OVERVIEW

- Analysis of C I spectral line shapes gives an independent way to distinguish carbon release mechanisms
  - Asymmetry and λ–shift observed in C I 9095 line
  - Effective C I temperatures cluster in ranges 0.8-1.2 and 5-8 eV, according to which sputtering mechanism dominates
  - Physical sputtering causes λ–shift which increases with mass and energy of incident ions

- Relative importance of physical and chemical sputtering supported by flux measurements of C I, C_2 and CD in the DIII-D divertor
  - $$\Gamma_{C\,I}^{molec} = \underbrace{52 \times \Gamma_{C_2}}_{C_xH_y} + \underbrace{(\Gamma_{CD} - 8 \times \Gamma_{C_2})}_{CH_4}$$

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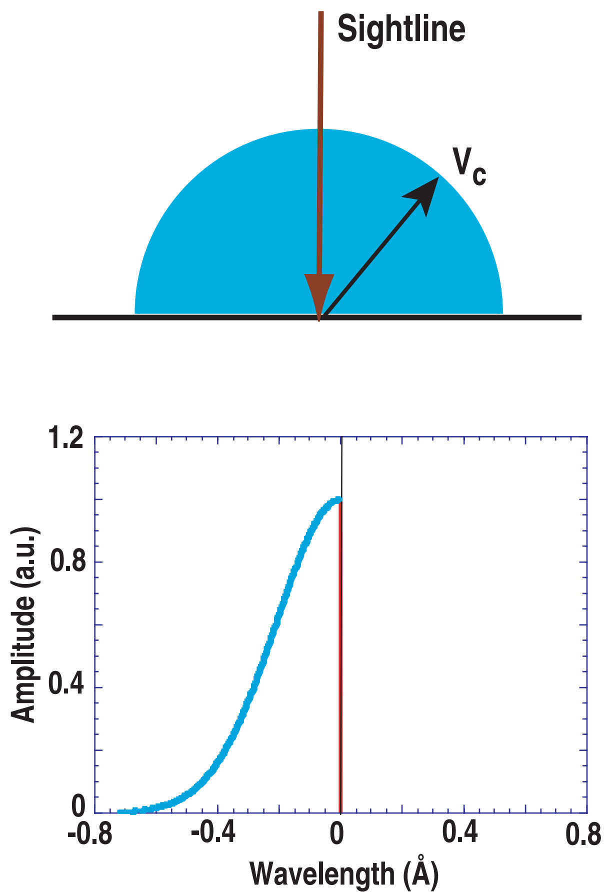
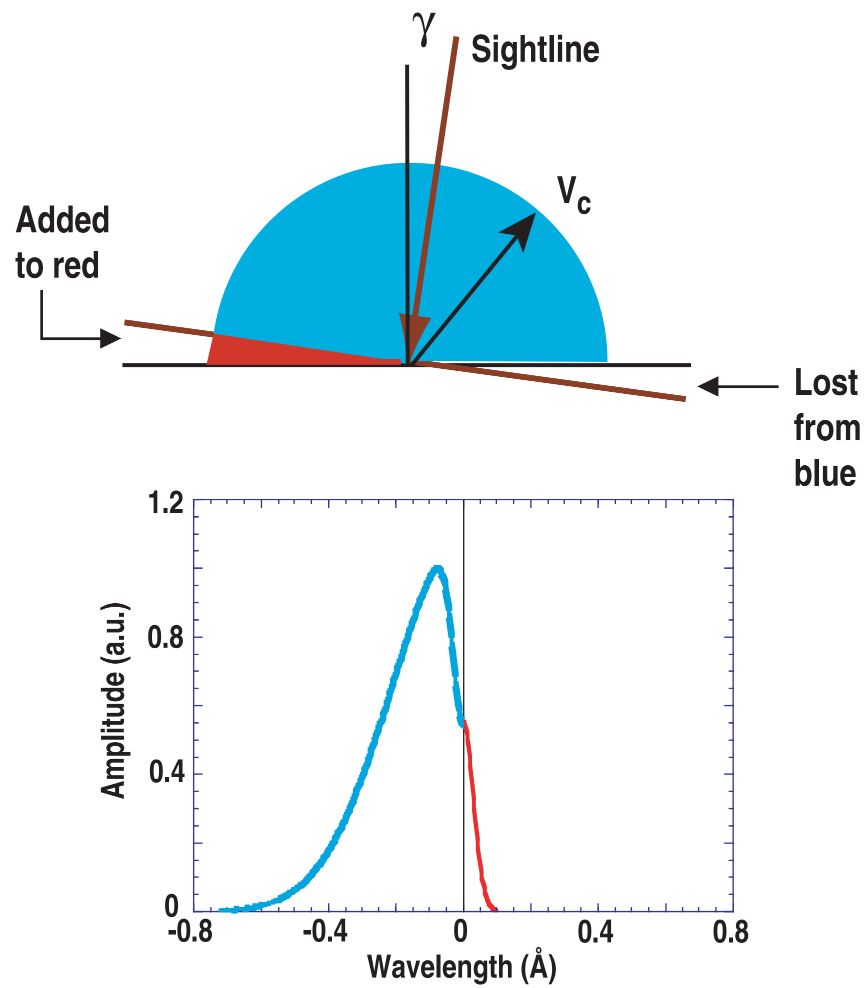
WITH PHYSICAL SPUTTERING, HEMISPHERIC VELOCITY DISTRIBUTIONS GIVE RISE TO ASYMMETRIC SPECTRAL PROFILES

Normal View



Angled View



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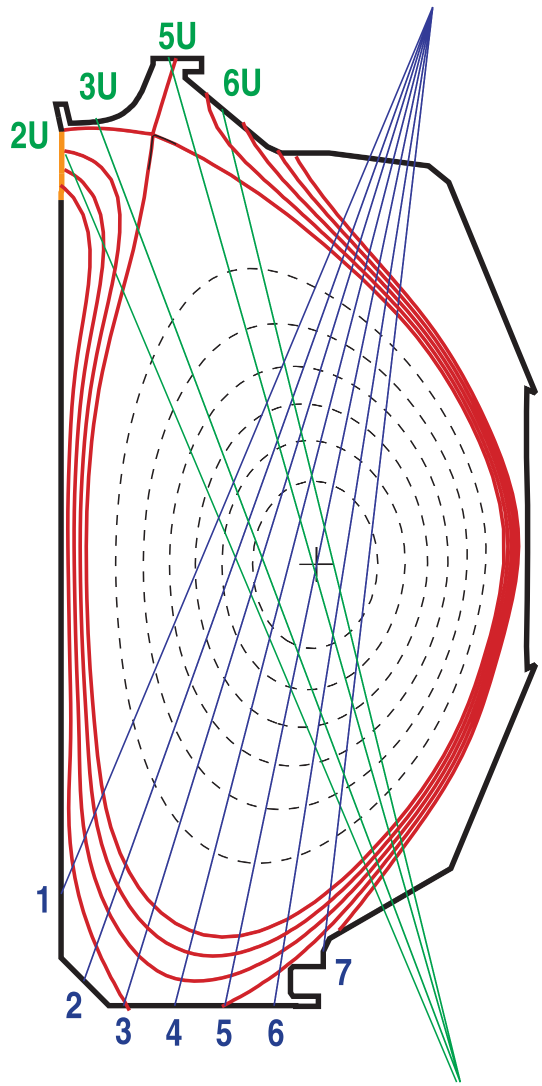
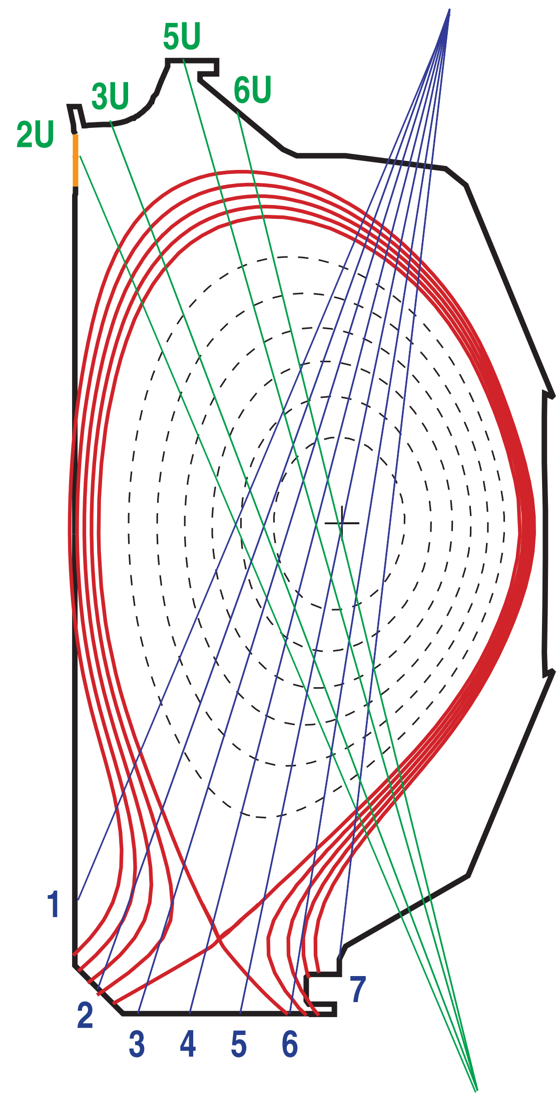
SPECTROMETER VIEWS OF UPPER AND LOWER SINGLE-NULL MAGNETIC CONFIGURATION IN DIII–D VESSEL





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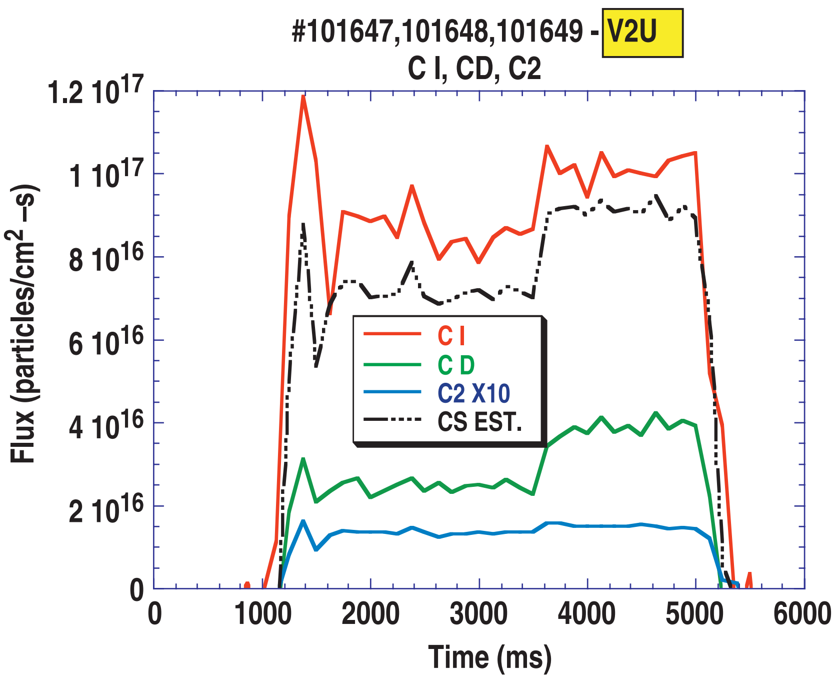
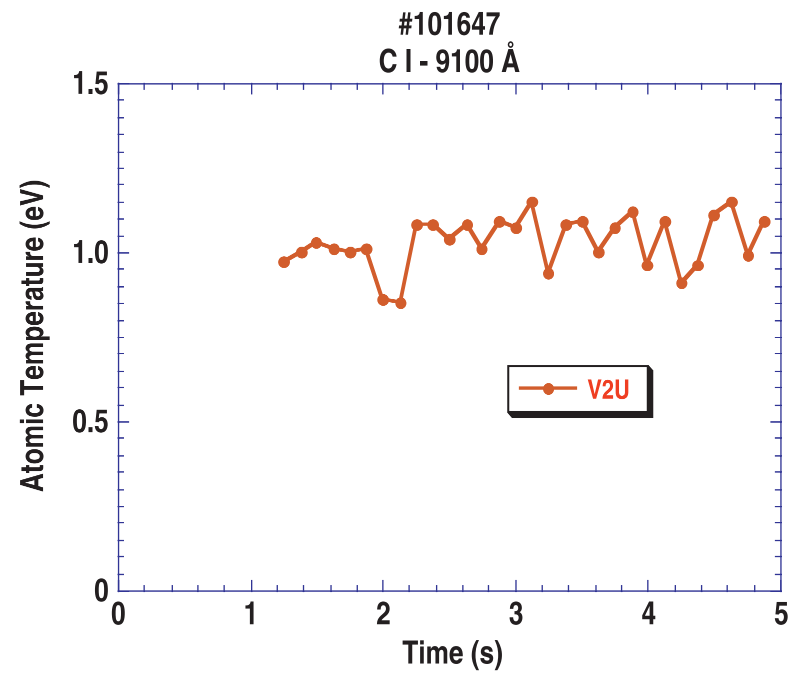
A CASE OF CHEMICAL SPUTTERING
UPPER SINGLE-NULL – "PUFF AND PUMP" – 4.5 MW





- The flux measurements are consistent with all carbon being produced by chemical sputtering
- The effective C I temperature is also consistent with molecular dissociation

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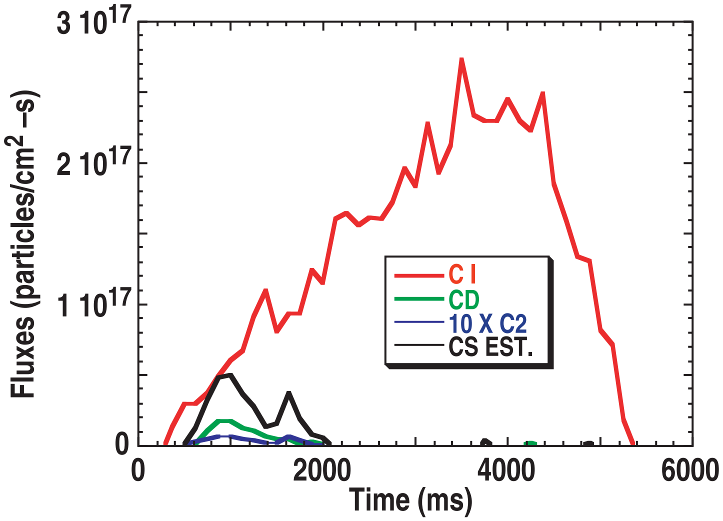
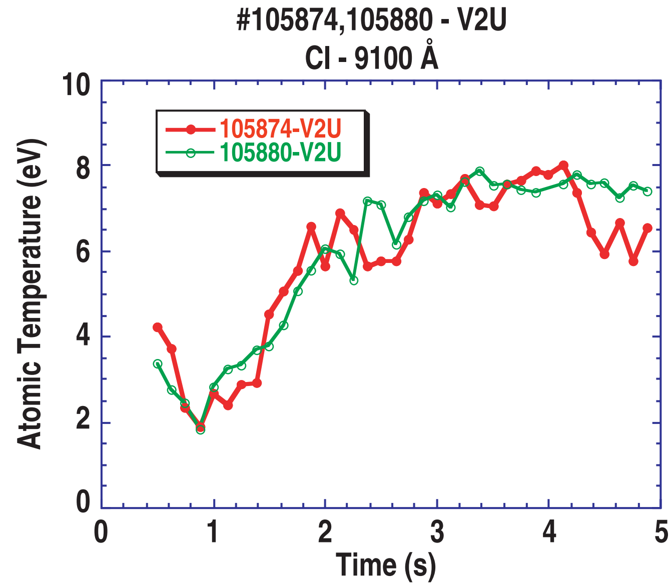
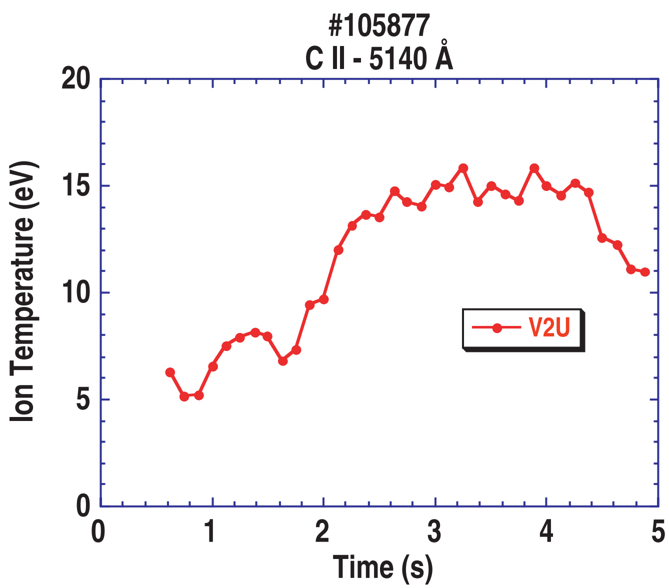
PHYSICAL SPUTTERING DOMINANT
USN – 9.5 MW (QDB) – COUNTER INJECTION







- Chemical sputtering appears to dominate startup, then physical sputtering takes over. C I and C II temperatures are high

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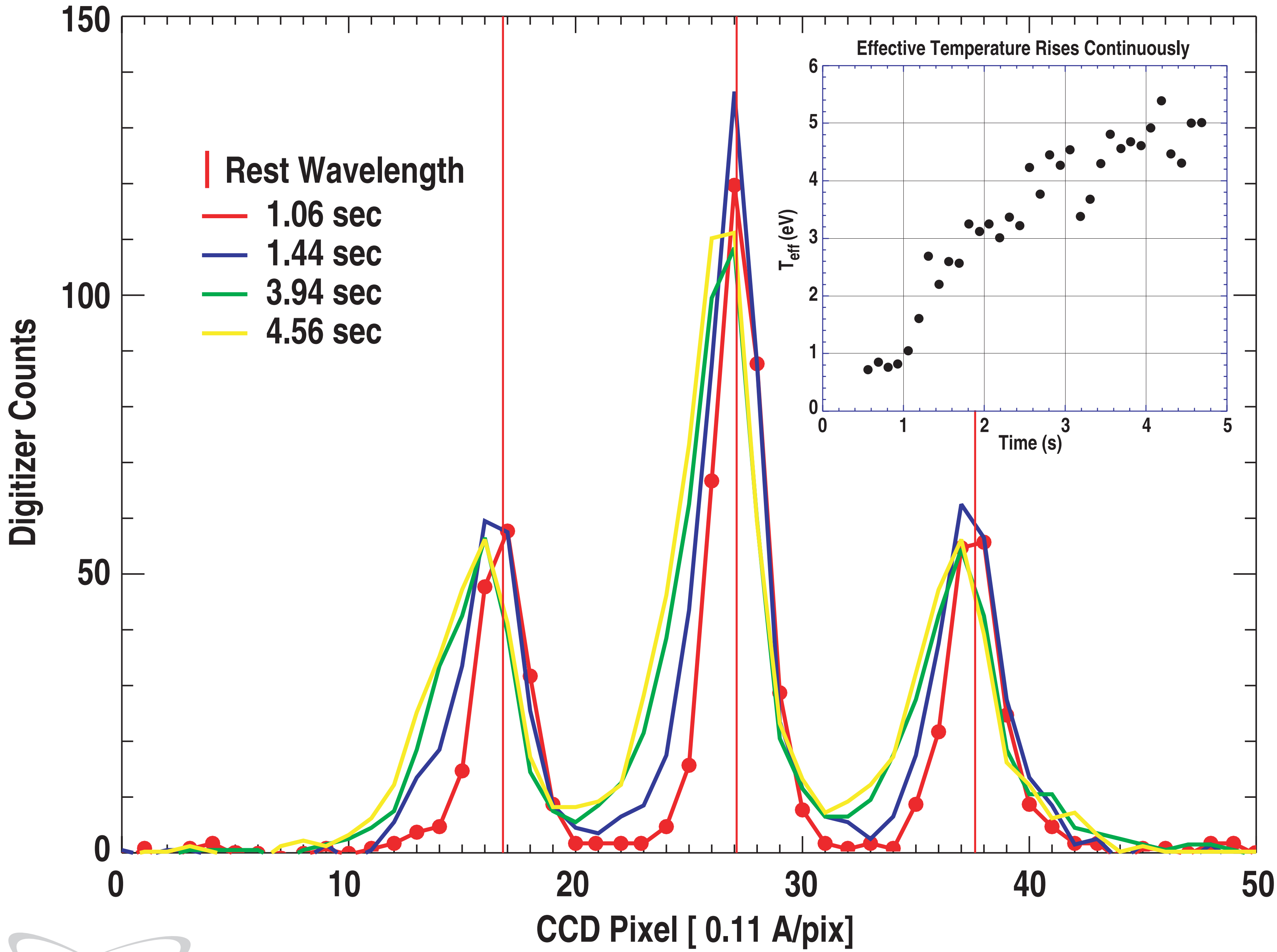
LARGE λ–SHIFT

C I LINE PROFILE BROADENS TO BLUE SIDE OF REST WAVELENGTH



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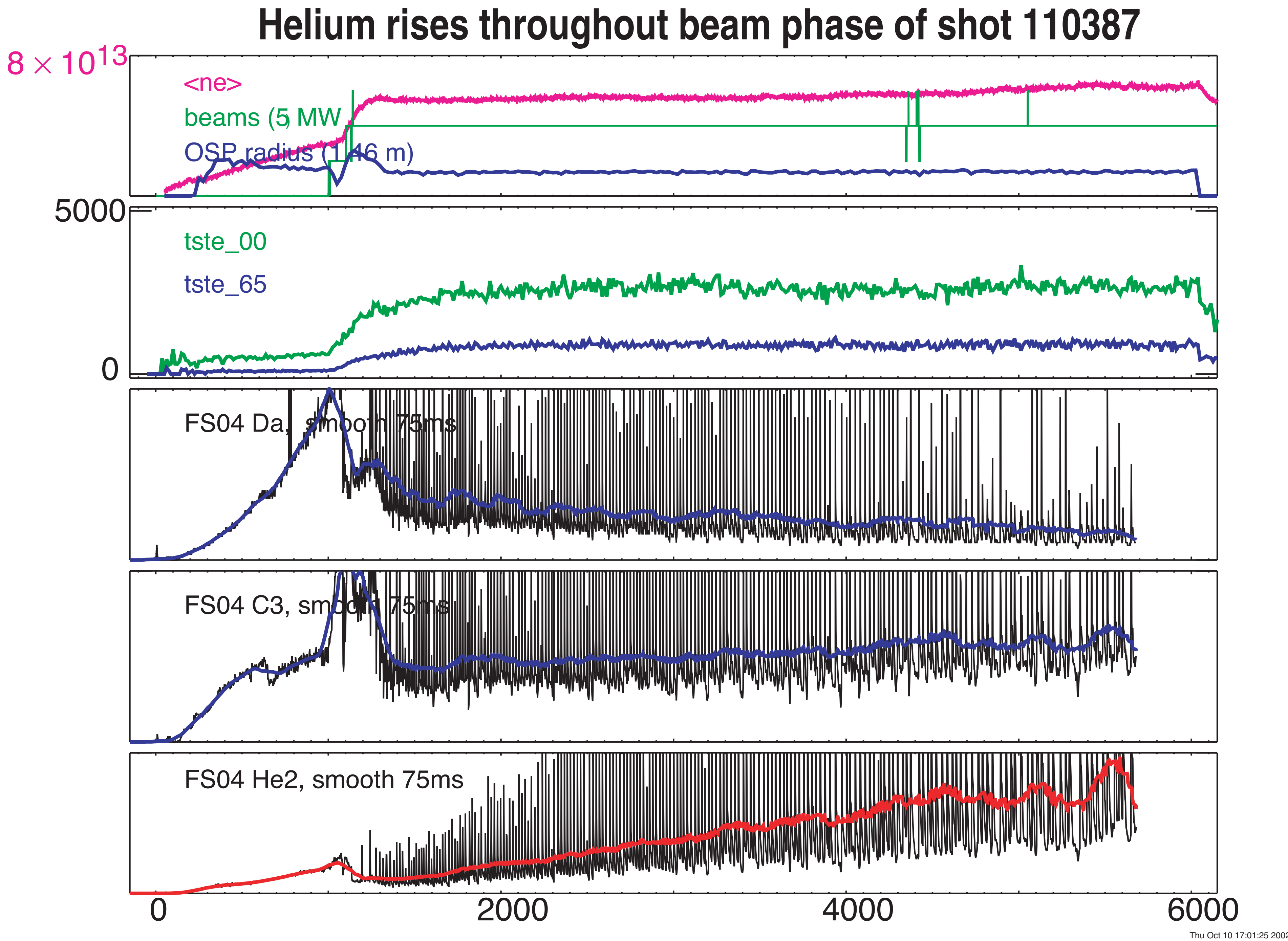

Helium rises throughout beam phase of shot 110387
8 × 10^13
<ne>
beams (5 MW
OSP radius (1.46 m)
5000
0
tste_00
tste_65
FS04 Da, smooth 75ms
FS04 C3, smooth 75ms
FS04 He2, smooth 75ms
0
2000
4000
6000
Thu Oct 10 17:01:25 2002

DETAILS OF PROFILE ANALYSIS

- Maximum entropy technique used to deconvolve source profile from measured one
- Source profile fit with analytically constrained, asymmetric and symmetric components by a non-linear, least squares method
  - Asymmetric part represented by a modified Thompson velocity distribution mapped to λ space

$$f(E)dE = \frac{E}{(E + U_0)^3} h(\theta)G(E)dE$$

where $$h(\theta) = \cos^{\alpha}(\theta - \delta)$$

  - Symmetric part described by single (or double) Gaussian
- In absence of λ fiducial from argon lamp, centroid of profile from detached, inner strike point used to locate λ_o

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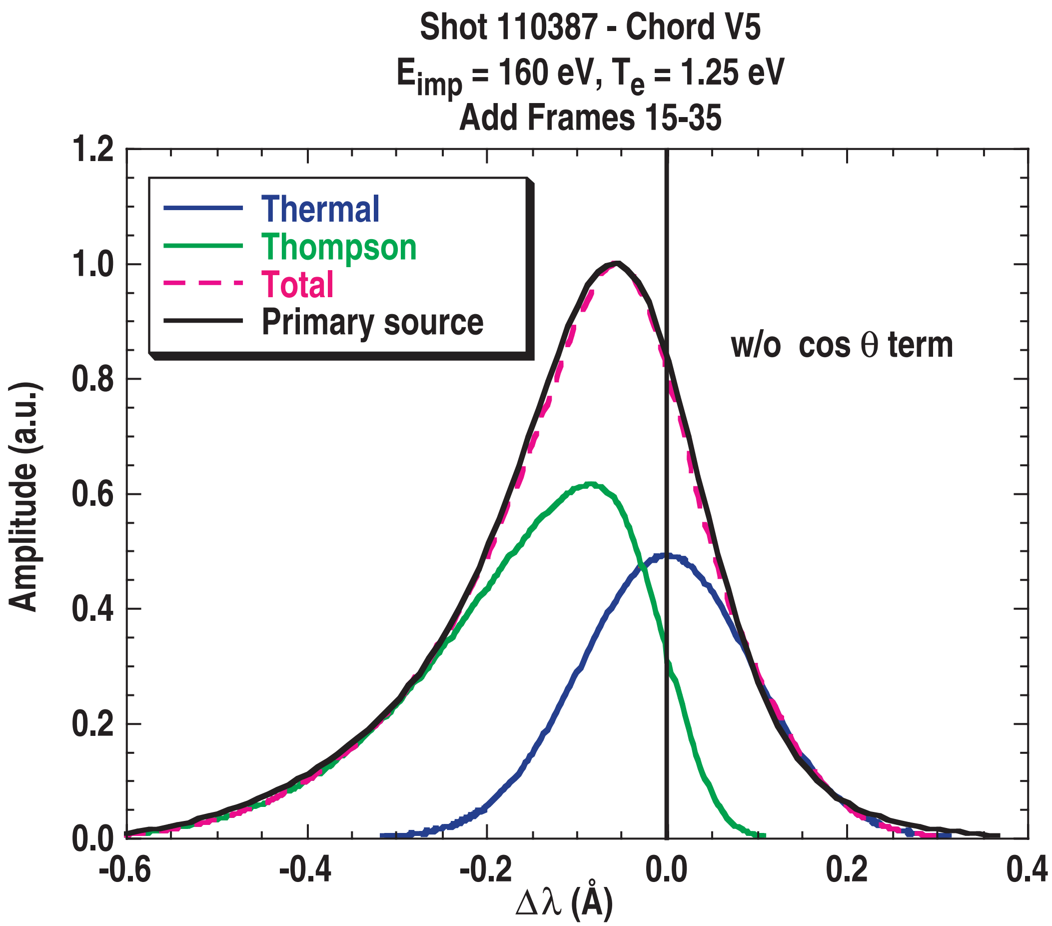
DECONVOLVED SOURCE PROFILE IS FIT BY SUM OF THOMPSON AND THERMAL COMPONENTS



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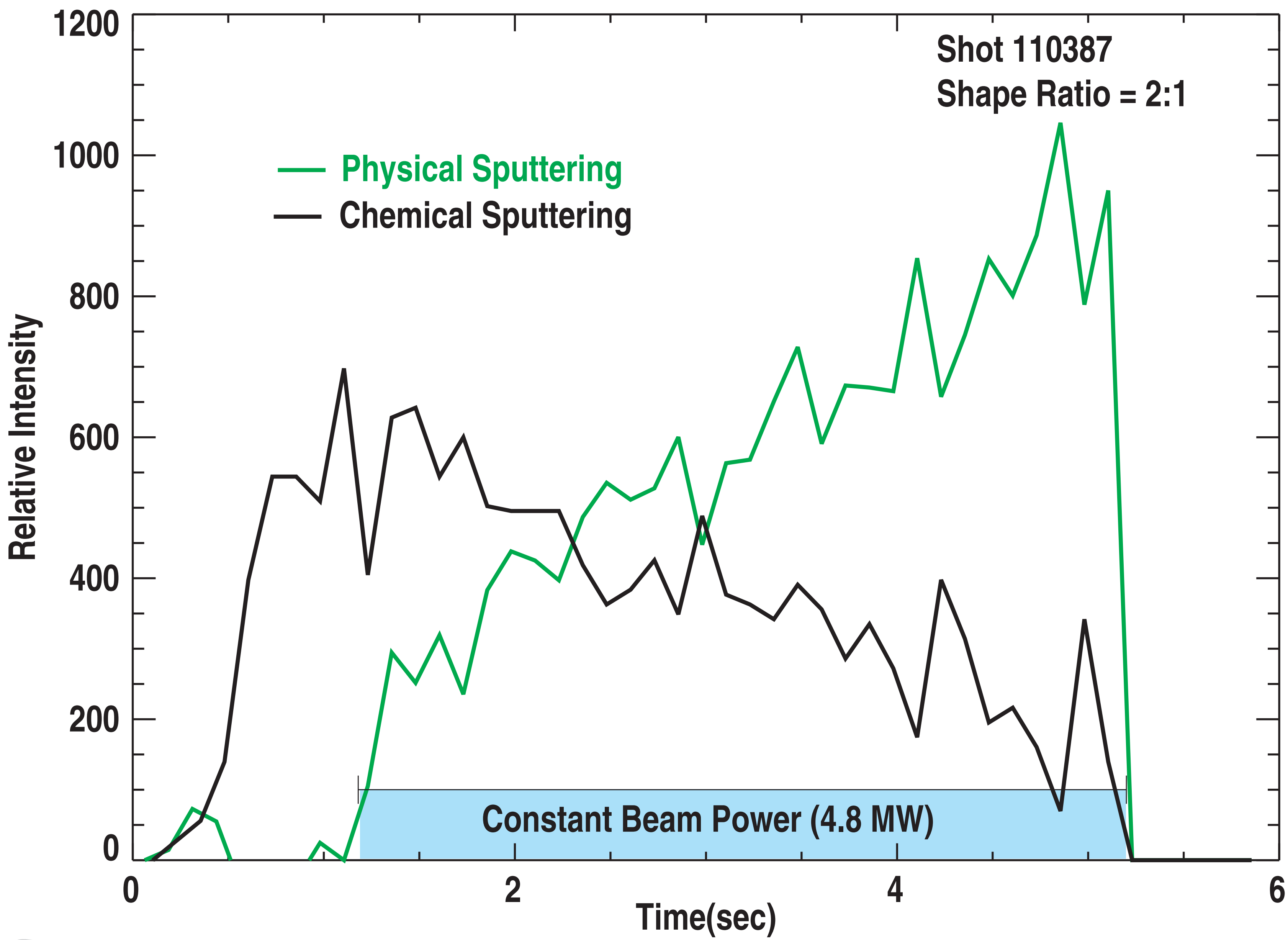
INTEGRATED INTENSITIES IN THOMPSON AND THERMAL PROFILES



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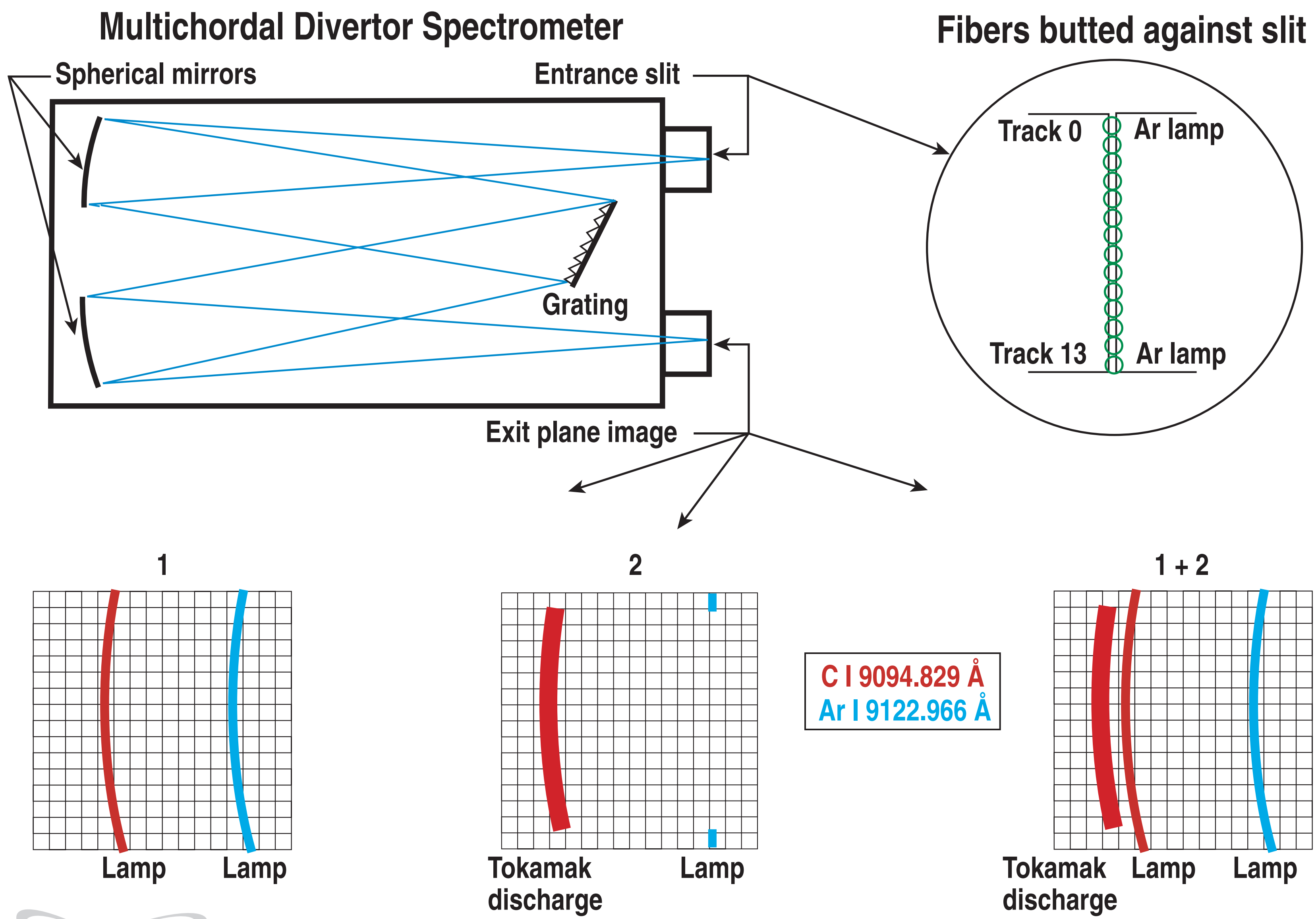
WHERE IS λ_0 ?

AN ACCURATE WAVELENGTH CALIBRATION IS NEEDED TO DETECT SMALL λ-SHIFTS



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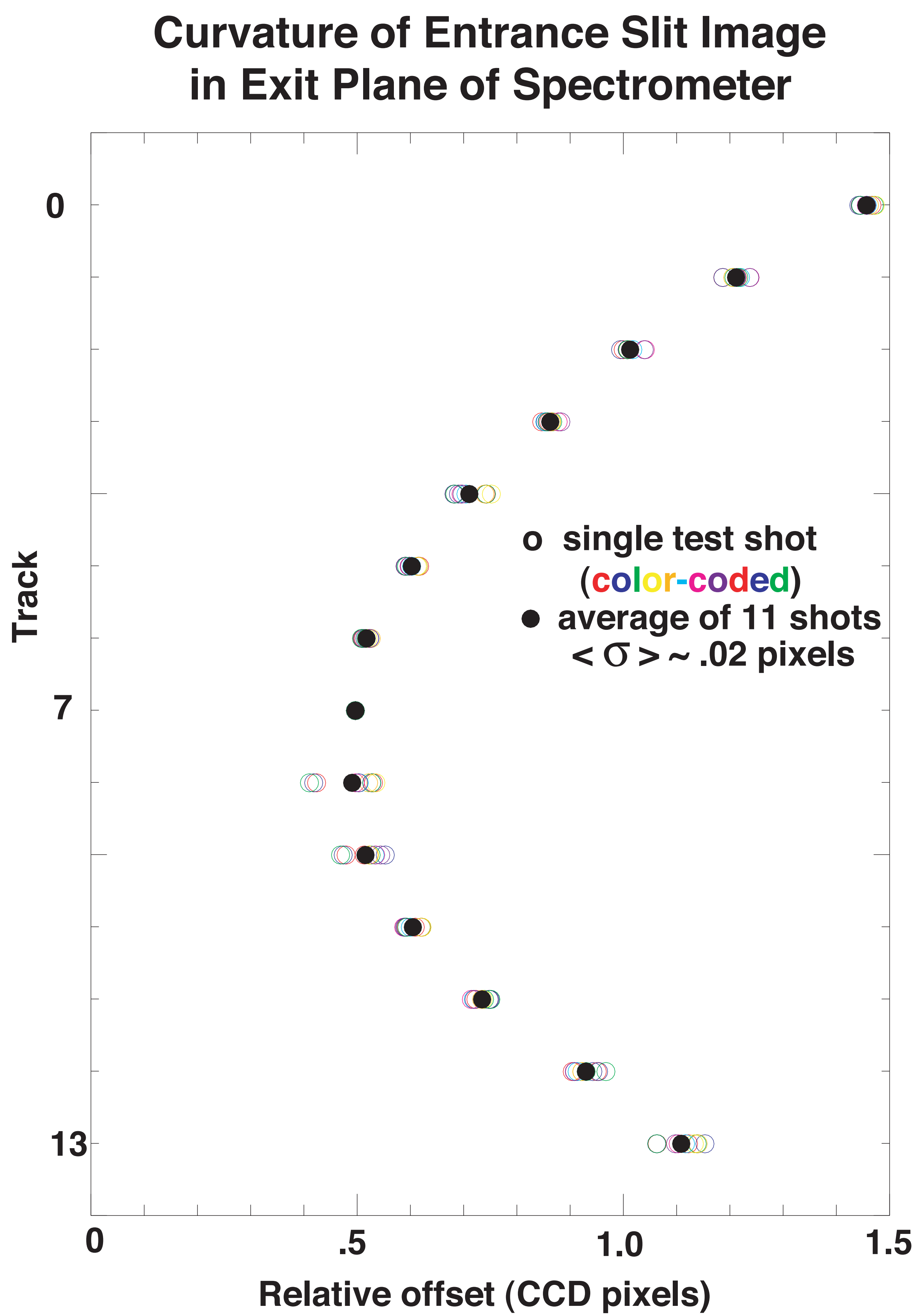
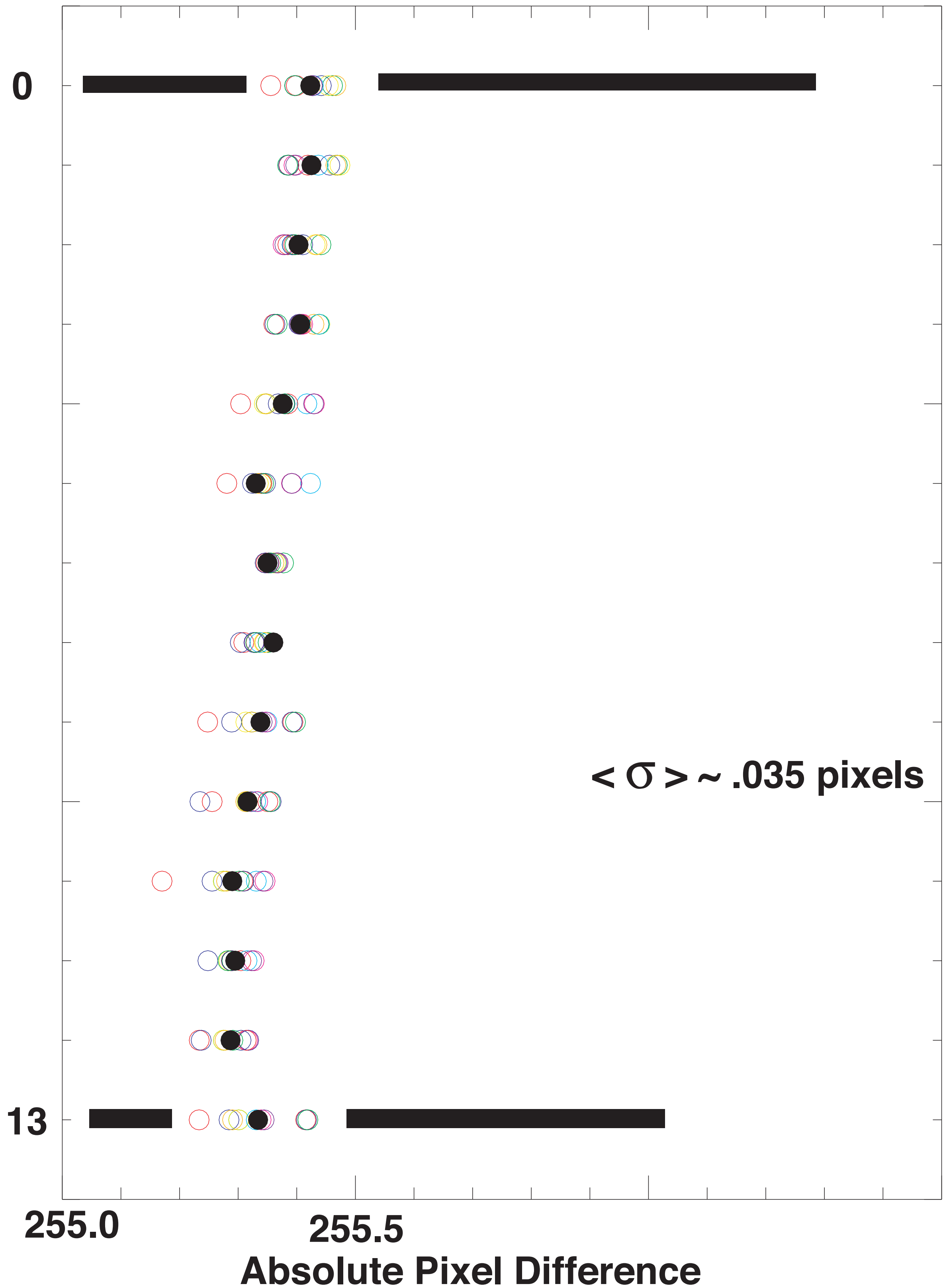


Curvature of Entrance Slit Image
in Exit Plane of Spectrometer
Track
0
7
13
o single test shot
(color-coded)
● average of 11 shots
< σ > ~ .02 pixels
0
.5
1.0
1.5
Relative offset (CCD pixels)

Pixel Offset between C I and Ar I Lines with Simultaneous Illumination



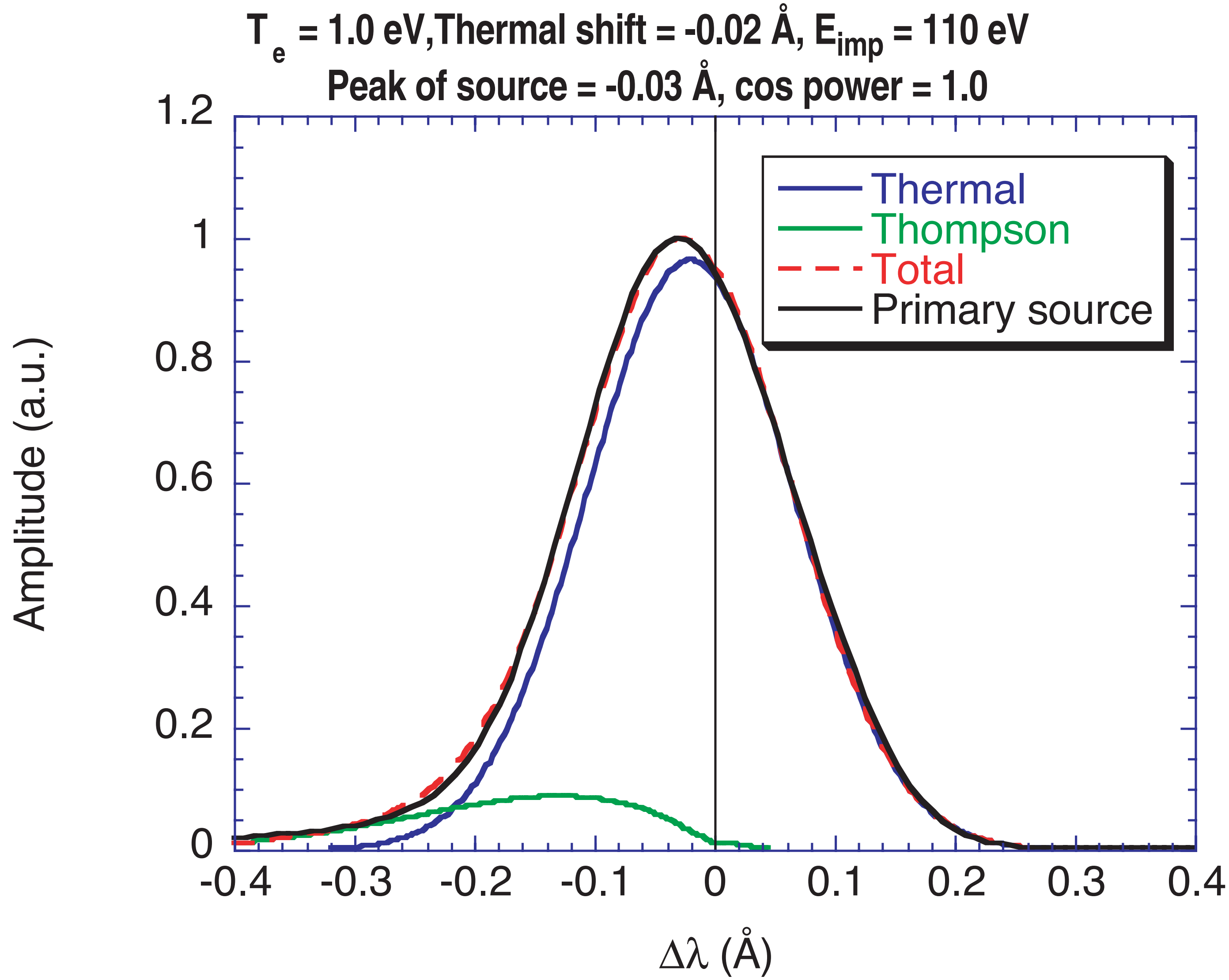
SMALL λ–SHIFT

LOW POWER, LOW DENSITY DISCHARGES

- Chemical sputtering dominates in L-mode discharges with 0.5 MW NBI
- Symmetric profile shifted by 0.014 A, consistent with thermal release velocity of CH_4
- Small asymmetric component required to fit blue wing of source profile

IN LOW POWER L-MODE, THOMPSON COMPONENT IS SMALL, THERMAL COMPONENT HAS RESIDUAL BLUE SHIFT

SHOT 110466 - fr 9



RADIAL DECAY LENGTH

EROSION FOOTPRINT DEPENDS ON OPERATING MODE

- T_{eff} (r) and $\Delta\lambda$(r) tell story at outer strike point
  - Continuous radial map provided by X-point sweep in time
  - Two chord comparison possible when magnetic configuration fixed
- In ELMy H-mode, decay length for physical sputtering is short
- In QDB discharges, physical sputtering stays strong far out in SOL

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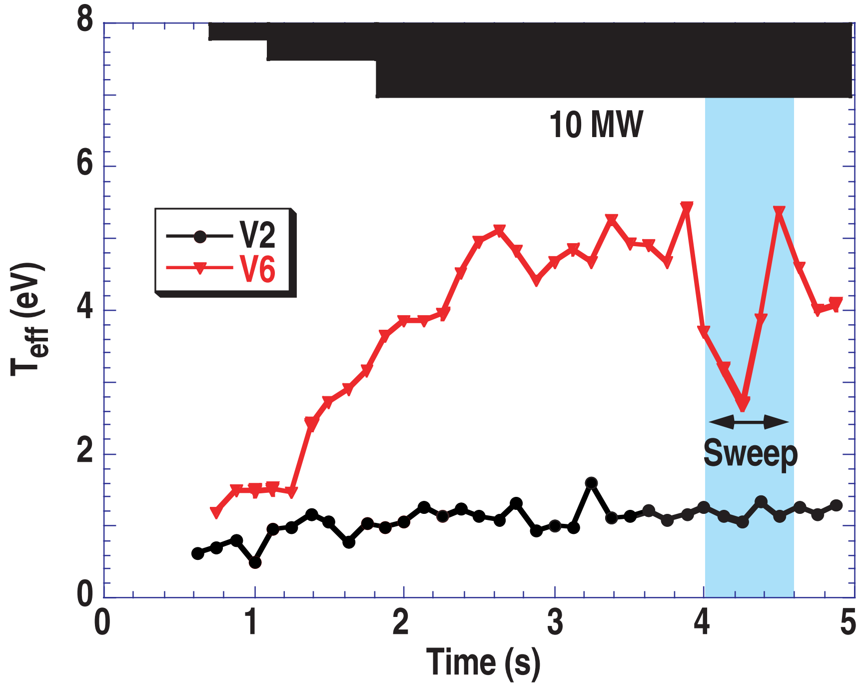
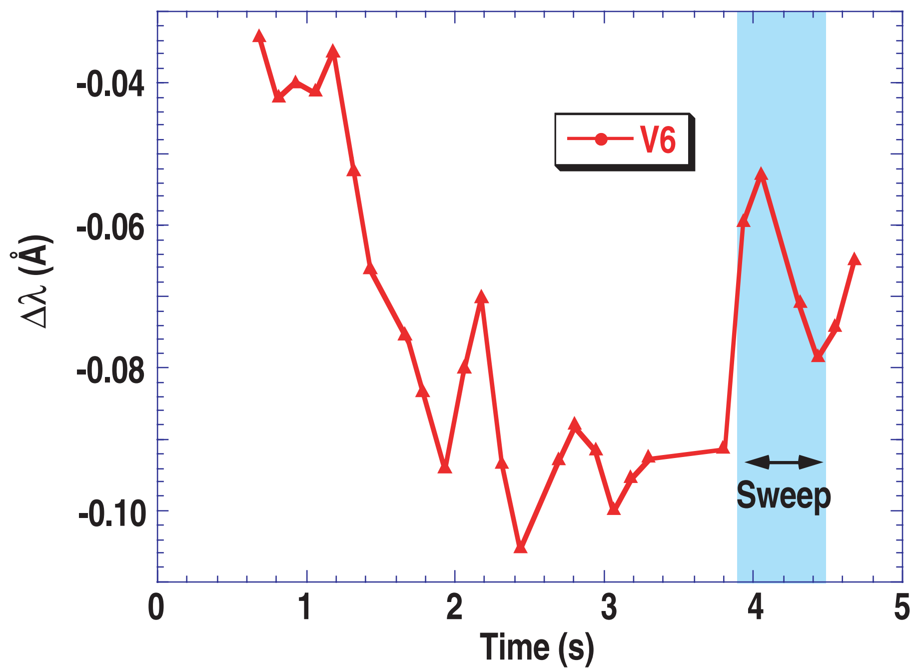
DURING RADIAL SWEEP, T_{eff} AND Δλ DECAY RAPIDLY OUTBOARD OF OUTER STRIKE POINT IN HIGH POWER, ELMing H-MODE

SHOT 102332

Effective Temperature of C I 9095 Å



Absolute shifts in peak relative to V2, 1.1 s



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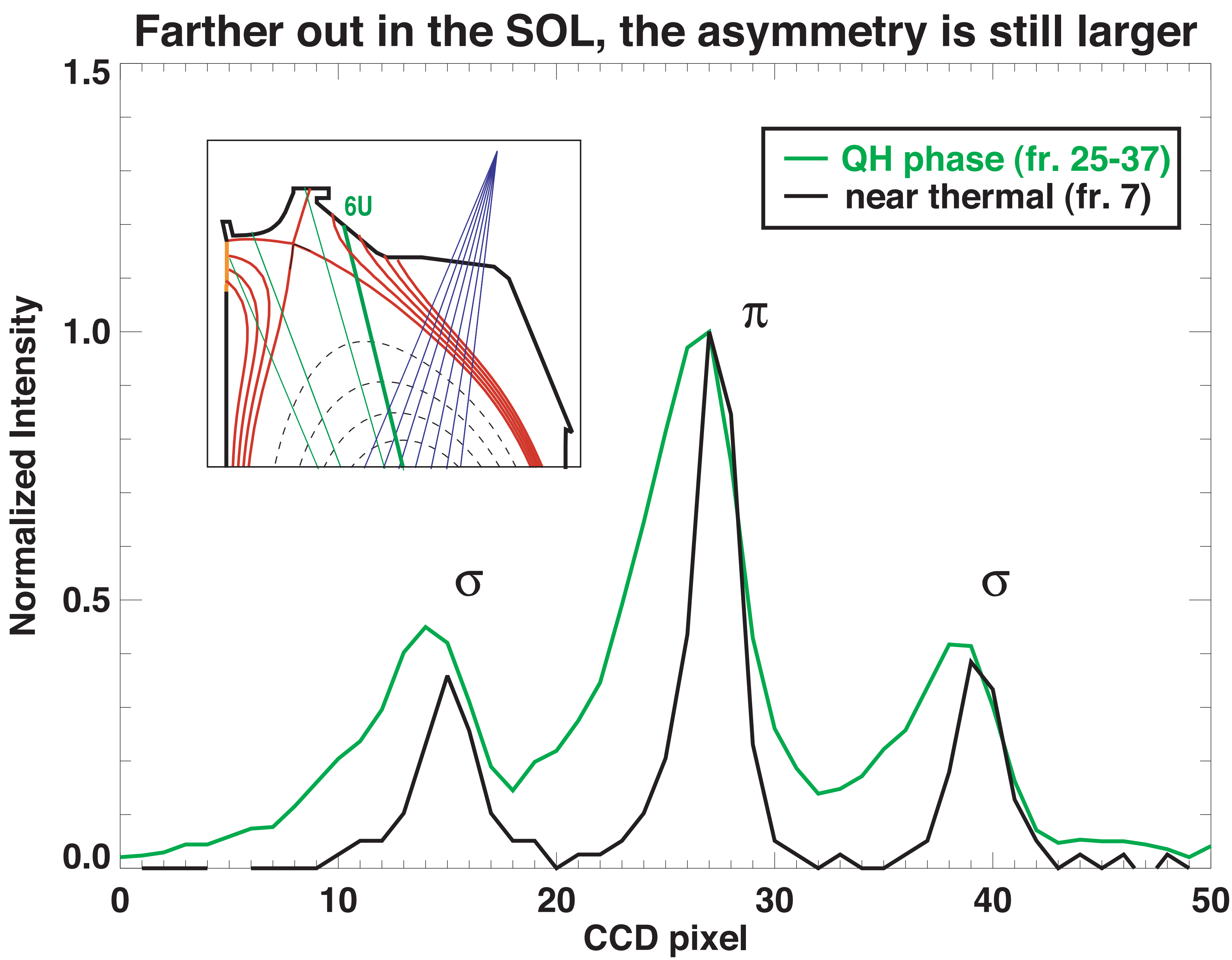
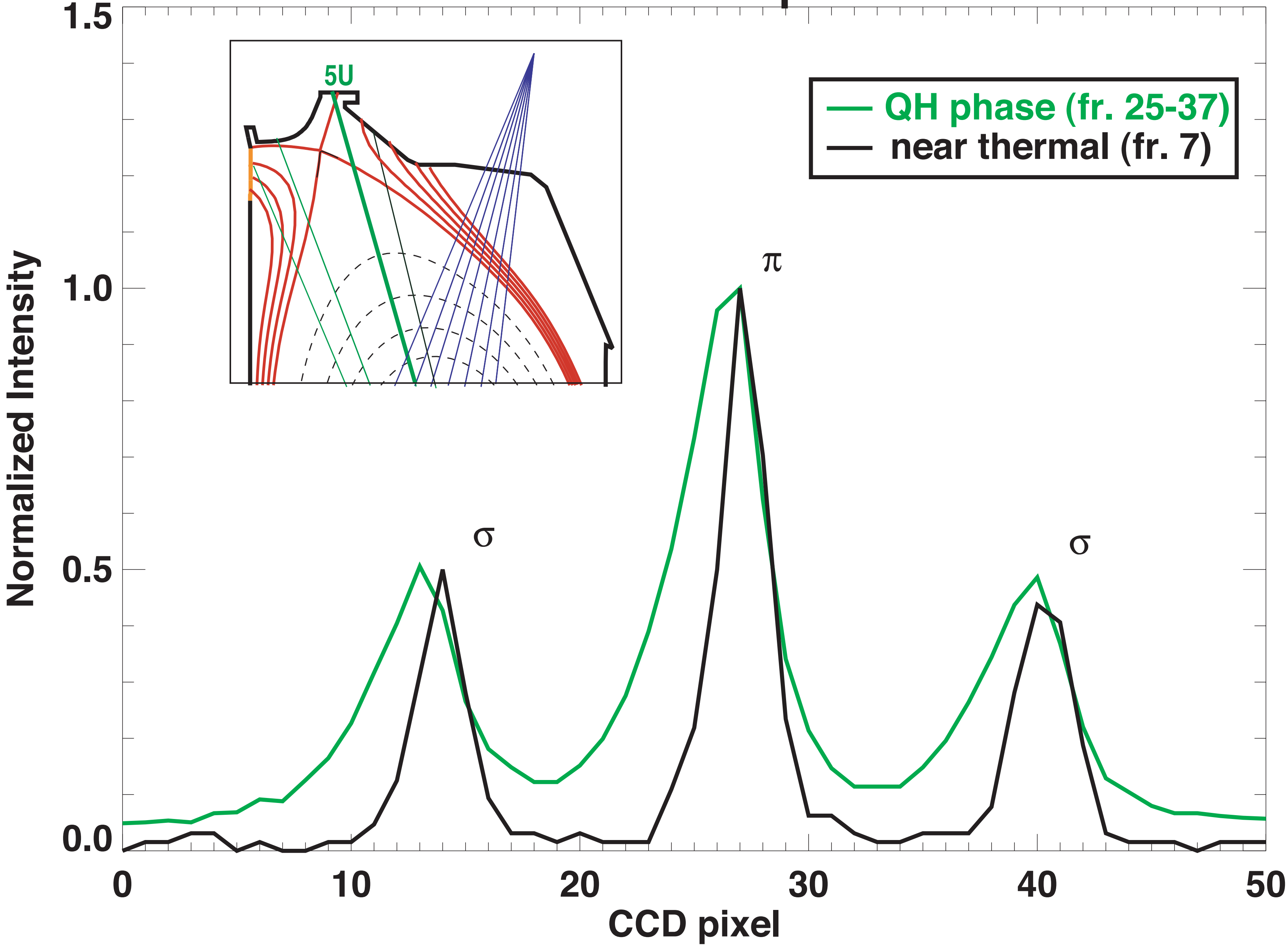


Farther out in the SOL, the asymmetry is still larger
1.5
1.0
0.5
0.0
Normalized Intensity
0
10
20
30
40
50
CCD pixel
QH phase (fr. 25-37)
near thermal (fr. 7)
6U
π
σ
σ

During QH discharges, C I shows strong asymmetry at outer strike point



IMPLICATIONS OF DIFFERENT RADIAL DECAY LENGTHS

- High divertor sheath potential (high T_e) or high energy ions required to produce strong physical sputtering

- In high energy ELMing H-mode discharges, pedestal electrons ejected at ELM onset produce high sheath potential localized near separatrix

  - Physical sputtering should occur during heat conduction phase of ELM only
  - Narrow radial profile consistent with parallel electron heat conduction

- In QDB discharges, high energy ions (5 keV) detected far out in SOL (see Poster RP1.045)

  - High T_i in SOL seen directly by CER, also in heat deposition on divertor
  - Broad radial profile of physical sputtering consistent
  - see Poster RP1.045

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SUMMARY

- C I lineshapes indicate relative importance of physical and chemical sputtering
- Experimental data can be fit with sum of asymmetric and symmetric profiles
  - Asymmetric calculated for a Thompson distribution of ejection velocities
  - Symmetric (gaussian) produced by isotropic breakup of C_xH_y molecules
- Physical sputtering accounts for ≥ 50% of C I flux in high power discharges; < 15% in low power discharges w/o ELMs
- Flux analysis of C I, CD and C_2 reinforce conclusions from lineshape analysis