Fast neutron monitor in space using scintillating fiber camera

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Advantages of Scintillating Fiber Camera Fast Neutron Dosimeter in Space

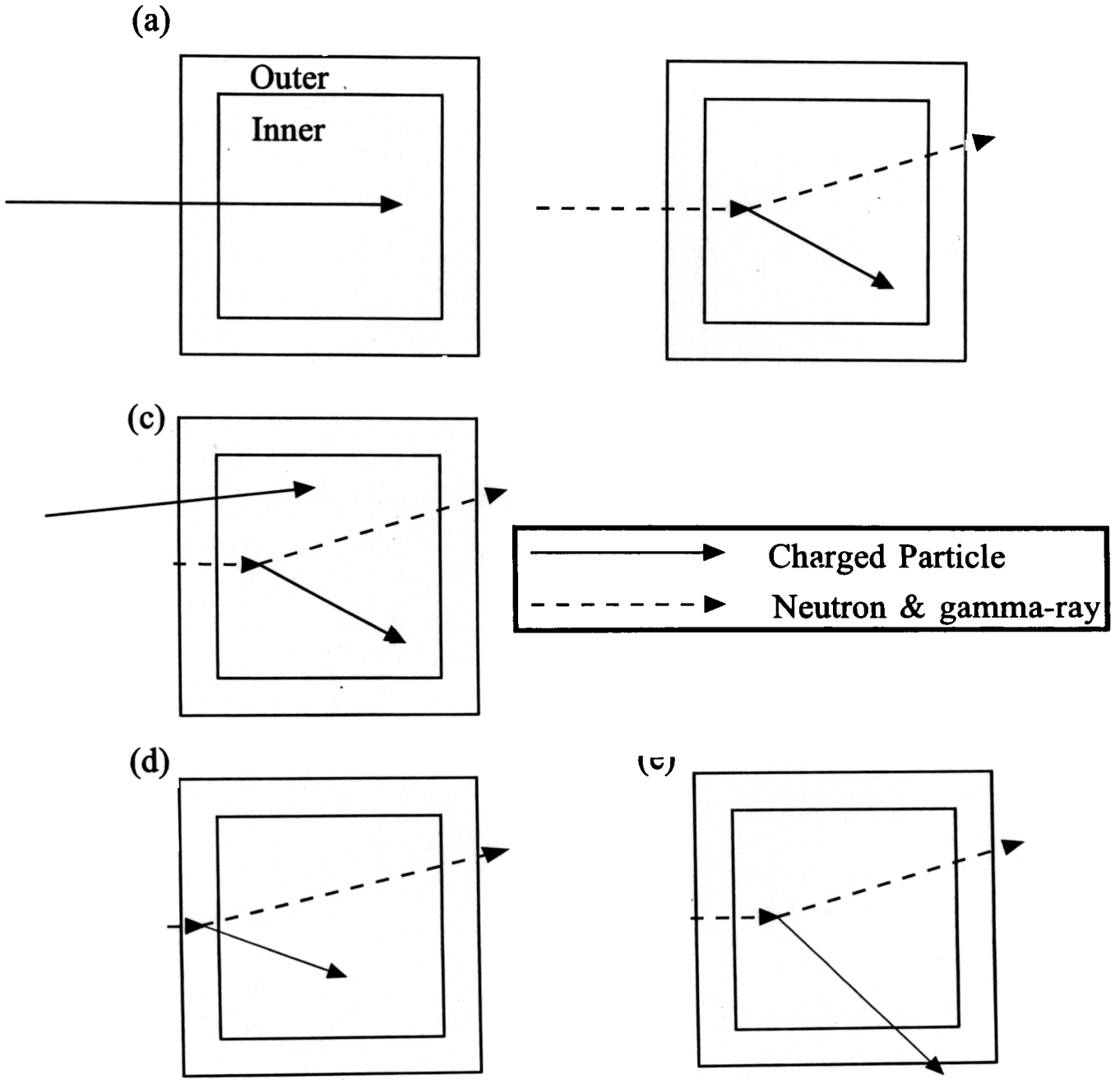
1. Scintillating fiber camera can measure scintillation yield along each particle passage and, using the result, we can get LET distribution in the camera.

2. n • γ discrimination is possible for neutrons with energies higher than 2 or 5 MeV.

3. Particle identification between protons, helium ions and carbon or oxygen ions is also possible.

4. From these properties, scintillation fiber camera can be used for measurement of dose equivalent in space without help of neutron energy spectrum.

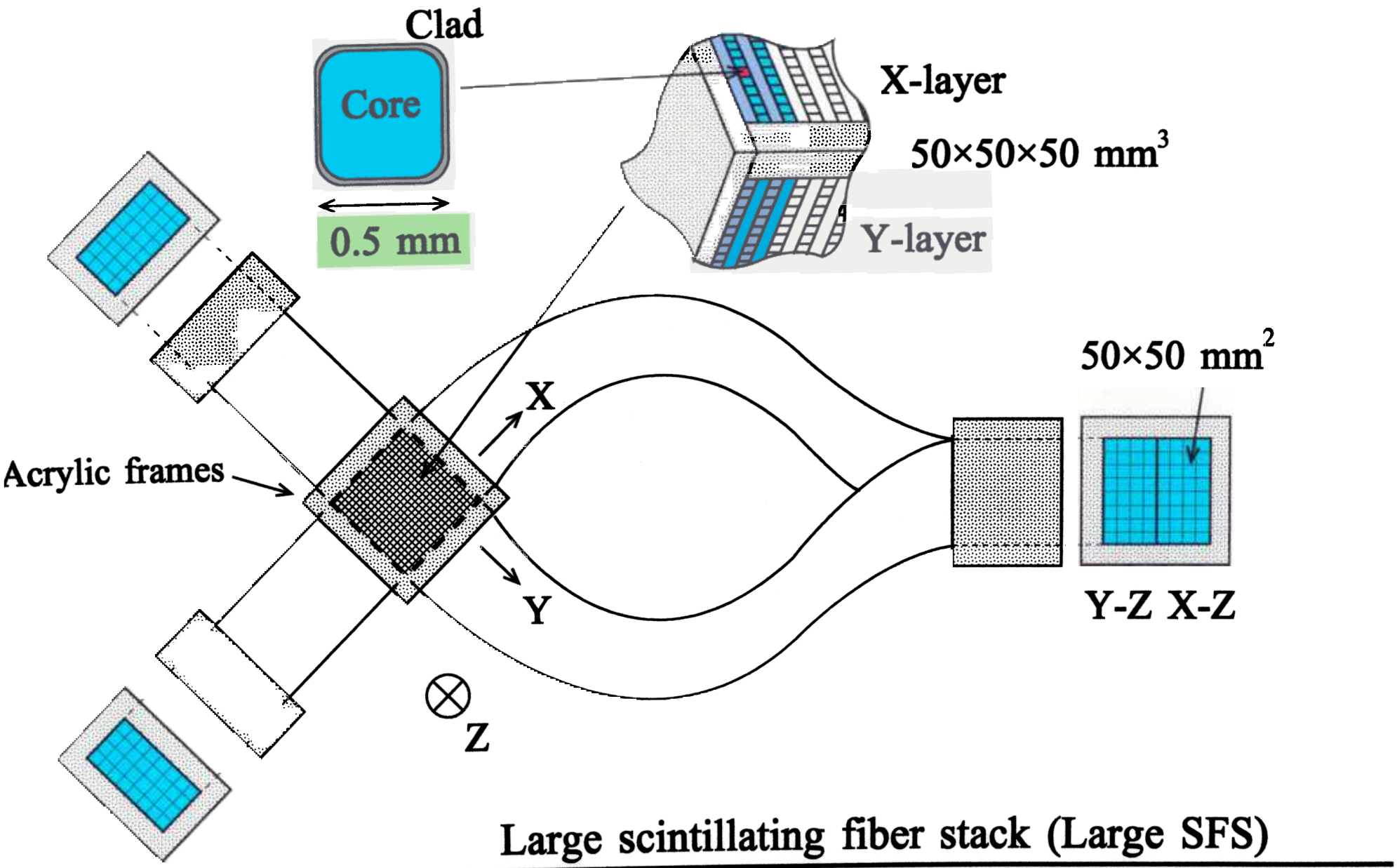
Content



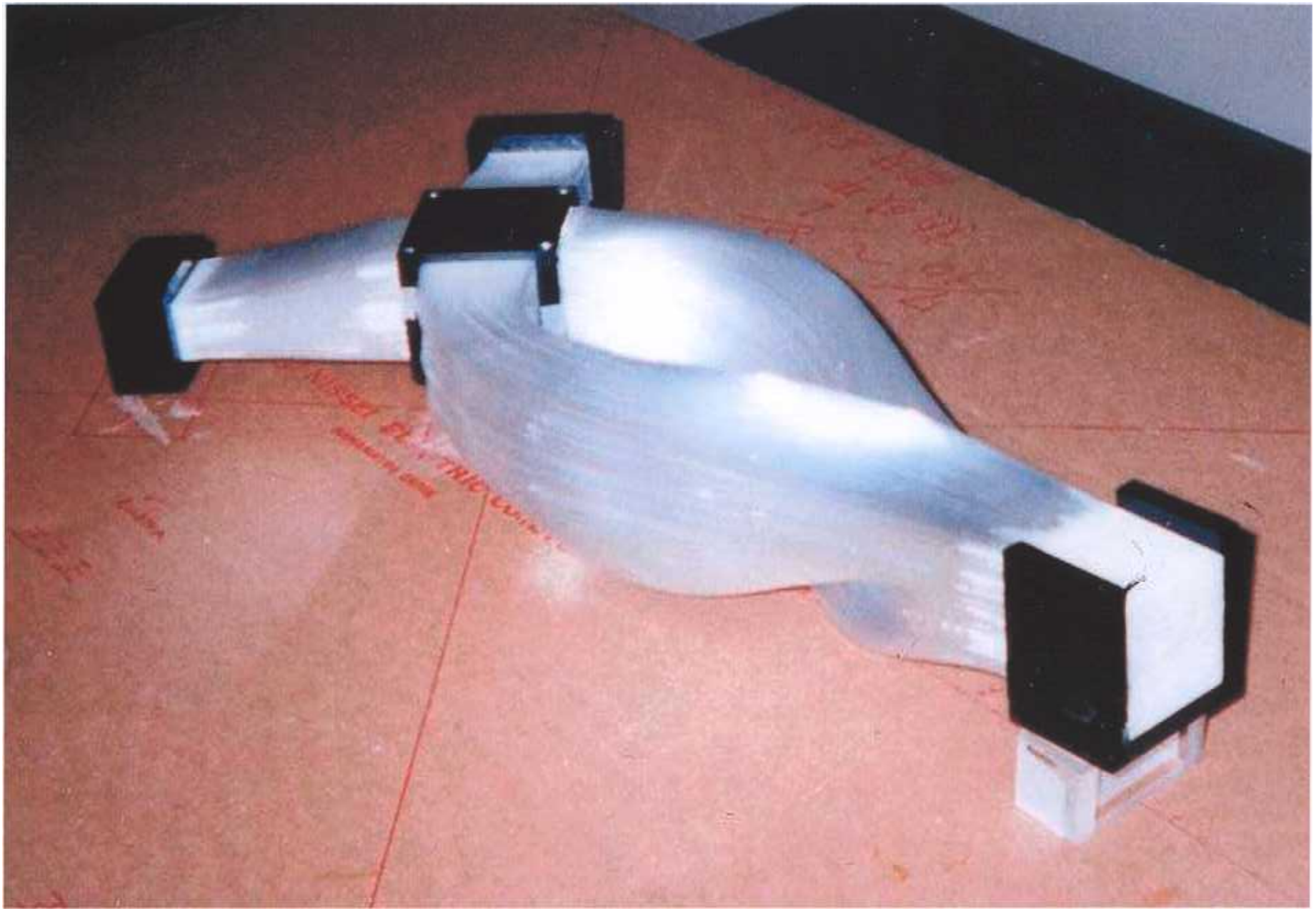
Outer scintillator is utilized as the anti-detector.

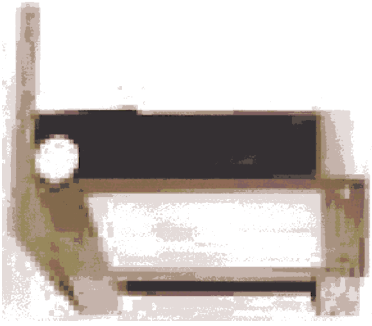
- Neutrons are identified from gamma-rays by pulse shape discrimination method.
- In the case of (c), (d) and (e), neutron events are rejected.
- Contribution from higher energy neutron will be underestimated.

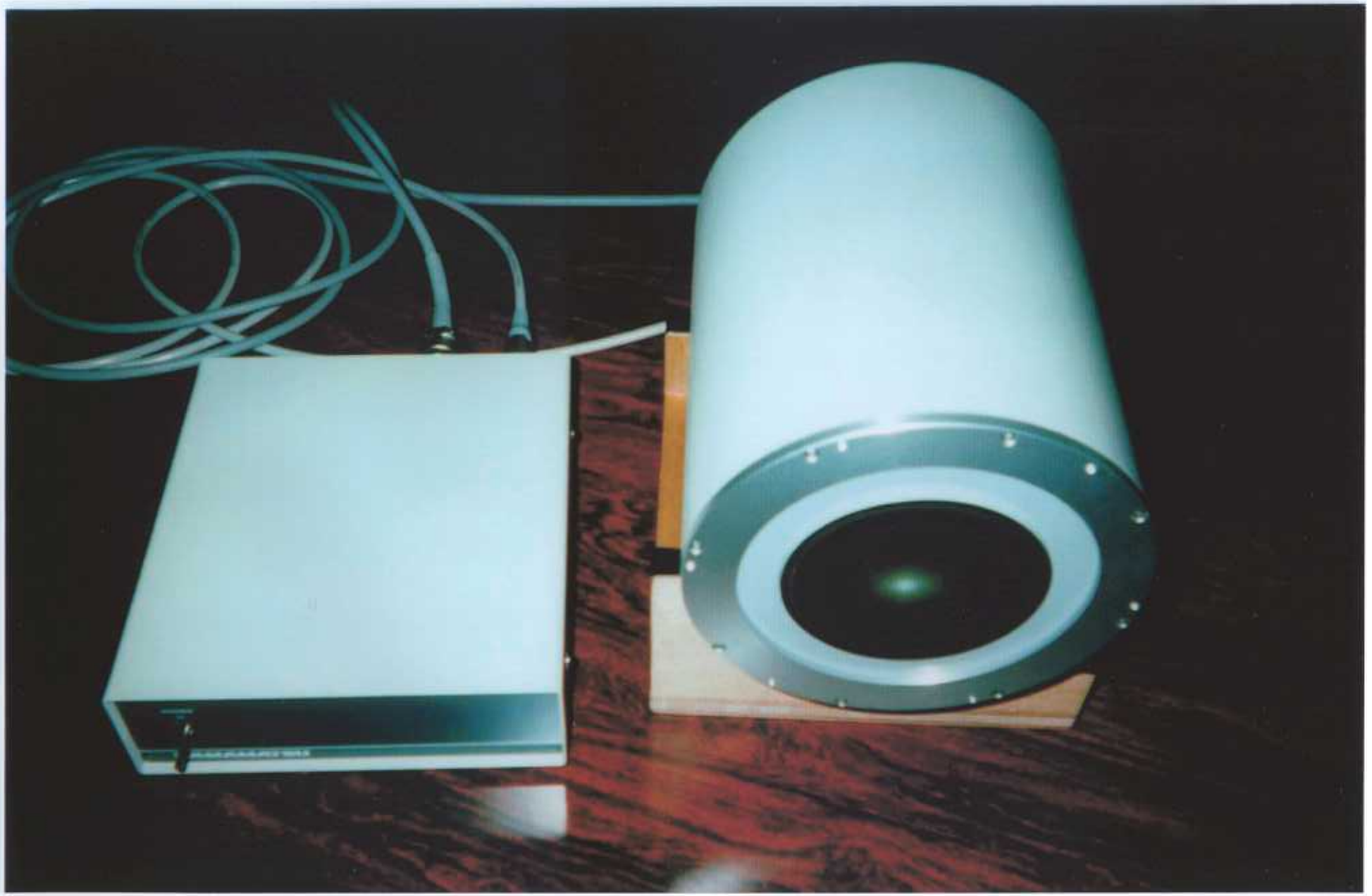
Schematic views of signals produced in Phoswich detector

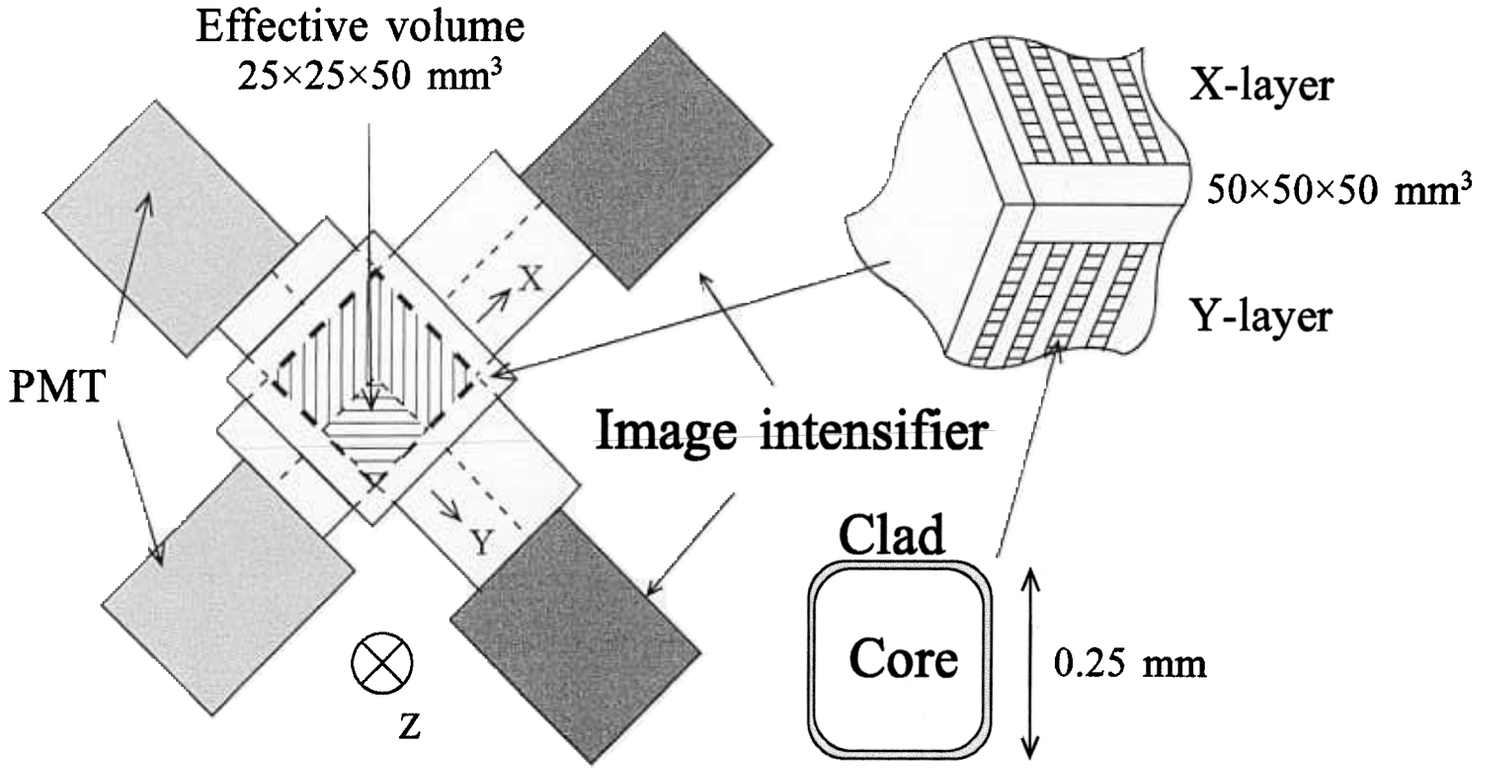


Large scintillating fiber stack (Large SFS)



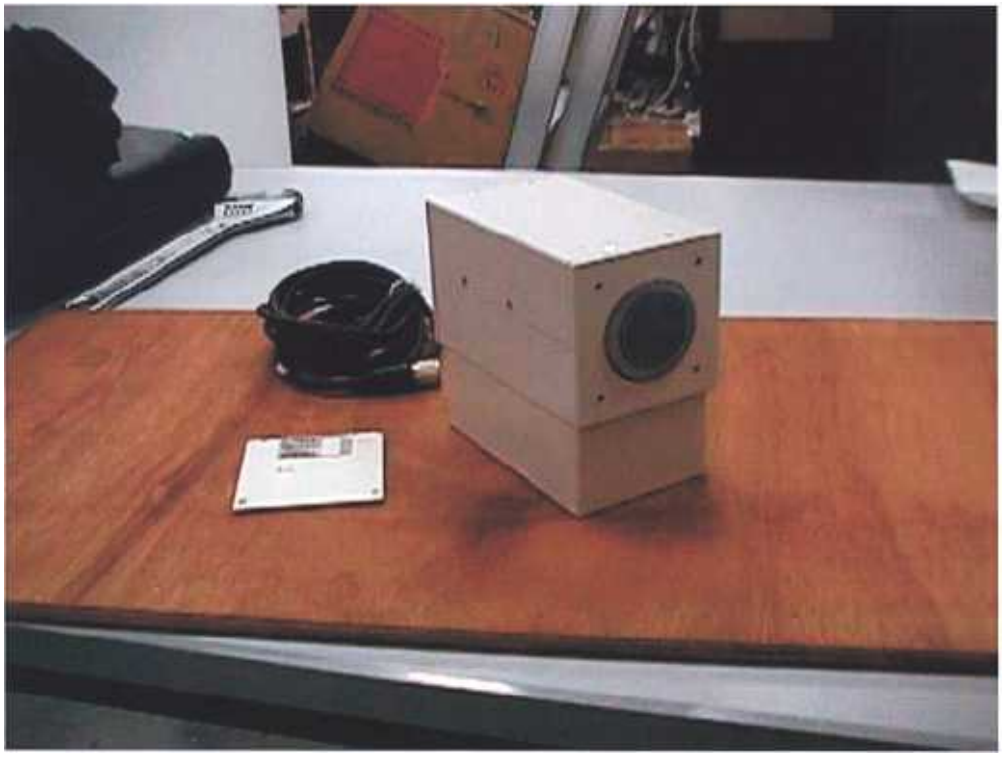






- System : a scintillating fiber stack, two image intensifier units and two photomultipliers
- Scintillating fiber stack : consisting of 0.25 mm square fiber,
  each fiber layer perpendicular to each other
- Image intensifier unit : 40 ϕ effective input window, two-stage type with the CCD camera
- Photomultuplier : triggering signals for image intensifier units and DAQ.
- Two 2-dimensional projections are viewed by two image intensifier units.

System of the small scintillating fiber camera



Properties of SFCs *)

	Large prototype	Small prototype
Fiber size	500 μ m Square	250 μ m Square
Effective volume @ SFS **)	$50 \times 50 \times 50$ mm^3	$25 \times 25 \times 50$ mm^3
Threshold energy of n-γ discrimination	5 ~ 10 MeV @ trig. of 2 PMTs ~ 2 MeV @trig. of 1 PMT	~ 5 MeV @ trig. of 2 PMTs ~ 2 MeV @trig. of 1 PMT
Non-effective vomule @ SFS	Scintillating fibers	Scintillating fibers
CCD pixel numbers	768 $\times$576	384 $\times$ 288
CCD pixel size on the input window of I.I.	132 μ m Square	110 μ m Square
CCD frame rates [Hz]	25 Hz	25 Hz

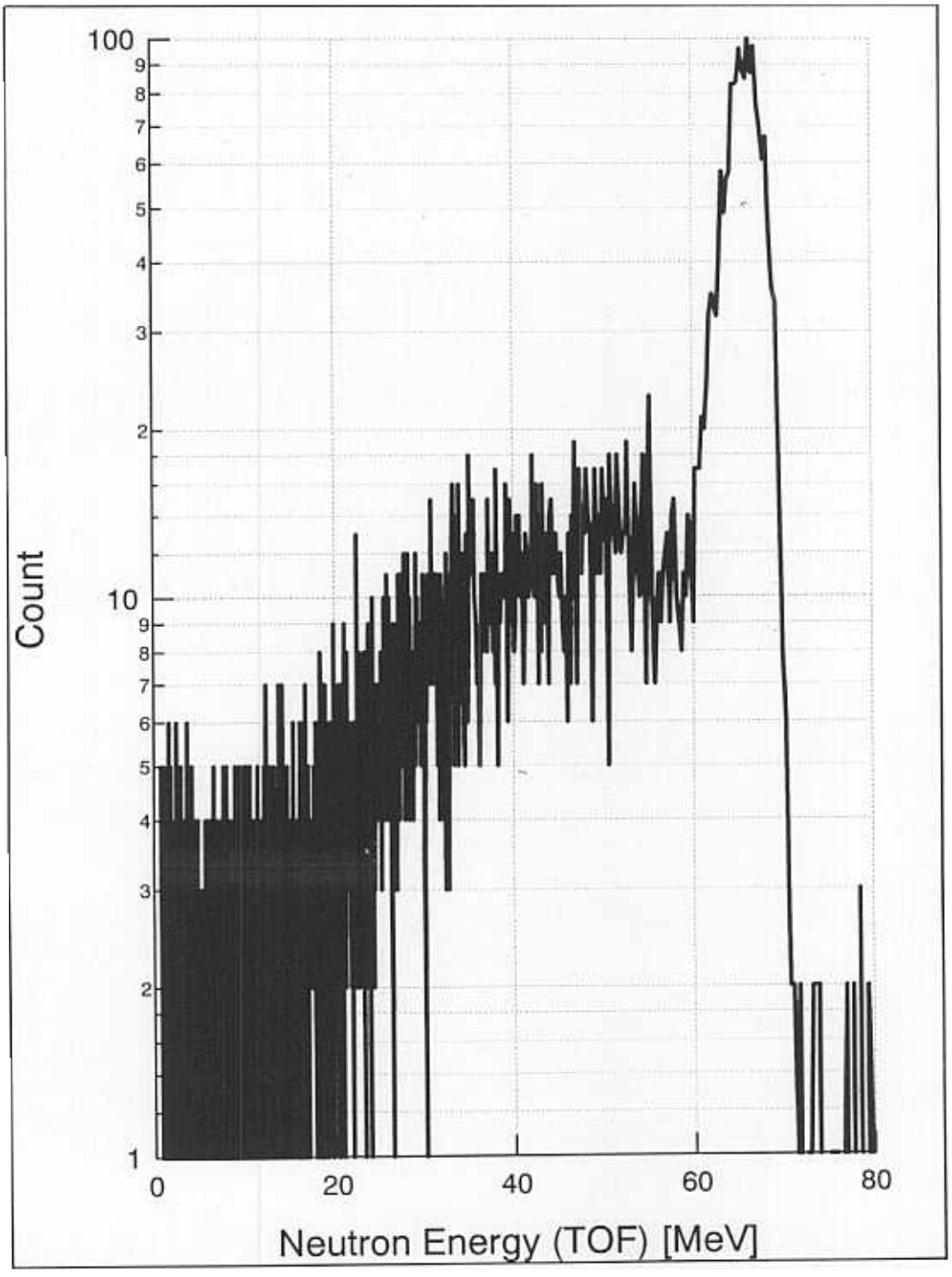
*SFC : Scintillating fiber camera (= SFS + Image intensifier unit)

**SFS : Scintillating fiber stack

List of beam tests

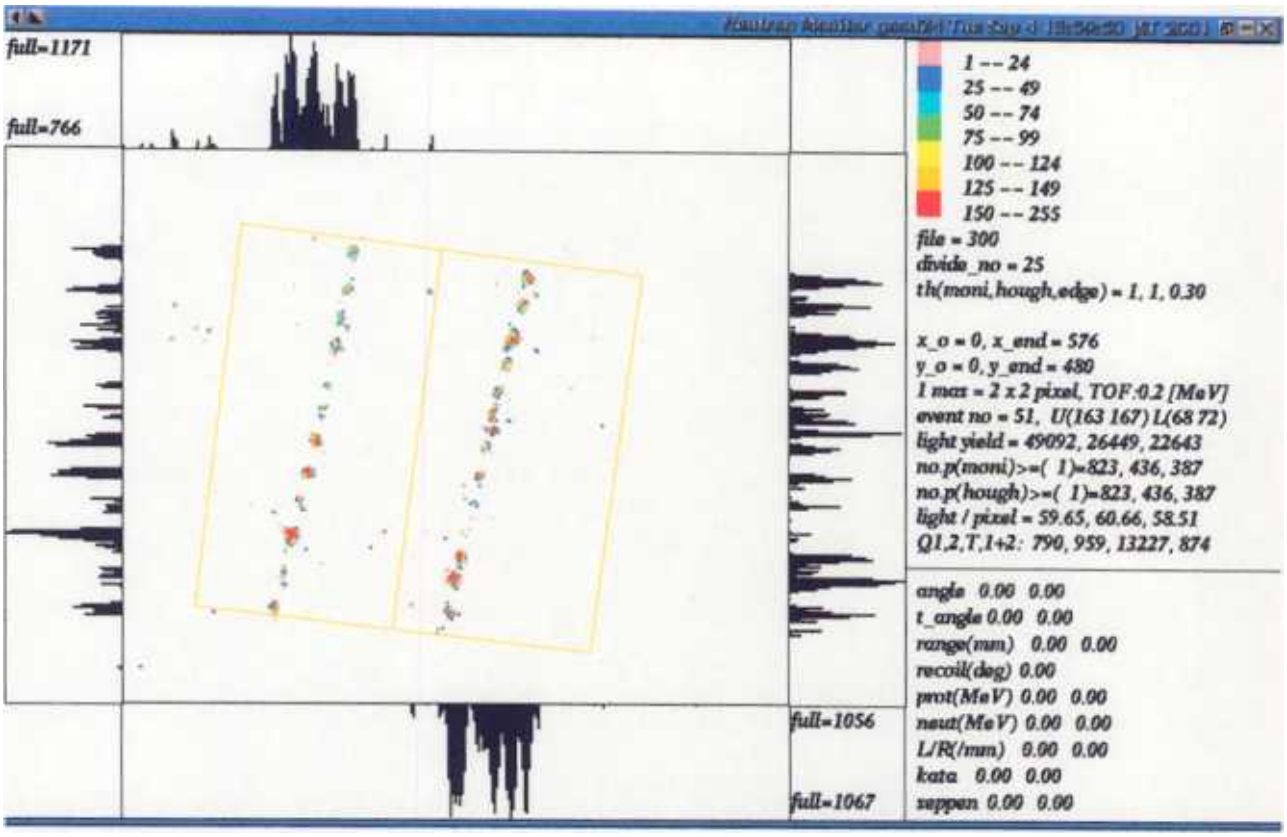
Particle	Energy	Accelerator facilities
^{40}Ar	650 MeV/n	HIMAC[1] @ NIRS[2]
neutron $^{7}Li(p,n)\,^{7}Be$	~ 66 MeV	Ring cyclotron @ RIKEN[3]
D-T neutron	14.6 MeV	Van der Graaff @ ETL[4]
D-D neutron	5.0 MeV	Cockcroft-Walton @ ETL

1) HIMAC : Heavy Ion Medical Accelerator in Chiba
2) NIRS : National Institute of Radiological Sciences (in Japan)
3) RIKEN : Rikagaku-Kenkyujo, Institute of Physical and Chemical Research (in Japan)
4) ETL : Electro Technical Laboratory (in Japan)
New name : national institute of Advanced Industrial Science and Technology (AIST)

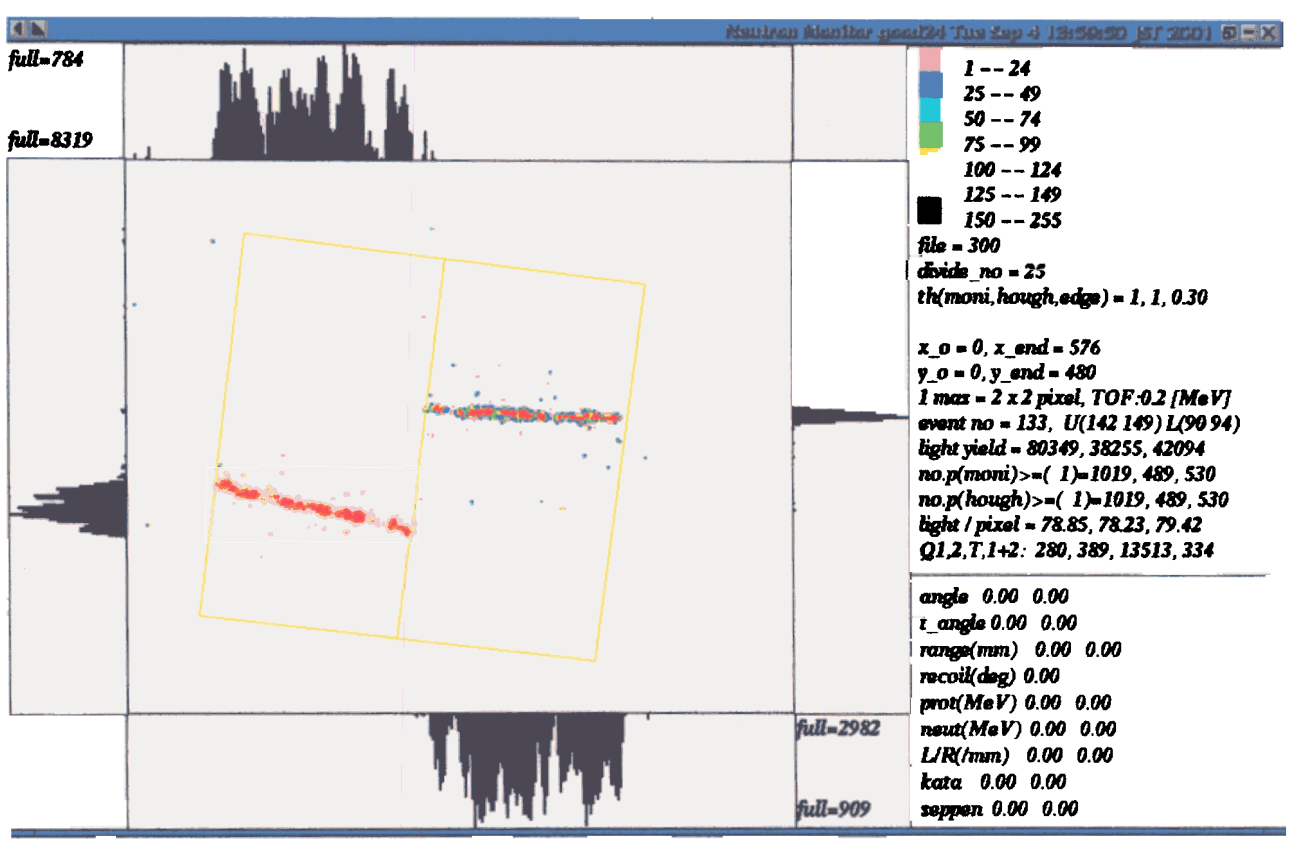


Energy spectrum of neutrons from p-^{7}Li reaction.
70 MeV protons were bombarded.

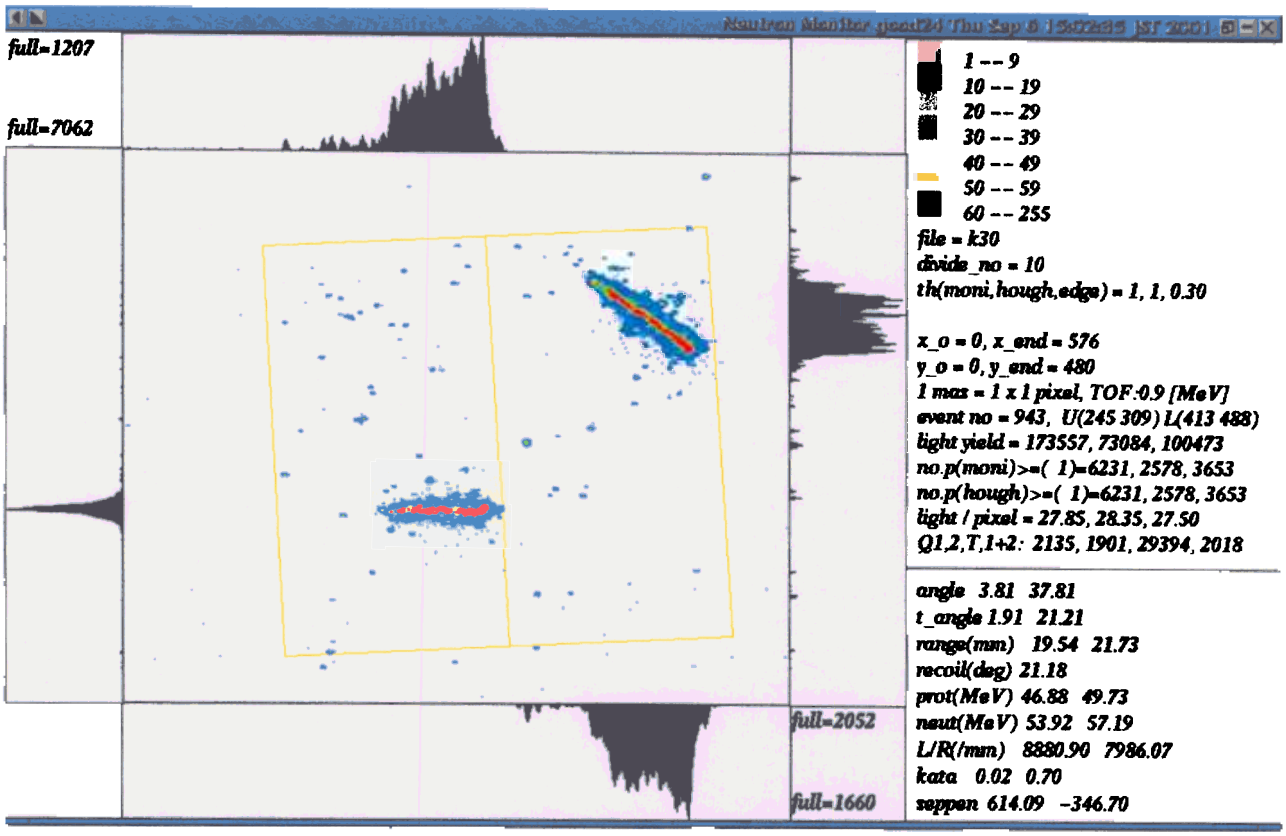
Cosmic muon (500 μ m) @ HIMAC



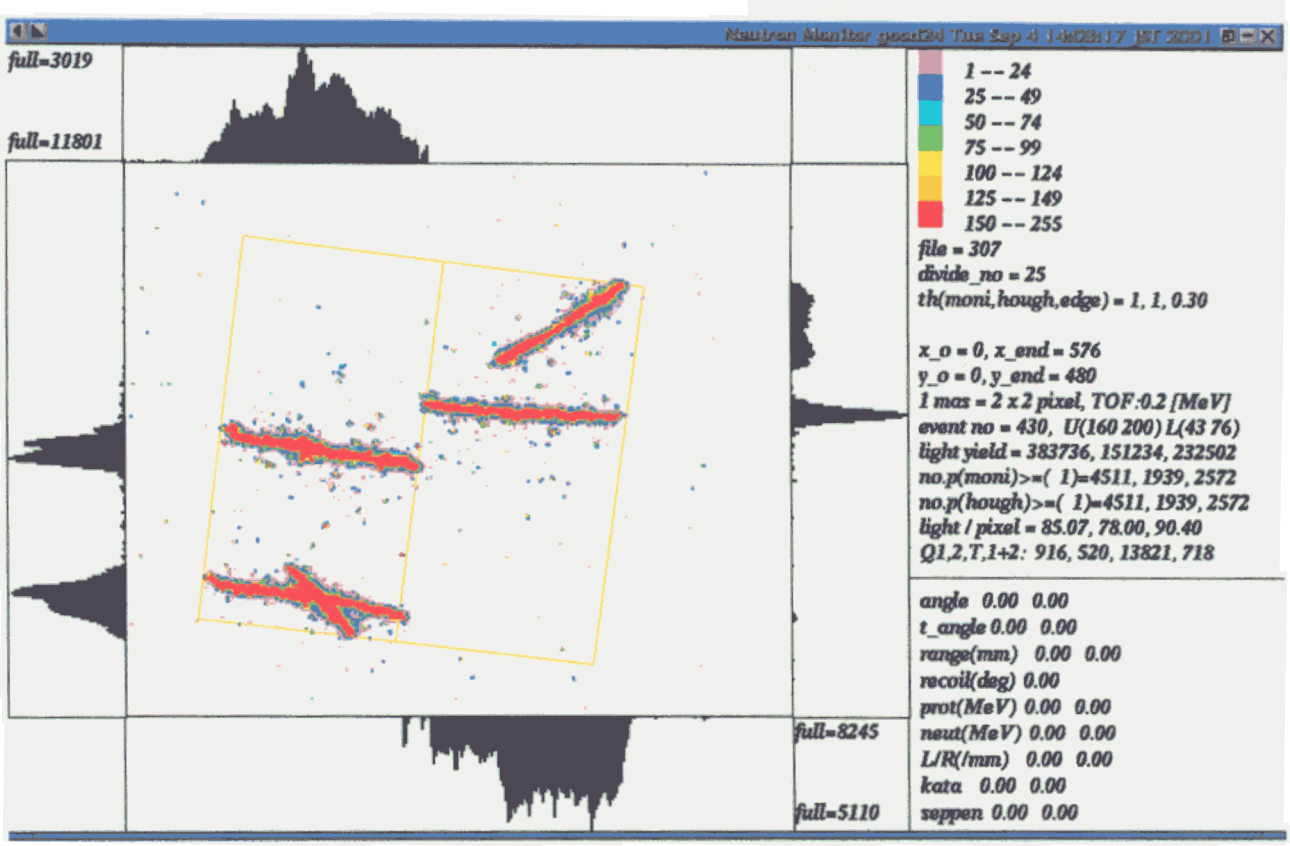
Penetrating proton, ^{40}Ar 650 MeV/n (500 μ m) @ HIMAC



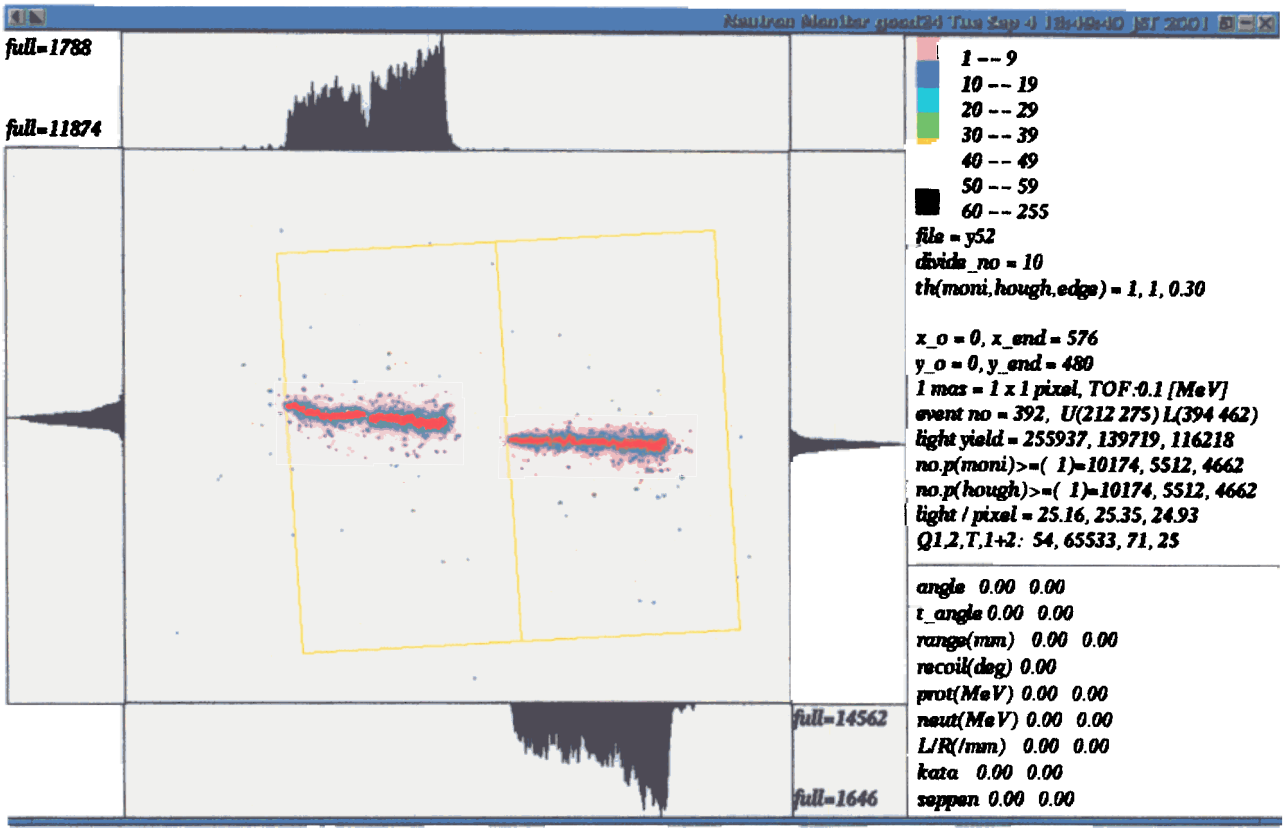
Recoil proton, proton 70 MeV, ^{7}Li (p, n)^{7}Be (500 μ m) @ RIKEN

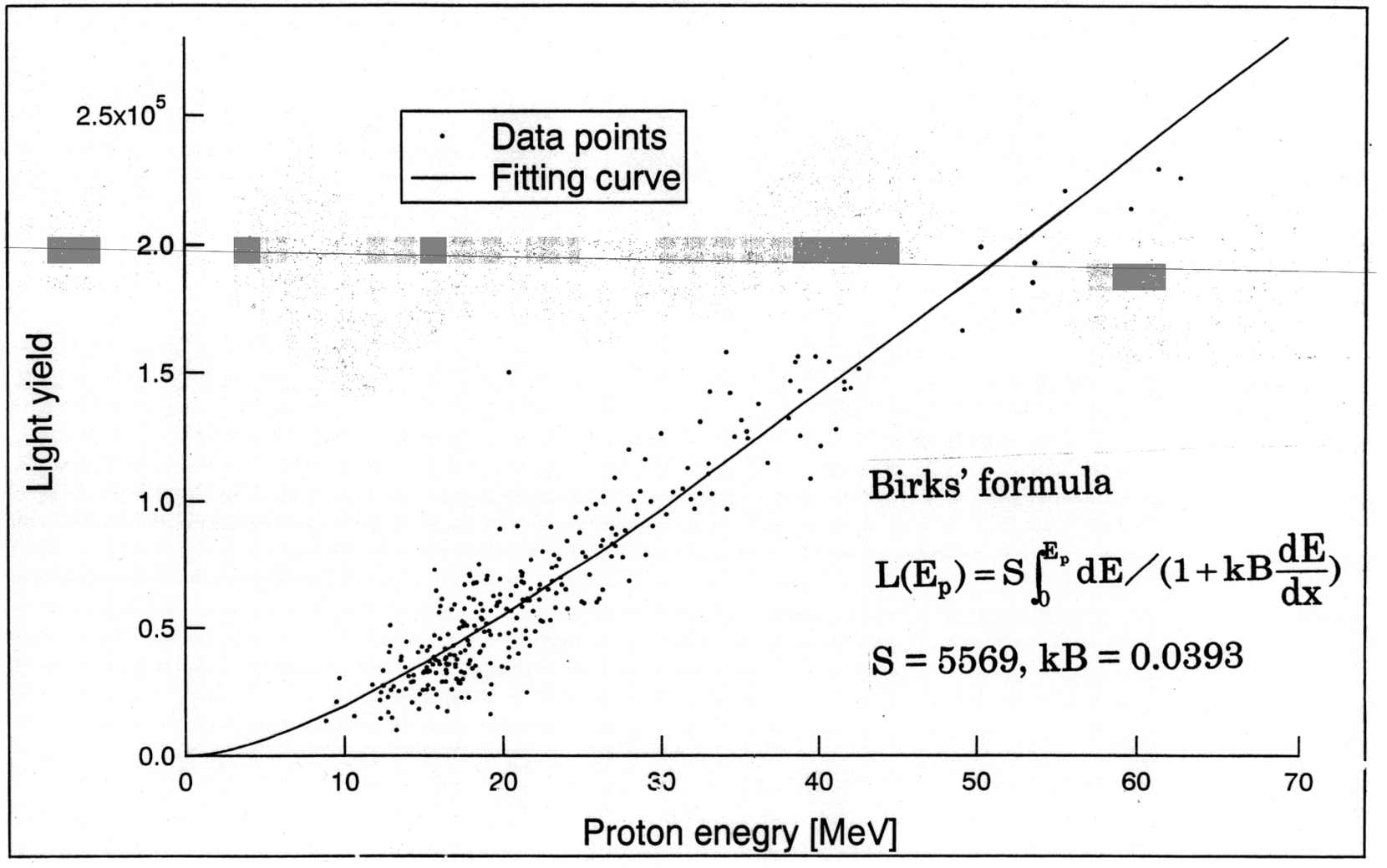


^{40}Ar 650 MeV/n (500 μ m) @ HIMAC

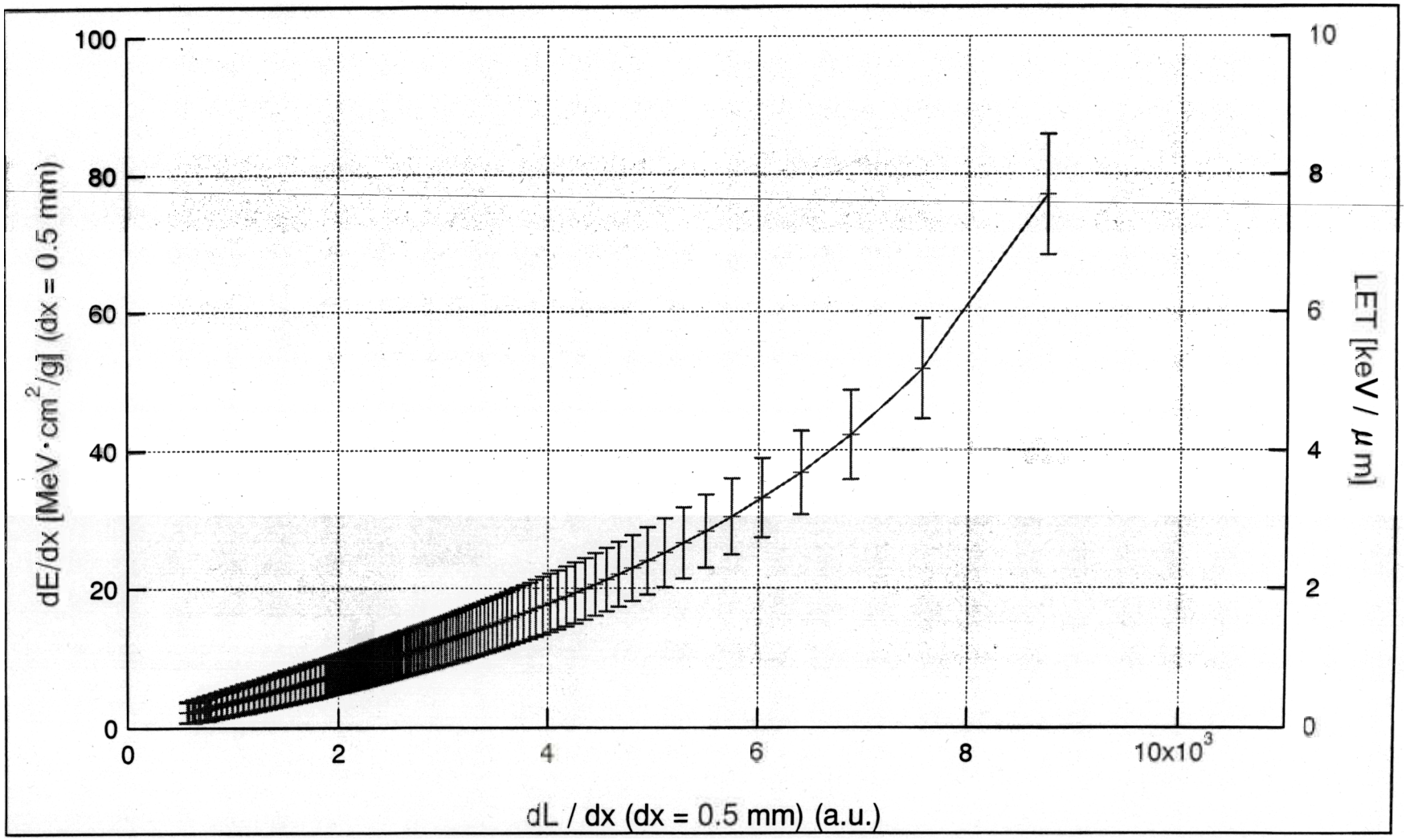


^{4}He 270 MeV, ^{4}He 230 MeV/n (500 μ m) @ HIMAC

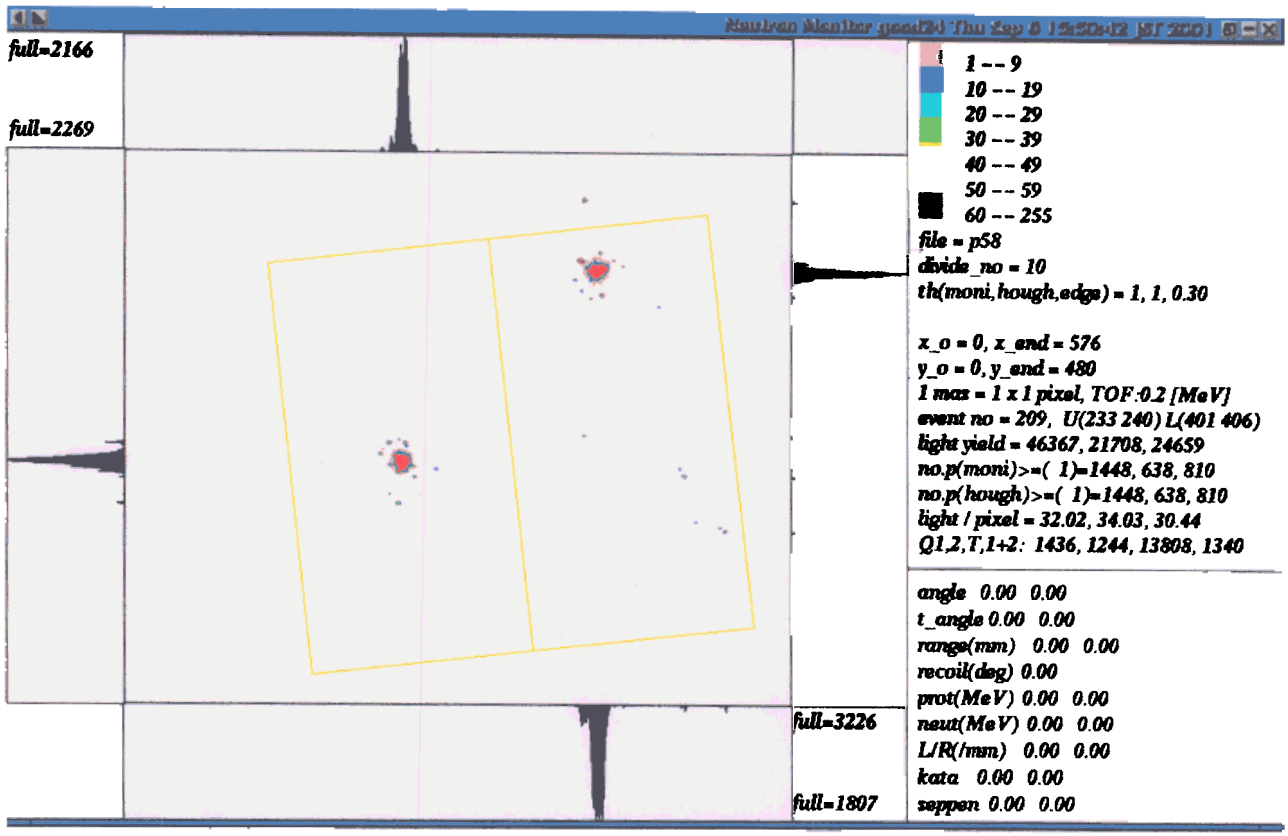




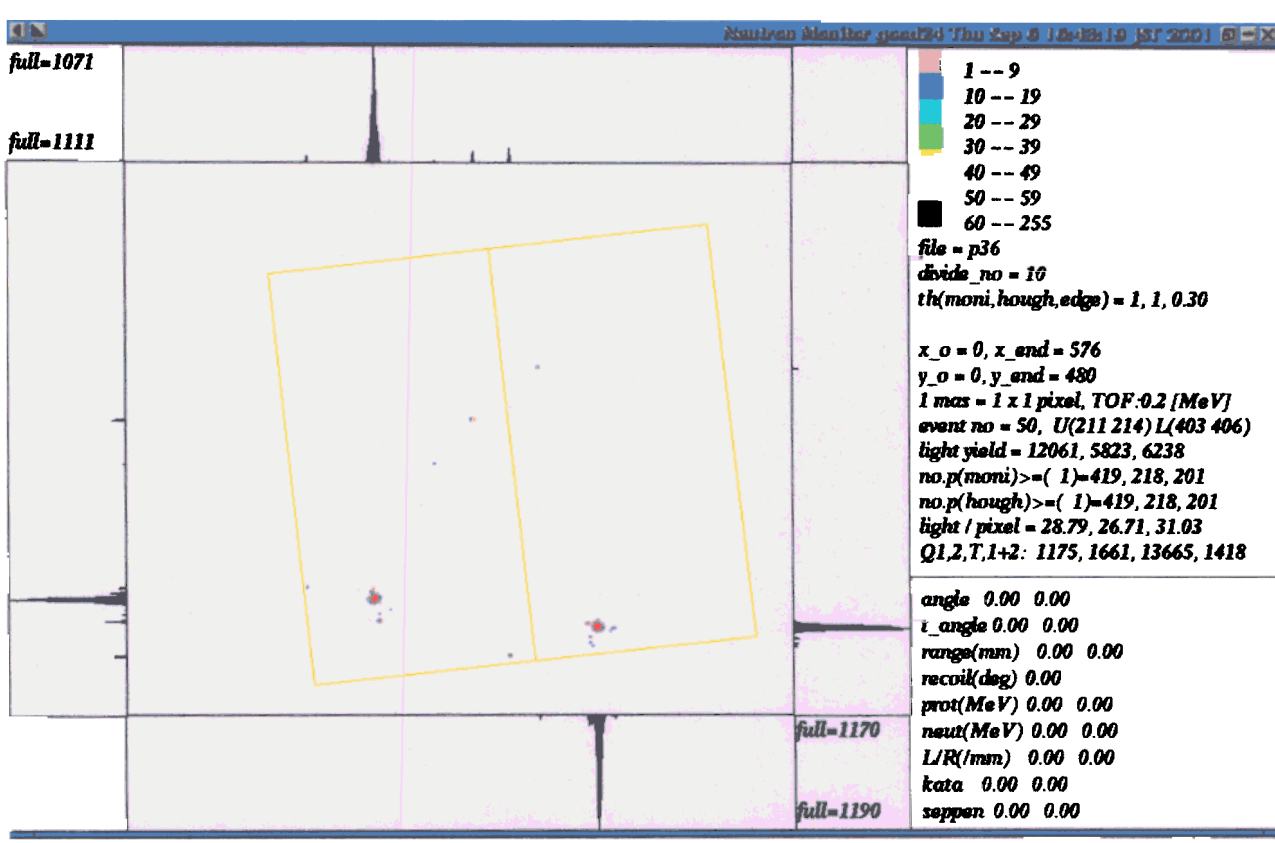
Relation between recoil proton energy and light yield


100
80
60
40
20
0
0
2
4
6
8
10x10^3
dE/dx [MeV·cm^2/g] (dx = 0.5 mm)
dL / dx (dx = 0.5 mm) (a.u.)
10
8
6
4
2
0
LET [keV / μm]

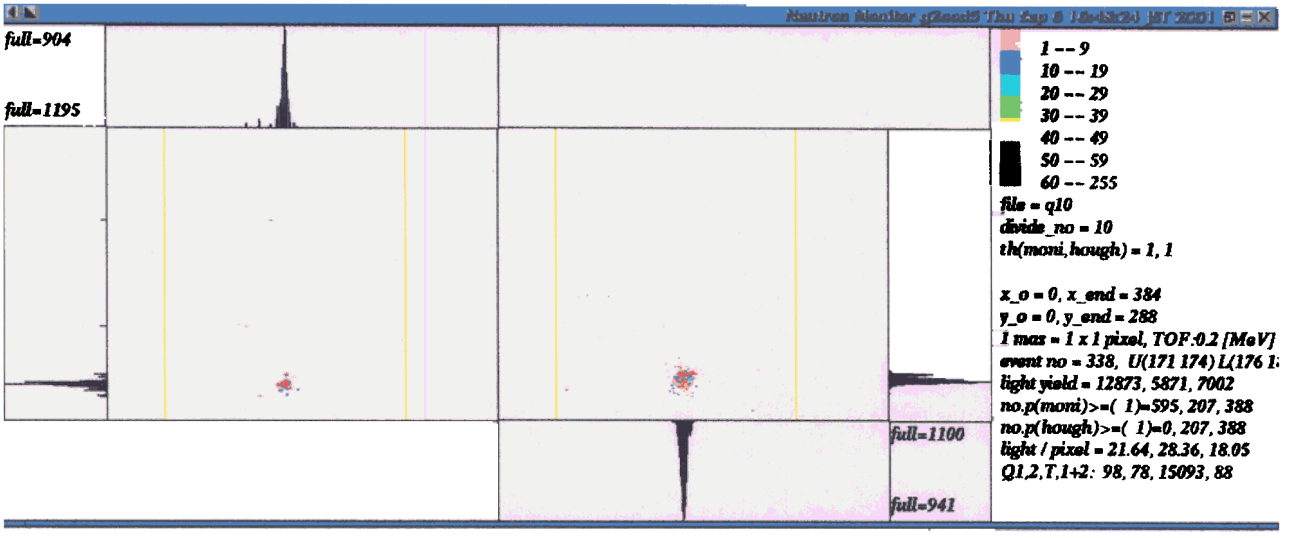
Recoil proton, D-T neutron (500 μ m) @ ETL



Recoil proton, D-D neutron (500 μ m) @ ETL

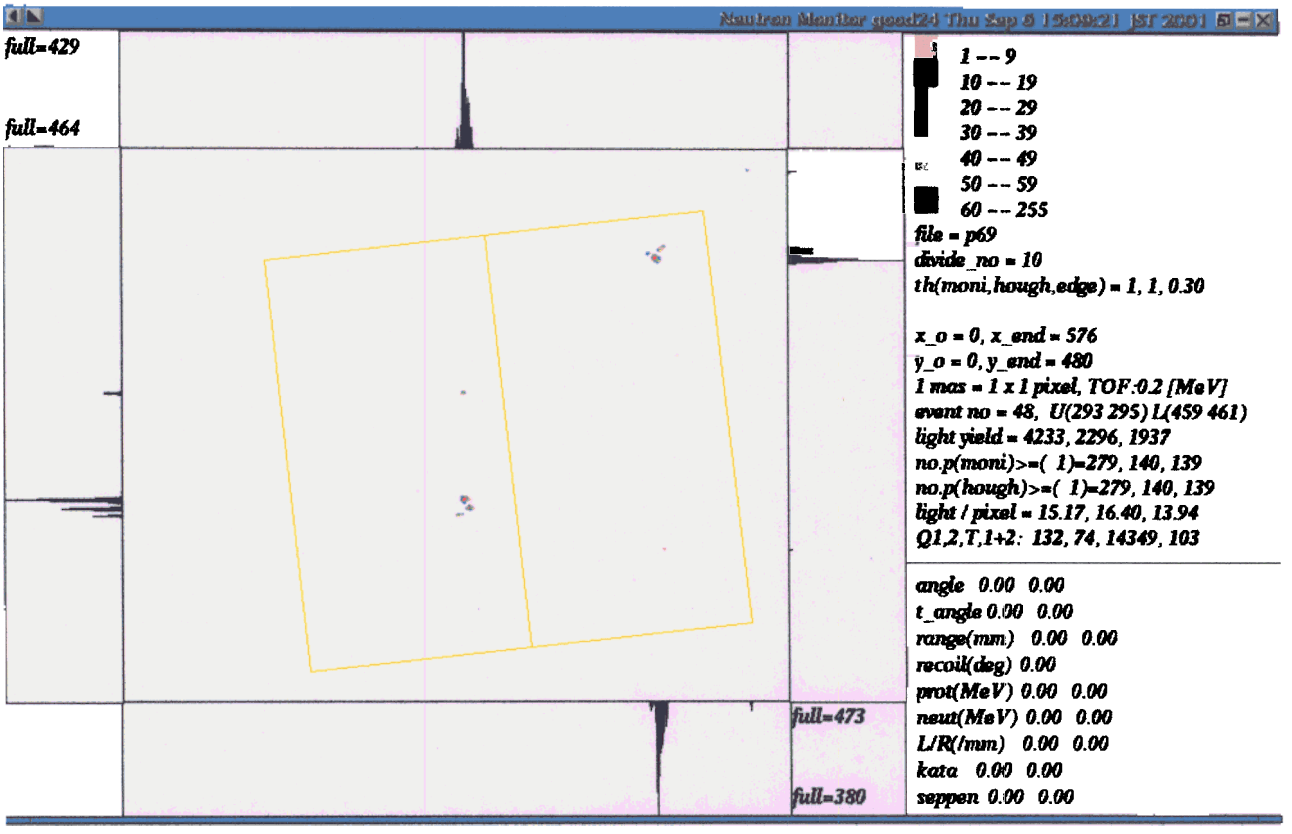


Recoil proton, D-T neutron (250 μ m) @ ETL

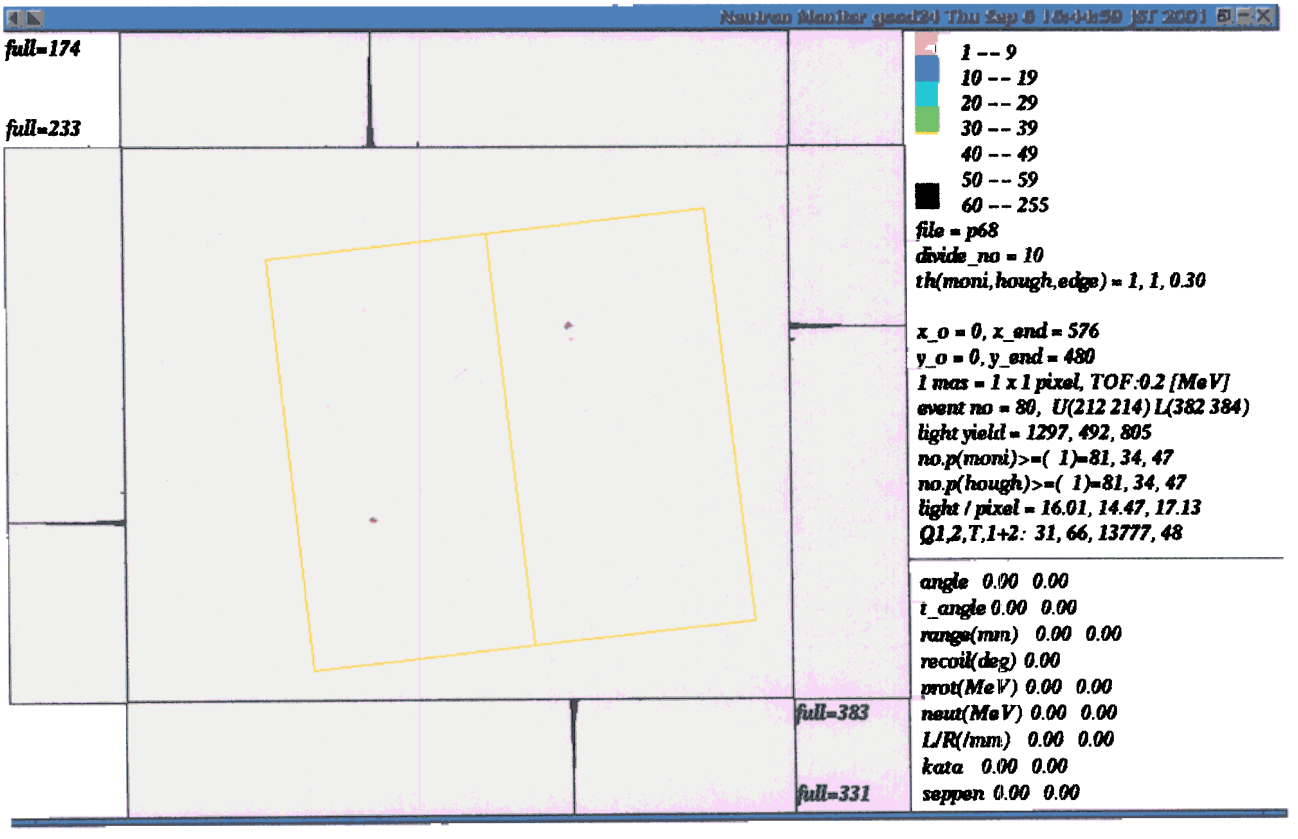


Recoil proton, D-D neutron (250 μ m) @ ETL

Electron, ^{60}Co gamma (500 μ m) @ ETL



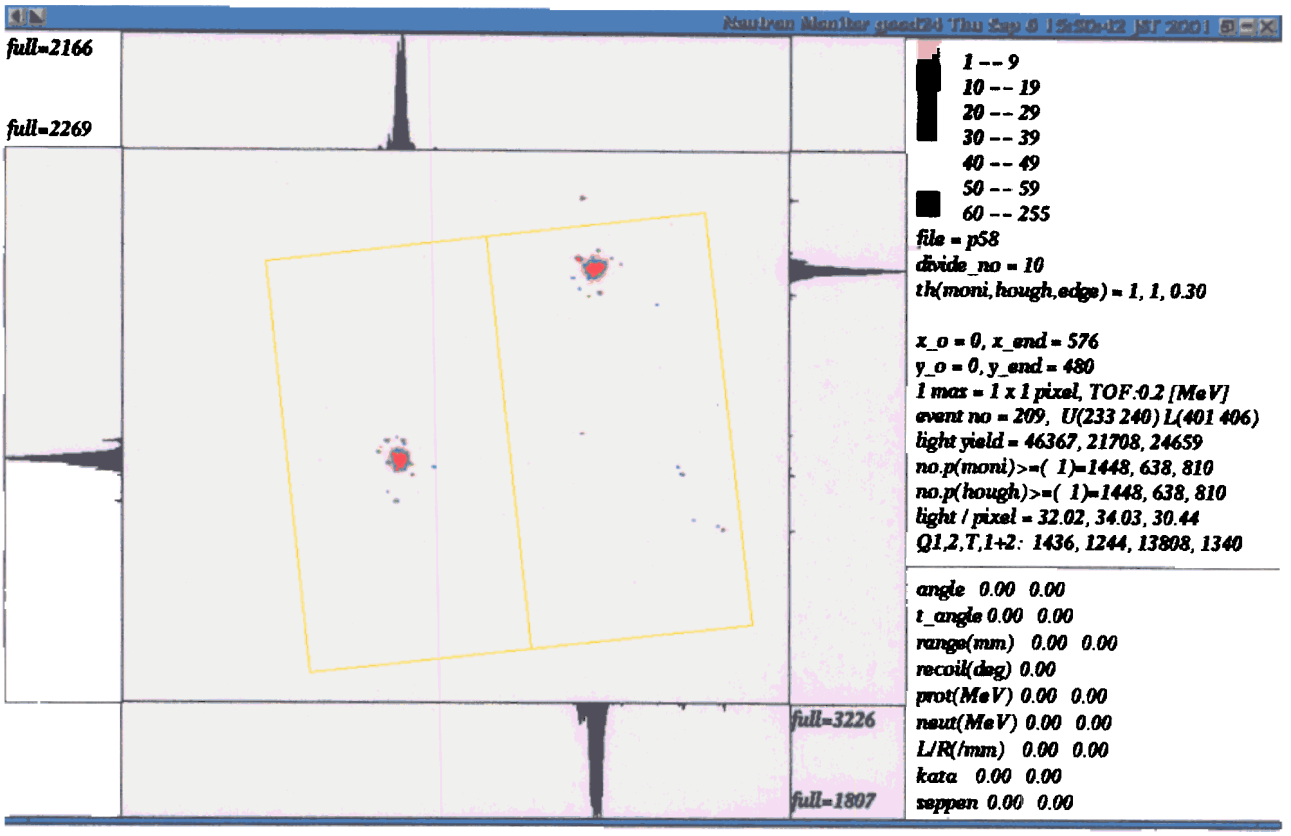
Electron, ^{137}Cs gamma (500 μ m) @ ETL



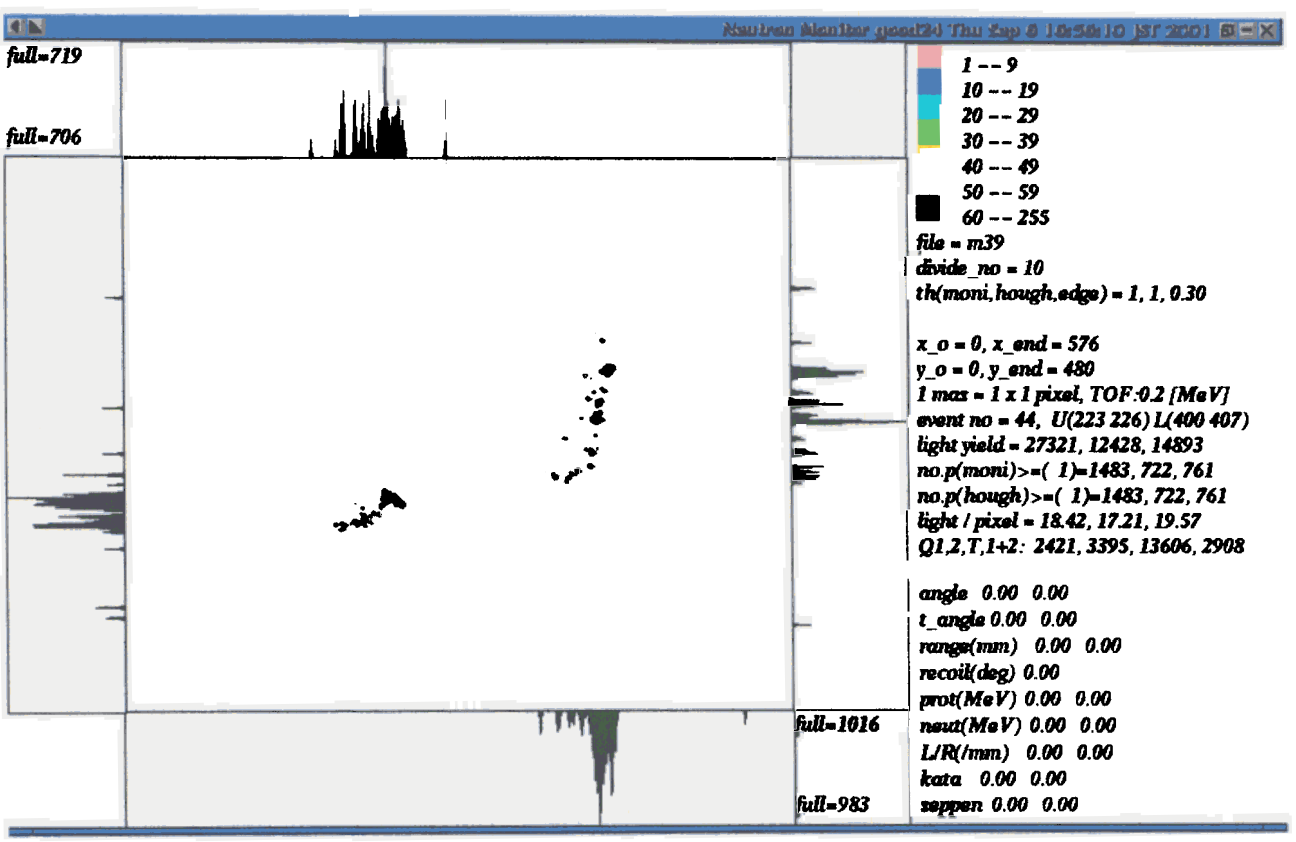
Electron, ^{60}Co gamma (250 μ m) @ ETL

Electron, ^{137}Cs gamma (250 μ m) @ ETL

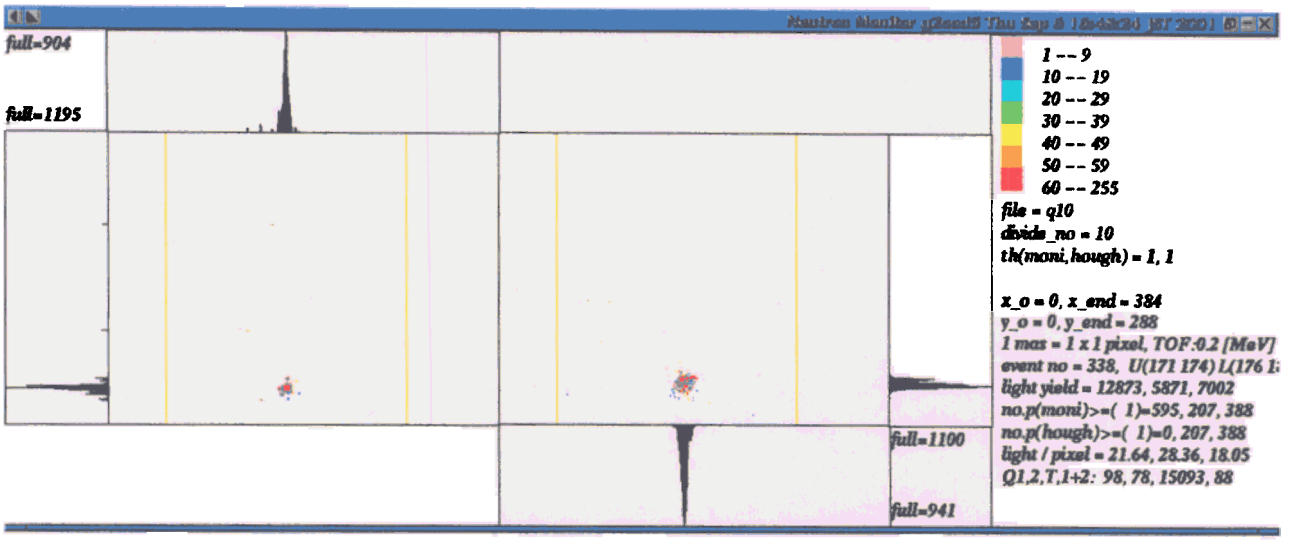
Recoil proton, D-T neutron (500 μ m) @ ETL



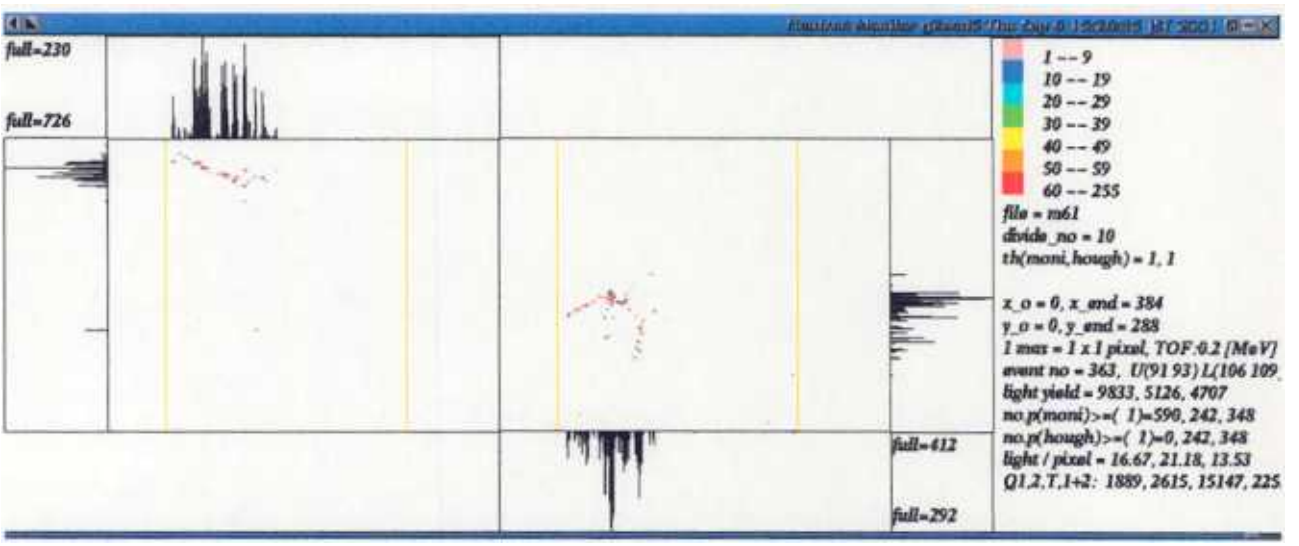
Electron, p-gamma 6-7 MeV (500 μ m) @ ETL



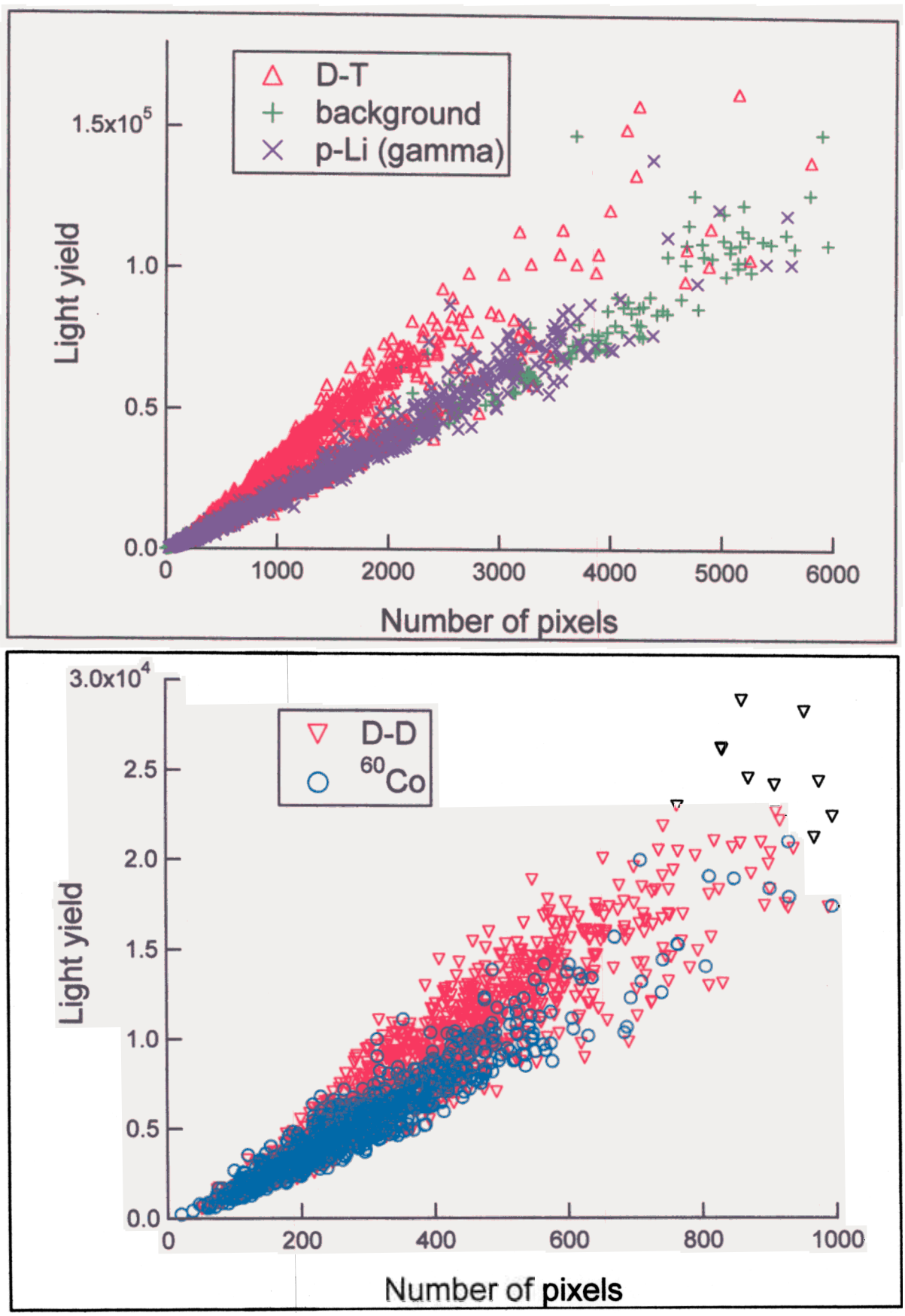
Recoil proton, D-T neutron (250 μ m) @ ETL



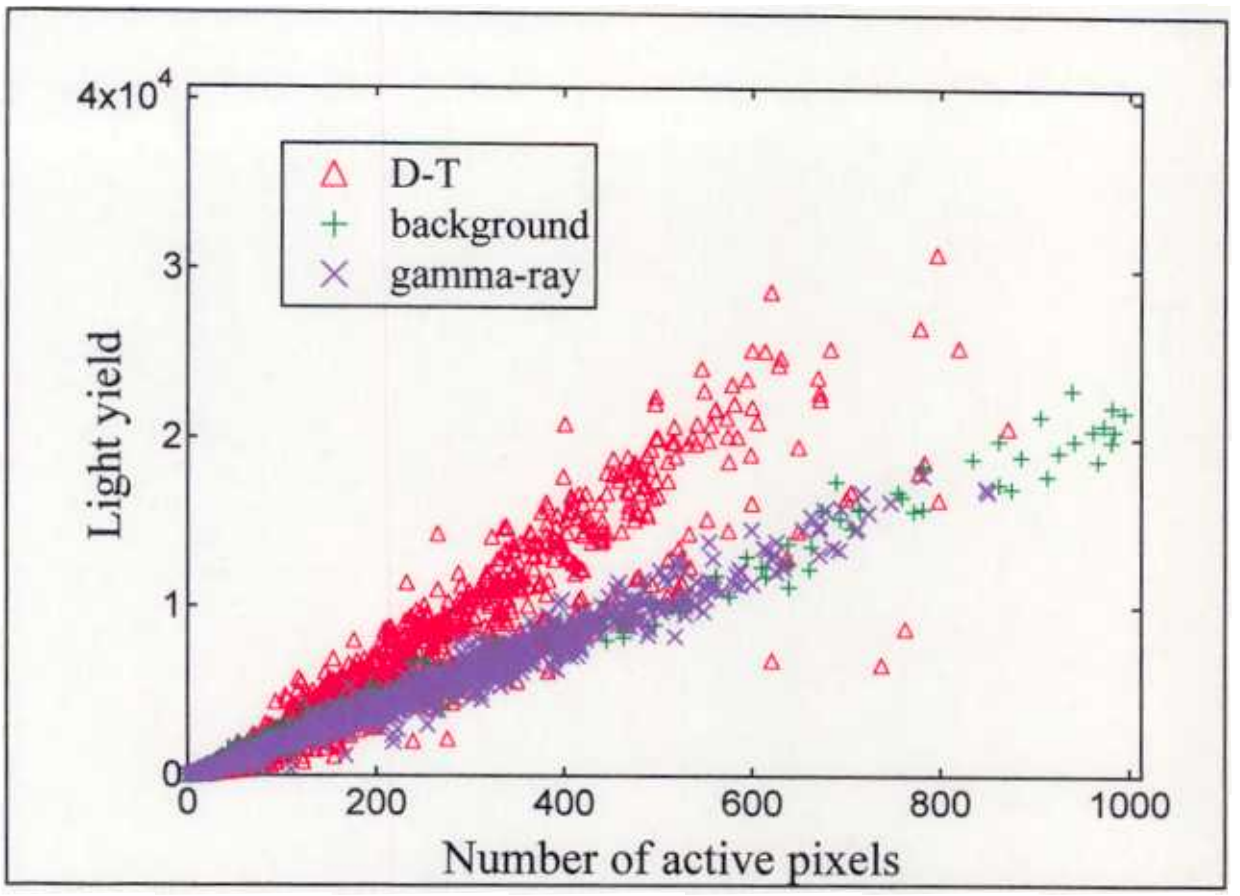
Electron, p-gamma 6-7 MeV (250 μ m) @ ETL

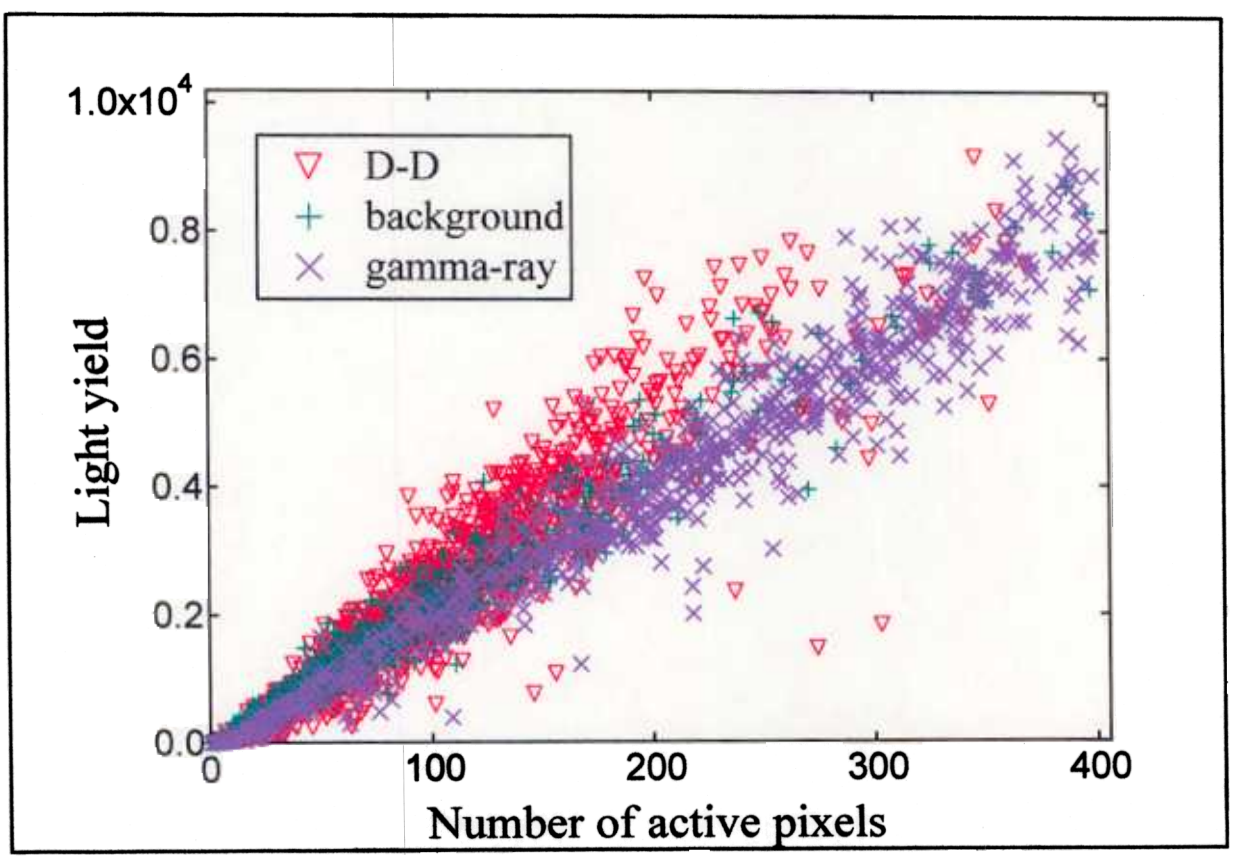


500 μm

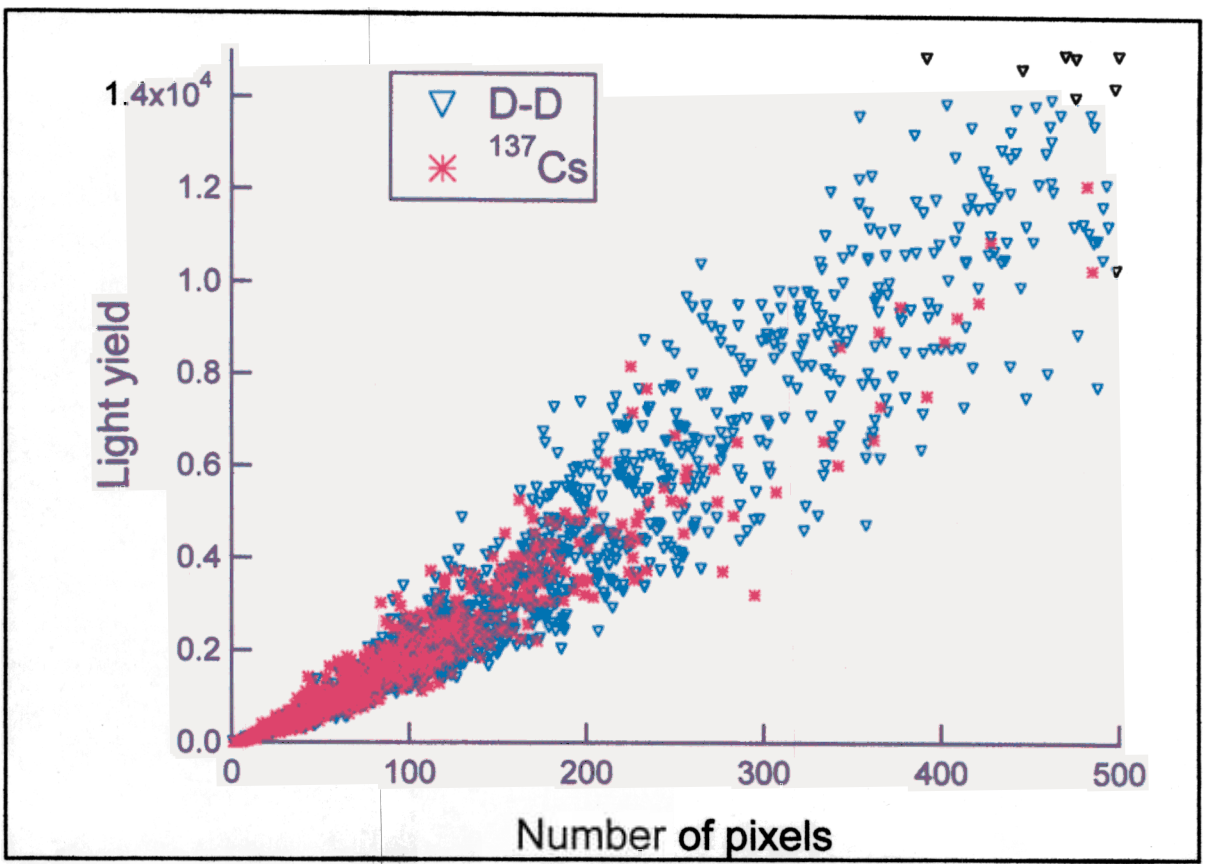

D-T
background
p-Li (gamma)
1.5x10^5
1.0
0.5
0.0
Light yield
0
1000
2000
3000
4000
5000
6000
Number of pixels
3.0x10^4
2.5
2.0
1.5
1.0
0.5
0.0
D-D
60Co
Light yield
0
200
400
600
800
1000
Number of pixels

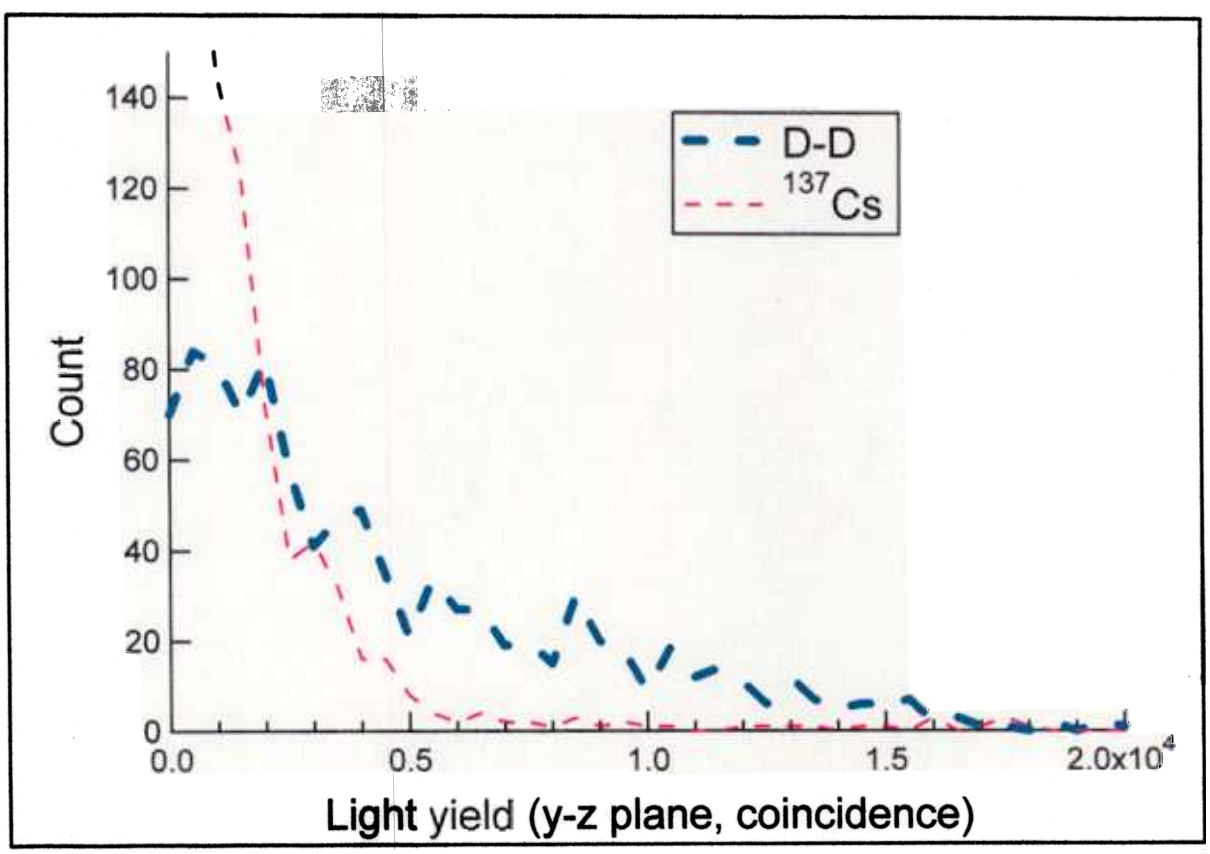
250 μm


4x10^4
D-T
background
gamma-ray
Light yield
0
1
2
3
0
200
400
600
800
1000
Number of active pixels

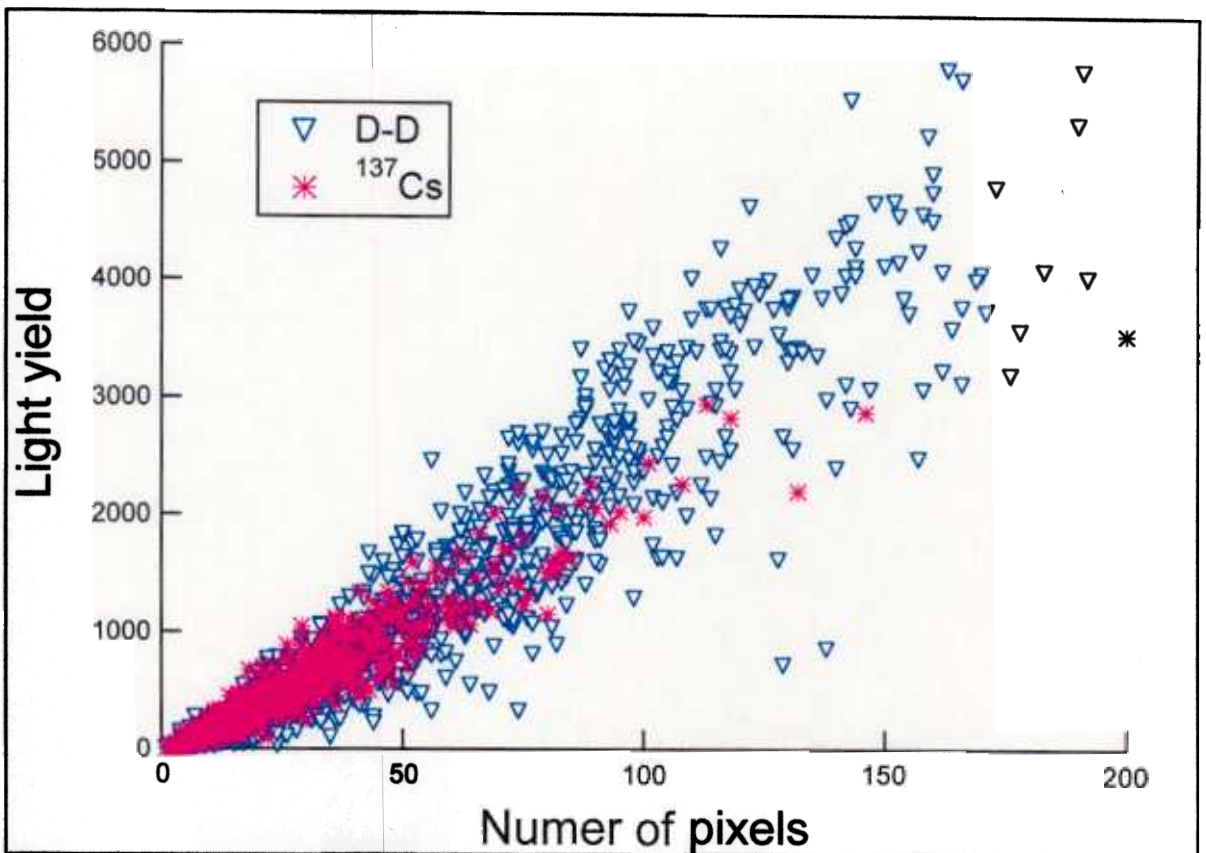

1.0x10^4
D-D
background
gamma-ray
Light yield
0.0
0.2
0.4
0.6
0.8
0
100
200
300
400
Number of active pixels

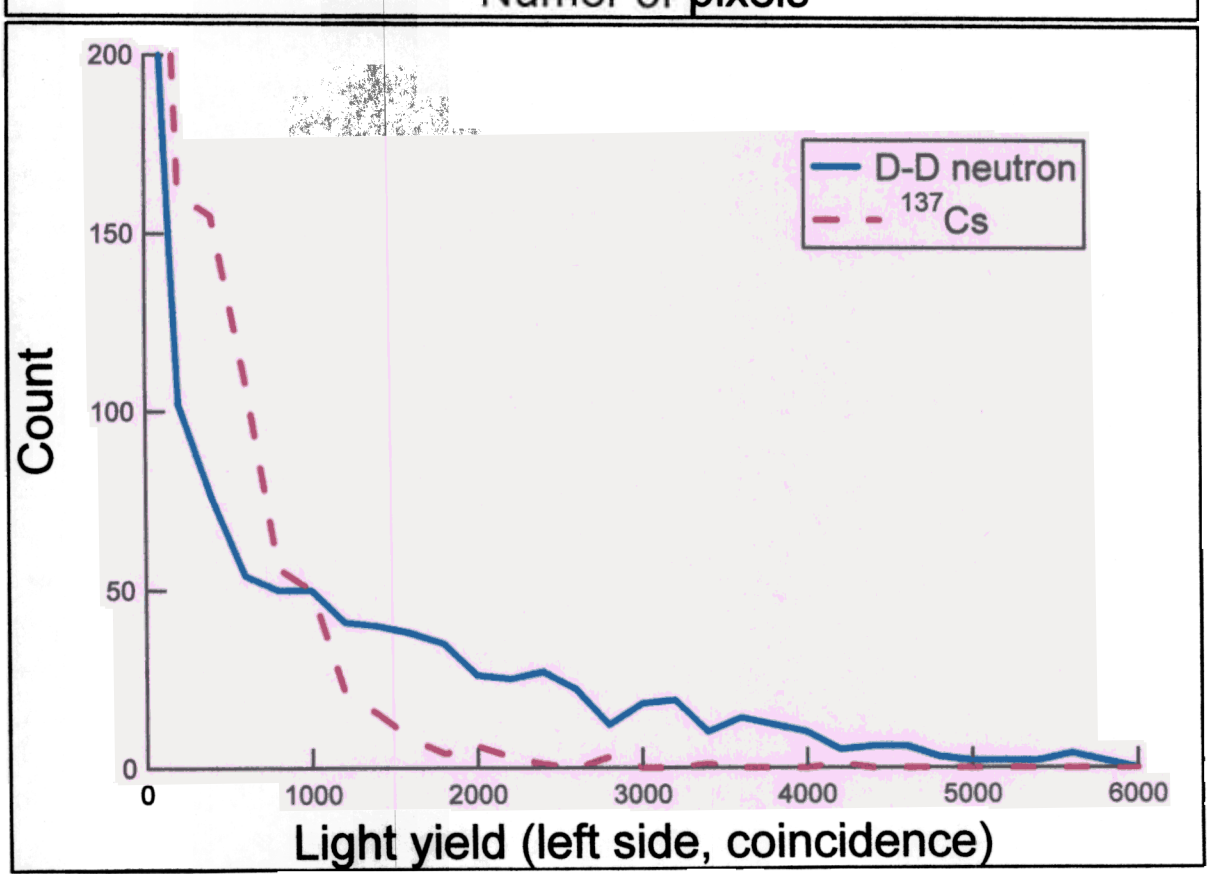
500 μ

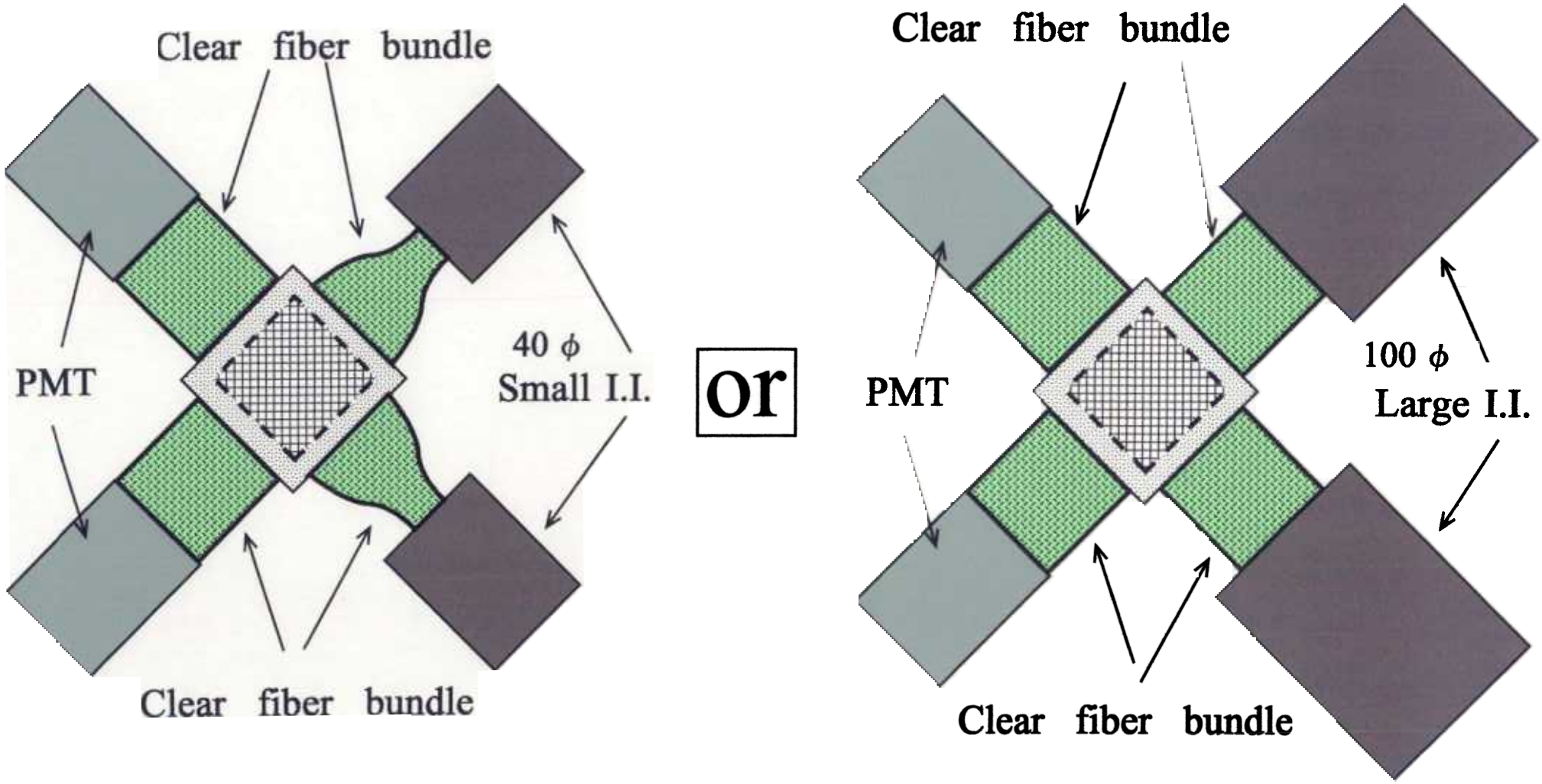

1.4x10^4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Light yield
D-D
137Cs
0
100
200
300
400
500
Number of pixels


140
120
100
80
60
40
20
0
Count
D-D
137Cs
0.0
0.5
1.0
1.5
2.0x10^4
Light yield (y-z plane, coincidence)

250 μ


6000
5000
4000
3000
2000
1000
0
D-D
137Cs
Light yield
0
50
100
150
200
Numer of pixels


200
150
100
50
0
D-D neutron
137Cs
Count
0
1000
2000
3000
4000
5000
6000
Light yield (left side, coincidence)



Final design of a scintillating fiber camera

Properties of SFCs*) for final detector design

	Final detector design
Fiber size	0.25 mm Square
Effective volume @ SFS**)	50 mm×50 mm×50 mm
Threshold energy of n-γ discrimination	~ 5 MeV @ trig. of 2 PMTs ~ 2 MeV @trig. of 1 PMT
Non-effective vomule @ SFS	Clear fiber bundles (Image guide)
CCD pixel numbers	256 × 256
CCD pixel size on the input window of I.I.	100 ~ 200 μ m Square
CCD frame rates [Hz]	4500 Hz (Max.)

*SFC : Scintillating fiber camera (= SFS + Image intensifier unit)

**SFS : Scintillating fiber stack

Table 1
Properties of polystyrene

General properties	
Average atomic number	3.5
Density [g cm^{-3}]	1.03
Proton/neutron ratio	1.17
Melting point [°C]	240
Thermal conductivity [W cm^{-1} K^{-1}]	0.105
Linear thermal expansion coeff. [K^{-1}]	7×10^{-5}
Tensile modulus (E) [MPa]	3200
Dielectric constant	2.5
Optical properties	
Refractive index	1.59 (590 nm) 1.58 (480 nm)
Optical dispersion [ns m^{-1}]	0.04 (400 to 500 nm)
Light decay (1/e) [ns]	2 to 3 (depending on dopant)
Light velocity in PS [m ns^{-1}]	0.21
Numerical aperture	0.53 (n cladding = 1.49) 0.69 (n cladding = 1.42)
Photon yield (with dopant) [$(keV)^{-1}$]	~ 10 (depending on dopant)
Absorption peak [nm]	265
Emission peak [nm]	330
Fluorescence yield (pure)	0.03
Radiation properties	
Radiation length [cm]	42.4
Gamma conversion length [cm]	54.5
Nuclear interaction length [cm]	79.6
Multiple scattering angle [mrad]	0.73 (1 GeV/c; 1 mm PS)
(dE/dx) min [MeV/cm]	2.0