Electron Transport in Auxiliary Heated NSTX Plasmas

B.P. LeBlanc, R.E. Bell, W. Horton, B. Holder, S.M. Kaye, S.F. Paul, C.K. Phillips, M.H. Redi, A. Rosenberg, D.H. Stutman, J.R. Wilson, V.A. Soukhanovskii,

and the NSTX Research Team

45th Annual Meeting of the Division of Plasma Physics

October 27-31, 2003

Albuquerque, New Mexico

Abstract

Dear poster reader,

The content of this poster differs from the original abstract but still relates to the electron thermal transport in NSTX. In the following, two techniques are used to propagate the kinetic data error bars through the TRANSP "power balance" diffusivity calculations. Doing so allows us to see how the experimental error can affect the transport analysis. A high and a medium NBI power discharges are investigated. While χ_e remains the largest diffusivity for both time and radius spans, the ordering between χ_i, χ_i^{NC}, and χ_ϕ appears to change with plasma condition and radial location.

B.P.L.

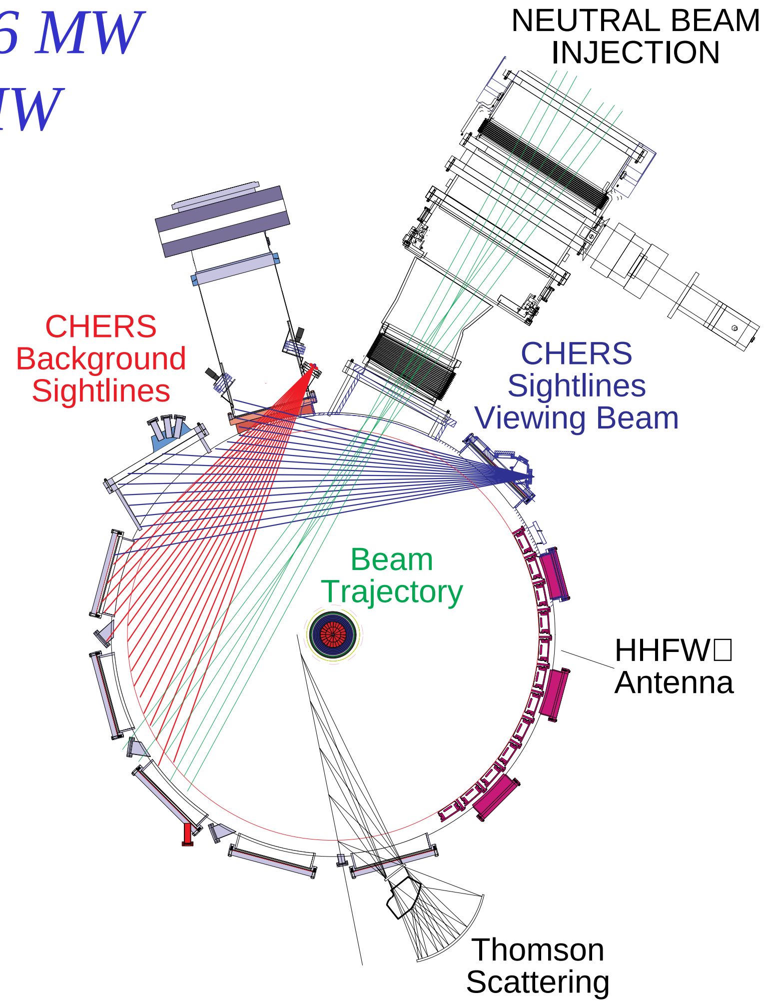
Outline

- Available kinetic profile set
- Mapping issues
  – Methodology
- Two diffusivity error computations
  – Transp "steps" and kinetic profile analysis
  – Kinetic profile local error sampling
- Diffusivity for NBI heated discharges
- Comments

Auxiliary Heating Systems and Kinetic Profile Measurements

- Thomson scattering
  - $T_e(R,t)$, $n_e(R,t)$
  - *60 Hz, 20 channels*
- Impurity charge exchange recombination spectroscopy
  - $T_i(R,t)$, $v_\phi(R,t)$, $Zeff(R,t)$
  - *17 channels, Δt = 20 msec*
- Bolometer
  - $P_{rad}(R,t)$, 16 channels
- Ultra soft x-ray arrays
  - 4 fans of 16 channels each

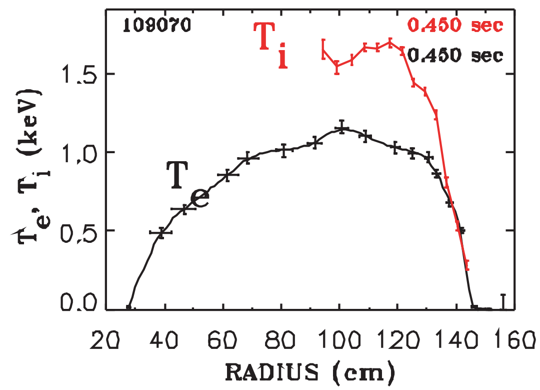
HHFW: 6 MW
NBI: 7 MW

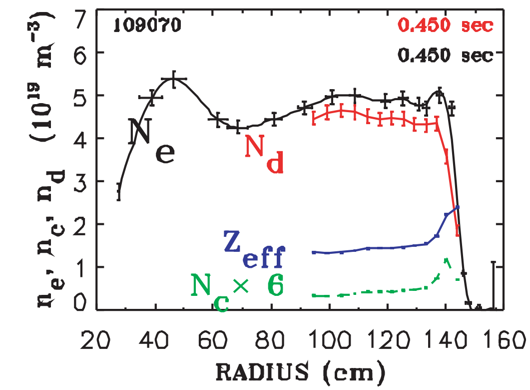


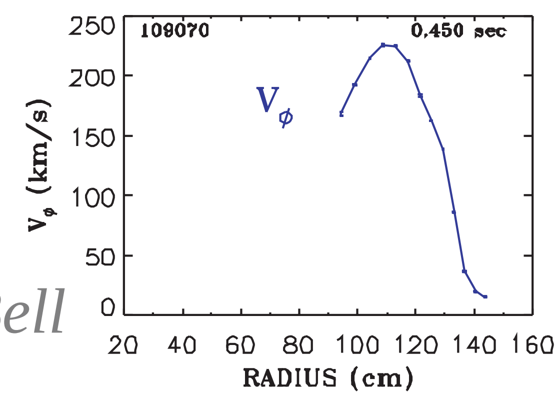
Kinetic Profile Coverage for Outer Plasma Region

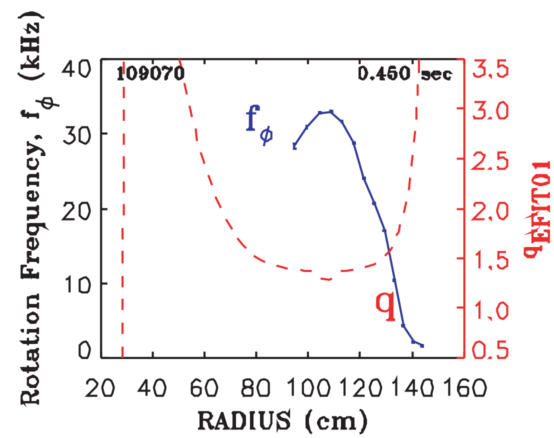
NSTX has a good kinetic data set, with all profile diagnostics covering the low field side of the magnetic axis.

Profile	In	Out
Te(R)	√	√
ne(R)	√	√
Ti(R)		√
Vf(R)		√
Zeff(R)		√









R.E. Bell

Low Field Side Data Mapping for TRANSP Analysis

NSTX

Good because:

Reproduces experimental (spatial) relationship between T_i and T_e profiles.

Limitation:

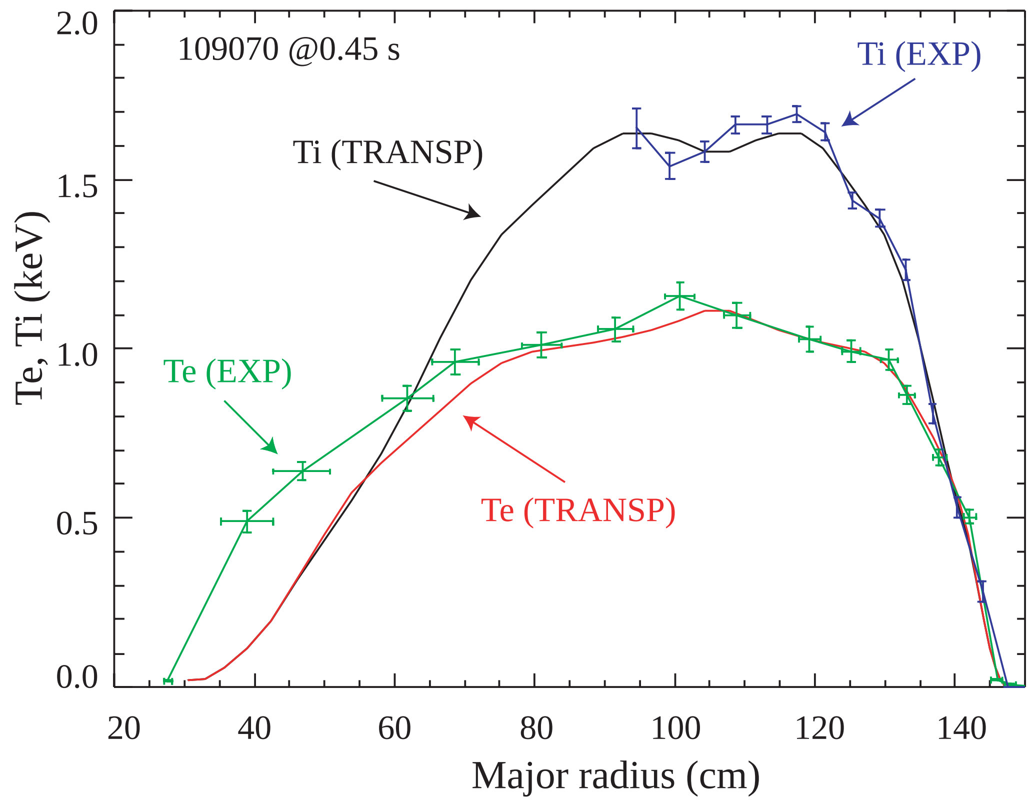
Current TRANSP "static" equilibrium solvers do not match magnetic axis with T_e apex.

This 4-cm effect (see fig.), translates into a mismatch up to 12 cm when compared to actual Thomson scattering data on the high field side.

Mitigating circumstance:

High field side contributes little to the stored energy.

More about mapping issues can be found in poster LP1.004.



Kinetic Profile Analysis with TRANSP "Steps" to Compute Diffusivity Error

$$\chi = k \frac{Vol\,\mathrm{int}(Pcond)}{S\,n\,\nabla T} \qquad (1)$$

$$\frac{d\chi}{\chi} = \sqrt{\left(\left(\frac{dVol\,\mathrm{int}(Pcond)}{Vol\,\mathrm{int}(Pcond)}\right)^2 + \left(\frac{dn}{n}\right)^2 + \left(\frac{d\nabla T}{\nabla T}\right)^2\right)} \qquad (2)$$

Estimated from "step" TRANSP analysis

Readily available from measurement

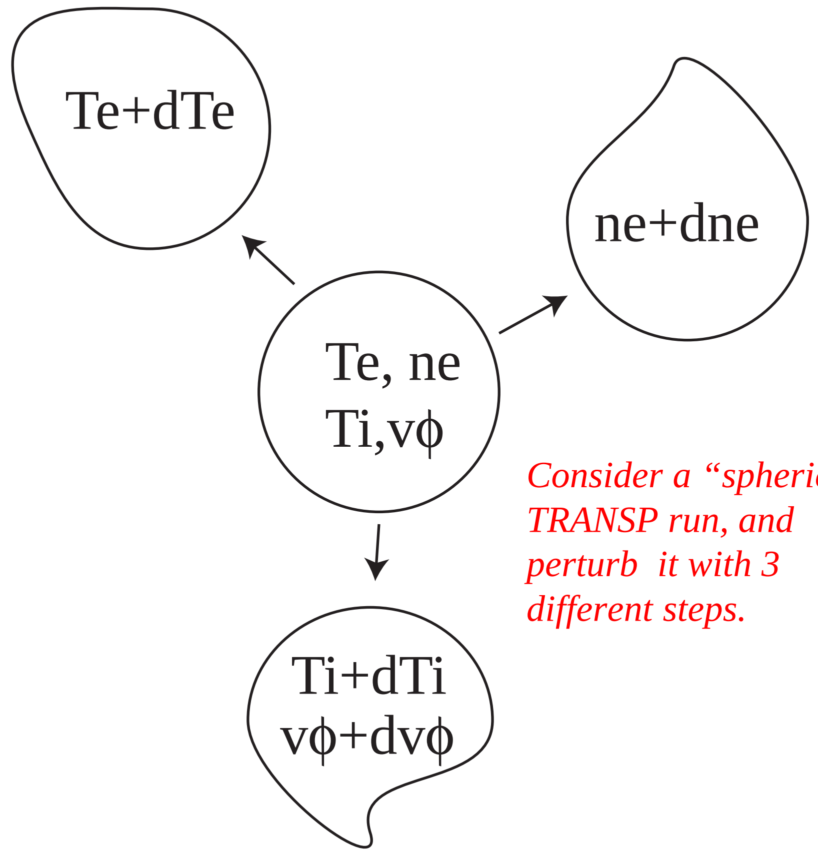
Estimated from profile analysis

TRANSP ANALYSIS SETTINGS

- Low field side kinetic data mapping
- Assume $T_i = T_e$ at outer major radius where T_i is not measured.
- Plasma boundary from EFIT
- Asymmetric VMEC equilibrium solver
- NCLASS calculation of χ_i^{NC}

TRANSPP Step Analysis
Computation of dVolint/Volint(Pcond)

- Establish "base" run
- Do three "step" runs:
  - Te → Te+dTe
  - Ne → ne+dne
  - Ti, vϕ → Tϕ+dTi,
→ vϕ+dvϕ
  - where the "d*" correspond experimental error bars
- *dVolint(Pcond*) = sum in quadrature of incremental differences

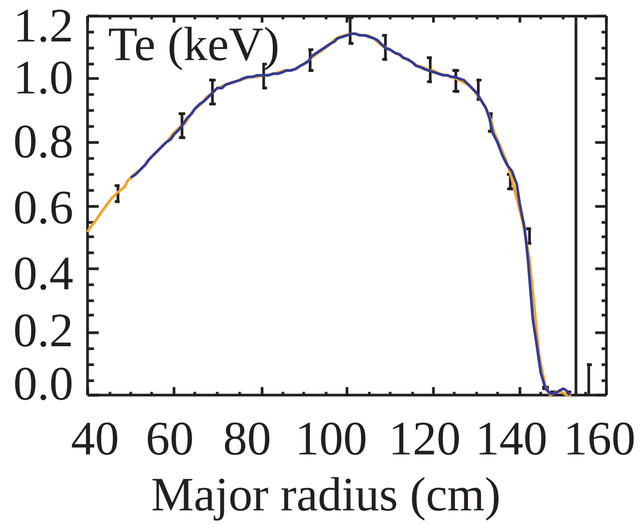


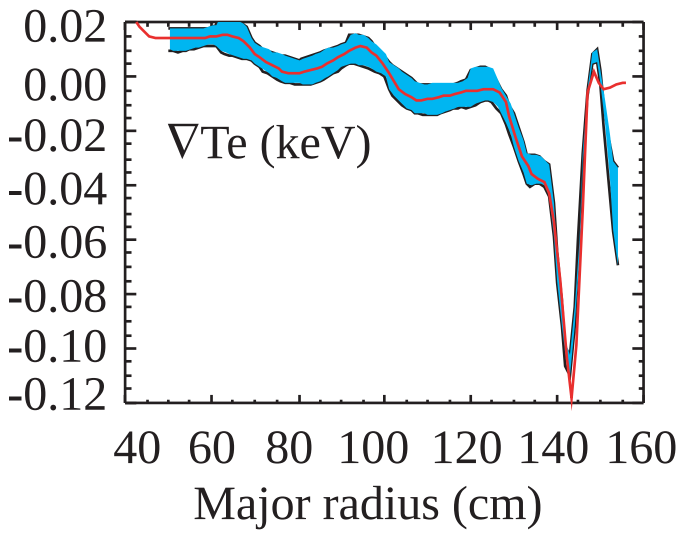
Consider a "spherical" TRANSP run, and perturb it with 3 different steps.

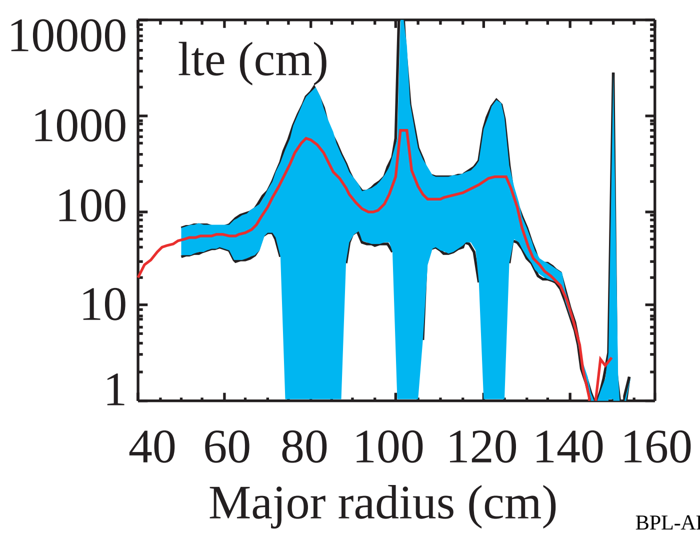
Kinetic Profile Analysis: Real Space

Estimation of Local of ∇T/T and d∇T/T

- Select 6 experimental points in the vicinity of point of interest
- Use polynomial fits to estimate ∇Te, lte and errors, which are shown in blue





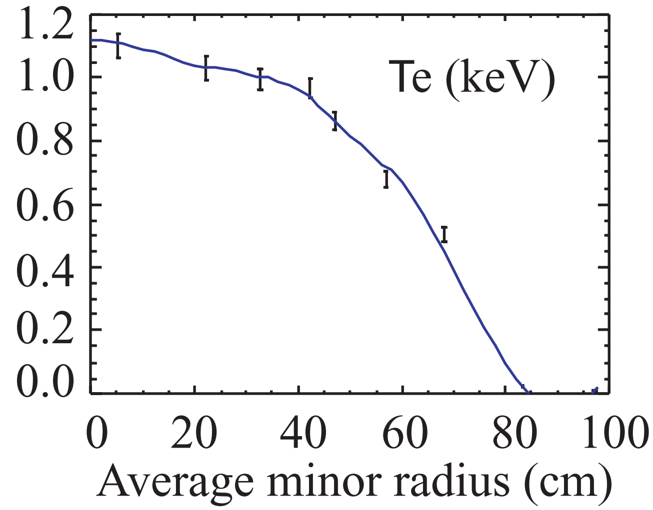


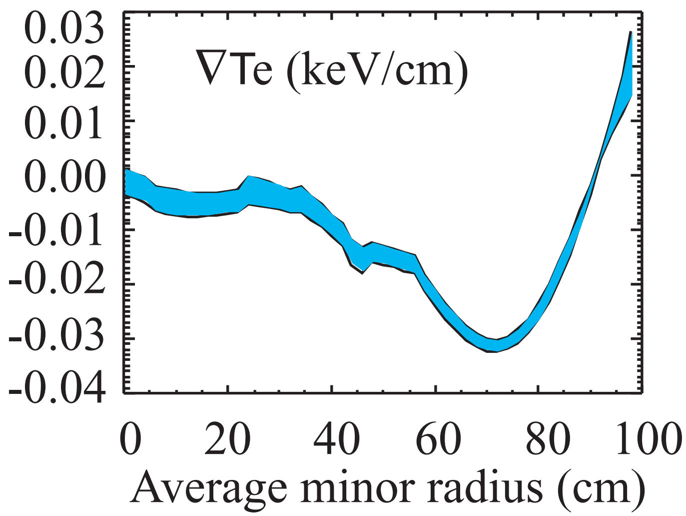
Kinetic Profile Analysis: Flux Surface Average

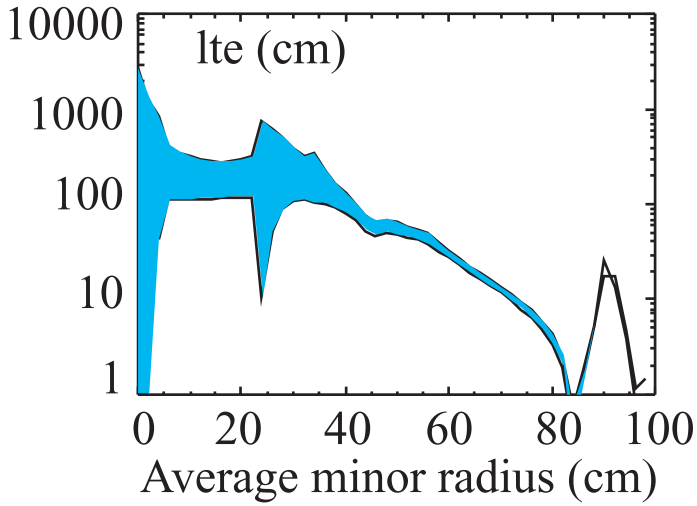
Estimation of Surface average ∇T/T and d∇T/T

NSTX

- Map Te over average minor radius as determined by TRANSP
- Use polynomial fits to estimate ∇Te, lte and errors, which are shown in blue

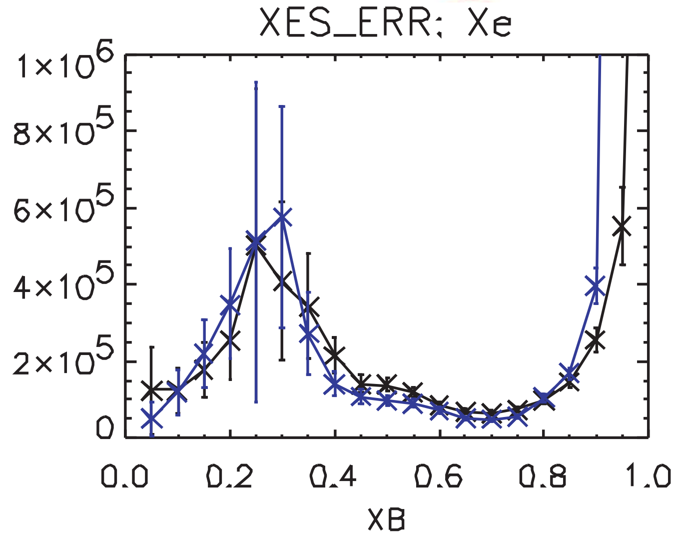


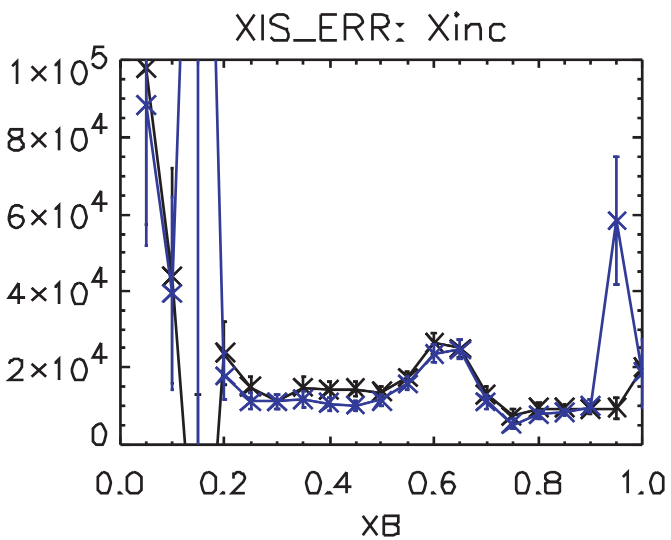


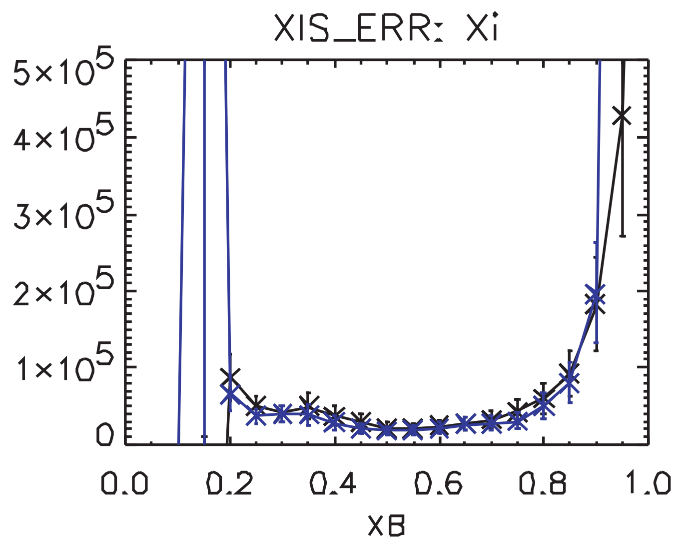


TRANSP Steps and Profile Analysis
Consistency check

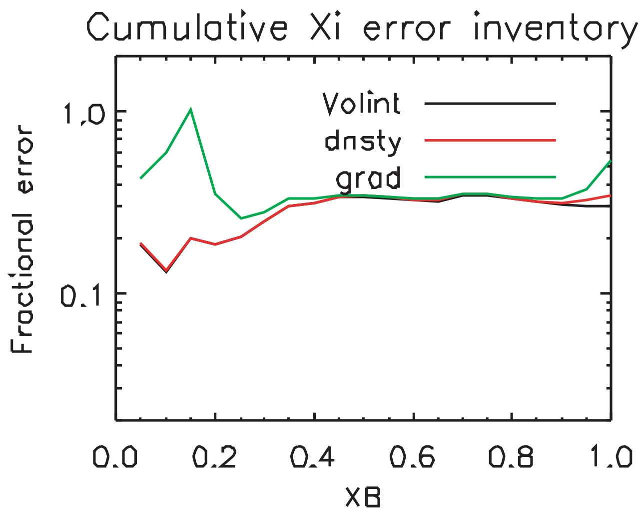
- Comparison between computation using eq.1 shown in black and TRANSP shown in blue
- Good agreement between both calculations

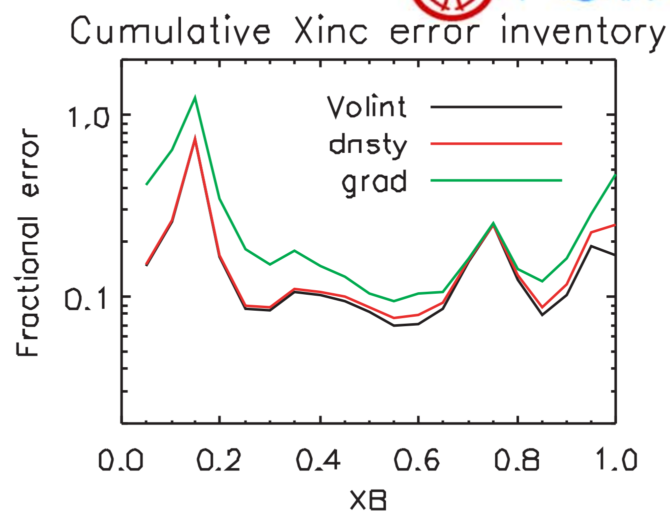


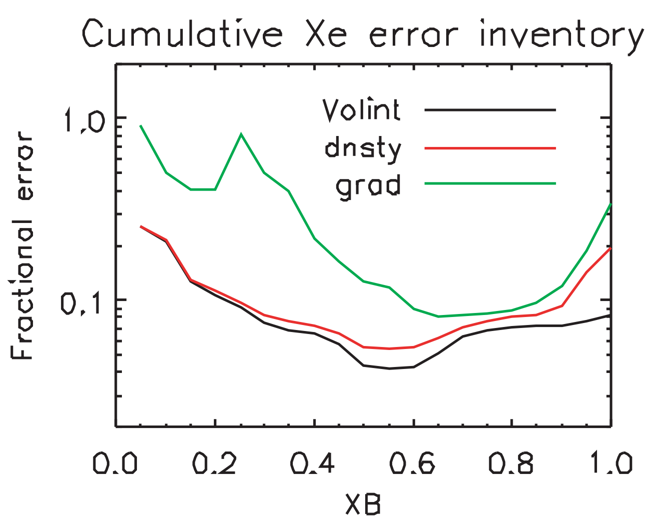


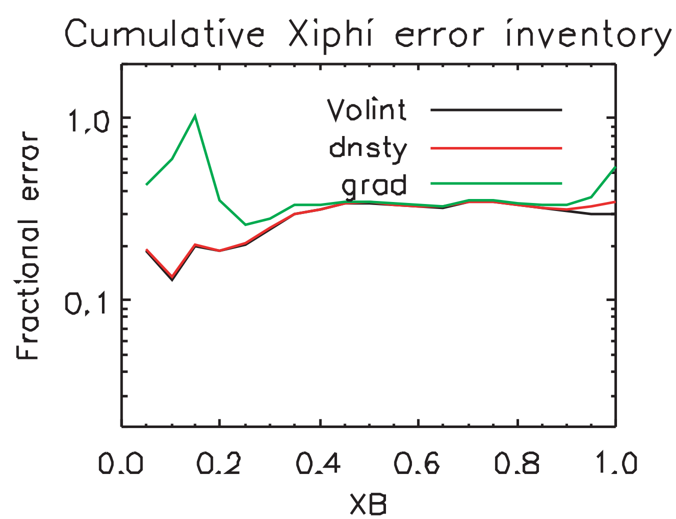


Cumulative Error Bar Inventory on Diffusivities









High Power NBI Heating

I_p = 0.8 MA

B_T = 0.5 T

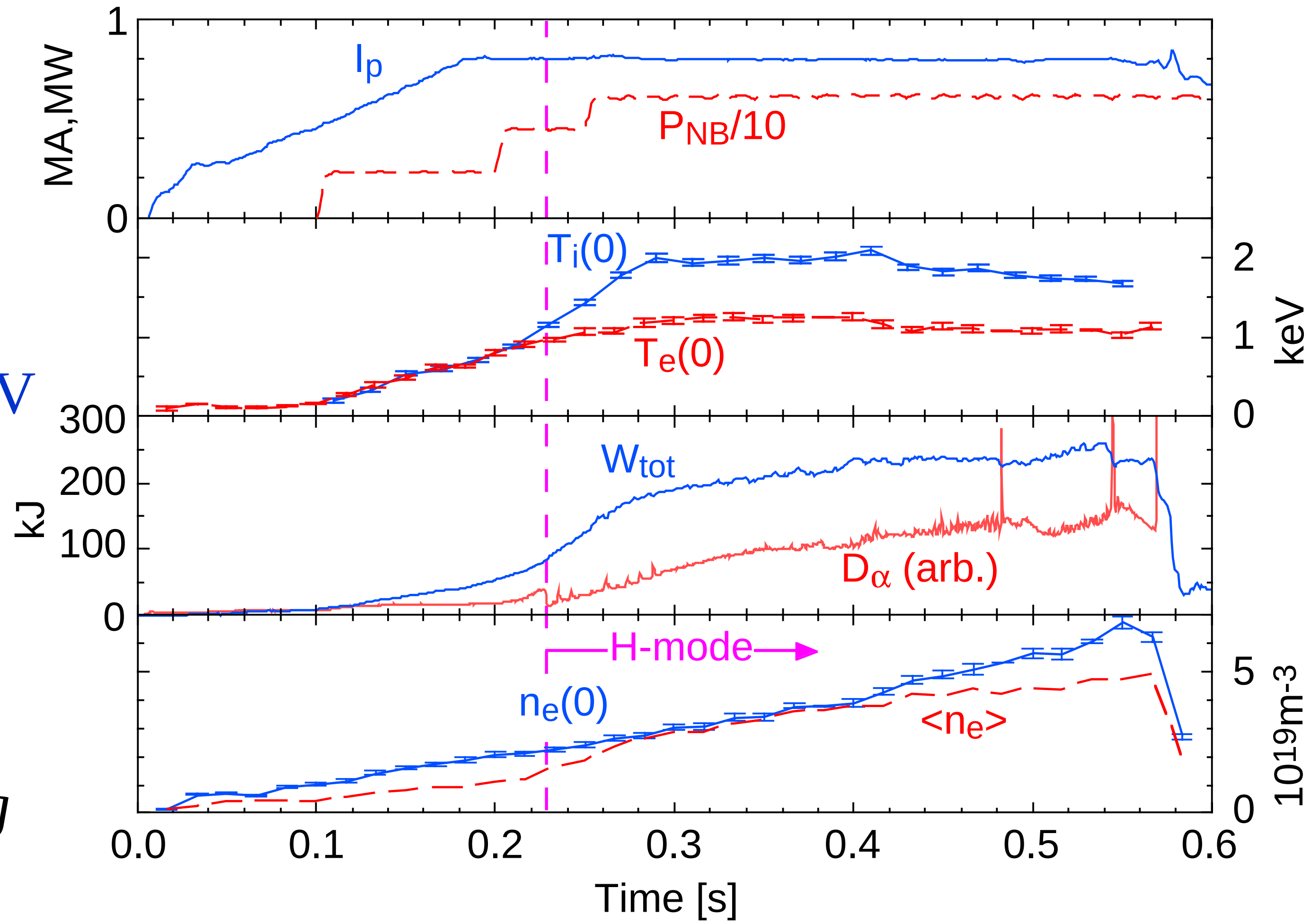
P_{NBI} = 6 MW

E_{NBI}= 80-100 keV

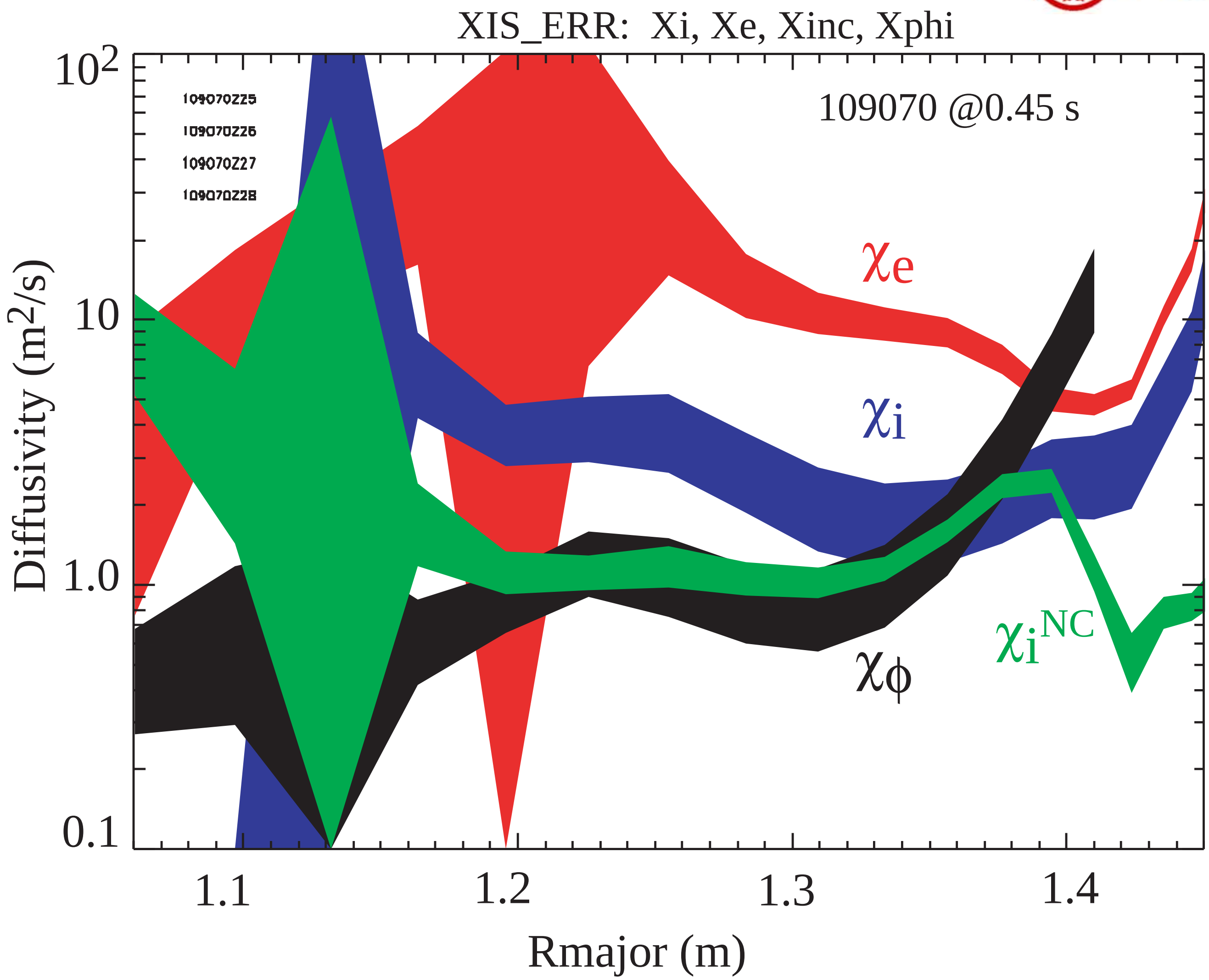
β_T = 18%

W = 0.25 MJ

Density profile broadens during H-mode



Diffusivity Profiles with Error from *TRANSP Steps and Kinetic Profile Analysis*

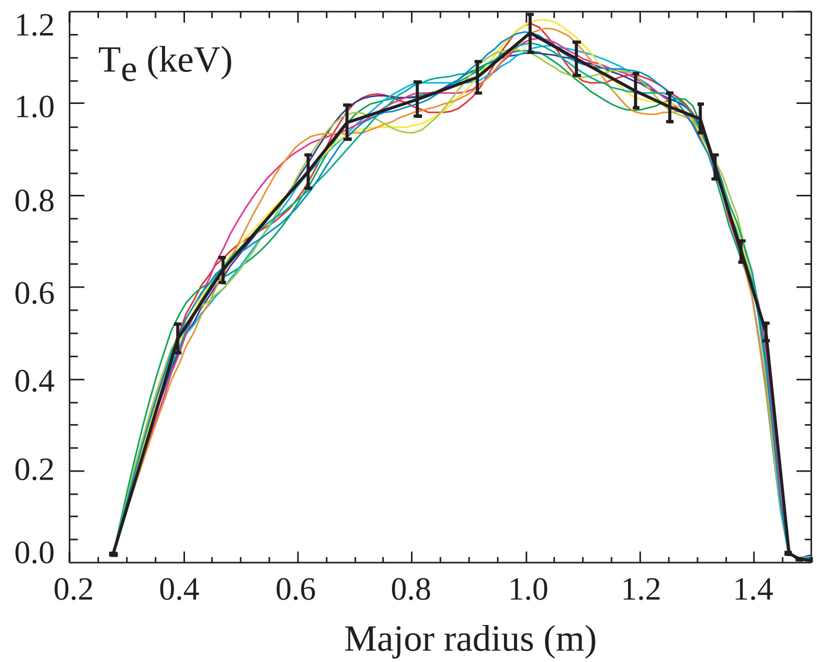


Diffusivity Error Estimation by Kinetic Profile Local Error Sampling

- TRANSP runs with Te, ne, Ti and vϕ prepared by "rolling the dice" at each time and spatial experimental point.
- "Dice" used is random number generator of mean 0 and standard deviation 1.
- For example
  - Te → Te +(rand. #)*dTe

  where dTe is the experimental T_e error bar

Experimental data overlaid with 10 error sampling profiles

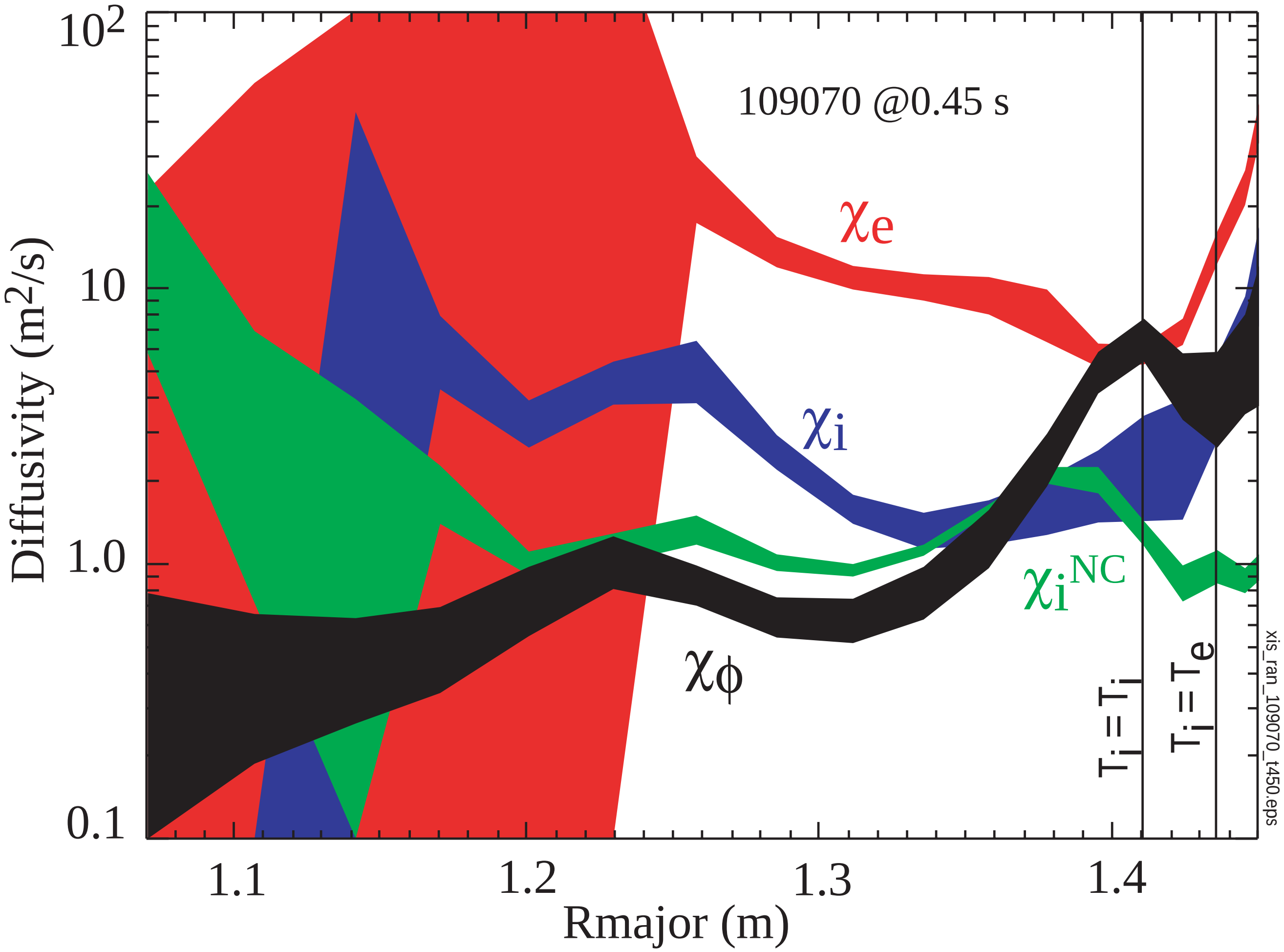


Diffusivity Profiles vs Rmajor with Error Bars

Kinetic profile local error sampling

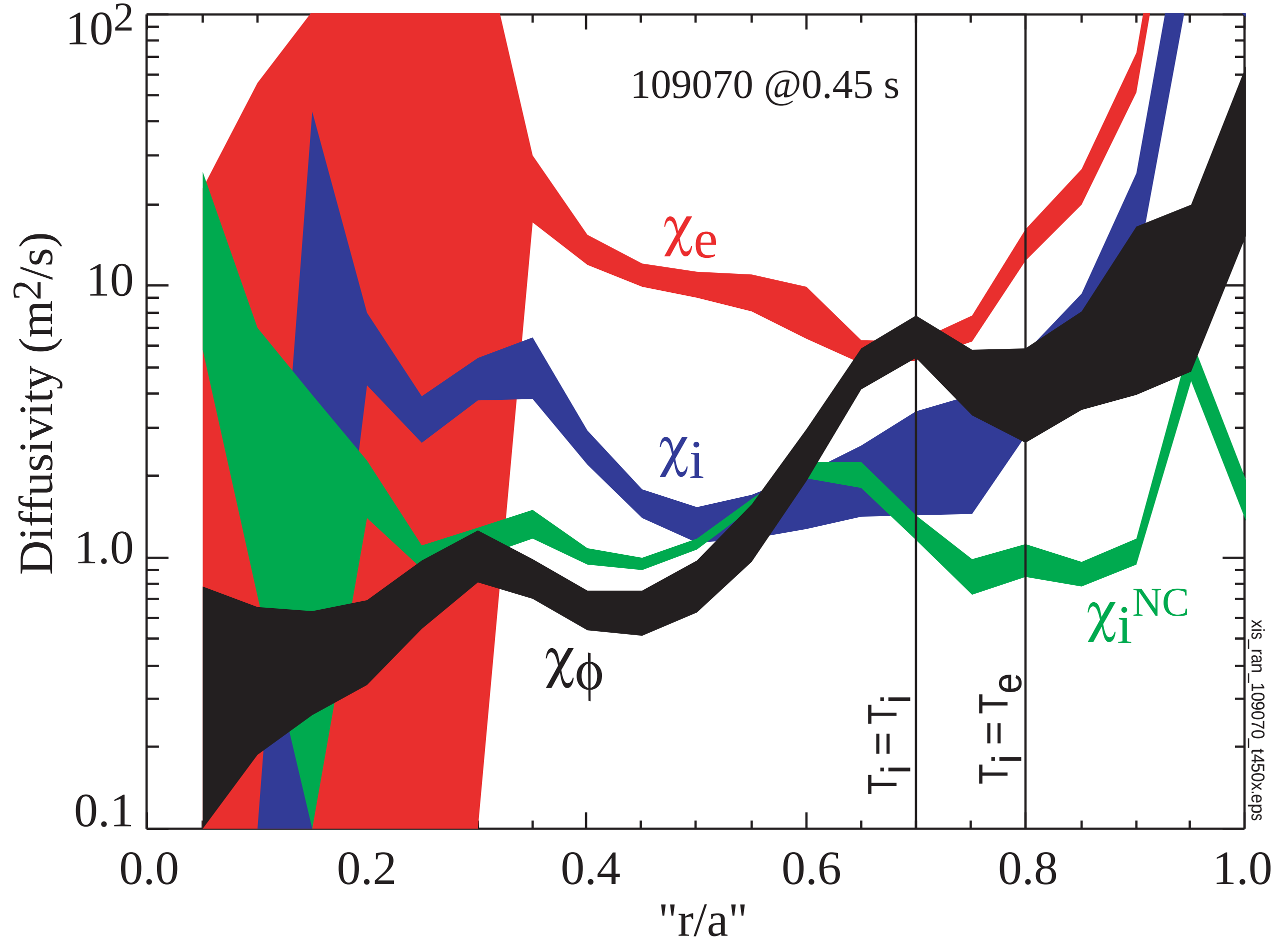
NSTX

Steady state phase of a high power NBI plasma



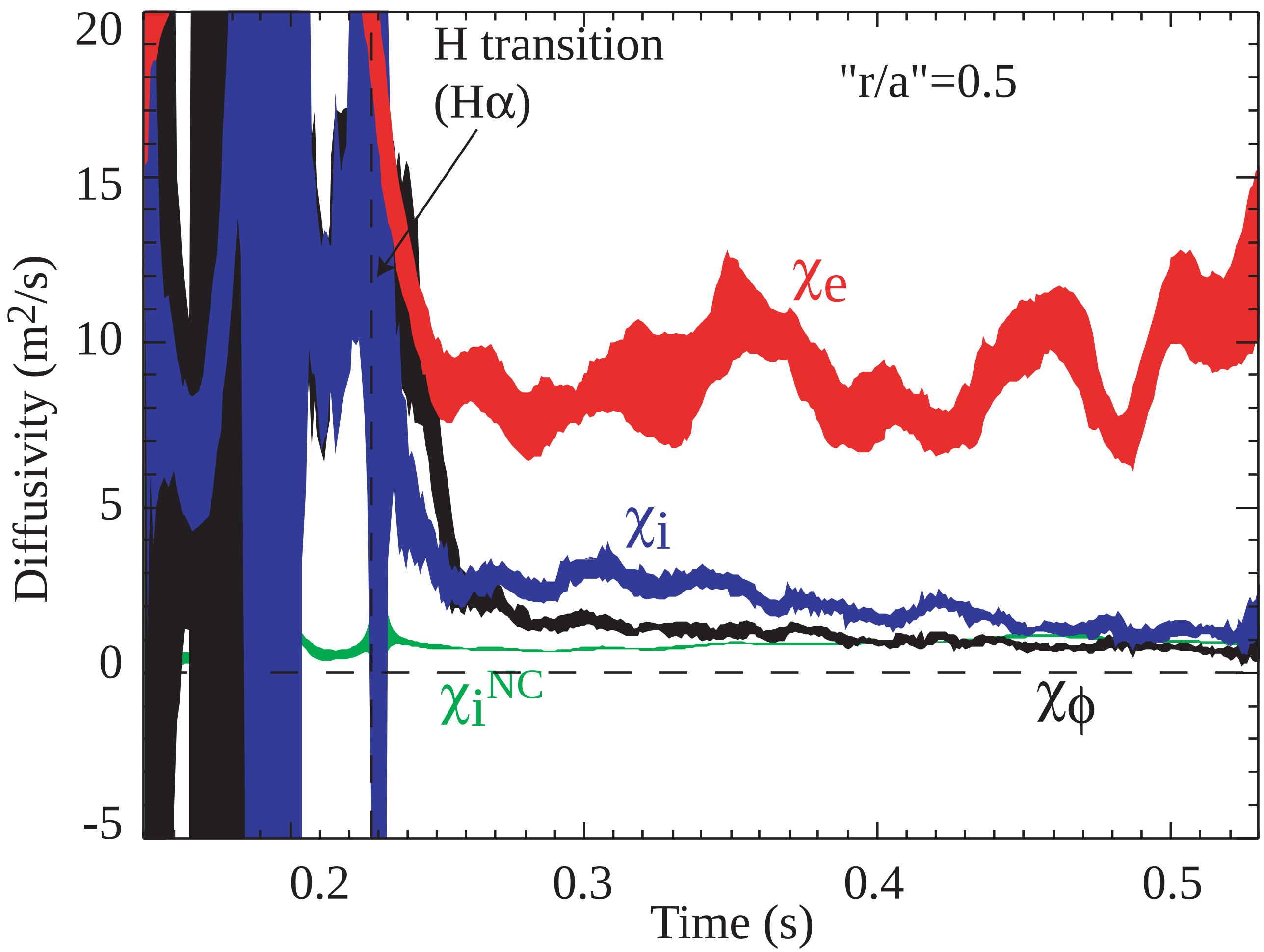
Diffusivity Profiles vs “r/a” with Error Bars
Kinetic profile local error sampling

Steady state phase of a high power NBI plasma



Diffusivity Time Evolution with Error Bars
Kinetic profile local error sampling

High power NBI plasma



Medium NBI Power in MHD Quiescent Discharge

I_p = 0.8 MA

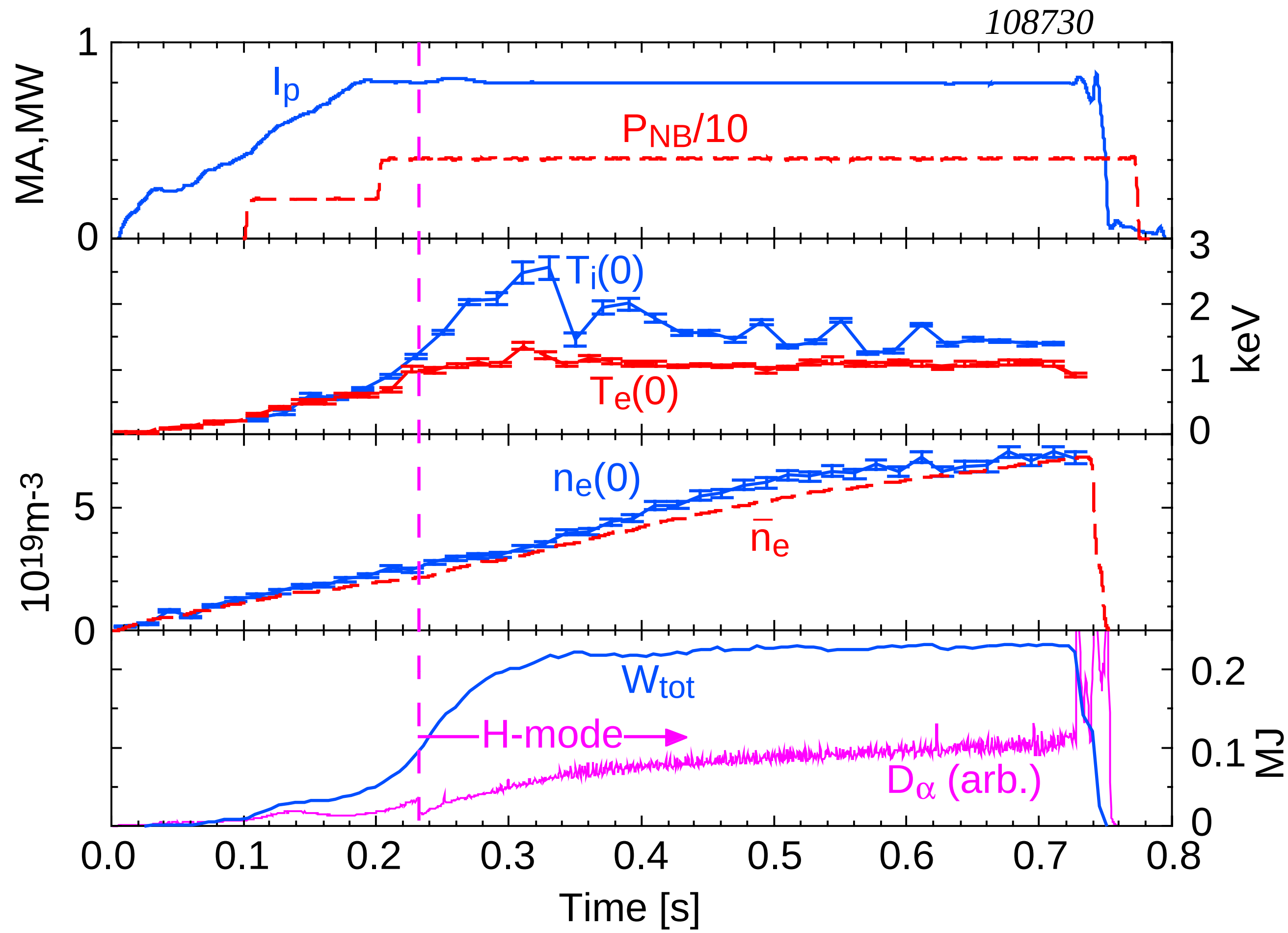
B_T = 0.5 T

P_{NBI} = 4 MW

E_{NBI} = 90 keV

β_T = 16%

W = 0.23 MJ

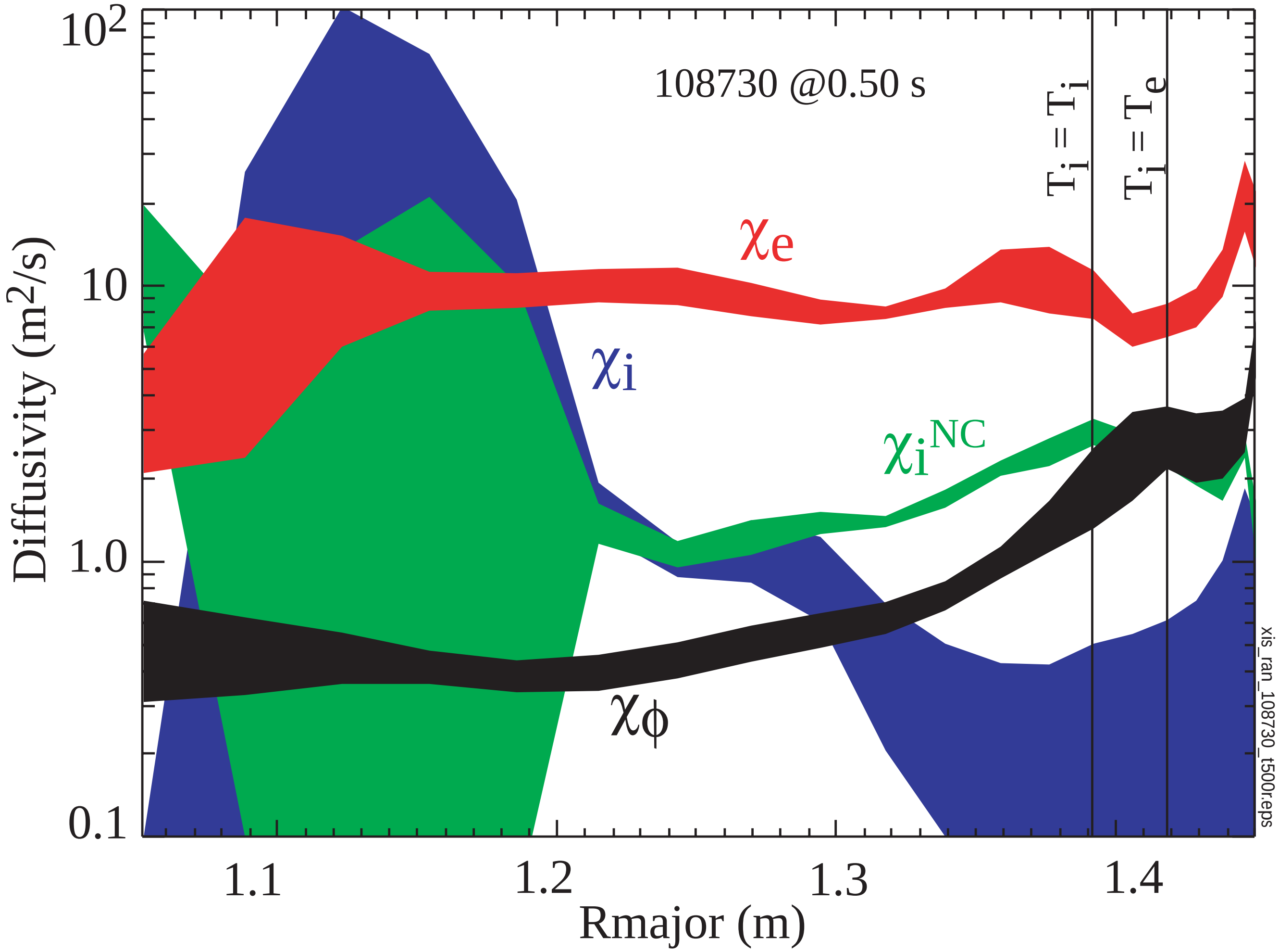


Diffusivity Profiles vs Rmajor with Error Bars

Kinetic profile local error sampling

NSTX

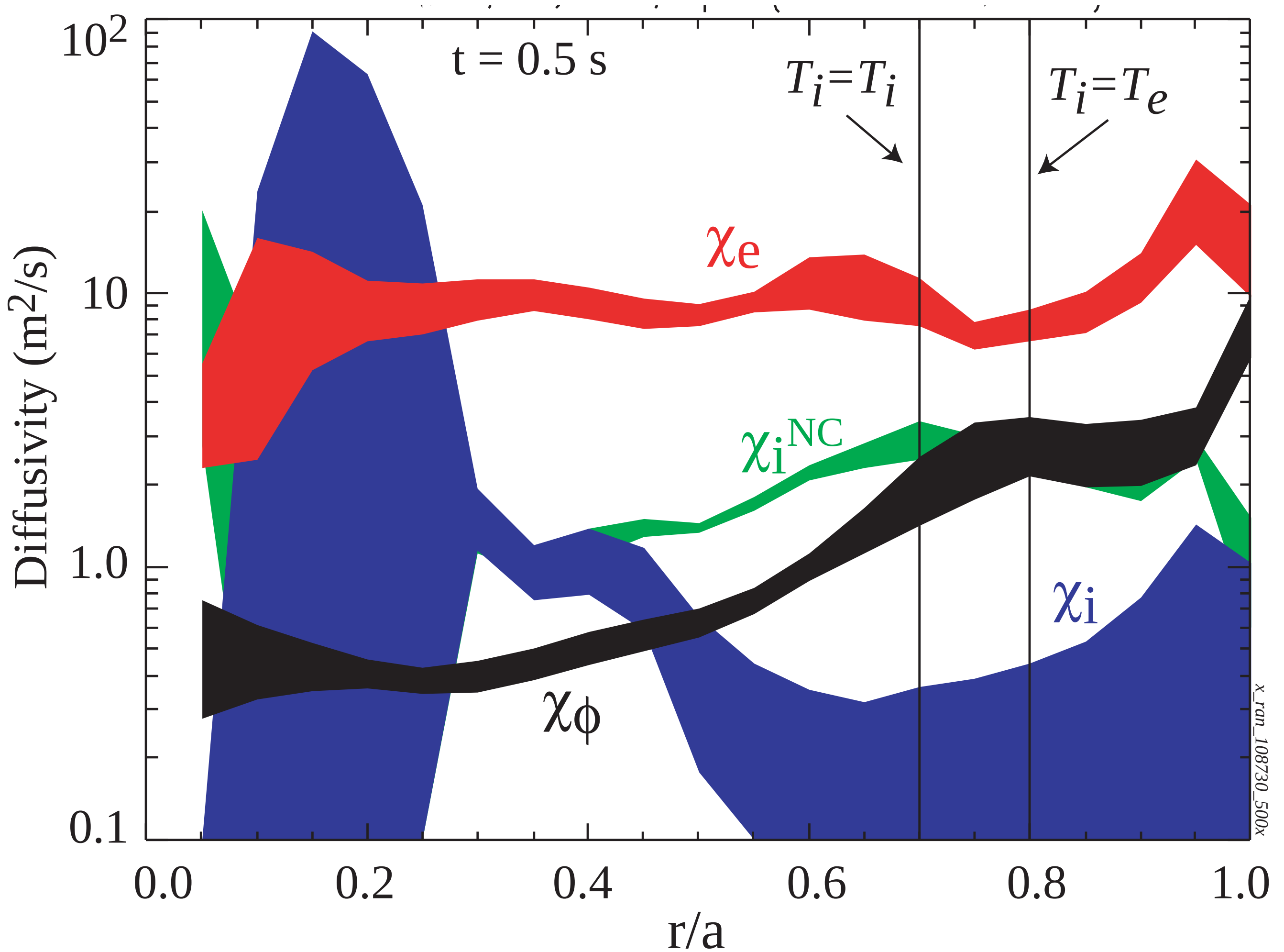
Steady state phase of a medium power NBI plasma



Diffusivity Profiles vs "r/a" with Error Bars

Kinetic profile local error sampling

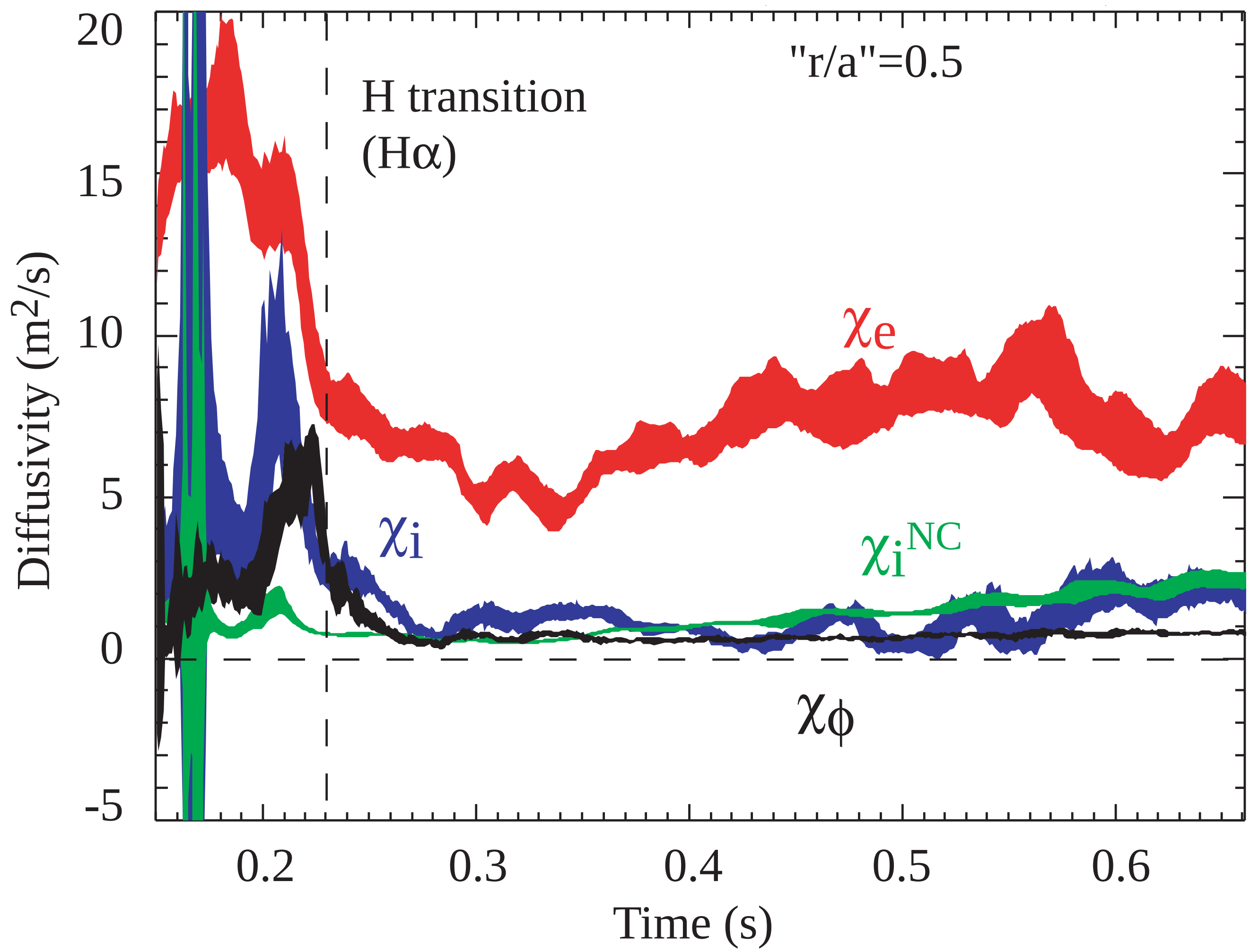
Steady state phase of a medium power NBI plasma



Diffusivity Time Evolution with Error Bars
Kinetic profile local error sampling

NSTX

Medium power NBI plasma



CONCLUSION (1)

- Error estimates of transport diffusivities have been made using two methods, which produce similar results.
- Experimental kinetic quality is such that the different diffusivities can readily be resolved in time and radially
- Gradient estimate constitutes main source of error in core region

CONCLUSION (2)

- High power NBI plasma during H mode
  - Time evolution at r/a = 0.5:
    - $\chi_\phi < \chi_i << \chi_e$, and $\chi_i^{NC} < \chi_i$
    - $\chi_i^{NC} \leq \chi_\phi$ or $\chi_i^{NC} \geq \chi_\phi$ depending on time
  - Profile during steady state phase:
    - Inner region: $\chi_\phi < \chi_i^{NC} < \chi_i << \chi_e$ but

    find $\chi_i \approx \chi_i^{NC} \approx \chi_\phi$ at r/a ≈ 0.55 (Rmajor ≈ 1.37 m)
- Medium power NBI plasma during H mode
  - Time evolution at r/a = 0.5:
    - $\chi_\phi \leq \chi_i << \chi_e$, $\chi_i \leq \chi_i^{NC}$ or $\chi_i \geq \chi_i^{NC}$ depending on time
  - Profile during steady state phase:
    - Inner radial points exist where $\chi_\phi \approx \chi_i$ and $\chi_i \approx \chi_i^{NC}$, χ_i and $\chi_\phi << \chi_e$
    - $\chi_i < \chi_\phi \leq \chi_i^{NC}$ pervasively in the outer region

END OF TALK