Measurements with the KSTAR Beam Emission Spectroscopy diagnostic system

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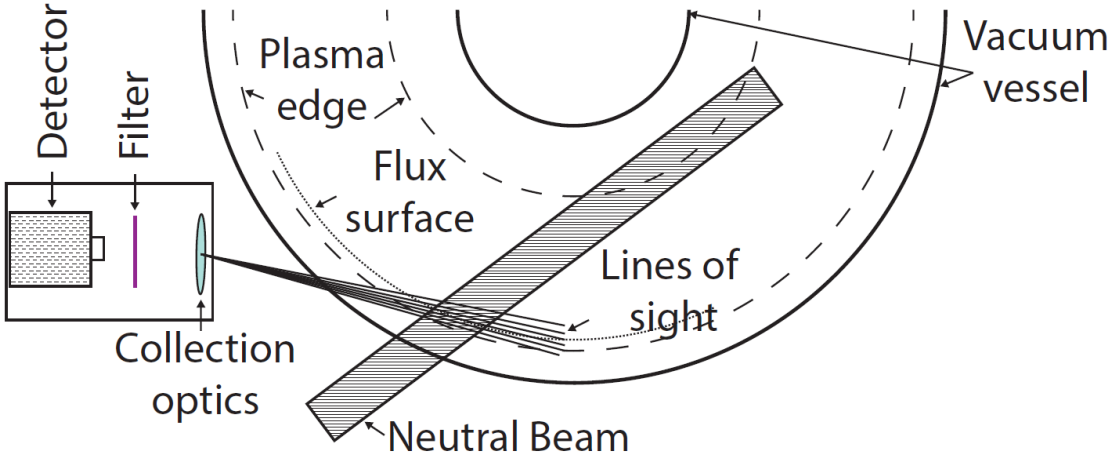
Plasma transport is dominated by turbulence causing fluctuations in plasma parameters

- Beam Emission Spectroscopy (BES) is a suitable method for measuring fluctuations:
  - The plasma is being heated by the Neutral Beam Injection (NBI)
  - The particles of the beam are excited and emit light
  - The intensity of the light is roughly proportional to the plasma density
  - By measuring the light intensity, one can get information about turbulence
  - From the movement of turbulence eddies, flow velocity can be determined



Schematic view of a BES system

Two important design constraints:

- Sufficient Doppler-shift (separation from edge D_α)
- View along field lines (spatial resolution)

BES diagnostic setup

Design aspects:

- Direct imaging from plasma to multi-channel detector
- Combined system for HBES and LiBES measurements
- Wavelength: H: ~662nm (Doppler shifted H_α), Li:~670nm

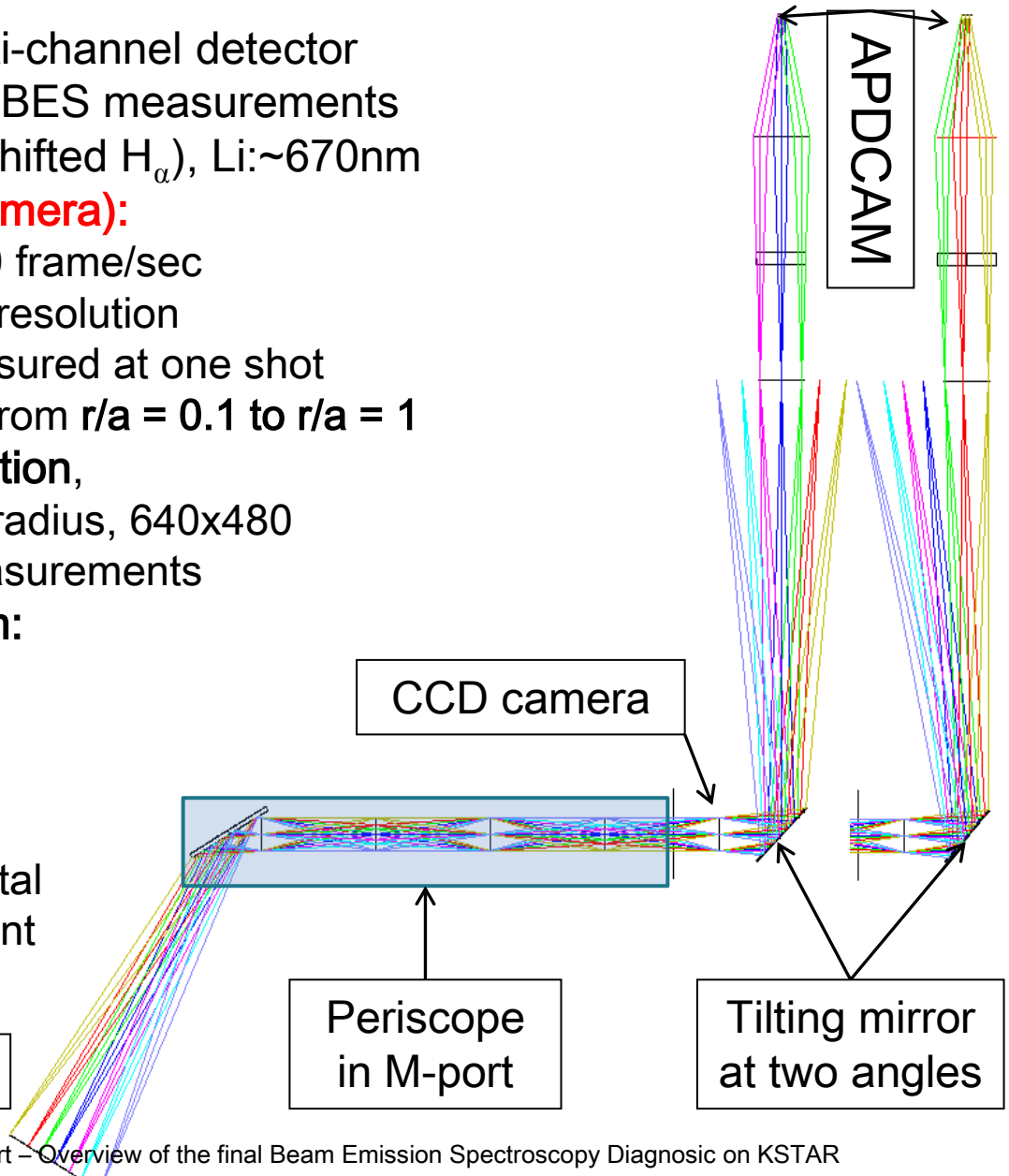
APDCAM (Avalanche Photo Diode Camera):

- 4 x 8 channel array @ 2.000.000 frame/sec
- 1cm by 1cm per channel spatial resolution
- 4cm x 8cm of the plasma is measured at one shot
  - Continuously adjustable from **r/a = 0.1 to r/a = 1**

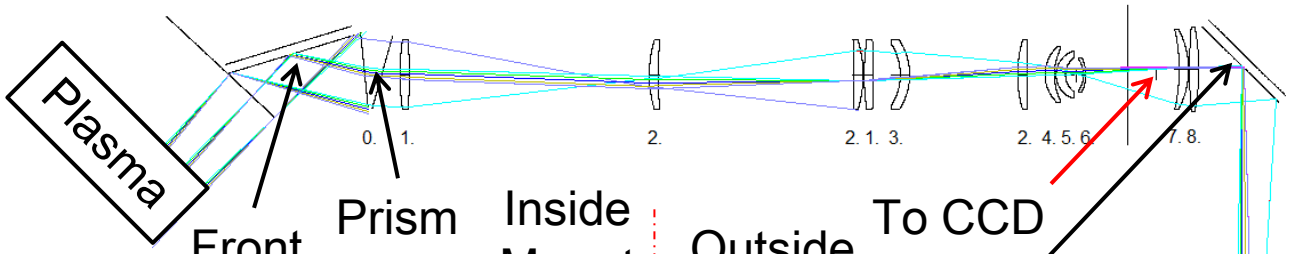
CCD camera: **inter-shot spatial calibration**,

- 100Hz beam imaging, full minor radius, 640x480
- Lithium beam density profile measurements

- **Novel design features of the system:**
  - Heatable and rotateable filter for Wavelength tuning
  - Filter changer for Lithium and Deuterium beam measurements
  - Rotateable APDCAM for horizontal (4x8) and vertical (8x4) measurement



The BES system



Front mirror

Prism

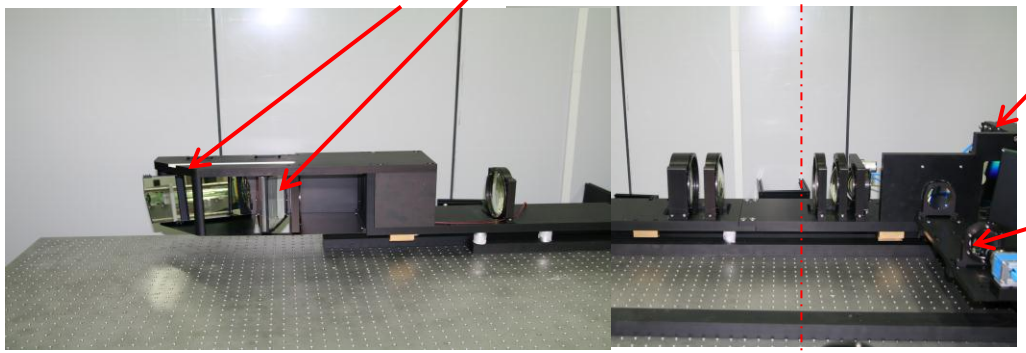
Inside M port

Outside

To CCD

APDCAM

Rotatable mirror



CCD arm

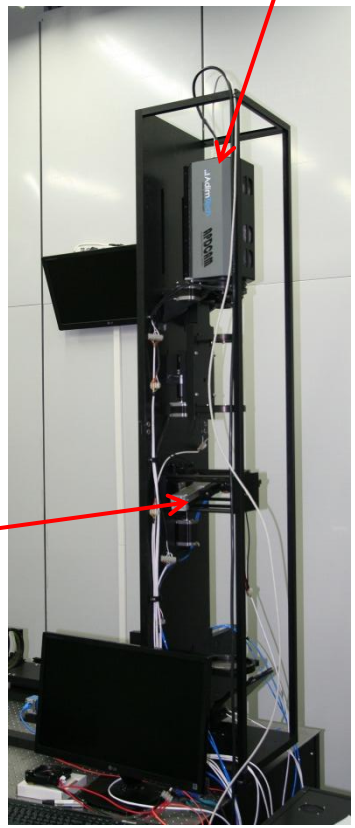
Filter

9.

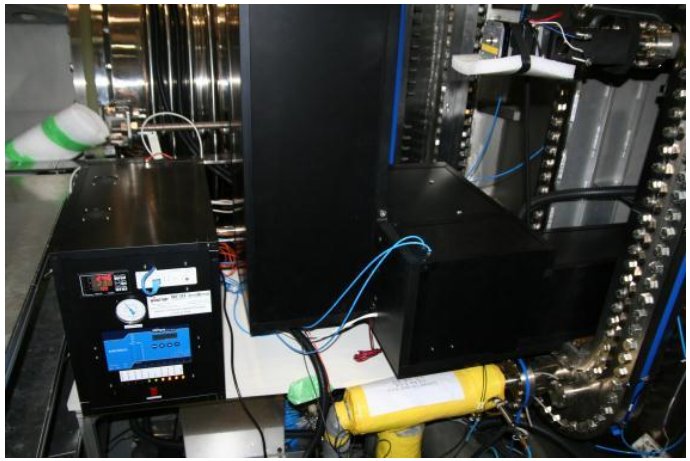
10.

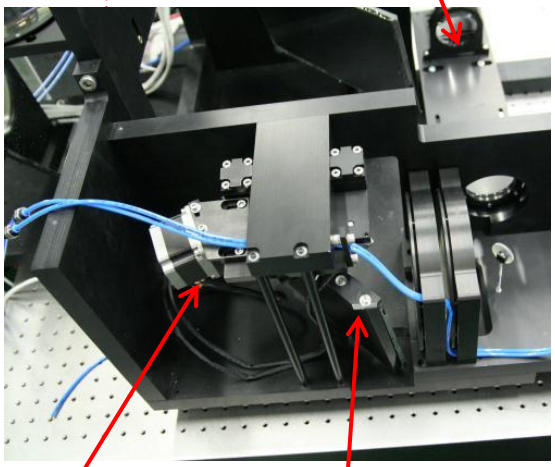
11.

12.



BES tower





BES installed in M port

Stepmotor for mirror rotation

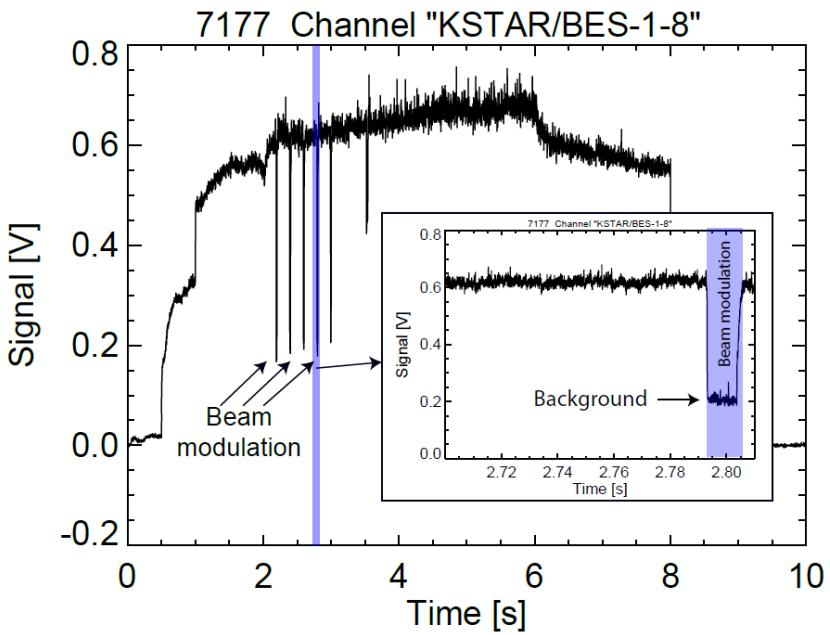
APDCAM

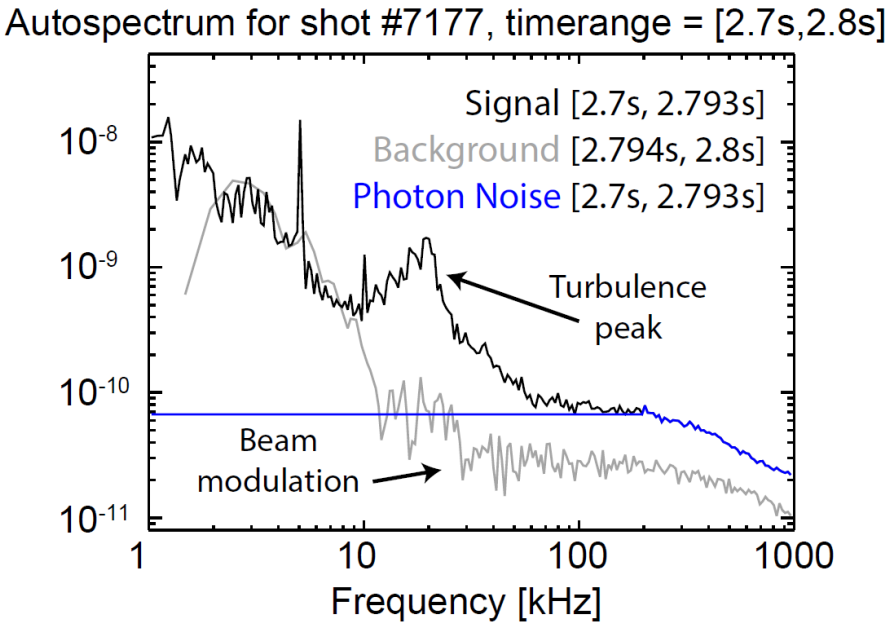
Measurement possibilities

The BES system was operated by me during the 1000 shots of the 2012 campaign

The system is capable of measuring:

- Turbulence
  - Amplitude, wavelength
  - Poloidal velocity
  - 3D fluctuation together with Electron Cyclotron Emission imaging
  - Signals are analyzed through Fourier / correlation methods
- During steady state plasma
  - Radial density profile measurement (when NBI is modulated)





• Measured signal for shot 7177

Turbulence detection

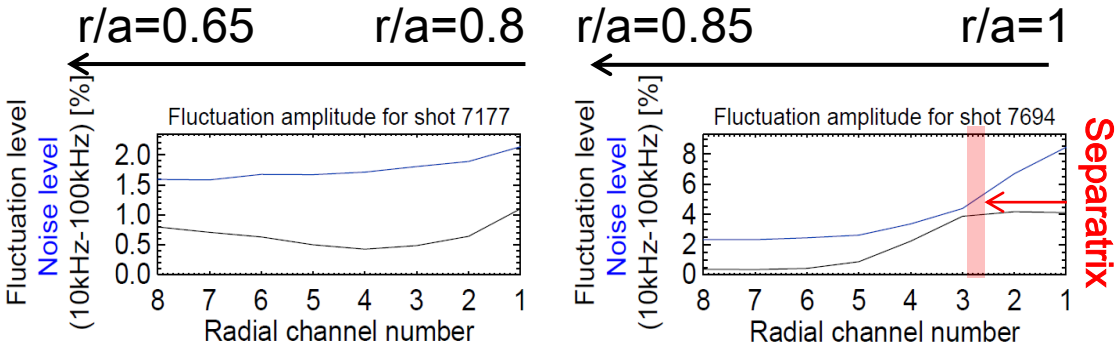
Core measurement: (r/a~0.7-0.8)

- SNR ≈ 60
- Fluctuation amplitude is low
  - **Around 1 - 1.5%**
- Noise level is 1.5 times higher then fluctuation
- **Turbulence is hard to detect**

Edge measurement: (r/a ~ 0.9-1)

- SNR ≈ 45
- Fluctuation amplitude is higher
  - **Around 3 - 4%**
- Noise level is around the fluctuation level at channel 3
- **Turbulence can be detected**

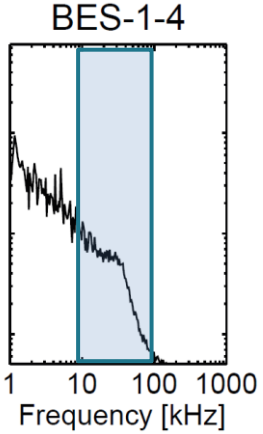
- Background fluctuation (<10kHz) is high compared to fluctuation at [10kHz, 100kHz]



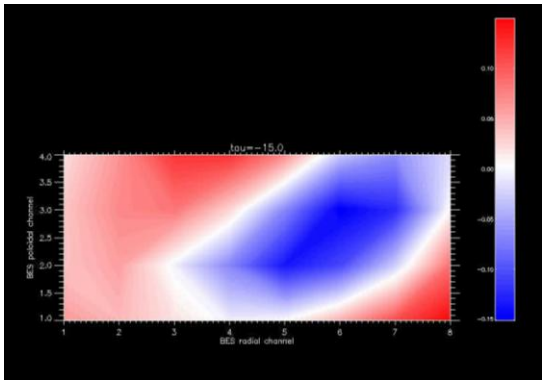
Fluctuation level and noise level

Flow analysis with cross-correlation

- Cross correlation was calculated between a reference channel and all 32 BES channel between 10kHz and 100kHz
- Each time slice was plotted as a pixel on a contour plot: movie shows flow direction, correlation length



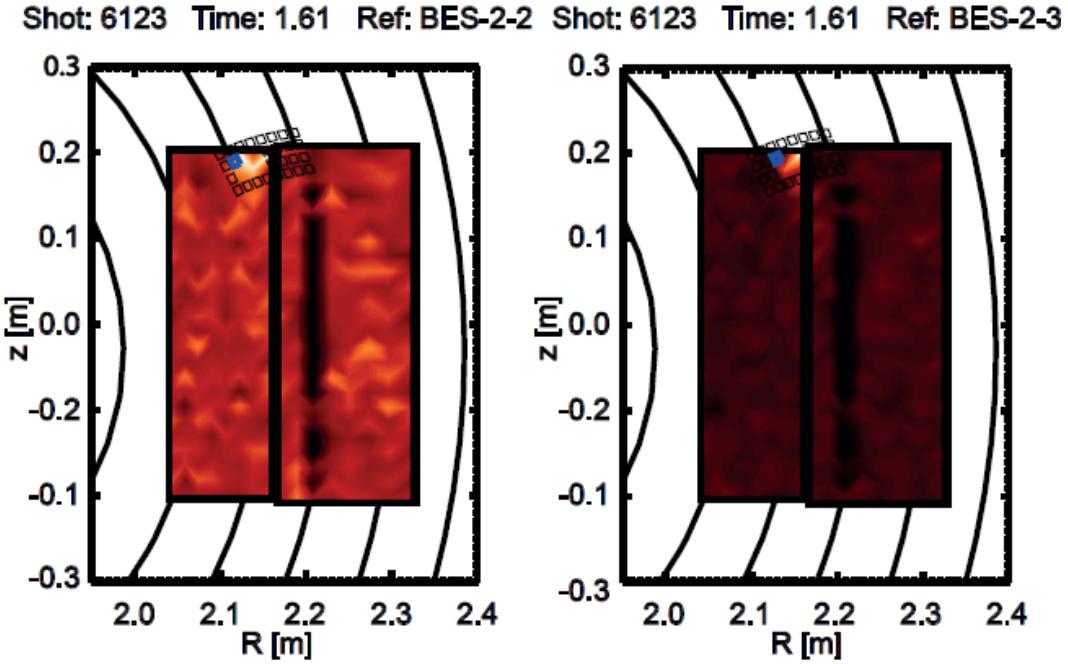
Reference spectrum



Cross-correlation movie

Long range correlation along flux tube

- ECEi: Electron Cyclotron Emission imaging
  - 2 x 192 channels; 2cm spatial, 2μs temporal resolution
  - Measures 2D distribution of temperature and fluctuations
  - 90° toroidaly away from BES (2m spatially)
- Traces of turbulence were found in ECEi spectra
- The cross-correlation was calculated between:
  - 1 reference BES channel – all 384 ECEi channels
  - The maximum values of all cross-correlation functions were plotted on a map
- The BES channels plotted on the map are projected along the field lines onto the ECEi plane
- **The correlation maximum moves with the reference channel**
  - **The result is a sign of a correlation along magnetic flux tube**
- Measurement possibility: B parallel correlation length, q profile



*Cross-correlation map, **blue** is the reference BES channel*

Summary

Beam Emission Spectroscopy diagnostic was designed, built and installed on KSTAR in 2012

- The system successfully measured density fluctuations during the campaign
- The first goal of data analysis was to determine the main system parameters
- **Results:**
  - Turbulence detection is possible at the edge of the plasma
  - Core turbulence measurement is marginal
  - Long range turbulence analysis is possible with ECEi
- **Future plans**
  - CMOS camera installation (CCD suffered neutron damage)
  - Measurement position adjust in the vertical direction
  - Lithium Beam measurements in 2013 August
  - Microlens array installation on APD detector for better statistics

Thank you for your attention!