# IAEA FUSION ENERGY CONFERENCE

## THEORY SUMMARY (S/1-3)

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# INTRODUCTION

## Key Questions for Fusion Power

- **Confinement:** scalings, improved confinement (transport barriers)
- **Stability**: pressure limits, loss of control (disruptions), fast particle MHD
- **Exhaust:** divertor heat loads, ELM transients
- **Steady State**: simultaneous achievement of plasma performance, exhaust and current drive

Plus **Basic Understanding:** provides scientific underpinning

Review **Progress** from **Theory** against these objectives

# STATISTICS

**91 papers**: 1 Overview (**new**) - Diamond: *Zonal flows in plasma turbulence*; 32 0ral (11 rapporteured), 58 Posters

**Configurations**: Mainly tokamaks (9 ITER, 8 STs)

- 10 non-axisymmetric, 2 other alternates

**Topics:**

- Confinement 48 (ZFs 19, barriers 15)
- Stability 30 (NTMs 6, RWMs 4, ballooning modes 6, disruptions 4, fast particle MHD 10)
- H&CD, fuelling 7 (ICRH/LH 3, ECRH 3, pellet 1)
- Exhaust 14 (ELMs 7)

# THEMES AND METHODOLOGIES

- Increasingly **sophisticated physics** and **geometric realism**
- Moves to **Integrated Modelling**
- Analytic interpretation of **‘Numerical Experiments’**

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**Numerical** approaches vastly dominate:

- Turbulence simulations 21 (Edge/SOL 9)
- Transport codes 12
- Non-linear MHD 10 (hybrid fast particle codes 4)
- Fokker-Planck/Monte Carlo 10

# PROGRESS (1): CONFINEMENT

## BASIC UNDERSTANDING

**- Zonal flows and turbulence**: **Overview** (Diamond )

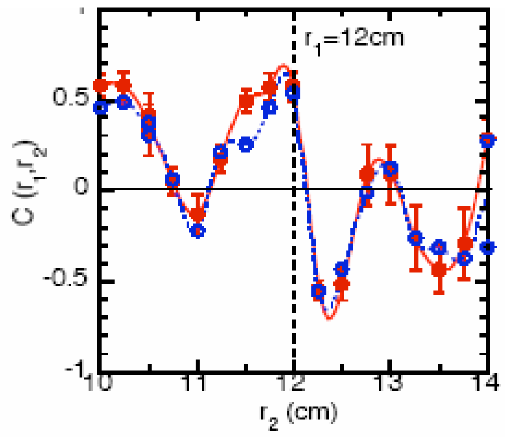
- ZFs have fast **radial** variation but **azimuthally symmetric**
- **Ubiquitous** and **robustly** generated in drift-wave turbulence
- Critical players in regulating non-linear dynamics ('predator-prey', 'burstiness') of turbulence: the **drift-wave/ZF paradigm**
- Reduce drift wave energy and **transport**

$\chi \sim R\chi_{GB}$; $\quad R = \gamma_{ZF}^{DAMP}/\omega \ll 1$

$\Rightarrow$ **Cost** of power plant $\propto R^{-0.8}$

- $\gamma_{ZF}^{DAMP} \propto \nu_{ii} f(q) \Rightarrow$ **control** (also Falchetto TH-1/3Rd)
- Also **critical gradient** increases (**Dimits-upshift**)
- Can have **collisionless** damping of ZFs; eg via **tertiary** instabilities, say Kelvin-Helmholtz

- Seen in **expt -** CHS (A Fujisawa et al, PRL 95 (2004) 165002)



Radial distance

- **Unification** of many physical situations in terms of **two** parameters: K and S (Kubo number, Drift wave stochasticity parameter)

- Zonal **fields** - current corrugations: impact on RWMs, NTMs?

- Valuable **analysis** of *'what we know, what we think we know and what we don't understand'*

# TURBULENCE THEORY-CONTD

- **Multiscale effects**: ETG/ITG (Holland TH-P-6/5)

  Long wavelength drift-ITG **straining** suppresses ETG streamers, but the corresponding **temperature** perturbations increase ETG growth

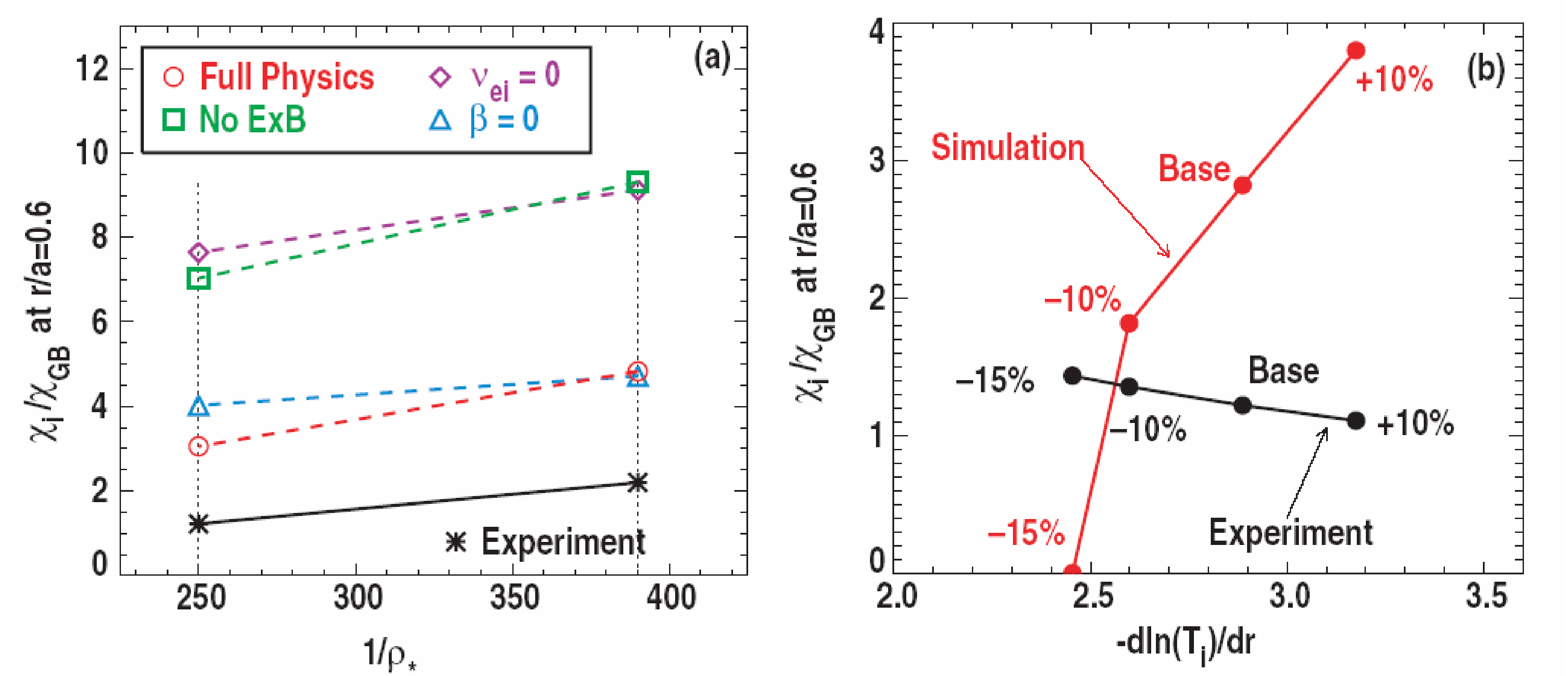
- **Damped modes**: key role in TEM/ZF dynamics and saturation (Terry THP-6/9)

- **Lagrangian formulation** of Hasagawa-Mima turbulence and ZF eqns. (Dewar TH-P-6/1)

# CORE TRANSPORT

**Theme** - increasing role for simulation codes: global codes, more complete physics and geometry, low magnetic shear

GYRO: **Global code** with **full physics** describes DIII-D $\rho_*$ **scaling** in L-mode; feedback on profiles to achieve steady-state (Waltz TH-8/8)



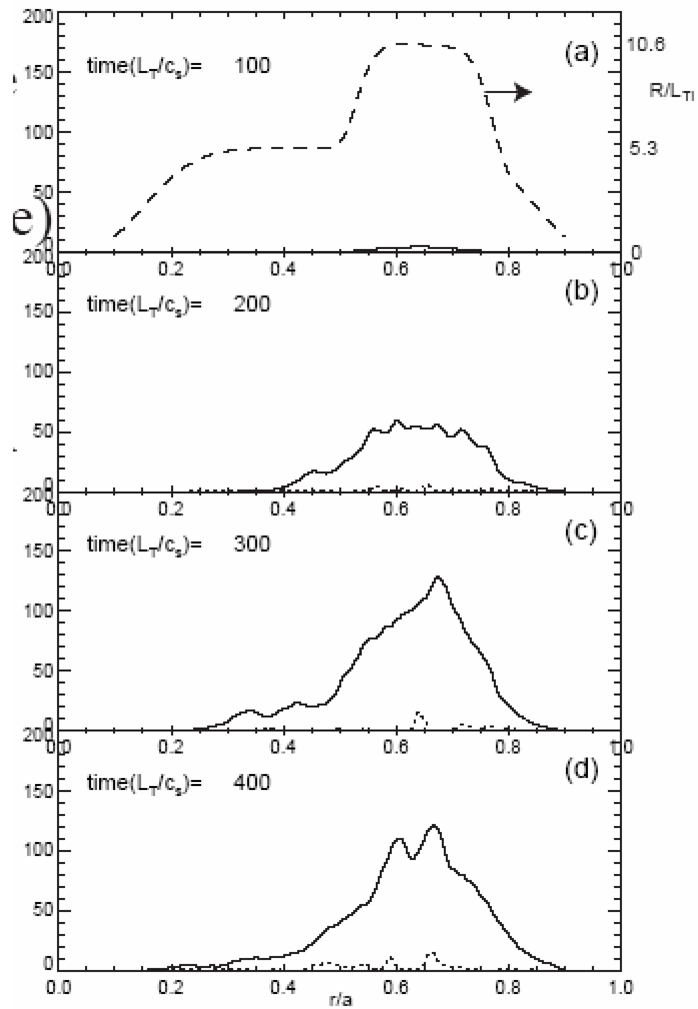
# GTC: allows **steep gradients** - turbulence **spreading** from edge to **stable core**, affecting $\rho_*$ scaling (Hahm TH-1/4); analytic theory (Holland TH-P-6/5)

**Nonlinear GTC Simulation**

**of Ion Temperature Gradient Turbulence**

$\frac{R}{L_T}$ = 5:3 at core (within Dimits shift regime)

$\frac{R}{L_T}$ = 10:6 at edge:




Initial Growth at Edge and Local Saturation

$\rightarrow$ Penetration into *stable* Core:

Lin,Hahm,Diamond,... PRL '02, PPCF '04

Saturation Level at Core:

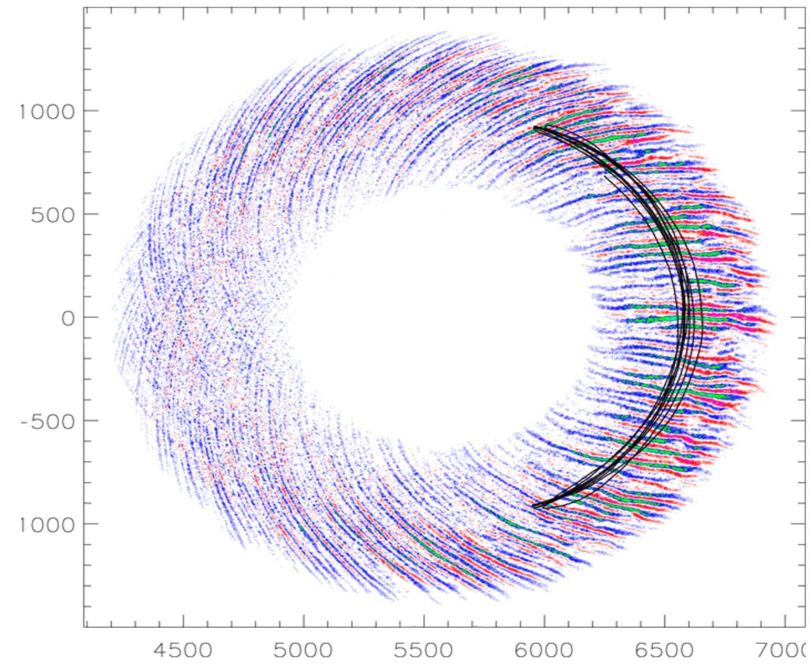
$$\frac{e\delta\phi}{T_e} \sim 3.6\frac{\rho_i}{a}$$

$\rightarrow$ sometimes $\nabla\bullet\Gamma_{\text{spreading}}$ >> $\gamma_{\text{local}}$

Can increase transport in unstable core, say fluctuations x2

# ETG MODES

- **Global** code (GTC) shows **streamers** but $\chi_e \sim 3\chi_e^{ML} \Rightarrow$ need TEM; non-linear **toroidal** coupling essential for **spectral** cascade (Lin TH-8/4)

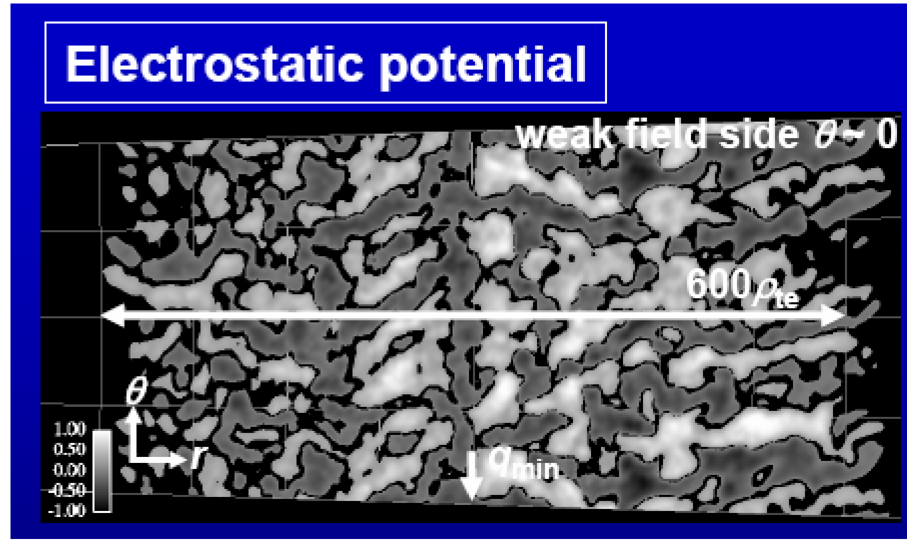


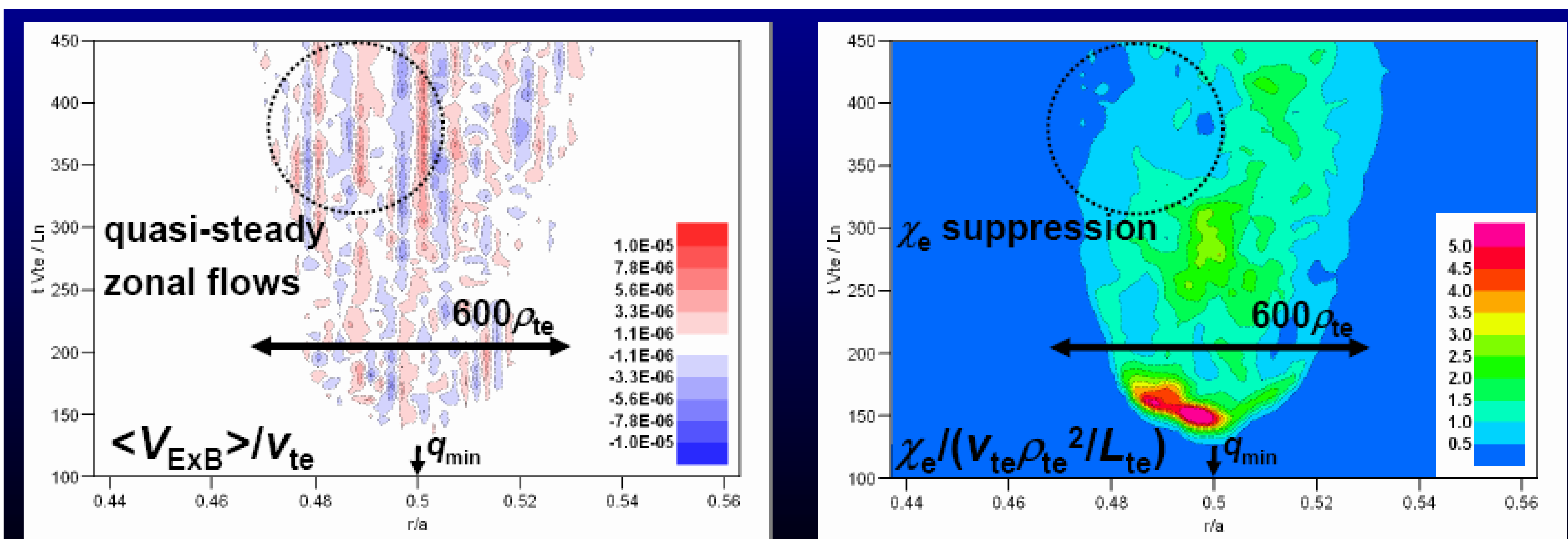

- Low s, low $\chi_e$; high s, streamers (Li TH-8/5Ra)

- Global code: near $\mathbf{q_{min}}$, $s < 0 \Rightarrow$ low $\chi_e$
  $s > 0 \Rightarrow$ streamers and large $\chi_e$;
  role for toroidal mode coupling (Idomura TH-8/1)

## $\chi_e$ gap structure in RS gap structure in RS-ETG turbulence

- RS-ETG turbulence shows qualitatively different structure formations across $q_{min}$
- **Zonal flows (streamers)** appear in negative (positive) shear region
- $\chi_e$ distribution has a **gap** structure across $q_{min}$



# ELECTRON & ION TRANSPORT

## TEM

- GS2 - non-linear **upshift** on critical $L_n^{-1}$ for C-Mod ITB; equilibrium with off-axis ICRH where $\Gamma_{TEM}$ balances Ware drift

  $\Rightarrow$ on-axis ICRH gives **control**

  GS2 fluctuations compare with PCI on expt (Ernst TH-4/1)

## ITG

- Competition between **ZFs, GAMs** and **parallel flows**

  $\Rightarrow$ **q-dependent** $\chi_i$ (Miyato TH-8/5Ra, Hallatschek TH-P-6/3)

  - cf Hirose (TH-P-6/4)

# ITG-CONTD

- **Benchmarking** turbulence characteristics in codes (Nevins TH-P-6/6)

  - GTC, GYRO: identify origin of discrepancies in $\chi_i$, eg due to cross-phase

  - mixing length model fails

**MISCELLANEOUS MODELS**

**FLUID**

- ZF **upshift** of critical gradient (Falchetto TH-1/3Rd)
- **flow generation** due to $\mathbf{L_n}$ (Sarazin TH-P-6/7)
- **reduced** models (18 ODE's needed) and **relaxation oscillations** (Hamaguchi TH-8/3Ra)

**KINETIC**

- **entropy** balance accounting in **velocity** space: **fine-scale structures** and phase-mixing (Watanabe TH-8/3Rb)

# ‘NEOCLASSICAL’

- **$\delta$f codes**: GTC-Neo $\rho_{ban} \sim L_p \Rightarrow V_{\theta i}$ different from ‘NC’ - depends on $\omega_\phi$ ($\psi$) (Hahm TH-1/4);
- Finite orbit width, non-axisymmetric geometry and $E_r$ (Satake TH-P-2/18)
- ‘**Omniclassical**’ in STs - doubles $\chi_i^{NC}$ due to gyro-orbits (White/Goldston TH-P-2/19)
- ‘**Paleoclassical’:** Classical resistive diffusion $\Rightarrow$ **stochastic diffusion** of field lines: captures many experimental features (Callen TH-1/1)

# TOROIDAL MOMENTUM

**Losses**: (i) QL theory; (ii) non-resonant MHD and magnetic island effects.

**Source**: Identified toroidal ‘travelling’ modes along **B** for inward transport in **accretion** model (Shaing/Coppi TH-P-2/9)

# TRANSPORT MODELLING

- Integrated modelling of advanced, **steady state** ST based on NSTX data $\Rightarrow \beta \leq 40\%$ (Kessel TH-P-2/4)

- ITBs with **mixed Bohm/gyroBohm** model: need $\alpha$-stabilisation for DIII-D; **real time q control** simulation for JET (Tala TH-P-2/9)

- ETG transport modelling of **Tore Supra**, **NSTX** (Horton TH-P-3/5)
- Analysis of **ECRH switch on/off** in T10 - ballistic response (Andreev TH-P-3/1)
- Calibration of the model for **barrier formation** in **CPTM**; simulations of MAST, DIII-D, JET, TFTR with similar fitting parameters; effective **critical** $\rho_{*Te}$ values (after JET) similar (Dnestrovskij TH-P-6/55)
- **Integrated modelling** -TASK (Fukuyama TH-P-2/3)

# NOVEL TRANSPORT MODELS

- **Avalanches** and **non-diffusive transport** observed in turbulence simulations represented in transport modelling by **fractional derivatives** (del-Castillo-Negrete TH-1/2)

- Model with **critical gradients** and **Levy Flights** captures **density pinch**, fast transients, power degradation (van Milligen TH-P-6/10)

- **Stationary Magnetic Entropy** model tested on JET and FTU: predicts q-profile in range of discharge types; less success with temperature profiles (Sozzi TH-P6-13)

- **Control** of test-particle transport in fusion relevant Hamiltonian systems (Chandre TH -PD-1)

# EDGE TRANSPORT, PEDESTAL & BARRIER

- **Relaxation** model with **flows** and **ballooning** $\nabla p_{crit}$ (GuzdarTH-5/4)

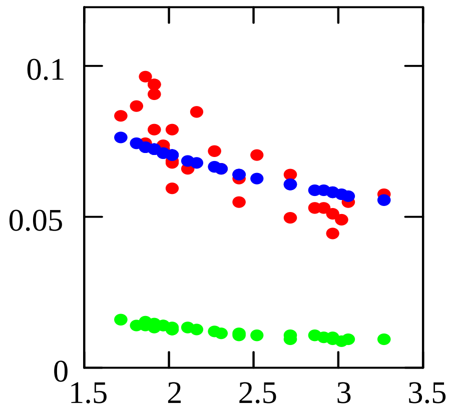
  $\Rightarrow T_{ped} \propto n^{-1}$ and $\Delta_{ped} \propto n^{-3/2}$

  - matches **JT-60U**;

  but drift waves robustly

  **unstable** in pedestal (GS2)

  (universal mode!)




- **Trans-collisional** gyrofluid code (GEM)

  - gradual **change** from edge drift waves to core ETG/ITG

  - drift wave/ZF system stable against bifurcation

  New GK code developed:

  -find similar results but more **high** $\mathbf{k}_\perp$ activity (Scott TH-7/1)

# EDGE-CONTD

## Computational models

- XGC: NC + neutrals +X-point

  $n_{ped}$ develops in 10ms;

  $\Delta_{ped} \propto (T\text{-}T_c)^{1/2}/B_T$;

  T pedestal broader

  (Chang TH-P-6/39)

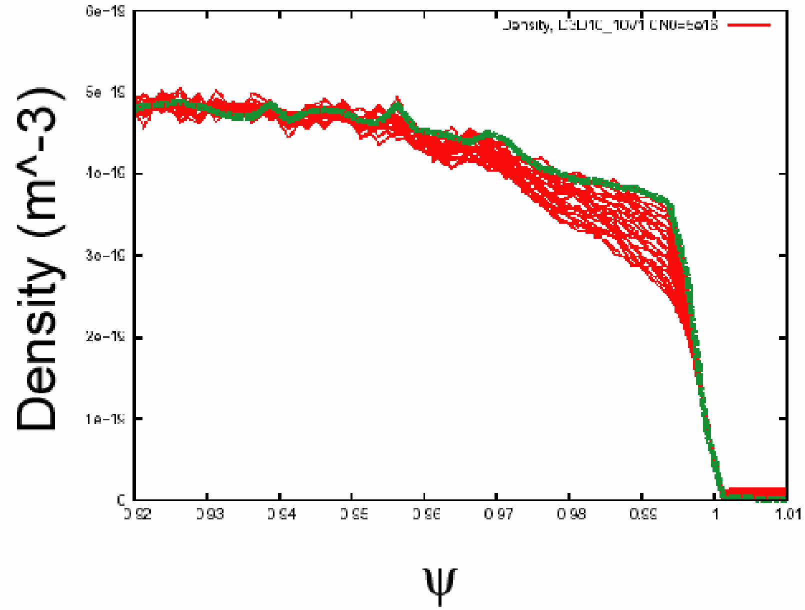



Fig. 1

- ASCOT: NC + $E_r$; ELMFIRE (new ‘f’-code): NC + $E_r$ + turbulence; evidence for ITB formation in FT-2 simulation - (Kiviniemi TH-P-3/7)

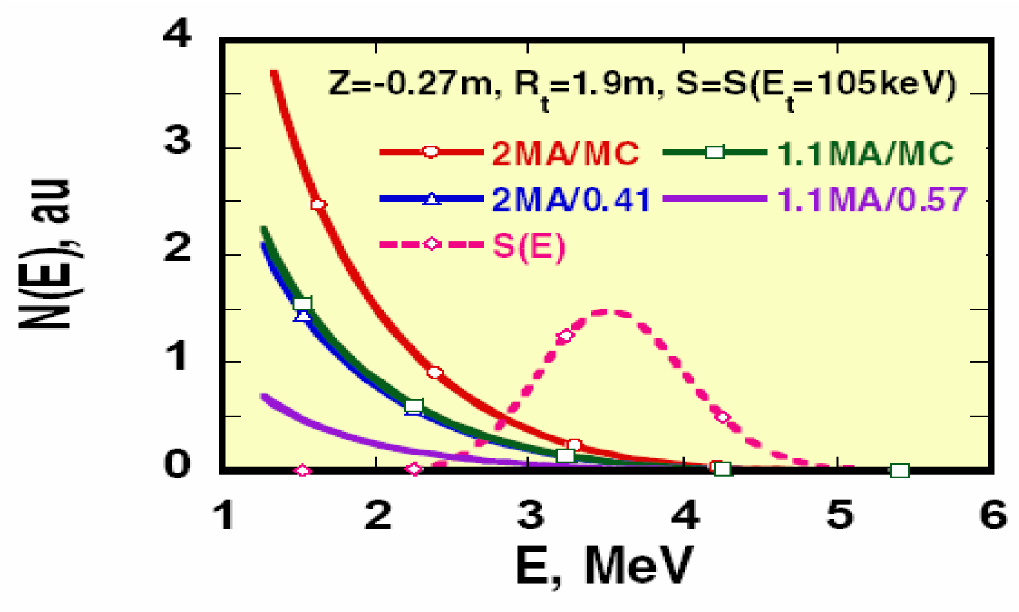
## Analytic & transport models

- poloidal and toroidal flows and neoclassical edge barrier (Fukuyama TH-P-2/3);
- coupled non -linear fluid model for $V_\phi$ , $V_\theta$ (Daybelge TH-P-4/2);
- improved modelling of impurity modes (Morozov TH-P-5/26);
- drift-Alfven transition model; role of $L_n$, $\Delta_{ped} \sim 1/n$ (Kalupin TH-P-3/6)

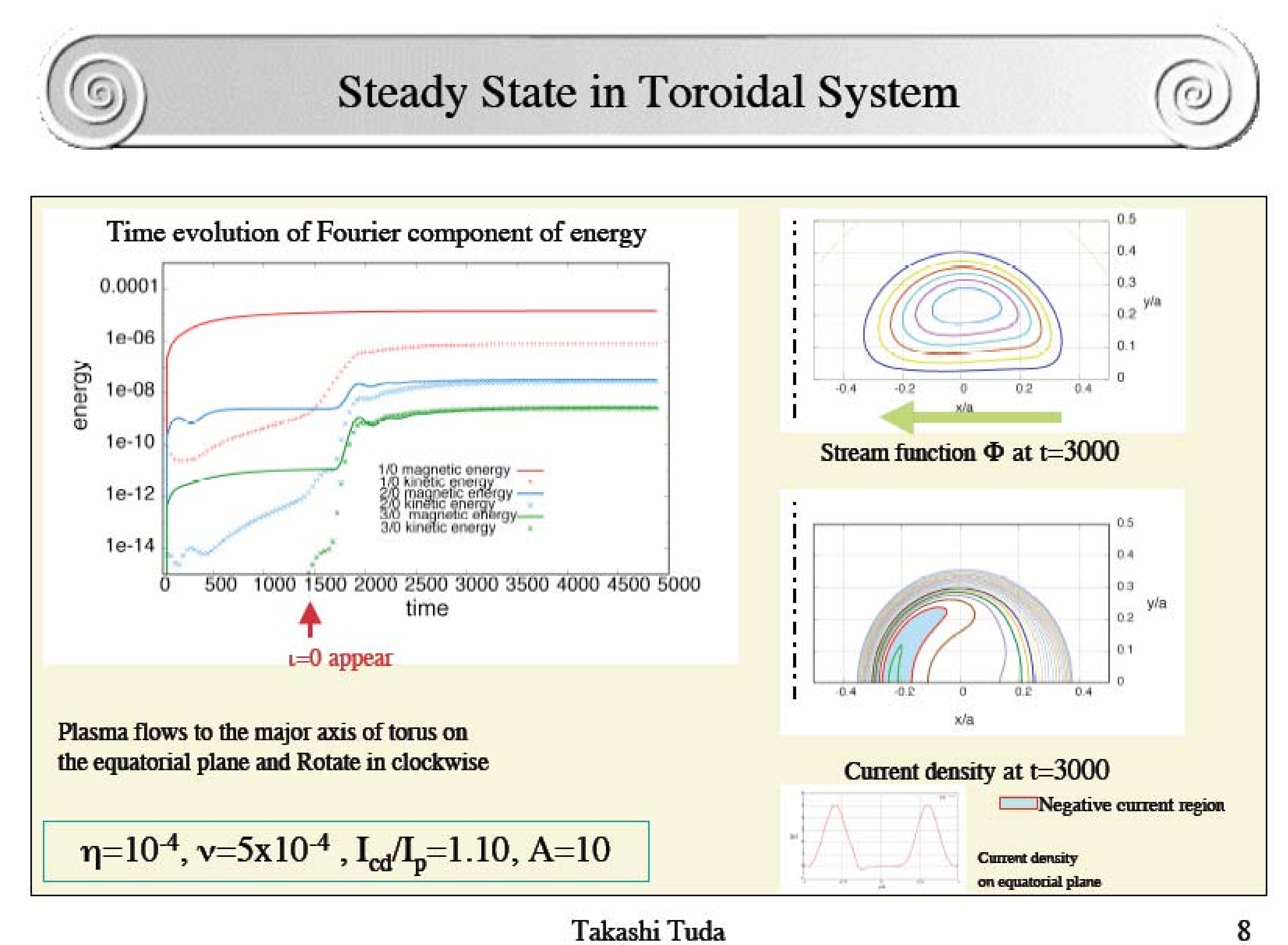
# IMPROVED CORE CONFINEMENT, ITBs

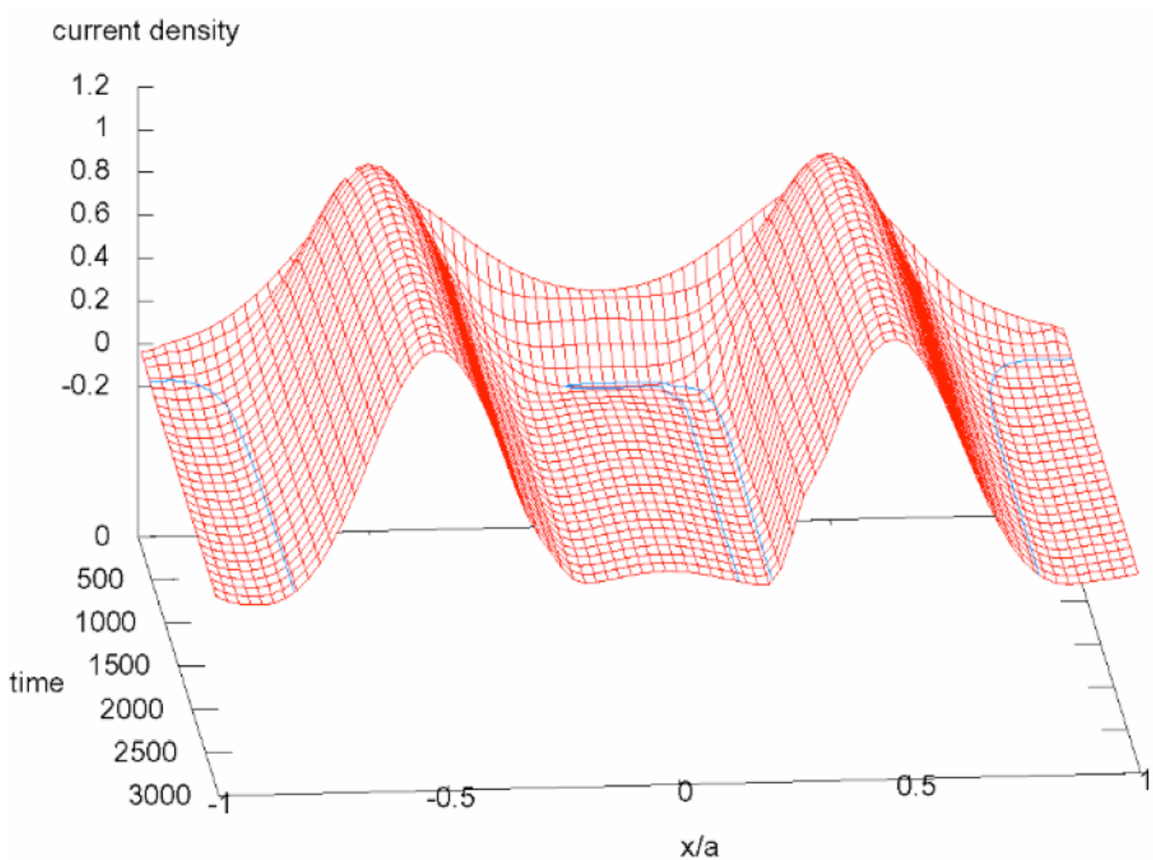
## Current Hole (CH)

- Simulation of $\gamma$ decay due to **redistribution** of $\alpha$**'s** in the poloidal plane in JET: 2MA with CH ( $\rho_{CH} \sim 0.4$) $\equiv$ 1MA in normal shear (Yavorskij TH-P-4/49)



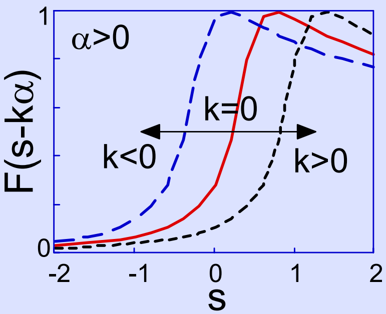
- Formation of current hole by **vortex pair** in core (Tuda TH -P-2-10)




current density
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
500
1000
1500
2000
2500
3000
time
-1
-0.5
0
0.5
1
x/a

# Profile Formation and Sustainment of Autonomous Tokamak Plasma with Current Hole Configuration -3 magnetic island model for CH ( Hayashi, et al., TH-1/6 )

$$\chi_{ano} = \chi_0 F(s - k\alpha)$$

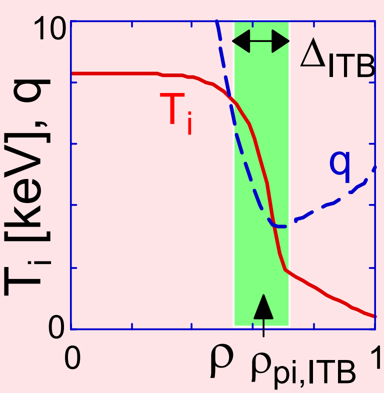


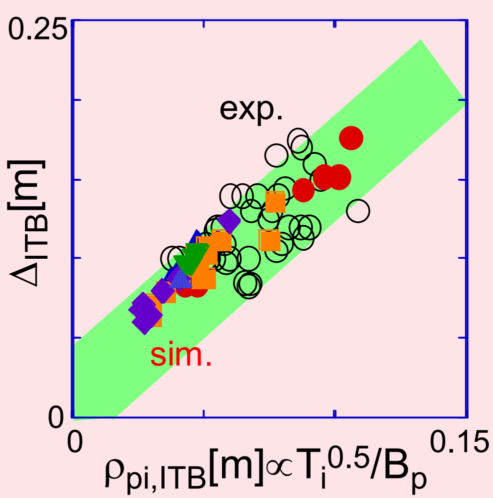

Sharp reduction of anomalous transport in RS region (k~0) can reproduce JT-60U experiment.

Transport becomes neoclassical-level in RS region, which results in the autonomous formation of ITB and current hole through large bootstrap current.

**1.5D transport simulation can reproduce JT-60U scalings.**

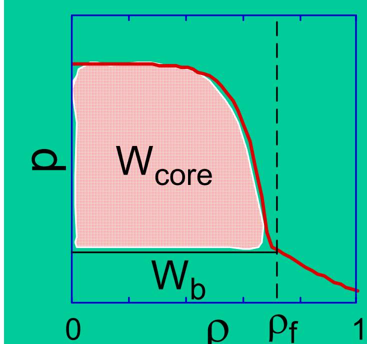
ITB width determined by neoclassical-level transport agrees with that in JT-60U : $\Delta_{ITB} \sim 1.5\ \rho_{pi,ITB}$.



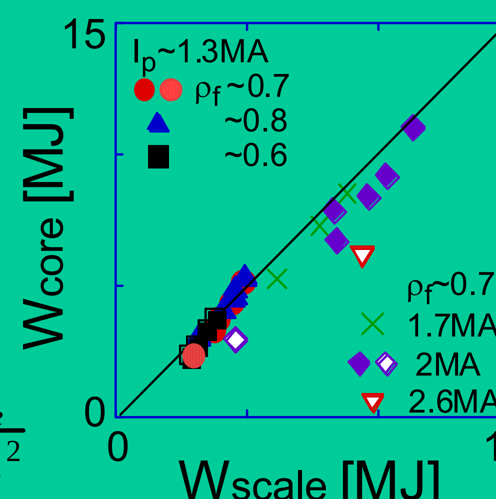




Energy confinement inside ITB agrees with JT-60U scaling : $\varepsilon_f \beta_{p,core} \sim 0.25$.

Same value at MHD equilibrium limit in analytical model.




$$\beta_{p,core} = \frac{4\mu_0 W_{core}}{3V_{core} B_{p,f}^2}$$



# ITBs AT $q_{min}$, RI-MODE

- **Trigger** by DTM **magnetic island** (Dong TH-P-2/7)

- **Stability** at **low shear** and with **flow shear**

  - **failure** of ballooning theory and complementary approach based on **'modelets'** (Connor TH-5/5)

  - effects of s, $v_{\|}'$, $v'$, $\beta$, $j'$ in cylindrical stability calculations (Wang TH-P-6/11)

- **RI Mode**: trigger bifurcation by flows resulting from torques due to **poloidal radiation asymmetry**; stabilises at **lower impurity** concentration (Singh TH-P-5/31)

# PROGRESS (2): STABILITY

**Themes**: Non-linear codes, realistic geometry with wall, improved fast particle models

## NTM: (i) Triggers

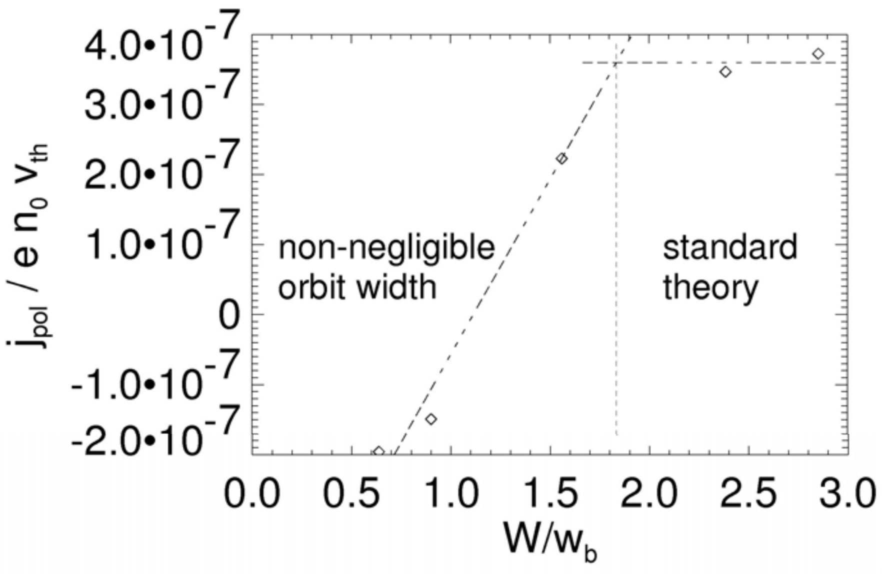
- Forced reconnection by **non-linear** coupling to MHD modes - frequency miss-match not a problem (Coehlo TH-P-5/2)

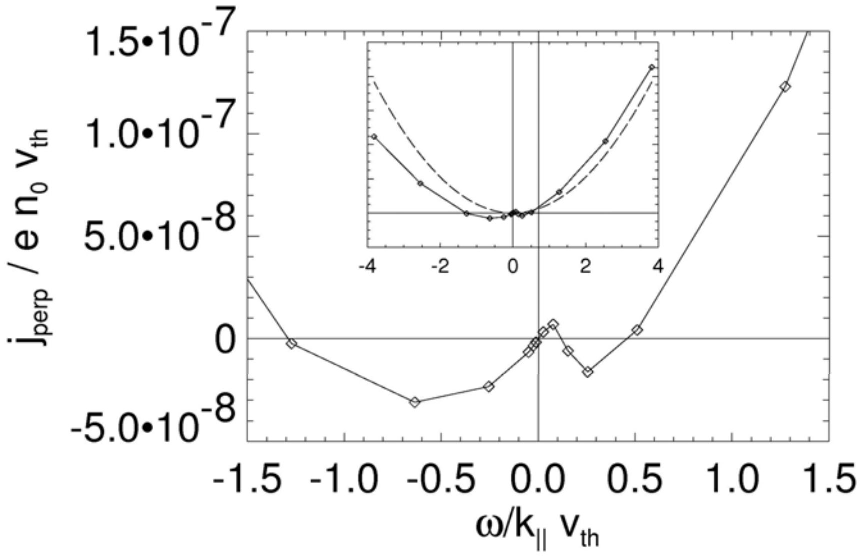
- **Error field amplification** (Pustovitov TH-P-6/3)

## (ii) Critical island width w

- **Turbulent viscosity**:dominant stabilising effect on $\mathbf{j_{BS}}$ **drive** for island rotating in **electron** direction $\Rightarrow$ not explanation of $\beta_{Th}$ in expts; effect on $j_{Pol}$? (Konovalov TH-P-5/10)

- **Rotation shear** destabilises, differential rotation stabilises (Sen TH-6/1)




**Finite orbit** ($w \sim \rho_{ban}$) effects on $j_{bs}$ , $j_{pol}$ (HAGIS): $j_{pol} \propto w$, $w < \rho_{ban}$; $j_{pol}$ changes **sign** near $\omega = \omega_{*e}$ (Poli TH-6/2)

# TEARING MODES

- **Non-linear** enhancement of growth by **drift wave** turbulence (Yagi TH-P-5/17)

- Enhanced **reconnection** in collisional drift-tearing model - parallel electron thermal conduction plays key role (Coppi TH-P2-29)

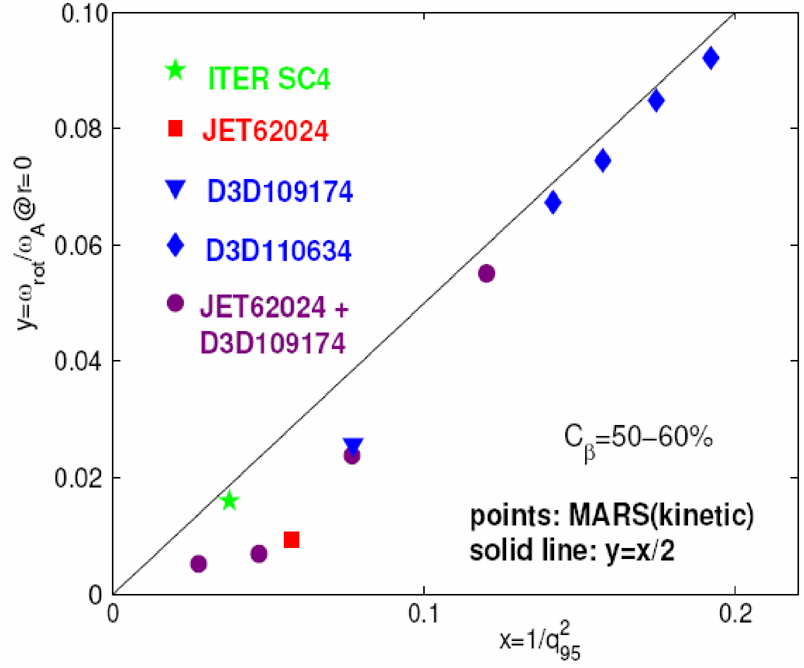
- Non-linear stabilisation of island at finite island **width**, w:

$$\Delta' \to \Delta' - c_1 w \ln(1/w) - c_2\, w$$ (Porcelli PD-1)

# RWMs

**Rotation** stabilisation

and **control:**




- **validated** kinetic model

  for **damping** in MARS

  - stabilisation of n = 1 in **ITER** for $\omega_\phi \sim (1.5 - 3)\%\ \omega_A$;

  - but predicted rotation < 2%

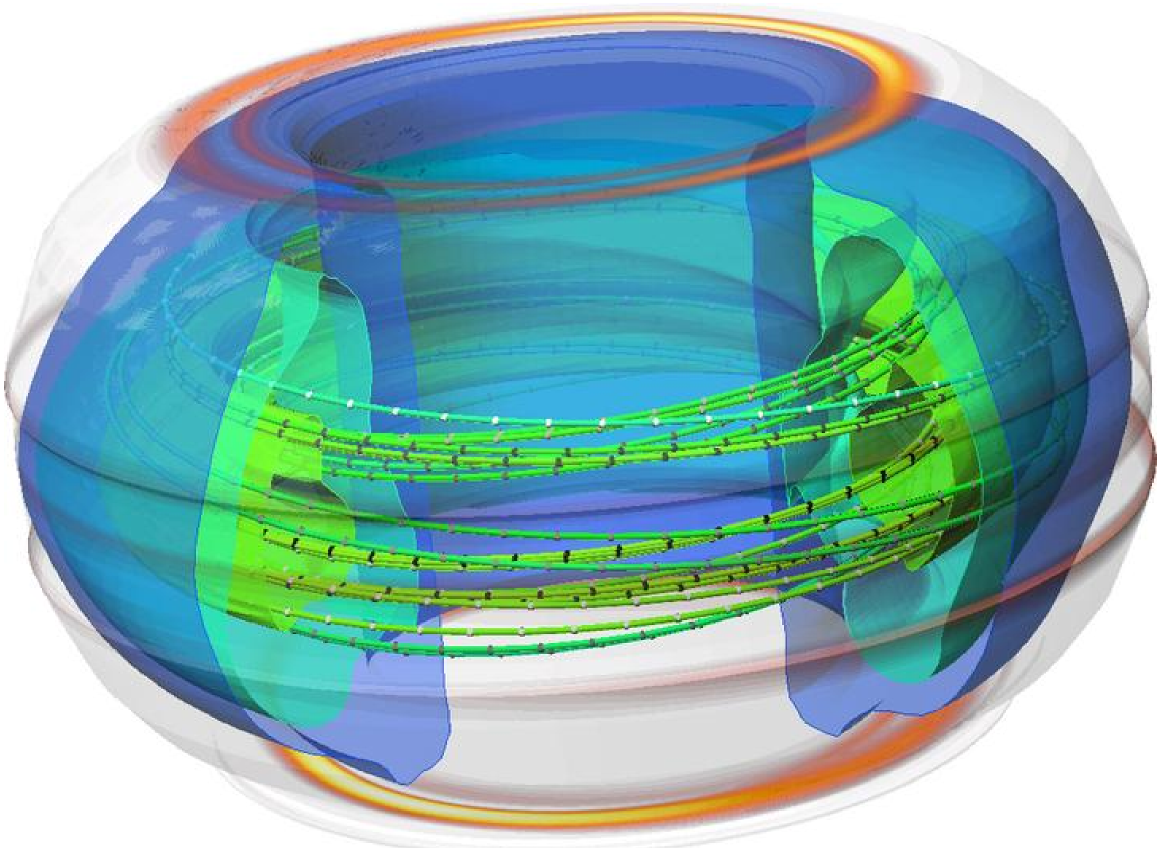
  $\Rightarrow$ need **control**: possible to approach 80% of way between no-wall and ideal-wall limits (Liu TH-2/1)

- Effect of coupling to **stable** internal modes on external modes - generate a 'peeling like' structure (Tokuda TH-P-4/46)

- **Thick walls** in **ITER** slow down growth rate (Strauss TH-2/2)

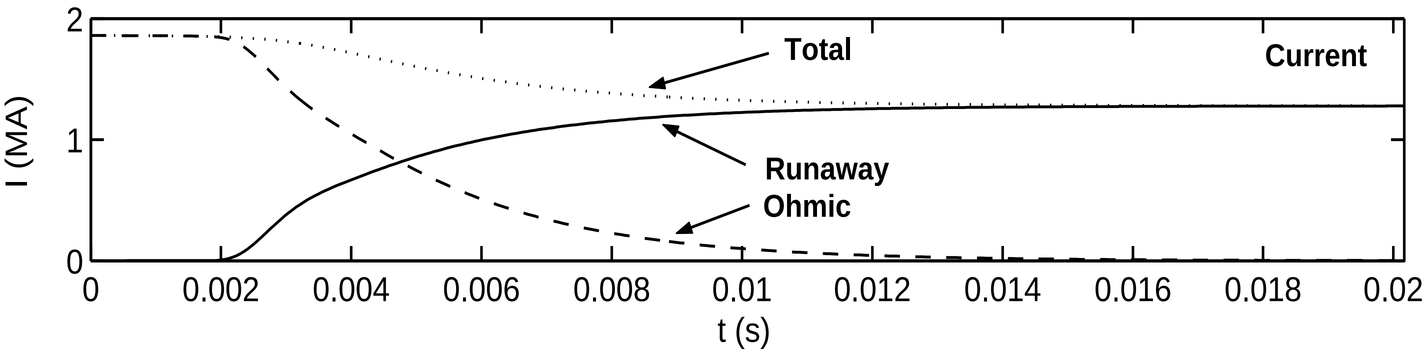
# DISRUPTIONS

- Simulation of **heat deposition** due to disruption for DIII-D RS with NIMROD - asymmetric heat deposition from n =1 distortion (Kruger T-P-2/25)



- Modelling **ITER** halo current database with M32D - VDEs: **halo current fraction** ~ 0.35, **toroidal peaking factor**, TPF ~ 2 (Strauss TH-2/2)

- Self-consistent evolution of **runaways** and **current** in disruptions - central **peaking** of current - simulates JET; 1/2 of current in JET and 3/4 in **ITER** converted to runaways (Helander TH-P-4/39)




- **Eddy current** calculations in ETE ST (Ludwig TH-P-4/7)

# PRESSURE LIMITS

- **Non-axisymmetric** studies of ideal MHD **ballooning** and **interchange** modes (Miura TH-2/3, Nakajima TH-5/6) and equilibrium & orbits (Suzuki TH-P-2/31), particularly **LHD** and for **NCSX**

  - reduced **disruptivity** from toroidal flow generation $\Rightarrow \beta \sim 1.5\%$ (Miura)
  - perturbative approach to identifying **second stability** (Hudson TH-P-2/24)
  - 'realistic' treatment of boundary, reducing '**bumpiness**' improves stability and agreement with expt, $\beta \sim 3\%$ 'stable' - $\beta \sim 1\%$ more unstable (Nakajima)

- **2-fluid non-linear** modelling with M3D: better explains experiment; stabilises ideal and resistive modes $\Rightarrow$ **soft beta** limit due to **confinement degradation** as **islands** grow large (Sugiyama TH-P-2/30)

- **Rotation damping** of ballooning modes

  - interpretation in terms of damping on **stable modes** (Furukawa TH-P-1/1);

  **- transition** from zero flow calculation of standard ballooning theory (Connor TH-5/5)

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Instability suppression by sheared flows in dense **Z-pinch** (Herrera Velazquez TH-P-2/23)

# FAST PARTICLE MHD

**Themes**: Realistic $f_h$, frequency-sweeping, diagnostic opportunities, alpha-losses

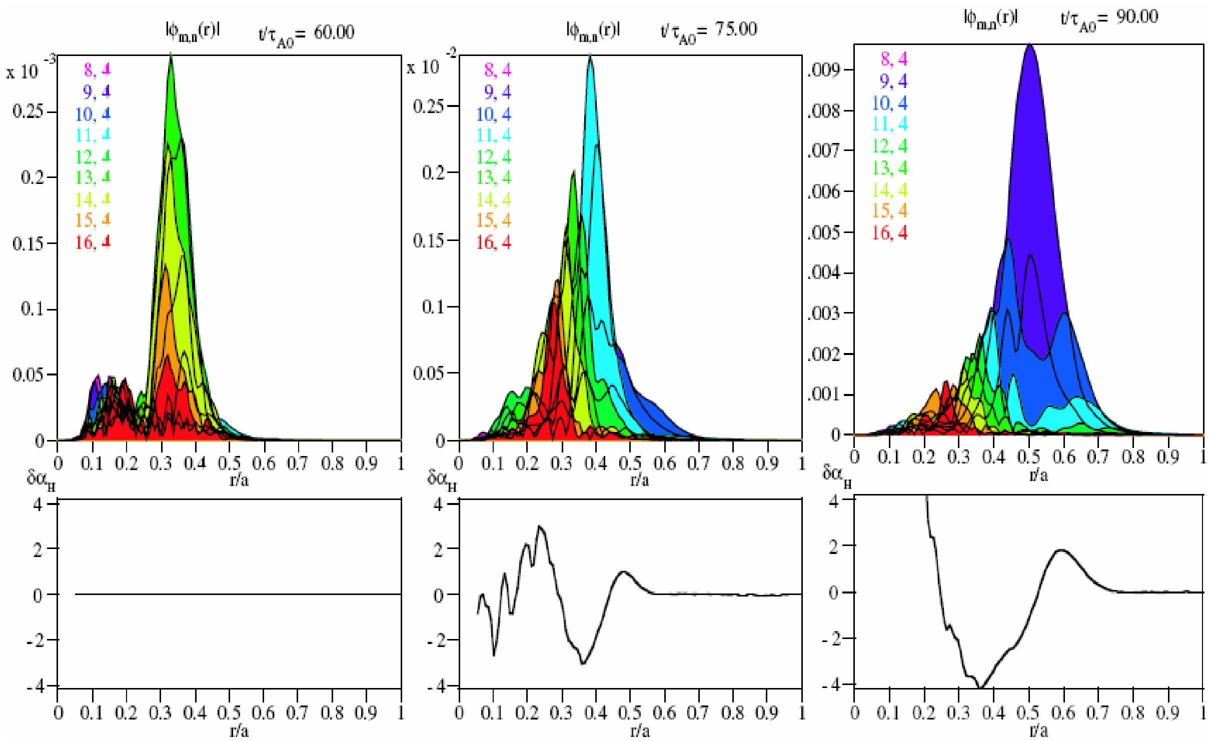
## Fishbones & internal kink mode

- non-perturbative treatments of $f_h$, new branches

- Explain **low frequency** modes on JET with NOVA-K (Gorolenkov TH-P-5/2Rb)
- **Hybrid fishbones** and coalescence of fishbones during JET monster sawteeth, operating diagram in ( $\gamma_{MHD}$, $\beta_h$, $\omega_{*i}$) (Nabais TH-5/3)
- **Non-conventional** modes in ST (low **B**) and doublet frequency modes from passing particles in AUG (Kolesnichenko TH-P-4/42)

# TAEs, EPMs

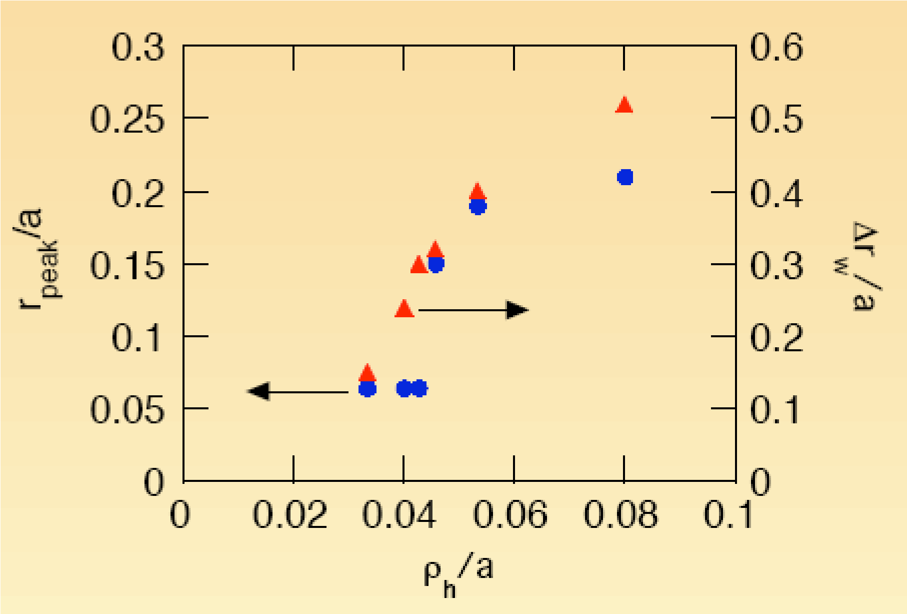
- Hybrid MHD-GK code: **Avalanching** transport of alphas, theory shows **threshold** near linear stability: $\tau_{loss}$ - few $\gamma_{lin}{}^{-1}$; radial redistribution, loss only for **ITER RS** (Zonca TH-5/1)



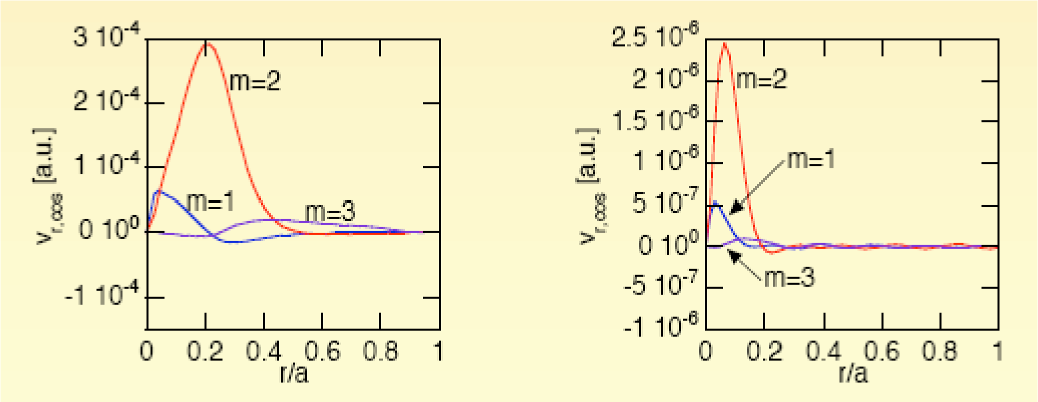

- Non local EPM - width and location depends on energetic ion orbit width (Todo TH-3/1Ra)

# Non-local Energetic Particle Mode

(Todo TH-3/1Ra)

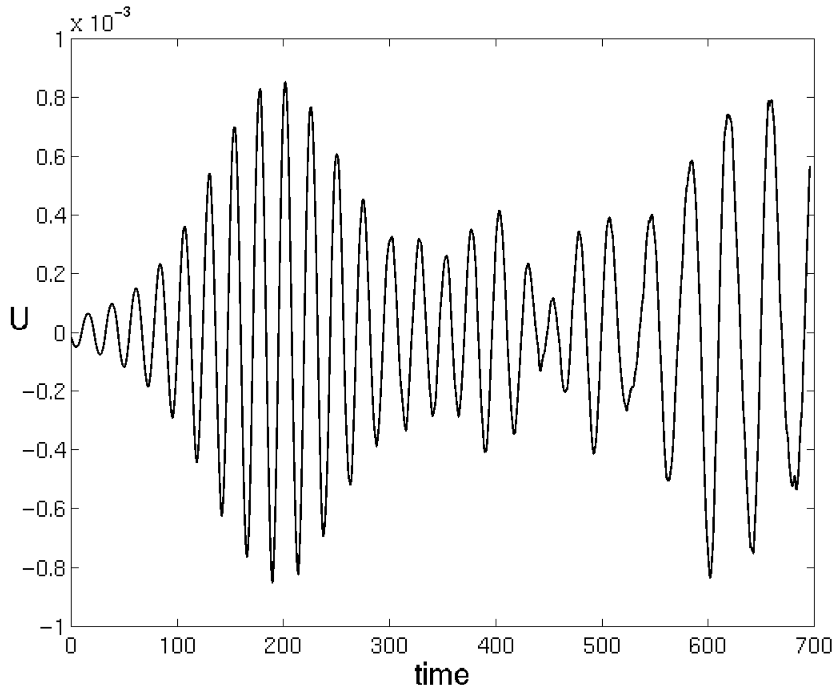


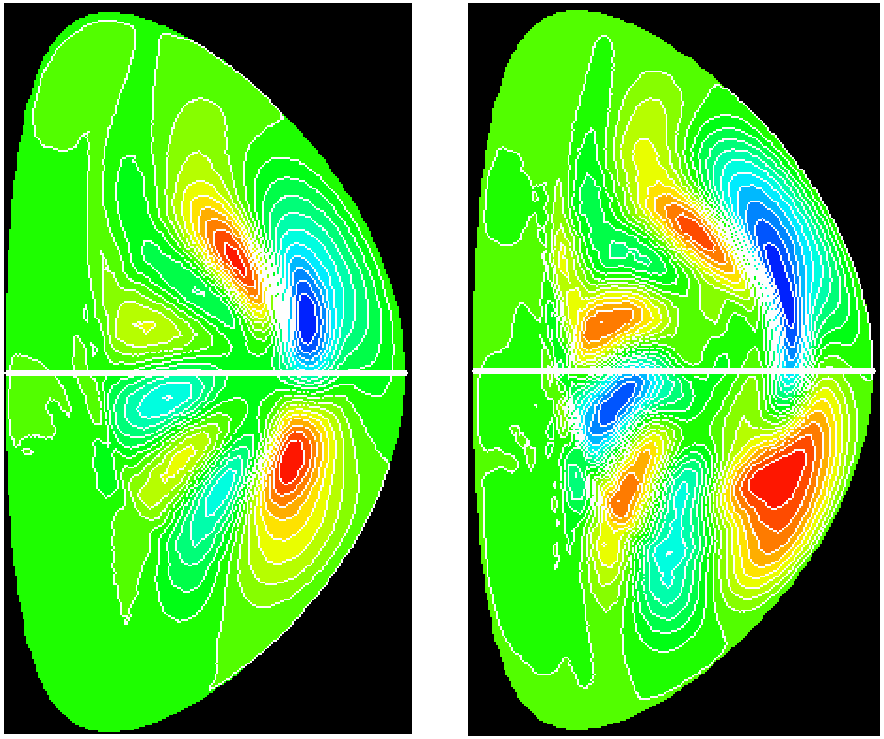

The **radial width** of the non-local EPM significantly depends on the **orbit width** of the **energetic ions**. They are **induced** by the energetic ions.




Examples of the **spatial profile**. The toroidal mode number is n=1.

# M3D Nonlinear hybrid simulations of **beam-driven modes** in NSTX shows a bursting n=2 TAE as the mode moves out **radially** (Fu TH-P-4/38).



t=0.0 t=336

- **Frequency sweeping**: slow sweep from equilibrium changes (Fu; Berk TH-P4/38); **fast** sweep from **phase-space holes** (Todo, Berk) $\Rightarrow$ **diagnostic** for $\delta$**b** (Berk)

- $\gamma_{\mathbf{NBI}} \sim \gamma_{\mathbf{Alpha}}$ for n = 10 in **ITER**; $f_{Loss} \sim 5\%$ at 23keV (Berk)

- **Alfven Cascades**: , low frequency modes near $q_{min}$ in JET (Berk); modes in cylinder due to $\nabla$n (Konovalov TH-P-4/43)

- New modes in **2nd stability**, MAST, NSTX (Berk)

- **Self-consistent dynamics** of $f_h$ from **ICRH** and **GAE** with SELFO code ; captures **experimentally** observed amplitude oscillations (Hellsten TH-P-4/40)

- **Thermal quench**, $T_e$, from $\chi_e$ due to GAE + KAW islands in W7AS (Yakovenko TH-P-4/48)

# PROGRESS (3): FUELLING, H&CD

**Themes**: realistic physics / geometry, integrated modelling

$\Rightarrow$ **major** computation!

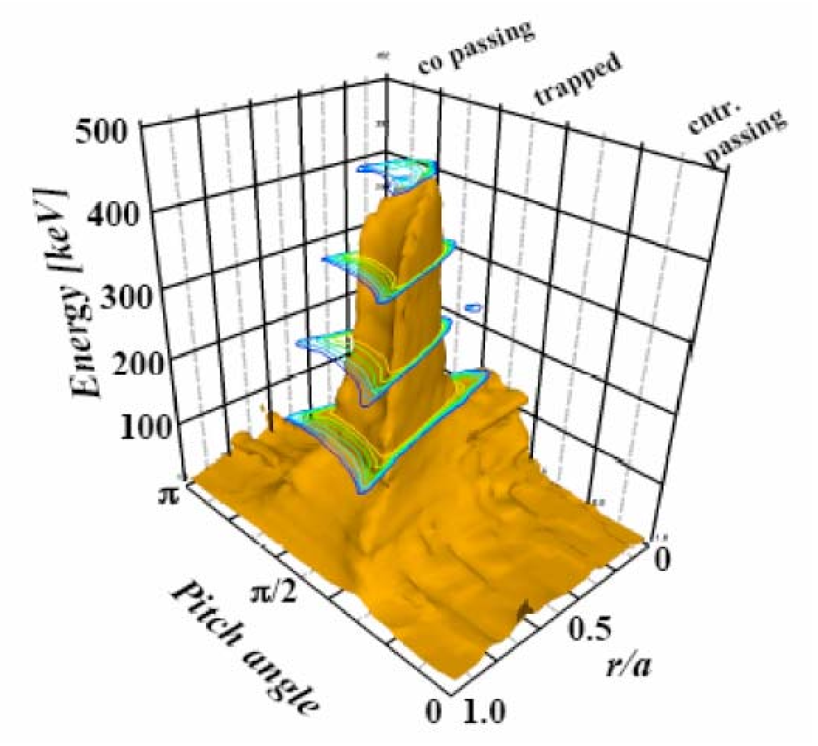
**ICRH/LH**: self-consistent energetic particle $f_h$, full wave

- **3D global** modelling for **LHD**; models phase space iso-surfaces

  →

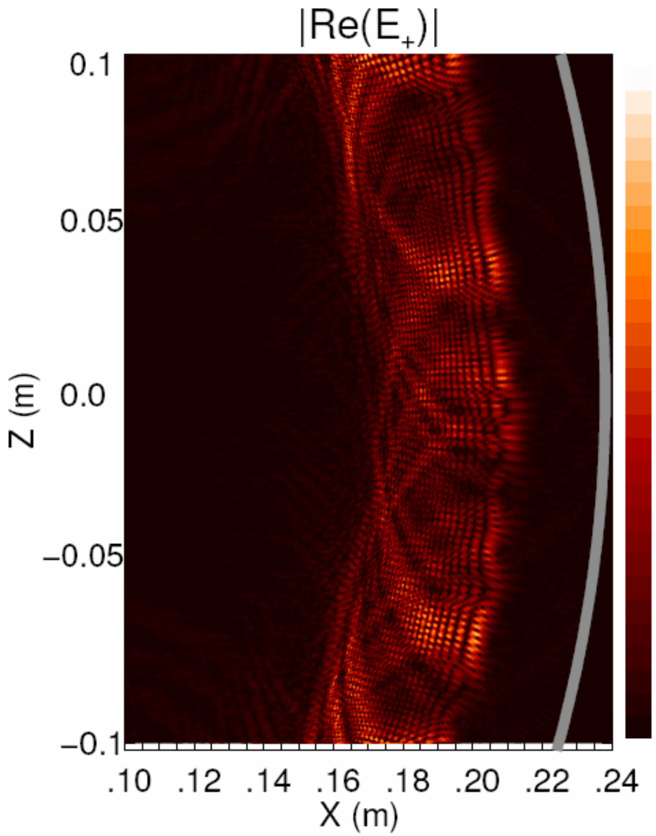
  & satisfactory experimental comparisons for NDD-NPA **energy spectrum**

  (Murakami TH-P-4/30)



- **FW**: alpha absorption in **ITER** tolerable, < 5%

- **LH**: model validated on C-Mod →
  TORIC full wave code shows **diffraction** sufficient to fill the **spectral gap**; damping at 2 -3 $v_{the}$
  (Wright TH-P-4/35)



**EC/EBW**: **relatavistic** treatments, **suprathermal** tails (Nikolic TH-P-4/31, Ram TH-P-6/56)

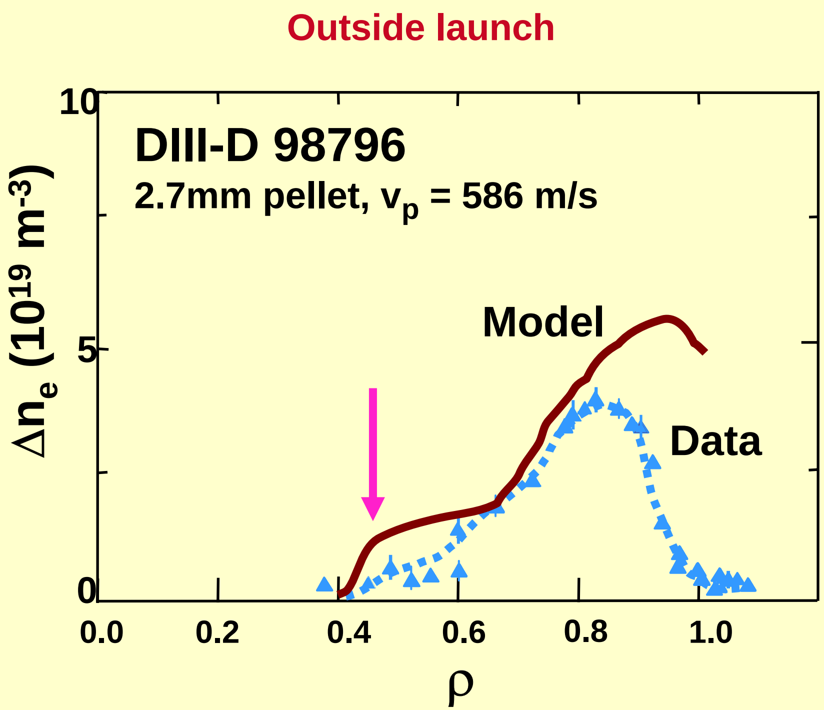
- **current drive** in NSTX: $\eta_{CD}$ = 3.2 at r/a = 0.5 (Okhawa); $\eta_{CD}$ = 1.9 at r/a = 0.2 (Fisch-Boozer) (Ram)

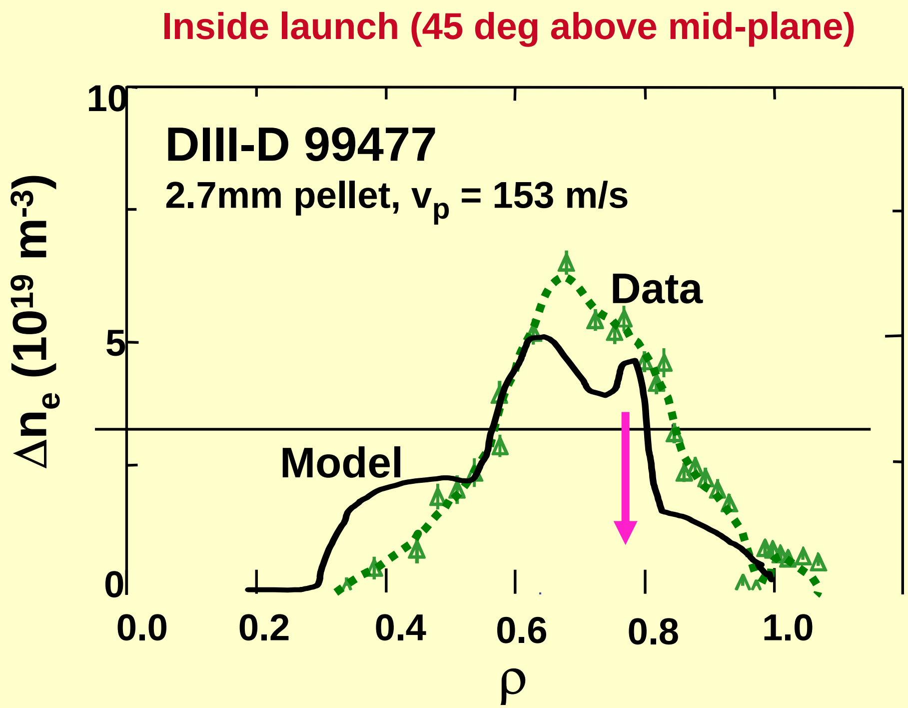
**EC wave transport**

- relevant to **ITER** in **RS** with $T_e \sim 35$ keV (Dies TH-P-4/18)
- self-consistent modelling of effects of **suprathermal** tails and wave transport: not important for thermal plasma, but ECCD significant? (Kukushkin TH-P-6/56)

**Low frequency and NBI**: for FRC, RFP, Spheromaks (Farengo TH-P-4/20)

# Theory and Experiments on DIII-D Compare Well




- Vertical arrows indicate pellet burnout point.
- Fueling efficiency for inside launch is much better (even with slower pellets)

outside launch $\eta_{theory}$ = 66% , $\eta_{exp}$ = 46% (discrepancy due to strong ELM)

inside launch $\eta_{theory}$ = 100% , $\eta_{exp}$ = 92% (discrepancy due to weak ELM)

(Parks TH-P-3/9)

# PROGRESS (4): EXHAUST

**Themes** : turbulence, integrated modelling, ELMs

**SOL: turbulence simulations** (Ghendrith TH-1/3Ra, Falchetto TH-1/3Rd, Ronglien TH-1/5)

- Coherent structures (**blobs**) with X-point: **analytic** modelling of **3-D** blob dynamics; interpretation of BOUT results (D'Ippolito TH-P-6/2)

- **Integrated** BOUT-UEDGE codes (turbulence + neutrals+ X-point + transport) (Ronglien)

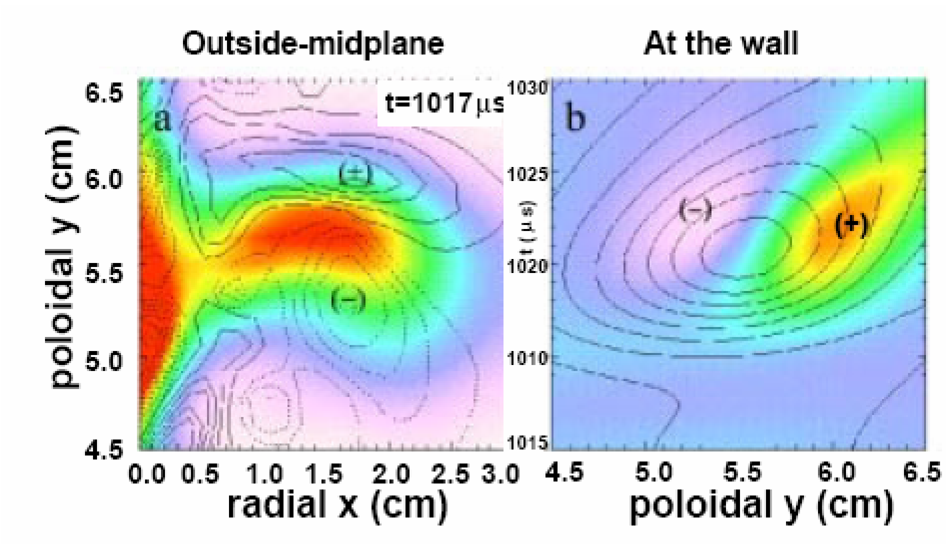
  -increasing **density**: **transition** from resistive X-point modes to RBM & greatly increased transport (with blobs)

  - predicts **Greenwald density limit** and X-point **MARFES**

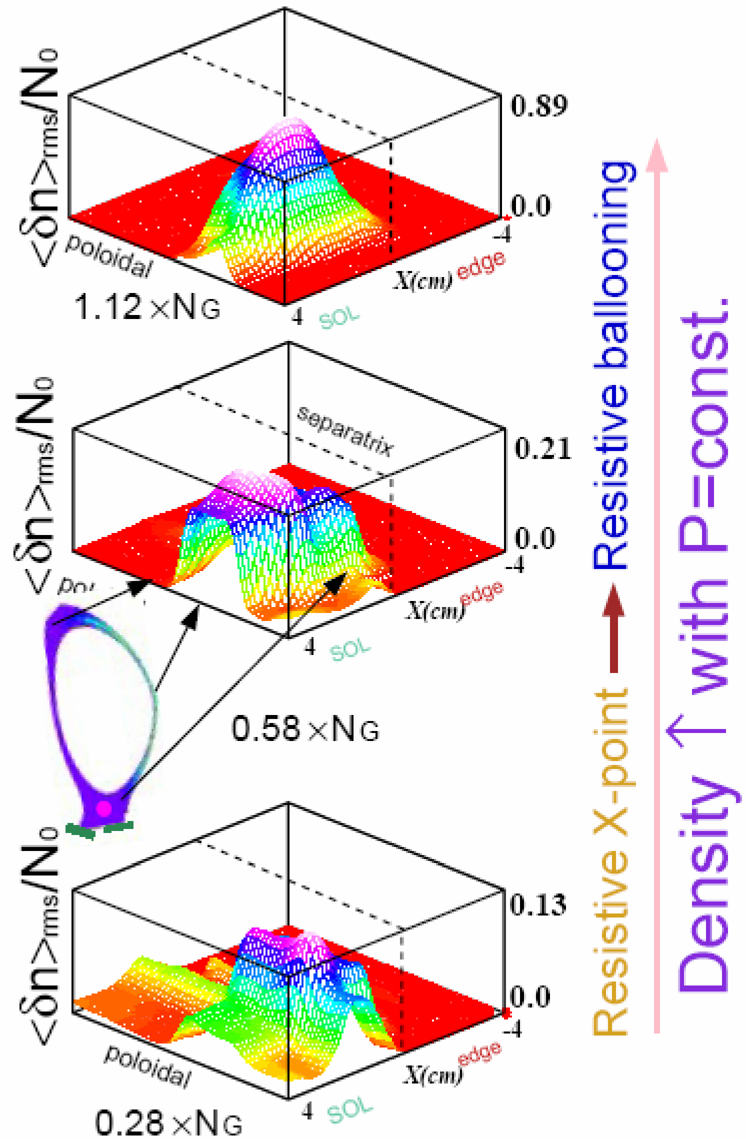
  - **Tail** of $\Gamma_{wall}$ due to blobs

# BOUT Simulations Show Strong Density Effects on Edge Turbulence

- **A transition of boundary turbulence from resistive X-point to resistive ballooning once n > nG**




- **Identification of convective transport by localized plasma "blobs" in the SOL at the high density during neutral fueling**

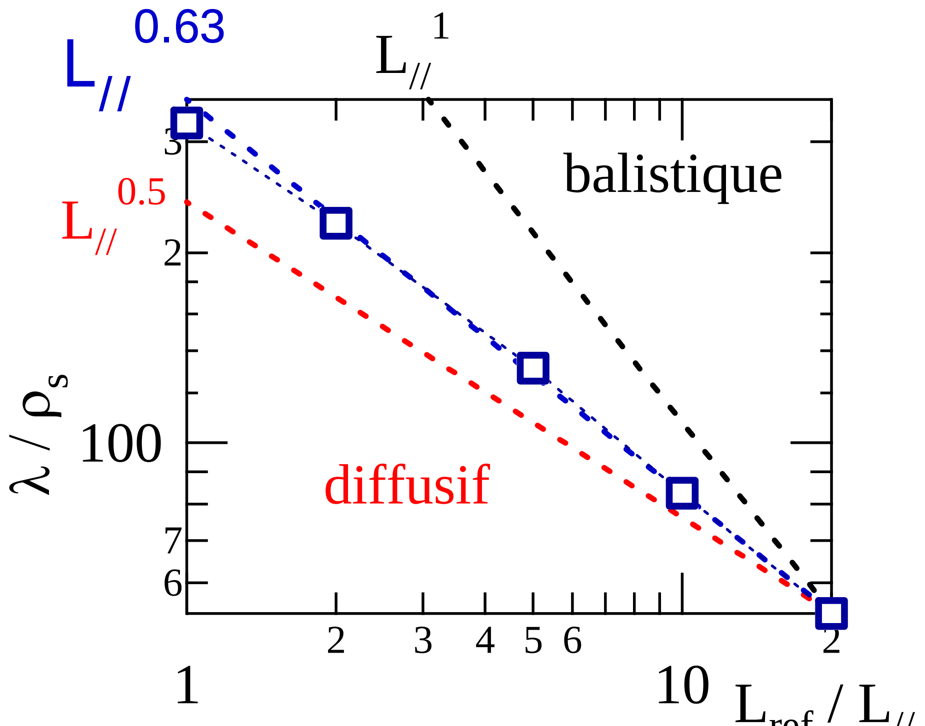


- ZFs suppressed in SOL due to connection to **sheath** (Falchetto)

- **Ballistic** density **front** propagation in 2D SOL turbulence

  $\Rightarrow$ $\Delta_{SOL} \sim L_{||}^{0.62}$ - agrees with analytic model

  - **ITER** implication: $\Gamma_{wall}$ up just 10% on **diffusion** model (Ghendrith TH-1/3Ra)



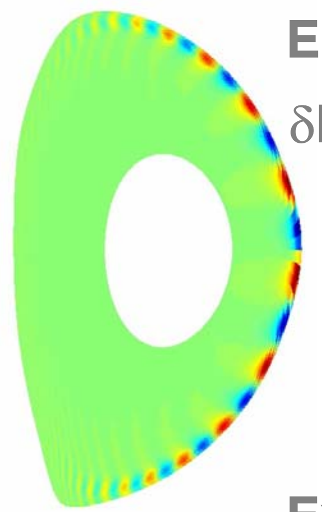
**Integrated Modelling**: core - pedestal - SOL + ELMs (Pacher TH-P-3/25, Guzdar TH-5/5)

- **Multi-mode model** element extended to low shear and **ETG** (Guzdar)

- Detailed analysis/modelling of **Carbon** erosion in JET, **migration** and **asymmetric deposition**

  - successful simulation by introducing **reflection** above some $T_e^{crit}$ (~ 5 - 10 eV) at edge (Coster TH-P-5/18)

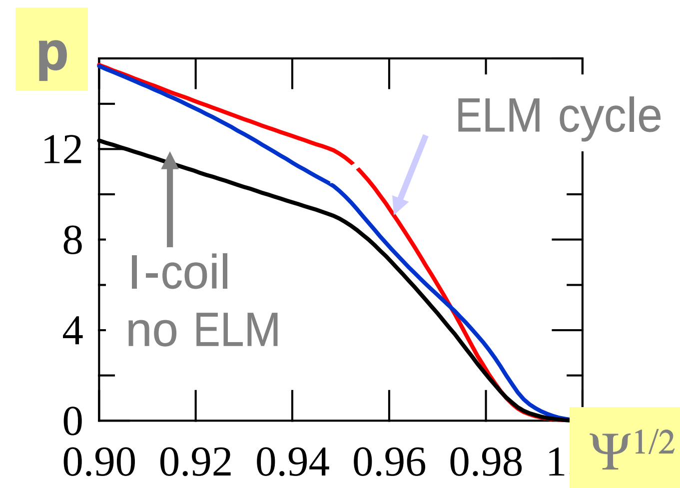
## Modelled controlled suppression of ELMs by stochastic field transport due to I-coils in DIII-D without significant confinement degradation ( Becoulet TH-1/3Rc)



ELM $\delta B_r$ (n=-10)

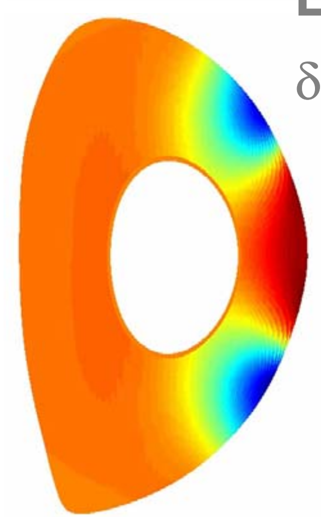
$\delta B_r \sim 10^{-2}$

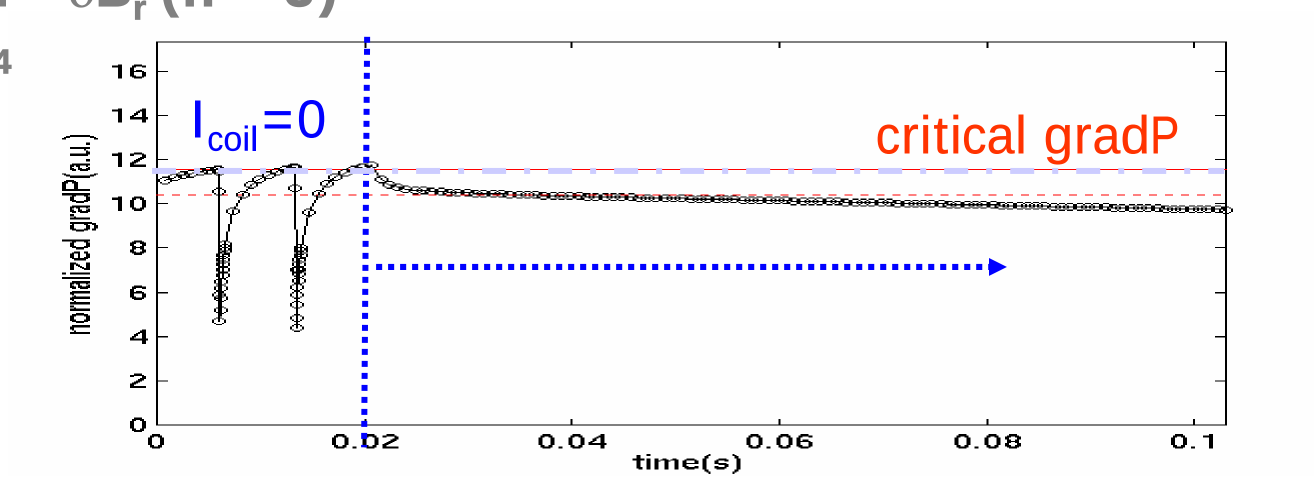
DIII-D:# 115467
1.6T/1.13MA
$q_{95}$=3.8
I-coil=4kA

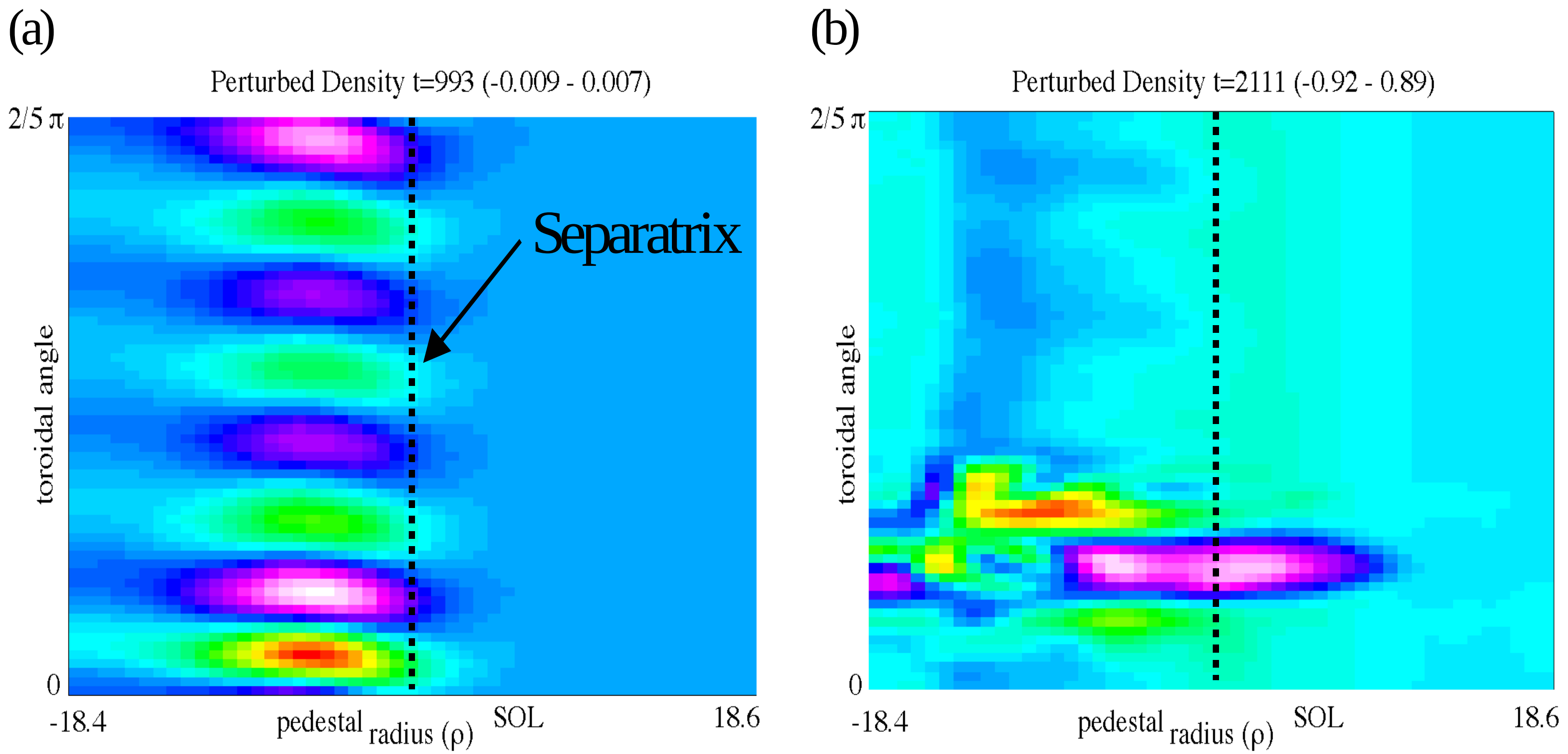



External ~$\delta B_r$ (n=-3)

$\delta B_r \sim 10^{-4}$








- **Non-linear** ballooning mode evolution leads to **explosive** growth of **filaments** (Wilson TH-P-1/5)
  - seen in MAST - and BOUT simulation

- Simulate r**elaxation** oscillations from RBM turbulence; result of transitory growth giving time delay before shear flow stabilisation (Benkadda TH-1/3Rb)