HIGH RESOLUTION, HIGH ENERGY and HIGH SPEED

By T. MARTIN

ESRF

OUTLINE

1. Introduction
2. State of the art: High-resolution detector at ESRF
3. Detector for high resolution and high energy
4. FRELON camera for high frame rate
5. Performance
6. Further developments

INTRODUCTION

- REQUEST for detector

  Microstructure evolving in few minutes

  – High spatial resolution: a few ?m ? small FOV
  – DR: 12 bit minimum
  – High energy (white beam, peak at 65keV)
  – 500 images to be acquired in 30 seconds ? 16 fps minimum

- PROBLEMS RADIATION DAMAGE FAST IMAGING SYSTEM

Mirror objective FRELON CCD camera

HIGH-RESOLUTION DETECTOR

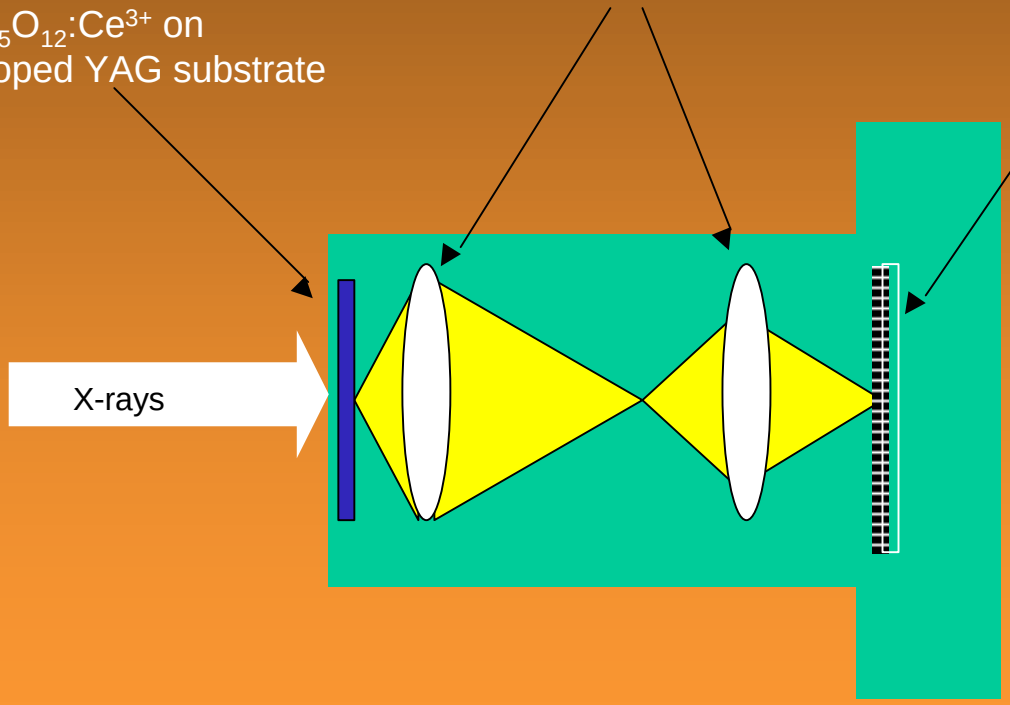
State of the Art

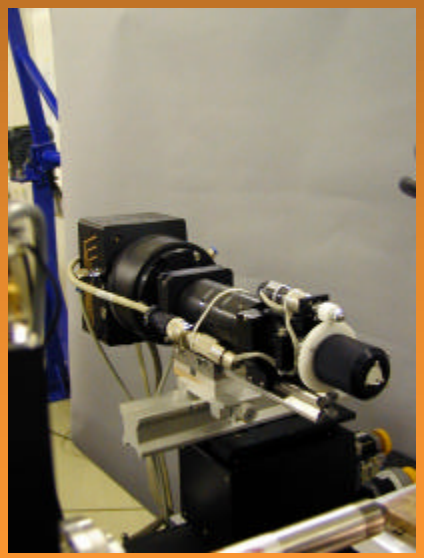
IN-LINE DETECTOR For Low Energy

PRINCIPLE:

LUMINESCENT SCREEN + OPTICAL MICROSCOPE + CCD DETECTOR

$Y_3Al_5O_{12}:Ce^{3+}$ on
170?m undoped YAG substrate



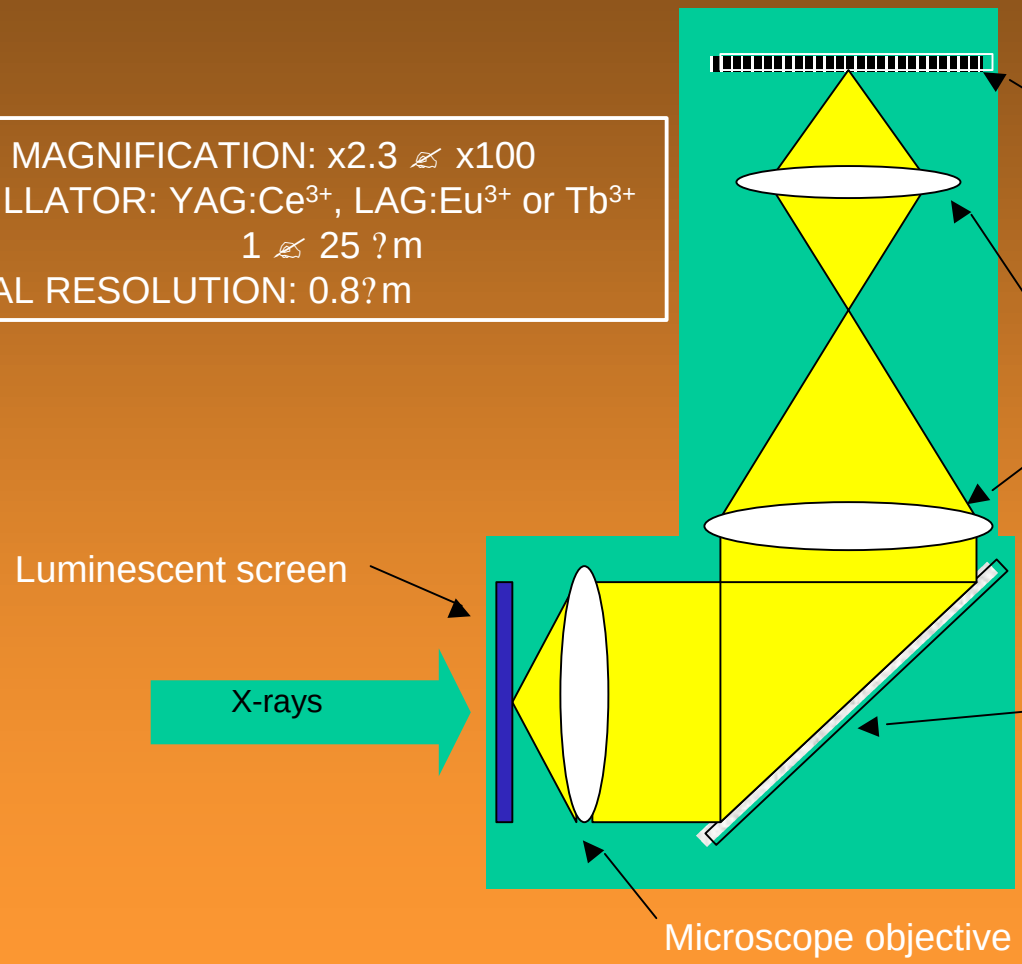


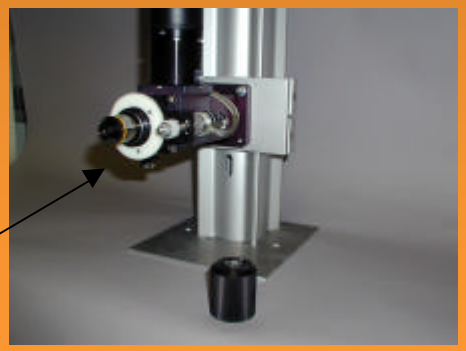
HIGH-RESOLUTION DETECTOR

State of the Art

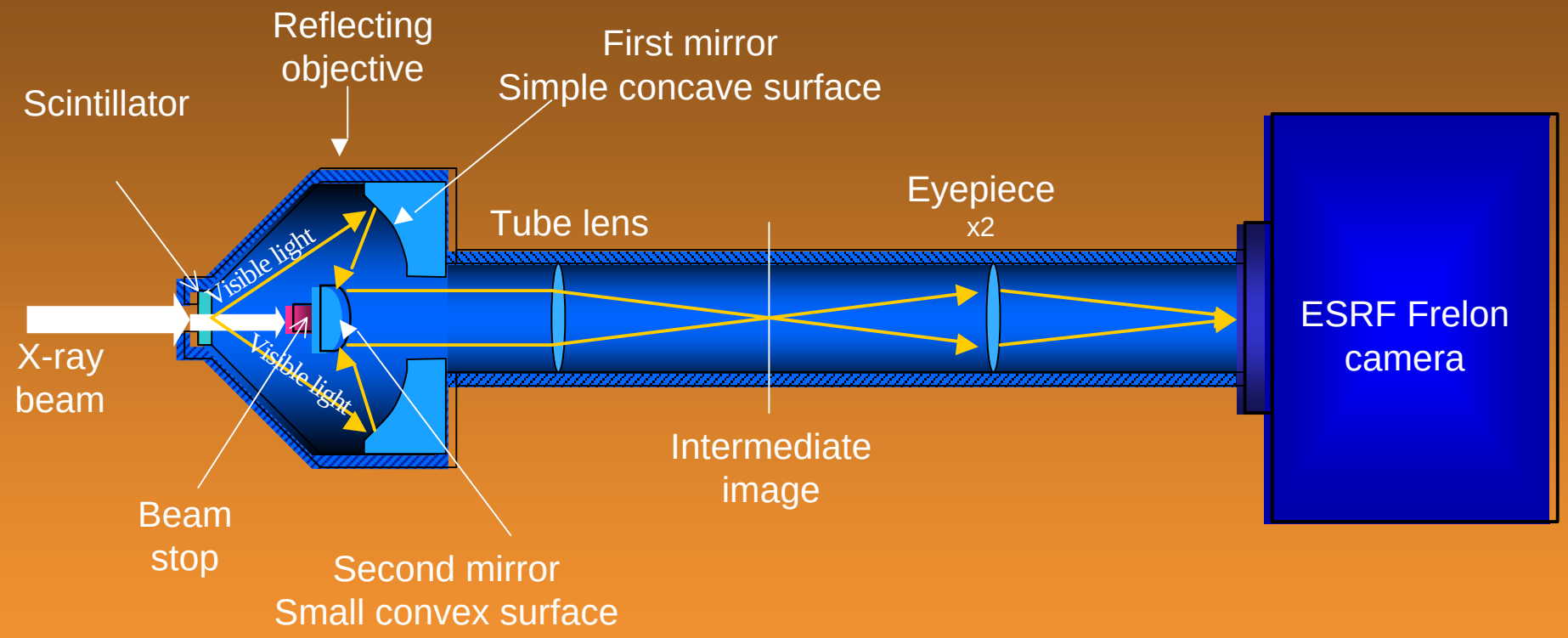
FOLDED DETECTOR For Low Energy

- TOTAL MAGNIFICATION: x2.3 ≤ x100
- SCINTILLATOR: YAG:Ce^{3+}, LAG:Eu^{3+} or Tb^{3+}
  1 ≤ 25 ?m
- SPATIAL RESOLUTION: 0.8?m





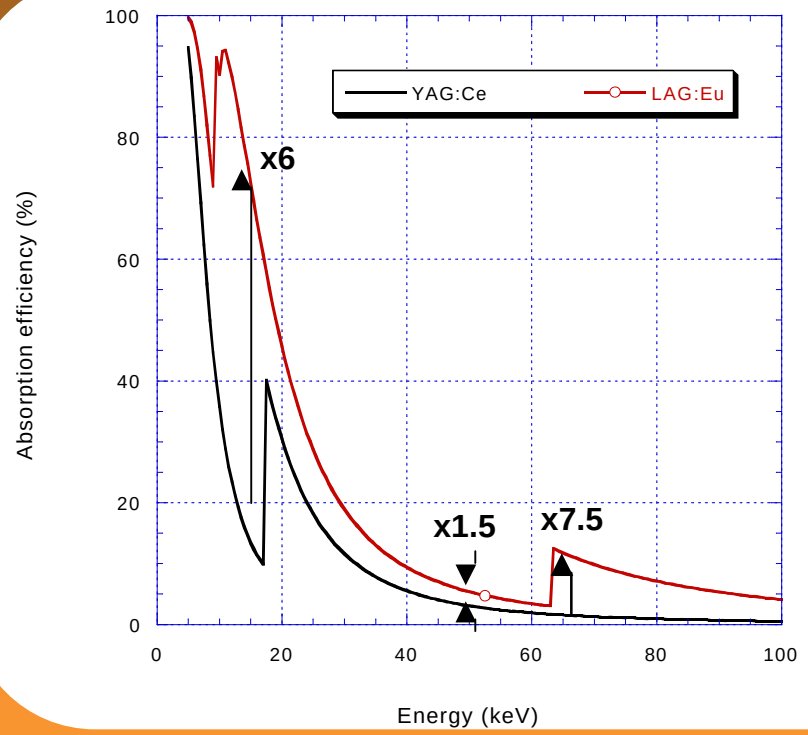
HIGH-RESOLUTION DETECTOR FOR HIGH ENERGIES



SCINTILLATOR

Its 4 main characteristics are:

- Absorption coefficient: ~Z_{eff}^4 x ?
- Light yield depends on activator and its concentration
- Spectral response must be matched with QE of CCD
- Afterglow depends on exposure time and activator concentration



YAG:Ce^{3+}

x= 25? m

?= 4.55g/cm^3

Z_{eff}= 32

$?_{x/?}$= 0.06

LAG:Eu^{3+}

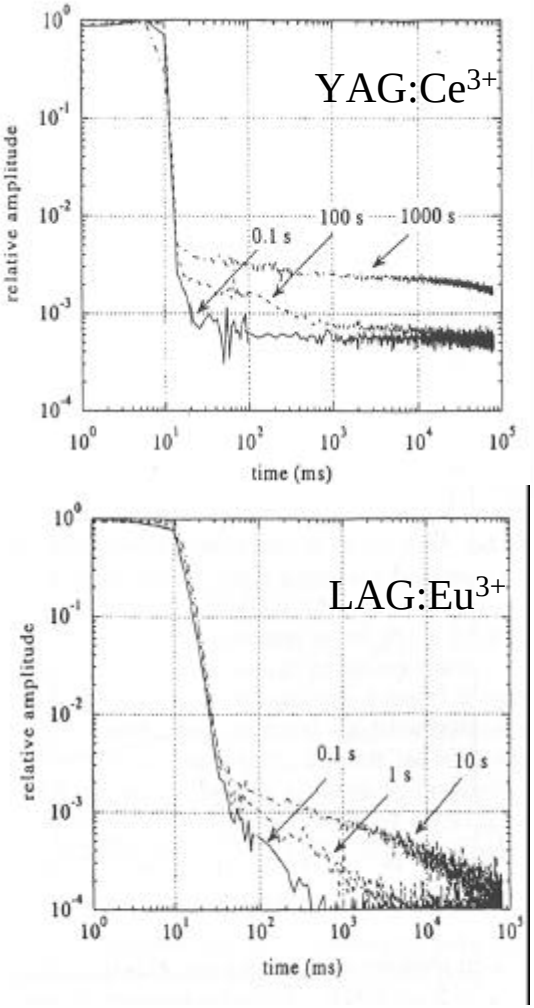
x= 25? m

?= 6.6g/cm^3

Z_{eff}= 63

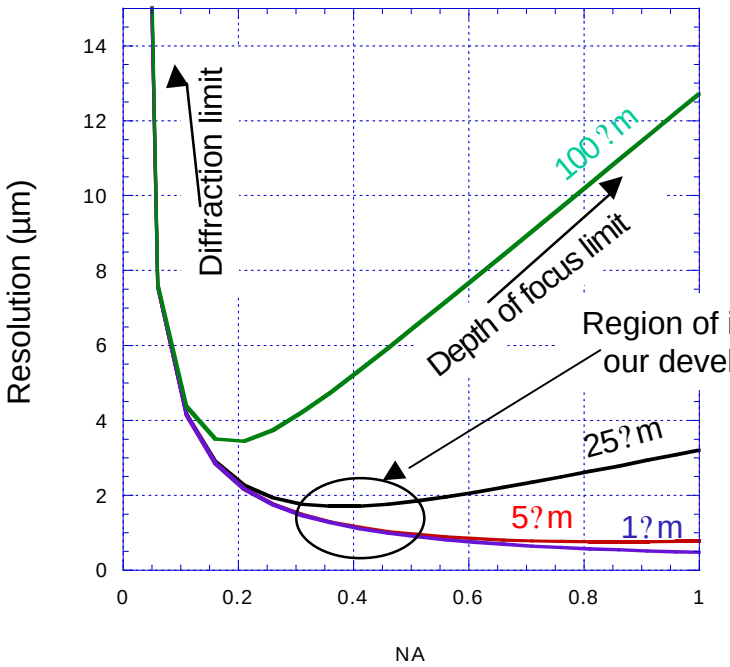
$?_{x/?}$= 0.03

Afterglow after different X-ray exposure times



X-RAY IMAGING with SCINTILLATOR

Limits of resolution



Spatial resolution is limited by

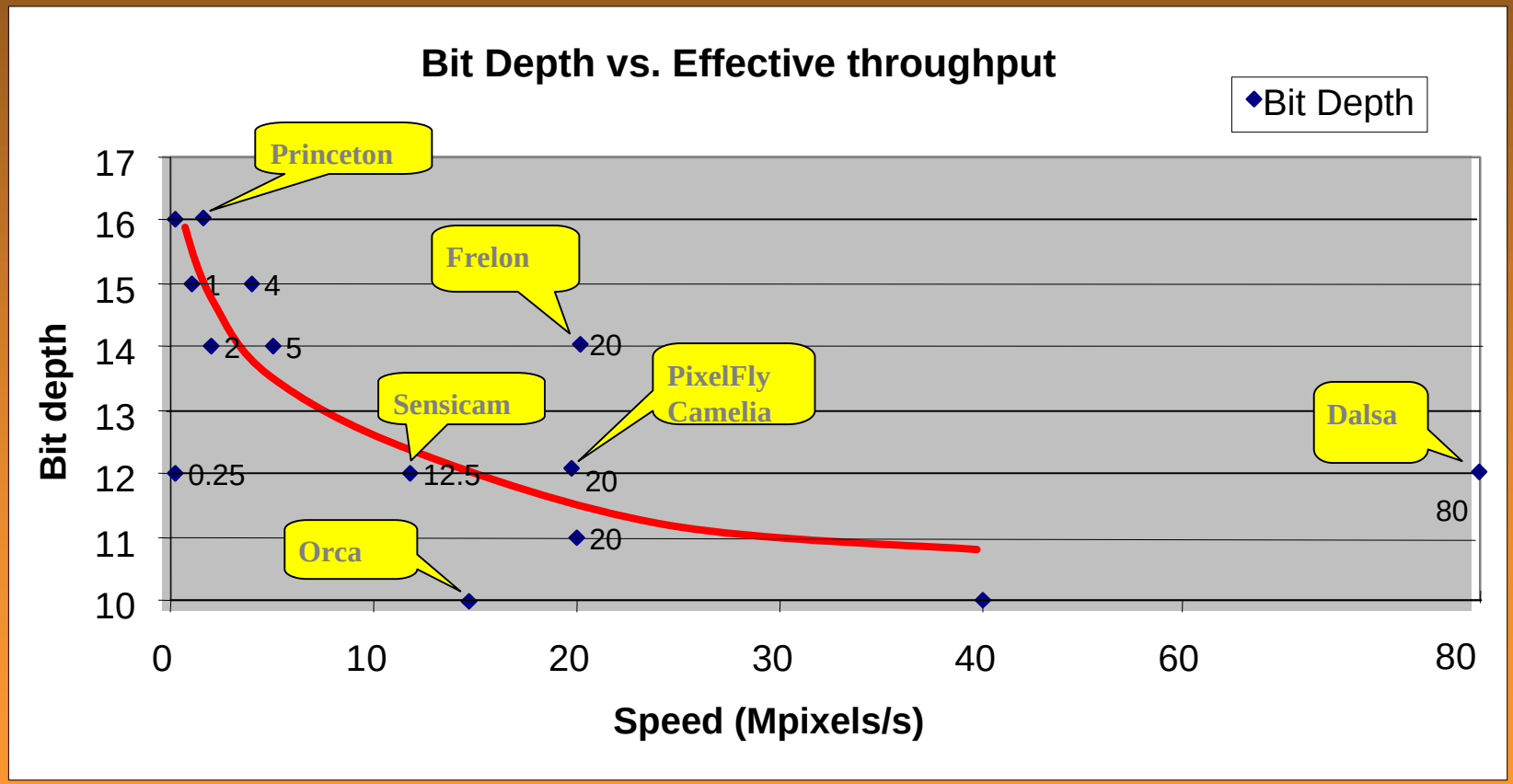
- Diffraction: R~?/NA
- Depth of focus: R~?z.NA
- Spherical aberrations of substrate: R~t.NA^3
- Photoelectron range

At high energy, we use

- LAG:Eu^{3+} scintillator 6?m to 25?m
- Reflecting objective x15 NA=0.5 (Ealing)
  x5 NA=0.2 (Nachet)

CHOICE OF CAMERA

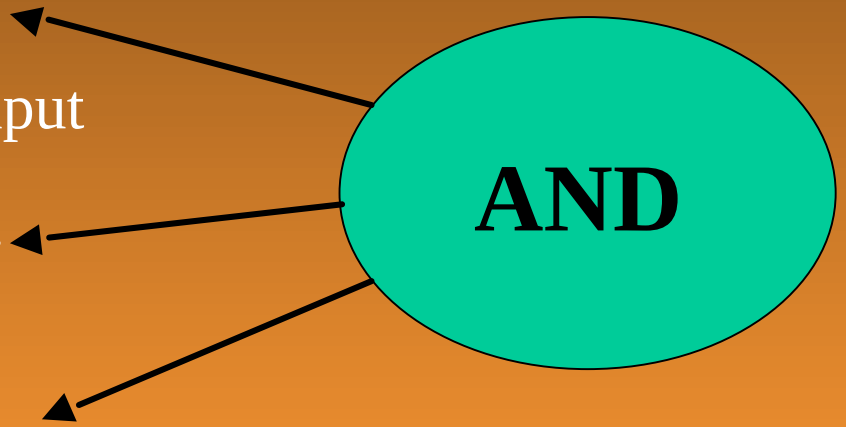
FReLoN camera on the market



The FReLoN PROJECT

Main Features

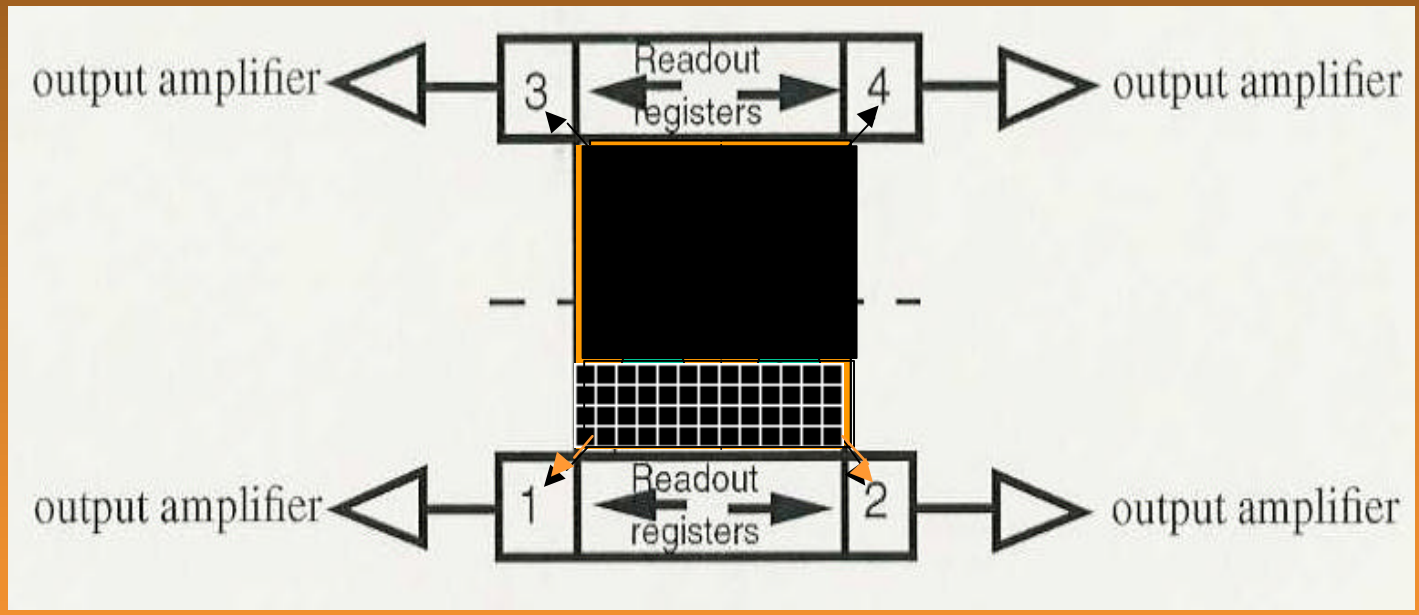
- High pixel rate
  - 20 Mpls/s throughput
- Low noise readout
  - 25 e^-
- Dynamic range
  - DR= 14 bit



The FReLoN PROJECT

Block diagram

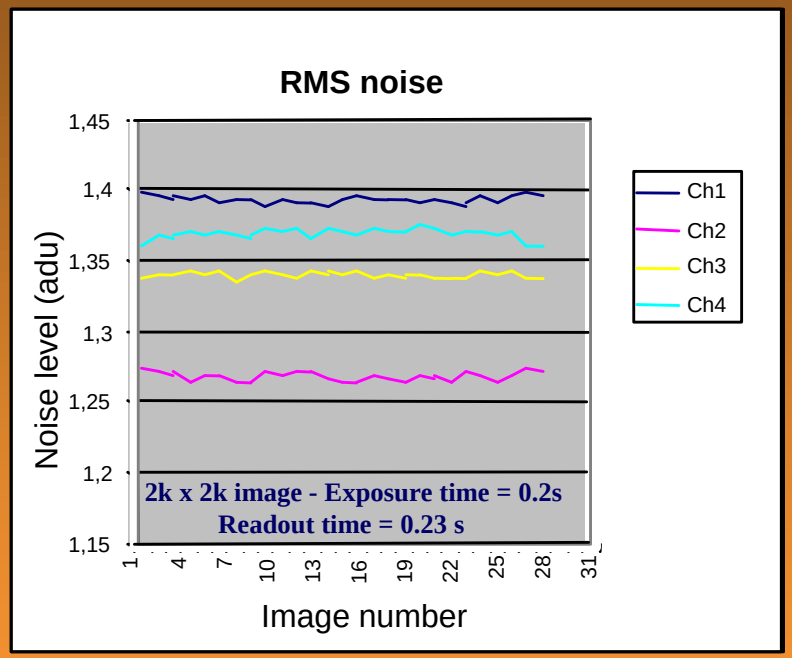
Parallel Readout **AND** Low Noise **AND** High Speed

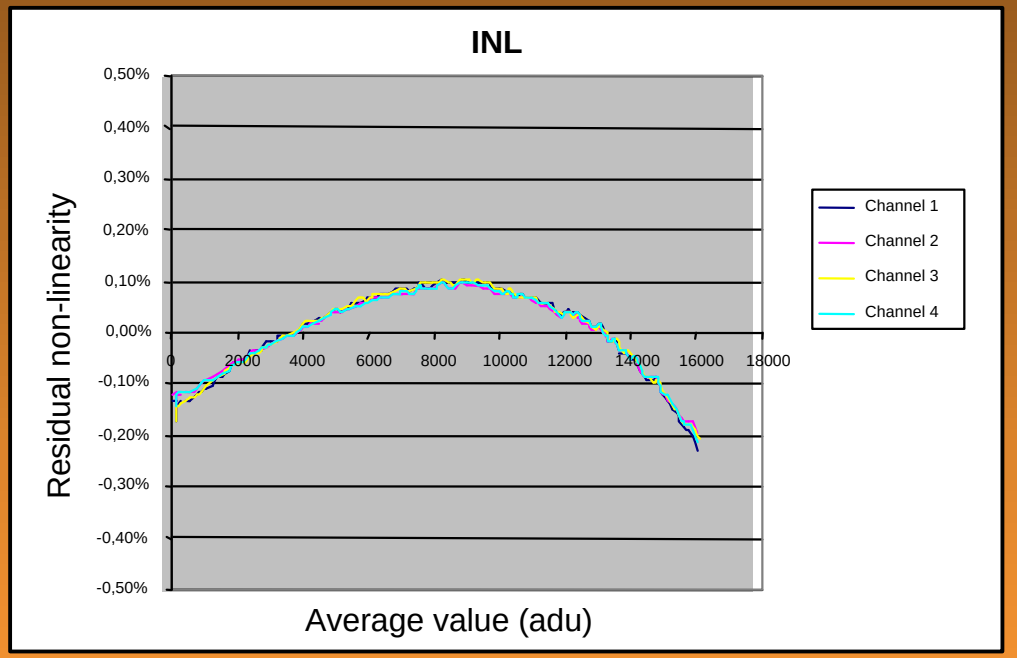


kinetic pipeline mode

FReLoN

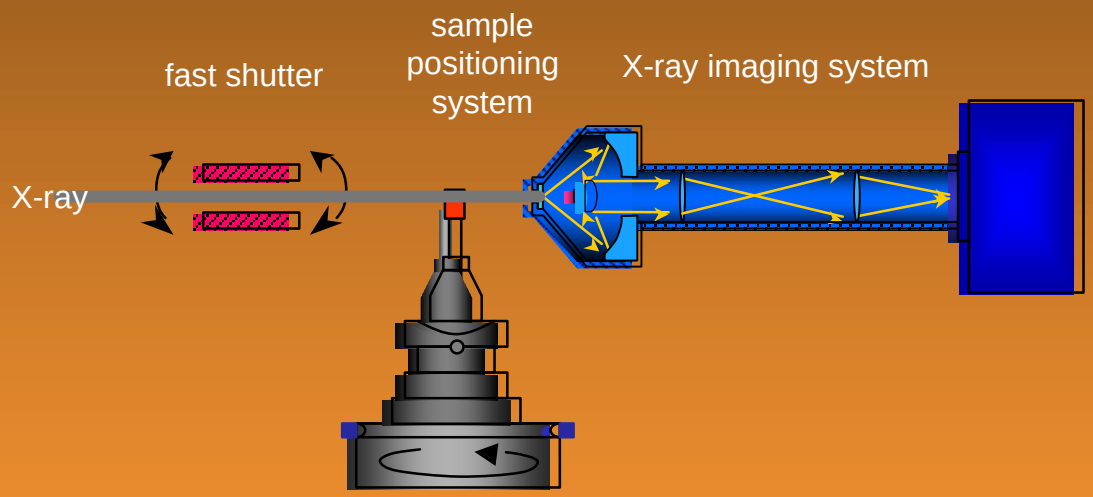
Noise and Integral Non-Linearity





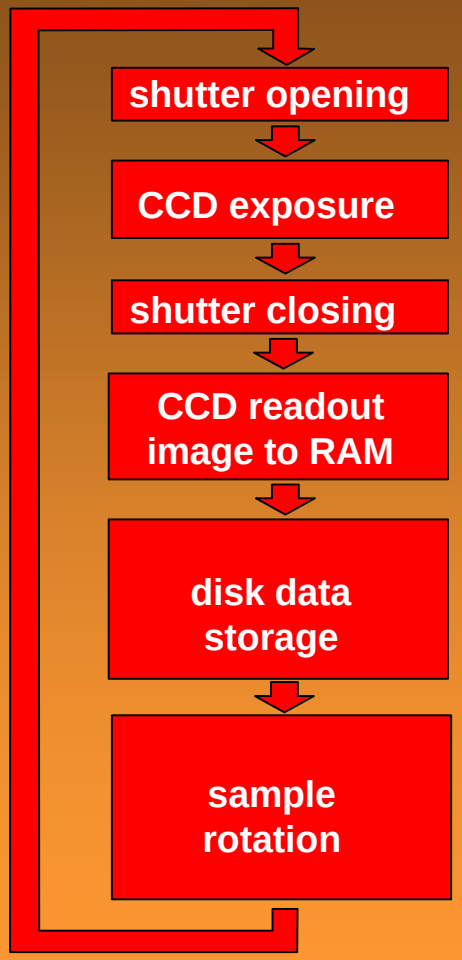
High resolution, high energy and high speed system

Application



Typical acquisition

9 minutes



High resolution, high energy and high speed system

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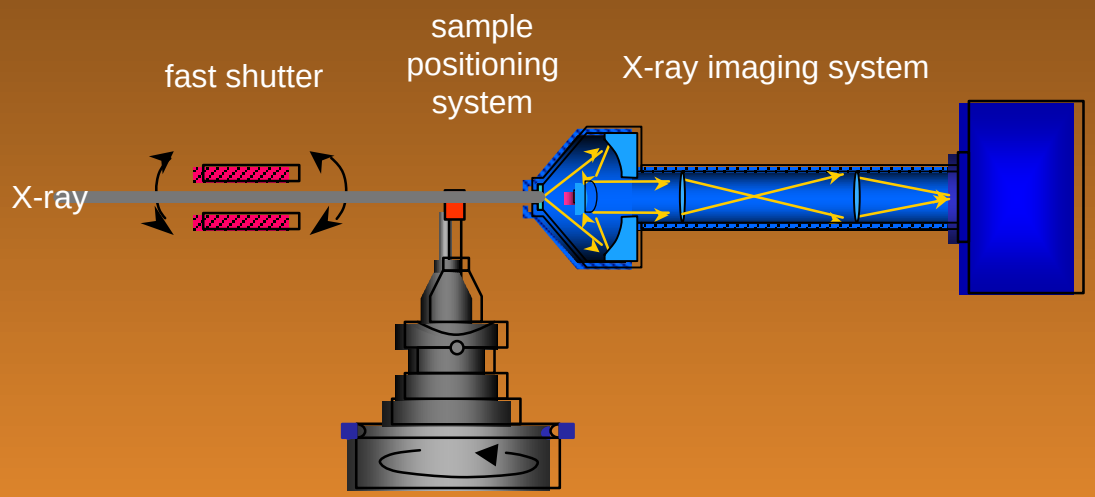
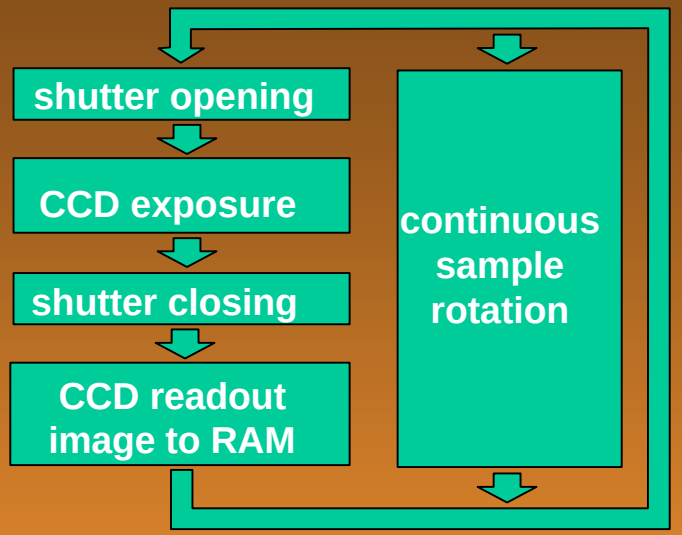


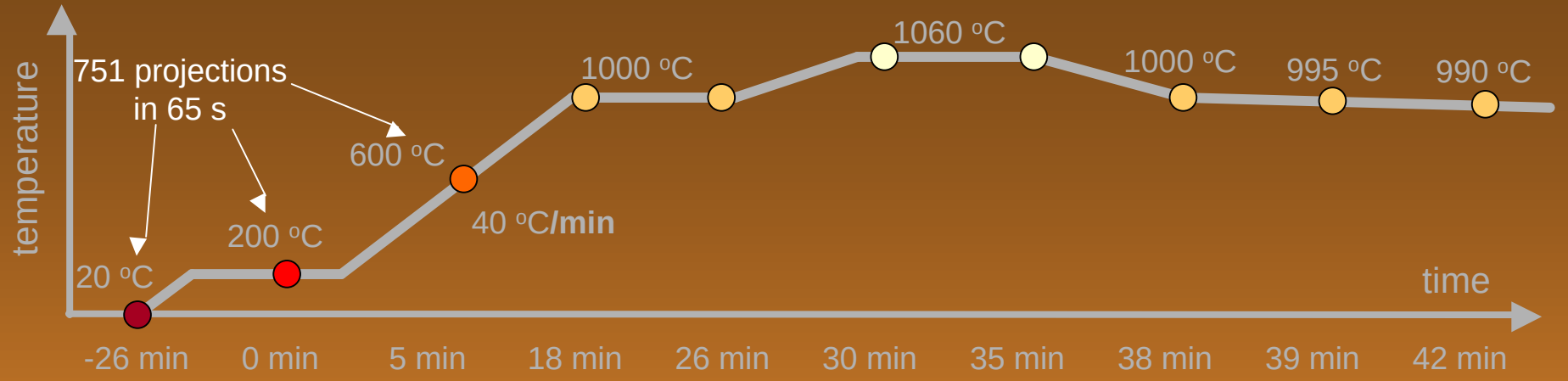


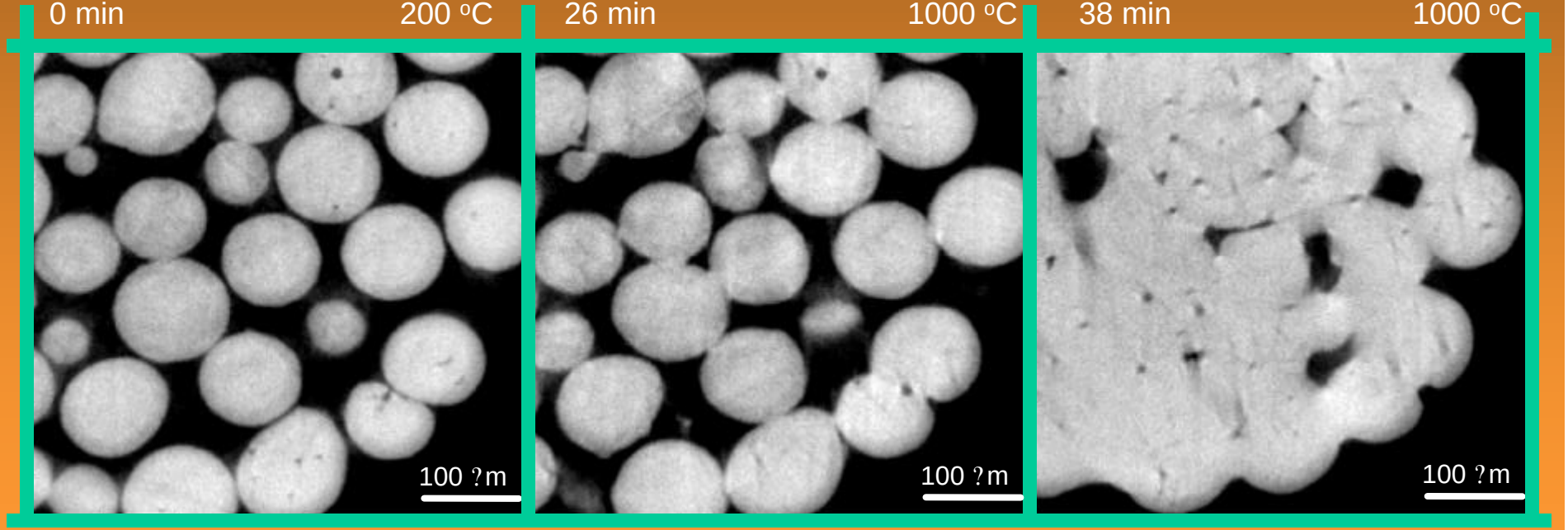
Typical acquisition time with kinetic pipeline mode

	Binning	CCD+Exposure(45ms)	Time for 1000 frames
2048 x 128	no	13.6fps	73sec
2048 x 256	no	9.7fps	104sec
2048 x 256	2x2	13.3fps	75sec

APPLICATION

Microstructure evolution during sintering process (copper particles)





7510 projections – Frelon 2K – no binning – exposure time 40 ms – ROI 1024 x 128 – LAG 1?m – magnification x 9

Courtesy: M. DI MICHIEL, ESRF

PERFORMANCE

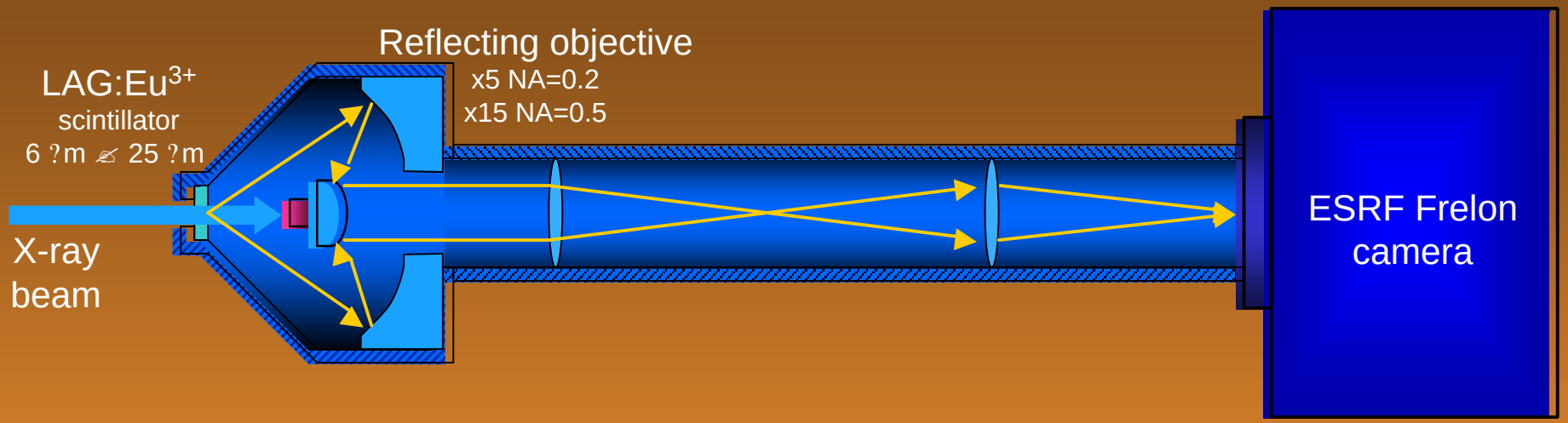


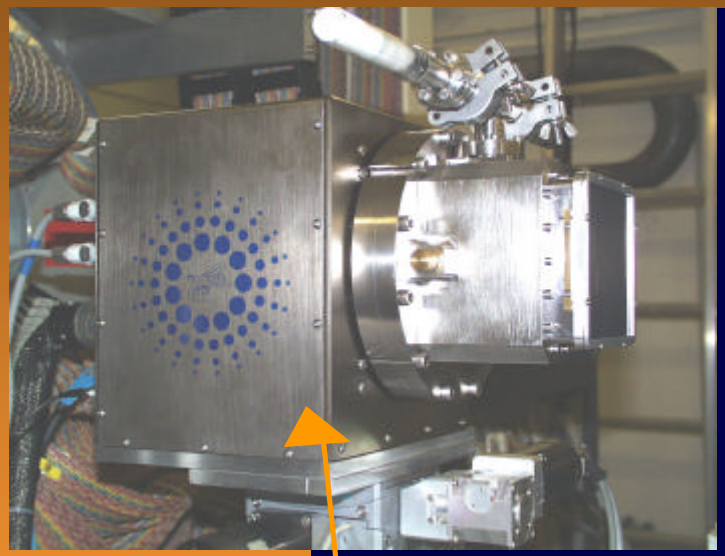
Image depth:	14 bit
Pixel size:	14 x 14 ?m^2
ADC unit:	20 e$^-$
Read-out noise:	25 e$^-$
Frame rate 2kx2k:	5 fps
	10 fps (2x2 binning)

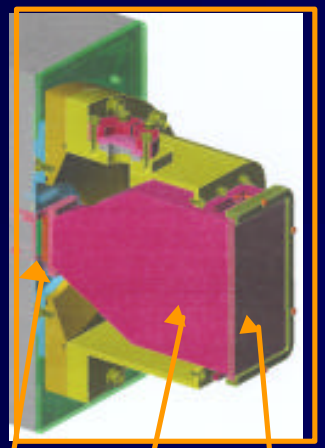
Input pixel size:	0.47?m or 1.4 ?m
Field of view:	1x1 mm^2 or 2.9x2.9 mm^2
Number of pixels:	2048 x 2048
Spatial resolution:	4?m @ 65keV
DQE (6 ?m LAG,65keV):	2.5%, mainly limited by absorption

FReLoN

Other applications: CCD camera with taper optic

Used at ID17





FRELON camera

CCD with Peltier stage

Taper

fluorescent screen

For more information,

see Poster

- Based on low noise, fast readout FReLoN system
- Tapered fiber optical coupling
- Exchangeable mammography phosphor screens
- Vitreous carbon window
- Full frame or continuous line-by-line readout
- 2000 x 2000 pixels
- 50 x 50 micron^2 input pixel size
- 93 x 93 mm^2 X-ray sensitive area
- 14bit dynamic range
- Spatial resolution: 110 µm LSF FWHM with MR detail HD-S phosphor screen @ 18keV

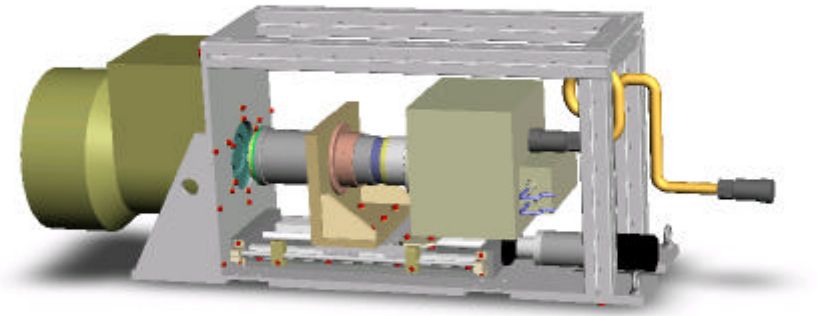
FReLoN

Other applications: FReLoN coupled to image intensifier

For more information,
see Poster

Developed for PX, SAXS, WAXS, materials diffraction

Used at ID2 (2 systems), ID11 and ID15



Characteristics with **FReLoN 2kx2k 14 bit:**

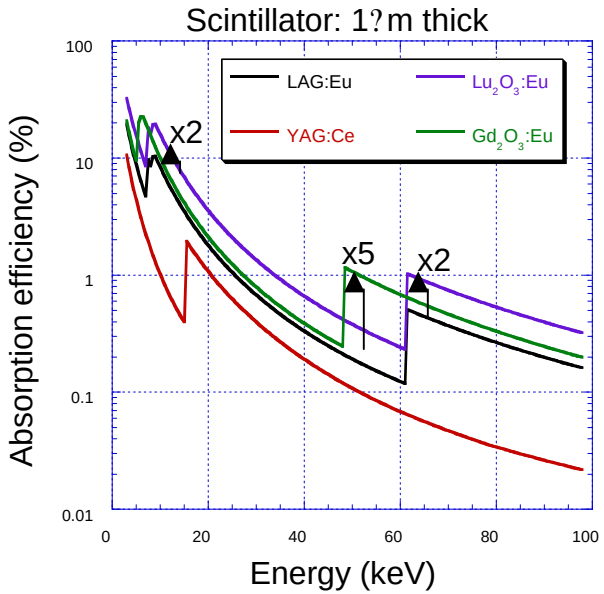
Detection area :	210 mm diagonal
Energy range :	5-30 keV (Be input window)
Spatial resolution :	200-300 µm LSF FWHM
DQE :	? 0.6 @ 8 keV
Noise :	? 5-10 keV/pixel r.m.s.
Readout time :	< 100 ms in 2x2 binning

FURTHER DEVELOPMENTS

SCINTILLATOR $Lu_2O_3:Eu^{3+}$ and $Gd_2O_3:Eu^{3+}$

1. Improves absorption
2. Improves light yield
3. Non-luminescent substrate

Absorption Efficiency

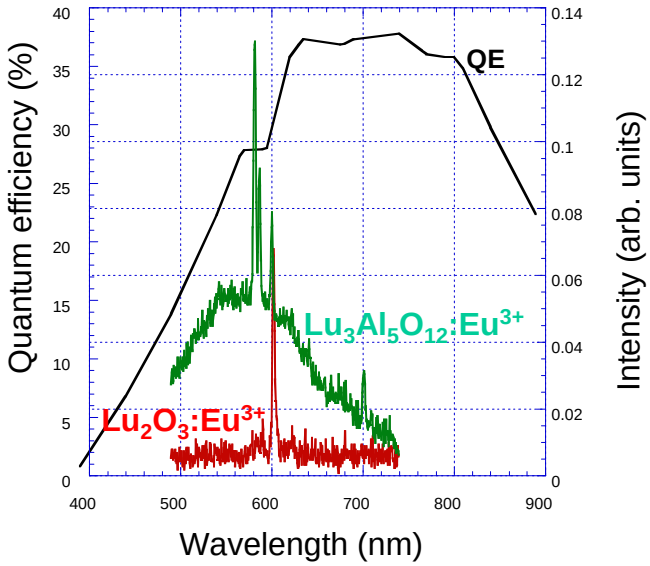


Light output

- $LAG:Eu^{3+}$ 11000Ph/MeV
- $Lu_2O_3:Eu^{3+}$ 19760Ph/MeV
- $Gd_2O_3:Eu^{3+}$ 18465Ph/MeV

NET GAIN
x3 ≃ x8
Compare LAG

Emission spectra



SCINTILLATOR

Choice of fabrication process

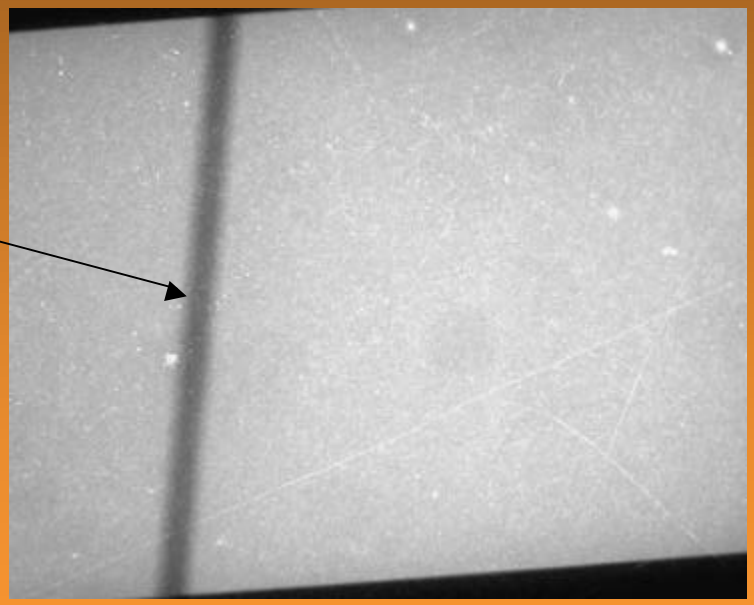
⇨ Sol-gel process

- ⇨ Making of very pure oxide film
- ⇨ High-density film and good optical quality
- ⇨ Homogeneous doping at molecular scale
- ⇨ Possibility to deposit on large area
- ⇨ Shape and kind of substrate
- ⇨ Price

SCINTILLATOR

W wire image with 800nm $Gd_2O_3:Eu^{3+}$ scintillator thickness

W wire: ? 30?m



X-ray generator with Cu anode, 30kV, 40mA.
Field of view: 1.4 x 1.1 mm^2.

CONCLUSION

- High resolution and high energy and high speed
  - R = 4?m fwhm with white beam, peak at 65keV
  - 751 images in 65s

- Scintillator
  - Encouraging result with 800nm $Gd_2O_3:Eu^{3+}$ scintillator
    - ? Beam position Monitoring
  - Thicker $Lu_2O_3:Eu^{3+}$ and $Gd_2O_3:Eu^{3+}$ scintillator
- New x10 reflecting objective (compromise between magnification and NA, reduced obscuration)
- 2nd FReLoN generation
  - FReLoN 16bit
  - Frame transfer mode
  - Fast readout board ? Extended to non-FreLoN camera, like Dalsa camera (60fps)

Staff involved in Project

- **ATEG Group (ESRF) for Frelon: J.C. Labiche, E. Collet, L. Siron and D. VanBrussel**
- **Special Detectors Group (ESRF): T. Martin, J. Borrel, C. Jarnias, F. Lesimple and C. Ponchut**
- **BLISS group (ESRF): D. Fernandez, G. Berruyer and V. Rey**
- **ID15 Beamline (ESRF): M. Di Michiel, T. Buslaps, J.M. Merino, V. Honkimaki**
- **Laboratoire de Physico-Chimie des Matériaux Luminescents, University of Lyons, France. C. Dujardin, A. Garcia-Murillo and C. Leluyer**