LIBS Analysis of the Polymer UDMA; Deuterated as well as Doped with Au nanoparticles

-A Part of the Nanoplasmonic Laser Inertial Fusion Experiment

Dr. Archana Kumari
For NAPLIFE collaboration

Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal

Aim of the NAPLIFE Project

- To explore alternative routes to existing fusion experiments
- To increase energy absorption by the target by using Plasmonic Enhancement
- To investigate how Au nanorods can be tuned to increase optical absorption of ultrashort laser pulses
- To achieve simultaneously ignition by two-sided laser shooting on the target to achieve fusion without thermal equilibrium
- To avoid hydrodynamical instabilities in fusion plasma

LIBS: Laser-Induced Breakdown Spectroscopy

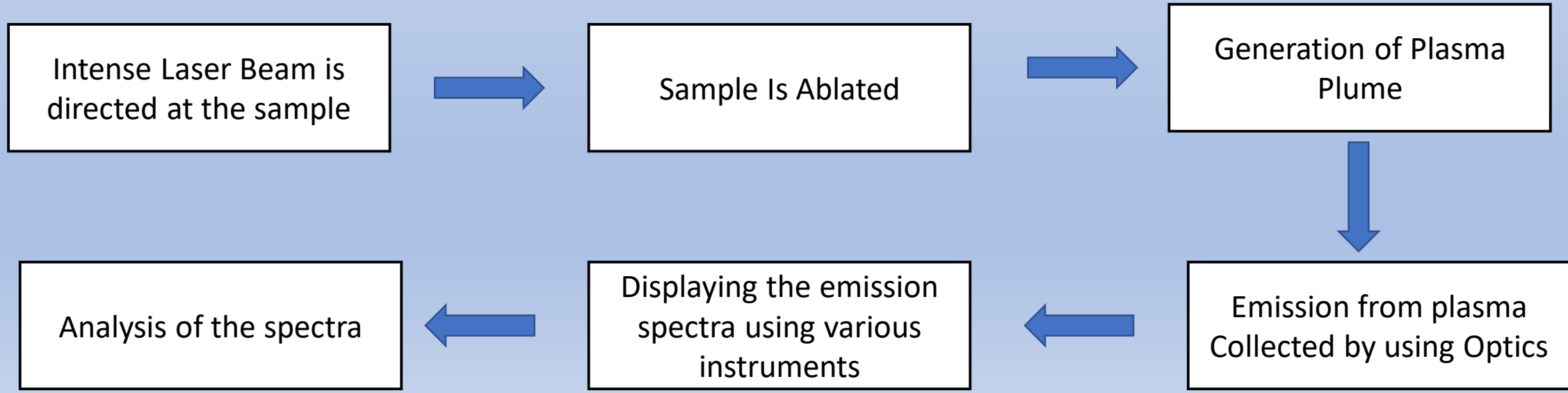
- An analytical method that helps in determining the elemental composition of Solid, liquid, or gaseous samples

LIBS Advantages

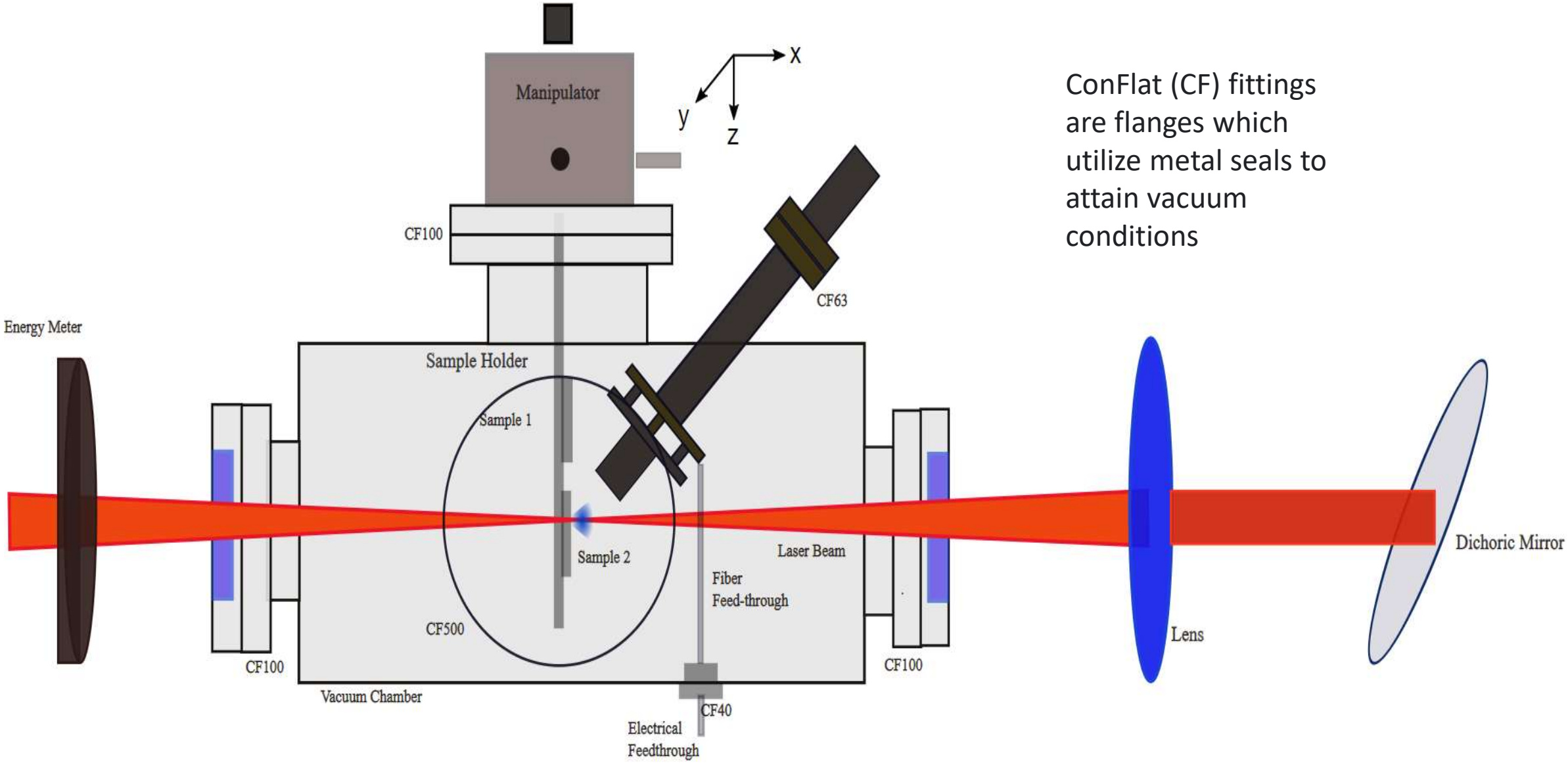
- Versatile Sampling: Solid, Liquid, or Gas
- Little or no Sample Preparation
- In situ Investigation
- Multielemental Analysis
- Local Analysis in micro-regions with high resolution
- Helps to analyze multilayer heterogeneous samples

LIBS Difficulties

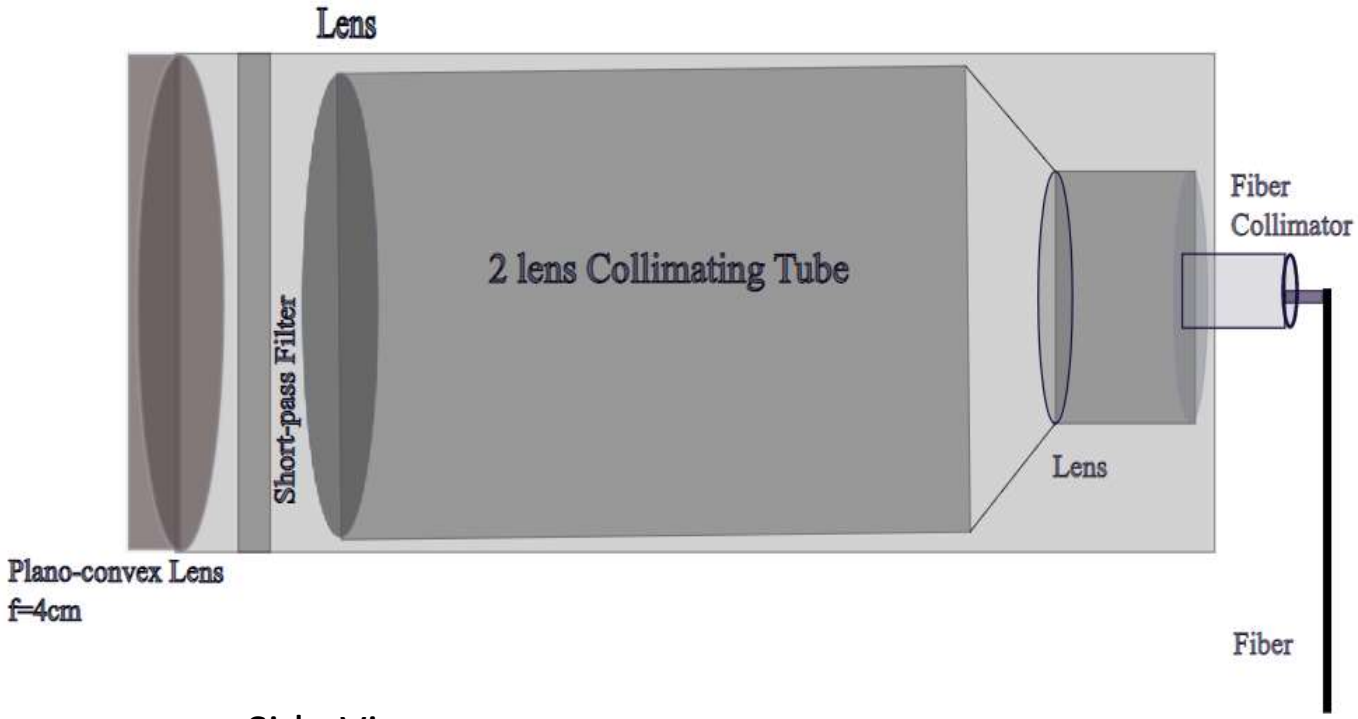
- Cost and system complexity
- Shifted spectral lines may appear
- Needs careful calibration
- Interference in the spectra by possible Doppler/Stark effects

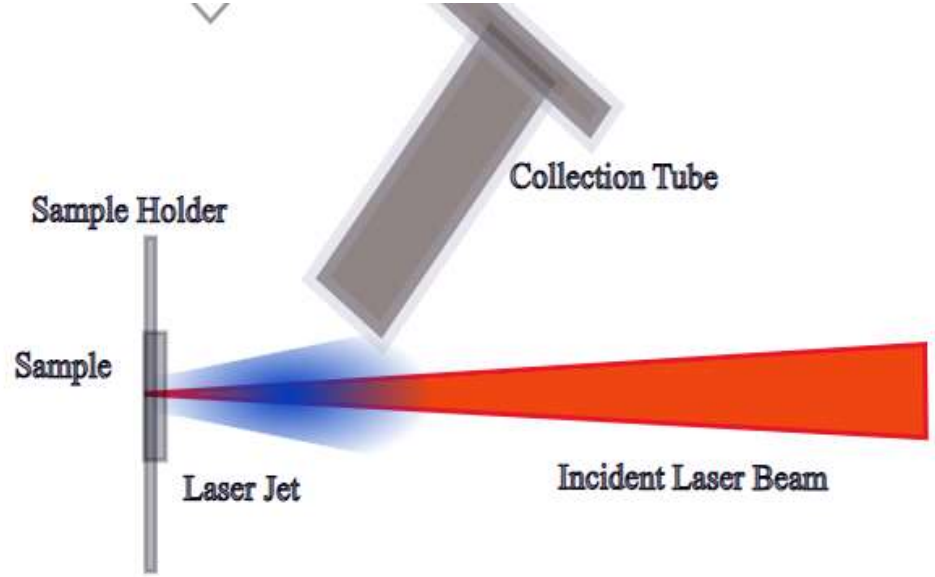


Experimental Setup for LIBS

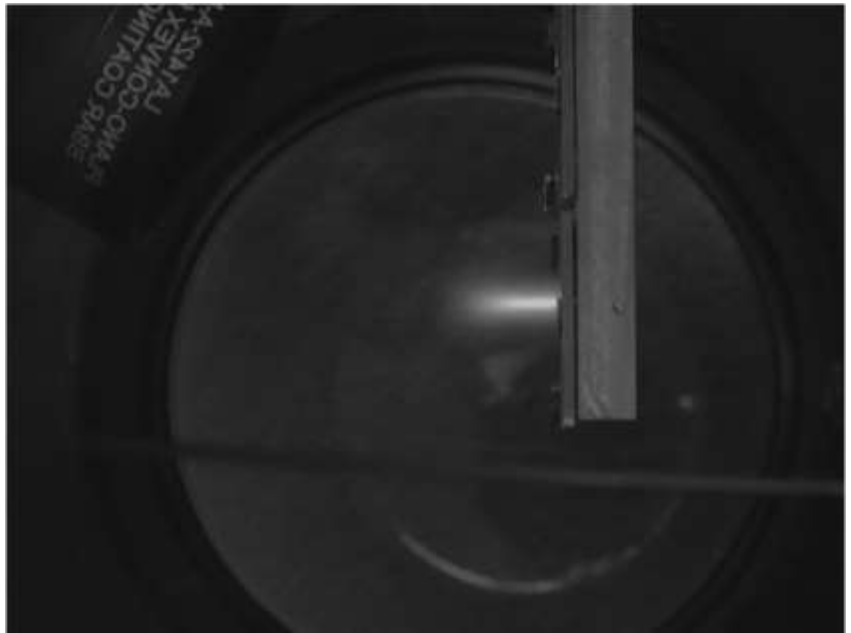


ConFlat (CF) fittings are flanges which utilize metal seals to attain vacuum conditions

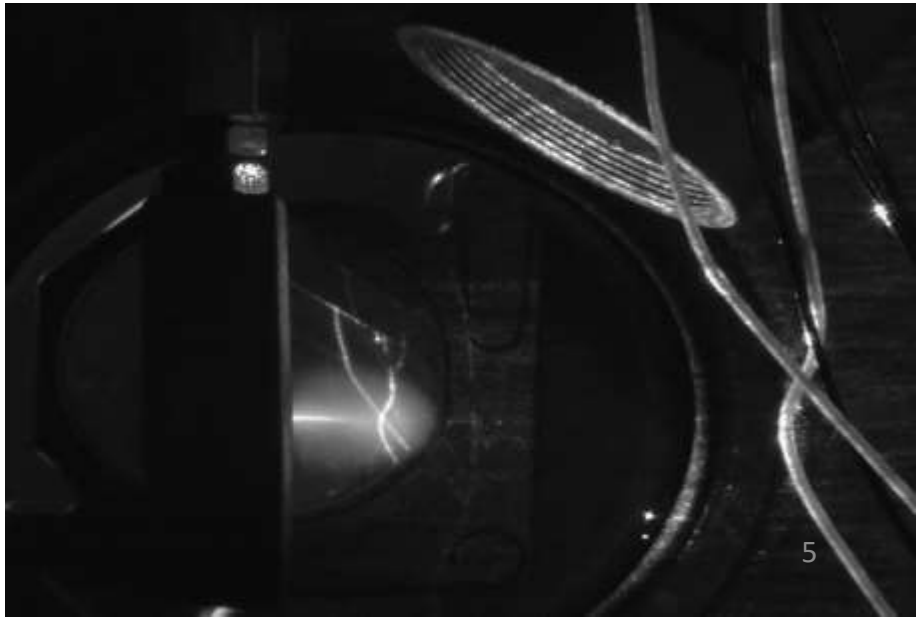




Side View



Top View



Instrumentation for LIBS

Applied Laser System:

Femtosecond Ti: Sapphire chirped-pulse amplifier

- Max. Laser Pulse Energy: 30 mJ
- Pulse length used: 40 fs
- Range of the pulse length: 40-120 fs
- Central wavelength: 795 nm
- Max Peak Power:1 TW
- Focused max. Peak intensity:10^{18} W/cm^2

Spectrometer:

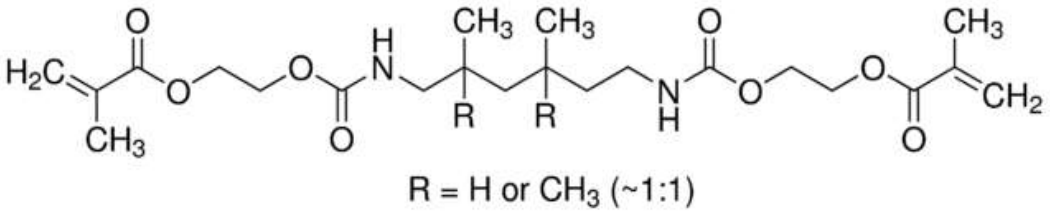
LTB Demon spectrometer (Double Echelle Monochromator)

- Detector: ICCD
- Wavelength range: 190-900 nm
- Spectral resolution: 2.5-12 pm
- Simultaneous inspection range: 3 nm

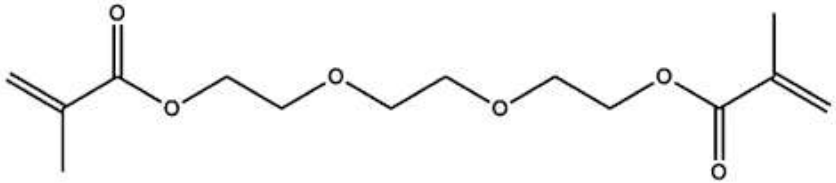
Target Polymer Samples

1. UDMA:TEGDMA mixture (3:1)

UDMA (Urethane Dimethacrylate), $C_{23}H_{38}N_2O_8$

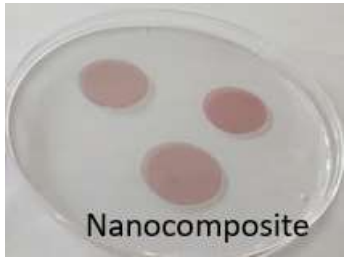


TEGDMA (Triethylene Glycol Dimethacrylate), $C_{14}H_{22}O_6$



2. Nanocomposite: UDMA:TEGDMA mixture (3:1) + Au nanorods

Size of Au nanorods: 85 nm x 25 nm,
Plasmonic resonance to 795 nm



3. UDMA: MMA-D mixture (3:1), also known as Deuterated Sample

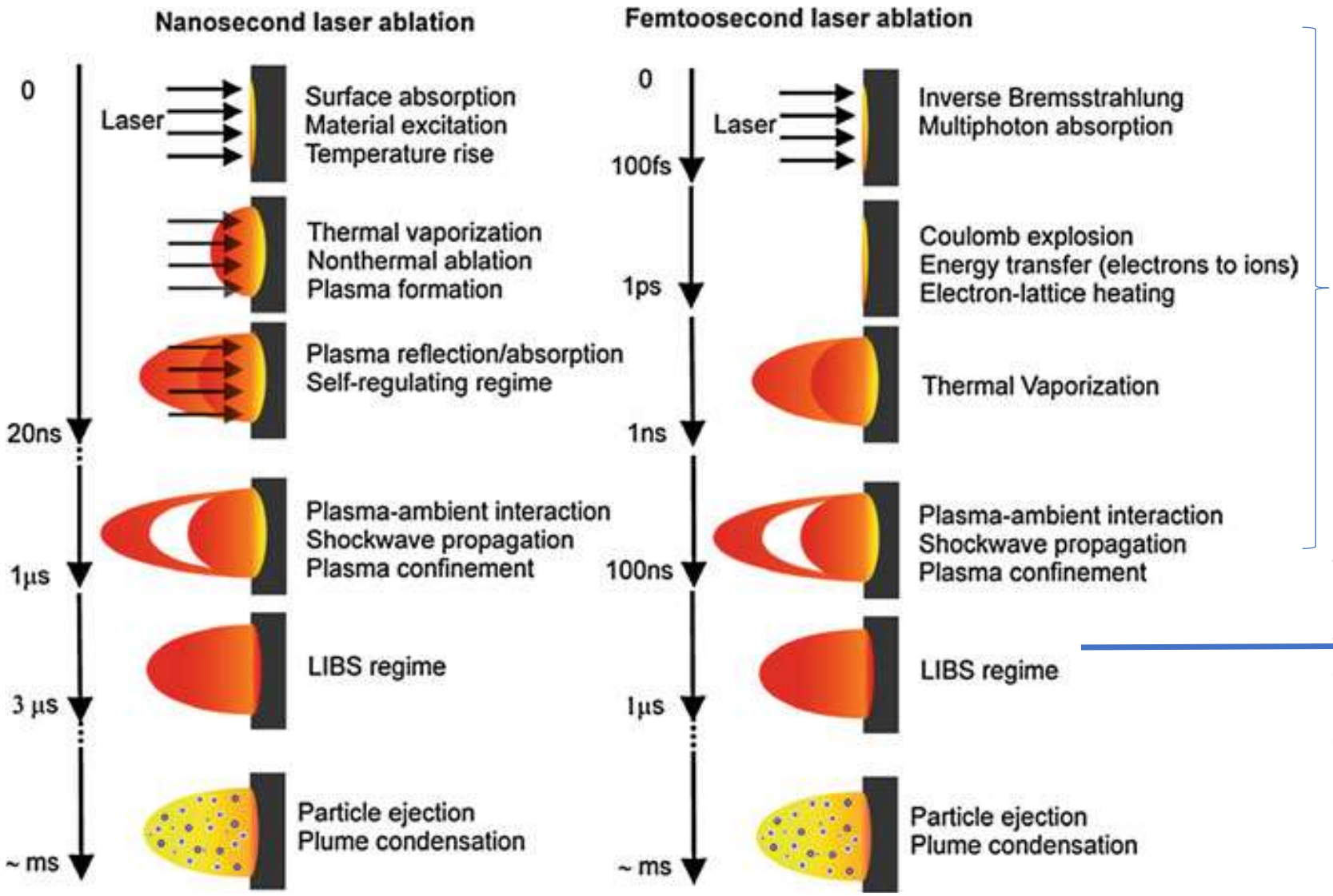
MMA-D (Methyl methacrylate**):** $C_5D_8O_2$

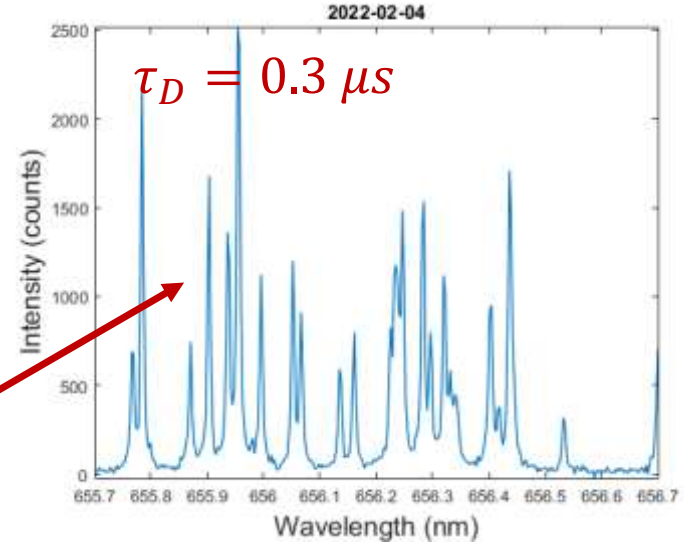
Please refer to Judit Kaman's talk for Sample Preparation!

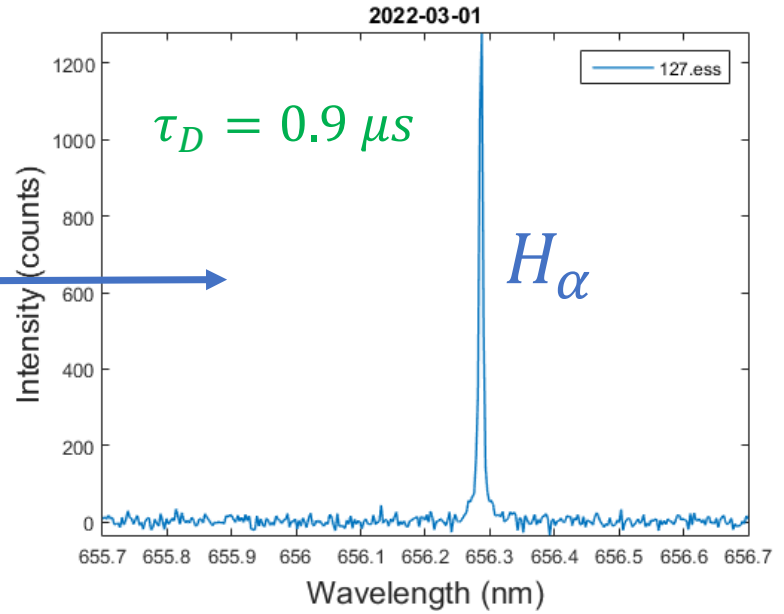
Requirements for the LIBS measurement

- Selecting the Laser pulse duration and energy
- Optimizing the delay and gate width for optimum signal
- Selection of the Balmer α line of Hydrogen for electron transition
- Hydrogen H_{α}: 656.28 nm
- Deuterium D_{α}: 656.11 nm
- Estimation of D/H ratio by integrating the spectra peak areas

Timeline for the Laser Shots



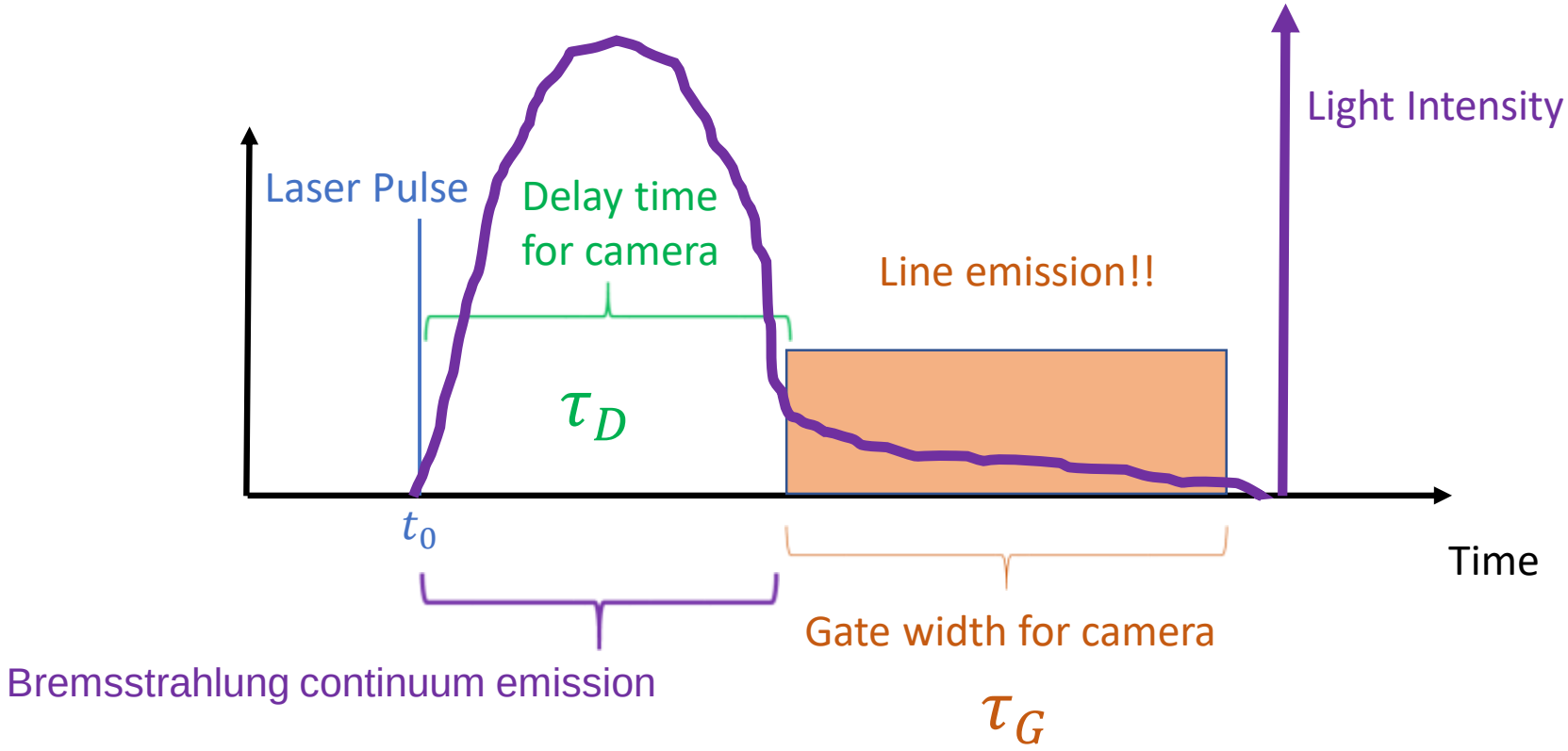




Musazzi et al. Approximate time scales of nanosecond and femtosecond energy absorption and laser ablation along with various processes happening during and after the laser pulse
Spectrochimica Acta Part B: Atomic Spectroscopy. 59. 1033-1039. 10.1016/j.sab.2004.05.009.

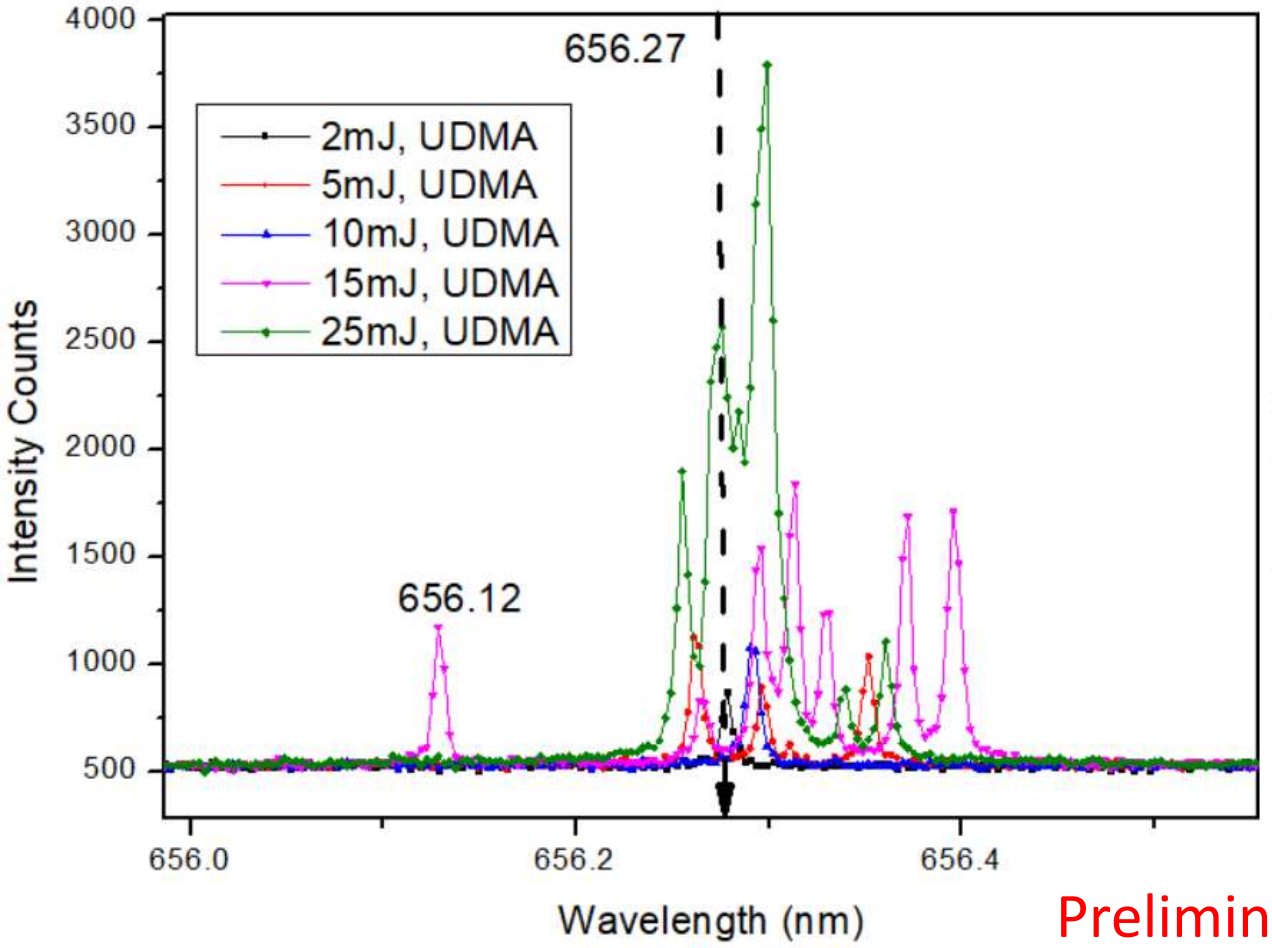
CCD camera with the image intensifier allows to accurately control of the time interval between the application of the laser pulse and the beginning of the signal detection (Known as **delay time**).

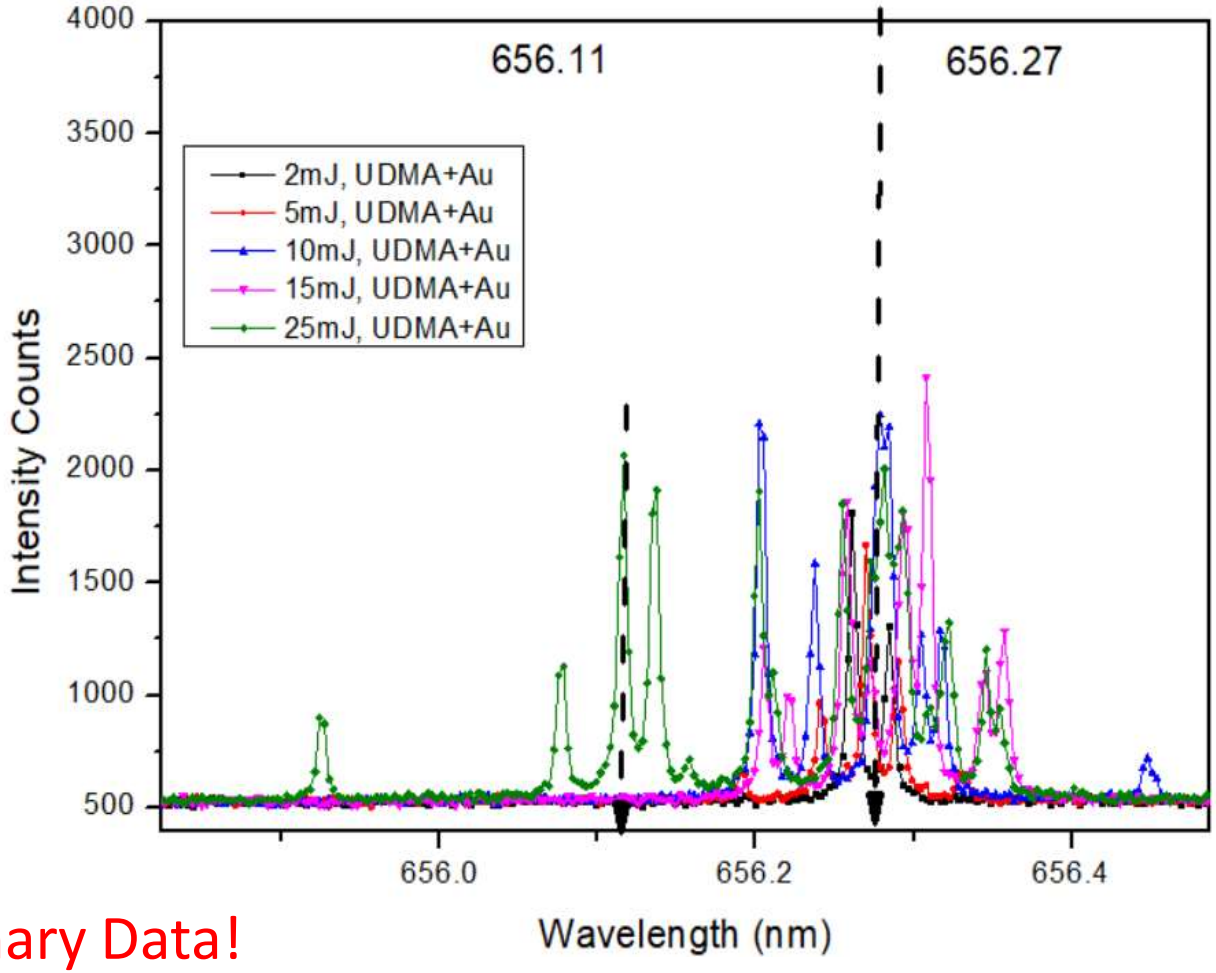
Gated CCD allows controlling not only the delay time and the time interval between the beginning and the end of the signal detection). This is called **gate width**.



The use of a properly selected delay time removes the high intensity Bremsstrahlung continuum emission (generated during the early phases of the plasma formation) from the detected signal which, if present, would hinder the line emission.

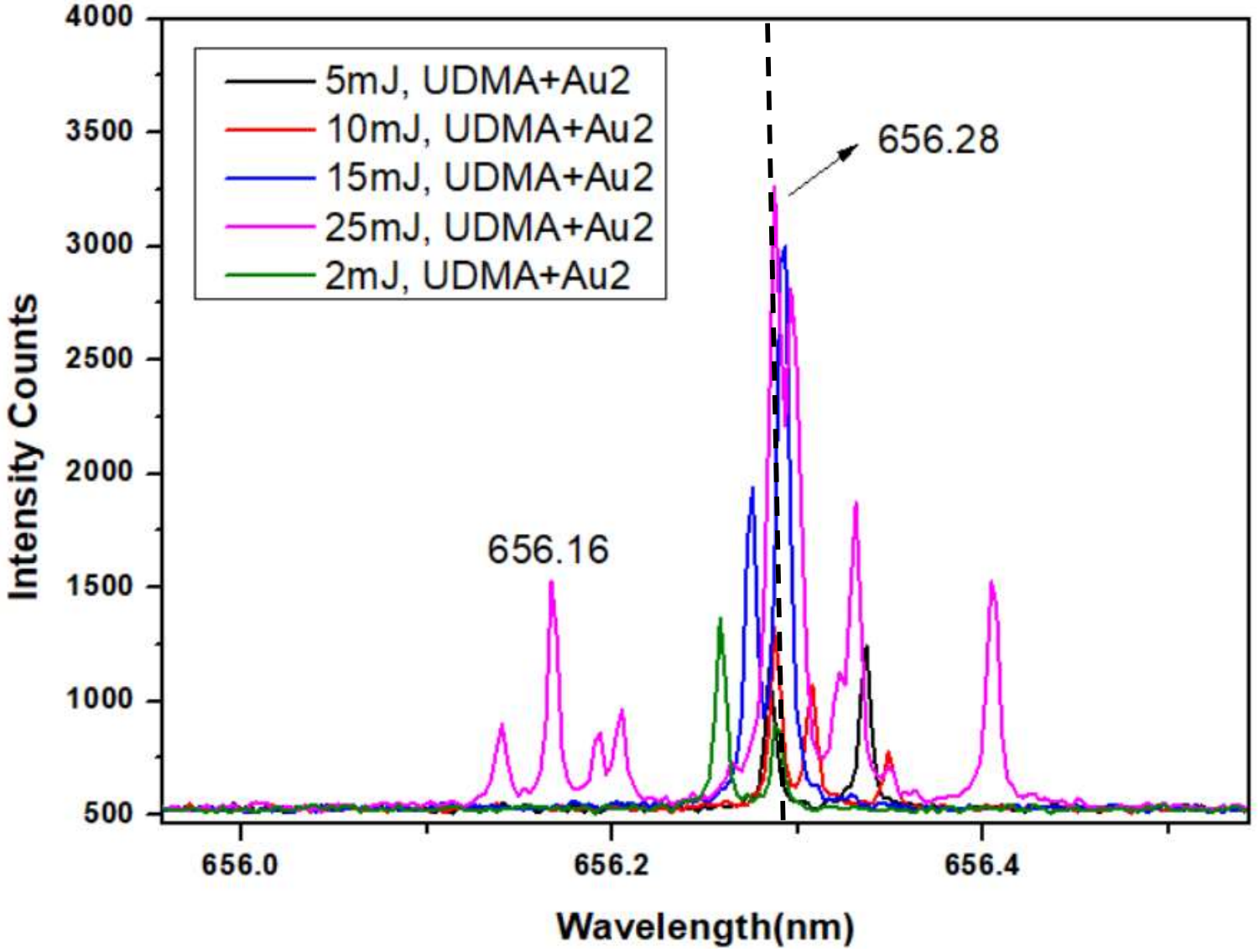
UDMA and UDMA+Au (at different Conc.)





Preliminary Data!

concentration of Au in UDMA: 0.05204 m/m%
concentration of Au2: 0.10408m/m%

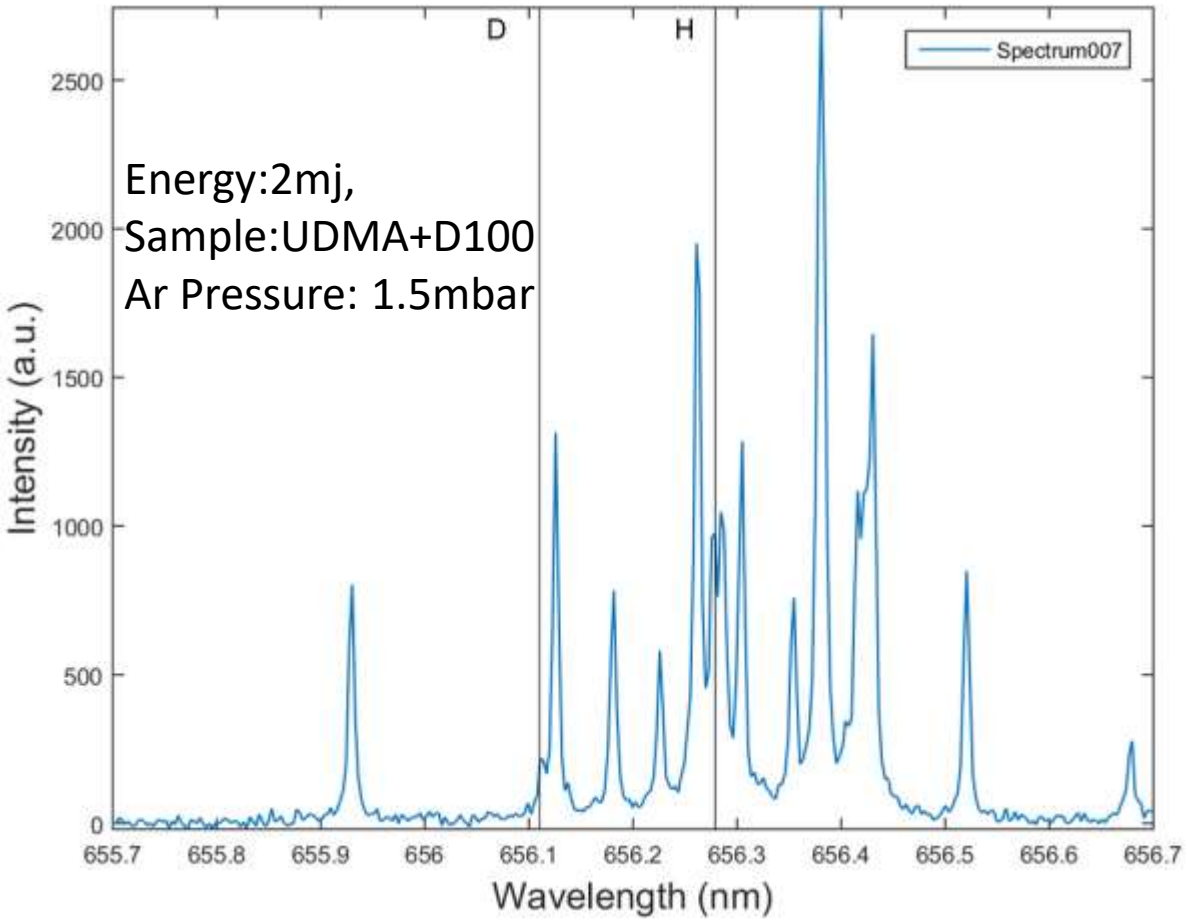


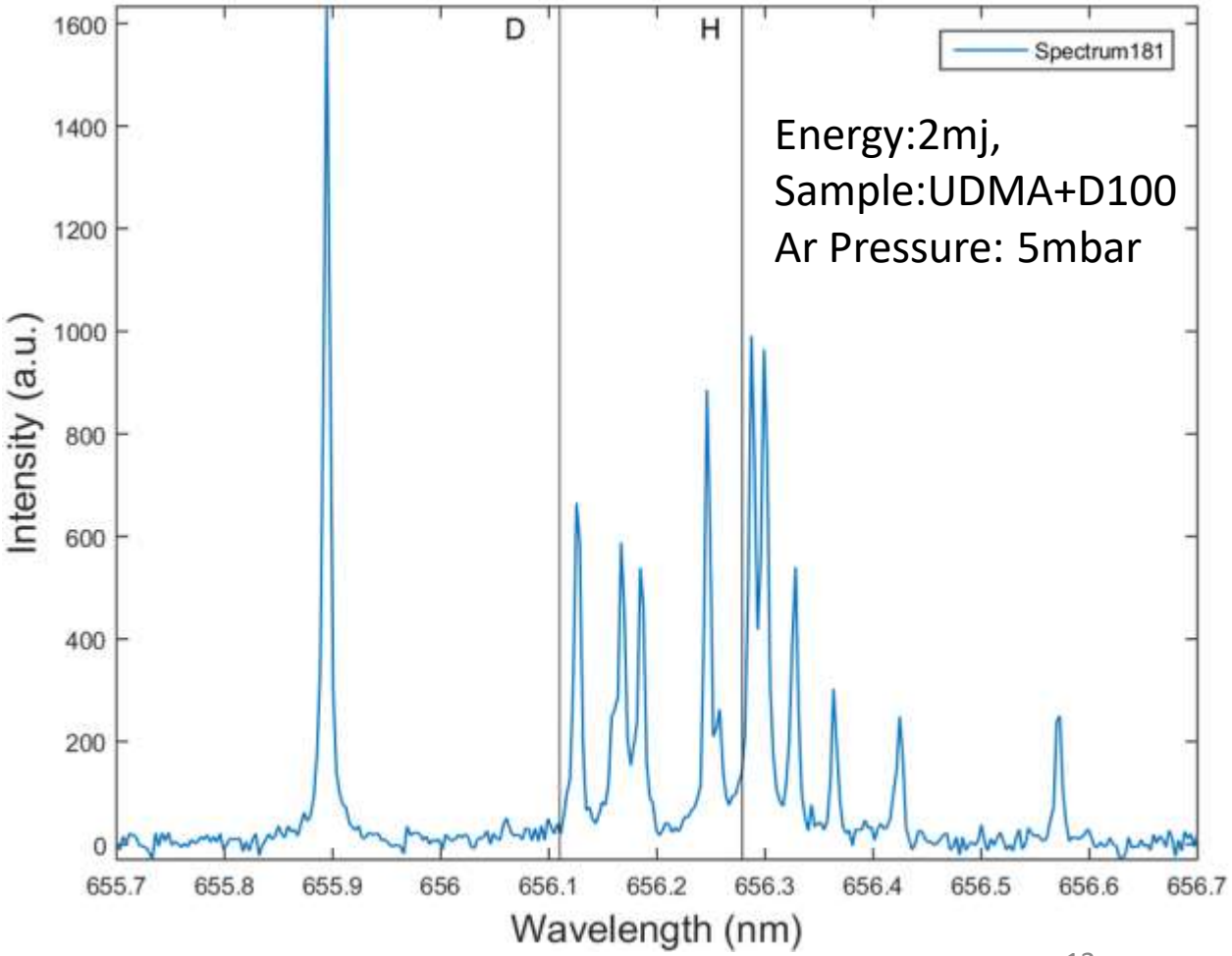
Preliminary Data!

Concentration of Au in UDMA: 0.05204 m/m%

Concentration of Au2: 0.10408m/m%

Deuterated UDMA Sample



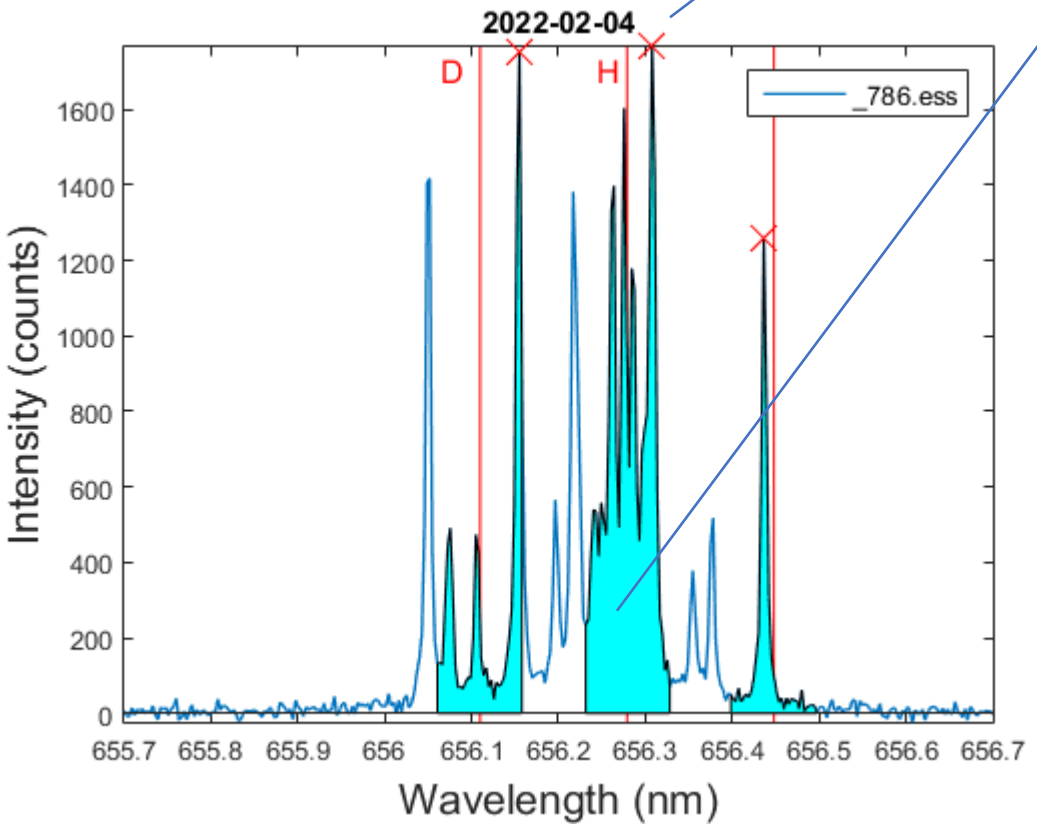


Choosing the spectral window for evaluation of D/H Ratio

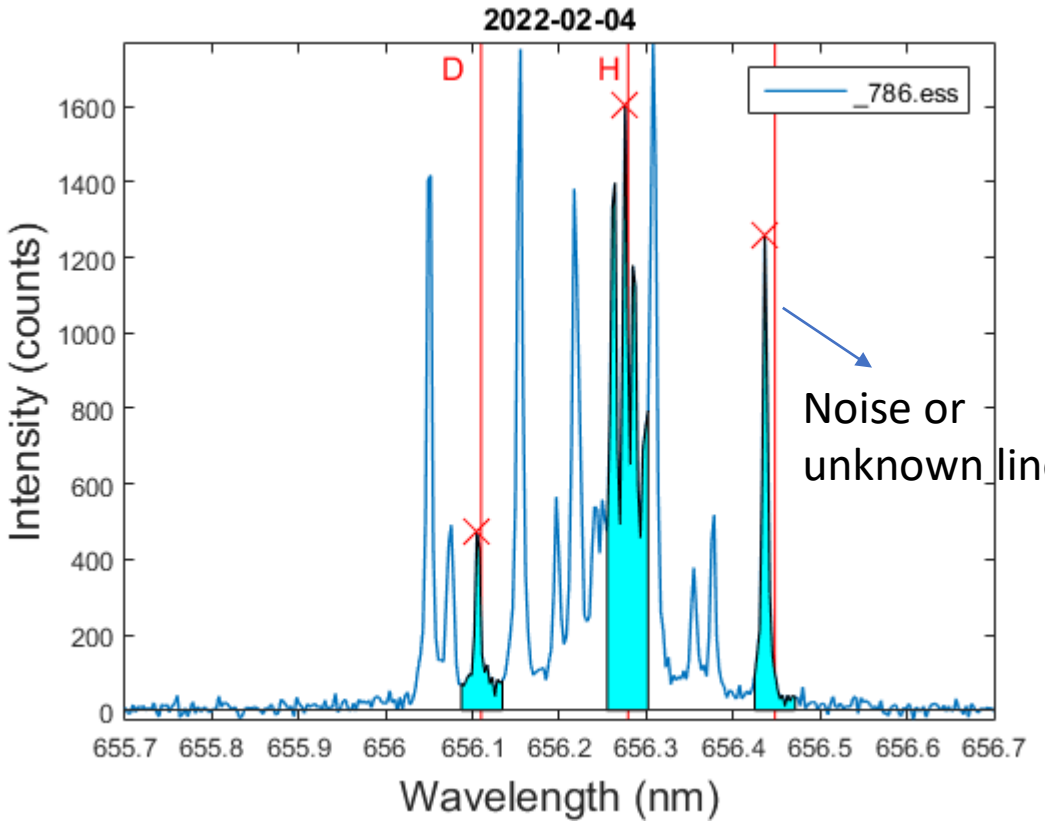
$\Delta\lambda = 0.1\ nm$

Peak intensity

Integrated intensity

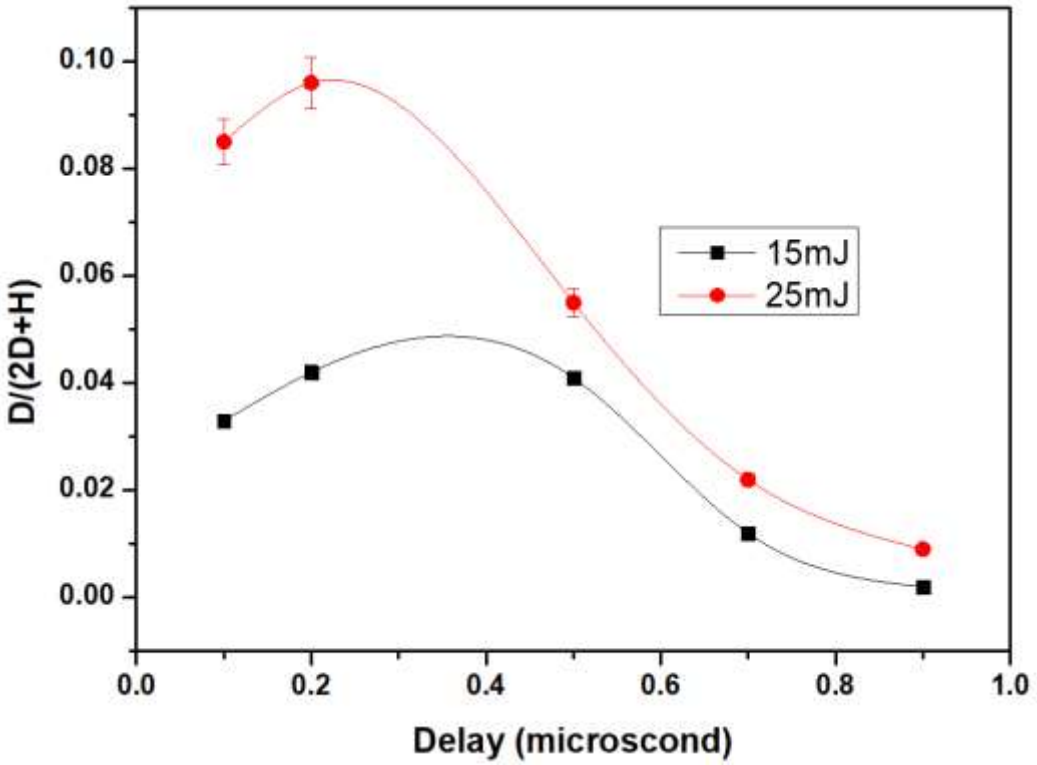


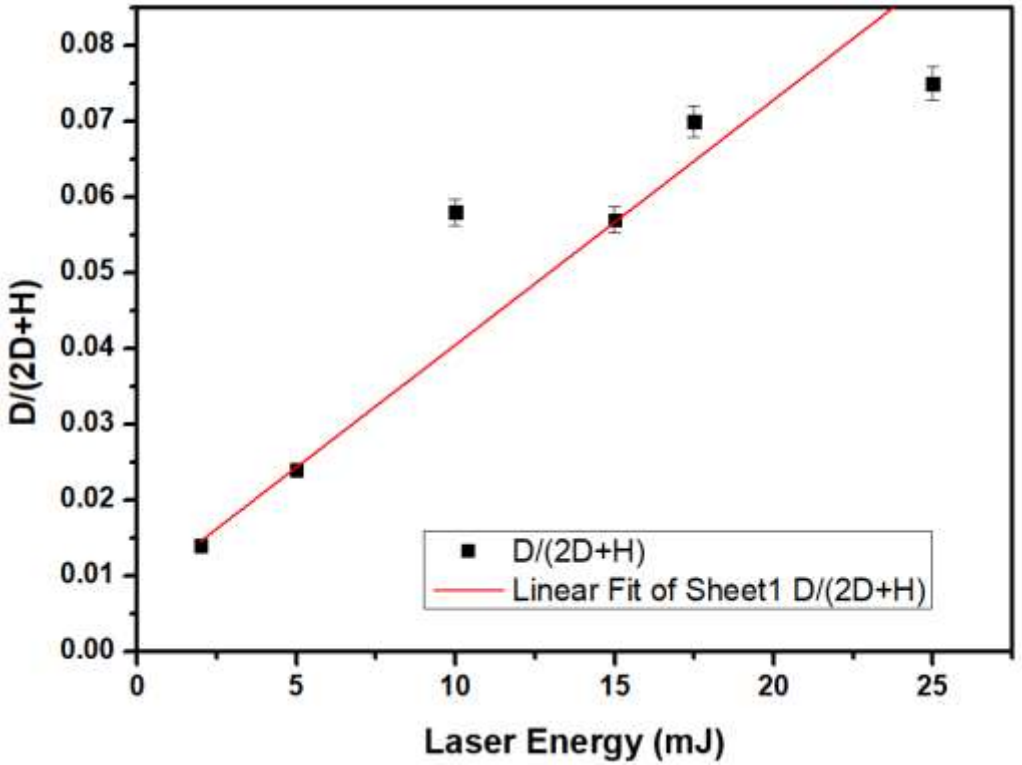
$\Delta\lambda = 0.05\ nm$



Noise or unknown lines

Calculation of ratio; D/(2D+H)





At 17.5 mJ, D(A)=1.828, H(A)=8.32
D(A)/H(A)=0.21
D(A)/[2*D(A)+H(A)]=0.15
No. of H atoms=2.51*10^16
No. of atoms that were converted from H to D=3.765*10^15

Please refer to Agnes Nagyne Sokol's talk on Crater Data Analysis!

Conclusion

- LIBS agrees with the assumption of extra deuterons during the experiment.
- The statistical error bar for estimating the D/H ratio is around 5%.
- Systematic errors are possible due to uncertainty in the shifted spectral lines.

Acknowledgments

- **Project Scientific Leader**: Biro Tamas Sandor(Wigner FK)

- **Scientific Advisors**: Prof. em. Csernai Laszlo (Uni. Bergan), Prof. em. Kroo Norbert (Wigner FK), Prof. Johann Rafelski (Uni. Arizona)

- **Theoretical Calculations**: Papp Istvan

- **Laser Group**:
  - Aladi Mark (Group Leader) (Wigner FK)
  - Kedves Miklos(Wigner FK)
  - Archana Kumari(Wigner FK)
  - Racz Peter(Wigner FK)

Thank You For Your Attention!