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Radiometry & few-photon metrology at the National Research Council of Canada

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Radiometry & Few-Photon Metrology at the National Research Council of Canada

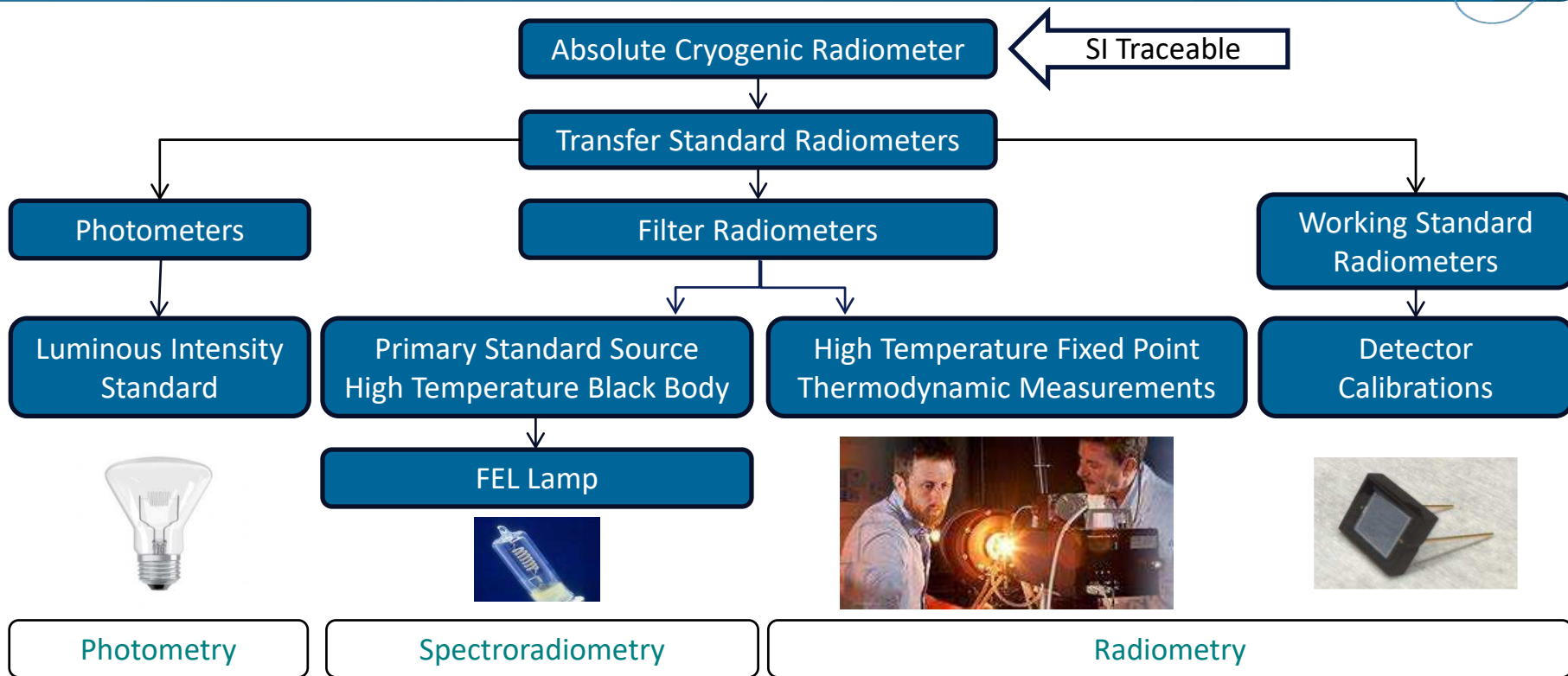
Angela Gamouras, Andrew D.W. Todd, Éric Côté, Arnold A. Gaertner,
Jeongwan Jin, Dan Dalacu, and Robin Williams

CALCON 2018

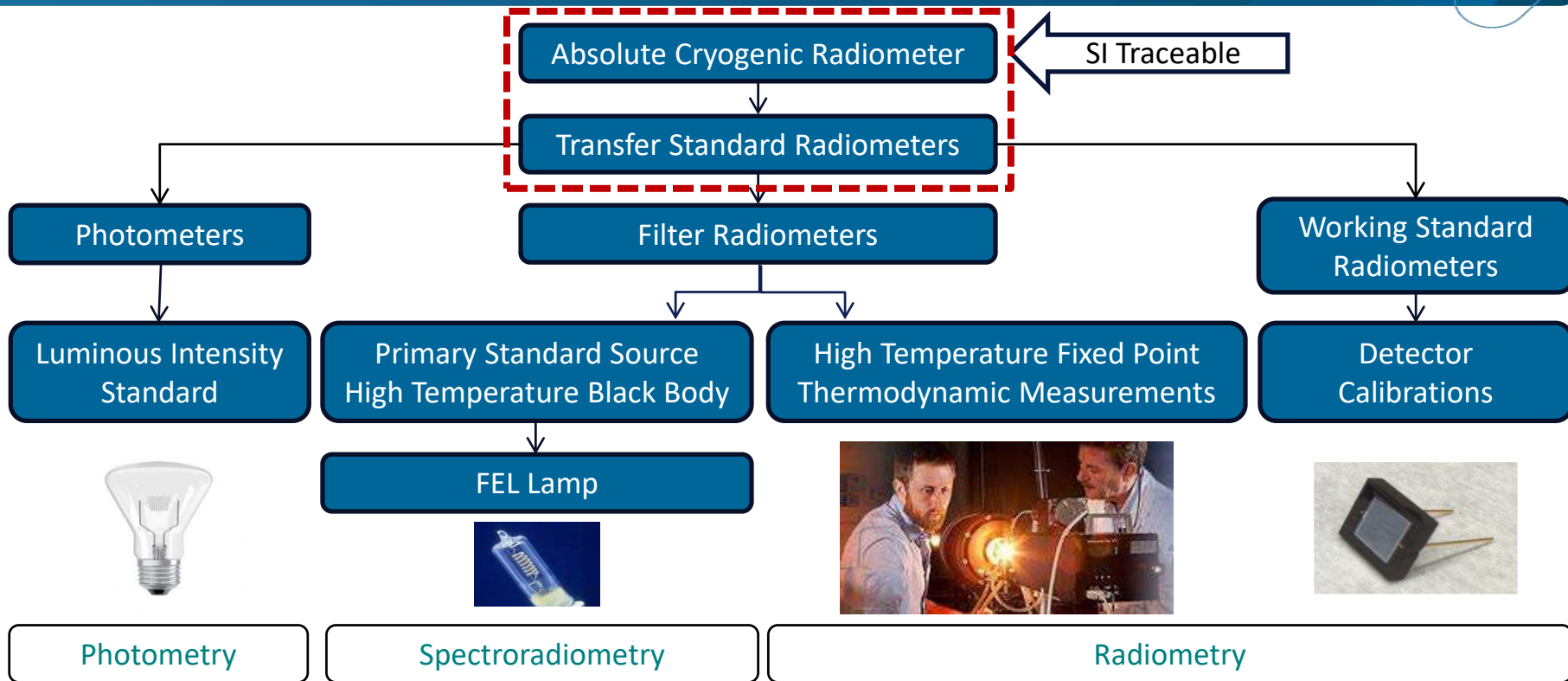
Outline

- Optical radiation calibration chain
 - Primary optical radiant power facility
 - Spectral irradiance facility
- Few photon metrology
 - Traceable characterization of single-photon detectors and NRC quantum dot-based single-photon sources

Optical radiation calibration chain



Optical radiant power scale

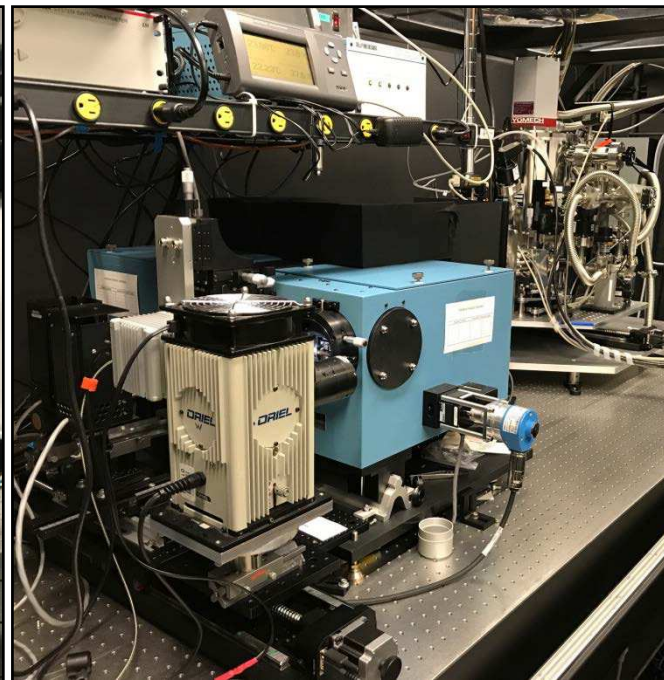
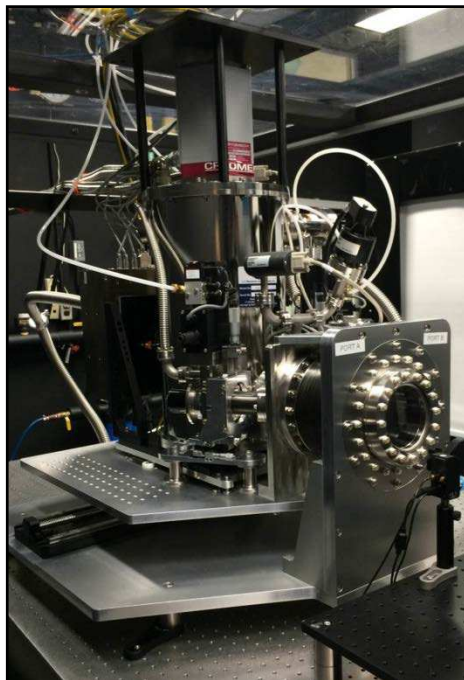


Advanced radiometry facility

- New cryogenic radiometer with closed-cycle helium cryocooler
- Double-subtractive monochromator
- Custom-designed motion apparatus for optical alignment

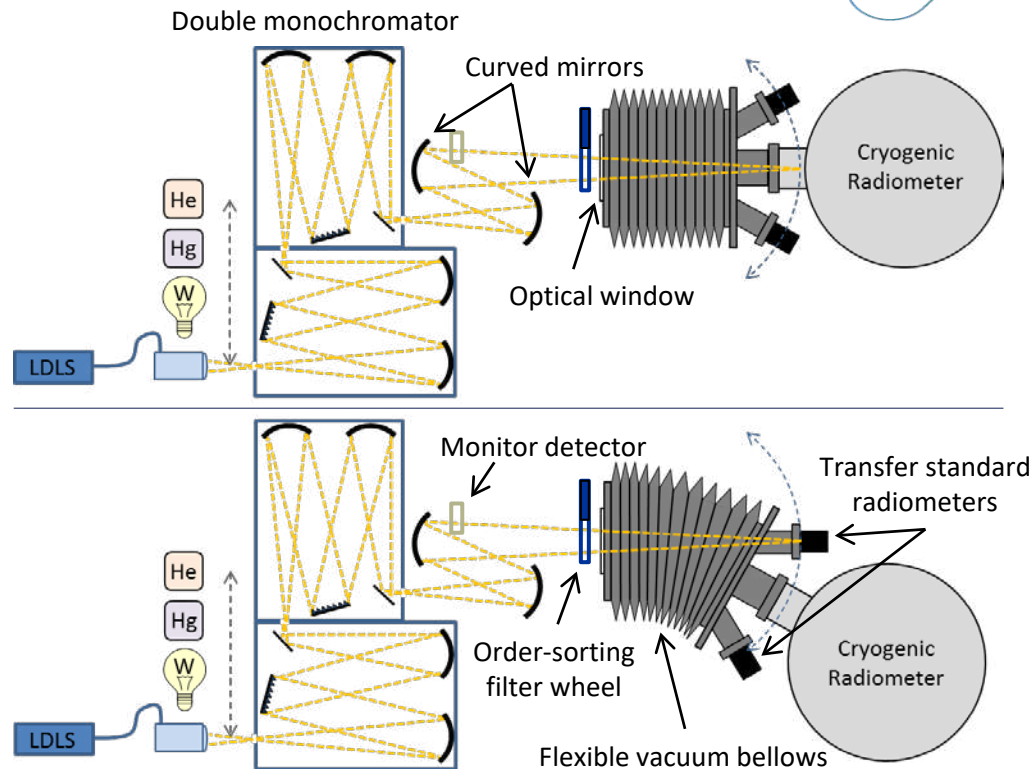
Cryogenic radiometer uncertainty improvements

Source	old (%)	new (%)
Cavity absorptance	0.01	0.004
Nonequivalence effects	0.01	0.001



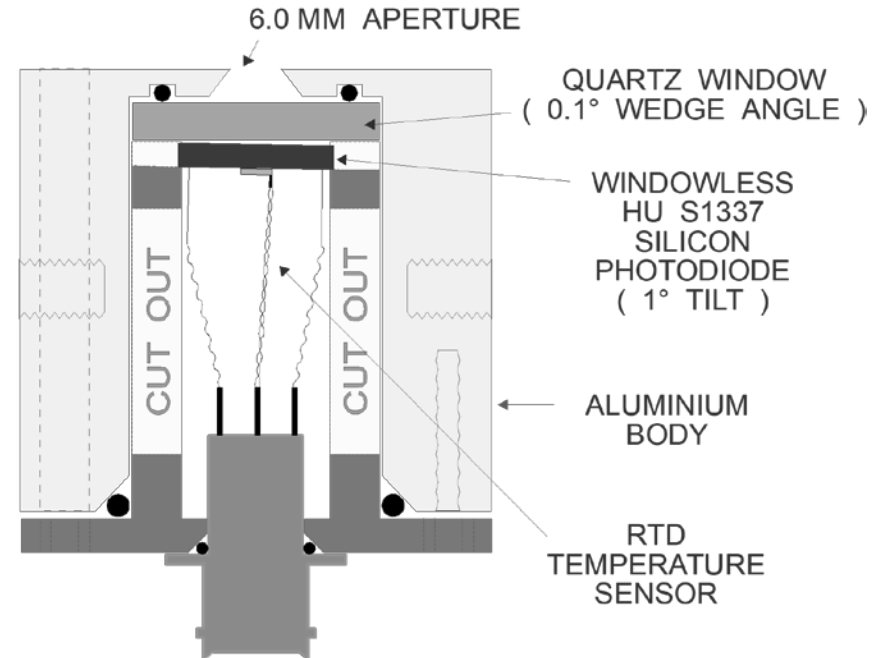
Advanced radiometry facility

- Broadband laser-driven light source (LDLS) and tungsten lamp
- Linear stage with pin and pivot system facilitates alignment to the common optical path (30° motion)
- Gate valves between the bellows vacuum chamber and the transfer radiometer mounting ports allow for detectors to be changed during system operation



Transfer standard radiometers

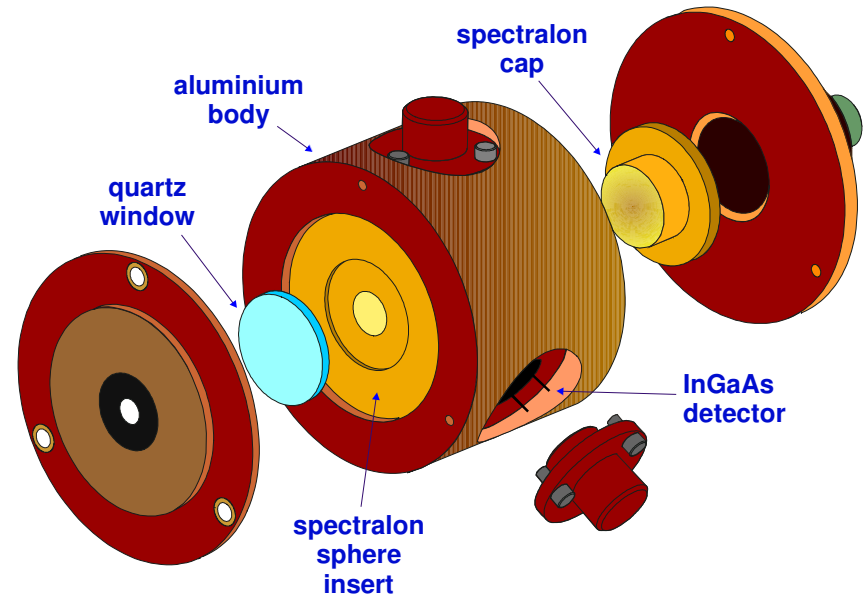
- Single element detector with quartz window
- Vacuum compatible front face
- Temperature monitoring
- Si and PtSi detectors for VIS and UV wavelength ranges



Boivin, Metrologia **32** 565 (1995)

Transfer standard radiometers

- Sphere radiometer design
- Small integrating sphere and three 5 mm diameter InGaAs detectors
- Improved spatial uniformity in NIR
- Vacuum compatible front face and temperature monitoring



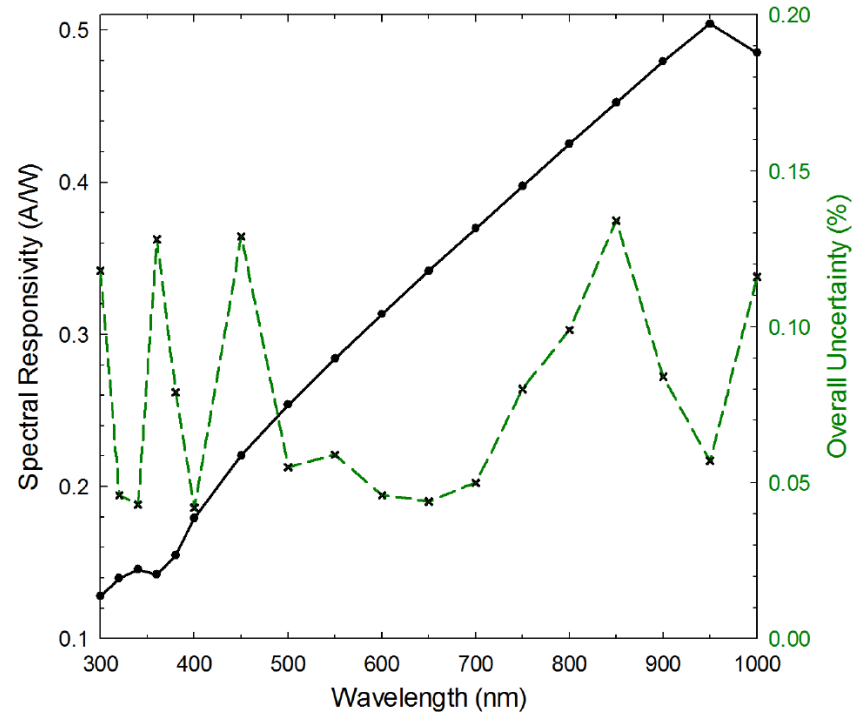
Boivin, Metrologia **37** 237 (2000)

Spectral responsivity scale

- Scale realization from 300 nm to 1000 nm using Si transfer standard detectors
- Presently working on scale from 900 nm to 1600 nm

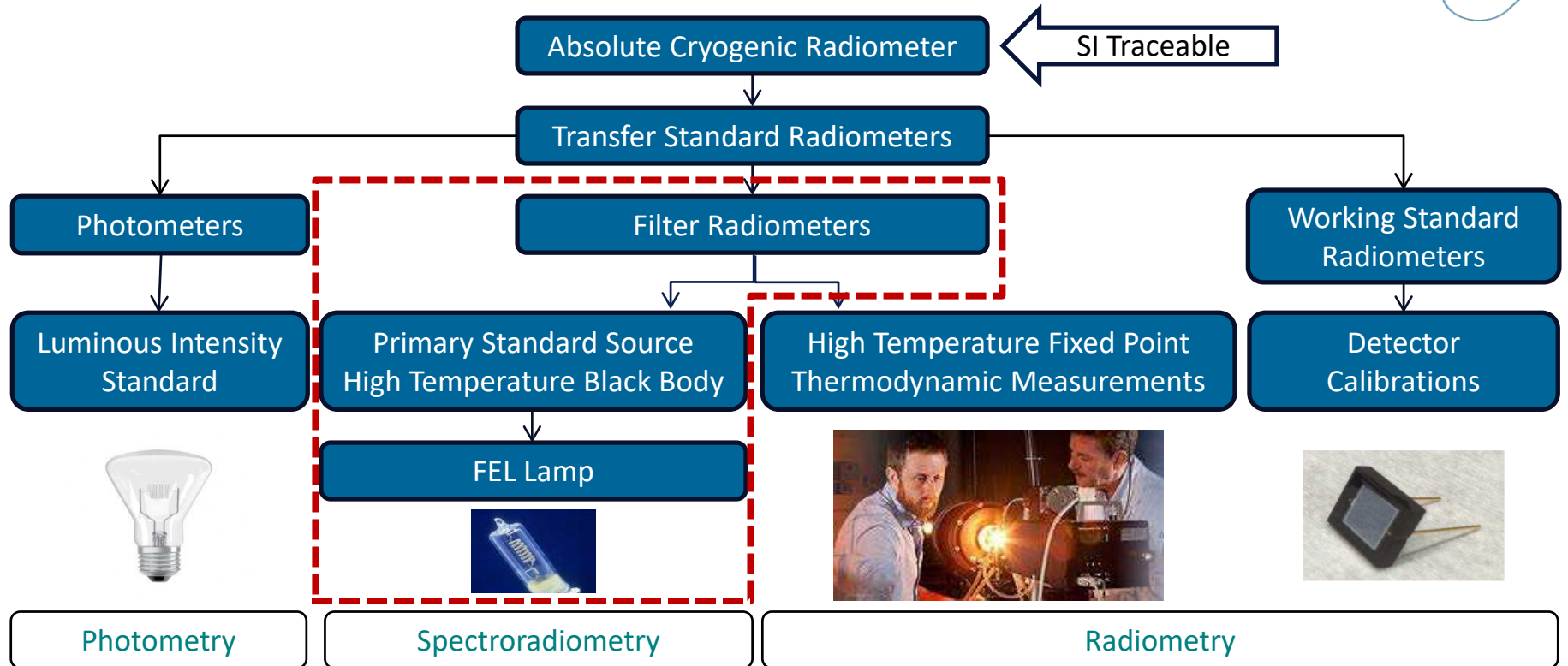
Next step:

- UV scale from 200 nm to 400 nm



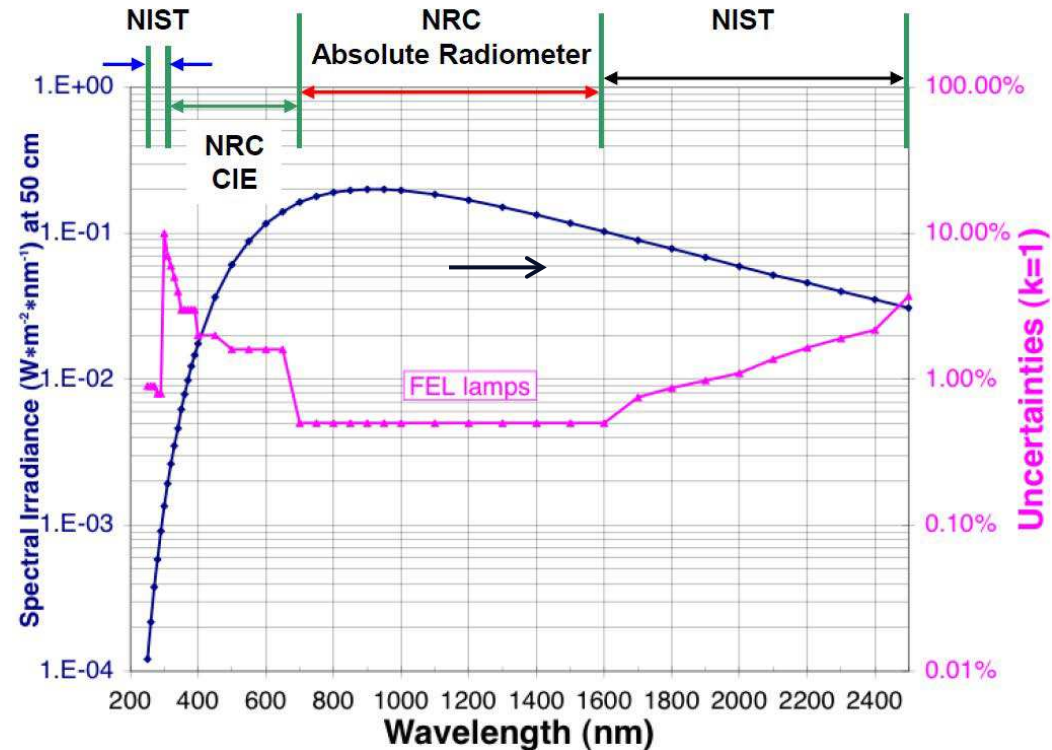
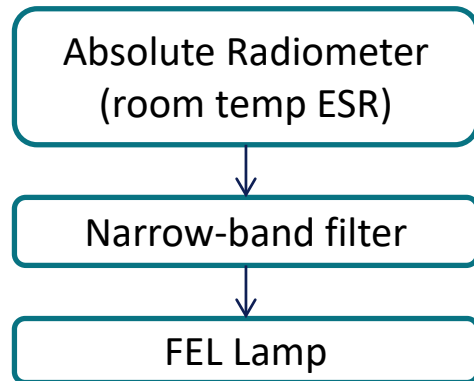
Average of uncertainty components from four Si transfer standard detectors

Spectral irradiance scale



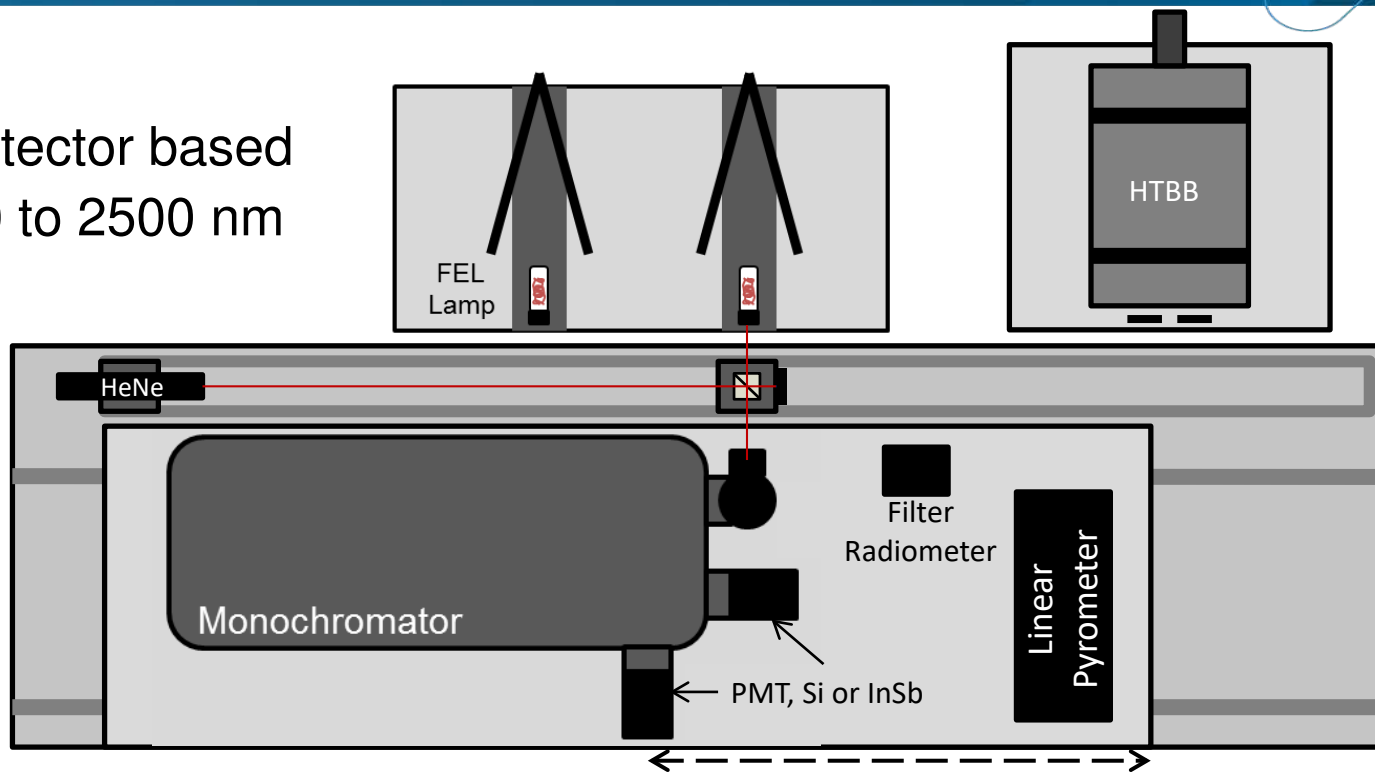
Spectral irradiance scale transition

Detector based scale 700 -1600 nm



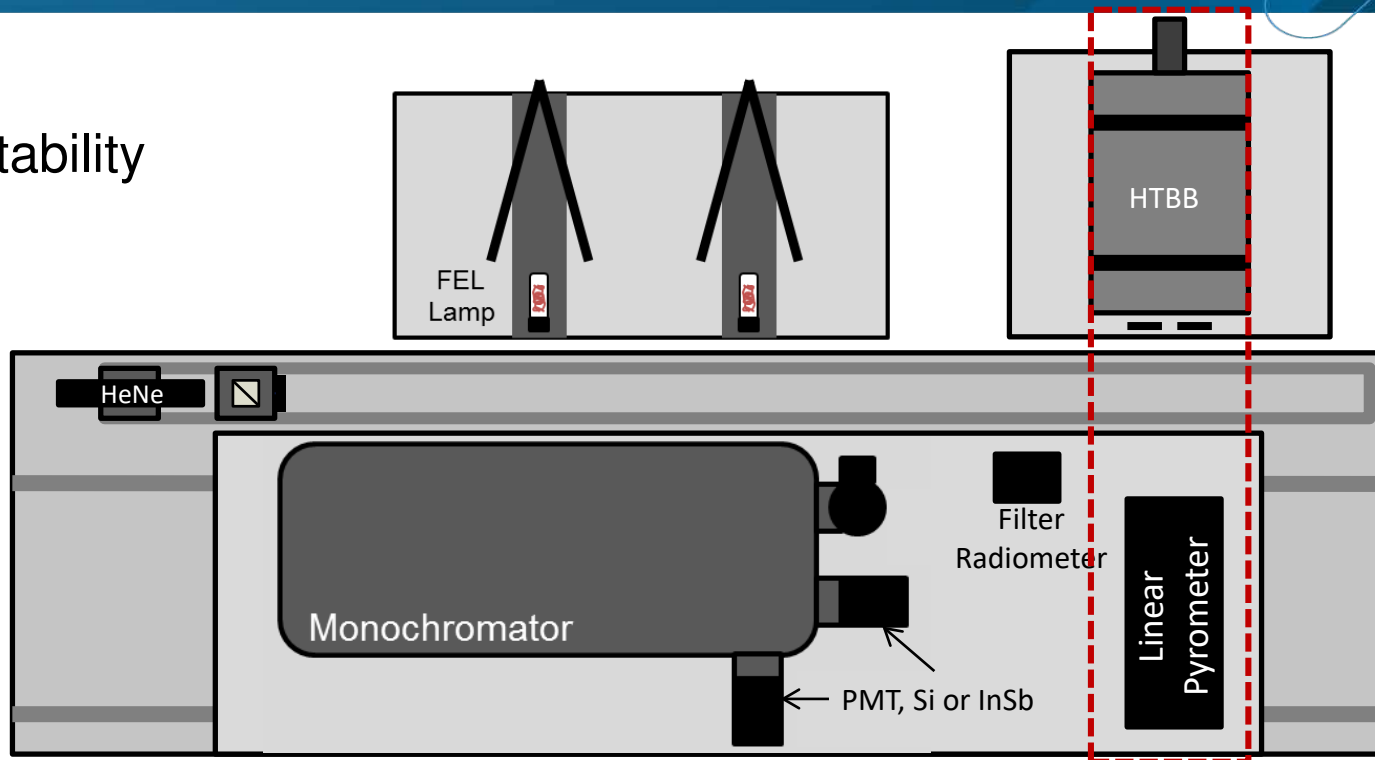
Spectral irradiance facility

- Source and detector based scale from 250 to 2500 nm



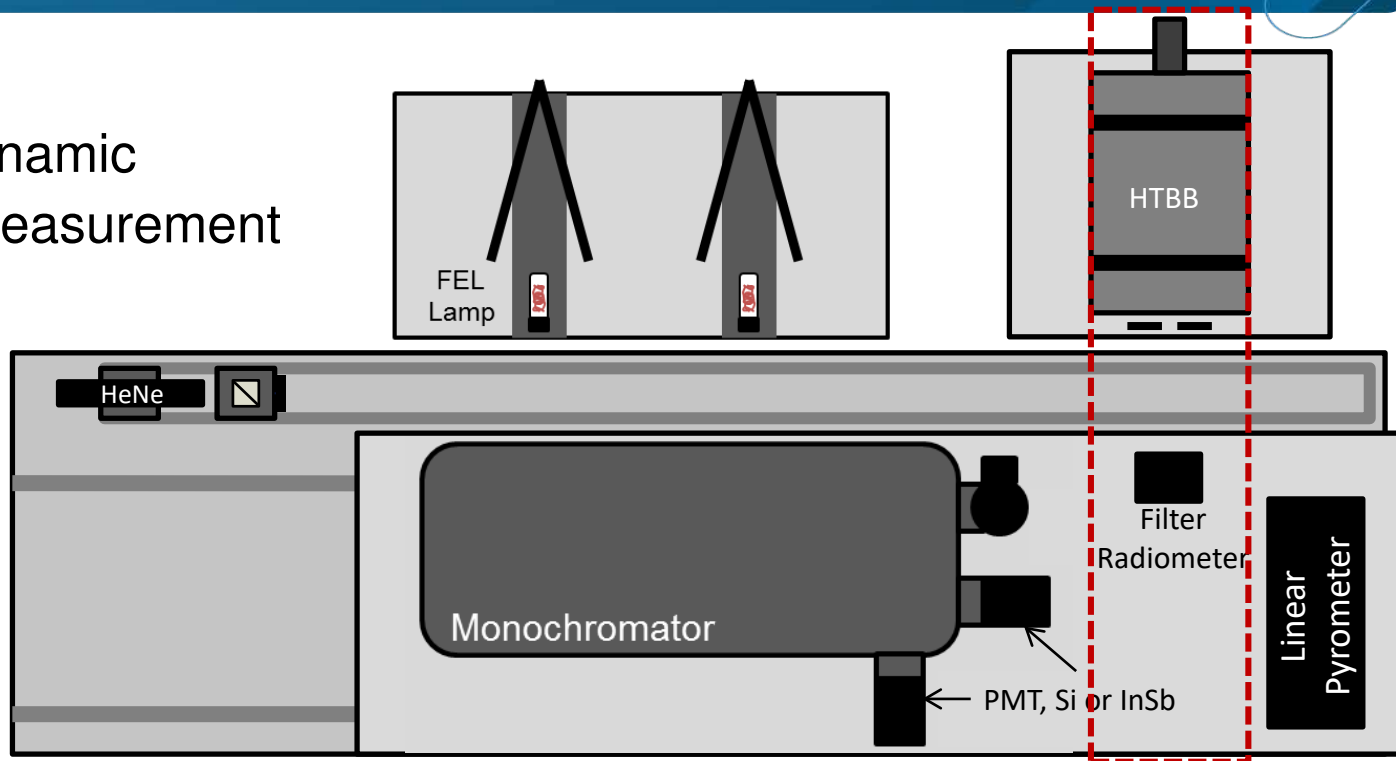
Spectral irradiance facility

- Temperature stability verification



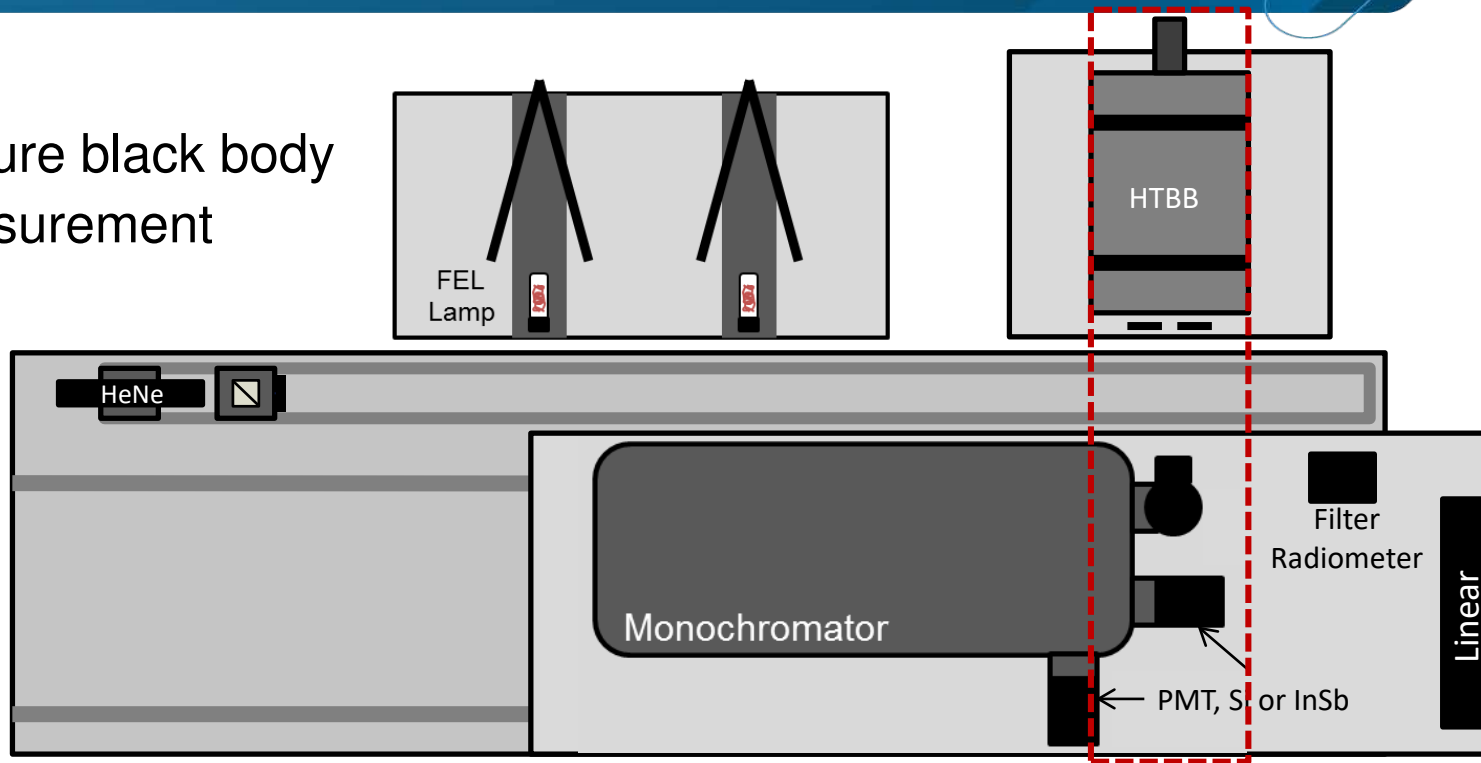
Spectral irradiance facility

- First thermodynamic temperature measurement



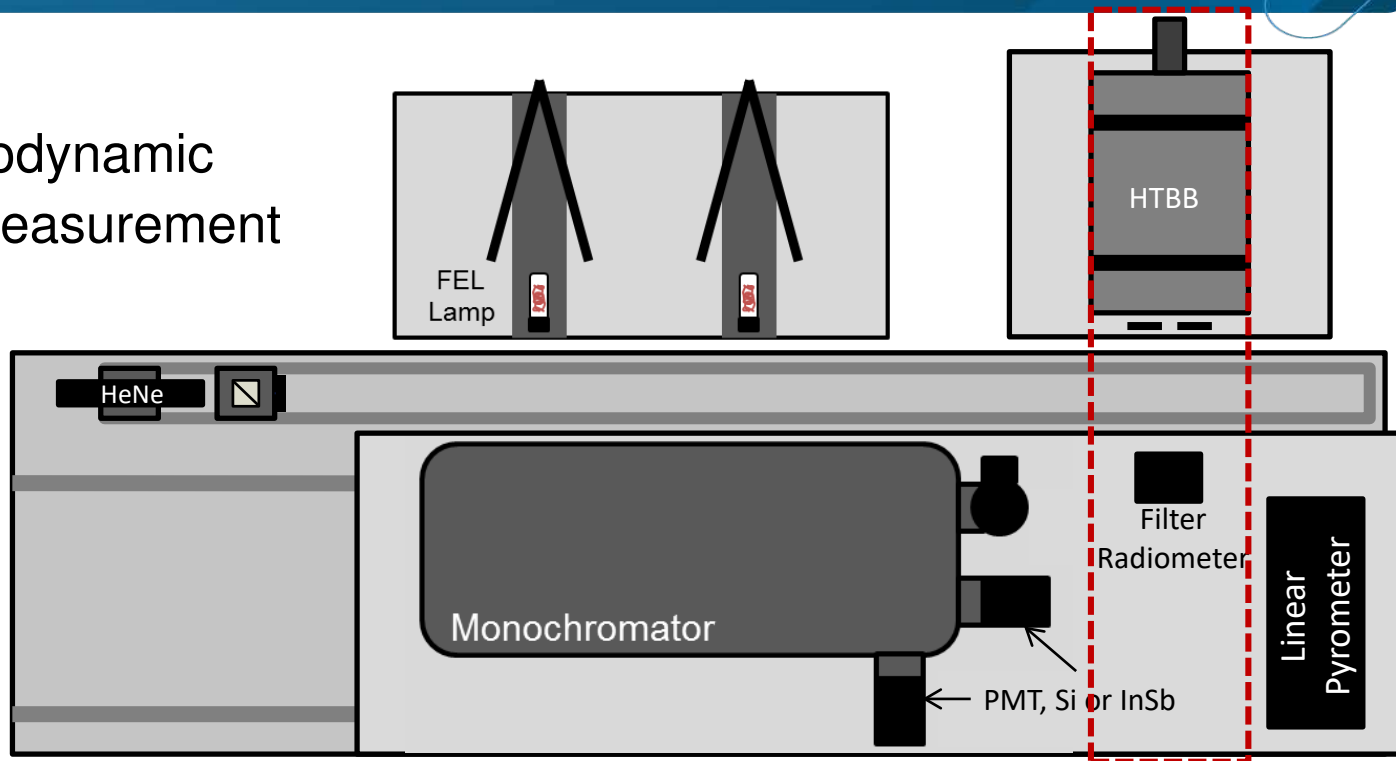
Spectral irradiance facility

- High temperature black body spectrum measurement



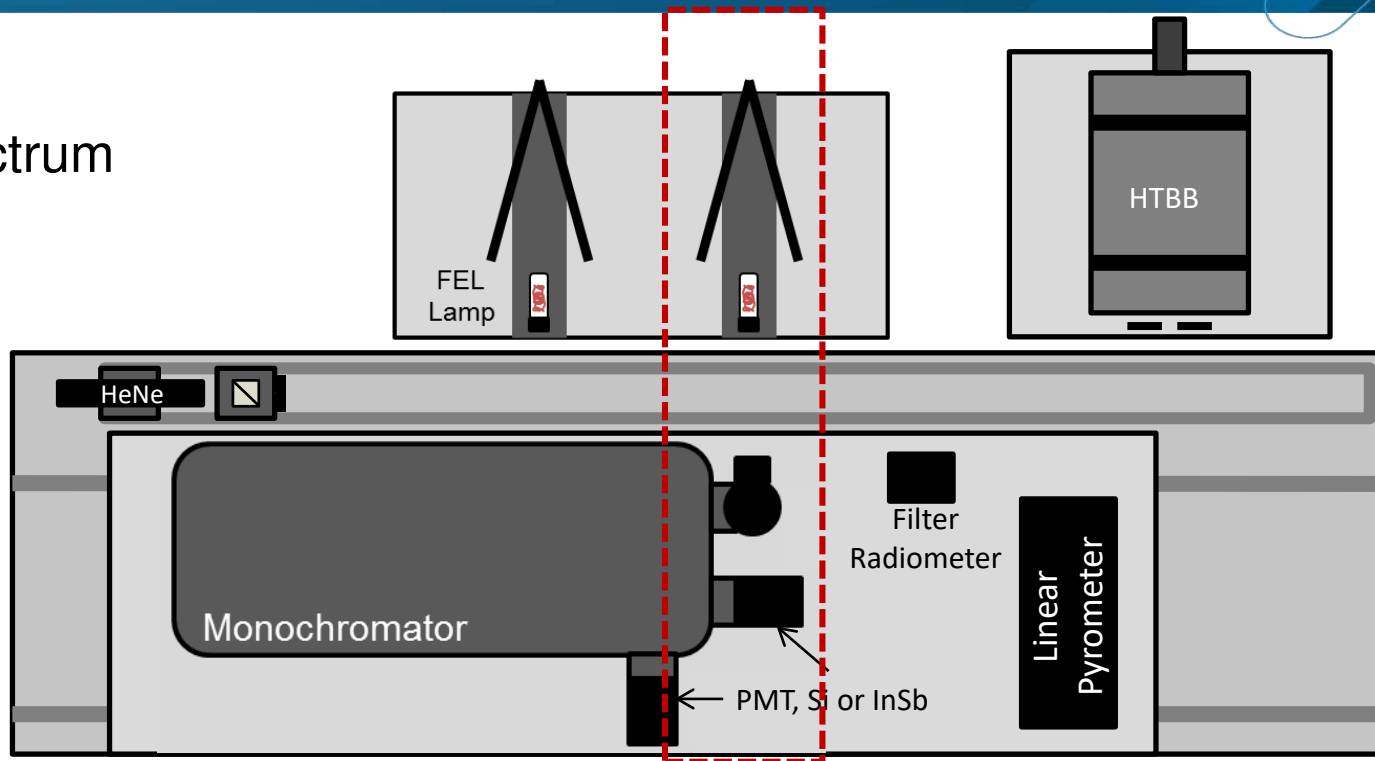
Spectral irradiance facility

- Second thermodynamic temperature measurement

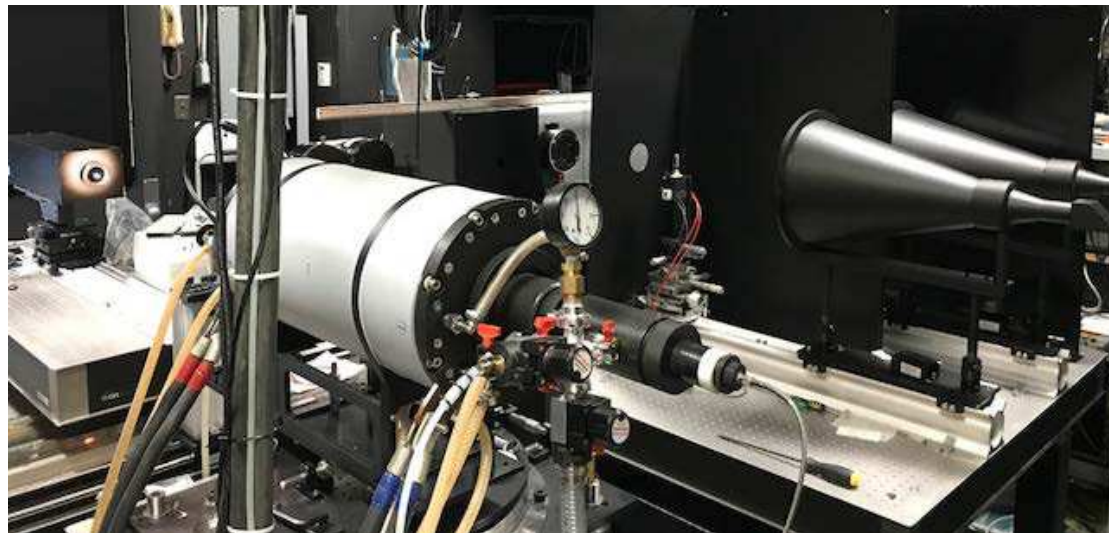
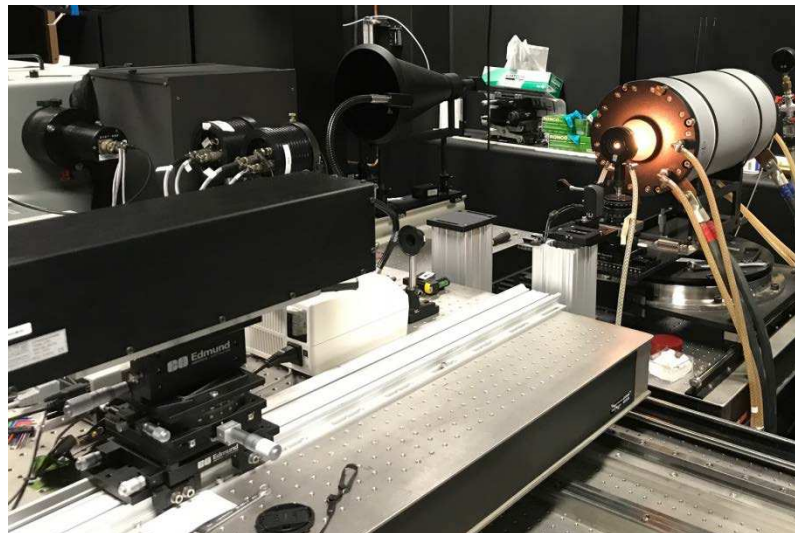


Spectral irradiance facility

- FEL lamp spectrum measurement

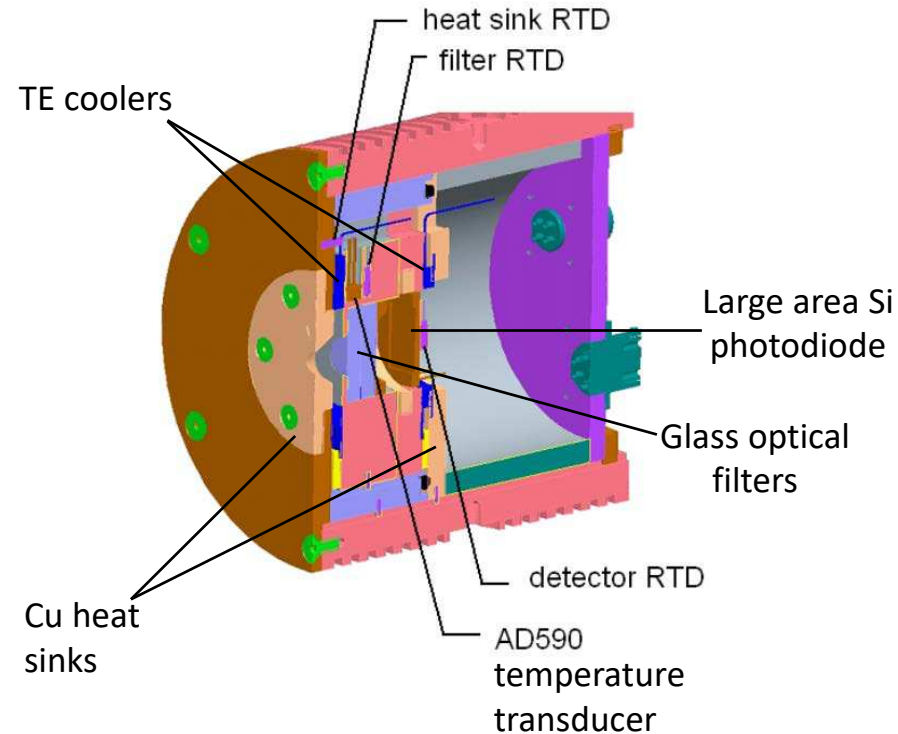
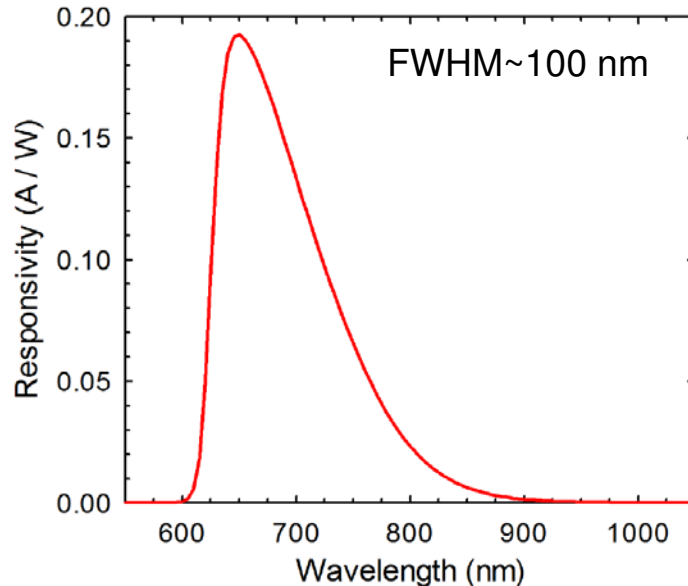


Spectral irradiance facility



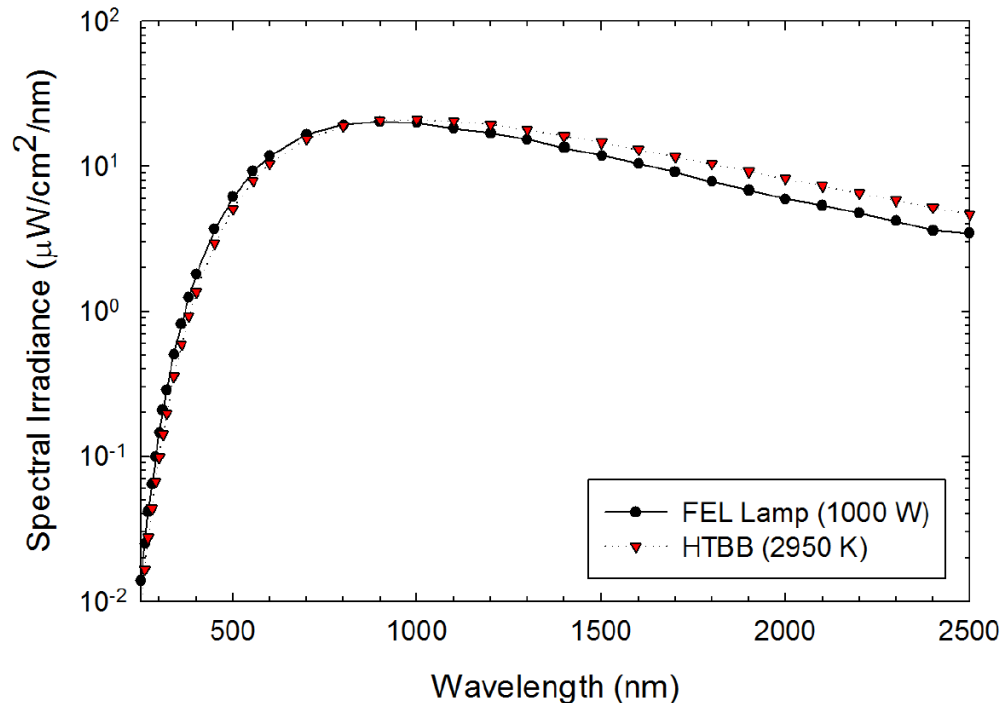
Thermodynamic temperature measurement

- NRC wideband filter radiometer
- Calibrated using transfer radiometers and monochromator based apparatus

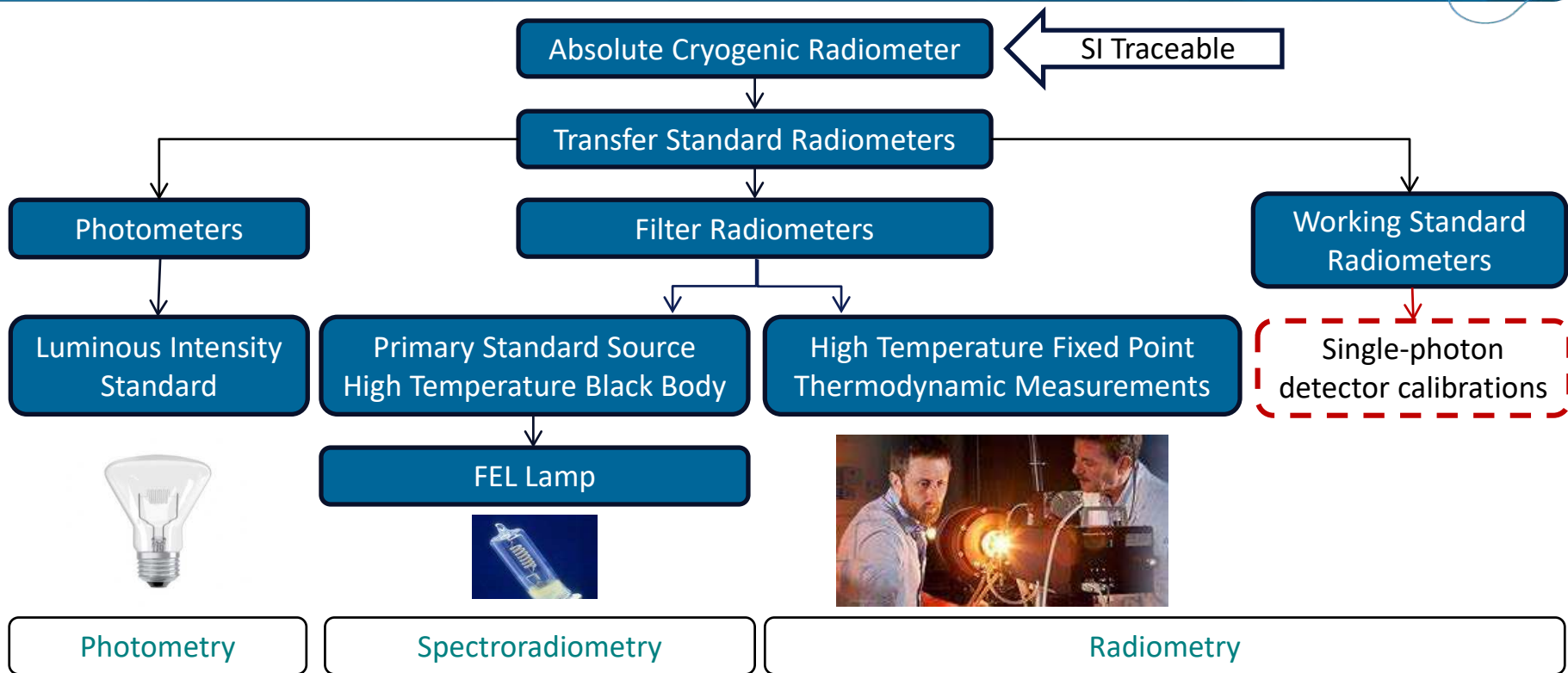


Spectral irradiance facility

- HTBB temperature stability 0.1 K/h
- Monochromator wavelength accuracy ± 0.05 nm
- Lamp distance of 50 cm
- Uncertainty budget in progress



Optical radiation calibration chain



Few Photon Metrology at NRC



› Project Goals:

- Single-photon detector efficiency measurements
 - Free space and fibre-coupled detectors
- Construction of superconducting nanowire single-photon detector system (NIST)
- Characterize single-photon sources (NRC)

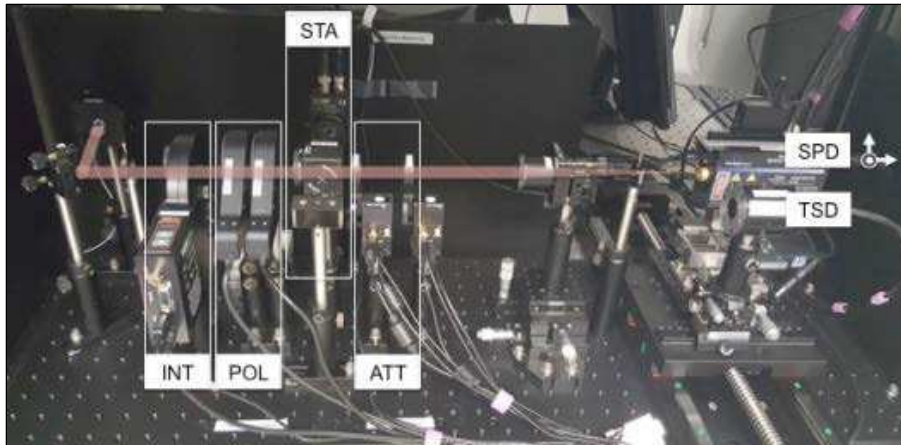
› *Looking forward:*

- Multi-particle quantum state measurements

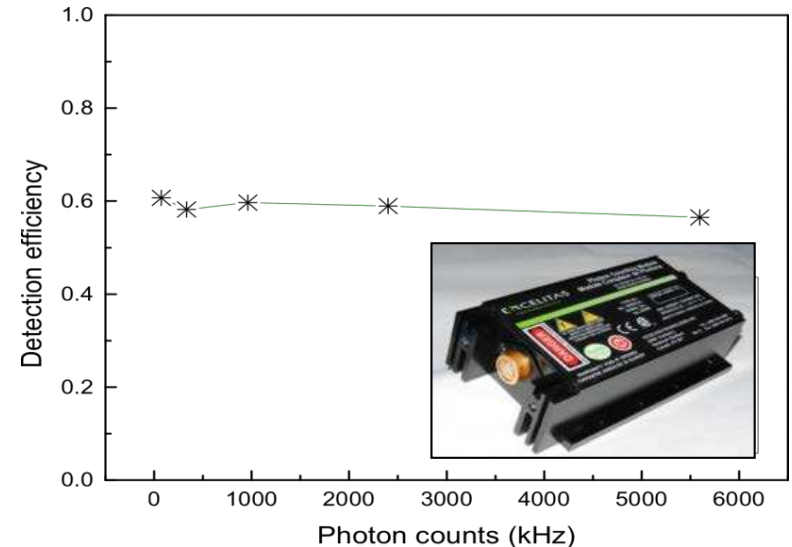
Single-photon detector characterization

Single-photon detector calibration capabilities → Free space Si SPADs

- Multiple filters are used to attenuate the input of a nano-joule laser beam to a level measurable by the single photon detector

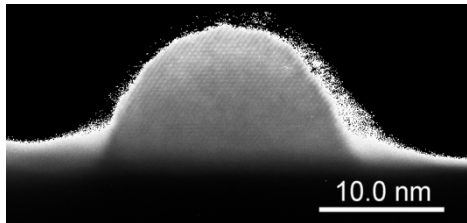


Efficiency measurements by substitution method

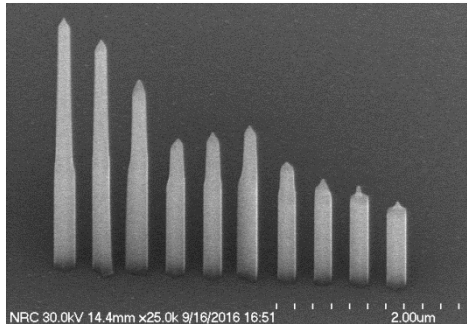


Quantum dot single-photon source

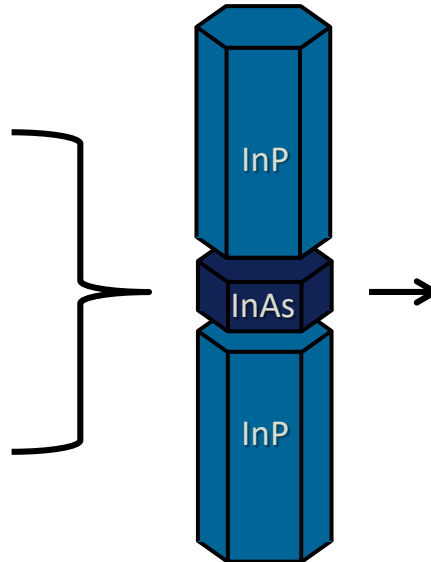
- For quantum information applications - Dan Dalacu and Robin Williams at NRC



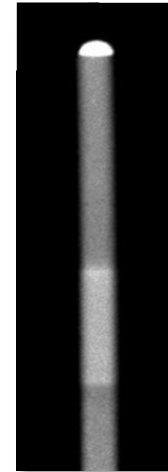
Self-assembled quantum dot



Site-controlled nanowires



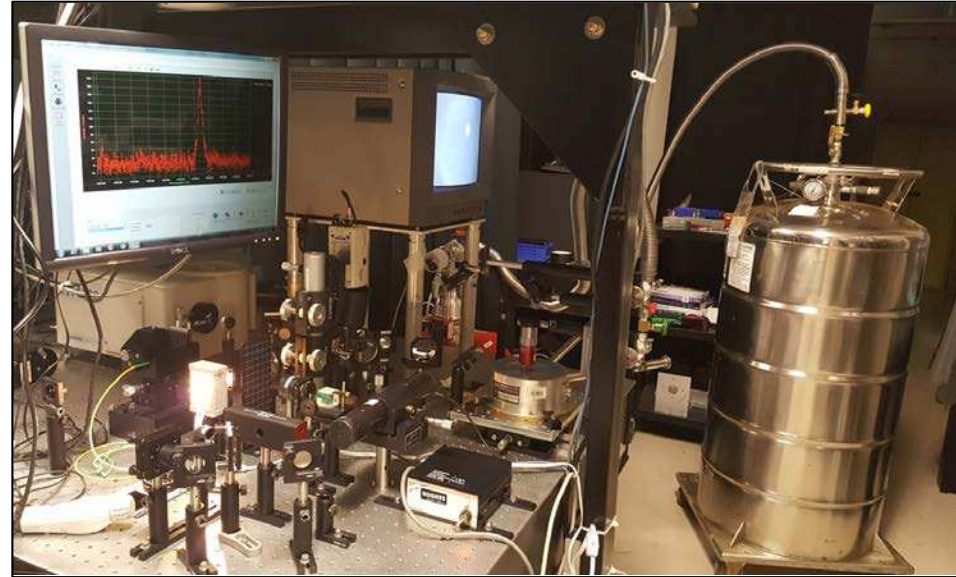
Structure of QD
embedded in
nanowire



InAs
quantum
dots within
InP nanowire

Single photon source efficiency

- Presently no *standard* way to characterize source efficiency
→ what has been accounted for?
- Efficiency ϵ : probability of collecting a photon
- Brightness β : number of photons collected per pump excitation pulse



Single photon source characterization apparatus

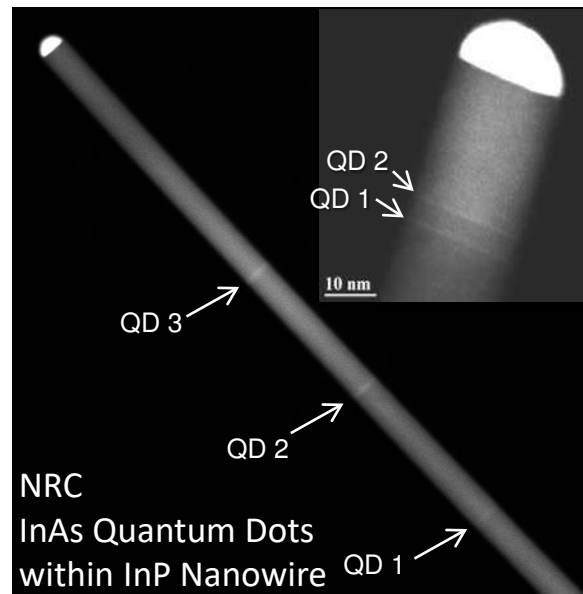
Few photon measurements

NRC quantum dot photon sources → photons for multiparticle entangled states

Higher-order entangles states - double or triple quantum dots in semiconductor nanowire



New single photon source measurement apparatus



NRC
InAs Quantum Dots
within InP Nanowire

Image: D. Dalacu



Thank you

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