution should be proven.

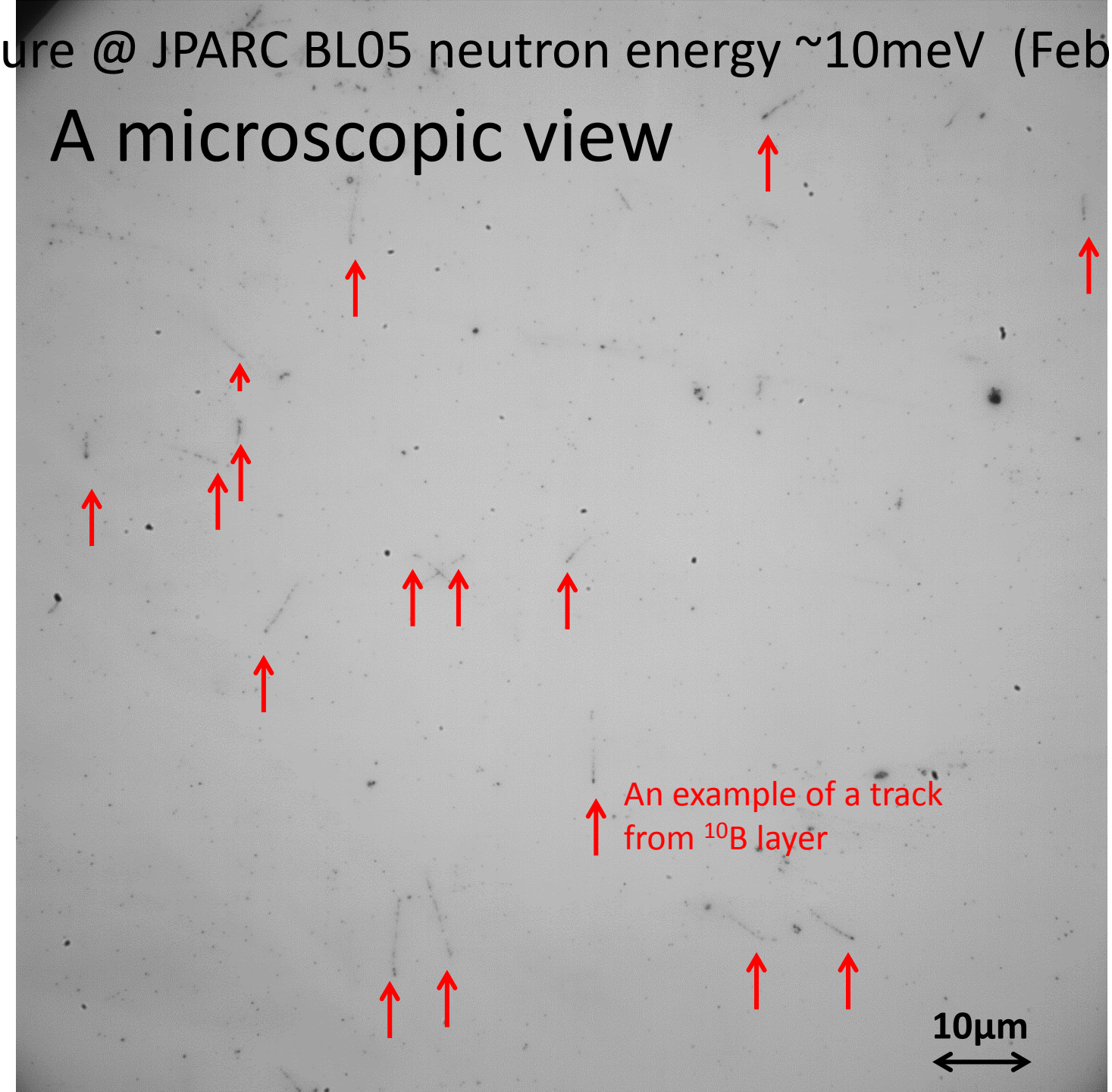
(II) Thin layer type



Spatial resolution ~ thickness of ^{10}B layer.

Sputtered by M. Hino (Kyoto Univ. reactor)

Exposure @ JPARC BL05 neutron energy ~10meV (Feb.2016)



Status

We are developing stable ^{10}B layer.

Summary

- High position resolution UCN detectors are having been developed by using fine grained emulsion and nuclides emitting high dE/dx particles after absorption of neutrons.

- In $LiNO_3$ doped type,
  - Spatial resolution of absorption points is ~0.5micron.
  - Measured counts was consistent with expected in cold neutron experiment.
    (4.4×10^{-4} absorption/n → extrapolation to UCN(5m/s) : ~9%)
  - Studies of uniformity and distortion are on going.

- In thin ^{10}B layer type,
  - Spatial resolution is decided by the thickness of ^{10}B layer should be ~50nm.
  - Tracks from the layer was successfully observed.
  - We are developing stable layer of ^{10}B .

Thank you.