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Reduced-model (SOLT) validation from comparisons with GPI data on NSTX

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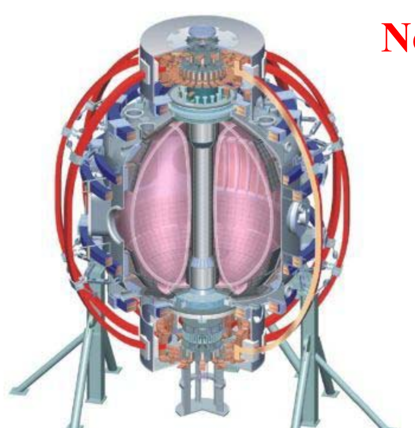

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SOLT 2D Turbulence Code
(**S**crape-**O**ff **L**ayer **T**urbulence)

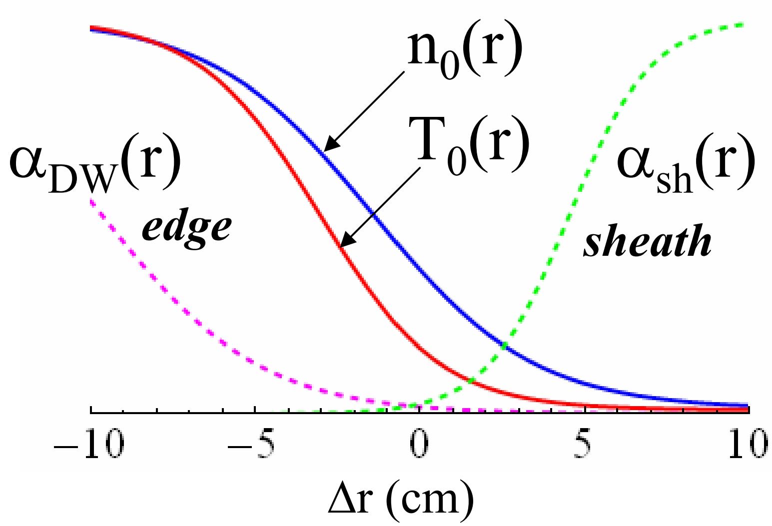
Reduced-Model Equations of Evolution in 2D (OM, ⊥ B)
for
Vorticity, Density, Temperature and Zonal Momentum

Two Radially Distinguished Regions:

➢Edge Region ($\Delta r < 0$)
•Sources of Density and Temperature
•Electron Drift Waves
•Curvature-Driven (Interchange) Instability
(Blob Birth Zone)

➢SOL Region ($\Delta r > 0$)
Sheath Absorption: a Sink for all Fields

Initial and Reference Profiles
(normalized)



(no zonal flow initially)

Model Equations
include drift wave, curvature and sheath effects

•Vorticity

• Electron Adiabatic and Sheath parameters, $\alpha_{DW}(x)$ and $\alpha_{sh}(x)$ model an x-dependent connection length $L_{//}$.

$$\partial_t \nabla^2 \tilde{\varphi} =$$

$$= \left\{ -\mathbf{v}\cdot\nabla\nabla^2\varphi + \alpha_{DW}\frac{\overline{T}^{3/2}}{\overline{n}}\left(\varphi - T\ln(n)\right) + \alpha_{sh}T^{1/2}\left(1-\exp(\varphi_B-\varphi)/T\right) - \frac{\beta}{n}\partial_y(nT) + \mu\nabla^4\varphi \right\}$$

• $\beta = 2\,\rho_s / R$, the familiar curvature coefficient.

•Density

$$(\partial_t + \mathbf{v}\cdot\nabla)n = \alpha_{DW}\overline{T}^{3/2}\{\varphi - T\ln(n)\} - \alpha_{sh} n T^{1/2}\exp\left((\varphi_B - \varphi)/T\right) + D\nabla^2 n + S_n$$

•Temperature

• $S_n = \nu_n(x)\,(n_0(x) - n)$ and $S_T = \nu_T(x)\,(T_0(x) - T)$ ($\nu_{n,T} \sim 1$ as $x \rightarrow 0$ and are ignorably small in the SOL.)

$$(\partial_t + \mathbf{v}\cdot\nabla)T = -\alpha_{sh} s_E T^{3/2}\exp\left((\varphi_B - \varphi)/T\right) + S_T$$

•Zonal Momentum

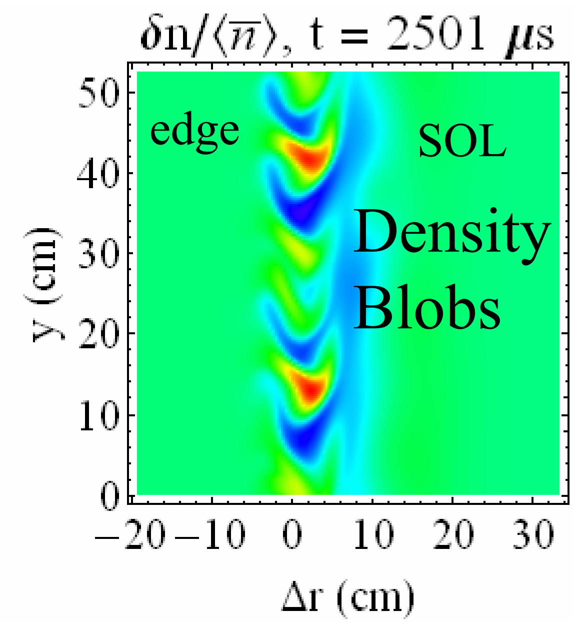
$$\partial_t p_y + \partial_r \overline{n v_r v_y} = \int_r^{L_r} dx\, \alpha_{sh}\overline{nT^{1/2}\left(1-\exp\left((\varphi_B-\varphi)/T\right)\right)} + \overline{\mu}\,\partial_r^2\overline{v_y} - \nu_{p_y} p_y$$

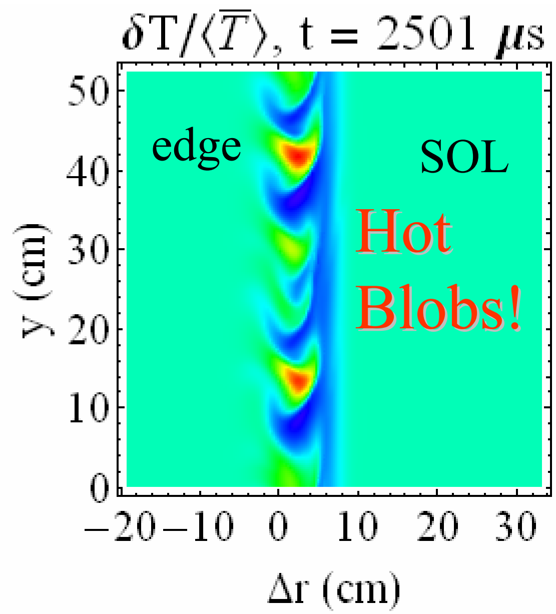
$p_y \equiv \overline{n v_y}$, $\overline{v_y} = \partial_r\overline{\varphi}$, and where ν_{p_y} is a constant, varied to damp the flow.

Boundary Conditions: $p_y = 0$ (*no slip*) and $\overline{\varphi} = \overline{\varphi}_{Bohm}$ at $r = L_r$

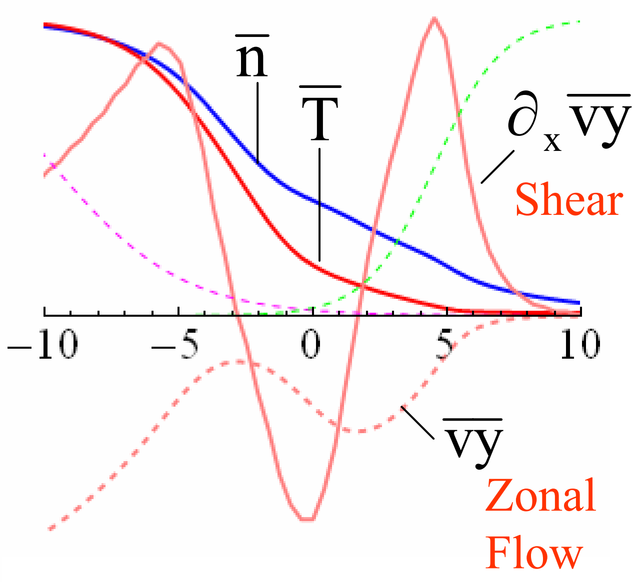
The SOLT code resolves strong ($\delta n/n \sim 1$) blob turbulence and zonal flows

- Split-step algorithm
- Convection: Flux-corrected transport (*phoenical SHASTA*, J. Boris and D. Book with the 2D flux-limiter by S. Zalesak – J. Comp. Phys. **31**, 331 (1979)).
- Diffusion: Crank-Nicholson (ADI).
- All other terms: evolved explicitly.



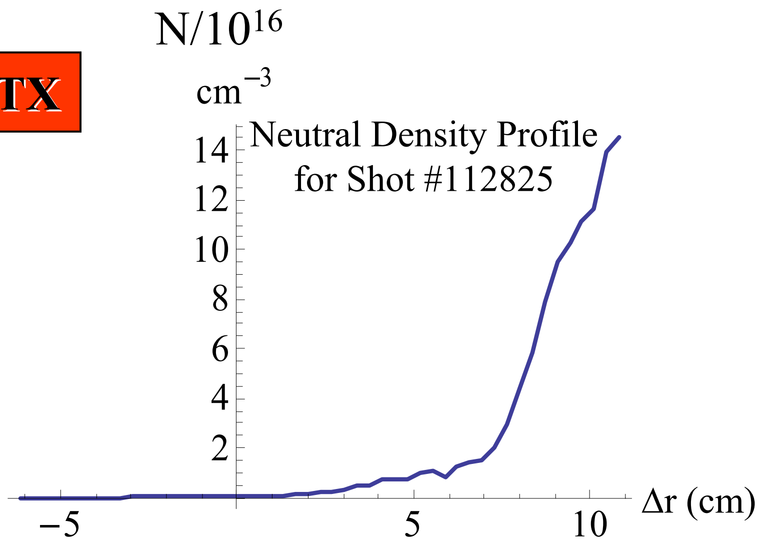


Radial Profiles
t = 2501 μs



Synthetic diagnostic of GPI intensity, $I = N f_A(n,T)$, allows direct comparison with experiment

NSTX



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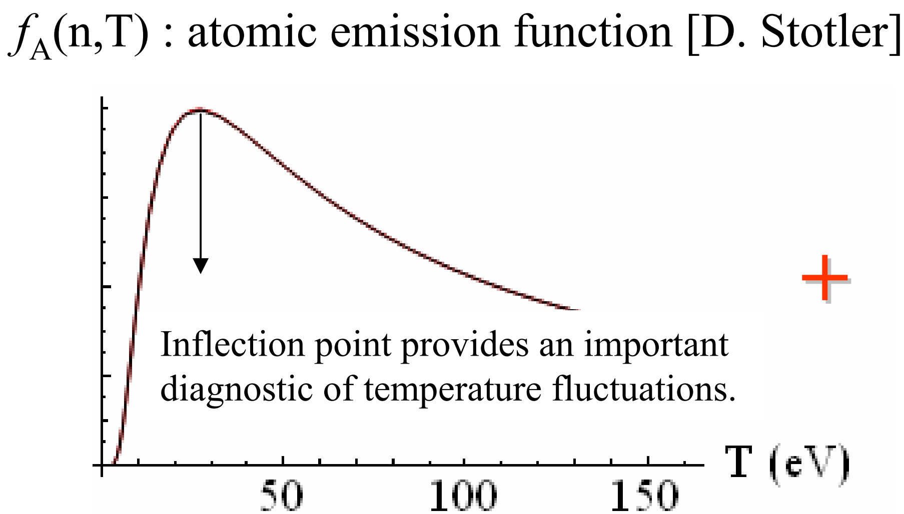

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SOLT

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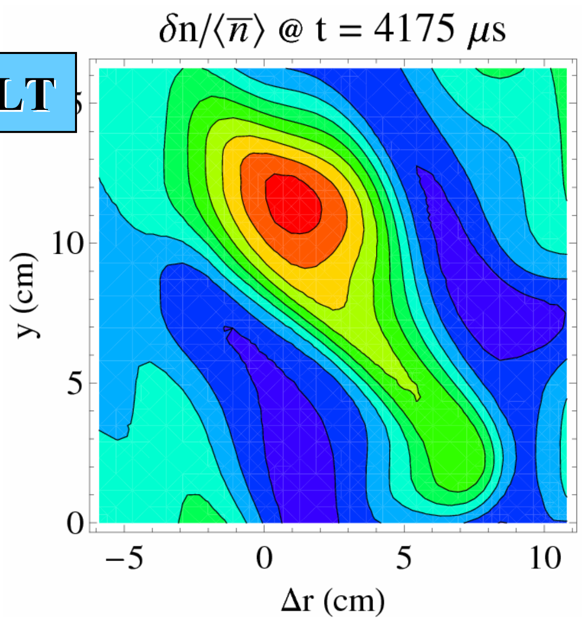

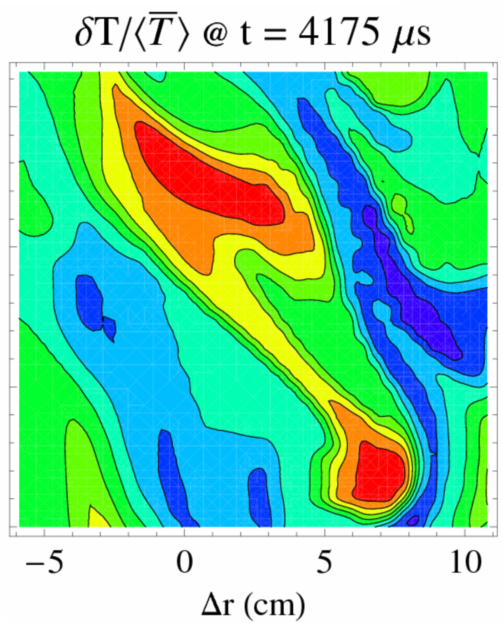

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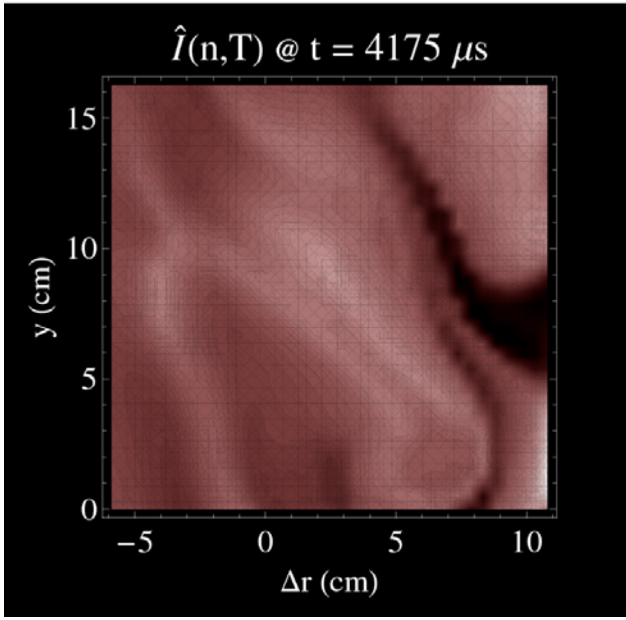


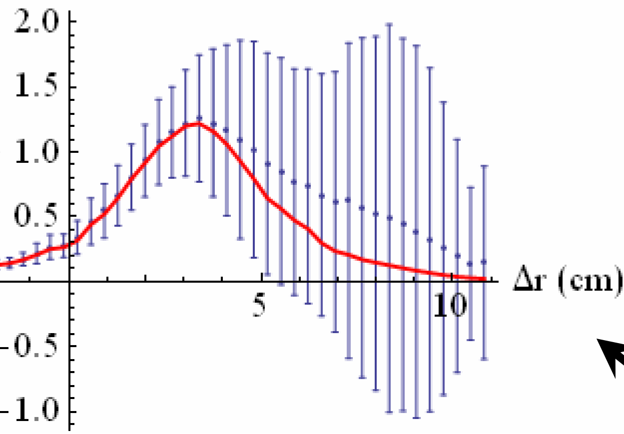
The radial distribution of edge turbulence depends on sheath absorption

GPI point data

⟨I⟩, σ_I & Median I (red)

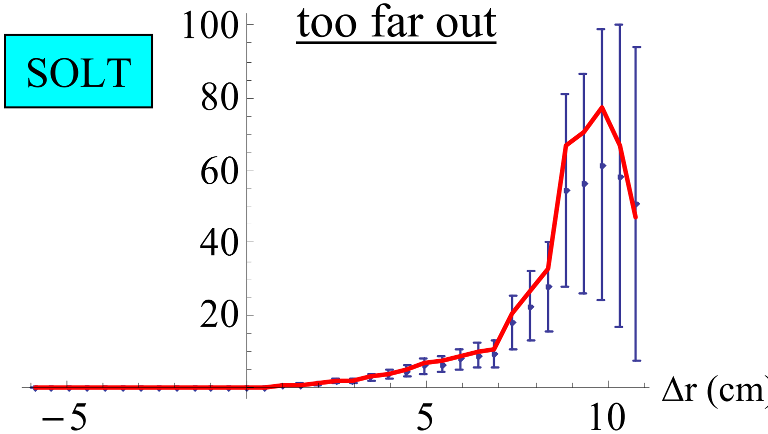
NSTX

shot #112825



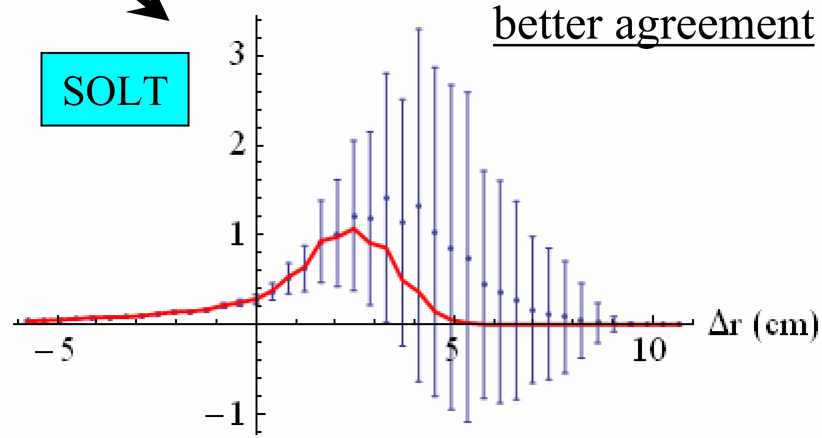
SOLT

SHE at Δr = 10.5 cm
too far out



SOLT

SHE at Δr = 6.7 cm
better agreement



The shape of the GPI intensity curves is a function of the **sheath absorption**, especially the location of the sheath entrance (SHE).

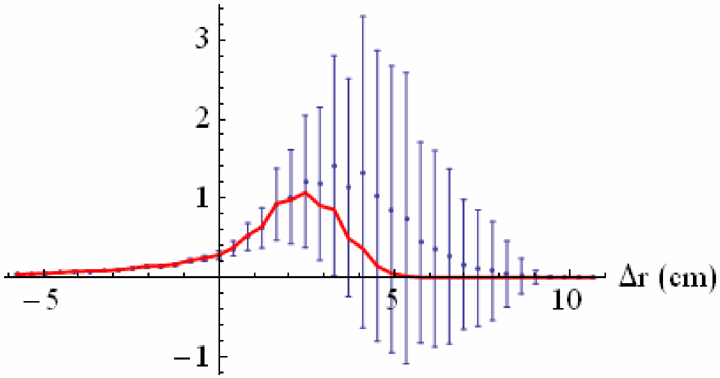
⇒ We can map out the connection length $L_{//}$ (Δr) in the SOL.

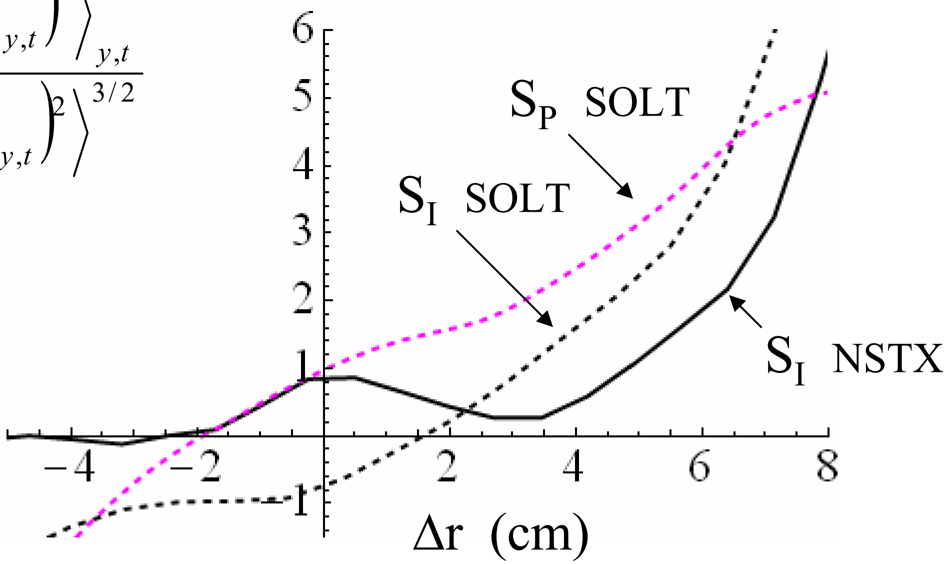
The skewness of intensity fluctuations, S_I, indicates the ballistic (blob) nature of the turbulence

$$S_I(\Delta r) = \frac{\left\langle \left(I(\Delta r, y, t) - \langle I \rangle_{y,t} \right)^3 \right\rangle_{y,t}}{\left\langle \left(I(\Delta r, y, t) - \langle I \rangle_{y,t} \right)^2 \right\rangle^{3/2}}$$

S_P , S_n , S_T - similar

⟨I⟩, σ_I & Median I (red)

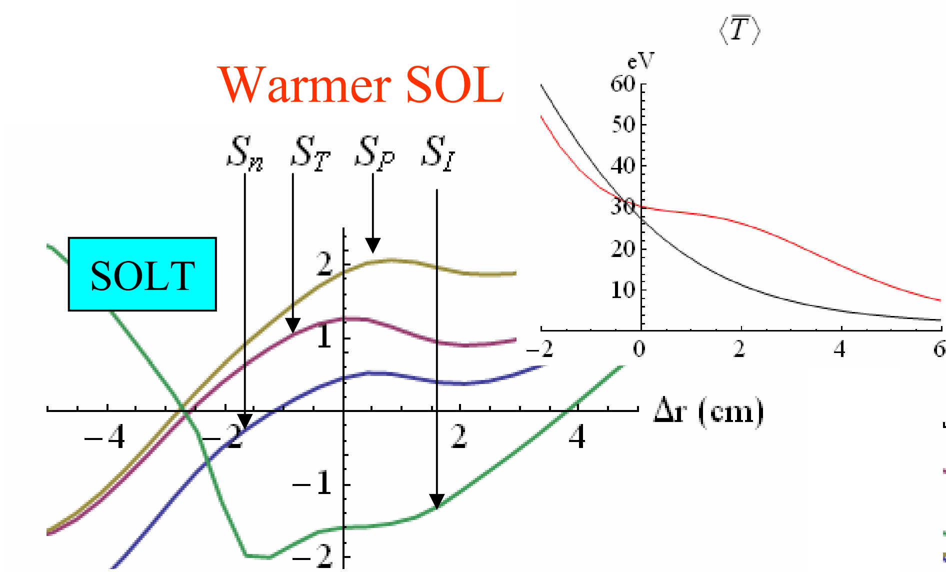


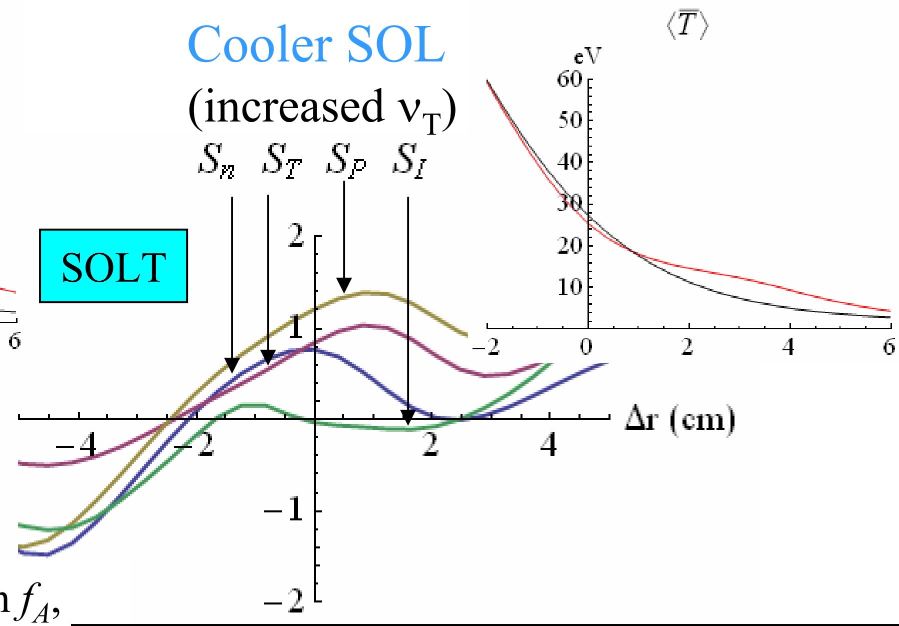


Reasonable agreement is observed where the GPI intensity fluctuations are large, $0 < \Delta r < 8$ cm.

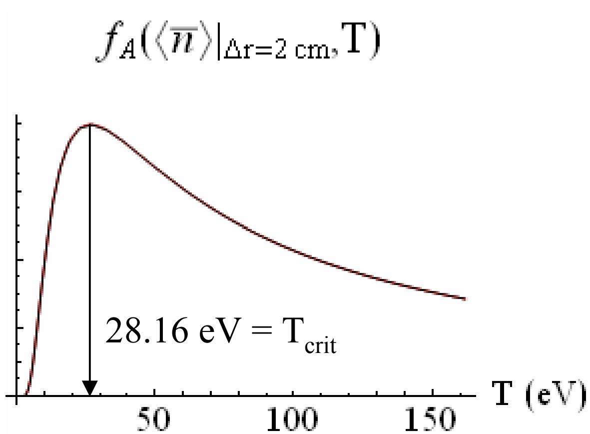
But note $S_I < 0$ near SEP ($\Delta r = 0$) in the SOLT simulations. Cause? (next page)

S_I is a sensitive measure of temperature fluctuations



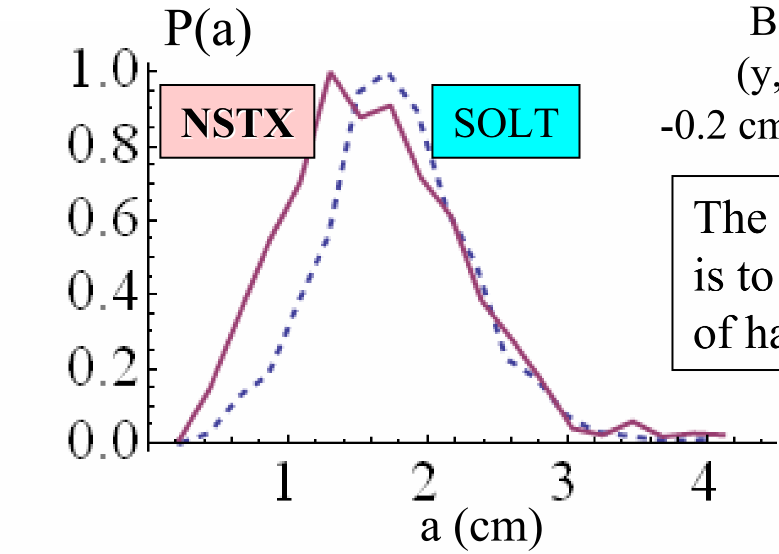


For temperature fluctuations above the inflection point in f_A, δT and δI are anti-correlated, and S_T and S_I *tend* to have opposite sign. As $\delta T \to 0$, S_I is dominated by δn.



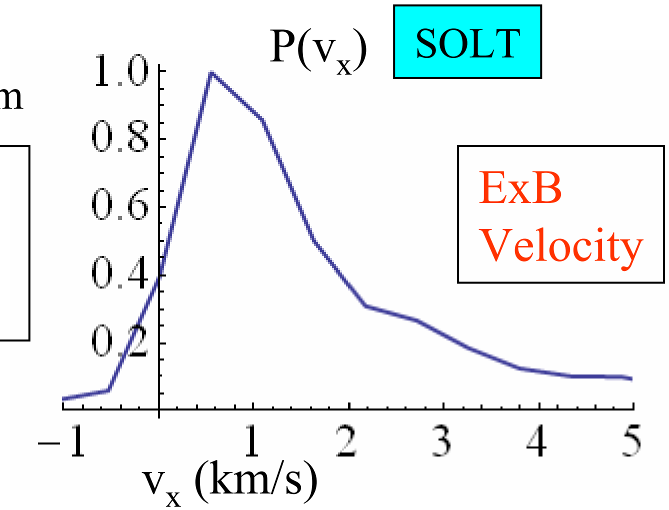
- f_A is max at T_{crit}: $S_I < 0$ when $T_e > T_{crit}$
- In the simulation, T_e is too large outside SEP ($\Delta r > 0$) due to turbulent heat transport.
- *Note that NSTX data has $S_I > 0$ near the SEP.*

PDFs of blob size and velocity provide a stringent test of theory



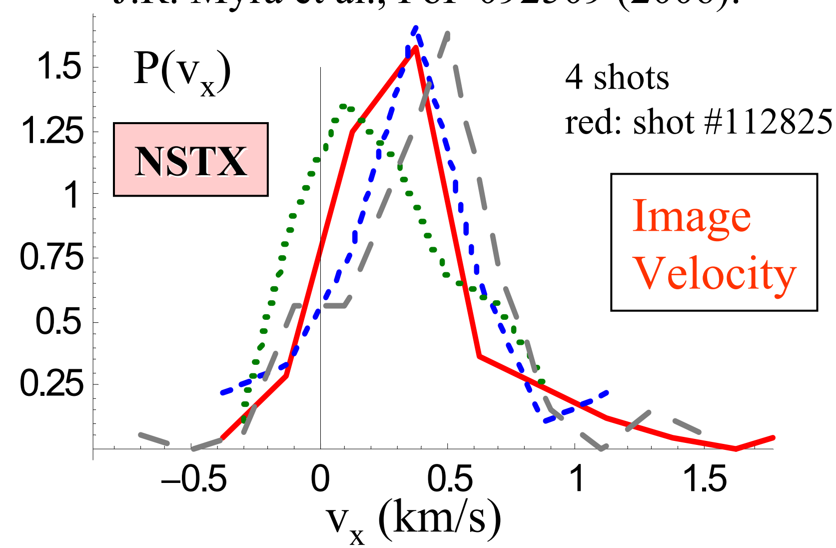
Blob Filter:
(y,t)-maxima
-0.2 cm < Δr < 9.3 cm

The local fit in y is to a Gaussian of half-width a.



- PDFs of blob size are in close agreement.
- SOLT blobs appear to be moving about twice as fast as NSTX blobs.
- We need a less ambiguous measure of image velocity (coming, from Tobin Munsat) and to compare that measure with ExB velocities in the simulations.

J.R. Myra et al., PoP 092509 (2006):



SOLT parallel particle and energy fluxes at the midplane have comparable radial widths

Sheath Boundary Conditions on Open Field Lines (Δr > 0)

$$\Gamma_{//} = \langle c_s n_e \exp[e(\phi_B - \phi)/T_e] \rangle_{y,t}$$

$$q_{//} = \langle s_E c_s n_e T_e \exp[e(\phi_B - \phi)/T_e] \rangle_{y,t}$$

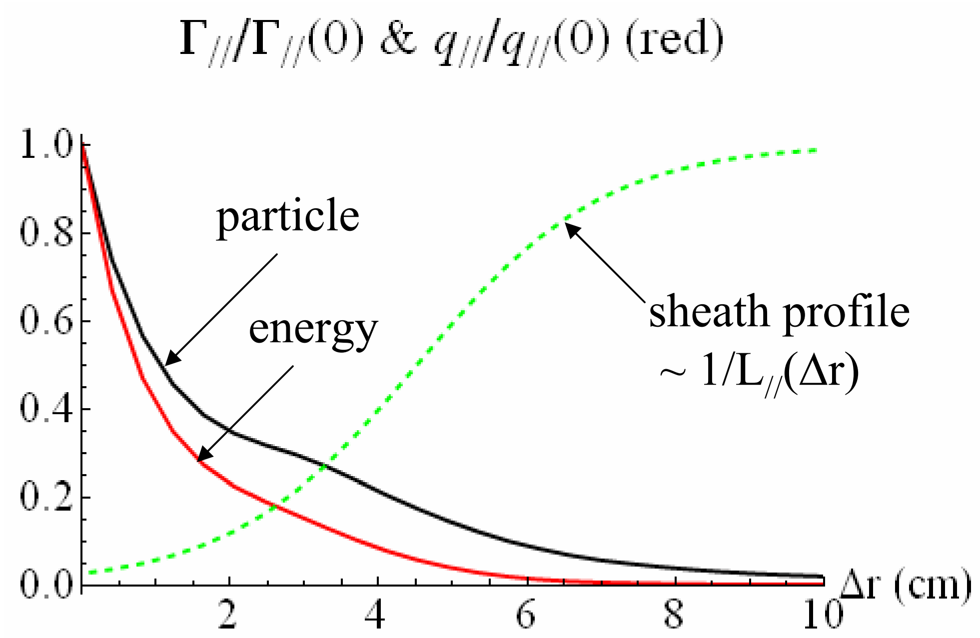
s_E : energy transport enhancement factor (= 6)

$\Gamma_{//}(0)$:

$4.6x10^{19}\ s^{-1} cm^{-2}$

$q_{//}(0)$:

$1.4\ kW / cm^2$



SOLT simulation: same as above for comparison with NSTX shot #112825

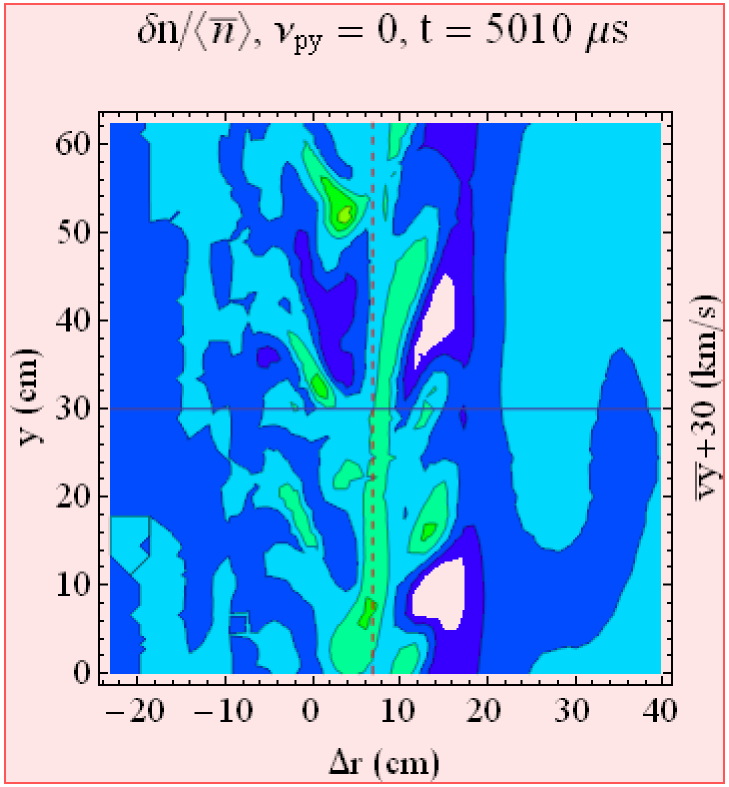
Similar Widths : Both particles and energy are transported ballistically by blobs.

Quantitative comparisons are now feasible between synthetic (SOLT) and experimental GPI data.

- It is essential to analyze the simulation and diagnostic data using the same post-processing algorithms (smoothing and blob filtering).
- The simulated turbulence is sensitive to the parameters that control the stability of the system, e.g. sheath dissipation and sheared flows.
    - The simulated GPI signal is sensitive to the details of temperature and density fluctuations.
    - Still better agreement ($S_I > 0$, slower blobs) will likely be obtained by increasing temperature dissipation in the SOL.
- *Beyond validation*, SOLT *predictions* can be explored.
    - The role of sheared zonal flow in mediating blob transport across the LCS is under study.

Epilogue

High-flux, intermittent blob bursts and zonal flow reversal (spin-up) observed in a SOLT simulation driven more strongly than the NSTX reference cases above:



Relevant to anticipated higher-gradient NSTX profiles?