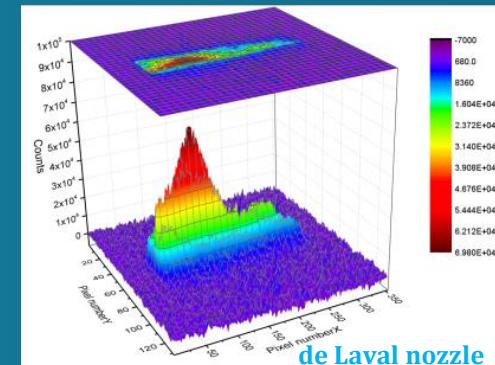
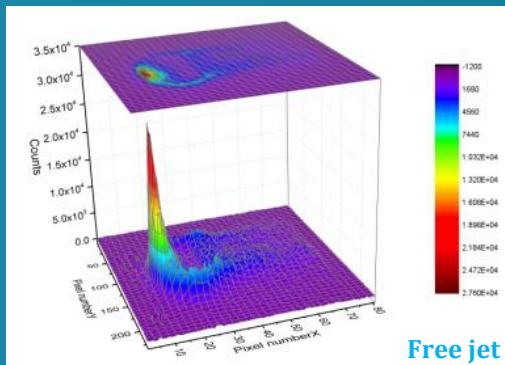




Visualization and characterization of supersonic gas jets for nuclear structure studies



Alexandra (Sasha) Zadvornaya
KU Leuven, Belgium

25 October 2016



Outline:

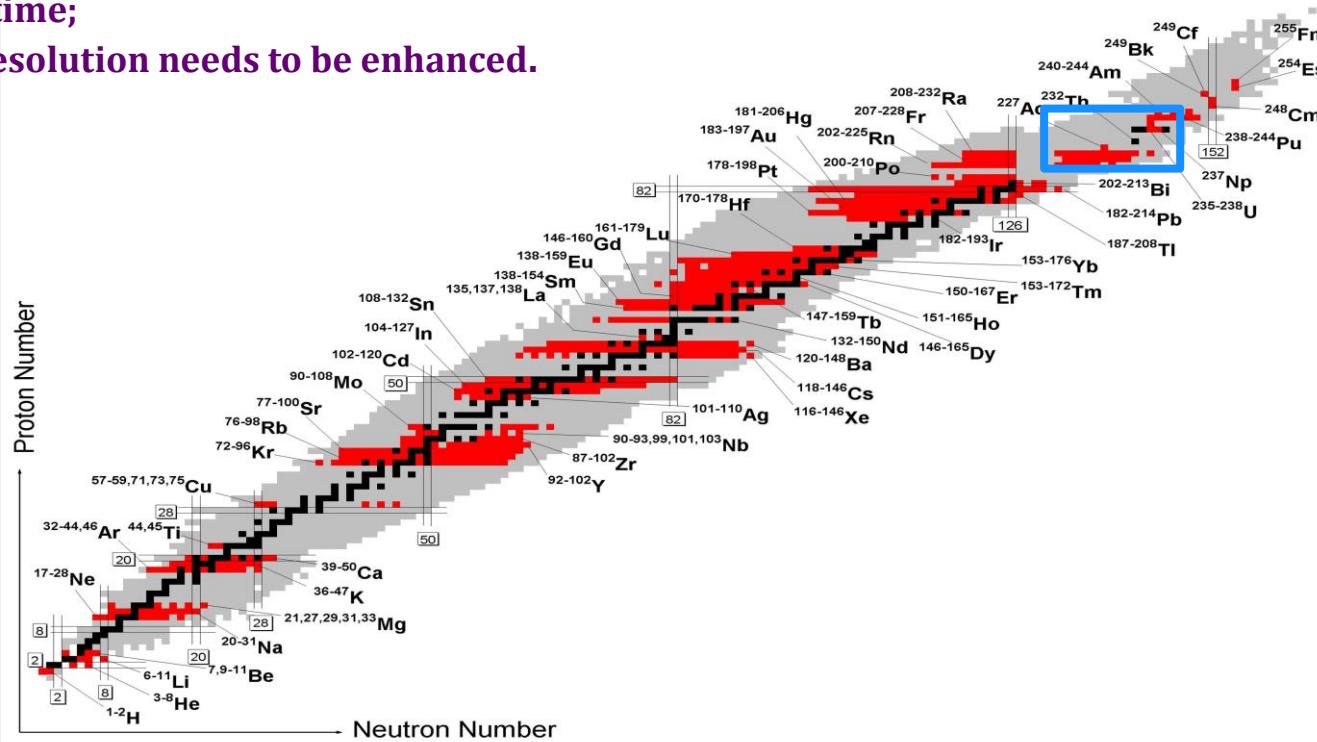
1. Goal of the research. HELIOS-project
2. Simulations in COMSOL Multiphysics software
3. PLIF-spectroscopy:
 - free jet
 - jet, formed by de Laval nozzle
4. Conclusions and Outlook

Goal of the project: study nuclear and atomic properties of exotic isotopes (actinides and super heavy elements)

→ resonant laser ionization.

Challenges to overcome:

- low production rates;
- short lifetime;
- spectral resolution needs to be enhanced.



HELIOS project → Heavy Elements Laser IOnization and Spectroscopy

In-gas-jet laser spectroscopy: HELIOS-project.

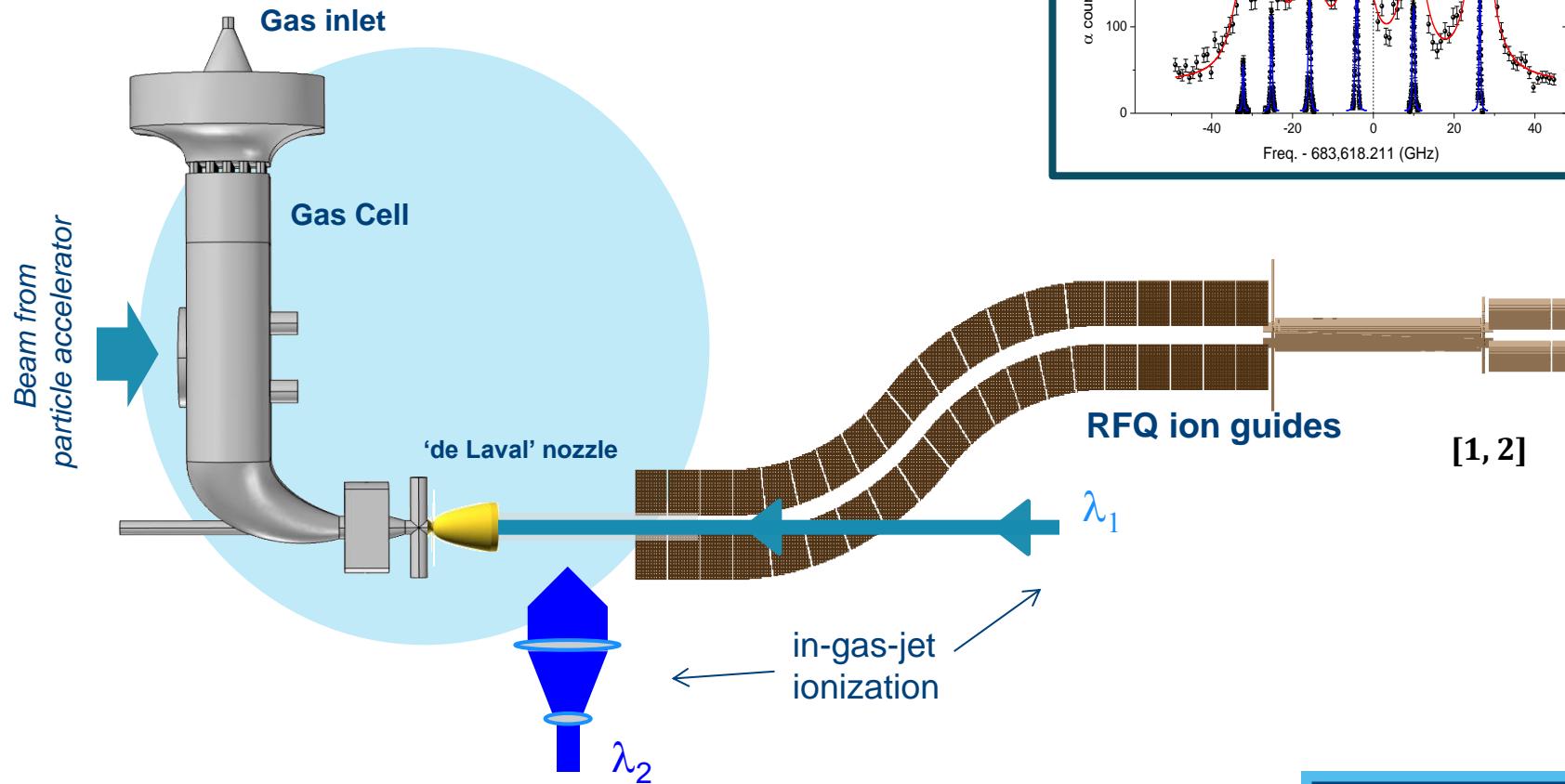
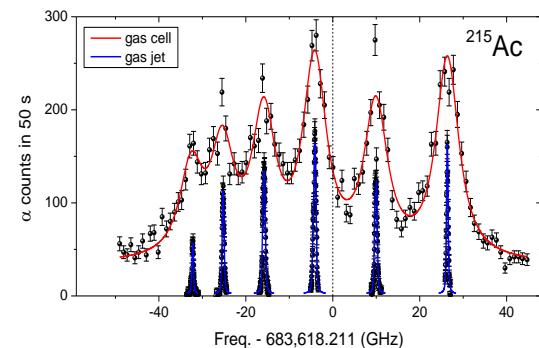
In-gas-cell

(May 2014, ^{215}Ac)
 $\Delta\vartheta_{\text{Lorentz}} \approx 3800 \text{ MHz}$
 $\Delta\vartheta_{\text{Gauss}} \approx 1500 \text{ MHz}$

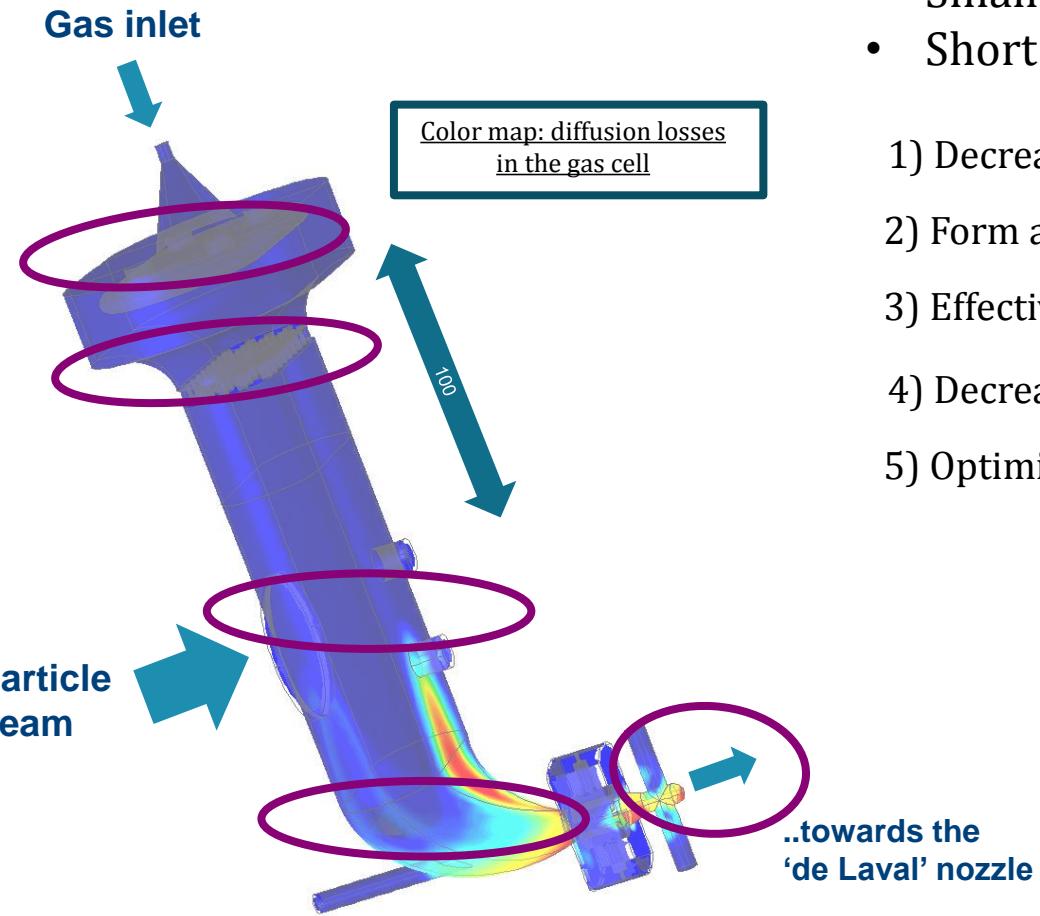
In-gas-jet

(December 2014, ^{215}Ac)
 $\Delta\vartheta_{\text{Lorentz}} \approx 40 \text{ MHz}$
 $\Delta\vartheta_{\text{Gauss}} \approx 300 \text{ MHz}$

→ improved resolution!



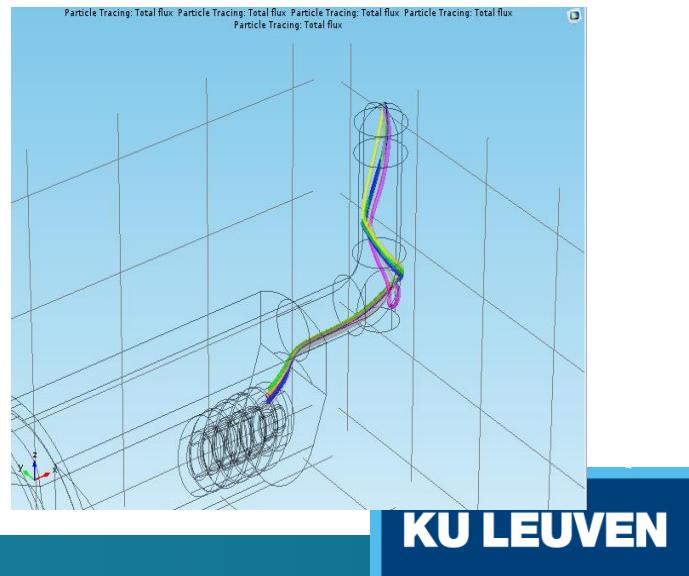
Gas cell shape optimization



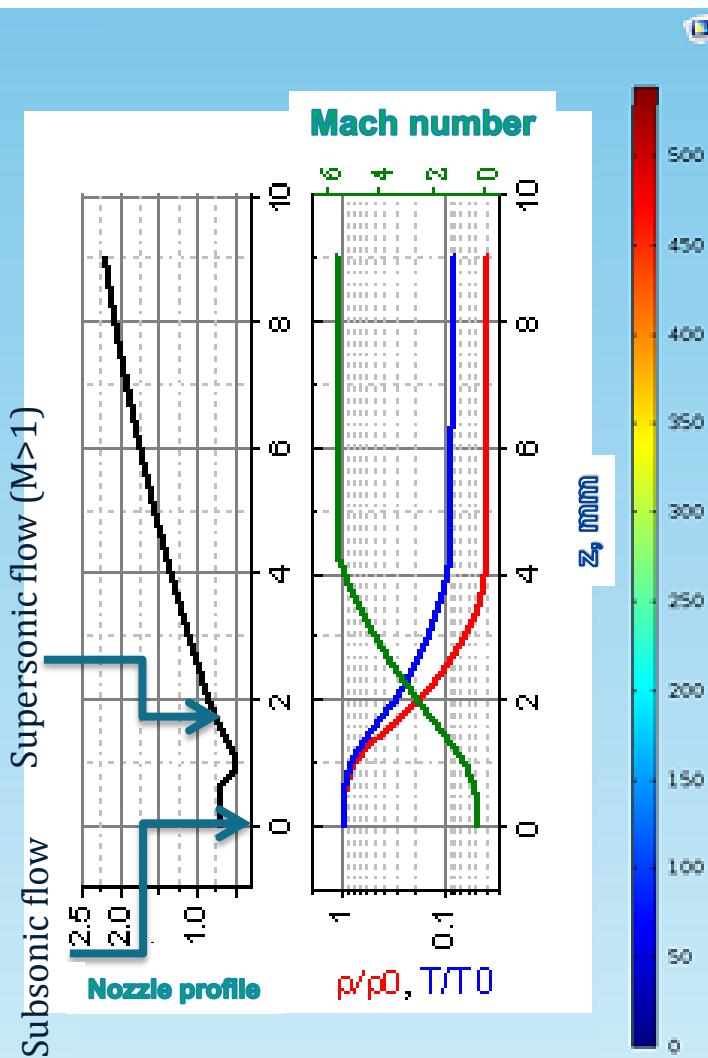
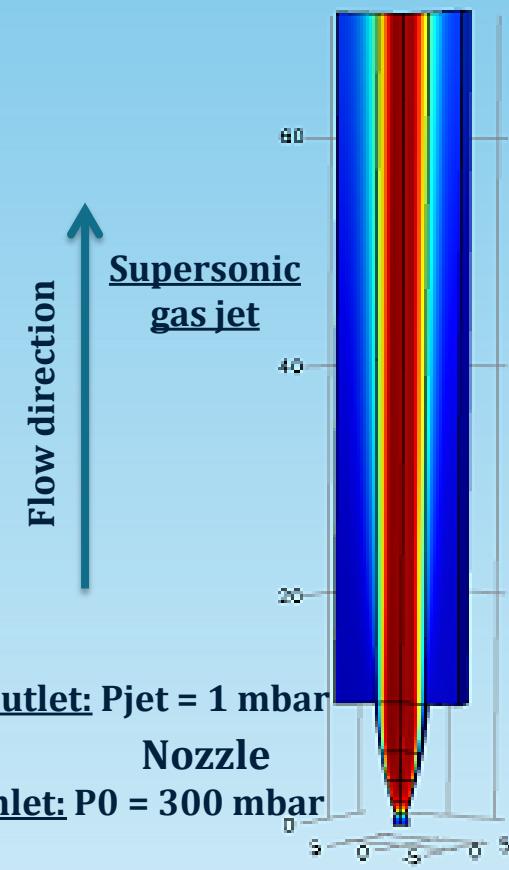
Criteria of a 'good' gas cell:

- Small transmission losses;
- Short extraction time.

- 1) Decrease the gas flow velocity after the inlet;
- 2) Form a uniform flow;
- 3) Effectively stop the nuclear reaction products;
- 4) Decrease losses on the turning path;
- 5) Optimization of the exit diameter.

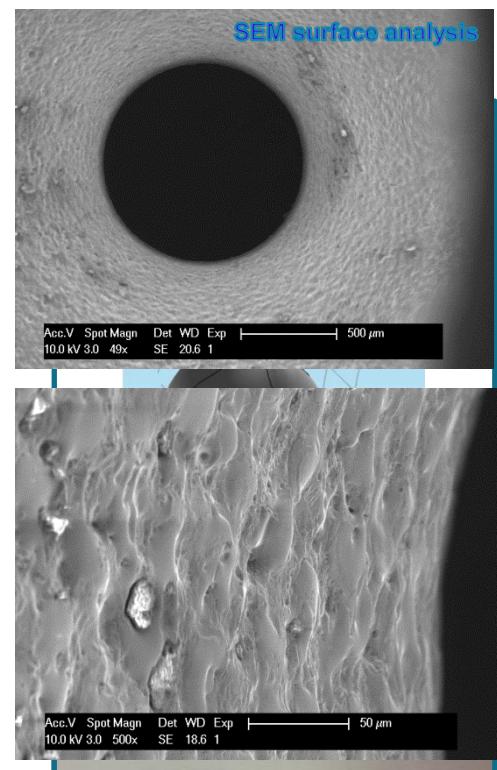


De Laval nozzle's shape optimization

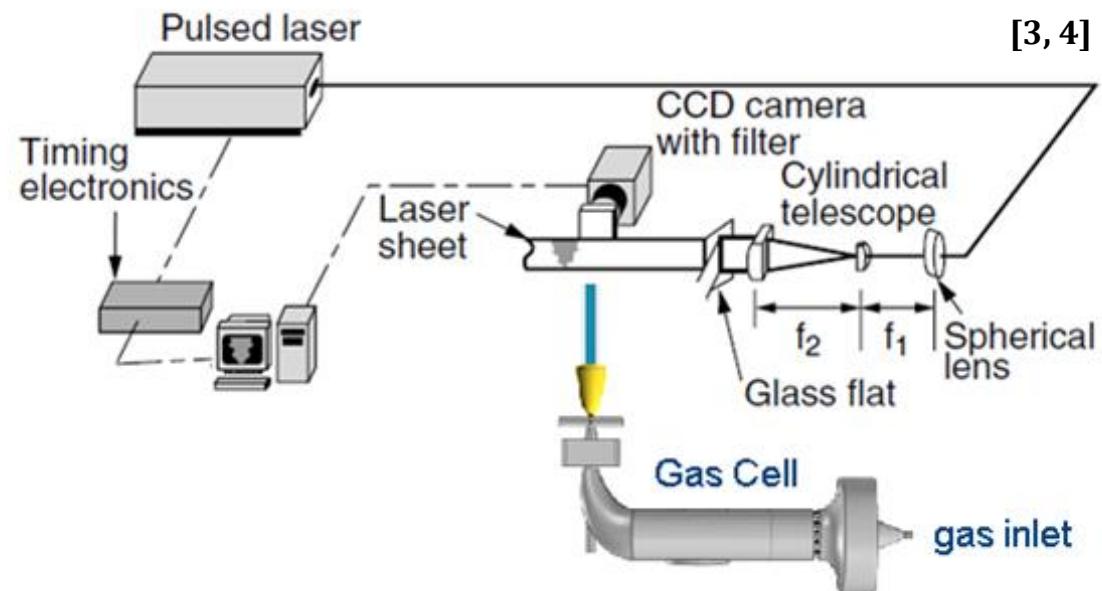
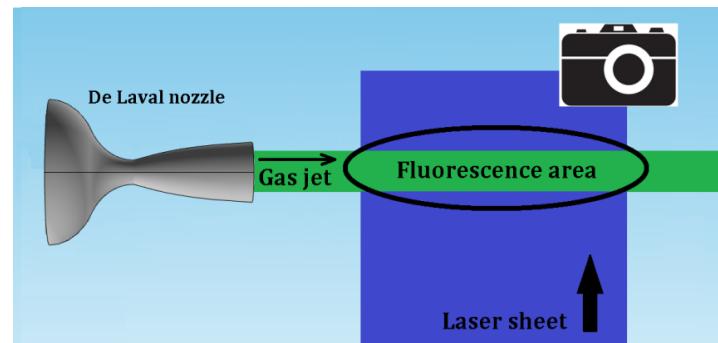
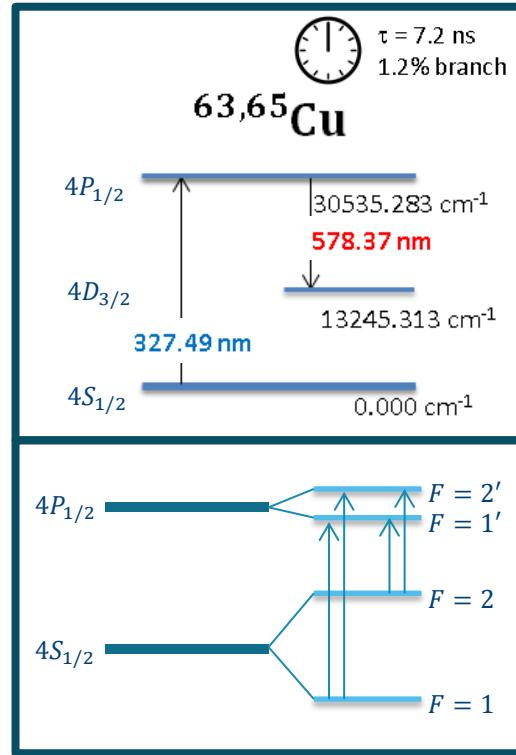


Goals:

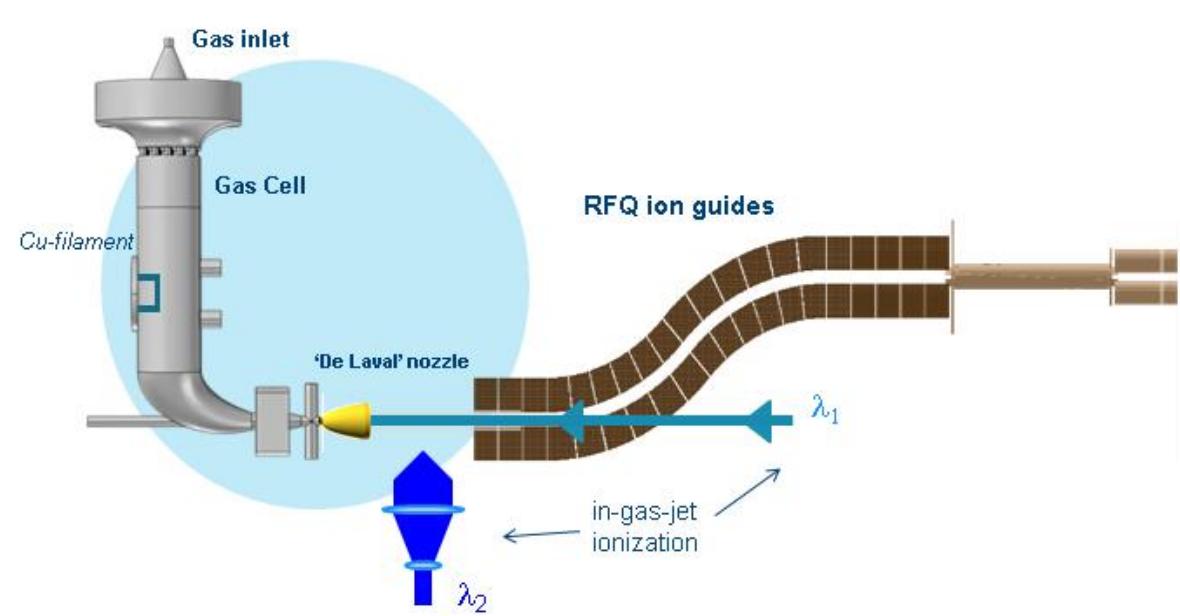
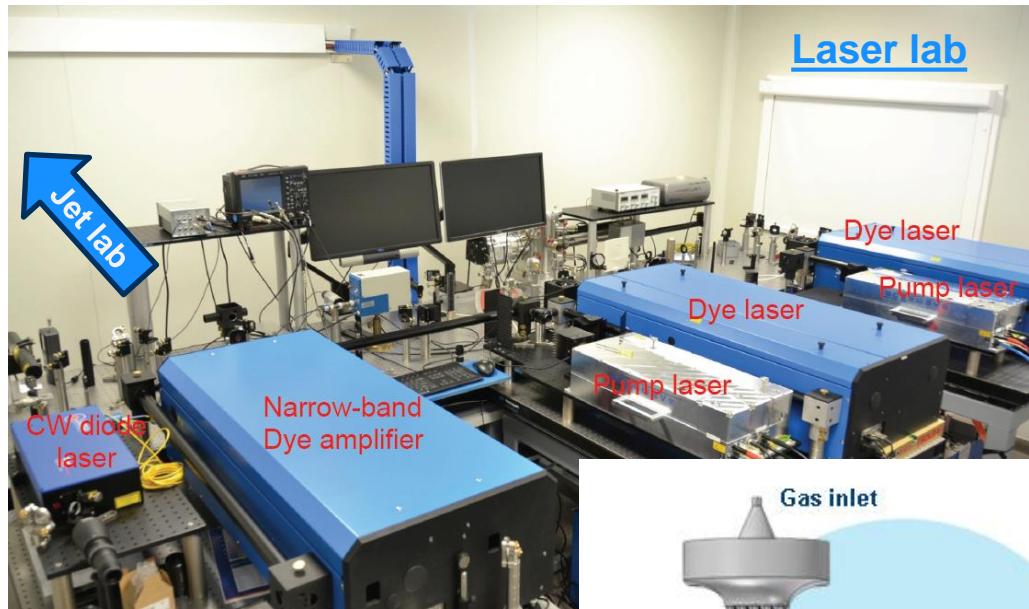
- uniform gas jet;
- low temperature;
- low density.



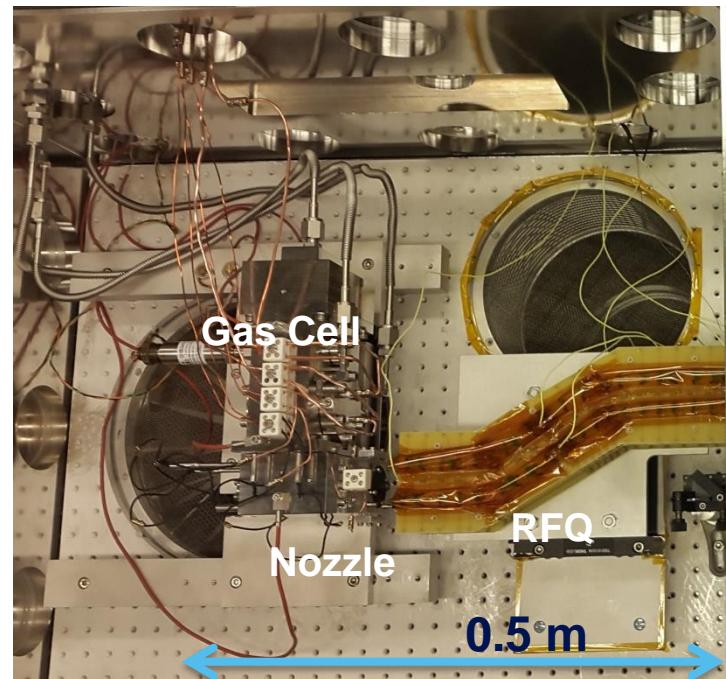
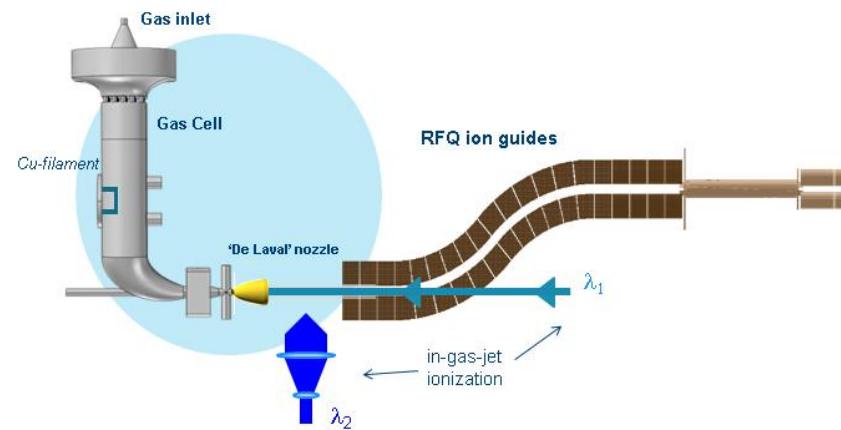
Planar Laser Induced Fluorescence (PLIF) - technique



Experimental setup



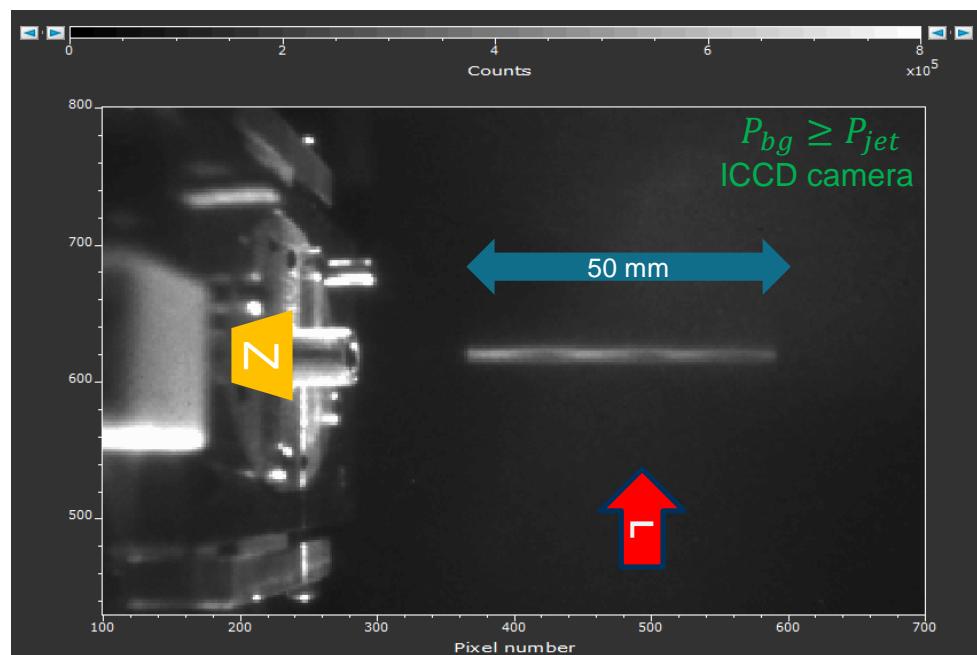
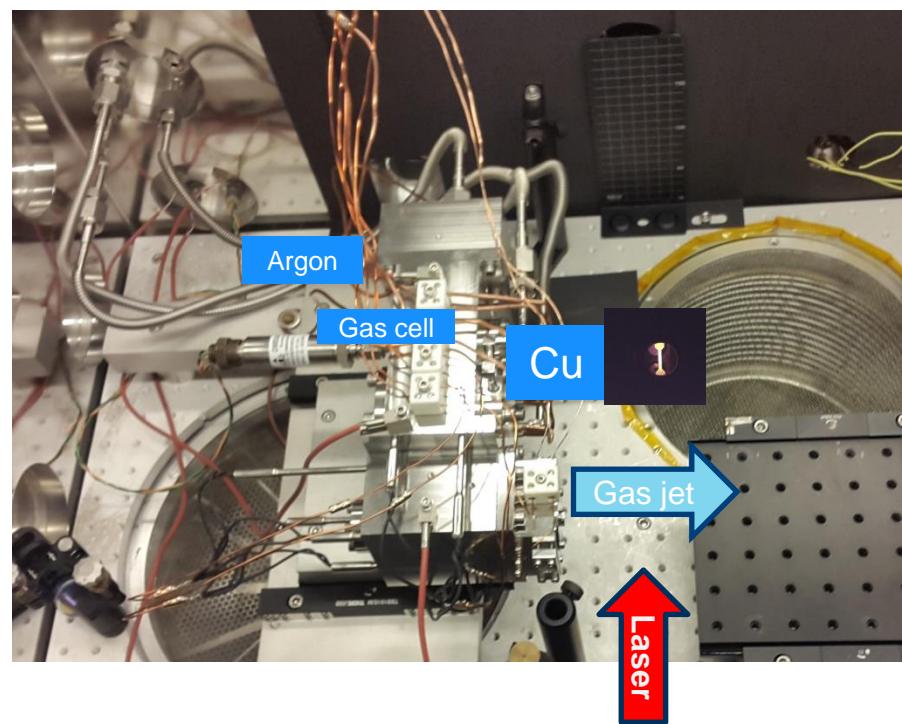
Experimental setup



Inside view

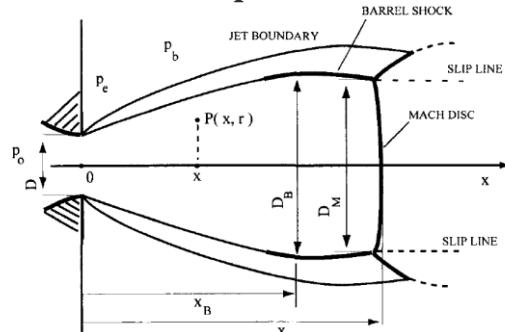
PLIF-technique

Eureka! The very first supersonic gas jet images obtained at our laboratory.

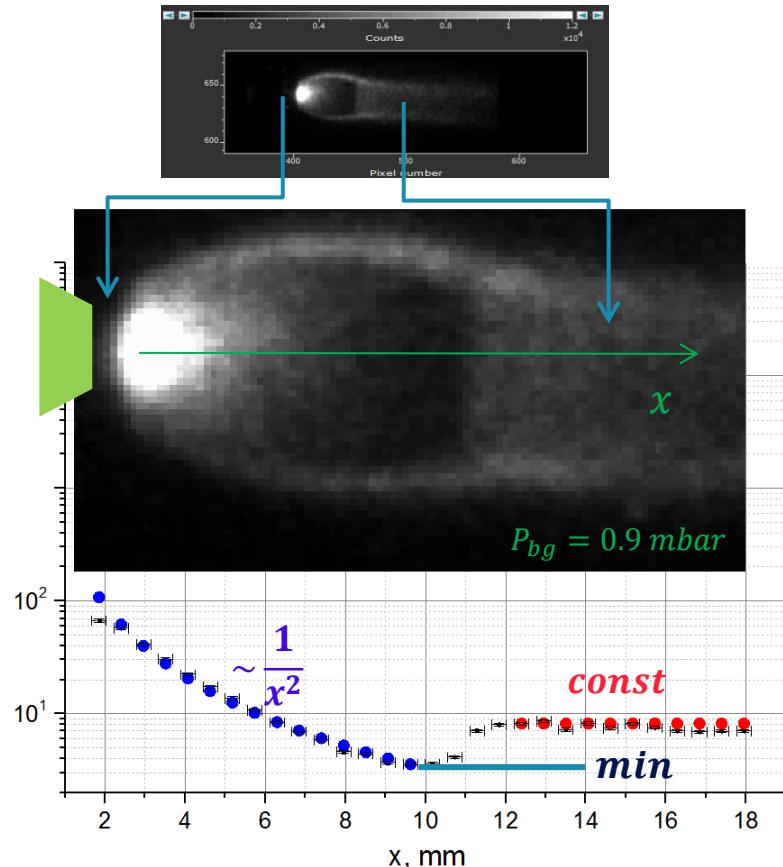
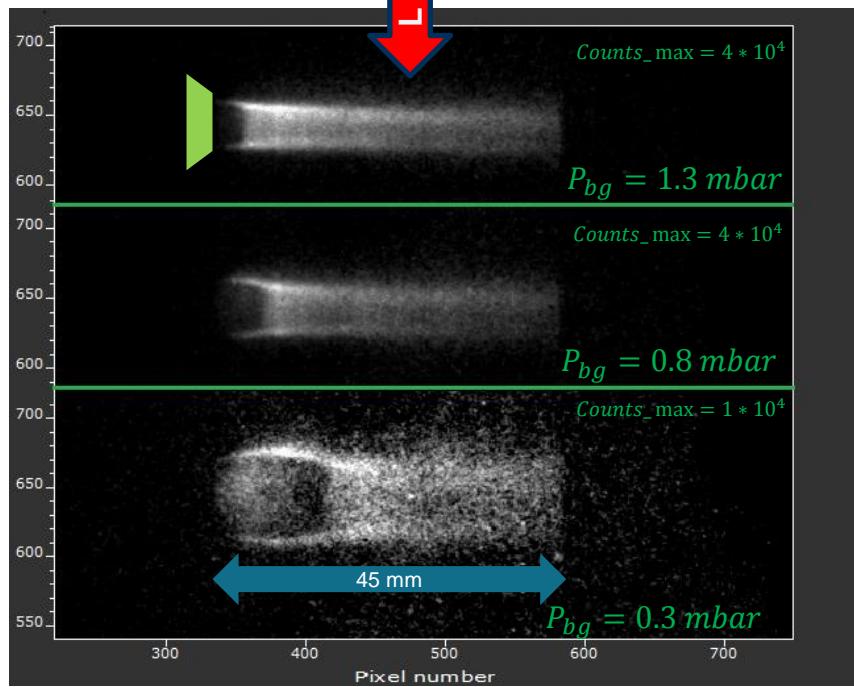


1. Free jet

Mach disk position and density drop in the expansion zone



$$\frac{x_M}{d} = 0.67 * \sqrt{\frac{P_0}{P_{bg}}} \quad [5, 6]$$



[5] H. Ashkenas, M. Sherman, Rarefied Gas Dynamics, Academic Press, 1965, p. 94

[6] S. Crist , M. Sherman and D.R. Glass, AIAA Journal Vol. 4, No. 1 (1966), pp. 68 – 71

1. Free jet

What's next? Broad- and narrowband PLIF of $^{63,65}\text{Cu}$

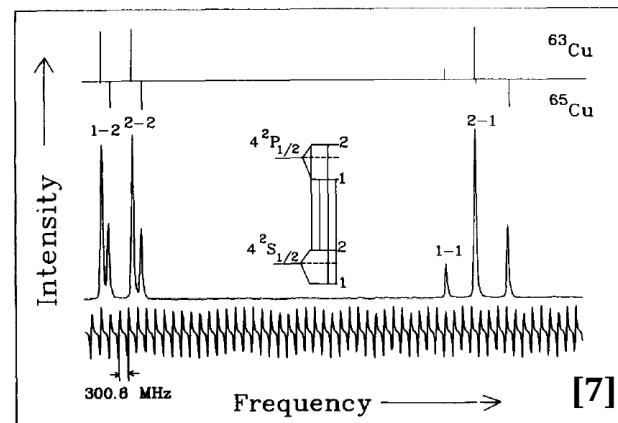
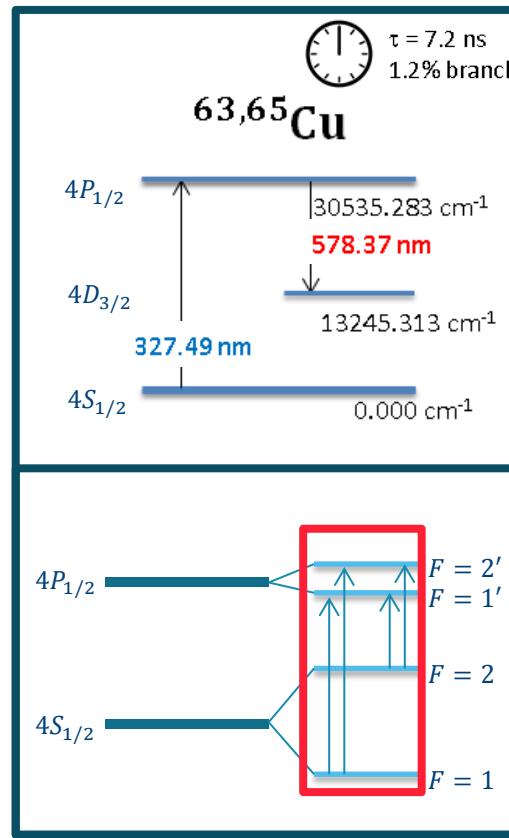


Fig. 2. Hyperfine spectrum of the 327.4 nm D_1 line of ^{63}Cu and ^{65}Cu (natural abundance), both with $I = 3/2$. Upper trace: atomic beam fluorescence spectrum; lower trace: marker cavity transmission signal for calibration.

Spectral line broadening

Lorentz broadening

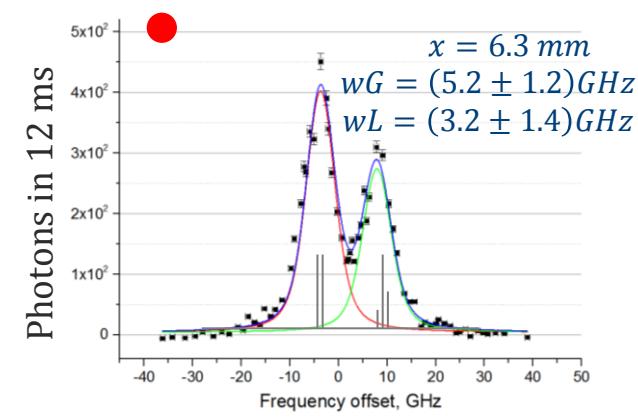
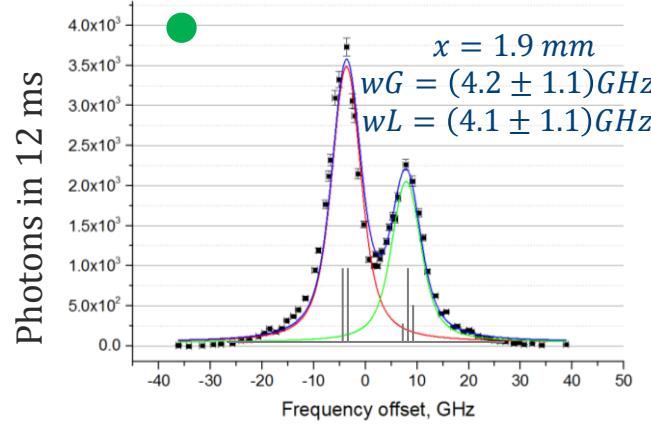
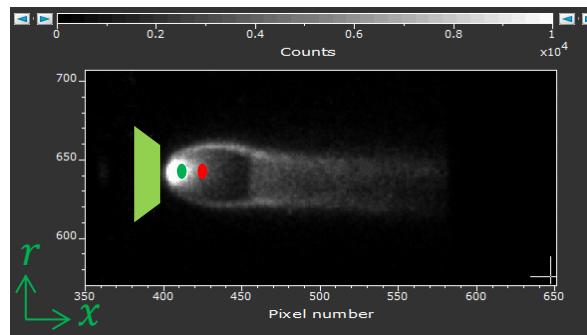
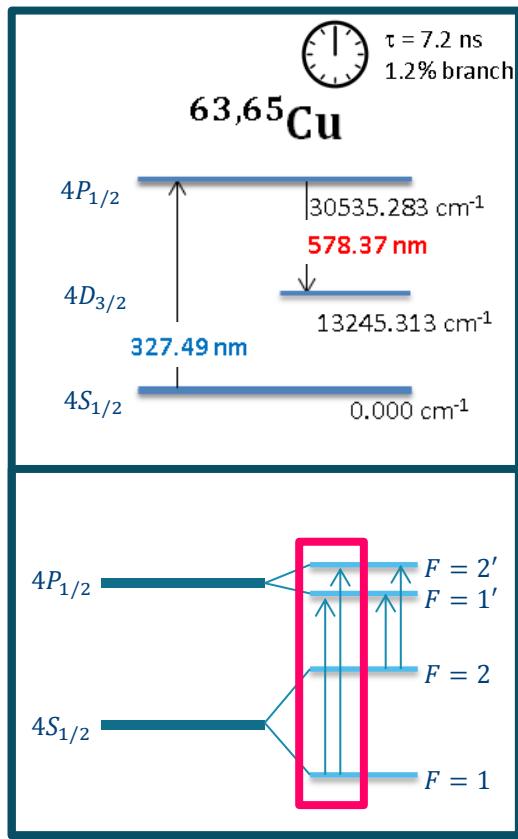
- Jet-related:
- collisions $\Delta\vartheta_\rho \sim \left(\frac{T}{T_{293K}}\right)^{0.3} * \rho$
- Laser-related:
- laser power

Gauss broadening

- Jet-related:
- temperature $\Delta\vartheta_T \sim \vartheta_0 \sqrt{T/A}$
- divergence $\Delta\vartheta_\alpha \sim \vartheta_0 * v * \sin\alpha/c$
- Laser-related:
- laser linewidth

1. Free jet

Broadband PLIF of $^{63,65}Cu$



Necessary upgrade:

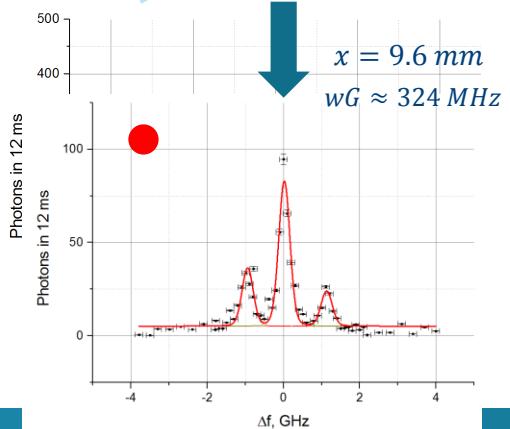
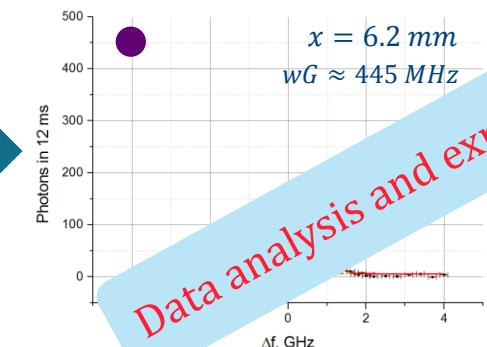
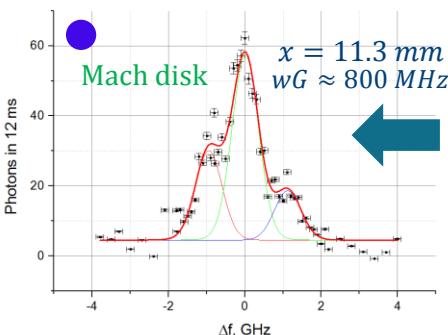
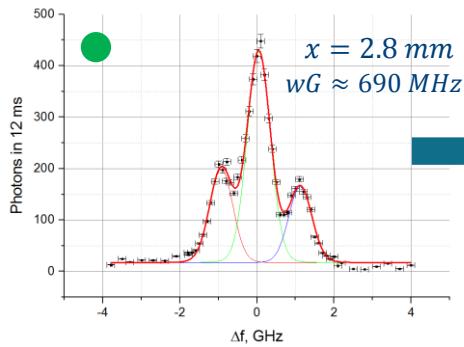
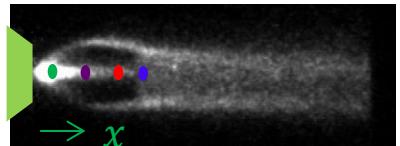
→ reduce laser power ($wL \downarrow$) and reduce linewidth ($wG \downarrow$).

1. Free jet

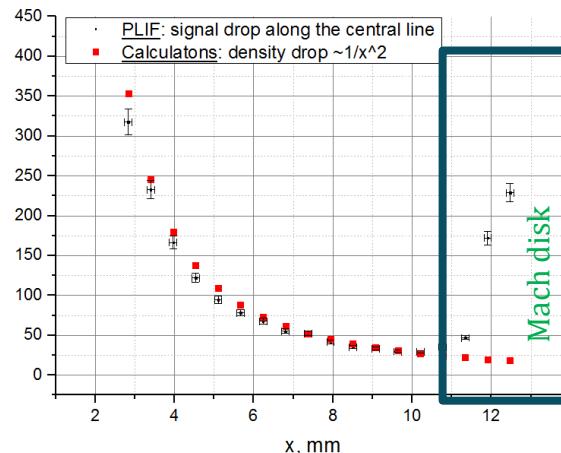
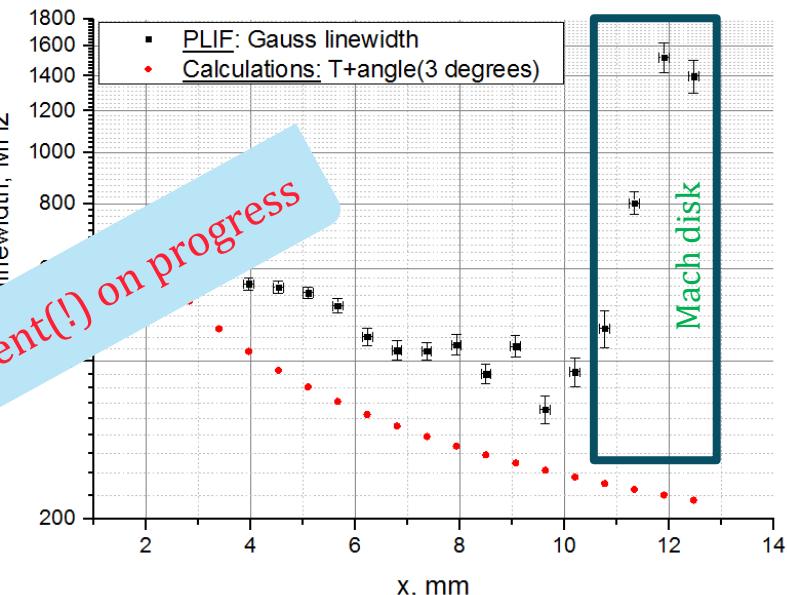
Narrowband PLIF of $^{63,65}Cu$.

Spectral linewidth reduction due to $\downarrow \rho$ and $\downarrow T$ along the free jet's central line.

Temperature estimation.

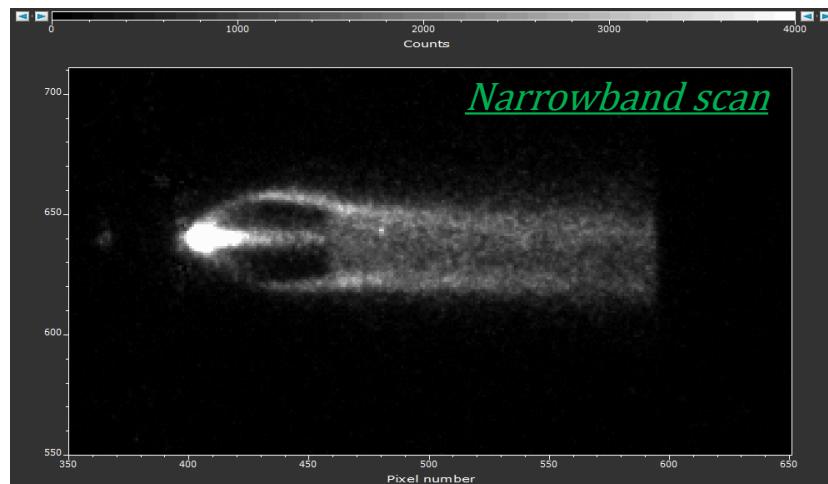
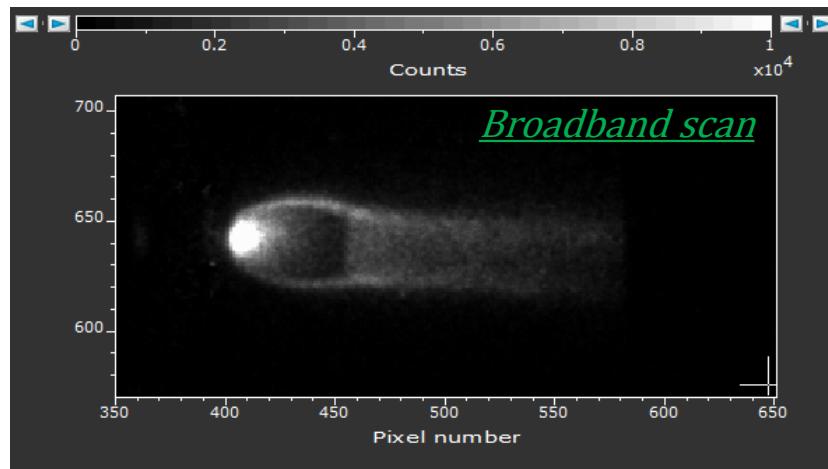
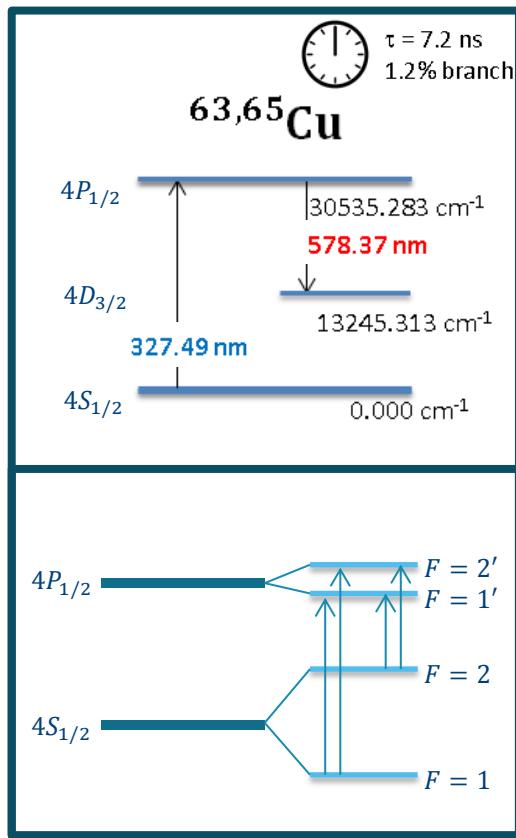


Data analysis and experiment(!) on progress



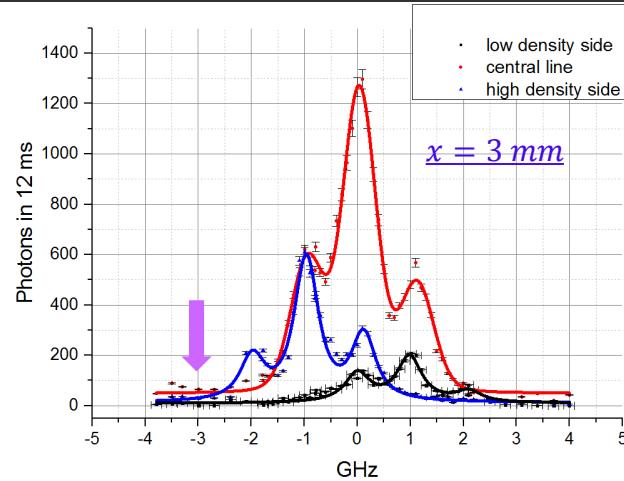
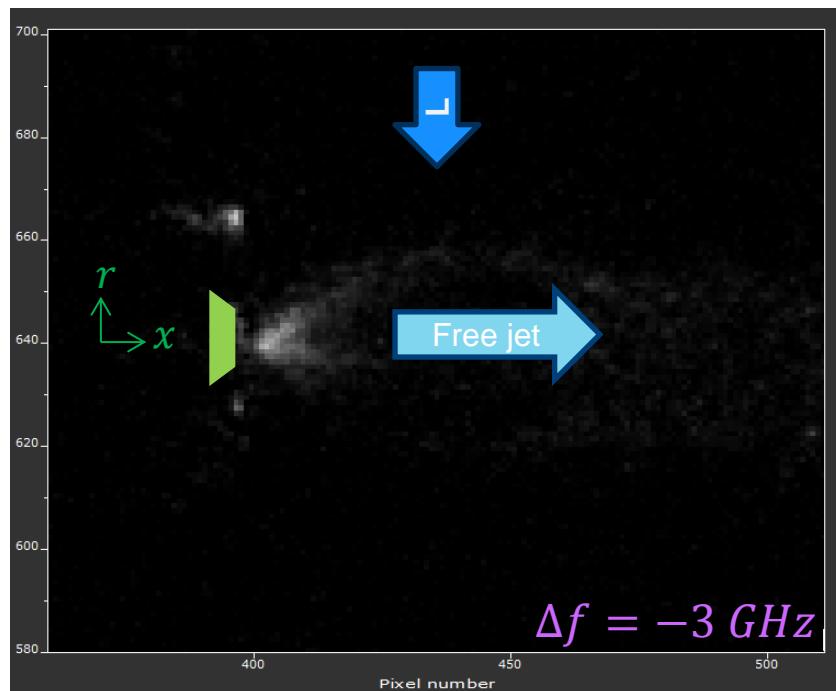
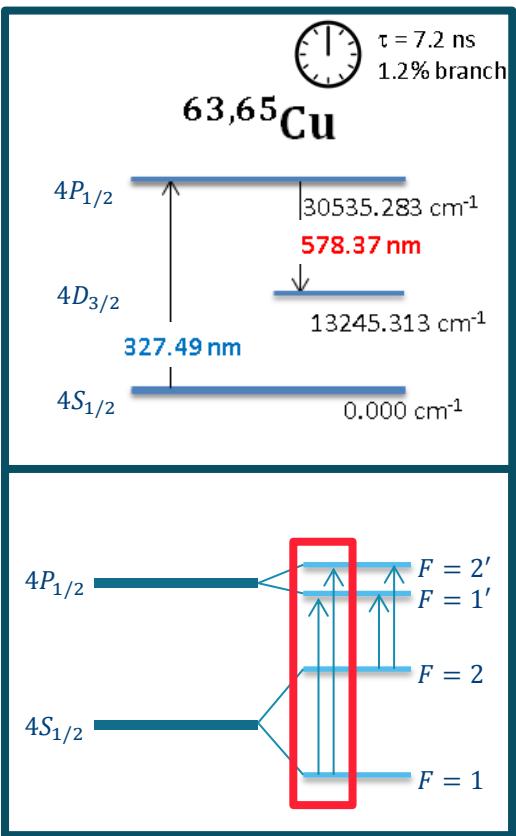
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$.



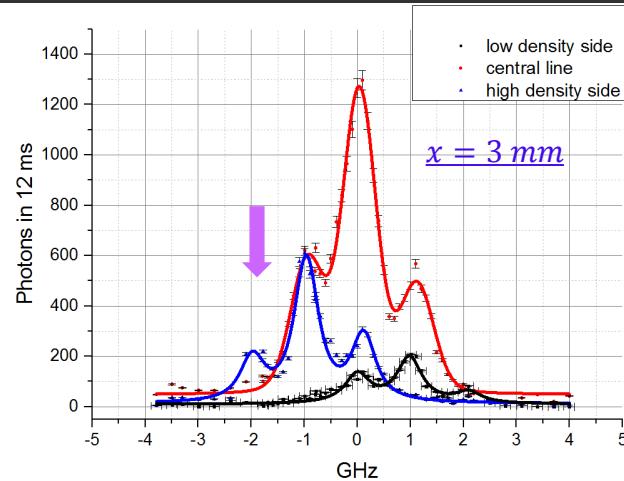
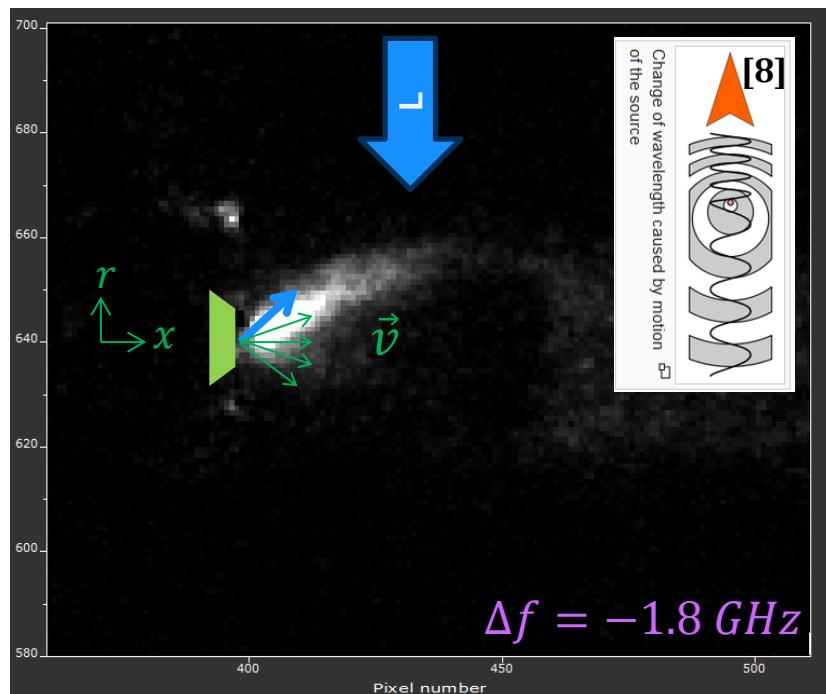
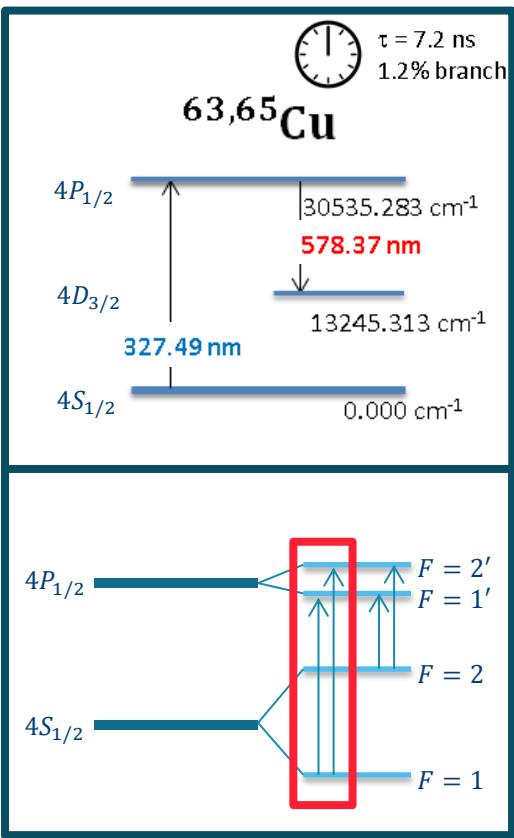
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



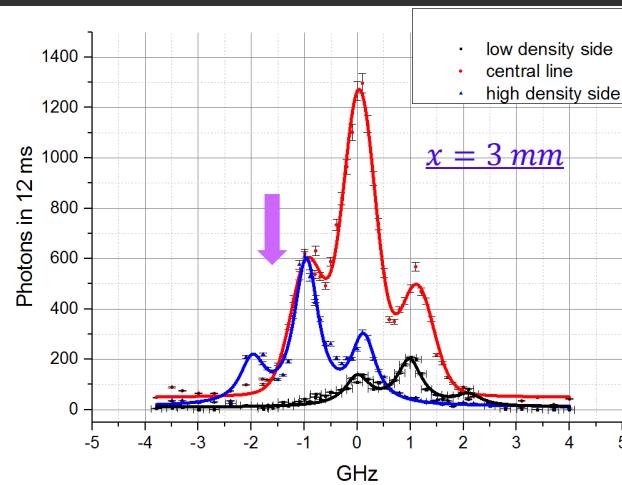
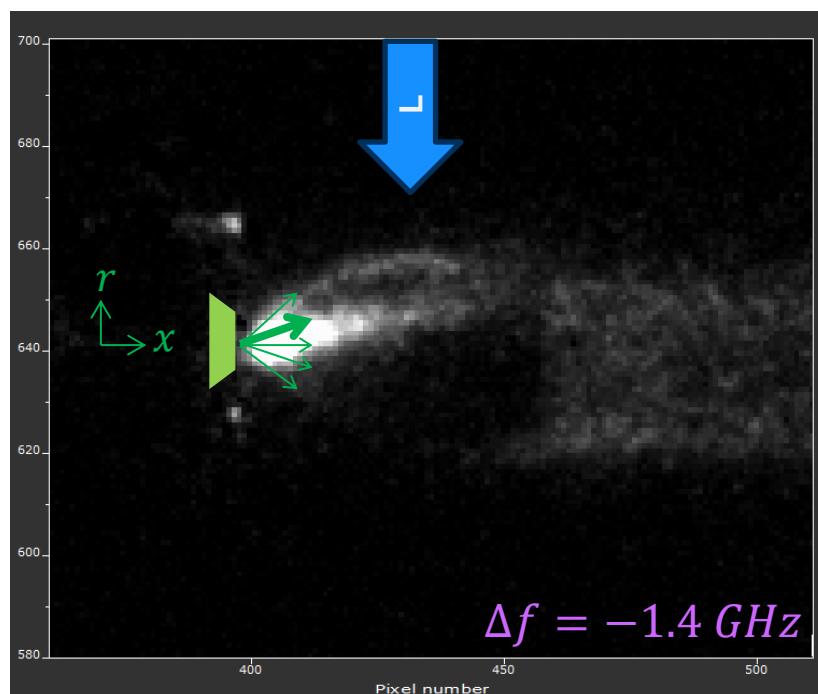
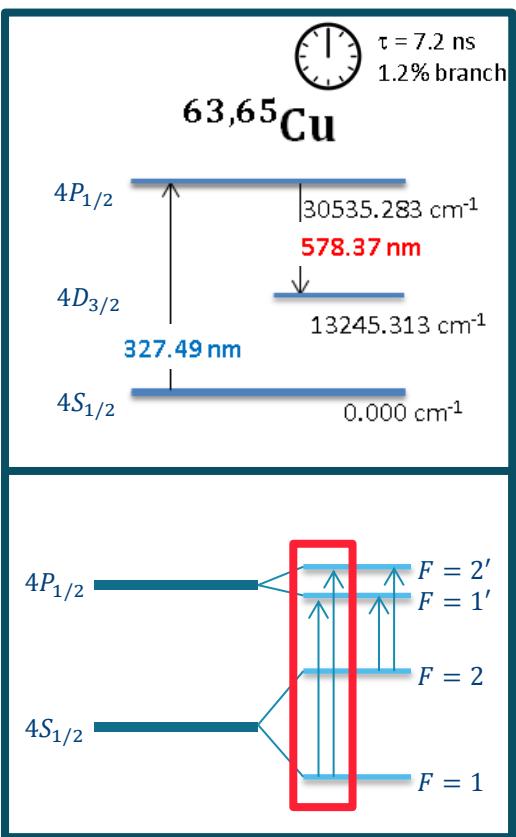
1. Free jet

Narrowband PLIF of $^{63,65}Cu$



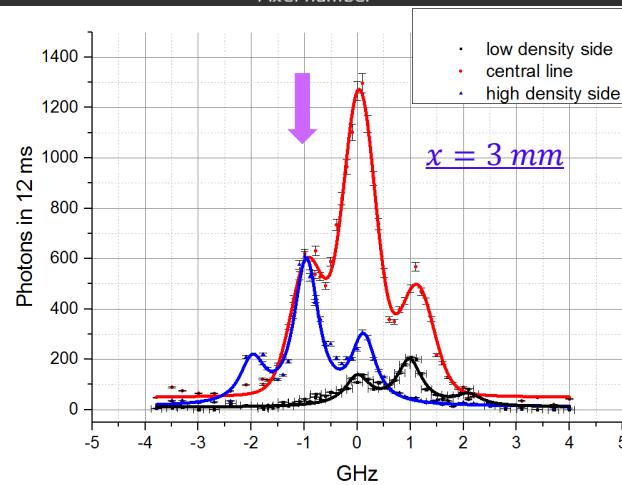
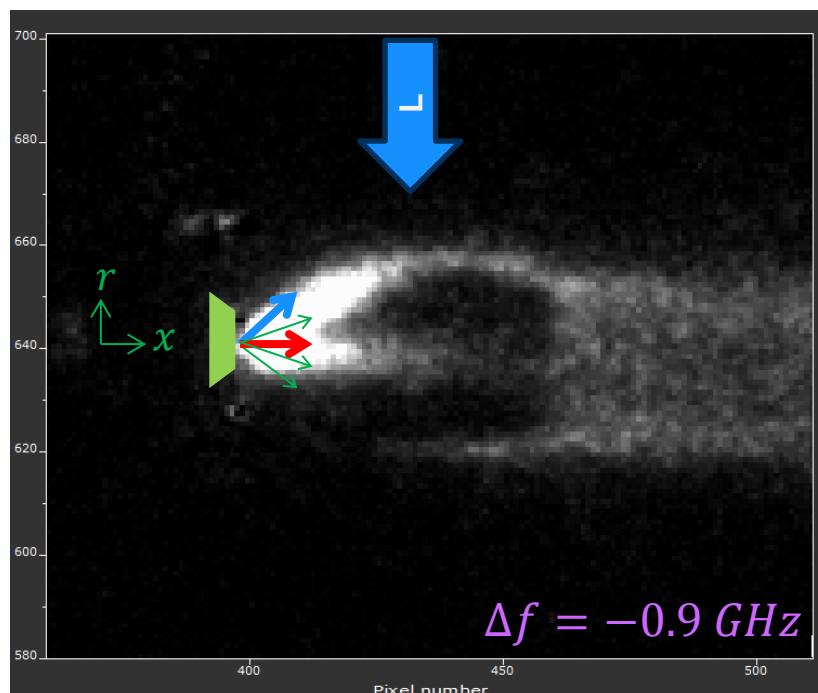
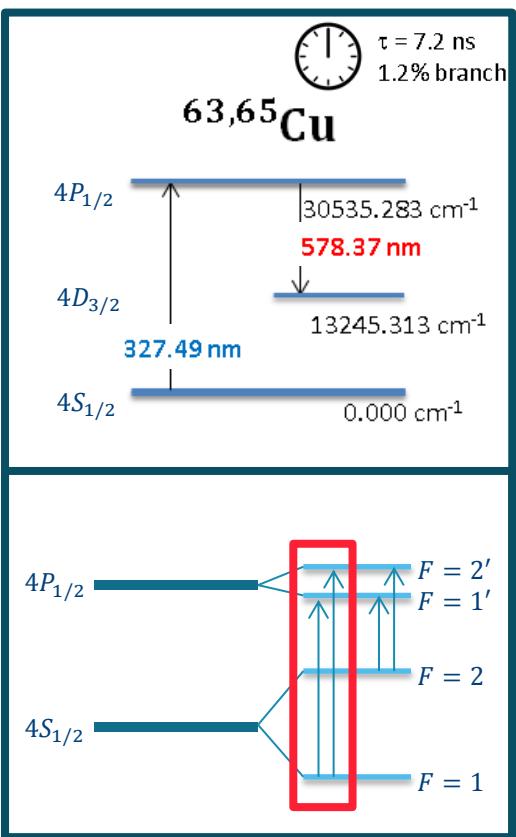
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



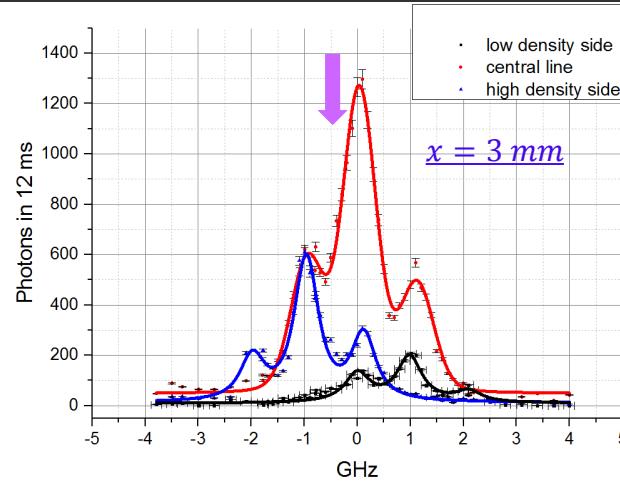
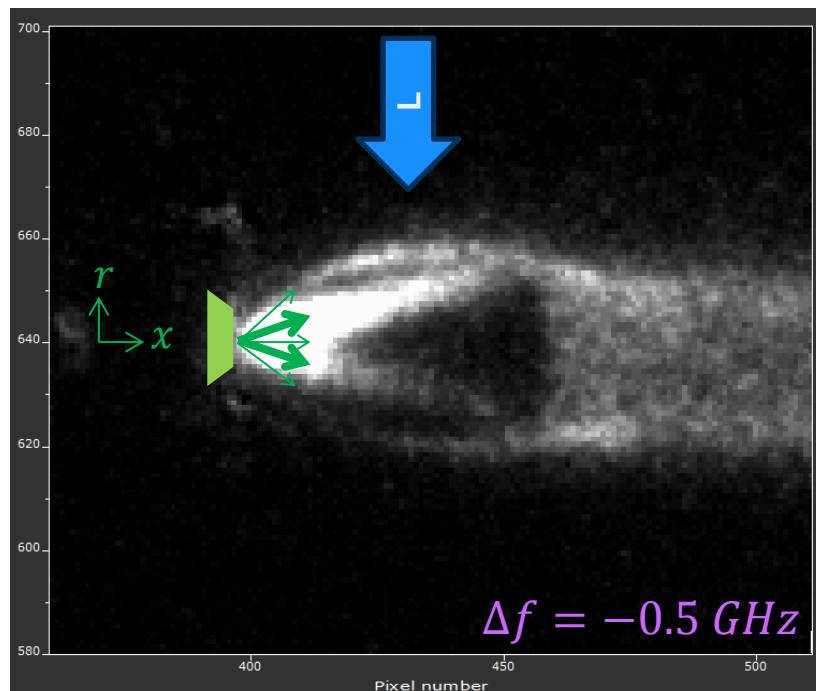
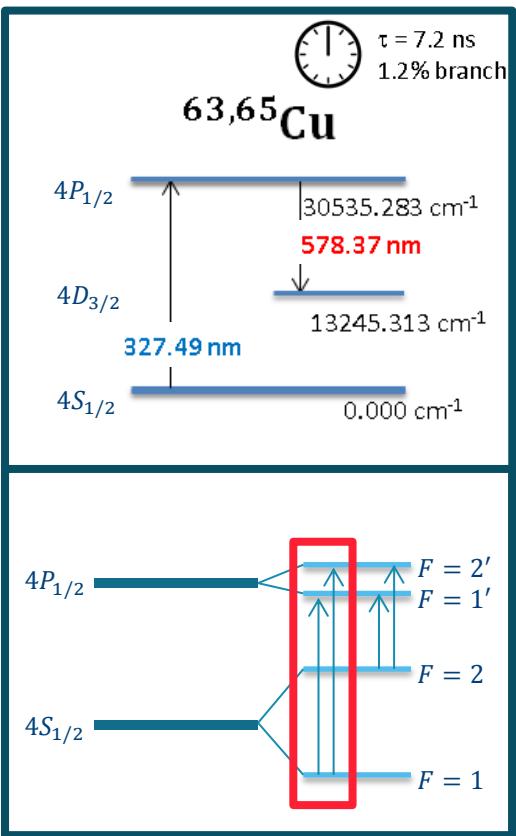
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



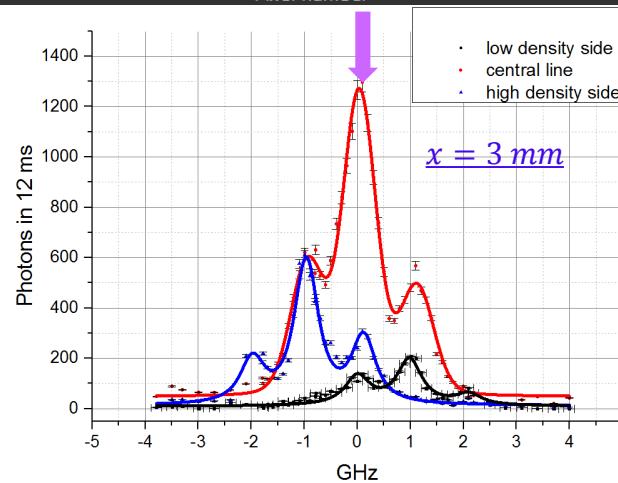
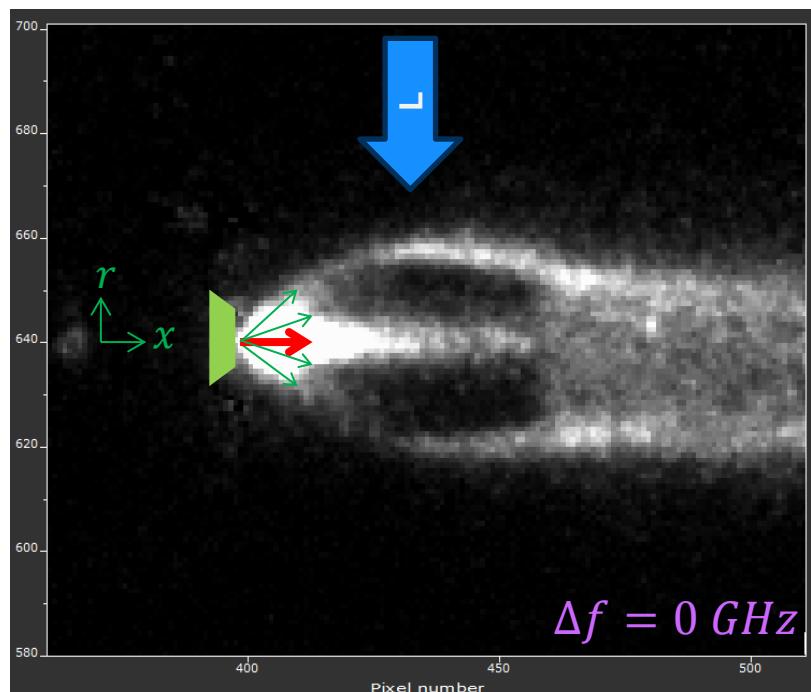
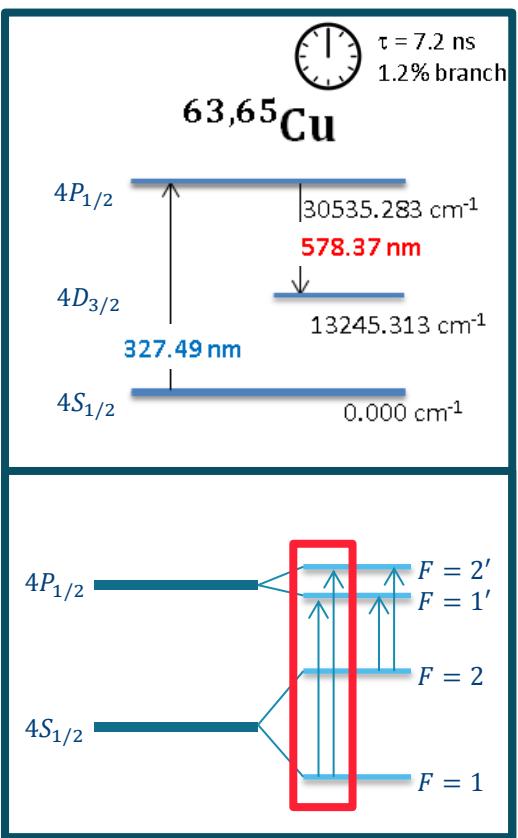
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



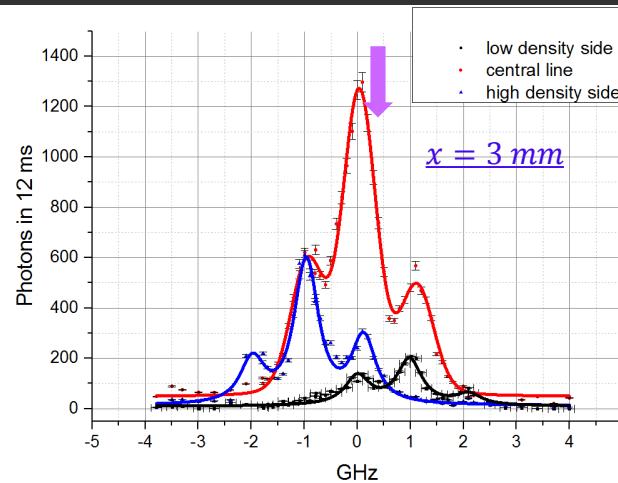
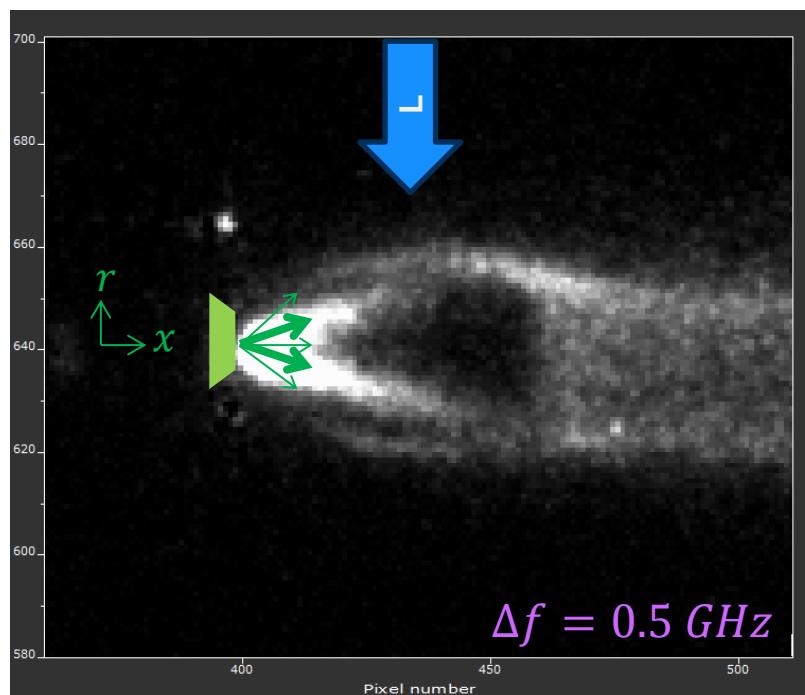
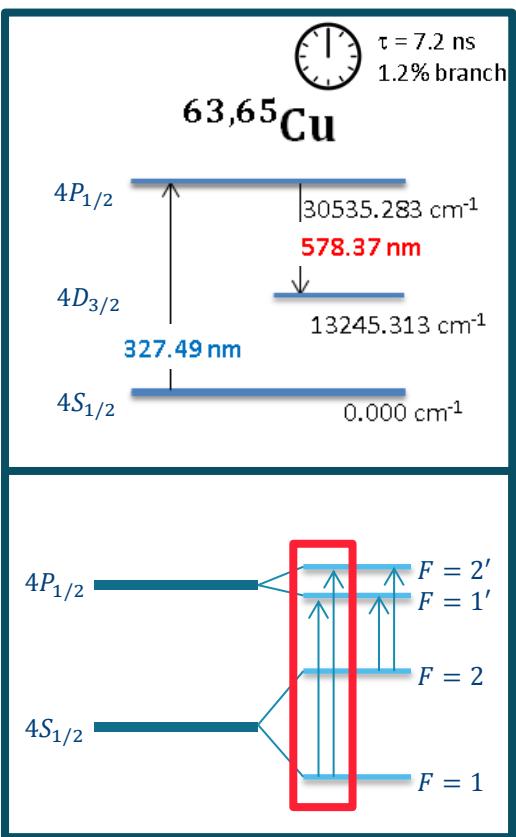
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Narrowband PLIF of $^{63,65}\text{Cu}$



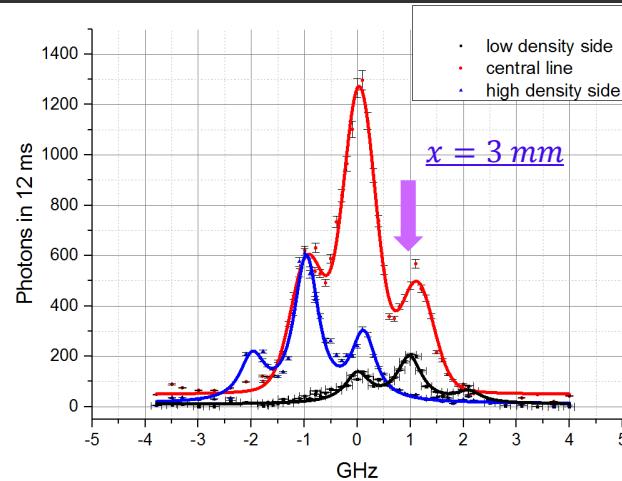
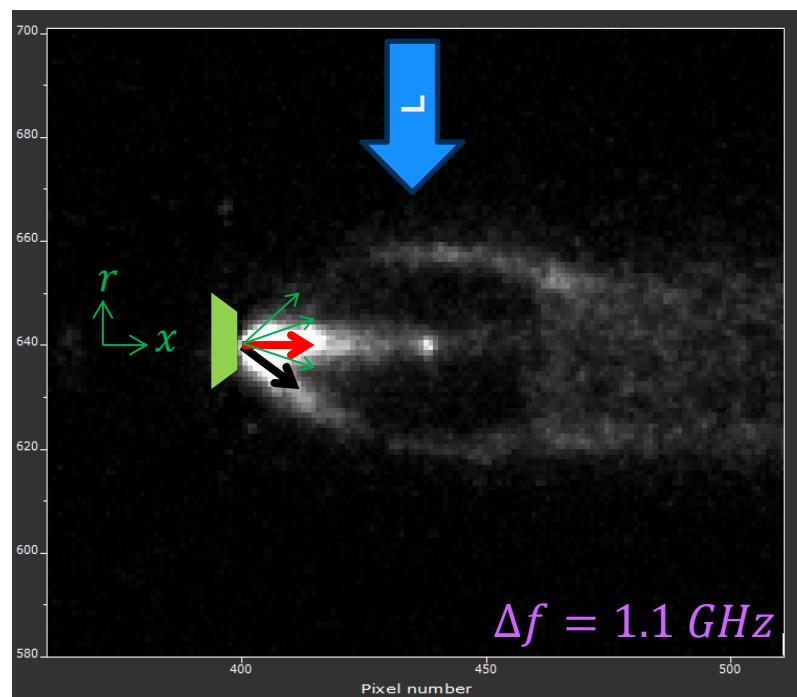
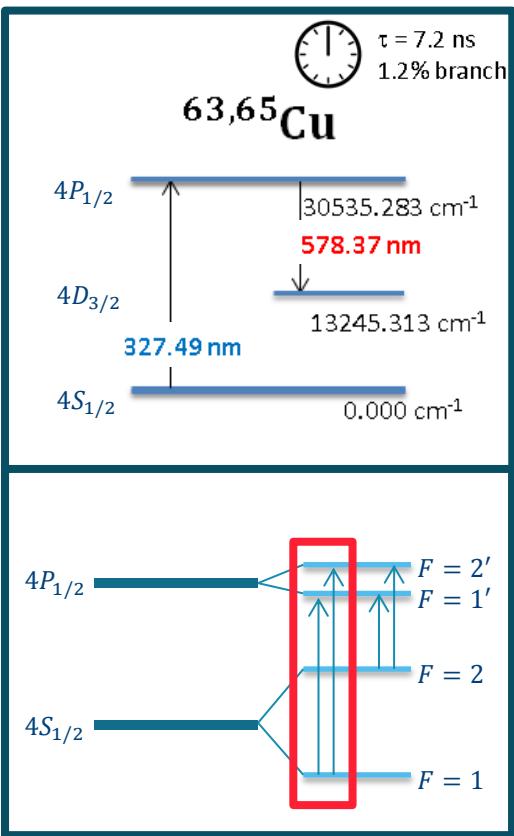
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



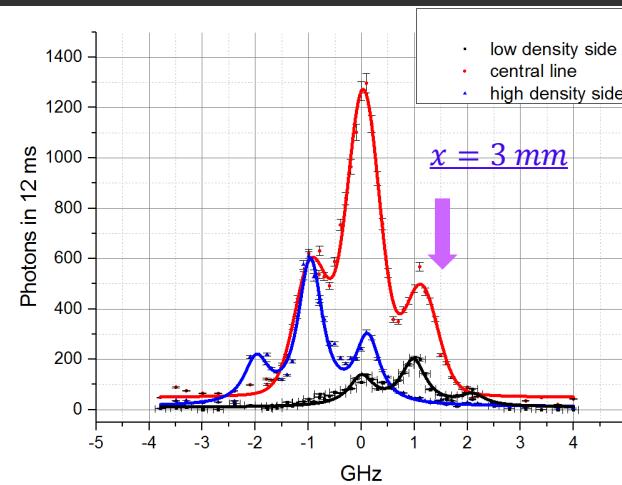
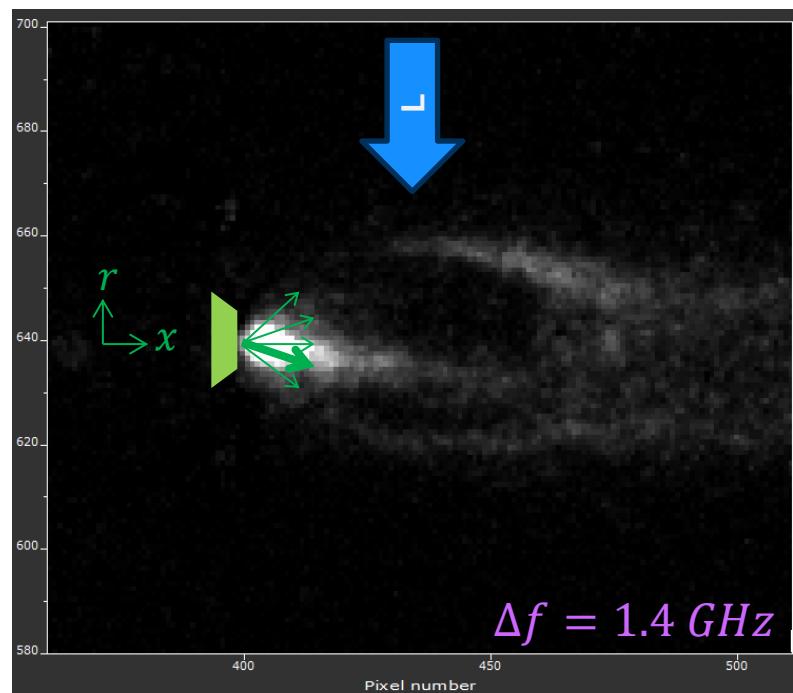
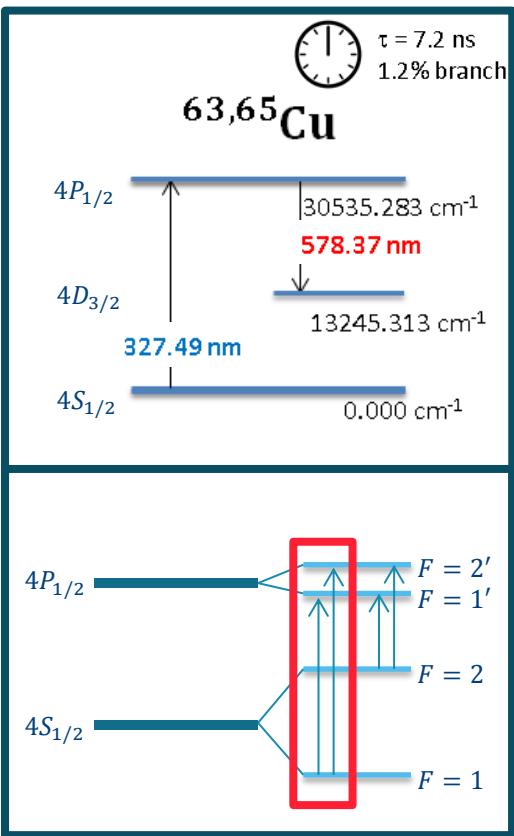
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



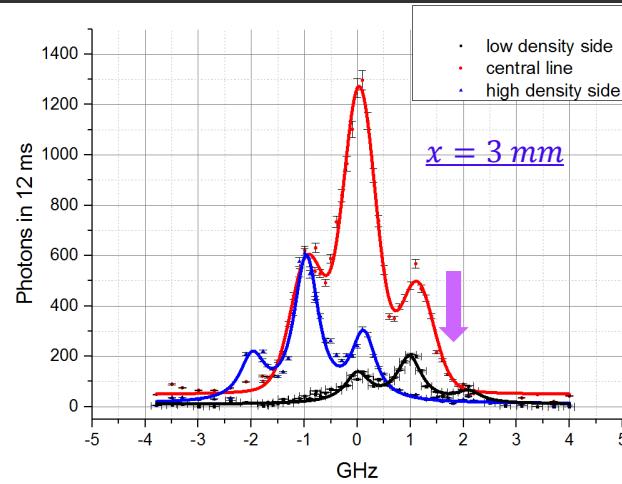
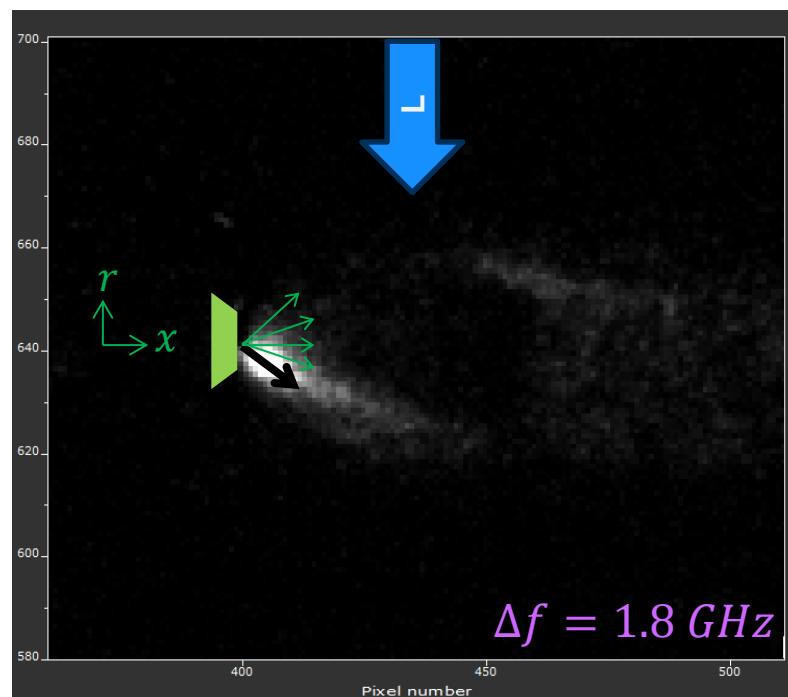
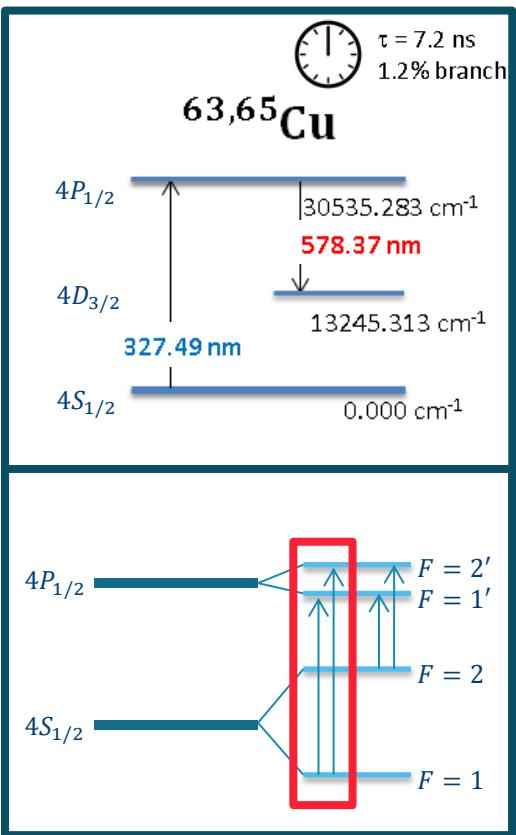
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



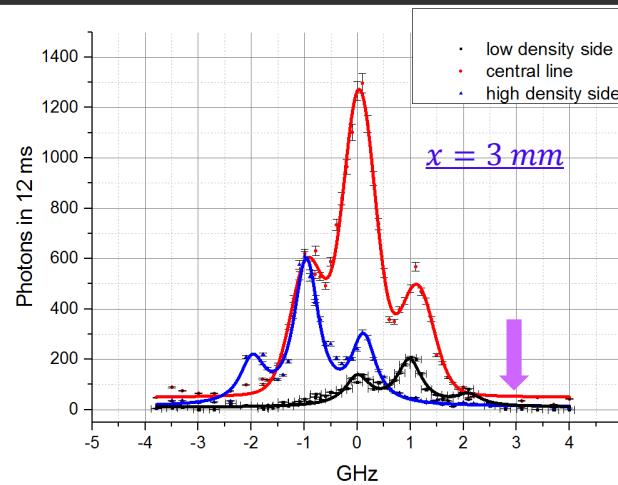
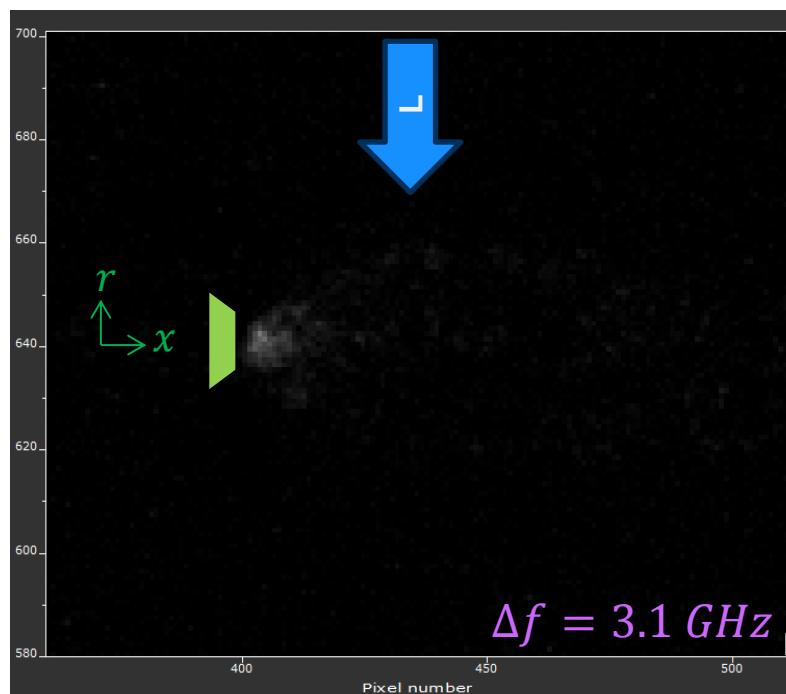
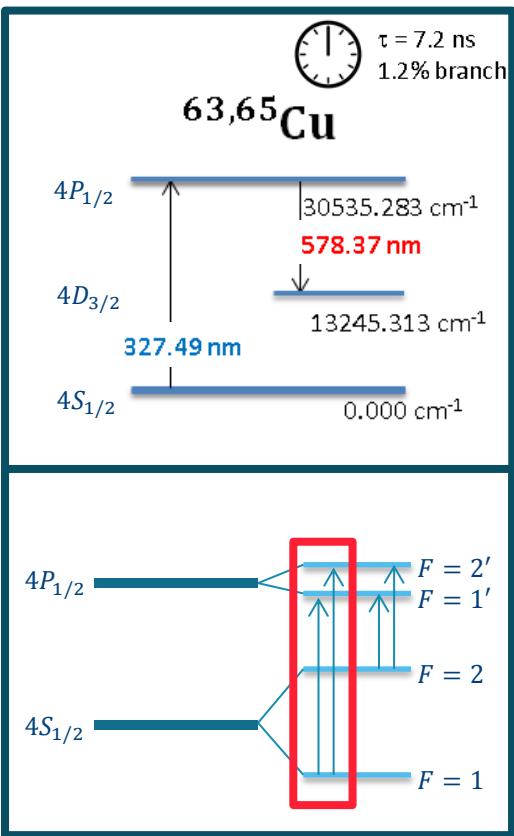
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



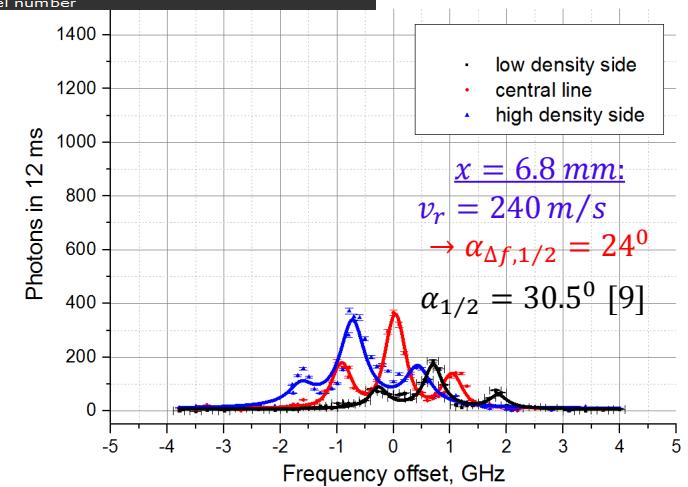
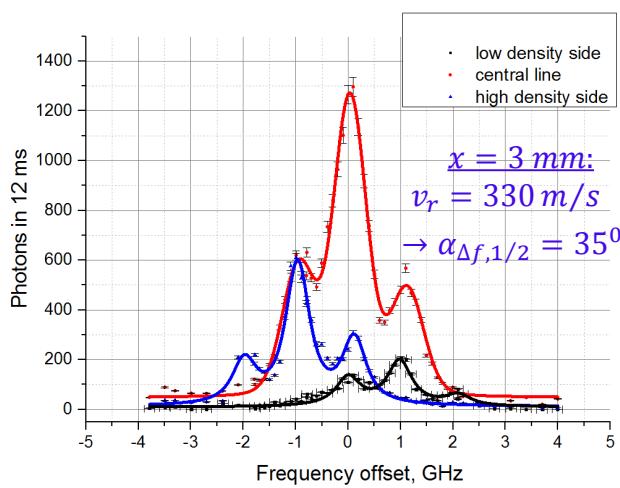
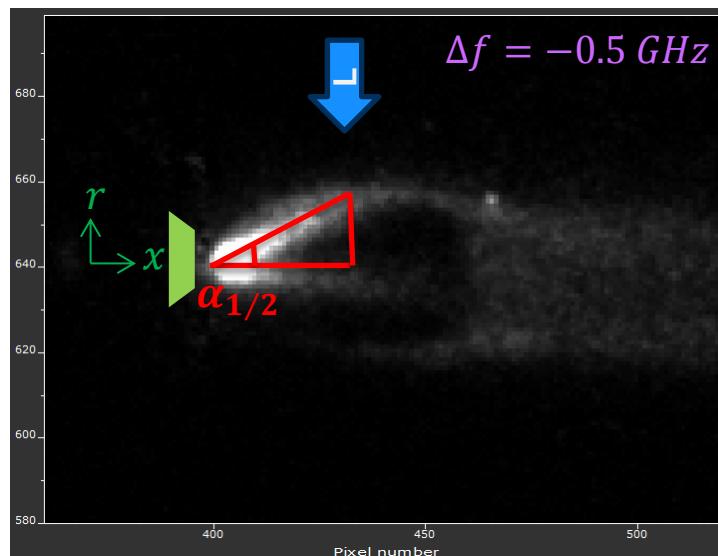
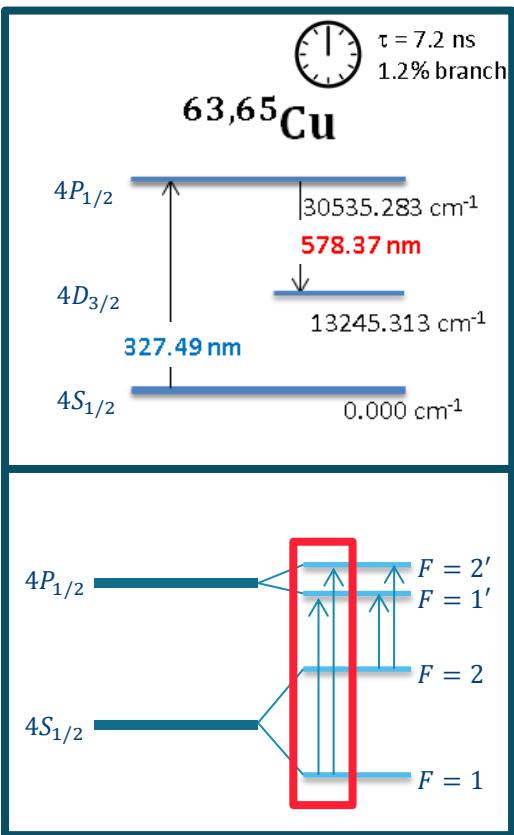
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



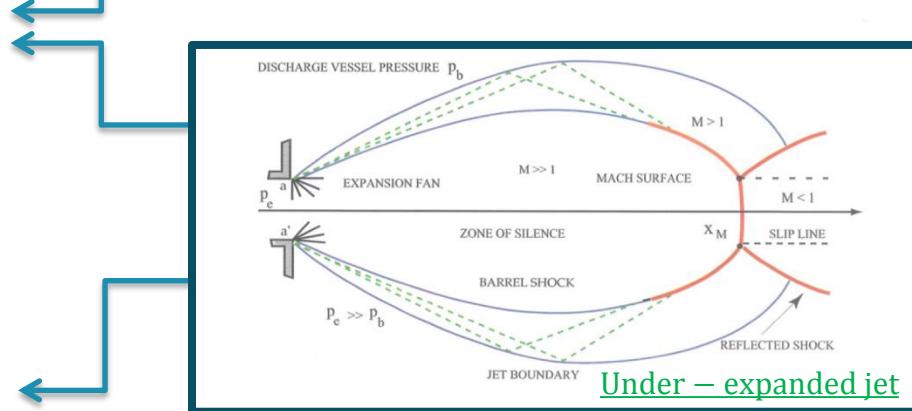
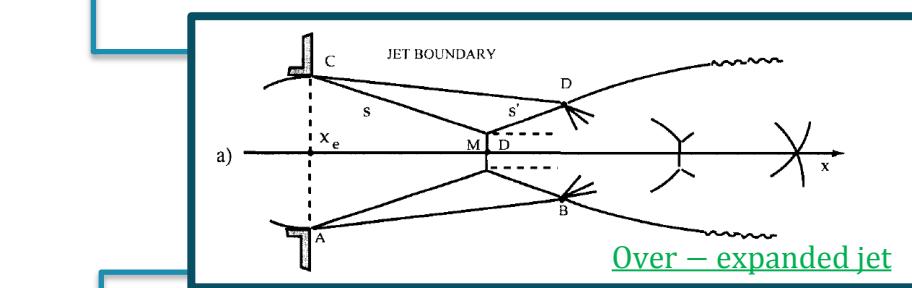
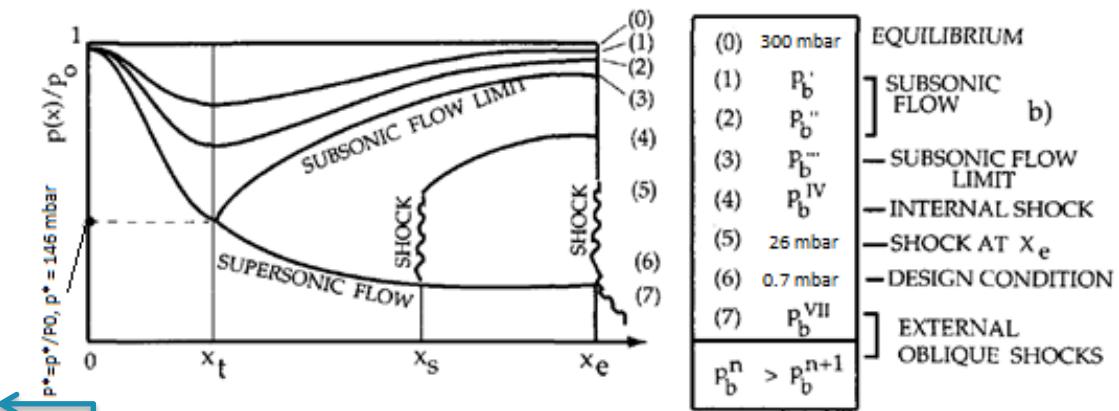
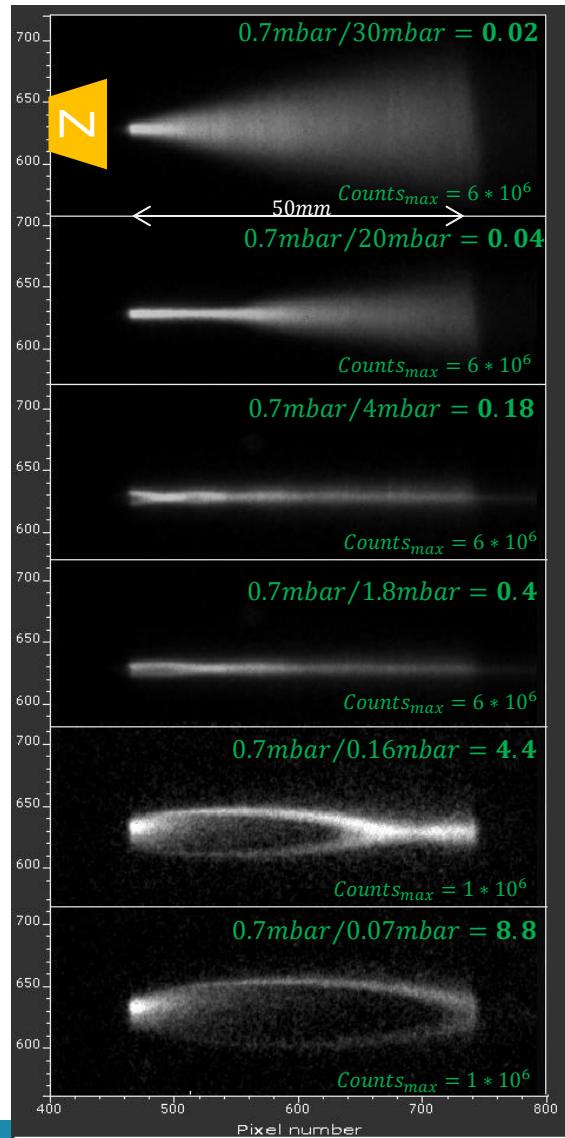
1. Free jet

Narrowband PLIF of $^{63,65}\text{Cu}$



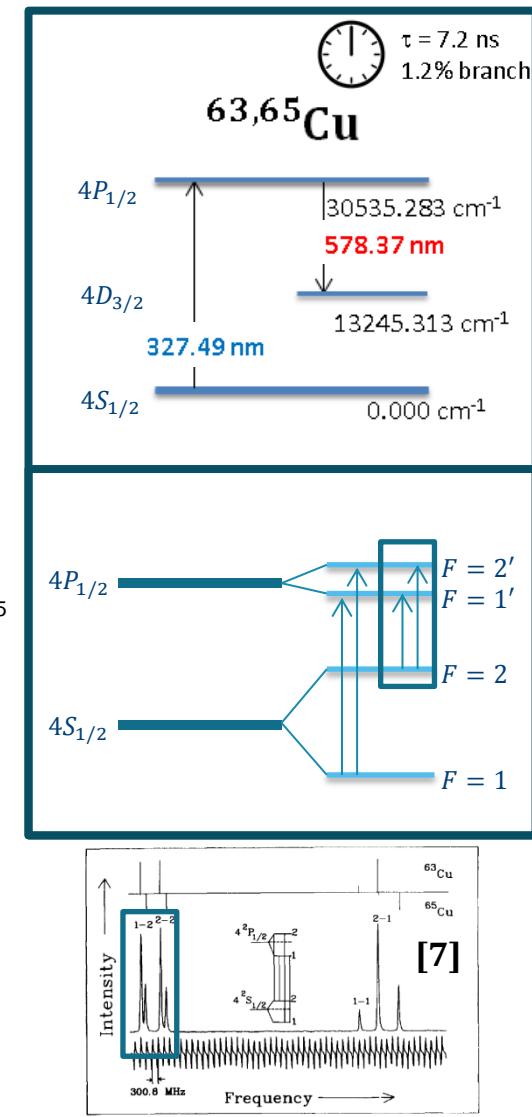
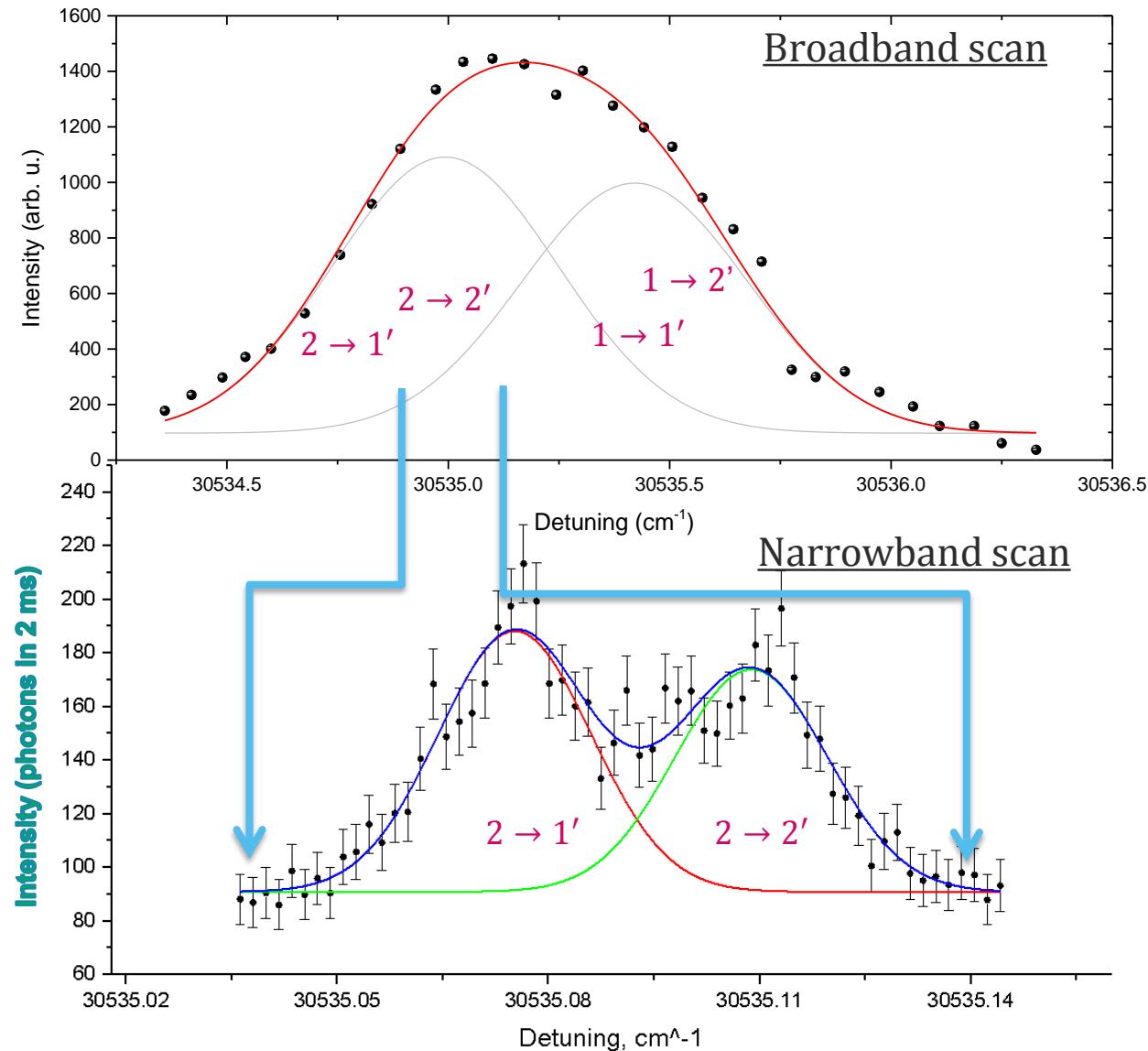
2. Jet formed by de Laval nozzle

Gas jet 'tailoring'



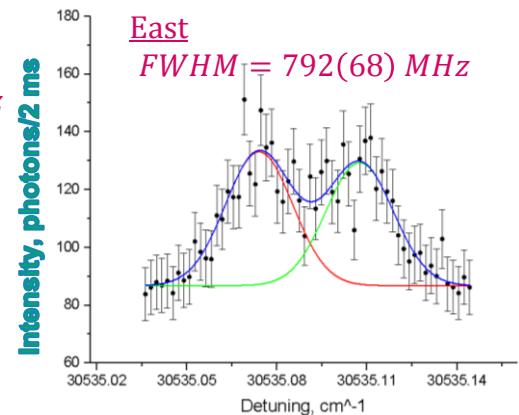
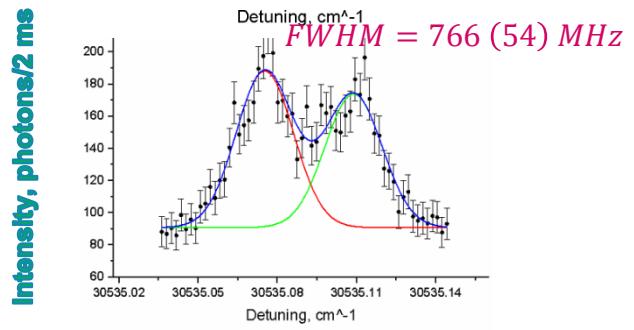
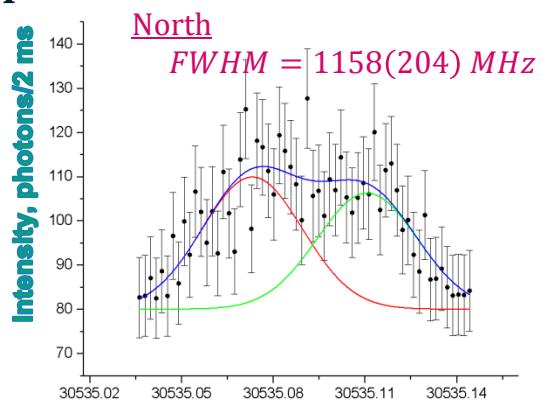
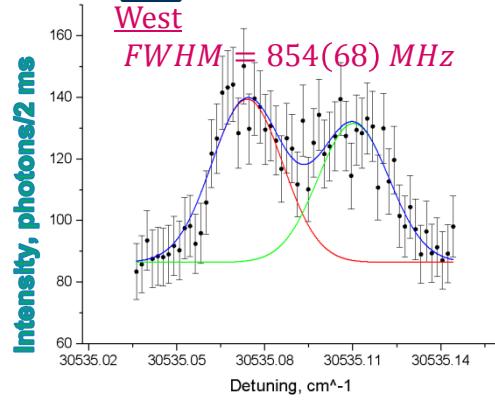
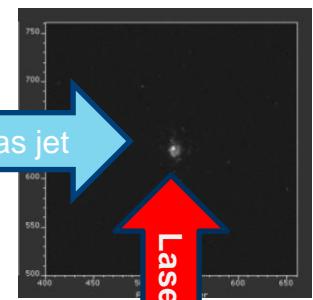
2. Jet formed by de Laval nozzle

Broad- and Narrowband PLIF of $^{63,65}\text{Cu}$



2. Jet formed by de Laval nozzle

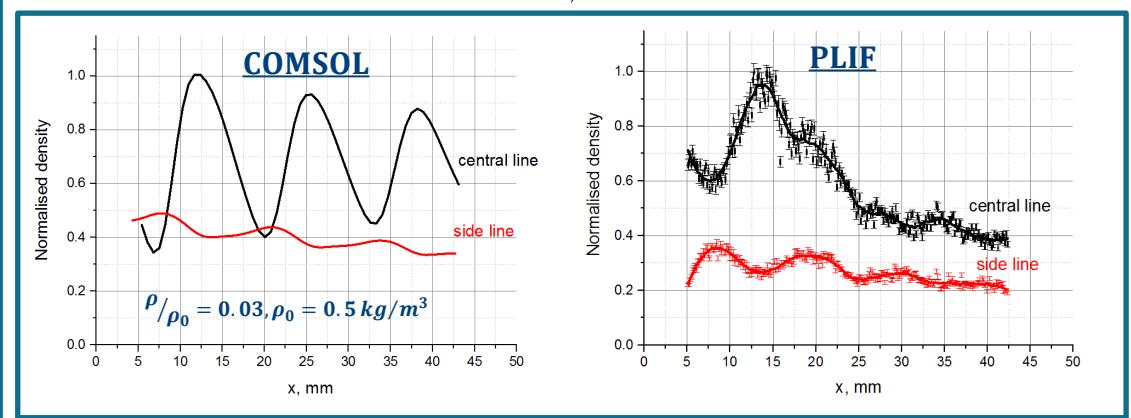
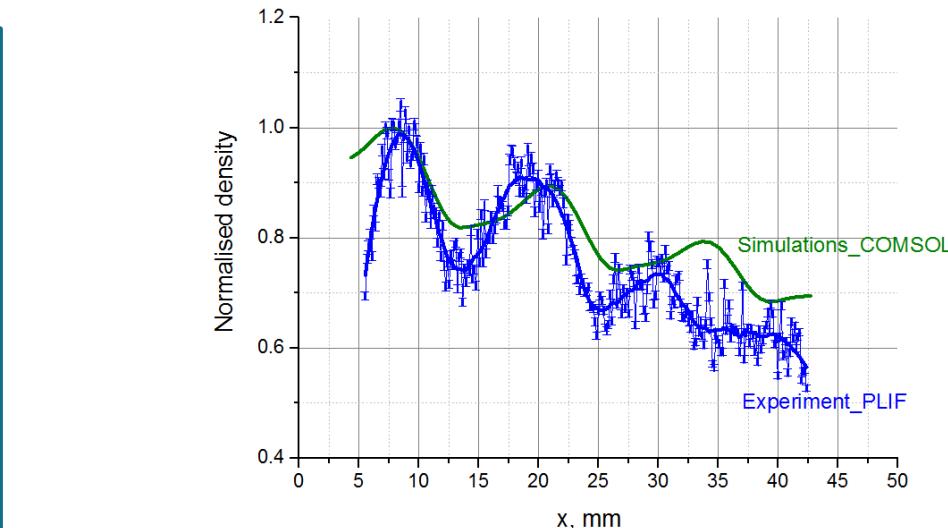
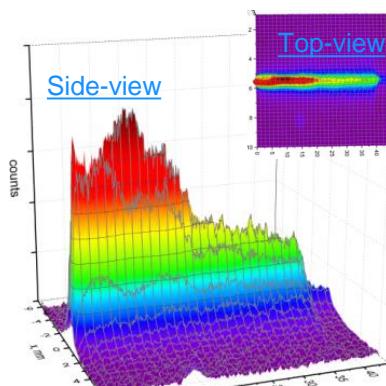
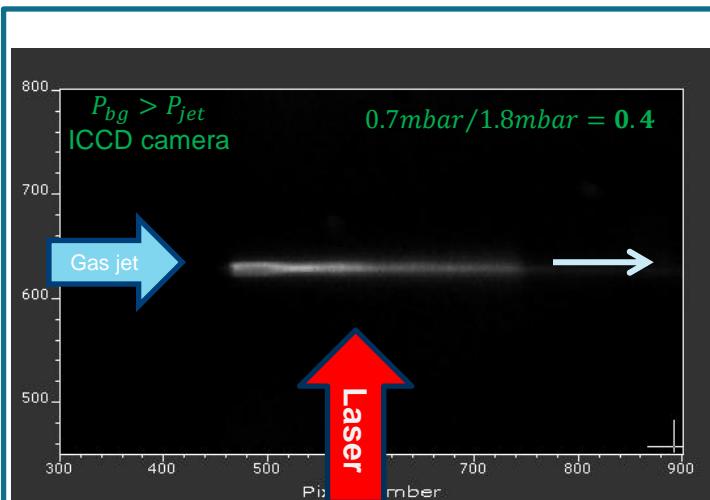
Narrowband PLIF of $^{63,65}\text{Cu}$
 → supersonic gas jet 'map'



→ reduce power broadening.
 But! we still will have $\sim 400 \text{ MHz}$
 from the Doppler broadening at $\text{Mach} = 5.5$

2. Jet formed by de Laval nozzle

Simulations in COMSOL vs. Experimental data



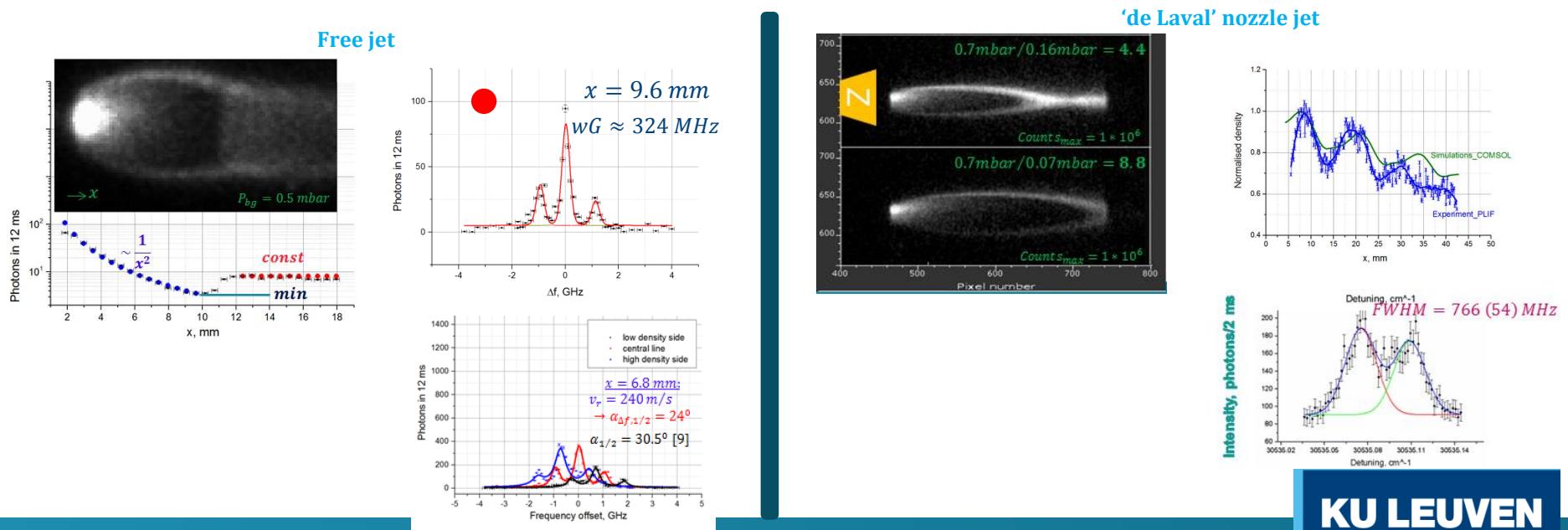
- partial agreement between COMSOL simulations and experimental data;
- more tests to be performed!

Conclusions/Outlook

- First results on the visualization of free jets and jets, formed by de Laval nozzle, were obtained at the IGLIS laboratory
- Geometry optimization of the gas cell and the de Laval nozzle was performed with COMSOL Multiphysics software. Simulations of the supersonic gas jet reproduce partially the obtained experimental data
- Spectroscopy in free jet is progressing well now
- Tests with spectroscopy in the de Laval nozzle jet are starting soon

Future plans:

PLIF-spectroscopy as a tool for characterization of the supersonic gas jets (T, V, ρ – profiles)



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Thanks for your attention!