NCSX
Confinement and Heating

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PPPL

NCSX PAC-4
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Outline

- Confinement Methodology & Development
- New Configurations
- Heating method choices
  - Counter-NBI & HHFW
- Planned Activities

Confinement Methodology

Past:

- Used GTC Monte-Carlo code to evaluate neoclassical transport for specified profiles. Assumed $e\Phi(0) = - T_i$, linear profile in s.
- Typically, use empirical profiles
- Calculate fast-ion losses vs. B using Monte-Carlo codes
- Combine in 0-D spreadsheet model, imposing global scaling constraint

Improvements:

- GTC being modified to calculate self-consistent E_r
- New 1-D power balance solver, including models for anomalous and neoclassical transport (toroidal & helical), self-consistent E_r.

Monte-Carlo Self-Consistent E_r

J. Liewandowski(PPPL), A.Boozer, J. Williams (Columbia)

- toroidal component of the momentum-balance equation gives

$$\iota \frac{dQ}{dt} - \left\langle \frac{dL_\varphi}{dt} \right\rangle = S(E_r)$$

- where Q is the charge within a surface, L_φ is the canonical toroidal momentum, and S is the toroidal viscous force. In Boozer coordinates,

$$S = \tfrac{1}{2} \left\langle \partial_\varphi \left(p_\parallel + p_\perp \right) \right\rangle$$

- Directly calculate S in a δf simulation for each species as a function of E_r, solve for where charge fluxes balance.
- Avoids noisy simulated fluxes
- In testing and benchmarking

Power-Balance Solver (STP)

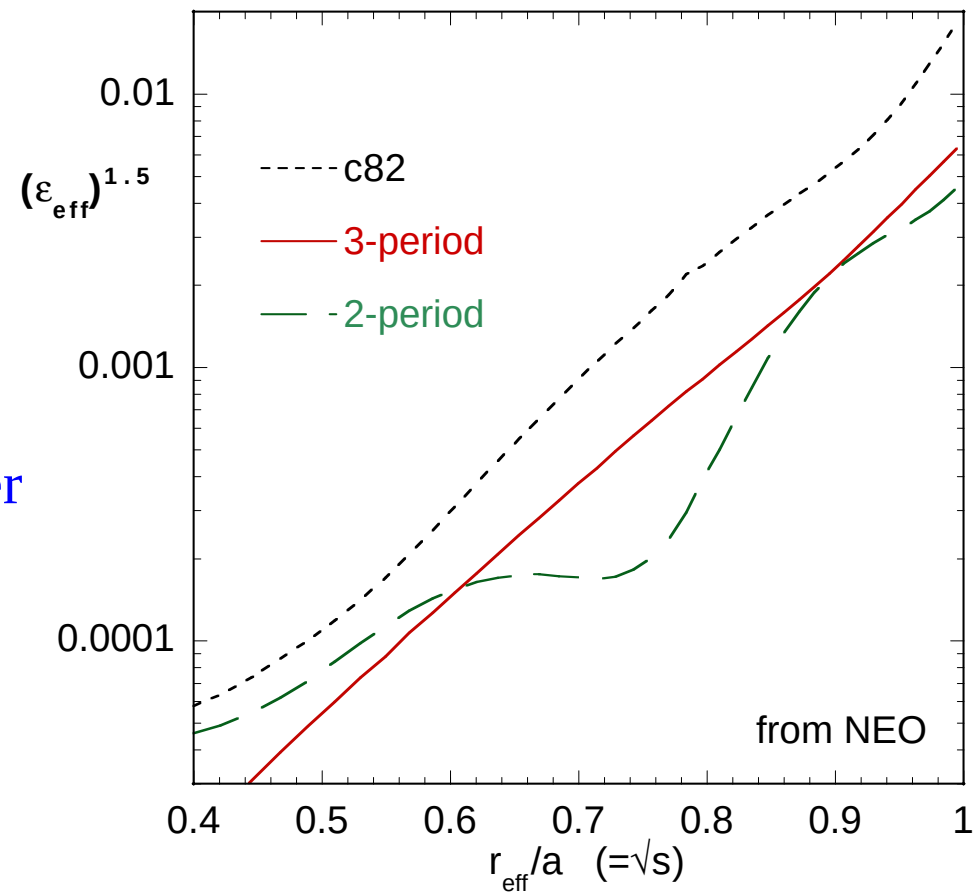
D. Mikkelsen, W. Houlberg, P. Strand

- Steady-state 1D Power balance solver for T_e and T_i, assumes edge boundary condition and density profile
- Transport model includes full transport matrix, combines
  - 'Shaing-Houlberg' helical neoclassical transport
  - Nemov-Kernbichler calculation of effective helical ripple (correct for $1/\nu$ regime)
  - Axisymmetric (toroidal) neoclassical transport (Chang-Hinton)
  - Anomalous transport models (Lackner-Gottardi, Mixed-shear,…)
- Self-consistent calculation of E_r from helical transport
- Neutral-beam deposition in axisymmetric shape
- Can constrain confinement to global scaling law (with multiplier)

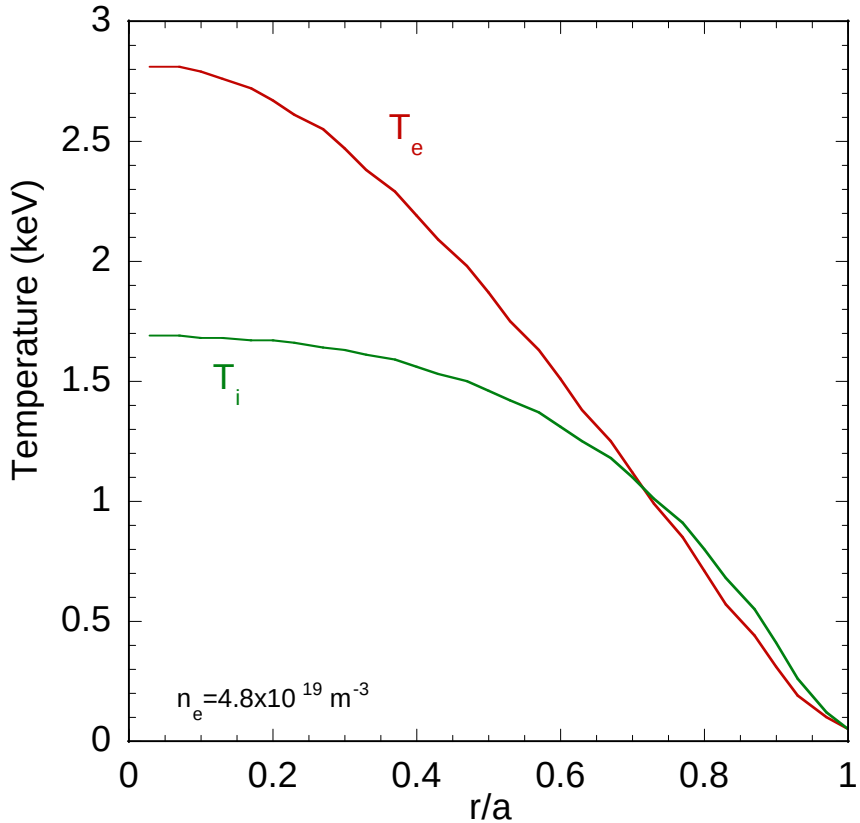
GTC benchmark: STP calculates more helical transport (< factor of 2) at a specified $E_r \neq 0$

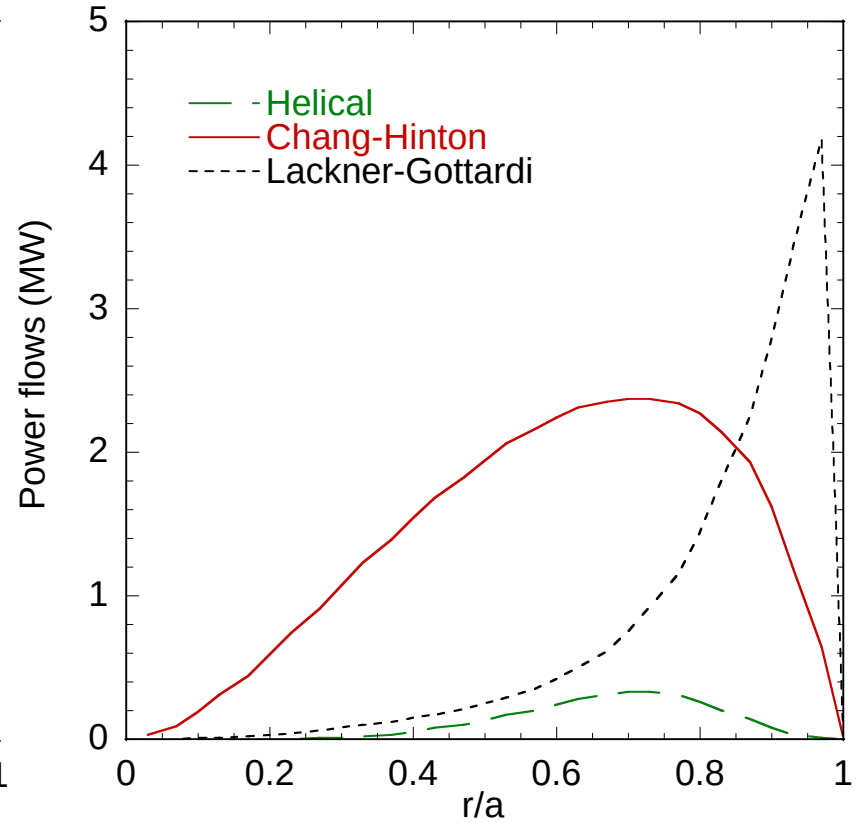
New Configurations: Low effective ripple

- ε_{eff} from NEO code by Nemov-Kernbichler
- In $1/\nu$ regime, neoclassical transport scales as $\varepsilon_{eff}^{3/2}$
- New configurations are better
  By factor ~2 across profile
- Edge ε_{eff} ~ 2.7% (2 period)
  ~ 3.5% (3 period)



New 3-period: Low Helical transport



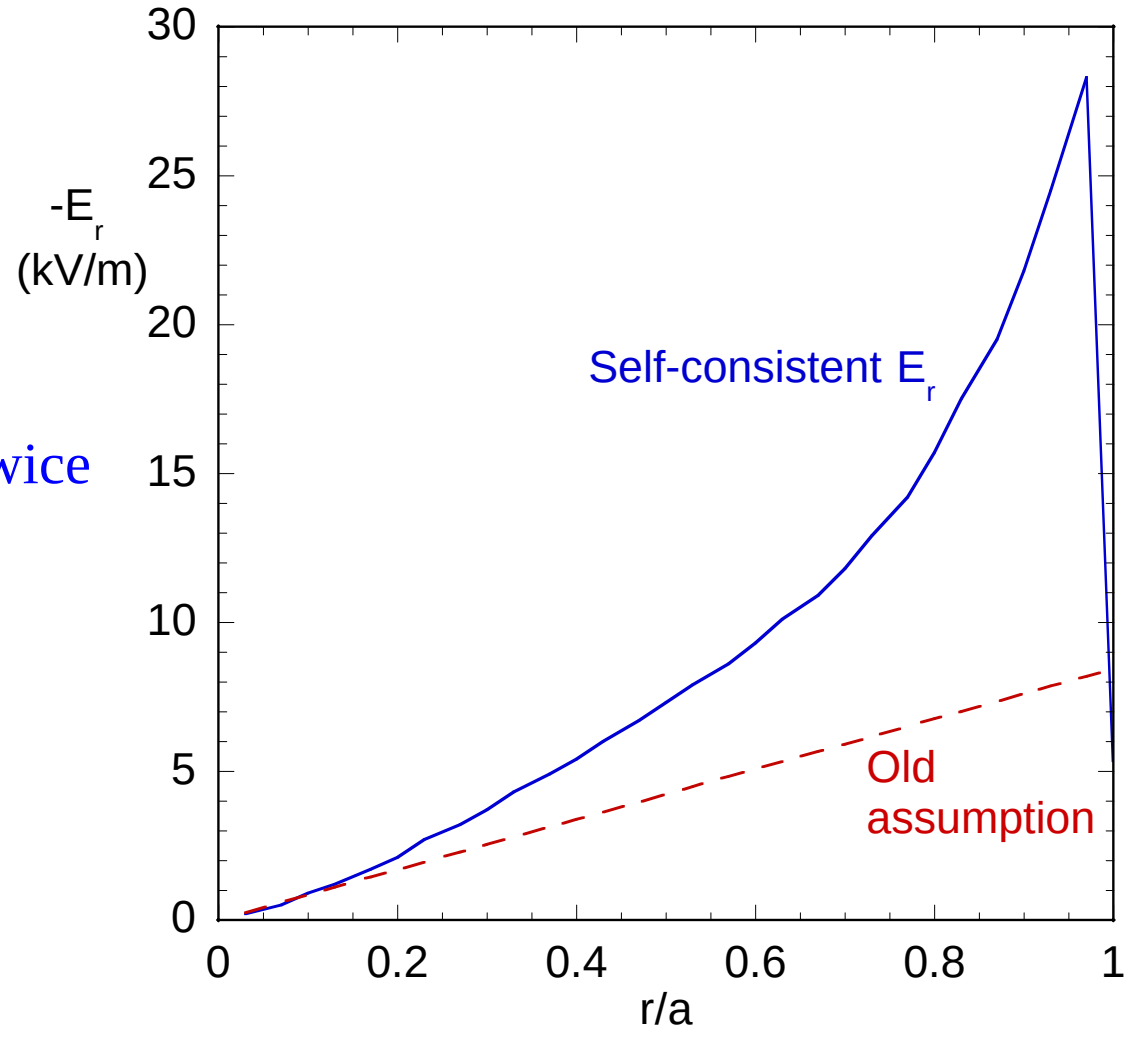


- Helical transport is sub-dominant with self-consistent E_r
- Assume B=1 T, H(ISS95) = 2.6, P_{heat} = 5 MW $\Rightarrow \nu^* \sim 0.25$ at r/a~1/2
- Toroidal neoclassical dominates, due to moderate size and 'reversed shear' $\Rightarrow$ limited poloidal flux

Helical Transport Reduced By Larger E_r

Self-consistent E_r is > twice as large as previously assumed in GTC

$\Rightarrow$ substantial reduction in helical-χ_i, modest increase in χ_e.



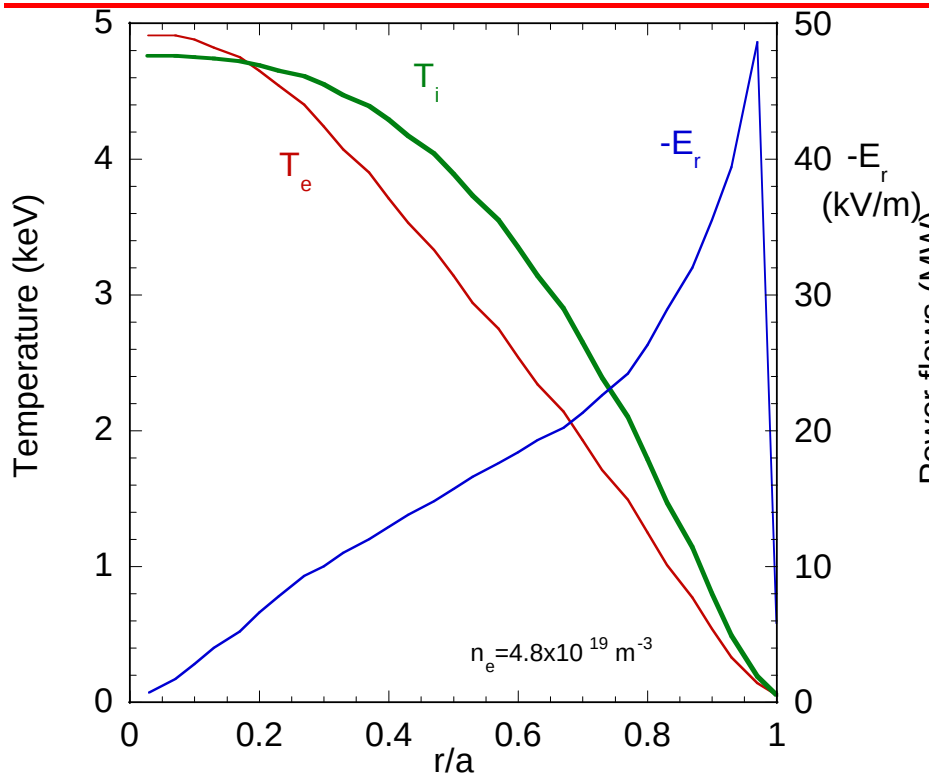
New Configuration Projections

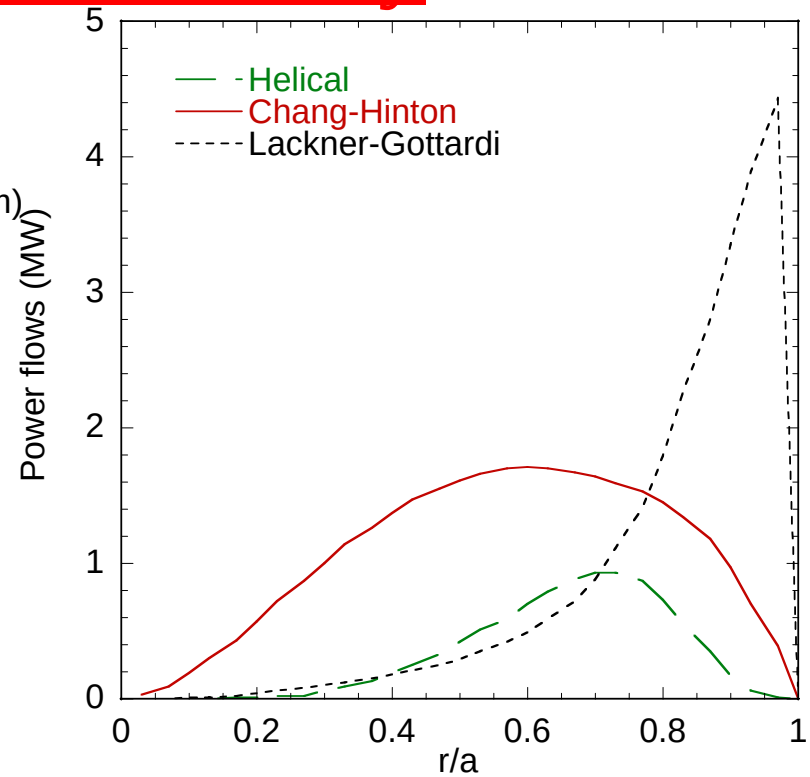
- Projected ISS-95 enhancement to get to the β-limit at 6MW, 20% loss, B=1 T, $H^0 \rightarrow H$, same volume as C82.

	3-period	3-period	2-period	2-period
H (ISS-95)	2.5	2.0	2.4	1.9
H (ITER-89P)	1.1	1.1	1.0	0.9
τ_E (sec)	0.024	0.024	0.021	0.021
ν^* (r/a ~ 0.5)	0.25	1.0	0.25	1.0
ne (10^{19} m^{-3})	5.0	7.9	5.3	8.4
T (0) (keV)	2.1	1.3	1.9	1.2

- ITER-89P evaluated by determining equivalent I_P to match iota(a) for average geometry. The scaling laws do not have the same parametric dependence…
- If not constrained by neutral penetration, can reduce plasma size to decrease required power or confinement enhancement.

B = 2T Allows Low Collisionality

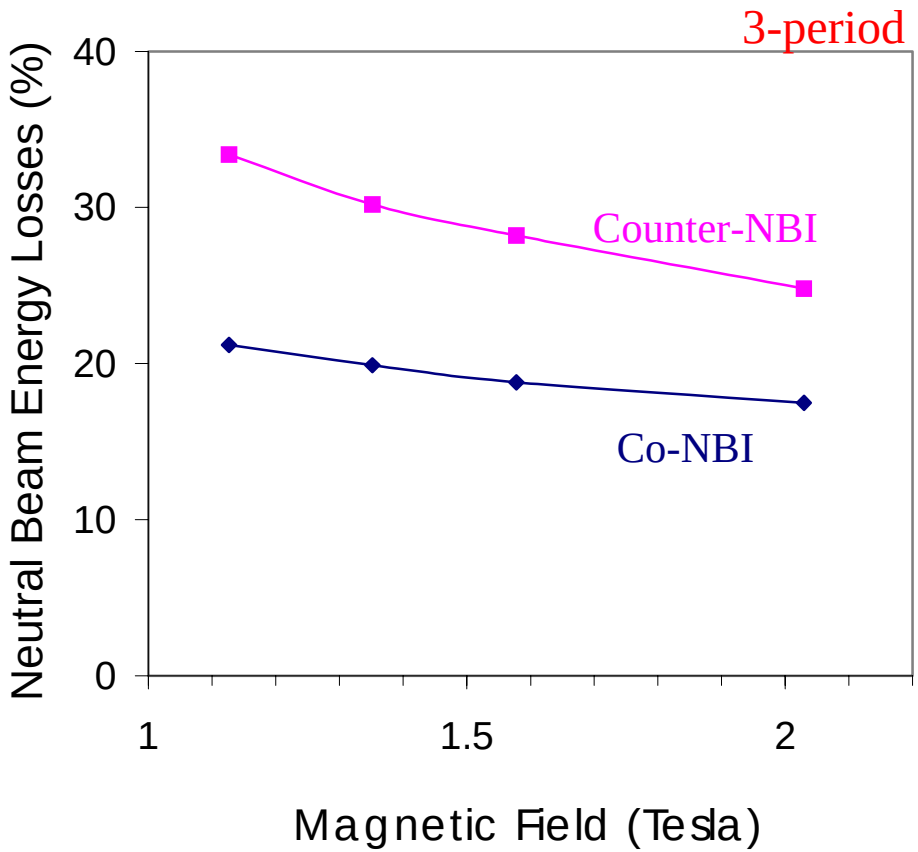




- Helical transport is still sub-dominant
- Assume H(ISS95) = 2.6, P_{heat} = 5 MW $\Rightarrow \nu^* \sim 0.04$ at r/a~1/2
  H(ITER-89P) = 0.95
- Allows reactor-like collisionality

New Configurations May Allow Counter-NBI

- Co-only NBI may produce too much NBCD
- Mixed co- and counter-NBI would give rotation control
- Assumed tangent to mag.-axis at oblate cross-section
- 2-period has 2/3 as much co-NBI loss, may also allow counter-NBI



D. Spong

High harmonic fast wave (HHFW) heating for NCSX

R. Majeski

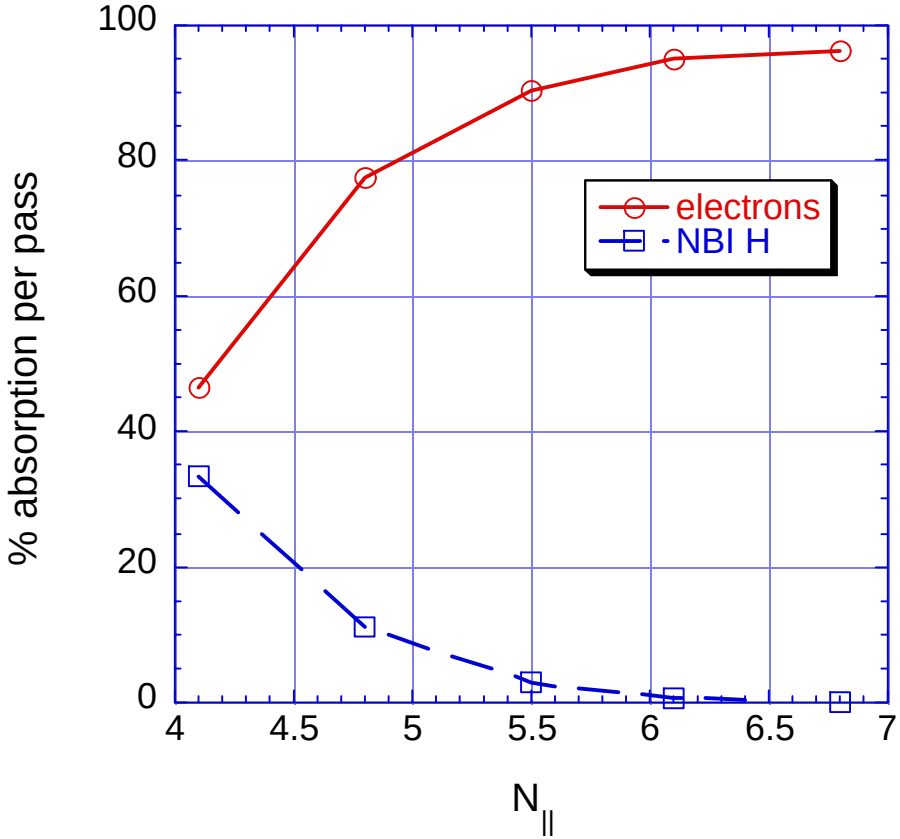
- NCSX will typically operate at moderately susceptibility ($\omega_{pe}^2/\Omega_{ce}^2 \sim 5$)
- Very high frequency fast waves can be strongly damped
- High power, CW sources are available for frequencies > 300 MHz
- HHFW heating and current drive is being implemented on NSTX
- Consider 350 MHz HHFW heating for NCSX
  - Compact launchers, probably folded waveguide
  - Isolators can be implemented at this frequency

    $\Rightarrow$ Reduced sensitivity of the system to changes in the plasma edge
  - Current drive capability is significant
  - Sources are typically CW, > 1 MW per tube

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

350 MHz HHFW strongly absorbed in NCSX

350 MHz, $n_e(0) = 6 \times 10^{19}\ m^{-3}$ (parabolic$^{0.5}$), $T_e(0) = T_i(0) = 2$ keV, $B_0 = 1.2T$, 2%NBI H

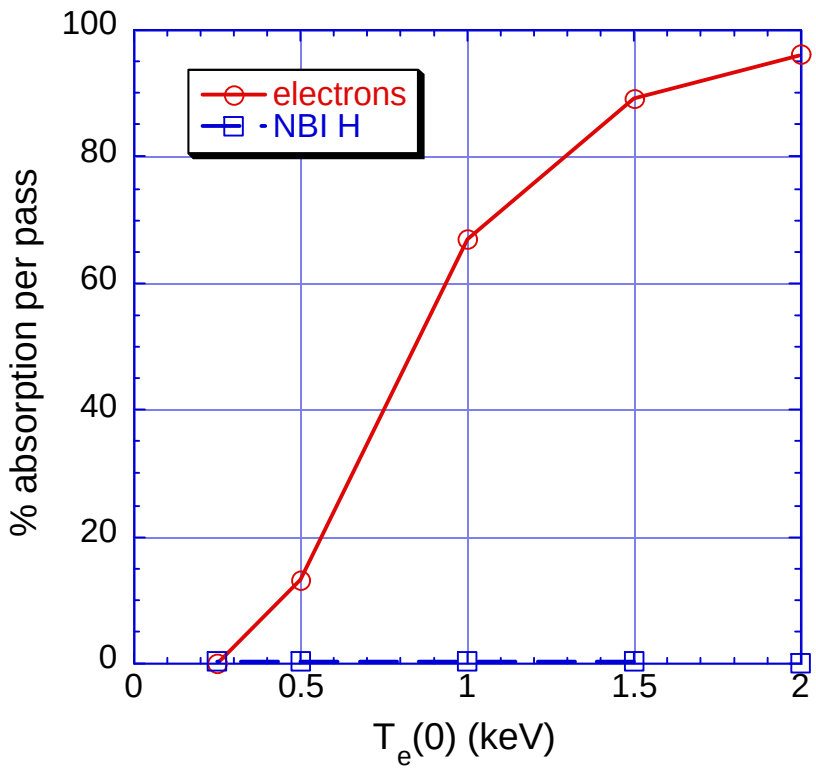


- High $N_{||}$ <u>not</u> required for strong absorption
- Significant noninductive current drive capability
  - ~0.03 - 0.05 A/W (TORIC)
  - Accurate estimate requires detailed geometry

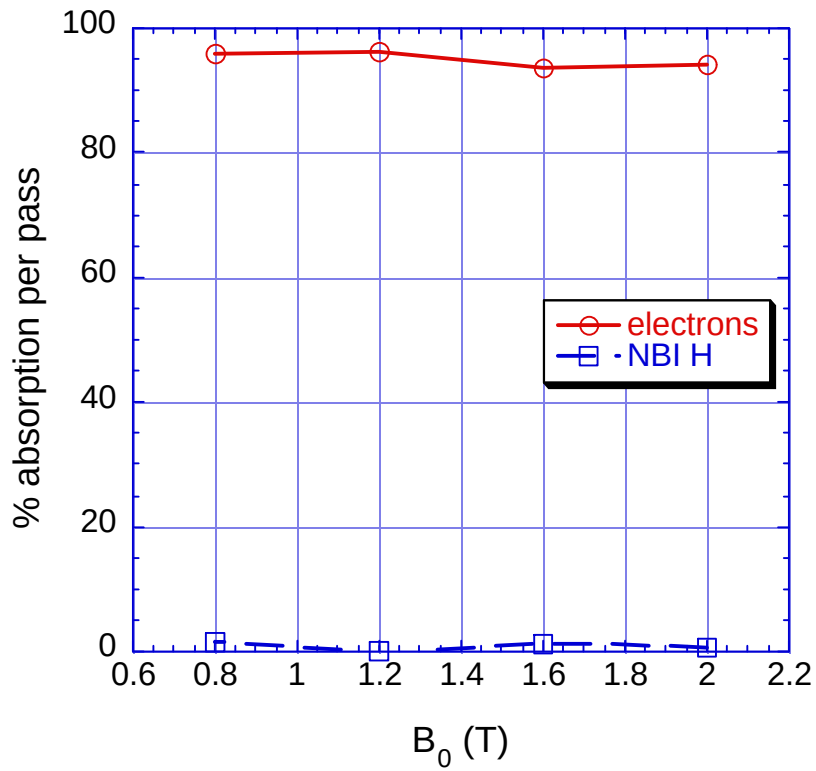
1-D results from METS

HHFW absorption is strong over a wide range in T_e, B_0

350 MHz, $n_e(0) = 6 \times 10^{19}\ m^{-3}$ (parabolic$^{0.5}$), $T_e(0) = T_i(0)$, $N_{||} = 6.8$, $B_0 = 1.2T$, 2%NBI H



350 MHz, constant β, $N_{||} = 6.8$, 2%NBI H



Techniques for Enhancing Confinement

Planned strategies:

- Wall conditioning (bake, HeGDC)
- Wall coatings (B, Li?)
- Pellet Injection
  LHD & tokamaks

Starting to investigate:

- Neutral baffling to control recycled flux
- Divertor (probably as upgrade)

Need to investigate:

- Expected access to H-mode (divertor or limiter), RI-mode
- Effect of self-consistent E_r on turbulence, and vice-versa

Divertor/Limiter Investigation Begun

LLNL, ORNL, PPPL, UCSD, IPP-Garching

- Working group formed
- Initial requirements for divertor/limiter established
- MFBE code (E. Strumberger) has been imported from Garching, now operating at NERSC, maps field lines outside VMEC equilibrium
- Plan:
  - Use MFBE to establish magnetic topology of edge region
  - Develop range of limiter/divertor options by end of September
  - Down select & revise physics requirements then
  - Develop and integrate a narrow range of options into configuration for PVR

Summary

- New configurations have substantially reduced helical transport
  - Reduced effective ripple
  - Reduced fast-ion losses
- Self-consistent electric field suppresses helical thermal transport
  - Toroidal neoclassical χ_i dominates predictions
- New configurations may allow counter-NBI
  - Control of NBCD, driven rotation
- 350 MHz High-Harmonic Fast Wave heating looks attractive
  - Heating without current-drive or rotation
  - Can be phased to drive current
- Boundary design studies are beginning