Center for the Exploration of Energy and Matter

And Department of Physics

RESEARCH at INDIANA UNIVERSITY

3D Neutron Tomography and Future Possibility

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Outline

- Traditional Neutron Radiography (NR)
- 2D -> 3D Computed Neutron Tomography (NT)
- Current NT Beam Station and Experimental Set up in LENS
- MCNP Tomography Simulation
- Reconstruction and Volume Rendering
- Movie
- Future Cyber Web and Possibility

Image Technology

Basic principle of image :

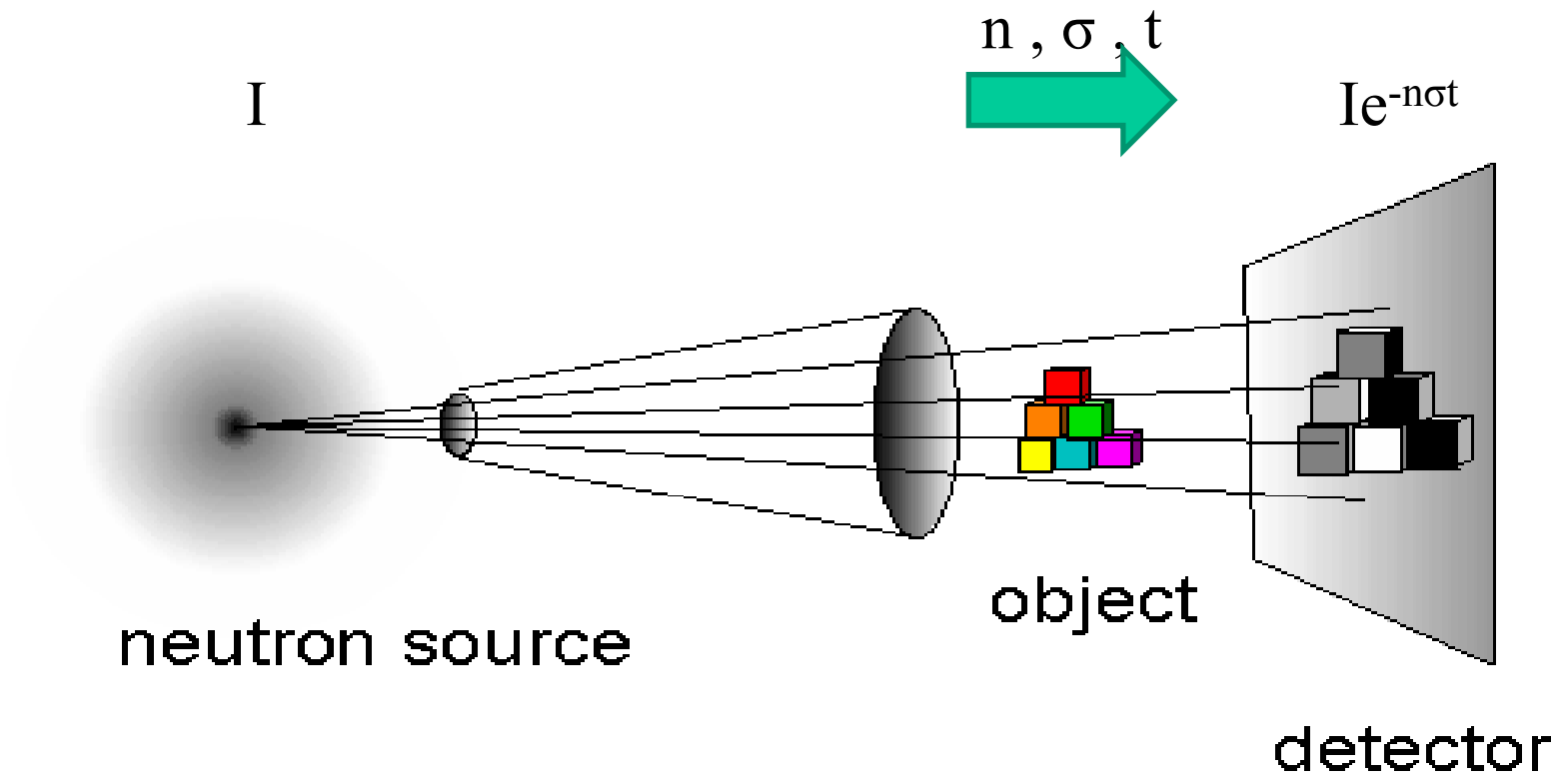
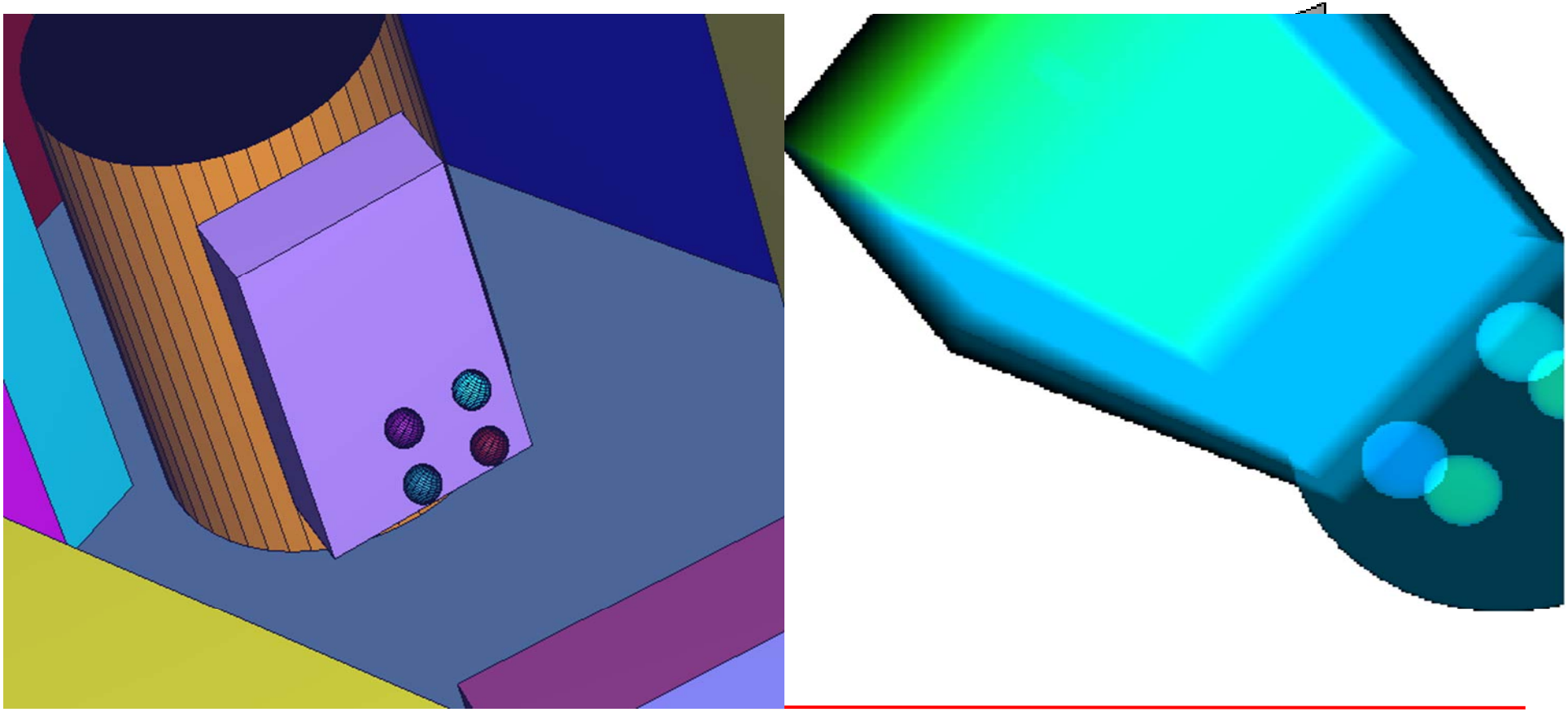


Image Technology

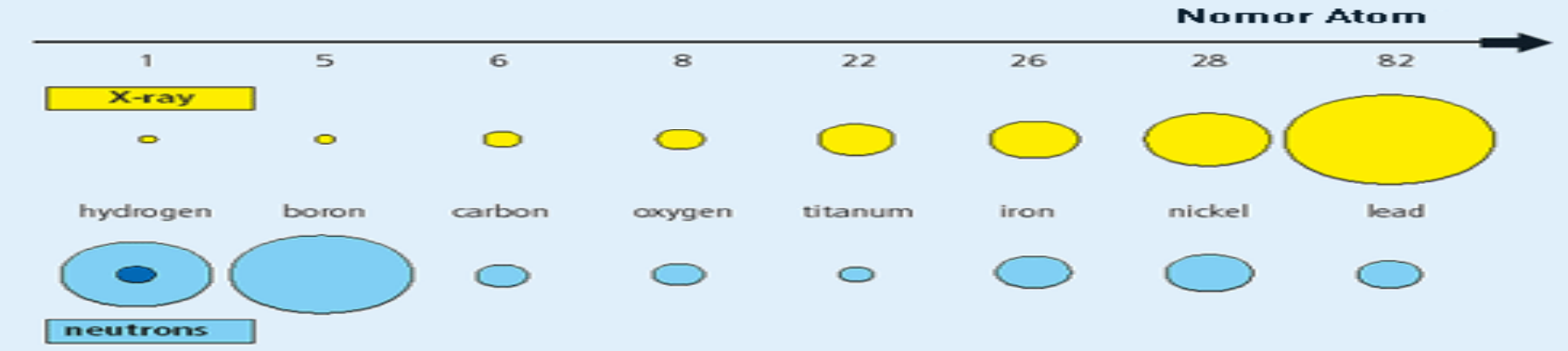
MCNP attenuation difference Simulation:

n , σ , t

I → $Ie^{-n\sigma t}$



Different Cross section: of X-ray and Neutron



- Monotonically increasing attenuation
- medical diagnostics, detecting flaws in material

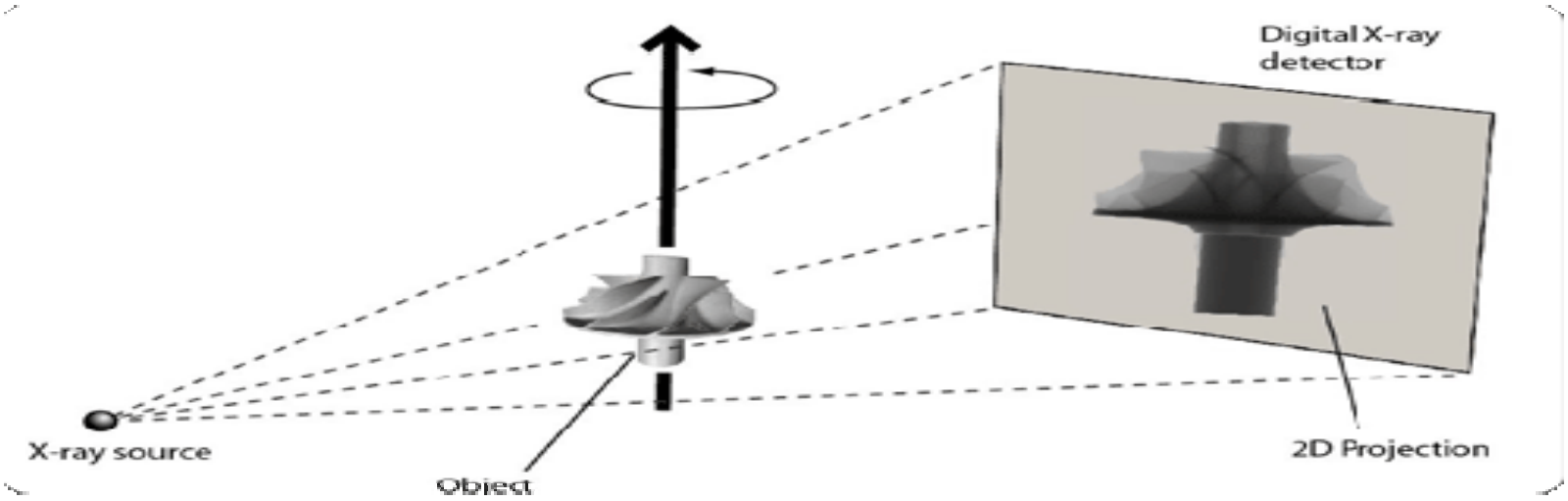
- Only interact with nuclei

Higher attenuation, lower atomic number

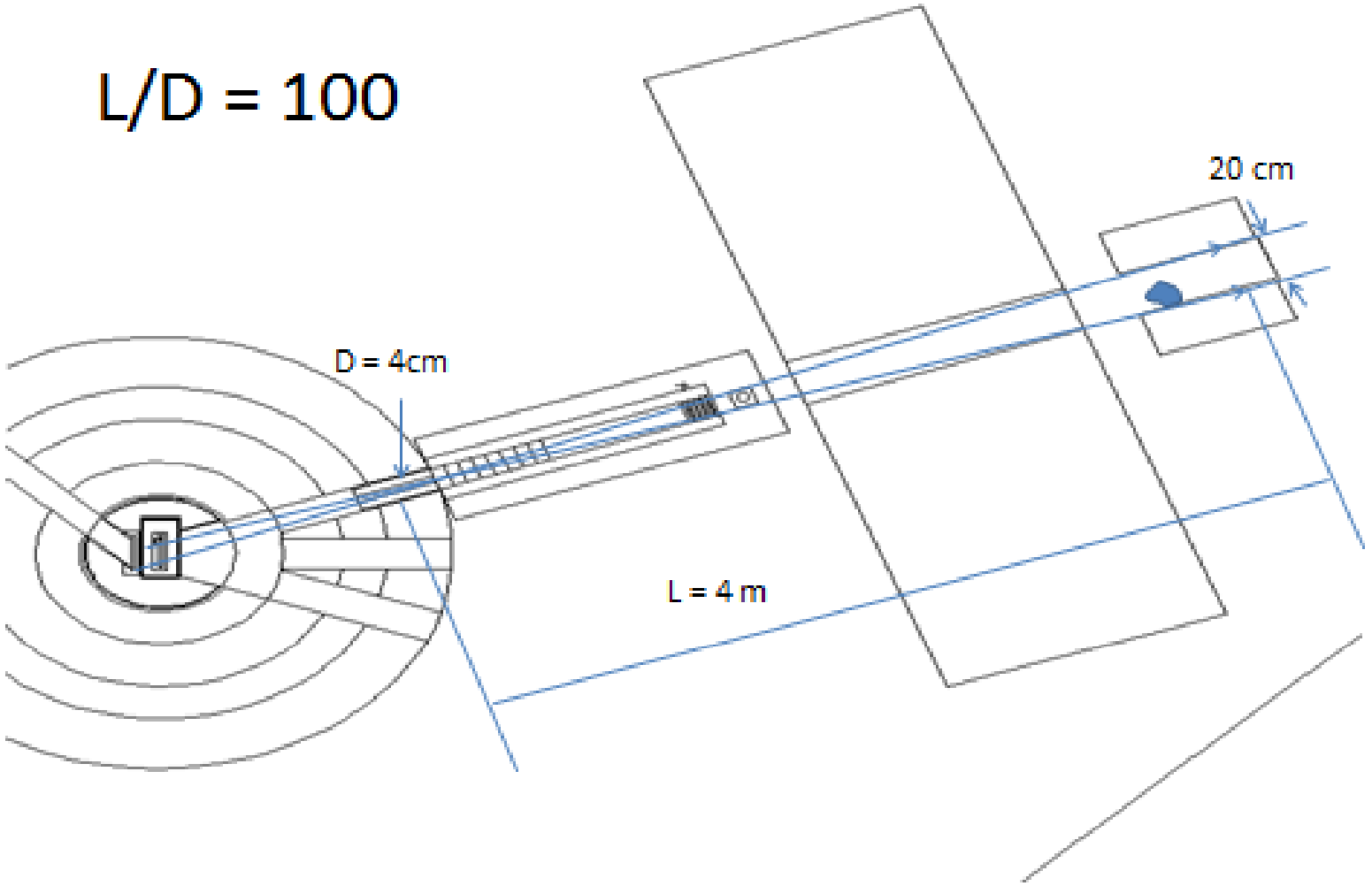
- hydrogen rich materials such as water, oil, plastic and other organic materials and Security, Drugs….

Computed Tomography (CT)

2D Image → More Computer power and cutting edge technology (Volume Reconstruction, Rendering, GPU and so on) → 3D Image ?



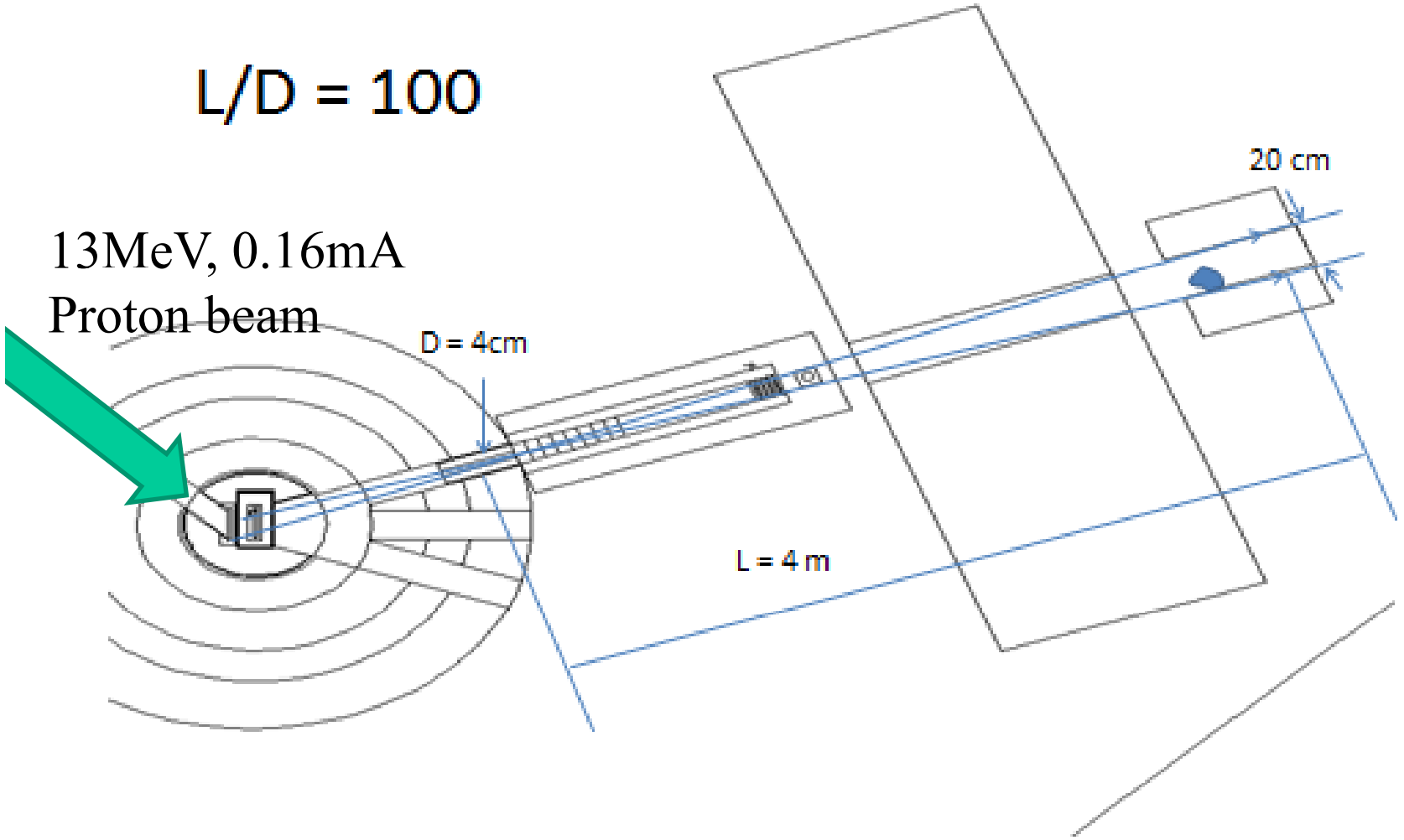
FNT Beam Station and Experimental Procedure



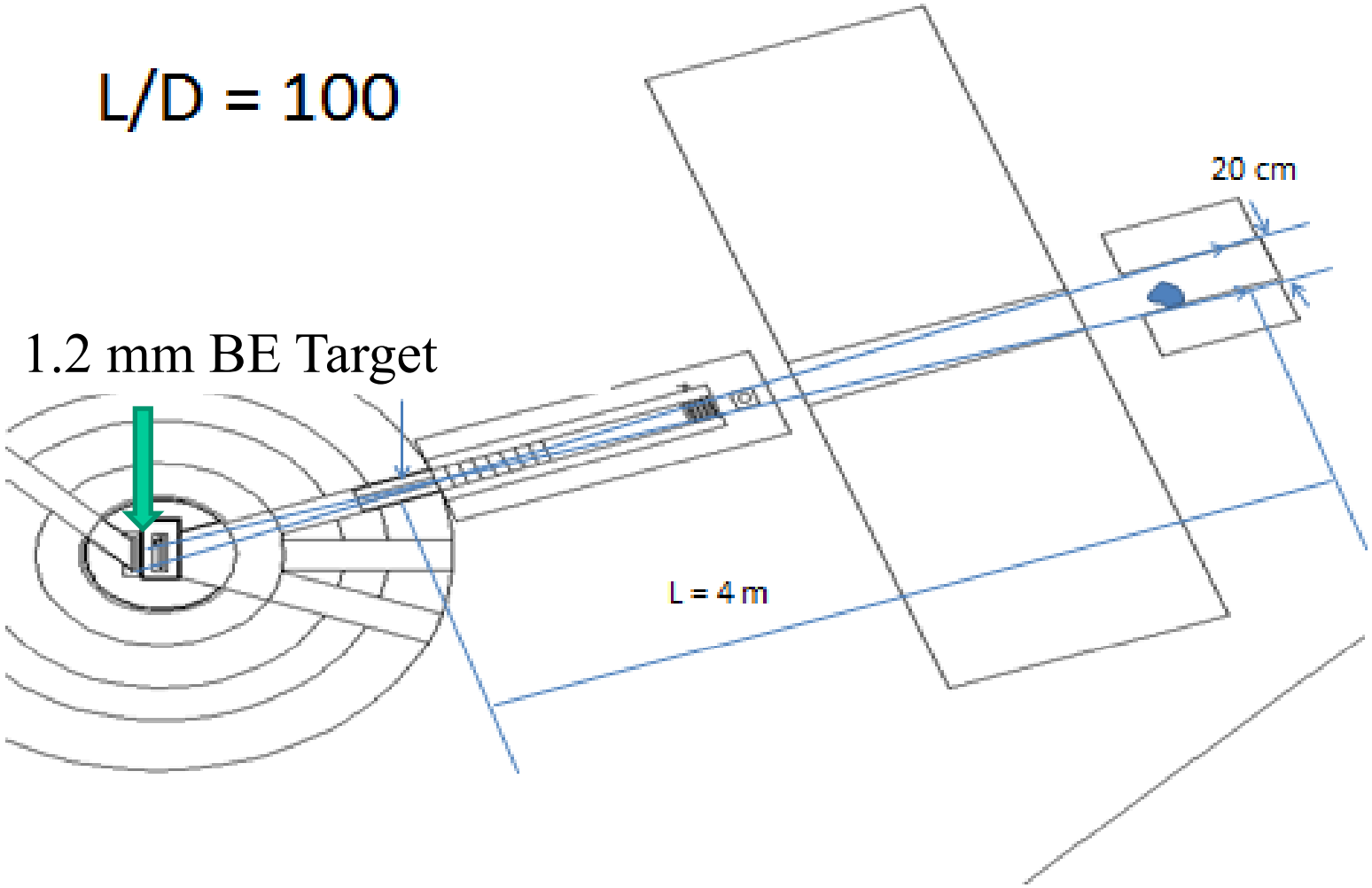
FNT Beam Station and Experimental Set up

L/D = 100

13MeV, 0.16mA
Proton beam



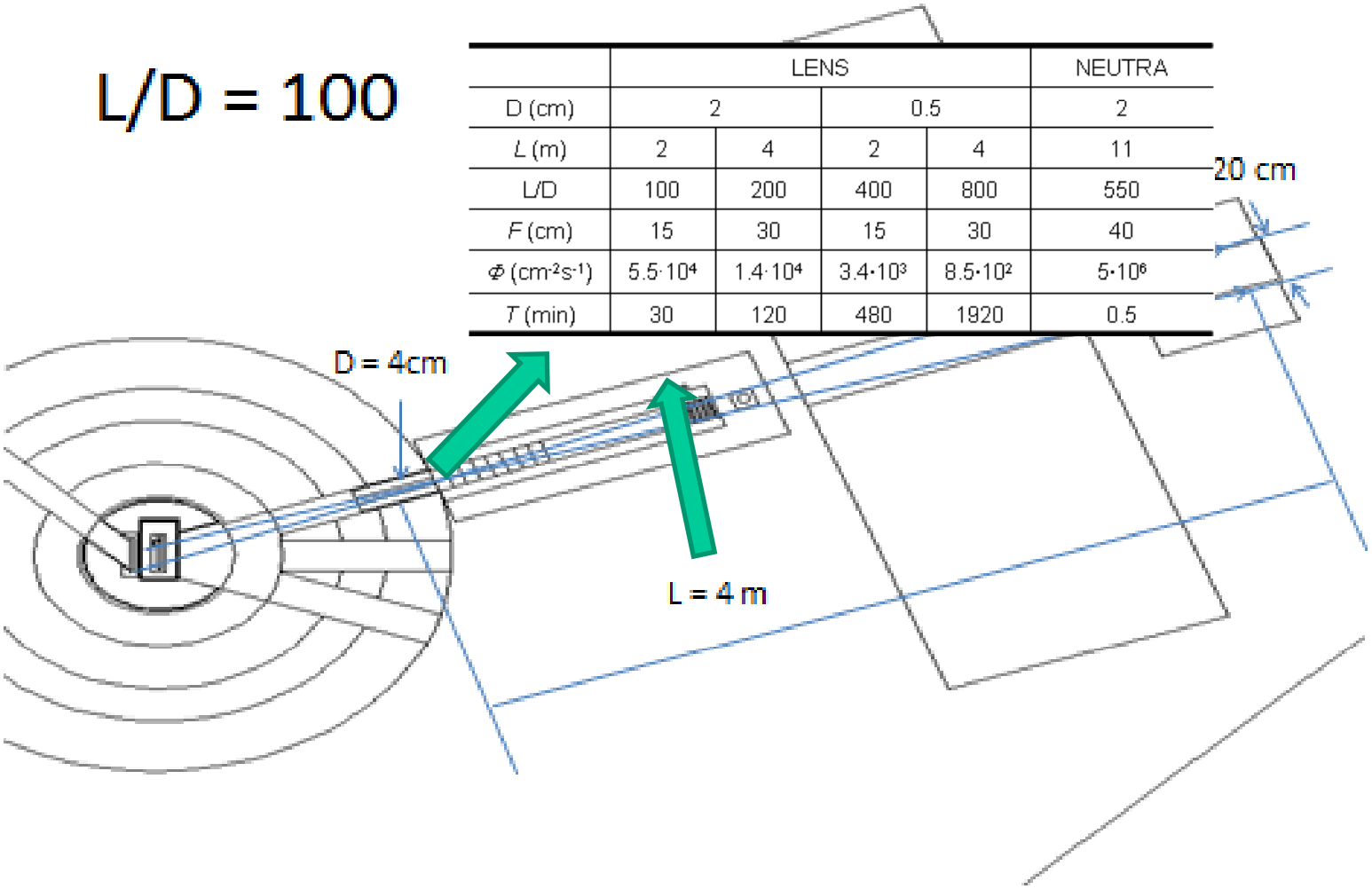
FNT Beam Station and Experimental Set up



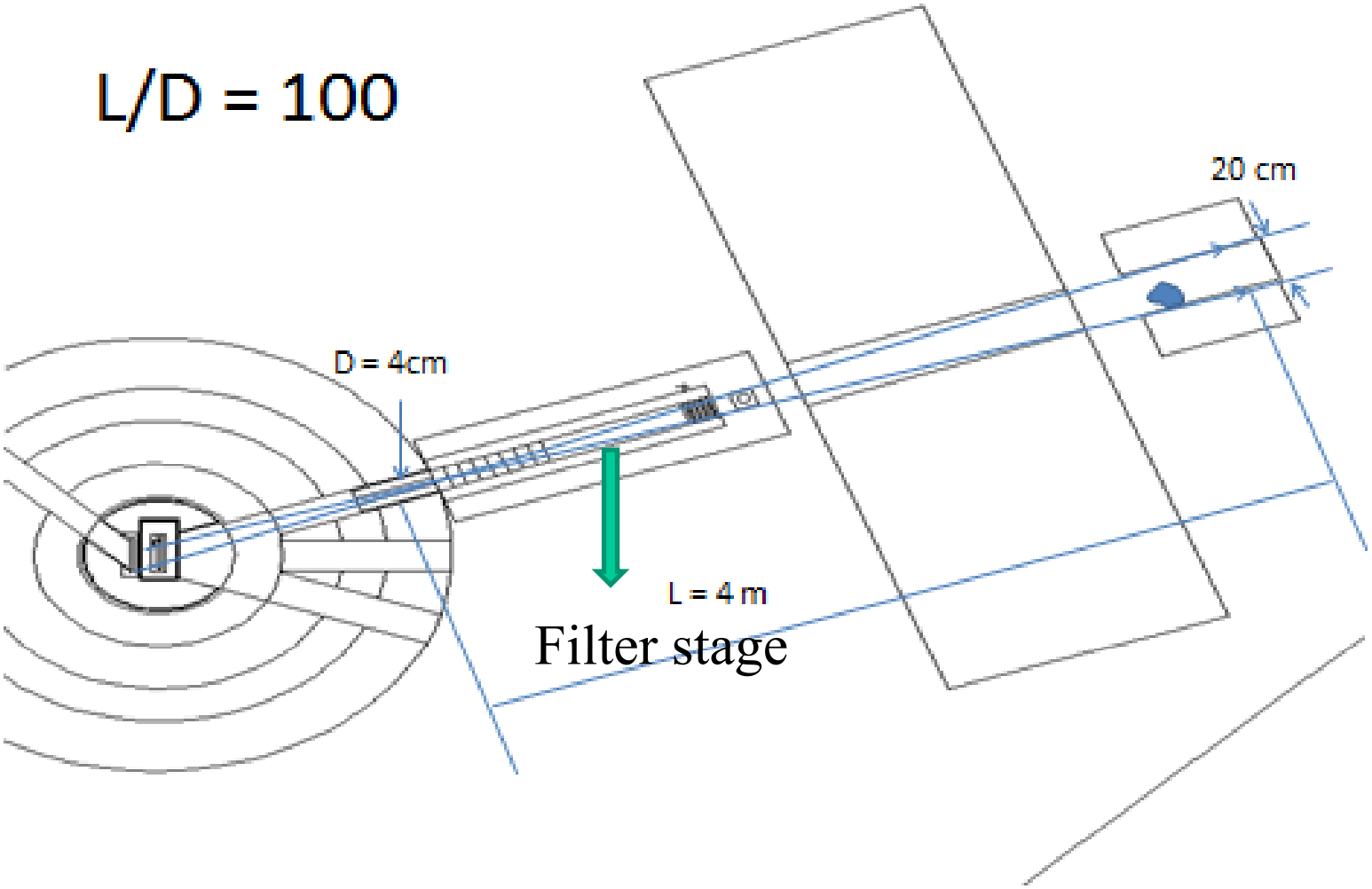
FNT Beam Station and Experimental Set up

L/D = 100

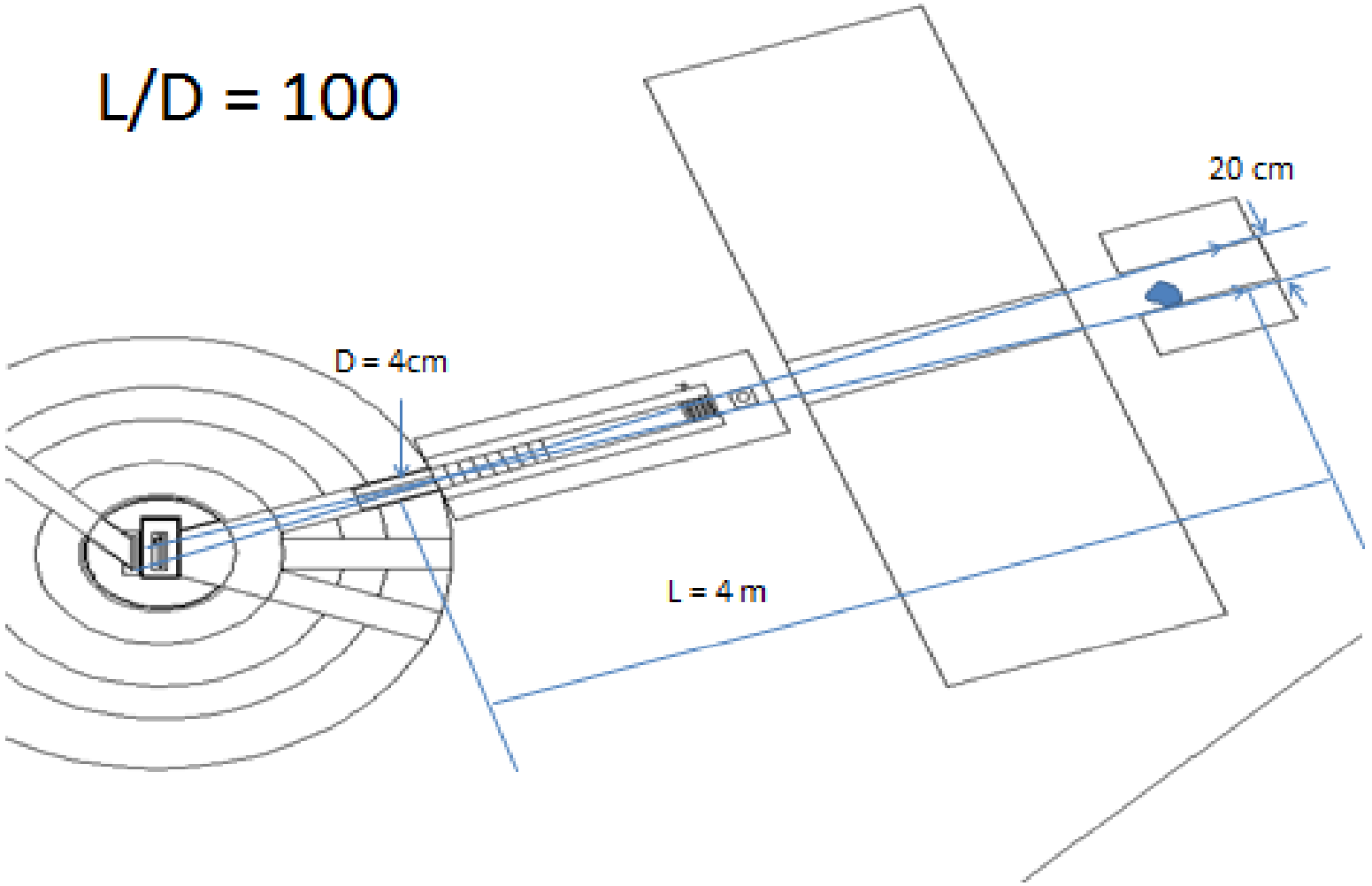
	LENS				NEUTRA
D (cm)	2		0.5		2
L (m)	2	4	2	4	11
L/D	100	200	400	800	550
F (cm)	15	30	15	30	40
Φ (cm^{-2}s^{-1})	$5.5 \cdot 10^{4}$	$1.4 \cdot 10^{4}$	$3.4 \cdot 10^{3}$	$8.5 \cdot 10^{2}$	$5 \cdot 10^{6}$
T (min)	30	120	480	1920	0.5



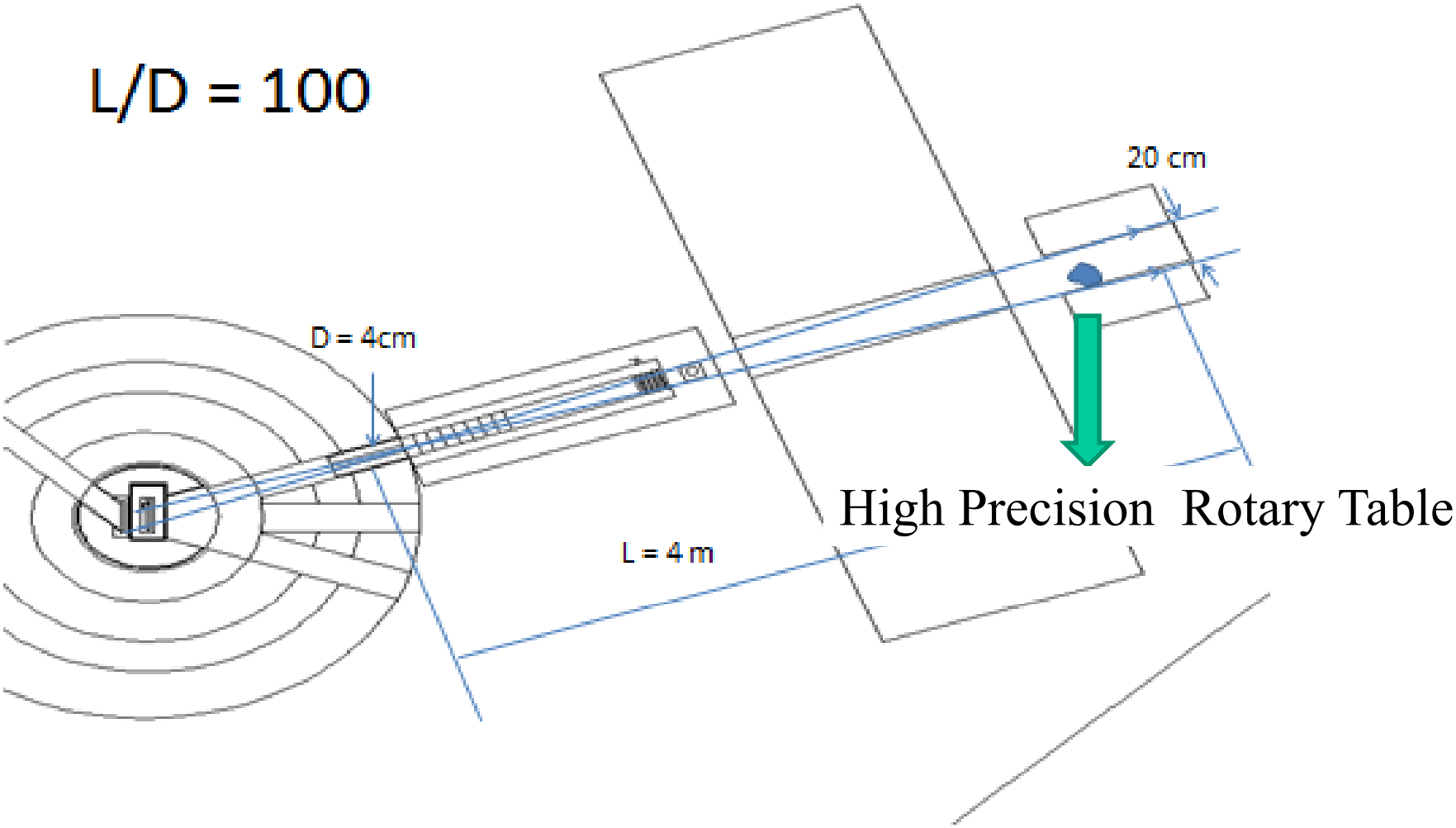
FNT Beam Station and Experimental Set up



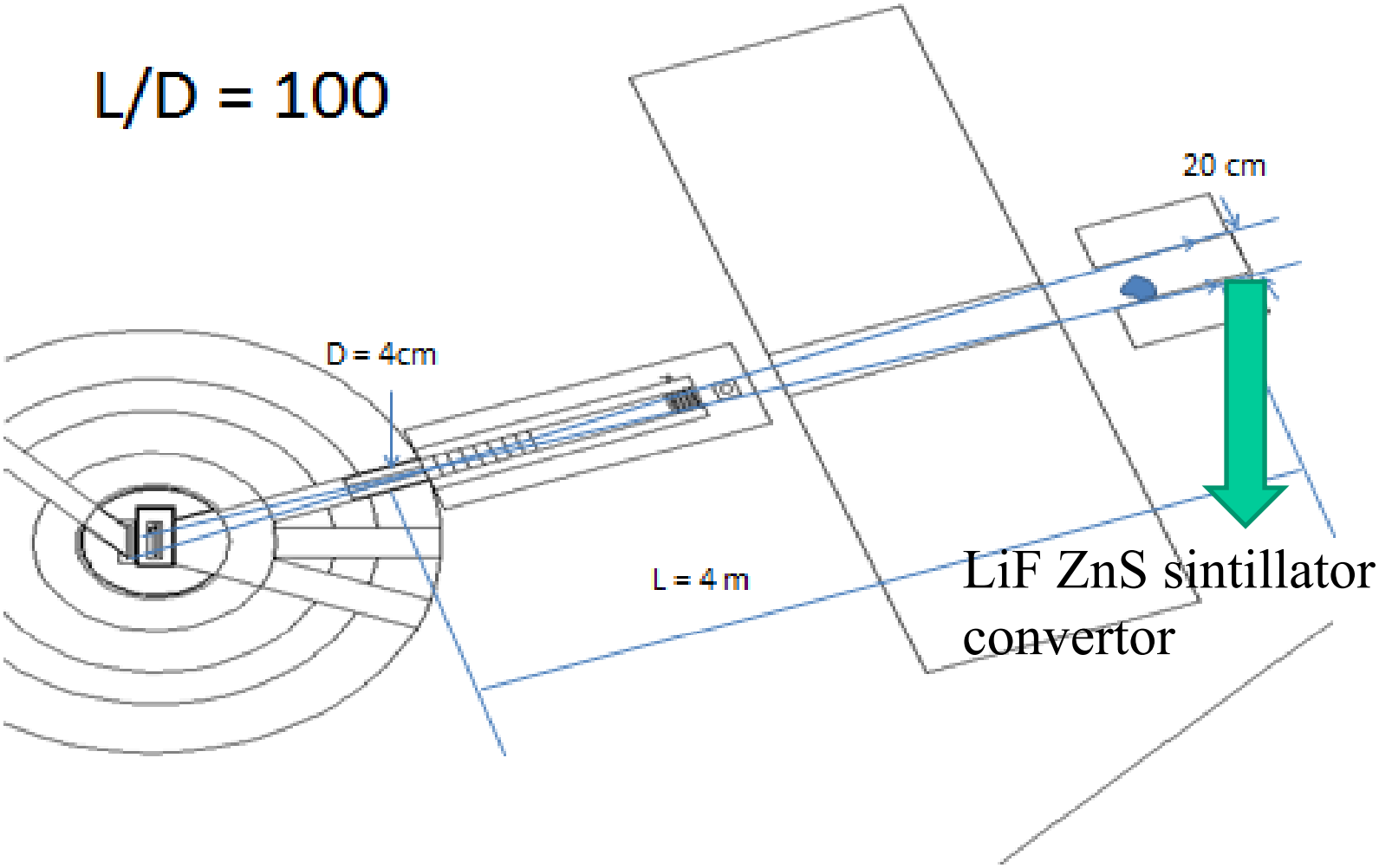
FNT Beam Station and Experimental Set up



FNT Beam Station and Experimental Set up



FNT Beam Station and Experimental Set up



Scintillator Screen spec

6Li + n -> 4He + 3H + 4.8MeV -> 4He + 3H + Zn + n (The ejected particle and triton interact with the zinc atom to create scintillation light)

The detection efficiency of the scintillator screen for fast neutron is ~ 30 %

phosphor scintillator - 20 cm by 20 cm

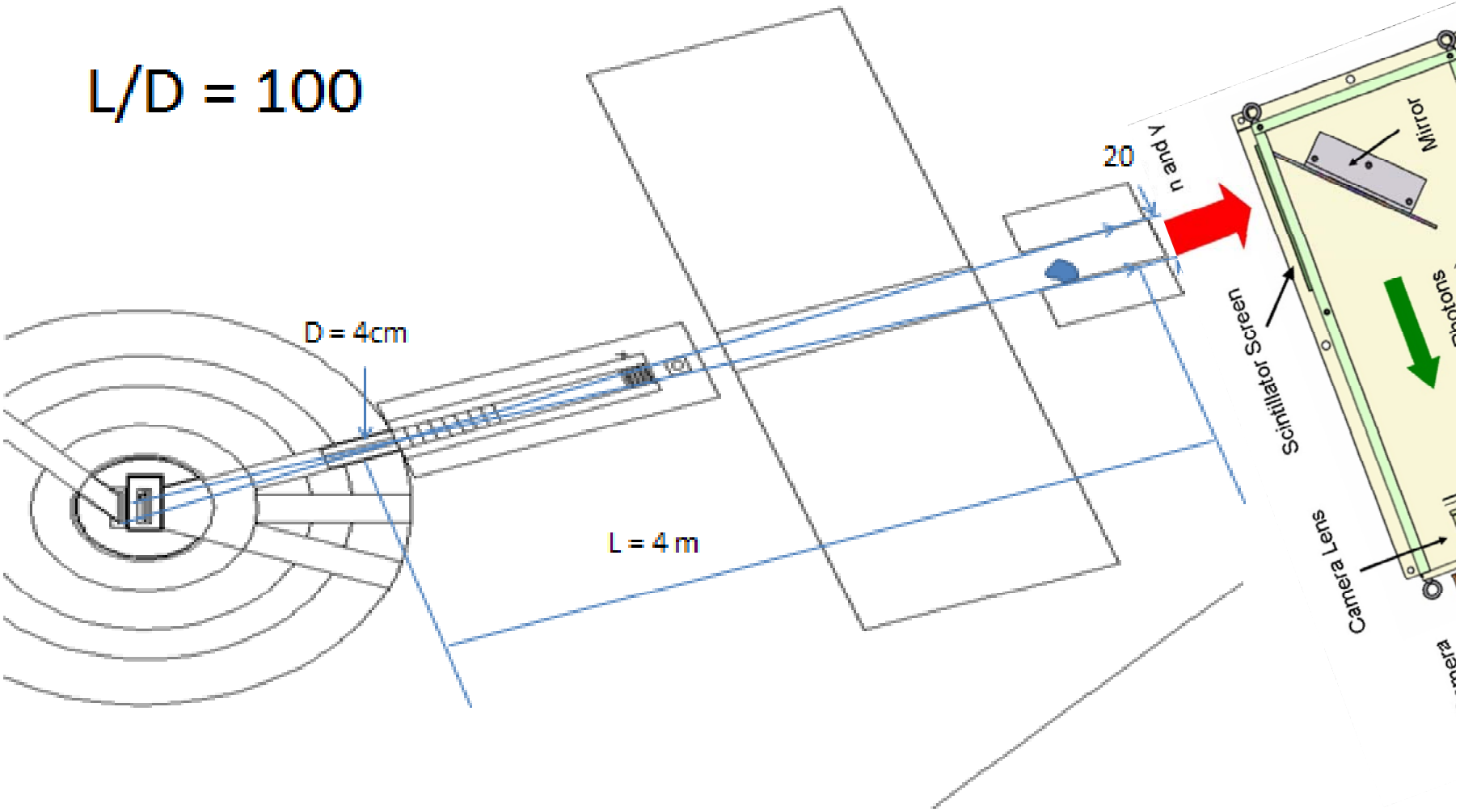
the coating thickness is 0.42(±10%) mm,

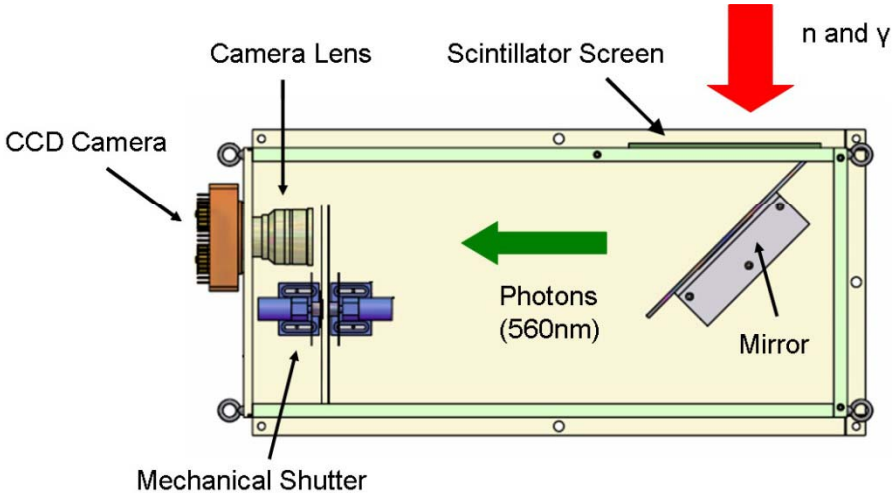
LiF : ZnS(Cu,Al,Au) : binder (organic material (CH2)) = 9 : 36 : 5

The peak wavelength of the scintillation light is at 560 nm

No.	Type	Size in (mm)	linearity slope B	FWHM (mm)	MTF at 10% (lp/mm)	γ/n (%)	S/N (dB)	Relative sensitivity
	Fast neutron luminescence (pp:ZnS = 1:1)	200 × 300 × 2	4.66E−07	0.90	0.9	20	36.5	1.0
	Fast neutron scintillation (30%ZnS in pp-matrix)							
	300 × 300 × 2.4		1.35	0.6	21	38.9	2.1	
		9.74E−07						
	Thermal neutron screen (Li-6, LEV-20-00183)							
	300 × 300 × 0.4		0.67	0.8	25	35.1	0.7	
		3.22E−07						
	Plastic scintillator (PKU)	Ø = 125, t = 3.8	1.09E−07	1.15	0.8		28.6	0.2
	Luminescence (ZnS:silica polymer = 1:1, PKU)	110 × 100 × 2	2.53E−07	1.12	0.6	30	33.8	0.5
	Co-60 gamma-sensitive (LEV-20-00185)	300 × 300, foil	9.93E−08			35	29.2	0.2
	X-ray green sensitivity film FG-8 (Fuji)	240 × 300, foil	3.94E−07			55	36.2	0.8
	Plastic scintillator (PTB)	200 × 200 × 3	1.07E−07	1.31	0.8	14	29.0	0.2
	Plastic scintillator (PTB)	200 × 200 × 10	3.69E−07	1.40	0.7	14	34.1	0.8
0	Plastic scintillator (PTB)	200 × 200 × 20	7.57E−07	1.77	0.5	12	35.2	1.6
1	Plastic scintillator 8+9	200 × 200 × 13	5.13E−07	1.70	0.6	12	33.2	1.1
2	BC-412 (PSI)	300 × 300 × 3	1.02E−07	1.06	0.8	28	29.8	0.2
3	BC-416 (PSI)	140 × 115 × 2	7.10E−08	1.20	0.7	14	28.4	0.2
4	Gd_2O_2S:Tb+pp (8% Vol., VNIIA)	Ø = 35, t = 2	6.67E−07	1.63	0.4		33.2	1.4
5	Gd_2O_2S:Tb+pp (16% Vol., VNIIA)	Ø = 35, t = 2	9.74E−07	1.30	0.6		33.7	2.0
6	Gd_2O_2S:Tb+pp (24% Vol., VNIIA)	Ø = 35, t = 2	1.19E−06	1.25	0.6		34.6	2.4
7	Gd_2O_2S:Tb+pp (30% Vol., VNIIA)	Ø = 35, t = 1	9.06E−07	1.02	0.7		36.5	2.1

FNT Beam Station and Experimental Set up





CCD Camera : Alta U6 CCD camera, AF Nikkor 85mm f/1.4D IF autofocus lens, from Nikon Corporation, Fuji Bldg., 2-3
Marunouchi 3-Chome, Chiyoda-Ku, Tokyo 100-8331, Japan. www.nikon.com

Software:

CCD Camera- Maxim DL (http://www.cyanogen.com/)

CCD spec

Sensor array - 1024 by 1024 pixels , sintillator size : 20 by 20 cm -> spatial resolution: ~ 200 μm

The pixel size -24 μm by 24 μm.

The imaging area - 24.6 mm by 24.6 mm (605 mm2)

The peak quantum efficiency - 70% at 560 nm

The typical linear full well for a pixel - 500,000 electrons

16-bit gray-scale format->Thus, the maximum gray scale number, $2^{16} - 1 = 65535$

each gray scale unit (GSU) represents 500000/65536 -> 7.63 photo-electrons

The exposure time - from 20 ms to 183 minutes (in 2.56 μs increments)

The sensor is cooled to -16 C to reduce the dark current Upgrade to -24 C

The temperature stability is ±0.1 C

the measured dark current accumulation rate is 3 electrons per pixel per second

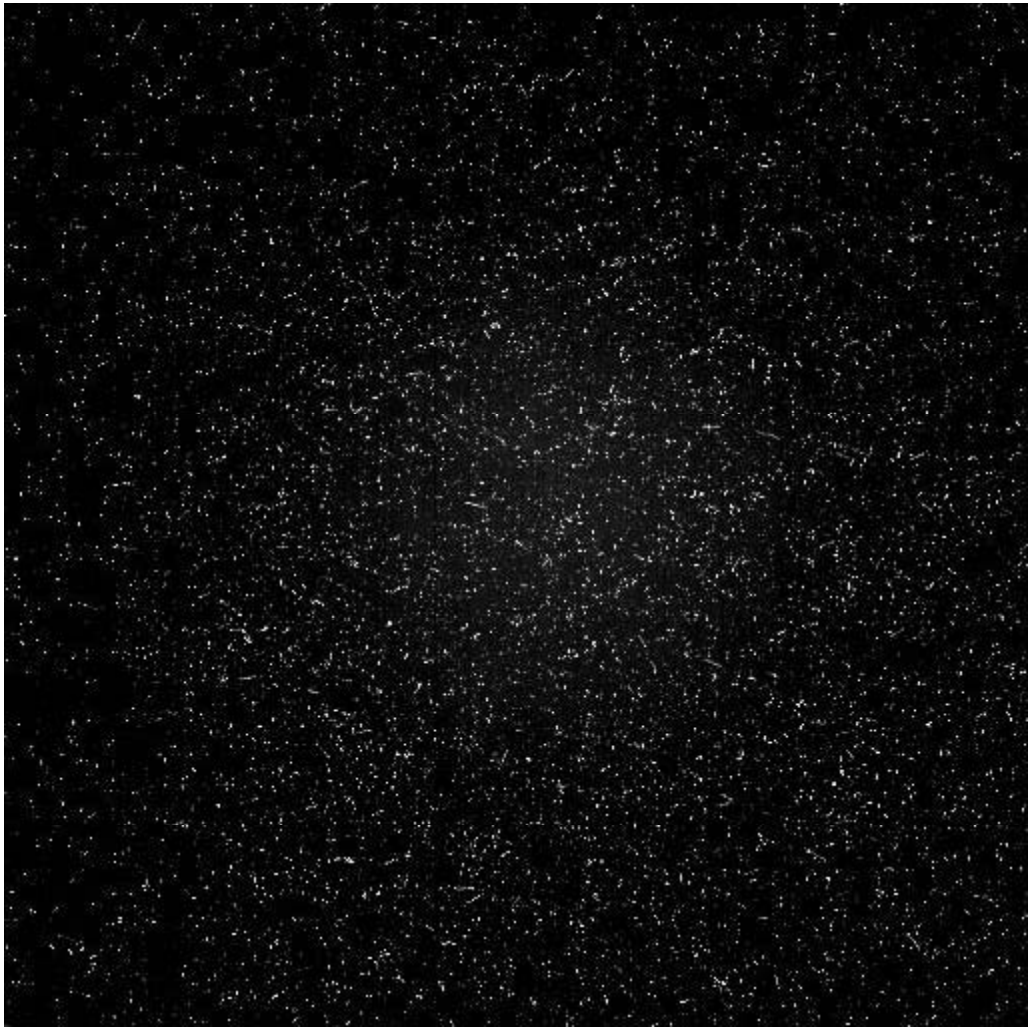
Mirror spec

aluminum first-surface mirror - 254 mm by 313 mm

thickness of the glass substrate is 6 mm.

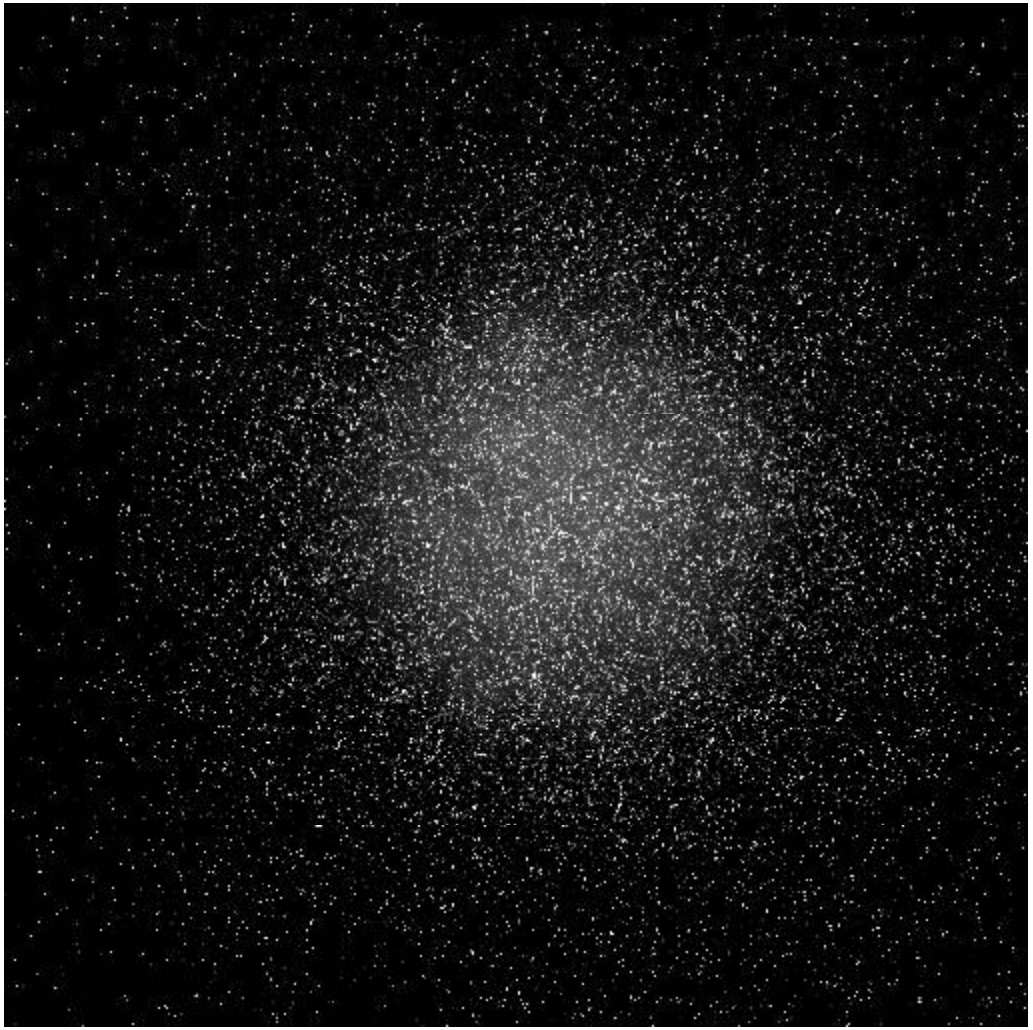
>90% reflection for visible light

CCD with only 7MeV beam,
No samples, and filters
exposed time : 1 sec



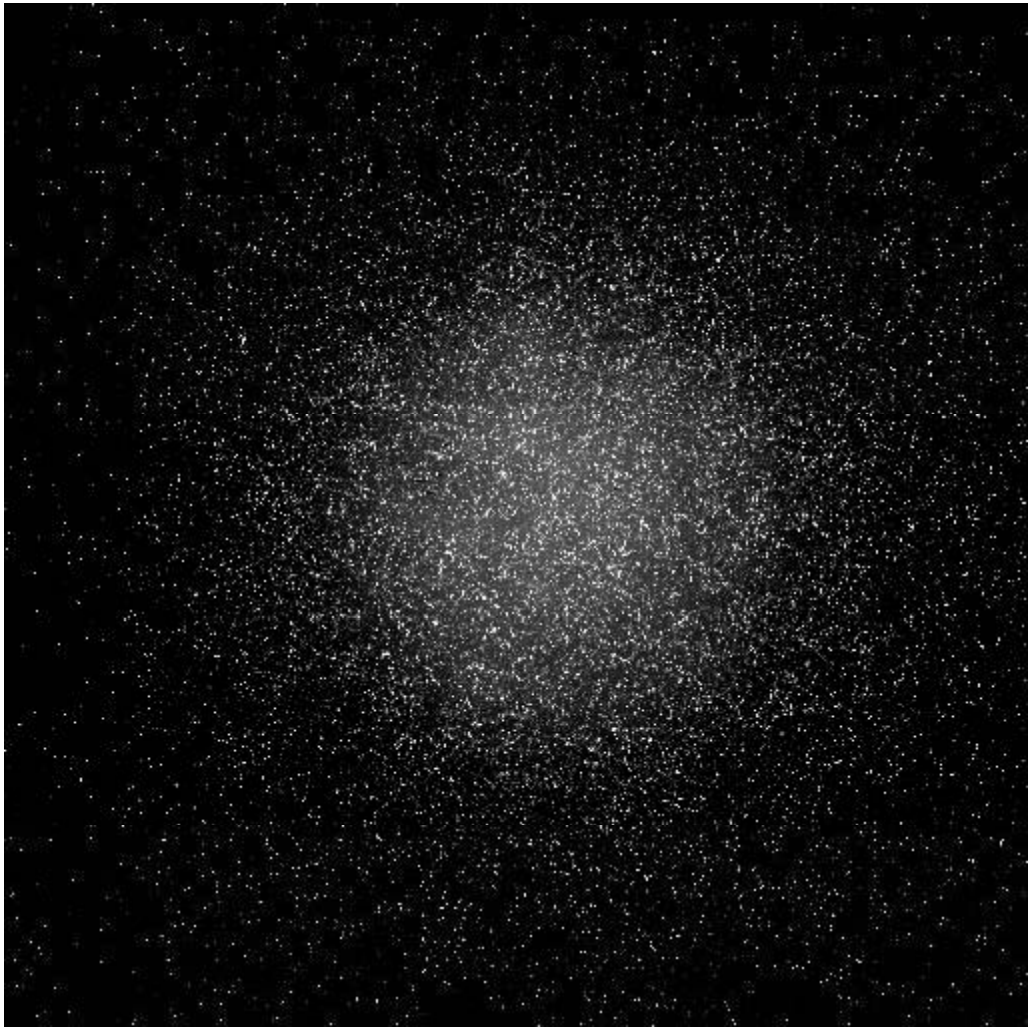
1 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 6 sec



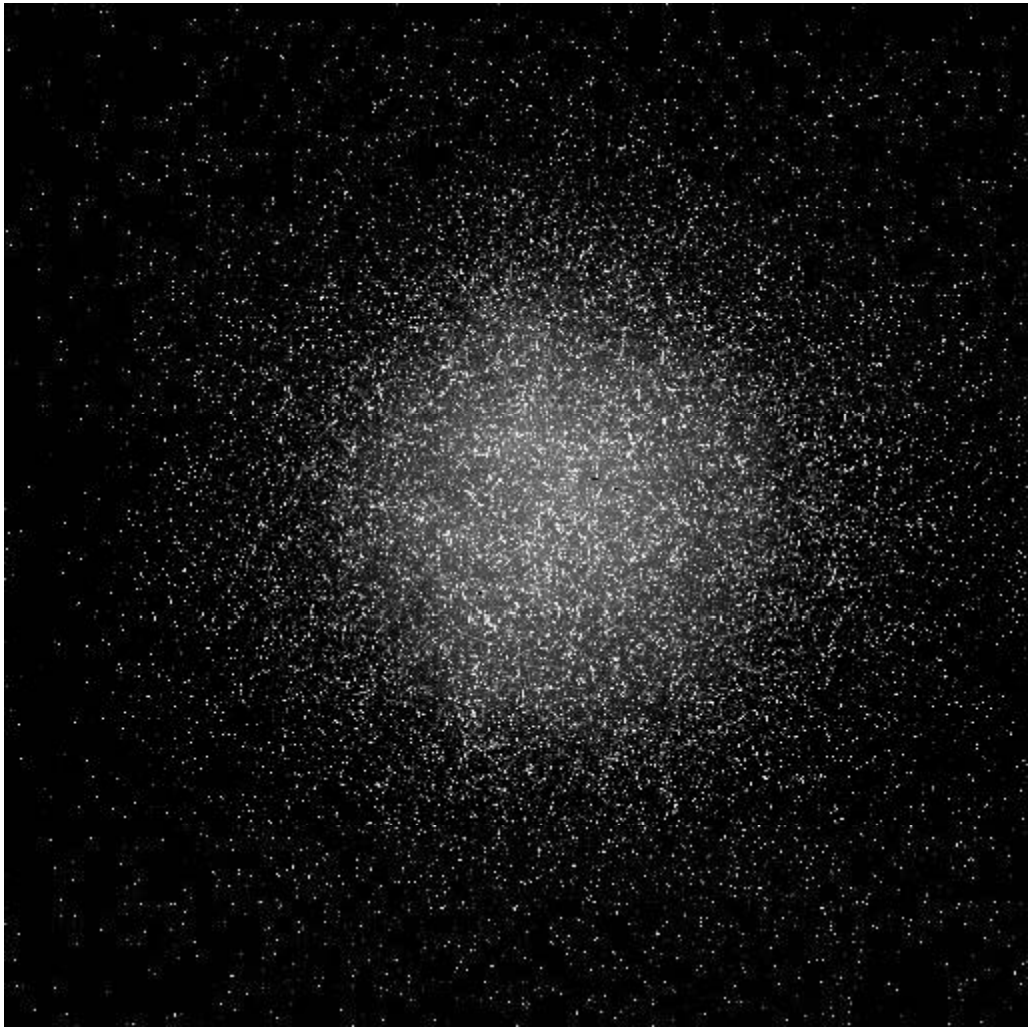
6 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 8 sec



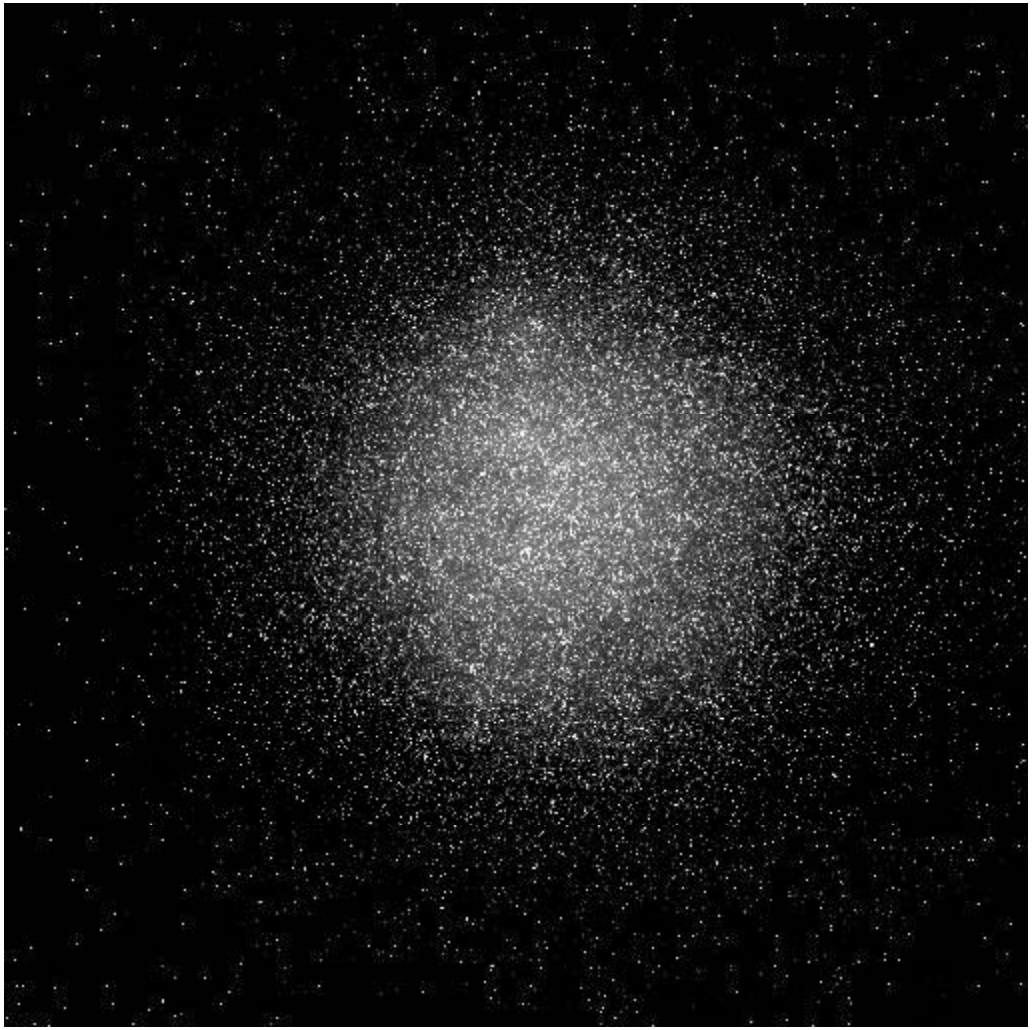
8 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 10 sec



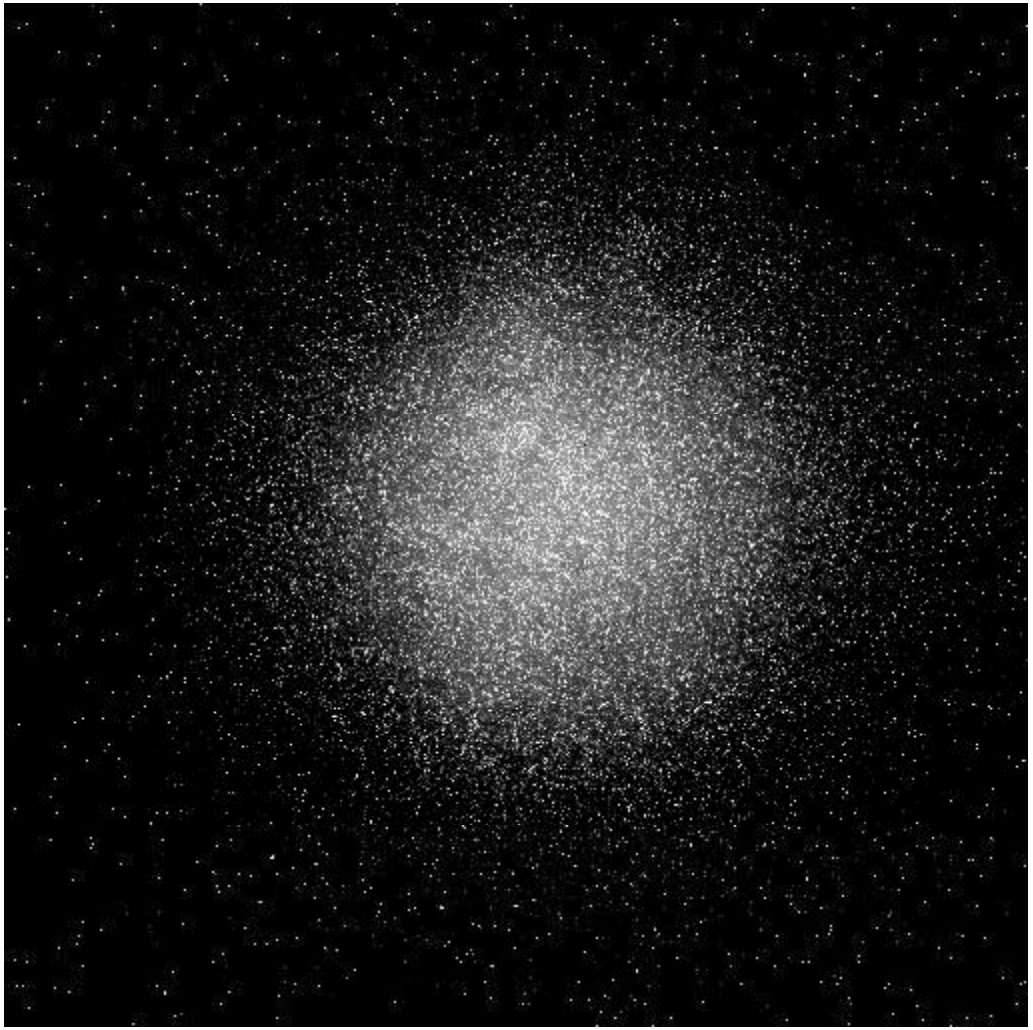
10 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 20 sec



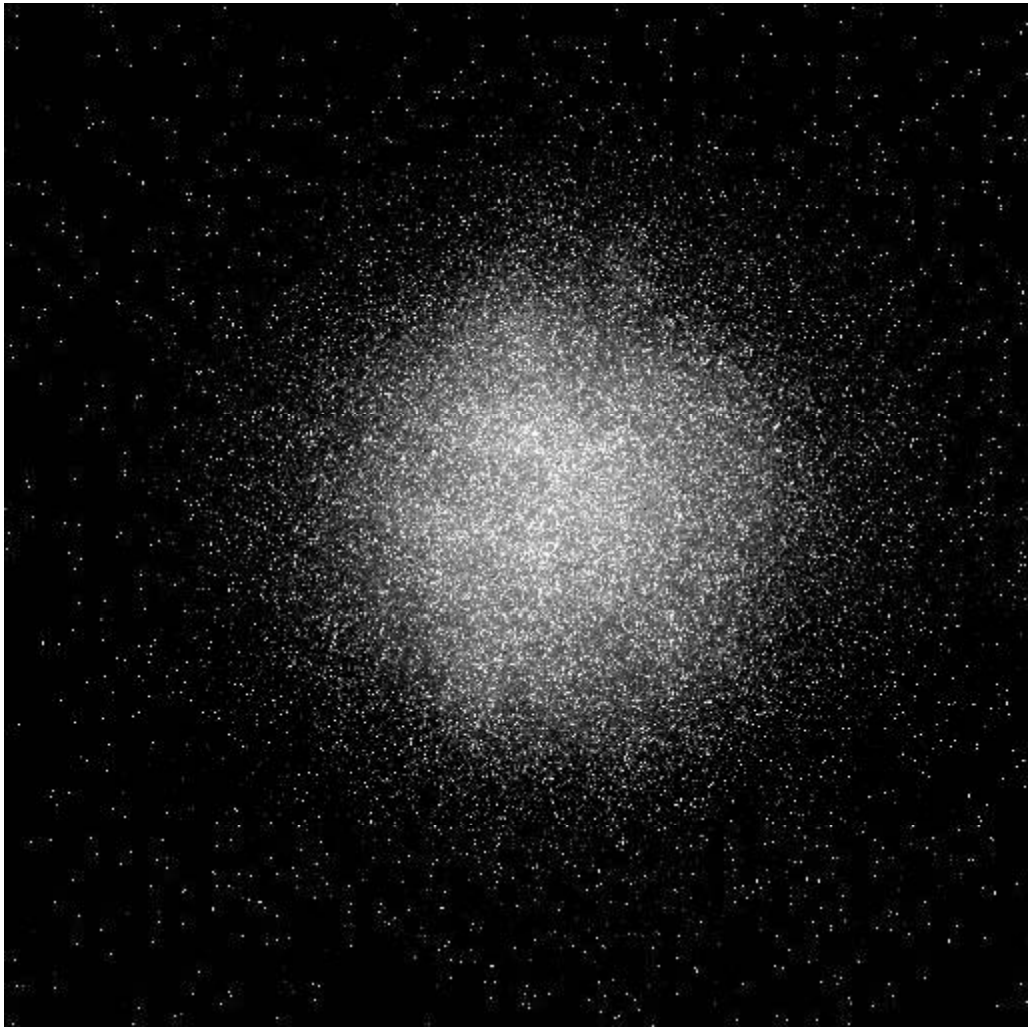
20 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 30 sec



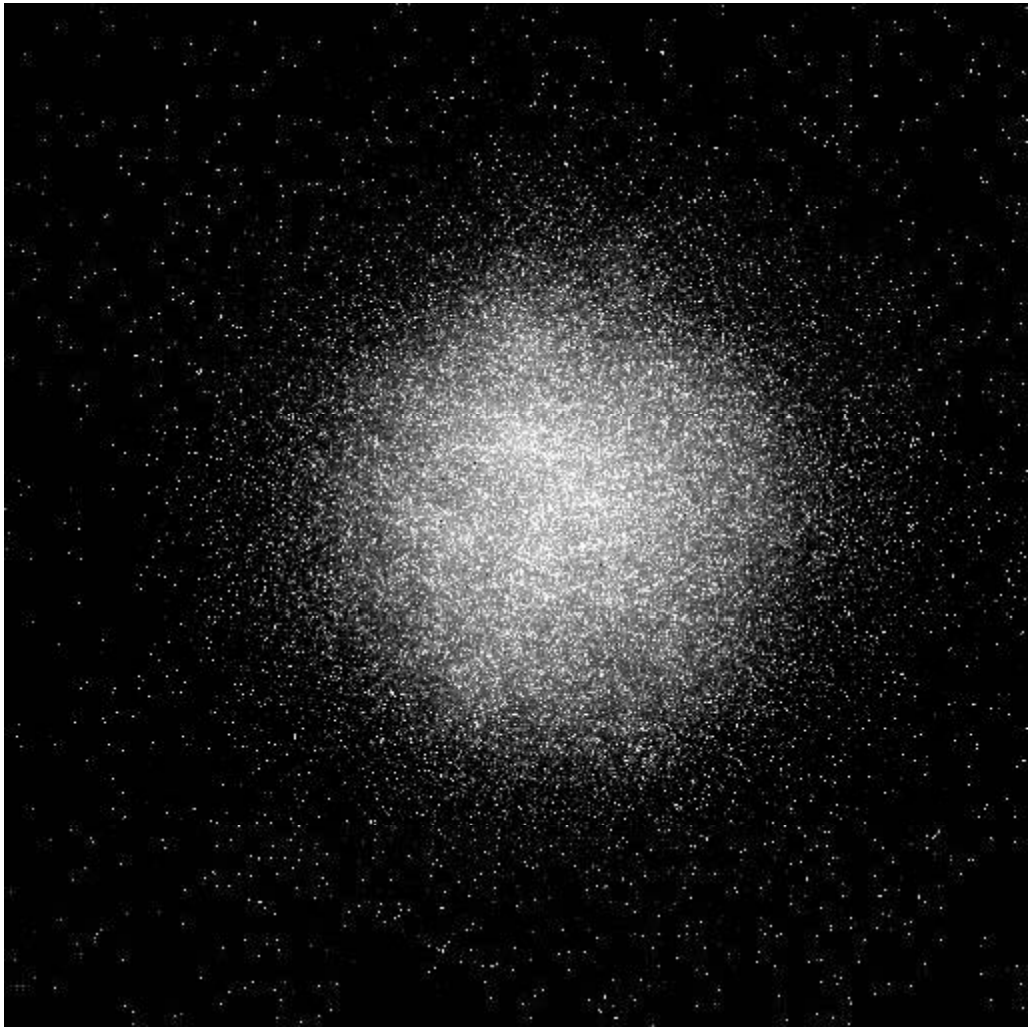
30 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 40 sec



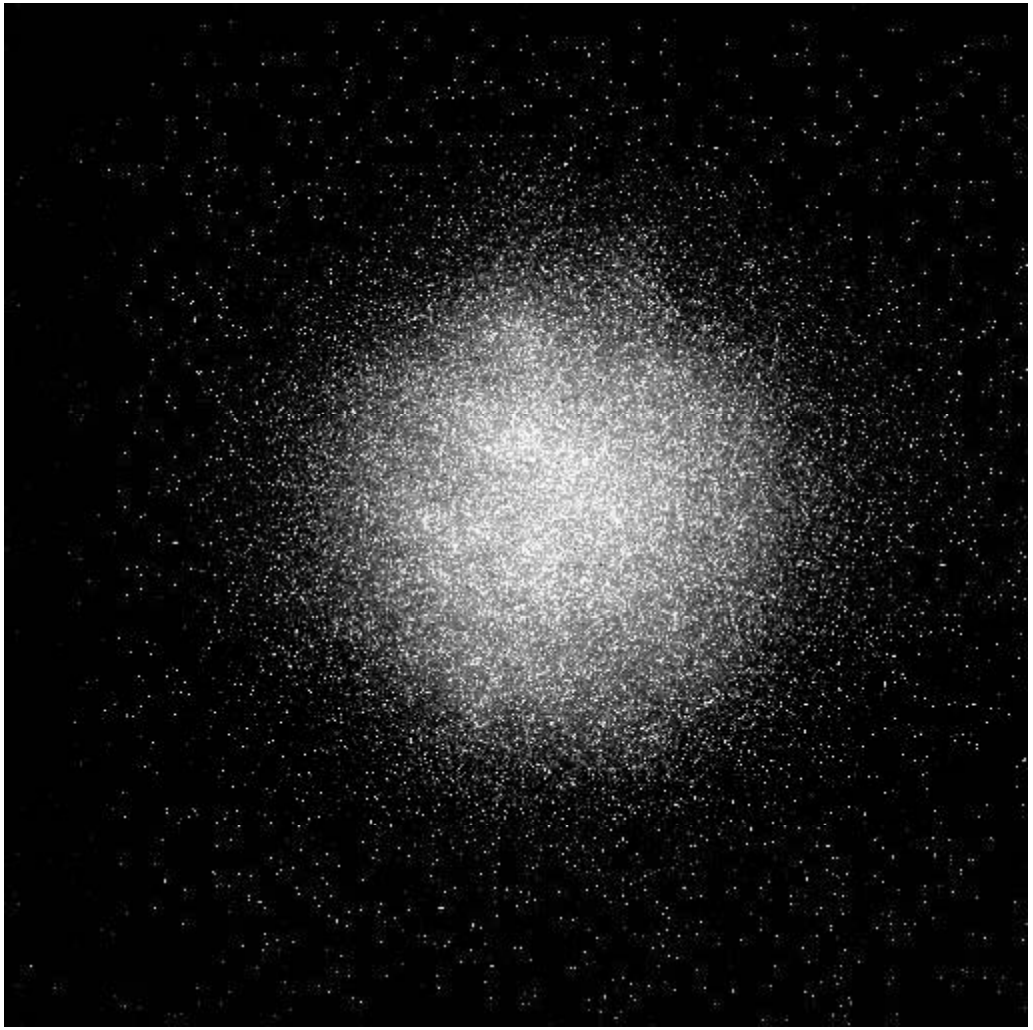
40 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 50 sec



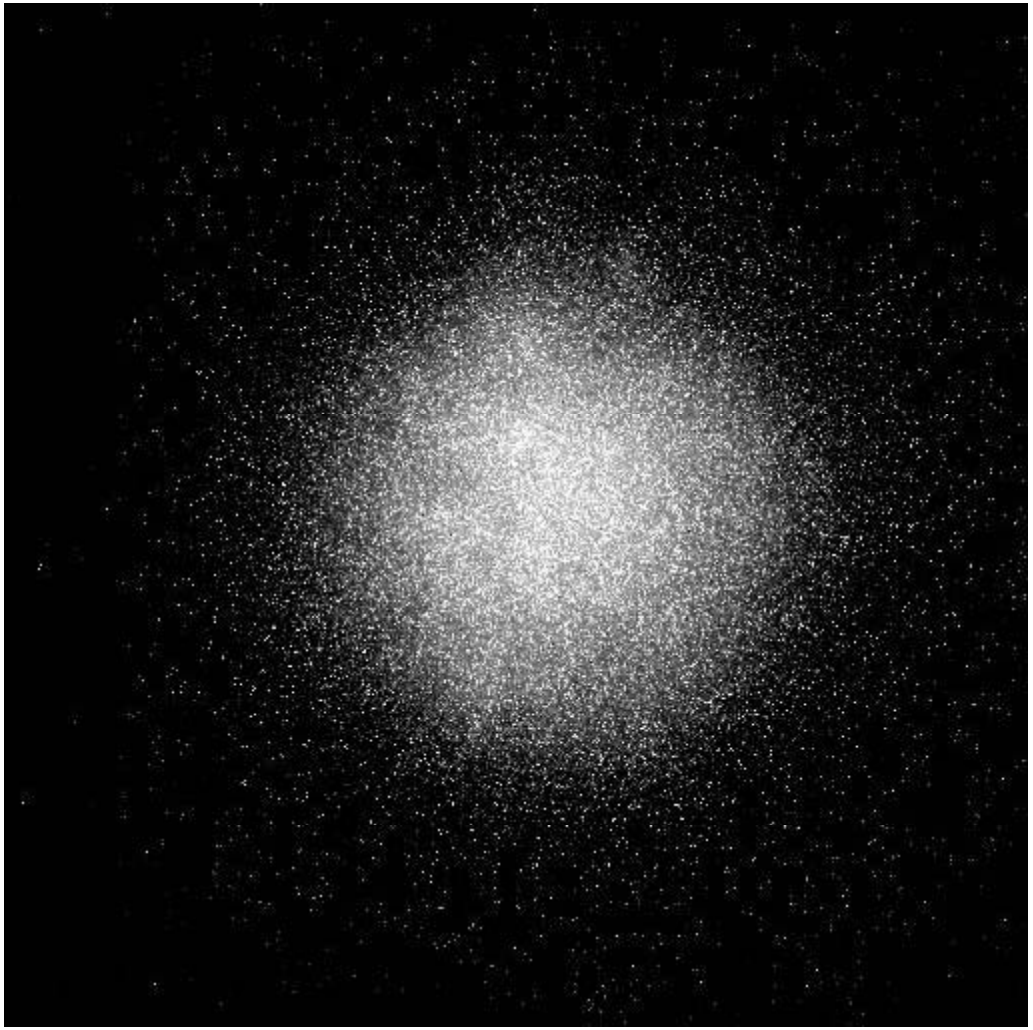
50 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 60 sec



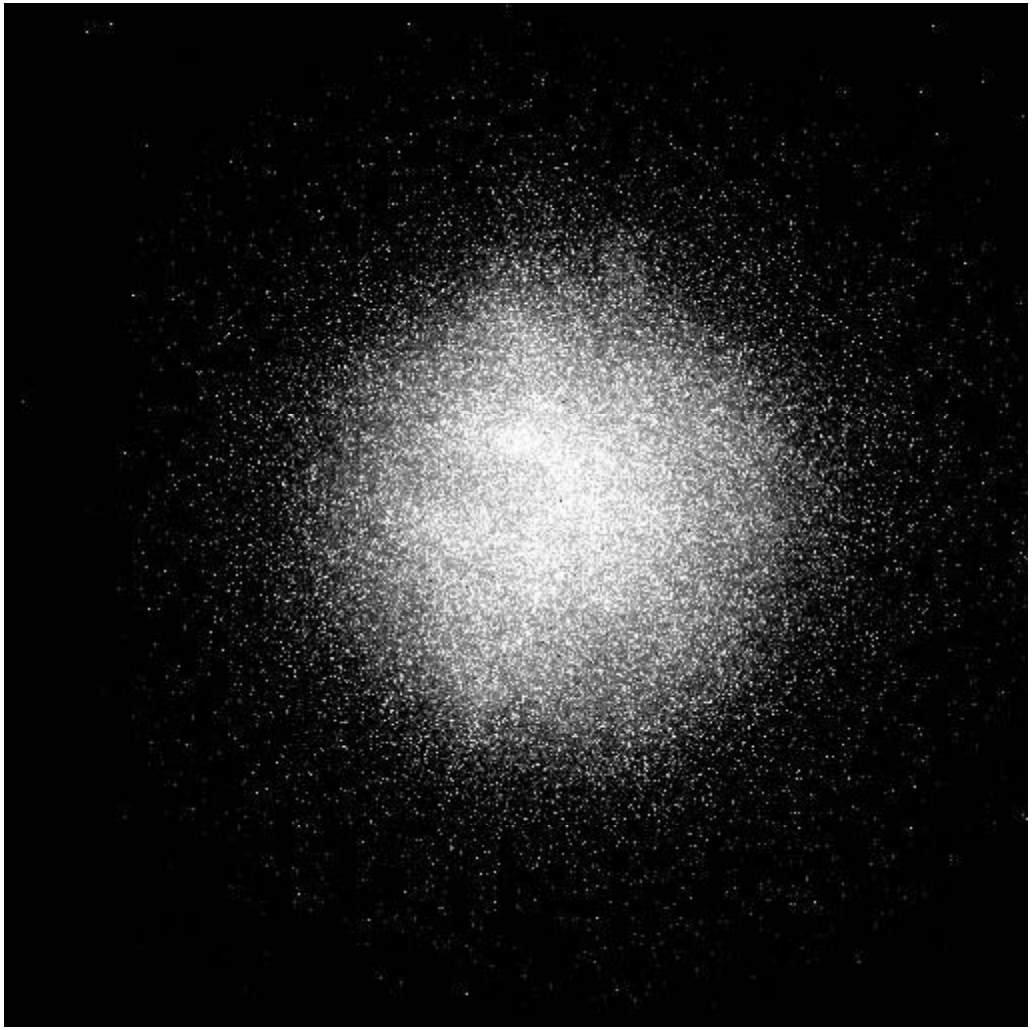
60 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 70 sec



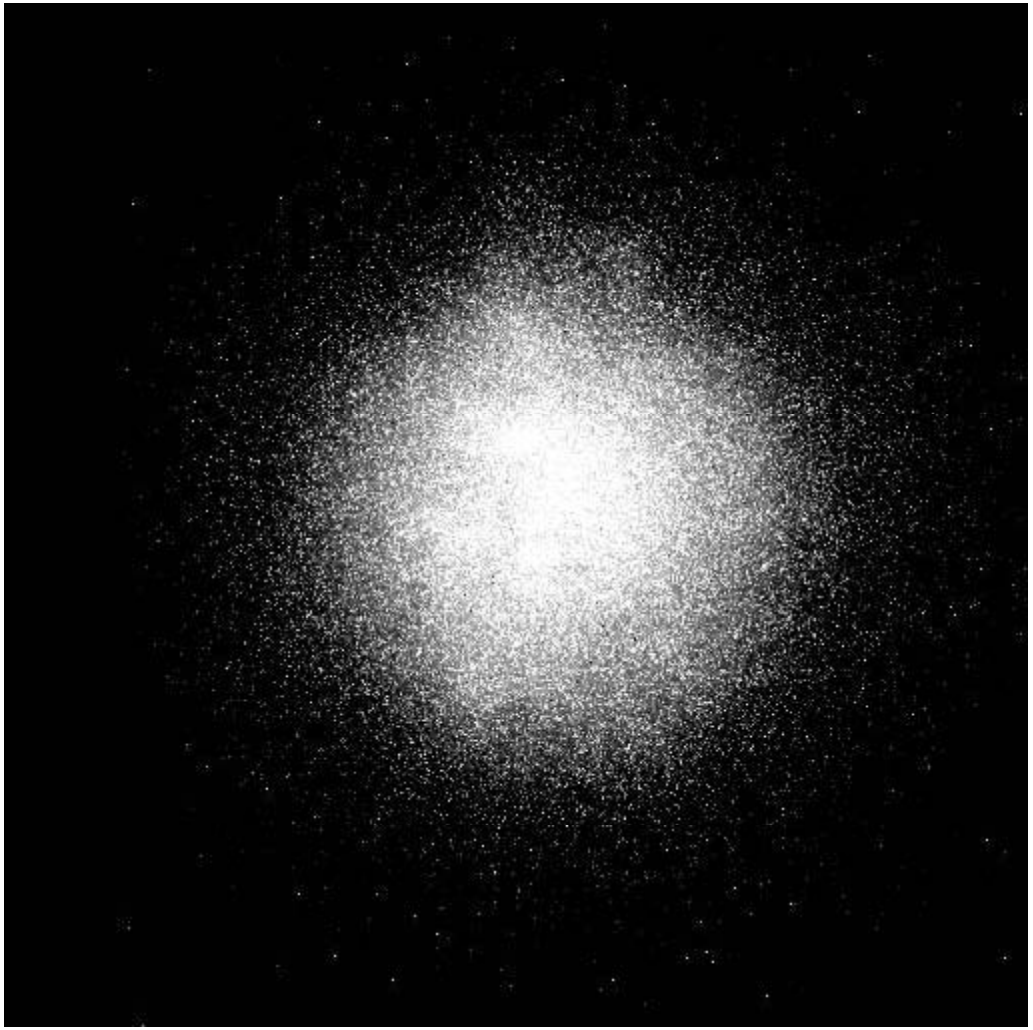
70 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 80 sec



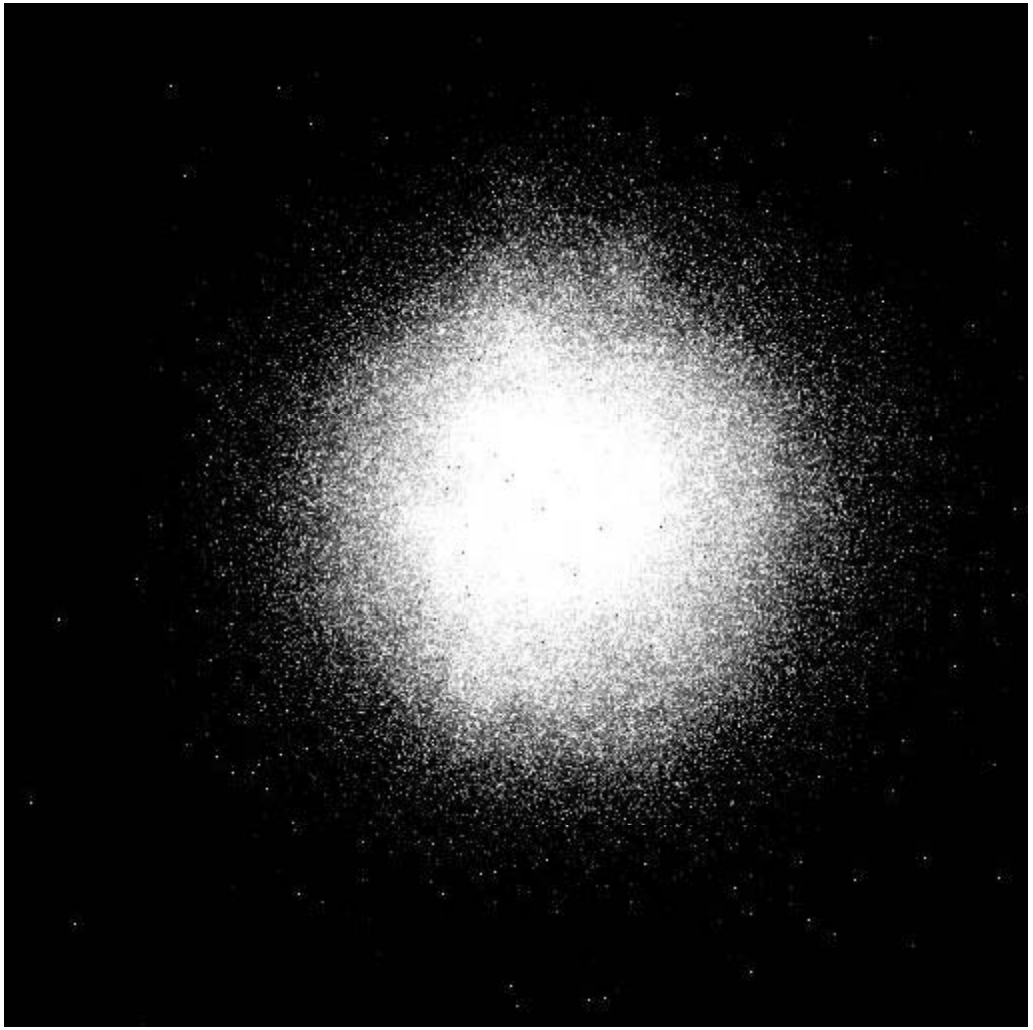
80 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 90 sec



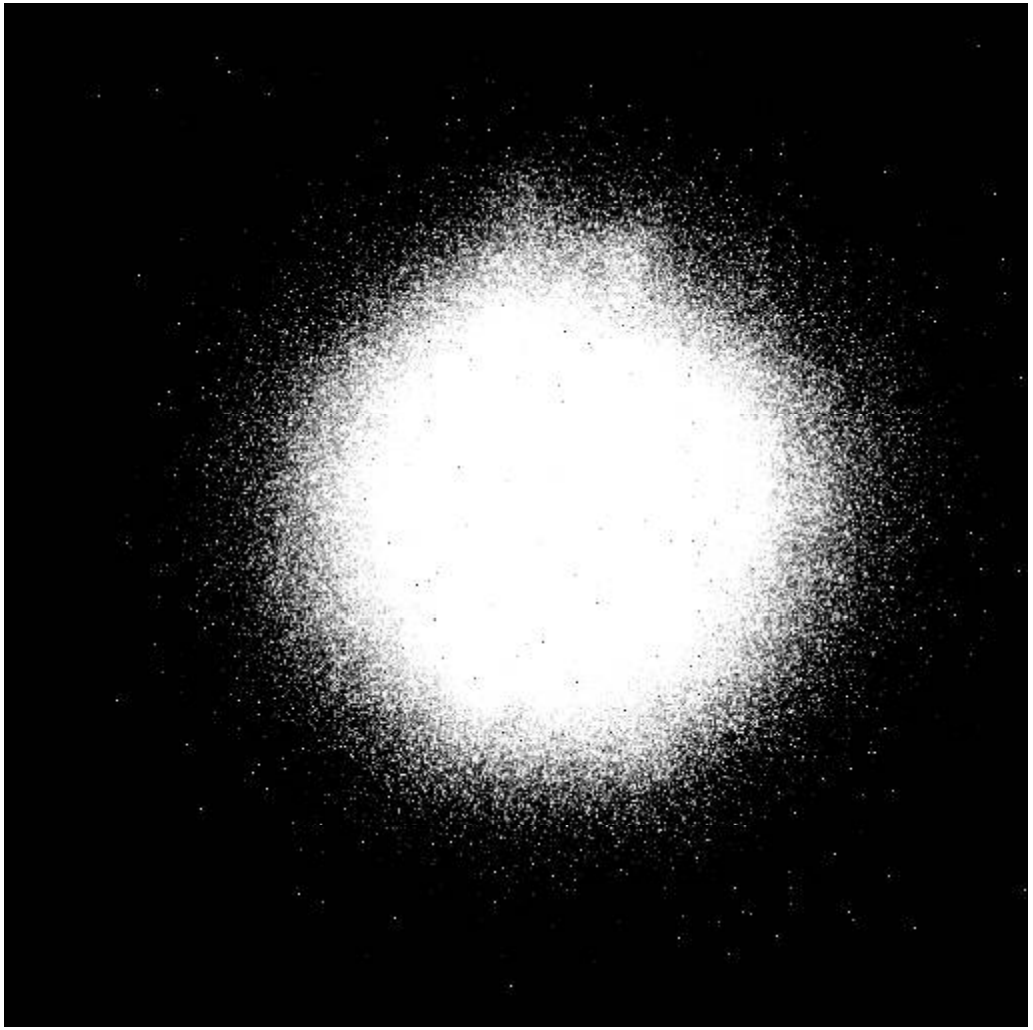
90 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 100 sec



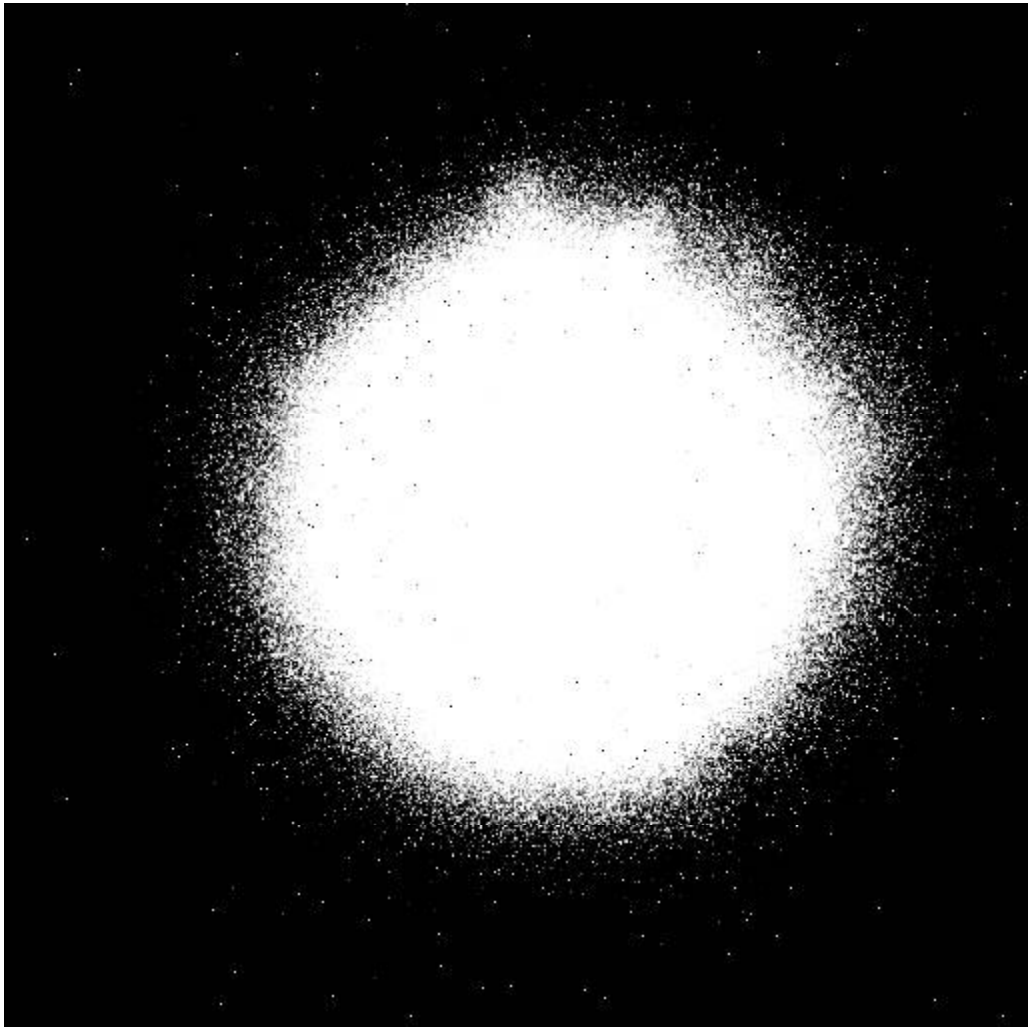
100 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 110 sec



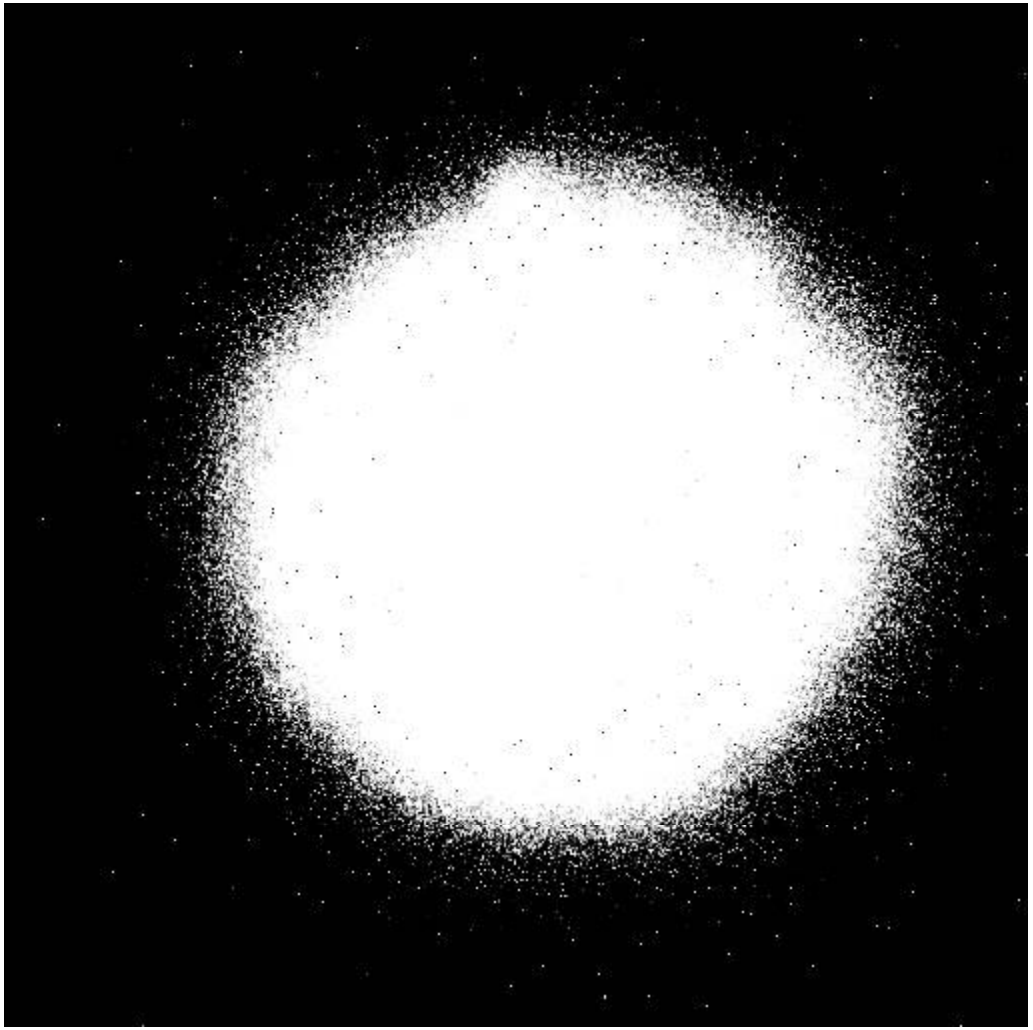
110 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 120 sec



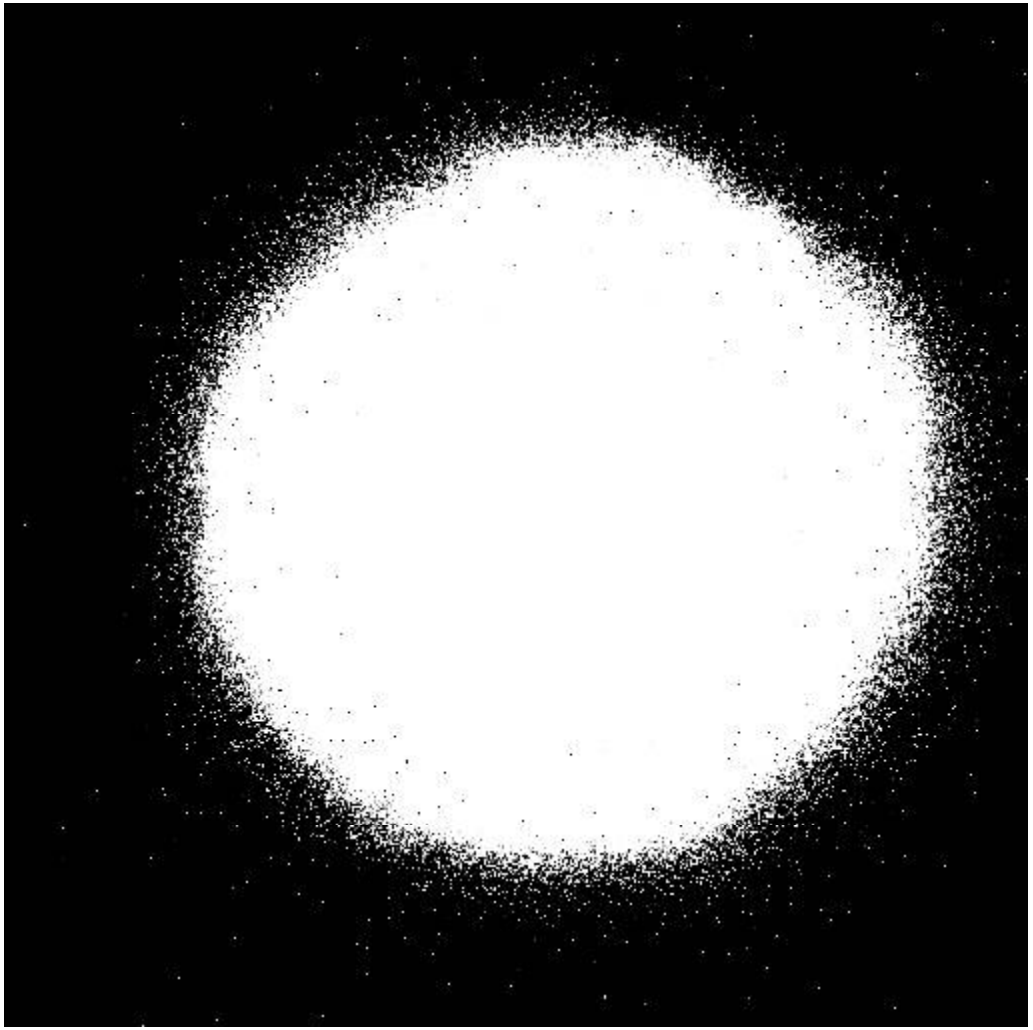
120 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 130 sec



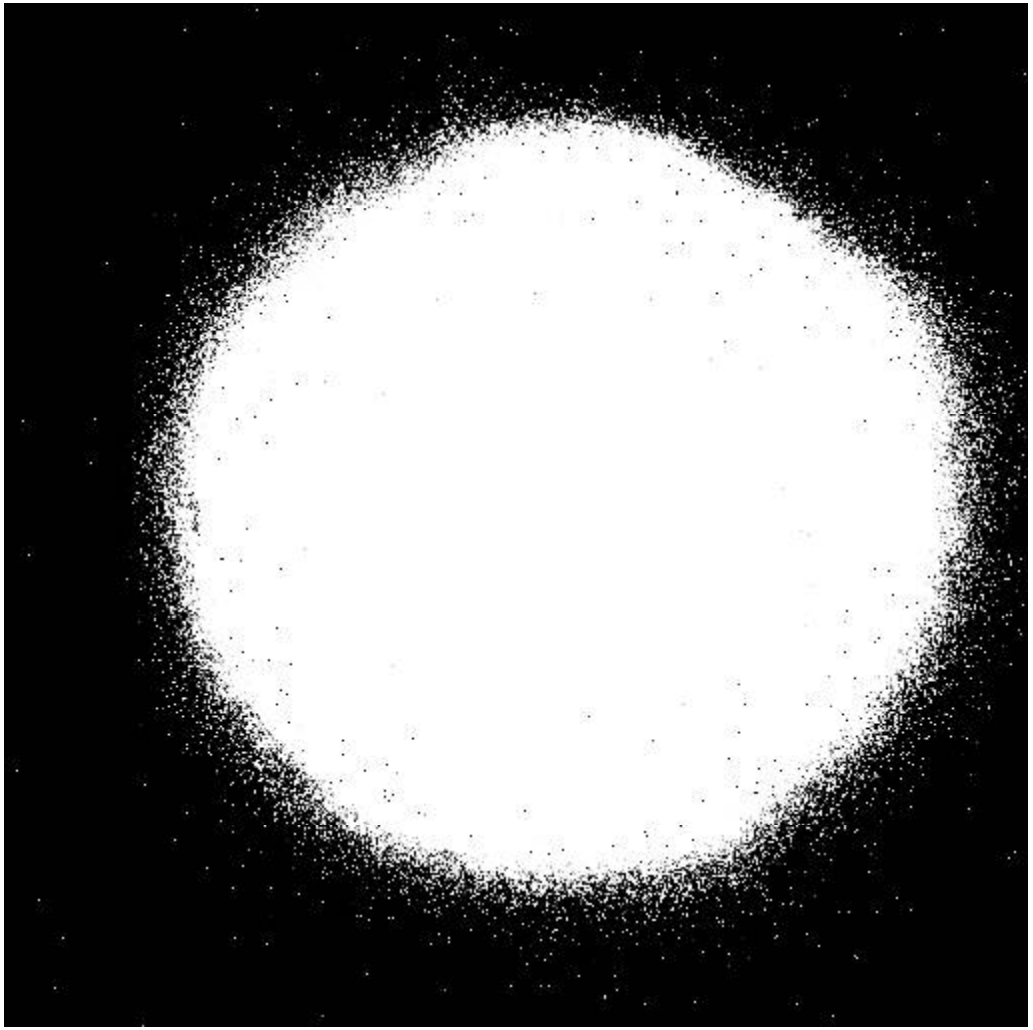
130 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 140 sec



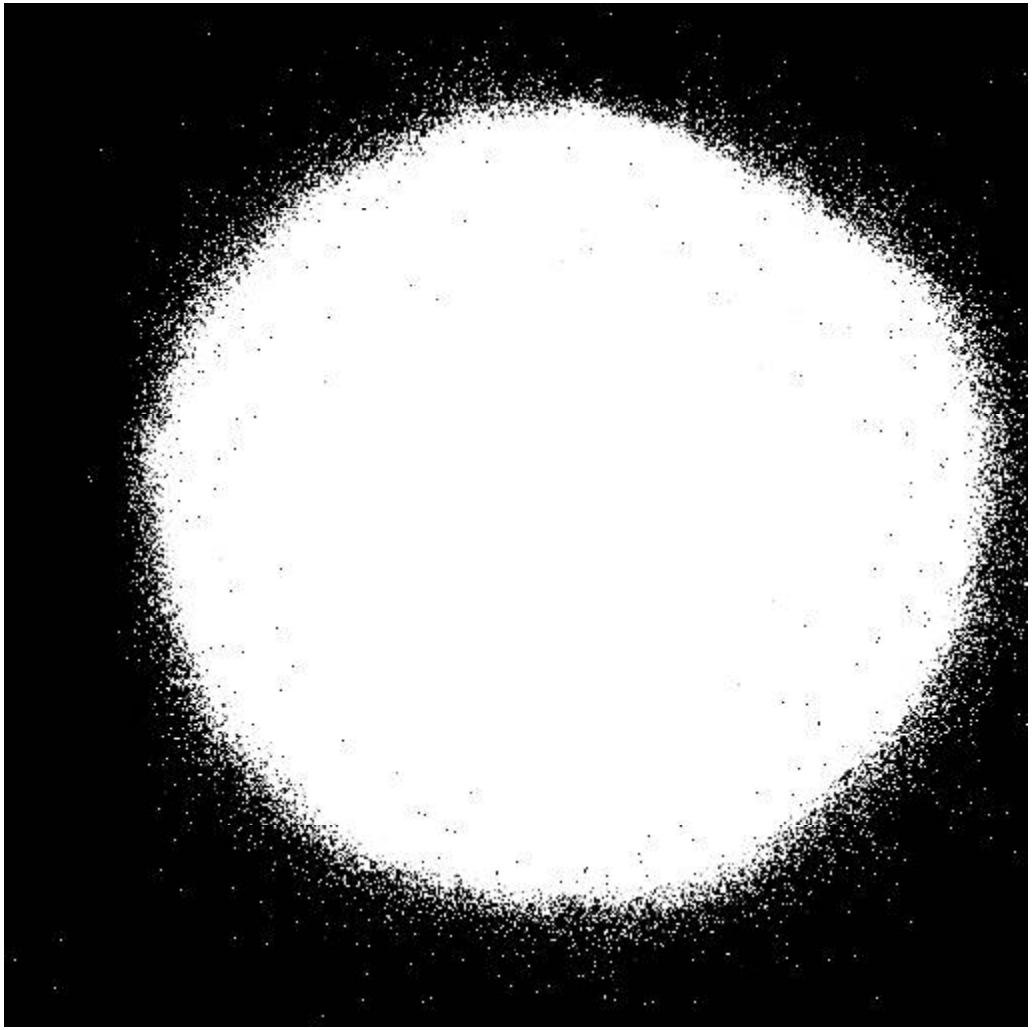
140 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 150 sec



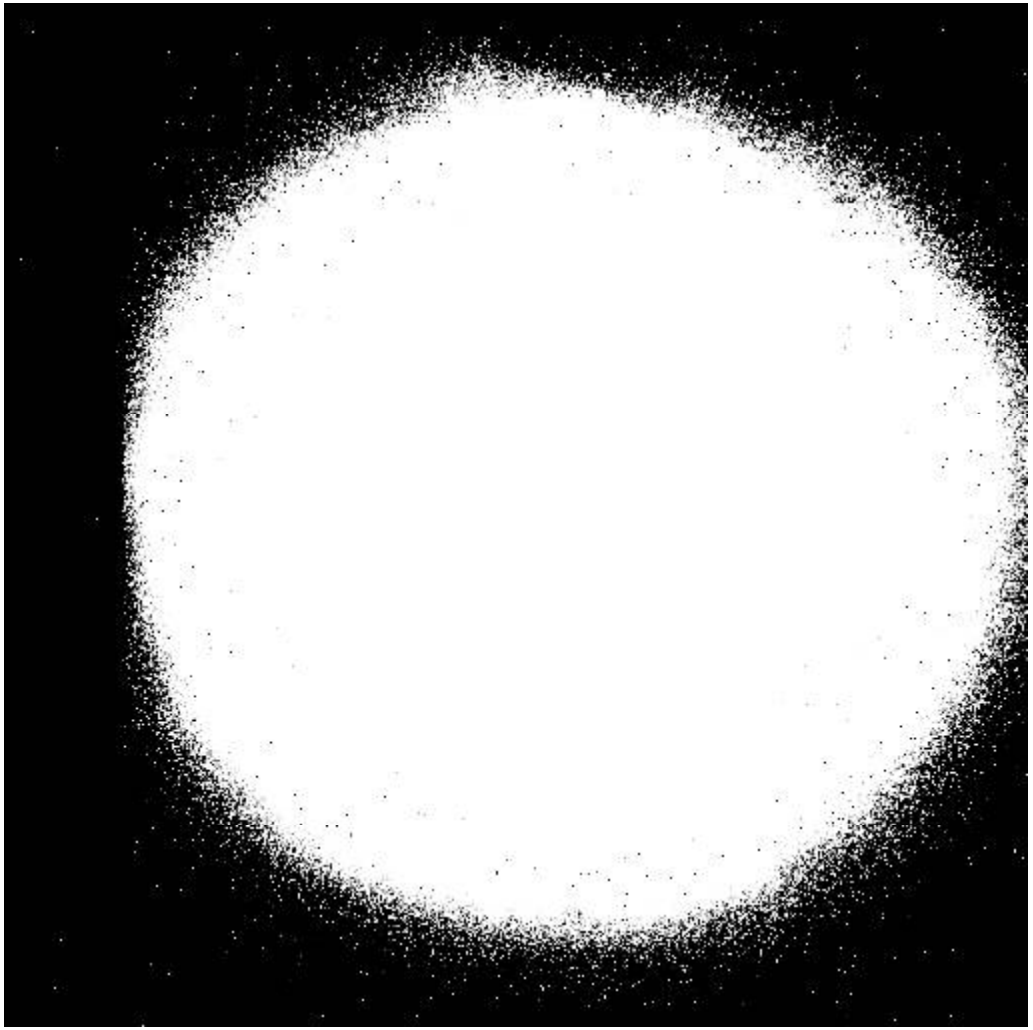
150 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 160 sec



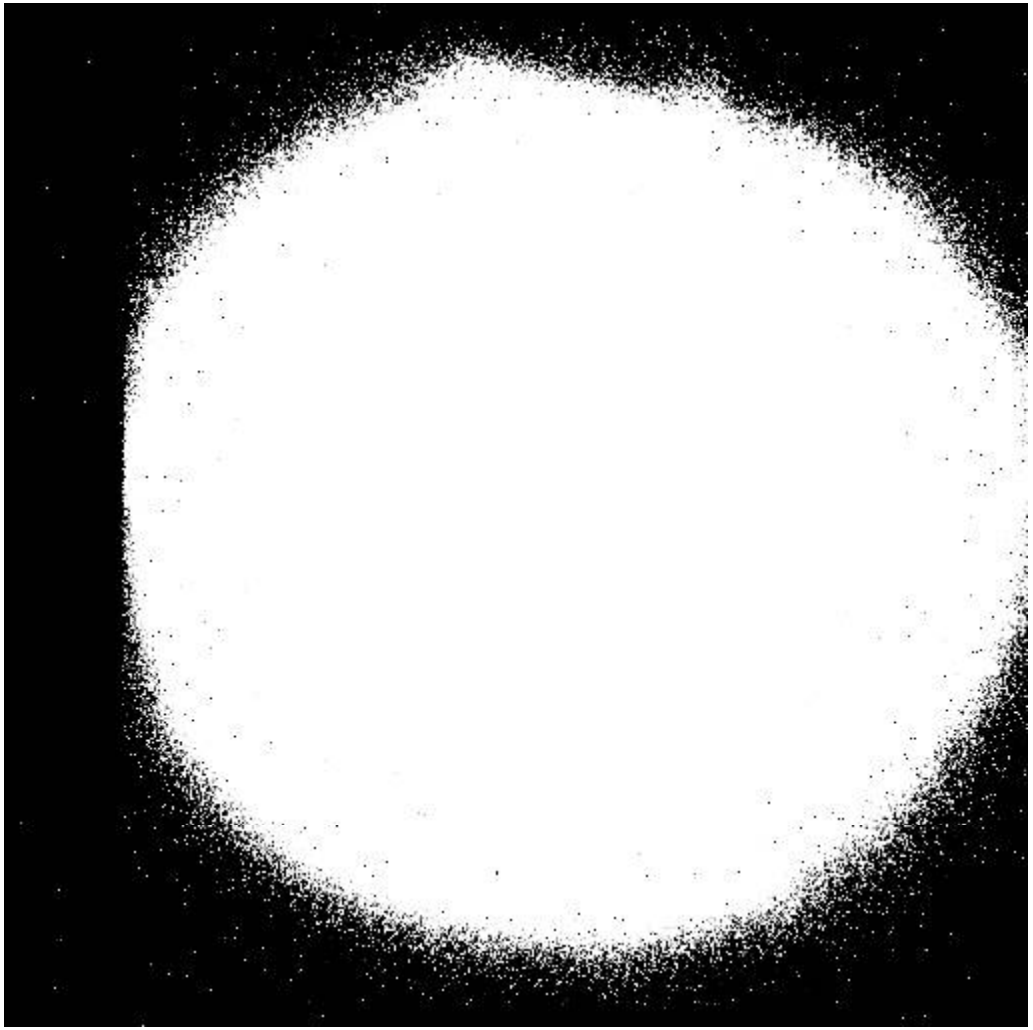
160 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 170 sec



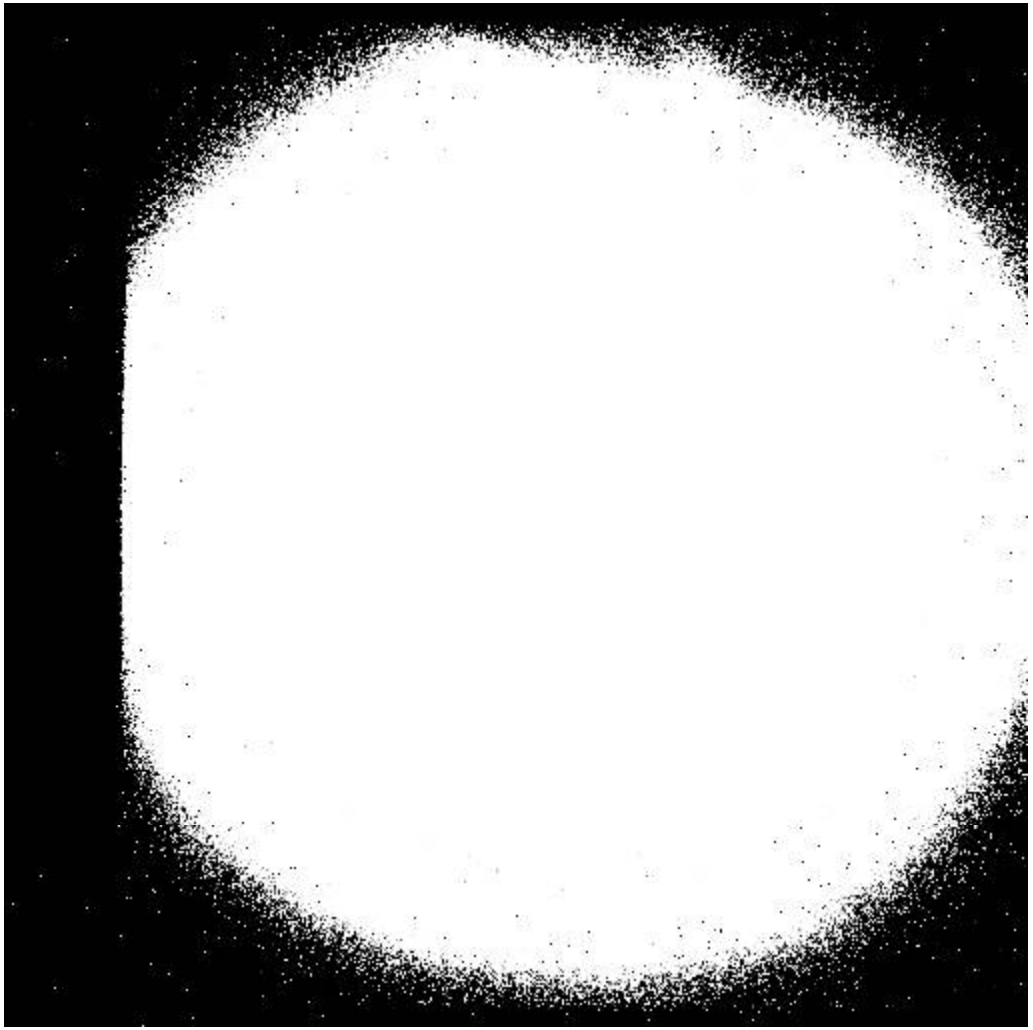
170 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 180 sec



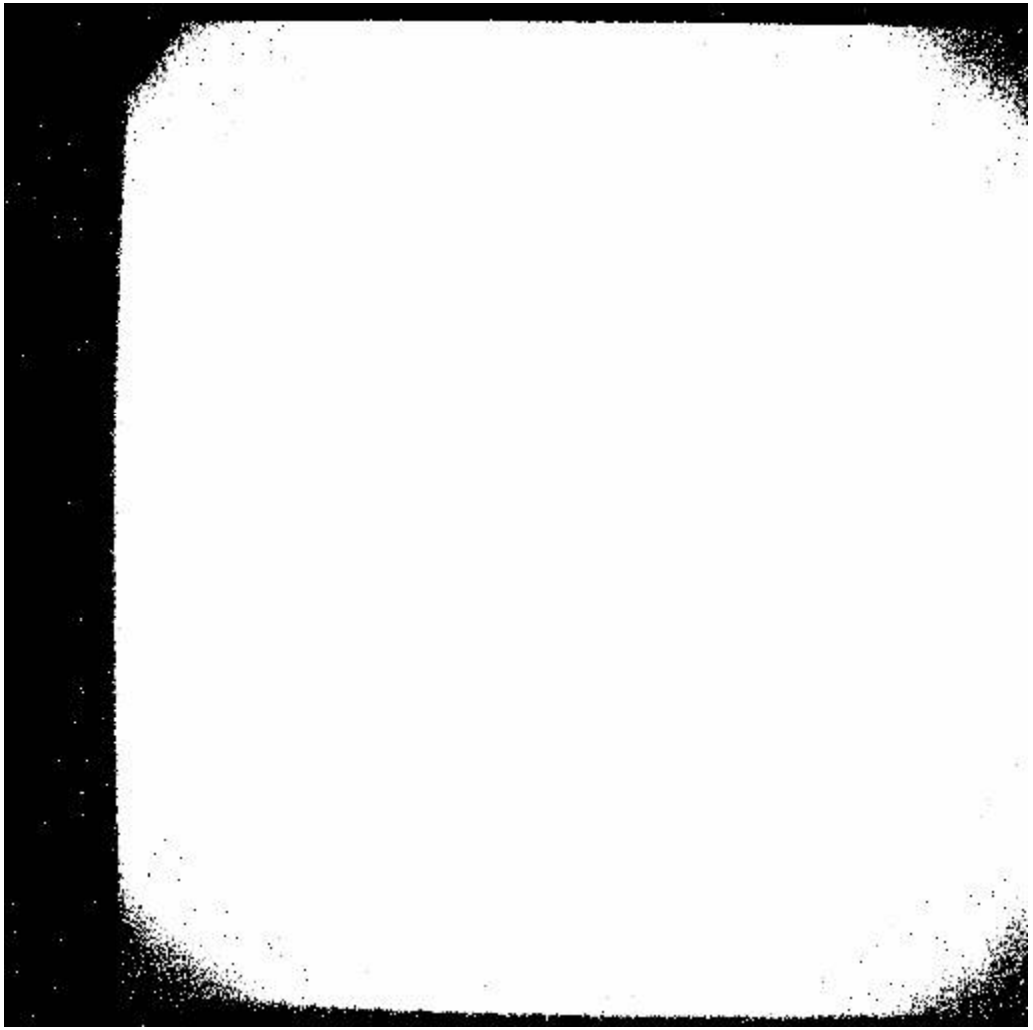
180 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 200 sec



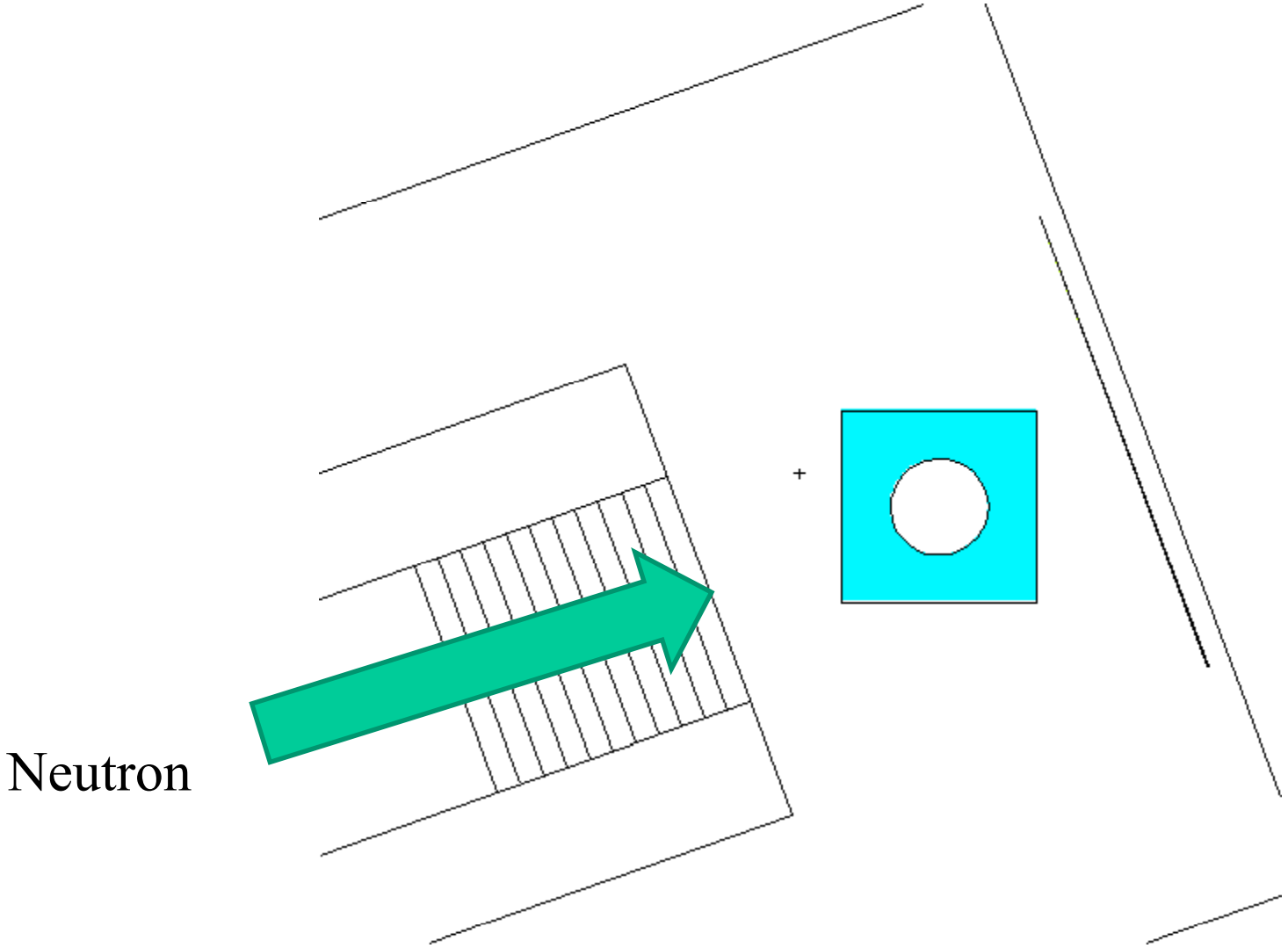
200 sec

CCD with only 7MeV beam,
No samples, and filters
exposed time : 300 sec

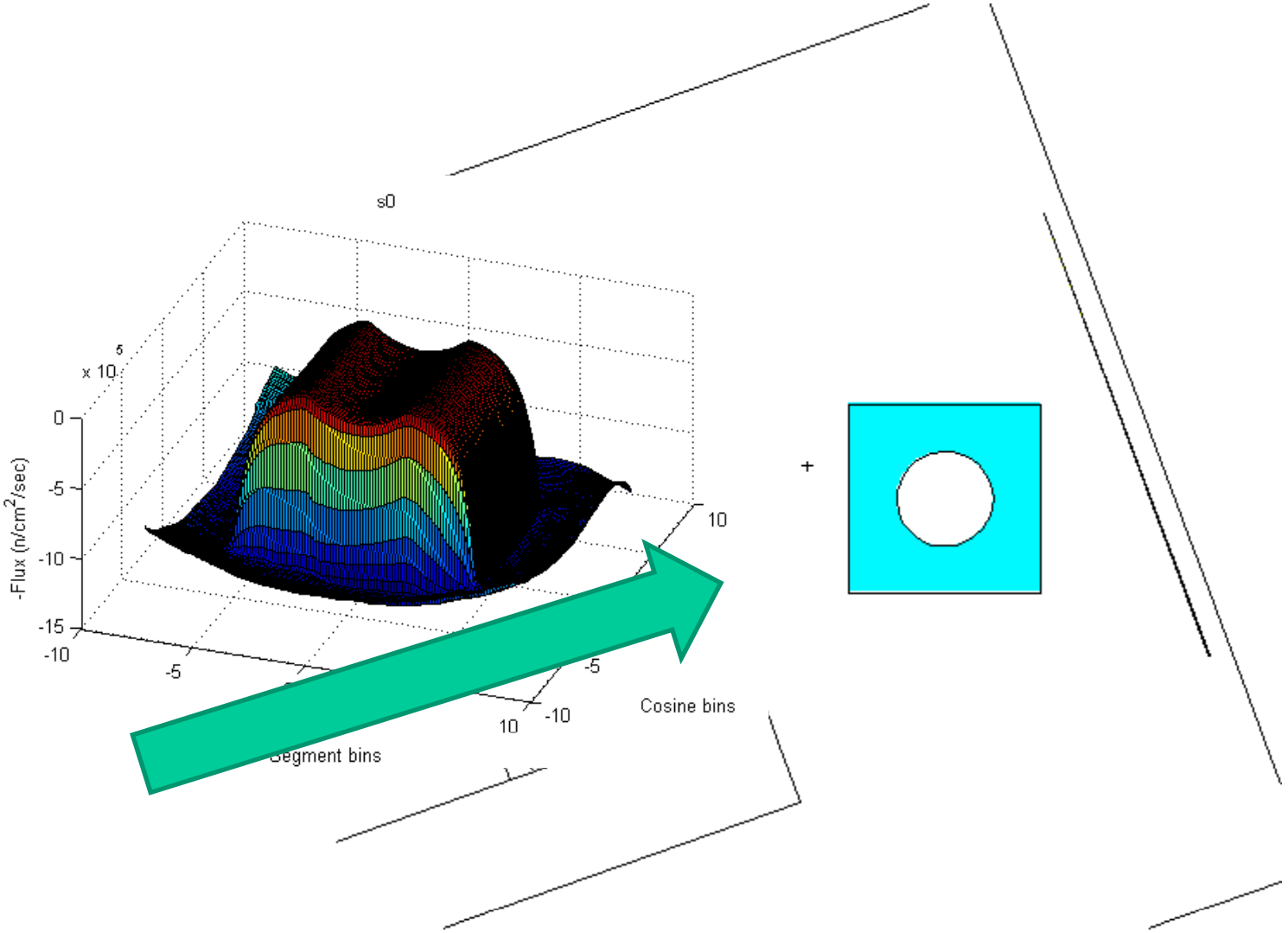


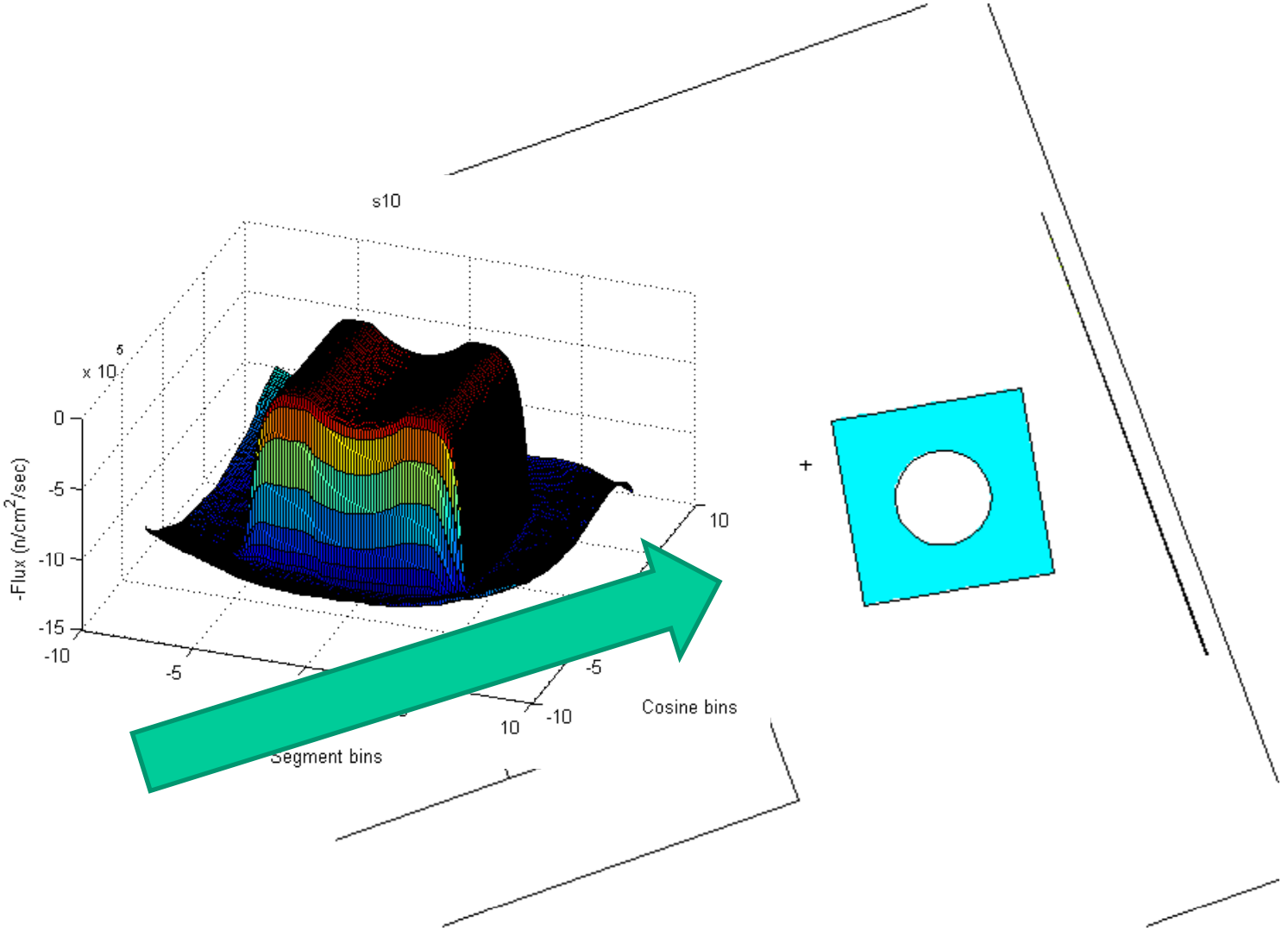
300 sec

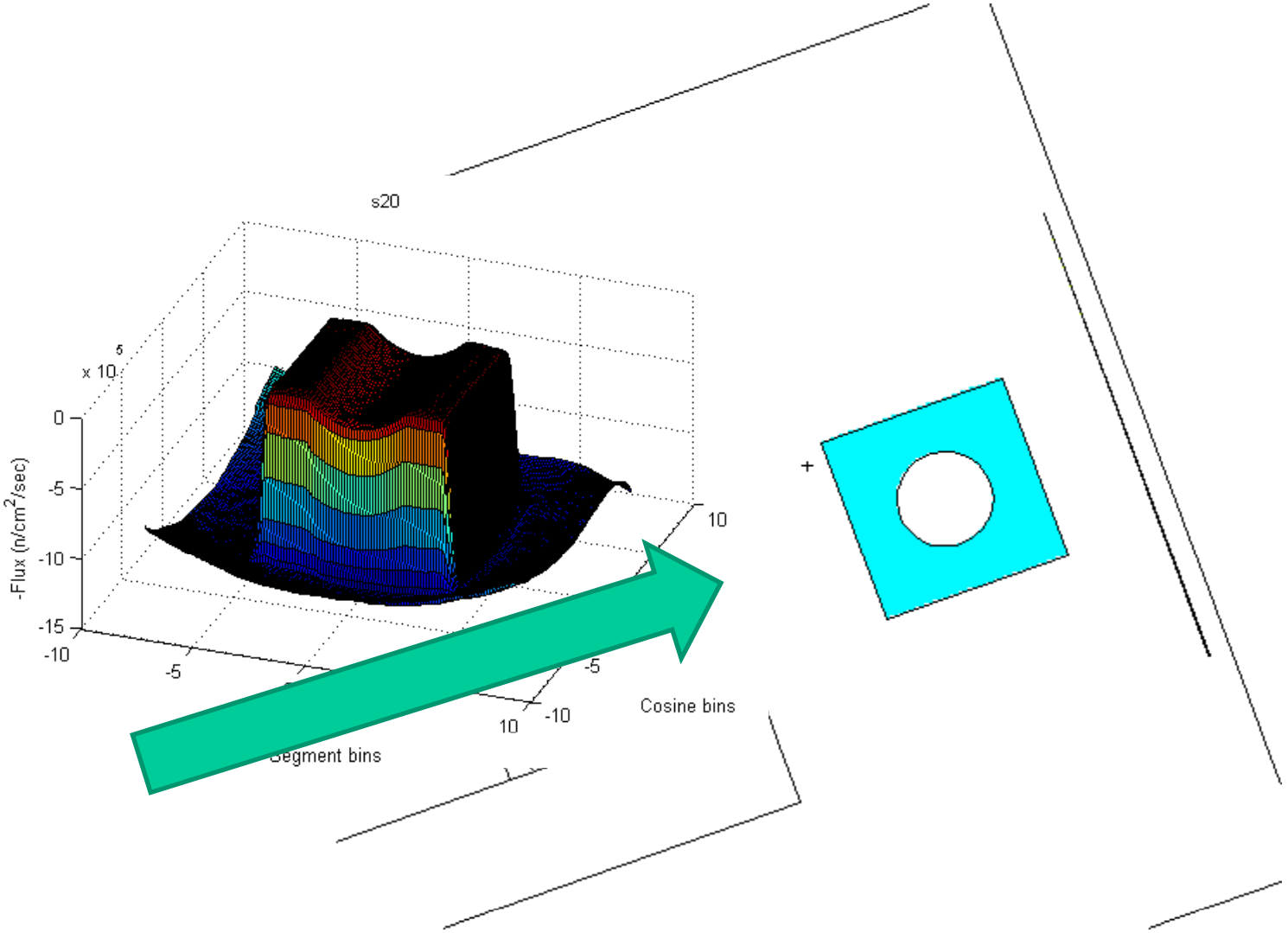
MCNP simulation and tomography

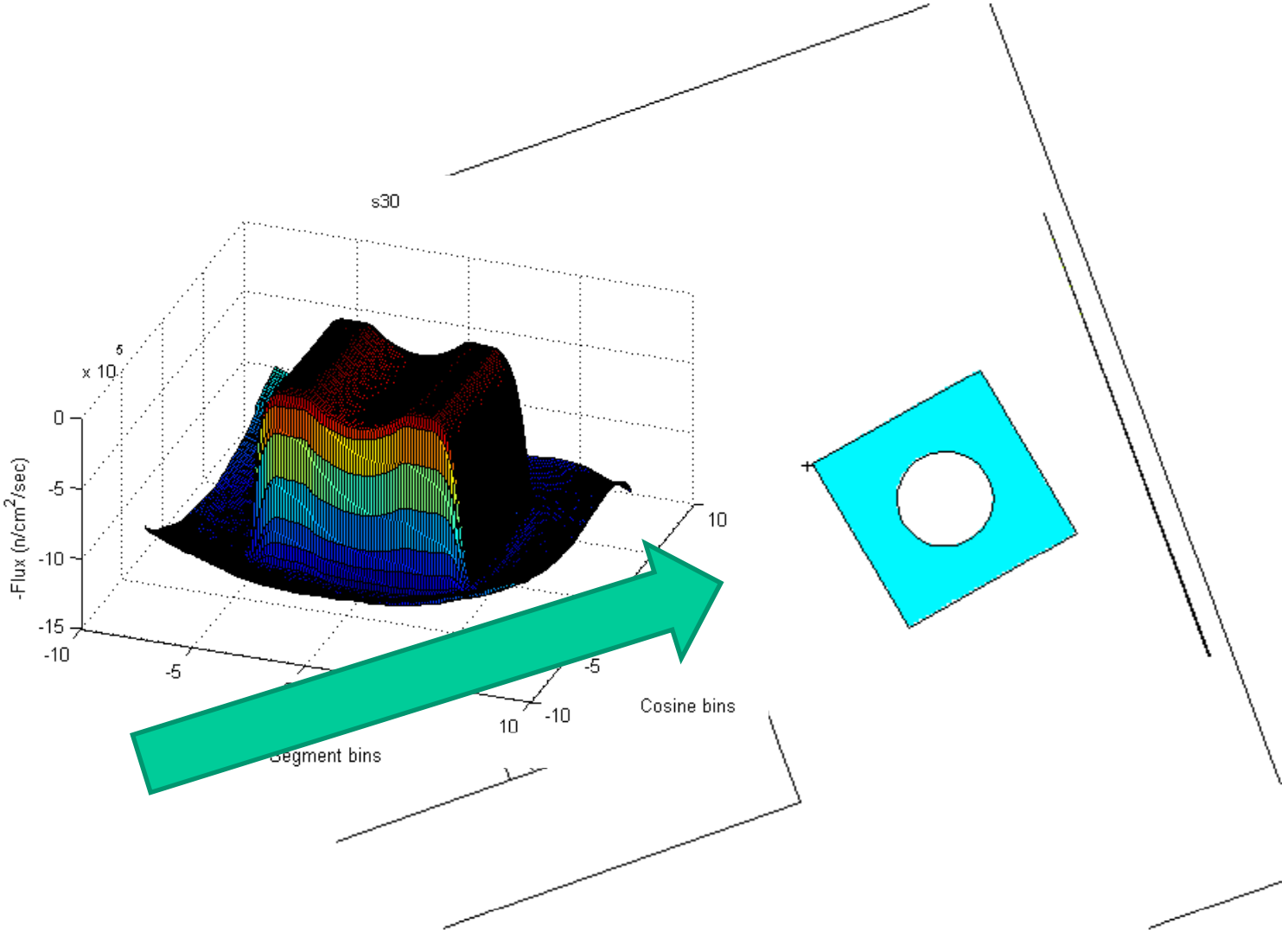


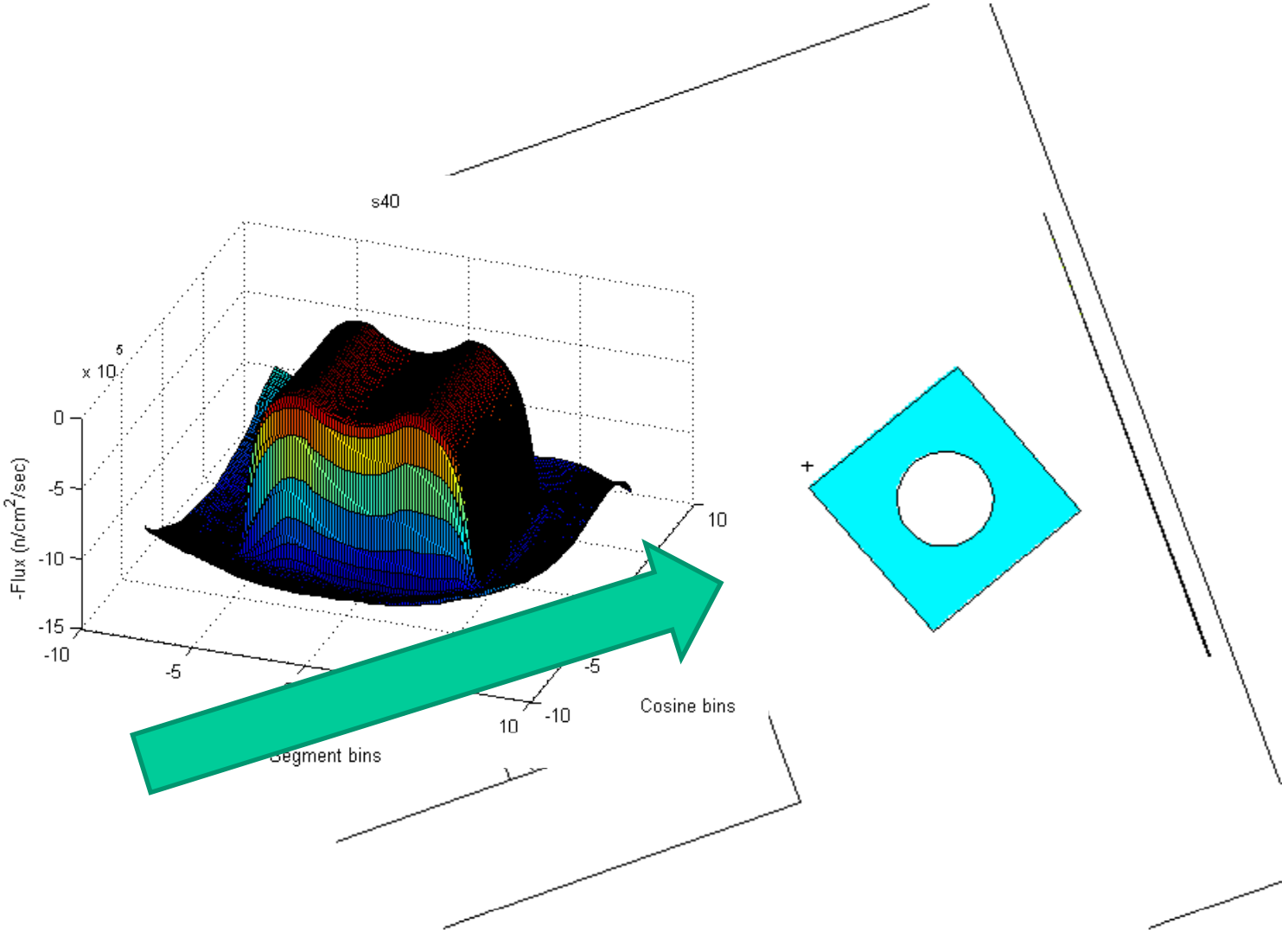
MCNP simulation and tomography

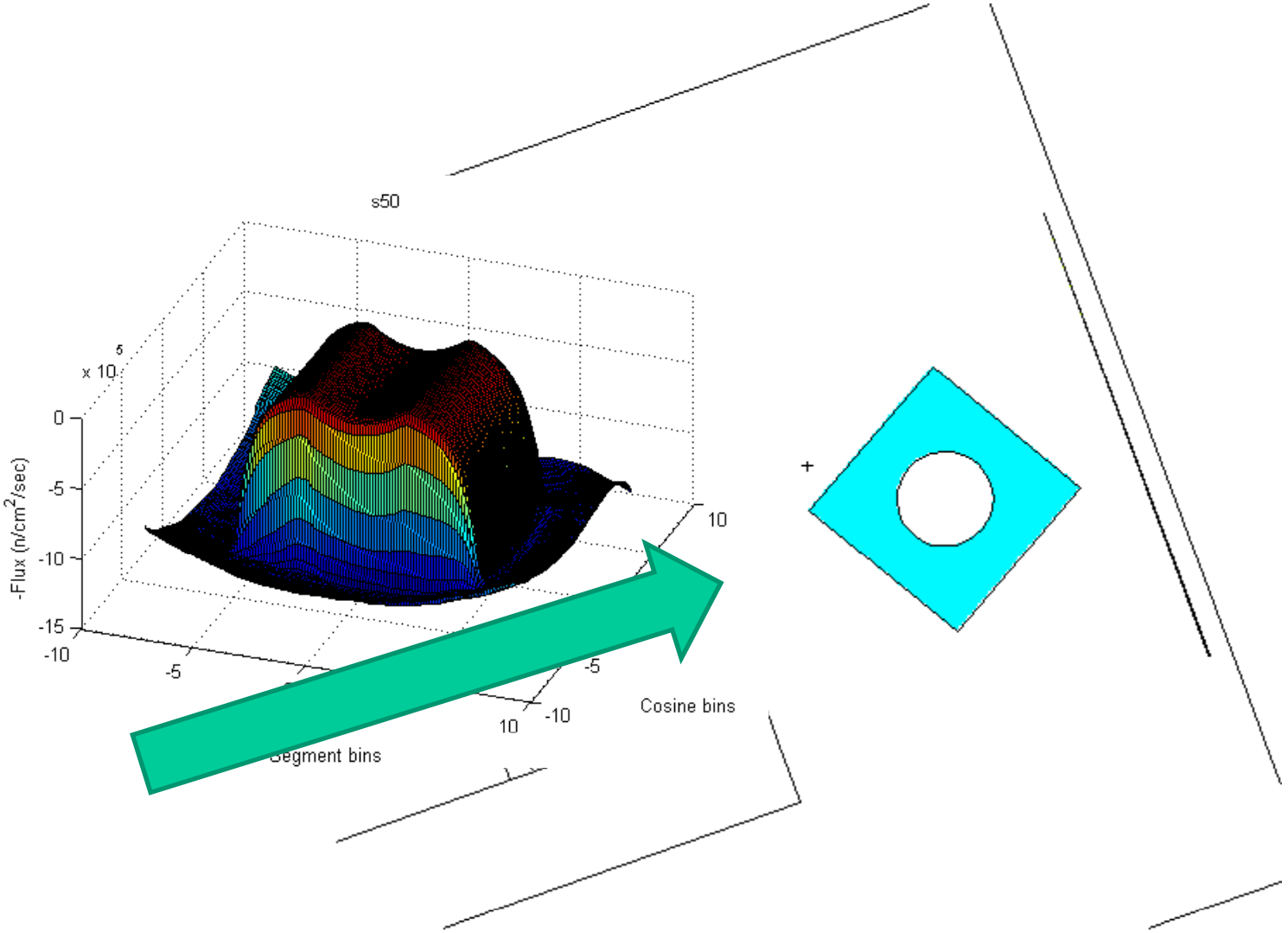


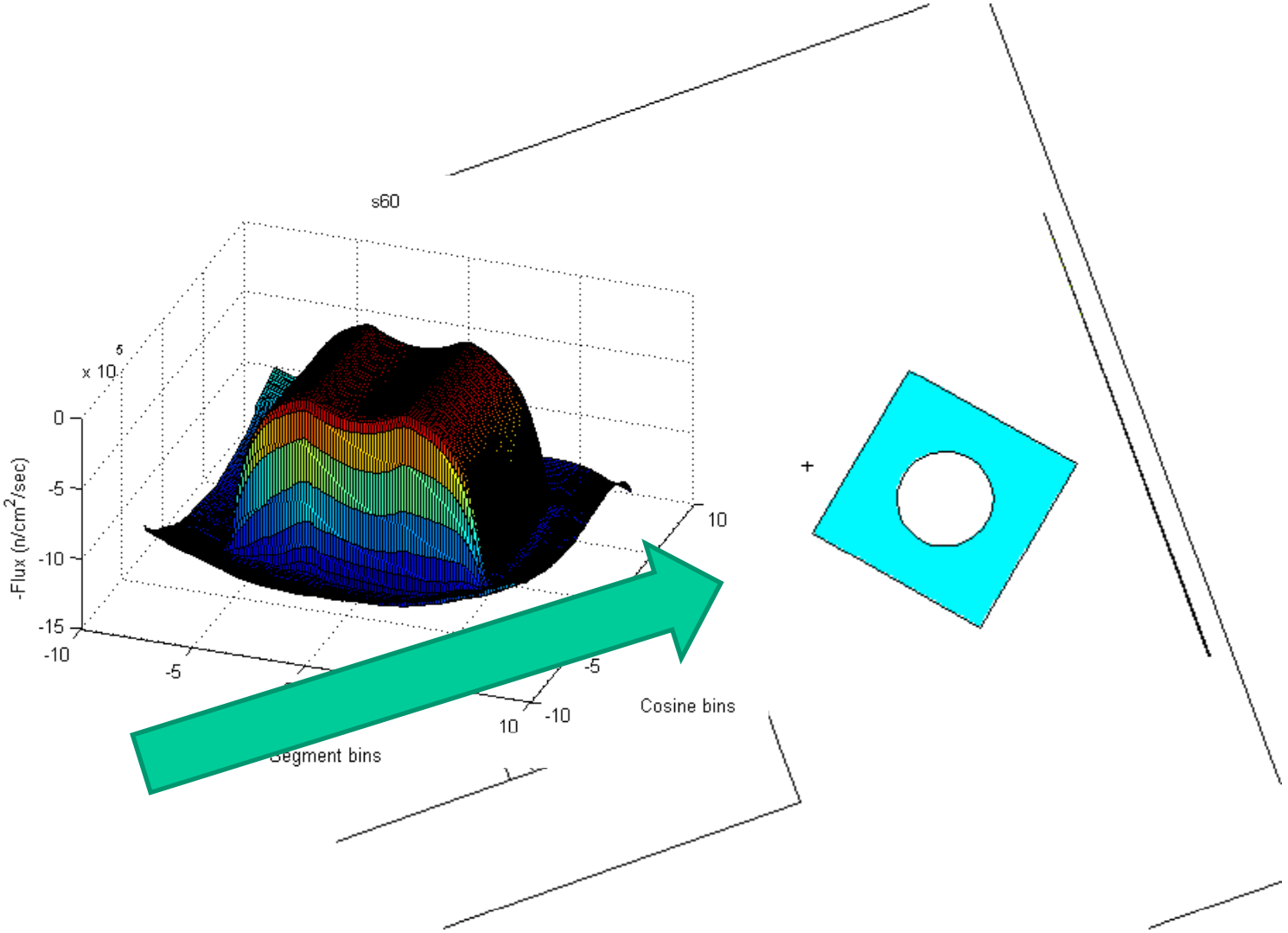

s10
x 10
5
0
-5
-10
-15
-Flux (n/cm2/sec)
-10
-5
10
Segment bins
-10
-5
10
Cosine bins
+

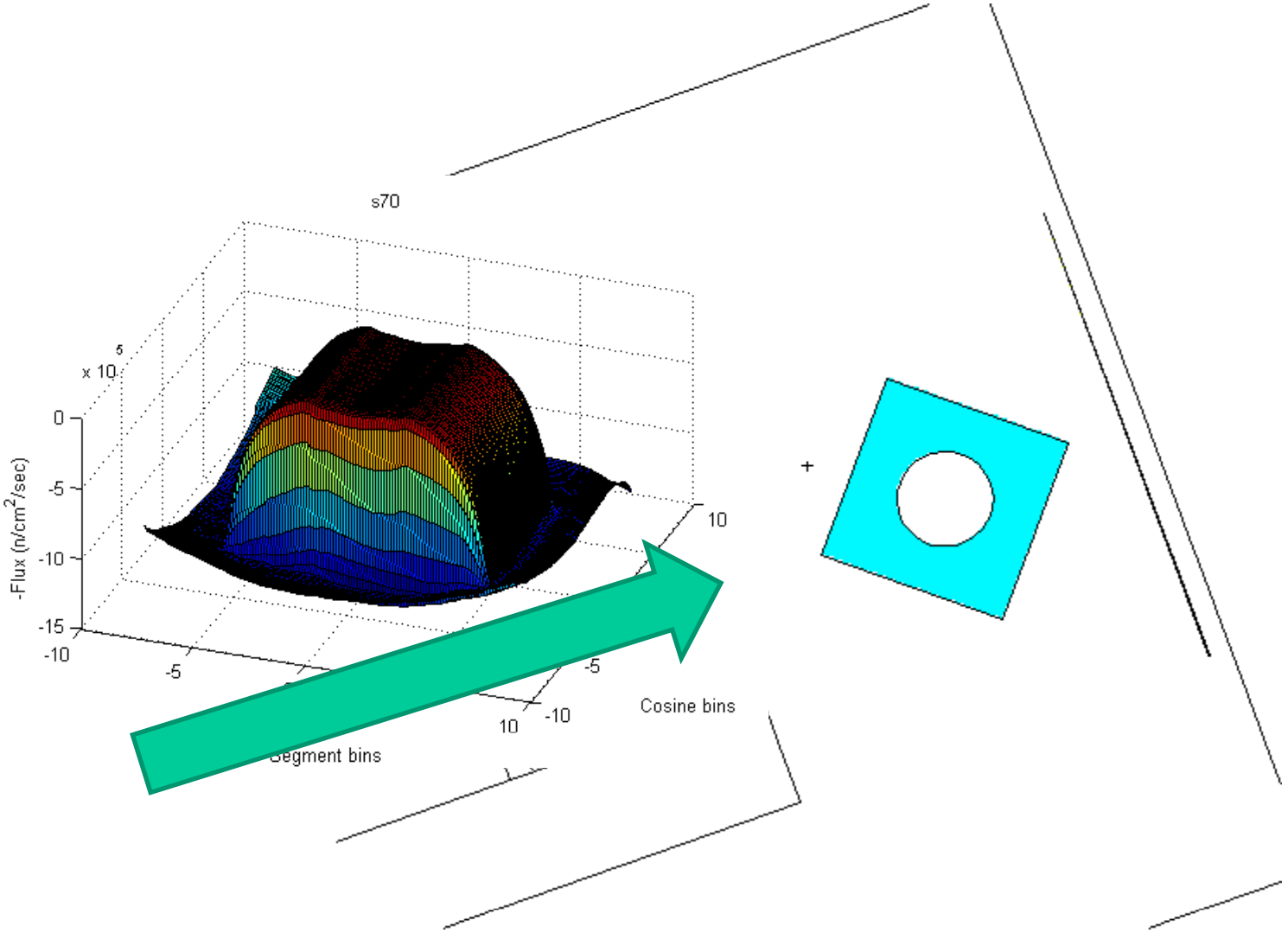

s20
x 10^5
0
-5
-10
-15
-Flux (n/cm^2/sec)
-10
-5
10
Segment bins
-10
-5
10
Cosine bins

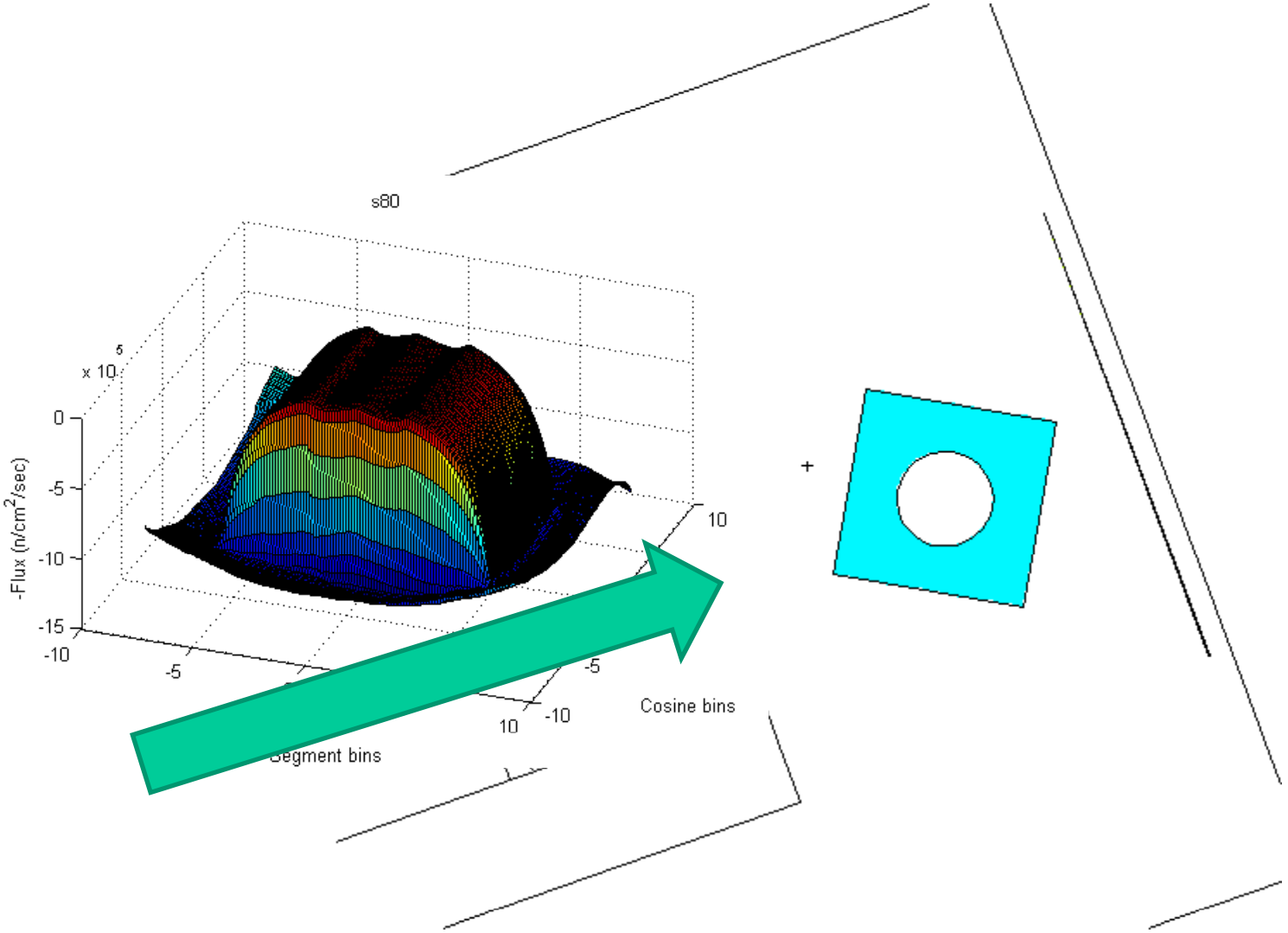

s30
x 10^5
0
-5
-10
-15
-Flux (n/cm^2/sec)
-10
-5
10
Segment bins
-10
-5
10
Cosine bins


s40
x 10^5
0
-5
-10
-15
-Flux (n/cm^2/sec)
-10
-5
10
-10
-5
10
Segment bins
Cosine bins

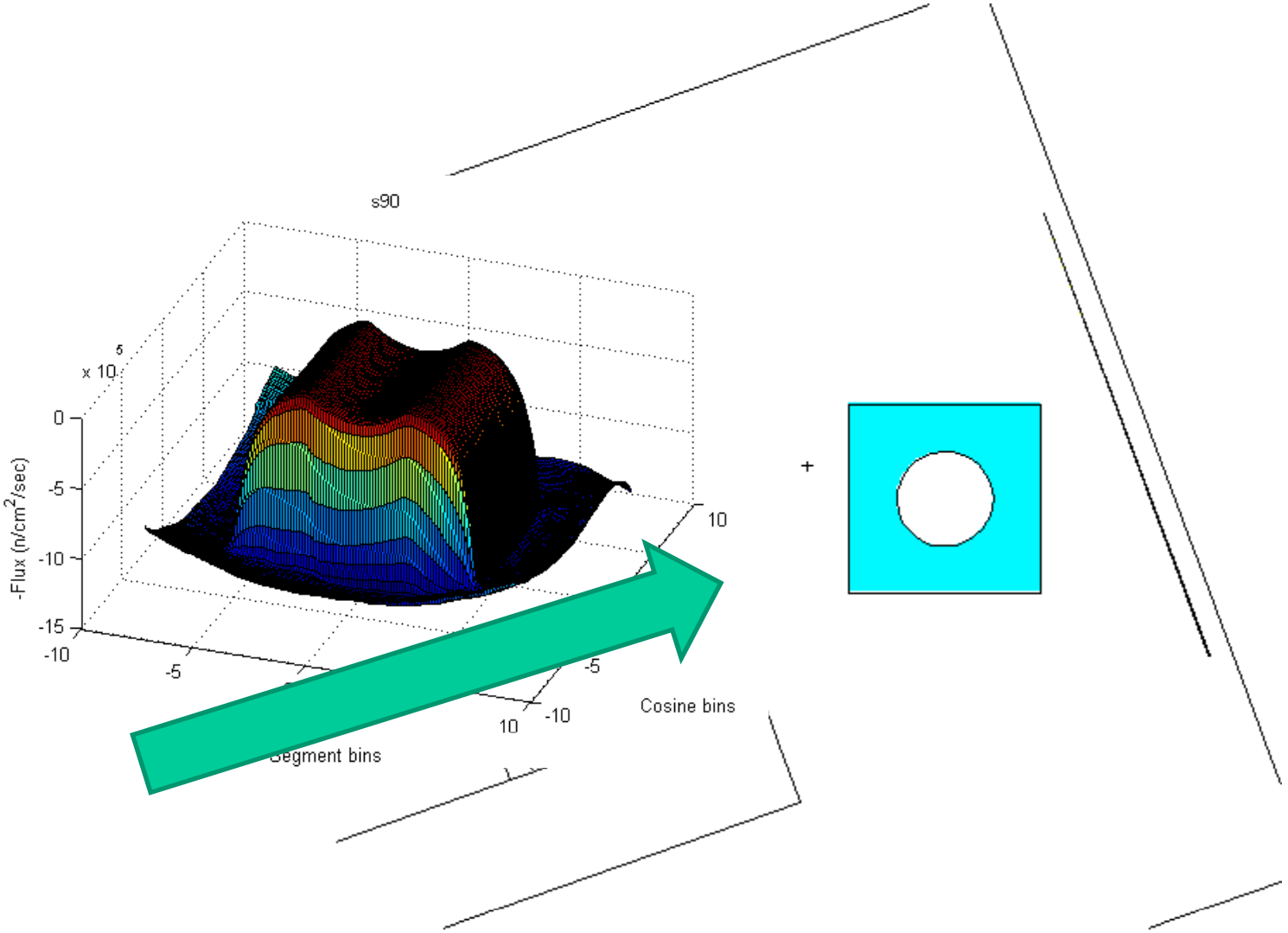

s50
x 10^5
0
-5
-10
-15
-Flux (n/cm^2/sec)
-10
-5
10
Segment bins
-10
-5
10
Cosine bins


s60
x 10^5
0
-5
-10
-15
-Flux (n/cm^2/sec)
-10
-5
10
Segment bins
-10
-5
10
Cosine bins
+


s70
x 10^5
0
-5
-10
-15
-Flux (n/cm^2/sec)
-10
-5
10
Segment bins
10
-10
-5
Cosine bins
+


s80
x 10^5
0
-5
-10
-15
-Flux (n/cm^2/sec)
-10
-5
10
Segment bins
-10
-5
10
Cosine bins
+

MCNP simulation and tomography



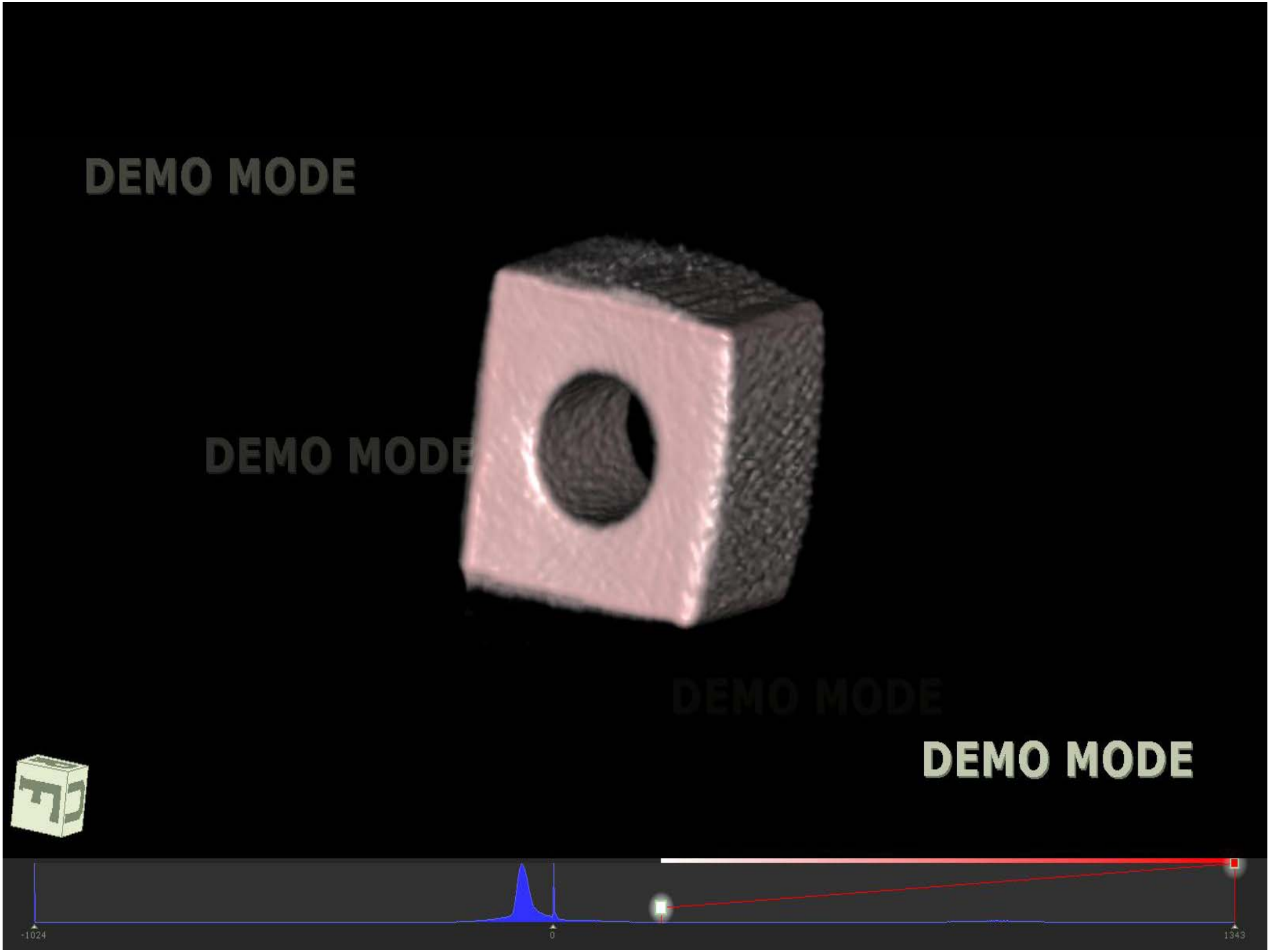

DEMO MODE
DEMO MODE
DEMO MODE
DEMO MODE
-1024
0
1343

Image Reconstruction

Image Reconstruction

: Scanned 2D images (projection) 

Volume information contained images (voxel or slice)

COBRA Code

filtered back-projection algorithm(Feldkamp) or Exxim's special algorithm (SAMARA, extended view technology).

Advantage of COBRA Code

– Fast reconstruction processing times using GPU technology (360 projections, 512 voxels slice with i7 quad Core 2.2ghz 12gb Memory, Nvidia GTX 480 : ~ 10 Second)

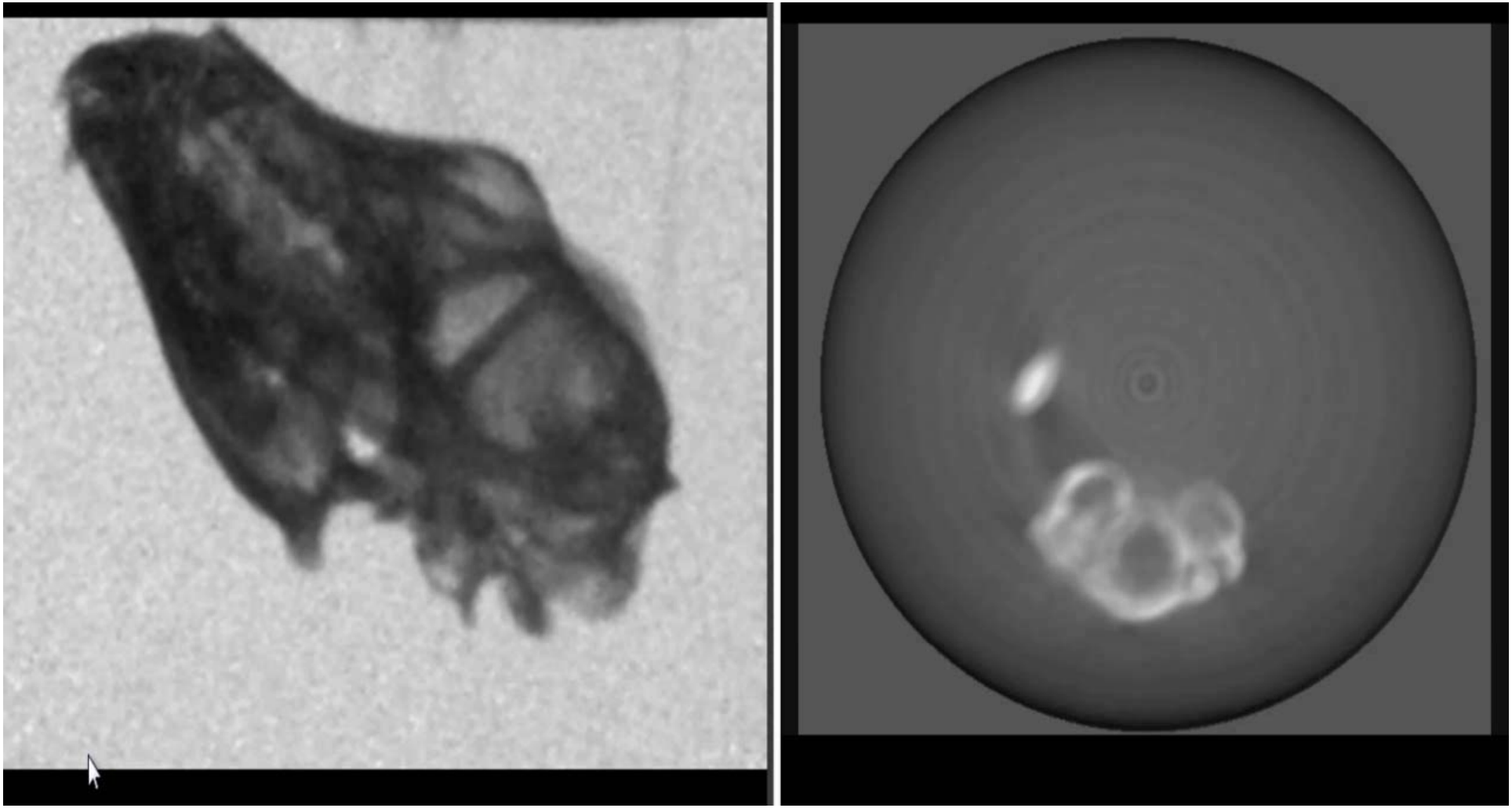
Disadvantage of COBRA Code

– You have to pay (Code – 5K , viewer -6K)

Reconstruction

Scanned 2D images (projection)

Volume information contained images (voxel or slice)



Volume Rendering

Volume Rendering Process

:Volume information contained images (voxel)

 One 3D data set

3D Slicer

Scientific visualization and image analysis software package

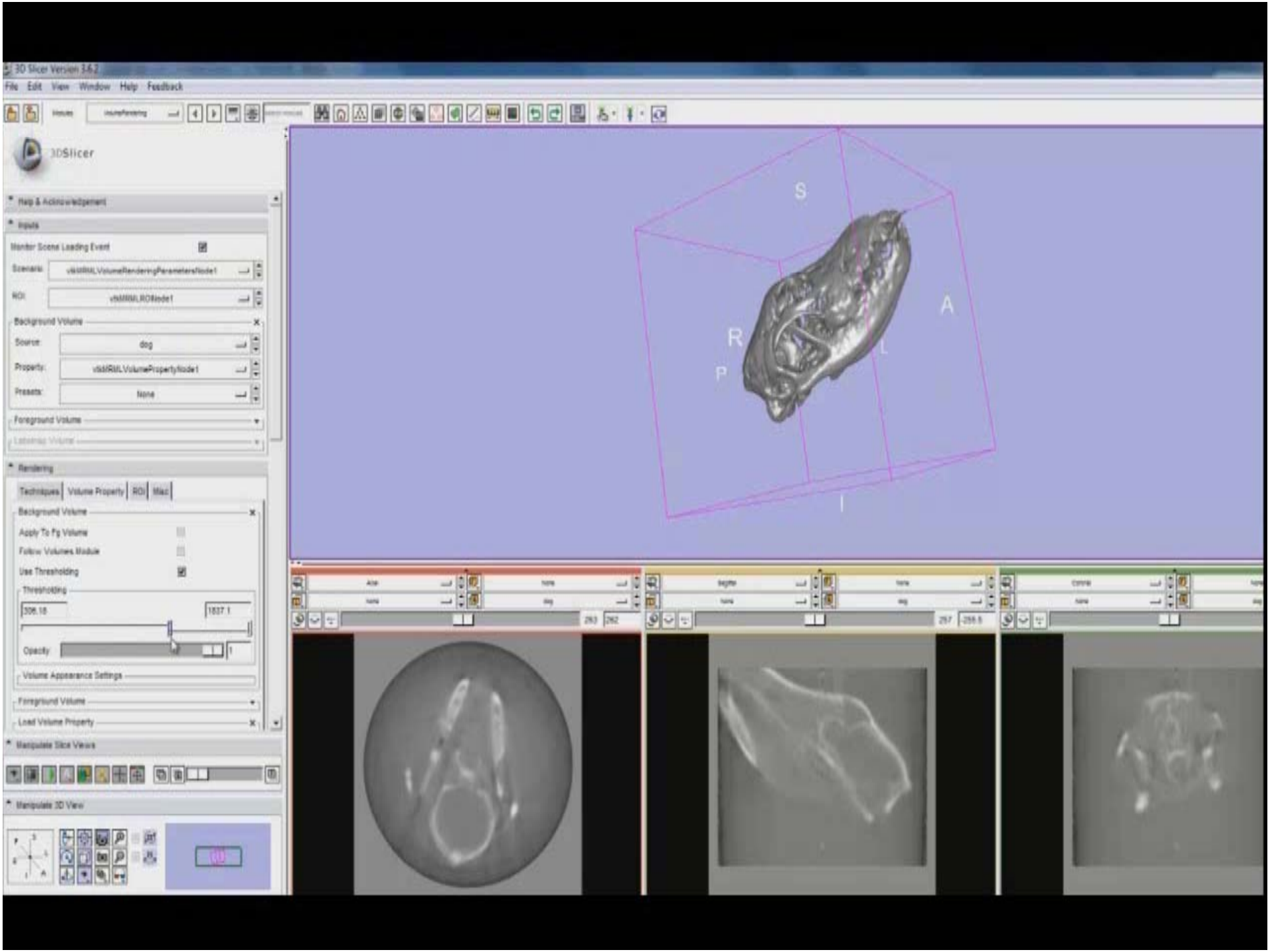
Advantage of 3D Slicer

– Free, GPU technology (Voxel Uploading and Rendering time with i7 quad Core 2.2ghz 12gb Memory, Nvidia GTX 480 : ~ 10 Second)

User friendly interface (Society can access easily)

Disadvantage of 3D Slicer

– Most powerful scientific visualization and image analysis software package


3D Slicer Version 3.6.2
File Edit View Window Help Feedback
3DSlicer
Help & Acknowledgement
Inputs
Monitor Scene Loading Event
Background Volume
Source:
dog
Property:
Presets:
None
Foreground Volume
Rendering
Techniques
Volume Property
ROI
Misc
Background Volume
Apply To Fg Volume
Follow Volumes Module
Use Thresholding
Thresholding
306.18
1837.1
Opacity
Volume Appearance Settings
Foreground Volume
Load Volume Property
Manipulate Slice Views
Manipulate 3D View
S
A
R
P
I

Experimental Tomography Example: Dog head, Timing and Results

Full Scanning time

full degree (360 degree) in one angle step with beam exposure time 5 sec, data correcting time 2 sec, and table rotation time .5 sec per angle, and dead time .5sec : total scanning time ~50 Min

(Good thing: All scanning process is automatic – one touch mouse click)

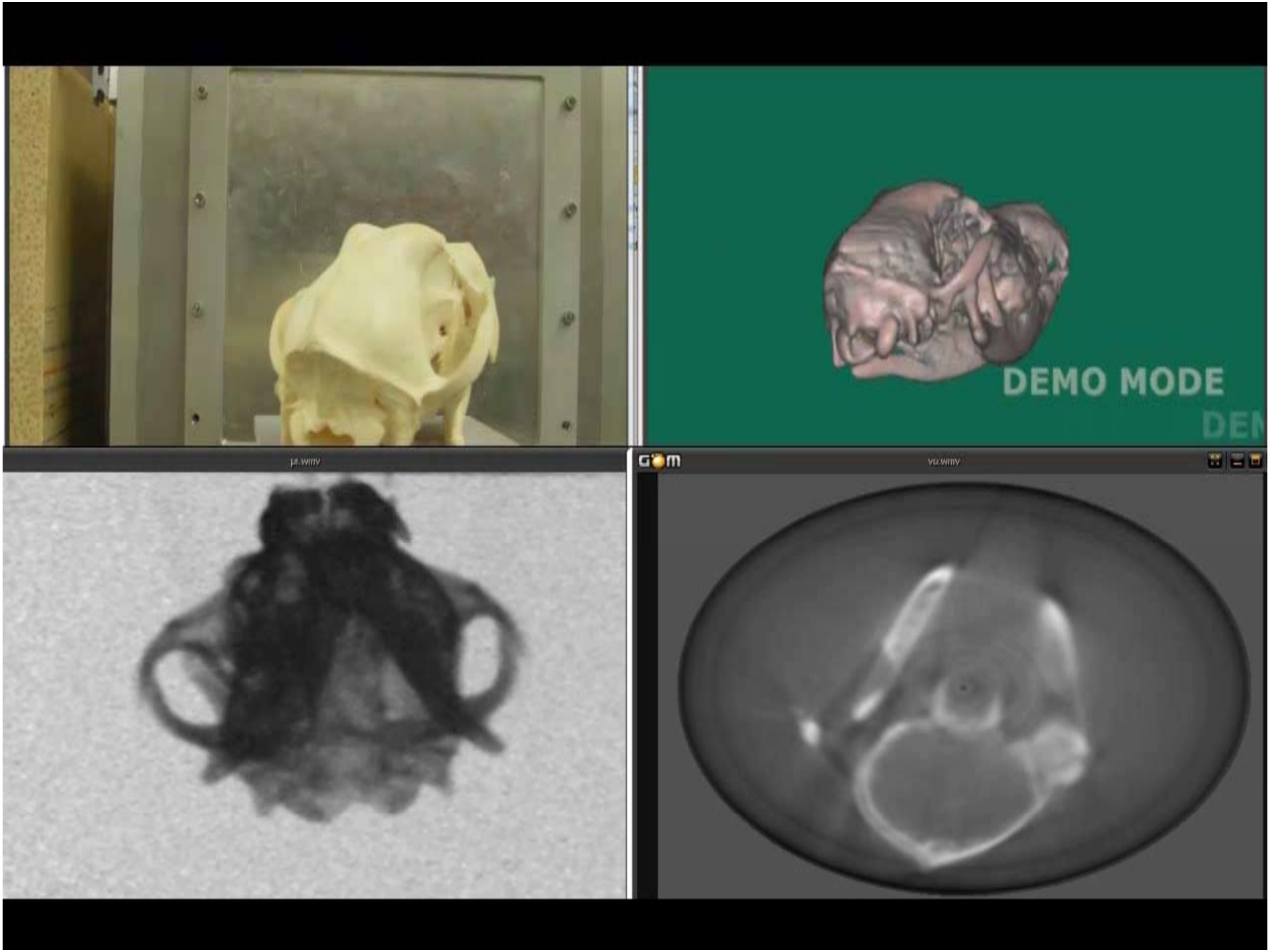
Code coding time: ~1 hour

Reconstruction Computer time (GPU): 10 sec

Volume Rendering Computer time: 15 sec

Color Mapping: .5 hour

Total 3D Tomography time per one sample : ~ 2.5 hour


DEMO MODE
GOM

Future possibility and challenge

- Connection with other area and construction of future cyber infrastructure. (~100 Thounds Samples around Indiana St : Scanned Time is matter
- Optimising neutron detection and image processing
- 3D, 4D (+time): Geant4 has capability of making time dependent and reverse Tomography

Summary

- Traditional image technics
- Current beam station and scanning system
- Simulation and experimental tomography
- Future possibility and challenge