Cost-Effective EMCCD-Based Detector for Time-Resolved Biological SAXS Applications

V. Nagarkar, B. Singh, V. Gaysinskiy, L. Ovechkina, I.Shestakova, and S. Miller
Radiation Monitoring Devices, Inc.,
Watertown, MA 02472, USA

L. Guo, D.Gore, and T. Irving
BioCAT, Center for Synchrotron Radiation Research, Illinois Institute of Technology,
Chicago, IL 60616, USA

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Outline

- Background on time-resolved SAXS
- Detector requirements
- Detector concept and related developments
- Preliminary experiments at Argonne National Laboratory
- Results
- Discussion

Background on Time Resolved SAXS

- Time resolved X-ray diffraction of muscle
  - Elementary force generation in muscle contraction
- Static and time-resolved scattering from macromolecules in solution
  - Addresses the kinetics of “protein folding”
- Phase transitions in model membrane systems
  - Understanding membrane fusion
  - Biotechnological applications, especially in designing various drug delivery systems

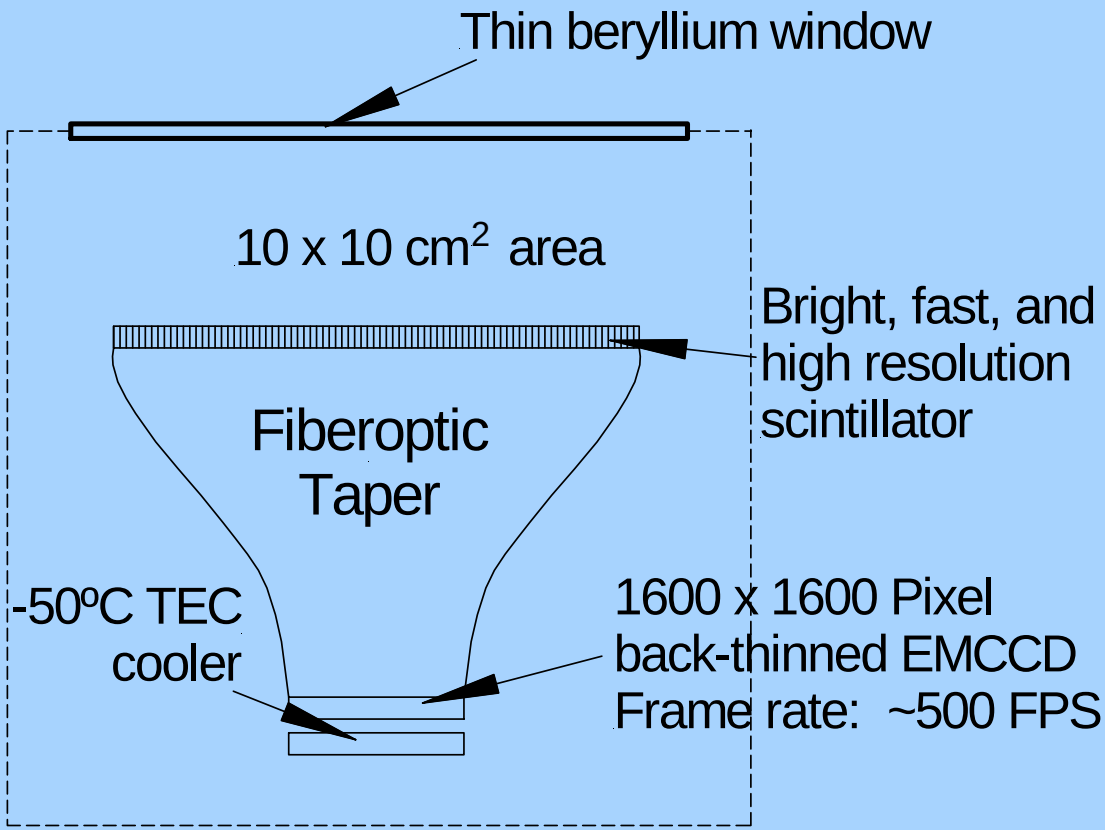
Technical Challenges in X-Ray Data Acquisition in Partially Ordered and Disordered Systems

- Scattering from such systems is intrinsically weak
- Time scale of interest is ms or sub-ms level
- In solution, the weak scattering at higher angles is spread out isotropically – difficult to detect over the background
- In muscle, the fiber patterns from biological tissues are complex with the need to resolve closely spaced peaks over a wide intensity range
- Cover a wide solid-angle

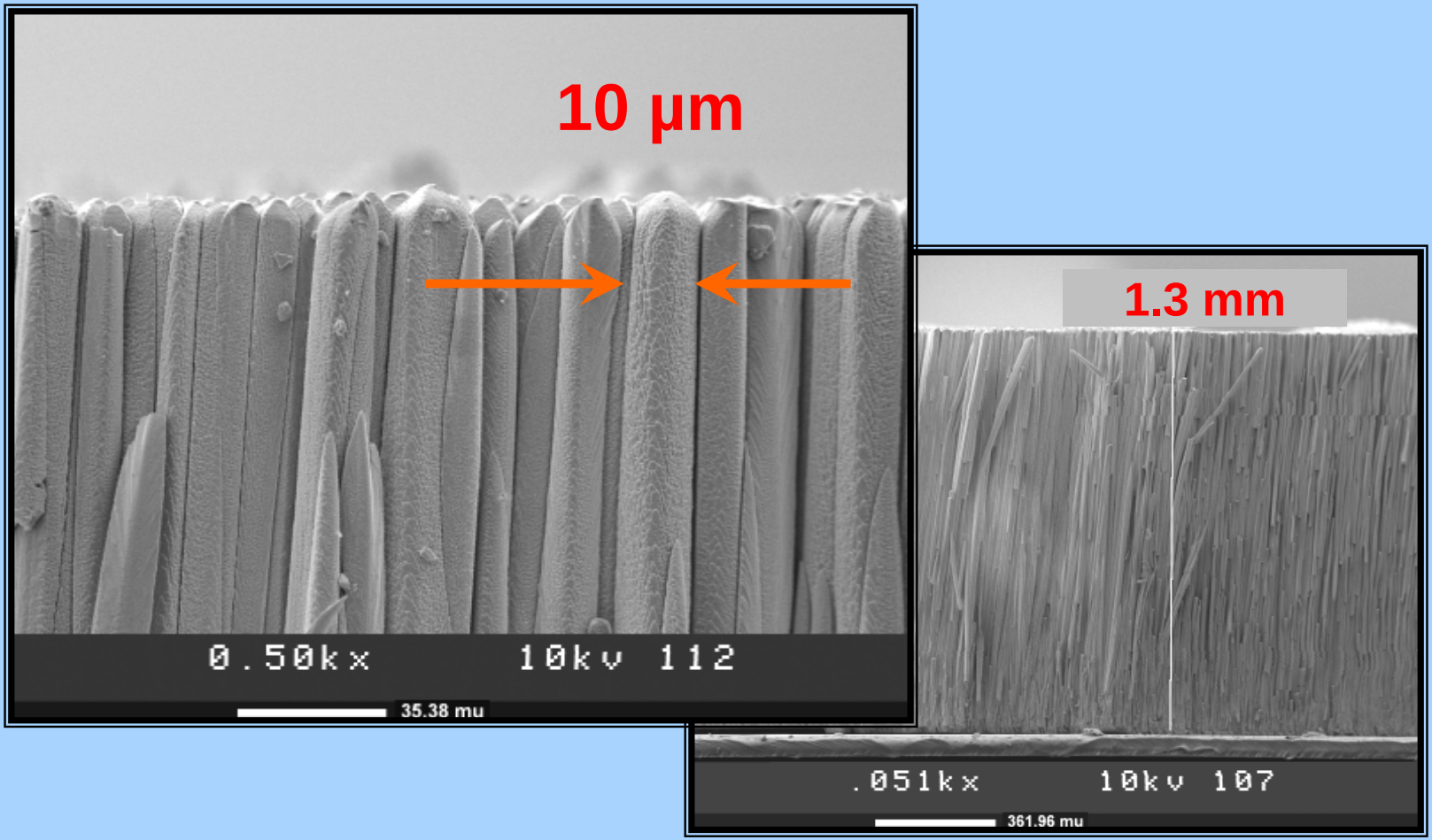
Detector Requirements

- Scintillator
  - Bright
  - Fast decay time with no afterglow
  - High x-ray absorption efficiency
  - Excellent Spatial resolution
  - Our Choice - New columnar CsI(Tl,Eu)
- Readout Sensor
  - High pixel resolution
  - High frame rates
  - Low read and dark noise
  - Wide dynamic range
  - Our Choice - New EMCCD Sensors

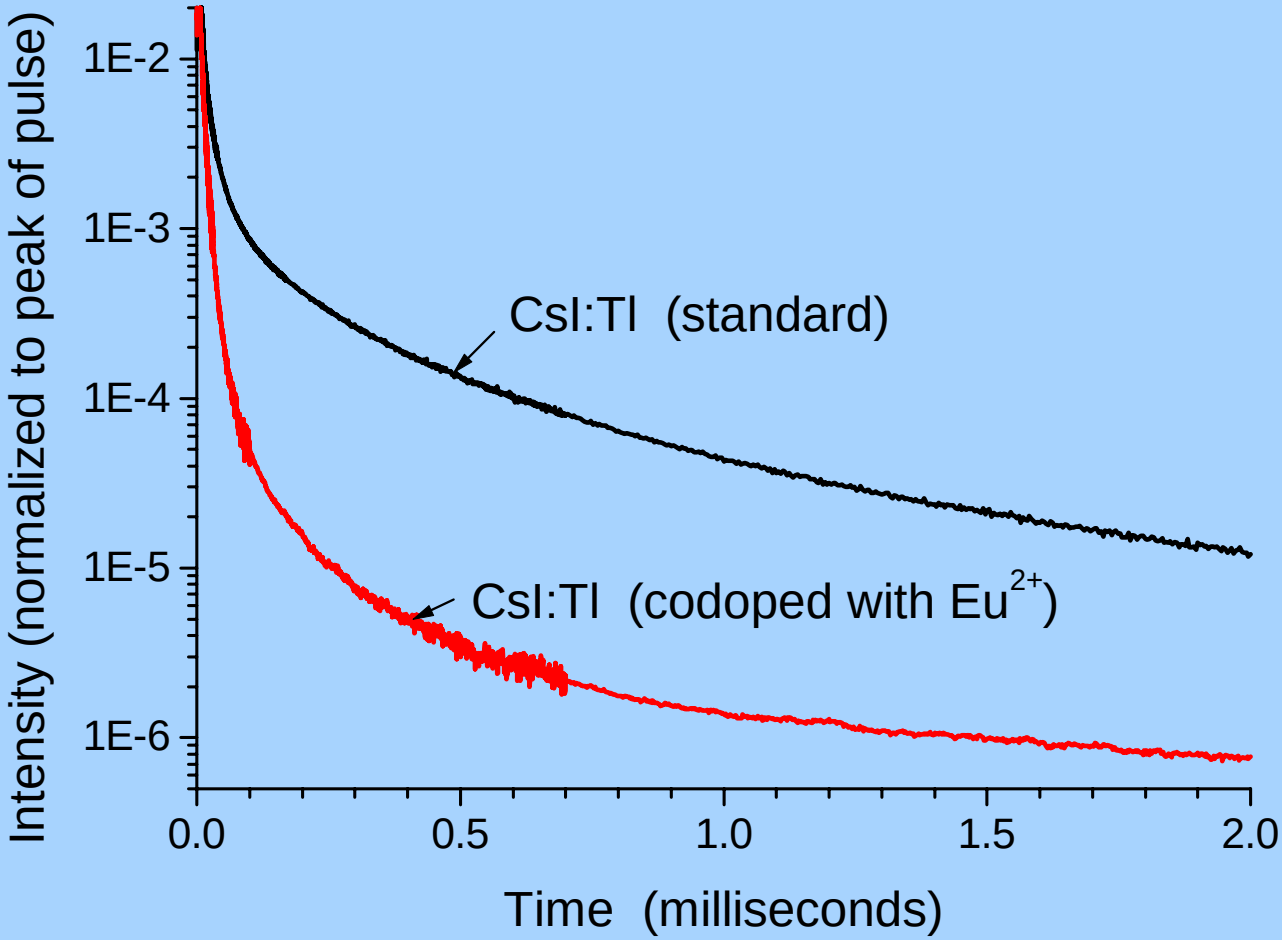
The Detector Concept



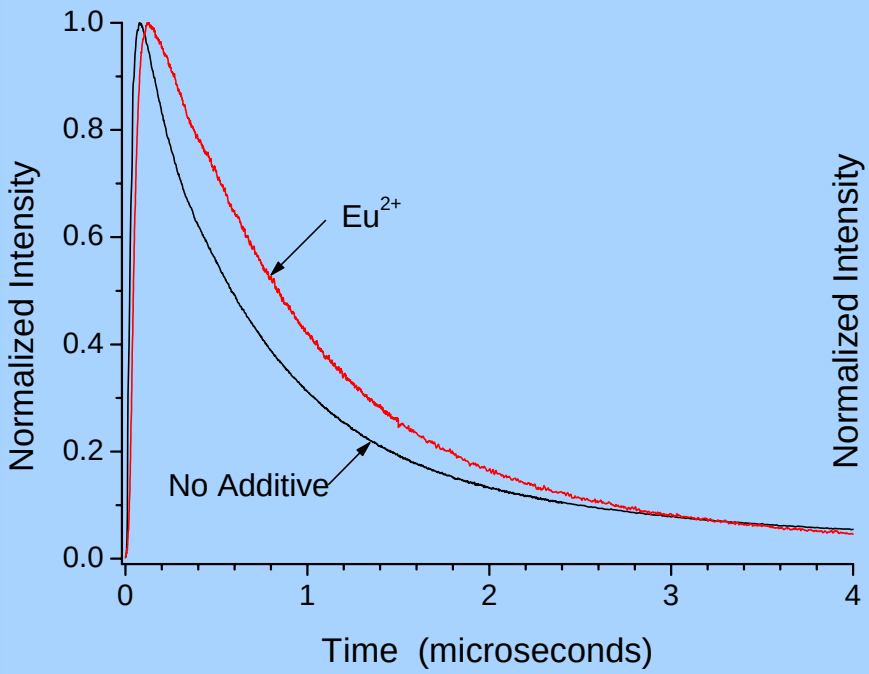
RMD Columnar CsI(Tl)

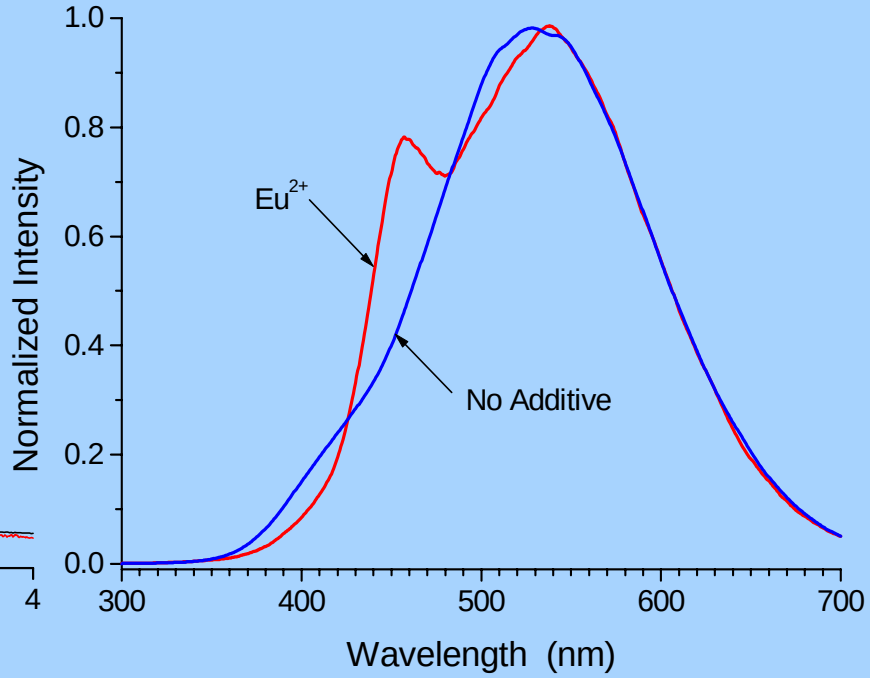


Fast scintillator development and evaluation



RMD Columnar CsI(Tl,Eu)





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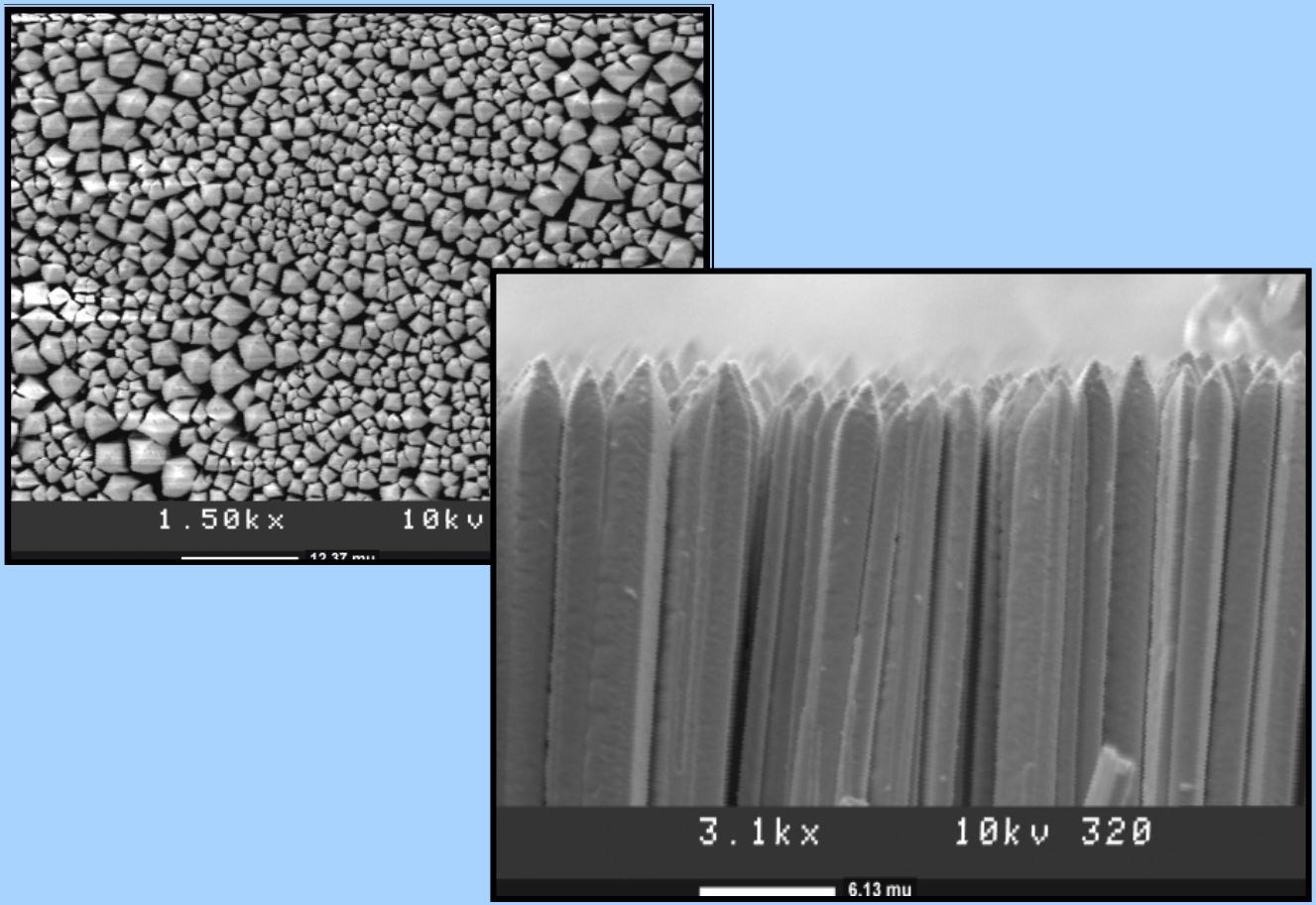

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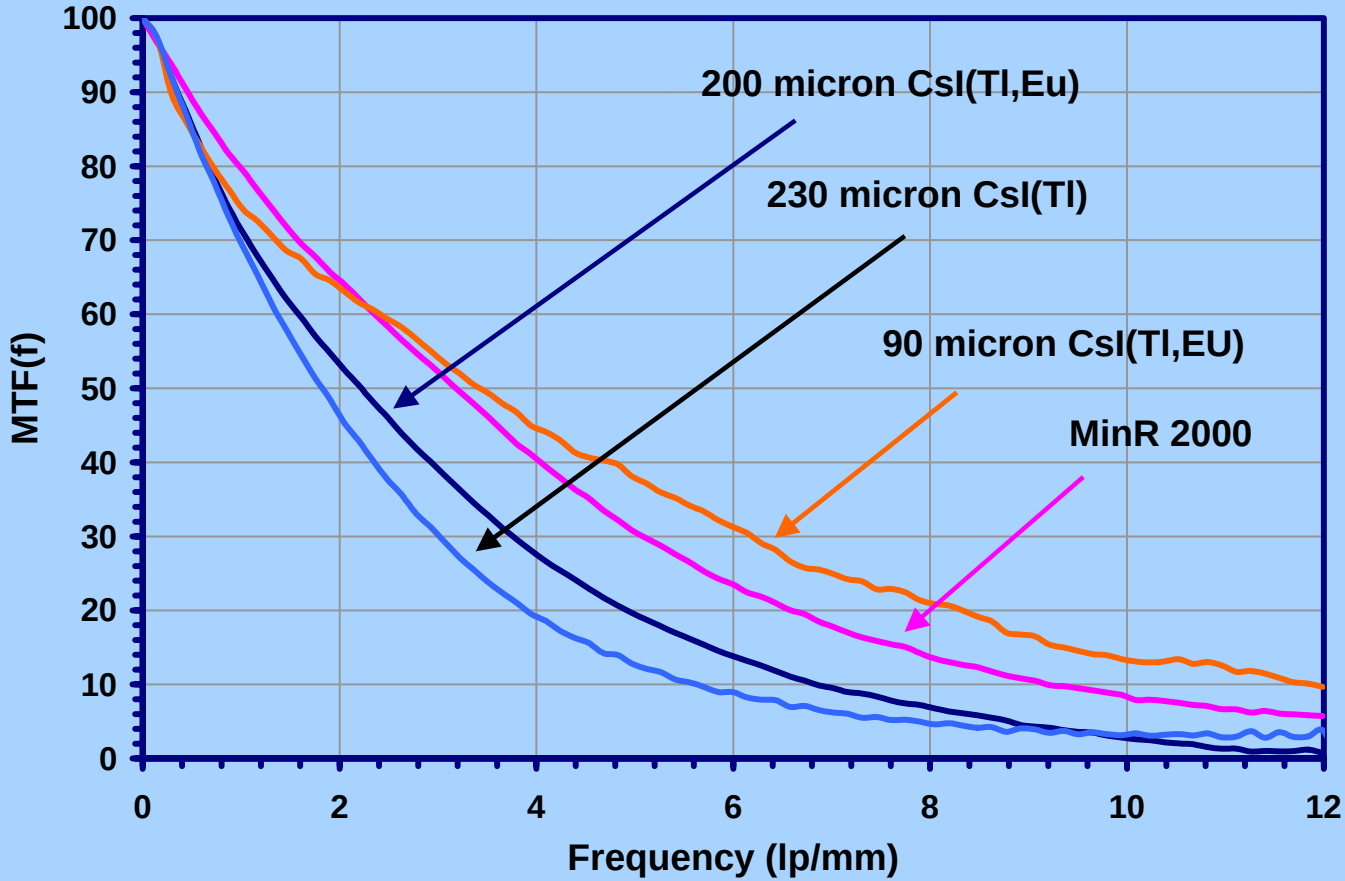
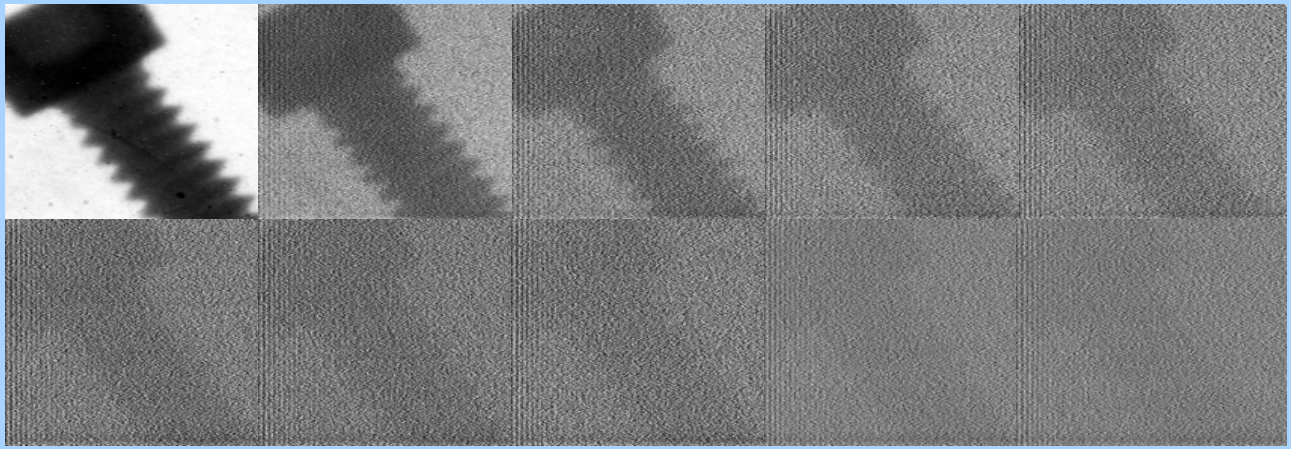
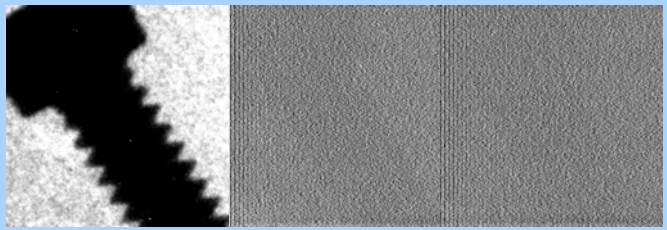


Scintillator persistence: 30 ms/frame

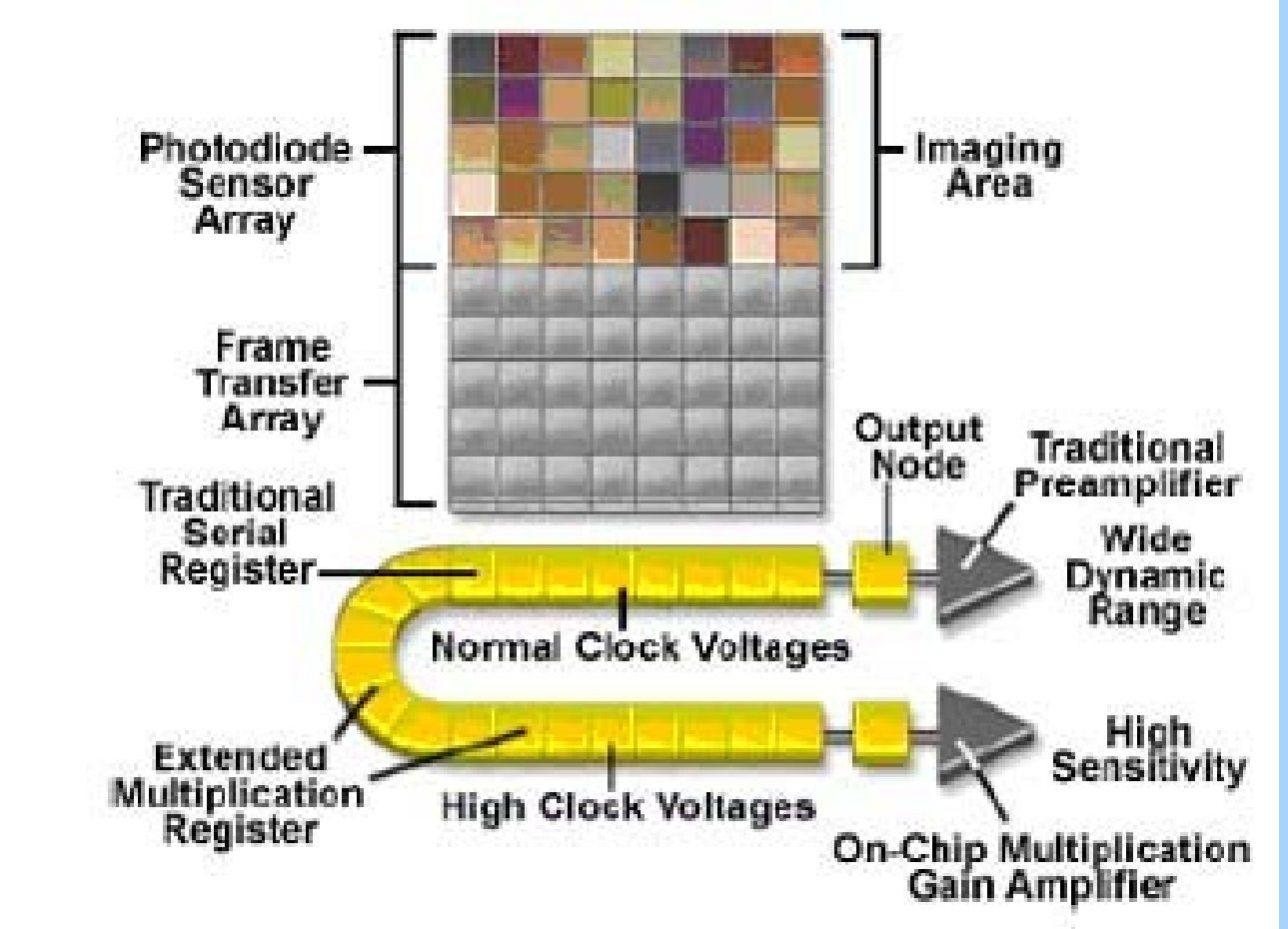


Current CsI(Tl) Scintillator



Co-doped CsI(Tl,Eu)

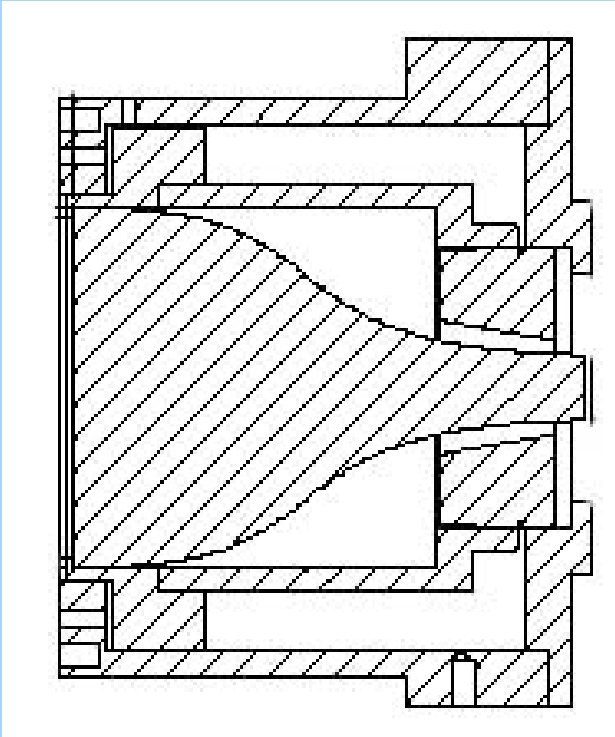
Background on EMCCD

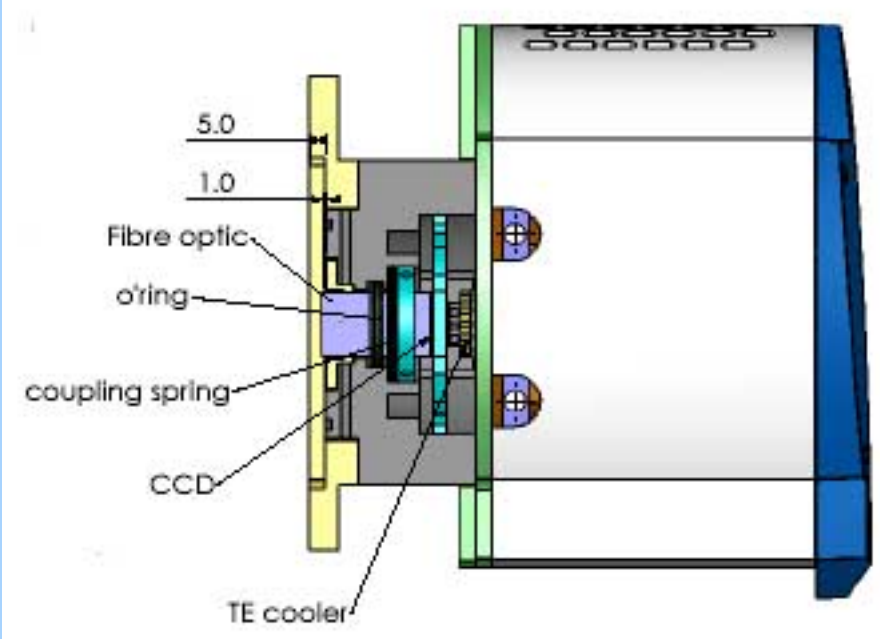


Advantages of EMCCD

- Low noise
  - Low read noise at high speeds through EM gain
- High speed readout
  - 30 fps to over 500 fps
- High sensitivity
  - Improved SNR for “light – starved” applications
- Adequate dynamic range

Custom Designed BI EMCCD



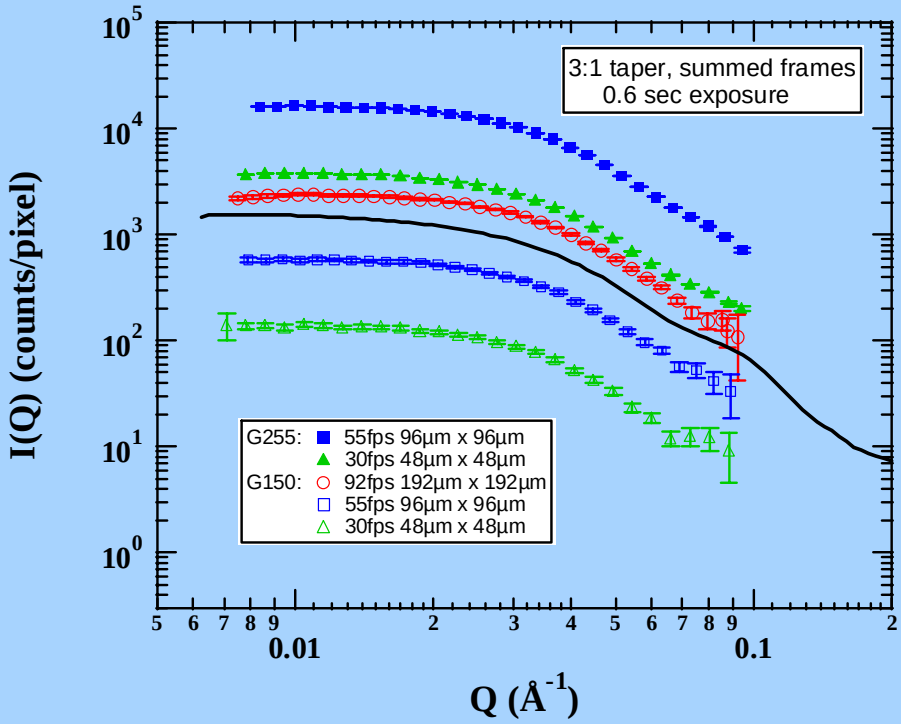


Custom Designed IXON 887 BI EMCCD

Detector Evaluation at the Argonne National Laboratory: Solution scattering of NtrC1C protein

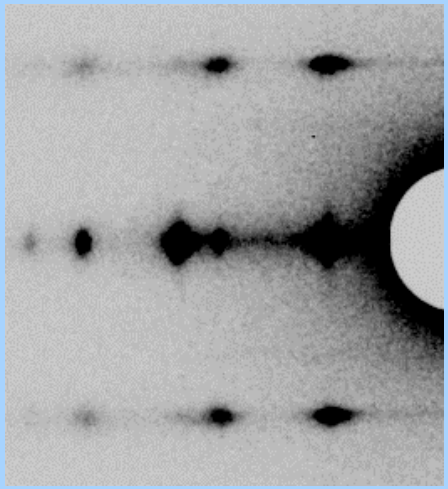
- Used standard SAXS instrument on the BioCAT beamline 18-ID
- Camera length: 1.82 m
- X-ray wavelength: 0.103 nm
- Detectors used:
  - Current EMCCD-based (512×512 pixels, 16×16μm^2 pixels)
  - Existing state-of-the-art “Brandeis” detector (4k×7k pixels, 12×12μm^2 pixels)

Scattering Intensity (I) Versus Scattering Vector (Q) where Q = $(4\pi/\lambda)*\sin(\theta/2)$



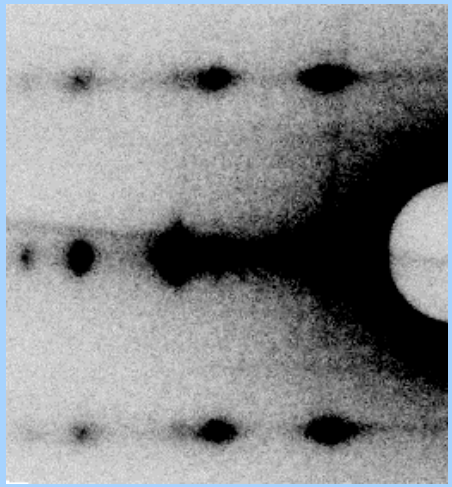
Solution scattering of NtrC1C protein measured using the state-of-art detector and the new EMCCD detector with 3:1 Taper

Fiber Diffraction Pattern from the Embedded Muscle Specimen



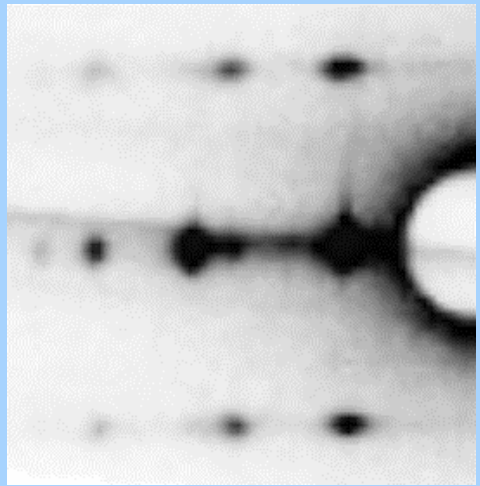
State-of-the-art detector

(30 ms data)



EMCCD with 3:1 taper, no binning

(33 ms data)



EMCCD with 3:1 taper, 4×4 binning

(11 ms data)

Z scale adjusted to account for higher EMCCD sensitivity

EMCCD Gain = 255

Summary

- Newly developed CsI(Tl,Eu)
  - Preserves excellent emission properties of CsI(Tl)
  - Enhances prompt emission by 20%
  - Reduces afterglow by a factor of 30
- EMCCD are an excellent choice for SAXS application
  - Fast readout rates with minimal read noise
  - High frame rates of 500+ fps possible
- Large area fiberoptic coupled EMCCD detector development is currently underway at RMD
  - Effective area 10.25 x 10.25 cm^2
  - High resolution of 1600 x 1600 pixels

Acknowledgements

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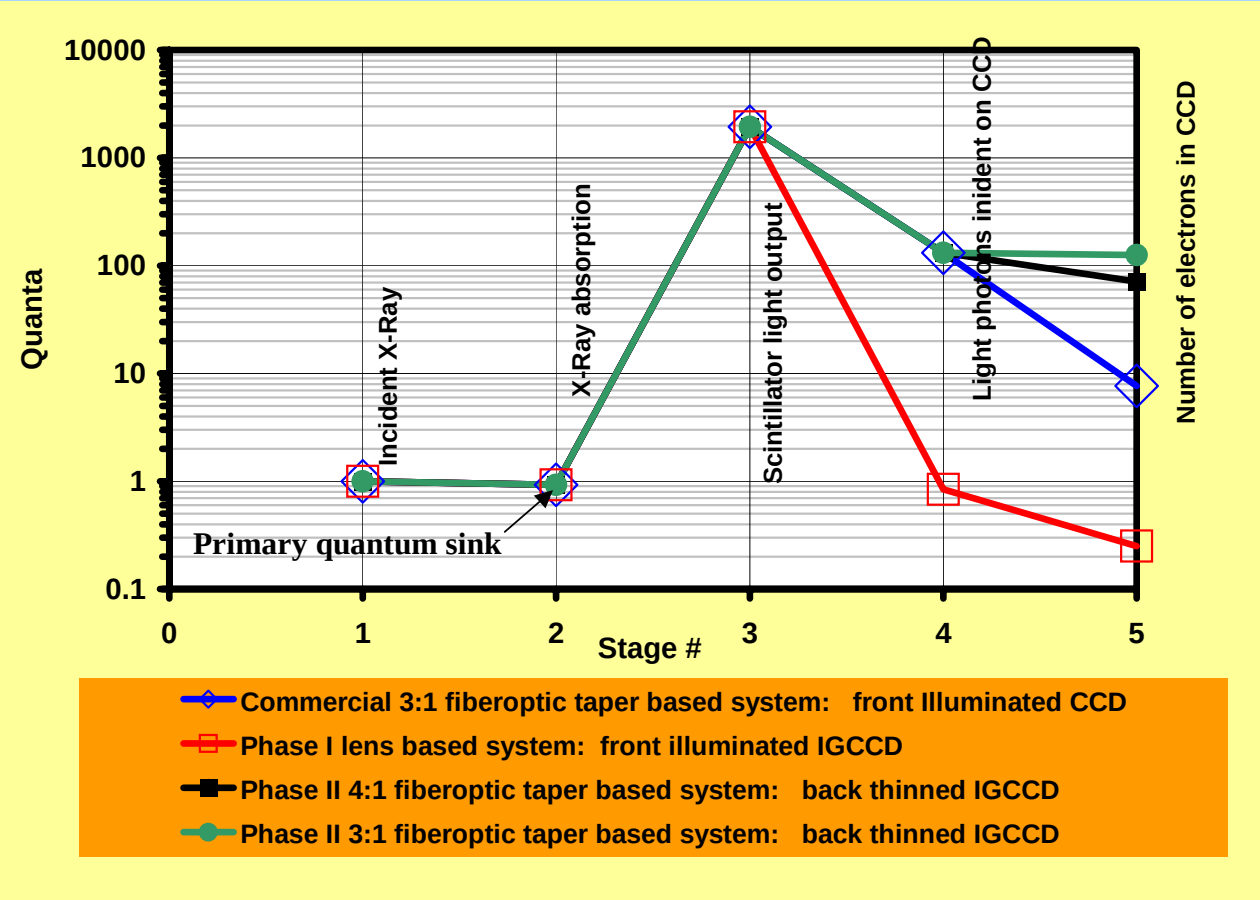
Quantum Accounting Diagram: Commercial VS EMCCD Based X-ray and γ-ray imaging systems



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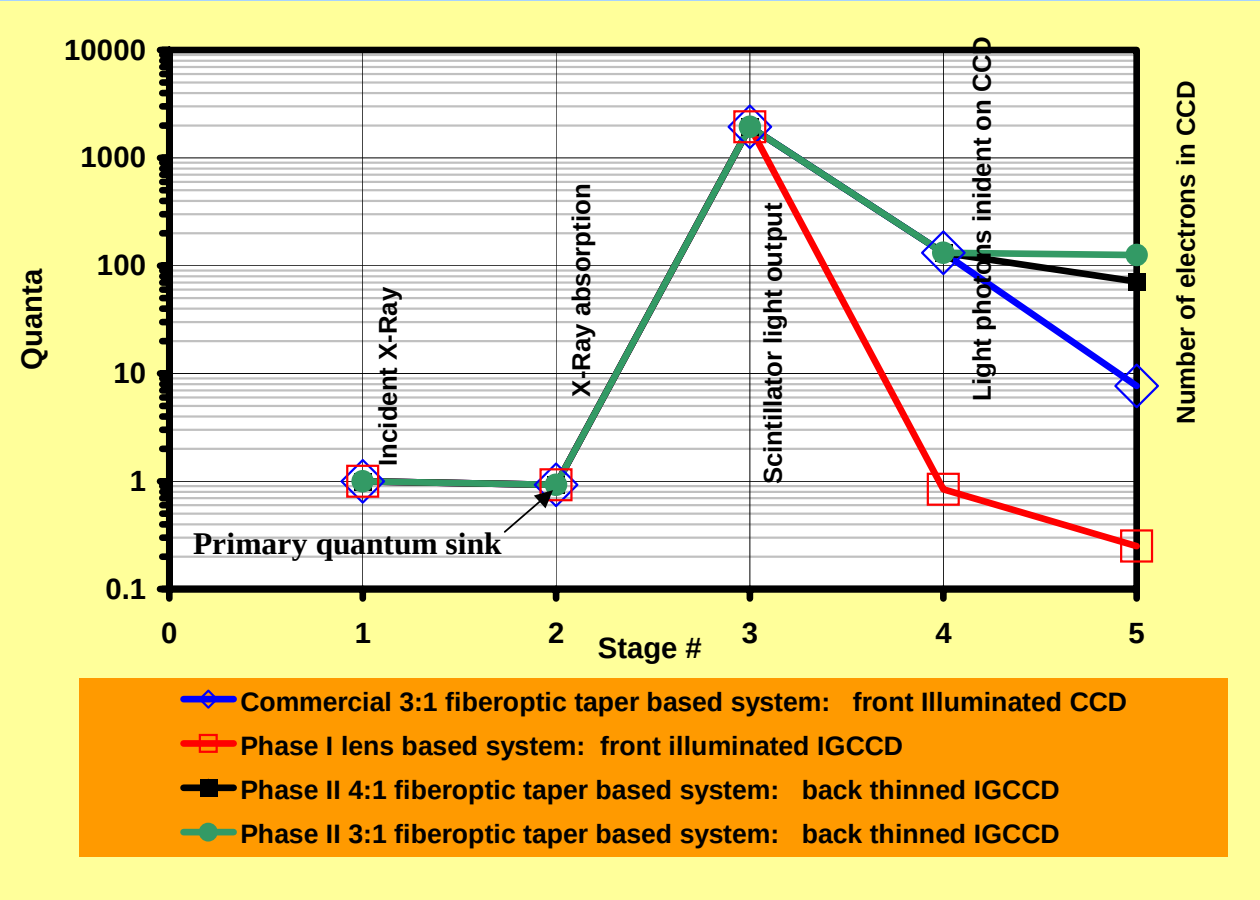
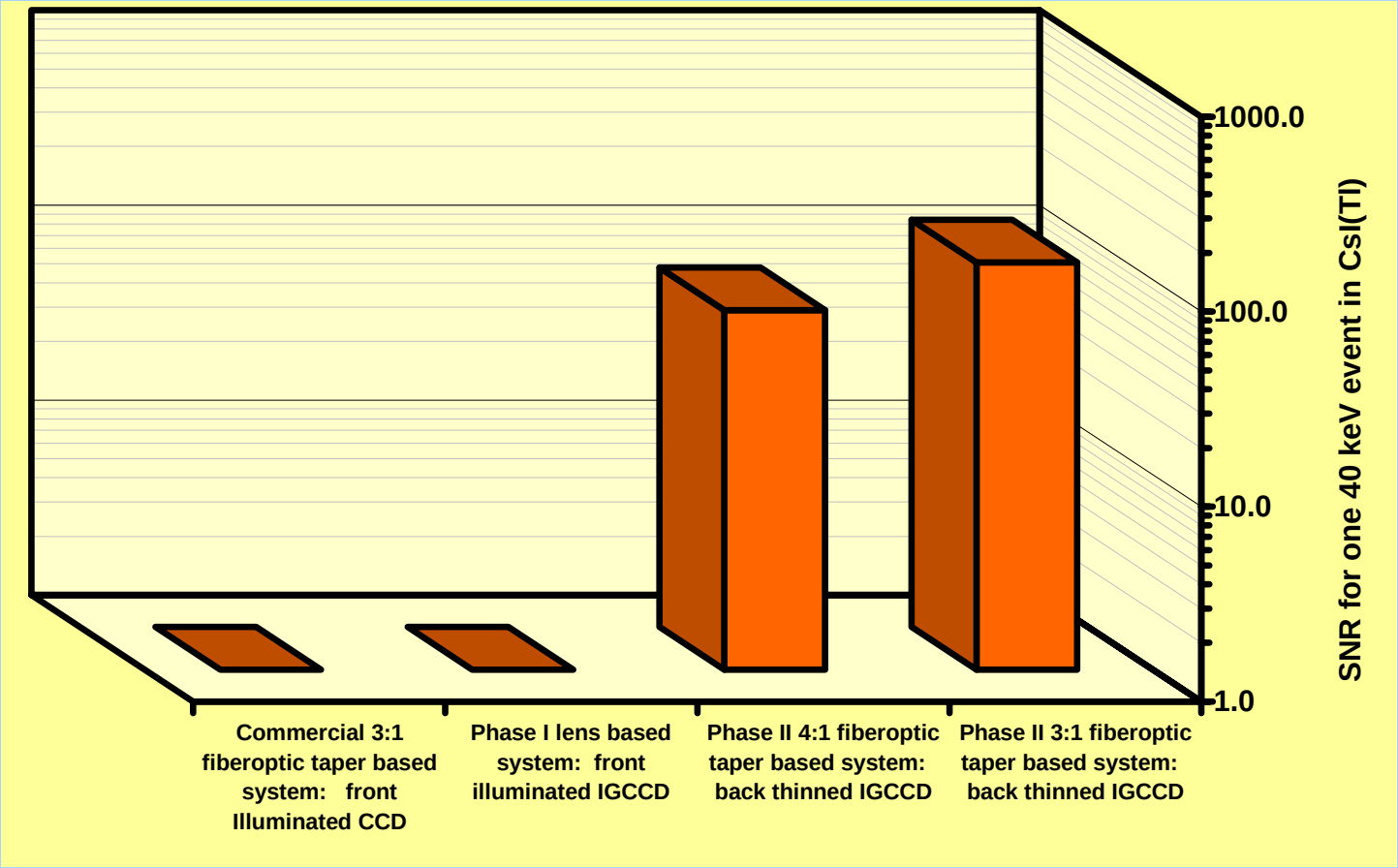


SNR at 10 MHz Readout Speed: Commercial VS EMCCD Based X-ray and γ-ray imaging systems



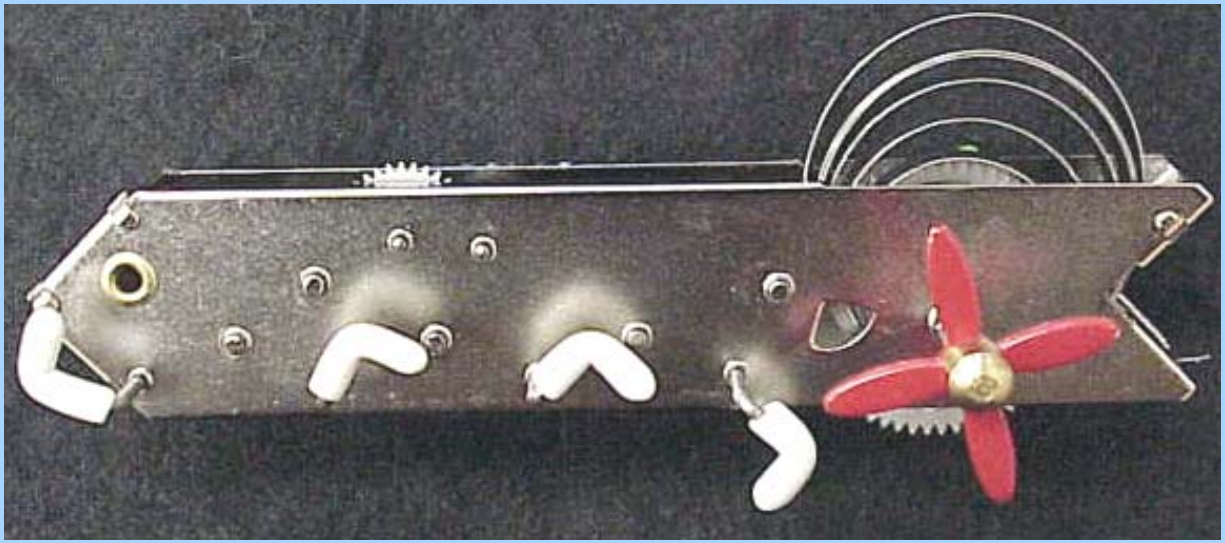
Imaging System Requirements

- Operate at the high global count rates (~10^7-10^8 photons/s)
- High sensitivity (ability to detect single photons)
- High spatial resolution (50µm-100µm)
- Large active area (>10cm×10cm)
- Read out with millisecond time resolution
- Wide dynamic range

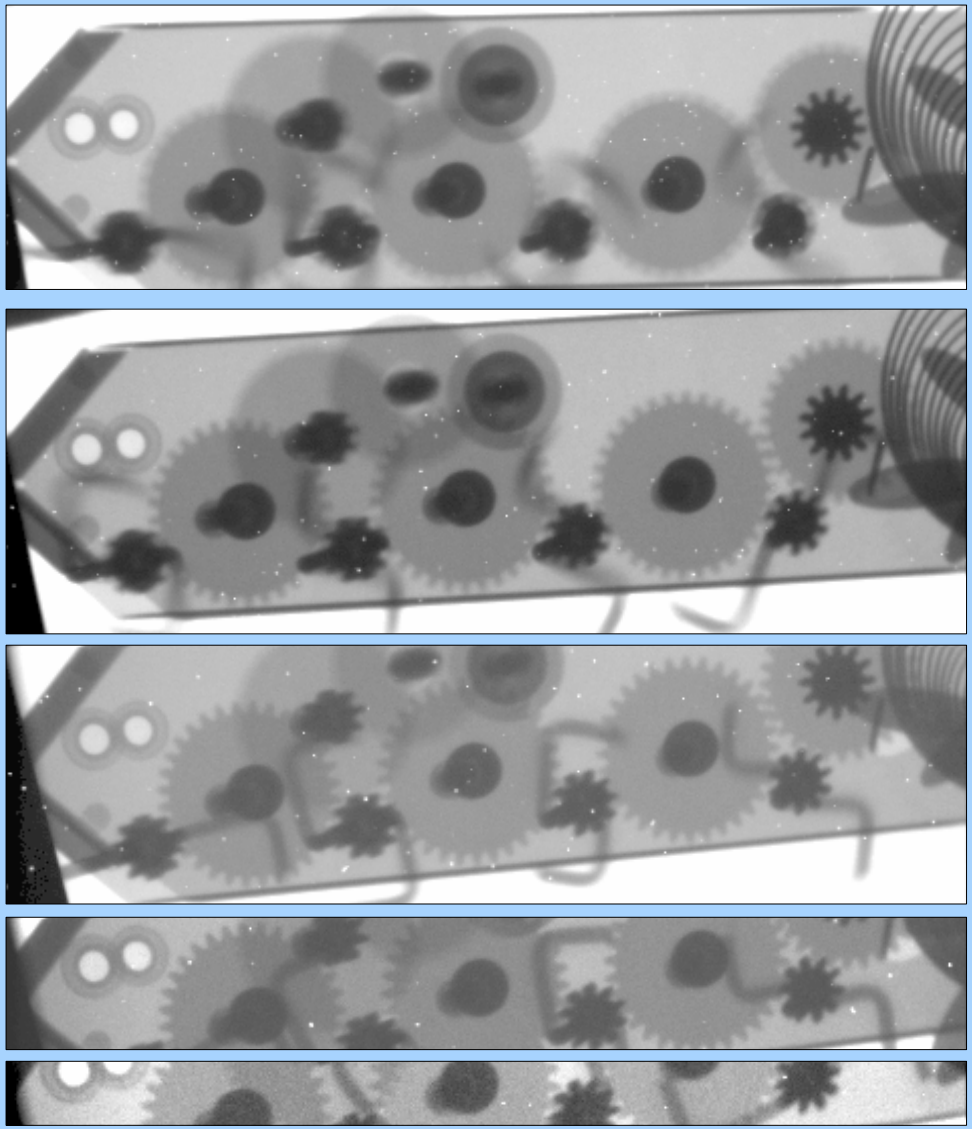
EMCCD Specifications

Parameter	*Specification*
CCD Chip	E2V CCD887 BI
Illumination	Back Illuminated
CCD Format	512 x 512 Pixels
Pixel Size	16 μm Square
Active Area (1:1 fiberoptic window)	8.2 x 8.2 mm^2
Active Area (3:1 fiberoptic window)	24.6 x 24.6 mm^2
Readout	16 bits; 10MHz
Frame rate (full resolution)	32 fps
Binning	Flexible binning
Frame rate binned mode	Up to 520 fps
On-chip gain	1 to >1000x
Operating temperature	-30C
Dark current	1 e-/pixel/sec @-30C
Read noise at 10 MHz	30 e- (Unity gain)
Read noise at 10 MHz	<1 e- (Gain of 40)

High-speed test object



High Speed X-ray Imaging



27 fps

50 fps

80 fps

120 fps

224 fps