Off-axis Neutral Beam Experiments in DIII-D

Presented by
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For Evaluation of Off-axis Neutral Beam Physics Working Group

FEST Seminar
Aug 24, 2011

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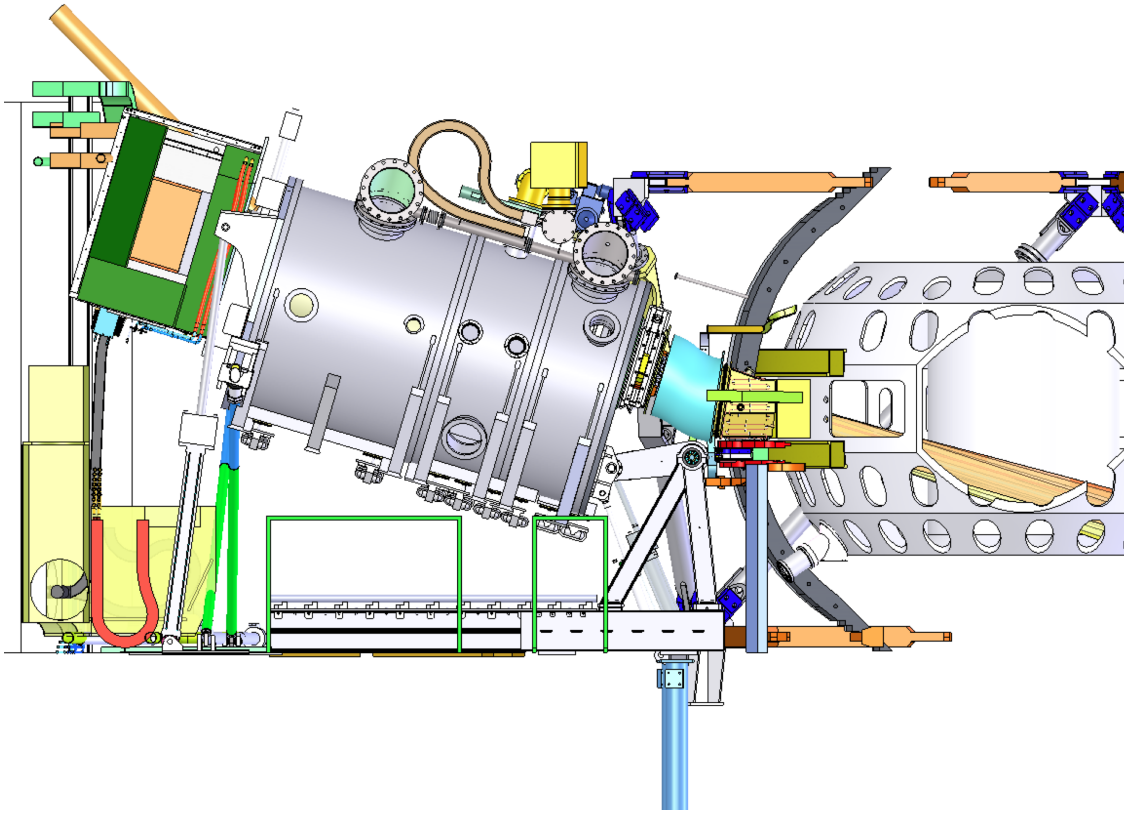
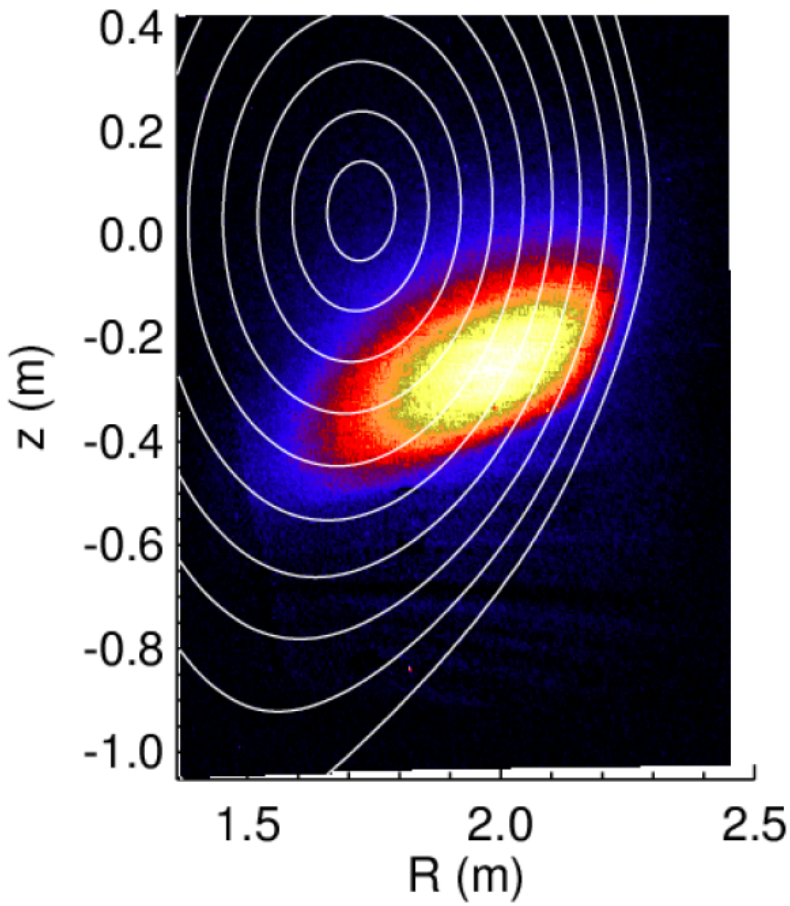
OAK RIDGE National Laboratory

150 Beamline Tilted to Drive Current Off-axis

- **Beamline Tilt : 0-16.4°**
- **Source Tilt : 0-32'**



- **Beam Into Gas Image (16.4° , 32')**



→ **Significant off-axis deposition**

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Evaluation of Off-axis Neutral Beam Physics (OANBP) Working Group

- **Questions we are trying to answer:**
  - Does the new off-axis beam work and does it behave as we expect?
  - Most importantly, does the off-axis beam drive current where we expect?
- **Ultimate goal is a validated set of tools/models, such as NUBEAM, describing the off-axis beam behavior and an estimate for the range of applicability**
  - Important to Steady-State Mission

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Three Experiments for the OANBP Group Have Been Carried Out Successfully

- **Off-axis beam checkout and classical fast ion confinement:**
  - Obtain measurements of the OANB profile, steering, and divergence
  - Use low beam power quiescent plasmas to validate modeling of OANB ion confinement in classical conditions
- **Off-axis NBCD measurement:**
  - Determine local profile of off-axis NBCD and compare with modeling
  - Carry out for range of conditions – power (and plasma β), injection voltage, +/-BT
- **Effects of microturbulence on fast ion confinement:**
  - Measure fast ion density and turbulent fluctuation simultaneosly
  - Compare with TGLF and Gyro modeling

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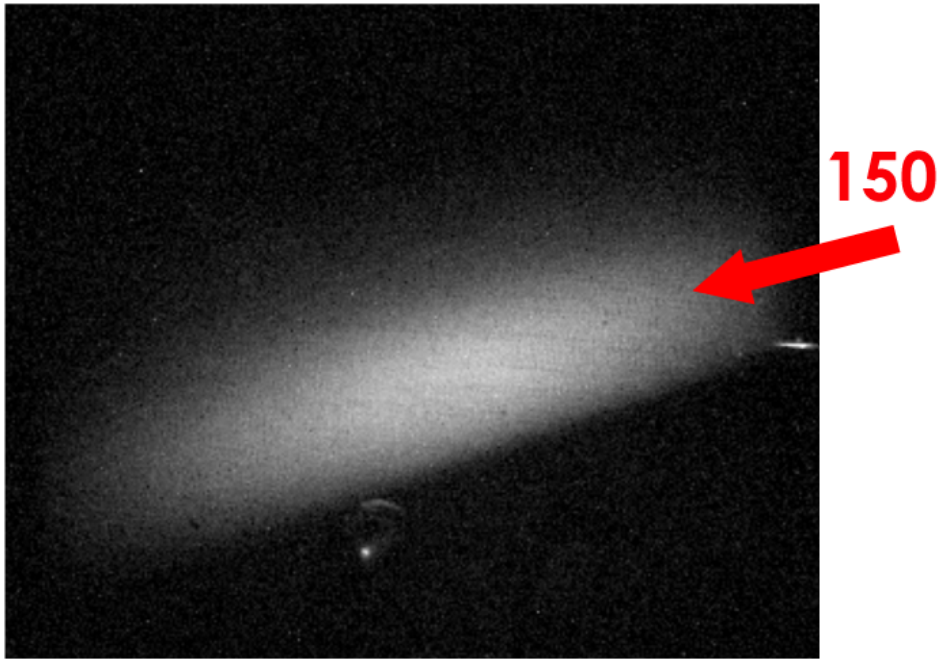
Initial Beam Characterization Used Beam Into Gas

143991, 1

DIII-D - Beam into Helium Gas

143995



- Images taken with D_α filter
- Initial images show interaction with port-box and/or dust
- Contaminants were much reduced in subsequent shots

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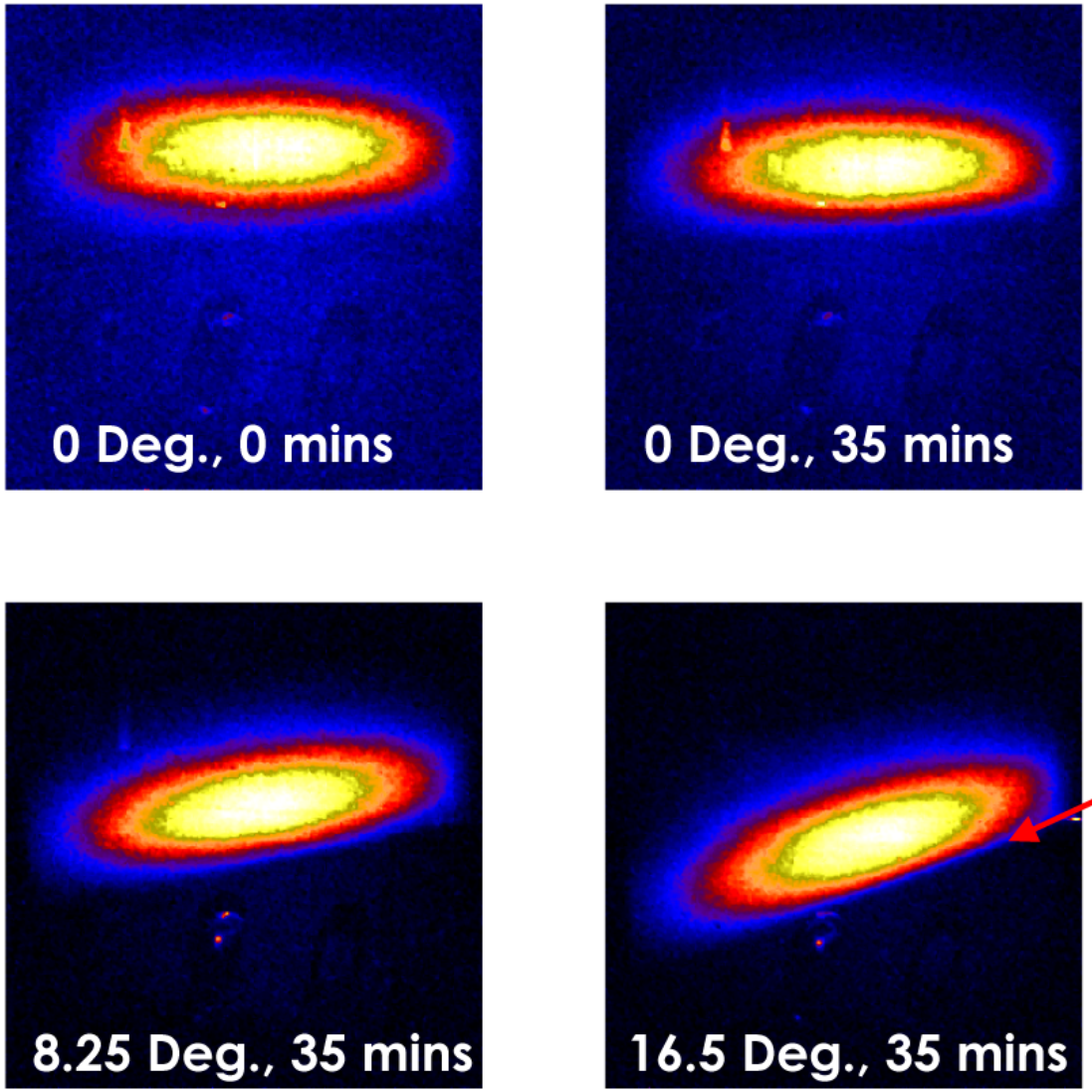
Beam Injection Into Gas Was Carried Out for a Range of Beam and Source Tilts



- D_α images show beam emission and yields neutral profile
- Range of angles and tilts allows check on steering
- Clipping of beam is evident as beam tilt increases

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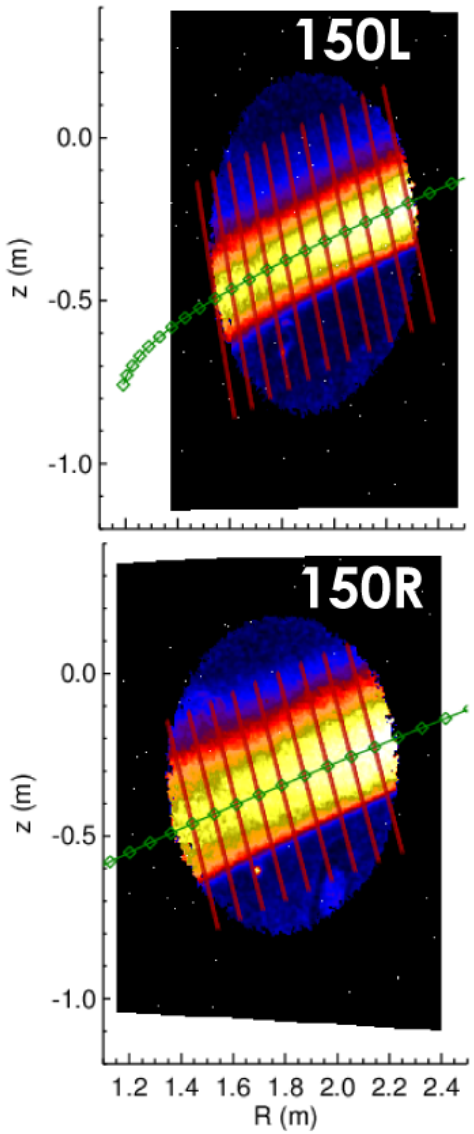
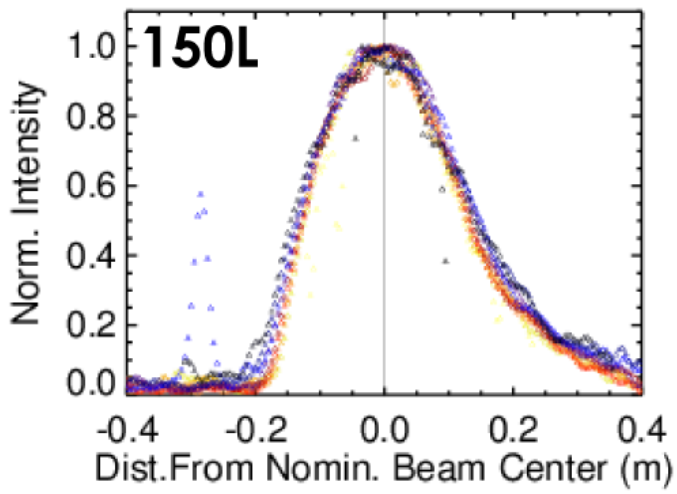
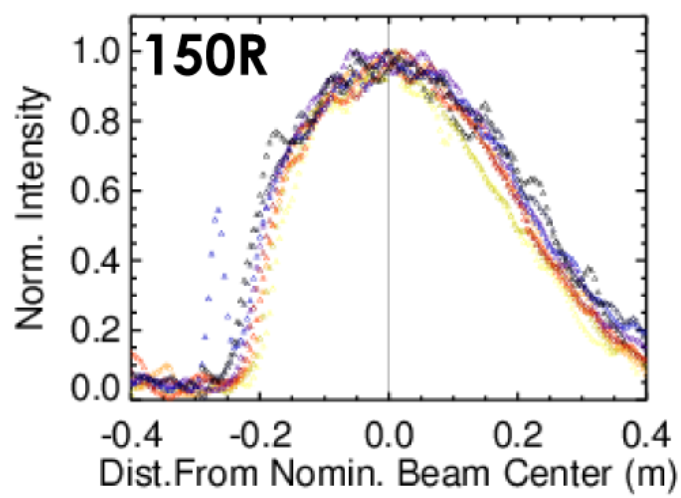
Images Show a Significant Difference in Size Between the 150L and 150R Beams







- **The 150R beam appears to be larger than the 150L**
- **HWHM of each beam (Gaussian fit to central portion)**
  - 150L ~ 14 cm
  - 150R ~ 24 cm
- **Caution – 150R has more reflections and background light, possibly contributing to diecrepancy**

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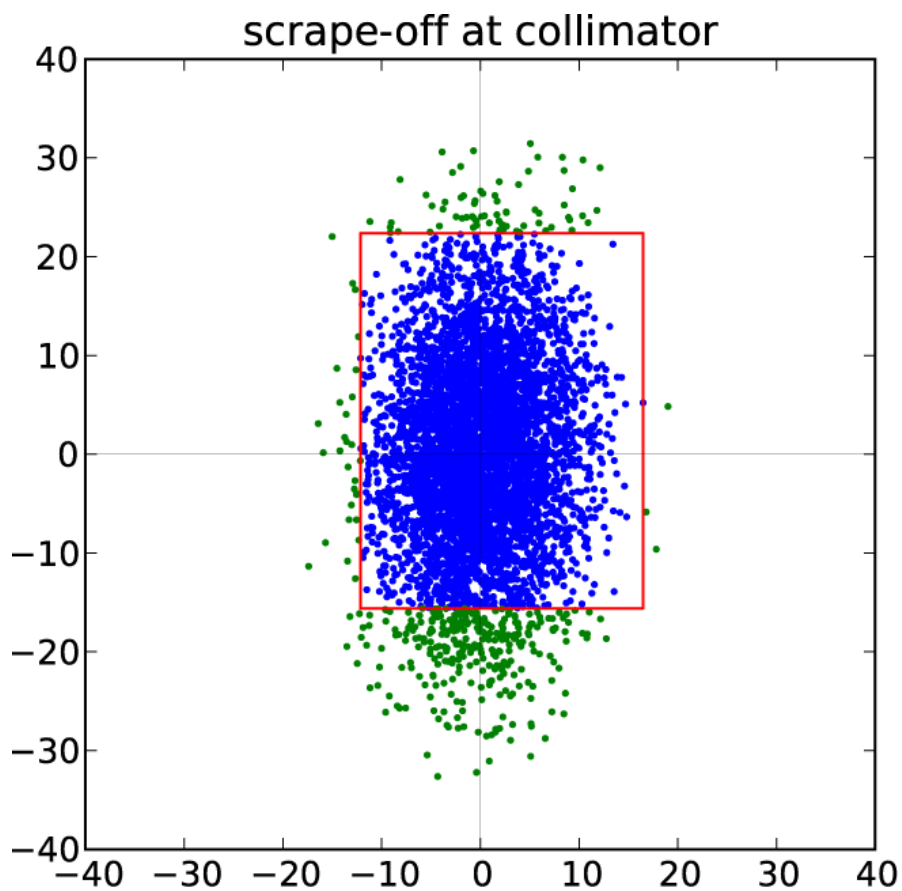
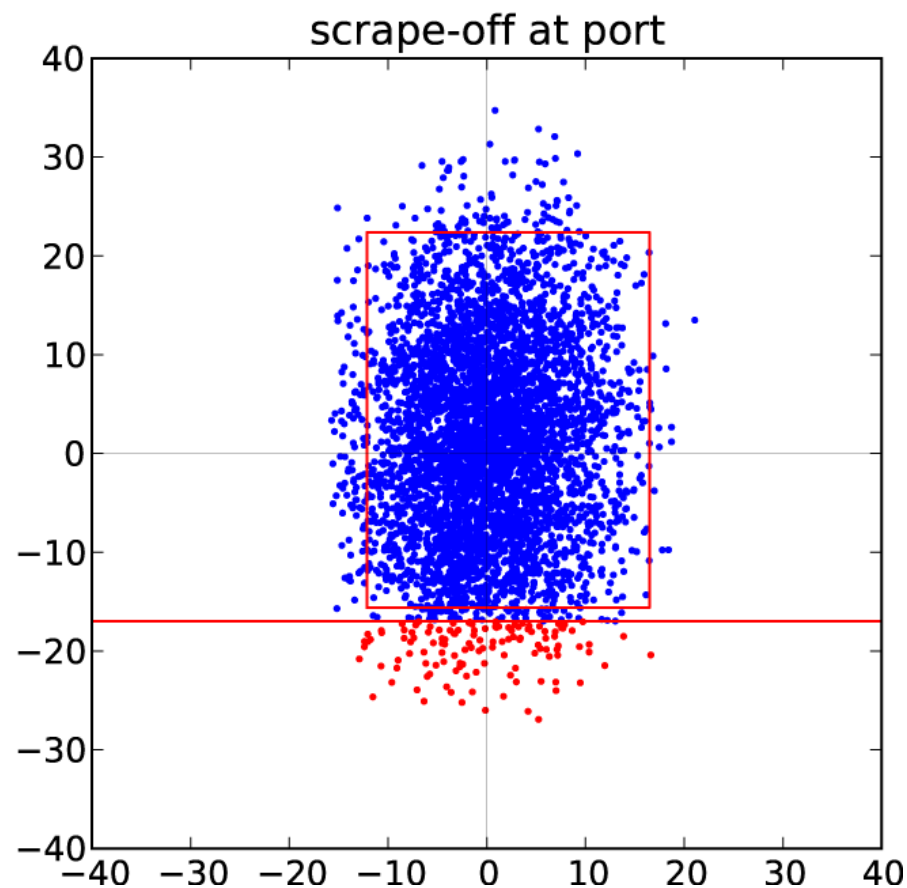
Modeling Indicate Additional Beam Scrape-off at the Port-Box





- **Monte Carlo simulation of NB particle injection**

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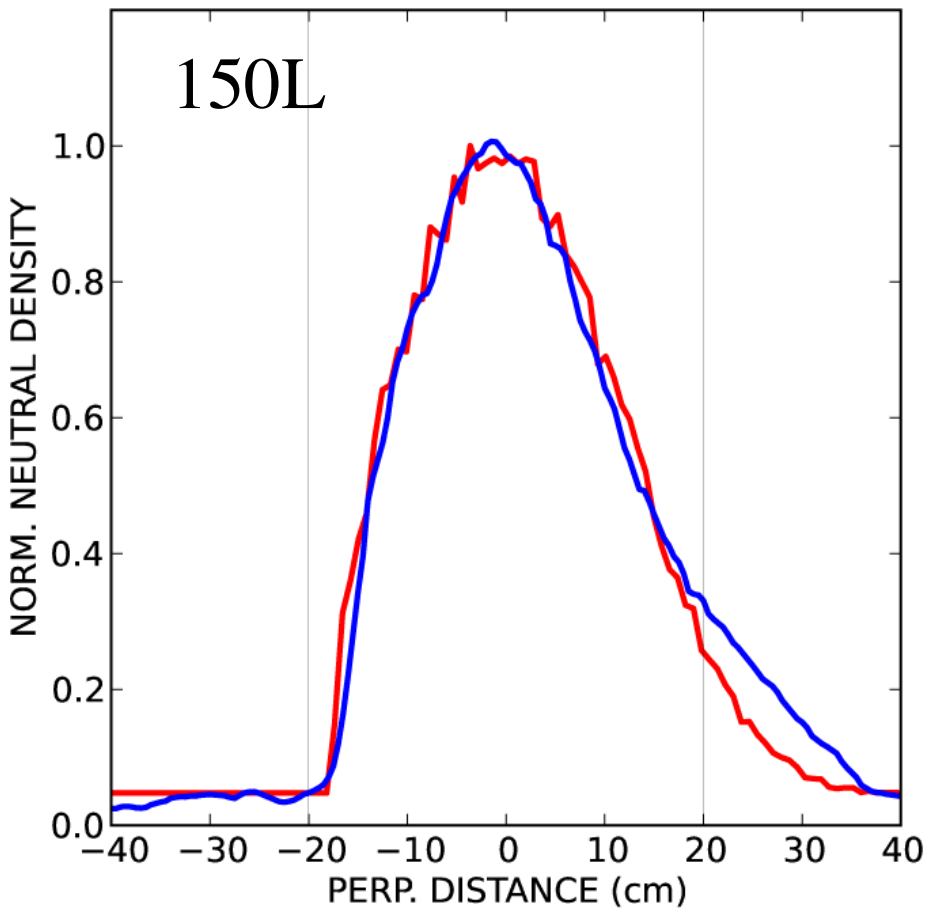
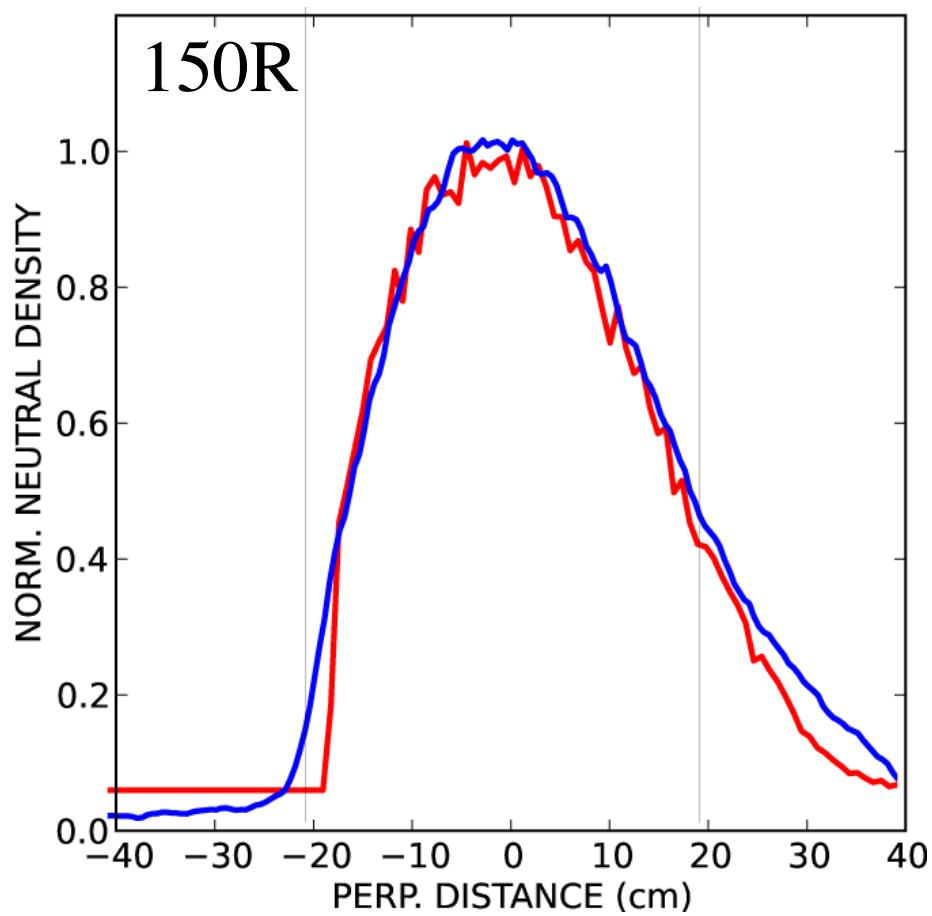
Modeling Indicate Difference in Beamlet Divergence between 150L and 150R





- **Beamlet divergence adjusted to best match the images**
  - 150L : 1.0 °, 150R: 1.3 °

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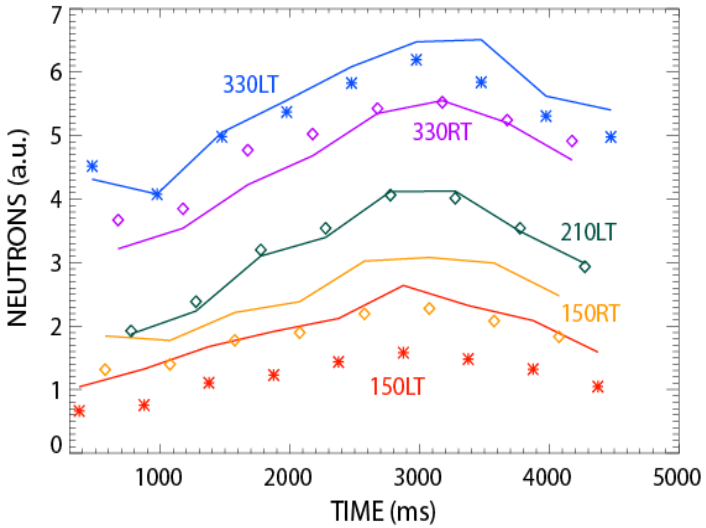
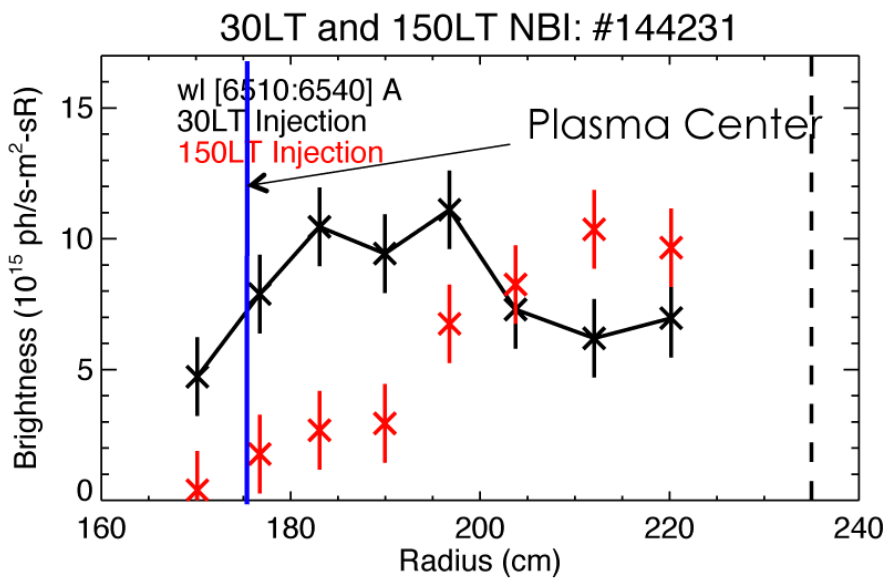
Fast Ion Confinement Measured to Validate Classical Model





- On-axis beams produce far more neutrons than on-axis beam
- FIDA (Fast Ion Da) data show hollow ion density profile during off-axis injection
- SSNPA (Solid-State Neutral Particle Analyzer) data show that the off-axis beams produce very few trapped fast ions when the filed-line pitch is favorable for current drive

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Off-axis NBCD Measurement Experiment

- **Confirm in experiments that new off-axis beams drive current where we expect***
  - Accurately measure the difference in local NBCD profiles for on- and off-axis injections
- **Measure off-axis NBCD in a range of beam injection and discharge conditions for comparison with theoretical models**
  - +/-BT, E_b, injection power (and β), T_e (E_b/T_e), Z_{eff}, ρ_{NBCD}

→ **Validate/test the classical off-axis NBCD model**

→ **Identify domain of good and poor agreement between experiment and theory**

* = Classical model, NUBEAM

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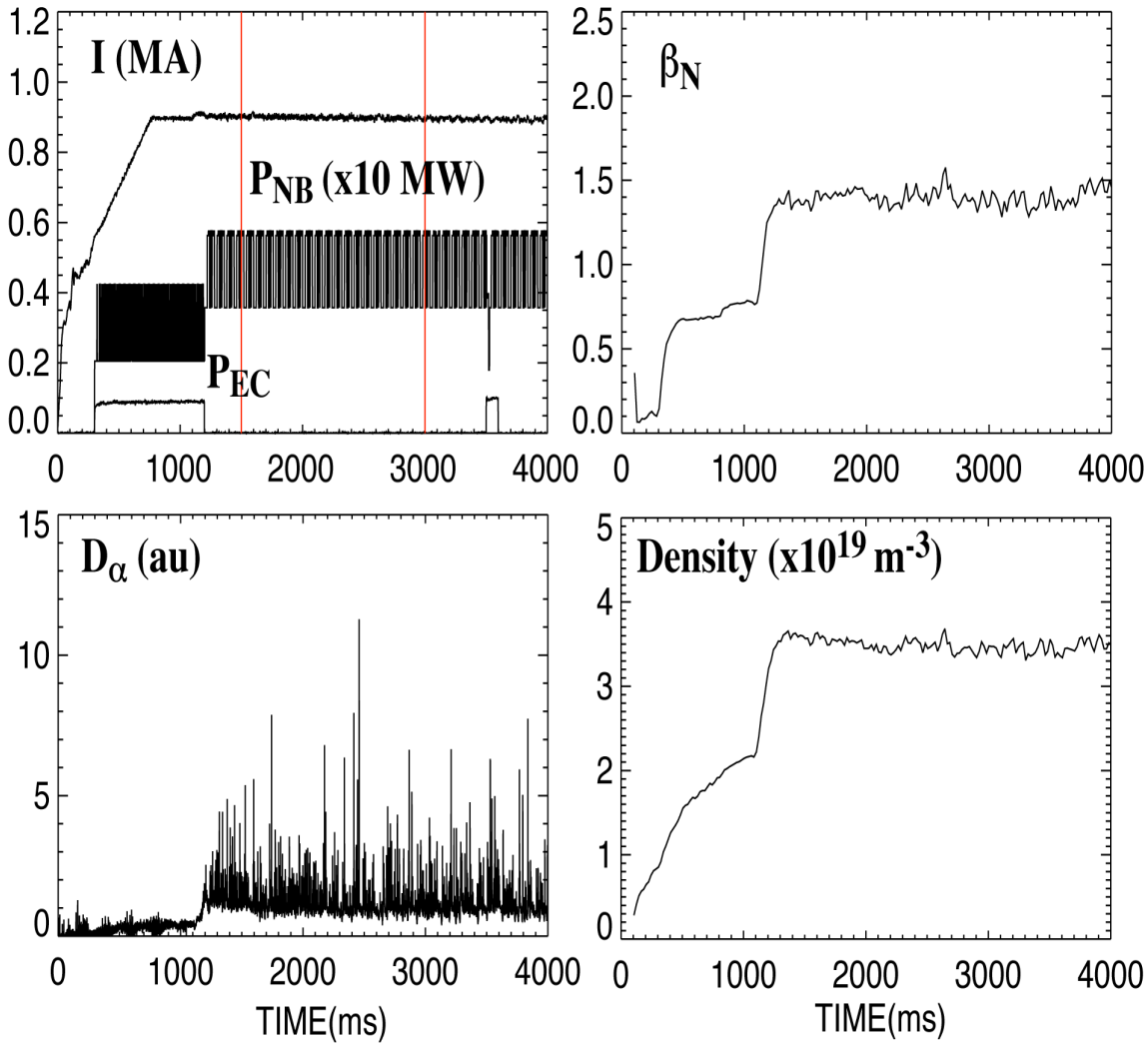
Focus Was on ELMy H-mode Discharge in +BT



- B_T = +2.0 T, I_p = -0.9 MA
- Upper-biased DND
- n_e ~ 3.8x$10^{19}m^{-3}$, Z_{eff} ~ 2.3
- Avoid any significant MHD (ST, AE, NTM, …) except ELMs
- Delay ST
  - Early heating (EC + NB)
- Stationary as long as possible for CD analysis
- Add balance NB and/or ECH on top of NBCD beams

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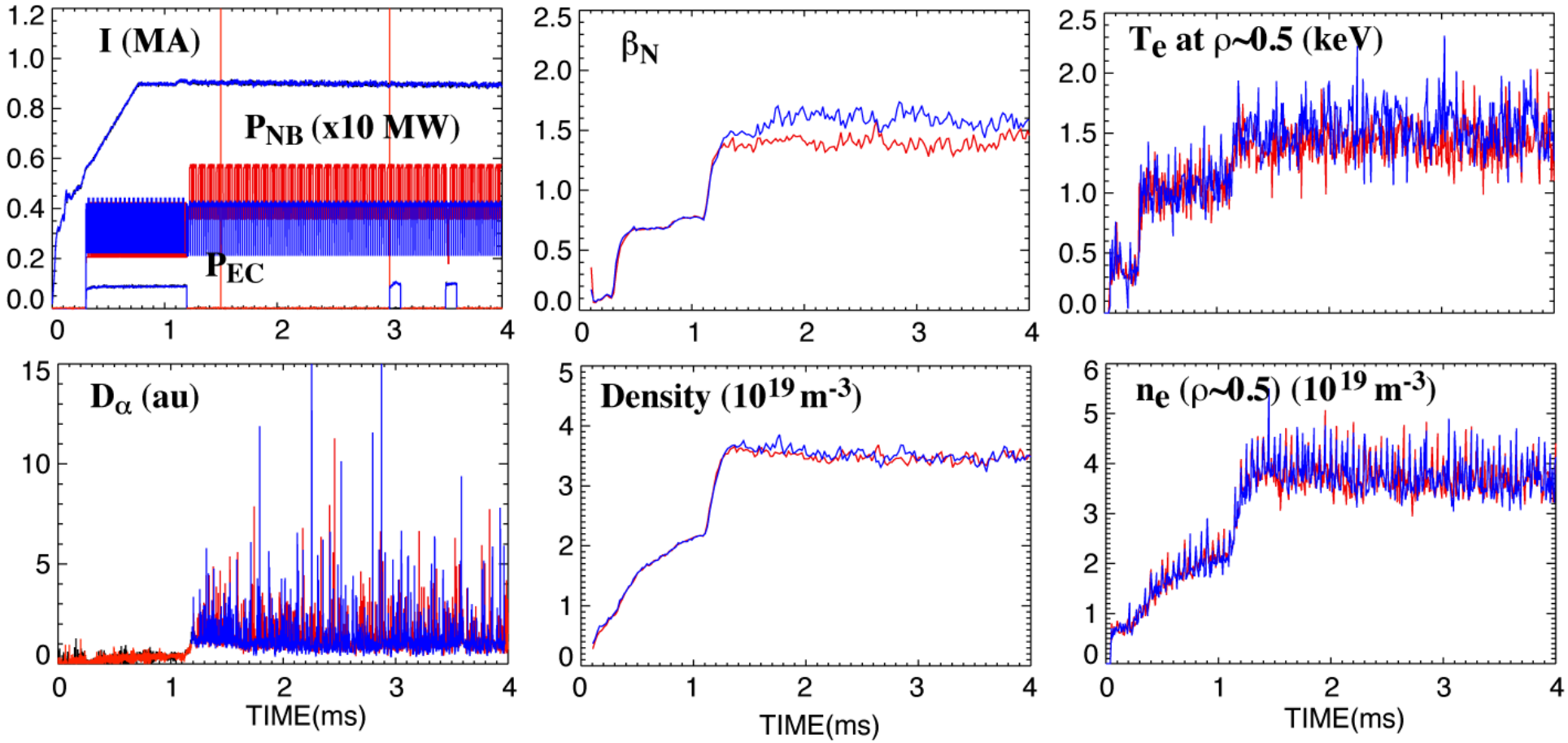
Compare Two Discharges for on- and off-axis NB at ~ Same T_e and n_e

On-axis Off-axis



- **Adjust on-axis beam power to match T_e and n_e**
- **Did not try to match β_N**

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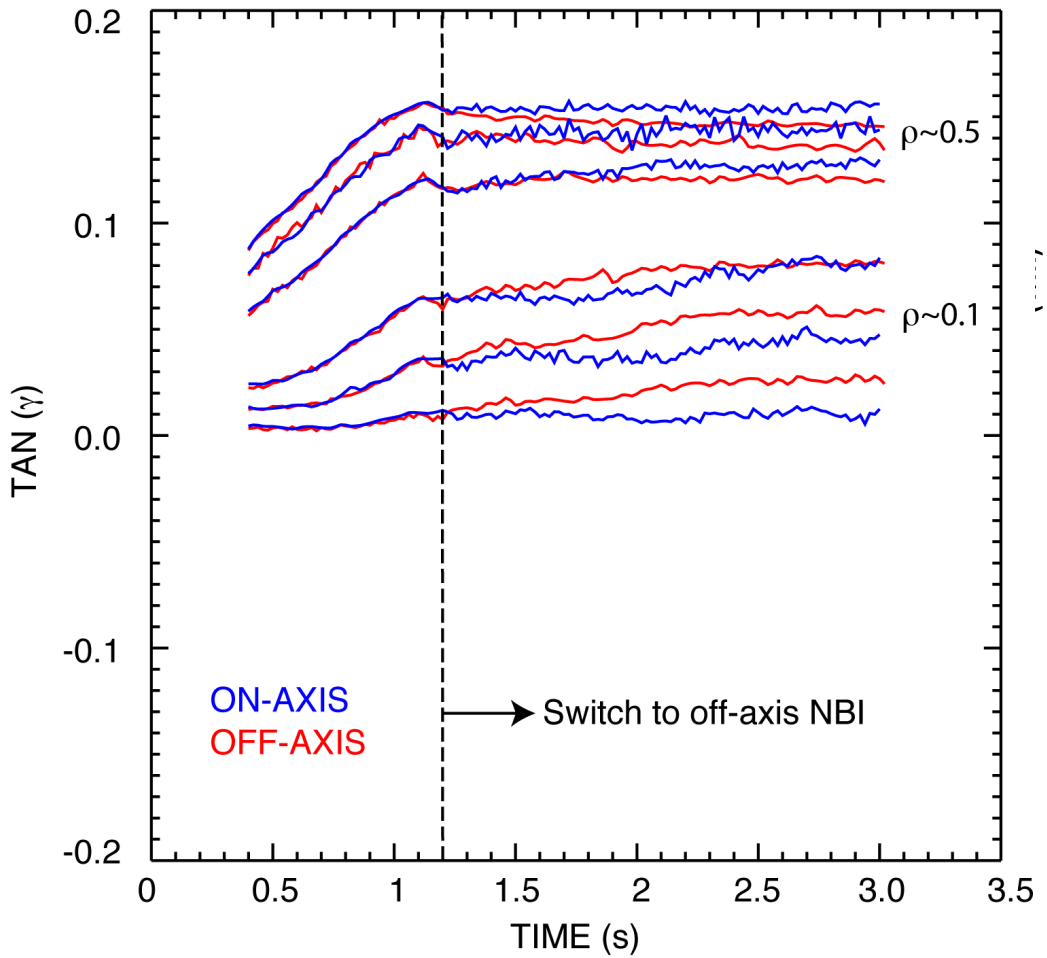
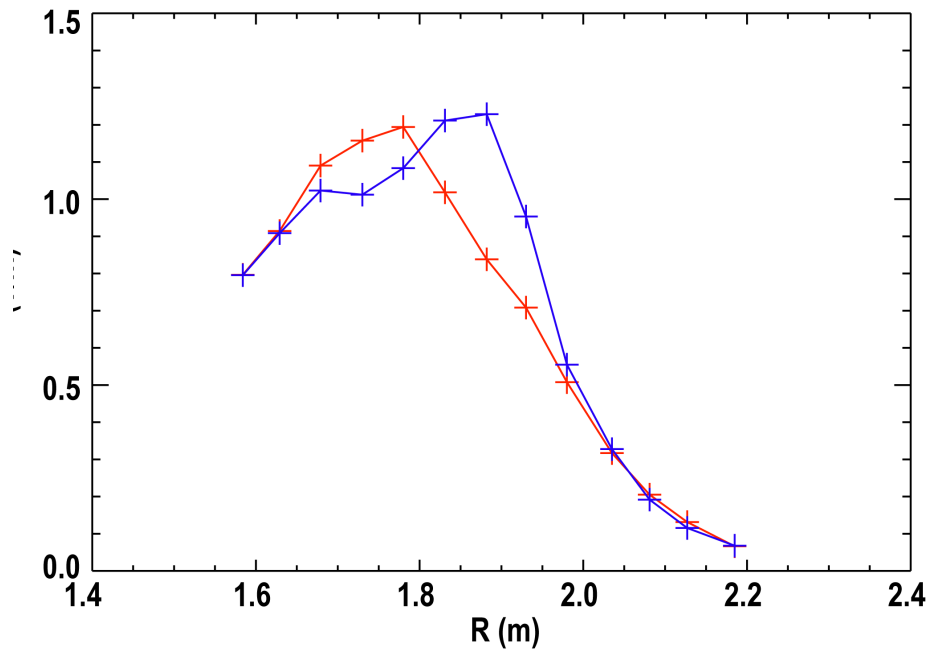
Change Observed in Magnetic Pitch Angles for On- and Off-axis NBCD at ~ Same T_e and n_e

- **Magnetic pitch angles**



- **$dB_Z/dR \sim \mu_0 j_{tor}$**



→ **Clear evidence of off-axis NBCD**

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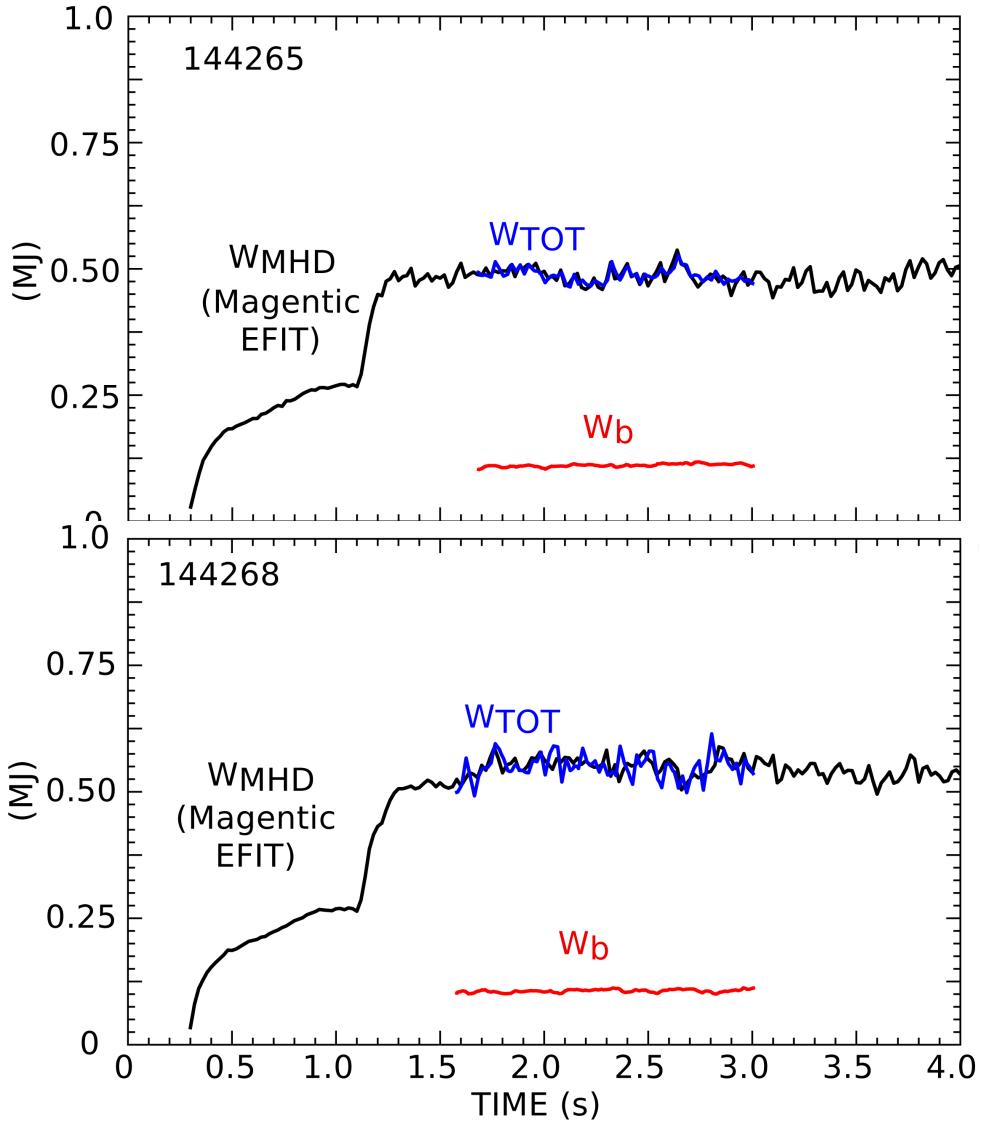
Beam Stored Energy Estimated by Equilibrium Reconstruction Consistent with the Classical Model Calculation



- **Off-axis**
- **On-axis**

→ **No large anomalous loss of fast ion**

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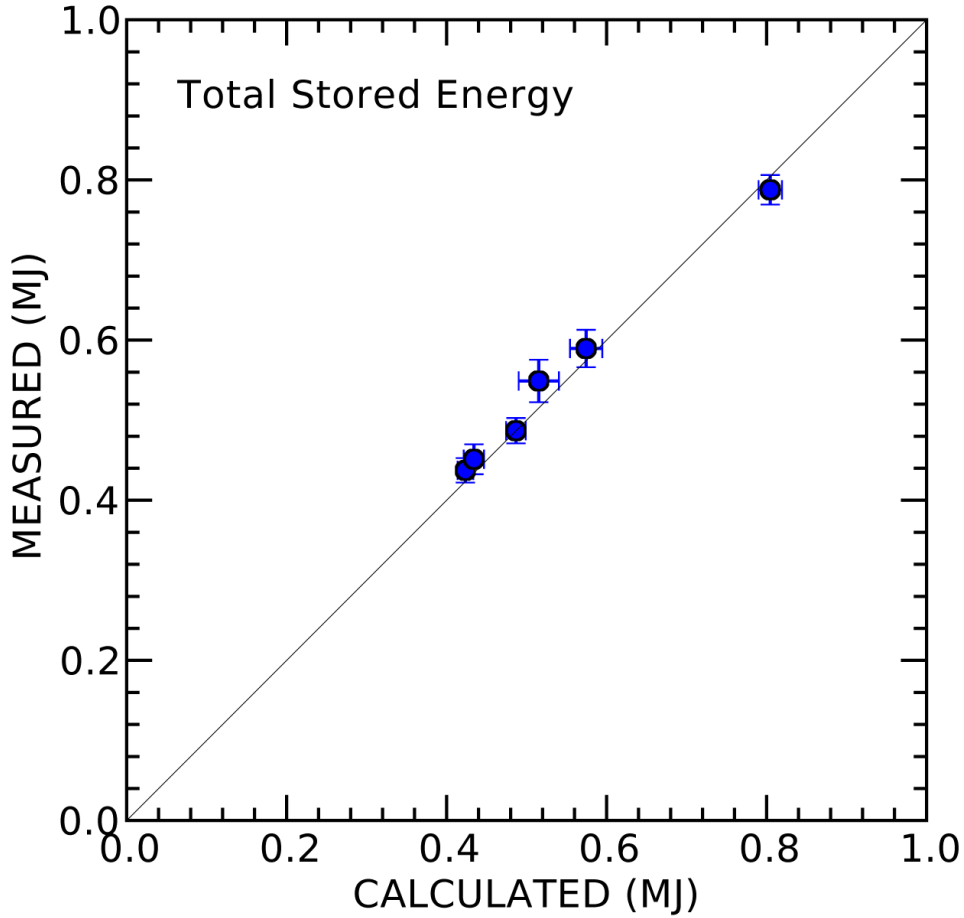
Beam Stored Energy Estimated by Equilibrium Reconstruction Consistent with the Classical Model Calculation



- **Off-axis NBI Discharges (Part of NB power scan)**
- **3 MW < P_{NB} < 8 MW**
- **No ECH, +BT**

→ **No large loss anomalous loss of fast ion**

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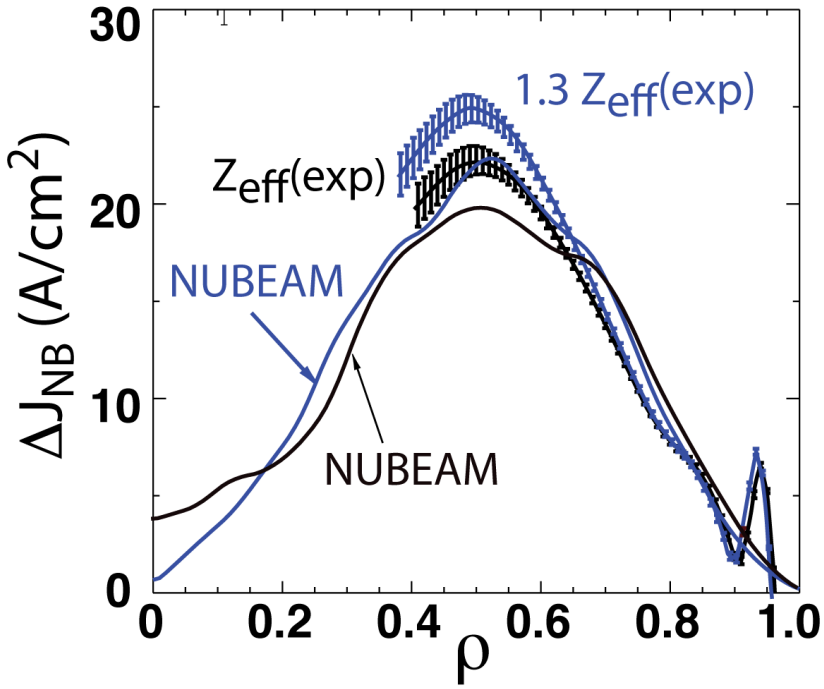
Accurate NBCD Measurement to Reduce Systematic Uncertainties

Differential CD Analysis



Fiducial of tilted 150 NB:

(1) On-axis NB

(2) Balance NB

- **NBCD Measurement:**
  - Local measurement of the magnetic field pitch form MSE diagnostics

    $\Rightarrow J_{TOT}$, $E_{//}(=\delta\psi/\delta t|_{\rho})$
  - $J_{NB} = J_{TOT} - J_{BS} - \sigma_{NEO}E_{//}$

- **Differential CD analysis compares two discharges, for example, with co– and balance–NBI at ~same T_e and n_e**

  ➔ Reduce systematic sources of error (model dependency and uncertainties in measurement, e.g. Z_{eff})

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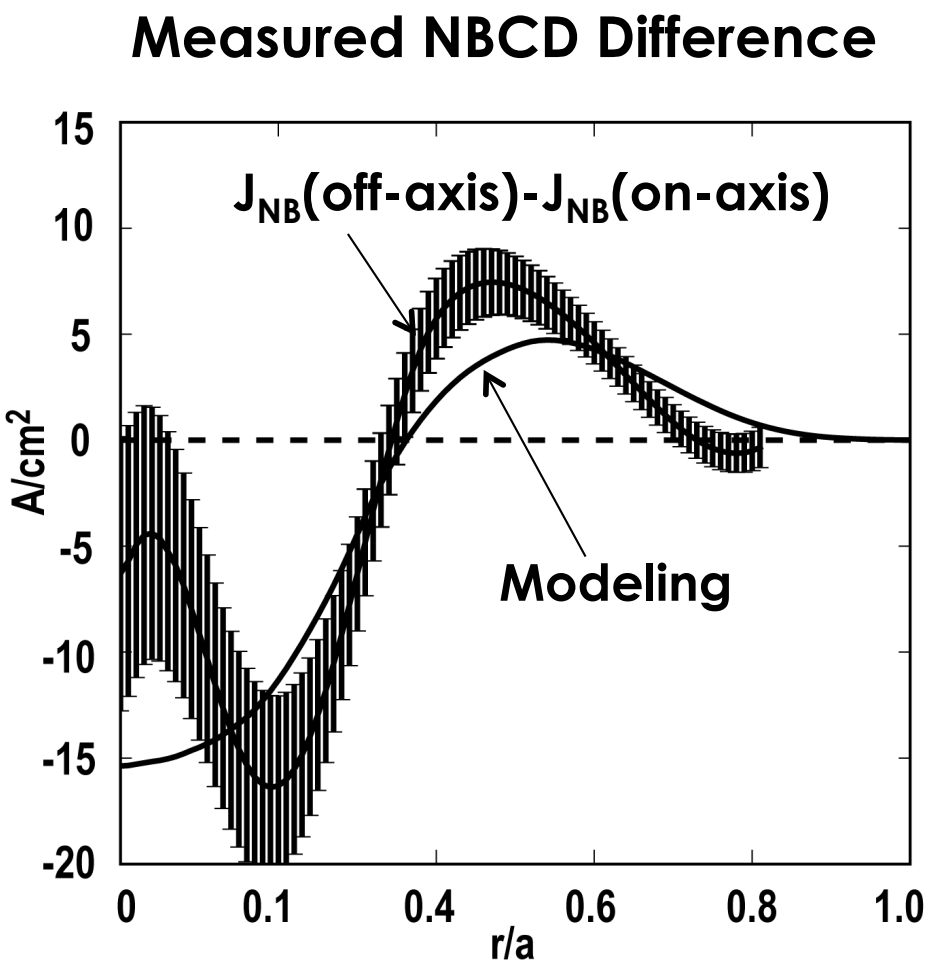
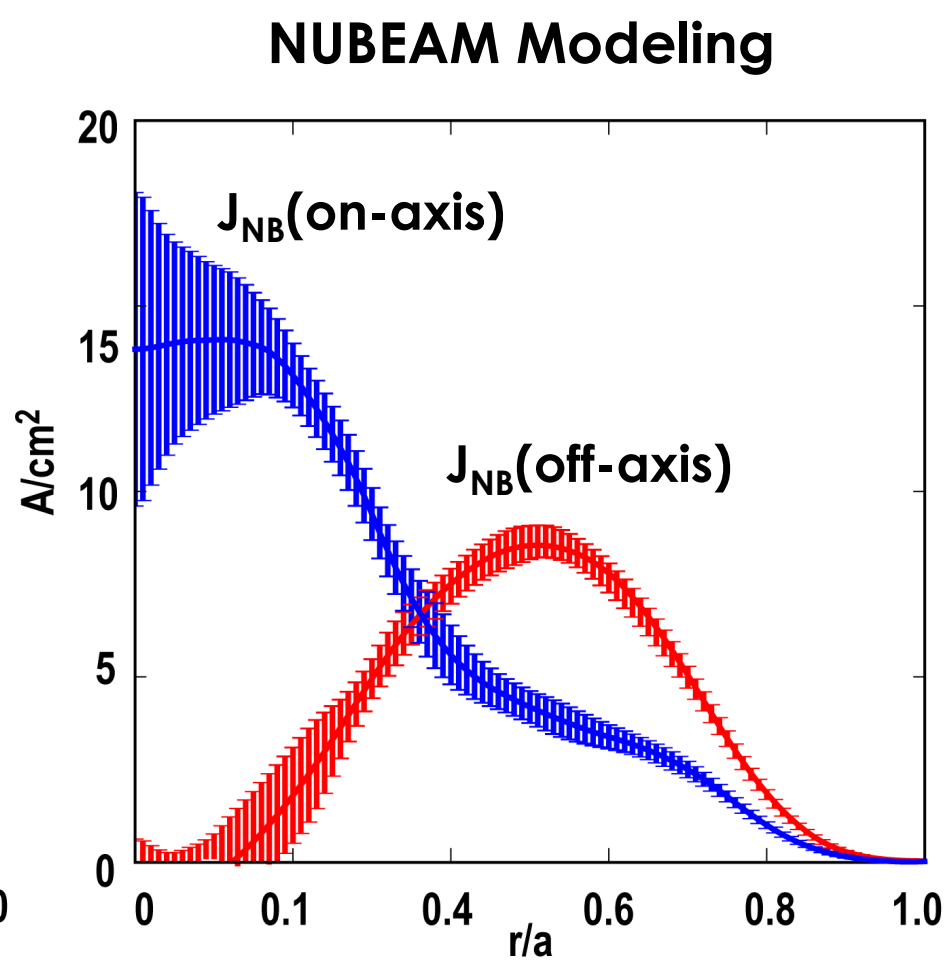
We Have Driven Off-axis Neutral Beam Current Using the New Tilted 150 Beams, as Expected





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Effects of Microturbulence on Off-axis NBCD and Fast Ion Confinement

- **Obtain measurements necessary to quantify the turbulent transport of beam ions during maximum tilt angle off-axis neutral beam injection**

- **Focus on simultaneous measurement of turbulent fluctuation characteristics and fast ion distribution**

TRANSP
plasma profiles, gradients

→

TGLF
D_B, beam ion turbulent diffusivity
$D_B(E, v_{//}/v, R, t)$

→

NUBEAM
adjusts beam ion distribution using D_B

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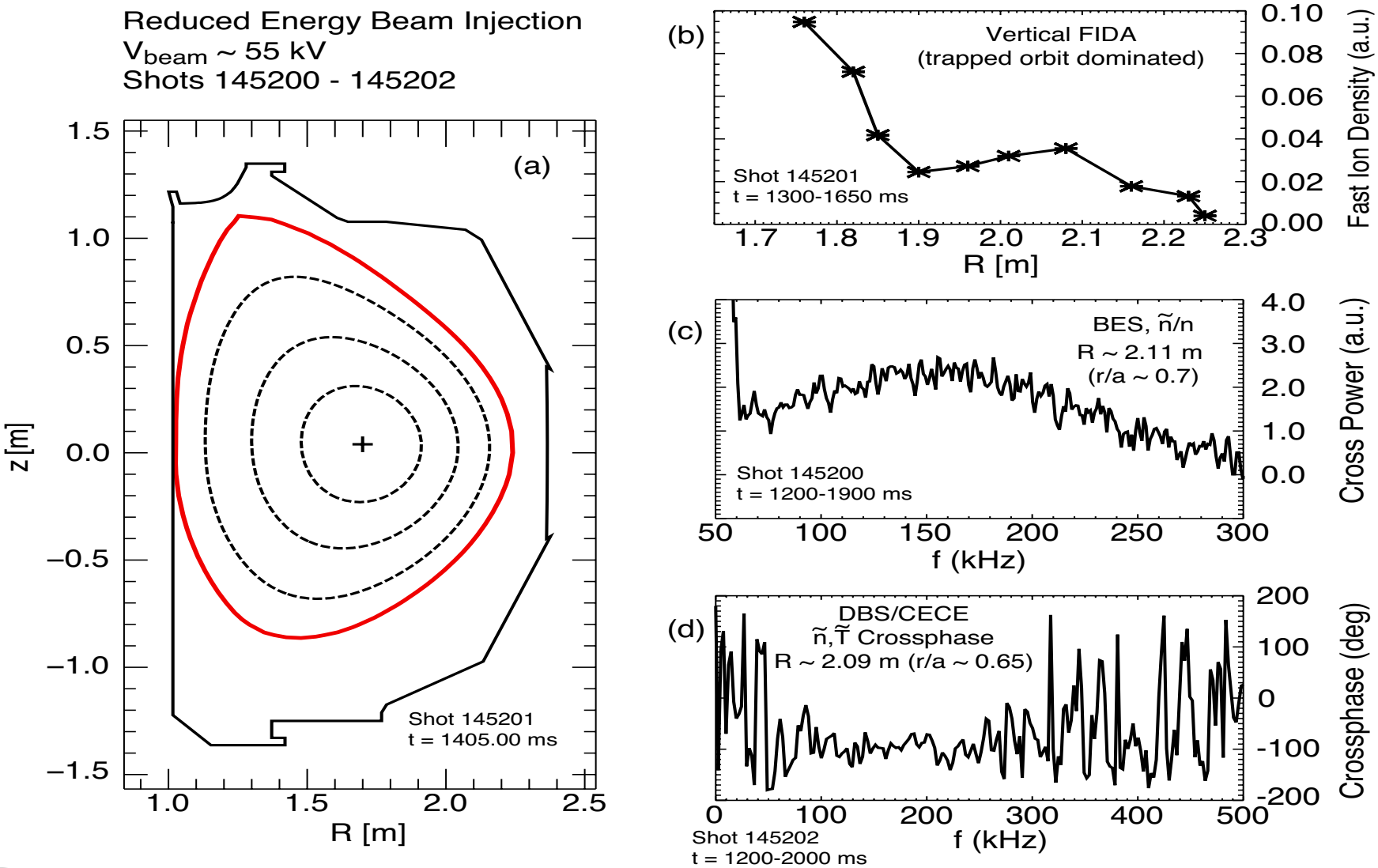
Measured Characteristic and Profiles of Both the Fast Ion Distribution and Background Microturblence



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OANB Is Definitely Working and Being Used for Physics

Sep 17th, 2011