IAEA FEC 2014

IAEA FEC 2014 Meeting – Brief Summary

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25TH IAEA FUSION ENERGY CONFERENCE

13–18 October 2014
St. Petersburg, Russian Federation

presented at the

November 2014 PPPL Research Meeting

PPPL

Princeton, NJ

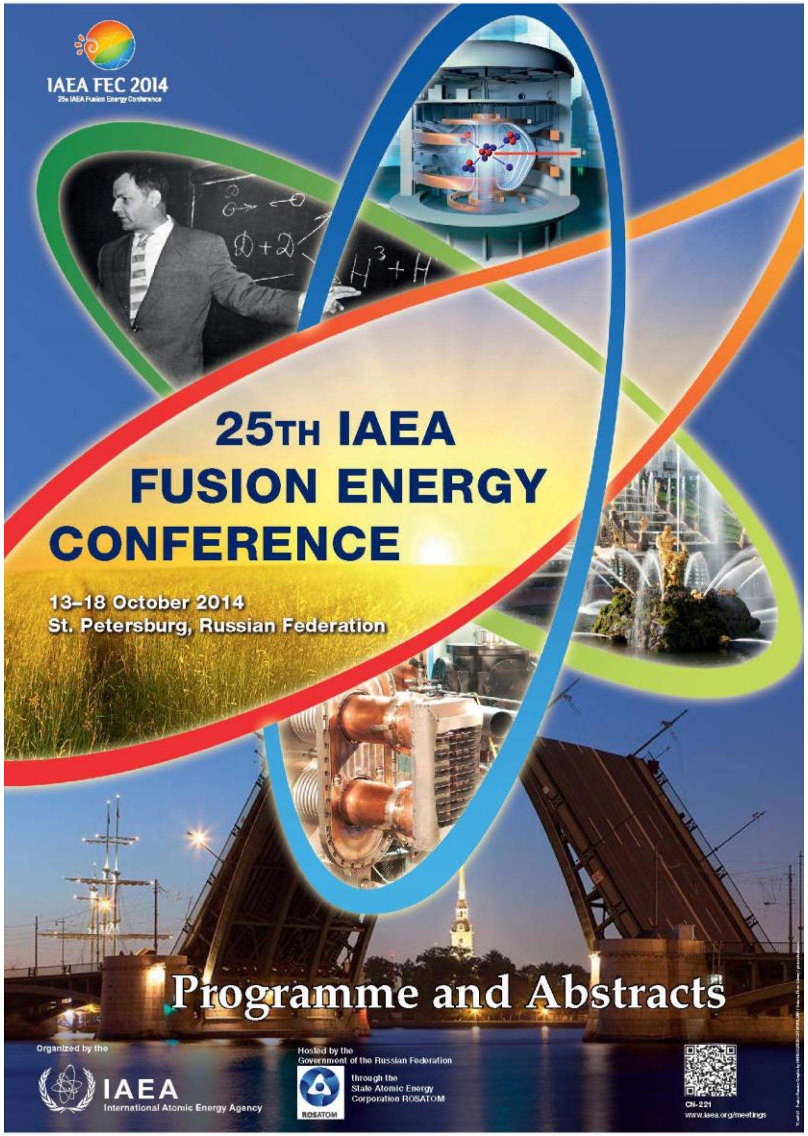
November 10th, 2014

How was the IAEA Meeting?

- Answer: Excellent
  - Usual excellent meeting organization by the IAEA
  - Usual organization of topical areas, except
    - No separate, dedicated ITER topical area
    - Performance / control, and other technology, safety/environment topical areas added

- US not fully staffed / co-authors filled-in
  - US national lab scientists not supported to attend meeting
  - All US magnetic fusion oral presentations “saved” by co-authors making presentations on behalf of lead authors
  - US colleagues were missed, but at least the presentation alternates made US presentations appear seamless
    - Exception: IFE lost two oral presentations / posters withdrawn

Programme and Abstracts Available



- Presentations
  - 23 Overview talks / 4 OV posters
  - 73 Regular talks
  - 23 Rapporteured papers
  - 606 Regular poster presentations
  - 2 Post-deadline talks
  - 5 Summary talks
- Programme and Abstracts document available here:
  - http://nstx.pppl.gov/DragNDrop/Scientific_Conferences/IAEA/IAEA_2014/Summary_Talk_etc/
- Summary talk / movie also available at this URL

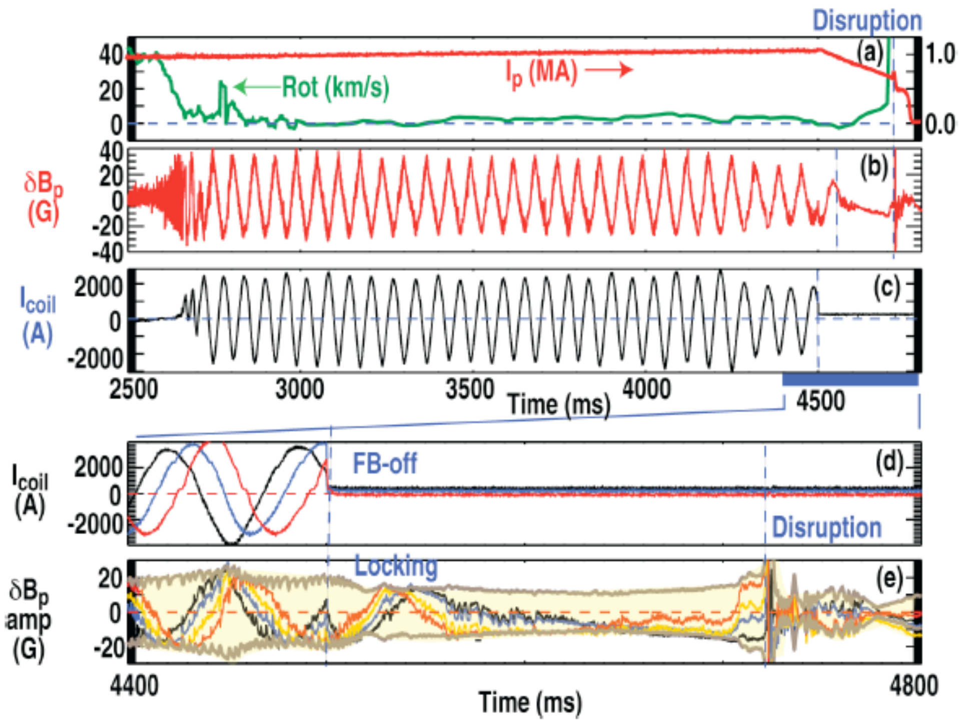
Experimental: Stability, Energetic Partcles & Waves, Innovative Confinement Concepts (not comprehensive!)

- Disruptions / Runaways
- 3D Physics / ELMs
- EPs / Waves
- Current Drive and RF Heating
- Innovative Confinement Concepts

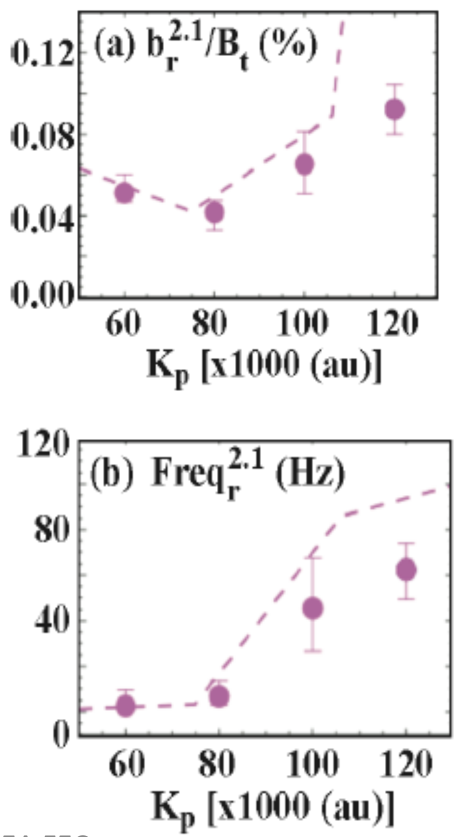
Disruption Avoidance / Control

EX/P2-42, Okabayashi

Avoidance of tearing mode locking and disruption with electro-magnetic torque introduced by feedback-based mode rotation control in **DIII-D** and **RFX-mod**



DIII-D

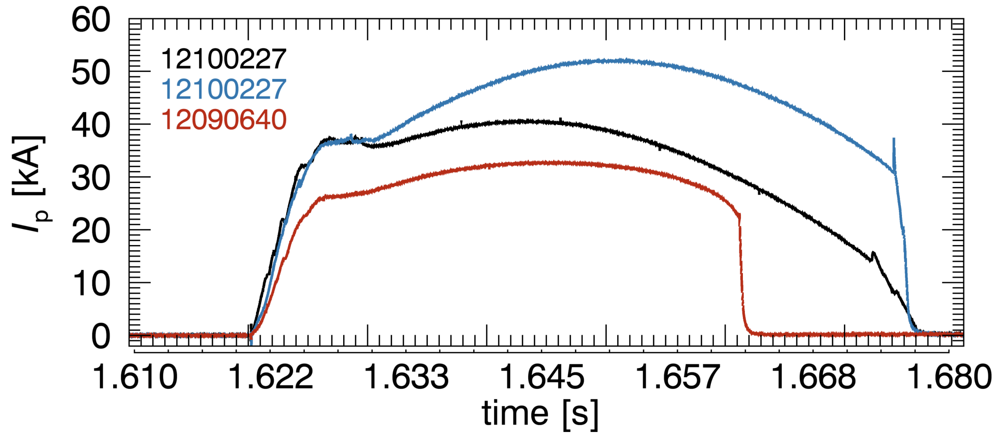


RFX

Disruption Avoidance / Control

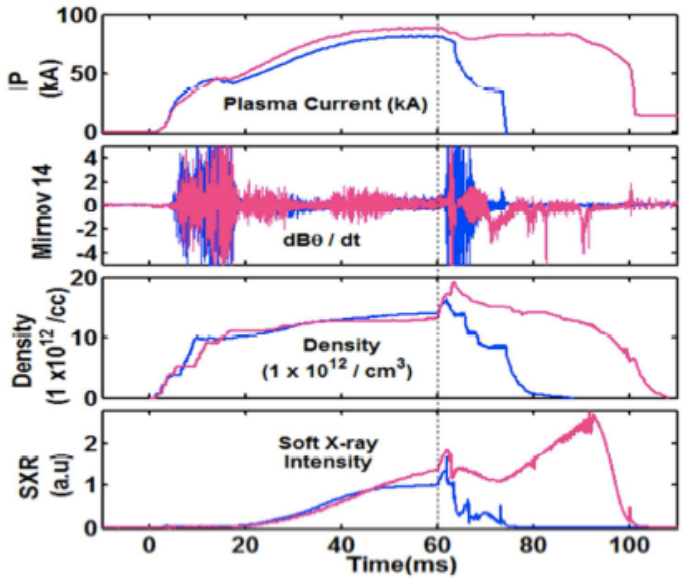
EX/P4-18, Maurer

Strong 3D equilibrium shaping, applied to tokamak like discharges on the **Compact Toroidal Hybrid (CTH)** expand its disruption free operating regime



EX/5-3, Tanna; EX/P7-16, Kulkarni; EX/P7-17, Dhyani

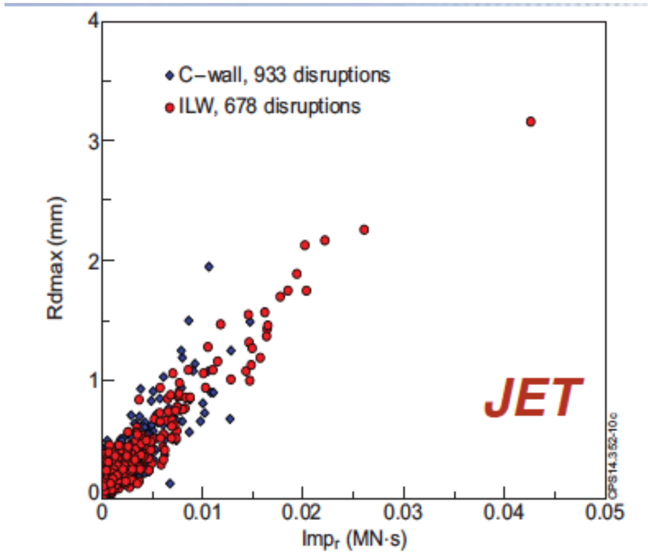
- Disruption control using biased electrodes in ADITYA tokamak to control MHD modes
- Similar effects also observed with the use of ICRF at the edge

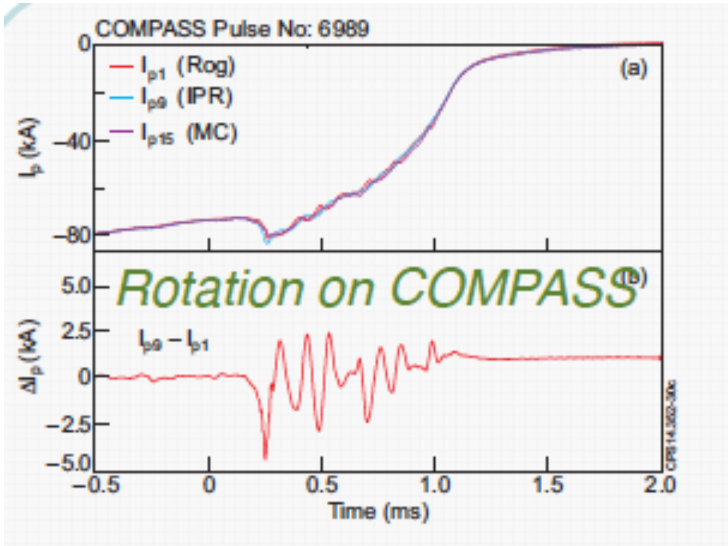


Asymmetrical Disruptions in JET and COMPASS

P5-33, Gerasimov

- **Highlights the frequent occurrence of asymmetric disruptions in JET and the magnitude of their consequent sideways forces**
- Resonance rotation with the natural vessel frequencies
- 3D JET model calculations for vessel poloidal currents
- Comparison with COMPASS data – consistency in terms of amplitude of asymmetry and rotation behaviour





Runaway electrons and massive gas injection experiments at JET-ILW

- Massive gas injection radiation **efficiency decreases down to 75%** at high plasma thermal energy content ($W_{th}/(W_{th}+W_{mag}) = 0.5$)
- Toroidal radiation asymmetries depend on mode lock phasing before the disruption.

- Runaway electrons at JET-ILW can be produced in similar conditions as with the carbon wall using argon MGI
- **Runaway electron beams can be stopped if low-Z gas (D_2) is injected before the thermal quench**
- Mitigation of **already accelerated beams** (during current quench) using either high-Z or low-Z gases is **ineffective** in the mitigation pressure range tested.
- Impacts of ~770 kA RE beam leads to significant melting of PFC.

- **Radiation asymmetries studies** using two disruption mitigation valves are planned.
- **Investigation of mitigation of an already accelerated runaway** beam using higher pressures is planned
- Investigation of **runaway beams relation to vertical stability, control and plasma shape** is to be continued

Runaway Generation / Control

An ITPA joint experiment to study runaway electron generation and suppression

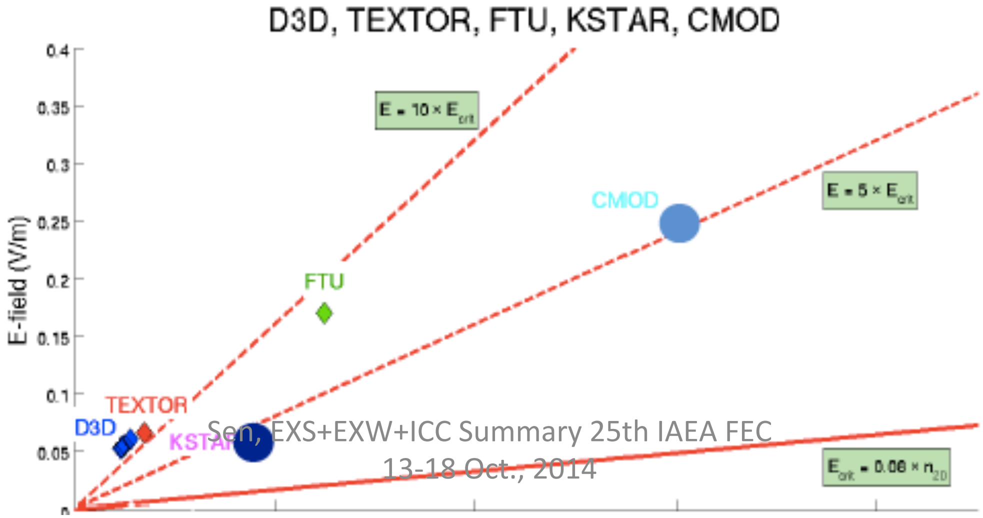
A study of runaway electrons under well-controlled, well-diagnosed conditions in a number of tokamaks finds that the threshold *E*-field for both onset and decay of runaway electron (RE) signals is at least 4 – 5 times above the Connor-Hastie E_{crit}

- Conversely, the density at which RE's are suppressed for a given loop voltage is at least a factor of 4-5 less than theoretically predicted

This suggests that there are other significant RE loss mechanisms in addition to collisional damping, even in steady-state quiescent plasmas.

It also suggests that mitigating runaways on ITER may not require fueling to the Rosenbluth density.

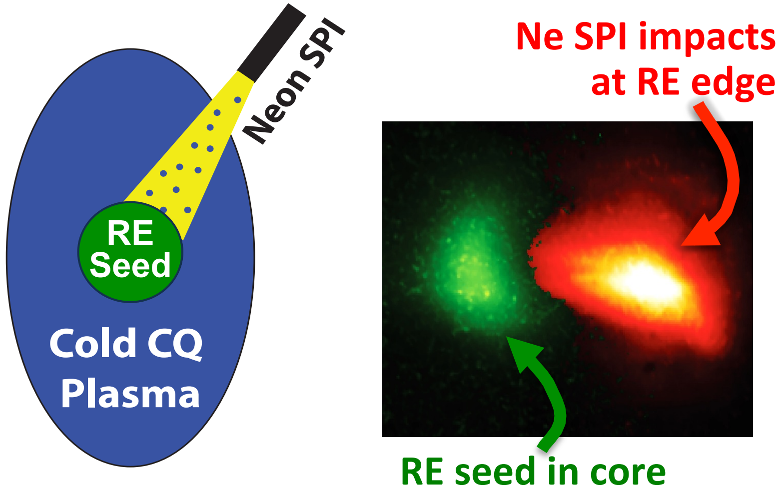
EX/5-1, Granetz

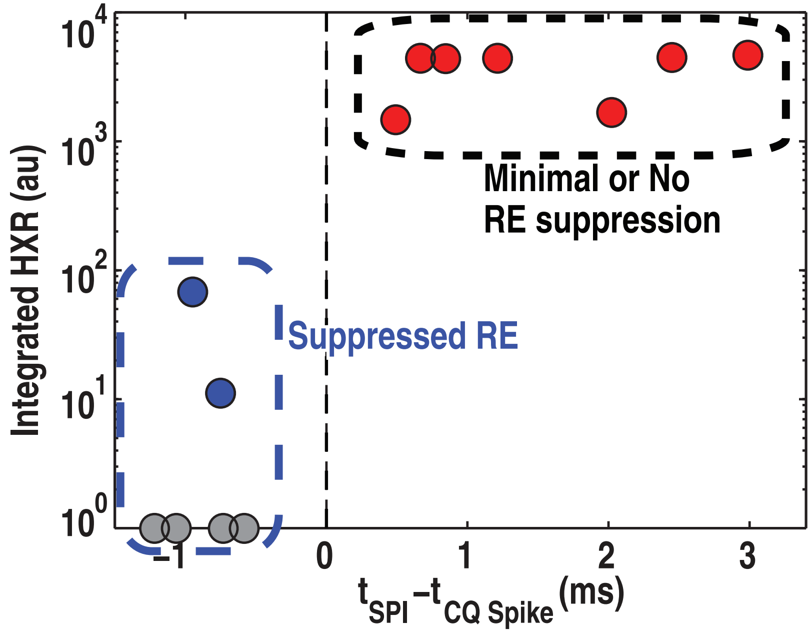


DIII-D Expt on RE Mitigation using SPI

- Injection of Ne Shattered Pellets into early CQ is effective in suppressing runaway growth
- RE current dissipation explained by RE-ion pitch angle scattering
  - Higher Z more effective at RE dissipation

EX/PD/1-1, Eidietis





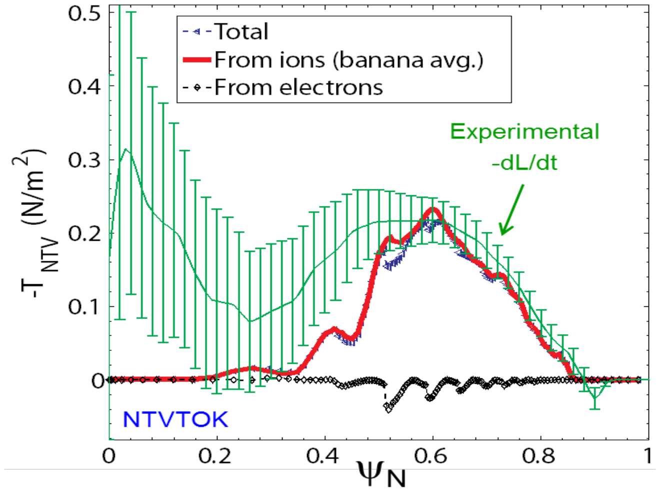
Neoclassical Toroidal Viscosity for Rotation Control and the Evaluation of Plasma Response

EX/1-4, Sabbagh

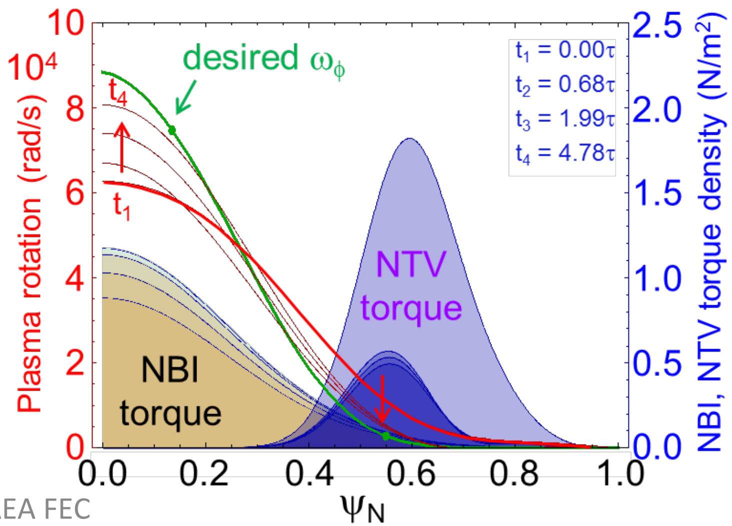
Highlights

- Experimental NTV characteristics
  - NTV experiments on NSTX and KSTAR
  - NTV torque T_{NTV} from applied 3D field is a radially extended, relatively smooth profile
  - Perturbation experiments measure T_{NTV} profile
- **Aspects of NTV for rotation control**
  - Varies as $\delta \boldsymbol{B}^2$; $T_{NTV} \propto T_i^{5/2}$ in primary collisionality regime for large tokamaks
  - No hysteresis on the rotation profile when altered by non-resonant NTV is key for control
  - Rotation controller using NTV and NBI tested for NSTX-U; model-based design saves power
- NTV analysis to assess plasma response
  - Non-resonant NTV quantitatively consistent with fully-penetrated field assumption
  - Surface-averaged 3D field profile from M3D-C[1] single fluid model consistent with field used for quantitative NTV agreement in experiment

Perturbation experiments measure NTV torque profile and compare to theory



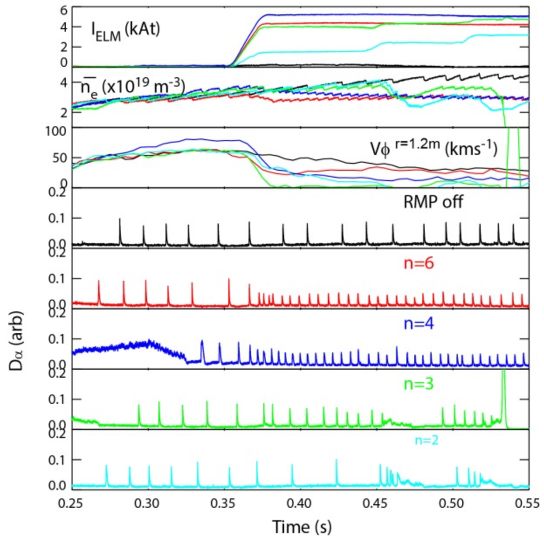
Rotation controller using NTV and NBI



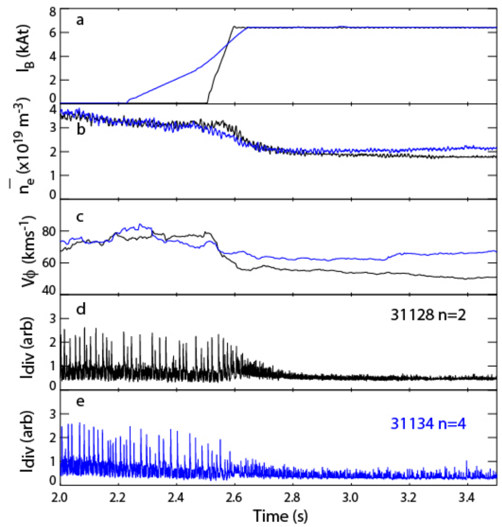
Expanded Operating Space

EX/1-2, Kirk

MAST

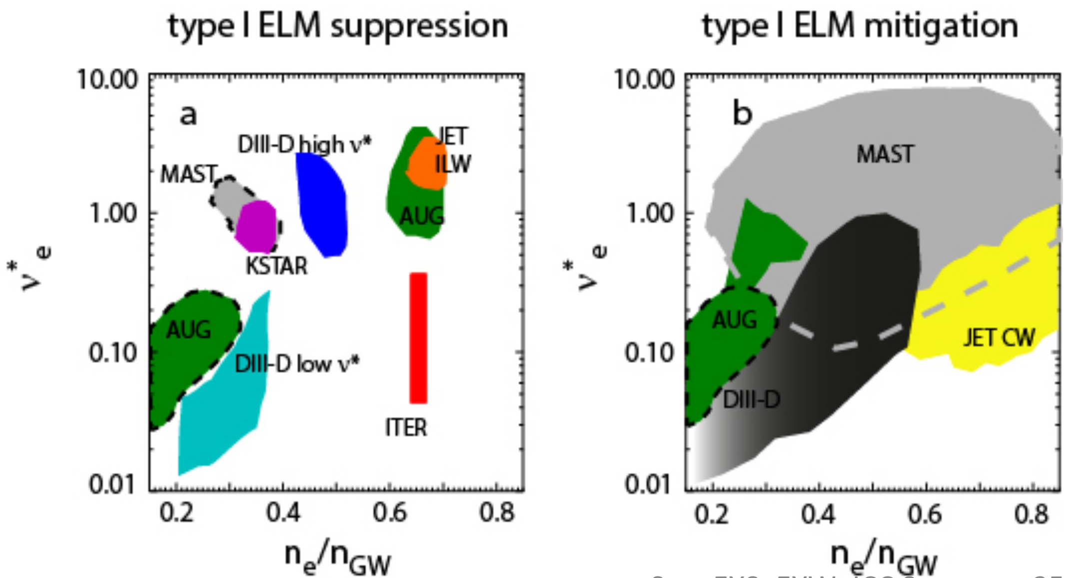


AUG



Sustained ELM mitigation/type I ELM suppression has been achieved on MAST and AUG with magnetic perturbations with a range of toroidal mode numbers

ELM size and target heat loads are reduced but at a price of a reduction in confinement

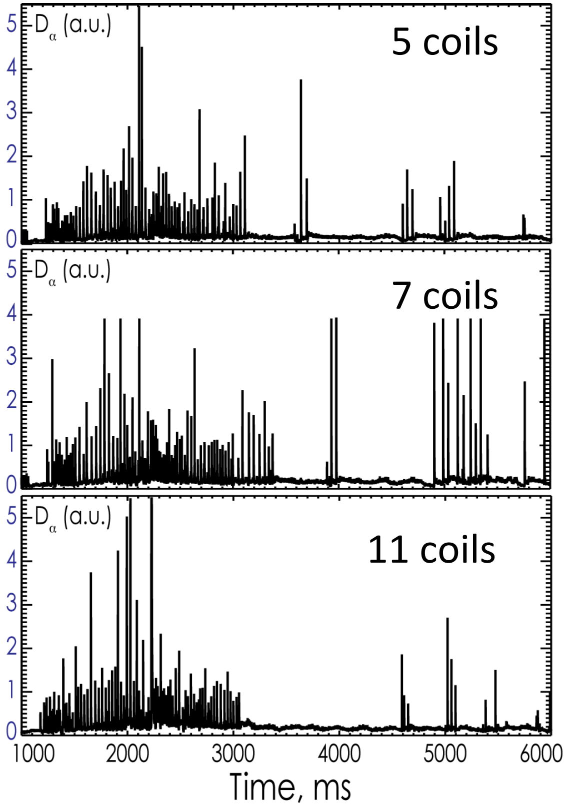


Dashed curves expanded operating space for the type I ELM suppression/mitigation from MAST and ASDEX Upgrade

Results show that regimes with tolerable ELMs can be established over a wide operating space in a range of devices

Advances in Basic Understanding of ELM Suppression

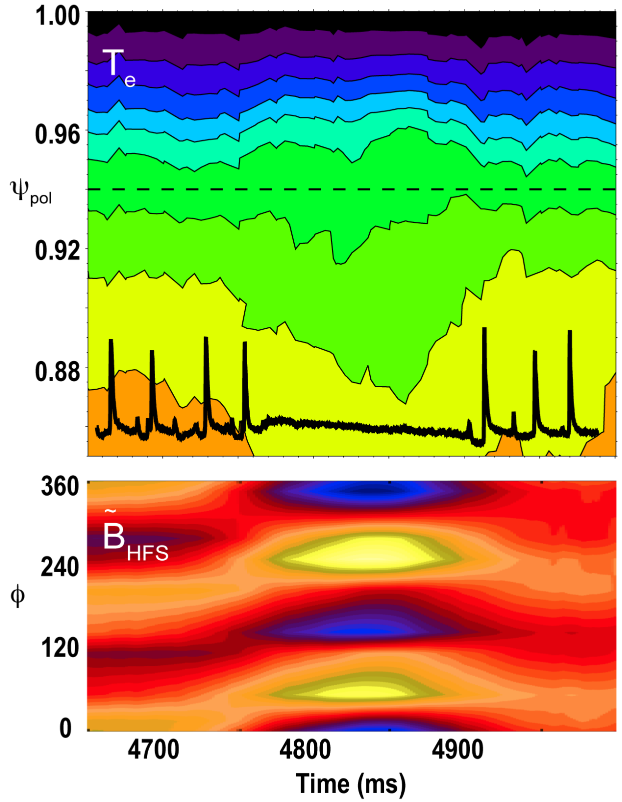
- **ELM suppression achieved with as few as 5 internal coils**



DIII-D results

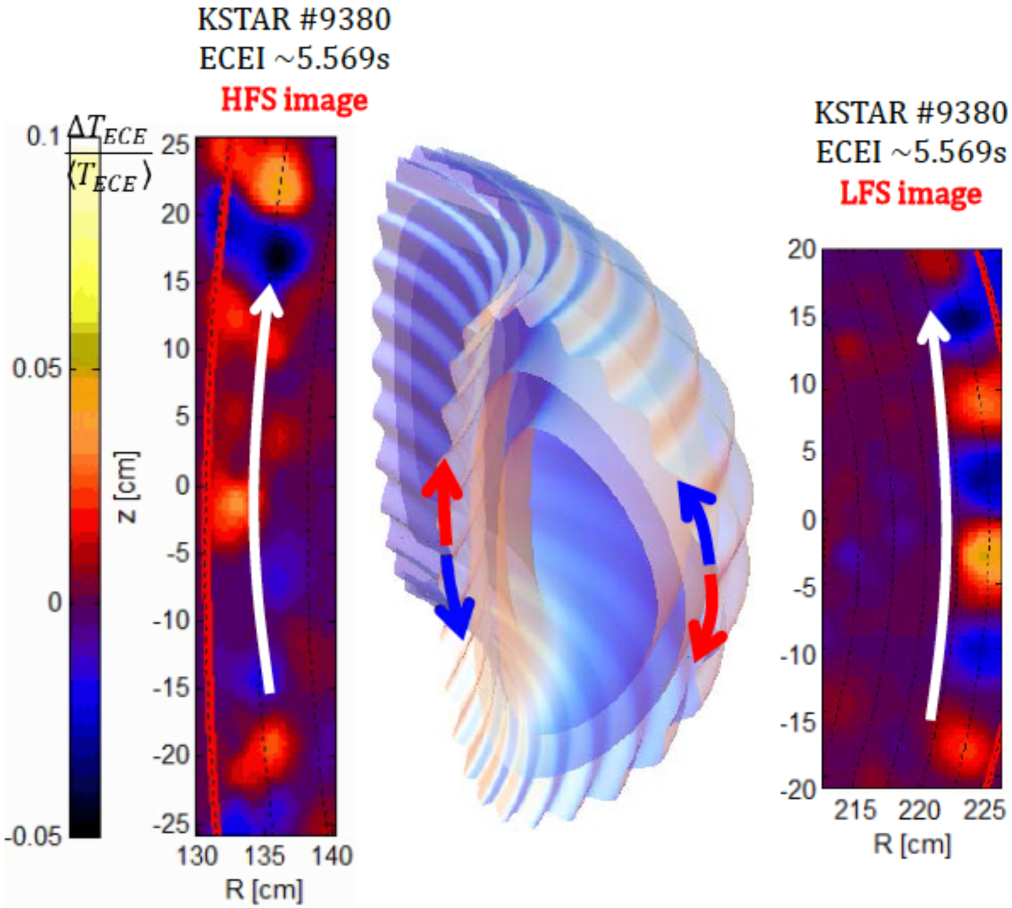
EX/1-1, Wade; EX/P2-21, Orlov

- **New data reveals bifurcation indicative of resonant field penetration at ELM suppression**



Highlights importance of plasma response to RMP fields

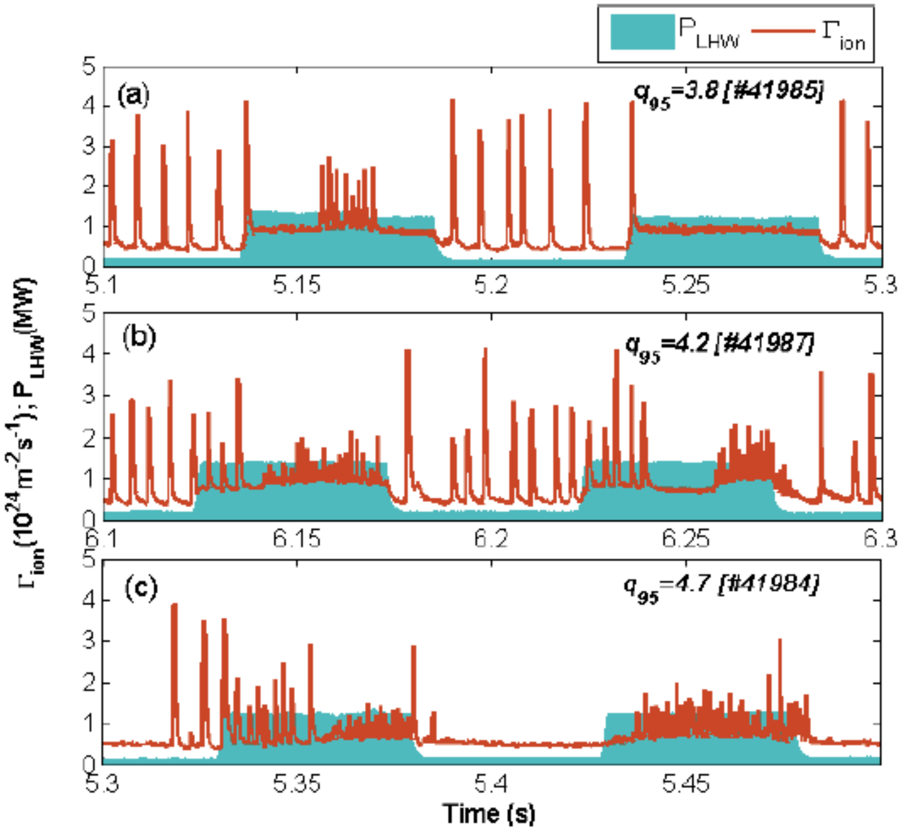
Simultaneous Measurement of ELMs at both High and Low Field Sides in KSTAR



- **Comparable mode strength at HFS and LFS**
- **Asymmetries in toroidal/poloidal rotation velocities**
- **Mode structure at HFS not consistent with Ballooning Mode model**
- **Mode numbers different on the two sides**

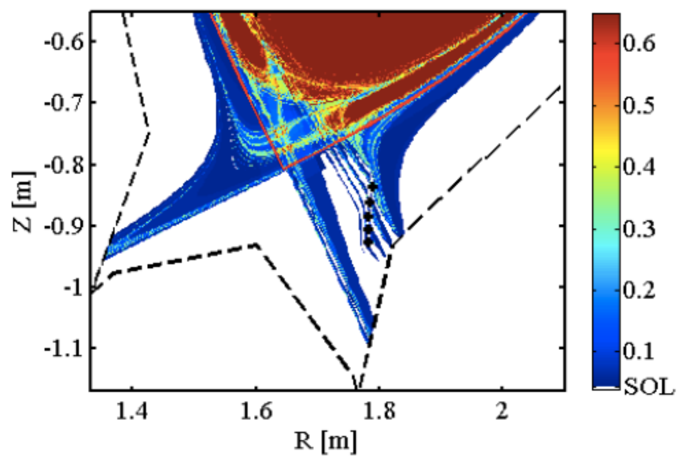
EX/8-1, Park

ELM mitigation by Lower Hybrid Waves in EAST



EX/P3-8, Liang

- ELM mitigation with LHW obtained over a wide range of q_{95}
- Attributed to formation of helical current filaments in SOL
- ELM freq. increases from 150 Hz to about 1 KHz

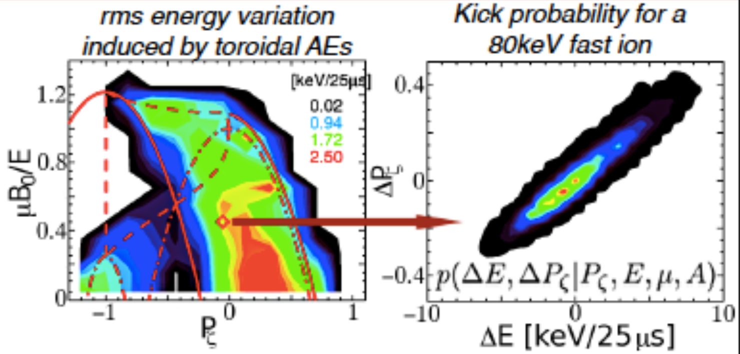


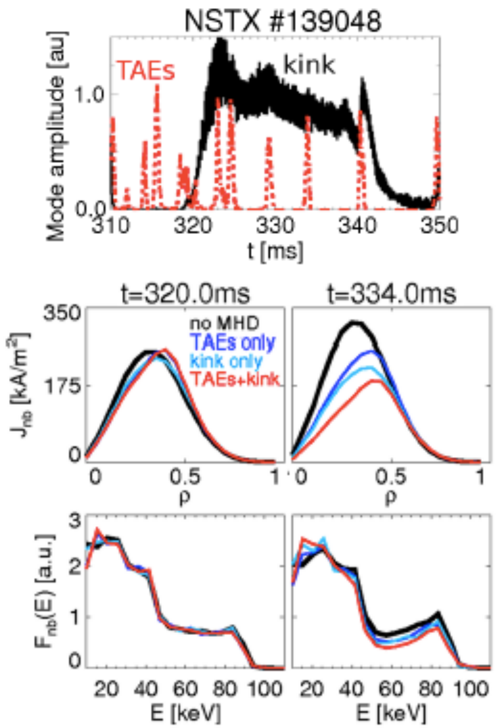
Strong modification of plasma edge

EX/10-4: Effects of MHD instabilities on Neutral Beam current drive

M. Podestà, M. Gorelenkova, D. S. Darrow, E. D. Fredrickson, S. P. Gerhardt, W. W. Heidbrink, R. B. White

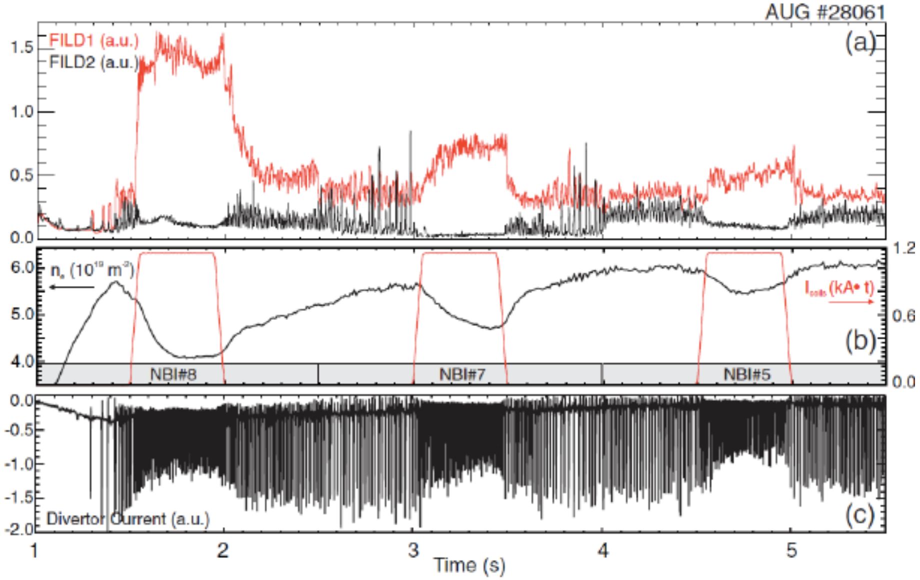
- Neutral Beam heating and current drive are crucial for the success of ITER, Fusion Nuclear Science Facility (FNSF)
- MHD instabilities (e.g. Alfvénic modes, AEs) can reduce NB-CD efficiency
- A new model is developed to quantify and predict AE effects on NB-CD *[Podestà, PPCF **56** (2014) 055003]*
  - Fast ion evolution is consistently treated *in phase space* (energy, canonical angular momentum, magnetic moment)
  - Interactions modeled through *kick probability* $p(\Delta E,\Delta P_\zeta|E,P_\zeta,\mu)$
  - Implementation in the transport code TRANSP under way
- Results from NSTX confirm strong effect of AEs on NB-CD
  - **Up to 40% of local current density can be redistributed**
  - **Effects not correctly accounted for by models based on *ad-hoc* spatial diffusion**





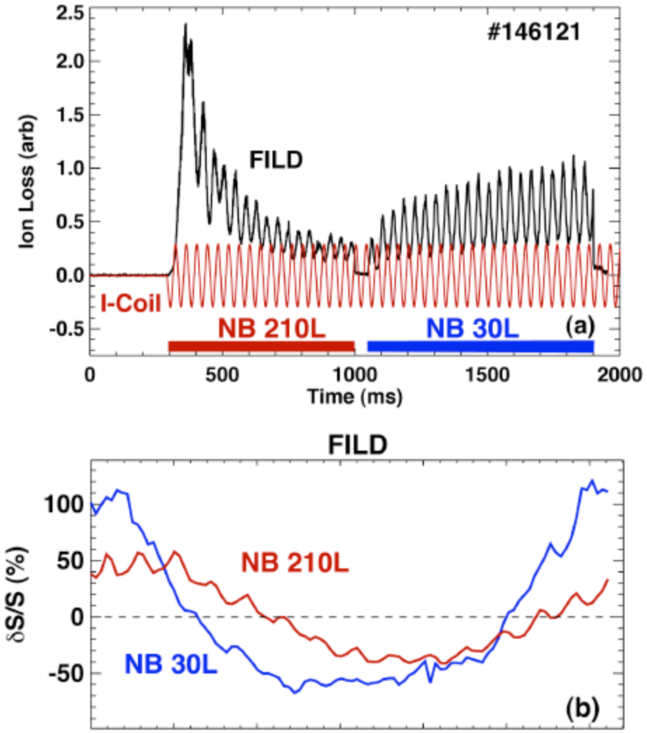
Fast-ion response to externally applied 3D magnetic perturbations

ASDEX-U **EX/P1-22, Garcia**



strong plasma & fast-ions response is observed in H-mode regimes with low collisionality / density and low q95.

DIII-D **EX/10-2, Van Zeeland**

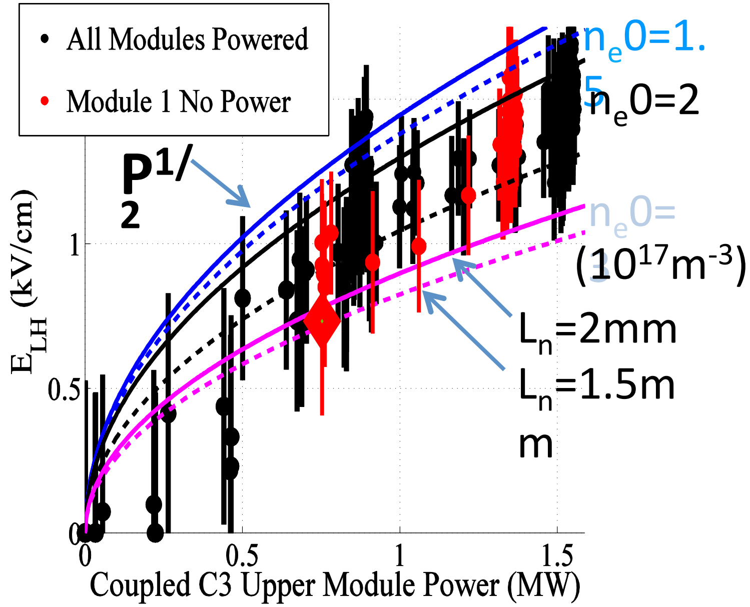


Pitch angle and energy resolved measurements + wide field-of-view infrared imaging show fast ion losses correlated with applied 3D fields. in L-mode plasmas. Good agreement with model simulations.

Near-Field Physics of Lower-Hybrid Wave Coupling

EX/4-2, Goniche

Tore Supra



Large data base (~230 points) indicate that E_{RF} scales as ($P_{coupled}^{1/2}$) assuming edge density near the cut-off density (~$2\times10^{17}m^{-3}$)

EX/P6-17, Parker

Alcator C-MOD

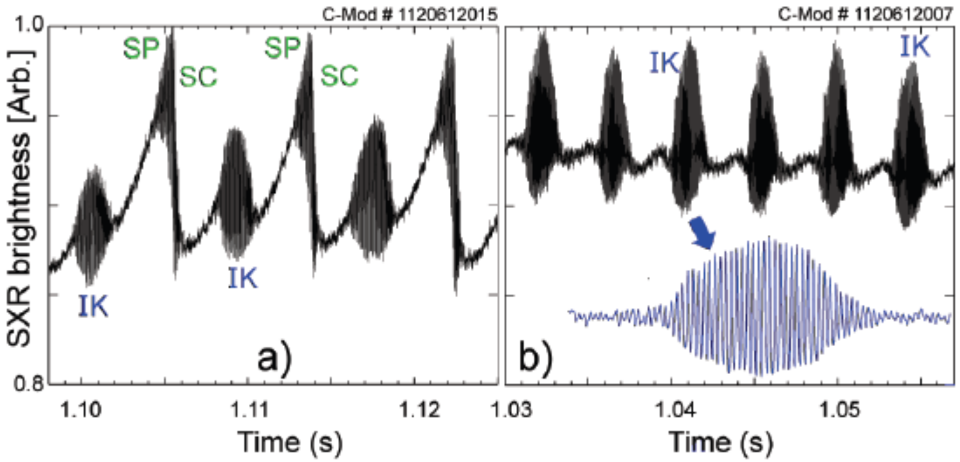
Loss of LHCD efficiency at high density is associated with Excitation of Parametric Decay Instabilities. PDI are excited near the separatrix and onset can be mitigated by modifying conditions in the scrape-off layer. **Launch from HFS may be more efficient – scheme for next machine.**

EX/P3-11, Ding

EAST

High density experiments with LHCD analyzed by simulation using experimental parameters, show that parametric instability , collision absorption in the edge region, and density fluctuations could be responsible for the low current drive efficiency at high density.

EX/P6-20, Delgado-Aparacio: Destabilization of Internal Kink by Suprathermal Electron Pressure Driven by Lower Hybrid Current Drive (LHCD)



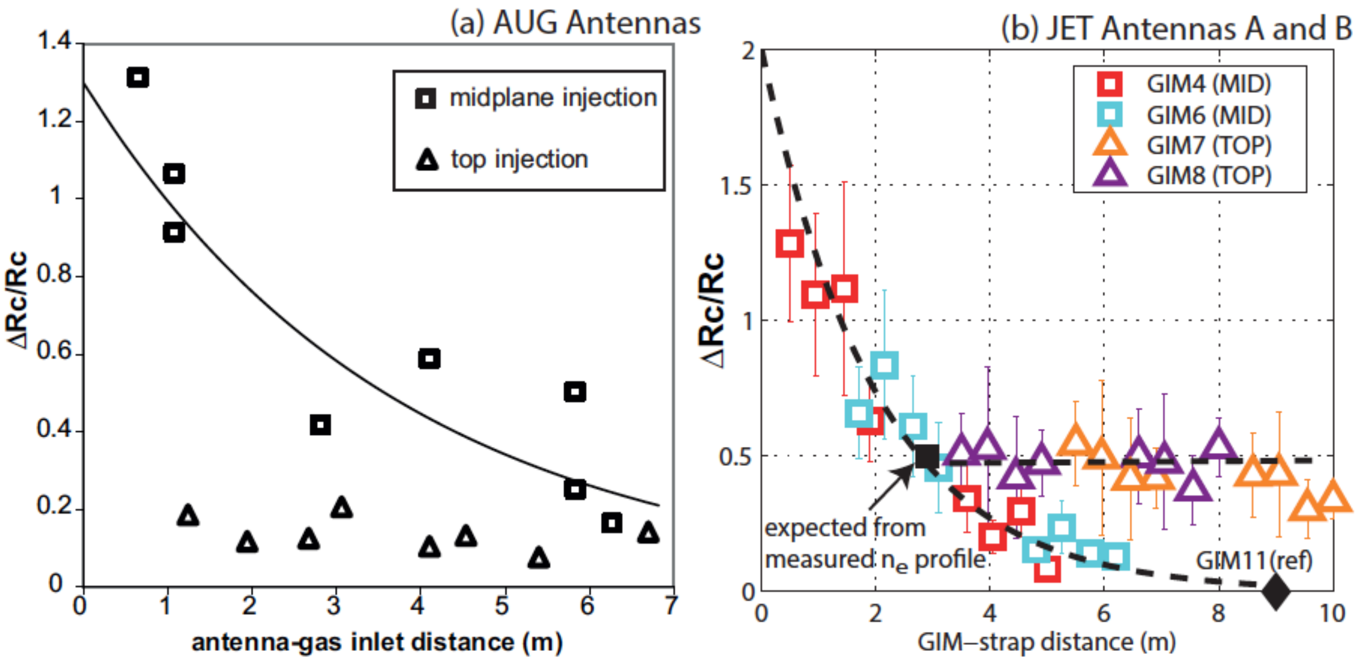
On-axis SXR signatures of a (1,1) internal kink-like (IK) mode in the a) presence or b) absence of Sawtooth precursors (SP) and crashes (SC).

- *A new type of periodic fishbone-like instability with a (1,1) internal kink-like structure*
- *distinct from the sawtooth instability*

Demonstrate a direct dynamic relation between LHCD generated fast electrons and a fishbone-like mode

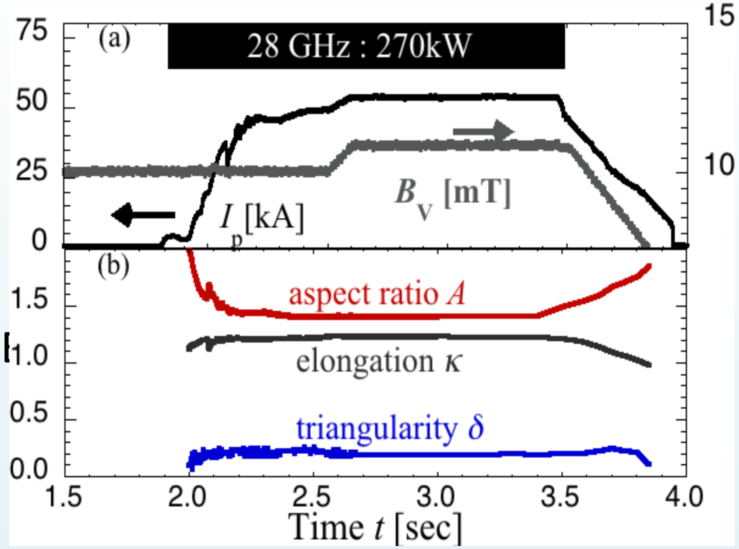
Maximization of ICRF Power by SOL Density Tailoring with Local Gas Injection. EX/P5-39

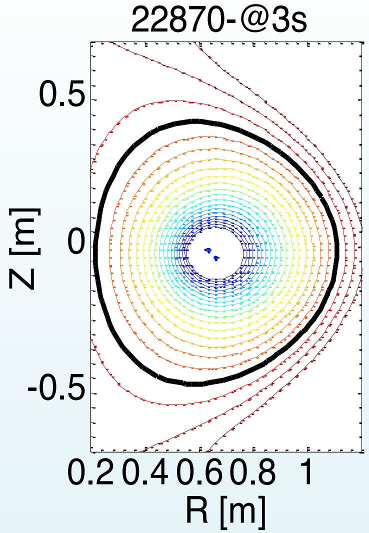
- Proximity between antenna and outer midplane (OMP) gas injection maximises the effect of local gas injection on ICRF antenna coupling resistance (JET, AUG, DIII-D).
- Top injection leads to a lower coupling improvement, toroidally uniform.
- To assess efficiency of local gas injection on ITER ICRF antenna coupling, need to take into account the field lines topology and use 3D SOL modelling codes.



Fully Non-inductive Current Drive Experiments using 28 GHz and 8.2 GHz Electron Cyclotron Waves in QUEST H. Idei, *et al.*

54 kA Plasma Sustainment in Low Aspect Ratio Config. by 28GHz Injection





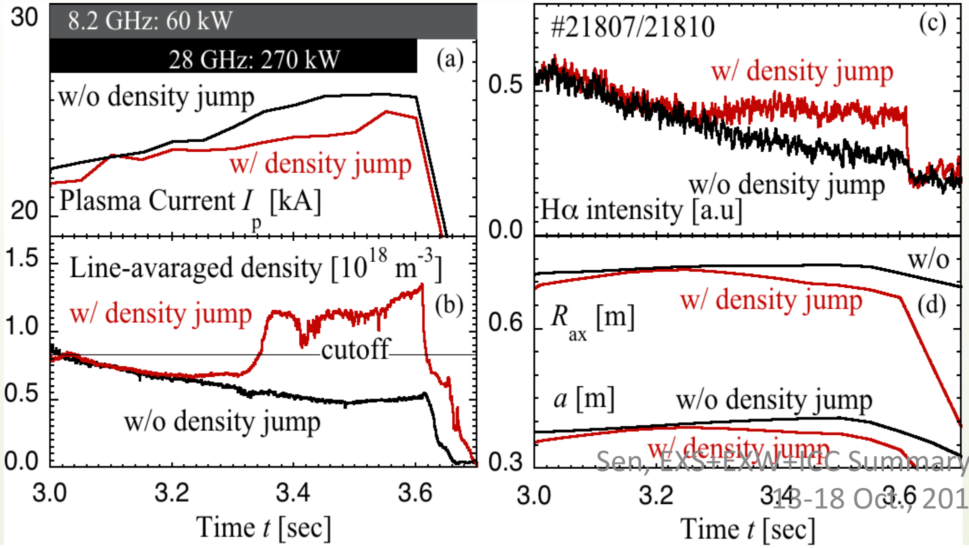
Plasma current of 54 KA was non-inductively sustained for 0.9 sec by only 28 GHz injection.

Plasma shaping was almost kept for 1.3 sec.

Higher current of 66 kA was non-inductively obtained by slow ramp-up of vertical field also.

Non-inductive high current plasma start-up by 2nd ECH/ECCD has been demonstrated.

Over Dense Plasma Sustainment by 28 /8.2 GHz Injections after Spont Density Jump



Spontaneous density jump across the cutoff density was observed in superposed 28 and 8.2 GHz injections.

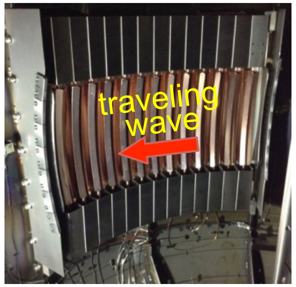
Hα intensity was kept, magnetic axis R_{ax} and minor radius a were slightly decreased in the density jump case.

Plasma current I_p was once decreased, but wa recovered after the plasma shaping became more stable.

Non-inductive Plasma Start-up Experiments on the TST-2 Spherical Tokamak Using Waves in the Lower-Hybrid Frequency Range

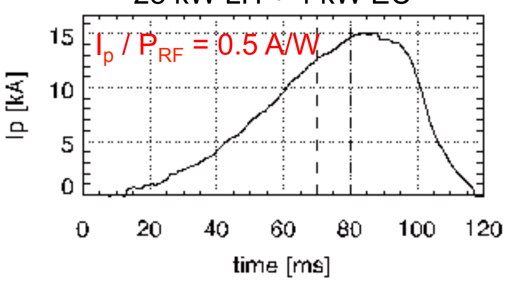
Y. Takase for the TST-2 Group

- **Economically competitive tokamak reactor may be realized at low A = R/a by eliminating the central solenoid**
  → Objective: Demonstrate I_p ramp-up by LHW on ST
- Three antennas were used:
  - Combline antenna
    - Nonlinear excitation of LHW
  - Grill (dielectric-loaded WG array) antenna
    - Optimum $n_{||}$: 3-4
  - CCC (capacitively-coupled combline) antenna
    - Highest η_{CD} achieved (sharp $n_{||}$ spectrum, good directivity)



CCC antenna

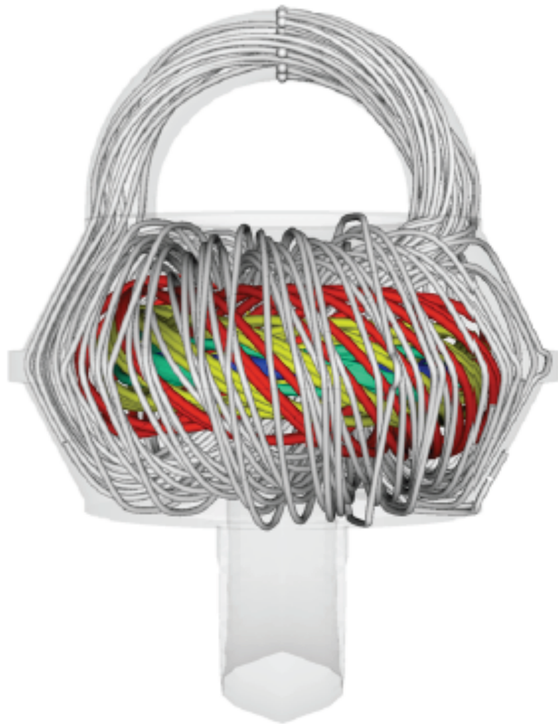
- Characteristics of LH driven plasma
  - Pressure dominated by fast electrons
    - 3-fluid equilibrium being developed
    - Importance of E_r and flows
  - Fast electrons are poorly confined at I_p ~ 10 kA
    - η_{CD} much smaller than in typical tokamak experiments
      - Due to poor orbit confinement of fast electrons
    - Expected to improve significantly at higher I_p and B_t (need power supply upgrade)



- Various diagnostics and analysis tools are being developed
  - Wave diagnostics, HX profile, E_r, flows, j profile, etc.

Spherical Configuration

- Significant progress on Current Drive in HIT-SI
- By increasing the frequency of the Imposed Dynamo Current Drive (IDCD) up to 68.5 kHz
- Toroidal currents of 90 kA and current gains of nearly 4, a spheromak record, have been achieved.
- dynamo current drive does not need plasma-generated fluctuations -a stable equilibrium with profile control can be sustained with imposed fluctuations
- Extrapolation to ITER - 80 kHz gives injector powers less than 10 MW and $\delta B/B \approx 10^{-4}$ indicating the effect on confinement may be acceptable.



ICC/P4-31, Victor

1 Gwe Reactor Dynomak

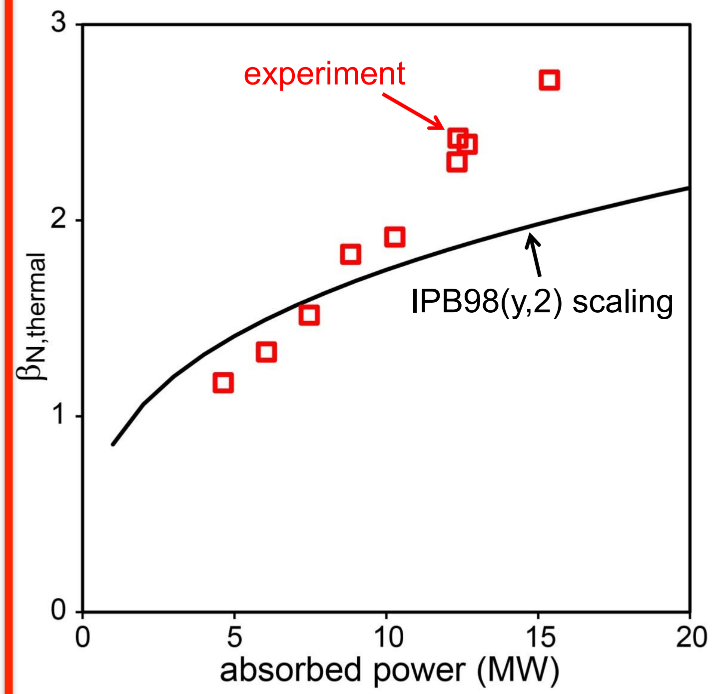
Jarboe

Experimental: Transport, Plasma-Material Interactions, Plasma Performance / Control (not comprehensive!)

- Core / Edge Transport
- Plasma – Wall Interactions
- Impurity Transport
- Operational Limits
- Plasma Performance and Integration

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

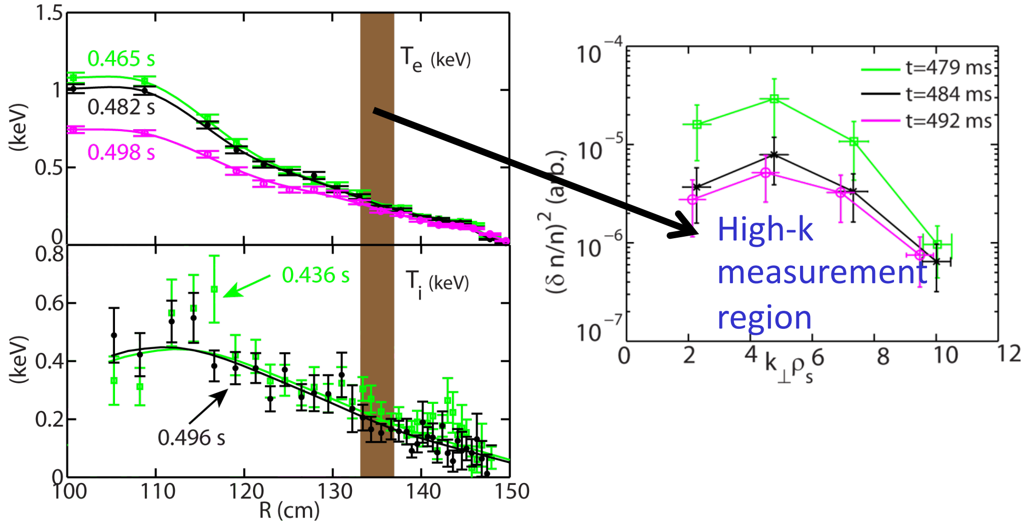
Laboratorio Nacional Fusión



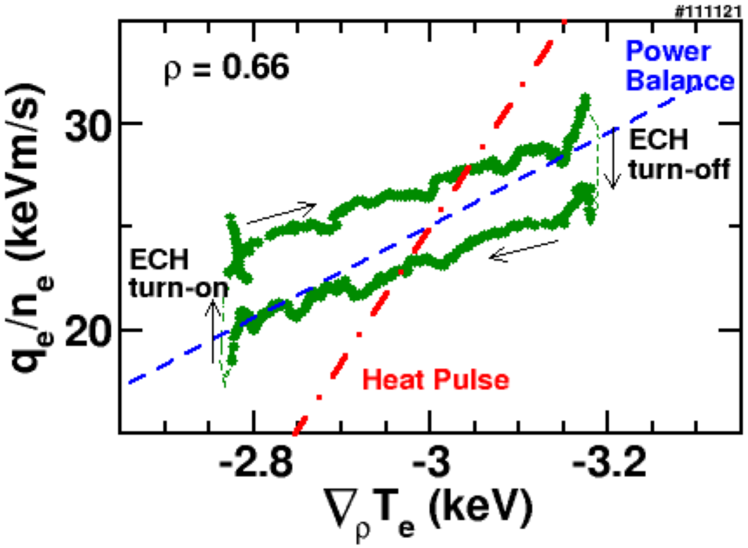
Weak confinement degradation with power in high β plasmas due to increase in **pedestal pressure** and **pressure peaking** (by collisionality and **suprathermal pressure** [TH324 Garcia]).

[EXC321 Challis JET]

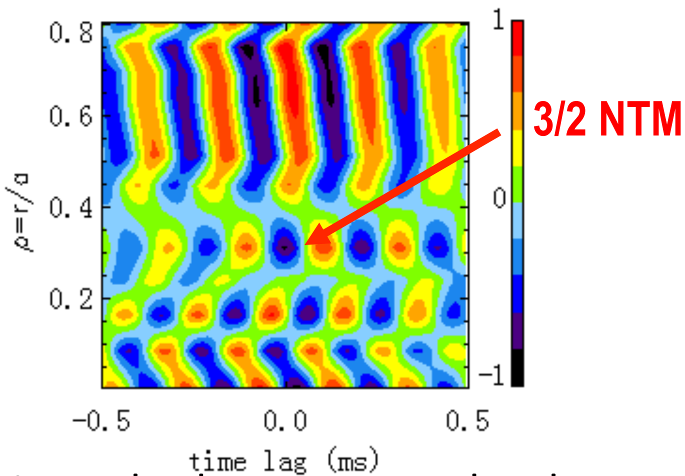
TRANSPORT: flux-gradient relation



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



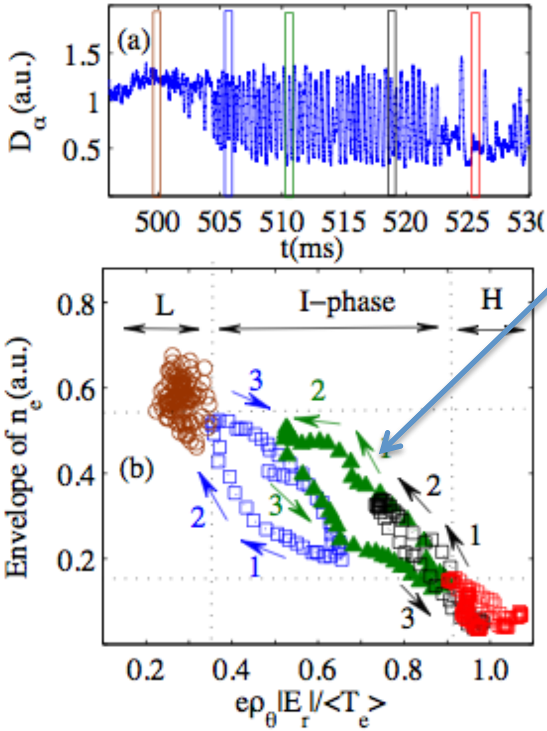
Dynamic method to study turbulence and turbulent transport, showing hysteresis in the flux-gradient relation [EXC237 Inagaki LHD]



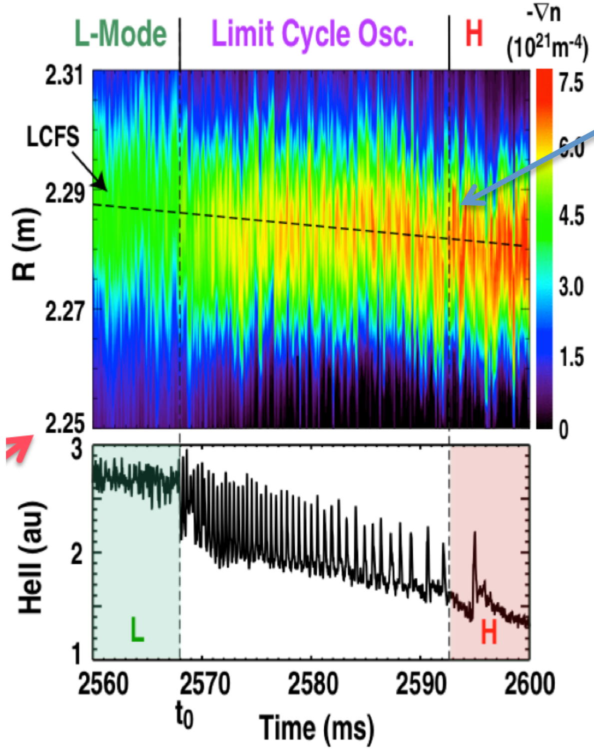
Interplay between non-local transport and MHD [Ji / HL-2A]

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

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

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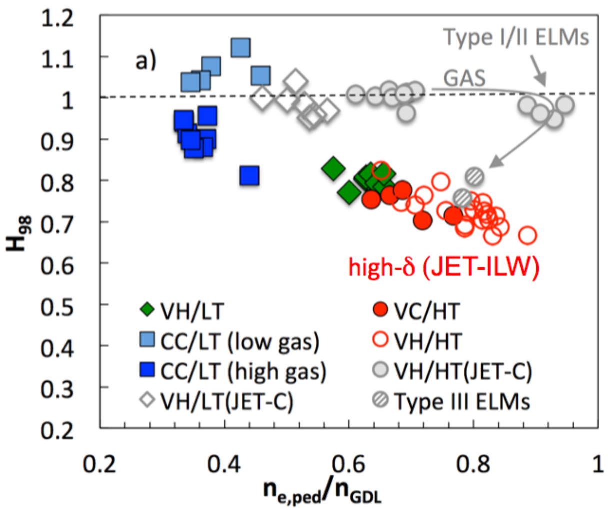
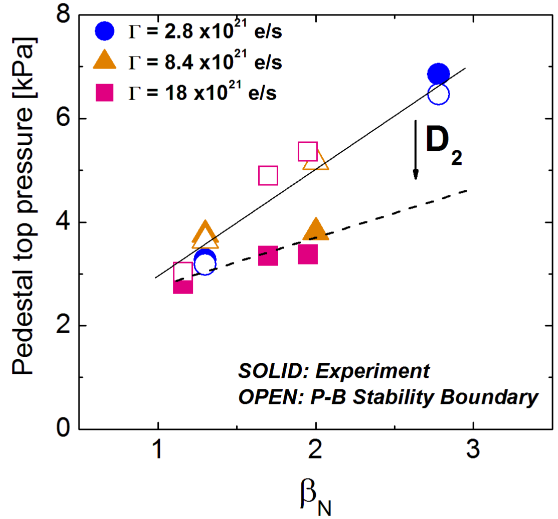
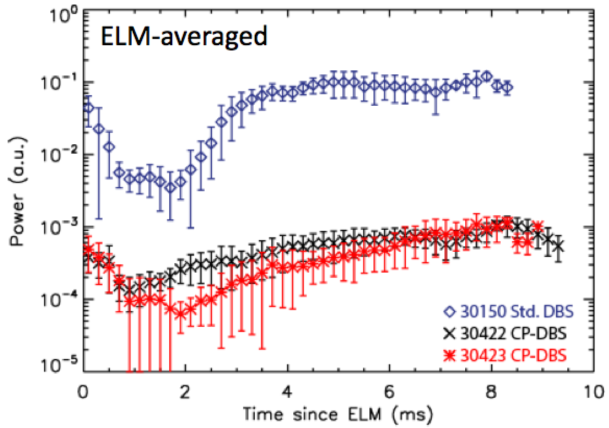
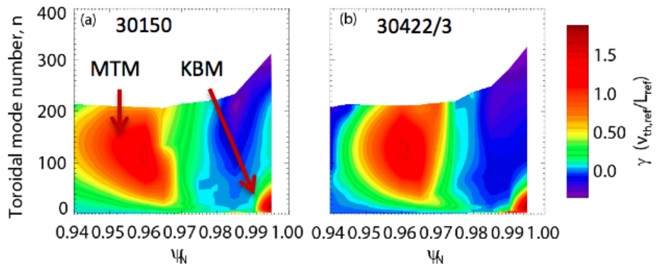




Positive influence of **triangularity** on confinement has not been recovered in ILW due to higher collisionality in consistency with **P-B** expectations [EXC195 de la Luna JET]



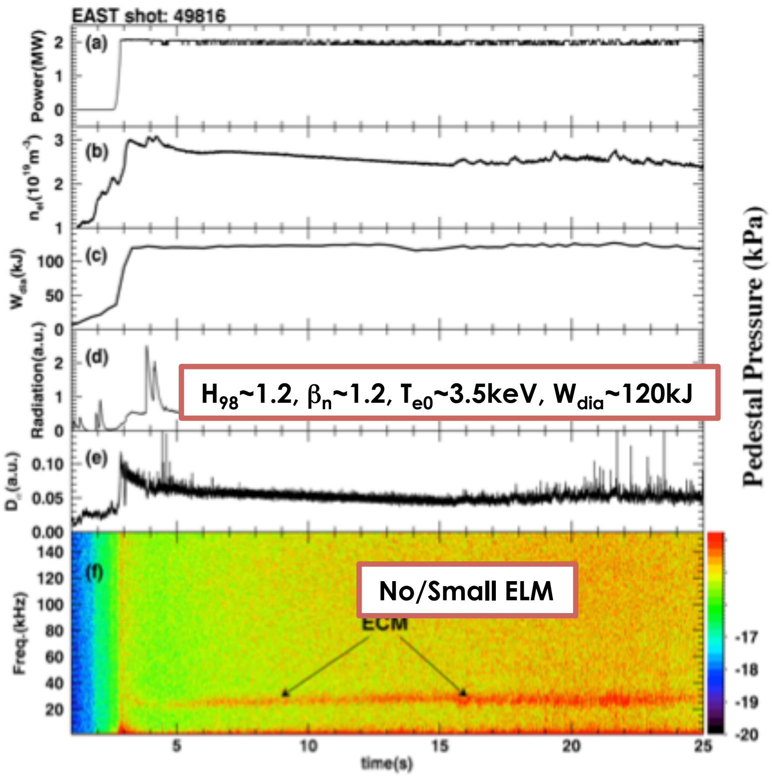


At **high neutral recycling**, pedestals are found in stable. Then, additional physics is required to explain the onset of the ELM instability. Beneficial effect of N_2 seeding [EXC429 Maggi JET]

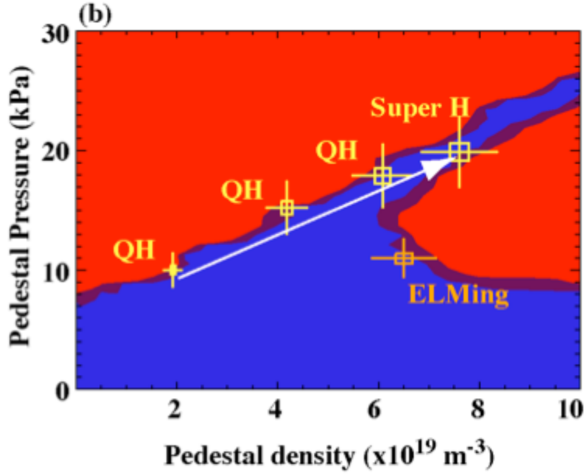
Searching for Microtearing modes at the pedestal in MAST using novel diagnostic techniques and comparison with GK [EXD361 Hillesheim]

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)

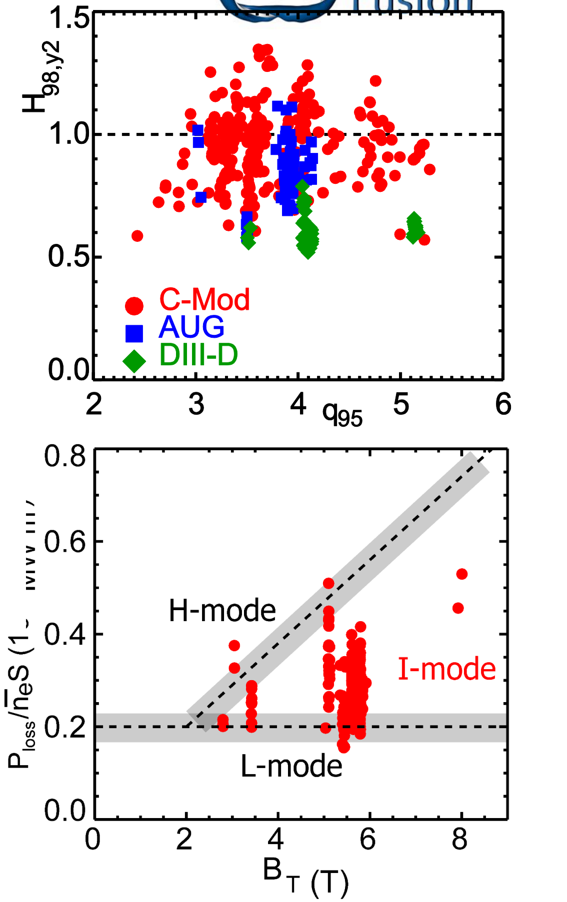
Pedestal transport and stability: alternative regimes



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



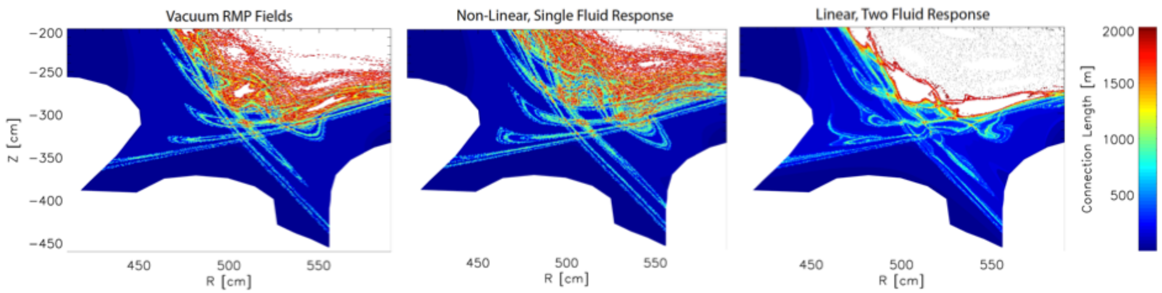
QH-mode maintained to high Greenwald fraction in strongly shaped plasma [PPC243 Solomon DIIID] / [TH/2-2 Snyder]



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

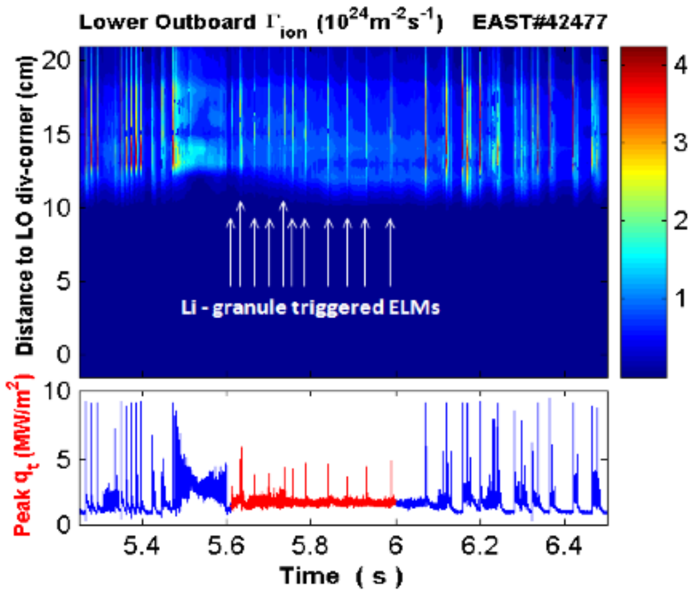
New regimes (as an alternative to type I EMLs) to a burning plasma scenarios look promising.

ELMs control



Device	Mode	Heat split	Part. split	MHD	ν_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

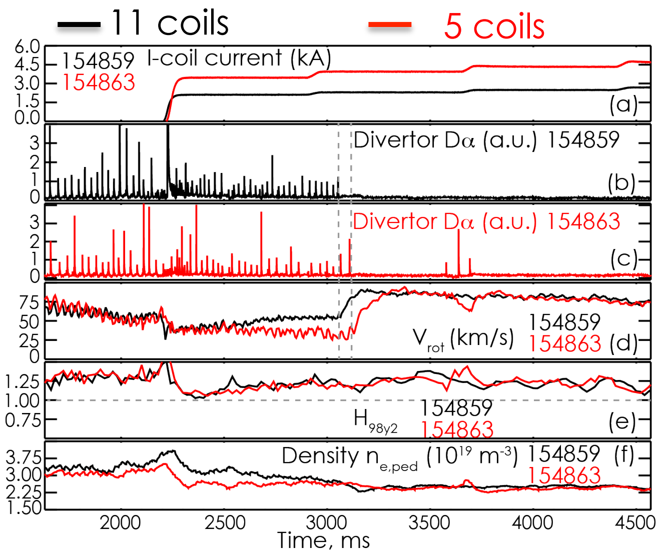
Strike line striation as signature for 3-D boundary formation [EXD630 Schmitz]



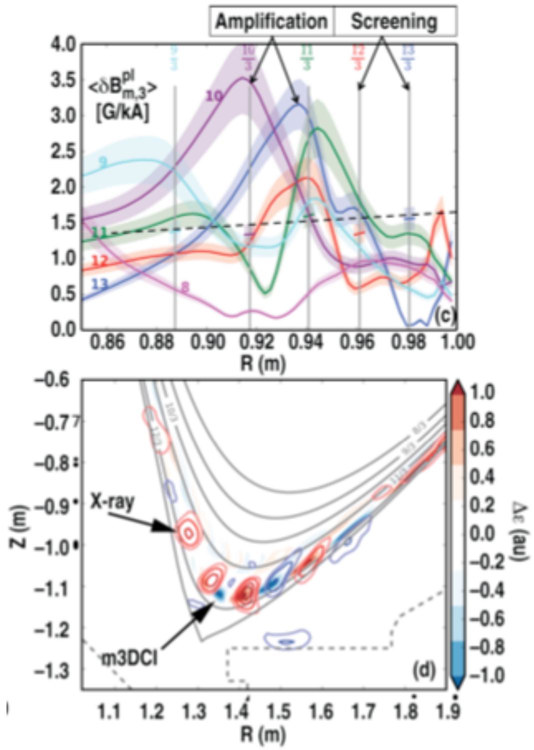
Comparison of Li-granule triggered ELMs with intrinsic type-I ELMs [EXD62 Wang EAST]

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

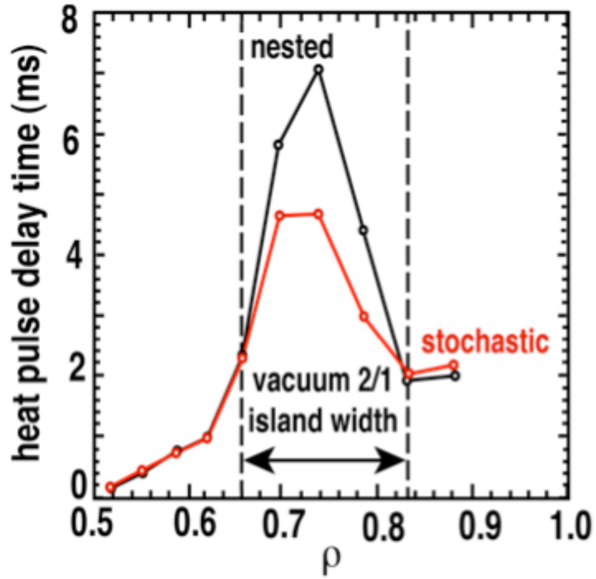
Power Exhaust: 3-D effects and ELMs control



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

Innovative exhaust magnetic configurations

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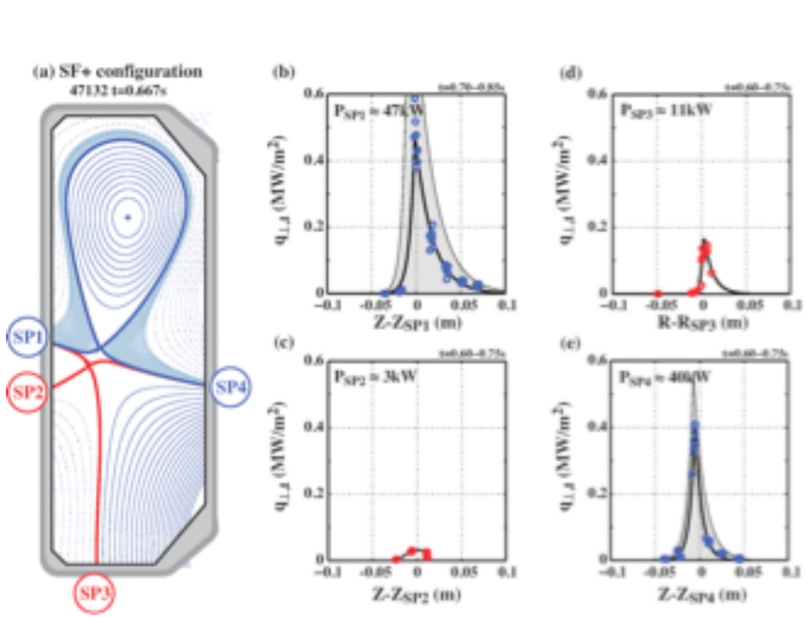
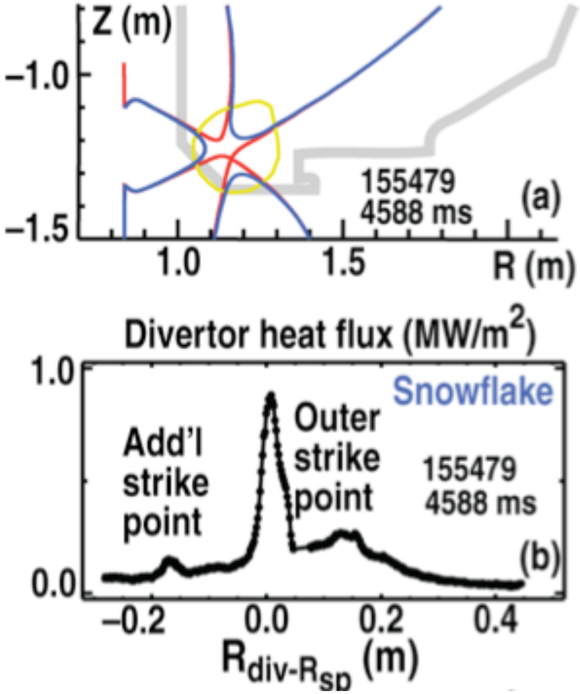
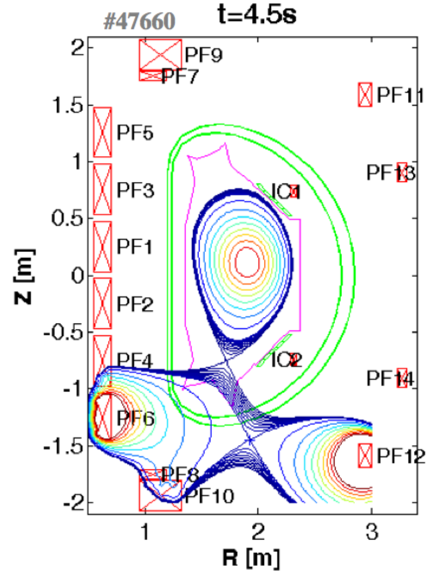


Power distributed to all 4 SPs but not reproduced yet by EMC3-Eirene. No evidence of scrape-off layer broadening. Transport in the private flux region [EXD124 Duval TCV]



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

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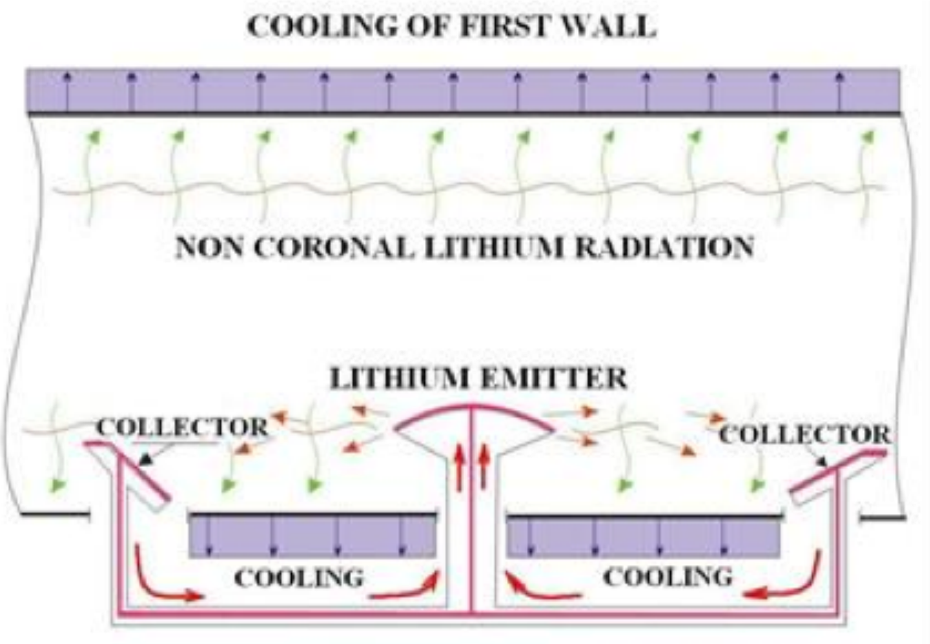


Lithium Capillary-pore-system CPS limiters with closed circulation loop [EXD159 Vertkov T11M]

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

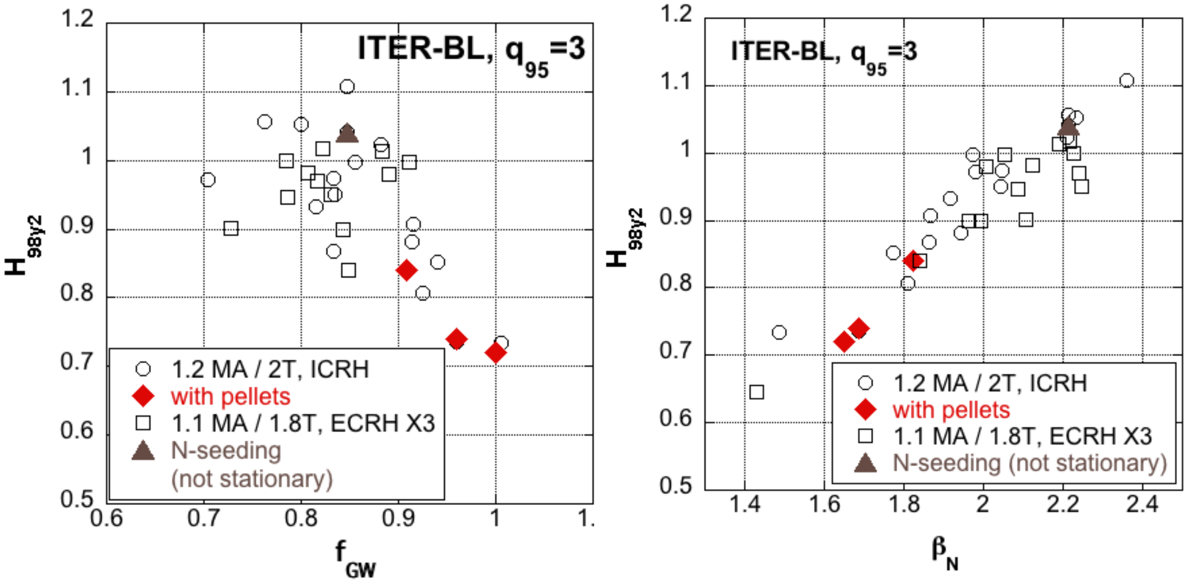
Lithium conditioning and confinement: NSTX / EAST [EXD81 Maingi] / [PD Jackson DIIID]

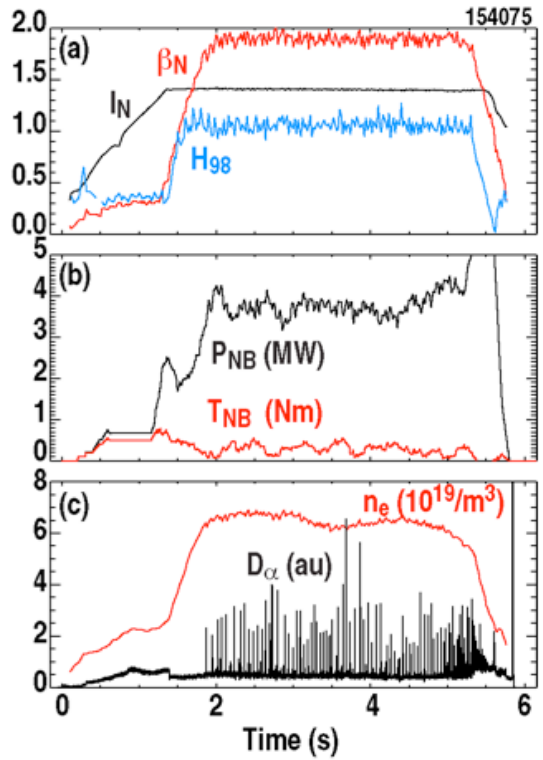
CPS is a promising solution with a need to find the best candidate material (Li/Sn/Ga) that fits all the necessary properties.

Alternative power exhaust solutions need to be vigorously pursued.

Plasma 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, β_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, β_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

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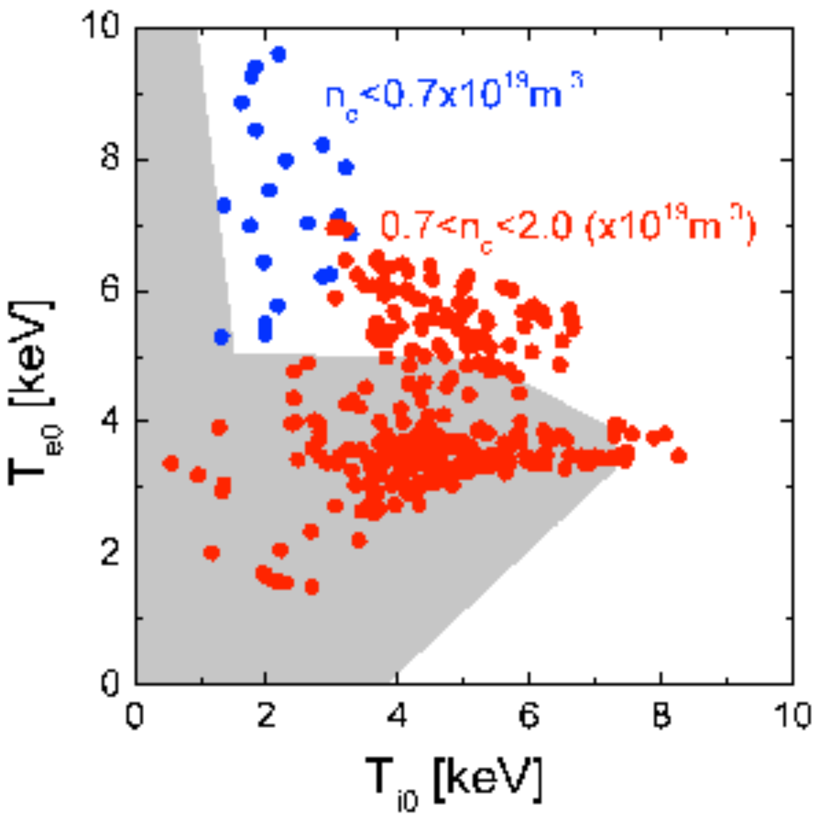
JET: Integrated performance with N-seeding and divertor compatibility

- **H_{98}~0.85**
- **β_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 τ_E)**
- triangularity δ~ 0.36

ITER
H_{98}~1.0
β_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.

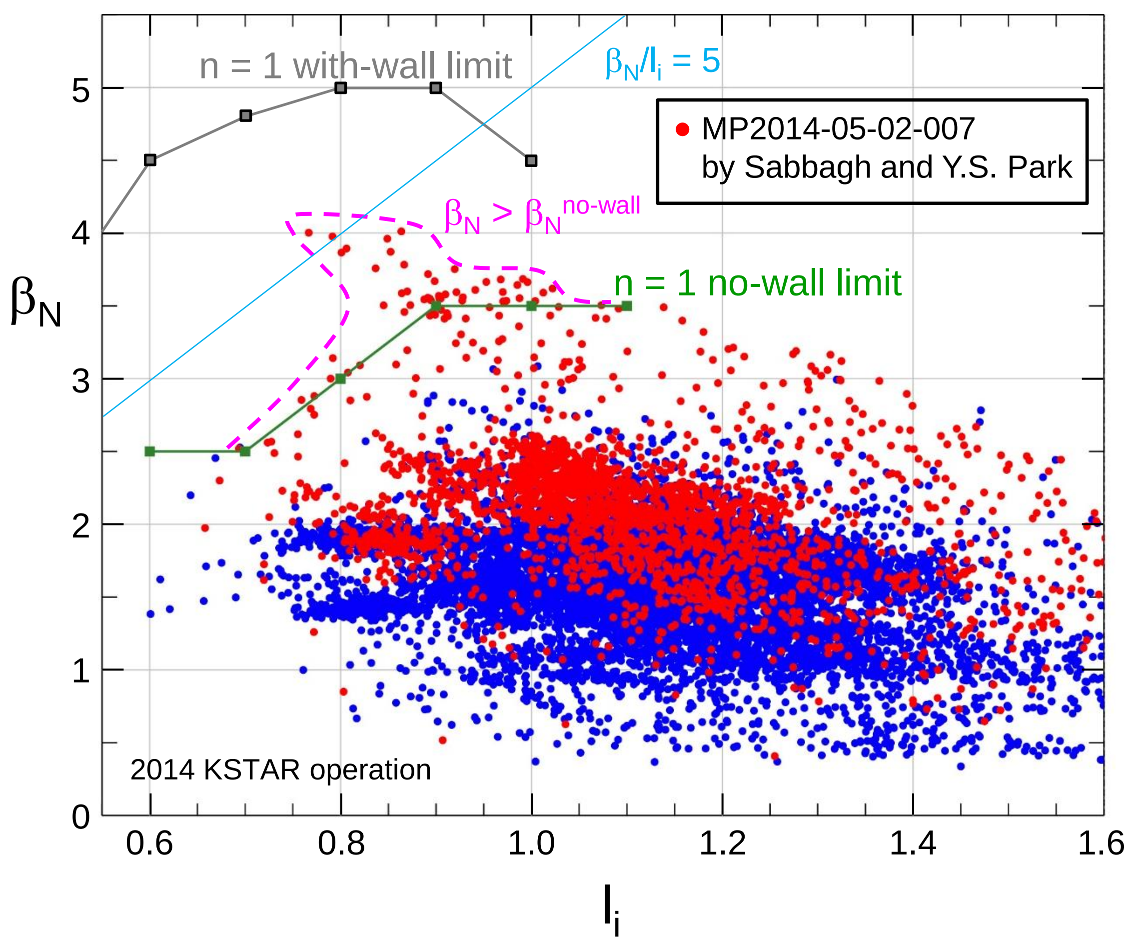


High temperature regime has been significantly expanded in helical plasmas [EXD348 Nagaoka]

Very recently, high beta plasmas transiently reached β_N = 4 in 2014 campaign

OV/3-4 S.W. Yoon

KSTAR operating space containing ~11,500 equilibria



- Values obtained using fully converged KSTAR EFIT reconstructions
- High values reached transiently at lowered B_t
  - B_T in range 0.9 - 1.5 T
  - β_N up to 4 with l_i ~ 0.8 (transient ~ 2 s pulses)
  - β_N/l_i = 5 is ~ 40% over the computed n = 1 ideal MHD no-wall limit
- Adding newly available 3rd neutral beam source may further increase the operating performance in the ongoing device campaign

Y.S Park, S.A. Sabbagh, W.H. Ko, et al., IAEA FEC 2014: EX/P8-05 (Fri. PM)

Theory Presentations (not comprehensive!)

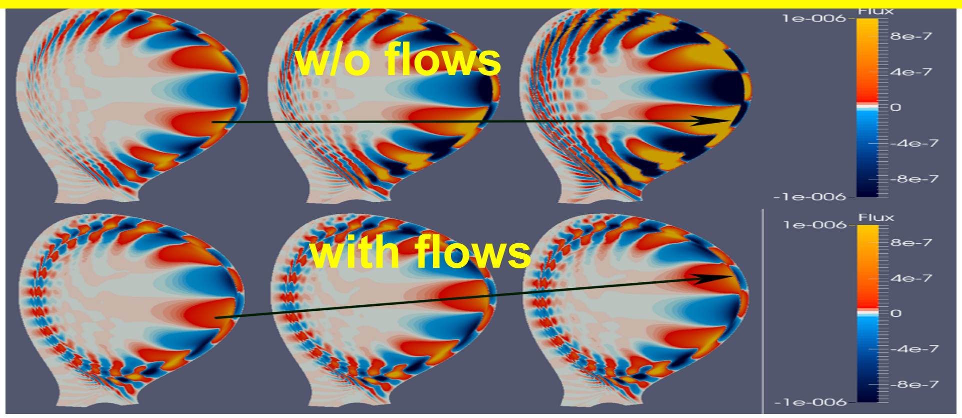
- ITER: Disruption physics and REs, ELMs, SOL transport
- Confinement
- Stability
- EPs
- Heating and Current Drive
- Integrated Modeling

Nonlinear MHD modelling of ELMs

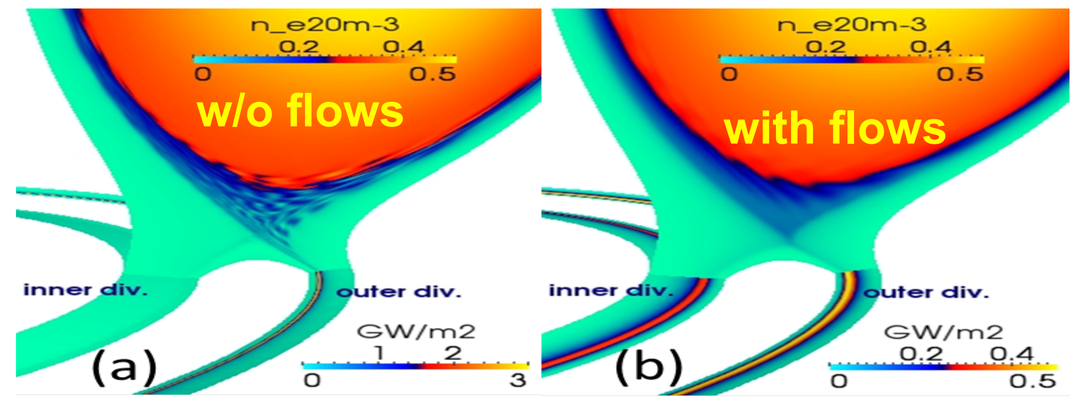
TH/6-1Rb Becoulet

- ✦ **Nonlinear modelling of ELM and their interaction with RMP in rotating plasmas (JOREK with flow)**

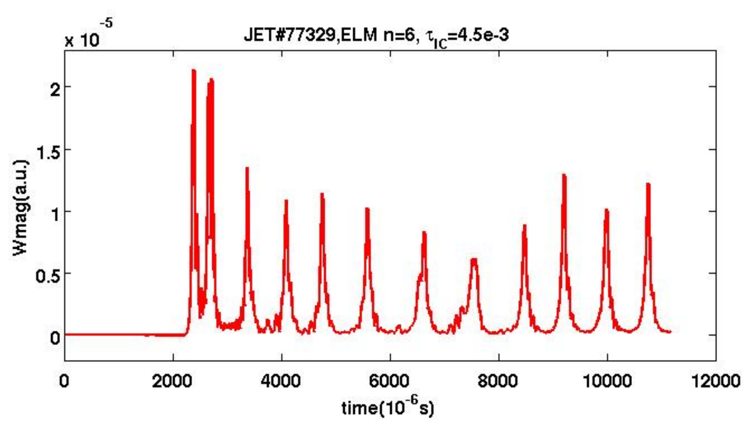
ELM precursor rotation in **ExB** (=el.dia) direction



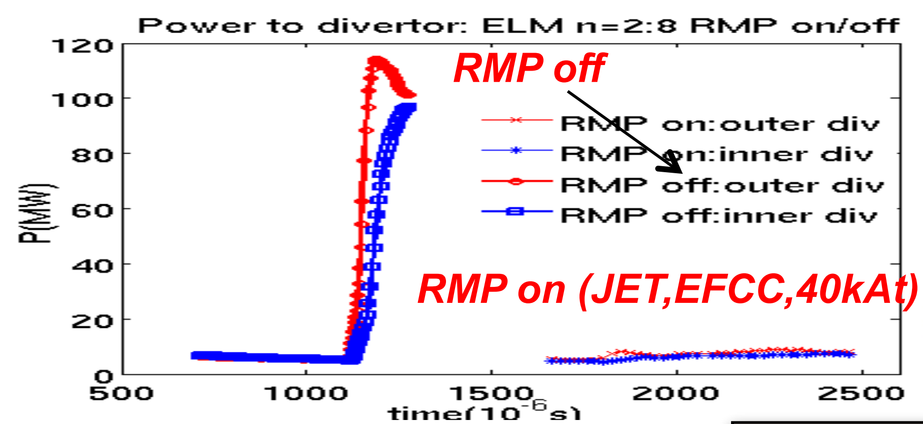
Divertor heat flux during an ELM : in/out symmetry

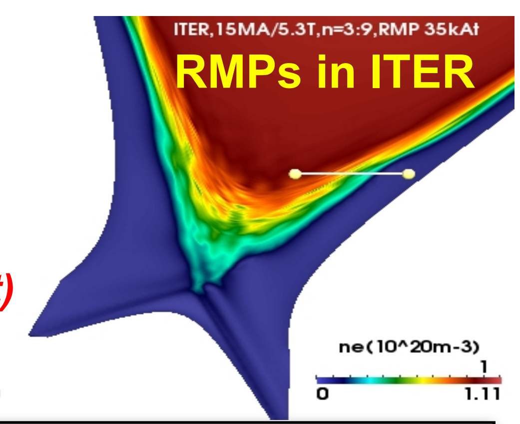


Multi-cycles ELMs with diamagnetic stabilization



Non-linear drive of edge MHD turbulence by RMPs => mitigated ELMs =>Divertor heat flux is reduced by ~10





- ✦ **Nonlinear MHD simulation for ITER**

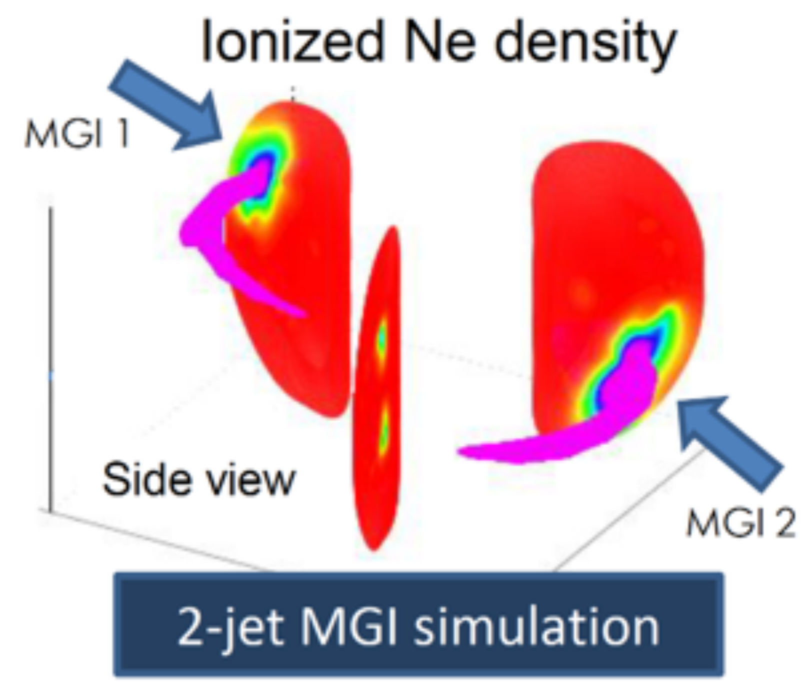
TH/6-1Ra Huijsmans

  - **ELM control**
    - pellet pacing, QH-mode
  - **SOL MHD stability**

Disruption Mitigation

TH/4-1 Izzo

- **2-Jet Massive Gas Injection on DIII-D**
  - **NIMROD predicts**
    - Relative location of 2 gas jets with respect to field line pitch affects toroidal radiation asymmetry
    - No unacceptably high peaking factors for DIII-D or ITER



TH/P3-31 Konovalov

- **Integrated Modelling of ITER Disruption Mitigation**
  - **DINA-ASTRA-ZIMPUR simulation confirms**
    - Mitigated disruption scenarios in ITER
    - The use of Ne is preferable to Ar providing longer current quench time

TH/P3-35 Leonov

  - **ASTRA-ZIMPUR simulations demonstrated that**
    - radiating impurity dynamics plays the dominant role in the pre thermal quench stage in MGI scenarios

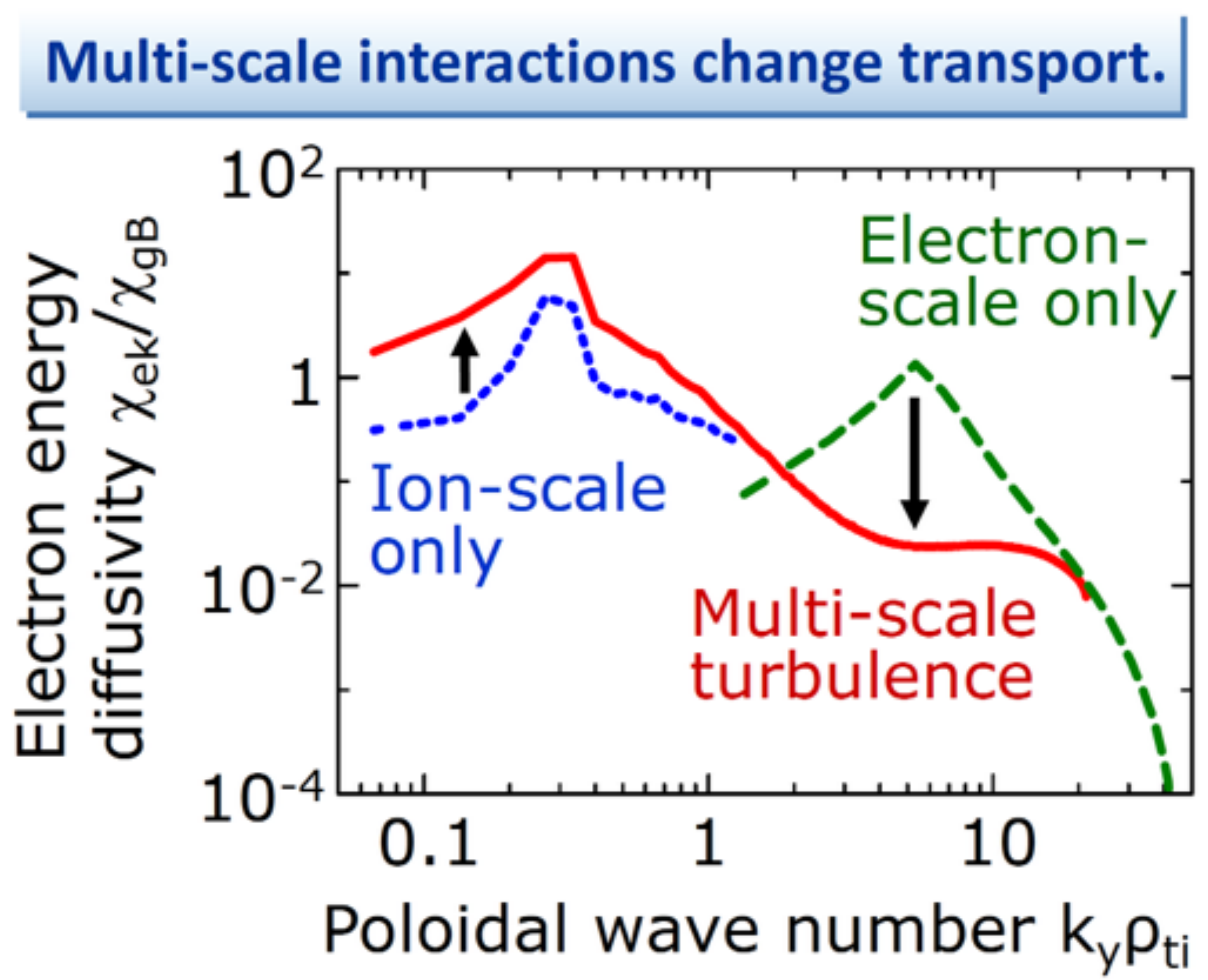
Runaway Electrons

- ✦ **Kinetic modelling of runaway electrons (RE) and their mitigation in ITER** TH/P3-38 Aleynikov
  - **Self-consistent modelling**
    - 2D Fokker-Planck equation
    - Toroidal electric field evolution in 1D transport code
    - Scattering on high-Z nuclei, collisional friction force, synchrotron radiation, and knock-on source term
    - Ar gas densities required for successful RE mitigations are within the limitation of envisioned ITER DMS
- ✦ **Formation and termination of RE in disruptions and implications for ITER** TH/P3-43 Martín
  - **0D modelling of RE with Ar and Ne injection**
- ✦ **Monte-Carlo simulation on energy-dependence of RE loss induced by low-n MHD instabilities** TH/P5-13 Matsuyama
    - Near the stochastic threshold, drift resonance characterises the energy dependence of the RE orbit

Turbulent Transport (Tokamak)

TH/1-1 Maeyama

- ✦ **Multi-scale ITG/TEM/ETG Turbulence**
- ✦ **Simulations with Real Mass Ratio and β value**
  - **Shearing of ITG/TEMs suppresses ETG/Streamers**
  - **ETG/Streamers enhance ion-scale transport via ZF damping**

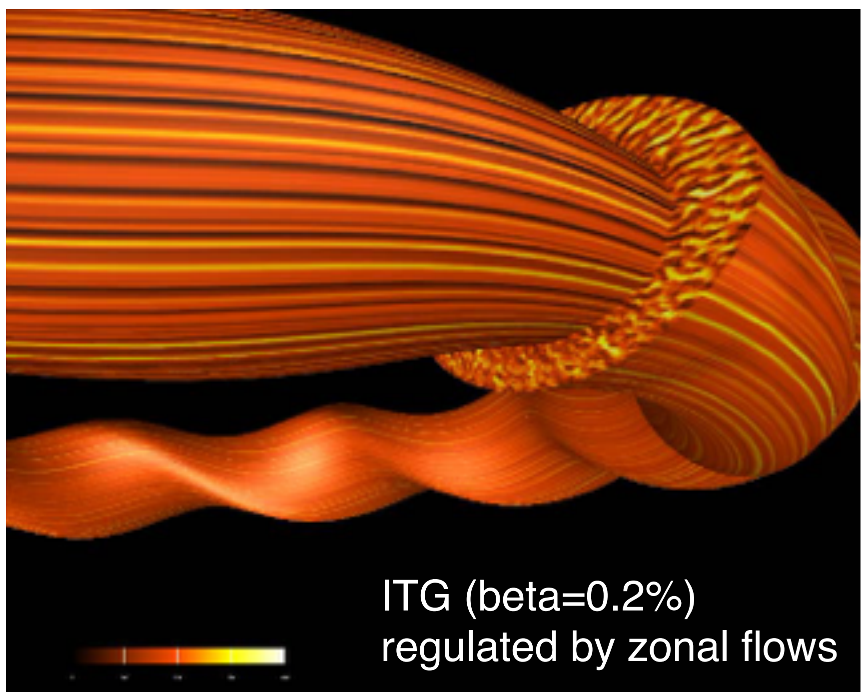


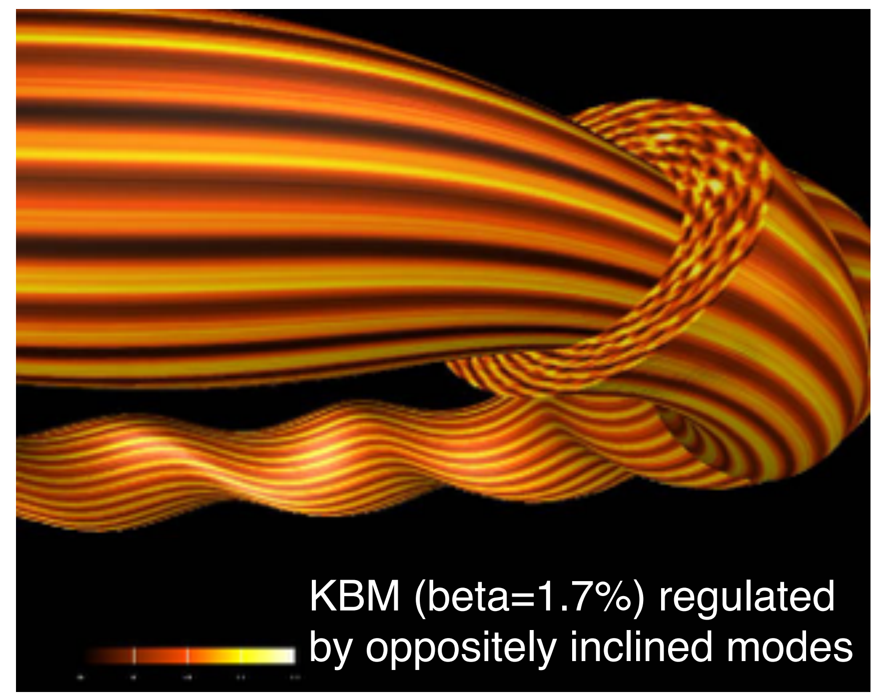
- **GKV:**

Turbulent Transport (Helical)

TH/P6-40 Ishizawa

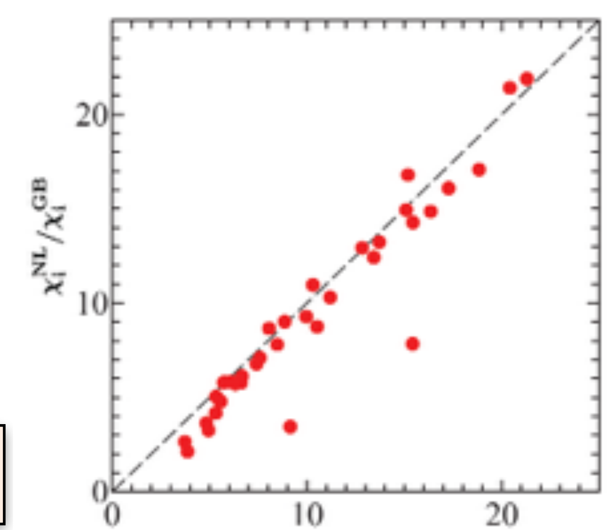
- **Electromagnetic Gyrokinetic Analysis of Turbulent Transport in Finite-Beta LHD Plasmas by GKV**
  - Coupling between oppositely inclined convection cells leads to the saturation of KBM
  - Transport due to KBM turbulence is much less than ITG





- **Derivation of Reduced transport model**

$$\frac{\chi_i^{\mathrm{model}}}{\chi_i^{\mathrm{GB}}} = \frac{A_1 \left(\sum_k \tilde{\gamma}_k / \tilde{k}_y^2\right)^{\alpha}}{A_2 + \tilde{\tau}_{\mathrm{ZF}} / \left(\sum_k \tilde{\gamma}_k / \tilde{k}_y^2\right)^{1/2}}$$

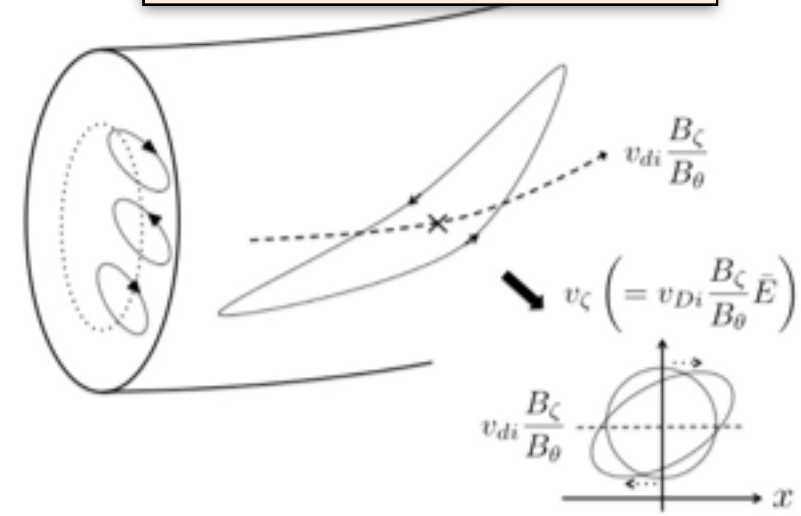


TH/P7-9 Nunami

Turbulence Physics

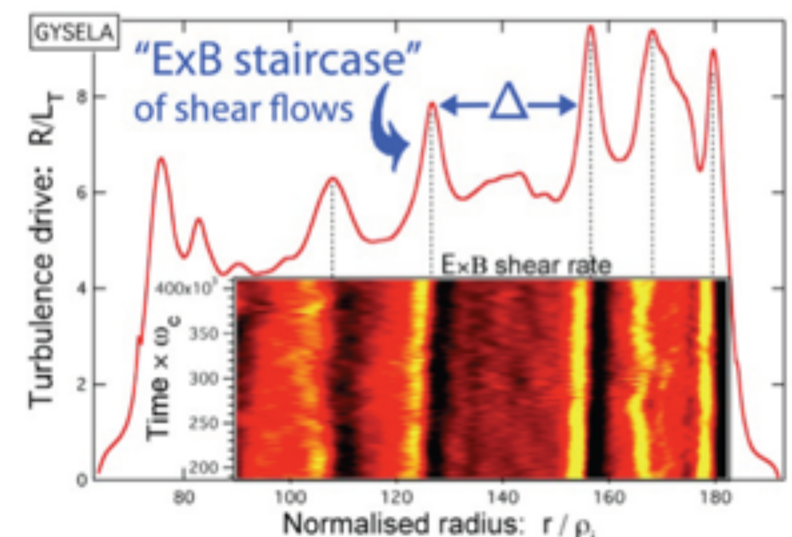
- **Turbulence driven by trapped ions**
  - **clusters of resonant trapped ions (granulations)**
  - **poloidal flows converted into toroidal flows**

TH/P2-14 Kosuga



- **New theory of mixing scale selection**
  - **What determines Avalanche Scale?**
  - **Formation of staircase**
    - co-existence of heat avalanches and ExB sheared flows
    - finite time delay allows heat flux waves; jamming happens

TH/P7-7 Diamond



- **Turbulent elasticity and the physics of time delay**

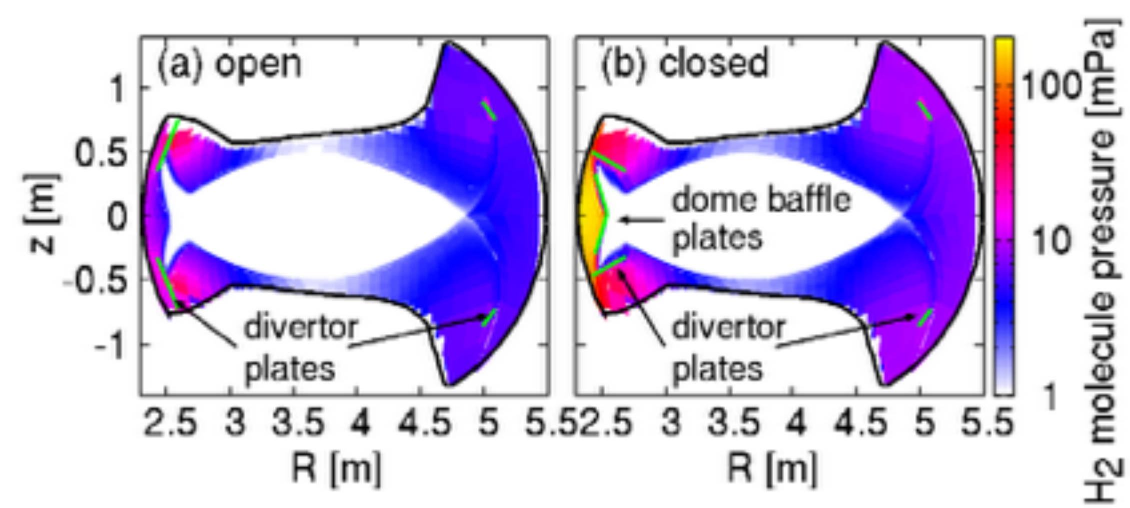
TH/P4-16 Guo

- **Effects of magnetic shear and toroidal rotation shear on turbulence spreading**

TH/P6-10 Yi

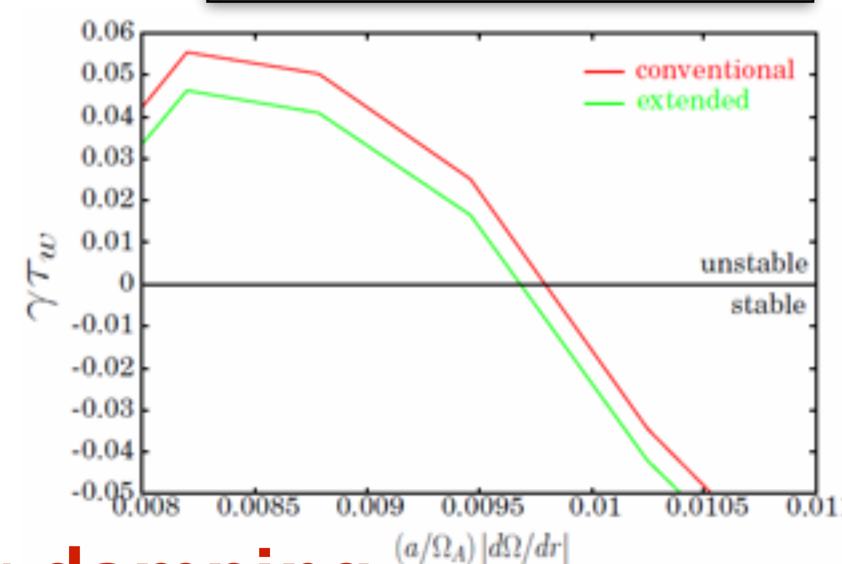
Advanced Divertor

- ✦ **Divertor design and analysis of HL-2M** TH/3-1Rb Zheng
  - **Standard, snowflake, tripod**
  - **Tripod: long divertor leg and large low-B_p area**
- ✦ **X-divertors in ITER, current machines and DEMO** TH/P3-34 Kotschenreuther
  - **X-divertor magnetic configuration can be created on ITER without hardware changes**
- ✦ **Modeling divertor concepts for spherical tokamaks: NSTX-U and ST-FNSF** TH/P6-50 Mwier
  - **snowflake divertor: effective heat flux mitigation**
  - **divertor with vertical target and super-snowflake for ST-FNSF**
- ✦ **Analysis of open and closed LHD divertor** TH/P6-39 Kawamura
  - **Neutral gas compression under the dome**



MHD Modes and Flow

- ✦ **MHD instability in rotating tokamak plasmas** — TH/P2-15 Aiba
  - – excited by interplay between RWM and stable MHD modes
- ✦ **Extension of kinetic-MHD model to include toroidal rotation shear effects** — TH/P6-12 Shiraishi
  - – RWM growth rate vs rotation shear at q=2
  - – Kinetic-MHD model enhances the stabilizing effect of flow shear



- ✦ **RMP filed do not produce significant flow damping** — TH/P3-44 Liu
  - – Strong screening of resonant harmonics due to resistive plasma response
- ✦ **Finite toroidal flow generated by resistive wall tearing modes** — TH/P5-9 Har
  - – Initially unstable tearing mode can be stabilized by the self-generated toroidal flow
- ✦ **Tokamak toroidal rotation caused by disruptions and ELMs** — TH/P2-16 Strauss
  - – AVDE disruptions and ELMS can drive v_φ

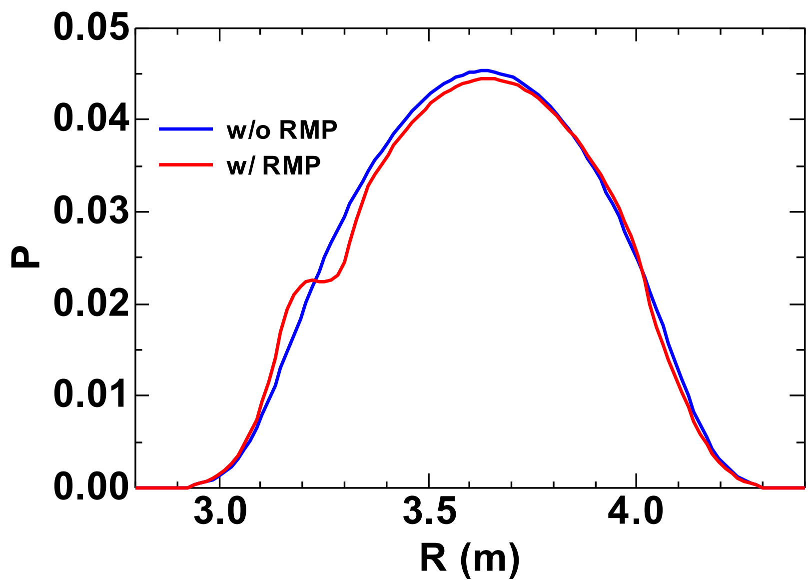
MHD Modes in Helical Plasmas

✦ 3D MHD analysis of heliotron plasma with RMP

TH/6-2 Ichiguchi

– Pressure driven modes in heliotron equilibria with RMP

► An m=1/n=1 magnetic island is generated.
Equilibrium pressure profile is locally flat at the O-point.

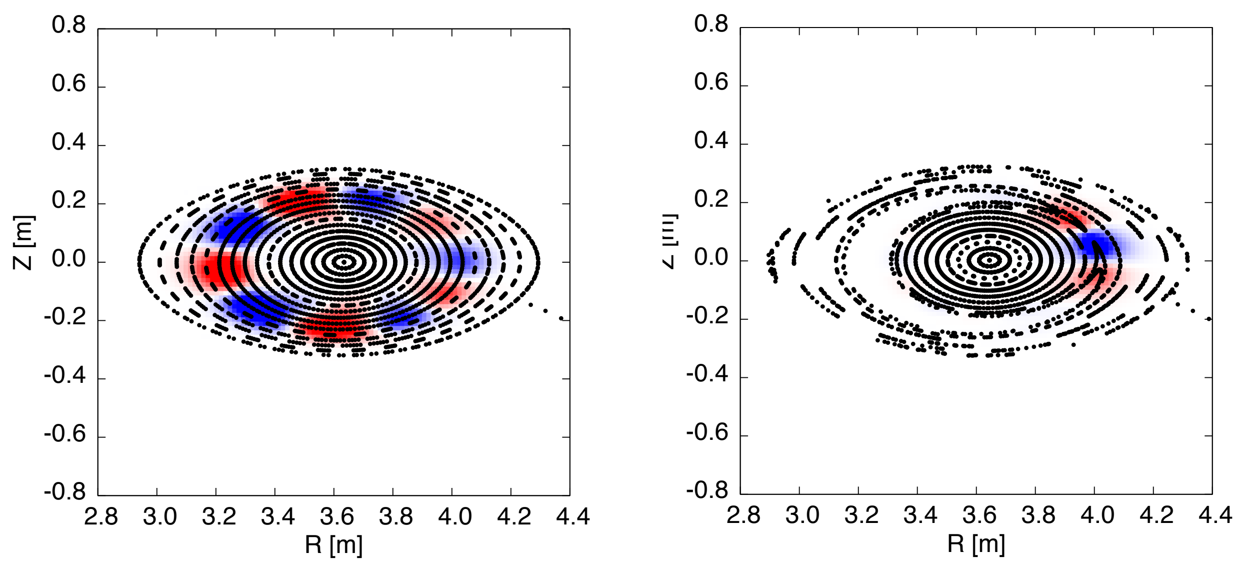


Equilibrium pressure profile on Z=0 plane.

► Different mode structures are obtained.

Without RMP :
A typical interchange mode

With RMP :
A ballooning type mode localized at the X-point



Puncture plots of field lines and mode pattern of perturbed plasma pressure in the linear phase (red and blue patterns).

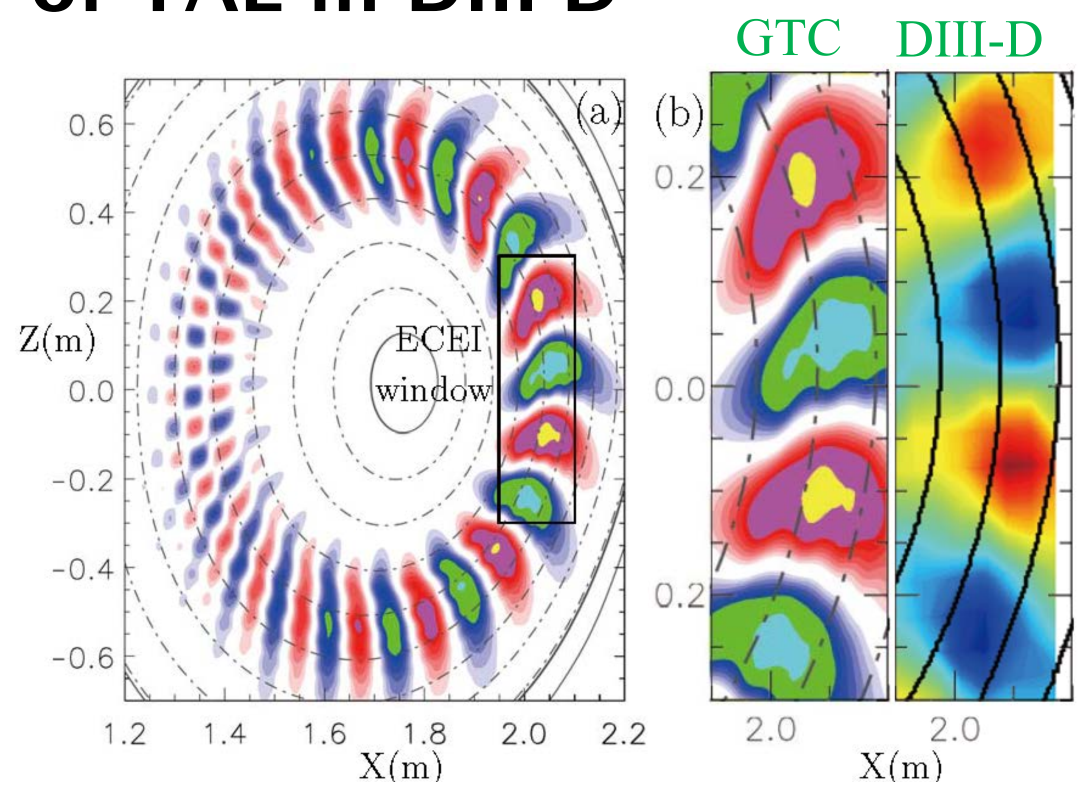
✦ Two-fluid and gyro-viscous effects on the pressure-driven modes in heliotron plasma

TH/P5-17 Miura

– Two-fluid effect can deteriorate pressure profile
– Gyro-viscosity effect does not explain mild saturation

AE, Zonal Flow, Transport

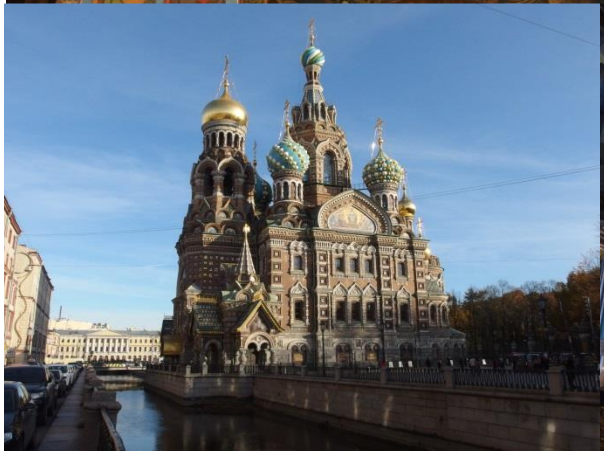
- **Saturation of TAE caused by zonal flow generation** TH/7-2 Lin
  - GTC simulation of TAE in DIII-D

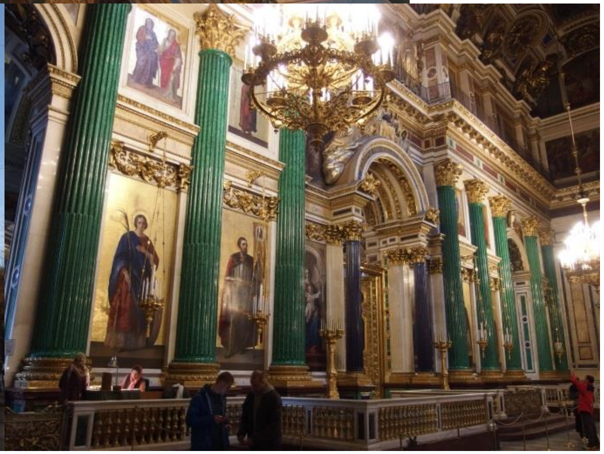


- **Predictive models for fast ion relaxation in burning plasmas**
  - Critical gradient model based on linear stability theory of AE excited by AE TH/P1-2 Gorelenkov
- **Chirping AEs drive convective and diffusive transport**
  - Electrostatic self-trapping TH/P7-15 Lesur
- **Energetic particle driven geodesic acoustic mode (EGAM)**
  - New kind of EGAM observed in LHD TH/P1-12 Wang

How was St. Petersburg?

- Wonderful venue for IAEA
  - Conference hotel well-run, with good accommodations
  - No issues getting everyday needs (e.g. easy access to ATMs, local supermarkets)
  - Easy metro or shuttle ride to central area of city
- Excellent cultural aspects
  - Mon: Academy Fine Arts
    Thu: Mariinsky Theater
  - Historical sights (Winter Palace, Peter & Paul Fortress)
  - Museums (Hermitage, Russian, Faberge)
  - Beautiful landmarks (Cathedral on Spilled Blood, St. Issac's)





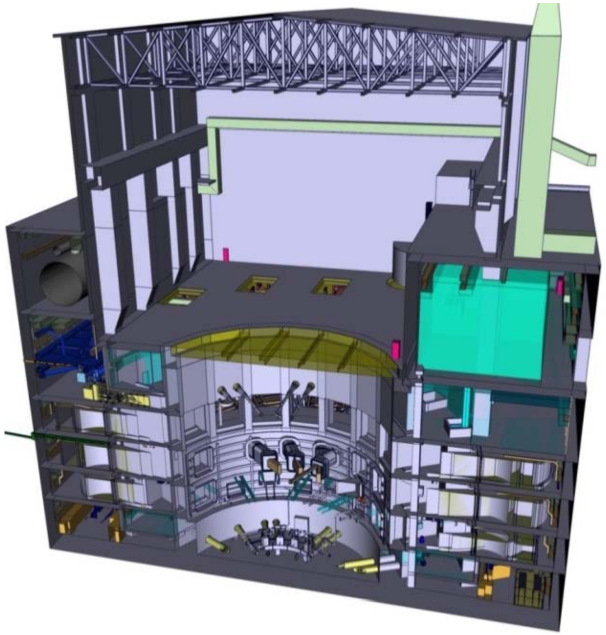
Motojima's talk and ITER-relevant discussion

- Motojima's talk
  - ITER project must be successful, to this end any necessary action should be taken
  - Tokamak complex building foundation is completed
    - "ITER project is past point of no return" (not accepted by many)
  - Building RFE-1C and vacuum vessel are now the critical elements
    - assembly hall building next to test cell has started construction
  - 47 diagnostic systems (37 signed with domestic agencies)
  - Inner wall first wall panel reshaped to handle heat loads
    - reduced peak heat loads by a factor of 2
  - Plasma fuelling programming is important for ITER reaching Q = 10
  - ITER NBI test facility in Padua - new building shown
  - PF coil system - from Efremov Institute (Motojima thanks them for this)
    - Did not see a slide on the in-vessel control coil

- Rumors late in the week
  - (frightening) That ITER might be delayed until later 2020s
    - Perhaps due to nuclear regulatory issues

Tokamak Complex Buildings

- Dimensions 80*110*60^{ht} m (-16m underground, 350,000tons)
- 493 Seismic Isolation Pit completed on 18 April 2012
- Main B2 slab completed (~14, 000m^3 concrete) on 27 August 2014
- Start erection of walls in October 2014



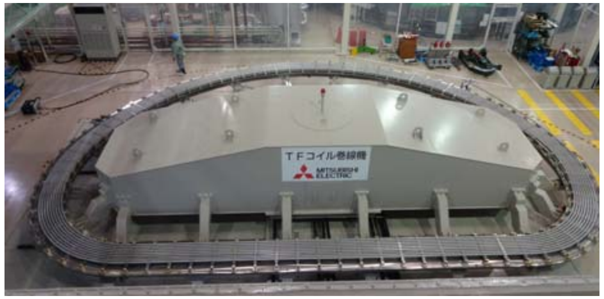
Tokamak Complex

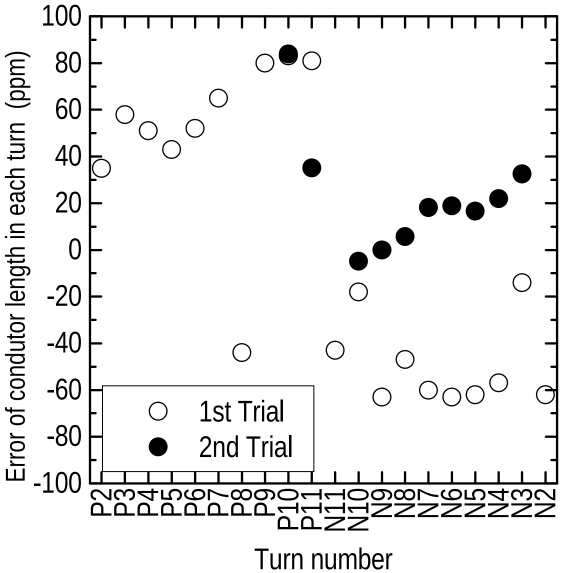
B2 Slab

Full-scale trial results to qualify optimized manufacturing plan for ITER Toroidal Field coil winding pack in Japan

FIP-1-3
N. Koizumi et al.

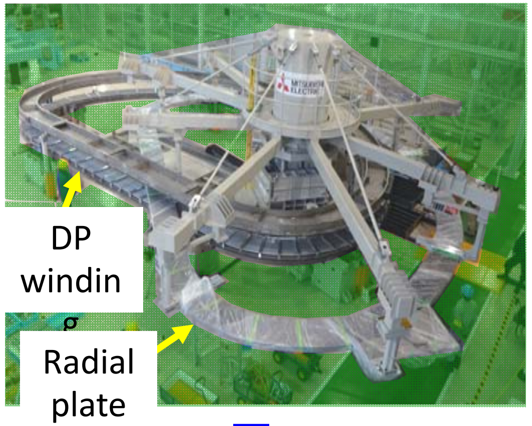
Dummy double-pancake (DP) winding was completed.

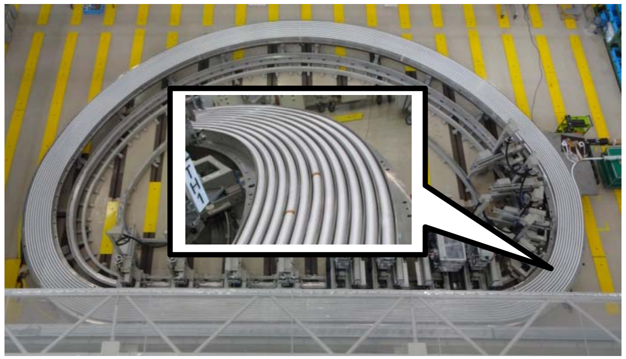




Target tolerance of ±0.01% in conductor length was achieved.

Transfer of RP between dummy DP was completed.





Conductor could be transferred into RP groove after turn insulation.

Heat treatment trial of dummy windings was carried out.

Elongation of heat-treated conductor was evaluated to be about 0.06% with scatter smaller than 0.01%. This enables highly accurate prediction of conductor elongation by heat treatment to determine the winding dimension.

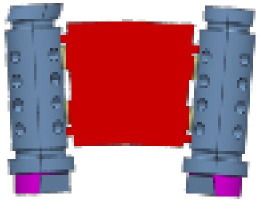
- These successful results allow JADA to start the first TF coil fabrication. 4 DP winding was completed and the 1st DP was successfully heat-treated.

Manufacturing Design and Progress of the First Sector for ITER Vacuum Vessel (FIP/1-6Rb)

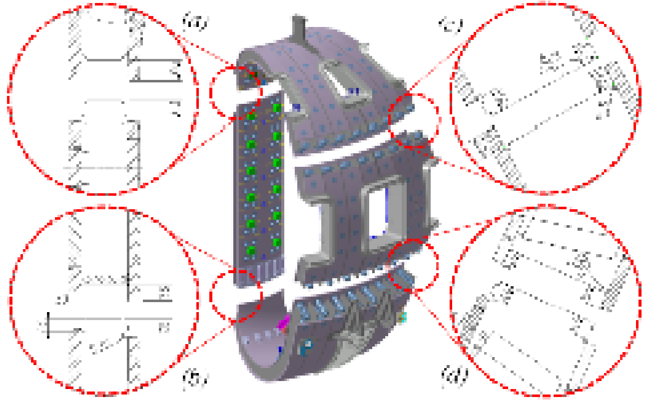
H.-J. Ahn et al.

☐ Manufacturing Design of the First Sector

- The manufacturing design of the first sector has been developed in accordance with the RCC-MR code and the regulatory requirements by HHI as a supplier.
- The design of Korean VV sectors introduces special concepts like a self-sustaining welded IWS rib and cup-and-cone type segment joints to minimize welding distortion.



Self-Sustaining IWS Rib



Cup-and-Cone Type Segment Joints

☐ Manufacturing Progress in Korea

- Several real scale mock-ups had been constructed to verify and develop the manufacturing design and procedures.
- The first sector has been manufacturing slowly at the front of ITER project as a nuclear component since 2012.
- All poloidal segments for the first sector are being fabricated simultaneously. Fabrication speed could be getting better after solving current issues.

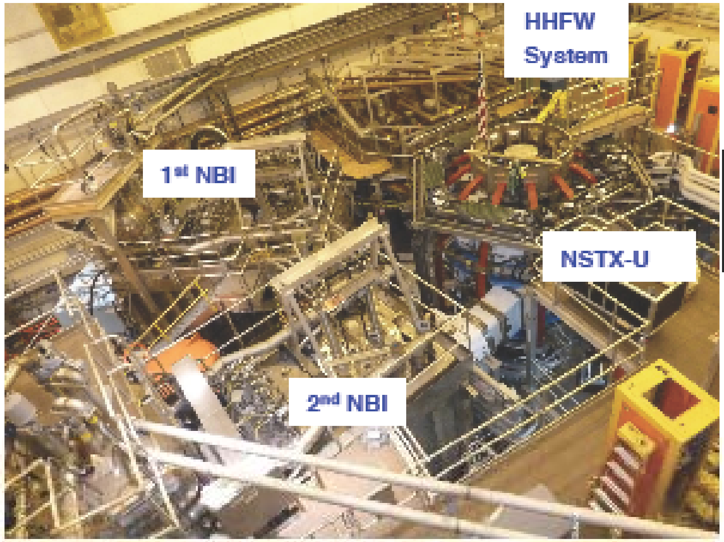
Progress of Upper Segment for the First Sector

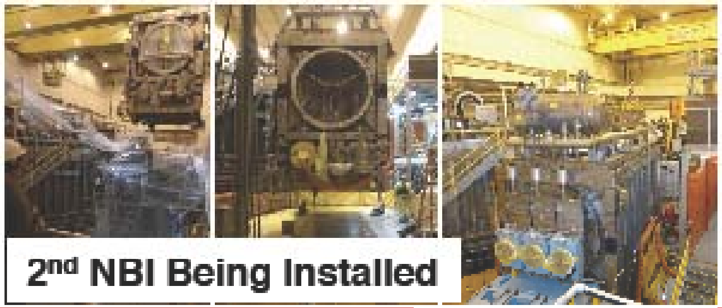
FIP/P8-30: NSTX-U First Plasma Scheduled in February 2015

To provide data base to support ST-FNSF designs and ITER operations

Key issues to resolve for next-step STs

- Stability and steady-state control at high β
- Confinement scaling (esp. electron transport)
- Non-inductive start-up, ramp-up, sustainment
- Divertor solutions for mitigating high heat flux





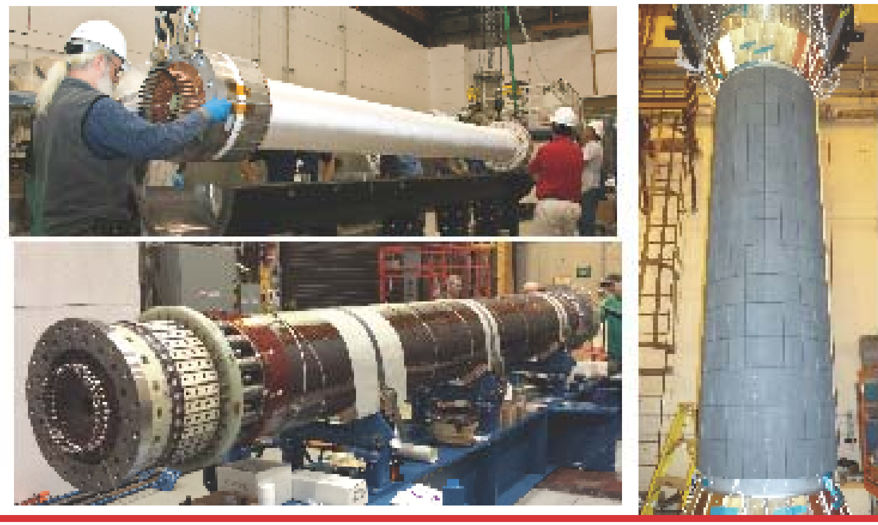
2nd NBI Being Installed

	R_0 (m)	A_{min}	I_p(MA)	B_T (T)	T_{TF}(s)	R_{CS} (m)	R_{OB} (m)	OH flux (Wb)
NSTX	0.854	1.28	1	0.55	1	0.185	1.574	0.75
NSTX-U	0.934	1.5	2	1	6.5	0.315	1.574	2.1

~ X 5 - 10 increase in $n\tau T$ from NSTX

NSTX-U average plasma pressure) ~ Tokamaks

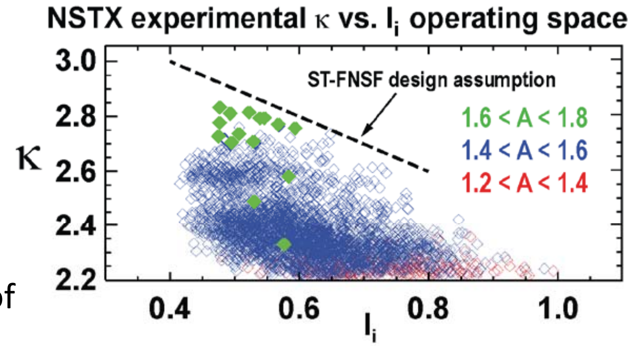
New Center-Stack Nearing Completion



Configuration Studies for an ST-based Fusion Nuclear Science Facility FNS/1-1

J. Menard/L. El-Guebaly et al.

κx-point = κmax-ST (li) ≡ 3.4 - li



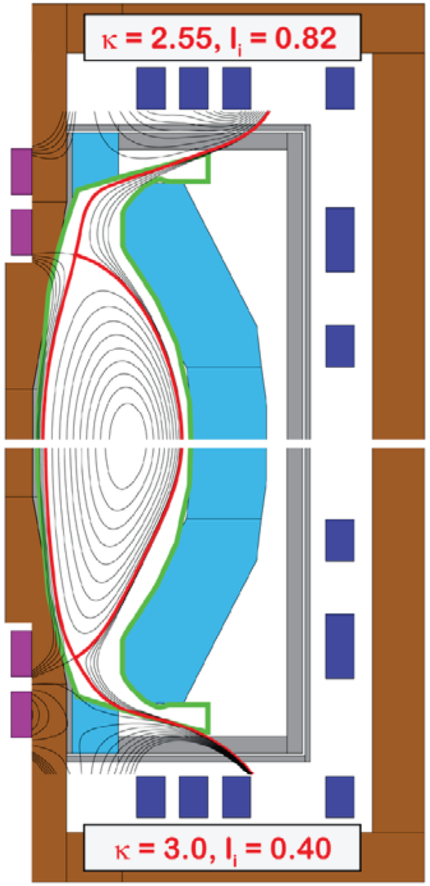
During the past two years, U.S. studies have for the first time developed ST configurations simultaneously incorporating:

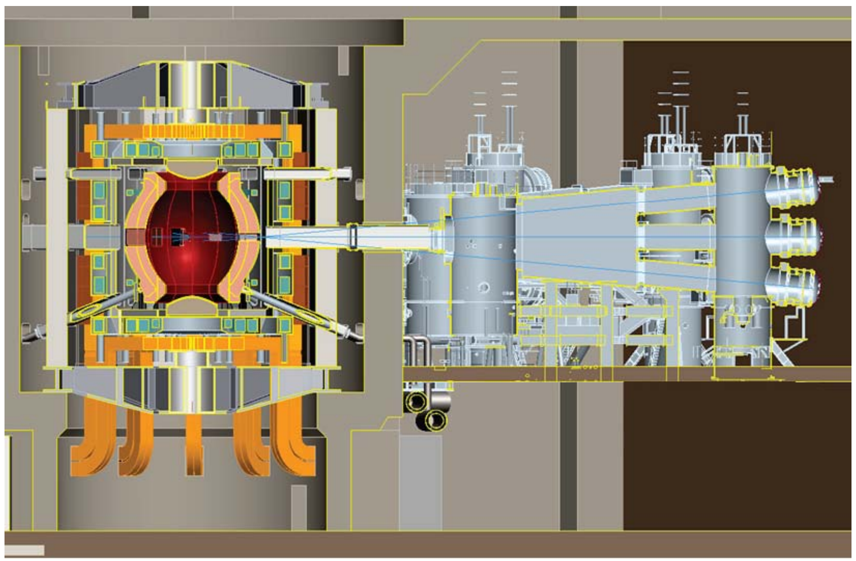
(1) a blanket capable of TBR ~ 1 with ports provided for test modules and heating and current drive,

(2) (2) a poloidal field (PF) coil set supporting high κ and δ for a range of li and βN values consistent with NSTX/NSTX-U operation,

(3) (3) a long-legged / Super-X divertor [8] analogous to the planned MAST-U divertor [9] which substantially reduces projected peak divertor heat-flux and has all outboard PF coils outside the vacuum chamber and as superconducting to reduce power consumption, and

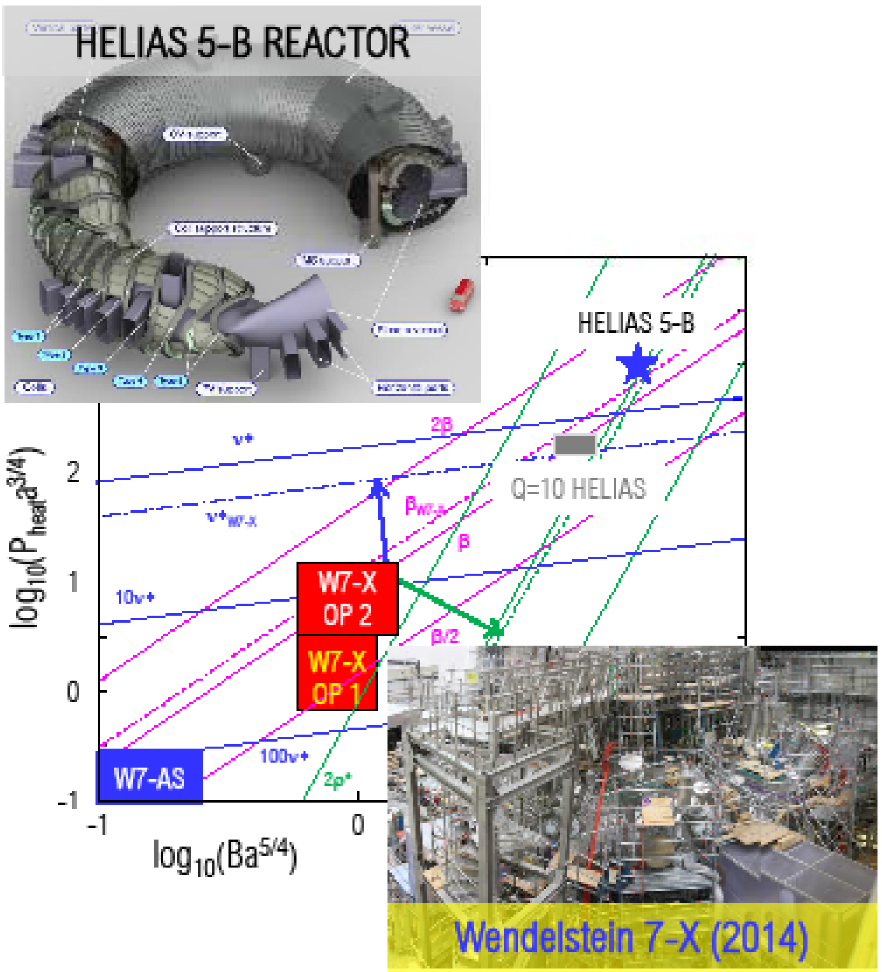
(4) (4) a vertical maintenance scheme in which blanket structures and the centerstack (CS) can be removed independently.





Progress in these ST-FNSF mission vs. configuration studies including dependence on plasma major radius R0 for a range R0 = 1 – 1.6m was described.

The Road to a HELIAS Reactor



W7-X Initial Operation Phases (OP)

2015 - OP1.1 (short-pulse limiter phase)

- verify good flux-surfaces
- first plasma

2016/17 - OP1.2 (pulsed, un-cooled divertor)

- prepare for steady-state/high-power operation
- assess impact of stellarator optimization

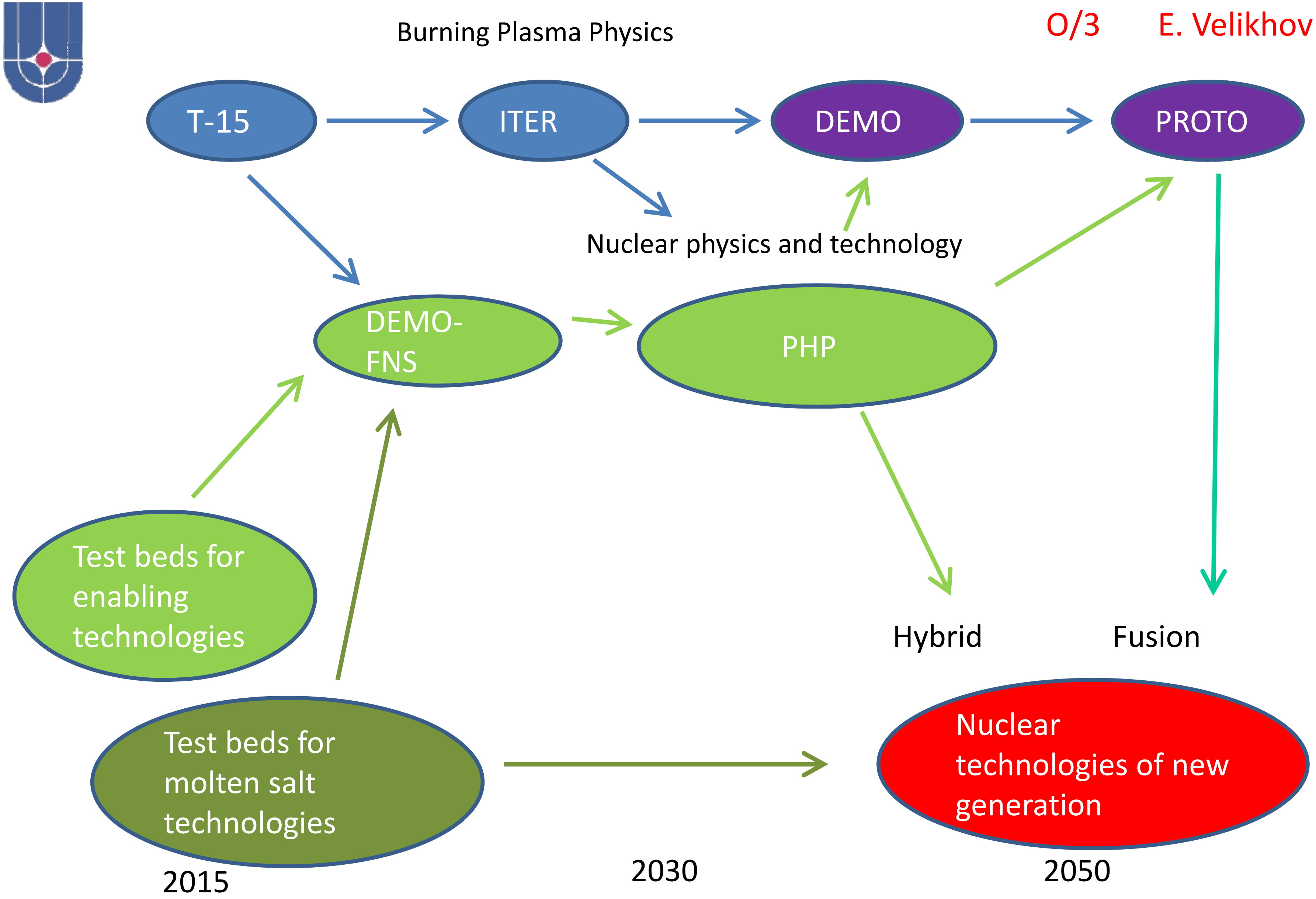
1) increase density & develop scenarios
   - fuelling/density control, heating
   - prepare safe divertor operation
2) use configuration flexibility
   - study effects of optimization
3) <u>begin</u> to address physics topics
   - divertor physics
   - impurity transport/PWI
   - transport: neoclassical, turbulence, …
   - fast ion generation
   - high-beta & MHD

>2019 – OP 2 (steady-state divertor)

- to integrated, steady-state, high-power/high-density operation

A. Dinklage
FIP/3-1

Strategy 2013 for Fusion-Fission development in Russia



Major facilities on the path to Industrial Hybrid Plant

O/3 E. Velikhov

Test beds

Steady State Technologies

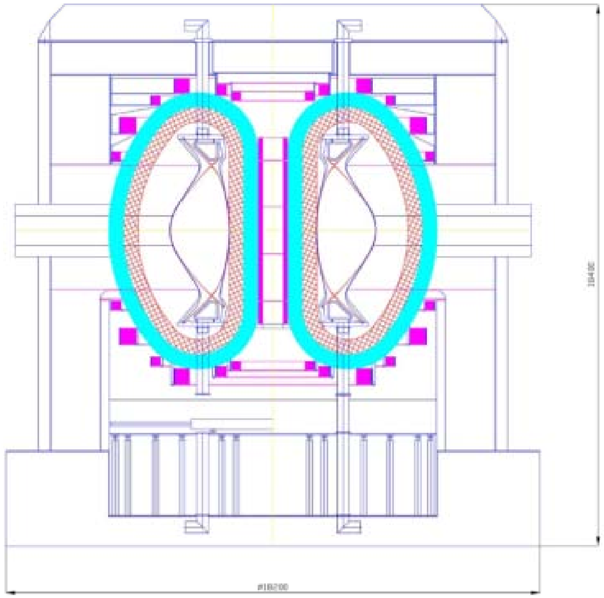
- Magnetic system
- Vacuum chamber
- Divertor
- Blanket
- Remote handling
- Heating and current drive
- Fuelling and pumping
- Diadnostics
- Safety
- Molten salts

Russian Tokamaks

- **Integration**
- **Materials**
- **Components**
- **Licensing**

DEMO-FNS

DT neutrons **MS blankets**



- **Hybrid Technologies**

Pilot Hybrid Plant construction by 2030 **P=500 MWt, Q_{eng} ~1**

Industrial Hybrid Plant construction by 2040

P=3 GWt, Q_{eng} ~6.5, P=1.3 GWe, P=1.1 GW(net), MA=1t/a, FN=1.1 t/a

Switch to movie clip here to end the presentation…