# APPLICATIONS OF THE POLOIDAL ULTRASOFT X-RAY SYSTEM ON NSTX

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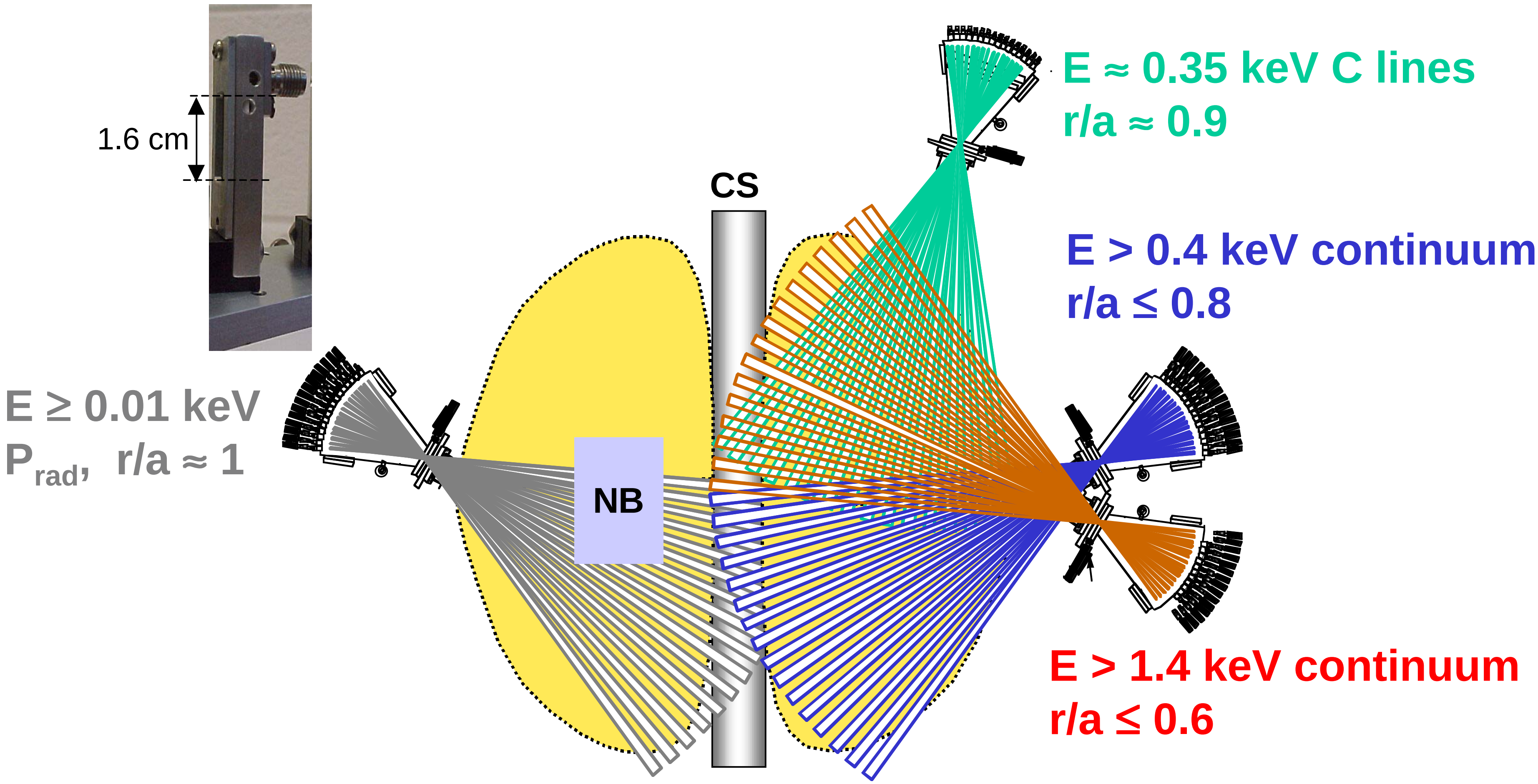
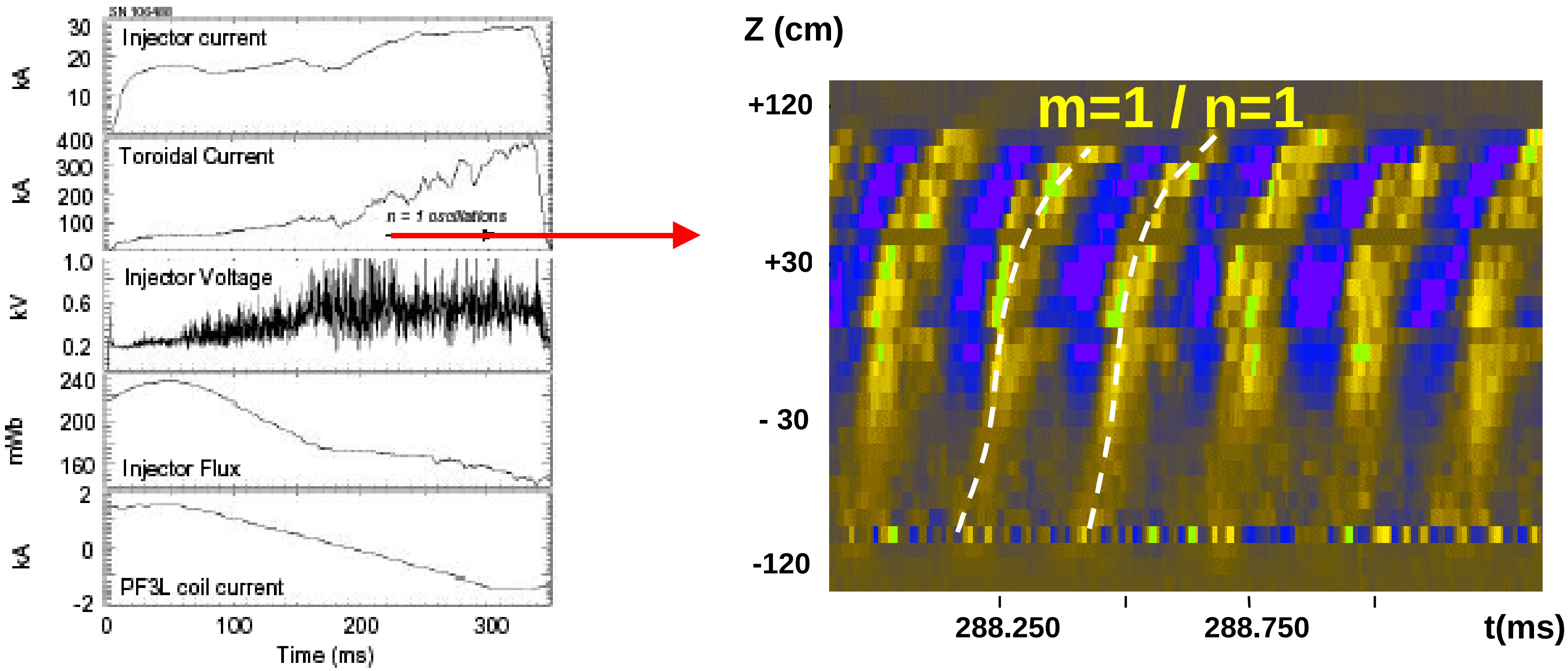
**PPPL**

# USXR system on NSTX




- **Large area, low capacitance absolute diodes for high sensitivity, large bandwidth and flat spectral response**
- **Versatile filtering system (‘spectroscopic’ or ‘imaging’ configuration)**
- **Low energy capability (E ≥10 eV) for low $T_e$ imaging (e.g., start-up)**

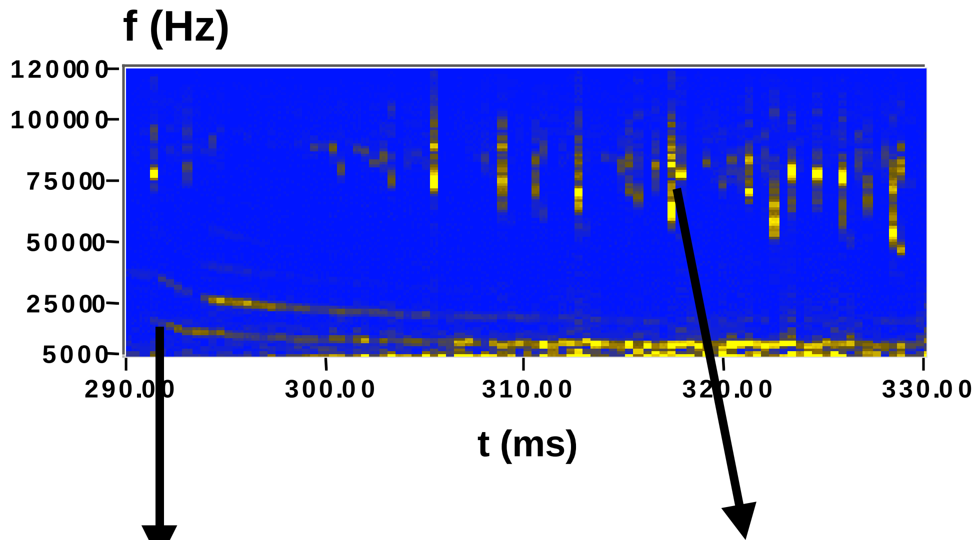
# Low energy ($P_{rad}$) imaging of MHD during CHI

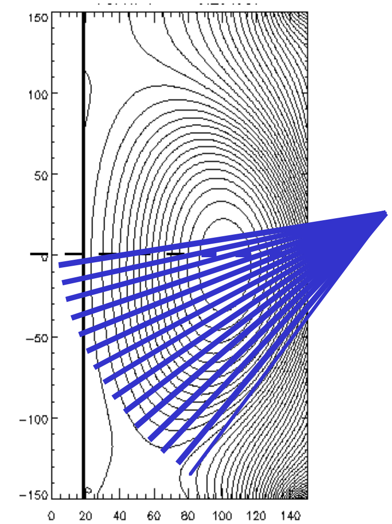


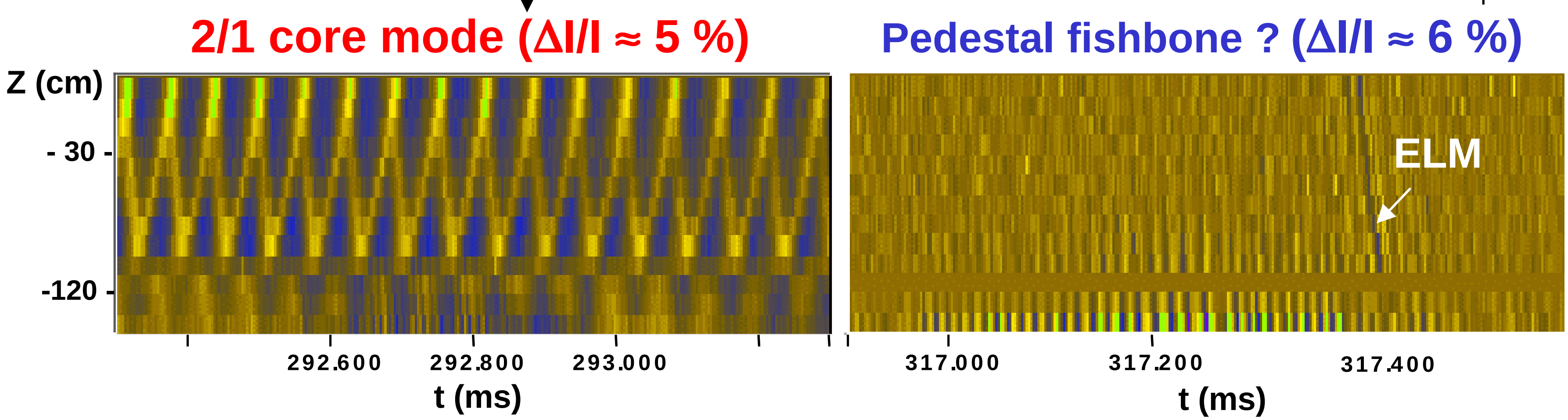

- f≈ 4.3 kHz, n =1 'CHI' mode
- **Large outboard amplitude**
- **Mode trajectory consistent with open flux surface**
- **Tens of eV core from 'two-color' (USXR/$P_{rad}$) imaging**

# High speed and sensitivity needed for NSTX MHD

**USXR spectrum in $q_0 > 1$ H mode (record $\beta_p$ 109070)**



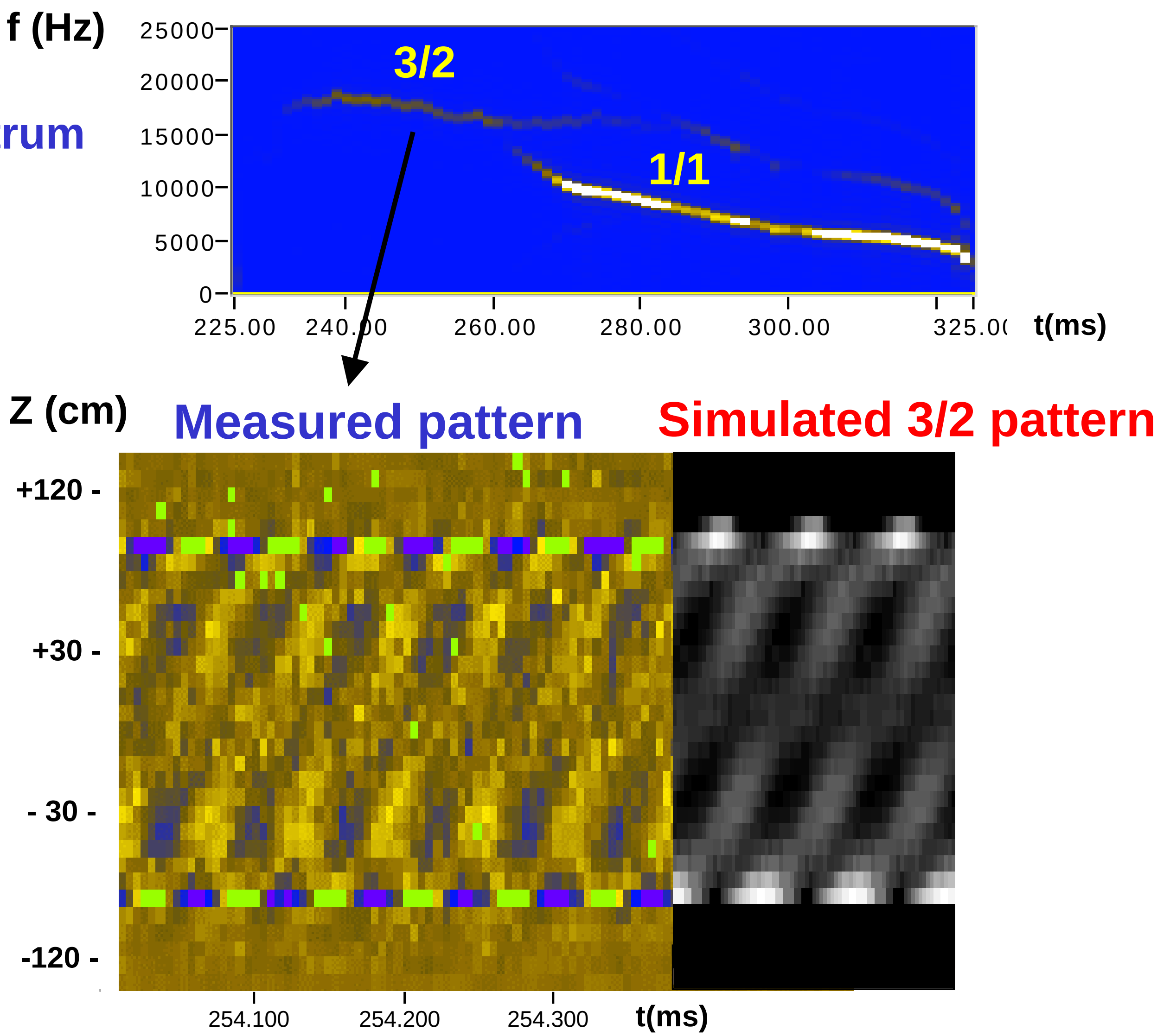




• **300 kHz bandwidth, up to 600 kHz sampling and SNR ≈ 100 enable imaging of the low amplitude modes typical of $q_0$ >1 operation**

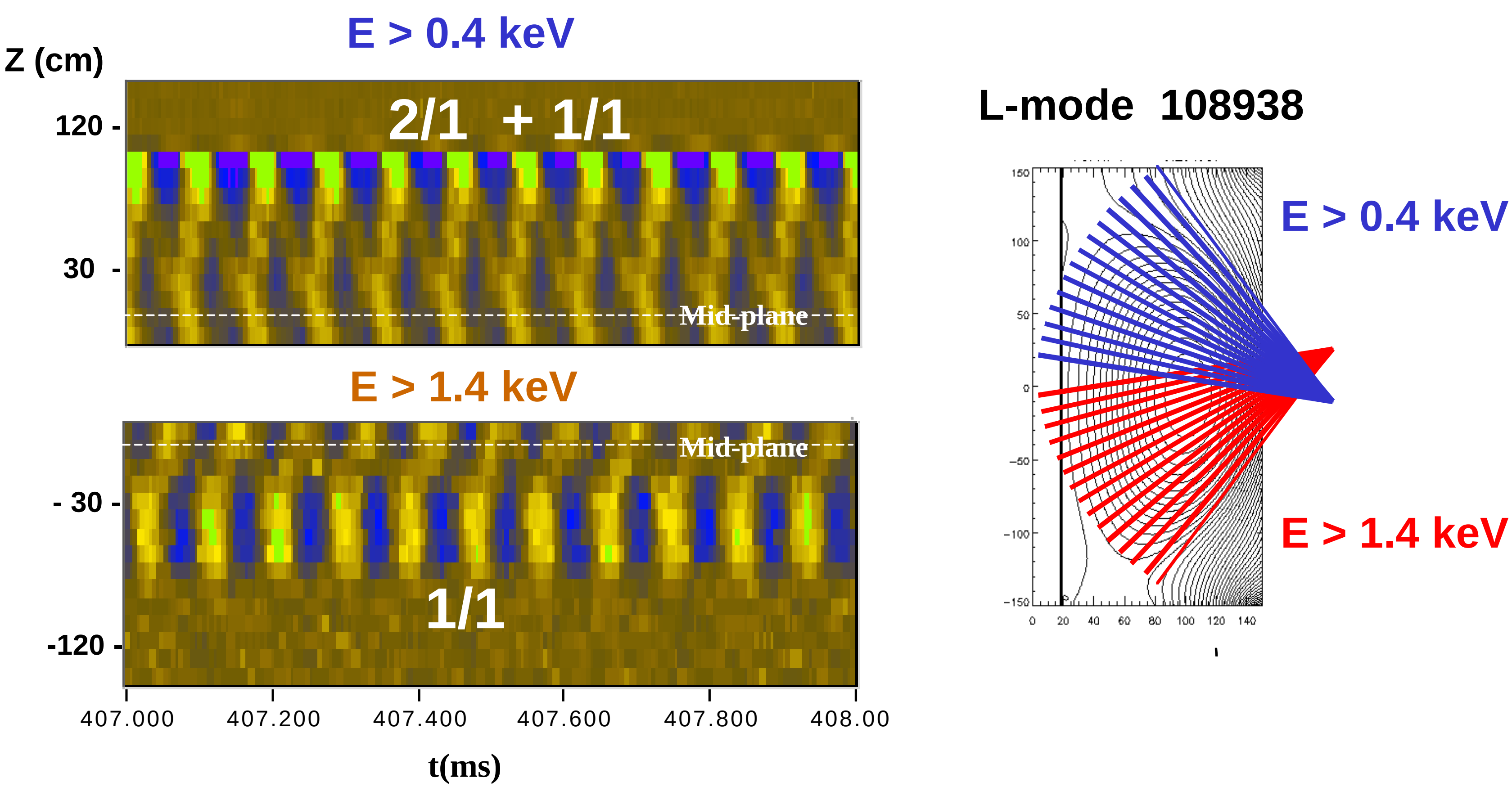
# Isolated modes identified through phase analysis

**USXR spectrum**
**Z ≈ -60 cm**
**L-mode**



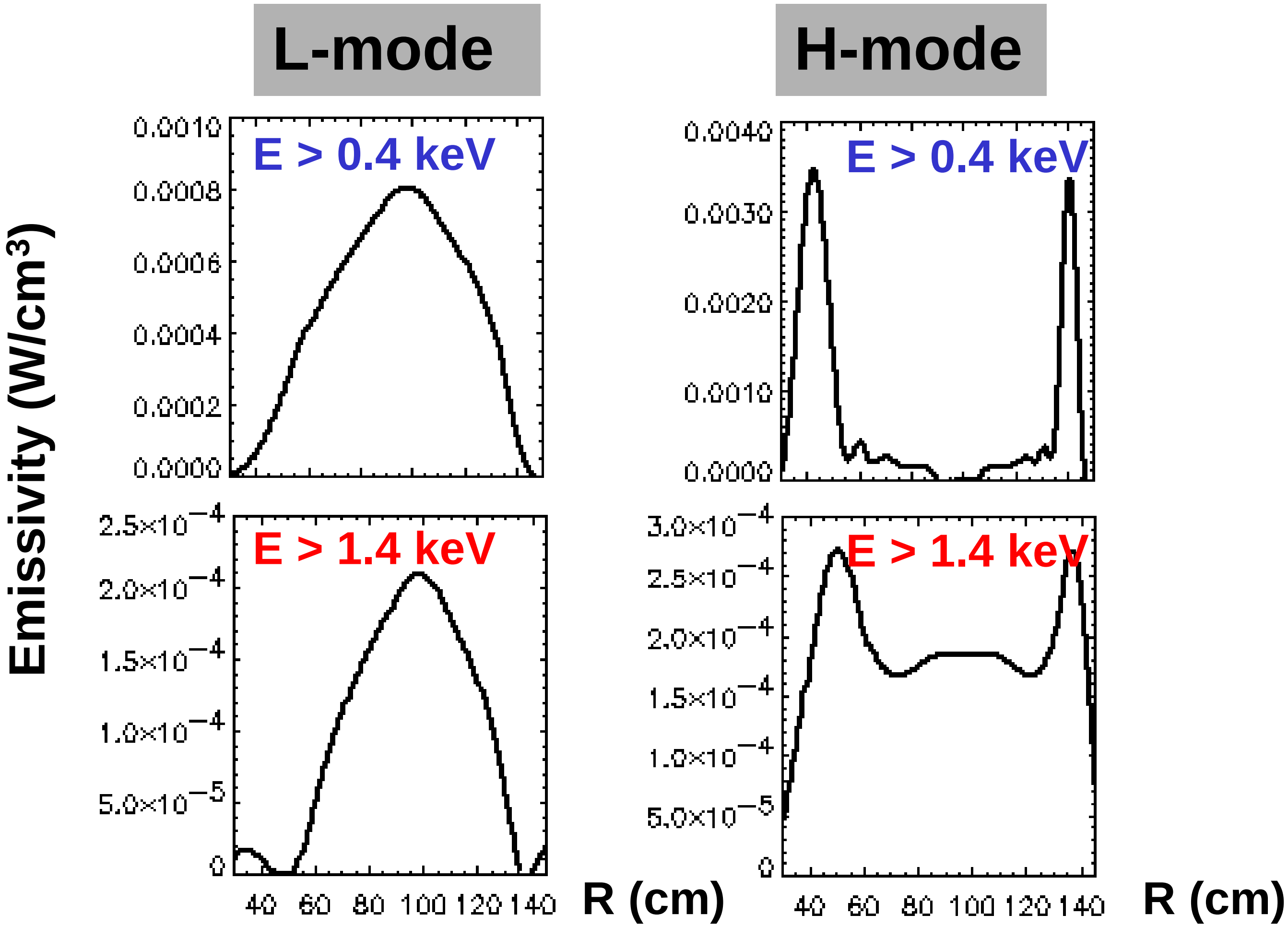

- **Good match between USXR and EFIT field line trajectory in L-mode**

# ‘Two-color’ imaging used for coupled modes



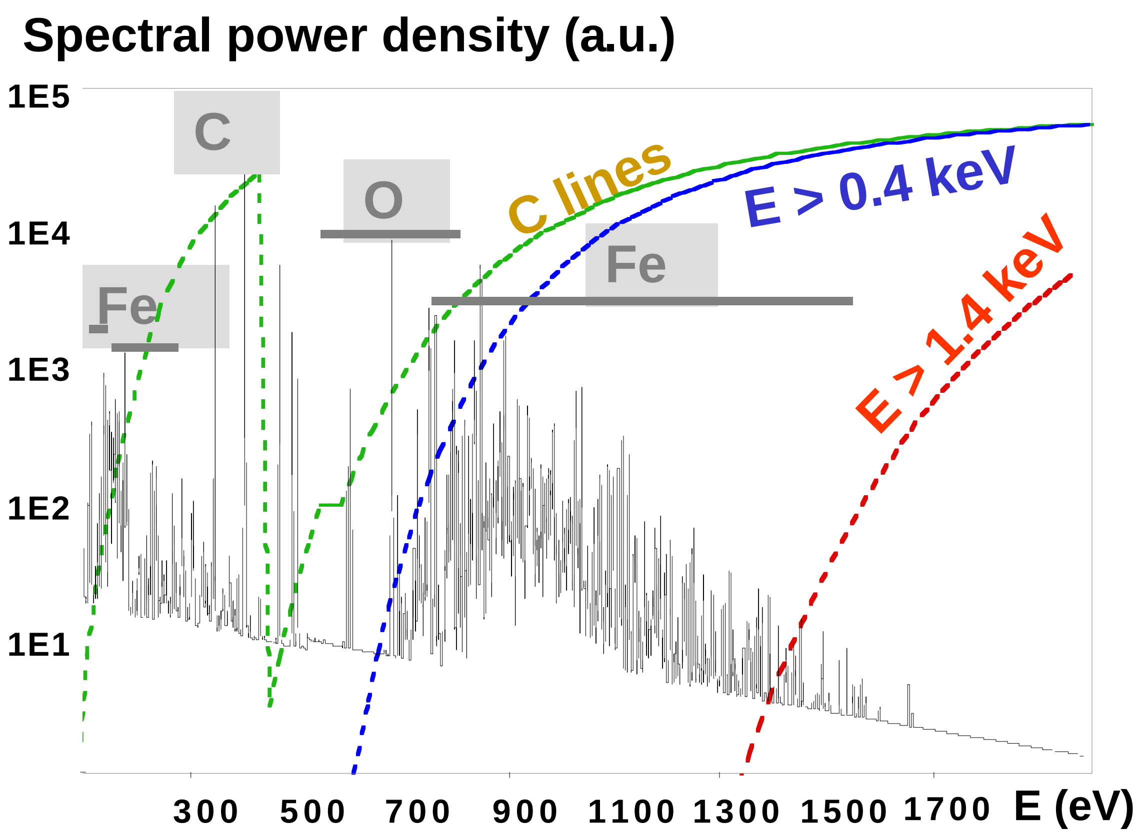

- **Strong NSTX toroidicity couples core and peripheral MHD**
- **Simultaneous ‘two-color’ filtering often enables separating the modes**

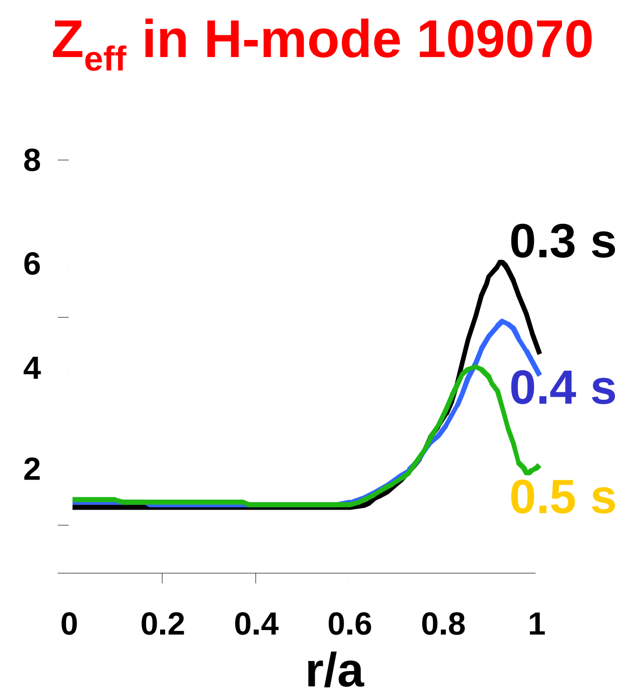
# Hollow USXR emissivity complicates H-mode imaging




- Intense periphery and faint core emission in H-mode
- Large peripheral fluctuations ‘hide’ weak core fluctuations
- Hollow impurity profile + low $Z_{eff}$ the main reason

# Impurity profiles from modeling of USXR data




- USXR data + high resolution spectra modeled with HULLAC + MIST
- Hollow $Z_{eff}$ with central $Z_{eff}$ -> 1 in high performance H-modes
- Two transport 'barriers' at r/a ≈ 1 and r/a ≈ 0.6 ?

# USXR system applied to impurity transport

## Motivation

- **Low-Z impurity transport offers <u>independent</u> probe of the ion channel:**

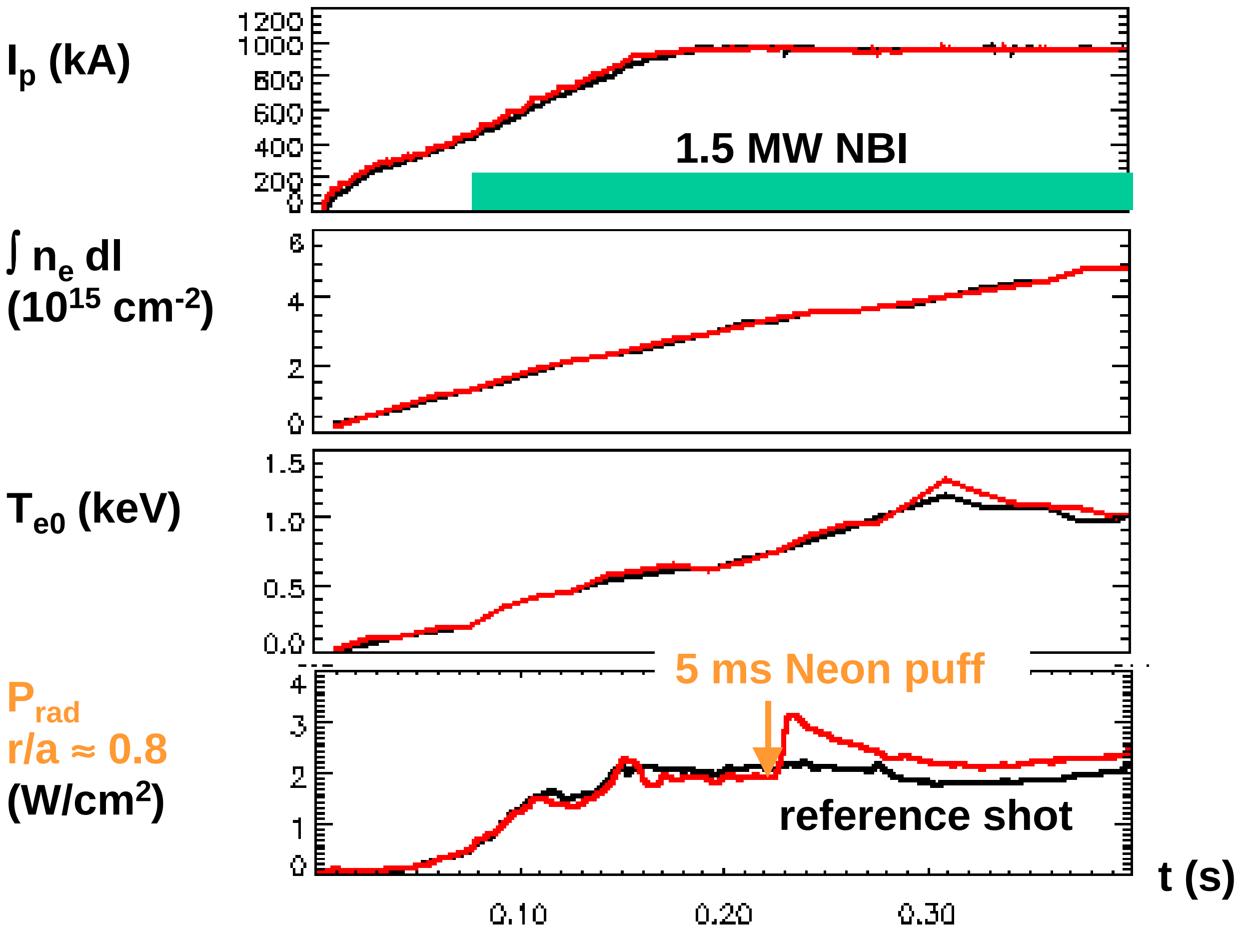
  **- $\chi_i$ from power balance still uncertain (*D. Gates APS02*)**

  **- electron channel strongly dominates**

## Tools

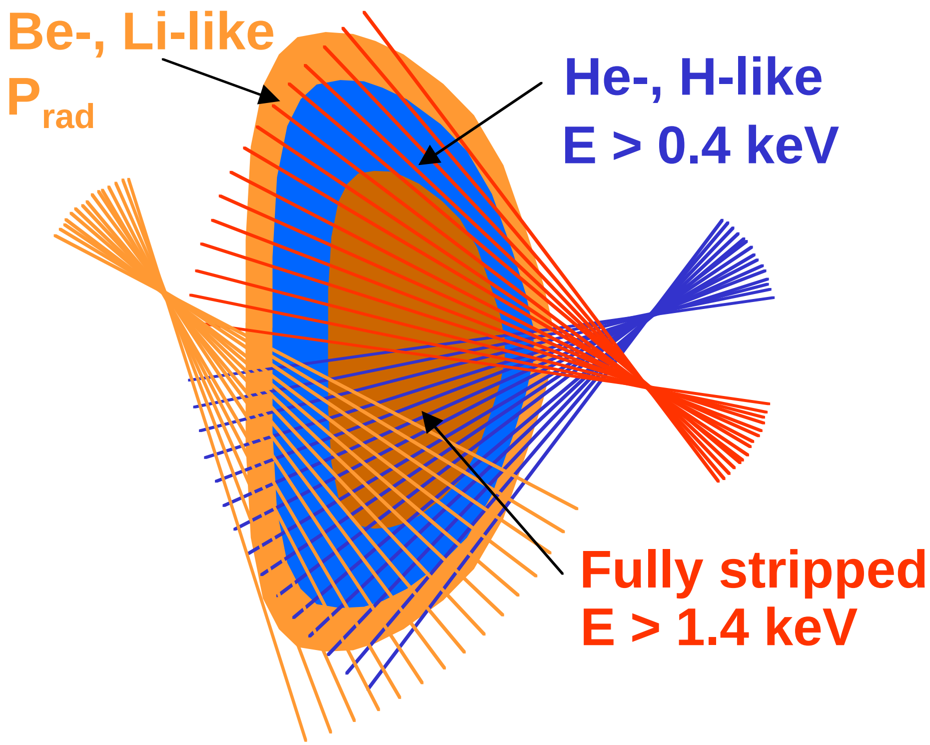
- **Brief, non-perturbing Neon puff into beam heated discharges**
- **Ultrasoft X-ray imaging + high resolution spectroscopy**
- **Atomic physics + transport modeling**

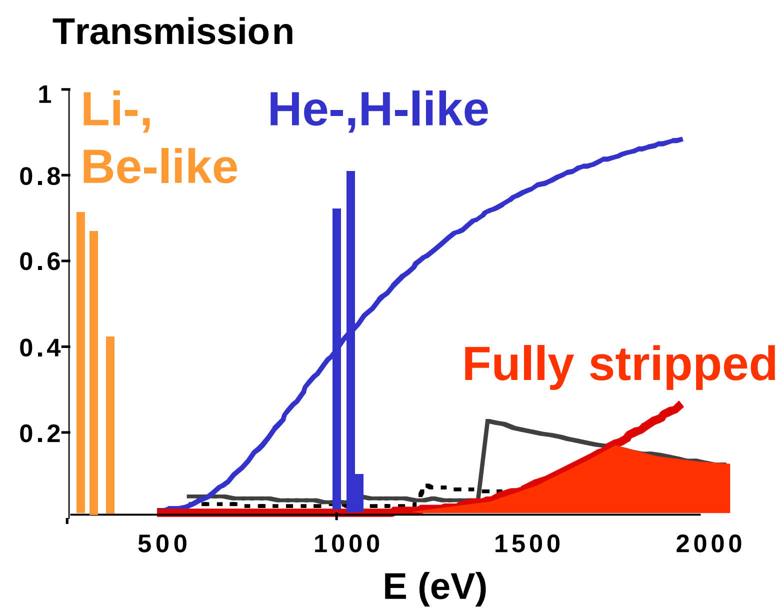
# Neon injected in quiescent, DND  L-mode shots




- Injection is non-perturbing ($n_{Ne}/n_e \approx 0.5\%$)
- Fast puff enhances contribution of diffusive term

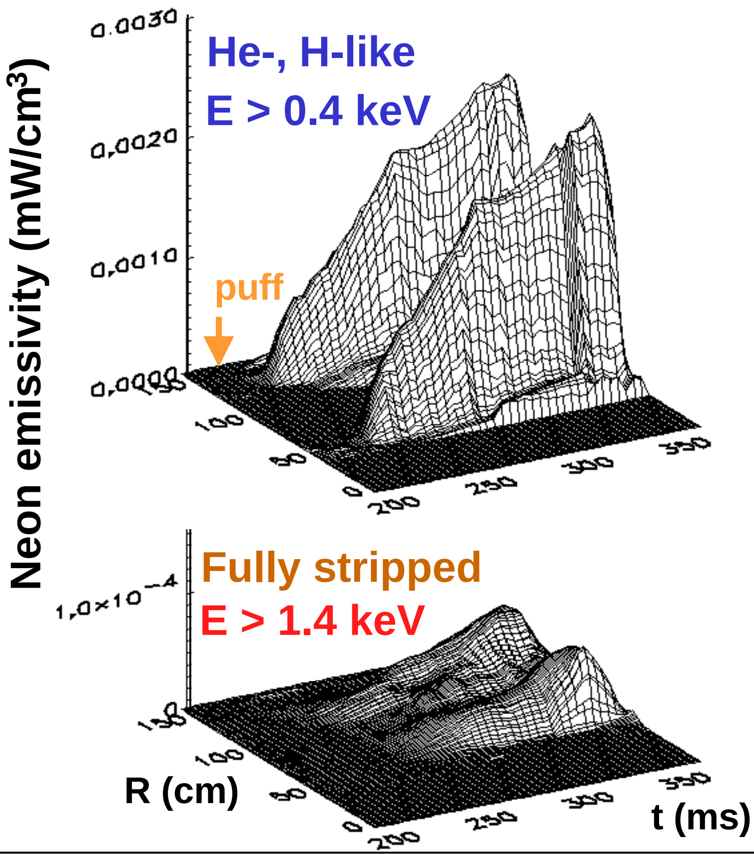
# ‘Three color’ setup measures all Neon charge states

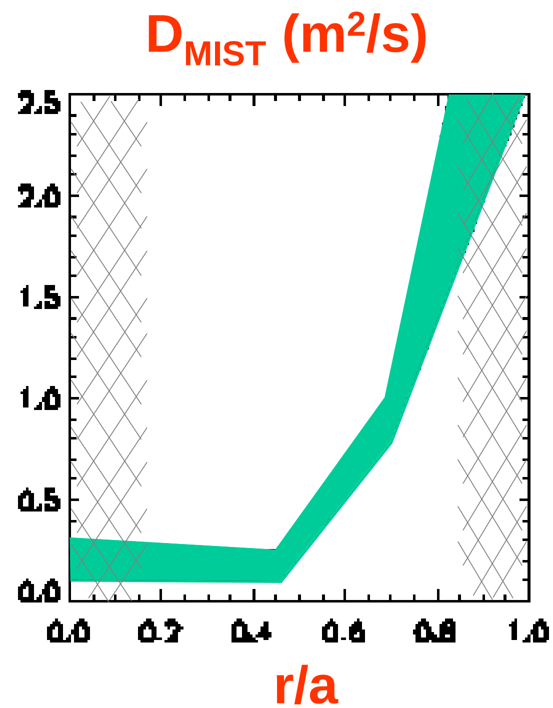



- Neon contribution from consecutive, reproducible shots
- Average emissivity from the up/down profiles (symmetric)
- Inclusion of peripheral charge states ($P_{rad}$) improves D, V estimate

# Neon penetration at 4.5 kG/1 MA

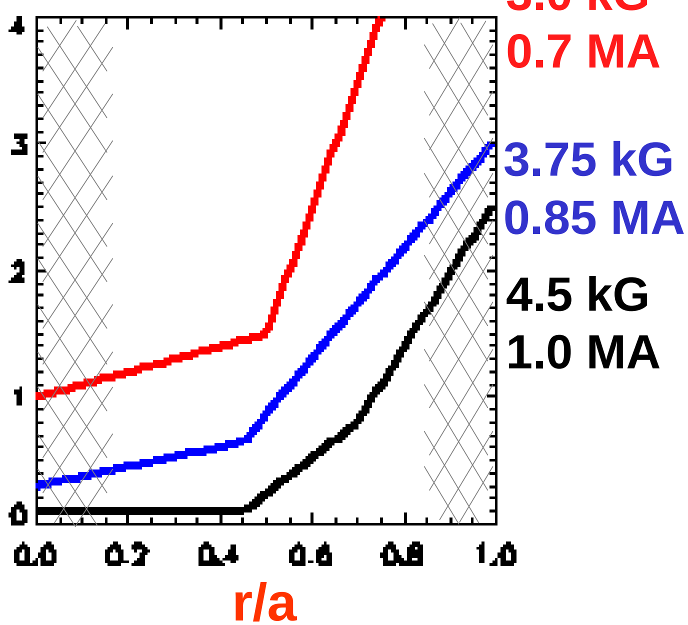


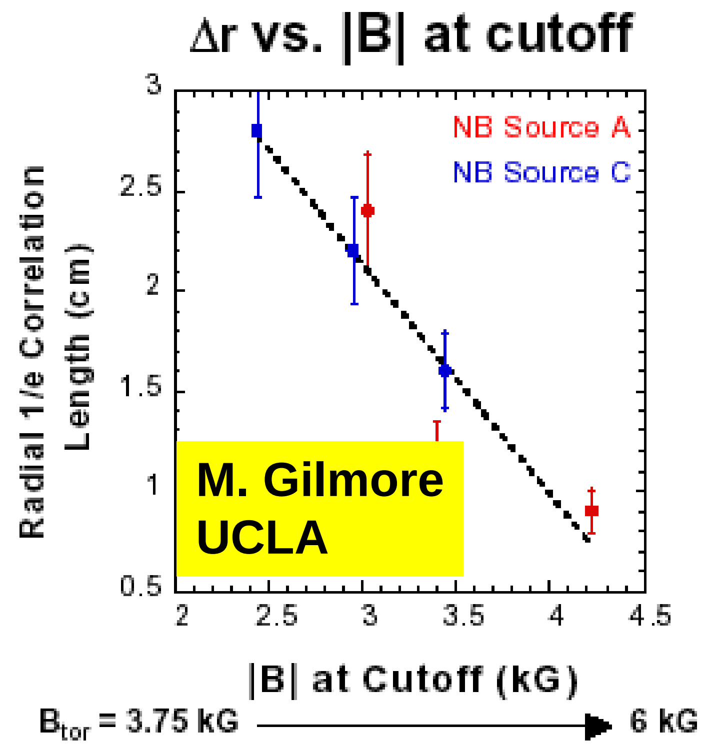

- Slow core penetration despite fast rise in peripheral Neon density
- Best fit modeling (MIST) indicates core D in the neoclassical range
- No significant pinch velocity (V < 0.5 m/s)
- Microstability computations predict ITG turbulence intrinsically suppressed in NSTX and *not* ExB shear effect (C. Bourdelle NF 02)

# Neon diffusion and turbulence decrease at high field

**Neon diffusion coefficient ($m^2/s$)**

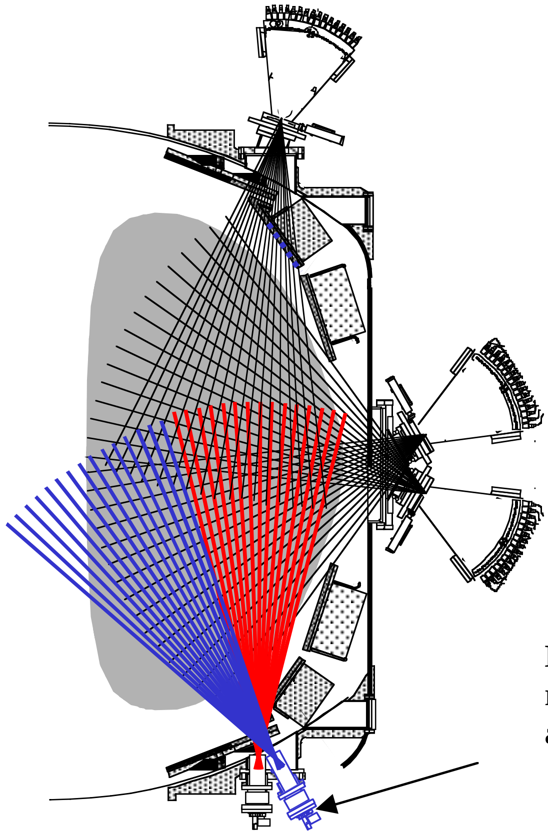



**Turbulence correlation length at r/a ≈ 0.9**



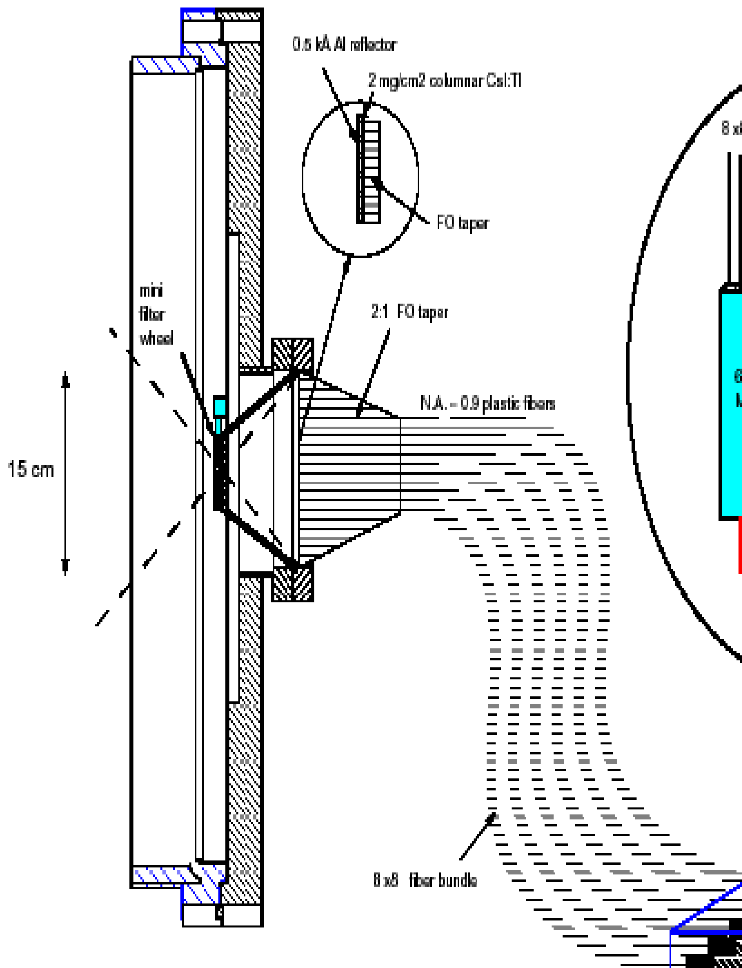

- **Field scaling of Neon diffusion and of peripheral turbulence suggest strong and favorable scaling of ion transport with ρ***
- **Electron transport seems to be the main challenge for STs**

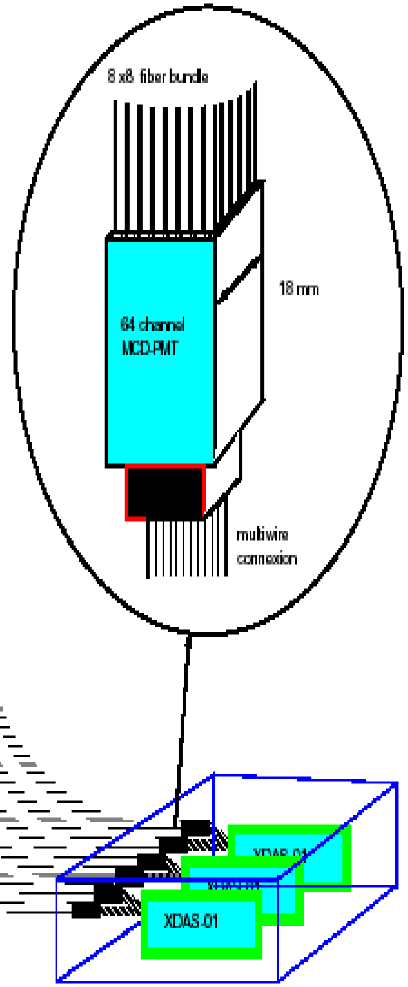
# Miniature re-entrant array developed for tomography

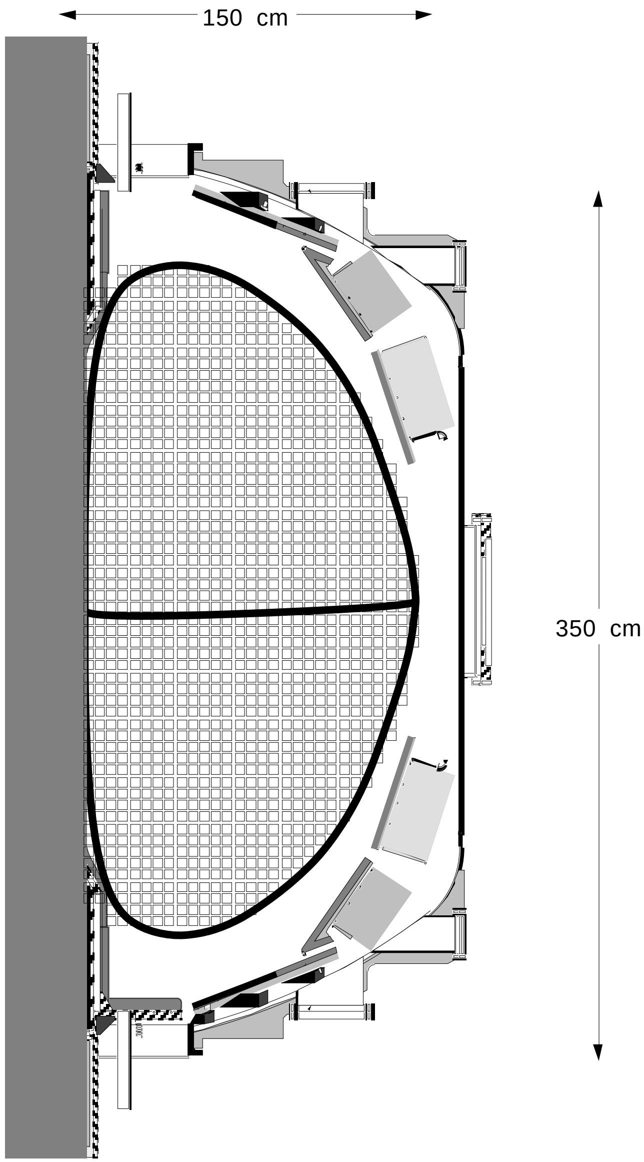



- Re-entrant vertical array  avoids vignetting by in-vessel structures
- Prototype 200 kHz array (outboard) installed for the coming run
- Toroidally displaced arrays for RWM work

# 100 kHz 1300-pixel tangential USXR array



# Summary

- Fast and sensitive USXR system uses large area AXUV diodes
- MHD imaging/tomography challenging in NSTX due to mode coupling and hollow emissivity profiles (H-mode)
- Re-entrant 200 kHz arrays developed for tomography of low-m modes
- Continuously sampling tangential array proposed for imaging of high-m modes, RWM, ELMs
- USXR system offers powerful tool for perturbative transport