パルス中性子透過分光撮像法のための カメラ検出器の開発

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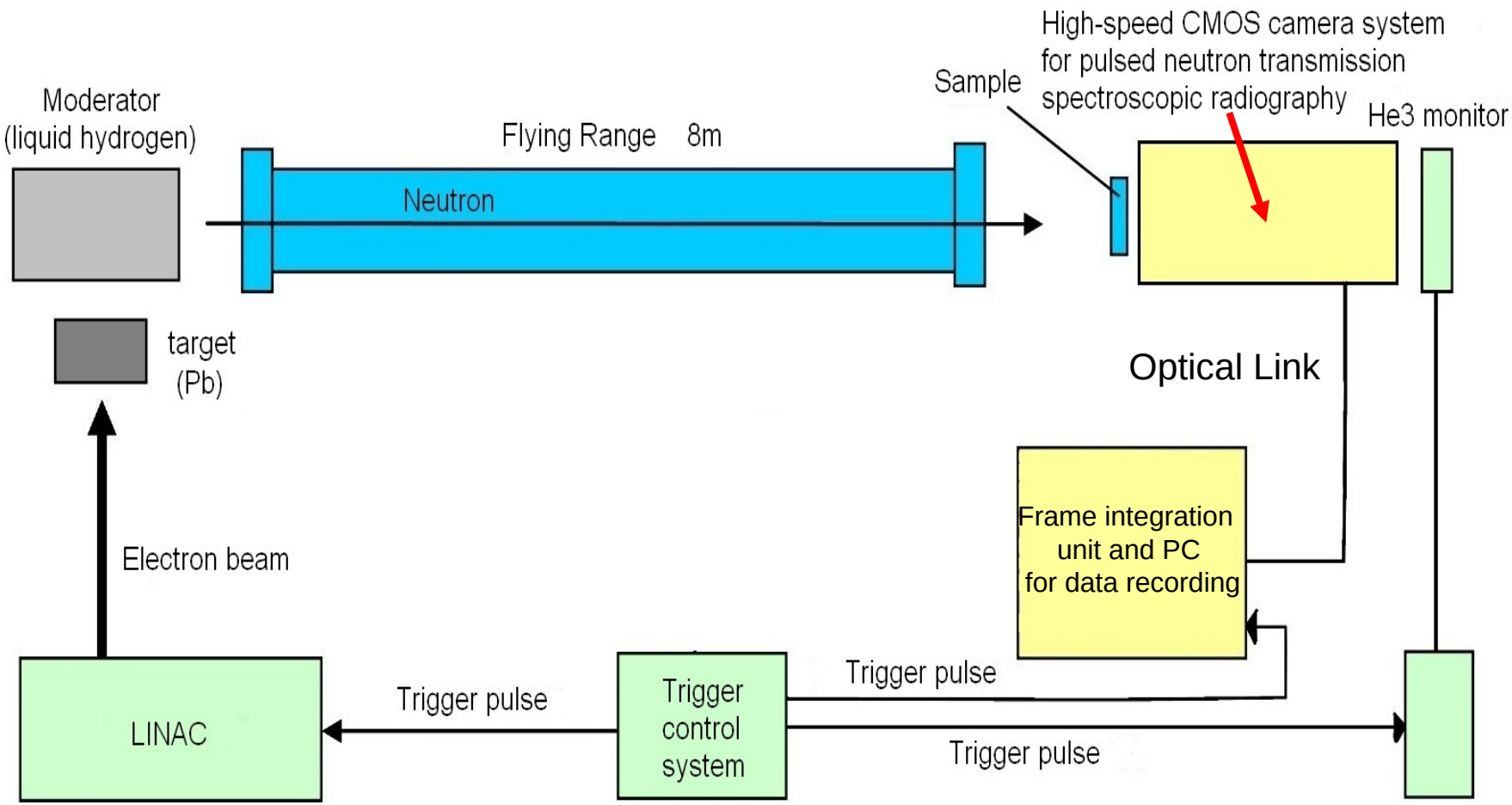
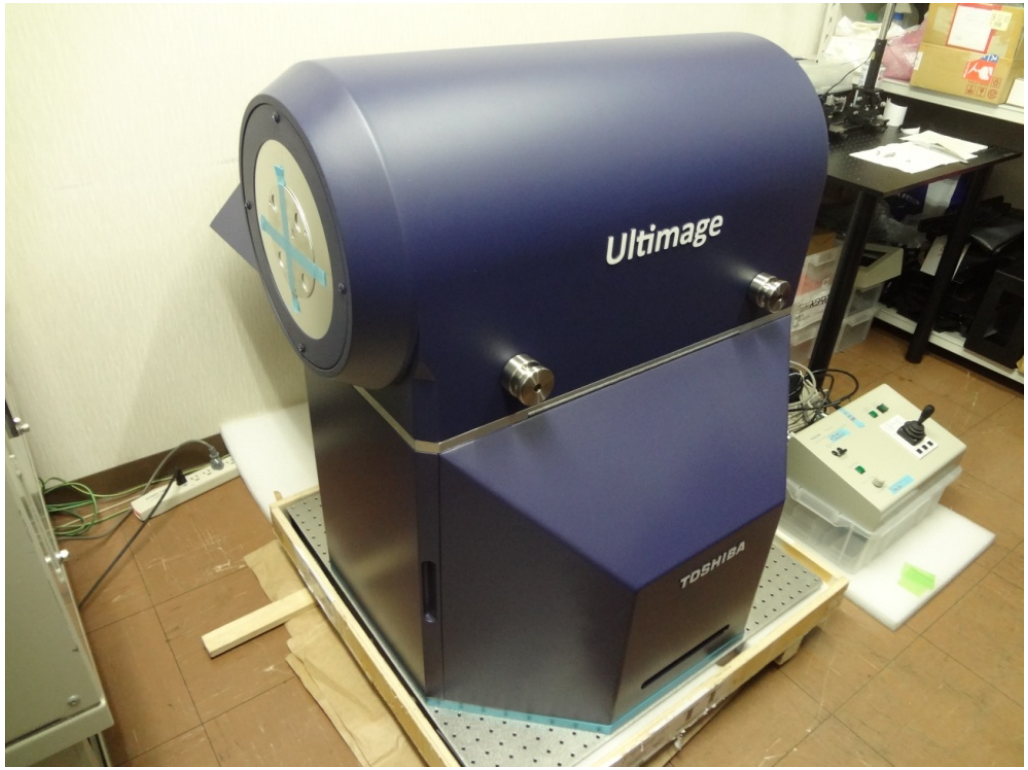
平成２６年度　中性子イメージング専門研究会　１２月２６日

Pulsed Neutron Transmission Spectroscopic Radiography System at HUNS



New Image Intensifier for Pulsed Neutron Radiography



TCN9100B
(Made by Toshiba)

View field: 9, 7, 5.5 inch

Input: B_4C
B-10 >99.7%
Output: Y_2SiO_5:Ce
Decay 5μs
Gating function

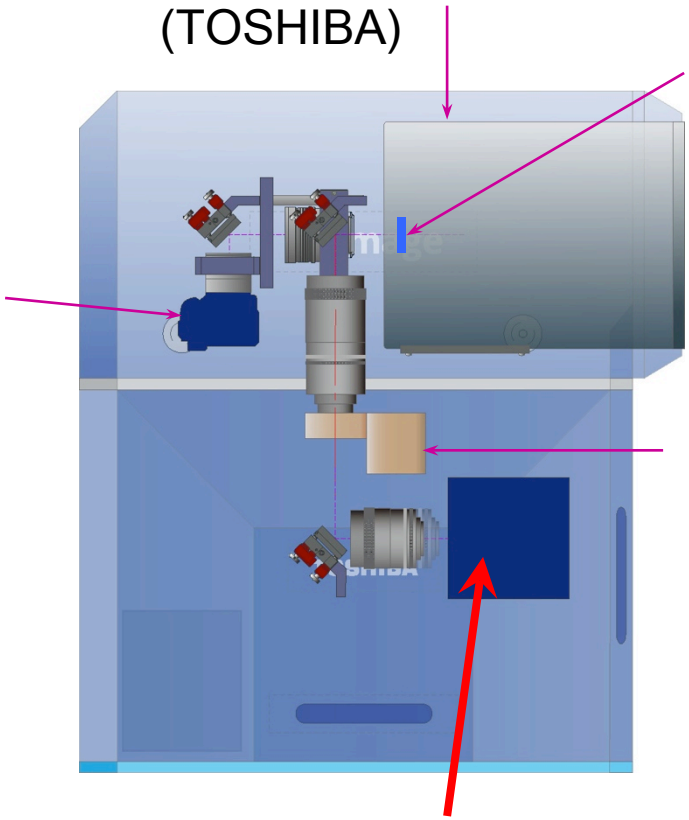
Spatial Resolution:
< 30 μm

Configuration of Neutron Image Intensifier and Cameras

Neutron color image intensifier
Ultimage TCN9100B nαb
(TOSHIBA)

Short afterglow
phosphor
(Y_2SiO_5:Ce)

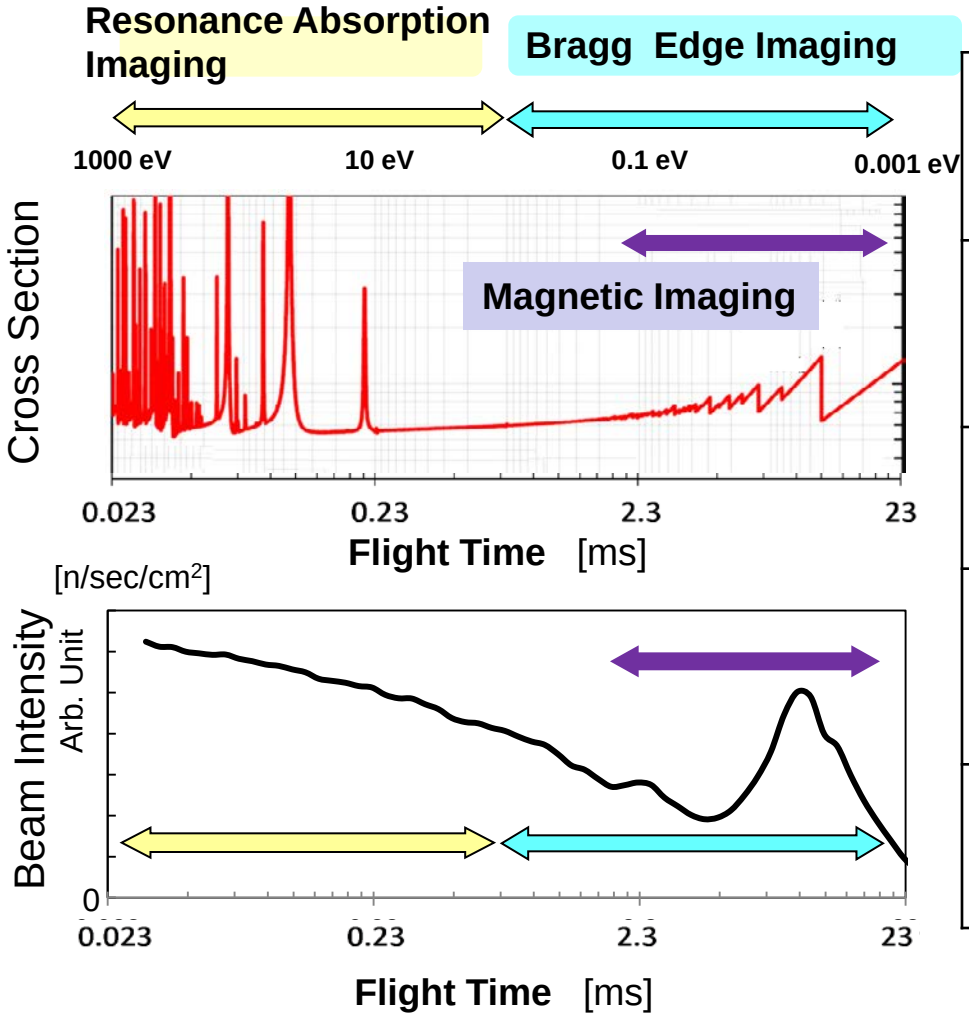
High resolution CMOS
D800E (Nikon)
max 7360x4912 pixels



High-speed gated image
intensifier unit
C9547-02 MOD
Short afterglow
phosphor P46
(HAMAMATSU)

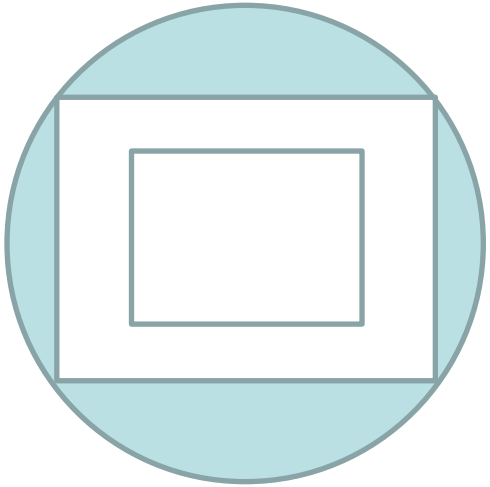
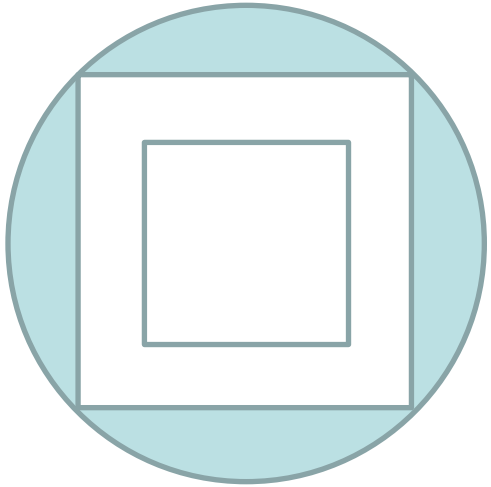
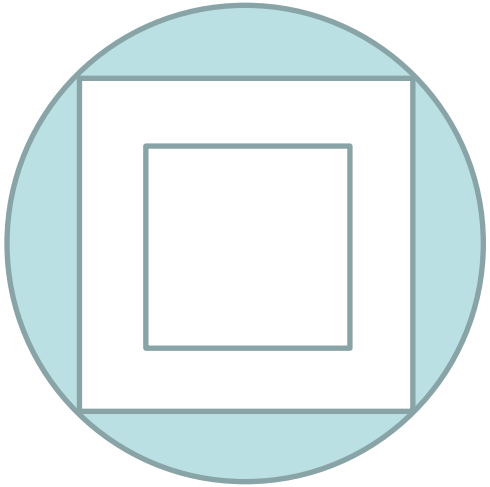
High-frame-rate Camera MEMRECAM ST-821-HX
(NAC Image Technology)

Time Resolution, View Field and Spatial Resolution for Three Applications

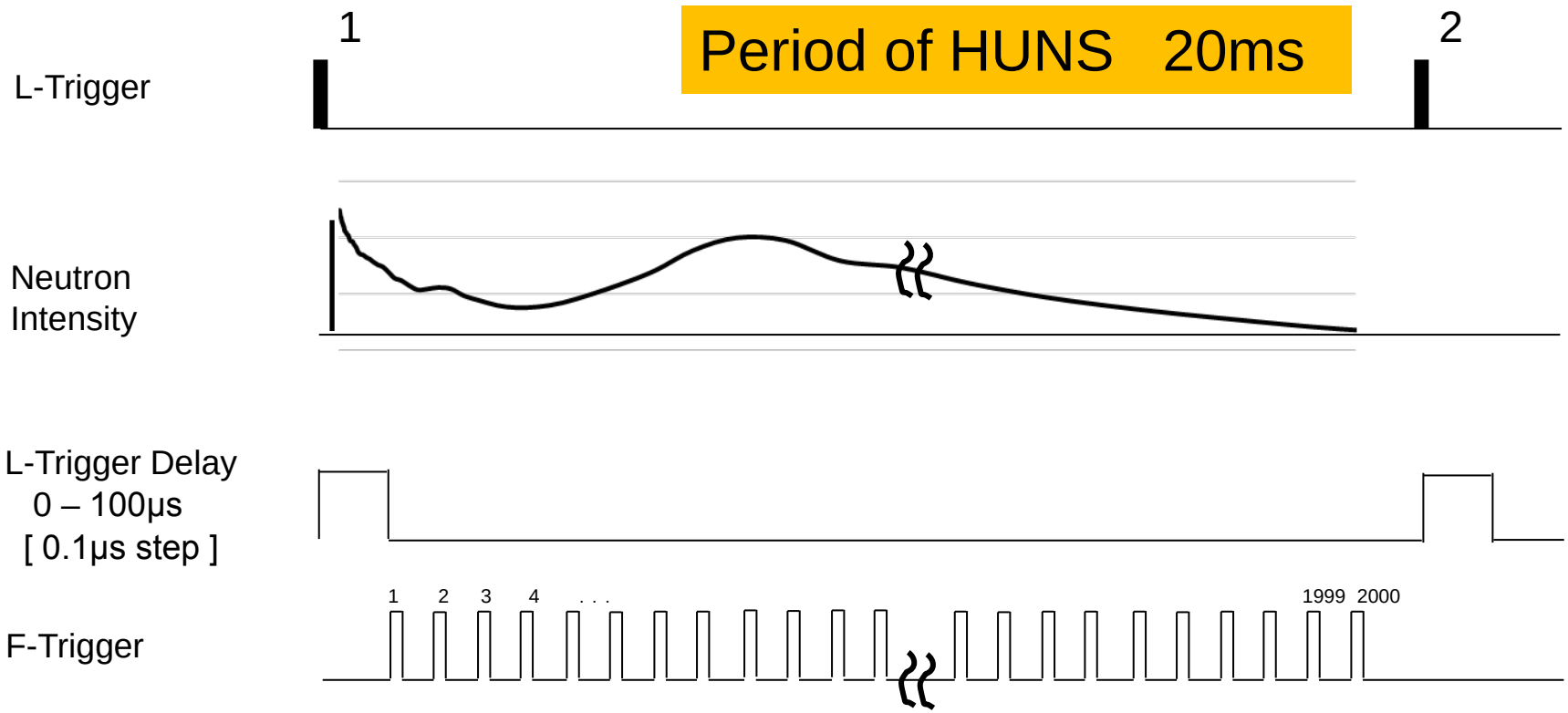


Mode	Resonance Absorption Imaging	Bragg Edge Imaging	Magnetic Imaging
E	1keV-1eV	Low <1eV	Low <0.1eV
ΔT	10μs	33μs	100μs
Area [mm]	183× 137 112× 84	162× 162 99× 99	162× 162 99× 99
ΔX	572μm 349μm	316μm 193μm	169μm 103μm

View Field, Pixel Number and Pixel Resolution

100,000 fps (10μs)	30,000 fps (33.3μs)	10,000 fps (100μs)
		
320 x 240 pixel	512 x 512 pixel	960 x 960 pixel
9: 183x 137 mm [572μm] 5.5: 112 x 84 mm [349μm]	162 x 162 mm [316μm] 99 x 99 mm [193μm]	162 x 162 mm [169μm] 99 x 99 mm [103μm]

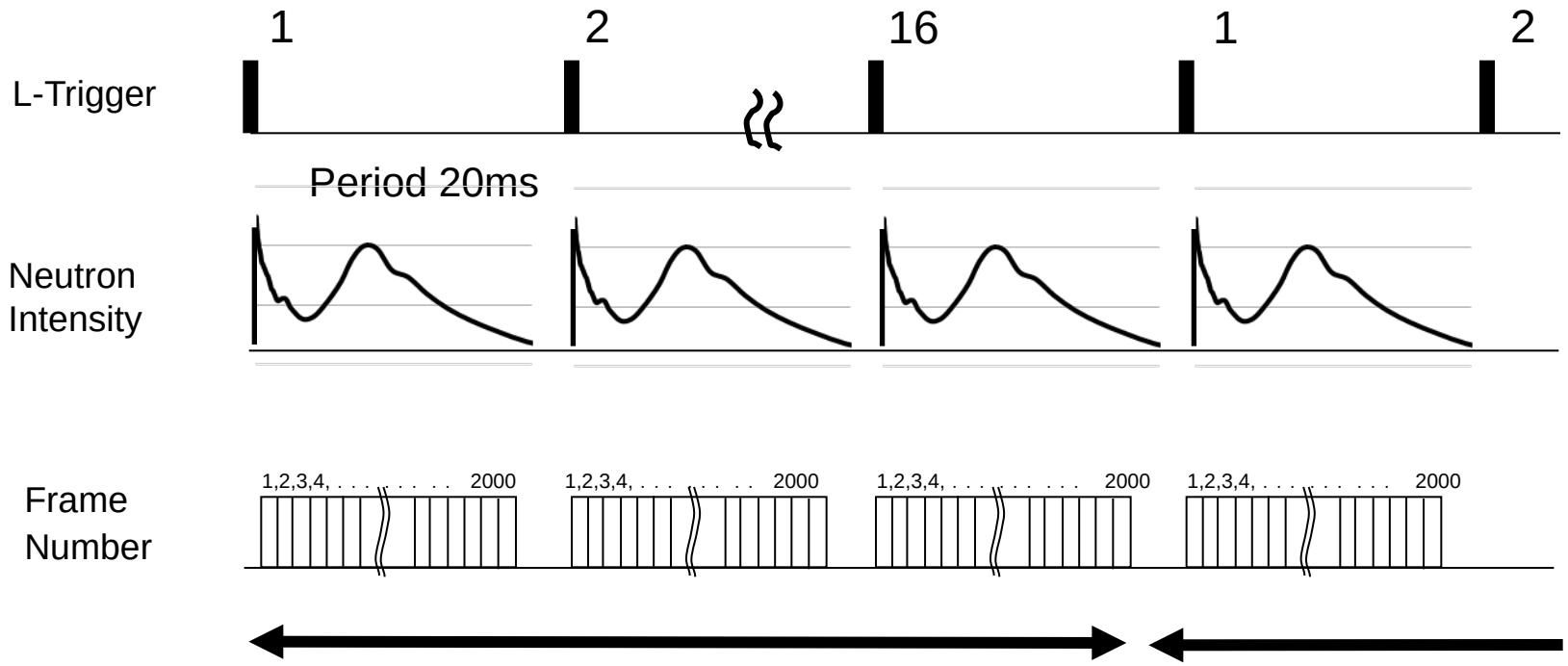
Frame Configuration



In case of 100 kfps（frame period 10μs）

320 x 240 pixel 2,000 frames/pulse

Seamless Accumulation Function



In case of 100 kfps（frame period 10μs）

320 x240 pixel , 2,000 frames/pulse

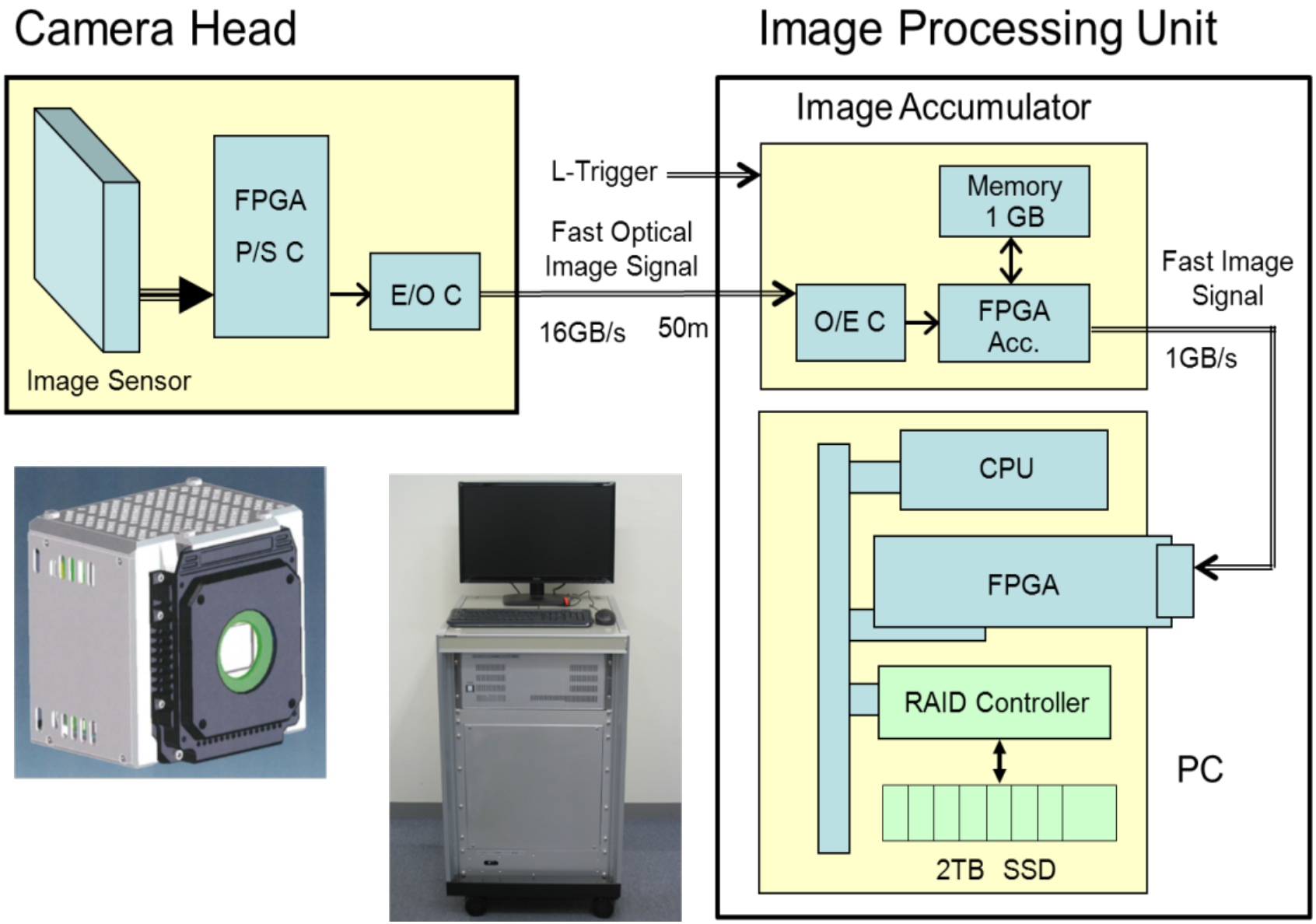
Pulse Number of Accumulation : N_A=16, 64, 256, 1024, 4096

Accumulated Data per each frame 12bit x N_A ＝ 16 bit ～ 24bit

Data File : 2000 frame x (16 bit ～ 24 bit)

Seamless Accumulation

High-Frame-Rate Camera System



Accumulation Time and Recording Period

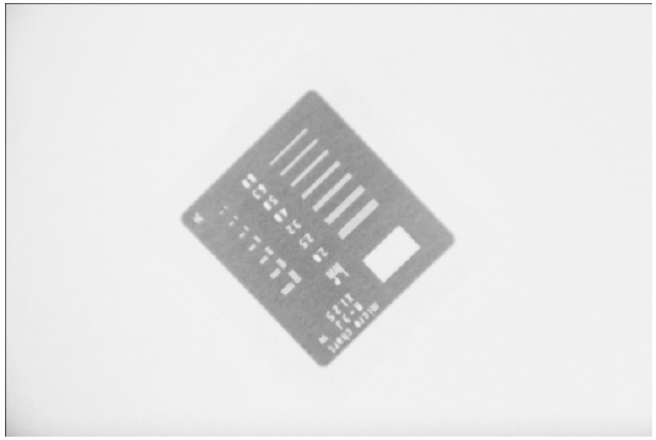
Acc. Time	Data Length	Acc. Period		320x240 pixel, 100k fps (10us), 2000frame/pulse				
				File Volume	Data Rate		Recording Period for 2TByte Memory	
[pulse]	[bit]	[s]	[min]	[Gbit]	[Mbit/s]	[MByte/s]	[min]	[hr]
16	16	**0.64**	0.01	4.76	**7617**	952	**37**	0.6
64	18	2.56	0.04	5.36	2142	268	131	2.3
256	20	10.24	0.17	5.95	595	74	470	7.8
1024	22	40.96	0.68	6.55	164	20	1709	28.5
4096	24	163.84	**2.73**	7.14	45	**5.6**	6265	**104.4**

Accumulation Time and Recording Period

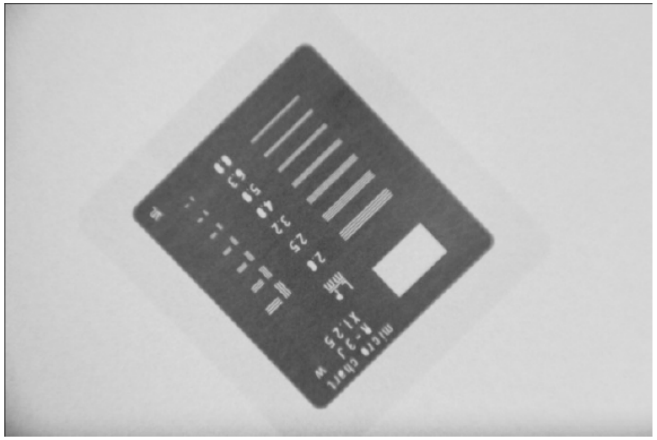
Accumula-tion Times	Data Length	Accumula-tion Period	100 kfps (10us, 2000f)			30 kfps (33.3us, 600f)			10 kfps (100us, 200f)		
			File Volume	Data Transfer Rate	Recording Time	File Volume	Data Transfer Rate	Recording Time	File Volume	Data Transfer Rate	Recording Time
[Pulse]	[bit]	[s]	[Gbit]	[MByte/s]	[hr]	[Gbit]	[MByte/s]	[hr]	[Gbit]	[MByte/s]	[hr]
16	16	0.32	2.38	952.15	0.61	2.34	937.50	0.62	2.75	1098.63	0.53
64	18	1.28	2.68	267.79	2.18	2.64	263.67	2.21	3.09	308.99	1.89
256	20	5.12	2.98	74.39	7.83	2.93	73.24	7.95	3.43	85.83	6.79
1024	22	20.48	3.27	20.46	28.48	3.22	20.14	28.92	3.78	23.60	24.68
4096	24	81.92	3.57	5.58	104.42	3.52	5.49	106.05	4.12	6.44	90.49

X-Ray Test with Neutron Image Intensifier and Nikon D800E

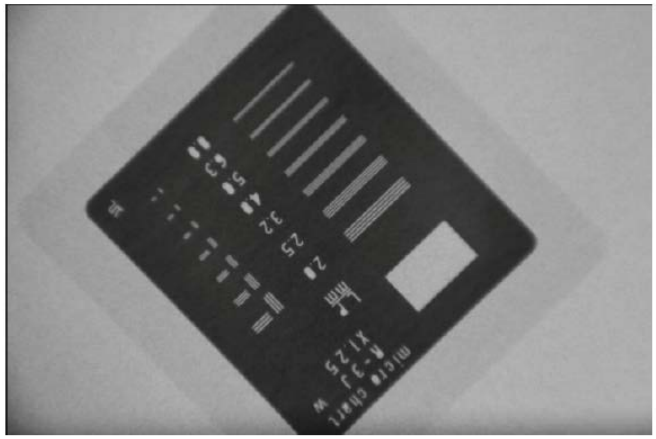
X ray



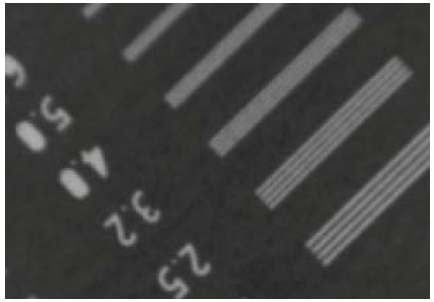
9 inch



7 inch



5.5 inch



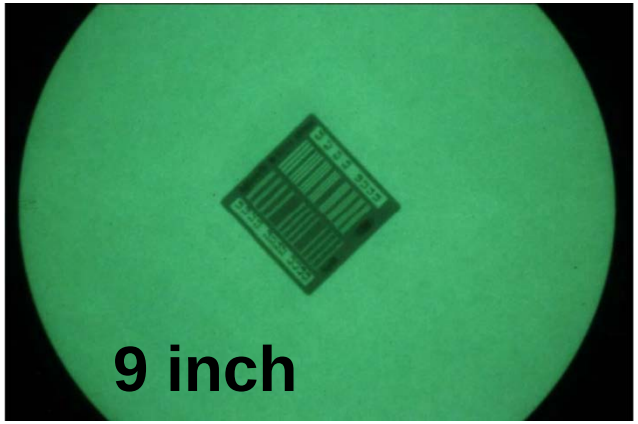
5 LP/mm

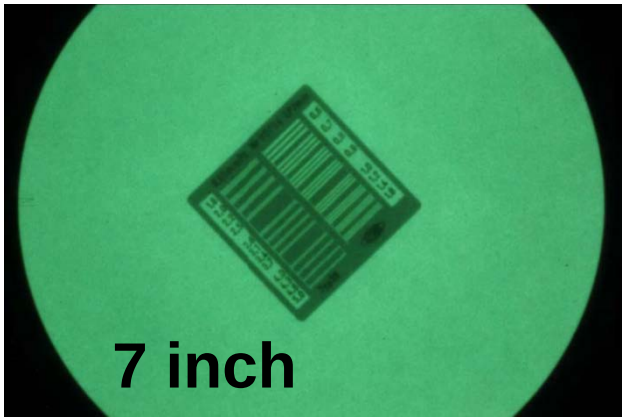
X-ray source
8μm, 50 kV,
160μA
Camera D800E
ISO100,
shutter speed 10s

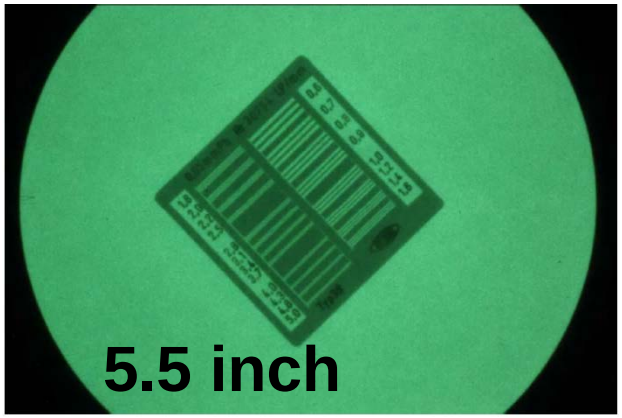
X-Ray Test with Neutron Image Intensifier, Photon Image Intensifier and Nikon D800E

X-Ray High Resolution Image by Nikon D800E

X ray

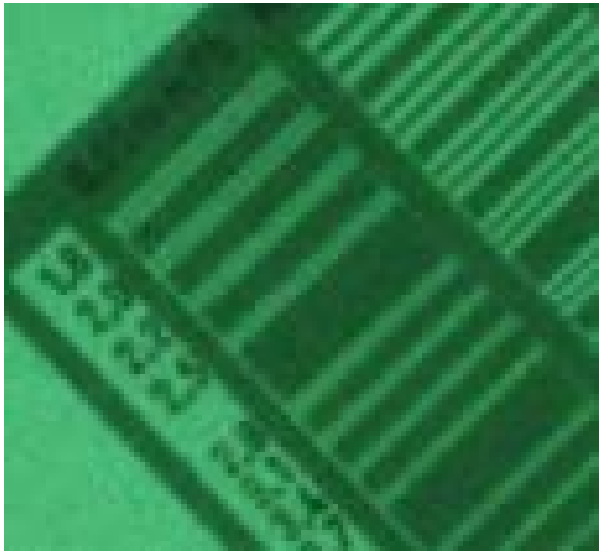






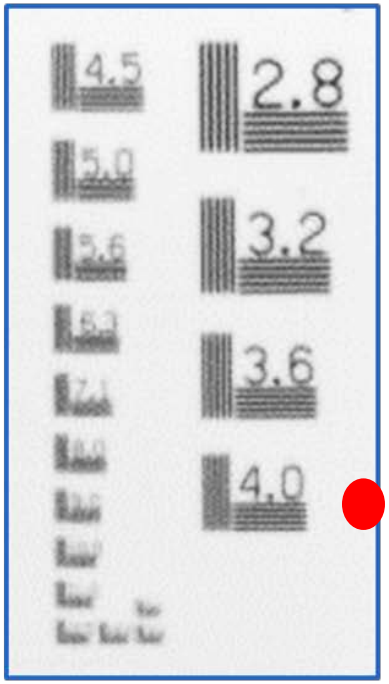
Photon Image Intensifier
C9547-02MOD-06

Input : GaAsP (280 – 720 nm)
Output : P46
480 – 670 nm, peak 530 nm
Decay time : ～300 ns (10%)
Resolution : 450 TV line

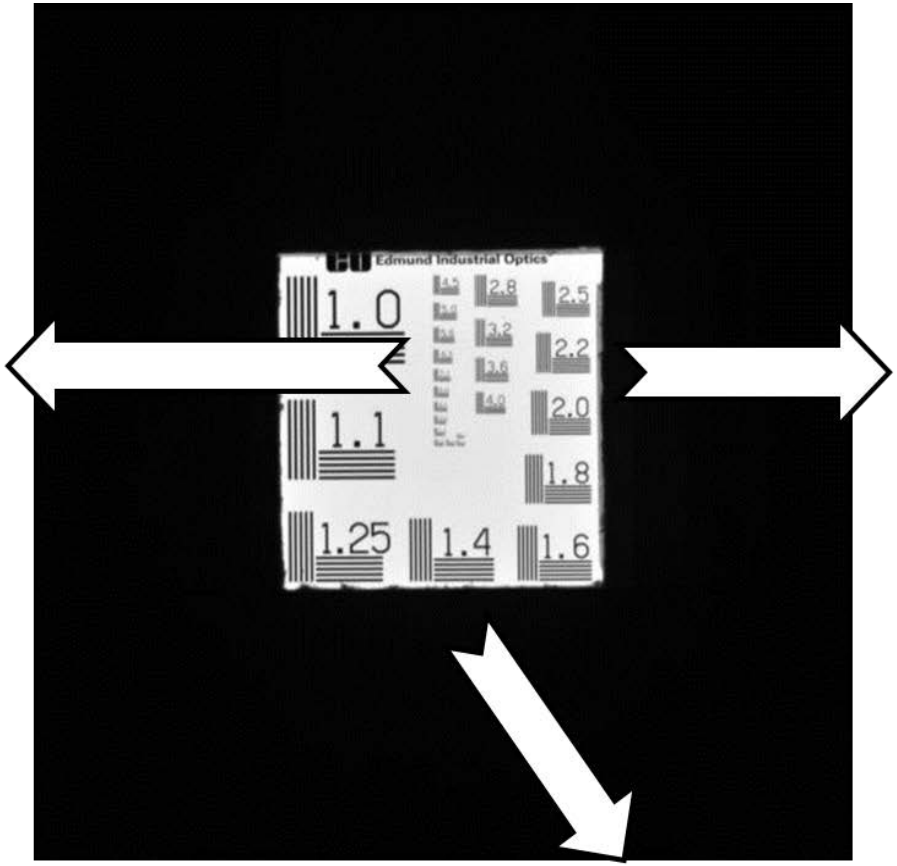


Spatial resolution of high-frame-camera MEMRECAM ST-821-HX

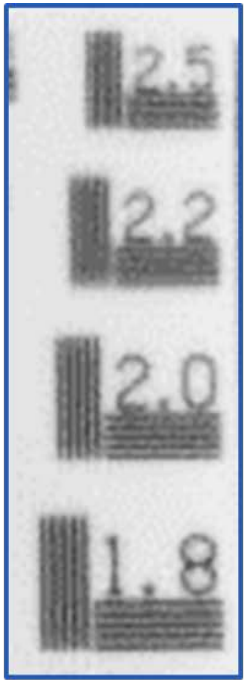
Optical



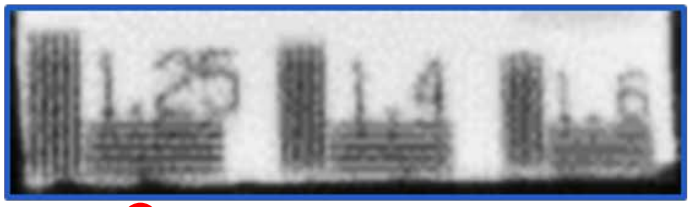
(d) 10 kfps
960 x 960 pixel



(a) 960 x 960 pixel

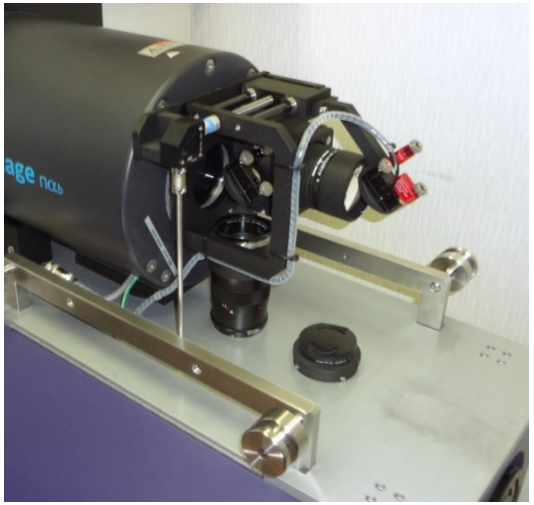


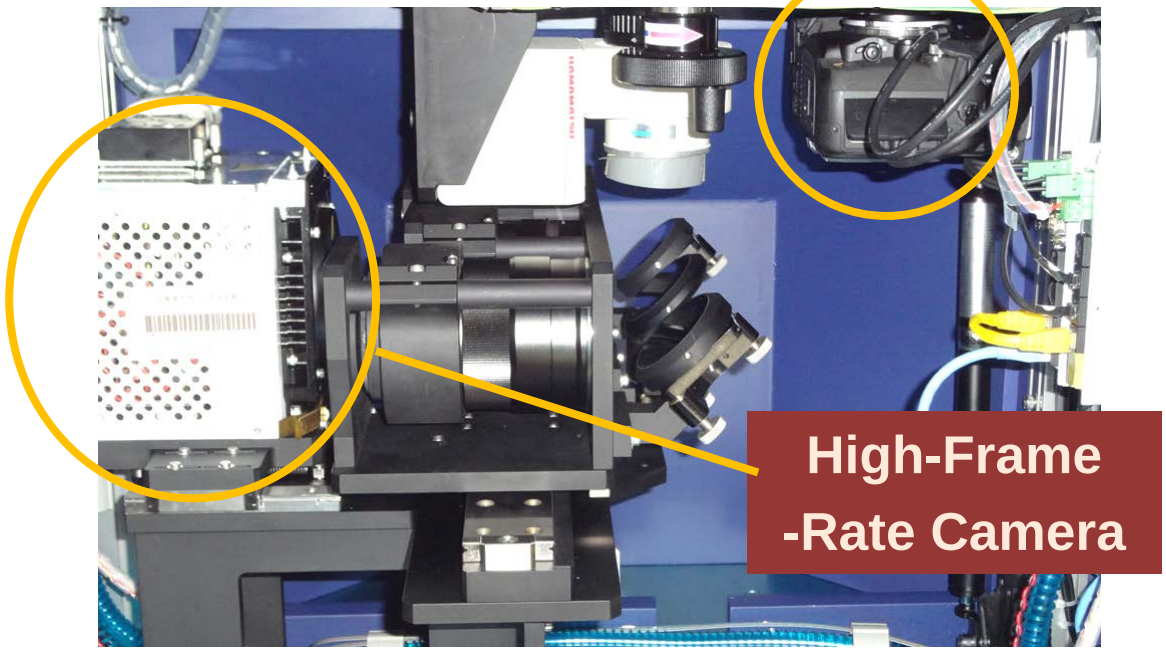
(c) 30 kfps
512 x 512 pixel



(b) 100 kfps 320 x 240 pixel

X-Ray Test with Neutron Image Intensifier, Photon Image Intensifier and High-Frame-Rate Camera

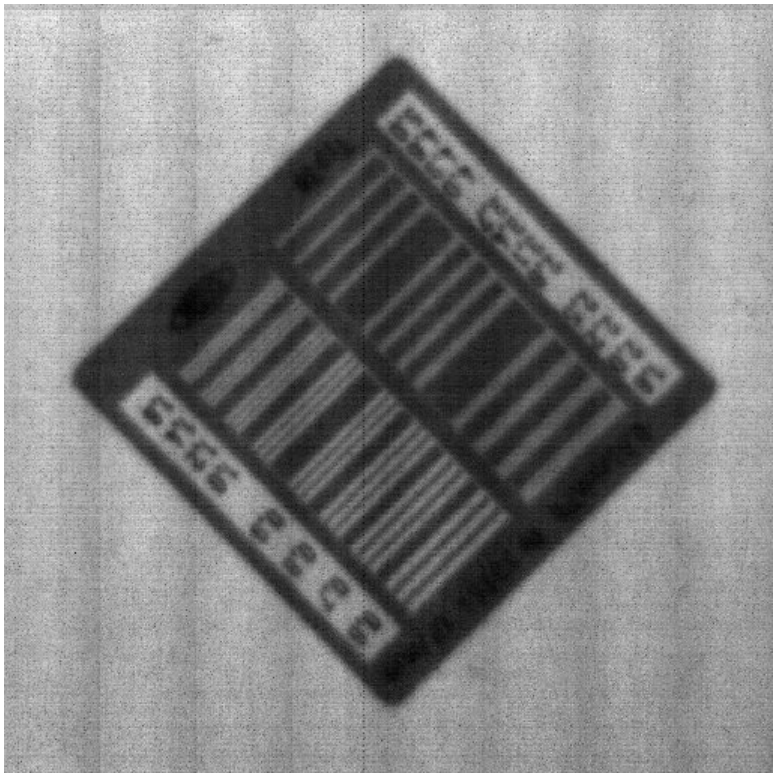


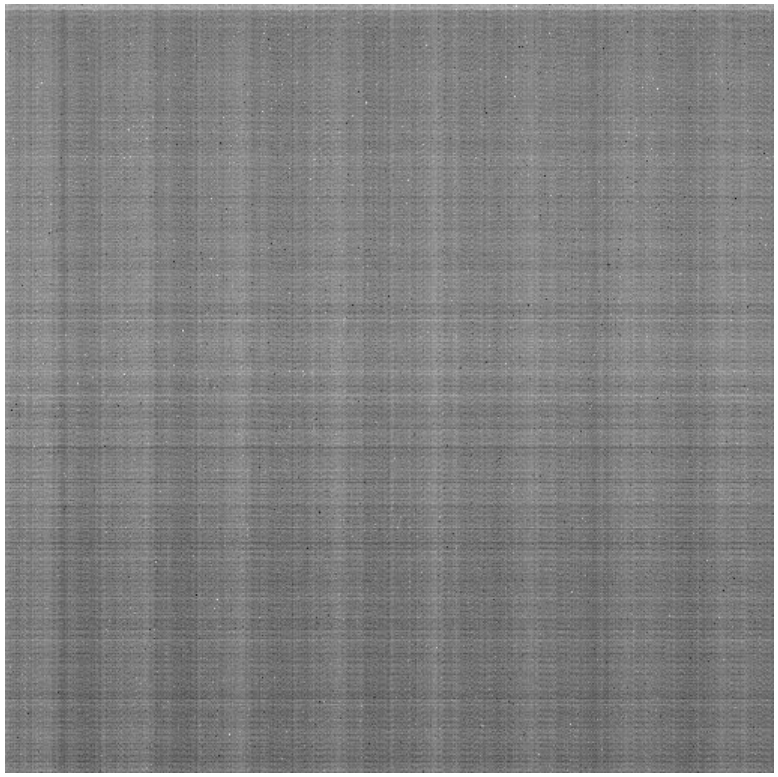


Software Image Processing

X ray

Test object image





① MCP gate On

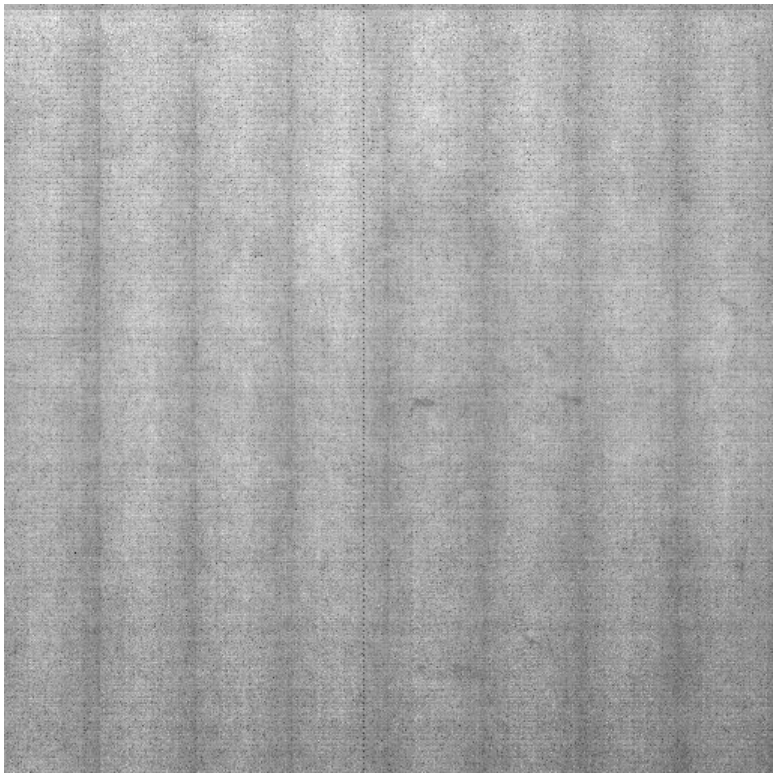
② MCP gate Off

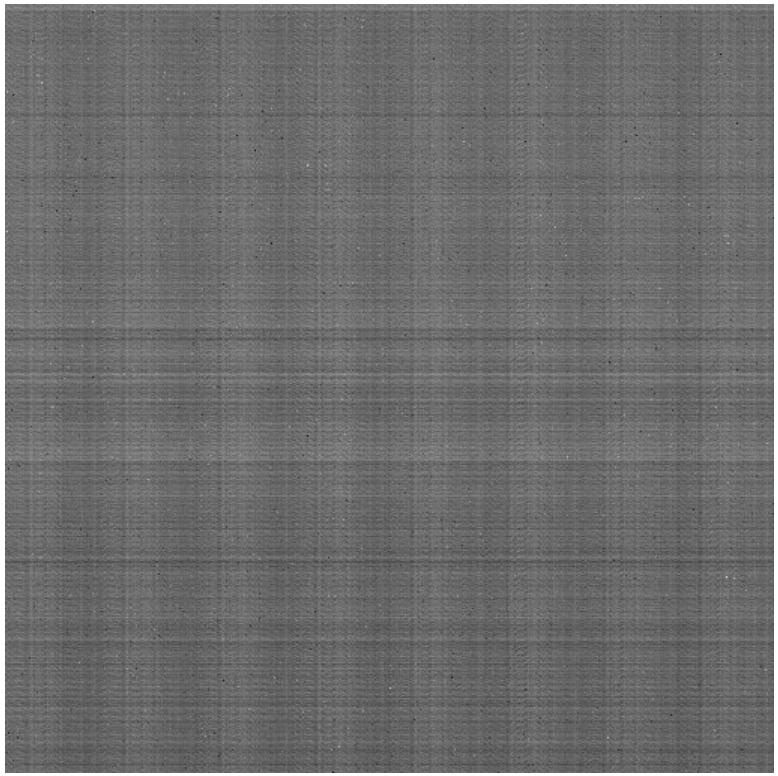
①－②　Offset Subtraction

Software Image Processing

X ray

Shading image





③ MCP gate On

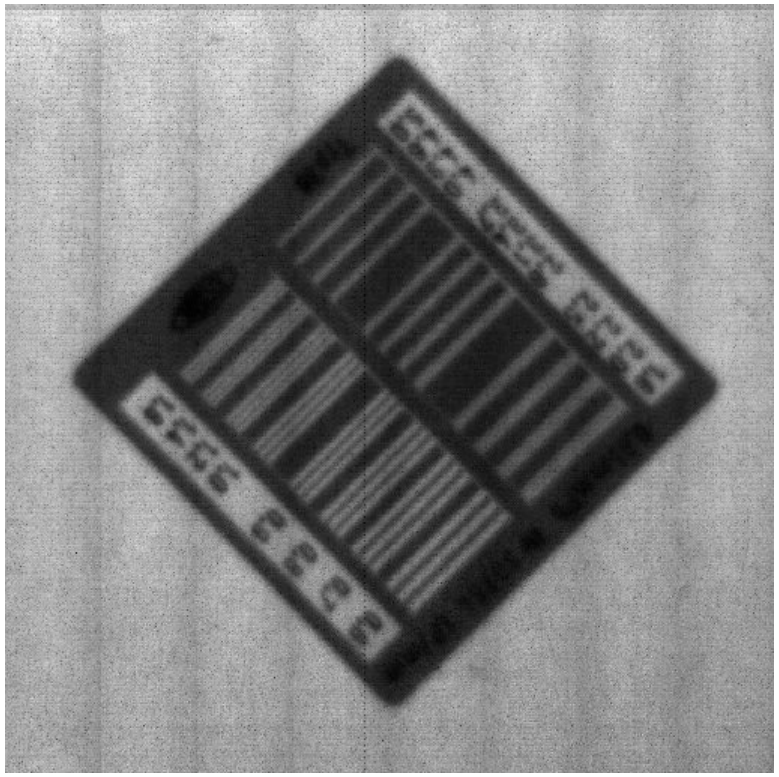
④ MCP gate Off

③－④ Offset Subtraction

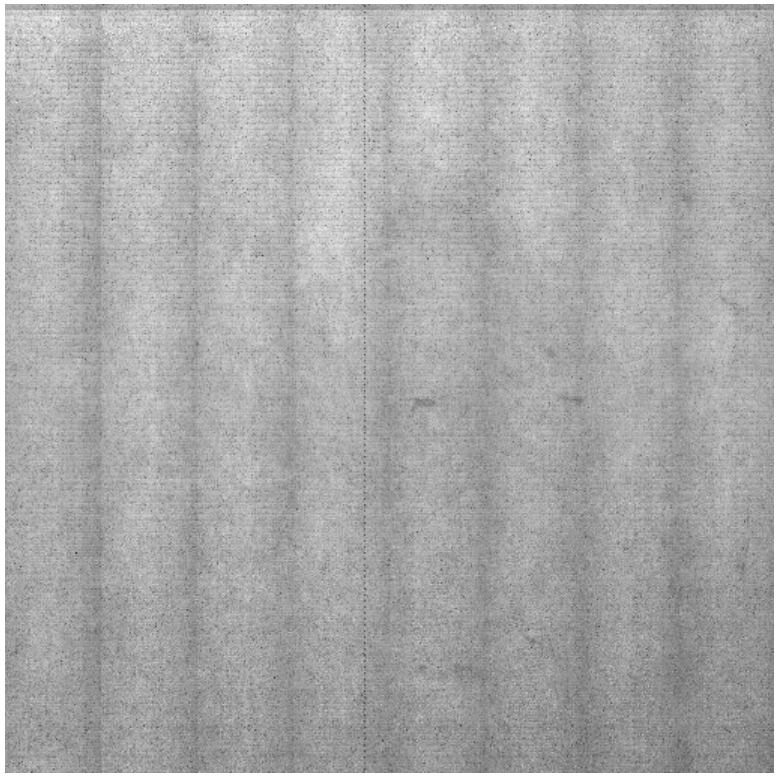
Software Image Processing

X ray

Test object image



Shading image



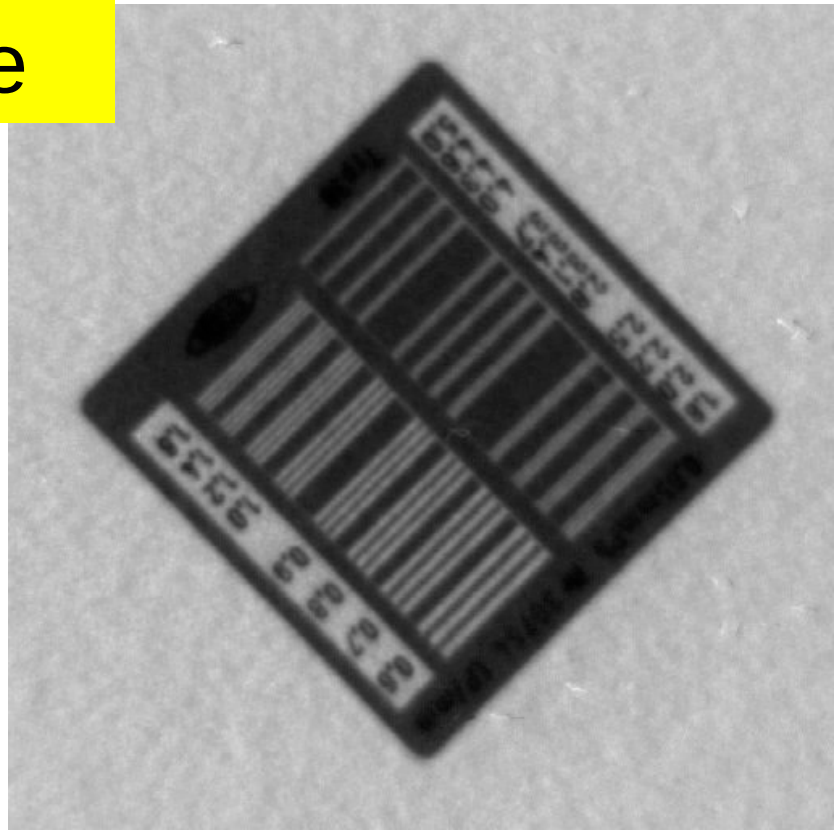
①－② Offset Subtraction

③－④ Offset Subtraction

Software Image Processing

X ray

Processed image



5.5 inch
30kfps
512 x 512 pixel
Acc. 4096 frames

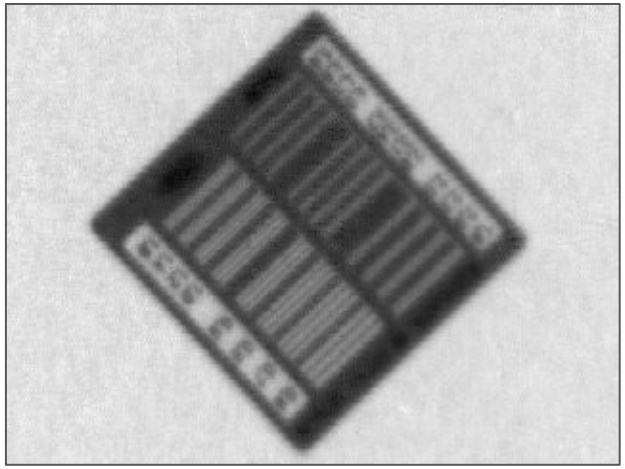
Test object image
①－② Offset Subtraction

÷

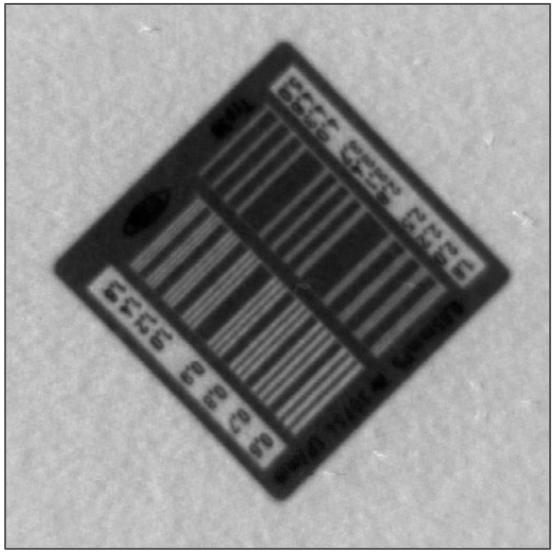
Shading image
③－④ Offset Subtraction

View Field

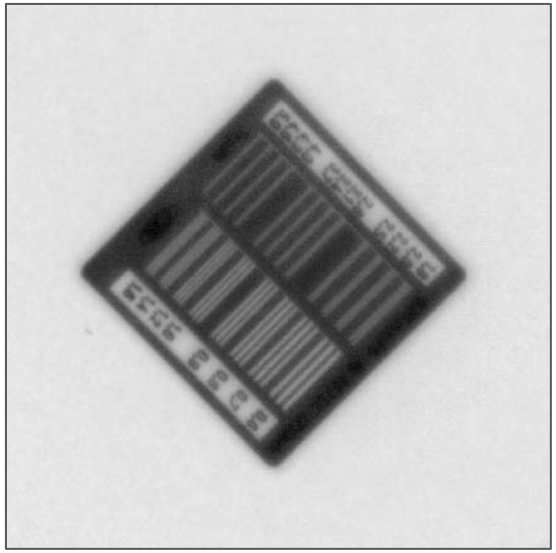
X ray



100kfps
124 x 84 mm
320 x 240pixel



30kfps
99 x 99 mm
512 x 512 pixel

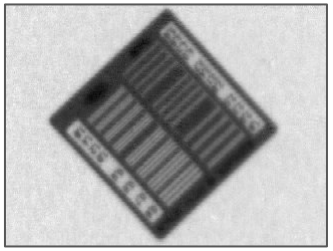


10kfps
99 x 99 mm
960 x 960 pixel

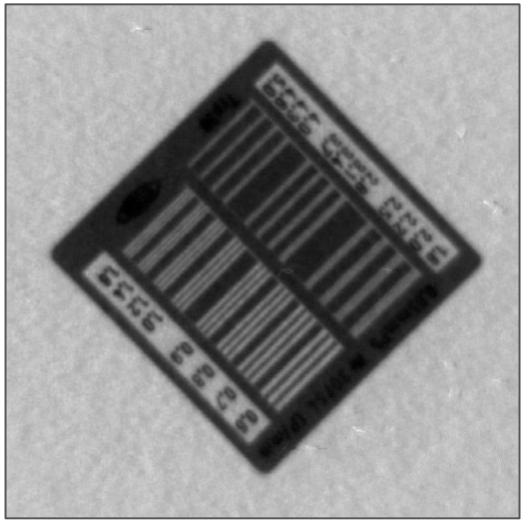
5.5 inch **Acc. 4096 frames**

Pixel Resolution

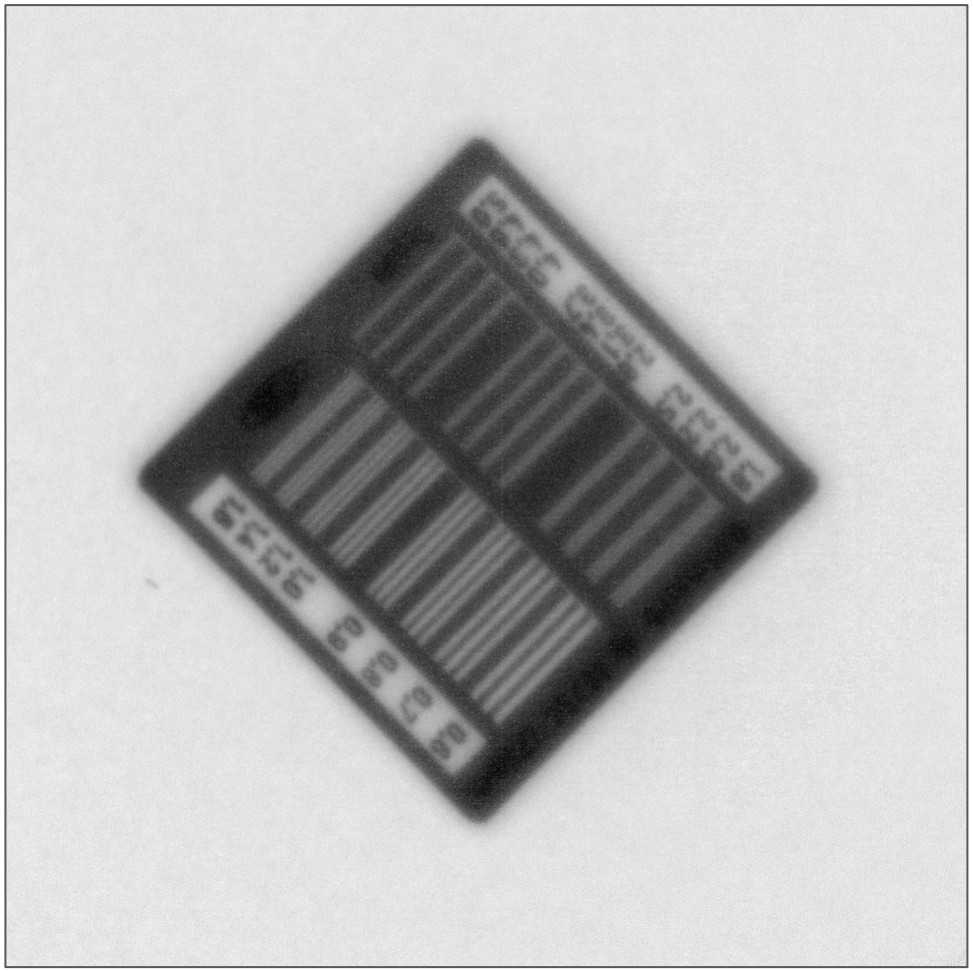
X ray



100kfps
320 x 240 pixel
112 x 84 mm
[349μm]



30kfps
512 x 512 pixel
99 x 99 mm
[193μm]



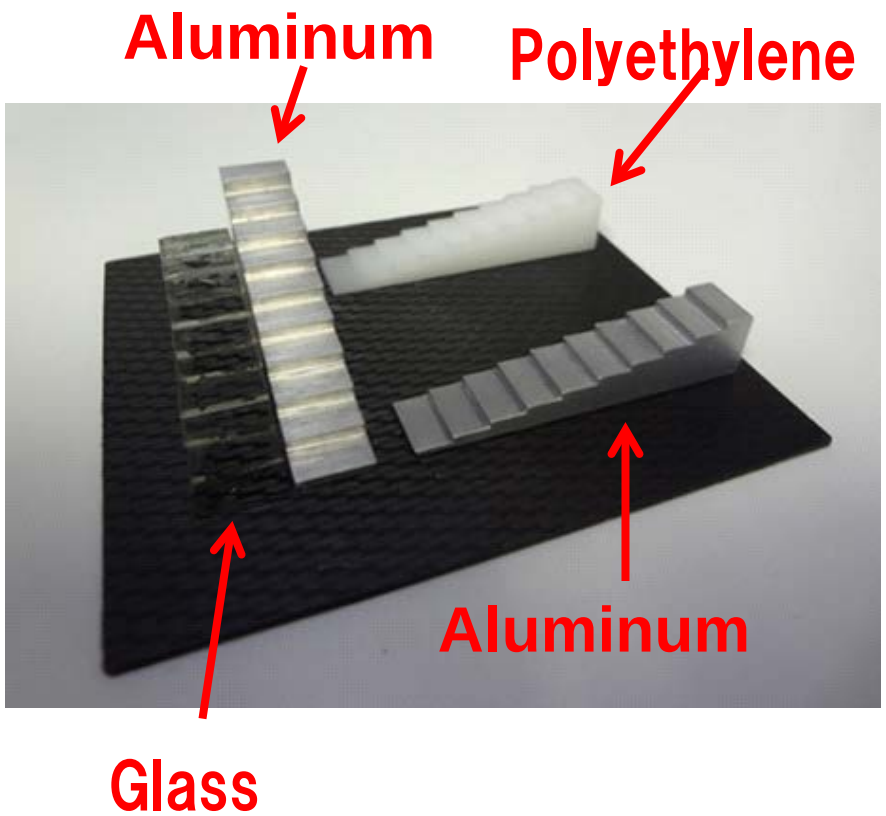
10kfps 960 x 960 pixel
99 x 99 mm [103μm]

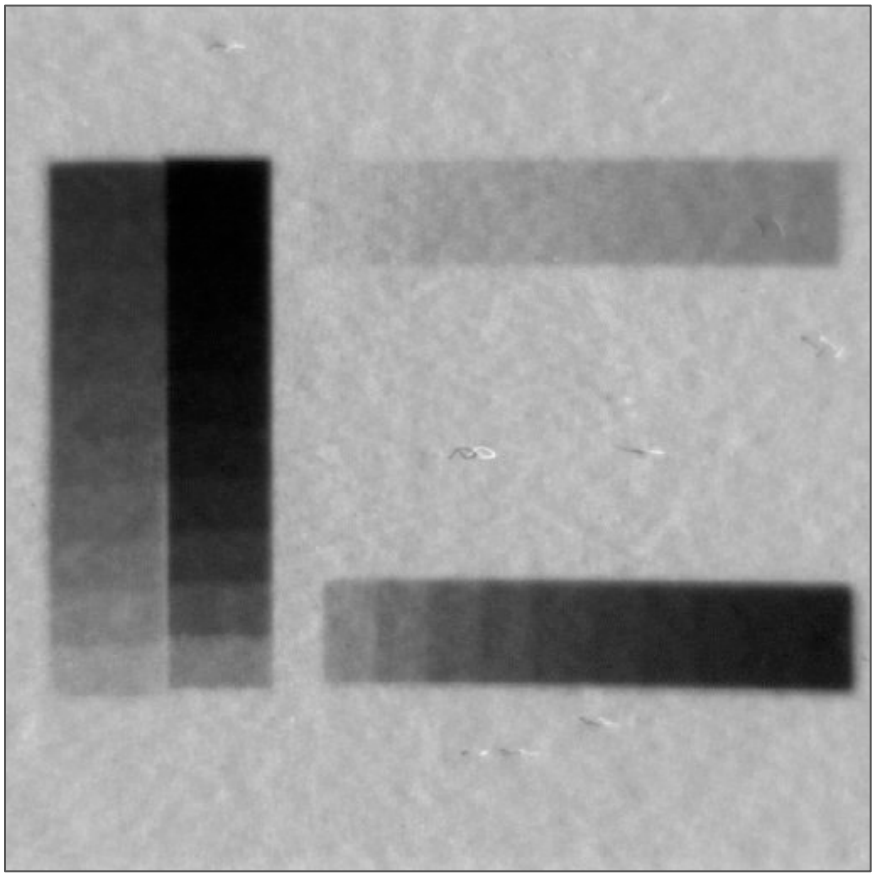
5.5 inch

Acc. 4096 frames

Step Wedge

X ray



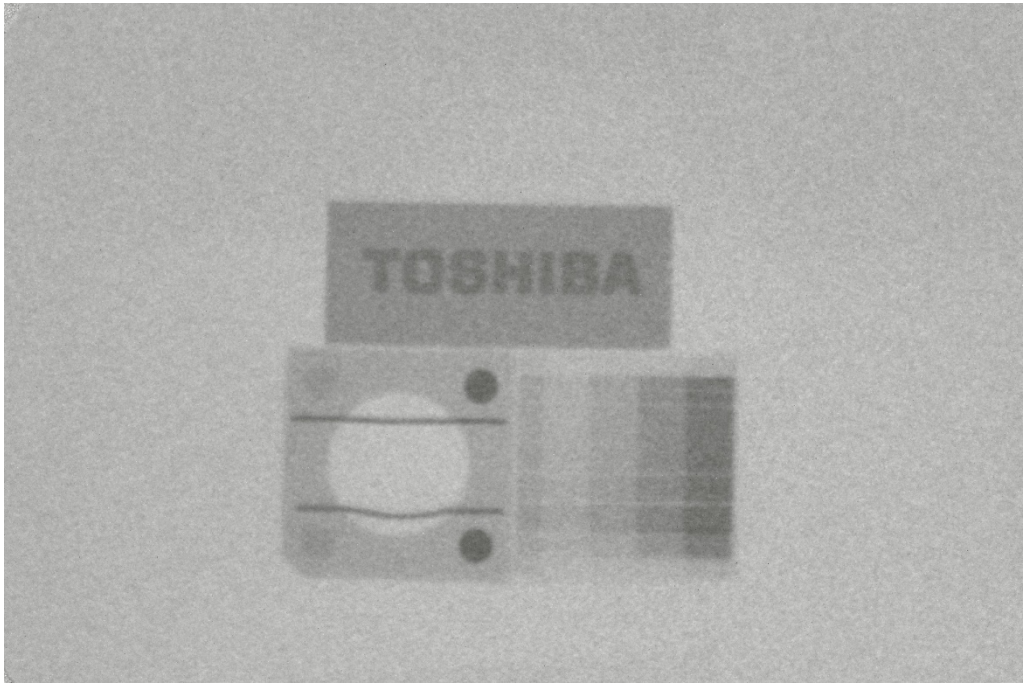


5.5 inch 30kfps (512 x 512 pixel）Acc. 4096 frames

HUNS Pulse Neutron Experiment

Neutron

Thermal Neutron Source

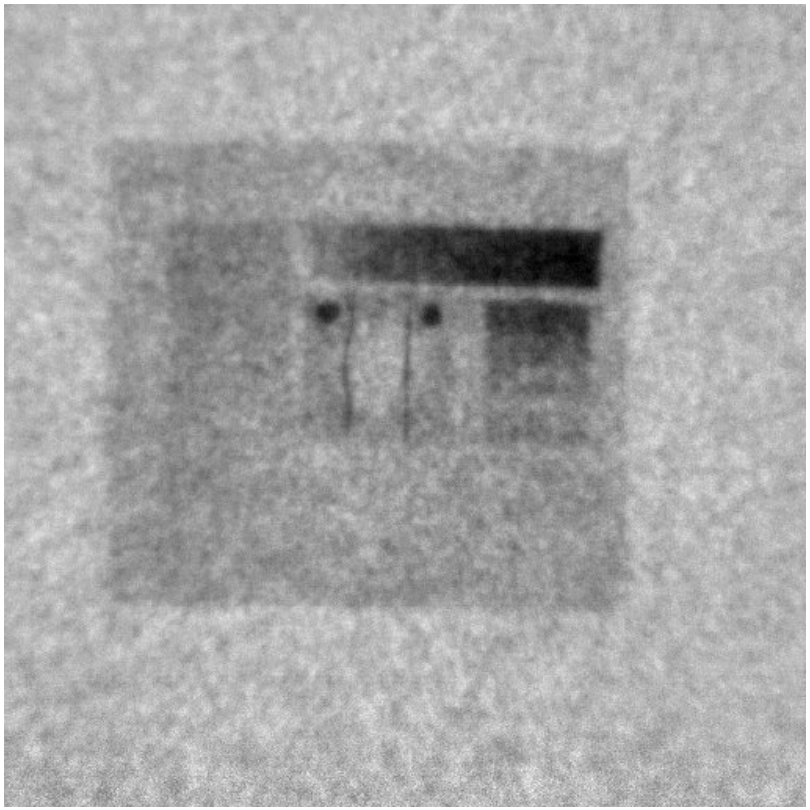


Nikon D800E

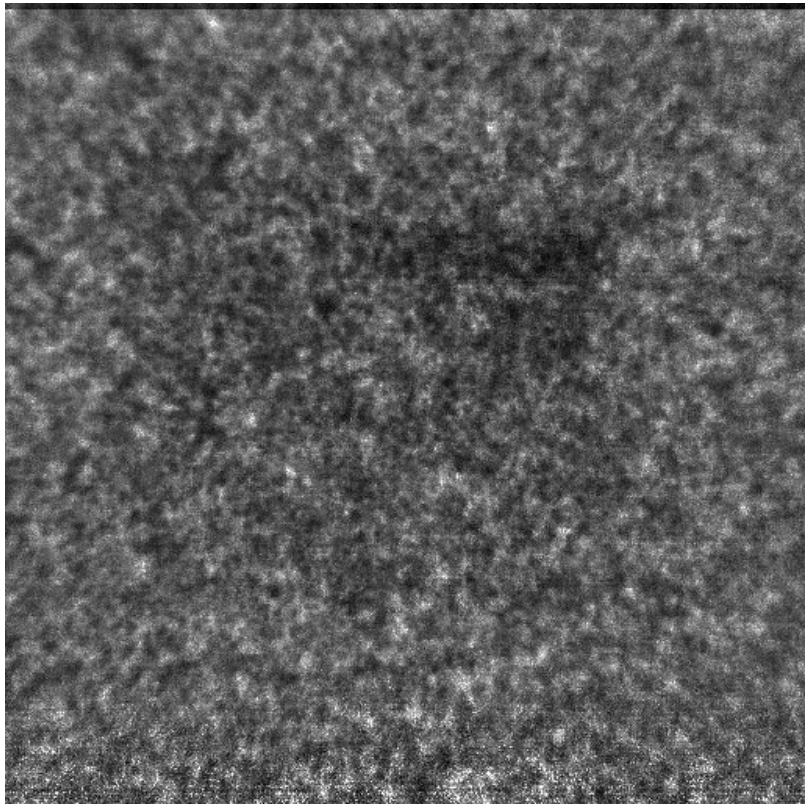
5.5 inch Pb filter : 17mm
Exposure : 6min ISO:400 8 times
With shading correction

HUNS Pulse Neutron Experiment

Neutron



(61-63 Frame) x 20
Exposure 8.19 s



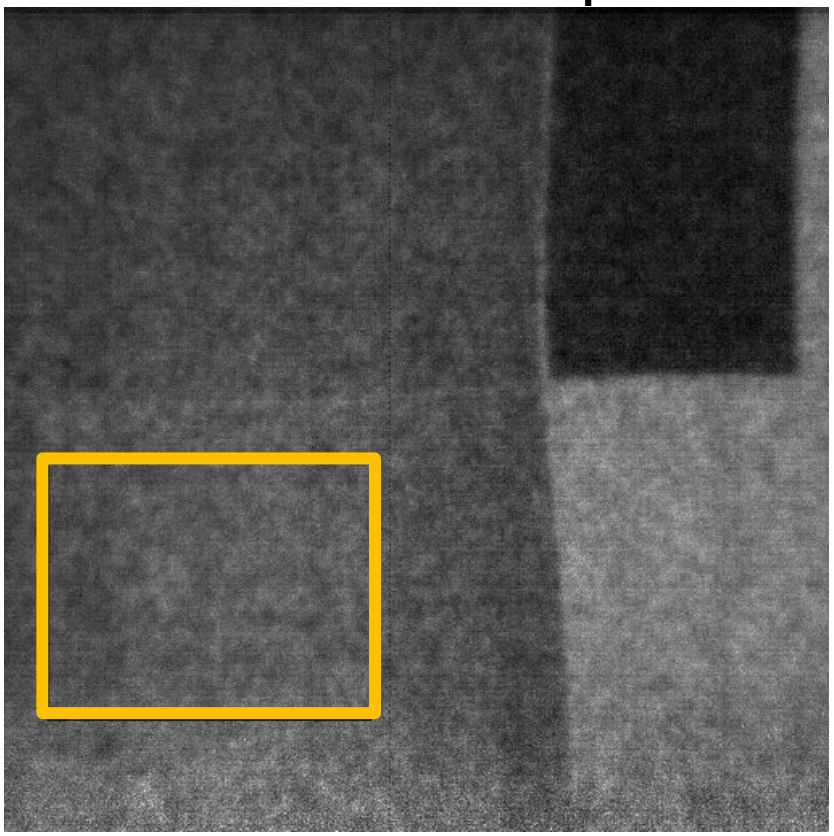
61 Frame
Exposure 0.14 s

9 inch 30kfps (512 x 512) Acc.4096 frames x 20 folders（≒27min)

Bragg Edge Experiment

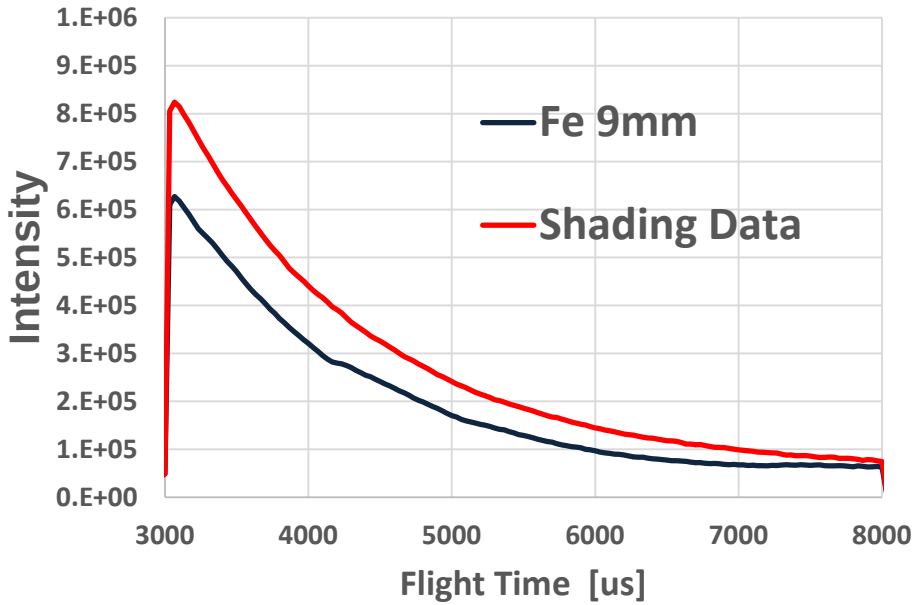
Neutron

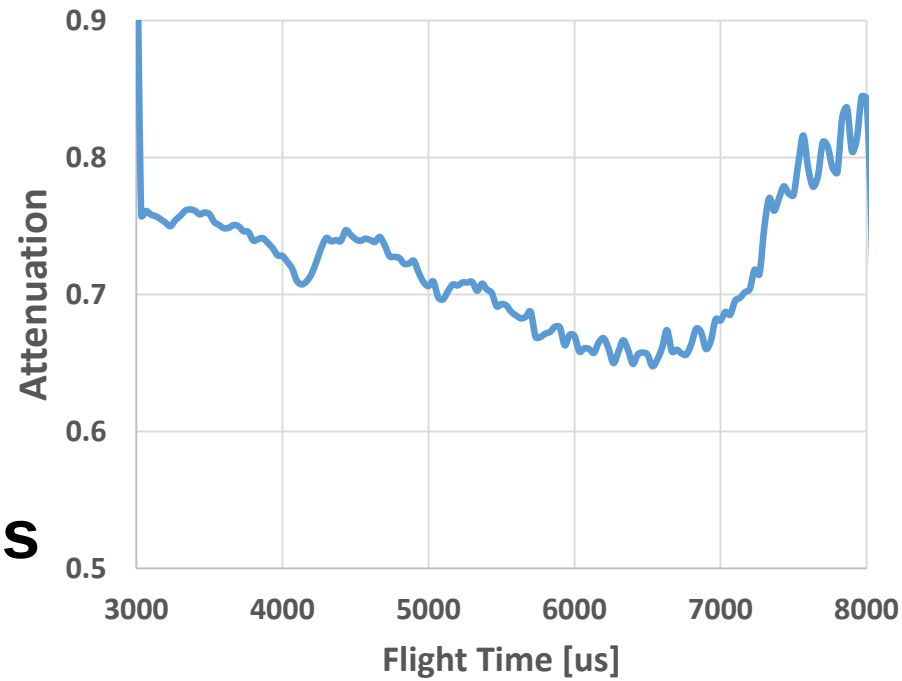
Cu 11.6 mm **B_4C 10 mm**



Fe 9 mm ROI：200x160 pixels

9 inch 30kfps (512 x 512)

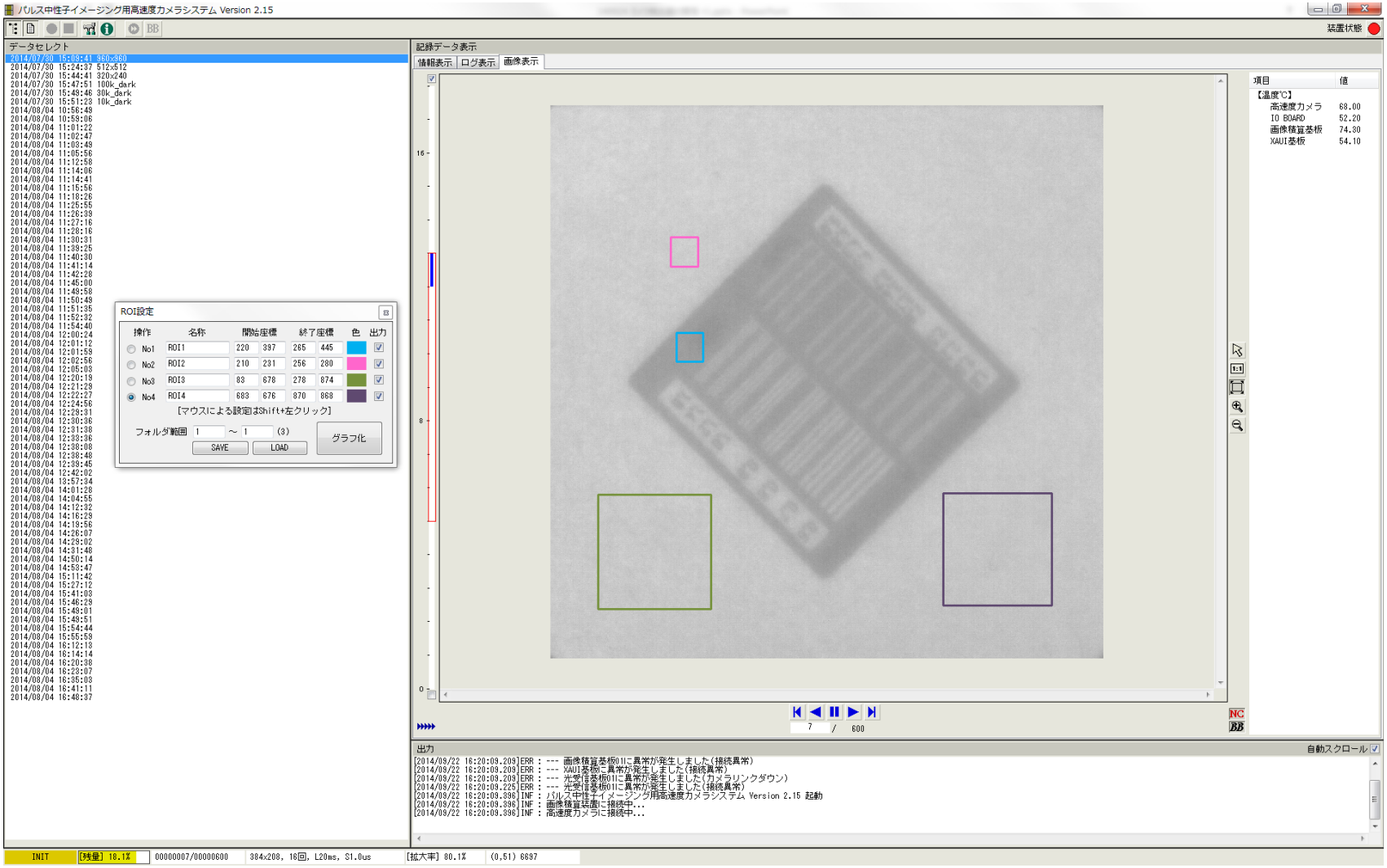




PC Display

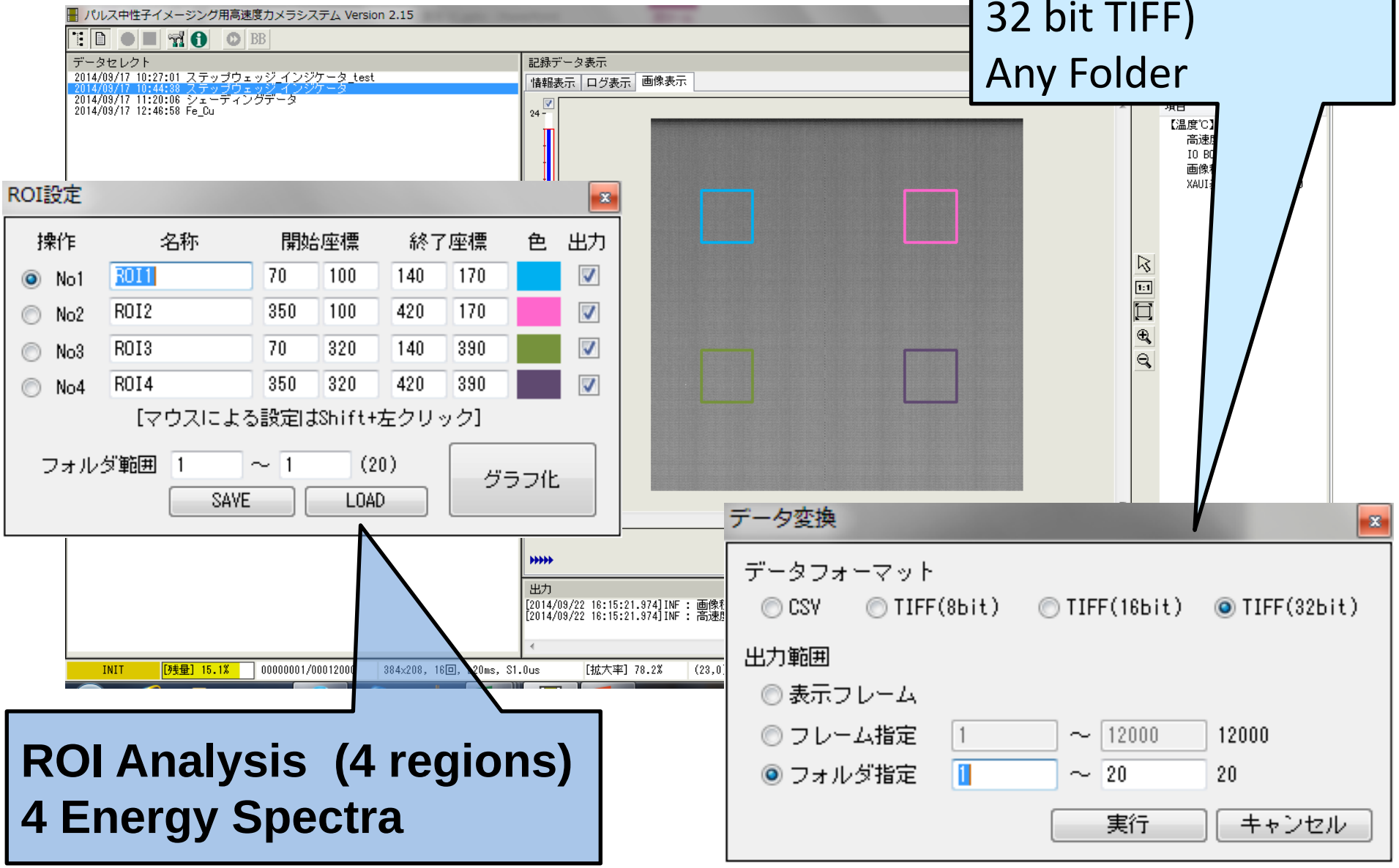
X ray

10 kfps　960 x 960 pixel



Pre-processing by System PC

Data File Conversion (Raw→CSV, 8 , 16 or 32 bit TIFF)
Any Folder

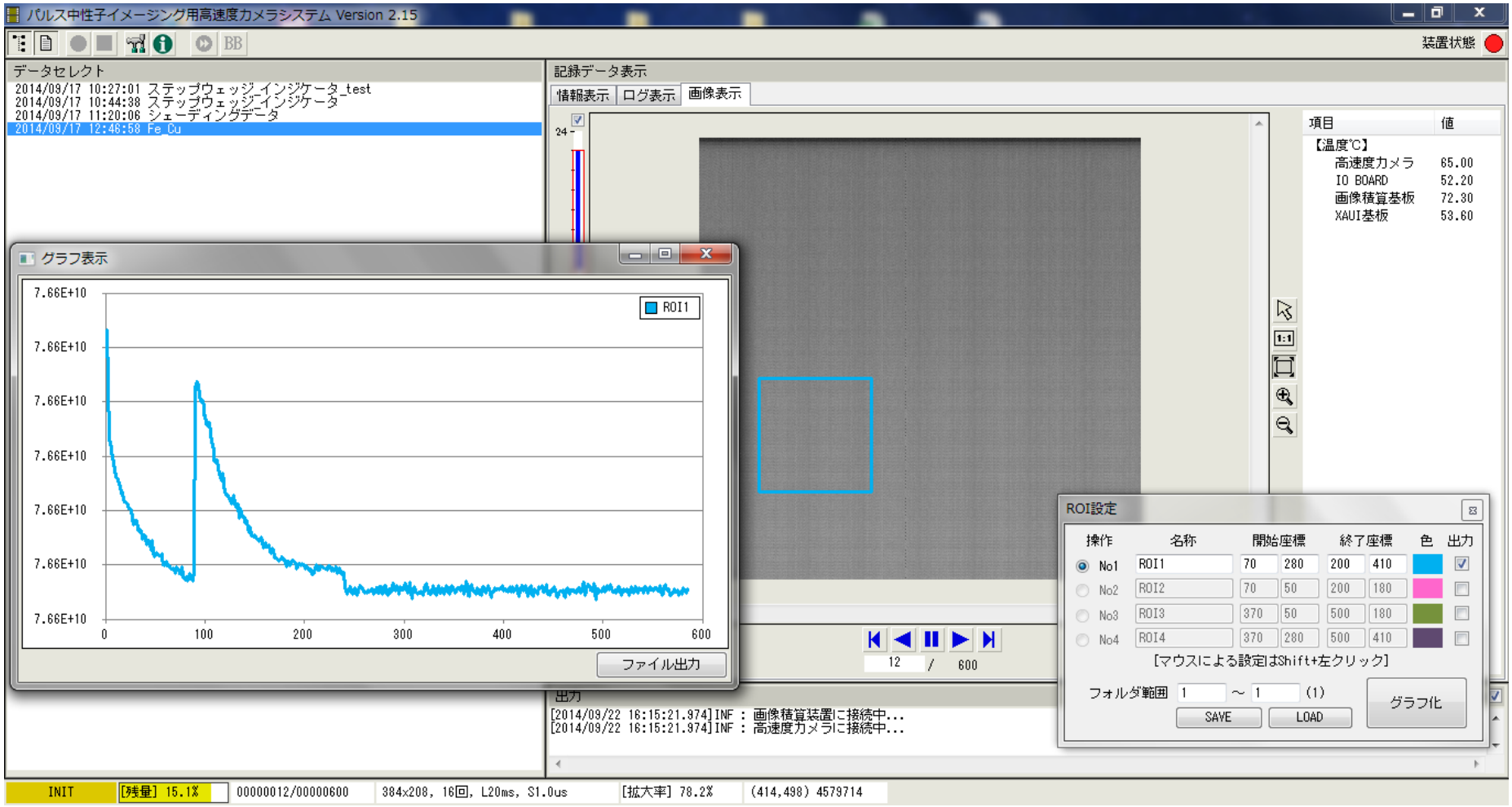


ROI Analysis (4 regions)
4 Energy Spectra

Pre-processing by System PC

Neutron

30 kfps　512 x 512 pixel



まとめ

◆ パルス中性子透過分光撮像用の高速度カメラを開発

1) ３種類の動作モード （時間分解能・画素数）

2) 中性子の有効利用 （無駄なく録画）

3) 露光時間は1μs単位で調整可

◆ 北大でブラッグエッジ・イメージング実験を実施

◆ 簡易データ表示用ソフトウェアを作成

画像積算、４つのROI指定、スペクトル表示