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Durham University

TRANSP use for Neutron and Fast Ions interpretation at MAST and JET

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TRANSP User's Group Meeting, PPPL, March 23-24, 2015

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Content

Use of TRANSP at **MAST** for forward modelling of:

- neutron camera measurements: routine
- FIDA diagnostic (with FIDASIM): routine
- Charged Fusion Product Detector (W. Boeglin, R. Perez from FIU and D. Darrow from PPPL): in progress

Use of TRANSP at **JET** for forward modelling of:

- TOFOR & MPRu neutron spectrometer data

Physics topics for which TRANSP is used:

- fast ion physics: confinement and redistribution
- sawtooth
- current drive (see D. Keeling presentation)
- neutron spectrometry analysis
- fuel ion ratio in DD and DT plasmas

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MAST

Mega Ampere Spherical Tokamak:

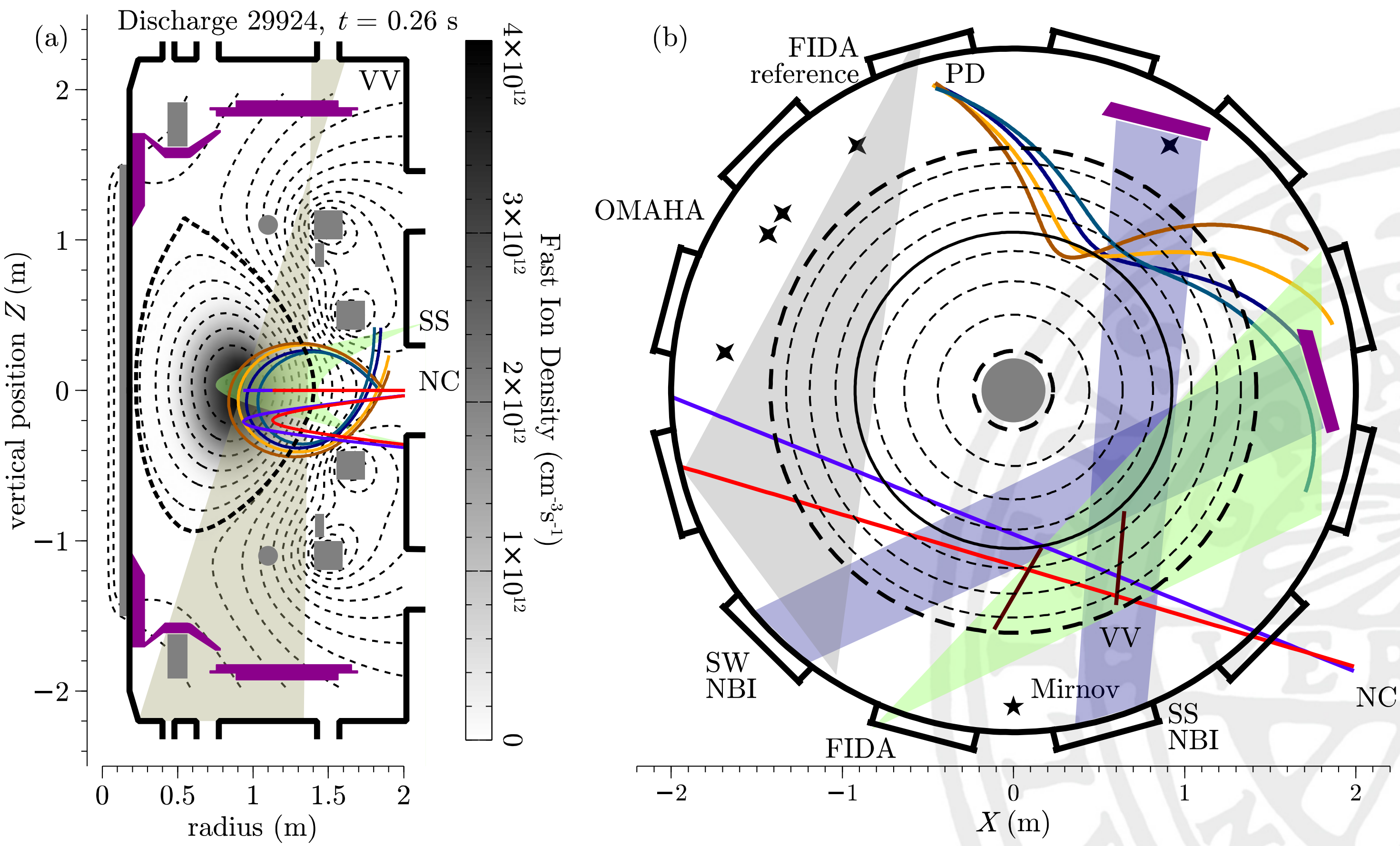
- Aspect ratio $R/a \approx 1.3$ ($R \approx 0.85$ m, $a \approx 0.65$ m)
- high elongation $1.5 \leq \kappa \leq 2.5$
- high triangularity $\delta \leq 0.5$
- plasma current $I_p \leq 1.5$ MA
- electron temp. $T_e \leq 2$ keV
- plasma density $n_e \approx 0.1 - 1.0 \times 10^{20}$ m^{-3}
- toroidal field $B_T \approx 0.35 - 0.6$ T (at $R \approx 0.75$ m)
- NBIs $P_{NBI} \leq 5$ MW, $\leq$ 75 keV D ions
  $v_{NBI} \approx 2.5\, v_A$

Fast Ion Diagnostics (FIDs):

- Vertical and tangential Fast Ion D_a (FIDA) system
- Fission chamber, D_a edge monitors
- Prototypes:
  - Neutron Collimated flux monitor (NC)
  - Charged Particles Detector array (CPD)

Fast ions in MAST

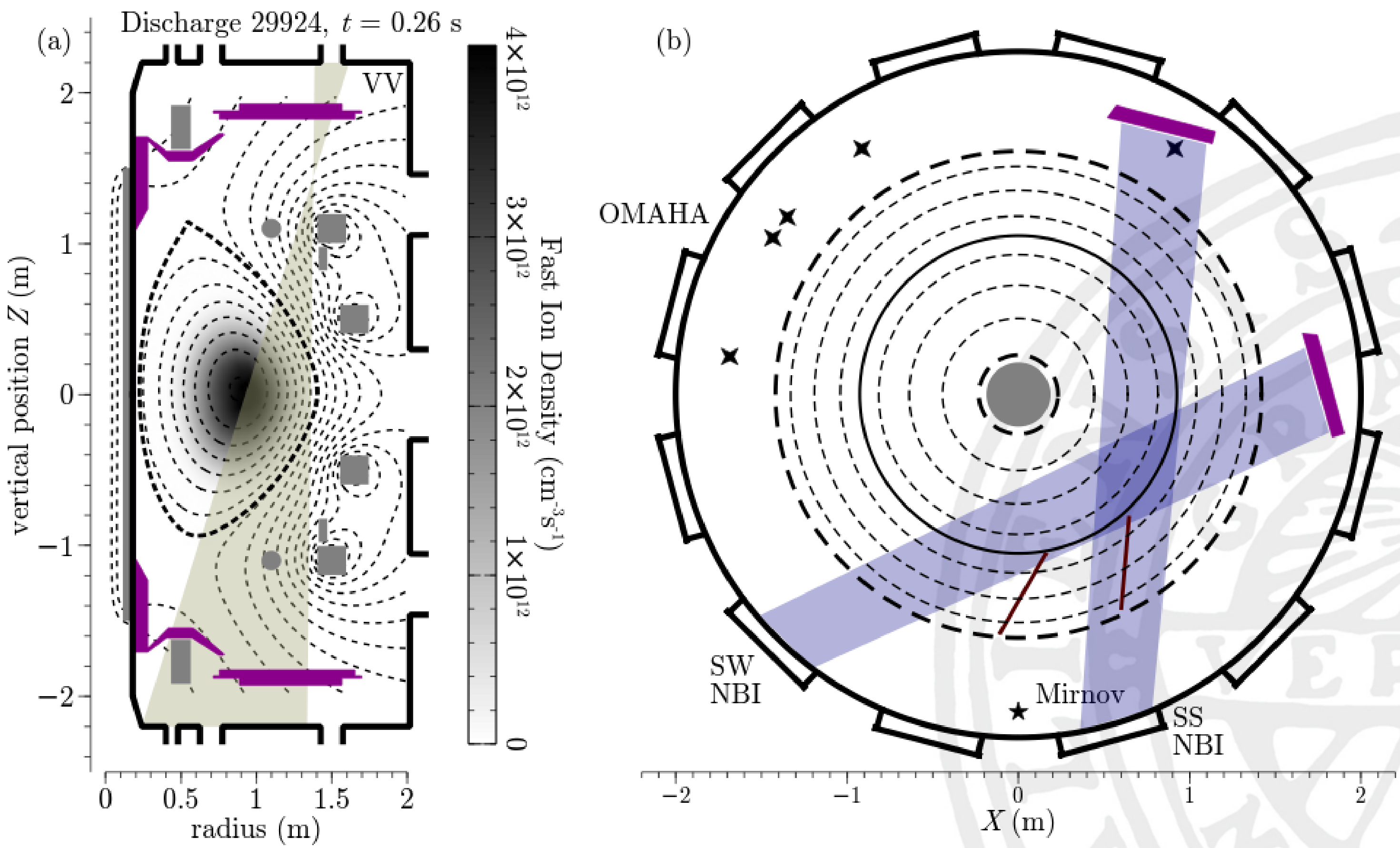
Typically 90 % of DD reactions are: $D_{fi} + D_{th} \rightarrow {}^3He + n$; $D_{fi} + D_{th} \rightarrow T + p$



Vertical Fast Ion D-α diagnostic

Time resolution: 1 ms
Spatial coverage: 0.9 – 1.4 m
Fast ion range: 5 – 70 keV
Sensitive mainly to trapped fast ion population

$$D_{fi} + D_{th} \rightarrow \begin{cases} {}^{3}He + n \\ T + p \end{cases}$$



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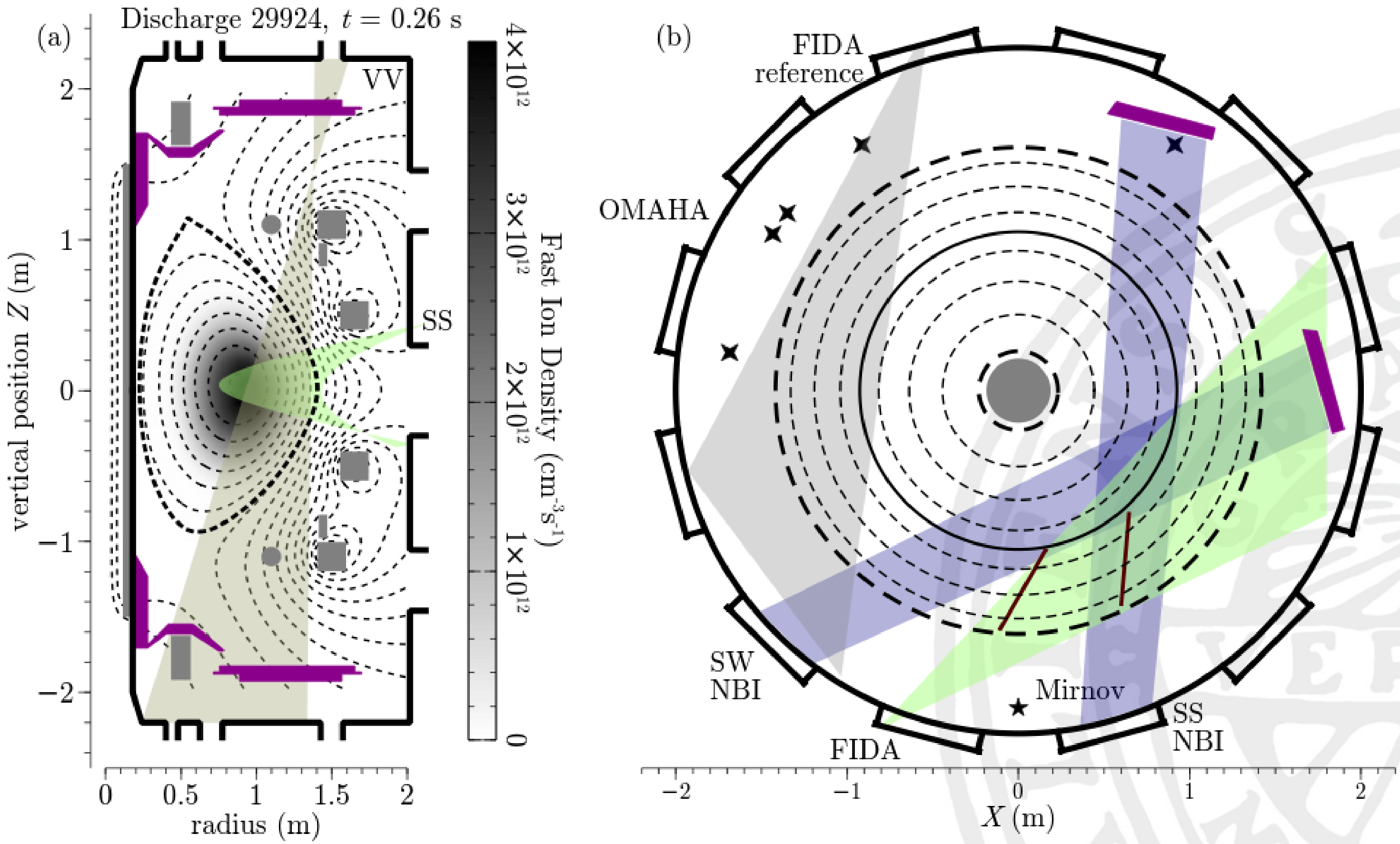
Tangential Fast Ion D-α diagnostic

Time resolution: 1 ms
Spatial coverage: 0.8 – 1.4 m
Fast ion range: 30 – 70 keV
Sensitive mainly to the passing fast ion population

$$D_{fi} + D_{th} \rightarrow \begin{cases} {}^3He + n \\ T + p \end{cases}$$



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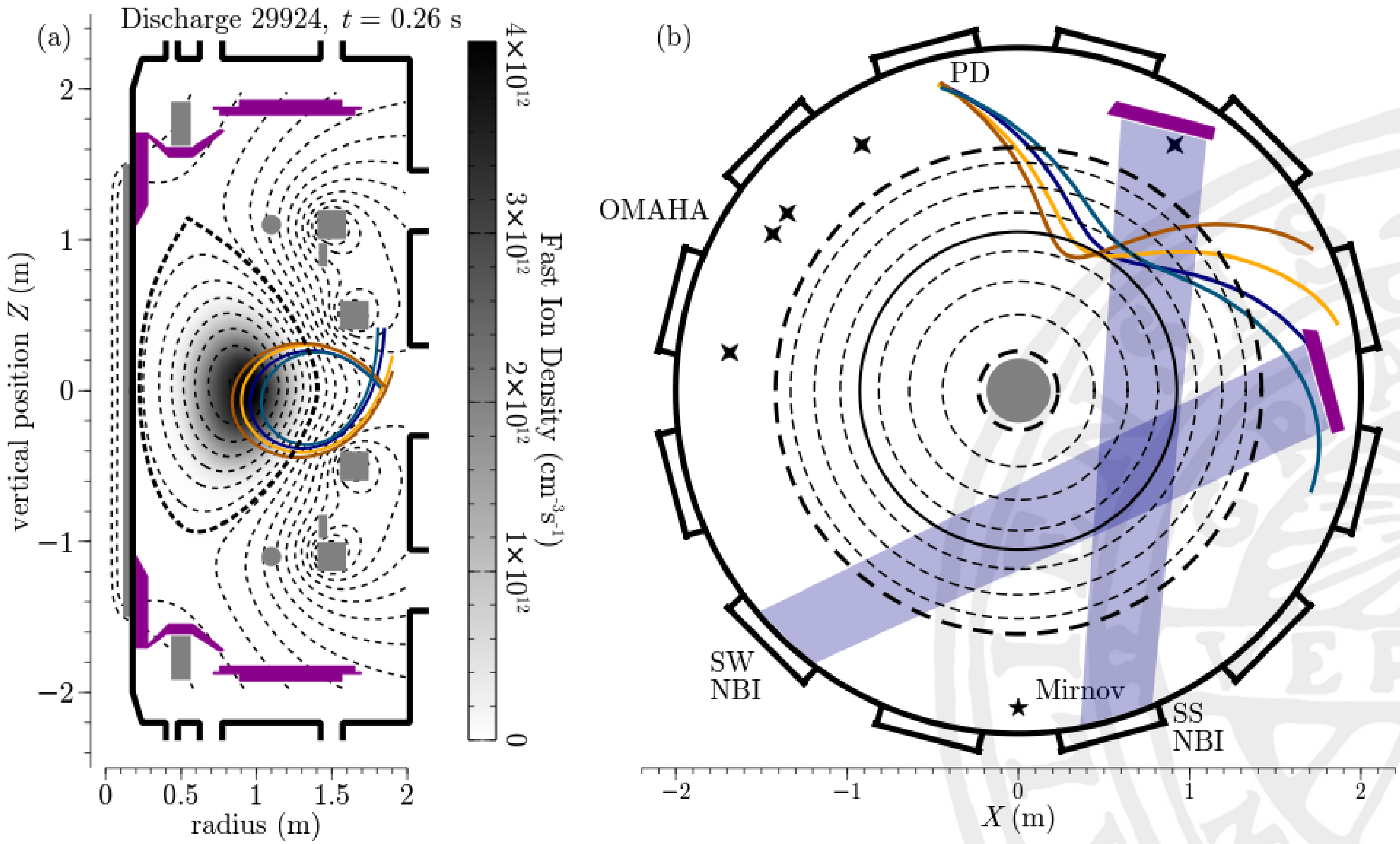
Charged Particles Detector

Number of channels: 4
Time resolution: 1 ms
Spatial coverage: 0.8 – 1.4 m
Sensitive to: protons and tritons (simultaneously)

$$D_{fi} + D_{th} \rightarrow {}^{3}He + n$$
$$D_{fi} + D_{th} \rightarrow T + p$$



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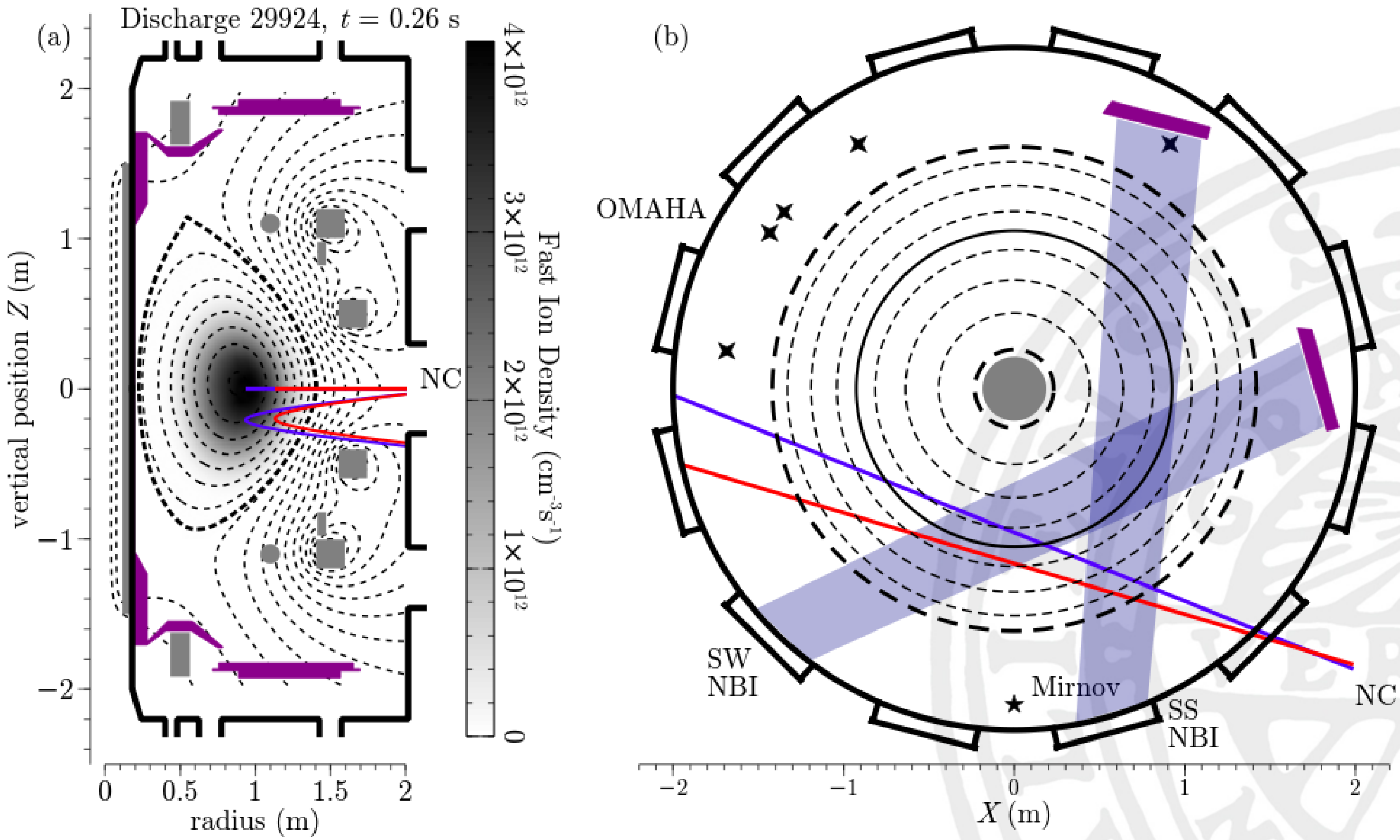
Neutron collimated flux monitor

Number of channels: 4 (2 mid-plane, 2 diagonally inclined)
Time resolution: 1 ms
Spatial coverage: 0.2 – 1.3 m
Sensitive to: neutrons above 1 MeV

$$D_{fi} + D_{th} \rightarrow \begin{cases} {}^{3}He + n \\ T + p \end{cases}$$



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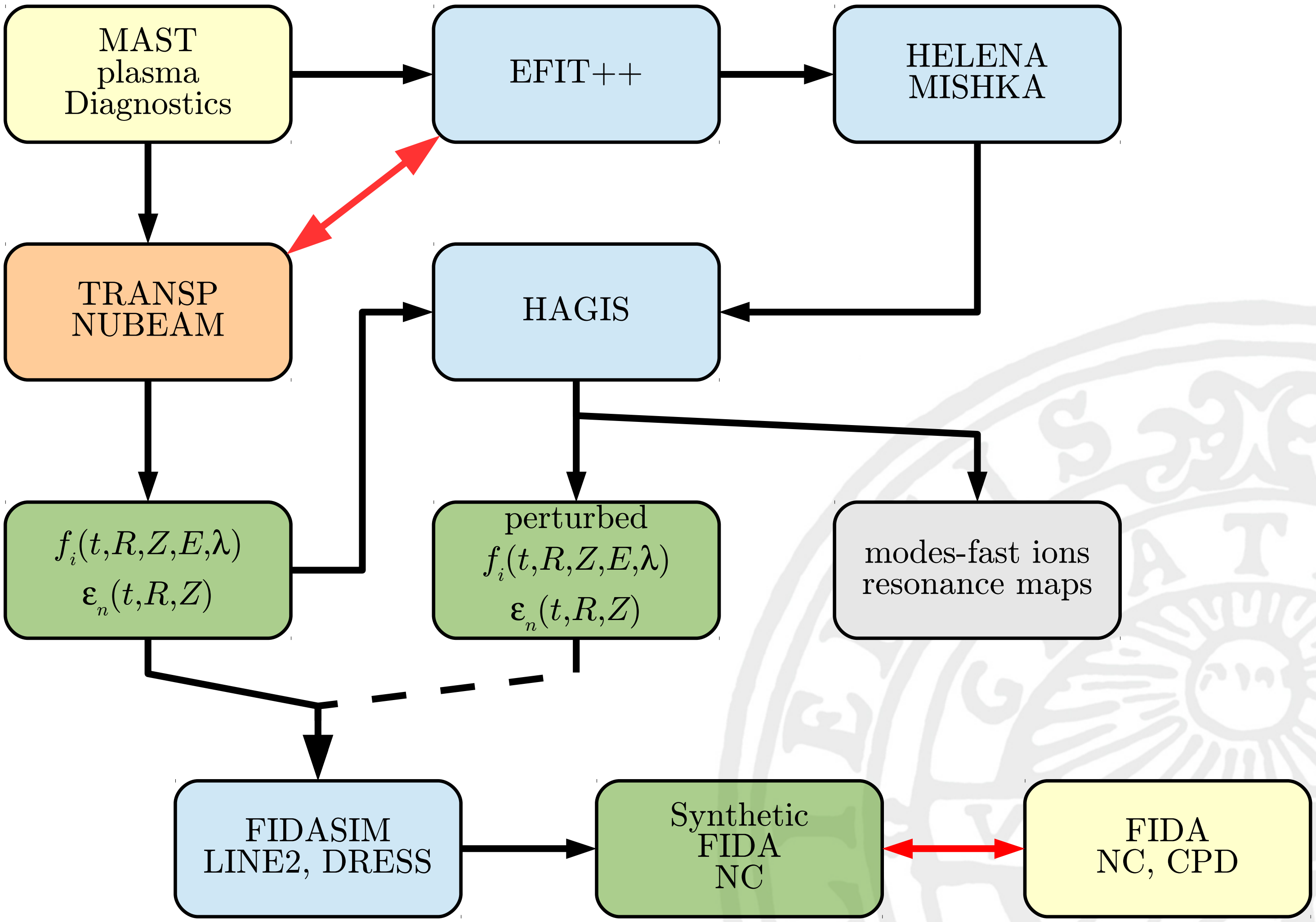
Forward Modelling



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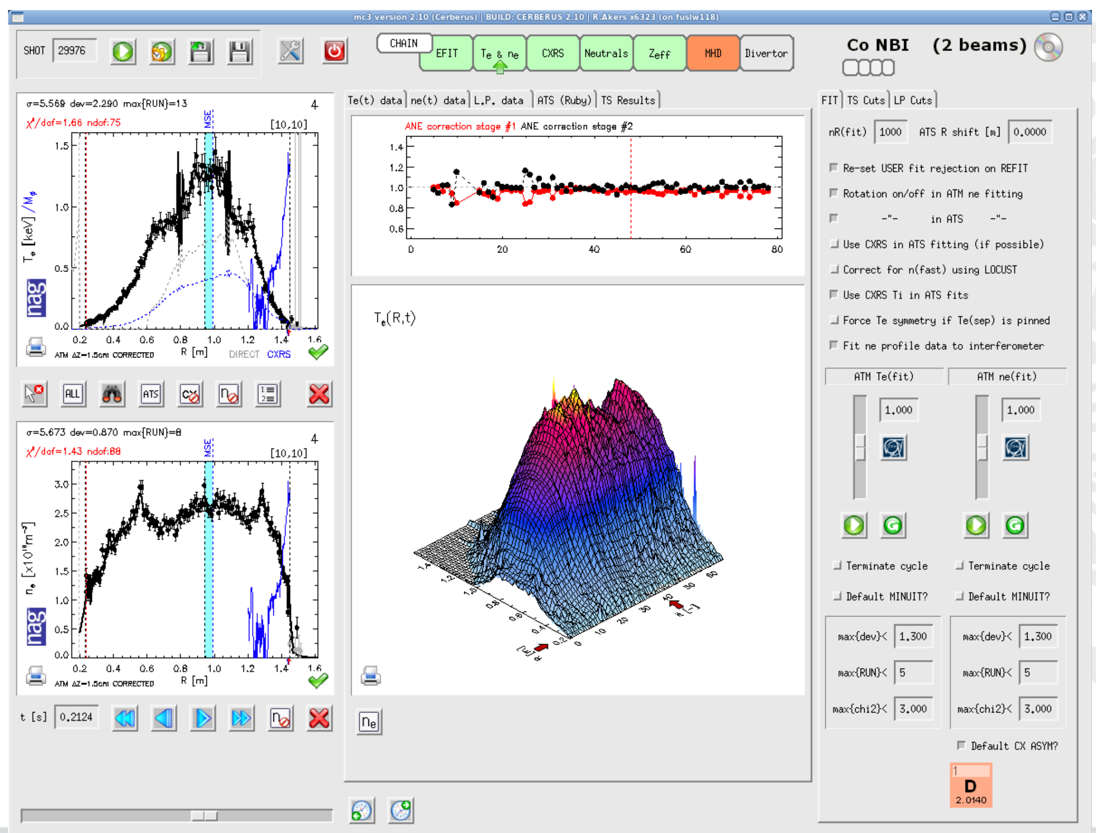
TRANSP input preparation

The MAST Chain Control Centre - mc^3 - is an interactive data preparation tool developed by Rob Akers at CCFE to allow the user to generate a self consistent set of MAST data for TRANSP.

Extremely power and flexible:

- data from multiple diagnostics integrated (TS, CXRS, MSE, FC, Neutrals, magnetics, Zeff, …) and mapped onto EFIT flux surfaces
- EFIT flux surfaces detailed analysis
- MSE constrained
- multiple smoothing/ interpolation methods
- time slicing
- FI pressure from TRANSP
- iterative equilibrium reconstr. with diagnostics constrains
- automatic generation of UFILES
- interactive generation of TR.DAT file



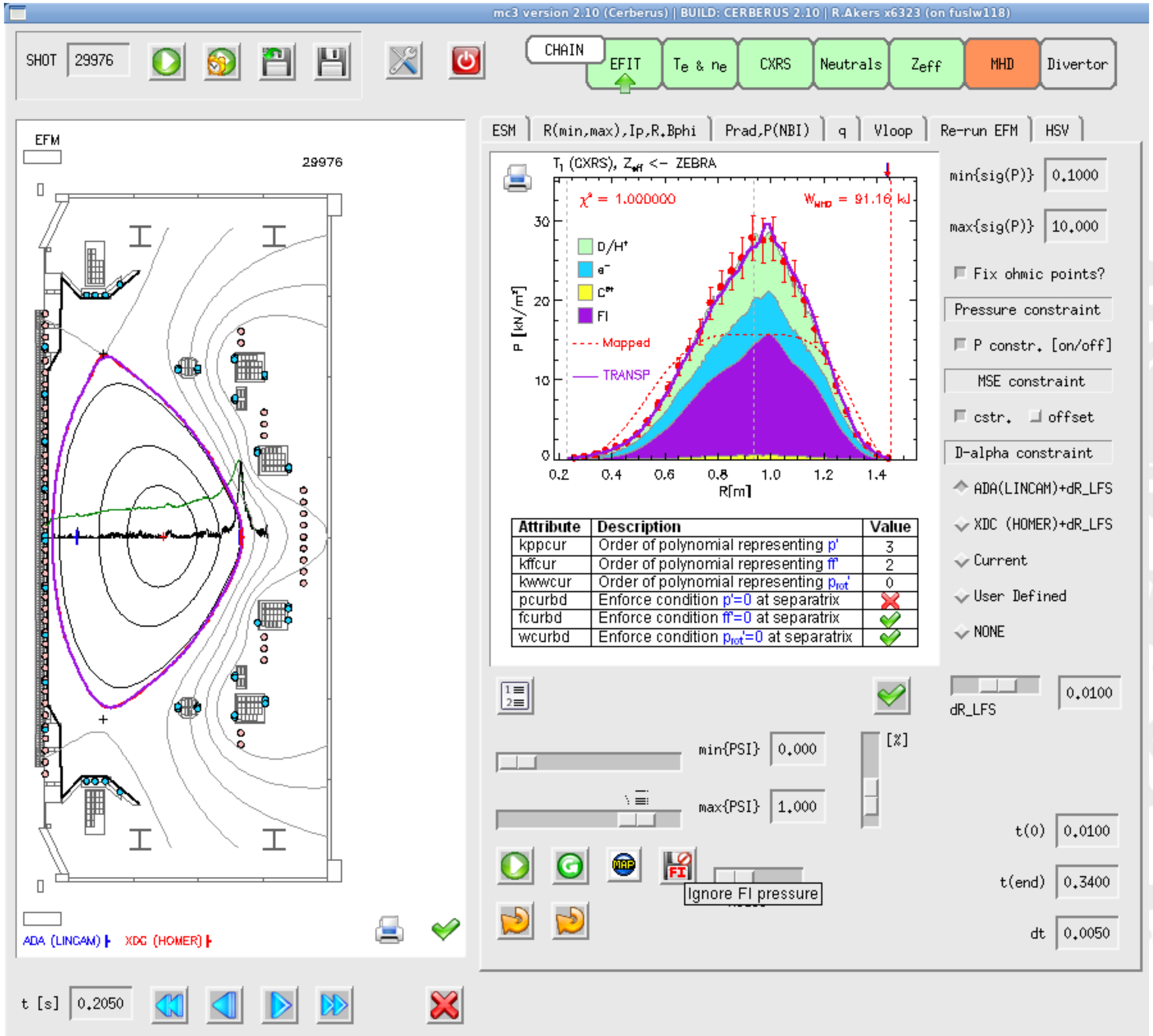
TRANSP and MC^3 for FI pressure

TEQ solver in TRANSP (from CORSICA) cannot account for:

1) pressure anisotropy
2) toroidal flow

NUBEAM used to determine the FI velocity distribution function and pressure:

$$f_{\mathrm{FI}}(R, Z, E, p)$$



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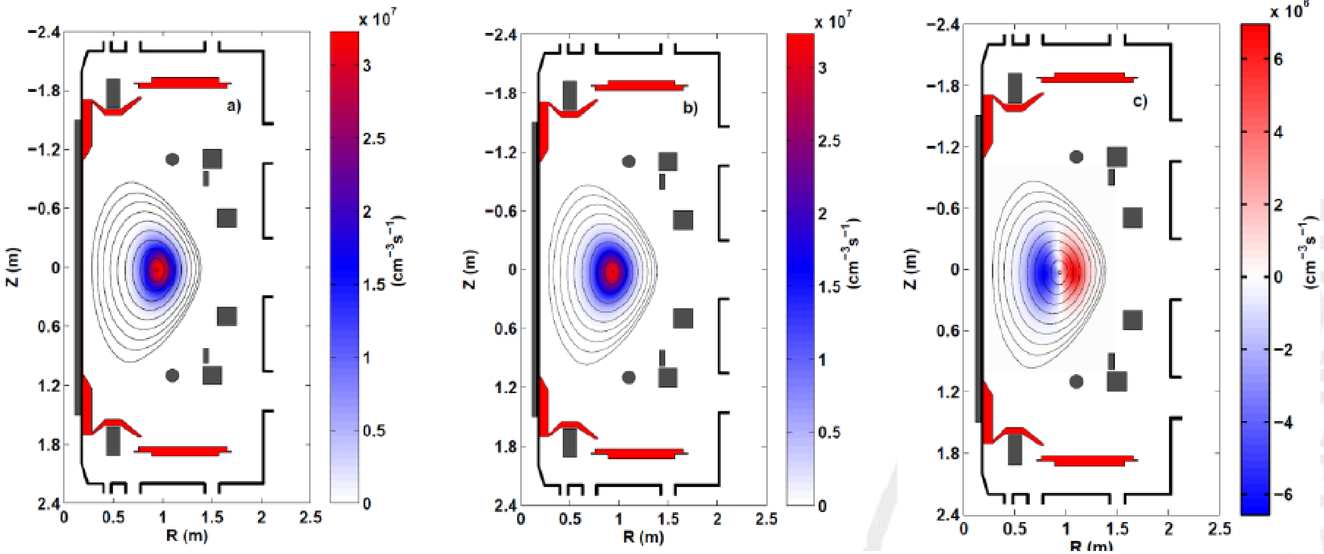
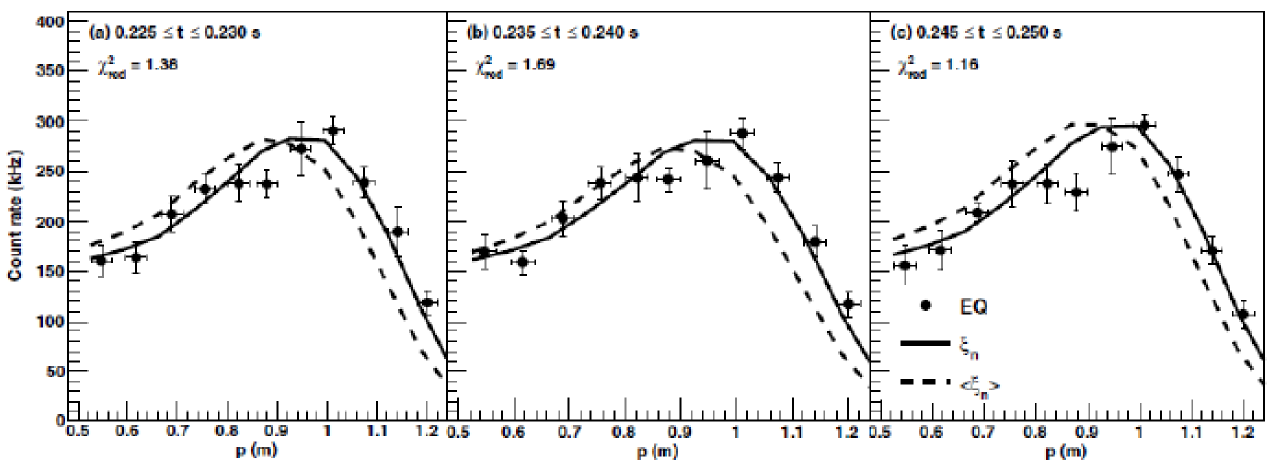
TRANSP modelling of NC measurements

Field of view of NC not pencil-like: non-flux averaged neutron emissivity required.





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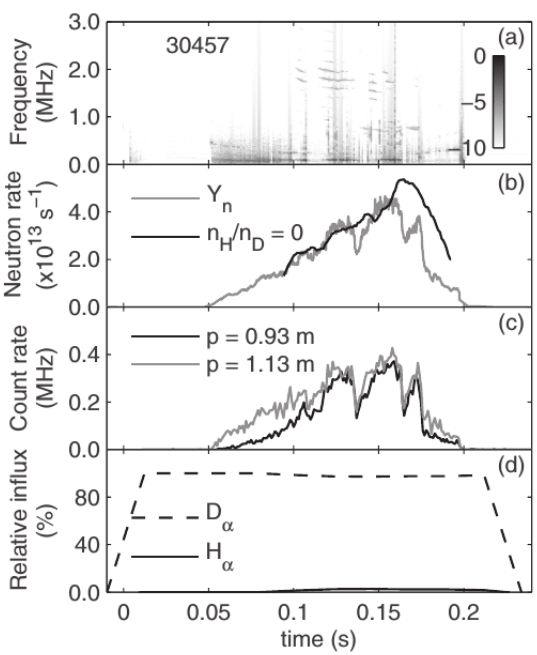
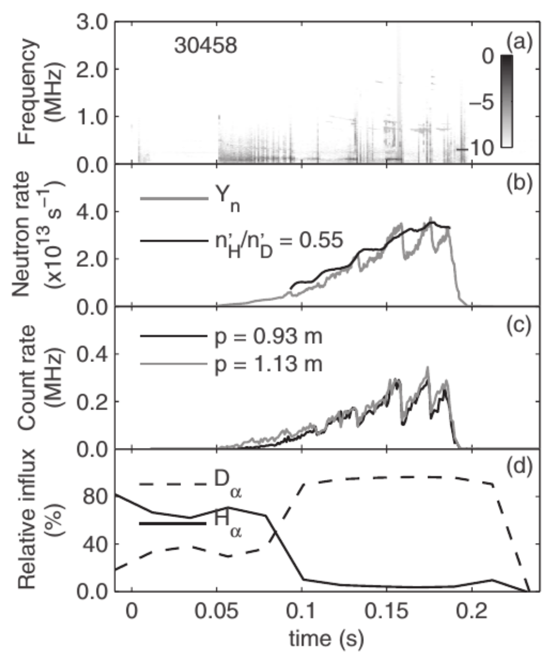
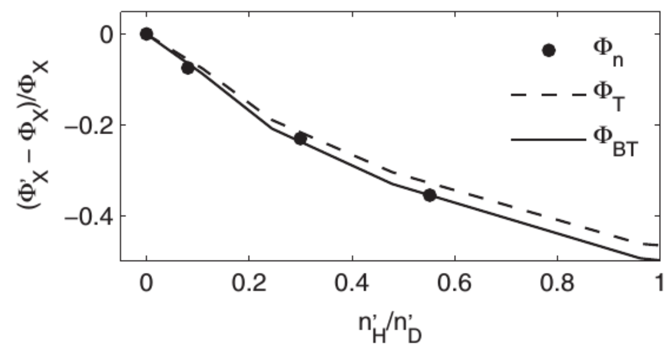
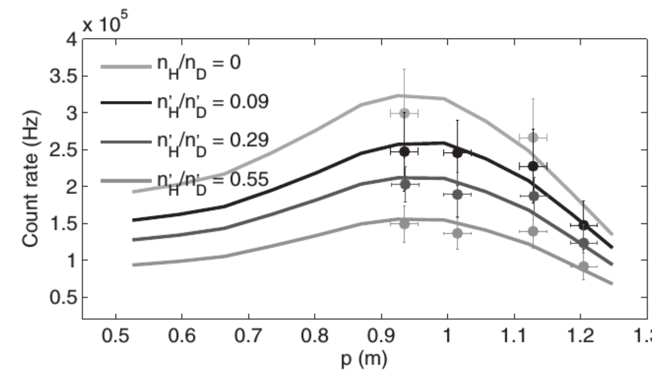
TRANSP modelling of NC measurements: H/D ratio

Plasma discharge	Hydrogen puff (ms)	n'_H/n'_D Eq. (1)	n'_H/n'_D TRANSP
30457	0	0	0
30460	40	0.08	0.09
30464	65	0.30	0.29
30458	75	0.55	0.55

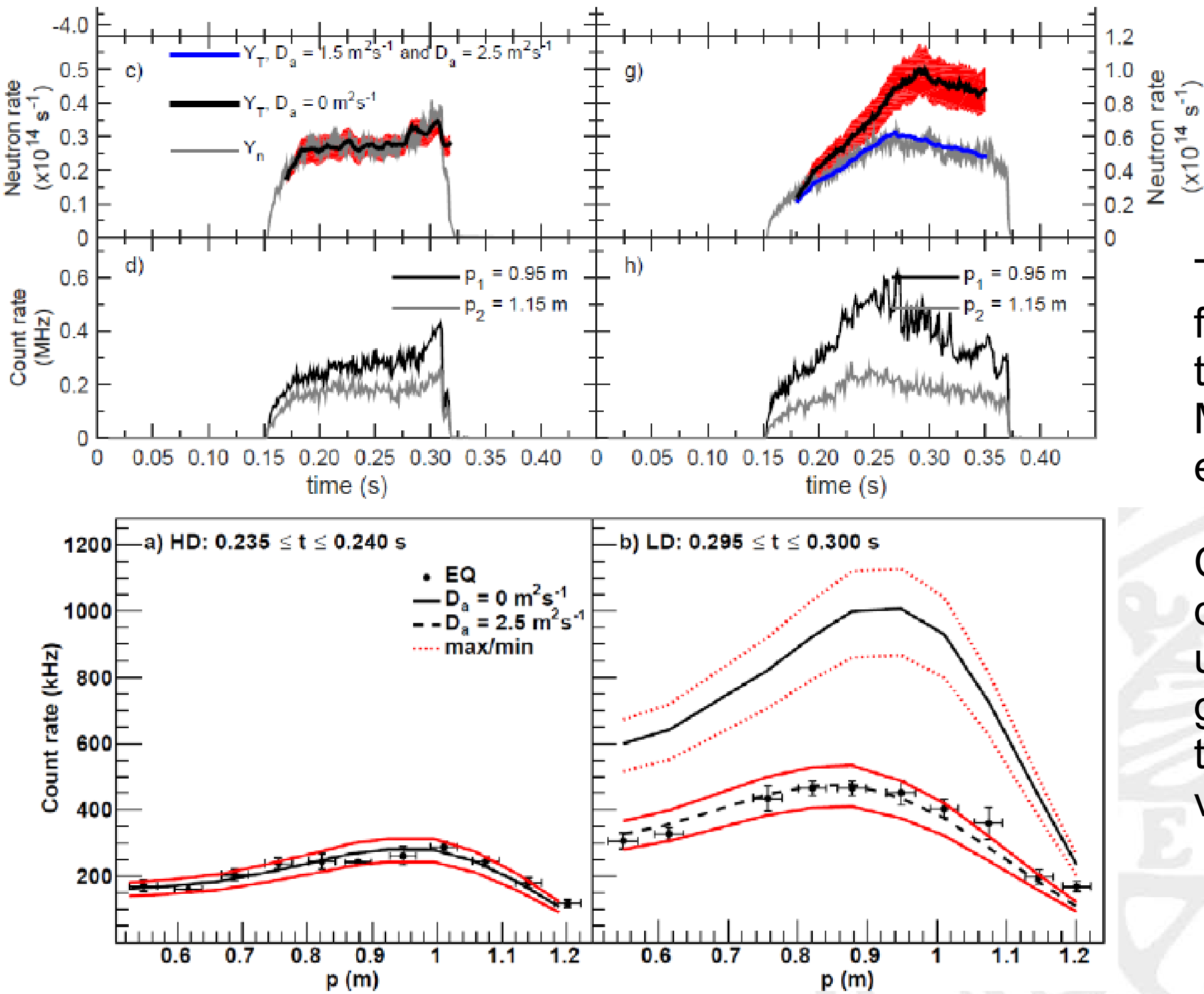








TRANSP modelling of NC measurements: AFID



Time-dependent anomalous fast ion diffusion necessary to reproduce FC and NC Measurements within experimental errors.

Choice of appropriate diffusion coefficient usually enough to get good agreement but for those scenario with very strong MHD activity

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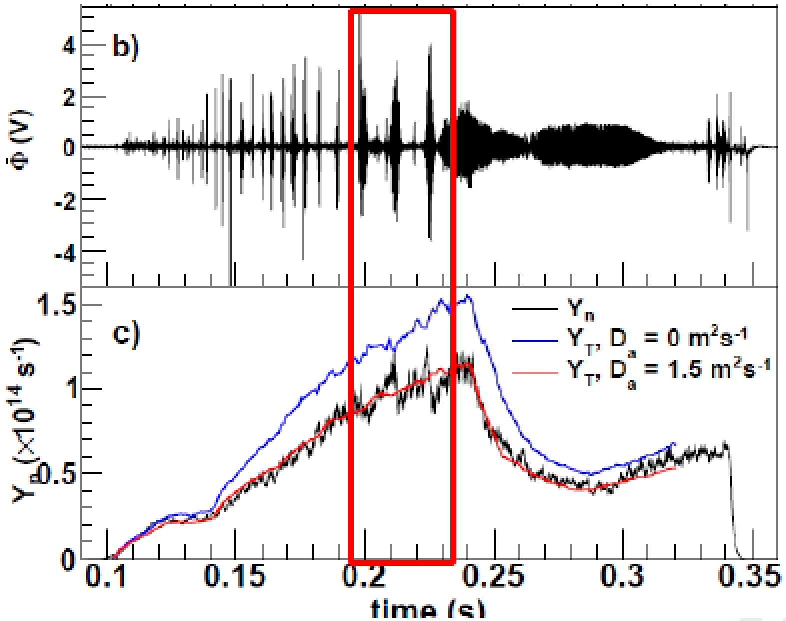
TRANSP modelling of NC measurements: fishbones



Effect on fast ion distribution function:

- Loss Model 1: energy and $v_{\parallel}/v$
- Loss Model 2: energy and T_{DEPTH}

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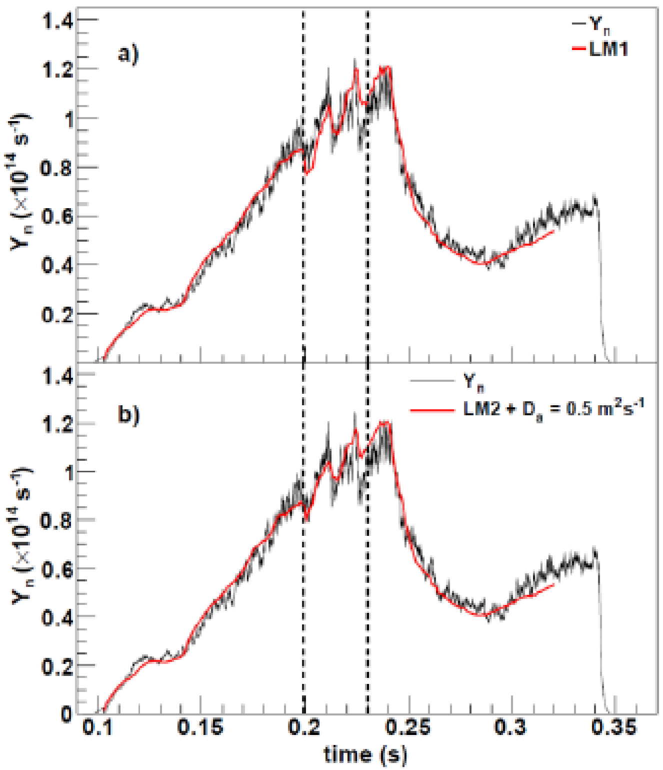
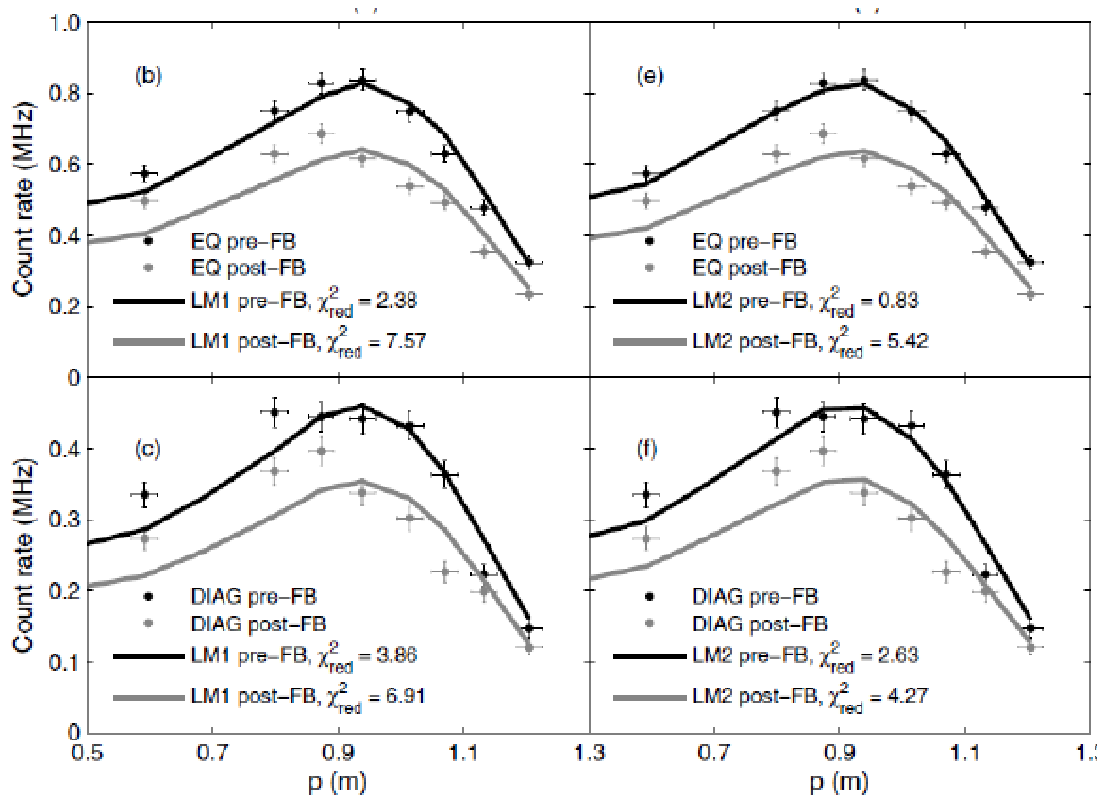
TRANSP modelling of NC measurements: fishbones

LM1:
$E \geq 55$ keV
$-0.5 \leq v_{||}/v \leq 0.5$

LM2:
all trapped ions
$E \geq 37$ keV
$+ D_a = 0.5\ m^2s^{-1}$

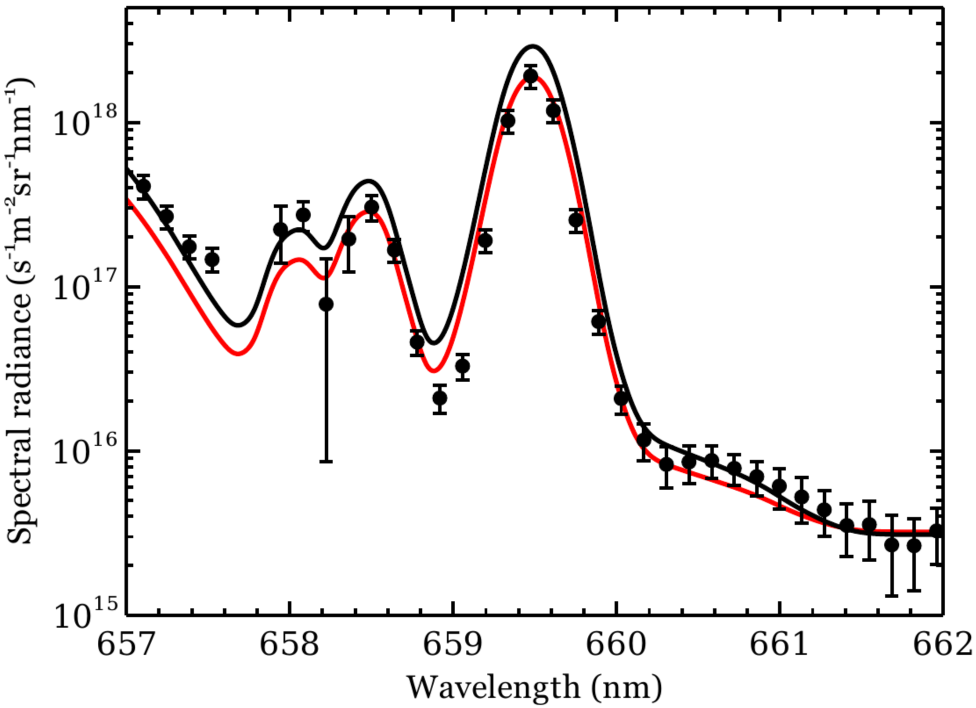




TRANSP use for modelling of FIDA measurements

NUBEAM models the FI from beam injection to thermalization including CX loss process but does not provide the re-neutralized FI trajectories nor distribution among atomic levels.

FIDASIM with FI distributions from TRANSP/NUBEAM used to simulate FIDA measurements on MAST



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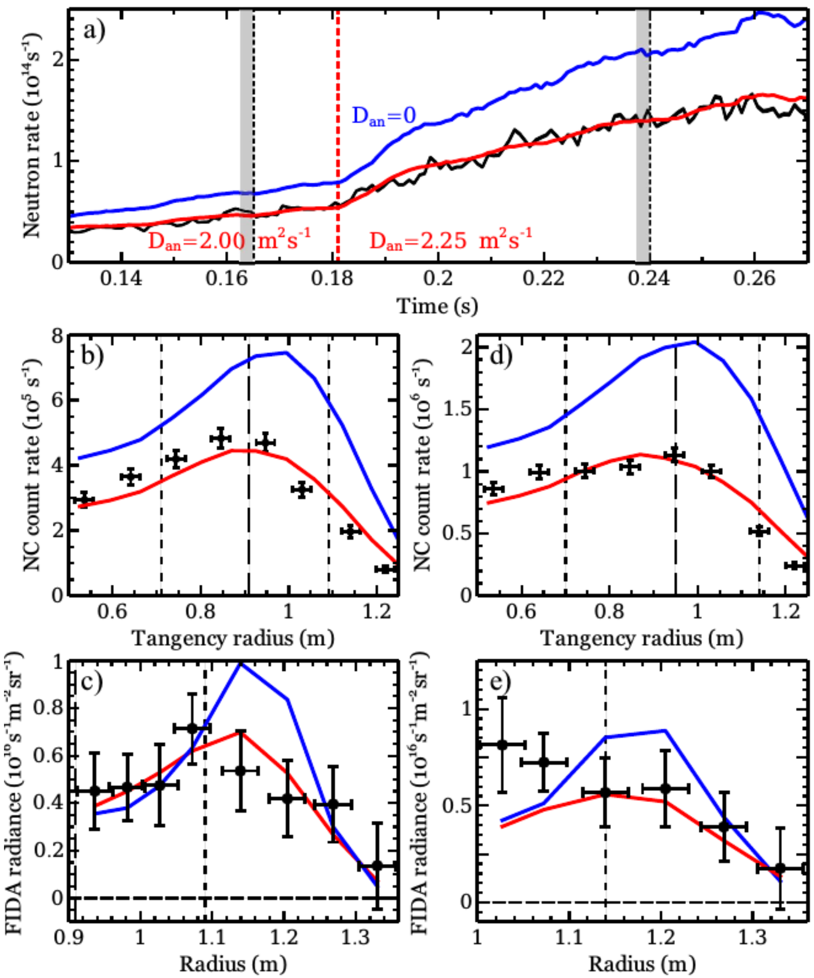
TRANSP/NUBEAM modelling of NC & FIDA measurements: an integrated approach

Example of the same TRANSP run output used to simulate:

- NC via LINE2
- FIDA via FIDASIM

In presence of TAEs using the anomalous fast ion diffusion coefficient.



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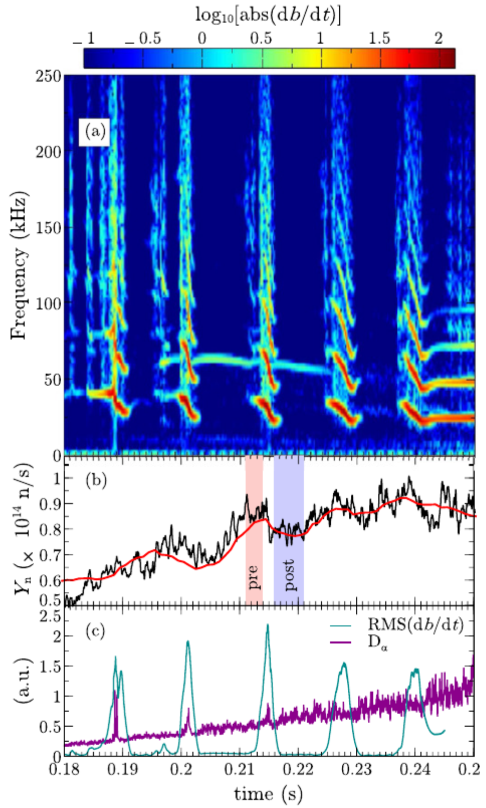
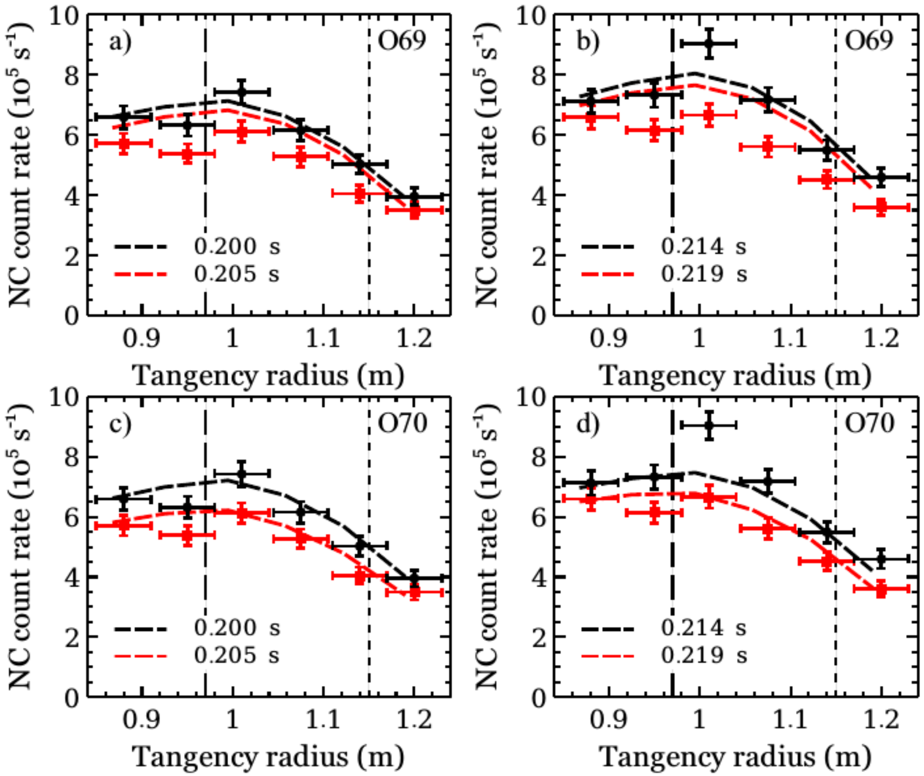
TRANSP/NUBEAM modelling of NC & FIDA measurements: an integrated approach to FBs



Small AFID was applied to FI with $E \leq 75$ keV



50 keV ≤ E ≤ 75 keV
0.69 ≤ p ≤ 0.93

Co-passing FI

60 keV ≤ E ≤ 70 keV
0.00 ≤ p ≤ 0.70

Trapped & co-passing

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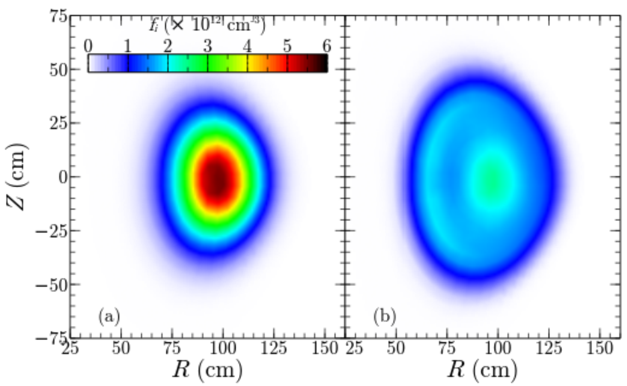
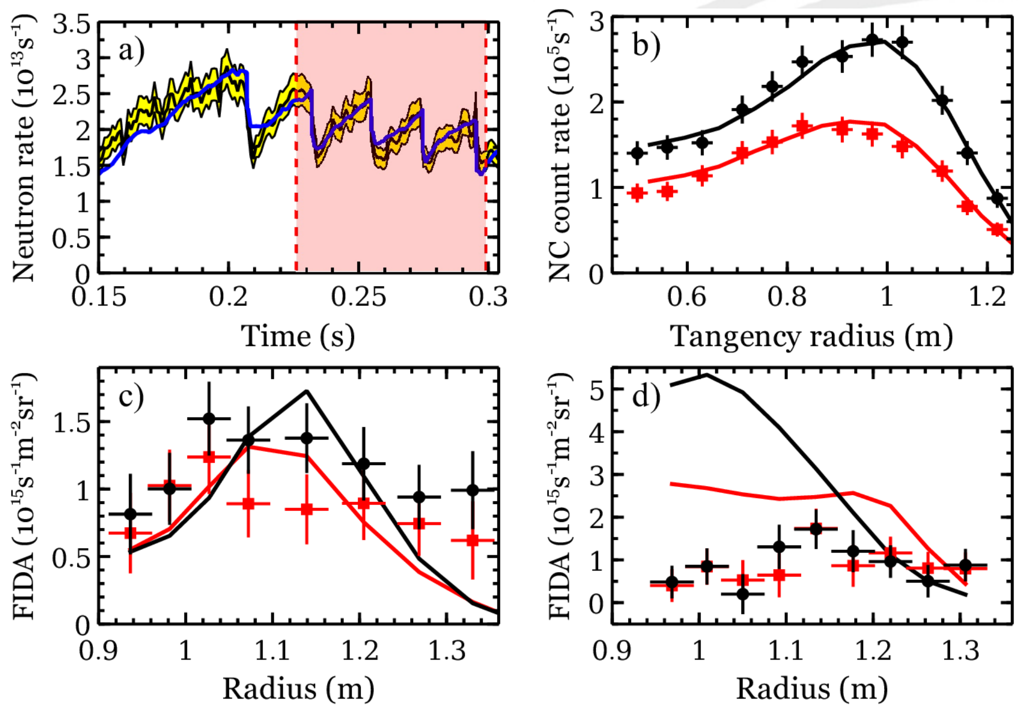
TRANSP/NUBEAM modelling of NC & FIDA measurements: an integrated approach to sawtooth

Kadomtsev mixing model with full mixing (actually mixing parameter not making a huge impact).

TRANSP indicates that the crash causes a large radial redistribution of fast ions from the core to regions of the plasma outside the mixing radius.

Passing fast ion population is reduced at each crash while the trapped population is increased: pitch angle scattering





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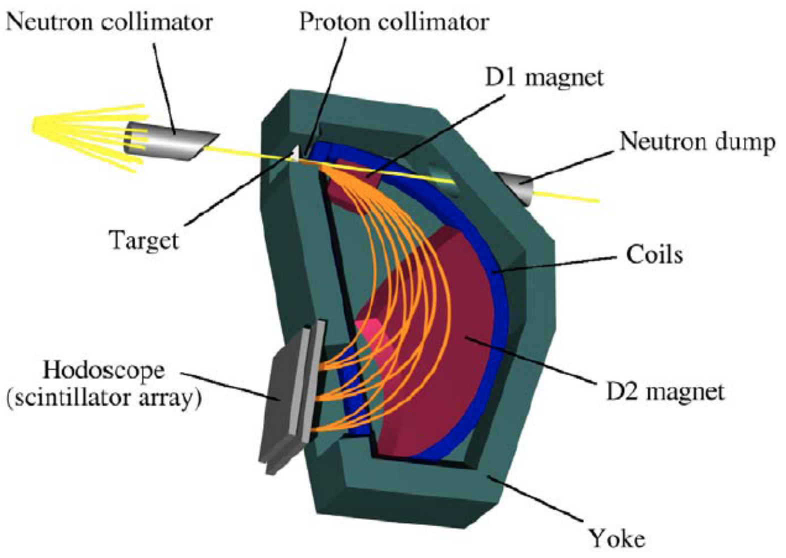
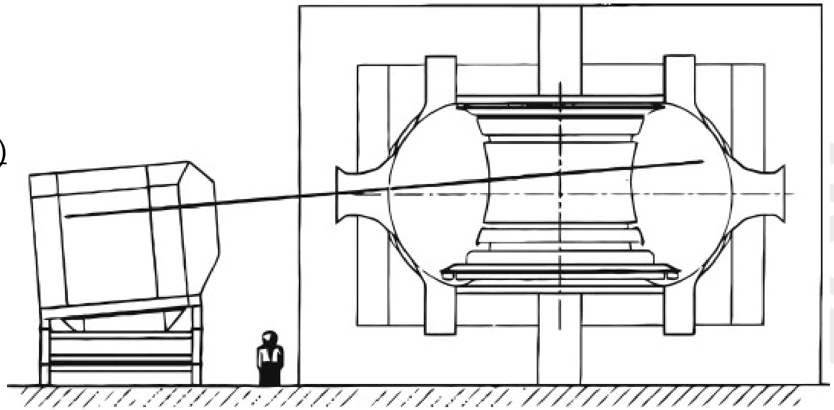
Neutron spectrometer at JET: MPRu

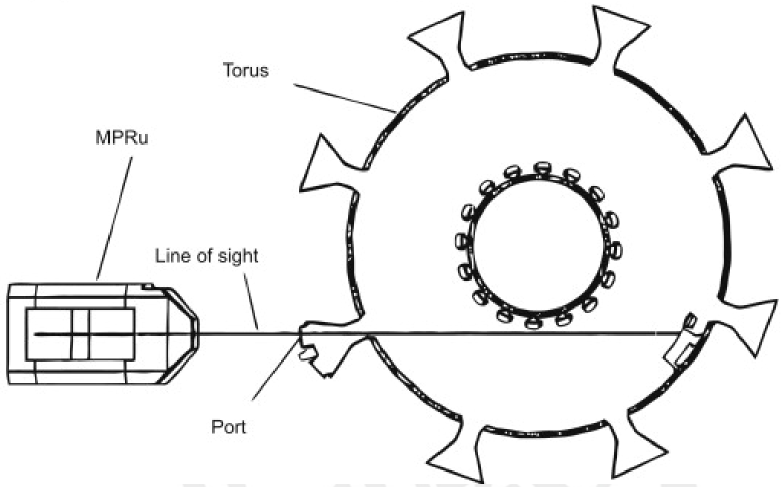
The upgraded magnetic proton recoil (MPRu) spectrometer for DT mainly

- Neutron energies deduced from the positions of elastically scattered protons on an array of scintillators.

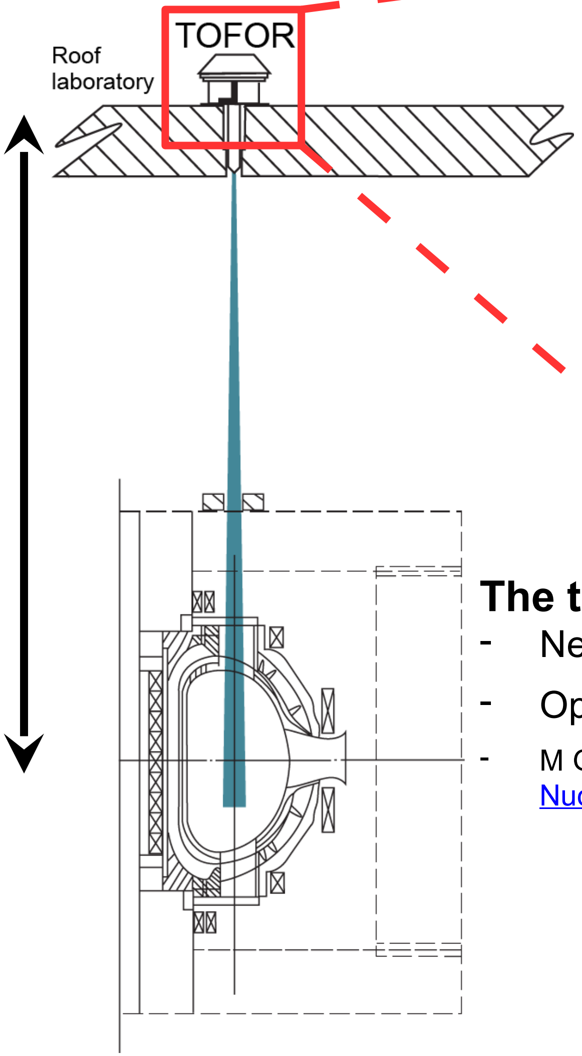
- G. Ericsson *et al*, Review of Scientific Instruments, **72**, 759 (2001)
- E. Andersson Sundén et al, Nuclear Instruments and Methods in Physics Research A, **610**, 682 (2009)

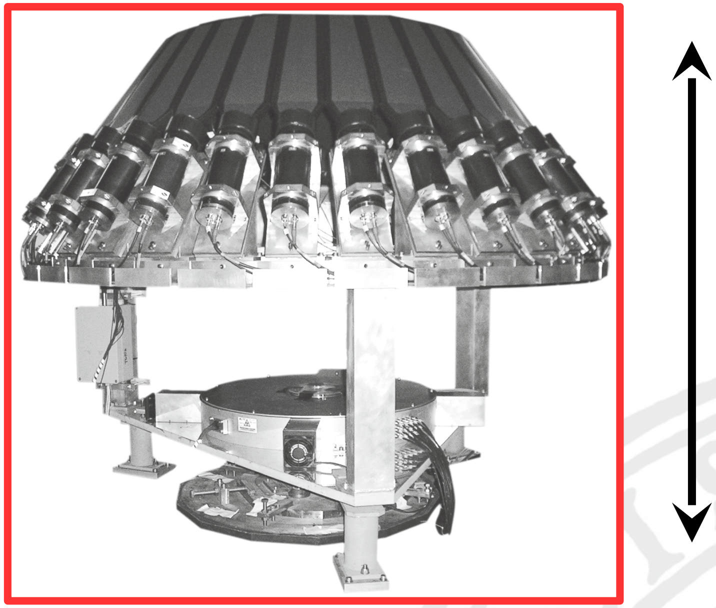






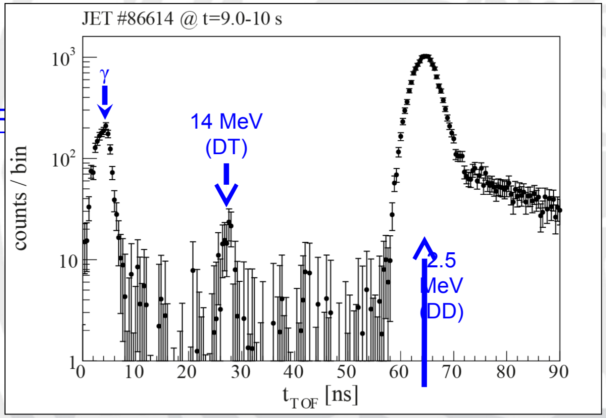
Neutron spectrometer at JET: TOFOR





The time-of-flight spectrometer TOFOR

- Neutron energies deduced from time-of-flight
- Optimized for DD operation
- M Gatu Johnson *et al*, [Nuclear Instruments and Methods in Physics R](#)



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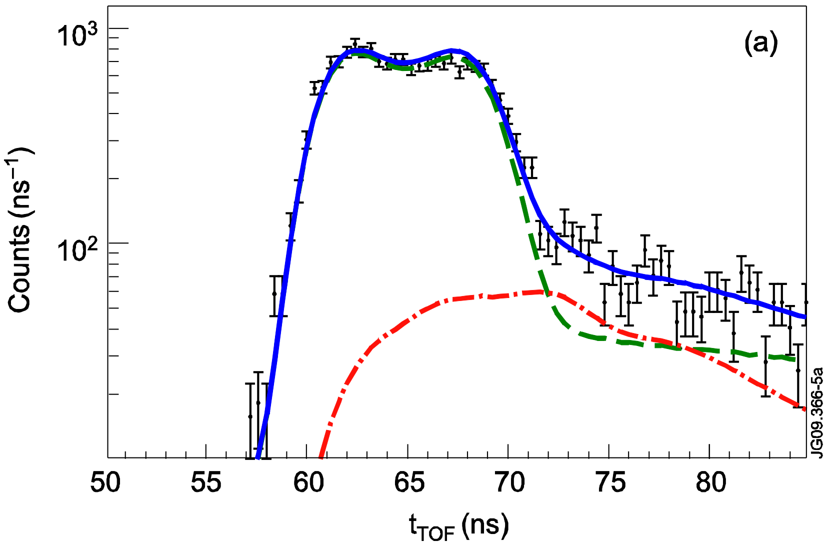
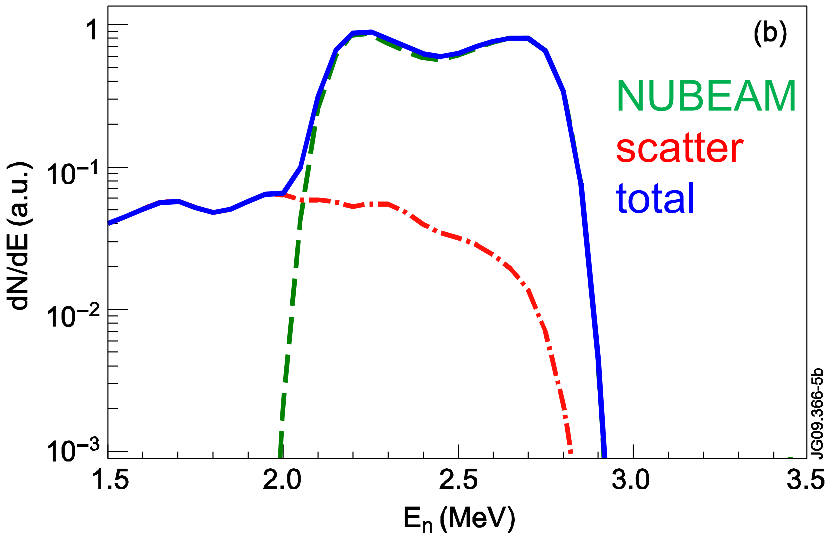
TRANSP for neutron data analysis at JET

- Fast ion distributions from NUBEAM are used for neutron spectrometry analysis
- The expected neutron spectrum from beam-target and beam-beam reactions can be calculated and compared with measured data (C. Hellesen et al, Plasma Phys. Control. Fusion **52** (2010) 085013)
- **RF capabilities in TRANSP would make this framework even more useful**



TOFOR data from JET discharge 68138 heated with 116 keV NBI, and a fit of the calculated spectral components.



Energy representation of the fitted components

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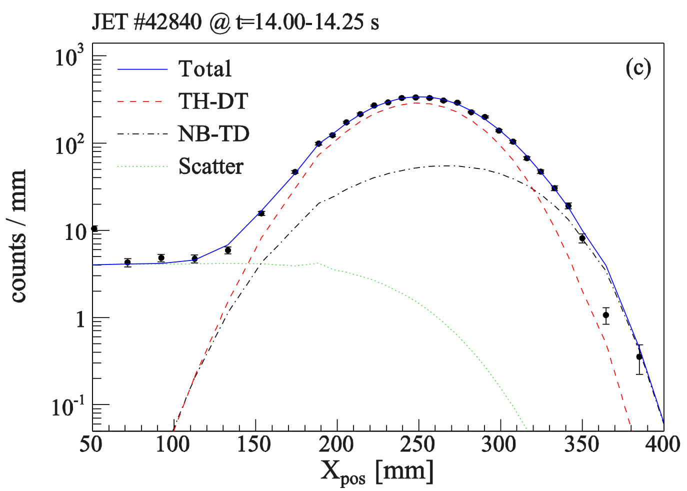
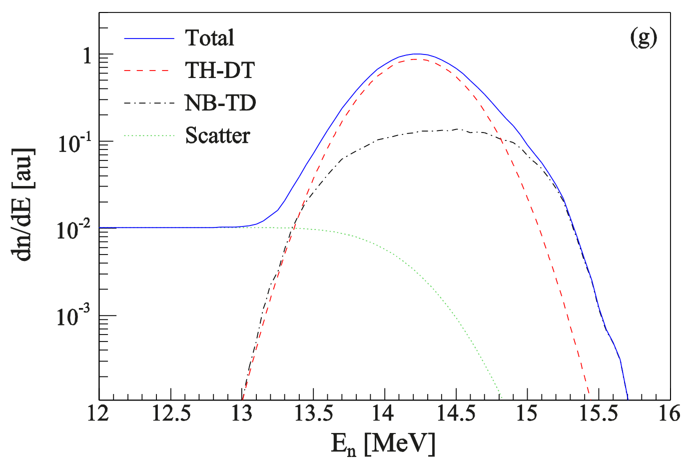
TRANSP for neutron data analysis at JET

- The calculated spectral shapes and the corresponding reactivities can be used to estimate the fuel ion ratio in DT plasmas
  - n_t and n_d are related the components intensities (obtained from the spectral analysis of the data) and the corresponding reactivities (calculated from the NUBEAM distributions)
- n_t/n_d in DT plasmas from the JET DTE1 campaign has been estimated using data from the Magnetic Proton Recoil spectrometer (C. Hellesen, J. Eriksson *et al,* Nucl. Fusion **55** (2015) 023005)



Beam-target T-on D (BT-TD) and thermonuclear DT (TH-DT) neutron emission components fitted to MPR data from JET discharge 42840



Energy representation of the fitted components

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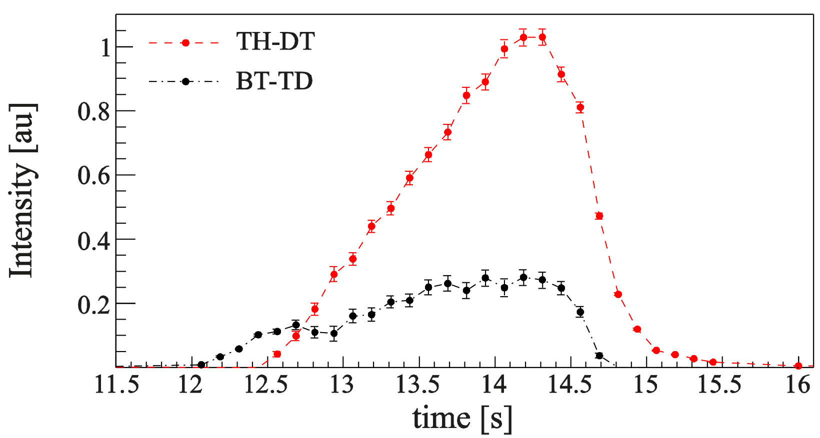
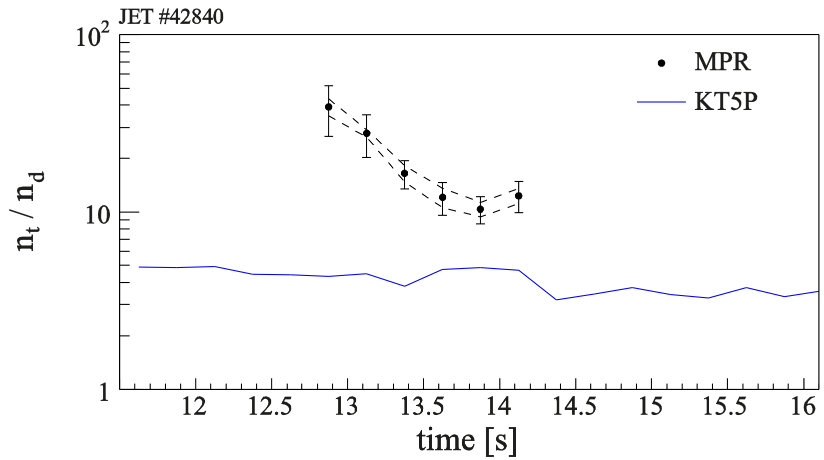


Time evolution of fitted beam-target T-on D (BT-TD) and thermonuclear DT (TH-DT) neutron emission components



Estimated values of n_t/n_d in the plasma core, *compared with Penning trap (KT5P) measurements of* n_t/n_d at the edge

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Wishlist

TRANSP/NUBEAM code

- Faster NUBEAM MC module: 50.000 particles take a long time!
  Needed for smoother FI velocity distribution functions
- SXR synthetic diagnostic
- Integration with orbit following code
- RF heating modelling
- “kick” model for fast ion transport developed by PPPL

TRANSP/NUBEAM user support

- netCDF viewer (http://meteora.ucsd.edu/~pierce/ncview_home_page.html)
- examples
- training sessions

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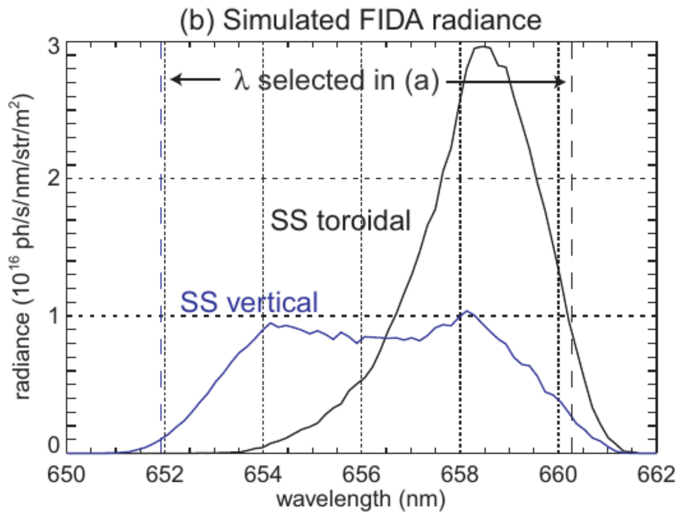
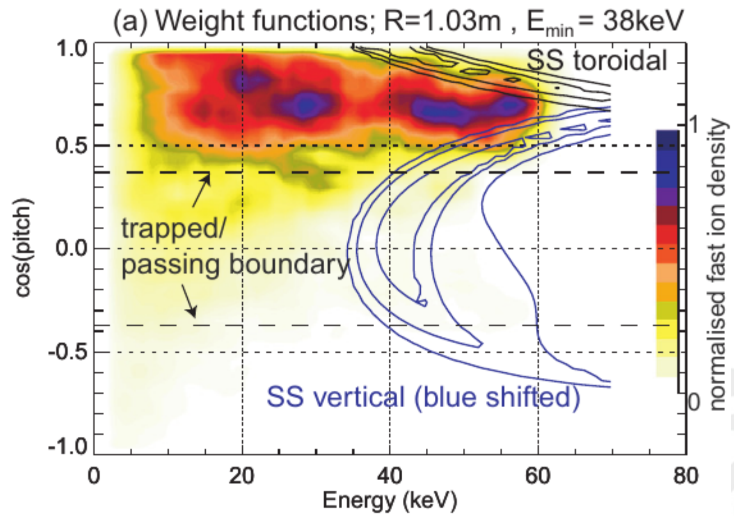
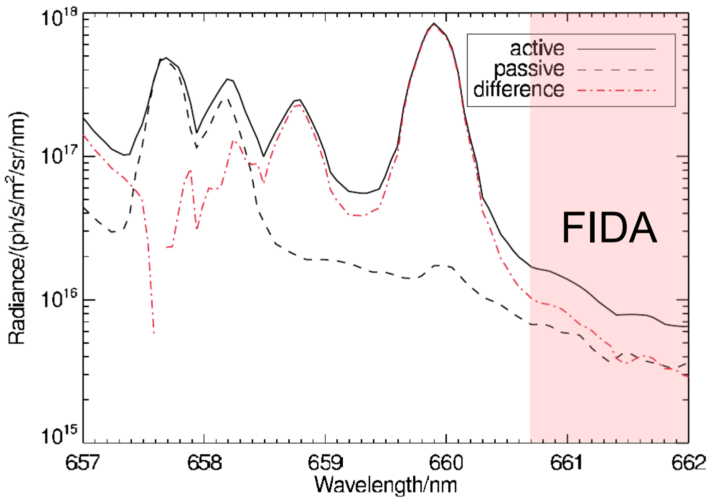
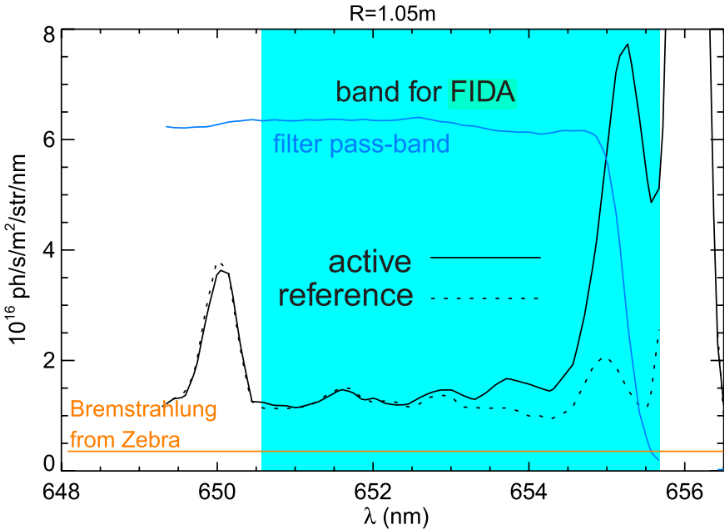
Fast Ion D-α diagnostic

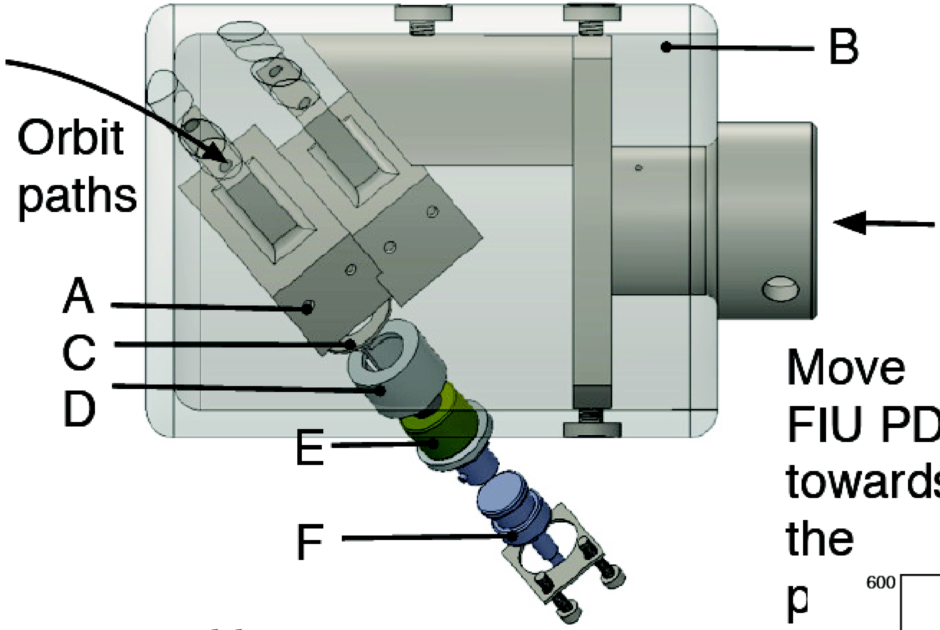








Proton Detector (2013)



Move FIU PD towards the p

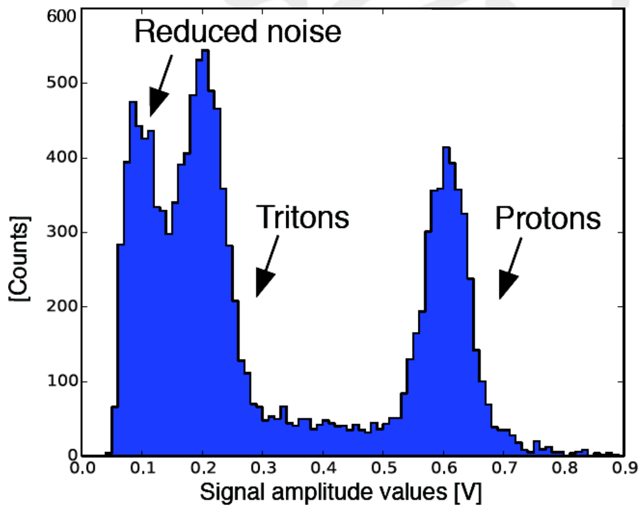
Compact detector assembly

Silicon surface barrier detectors:

- 0.8 μm Al shield
- 100 μm active layer

Charge-sensitive amplifiers

Full digital acquisition 60 MS/s and post-processing.



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Neutron measurements (2010)

Large neutron shield and collimation assembly.

Liquid scintillators ($2 \times 5 \times 1.5$ cm) coupled to PMTs

Full digital acquisition 250 MS/s and post-processing with PSD.