S/1-2

Summary of EX/D, EX/S and EX/W

EX: Magnetic Confinement Experiments

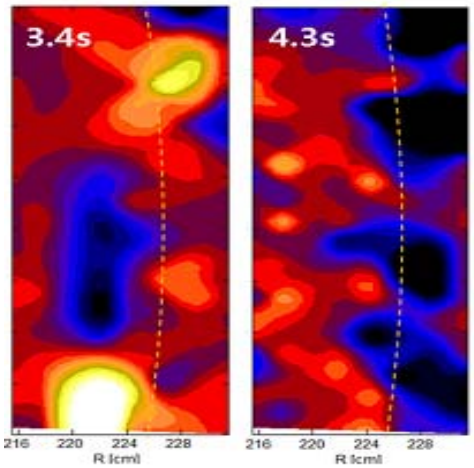
D: Plasma–material interactions, Divertors, Limiters, Scrape-off layer

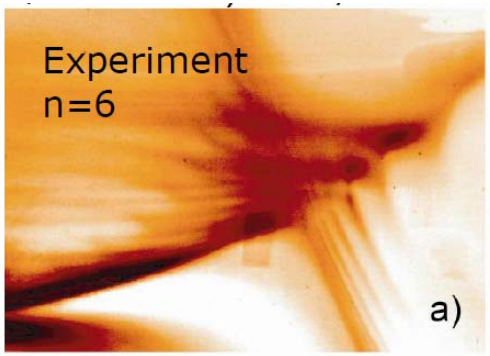
S: Stability

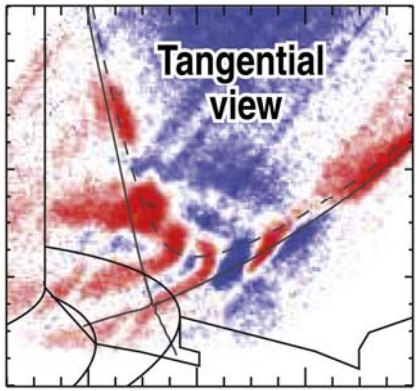
W: Wave–plasma interactions, Current drive, Heating, Energetic particles

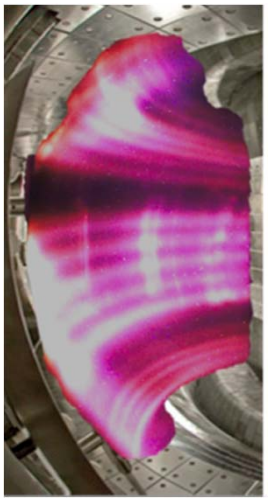
- Thanks to IAEA, IPC and local organizers
- Acknowledgements to all contributors, in particular, OV speakers
- All my apologies for NON-thorough summary

➔ send your suggestions to hyamada@lhd.nifs.ac.jp to be included in the article of NF









H.Yamada

National Institute for Fusion Science

Japan

24th IAEA Fusion Energy Conference, San Diego, USA, 2012

Terms of Reference to Summary Speakers

- Capture the essence of the progress made
- What has the fusion community achieved over the past two years?
- Where does fusion R&D stand right now ?
- Which critical issues, next steps and/or major challenges definitely need focused attention in the immediate future or medium term in order to ensure avoiding gaps and unnecessary delays/surprises on the way towards fusion demonstration ?

Summary of the last FEC2010 at Dajeon by J.Jacquinot

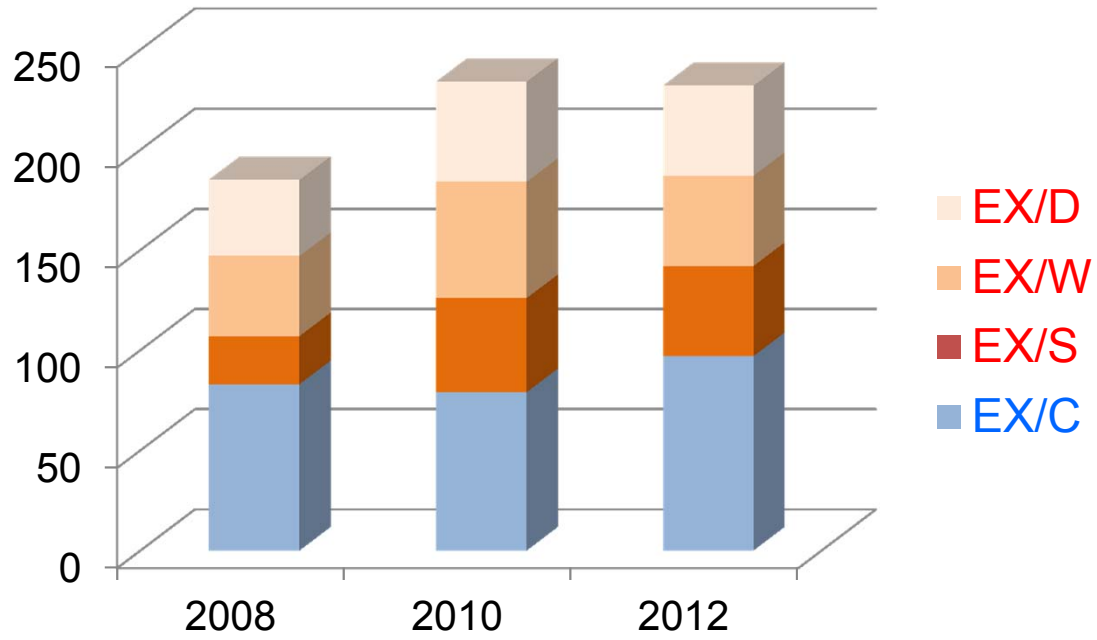
"Particular attention has been given to issues in the critical path of ITER construction"

- Urgent issue to impact the critical path of the ITER construction is becoming much clearer
- Request of more distinct materials to enable us to choose A before B
  - ✓ In-Vessel Coil in ITER: PA will start in Aug. in 2013
  - ✓ Full Tungsten Divertor in ITER: Strategy will be fixed in the fall in 2013

    etc.

"The experimental results can be qualitatively understood but ……. The extrapolation to ITER requires a more accurate knowledge of the plasma...."

Statistics



EX/D	45	←	50
EX/W	45	←	58
EX/S	45	←	47
PD	7		

Total 142 papers

Highlighted Topics

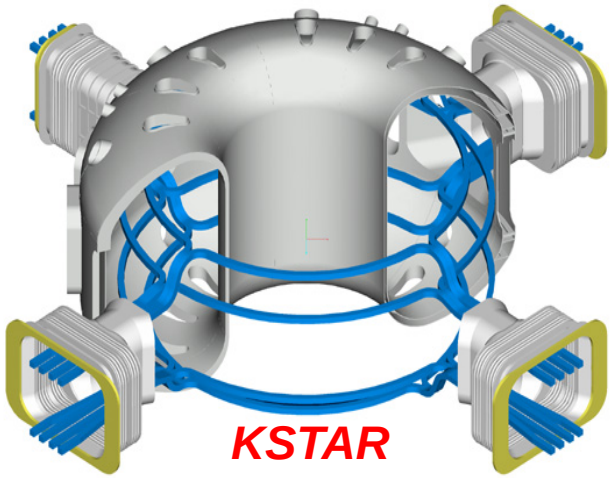
1. Pedestal Stability & Control (ELM mitigation/suppression, 3-D physics)
2. Reduction of Heat Load (Advanced divertor, Detach, Accurate evaluation)
3. Plasma Wall Interaction (ITER Like Wall)
4. Plasma Facing Materials (Wall conditioning, Materials)
5. Disruptions (Runaway electrons, Stabilization&Mitigation, Prediction)
6. Effect of Rotation on MHD
7. ST Startup
8. Plasma Scenario (Real time control of MHD, Heating, CD)
9. Waves & Energetic Particles

1. Pedestal Stability & Control

- ELM mitigation/suppression, Physics of 3-D magnetic field -

✓ ELM-free regime, pellet pace-making, SMBI
➔ Discussed in EX/C

✓ **Resonant Magnetic Perturbation (RMP) : 3-D**
from DIII-D, MAST, JET, NSTX(trigger) in FEC 2010 at Daejon
JJ : "need to describe accurately the response of the plasma to *RMP*"
"require a more accurate knowledge of the plasma screening of *RMP*"



in this FEC2012

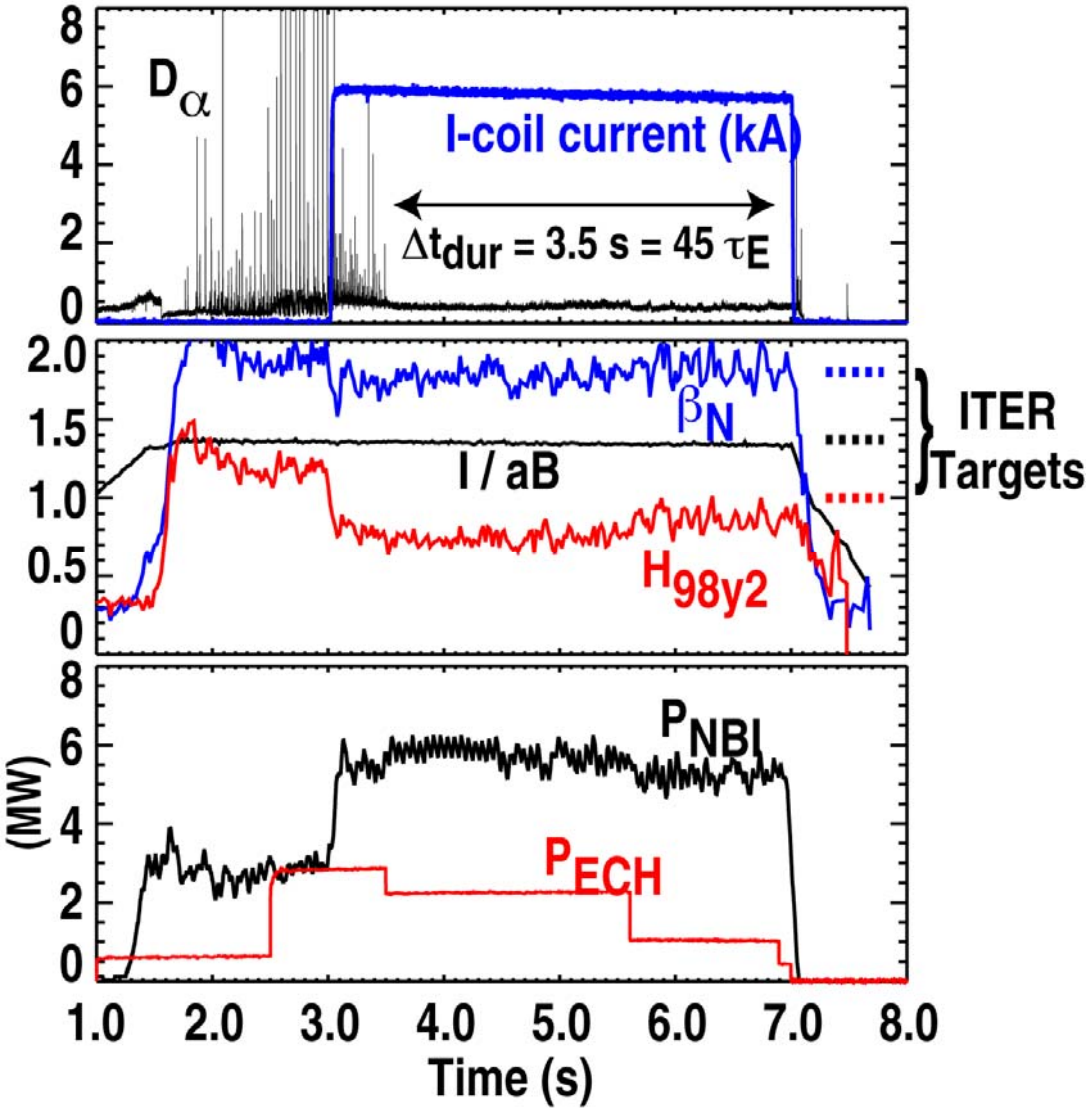
- New experimental results from
  in-vessel coils: DIII-D, AUG(EXC), MAST, KSTAR
  external coils: JET, LHD(EXC)

- Remarkable progress in study of 3-D magnetic fields
  MAST, KSTAR, DIII-D, LHD and
  EX/P4-19: J.Levesque "*High Resolution Detection* and 3D Magnetic Control of the Helical Boundary of a Wall-Stabilized Tokamak Plasma (**HBT**)"
  EX/P4-24: S.Masamune "*Direct Observation* of Soft-X Ray Filament Structure and High Current Operation in Low-Aspect-Ratio RFP (**RELAX**)"
  EX/P6-01: B.Chapman "*Direct Diagnosis* and Parametric Dependence of 3D Helical Equilibrium in the **MST** RFP"

Sustained RMP ELM Suppression Extended to ITER Baseline Scenario

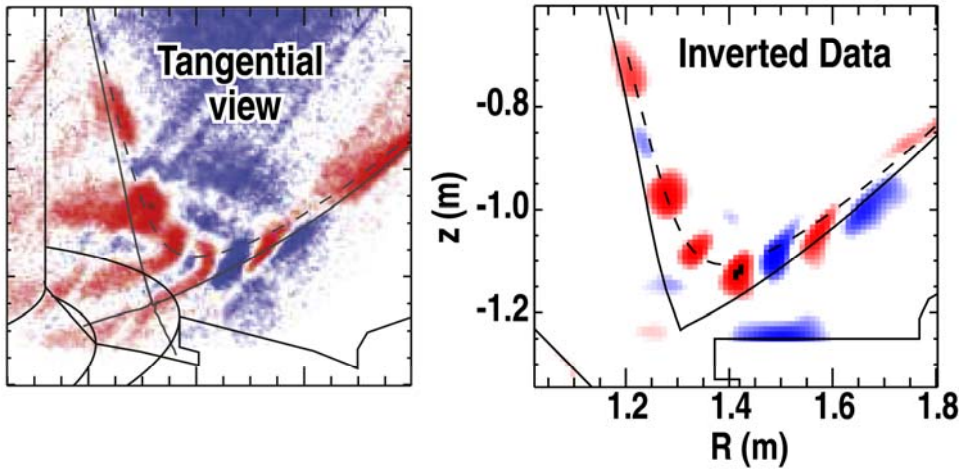
EX/3-1 M.Wade

- **n=3 perturbation with internal coils**
- **Match ITER**
  - Shape and I/aB
  - β_N = 1.8 and **ν^* = 0.12**
- **ELM suppression also shown in helium (n_{He}/n_e=0.25) plasmas**



Identification of change of topology
⇔ Comparison with simulation

Experiment: SXR data



Complementary (Contrast?) to AUG

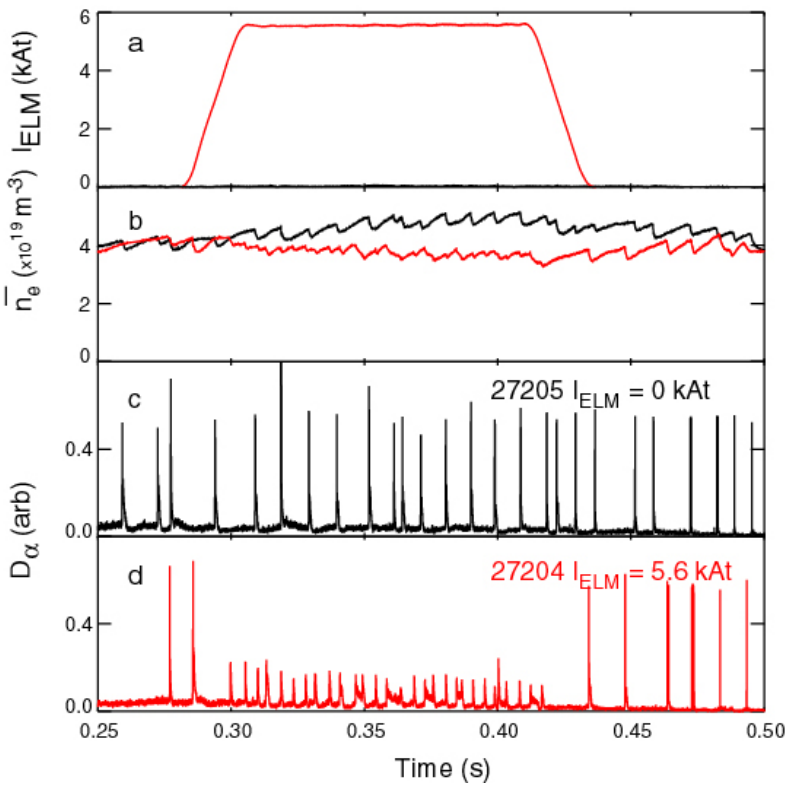
EX/3-4 (EXC) W.Suttrop

ELM mitigation in MAST

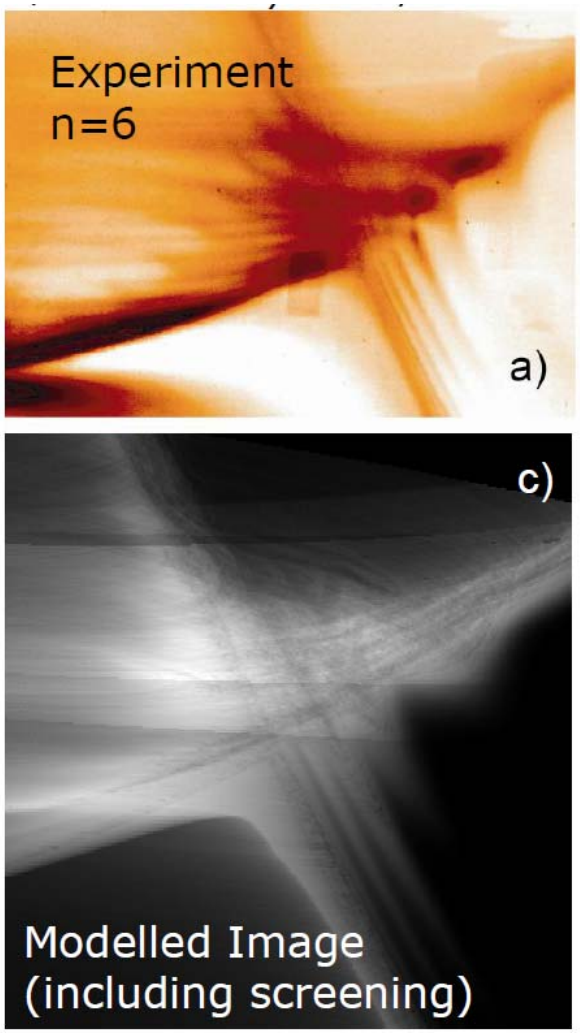
EX/3-2 A.Kirk

ELM mitigation established on MAST using RMPs with n=3, 4 and 6

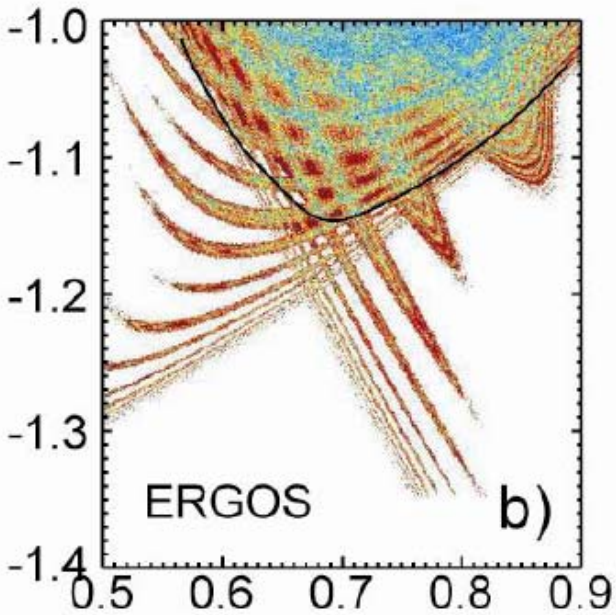
Example of ELM mitigation with n=6 RMPs



ELM frequency increased by up to a factor of 5 with similar reduction in ΔW_{ELM}



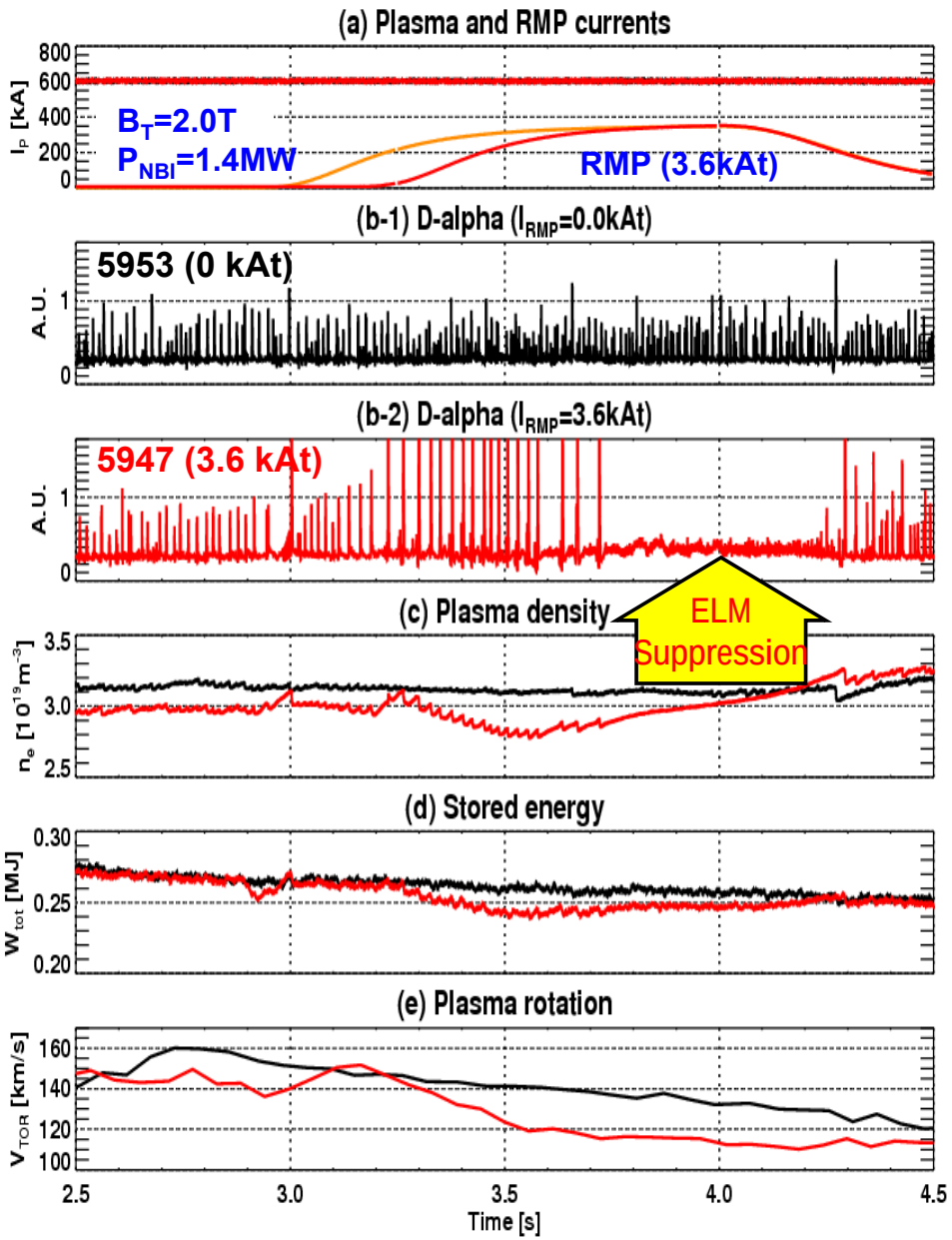
X-point lobe structures are observed



Can get good description of Lobe structures if ideal screening $\Psi_N < 0.98$

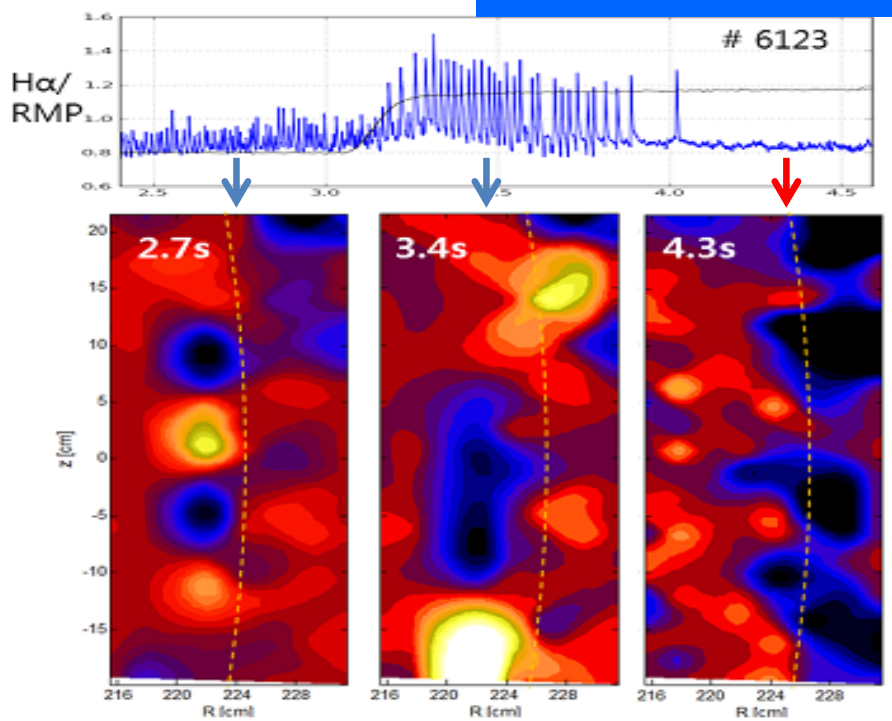
ELM suppression achievement by applying n=1 RMP at 90 phasing

EX/3-3 Y.-M. Jeon



- **ELM was suppressed at n=1**
  JET mitigated ELM at n=1
  DIII-D suppressed ELM at n=3
- **No mitigation with non-resonant anti-phase**
- Density pumped out initially (~10%)
- Stored energy drop (~8%)
- **ECE imaging** at 4.3sec shows no edge filamentary structure (ELM suppressed)

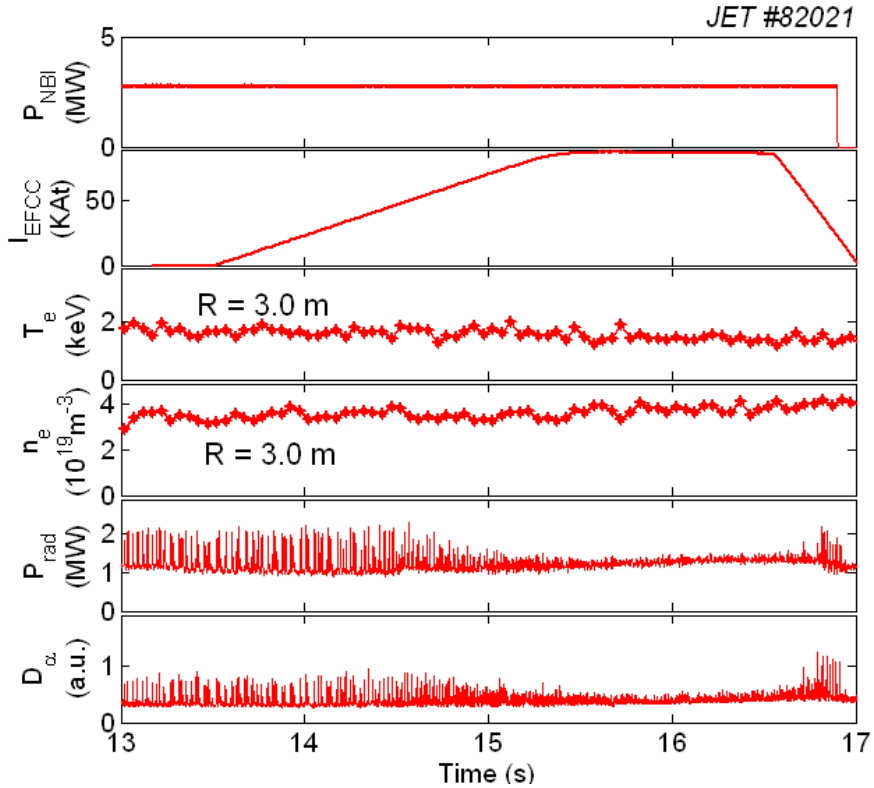
EX/11-3 H.-K. Park



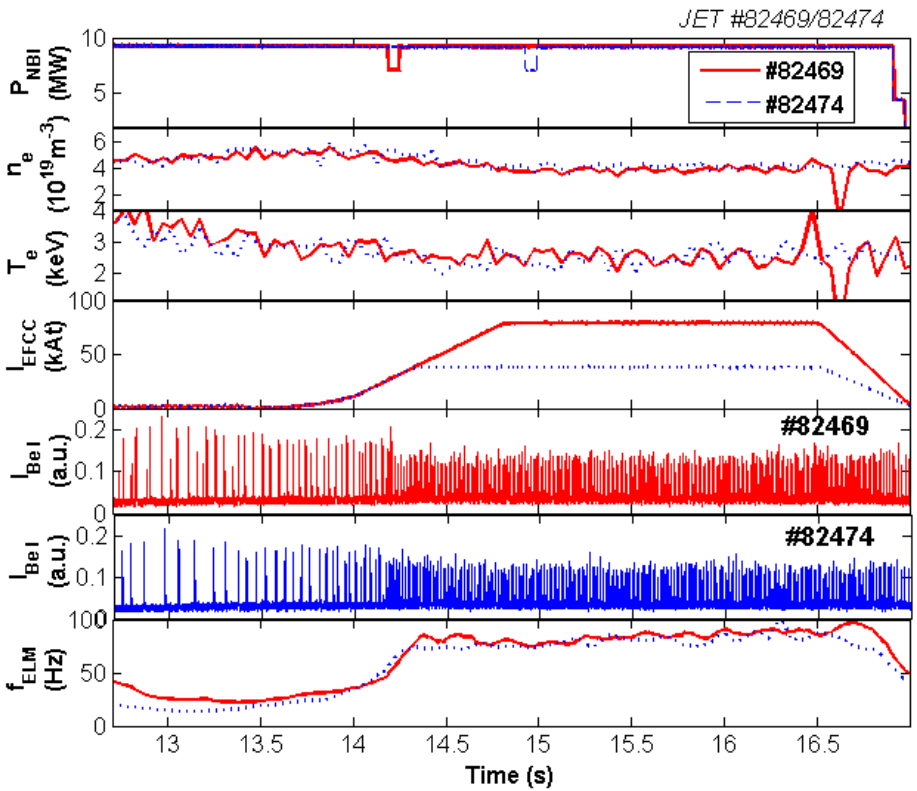
Mitigation of Type-I ELMs with n =2 Fields on JET

EX/P4-23 Y.Liang

High collisionality ν_e^* =2.0 at the pedestal



Low collisionality ν_e^* =0.8



Type-I ELM ➔ Small and high frequency (few hundreds Hz) ELMs

ELM frequency increases from 20 to 80 Hz ➔ Saturation of effect

LHD: EX/P4-11 (EXC) K.Toi

Mitigation with resonance in stochastic layer

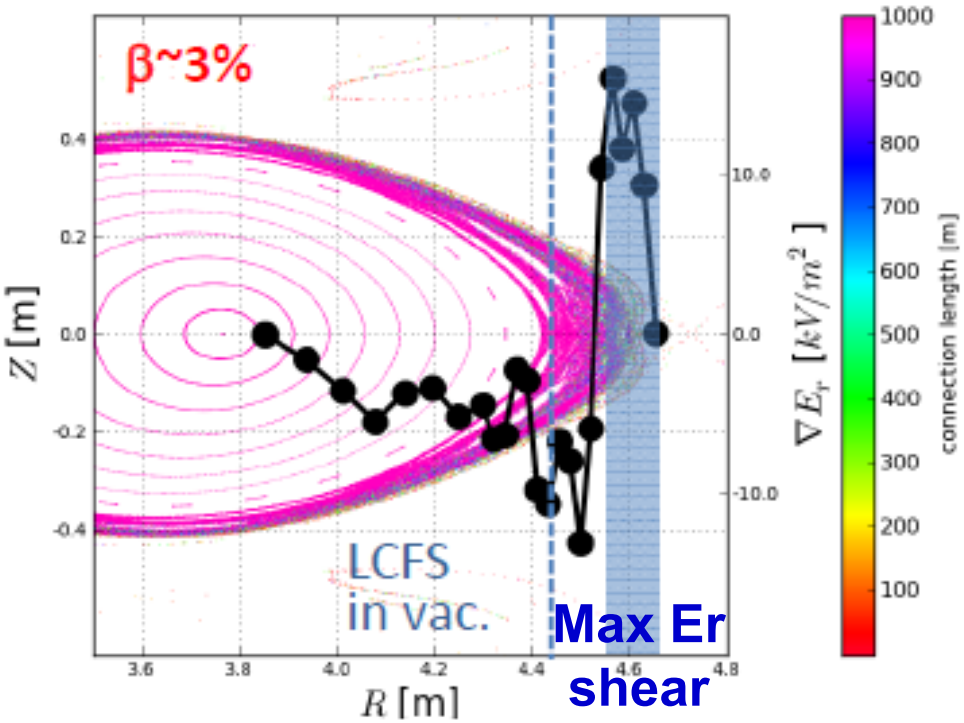
EX/P5-17 G.Fishpool
EX/P7-23 M.Kočan

First diverotor ion temperature measurement in MAST and AUG

3D plasma response to magnetic field structure in LHD

EX/8-1 Y.Suzuki

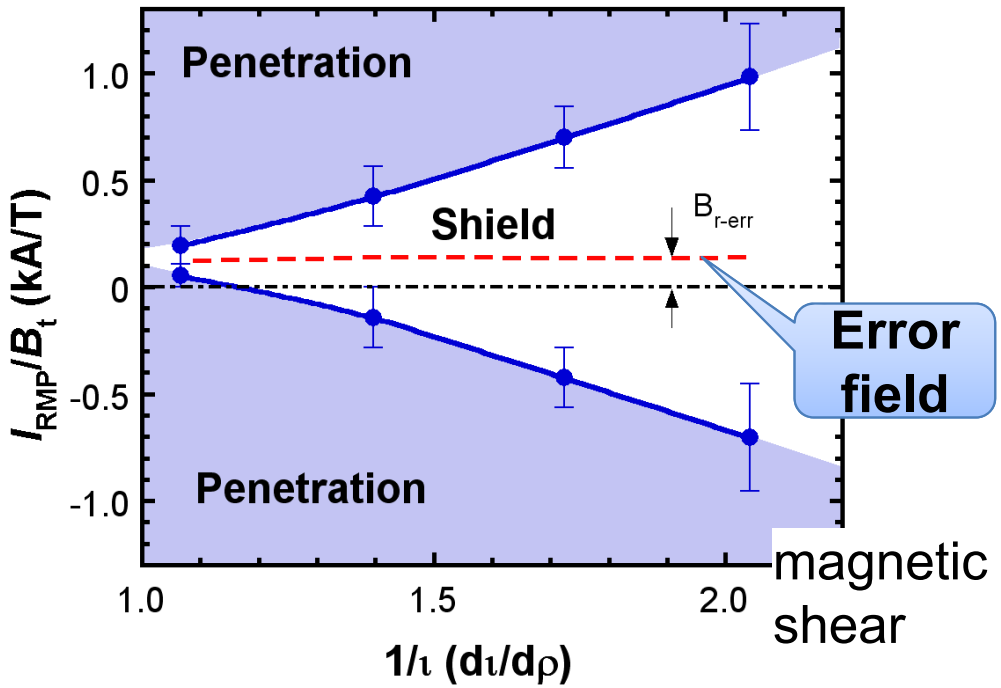
Comparison between E_r shear and 3D MHD equilibrium modeling



Transition point to strong E_r shear would be a good index of LCFS.

EX/P4-30 S.Sakakibara

RMP penetration depends on stability criteria (magnetic shear and/or magnetic well/hill)



Threshold of penetration linearly increases with magnetic shear

← Plasma flow is almost constant

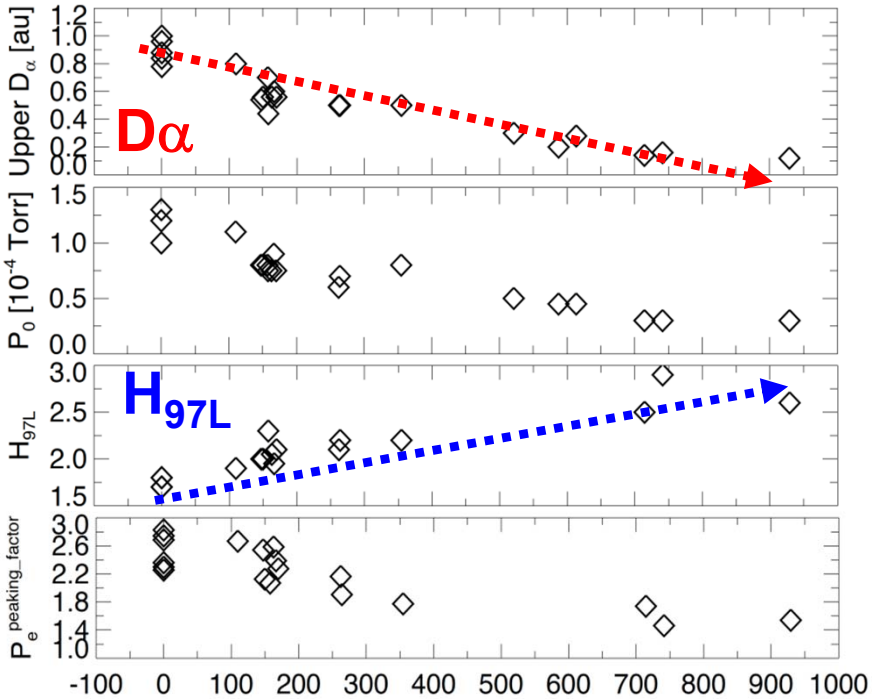
EX/P4-31: R.J.Buttery "Addressing New Challenges for Error Field Correction (**JET**)"

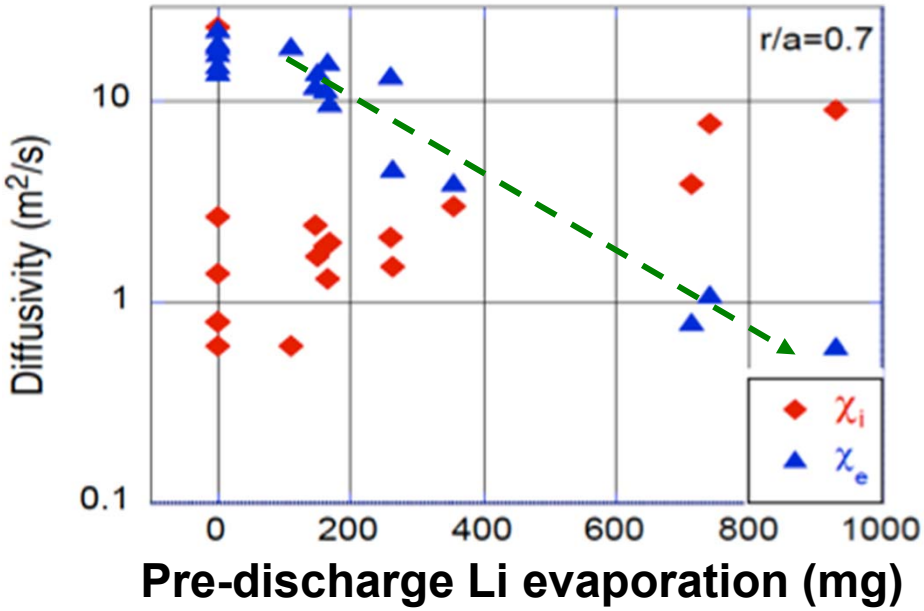
EX/P4-21: L. Frassinetti "Plasma Response to Applied Nonaxisymmetric External Magnetic Perturbations in **EXTRAP T2R**"

EX/P6-03: M.Garcia-Munoz "Fast-ion Redistribution and Loss due to Edge Perturbations in the **AUG**, **DIII-D** and **KSTAR**"

Edge recycling, neutral pressure, and pressure peaking decrease, while confinement and edge stability increase with increasing pre-discharge lithium in NSTX

EX/11-2 R.Maingi





- Global parameters generally improve
- **ELM frequency declines - to zero**
  - ELMs stabilize
- Edge transport declines
  - As lithium evaporation increases, transport barrier widens, pedestal-top χ_e reduced

2. Reduction of Heat Load

(Advanced divertor, Detach, Accurate evaluation)

Advanced Divertor Concept

EX/P5-17: G.Fishpool "***Super-X*** in **MAST**"
EX/P5-21: V. Soukhanovski "***Snowflake*** in **NSTX**"
EX/P5-22: W.A.J.Vijvers "***Snowflake*** in **TCV**"
PD /1-2: S.L.Allen "**Snowflake** in **DIII-D**"
EX/P5-29: T.Morisaki "***Closed Helical Divertor*** in **LHD**"

Challenge to Reduce Heat Load

EX/4-4: M.Koyabashi "Stabilization of Radiative Divertor by RMP in **LHD**"
EX/P5-12: T.W.Petie "Effect of Changes in Separatrix in **DIII-D**"
EX/P5-24: P.Mertens "Power Handling of the Tungsten Divertor in **JET**"
EX/P5-30: C.Giroud "Nitrogen Seeding for Heat Load Control in **JET**"
EX/P5-33: J.-W Ahn "Heat Deposition during the ELM and 3-D Field Application in **NSTX**"
EX/P5-34: M.Wischmeier "Divertor Detachment in **ASDEX Upgrade**"
(EXC) EX/6-2 Pellets in **DIII-D**

Towards Accurate Evaluation of Heat Load

EX/P5-13: L.Wang "Characterization of Particle and Power Loads in **EAST**"
EX/P5-16: M.A.Makowski "Scaling of the Divertor Heat Flux Width in the **DIII-D**"
EX/P7-23: M.Kočan "Intermittent Transport across the Scrape-off Layer: **ASDEX Upgrade**"
EX/P8-02: N. Vianello "3D Effects on **RFX-mod** Helical Boundary Region "

Suppression of Impurity Contamination

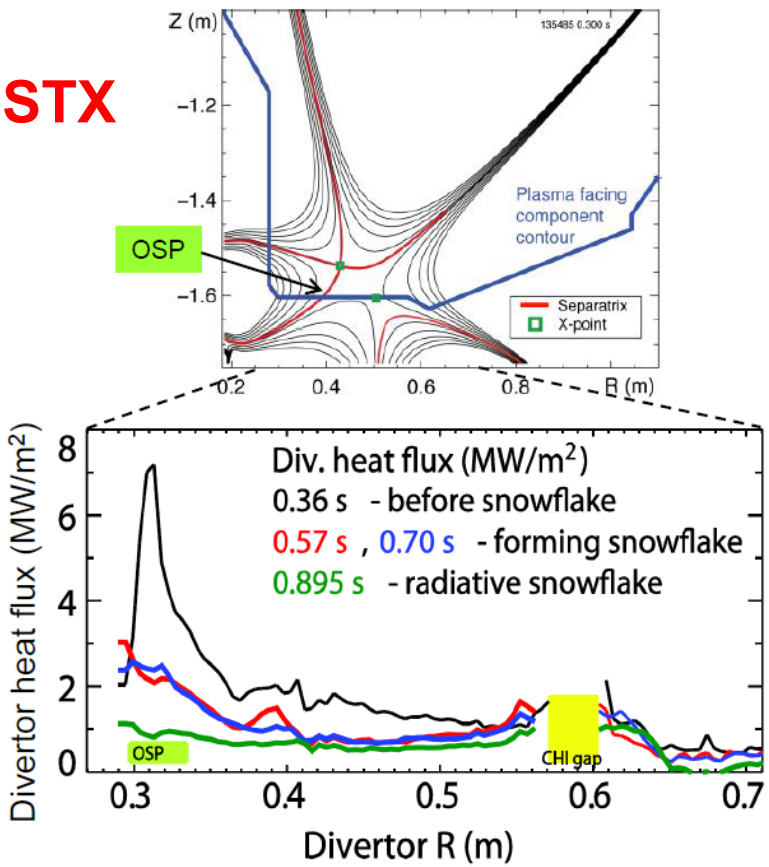
EX/P5-18: S.Morita "Low Concentration of Iron in **LHD** Plasmas with Edge Ergodic Layer"

Snowflake divertor to mitigate divertor heat flux

- Divertor heat flux width strongly decreases as I_p increases in NSTX, DIII-D, C-Mod
- Snowflake divertor experiments in NSTX (P_{NBI}=4 MW, P_{SOL}=3 MW)

➔ Significant reduction in divertor heat flux (from 3-7 to 0.5-1 MW/m^2)

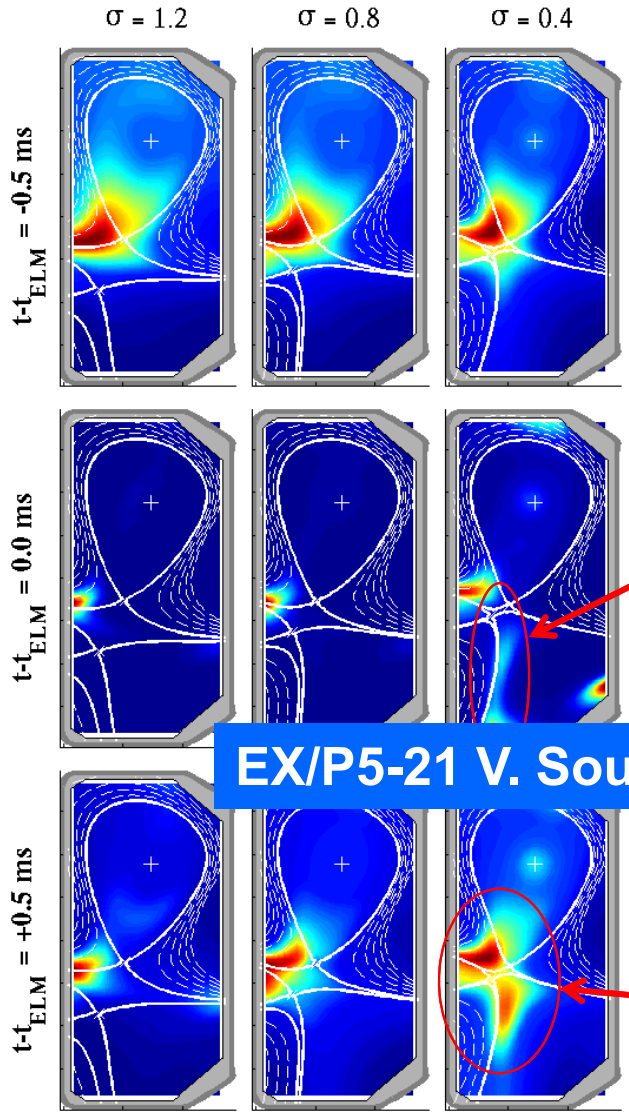
NSTX



EX/P5-22 W. Vijvers

- Power redistribution to secondary strike points investigated as shape transitions from SN to SF
- Peak ELM heat load on primary strike point reduced by factor 3.5

TCV



Inverted AXUV data: radiated power

Activation additional strike point visible

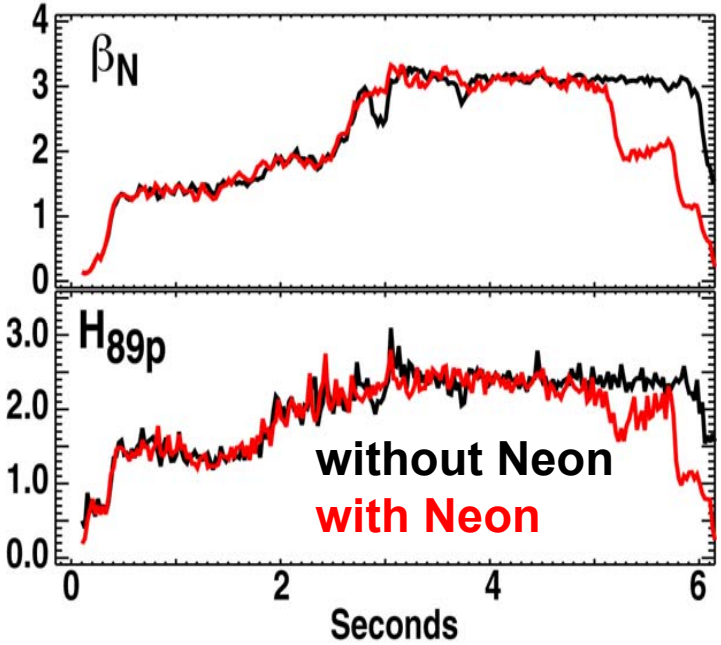
EX/P5-21 V. Soukhanovski

Enlarged radiating volume

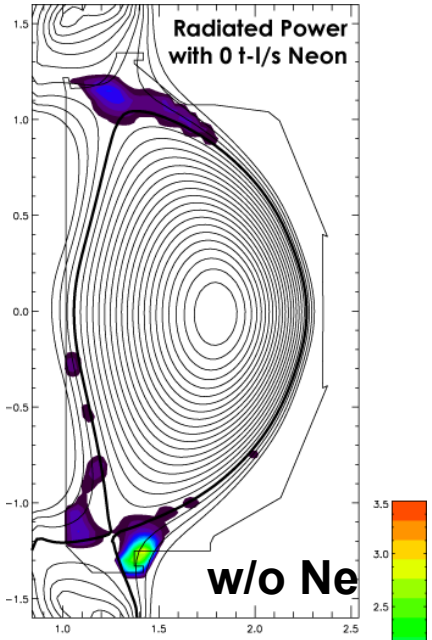
• q_{min}≈1.5 Scenario Appears Compatible With Radiating Mantle for Divertor Heat Flux Reduction
• Snowflake Divertor Configuration Strongly Reduces Peak Divertor Heat Flux and Increases Radiative Volume

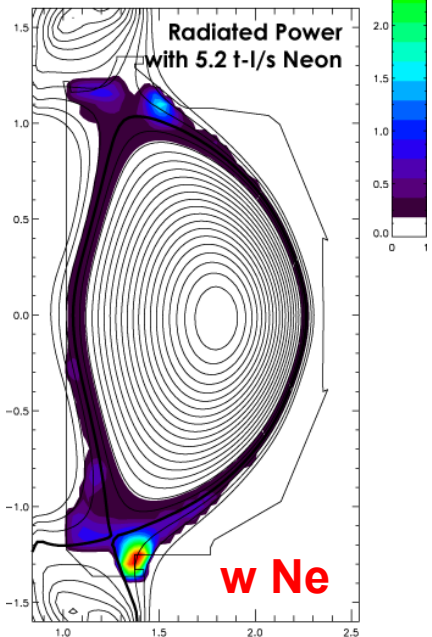
EX/1-5 C.Holcomb
EX/P5-12 T.Petrie
PD/1-2 S.L.Allen

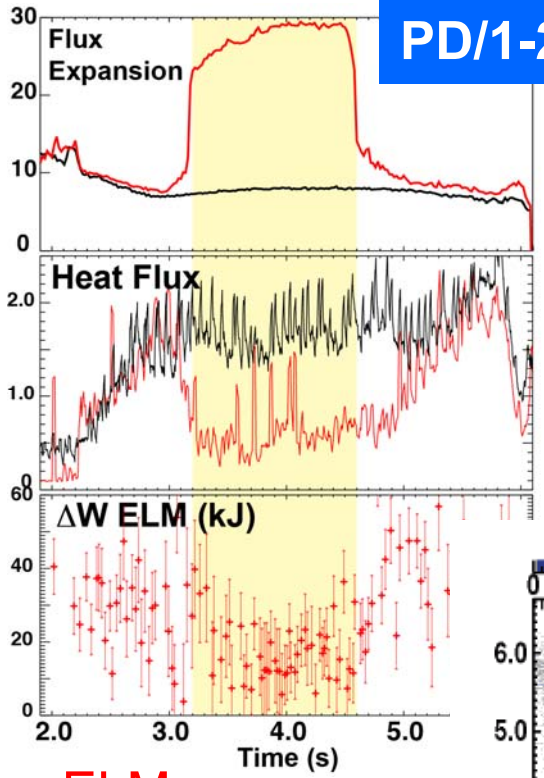
- Neon injected into private flux region
- P_{RAD} doubles without significant performance degradation



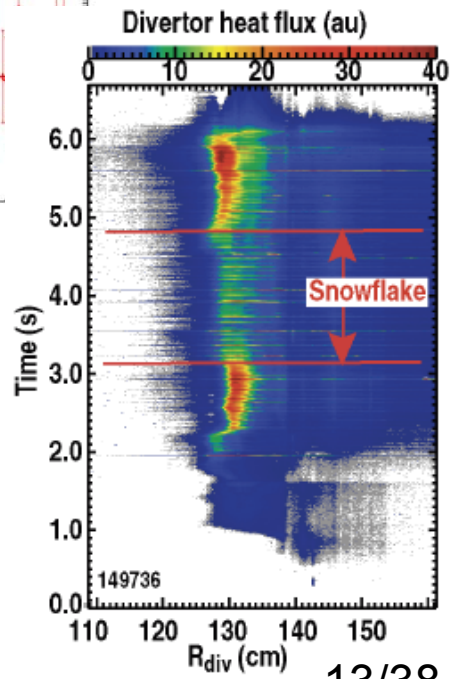
Peak divertor heat flux reduced ~35%







ELMs are also mitigated



Reduced Divertor Heat Flux

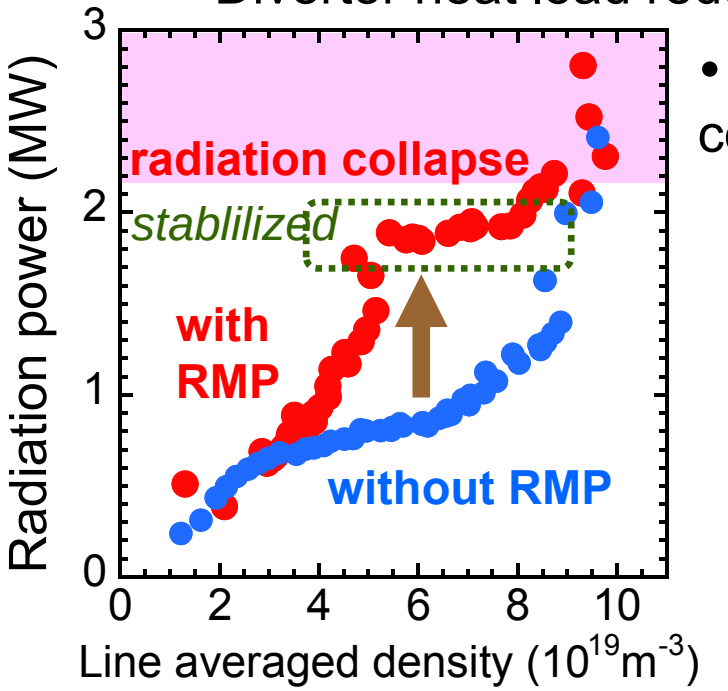
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Influence of perturbation coils on divertor heat load

EX/4-4 M.Kobayashi

LHD

- RMP stabilizes radiative divertor
- Divertor heat load reduction by 3~10

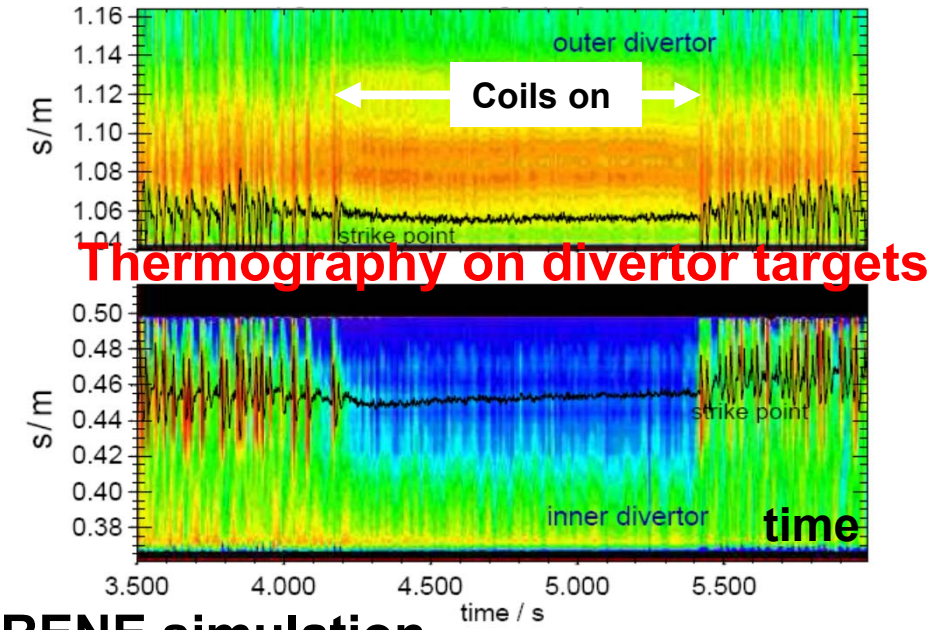


- Recovery of confinement

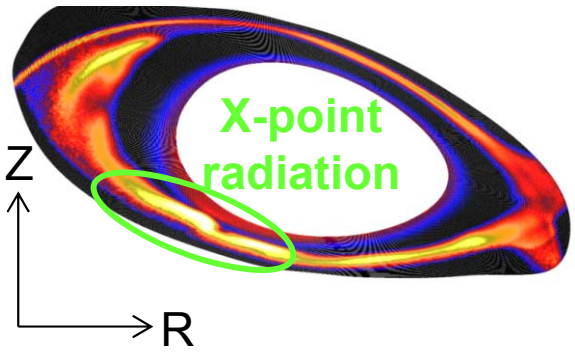
EX/P5-34: M.Wischmeier

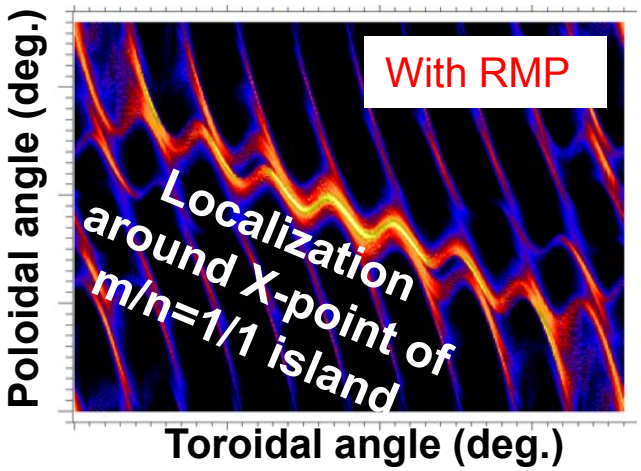
AUG

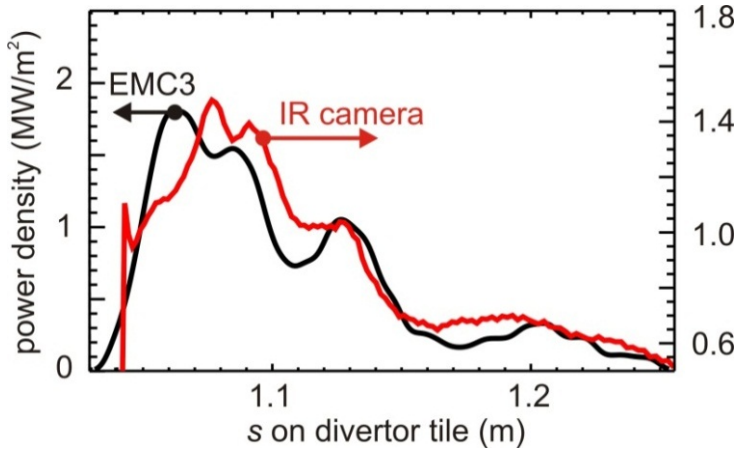
- Reduce peak power load
- Make strike line split up



EMC3-EIRENE simulation



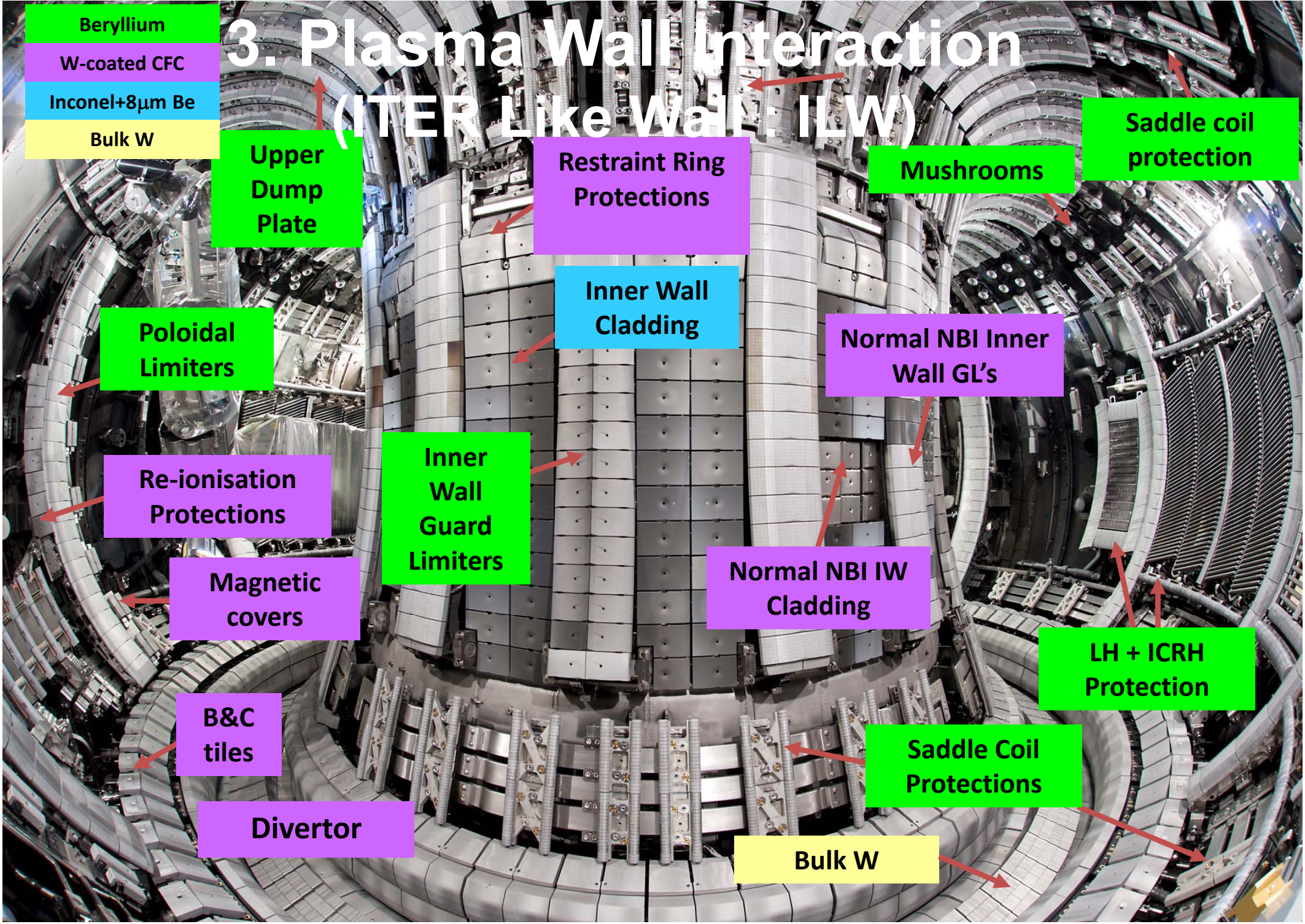




EX/P5-33 J.-W Ahn

"Degree of asymmetry is related to the external 3-D field

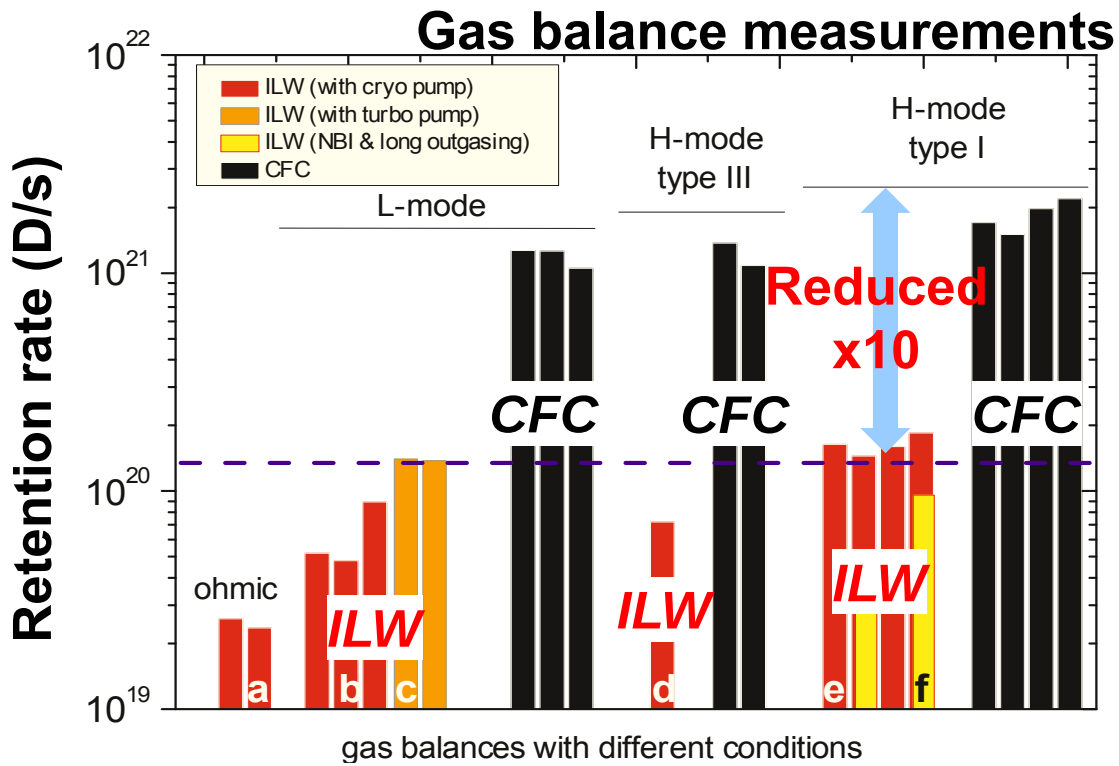
3. Plasma Wall Interaction (ITER Like Wall : ILW)

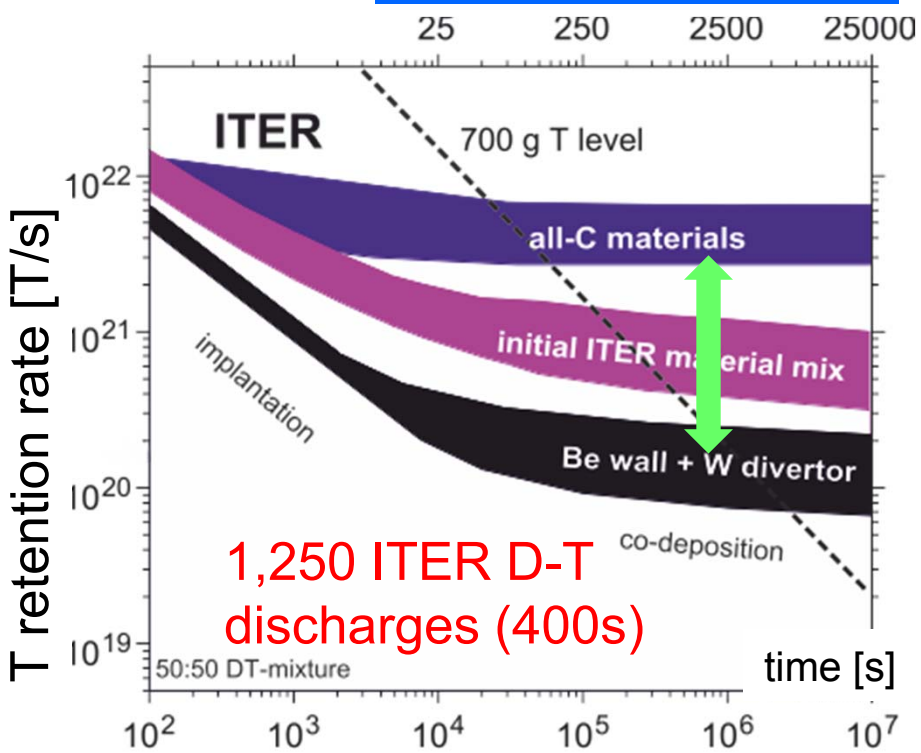


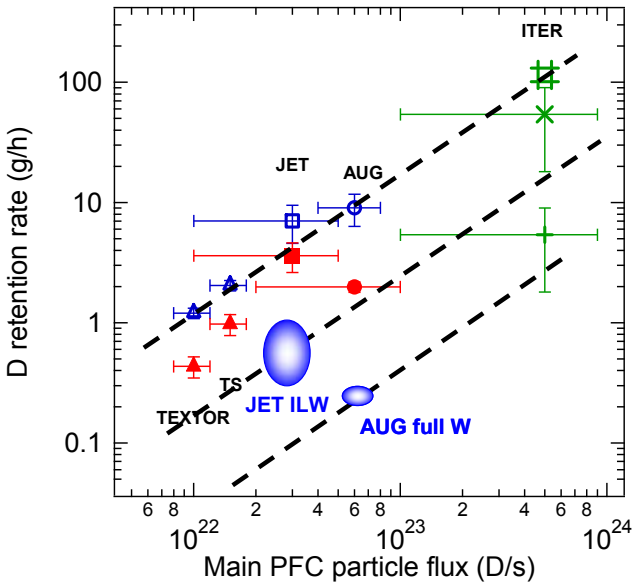
ILW = 2880 installable items, 15828 tiles (~2 tonnes Be, ~2 tonnes W)

JET-ILW: Low Long Term Fuel Retention

EX/4-1 S.Brezinsek







EX/P5-07 E.Tsitrone

From multi machine scaling, retention rate during shot expected to range from ~1g of T/hour (full tungsten machine) up to ~100 g of T/hour (full carbon machine) for a nominal ITER shot.

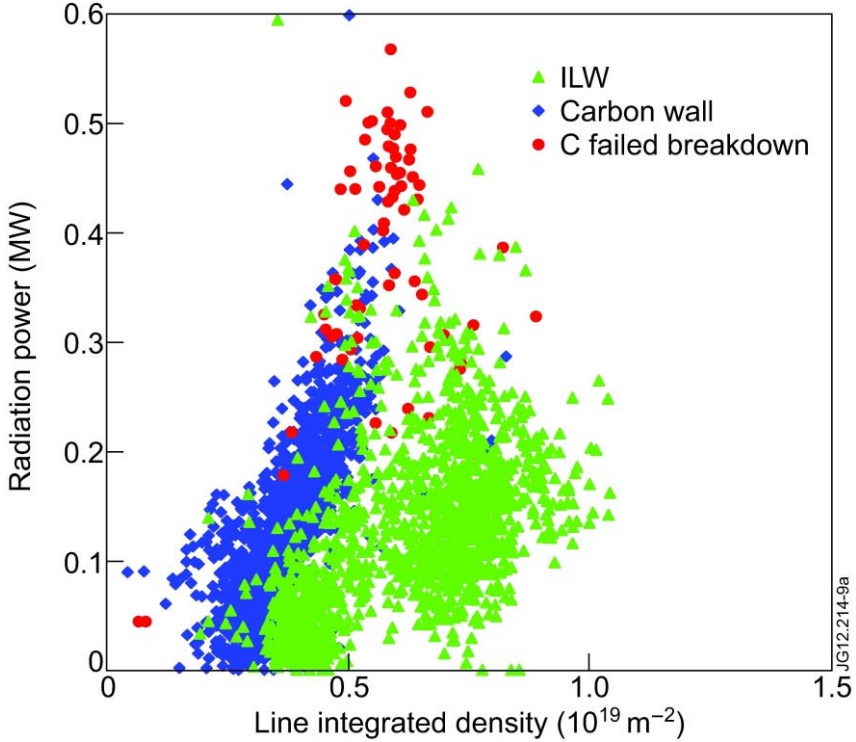
- **Retention with JET-ILW is reduced by about one order**
- Main mechanism is co-deposition: **Be-layers have lower fuel content than C-layers**
- **Retention reduction is in line with predictions for ITER from C to Be/W walls** (Roth et al.)

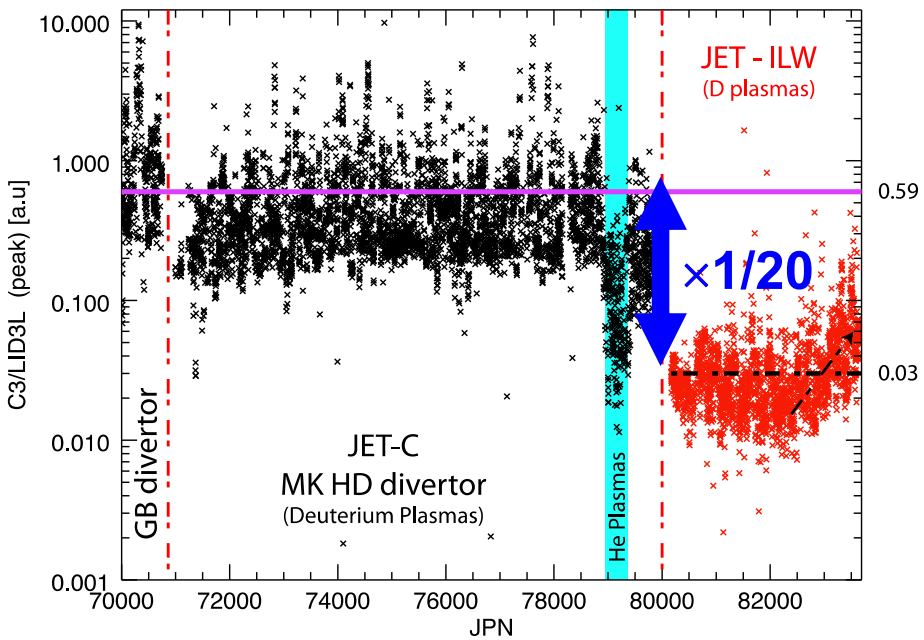
Plasma breakdown with C and Be/W plasma facing components

Full characterization of breakdowns has been carried out for operations with carbon PFCs (JET-C) and the ITER-like wall (JET-ILW)

EX/4-2 P.de Varies

- Non assisted breakdown demonstrated down to 0.35V/m (ITER value).
- Lower radiation level at higher density achieved making the breakdown more robust.
- Unlike the C-wall, no de-conditioning event following disruptions with the ILW. No need for GDC or Be evaporation during operation





EX/P5-04 J.W.Coenen

Edge carbon drops by a factor of ×**20** JET-C vs JET-ILW (ILW 0.1% C, 2-3% Be)

4. Plasma Facing Materials
(Wall Conditioning, Basic Research of Materials)

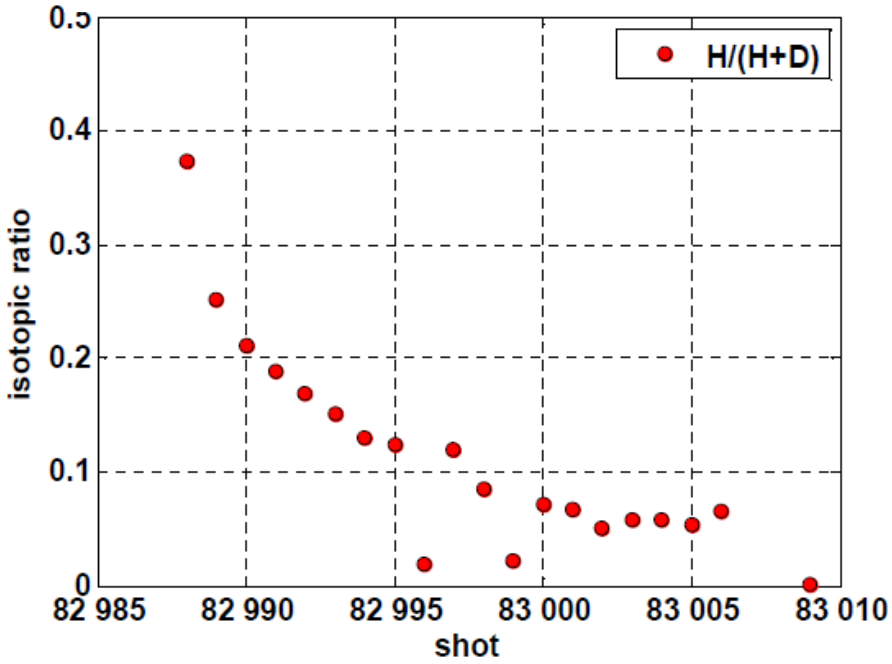
Wall Conditioning

EX/P5-09 D.Douai

International Research on Ion Cyclotron Wall Conditioning

- Integrated into the ITER baseline using the ITER ICRF heating system
- Experimental and modeling efforts coordinated by ITPA DivSOL

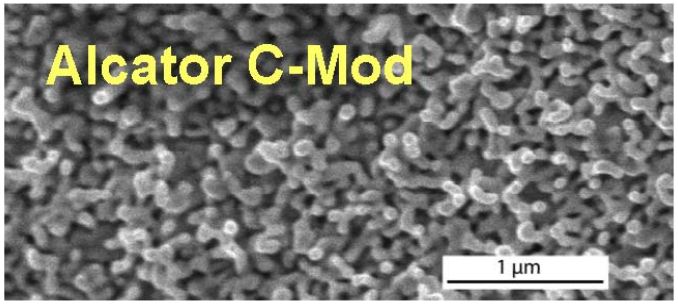
Isotropic ratio in the post-ICWC discharges in JET

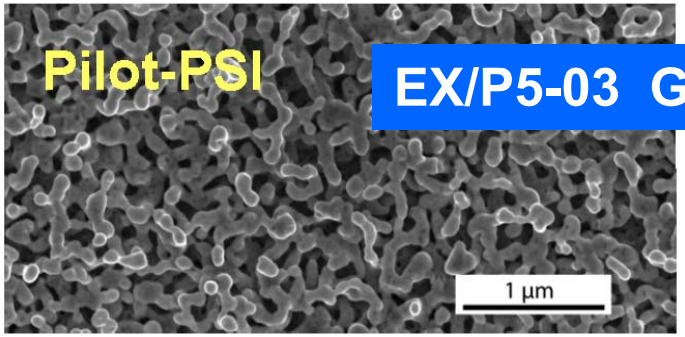


Lithium

EX/P5-25: S.Mirnov "Recent Achievements of the **T-11M** Lithium Program"
EX/P5-27: T.Gray "The Effects of Increasing Lithium Deposition on the Power Exhaust Channel in **NSTX**"
EX/P5-31: M.Jaworski "Liquid Lithium Divertor Characteristics and Plasma-Material Interactions in **NSTX** High-Performance Plasmas"
EX/P5-36: F.Tabares "Studies of Plasma-Lithium Interactions in **TJ-II**"
(EXC) EX/P5-01 **RFX**, EX/P5-02 **EAST**

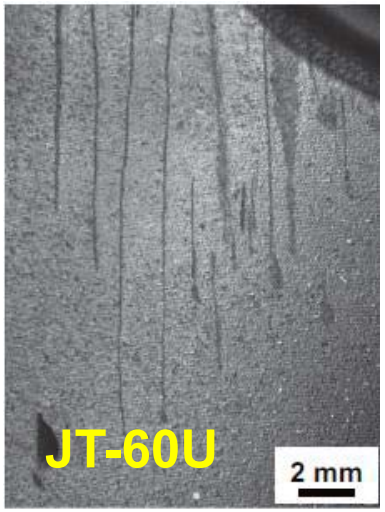
Basic Characterization of Materials

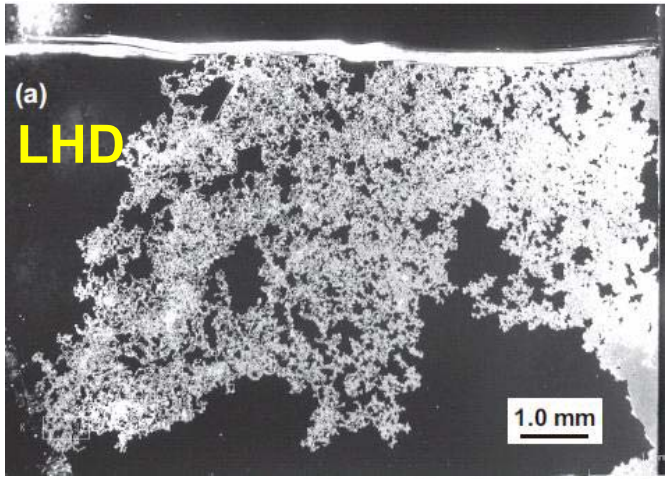




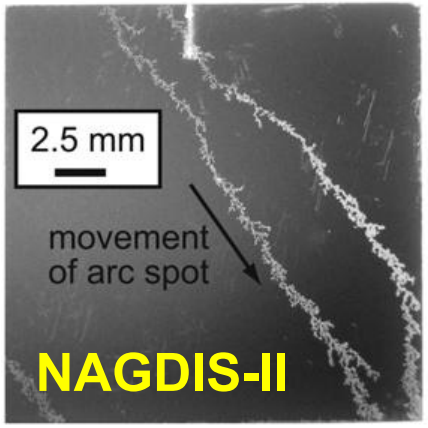
EX/P5-03 G.Wright

Tungsten Nano-tendril Growth in the **Alcator C-Mod** Divertor





EX/P5-08 S.Kajita



Arcing on Carbon and Tungsten in **JT-60U**, **LHD**, and **NAGDIS-II**

"*Provides confidence that key growth parameters, from smaller devices, can be used for prediction in future devices*"

Tungsten

EX/P5-05: G. van Rooji "Characterization of Tungsten Sputtering in the **JET** Divertor"

EX/P5-06: S.Takamura "Cooling Characteristics of He-Defected Tungsten with Nanostructure"

Erosion

EX/P5-11: D.L. Rudakov "Measurements of Erosion of Molybdenum Divertor Surface in **DIII-D**"

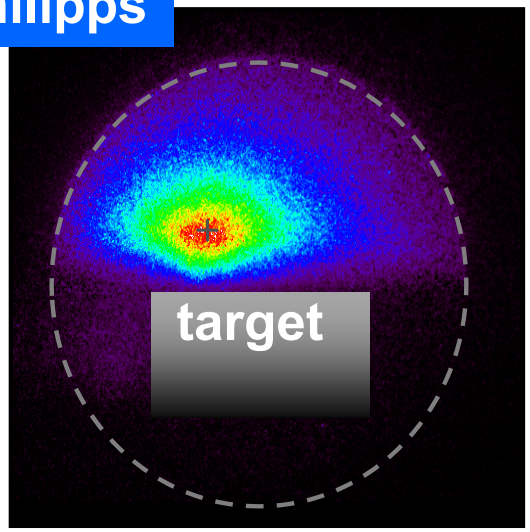
Dust : *still remains a Cinderella issue*

EX/P5-32: K.Koga "Control of Dust Flux in **LHD** and in a Divertor Simulator"

In-situ Measurements of PWI
beyond postmortem analysis

EX/P5-14 V.Philipps

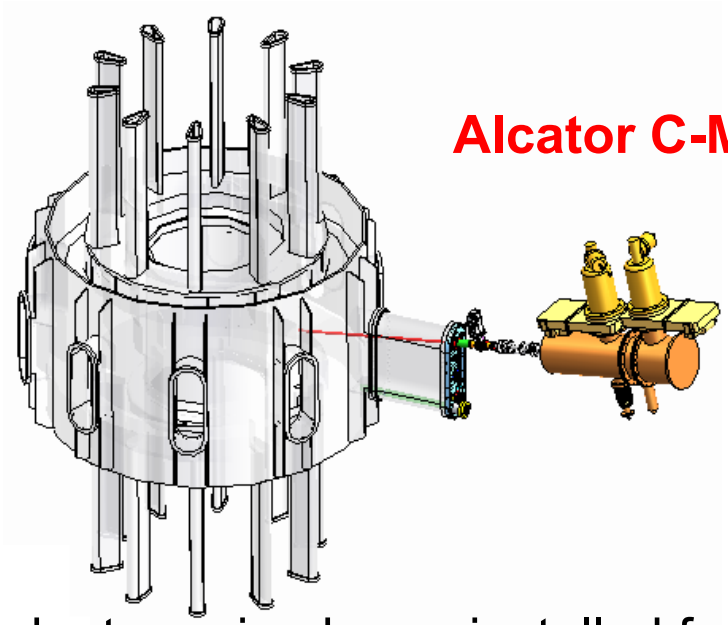
TEXTOR



LIDS : Laser Induced fuel Desorption by spot laser heating (1ms , ≈ 0.1 cm^2 (TEXTOR), 1cm^2 (ITER)) + Spectroscopic H (D) detection in edge plasma
→ Quantitative local fuel retention

Laser Induced fuel Ablation by spot laser heating + Spectroscopic material and H (D) detection in edge plasma
→ Quantitative composition and fuel retention

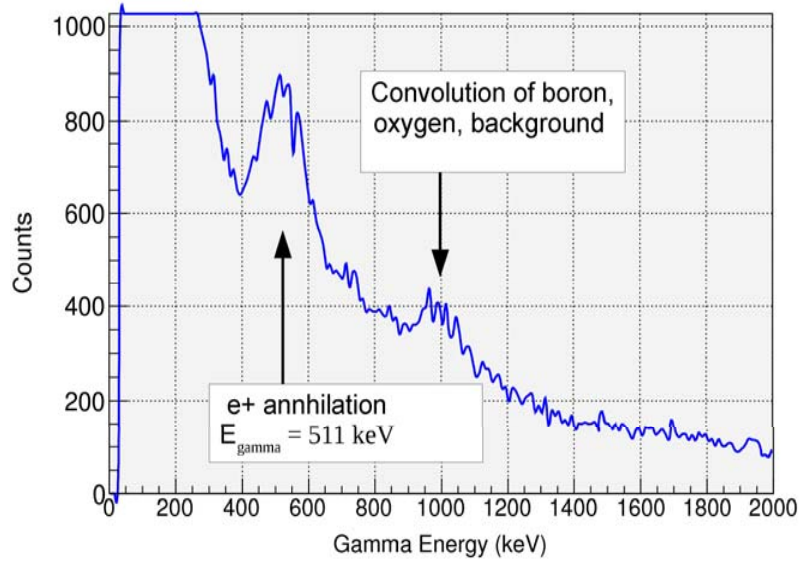
Alcator C-MOD



1 MeV deuteron ion beam installed for first time-resolved, *in-situ* measurements of plasma-wall interactions
reactions exploited:

$D + B^{11} \Rightarrow P + B^{12} + g$ Measures boron coating

$D + D \Rightarrow He^3 + n$ Measures fuel retention



5. Disruptions
(Runaway Electrons, Stabilization & Mitigation, Prediction)

Runaway Electrons

EX/9-2: E.M.Hollmann "Control and Dissipation of *Runaway Electron* in **DIII-D**"
EX/P8-05: V.V.Plyusnin "*Runaway Electrons* in **JET**"
EX/P8-06: F. Saint-Laurent "*Runaway Electrons* Control and Mitigation on **Tore Supra**"
EX/P8-12: G.Pautasso "Density Required for *Runaway* Electron Suppression in ITER (**AUG**)"
EX/P8-15: Y.Zhang "*Runaway Electron* Generation in Synergetic ECRH & SMBI in **HL-2A**"
OV/2-4: J.-G.Kwak "**KSTAR** "

Stabilization & Mitigation

EX/9-1 M.Lehnen "Impact and Mitigation of Disruptions with the ITER-like Wall in **JET**"
EX/P8-07: J.Berkery "Global Mode Control and *Stabilization for Disruption Avoidance* in High-Beta **NSTX** Plasmas"
EX/P8-08: F.A.Volpe "*Stabilization of Disruptive* Locked Modes by Magnetic Perturbations and Electron Cyclotron Current Drive at **DIII-D**"
EX/P8-09: R.Granetz "*Disruption Mitigation* Experiments with Two Gas Jets on **Alcator C-Mod**"

Prediction

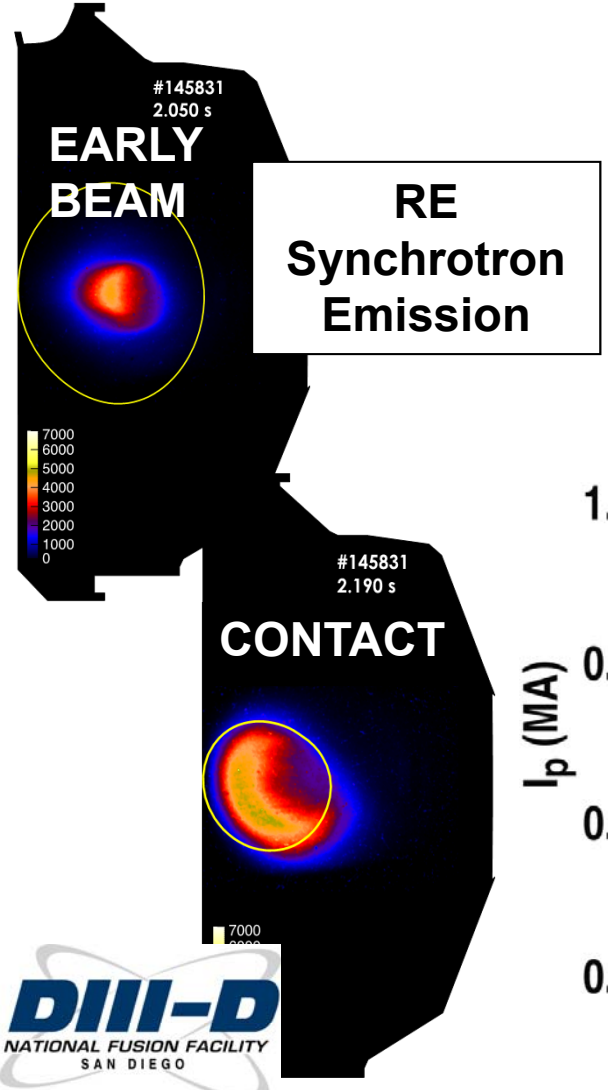
EX/9-3: S.P.Gerhardt "Disruptions in the High-beta **NSTX**"
EX/P8-04: A.Murari"Latest Developments in Data Analysis Tools for *Disruption Prediction* and for the Exploration of **Multimachine** Operational Spaces"
EX/P4-34: P.Savrukhin "Fast-scale Magnetic Perturbations and Onset of the Energy Quench during Disruption Instability in the **T-10** tokamak"

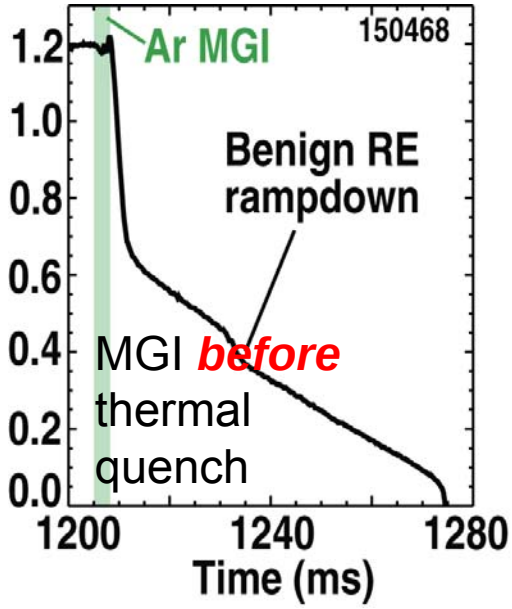
DIII-D experiments provide the physics basis for Runaway Electron control in ITER

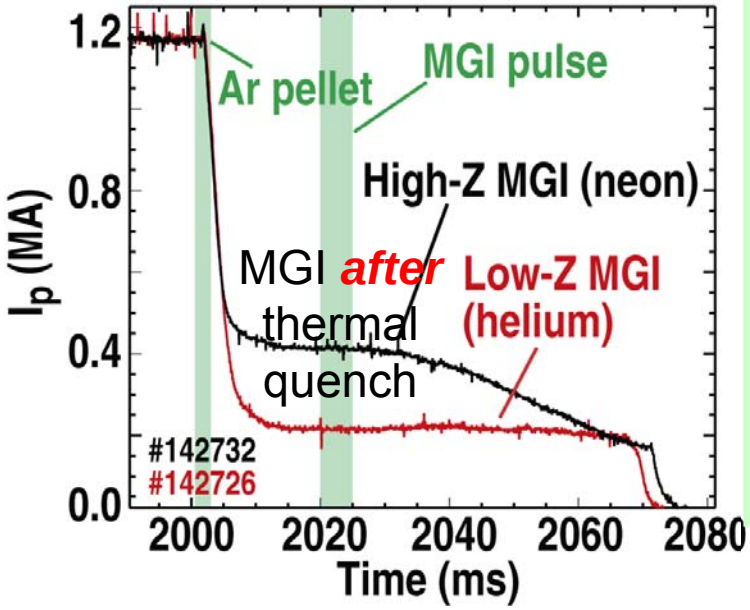
EX/9-2 E.M.Hollmann

High-Z gas injection increases RE dissipation

Radial stability provides time to dissipate runaways







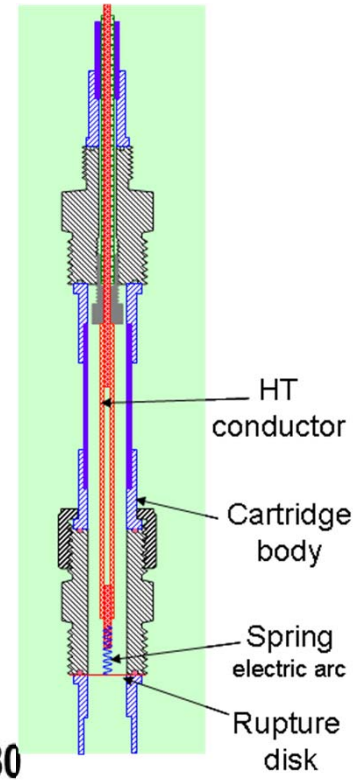
Tore Supra

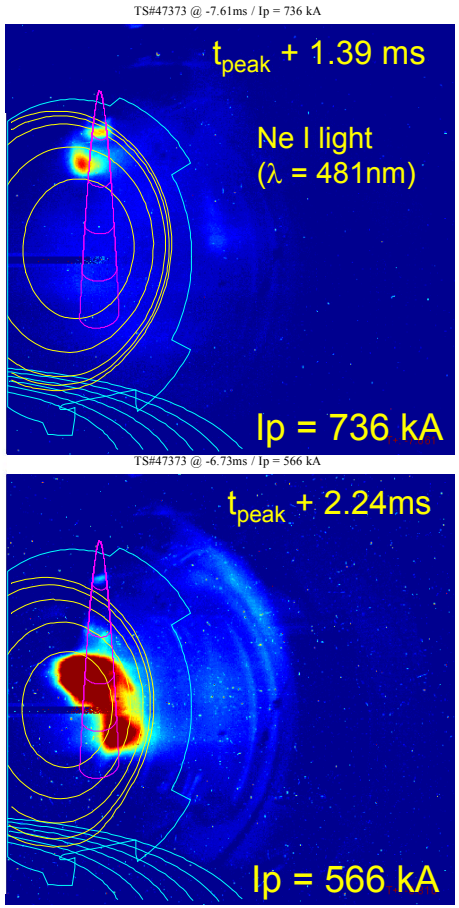
EX/P8-06: F. Saint-Laurent

New concept:

Bursting Disk Cartridge Injector

Neon gas injection into current quench plasma

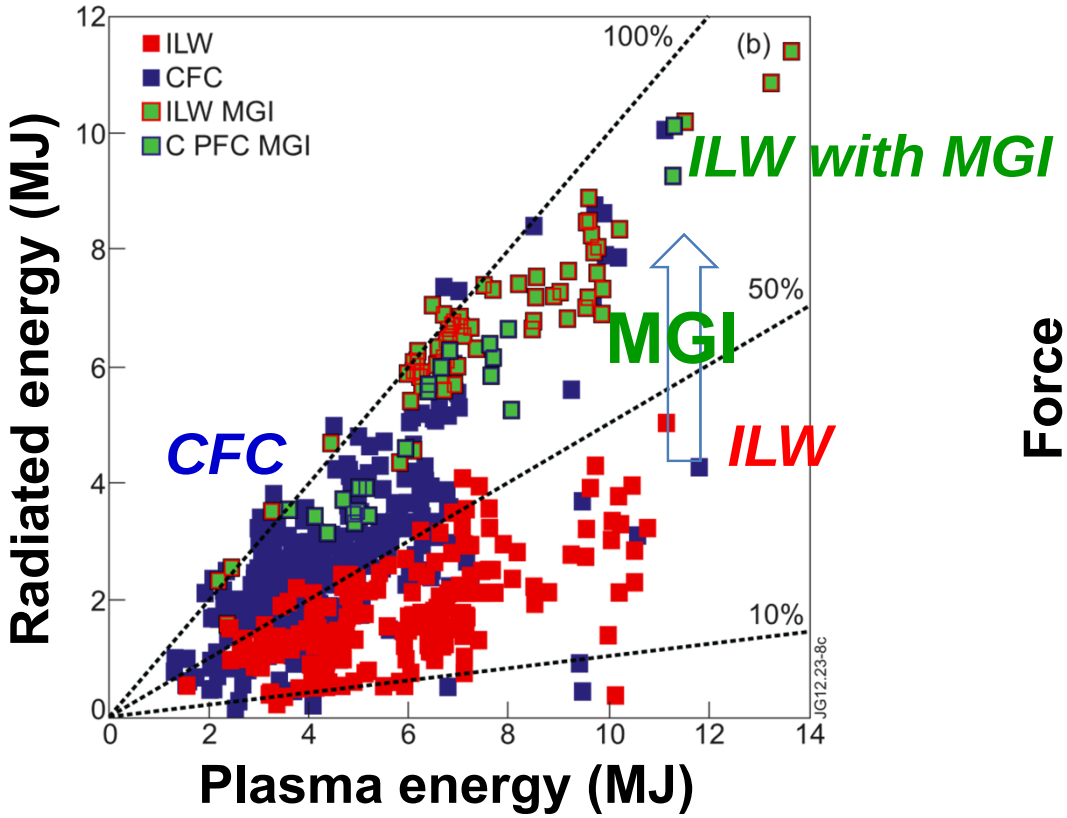


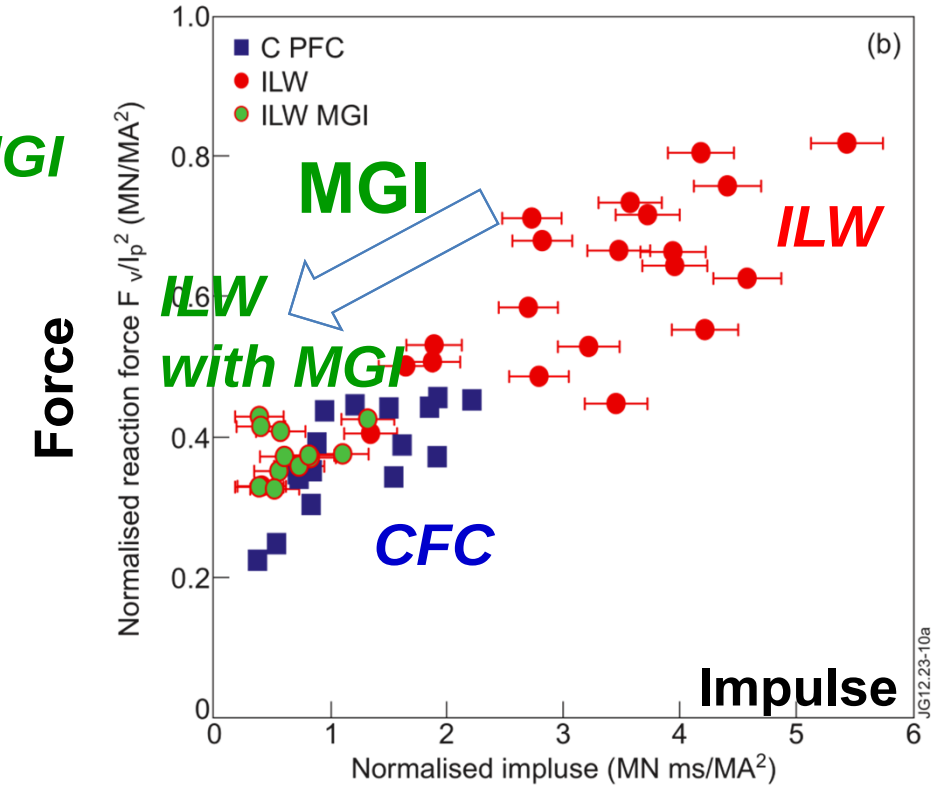


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Massive gas injection required to mitigate disruptions with the ILW

- The dynamics of disruptions are very different with the ILW
  ➔ Higher plasma purity ➔ lower radiation during disruption ➔….
- **Massive Gas Injection** as a disruption mitigation tool is now mandatory
- With the mitigation by MGI, the forces and power loads resulting from disruptions are returned to the level with C wall
- NO runaway electron formation in ILW



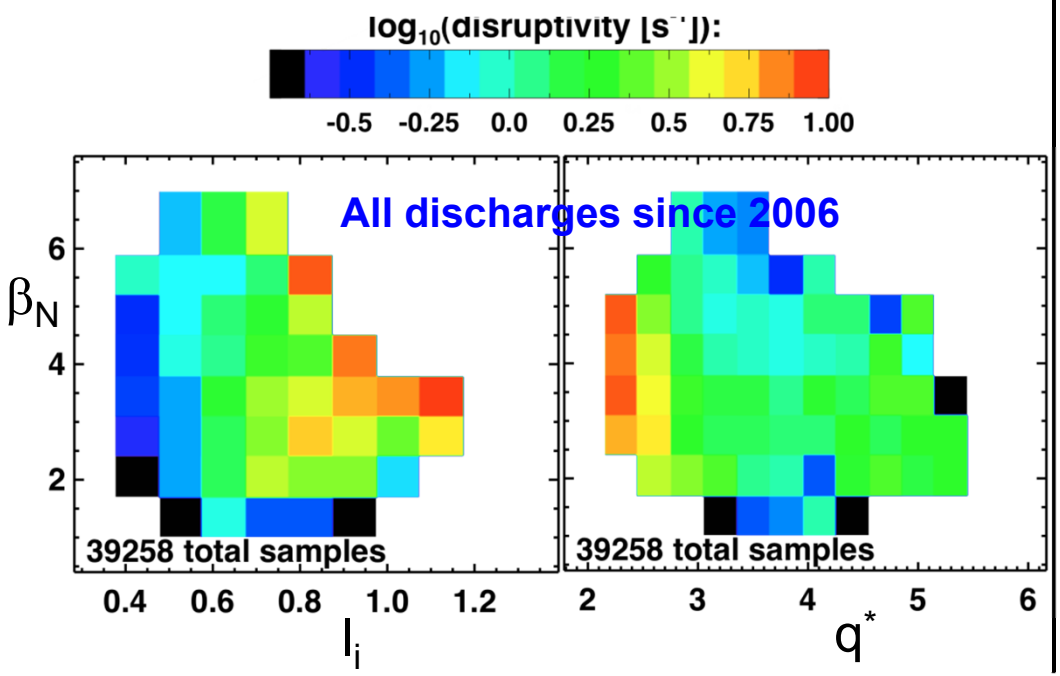


EX/9-1 M.Lehnen, EX/P8-4 A.Murari, EX/P8-05 V.V.Plyusnin

Disruptivity Studies and Warning Analysis of NSTX database are Being Conducted for Disruption Avoidance in NSTX-U

EX/9-3 S.P.Gerhardt

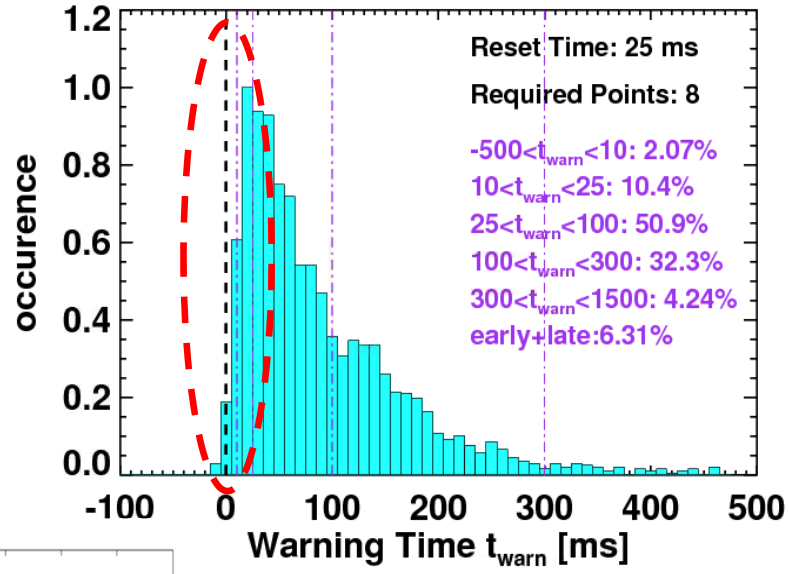
Disruptivity



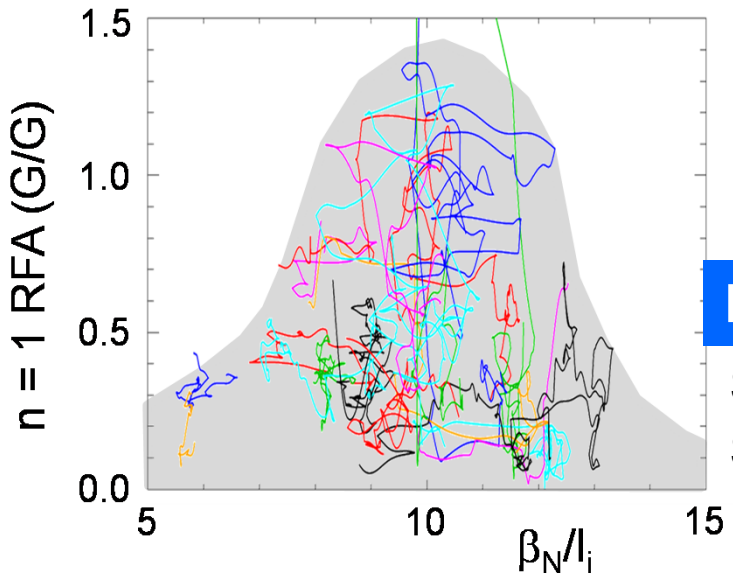
- Low disruptivity at relatively high $\beta_N \sim 6$; $\beta_N / \beta_N^{\text{no-wall}(n=1)} \sim 1.3\text{-}1.5$
- Consistent with specific disruption control experiments, Resonant Field Amplification analysis

Warning Algorithms

- Disruption warning algorithm shows high probability of success



~ 98% disruptions flagged with at least 10ms warning, ~ 6% false positives



EX/9-3 S.P.Gerhardt

Stability decreases up to $\beta_N/l_i = 10$

Stability increases at higher β_N/l_i

6. Effect of Flows on MHD instability

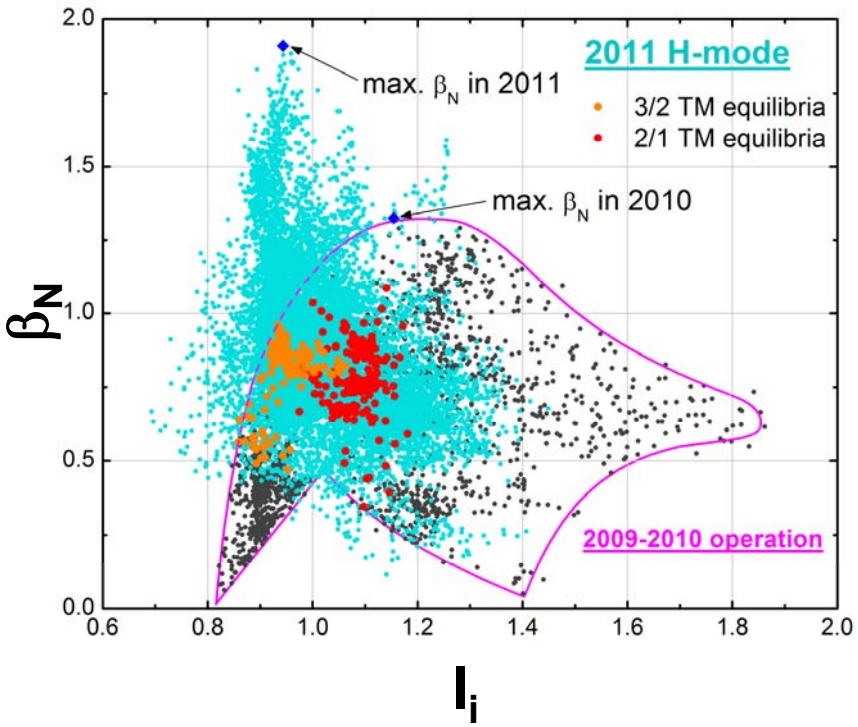
EX/P2-07: Y.-S.Park "Plasma Rotation Alteration and MHD Stability in H-mode of **KSTAR**"
EX/P4-22: Y.Lin "Neo-classical Tearing Modes in I-Mode Plasmas with ICRF Flow Drive on **Alcator C-Mod**"
EX/P4-26: Z.Ji "Modification of Toroidal Flow in the **STOR-M** Tokamak"
EX/P4-32: E. Lazzaro "Effect of "Natural" Rotation on Neoclassical Tearing Modes in **TCV**"
EX/P8-11: J.-C. Seol "Effects of RF-Heating Induced MHD Activities on the Toroidal Rotation in **KSTAR**"
EX/P8-14: J.Kim "The Effect of Toroidal Rotation on Sawtooth Activity in **KSTAR**"

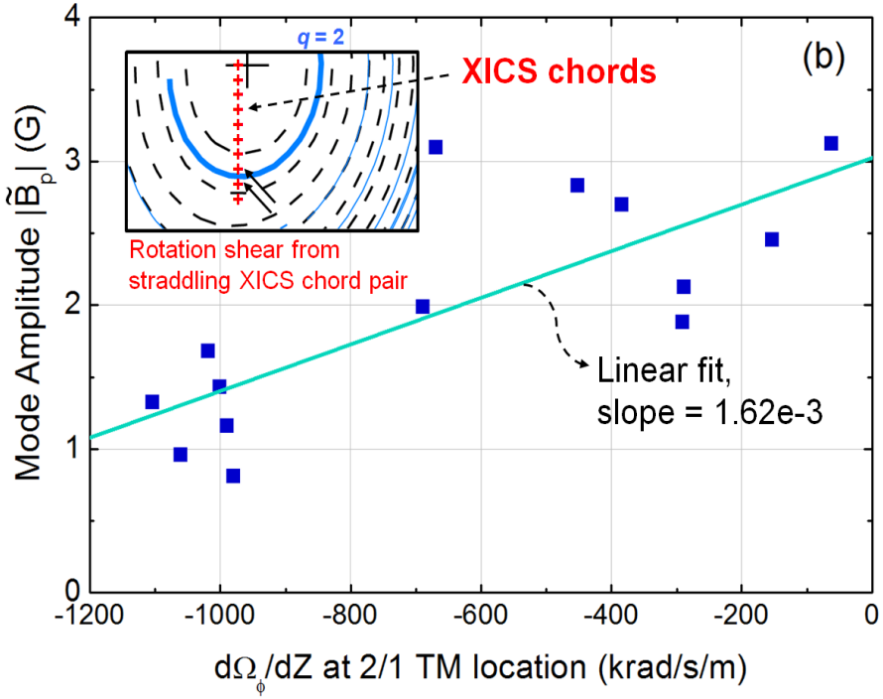
7. ST Start-up

EX/8-2: Y.Ono "High Power Heating of Magnetic Reconnection for High-Beta ST formation in **TS-3** and **UTST** ST Merging Experiments"
EX/8-3: V.K.Gusev "From **Globus-M** Results Toward Compact Spherical Tokamak with Enhanced Parameters"
EX/P2-10: R.Raman "Non-inductive Plasma Start-up in **NSTX** Using Transient *CHI*"
EX/P2-11: Y.Takase "Non-inductive Plasma Initiation and Plasma Current Ramp-up on the **TST-2**"
EX/P2-14: H.Zushi "Non-inductive Current Start-up by Means of Electron Cyclotron Waves in **QUEST**"
EX/P4-36: A.Redd "Local Helicity Injection Startup in the **Pegasus**"
EX/P6-18: M.Uchida "Noninductive Formation of Spherical Tokamak at 7 Times the Plasma Cutoff Density by Electron Bernstein Wave on **LATE**"

Investigation of Plasma Rotation Alteration and MHD Stability in the Expanded H-mode Operation of KSTAR

EX/P2-07 Y.-S.Park





- H-mode operation of KSTAR has been expanded toward higher β_N and lower l_i
- 3/2 & 2/1 tearing modes are characterized with their dependence on plasma rotation
- Alteration of rotation profile by applied n = 1, 2 non-axisymmetric fields initially demonstrated

ST merging produces bi-directional outflows, causing high-power~5MW reconnection heating. It transforms low-β STs into a high-β(~40%) ST with absolute min-B profile.

EX/8-2 Y.Ono

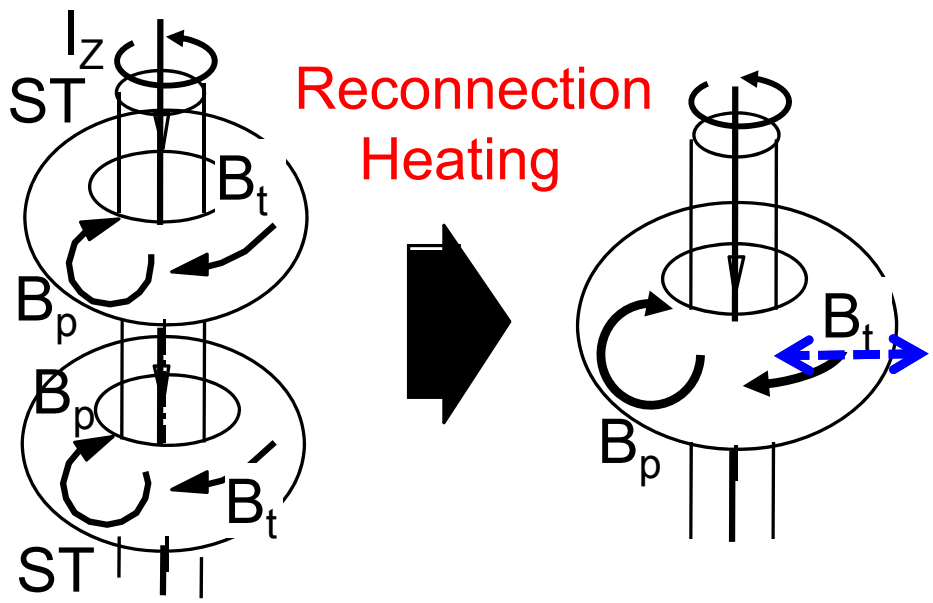
TS-3 Merging Experiment (U. Tokyo)

R~0.2m, a~0.15m, n_e~1-5x$10^{19}$$m^{-3}$

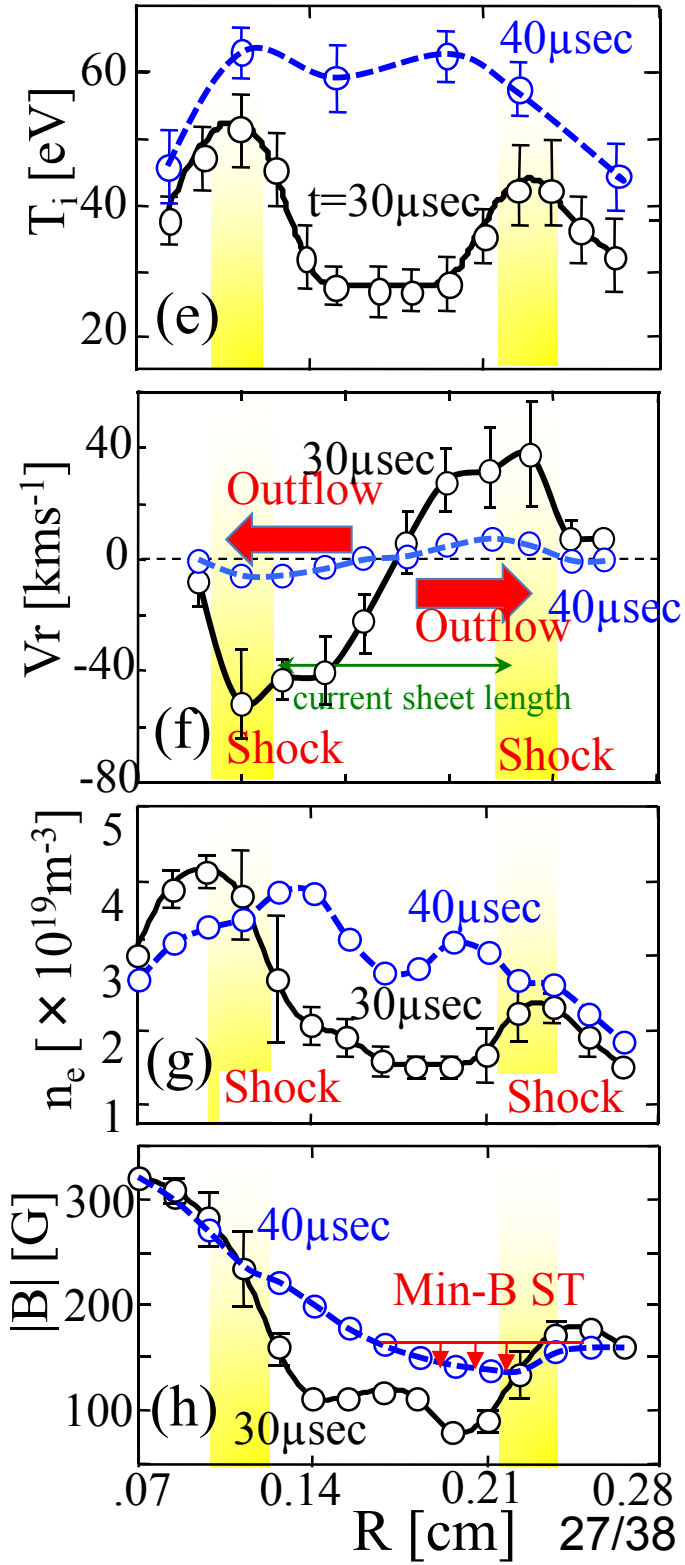
B~0.05T, T_i~10-250eV, T_e~10-20eV

Low-Beta ST β~5%

High-Beta ST β~40%

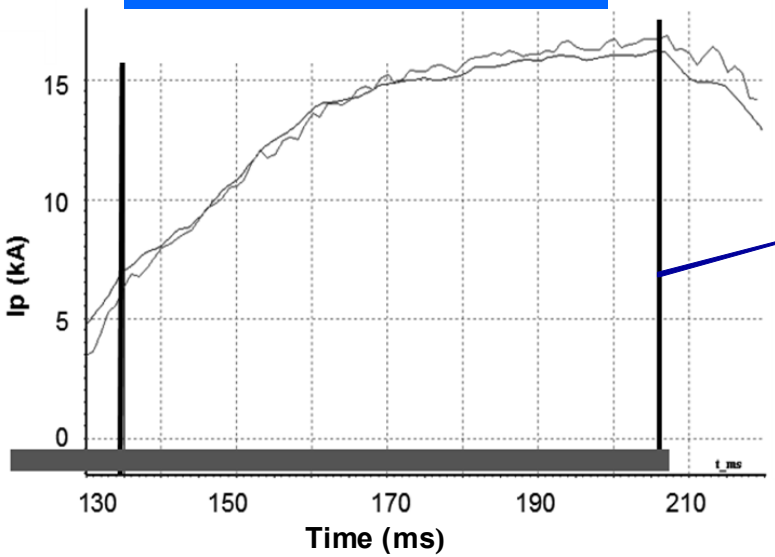


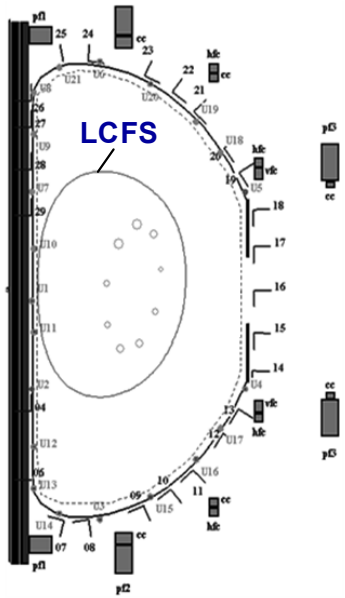
To be applied to MAST



The non-inductive current drive scenario development will be the focal point of Globus-M2 spherical tokamak programme

EX/8-3 V.K.Gusev





Globus-M (0.4 T)

non-inductive LHCD experiment (f =900 MHz, P_{RF}=60 kW)

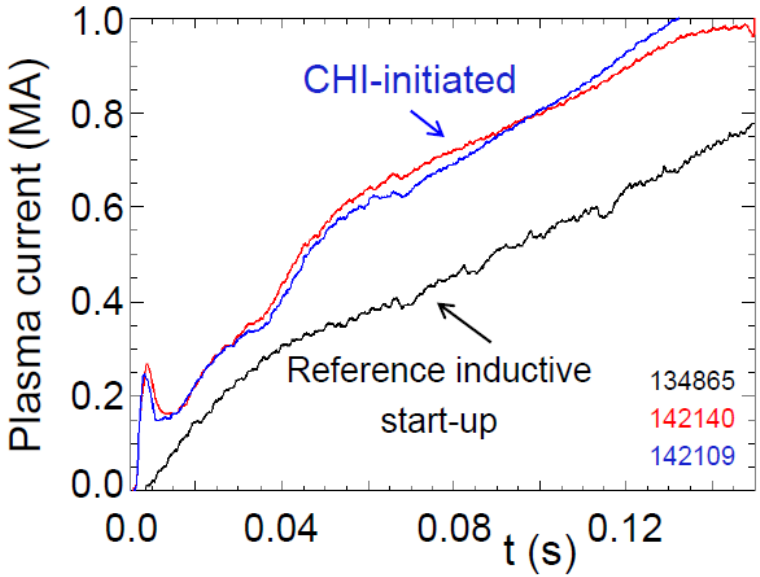
Left – measured and reconstructed plasma currents

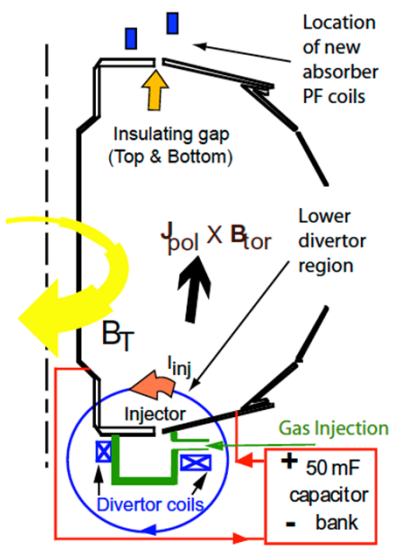
Right – magnetic reconstruction of LCFS

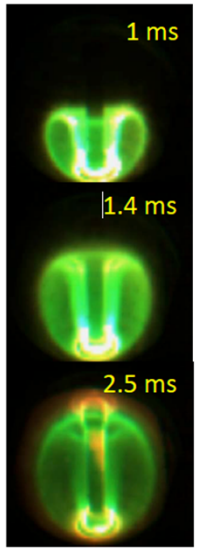
L-mode discharge ramping to 1MA requires 35% less inductive flux when coaxial helicity injection (CHI) is used

EX/P2-10 R.Raman

NSTX







8. Plasma Scenario (Real time control of MHD, Heating, CD)

Real Time Control of MHD Modes

High Power Heating in Metallic Wall

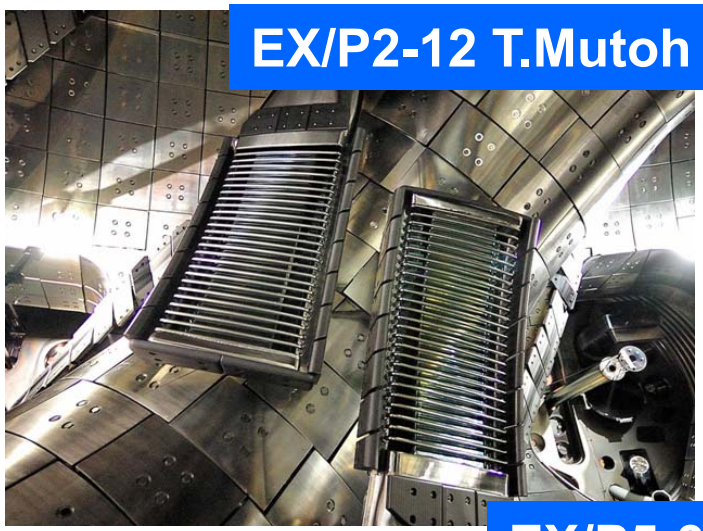
Steady State Operation (SSO) Scenario

Off-Axis NBI CD

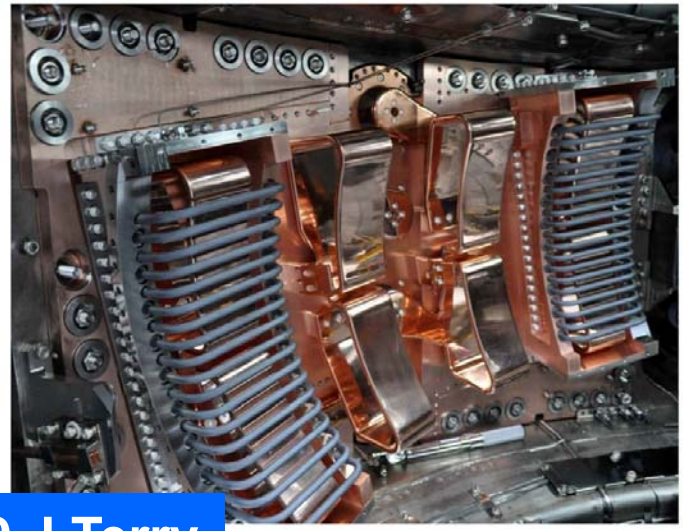
EX/P2-06: X.Gong "Integrated Operation Scenarios for Long Pulse Discharges in **EAST**"
EX/P2-08: G.L.Jackson "Long-pulse Stability Limits of ITER Baseline Scenario in **DIII-D**"
EX/P2-12: T.Mutoh "Steady State Operation Using ICH and ECH in **LHD**"
EX/P2-16: S.Shiraiwa "Progress toward Steady-state Regimes in **Alcator C-Mod**"
EX/P5-15: H.Guo "Steady-State Advanced Divertor Operations on **EAST**"

Phase-control ICRF in **LHD**

EX/P2-12 T.Mutoh

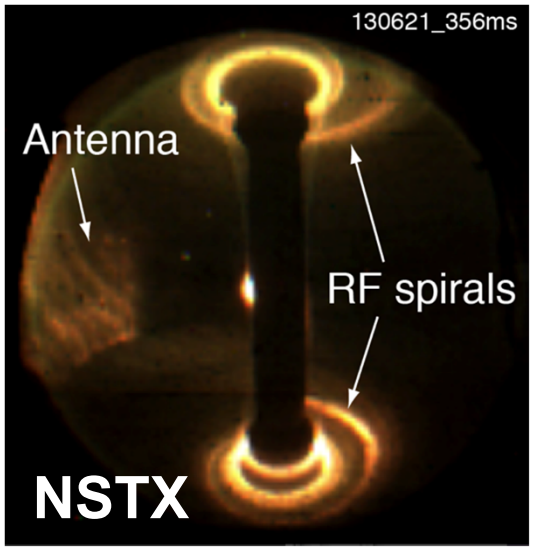


Field-aligned ICRF in **C-Mod**



EX/P5-39 J.Terry

EX/P5-40 R.J.Perkins



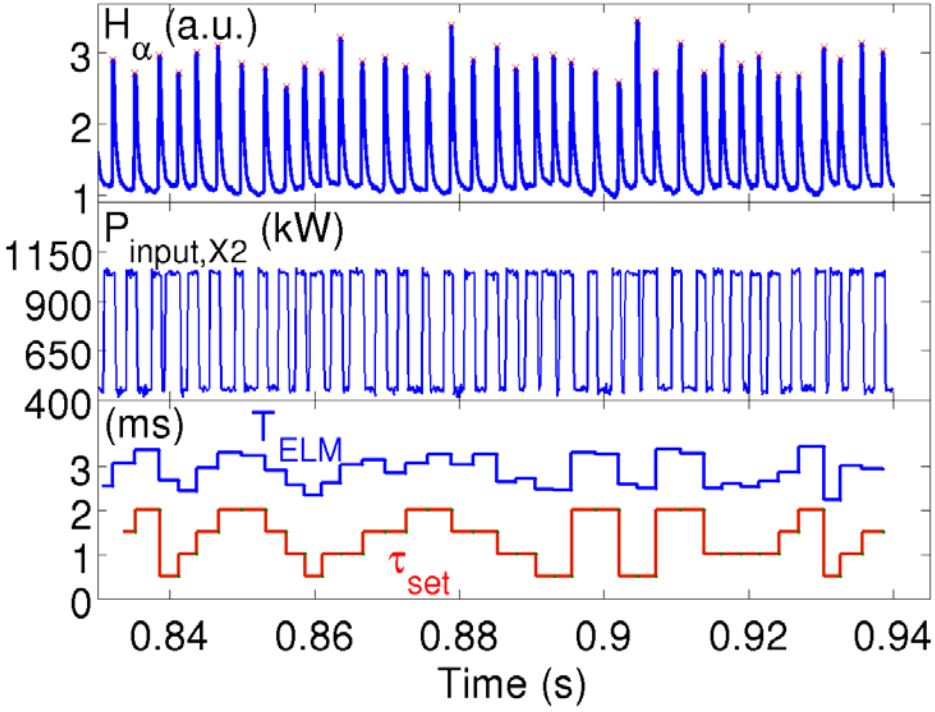
RF edge losses suggest FW propagation in SOL

← Dipole field: request to reduce RF sheath potentials

Real time ELM, NTM and Sawtooth control on TCV

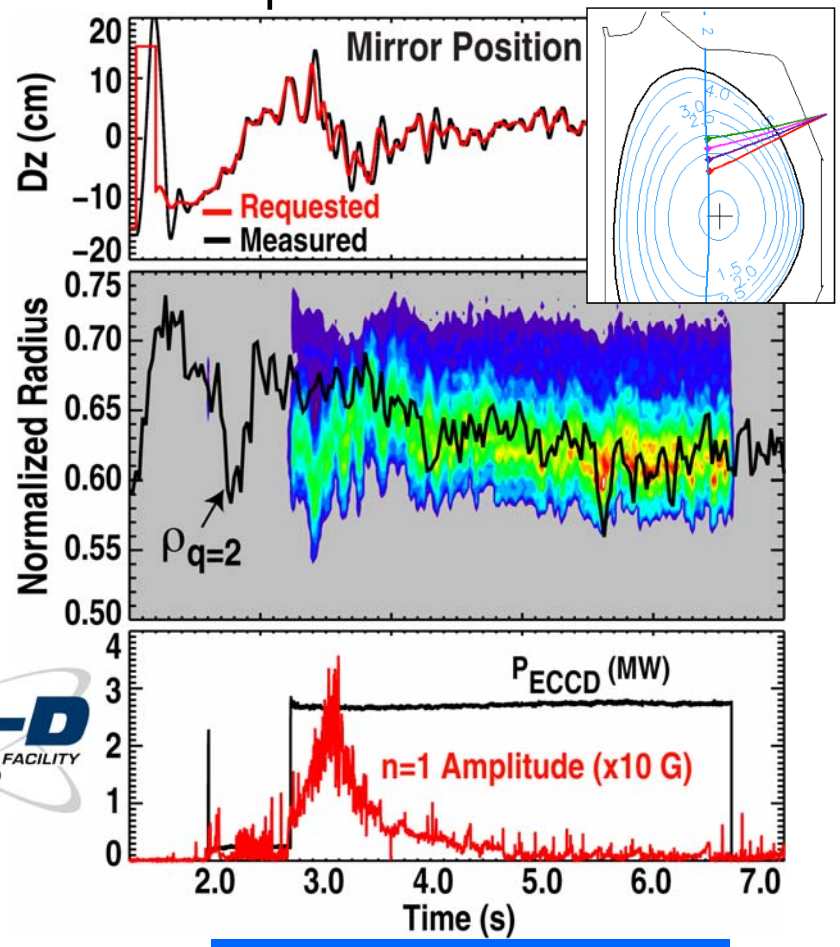
PD/1-1 E.Kolemen

ECRH triggers individual ELMs independently of preceding ones



For a given trigger sequence, the resulting ELM sequences are highly reproducible

- *Real-time* control of EC power and mirror steering provides complete stabilization of *m/n*=2/1 NTM
- Advanced control (MSE detection etc.) saves time and power



- NTM control with ECH: Long sawtooth period NTM stimulation

➔ Pre-emptive synchronous "healing"

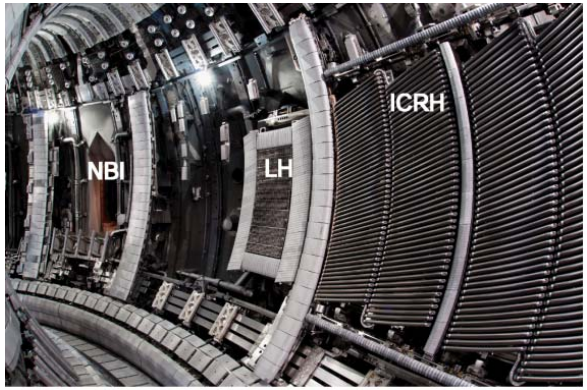
Real-Time ECRH/ECCD system to control NTM as well as sawtooth pacing with pulsed ECH also reported from **FTU**

EX/P6-04 C.Sozzi
EX/P4-20 S.Nowak

A safe application of the heating power and high performance scenario development in a metallic wall

On the Challenge of Plasma Heating with the JET Metallic Wall

EX/4-3 M.-L. Mayoral



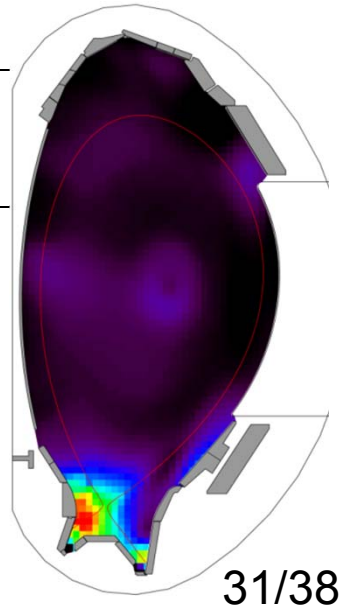
- **Neutral beam Injection**
  - Upgraded to increase power, pulse length & reliability ➔ 25.7MW record power; 15s pulse ➔ 34MW planned
- **Ion Cyclotron Resonance Heating**
  - Private & surrounding limiters changed to Be ➔ 4MW in H-mode
  - Bulk radiation higher than for NBI ➔ mainly due to higher W & Ni levels (80% & 20% of additional radiation)
  - Higher W concentration observed with ICRH but sources not yet identified

EX/P5-19 V.Bobkov

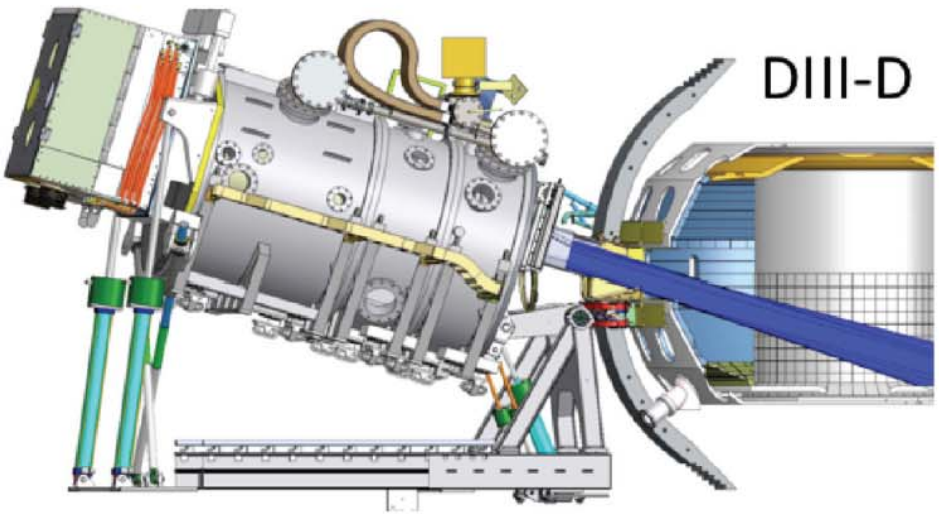
High performance discharges with P/R = 14 MW/m in AUG

IPP

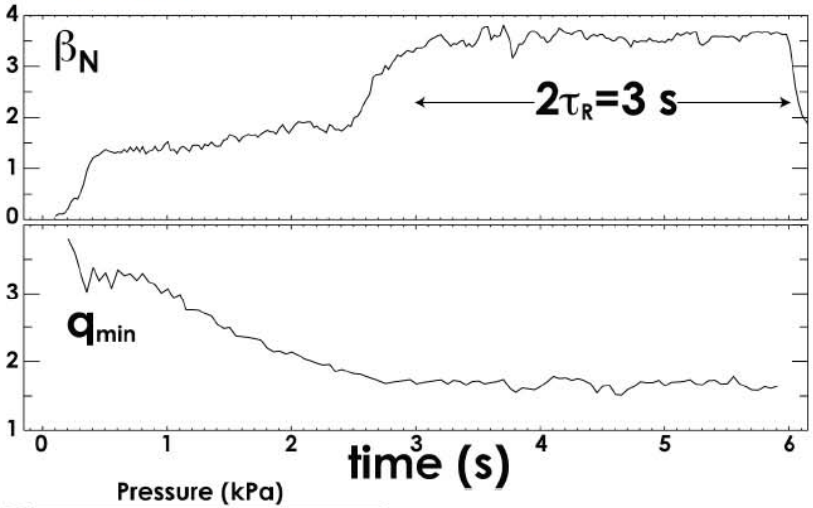
- NBI+ECRH+ICRH of 23 MW with nitrogen puff to control divertor radiation
- Total radiated power: 20 MW Divertor radiation: 9 MW
- Divertor heat load < 5 MW/m^2 at H ≈ 1; $\beta_N \approx$ 2.8
- 4 MW ICRH: progress on ICRH compatibility with the W wall



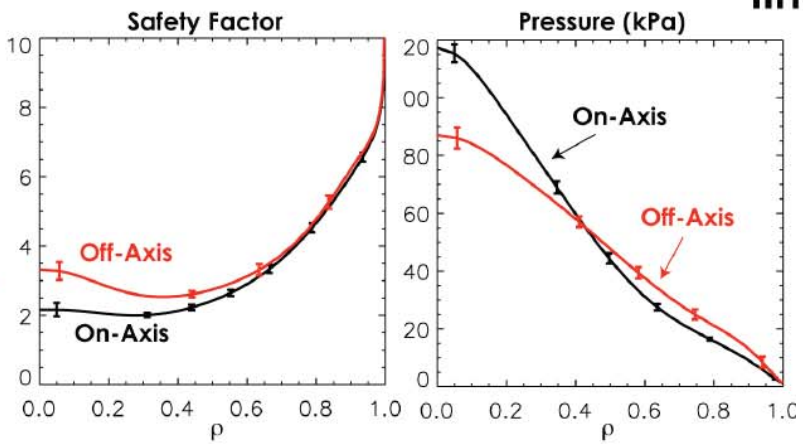
DIII-D is Using Off-Axis Neutral Beam Injection to Develop & Test Scenarios for High β_N, Steady State Operation

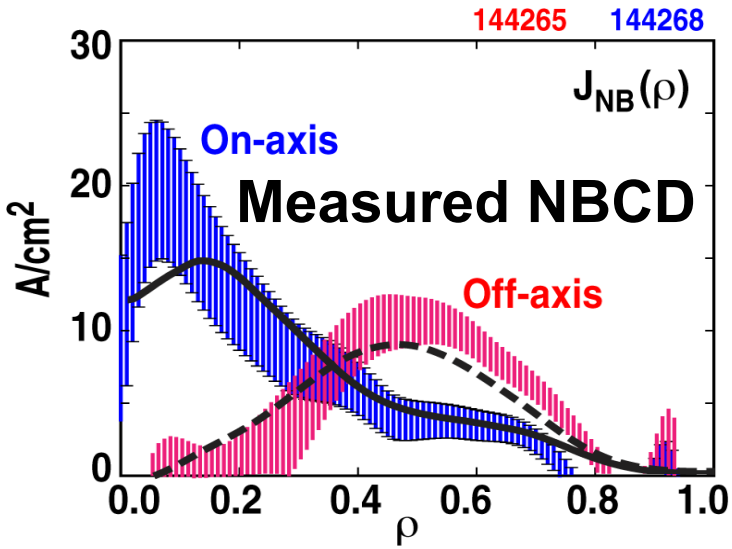


Demonstrated quasi-stationary scenario with performance that projects to Q=5 in ITER-sized device



Improves access to high q_{min} & broad pressure where modeling predicts higher ideal MHD β_N limits



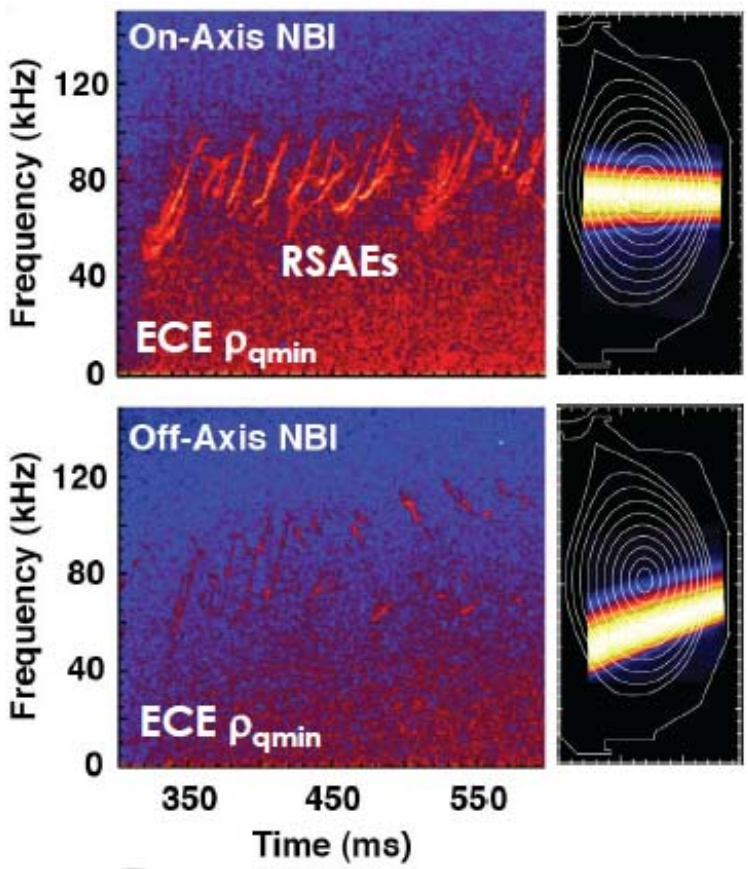


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

EX/1-5 C.T. Holcomb
EX/P2-13 J.M.Park

9. Waves & Energetic particles

EX/P6-22 W.W.Heidbrink



DIII-D: Off-Axis NBI allows variation of Alfvén Eigenmode drive and tests of stability models

EX/P6-06 M.Turnyasnkiy

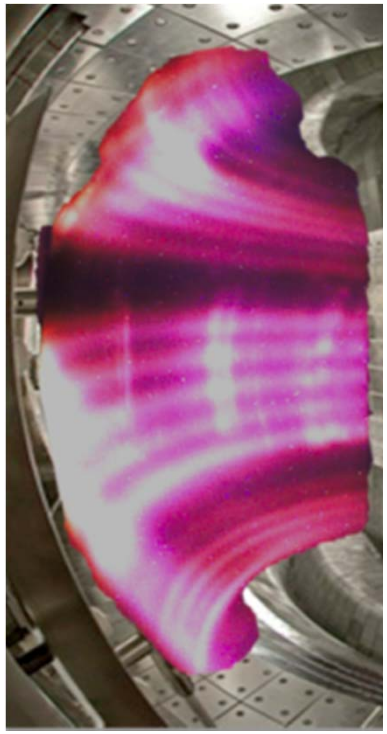
Off-axis NBCD in MAST

- close to classical
- broadens fast ion distribution, reducing fishbone modes and reducing redistribution of fast ions

PD/P8-09 Y.Liang

Edge magnetic topology change induced by LHCD in EAST

Helical Radiation Belts lead to the splitting of divertor strike points with similar effects to RMP.



EXP/P4-33 J.-K.Park

NSTX: Optimized HHFW can drive EHOs with larger displacements, which can be used to control ELMs

Waves & Energetic particles (continued)

Energetic Particle Driven Mode

EX/P6-02: N.Croker "CAEs and GAEs in **NSTX**"
EX/P6-05: E.Fredrickson "Fast-ion Energy Loss during TAE Avalanches in **NSTX**"
EX/P6-07: Z.Guimaraes Filho "Electron Fishbones in LHCD Plasmas on **FTU** and **Tore Supra**"
EX/P6-09: M.J.Hole "Analysis of Alfvén Wave Activity in **KSTAR**"
EX/P6-14: L.Yu, "E-Fishbone during High Power ECRH on **HL-2A**"
EX/P6-15: X.Ding "Alfvénic Modes Induced by Energetic Electrons with ECRH on **HL-2A**"
EX/P6-23: B.Blackwell "MHD Activity in the Alfvén Range of Frequencies in **H-1NF** Heliac"

Electron Bernstein Wave

EX/P6-16: Y.Yoshimura "EBW Heating in **LHD**"
EX/P6-17: H.Idei "EBW Heating and Current Drive Effects in **QUEST**"
EX/P6-18: M.Uchida "Noninductive Formation of ST by EBW on **LATE**"

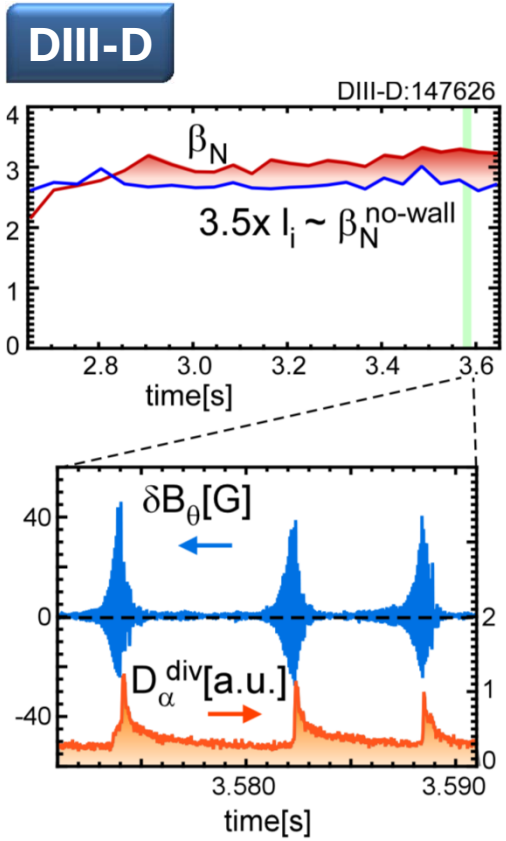
Lower Hybrid Wave

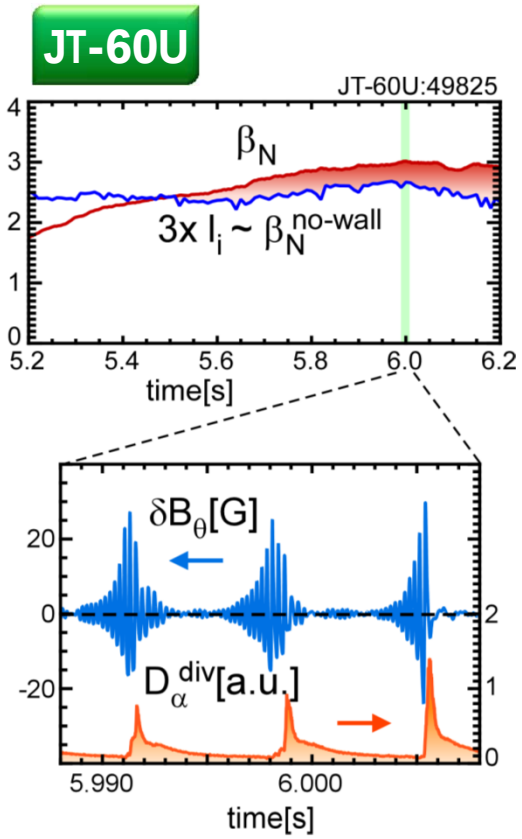
EX/P6-21: B.Ding "LHW-plasma Coupling and Current Drive in H-mode Experiments in **EAST**"
EX/P6-24: J.Hillairet "Lower Hybrid Current Drive and Implications for ITER (**ToreSupra**)"
EX/P6-29: R.Cesario "Lower Hybrid Current Drive in High Density Tokamak Plasmas (**FTU**)"

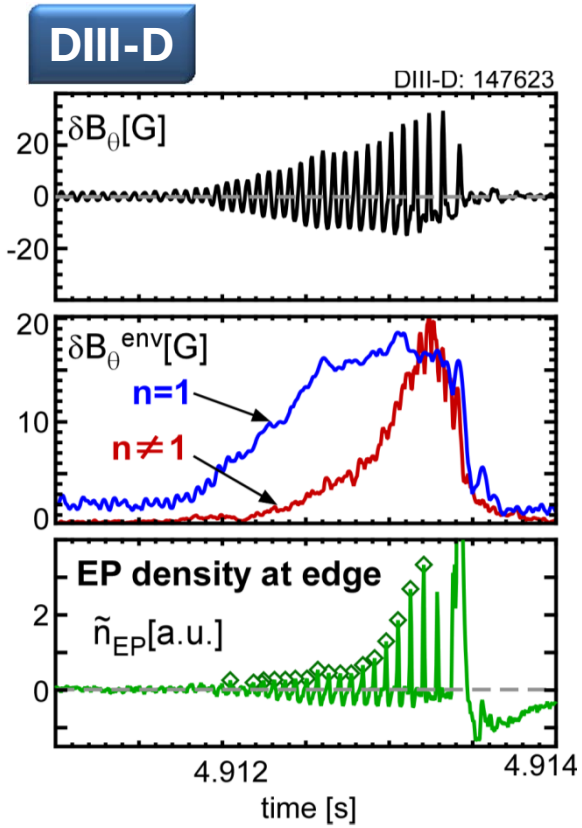
Dynamics of Energetic Particle driven Modes in wall-stabilized high beta plasmas on JT-60U and DIII-D

EX/5-1 G.Matsunaga

- **ELM triggering by EP driven modes is observed in JT-60U and DIII-D**







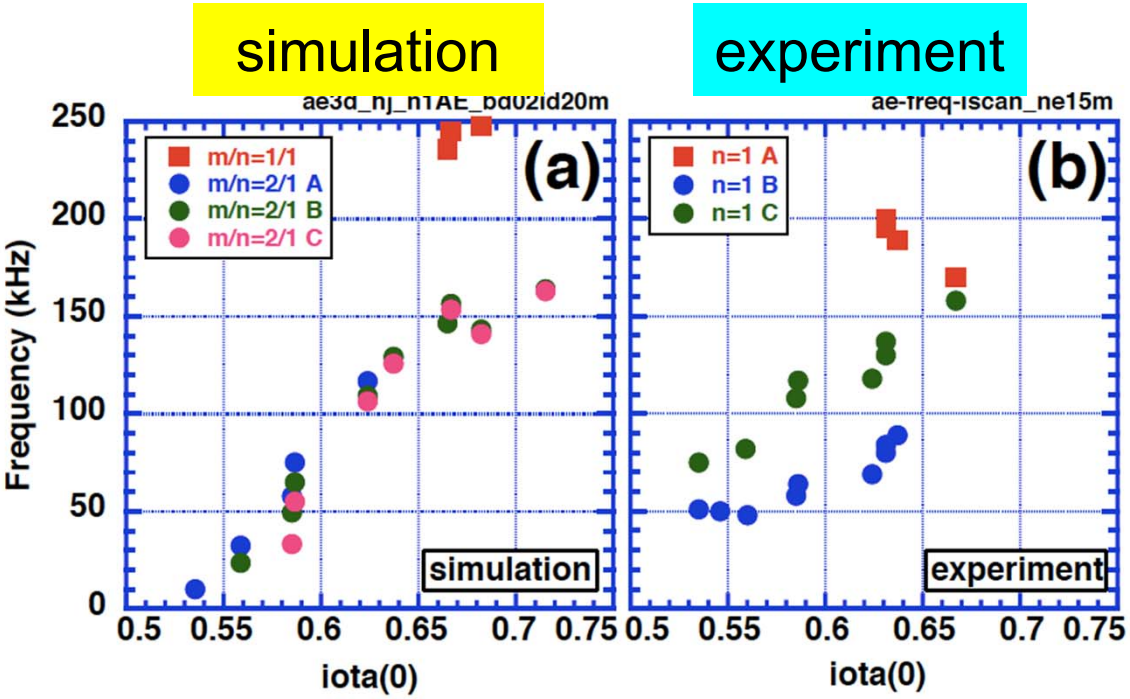
EP driven modes (EPdMs)
DIII-D : Off-axis Fishbone Mode (OFM)
JT-60U : Energetic particle driven Wall Mode (EWM)

- **ELM triggering by EPdMs occurs with strong distortion (n≠1) amplitude,**
- **EP transport to edge by EPdMs affects edge ELM stability.**

Studies of Energetic-ion-driven MHD Instabilities in Helical Plasmas with Low Magnetic Shear

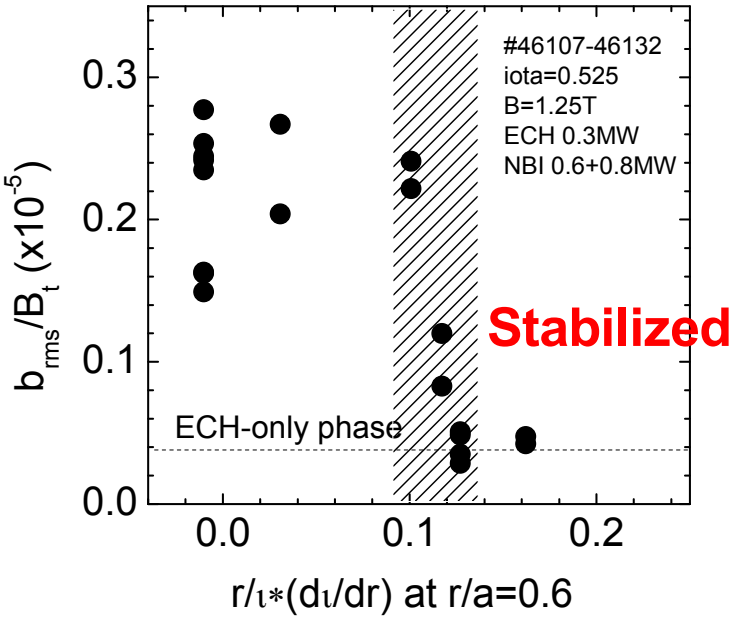
EX/5-2 S.Yamamoto

- In order to clarify the energetic-ion-driven MHD instabilities in ***helical plasmas with low magnetic shear*** : **Heliotron J** with low iota and **TJ-II** with high iota.
- Results of iota scan experiments in both devices indicate that ***GAEs are mainly destabilized in low shear helical plasma and HAEs are destabilized in high iota configuration.***



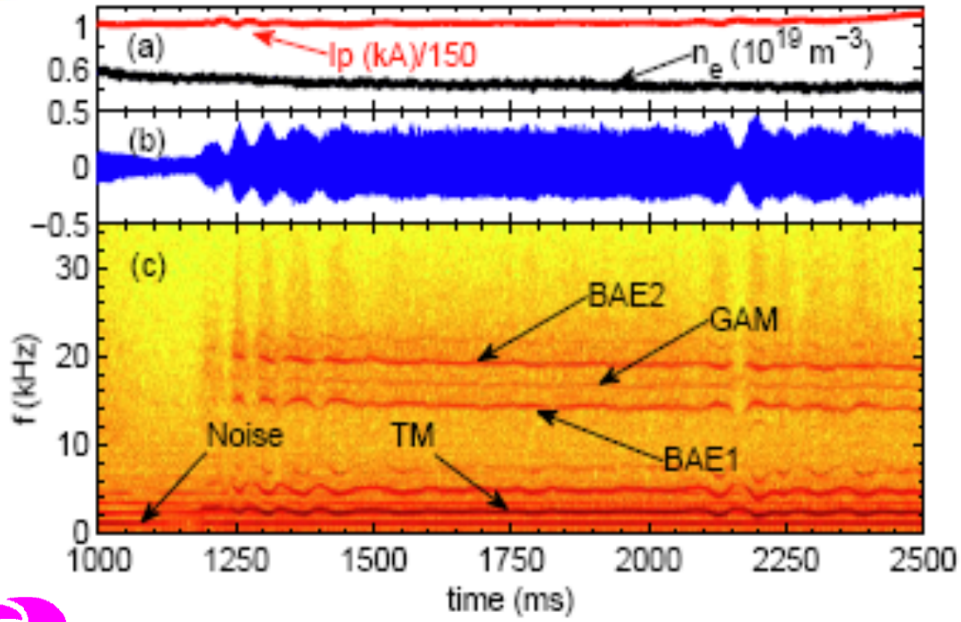
EX/P8-10 K.Nagasaki

EPMs are suppressed when the magnetic shear exceeds threshold by ctr-ECCD in **Heliotron-J**



Multi-mode Co-existence of e-BAE

HL-2A



EX/5-3 W.Chen

A new mode is excited during strong TMs+BAEs with GAM in Ohmic plasmas. Its mode-numbers are m/n=2/0, and f~=f_BAE.

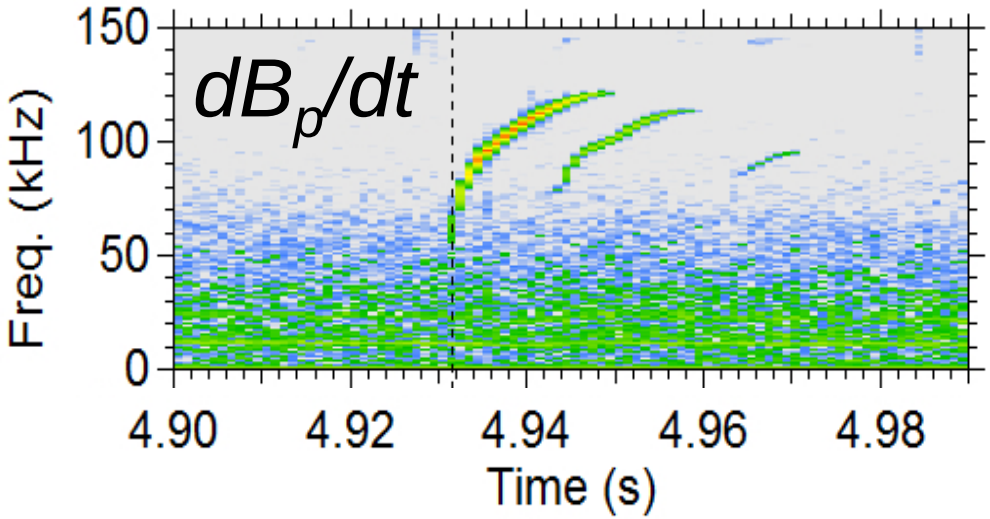
The GAM is localized in the core, and is different from one excited by the drift-wave turbulence in the edge plasma.

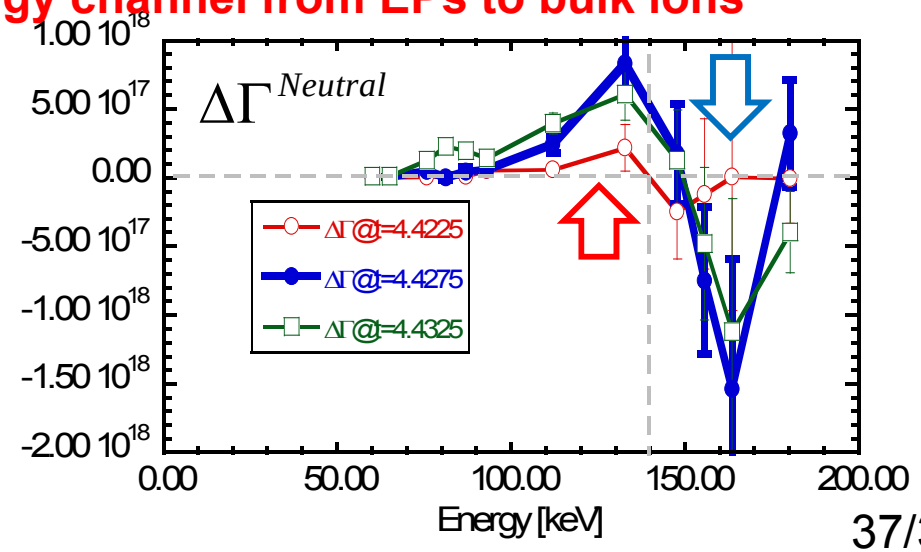
Energy transfer between ions and the GAM is observed

LHD

PD/P8-16 T.Ido

- During the burst of the GAM, the energetic ions lose the energy, and the ions in the lower energy range gain the energy.
- **The GAM can become an efficient energy channel from EPs to bulk ions**





Concluding Remarks

JJ in 2010 " The experimental results can be qualitatively understood but ……. The extrapolation to ITER requires a more accurate knowledge of the plasma...."

- ✓ Understanding of experimental results has remarkably progressed, in particular, in RMP (3-D plasma response) and ILW

  PWI used to be out of scope, but now it is a super-critical topic

- ✓ Still need tenacious efforts to get a more accurate and comprehensive knowledge to extrapolate to ITER and beyond.

  "ITER relevant" could be lighthearted wording. Backcast how to resolve issues. Identification of the bridging mechanism between the actuator and the consequence, otherwise, no reliable application to ITER/DEMO

- ✓ New interesting findings (GAM channeling ?, Edge modification of LHW, etc.)

Fusion community has to prepare resolutions in time to lead ITER to success. Any single experiment cannot resolve the issue. Rally all kindred to resolve critical issues ➔ reconstruct categories in IAEA-FEC

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Science & Technology is an eternal challenge to approach the truth & the perfect. ***A chance would arrive at the most prepared one !***