Neutrino-nucleus reaction with emulsion

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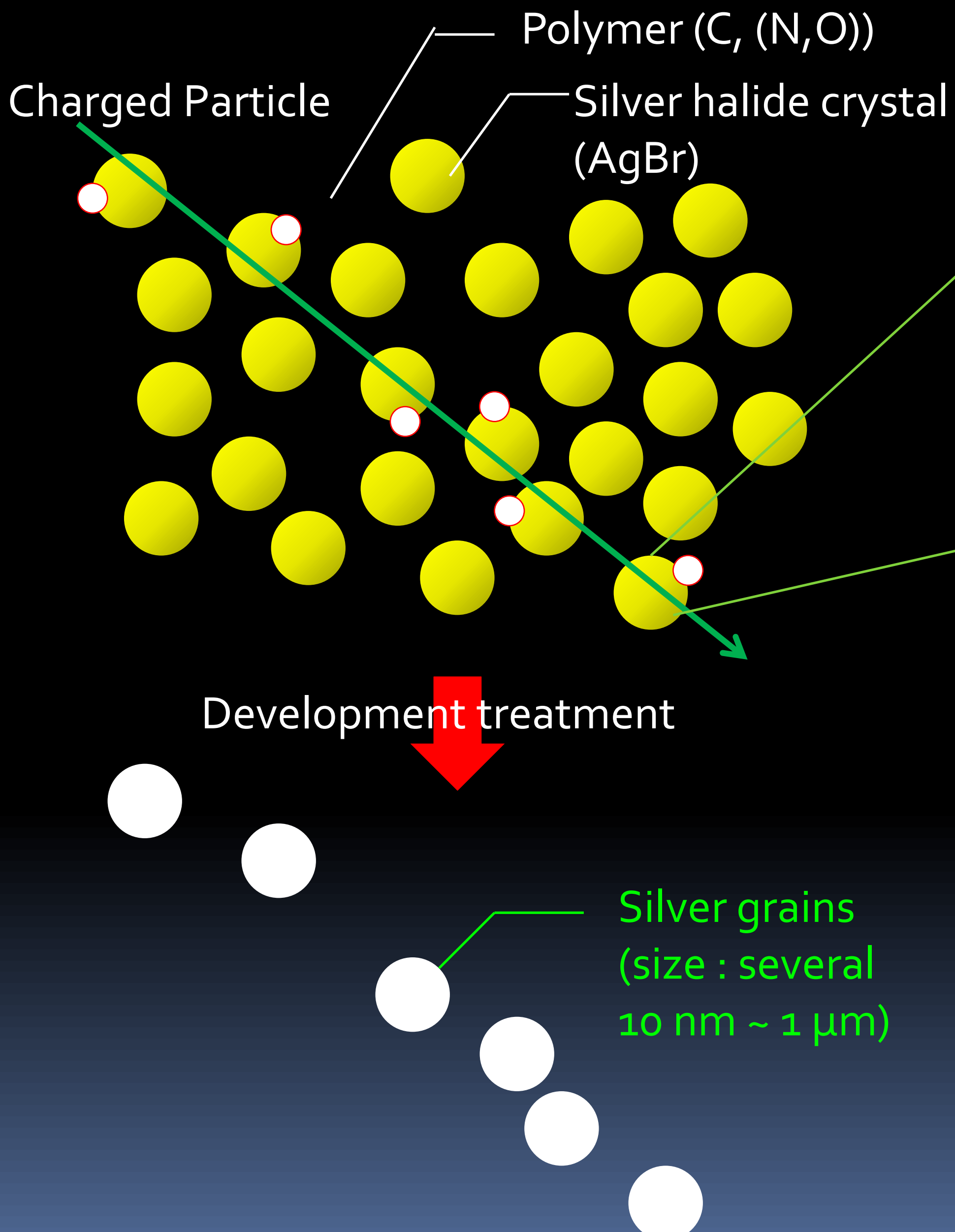
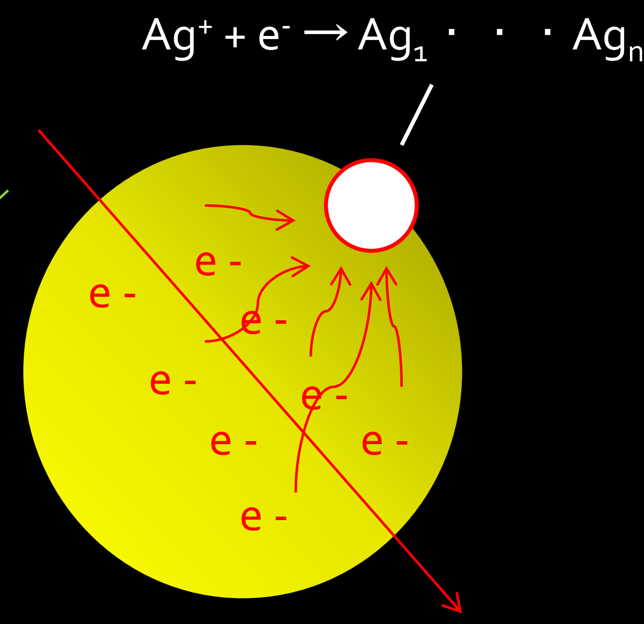
Today’s mission of talk

- Showing potential of emulsion for tracking, particle id etc.

- Then collecting opinions from you.
- What should be done by emulsion.
- Or what neutrino-nuclear physics suit for emulsion experiment.
- We hope emulsion technique can provide good measurements.
- Advices for target physics are very welcome.

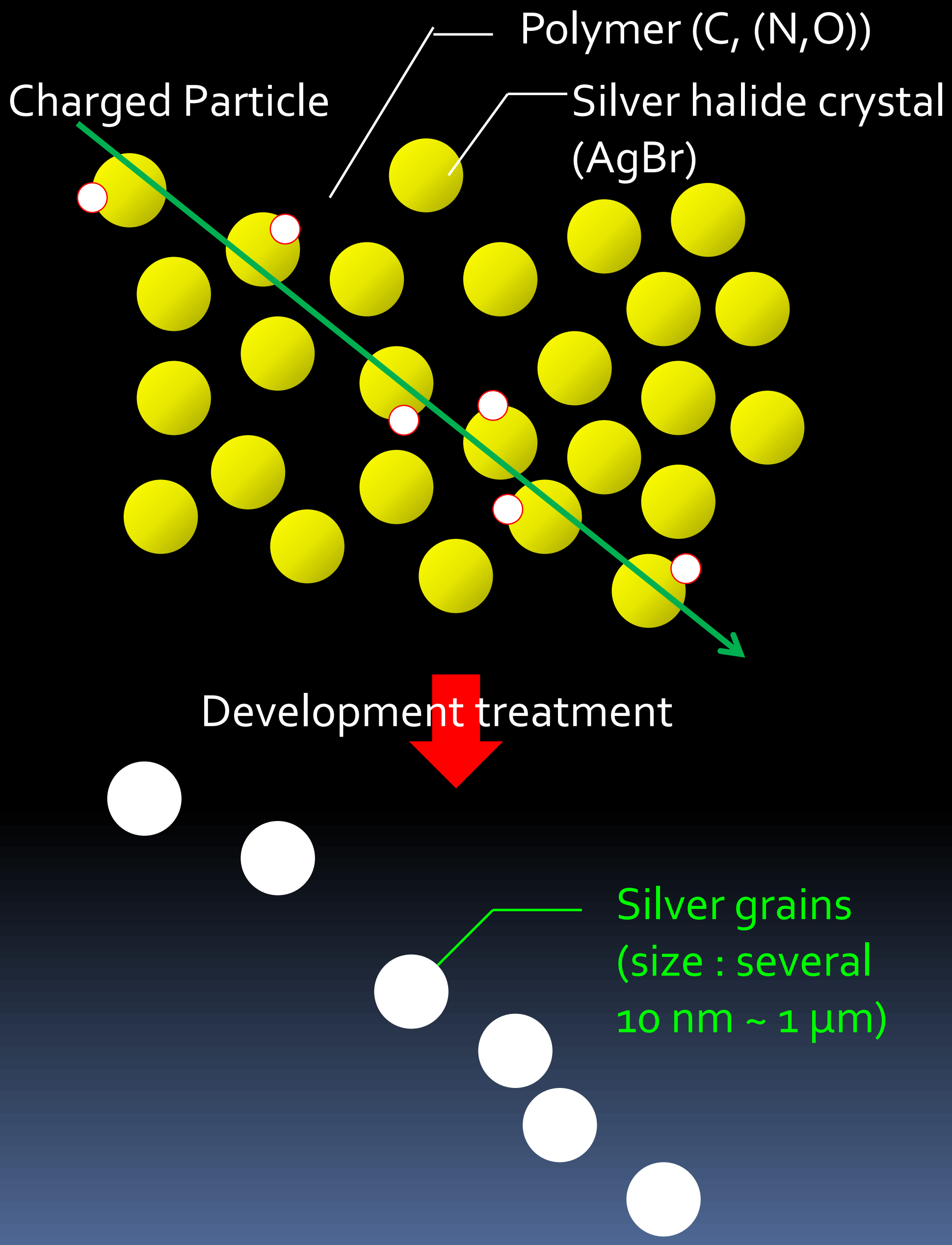
Nuclear Emulsion Detector



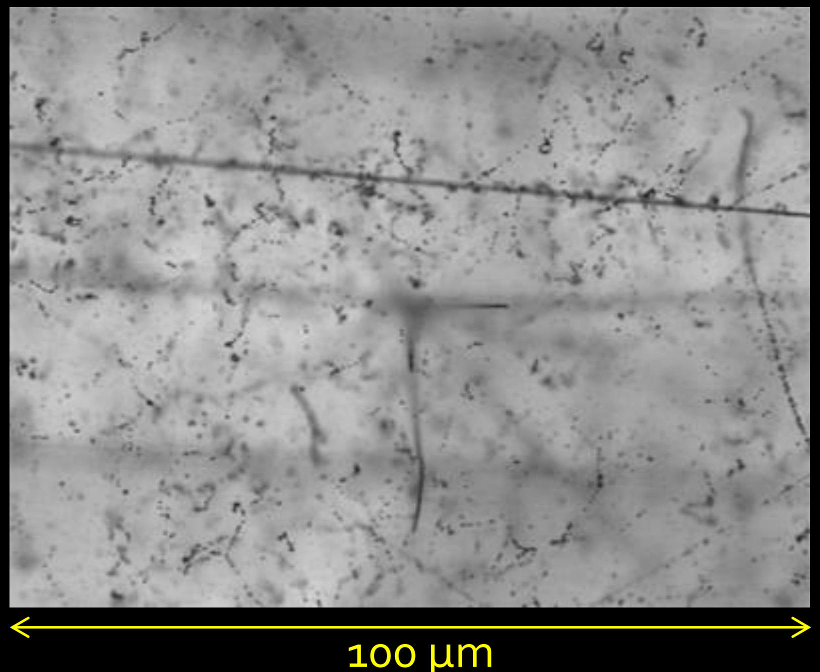


Ionized electrons concentrated on the electron trap to form the latent image specks in a crystal

Nuclear Emulsion Detector



Nuclear spallation reaction by heavy ion



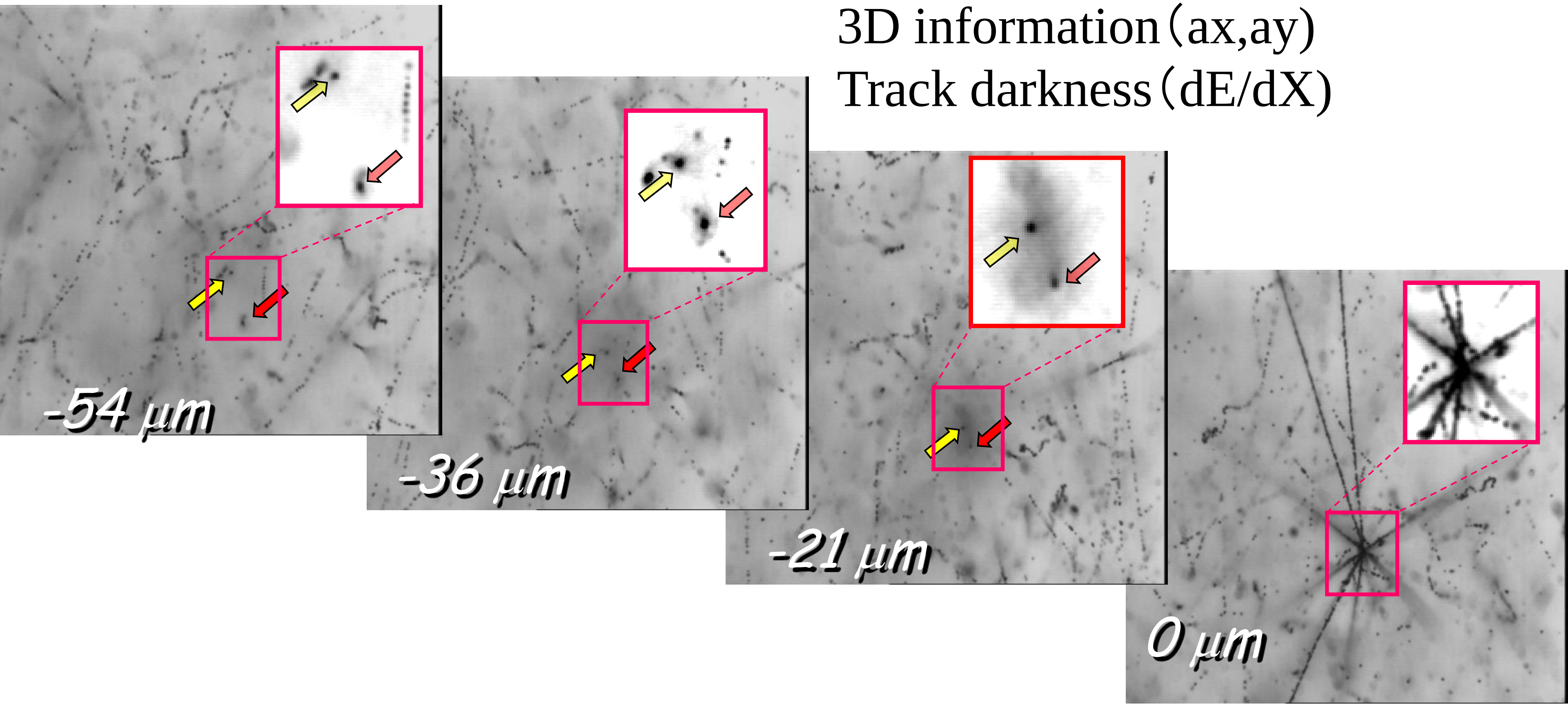
Spatial resolution
- silver halide crystal size
- number density of silver halide crystal

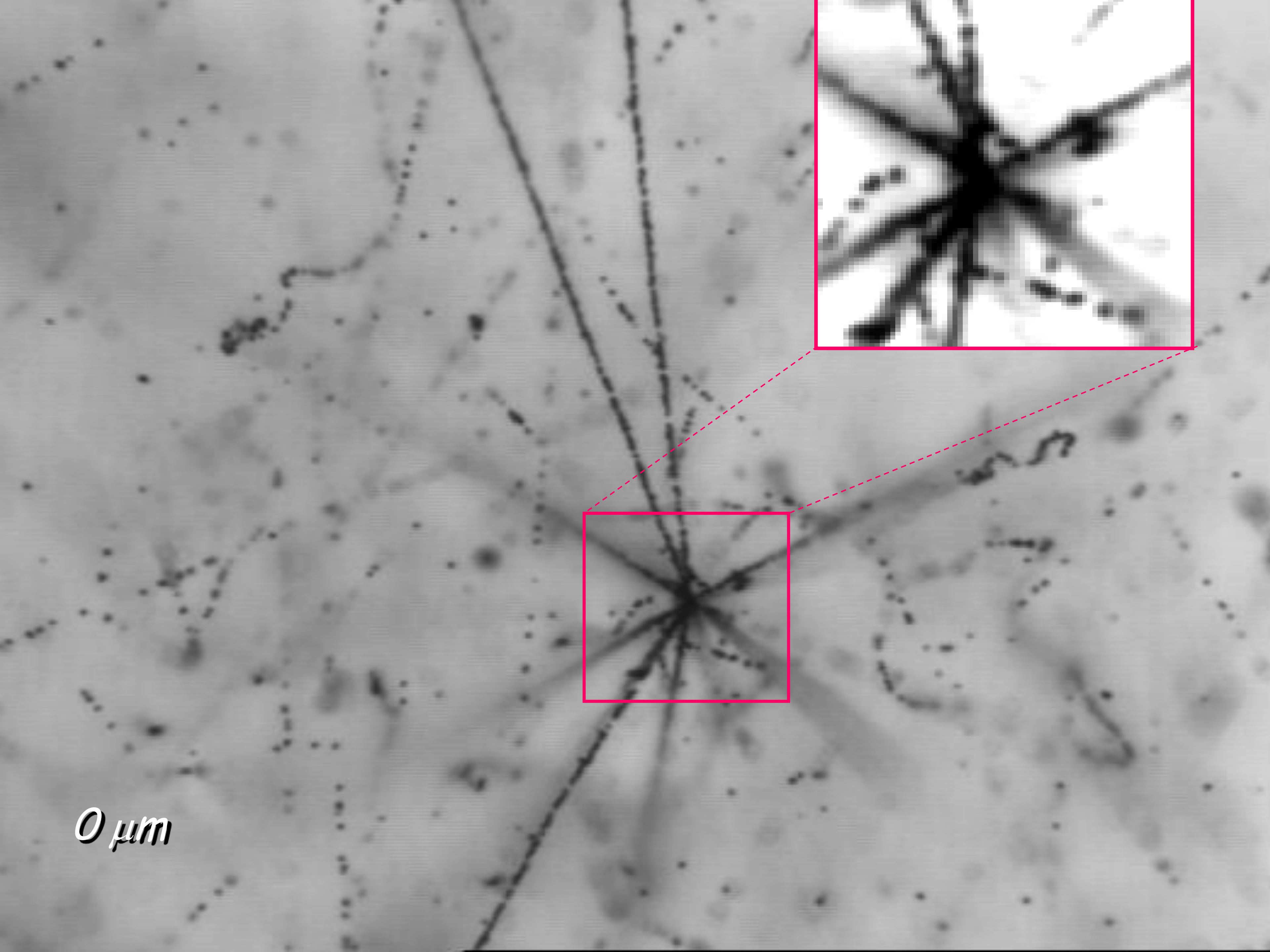
Sensitivity
- Chemical treatment
- Crystal defect and doping etc.

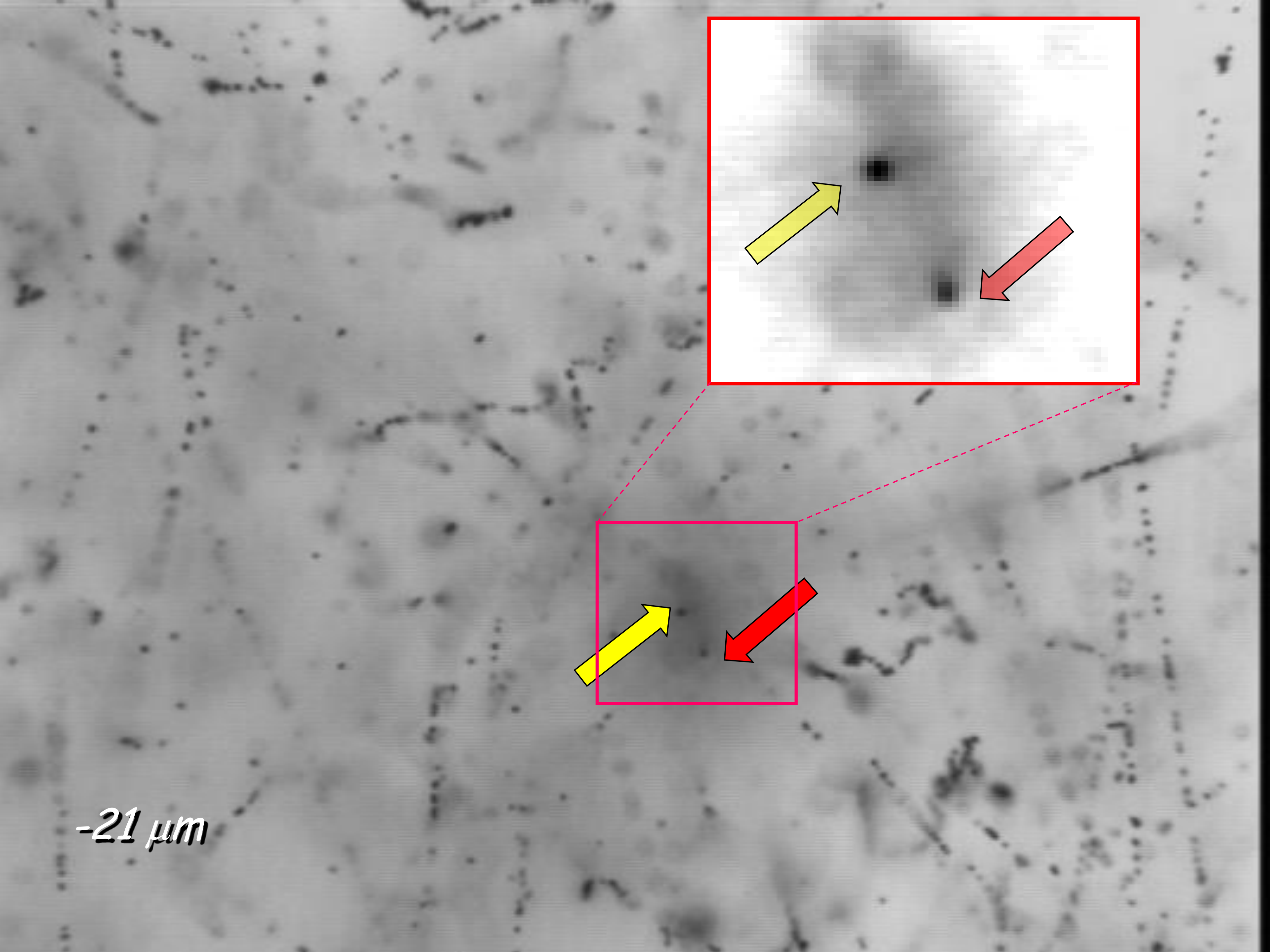
A neutrino event recorded in Nuclear Emulsion

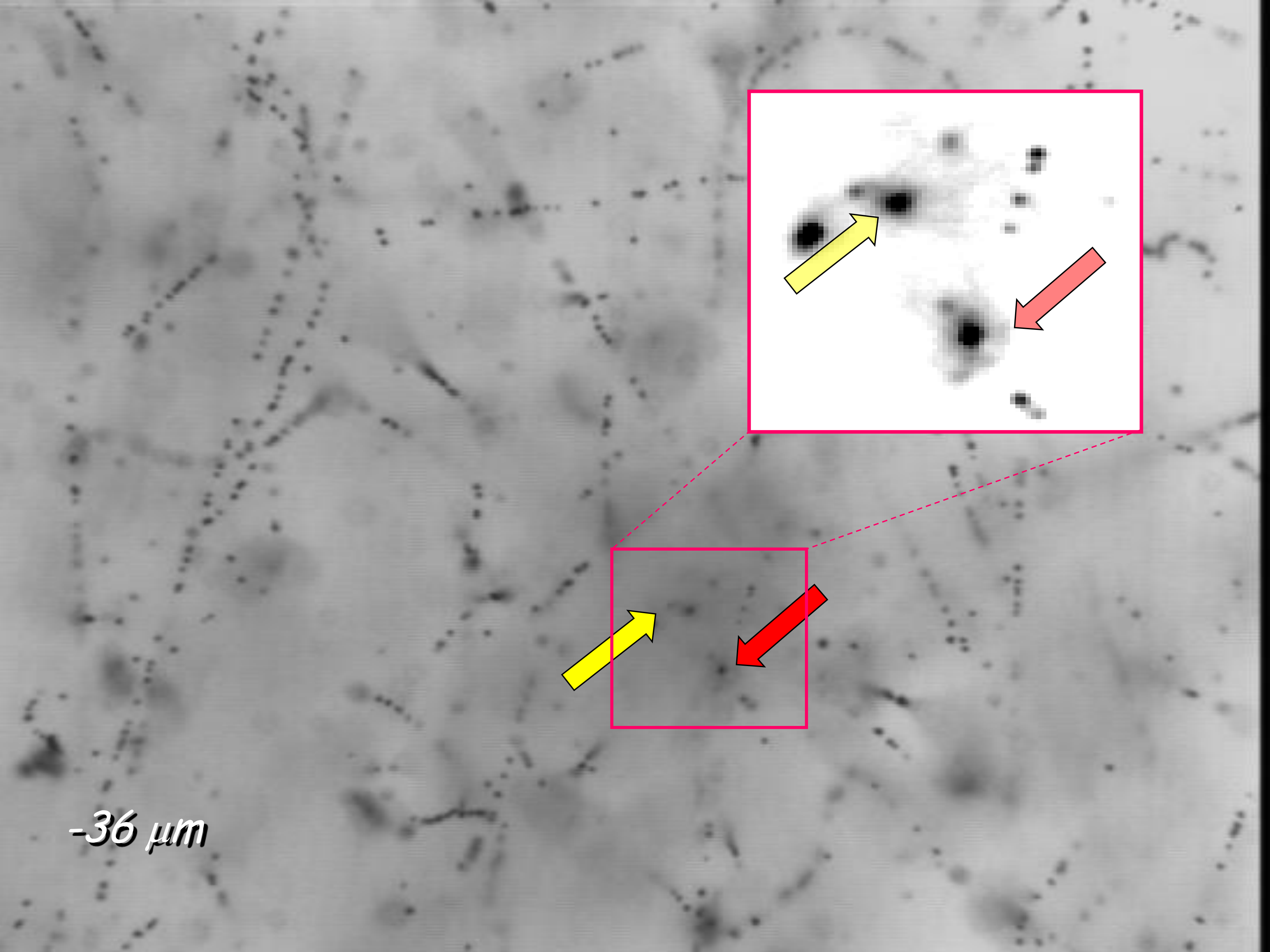
All charged track

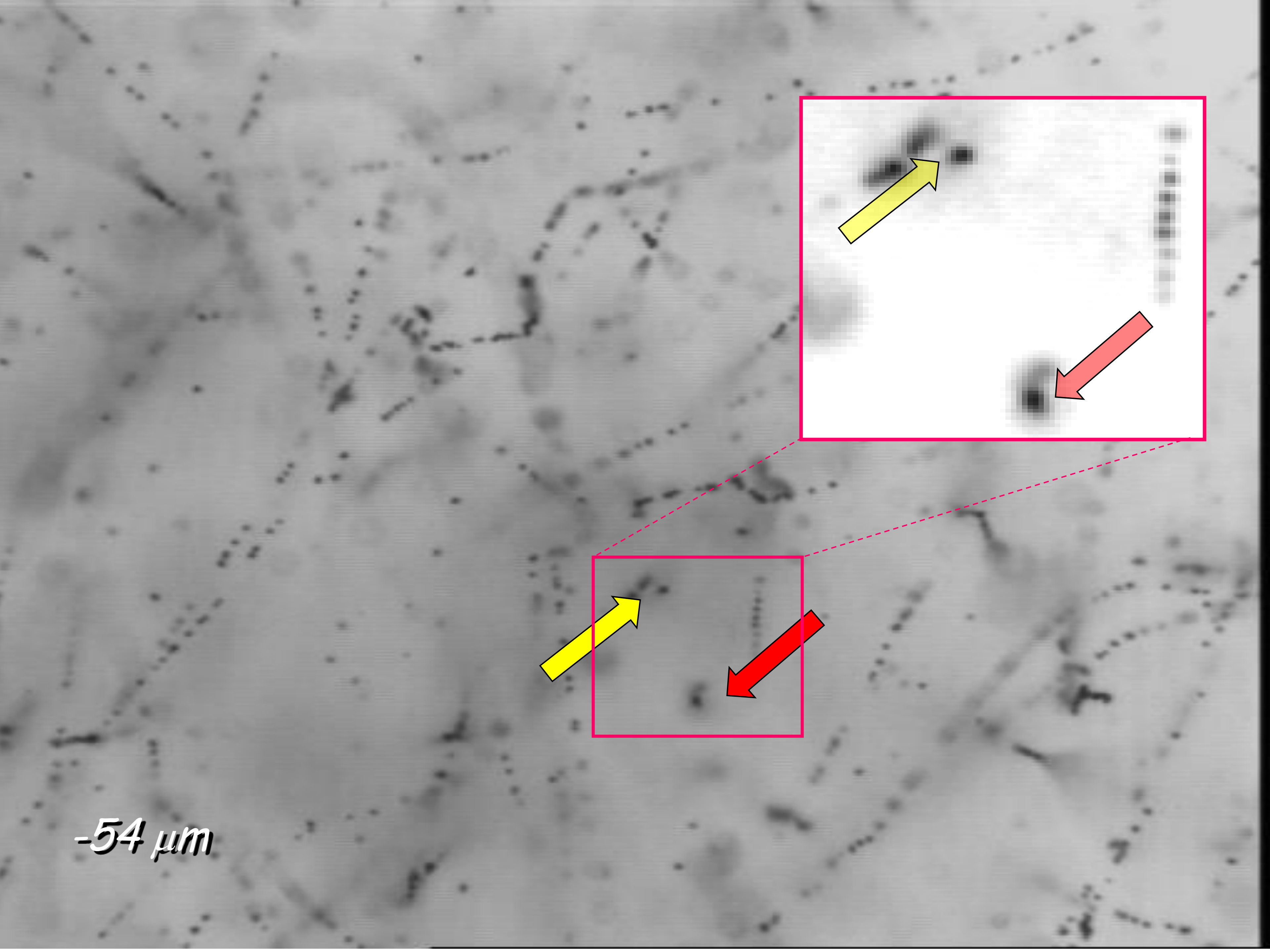
Sub micrometric spatial resolution
3D information (ax,ay)
Track darkness (dE/dX)



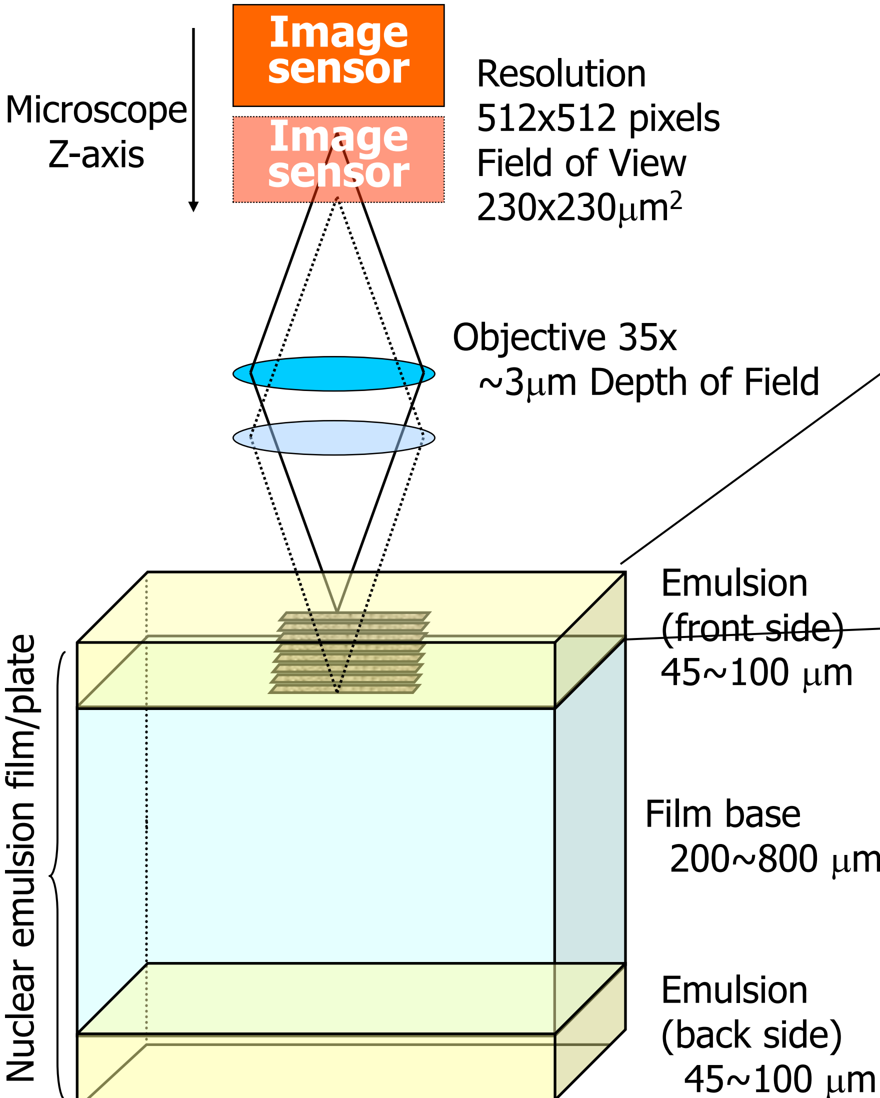

0 μm


-21 μm

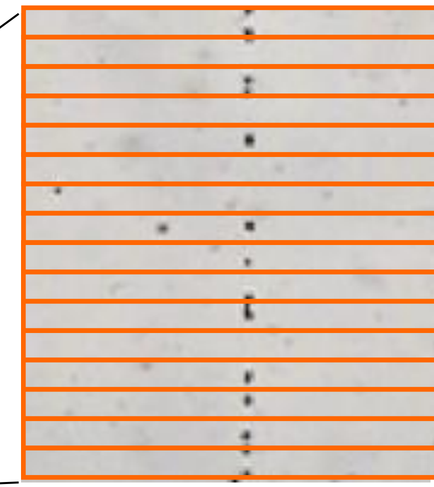

-36 μm


-54 μm

Readout of tracks in Emulsion



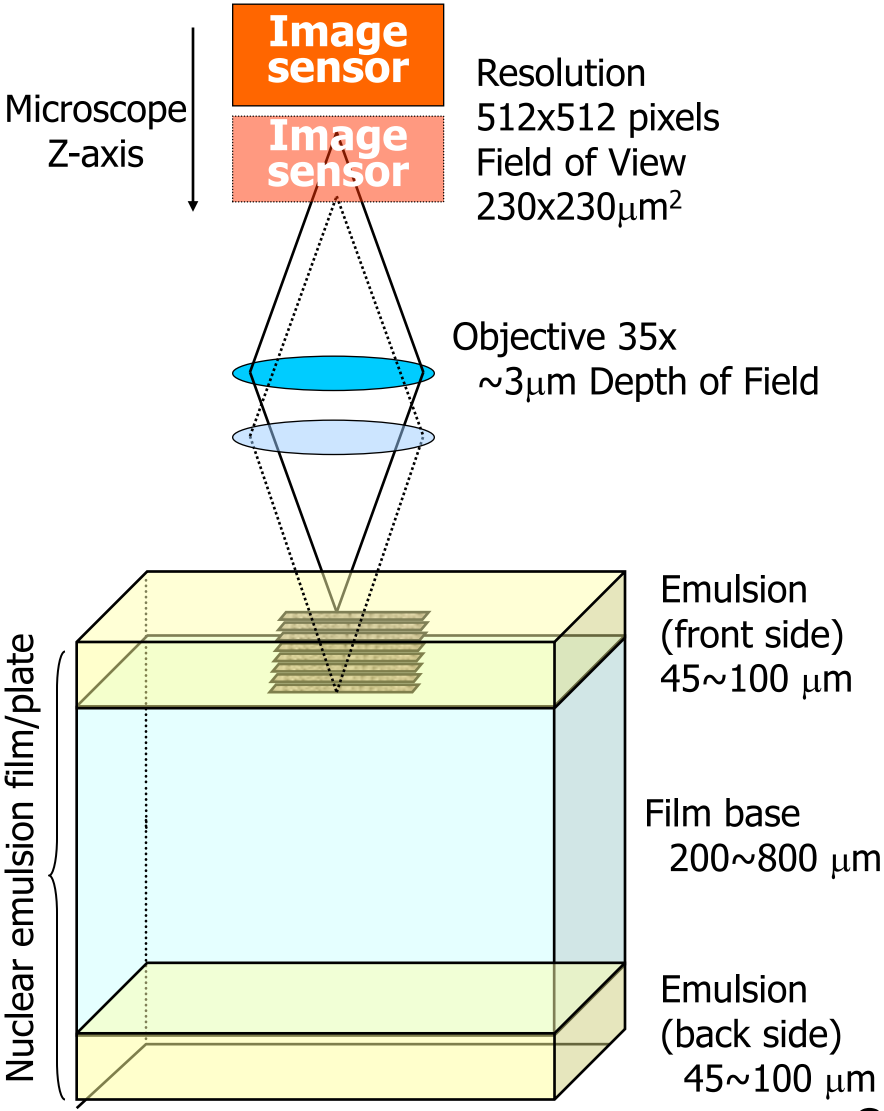
Microscope view



Sensitivity

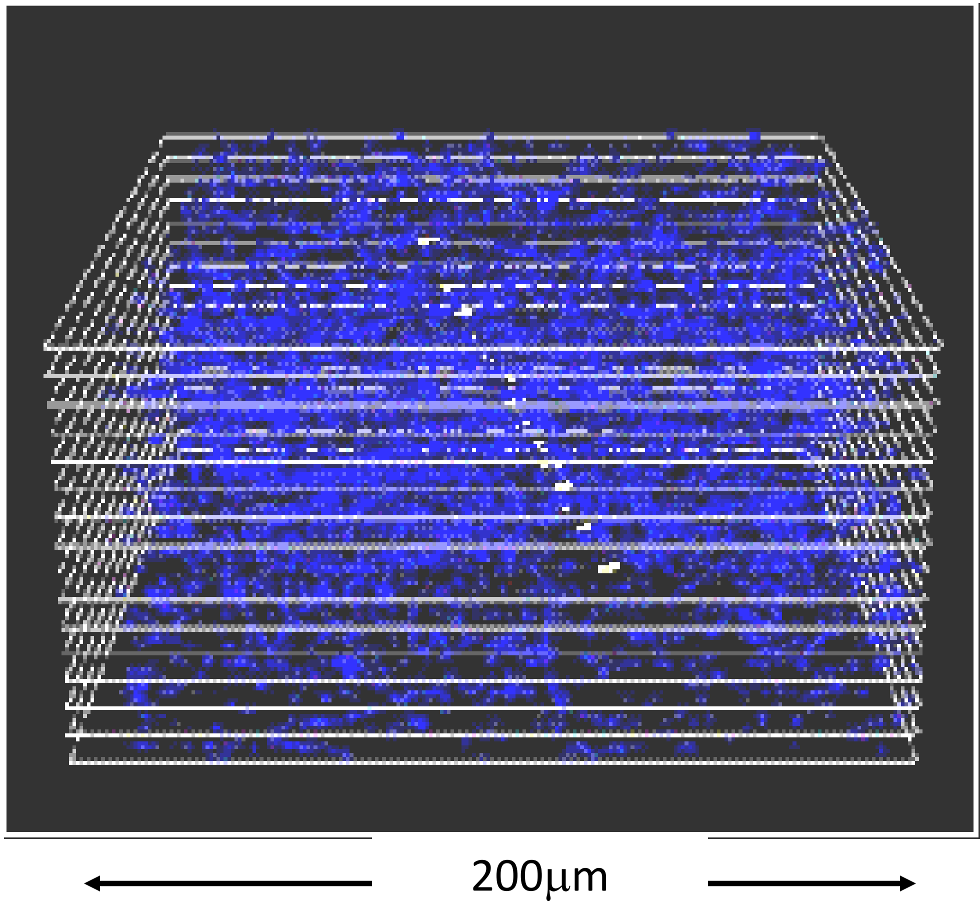
35 silver grains /100µm

Digitizing Nuclear Emulsion Film

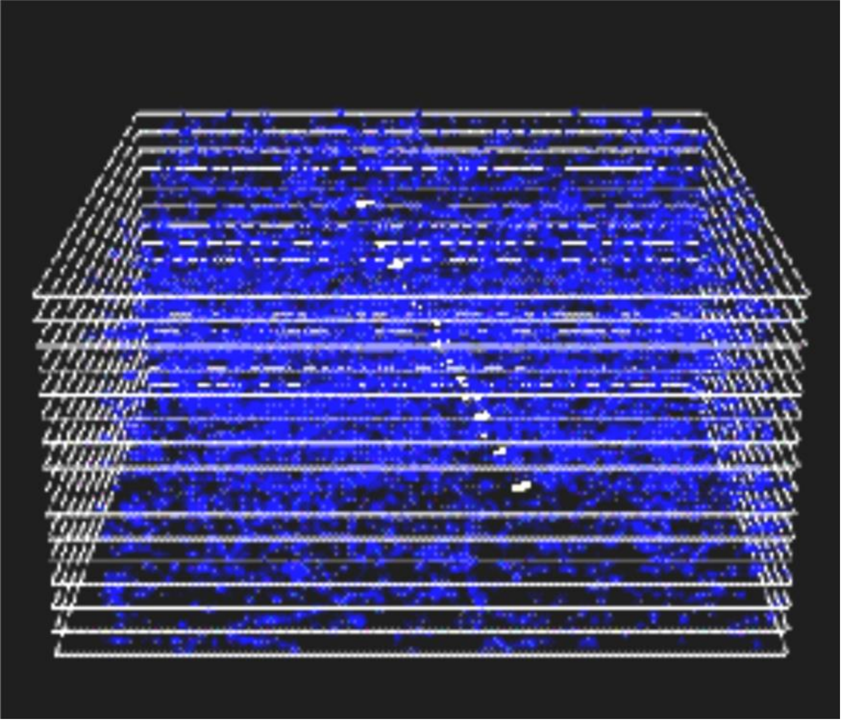


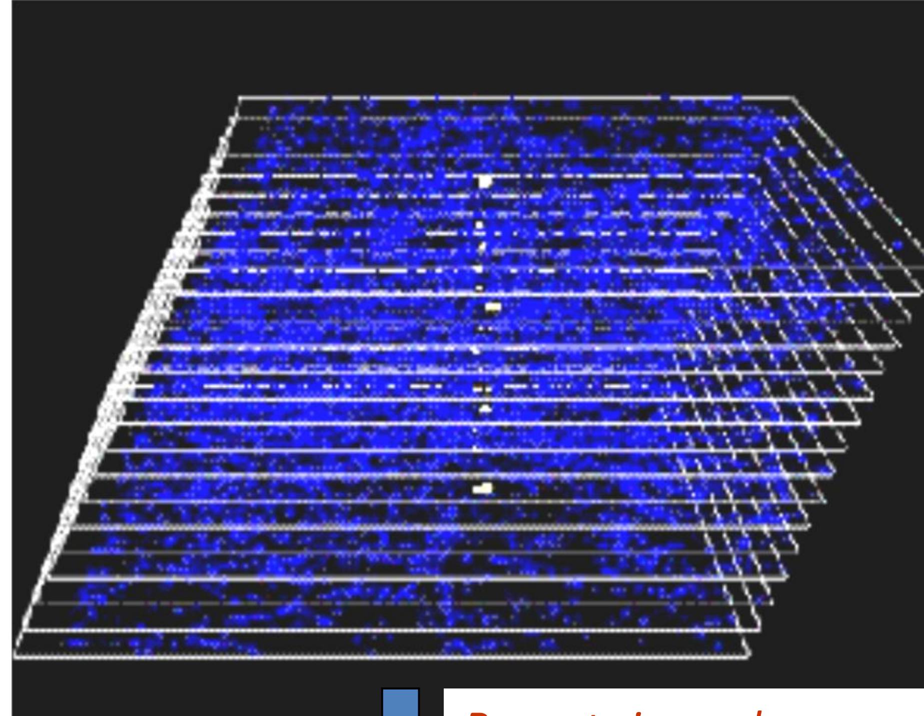
2×10^{12}pixels in each film

(100cm^2 ,w doble side)

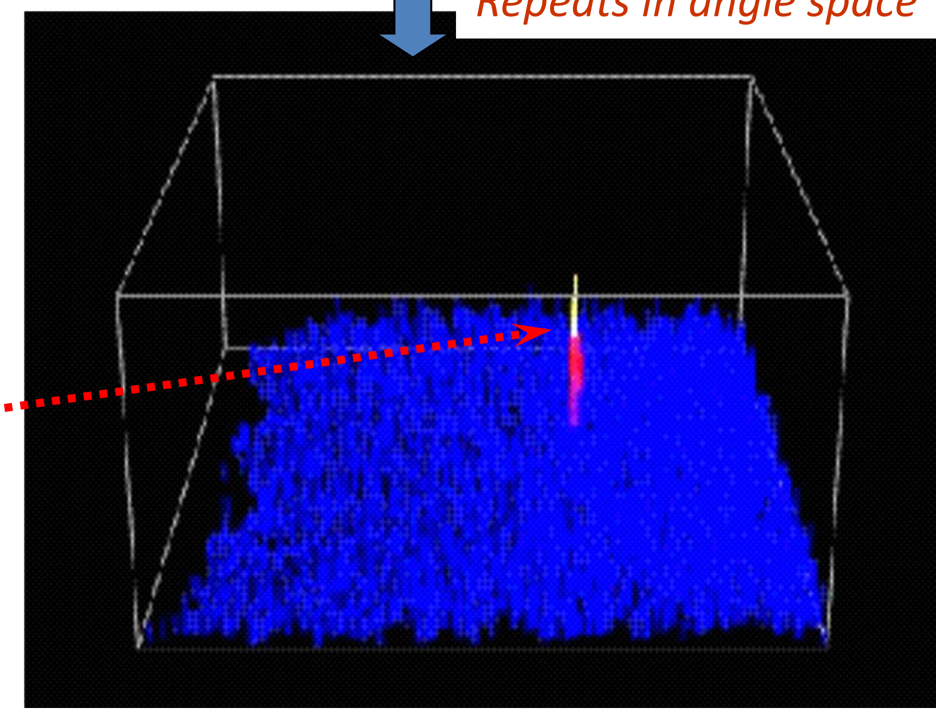


Grain Density ~15 (/45μm), FOG>3000 grain(/view)





Repeats in angle space

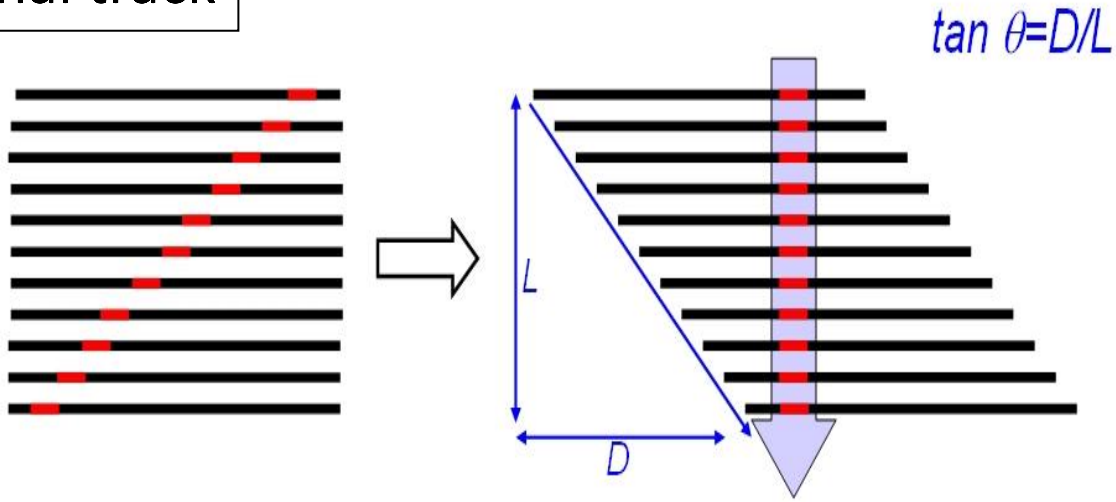


- Take 16 different depth images by microscope optics.
- Shift images to aim at specific angle tracks
- Sum up 16 images to examine coincidence.
- Find signal of tracks.
- Repeat for all angles in FOV : >2000 times

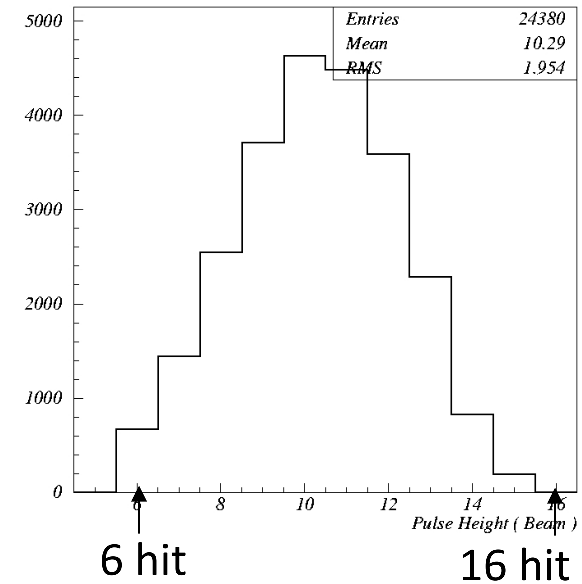
Invented by K.Niwa in 1974

Signal and noise track

Signal track

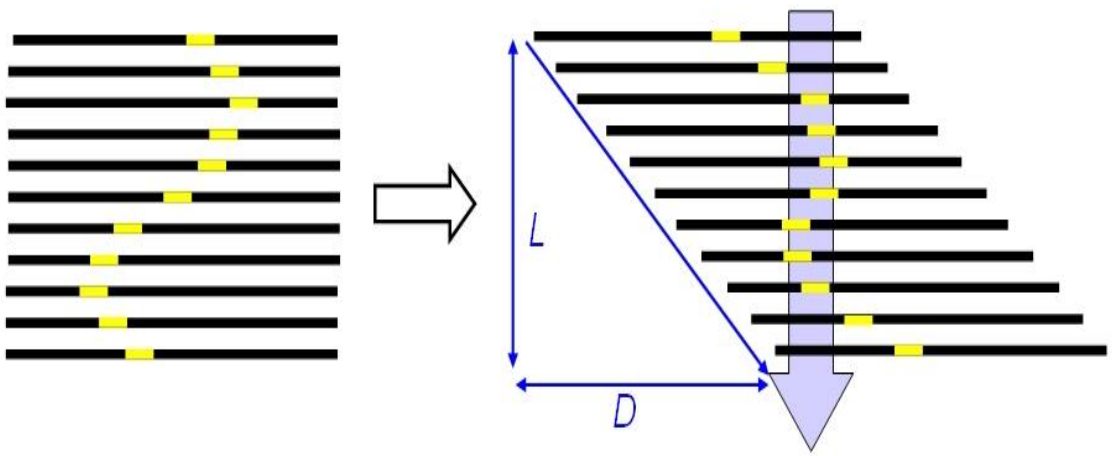


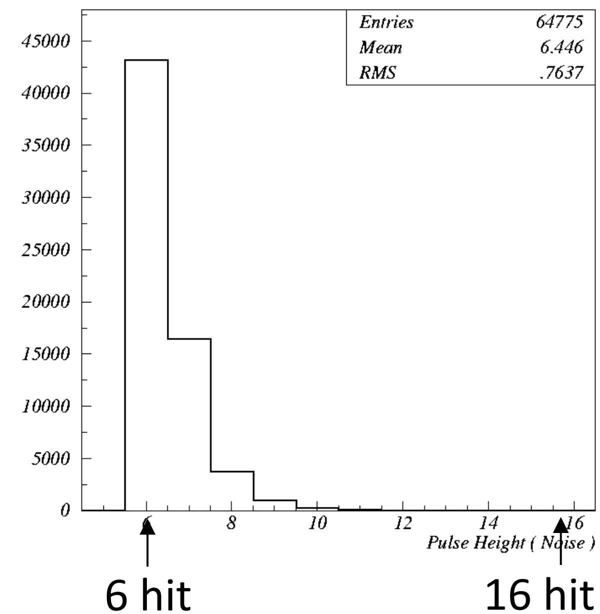
PH分布 (/6mm²)



Noise track

- low energy electron produced by gamma (<1MeV)
- random noise –chance coincidence



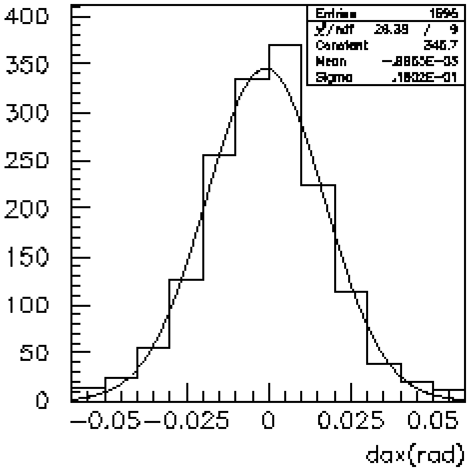


Signal's Ph is higher than noise

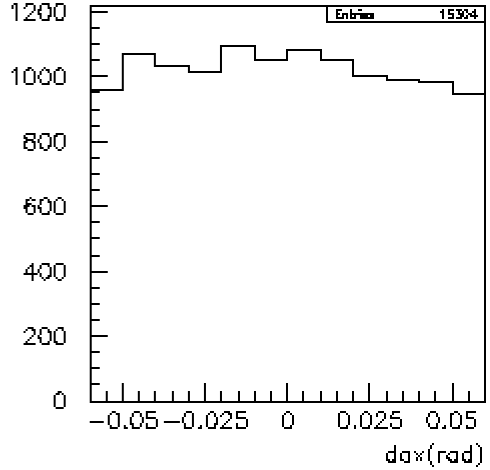
Reconstructed track between base

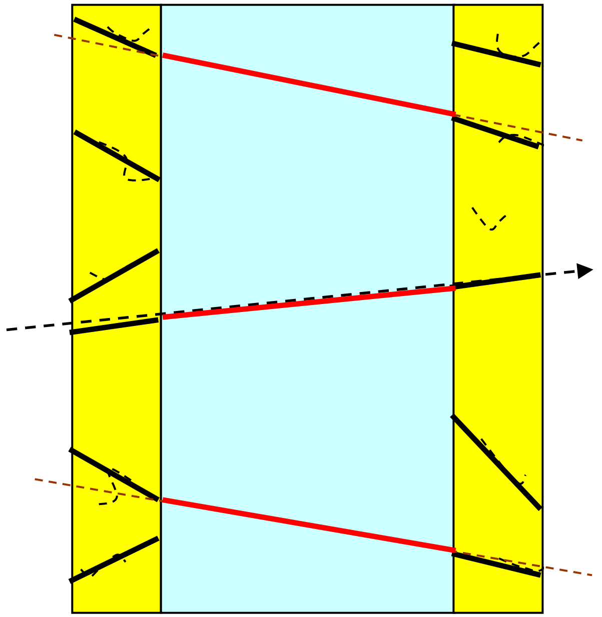
- **Further noise reduction by angle residuals**

Signal track



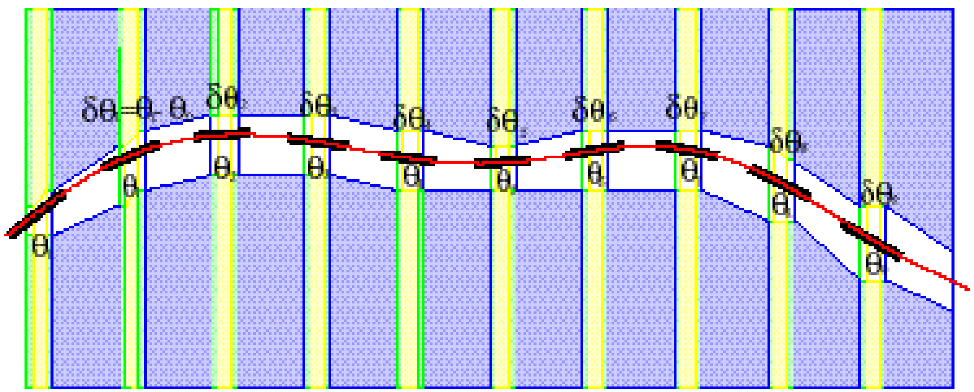
Noise tracks



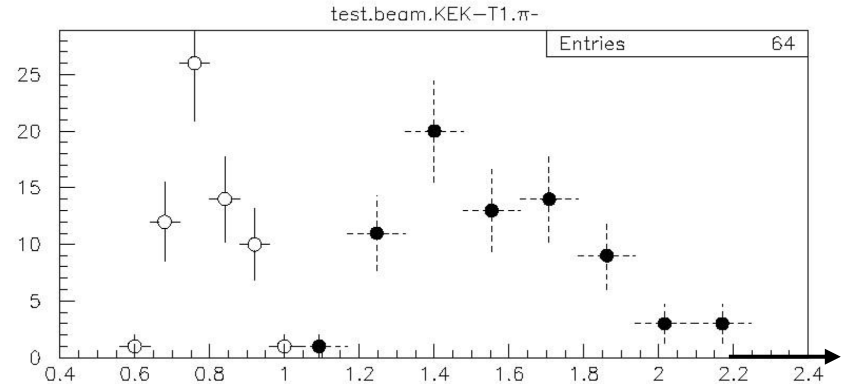


Momentum measurement
： multiple coulomb scattering

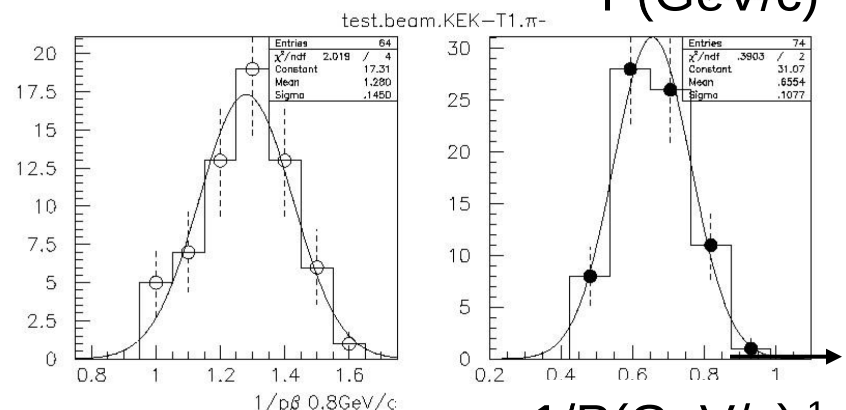
[Angle Method]



$$P\beta = \frac{13.6\ (\mathrm{MeV/c})}{\delta\theta}\sqrt{\frac{x}{X_0}}$$



P(GeV/c)



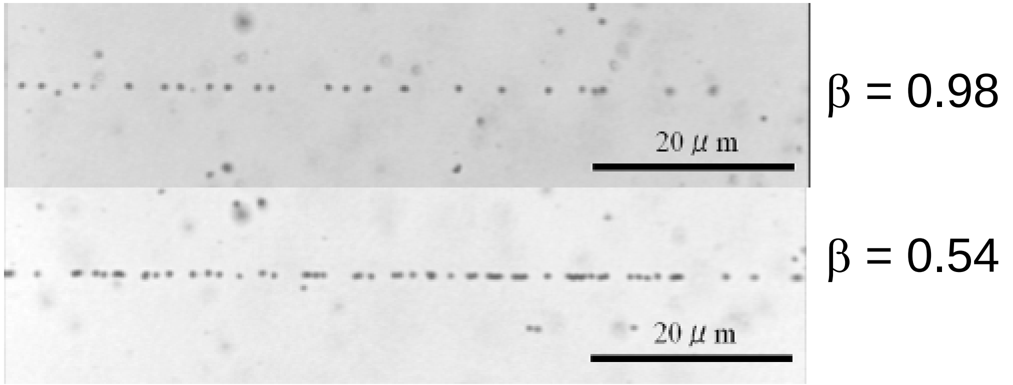
$1/P(\mathrm{GeV/c})^{-1}$

0.8GeV/c pion : P =0.79(GeV/c), dP/P =**11**%
1.5GeV/c pion : P =1.53(GeV/c), dP/P =**16**%

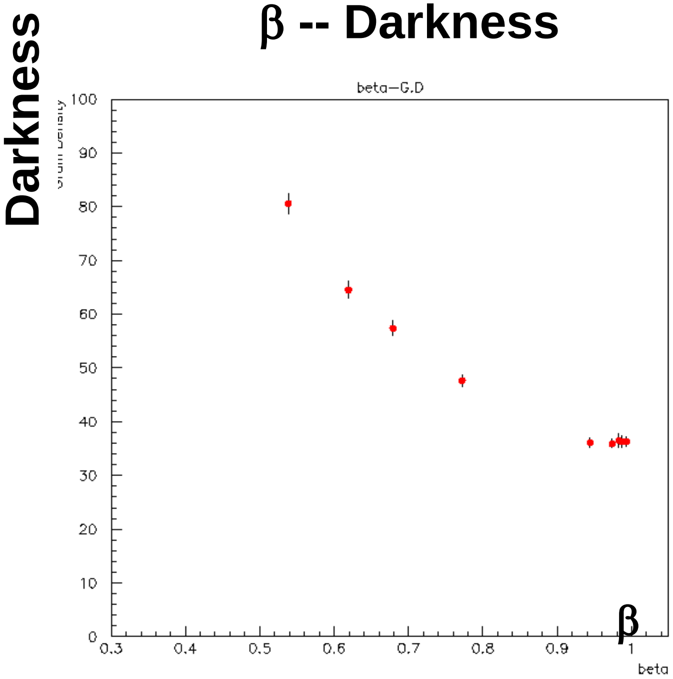
Particle ID

Energy deposition dE/dX measured by track darkness
➔ measurement of β

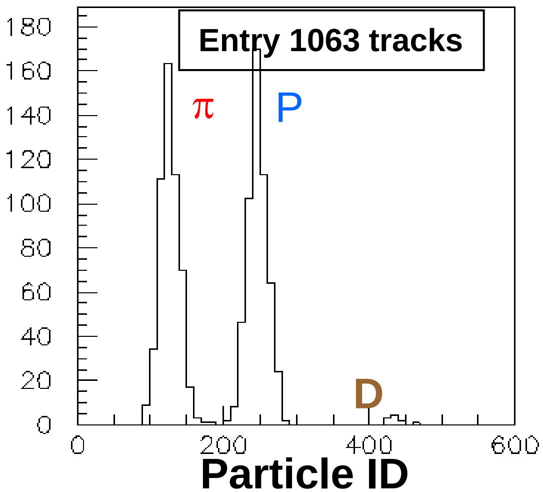
Combining with momentum particle ID.



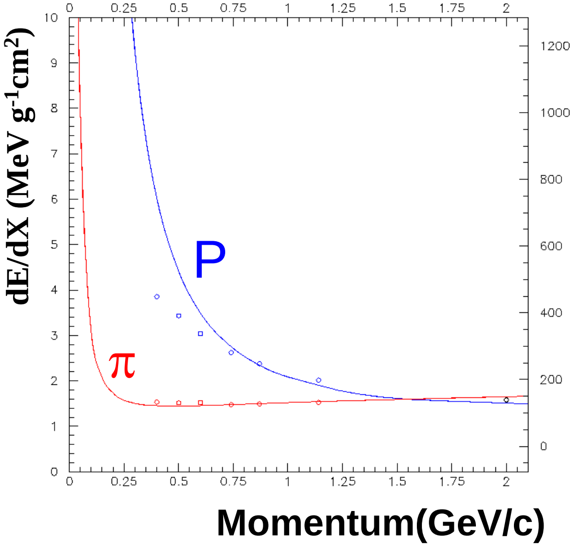
β -- Darkness



0.87 GeV/c



Momentum-dE/dX



Charge determination of nuclear fragment by C 200-400MeV/nucleon interaction with polycarbonate

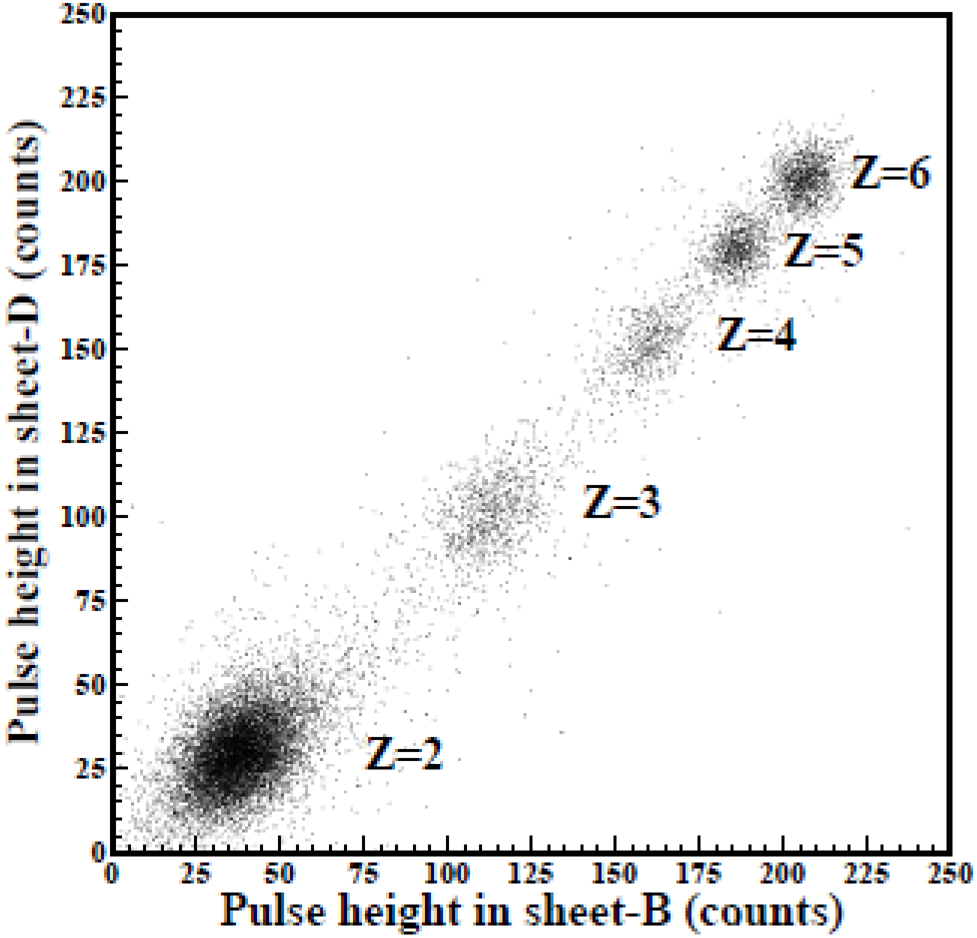


FIG. 3: A scatter plot between averaged pulse heights in sheets-B and sheets-D for secondary tracks. One can see clear discrimination of track charges from Z = 2 to Z = 6.

Long history in Neutrino Research

- 1978-1983 Fermilab E531 <20GeV> ~ 100kg
  charm
  $\nu\mu \to \nu\tau$
- 1990-2000 CERN WA95 CHORUS <27GeV> ~ 1 ton
  ν= Dark matter ? Check by $\nu\mu \to \nu\tau$
  charm
- 1994-2001 Fermilab E872 DONUT <80GeV> ~ 1 ton
  $\nu\tau$ direct observation discovery
- 2000- CERN CNGS01 OPERA <17GeV> 1250 ton
  $\nu\mu \to \nu\tau$

CHORUS

CHORUS detector

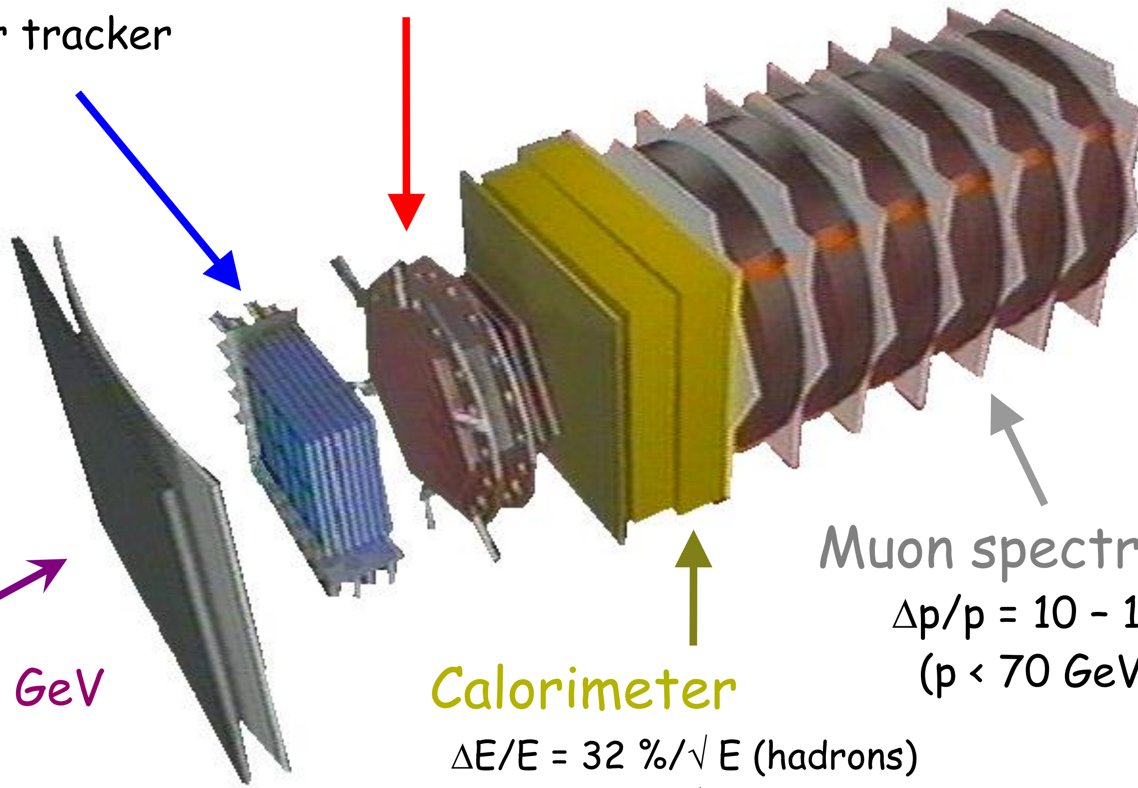
Active target

nuclear emulsion target (770kg)

scintillating fiber tracker

Air-core magnet

$\Delta p/p = 0.035\ p\ (\mathrm{GeV}/c) \oplus 0.22$



ν_μ

~ 27 GeV

CERN SPS

Veto

Calorimeter

$\Delta E/E = 32\ \%/\sqrt{E}$ (hadrons)

$= 14\ \%/\sqrt{E}$ (electrons)

$\Delta\theta_h = 60$ mrad @ 10 GeV

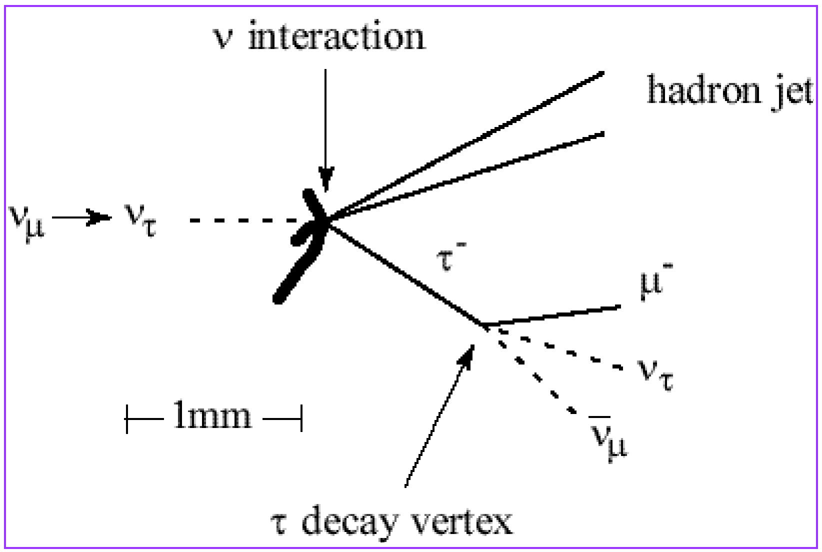
Muon spectrometer

$\Delta p/p = 10 - 15\%$

($p < 70$ GeV/c)

CHORUS search for ν_τ appearance

Direct observation of τ decay in emulsion



$\boxed{\tau \text{ signature = kink}}$

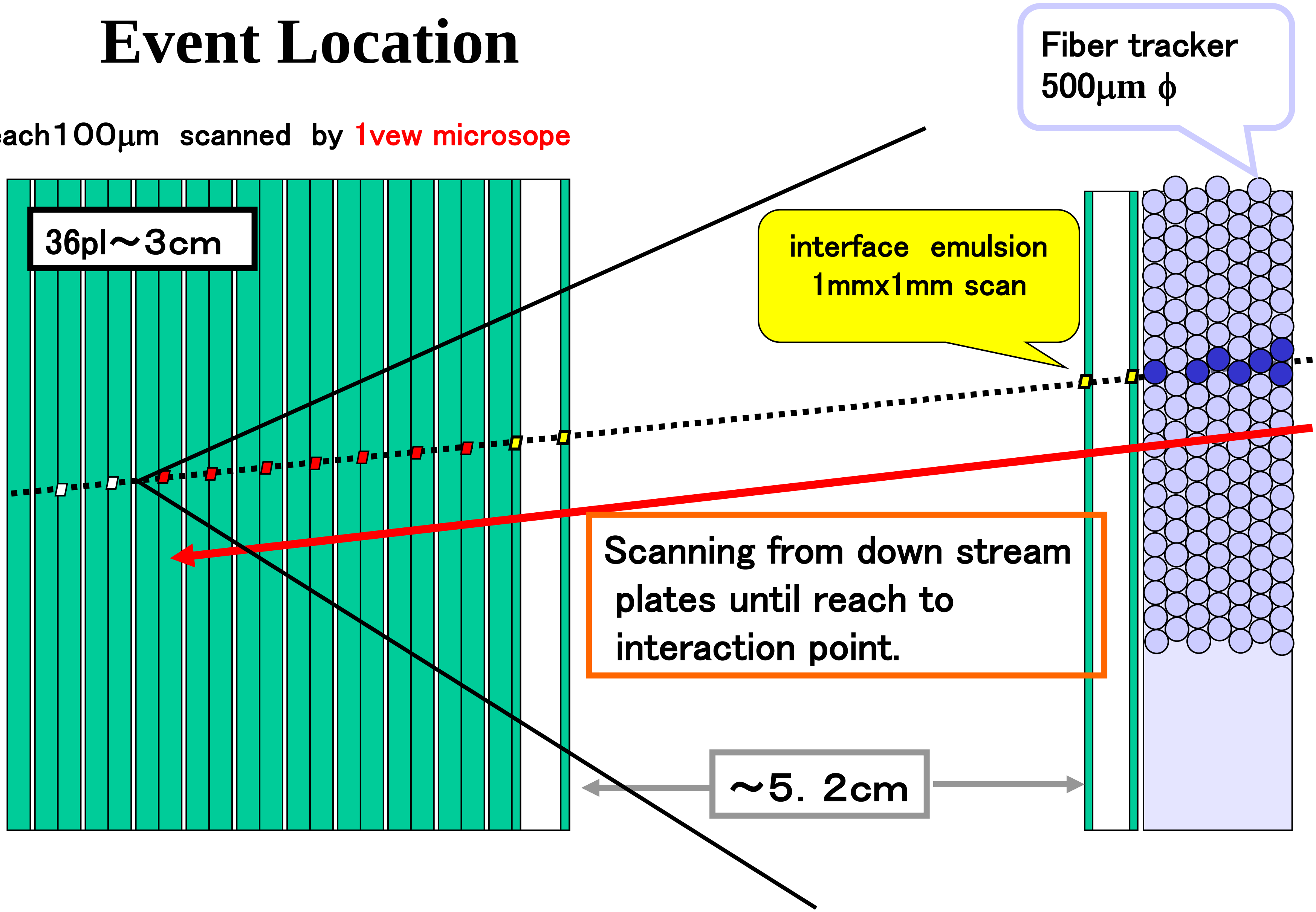
負電荷

τ decay mode	BR
$\tau^- \rightarrow \mu^- \ \nu_\tau \ \bar{\nu}_\mu$	18%
$\tau^- \rightarrow h^- \ \nu_\tau \ n(\pi^o)$	50%
$\tau^- \rightarrow e^- \ \nu_\tau \ \nu_e$	18%

need very high spatial resolution ➡ tracking by emulsion

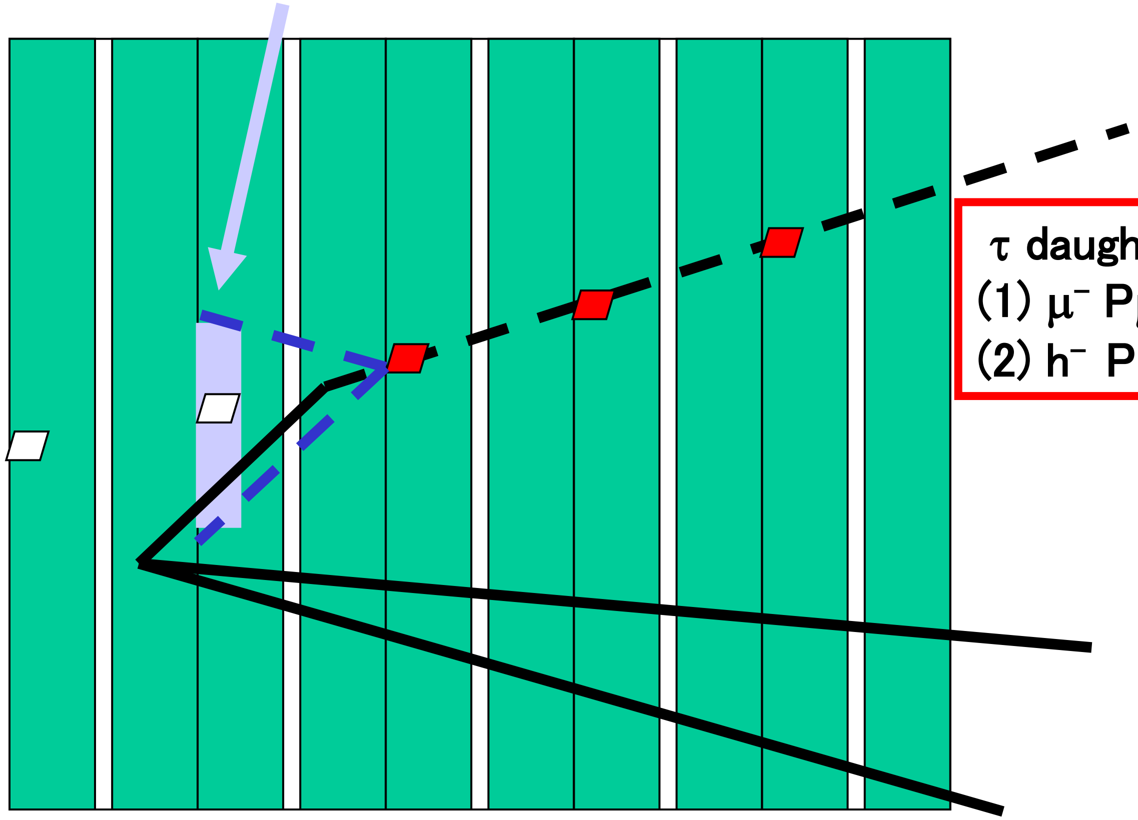
Event Location

each100μm scanned by 1vew microsope



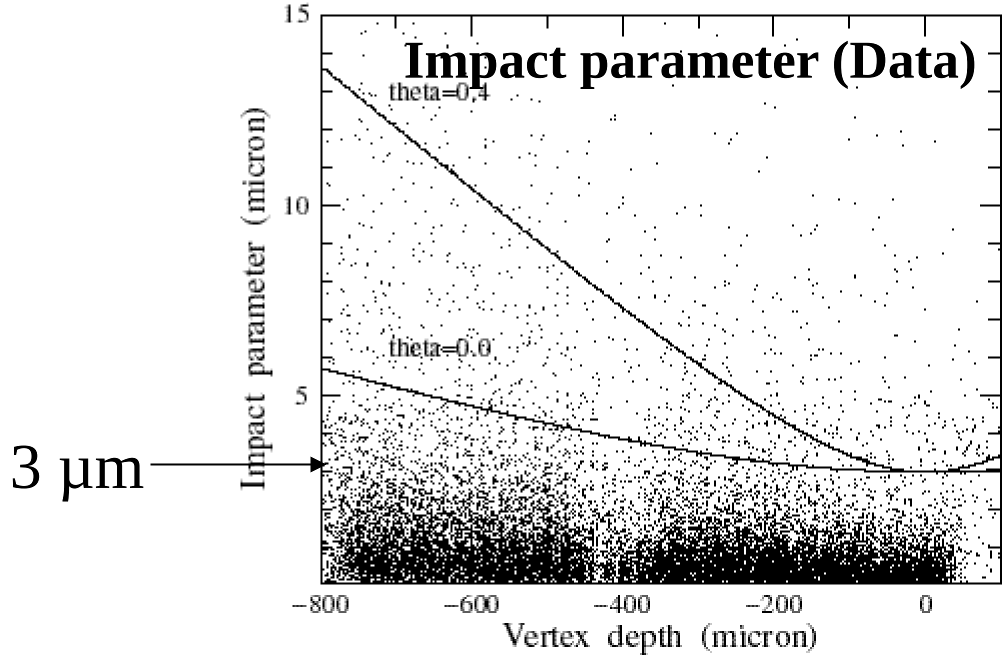
Parent search

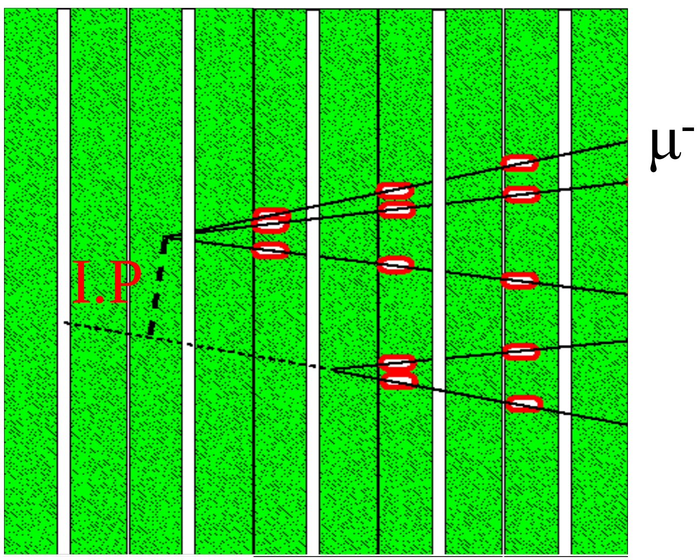
Search and pick up all track segments for possible tau angle assuming decay PT<1GeV.
Human eye inspection for concluding



τ daughter selection
(1) μ^- $P\mu < 30$ GeV/c
(2) h^- Ph 1～20 GeV/c

NetScan Offline selection





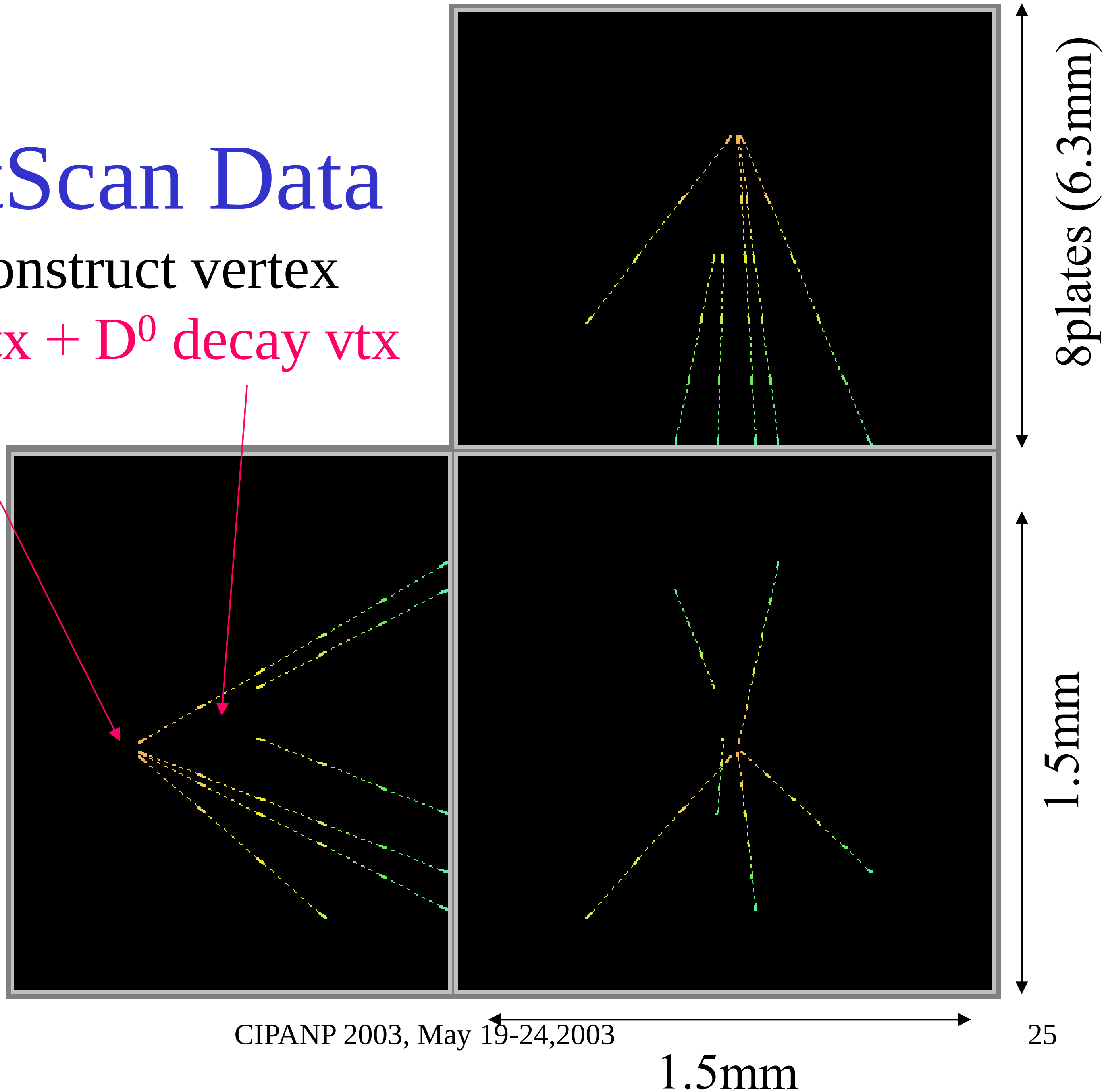
- **Tracks confirmed by fiber tracker at downstream of emulsion**
  - **Even not reconstructed tracks by Target Tracker**
- **Big impact parameter to 1ry vertex, $r > \sqrt{(3.^2 + (2\sigma dz)^2)}$ μm**

⇒ Eye confirmation or further selection

NetScan Data

reconstruct vertex

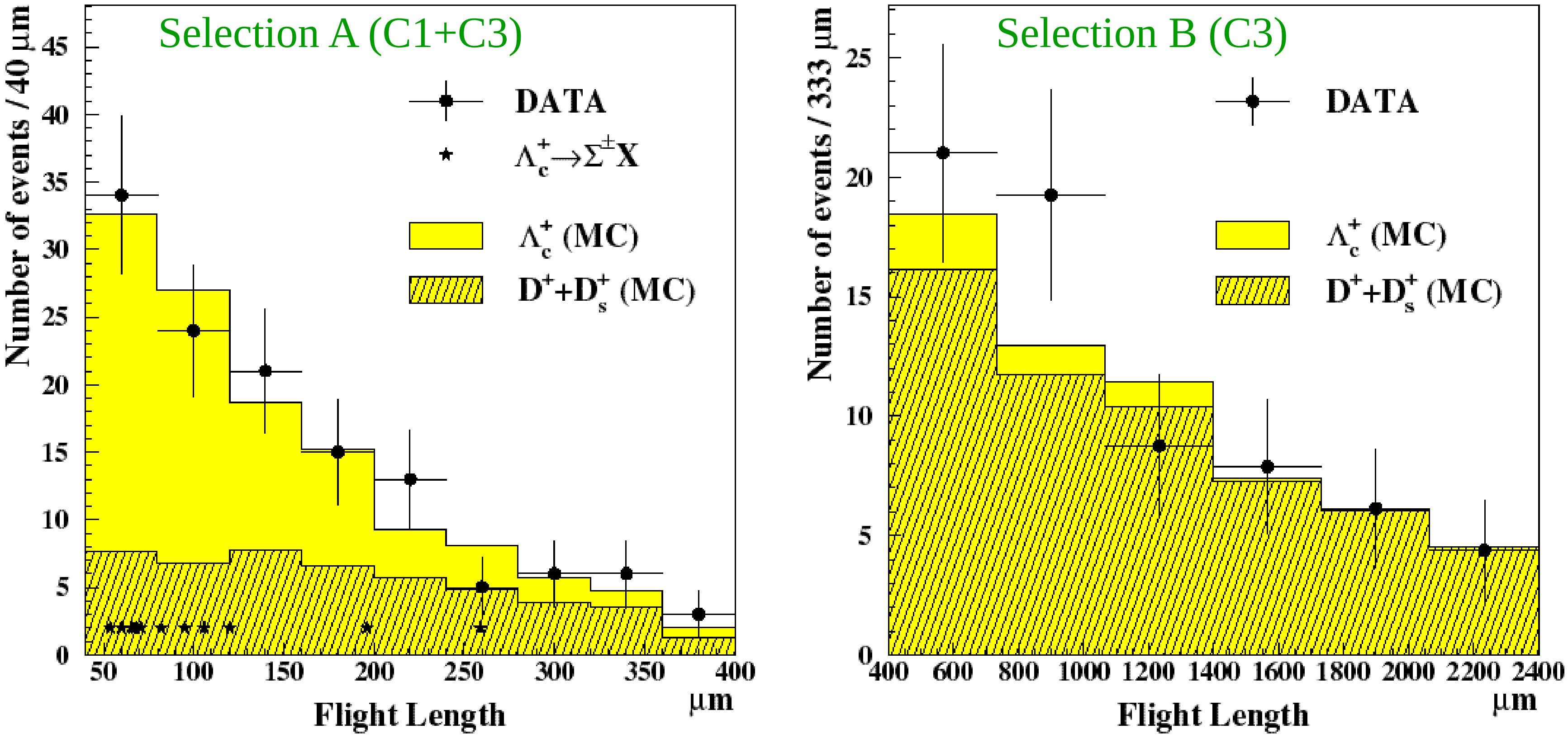
vint.vtx + D^0 decay vtx



Detected Charmed particle in CHORUS

Decay topology	Detected events	Back ground estimation
C1 Charged 1prong	**452**	**43.4 ± 2.4**
N2 Neutral 2prong	**819**	**36.6 ± 3.5**
C3	**491**	**3.8 ± 0.2**
N4	**226**	**negligible**
C5	**22**	**1.5 ± 0.1**
N6	**3**	**negligible**
計	**2013**	**85.2**

Charged charm flight length
(In Λ_c^+ analysis)



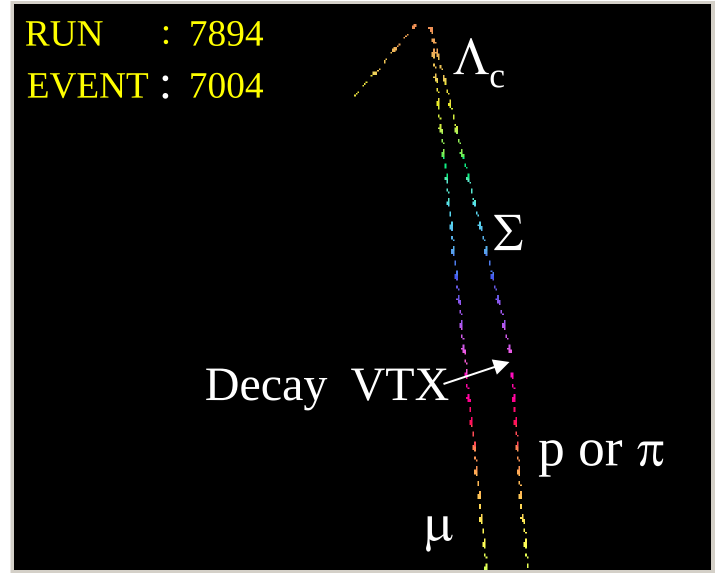
$\Lambda_c^+ \rightarrow \Sigma^{\pm}$ Event

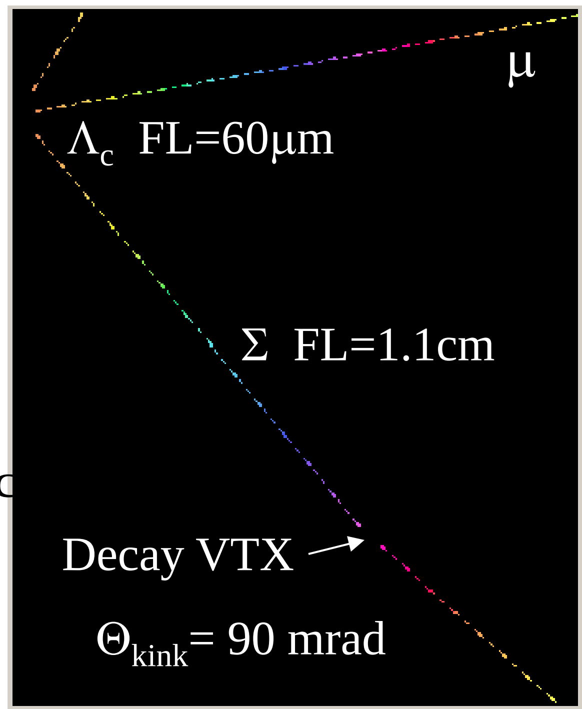
Λ_c^+ evidence search

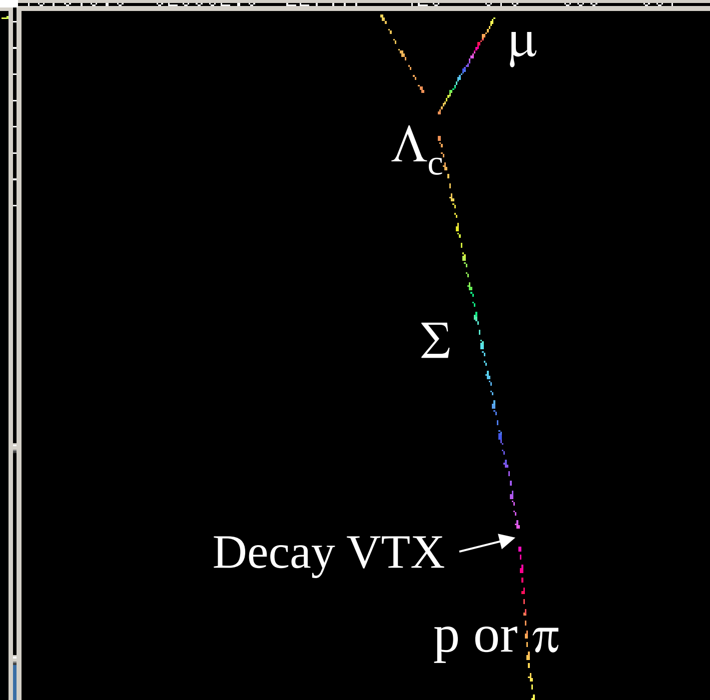
12 candidates has found

$$B(\Lambda_c \rightarrow \Sigma^{\pm}\ \text{any}) = 10 \pm 5\ \%$$

Phys Rev. D33:1(1986) : 5 events







$P_{\text{daughter}} = 2.6^{+1.7}_{-0.8}$ GeV/c

$\sin\theta_{\text{kink}} = 0.09$

⇨ $P_T = 234^{+153}_{-72}$ MeV/c

Summary of τ search in CHORUS

Proton on target (1994,1995,1996,1997) 5.06 $\times 10^{19}$

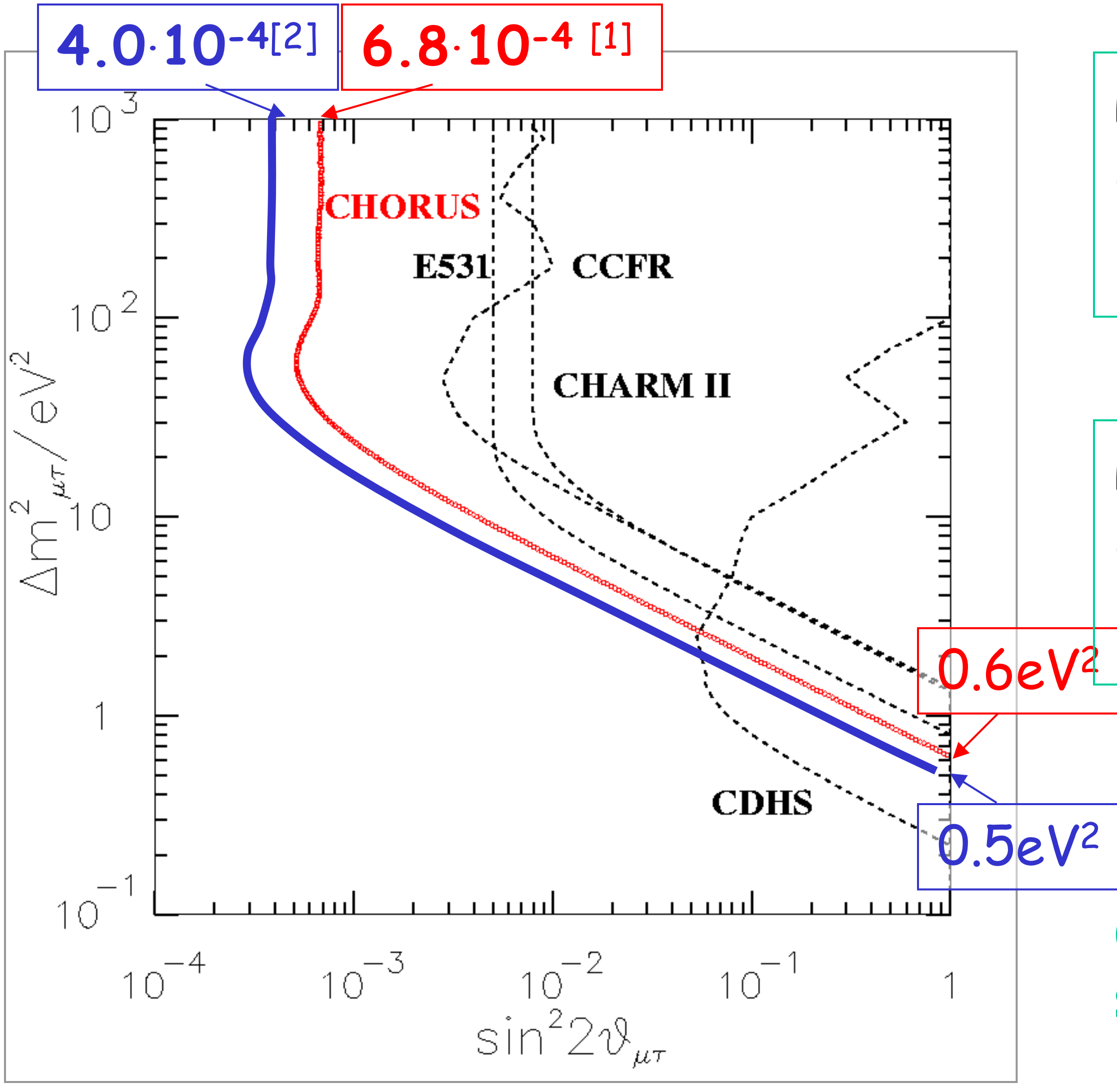
1μ

Events with 1 μ- and vertex in emulsion	713,000
p μ- < 30 GeV/c and angular selections	477,600
Events scanned	355,395
Vertex located	143,742
Events selected for eye-scan	11,398
Kink candidates after eye-scan	0

0μ

Events with vertex in emulsion	335,000
1 < P_h- < 20 GeV/c and angular selections	122,400
Events scanned	85,211
Vertex located	20,081
Events selected for eye-scan	2,282
Kink candidates after eye-scan	0

Exclusion Plot



at 90% CL [1]

$P_{\mu\tau} < 3.4\cdot10^{-4}$
Or, for large Δm^2
$\sin^2 2\theta_{\mu\tau} < \mathbf{6.8\cdot10^{-4}}$

at 90% CL [2]

$P_{\mu\tau} = 2.0\cdot10^{-4}$
Or, for large Δm^2
$\sin^2 2\theta_{\mu\tau} < \mathbf{4.0\cdot10^{-4}}$

Phys.Lett B497:8-22,2001

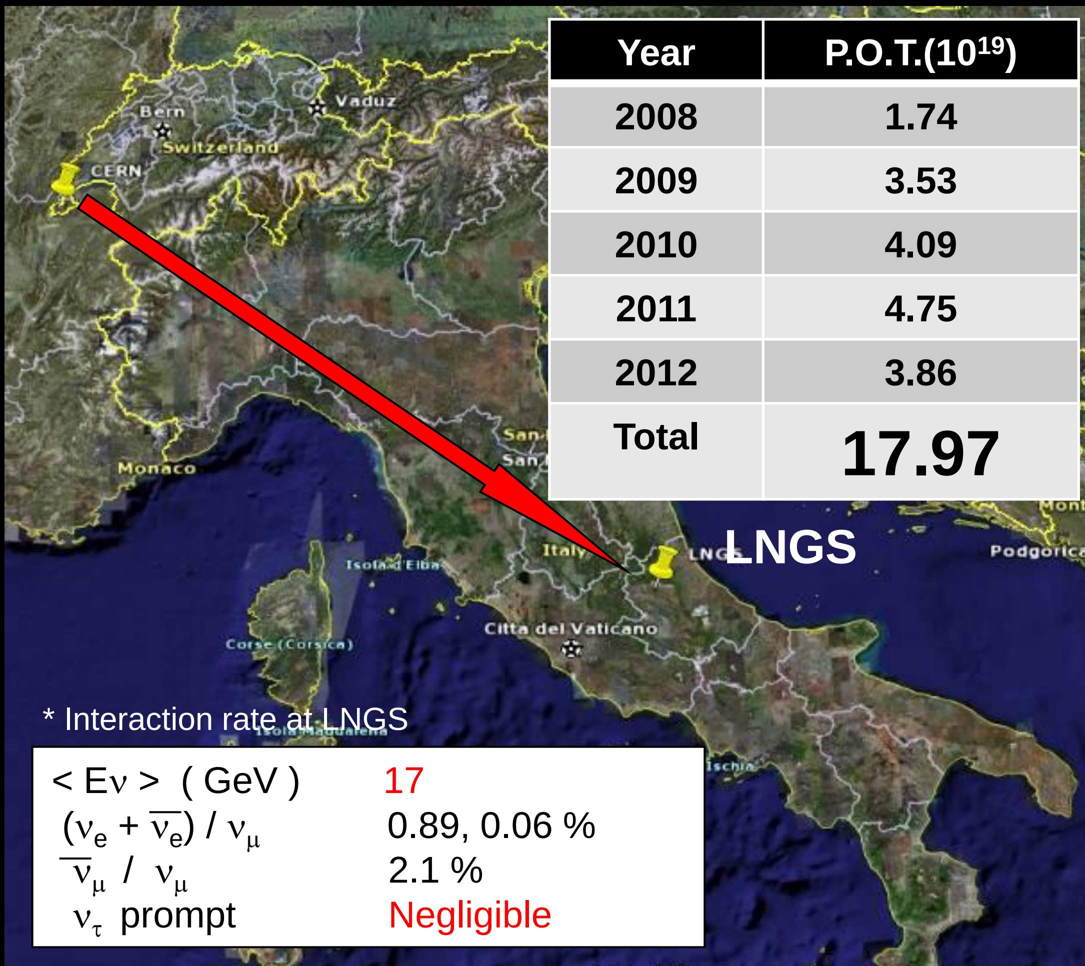
Comparable with NOMAD
$\sin^2 2\theta_{\mu\tau} < \mathbf{4.0\cdot10^{-4}}$

[1] T.Junk, NIM A434 (1999) 435
[2] G.J.Feldman and R.D. Cousins, Phys.Rev. D57 (1998) 3873

OPERA

CNGS （Baseline 732 km、<Ev>17GeV）

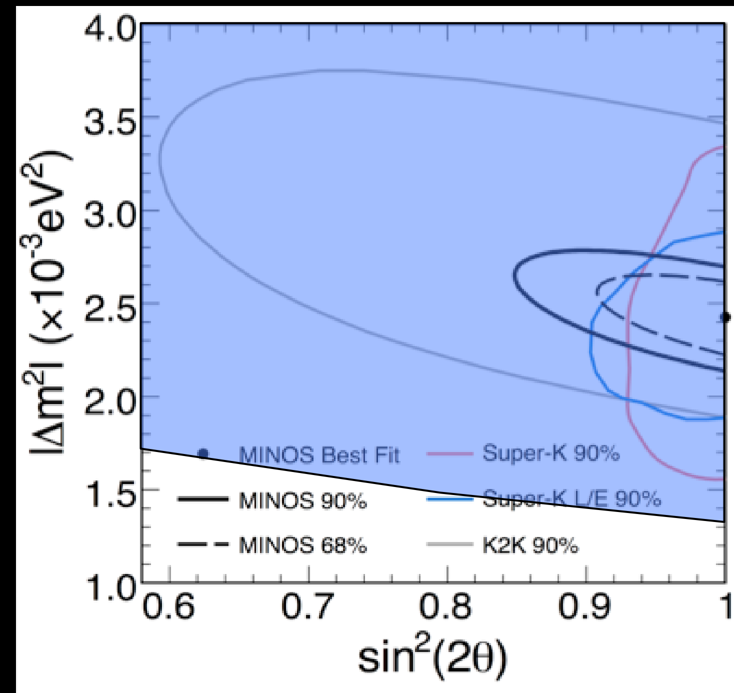
$$P(\nu_\mu \to \nu_\tau) \sim \sin^2(2\theta_{23}) \cdot \sin^2\left(1.27 \cdot \Delta m^2_{23} \cdot \frac{L}{E}\right) \sim 1.7\%$$



Year	P.O.T.(10^{19})
2008	1.74
2009	3.53
2010	4.09
2011	4.75
2012	3.86
Total	**17.97**

* Interaction rate at LNGS

< Eν > (GeV)	17
$(\nu_e + \overline{\nu}_e) / \nu_\mu$	0.89, 0.06 %
$\overline{\nu}_\mu$ / ν_μ	2.1 %
ν_τ prompt	Negligible

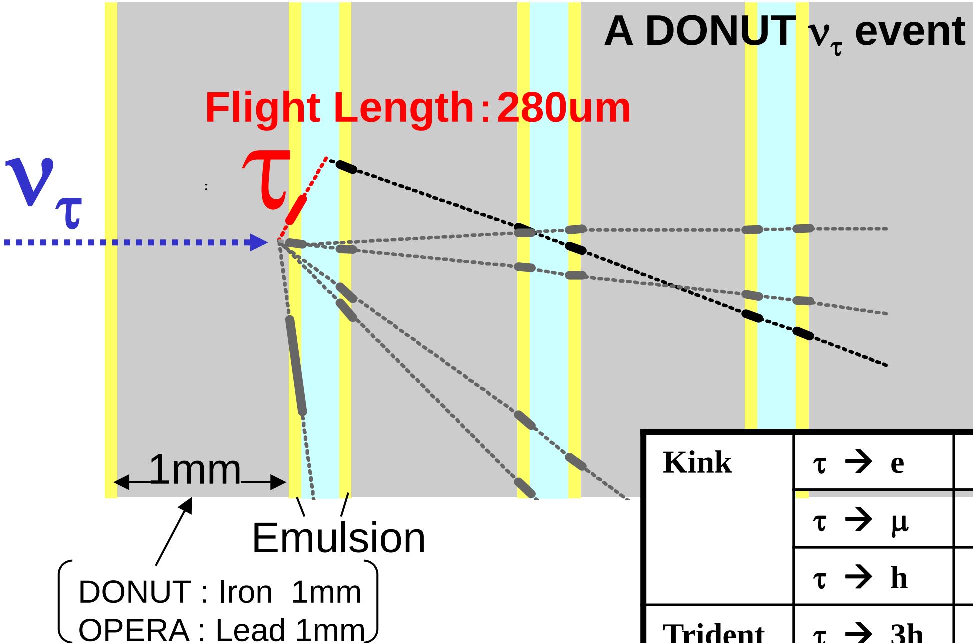


Covers the region indicated by Super-K, K2K & MINOS

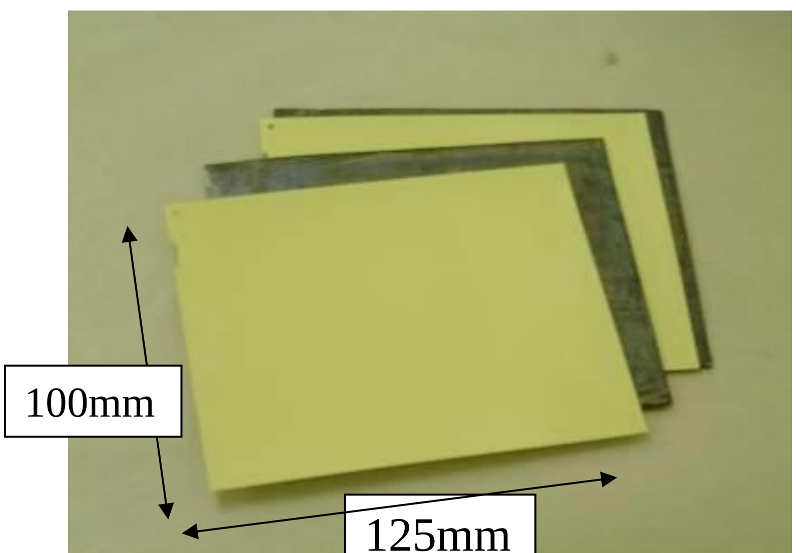
22.5×10^{19} POT (proposal) → Expected Events 7.6 Signal, 0.8 Background

OPERA ECC : Camera for neutrino interactions

Pb(1mm) / emulsion (OPERA film) interleaved structure



Kink	$\tau \rightarrow e$	18 %
	$\tau \rightarrow \mu$	17 %
	$\tau \rightarrow h$	49 %
Trident	$\tau \rightarrow 3h$	15 %



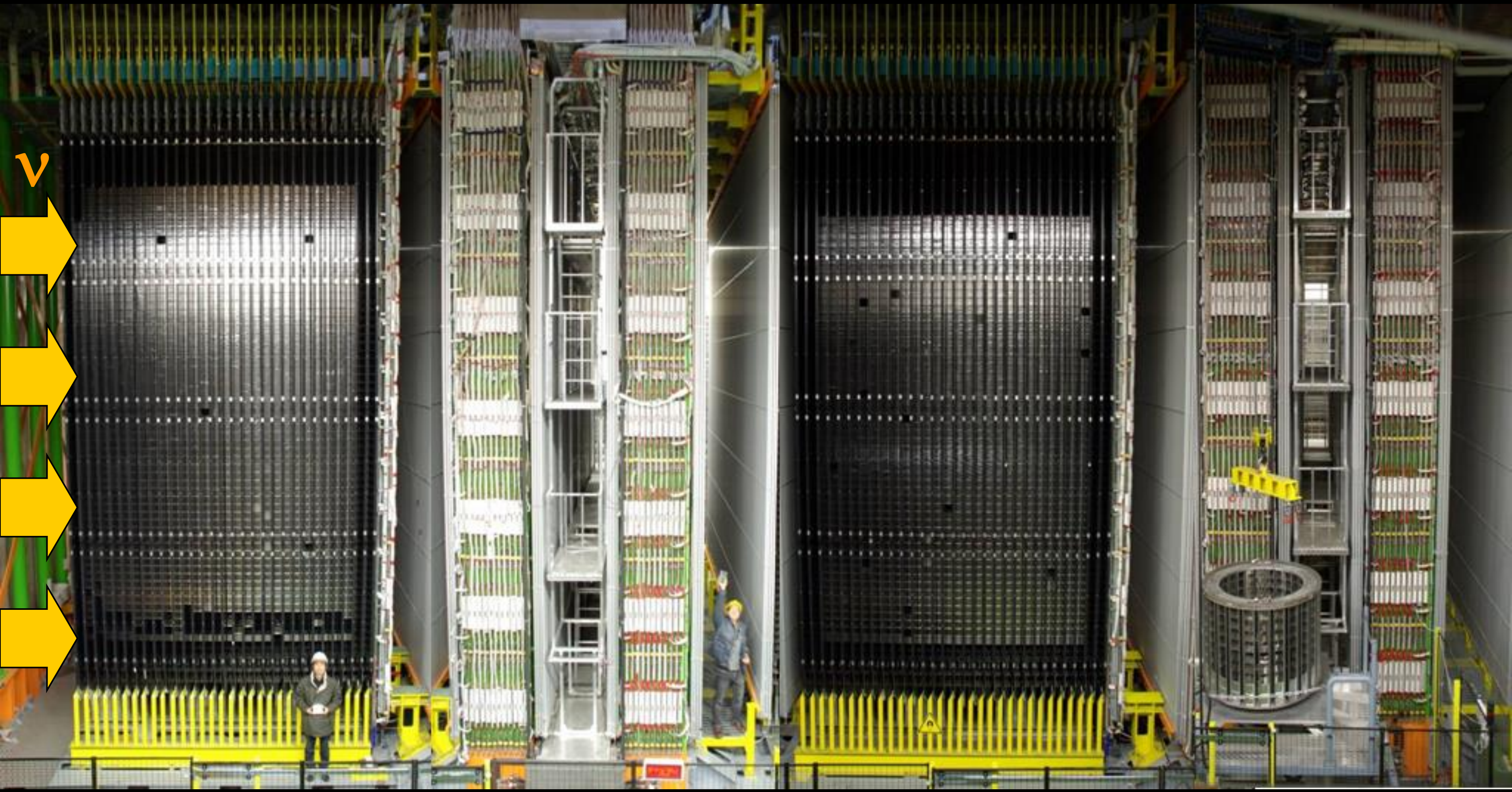
56 Pb plates + 57 emulsion plates , weight 8.3 kg

150,000 ECC 1250 ton target

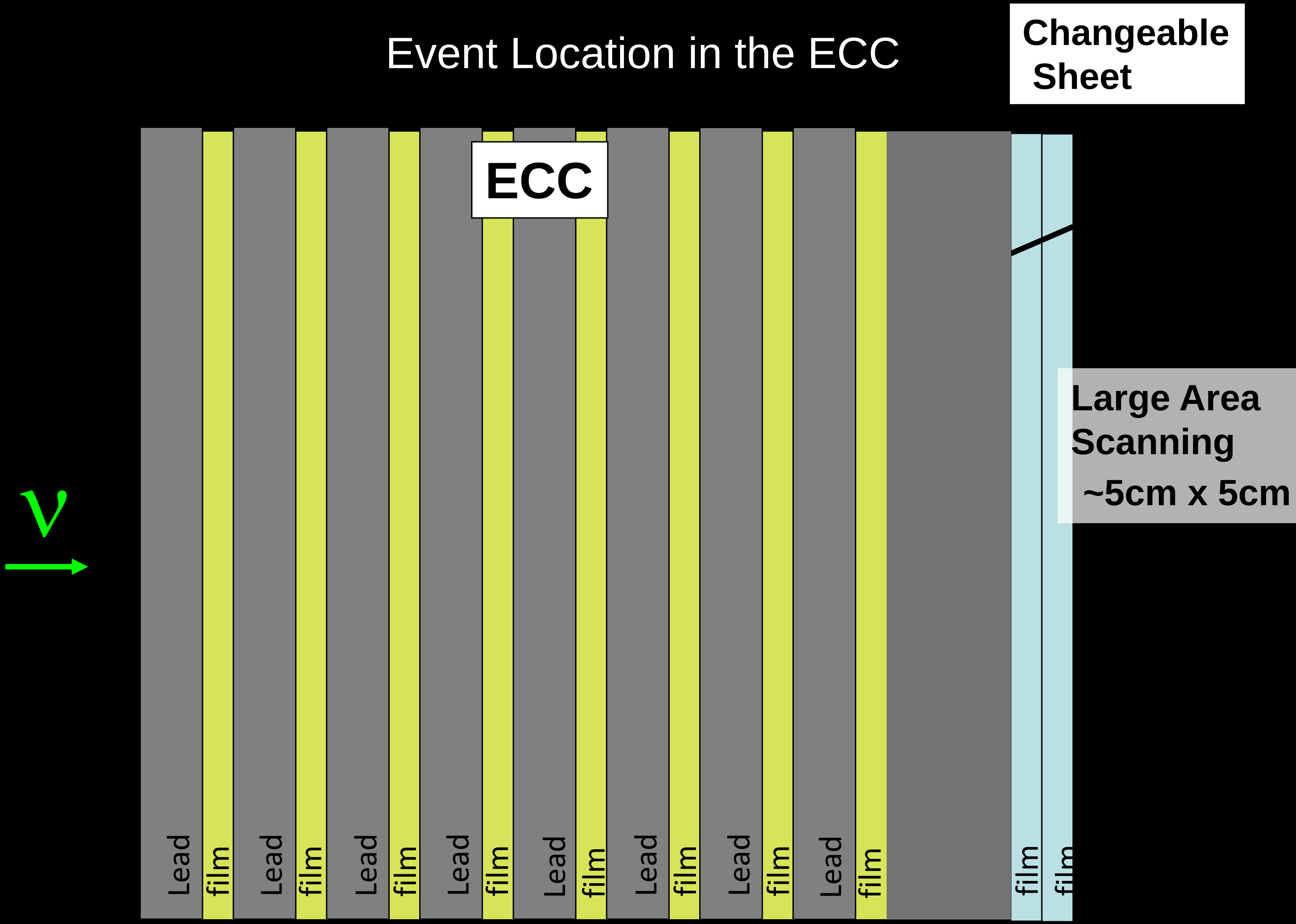
9.3 million emulsion sheets

OPERA detector @ 1400m Underground Gran Sasso

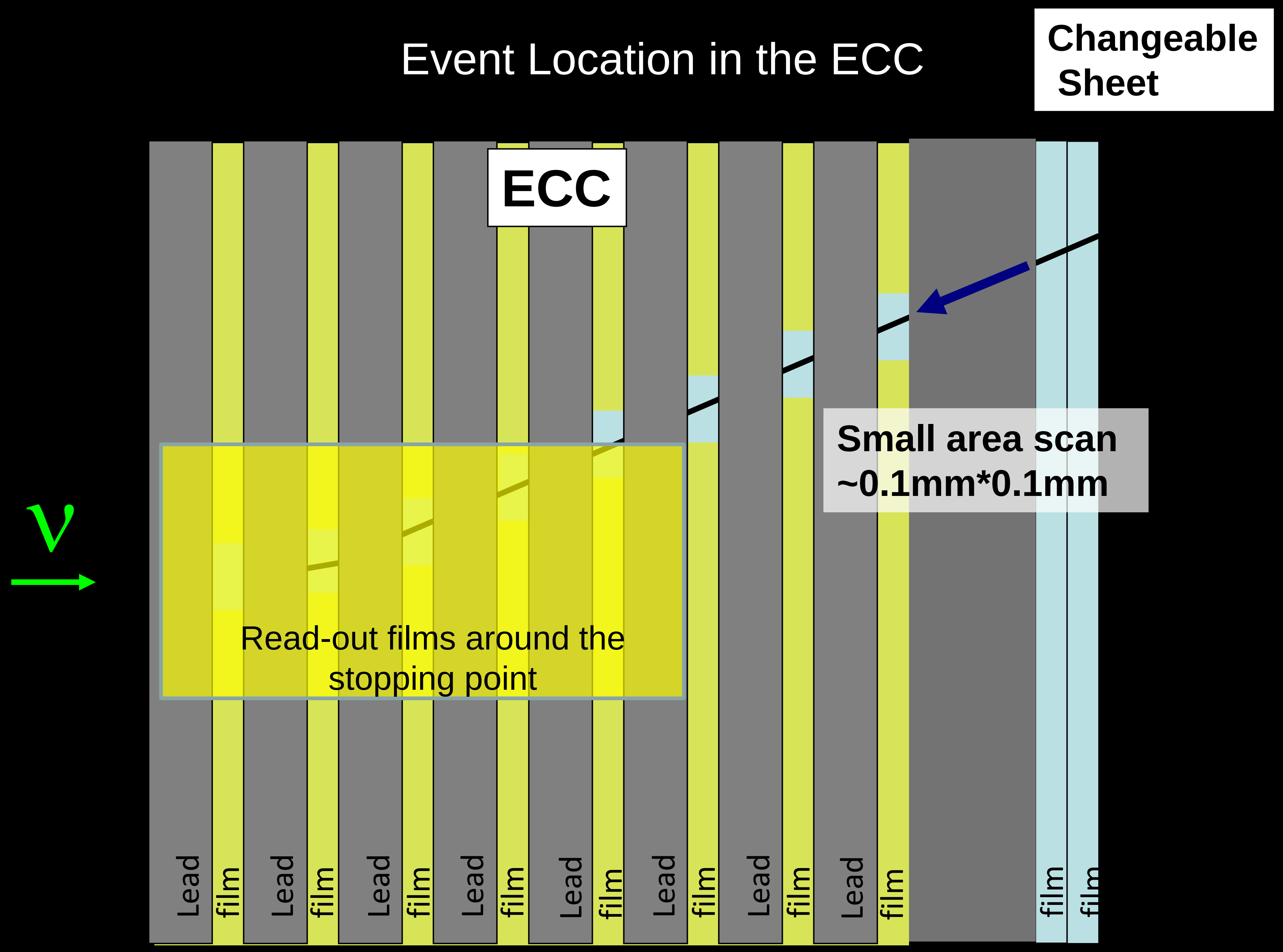
150,000 ECC 1.25kt: exposed to the neutrino beam



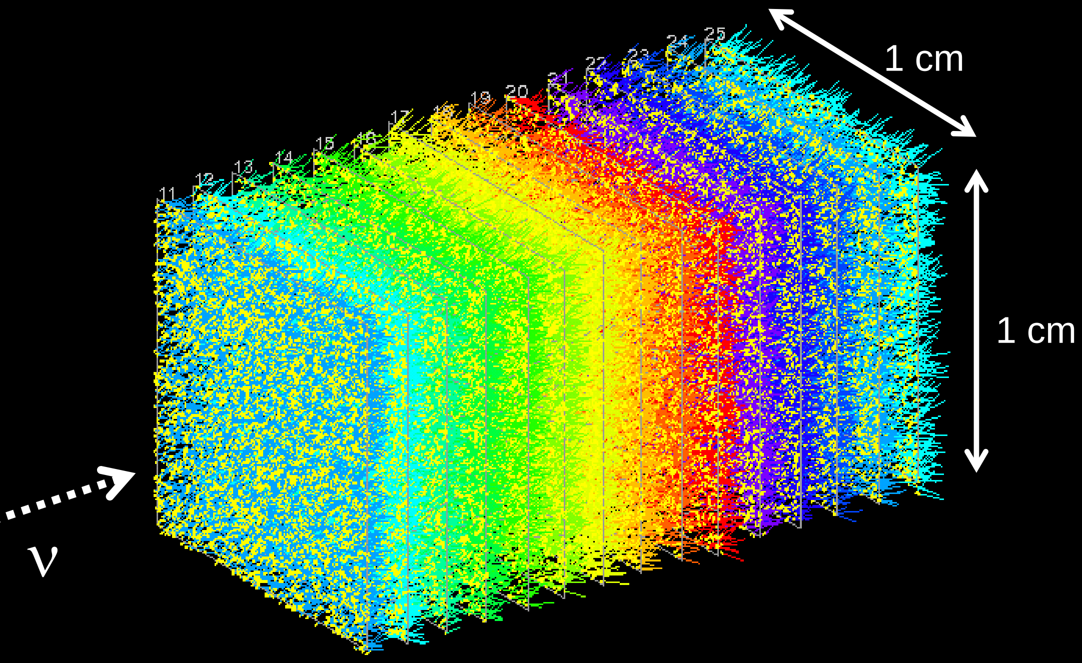
Event Location in the ECC



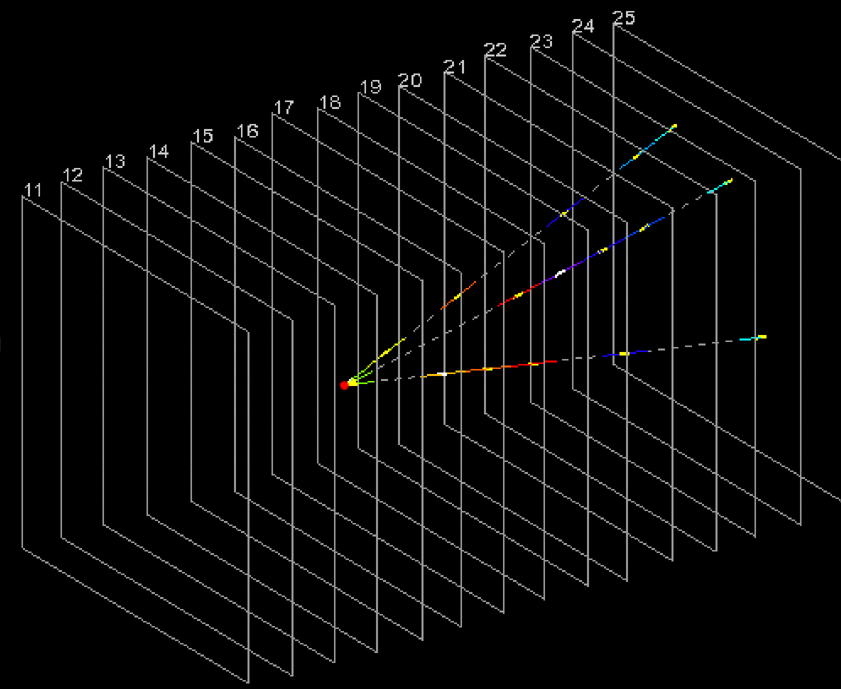
Event Location in the ECC



Neutrino interaction reconstruction



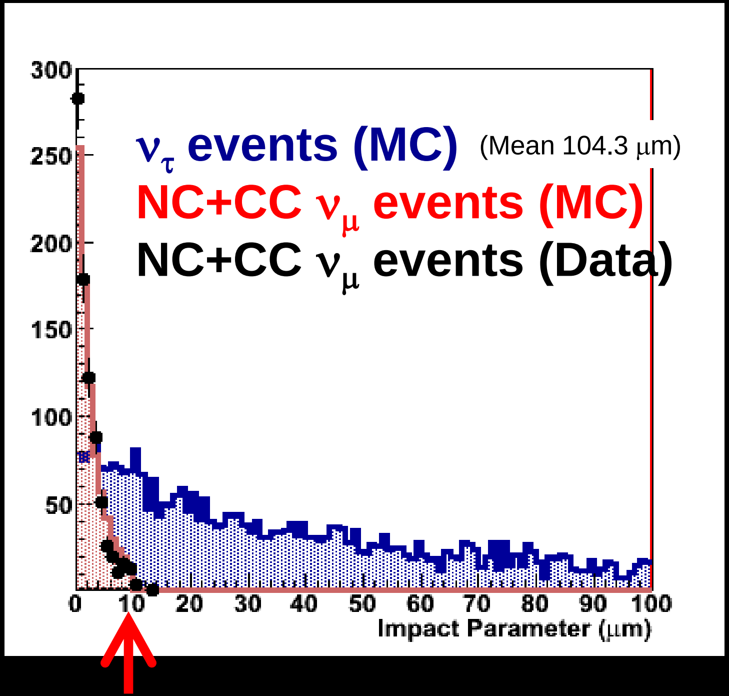
Raw track segments



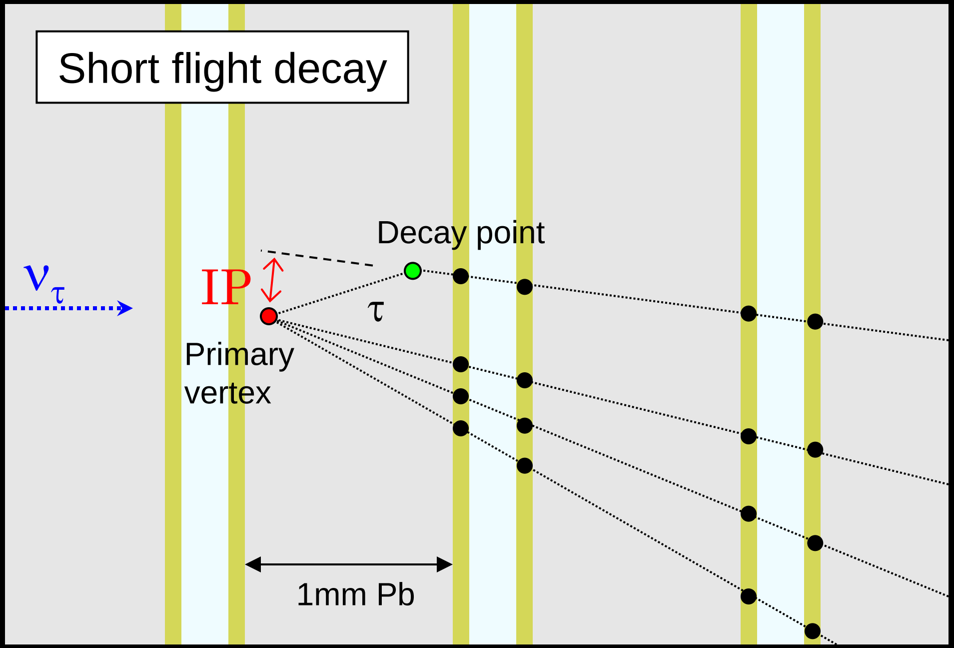
Connecting track originating from the volume.

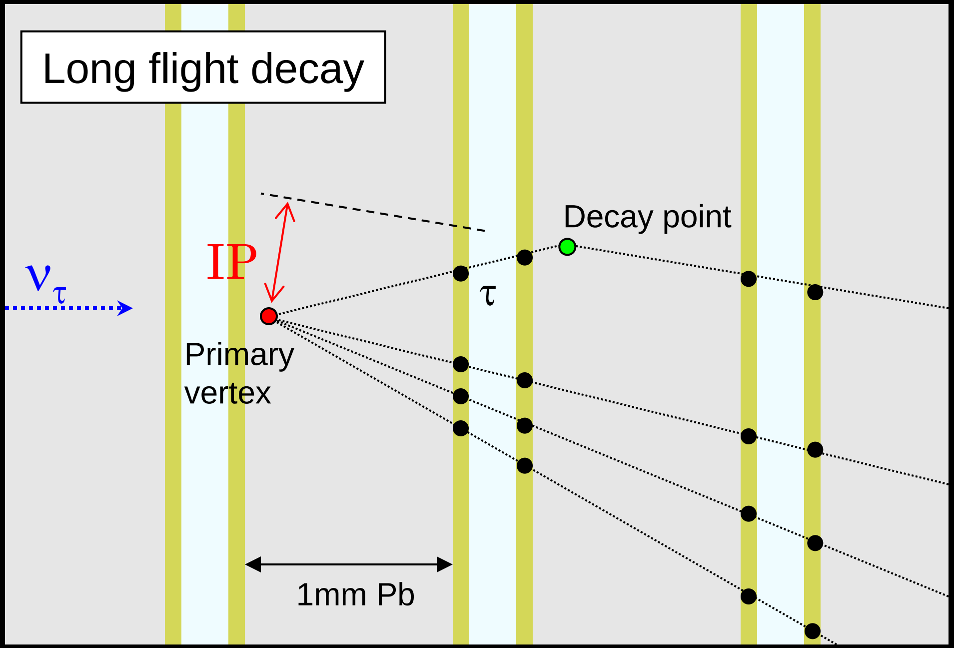
ν_τ CC Detection

Impact Parameter distribution

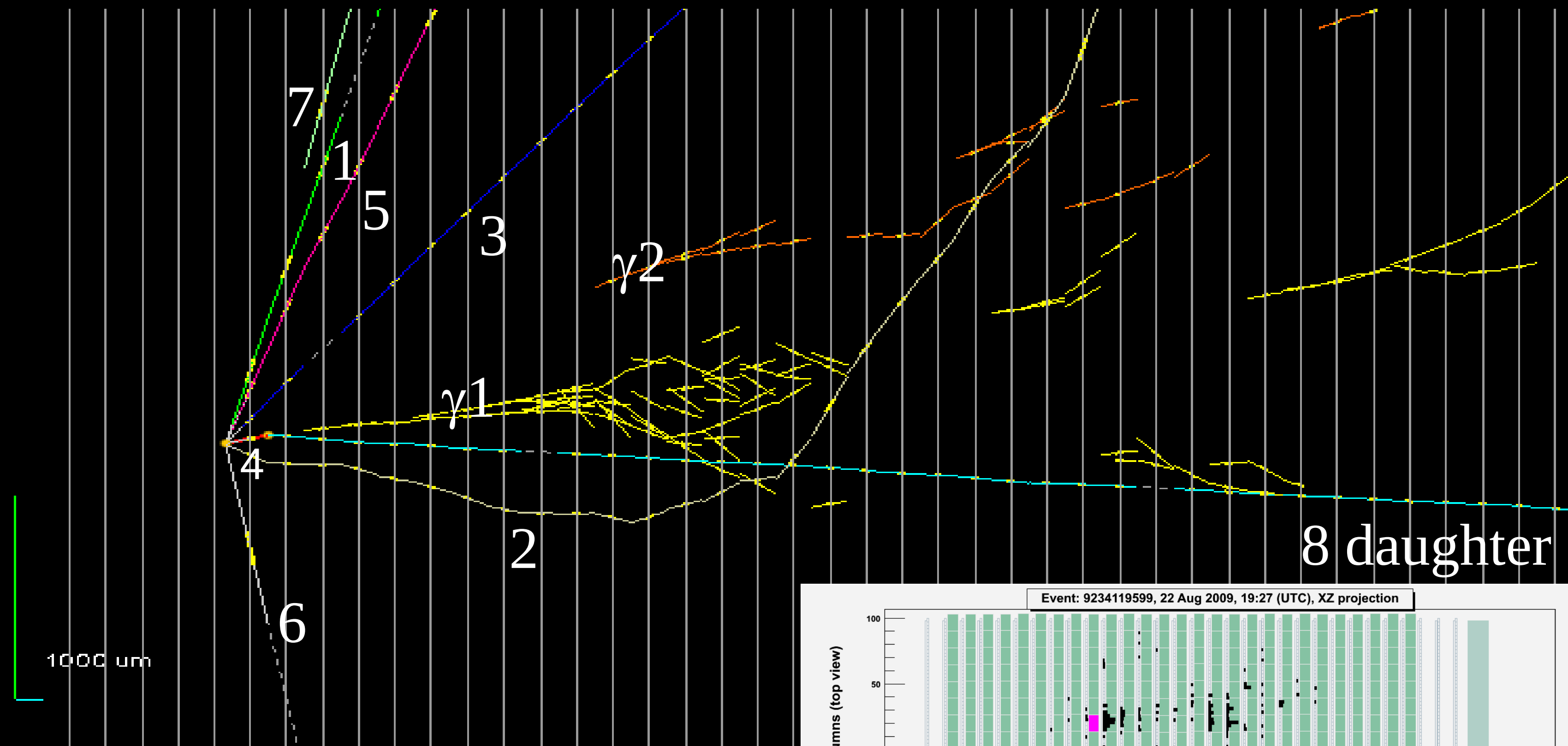


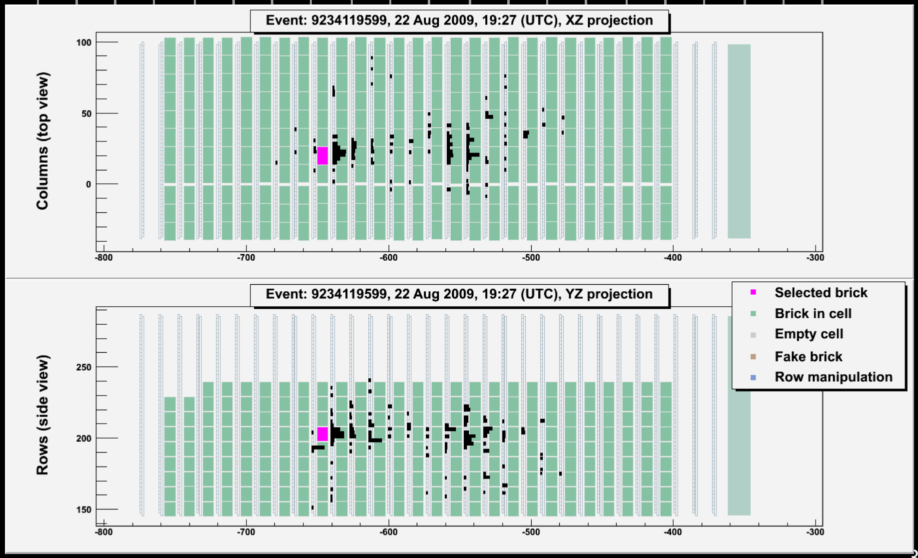
10 μm ↔ ($c\tau$ = 87μm)

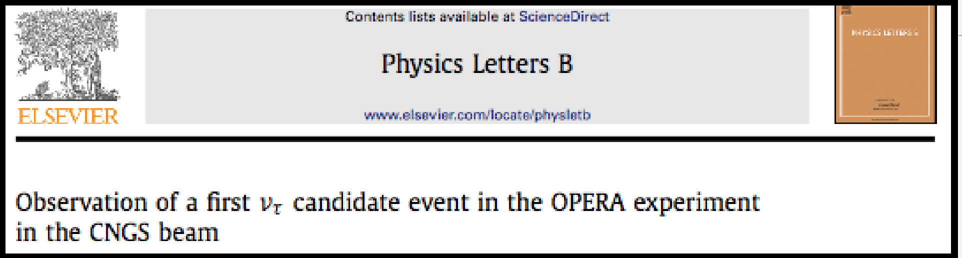




The first ν_τ event NEUTRINO2010 (O.Sato)







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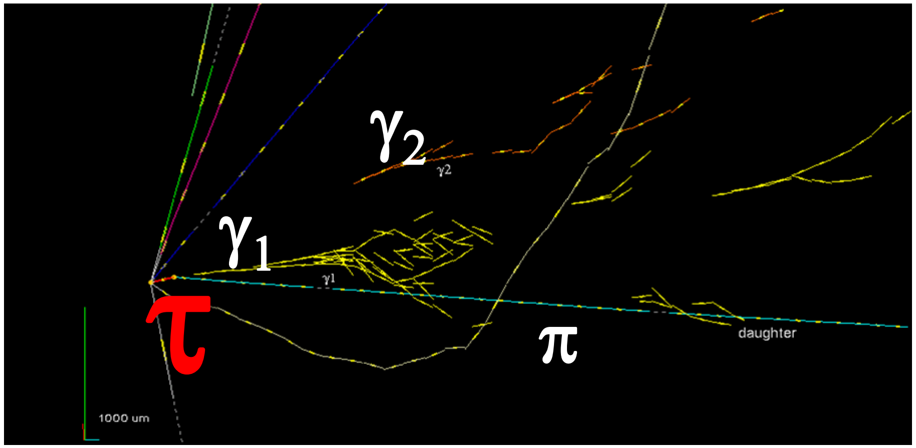
ELSEVIER

Observation of a first ν_τ candidate event in the OPERA experiment in the CNGS beam

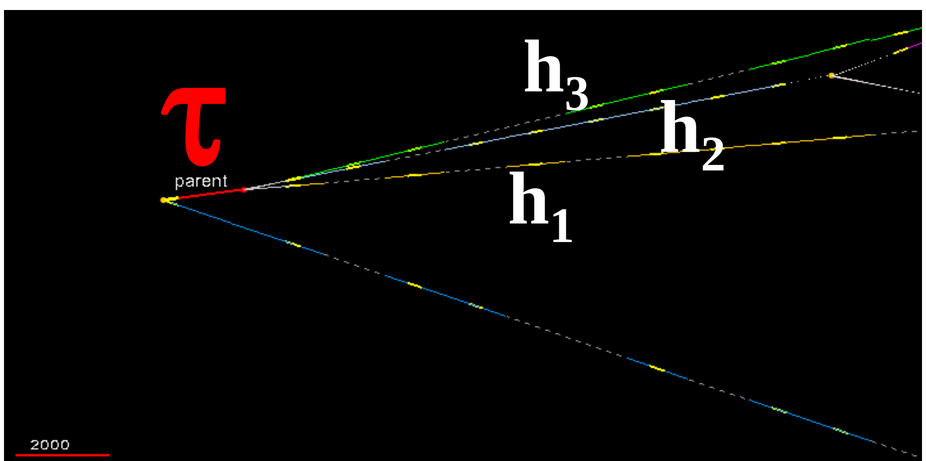
$\nu_\mu \rightarrow \nu_\tau$ oscillation evidence by detection of tau flavor appearance

OPERA

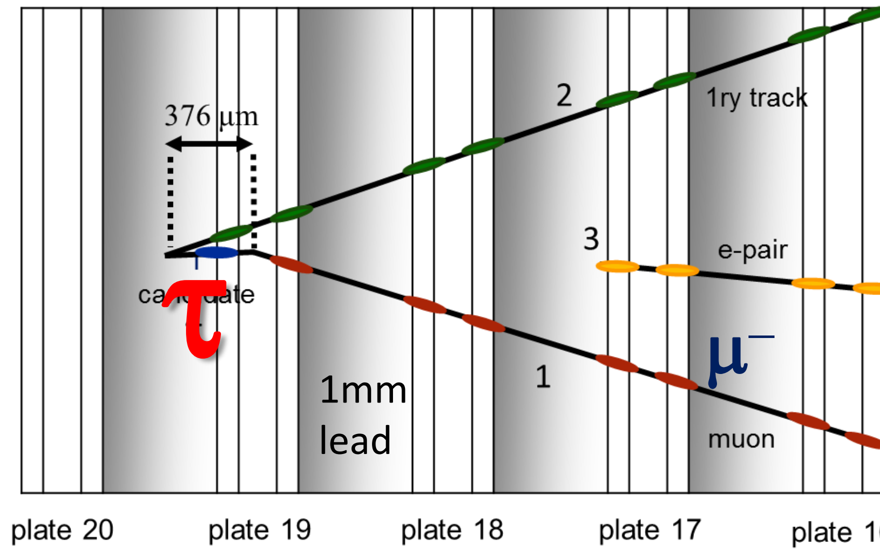
1st event:
τ -> 1h, May 2010 ($\tau \rightarrow \rho\nu_\tau$, $\rho \rightarrow \pi^0\pi$, $\pi^0 \rightarrow 2\gamma$)



2nd event: ν_τ τ -> 3h, June 2012

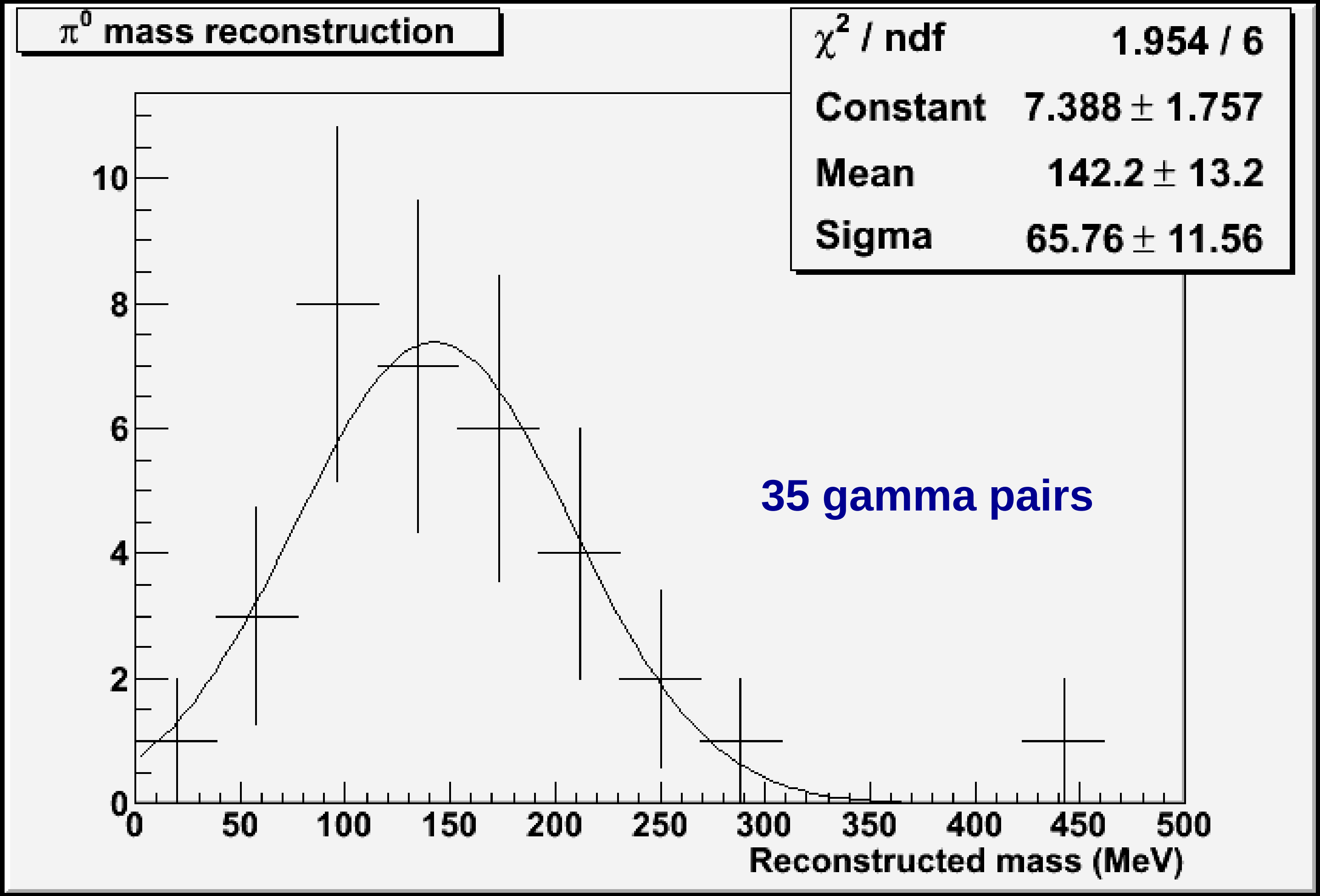


3rd event: $\tau^- \rightarrow \mu^-$, May 2013
The appeared neutrino lepton number was measured through muon charge measurement.



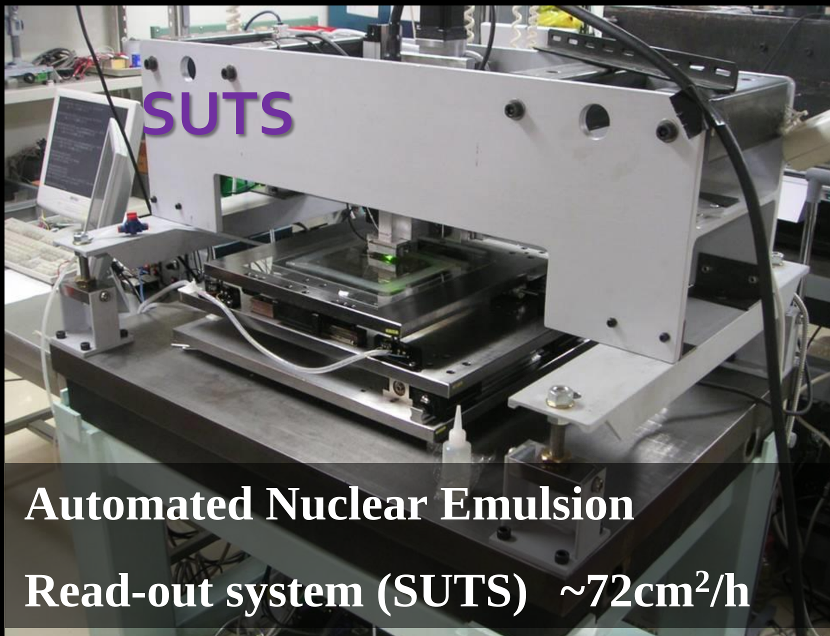
Neutrino beam exposed during 2008-2012.
So far, 5272 events were analyzed in emulsion cloud chamber (ECC) by micrometric accuracy.
3 ν_τ events have been identified among them.
It allows to exclude the absence of a $\nu_\mu \rightarrow \nu_\tau$ oscillation signal with a significance of **3.4 σ** (**p-value=2.9x10^{-4}**).

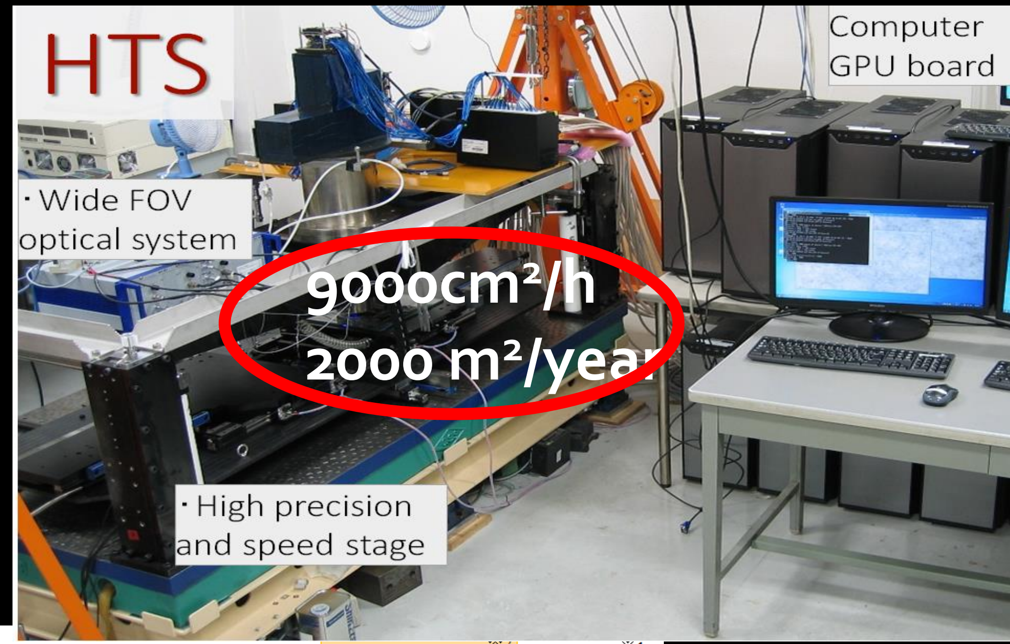
π^0 mass resolution (OPERA data)

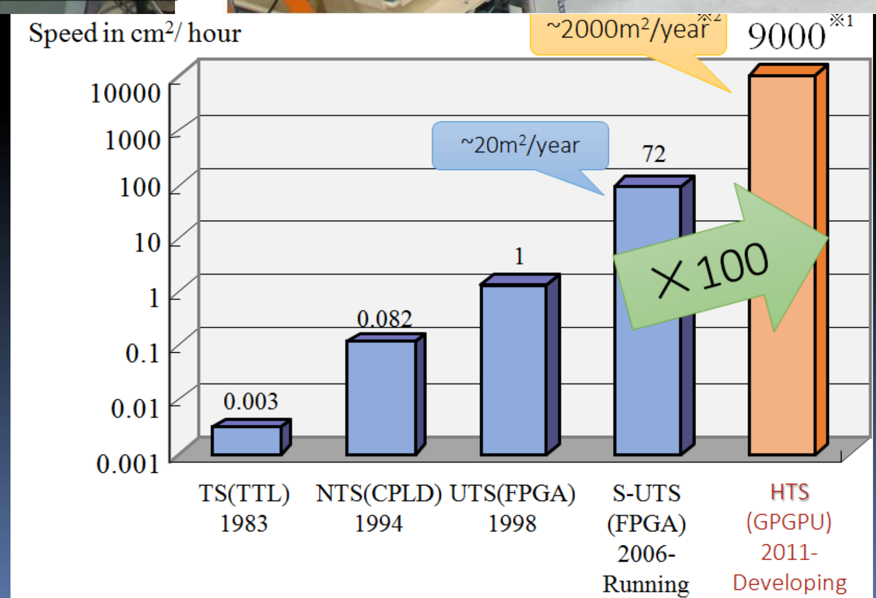


1 σ mass resolution: ~ 45%

Readout system continuous upgrade



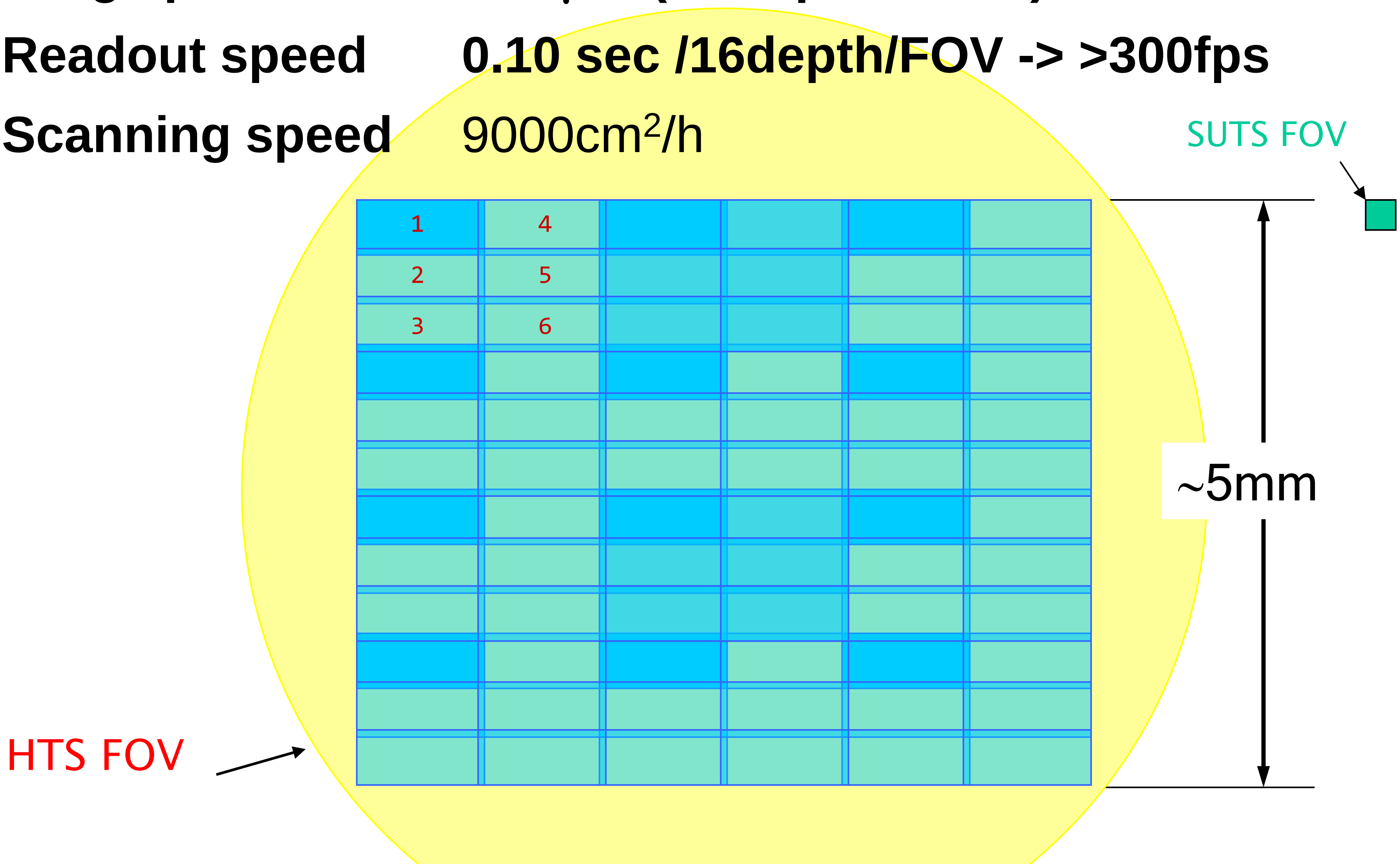




Development of
Automatic readout system
From 1970's

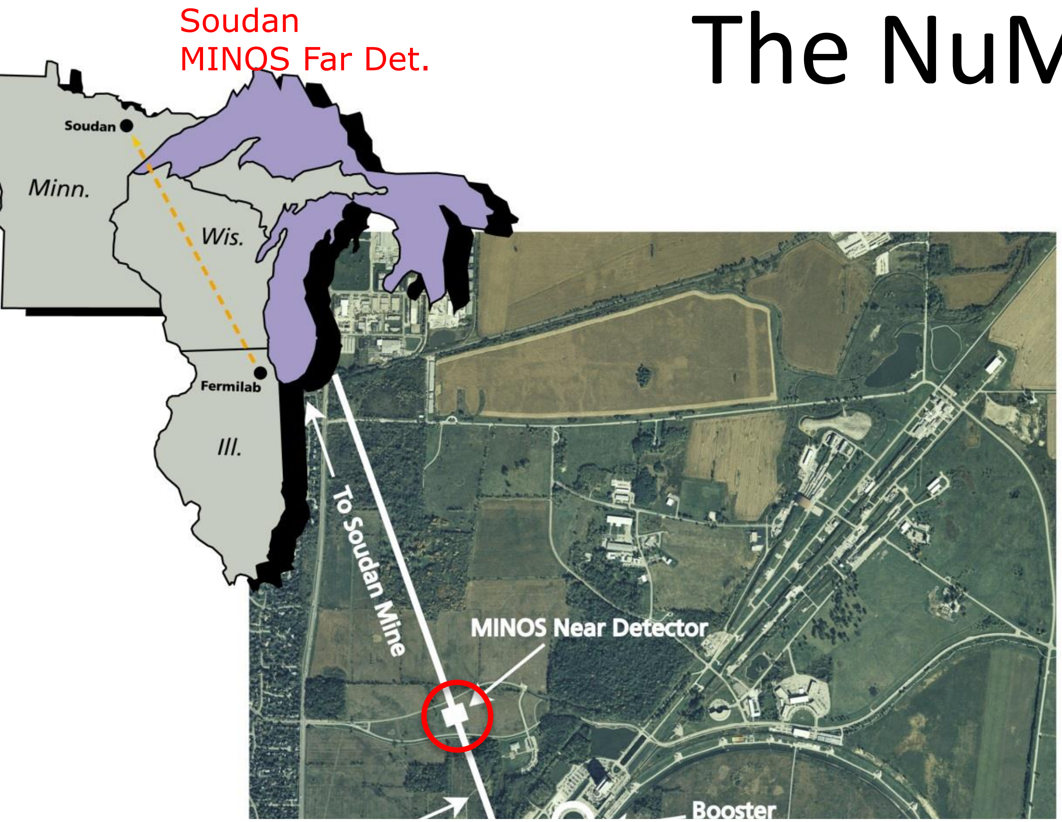
Huge field of view by Huge lens

Field of view	**5.1×4.9 mm^2**
Image pixel size	**0.45μm (120Mpixel/FOV)**
Readout speed	**0.10 sec /16depth/FOV -> >300fps**
Scanning speed	9000cm^2/h

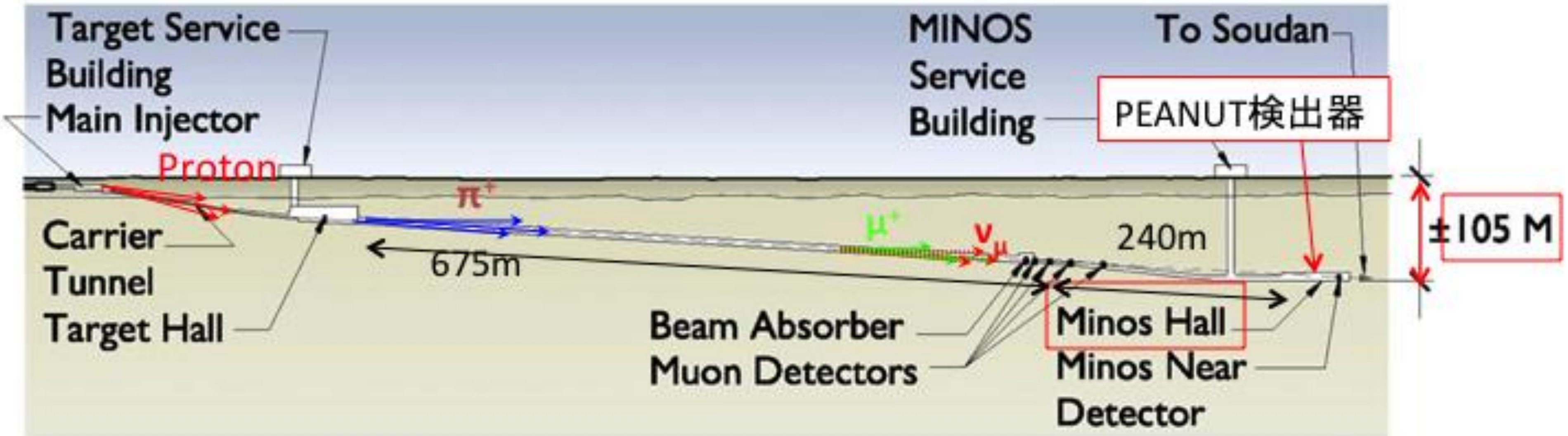


PEANUT

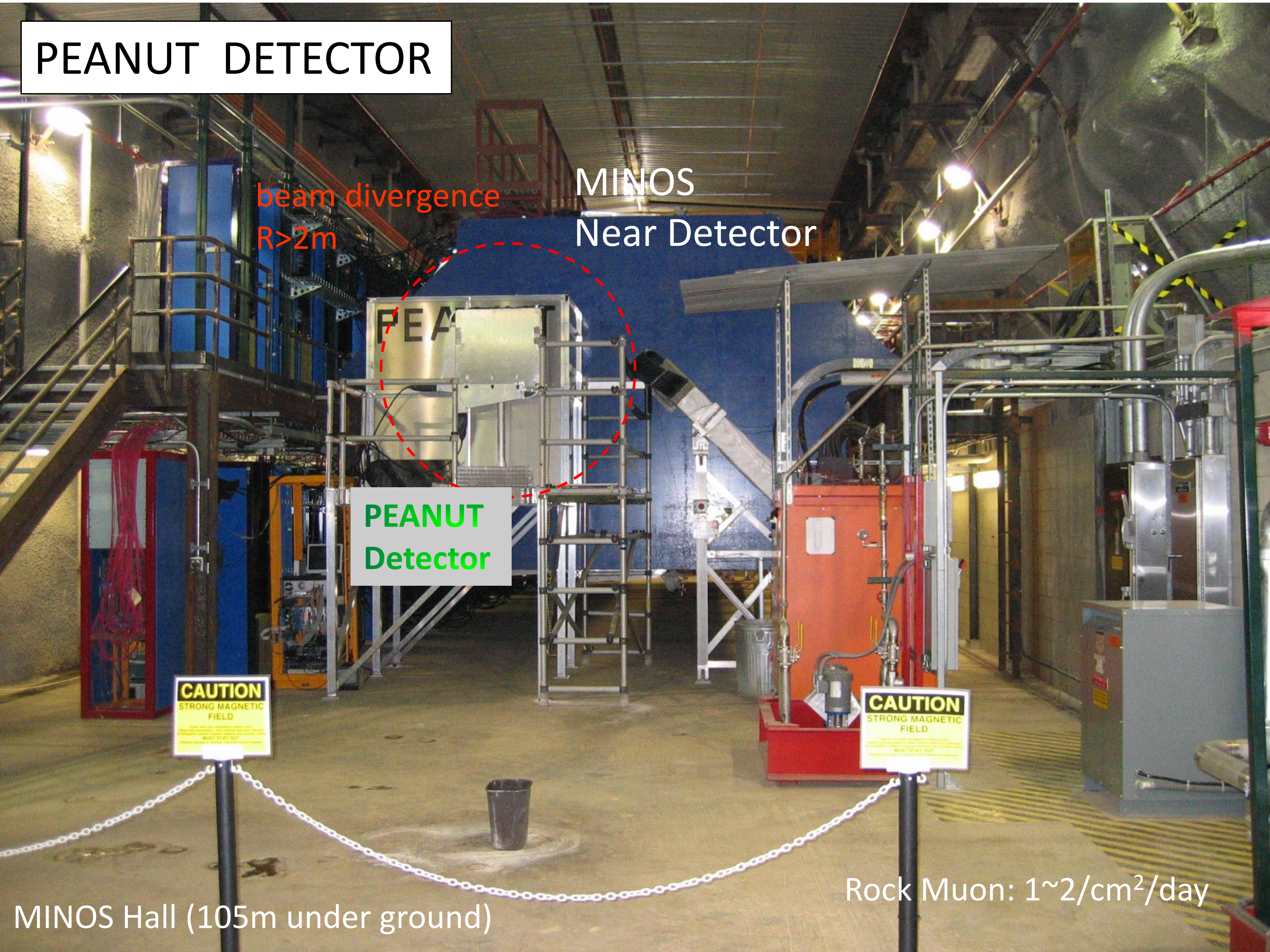
The NuMI beam



- ★ 120 GeV protons
- ★ 8.7μs spill time
- ★ 1.9 s cycle time
- ★ 8.7μs every 1.9 s
- ★ $2.5\text{x}10^{13}$ protons/spill
- ★ $2.5\text{x}10^{20}$ protons/year
- ★ 0.3 MW on target



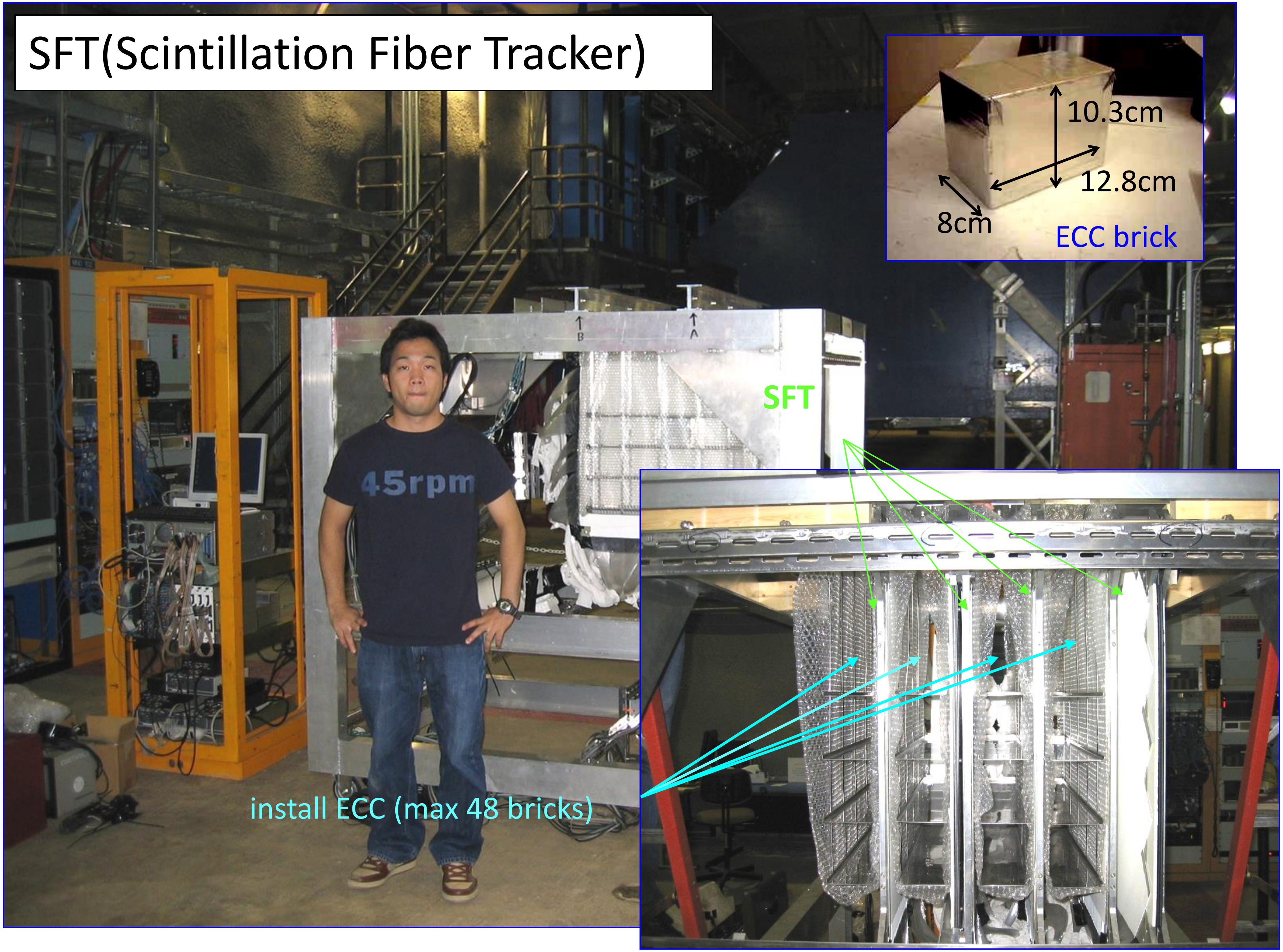
PEANUT DETECTOR



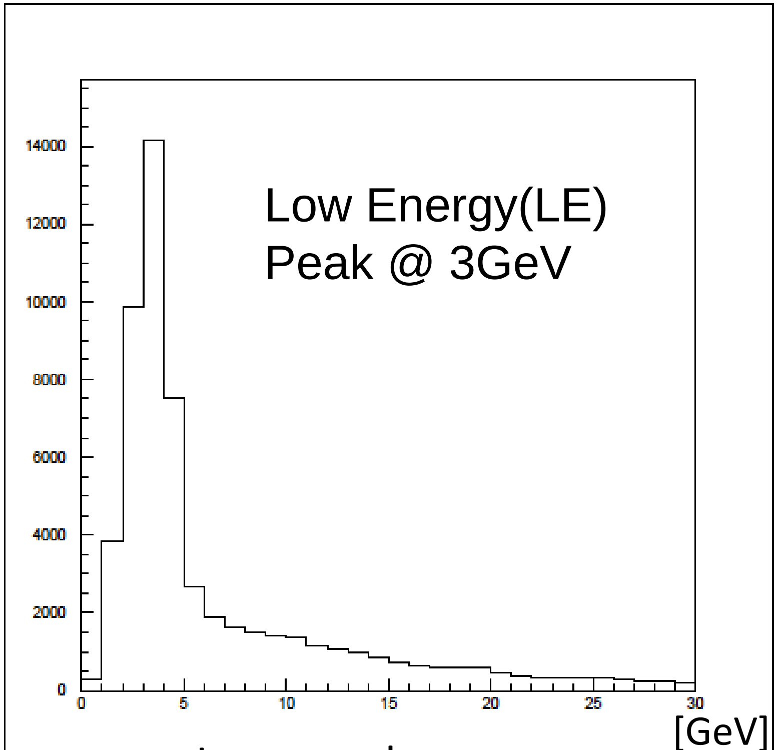
MINOS Hall (105m under ground)

Rock Muon: 1~2/cm^2/day

SFT(Scintillation Fiber Tracker)



Neutrino exposure in PEANUT



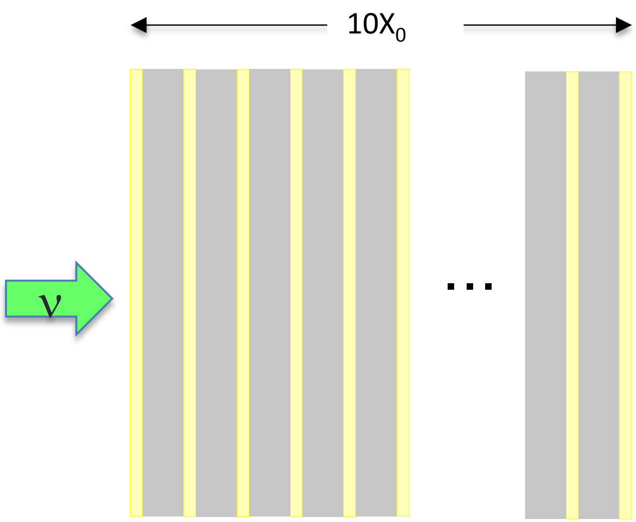
Interacted ν energy

Beam component of NuMI	
ν_μ	91.7 %
anti-ν_μ	7.0 %
ν_e + anti ν_e	1.3 %

	RUN1	RUN2
Exposure time	2005.09 – 2007.03	2007.06 – 2008.09
Aim	test for OPERA	study for NuMI beam
# of interactions in ECC	~10000 events	~10000 events

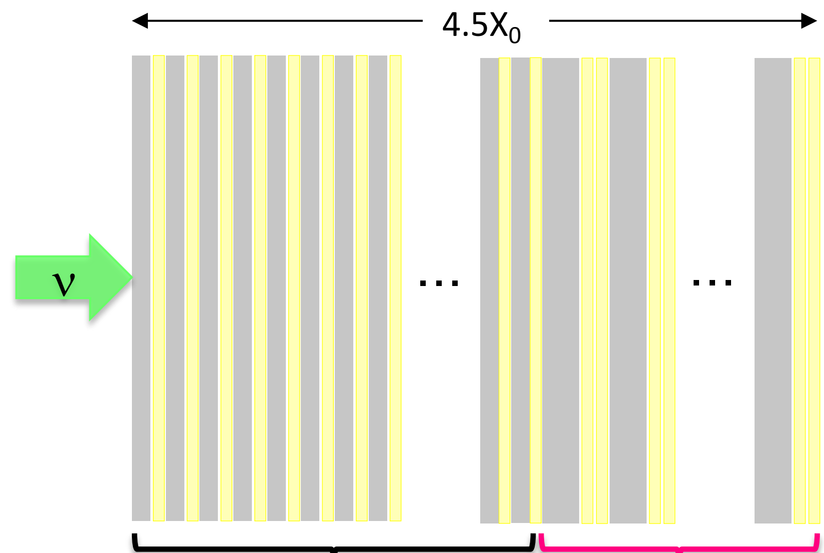
Configuration of ECC

PEANUT RUN1
(for high energy)



film+56x(film+ lead plate 1mm thin)

PEANUT RUN2
(for low energy)



61x（film＋steel plate 0.5mm thin） 15 x（2 films＋lead plate 1mm thin）

precise detection part of ν interaction

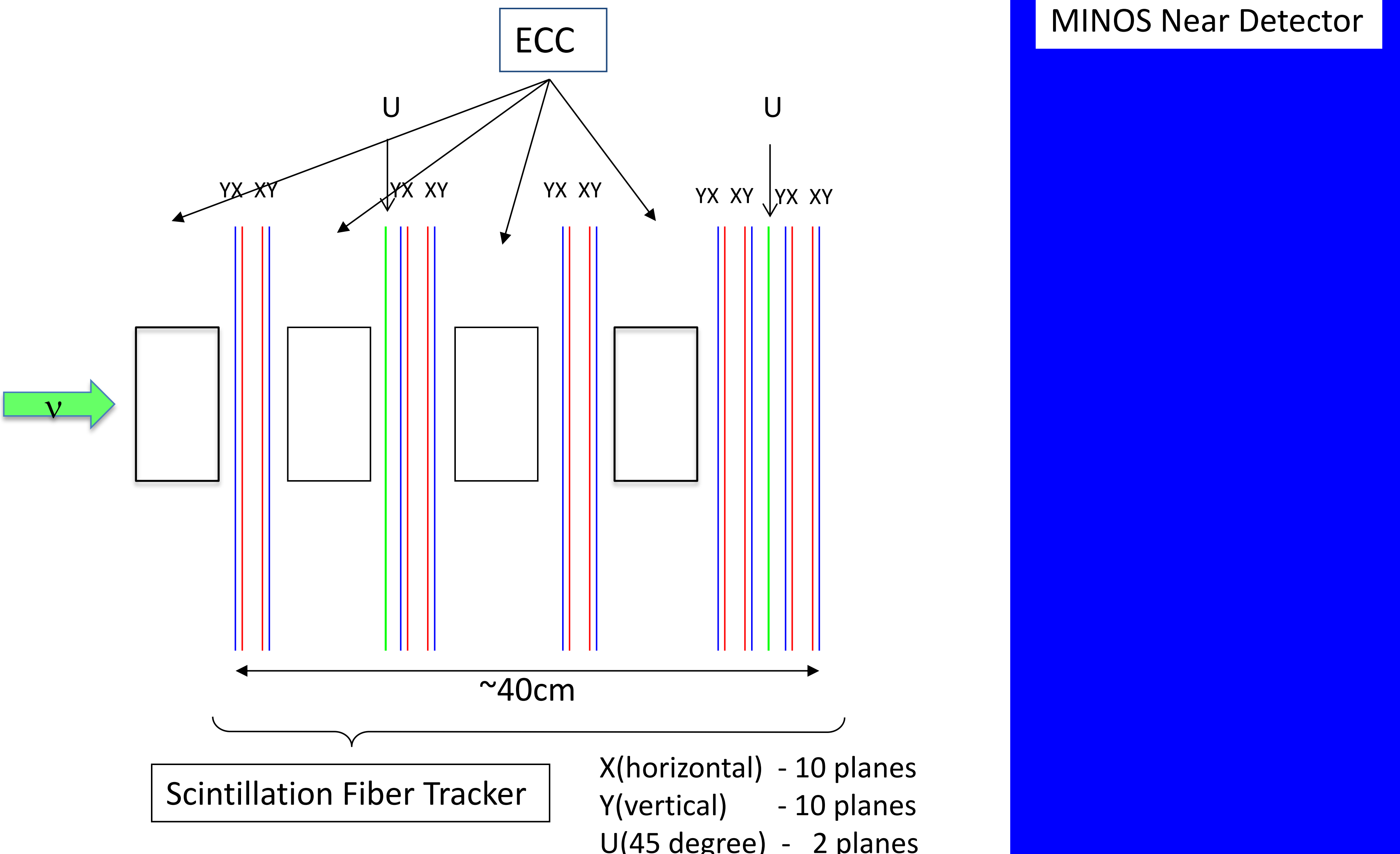
em shower developing part (= electron ID)

RUN1 : lead plate 1mm thin = $0.18X_0$

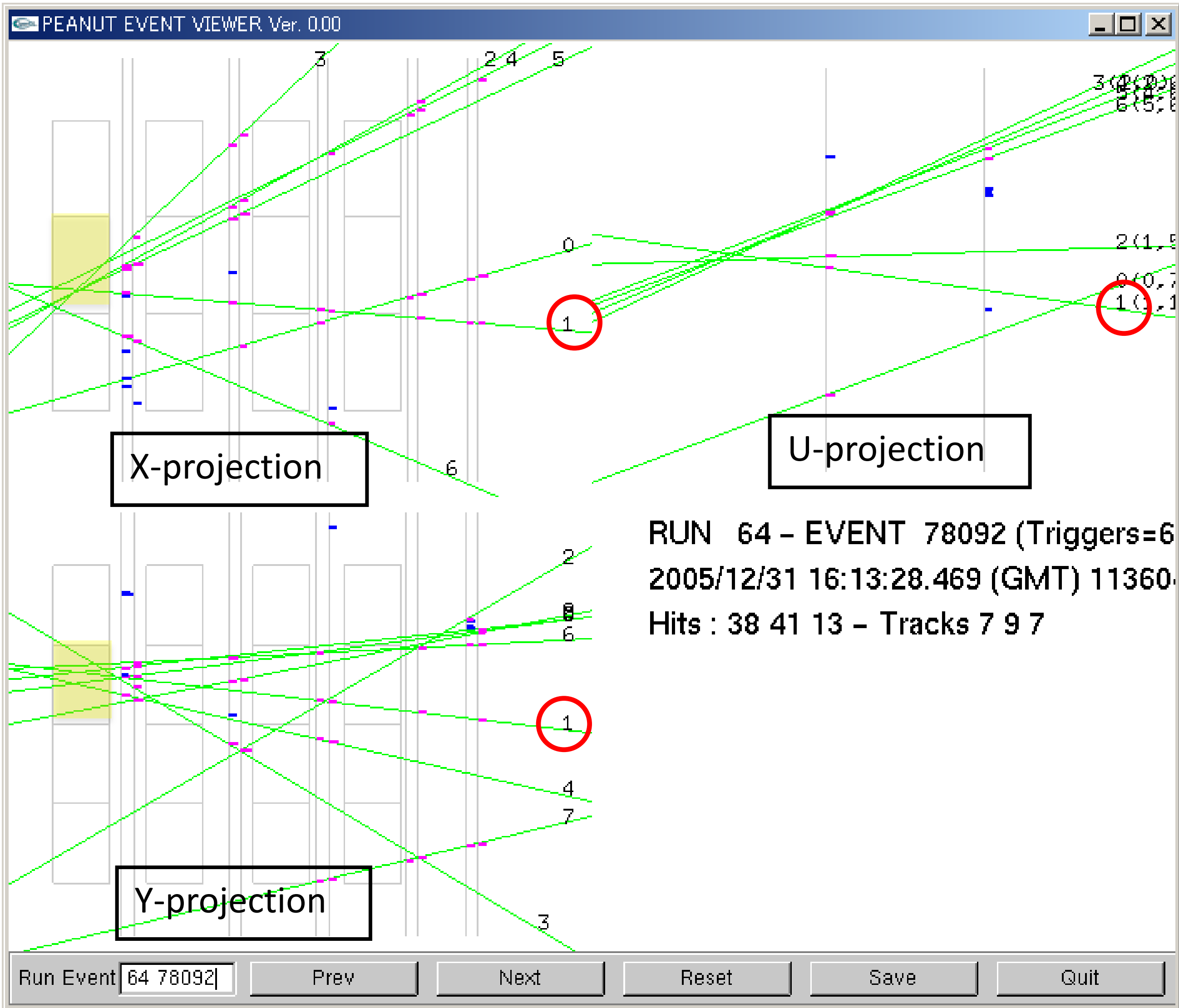
RUN2 : steel plate 0.5mm thin = $0.03X_0$

easier connection of low momentum (several hundred MeV/c) track plate by plate

PEANUT Detector



Event Viewer of SFT

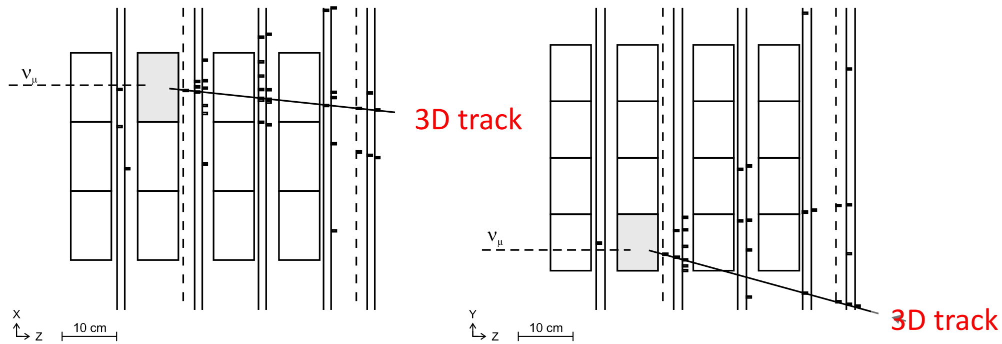


Analysis in RUN1 data

- **Event selection**

at least one 3D track reconstructed in SFT

(X,Y-projection >= 6 hits && U-projection>=1 hit)

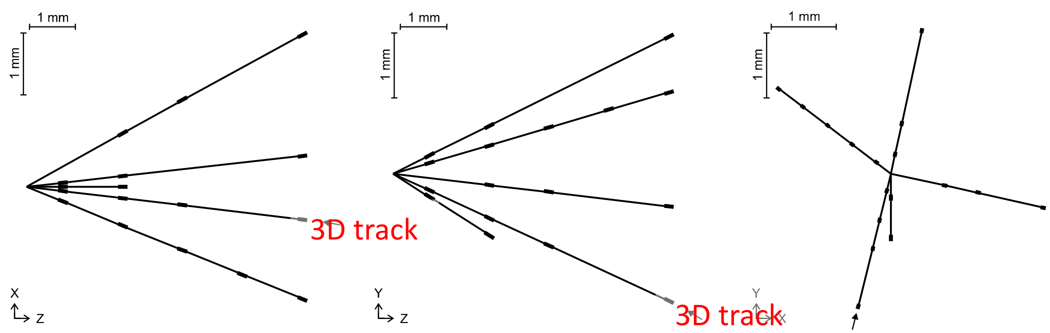


3D tracks associated with muon ~ 98%

NC contamination ~ 1%

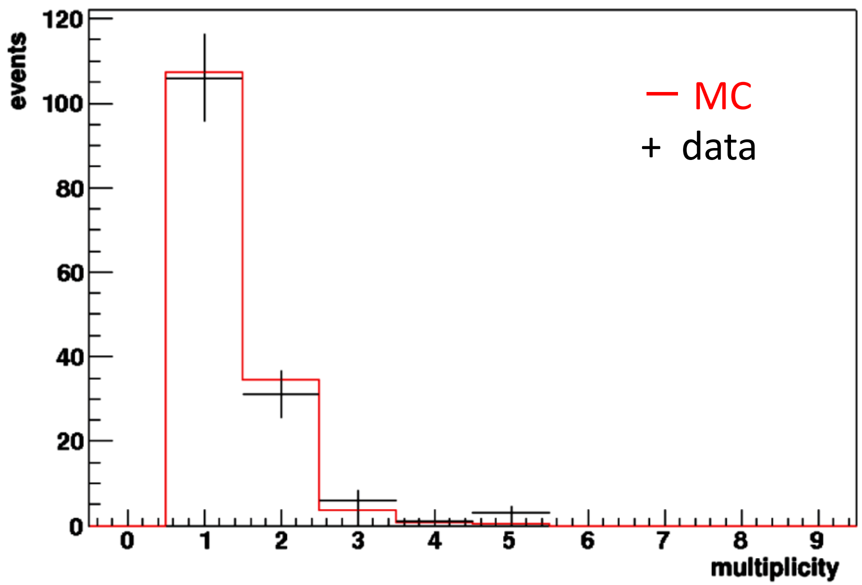
- **Event location**

- search the track consistent with 3D track in ECC and follow it toward upstream
- data taking around “stopping point” and reconstruct some tracks

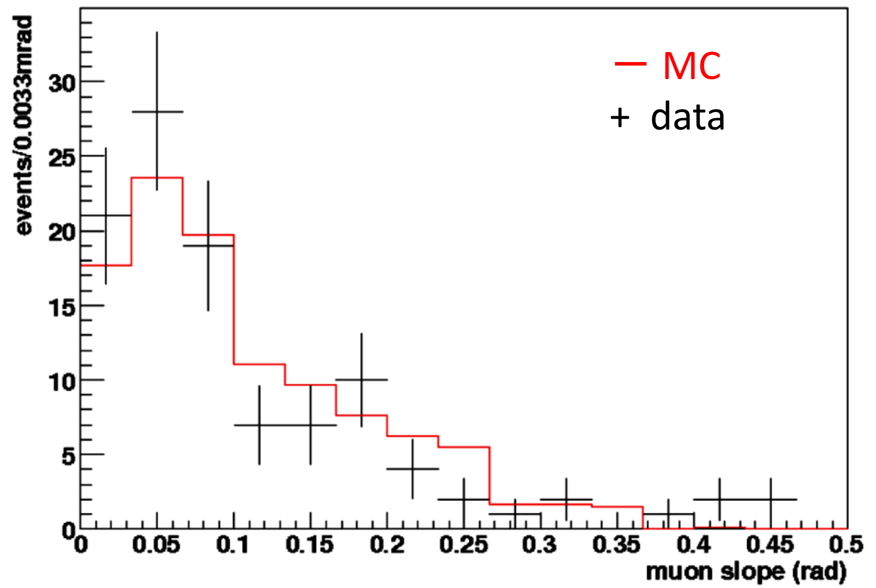


Results in RUN1 data

New Journal of Phys 12 (2010) 113028



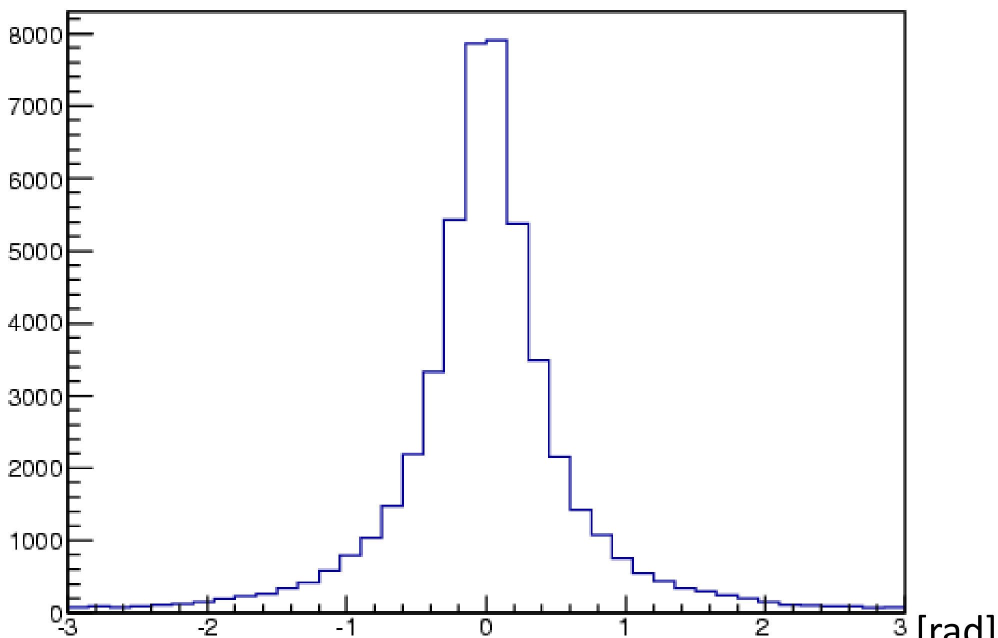
Charged particle multiplicity distribution for ν_μ CC interactions (θ<0.4rad)



Muon slope distribution in ν_μ CC interactions

Multiplicity distribution and μ slope distribution are well matched with MC.
However, there are some biases (SFT 3D track selection, angle allowance of emulsion data (θ<0.4rad)) in this analysis.

So we would like to try the analysis using a non-bias emulsion data (θ<1~3rad)



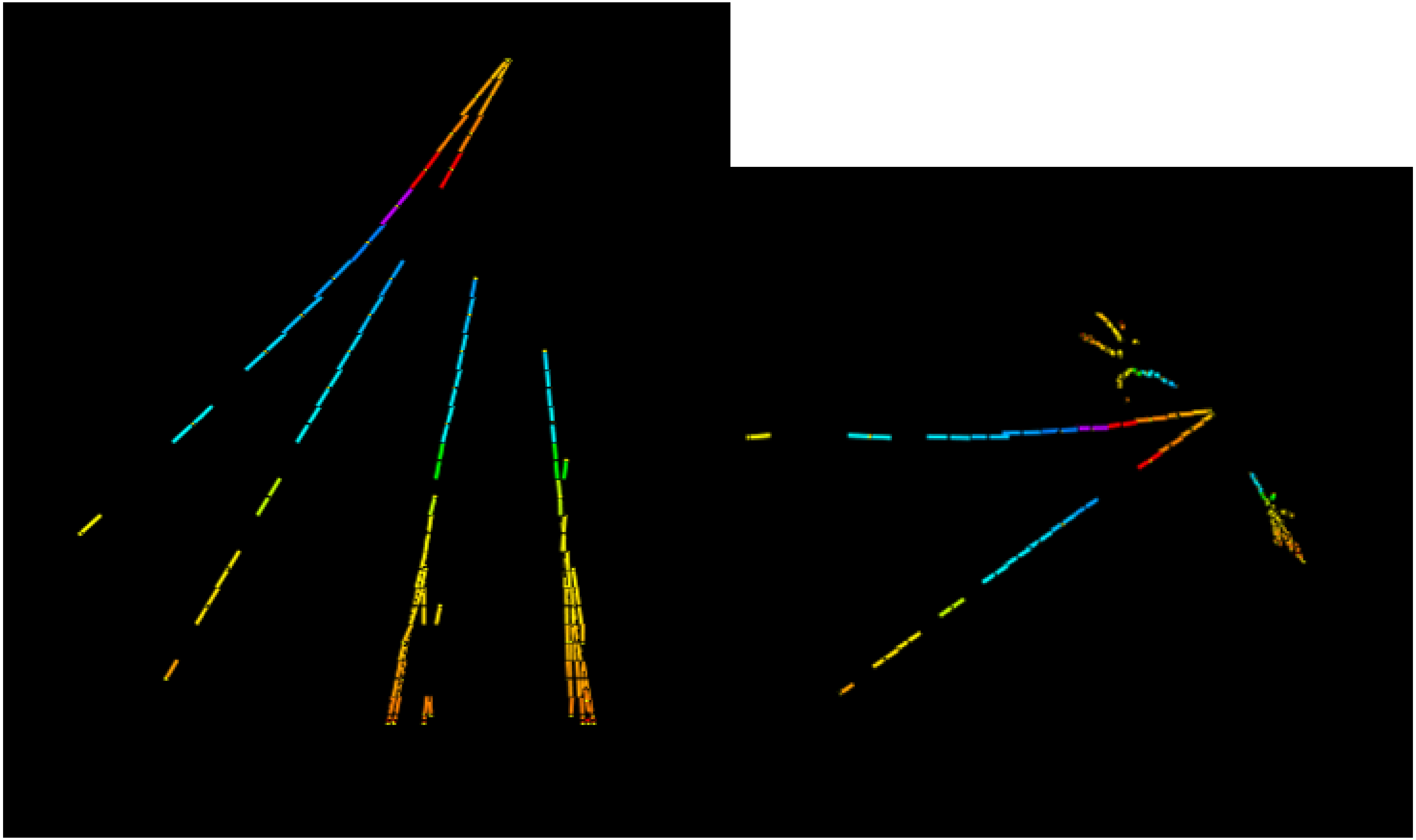
Angle (θx,θy) distribution of charged tracks (MC)

Target is treated as free nucleon.

angle allowance	detection efficiency
0.4 rad	45%
1.0 rad	76%
2.0 rad	90%
3.0 rad	93%

*scanning efficiency 100%

π^0 candidate in PEANUT RUN1

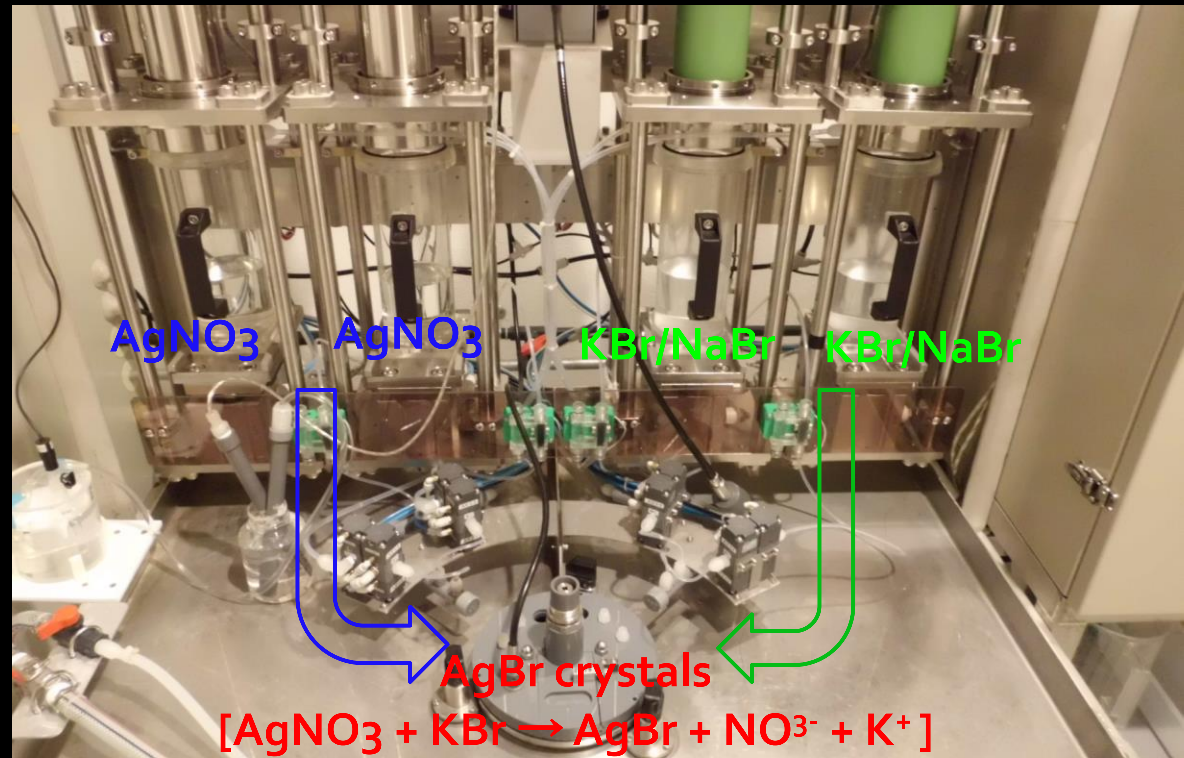


RUN-II

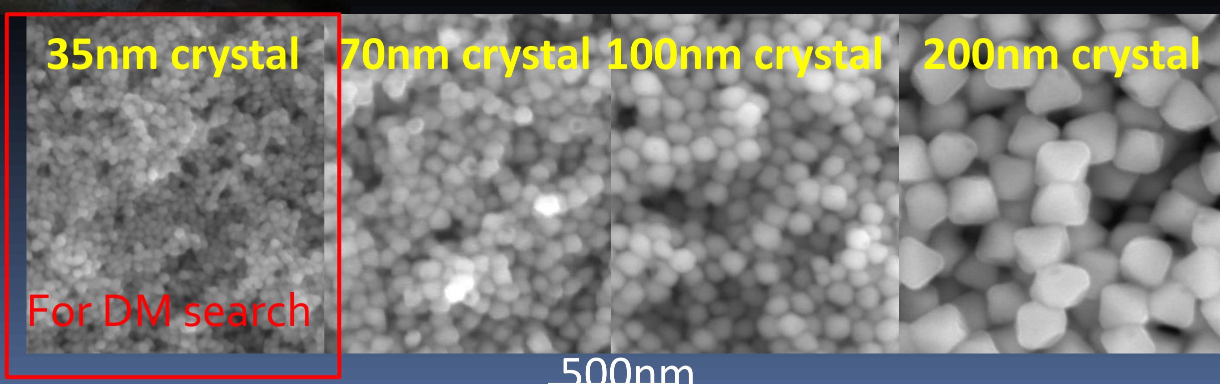
- NON-BIAS STUDY Without SFT
- MULTIPLICITY & TRACK SLOPES
- QE LIKE EVENTCROSS SECTION
- NU_E CROSS SECTION
- QE PP

- MUON ID efficiency low -> new experiments is favour

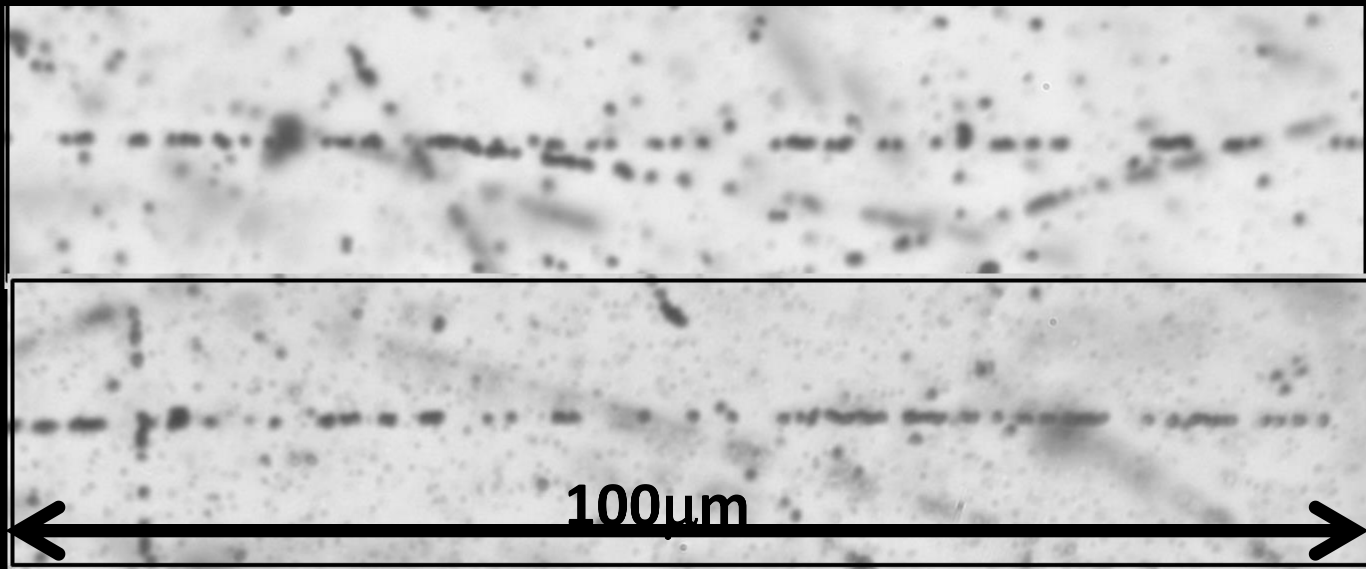
Emulsion Self-Production at Nagoya University



Production scale ~ 1 kg detector/week

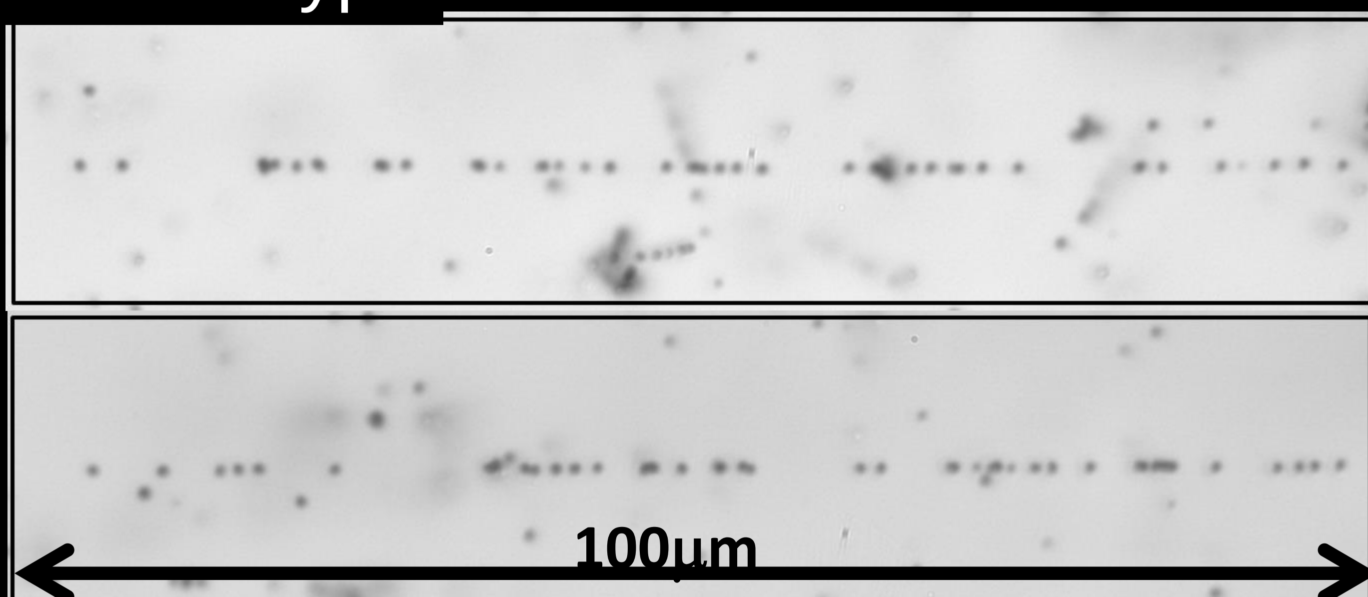


A very high grain density emulsion (dense AgBr portion)



GD= 86.1± 4.7
FD= 2.9 ± 0.9

OPERA type



GD=34.8±0.6
FD= 3.7±0.4

Summary

Emulsion records all charged track and its precise position and angular information by vector.
Especially used for study of short lived particle such as charmed particle, tau particle.

Emulsion could chamber, ECC can perform particle ID by its-self.

1. Momentum measurement by Multiple Coulomb Scattering . dP/P ～20-30%
2. Energy deposition dE / dX measurement.
3. Energy measurement by Range, Proton, nuclear evaporation tracks, low energy muon.

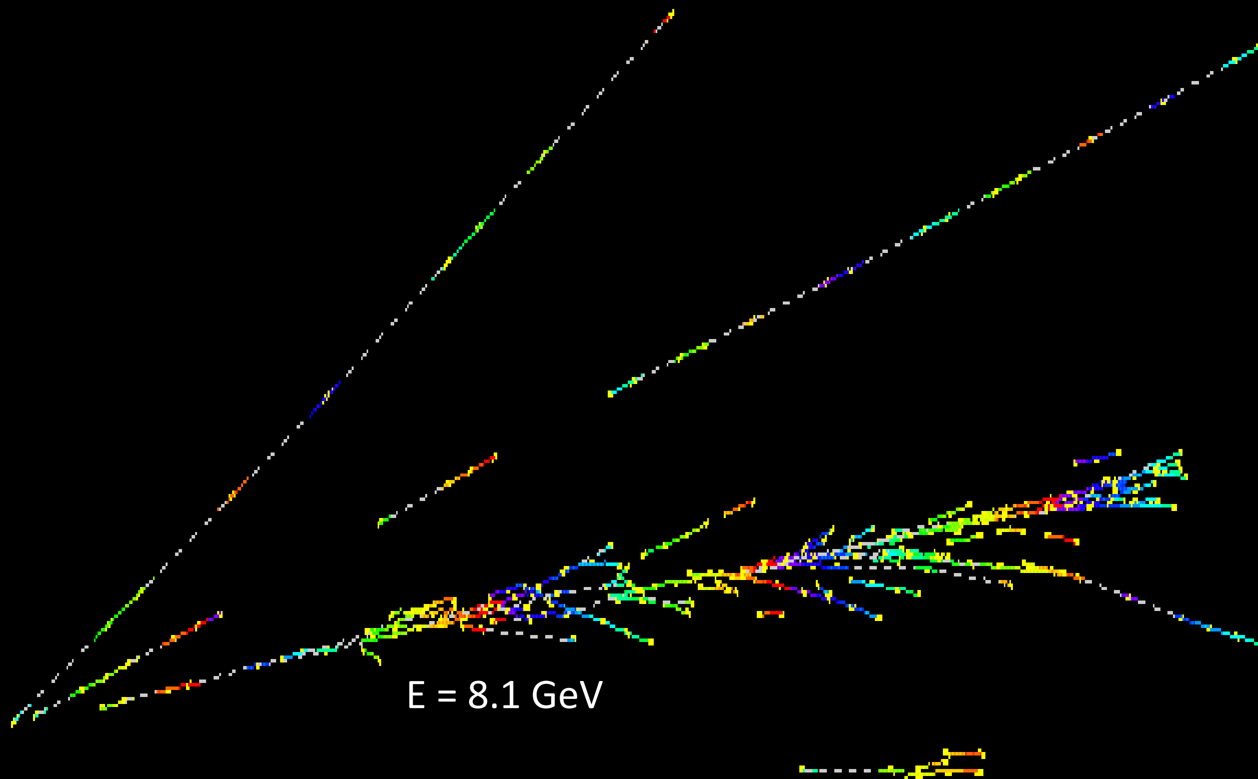
Proton / Pi separation	< 1 GeV
Electron / Pion separation	> several x 100 MeV
An electron and gamma separation	> a few x 100 MeV

ECC can be used for neutrino or hadron interactions with
H : (Liquid Hydrogen , in side Bubble chamber, E-564)
C : Graphite plate, Plastic
O : Water
Fe : DONUT
Pb : OPERA
Ag, Br: component of crystal
Now automated scanning can it possible to scan 1. m^2/month.
And Next generation track selector can scan 2000 m^2/year.

Backup

電子同定：　電子シャワー
２個のγ線が放出されている例。

この2γでの不変質量　~160 MeV



E = 8.1 GeV

E = 0.5 GeV

電磁シャワーの測定：
シャワーの発展の形＋MCSの運動量測定。

GRAINE project

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

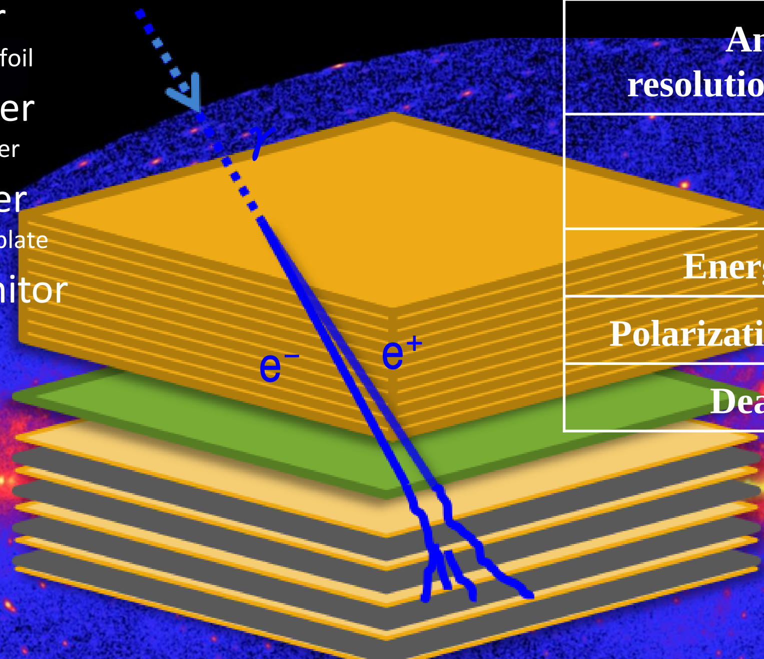
33 collaborators, 6 institutes, PI : S.Aoki (Kobe Univ.)
Aichi University of education, ISAS/JAXA, Kobe University, Nagoya University, Okayama University of science, Utsunomiya University

Converter
emulsion + metal foil

Timestamper
multi-stage shifter

Calorimeter
emulsion + metal plate

Attitude monitor
star camera

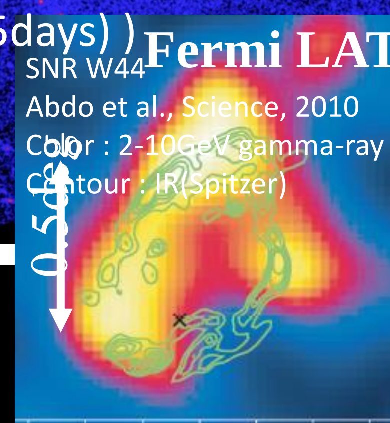


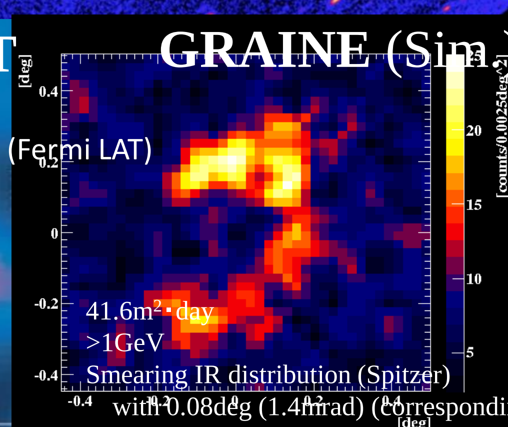
	Fermi LAT	GRAINE
Angular resolution@100MeV	6.0deg(105mrad)	0.93deg(16mrad)
@1GeV	0.90deg(16mrad)	0.10deg(1.7mrad)
Energy range	20MeV-300GeV	10MeV-100GeV
Polarization sensitivity	No	Yes
Dead time	26.5usec	Dead time free

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

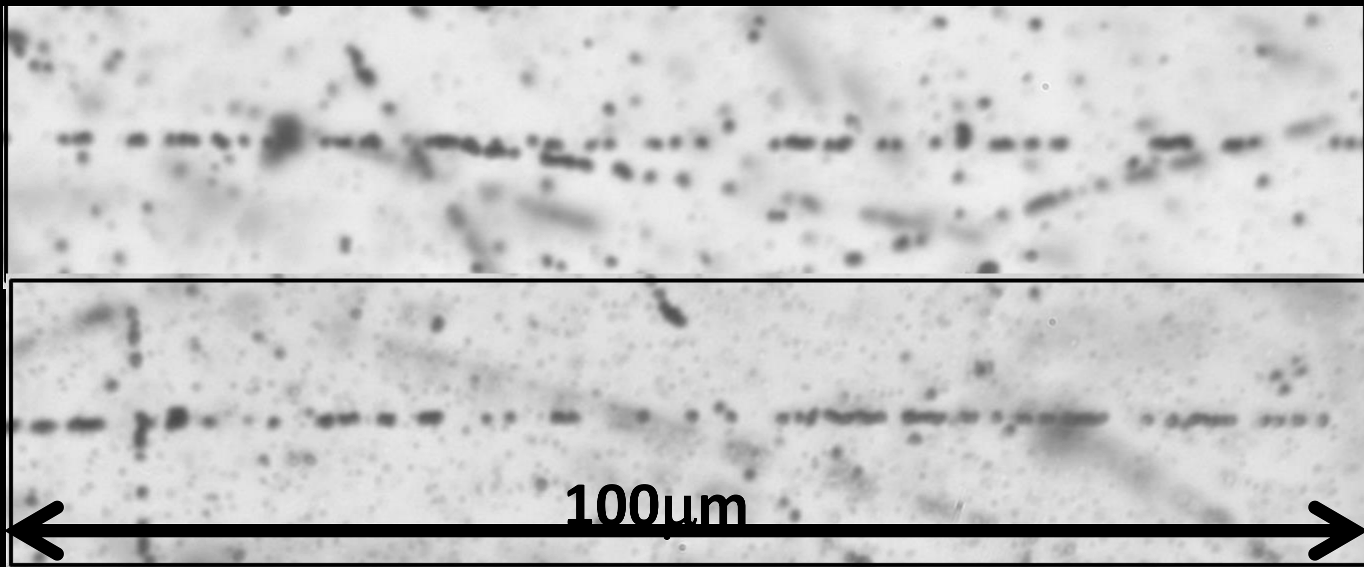
Fermi Gamma-ray Space Telescope

Credit: NASA/DOE/Fermi/LAT Collaboration



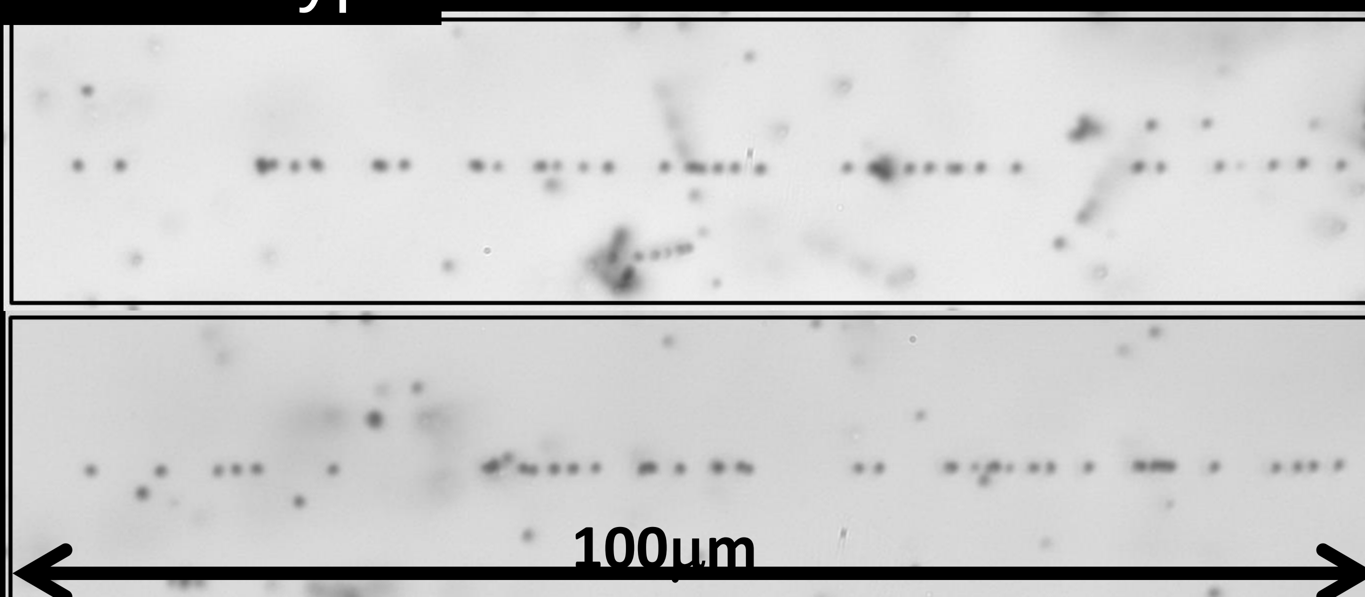


A very high grain density emulsion (dense AgBr portion)



GD= 86.1± 4.7
FD= 2.9 ± 0.9

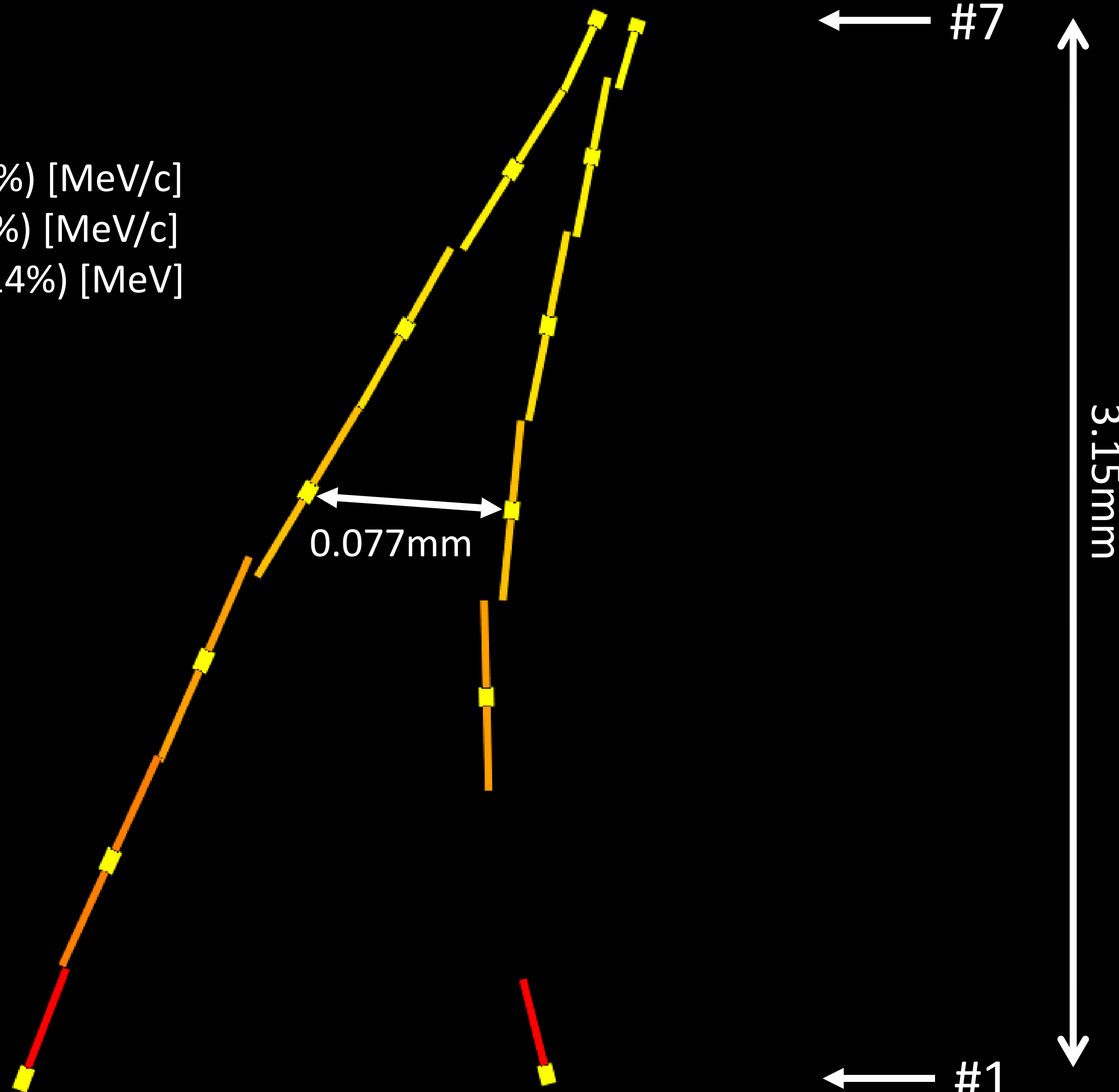
OPERA type



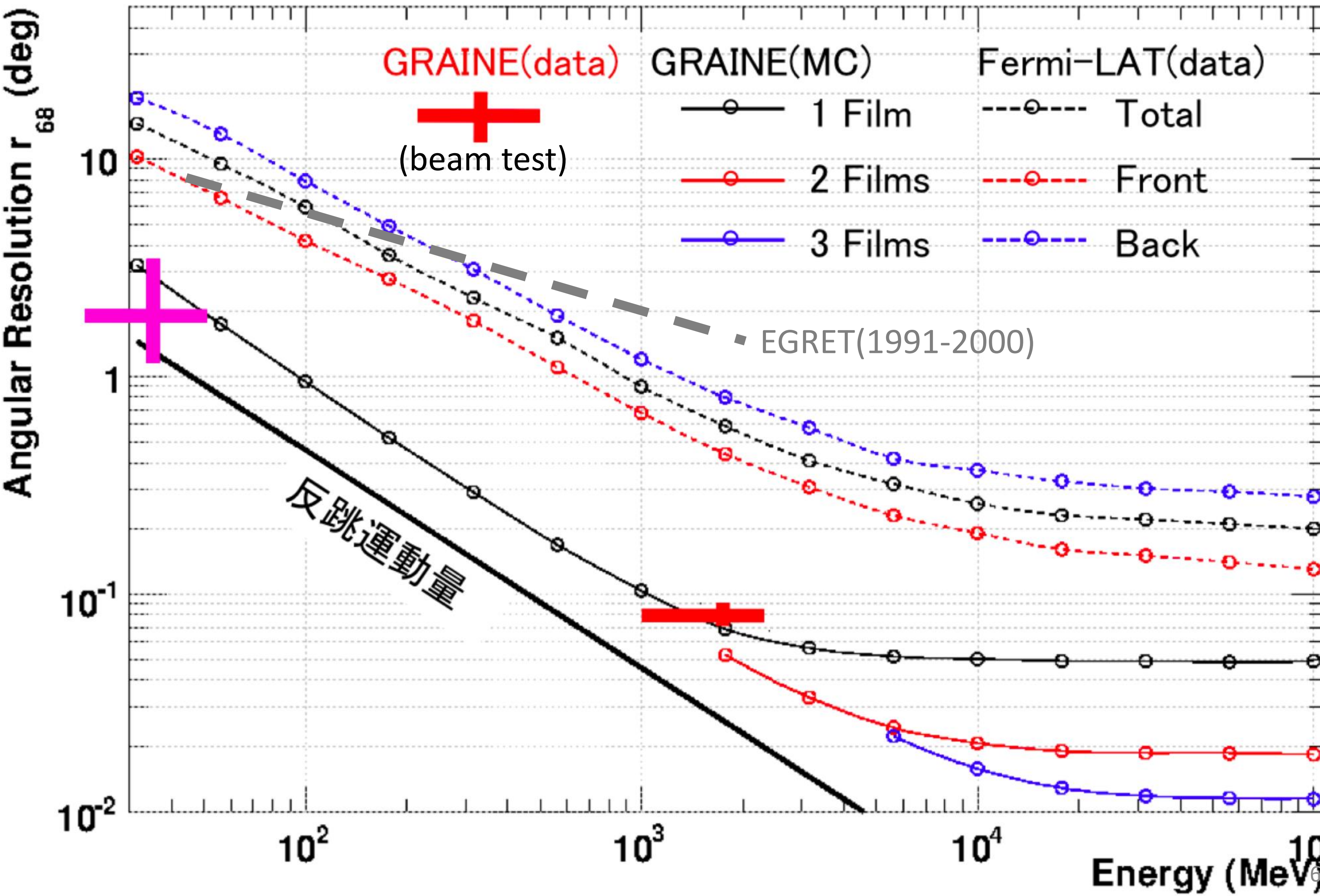
GD=34.8±0.6
FD=   3.7±0.4

A detected γ ray

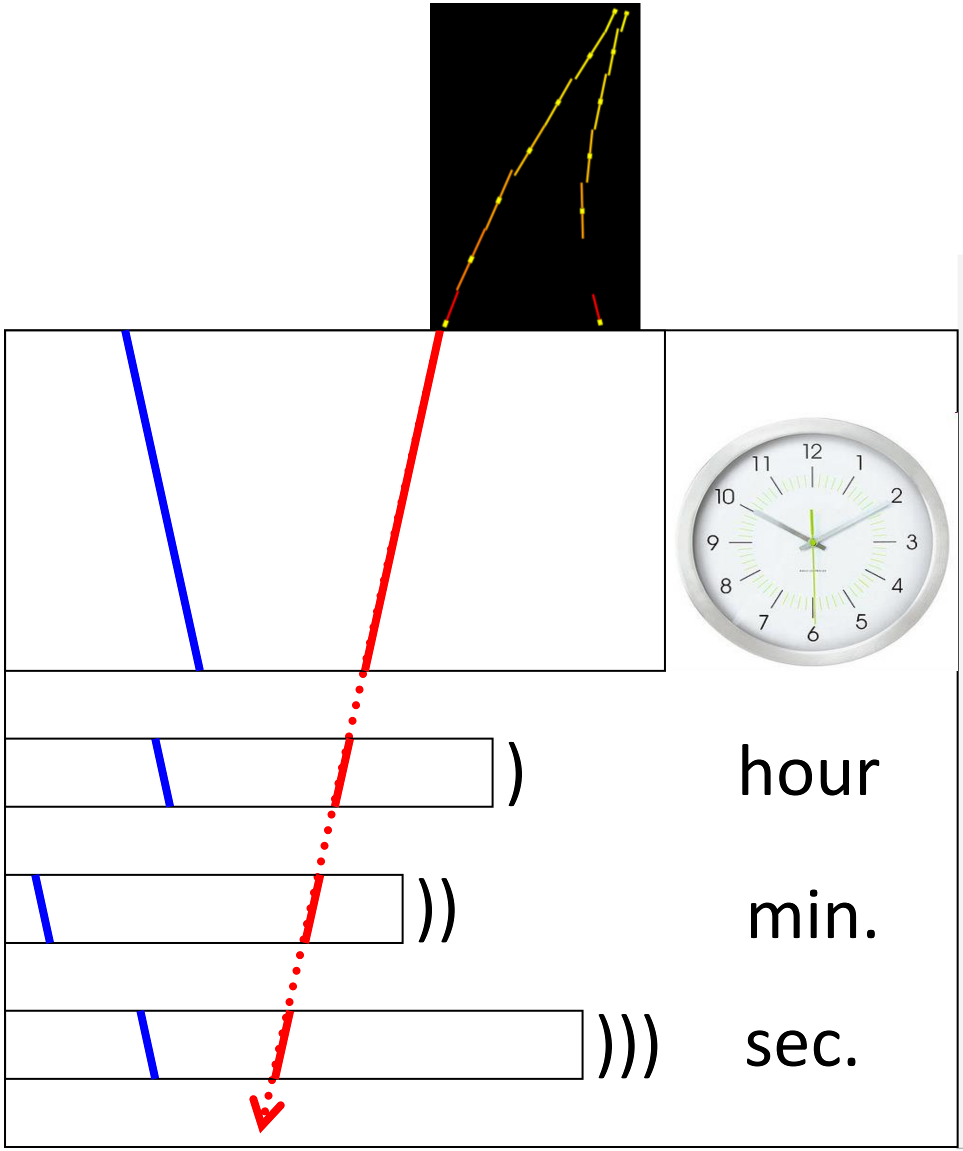
Event : 71 6923485
Start : #7
$\theta_{incident}$: 9.748 [deg]
$p\beta_1$(left) : 60 +20 -12 (25%) [MeV/c]
$p\beta_2$(right) : 32 + 9 - 6 (22%) [MeV/c]
E_γ : 92 +22 -13 (+24% -14%) [MeV]

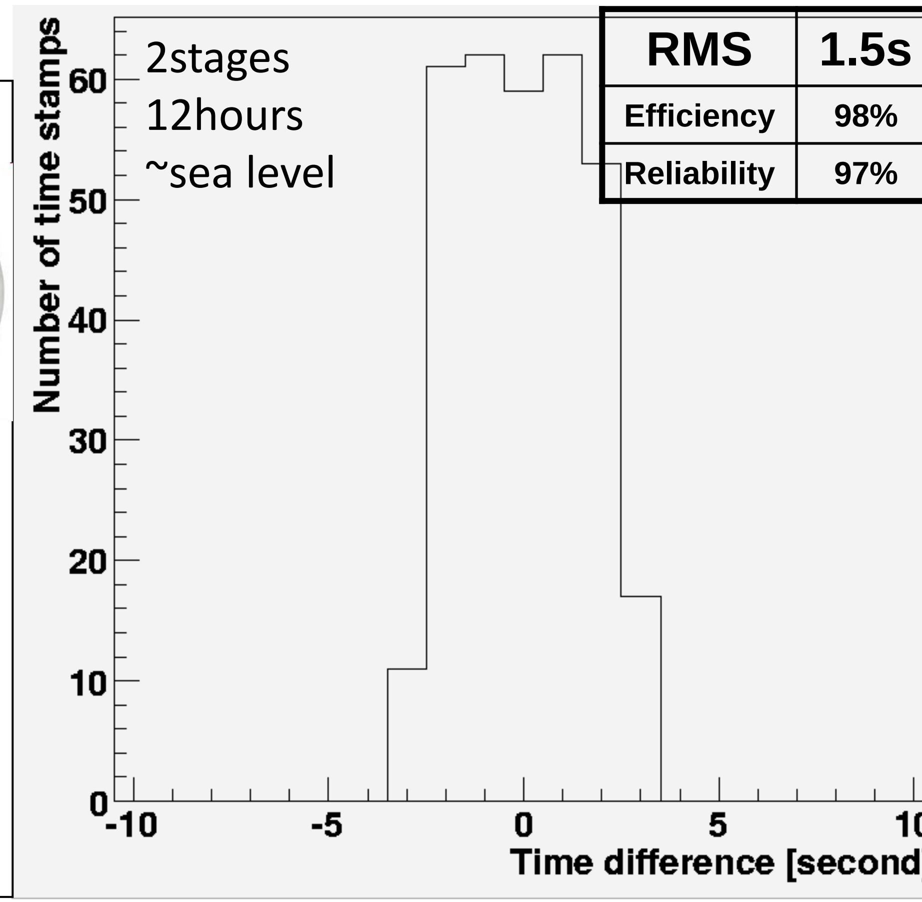


Angular resolution for a γ



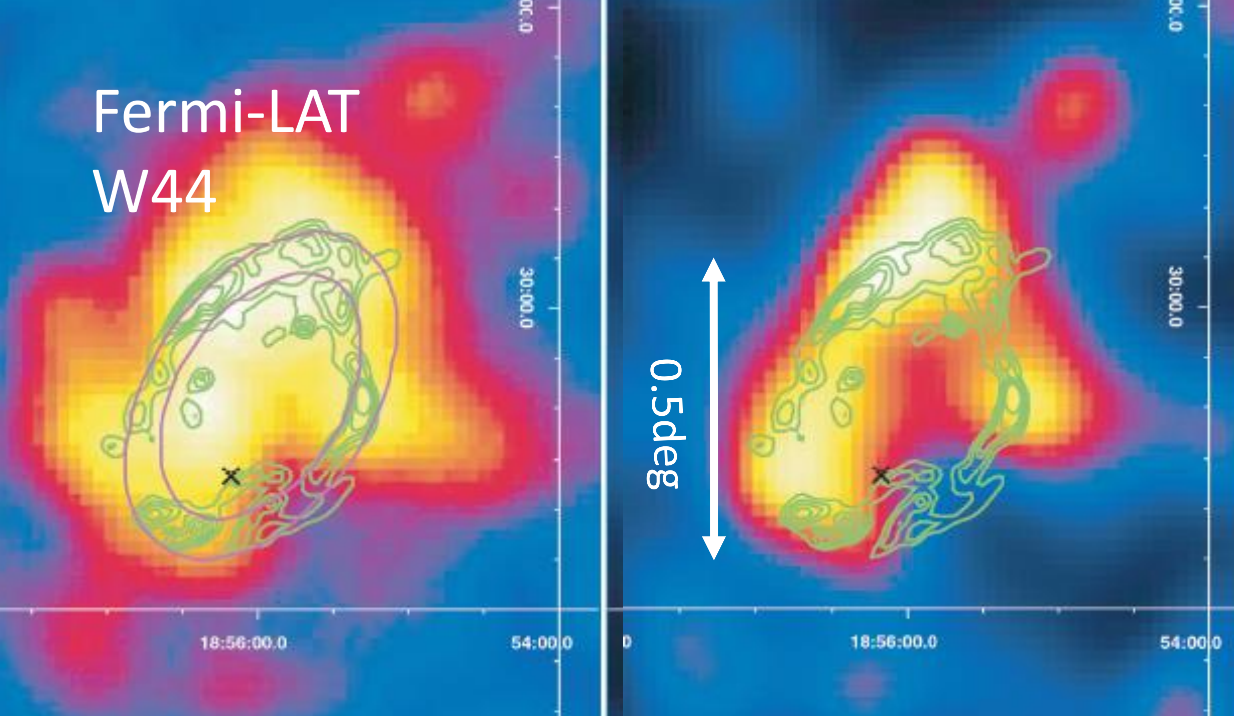
γ ray observation with time information !



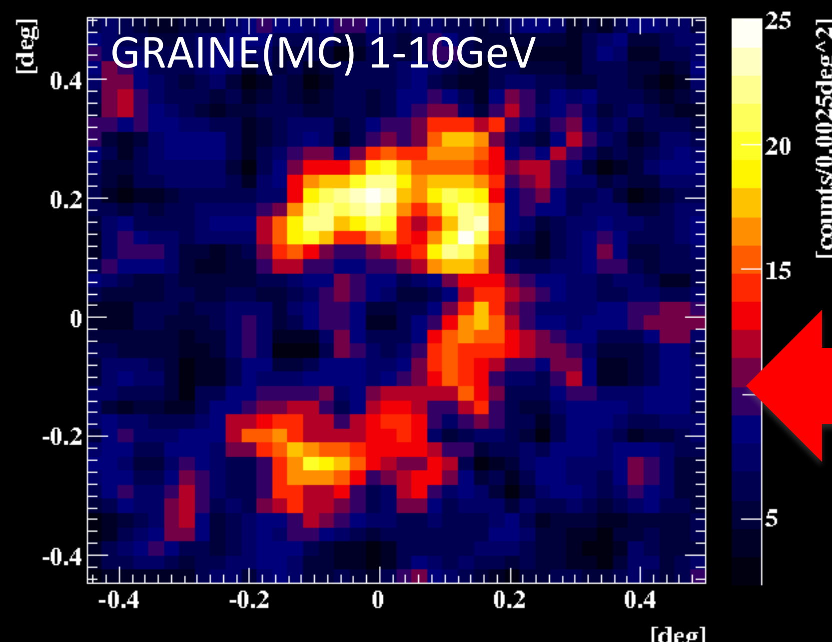


RMS	1.5s
Efficiency	98%
Reliability	97%

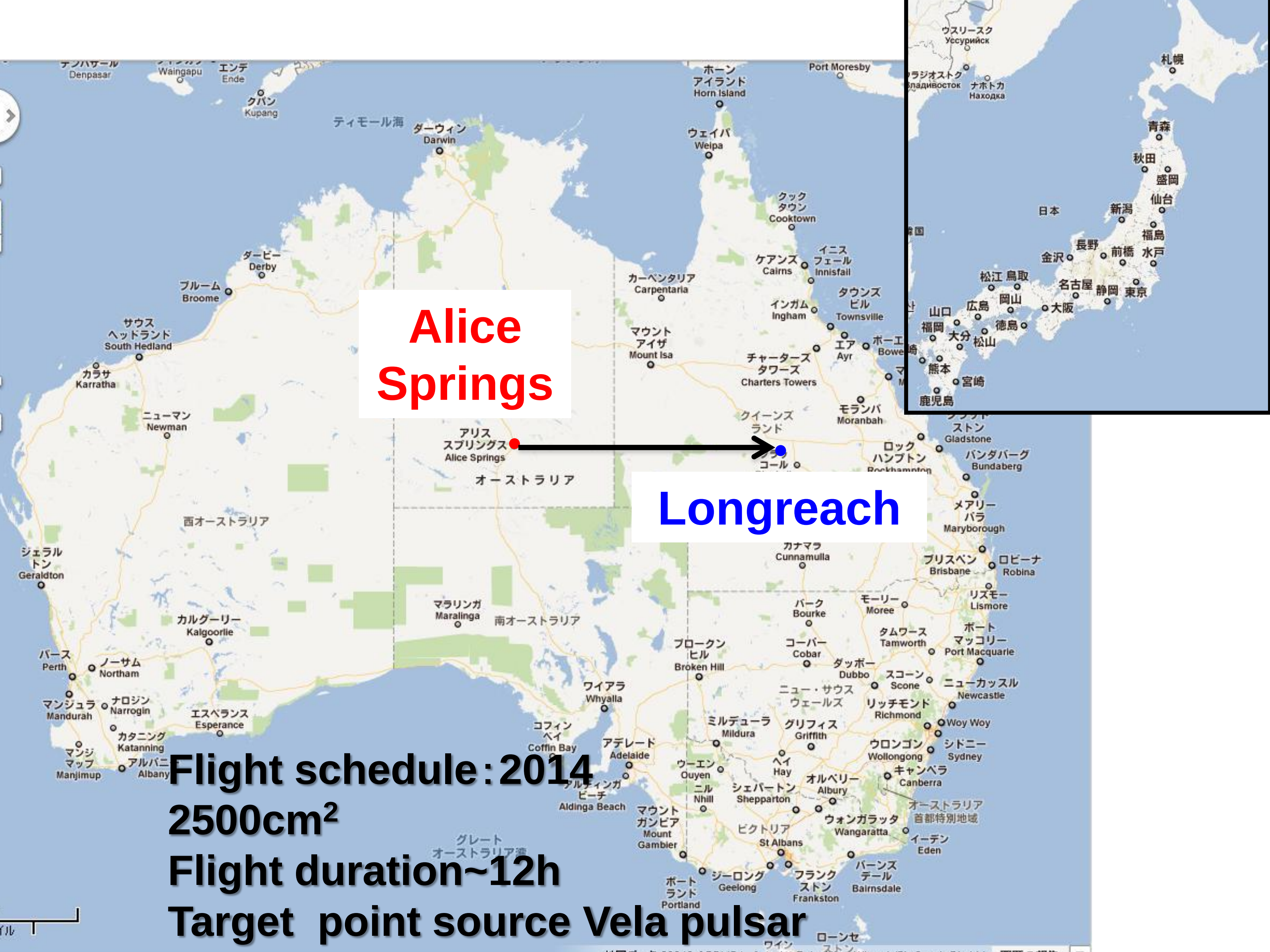
S.Takahashi et al., Nucl. Instr. And Meth. A, 620 (2010) 192-195



Finer structure observation



Spitzer(4.5µm IR)
Data smeared
By expected resolution



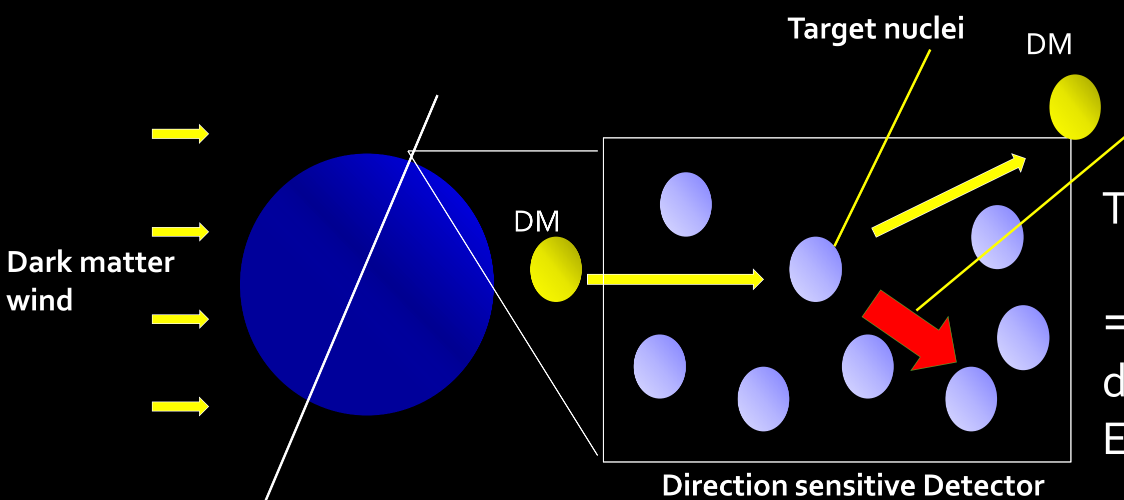
Flight schedule：2014

2500cm^2

Flight duration~12h

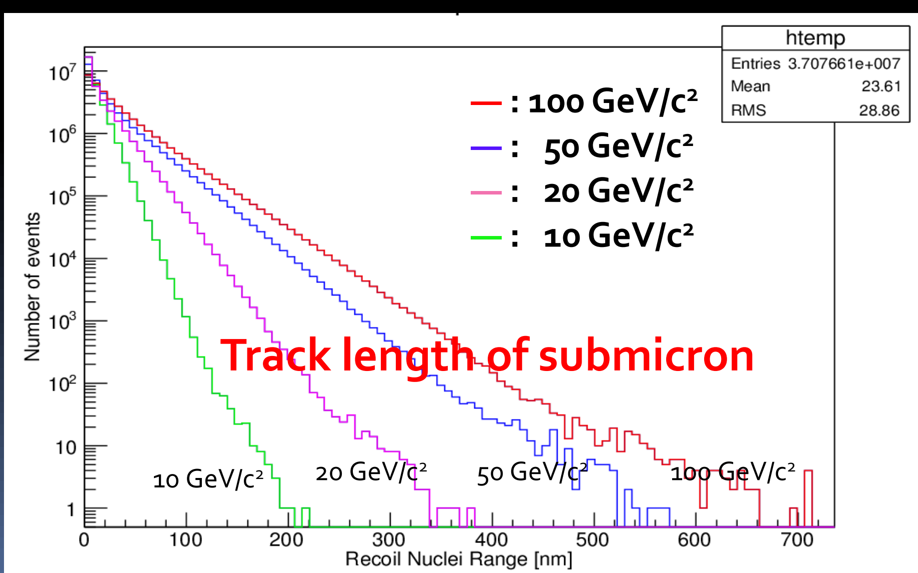
Target point source Vela pulsar

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.

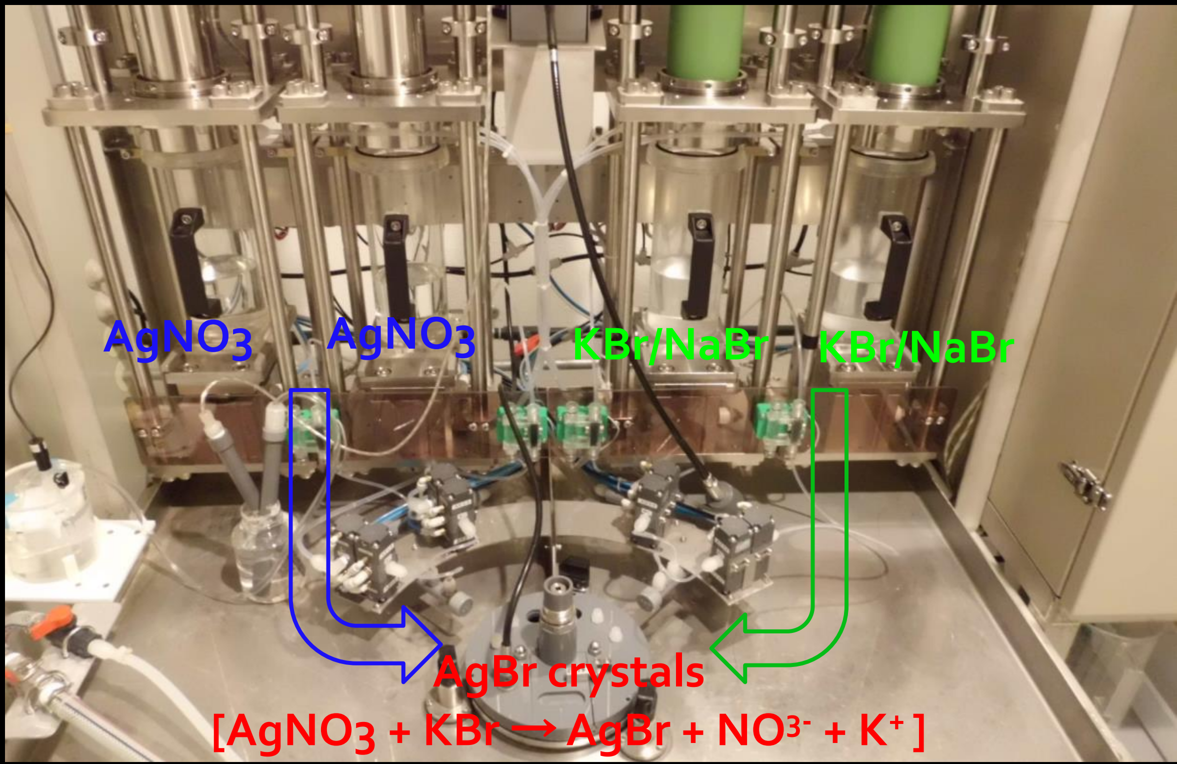


Track length [nm]

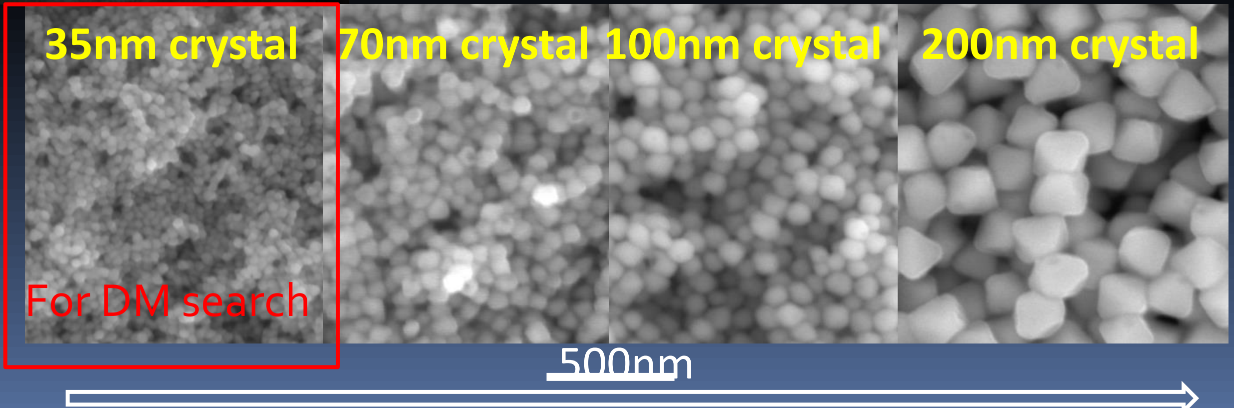
⇩

Emulsion detector will mount the equatorial telescope to keep the direction because it has no time resolution.

Emulsion Self-Production at Nagoya University



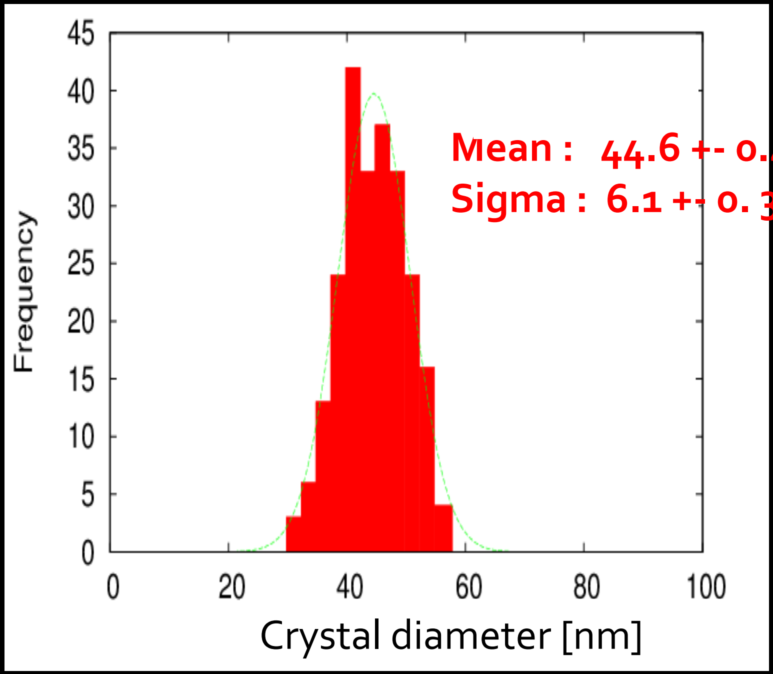
Production scale ~ 1 kg detector/week



Nano Imaging Tracker

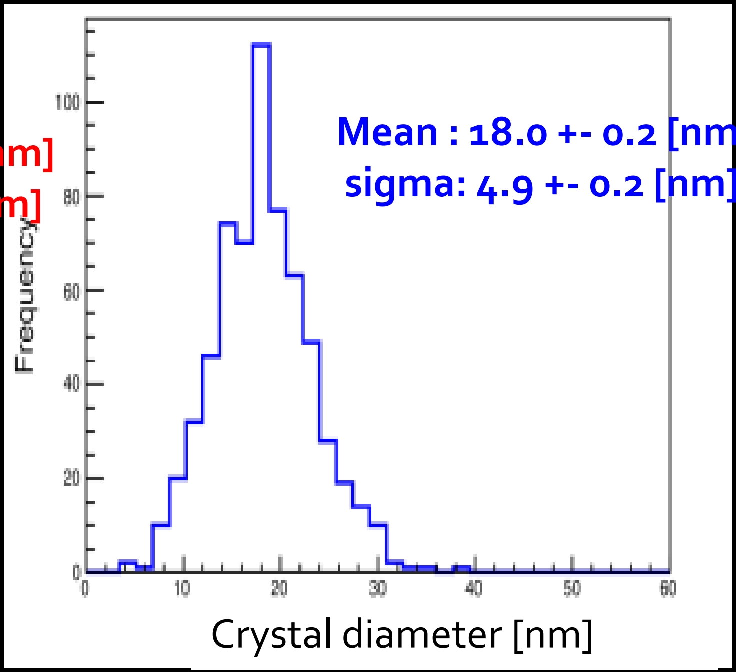
NIT

Current R&D emulsion



U-NIT

Finest grain emulsion



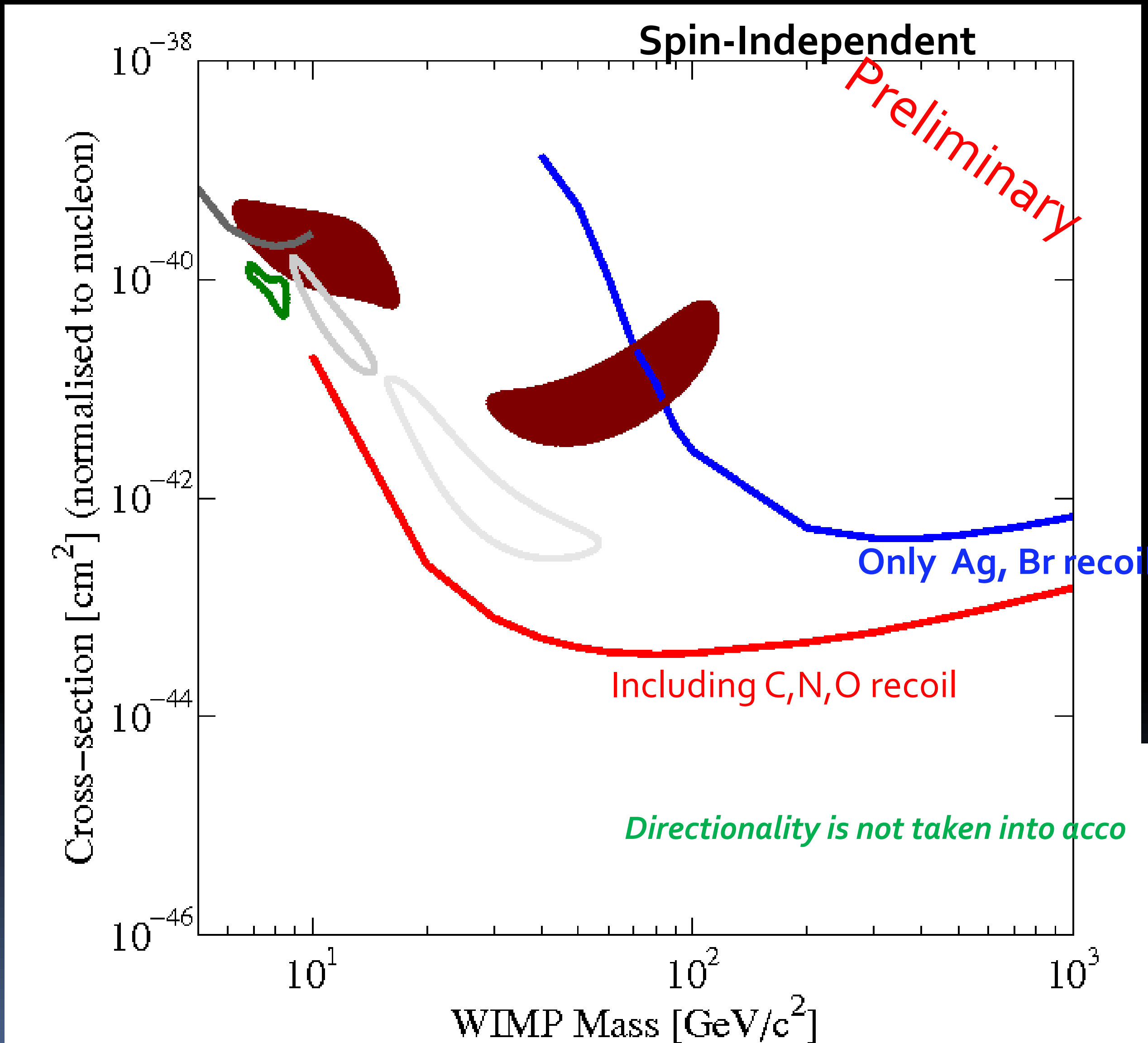
Current R&D emulsion

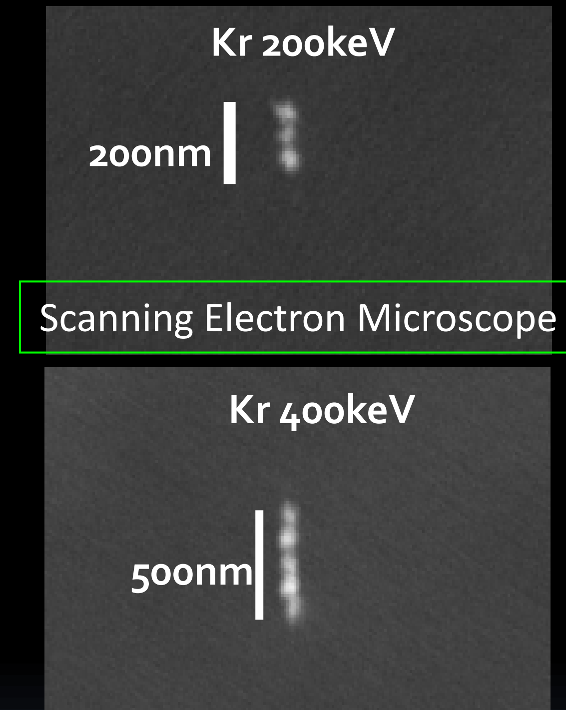
Further detector for physics run

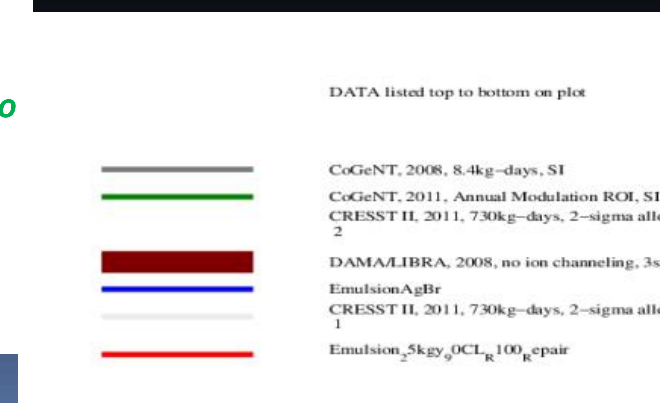
	NIT	U-NIT
AgBr density	12 AgBr/μm	29 AgBr/μm
Detectable range	> 200 nm	> 100 nm
Tracking E threshold	> 80 keV@C	> 35-40 keV@C
One crystal sensitivity	> 90 % @ C of 35keV	Not yet

Ideal Sensitivity for SI interaction with emulsion detector

Emulsion 25kg・y, 90% C.L., Track length > 100nm

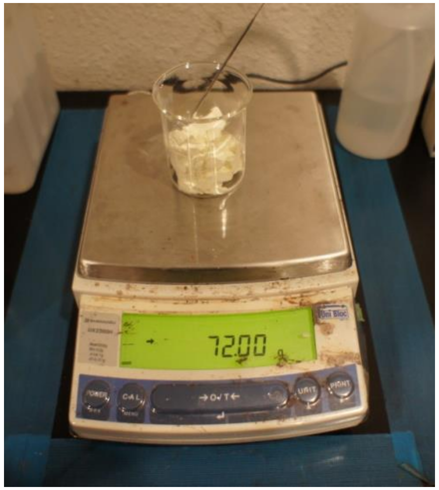




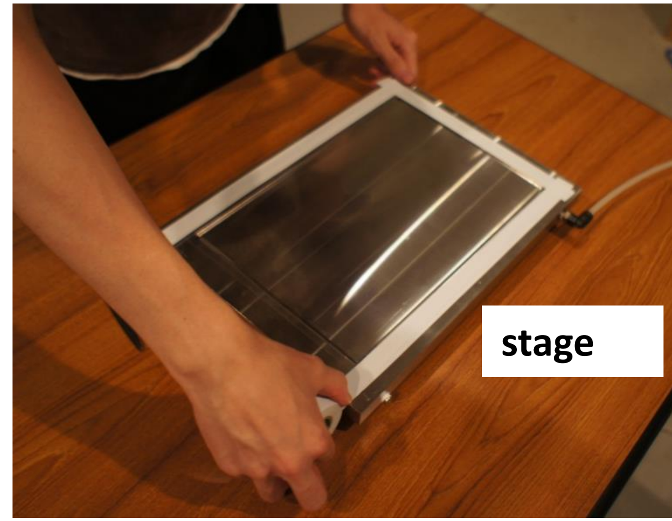


Pouring

①pick up emulsion put in hot bath

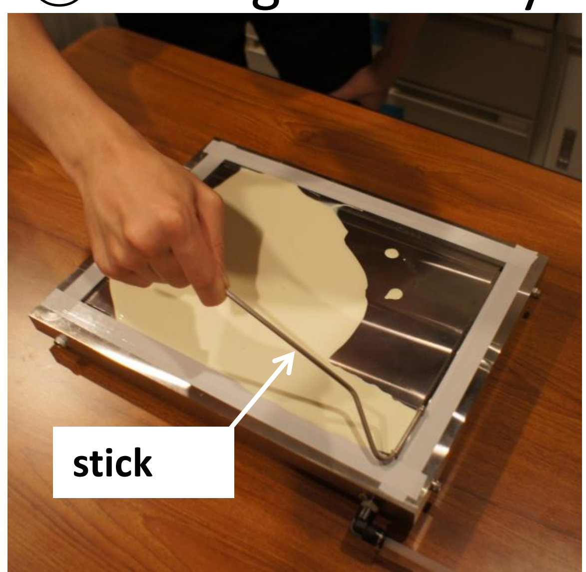


②sticking base on pouring stage



③pouring gel

④coating uniformly



⑤wait for setting and
Move to drying cabinet

Pouring room in Nagoya university

1day ~ 1 m^2

気球搭載型大口径高精度 γ線望遠鏡 GRAINE
（Gamma-Ray Astro-Imager with Nuclear Emulsion）

対象γ線エネルギー：50MeV～数100GeV
角度分解能　　　　：2～0.01 度（Fermi比一桁上）
偏光検出能力を持つ

目標フライト　：～10m^2×～35日/年
検出γ線光子数：～　Fermi（定常源）
　　　　　　　　～ 10×Fermi（バースト源）

経過と予定
2011年6月　　1号機(125cm^2) 北海道フライト
2014年5/10月 2号機(2500cm^2) オーストラリアフライト(予定)
2015年～　　　実用観測望遠鏡(1-10m^2)

GRAINE計画

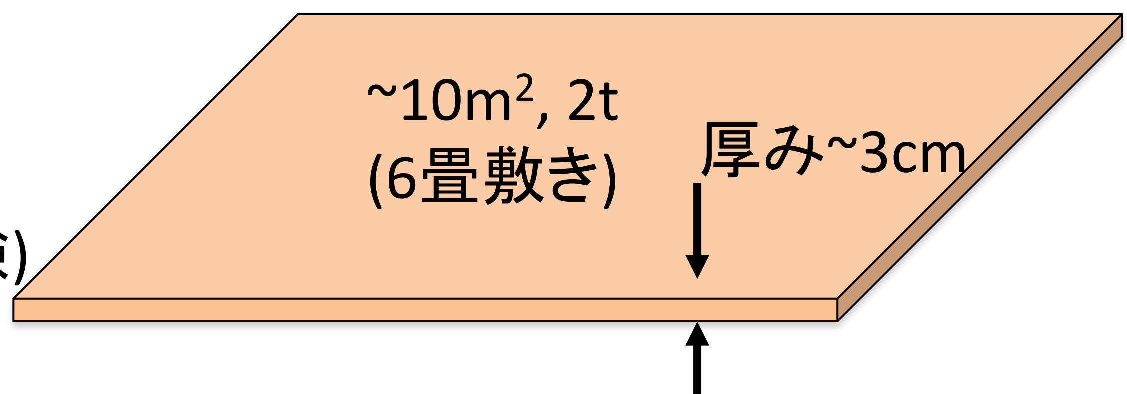
Gamma-Ray Astro-Imager with Nuclear Emulsion

大面積、高分解能、かつ偏光感度を持つ原子核乾板による
長時間気球観測を行うことで、宇宙ガンマ線の精密観測を実現。

GRAINE 2011

1st step	プロトタイプ1 (1/10m)	•**上空での観測コンセプトの実証** •バックグラウンドの実測
2nd step	プロトタイプ2 (1/2m)	•既知のガンマ線天体の最高精度で検出
Final step	フルスケール (～3m)	•科学観測

7日間 x 5～10フライト
(=JACEE実験、RANJOB実験)



Emulsion in Magnetic Field

- Charge Sign determination
  + Distinguish Neutrino and Anti-Neutrino

  + increase sensitivity
  + increase BG-rejection power

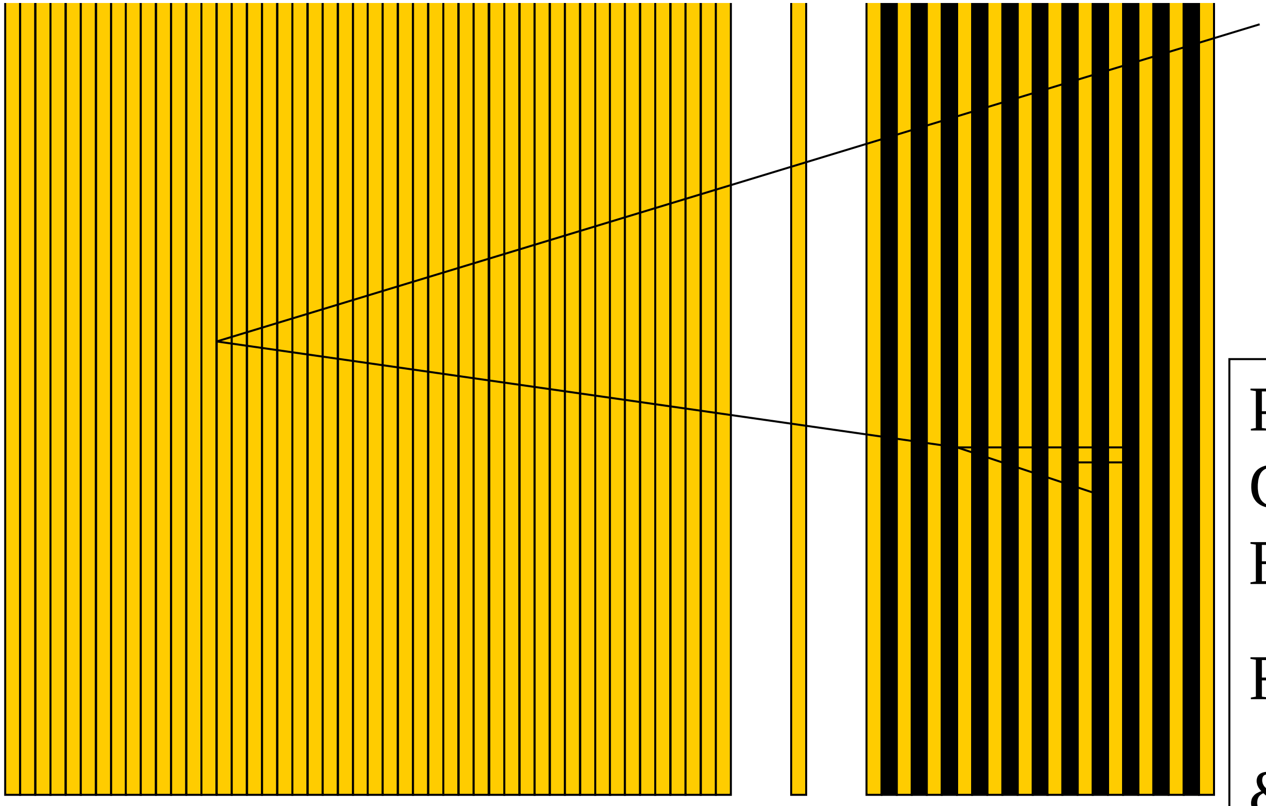
- We have experience
  in CHORUS/ET (Emulsion Tracker by TOHO Univ.)

- Iron Core type : Cheap, for h and Mu.
  Air Core type : Expensive for e, h and mu.

All neutrino flavor tagging detector with Magnetic Field

$\nu_\tau/\overline{\nu_\tau}/\nu_\mu/\overline{\nu_\mu}/\nu_e/\overline{\nu_e}$

Satisfy Heavy mass and Sign determination



Pb
Calorimeter
ECC

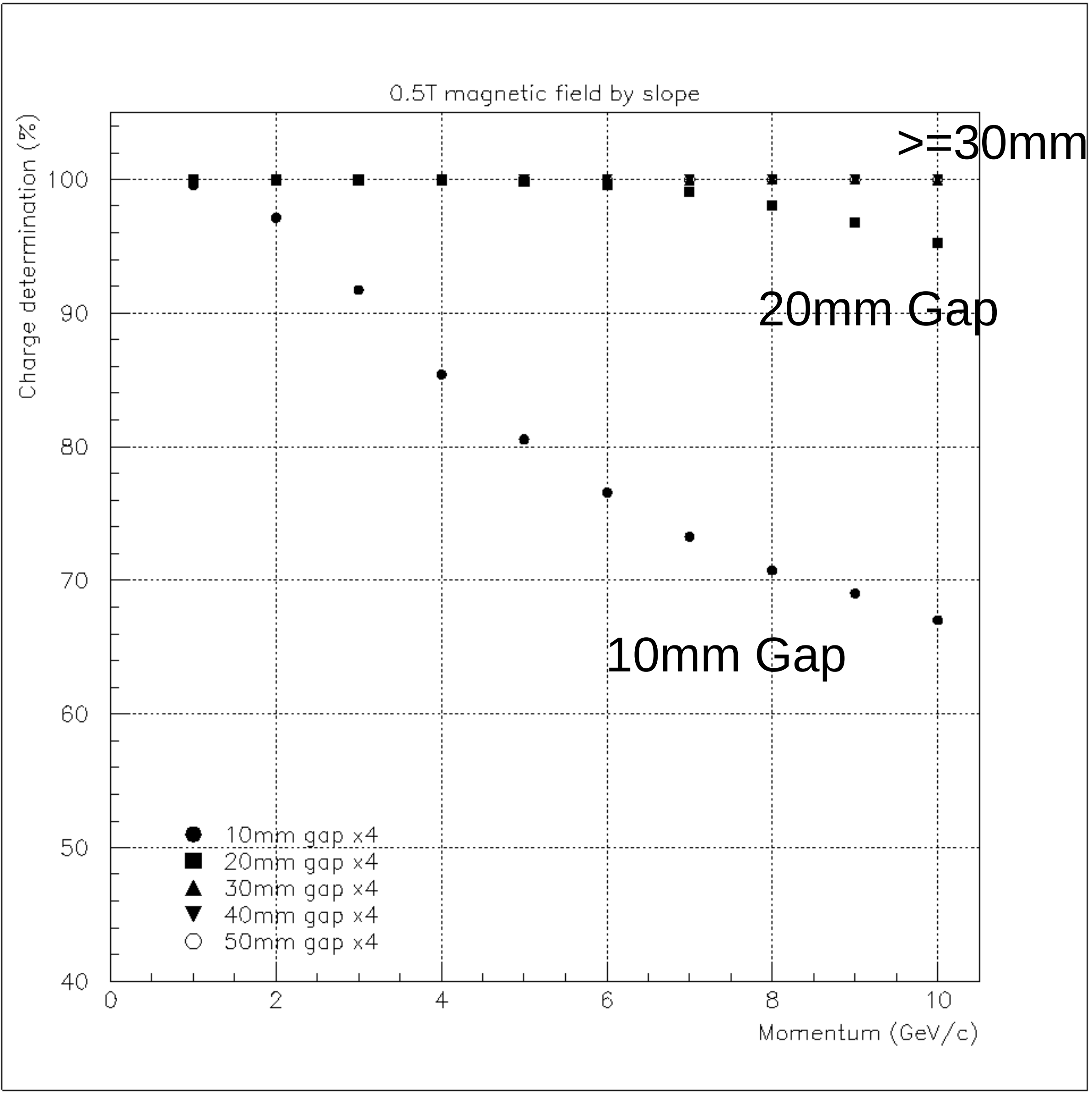
For P meas.

& e-id.

Producer: low~Medium Z ECC

Space for Sign Det.

Charge determination (0.5T)   MC

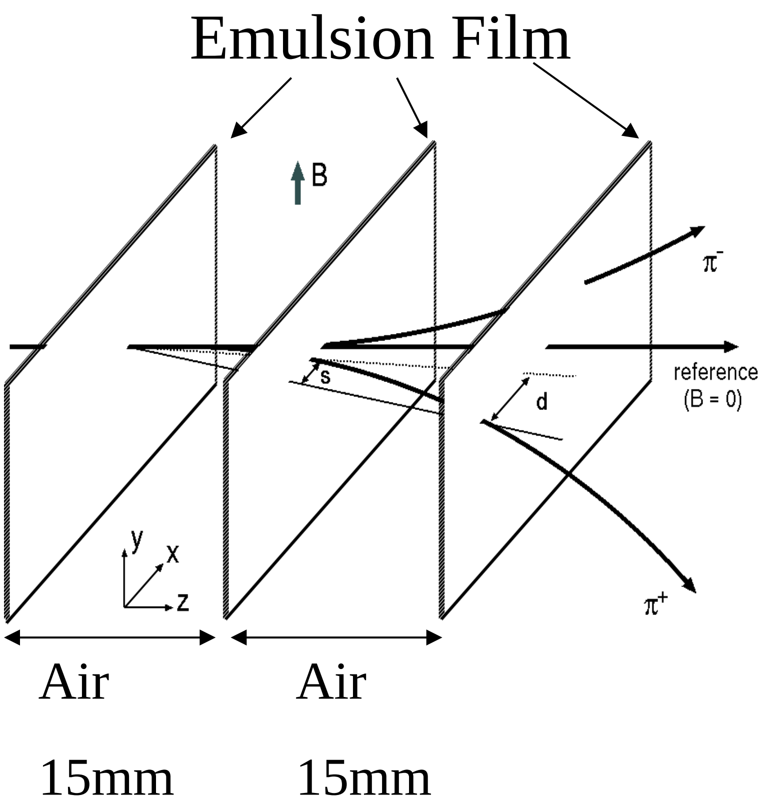


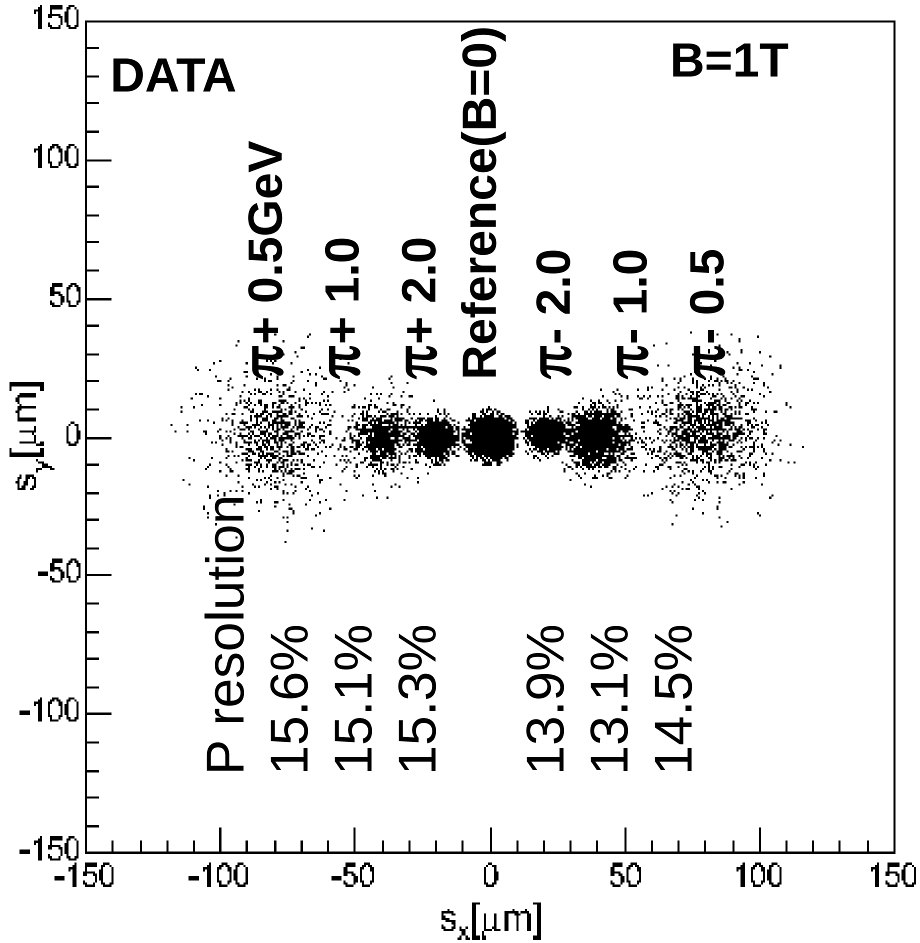
P(GeV/c)	Eff. 20mm	Eff. 30mm
1	99.93%	99.96%
2	99.95%	99.97%
3	99.94%	99.67%
4	99.90%	99.98%
5	99.83%	99.96%
6	99.58%	99.97%
7	98.98%	99.97%
8	97.97%	99.96%
9	96.78%	99.97%
10	95.32%	99.95%

Sign determination for ν-$\bar{\nu}$ separation with thin Air Gap (~1cm) filled with B

TOHO Univ. Group

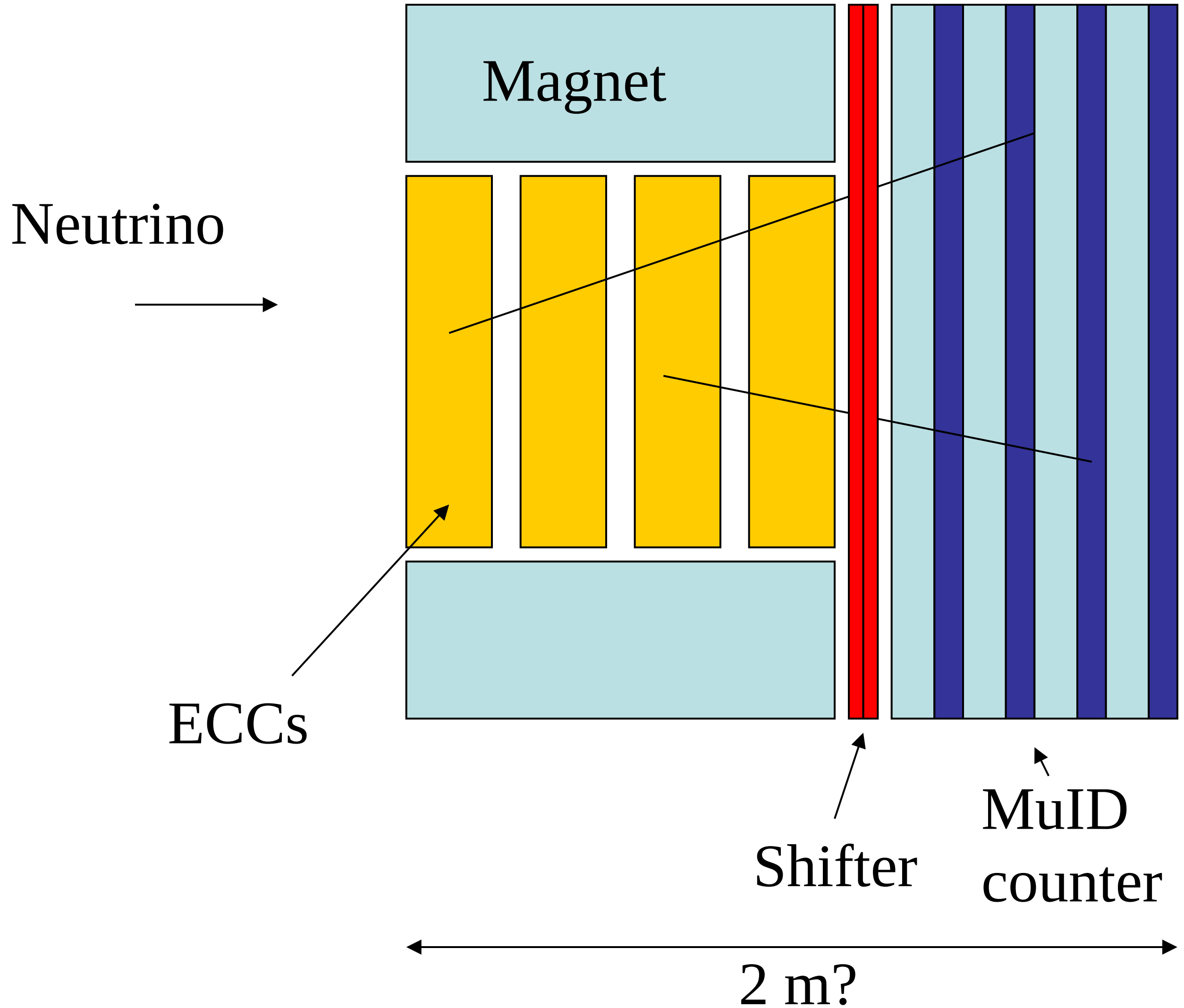
Test Experiment at KEK T1 beam line





* Proton contamination were rejected by dE/dx measurement

Set up



By-product?

- Charm Physics??

  D0-D0bar Oscillation?

  Charmed penta-quark study ?

  Charmed hadron mean free path ?

  Charmed Nucleus study?

…..

Charm related ”Hadron Physics"

LHC Neutrino

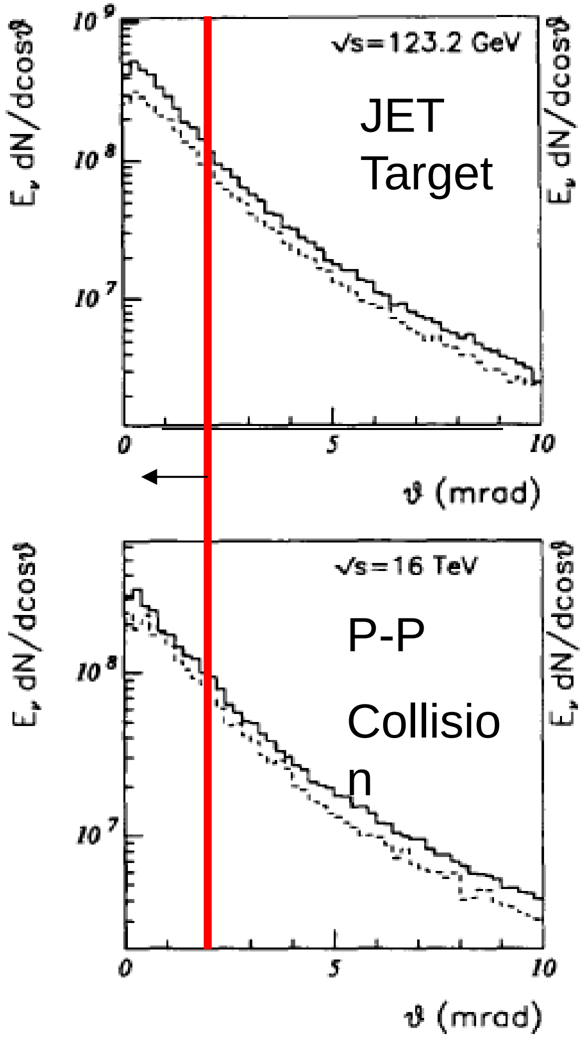
Ref: A.De Rujula et al., Nucl.Phys.B405(1993)80-108.

- High energy neutrinos from decays of Charm and Bottom.
- Main part within 2mrad from the beam axis

➢ Tau neutrino physics

Cross section, Magnetic Moment measurement

➢ Exotic neutrino like particle or 4th generation ν



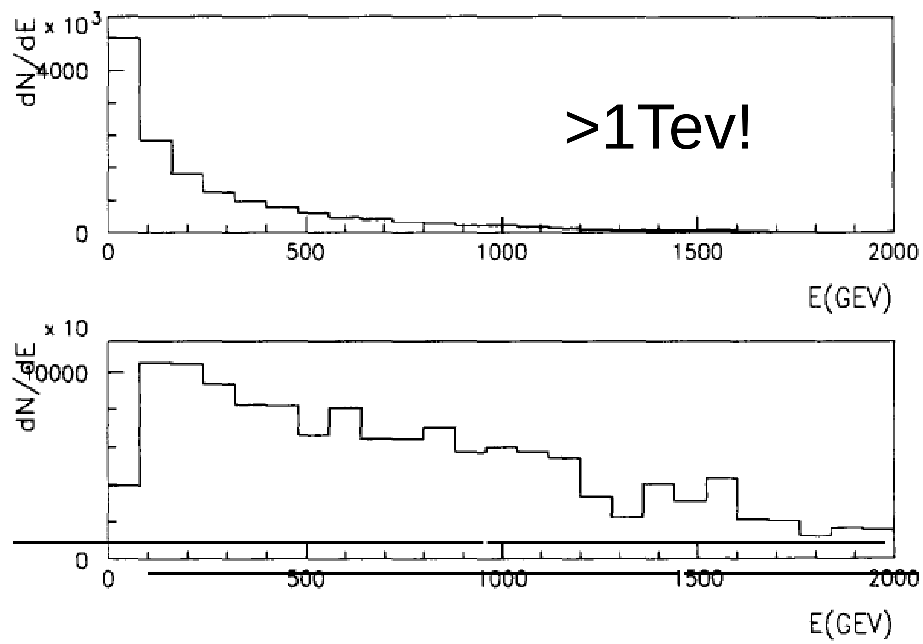


Fig. 13. Some properties of a ν_τ beam produced in LHC collisions. The decay $D_s \to \tau\nu_\tau$ and the subsequent τ decay are taken as an example. (a) Neutrino emission angle versus neutrino energy; (b) emitted neutrino's energy; (c) energy of the neutrinos intercepted by a 2 mrad-wide target, where the

LHC neutrino

Interaction event rate in a year

Target Thickness : 8kg/cm2 in 2mrad cone. ~100 OPERA ECC

	JET target	P-P Collision
Base	5×10^{17} p.o.t.	$L_{LHC}=2 \times 10^{34} cm^{-2} \cdot s^{-1}$
ν_l ＋anti-ν_l	17000～21000	12000～15000
ν_t＋anti-ν_t	1400～2000	1100～1700

About 100 ECC accumulate 10000-20000 nt events, ie. 100 $\nu\tau$/ECC
$\nu\tau$ Purity in neutrino interaction is about 10% and 1000 events.
→ Cross section measurement