MAST Beam Emission Spectroscopy System

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Abstract

A Beam Emission Spectroscopy diagnostic (BES) system optimized for density turbulence measurements has recently been installed at the MAST tokamak on a Deuterium heating beam. The MAST BES observation system resolution is optimized for mid-radius, where the radial spatial resolution is ~2cm. The diagnostics will be able to measure in the r/a=0-1.1 range but the spatial resolution is poorer towards the edges. The beam is directly imaged to a a 4*8 pixel Avalanche Photodiode (APD) array, which has a near ideal signal to noise ratio at the predicted photon-flux level of few times 10^{11} photons/sec. The measurement frequency bandwidth is 1 MHz while sampling is done at 2 MHz. The resulting 125-330 signal to noise ratio is predicted to be sufficient to detect fluctuatios in the D_α beam emission intensity at the few times 0.1% level. The 2D detector arrangement allows us to measure poloidal flows and radial propagation of turbulent sturctutres.

BES on heating beam

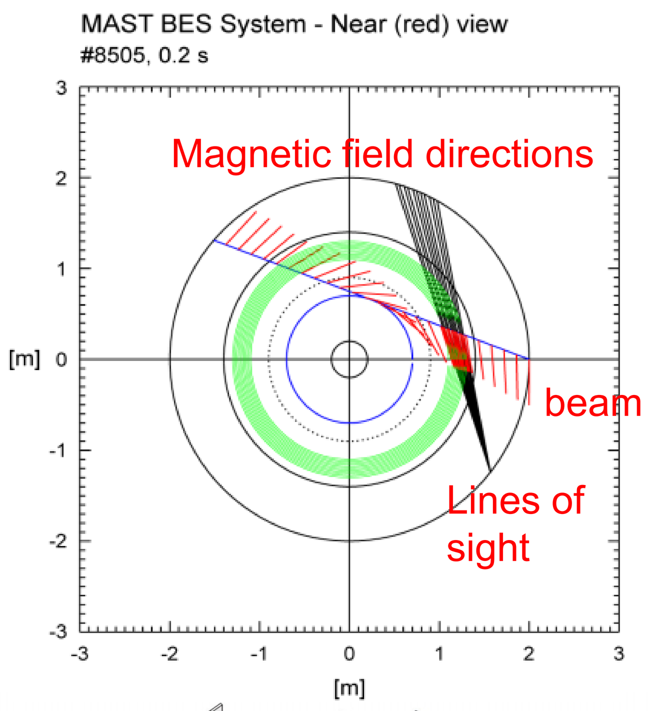
BES with heating beams can provide core measurements with 2D resolution:

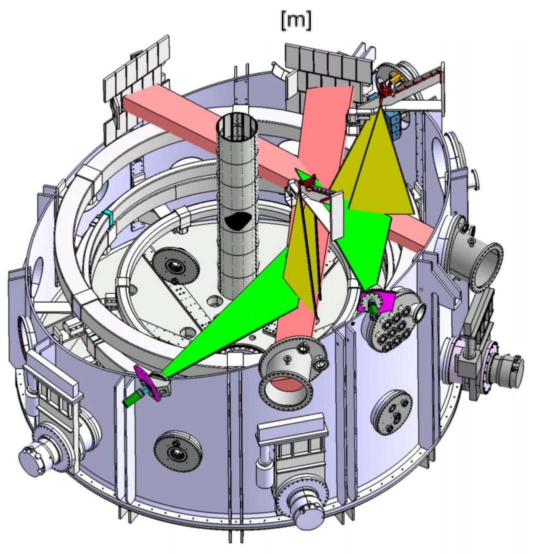
- Technique developed in the US turbulence task force in the 1990's
- Demonstrated on several devices including TFTR
- Since then measurements on DIII-D, Alcator, …
- $\tilde{n}_e$ and v_p (from movement of structures)

Key elements :

- Need observation at an angle to avoid edge H-alpha
- Light intensity is limiting: High efficiency optics and detection are needed
- Spatial resolution is better than beam width by looking along field lines
- Can have full 2D poloidal-radial resolution
- Optimal view can not be fulfilled at all radii, especially in a spherical tokamak → Edge region can be better resolved by Lithium BES.

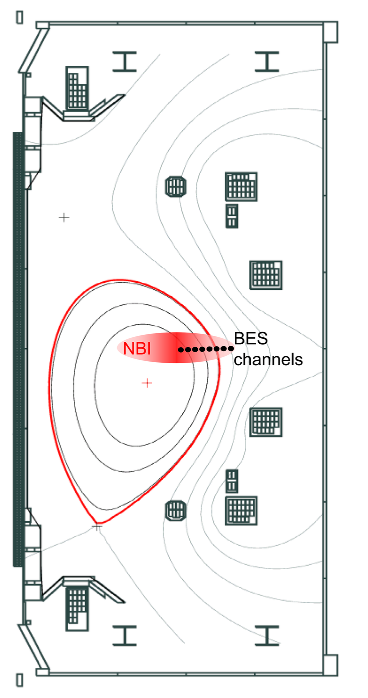
  (see S. Zoletnik poster on GAM measurements on TEXTOR Li BES)





Trial BES on MAST

- 8 channel APD detector array, low noise amplifiers
- 4 cm channel separation
- Beam light is spectrally close to C II lines → some background (10% in L-mode)
- SNR=5-10 @ 1 MHz bandwidth
- It fulfilled the original aim:
  - benchmarked the simulation codes
  - APD detector test, proof of principle measurements
- Operation since November 2006

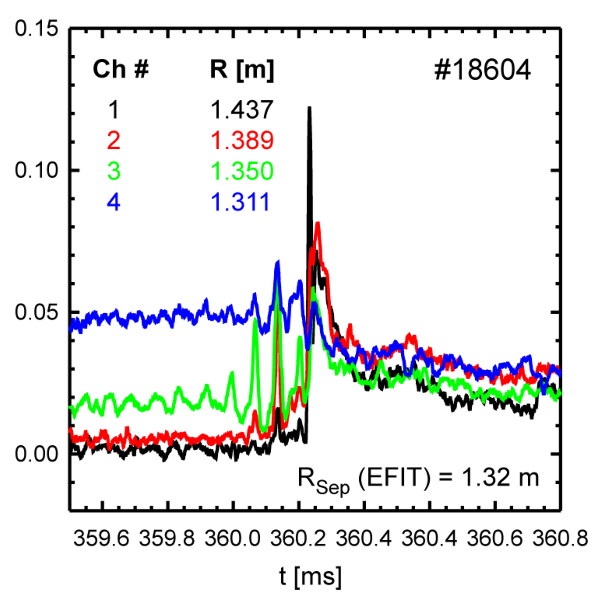


Measurement results

- Edge turbulence detected
- Fast particle modes radially localized
- BES ELM measurements in extreme SND configuration.

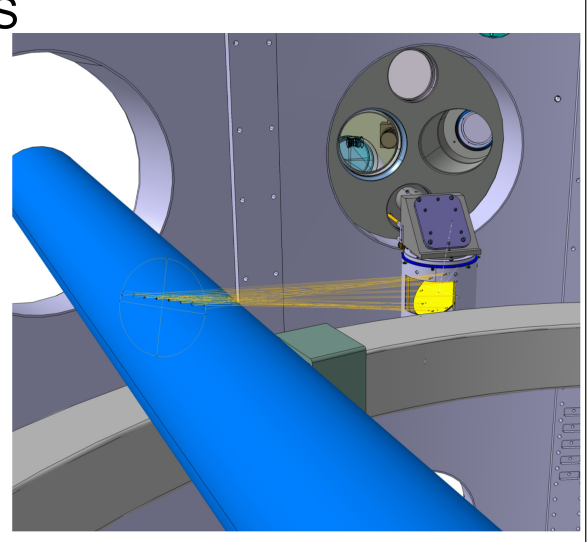
  Strongly off-axis NBI heating (1.5 MW), Ip=600 kA, q95≈3-4
  Sawteeth in L-mode
  Irregular large ELMs, some global effect on plasma

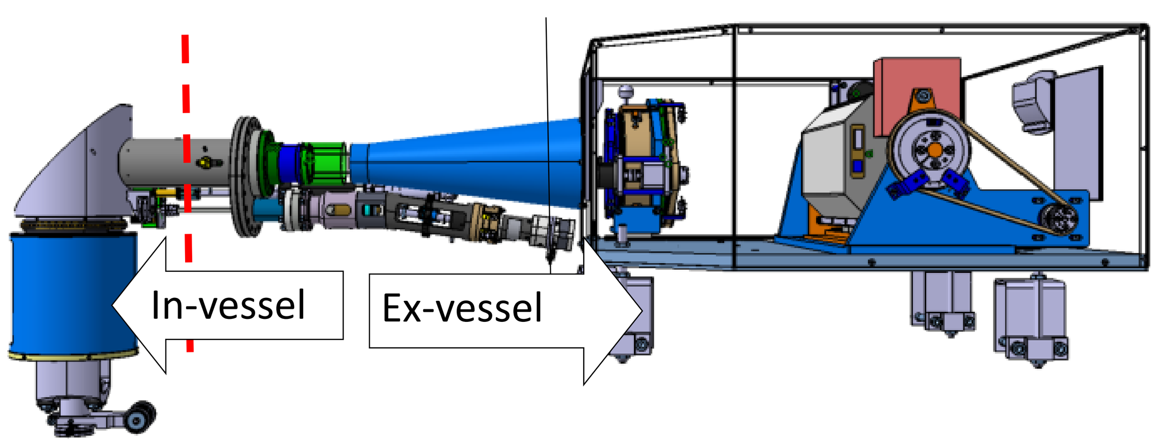
  Three clear stages can be identified during/before an ELM:
  - Precursor growth in pedestal → fingers penetrate SOL → splitting into sub-structures
  - Wall/divertor contact → fingers retract
  - "Classic" ELM starts 50-100 μs later or no ELM is seen

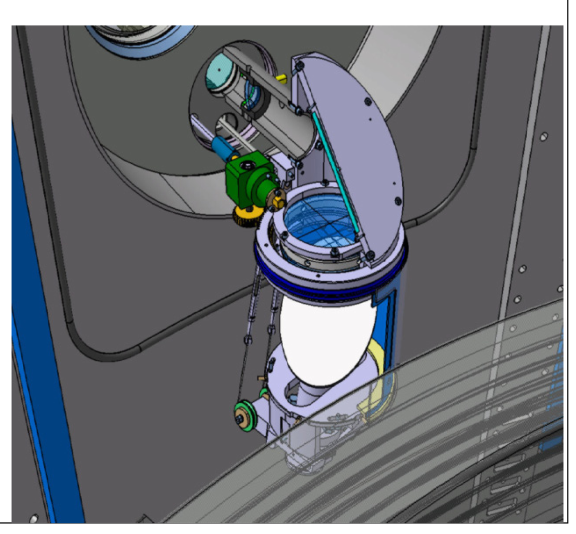


2D MAST BES Diagnostic

- Based on the success of the trial system a dedicated BES imaging diagnostic was designed and manufactured
- Both the core and edge turbulence could be studied by changing the observation volume (rotatable first mirror)
- Light intensity is limiting: must collect all light possible (optics optimized for collection, special camera unit)
- 2D poloidal resolution, ~2cm spacing, 4*8 pixel 16*8 cm observation volume at R=1.2 m
- Observation range: R=0.7m -1.6m (r/a 0.-1.1) Position changed shot to shot
- Filter, camera, objective has to rotate synchronized to mirror rotation. 4 electrical stepper motors are used

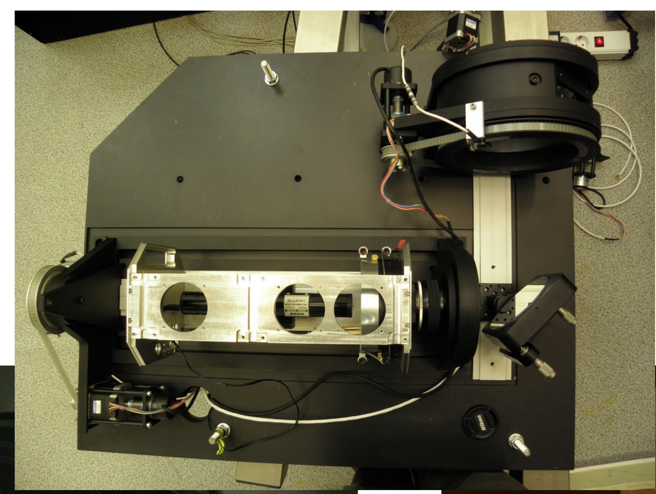




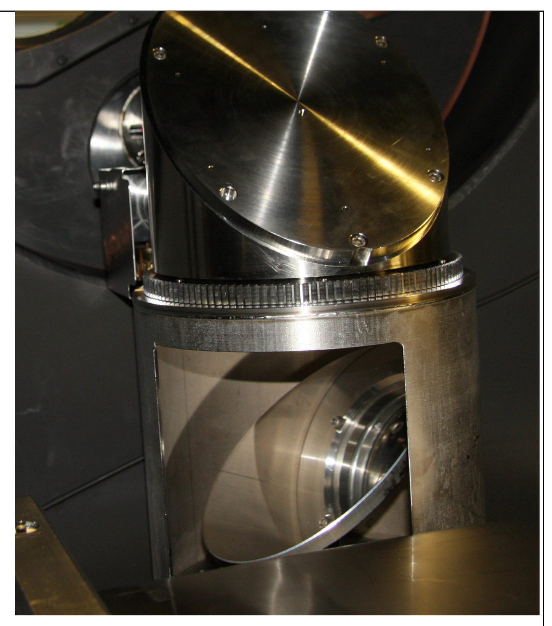


Installation of the system

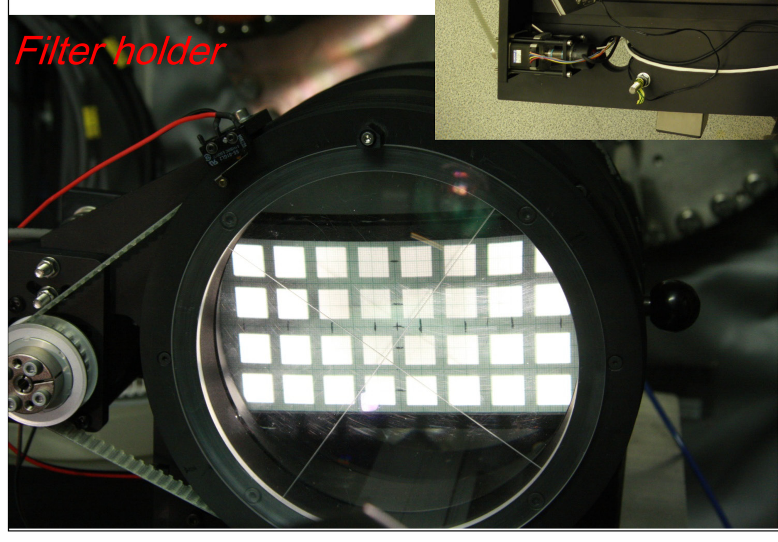
- Camera housing without electronics was manufactured
- Laser is installed within the camera for spatial calibration
- Reproducibility tests have been done with digital camera
- A mask was produced, which mimics the APD detector. Back lighting the mask the imaging can be set and tested
- positions of the 4 stepper motor have been set and tested



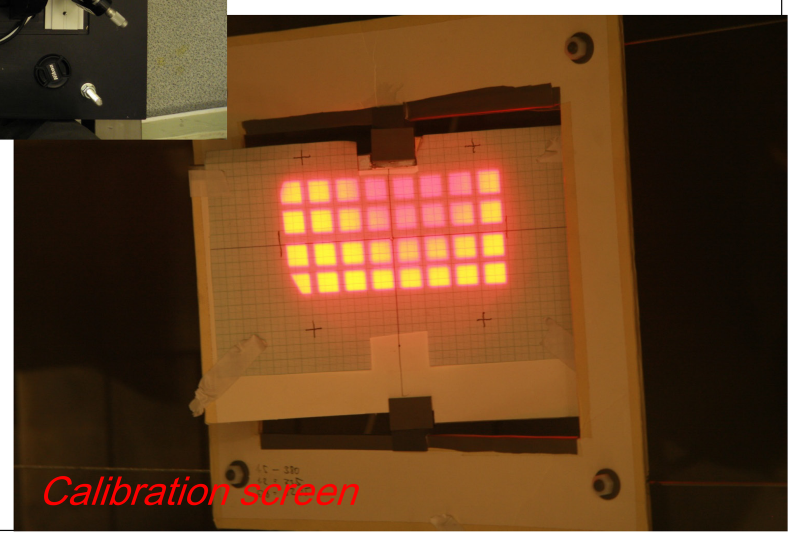
ex-vessel optics installed



In-vessel optics installed



Filter holder



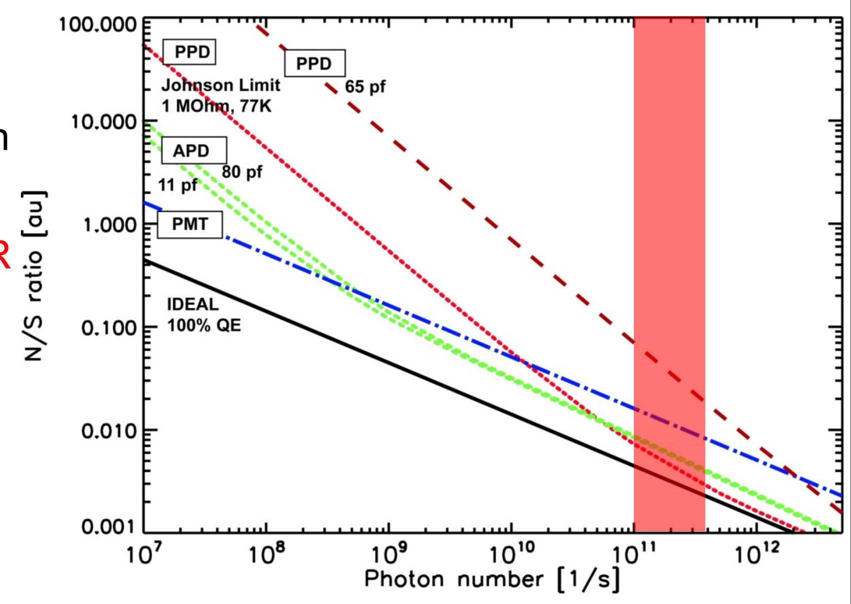
Calibration screen

Fast Detector

At the expected signal level our APD system noise will definitely be at the photon statistics limit.

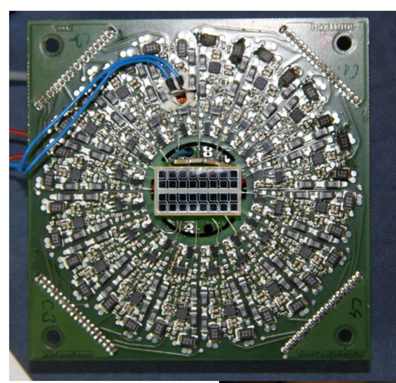
QE=85%, detector HV is optimized for SNR → calculated SNR is within factor of 2 to ideal detector.

Expected SNR from intensity calculations 100-300



Noise to signal ratio of different type of detectors are shown as a function of incident photon flux

- Detector head
  - 4x8 channel Hamamatsu APD array
  - 32 individual 2-stage amplifiers based on earlier APD systems (TEXTOR, JET, MAST)
  - 2 computer controlled HV power supplies
  - Temperature stabilisation
  - No cryogenical cooling is needed



APDCAM Analog Board

- APD camera

  Compact detector unit with all services integrated:
  - 4 piece 8-channel 14 bit ADC, up to 50 MHz
  - FPGA controls triggering, synchronisation, data rate
  - Digital filtering (10 kHz – 10 MHz)
  - Converts data to UDP stream, standard 1 Gbit Ethernet communication (10 Gbit is planned)
  - Complete computer control: shutter, calibration light, detector temperature, HV, etc.
  - C, IDL/Matlab interface

  APDCAM is designed and produced by ADIMTECH Ltd, a spin off company of RMKI

APDCAM

Predicted Capabilities of the 2D BES system

The MAST BES imaging (SNR 100-300) system with data analysis program package will be capable of:

Core measurements:

- Core fluctuation measurements with correlation technique, where the relative fluctuation amplitude is ~ few times 0.1% (ms time integration interval)
- Poloidal flow measurements - with 2-point correlation method (ms)
- ITB formation study
- MHD activity (Fast particle driven instabilities)
- Flow modulations, GAMs

Edge measurements:

- Direct edge fluctuation observation
- L-H transition (poloidal flows, turbulence suppression…)
- ELM evolution and filament observations with μsec resolution (Precursors, pedestal collapse)

Input to transport simulation codes.
Expected to become a standard a diagnostic

References

[1] A. R. Field, D. Dunai, N. J. Conway, S. Zoletnik, J. Sárközi *Rev. Sci. Instrum.* **80** 073503 (2009)
[2] D. Dunai, S. Zoletnik, J. Sárközi, A. R. Field, Avalanche Photodiode based Detector for Beam Emission Spectroscopy, *Rev. Sci. Instrum.* (submitted)