Observation of Particle Transport Barriers in Reverse Shear Plasmas on TFTR

P. C. Efthimion, S. von Goeler, M. Bitter, S. H. Batha*,
W. A. Houlberg[+], F. Levinton*, D. McCune, D. Mueller,
A. L. Roquemore, E. J. Synakowski, and M. C. Zarnstorff

Princeton Plasma Physics Laboratory,

*Fusion Physics & Technology
[+]Oak Ridge National Laboratory

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Combined Multiple Ion Species Measurements in Reverse Shear Plasmas is a Stringent Test of Transport Theory

TFTR

I. Introduction to Reverse Shear Plasmas

II. Measurement Techniques

III. Tritium Transport Measurements

- Enhances understanding of hydrogenic transport.
- Transport is a key component of profile density control in reactors.

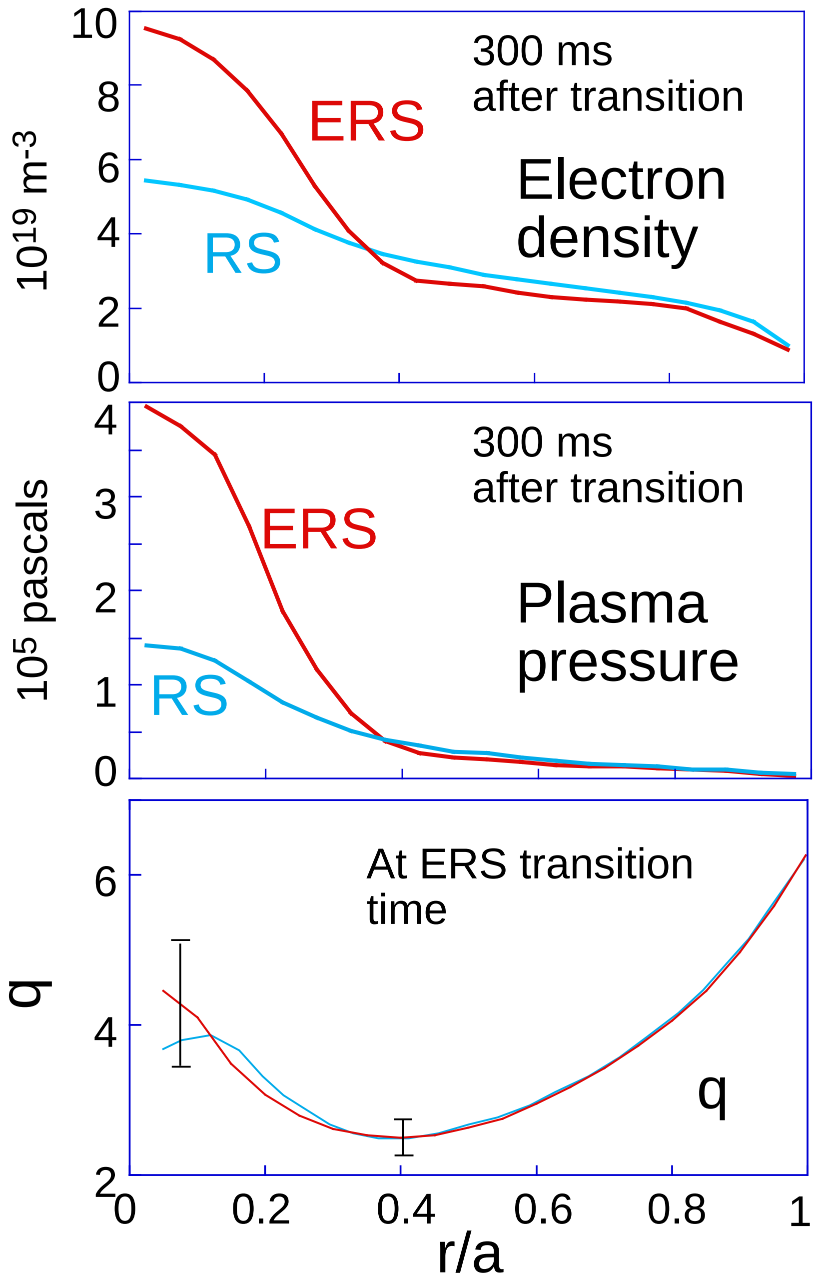
III. Helium Measurements

- Ash accumulation can limit fusion power in reactors, like ITER.

Anomalous transport mechanisms are reduced to where neoclassical theory can be critically examined.

Two distinct confinement regimes can develop in the core of TFTR reverse shear plasmas

TFTR



- Both particle and energy confinement improve inside shear reversal region

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Nearly steady-state ERS aided transport experiments

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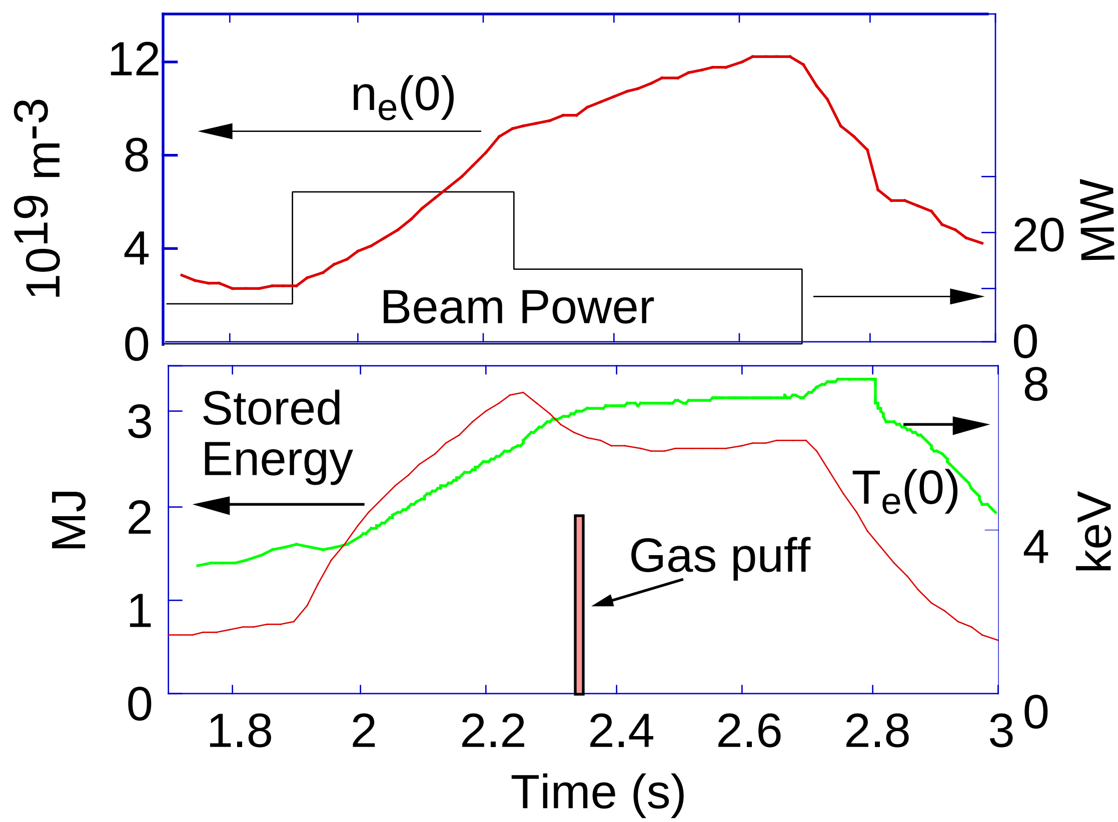
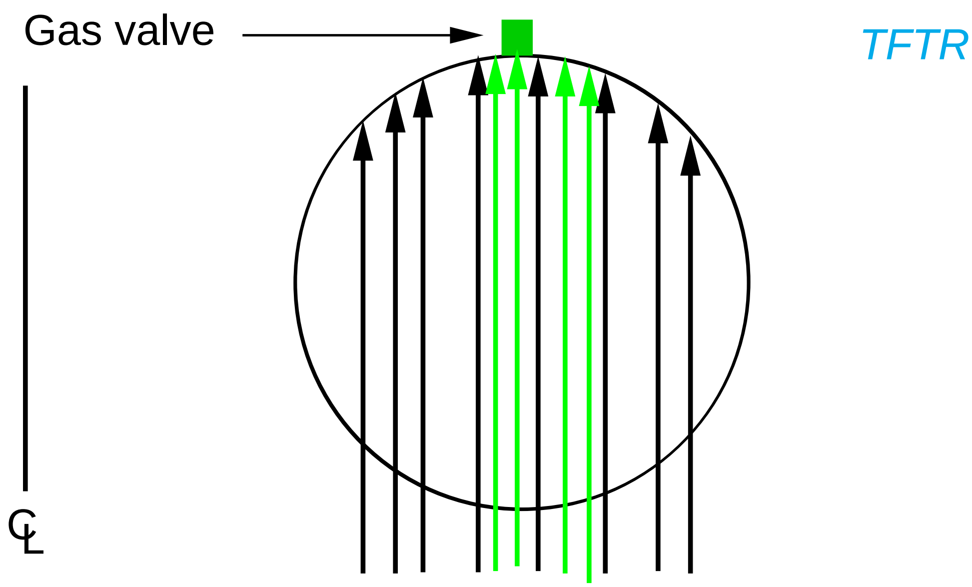


- Steady-state permits detailed studies of T and He transport utilizing gas puffs
- Steady-state ensures that Shafranov shift is constant during particle transport experiments

Local Tritium Transport Inferred from DT Neutron Emission



- 8 NE451 ZnS detectors and 4 new BC400 plastic detectors to improve spatial resolution.
- Ion Density Profile

n_t^* → **TRANSP** → S_{dt}^* (r,t)

Tritium density, $n_t(r,t)$, inferred from measured neutron emissivity, $S_{dt}(r,t)$:

$$n_t(r,t) = n_t^* \, S_{dt}(r,t) / S_{dt}^*(r,t).$$

- Transport coefficients determined from regression analysis.

$$\delta\Gamma_T(r,t) = - D_T(r) \, \delta\nabla n_t(r,t) + V_T(r) \, \delta n_t(r,t).$$

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Local helium transport measurements are made with charge exchange recombination spectroscopy (CHERS)

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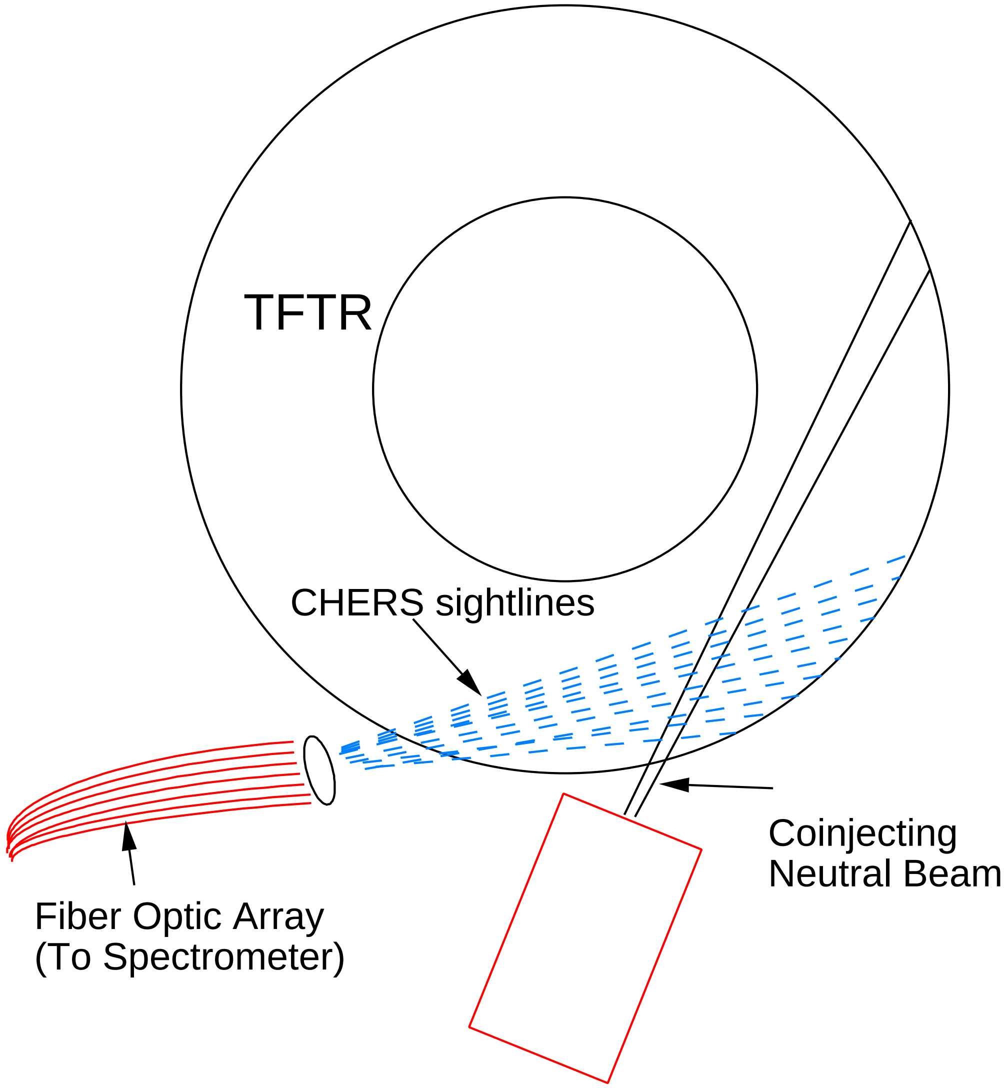
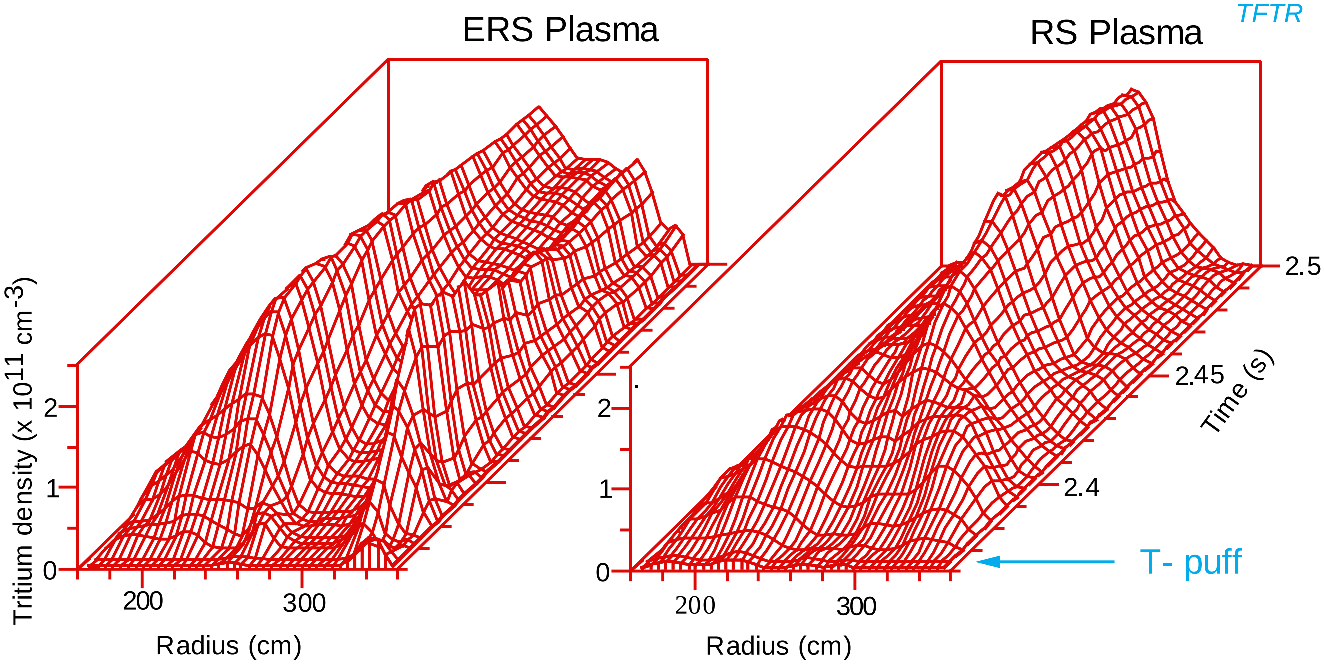


$D^0 + He^{2+} \rightarrow D^+ + He^+ + \gamma$ (4686Å)

- Measurement is local
- Time resolution 10 ms

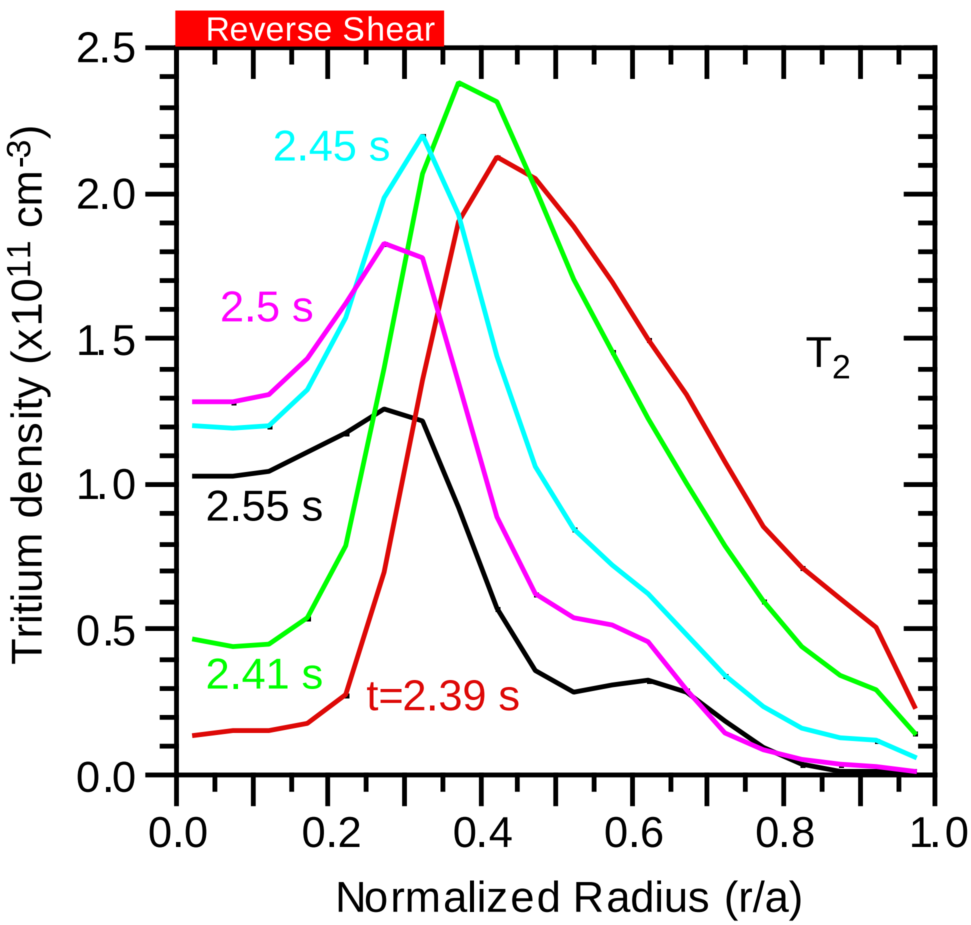
Transport Barrier is Formed in Enhanced Reverse Shear Plasmas



- Ehanced reverse shear plasma remains hollow or flat..
- Reverse shear plasma fills in and peaks in less than 100 ms.
- Density profiles constructed from neutron emissivity and basis function computed by TRANSP.

Transport Barrier Observed in Tritium Density Evolution of ERS Plasmas

TFTR



- Transport barrier is within the reverse shear region.
- Recycling coefficent for tritium ≈ 0.02 - 0.05.

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RS Plasmas Do Not Exhibit Transport Barrier

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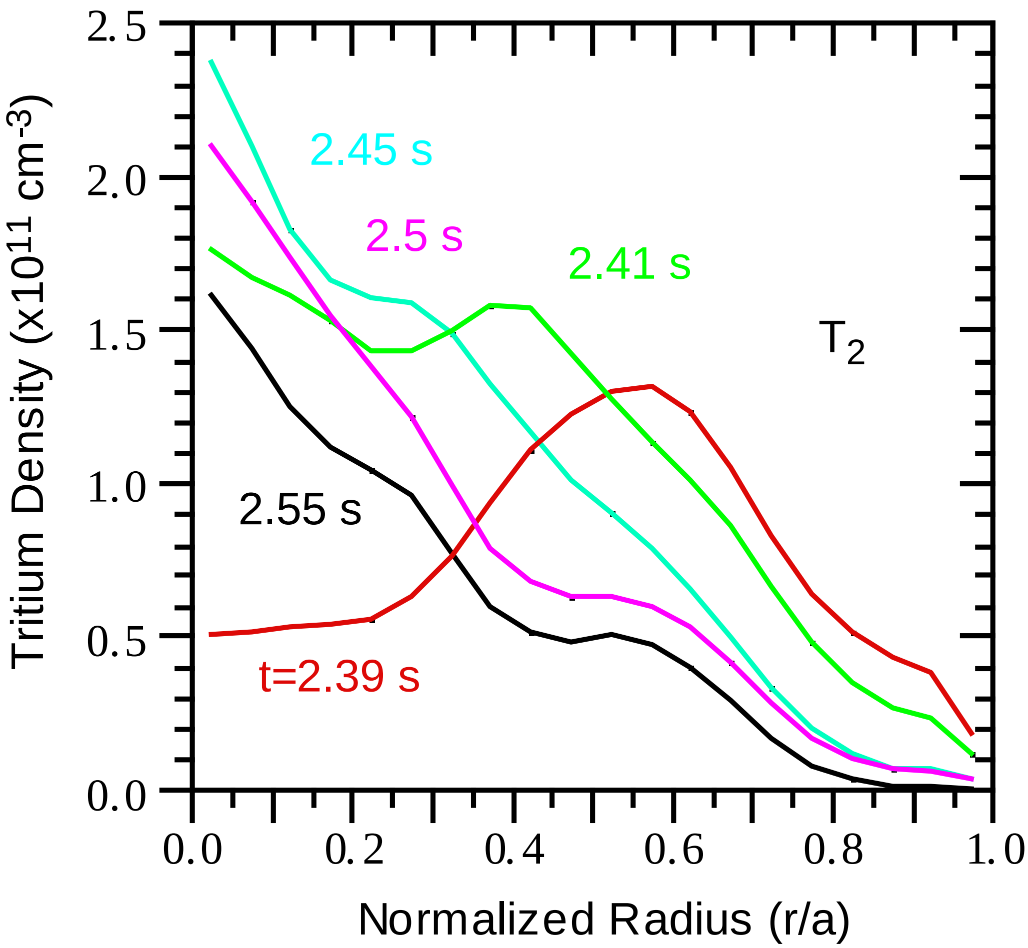

- Profile fills quickly compared to ERS plasmas.

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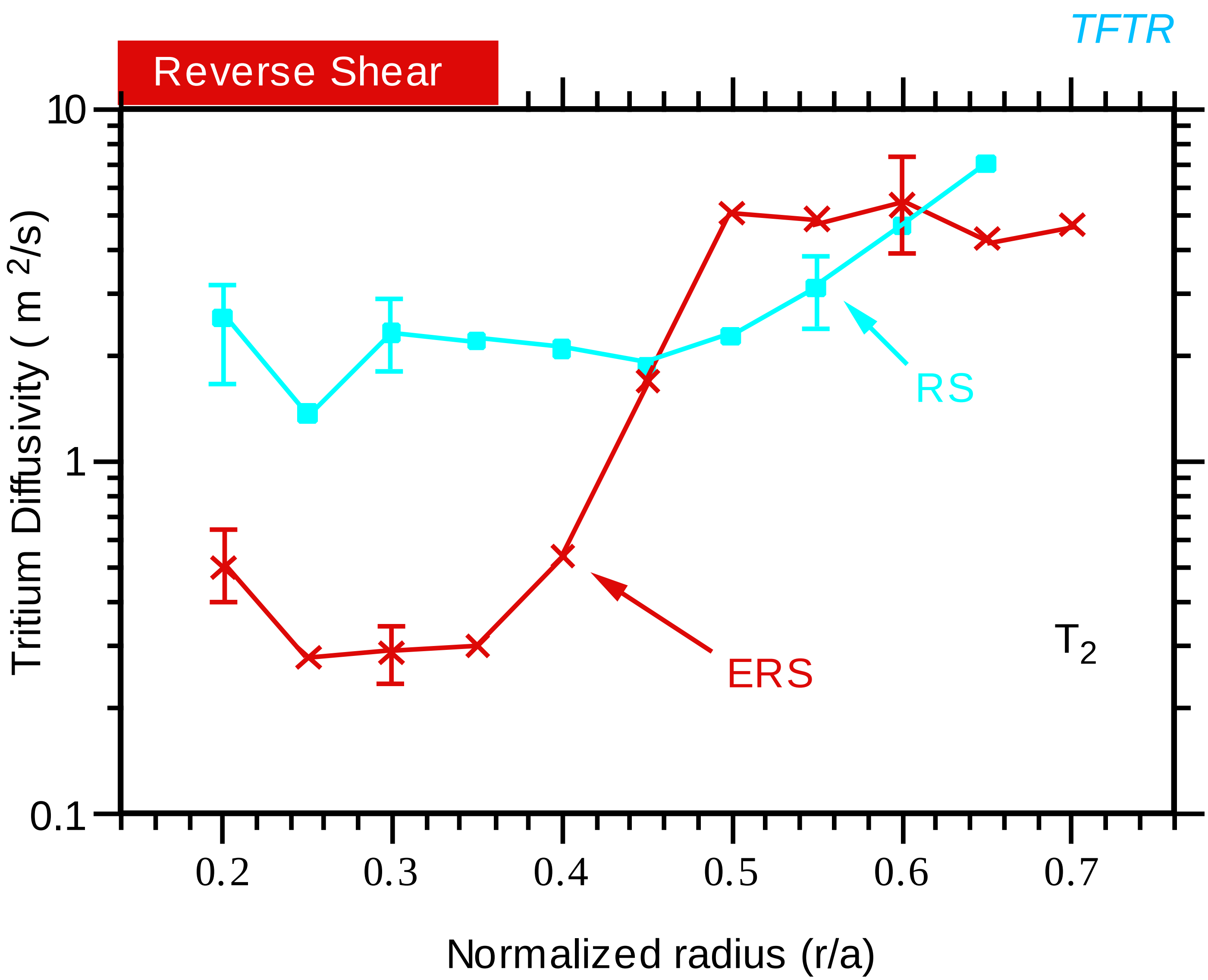
ERS has Low Diffusivity In Reverse Shear Region



- Tritium diffusivity is 20 times larger than electron diffusivity determined from neutral beam fueling.

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In ERS Core, Helium & Tritium Diffusivities are Similar and Agree with Neoclassical Theory

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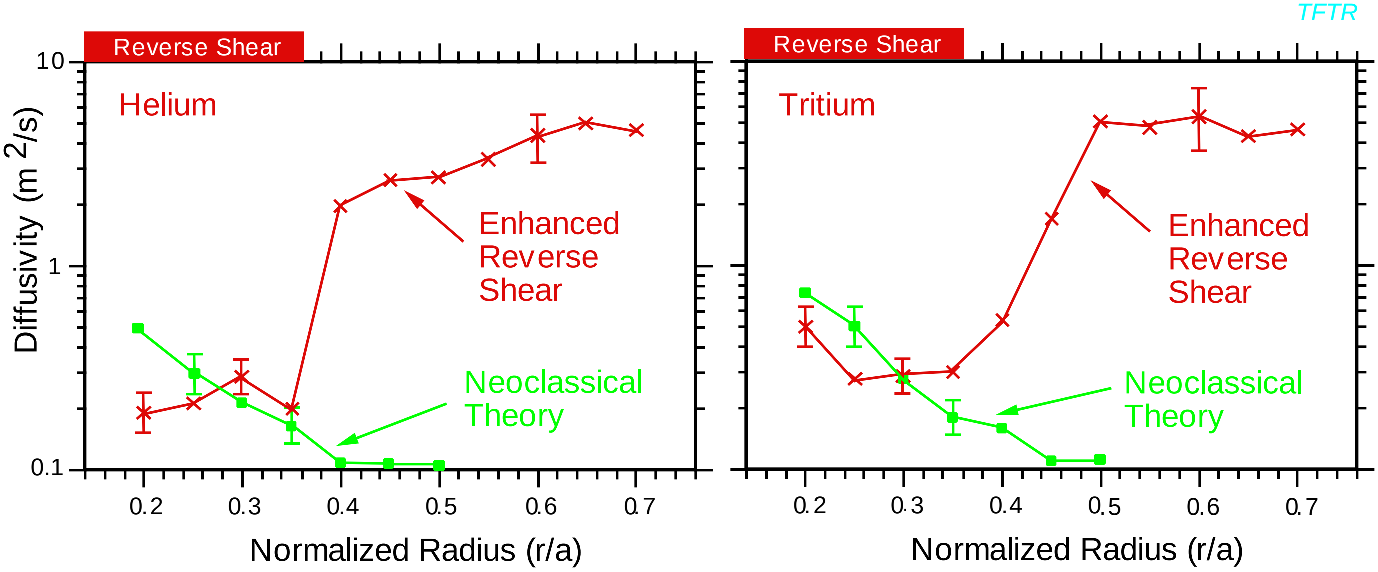

- Neoclassical helium & tritium diffusivity calculated by NCLASS using measured profiles.

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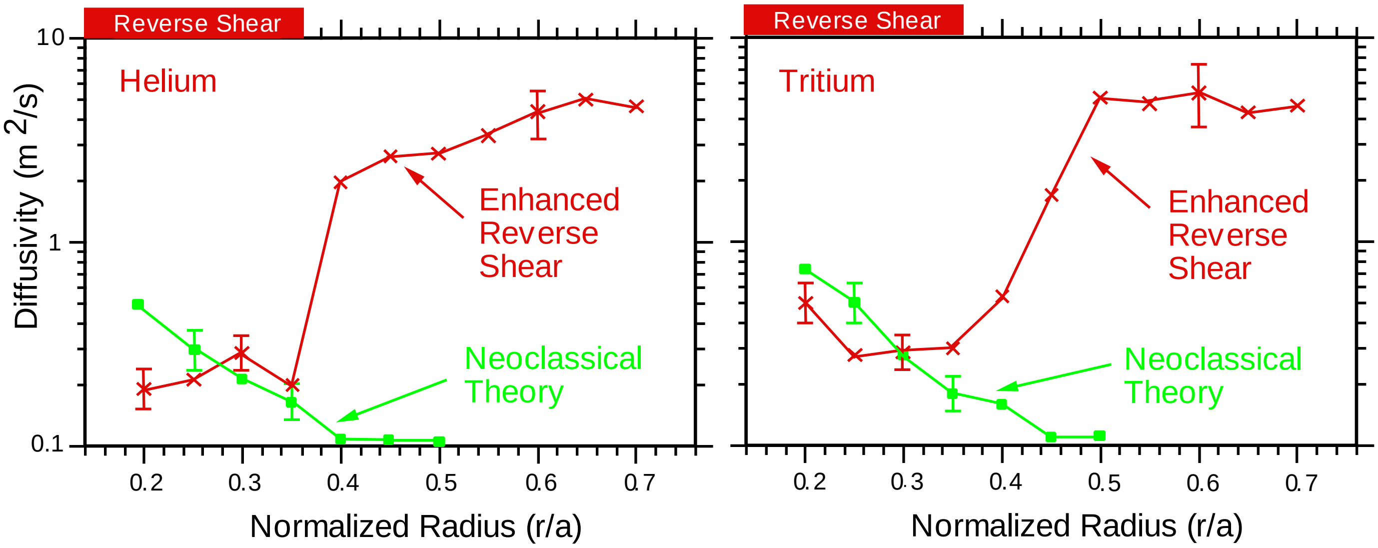

- Neoclassical helium & tritium diffusivity calculated by NCLASS using measured profiles.

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Diffusivity of RS Plasmas is Substantially Larger Than Neoclassical Predictions

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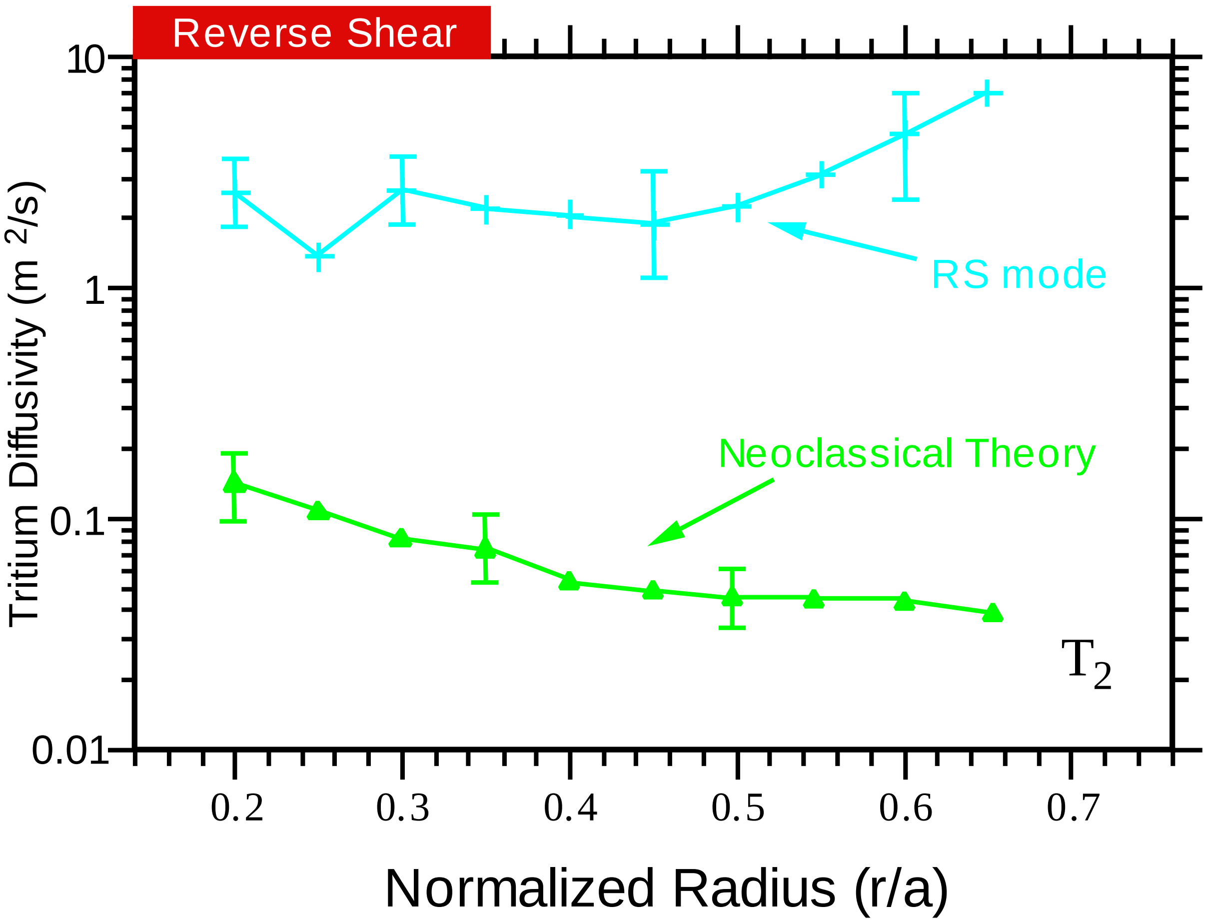

- Neoclassical predictions in RS mode are lower than in ERS because gradients in background plasma are smaller.

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Core Pinch is Modest in ERS PLasma

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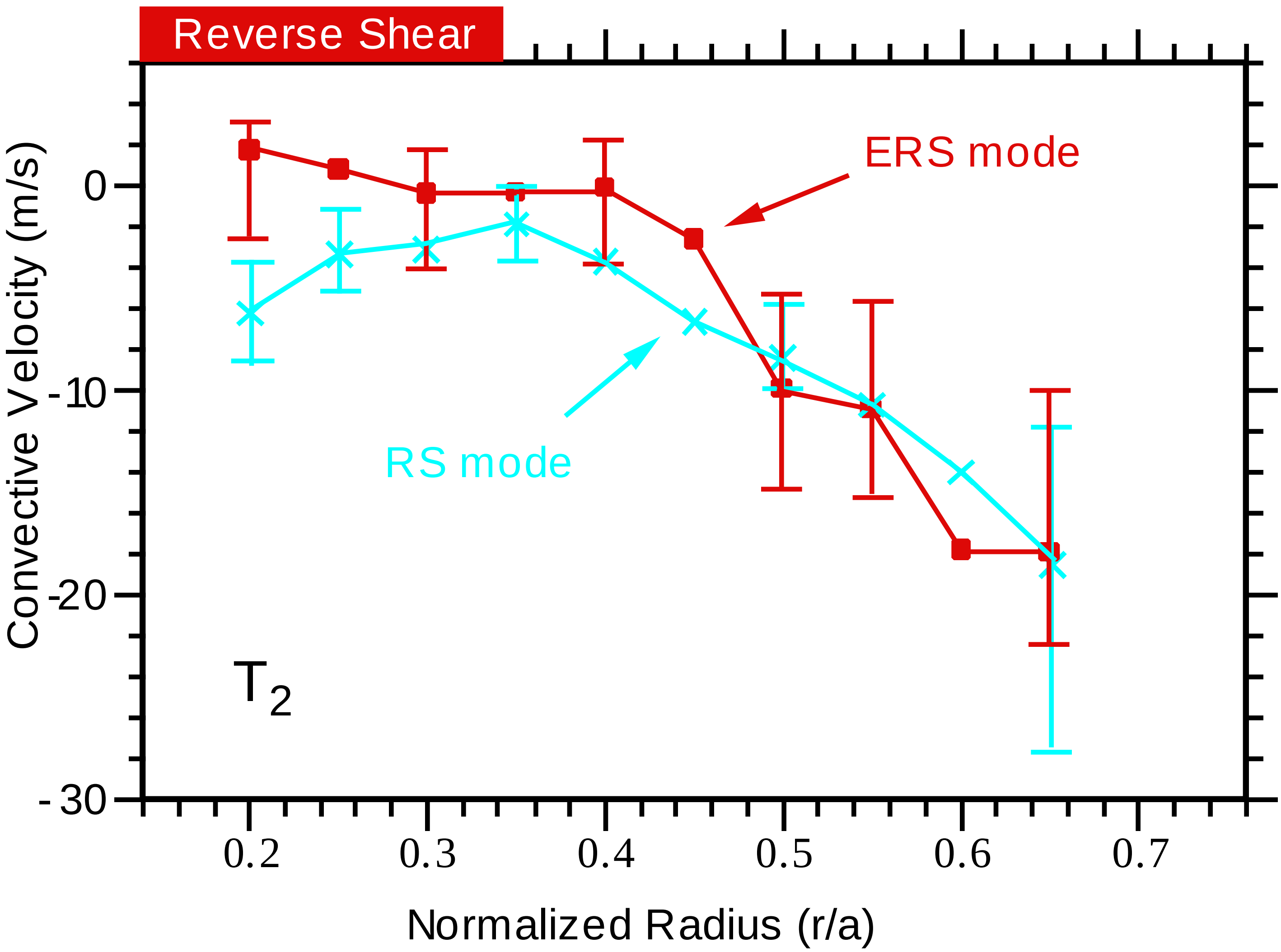
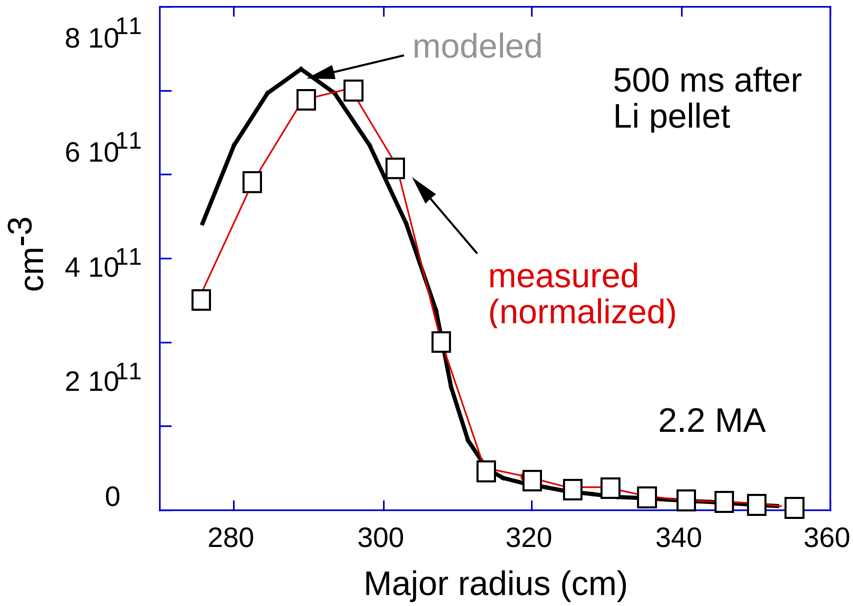


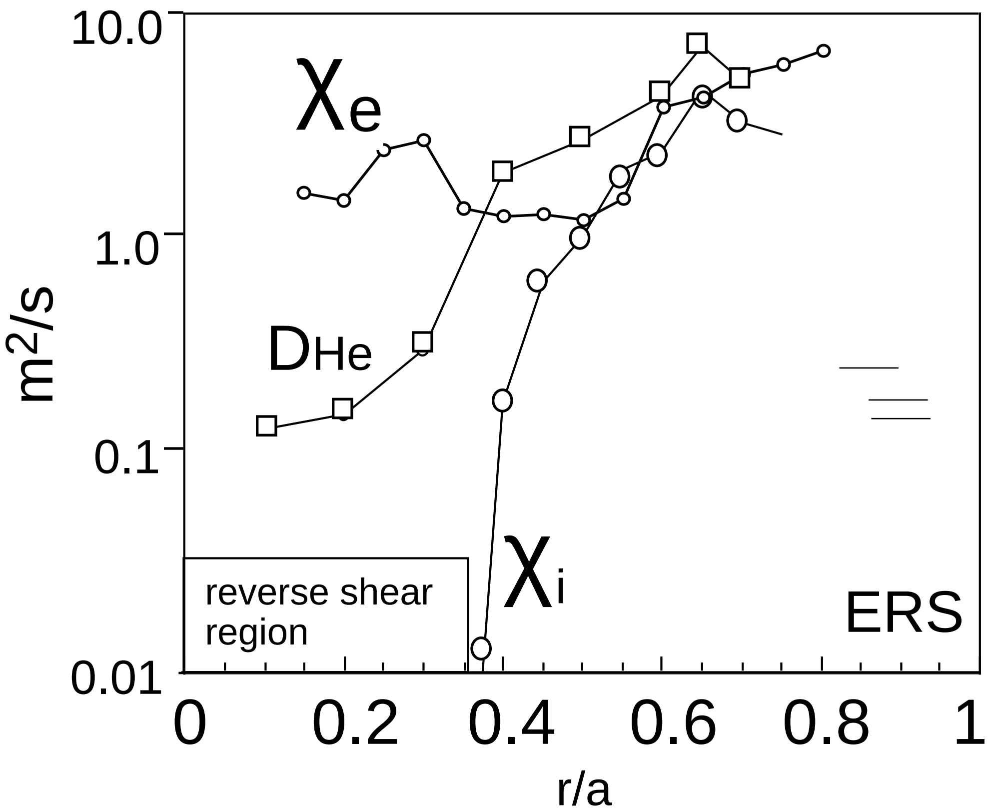
- Helium has similar convective velocities.
- Within uncertainties, velocities similar to Neoclassical.

Lithium evolution after pellet injection is consistent with steep gradients in diffusion coefficients in core

TFTR



- Density time evolution modeled with TRANSP using D_{He}, V_{He}, and Li deposition measured from perturbed n_e



10.0
1.0
0.1
0.01
m2/s
χe
DHe
χi
reverse shear
region
ERS
0
0.2
0.4
0.6
0.8
1
r/a

Conclusions

Trace ion density (T, He, Li) evolution indicates transport barrier in ERS plasmas.

Sharp gradient in diffusivity near reverse shear layer & low core pinch are responsible for barrier.

D_T & D_{He} $\approx$ D_{neo} inside reverse shear region of ERS plasmas.

ERS is only regime where D_T & $D_{He} >> \chi_I$, consistent with neoclassical theory.

No He ash problem with TFTR ERS diffusivities. Situation uncertain in reactor due to unknown χ_e scaling.

Observe D_T neoclassical dependence on B^2 inside reverse shear region of ERS.

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