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3d Halo Neutral Simulations In TRANSP Code And Application To NPA Diagnostic On NSTX

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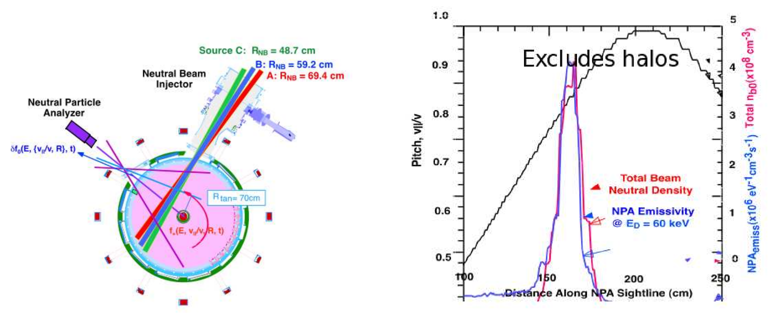
Introduction

- NUBEAM fast ion model = Monte Carlo + time dependent + axisymmetric tokamak
- Detailed physics for fast ions
  - Classical guiding center drift orbiting
  - Coulomb collision,atomic physics, anomalous diffusion
  - heat, particle, torque, current sources
  - Recent update to NUBEAM computes ICRH heating effects on fast ions
- Excited state atomic physics in NUBEAM
- Realistic geometry (shape of plasma, outgoing CX flux direction, neutral beam/s geometry)
- Computes 3d halo neutrals halo generation during neutral beam injection

Motivation For 3d Halo Simulation

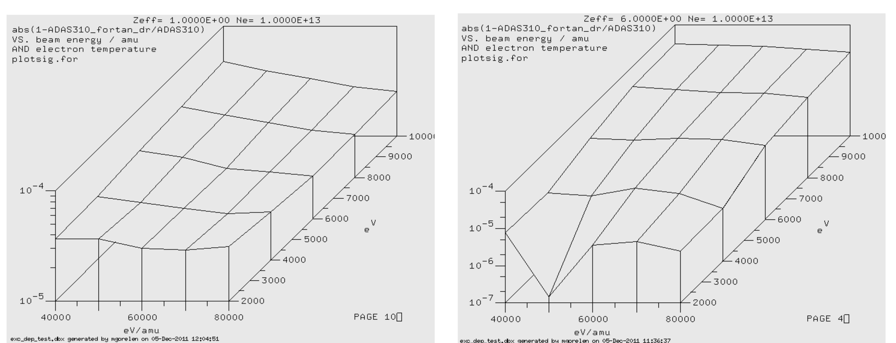
- NPA diagnostic measured the energy spectra of escaping charge exchange neutral particles:
  - ion temperature of the bulk ion component of the plasma
  - energy spectrum of the beam-injected fast ion component
  - the NPA flux is spatially localized by charge exchange on the beam and halo neutrals



- To model 3d effects on plasma charge-exchange flux (NPA diagnostic)
  - NUBEAM did not include 3d halo neutrals into NPA diagnostic simulation

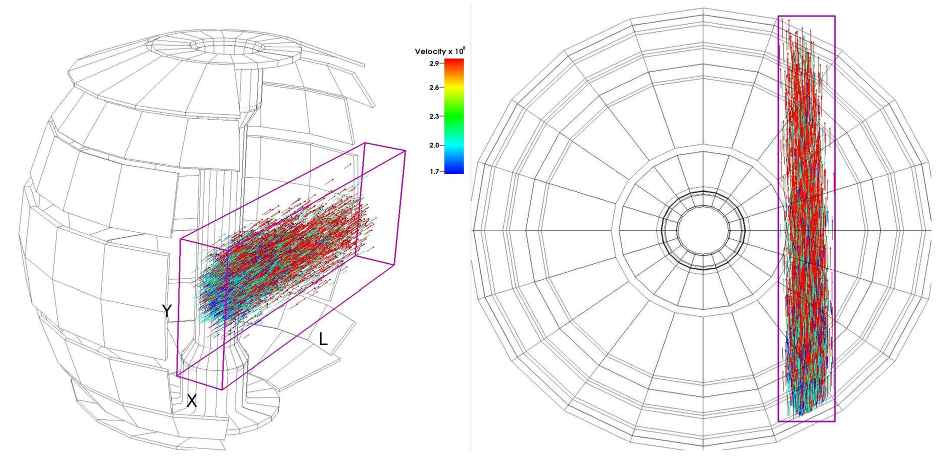
Atomic Physics Data For 3d Halo Model

- Ground State Model, ADAS or PREACT
  - beam stopping coefficients and partial cross sections CX, II, IE, IZ
- Hybrid Excited-Ground state, ADAS
  - using beam stopping rate coefficients
  - using ground state model to calculate contribution form CX, II, IE, IZ reactions
- ADAS310.FORTRAN.DRIVER
  - Parallelized in client-server model
  - Resolves over hydrogen isotopes $H/D/T$
  - $T_e \neq T_p \neq T_{imp}$
  - Obtains contributions from CX, EI, II, andIZ
  - Benchmarking with ADAS beam stopping data



Design

- Each neutral beam prescribed with own 3d box
  - boxes can overlap in space
  - each box has his own coordinate system (X_b, Y_b, L_b)
  - transformation matrices form machine's Cartesian coordinate system to box's Cartesian coordinate system is defined.
- The position of the box is symmetrical to the beam's axis



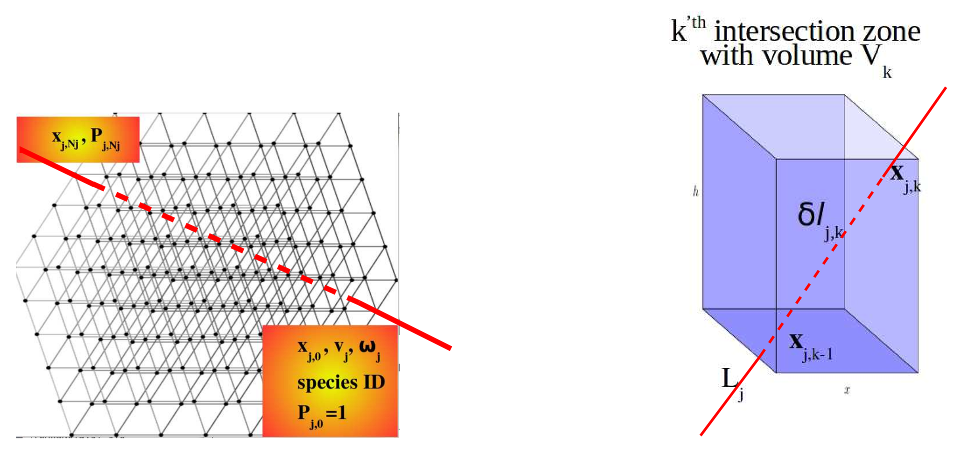
- 3d boxes are expanded to encompass halo, not just the beam

3d Halo Source

- Distinguish axisymmetric neutral populations vs. halo source
- NUBEAM axisymmetric neutral populations are:
  - wall recycling and gas flow source (thermal)
  - recombination (thermal)
  - fast neutrals due to CX with axisymmetric populations
  - thermal volume source due to axisymmetric fast neutral recapture by CX
- Independent control of CX-halo statistics: for 'fast' halo and for thermal halo
- Plasma toroidal rotation taken into account

3d Model -Key Concepts

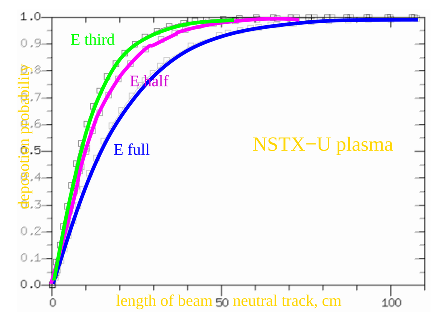
- Sum over neutral tracks L_j



- time a particle exists in each zone, $\delta t_{j,k} = \frac{\delta l_{j,k}}{|V_j|}$
- Neutral density, $\delta n_{j,k} = \omega_j \frac{P_{j,k-1}+P_{j,k}}{2V_k}$
- Deposition source, $\delta S_{j,k} = \omega_j \frac{P_{j,k-1}-P_{j,k}}{V_k}$

Sampling New Generation Neutrals

- *RNG* to sample
  $P_{j,k}(l)$ to launch new neutral track x_l in space
- Only *CX* results to halo,
  $f_{cx} = \sum_i N_i < \sigma V >^{(i)}_{cx} \tau_{fl}(l)$
- *RNG* to assign species *ID* base on probability
  $f^i_{cx} = N_i < \sigma V >^{(i)}_{cx} / \sum_k N_k < \sigma V >^{(k)}_{cx}$
- to get velocity $\vec{V}_l$ at launch point $\vec{X}_l$
  'THERMAL' - sample from Maxwellian distribution
  'FAST' - $F^{fast-ion}_{FLR}(R, Z, E_{lab}, \frac{V_\parallel}{V}, \alpha_V)$
- Apply(?) kinetic adjustment $f^{(i)}_{KIN} = \sigma^{(i)}_{cx}(V_{rel})V_{rel} / < \sigma V >^{(i)}_{cx}$

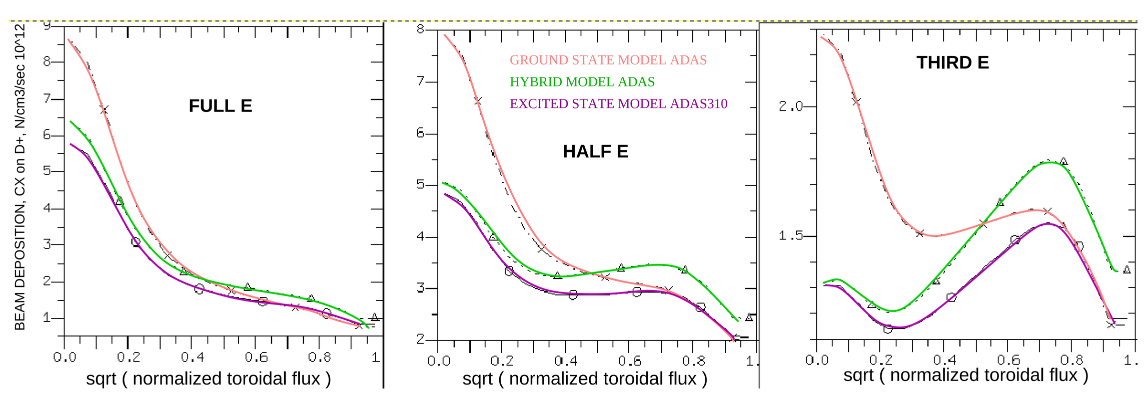


Model Controls

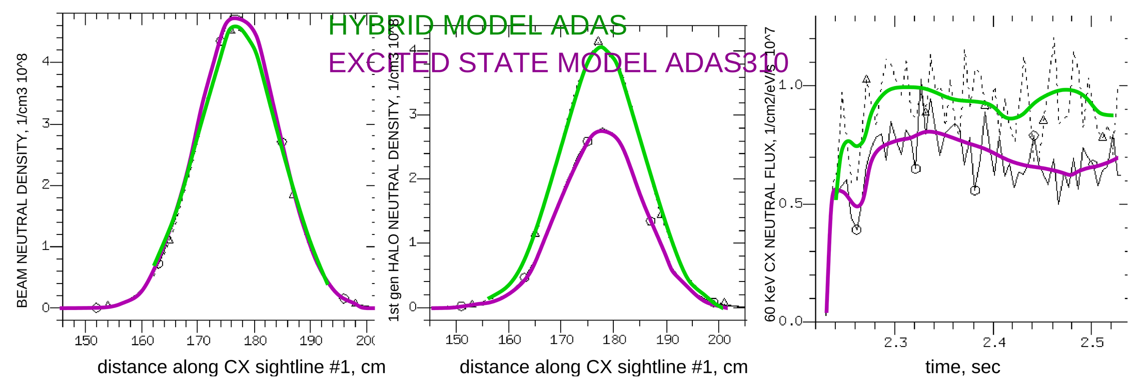
- N_{launch} - beam neutral tracks launched
- $N_{split_{geo}}$ - halo neutral tracks launched in space
- $N_{split_{v,in}}$ - halo neutral tracks in velocities space at each *CX* event
- $N_{split_{geo}}$: $N_{split_{v,in}} = const$
- Effective splitting reduced as $\omega_j \to \omega_{min}$
  $\omega_{min} = I_0/(N_{launch} * N_{split})$

Atomic Physics And Halo Source

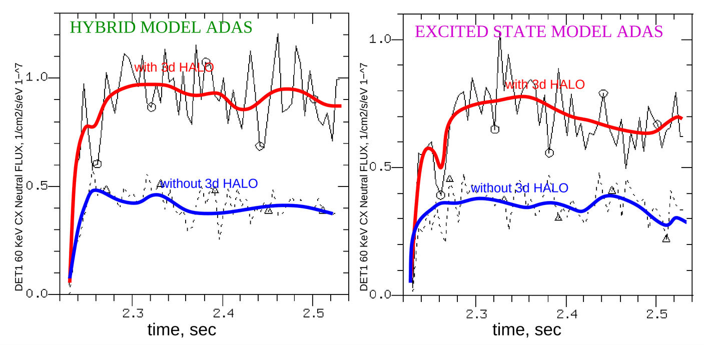
- Source of neutral strongly depends on atomic physics



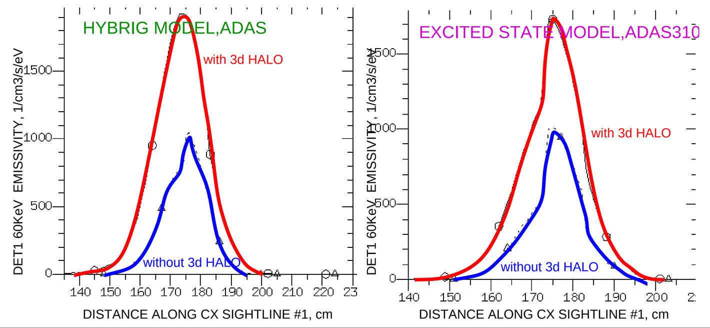
- Sensitivity of $E||B$ NPA diagnostic to atomic physics data



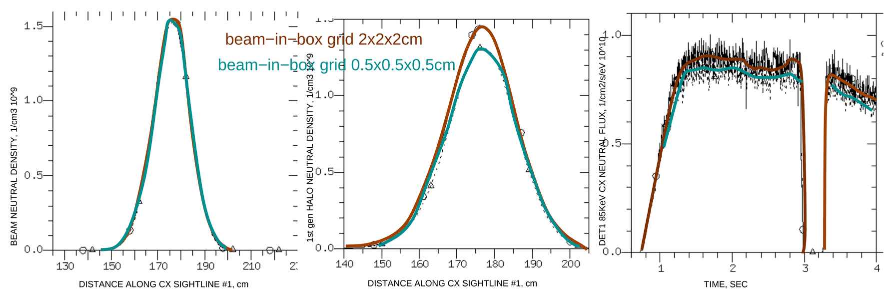
3d Halo Increases CX Neutral Flux by 70% – 90%



NPA Emissivity Is About To Be Doubled Due To 3d Halo



Beam-In-Box Grid Size On $E||B$ NPA Results



Results And Discussion

- 3d halo model is sensitive to atomic physics data as halo neutral density strongly depends on the fraction of CX reactions in neutral deposition
- NPA simulations gave about same relative changes in CX neutral flux and emissivity regardless atomic physics
- Cartesian grid size of beam-in-box increases statistical error
- Good statistics in beam neutrals and halo neutrals need to be applied to get reliable NPA simulation result

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