Transport and Confinement ITPA JEX/JAC Plans for 2011

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Most of JEX/JACs have focused on high and medium priority ITPA issues

- High priority
  - Transport and confinement during transient phases (physics model validation)
  - Access to high confinement regimes during steady-state and ramp-up/down H, D, and DT phases ($L \rightarrow H$, $H \rightarrow L$, ITB, I-Modes,…)
  - 3-D effects: stellarator vs tokamak (L-H threshold, rotation, impurity transport)
- Medium priority
  - Momentum transport and rotation drive
  - Electron transport
- Started 2010 with 12 JEX/JACs
  - Combine two into one for 2011
  - Many JEXs are in “analysis” stage (to close out in one to two years)
  - FIVE new JEX/JACs proposed for 2011
- Many machines dormant for good part of 2010
  - Much work was in analysis arena

Many Joint Experiments Address the High Priority Research Topics

JEX	Title	Comments
TC-1	Confinement scaling in ELMy discharges: β scaling	MAST expts in 2011 Close-out end 2011
TC-2	Hysteresis and access to H-mode with H~1	AUG, JET, MAST, NSTX, TCV Further expts in 2011
TC-3	Scaling of low density limit to the H-mode threshold in H & D plasmas	AUG, DIII-D, JET, TCV Analysis of existing data, new expts in 2011
TC-4	Species dependence of L-H threshold	AUG, DIII-D, JET, NSTX Assess expt gaps, analysis Close out end 2011
TC-7	ITG/TEM transport dependence on T_i/T_e, q and rotation in L-modes	DIII-D, JET Close-out; combine with TC-13
TC-9	Scaling of intrinsic rotation with no external momentum input	C-Mod/TCV similarity expt.
TC-10	Expt'l identification of ITG, TEM, and ETG turbulence and comparison to codes	Ongoing Joint Activity Focus on electron transport, "no-man's land" in 2011
TC-11	He profiles and transport coefficients	Joint Activity; DIII-D provided, preliminary analysis done
TC-12	H-mode transport at low aspect ratio	NSTX (Li conditioning), MAST(q-scan)

Many Joint Experiments Address the High Priority Research Topics

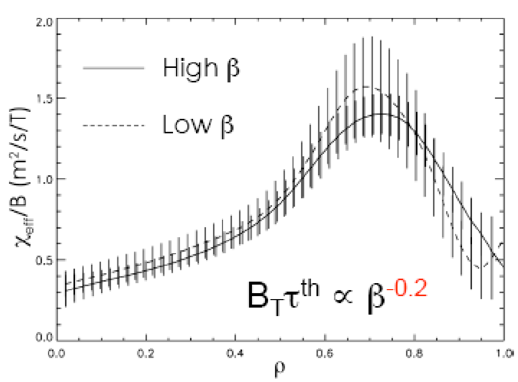
JEX	Title	Comments
TC-13	Ion and electron critical gradient and profile stiffness	JET, DIII-D, C-Mod, AUG Combined with TC-7
TC-14	RF rotation drive	C-Mod, JET, DIII-D, TCV, JT-60U, AUG, NSTX
TC-15	Dependence of momentum and particle pinch on collisionality	NSTX, DIII-D, JET, AUG, C-Mod Analysis of existing data, new expts in 2011
TC-16	Dependence of momentum pinch and diffusivity on β	AUG, DIII-D, JET New
TC-17	$\rho*$ Scaling of the Edge Intrinsic Torque	NSTX, DIII-D, JET, AUG, C-Mod, JT-60U (?) New
TC-18	Dimensionless Identity Experiments in I-Mode	C-Mod/AUG (DIII-D?) similarity expt. New
TC-19	Characteristics of I-mode plasmas	C-Mod, NSTX, AUG, DIII-D, (JET?) New
TC-20	Validation of transport models in ITER-similar current-ramp plasmas	Joint Activity, JET, DIII-D, AUG, C-Mod, ISM New

TC-1: β-dependence of confinement (C. Petty)

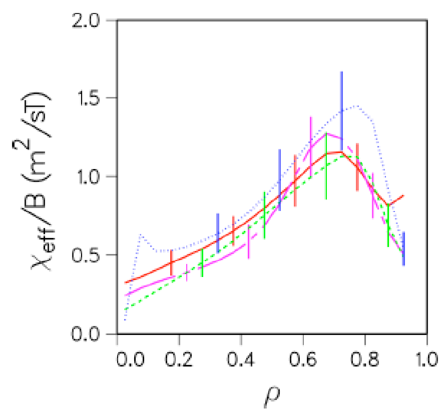
JET, DIII-D, JT-60U, AUG, MAST, NSTX, Tore-Supra

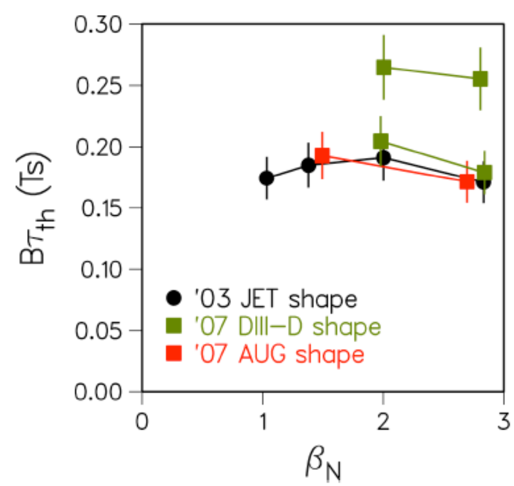
- 2010 Results
  - MAST: attempted, but found β strongly coupled to ν*
  - No other new experiments
  - Full time history analysis for **AUG/DIII-D** experiment (2007) in hybrid discharges
    - Modest beta degradation of confinement
    - Little difference in normalized diffusivity

- '07 AUG shape, High Rotation



- '03 JET shape, High Rotation





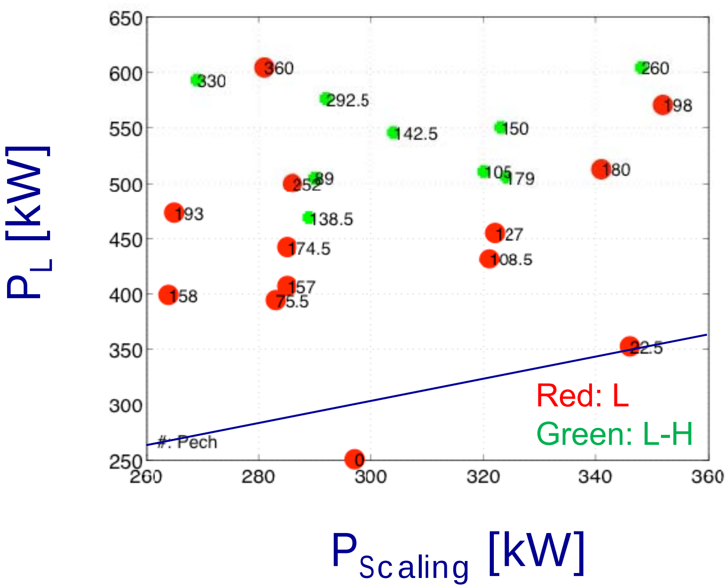
DIII-D

- 2011 Plans: additional MAST expts., NSTX data-mining for Li-conditioned plasmas
  - Reach consensus by end of year (shape dependence, pedestal/core dependences)
  - Plan to close-out by end of 2011 (paper for H-mode workshop?)

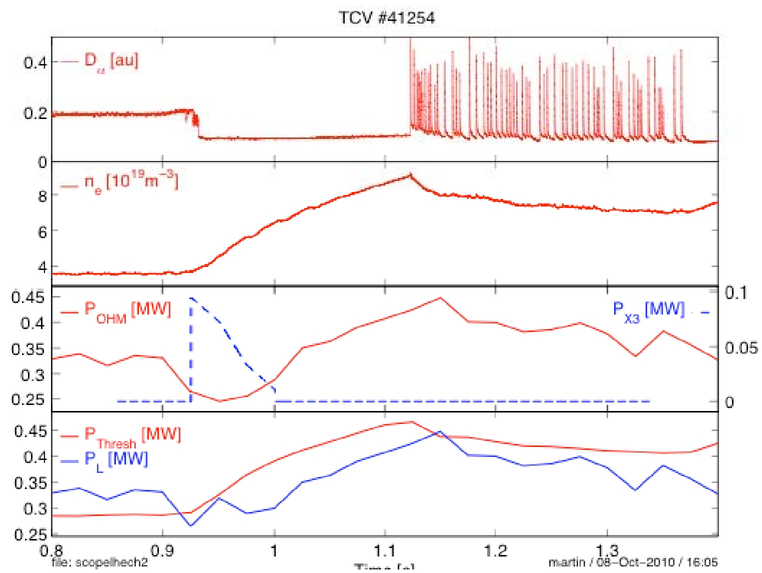
TC-2: Hysteresis and access to H-mode with H~1 (Y. Martin)
JET, DIII-D, AUG, MAST, NSTX, TCV

- Use RF + density ramps to explore confinement for $P >\sim P_{LH}$ and to assess hysteresis characteristics (if any) – focus on H~1 regimes (decided last year)
  - Previous expts showed for most part, need $P > P_{LH}$ to achieve H~1 in Type I ELMs
    - NSTX finds H~1 in “steady-state” ELM-free in **strongly** shaped plasmas
  - Hysteresis results mixed
- Dedicated experiment in 2010 performed on **TCV** using ECH

- Threshold power ~ 1.6 x scaling



Remains in H-mode with $P<P_{LH}$

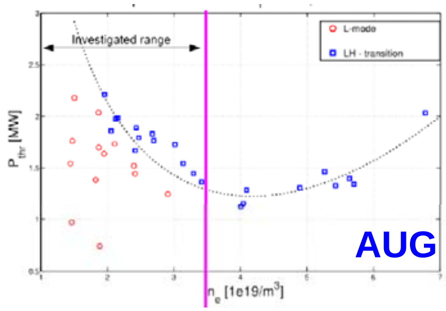


- 2011 Plans:
  - TCV: Confirm ECH power absorption, analyze confinement
  - Additional expts on TCV, AUG, synthesis of data from all devices

TC-3: Scaling of critical density for $P_{th,min}$ (J. Hughes)

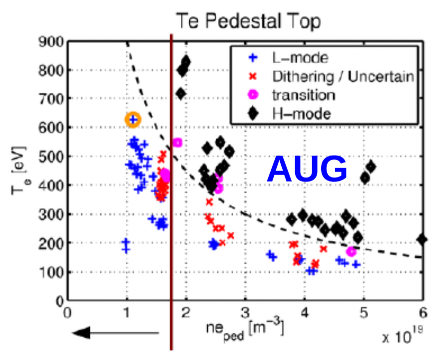
JET, DIII-D, AUG, MAST, TCV, C-Mod

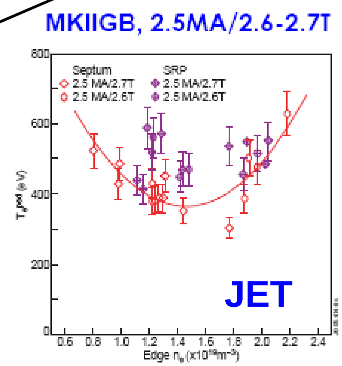
- Well established that each device sees a density for with P_{th} is a minimum (generally around 3 to 4 x 10^{19} m^{-3} but higher in C-Mod: B_T dependence)
- 2010 work has focused on studying local edge parameters to determine if anything is changing below $n_{th,min}$
- .

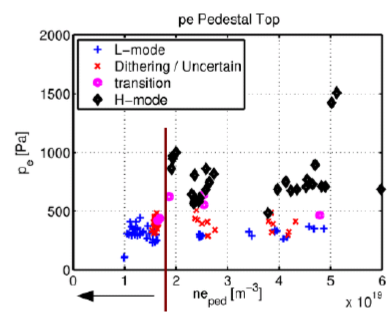


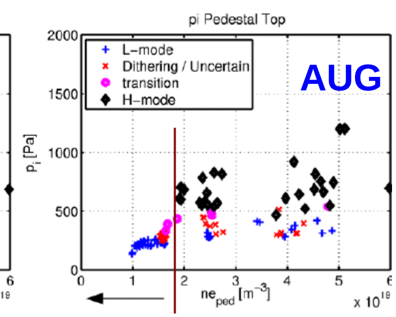
$T_{e,edge}$ does not seem to be controlling parameter (also DIII-D, C-Mod)

Is p_{edge} more important?









No LH transition so far with available P_{ECRH}

- 2011 Plans
  - AUG: P_{ECRH} up to 3 MW for lower n_e H-mode access
  - New expts on C-Mod (with fluctuation data, T_i), TCV
  - Analysis of existing data: DIII-D, JET

TC-4: Species dependence of L-H power threshold (P. Gohil)

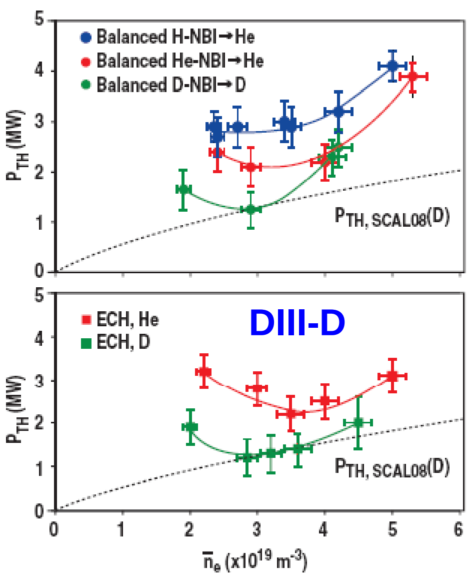
JET, DIII-D, AUG, MAST, NSTX, C-Mod, JT-60U

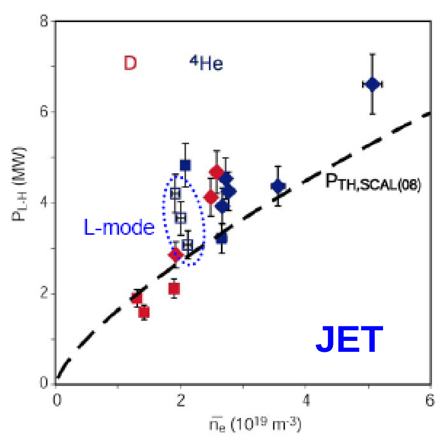
- 2009 Results: Large amount of work done in 2009

Device	Heating Method	H^+	He^{++}
AUG	H,D-NBI, ECH		1 x D
C-Mod	ICRH		1.2-1.8 x D
DIII-D	D,H, He-NBI, ECH	2 x D	1.3-1.5 x D
JET	D,H,He-NBI, ICRH	2 x D	1.3 x D
MAST	D-NBI		1.4 x D
NSTX	HHFW		1-1.4 x D

τ_E (H, He) ~ 0.6-0.8 τ_E(D)

- 2010 Results
  - Density plays an important role in He/D P_{LH} ratio



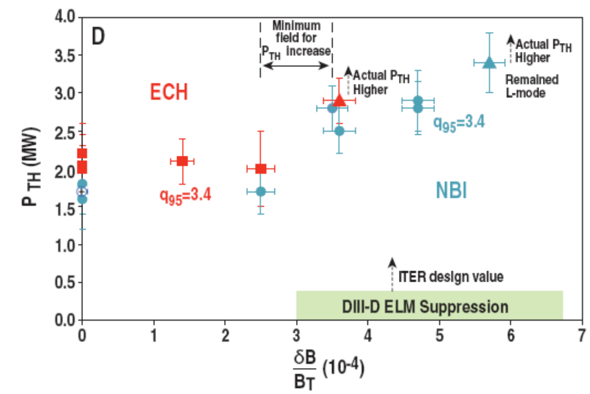


2011 Plans

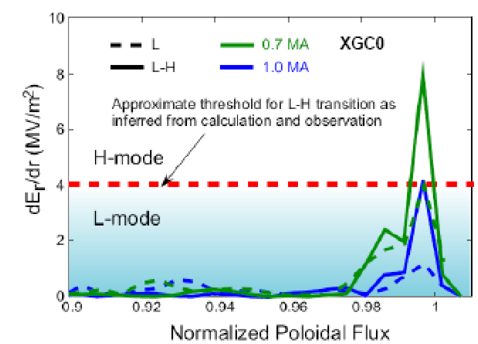
- Assess experimental gaps
- Finish analysis
- Prepare paper for H-mode wkshp
- Close-out after this year

Other variables can have a significant effect on the L-H threshold

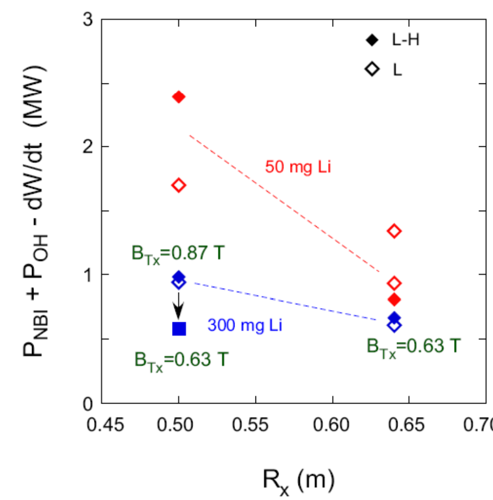
- 3D effects
  - Application of 3D fields in toks
    - Significantly higher P_{th} in NSTX with n=3
    - Delayed transition in MAST with n=1
    - Threshold for increase in P_{LH} in DIII-D
- Scalings based on B_T, n_e, S or R alone are inadequate
  - Other global and local parameters important, although no local trigger identified by expt.
  - ∇E_r may be key; challenge for expts
- X-point location
  - Higher P_{LH} with increased X-point height in DIII-D
  - Higher P_{LH} with increased δ (lower R_x) in NSTX
    - B_T at X-point location is controlling parameter, not recycling
- 2011 Plan
  - Continue to explore parameters influencing L-H threshold
    - Some may offer challenge to experimentalists (e.g., ∇E_r)
  - Expand P_{th} db with local & additional info



DIII-D



NSTX

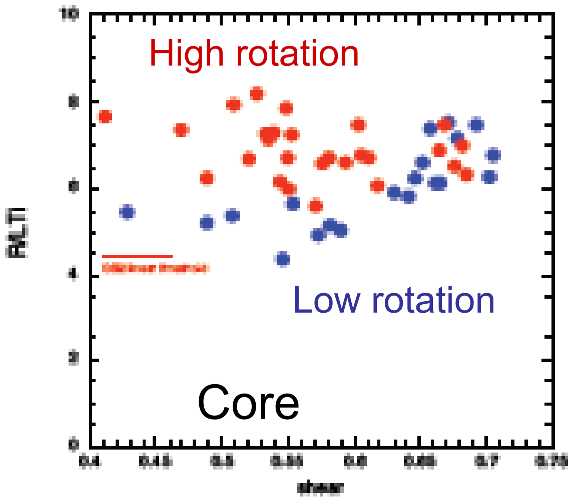


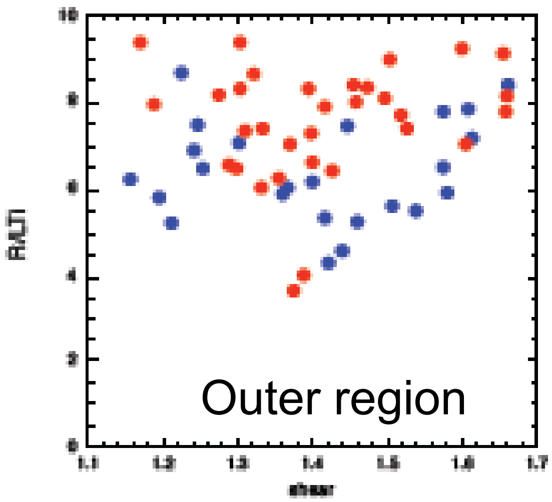
NSTX

TC-7: ITG/TEM transport dependence on T_i/T_e, q and rotation in L-modes (P. Mantica)

JET, DIII-D

- Explore parameters that affect stiffness of ions and electrons in H-modes, extend to Hybrids, ITBs
- 2010 results
  - Analysis of **JET** 2009 data
    - The effect of rotation and magnetic shear is complex, and depends on plasma region of interest
    - Decreasing stiffness: low rotation → high rotation peaked q → high rotation flat q



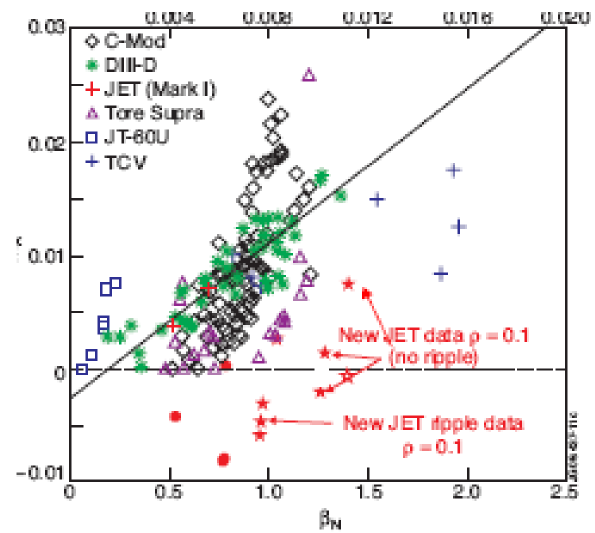


- 2011 Plan
  - Combine with TC-13 (see vg on that JEX)

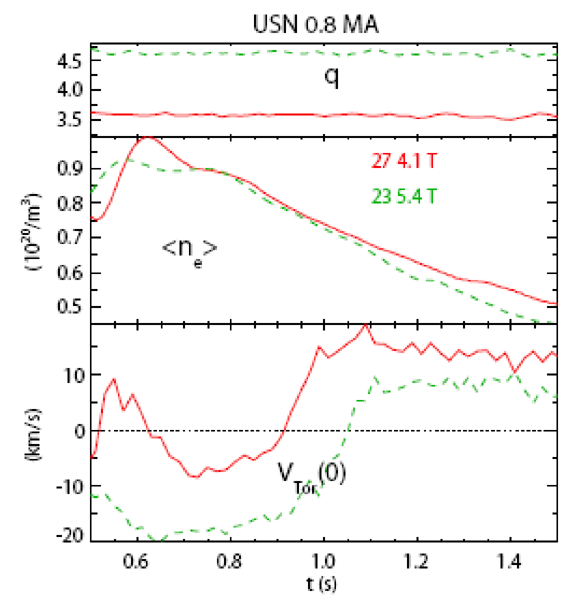
TC-9: Scaling of intrinsic rotation with no external momentum input (J. Rice)

C-Mod, AUG, DIII-D, JET, NSTX, JT-60U,TCV, Tore-Supra

- 2010 Results
  - New data from JET added to multi-machine H-mode database; does **NOT** match established M_A vs β_N scaling for ρ=0.1 or 0.8
  - Further work in rotation inversion in L-mode
    - Density at which rotation inverts depends on q
    - Can be varied by changing either current or field
- 2011 Plans
  - Expand H-mode intrinsic rotation db to include full velocity profiles
  - Further exptl work
    - C-Mod: DIII-D similarity, TCV rotation inversion
    - DIII-D: Extend to higher β_N with balanced injection
    - JET: similarity expts with DIII-D
    - JT-60U: data mining
    - EAST: possible new data with ECH
    - Others: data for intrinsic rotation db requested



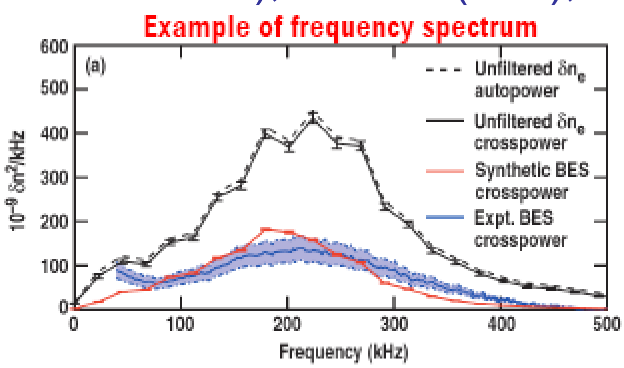
JET



C-Mod

TC-10: Expt'l id of ITG/TEM/ETG turbulence and comparison with codes (C. Angioni)

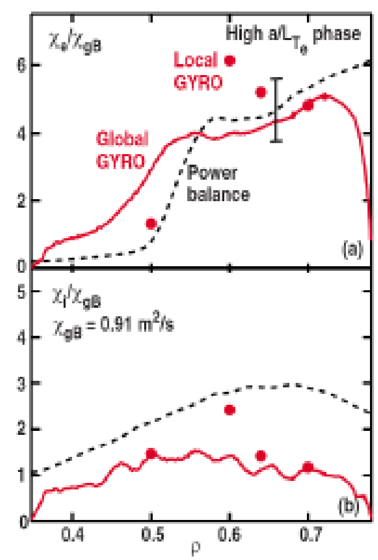
- Ongoing Joint Activity: goal is validation of core transport theory
- 2010 Results
  - Development of synthetic diagnostics: DIII-D (BES, CECE), NSTX (high-k, BES), C-Mod (PCI), Tore-Supra (Doppler and fast sweeping reflectometry)



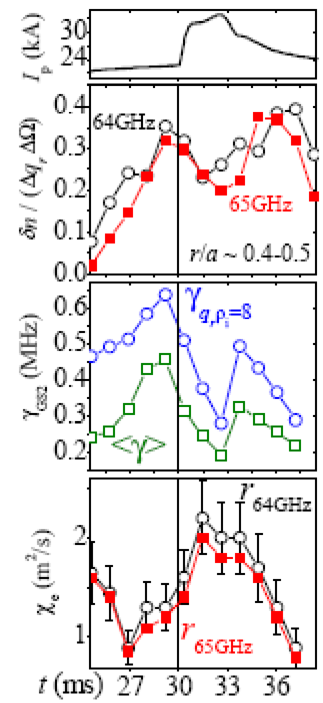
Also for radial and vertical correlation lengths

DIII-D

DIII-D



FT-2



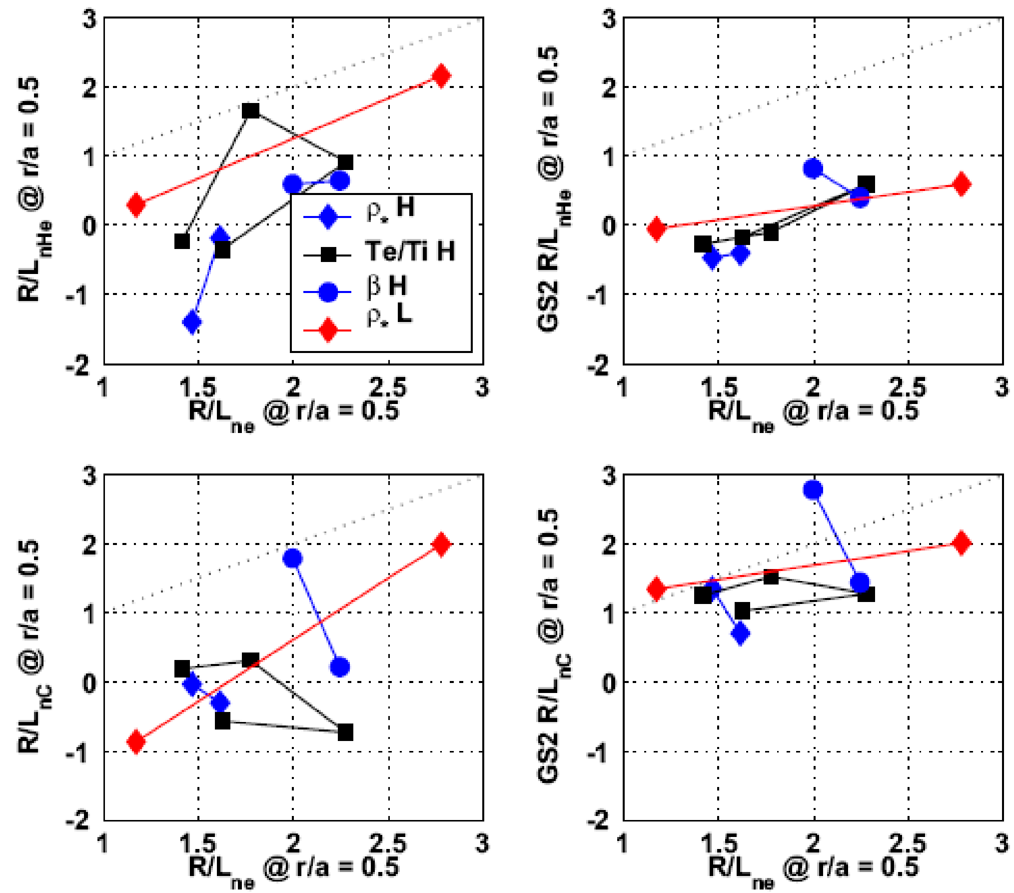
DIII-D modulated R/L_{Te}: transport levels agree with 4 gyrotrons, not with 6. Other expts not as good

FT-2: highest-k not sole cause of transport (also NSTX)

- 2011 Plans: Continue encompassing validation work. Empasize:
  - Electron-scale turbulence and related transport (TEM, ETG, microtearing)
  - Turbulence in "no-man's land" (transition between core and edge, r/a~0.8)

TC-11: He profiles and transport coefficients (H. Weisen)

- JAC to measure and understand He (and impurity) transport in H, hybrid, AT and ITB plasmas
  - Initial task is coordinated data mining, which could lead to JEX
- 2010 Results
  - 10 observations from DIII-D uploaded to ITPA Profile Database
    - Dimensionless ρ^* (L, H), T_e/T_i (H), β (H)
  - Uploaded data was reanalyzed with updated ADAS model
  - PRELIMINARY GS2 results (ITG only) qualitatively consistent with expt
    - Both He and C profiles less peaked than that of electrons

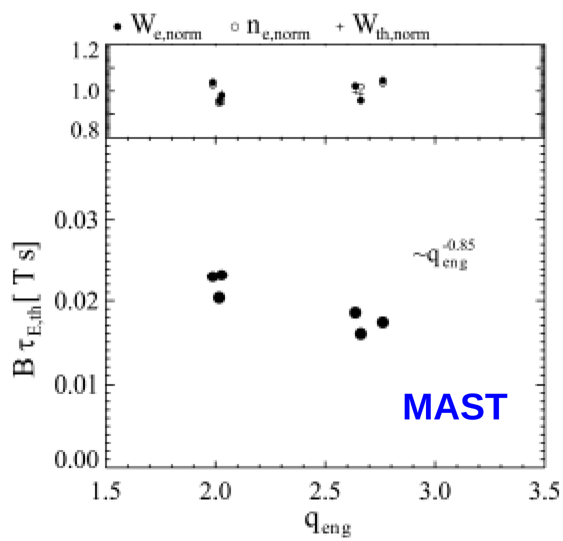


- 2011 Plans
  - Model electron density profile, extend to other radii
  - Include neoclassical and centrifugal effects
  - Compare with recent AUG boron modeling results

TC-12: H-Mode transport at low aspect ratio (M. Valovic)

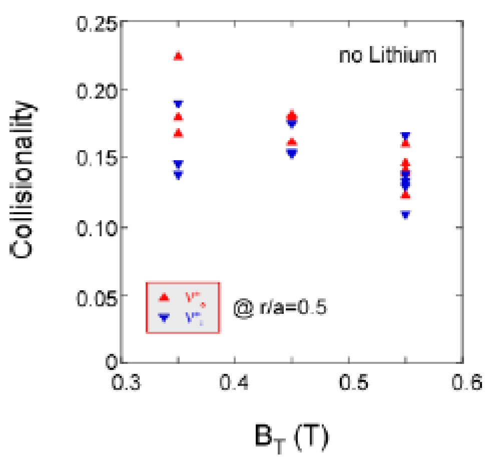
MAST, NSTX

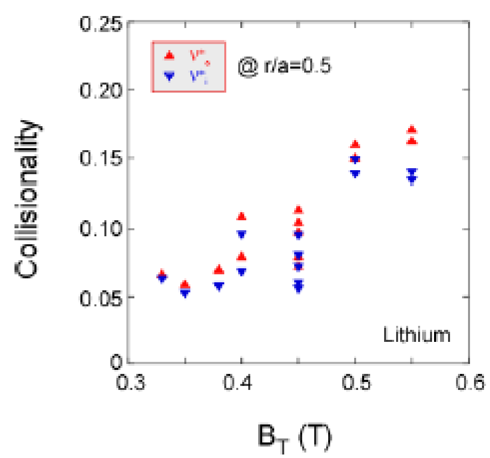
- 2010 Results
  - MAST: q-scan at constant n, T, B_T
    - $B\tau_E \sim q^{-0.85}$ (weaker than 98y2, q^{-3})
  - MAST: strong dependence on ν_* ($\nu_*^{-0.85}$)
  - NSTX: with Lithium conditioning, B_T, I_p scalings closer to 98y,2 ($I_p^{0.65} B_T^0$) than without ($I_p^{0.4} B_T^{0.9}$)
    - Lack of strong B_T scaling, observed w/o Li, consequence of increasing n_C (and ν_*) with B_T



- 2010 Plans
  - MAST: investigate β-scaling
  - NSTX: more analysis of Li-conditioned discharges, address roles of low → high-k turbulence with BES, high-k diagnostics

NSTX

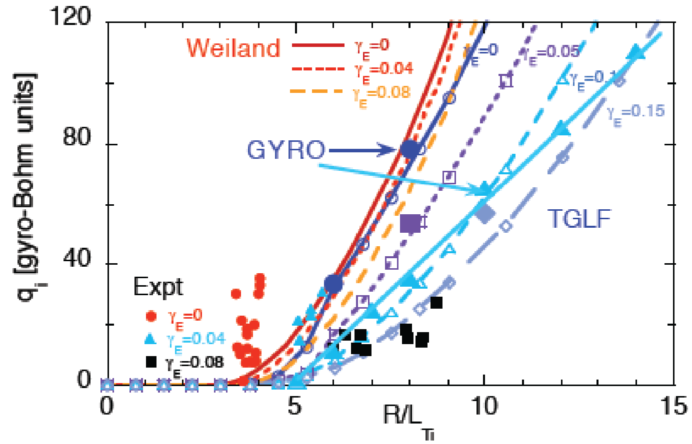




TC-13: ITG critical gradient and profile stiffness (P. Mantica)

JET, C-Mod

- Measure ITG threshold, profile stiffness as a function of Ω, ∇Ω by changing heating deposition profile using ICRH
- 2010 Results
  - JET results: relaxed stiffness at higher rotation consistent with GYRO, TGLF
    - Weiland model predicts upshift only
  - First C-Mod results
    - Not much difference in T_i peaking between on- and off-axis heating, rotation and no-rotation
    - Need more data analysis

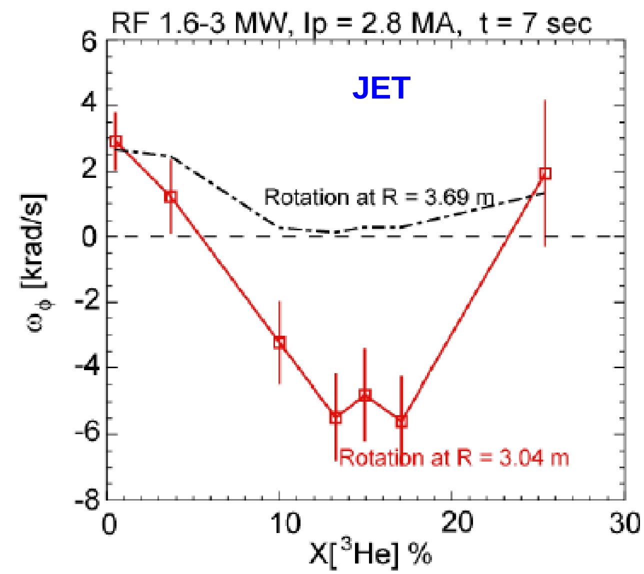


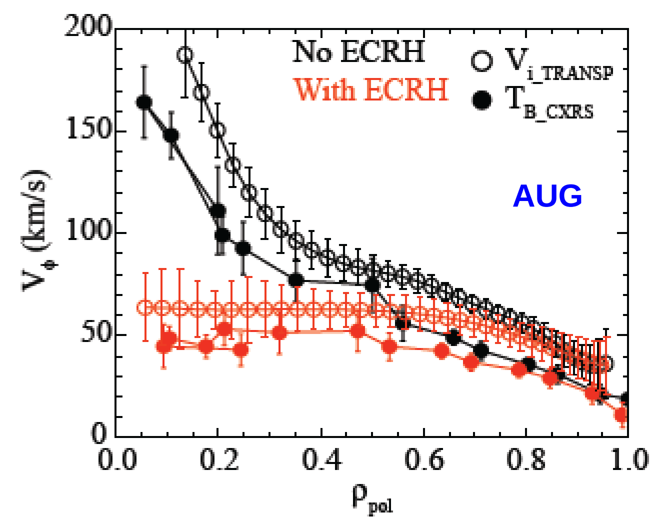
- 2011 Plans
  - Combine with TC-7 (JET, C-Mod, DIII-D, AUG)
  - JET plans expts on effect of impurities in 2011-12
  - AUG plans expts using internal coils to slow plasma in 2011
  - Data analysis ongoing: JET, C-Mod, DIII-D

TC-14: RF rotation drive with ICRH, LH and ECH (J. Rice)

JET, C-Mod, JT-60U, JET, TEXTOR (,DIII-D, TCV, EAST, AUG)

- 2010 Results
  - C-Mod: focus on MCFD
    - Generally find $v_{driven} \sim P_{RF}^{1.3}\ I_p^{0.5}\ n_{e0}^{-0.9}\ f_{RF}^{-0.8}$
    - MFCD does not fit the usual intrinsic rotation scaling
      - Different physics
  - JET: sensitive to ^{3}He level in D-^{3}He plasmas
    - Related to larger $k_{\parallel}$, up-down asymmetry of waves
  - AUG: profile flattening with ECH
    - Connected to change in $T_{e,i}$ profiles
    - Need additional torque or outward pinch to explain results
    - Can RF-driven rotation be considered to be "intrinsic"
      - RF torques (NSTX also)
- 2011 Plans
  - C-Mod: continue MCFD optimization studies and understanding, LHCD drive
  - *JT-60U, JET: continue analysis*
  - *DIII-D, TCV, EAST: explore ECH flow drive*
  - For LHCD/ECH – drive or secondary effect?

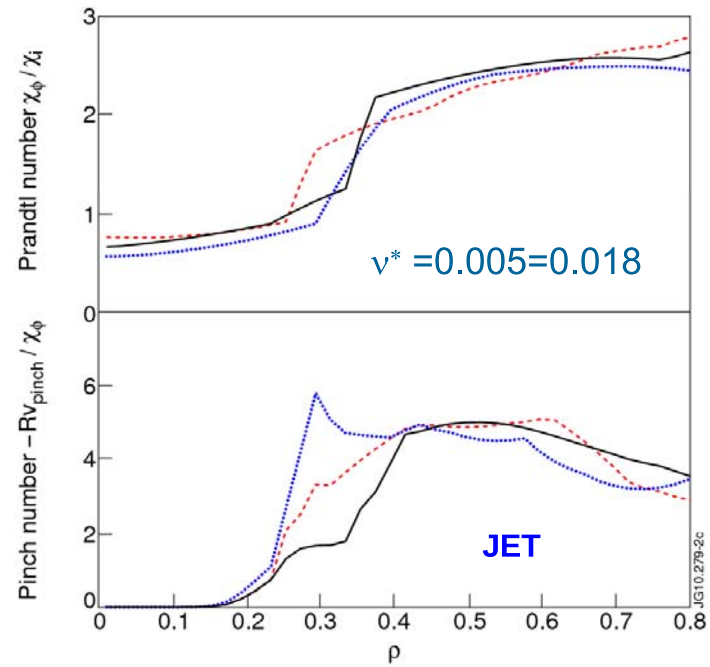


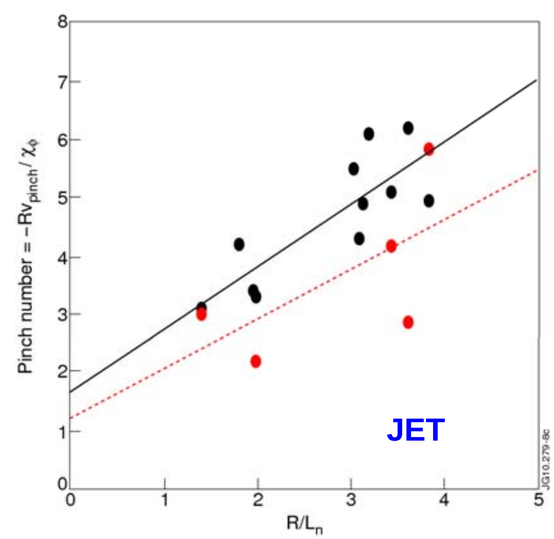


TC-15: Dependence of momentum and particle pinch on ν^* (T. Tala)

DIII-D, NSTX, JET, (C-Mod, AUG, JT-60U)

- Test low-k turbulence theory predictions
- 2010 Results: expts done on 3 devices
  - JET: 3 point ν^* scan for mom./part. pinch
    - No dependence of Prandtl #, Rv_{pinch} / χ_ϕ on ν^*
    - Rv_{pinch} / χ_ϕ depends on R/L_n
    - Consistent with previous NSTX, DIII-D results
    - Consistent with gyrokinetic theory predictions
    - Gas puff modulation expt to determine particle pinch, diffusivity
      - Data being analyzed
- 2011 Plans
  - Continue and complete analysis for DIII-D, NSTX, JET
  - C-Mod, AUG expts
  - Closeout in 2011 (?)

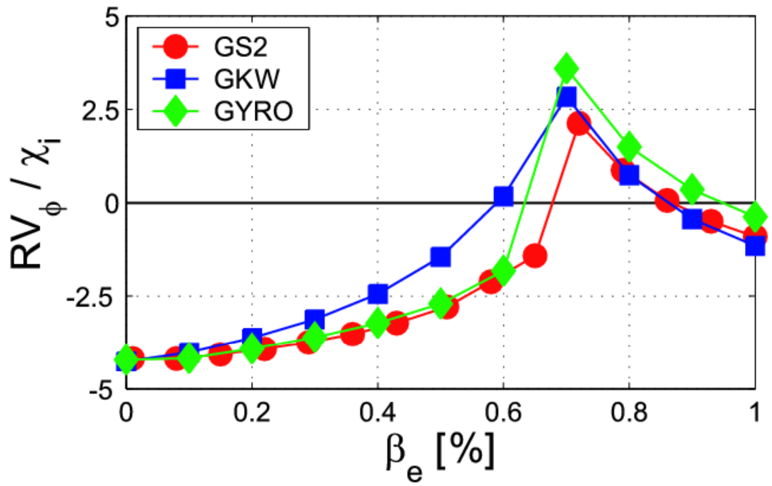




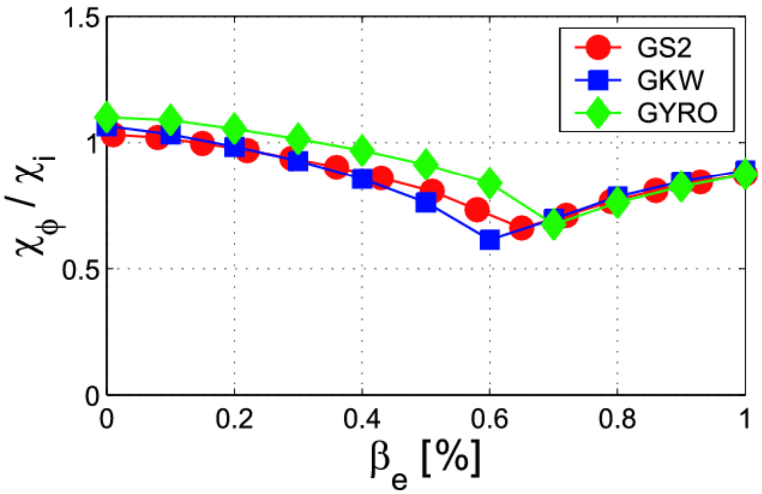
TC-16: Dependence of momentum and particle pinch on β

DIII-D, AUG, JET; T. Tala

- Gyrokinetic codes indicate that the momentum pinch decreases and changes directions as β_e increases above 0.6 in conventional aspect ratio tokamaks
  - Consequence of Kinetic Ballooning Modes dominating over ITG at high β_e
  - STs (NSTX, MAST) typically operate at much higher β_e
    - Kinetic ballooning mode boundary much higher β_e as well
    - Calculations on NSTX indicate KBM threshold has not been reached for typical H-mode plasmas for $r/a \geq 0.5$



- 2011 Plans
  - Perform β-scan keeping other dimensionless parameters as fixed as possible (including R/L_n)
  - Use NBI modulation to induce rotation perturbation
  - AUG: expt. planned
  - DIII-D, JET: to be proposed



TC-17: ρ_* scaling of the edge intrinsic torque

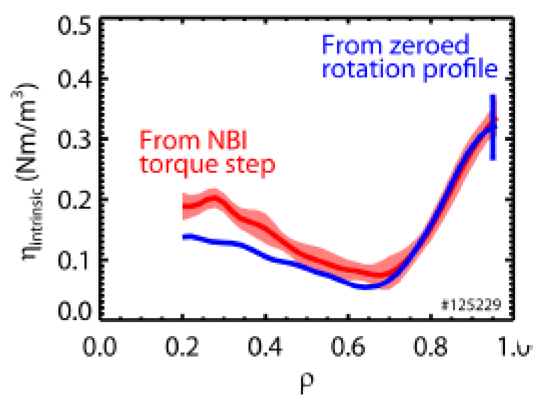
DIII-D, NSTX, AUG, JET, C-Mod, JT-60U: W. Solomon

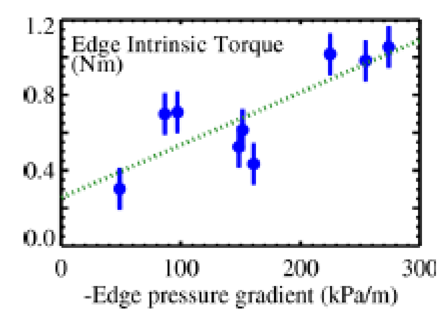
- Aim is to investigate the ρ_* scaling of intrinsic torque at the edge of the plasma
  - Purpose is to extrapolate intrinsic rotation to ITER
  - Need to consider underlying drive mechanisms (i.e., residual stress)
- Previous work has relied on plasmas with zero rotation
  - Limits the number of devices able to participate
- Can use simple 0D angular momentum balance equation to model the plasma rotation response to a change in known torque (e.g., NB-step)
  - Can determine both the momentum confinement time and “residual” torque (assuming these are the only unknowns)

$$\frac{dL(\rho)}{dt} = T_{\text{NBI}}(\rho) + T_{\text{intrinsic}}(\rho) - \frac{L(\rho)}{\tau_\phi(\rho)}$$

  - Technique has worked in DIII-D; data seems good from NSTX expt (2010)

- 2011 Plans
  - Initial parametric scans to be performed in AUG and JET analysis continuing for DIII-D, NSTX data
  - DIII-D/JET similarity expt (different ρ_* at fixed q, β_N and ν_*) in 2012 (?)
  - Extend to C-Mod if MFCD torque can be calculated





TC-18: Dimensionless identity experiments in the I-Mode

AUG, C-Mod, DIII-D: F. Ryter

- Aim is to compare I-mode access, performance at same values of dimensionless physics variables
  - Extensive coverage of edge profiles and turbulence

- I-mode usually develops in conditions of high P_{LH}
  - Increase in energy confinement owing to development of temperature pedestal (generally not as much as in H-mode)
  - No density pedestal development
  - Drop in low-f turbulence, little difference in higher-k
  - Intermediate stage between L- and H-modes

- At present, not obvious as an operational scenario for ITER
  - Generally high power (>favorable P_{LH}), H<1
  - **Further optimization studies called for**

- Provides an attractive scenario for the study of pedestal and L-H transition physics at the very least
  - Dimensionless identity expts between AUG/C-Mod (DIII-D?) using RF heating will assess generality and main physics properties

TC-19: Characteristics of I-Mode plasmas

AUG, C-Mod, DIII-D, NSTX, TCV (?), JET(?): J. Rice

- Aim is to document the access conditions, power scaling and general characteristics of I-mode plasmas
  - Target density, current, plasma shape (geometry)
  - Turbulence characteristics
  - Edge profile shapes (density, temperature, velocity)

- **Optimization studies**
  - Assess power requirements for access, confinement

- Much more general and inclusive than proposed XP-18

TC-20: Transport model validation during current ramp-up

AUG, C-Mod, DIII-D, JET, ISM: D. Mikkelsen

- This Joint Modeling Activity will test thermal transport models by predicting the temperatures and plasma current evolution in ITER-similar current-ramp plasmas in present day tokamaks

- Progress reported in prior presentation

Ongoing and Longer Term Activities

- Databases
  - Momentum (M. Yoshida)
    - Being developed with global and local parameters
    - Enable gyrokinetic calcs to study source of momentum diffusivity and pinch
    - Populated with data from (JET, NSTX, DIII-D, JT-60U, C-Mod)
  - L-H threshold (J. Hughes)
    - Include local/profile (edge) info for model testing and understanding uncertainties in P_{th}
    - Need to progress on this before next ITPA meeting
  - Profile database
    - Used for TC-11 (He/impurity transport, TC-20?)
- L-H Threshold (in conjunction with Pedestal group)
  - Study “unhidden” variables and effect on P_{th}
  - Role of turbulence, ExB shear
    - Source of turbulence In L, change going to H, GAM/ZF, oscillating flows
- 3D effects in stellarators vs. tokamaks
  - Small group to determine focus/benefit of joint work between configurations
- Momentum transport
- ITBs
- Electron transport