Alpha Particle Confinement and Losses in JET's Tritium Campaign

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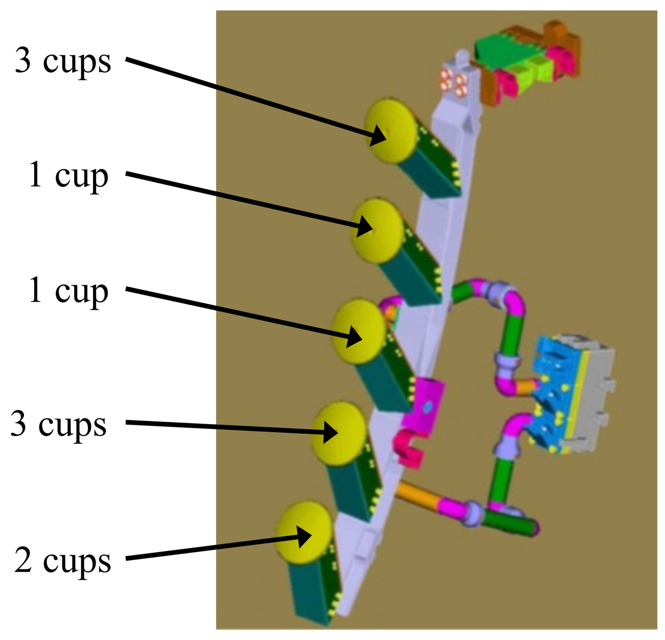
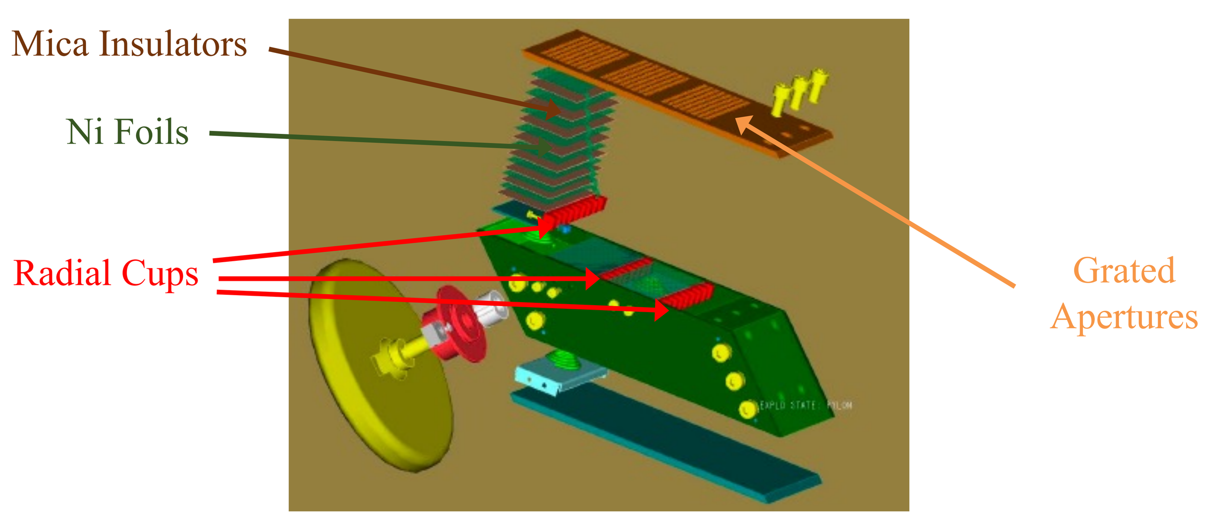
JET's Fast Ion Loss Detectors

Faraday Cup Array[1]

Radial Cup Distribution



Faraday Cup Assembly (Old 8-stack Design)



General

- 5 pylons, up to 3 radial cups per pylon, stack of 4 foils per cup
- Wide spatial distribution poloidally and radially near the wall
- Poloidal locations below midplane: 9°, 15°, 21°, 27°, 33°
- Foil stacks are alternating layers of 2.5 µm Ni and 2.5 µm mica
- Ion energy and species determines deposition depth
- Measure raw current in Ni foils → Contributions from multiple species
- Nomenclature: Signal ID = Pylon #, Cup #, Foil #
- e.g. 213 = 2nd pylon from top, 1st radial cup, 3rd foil deep
- Rough energy resolution, pitch resolution from apertures, wide spatial resolution

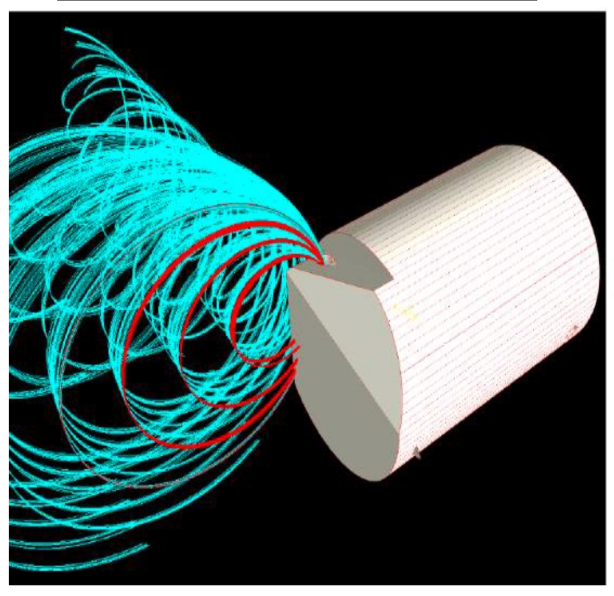
Energy Resolution per Foil†

Foil	Proton (Mev)	Deuteron (Mev)	Triton (Mev)	He3 (Mev)	Alpha (Mev)
1	0.0 – 0.49	0.0 – 0.49	0.0 – 0.50	0.0 – 1.55	0.0 – 1.54
2	0.68 – 0.96	0.79 – 1.10	0.84 – 1.20	2.30 – 3.35	2.48 – 3.55
3	1.10 – 1.32	1.35 – 1.60	1.48 – 1.76	3.90 – 4.70	4.17 – 5.09
4	1.45 – 1.65	1.78 – 2.00	2.00 – 2.25	5.20 – 5.80	5.60 – 6.35

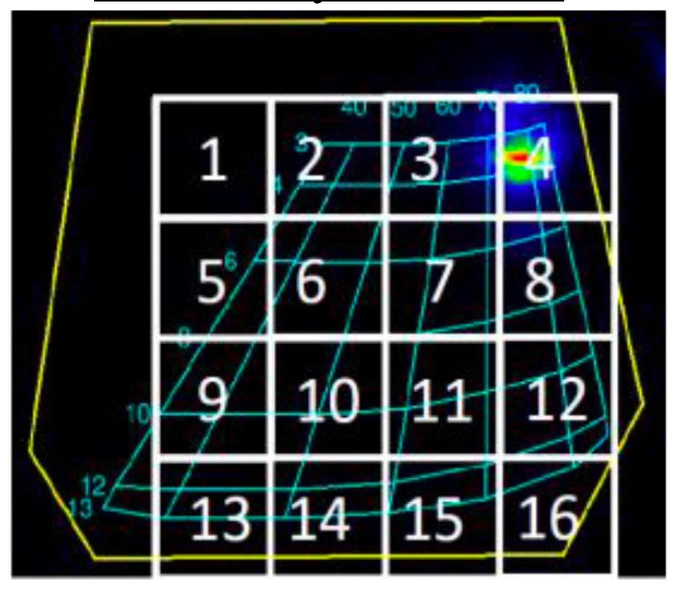
†Found via SRIM code (www.srim.org)

Scintillator Probe[2]

Probe and Loss Orbits



PMT Array Locations

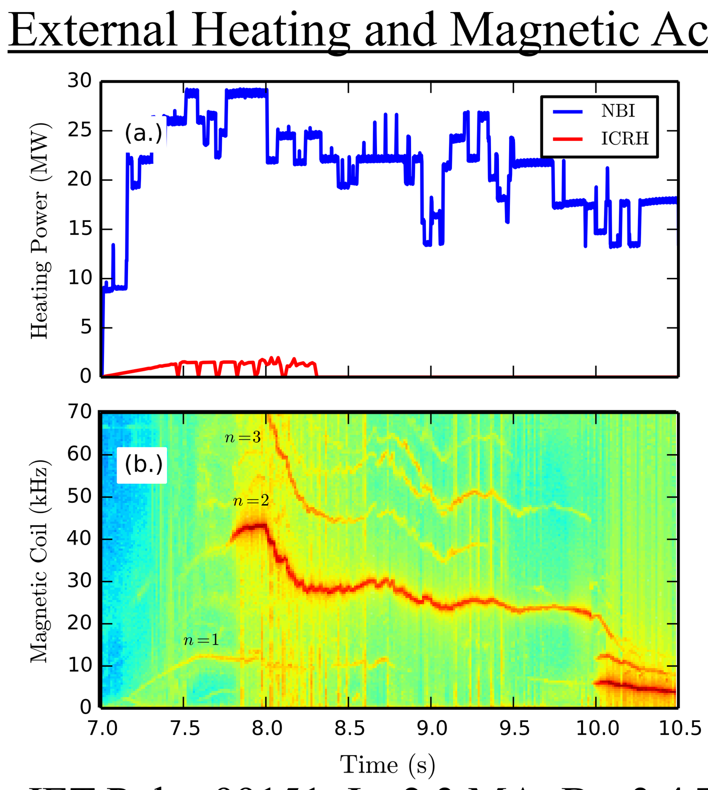


General

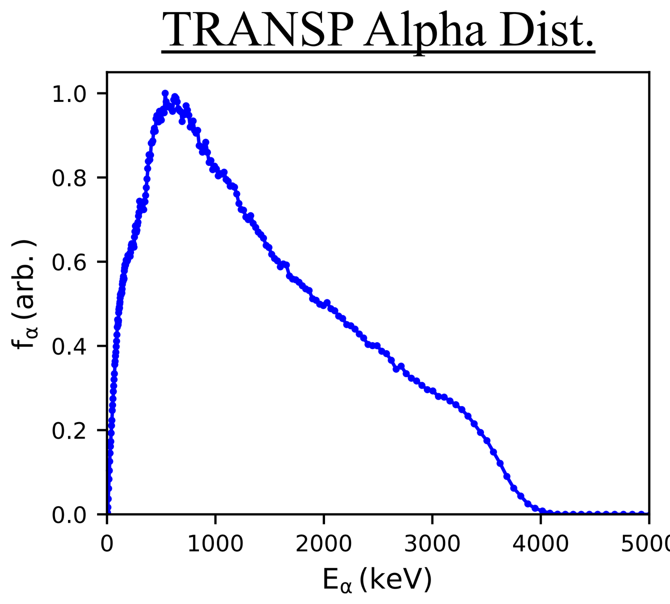
- Functions like a mass spectrometer
- Scintillator light passes through a beamsplitter on to a CCD camera and PMT array
- 16 PMTs correspond to varied zones in pitch and gyroradii (energy)
- Single location 180° toroidally opposite of Faraday cup array and poloidally consistent with the 3rd Faraday cup pylon
- Good gyroradii resolution (perp. energy), good pitch resolution, limited spatial resolution
- Predominantly sensitive to fusion products and RF-heated ions. Beam ions can appear at top edge of PMT and CCD array

Reference Discharge

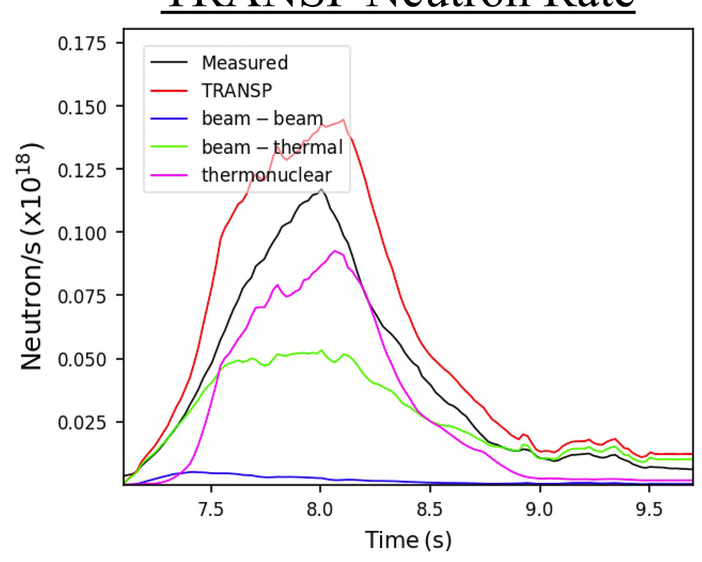
External Heating and Magnetic Activity



TRANSP Alpha Dist.



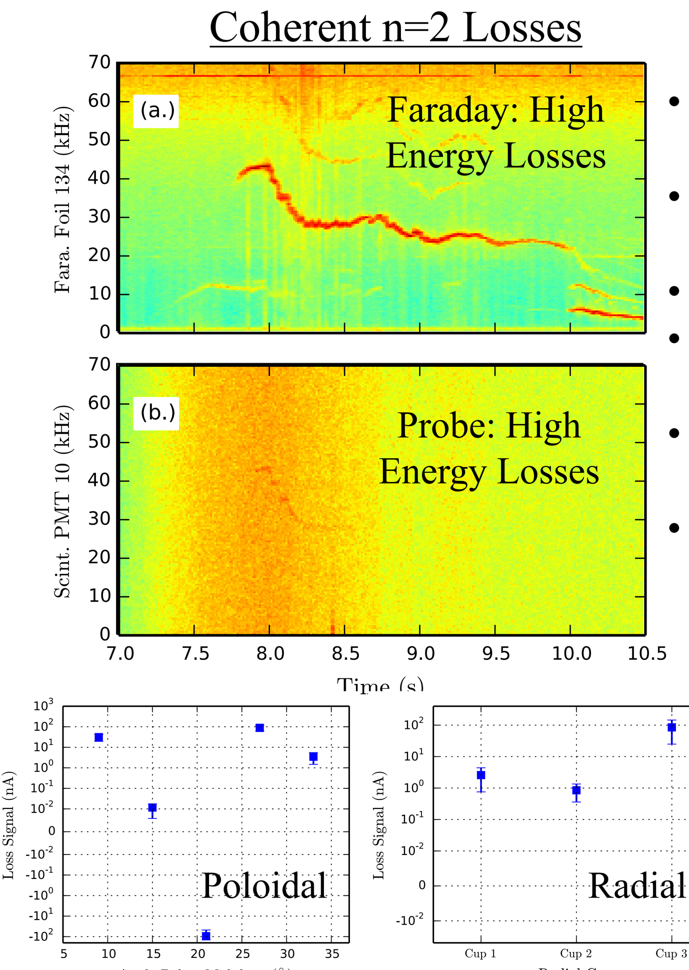
TRANSP Neutron Rate



- JET Pulse 99151: I_p=2.3 MA, B_0=3.4 T, n_e=7x10^{19} m^{-3}, T_e=8.5 keV, 95% tritium with residual deuterium and hydrogen for minority RF heating
- Strong, low freq., MHD observed with a prolonged n=2 NTM
- Alpha distribution from TRANSP[3] shows majority of distribution > 1 MeV and originates from thermonuclear fusion with some from beam-thermal interactions

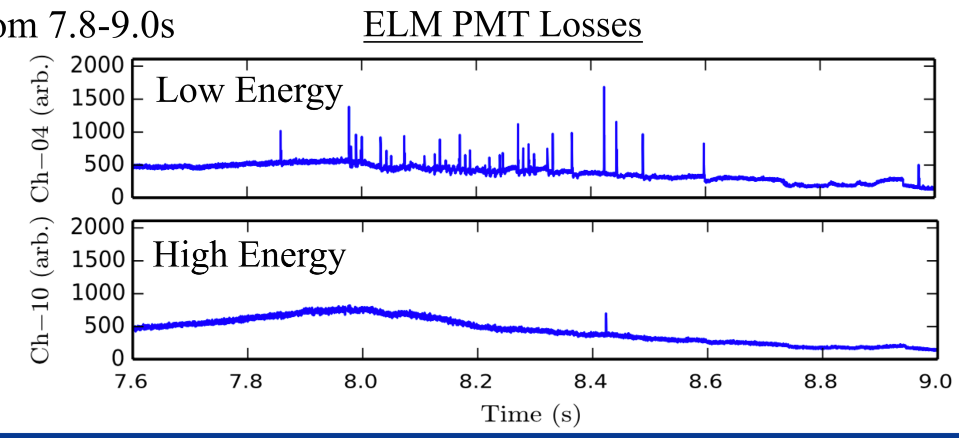
Measured Losses

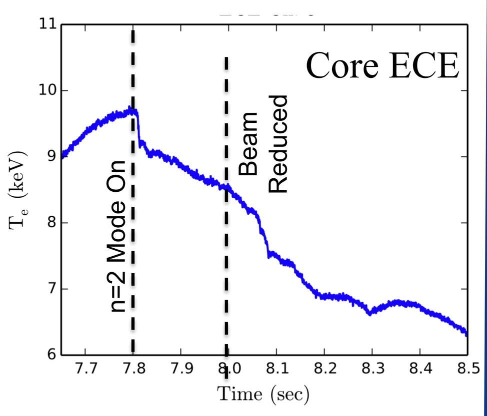
Coherent n=2 Losses



- Faraday cup losses are corrected with the deepest foil in the stack and limit signal to the n=2 spectral feature[4]
- High energy alphas interact more with NTM while low energy alphas (and beam tritons) interact with ELM bursts
- Poloidal variation is evident and needs to be explained with modelling
- Radial losses are highest near wall and are suspected to be due to the large Larmour radii of alphas (10-14 cm). Needs computational support.
- No strong change in neutron rate due to n=2 NTM. At mode onset, neutron rate continues to grow but core T_e drastically drops
- Spatial loss signals are summed over n=2 mode frequency from 7.8-9.0s

ELM PMT Losses

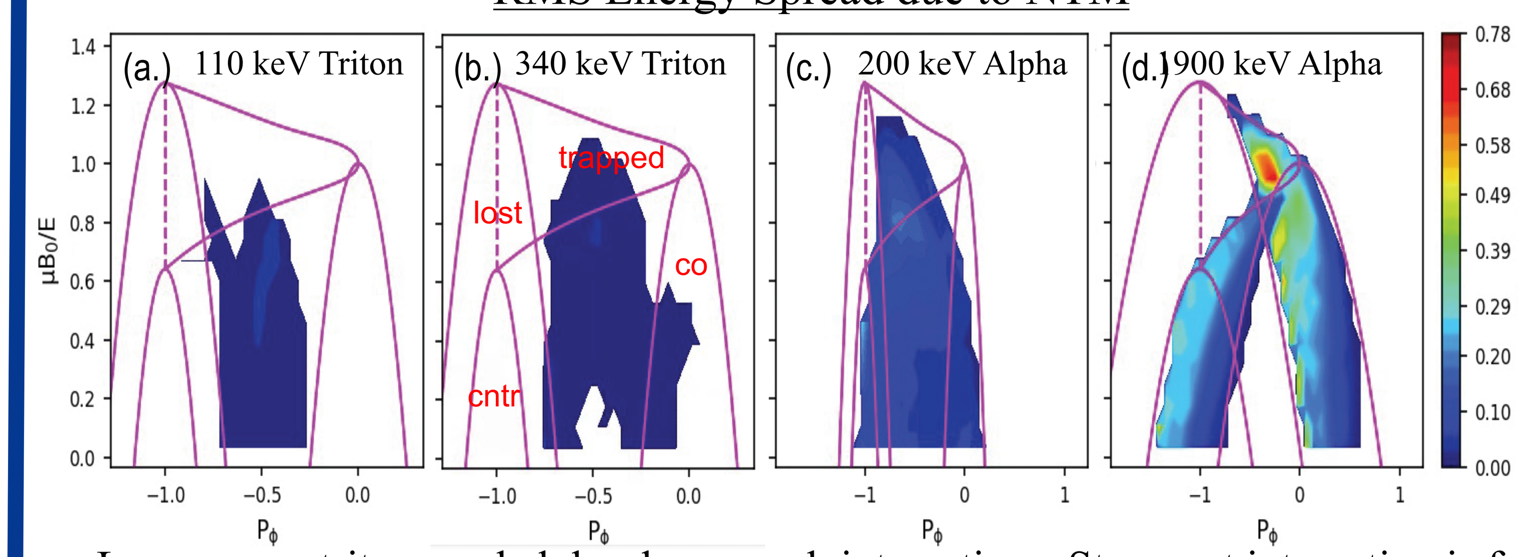




ORBIT-kick Modeling Results

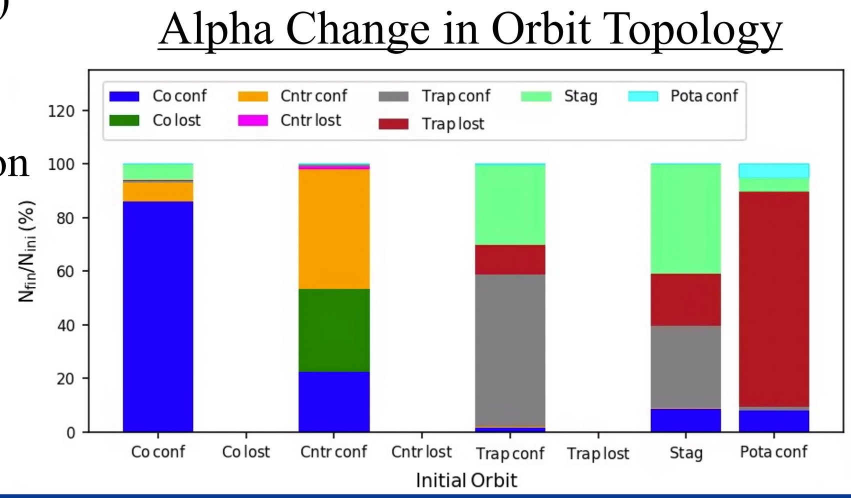
- ORBIT-kick[5]: Hamiltonian guiding-center code that calculates changes in the particles' constants of motion (E - energy, P_ϕ - canonical momentum) due to a supplied perturbation
- An analytic form was used for NTM mode structure[6] while the mode amplitude was reasonably estimated to be $\delta b/_B = 10^{-5}$
- Run Parameters: 200,00 particles for each species, 1ms runtime, electrostatic potential (from TRANSP) included, allow transitions beyond LCFS

RMS Energy Spread due to NTM



- Low energy tritons and alphas have weak interactions. Strongest interaction is for trapped alphas with energy in the MeV range
- Alphas experience 6.7% losses; tritons well confined with 0.02% losses
- Agrees with measured losses (left)
- Trapped, potato, and stagnation orbits most susceptible to be lost
  - Region of strongest interaction above
  - FILDs most likely to detect lost trapped orbits, so in good agreement with measurement

Alpha Change in Orbit Topology



Ongoing and Future Work

- Compare measured spatial loss distribution to that obtained with ORBIT
- Further constrain with synthetic diagnostic simulations[7]
- Investigate any alpha effects related to heating and neutron production
- Interpret and compare to alpha losses in the DT-campaign
- Extend DT scenarios to ITER to estimate alpha transport and losses due to low freq. MHD

References

[1]P. J. Bonofiglo, V. Kiptily, A. Horton, P. Beaumont, R. Ellis, F. E. Cecil, M. Podesta, and JET Contributors 2020 *Rev. Sci. Instrum.* **91** 093502
[2]S. Baeumel, A. Werner, R. Semier, S. Mukherjee, D. S. Darrow, R. Ellis, F. E. Cecil, L. Pedrick, et al. 2004 *Rev. Sci. Instrum.* **75** 3563
[3]B. Joshua, G. Marina, P. Francesca, S. Jai, P. Alexei, and P. Gopan 2018 *TRANSP Software* USDOE Office of Science (SC), Fusion Energy Sciences (FES) (https://doi:10.11578/dc.20180627.4)
[4]P. J. Bonofiglo et al. "Lost Alpha Faraday Cup Foil Noise Characterization During JET Plasma Post-Processing Analysis" *Rev. Sci. Instrum.* (Under Review)
[5]M. Podesta, et al. 2017 *Plasma Phys. Control. Fusion* **59** 095008
[6]M. Gobbin et al. 2009 *Nucl. Fusion* **49** 095021
[7]P. J. Bonofiglo et al. 2022 *Nucl. Fusion* **62** 026026

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