Initial Off-Axis Neutral Beam Characterization and Physics Experiments on DIII-D

by

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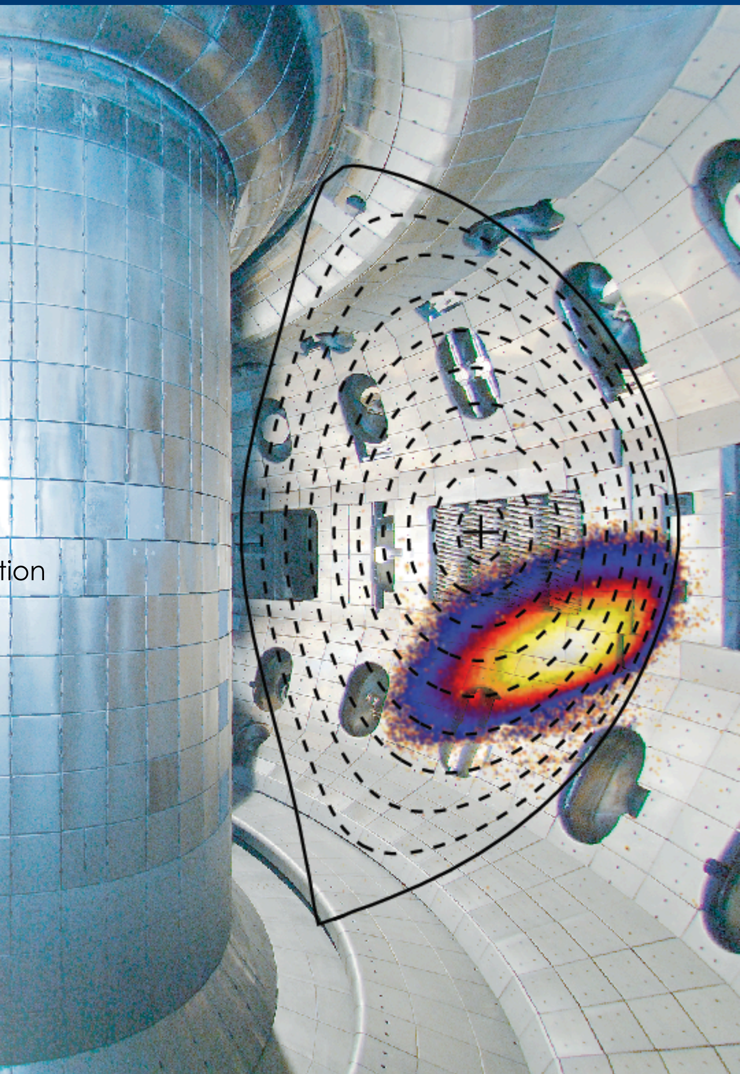

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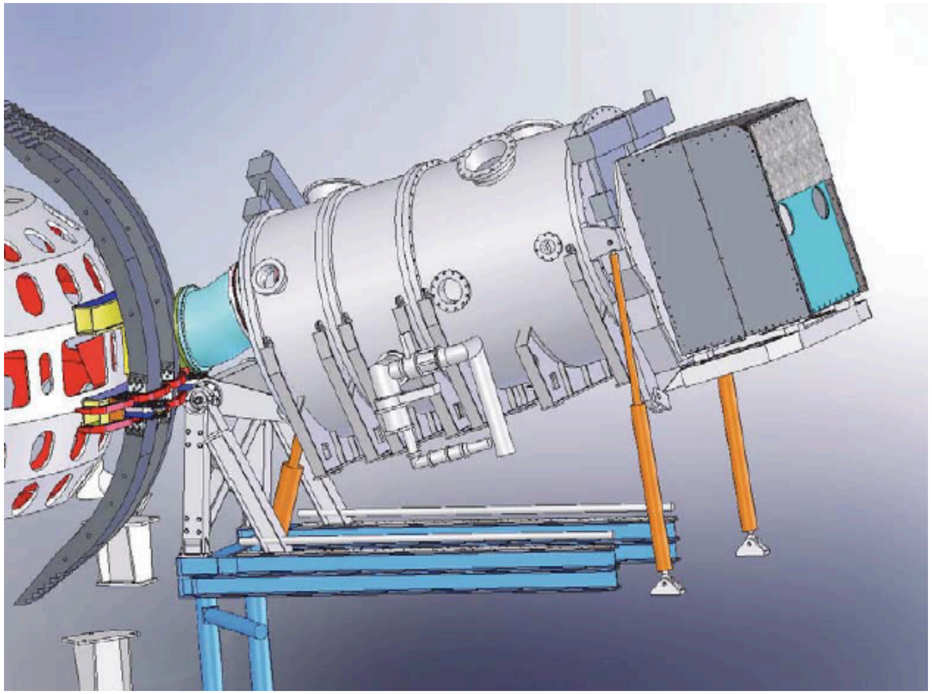
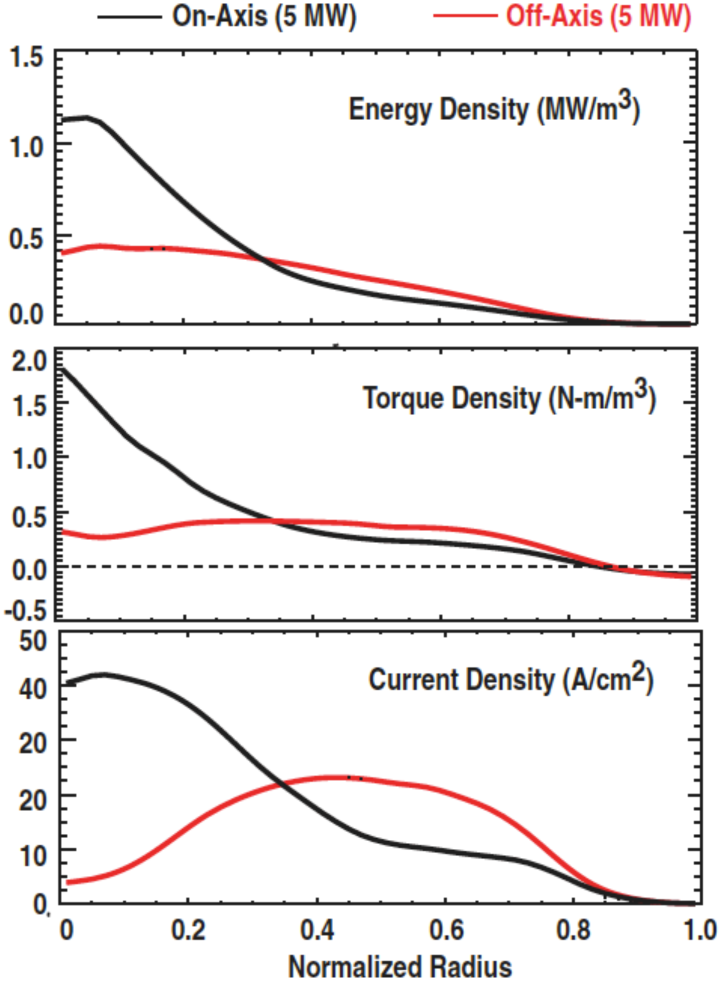
In 2010-2011, One of DIII-D's Beamlines was Modified to Allow Off-Axis Injection – Enabling A Broad Range of Profile Control

16.5 Deg. Max Beamline Tilt



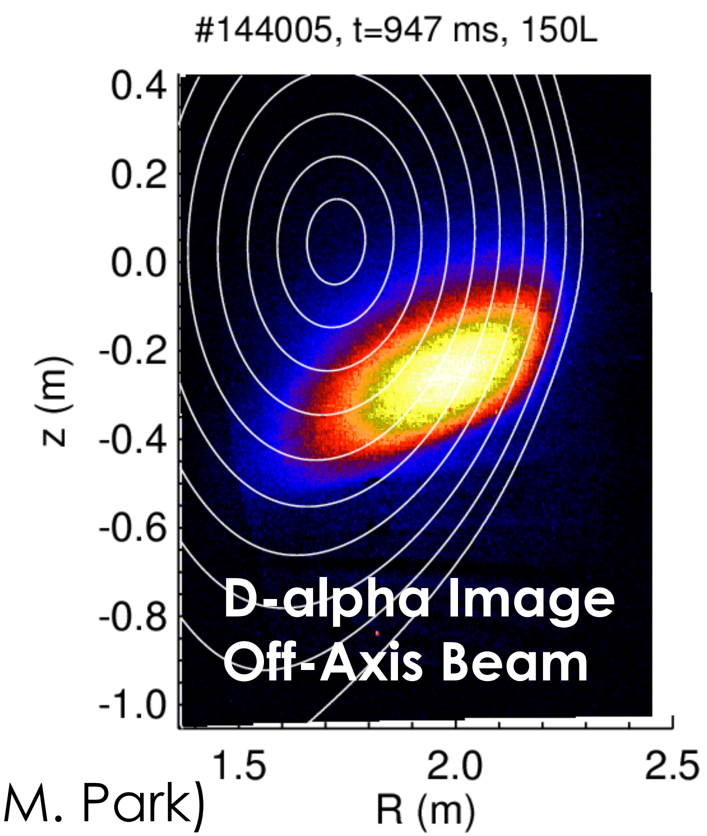
***Engineering Challenge - Required major source modifications to fit beam through reduced aperture**

Calculated Profiles



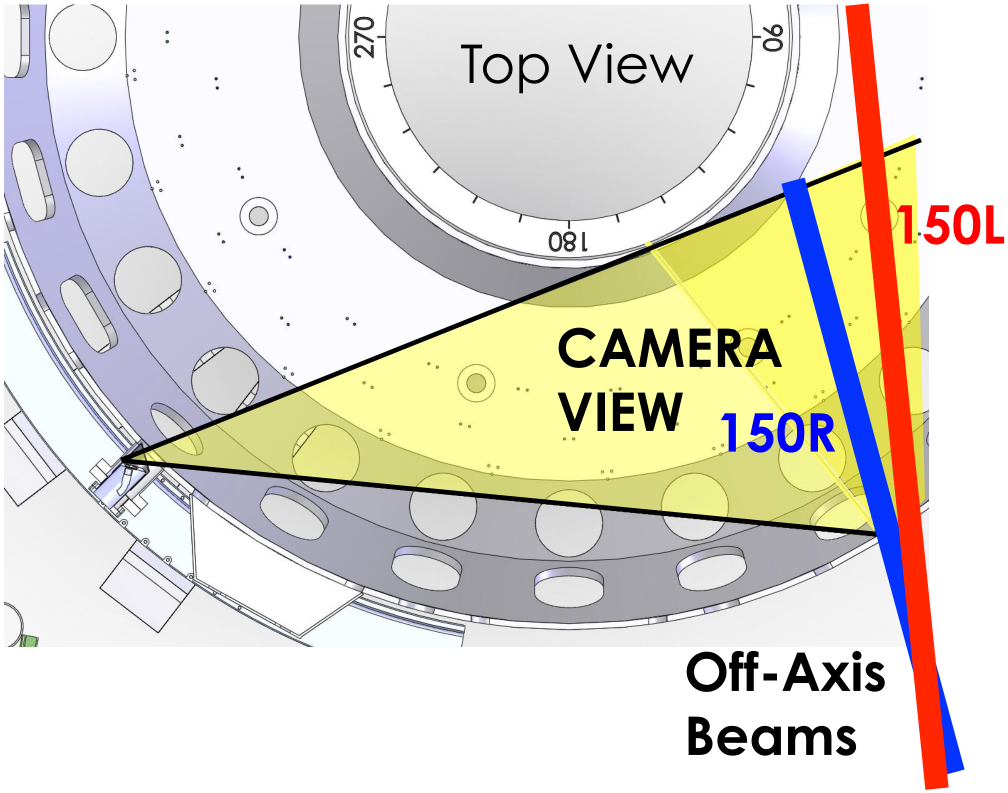
Initial Experiments Focused on Characterizing the Beam and Developing Models to Describe it

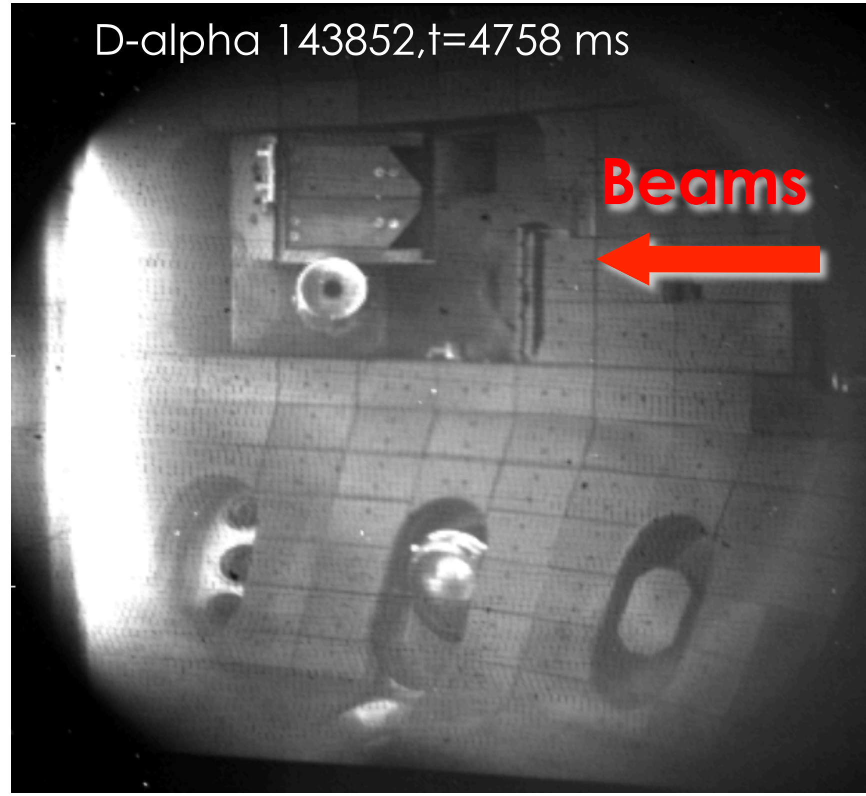
- **Trajectory, shape, divergence, power, confinement, fast ion profile etc. were measured**
  - Imaging of beam injection into gas
  - Beam blips into Ohmic discharges
  - MHD quiescent low beam power discharges



- **Subsequent experiments focused on**
  - Off-axis neutral beam current drive (J.M. Park)
  - Impact on Alfvén eigenmodes
  - High q_{min} steady state discharges (C.T. Holcomb)

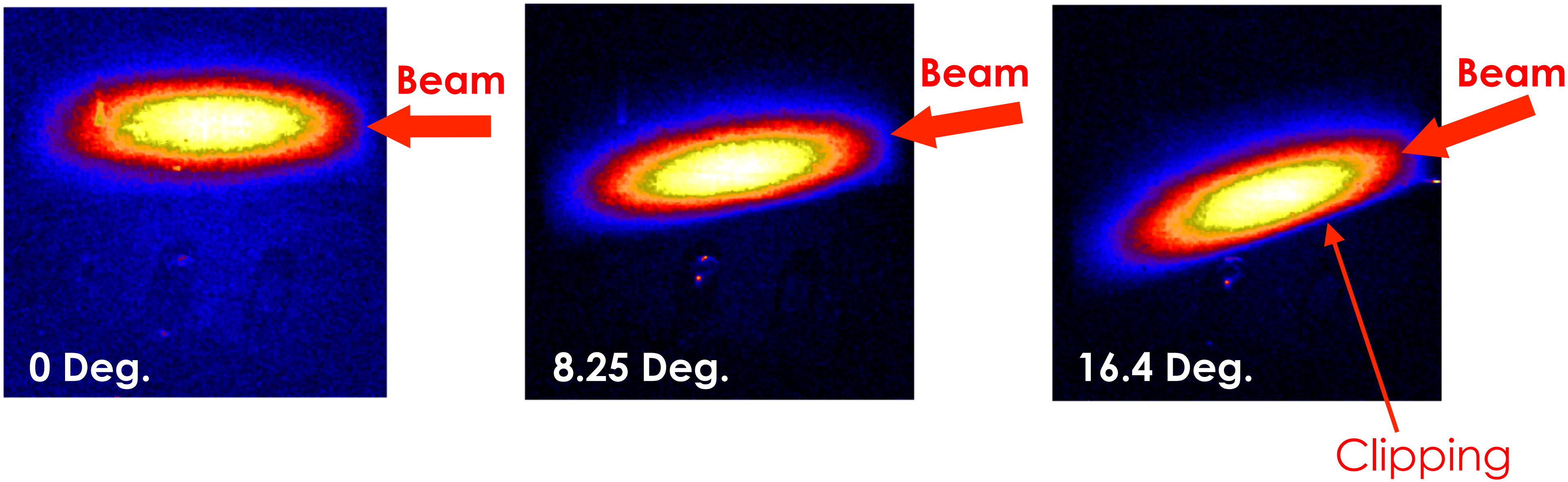
To Support Beam Characterization, an Imaging View the Off-axis Neutral Beam Was Installed





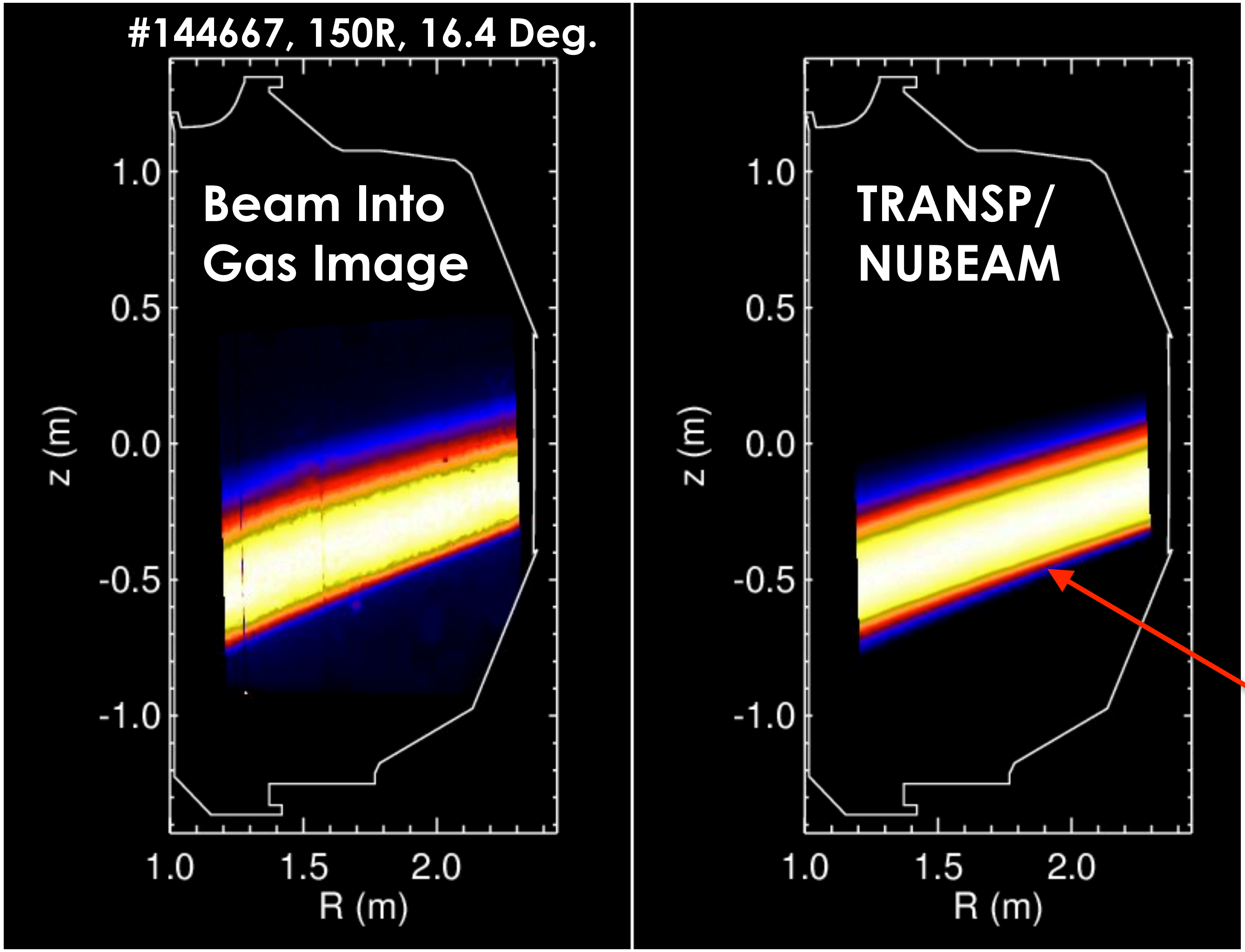
- **Camera view spans from outer to inner wall**

D-alpha Imaging of Beam Injection Into Neutral Gas Was Carried Out for a Range of Beam and Source Tilts



- **Images show beam emission and yield neutral profile**
- **Range of angles and tilts allows check on steering**
- **Some clipping of beam on portbox is evident as beam tilt increases**

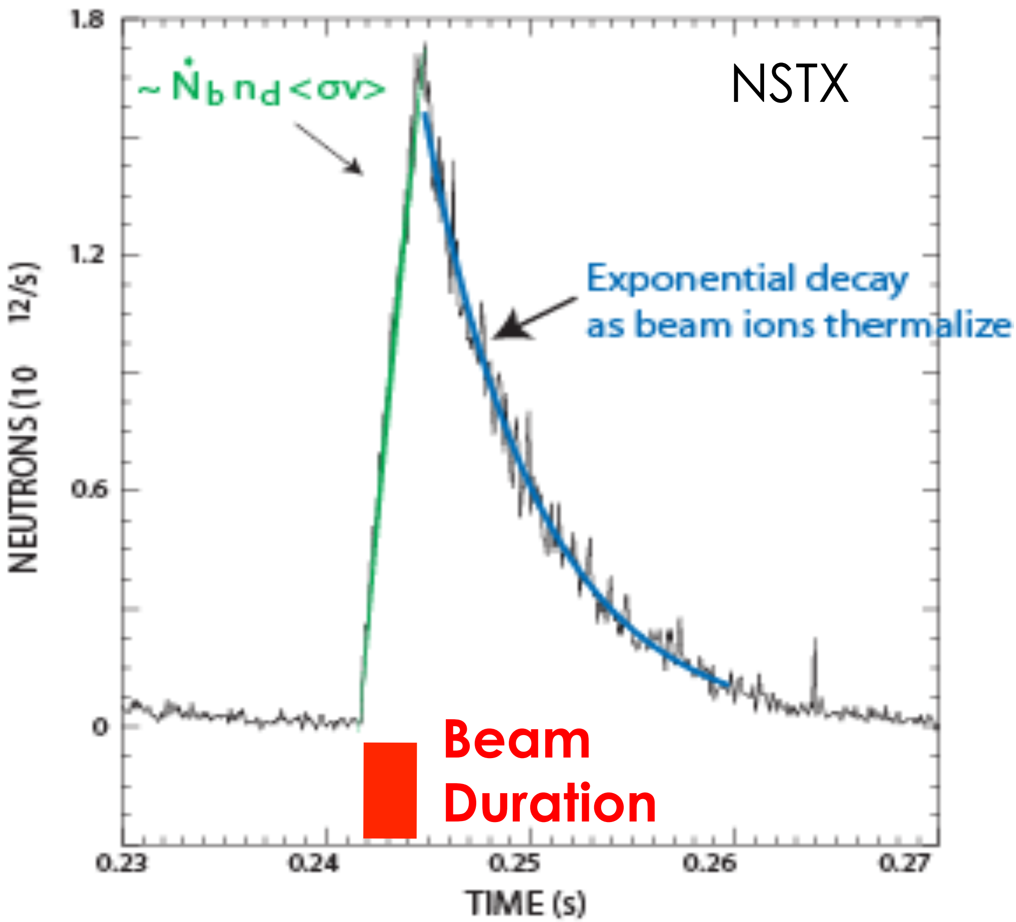
NUBEAM* Model Based on Imaging Data was Developed that Accurately Describes Off-axis Beam Profile Throughout Tilt Range



- Off-axis beam is described by four sources with several collimators that change with tilt – previously only one source was required
- Model properly describes beam profile modification and power loss due to clipping as beam and source are tilted

*A.Pankin, D. McCune, R. Andre et.al., Comp. Phys. Comm. 159, 3 (2004)

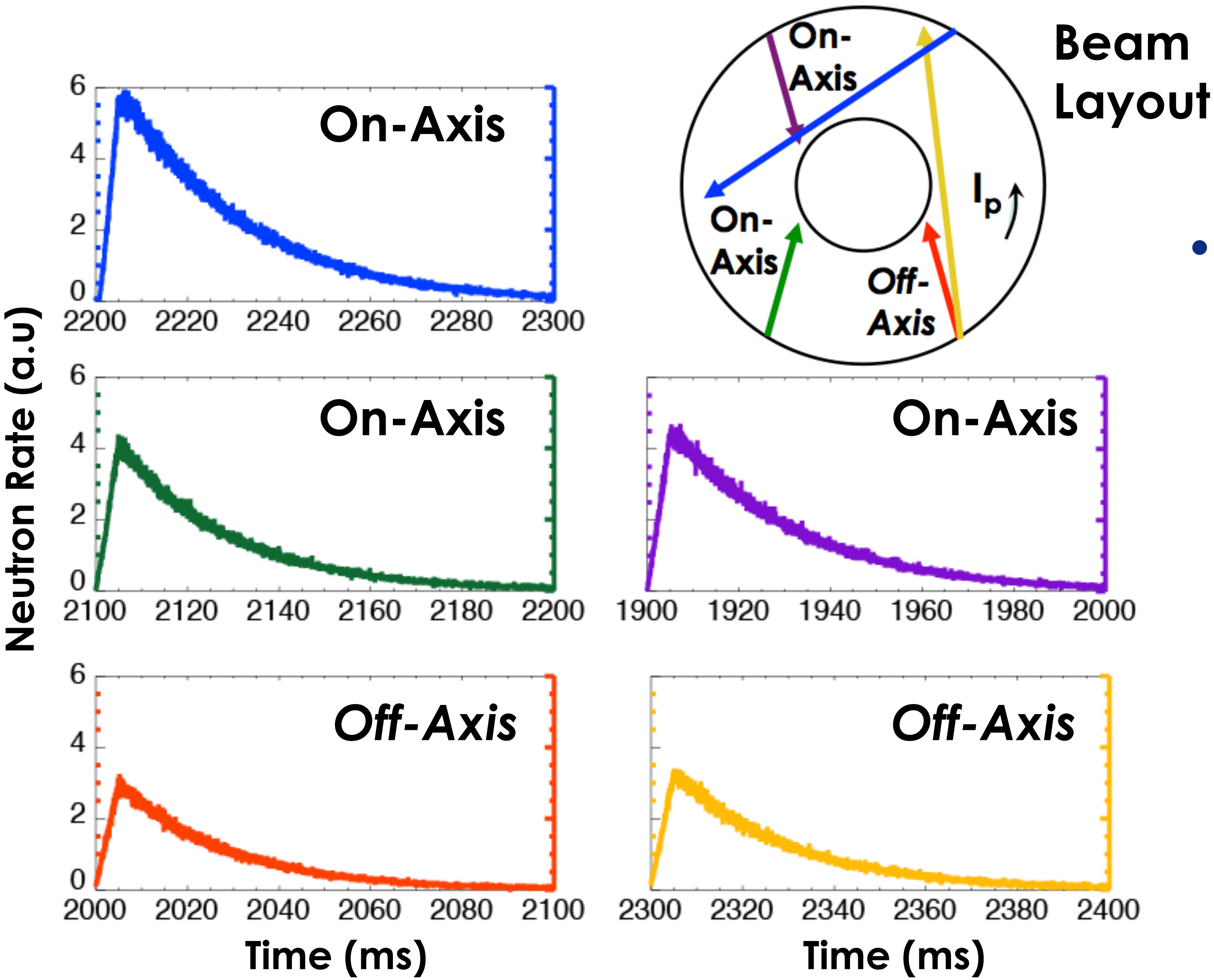
Short Beam Blips Were Used to Investigate Beam Fueling, Prompt Loss, and Confinement



- **Neutron rise depends on number of confined beam ions injected and target density**
- **Decay depends on slowing down & losses on τ_s timescale**
- **Minimal beam power leaves essentially Ohmic plasma, free from large MHD**

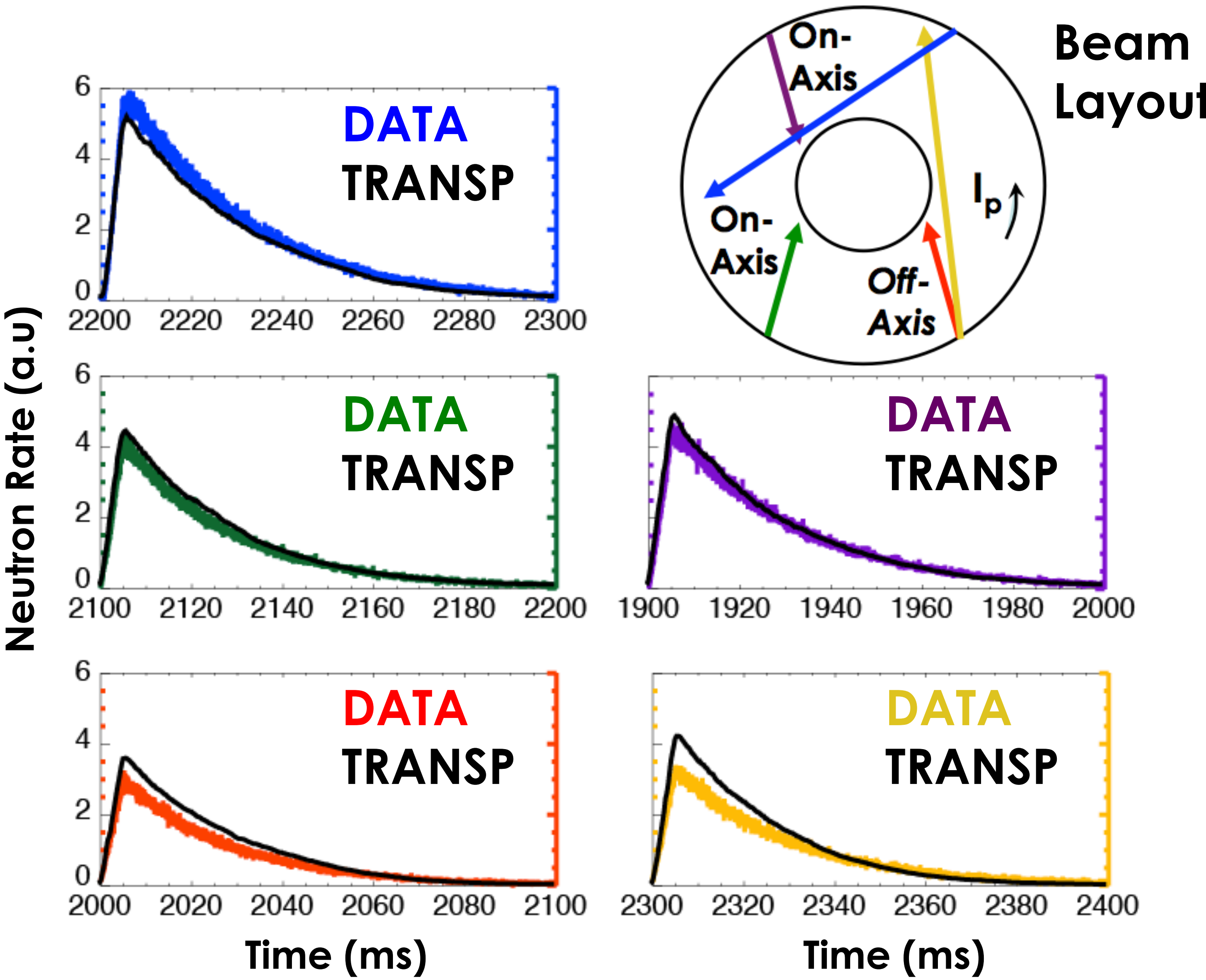
W.W. Heidbrink, et.al., Nucl. Fusion 43 (2003) 883.

Beam Blip Neutron Measurements Are Compared For Several Beams



- **Off-axis beams clearly produce less neutrons than on-axis beams**
  - Some reduction expected with deposition at larger radii (lower density and temperature

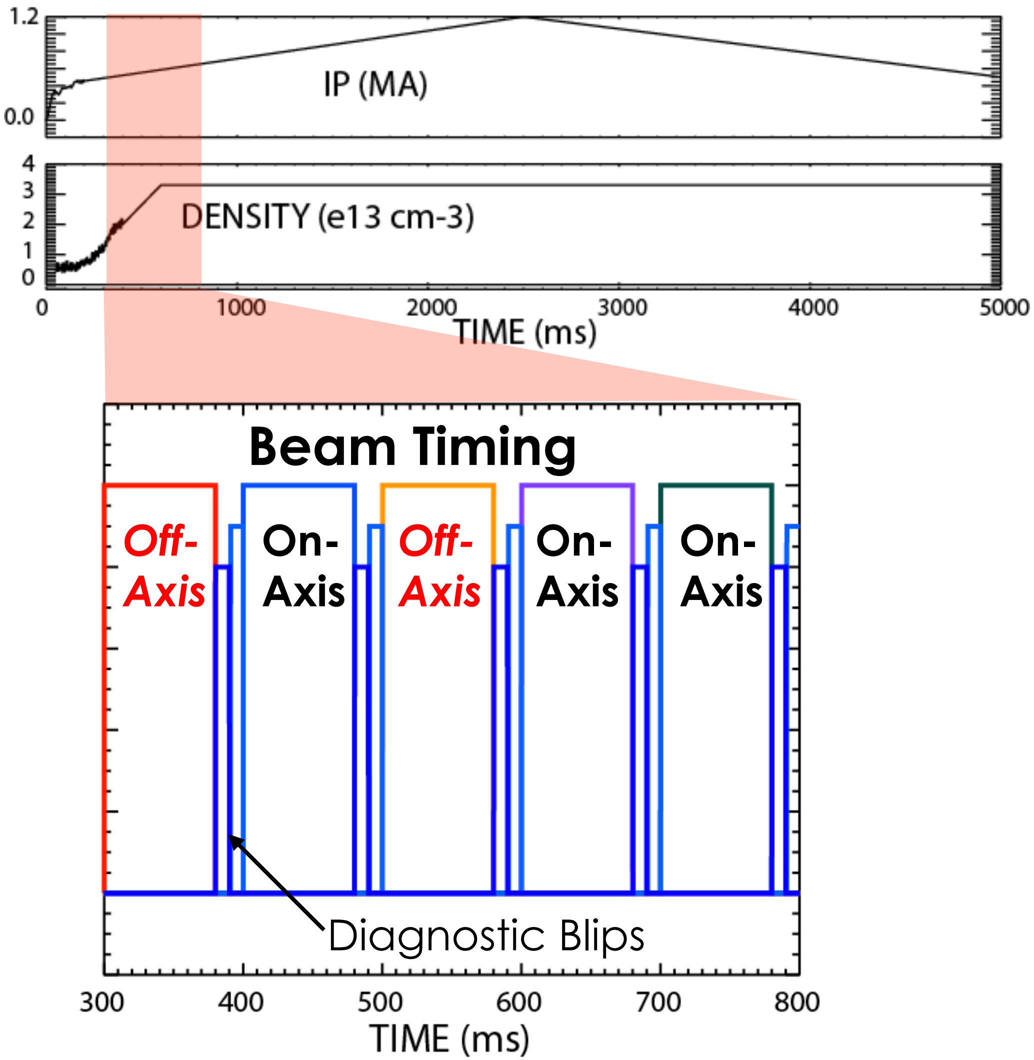
TRANSP* Predictions Reproduce Trends but Show Off-axis Beams Produce Fewer Neutrons Than Expected



- Simulations are consistent with less neutron emission from off-axis beam
- Decay timescales generally match well indicating no losses on slowing down timescale
- Overall peak neutron rate is below expectations from off-axis beams

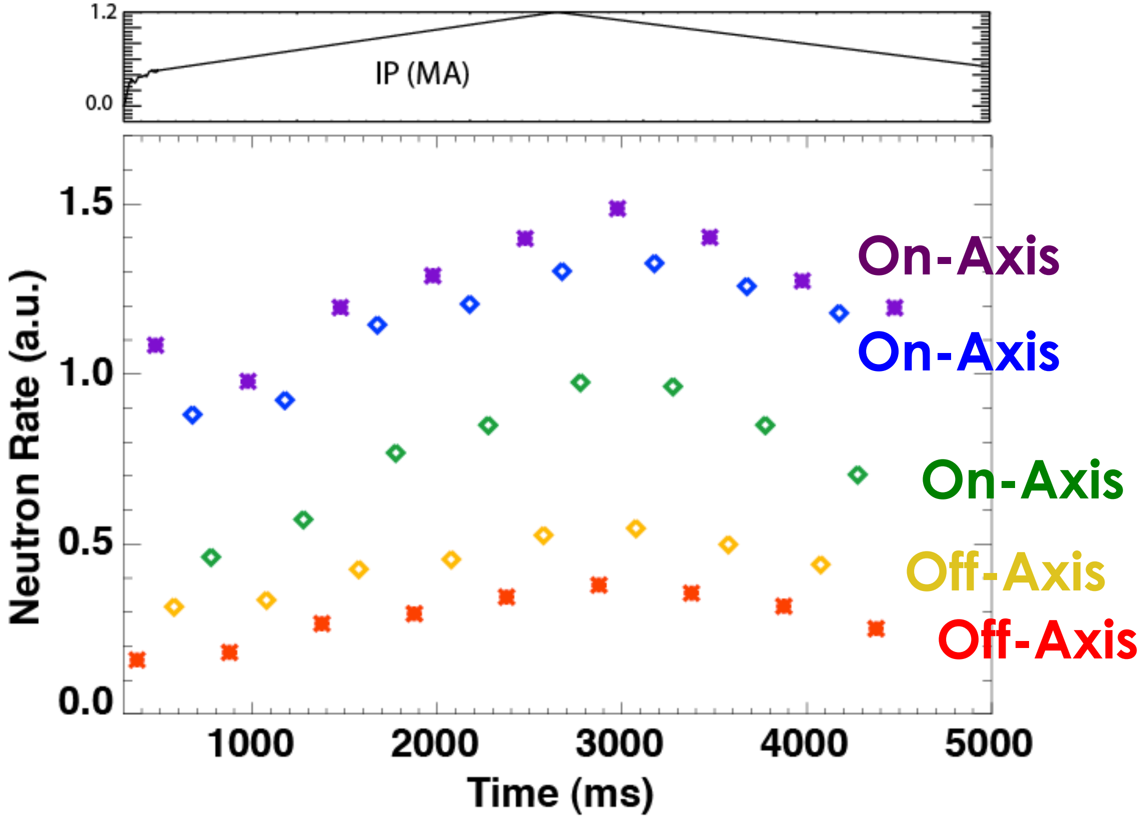
* w3.pppl.gov/transp

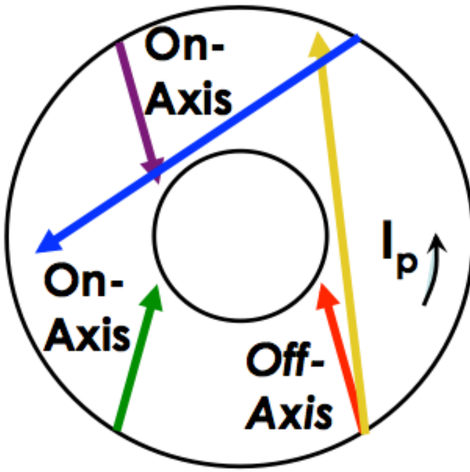
Experiments Were Also Carried Out to Compare Neutron Emission For Pulses Comparable to Slowing Down Time



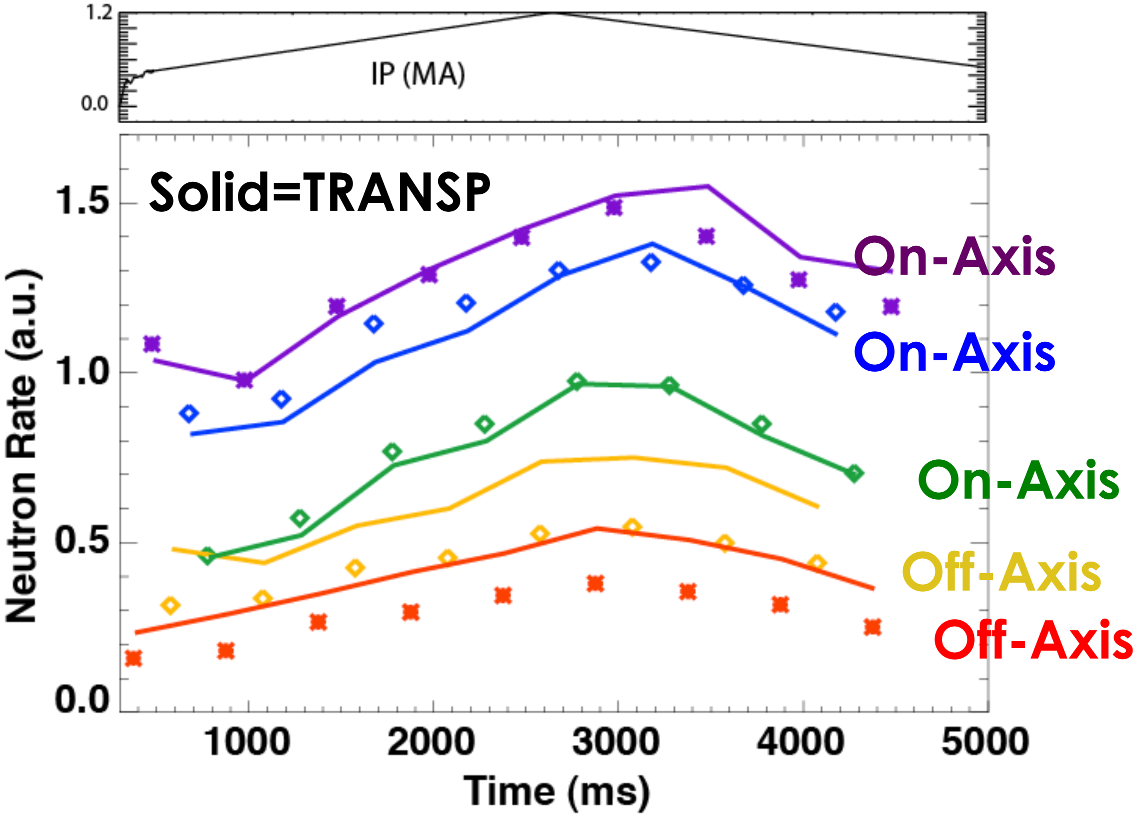
- **Longer pulses mitigate sensitivity to density profile uncertainties**
- **Beams were cycled through for entire discharge**
- **Diagnostic beams were blipped after ~ one slowing-down time and beams switched**
- **Current ramp was used to alter fast ion confinement/prompt losses**
- **Single beam heated L-mode discharges like this are typically free from large MHD – ideally classical behavior**

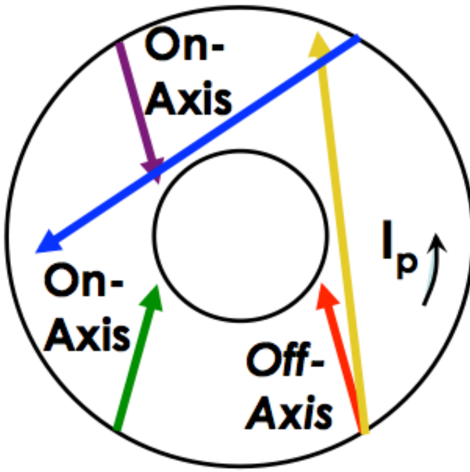
Long Beam Pulse Data Show Plasma Current Dependence as Well as Lower Neutron Emission From Off-Axis Beams





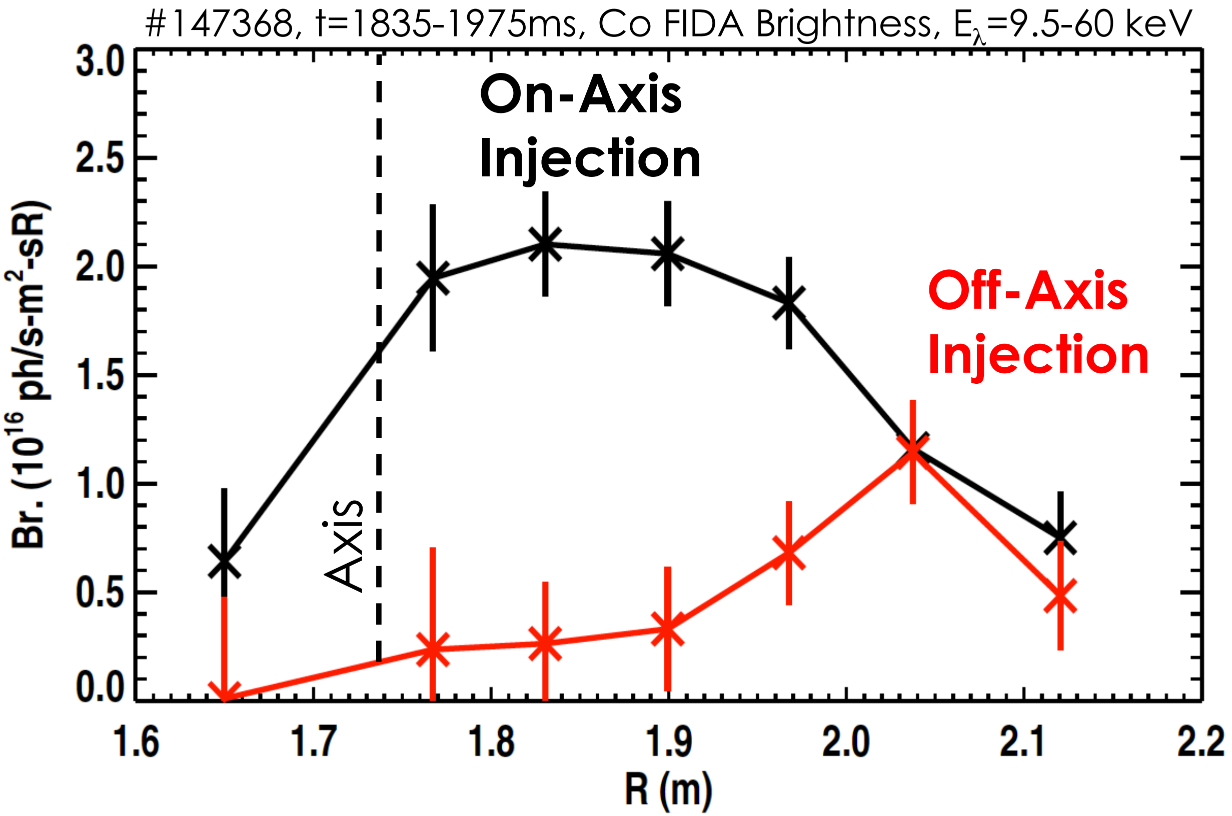
TRANSP Reproduces Trends but Overpredicts Neutron Emission from Off-Axis Beams





- Current dependence is correctly captured for all beams but relative emission of off-axis beams is low
- For collection of similar discharges *Off-axis Expt/TRANSP ~0.7-0.95*

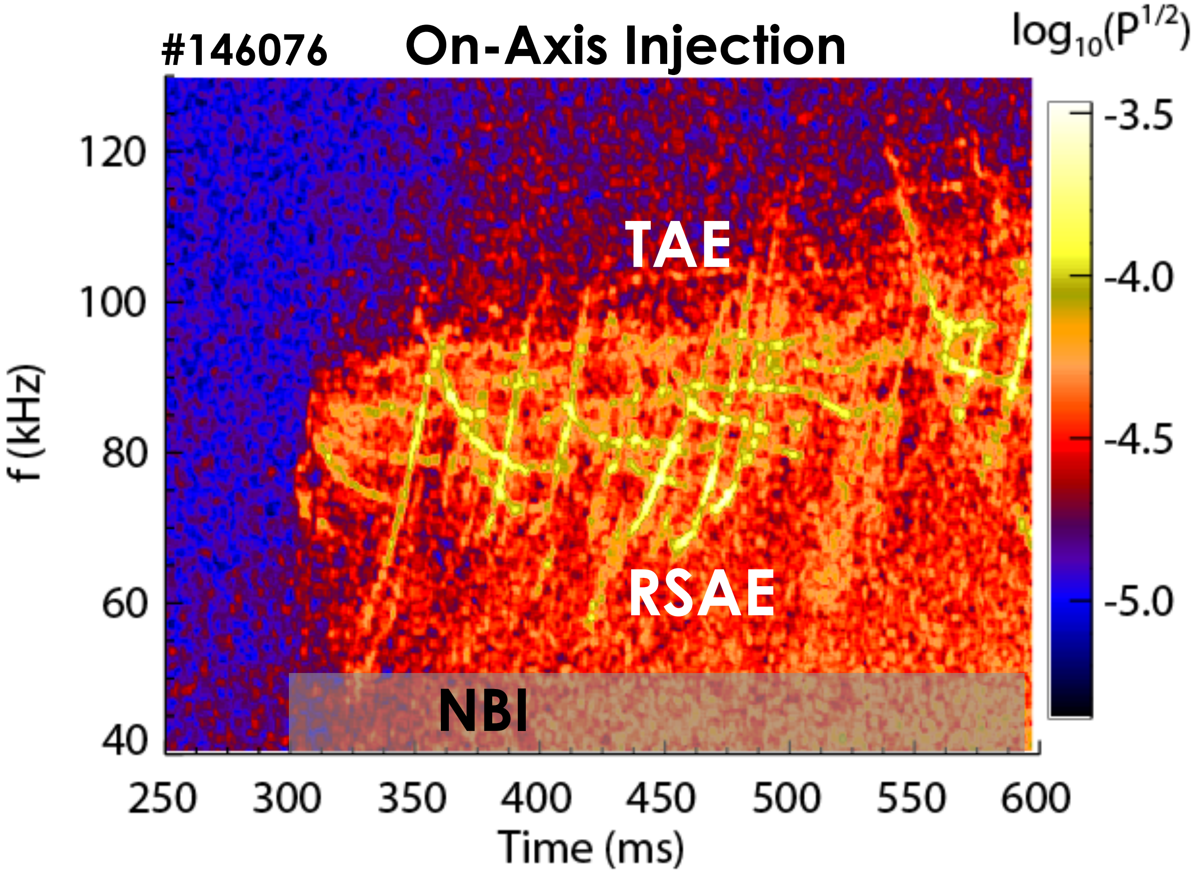
FIDA Measurements Clearly Show Off-Axis Peak in Fast Ion Profile



- **FIDA (Fast Ion D-alpha) is used to measure fast ion density in portion of phase space**
- **Data will be compared to FIDA simulation code to evaluate expected emission**

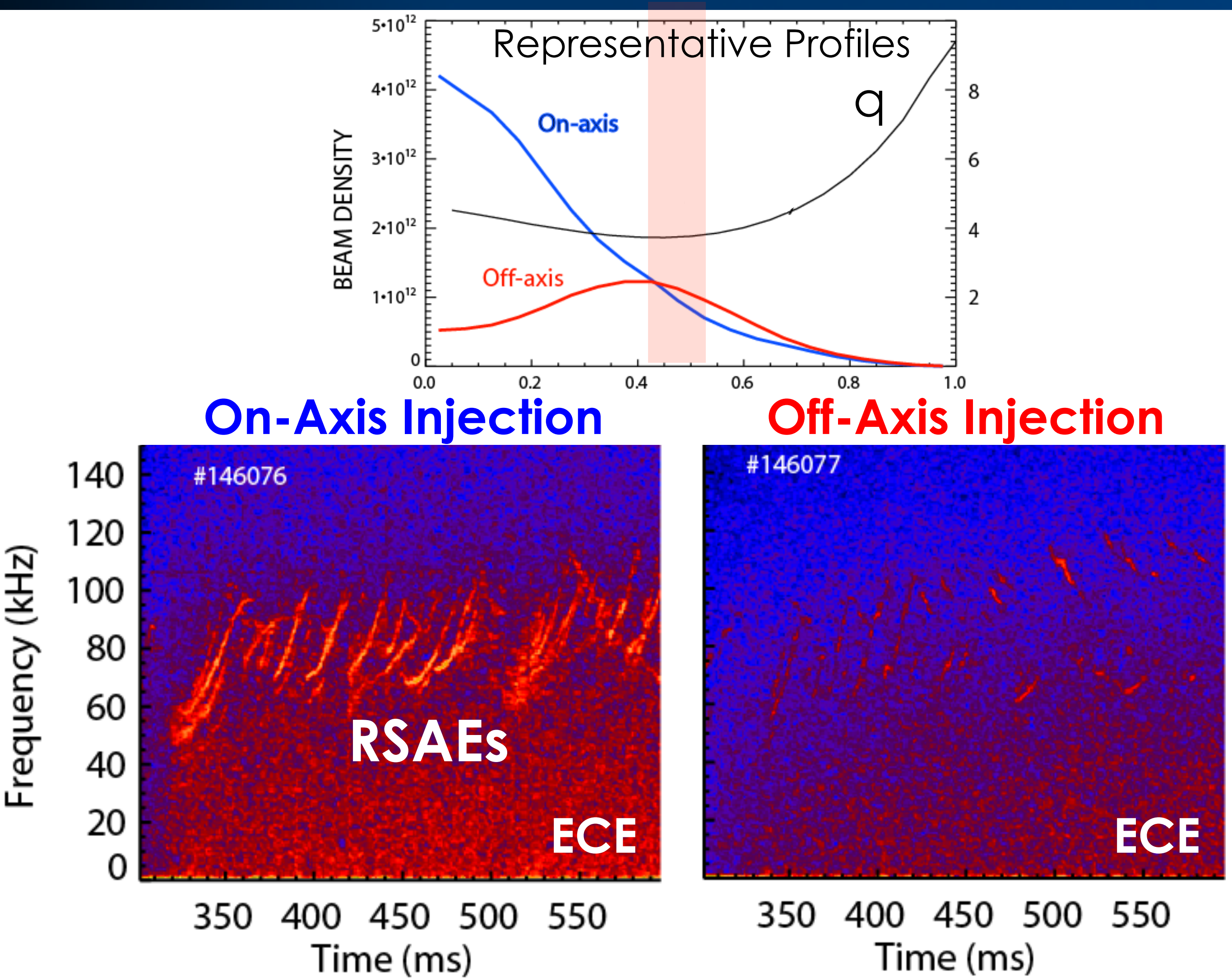
B. Grierson, Wed. 11:30, NI2.00005

Initial Physics Expt. Tested Variation in Alfvén Eigenmodes as Beam Injection Was Varied From On to Off-Axis



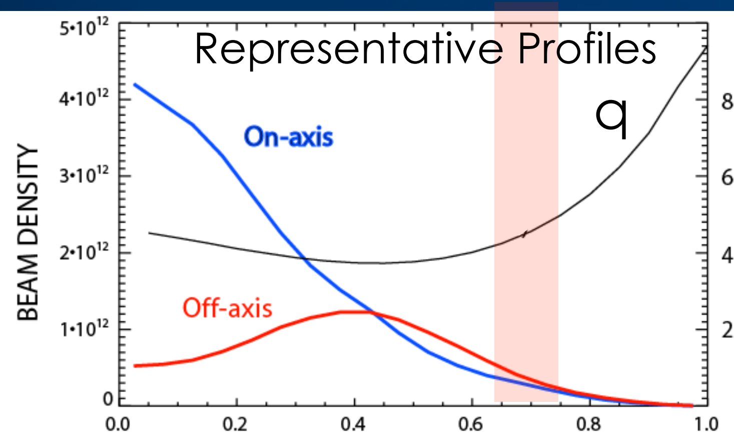
- Variety of Alfvén Eigenmodes are typically observed with beam injection during current ramp
- Modes are driven by gradients in the fast ion pressure

Near q_{min}, RSAEs are Driven Strongly By On-Axis Beams but Weaker Gradient From Off-Axis Beams Provide Less Drive

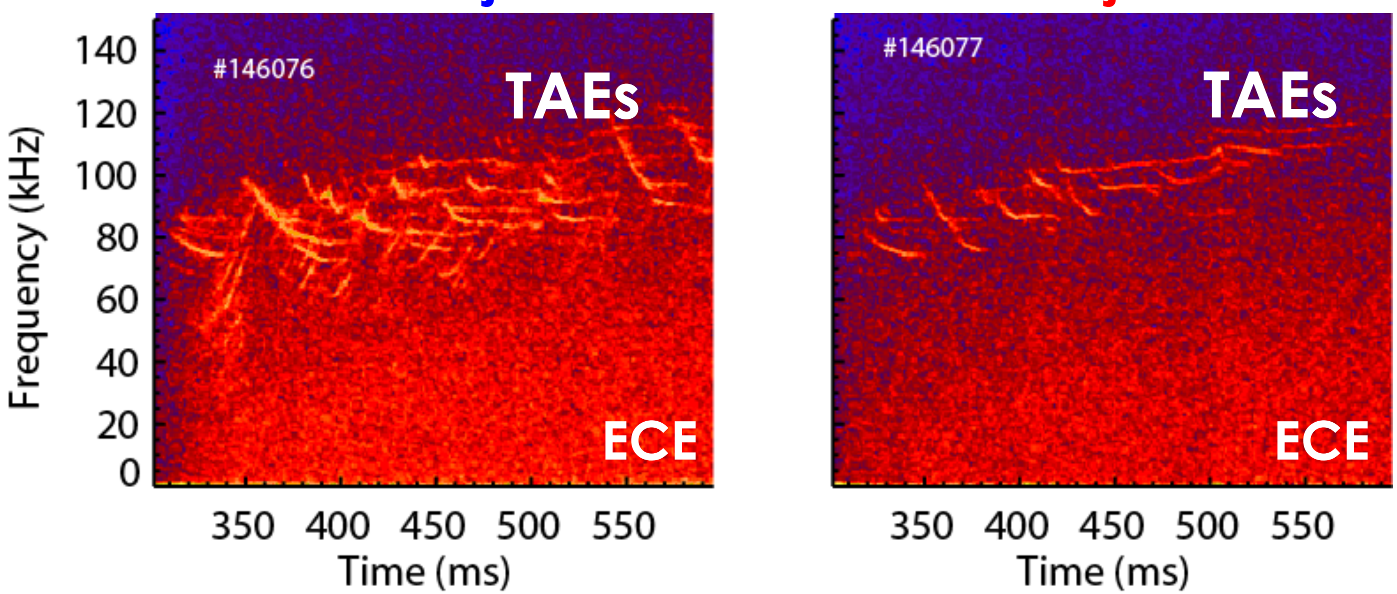


- **Reversed shear Alfvén eigenmodes are typically weak or not observed during discharges with only off-axis beams**
- **Consistent with weaker fast ion gradient near q_{min}**

TAEs Are Observed During Both On and Off-Axis Beam Injection



On-Axis Injection **Off-Axis Injection**



- **Toroidal Alfvén eigenmodes (TAE) typically unstable at larger minor radii where fast ion gradients are comparable**

Conclusions

- One of DIII-D's beamlines was tilted allowing up to 5MW off-axis injection and experiments clearly show radial shift in deposition profile
- Initial experiments included careful characterization of beam profile and focus on developing model to describe beam
- Predicted neutron rate from beam blips and single beam low power discharges appears to be high for off-axis beam
  - Next talk will discuss comparisons with current drive and stored energy
- In Alfvén eigenmode current ramp experiments, off-axis beams produce weaker drive for RSAEs than on-axis beams while TAEs at larger radii are often unstable during both on/off axis injection