

# The pnCCD (S)TEM Camera – a Pixelated, Fast and Direct Detector for TEM and STEM

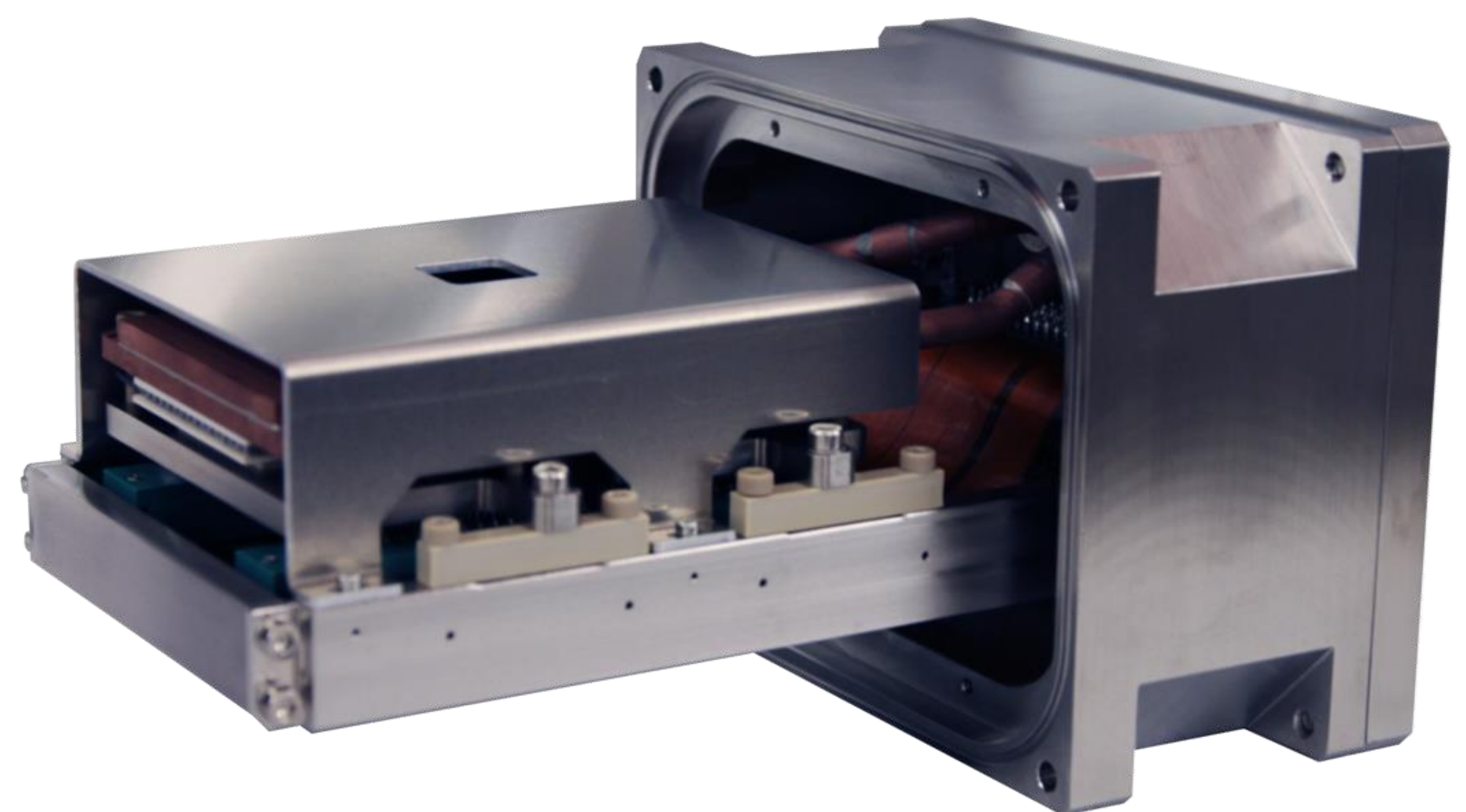
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|---|--|
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| 2. FZ Jülich, Ernst Ruska-Centre, Jülich, Germany | 6. University of Siegen, Germany   |
| 3. PNSensor GmbH, München, Germany                | 7. Helmholtz-Zentrum Berlin, Institut Nanoarchitekturen für die Energiewandlung, Berlin, Germany |
| 4. Sandia National Laboratories, Albuquerque, USA |  |

## The ultrafast pnCCD (S)TEM camera

### pnCCD specifications

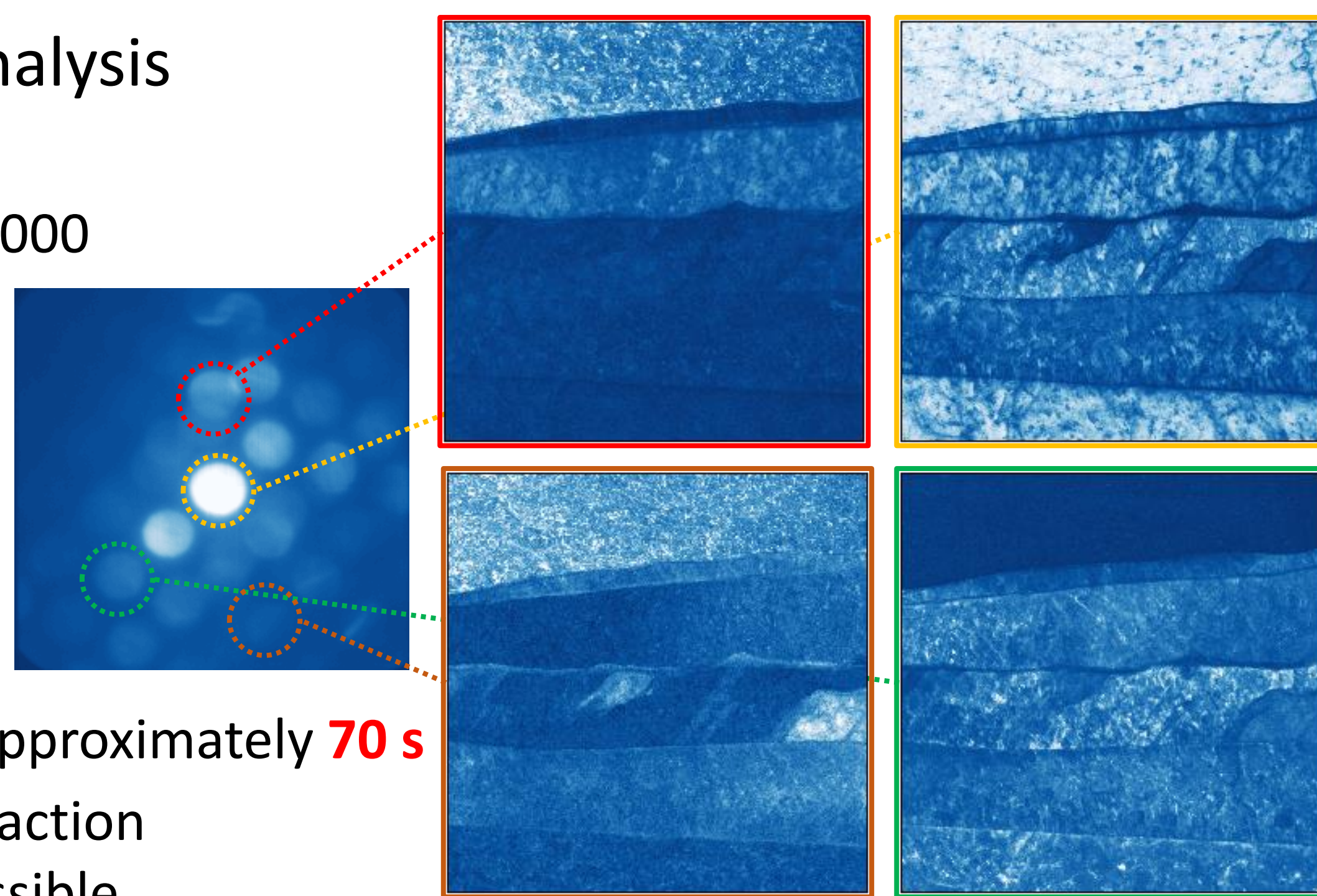
- Direct electron detection
- Speed: **Routinely 1,000 full frames per second**
- Up to 10,000 images per second in windowing mode (e.g., 4,000 fps @ 66 x 264 pixels)
- Low keV to high keV: Energy Range 5 keV – 300 keV
- Low noise (SNR 300:1)
- Extremely radiation hard: >  $5 \times 10^{11}$  e-/pixel @300keV
- Image area: 12.7 x 12.7 mm<sup>2</sup>
- Physical pixels: 264 x 264
- Sub-pixel resolution: 1,320 x 1,320 points
- Dynamic range: from single electron sensitivity to high flux conditions



## Application examples

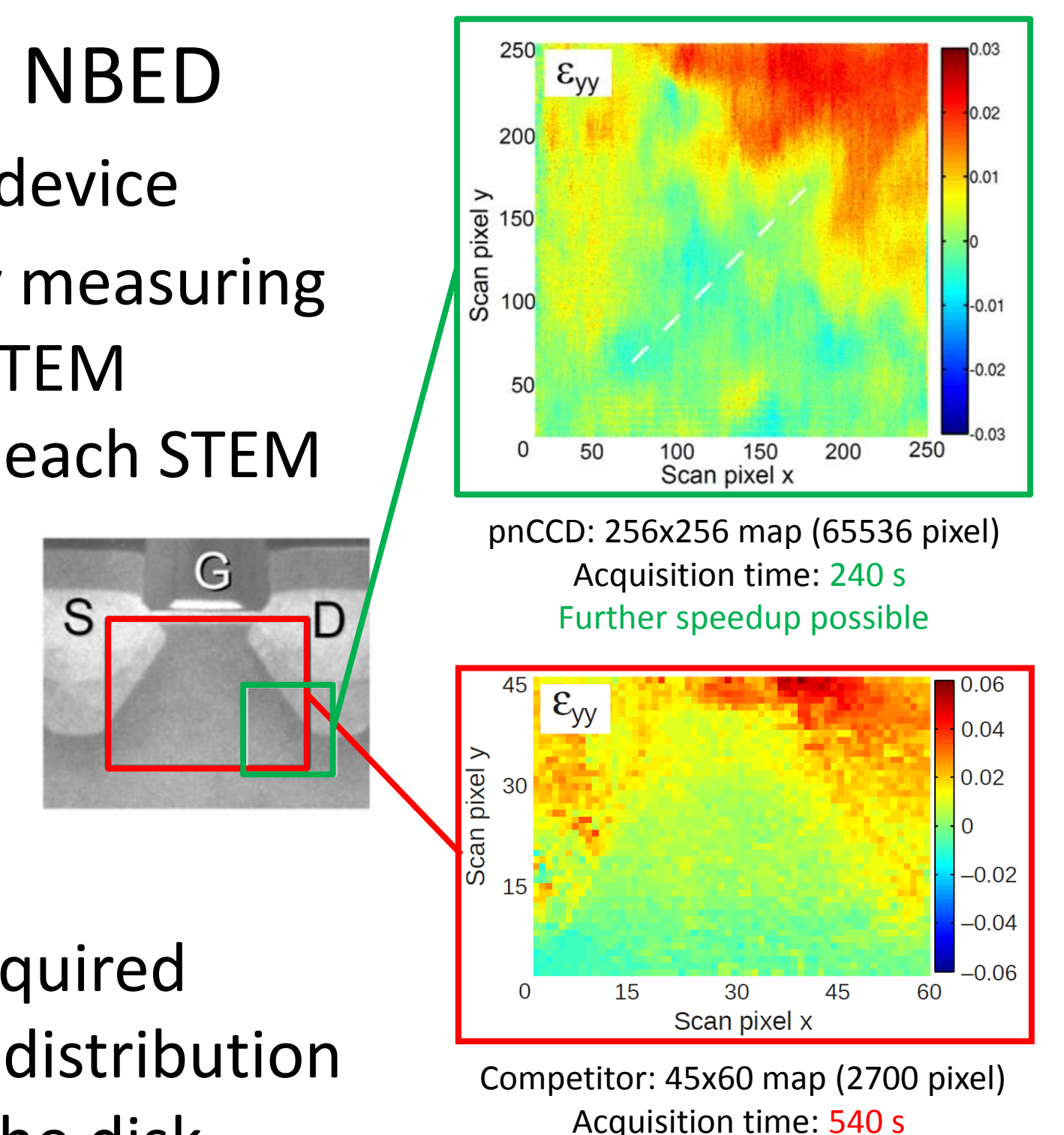
### STEM diffraction pattern analysis

- Sample: Meteorite
- Image diffraction pattern of 1,000 STEM pixels per second
- Camera readout mode:
  - Full frame (264x264 pixels)
  - Triggered readout @ 1,000 fps
- One STEM image with 256 x 256 STEM probe positions can be recorded in approximately **70 s**
- User-defined selection of diffraction pattern subset for analysis possible



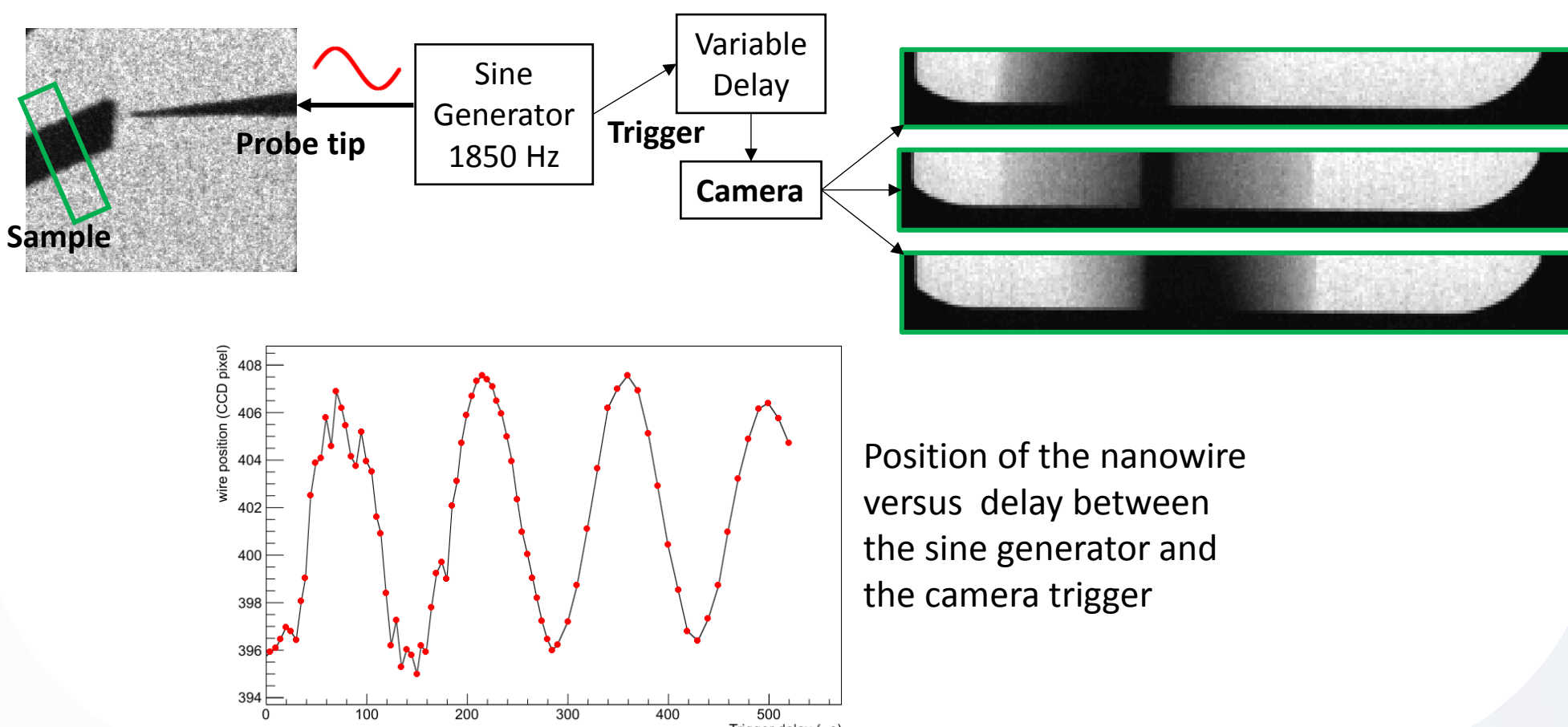
### Strain analysis by NBED

- Sample: MOSFET device
- Measure strain by measuring displacement of STEM diffraction disk at each STEM probe position
- Camera readout:
  - Full frame (264x264 pixels)
  - 1,000 fps
- 2D information required because intensity distribution fluctuates inside the disk



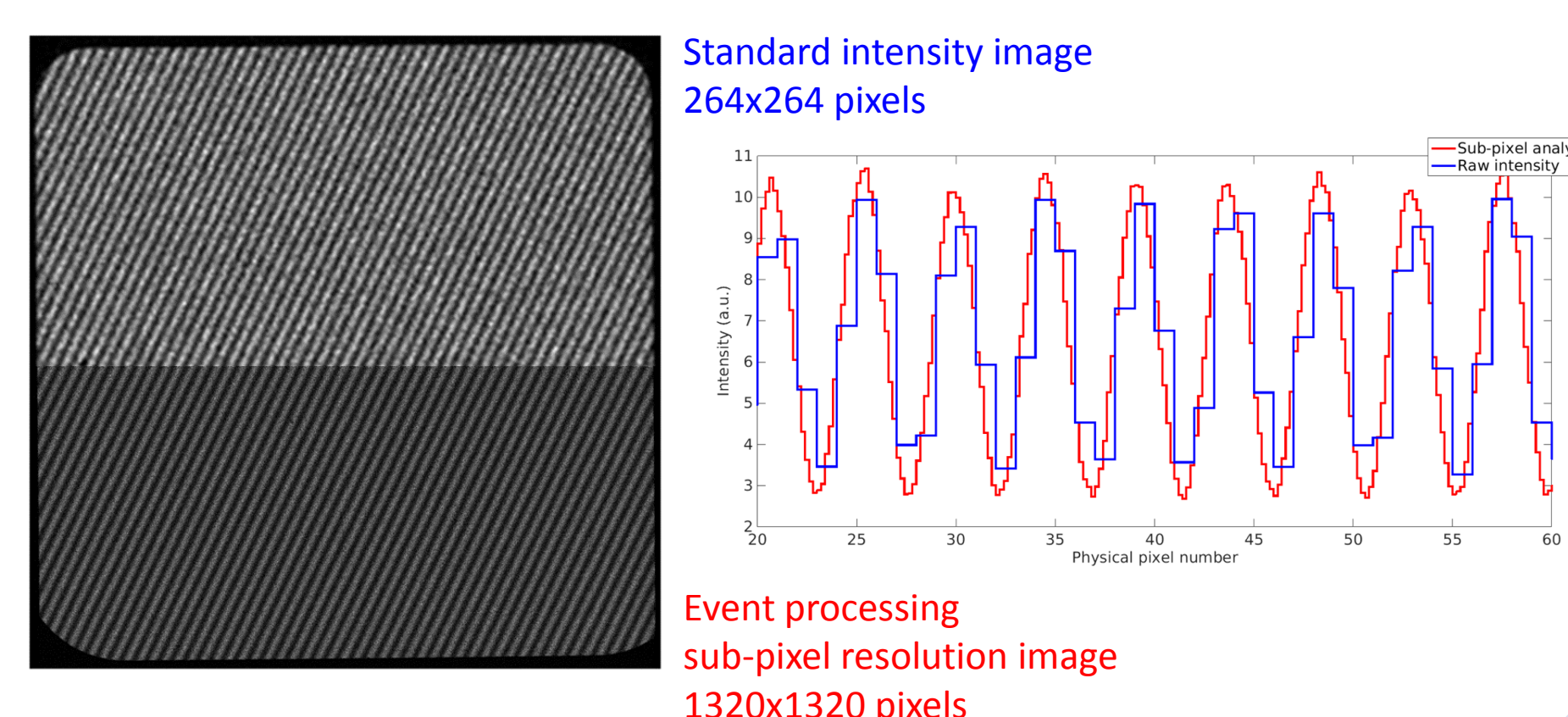
### Nanowire oscillations

- Sample: CdS nanowire
- Resonant vibrations induced by sine voltage on probe tip close to the sample
- Time resolved TEM imaging
- Camera readout mode:
  - Windowing (2x 33x264 pixels)
  - Triggered readout @ 1,850 fps
  - **Integration time 25 μs per frame**
- Measurements with variable trigger delay reveal nanowire oscillations with 4 times the excitation frequency



### Electron holography

- Sample: Electron biprism
- Interference causes fringes in the TEM image
- Camera readout mode:
  - Full frame (264x264 pixels)
  - **Sub-pixel resolution 1320x1320 pixels**
- Sub-pixel resolution improves the clarity of the sine oscillations



### Fast EELS

- Sample: AgCl
- Electron Energy Loss Spectrum (EELS) forms a narrow line on the pnCCD
- Camera readout mode:
  - Windowing (24x264 pixels)
  - **Readout rate 7,400 fps**

