# First Experimental Results of WDM Target Experiments

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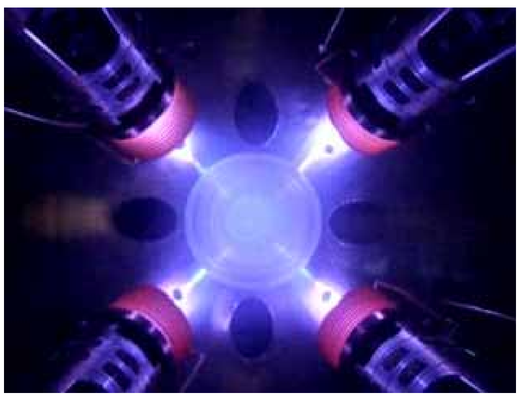
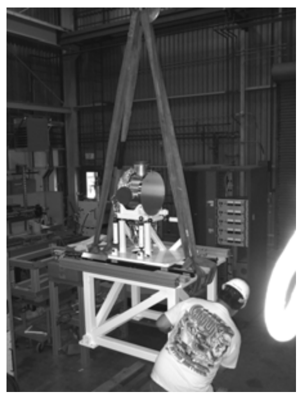
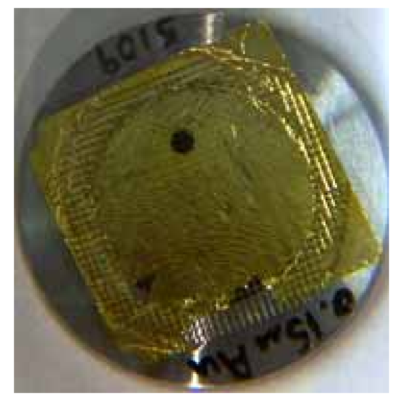


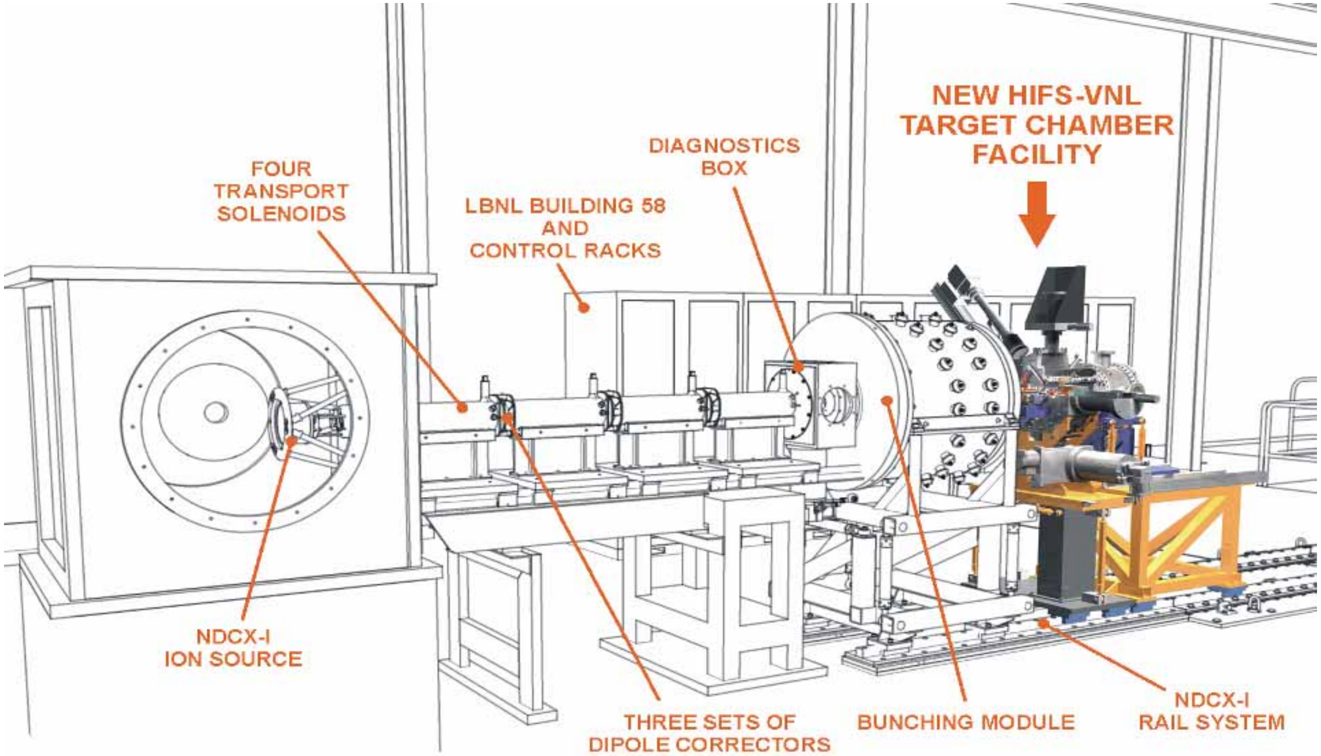




# Outline

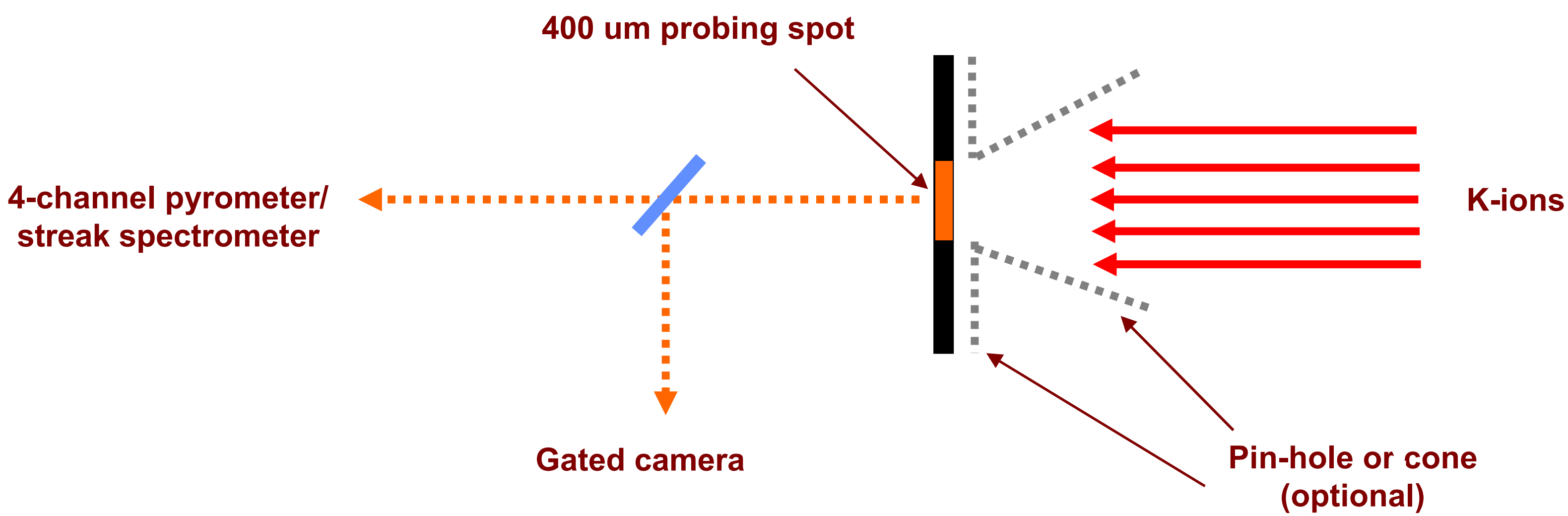
- Experimental area and setup
- Optical diagnostics
- Experiment with Au, Si and Scintillator
- Summary

# Experimental facility: NDCX-I

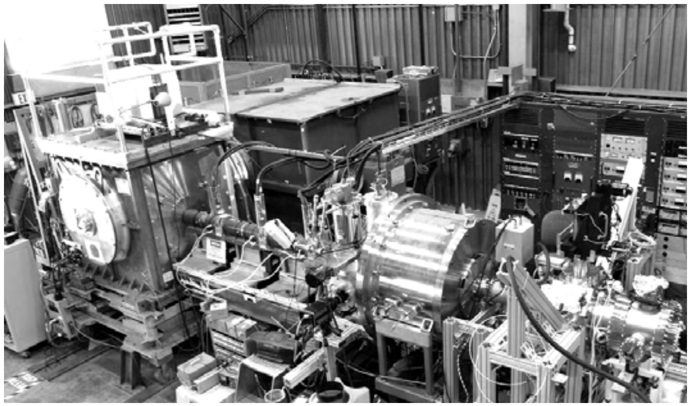


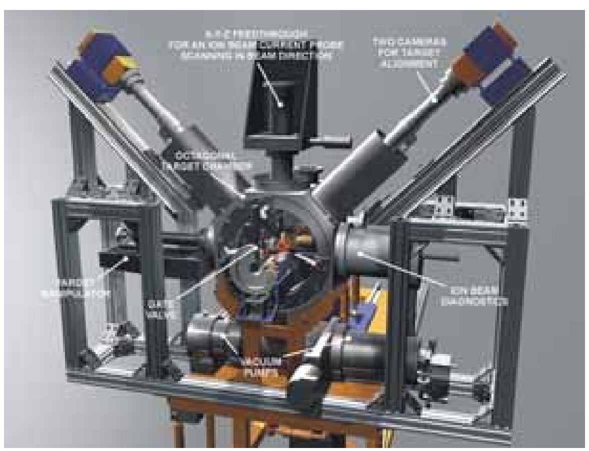

- Beam: K (+1) neutralized, drift compressed
- Intensity:~$10^{10}$
- Energy: 300keV/ion
- Focal spot: >=1 mm
- Duration (FWHM): 2 ns

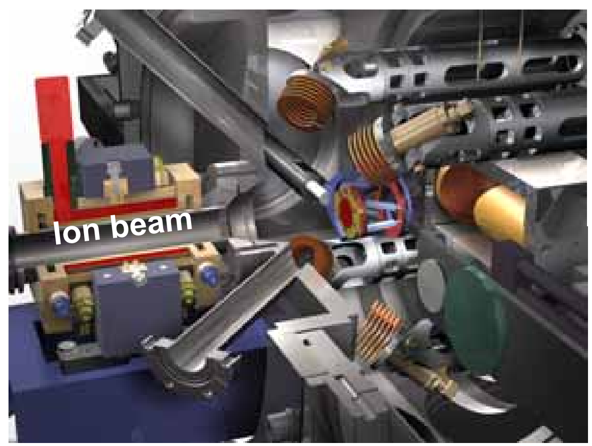
# Experimental scheme

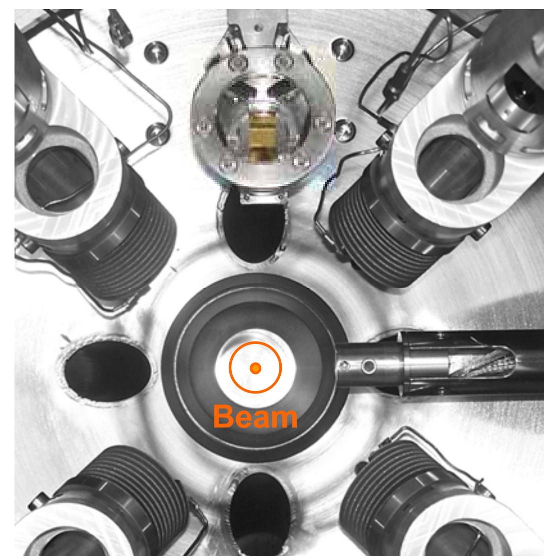


# Experimental area



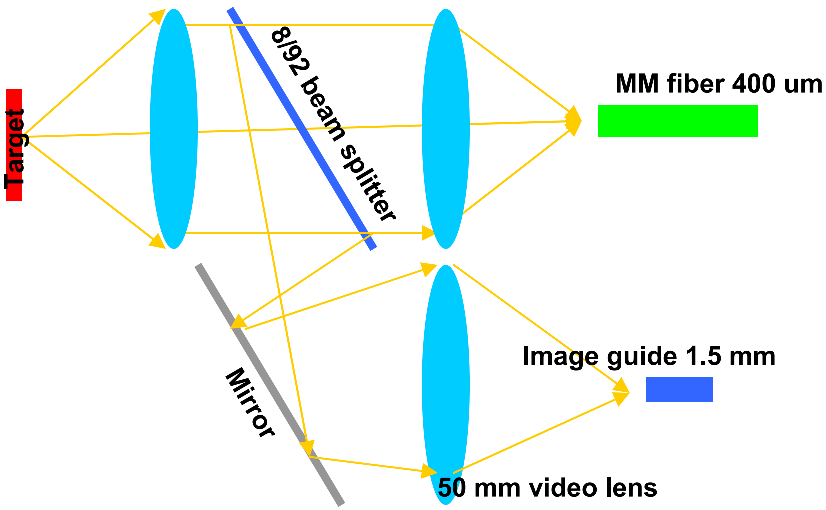



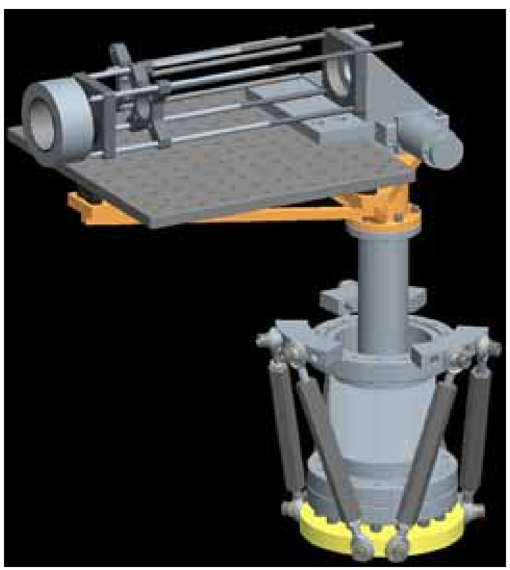



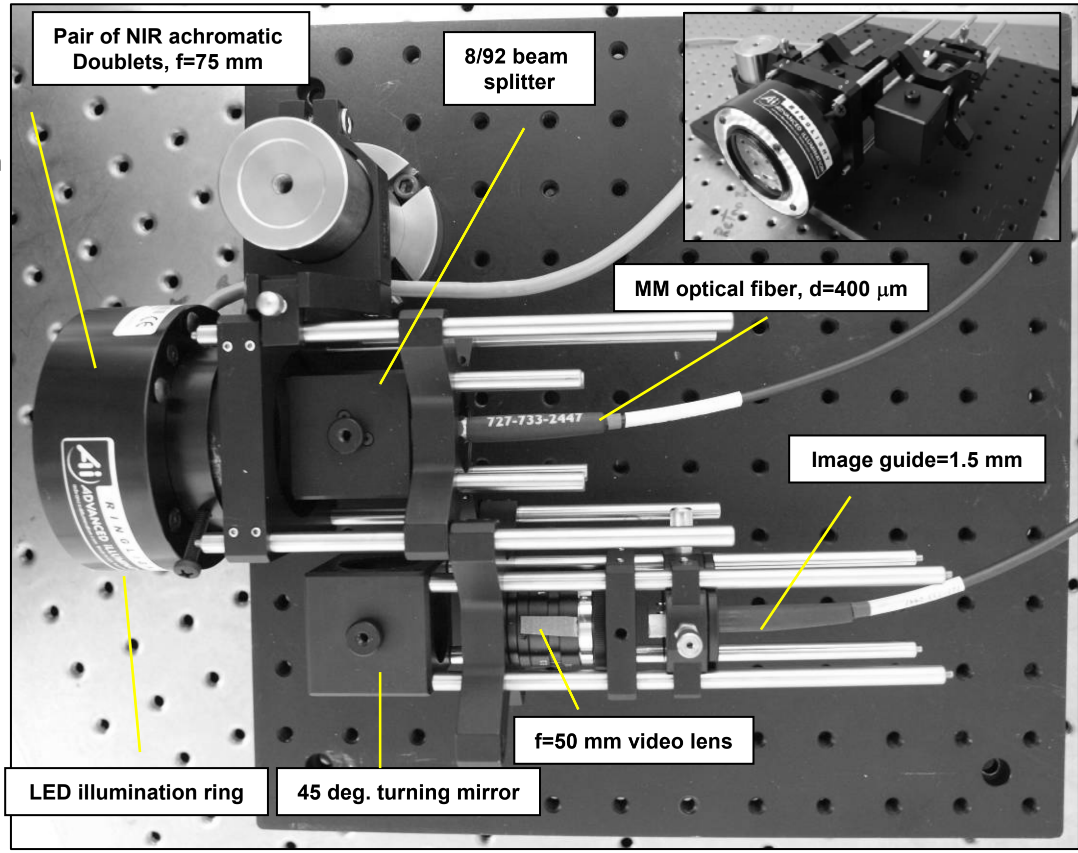



# Intergrated light collection system

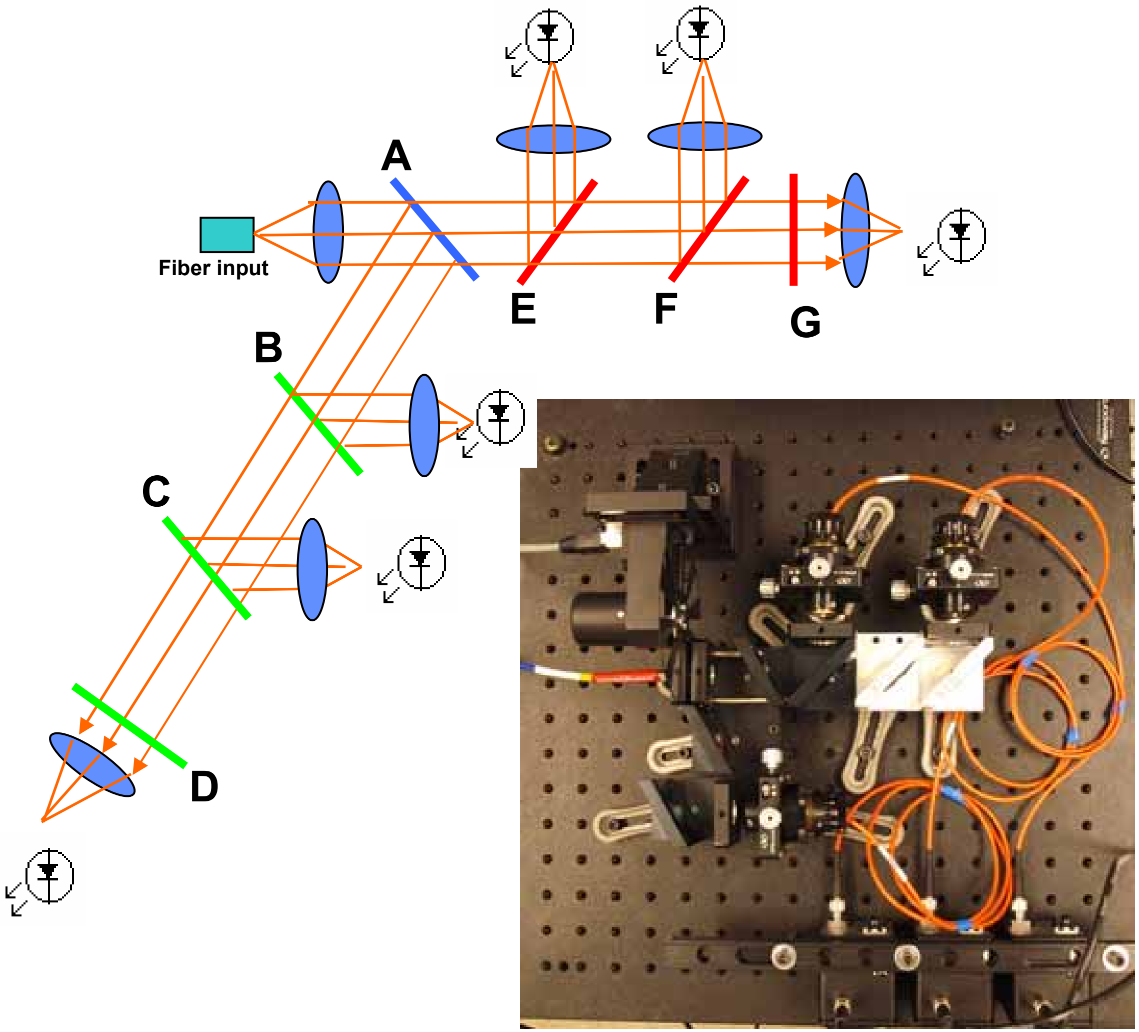
2 x NIR achromatic doublets, f=75, d=50.8






# Ultra-fast optical pyrometer for experiments at NDCX




**Challenges and requirements:**

**Being able to detect at least ~1 mW of light from 400 nm to 2000 nm in a sub-ns time scale:**

- **Ultra fast response (sub-ns)**
- **Higher sensitivity (>=1500 K)**
- **Different, more efficient beam splitting mechanism**
- **No published paper**

**Technical issues:**

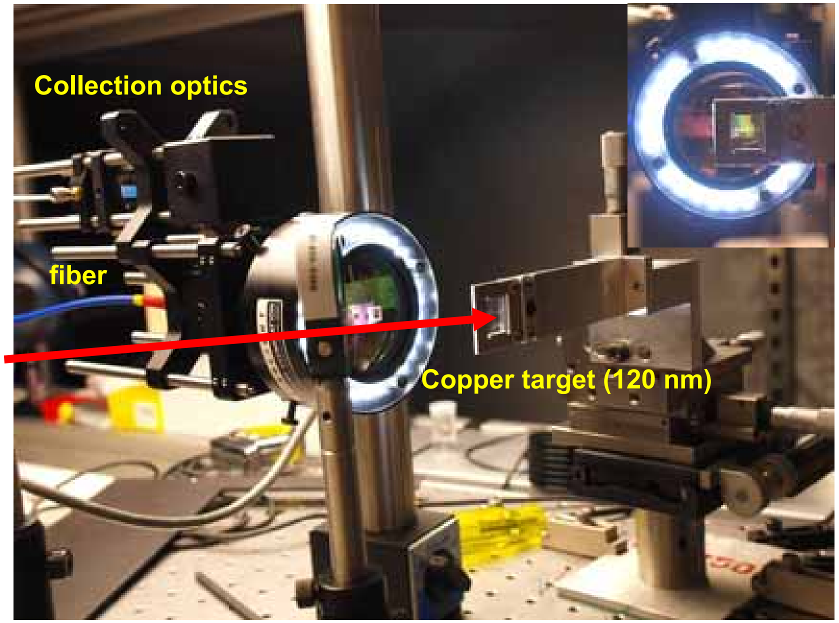
- **Need low noise amplified photo receiver with flat gain from DC to 4GHz and big active surface.**
- **Fiber coupling limits the efficiency**
- **Picoseconds time scale means: Modal (temporal) dispersion in MM fiber, careful cabling, impedance match and termination of detectors**

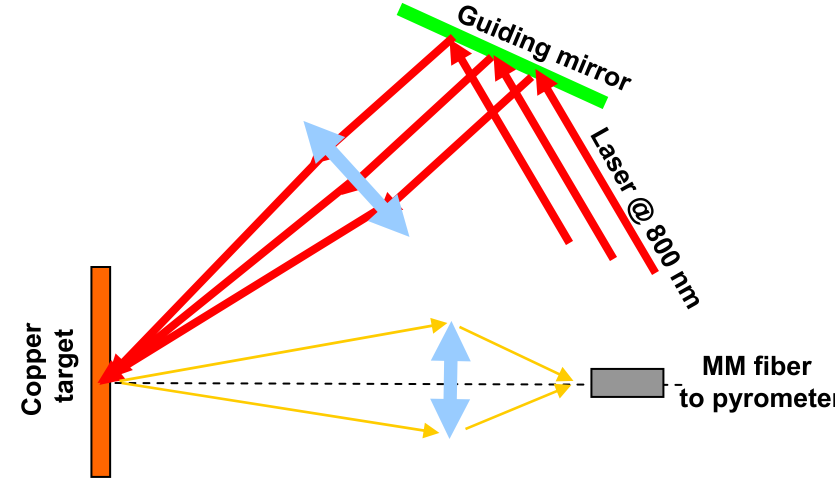
**Channel #1: 750 nm+-75 nm, 76 ps rise/fall time**
**detect[illegible] level ~2500 K (blackbody)**
**Channel #2: 1000 nm+-75 nm, 72 ps rise/fall time**
**detectable level ~1500 K (blackbody)**
**Channel #3: 1400 nm+-75 nm, 70 ps rise/fall time**
**detectable level ~2000 K (blackbody)**

**Can be upgraded up to 7 channels**

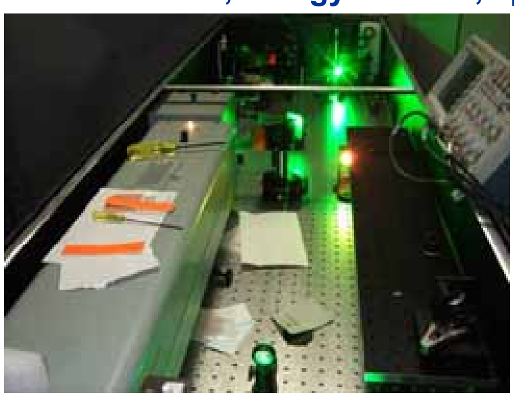
# Pyrometer testing in laser experiment

## Experimental setup

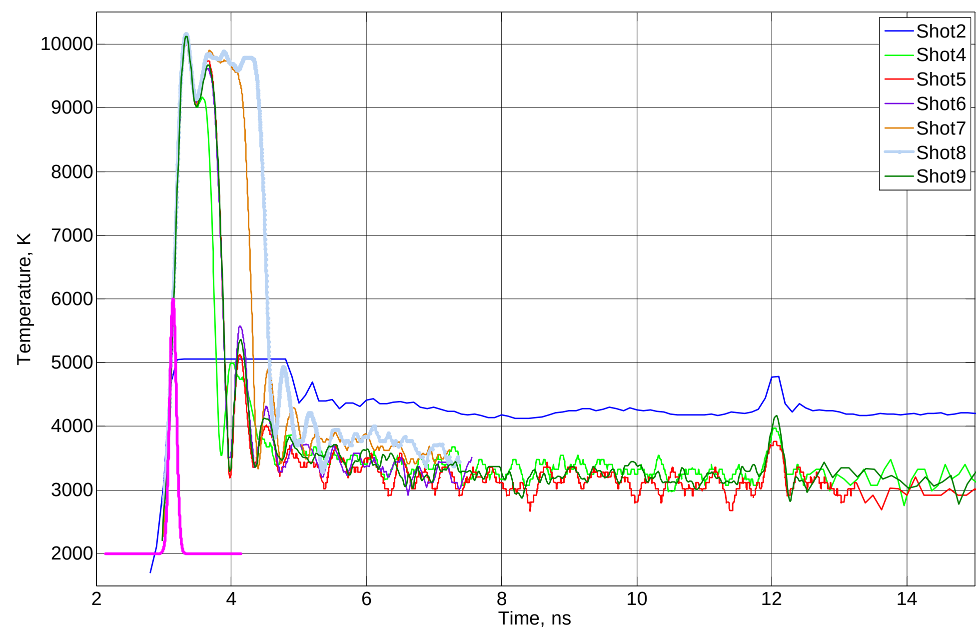



**Amplified Ti-Sapphire laser @ 800 nm, pulse duration ~ 100 fs, energy 5-10 mJ, spot size 400 um**

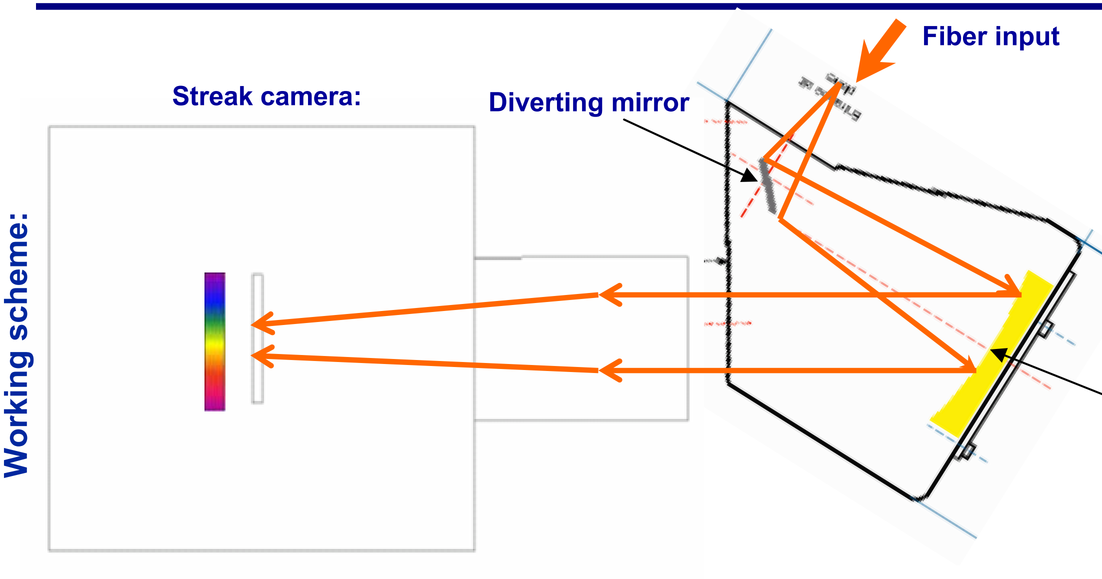


**Color temperatures@1000 nm**



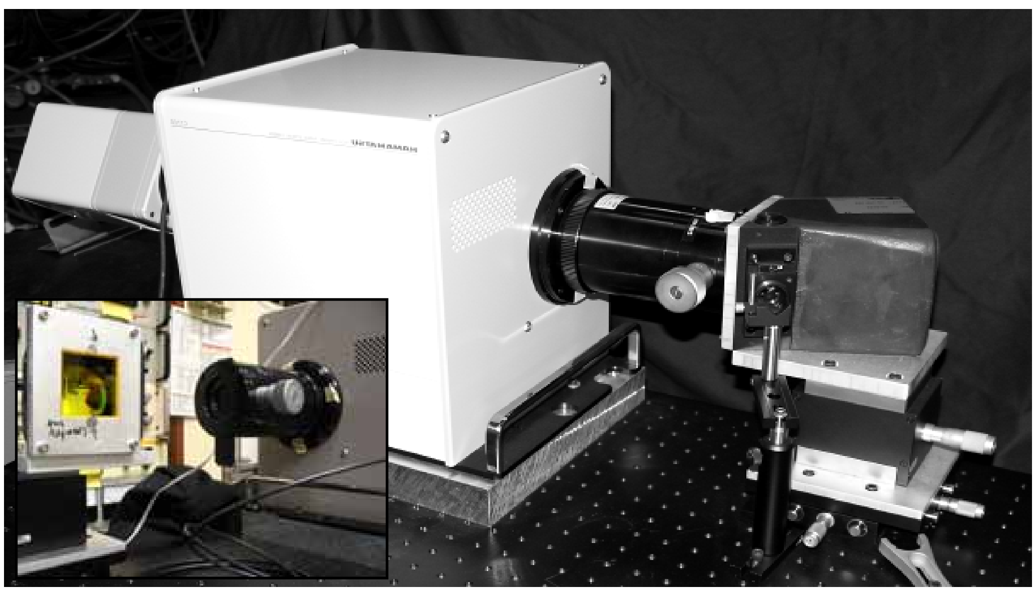
# Streak camera for time resolved absolute spectroscopy

Working scheme:

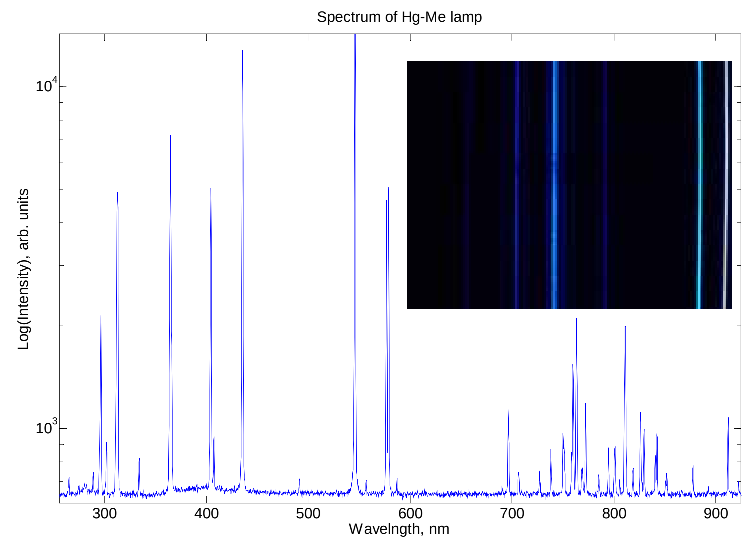



- Records continuous spectrum from 500 nm to 850 nm
- Temporal resolution down to 5 ps
- Linear response cathode
- 15 nm wavelength resolution with 400 um input fiber

Implementation:

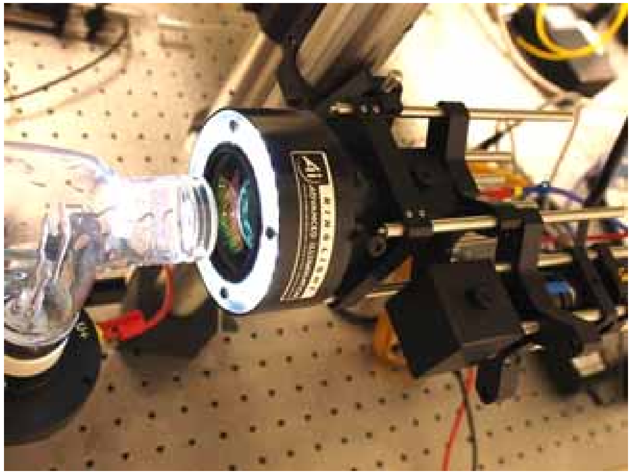


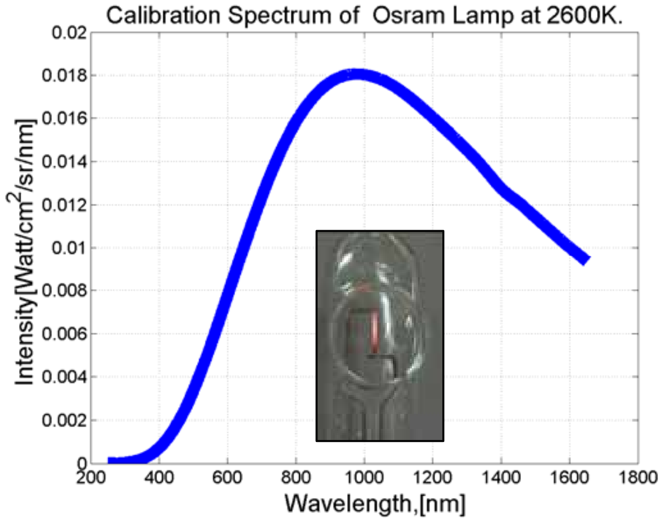
**Wavelength calibration:**



# Absolute spectral calibration

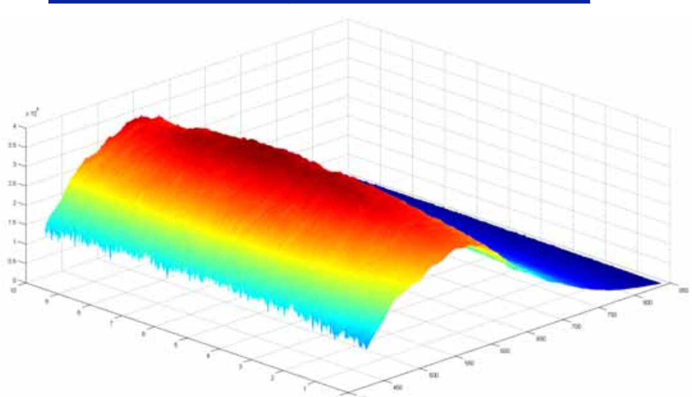
**Light collection optics aligned to calibration lamp:**



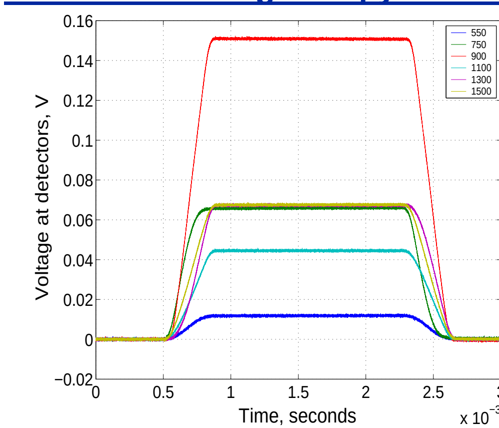



- **Pyrometer and streak camera are calibrated absolutely with tungsten ribbon lamp**
- **Filament calibration temperature is 2600 K, which is close to temperatures expected in our experiments**

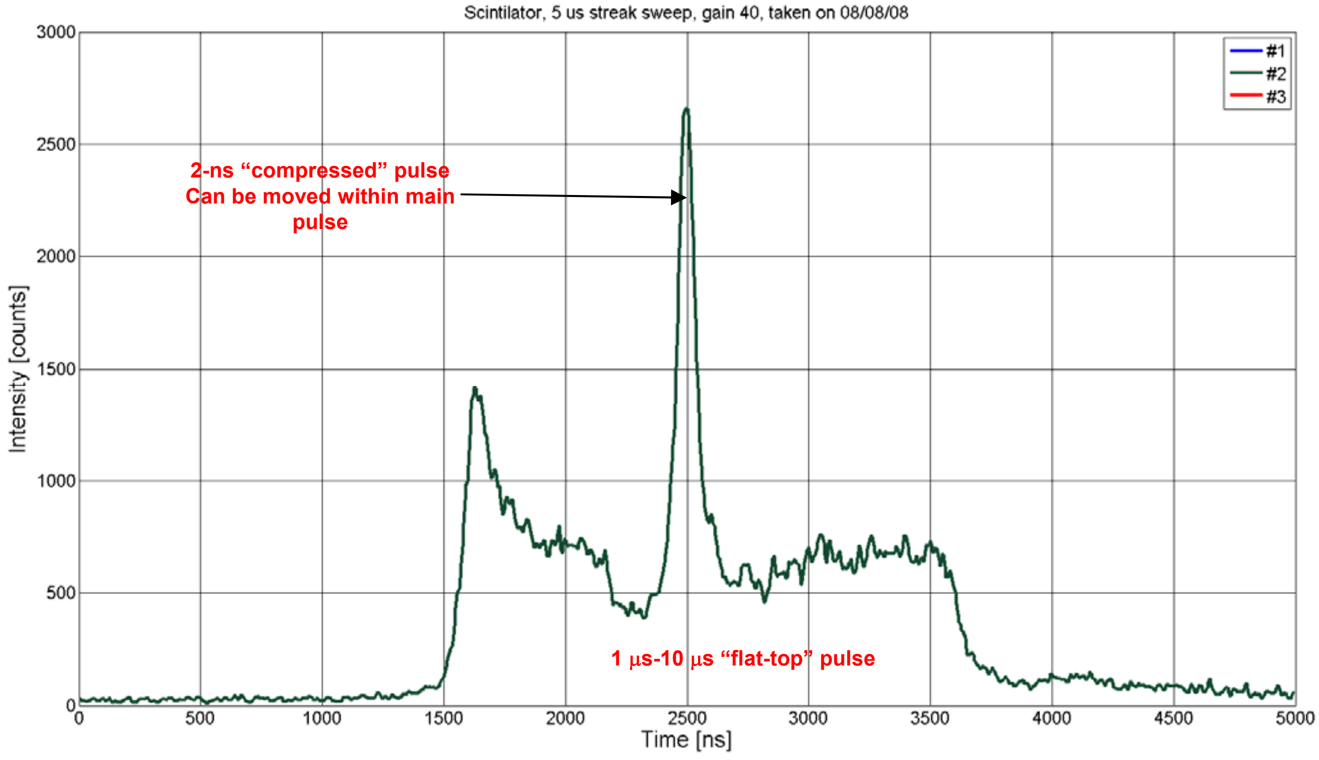
**Calibration image of streak camera:**



**Calibration voltages of pyrometer:**



# NDCX-1 beam pulse structure

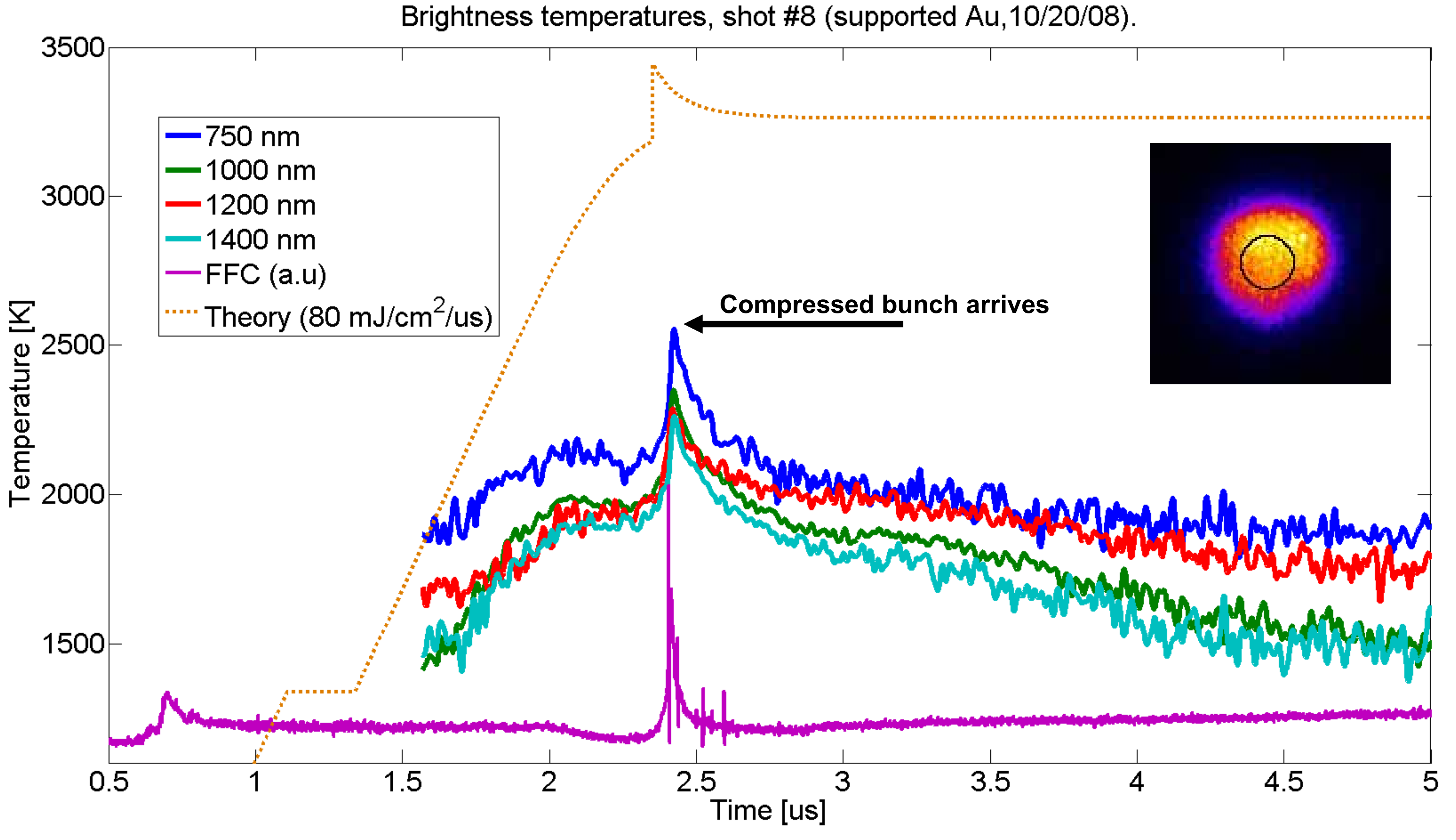



**Beam current structure consists**

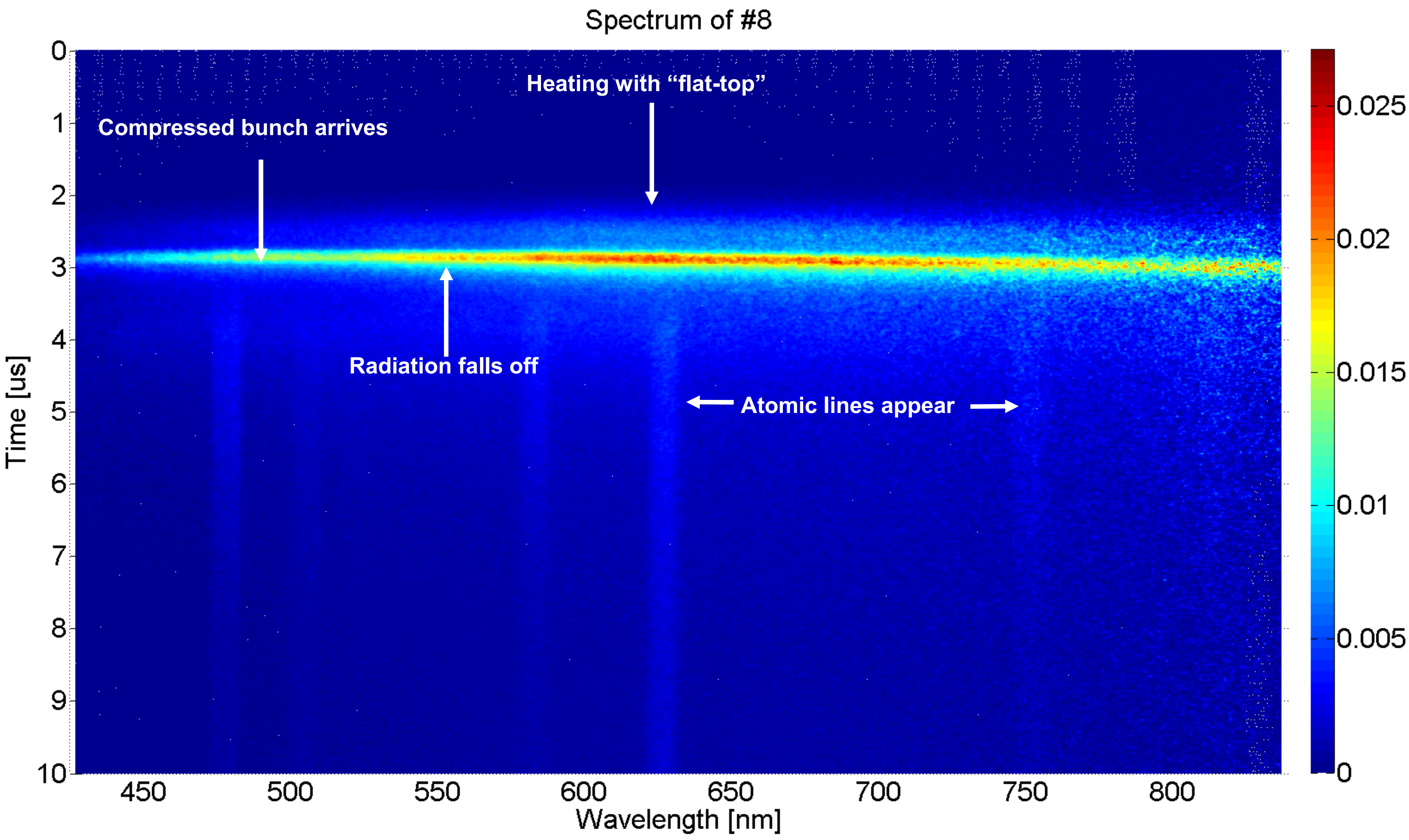
- **main, flat-top 1 μs pulse (variable up to 10 μs) with flux on target ~100 mJ/cm2/μs**
- **bunch-compressed 2-ns pulse with fluence ~10 mJ/cm2.**

**The compressed pulse can be delivered controllably at any time within the duration of the main pulse.**
**The 2-ns compressed pulse width is at a comparable time scale to the hydrodynamic response of our targets**

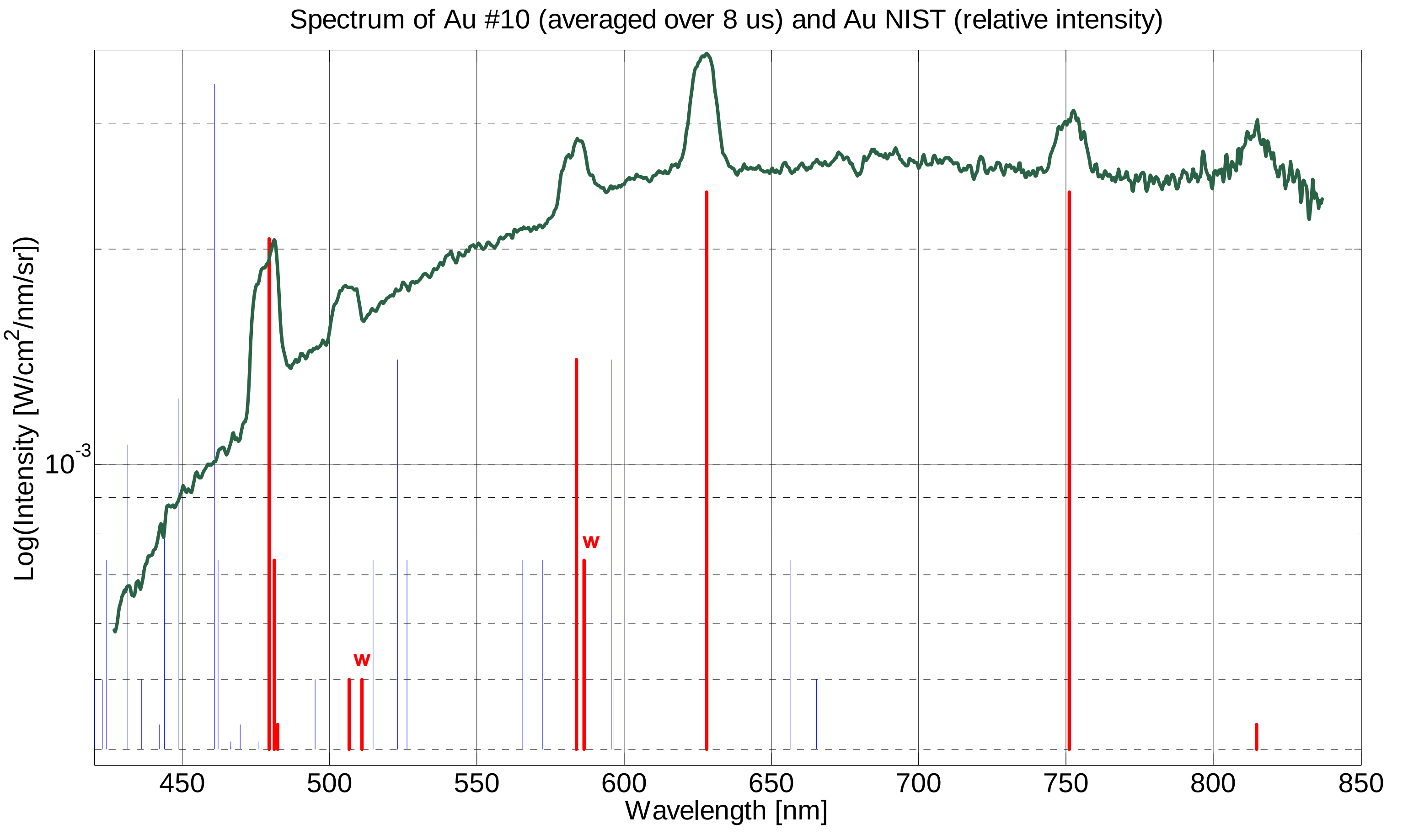
# Pyrometer record: Au



# Streak camera record: Au



# Lines indentification




- In red shown lines which overlap with experiment
- "w"-wide line
- <u>We could identify all lines as Au lines, but what is their nature?</u>

# Temperature reconstruction

$$I(\lambda,T)=\varepsilon(\lambda)\cdot\frac{C_1}{\lambda^5}\frac{1}{e^{\frac{C_2}{\lambda T}}-1},$$

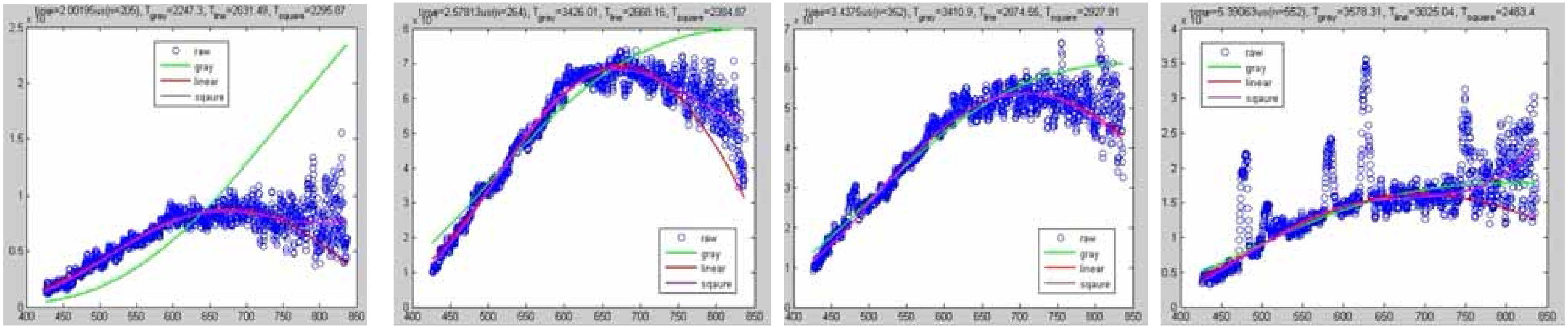
where emissivity $\varepsilon(\lambda,T)\le 1.$

$$\begin{bmatrix} I_{experim}(\lambda_1) \\ \dots \\ I_{experim}(\lambda_N) \end{bmatrix} \xrightarrow{\text{nonlinear fit}} \begin{bmatrix} \varepsilon(\vec{A},\lambda_1)\cdot I_{Planck}(\lambda_1,T) \\ \dots \\ \varepsilon(\vec{A},\lambda_N)\cdot I_{Planck}(\lambda_N,T) \end{bmatrix}$$

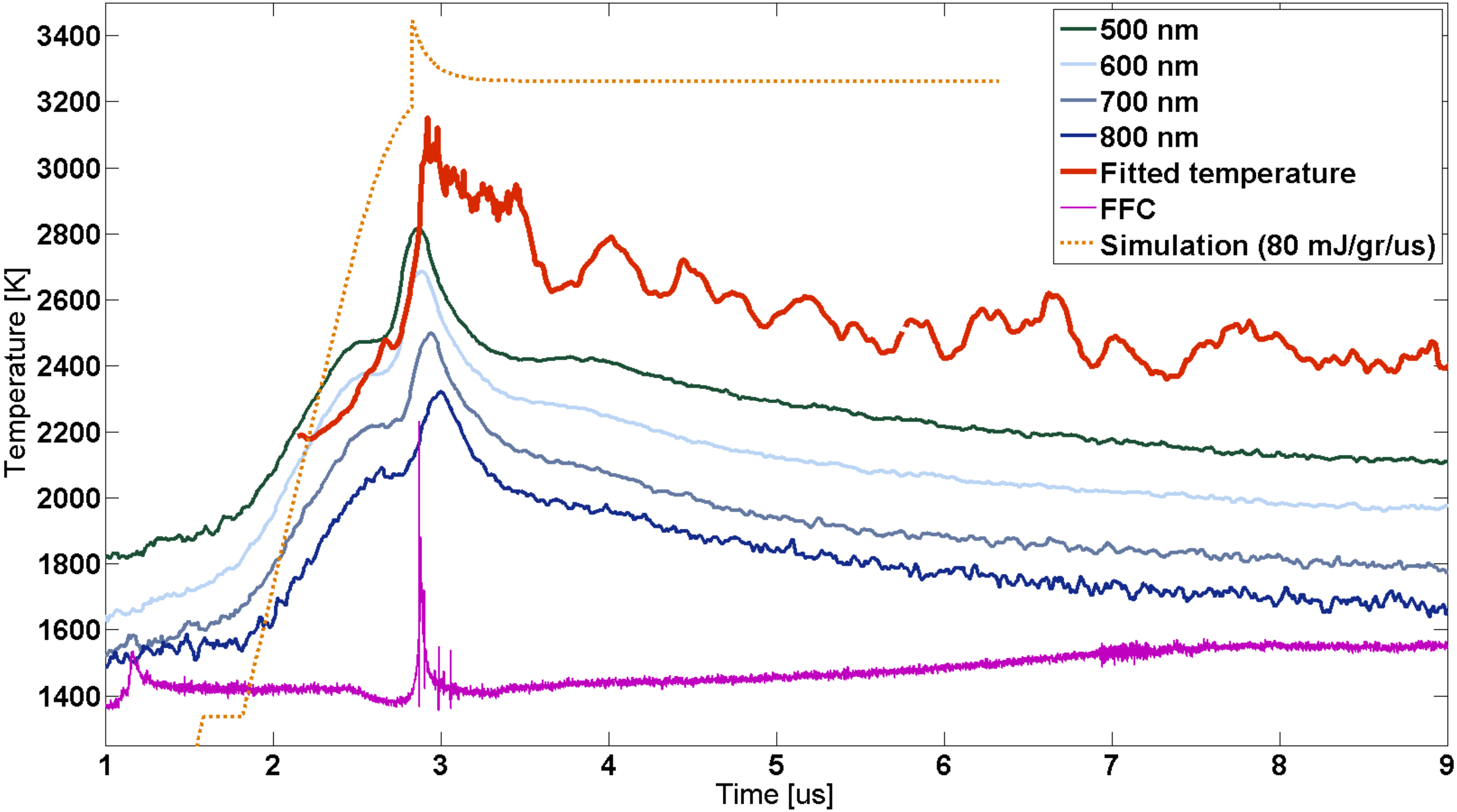
$\vec{A}$ and T are the fitting parmeters

- Attempted to fit “grey”, “linear” and “square” laws of emissivity
- Performed non-linear least square optimization (Levenberg-Marquardt) with statistical weights.
- Used sensitivity of spectrometer as a weight function
- Fitting is a “Bonus” and serves as a reference only.

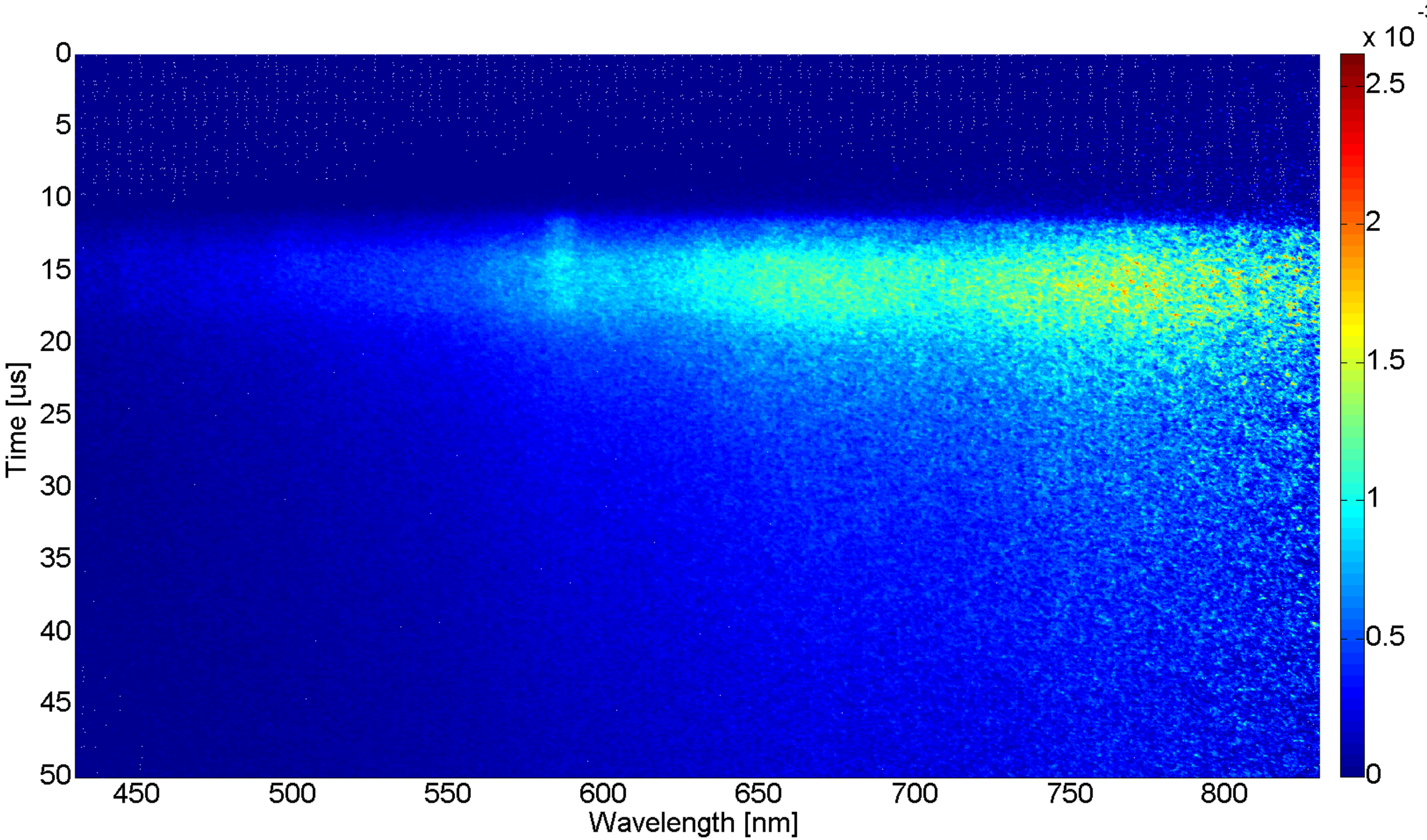
- Discrepancy can be explained by many reasons: non-equilibrium, scintillation, low-level of signal, sample is not optically thick, screening hot vapor, gas-droplet mixture etc…



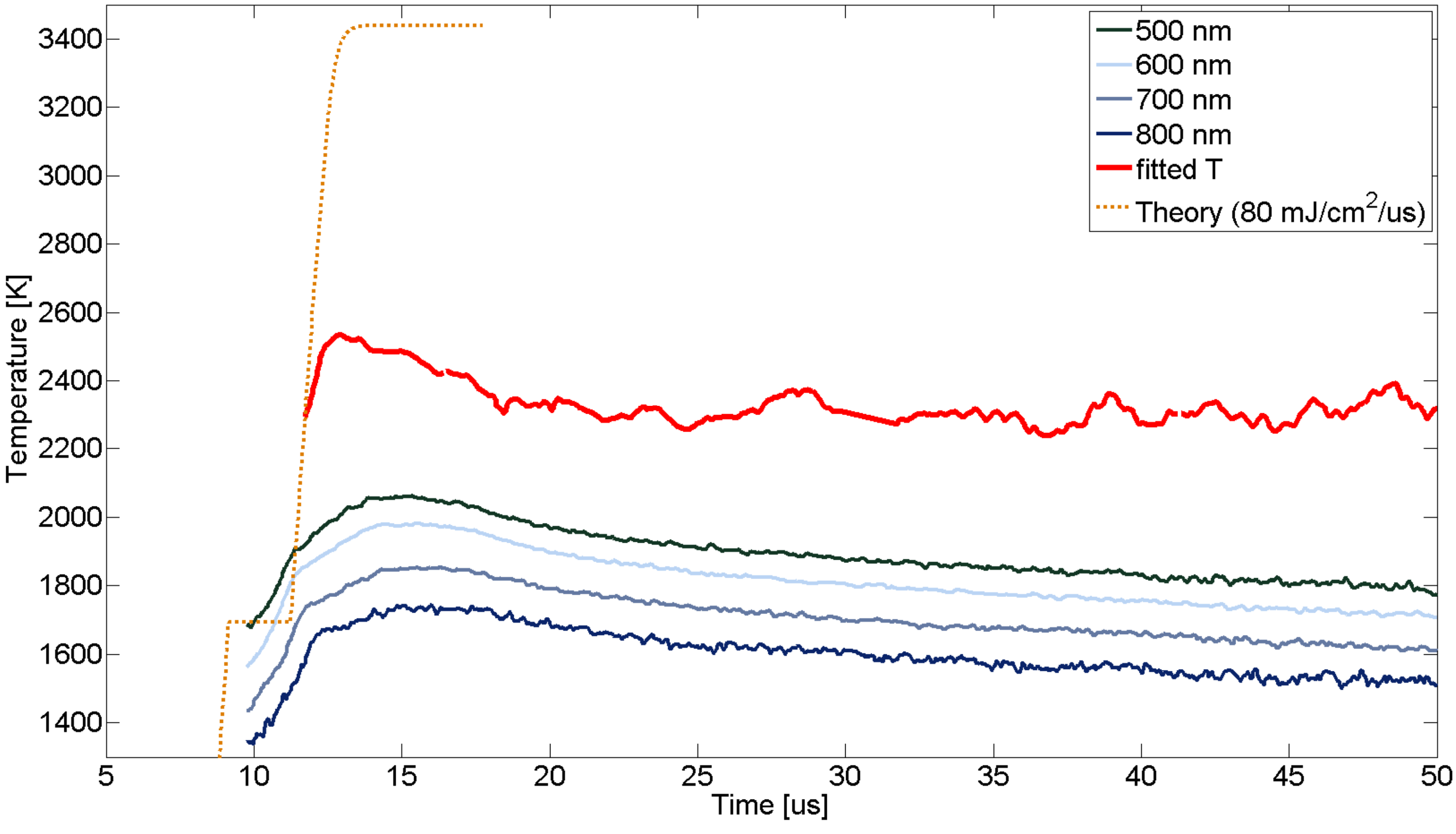
# Temperatures reconstucted from streak camera data: Au



# Streak camera record: Si

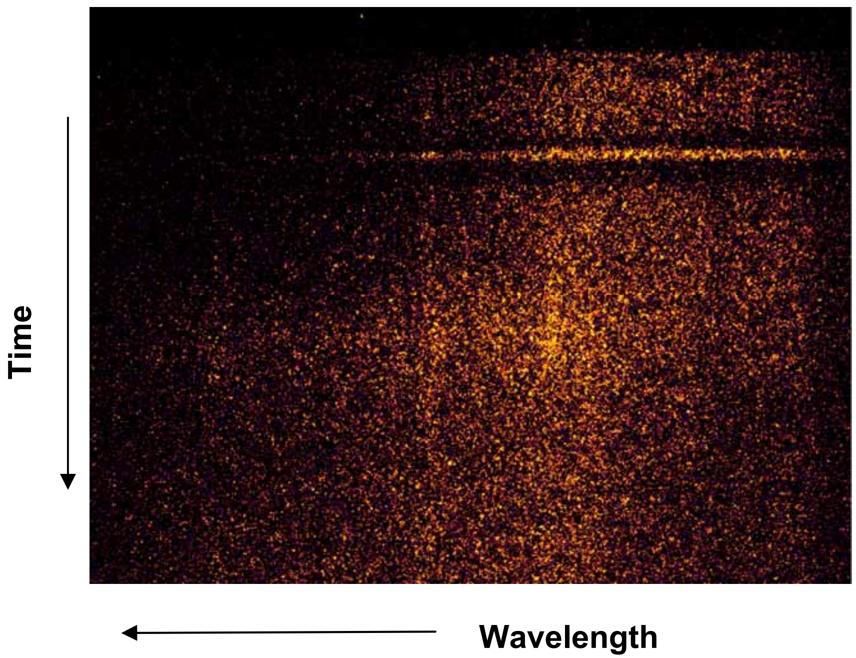


# Temperatures reconstucted from streak camera data:Si

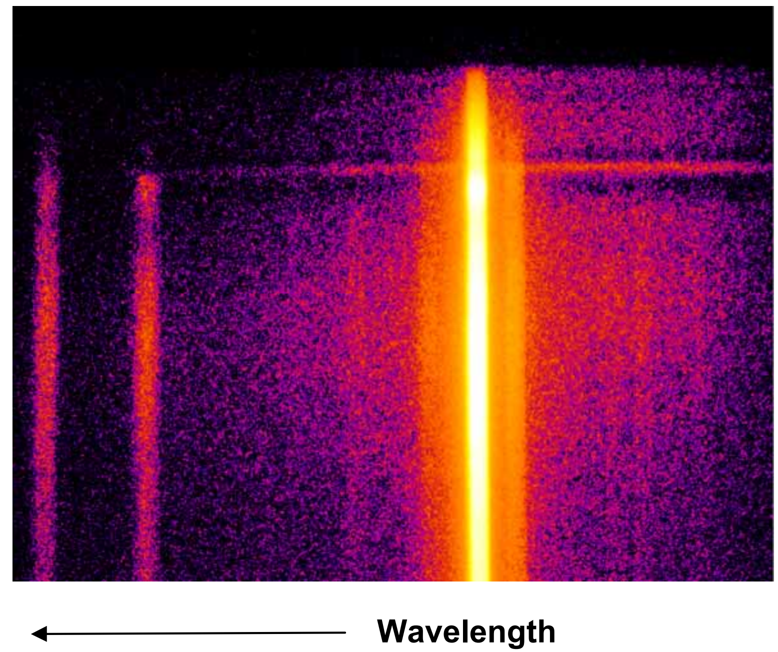


# Bonus: scinitillator spectrums

**"Worn out" sample (>>100 shots)**




**"Fresh" sample (<100 shots)**



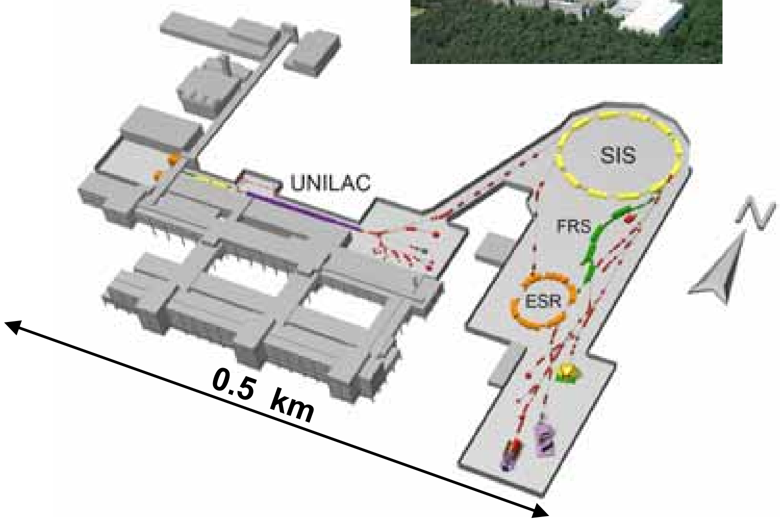

- Same machine and camera settings
- Identical scintillator materials

**Opened questions:**

- Why intensities are so different (x100)?
- Why temporal responses are different
- Why "lines-like" spectrum?
- Why IR lines show after compressed peak only?
- Why non-linear response
- Does the scintillator material degrade?

# GSI vs LBNL

## GSI-Darmstadt

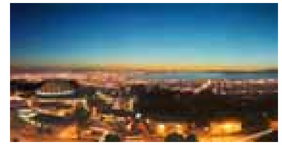


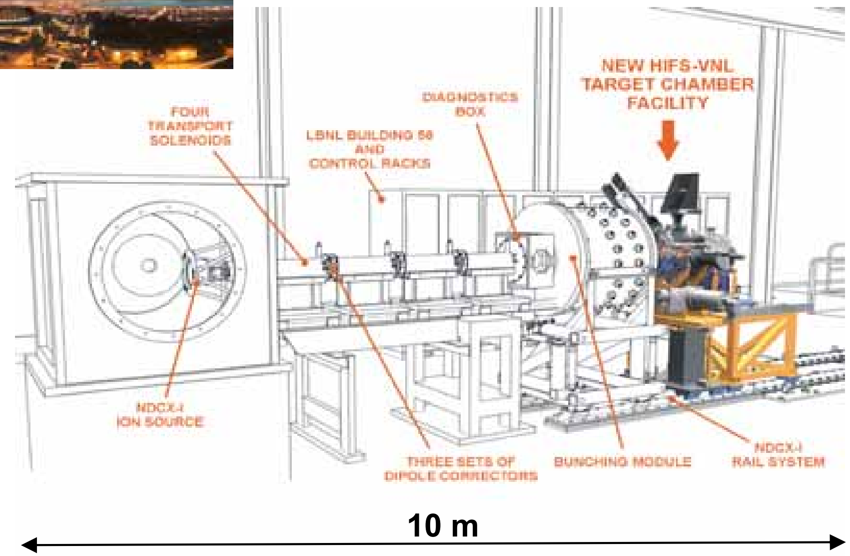

- •Beam: Uranium (+74) e-cooled, compressed
- •Intensity: (1 - 4.2)x$10^9$
- •Energy: 83GeV/ion
- •Focal spot: 0.150 mm - 1.5 mm
- •Duration: (FWHM): 120 ns - 1000 ns
- •Beam time: ~4 weeks/year

**HED samples :**

- •Edep~1 kJ/g (in lead)
- •temperatures up to 1.5 eV
- •kbar pressure range
- •@ solid state density, two phase vapor-liquid, near creatical

## NDCX-Berkeley






- •Beam: K (+1) neutralized, drift compressed
- •Intensity:~$10^{10}$
- •Energy: 300keV/ion
- •Focal spot: >=1 mm
- •Duration (FWHM): >=2 ns
- •Beam time: ~"unlimited"

**HED samples:**

- •Edep~0.2 kJ/g (in Al)
- •temperatures up to 0.3 eV (0.5 after upgrade)
- •@ solid state density, two phase vapor-liquid

# Summary

•**Commissioned pyrometer, streak camera, light collection optics, micro-positioning hardware, target chamber.**

•**Determined improvements and upgrades.**

•**Acquired initial data and made first attempts to simulate it.**

•**Demonstrated NDCX being a competitive machine for WDM research.**

•**Near term upgrades will increase temperatures.**