Low-k turbulence and correlation length dependencies in the edge region in quiescent periods in NSTX H-mode plasmas

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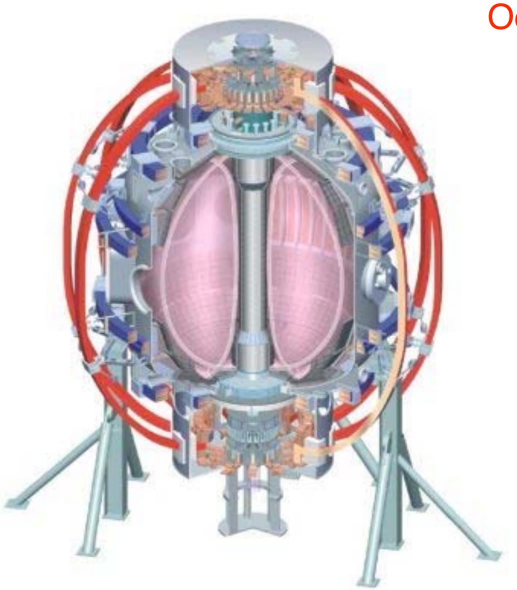

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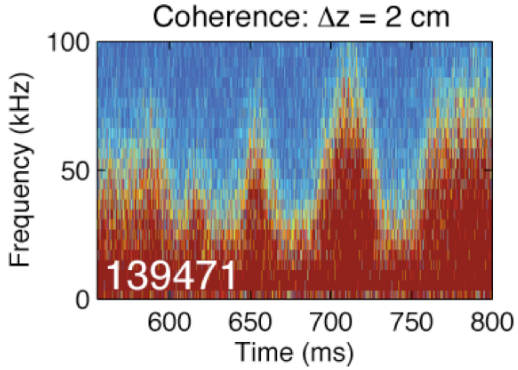
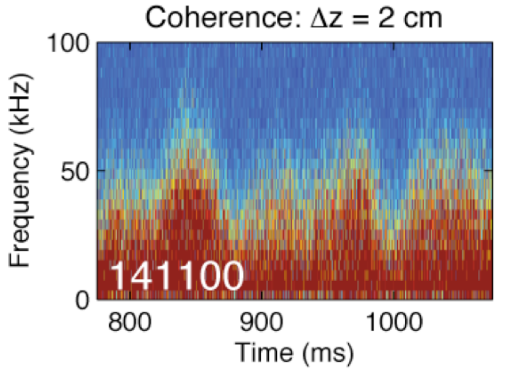
Overview

- Motivation
  - Identify the low-k turbulence modes present in NSTX plasmas
  - Assess the impact on transport
- Objective (initial)
  - Quantify poloidal and radial correlation lengths and decorrelation times of low-k turbulence
  - Identify parametric dependencies
  - With simulations, identify low-k modes present





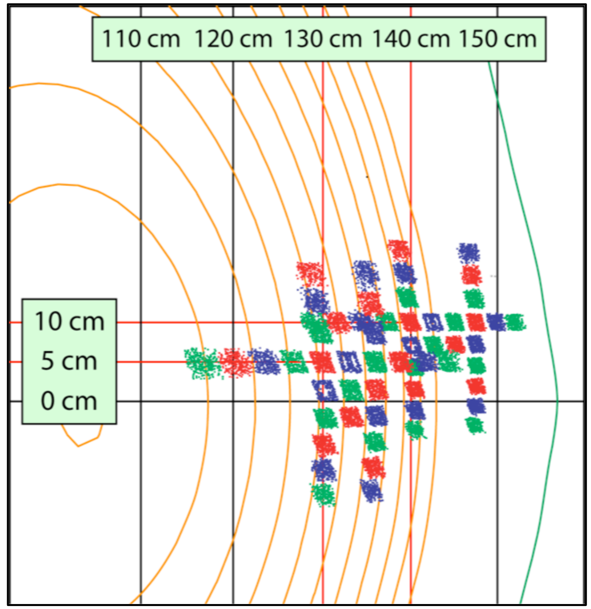
- Strategy
  - From 2010 BES data, identify **quiescent H-mode periods** (MHD quiescent and ELM-free; not "QH-mode")
  - Build **database** with poloidal correlation lengths (L_C) from BES poloidal array
  - Perform **regression analysis** to identify L_C scalings
    - For example, do correlation lengths increase or decrease at higher ∇n_e?

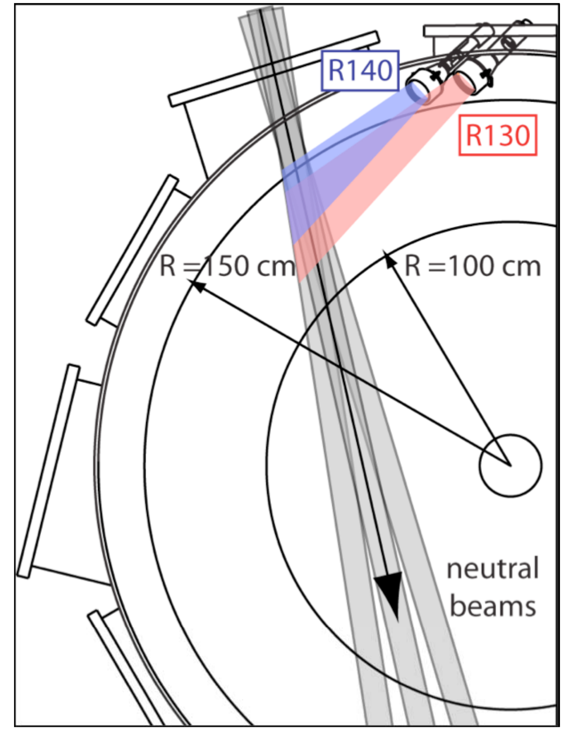
Outline

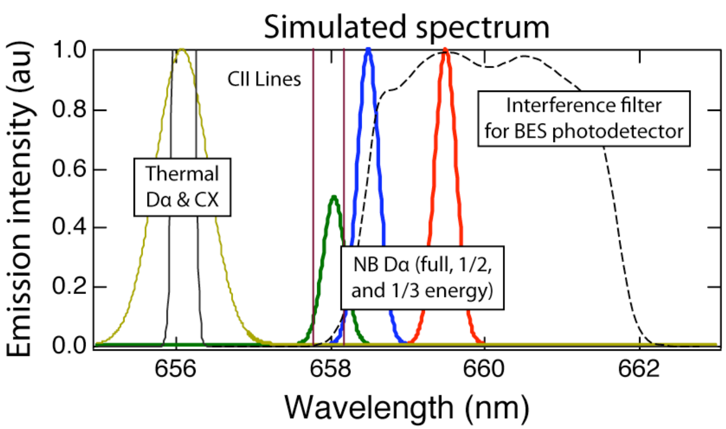
- Poloidal L_C calculations and database for quiescent periods in H-mode plasmas at R=140 cm
- Regression analysis to identify L_C parametric scalings
- Point spread function calculations
  - Characterize BES spatial and k-space resolutions
  - Synthetic BES diagnostic for simulations
- Future work

BES measures localized density fluctuations by observing D_α emission from collisionally-excited NB particles

- 32 detection channels with individual telescope and filter assemblies
- 56 sightlines in radial and poloidal arrays spanning core to SOL
- 2 MHz sampling
- $k_\perp \rho_i \leq 1.5$; 2-3 cm spot size
- Field-aligned optics with high throughput (etendue = 2.3 mm^2-ster)







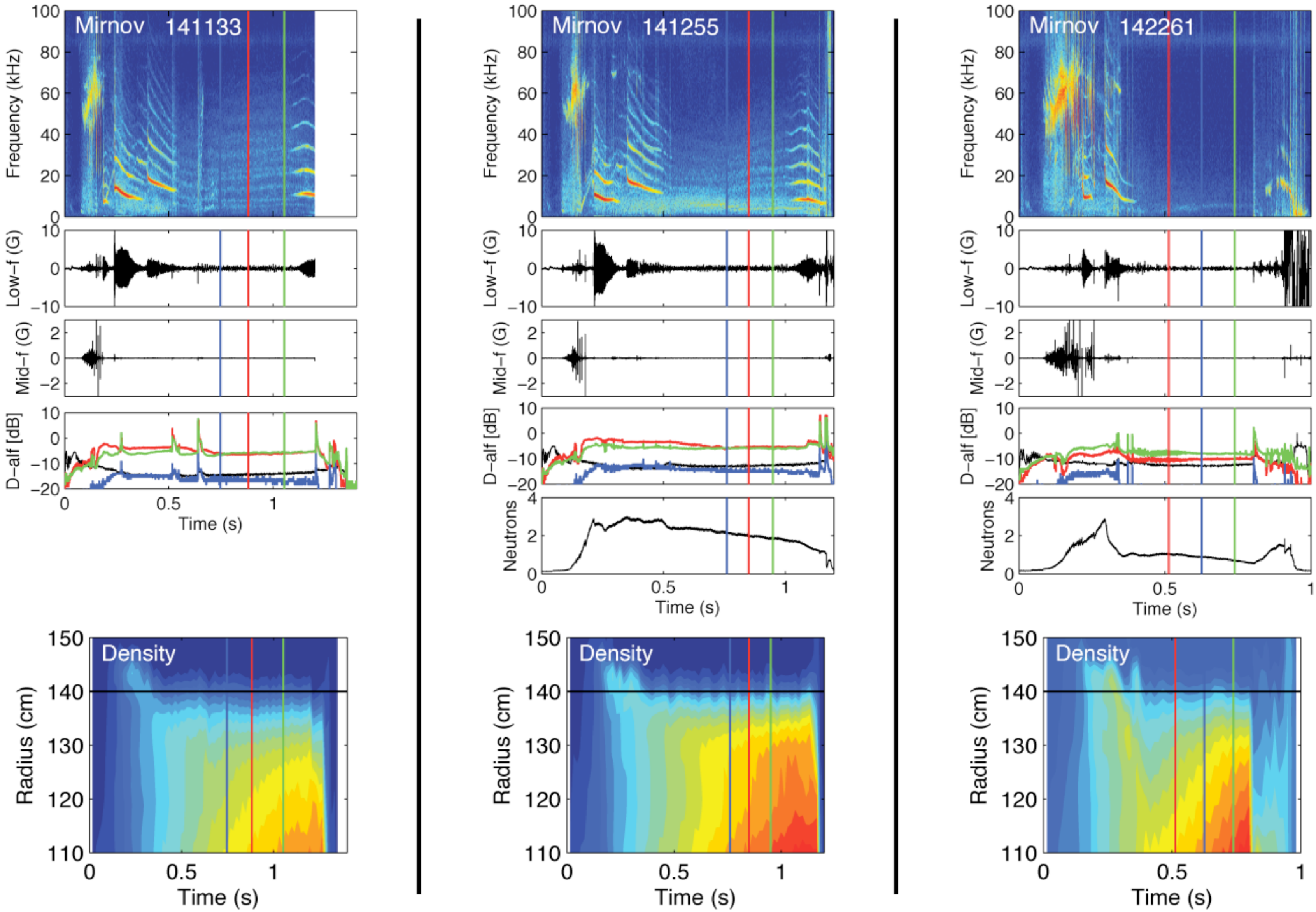
$$\frac{\delta I_{D\alpha}}{I_{D\alpha}} = \frac{\delta n_i}{n_i} \times C\left(E_{NB}, n_e, T_e, T_i, Z_{eff}\right)$$

neutral beam D_α emission

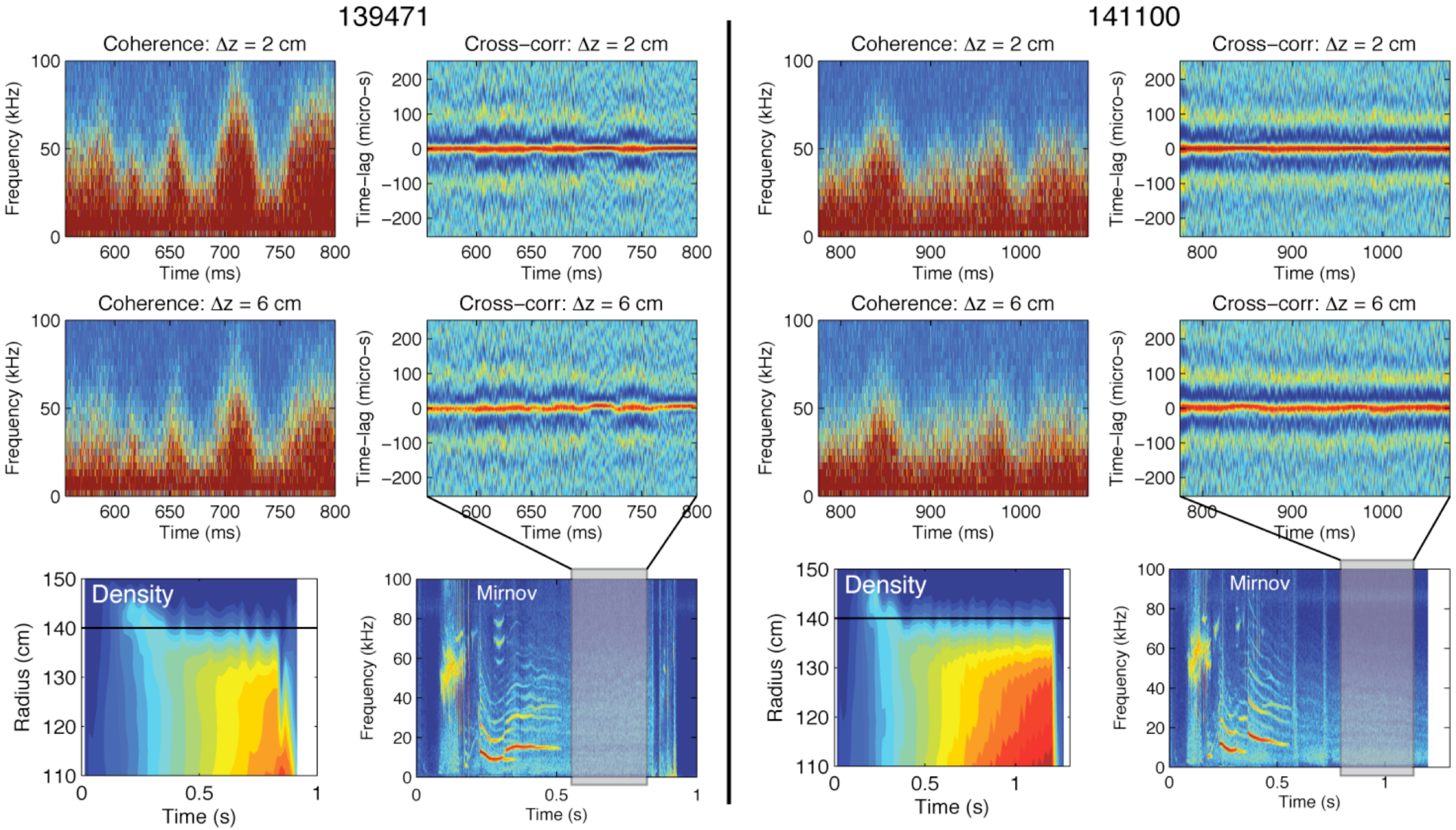
ion density fluctuation

$C \approx 1/2$

Database populated with 130+ quiescent periods from 29 shots with B_T=4.4 kG



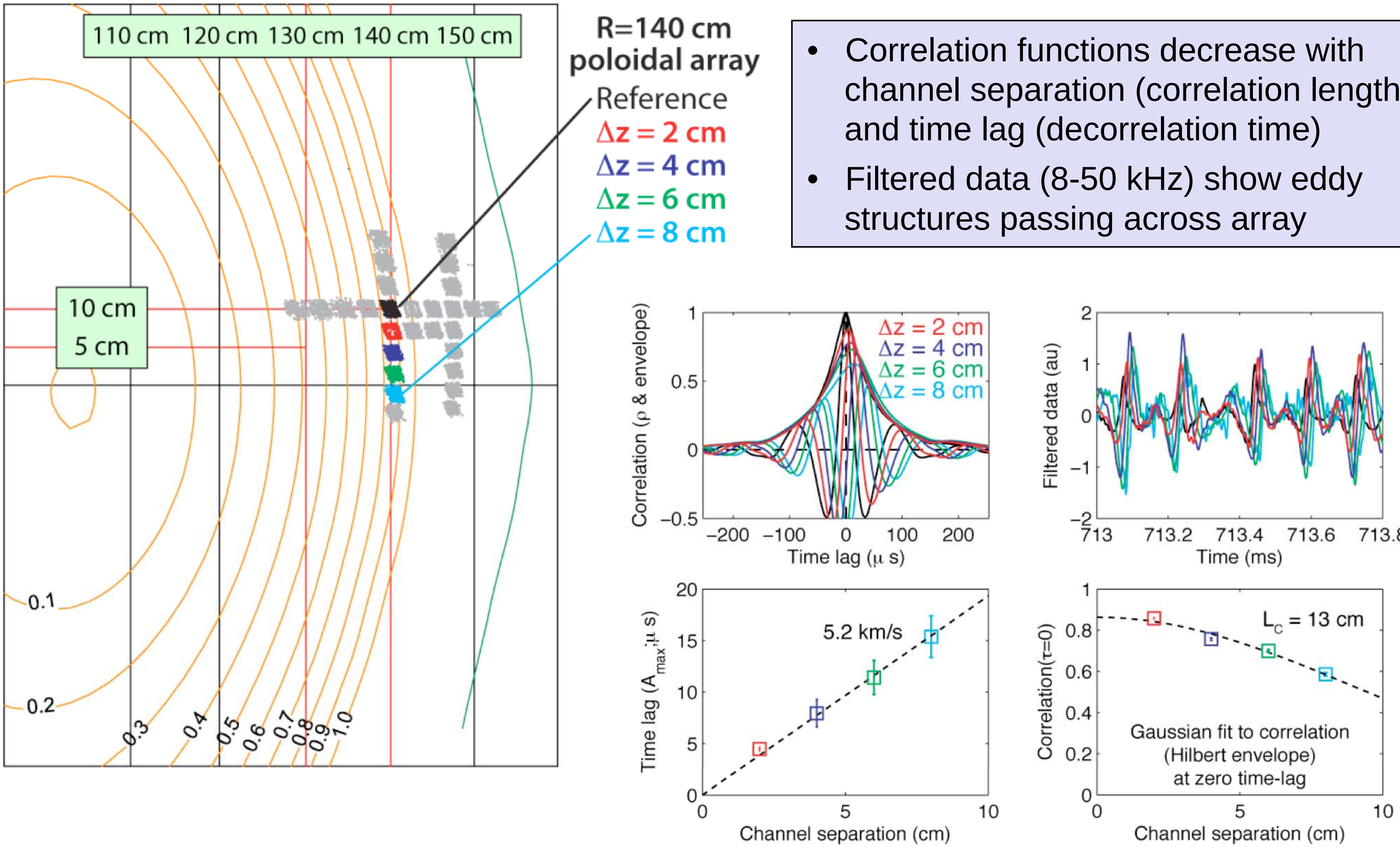
BES signals can show complex activity during quiescent periods – possibly due to plasma edge motion



Quiescent periods were partitioned into 15-40 ms segments to capture BES signal evolution

Poloidal L_C obtained from BES poloidal array at R=140 cm

- Correlation functions decrease with channel separation (correlation length) and time lag (decorrelation time)
- Filtered data (8-50 kHz) show eddy structures passing across array



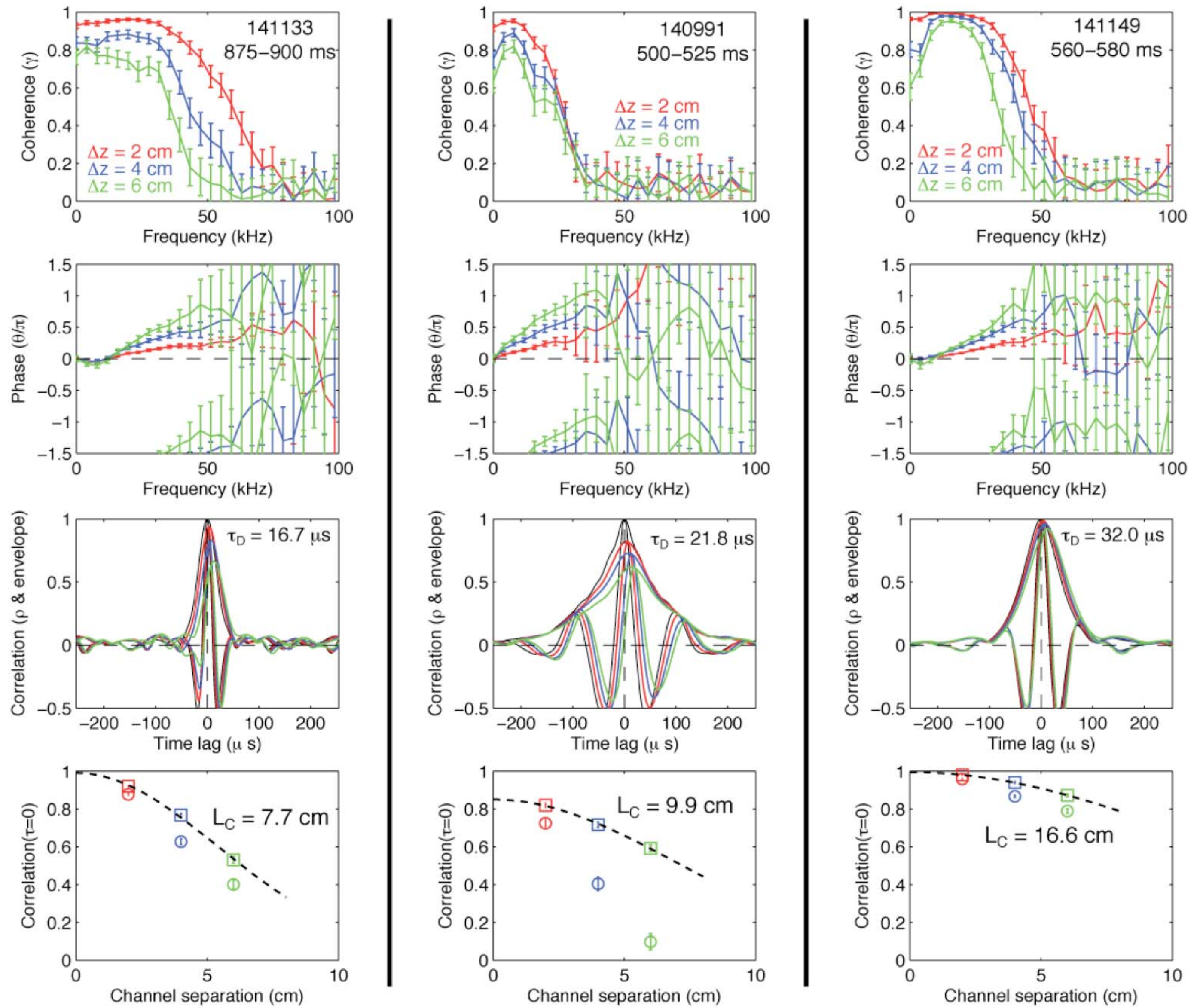
Poloidal L_C at R=140 cm are typically 5-20 cm and coherence spectra can extend up to 20-100 kHz

Coherence spectra

Cross-phase spectra

Time-lag cross-correlation (and Hilbert envelope)

Correlation vs. channel separation



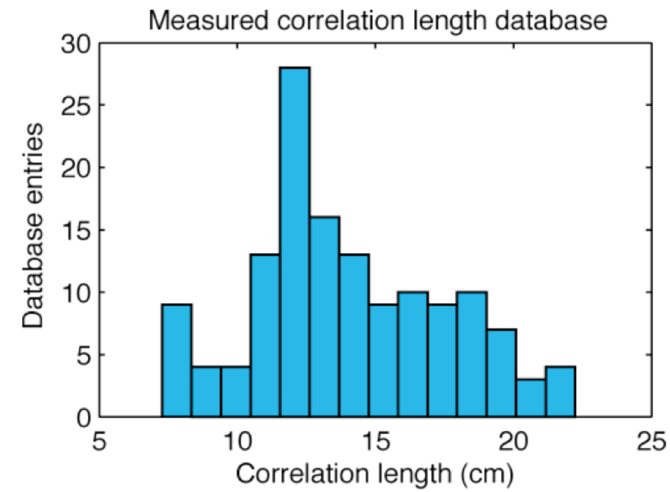
Poloidal L_C database includes many local and global parameters

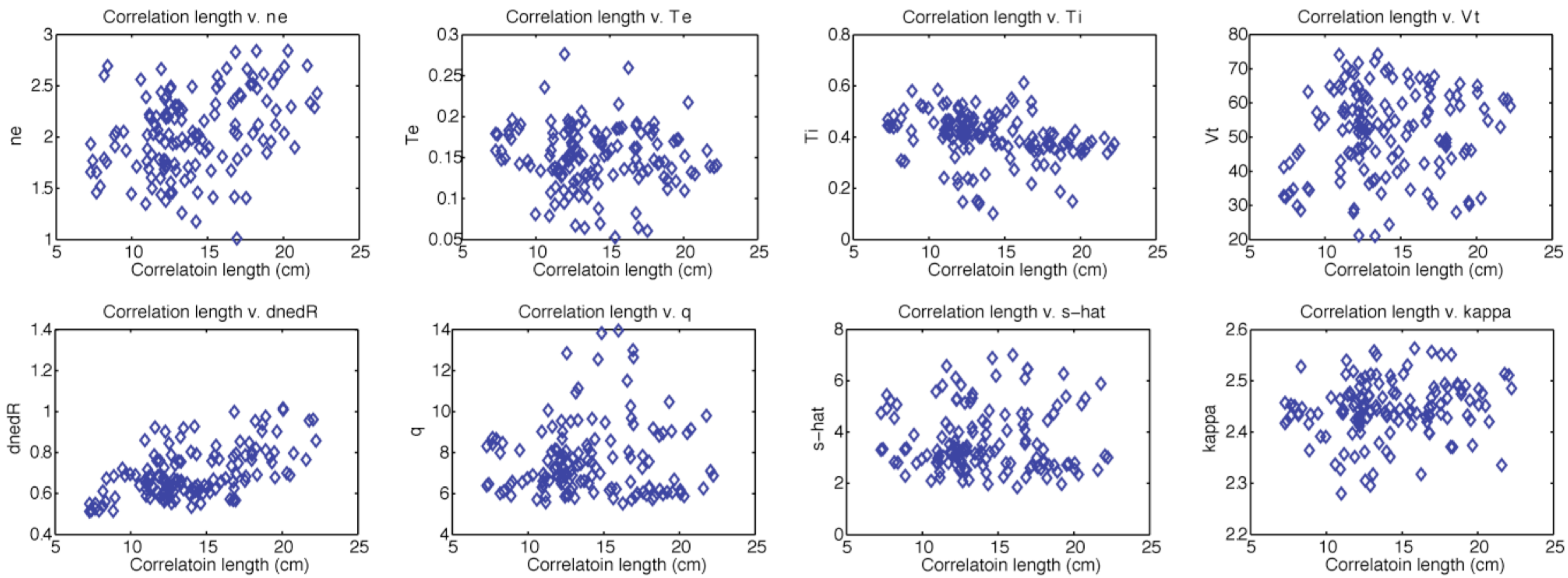
- Constructed from 2010 BES data using R=140 poloidal array
- Quiescent periods in H-mode plasmas
  - ELM-free and MHD quiescent
- 130+ entries from 29 shots with B_T = 4.4 kG
- 15-40 ms periods capture slow BES signal evolution
- Local plasma parameters in database
  - q, $\hat{s}$, $q/\hat{s}$, n_e, T_e, T_i, V_t, sqrt(n_e, T_e, T_i), ∇(n_e, T_e, T_i, V_t), $1/L_{(ne,\ Te,\ Ti)}$, κ, δ_{bot}, T_e/T_i, β_e, β_t, ν_e, ν_i
- Global/engineering parameters in database
  - I_P, P_{NB}, peak quantities (e.g. n_e), LCFS geometry

L_C database for R=140 cm poloidal array spans n_e = 1-3 × 10^{13}/cm^3 and T_e = 50-300 eV

Measured poloidal L_C show possible trends with ∇n_e and T_i without regression fit.

Other parameters show no clear trend with L_C.





Regression analysis can identify parametric scalings in the L_C database

- Stepwise multivariate linear regression

  n_e, q, κ, etc

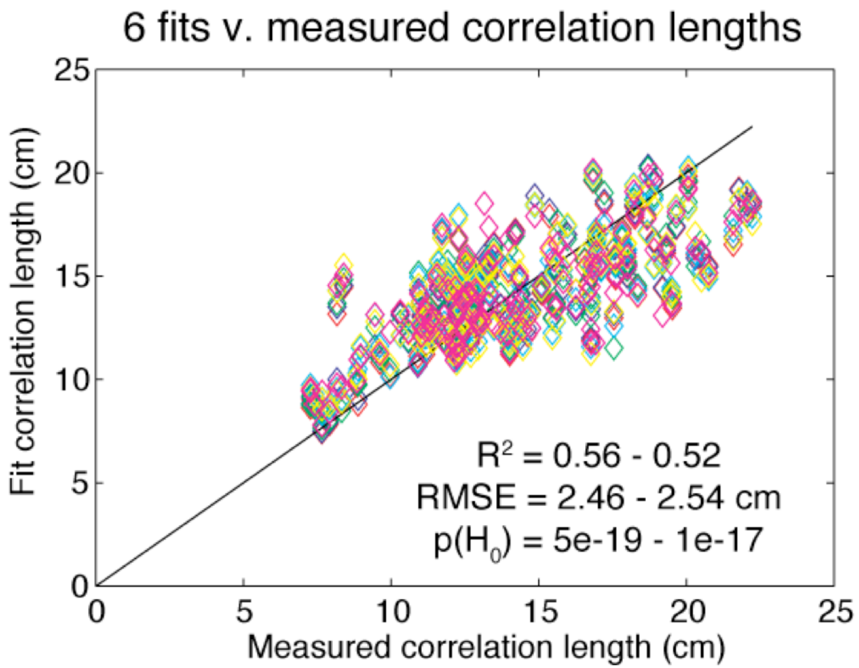
  - "Multivariate linear": $$L_C = \beta_0 + \sum \beta_i x_i$$
  - "Stepwise": iteratively test additional parameters (x_i) for statistical significance and RMSE reduction
  - Only **local physics** parameters in this presentation (e.g. q, n_e, κ, T_e/T_i)
- Normalized form allows **direct comparison** of parameters' scaling coefficients (β^N):

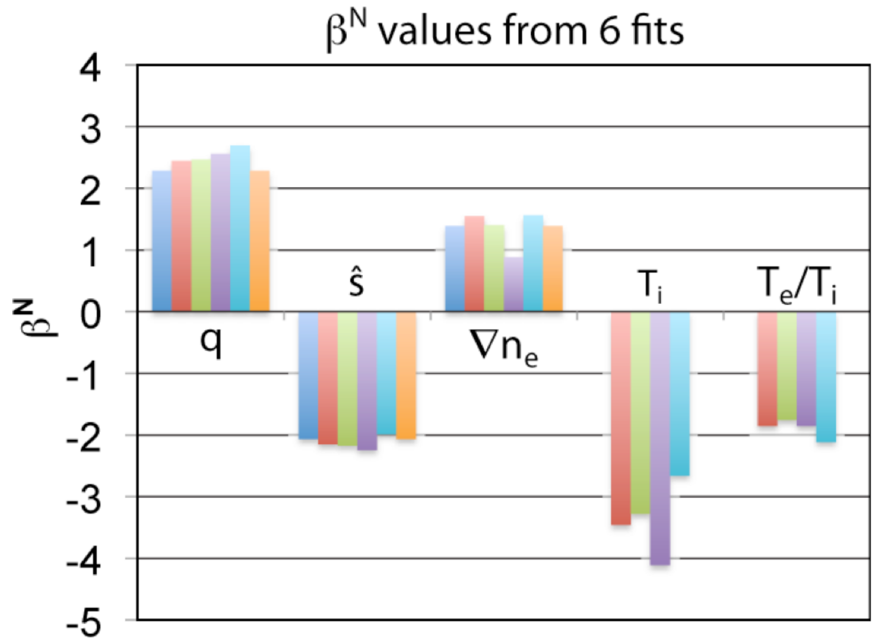
$$L_C = \overline{L}_C + \sum \beta_i^N \frac{x_i - \overline{x}_i}{\sigma_{xi}}$$

- Assessing regression fits and parameter scalings
  - Good fits exhibit large R^2 (amount of L_C variation captured by fit), small RMSE, small H_0 probability (null hypothesis: fit parameters do not explain L_C variation), and contain only **statistically significant** parameters
  - Good parameter scalings (e.g. β^N for n_e) appear in many fits with β_N values clustered around a typical value and comparable to or larger than fit RMSE

Consistent scalings (β^N's) emerge from regression fits

34 fits found by initializing stepwise search with every 2, 3, and 4 parameter combination

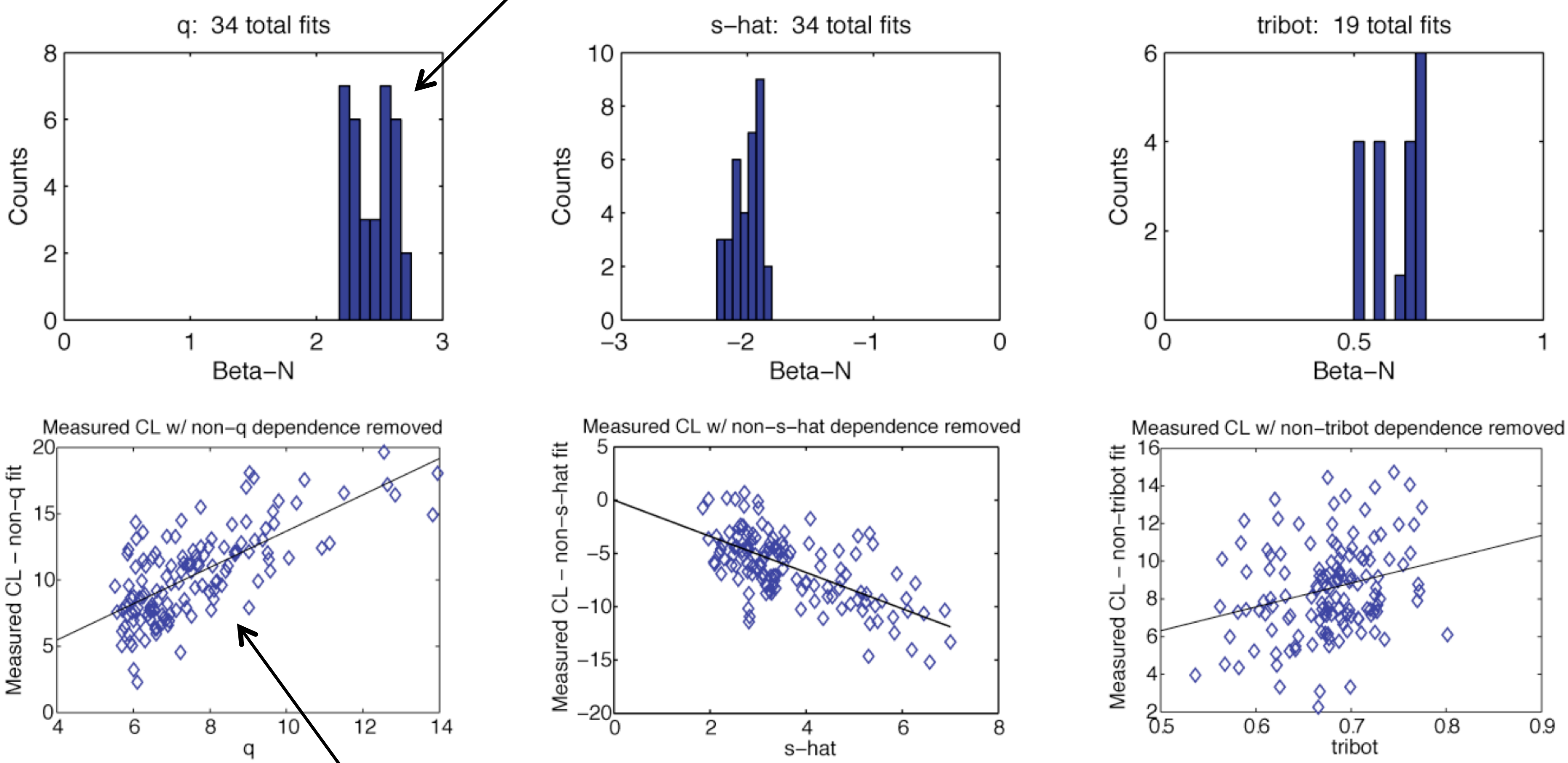




We can now make statements like
"poloidal correlations lengths in the edge region increase at higher q"
with some justification

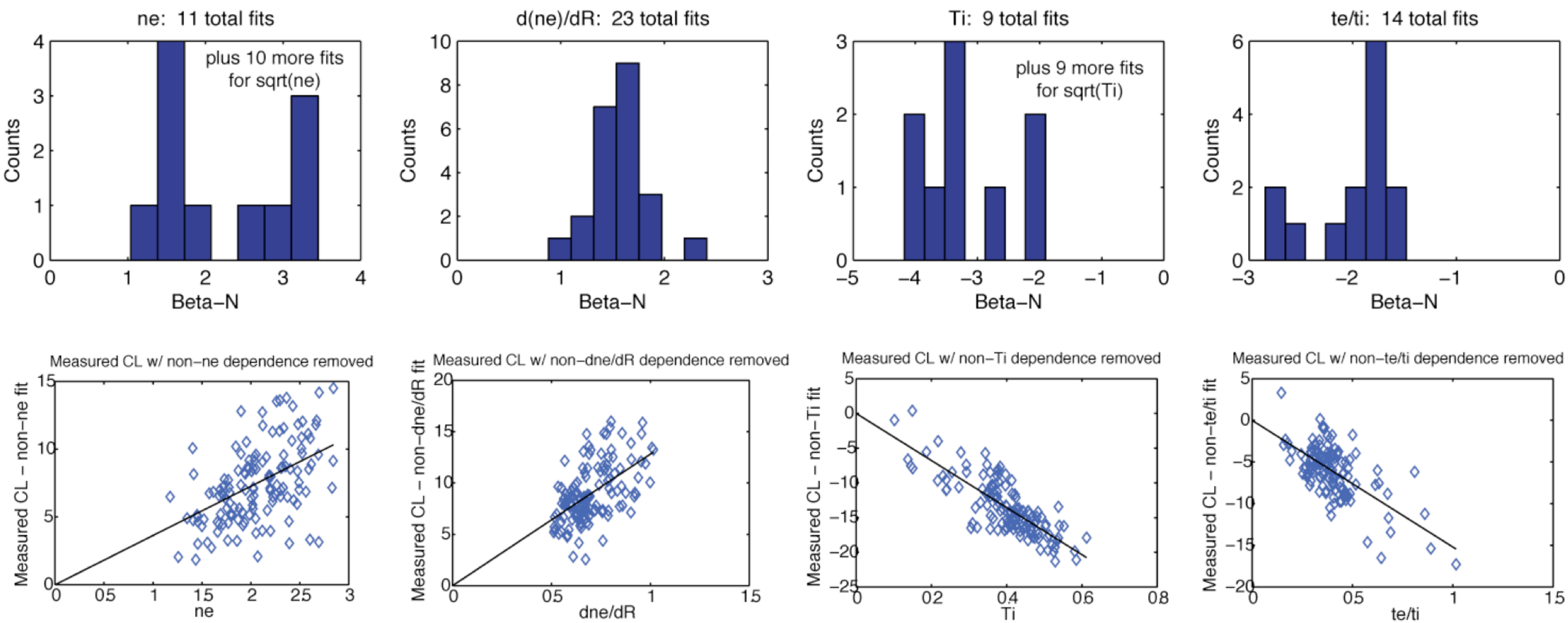
Among equilibrium parameters, positive scalings emerge for q and δ_{bot} and a negative scaling for $\hat{s}$

Distribution of parameter β^N's among fits



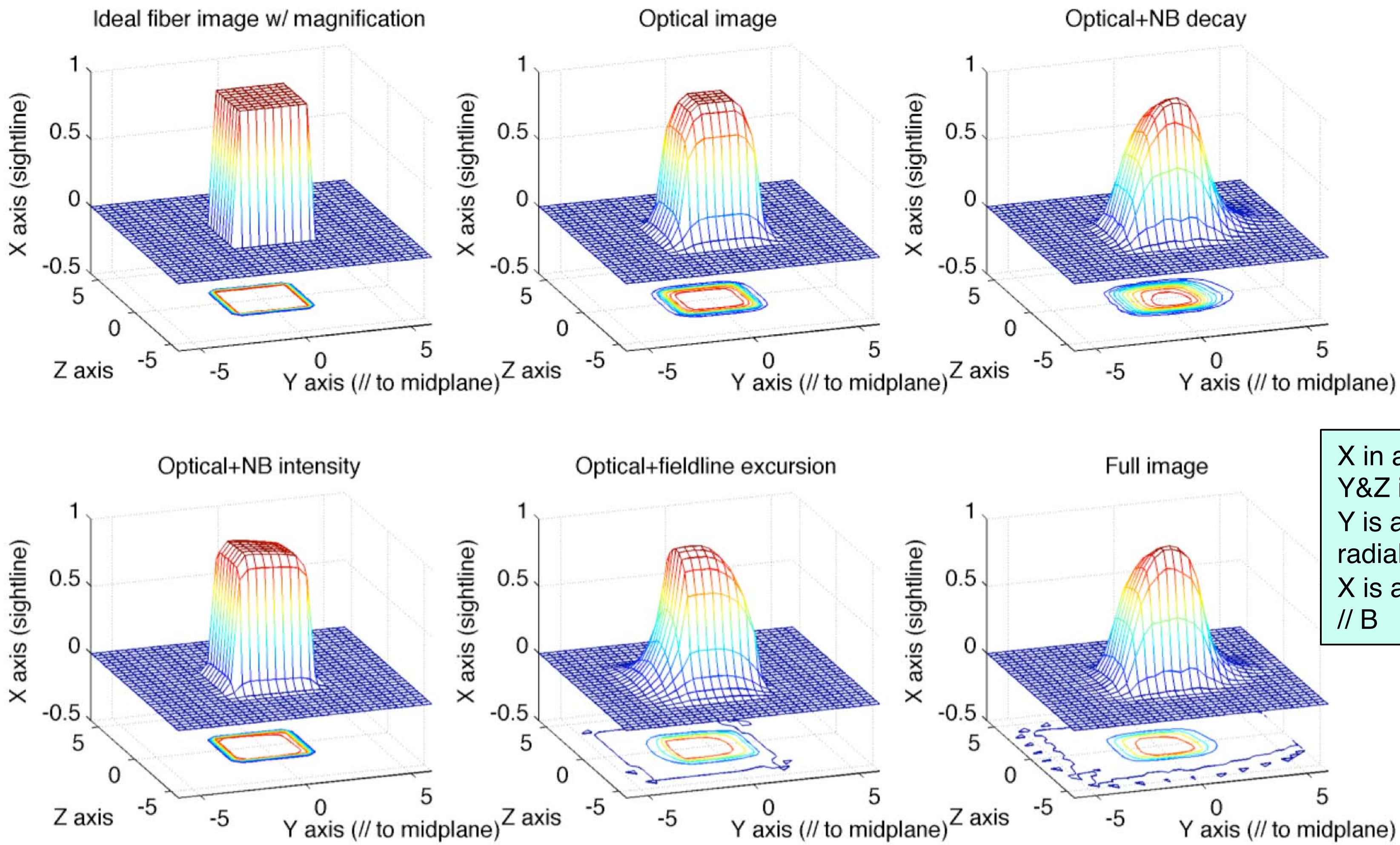
L_C dependence on parameter with non-parameter dependence removed (slope is β^N coefficient). Compare to scatter plots on pg 10.

Among species parameters, positive scalings emerge for n_e and ∇n_e, and negative scalings for T_i and T_e/T_i.



Point spread function calculations indicate NB excited state lifetimes and fieldline trajectory increase radial size by approx 40%

Model	Ideal fiber	Focusing optics	Optical+NB decay	Optical+NB intensity	Optical+fieldline excursion	All effects
Y 1/e^2 width (cm)	3.2	4.0	4.4	3.2	4.4	4.4
Y displacement (cm)	0.0	0.0	0.5	0.0	-0.5	0.3



X in a.u.;
Y&Z in cm;
Y is approx. radial;
X is approx. // B

Future work

- Additional analysis of 2010 BES data
  - Extend regression analysis to…
    - Global/engineering parameters
    - Decorrelation times and radial correlation lengths
    - Pre- and post-LH transition periods
  - Quantify **poloidal flow fluctuations** using time delay estimation (TDE) techniques
    - Identify zonal flows, if present
    - Assess predator-prey model of turbulence and flow shear
- Perform edge turbulence simulations
  - Complete PSF calculations for BES synthetic diagnostic
  - Validate simulations using analysis results from 2010 BES data
- Enhance BES measurement capabilities for NSTX-U
  - Expansion to 64 detection channels for better utilization
  - 2D imaging with high-resolution edge sightlines for better coverage

Summary

- **Poloidal correlation lengths** calculated from BES measurements
  - Decorrelation times are in hand
  - Radial correlation length calculations and TDE tools are under development
- Created database of poloidal L_C at R=140 cm for H-mode quiescent periods
  - 130+ entries from 29 shots in 2010
- Performed regression analysis to identify parametric scalings
  - Analysis indicates L_C **increases** at higher q, δ_{bot}, n_e, and ∇n_e; L_C **decreases** at higher $\hat{s}$, T_i, and T_e/T_i.
- Initial **PSF calculations** indicate excited state lifetimes and fieldline trajectory increase the radial spot size by 40% at R=140 cm
- Future plans
  - Extend analysis to decorrelation times, radial correlation lengths, global/engineering parameters, pre-/post-LH transition, and flow fluctuations
  - Perform edge turbulence simulations
  - Enhance BES capabilities for NSTX-U