Ion Cyclotron Emission in the Presence of Beam Ion Losses

by
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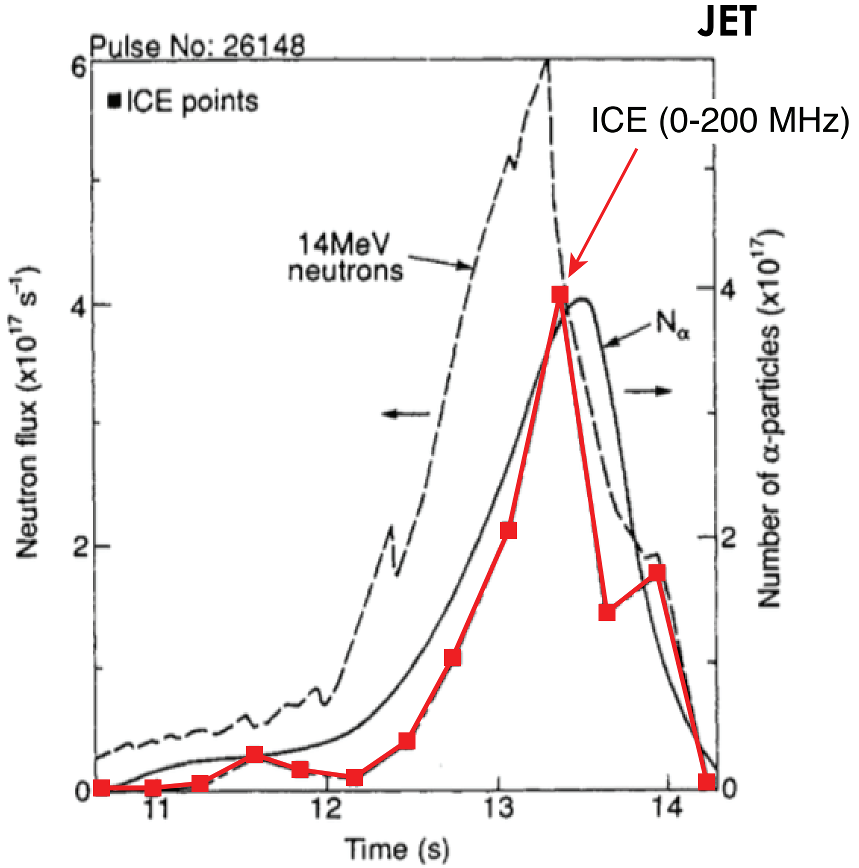
GENERAL ATOMICS

Ion Cyclotron Emission (ICE) is an Indicator of Energetic Ion Confinement that may be Relevant for ITER Plasmas

- **ICE measurements correlate with inverted energetic ion populations in the edge, or with losses**

- **ITER DT plasmas are expected to produce ICE***
  - magnetoacoustic cyclotron instability (MCI) as the production mechanism
  - measurement acquired through the ICRF antennas



Adapted from
G.A. Cottrell, et al., Nucl. Fusion **33**, 1365 (1993)

*K.G. McClements, et al., Nucl. Fusion **55**, 043013 (2015)

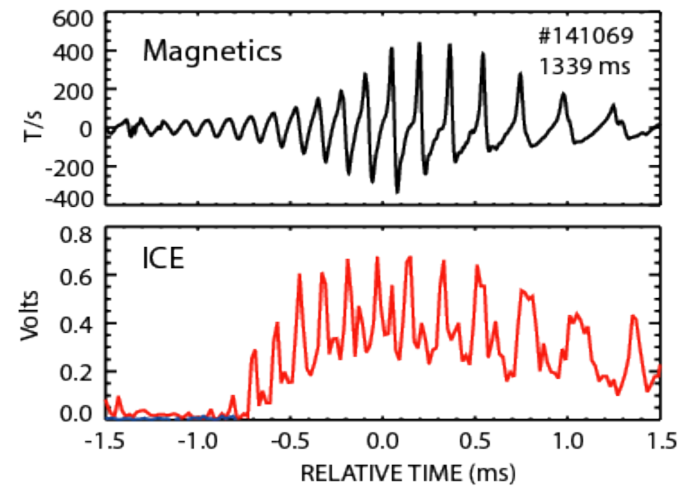
DIII-D Experiments with Well Known Neutral Beam Prompt Loss may be an Ideal Case for Developing ICE Synthetic Diagnostics

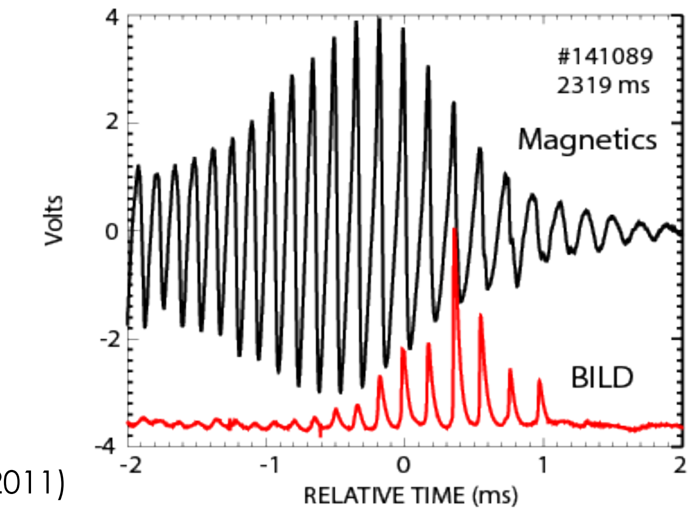
- **Full spectral measurements of ICE are being acquired from connections to an ion cyclotron range of frequencies (ICRF) antenna**

- **Eight neutral beams produce ICE spectral patterns according to their four unique injection geometries**

- **Synthetic diagnostics allow ICE measurements to be applied as a fusion-alpha diagnostic in ITER**

DIII-D





W.W. Heidbrink, et al.,
Plasma Phys. Control. Fusion **53** (2011)

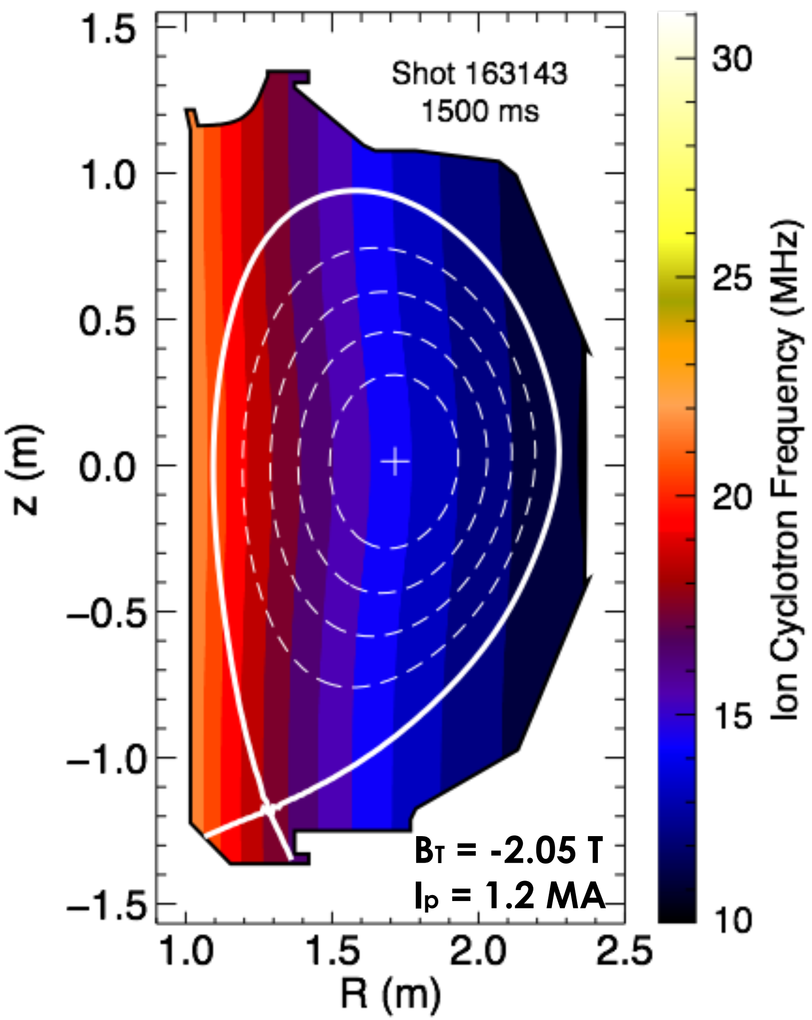
Wide Spectral Coverage is Required because ICE can be Produced at any Location within the Tokamak

- **Ion cyclotron frequency has a *simple* dependence on plasma parameters**

$$\omega_{ci} = \frac{qZB}{m}$$

- **Actual ion cyclotron emission has a *complex* dependency on plasma parameters**
  - non-monotonic velocity space distribution
  - fast ions hitting the wall
  - fast ions briefly passing through a region of the plasma

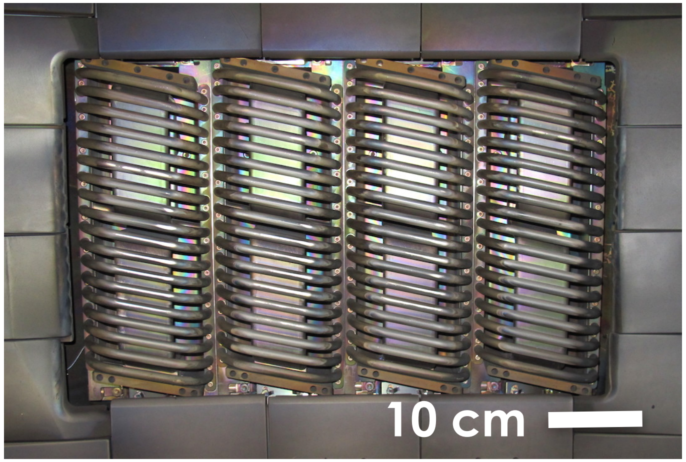
Deuterium Ion Cyclotron Frequency



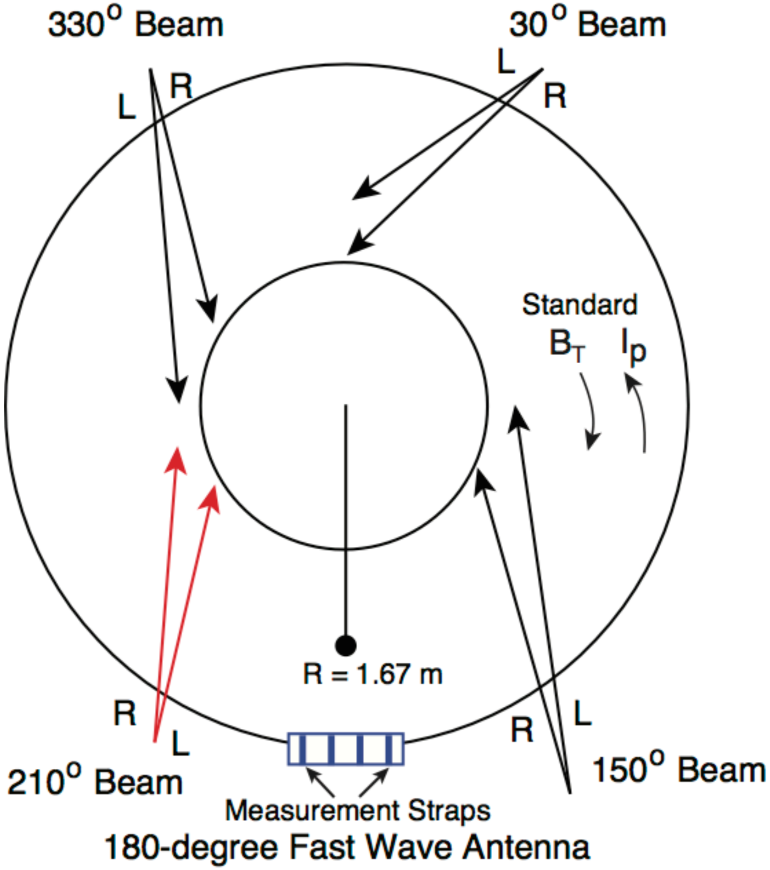
ICE Measurements are Collected from Fast Wave Antenna Straps Across a Wide Range of Plasmas Featuring Neutral Beam Injection

- **Eight neutral beams provide variety of injection and loss parameters**
- **Fast wave antenna formerly used for high harmonic electron heating and current drive (60 – 120 MHz)**
- **ICE measurement:**
  toroidal magnetic field fluctuations

Fast Wave Antenna

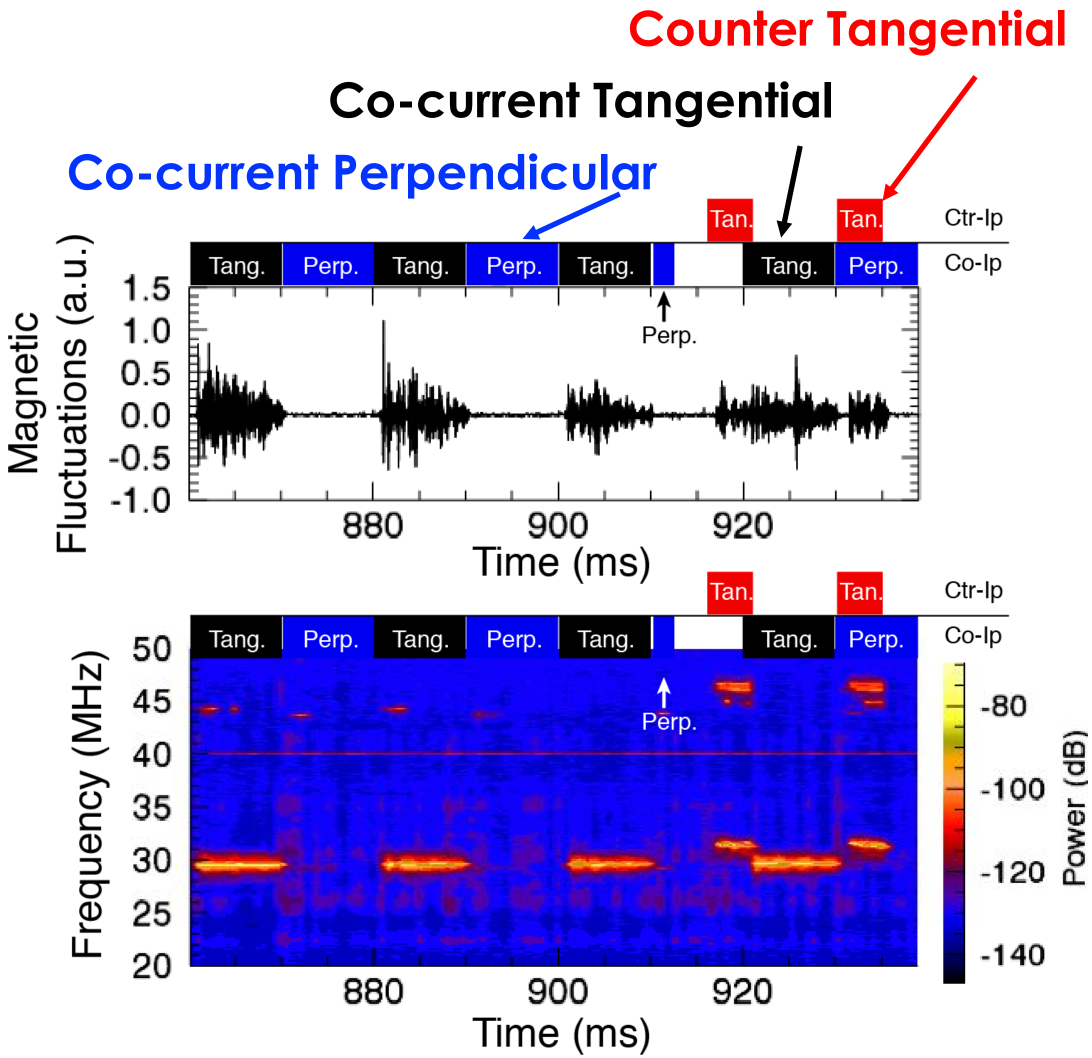


DIII-D Top View



Initial Measurements Indicate Unique ICE Spectra According to the Injection Geometry of Individual Beams

- **Instrument the antenna to collect data on every shot (200 MS/s)**
- **Shots featuring single-beam injection periods produce unique spectra**
- **ICE differences likely result from a combination of deposition and prompt loss variation between neutral beams**



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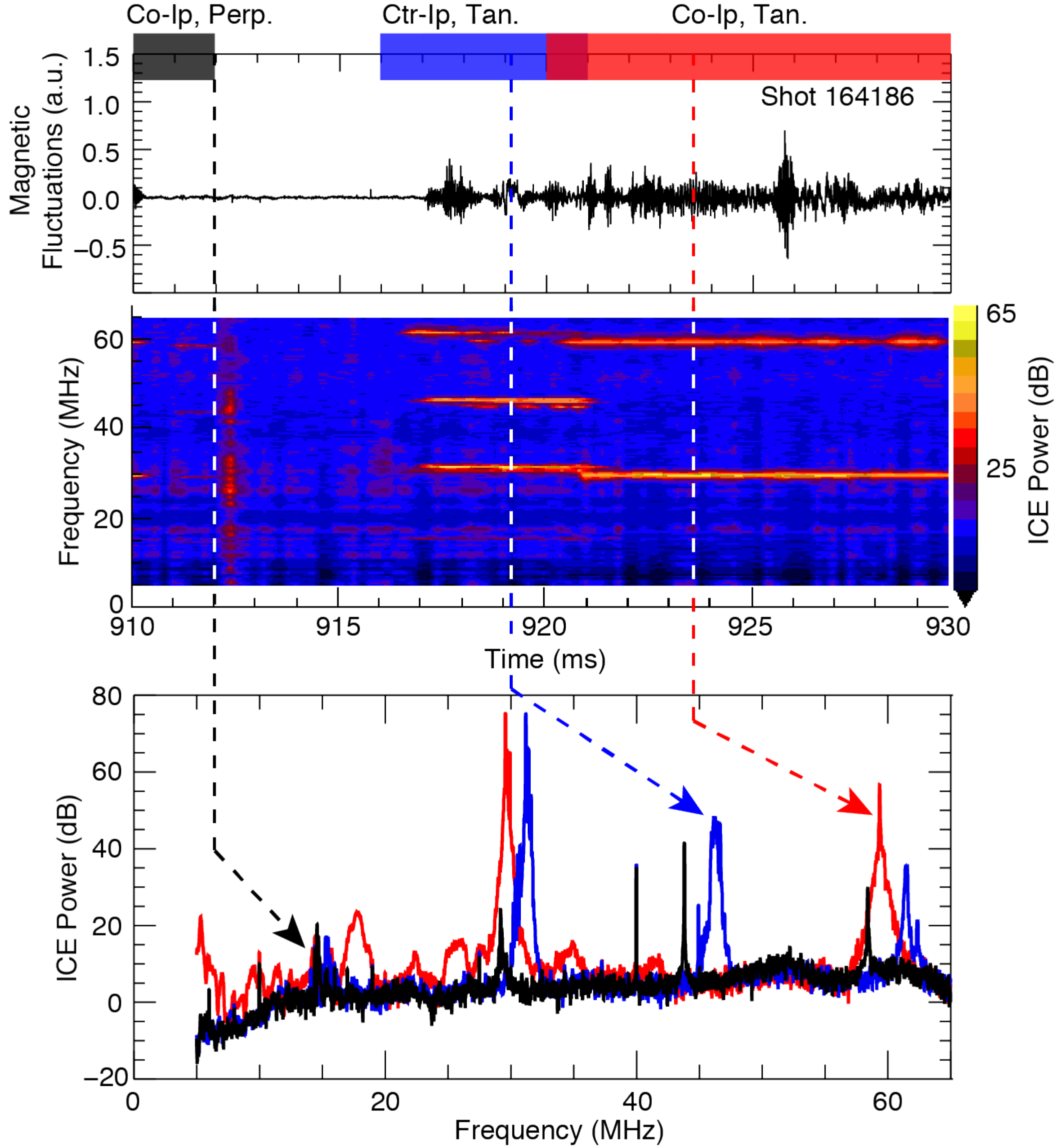

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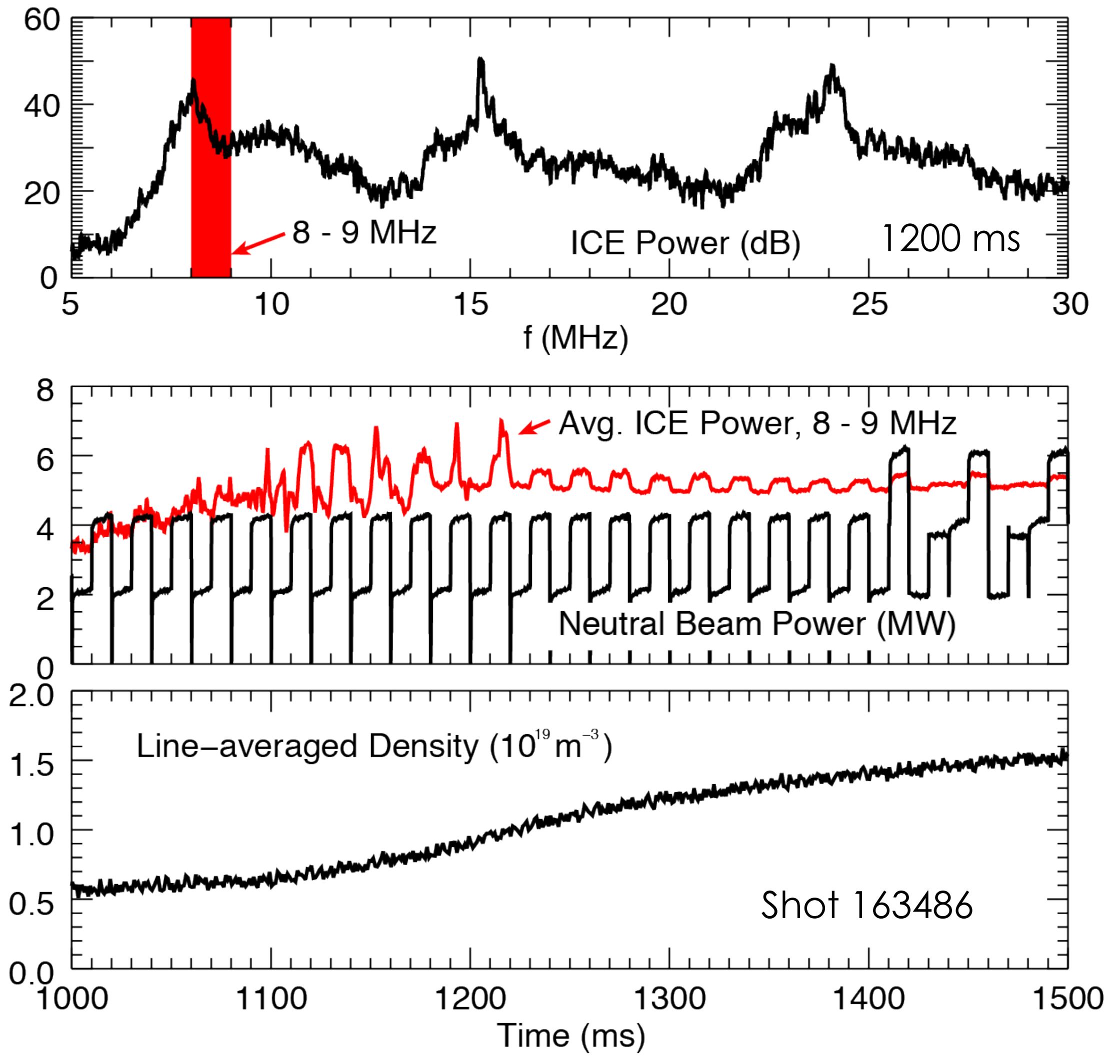
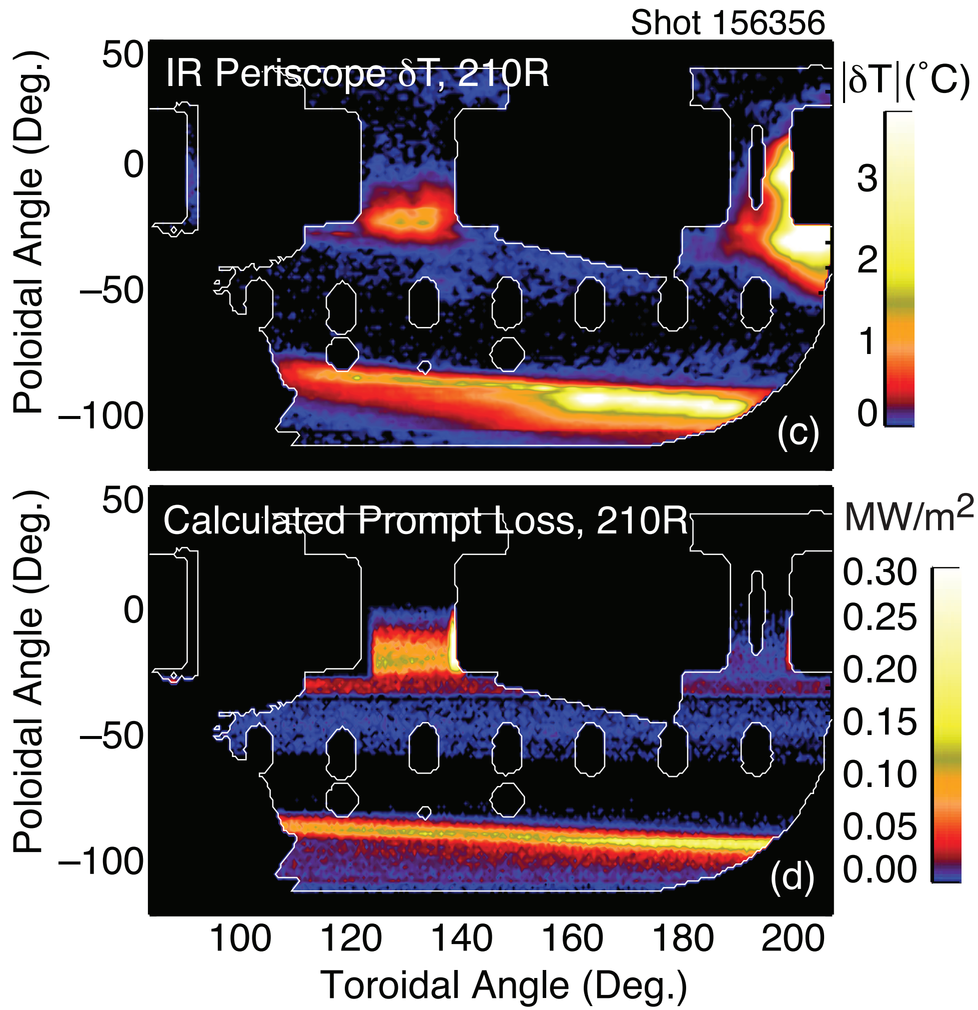
Variation of Edge ICE Power Suggests Sensitivity to Beam Deposition and Prompt Loss Profiles

- **Reversed-Ip plasma shot uses three beams with same ctr-Ip, tangential injection geometry**
- **ICE power in edge (8 - 9 MHz) increases with plasma density**
- **Edge ICE power is not linearly correlated with beam power**



Modeling Prompt Loss is used in Cases where Local Loss Measurements are Unavailable

- **Beam deposition is three-dimensional and includes ionization in the scrape-off layer***
- **Measurements with infrared camera identify prompt loss wall heating in agreement with modeled value**

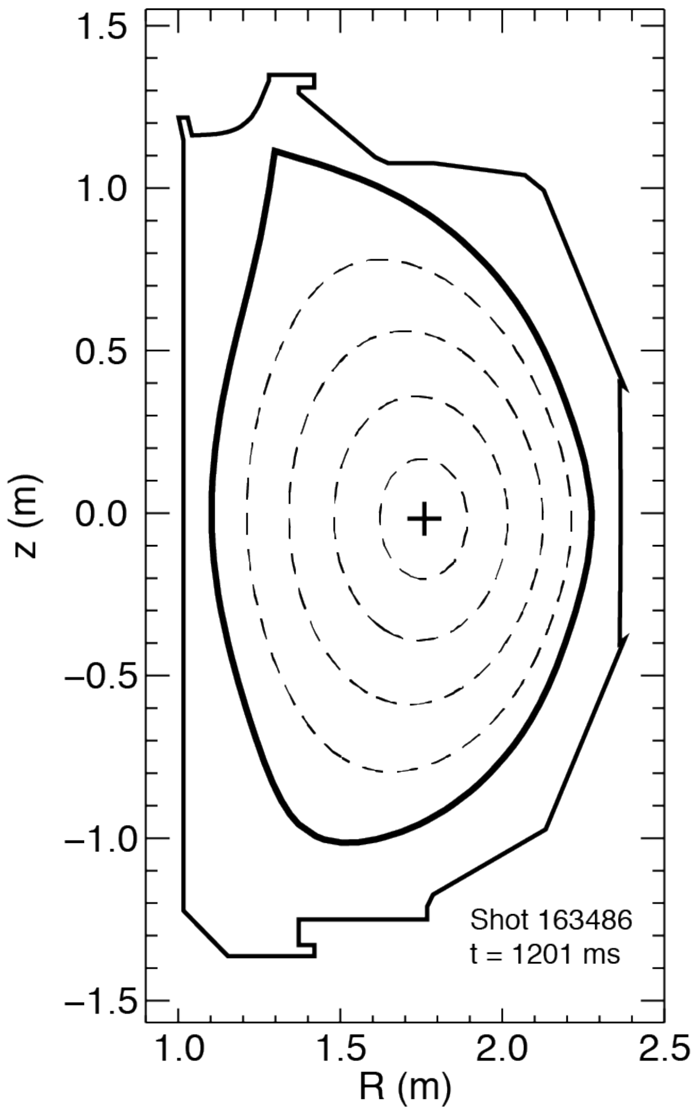


*M.A. Van Zeeland, et al.,
Plasma Phys. Control. Fusion **56**, 015009 (2014)

C.J. Lasnier, et al.,
Rev. Sci. Instrum. **85**, 11D855 (2014)

Source of ICE Peak near 9 MHz is Beam Ions in the Plasma Edge and Those Hitting the Outer Wall

- **Only consider the beam ions that occur outside of the 9 MHz ICE surface**
- **Deposition is most sensitive to electron density**
- **Prompt losses from counter-Ip beams are large, here ~22% of the injected 80 keV ions reach the wall as prompt losses**



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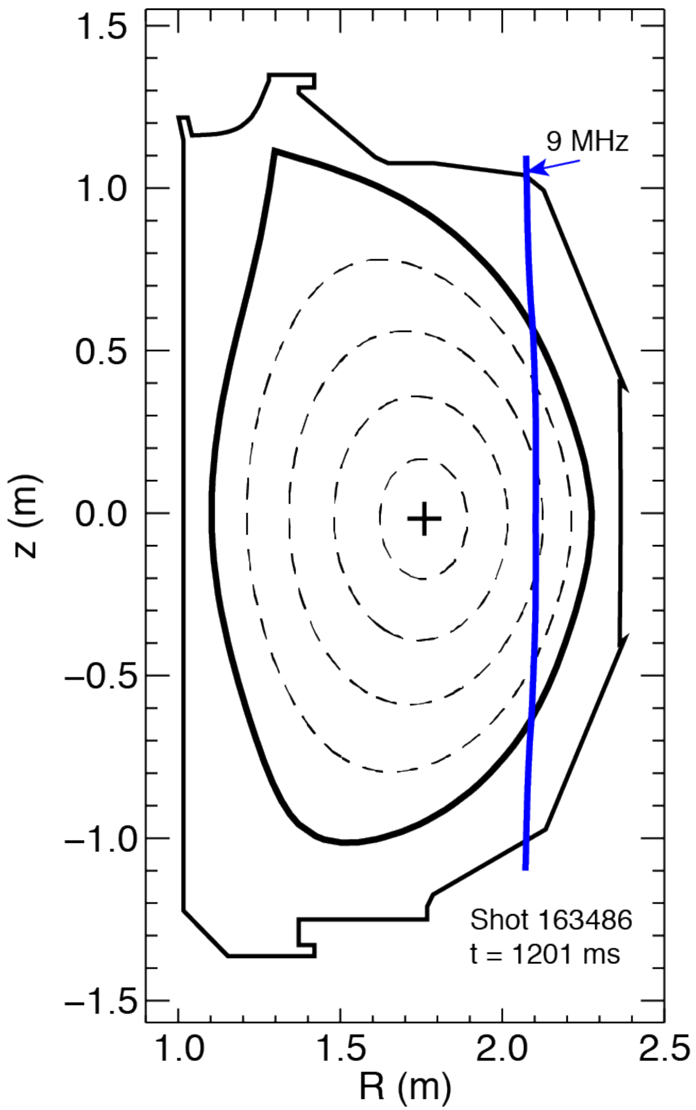

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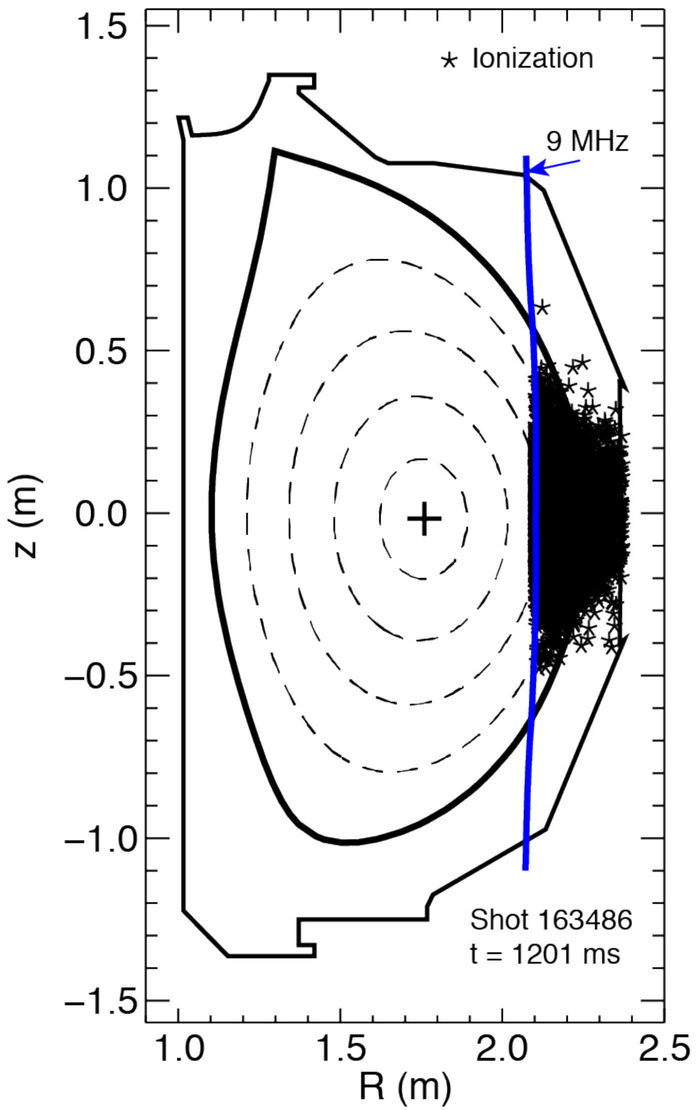

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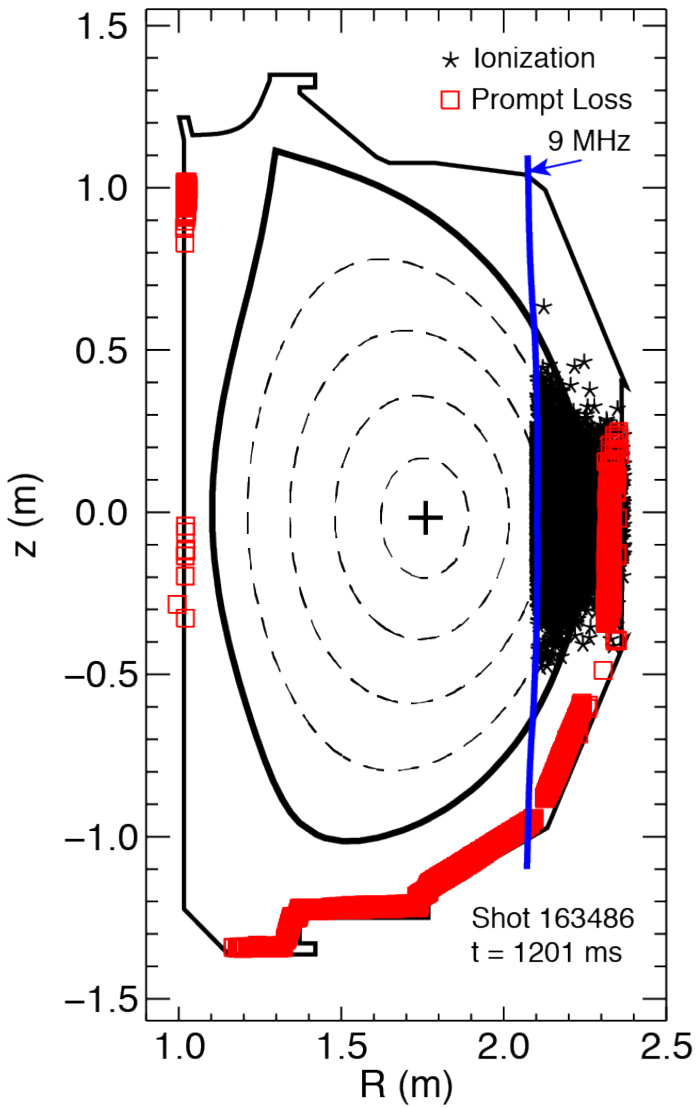
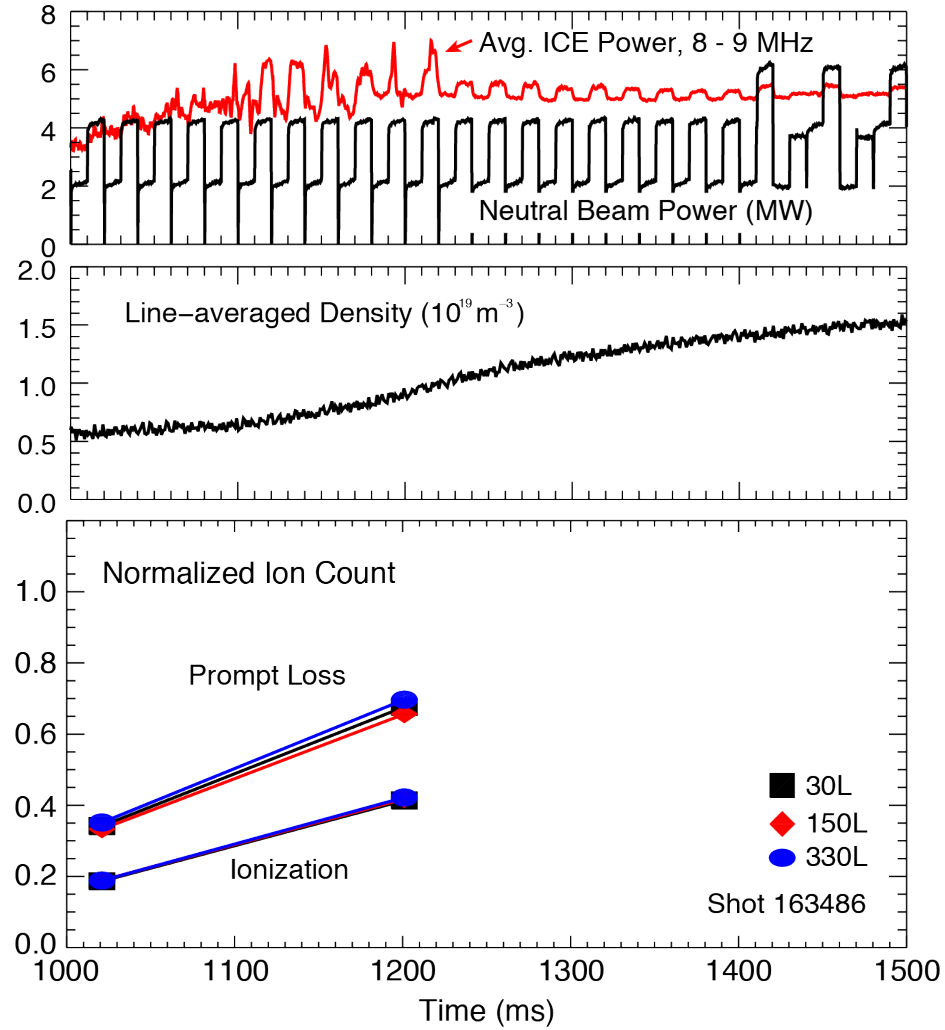


Edge Beam Ion Count is Consistent with Increase in ICE Power, but not its Saturated Value

- **All three beams behave similarly and demonstrate increases in edge ion deposition and prompt loss number as density rises**

- **ICE power in the 8 – 9 MHz band reaches a near steady-state value as edge ion count continues to rise**

- **Issues under review**
  - three-dimensional profiles of deposition and loss
  - full beam ion distribution in edge region



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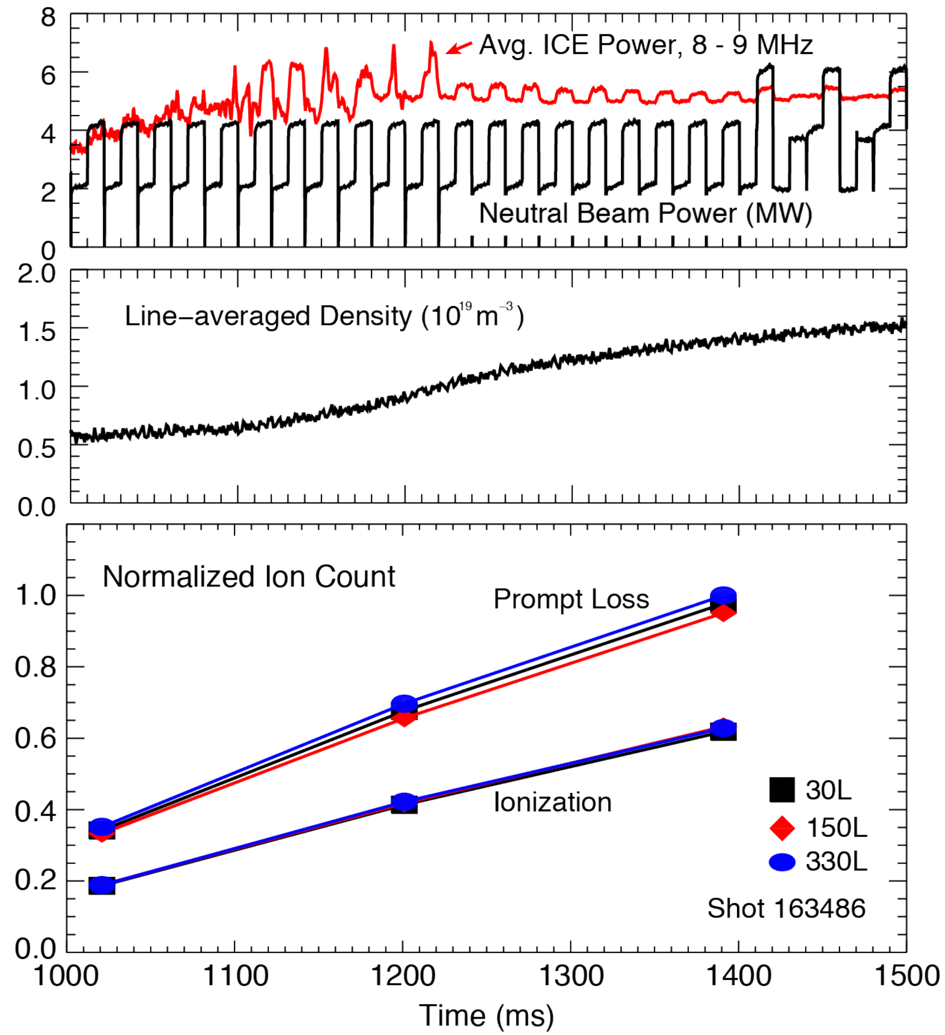

Full Spectrum Ion Cyclotron Emission (ICE) Measurements Provide Valuable Information Concerning Energetic Ion Confinement

- ITER: ICE measurements are relevant to the confined fusion-alpha population (*burn control*), and the population of energetic ions in the edge or lost to the wall (*machine protection*)

- DIII-D: full spectral measurements of ICE are being studied under beam ion prompt loss scenarios that produce unique spectral patterns

- Well known beam ion distribution may serve as an ideal test case for developing synthetic diagnostics that allow ICE measurements to applied as a energetic ion diagnostic in ITER

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