IRE-Induced Ion Acceleration in NSTX

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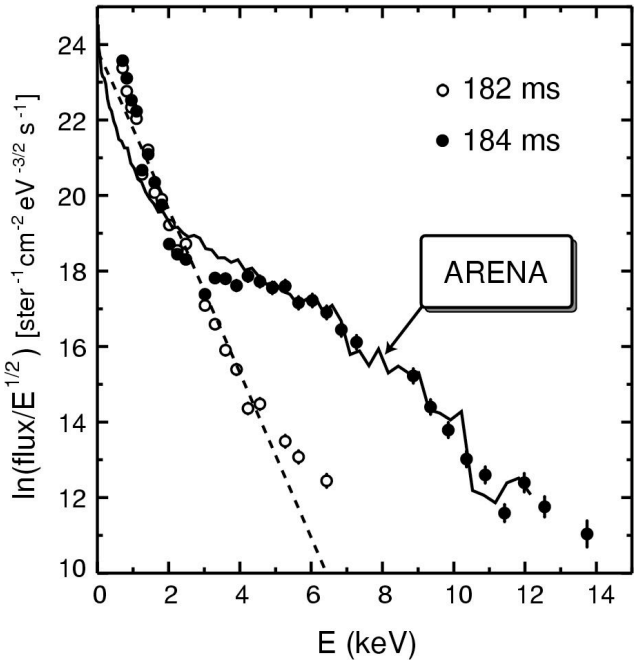
Introduction

- IRE-induced acceleration of ions has been observed in MAST
- Per Helander developed a theoretical model of the effect, as well as a three-dimensional Monte Carlo numerical simulation code, ARENA. Good agreement is observed between theory and experiment[1].



[1] "Acceleration of Energetic Ions during Reconnection in MAST," P. Helander, R. J. Akers, C. Byrom, L.-G. Eriksson, C. G. Gimblett and M. R. Tourniansk, Phys. Rev. Lett. 89, Dec. (2002).

Helander's Ion Acceleration Model

Ion runaway is possible if the 'effective electric field', E_* , satisfies

$$E_* > m_i \frac{\left(\nu_m + \nu_c^3/\nu_m^2\right)}{e\tau_s} = \left(\frac{3m_e}{2\pi m_i}\right)^{1/3} E_D \approx 6x10^{-2} E_D$$

where $E_D = n_e e^3 \ln\Lambda / 4\pi\varepsilon_0^2 T_e$ is the Dreicer field . Ions can be accelerated over a region $\Delta r = q\frac{m_i v}{eB} \sim 10$ cm in MAST and NSTX where q is the safety factor. Introducing dimensionless independent variables

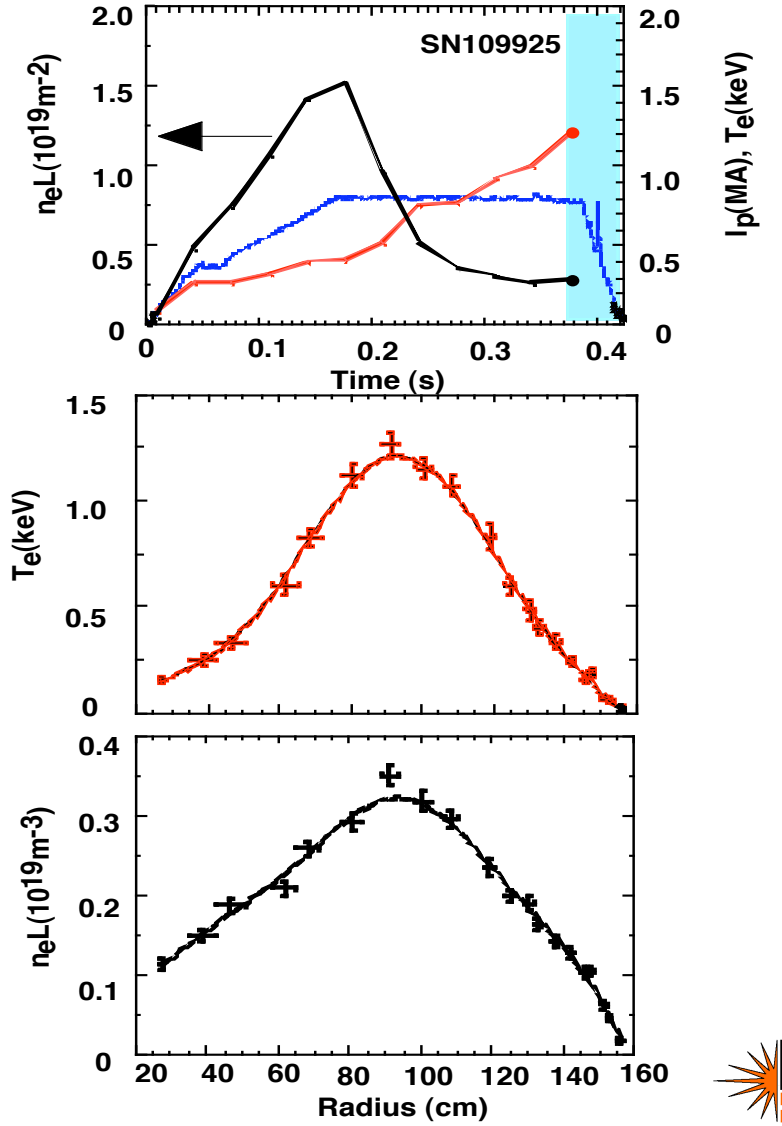
$$w = v/v_{Ti}, \quad \tau = 3\pi^{3/2}(\pi/2)^{1/2} t/\tau_{ii}, \quad \xi = v_\parallel / v$$

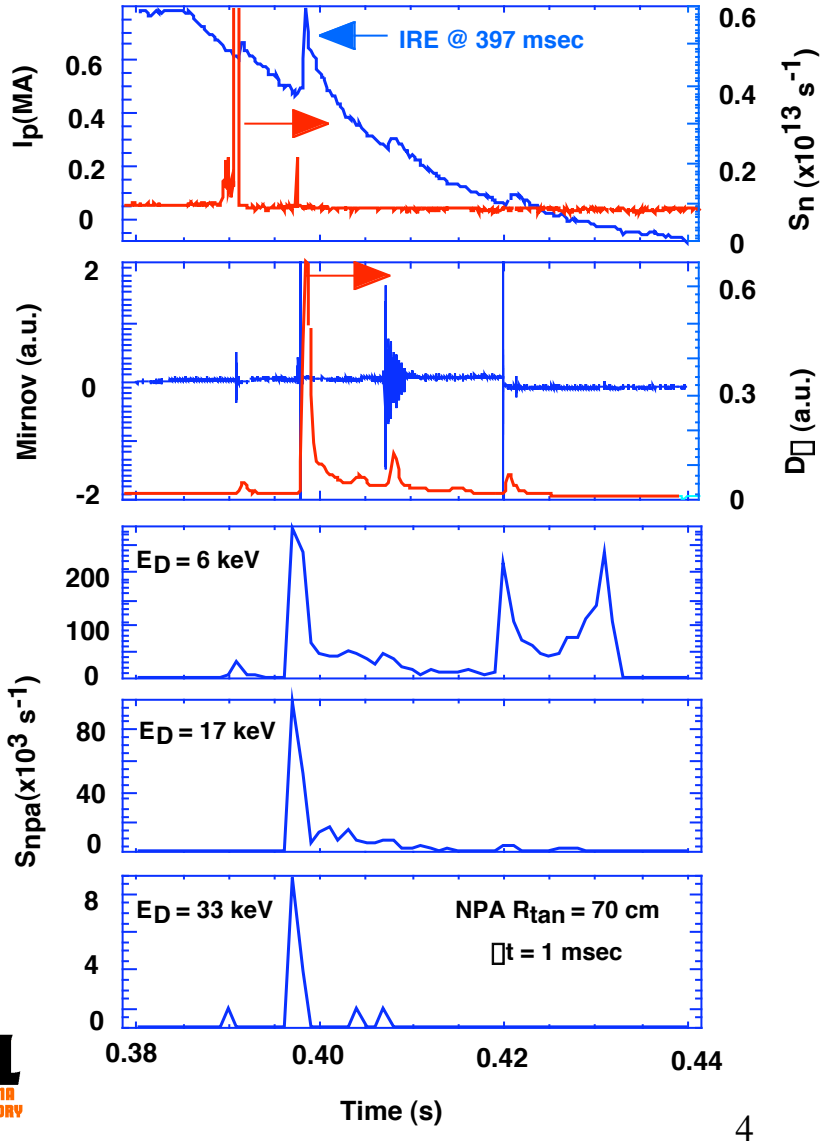
where $\varepsilon = E_* T_i / E_D T_e$, for weak accelerating fields ($w \gg 1$) an analytic solution to the ion kinetic equation yields the distribution function

$$f(w,\xi,\tau) \propto \exp\left(\frac{-2w^2 + w^4 - w^3(3\pi)^{4/3} H}{4\varepsilon} + 2w^2\sqrt{\frac{2(1+\varepsilon)}{\varepsilon Z_{eff}}}\right)$$

in agreement with the exponential nature of the measured distribution (H is the Heaviside step function). The tail is peaked in the forward direction around $\xi = 1$ if $\varepsilon \ll 1$.

IRE-Induced Ion Acceleration in Ohmic Plasmas: Waveforms





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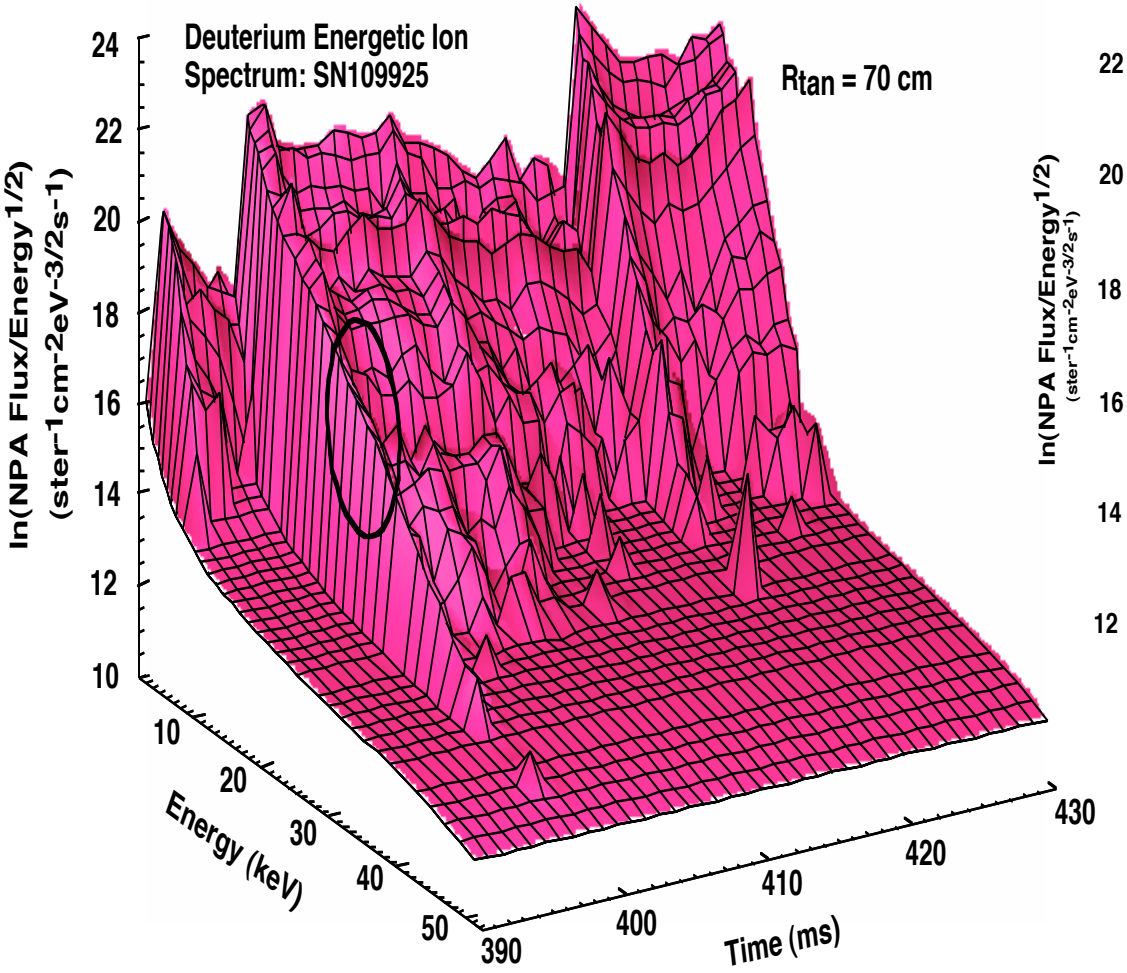
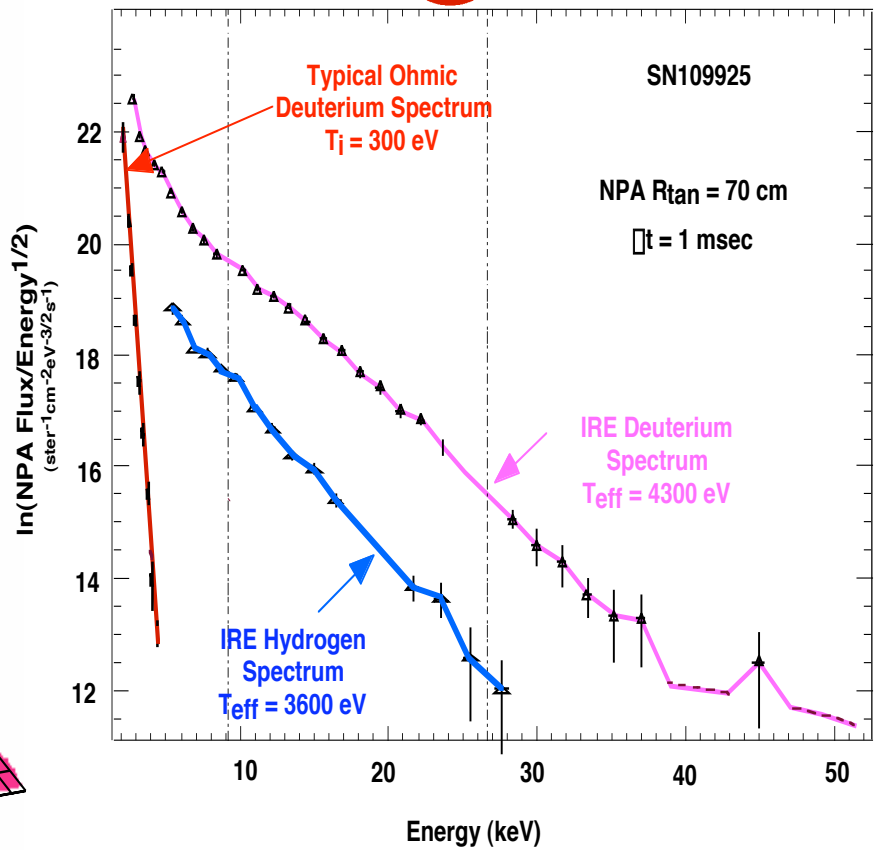
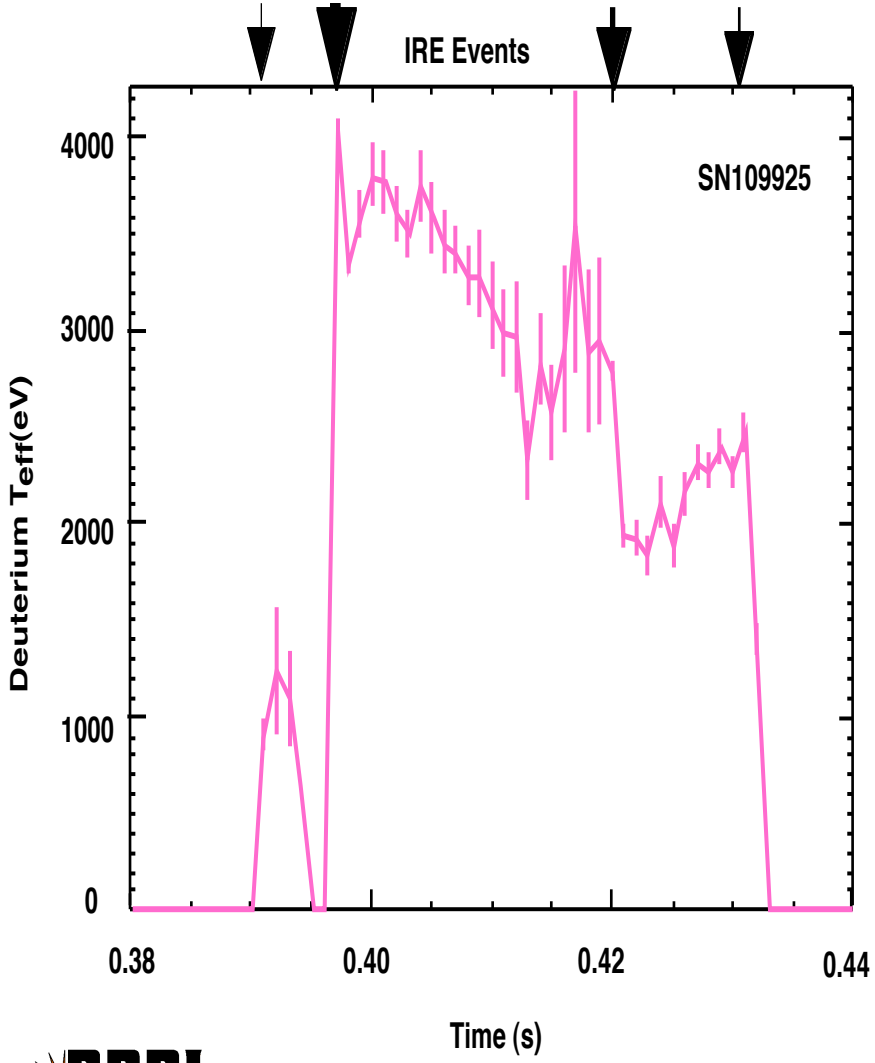
IRE-Induced Ion Acceleration in Ohmic Plasmas: Spectra





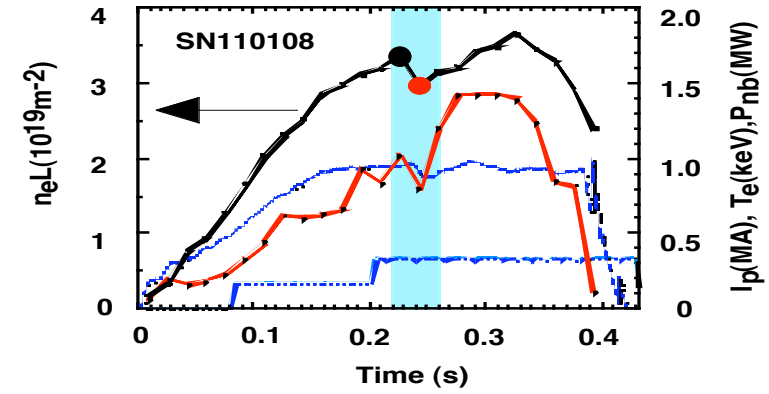
- **Deuterium and hydrogen thermal ions are accelerated by an IRE event in an Ohmic plasma.**

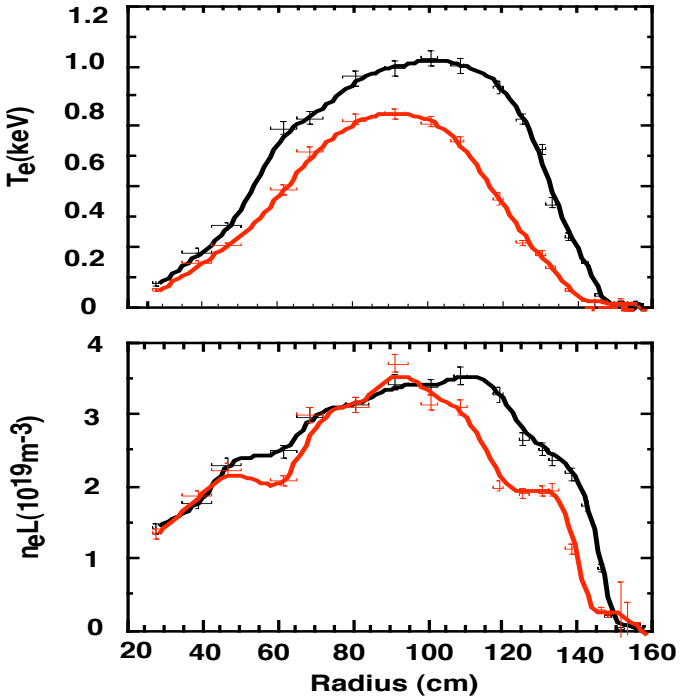
IRE-Induced Ion Acceleration in Ohmic Plasmas: Summary

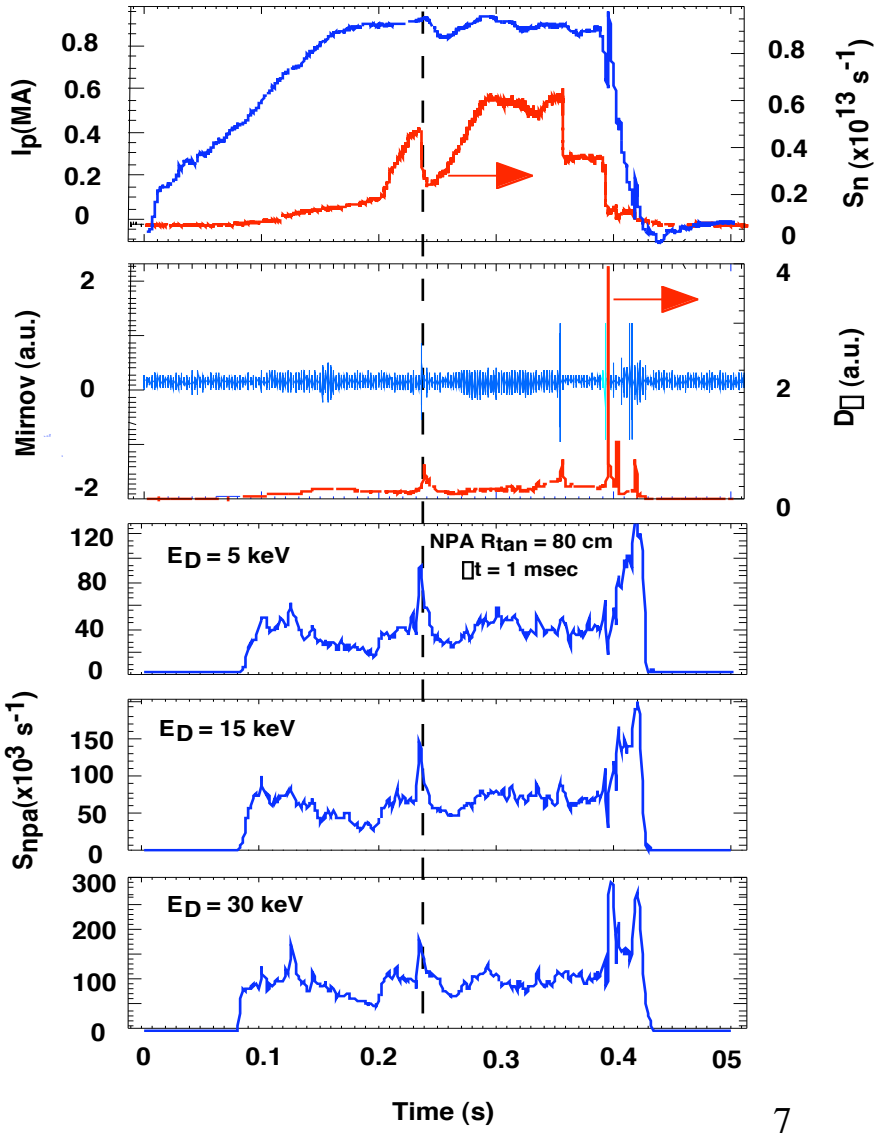


- IRE-induced H and D spectra are Maxwellian-like with effective temperatures T_{eff} ~ 1000 - 4000 eV.
- The amplitude and maximum energy of the IRE-induced spectra appear to scale with the 'severity' of the IRE as gauged by the magnitude of the spikes on the I_p, $D_{\square}$, and Mirnov signals.
- Decay of the IRE-induced spectra is consistent with classical slowing down of energetic ions.
- A simple ratio of the H and D spectra gives H/D ~ 2 - 5 %.

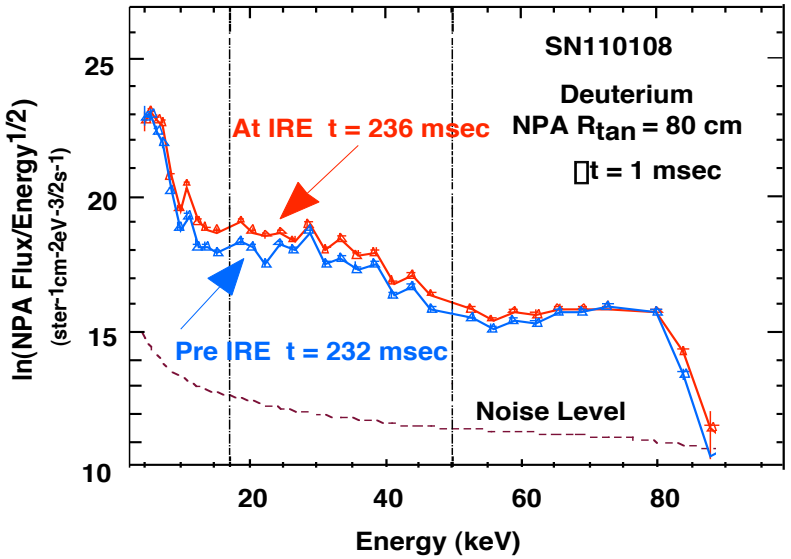
IRE-Induced Ion Acceleration in NB Heated Plasmas: Waveforms

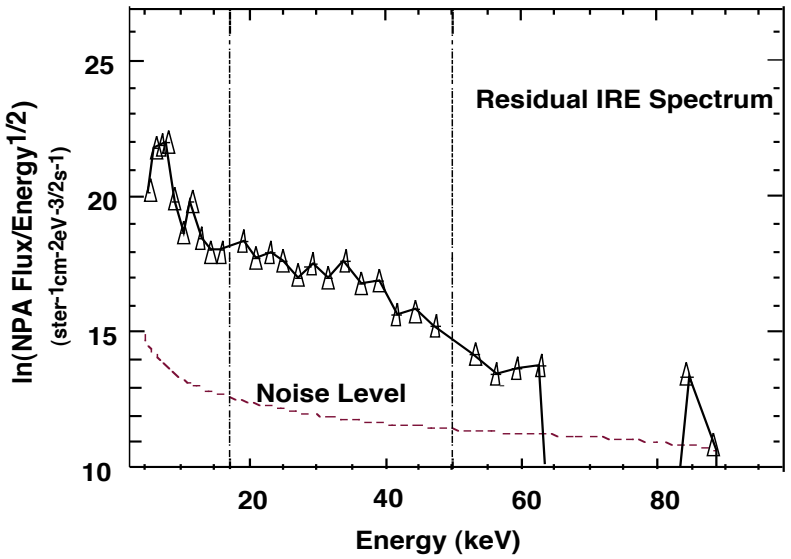






IRE-Induced Ion Acceleration in NB Heated Plasmas: Deuterium Spectra





- The IRE-induced D spectrum in a NB heated plasma is Maxwellian-like with an effective temperature of $T_{eff} \sim 8300$ eV.
- Residual IRE spectrum is the difference between the pre-IRE and IRE time slices.
- In the waveform plots, the spike in the NPA signal at the IRE event is not consistent with the drop in neutron yield. Does the NPA data reflect ion redistribution rather than acceleration due to the IRE event?

Summary

Ohmic Plasmas

- Deuterium and hydrogen thermal ions are accelerated by an IRE event in an Ohmic plasma. The spectra are Maxwellian-like with effective temperatures T_{eff} ~ 1000 - 4000 eV. Decay of the IRE-induced spectra is consistent with classical slowing down of energetic ions.

- The amplitude and maximum energy of the IRE-induced spectra appear to scale with the 'severity' of the IRE as gauged by the magnitude of the spikes on the I_p, $D_{\square}$, and Mirnov signals.

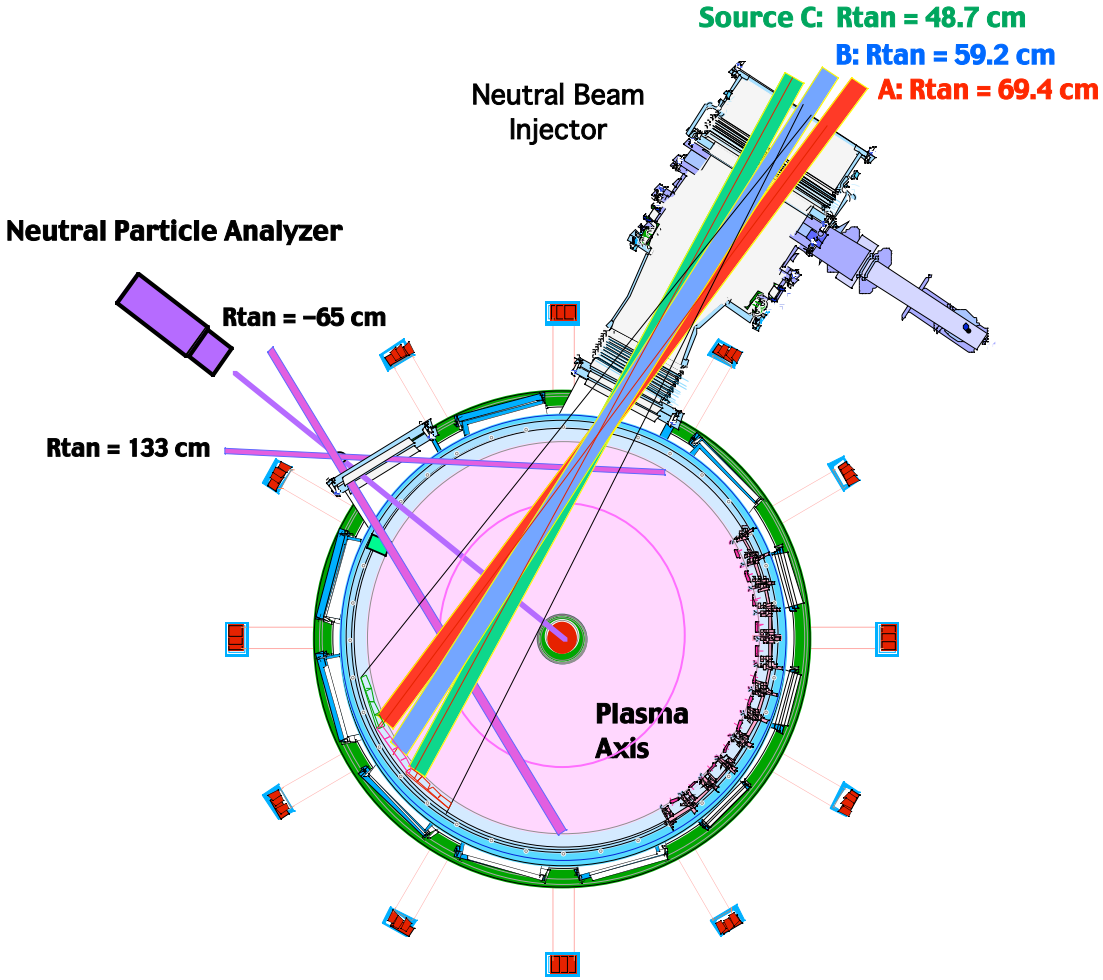
- A simple ratio of the H and D spectra gives H/D ~ 2 - 5 %.

NB Heated Plasmas

- The residual IRE-induced D spectrum in a NB heated plasma is Maxwellian-like with an effective temperature of T_{eff} ~ 8300 eV.

- IRE-induced ion acceleration in NB heated plasmas may be obfuscated by ion redistribution effects.

The NSTX NPA Can be Scanned over a Wide Range of Tangency Angles



- Covers Thermal (0.1 - 10 keV) or Energetic Ion (≤ 150 keV) Ranges