Collaboration with NSTX-U in Calculations of Radiofrequency and Neutral Beam Heating and Current Drive Sources

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At NSTX-Collaborator Research Planning Mtg., March 18, 2015

Research Goals/Plans FY15-17: (with 1 Mos/Harvey, 2.5 Mos/Petrov /year)

1) **Complete the coupling of the GENRAY ray tracing and CQL3D Fokker-Planck codes to TRANSP. [GENRAY work is presently underway by Jardin group, based on previous CompX/SWIM coupling to the PPPL Plasma State software. EC and LH works. HHFW next.**

2) **Calculate time-dep finite-orbit-width (FOW) NBI+HHFW distributions with CQL3D, and apply to synthetic diagnostics such as FIDA, neutrons, NPA, energy loss and wall loss spectra, H&CD. [Hybrid Model completed, Full neoclassical ~operational].**

3) **Work with and/support PPPL scientists in Fokker-Planck, ray tracing, and full wave calculations of (1) HHFW interaction with electrons and with fast ions, including from NBI, (2) ECH, and (3) EBW. [Presently with Gary Taylor, Deyong Liu, Bill Heidbrink, Jin Chen/Steve Jardin, Nicola Bertelli, Francesca Poli, and Sarah Newbury].**

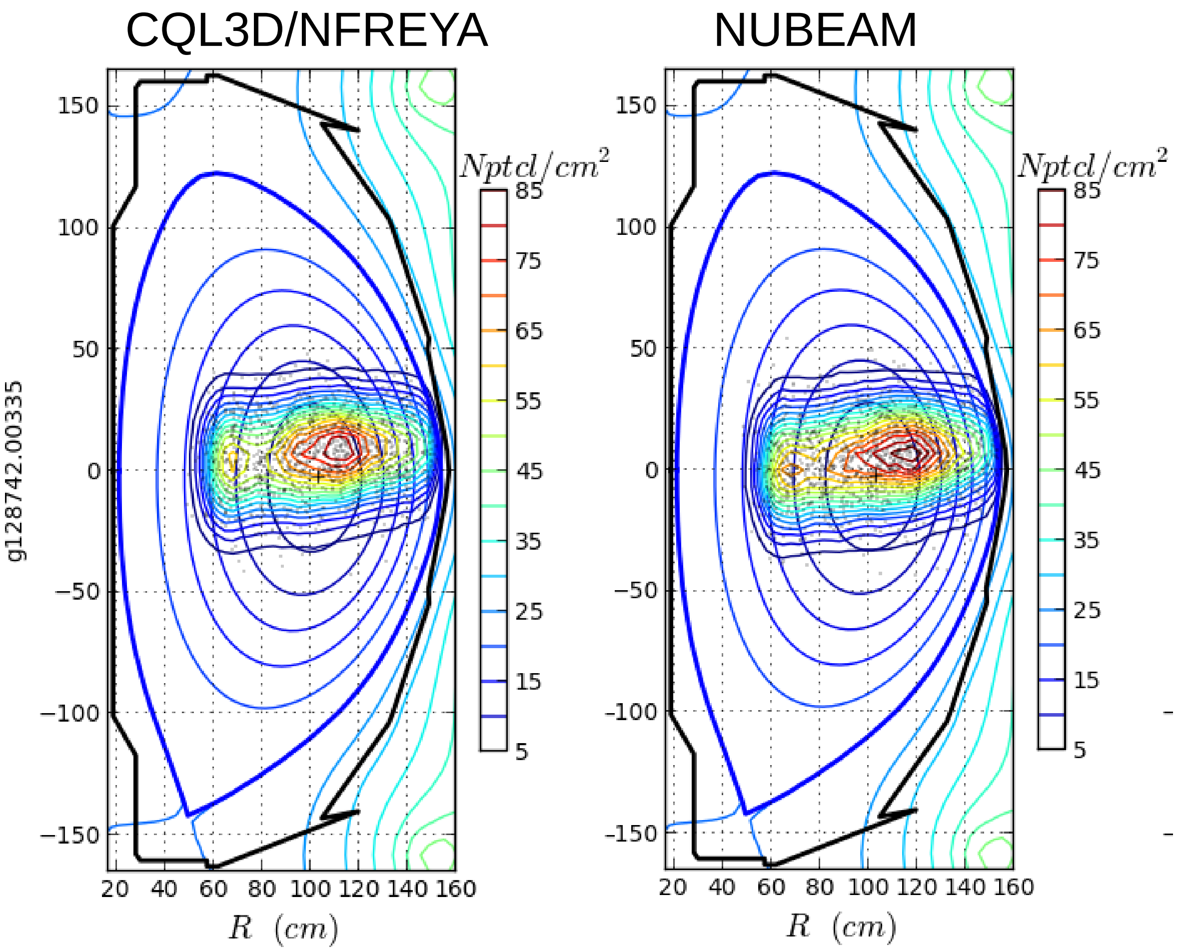
4) **One week collaborative visit at PPPL by Yuri Petrov, per year.**

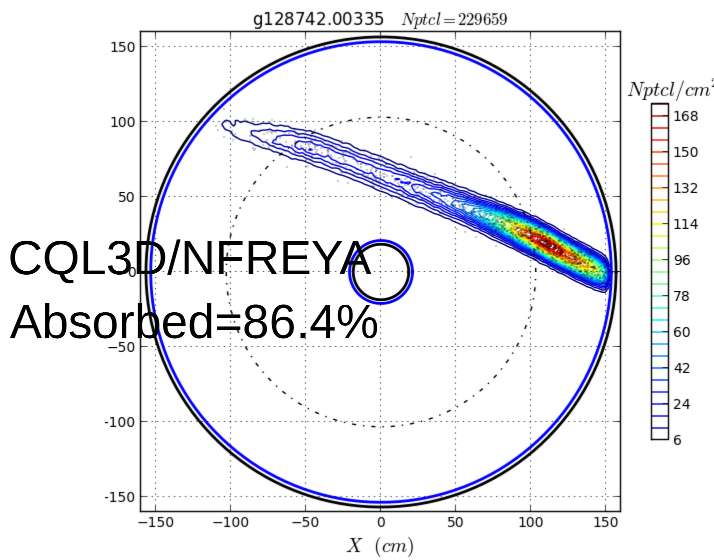
5) **Writeup CQL3D-FOW-Hybrid analysis of NSTX, and CQL3D-FOW (full neocl, except Er).**

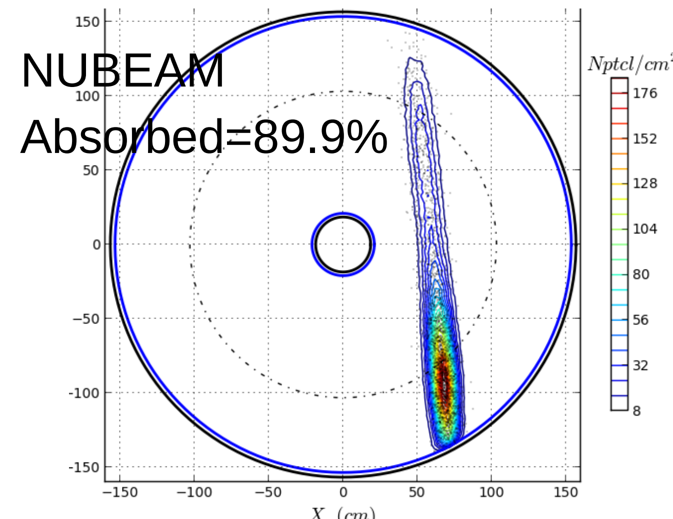
6) **Complete Study of Stochastic Heating by HHFW in front of antennas.**

Updated beam stopping cross-sections in CQL3D/NFREYA and added a gyro-orbit shift of the birthpoint to the GC-orbit position giving good comparison with NUBEAM deposition.

Required computer time is 1 CPU min for birth points, 6 additional min for SS ion distribution functions (nrho=40 flux surfaces). Parallelization over radial flux grid gives ~linear speedup to nrho.
1 hour w 128 core for full-FOW incl NL collisions.



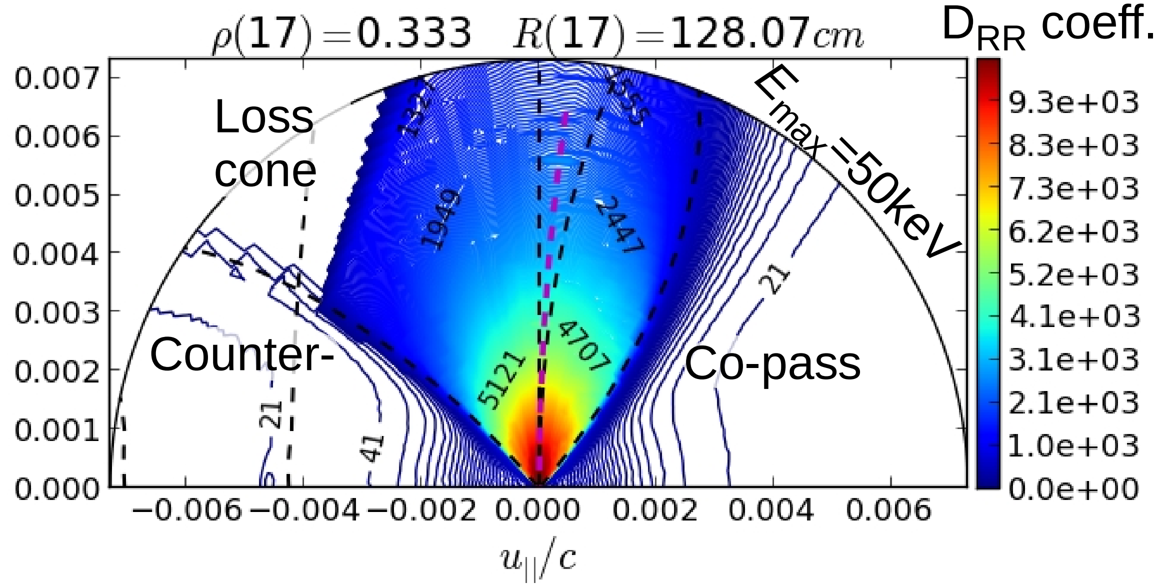




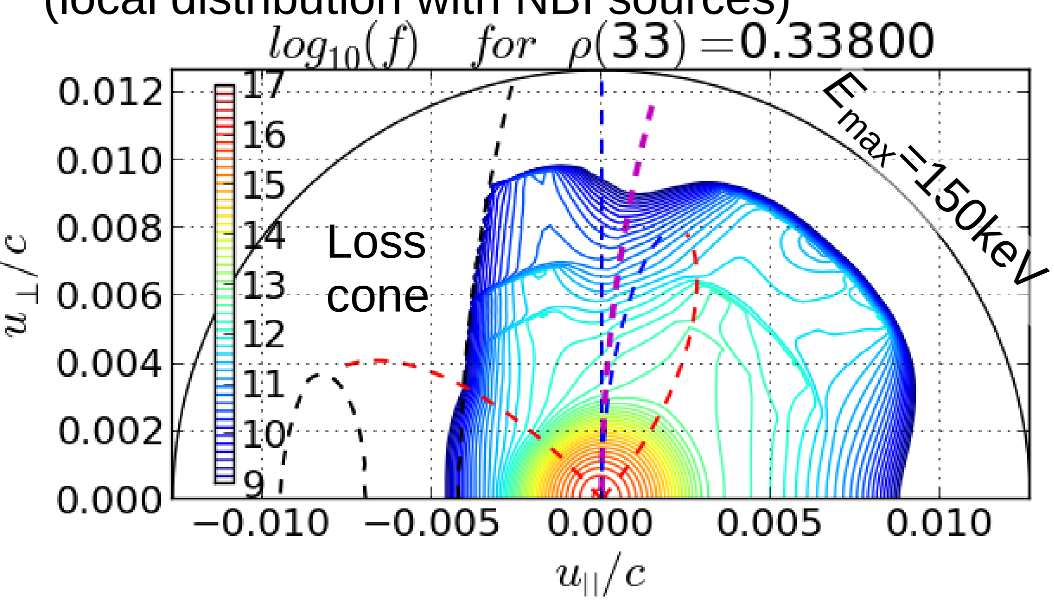
NB: curvature in top plot due to the inclusion of Bpol-gyro-shift, not in NUBEAM.

Status of CQL3D: Two Finite-Orbit-Width (FOW) extensions:
– Hybrid-FOW (fast, but only partial FOW capabilities; No neoclass.transp.)
– Full-FOW (strict neoclassical reformulation of the FP eqn) essentially complete

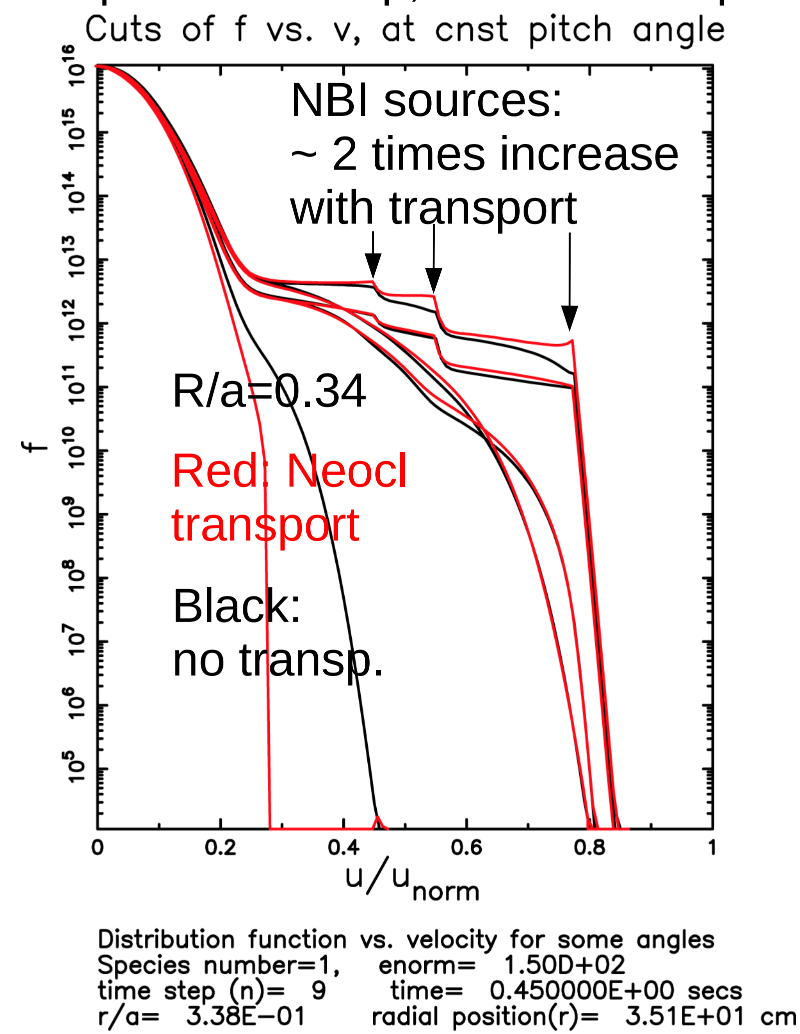
Example of NSTX coll. Radial diffusion coeffs. [cm^2/sec]



Example of Full-FOW solution
(local distribution with NBI sources)



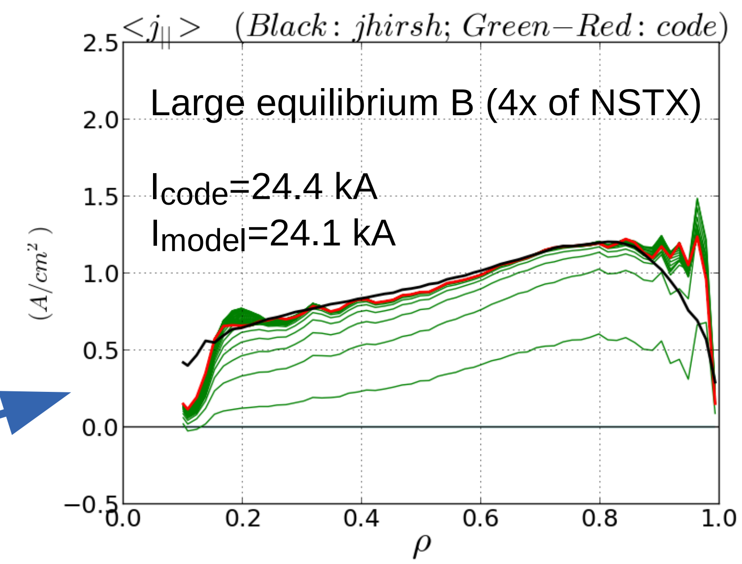
Compare no transp, w neocl transp



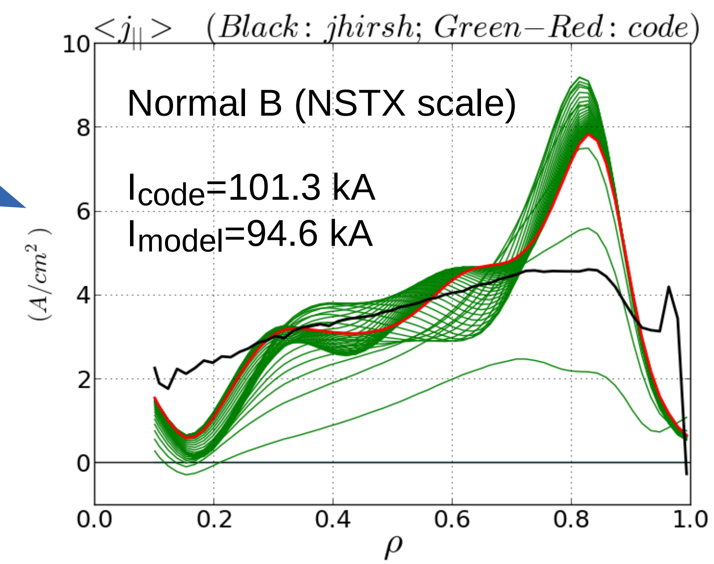
Bootstrap Current Validation of CQL3D-FOW

- The Full-FOW calculations are done in NSTX geometry for ions, using different scaled magnitudes of equilibrium magnetic field B_{eq} .

- For a large B_{eq} (narrow banana orbits) we expect the result to be close to semi-analytical fit formulas [Hirshman 1988; Sauter 1999]. Here, the poloidal and toroidal field B-field components are multiplied by factor of 4.



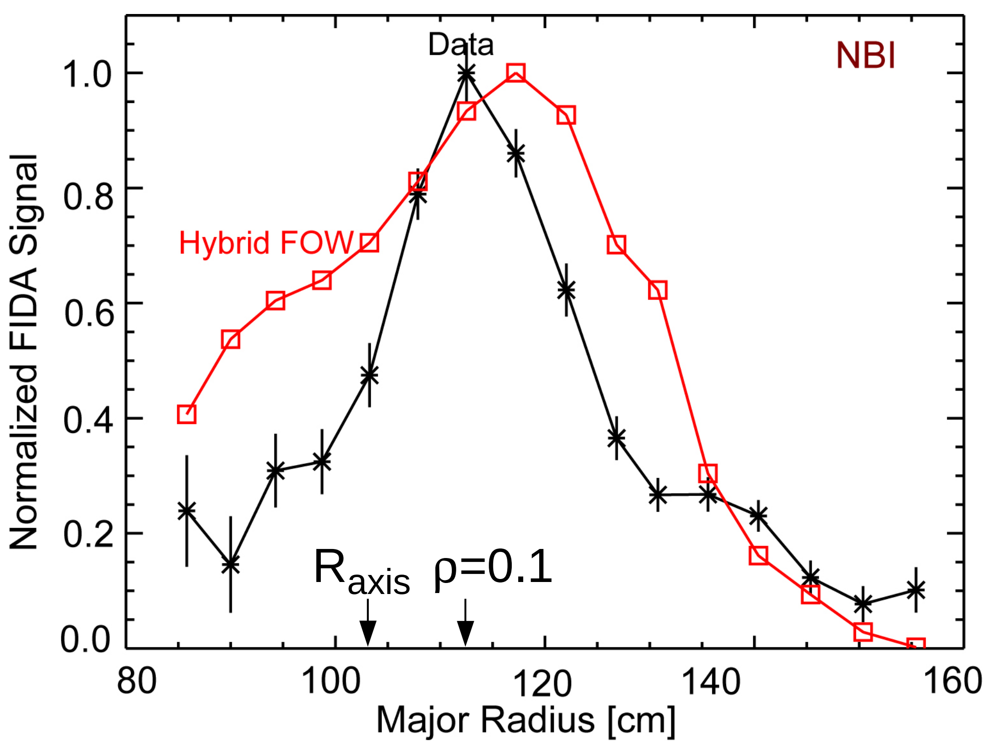
- For a low B_{eq} the results from Full-FOW run, giving clearly visible FOW effects, are not expected to match the model.

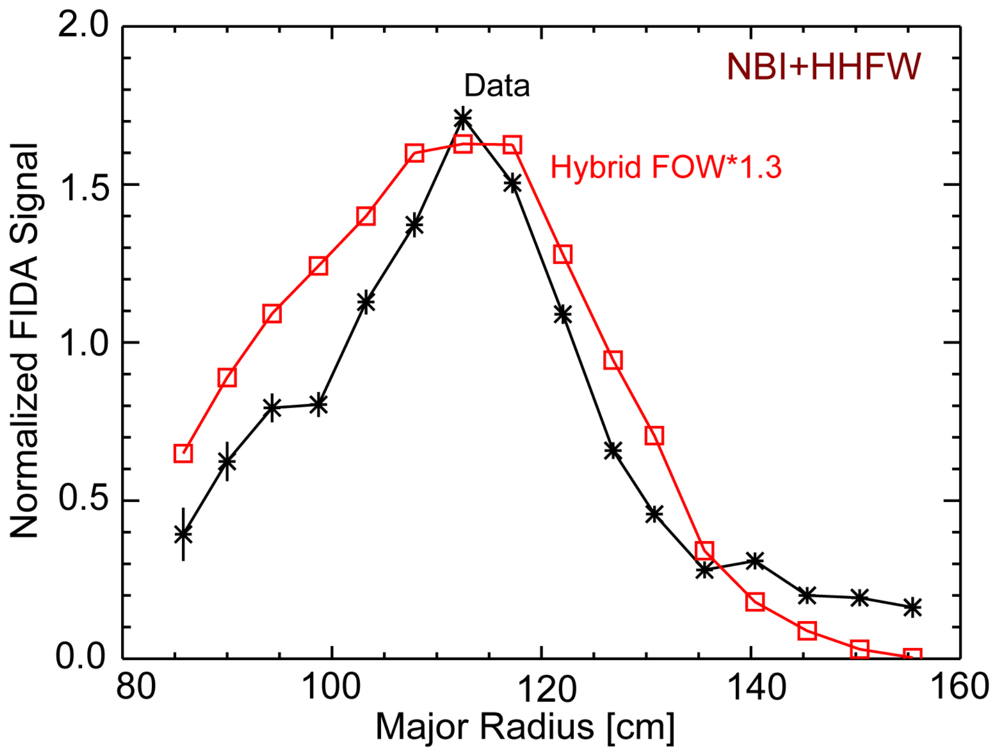


Recent addition: Losses of FI on neutrals through CX

– The radial profiles of neutrals are generated by TRANSP/FRANTIC (1D).
– Can be time-dependent: $n_n(\rho,t)$.
– Profiles are read by CQL3D at given time steps and interpolated in time.

FIDA: – Almost no effect in NBI-only case (after renormalization).
~18% reduction (at peak) in NBI+HHFW case.

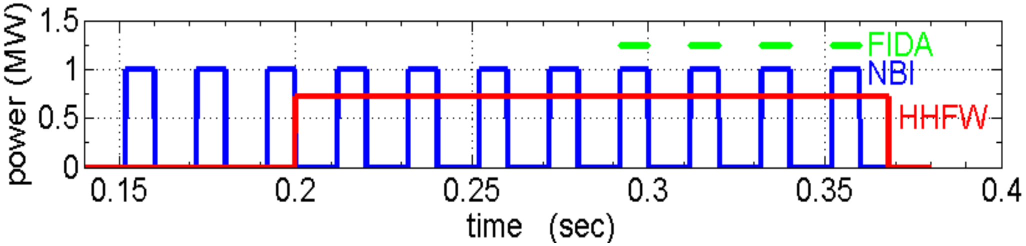


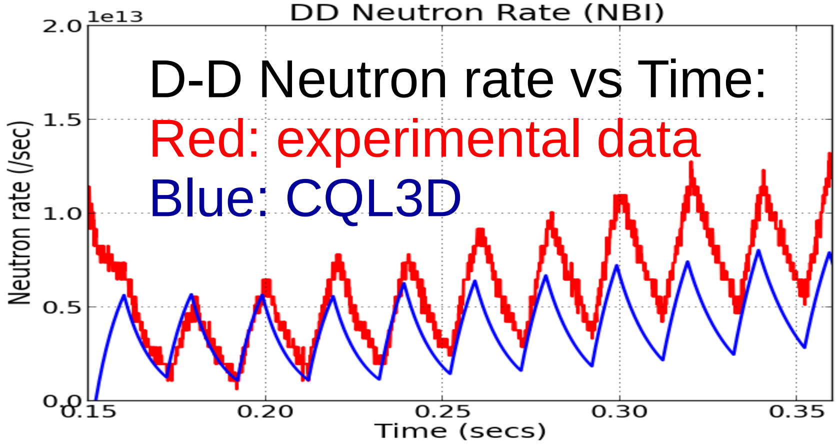


(Provided by Deyong Liu, using TRANSP plasma/FIDASIM with CQL3D distributions)

Latest: Finer radial gridding of NBI related profiles has significantly narrowed FI profiles with further improvement of the FIDA validation expected. Addition of gyro-orbit shift of Nfreya NBI birthpoints to GC positions, facilitates analysis of additional shots.

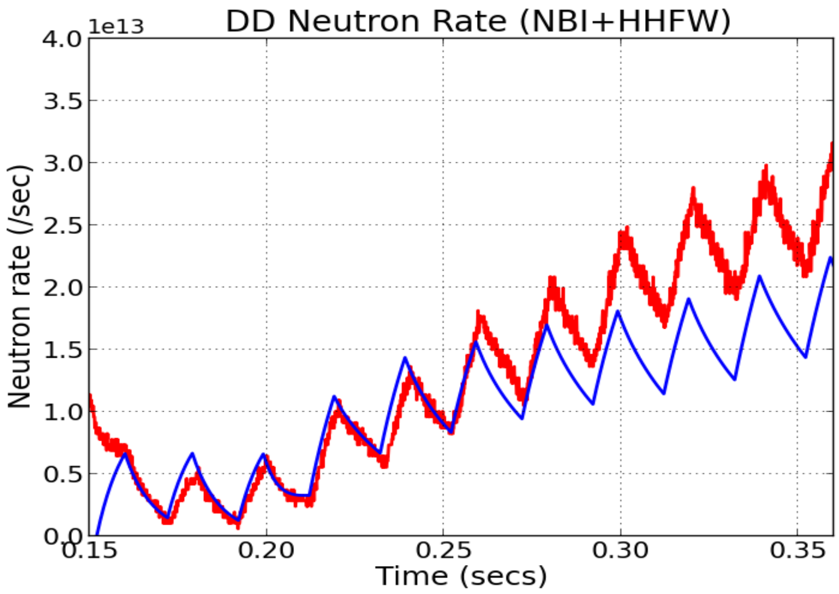
…cont-ed: **Effect of FI-CX losses: Neutron Rate**





NBI only

Experimental uncertainty: up to 20%



NBI+HHFW

<u>Before the FI-CX losses</u> were included, the simulated neutron rate was higher than experimental.

<u>With FI-CX losses:</u>
Good agreement at early times => Evidence of correct modeling of heating rates/QL diffusion (growth of tail), and coll. slowing down of the tail.

But, goes lower than experimental data at t>0.25s => Need more accurate 2D model for neutrals' profile?

New Topic: Parallel Electron Heating in Front of HHFW Antenna, as Possible Parasitic Loss Mechanism

Initial Simple Model for Electron Heating (~Fermi Acceleration):

1D along parallel to B, z-direction: m dv/dt = -e Ell

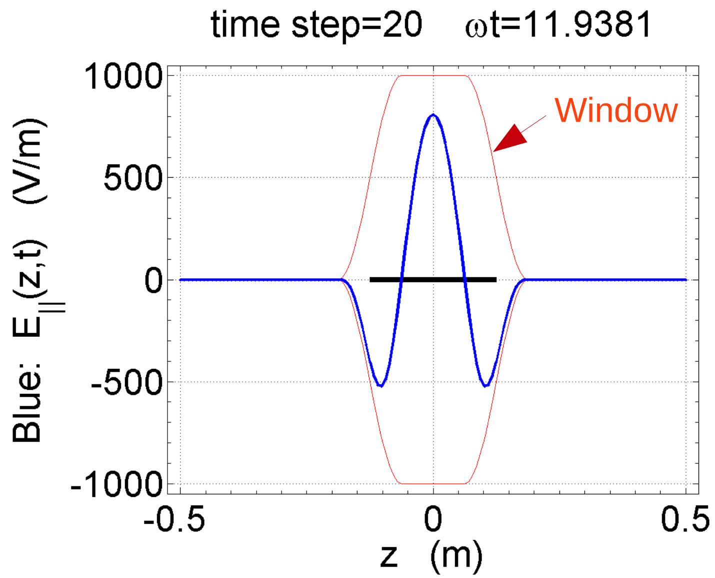
Plasma from -L/2 to +L/2, Antenna from -Lant/2 to +Lant/2

$E_{||}(z,t)=[E_{||1}\cos(kpar*z - omega*t) + E_{||2}*\cos(kpar*z+omega*t)]*Window$

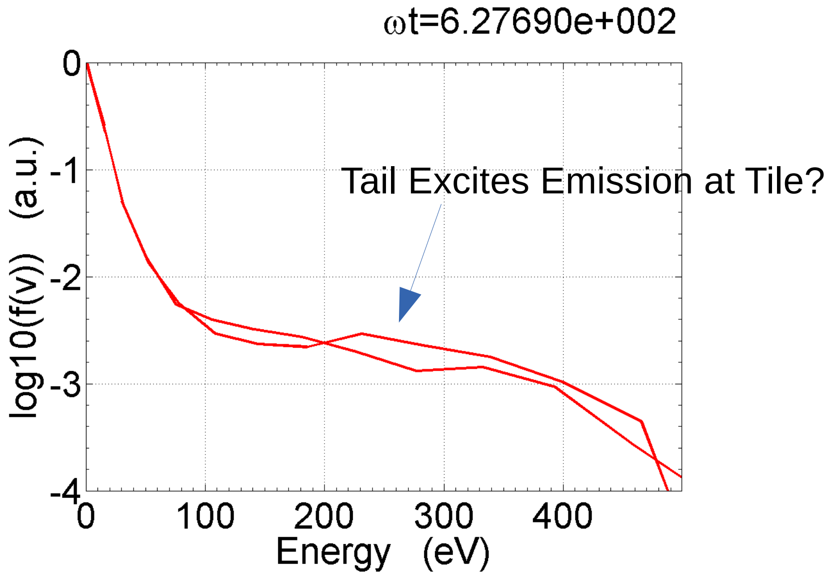
Example: $E_{||1}=E_{||2}=500$ V/m, Te=10 eV, f=35MHz, L=1 m, k=2*pi/Lant=25/m, Lant=L/4, L=1m

==> E_wp_trap=637 eV, V_wp_trap=1.5e7 m/sec, omega/k=8.75e6 m/sec, vte=1.3e6 m/s @10eV

A That is, most particles (here) experience NL trapping effect.
In expt, k much smaller, but interaction length larger. To be continued.



Electron Acceleration After 100 Wave Periods



The chosen fields ~kV/m are generally in accord with calculations by Myra, 1996, and recently by Jenkins, 2014 and Smithe, 2014 with VORPAL.
This work is being continued, using the VORPAL calculated fields.

Other work in progress

- QL operator for Full-FOW (Nearly completed).
- Extend radial grid to the left of magnetic axis (inboard FOW potatoes).
- A self-consistent, time-dependent toroidal electric field calculation.
- Publication (refereed) on CQL3D FOW-Hybrid Validation with NSTX.
- Publication on CQL3D-FOW.
- Coupling with 4D COGENT FP to include accurate edge and SOL region (a separate proposal) giving full-plasma 4D Fokker-Planck Transport (4DFPT).