Progress & Developments on MAST

Brian Lloyd for the MAST Team
& Collaborators

EURATOM / CCFE Fusion Association

Research Councils UK Energy For a Low Carbon Future

CCFE is the fusion research arm of the **United Kingdom Atomic Energy Authority**

Jointly funded by EURATOM & RCUK Energy Programme

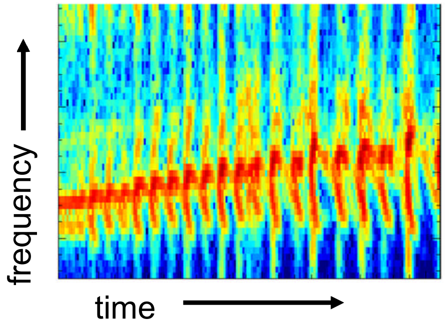
CCFE CULHAM CENTRE FOR FUSION ENERGY

Fast ion physics

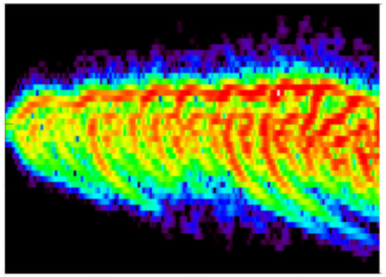
- Fast particle driven modes in MAST cover a broad frequency range
  - Alfvén Cascades (RSAE) → TAE ($\omega \sim v_A/2qR$) → CAE ($\omega \sim \omega_{ci}$)

- Dynamical friction important for describing nonlinear wave evolution with distribution of super-Alfvenic fast ions
– i.e. α-particles in ITER & DEMO and beam ions in MAST ($v_b >> v_A$)

- Drag and Krook relaxation have been introduced into HAGIS (non-linear drift-kinetic δf code) – quantitative comparison with MAST data underway



Frequency sweeping TAE in MAST #22807

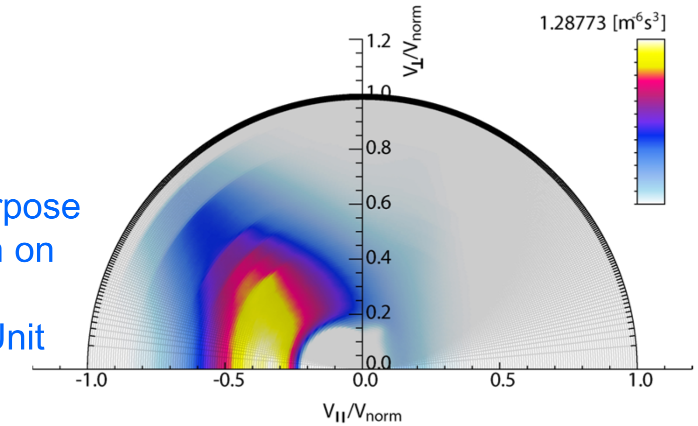

Realistic tokamak simulation of α-driven n = 3 core localized TAE using HAGIS

S Pinches, S. Sharapov, M. Lilley (Chalmers U.), B. Breizman (U. Texas) et al

Fast ion simulation

- GPGPU: supercomputer on desktop.
- Fast particle physics needs detailed distribution functions for
  - fusion product diagnostics (e.g. neutron cameras, proton first orbit detectors)
  - drive for and loss due to instabilities (e.g. HAGIS code)
- Full orbit, high resolution. Fast: 2 million orbits in ~6hrs.
- LOCUST-GPU calculates gyro-phase resolved, high resolution, smooth, fast ion distribution functions suitable for fast ion stability calculations – development of synthetic diagnostics to interpret neutron camera and FIDA data underway

GPGPU = General Purpose computation on Graphics Processor Unit

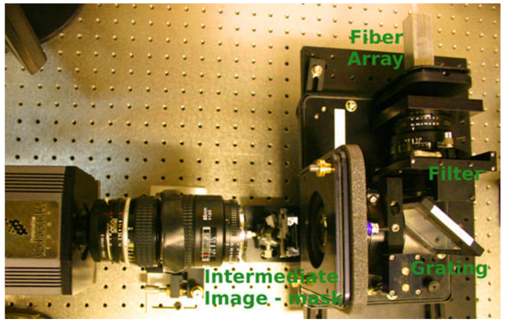


4 "gamer" GTX480 Fermi cards.

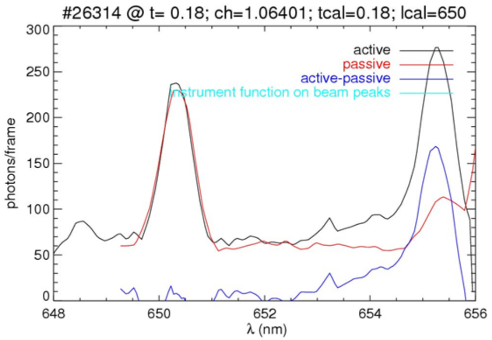
MAST steady-state fast ion distribution function. Two beams including E0, E0/2 E0/3 species (6 in all)

R. Akers

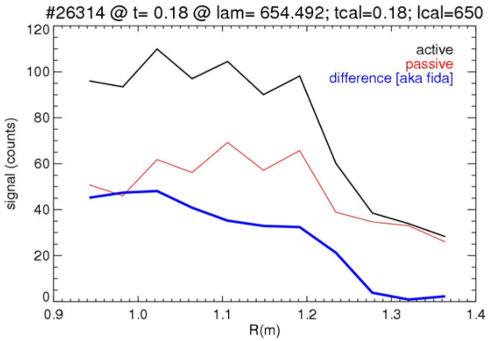
Fast ion Dα (FIDA)



- Vertical and toroidal views - sensitive to passing & trapped populations.
- Background views to exclude edge D_α
- 32 fibres/view (~ 2cm between channels) with patch panel. 24 channels [2 x 12]; time resolution: 0.28ms
- Spectral shape gives information on energy/pitch distribution and allows exclusion of impurity/beam emission lines.
- System designed to give fast spectral information at the expense of spatial resolution in order to follow fast events e.g. fishbone instabilities.



Spectra

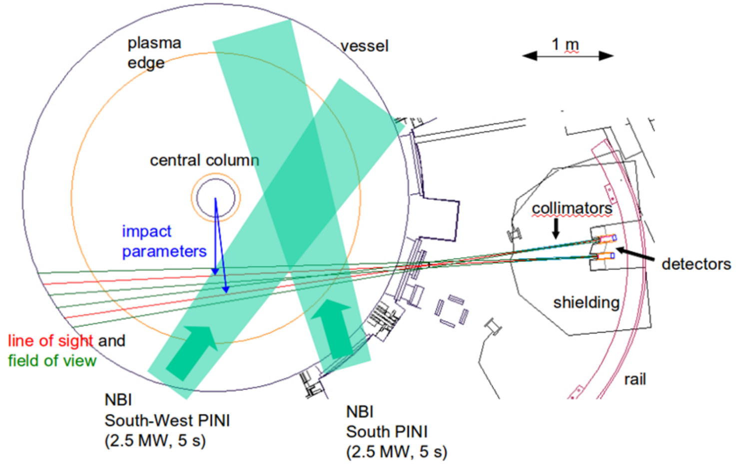


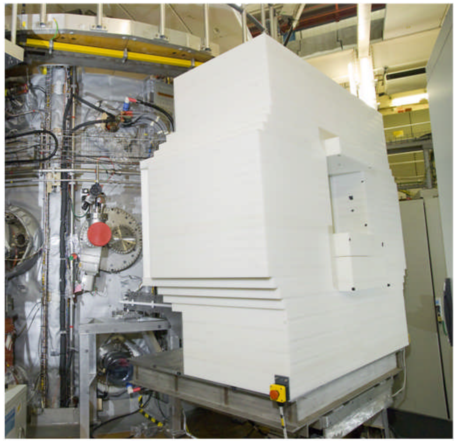
Profiles

- First FIDA data look promising

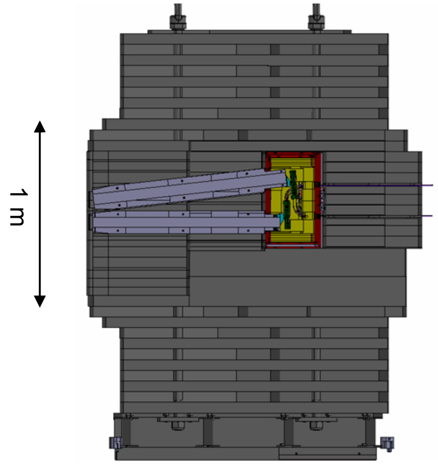
C. Michael et al

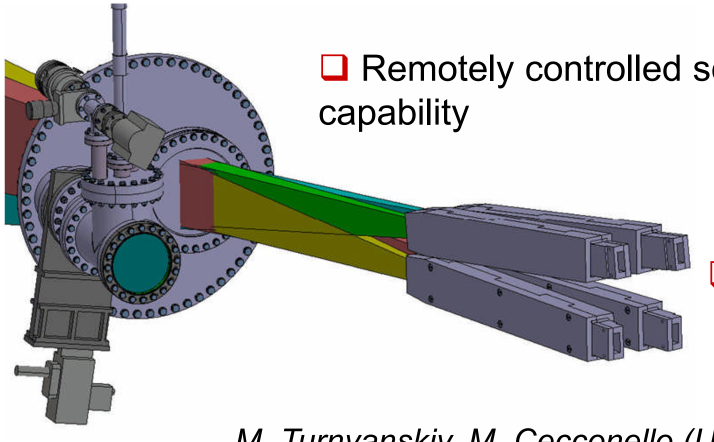
Neutron camera





UPPSALA UNIVERSITET

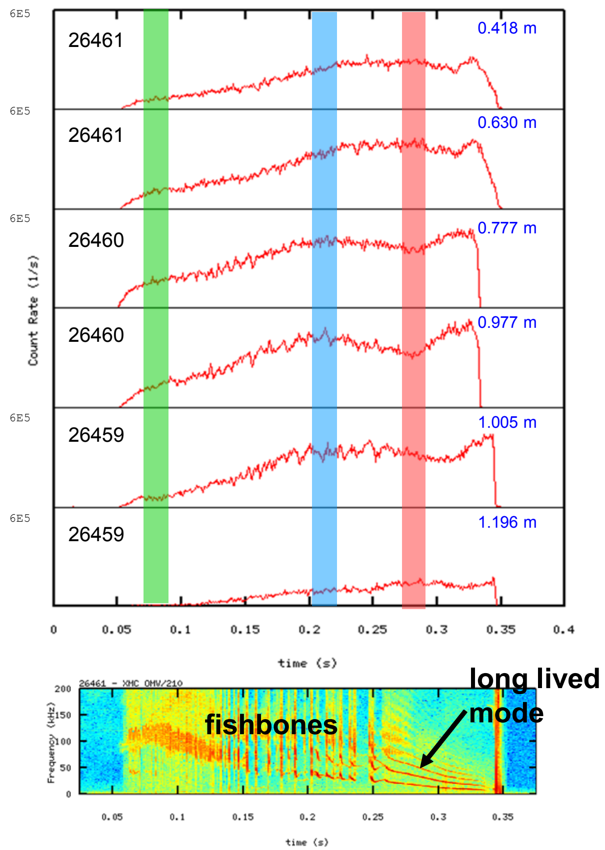




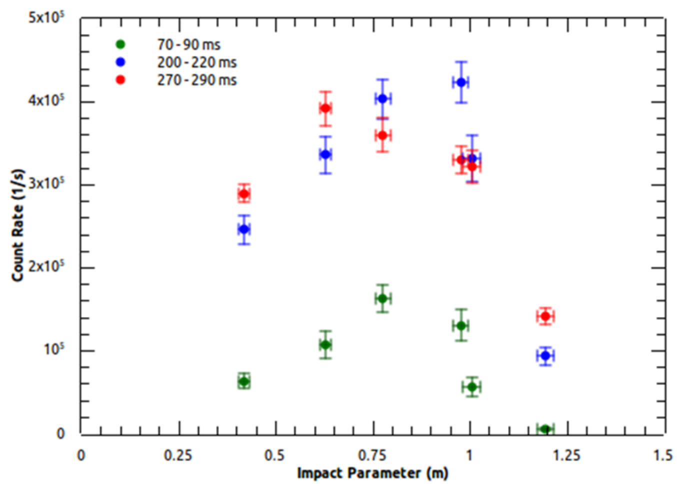
- Remotely controlled scanning capability
- 4 channels

M. Turnyanskiy, M. Cecconello (Uppsala) et al

Neutron emission measurements

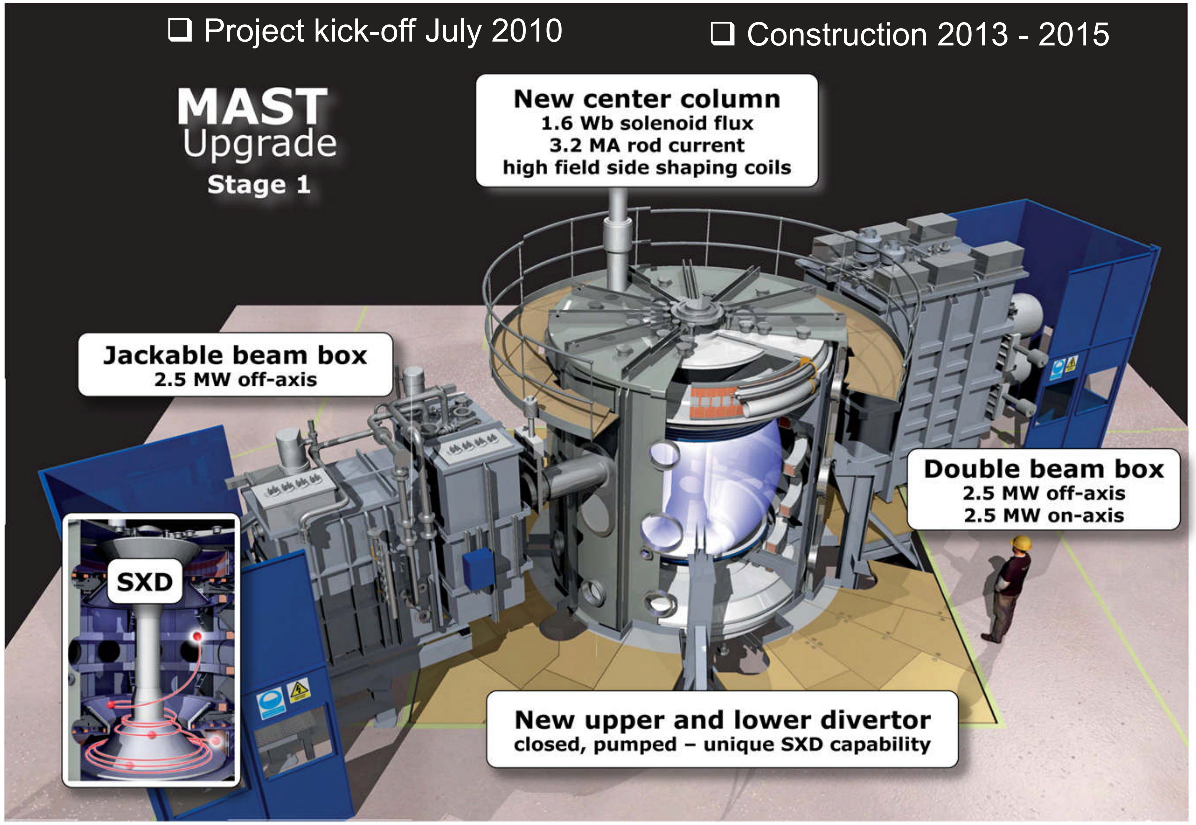


- Effects of 'fishbone' instabilities and the long lived mode (internal n = 1 kink mode)

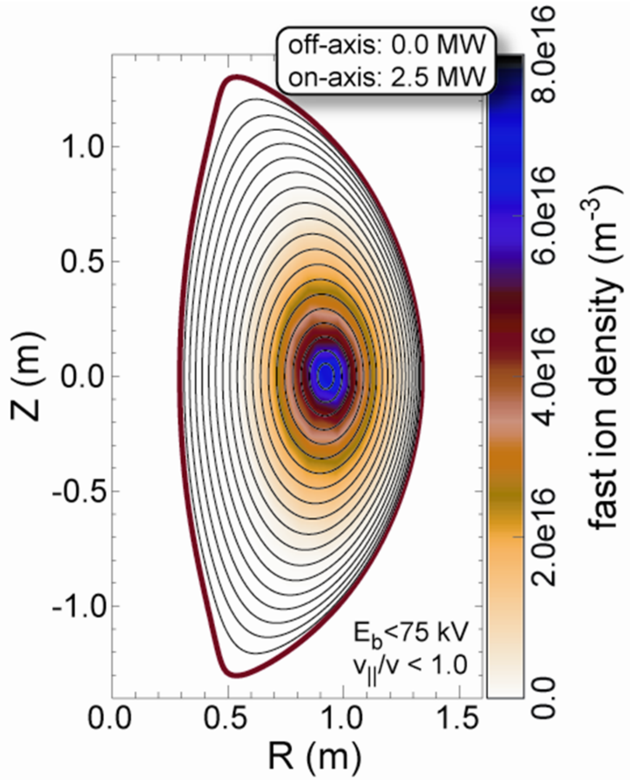


M. Turnyanskiy, M. Cecconello (Uppsala) et al

MAST Upgrade



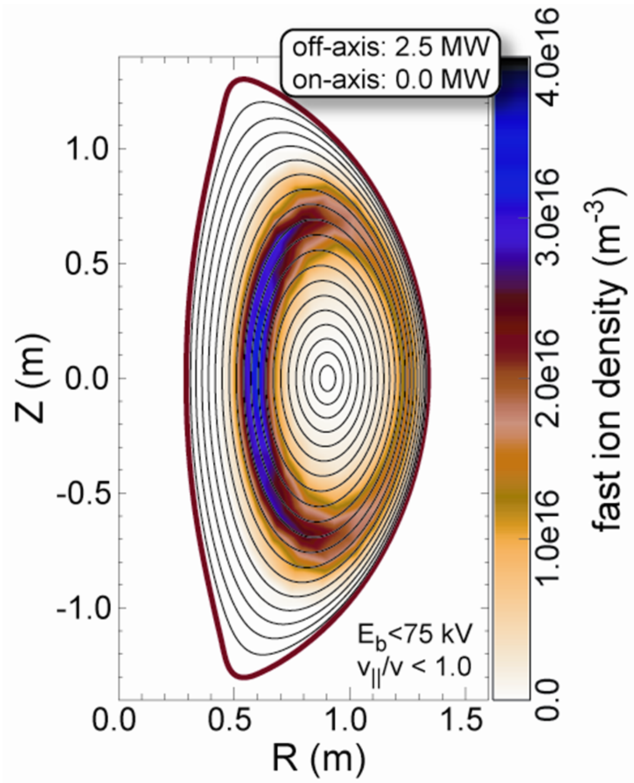
Flexibility on fast ion density profiles



Advanced profile control

- On-axis ⇒ peaked.

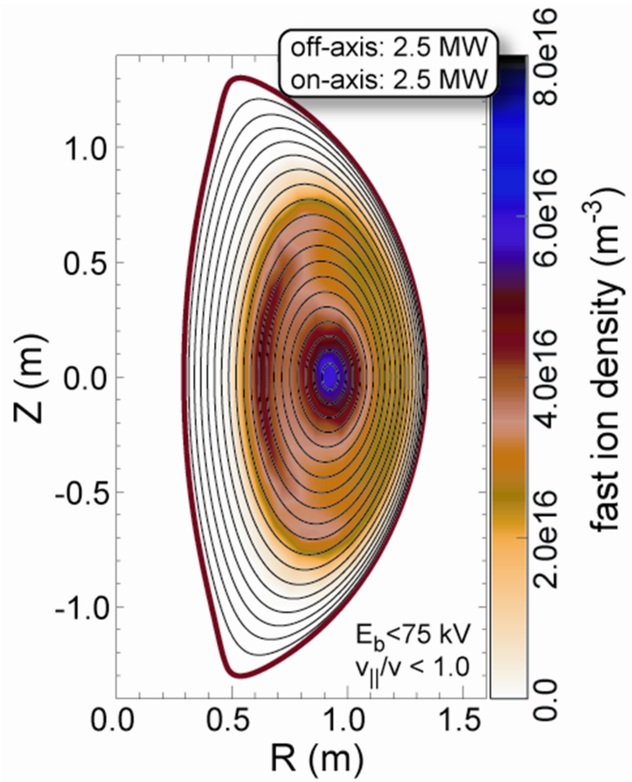
Flexibility on fast ion density profiles



Advanced profile control

- On-axis ⇒ peaked.
- Off-axis ⇒ hollow.

Flexibility on fast ion density profiles



Advanced profile control

- On-axis ⇒ peaked.
- Off-axis ⇒ hollow.
- On- and off-axis ⇒ broad.

Plasma Startup via Local Helicity Injection and Stability Studies at Near-Unity Aspect Ratio in the Pegasus Experiment

R.J. Fonck, J.L. Barr, M.W. Bongard, M.G. Burke,
E.T. Hinson, A.J. Redd, N. Schoenberg,
D.J. Schlossberg,K.E. Thome

University of Wisconsin-Madison

PEGASUS Toroidal Experiment

The Joint Meeting of 5th IAEA Technical Meeting on Spherical Tori

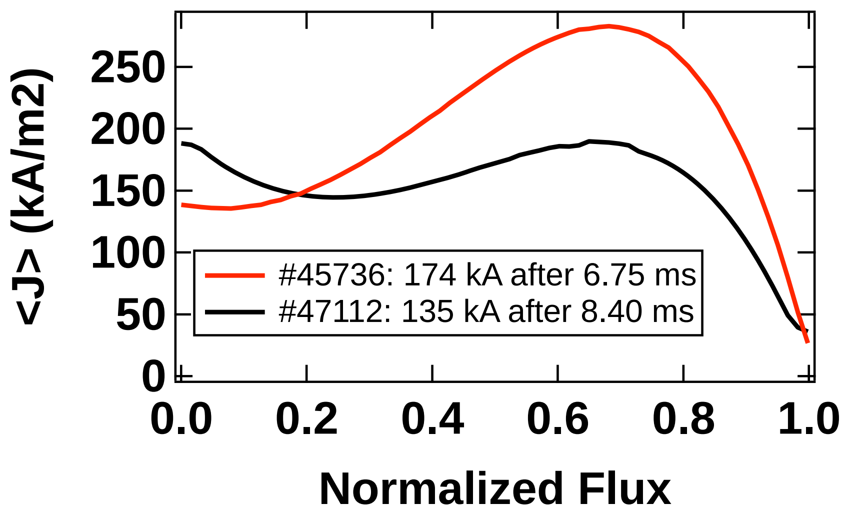
16th International Workshop on Spherical Torus (ISTW2011)

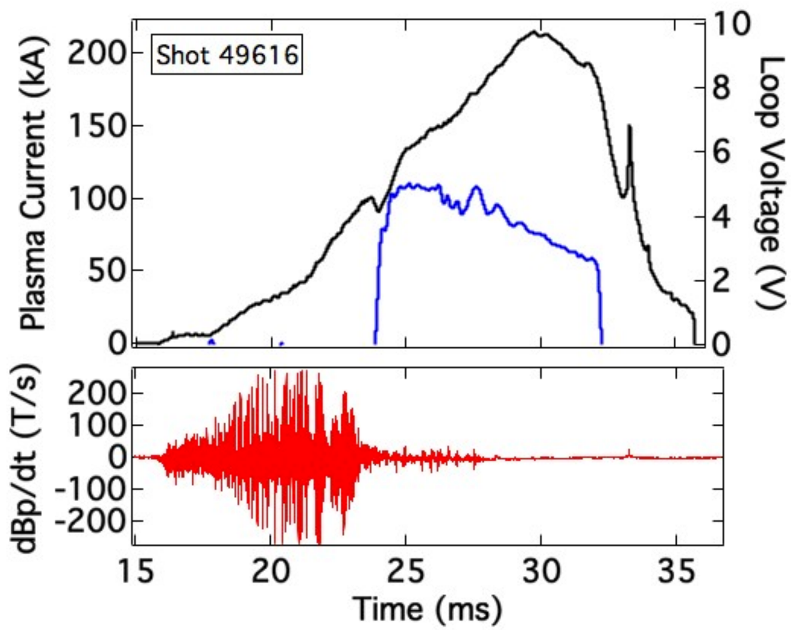
2011 US-Japan Workshop on ST Plasma

National Institute for Fusion Science, Toki, Japan September 27-30, 2011

Slowly-evolving Gun-driven Plasmas Hand Off Most Efficiently to Ohmic Drive

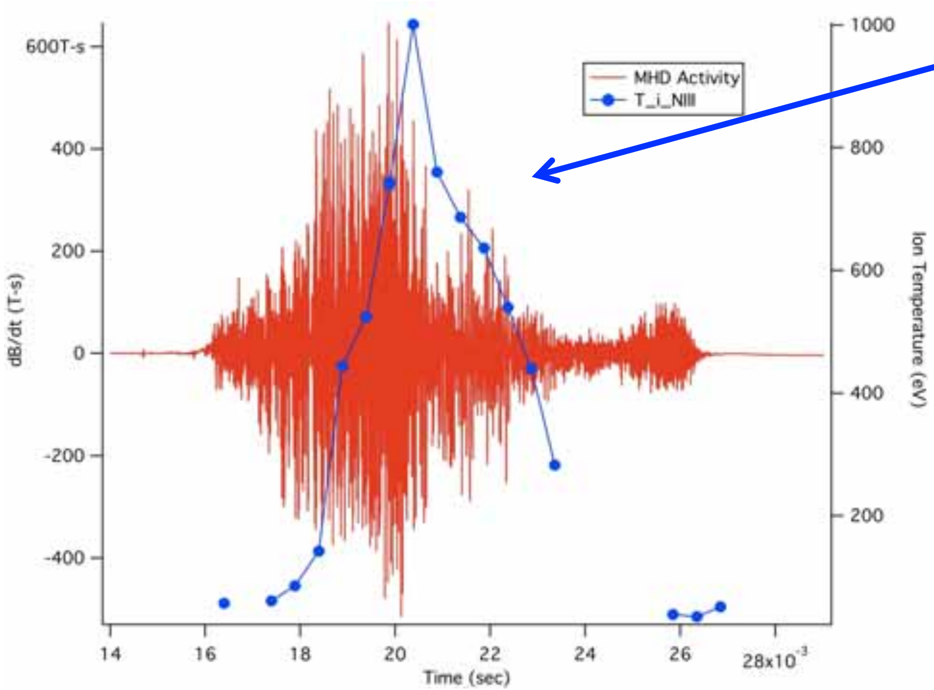
- Poloidal flux generated by helicity injection is equivalent to that generated by Ohmic Drive
  - $I_{total} = I_{HI} + I_{OH}$
- Excessive skin current => poor coupling to OH drive
- Slowly evolving: ~ flat j(r) (black)
  - Smooth handoff to Ohmic inductive drive (j(R) profiles from external-only equilibrium reconstructions; $l_i < 0.3$)
- Rapidly evolving: ~ hollow, strong skin j(r) (red)
  - Does not hand off efficiently to Ohmic drive





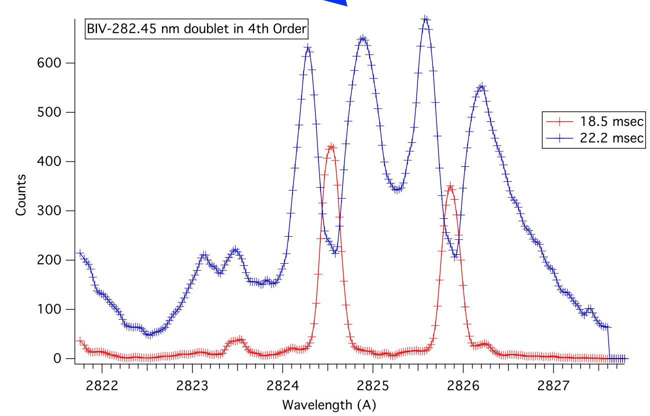
Initial Spectroscopy Measurements Suggest Energetic Ions

- Spectroscopic T_i suggest high ion energies during reconnection period



Doppler T_i from radial view

Complex multi-line structures from tangential view



- However, situation is much more complex if viewed toroidally
  - Need improved time-resolution and spatial scans

RJF ISTW 2011

THE UNIVERSITY of WISCONSIN MADISON

The Joint Meeting of 5th IAEA Technical Meeting on Spherical Tori, 16th International Workshop on Spherical Torus (ISTW2011), and 2011 US-Japan Workshop on ST Plasma
September 27-30, 2011 , National Institute for Fusion Science, Toki, Japan

Recent Progress in the SUNIST Spherical Tokamak

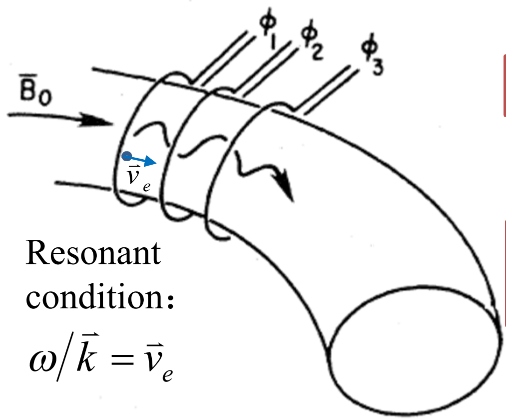
Yi Tan[1], Zhe Gao[1], Wenhao Wang[1], Lifeng Xie[1], Long Zeng[1], Huiqiao Xie[1], Ou Zhao[1], Yangqing Liu[1], Yanzheng Jiang[1], Song Chai[1], Xiaowei Peng[1], Kun Yao[1], Aihui Zhao[1]
Chunhuan Feng[2], Long Wang[2], Xuanzong Yang[2]
Guixiang Yang[3]
Email: tanyi@sunist.org

1) Department of Engineering Physics, Tsinghua University, Beijing, China
2) Institute of Physics, Chinese Academic of Science, Beijing, China
3) College of Nuclear Physics and Technology, Nanhua University, Hengyang, China

This work is supported by the Major State Basic Research Development Program from MOST of China under Grant No. 2008CB717804, 2009GB105002 and 2010GB107002, NSFC under Grant No. 10990214, 10775086 and 11005066.

Principle of Alfven wave current drive

- **Diagram of Alfven wave current drive (AWCD)**
  - The peristaltic Tokamak (Wort, 1971)

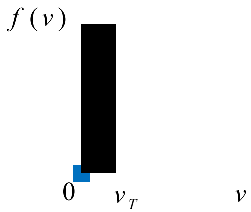


Resonant condition: $\omega / \vec{k} = \vec{v}_e$

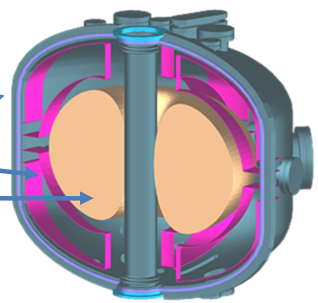
N J Fisch and C F F Karney, 1987

The driving force: $m\frac{dv_z}{dt} = -eE_z - \mu\frac{\partial B_z}{\partial z}$

V_{ph} is slow thus thermal electrons are driven:



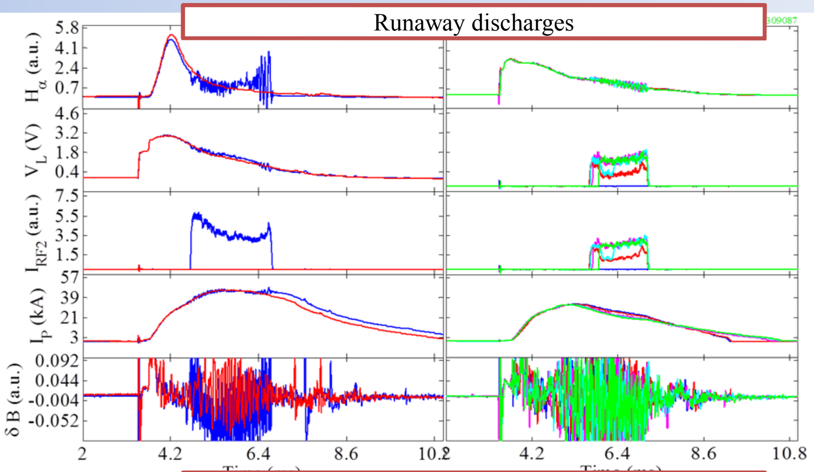
The schema:
Vacuum Vessel
Antennas
Plasmas

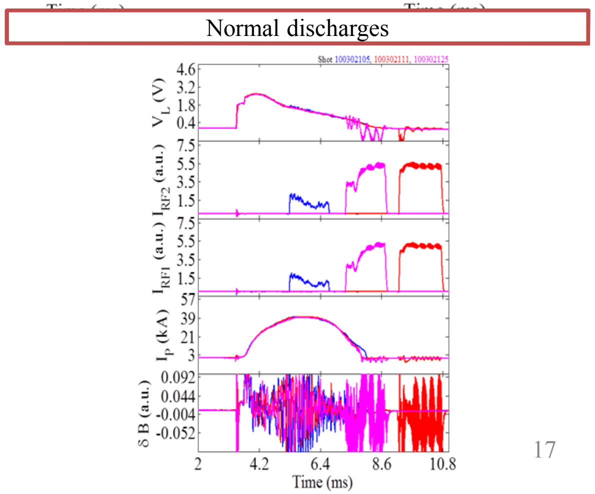


- **Apply AWCD to SUNIST**
  - 4 pairs of strap antennas
  - 0.15 T / 1E19 m^{-3}, resonant frequency: 0.4 ~ 1 MHz

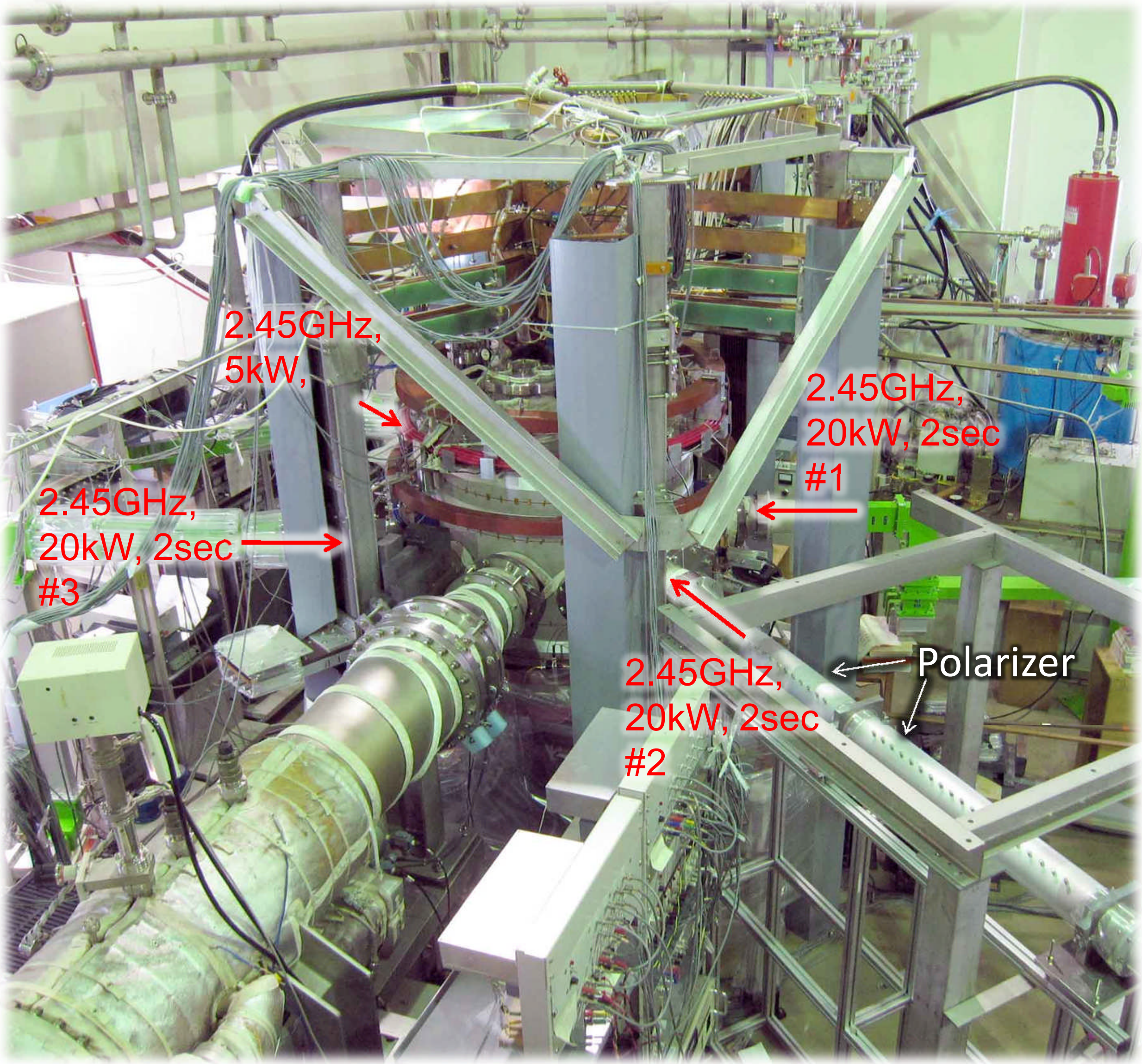
The effects of RF waves on I_P

- **Runaway discharges are enhanced when:**
  - Low I_P (~30 kA), low n_e (<1E19 m^{-3})
  - Hard to understand
    - The speed of rf phases and the runaway electrons differ by one order of magnitude
    - $V_c \sim 1.5*10^{-2}(2\pi Rn/V)/2 \sim 2*10^7$m/s (for $n_e \sim 10^{18} m^{-3}$)
    - $Vph \sim f2\pi R \sim 1.5*10^6$ m/s
- **Normal discharges**
  - 50 kA，>1E19 m^{-3}
  - No effects observed





LATE is exploring non-solenoidal start-up by ECH/ECCD



LATE Parameters:

Vacuum vessel: diameter = height = 1m
Center post : diameter = 11.4 cm
Toroidal coils : 60 kAT (Bt ~ 0.5 kG), 10 s. or 120 kAT(Bt ~ 1 kG), 0.3 s.
Vertical coils: 3 sets, Vertical position control coils: 1 set

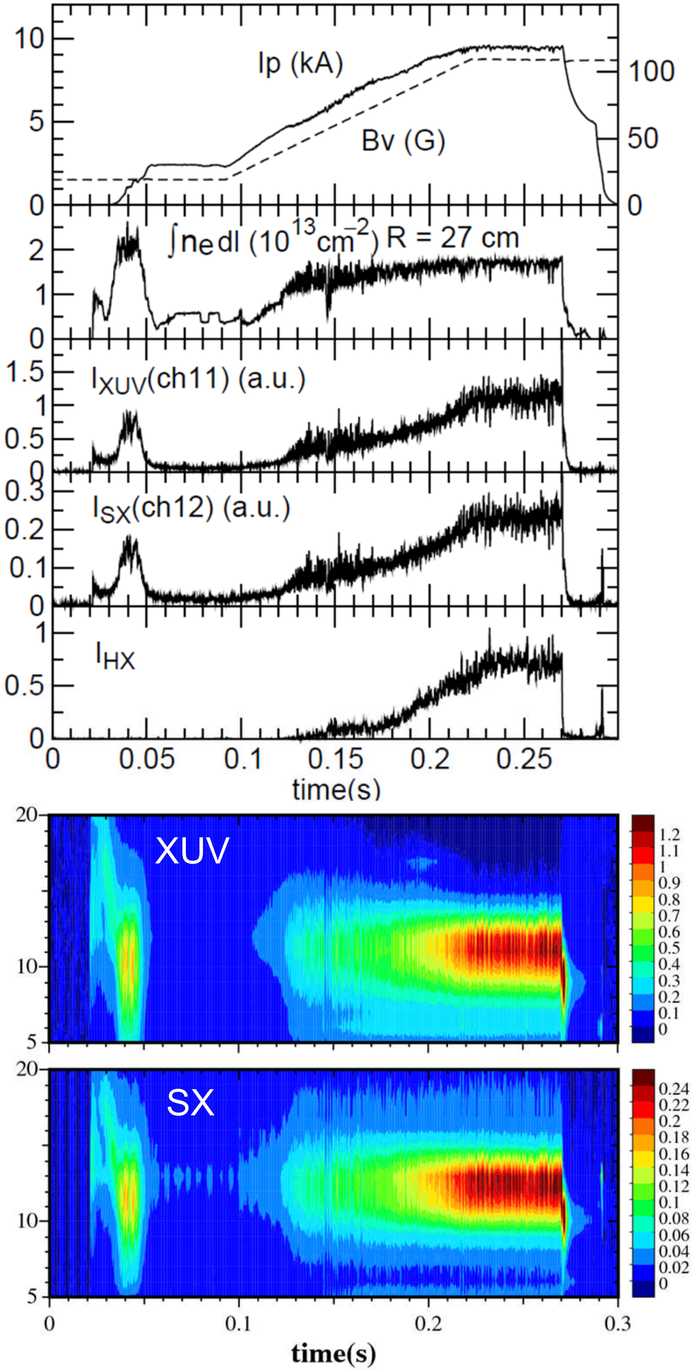
Microwave Power:
2.45 GHz (65kW 2sec.): 4 magnetrons
5.0 GHz (~200kW ~0.07 sec.)

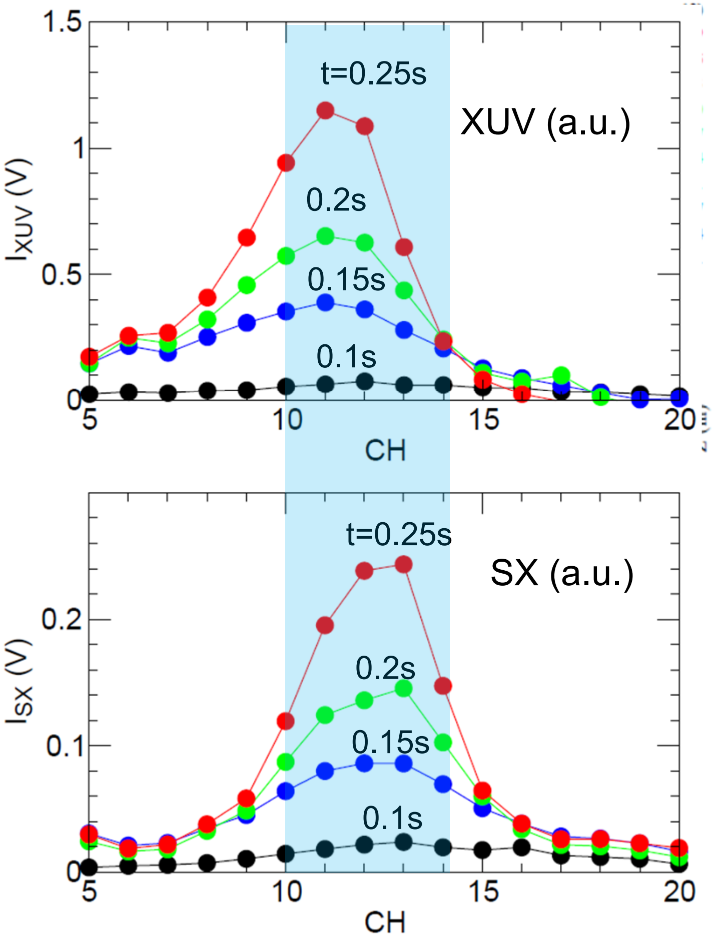
Diagnostics:

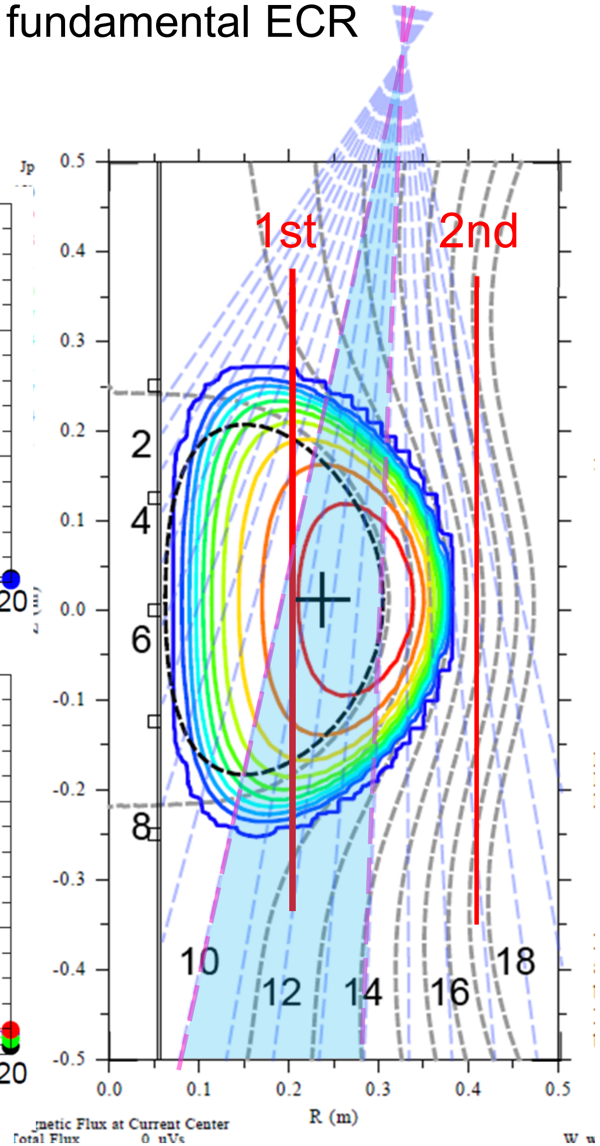
70GHz interferometer (4 chords),
Fast visible camera, Flux loops,
Langmuir probes, Spectrometer,
SX cameras (1-poloidal)
AXUV cameras (1-poloidal, 2-toroidal)
4-chord PHA system (2-tangential, 2-vertical),

XUV and SX profiles show heating just before ECR layer

- XUV and SX increase as Ip increases from 5 to 10 kA, while the line density is nearly the same.
- The increment is significant just outside the ECR layer, indicating heating at the fundamental ECR by EBW.

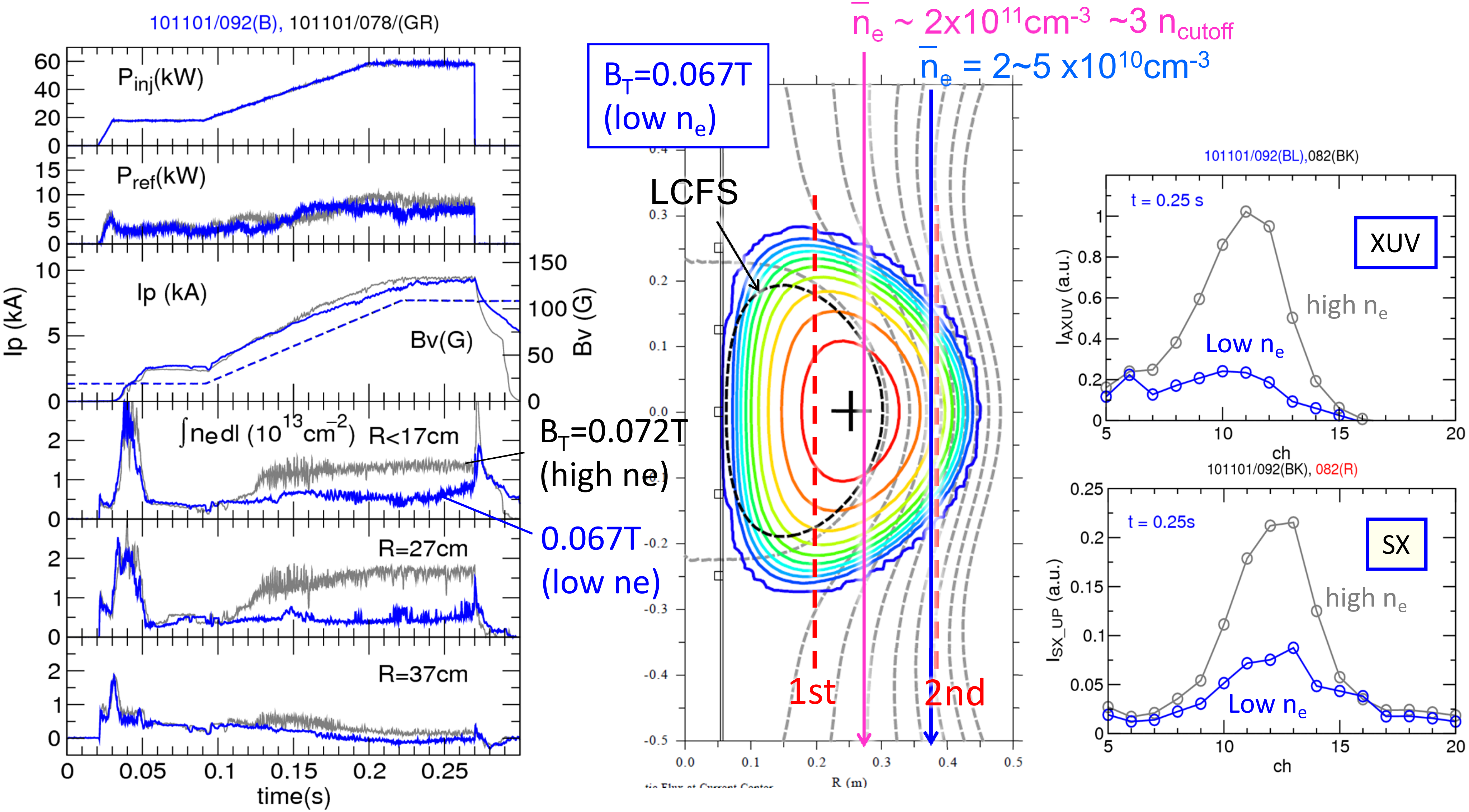






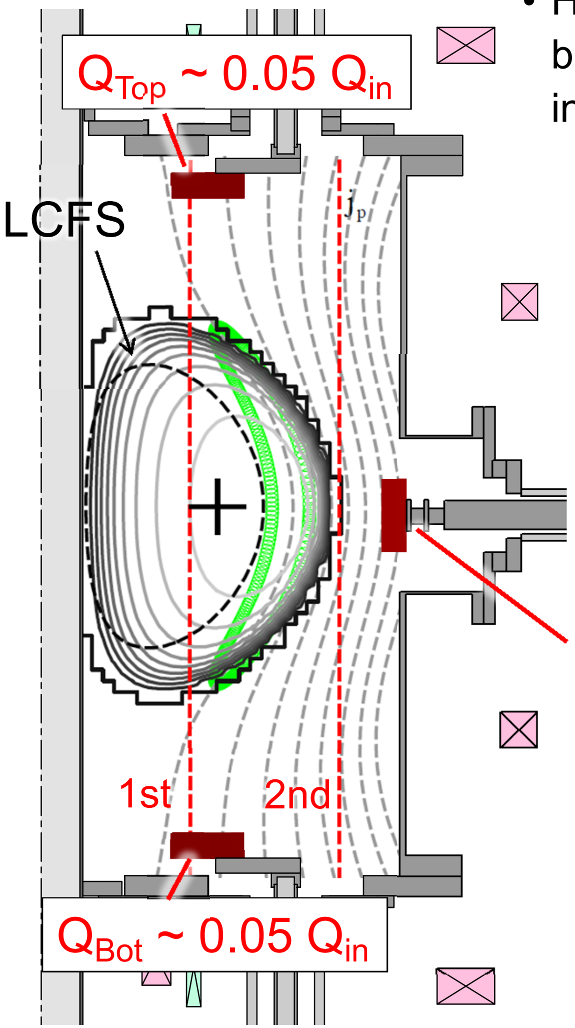
When we set the ECR layer at R<20cm, significant decrease in electron density is observed.

- When we set the R_{1st} < 20cm bulk density significantly decreased, while Ip ramps up almost the same value of Ip ~ 10kA.
- SX and XUV profile shows significant decreases in the core region.
- How such a large difference arises?



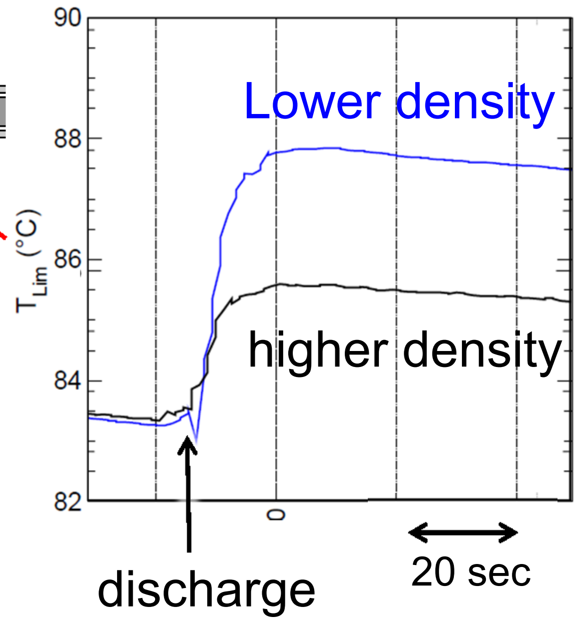
Clear difference in the heat load to the outboard limiter shows that the better coupling to bulk electrons at the higher density.

Heat load to the limiter in one shot (Q_{in} ~ 8kJ)



- Heat loads to the top and bottom limiter does not change in the two discharge

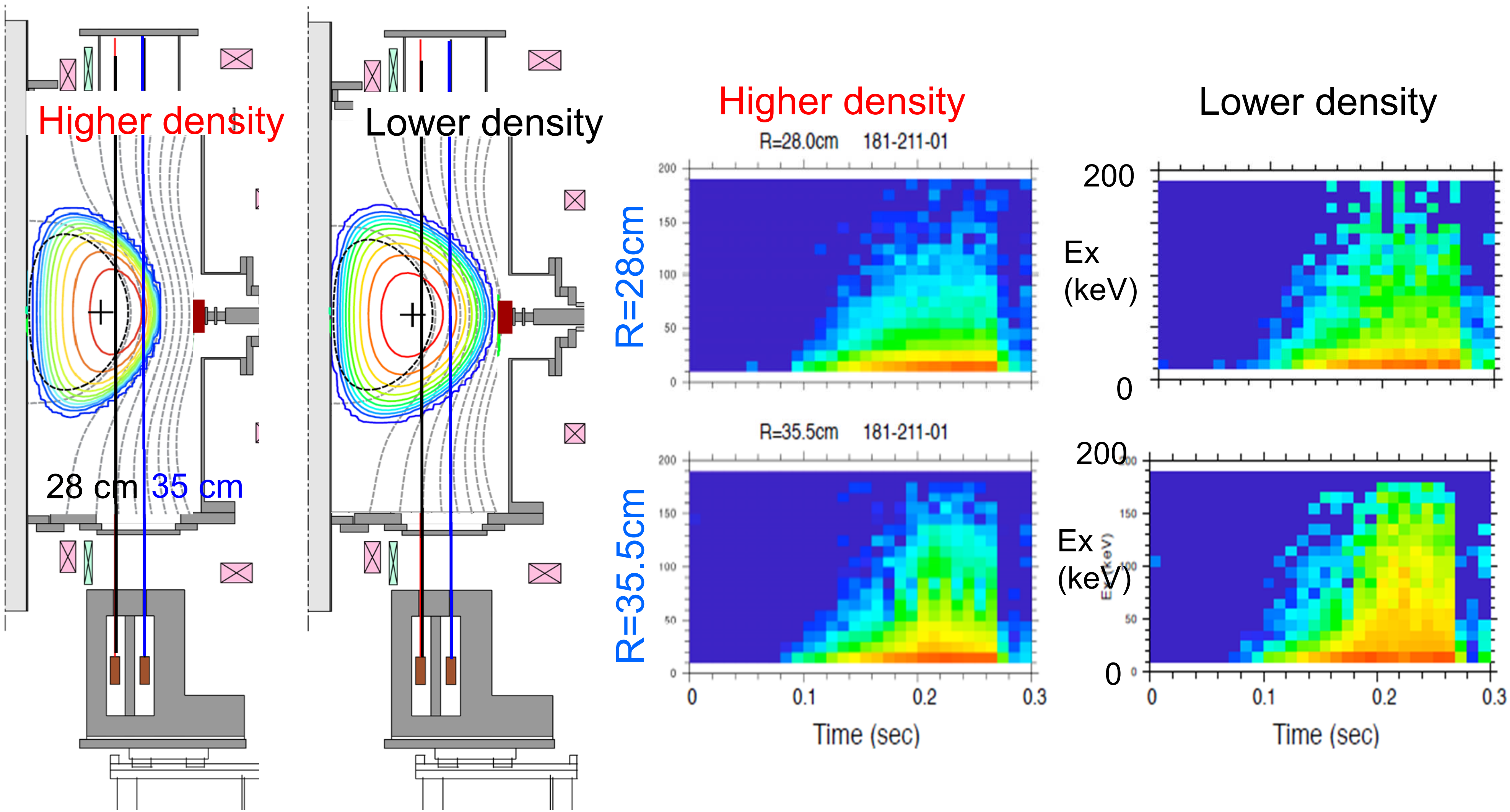
Outboard Limiter temperature



- At the lower density, heat load to the outboard limiters increases as $Q_{Lim(R)}/Q_{in}$ ~ 0.13 → 0.25 indicating larger loss.
- Since the outboard limiter is located far outside the LCFS, heat load is mainly from high energy trapped electrons.
- The results suggests that larger power is coupled to high energy trapped electrons and lost to the limiter at the lower density.
- 2nd harmonic heating by EBW may produce such electrons.
- Conversely, at the higher density, the 2nd harmonic heating is suppressed, better coupling to the bulk may be realized.

Evolution of HX spectra (vertical chords)

- This suggests that higher energy of trapped electrons exist outside LCFS at the lower density.
- At the higher density, X-ray energy becomes lower suggesting the production of trapped electrons are suppressed.



The difference forward and backward HX spectra exists for the both modes

- For both the modes, difference between forward and backward emission can be seen, suggesting that current carrying tail electrons are produced similarly, in spite of the trapped electrons.