



Real-time implementation of spectroscopy measurements at the ASDEX Upgrade tokamak

Ph.D. report a.a. 2025/2026

Beatrice Tosto

Outline



- Activities carried out during the second year: lectures, conferences etc...
- Advancements in the Ph.D. main project - Real-time implementation of spectroscopy measurements at ASDEX Upgrade

University activities

PhD courses

Physics courses:

- Introduction to Plasma Boundary in Fusion Devices

Interdisciplinary courses:

- Reading the world through a gendered lens: a methodological reflection

Students supervision

- Bachelor thesis titled «*Validation of a new fast analysis method for the Fast-Ion D α diagnostic at the ASDEX Upgrade tokamak*»
- Bachelor thesis titled «*Real-time spectral analysis algorithms: validation on ASDEX Upgrade*»

Paper

Published a paper on my Master's Thesis topic titled «*Fast evaluation of the Fast-Ion D α spectroscopy measurements at the ASDEX Upgrade tokamak*» in PPCF
(B Tosto et al 2026 Plasma Phys. Control. Fusion 68 085014)



All required PhD
CFUs completed

Other activities



- FuseNet PhD Event 2025, 4th - 6th November 2025 , ITER
- 52nd EPS Plasma Physics Conference, June 29th – July 3rd 2026, Edinburgh
- 25th ITER International School, 20th – 24th July 2026, Chengdu, China
- Research periods abroad:
 - Max-Planck Institute for Plasma Physics, Garching, Germany
 - November 10th - December 5th 2025
 - April 7th - 25th 2026
 - June 21th - 26th 2026
 - October 2026 scheduled

Mandatory period abroad
already completed during the
1st year

Real-time implementation of spectroscopy measurements at ASDEX Upgrade



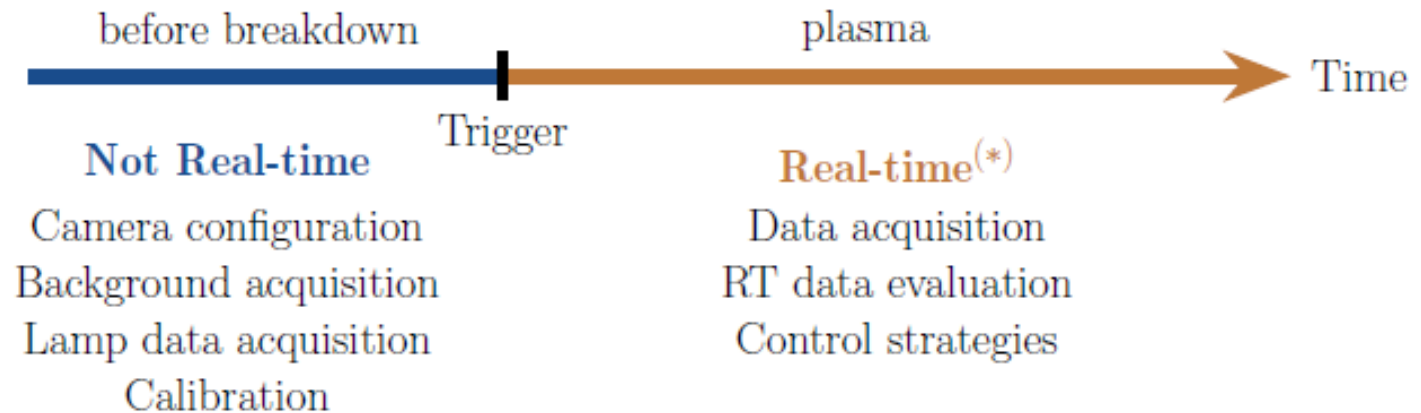
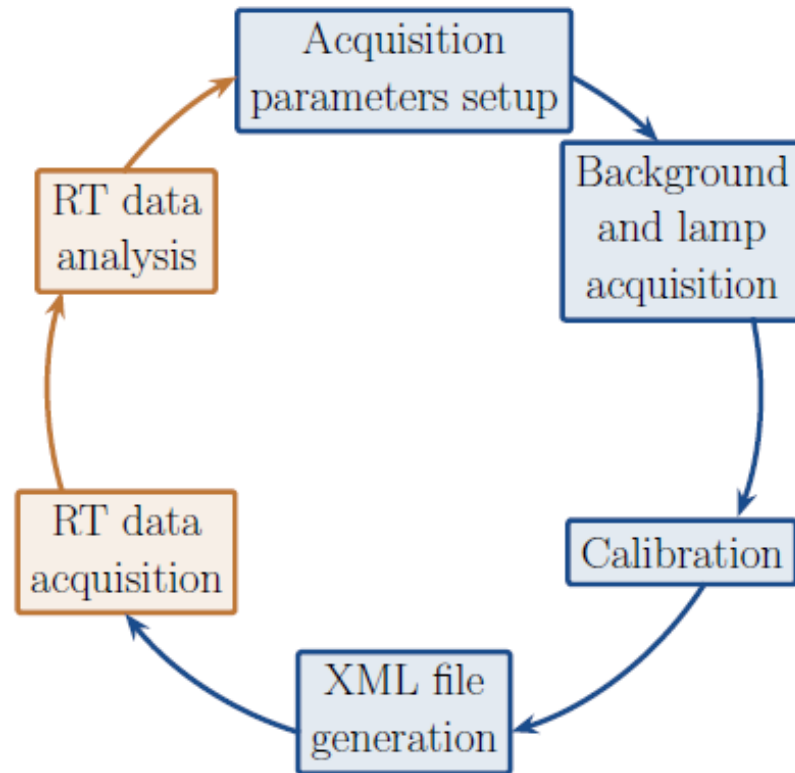
Motivation:

- **Plasma control** is a major challenge during tokamak operation, with several real-time (RT) applications currently under development
- Spectroscopy is likely one of the few diagnostics capable of withstanding reactor-like conditions [Biel et al., Fusion Eng. Des., 2022]
- **Real-time spectroscopy** is a key step toward developing reactor-relevant control strategies

Work done and planned:

- 1st year: ensuring RT data availability from spectrometers cameras, implementation of RT data acquisition, successful application during 2025 experimental campaign
- 2nd year: implementation of RT raw data calibration, focus on developing RT analysis algorithms
- 3rd year: online tests and application to plasma control

Real-time workflow



(*) implemented within the Discharge Control System (DCS) of AUG
[Treutterer et al., Fusion Eng. Des., 2014]

Up to **RT data acquisition**: flexible implementation, can be applied to both Charge Exchange Recombination Spectroscopy (CXRS) and passive spectroscopy

RT data analysis: specialised algorithms for each diagnostic and physics application

Status and future applications



Implemented and tested	
online	offline
✓ Full pre-discharge process ✓ Real-time data acquisition	✓ RT fitting routines for CXRS
To do	
• Full online test of the process • RT analysis algorithms for several applications • Application to control schemes	

RT control schemes	
CXRS	Passive spectroscopy
• RT T_i and v_{rot} • Control of T_e/T_i	• Detachment control via line ratios of D [1] and He [2] emissions • Fuelling composition (H/D) control [3]

[1] Rikala et al., Nucl. Mater. Energy, 2025

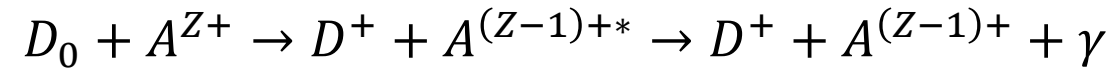
[2] Griener et al., PPCF, 2017

[3] Lennholm et al., PRX Energy, 2025

CXRS spectra



Charge exchange reaction:



Line emission shape, assuming thermalized impurity ions:

$$I(\lambda) = A \frac{1}{\sqrt{\pi}\gamma_\alpha} \exp\left(-\frac{(\lambda - \lambda_0)^2}{\gamma_\alpha^2}\right)$$

α ion specie

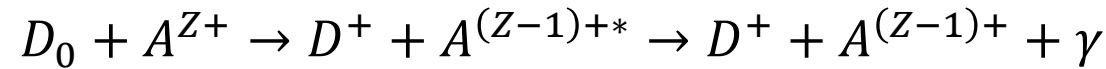
$$\lambda_0 = \lambda_{rest} \left(1 + \frac{v_\alpha}{c}\right)$$

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CXRS spectra



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Fundamental quantities obtained from the line emission:

- **Flow velocity:** $v_\alpha = c \frac{\lambda_0 - \lambda_{rest}}{\lambda_{rest}}$
- **Ion temperature** ($T_i \approx T_\alpha$): $T_i = \frac{m_\alpha c^2}{k_B} \left(\frac{\sigma}{\lambda_{rest}}\right)$
- Impurity density

Information obtained fitting the spectra
The worldwide offline suite used is CXSFIT
[Delabie et al., Rev. Sci. Instrum., 2024]

RT fitting of CXRS spectra

RT C++ fitting algorithm implemented and validated against CXSFIT



Features:

- solver time ≈ 1 ms
- fixed/constrained parameters
- parameters bounds
- coupled peaks
- reduced areas

Differences with CXSFIT:

- number of iterations
- parameter initialisation
- fixed recipes, no manual tuning

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Different recipe for each impurity

Tests performed on B spectra on a wide database of discharges

Discharges divided as follows:

- Density
 - Low: $\leq 5 \text{ cm}^{-3}$
 - Standard: $\approx 5\text{-}7 \text{ cm}^{-3}$
 - High: $\geq 7 \text{ cm}^{-3}$

- Distance from boronization

LOSs analysed:

- Innermost CER: $R \approx 1.72$ m
- Outermost CER: $R \approx 2.1$ m
- Mid CER: $R \approx 1.92$ m

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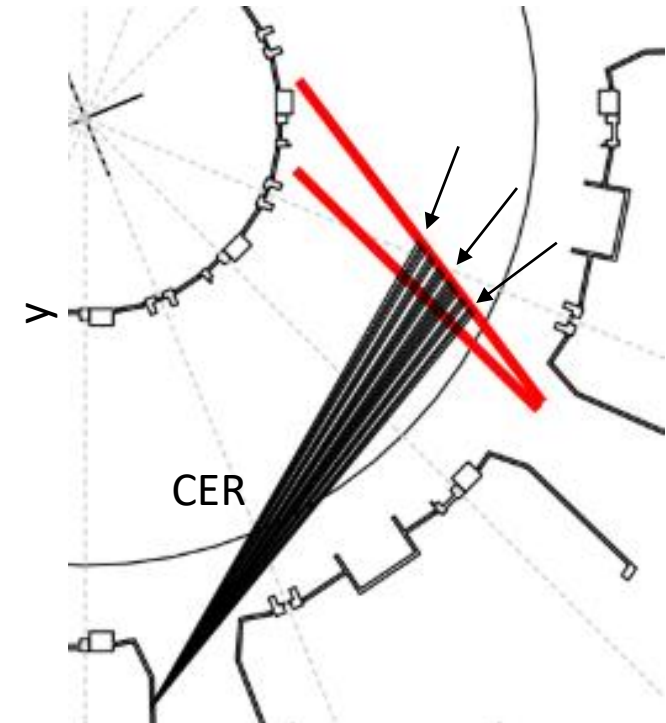
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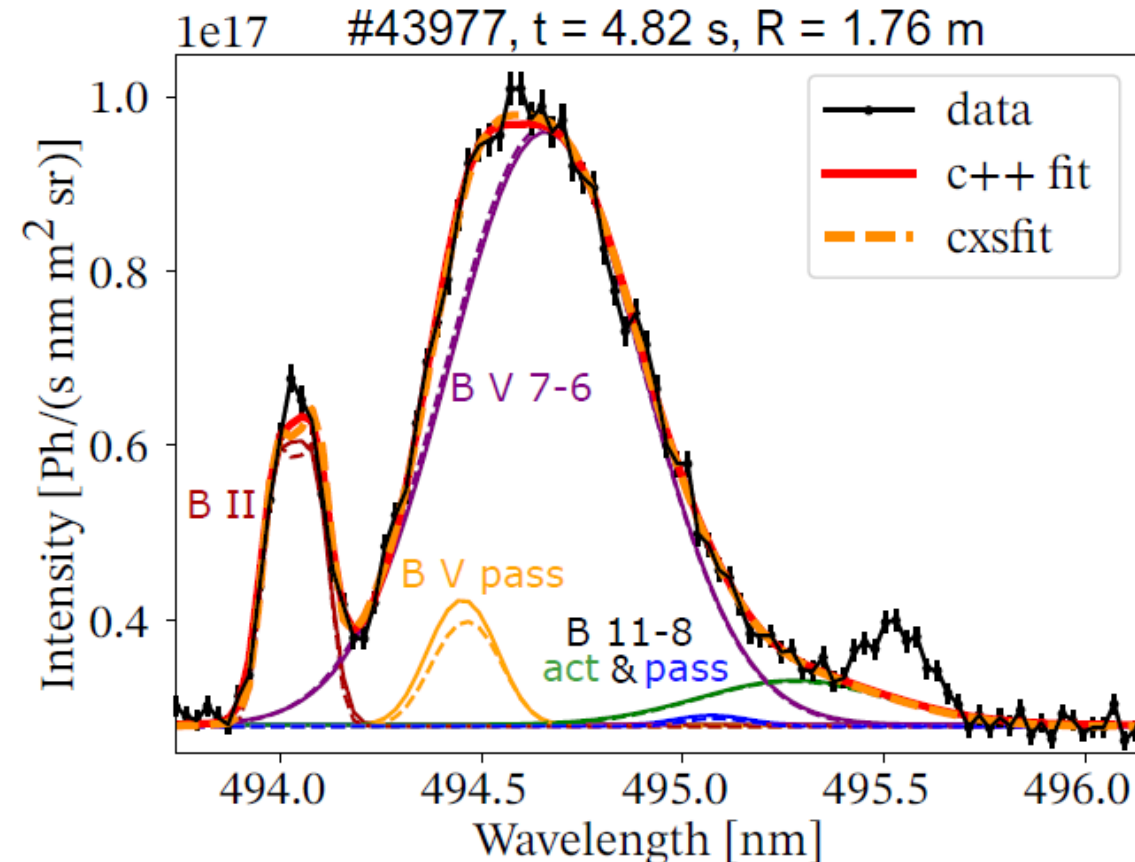
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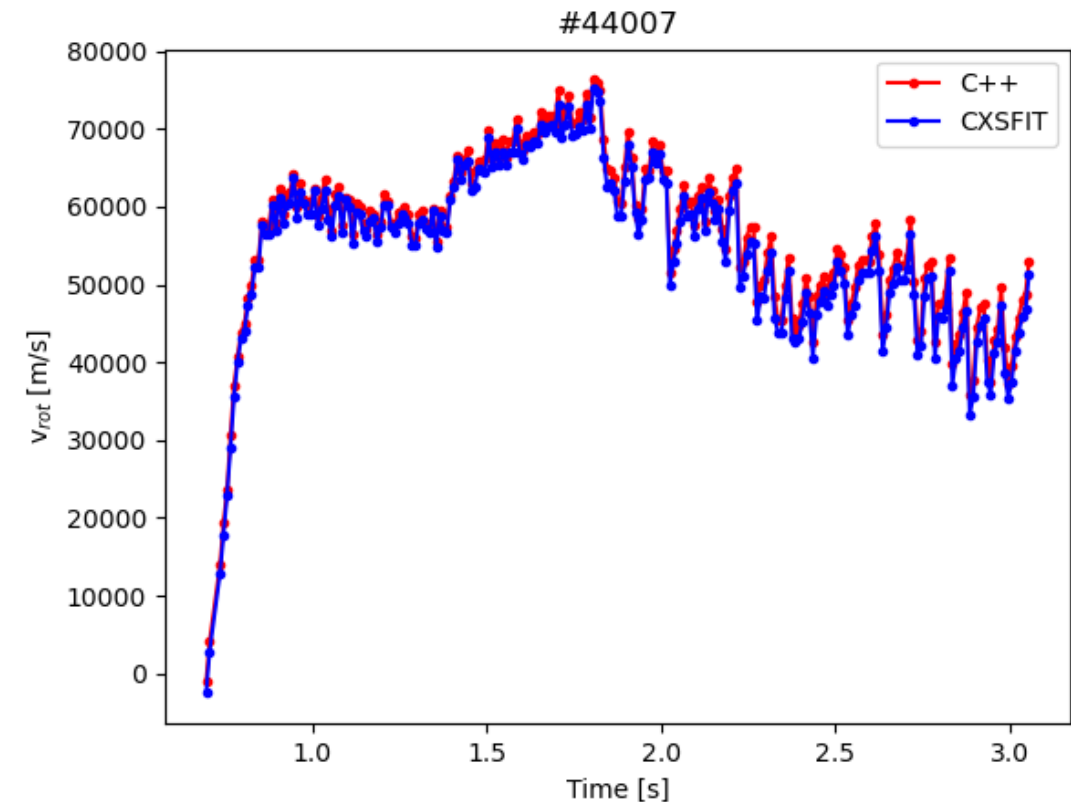
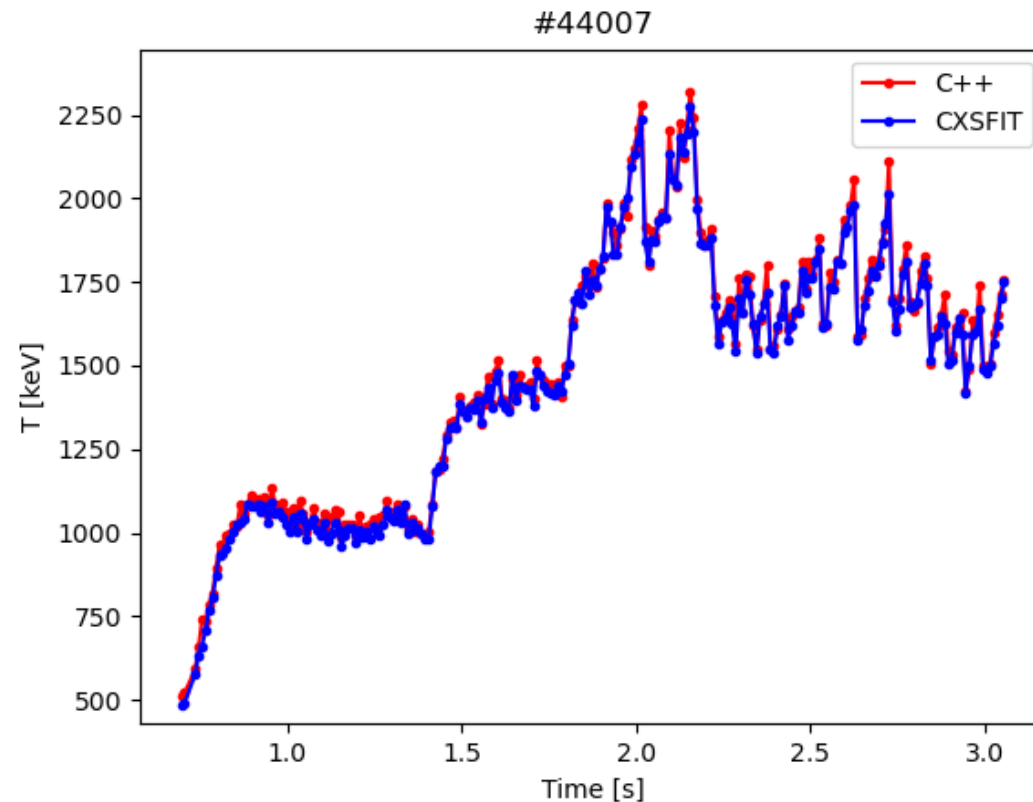
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RT fit performance

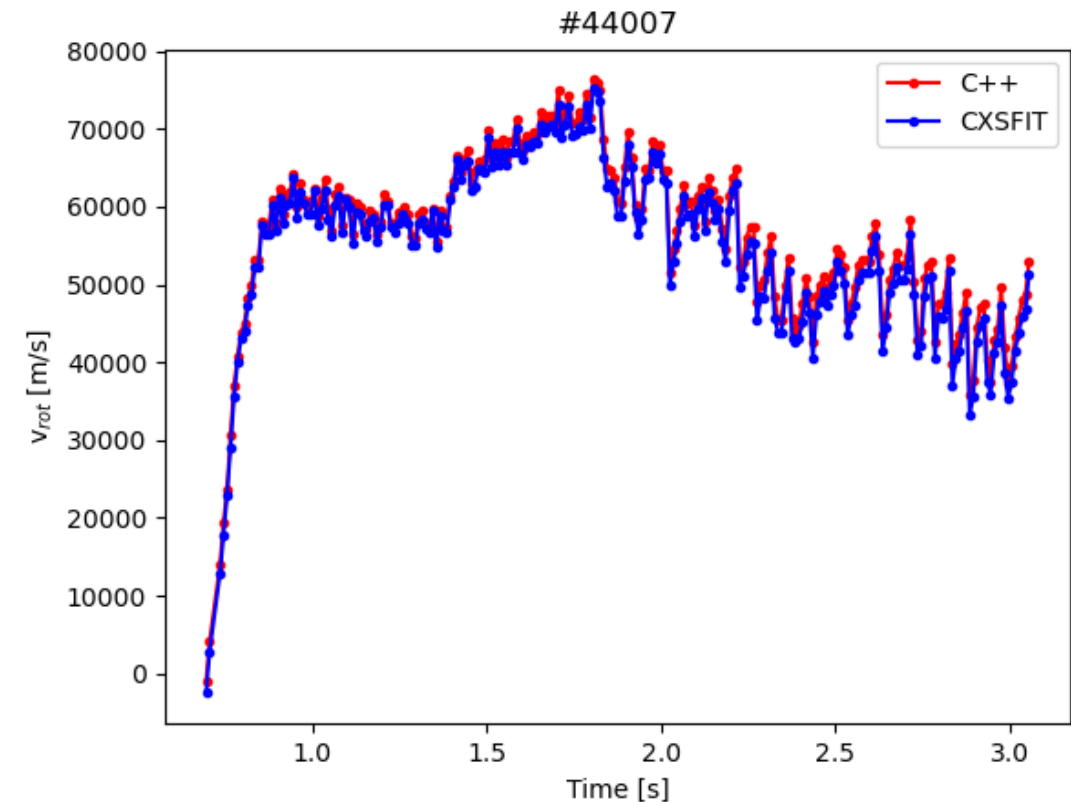
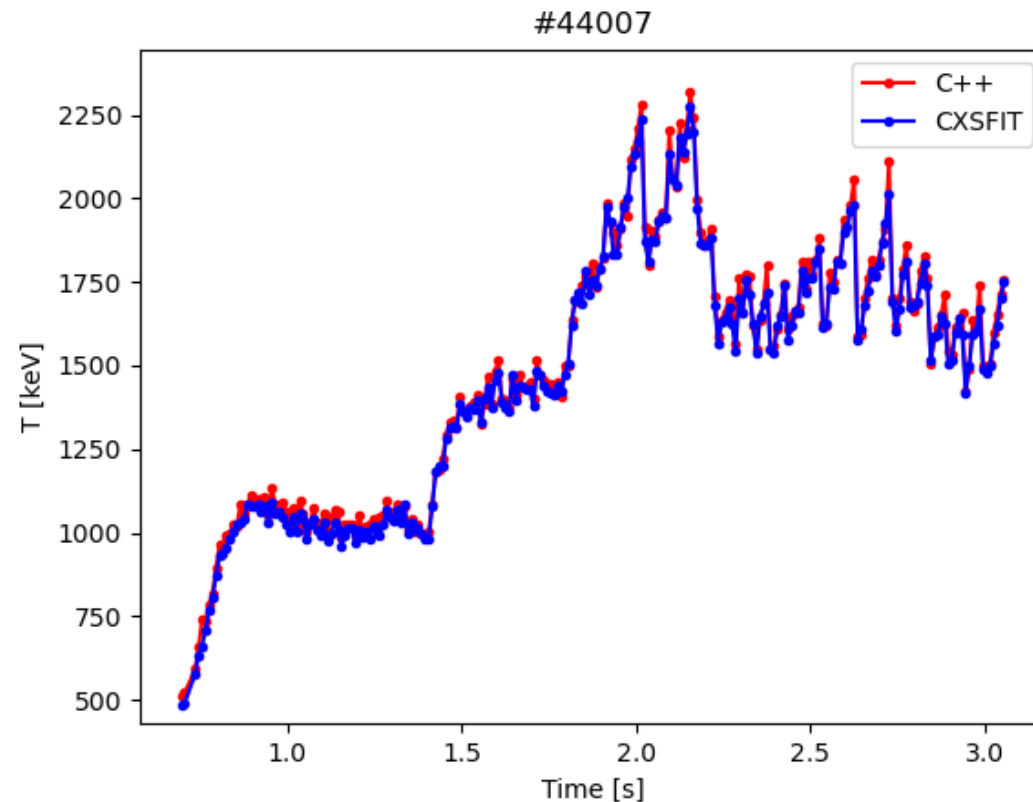
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- The trend of T_i and v_{rot} is reproduced correctly
- The total spectrum shape is always fitted properly, discrepancies present in single emission peaks



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N.B. CXSFIT not
always perfect!



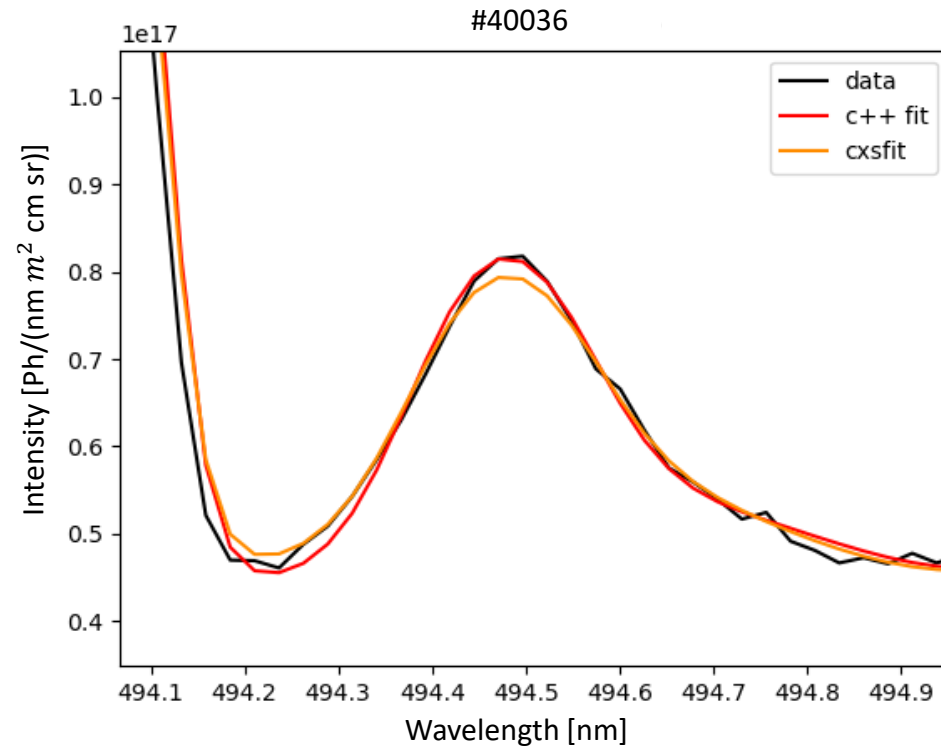
RT fitting routines: main issues (I)



1. B V 7-6 active and passive are superposed → underestimation of active peak
Observed for single time points

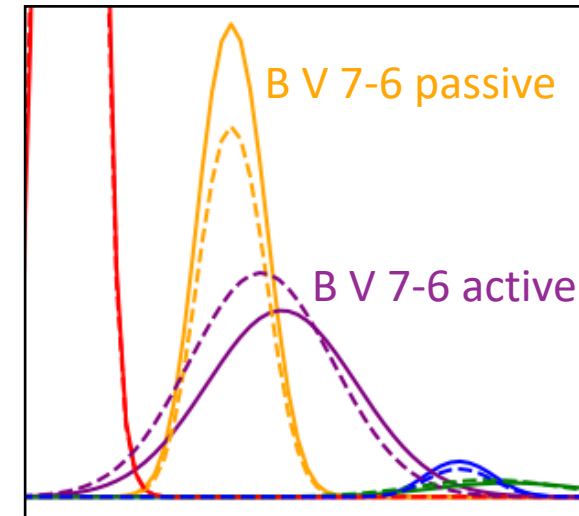
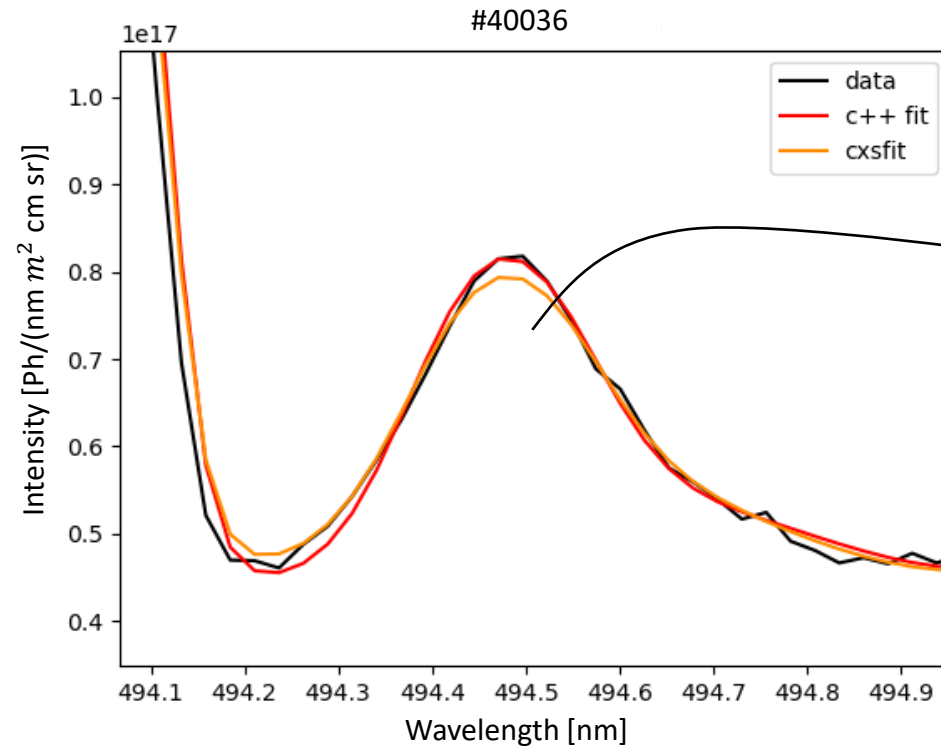
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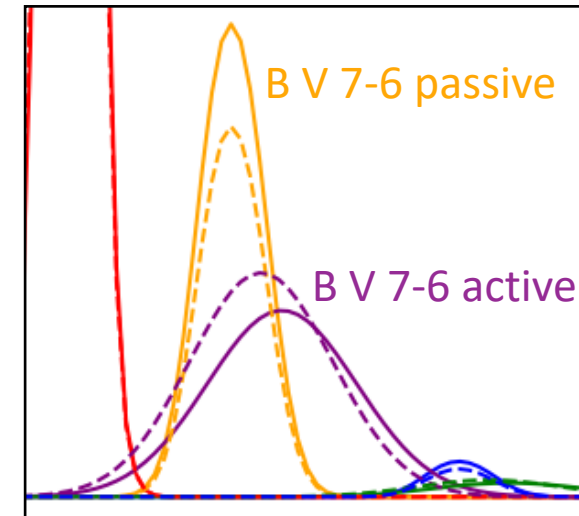
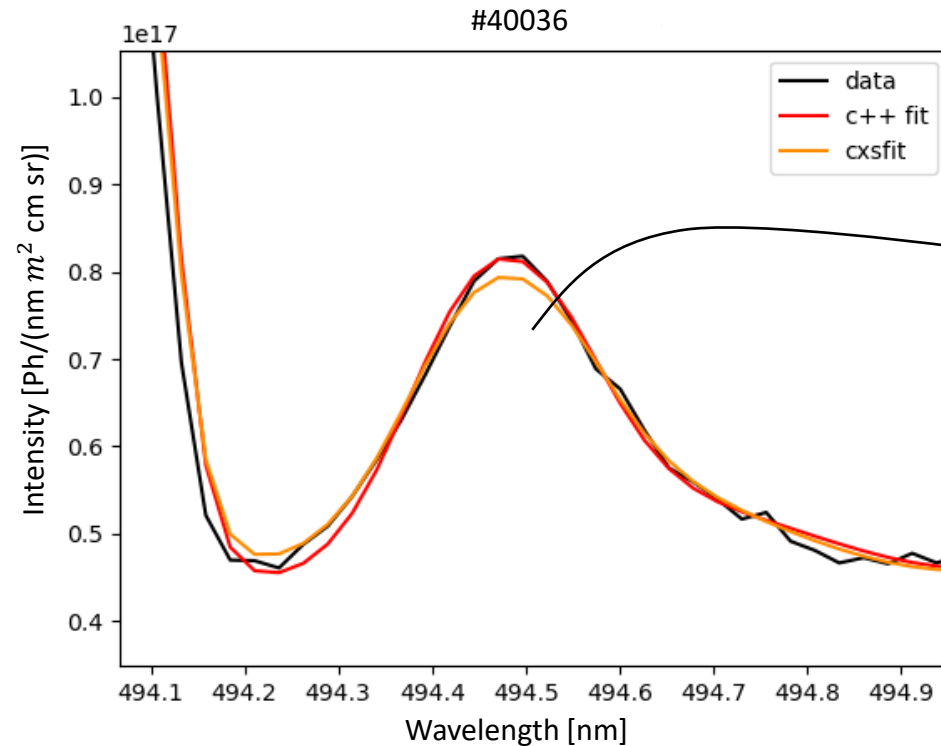
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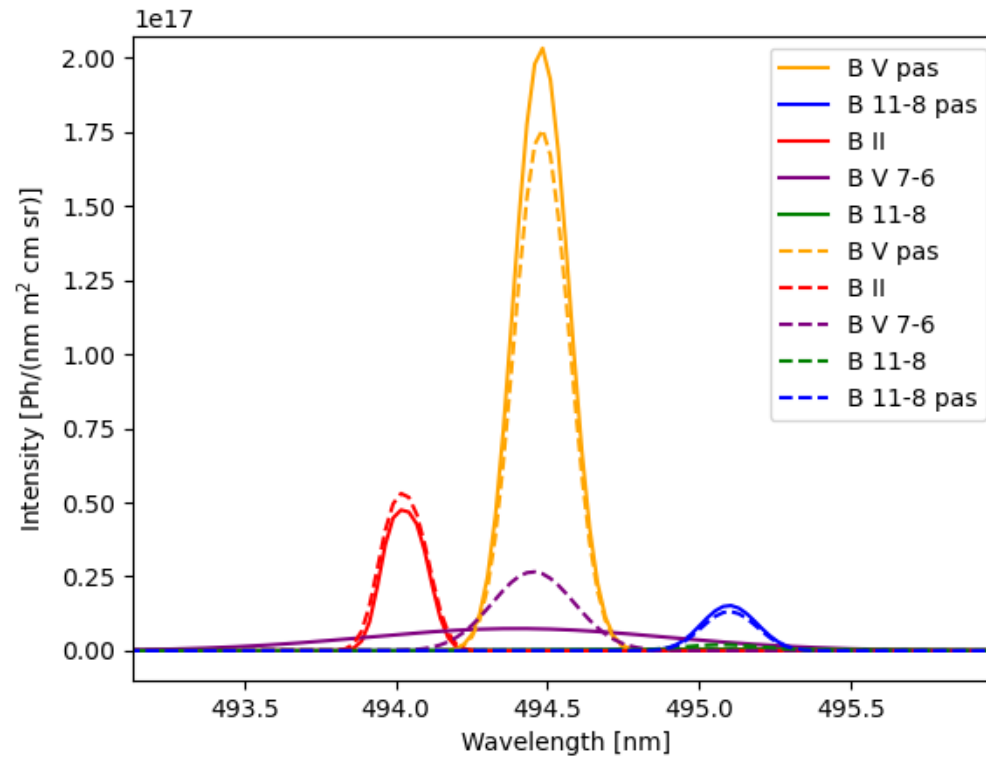
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N.B. Optimization of B V active and passive difficult also for CXSFIT

RT fitting routines: main issues (II)

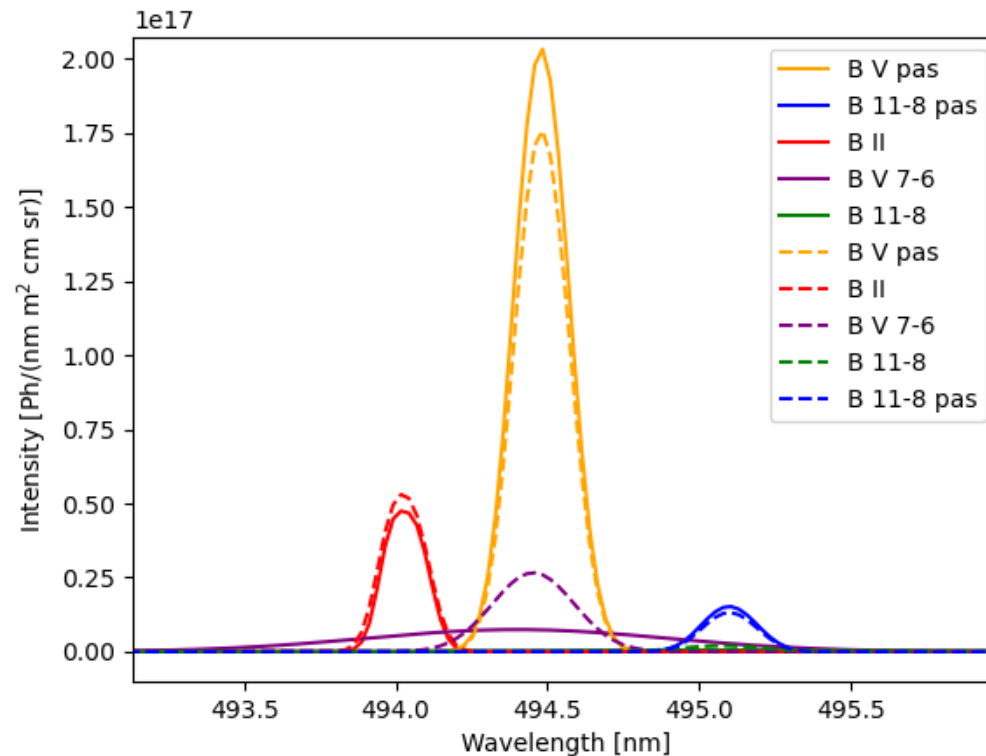
#43977 $t = 4.99$ s



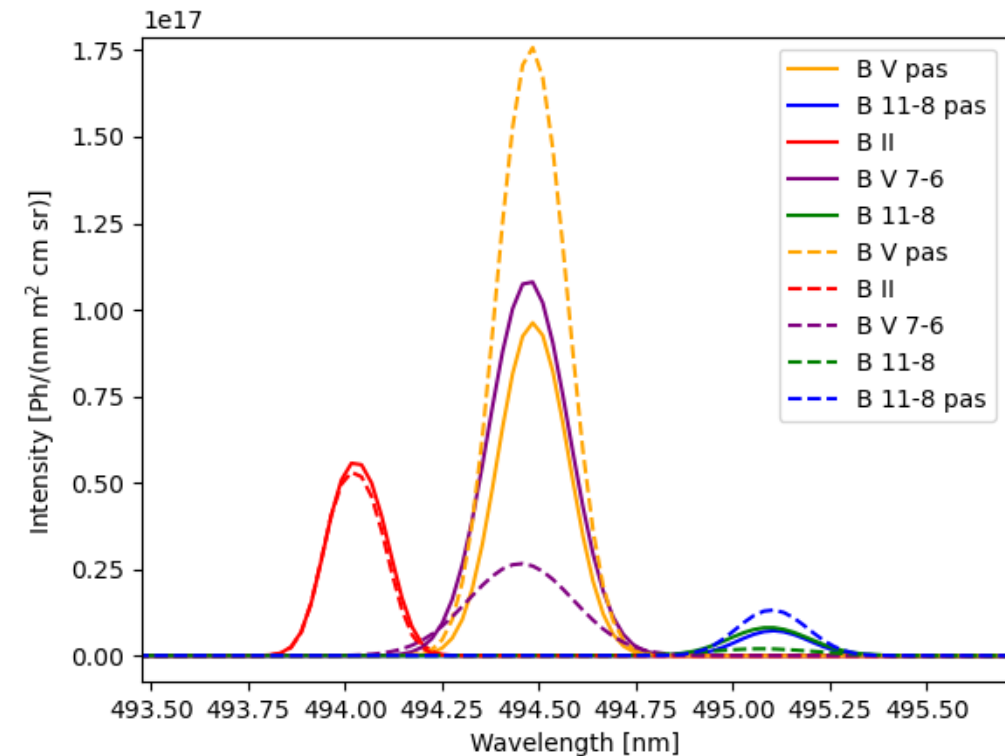
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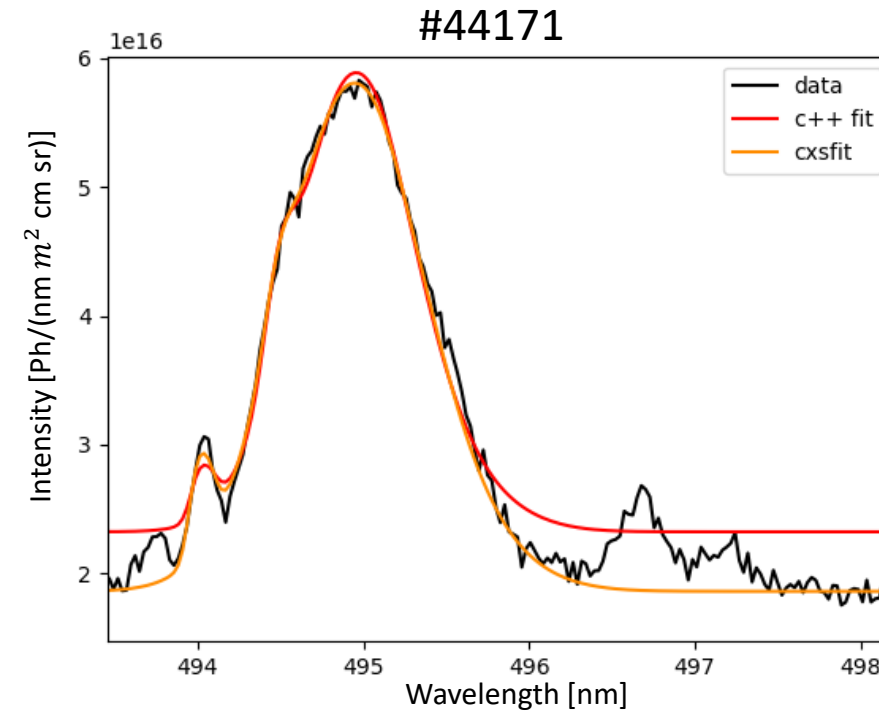
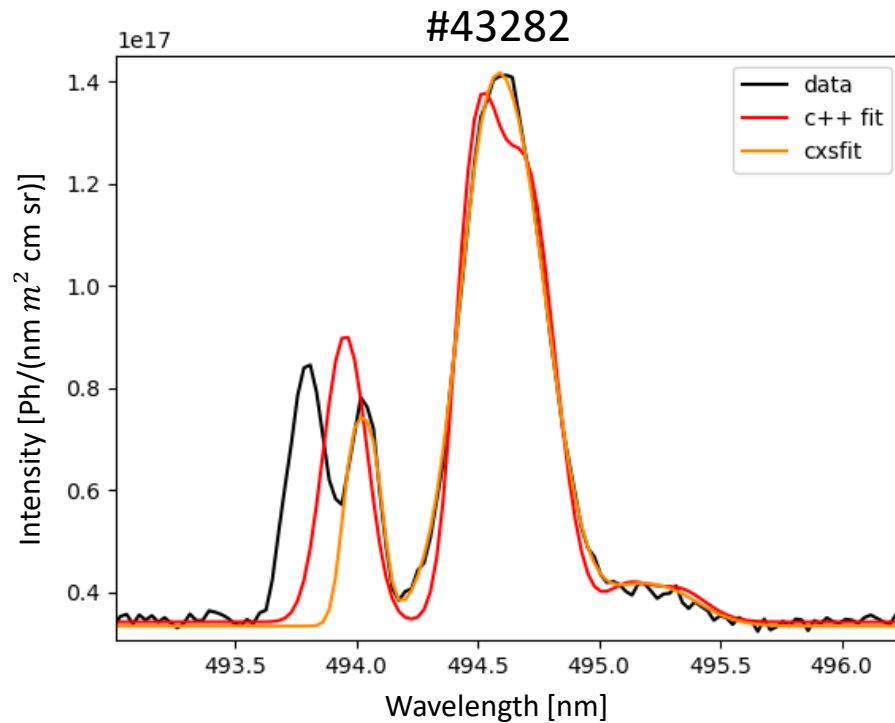
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Area of B V 7-6 passive constrained to
be within $\pm 50\%$ w.r.t. previous frame

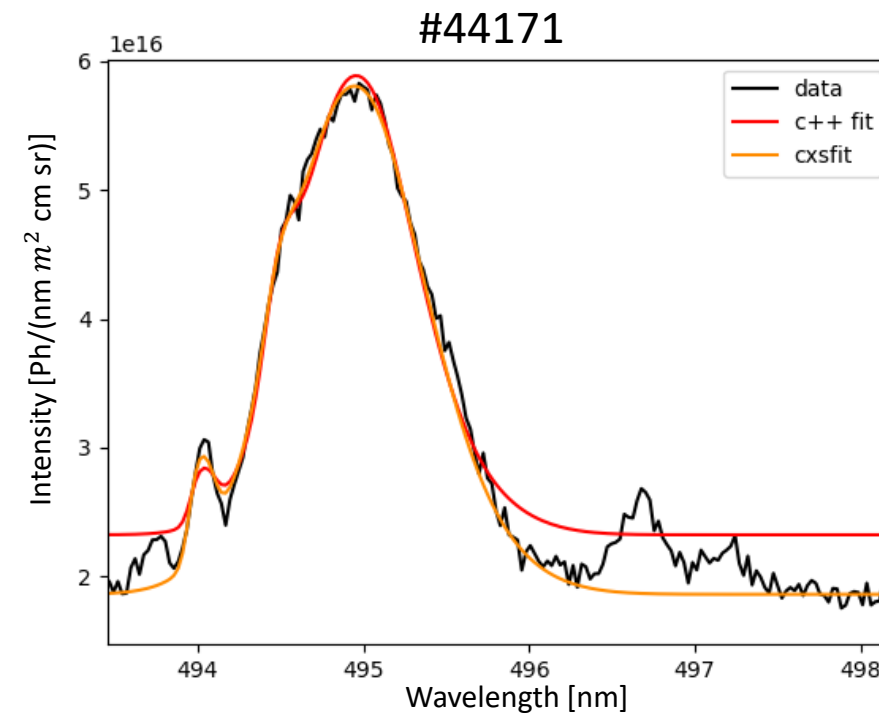
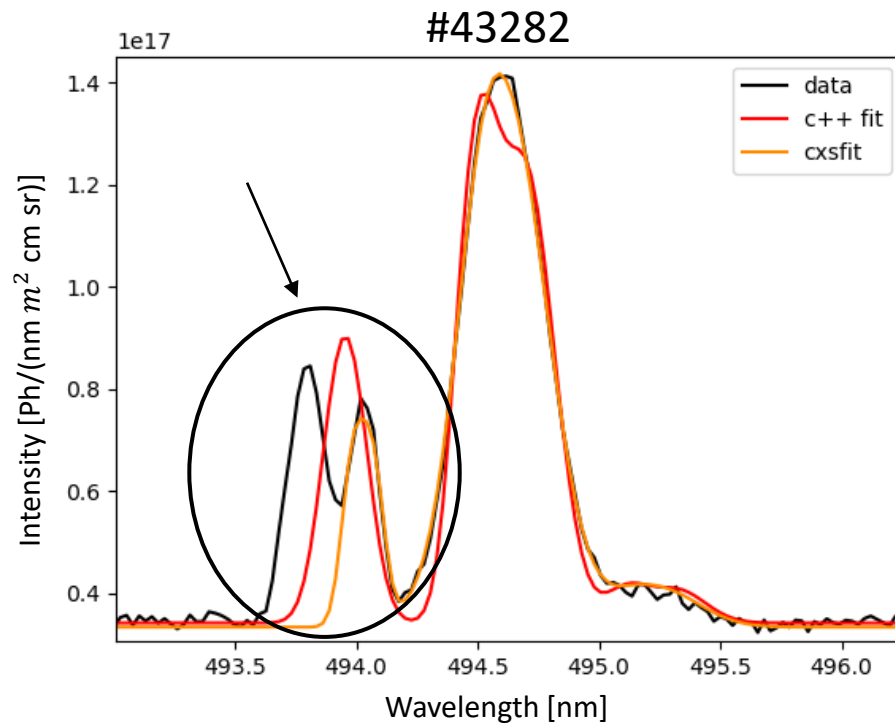
RT fitting routines: main issues (III)

2. Impurity peak next to B II, inside fitting window
3. Peak in background evaluation window



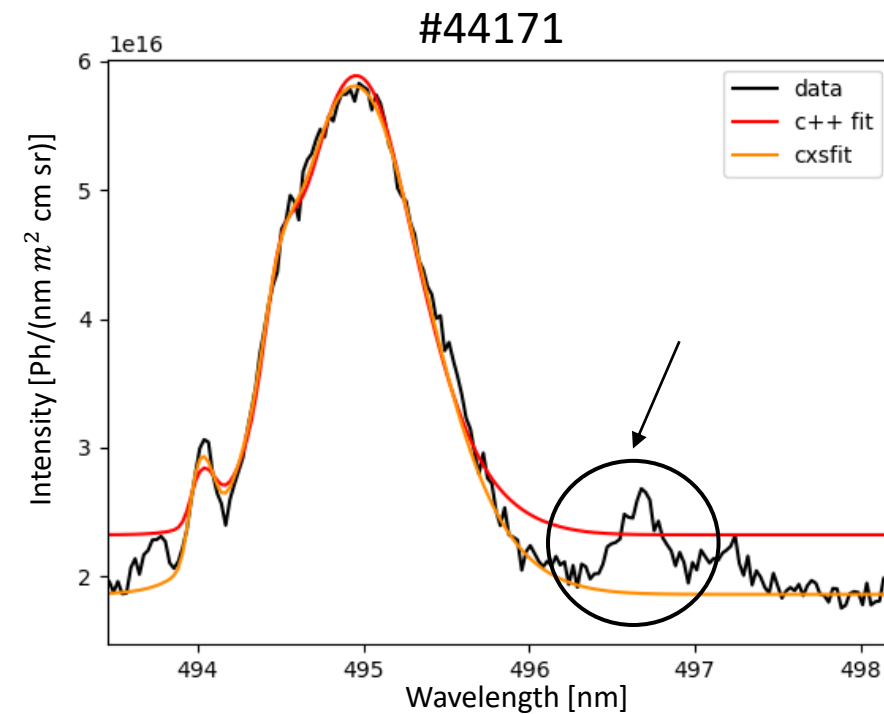
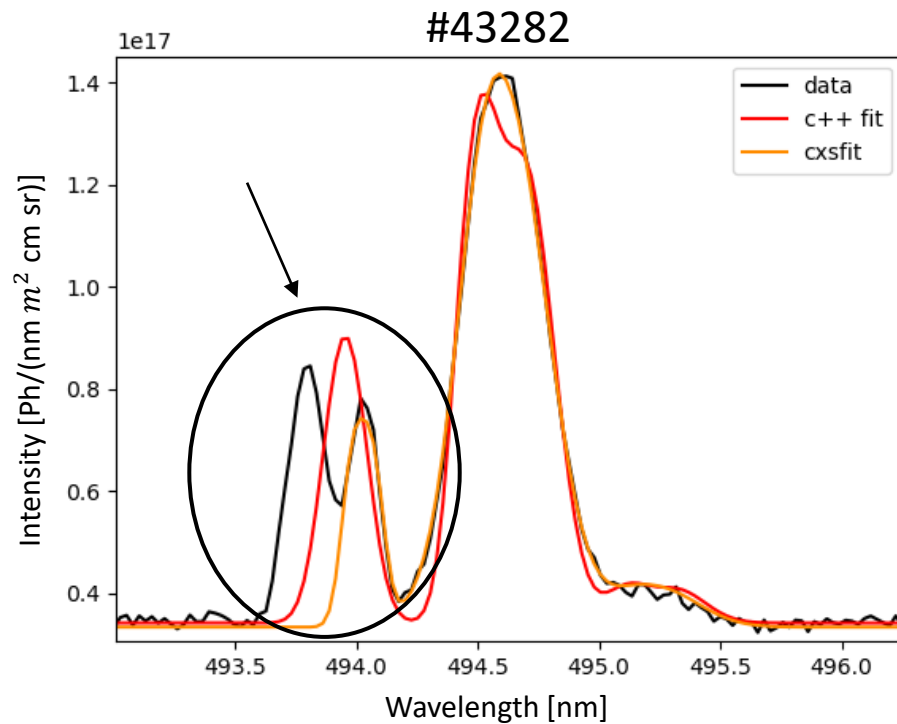
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Summary



- RT spectroscopy can represent a key step toward developing new reactor-relevant control strategies
- RT spectroscopy **data acquisition** and **calibration** successfully implemented at AUG and applicable to any spectrometer
- Specialized RT **analysis algorithms** under developement:
 - Fitting routines for CXRS spectra successfully implemented and tested offline
 - H and D density evaluation via divertor spectroscopy