Measurements of Ion and Electron Temperature Profiles on NSTX

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ABSTRACT

A new type of X-ray imaging crystal spectrometer was installed on NSTX for measurements of Te and Ti profiles from spatially resolved spectra of ArXVII. The spectrometer consists of a spherically bent 110-quartz crystal, with a radius of curvature of 3888 mm and a diameter of 100 mm, and a 10 cm x 30 cm 2D position-sensitive multi-wire proportional counter. It projects a de-magnified image of a large plasma cross-section (extension of +/- 40 cm above and below the horizontal mid-plane of NSTX) onto the detector. The spatial resolution in the plasma is 2.5 cm. It is determined by the height of the crystal, its radius of curvature, the Bragg angle, and the distance of the crystal from the plasma. The concept of this spectrometer is also of interest for ion-temperature measurements on ITER. Recent from NSTX and TEXTOR will be presented.

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Introduction

An X-ray imaging crystal spectrometer for measurements of the *radial profiles* of Ti, Te, V_tor, and the ion charge state distribution in tokamak plasmas is being developed on NSTX. The spectrometer is also of interest for Ti measurements on ITER.

The concept of the spectrometer has been experimentally verified on Alcator C-Mod in 2003, using a prototype instrument from NSTX [M. Bitter et al., Rev. Sci. Instrum. 75, 3660 (2004)]. Additional experiments were more recently performed on TEXTOR [G. Bertschinger et al., 37th EGAS Conference, Dublin, August 3 - 6, 2005] and NSTX in 2004 and 2005.

This paper presents results from the last NSTX run.

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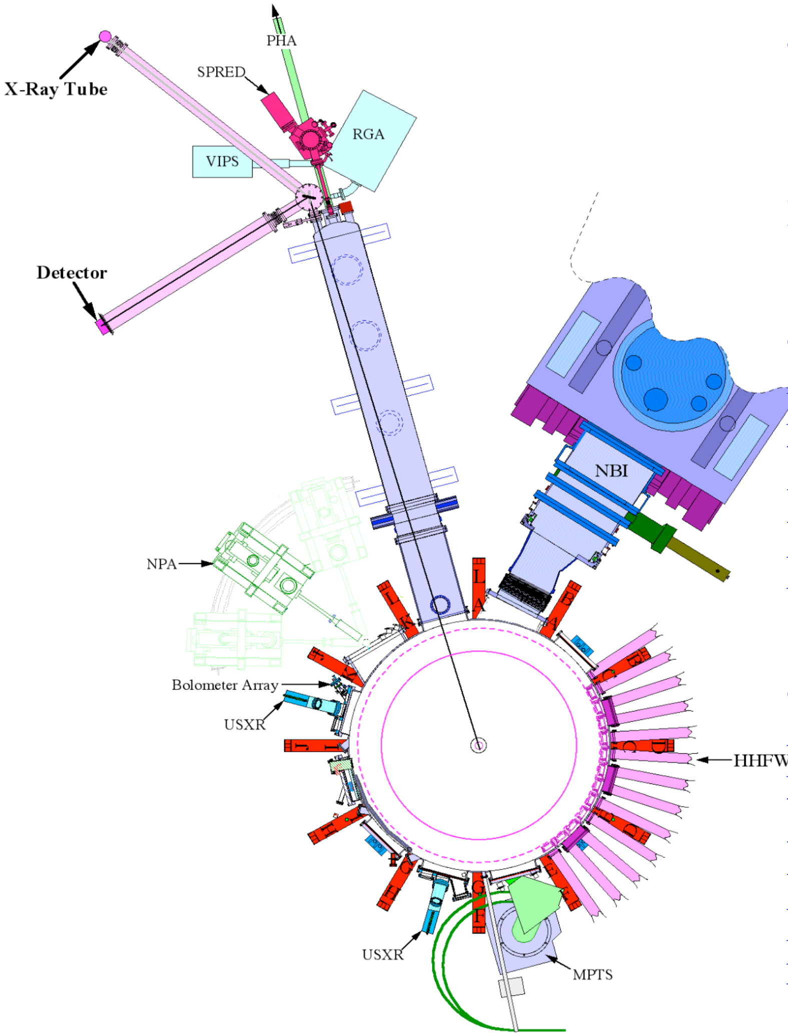
NSTX X-Ray Imaging Crystal Spectrometer

NSTX



•X-ray spectra from multiple sightlines through an 80 cm high cross-section of the plasma are simultaneously recorded on a 10 cm x 30 cm large 2D position-sensitive detector.

•The spatial resolution in the plasma of 2.5 cm perpendicular to the NSTX mid-plane is given by the height of the crystal, its radius of curvature, Bragg angle, and distance of the crystal from the plasma.

•The spectrometer was proposed in 1998 and patented in 2001. Since 2003 the development of the spectrometer is being funded by the US Department of Energy. First experiments were performed on Alcator C-Mod 2003. More recent results were obtained on TEXTOR and NSTX.

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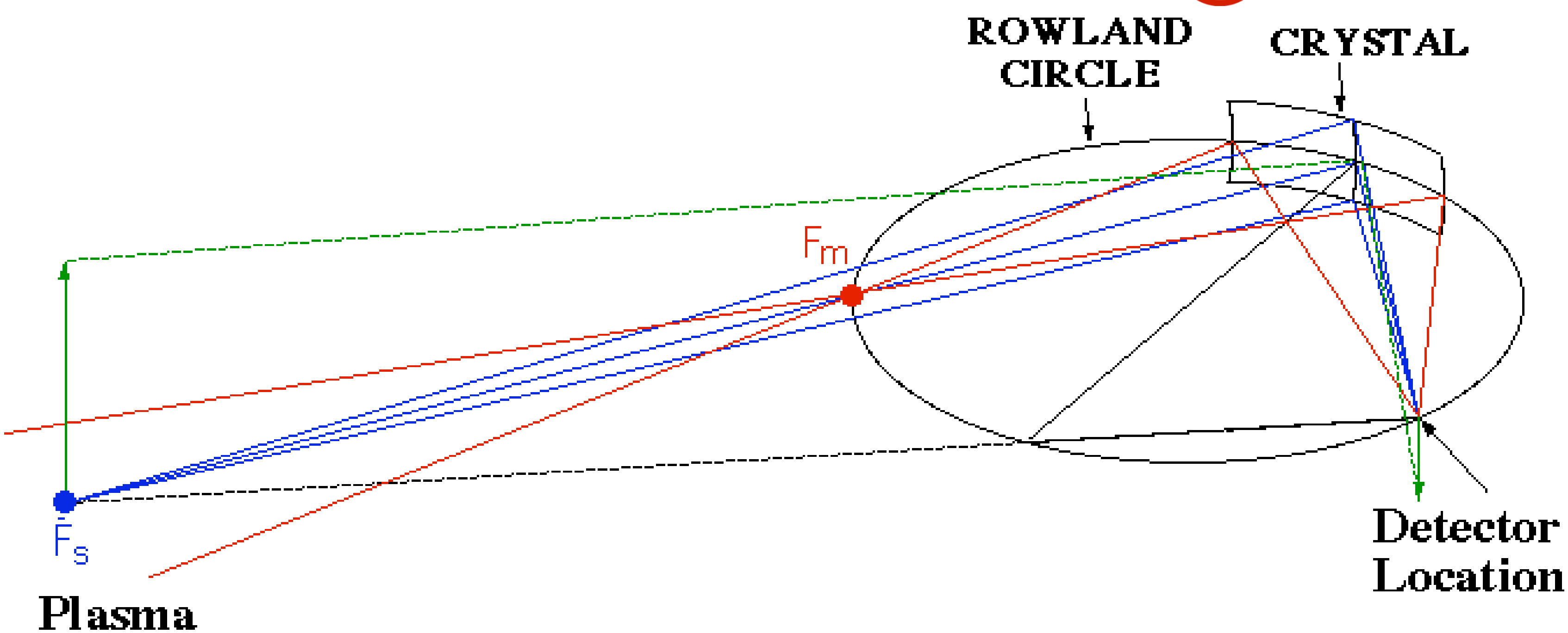
Imaging Properties *(Astigmatism)* of a spherical Crystal



- Due to the astigmatism a point source on the Rowland circle has two images at F_m and F_s, formed by the meridional and sagittal rays.
- For a Bragg angle of 45°, F_s is at infinity, so that - if the rays are reversed - a parallel bundle of X-rays from the plasma is focused to a point on the detector.
- The imaging is rotationally symmetric about the normal of the crystal.

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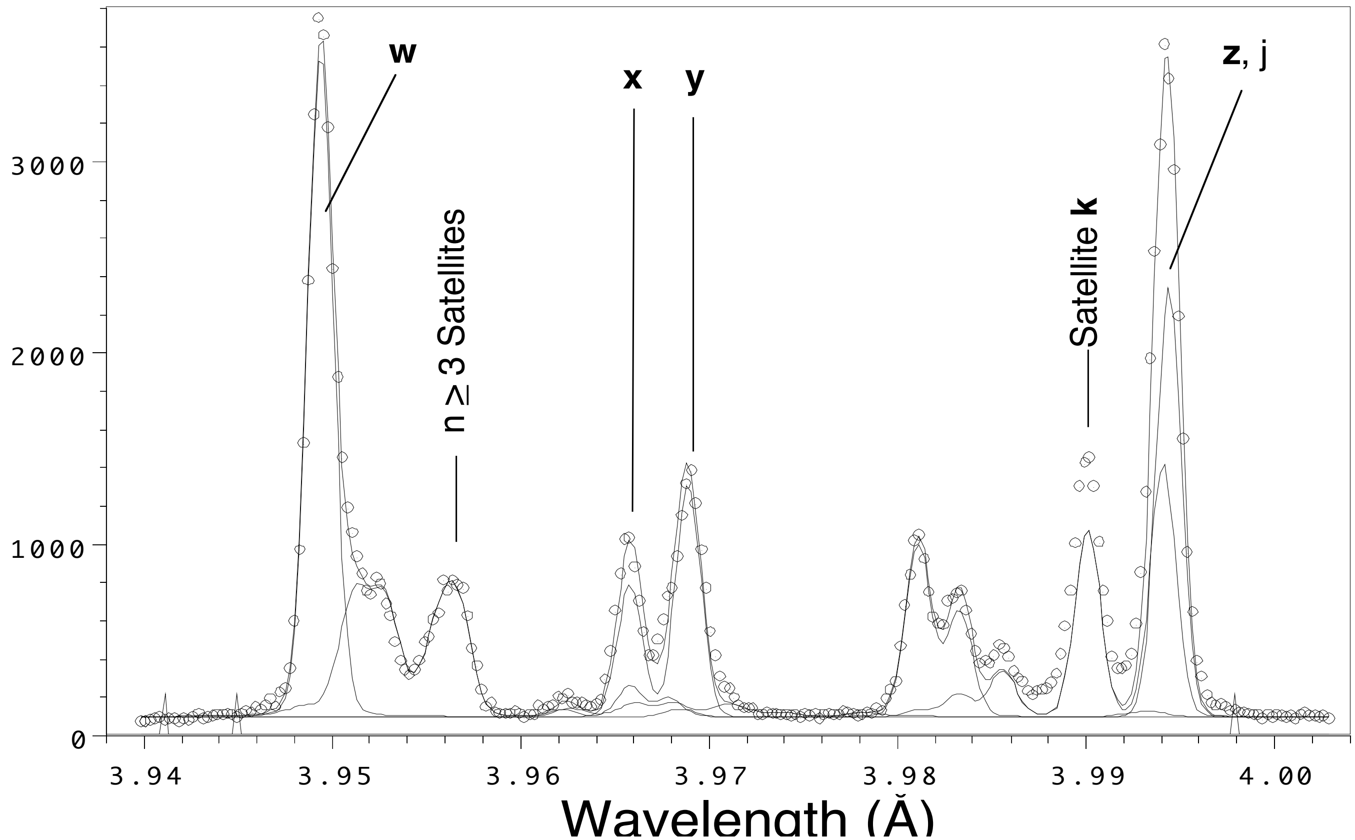
Spectra of ArXVII. T_i & T_e are inferred from theoretical fits to spectra*

NSTX

Te from least squares fit to n ≥ 3 Satellites *(Theory Vainshtein)*

Te = 0.72 keV ; Ti = 0.43 keV



*M. Bitter, M. F. Gu, L. A. Vainshtein, et al., Phys. Rev. Lett. **91**,265001 (2003)

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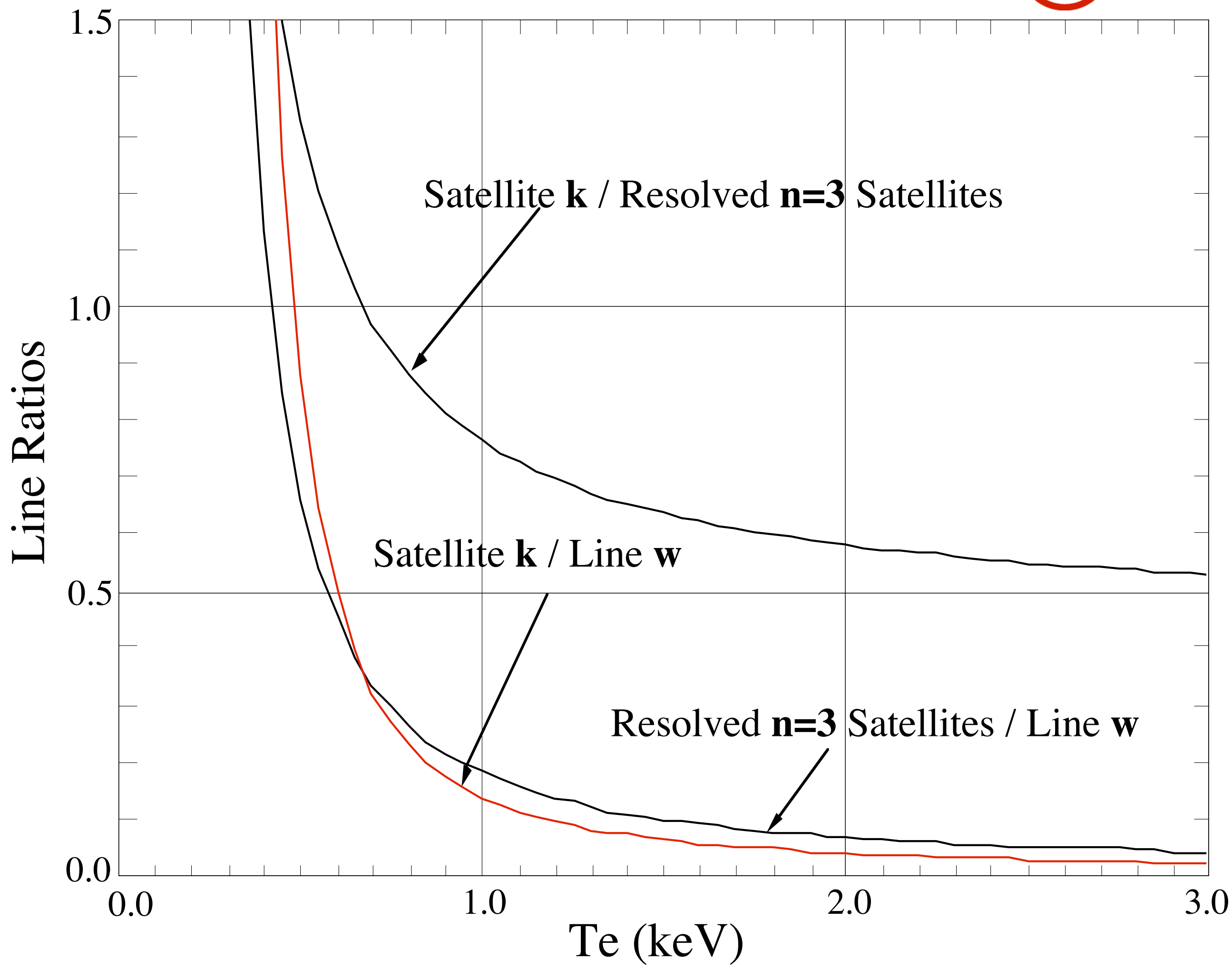
Sensitivity of Line Ratios to Te



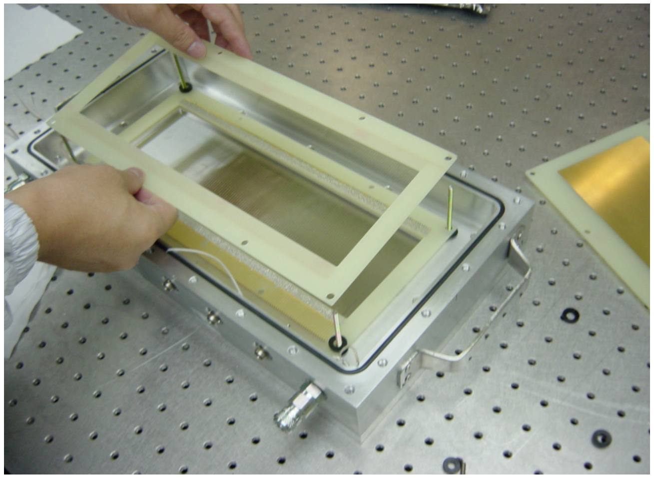
2D position-sensitive Detectors

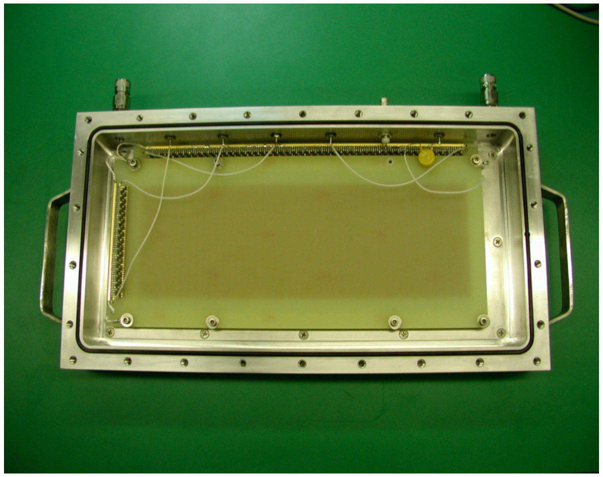
2D position sensitive multi-wire proportional counters (MWPC's) were chosen for the first (proof-of-principle) experiments because

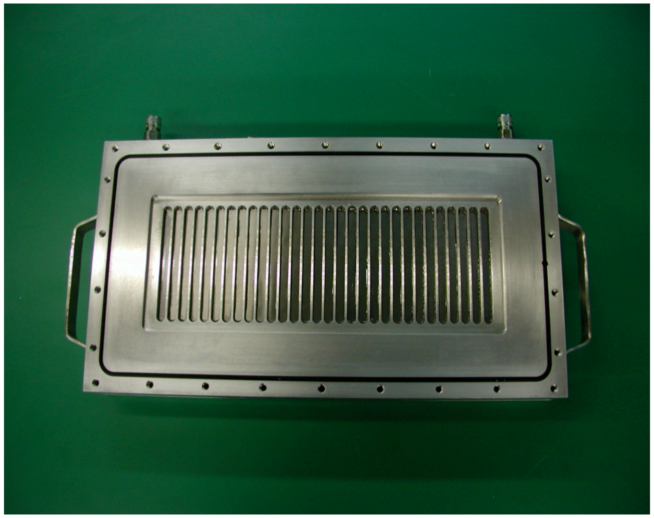
- they can be produced at affordable costs in any size based on proven technologies;
- they have a detection efficiency near 100% for the 3 keV photons from helium-like argon, ArXVII, if krypton is used as detection gas;
- and they have a high signal-to-noise ratio.

However, the count rate of MWPC's is limited to < 400 kHz. The present experiments show that new, high count rate, detectors with a sufficiently large area and sufficient spatial resolution will be needed in the future.

Two-dimensional position-sensitive detector







Sensitive area: 100 mm (X-axis)

300 mm (Y-axis)

Entrance window : 100 µm Be foil

29 supporting ribs : 2 mm wide

5 mm high

Gas mixture : Xenon 78%

C_2H_6 20%

CF_4 2%

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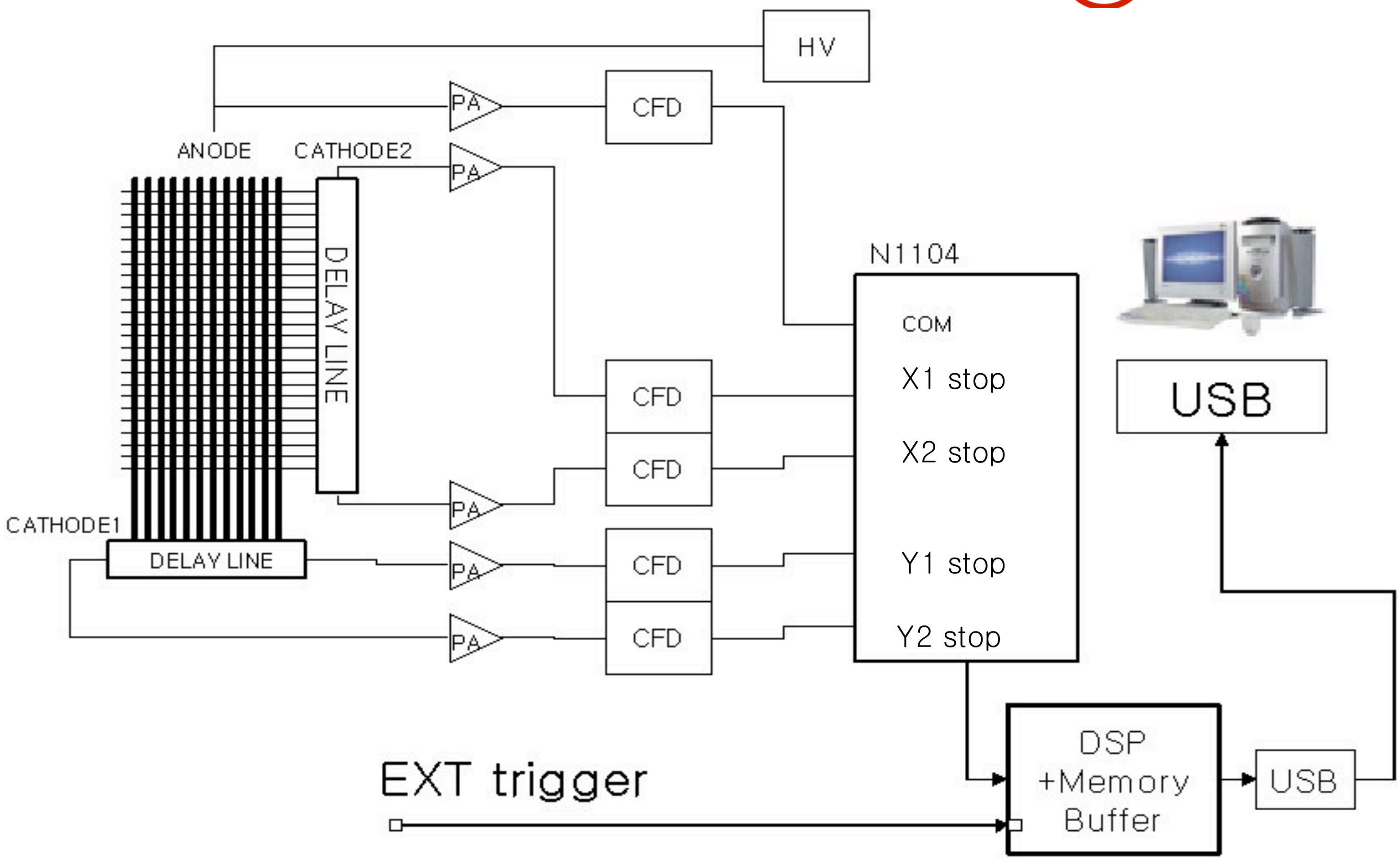
Readout and data-acquisition system for 2D detector



14 bit word for X, Y and Time information for single photon counts

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Throughput of the spectrometer & argon injection

High single-photon count rates of several MHz can be obtained on NSTX with *non-perturbing* argon puffs. Presently, the amount of argon has to be reduced to a minimum to avoid saturation of the detector.

Argon puffs are applied from a 140 cc plenum with a fill pressure of 300 mTorr at 1 to 2 seconds before a discharge for typically 100 ms. Under these conditions, only a small pressure blip to 10(-8) Torr is observed on the fast ion gauge.

The following Figures show the actual photon count rate on the detector, the throughput of processed data, and the corresponding survey spectra of impurity lines from the SPRED spectrometer for varying conditions of the argon injection.

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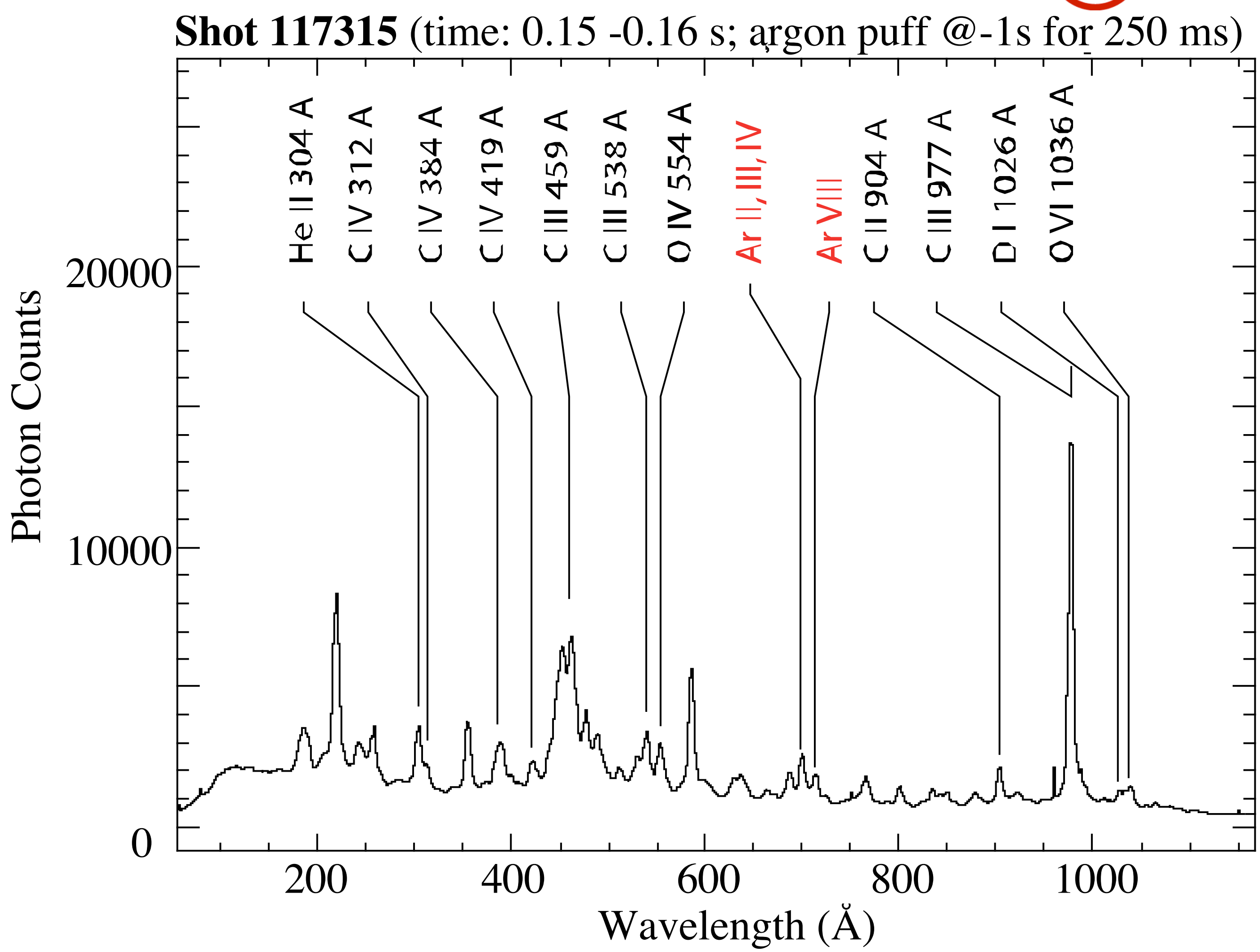
SPRED Survey Spectrum of Impurities from NSTX

NSTX



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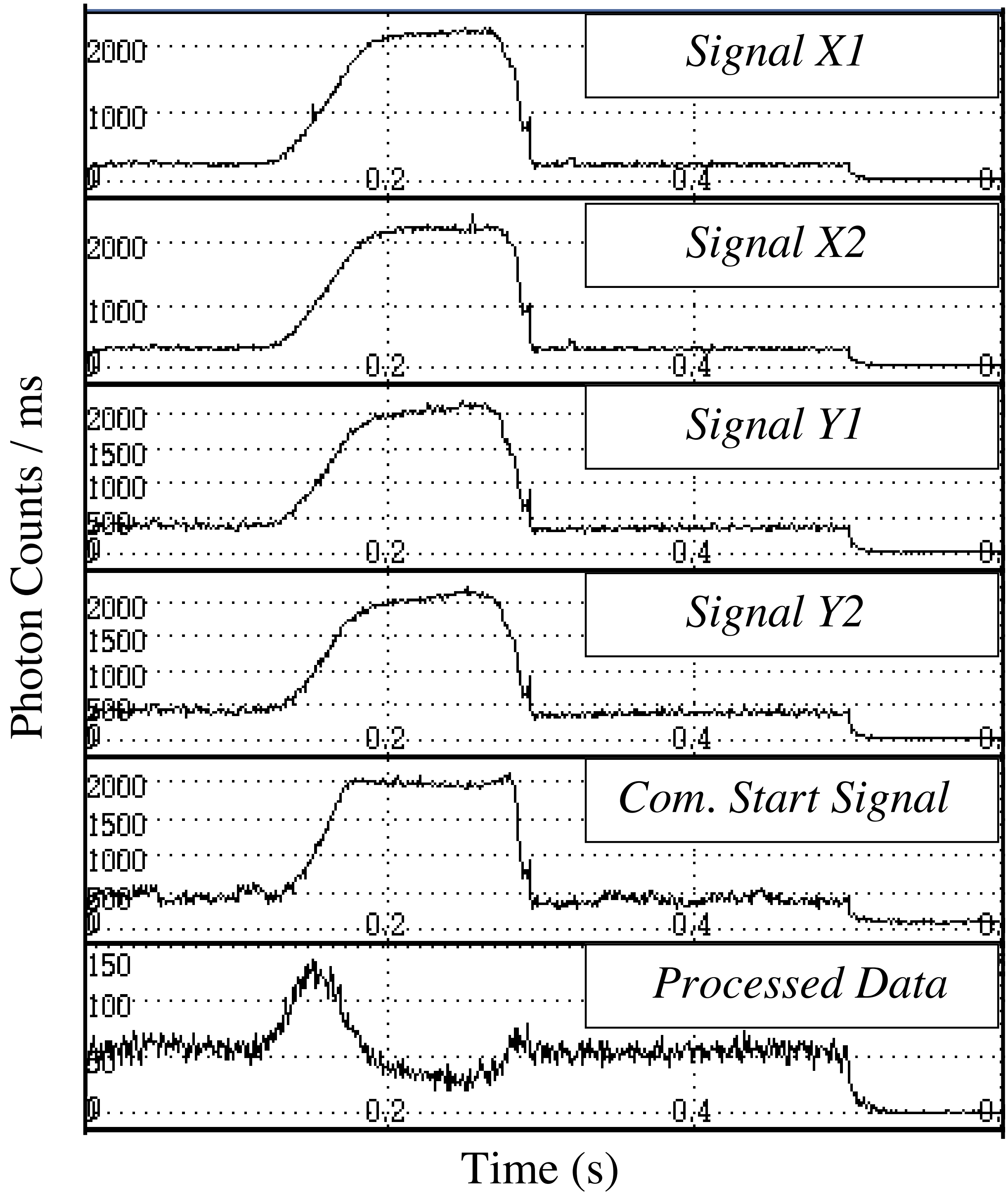
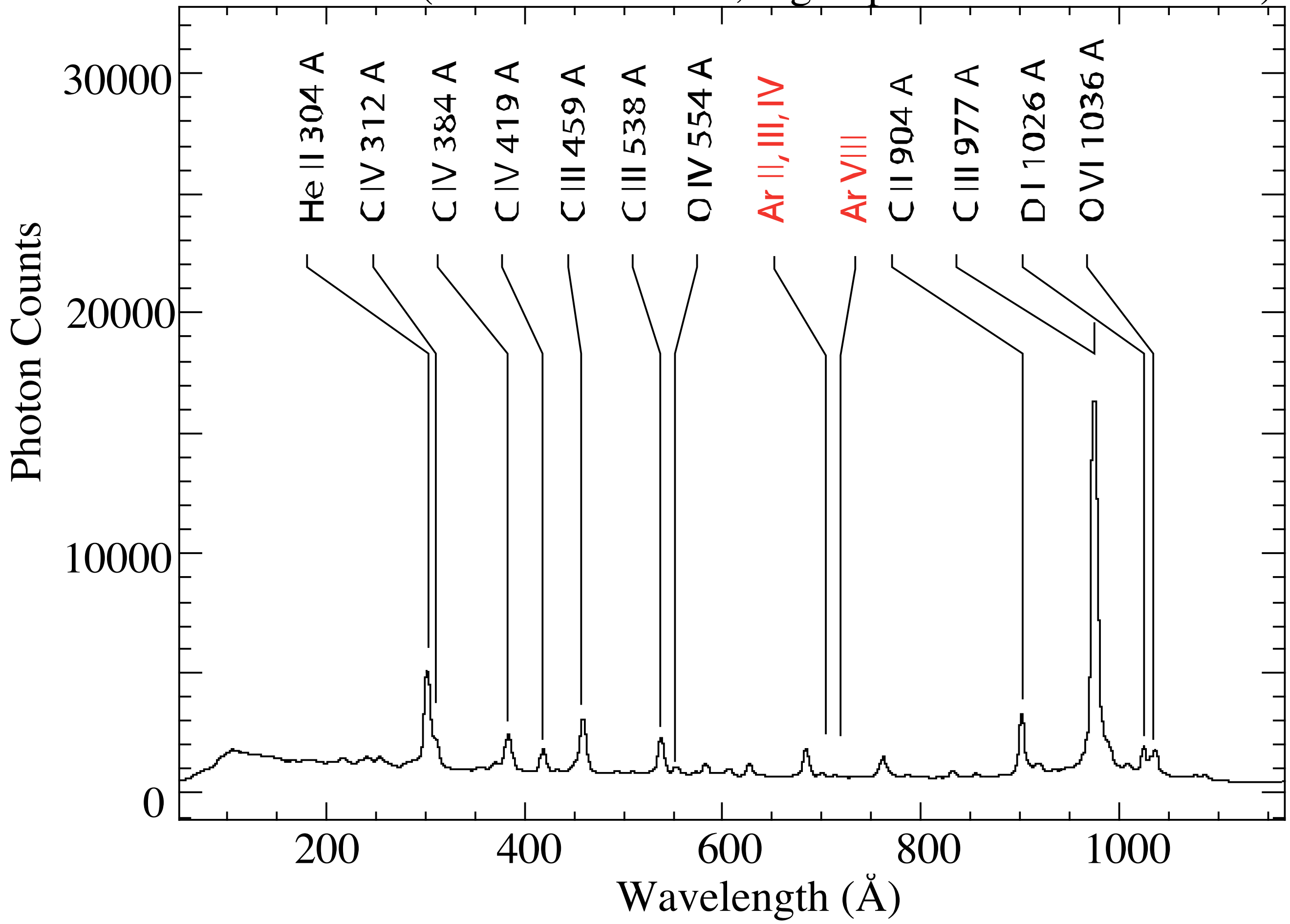
Signal Traces from 2D Detector & Throughput of Processed Data

Shot: 117315; argon puff @-1.0 s for 250 ms



SPRED Survey Spectrum of Impurities from NSTX

Shot 117329 (time: 015 - 016 s; argon puff @-1 s for 100 ms)



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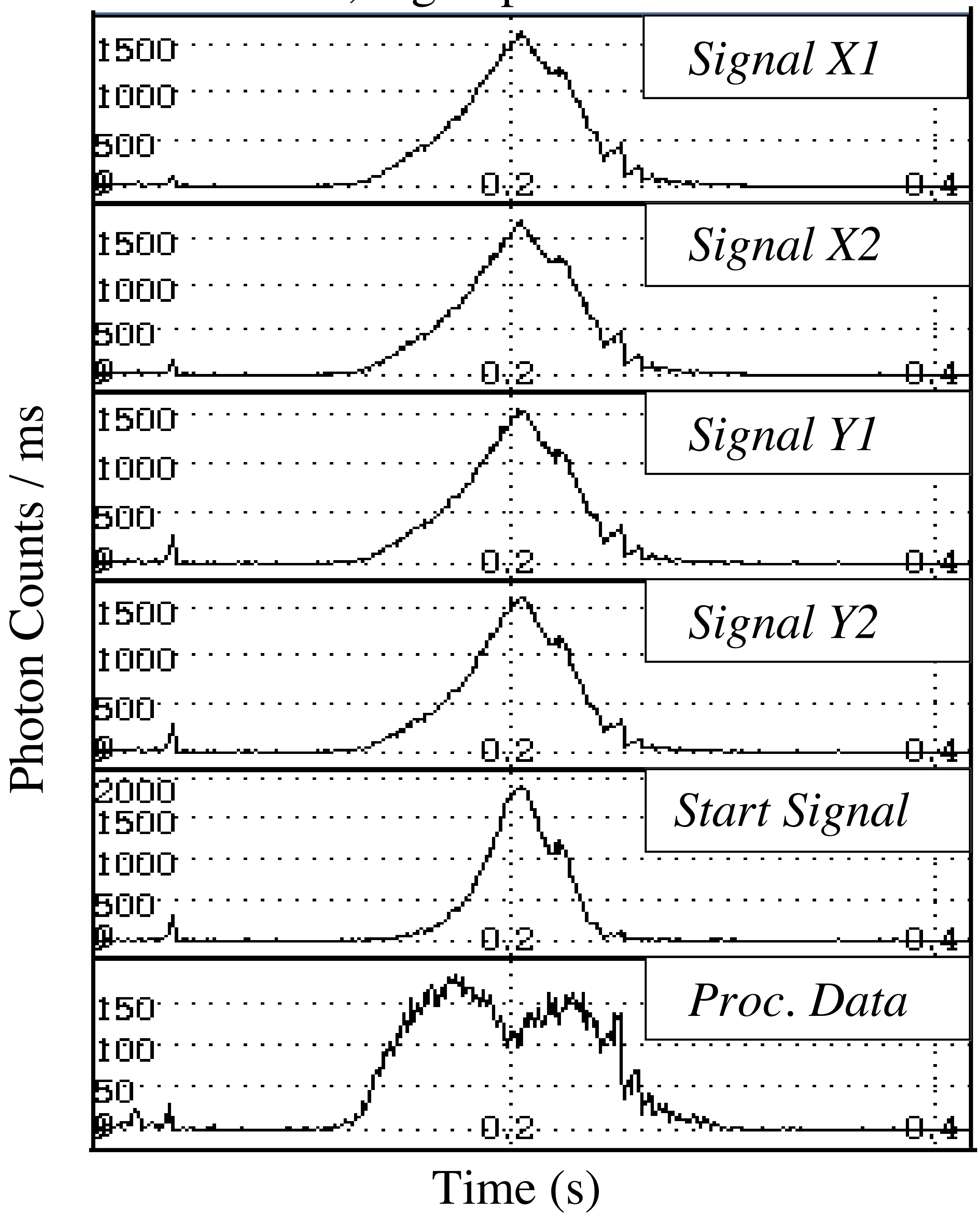
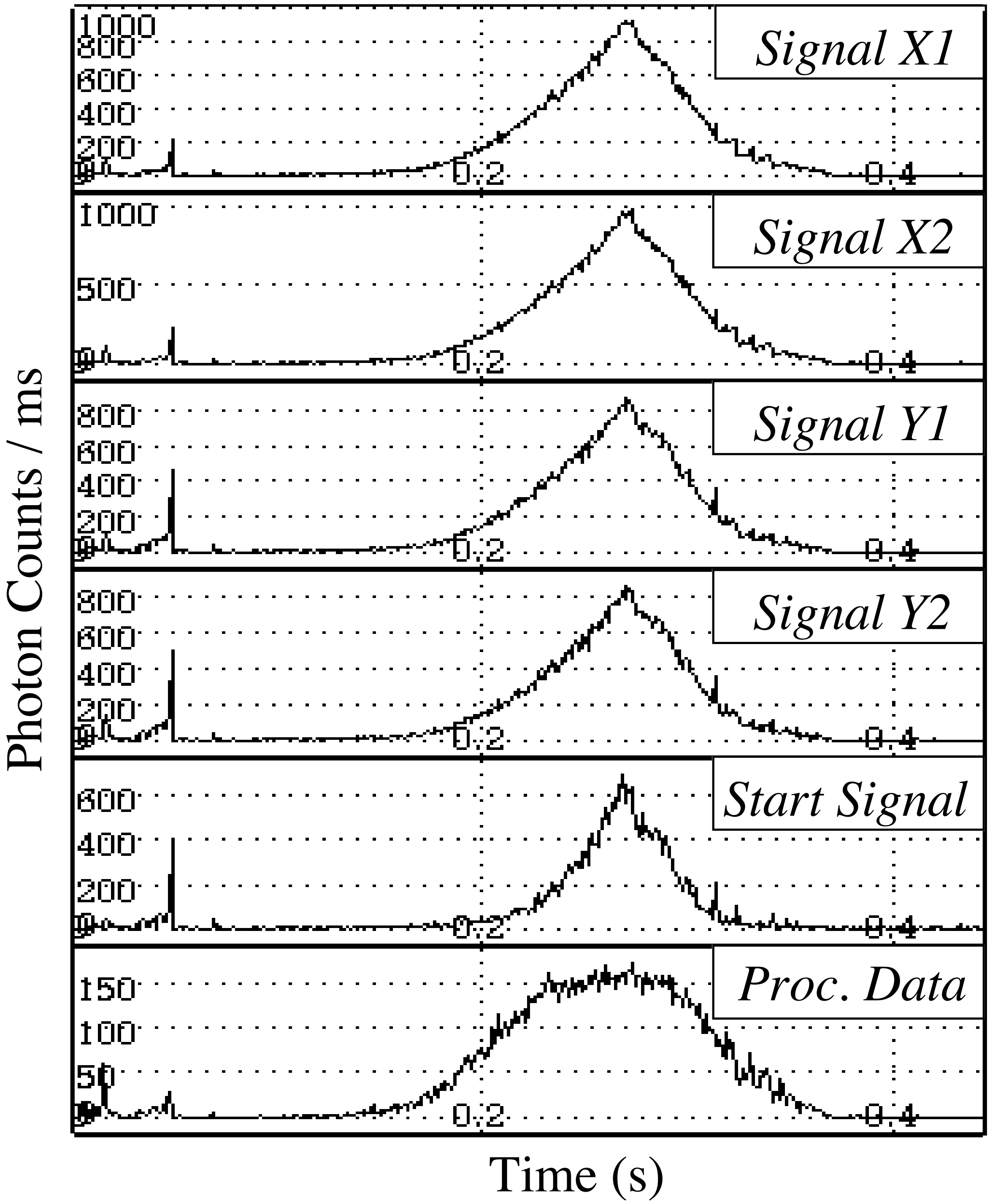
Signal Traces from 2D Detector & Throughput of Processed Data

Shot: 117329; argon puff @-1.0 s for 100 ms

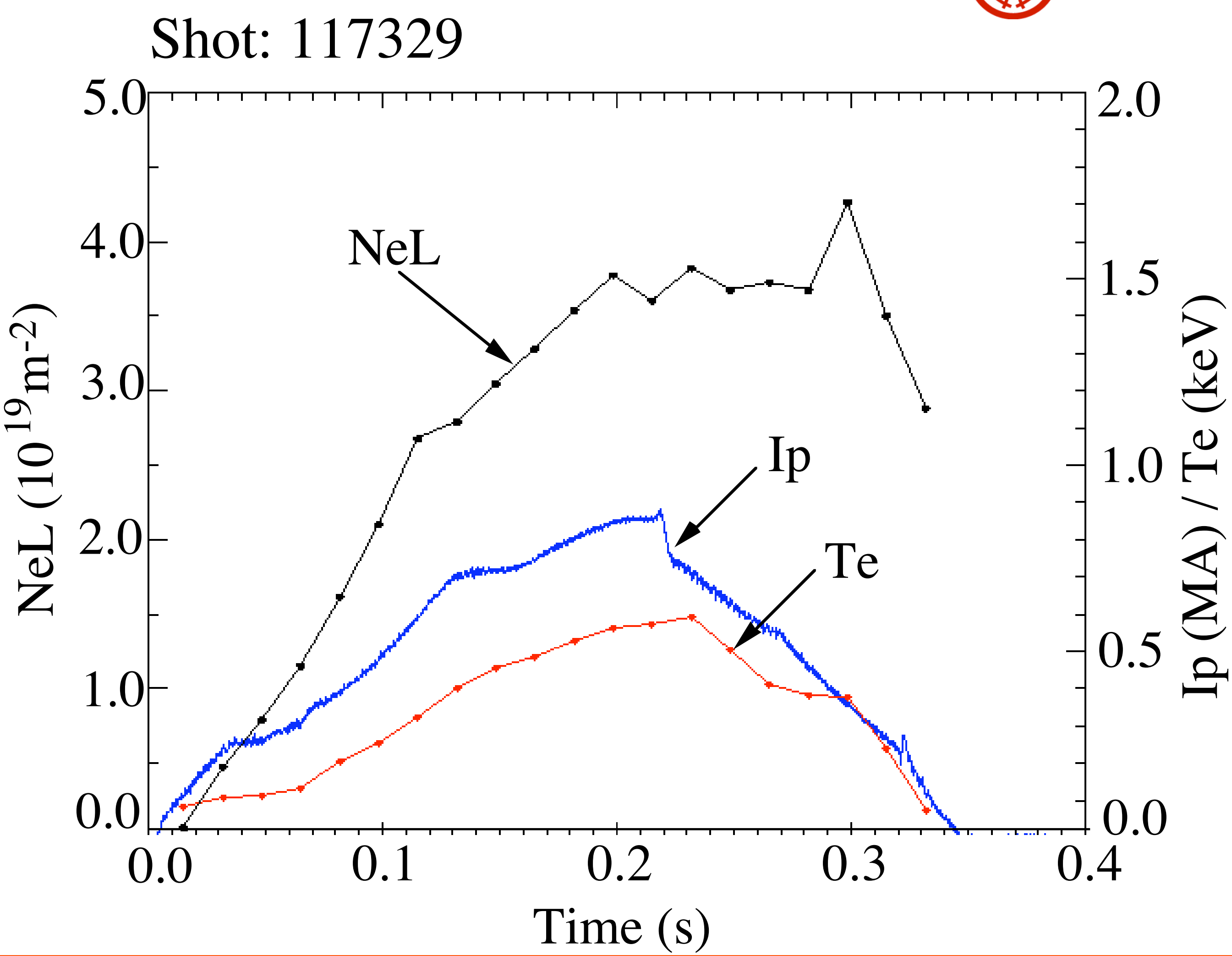


Signal Traces from 2D Detector & Throughput of Processed Data

Shot: 117349; argon puff @-1.5 s for 100 ms



Time history of NSTX plasma parameters



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Spatially resolved spectra of ArXVII from NSTX

The following Figures show spatially resolved spectra of the resonance line of ArXVII and the associated satellites. Unfortunately, only very few NSTX plasmas from the last run period had argon injection, so that it was not possible to test the performance of our spectrometer in a systematic way. Also, the duration of NSTX discharges is typically 300 - 400 ms and by a factor 10 shorter than on other tokamaks, as e. g. on TEXTOR. Since on NSTX it takes about 150 ms to obtain a sufficiently high electron temperature to produce helium-like argon, there remains only a small time interval of 100 ms per NSTX discharge to record ArXVII spectra. It was, therefore, necessary to accumulate data from several shots in order to reduce the statistical error, and since these shots were not identical, we obtained only qualitative information on the profiles of plasma parameters. - New high count rate detectors, which would allow us to obtain spectra with small statistical error from a single NSTX discharge, are therefore an absolute necessity for future experiments.

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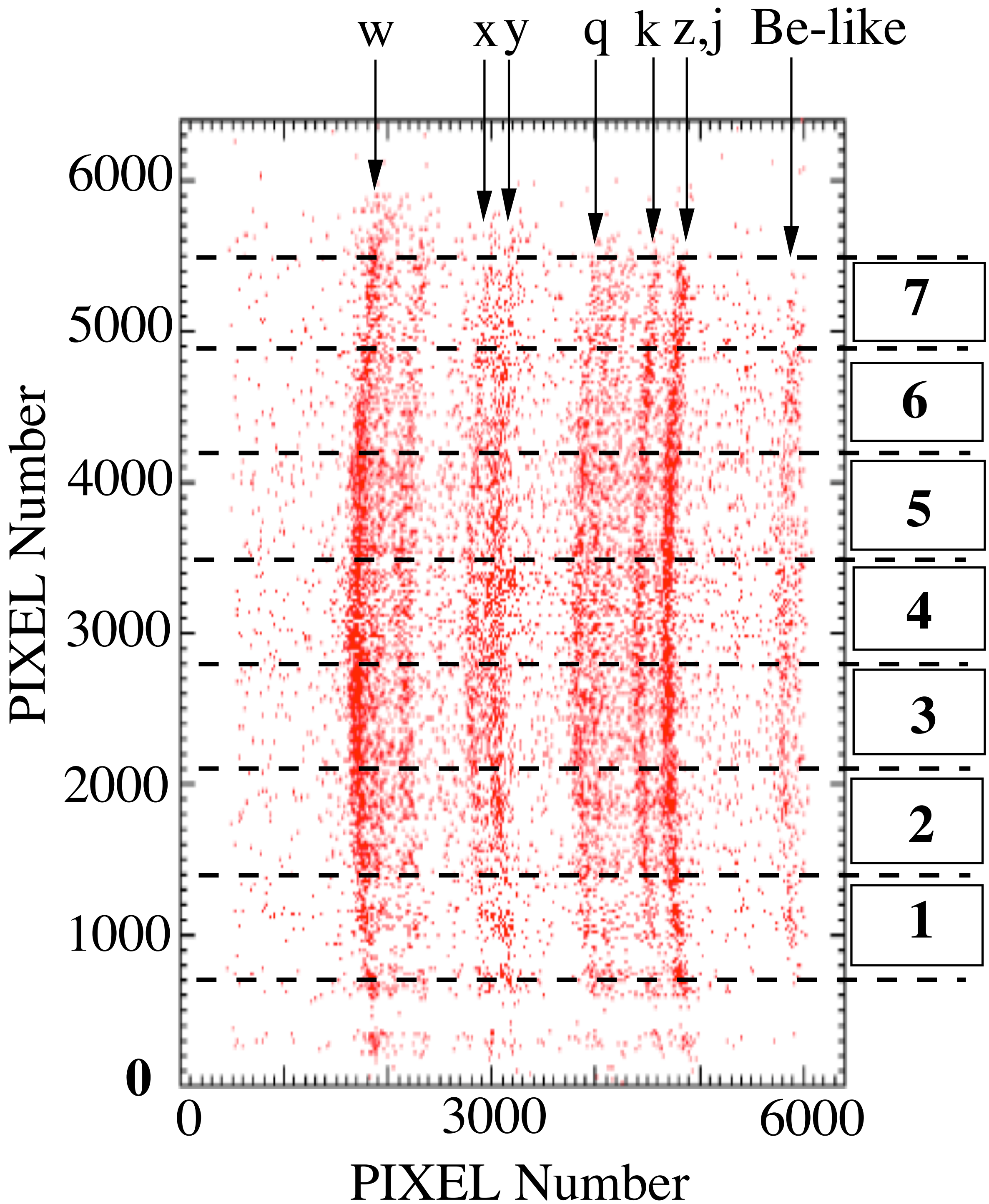
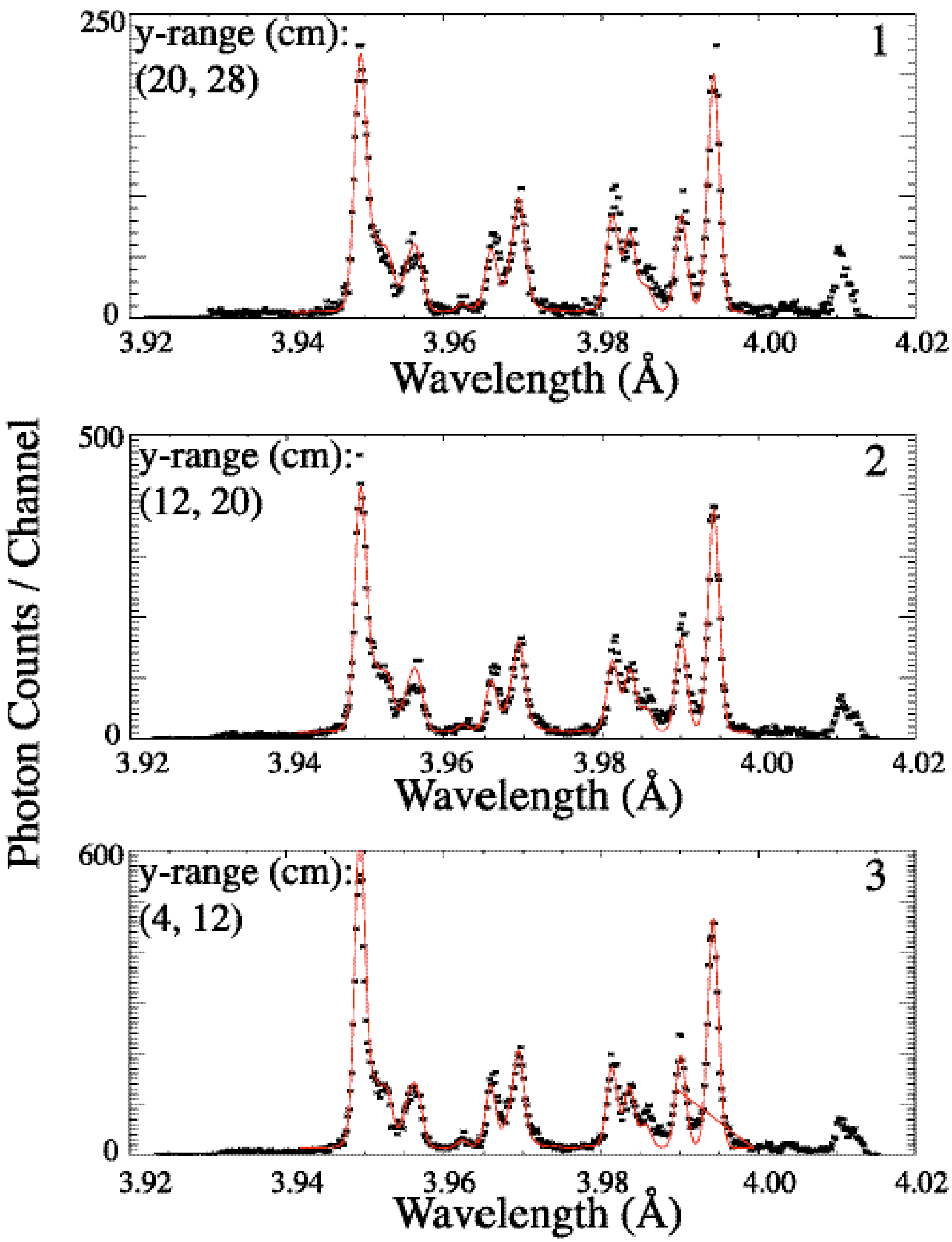
Spatially resolved Argon Spectra from NSTX

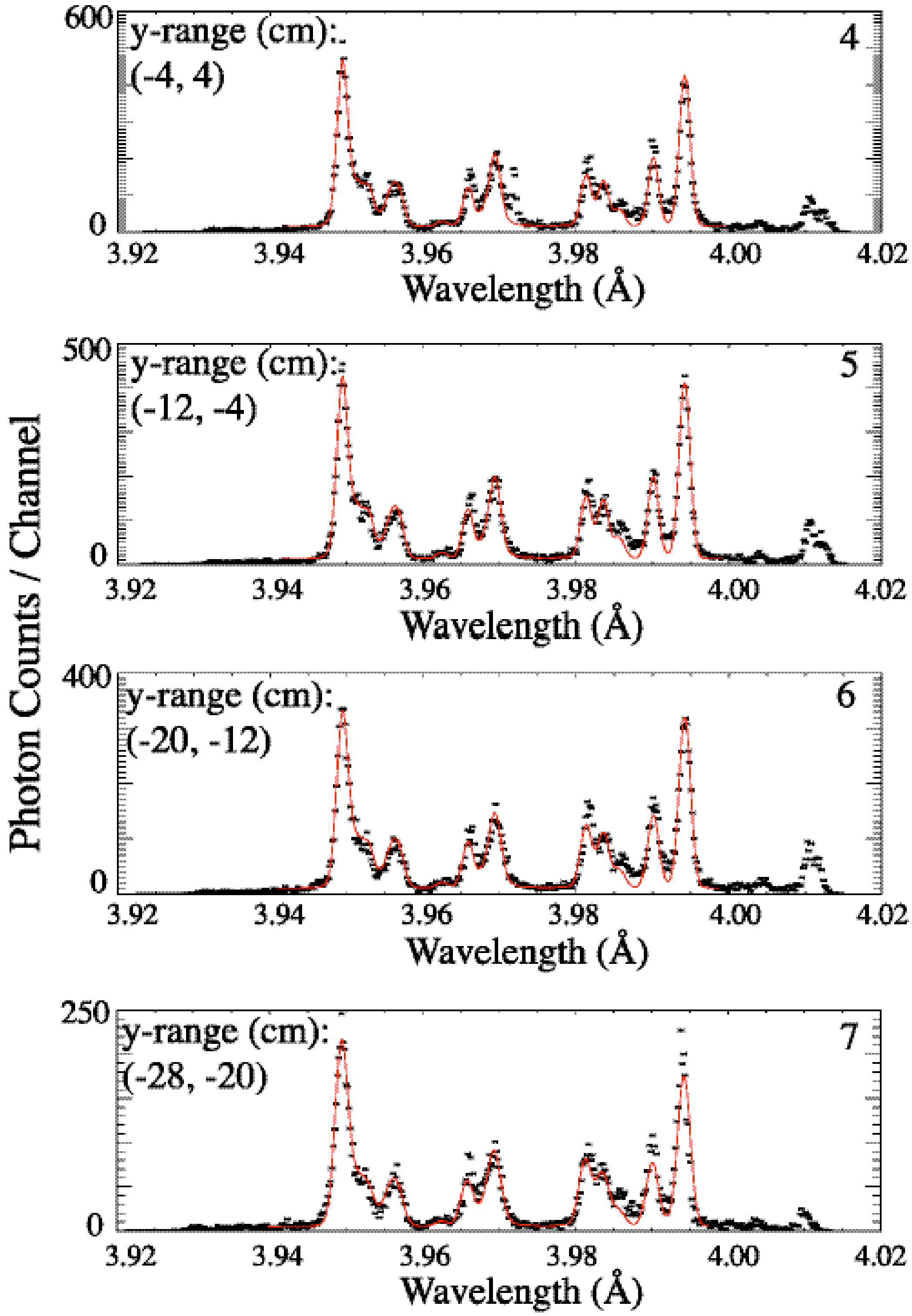
Accumulated data
(shots: 117848, 117849, 117853 - 117857)



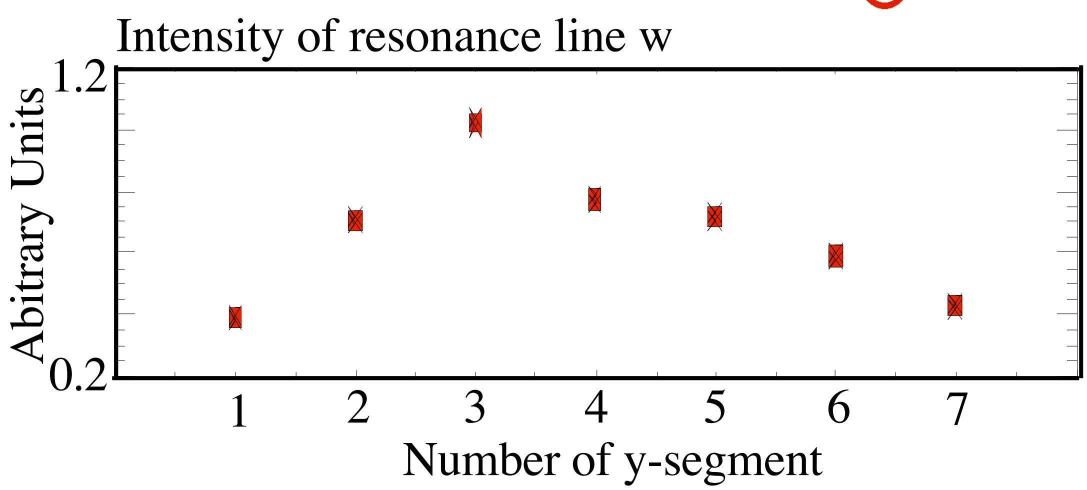
Spatially resolved Argon Spectra from NSTX with least-squares fit from Vainshtein's Theory

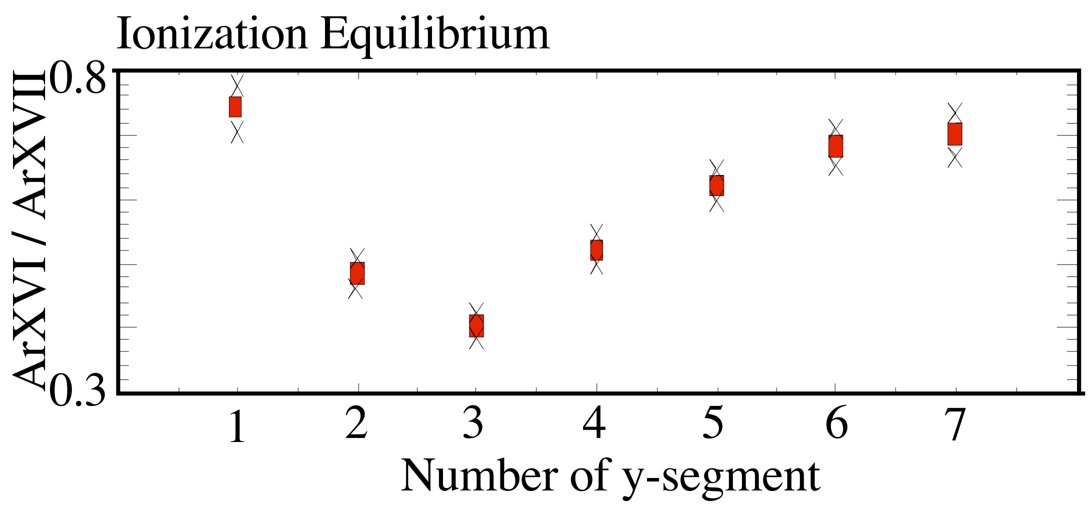


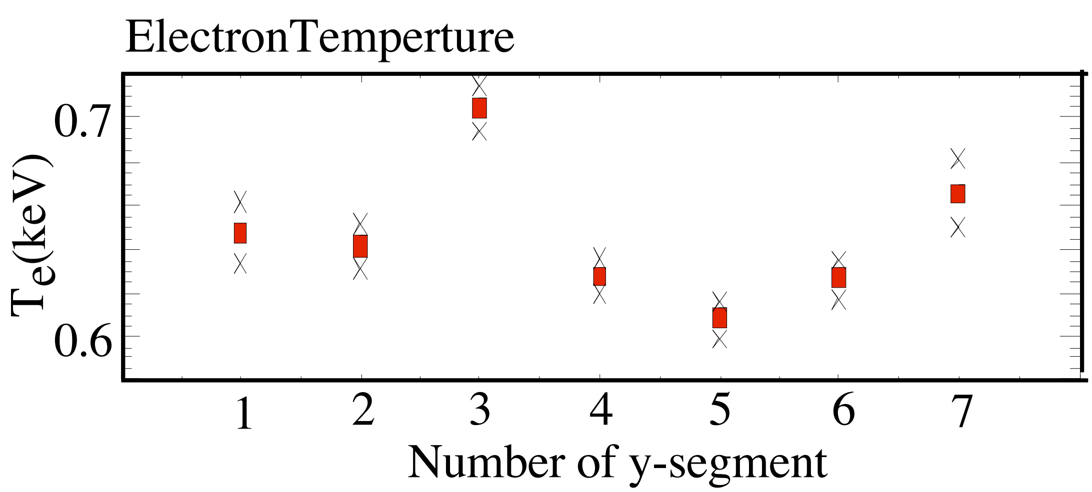
Spatially resolved Argon Spectra from NSTX with least-squares fit from Vainshtein's Theory



Profiles of plasma Parameters from least-squares fit results with Vainshtein's Theory







Development of high count rate detectors

Two detector concepts are presently being considered:

(1) Segmented 2D multi-wire proportional counters, with count rates of about 400 kHz per segment, are being developed by the Korea Basic Institute in collaboration with PPPL.

(2) A very promising new solid state detector, the so-called 'Pilatus' detector, which consists of 30 mm x 80 mm large silicon diode array with a pixel size of 0.172 mm x 0.172 mm, is being developed by the Paul Scherrer Institute in Switzerland. Since each pixel has its own amplifier and readout electronics, it is possible to do single-photon counting. Several 35 mm x 80 mm 'Pilatus' elements can be combined to form a large area detector. The count rate per pixel is about 1 MHz. We would like to test this new detector on our spectrometer in a collaboration with the Paul Sherrer Institute.

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Development of high count rate detectors (Pilatus II)

NSTX

The Pilatus II chip was designed in 2004 at the PSI and is fabricated in the UMC 0.25 radiation hard design.

Each chip contains an array of 60 x 97 pixels with a pixel size of 0.172 x 0.172 mm^2. The active area spans 10 x 17 mm^2. Each pixel contains a charge-sensitive preamplifier and shaper, a single-level comparator with a 6-bit individual threshold adjustment, a 20-bit counter with a count rate of 1 MHz per pixel.

The Pilatus II module consists of a Hamamatsu sensor bump-bonded to an array of 8 x 2 chips using indium balls. The 16 chips of a module are read out in parallel within a read-out time of 2 ms.

http://pilatus.web.psi.ch/pilatus.htm

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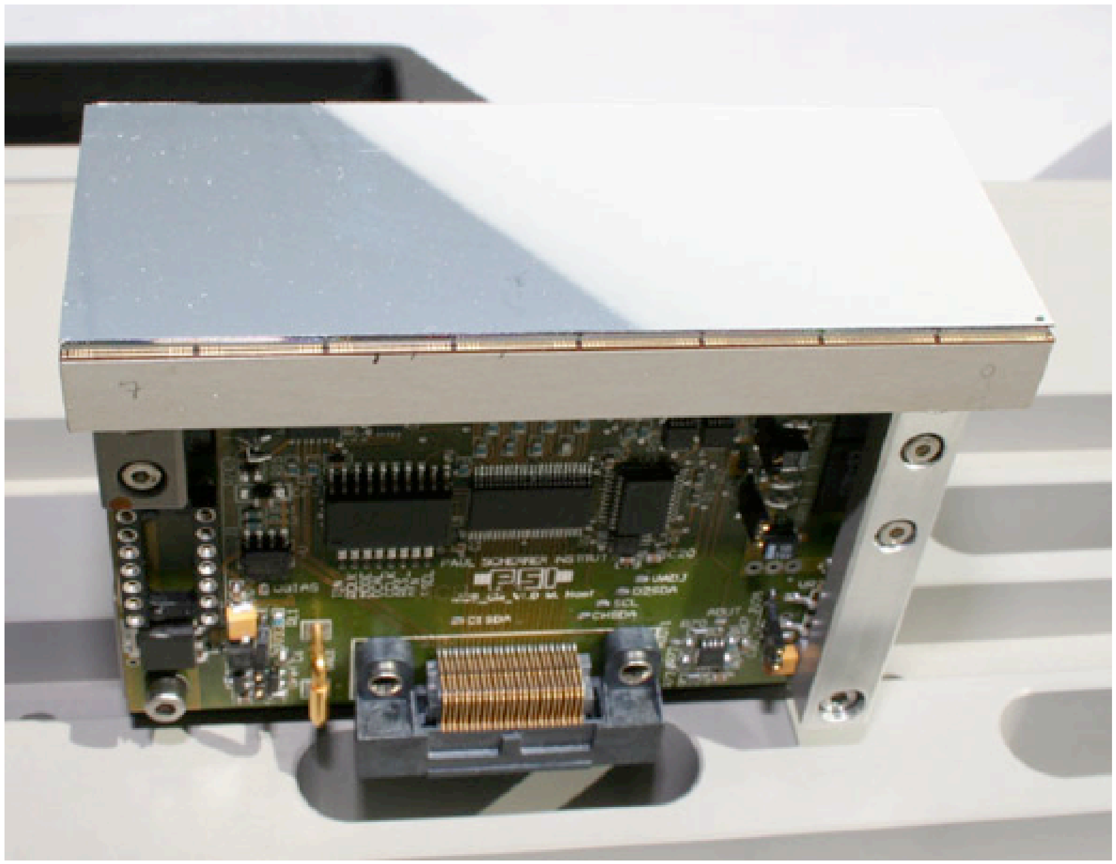
Development of high count rate detectors (Pilatus II)

NSTX

Pilatus II Module



http://pilatus.web.psi.ch/pilatus.htm

Conclusion

The new X-ray imaging crystal spectrometer has sufficient throughput for time-resolved measurements. In fact, photon fluxes of several MHz can easily be obtained with small argon puffs which do not perturb the plasma. However, the throughput is limited by the count rate of < 400 kHz of the presently used multi-wire proportional counters.

Two new detector concepts:

(1) segmented multi-wire proportional counters, and
(2) new silicon diode arrays, the so-called ‘Pilatus’detector,

are presently being considered to increase the throughput of the spectrometer.

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