

B02

ニュートリノ研究をささえる
原子核乾板の大規模展開

Large-scale Development of
Nuclear Emulsion Detector
Supporting Neutrino Research

名古屋大学 六條宏紀

Nagoya Univ. Hiroki ROKUJO

B02 outline

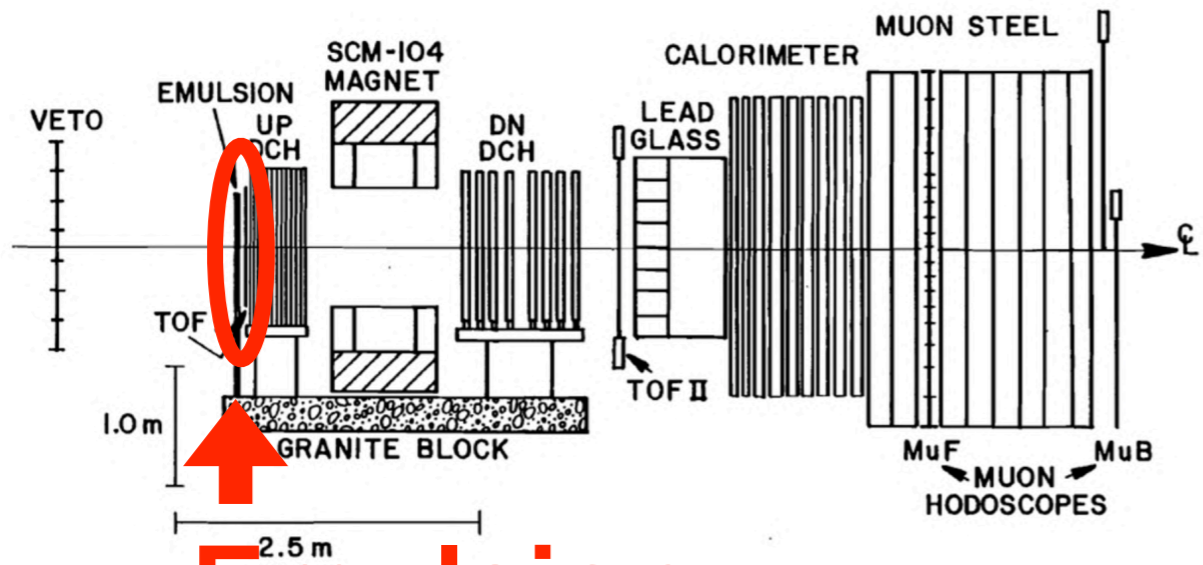
- **Introduction and next emulsion mass-production plans (Rokujo)**
- Study for long-term stability (Nishio)
- Ongoing Neutrino Projects (Ariga)
- Ongoing Other Projects (Sato)

1979-

Fermilab E531

Neutrino Charm Production

$\nu_\mu \rightarrow \nu_\tau$ Oscillation Search



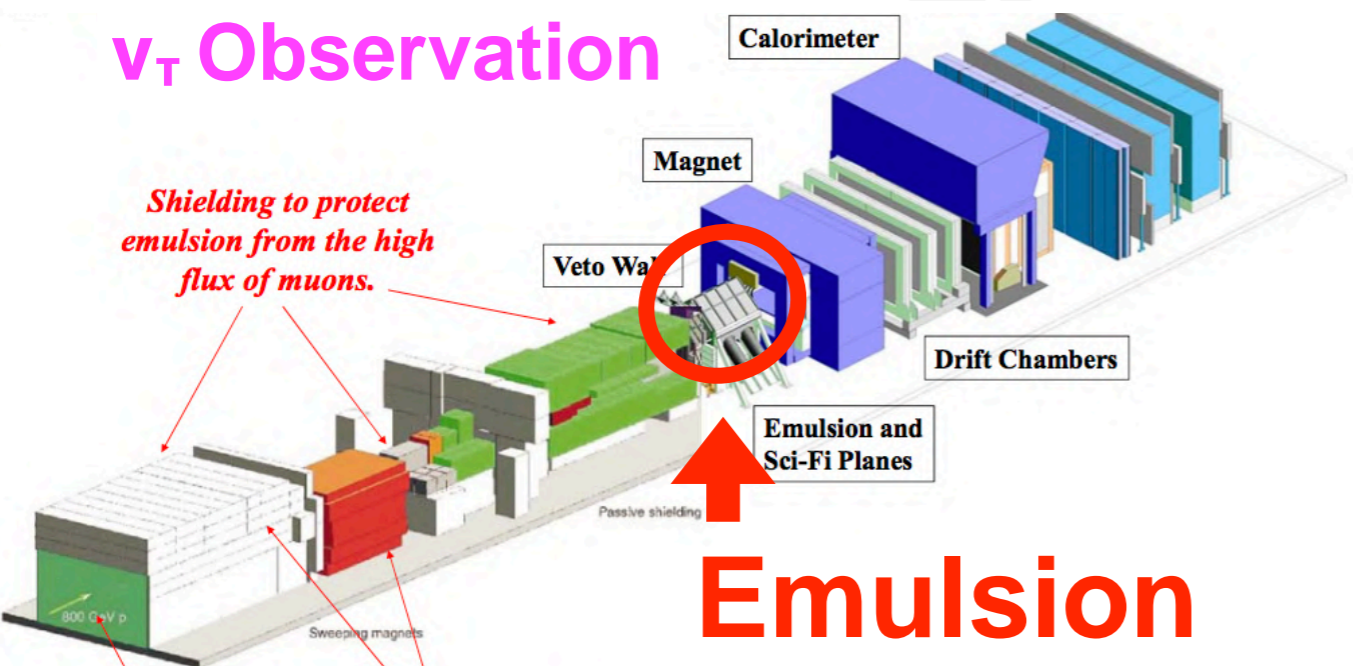
Emulsion

1997-

Fermilab E872 DONUT

Direct Observation of ν_τ

ν_τ Observation



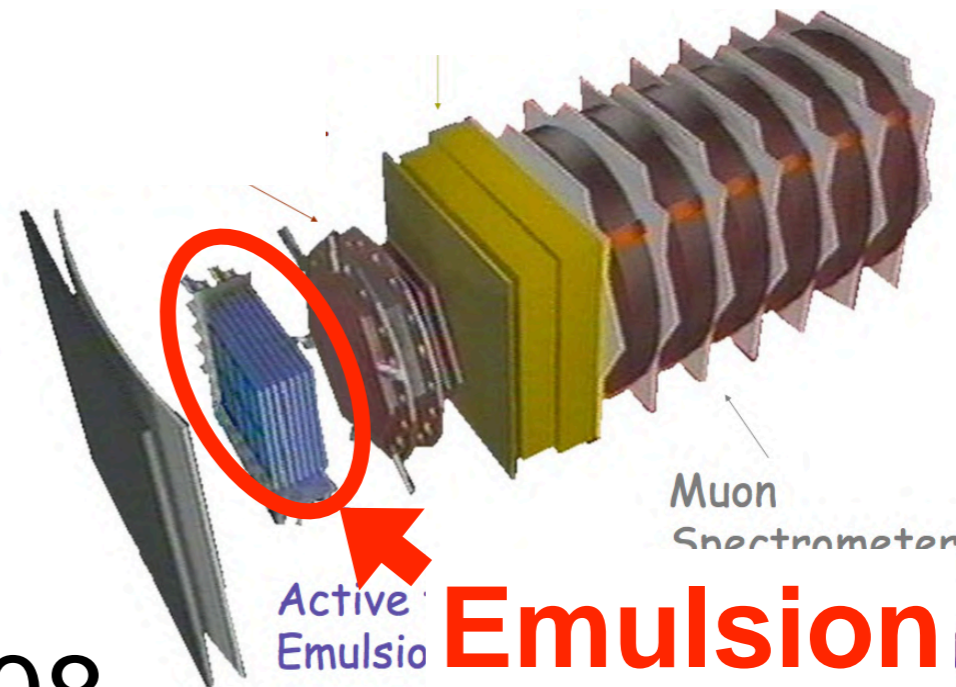
Emulsion

1994-

CERN WA95 CHORUS

CERN Hybrid Oscillation Research Apparatus

$\nu_\mu \rightarrow \nu_\tau$ Oscillation Search



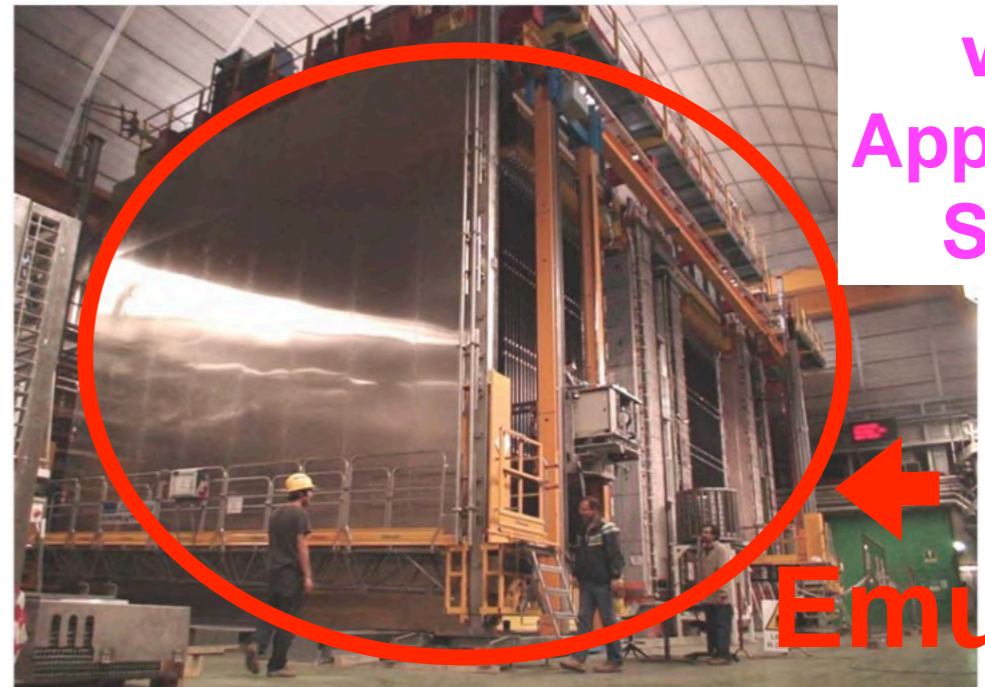
Emulsion

2008-

CERN CNGS1 OPERA

Oscillation Project with Emulsion Tracking Apparatus

$\nu_\mu \rightarrow \nu_\tau$ Appearance Search



Emulsion

Why do we use emulsion?

A: One and Only Vertex detector

Cross section
(Electron microscopic view)

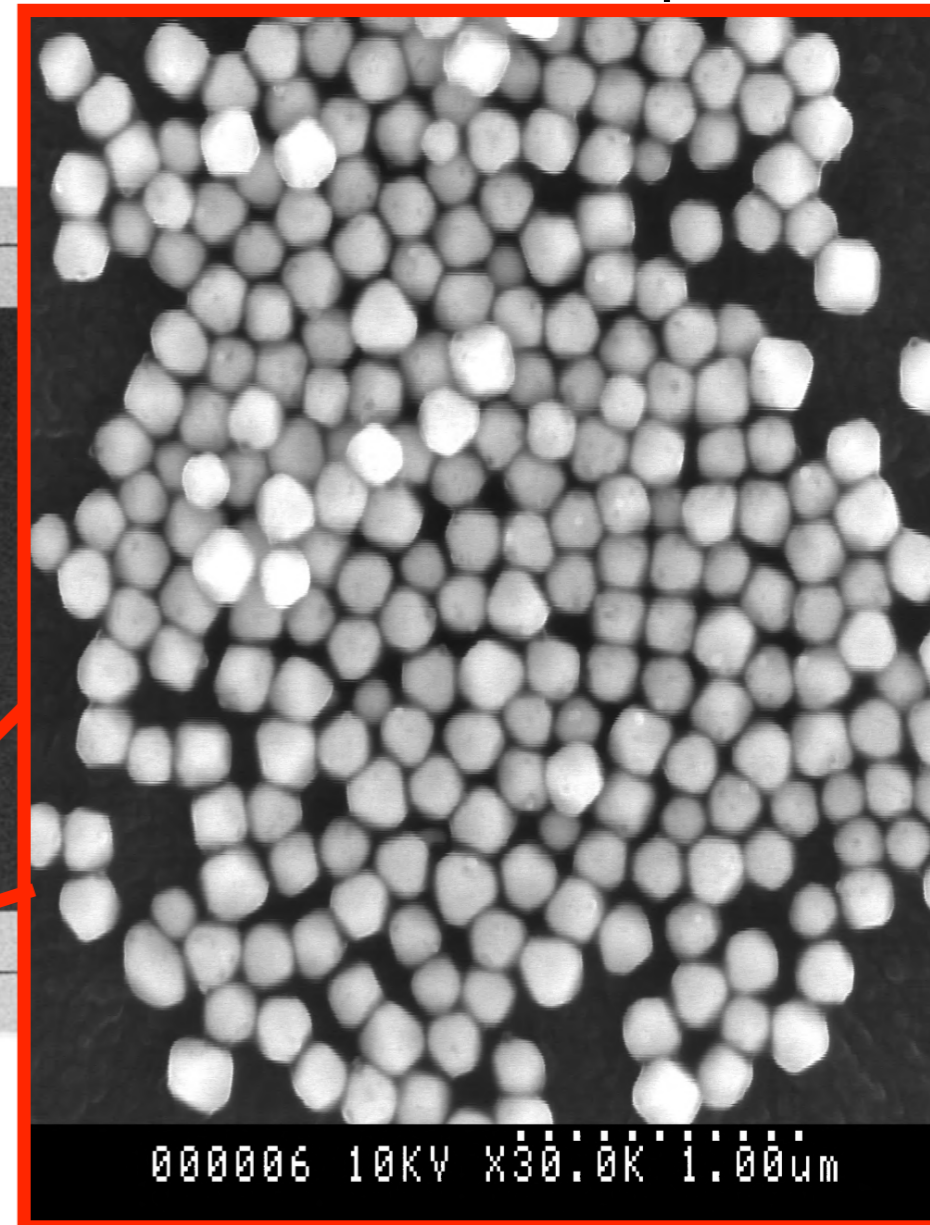
Electron microscopic view



~50 μm Emulsion

~200 μm Plastic

~50 μm Emulsion



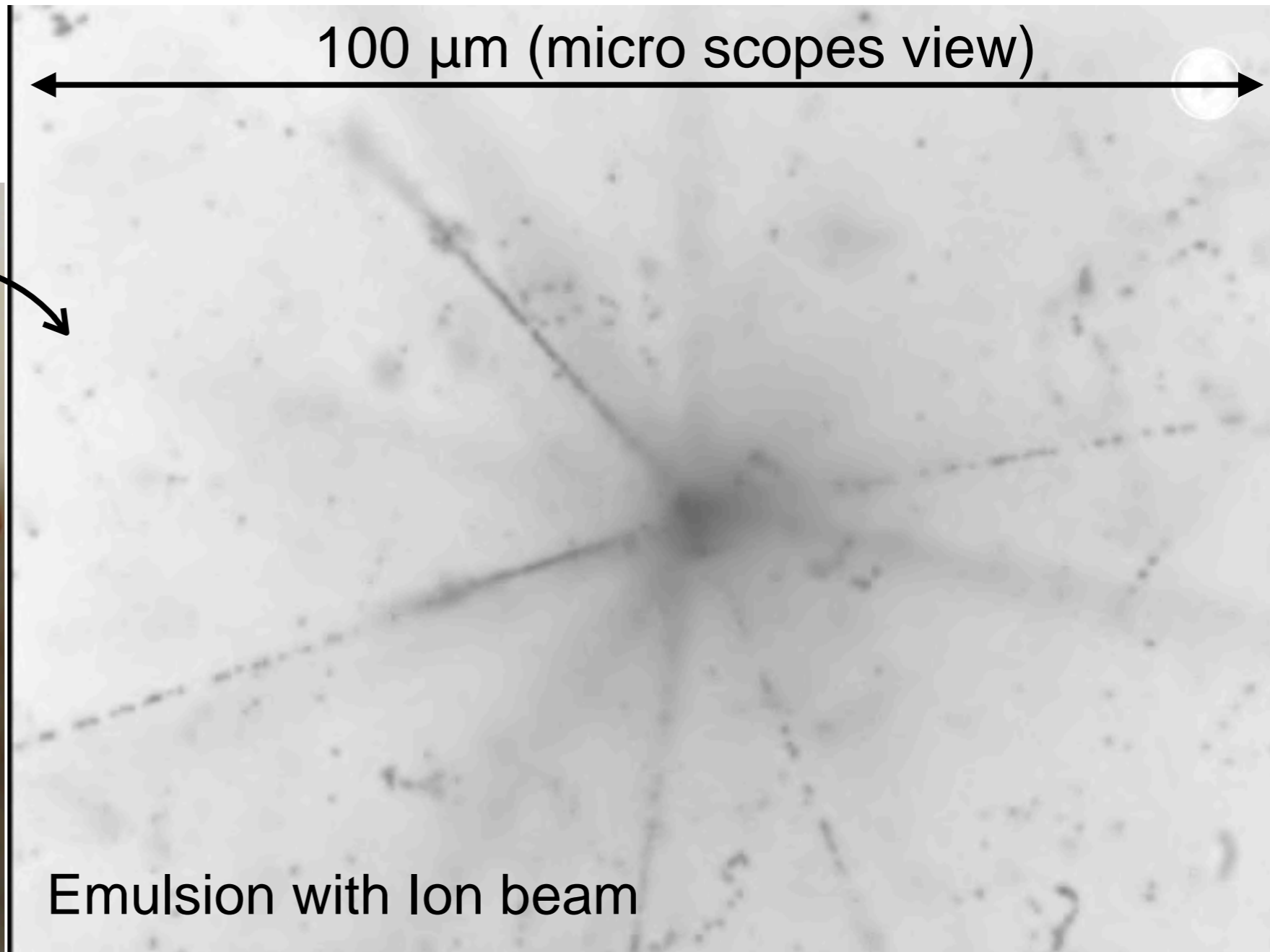
0.2 μm -diameter AgBr crystals in gelatine
function as 3-D position sensors.

Intrinsic resolution: $200/\sqrt{12} \sim 60 \text{ nm}$

Why do we use emulsion?

A: One and Only Vertex detector

After photo-finishing process
(Chemical development)

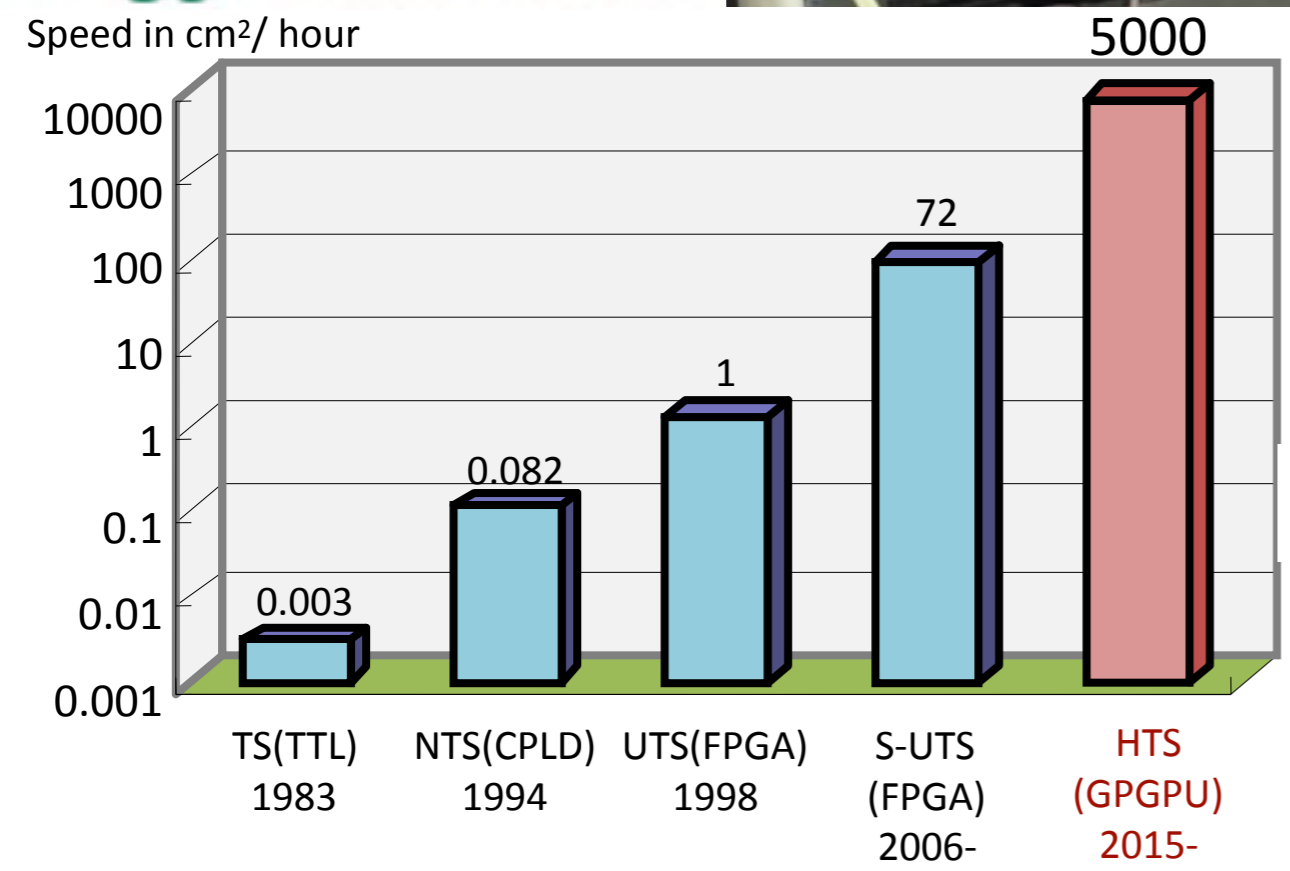


Emulsion with Ion beam

- ◎ **Observation of short-lived particles (c , τ)**
- ◎ **Precise 3D measurement of topology at VTX**

In manual measurement with microscope....,

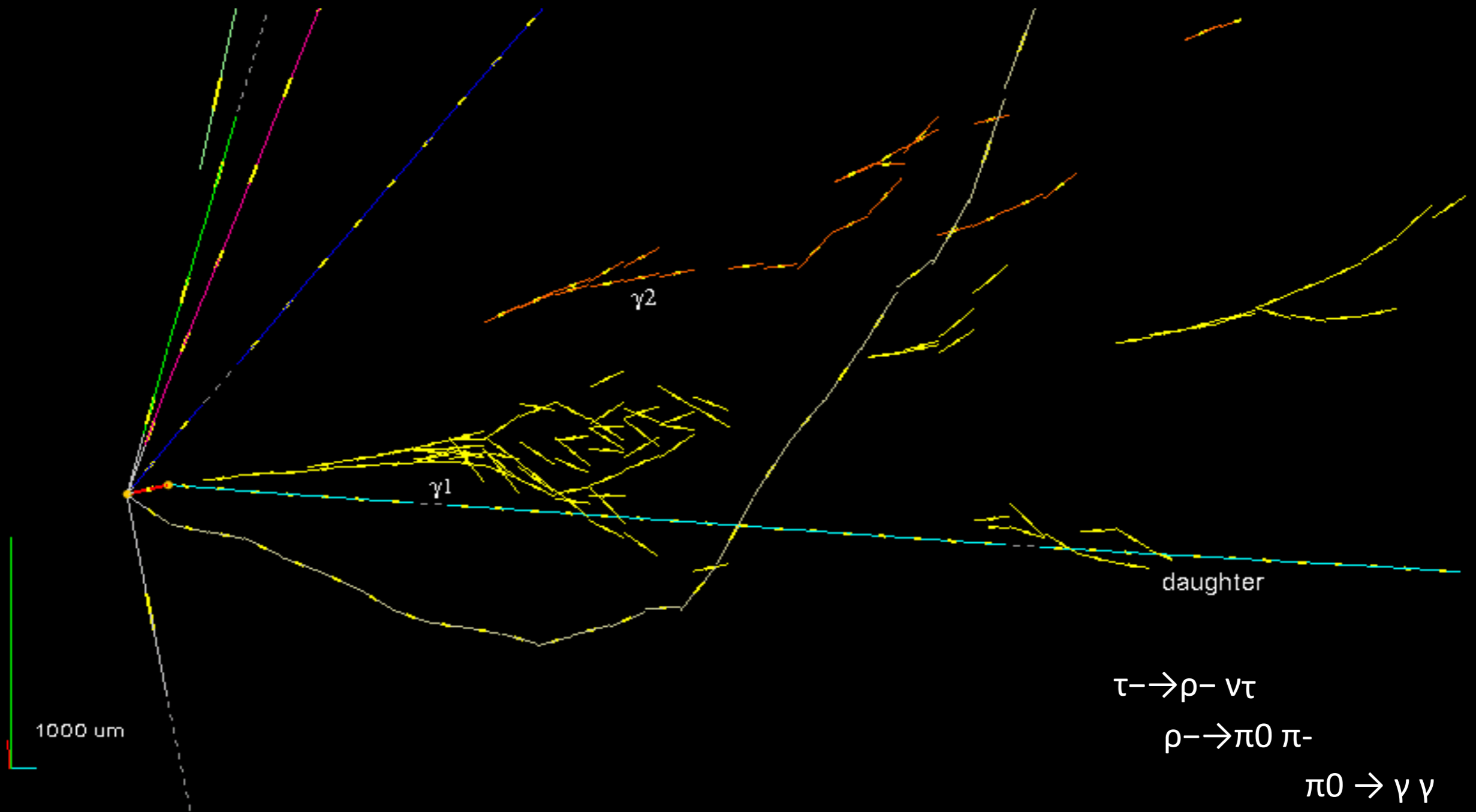
- huge time to take data
- unsystematic analysis



We broke through these problems with

Automated Emulsion Readout System

Confirmation of $\nu_\mu \rightarrow \nu_\tau$ in appearance mode



We detect total 10 ν_τ events (BG:2, 6.1 σ)

Final Results of the OPERA Experiment on ν_τ Appearance in the CNGS Neutrino Beam
N. Agafonova et al. (OPERA Collaboration) Phys. Rev. Lett. 120, 211801

In the 2000s, the coming of a DIGITAL era.

Photographic Film Companies stopped supply & development of nuclear emulsion.



~~CRISIS !?~~ CHANCE !!

We started development of nuclear emulsion by ourselves at our laboratory.

In 2010, Introduction of Emulsion Gel Production System

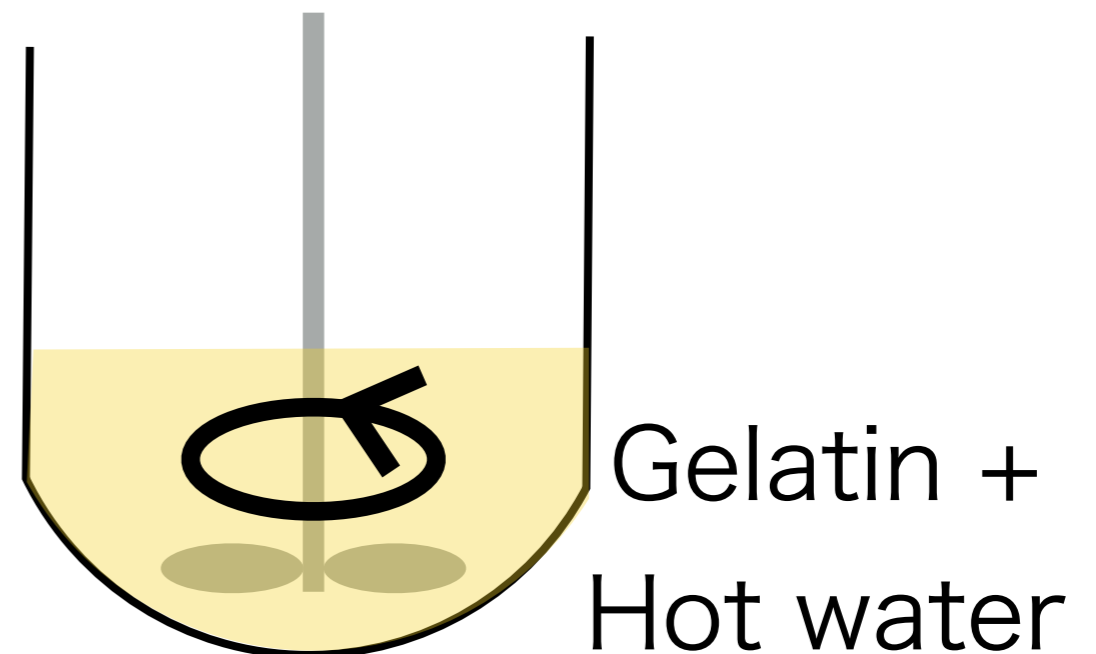
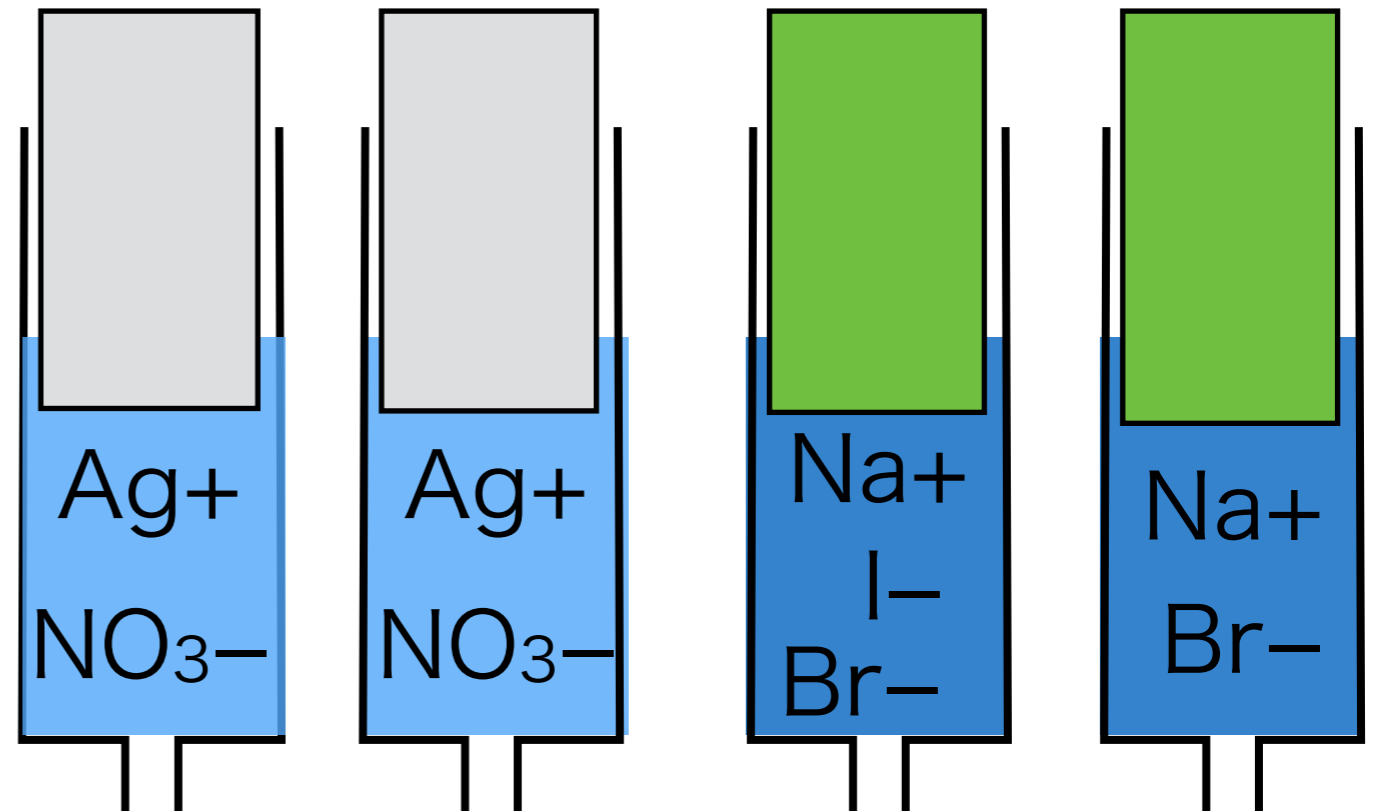
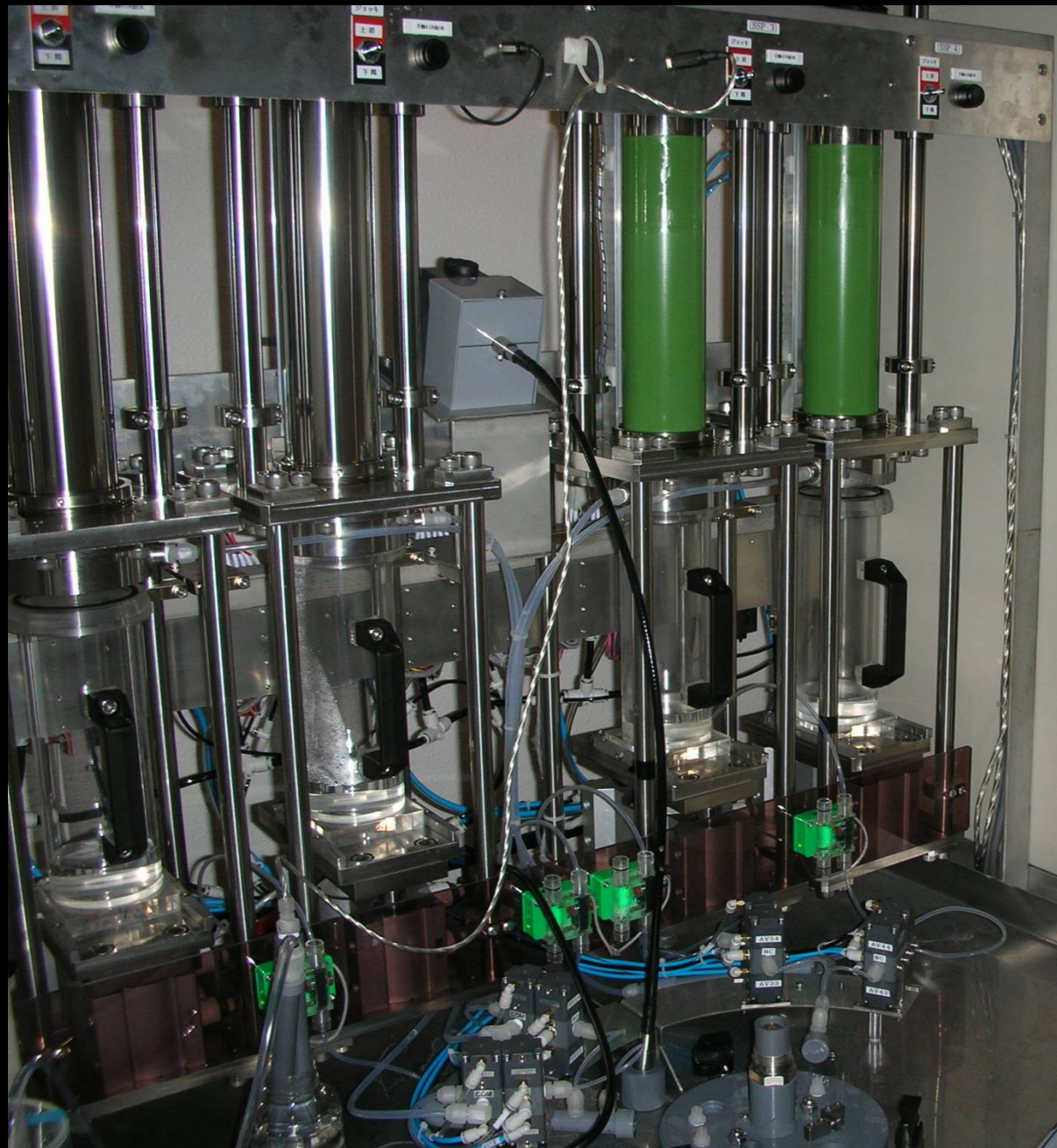
in cooperation with former members of Fuji Film



NAGOYA Univ. is the only one institute developing and producing nuclear emulsion in the world.

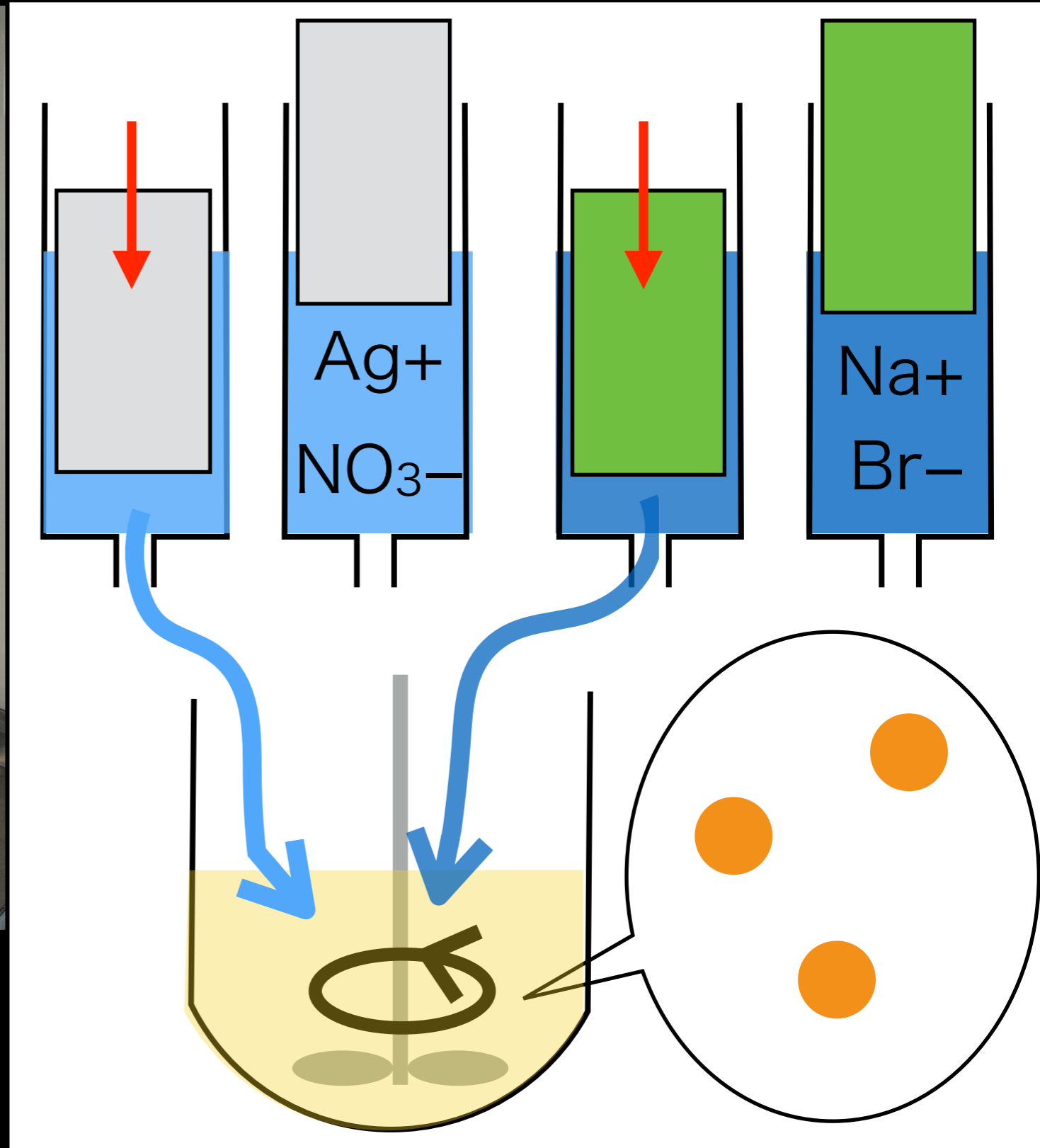
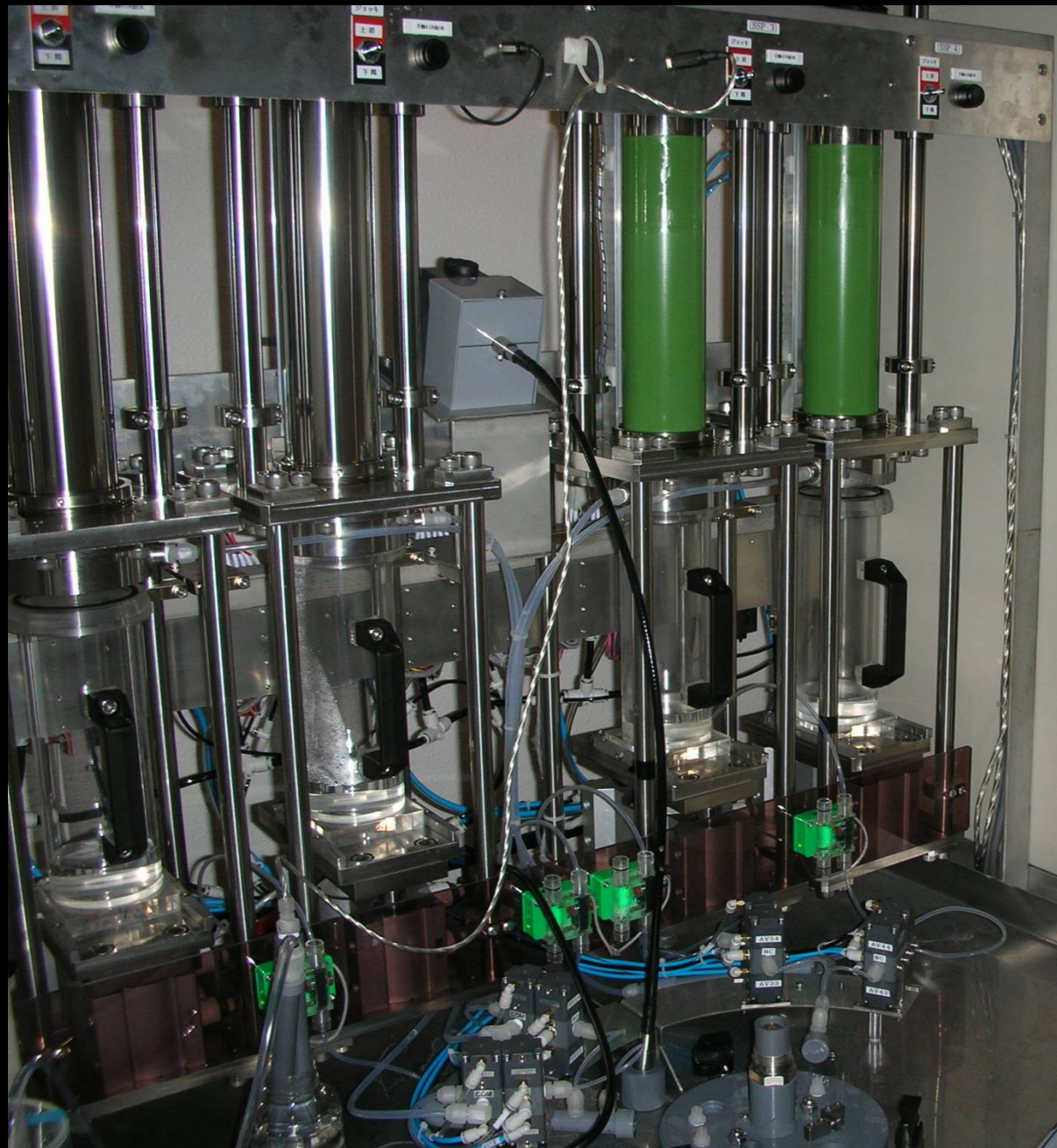
In 2010, Introduction of Emulsion Gel Production System

in cooperation with former members of Fuji Film



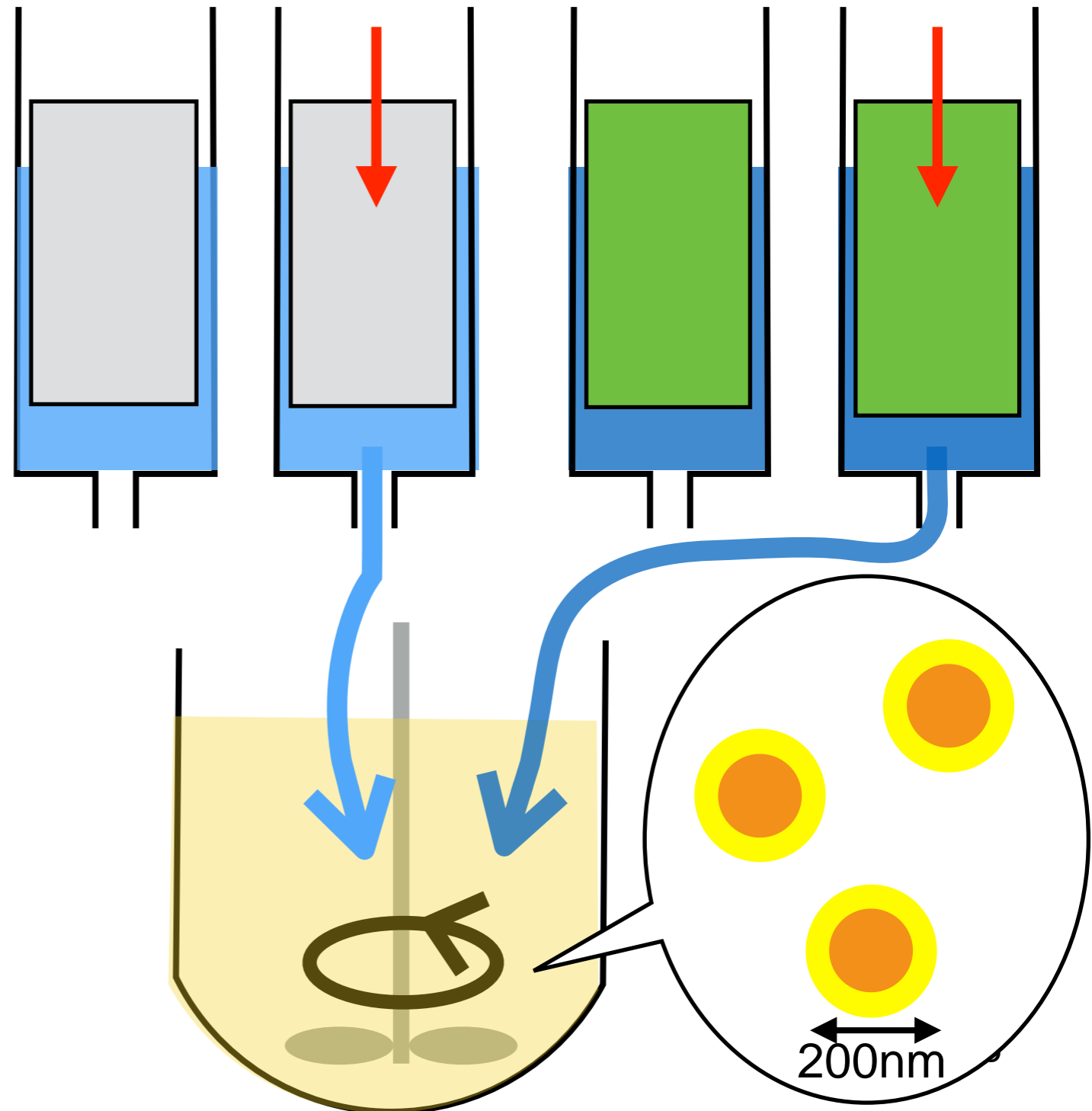
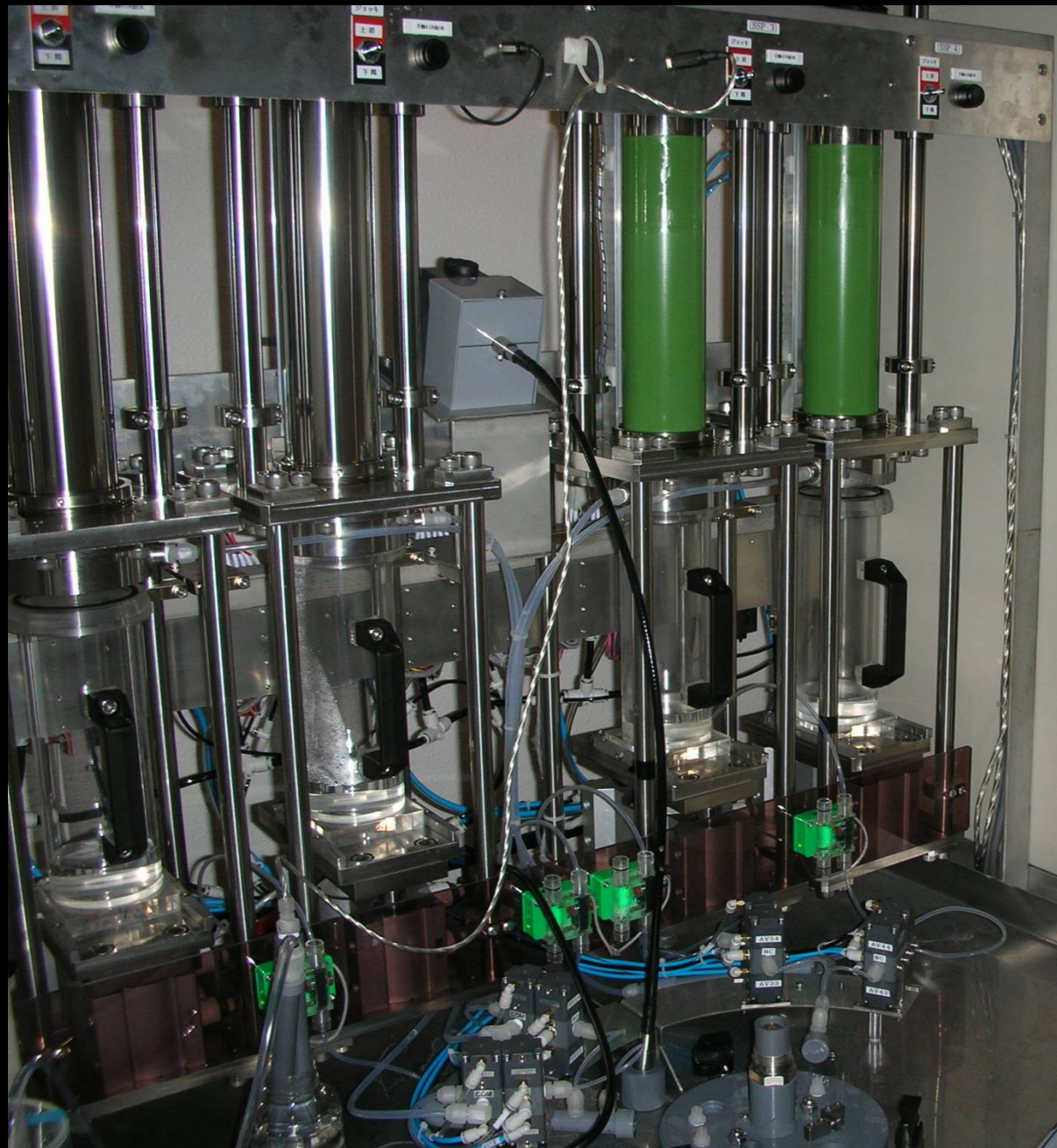
In 2010, Introduction of Emulsion Gel Production System

in cooperation with former members of Fuji Film

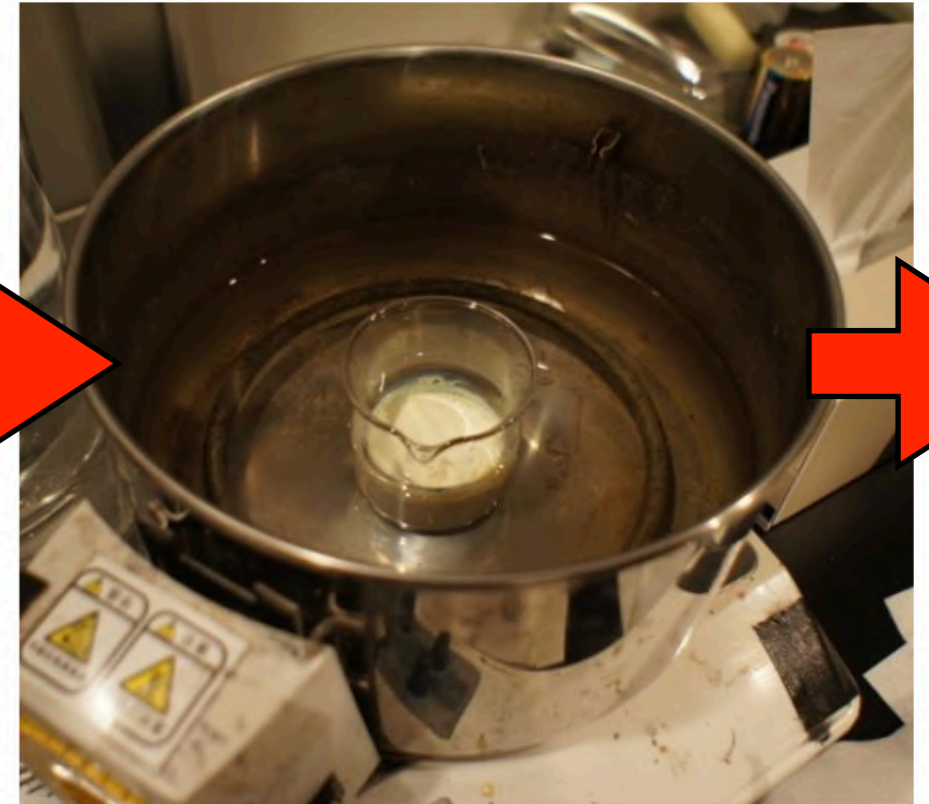
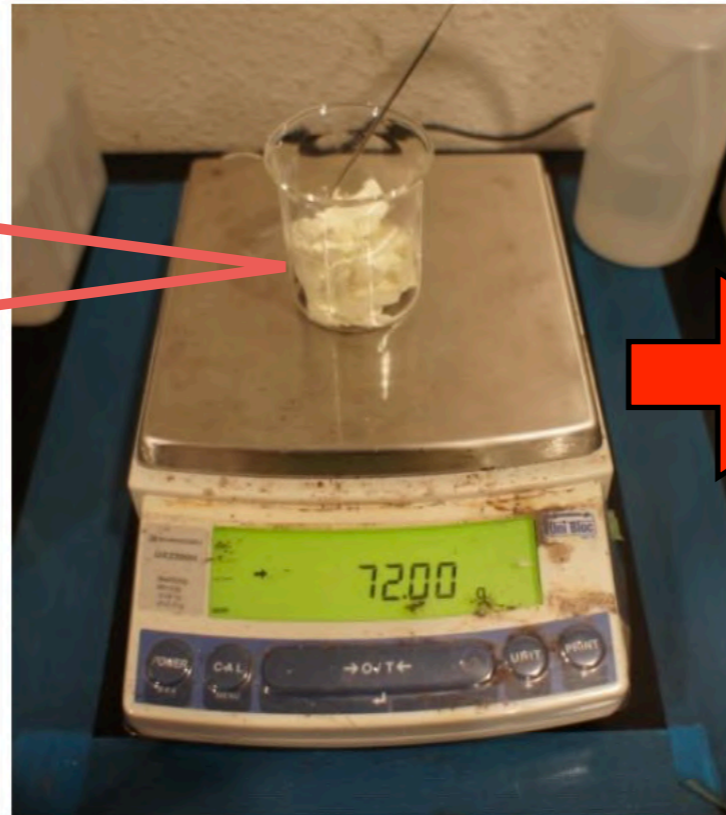


In 2010, Introduction of Emulsion Gel Production System

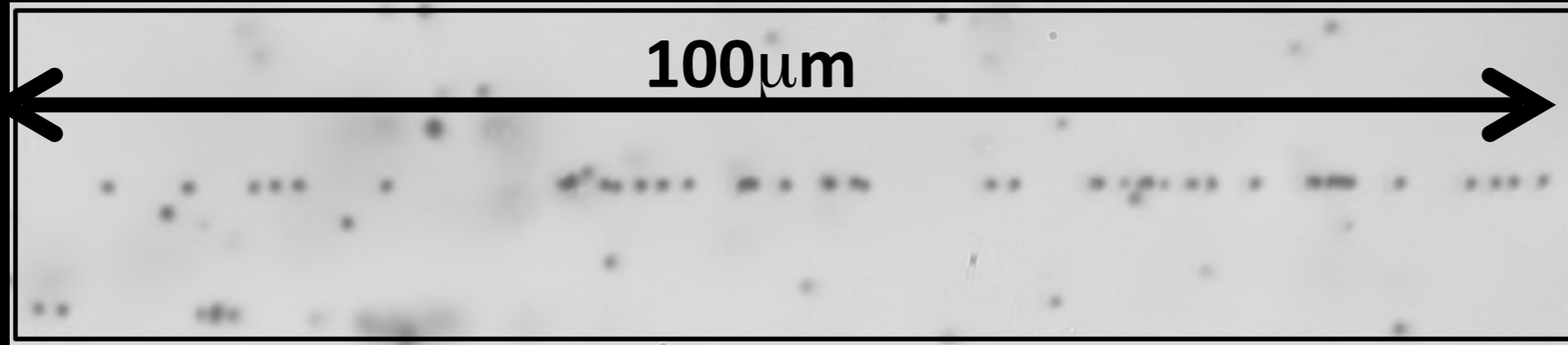
in cooperation with former members of Fuji Film



Film Production (coating & drying)

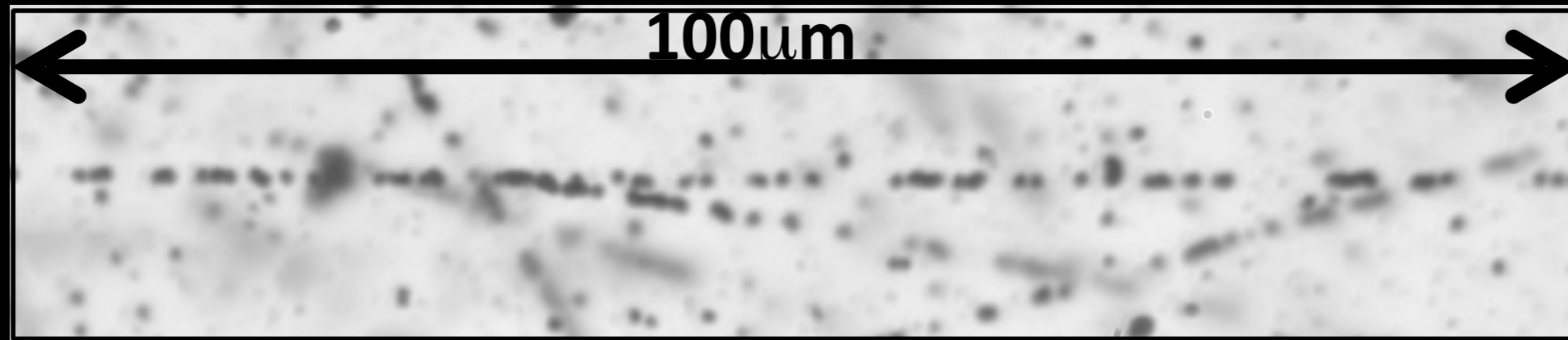
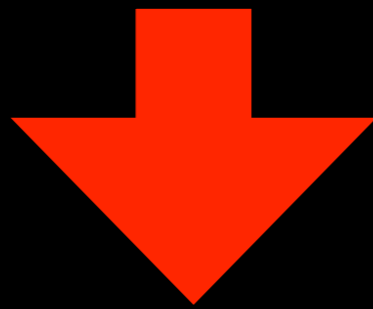


Emulsion with world record highest sensitivity



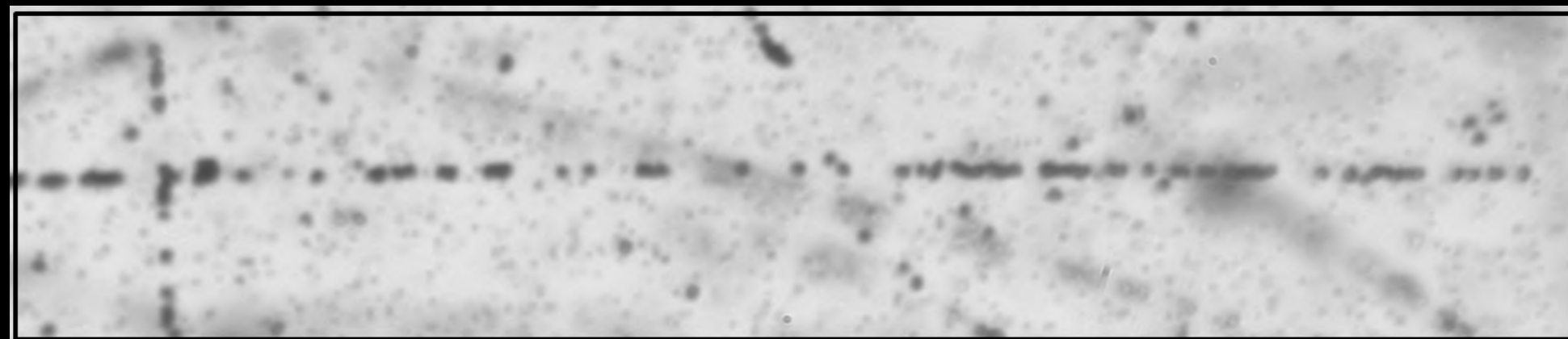
Film used in
OPERA

GD=34.8±0.6
FD= 3.7±0.4

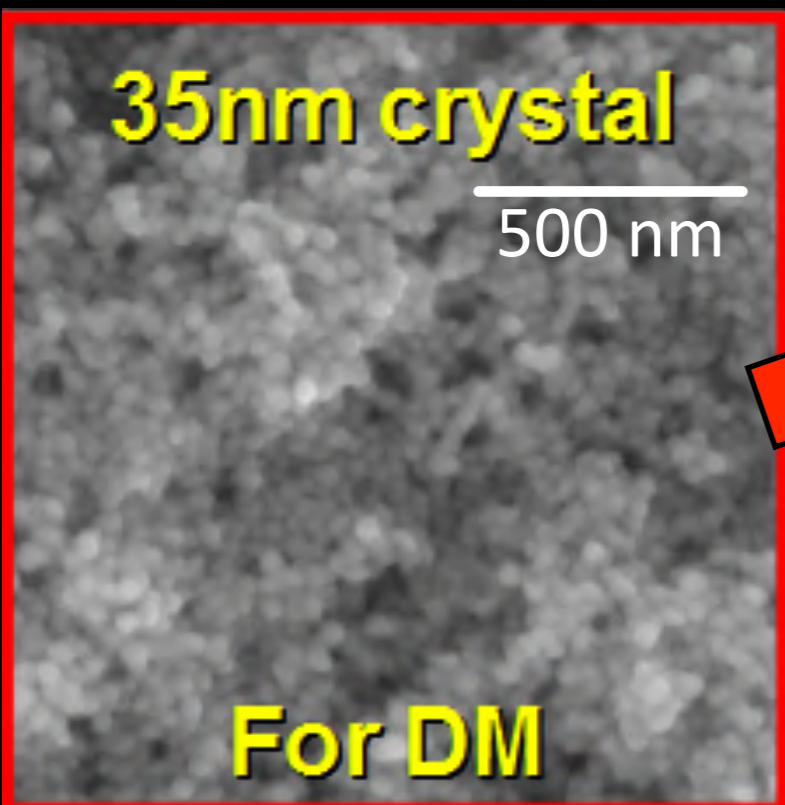
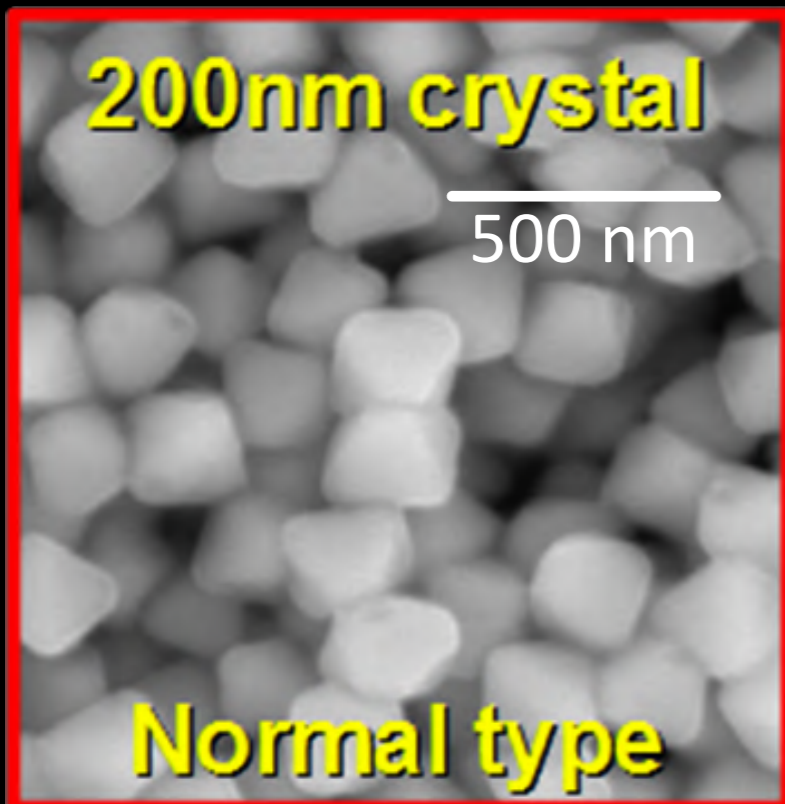


NAGOYA
high-sensitive
Emulsion

GD= 86.1± 4.7
FD= 2.9 ± 0.9



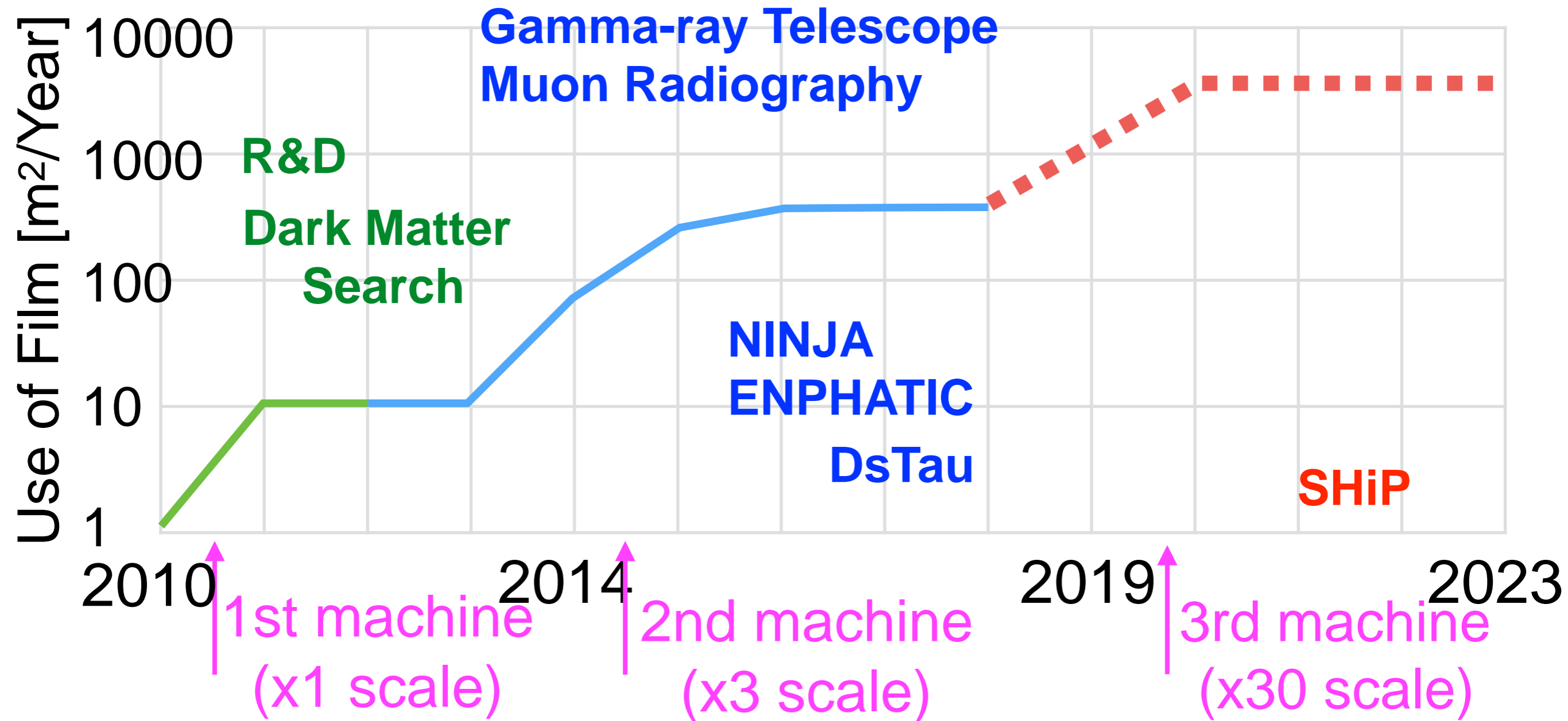
Emulsion with 35nm diameter crystal for Dark Matter directional detection



Electron microscope



Spread of the use of emulsions



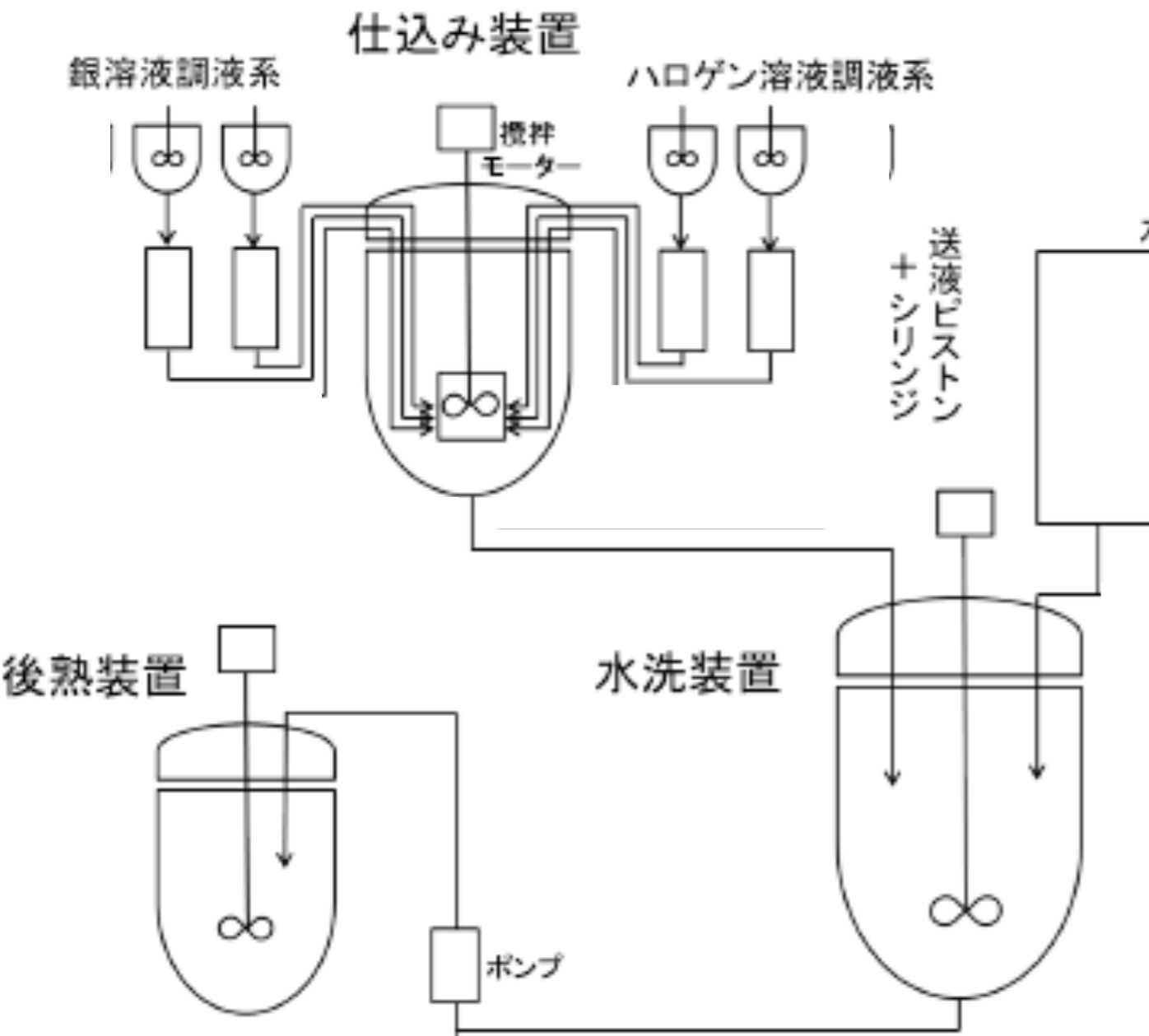
2010- Install & development started

2013- Supply to real experiments started. New projects launched.

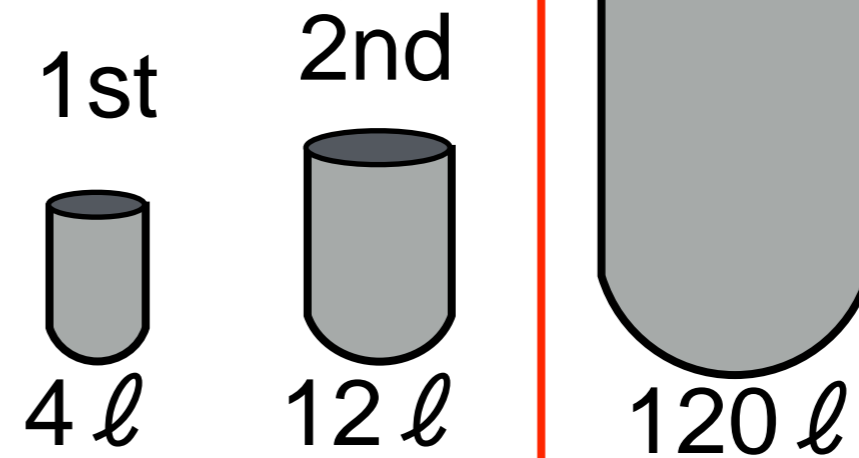
2020- All projects are planning to expand the scale of experiment ...

Next Break Through

→ Install of 10 times large-scale Gel Production Machine(3rd machine)



We automatize preparation, liquid transfer, washing, ...etc



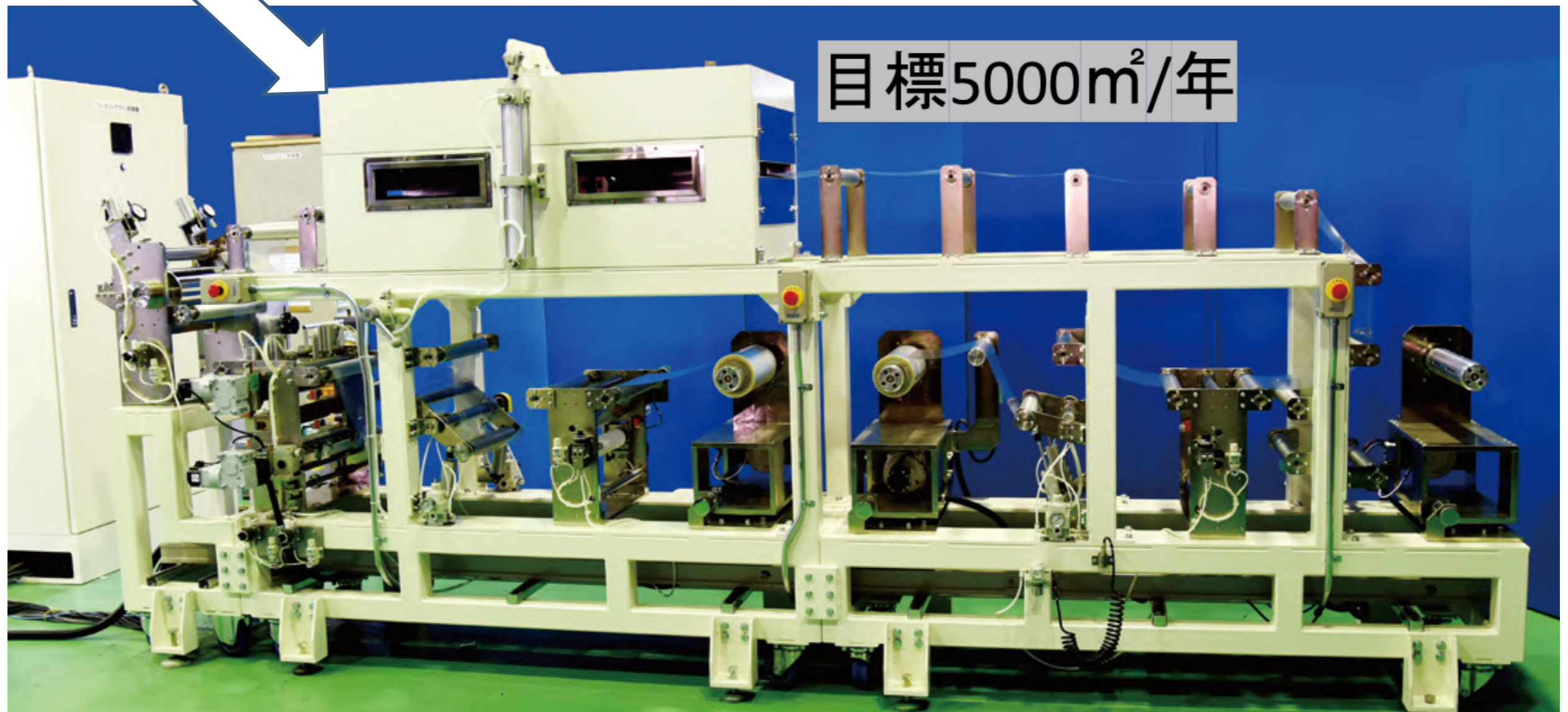
Next Machine enables the stable & long-term mass-production.



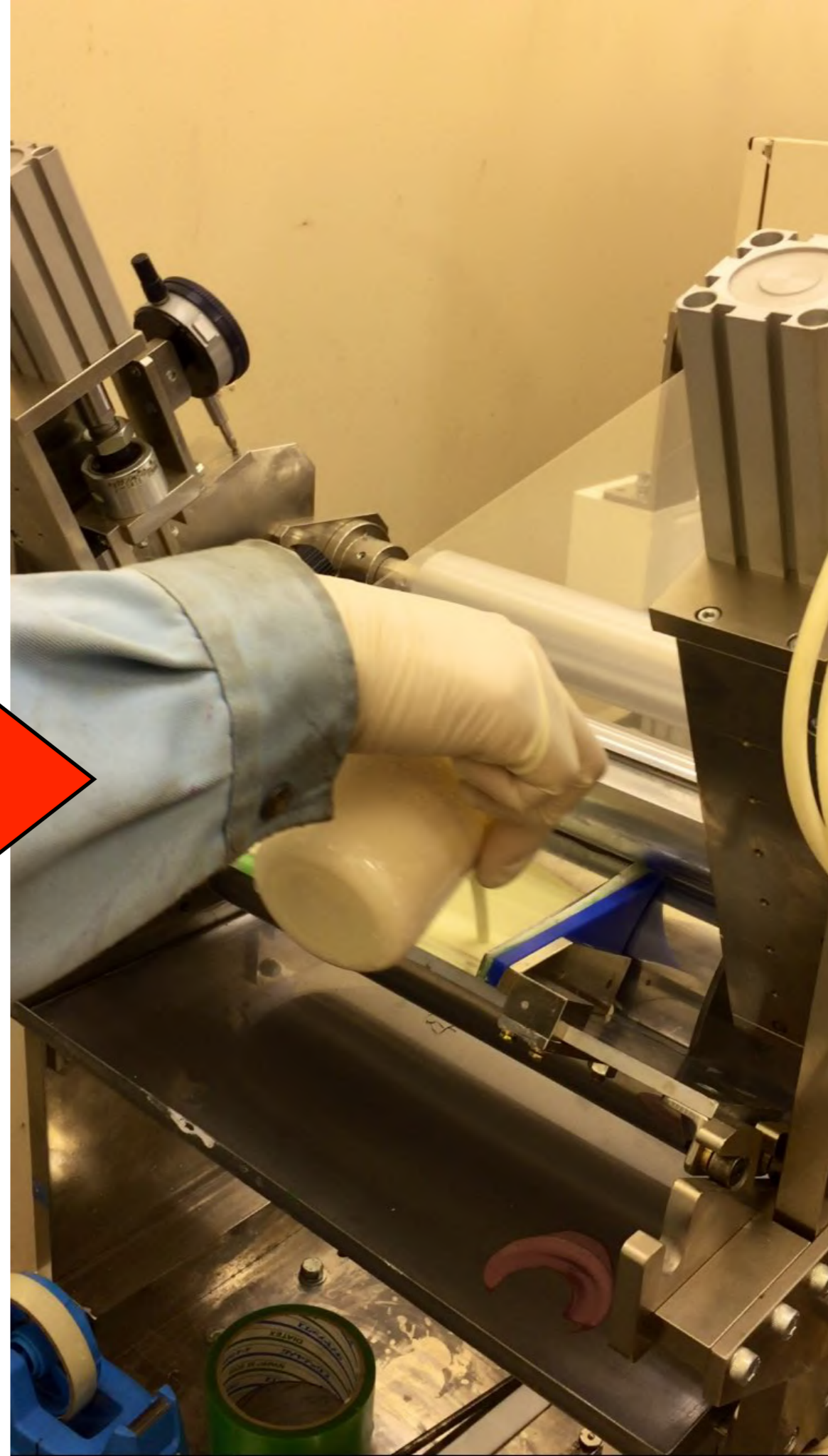
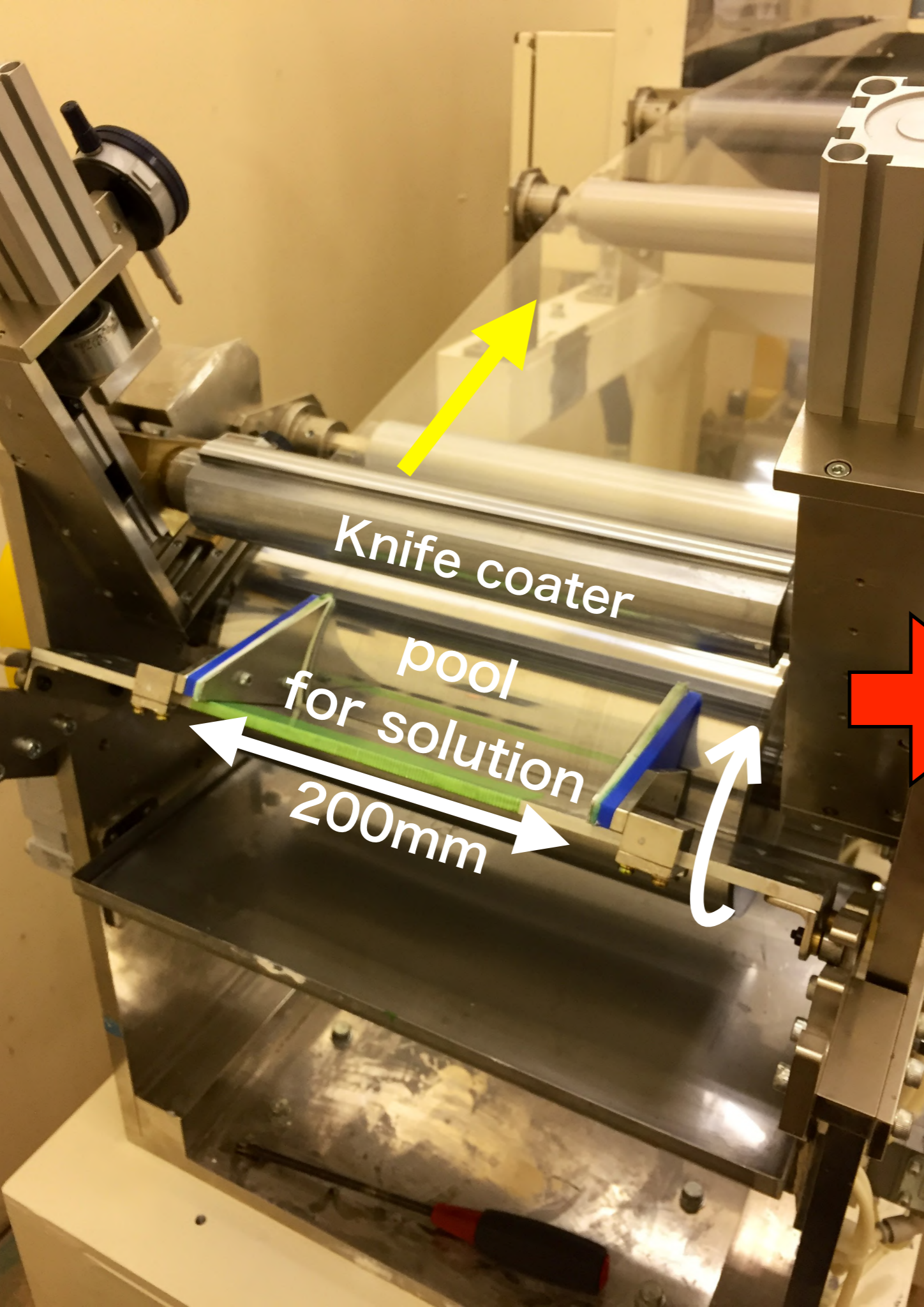
MAX600m²/年

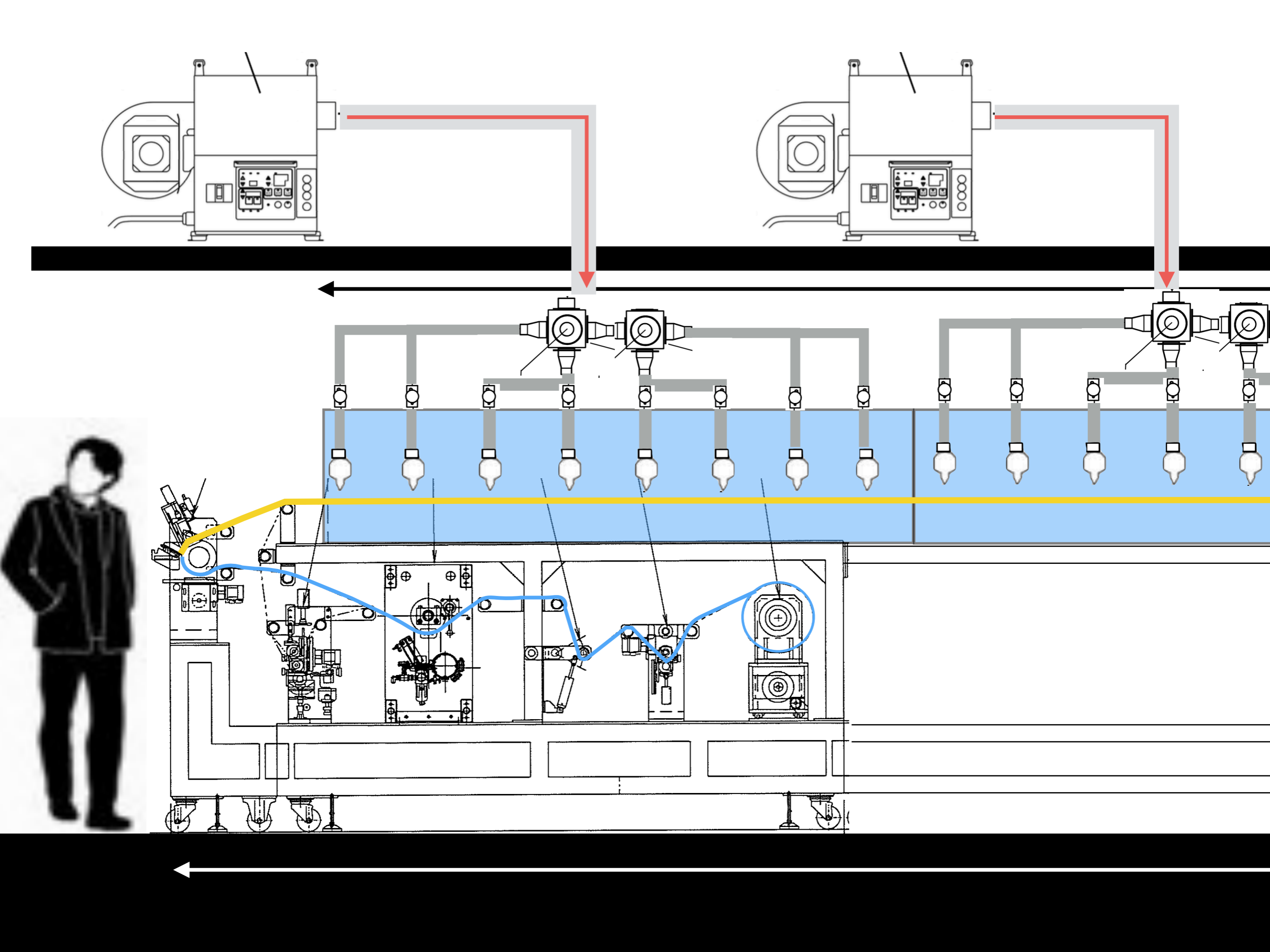
Upgrade of Film Production

“Roll to Roll Coater”



目標5000m²/年





Plan to Supply to Experiments

Installation

Start production

2018	2019	2020	2021	2022	2023	2024
Gel Production System Film Coating System	NINJA @JPARC			Beam		2025- →
	ENPHATIC @FNAL	Beam				
	DsTau @SPS/CERN		Beam			
✓ Design, Test ✓ Ordar ↓ Construction	SHiP @ SPS/CERN		Test Beam			2025- →
	FASERv @ LHC/CERN		Beam			
	GRAINE (Balloon)		Balloon			Balloon
Test Operation	Muon Radiography	Observation				

Summary

- **Since 2010, we have developed and produced emulsion itself by ourselves at own laboratory.**
 - Neutrino researches and other projects newly launched and are making progress.
 - All projects plan the upgrade of scale.
- **We plan to install 10 times large-scale gel and film production system.**
 - enable the stable mass-production for long term
- **In 2019, constructions are being started.**
 - New facility will start supply to each project in 2020.