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12th IAEA TM on Energetic Particles in Magnetic Confinement Systems
Austin, Sept. 7 -10, 2011

# Energetic particles study in MAST with a neutron emission profile monitor

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# Summary



Fast particles and neutron emission at MAST

Collimated neutron flux monitor diagnostic

First results

Modelling and interpretation

Future directions

Conclusions

# Fast particles diagnostics at MAST

Exploit specific capabilities of MAST:

- Super-Alfvénic beams, $V_{NBI} \sim 2.5\ V_A$
- Large fast ion fraction with high $\beta$ (above ITER values)
- Wide range of fast ion driven modes observed

Operating:

- Fast Ion D-alpha diagnostic (FIDA)
- Compact NPA
- Collimated Neutron Camera

Design stage:

- Lost proton detector

# Neutron emission and detection at MAST



Most of the fusion neutron production is due to injected neutral deuteron reacting with the thermal deuteron population (beam-thermal) while the beam-beam term accounts for 10 -20 % of the total and the thermal-thermal contribution is negligible.

$$D + D \Rightarrow {}^{3}He\ (0.82\ MeV) + n\ (2.45MeV),\ Q = 3.27MeV$$

Document fast particle driven collective instabilities

AE: TAE, EAE, BAE, Alfvén cascades, high frequency CAE energetic particle modes, chirping modes

Effects of other instabilities upon fast ions

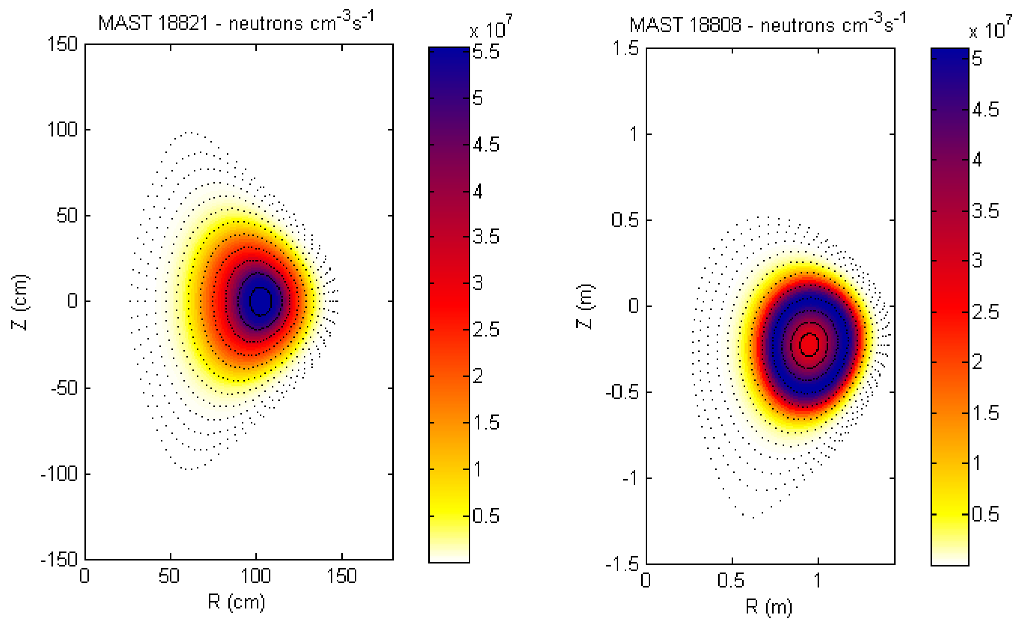
Typically $n$ = 1 internal kink: sawteeth, fishbones, infernal modes, long-lived modes

$^{235}$U Fission Chamber

# Neutron emissivity and design choices



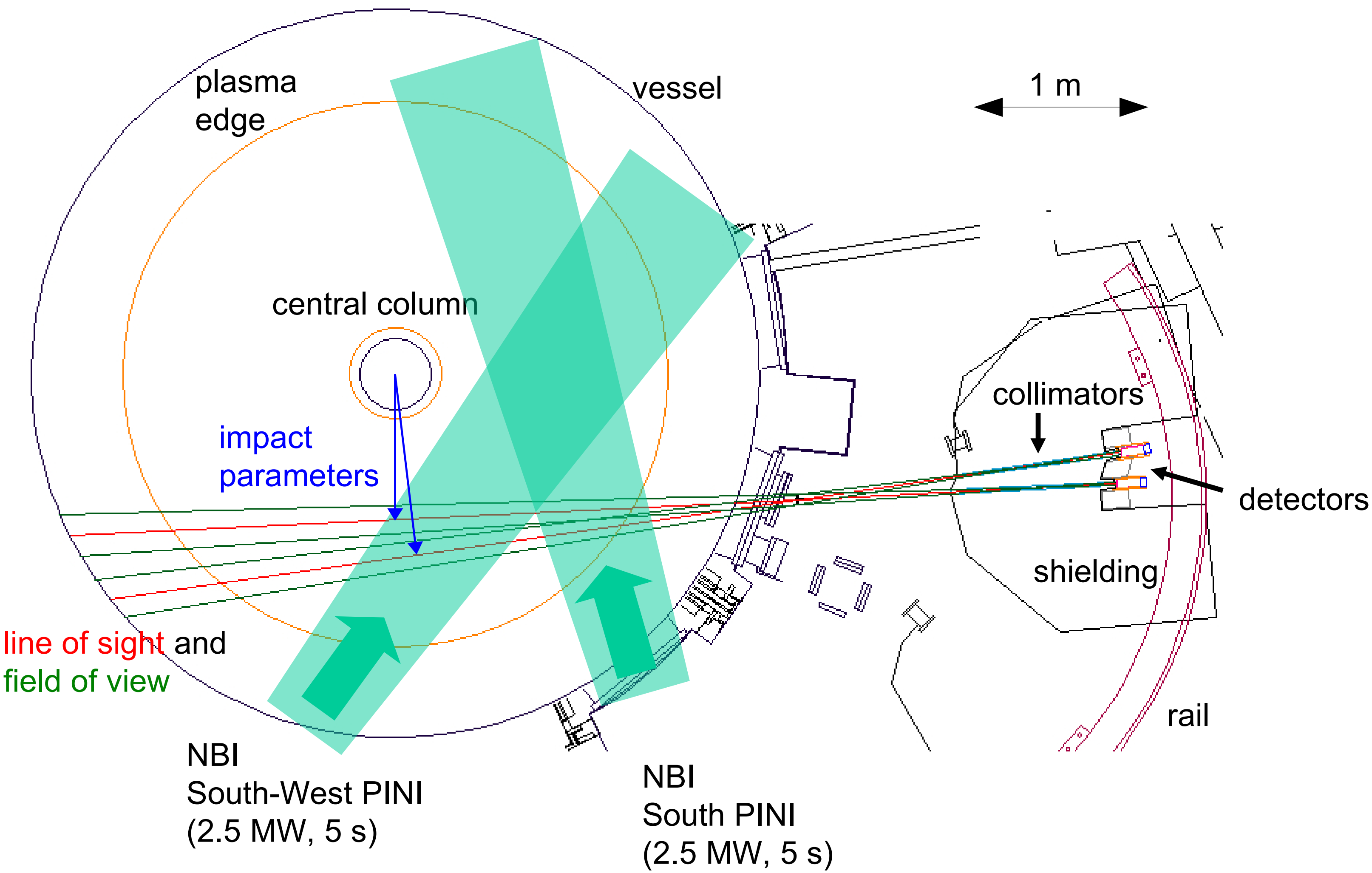
The neutron emissivity profile is strongly dependent on the fast ion spatial and energy distribution.




Separation between LOSs chosen to be approximately 20 cm, roughly corresponding to the spatial scale of the location of the projected co-passing orbits of the fast ions.

M. Cecconello et al, 4th IAEA Technical Meeting on Spherical Tori
14th International Workshop on ST – Rome, Italy, October, 7 – 10, 2008

# Lines of Sight and Fields of View layout




M. Cecconello et al, Rev. Sci. Instrum. 81, 10D315 (2010)

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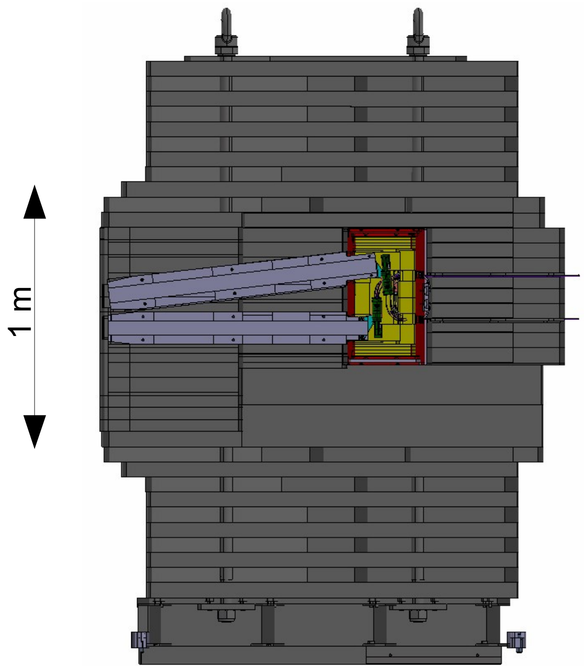
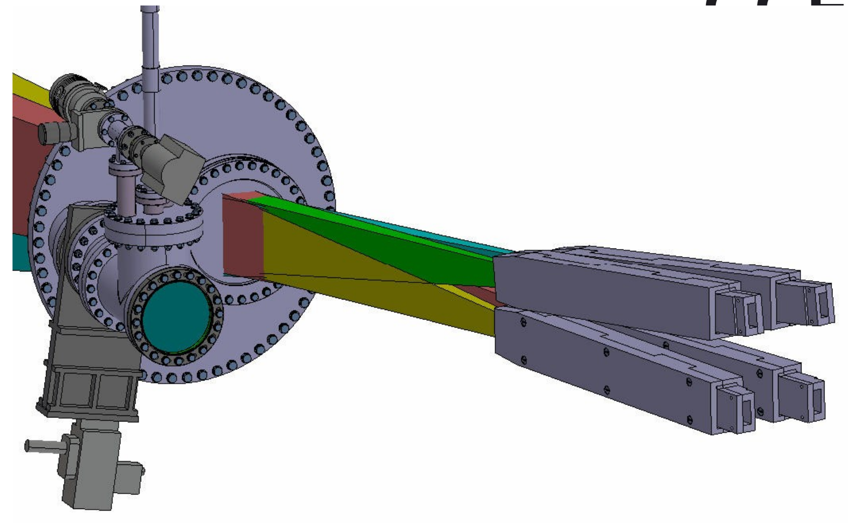
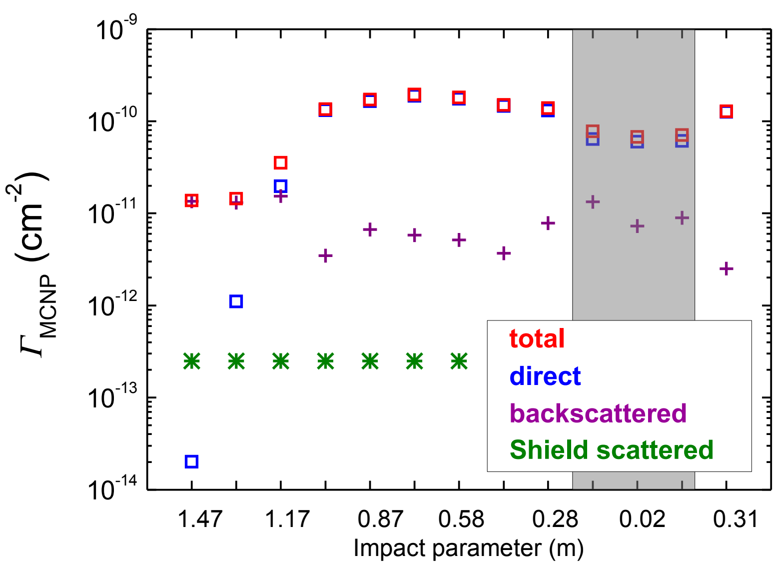
# Collimators, shielding and simulated neutron fluxes



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# Installation in the MAST area

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Back shield closed on the 6th June 2011.

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# Detectors and Data Acquisition System

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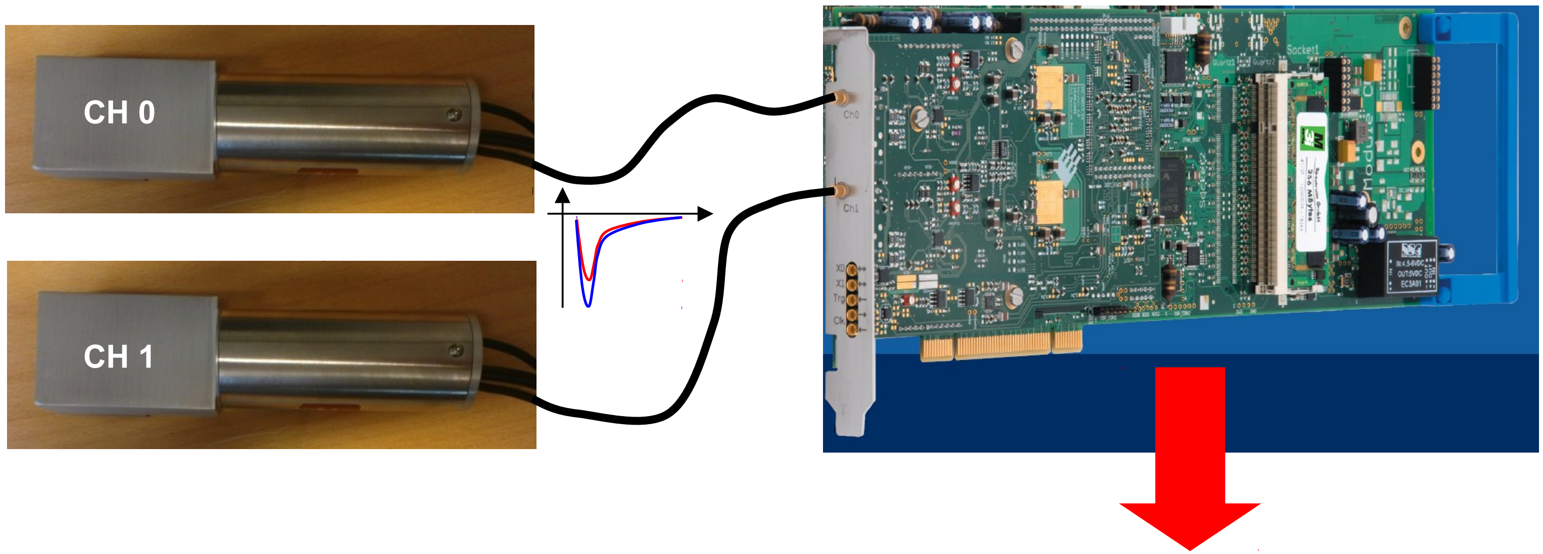
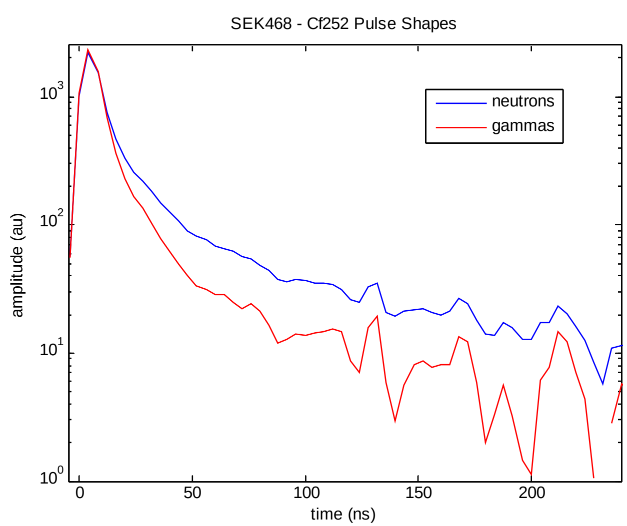
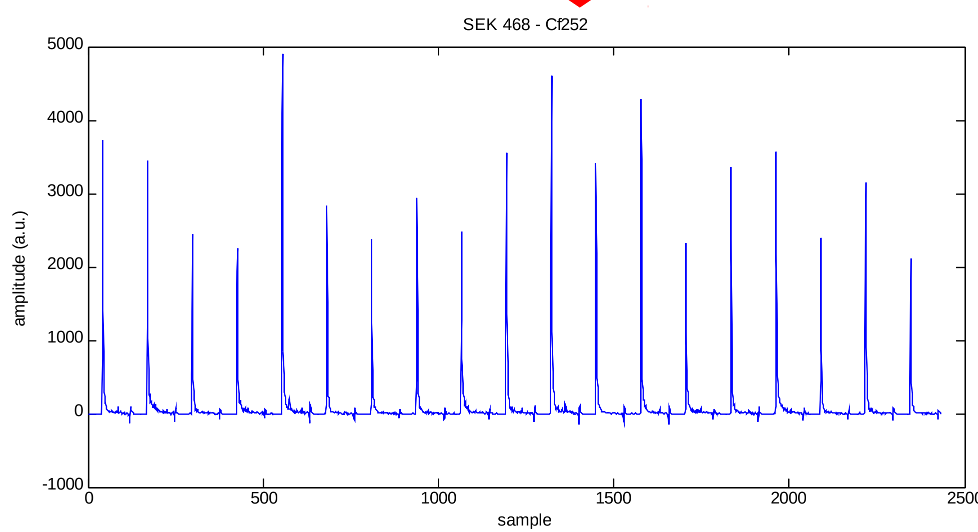
Liquid scintillator coupled to PMT
2 x 5 x 1 $cm^3$ active volume

14 bit, 256 MB mebory
250 MHz sampling rate

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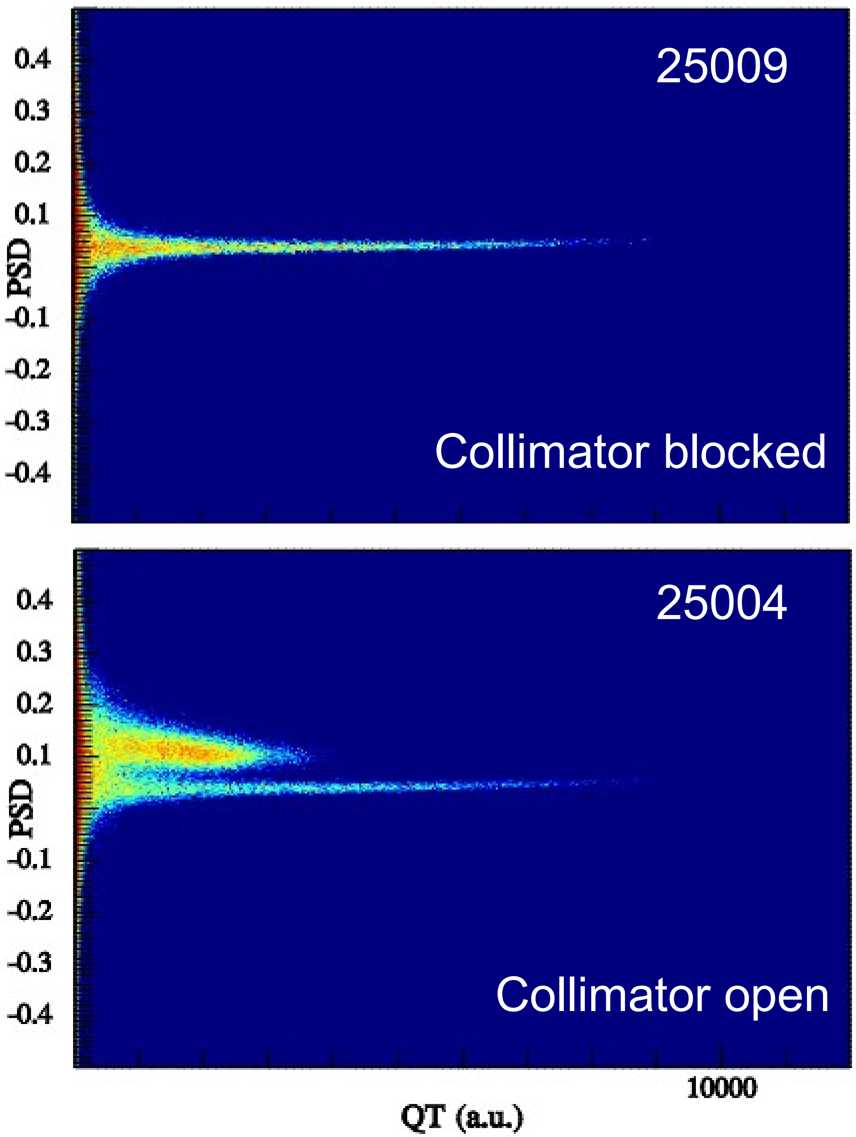
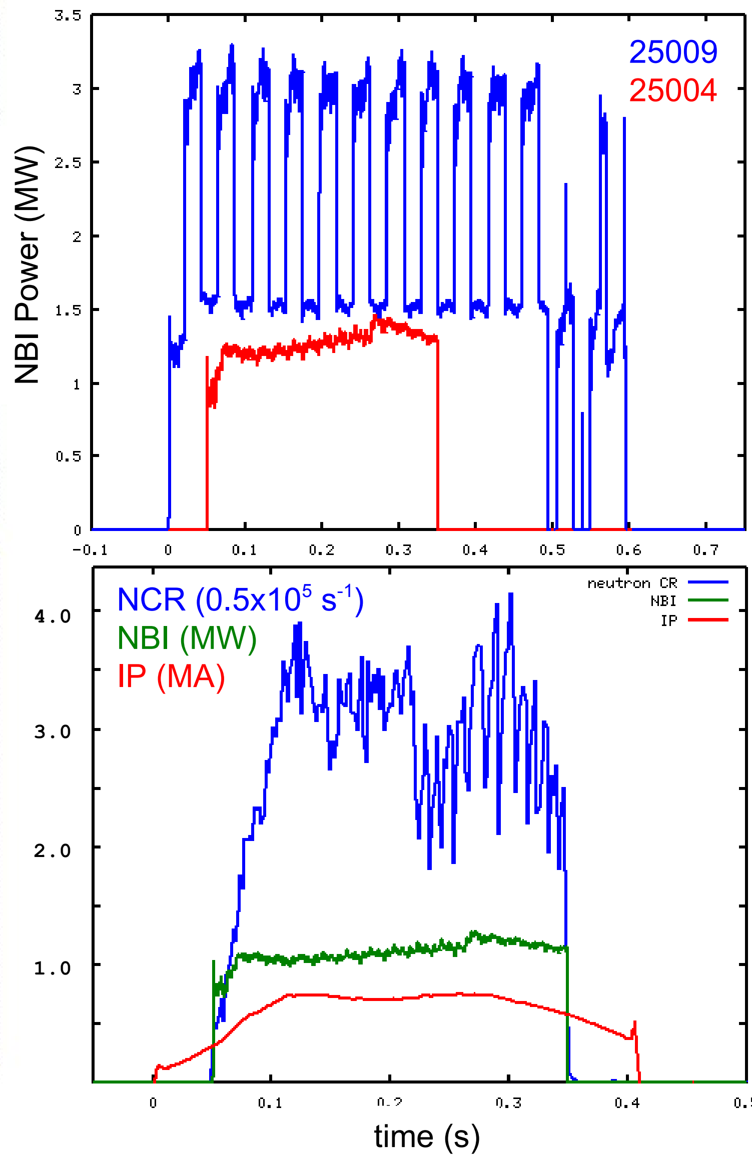
# Pulse Shape Discrimination

Separating gammas from neutrons



# Effects of MHD instabilities on fast ions

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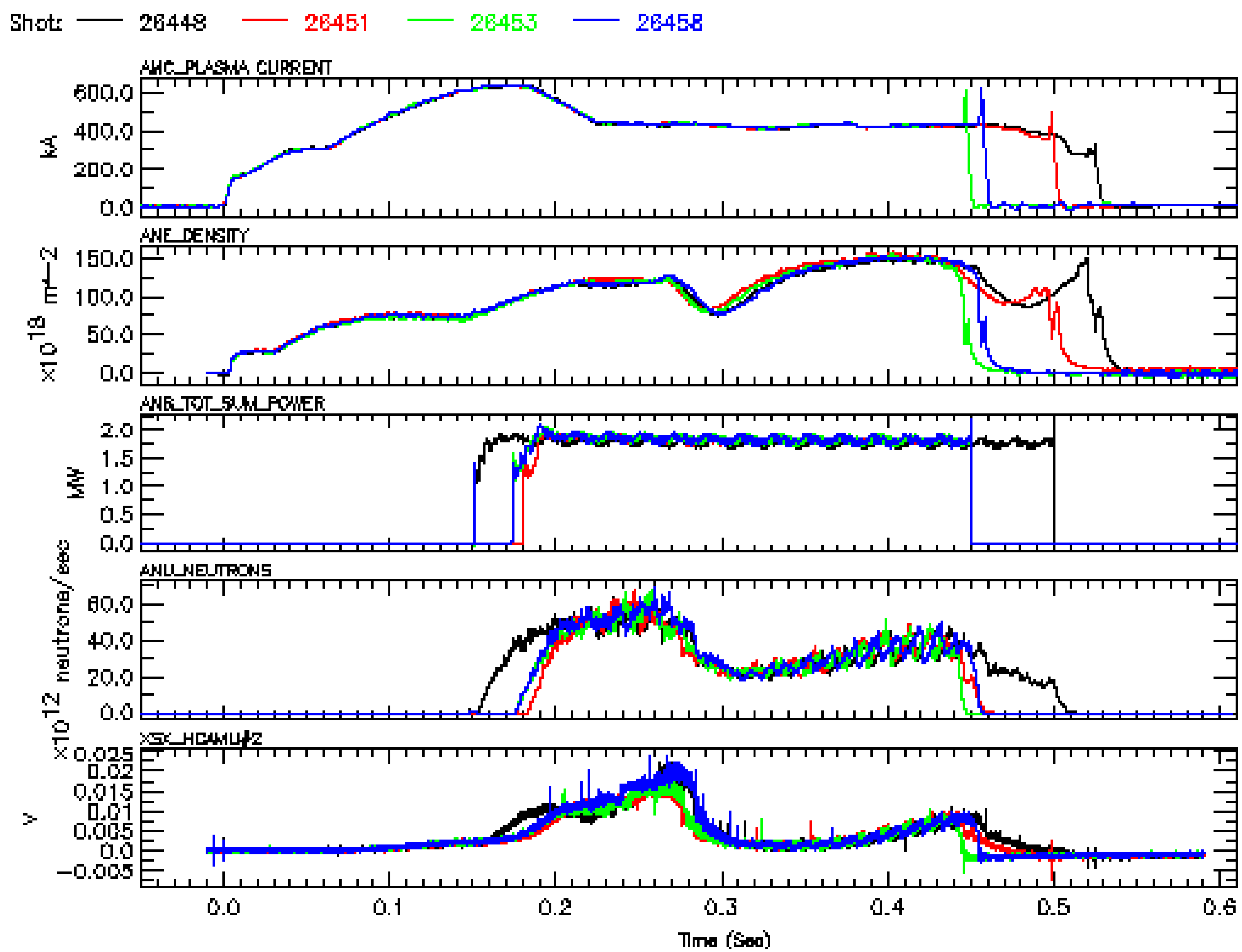
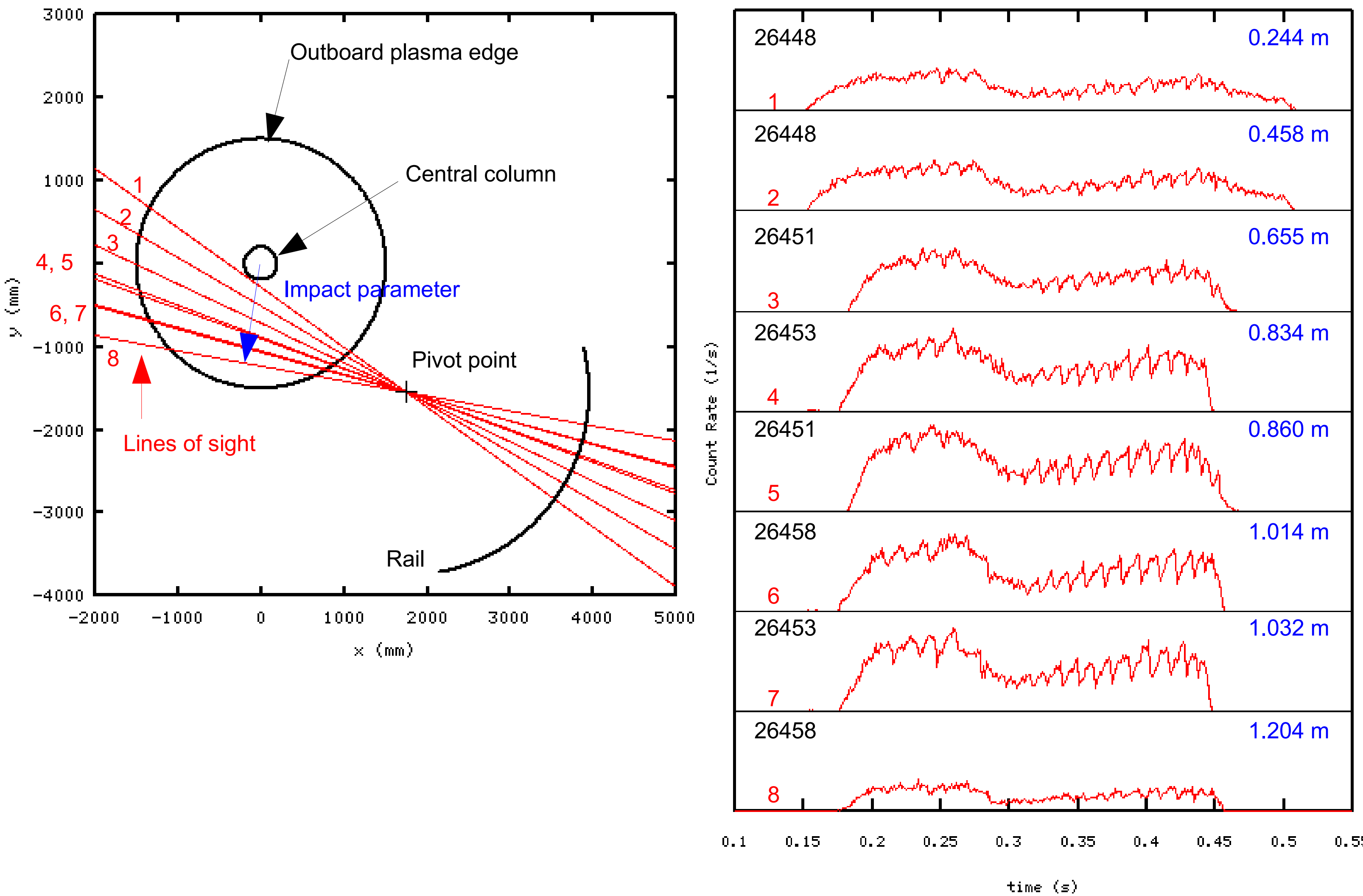
Parasitic radial scan on M8-IPS-005
q-profile evolution during current ramp
NBI timing for MSE, good pulse repeatability

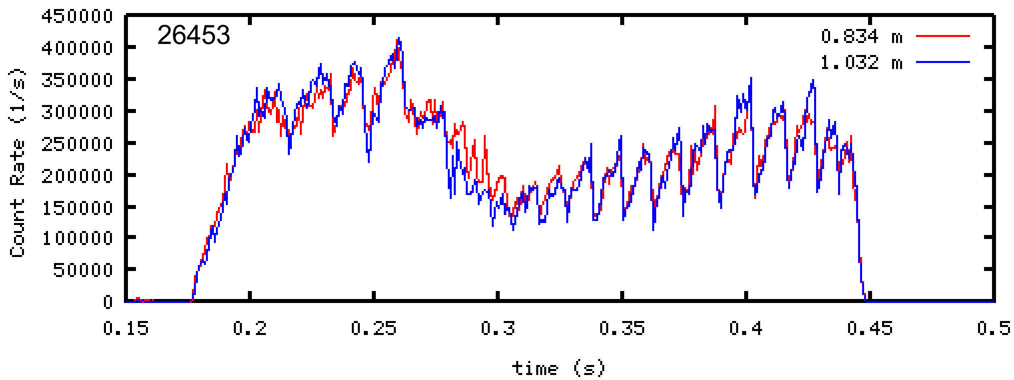


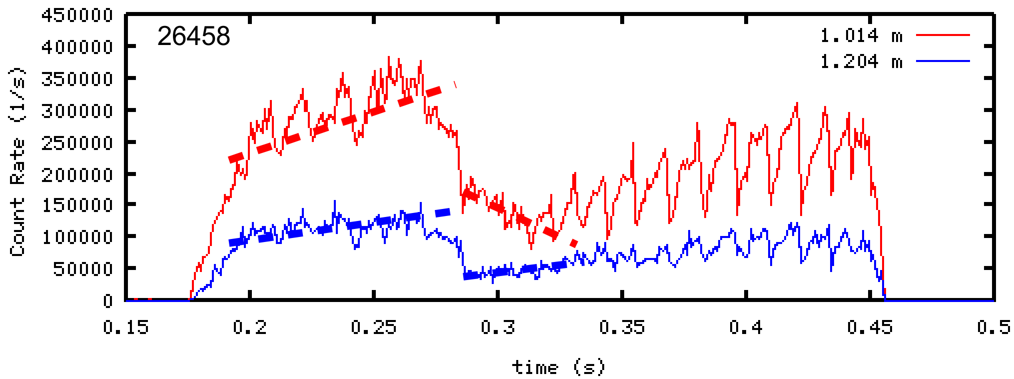
# n = 1,1 snake

Plasma region on the equatorial plane probed by radial scan in 4 pulses.



# Core vs edge comparison



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# Fields of view volume integrated emissivity

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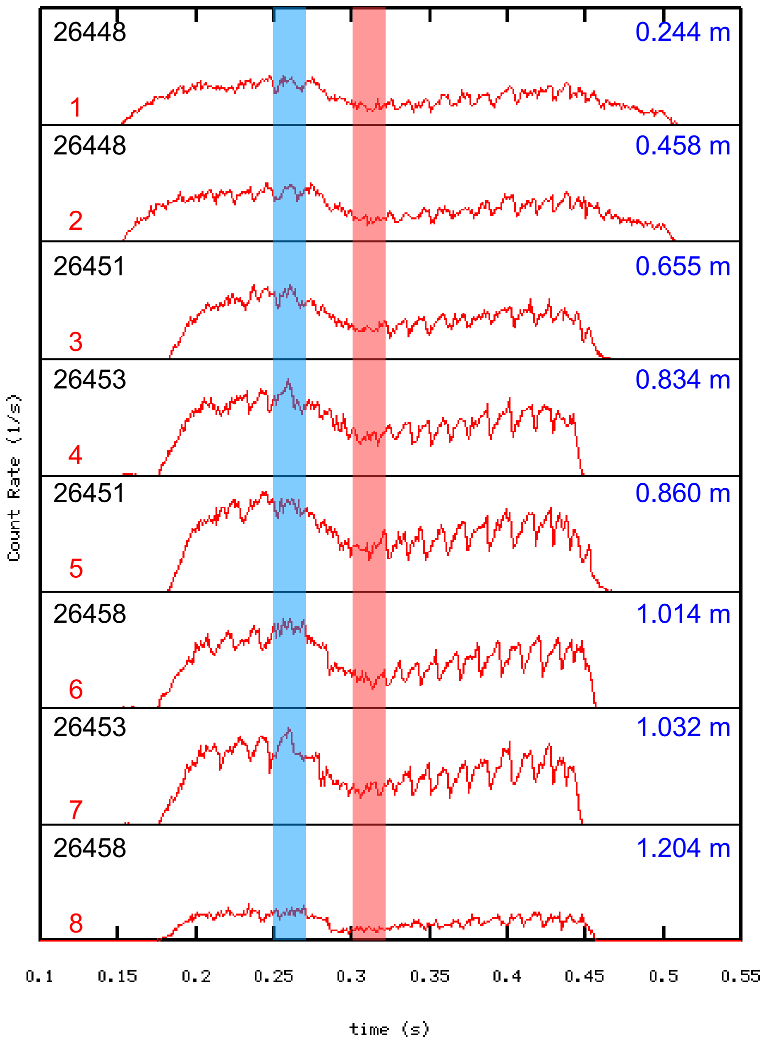
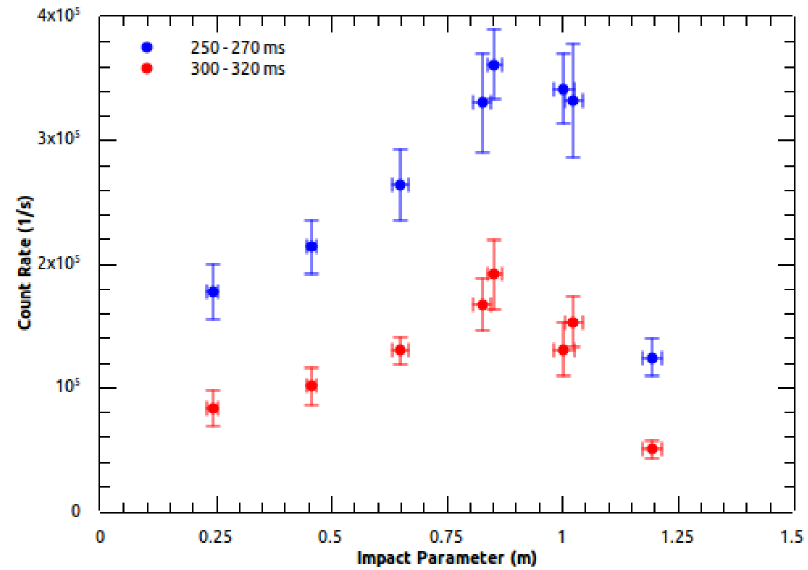
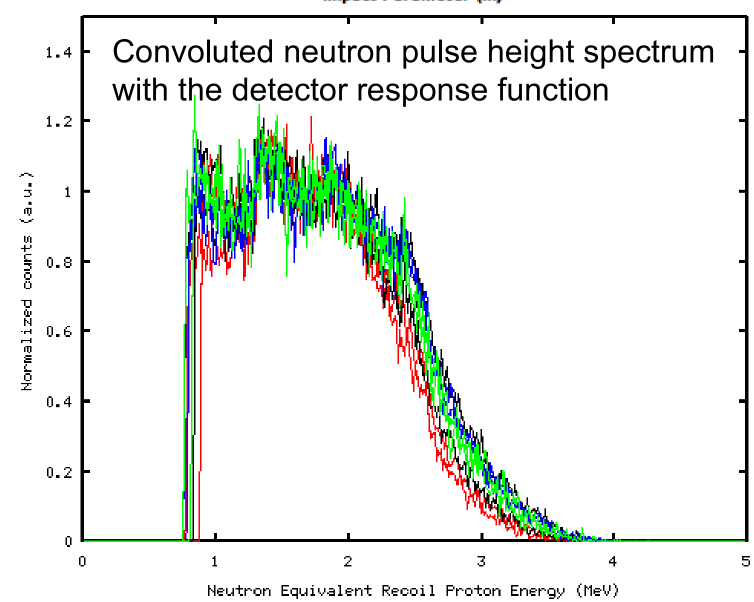
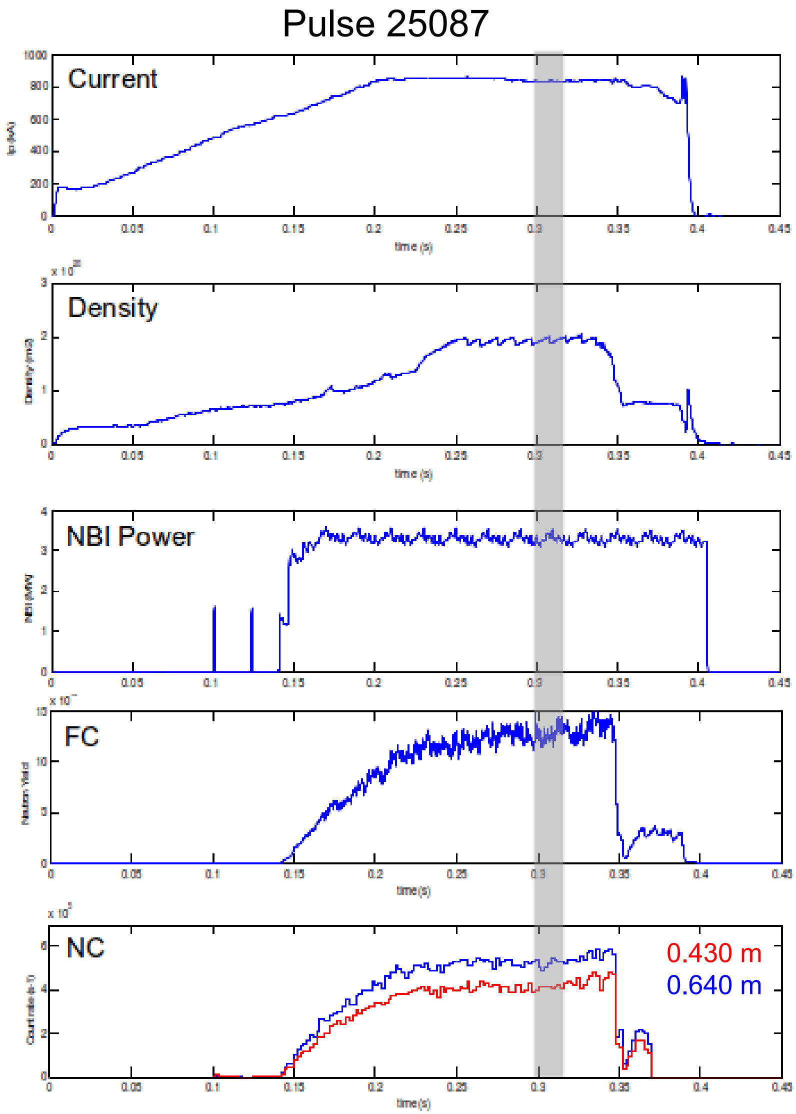


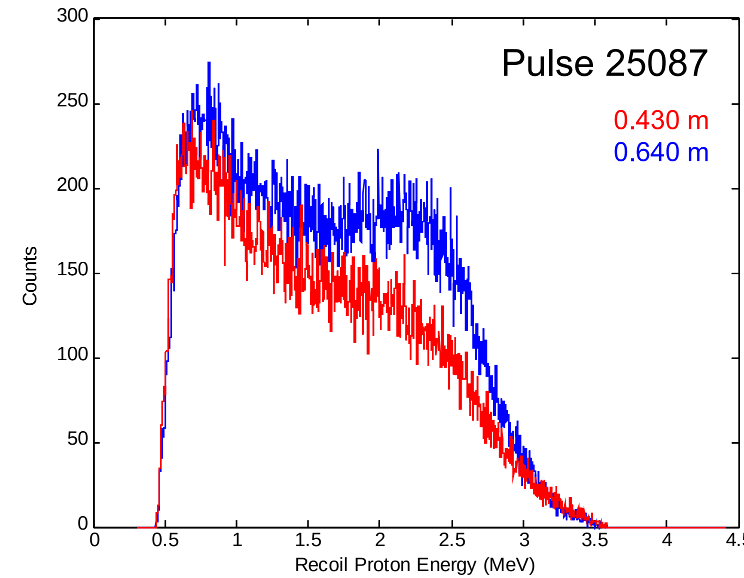



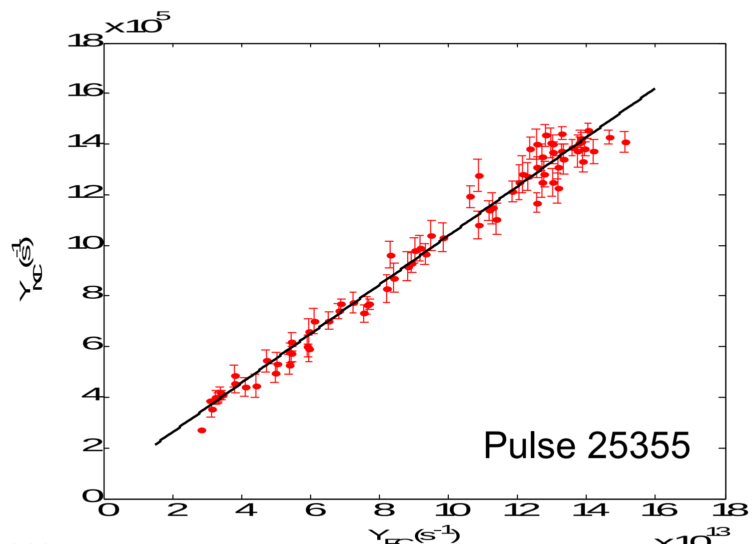



# Neutron yield and energy distribution effects

H-mode plasma with 3.2 MW NBI a 1.4 x $10^{14}$ n/s




S. Sangaroon, 38th EPS Conference, Strasbourg 2011, 27th – 1st July 2011

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# L-mode, sawtoothing, NTM activity.

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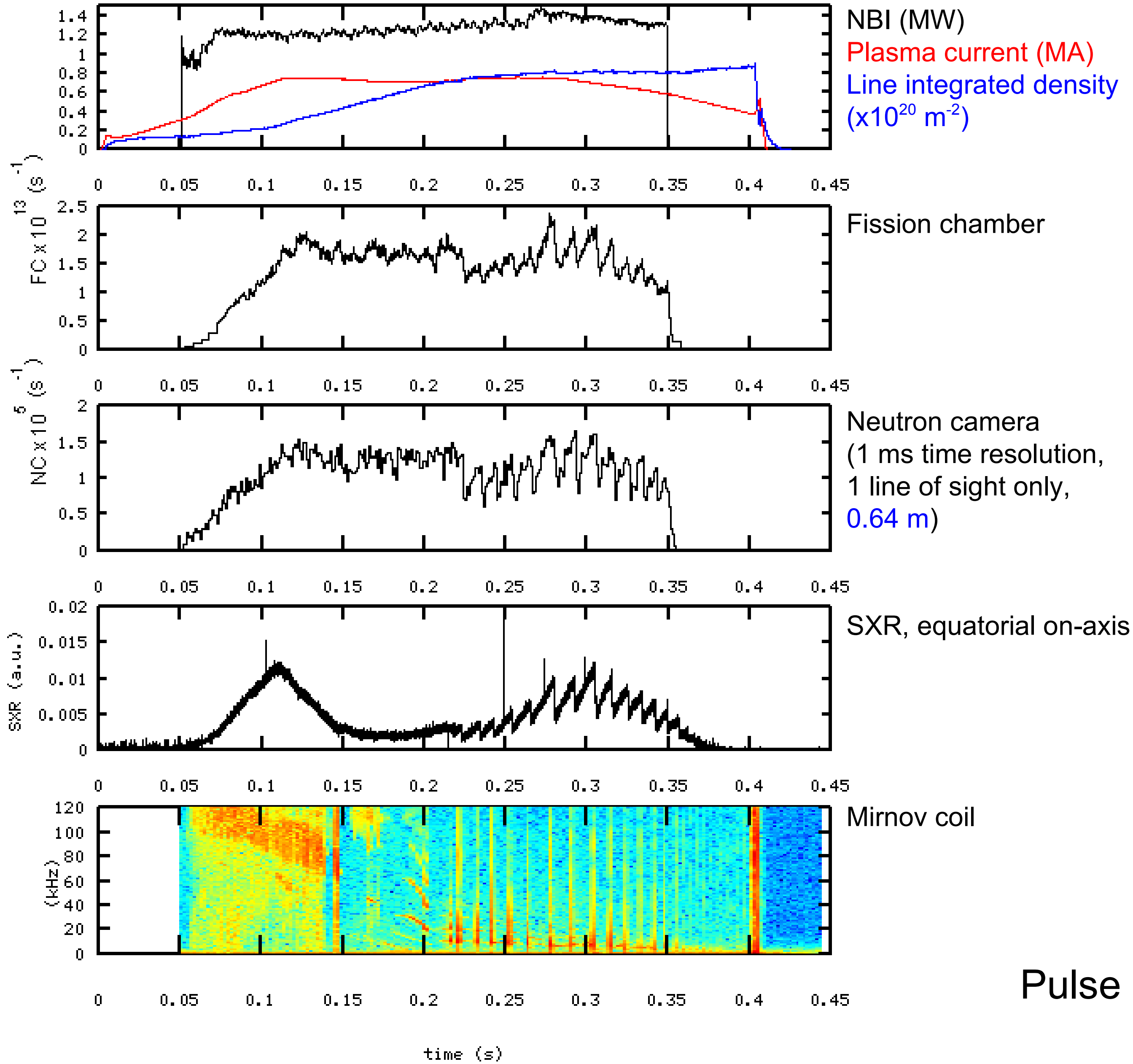
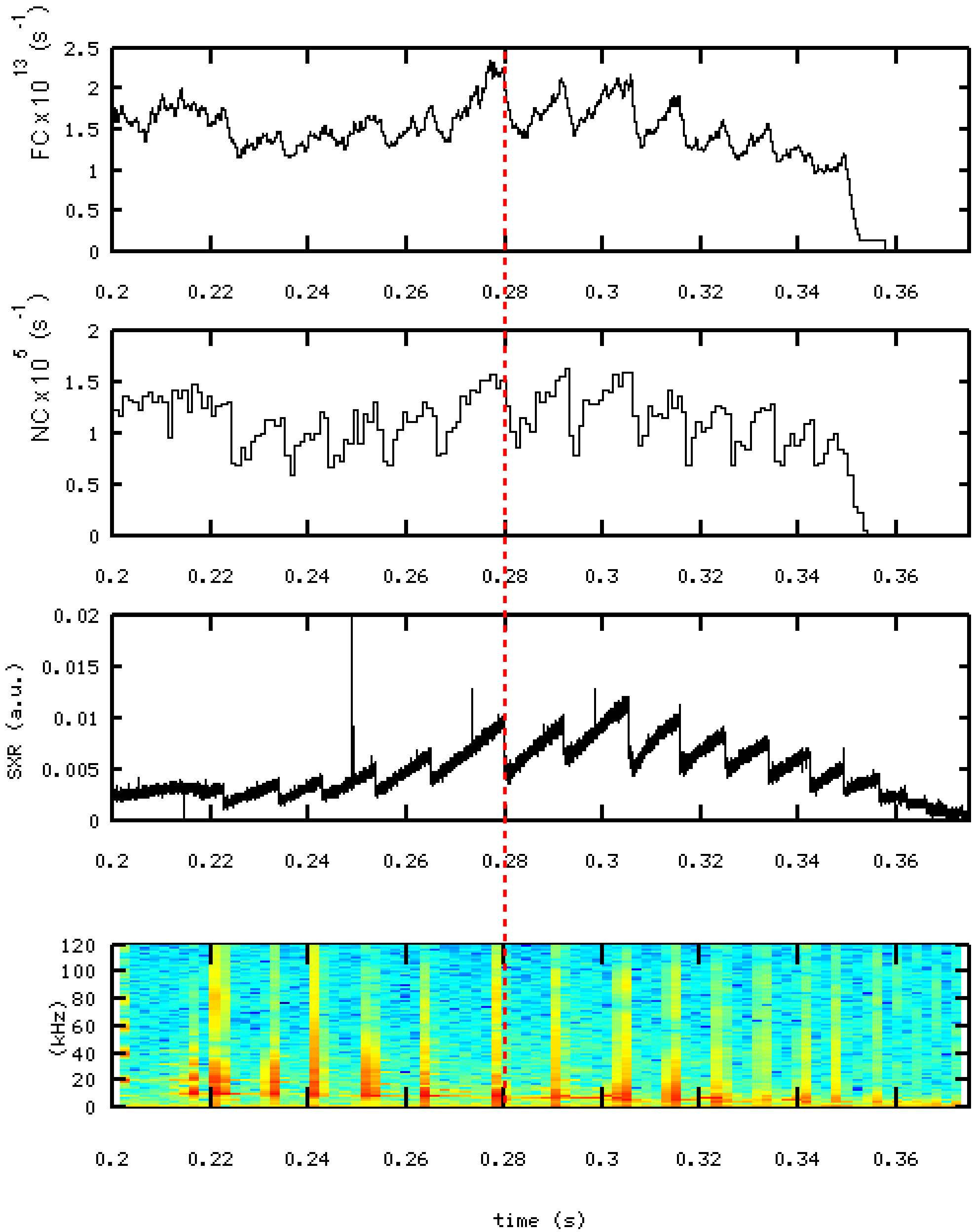



Pulse 25004

# L-mode, sawtoothing, NTM activity.




Fission chamber

Neutron camera (1 ms time resolution, 1 line of sight only, 0.64 m)

SXR, equatorial on-axis

Mirnov coil

Pulse 25004

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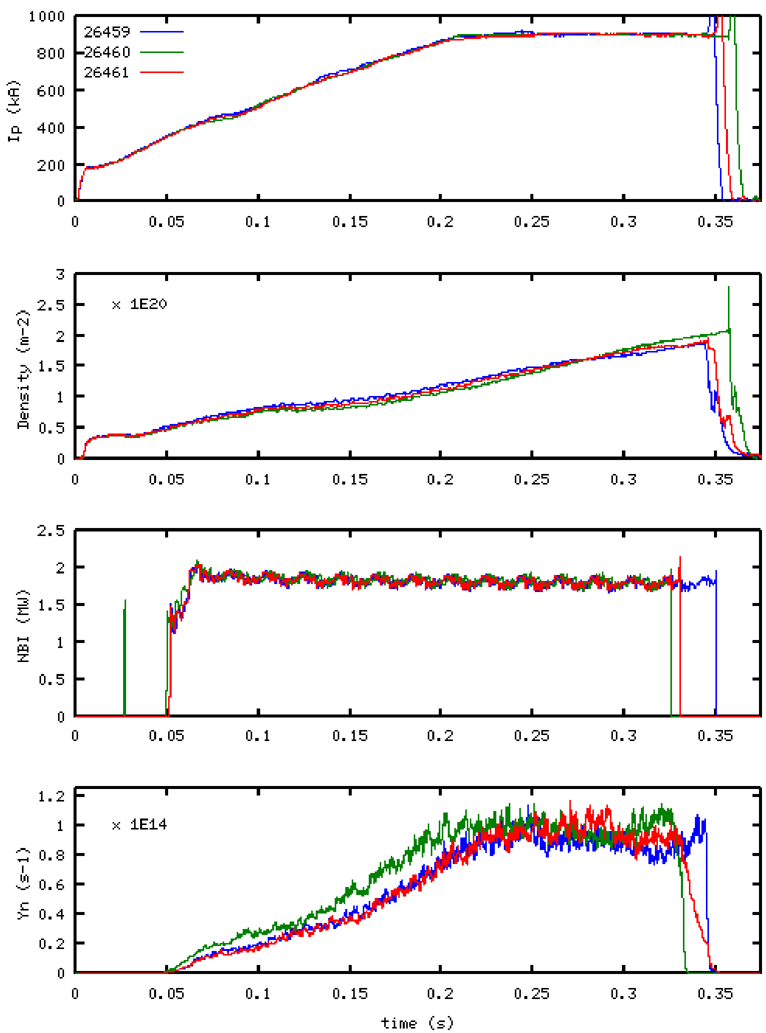
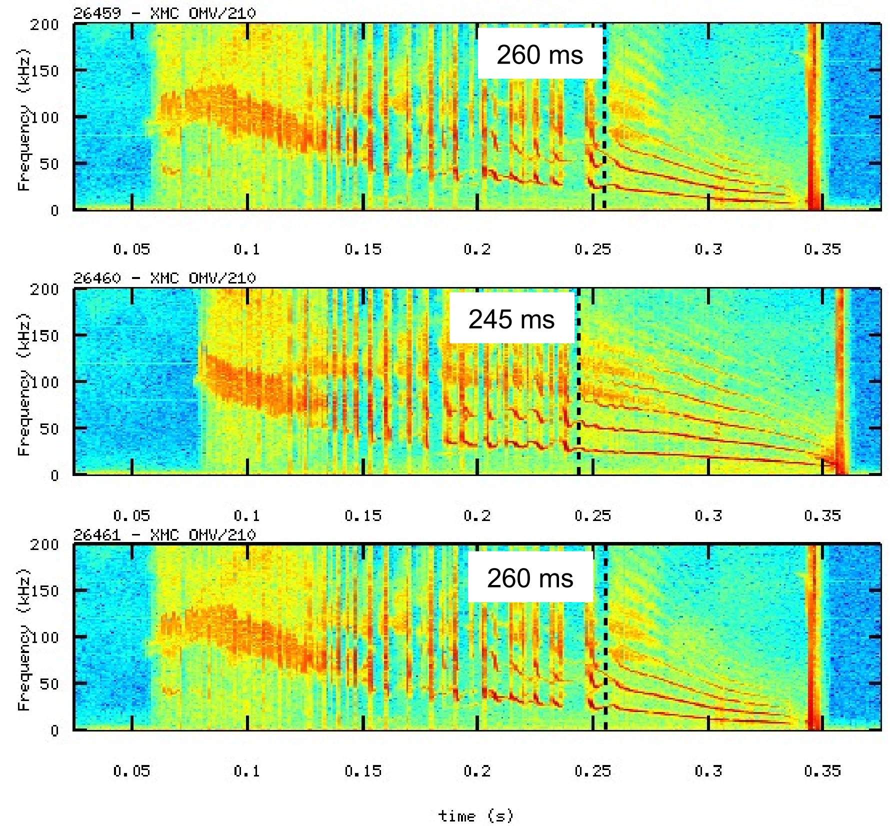
# Fishbones and long-lived modes

Parasitic radial scan on M8-IPS-005
Resonant Magnetic Perturbation
Good pulse repeatability



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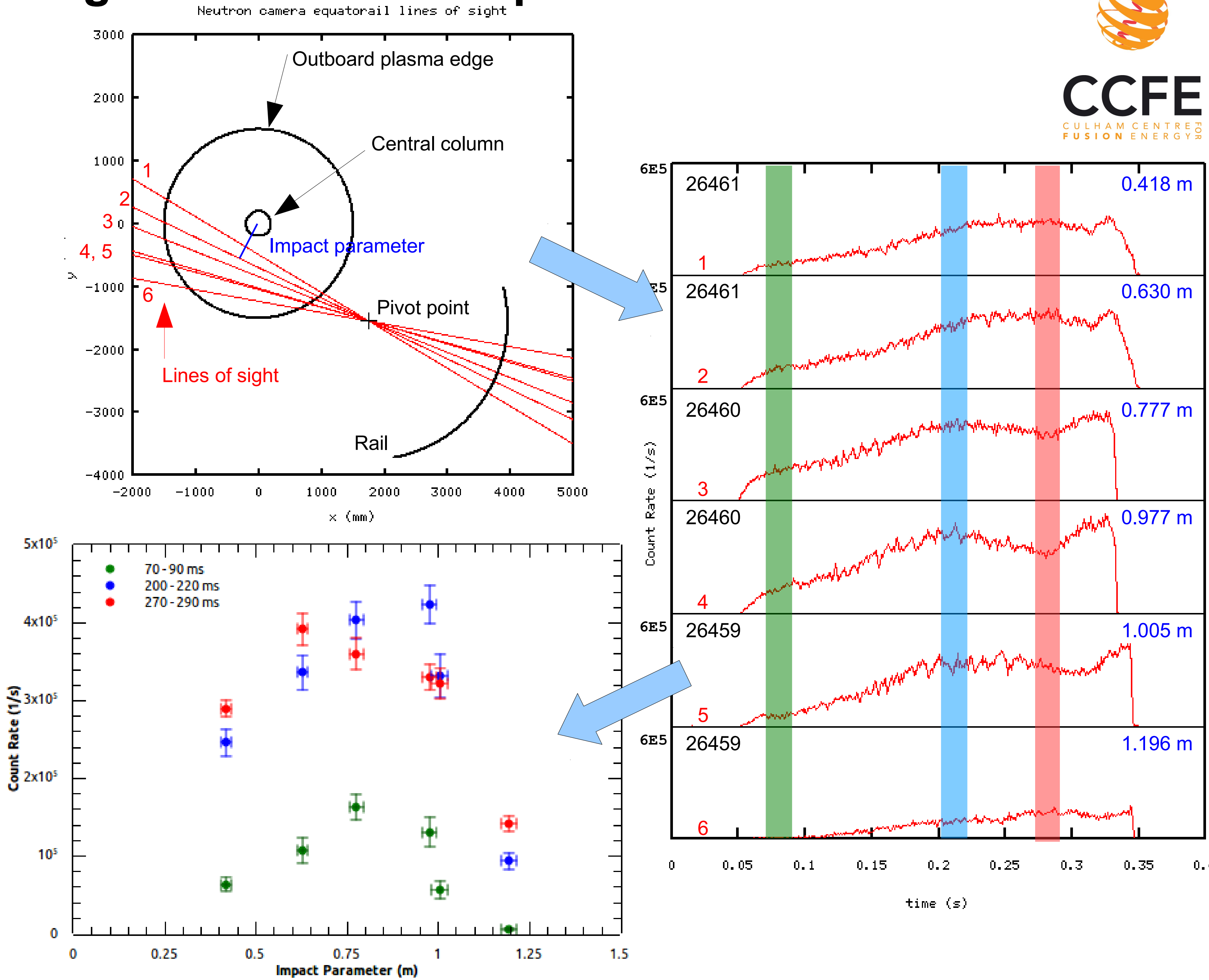
# Long lived modes and profile effects

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# Fishbones

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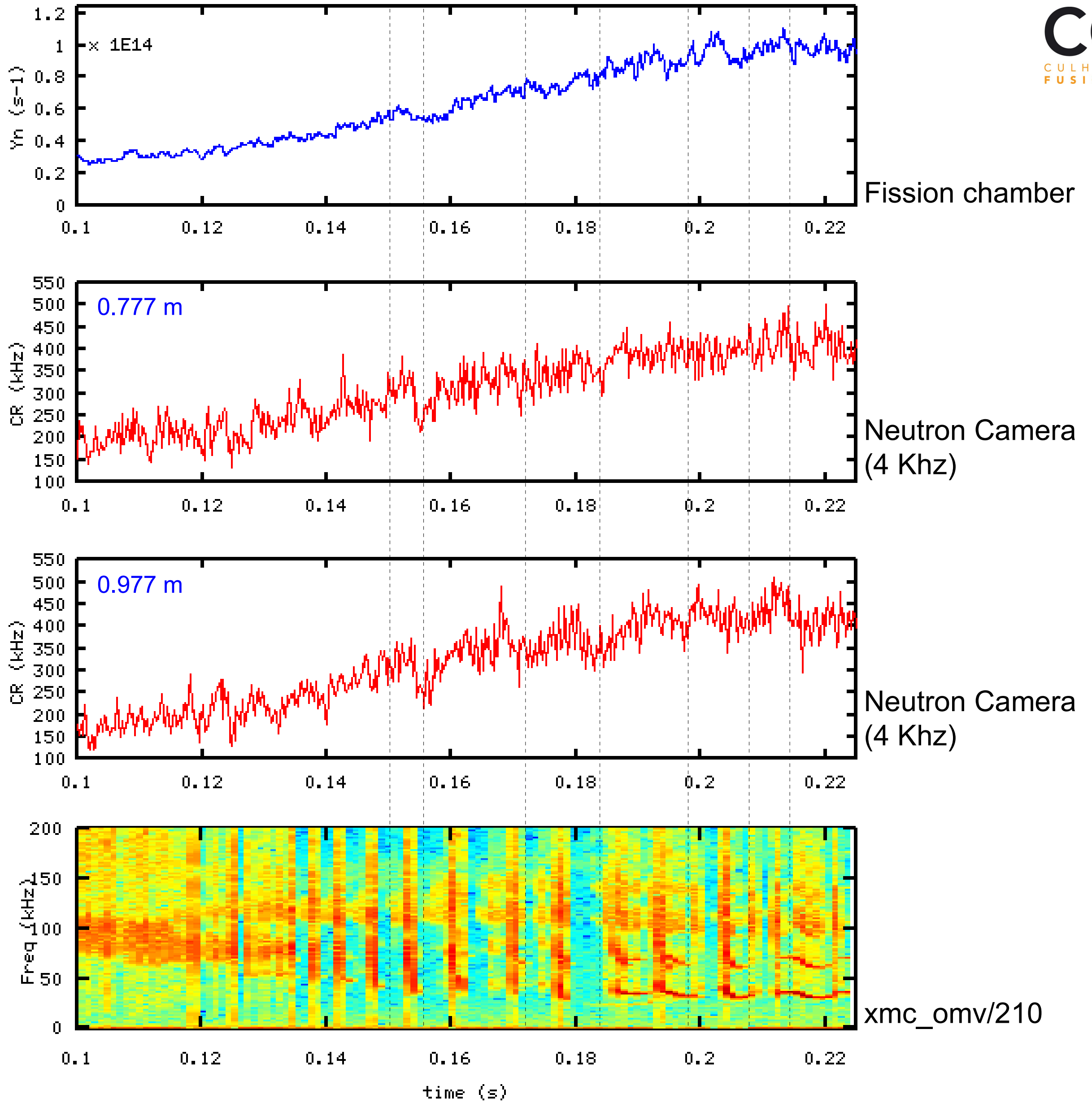
Pulse 26460



# Modelling of beam-thermal neutron spectra

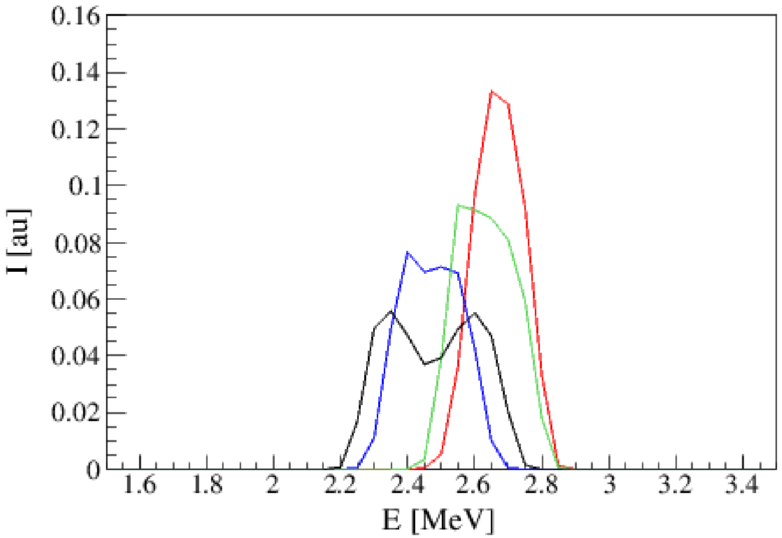
Beam-thermal neutron energy spectra for different NBIs and angles between the lines of sight and the beam injection direction.

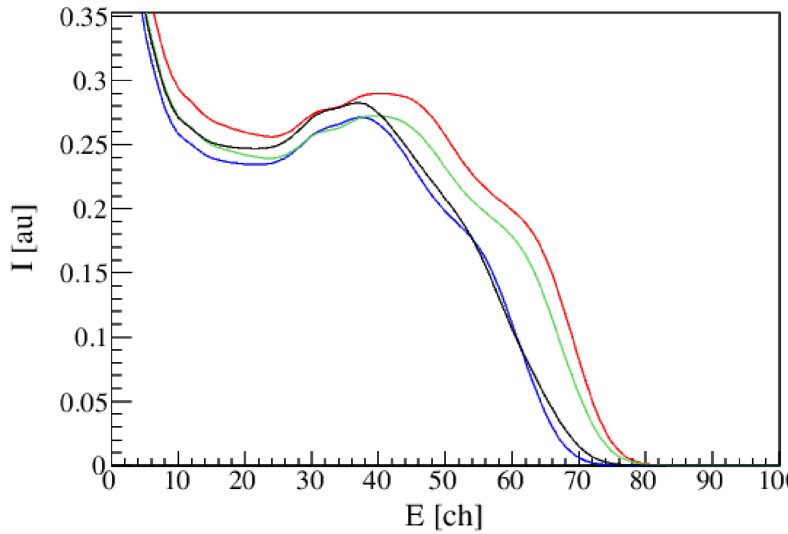
Spectra folded with a generic neutron response function for a liquid scintillator.

Cautionary notes:

1) 5 – 10 % uncertainty in total fluxes due to the shift in PHS for fixed threshold.

2) Anisotropy in DD cross-section for beam-thermal reactions can affect fluxes making the comparison of measured fluxes along different lines of sight tricky.

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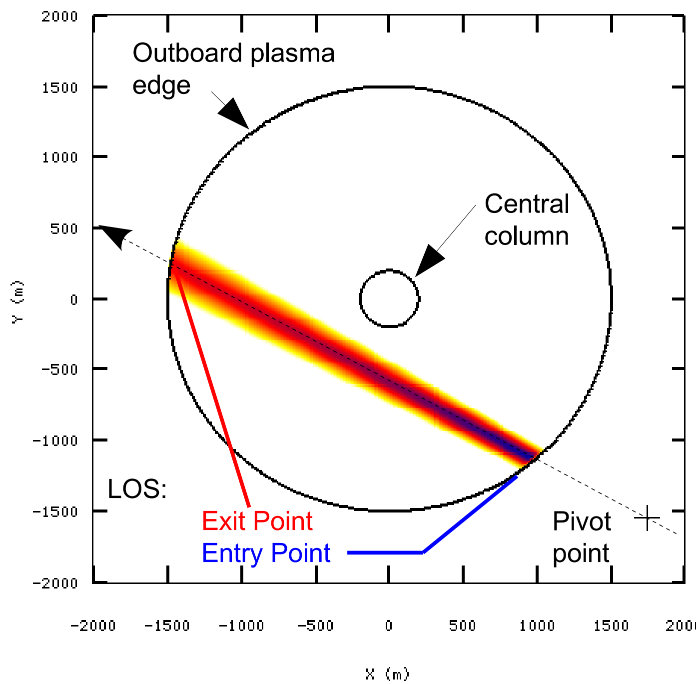
# Field of view modelling: LINE2.1

Full 3D Monte Carlo simulation of the contribution of each voxel to individual fields of view.

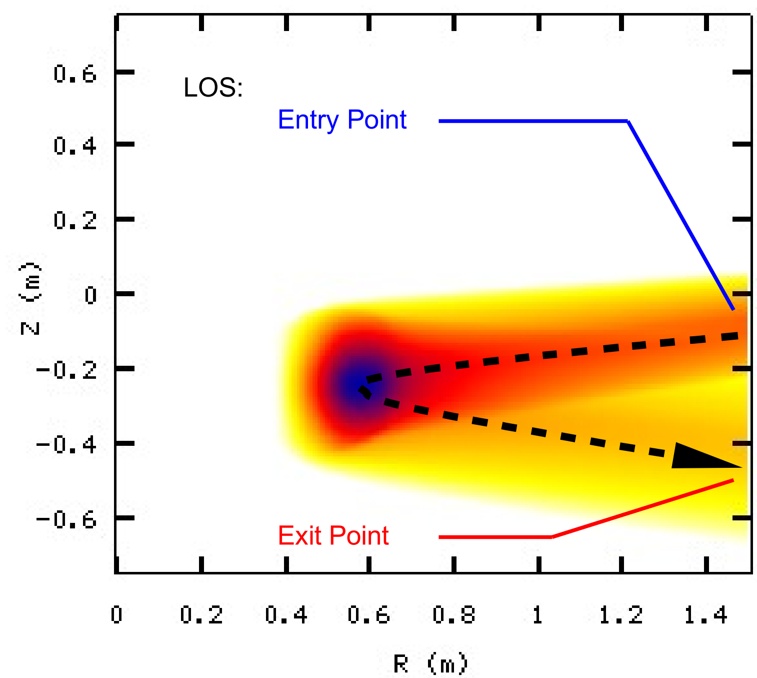
Example:

field of view weighting for the diagonal collimator using 1 $cm^3$ voxel size.

XY projection of a field of view




RZ projection of a field of view



# Voxelized field of view for a radial scan

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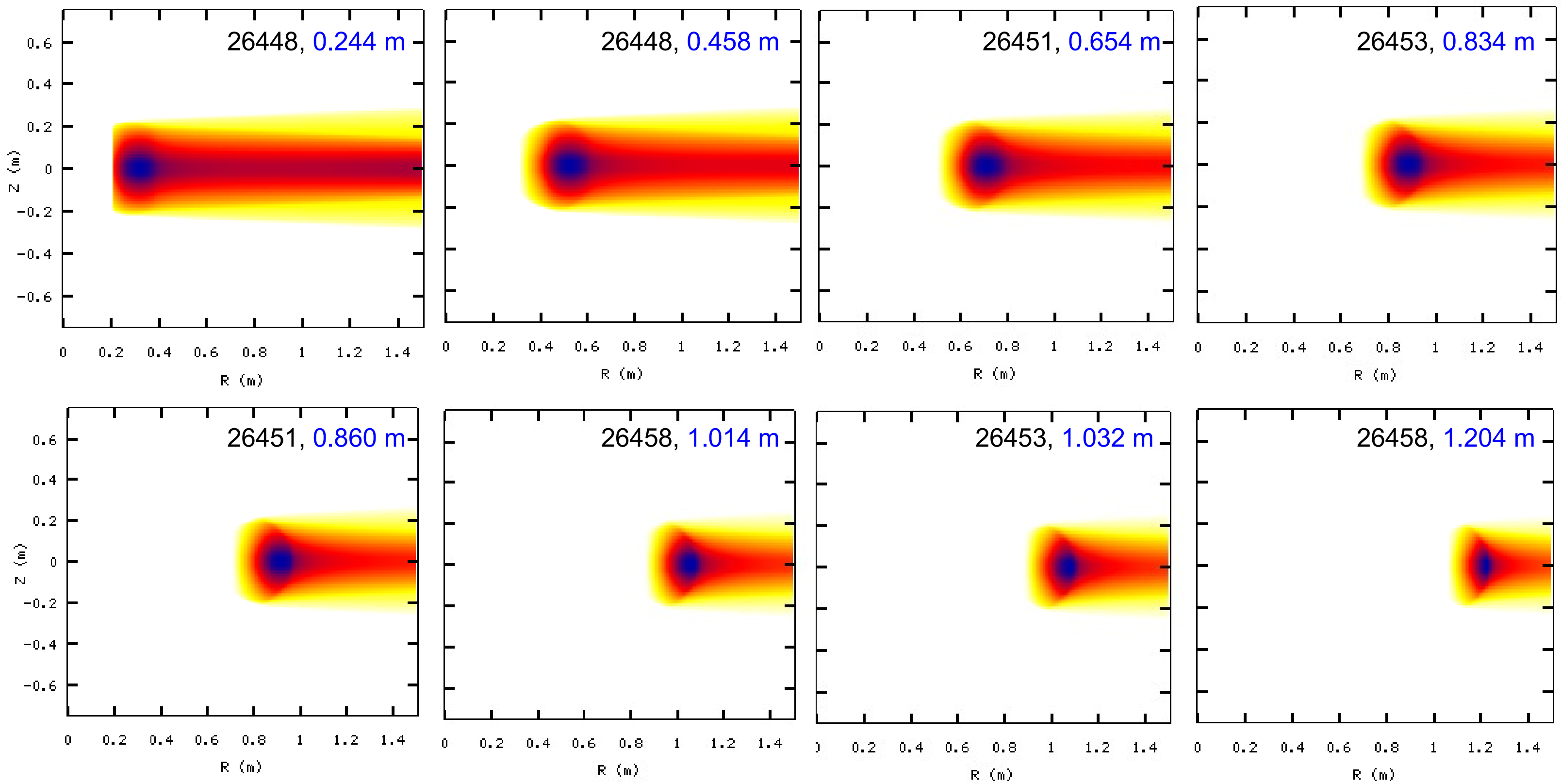
Equatorial lines of sight

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# Modelling the count rates: TRANSP x LINE21

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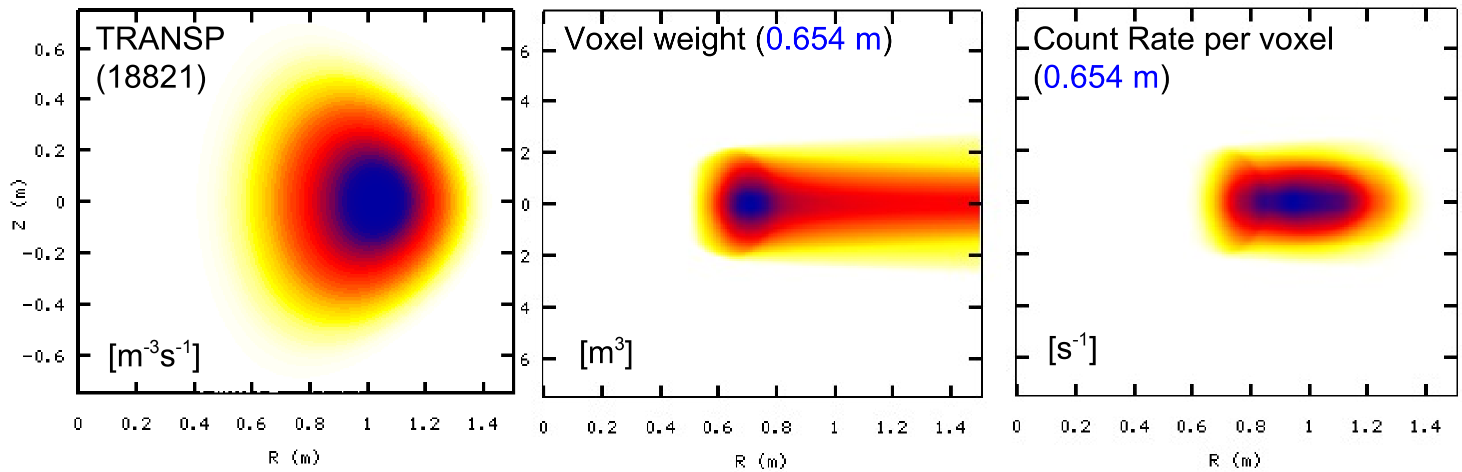
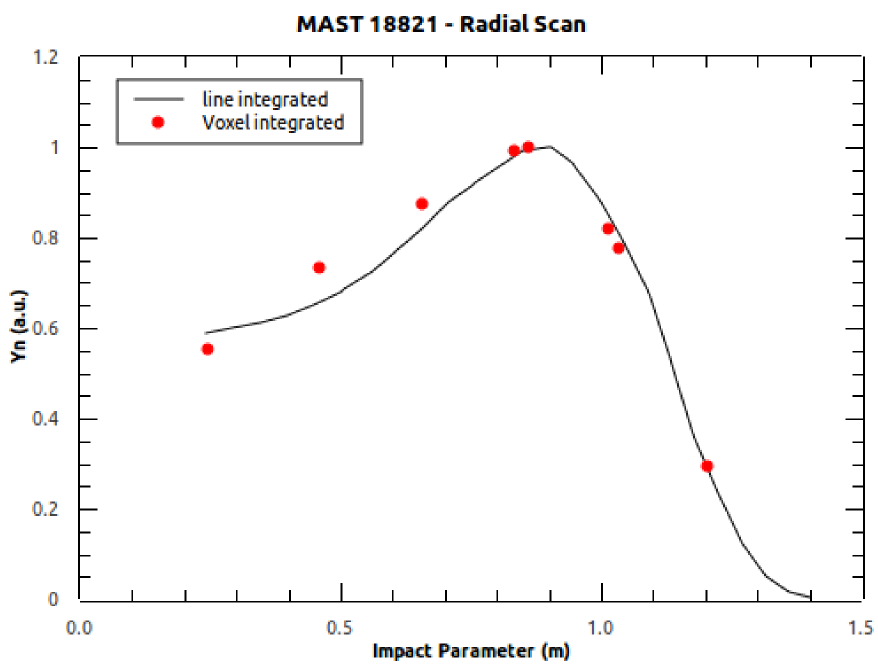
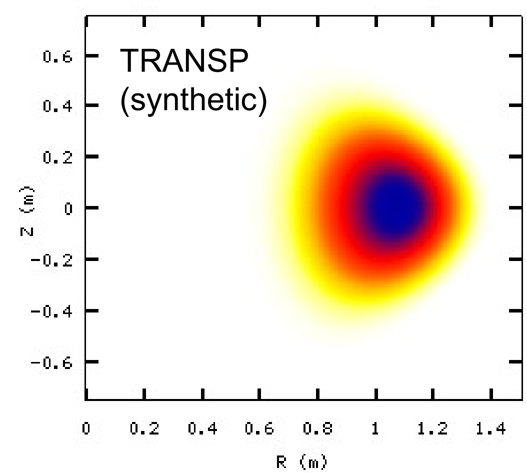
Neutron emissivity integrated in the volume within the field of view of each collimator.




TRANSP profile used to generate a synthetic profile to be used for comparison with experimental data

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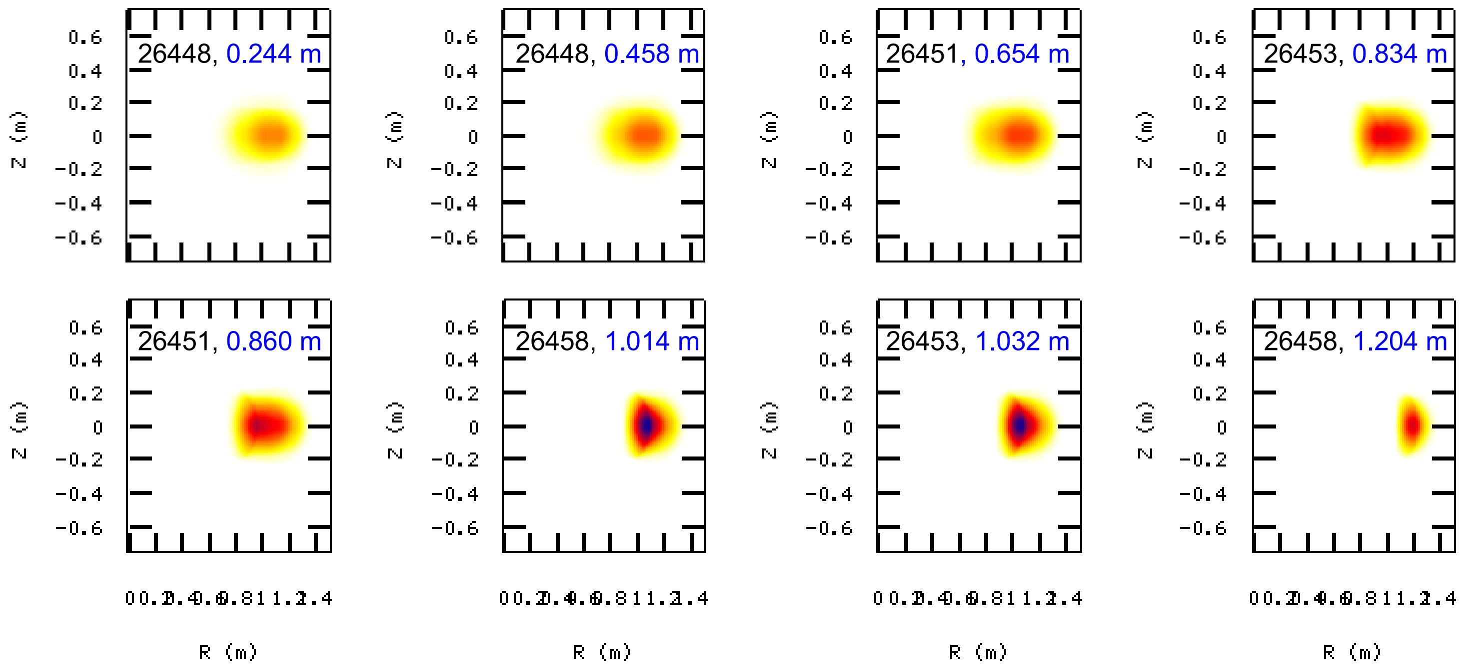
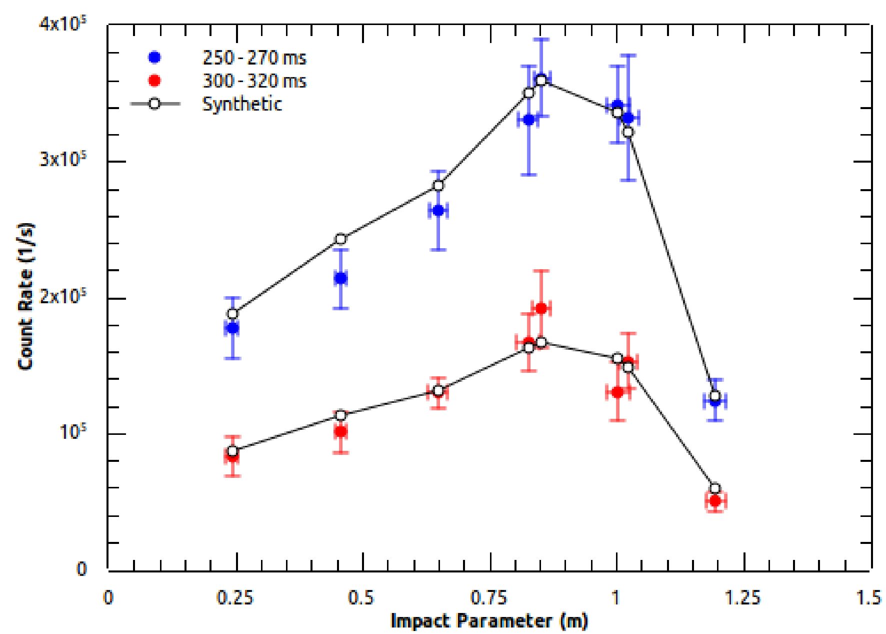
# TRANSP x LINE21 and experimental data




Comparison with experimental data, using a synthetic neutron emissivity profile:

1) detector efficiency, pile-up rejection
2) thin flange attenuation
3) back-scattering
4) anisotropic neutron emission

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# Future activities and developments



1] Absolute flux and pulse height spectra calculations:

controlroom

**D**irectional **RE**lativistic **S**pectrum **S**imulator (DRESS)

LOCUST

TRANSP

2] Detector response functions:

NRESP7, PRESP4, MCNP

3] Participation to experimental campaign M8

Neutral Beam Current Drive experiment

4] Design of a neutron camera upgrade for MAST–U

A neutron camera is on the list of high-priority diagnostics for MAST-U and space has been already reserved.

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# Conclusions

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Relatively young diagnostic (about 100 pulses old, no dedicated experiments to date) but:

1) fully operational (minor glitches being fixed soon) 4 lines of sight with scanning capability for full radial coverage;

2) MAST pulses repeatability allows for full radial scan, with optimal positioning in between pulse;

3) Time resolution, at present, can be pushed below 1 ms for flux measurements with appropriate statistical error;
pulse height spectra require much longer integration time;

4) Preliminary evidence of MHD effects on the volume integrated neutron emissivity that can be coupled to changes in the neutron profile emissivity following fast ions redistribution;

5) Still many exciting things to do!