Impurity transport studies in NSTX beam heated H-mode plasmas

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Abstract

•Motivation

i) Perform the first particle transport studies in high (Power & β) performance NSTX H-modes, important for NSTX and the next-step ST.

a) **D_Z** (diffusion) & **v_Z** (convective velocity)
b) Identify regimes with possible **impurity "screening" (v_Z>0)**.
c) ρ^* scaling at ***fixed q-profile*** and independent scans of I_p and/or B_ϕ.

•Experiment

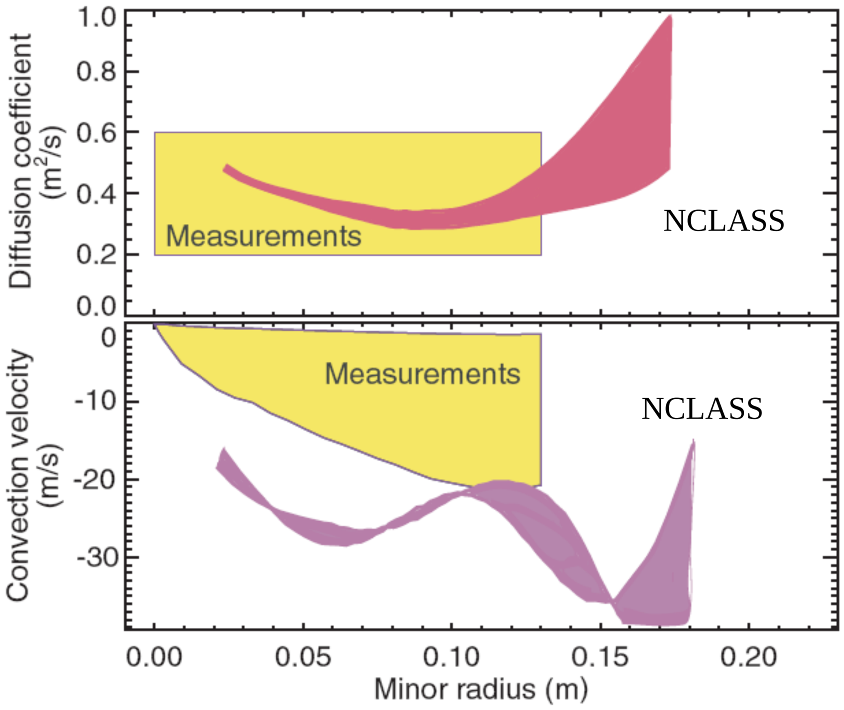
i) **Neon** injected in **MHD quiescent** high-β, high confinement H-modes.
ii) The main diagnostic used was the **newly-developed "multi-color" optical SXR array**.
iii) Atomic-based simulations constrained with the bolometer and poloidal USXR arrays.

•Results

i) **$D_{Ne}\leq 1 m^2/s$ for ($r/a \leq 0.8$) is in the neoclassical range**.
ii) Low particle diffusivity that **suggests anomalous transport driven by low-k electrostatic turbulence is suppressed**.

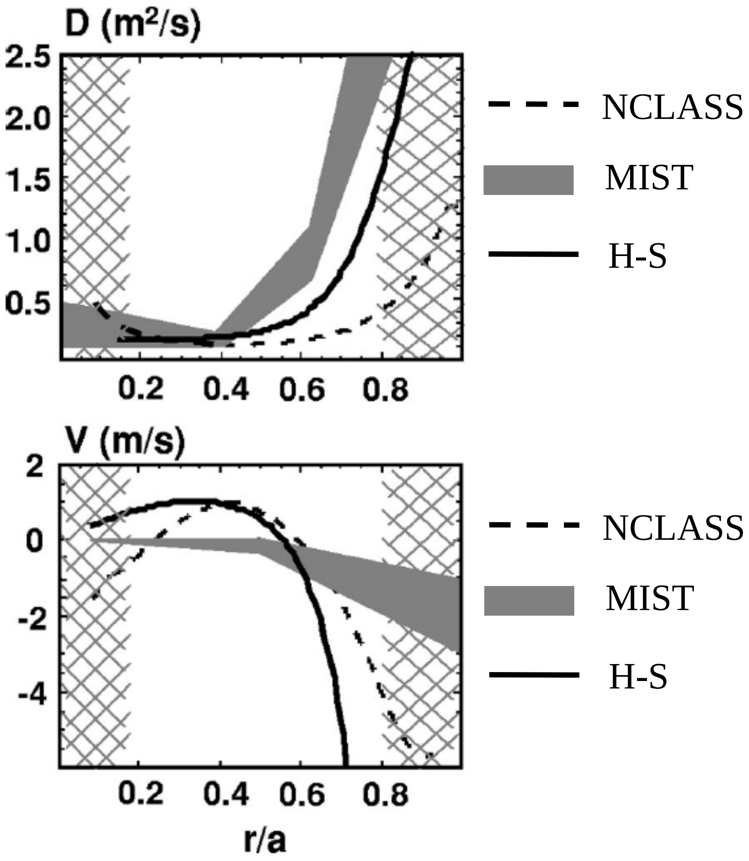
Previous experimental work done in STs

Neoclassical impurity transport in CDX-U ohmic plasmas



[1] V. A. Soukhanovskii, et. al.,
Plasma Phy. Control. Fusion, **44**, 2239, (2007).

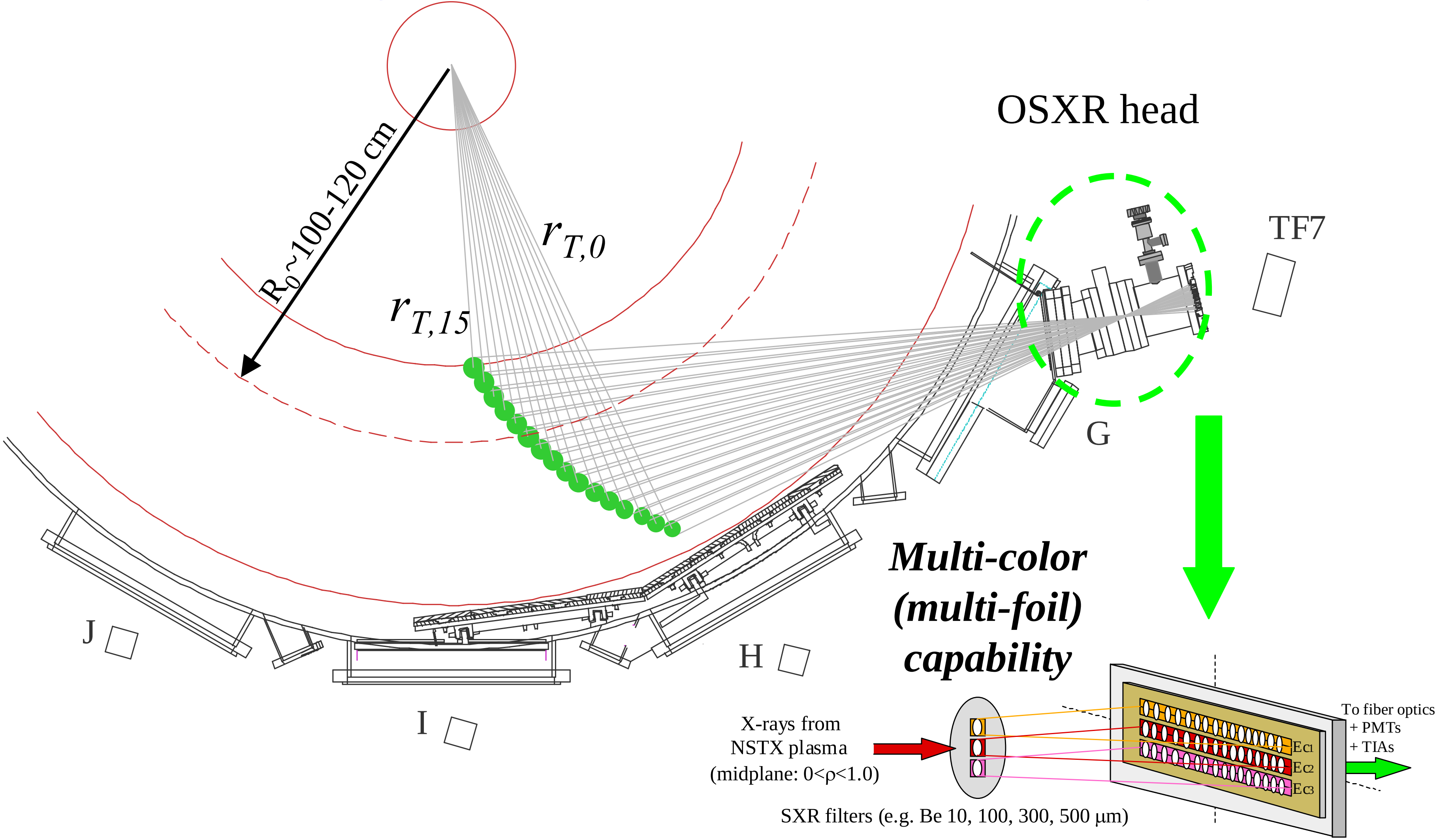
Neoclassical impurity transport in NSTX L-mode plasmas



[2] D. Stutman, et. al.,
Phys. Plasmas, **10**, 4387, (2003).

Main diagnostic used in impurity transport experiments

Tangential “multi-color” optical SXR array



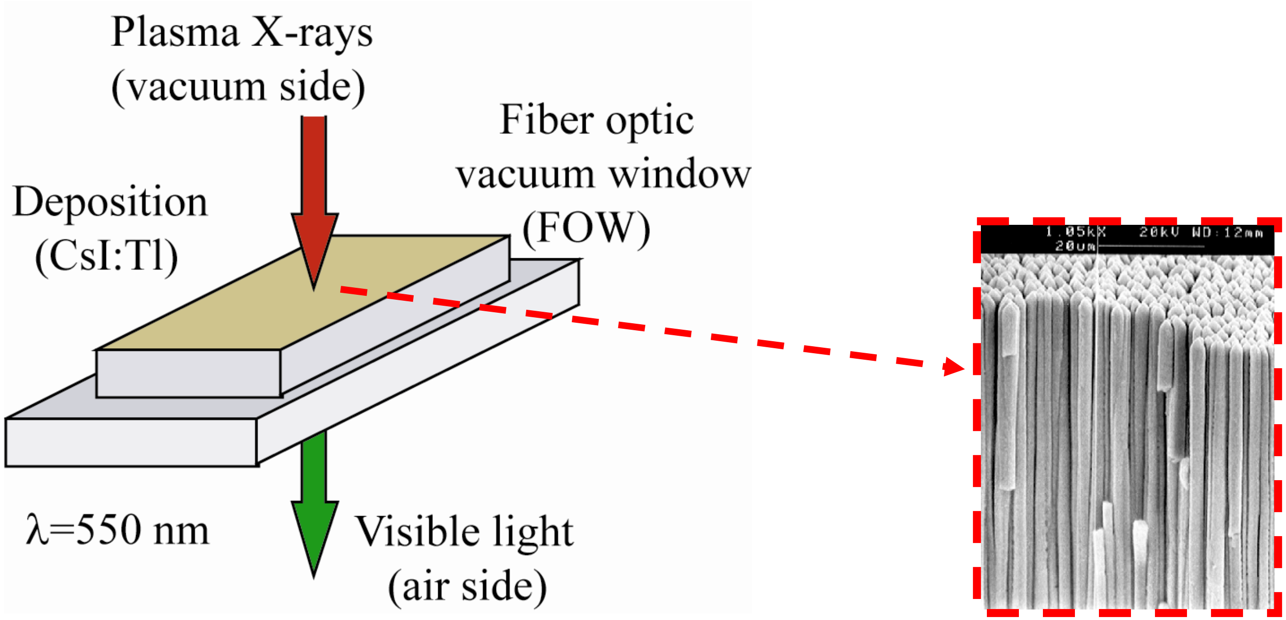
Multi-color (multi-foil) capability

[3] L. F. Delgado-Aparicio, *et. al*., to appear, PPCF, 2007.

[4] L. F. Delgado-Aparicio, *et. al*., to appear, J. Appl. Phys., 2007

Principle of the "optical" soft x-ray (OSXR) array

Conversion of XUV emission to visible light



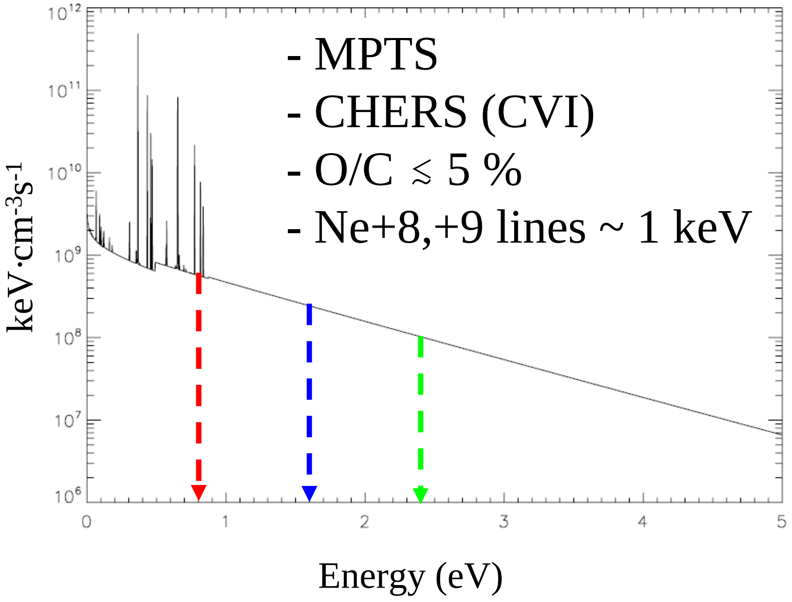
To discrete channels and light detectors (PMT and/or APDs) + (RC/TIA) amplifiers

It's a system that uses a **fast** (~1 μs) and **efficient** scintillator (CsI:Tl) in order to **convert soft x-ray photons** ($0.1<E_{ph}<10$ keV) to **visible green light (λ~550 nm).**

[5] L. F. Delgado-Aparicio, *et. al.*, RSI, 2004
[6] L. F. Delgado-Aparicio, *et. al.*, to appear, Appl. Opt., 2007

XUV energy discrimination & cut-off energies (E_c)

Select a line-radiation free region of NSTX's spectrum



- MPTS
- CHERS (CVI)
- O/C $\lesssim$ 5 %
- Ne+8,+9 lines ~ 1 keV

Notes:

a) After Boronization (TMB) O/C ~ 1 %

b) Negligible concentration of High Z impurities

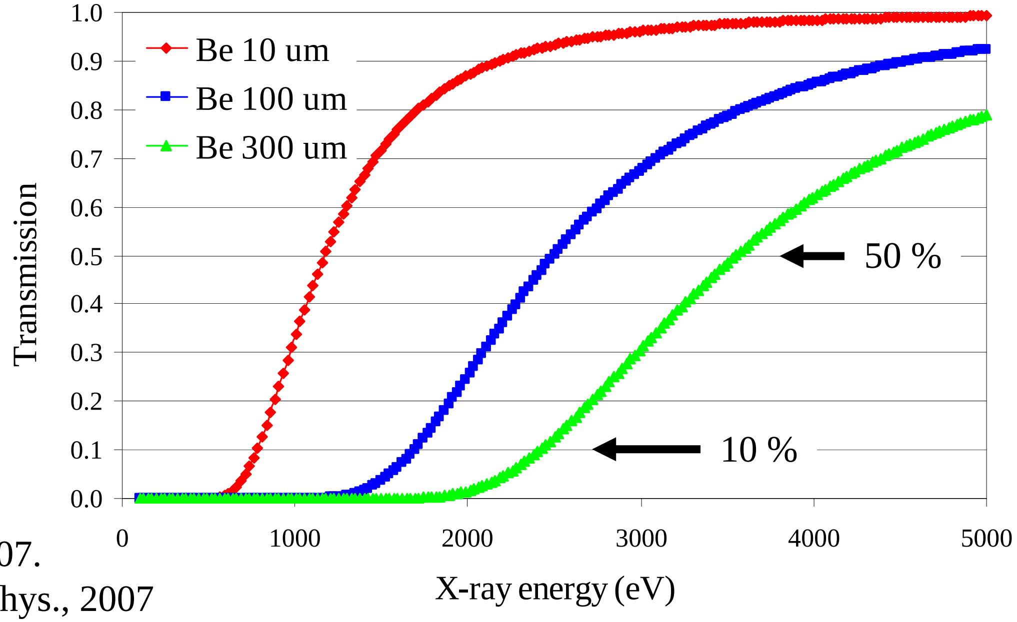
[3] L. F. Delgado-Aparicio, *et. al*., to appear, PPCF, 2007.

[4] L. F. Delgado-Aparicio, *et. al*., to appear, J. Appl. Phys., 2007

SXR metallic filters for the present tOSXR array

Metallic foil	E_c (eV) for Transm.=10%	E_c (eV) for Transm.=50%
Be 10 μm	780	1170
Be 100 μm	1690	2497
Be 300 μm	2416	3550

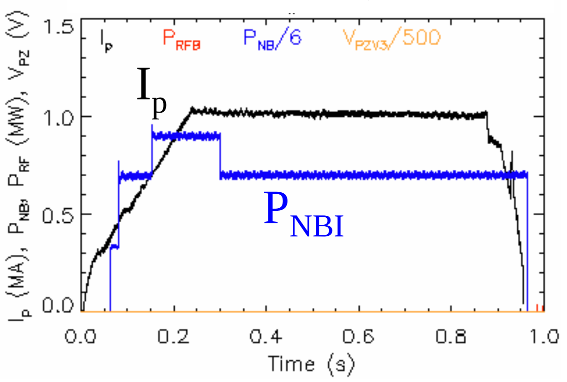
"Ideal" contrast factor (300/10 vs 100/10) ~ 1.81



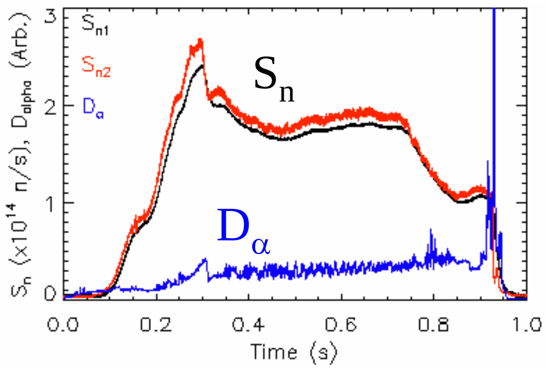
H-mode target (1MA, 4.5 kG) – background shots

- I_p=1 MA, B_0~4.5 kG, W_T~230 kJ, τ_E~50 ms (no large type I ELMs)
- MHD-free during time of interest.
- Constant boundary elongation (δ~2.25) & triangularity (κ~0.6) for ~ 500 ms
- NBI modulation: 5.4 MW and 4.2 MW
- Gas puff: 1.5 torr·*l*/s, Δt~50 ms, injection time: 0.35
- Target shots were reproducible; important for background subtraction (carbon accumulation)

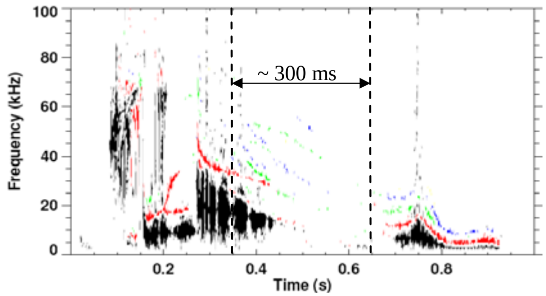
NSTX #s 121154, 121162



NSTX #s 121154, 121162

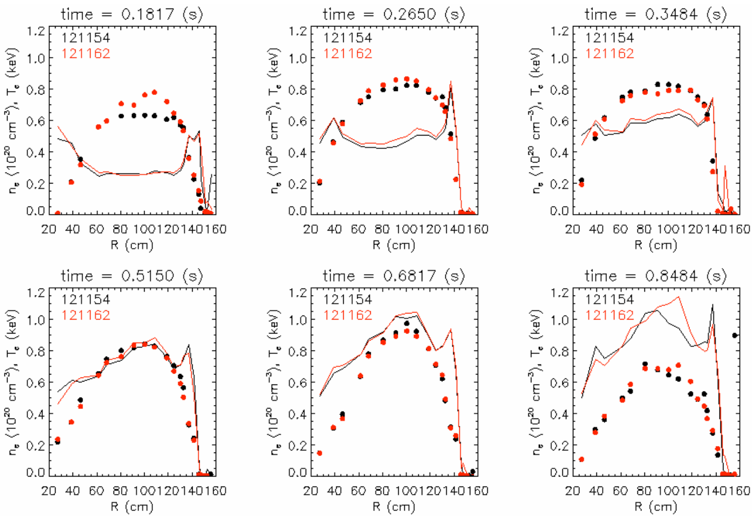


MHD mode spectrum



The background shots are reproducible

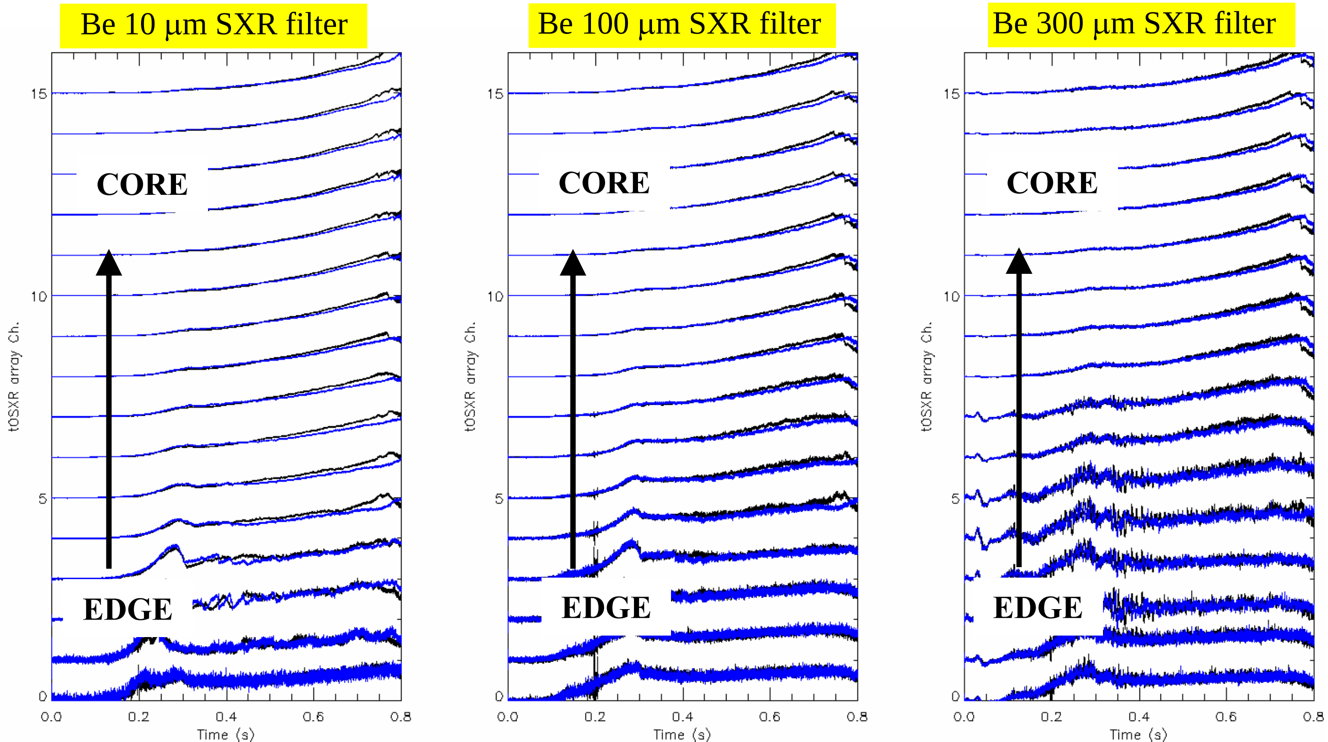
Multi-Point Thomson Scattering (B. LeBlanc, PPPL)



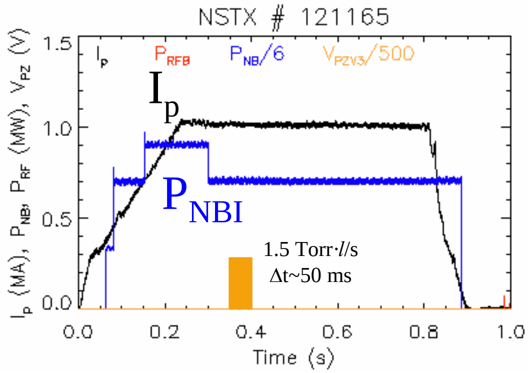
n_e ($\times 10^{20}$ m^{-3})

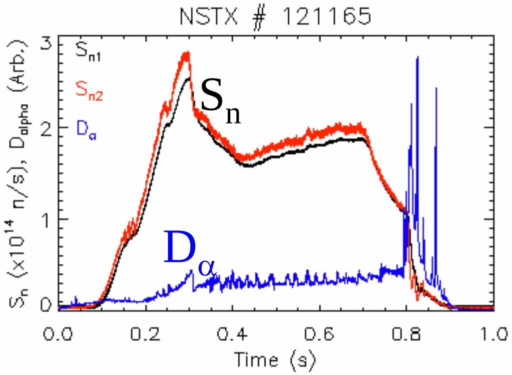
● ● T_e (keV)

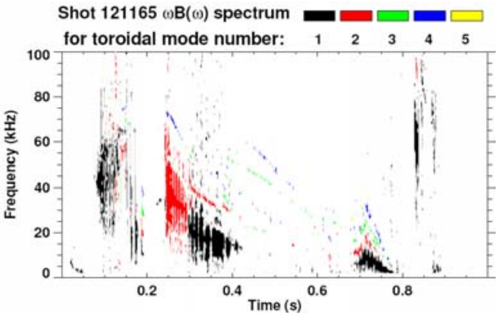
Tangential OSXR signals (121162 & 121154)



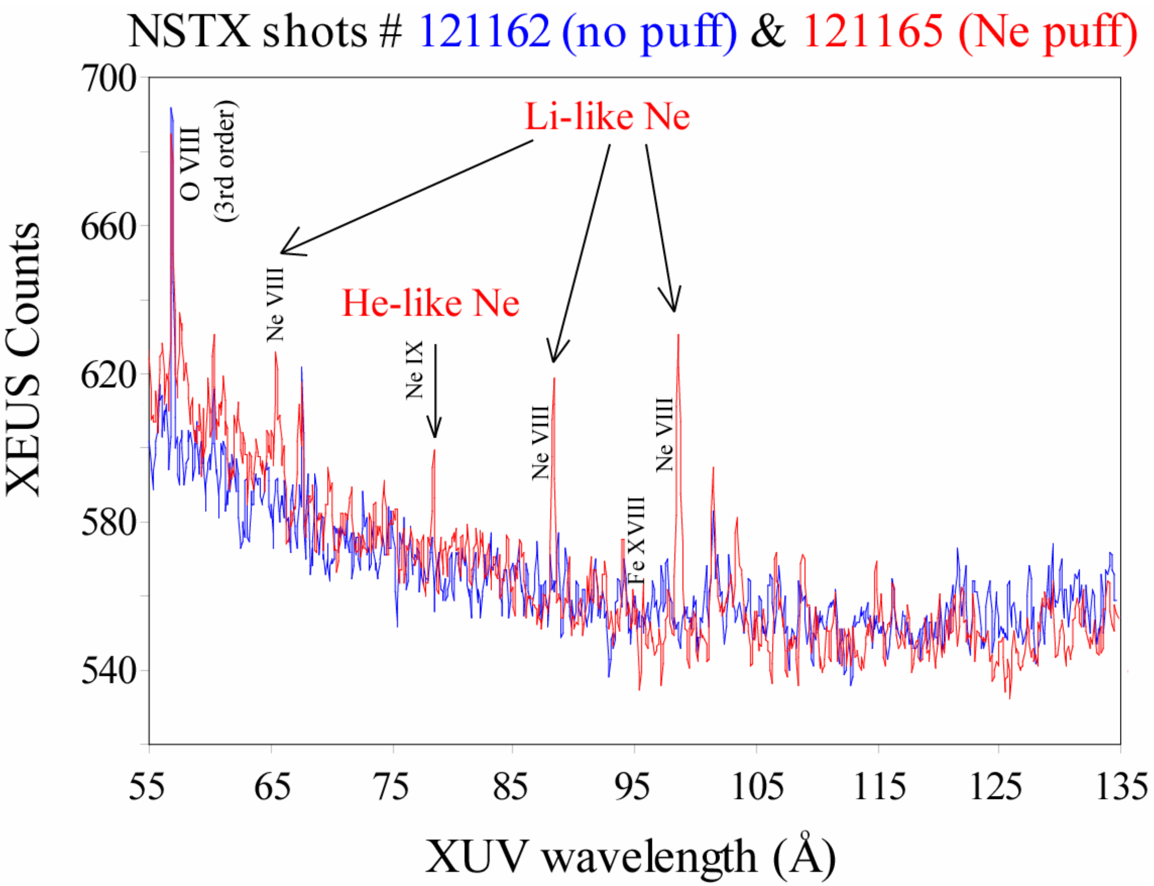
Small Neon perturbation of the background plasma





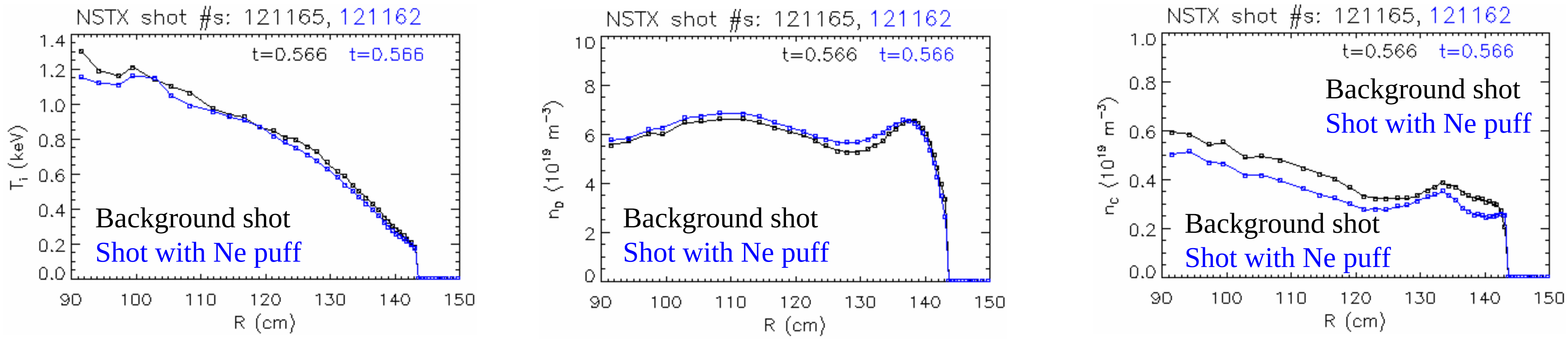


X-ray ***E***xtreme ***U***ltraviolet ***S***pectrometer (integrated signal)
(J. Lepson - UC – Berkeley, P. Beiersdorfer, LLNL)



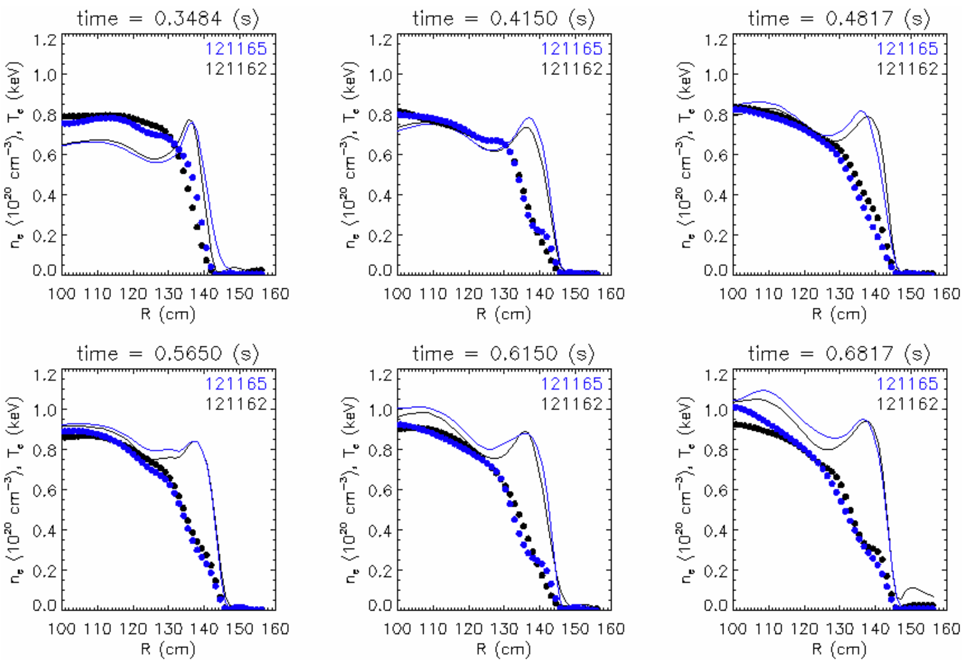
Neon plasmas don’t vary significantly from background shot

Carbon Charge Exchange Recombination Spectroscopy (R. Bell, PPPL)



Multi-Point Thomson Scattering
(B. LeBlanc, PPPL)

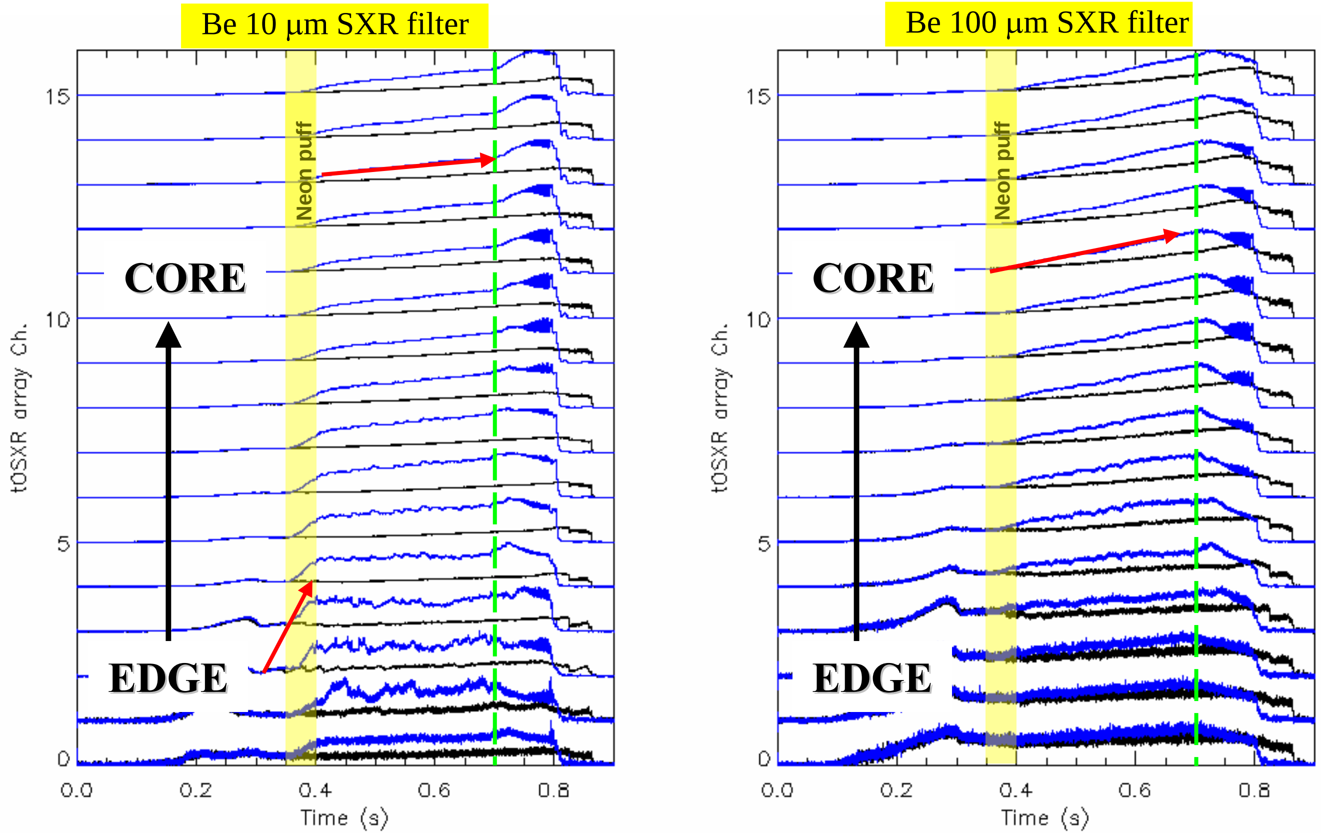
$n_e(R,t)$ — $T_e(R,t)$ •



OSXR show edge Neon builds up quickly, core builds up slowly

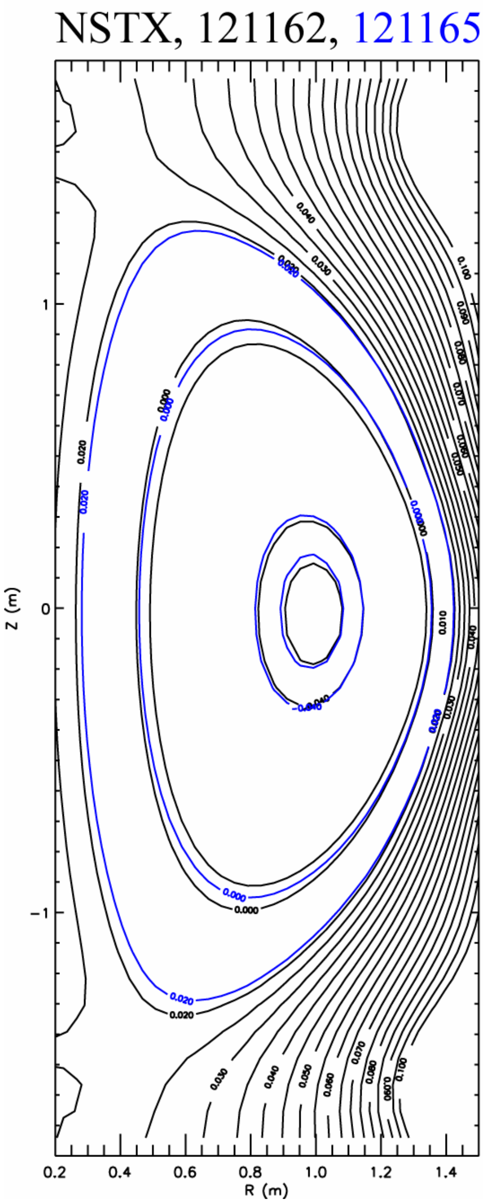
121165 (neon seeded) vs. 121162 (background)

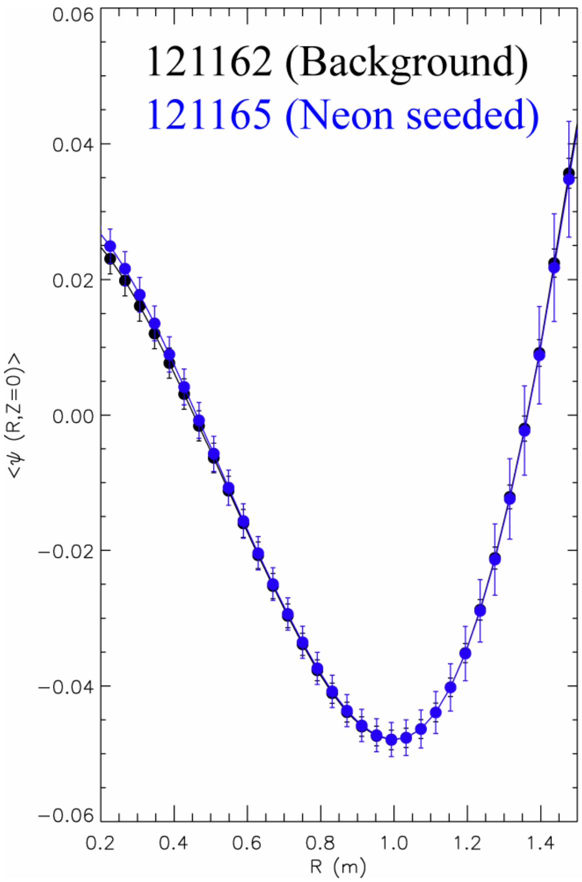
Tangentially line-integrated OSXR signals

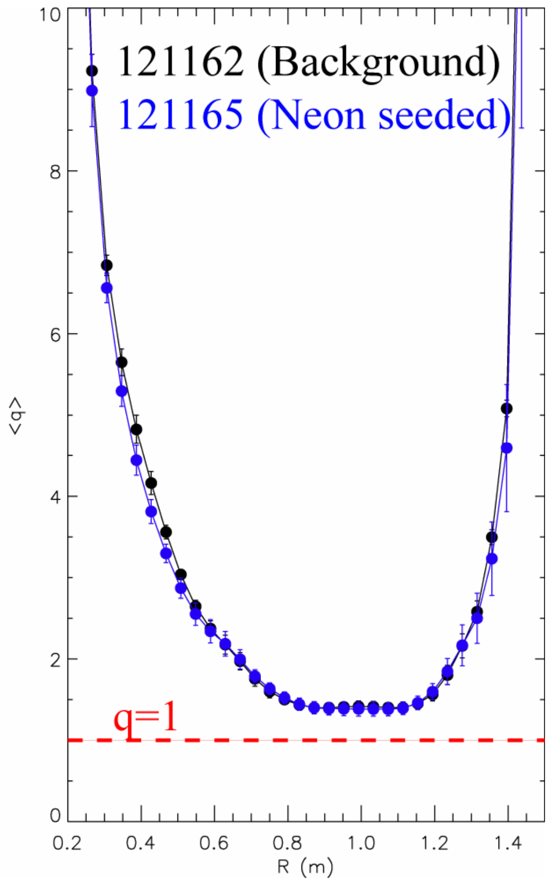


- Good SNR of OSXR signals when Neon was injected.
- Fast edge vs slow core Neon build up.
- Strong peaking of impurities (~0.7 s) and flattening of T_e (consistent with MPTS)
- Late *(1,1)* MHD mode (~0.75 s).

No difference in flux surfaces or q-profile in neon seeded plasmas

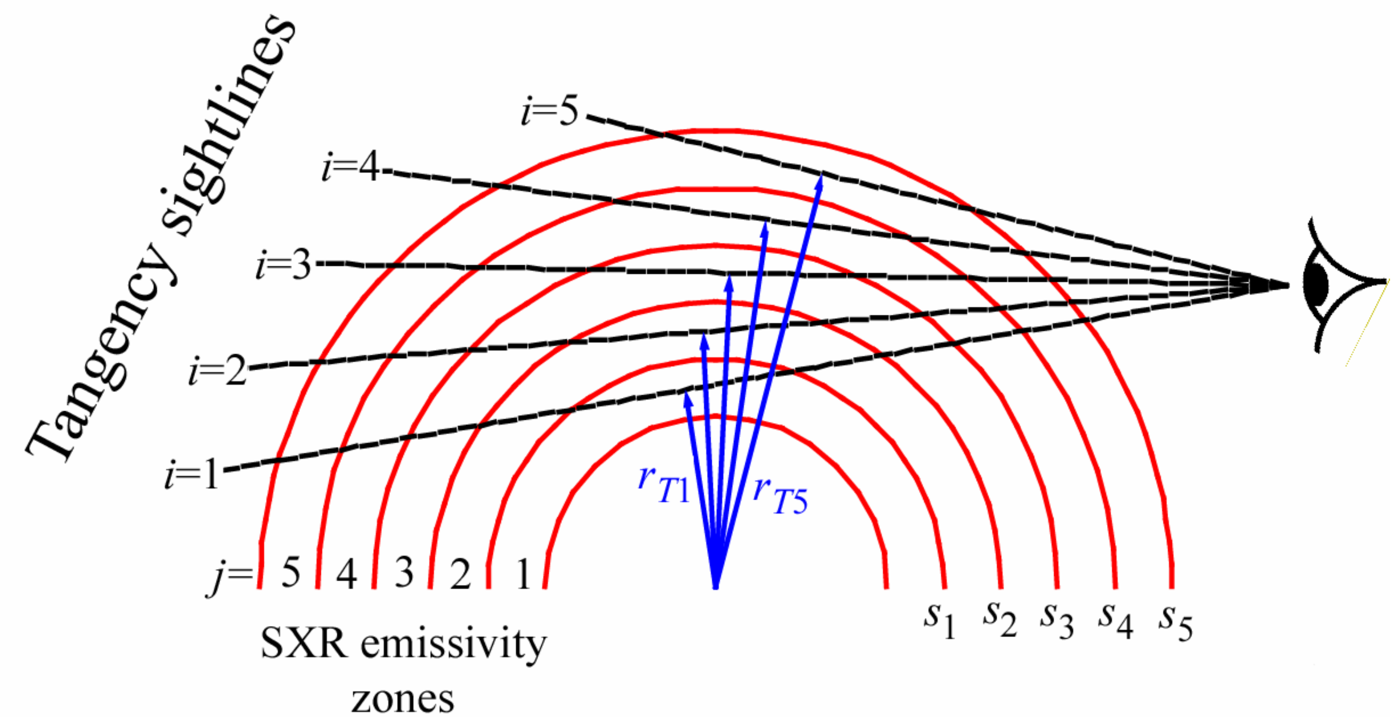






An important requirement was to operate well below the ideal β limit and a q_0>1, thus avoiding sawteeth, internal reconnection events and edge localized modes

Matrix-based 1-D Abel inversion



$$B_X(r_T,t) = 2\int_R^{R_{\max}} E_X(R,t)\frac{RdR}{\sqrt{R^2-r_T^2}} \Rightarrow E_X(R,t) = -\frac{1}{\pi}\int_R^{R_{\max}} \frac{dB_X(r_T,t)}{dr_T}\frac{dr_T}{\sqrt{r_T^2-R^2}}$$

equivalent to

$$B_i = \sum_j L_{i,j}E_j \Rightarrow E_j = \sum_i L_{j,i}^{-1}B_i$$

1D (radial) impurity transport simulation (MIST) code

The time evolution of the neon emissivity after the ***injection*** was modeled using the time-dependent **M**ultiple **I**onization **S**tage **T**ransport code (MIST).

- Atomic processes included in the model:
  i) Electron ionization ii) excitation iii) recombination

- Computes the evolution of all charge states through the experimental MPTS time history of **$n_e(R,t)$** & **$T_e\ (R,t)$** profiles assuming external profiles of diffusivity (*D*) and convective velocity (*V*).

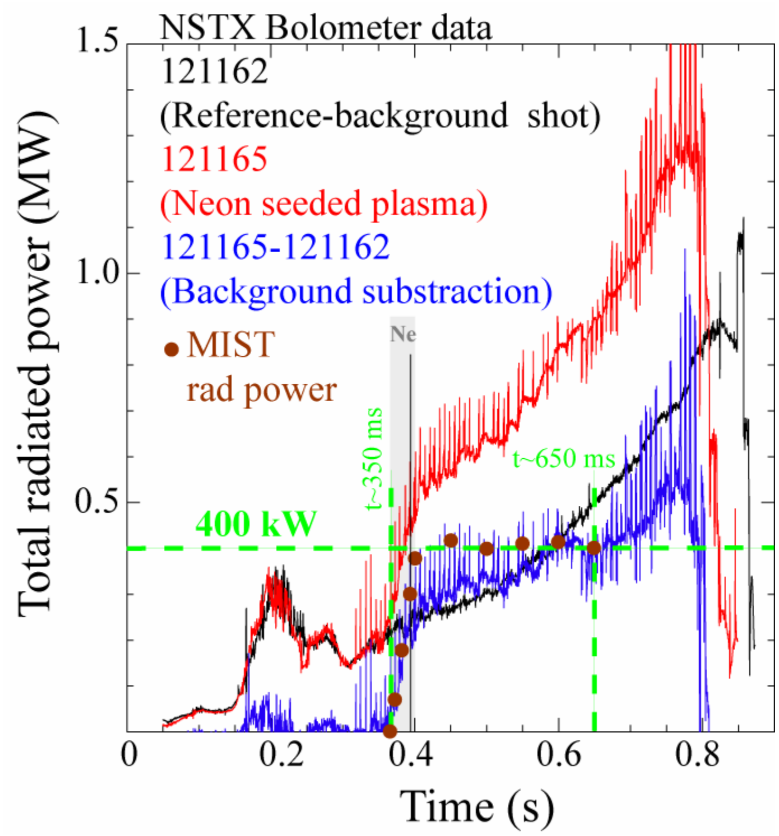
SXR filter contribution

1. He- & H- like ions emit resonances lines between 0.9-1.0 keV
   ⇒ detected through the Be 10 μm.

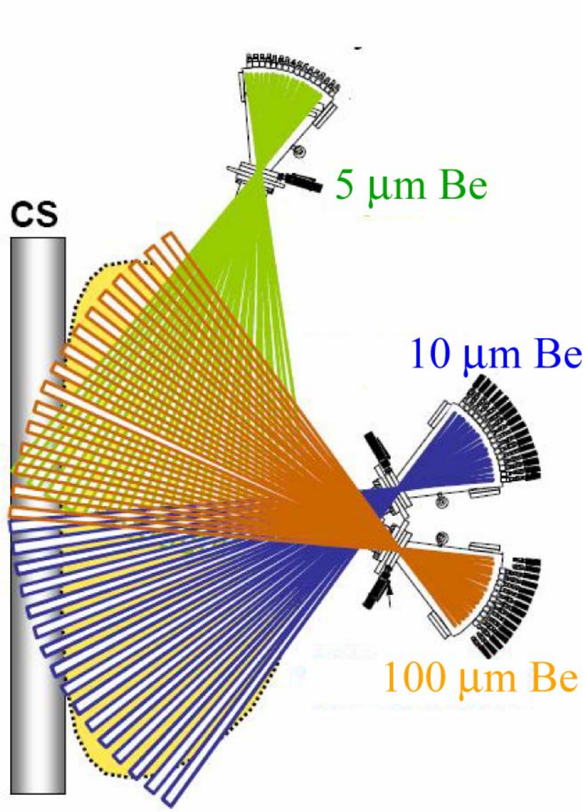
2. The fully stripped ions (Ne+10) emit strong recombination continuum radiation above the 1.4 keV ⇒ detected through the Be 100 μm.

MIST simulation constraints

a) Tangential bolometer

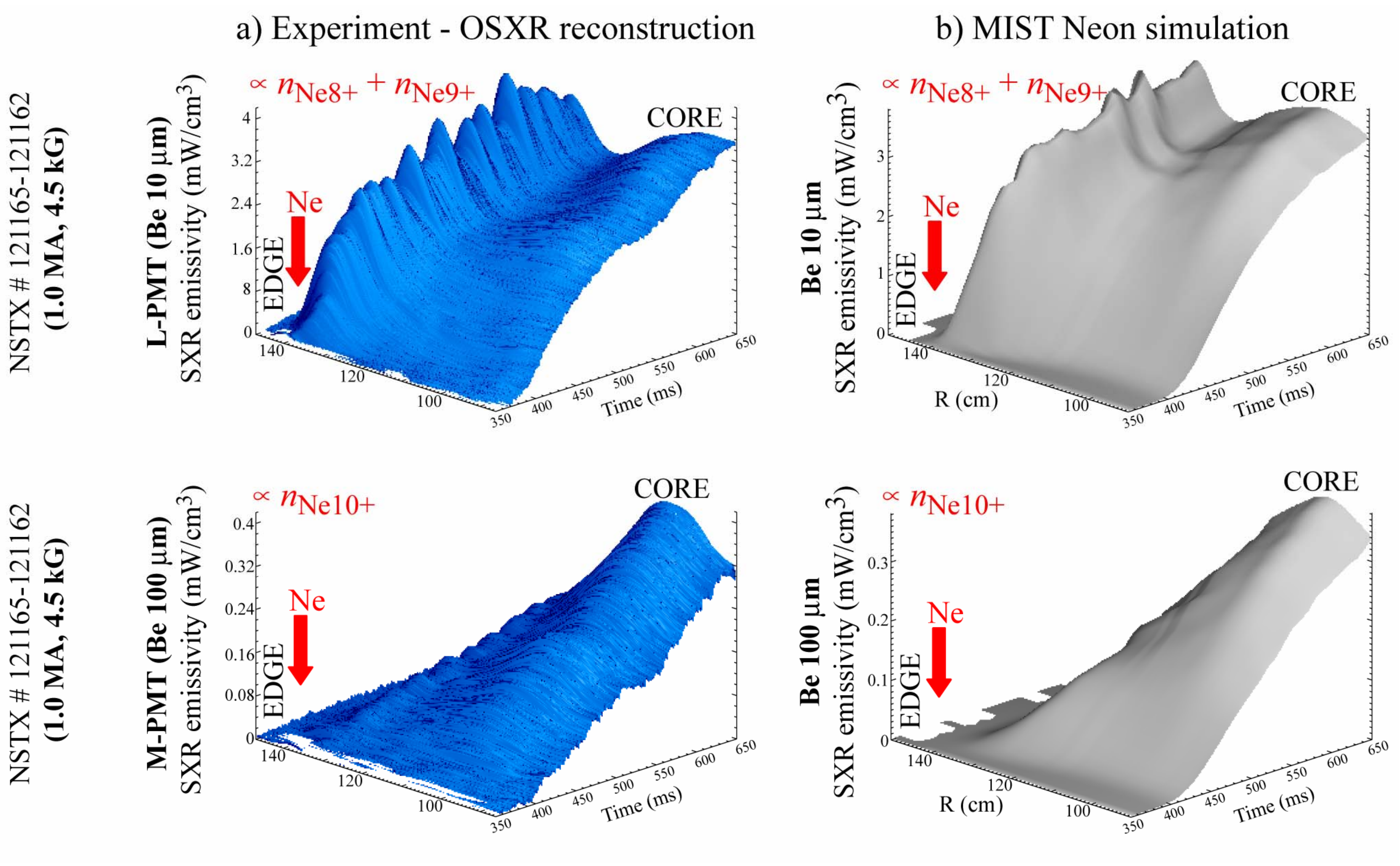


b) Poloidal USXR arrays

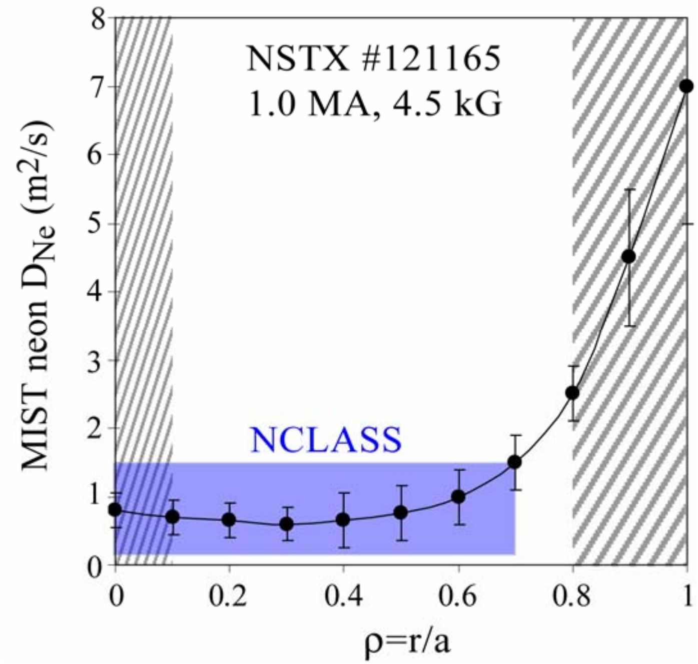


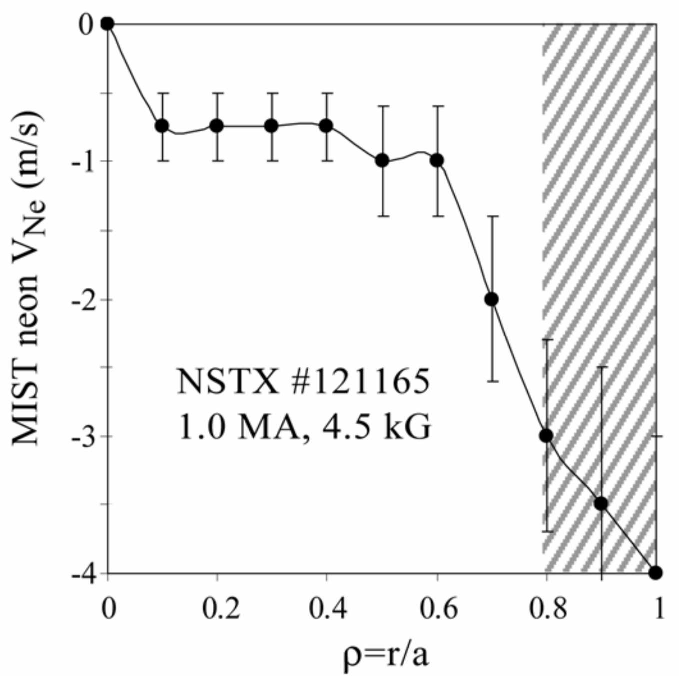
[7] D. Stutman, et. al., Phys. Plasmas, **3**, 4387, (2003).

Background subtracted OSXR and MIST simulation



First estimates of D_{Ne} in the neoclassical range





The impurity diffusivity estimated inside *r/a≤0.7* is in good agreement with the NCLASS predicted [8] neoclassical transport coefficients.

The existence of a small to moderate inward pinch velocity depend strongly on the plasma profiles.

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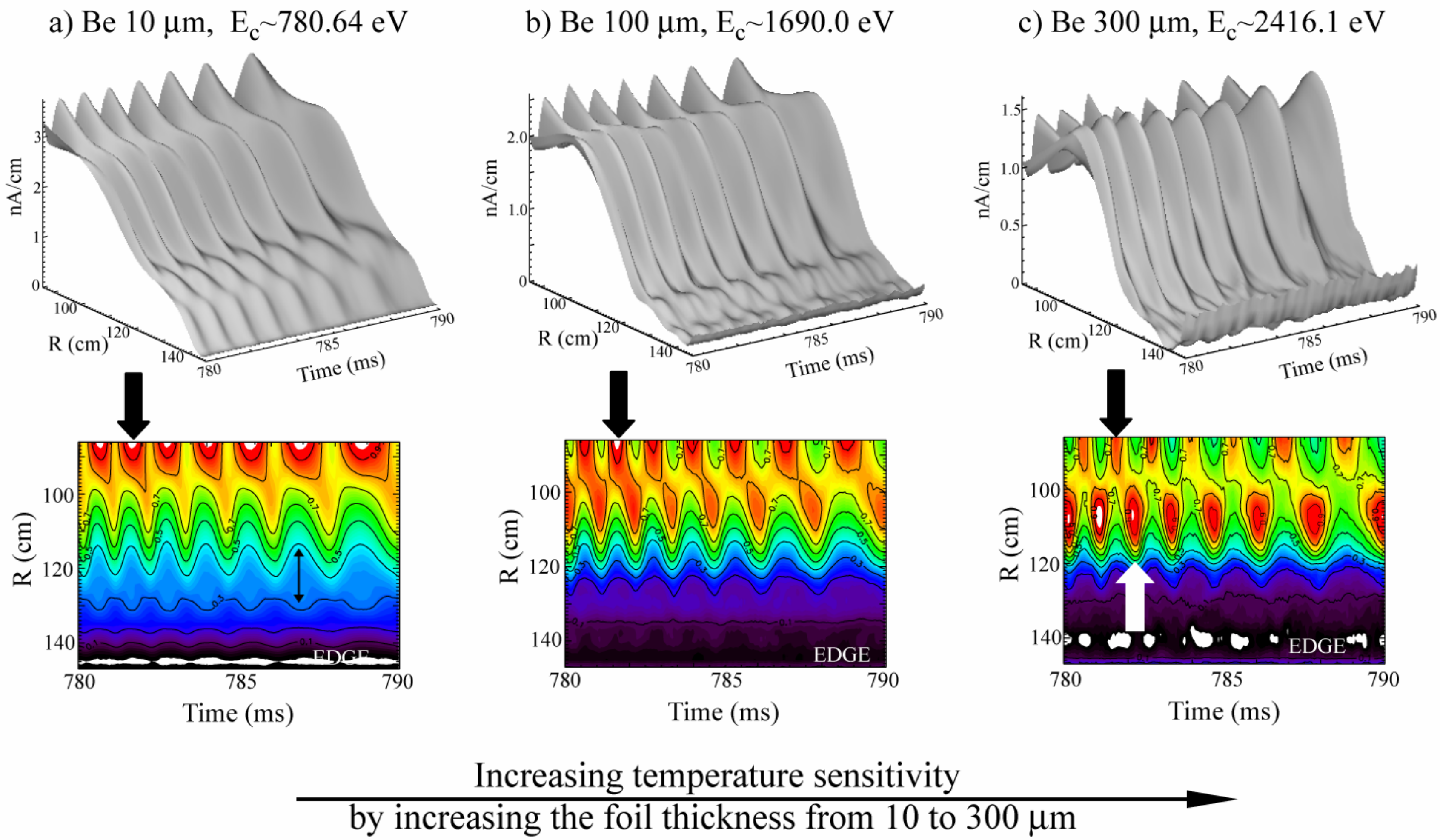
[8] W. Houlberg, et. al., Phys. Plasmas, **4**, 3320, (1997).

$n_Z(R,t)$ & $T_e(R,t)$ decoupling during late impurity accumulation



a) Be 10 μm, E_c~780.64 eV

b) Be 100 μm, E_c~1690.0 eV

c) Be 300 μm, E_c~2416.1 eV

Increasing temperature sensitivity
by increasing the foil thickness from 10 to 300 μm

[5] L. F. Delgado-Aparicio, *et. al*., to appear, PPCF, 2007.

Summary

- The neon penetrates the core on the tens to hundred ms, with a final peaking of the neon density indicating a **diffusivity $\leq 1\mathrm{m}^2/\mathrm{s}$**, and the existence of a small to moderate inward pinch velocity depending strongly on the plasma profiles.

- Preliminary NCLASS simulations indicate that the **particle diffusivity is in the order of the values predicted by the neoclassical transport theory**.

- Thermal ion transport from TRANSP is also in the neoclassical range.

- Particle **transport around the ion neoclassical values would suggest a very low level of turbulent ion transport**.

- Electron transport in this discharges is close to two orders of magnitude higher ($\mathcal{O}\ (m_i/m_e)^{1/2}$)

Acknowledgments

- **The Johns Hopkins University**: Gaib Morris, Scott Spangler, Steve Patterson, Russ Pelton and Joe Ondorff.

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