Edge Sheared Flows and Blob Dynamics

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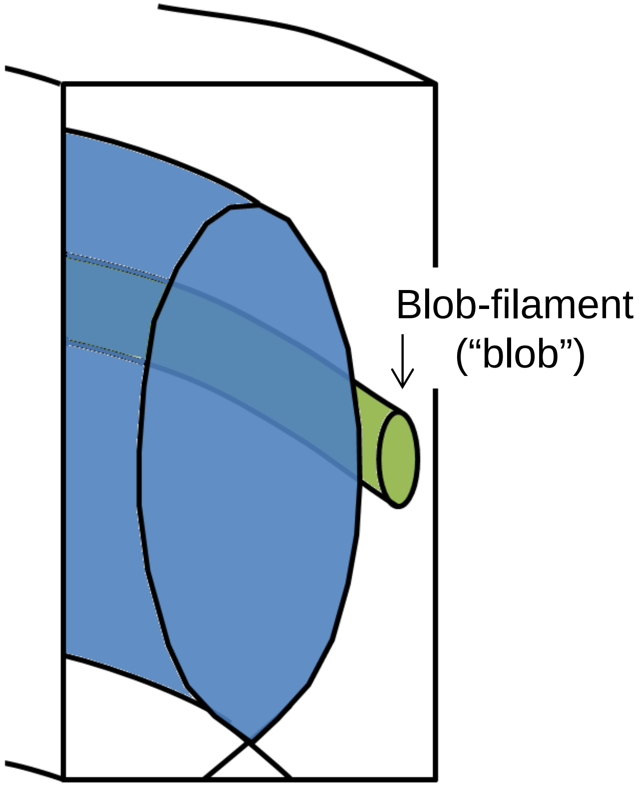
Motivation & Background

- Edge sheared flows:
  - important for the L-H, and H-L transitions
  - generated by, and regulate the turbulence
  - control the character and trajectories of emitted coherent structures such as blob-filaments

- Blob generation and dynamics impacts:
  - the (near-separatrix) scrape-off-layer (SOL) width, which is critical for ITER power handling in the divertor
  - far SOL blob interaction with plasma-facing components

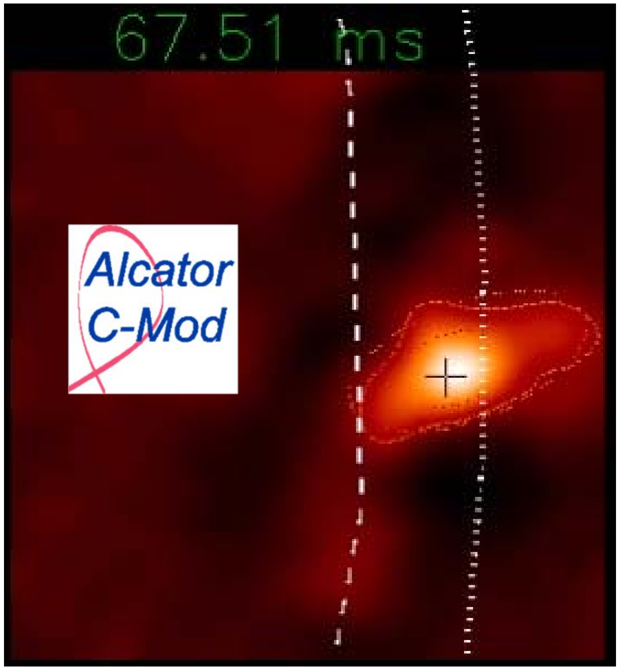


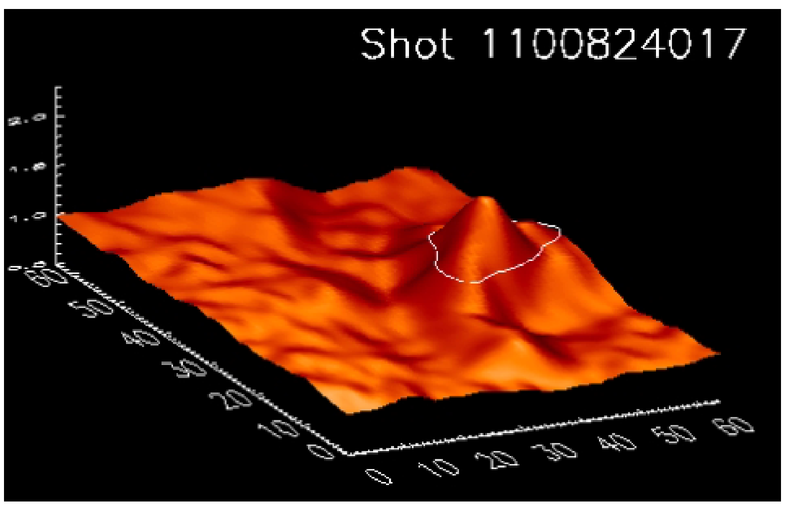
***Conclusion**: Mechanisms related to blob motion, SOL currents and radial inhomogeneity are sufficient to explain the presence or absence of mean sheared flows in selected NSTX and Alcator C-Mod shots.*

Outline

- Experimental method and observations
- Theory of blob motion and sheared flow generation
- Seeded blob and turbulence simulations for NSTX and C-Mod
- Conclusions

Gas Puff Imaging (GPI) and blob-tracking analysis tool



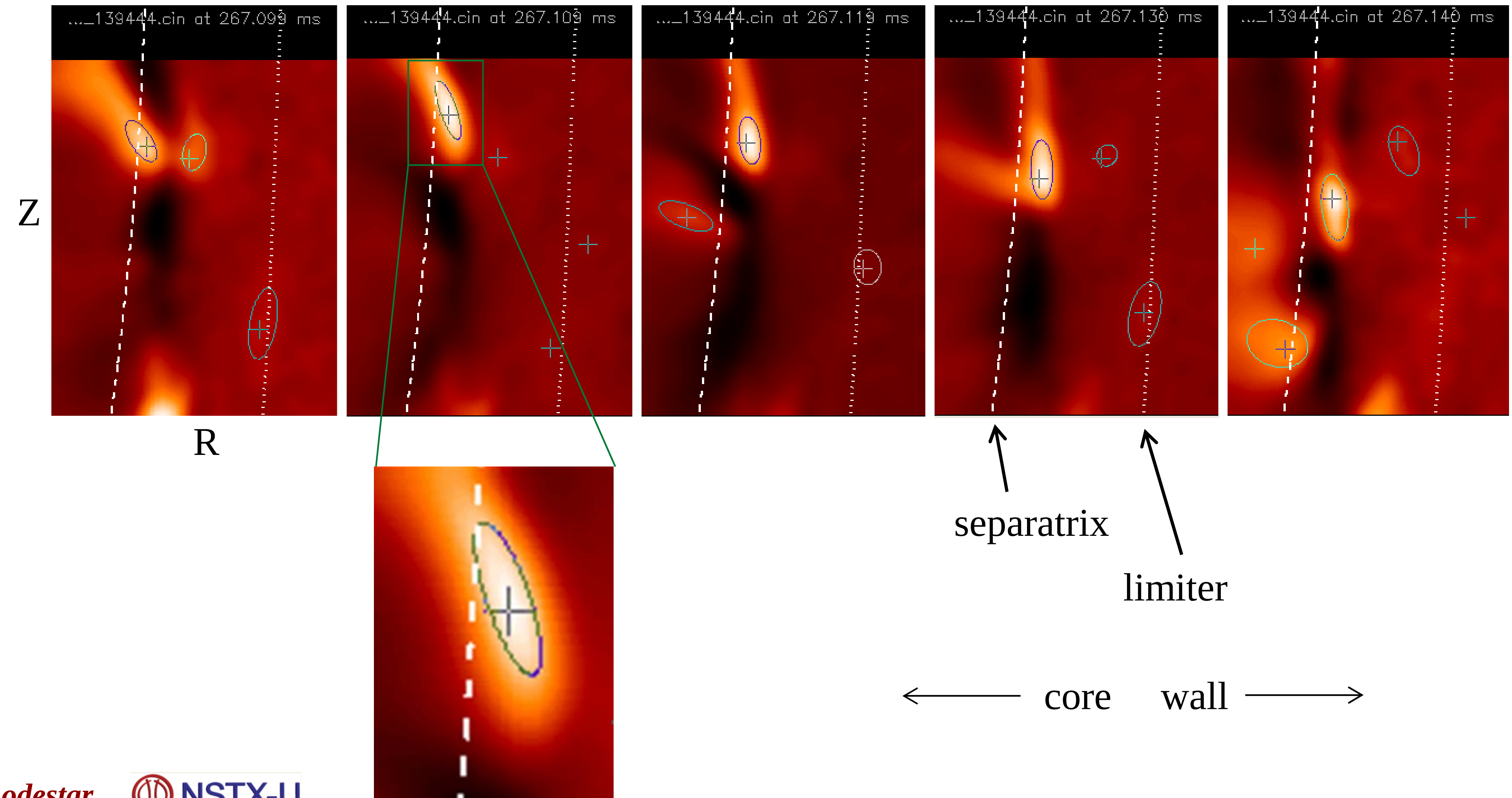


Davis et al. YP8.00038 (Fri. am)

- GPI: Small puff of neural gas (D or He) used to illuminate edge turbulence (via line emission)
- Use relative GPI intensity δI/<I> as the signal to analyze (in 2D space + time)
- For each frame: locate local maxima, fit ellipse to each ⇒ "blob"
  - wave crests & detached filaments
- Track the motion and structure evolution from frame to frame
- Analyze and compare blob tracks from
  - NSTX
  - Alcator C-Mod
  - SOLT code simulations

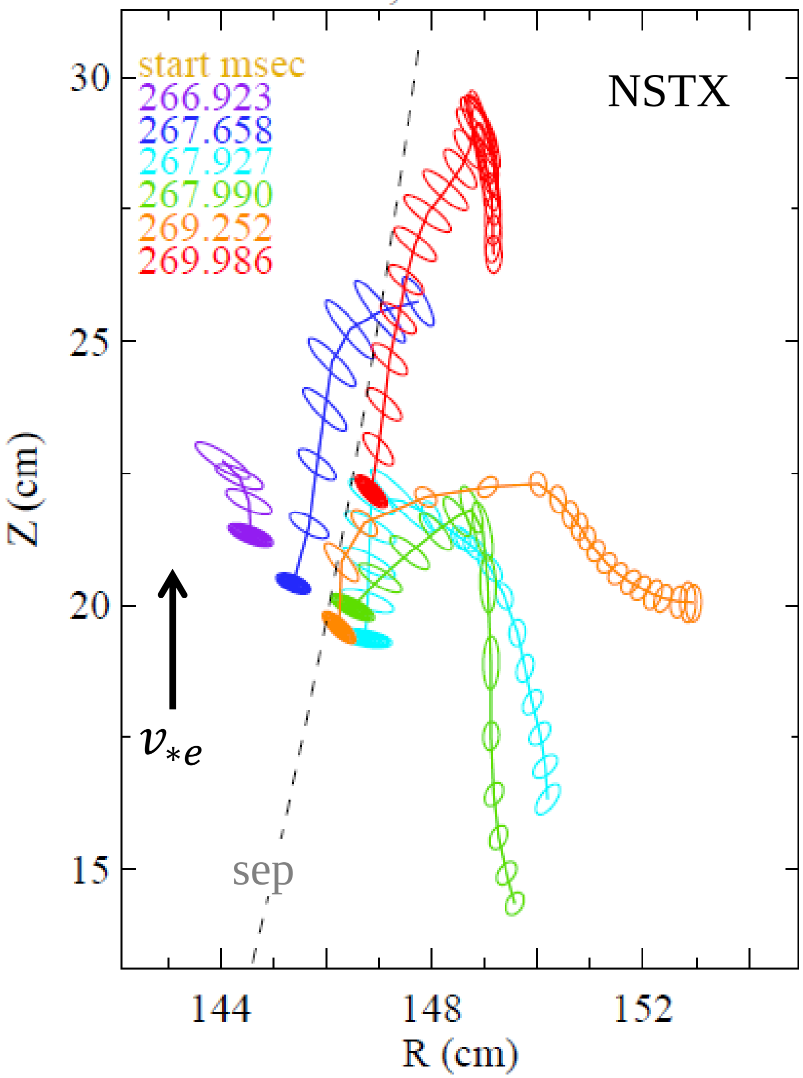
Sample NSTX experimental GPI movie frames

- normalized intensity, blob center (+) and fitted ellipse (0)
- 10 μs per image (every 4th frame of data)



Experimental NSTX blob tracks

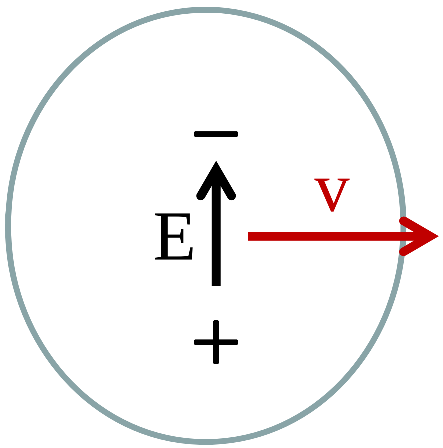
Preheated Ohmic 139444; 267 - 270 ms



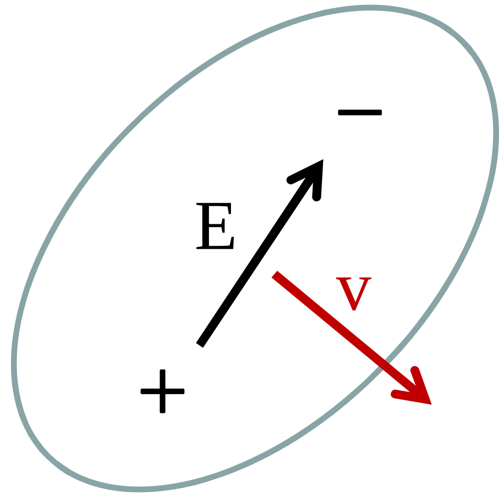
- Some blob tracks show:
  - outward motion (ejection)
  - confinement
  - reversal of v_y near the separatrix

	NSTX 139444	C-MOD 1100824017
$n_{e,sep}$ (cm^{-3})	5.8×10^{12}	1.0×10^{14}
$T_{e,sep}$ (eV)	19.	47.
$\rho_{s,sep}$ (cm)	0.26	0.025
$\Lambda_{SOL} \sim \nu_{e*}(m_e/m_i)^{1/2}$	0.3 – 0.8	1-3
blob size $a_{b,sep}$ (cm)	2.2 ± 0.5	0.4 ± 0.1
$\delta I/\langle I\rangle\|_{sep}$	0 – 1.6	0 – 0.6

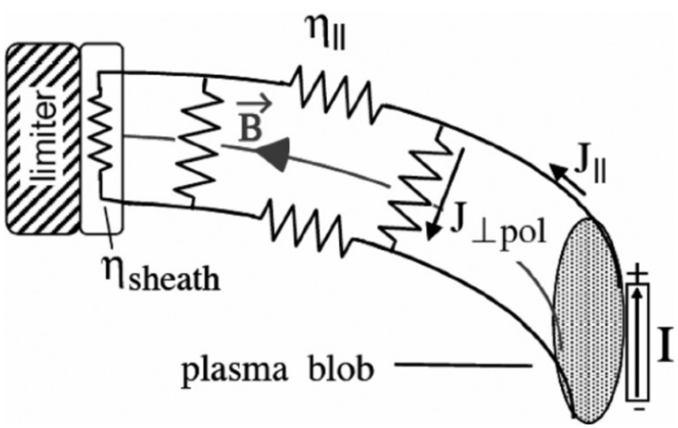
Blob motion is controlled by polarization charges



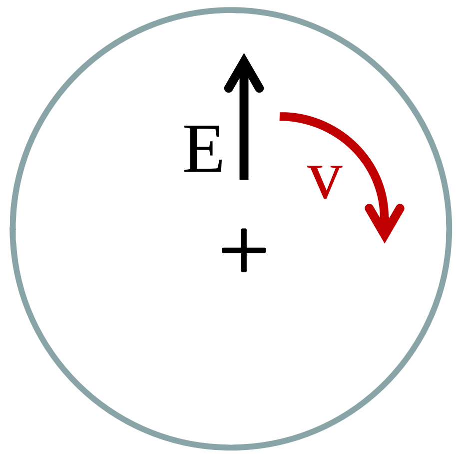
∇B and κ drifts charge-polarize the blob $\Rightarrow$ outward convection



Background flows or drifts rotate and shear converting radial motion to poloidal



Current flows neutralize charges; asymmetrically in SOL



Additional monopole charge (vorticity) component $\Rightarrow$ rotation of dipole

Related Refs.: Diamond and Kim, PF 1991; Terry, RMP 2000; Furno, PRL 2011; Bisai, PoP 2012; Myra PoP 2004; Manz TTF 2012, Horton RMP 1999

Simulation model

D. A. Russell, et al, Phys. Plasmas **16**, 122304 (2009)

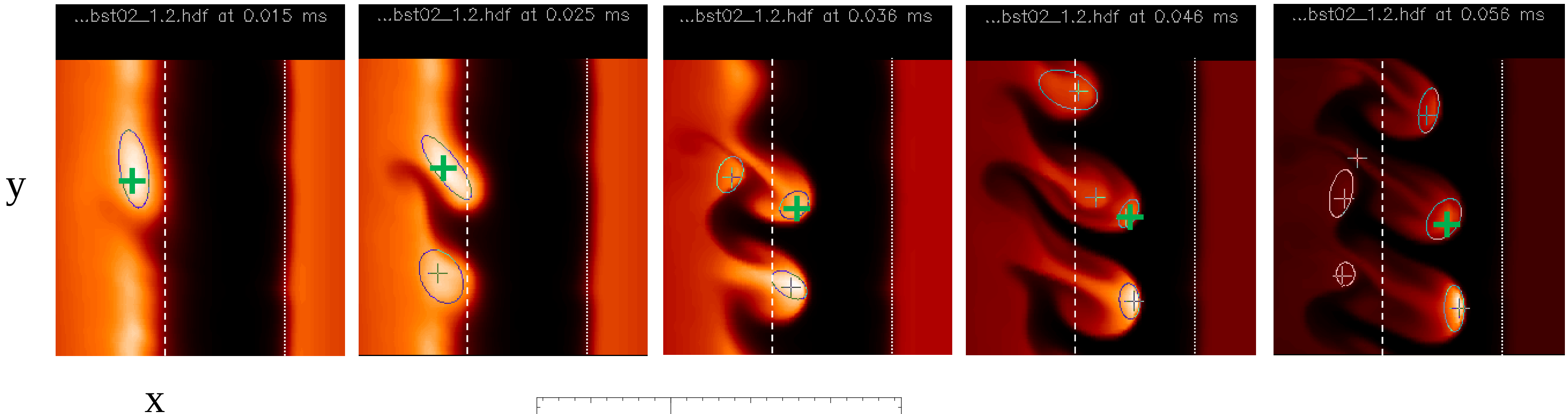
Scrape-Off-Layer Turbulence (SOLT) code

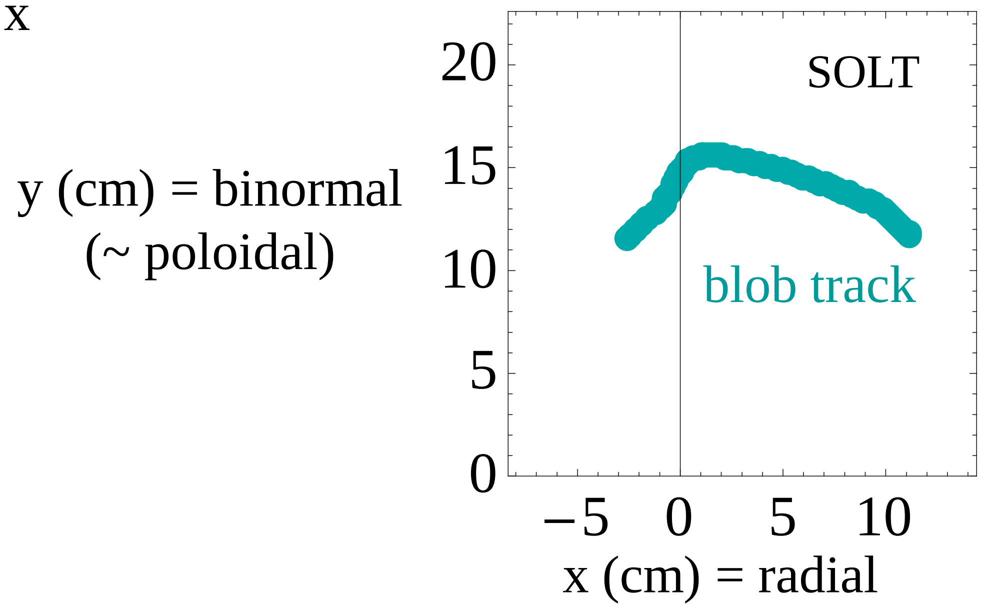
- 2D (x,y) fluid turbulence code: model SOL in outer midplane $\perp B\mathbf{e}_z$
  - classical parallel + turbulent cross-field transport
- Evolves n_e, T_e, Φ with parallel closure relations
  - sheath connected, with flux limits, plus collisional regimes
- Strongly nonlinear: $\delta n/n \sim 1 \Rightarrow$ blobs
- Model supports drift waves, curvature-driven interchange modes, sheath instabilities

- Here:
  - Seeded blob simulations (initial value)
  - Quasi-steady turbulence simulations

Trajectory for base case NSTX seeded blob

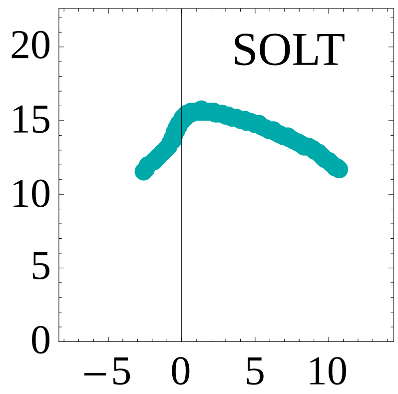
- In SOLT, initialize a typical NSTX blob (size, amplitude) on the experimental background profiles (n, T; R, B, $L_{||}$, …) and follow its trajectory +





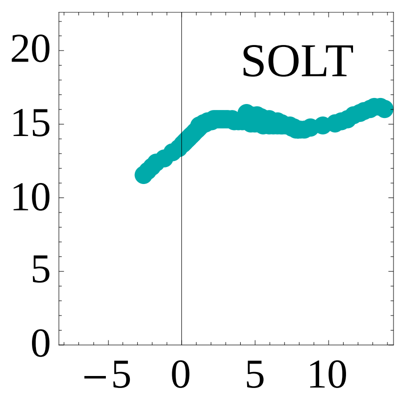
- Blob flows up in the edge (e-direction) and down in the SOL (i-direction)
- Track reversal near separatrix (like data)

Sheath interactions, electron drifts, shear layers, influence trajectories in SOLT



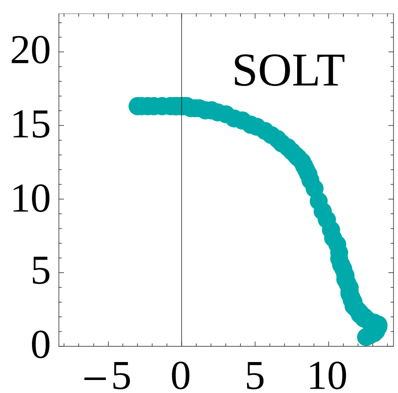
imposed $v_{Ey} = 0$

fully sheath connected
(~ NSTX base case)



sheath disconnected

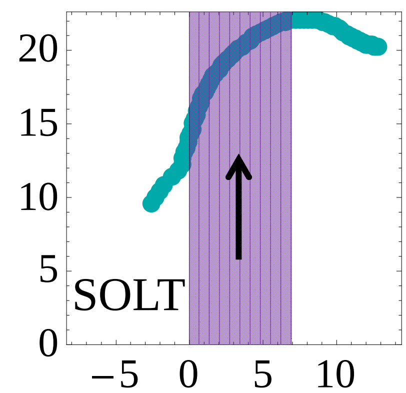
SOL sheath currents matter



electron adiabaticity and drifts off

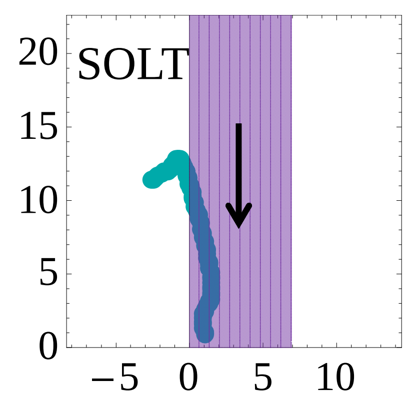
Diamagnetic drift shear matters

- Artificially vary simulation physics to infer mechanisms actually operative in the experimental data
- Acceleration a_y near separatrix related to Reynolds stress and sheared flow generation



imposed SOL $v_{Ey} > 0$

Counter-shear flow ejects blob

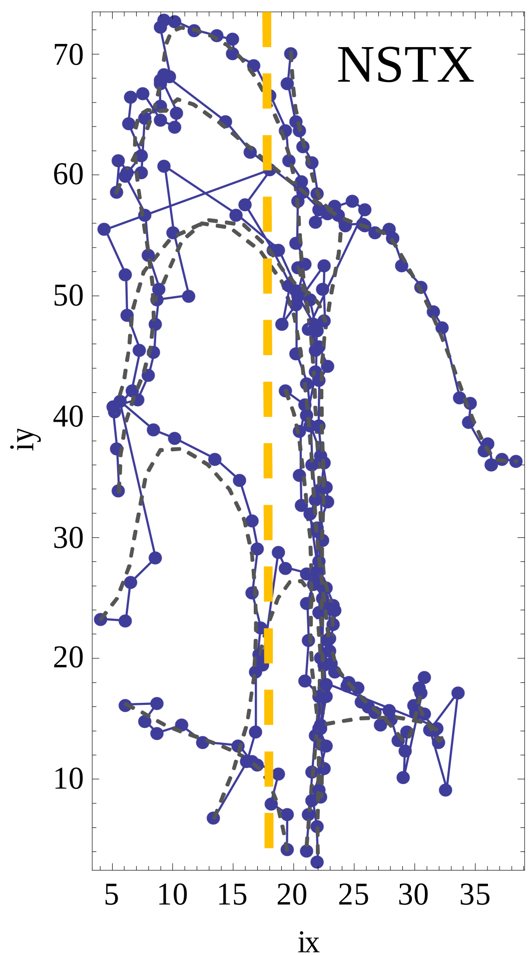


imposed SOL $v_{Ey} < 0$

Co-shear flow traps blob (shear confinement)

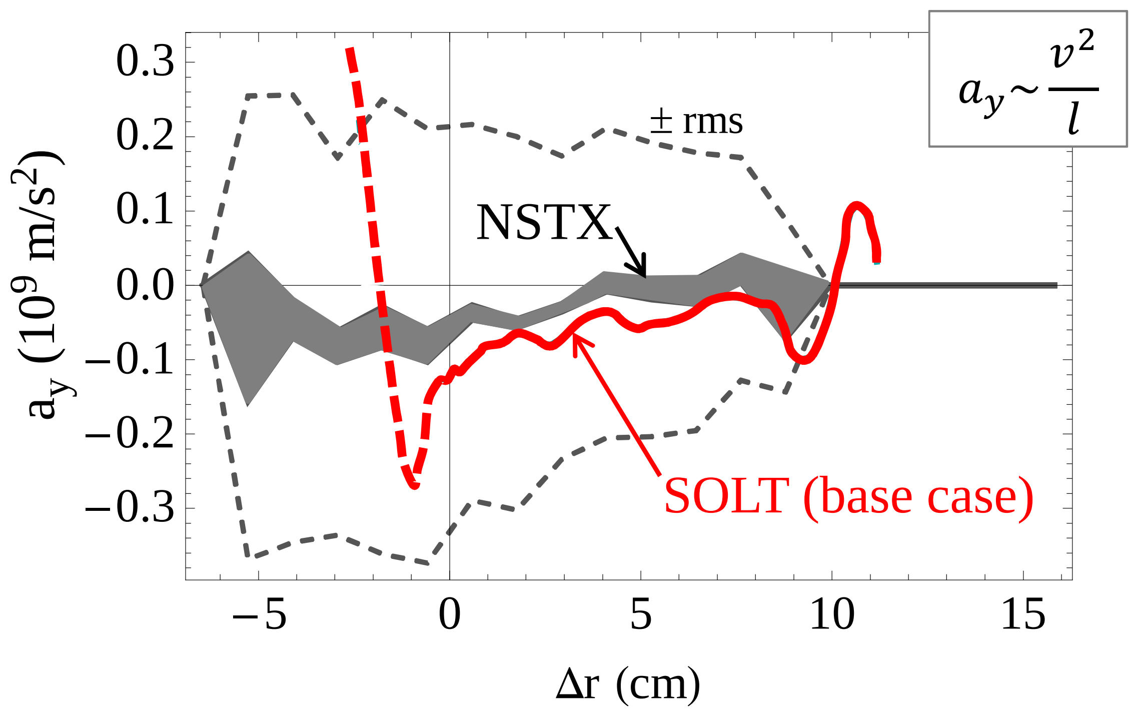
Blob trajectories allow determination of Reynolds stress

- Smoothed fits to blob tracks x(t), y(t) ⇒ accelerations and mean RS

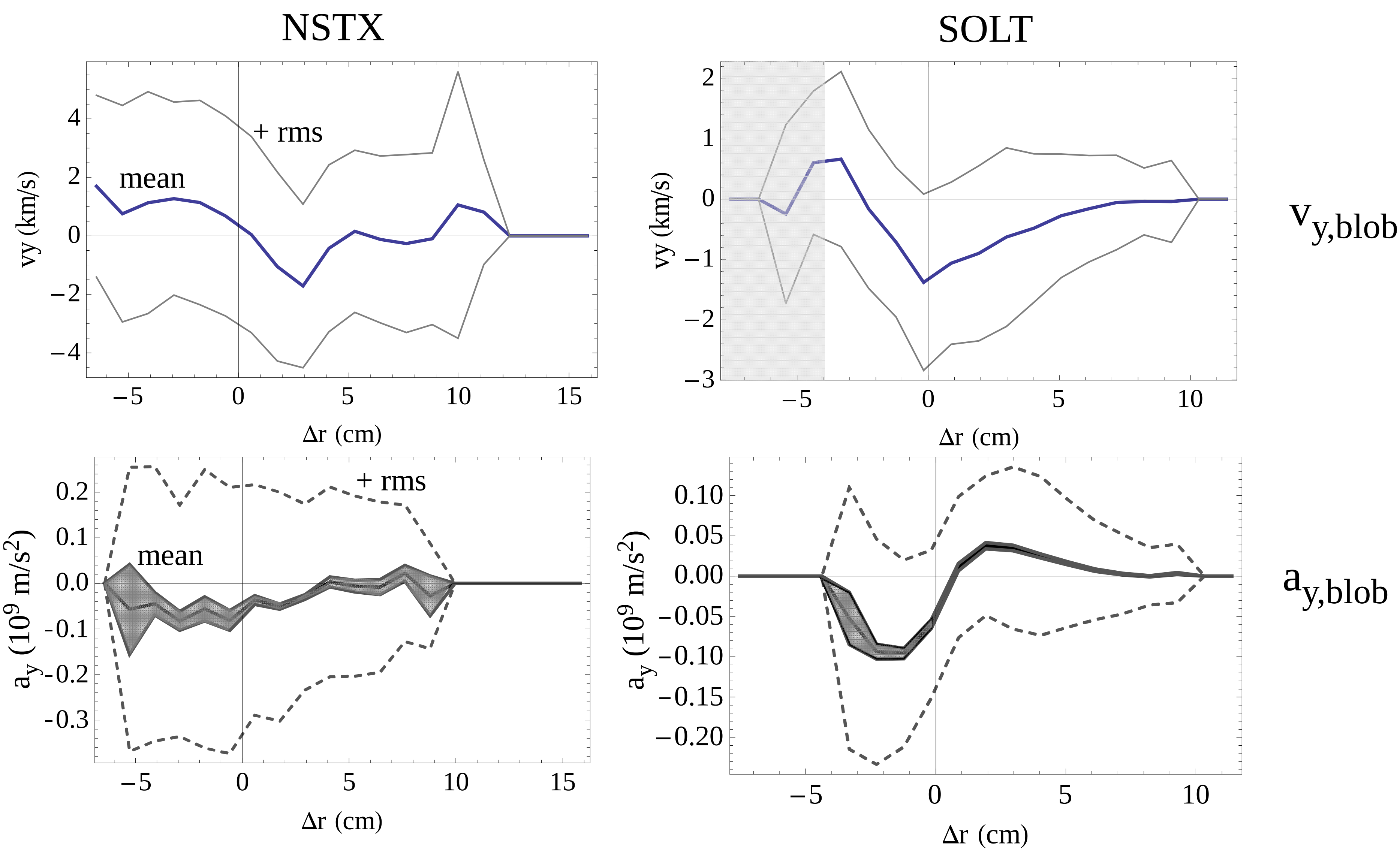


particle *fluid*

$$\langle a_y \rangle = \left\langle \frac{dv_y}{dt} \right\rangle = \langle \boldsymbol{v} \cdot \nabla v_y \rangle = \partial_x \langle v_x v_y \rangle$$



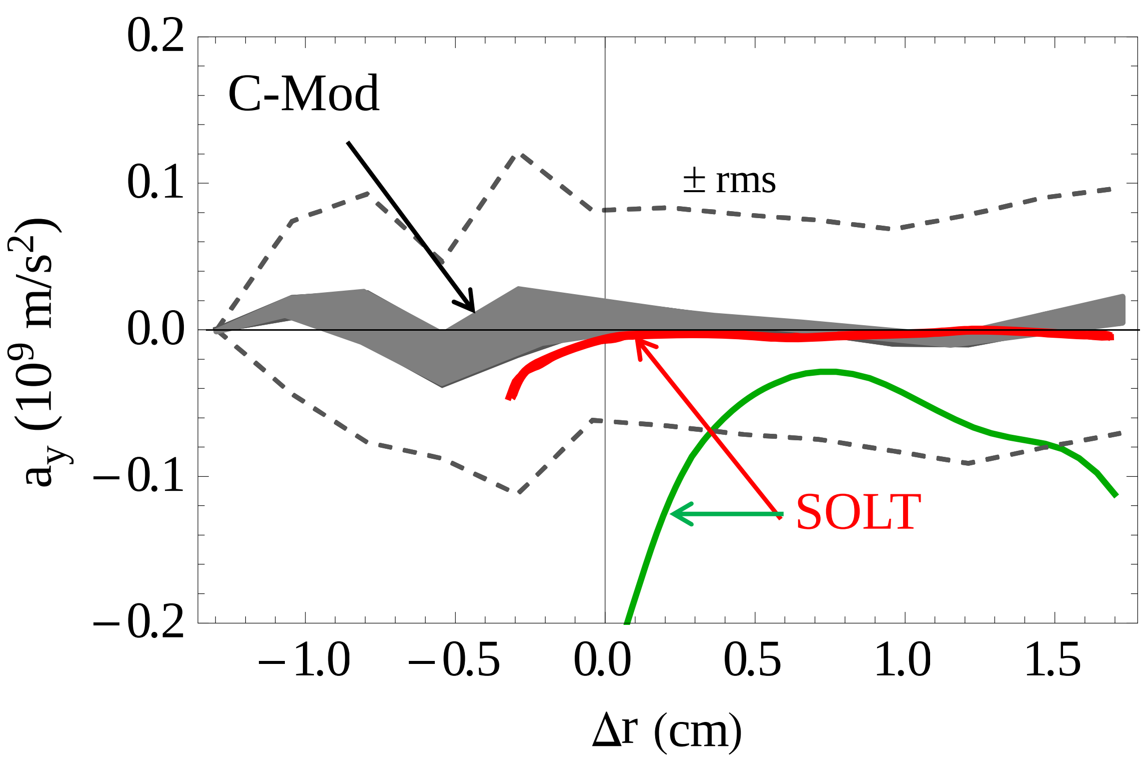
SOLT turbulence simulations run to quasi-steady state: similar blob flows and accelerations as NSTX



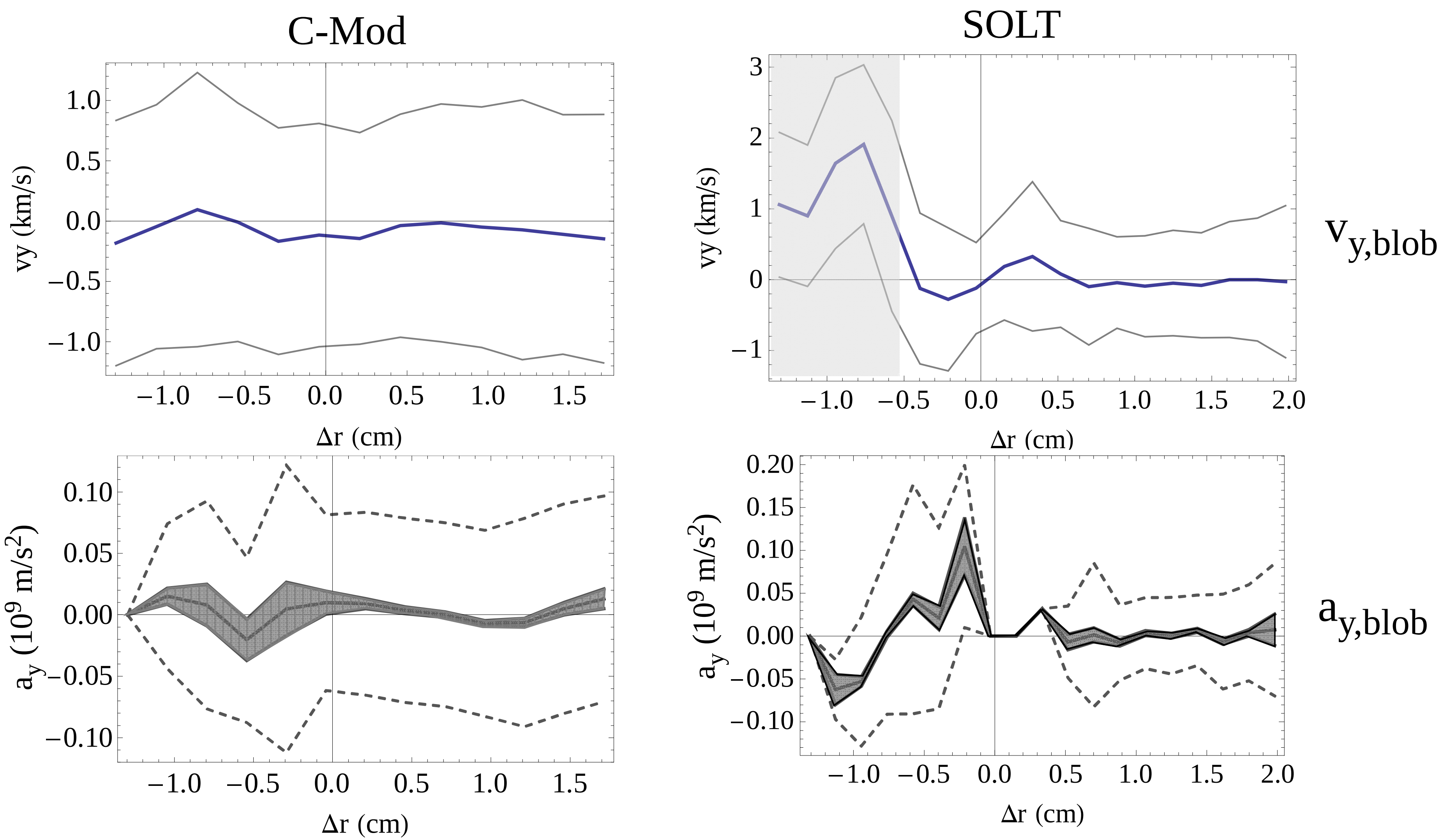
rms fluctuations > means

Seeded blob simulations of high collisionality C-Mod shot require modeling extra 3D physics

- High collisionality SOL ⇒ parallel variation along B, X-point effects
- SOLT model using midplane plasma parameters disagrees with data.
- Assuming sheath disconnection from the plates and extra charge dissipation from friction or cross-field X-point currents gives better agreement.



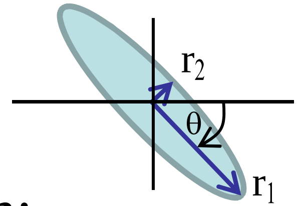
C-Mod turbulence simulations with these assumptions reproduce small mean blob flows with turbulent shearing



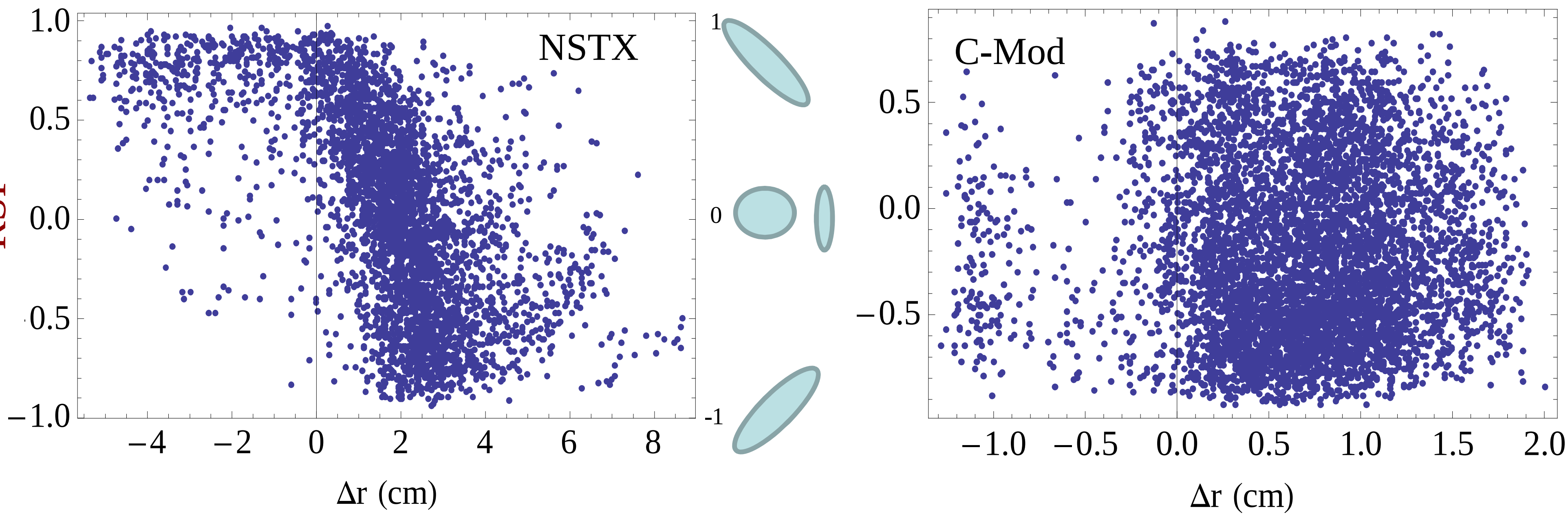
Qualitative agreement near separatrix and in SOL

Core-side flow BC in SOLT $v_E = 0$ is artificial (may contaminate a_y)

Blob ellipticity and tilt angle variation provide a Reynolds stress proxy (RSP)



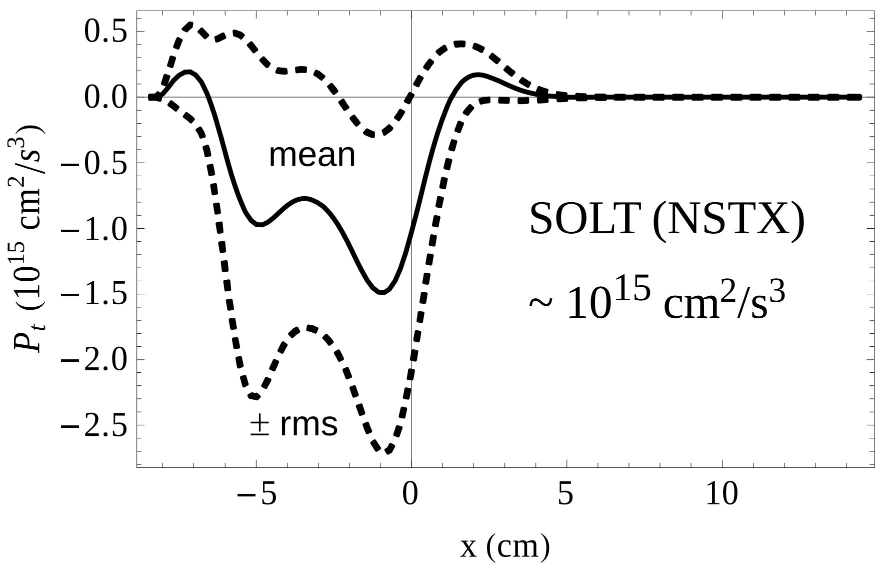
- Blob tracking algorithm fits ellipticity and tilt to tracked objects
- Order unity variation in RSP = $-\sin(2\theta)[1-(r_2/r_1)^2]$ consistent with:
  - Significant blob shearing
  - $\omega_E' \sim 1/\tau_c$ (shearing affects dynamics: distorts blob, regulates flux [Russell et al., 2009])
- Reynolds force is in the right direction to drive observed flows in NSTX

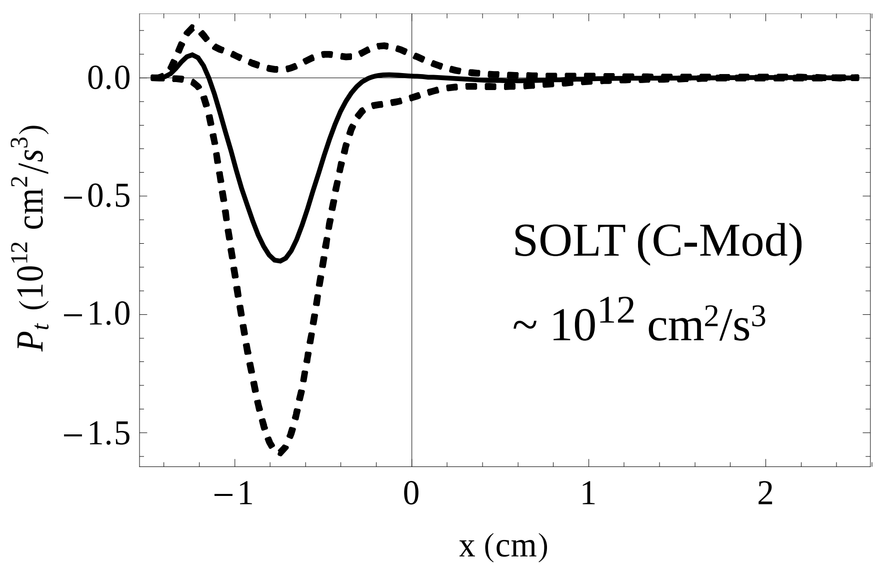


Turbulence production rate
SOLT simulations of NSTX and C-Mod

- Turbulence production rate $P_t = -\langle v_x v_y \rangle \frac{\partial \langle v_y \rangle}{\partial x}$

  $P_t < 0 \Rightarrow$ turbulent energy $\rightarrow$ mean flows





- Net perpendicular force on the plasma

$$F_\perp / P = -\langle n v_x v_y \rangle / \langle 2nTv_x \rangle$$

  - NSTX ~ 0.8 N/MW
  - C-Mod < 0.05 N/MW

Summary and Conclusions

- GPI blob tracking tools
  - motion and changes in structure of blob-filaments
  - applied to NSTX, Alcator C-Mod, SOLT simulations
  - enables a new kind of comparison of edge turbulence theory with data
- Coherent structures crossing the separatrix are sheared and rotated by:
  - radially varying drifts
  - parallel sheath currents from changes in magnetic topology

  $\Rightarrow$ flows
- Simulated accelerations from these mechanisms are large enough to account for the observed Reynolds stress and mean sheared flows in NSTX.
- Sheared flows in the NSTX and C-Mod edge are sufficiently strong to affect blob dynamics and transport.
- There is evidence for mean flow damping in a high collisionality C-Mod case, possibly due to 3D effects.
- Model caveats: cold ions, simplified DW physics model, 2D fluid theory, but captures the essence of nonlinear E×B dynamics.