Latest Development of Nuclear Emulsion technology

名古屋大学
理学研究科素粒子宇宙物理学D1
森下　美沙希

Short history of Nuclear Emulsion

1896 Becquerel Discovery of radioactivity by observing blackened Photo film

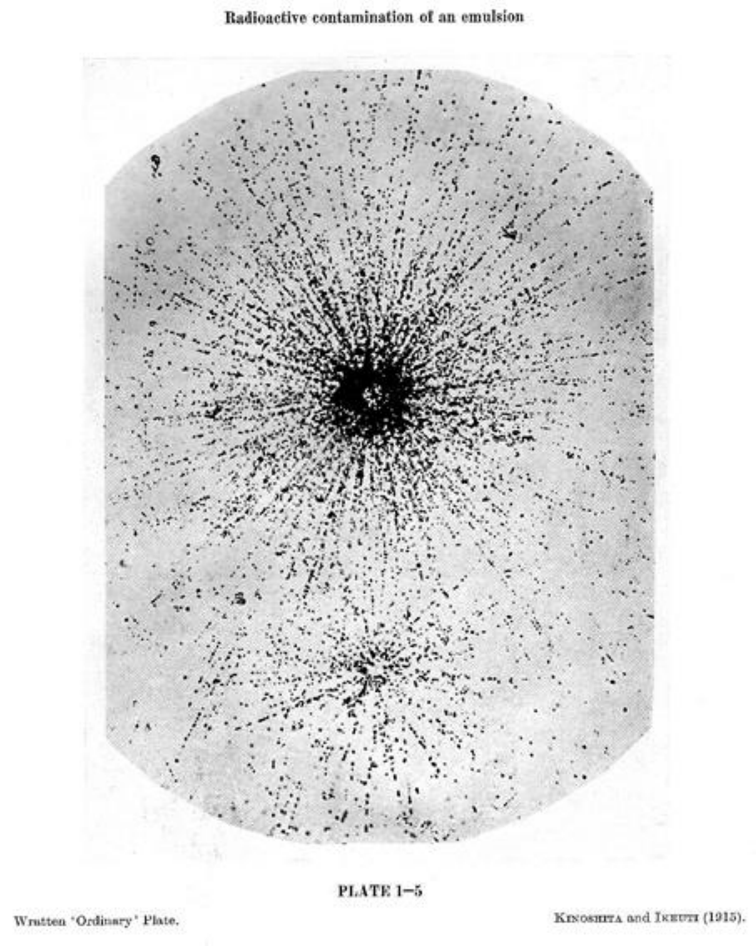
<u>1910 KINOSHITA Suekiti Detection of Alpha particle tracks by photographic film</u>

1911 Reinganum Sketch Alpha particle track detected by photographic film

1915 KINOSHITA S.& IKEUTI H.

“ The Track of the Alpha Particles in Sensitive Photographic Films.”

Philosophical Magazine and Jounal of Science Ser.6, Vol.29, No.171, pp.420-425 (1915)



1937 Marietta Blau et al.

Observation of Stars of Cosmic-ray Interactions by ILFORD plate

<u>1947 C.F. Powell et al.</u>

<u>Discovery of π meson</u>

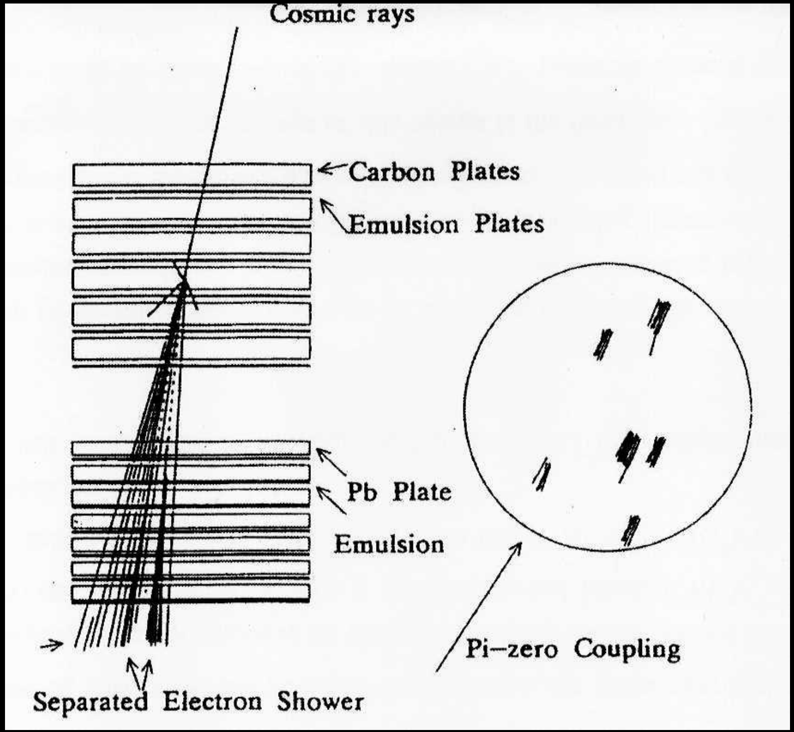
Development in Japan , the defeated country of 2nd world war

Cosmic-ray + Nuclear emulsion

Beam & Tracking device for the poor researcher

1950~ Study of multi-particle production in Cosmic-ray Int.

Balloon/Air Plane base experiments.



Emulsion Cloud Chamber (ECC)

with “cheap” double coated thin emulsion layer film

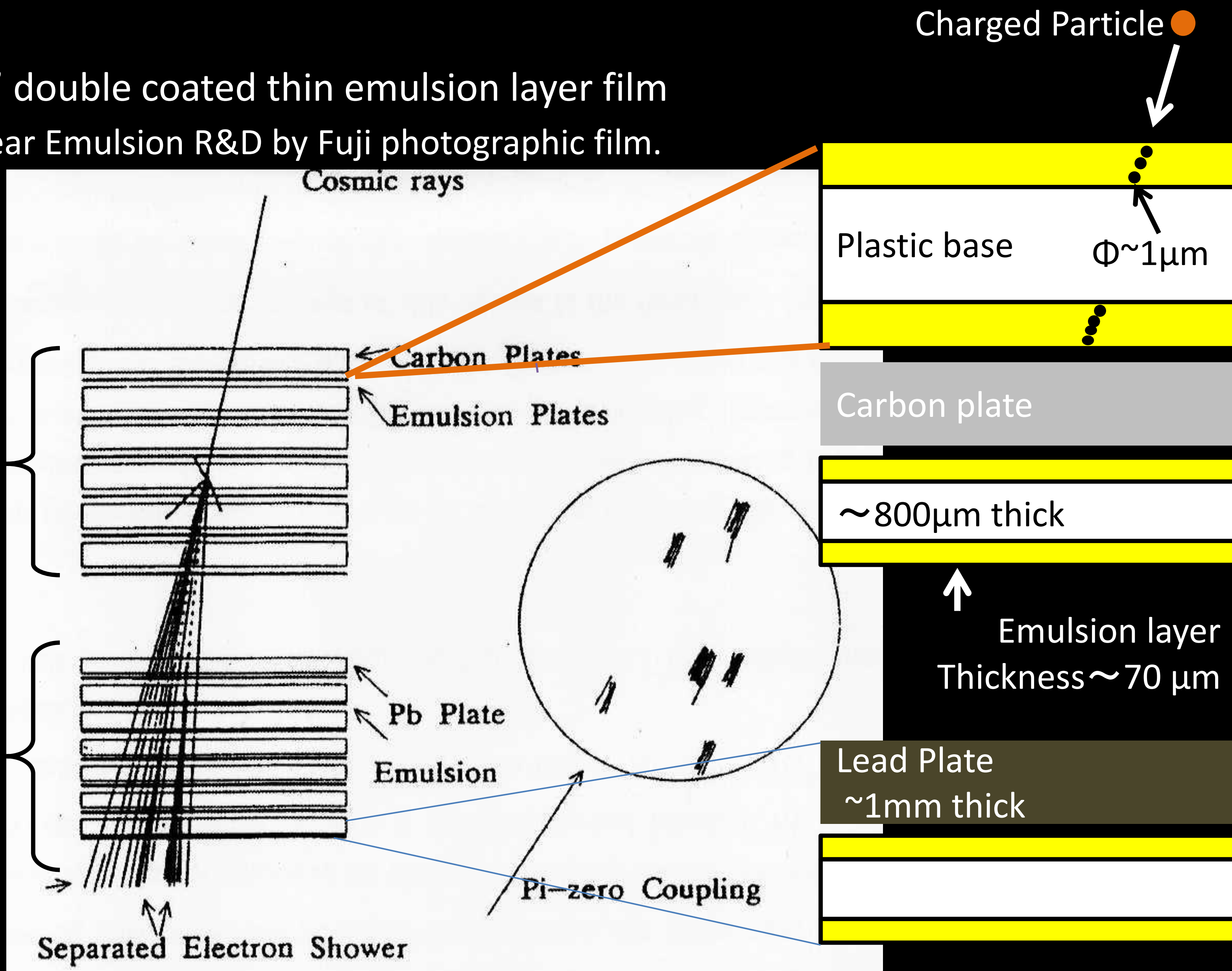
1950’s Nuclear Emulsion R&D by Fuji photographic film.

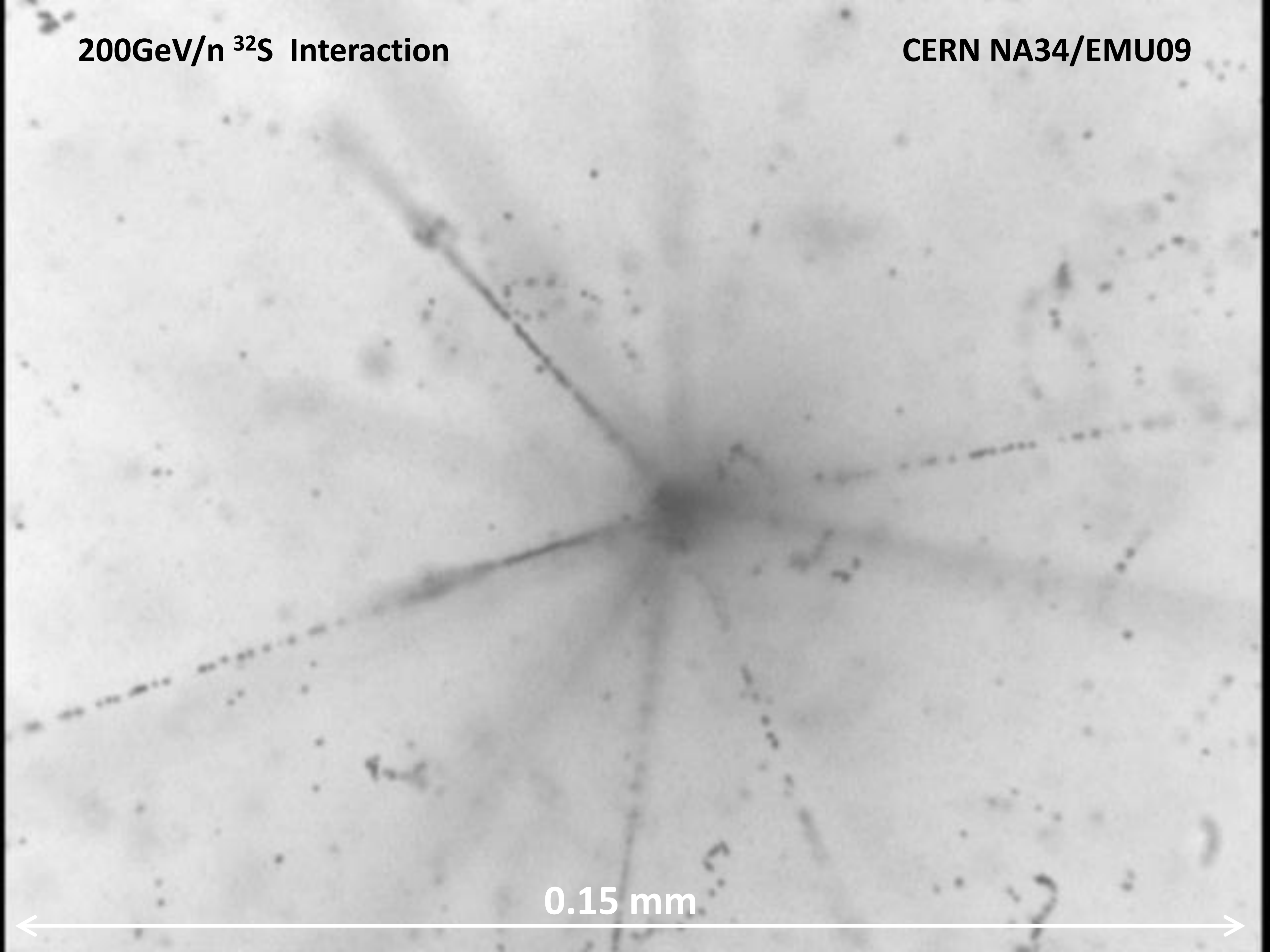
Interaction Vertex Detection

Separator

Shower Det. E-Cal & P Meas. by MCS

Multiple Coulomb Scattering



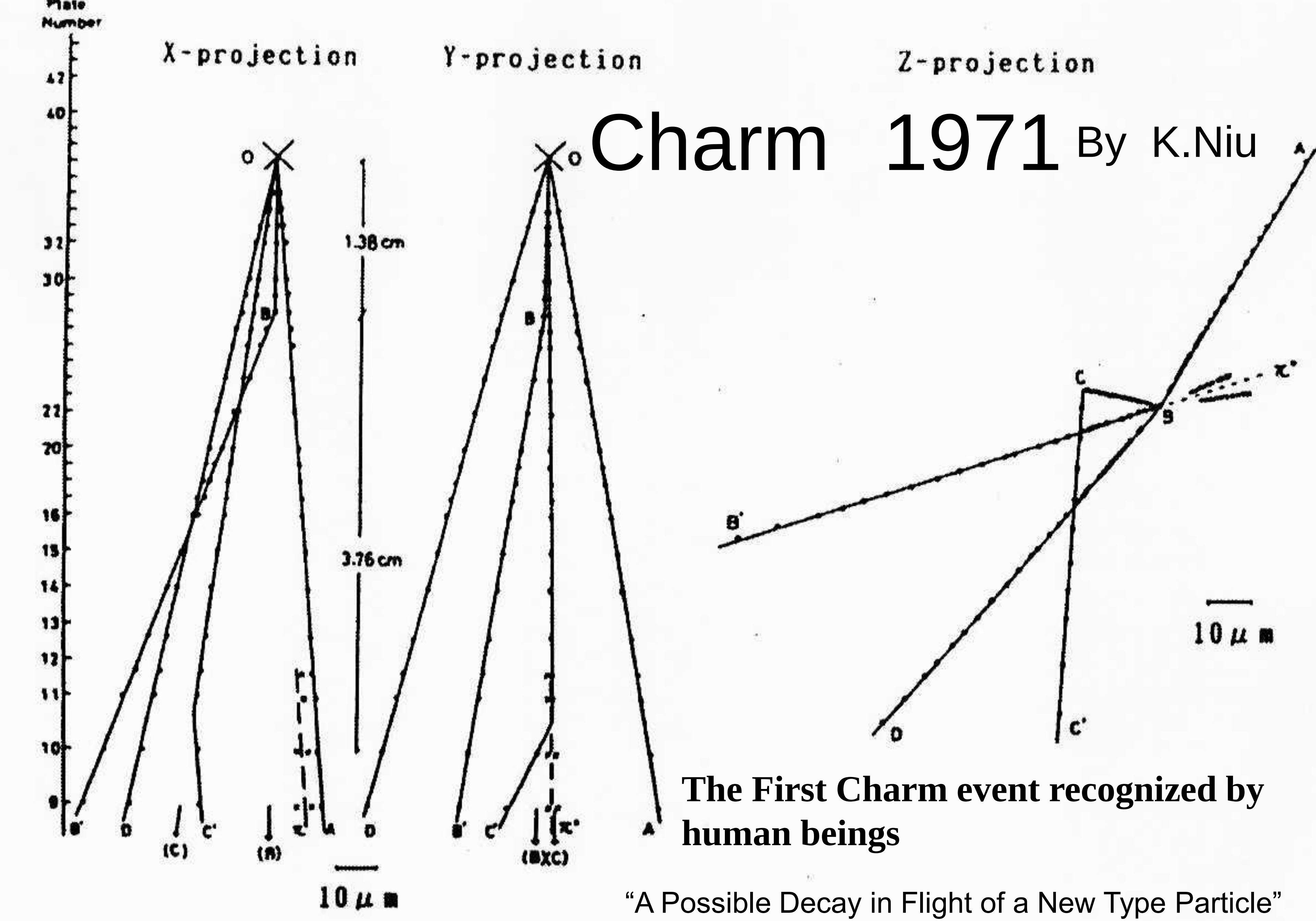

200GeV/n ^{32}S Interaction
CERN NA34/EMU09
0.15 mm

“素粒子” の発見

THE DISCOVERY OF ELEMENTARY PARTICLES

光子	γ	X-ray gerator	Compton scattering	Wilson Cloud Chamber	ウィルソン霧箱
電子	e^-	Discharge tube	Ratio of e/m	Fluorescent screen	蛍光板
陽電子	e^+	Cosmic rays	Ratio of e/m	Wilson Cloud Chamber	ウィルソン霧箱
μ 粒子	μ^+ μ^-	Cosmic rays	Absence of radiation loss in passage through Pb. (Also decay at rest)	Wilson Cloud Chamber	ウィルソン霧箱
π 中間子	π^+	Cosmic rays	π-μ decay at rest	Nuclear emulsion	原子核乾板
	π^-	Cosmic rays	Nuclear interaction at rest	Nuclear emulsion	原子核乾板
	π^0	Accelerator	Decay into γ-rays	Counters	カウンター
K 中間子（ストレンジ粒子）	K^+	Cosmic rays	$K_{\pi 3}$ decay	Nuclear emulsion	原子核乾板
	K^-	Cosmic rays	Nuclear interaction at rest	Nuclear emulsion	原子核乾板
	K^0	Cosmic rays	Decay into $\pi^+ + \pi^-$ in flight	Wilson Cloud Chamber	ウィルソン霧箱
中性子	n	Polonium plus Beryllium	Mass determination from elastic collisions	Ionisation chamber	電離箱
反陽子	$\bar{p}$	Accelerator	e/m measurement plus detection of annihilation	Counters	カウンター（TOF）
反中性子	$\bar{n}$	Accelerator	Detection of annihilation	Counters	カウンター
ハイペロン（ストレンジ粒子）	Λ^0	Cosmic rays	Decay in flight into $p^+ + \pi^-$	Wilson Cloud Chamber	ウィルソン霧箱
	$\bar{\Lambda}^0$	Accelerator	Decay in flight into $\bar{p} + \pi^+$	Nuclear emulsion	原子核乾板
	Σ^+	Cosmic rays	Decay at rest	Nuclear emulsion	原子核乾板
	Σ^-	Accelerator	Decay in flight into $\pi^- + n^0$	Diffusion chamber	拡散霧箱
	Σ^0	Accelerator	Decay in flight into $\Lambda^0 + \gamma$	Bubble chamber	泡箱
	Ξ^-	Cosmic rays	Decay in flight into $\pi^- + \Lambda^0$	Wilson Cloud Chamber	ウィルソン霧箱
	Ξ^0	Accelerators	Decay in flight into $\pi^0 + \Lambda^0$	Bubble chamber	泡箱
	Ω^-	Accelerators	Decay in flight into $\Xi^0 + \pi^-$	Bubble chamber	泡箱

Charm 1971 By K.Niu



The First Charm event recognized by human beings

“A Possible Decay in Flight of a New Type Particle”
K. Niu et al. Prog.Theor.Phys., Vol.46, No.5 (1971)

Discoveries

1971 NIU Kiyoshi , Discovery of X (=Charm) Particle

↔ 1974 J/ψ

1994 KEK/E176 Observation of Double Hyper Nucleus

2000 NIWA Kimio et al. Discovery of ντ

Fermilab E872 Donut (First event in 1998)

2015 CERN/LNGS CNGS1 OPERA (First event in 2010),

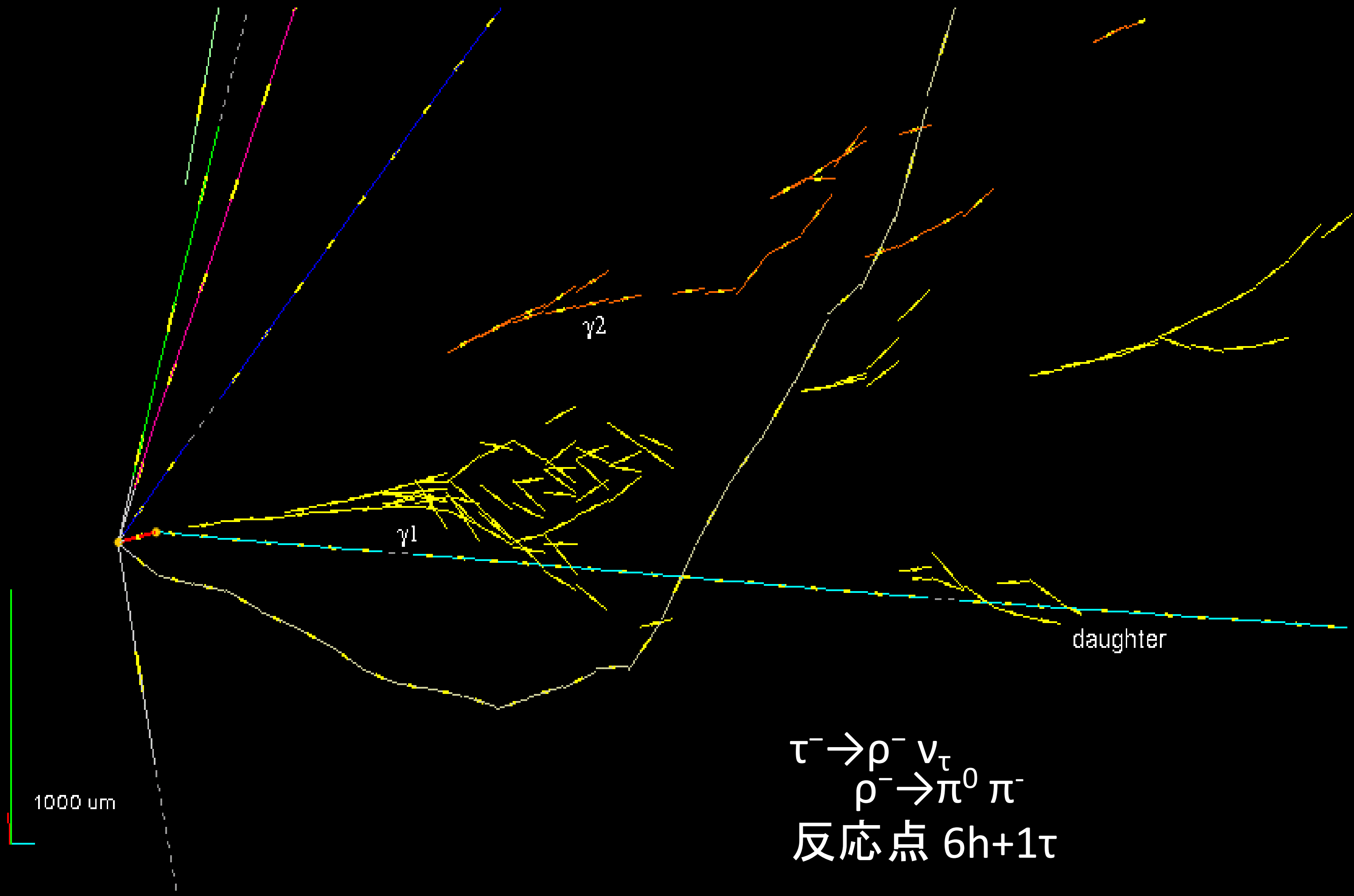
Discovery of ντ appearance by Neutrino Oscillation

2016 MORISHIMA K. et al. ScanPyramids,

Discovery of new structure in Khufu Pyramid

1^{st} $\nu_\mu \rightarrow \nu_\tau$ event in OPERA

2010



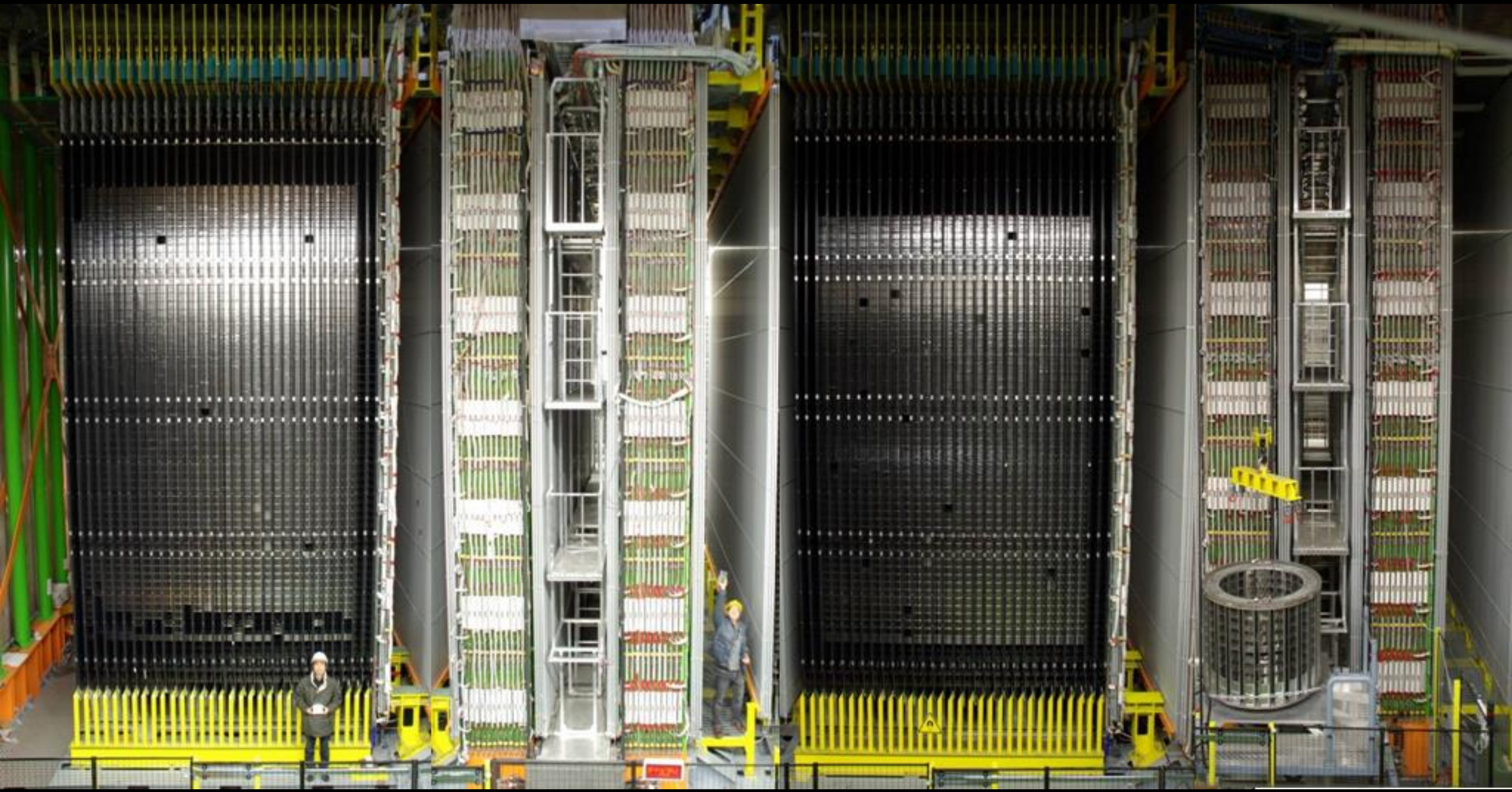
$\tau^- \rightarrow \rho^- \nu_\tau$

$\rho^- \rightarrow \pi^0 \pi^-$

反応点 6h+1τ

OPERA Detector

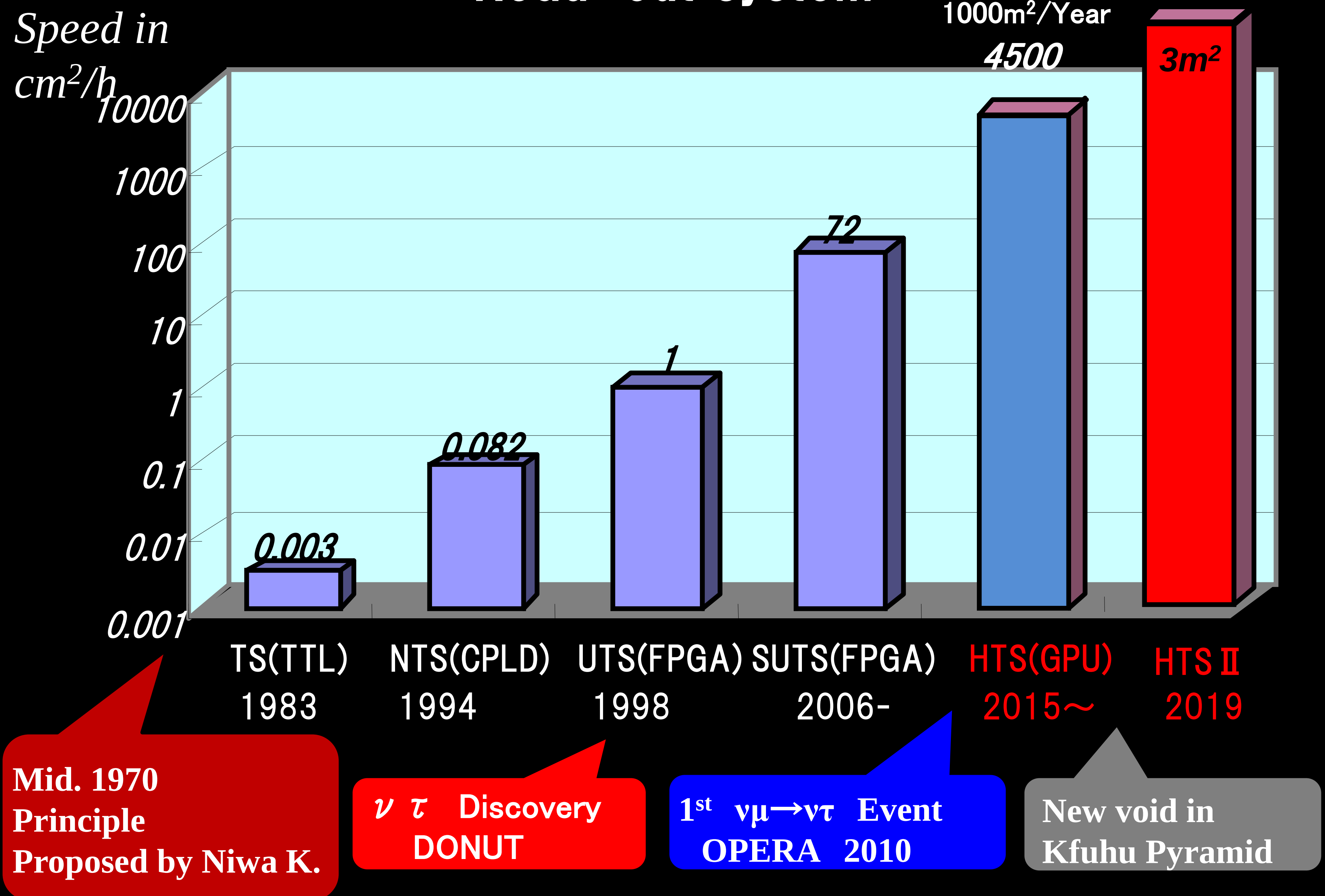
Italy Gran Sasso underground lab(2004～2016)



Nuclear Emulsion Film: 100000㎡

Fidutial Mass: 1250 Ton

Development of the Automated Nuclear Emulsion Read-out system



HTS: Current Main system

Nuclear Emulsion itself

- Photographic film lost markets by the Image digitizing storm . → No room in the company to develop and produce Nuclear Emulsion.

Good chance to retrieve Emulsion technology from Company to University.

- 2010: Installation of emulsion gel production system in our lab with helps of retired engineers

Emulsion R&D
without commercial restrictions
for best emulsion for specified experimental purpose

Nuclear Emulsion Gel Production Machine

Installed in Nagoya Univ.

R&D Machine

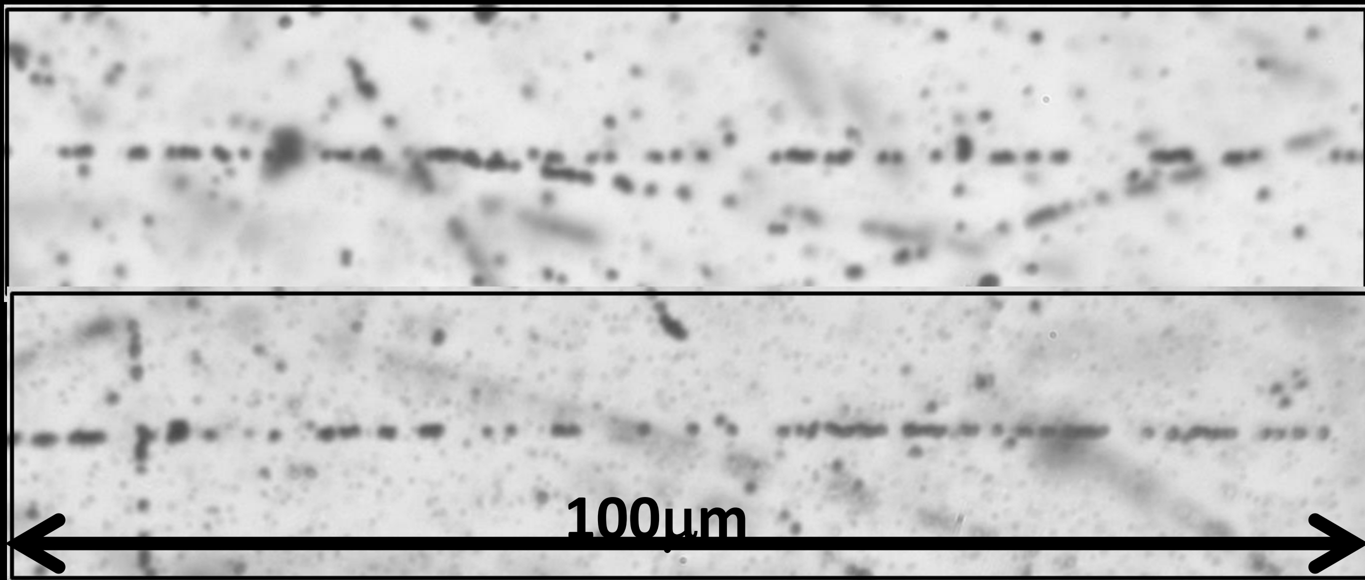
~1kg/lot

From 2010

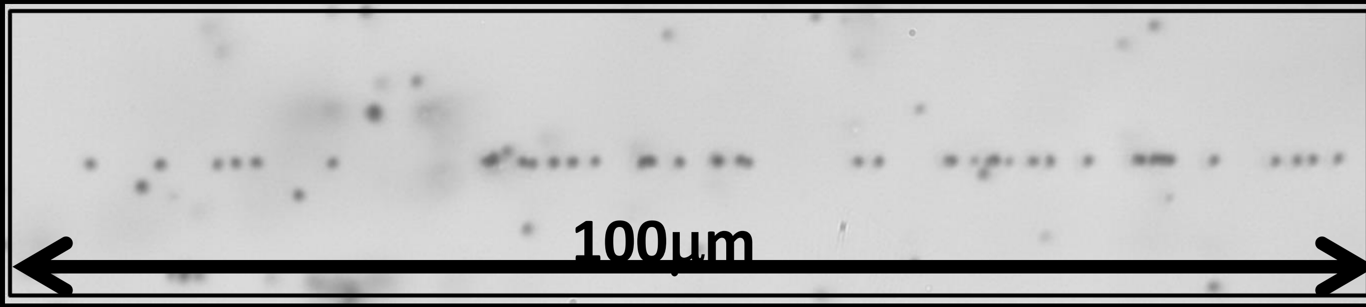
Composed by a Maker

Related to Fujifilm

First output: Emulsion with world record highest sensitivity



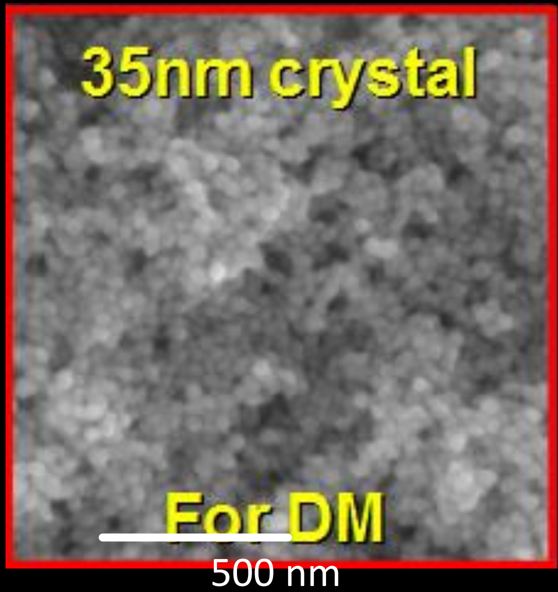
GD= 86.1± 4.7
FD= 2.9 ± 0.9

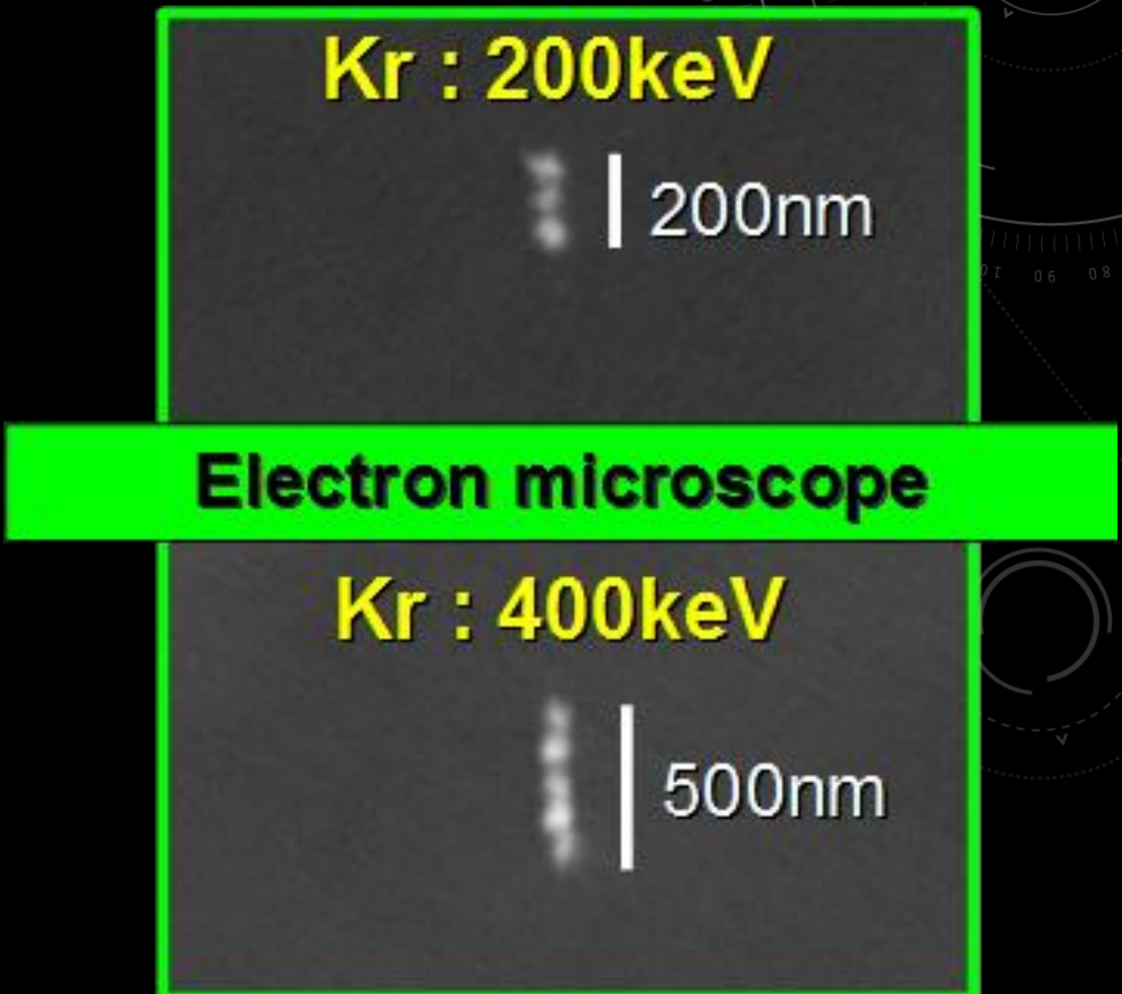


GD=34.8±0.6
FD= 3.7±0.4

Film used in OPERA

First output: Emulsion with 35nm diameter crystal for Dark Matter directional detection





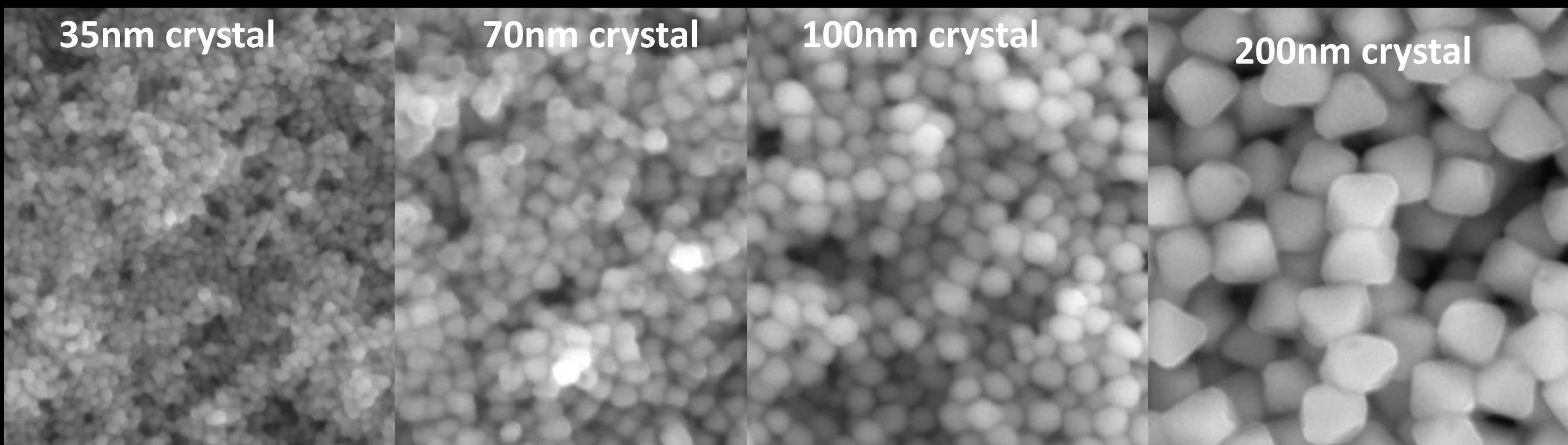
Crystal Size Control

Nano Imaging Tracker (NIT) Type

Directional Dark Matter detection
Neutrino Coherent Scattering

OPERA Type

Neutrino exp, Radiography
γ Telescope (GRAINE)



Down to 20nm

Up to 800nm

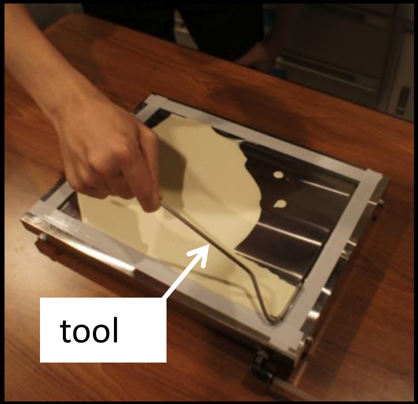
- Grain size 20nm ~ 800nm
- Sensitivity control by impurity doping & chemical treatment

Emulsion coating “technique”

Traditional method

1. Pour the gel

2. Spread the gel



3. Drying

Tuning the gel properties
- viscosity
- surface tension

Tuning and controlling the drying condition
- humidity
- temperature
- wind

New method (under development) -> Easy and fast

1. Pour the gel

2. Spread the gel

3. Drying

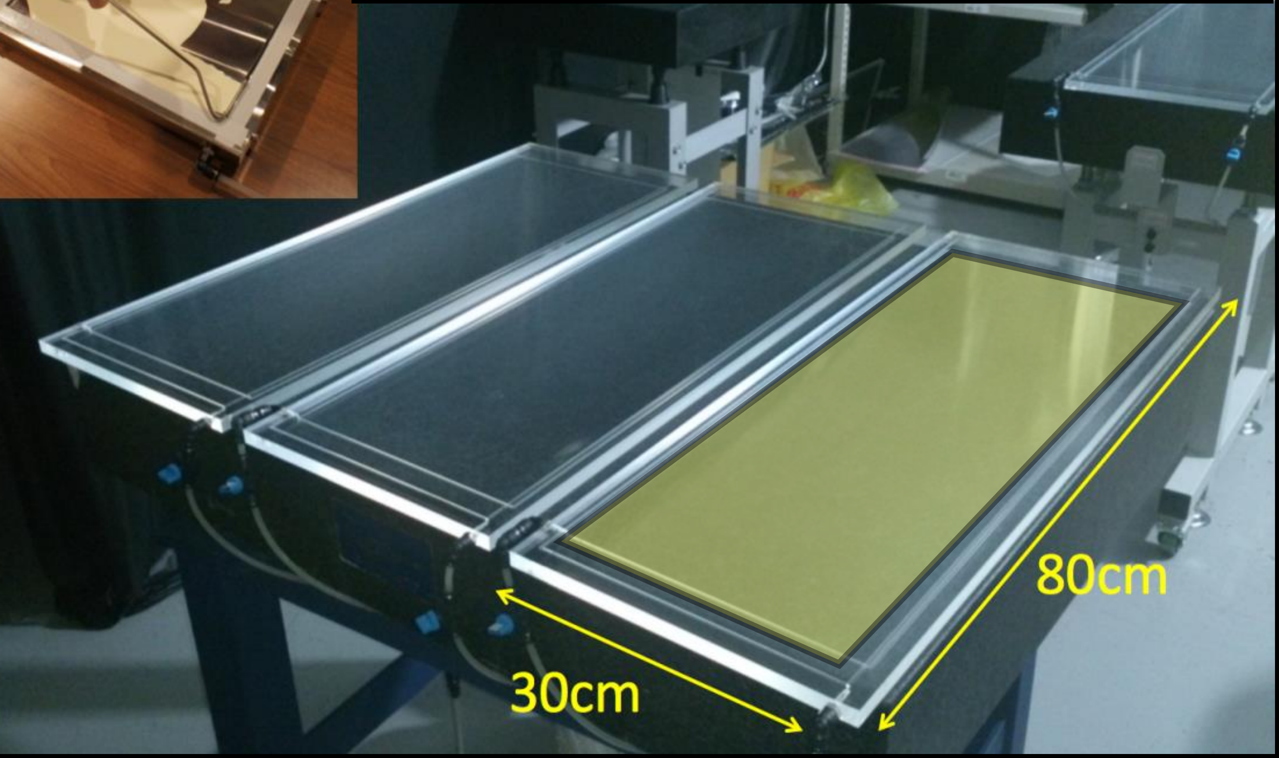
	OPERA film	Traditional	New
Flatness (/100cm^2) (1s)	<1µm	5µm	<2µm

Film Mass Production @ Nagoya

～7 m^2/Week → ～300 m^2/Year at Present
～1000m^2/Year within a year
～10000m^2/Year within 5 years

Pouring

Temp. 20℃ R.H. 80-90%



Drying

Temp. 30℃
R.H. 70-80%

Current Projects

- GRAINE : Balloon-borne Large aperture & High precision γ-ray telescope → Next Speaker
- NINJA: Precise study of low energy Neutrino interactions @JPARC
- SHiP : Search for Hidden Particles/ Study of Tau Neutrino interactions. Beam dump exp.@CERN
- DsTau: Study on Tau neutrino production in 400GeV proton int. Compact exp.@CERN
- NEWSdm: Directional Dark Matter search @LNGS
- Muons: Cosmic-ray Muon radiography

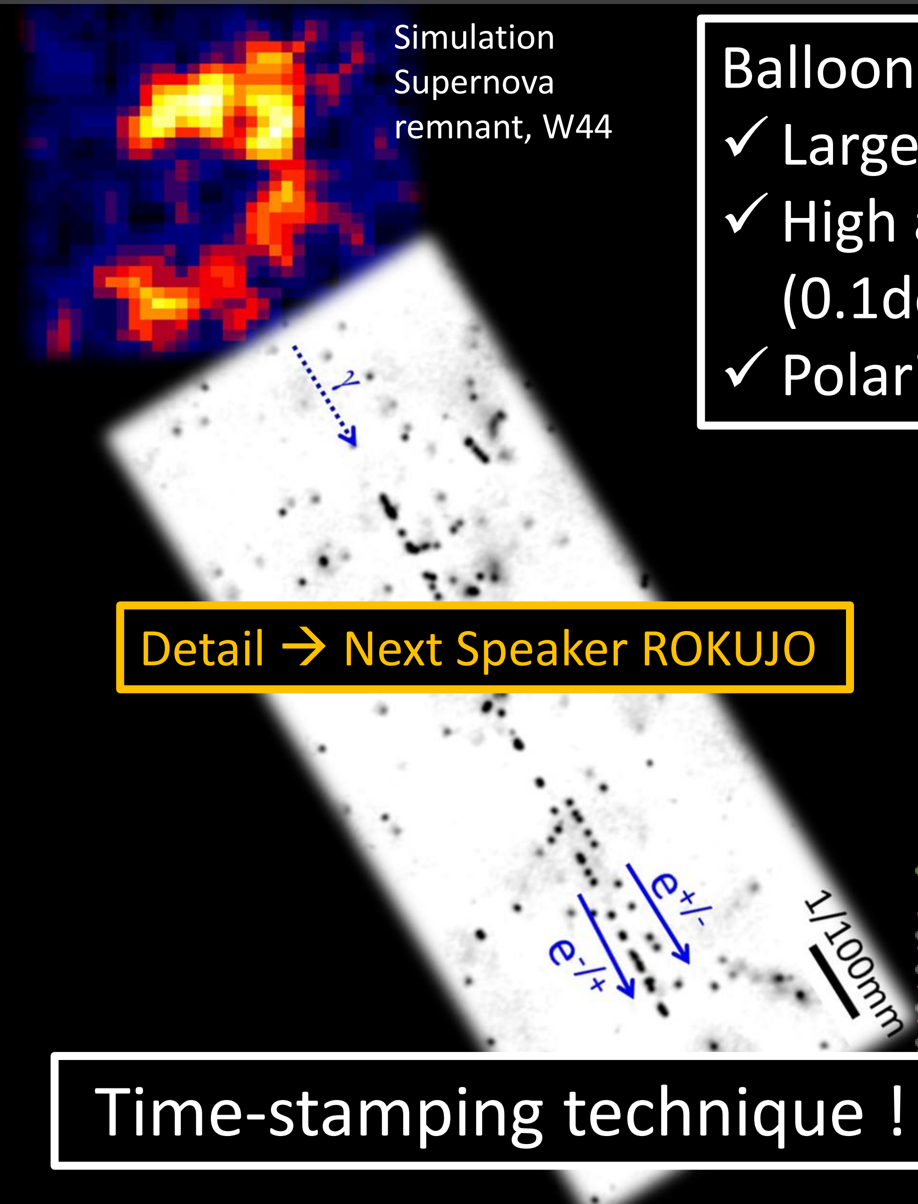
GRAINE project

Gamma-**Ra**y **A**stro-**I**mager with **N**uclear **E**mulsion

Precise observation of high-energy gamma-rays
Exploring extreme universe by balloon-borne emulsion telescope

PI: S. Aoki (Kobe Univ). Aichi Univ of Education, ISAS/JAXA, Kobe Univ, Nagoya Univ, Okayama Univ of Science

Simulation
Supernova
remnant, W44

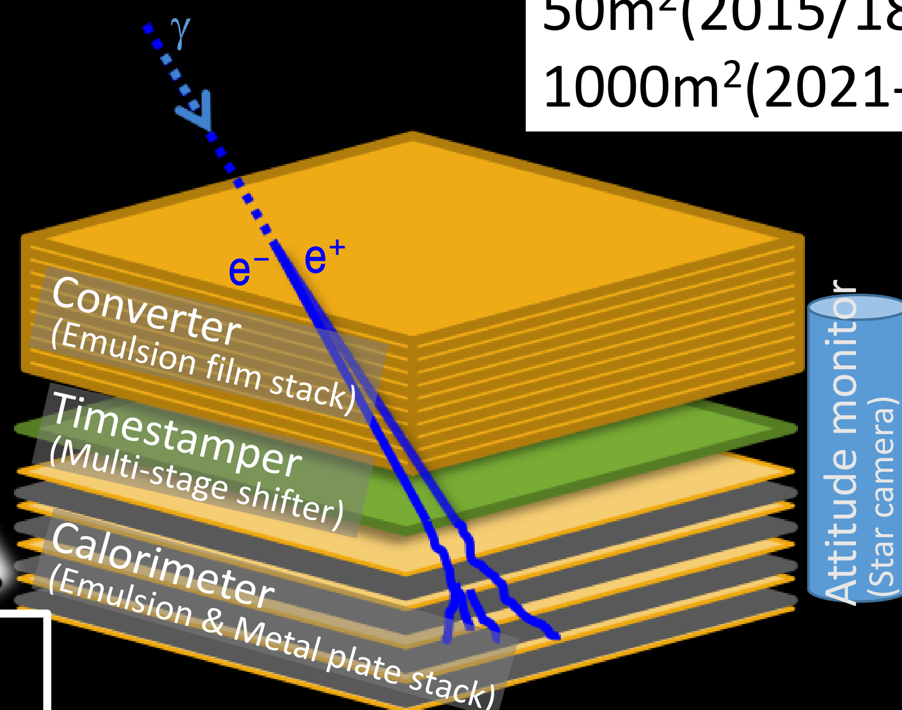


Balloon-borne Emulsion γ ray telescope

✓ Large aperture (10m²)
✓ High angular resolution (0.1deg@1GeV)
✓ Polarization sensitive

Emulsion
50m²(2015/18)
1000m²(2021-)

Detail → Next Speaker ROKUJO

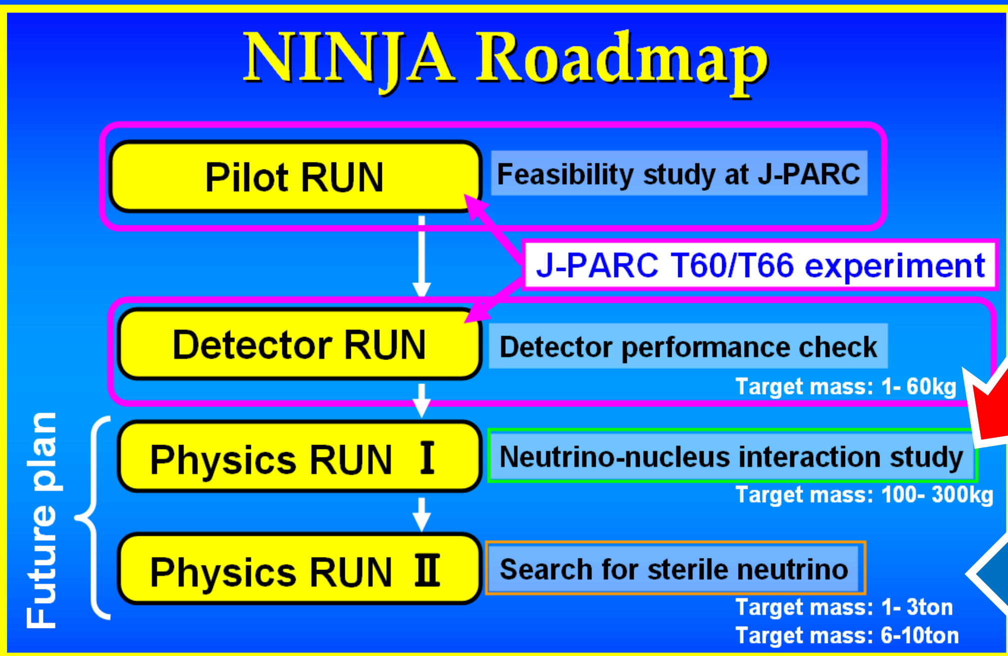


Time-stamping technique !

NINJA Experiment

SP: FUKUDA T.

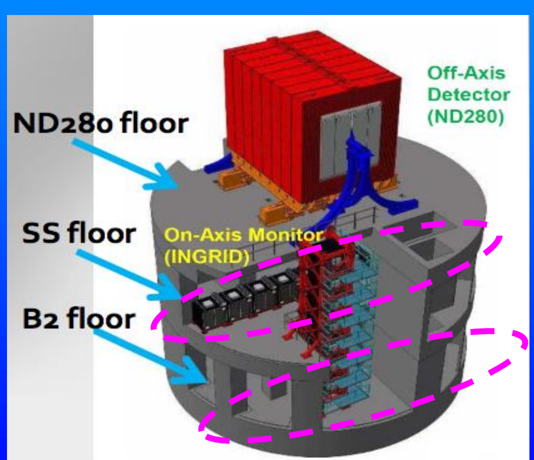
Neutrino **I**nteraction research with **N**uclear emulsion and **J**-PARC **A**ccelerator

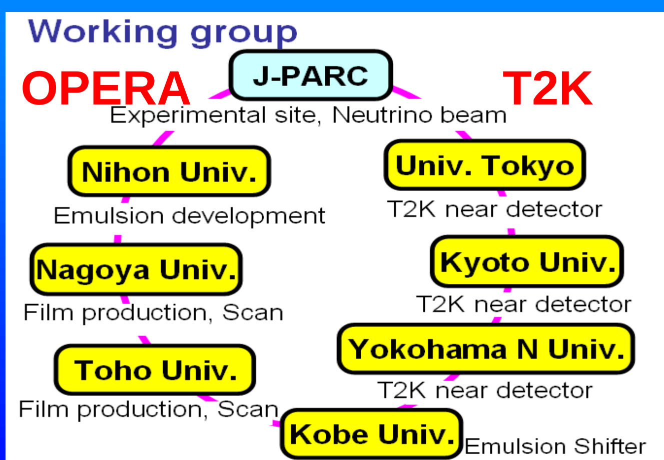


2018–2021
Study of Low energy ν Int.
- ν —Water int.
  with recoil proton detection
- Measurement of ν e content

2023—
Search for
Sterile ν

Emulsion
$40m^2$(- 2018)
$650m^2$(2019 -21)
$650m^2$(2023-)

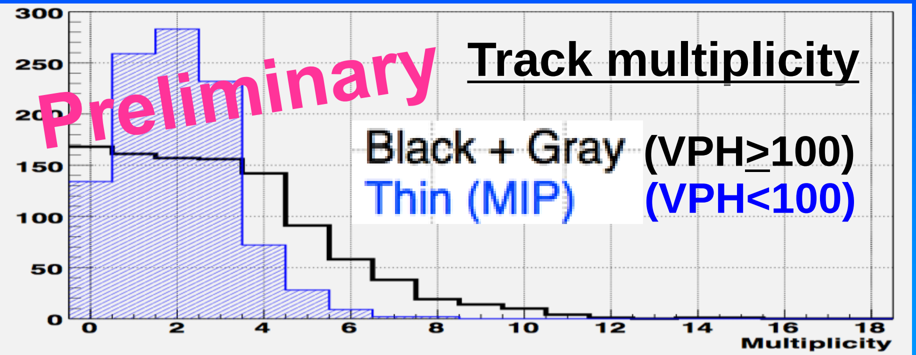


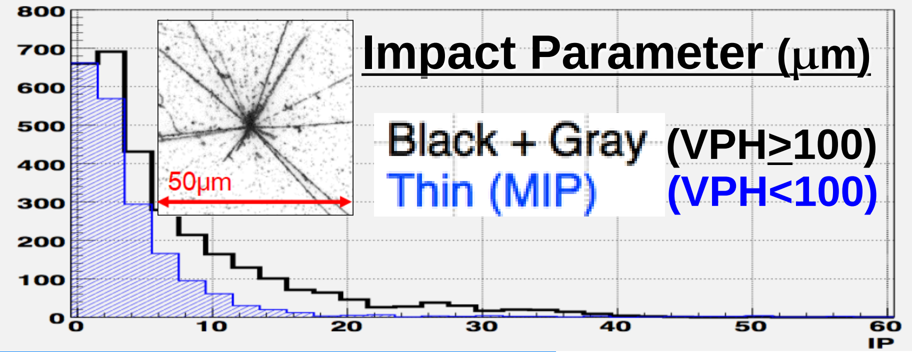


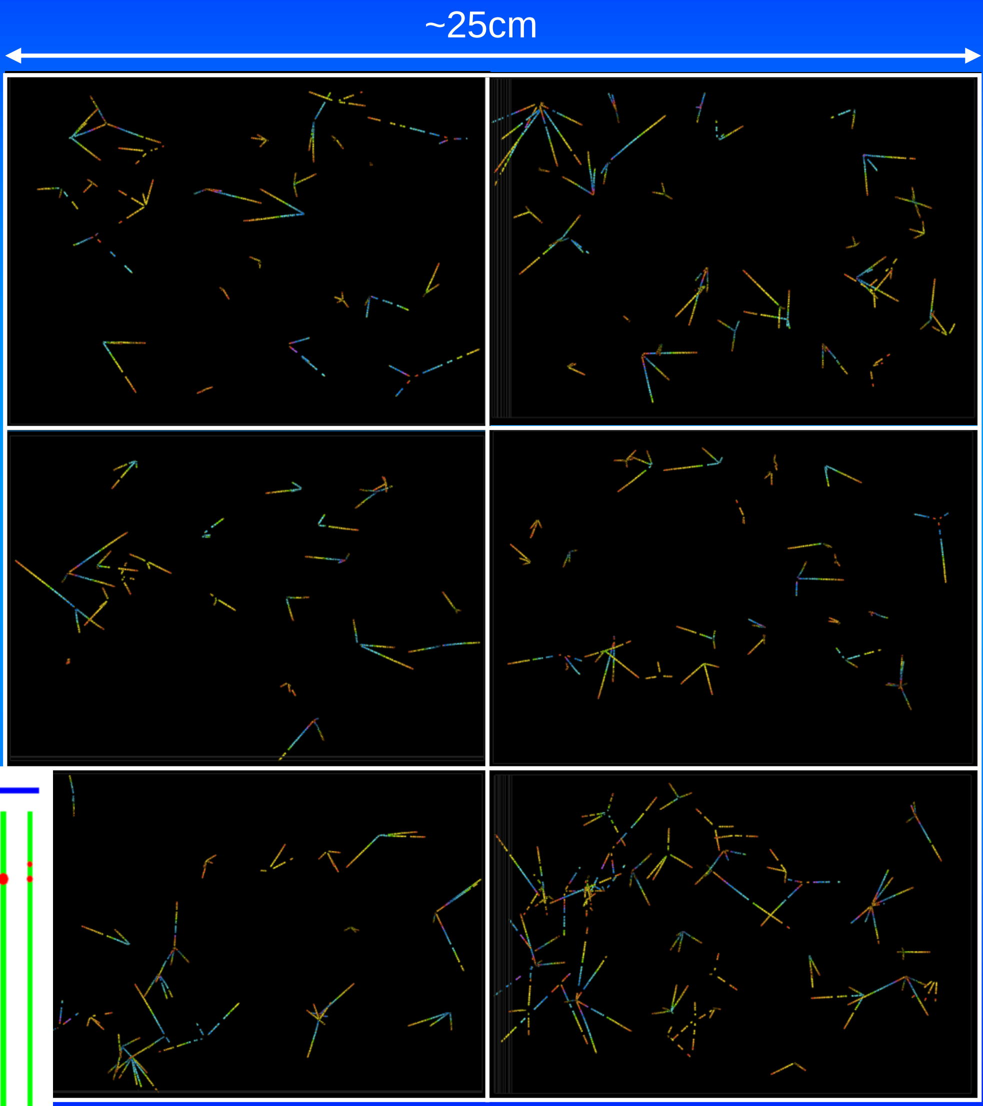
Detector run: 60kg Iron target ECC

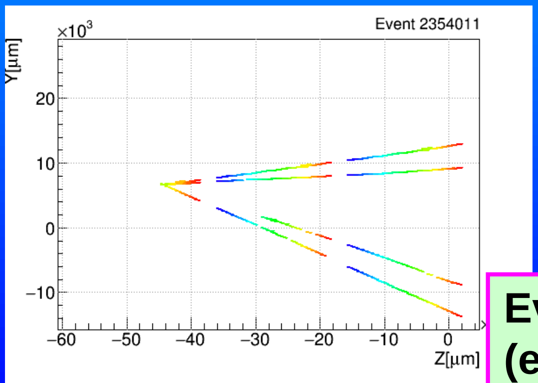
Multi-track vertex event search

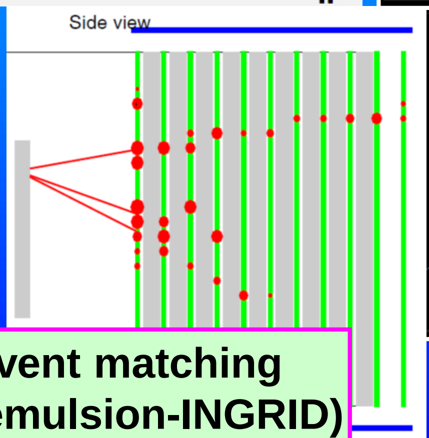
1021 vtx candidate events











Event matching (emulsion-INGRID)

(Multiplicity≥3)

Japan Group SP: KOMATSU M.

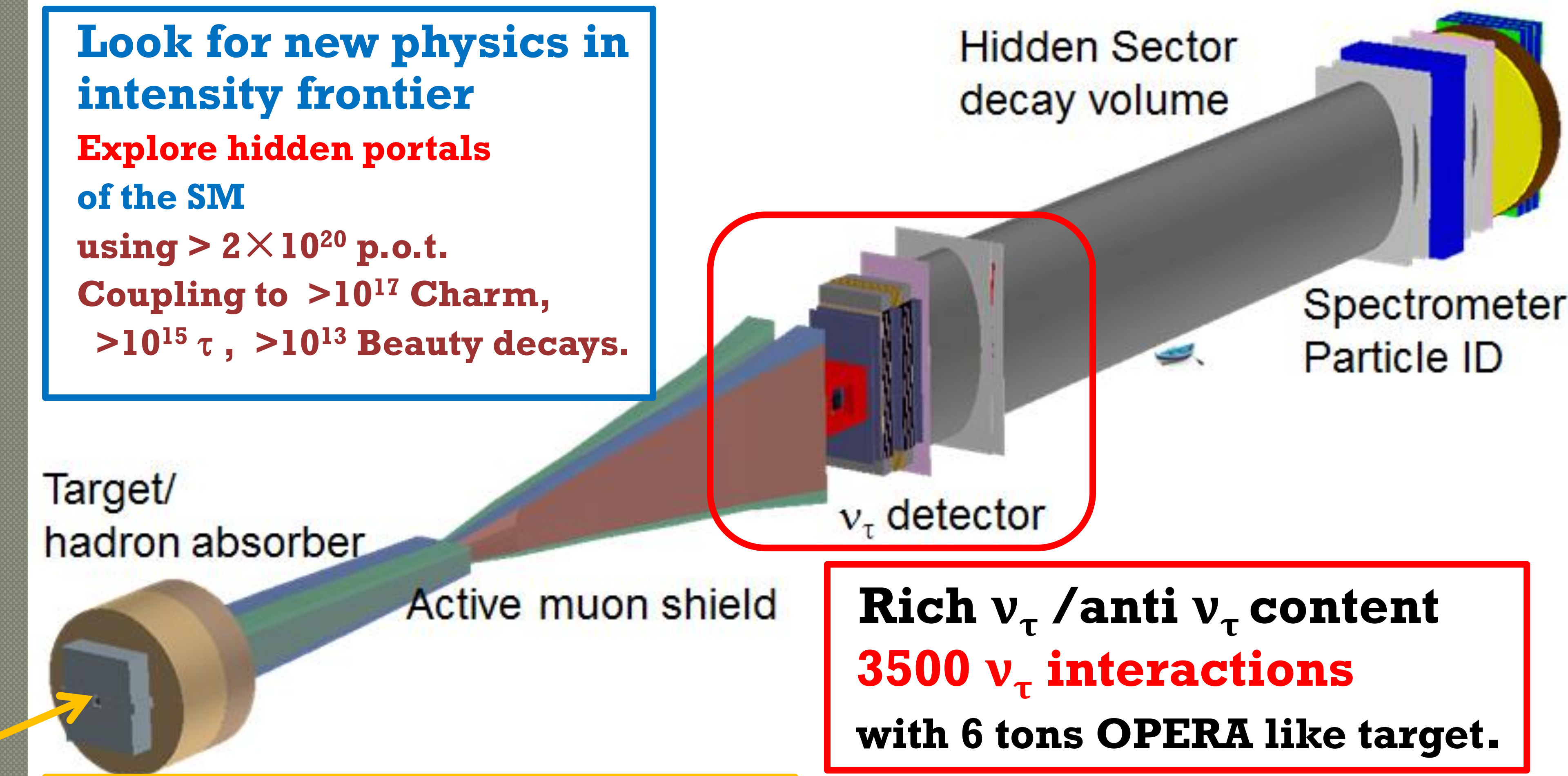
SHiP experiment @ CERN SPS

Look for new physics in intensity frontier

Explore hidden portals of the SM

using > 2×10^{20} p.o.t.

Coupling to >10^{17} Charm, >10^{15} τ , >10^{13} Beauty decays.



Rich ν_τ /anti ν_τ content

3500 ν_τ interactions

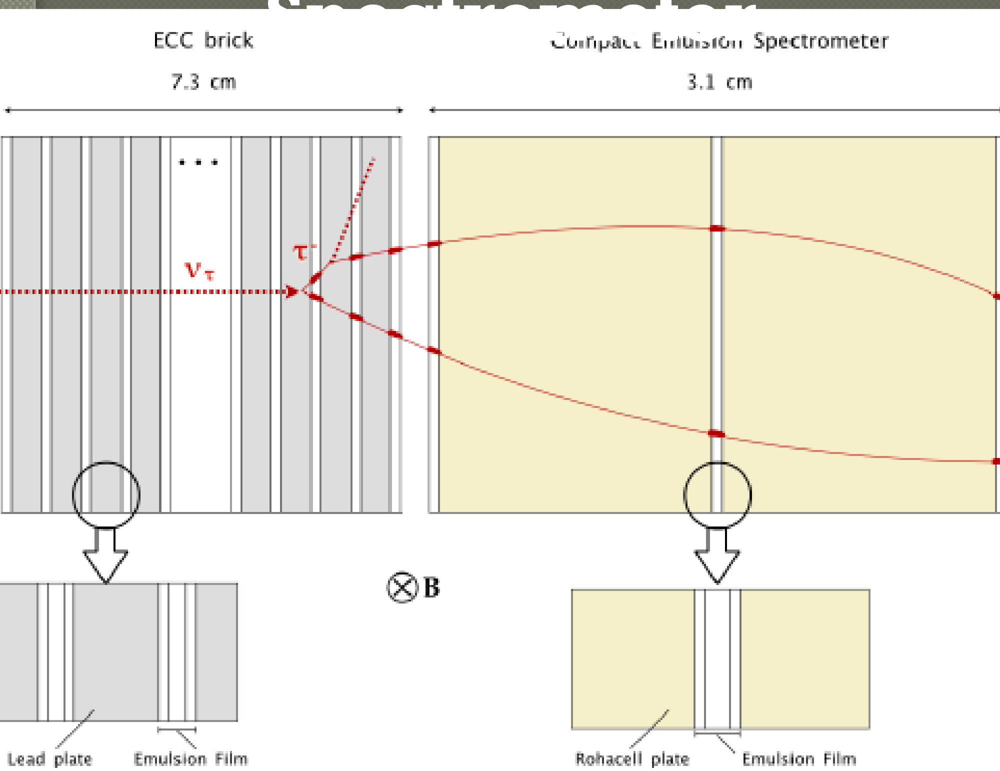
with 6 tons OPERA like target.

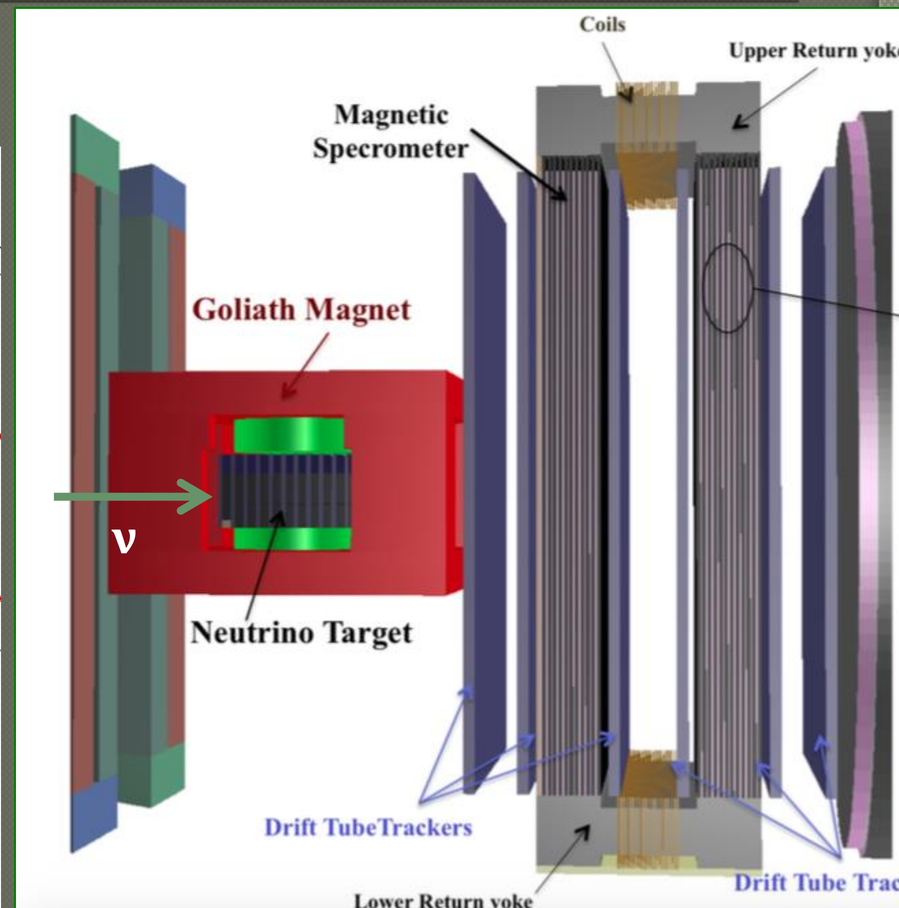
400GeV Proton Beam Dump exp.

SHiP neutrino detector

ECC
+ Emulsion Spectrometer

Emulsion ~3000m^2





OPERA Muon system

- P meas. up to 20GeV/c @ 1T
- Sign determination for νe/anti- νe

8k ν_τ /anti ν_τ
280k νe/ anti νe
500k ν_μ/ anti ν_μ

DsTau

SP: ARIGA T.

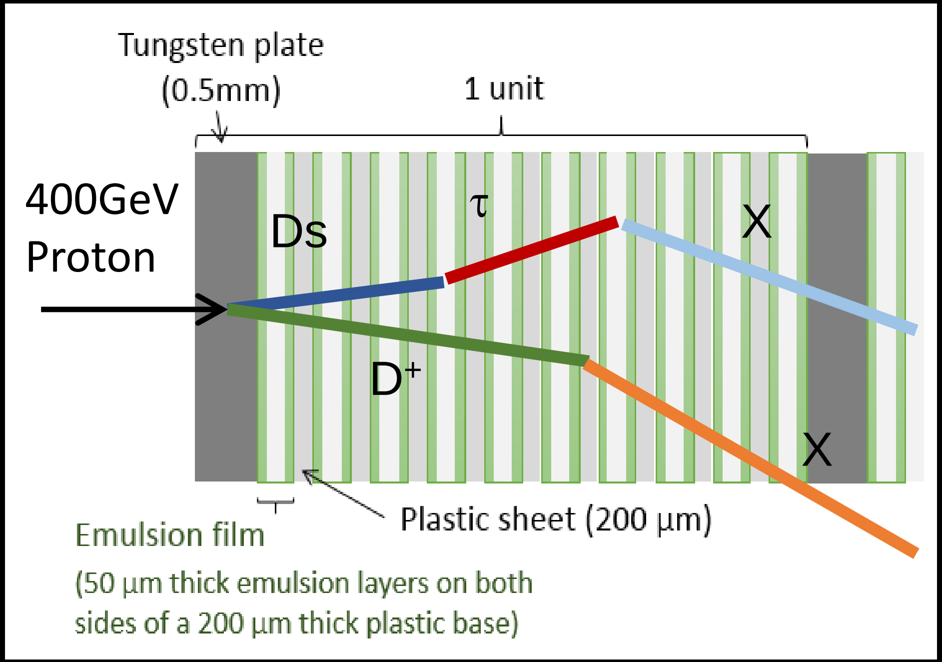
Precise ν_τ Flux evaluation for future ν_τ experiments

Nagoya, Kyushu, Kobe, Aichi, Bern, Bucharest, Ankara, Dubna

LOI (SPSC-I-245), Proposal (SPSC-P-354)

Beam exposure planning in 2018 and in 2021.

- ν_τ cross section measured by DONUT with large uncertainty(~50%) on ν_τ flux at beam source.
- Reduction of the uncertainty by measuring $D_s \rightarrow \tau \rightarrow X$ in high energy proton interactions



Observable of the experiment

- D_s production x decay branching ratio

$$\frac{N_{\nu_\tau}^{beam}}{N_{pot}} = \frac{2\times\sigma(pW \rightarrow D_s X)\times BR(D_s \rightarrow \nu_\tau \tau)}{\sigma(pW)}$$

With collecting **1000** detected Ds→τ

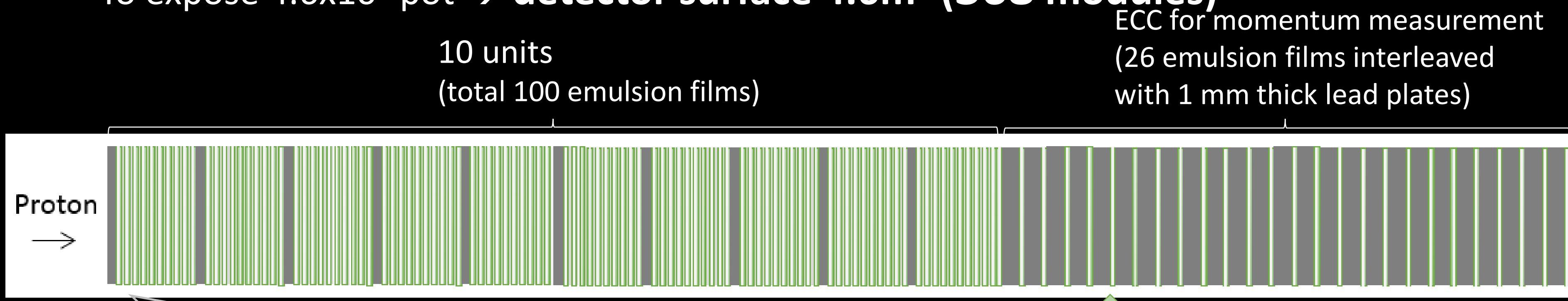
- Angular distribution of $D_s \rightarrow \tau$ events

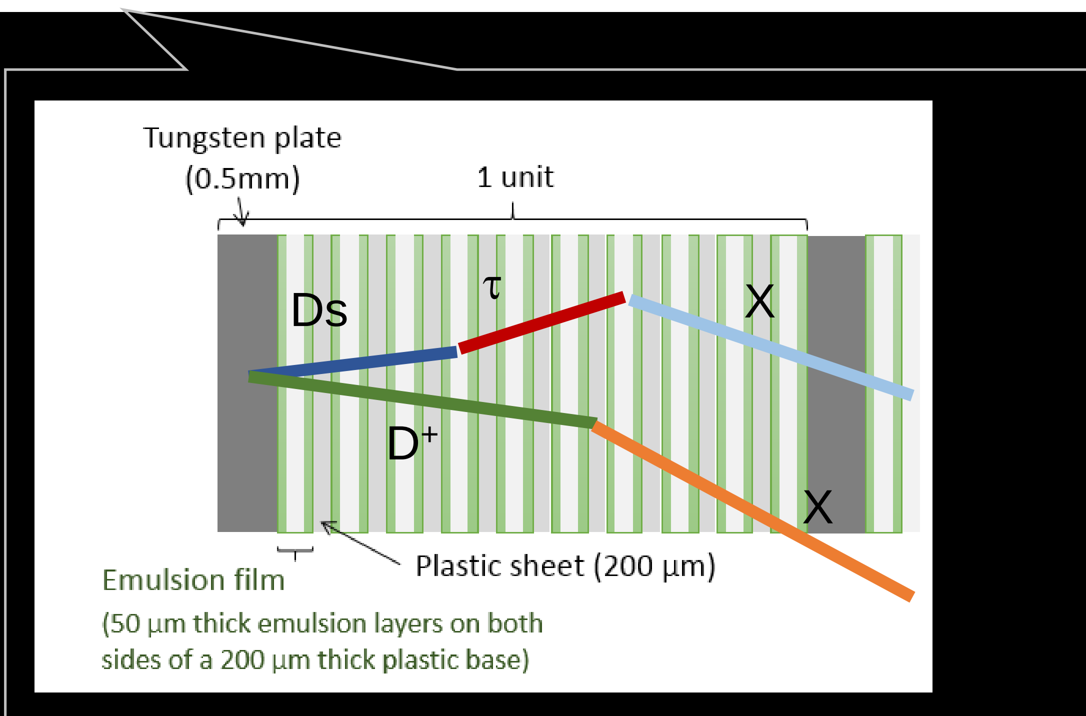
→ Energy distribution → x_F dependence

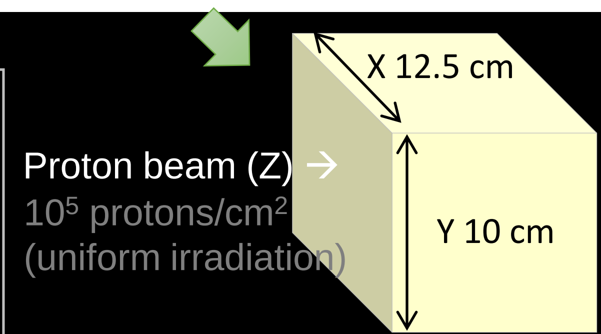
Systematic uncertainties	DONUT	With DsTau
D_s differential cross section (x_F dependence)	~0.5	0.1
Charm production cross section	0.17	0.03
Decay branching ratio	0.23	
Target atomic mass effects (A dependence)	0.14	

Module structure for $D_s \rightarrow \tau \rightarrow X$ measurement (current baseline)

- 0.05 λ_{int} in 10 units tungsten → 4.6x10^9 pot needed to get **2.3x10^8 proton int**.
- Track density in emulsion: **keep <10^5 tracks/cm^2** at the upstream side
- To expose 4.6x10^9 pot → **detector surface 4.6m^2 (368 modules)**





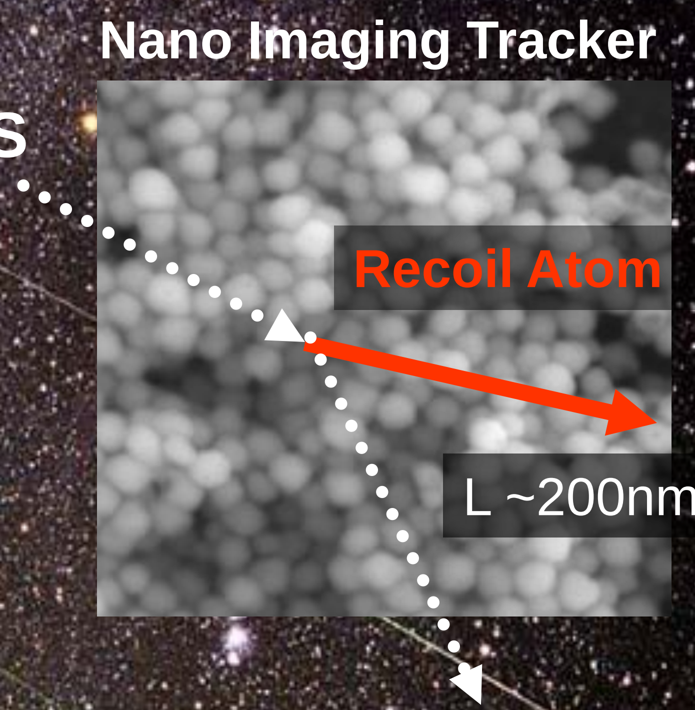


Emulsion ~500m^2

Directional WIMP detection by Nuclear Emulsion
NEWSdm @LNGS

Japan Group SP: NAKA T.

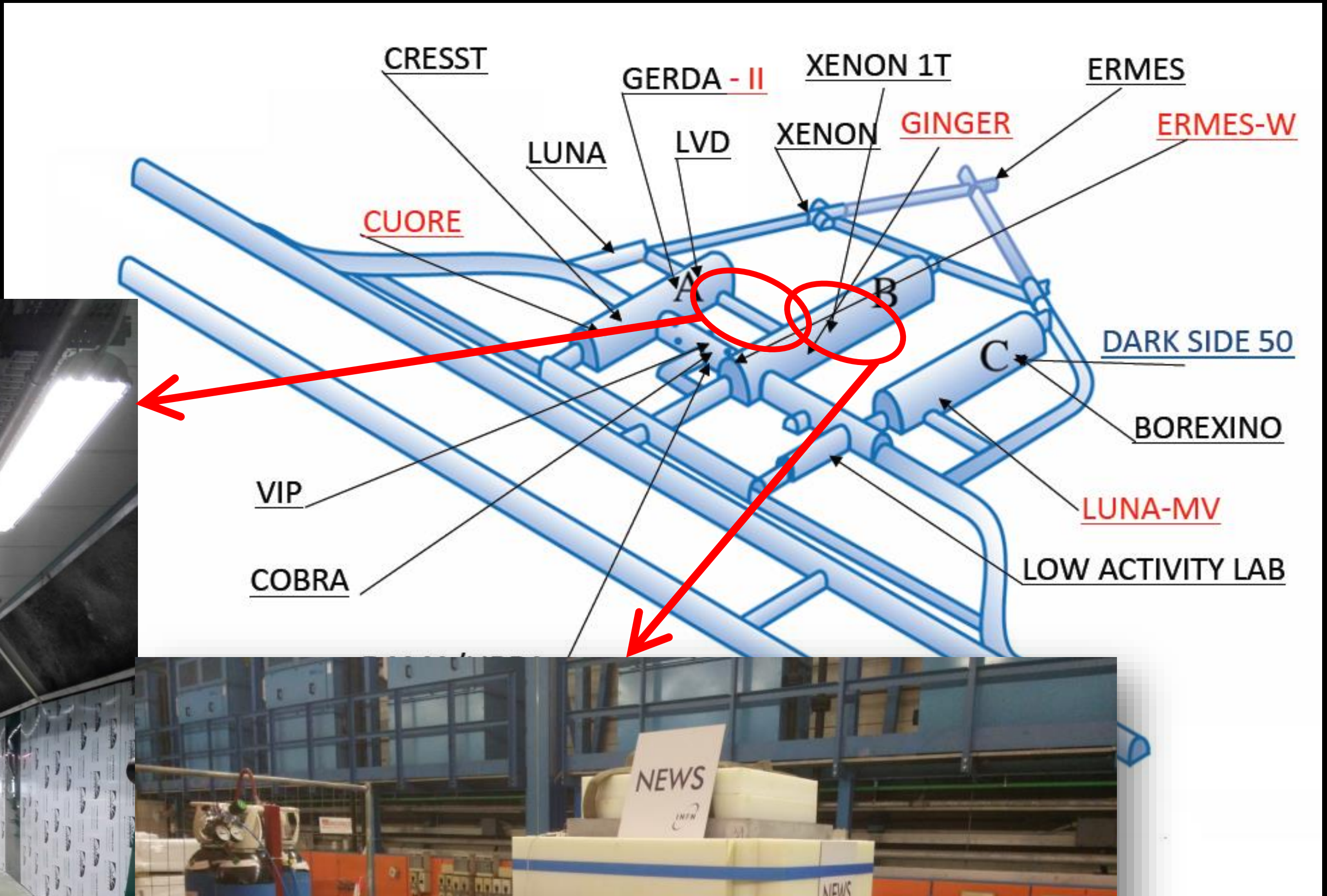
Japan – Italy- Russia- Turkey –Korea Collaboration



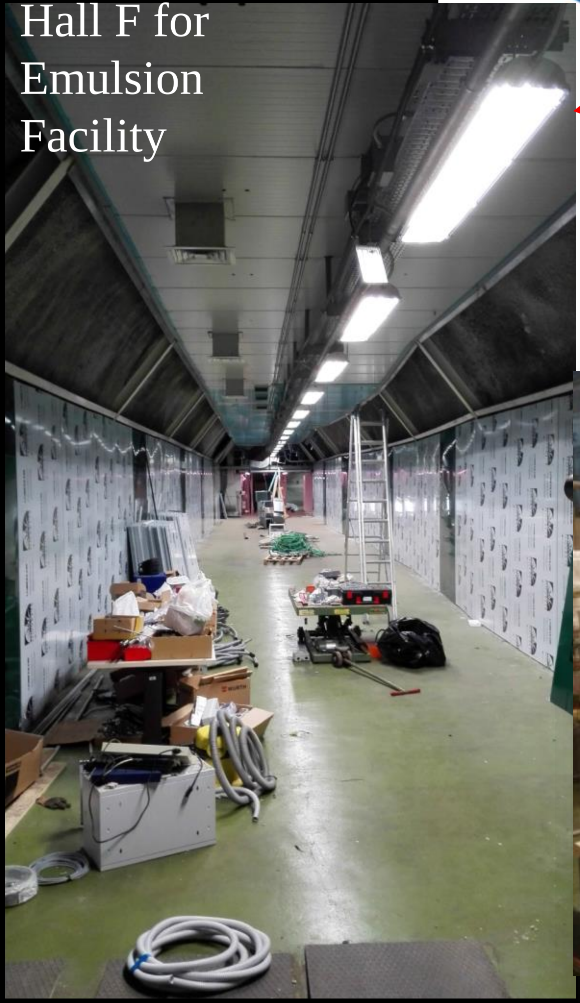
$$V_{recoil} = 2\,(V_{sun} + V_{WIMP})$$
$$= 100\sim1000\text{km/sec}$$

- Detect the direction of recoil atoms
  → Dark Matter Telescope
- Easy to realize Ton scale detector

NEWSdm in Gran Sasso underground laboratory, Italy 2017

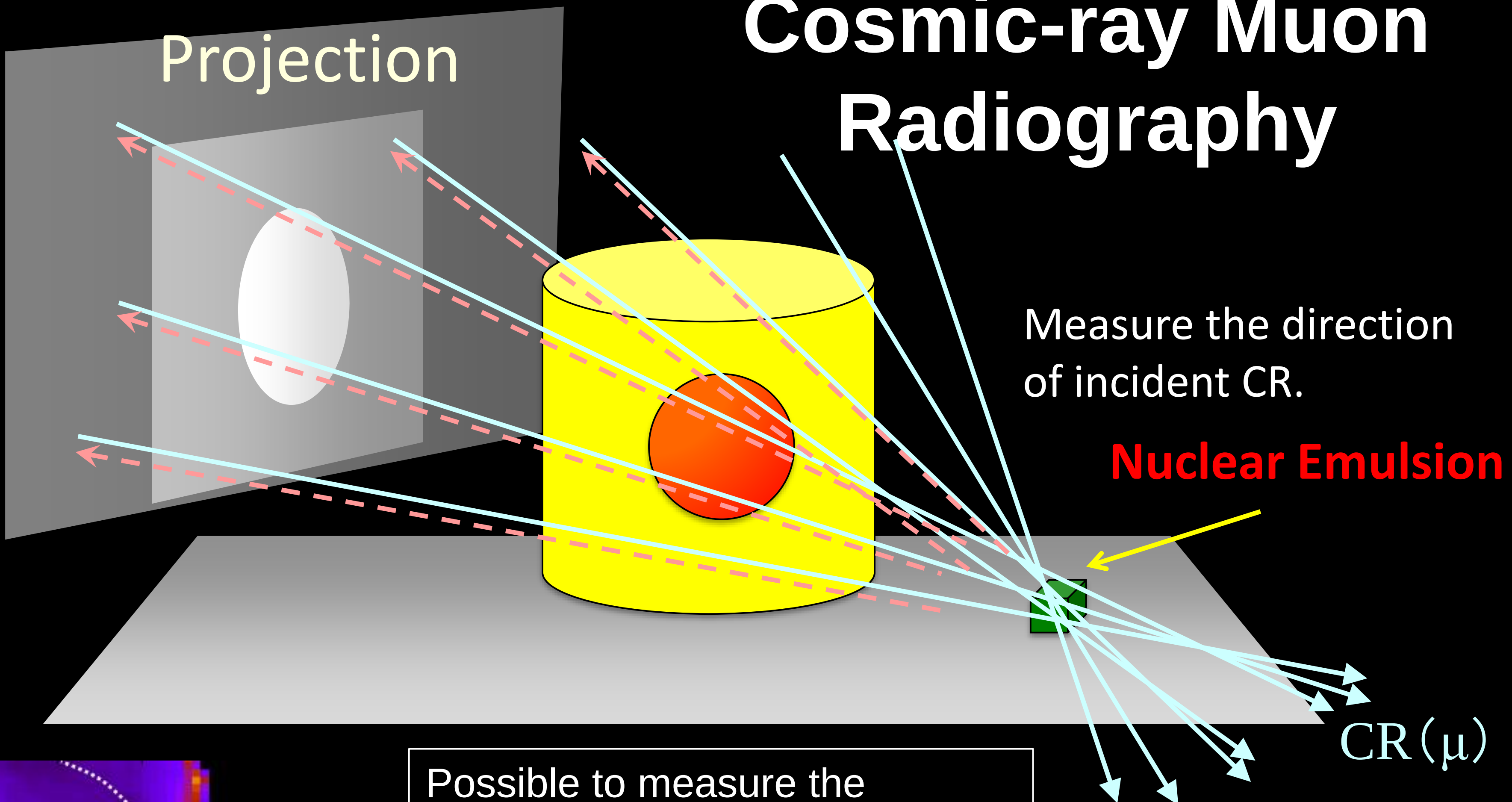


Hall F for Emulsion Facility

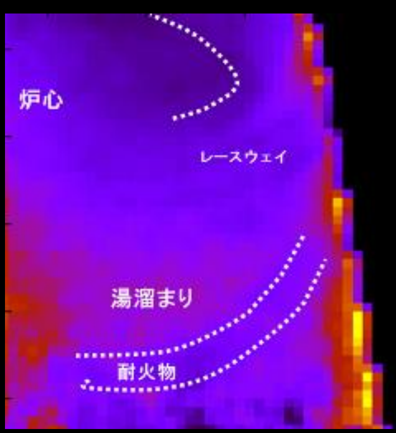


Part of Hall B for Detector Installation

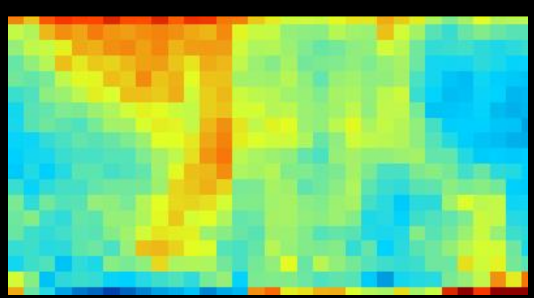
Cosmic-ray Muon Radiography



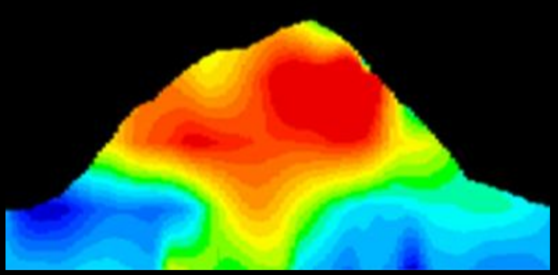
Possible to measure the material distribution of the object



Iron Furnace



Atomic Power Plant(F1)



Volcano (SHOWA SHINZAN)

Nuclear Emulsion : a kind of Photographic film

- **Photographic Film**:

  Young people has no experience to use photographic film.
  Then they believe

"Nuclear emulsion is a kind of leading edge device."

"原子核乾板は最先端デバイス"

This is true！

∵ Nuclear emulsion is

- Three dimensional device.
- Nano tech. device operating ～10nm size crystals
- Ultimate energy saving device. No electric-power needed
- Compact & Flexible device produced by only painting/pouring.
- The Read-out system is an incarnation of Digital technology treating three-dimensional Images ; the field of AI R&D.

Summary

- Nuclear Emulsion

  has a long History from1910, is

  contributing to elementary particle physics until today

  Still Alive , continue the contribution to the future science.

- Using emulsion, even students can be a Project Spokesman with their (good) ideas.

  Low cost & Almost every thing is in your hand.

→ probably one of the best detector to cover the burnt field remained after the decline of the energy frontier dinosaur.