# SUMMARY SESSION

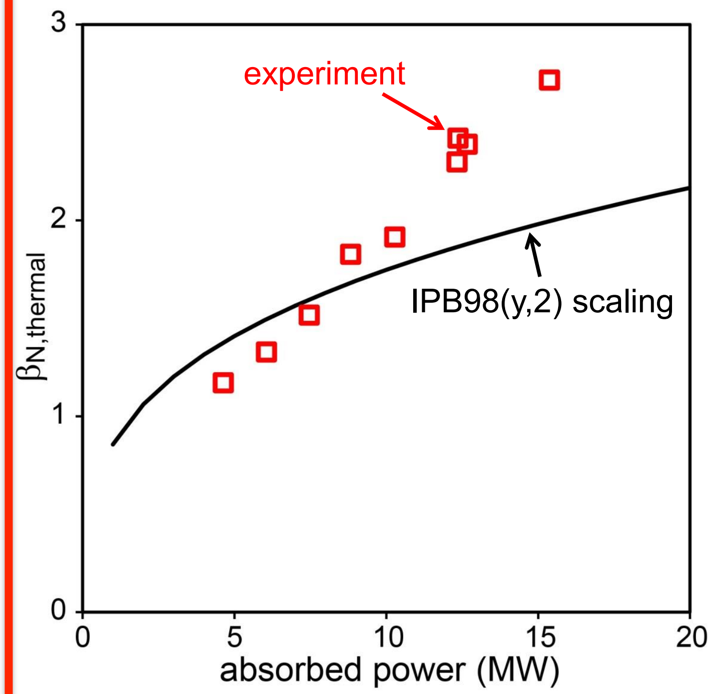
**EX/C** Magnetic Confinement experiments (Confinement)
**EX/D** Magnetic Confinement Experiments: Plasma-material interactions
**PPC**-Plasma Overall Performance and Control

**I. CORE TRANSPORT**
**II. EDGE TRANSPORT**
**III. PLASMA-WALL**
**IV. IMPURITY/PARTICLE TRANSPORT**
**V. OPERATIONAL LIMITS**
**VI. PLASMA PERFORMANCE AND INTEGRATION**

Carlos Hidalgo
Laboratorio Nacional de Fusión, CIEMAT, Spain

| | CORE TRANSPORT |
|---|---|
| **EMPIRICAL ACTUATORS**<br>✓ HEATING<br>✓ ROTATION<br>✓ MAGNETIC TOPOLOGY<br>✓ FUELLING | Efficient in existing devices<br>Limited in next step devices<br><br>Pellet [EXC186 Valovic MAST] |
| **TOWARDS BASIC UNDERSTANDING** | 1) **Flux-gradient, heating and transport** [EXP39 Yoshida JT-60U], [EXC543 Anderson HSX], [EXP237 Inagaki LHD], [EXP414 Vershkov T-10] / [EXC421 Razumova] / [70/506 Ren NCTX] / [85/605 Vermare TS] / [EXC321 Challis JET], [EXC481 Neudatchin T-10] / [EXC656 Ernst DIIID],high density operation [EXC33 Mizuuchi H-J], [EXC577 Hong KSTAR]<br><br>2) **Momentum transport** [EXC590 Ohsima H-J] [EXC443 Zhao J-TEXT mover RMPs], [EXC138 Lee KSTAR], [EXC284 Xu TEXTOR], [EXC393 Shi KSTAR], [EXC483 Tala AUG], [EXC306 Kobayashi H-J], [EXC406 Lee KSTAR], [EXC526 Severo TCABR], [EXC581 Na KSTAR], [EXC522 McKee DIIID], [EXC101 Lee KSTAR]<br><br>3) **Code validation** [EXC112 Porte TCV] / [EXC121 Field MAST] / [EXC249 Mordijck DIIID] / [EXC317 Stroth exp vs GK] / [EXC428 Altukhov FT-2] / [83/585 Sabot TEM] / [EXC648 Howard AlcatorCmod] Te Critical Gradient [EXC278 Smith DIIID], EXC418 Yokoyama LHD] |

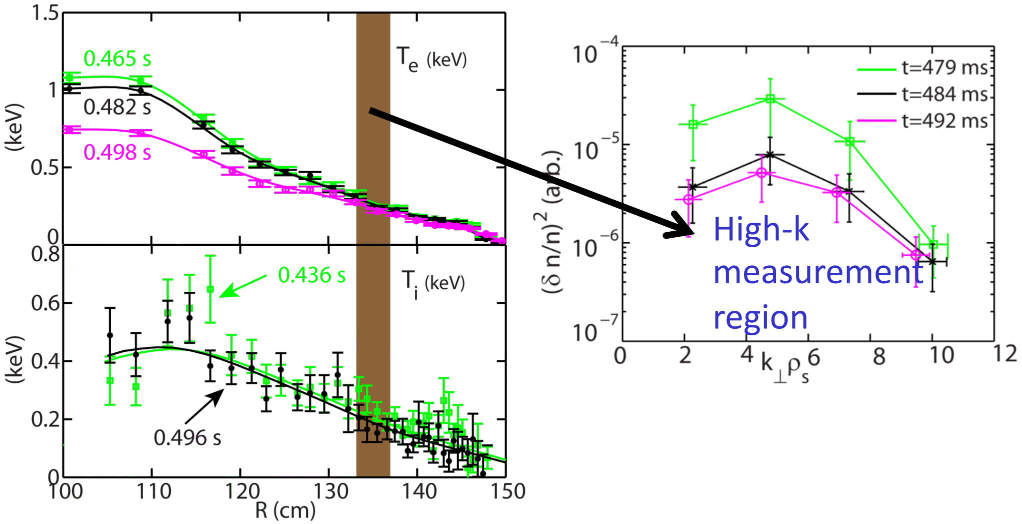
# TRANSPORT in high beta regimes, an echo for the fundamental unity and connectedness of fusion plasmas



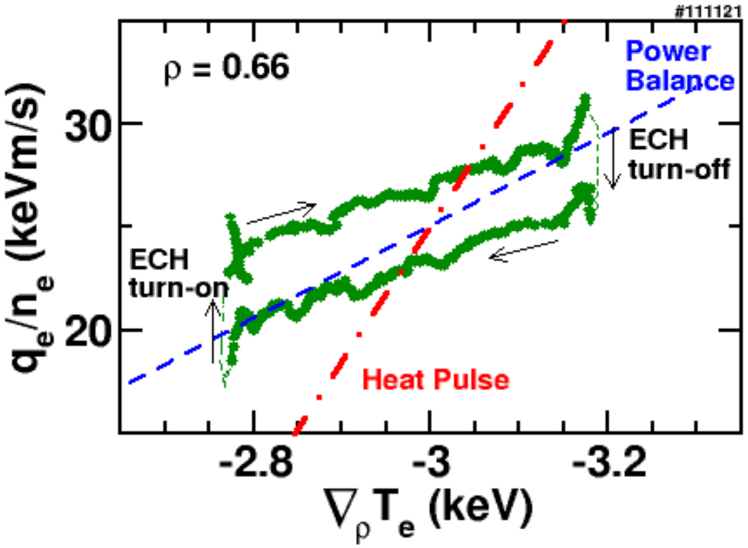

**Weak confinement degradation with power in high β plasmas** due to increase in **pedestal pressure** and **pressure peaking** (by collisionality and **suprathermal pressure** [TH324 Garcia]).

[EXC321 Challis JET]

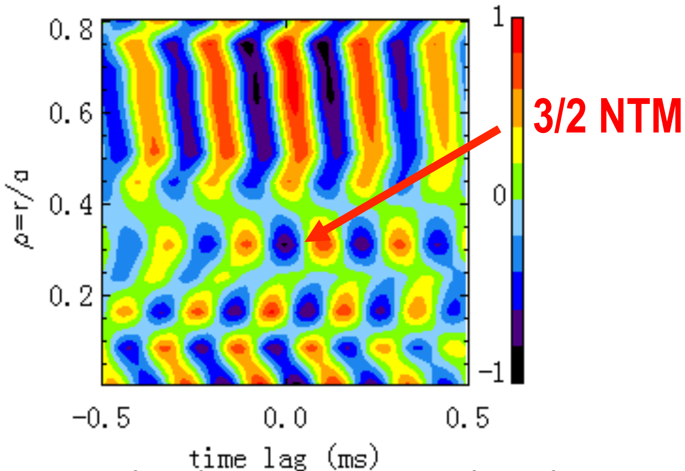
# TRANSPORT: flux-gradient relation




Non-local transport / turbulence spreading
(EXC506 Ren NSTX)



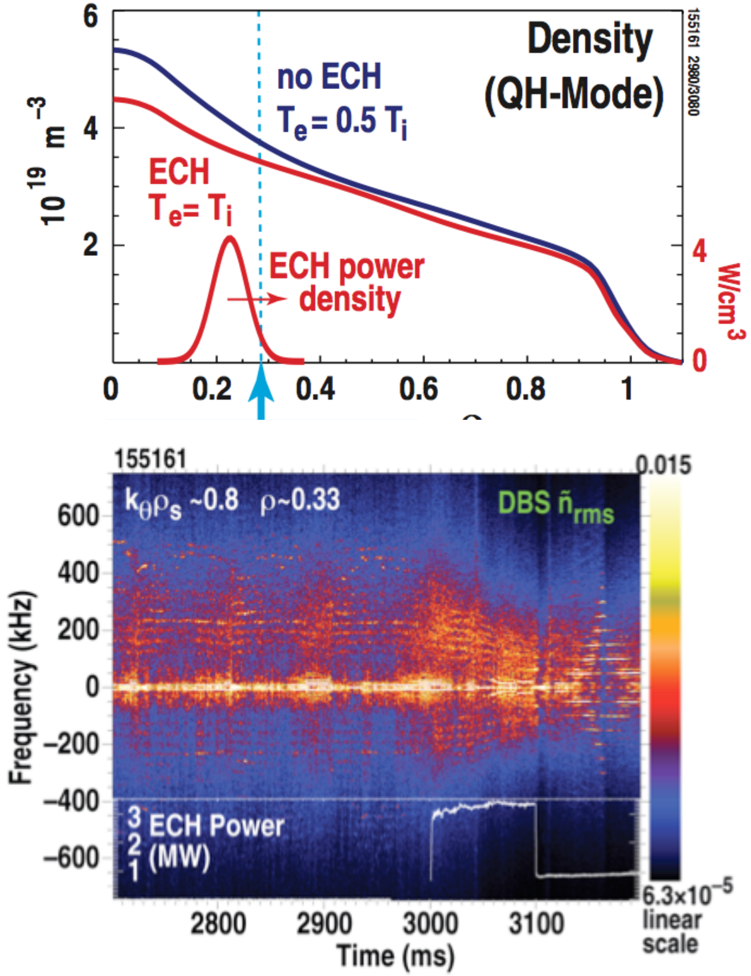

Dynamic method to study turbulence and turbulent transport, showing hysteresis in the flux-gradient relation
[EXC237 Inagaki LHD]



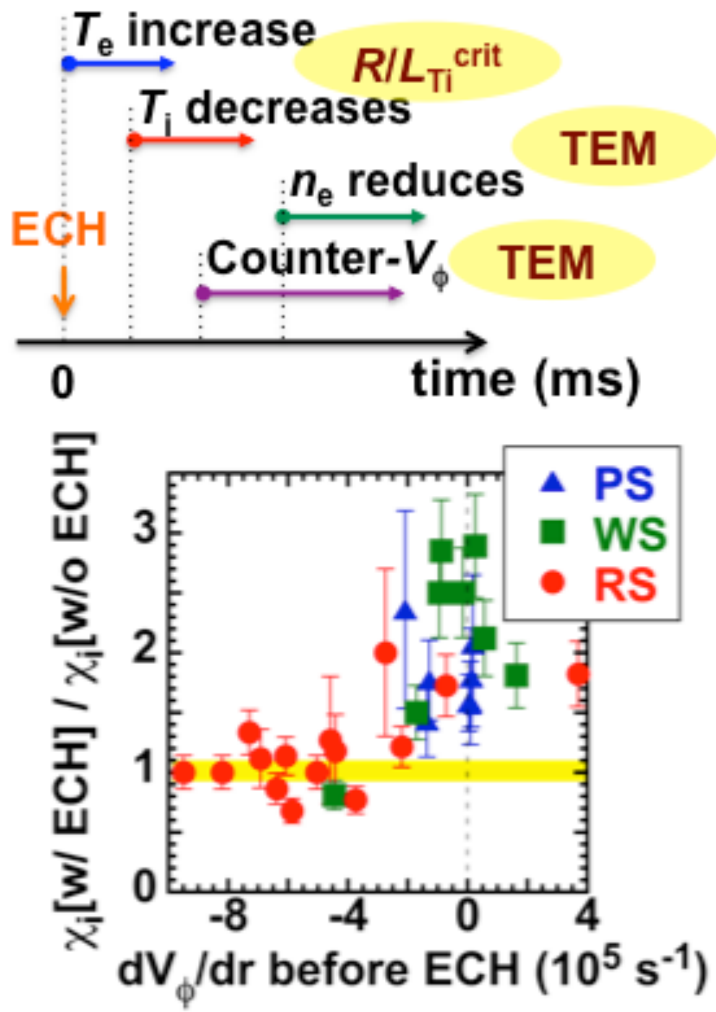

Interplay between non-local transport and MHD [Ji / HL-2A]

**Quantifying and understanding the level of profile stiffness in the plasma core in reactor relevant conditions (high beta, fast particle effects) is an outstanding issue with promissing results**

# TRANSPORT, physics understanding and empirical actuators (ECRH)

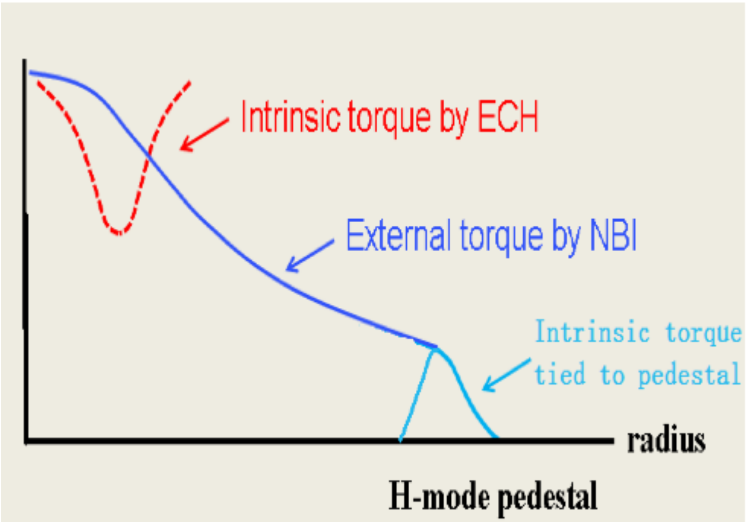



**Controlling gradients** and transport by ECRH and TEM
[EXC656 Ernst DIIID]




**ECRH Heating, transport and rotation**
[EXC39 Yoshida JT-60U]

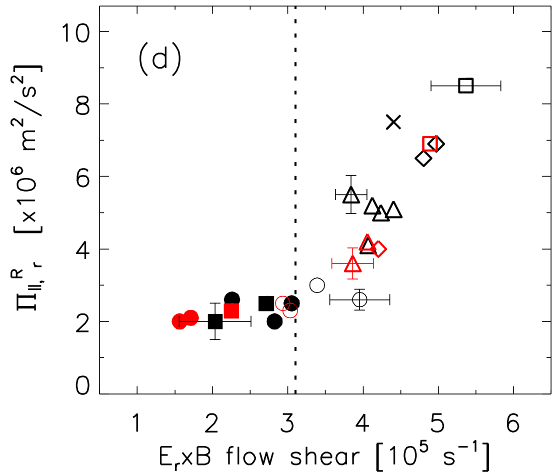
# MOMENTUM TRANSPORT: driving / damping mechanisms



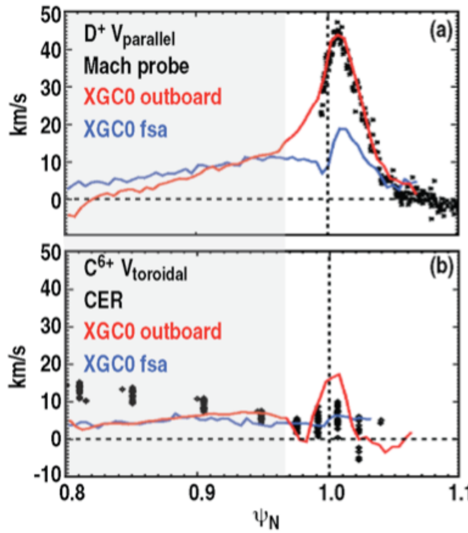

Interplay between NBI/ECRH and pedestal torques [EXC393 Shi KSTAR] / [EXC483 Tala AUG]

LOC-SOC transition occurs but no reversal in core rotation is detected. Dependency w.r.t collisionality is observed [EXC581 Na KSTAR].

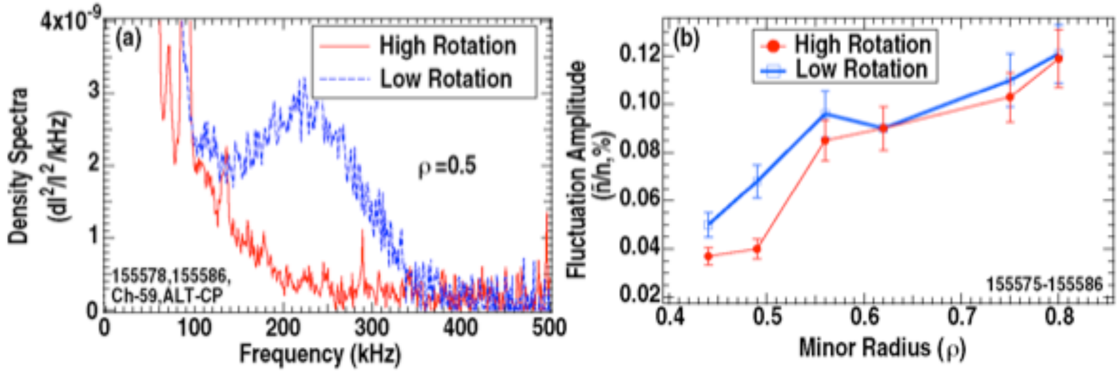
Reduction in electron density with ECRH and transition from ITG to TEM without a reversal in toroidal rotation [EXC249 Mordijck DIIID]




Role of radially sheared Er × B flows on residual stress [EXC284 Xu TEXTOR]

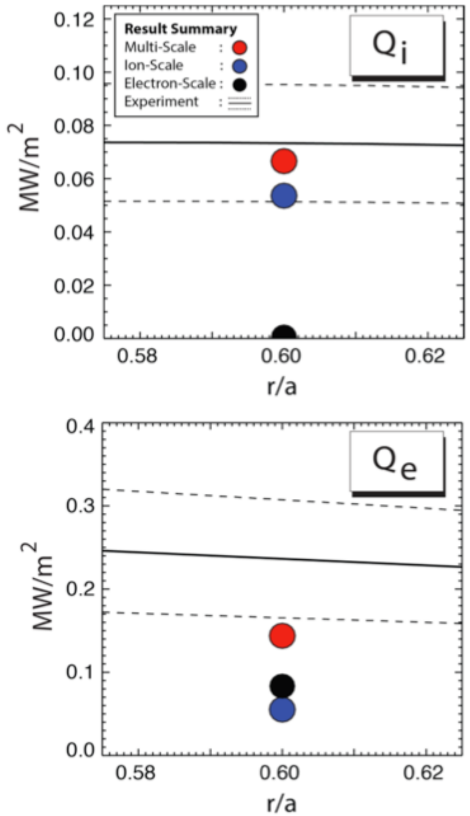



NC transport and intrinsic rotation [EXD374 Battaglia DIIID]

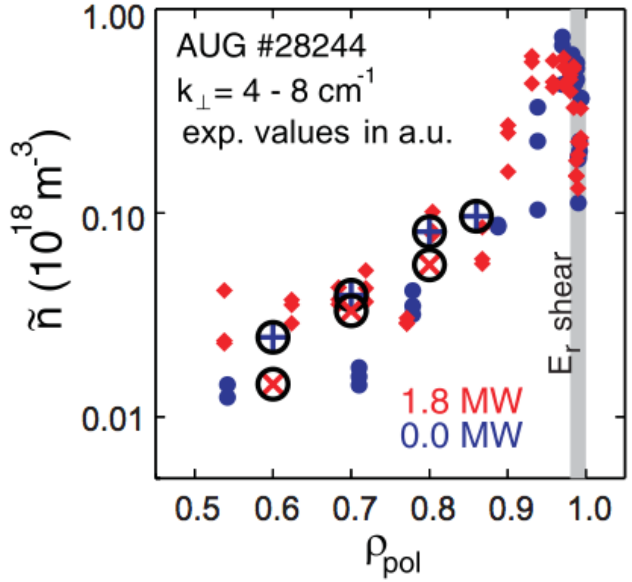



Turbulence behaviour approaching burning plasma relevant parameters (low rotation) [EXC522 McKee DIIID]

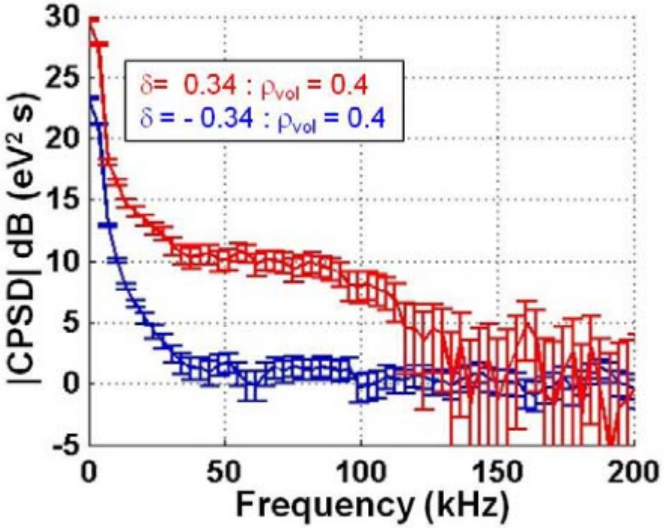
# CODE VALIDATION: Great challenge due to the existence of multiple plasma scales




Ion and electron heat fluxes GK and Alcator Cmod [EXC648 Howard]




GK (GENE) validation using advanced fluctuation diagnostics AUG [EXC317 Stroth]




Temperature fluctuatiom decreases as edge triangularity goes from positive to negative. Full global nonlinear simulations are required [EXC112 Porte TCV].

**Validated simulations would have important consequences for predicting burning plasma scenarios**

| | EDGE TRANSPORT AND PEDESTAL |
|---|---|
| **EMPIRICAL ACTUATORS**<br>✓ **HEATING**<br>✓ **MAGNETIC TOPOLOGY** | **PLASMA SCENARIOS**: L-H power threshold [EXC351 Verdoolaege], [EXC432 Lorenzini RFXmod], [EXC434 Delabie JET], [EXC446 Gurchenko FT-2] / [EXC153 Hahn KSTAR]<br>Conflict in optimization criteria: ELM control and confinement |
| **TOWARDS BASIC UNDERSTANDING** | 1) **TRIGGER OF L-H TRANSITION**: [EXC61 KobayashI JT60M], [EXC194 Estrada TJII], [EXC285 Dong HL-2A], [EXC384 Cheng HL-2A ], [ EXC539 Schmitz DIIID] / [EXC619 Cziegler AlcatorCmod], [EXC575 BelokurovTUMAN-3M]<br><br>2) **PEDESTAL STABILITY AND PROFILES**: triangularity [EXC195 de la Luna JET,], edge modes [EXC253 Zhong HL-2A], [EXC43 Xu EAST], [EXC88 Gao EAST], EP-Hmode [EXC618 Gehardt NSTX], Enhanced pedestal H-mode without turbulent reduction [EXC545 Canik DIIID-NSTX], edge non-stiffness Lmode [EXC170 Merle TCV], micro-tearing [EXC361 Hillesheim MAST], [EXC427 Kong HL-2A], [EXC429 Maggi JET], , I-mode regime [EXC612 Hubard], [EXD209 Golfinopouls Alcatorcomd]. GAMs [EXC112 Porte TCV] / [EXC242 Melnikov T-10] / [EXC564 Yu HT-7], [EXC444 Bulanin Globus-M]<br><br>3) **ELM CONTROL (3-D EFFECTS): P**ellet/Li injection [EXD62 Wang EAST], RMPs [EXD205 Nazikian DIIID] [EXD655 Ahn NSTX-DIIID], [EXC290 Nie HL-2A], SMBI[EXC303 Yu HL-2A/EAST/KSTAR], [EXC403 Lee KSTAR], / [EXC536 Orlov DIIID], RMP and particle pump-out [EXC607 Jakubowski] , RMP and detachement [ EXD488 OHNO LHD], Strike line striation [EXD630 Schmitz], [EXC269 Evans LHD-DIIID], |

# Scenario development (L-H power threshold)

# the whole mirrored in the smallest parts

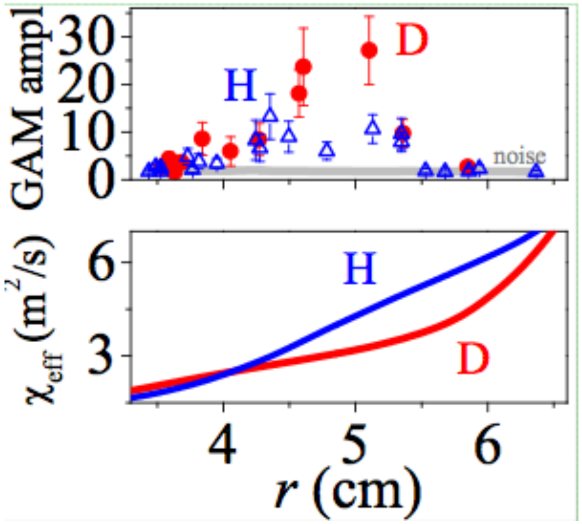
Laboratorio Nacional Fusión

| $n_e$ ($10^{20}$ $m^{-3}$) | $B_T$ (T) | S ($m^2$) | $P_{th}$ - $H_2$ (MW) | $P_{th}$ - He (MW) | $P_{th}$ - $D_2$ (MW) | $P_{th}$ - DT (MW) |
|---|---|---|---|---|---|---|
| 0.5 | 2.65 | 683 | 61 | 31 - 46 | 31 | 24 |
| 0.5 | 5.3 | 683 | 106 | 53 - 80 | 53 | 43 |
| 1.0 | 5.3 | 683 | 175 | 88 - 132 | 88 | 70 |

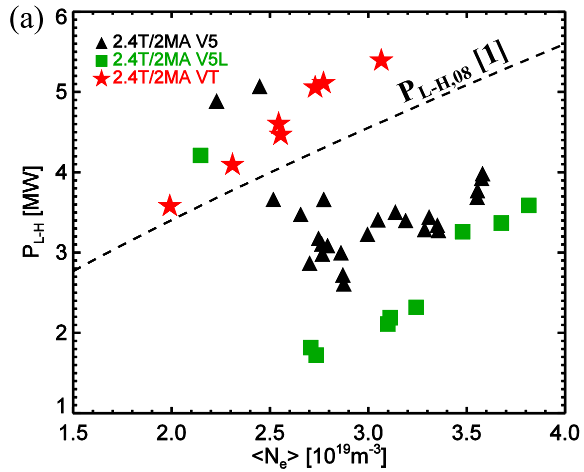
H-mode operation is expected to marginal in H but possible in He [EXC344 Sips]/[EXC351 Verdoolaege]

[EXC432 Lorenzini] RFXmod; isotope effect in Quasi-Single-Helicity state.

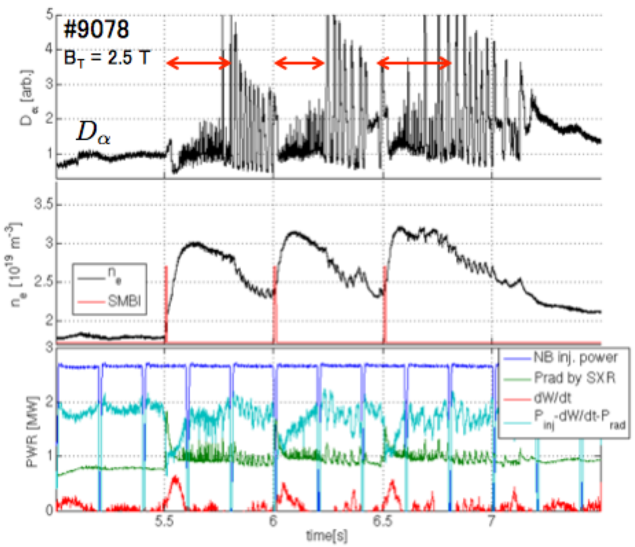
TCV] L-H threshold is 20% higher in both H and He than D




Isotope effect in GAM/transport [EXC446 Gurchenko FT-2] in consistentcy with previous results in TEXTOR

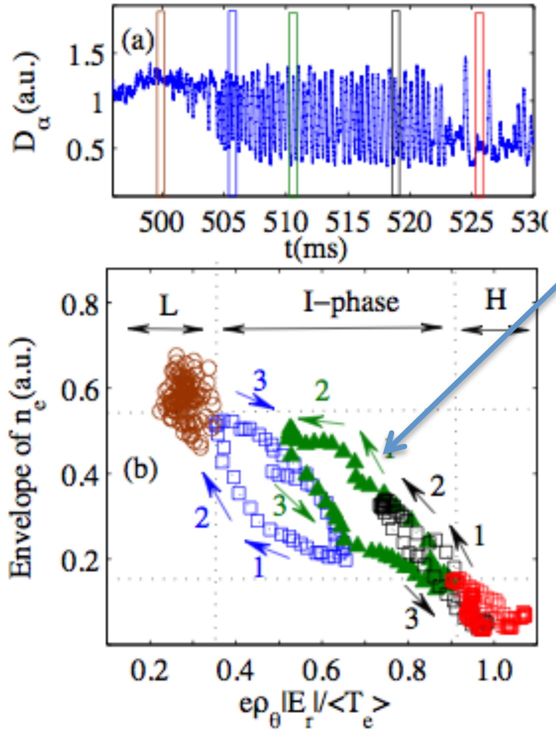



Impurities / neutrals and magnetic configuration [EXC434 Delabie JET]

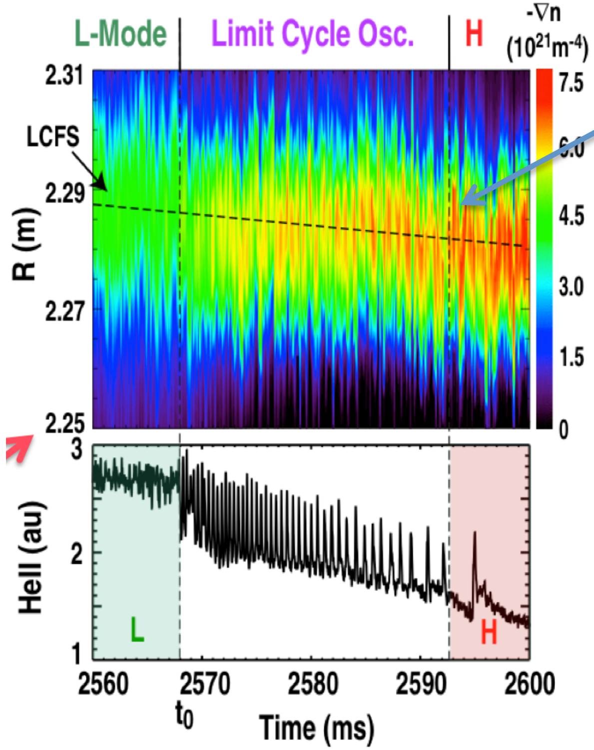



Stimulated L-H transition SMBI [EXC153 Hahn KSTAR]

# Trigger of the L-H transition: role of dynamical flows




Trigger linked to $E_r$/presure gradients In HL-2A

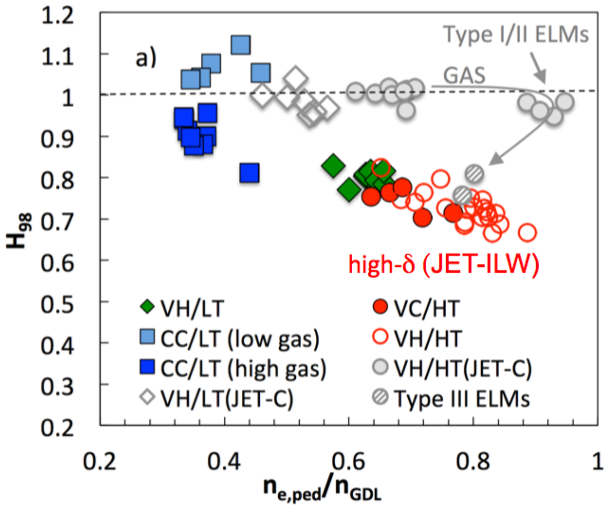


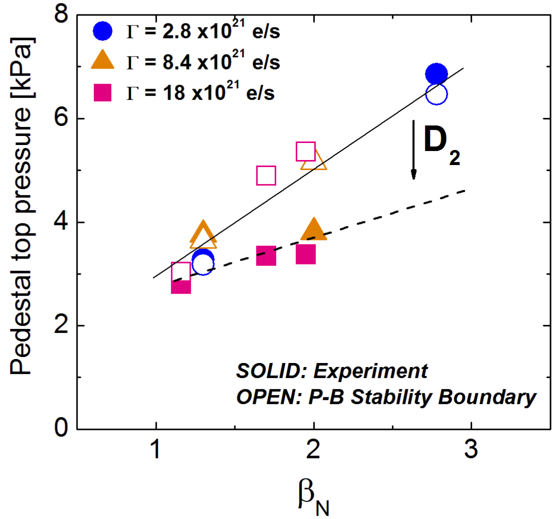

Turbulence driven flows triggers to transition to LCO Pressure gradient increase later and locks in the H-mode in DIIID

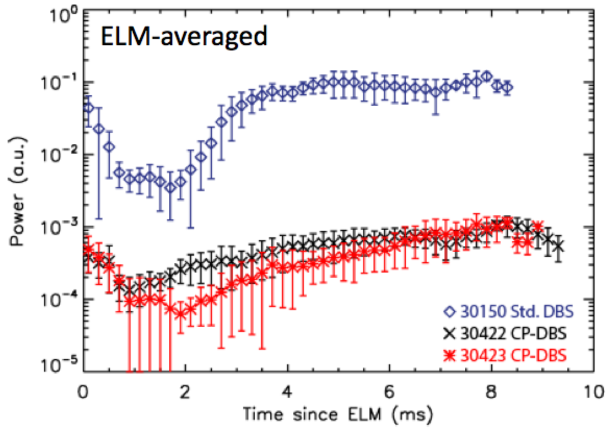
Recent experiments, HL-2A [EXC285 Dong], DIIID [EXC539 Schmitz], TJ-II [EXC19 Estrada], AlcatorCmod [EXC619 Cziegler], have pointed out towards a synergistic role of turbulence-driven flows (ZFs) and pressure gradient driven flows in the triggering and evolution of the L-H transition.

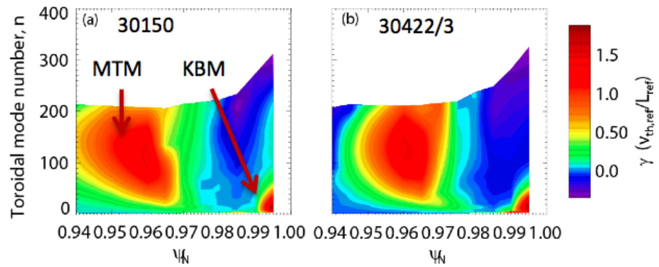
**Further R&D should be centred on identifying key players for H-mode transition in order to trigger it at reduced $P_{input}$**

# Pedestal transport and stability:
# key for global performance and power exhaust



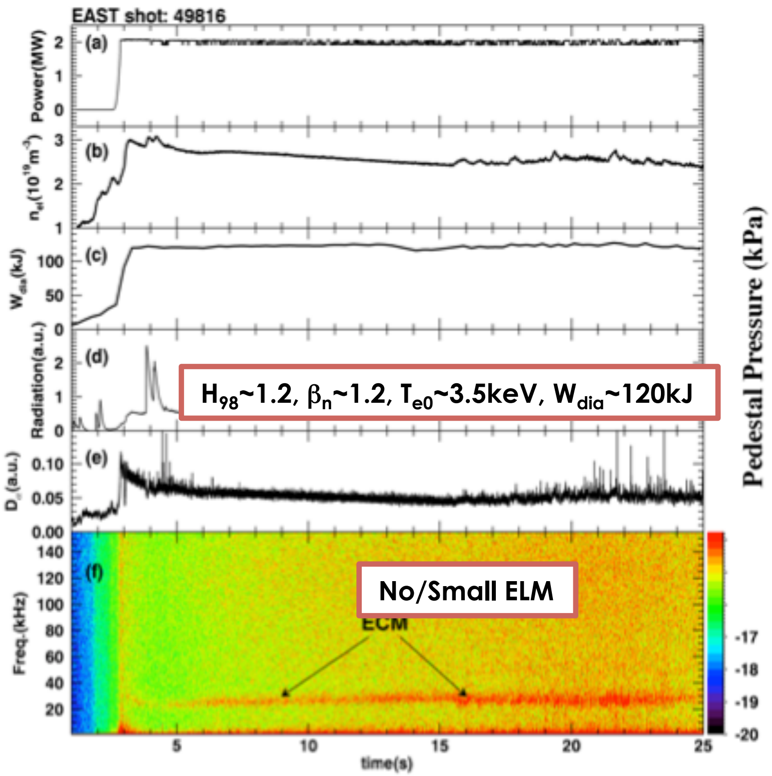

Positive influence of **triangularity** on confinement has not been recovered in ILW due to higher collisionality in consistency with **P-B** expectations [EXC195 de la Luna JET]

At **high neutral recycling**, pedestals are found in stable. Then, additional physics is required to explain the onset of the ELM instability. Beneficial effect of $N_2$ seeding [EXC429 Maggi JET]

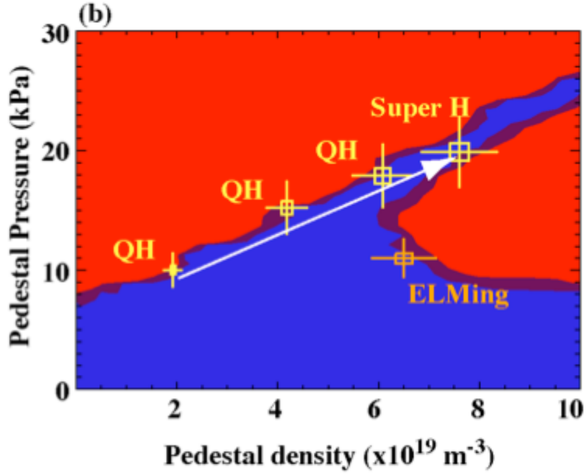
Searching for Microtearing modes at the pedestal in MAST using novel diagnostic techniques and comparison with GK [EXD361 Hillesheim]

**Qualitative agreement with P-B model, but missing physics needs to be addressed to provide full predictive capability of pedestal structure (including role of neutrals and impurities)**

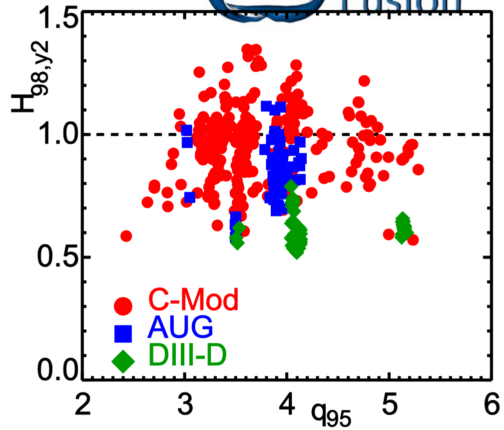
# Pedestal transport and stability: alternative regimes

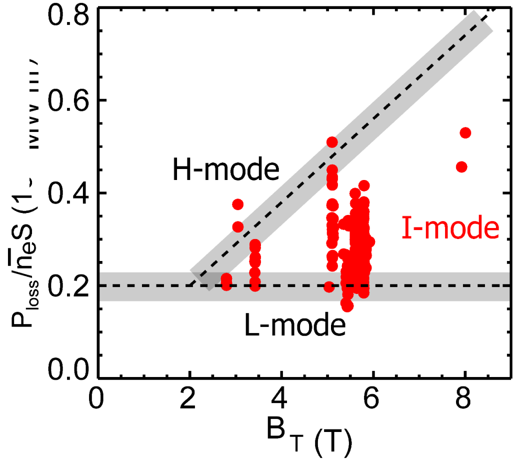



Long-pulse H-mode operation with edge coherent mode in EAST; GYRO simulations suggest DTEM [EXC43 Xu]




QH-mode maintained to high Greenwald fraction in strongly shaped plasma [PPC243 Solomon DIIID] / [TH/2-2 Snyder]

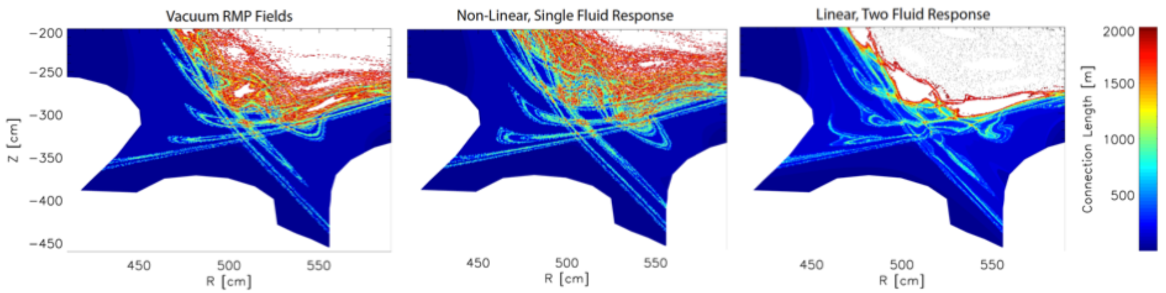


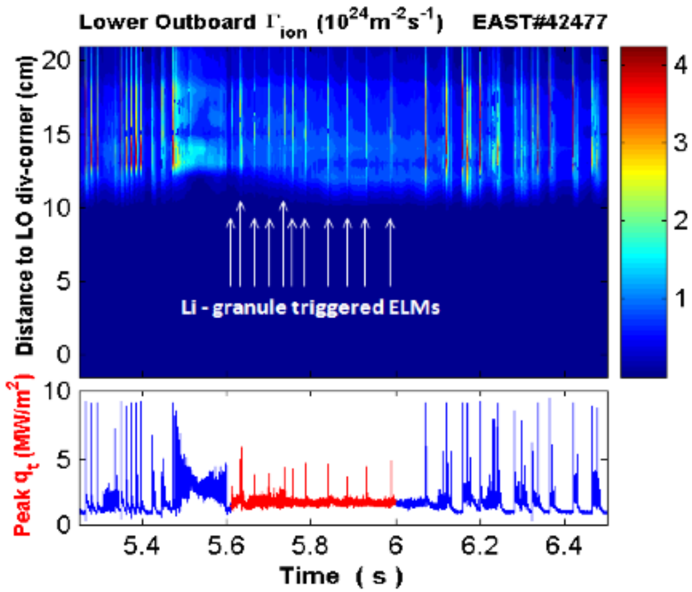




I-Mode with edge temperature pedestal while density profile remains unchanged from L-mode [ EXC612 Hubbard]

**New regimes (as an alternative to type I EMLs) to a burning plasma scenarios look promising.**

# ELMs control



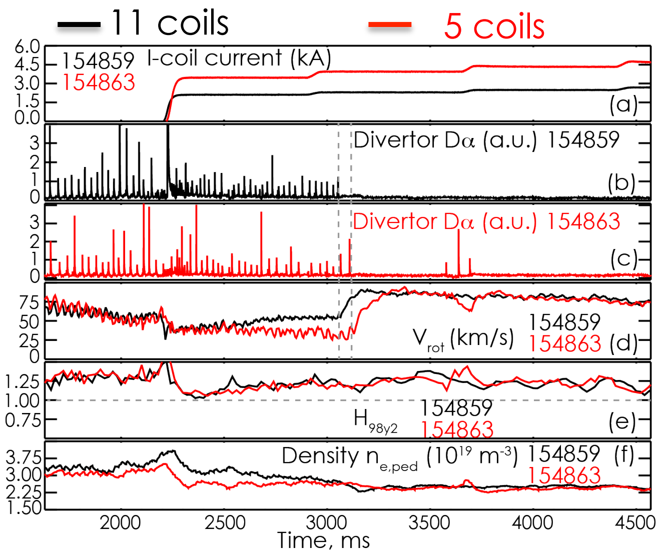

| Device | Mode | Heat split | Part. split | MHD | $\nu_e$* | Topology | ELM control |
|---|---|---|---|---|---|---|---|
| **DIII-D** | n=3, n=1 EFC | weak - no | yes | no | **<0.5** | Vacuum | Suppression |
| | n=3, n=1 EFC | yes | yes | n=1 LM | **>1.5** | RFA | Mitigation |
| | n=3, n=1 EFC | yes | yes | no | **>3.0** | Vacuum | **L-mode** |
| **TEXTOR** | n=1,24 | yes | yes | no | >5.0 | Vacuum | L-mode |
| **MAST** | n=3,4,6 | yes | yes | no | >2.0 | Res. MHD | Mitigation |
| **Asdex-U** | n=2,3 | yes | tbd | no | >8.0 | Vacuum | Mitigation |
| **JET** | n=1,2 | no | yes | 2/1 LM | <1.5 | Res. MHD | Mitigation |
| | n=2 | yes | yes | no | >6.0 | Vacuum | L-mode |
| **NSTX** | n=1,3 | yes | yes | no | >1.0 | Vacuum | ELM trigger |

Strike line striation as signature for 3-D boundary formation [ EXD630 Schmitz]

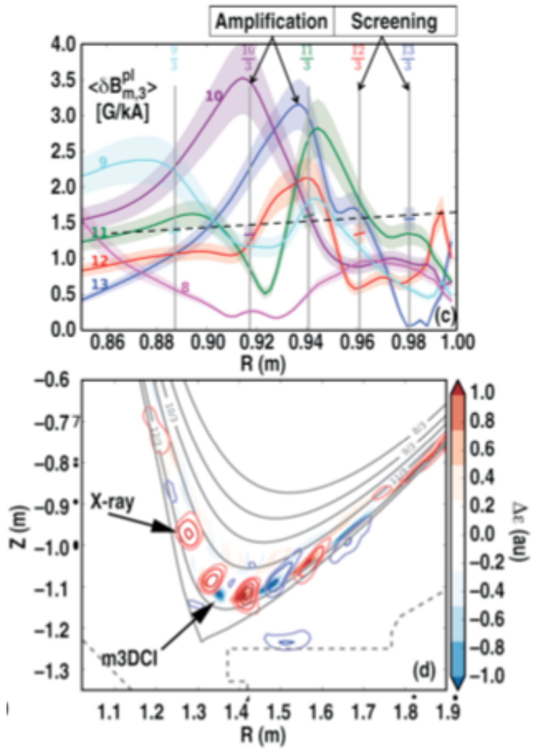
Comparison of Li-granule triggered ELMs with intrinsic type-I ELMs [EXD62 Wang EAST]

**Active ELM control has been demostrated including magnetic perturbations, pellet injection, SMBI (Supersonic Molecular Beam Injection), edge current control**

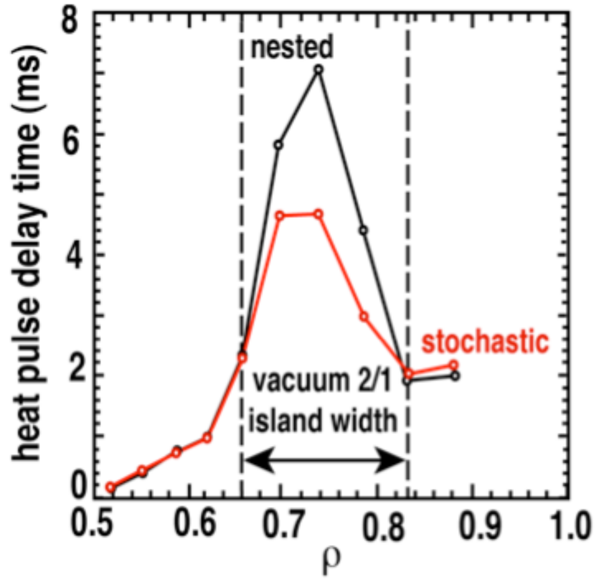
# Power Exhaust: 3-D effects and ELMs control




ELM control witH a reduced number of I-coils [EXC536 Orlov DIIID]




M3D-C1 simulation of amplification and screening of resonant poloidal harmonics [EXC205 NazikiaN]



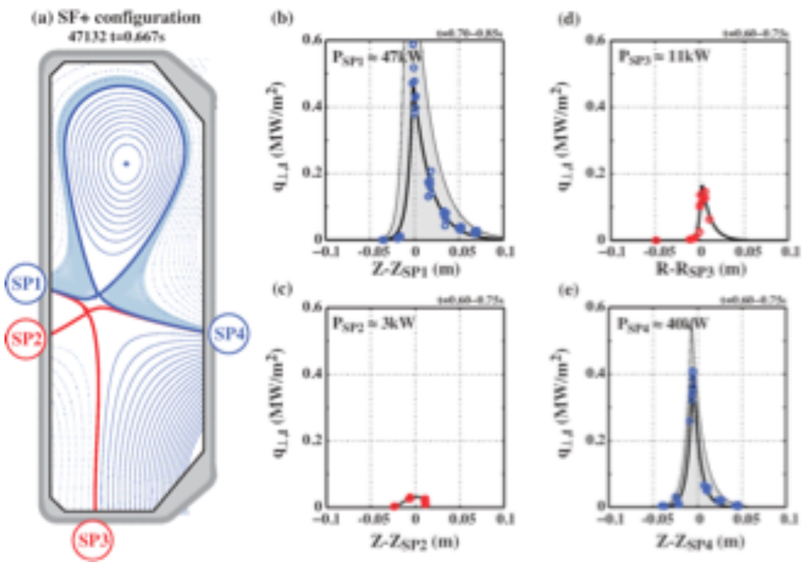

Modulate ECH analysis shows a spontaneous bifurcation at the heat transport across the island, observed in both DIIID and LHD [EXC269 Evans]

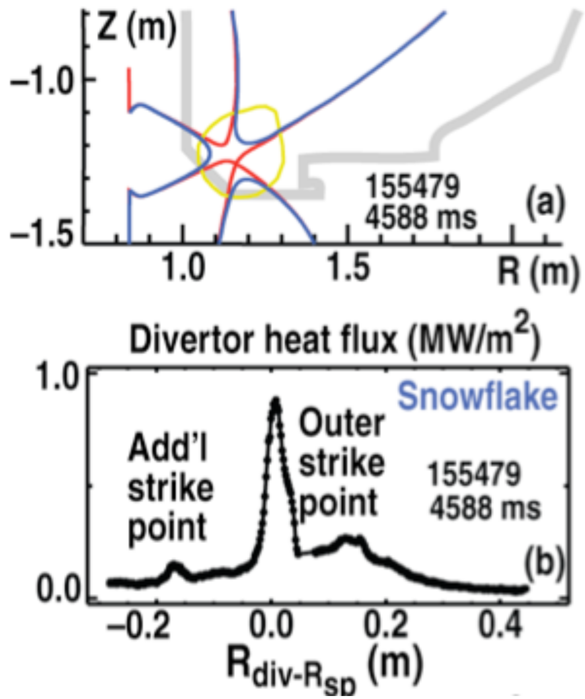
**Control of ELMs by magnetic perturbations has been achieved, but there is not yet completeness of understanding of ELM suppresion mechanisms**

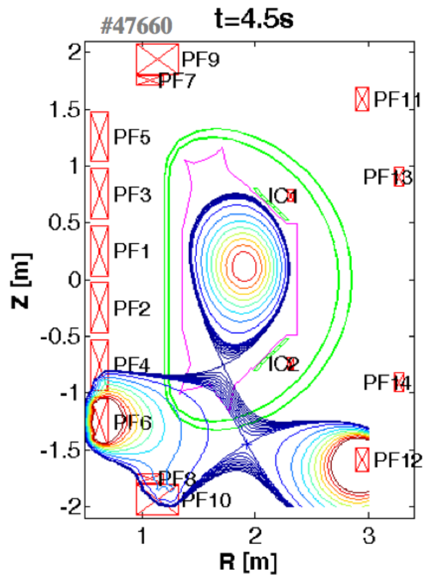
| | PLASMA-WALL / PLASMA EXHAUST |
|---|---|
| ✓ MAGNETIC TOPOLOGY | ✓ INNOVATIVE CONFIGURATIONS: **SNOWFLAKE** [EXD124 Duval TCV] [EXD352 Calabro EAST] [EXD497 Soukhanovskii DIIID] / SUPER-X / STELLARATORS |
| ✓ OPERATION AT HIGH DENSITY / detachment | Impurity seeding [EXD556 Mukai LHD], [EXD82 Kallenbach AUG] / [EXD660 McLean DIIID], W divertor [EXD632 Herrmann AUG], [EXD514 Wishmeier] |
| ✓ LIQUID METALS | liquid metals as alternative PFC [EXD159 Verkov T-11M], [EXD513 Mazzitelli FTU]/ [EXD664 Mirnov T11M] |
| ✓ PLASMA CONDITIONING | Li [EXD81 Maingi NSTX-EAST], [EXD426 Shcherbak T-11M], GDC [EXD126 Douai], ICRH [EXD600 Wauters JET], isotopic change[EXD268 Loarer JET] |
| ✓ EROSION-DEPOSITION-RETENTION-DUST | [EXD122 Rubel JET] / [EXD273 Brezinsek JET] / [25/356 Rudakov DIIID] / [EXD650 Halitovs], [EXD136 Shoji LHD], [EXD390 Hong KSTAR], [EXD92 Schmid], [EXD450 Zushi QUEST], mixed materials [EXD670 Scotti NSTX] |
| ✓ PW (LONG-PULSE) | [EXD280 Kasahara LHD], [EXD282 Hanada QUEST], W [EXD476 Tsitrone WEST] |
| ✓ DIAGNOSTICS | Stray light / Divertor [EXD634 Kukushkin ITER JET], [EXD662 Reichle ITER], Electromagnetic effects [EXD502 Spolaore] |
| ✓ MODELLING | [EXD123 Harrison MAST], [EXD514 Wishmeier] |
| ✓ SOL width | Extrapolating **SOL width** from present machines to ITER :[EXD96 Birkenmeier AUG], |

# Innovative exhaust magnetic configurations

Laboratorio Nacional Fusión



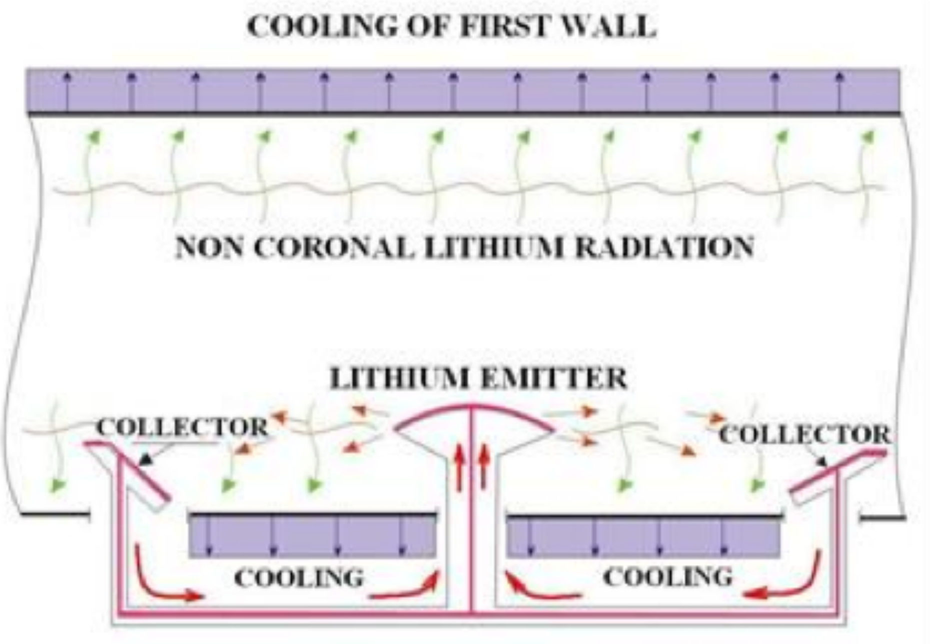

Power distributed to all 4 SPs but not reproduced yet by EMC3-Eirene. No evidence of scrape-off layer broadening. Transport in the private flux region [EXD124 Duval TCV]

Enhancement of heat transport and heat redistribution among additional strike points [EXD497 Soukhanovskii DIIID]

Snowflake scenario IN EAST [EXD352 Calabro EAST]

**Snowflake configuration: Encouraging results on DIIID, NSTX and TCV (and just first results in EAST) with activation of extra divertor legs.**

# Power exhaust, liquid metals




**Lithium Capillary-pore-system CPS** limiters with closed circulation loop [EXD159 Vertkov T11M]

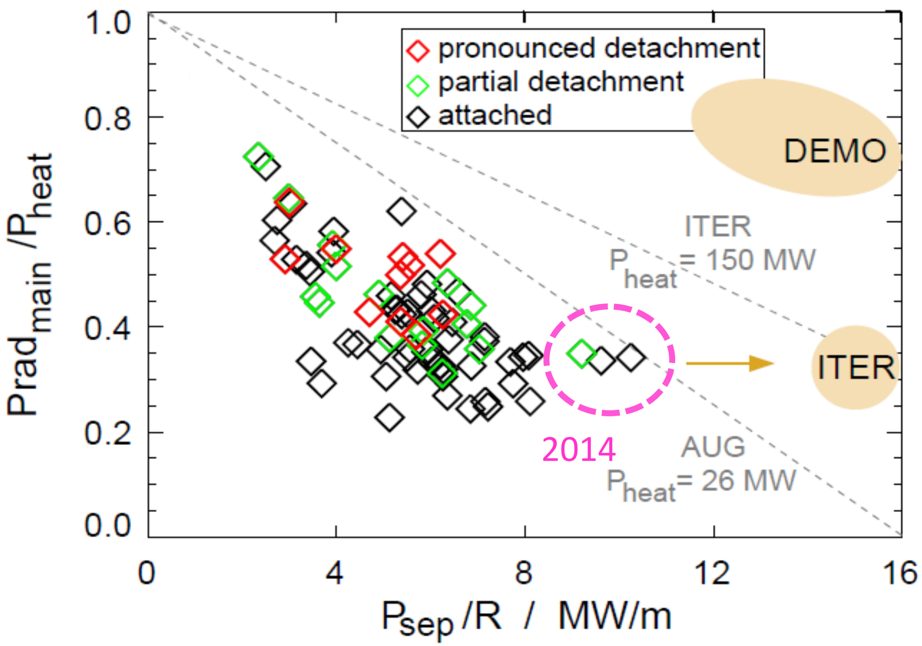
CPS experiments in FTU [EXC513 Mazzitelli] / TJII [Tabares]

**Lithium conditioning and confinement**: NSTX / EAST [EXD81 Maingi] / [PD Jackson DIIID]

**CPS is a promising solution with a need to find the best candidate material (Li/Sn/Ga) that fits all the necessary properties.**

**Alternative power exhaust solutions need to be vigorously pursued.**

# Plasma detachment and integrated control




AUG achieved the ITER required PD conditions for about half the values of the critical parameter Psep/R [EXD82 Kallenbach AUG]

## Integrated control

**Power exhaust and core performance**

**Power exhaust and magnetic topology**

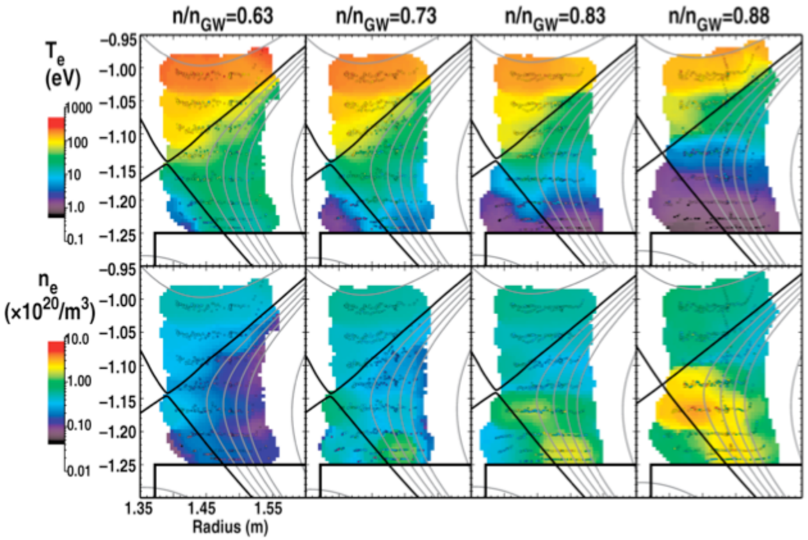
Plasma detachment is effectively stabilized with RMP [EXD488 Ohno]

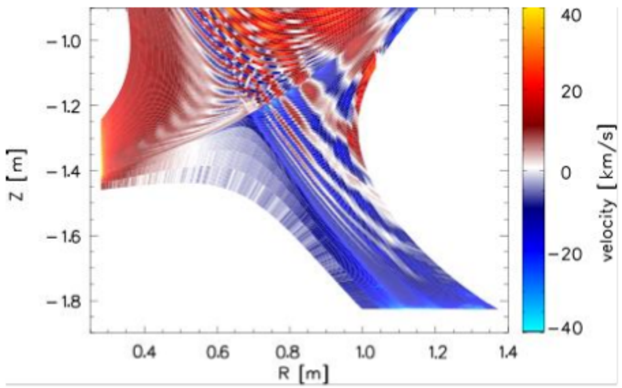
3-D fields have impact on divertor detachement [EXD655 Ahn NSTX-DIIID]

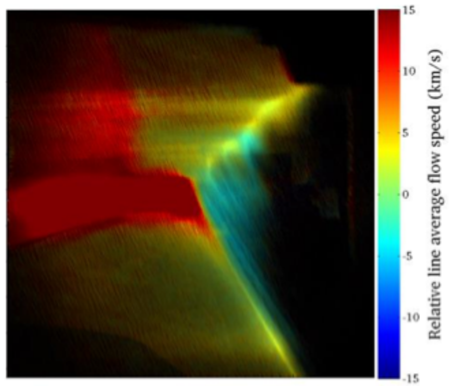
In stellarators the larger perturbation field (larger island) leads to detachement stabilization [ OV Kobayashi]

**Divertor detachment is a key to ITER mission. Robust target power flux control schemes need to be further tested across machines for a reliable application to ITER**

# Boundary diagnostics and edge validated simulations



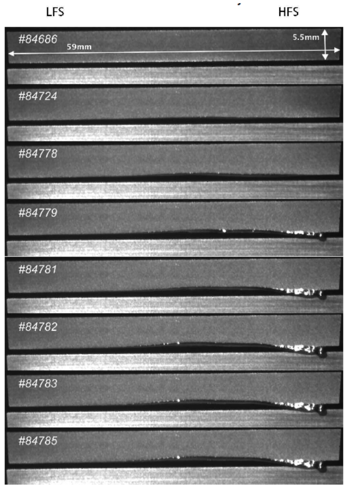



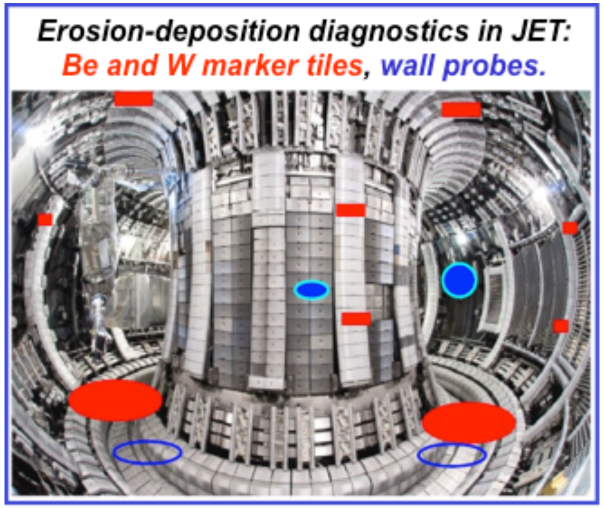

**PLASMA DIAGNOSTICS:** 2D characterization with Te below 1 eV essential for comparing simulation codes to experiment [EXD660 McLean DIIID]

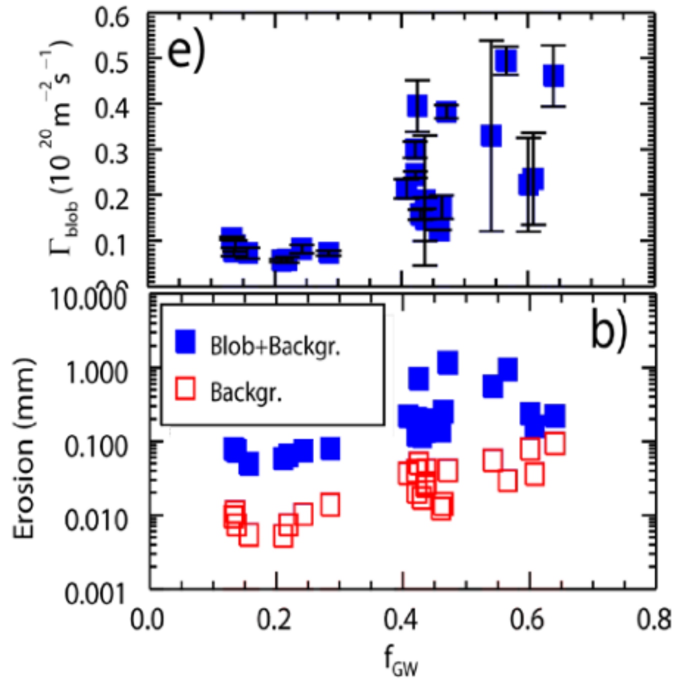
EMC3-EIRENE modelling and experimental results from imaging of lobe structures that form due to RMPs . The coherence imaging data support modelling predictions that the ion flow velocity within lobes differs from the unperturbed SOL [ EXD Harrison MAST]

Understanding of processes leading to divertor detechment is currently incomplete requiring **further development of validated simulations** [divertor asymmetries, neutral model, kinetic effects] [EXD514 Wishmeier]

# SOL transport and particle/impurity sources




In JET-ILW deposition and fuel inventory are strongly reduced (20x ) in comparison to JET-C.
[EXD122 Rubel / Exp273 Brezinsek JET].

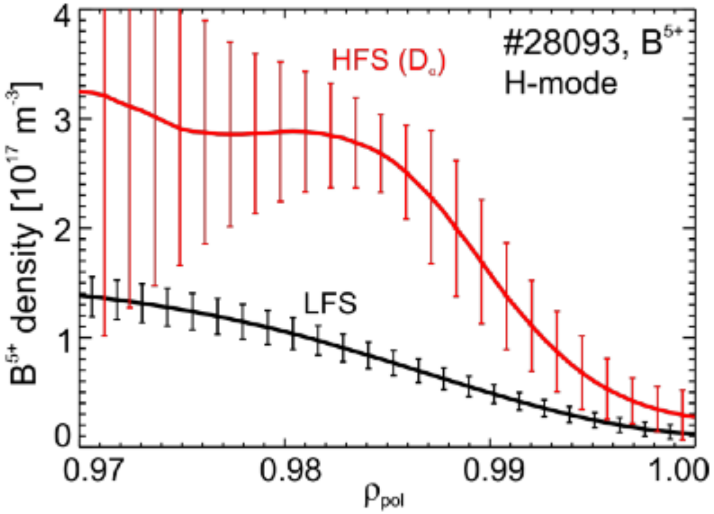
Melting of W by ELM heat loads [EXD235 Matthews JET/ ITER]

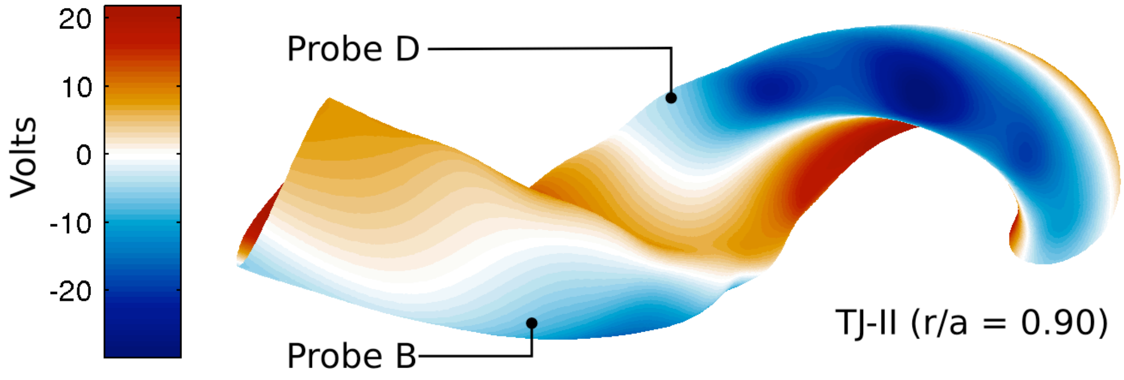
Transition from ion sheath-connected scaling to resistive blob regime as density increases with possible impact on backbround erosion, consistent role of finite ion temperature dynamics [EXD96 Birkenmeier AUG]

**Advances on retention, melting during ELMs, mixed materials, SOL width and ion dynamics.**

| | IMPURITY / PARTICLE TRANSPORT AND SOURCES |
|---|---|
| **EMPIRICAL ACTUATORS** | |
| ✓ **CORE HEATING** | Efficient to avoid impurity accumulation in existing devices [ECRH / EXC301 Klyuchnikov T-10], [NBI EXP310 Yoshinuma LHD], [ICRH/ |
| ✓ **MHD** | MHD EXC330 Valisa JET] |
| ✓ **SOURCES AND FUELLING** | fuelling + ICRH + pumping [EXC187 Nunes JET], [EXC195 de la Luna JET], source location [EXC228 Sudo LHD], [EXD161 Cui HL-2A], N puffing [EX244D Mazzotta FTU], melting of W [EXD235 Matthews JET], [EXD392 Murakami LHD], [EXC690 Joffrin JET], Neutrals/core [EXC305 Fujii LHD] |
| ✓ **REAL TIME CONTROL** | ELM (control with gas) + Sawtooth (ICRH Heating) [EXC Lennholm173 JET] |
| **TOWARDS BASIC UNDERSTANDING**<br><br>**Optimum profiles for achieving high fusion gain without impurity accumulation?** | 1) ROLE OF HEATING ON GRADIENTS (**NEOCLASSICAL effects**) [EXC330 Valisa JET]<br><br>2) ROLE OF HEATING ON **TURBULENT driven transport** [EXC575 KSTAR], [NBI EXP310 Yoshinuma LHD],<br><br>3) Flux surface plasma **POTENTIAL ASYMMETRIES** [OV4 Sánchez TJ-II]<br><br>4) Strong inertia and electrostatic forces resulting in **POLOIDAL ASYMMETRIES** (High Z) [EXC224 Mazon AUG] / [EXC236 Camenen TCV] / [EXPC330 Valisa JET] [EXP458 Hogeweij ITER]<br><br>5) **ASYMMETRIES AND NC TRANSPORT** [EXC534 Viezzer AUG]<br><br>6) **MODELLING IMPURITY/PARTICLE SOURCES AND TRANSPORT** [EXD392 Murakami LHD], modelling / power exhaust [EXD514 Wischmeir] |

# Physics basis for avoiding impurity accumulation: neoclassical and anomalous mechanisms

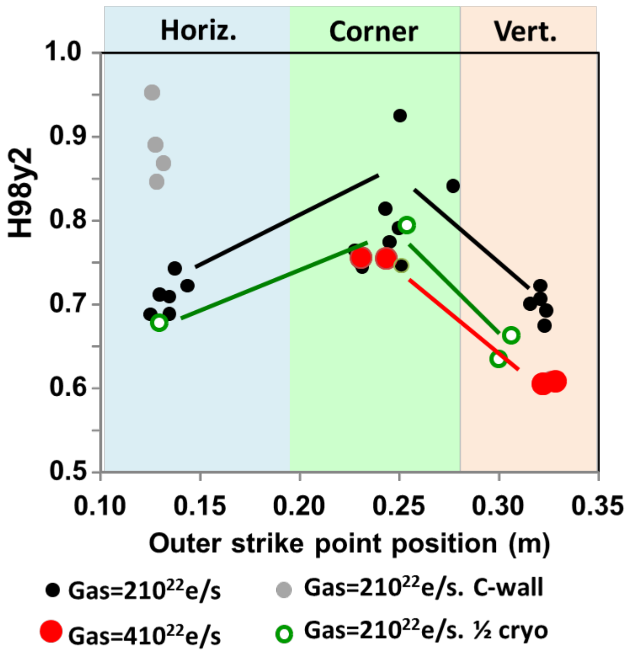


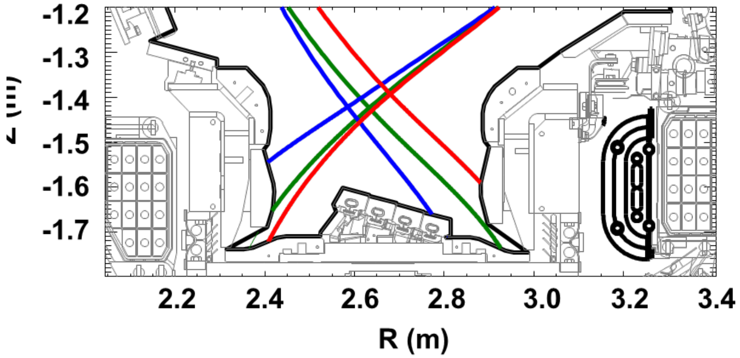




In-out impurity density asymmetry in the pedestal consistent divergence-free flows, which does not lead to a significant deviation from neoclassical transport l[EXC534 Viezzer AUG]

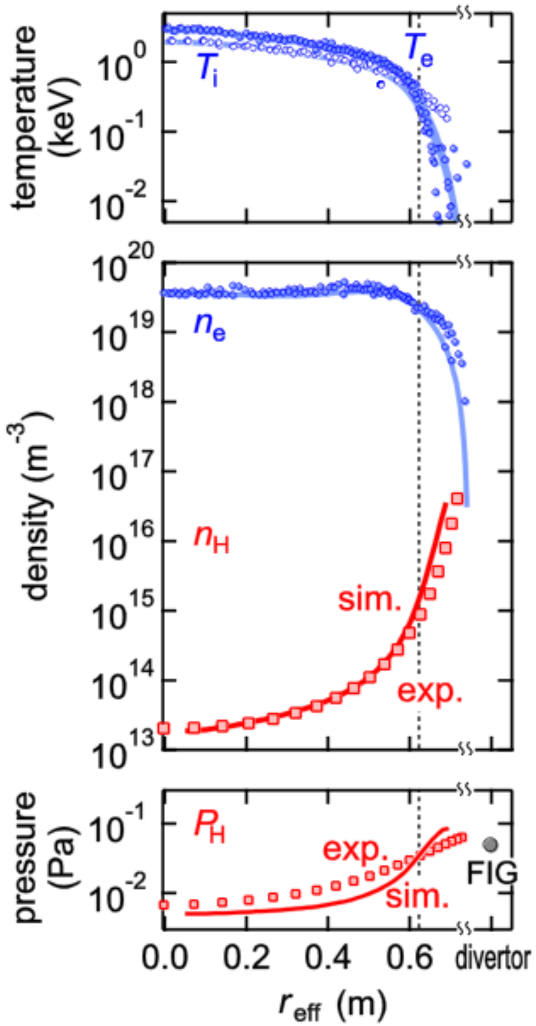
First direct observation flux surface plasma potential asymmetries consistent with MC calculations [OV TJ-II].

# EGDE IMPURITY/PARTICLE SOURCES:
# the importance of apparently insignificant details



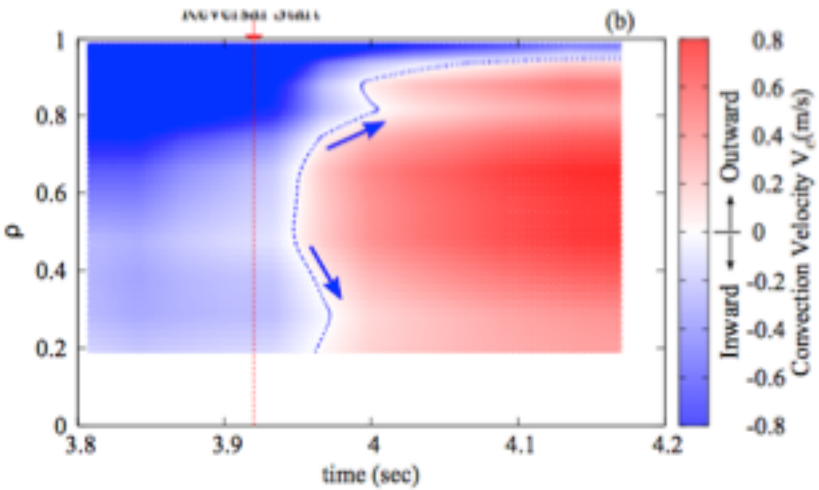

The corner configuration has the best energy confinement (green) in [EXP690 Joffrin JET]



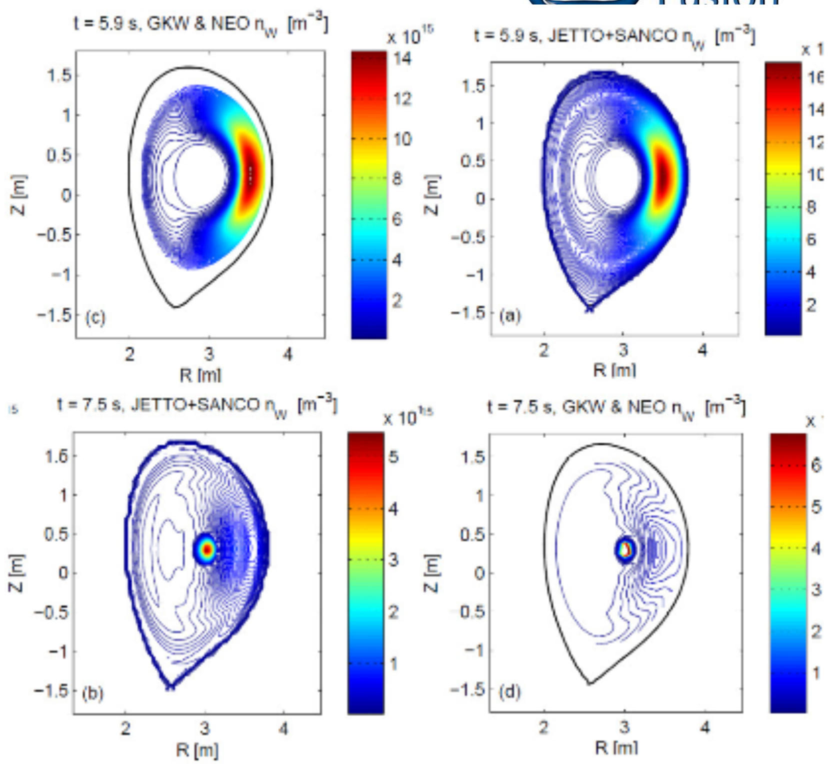

Neutral transport based on high dynamic range Balmer a spectroscopy [ EXC305 Fujii LHD]

Impurity source location is essential for determining impurity transport properties [EXC228 Sudo LHD]

# Heating and MHD to control core accumulation



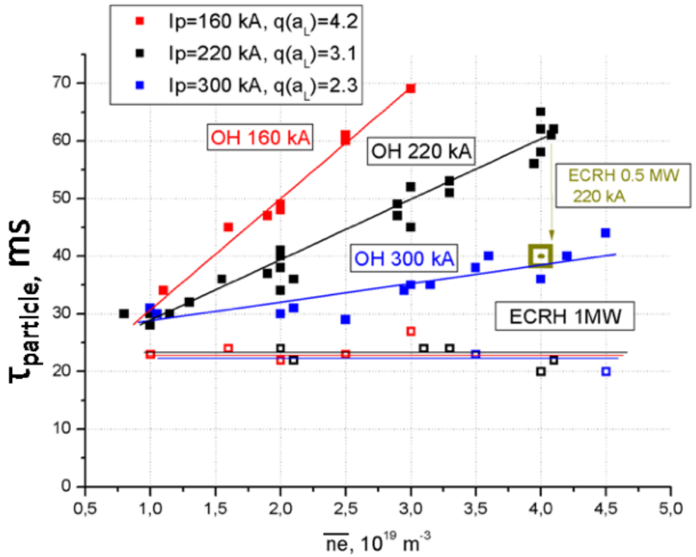

Reversal of C convection velocity with NBI heating (impurity hole) [EXP310 LHD ]




MHD + ICRH controls W

Neoclassical transport is the dominant channel in the core for W, affected by centrifugal forces and electrostatic poloidal asymmetries.

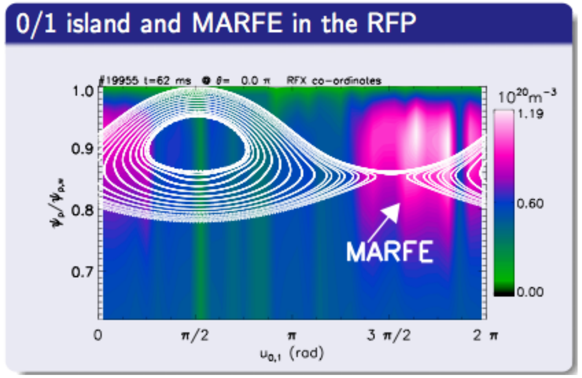
[EXC330 Valisa JET]



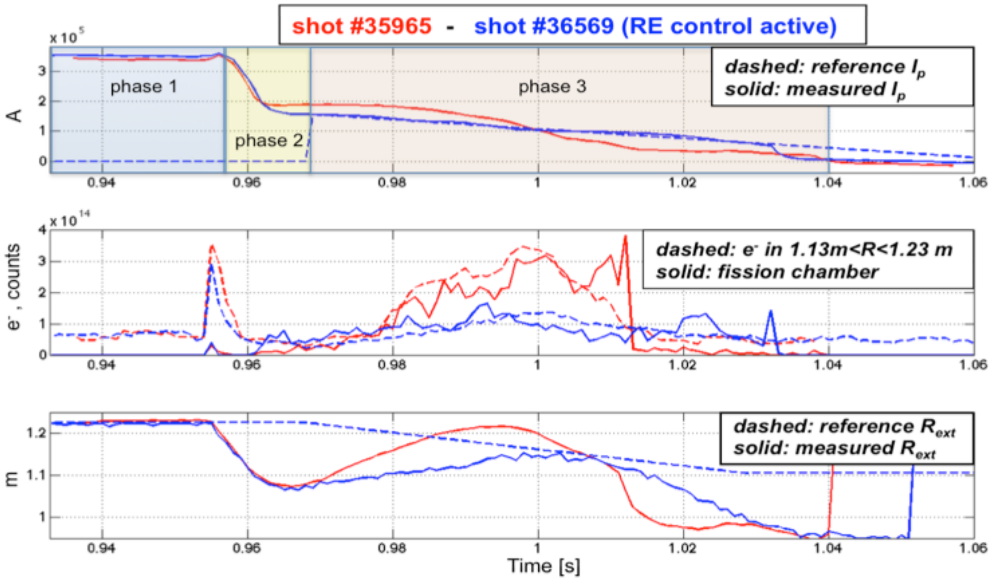

Particle confinement of Carbon in T-10, showing imputiies removal during central ECRH [EXC301 Klyuchnikov T-10]

| | OPERATIONAL LIMITS AND DISRUPTIONS |
|---|---|
| ✓ **DISRUPTIONS: MGI, SMBI, MAGNETIC PERTURBATIONS** | Mitigation with SMBI/ MGI [EXC495 Dong J-TEXT] / Runaway control[EXC500 Carnevale FTU] |
| ✓ **DENSITY LIMIT** | Configuration [EXC177 Kirneva TCV] / [EXC245 Spizzo FTU-RFX] |

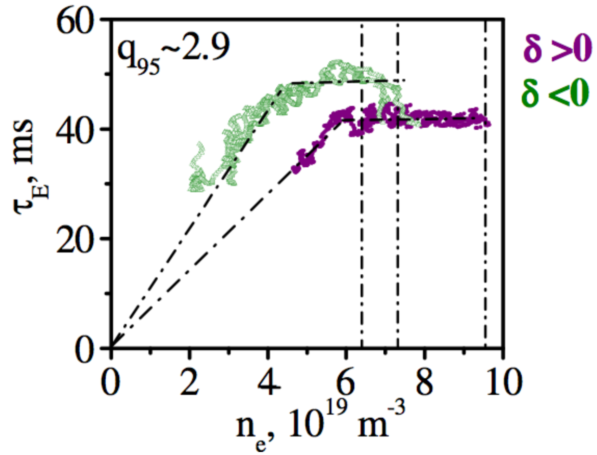
# OPERATINAL LIMITS and DISRUPTIONS CONTROL




High density is associated with the destabilization of edge resonating magnetic islands and perspectives of ECRH to overcome the critical edge density (RFP / FTU) [ EXC425 Spizzo]



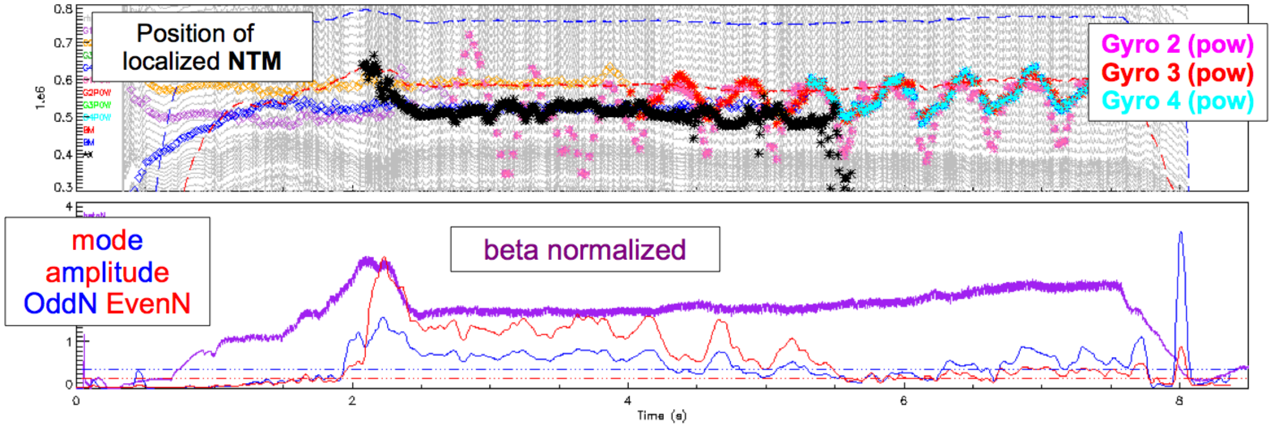

Runaway-control in the FTU tokamak, for position and ramp-down control of disruption-generated RE [EXC500 Carnevale]



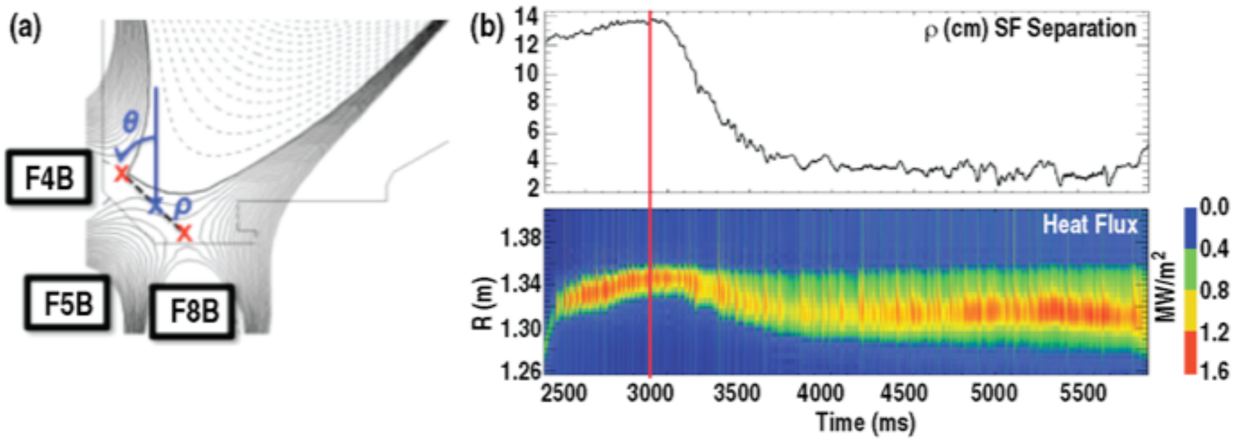

Plasma configuration and density limit [EXC177 Kirneva TCV]

| | PLASMA PERFORMANCE AND CONTROL |
|---|---|
| **FUELLING** | Fuelling He [PPC98 Romanelli ITER] |
| **BREAKDOWN** | Plasma initiation ITER [PPC255 Mineev]<br>Ohmic breakdown [PPC571 Yoo KSTAR]<br>Modelling non-inductive ramp-up [PPC Poli 542]<br>[EXC72 Mitarai STOR-M] |
| **CONTROL** | Magnetic and kinetic control [PPC190 Moreau]<br>Fast vertical control [PPC201 Mueller KSTAR, EAST, NSTX], [PPC248 Gribov ITER]<br>Design, prototype and manucturing in-vessel coils ITER [PPC691 Encheva ITER]<br>Control with non-asisymmetric coils [PPC376 Hawryluk DIIID]<br>Real time control NTMs / ECRH OPERATIONAL [PPC430 Reich AUG], [PPC553 Kim KSTAR]<br>Control plasma profiles [PPC636 Felici TCV, AUG ITER]<br>Physics model based control (q, betaN) [PPC520 Barton DIIID]<br>Magnetic conf (Snowflake) Divertor detachment CONTROL [PPC379 Kolemen DIIID]<br>Control burn in ITER feedback [PPC599 Kessel] / L-H transition |
| **PLASMA SCENARIO DEVELOPMENT** | Towards Steady state conditions / hybrid scenario [PPC277 Petty DIIID]<br>Scenarios for ITER operation [EXC344 Sips]<br>Integration operation of the ITER-Like Wall at JET [EXC433 Giroud JET] /[EXC187 Nunes JET]<br>ITER scenarios at AUG [EXC606 Schweinzer]<br>High inductance for steady-state operation [9/335 DIIID Ferron]<br>ITER BASELINE Q=10 [EXC342 Luce DIIID] Operation difficulties at low applied torque<br>Scenario in LHD [PPC348 Nagaoka LHD]<br>Plasma scenario development HL-2M [2/163 SONG HL-2M]<br>Quiescent H-mode [PPC243 Solomon DIIID]<br>Fully non-inductive scenario for Steady State Operation [EXC681 Gong EAST/DIIID]<br>Compativility of ITB and steady-stae operation [23/661 garofalo DIIID]<br>DEMO physics [PPC448 Wenninger] |

# PLASMA CONTROL



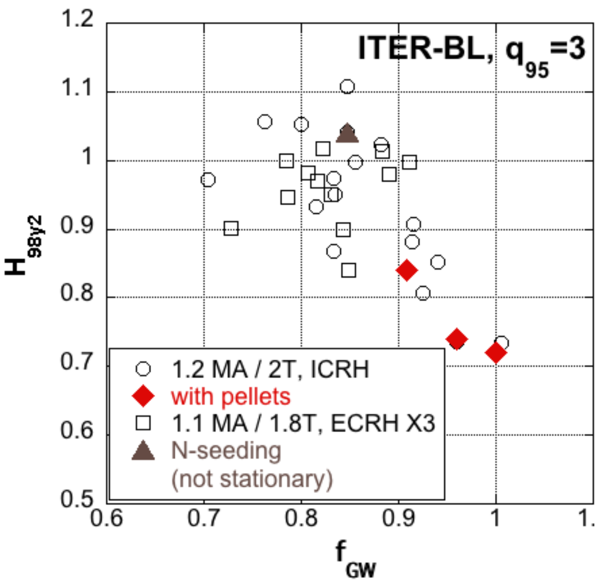

Real time control NTMs / ECRH main actuator FULLY OPERATIONAL [PPC430 Reich AUG]

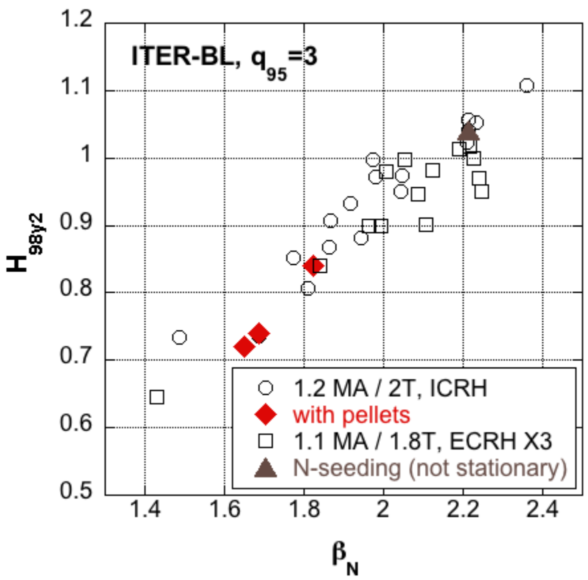


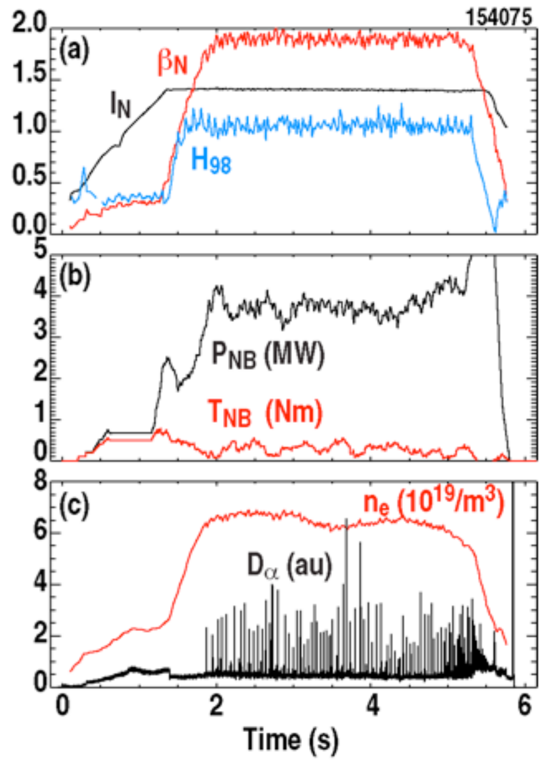

SnowFlake Divertor control [EXD379 Koleman DIIID]

# Plasma performance and integration:

## Towards ITER integrated scenario development: equilibrated ion/electron temperatures, low injected torque, low rho and collisionality, ELM control, divertor compatibility




**Development of the Q=10 Scenario on AUG.** Operation at $q_{95}$=3 demonstrated at $H_{98y2}$=1, $\beta_N$ ~2, $n/n_{GW}=f_{GW}$ ~0.85; alternative scenario $q_{95}$=3.6 under investigation.

BUT, Integration of ELM mitigation not achieved; No stationary behavior with N-seeding [EXC606 Schweinzer]

ITER-like conditions $H_{98y2}$=1, $\beta_N$ ~1.9 (low torque, electron heating and radiative operation)

BUT, challenge operation due to onset of TM.

[PPC342 Luce DIIID]

# Plasma performance and integration

Laboratorio Nacional Fusión

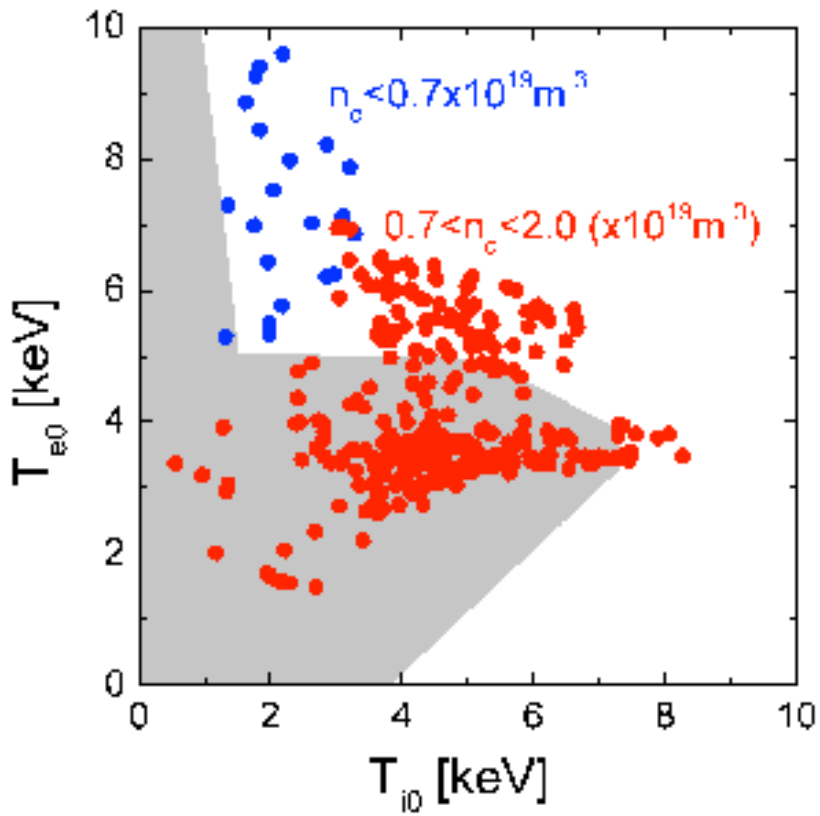
**JET: Integrated performance with N-seeding and divertor compatibility**

- **$H_{98}$~0.85**
- **$\beta_N$~1.6**
- **$f_{GW}$~0.85**
- **$Z_{eff}$~1.6**
- **$\Delta W_{ELM}/W_{ped}$~4%** (65kJ)
- **detached at Strike P.** ~3MW/m$^{-2}$
- stationary condition ~7s **(26 x $\tau_E$)**
- triangularity $\delta$~ 0.36

ITER
$H_{98}$~1.0
$\beta_N$~1.8
$f_{GW}$~0.85
$Z_{eff}$~1.6
$\Delta W_{ELM}/W_{ped}$<1 %

W accumulation control achieved with ICRH and gas puffing.
Energy confinement to H98(y,2) ≈ 1 achieved at Ip =2.5 MA, work ongoing to higher current. [EXC433 Giroud JET] / [EXC187 Nunes JET].

But operation in plasmas with high momentum input and need for ELM control.




High temperature regime has been significantly expanded in helical plasmas [EXD348 Nagaoka]

# Final remark

Laboratorio Nacional Fusión

Great contributions for the development of ITER / DEMO plasma scenarios including both:

I. **engineering approach** i.e. use of empirical control parameters to avoid possible fusion showstoppers

II. **physics research** i.e. basic understanding of underlying mechanism for predicting burning plasma with confidence

Acknowledgements:
I appreciate very much stimulating discusions and supporting material provided by my colleagues and IAEA organization.