TRANSP Status and Workshop Objectives

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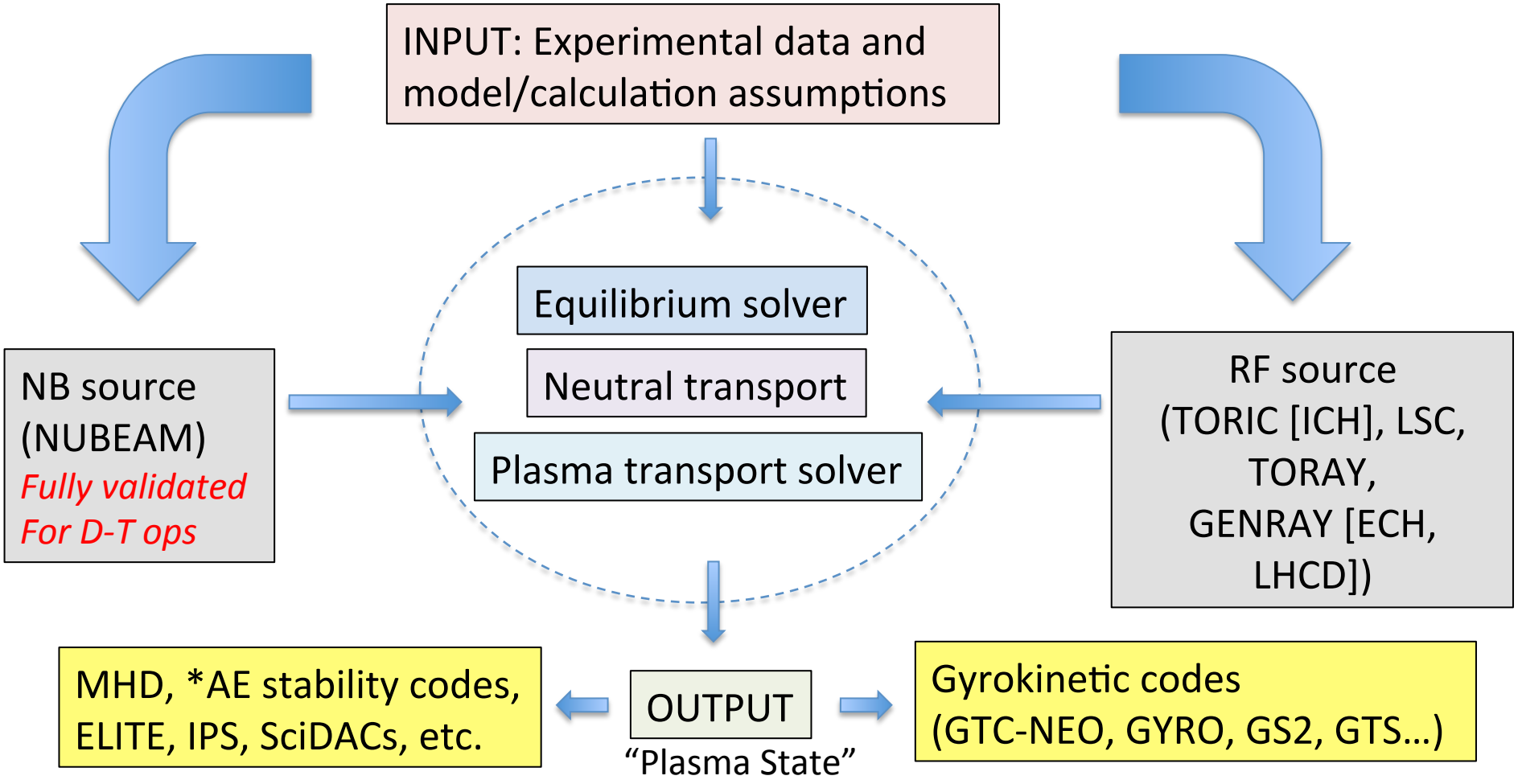
TRANSP is a time-dependent, 1 ½ D tool for interpretive and predictive analysis of tokamak, ST and RFP plasmas



Output of TRANSP (Plasma State File) is standardized for simplifying input to other computationally intensive codes

Kernel of the code is the solution of the particle, energy and momentum transport equations

Particle: $$\frac{\partial}{\partial t}\left(nV'\right)-\frac{\partial}{\partial \rho}\left(\left|\nabla\rho\right|^2 V'D\frac{\partial n}{\partial \rho}\right)=V'\left(S_{gas}+S_{beam}-L_{c-x,recomb,etc}\right)$$

Energy (e^-): $$\frac{\partial}{\partial t}\left[\frac{3}{2}V'n_e kT_e\right]+\frac{\partial}{\partial \rho}\left[V'\left\langle\left|\nabla\rho\right|^2\right\rangle n_e k\left(T_e v_e-\chi_e\nabla T_e\right)\right]=V'\left(P_{OH}+P_{beam}-P_{ie}-P_{rad}\right)$$

Momentum: $$\frac{\partial}{\partial t}\left(n_i m_i V'\left\langle R^2\right\rangle\omega\right)+\frac{\partial}{\partial \rho}\left[V'\Gamma_\Omega\right]=V'\left(\sum T_{input}-\nabla\cdot\Pi_\phi-mnR(\omega-\omega^*)\tau_{damp}^{-1}\right)$$

Interpretive: INPUT: T_e, T_i, n_e, ω,..... OUTPUT: $D_{e,I}$, $\chi_{e,I,\phi}$,.....

Predictive: INPUT: $\chi_{e,I}$, D, ... OUTPUT: $T_{e,I}$, n_e

Comparisons of inferred transport coefficients against those from models can be made in "interpretive" mode

The compute intensive parts of TRANSP now make use of parallel processing

PTSOLVER: is a modular multivariable Newton-based solver used in the predictive mode that advances T_e, T_i, n_i, ω from one plasma-state to the next.
Choice: NCLASS, NEO, TGLF, GLF23, CDBM, RLW, MMM, ….

- TGLF is parallel over wave-numbers and flux surfaces
- Scales well to over 1000 cpu at NERSC
- Stand-alone version for benchmarking XPTOR/TGYRO

NUBEAM: can now be run with 1000's of processors to allow much improved statistics over past versions

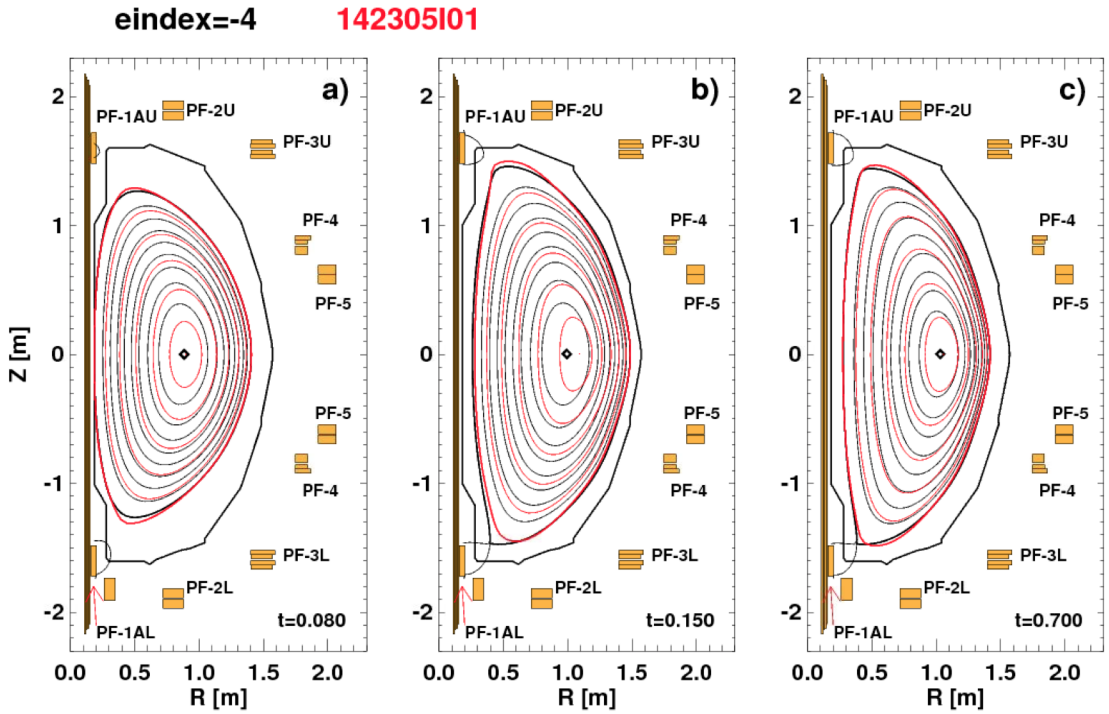
- Recent benchmark performed with PENCIL and BBNBI
- GPU version under development

TORIC: MIT parallel version of TORIC5 is used that is parallel over poloidal modes

GENRAY and CQL3D: Parallel versions are being interfaced

Free boundary equilibrium solver, ISOLVER, implemented – essential for full TRANSP predictive applications

Free boundary TRANSP "validated" against high elongation NSTX discharge



Used ISOLVER, TRANSP predictive simulations to project NSTX-Upgrade operating points

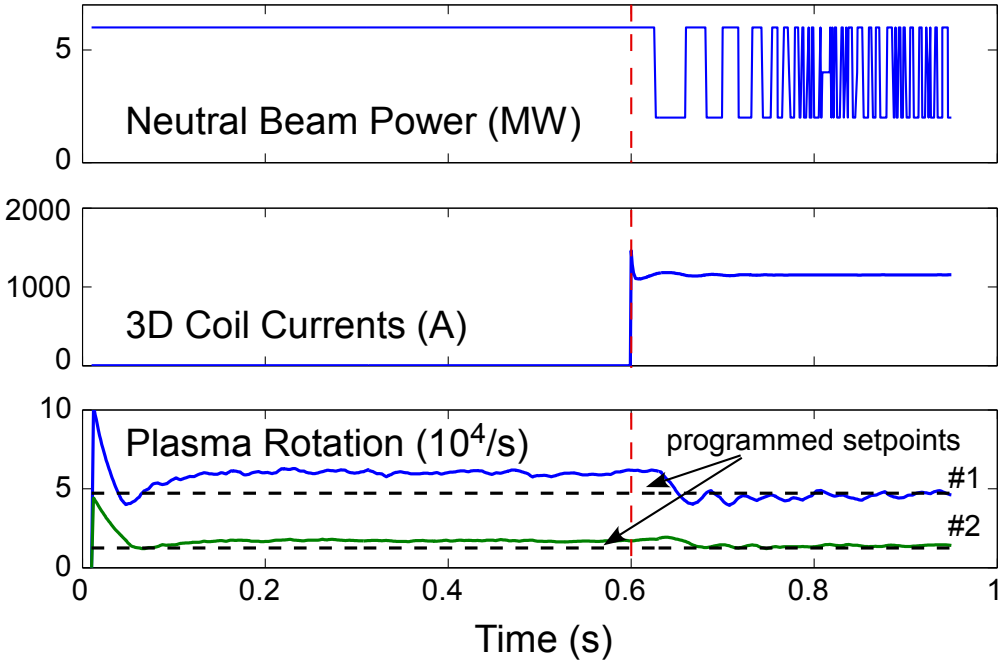
Validation has been performed against TSC

Now have ability for users to supply Fortran control algorithms

S. Gerhardt

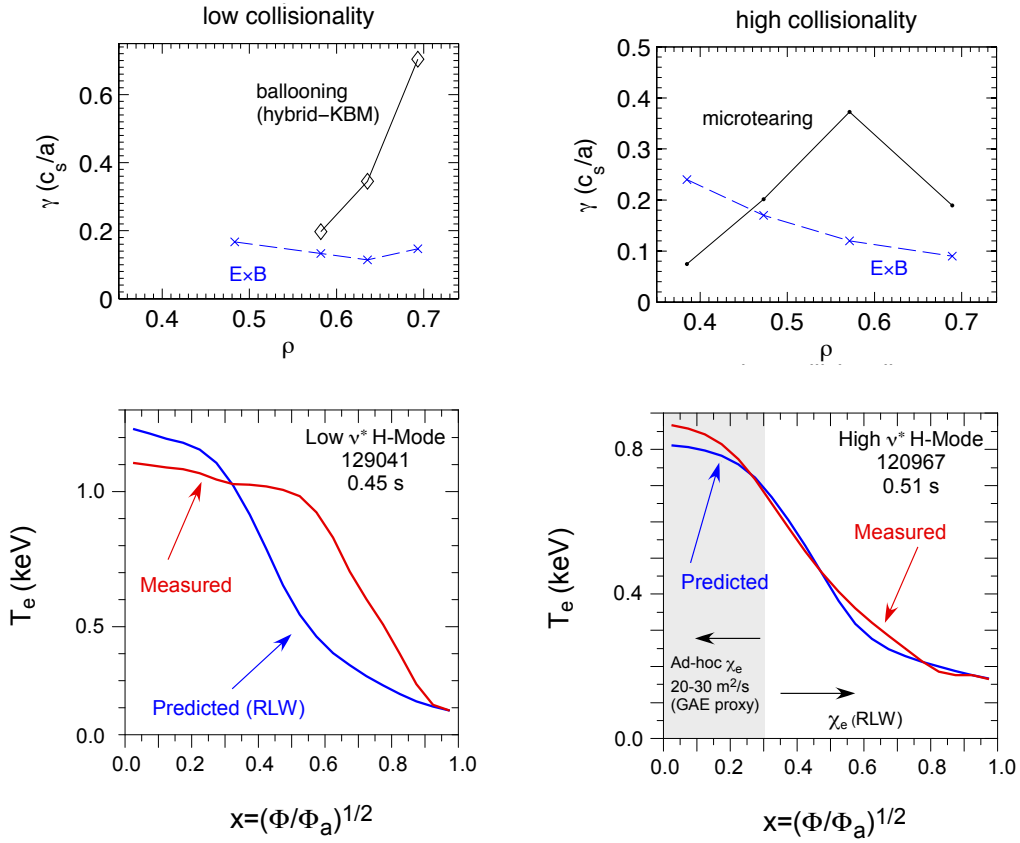
Control algorithms are presently being developed for NSTX-U

- Uses Expert file for
  - Rotation profile control (NBI, NTV through application of 3D fields as actuators) – NTV physics model incorporated in algorithm (plan to implement in code proper)
  - Plasma current profile control (NBI, current ramp rate as actuators)



Multi-zone PT_SOLVER (with model or user input) used for benchmarking physics models

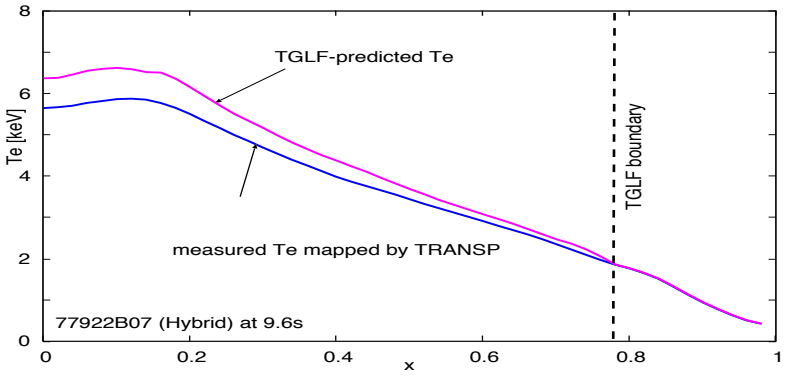
- Rebut-Lallia-Watkins model (μtearing-based) successful in predicting T_e profiles in NSTX plasmas where μtearing is calculated to be unstable

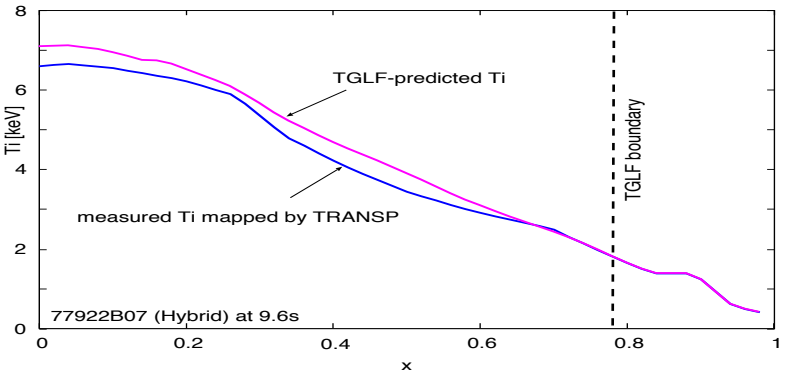


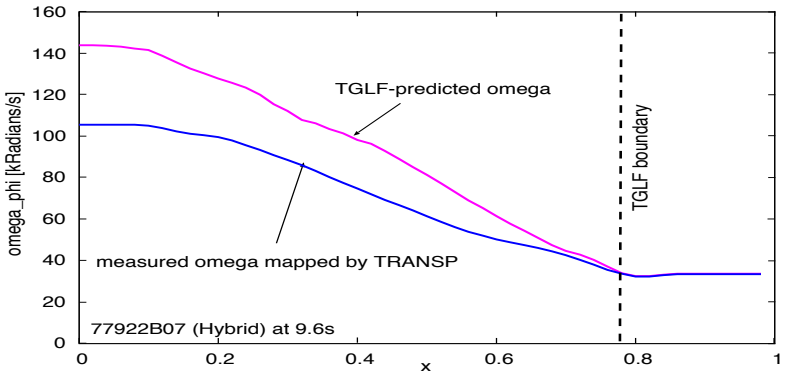
S. Kaye

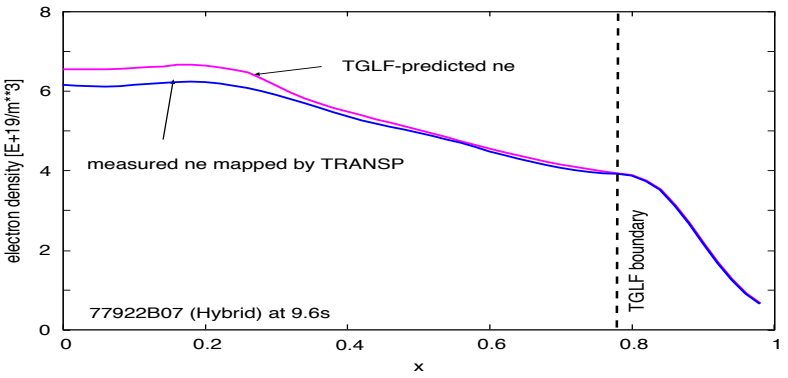
TGLF prediction of JET hybrid discharge

- Prediction of ion & electron temperature, density and rotation profiles



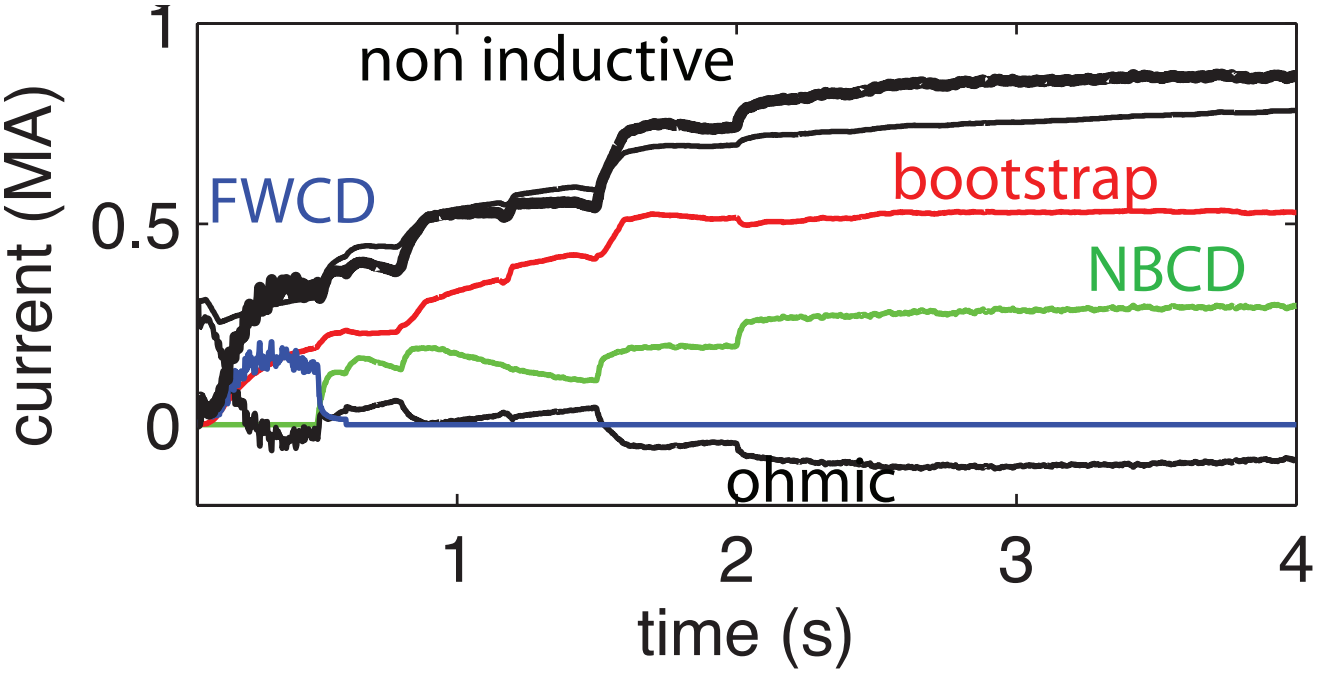






MMM model used as basis for predicting requirements for fully non-inductive discharge operation in NSTX-U

- Uses GENRAY (ECH), TORIC (HHFW), NUBEAM (NBI) modules



F. Poli

Operational Items

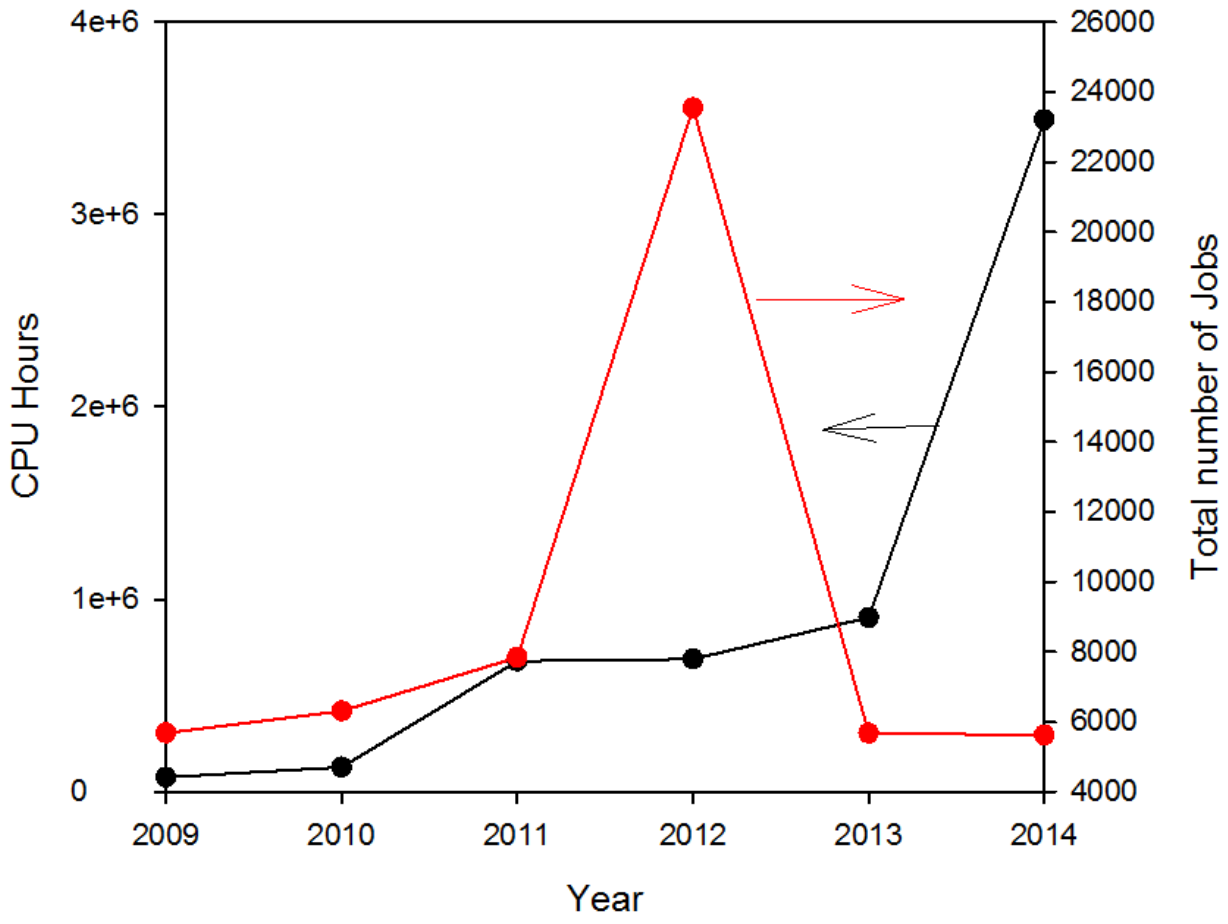
- Triage support
  - All failed runs are examined by a member of the support staff and users are notified…normally the same day
- Code Verification
  - Daily regression tests
- User Group Meetings
  - Normally meet yearly at APS-DPP meeting (not in 2014)
  - Dedicated meeting planned for week of March 23 at PPPL
- Strategic Planning
  - Group is preparing a report for PPPL Director by July 1
- Interfacing with IDM
  - FY15: develop translator from Plasma State ↔ IDM
  - FY15: make standalone NUBEAM and GENRAY compatible with IDM

TRANSP: status and progress

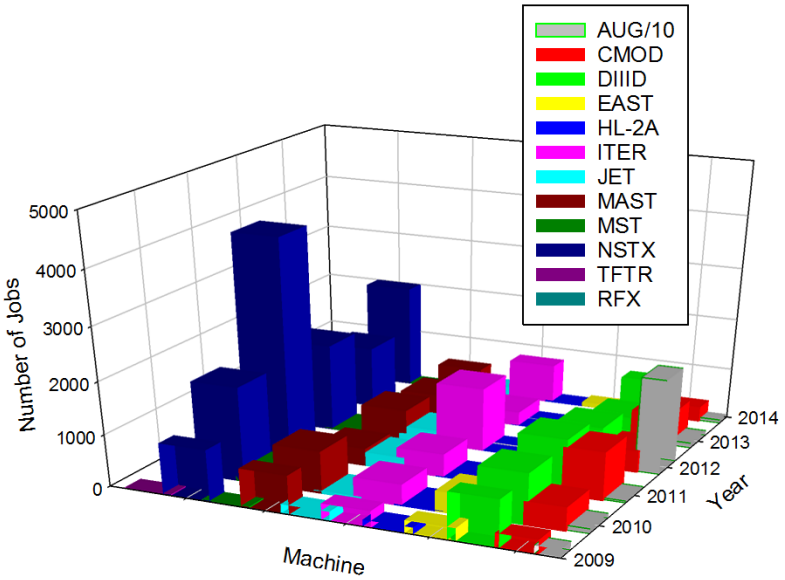
	2013	2014	2015
RF	EC: TORAY, GENRAY IC: TORIC LH: LSC	LH: GENRAY	EC: TORBEAM LH: GENRAY+CQL3D HHFW:GENRAY+CQL3D
NUBEAM		Halo neutrals for multiple CX events Fast ion diffusion due to MHD	GPU support SOL beam ionization (upgrade 2D neutrals, TF ripple loss model)
RF Coupling to Fast Ions		TORIC → NUBEAM	RF coupling: TORIC ← NUBEAM
Isolver FB equilibrium	Evolve q and IP consistent with coil and vessel currents	Shape control. Neo added to q-advance	Include toroidal rotation in equilibrium solution
PT-Solver	MMM, GLF23, TGLF, RLW, NEO, Chang-Hinton, Paleo	Density feedback (with gasflow rate and wall recycling)	Developing flux-based implicit solver (with AMG) to speed convergence of TGLF

Black: available to users Red: under development

TRANSP use has shown a sharp increase over the last two years - # runs and # cores



TRANSP is being used worldwide to analyze and predict performance on present and future devices



Also in 2014:

ARIS	21
FNSF	113
JT60	1
KDMO	10
KSTR	29
LTX	157

	AUG	CMOD	DIIID	EAST	HL-2A	ITER	JET	MAST	MST	NSTX	TFTR	RFX
2014	590	301	715	92	36	769	201	491	29	2007	61	0
2013	916	634	468	32	11	273	189	405	5	1188	99	0
2012	18237	425	779	28	1	1232	273	592	32	1691	149	2
2011	328	939	1076	1	19	454	275	338	7	4134	90	20
2010	890	462	989	401	34	417	62	816	277	1813	22	0
2009	1606	276	908	248	131	316	179	742	26	993	26	0

Summary

- TRANSP has incorporated state-of-the-art source and transport models for use as either an interpretive or predictive analysis tool
  - Driven by community input and needs
- Treatments and solvers are becoming increasingly sophisticated and comprehensive
- Provide links to other computationally intensive codes (macro-, micro-fast ion stability, RF full wave, etc.)
- Extensive use of TRANSP capabilities (presently and planned) by a large number of institutions around the world
- Running TRANSP on FusionGrid allows for timely support and quick debug turnaround by PPPL Computational Plasma Physics Group

The objective of this workshop is to make TRANSP more powerful and user-friendly

- Discuss present and future use of TRANSP
  - Short & long-term needs, desires
- What upgrades will make TRANSP more valuable to the international community, including ITER
  - Upgrades to physics modules
  - Code modernization and framework (i.e., single executable? Modularize? Both?
  - Attempted to leave plenty of time for discussion
- Identify and encourage development external to PPPL
- Discussions will aid in the development of the TRANSP strategic plan, which is to be presented to PPPL Director on July 1
  - Strategic plan will detail (additional) personpower resources and funding levels needed to address goals

Extra vugraphs

Use of experimental data is integral to TRANSP

Input

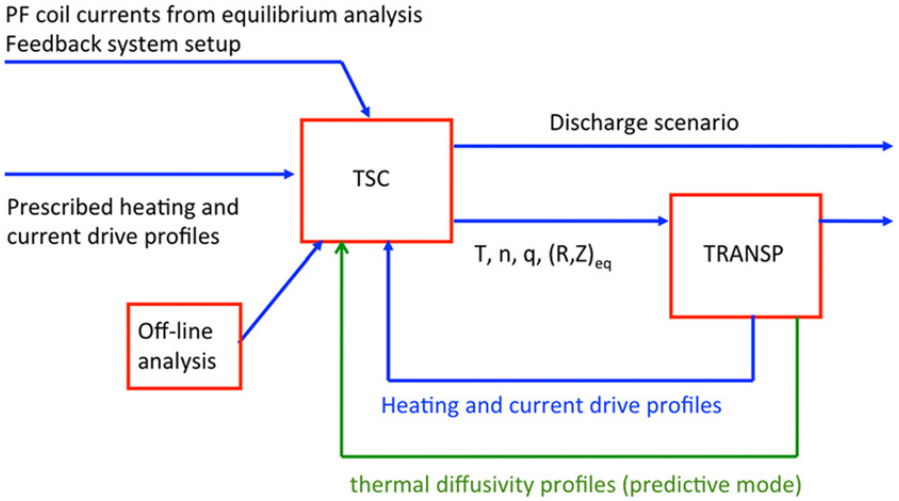
0-D Device geometry (walls, limiters, NB/RF source configuration, powers,…), neutral density b.c., ….

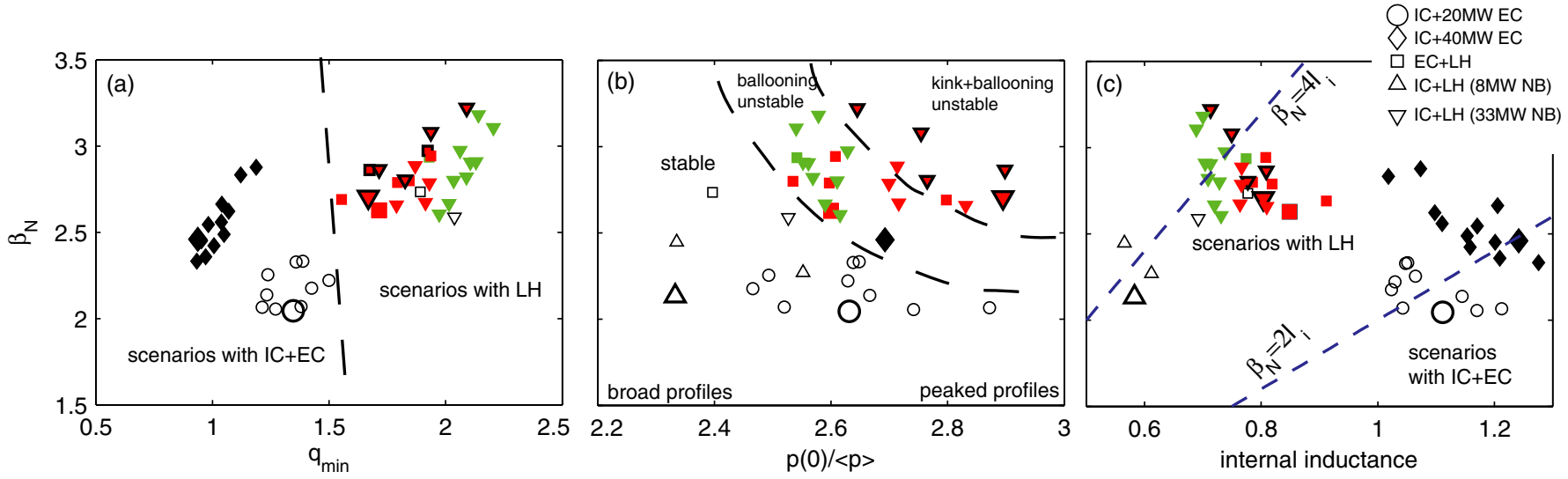
1-D $I_p(t)$, $B_{T'}$ outer boundary, ϕ_{dia}, V_{loop}, D_a, neutrons, recycling coefficient,….

2-D $n_e(\rho,t)$, $T_{e,I}$, n_{imp} or Z_{eff}, P_{heat}, P_{rad}, $v_{\phi,\theta}$, B_θ/B_ϕ, neutrons, full equilibrium (option)

Coupled TRANSP-TSC predictions have been done for ITER

- Use free-boundary, plasma control capabilities of TSC
- Source, transport solver capabilities of TRANSP
- Examine performance (confinement, MHD stability) of various heating mixes in ITER ITB plasmas



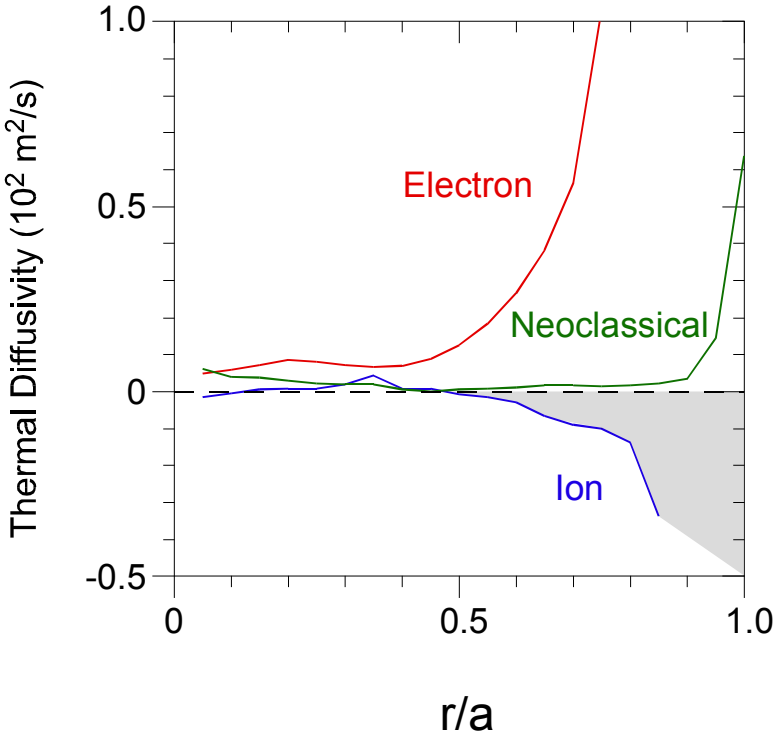


Poli, 2013

TRANSP has been used to validate data and identify issues with diagnostics

Analysis of early (~ FY00) NSTX discharges revealed energy balance results that were difficult to believe

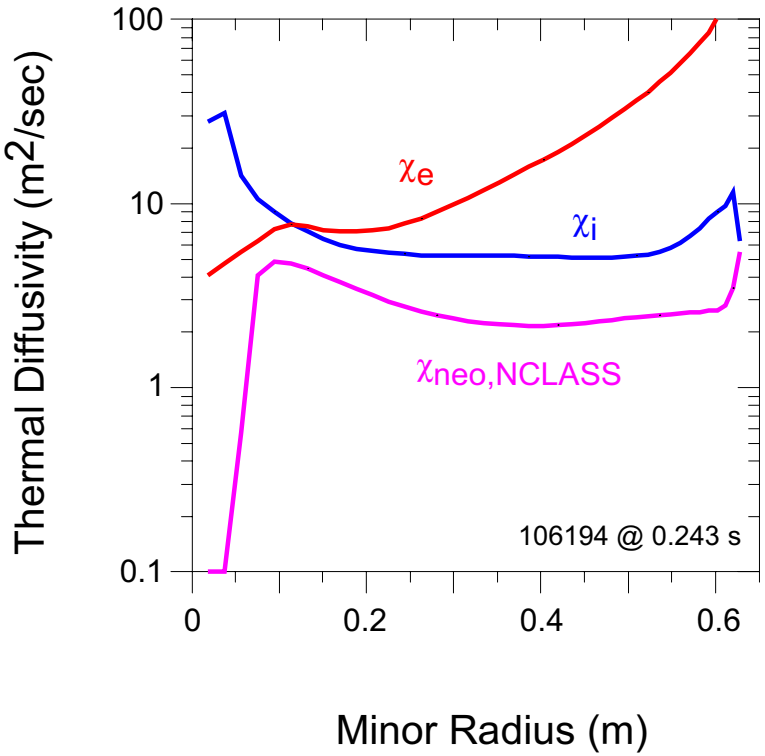
- Large negative ion heat diffusivity
- Large electron heat diffusivity



Results reflected large T_i-T_e near edge

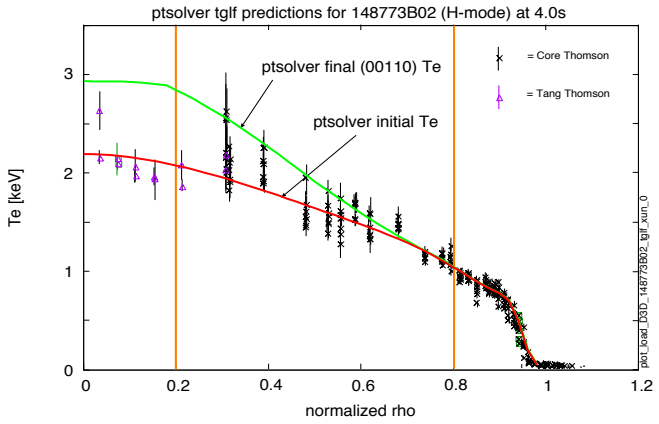
Led to recalibration of both CHERS (T_i, n_{imp}) and MPTS (T_e, n_e) diagnostics

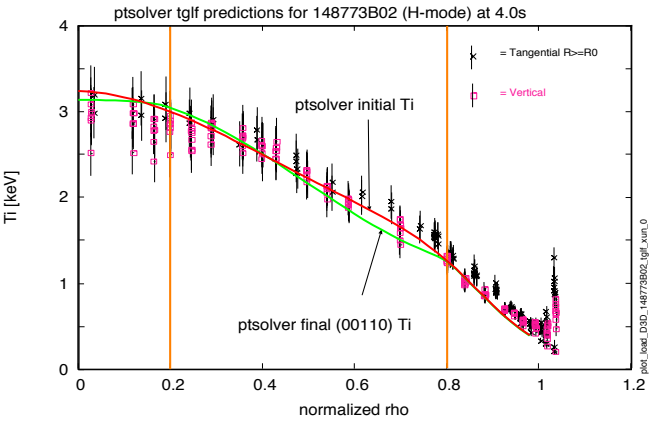
- More conventional behavior of both electron and ion energy balance

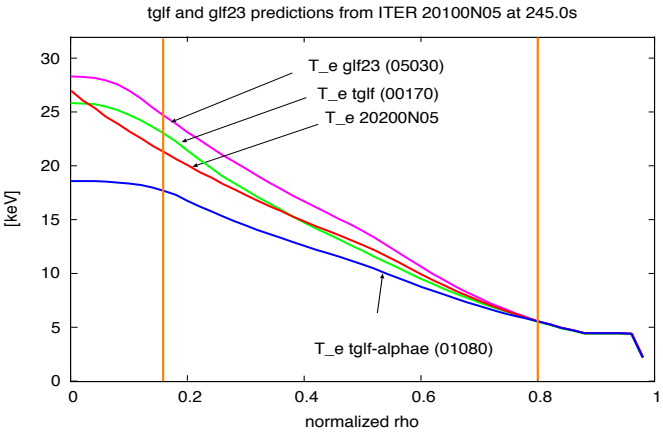


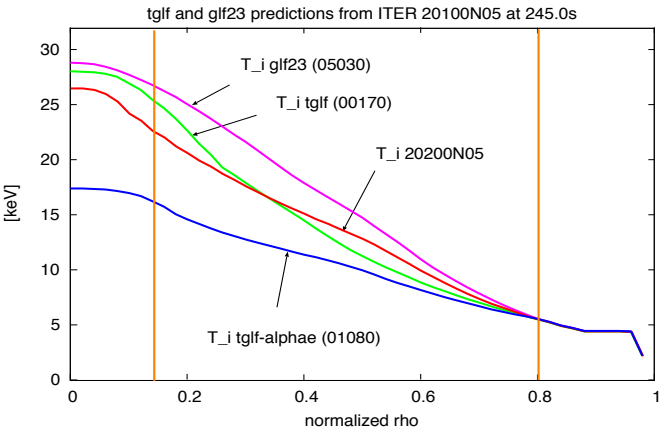
Robust transport solver "PT_SOLVER" implemented and being used for TGLF-based verification and prediction

TRANSP predictive calculation using TGLF has been benchmarked against stand-alone TGLF in XPTOR









Benchmark against ITER-baseline discharge in DIII-D

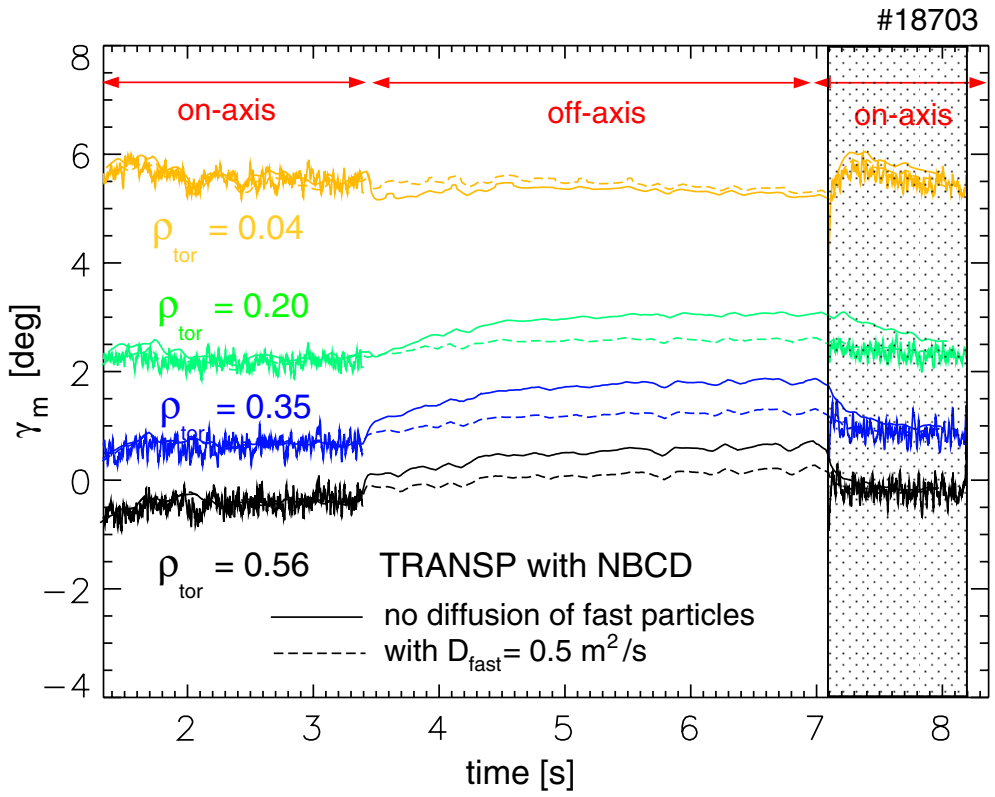
Budny, IAEA 2012

TGLF & GLF23 prediction for ITER using PT_SOLVER in TRANSP

Also being benchmarked against JET, NSTX data

TRANSP calculations can lead to identifying important physics, such as microinstability driven fast ion transport in ASDEX-U

TRANSP computed classical NBCD at the end of the off-axis NB phase higher than measured value in **MHD-free** discharge



Gunter et al., Nuc. Fusion, 2007

Anomalous fast ion diffusivity necessary to achieve agreement – attributed to microinstabilities (further work on AUG, DIII-D, JET)

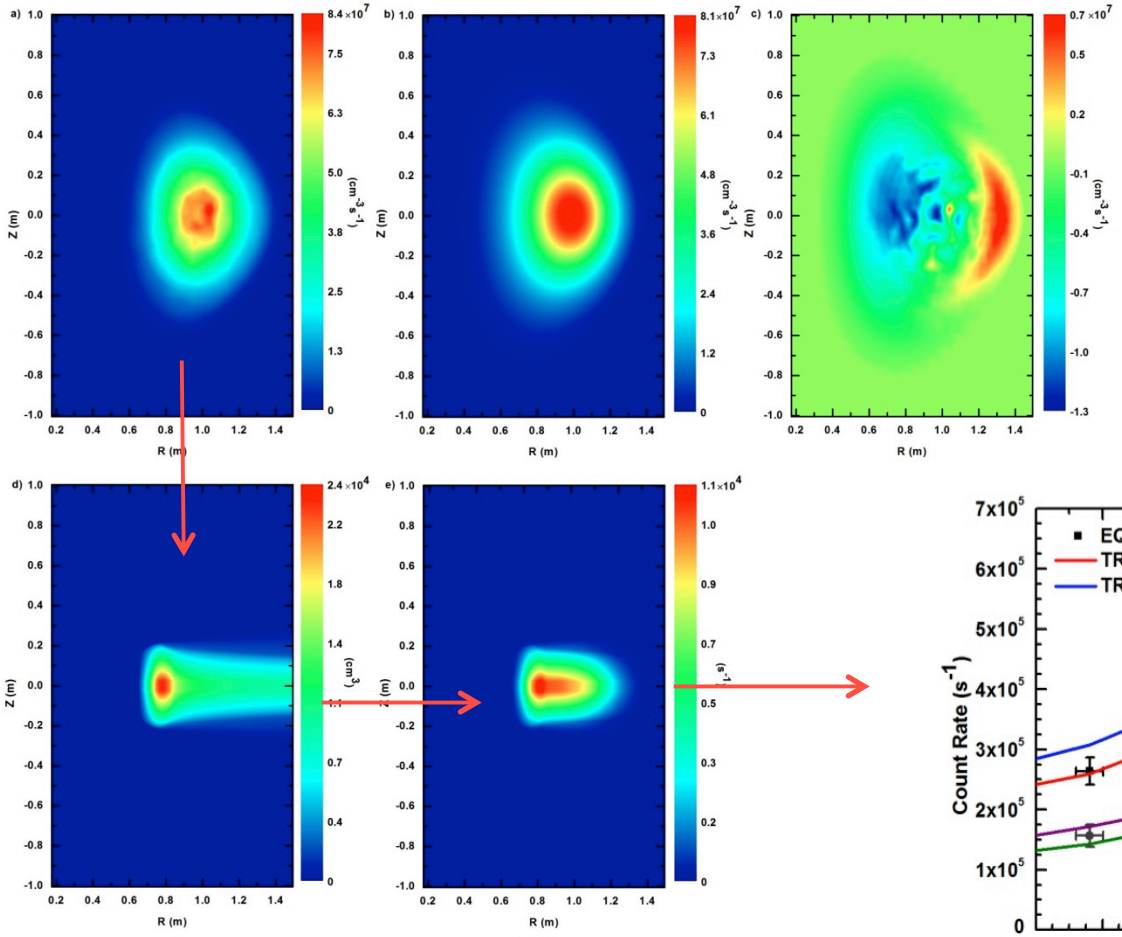
Microinstability-based (TGLF) anomalous fast ion diffusivity being implemented in TRANSP (collaboration with R. Waltz [GA])

Comparisons of measurements with diagnostic simulation results give confidence in accuracy of calculation

Non - flux averaged neutron emissivity NE

Flux averaged neutron emissivity FANE

NE - FANE

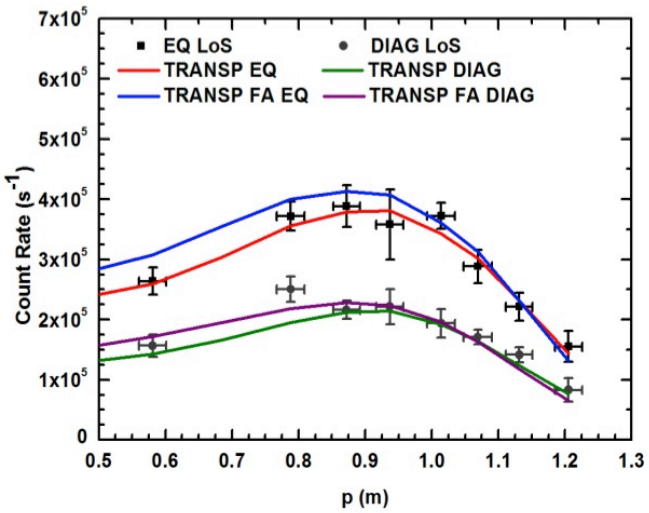


Poloidal projection of solid angle for given impact parameter

Product of neutron emissivity and projection of solid angle

MAST Neutron Camera

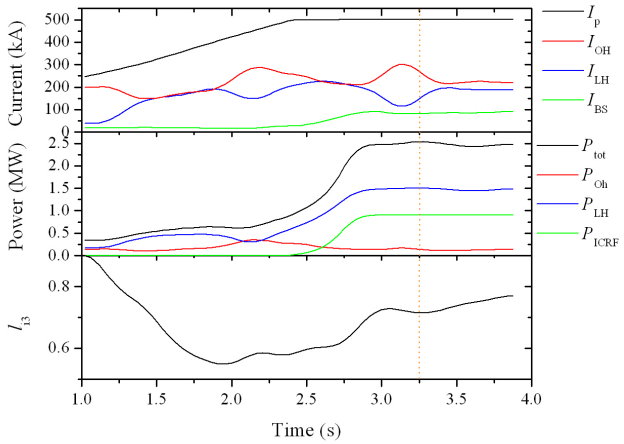
- population of fast particles at the outboard side of the plasma
- demonstration of the importance of considering non flux averaged neutron emissivity in fusion experiments

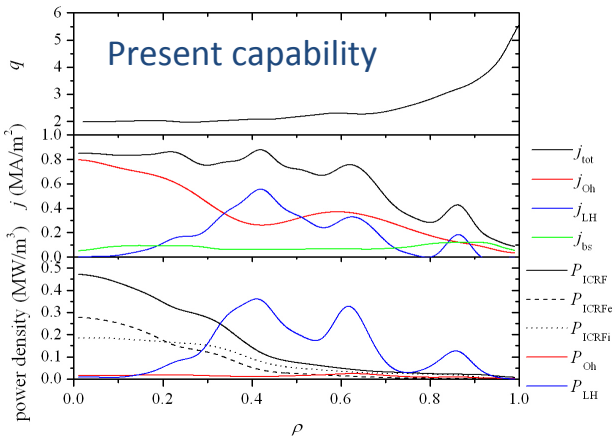


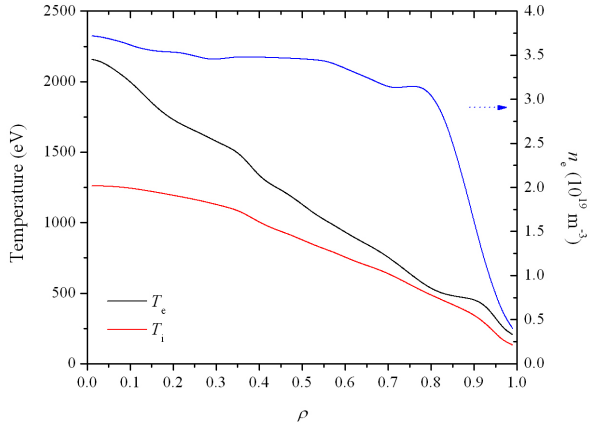
M. Cecconello et al., Upsala Univ.

Modeling of hybrid discharges for EAST with both present and future capabilities is being conducted with TRANSP

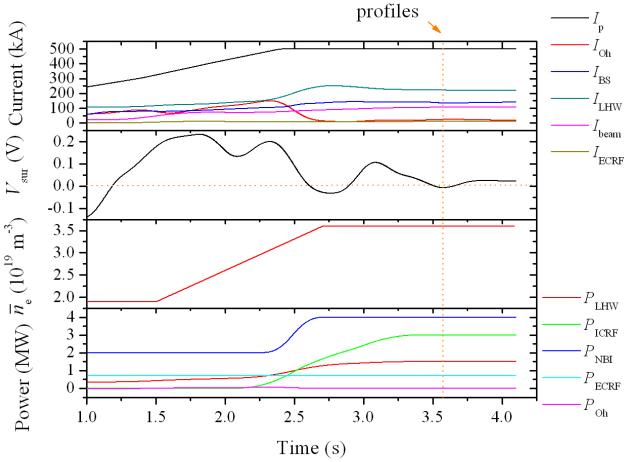
Hybrid operation is one of the major goals of EAST operation



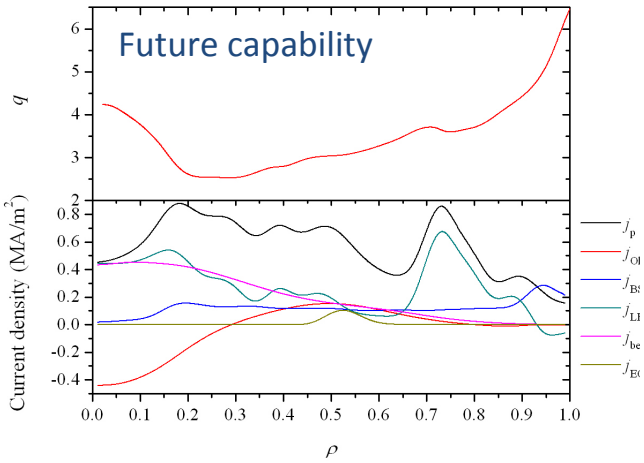




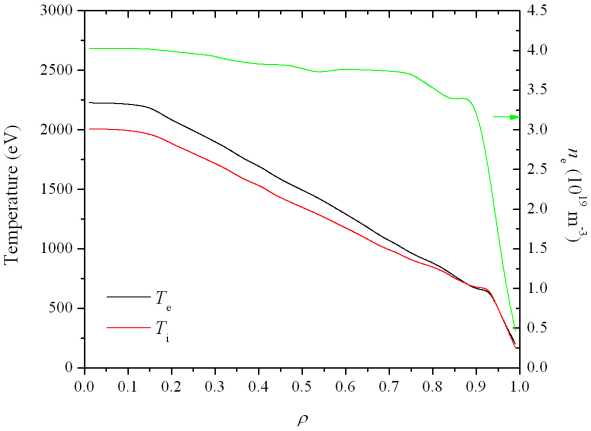
H_{98}~0.86; β_N~0.98



f_{ni}~95% f_{BS}~30%



S. Ding, EAST



H_{98}~0.80, β_N~1.94