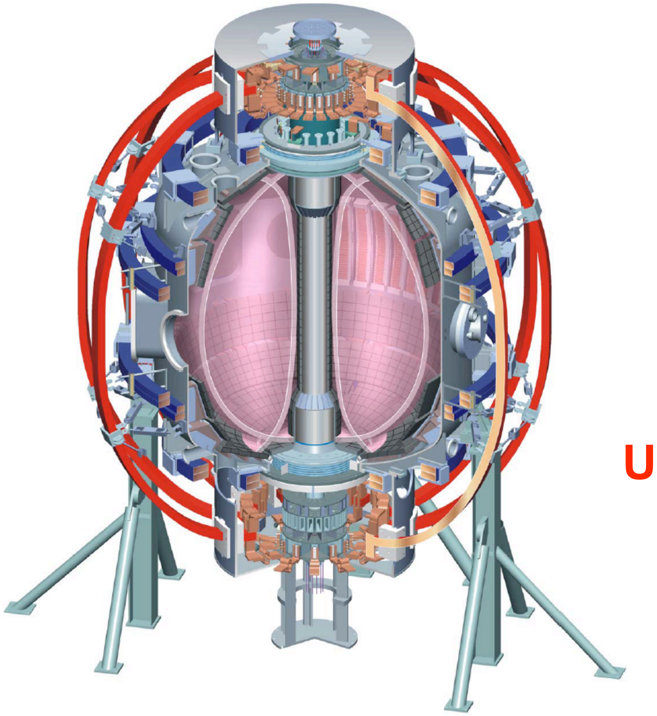
Supported by

Research tool development for high performance steady-state plasma operations on NSTX



Masayuki Ono
For the NSTX Team

Joint Spherical Torus Workshop and US-Japan Exchange Meetings (STW2004)

29th September – 1st October, 2004
Kyoto University, Japan

Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
NYU
ORNL
PPPL
PSI
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UC Davis
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U Maryland
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Hiroshima U
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Kyushu Tokai U
Niigata U
Tsukuba U
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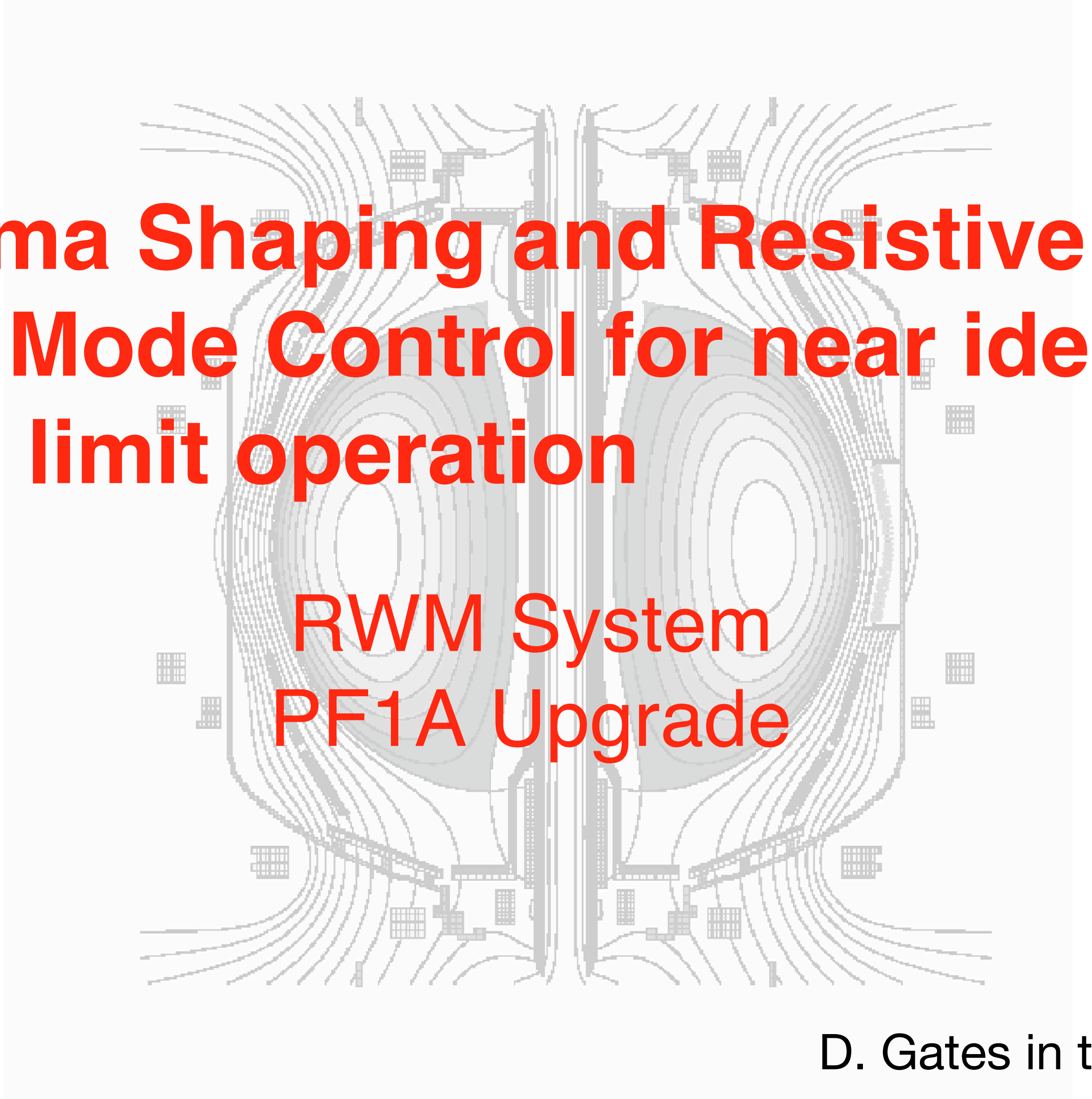
JAERI
Ioffe Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
U Quebec

NSTX Talk Outline

- Research Tool Development
  - RWM and PF1A for high beta operations
  - Core/Edge Fluctuations Diagnostics
  - HHFW/ EBW for heating and current drive
  - High frequency MHD for alpha-particle physics
  - Power and Particle Handling
  - Solenoid-free start-up
- Summary

Related presentations: M. Peng, ST Overview
D. Gates - MHD, Confinement, Scenarios
N. Nishino - Divertor fast camera
R. Raman - Coaxial Helicity Injection

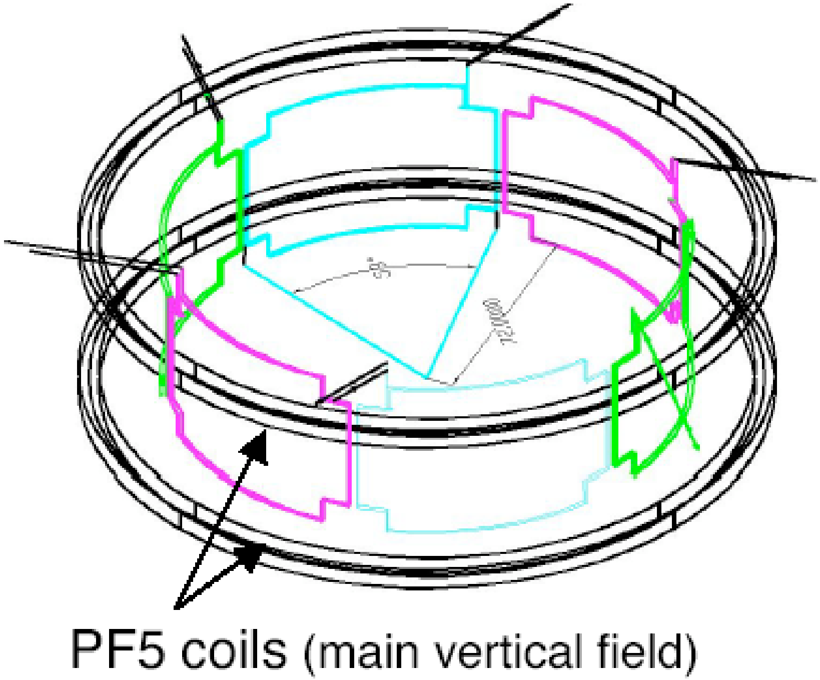
Plasma Shaping and Resistive Wall Mode Control for near ideal MHD limit operation

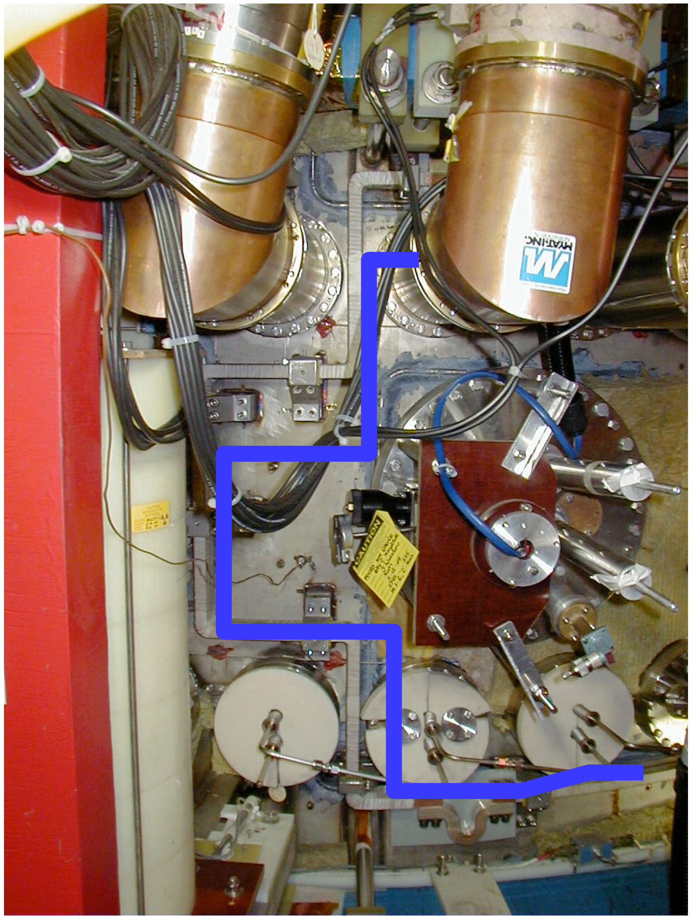


RWM System
PF1A Upgrade

D. Gates in this meeting

The full Six-element RWM coil system powered with the SPA supply scheduled to be available for the FY 05 run





- Error field reduction
- Rotation control
- Locked-mode control
- RWM feed-back stabilization

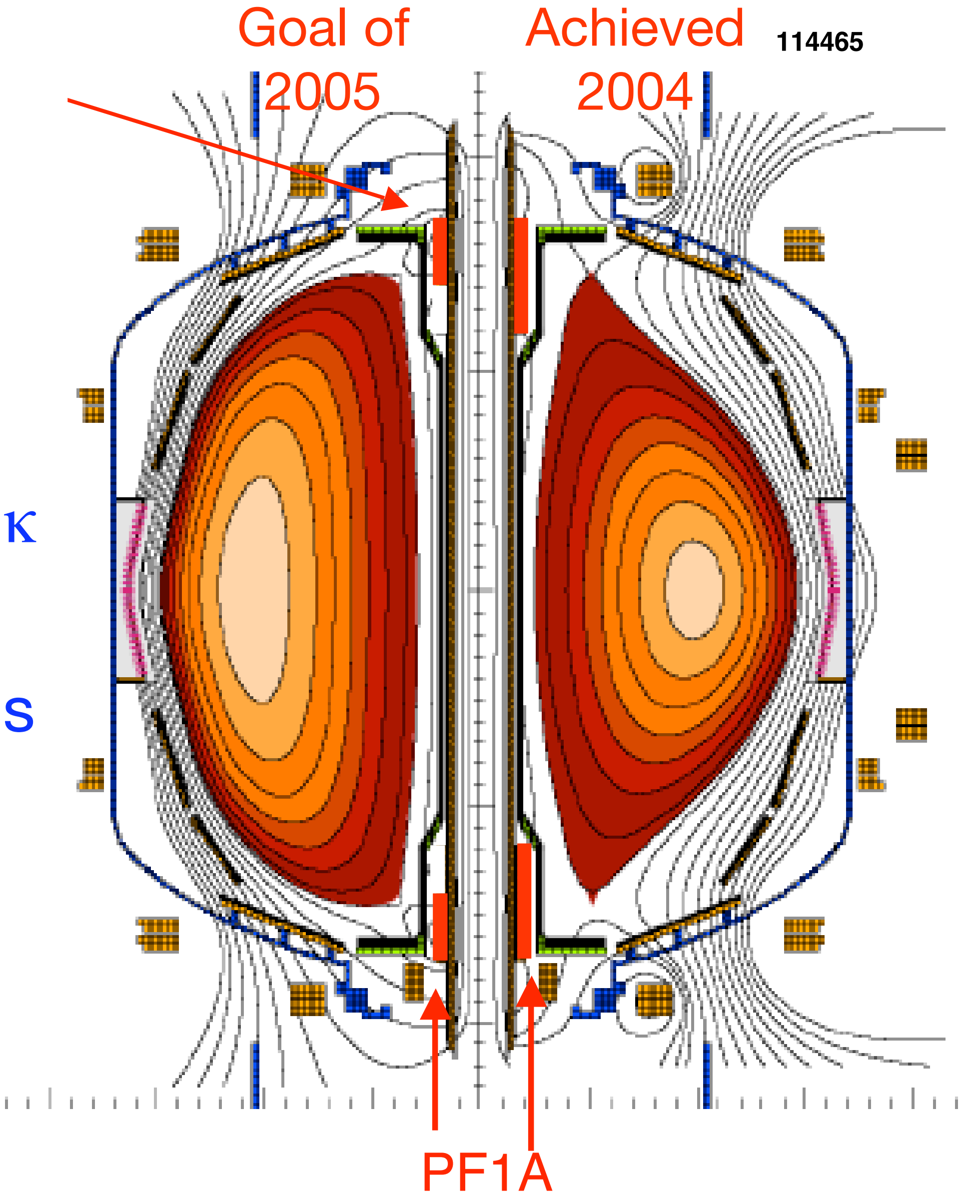
Columbia University

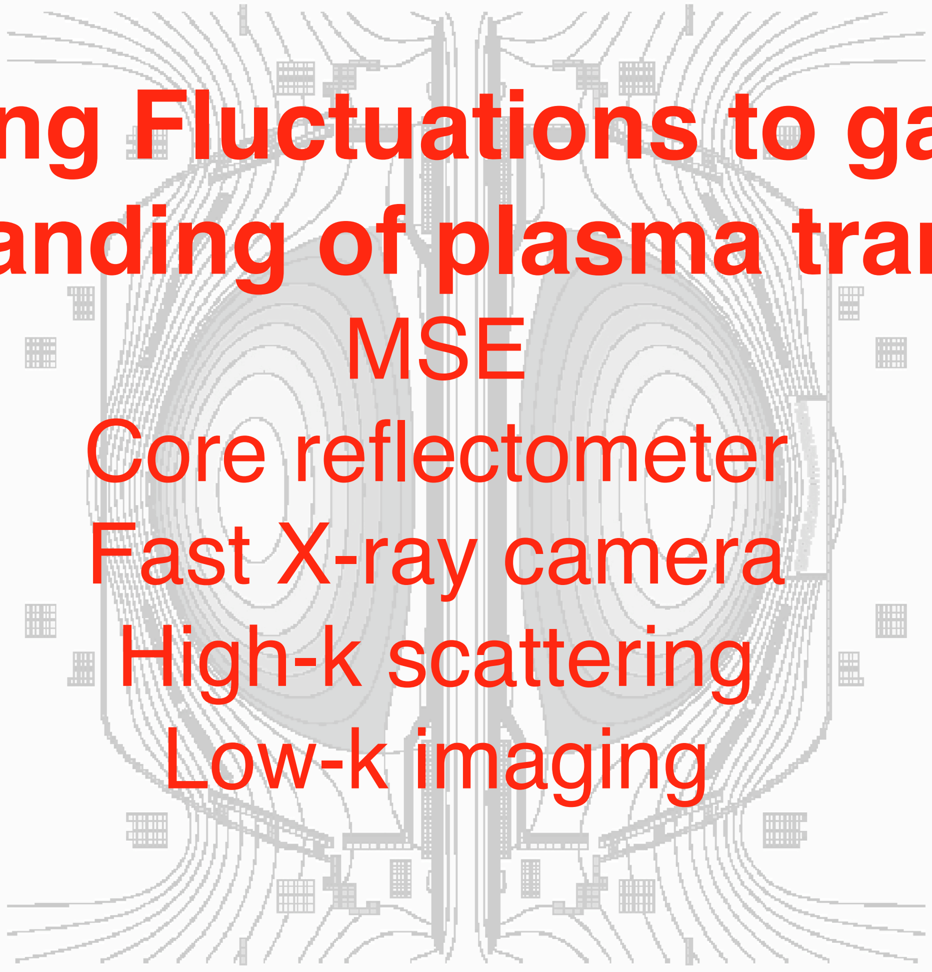
New PF 1A Coils to improve plasma shaping

- Shorter PF 1A is needed to improve the plasma shaping control (κ = 2.5 and δ = 0.8) for advanced ST operations.

- Due to the success of high κ operation this year, the new PF 1A coil will be installed this year ahead of schedule.

- Should be available for FY 05 run starting in Feb. 05.





Measuring Fluctuations to gain understanding of plasma transport

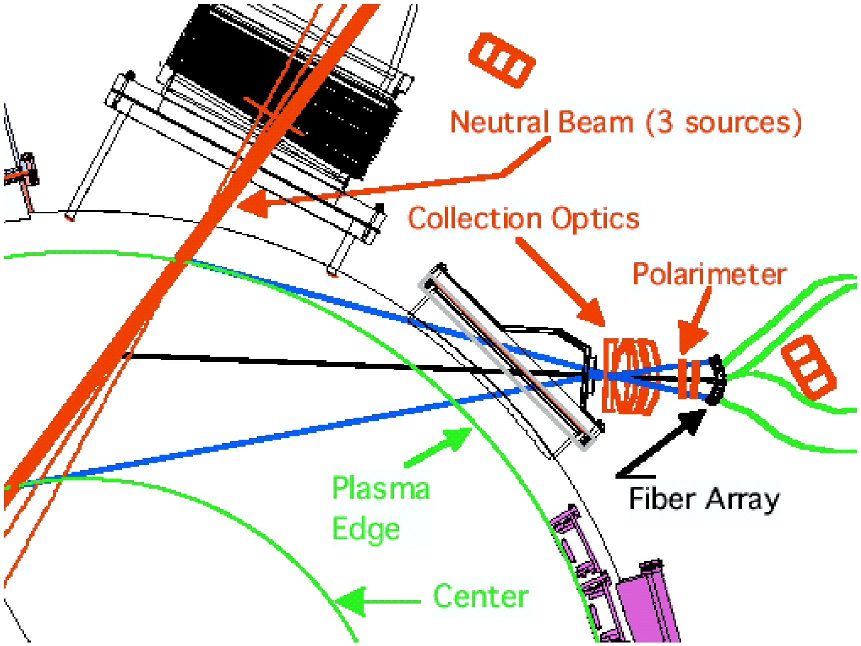
MSE
Core reflectometer
Fast X-ray camera
High-k scattering
Low-k imaging

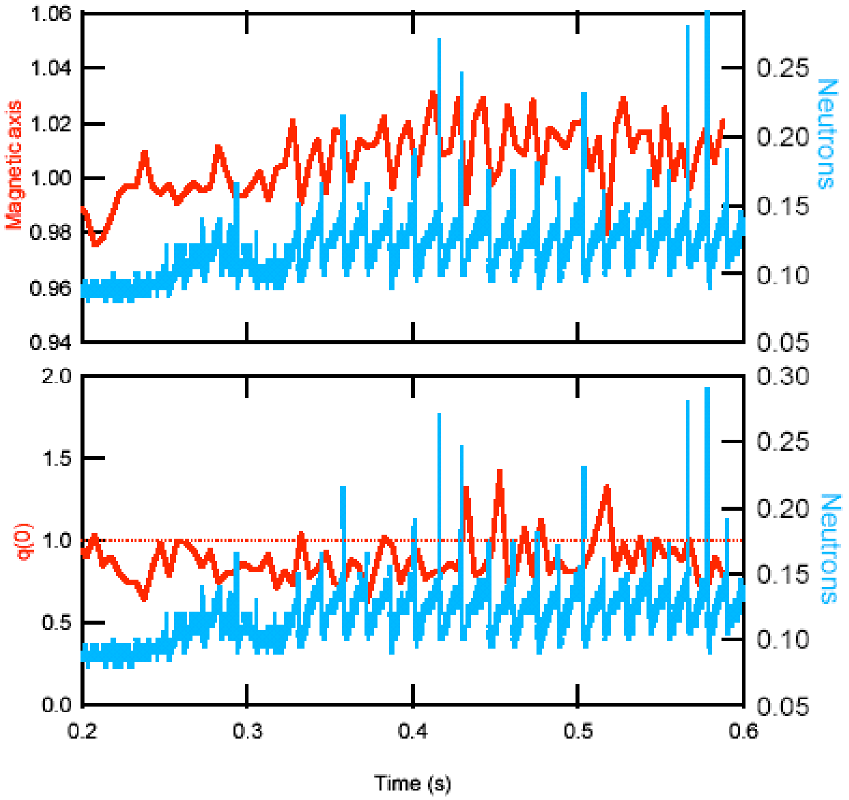
D. Gates in this meeting

MSE/CIF begun taking plasma current profile data

MSE-CIF Layout on NSTX

Nova Photonics, Inc.



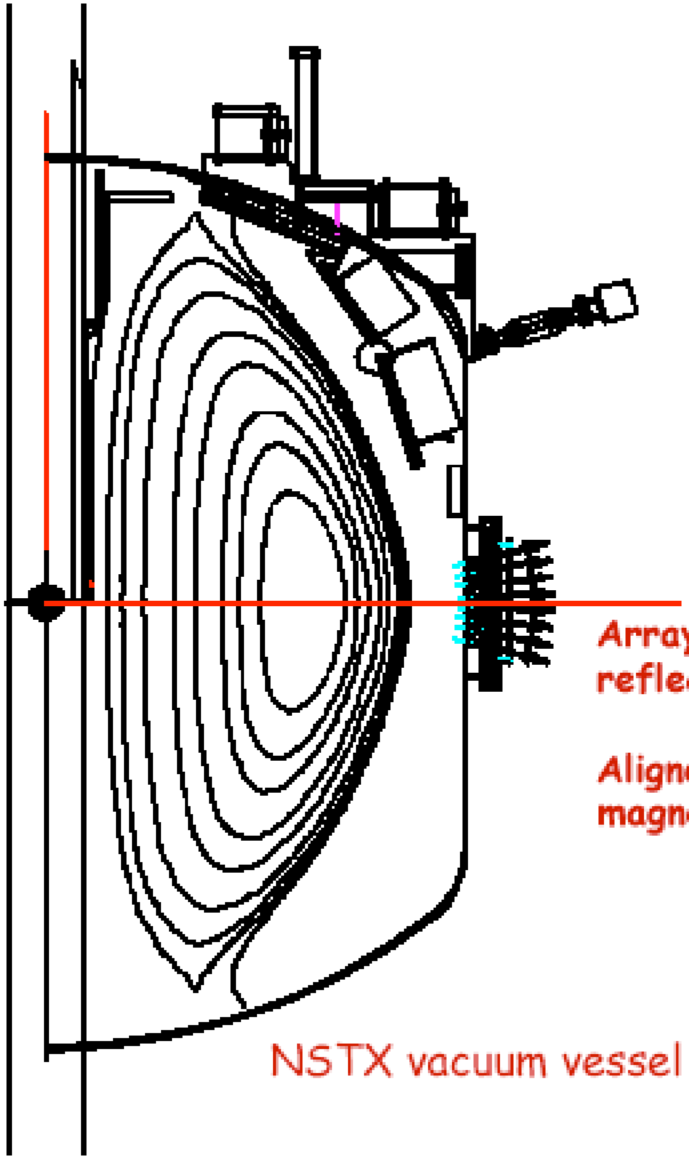


- Tangential sight-lines at edge and center provide optimal spatial resolution over a wide field of view. [*Goldston & Goldston*, Rev. Sci. Instrum. 66, 5638(1995)].
- MSE and CHERS share collection optics, but have separate fiber arrays.

- $q(0) \sim 0.8$ before sawtooth crash and rises to $q(0) \sim 1$ after crash. The magnetic axis shifts inboard ~2 cm after sawtooth.
- MSE integration time is 5 ms. Sawtooth period is 15 ms.

F. Levinton

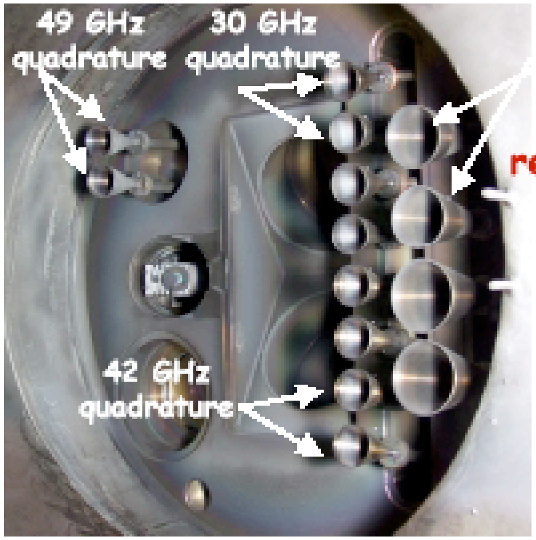
Reflectometry turbulence measurements on NSTX



Array of microwave reflectometer horns.

Aligned perpendicular to magnetic flux surfaces.

NSTX vacuum vessel



26-40GHz correlation reflectometer

Device Parameters for These Experiments:

R_0 = 95 cm

a = 62 cm

I_p = 0.58-.85 MA

B_T = 0.32-0.44 T

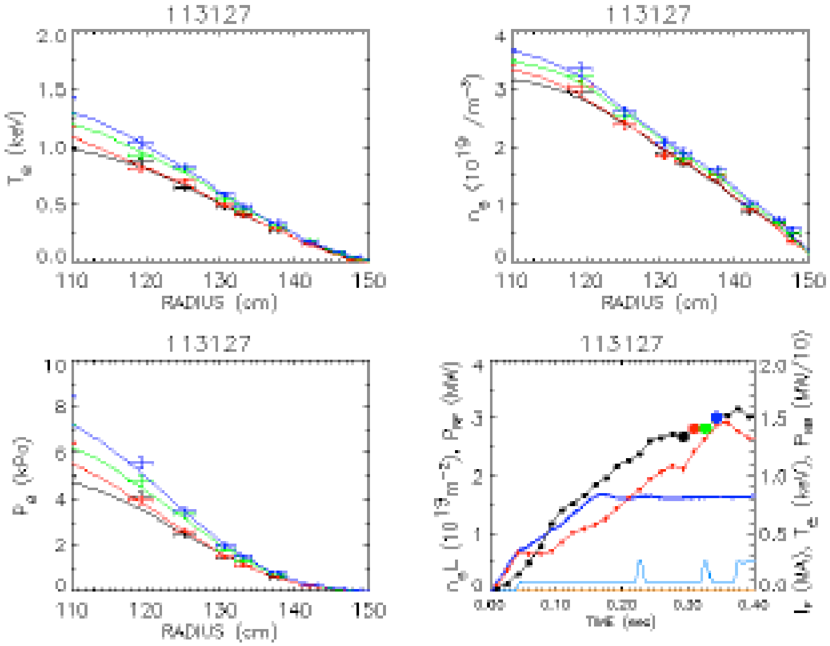
κ = 1.9

δ = 0.45

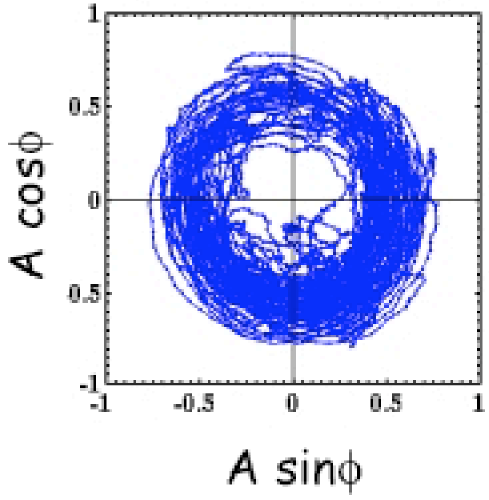
T. Peebles, UCLA

Turbulent Reflectometry Phase Spectra

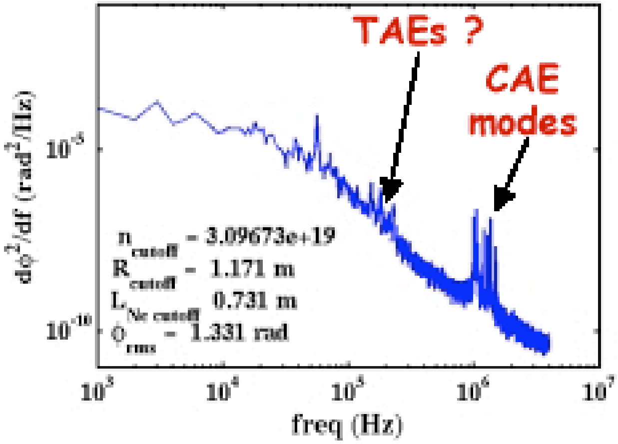
B_T = 4.4kG, Ip = 800 kA, ~1MW 60kV beam, rho ~0.25



50 GHz Quadrature Phaser
Shot 113127; t = 0.351 to 0.352



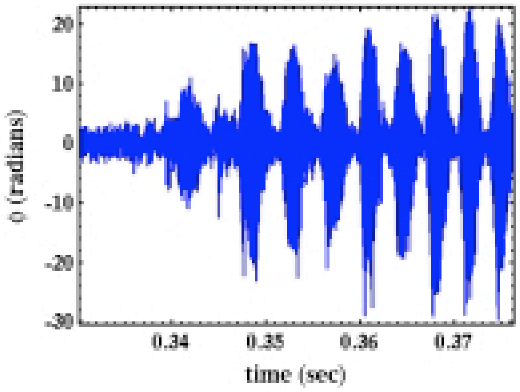
Phase spectrum for 50 GHz refl.
Shot 113127, t = 0.303 sec



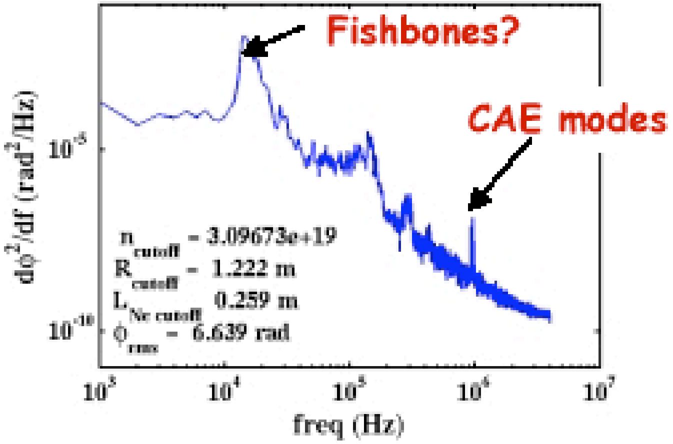
TAEs ?

CAE modes

phase fluctuation for 50GHz refl.
shot 113127



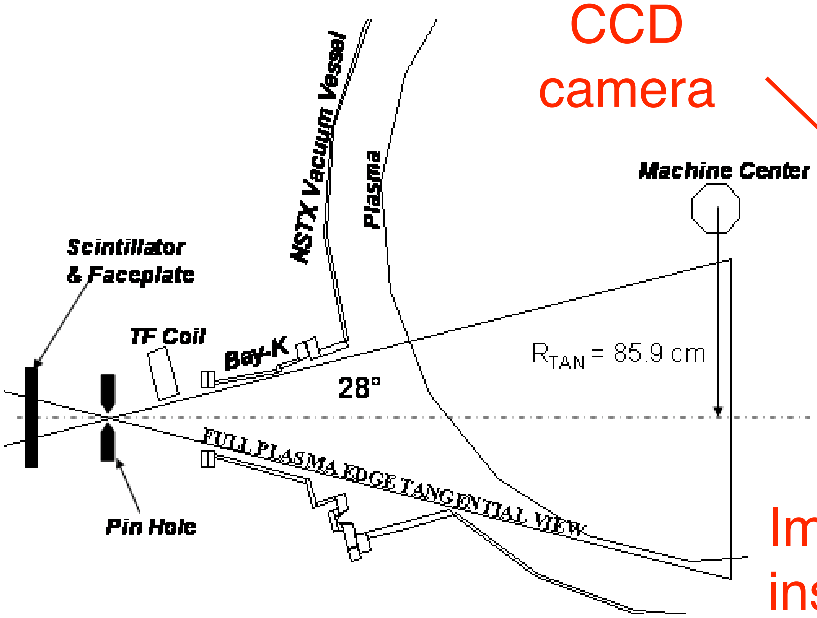
Phase spectrum for 50 GHz refl.
Shot 113127, t = 0.353 sec

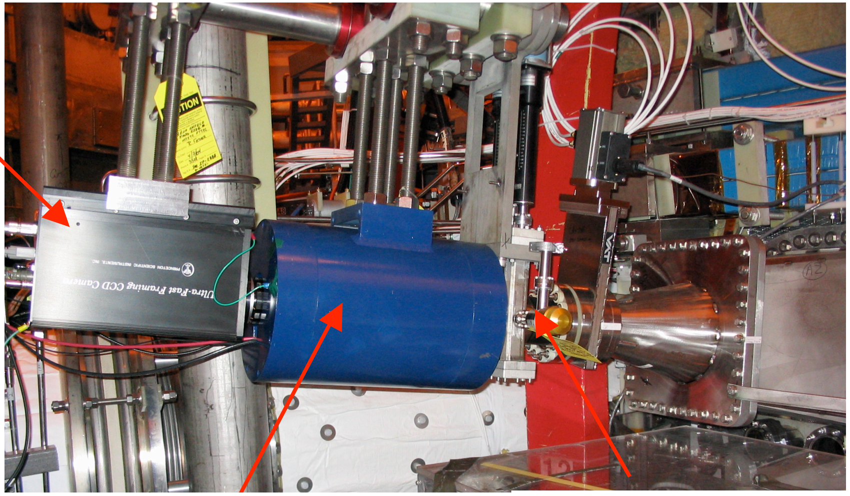


Fishbones?

CAE modes

Fast X-ray Camera Reveals Core Electron Dynamics



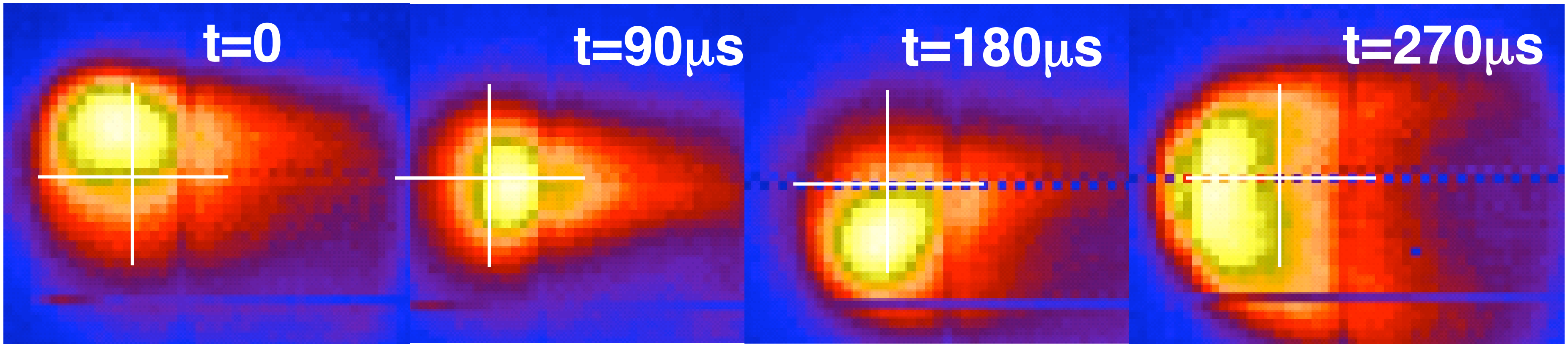


CCD camera

Image intensifier inside magnetic shield

Pinholes and Be foils

- Images of core n=1 tearing mode with time resolution down to ~ 2 *μs*

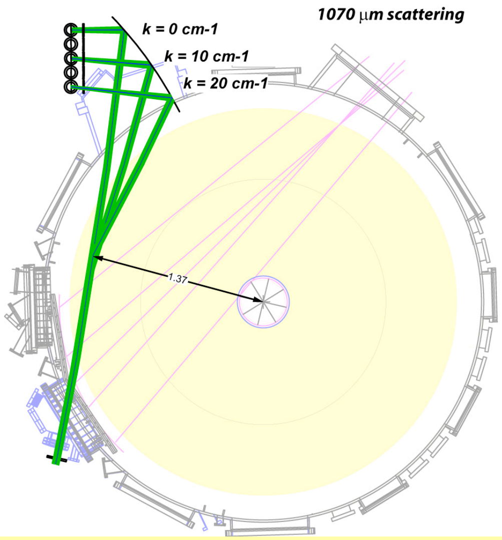


B. Stratton and PSI

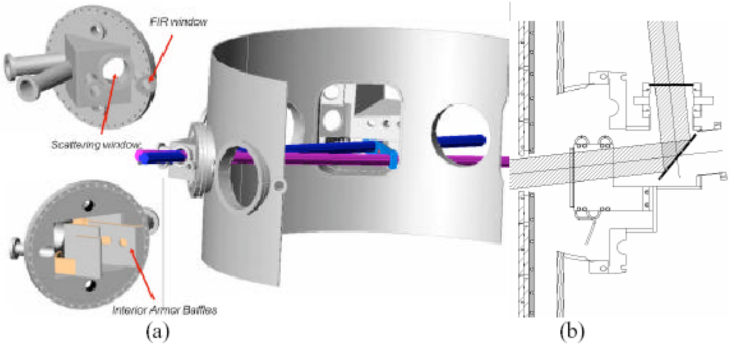
High k scattering measurements will be developed in FY' 05

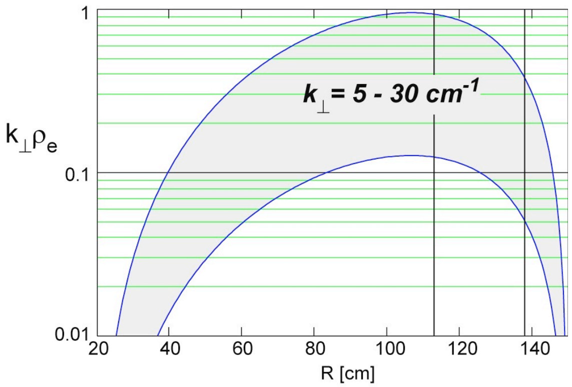
- Initial system will allow range of k measurements in select locations (2 - 20 cm^{-1})
- Major installation this opening.

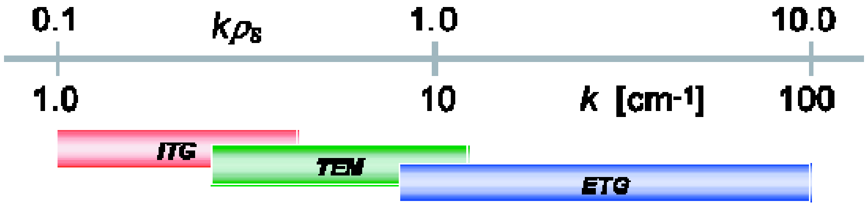
High k scattering



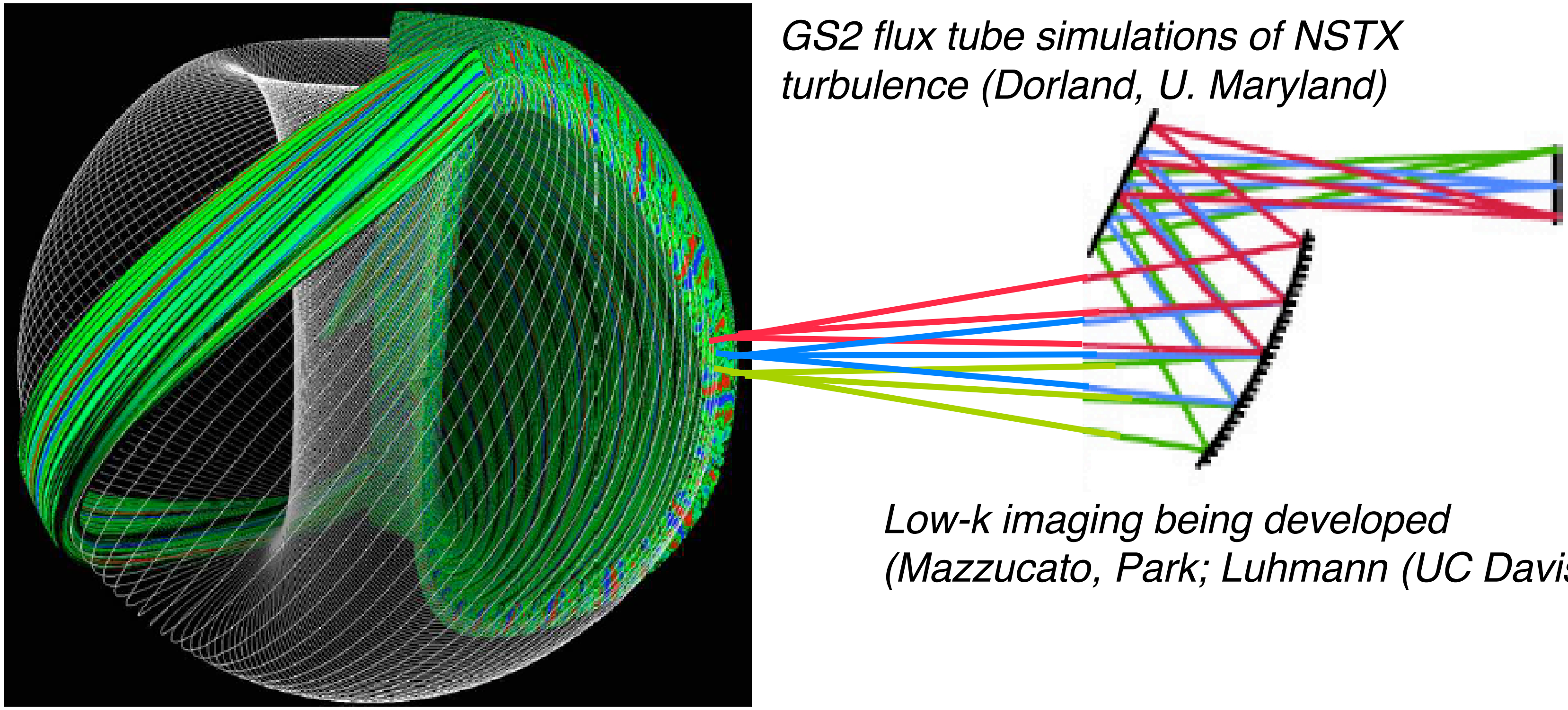
Luhmann (UC Davis), Munsat (U. Colorado)
Mazzucato, Park, Smith (Princeton U.)







The plan aims to make NSTX a test bed for turbulence theory validation on at least three leading fronts

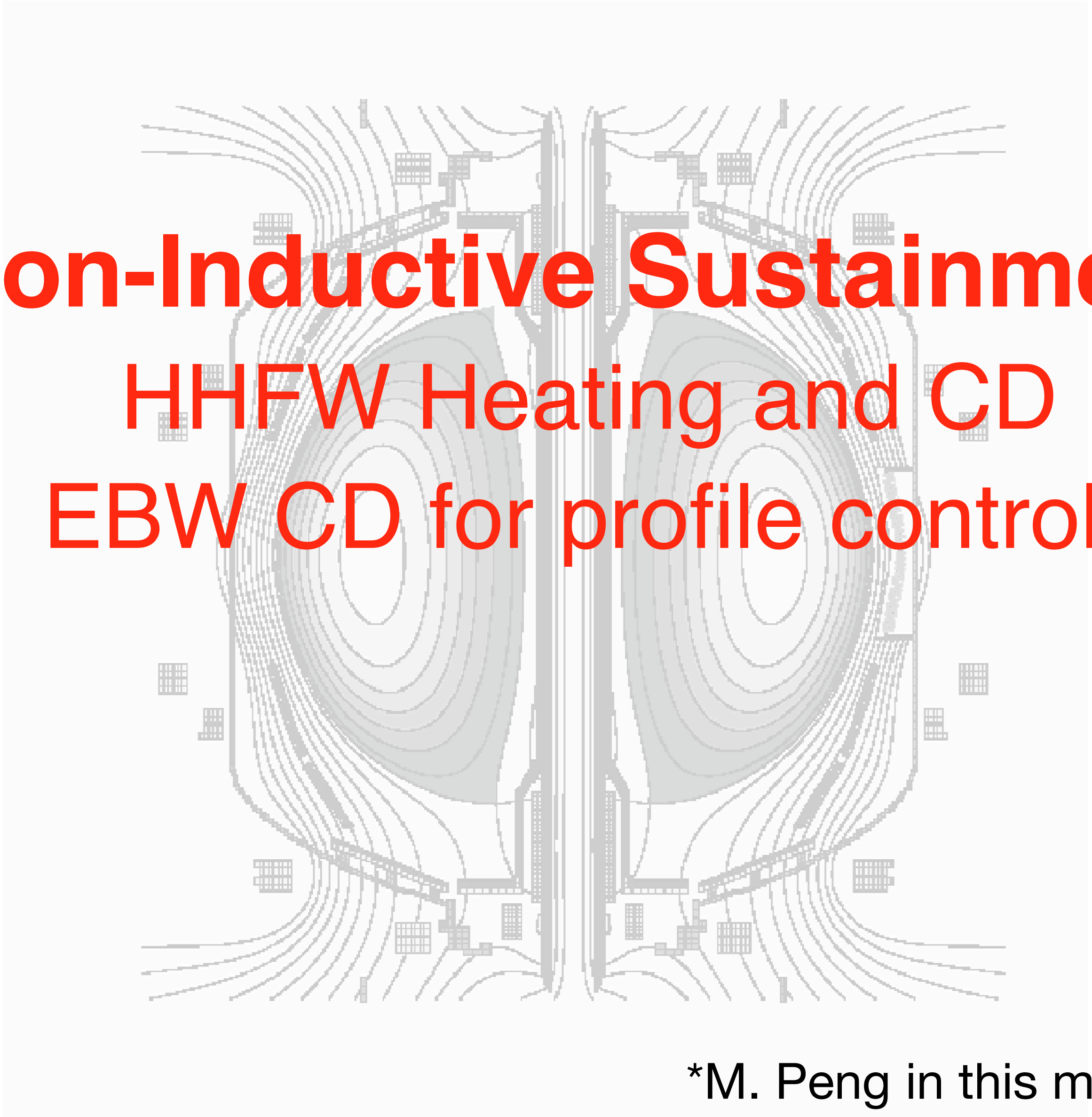


GS2 flux tube simulations of NSTX turbulence (Dorland, U. Maryland)

Low-k imaging being developed (Mazzucato, Park; Luhmann (UC Davis))

- <u>Critical physics</u> (1): interactions between ion and electron scale turbulence
- <u>Critical physics</u> (2): electron thermal transport
- <u>Critical physics</u> (3) electromagnetic effects in turbulence as local β --> 1

Need & opportunity: strong theory community coupling



Non-Inductive Sustainment

HHFW Heating and CD

EBW CD for profile control*

*M. Peng in this meeting

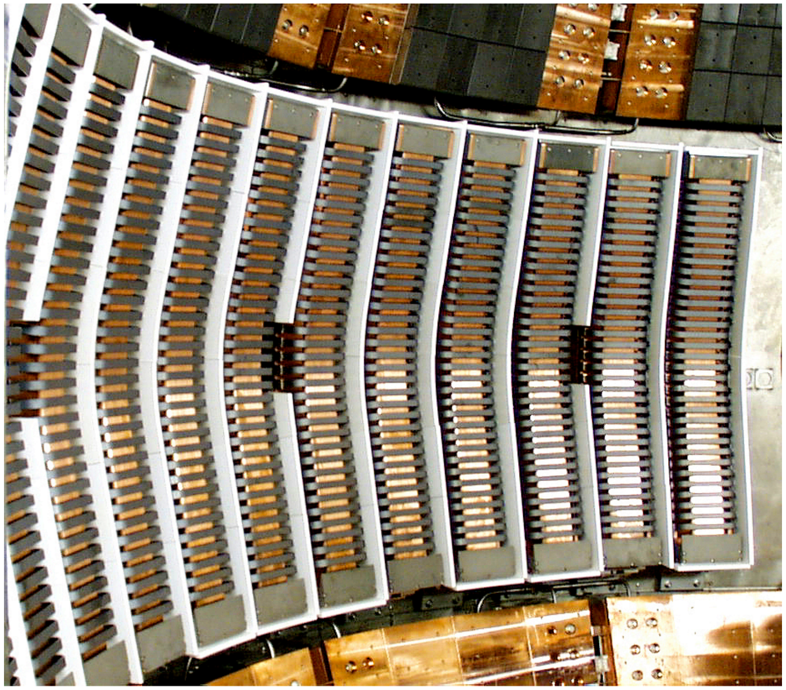
Multiple Roles of HHFW

- Bulk plasma heating to enhance bootstrap currents in advanced ST Operations

- Plasma start-up and current ramp-up

- Super-Alfvenic energetic particle physics (ITER)

- Edge physics for ICRF (ITER)

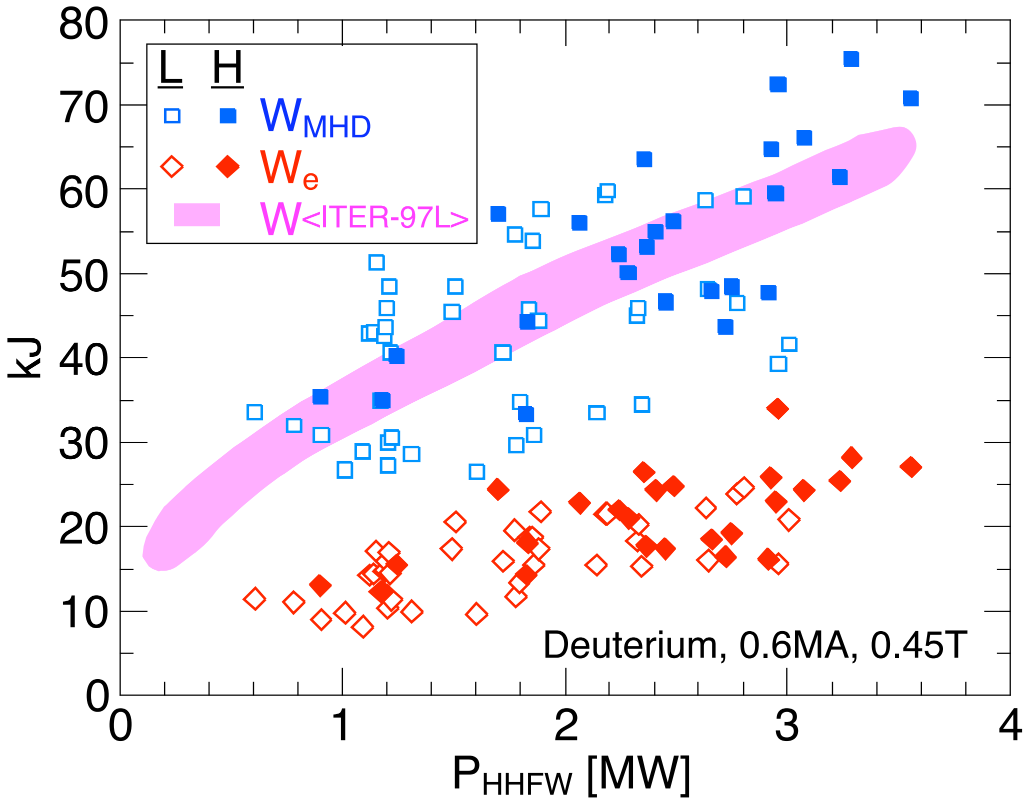


12 antennas powered by
6 MW sources

ORNL, PPPL, MIT, GA, CompX

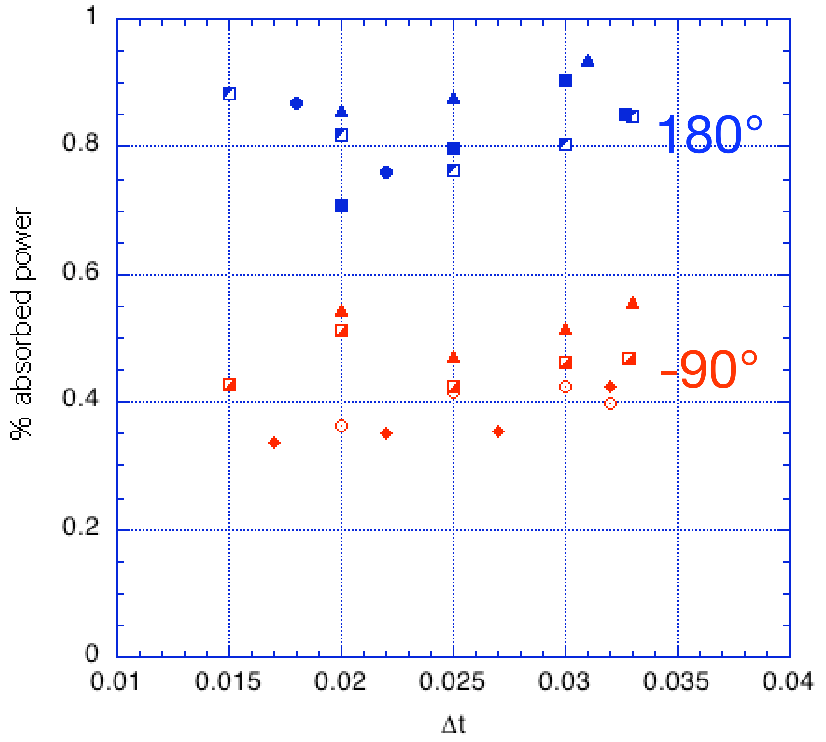
Increase understand of HHFW Heating

Lower than NBI heating efficiency



- Electron heating vs ion heating?
- Role of plasma rotation?
- Edge power loss?

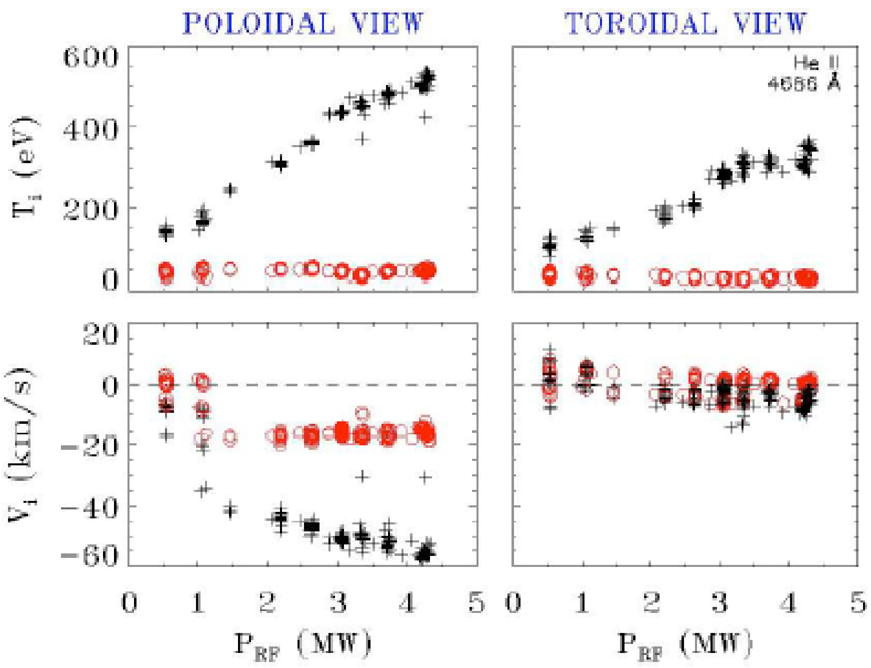
Modulation Exp performed

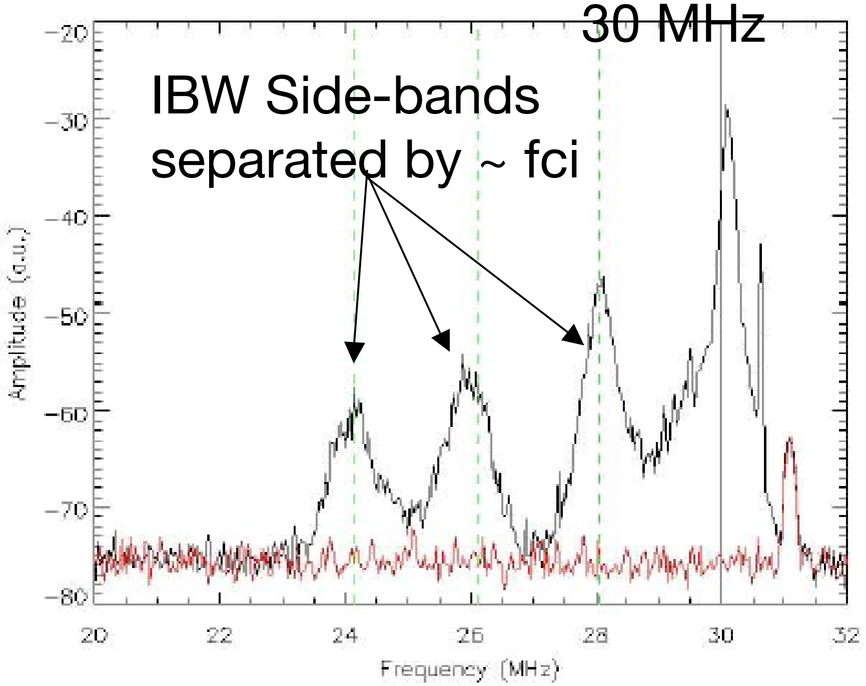


Heating efficiency decreases with $k_{\|}$
180° ~ 80%
+90° (counter CD) ~ 50%
Very little heating for 30°

J. R. Wilson

Edge Ion Heating Observed



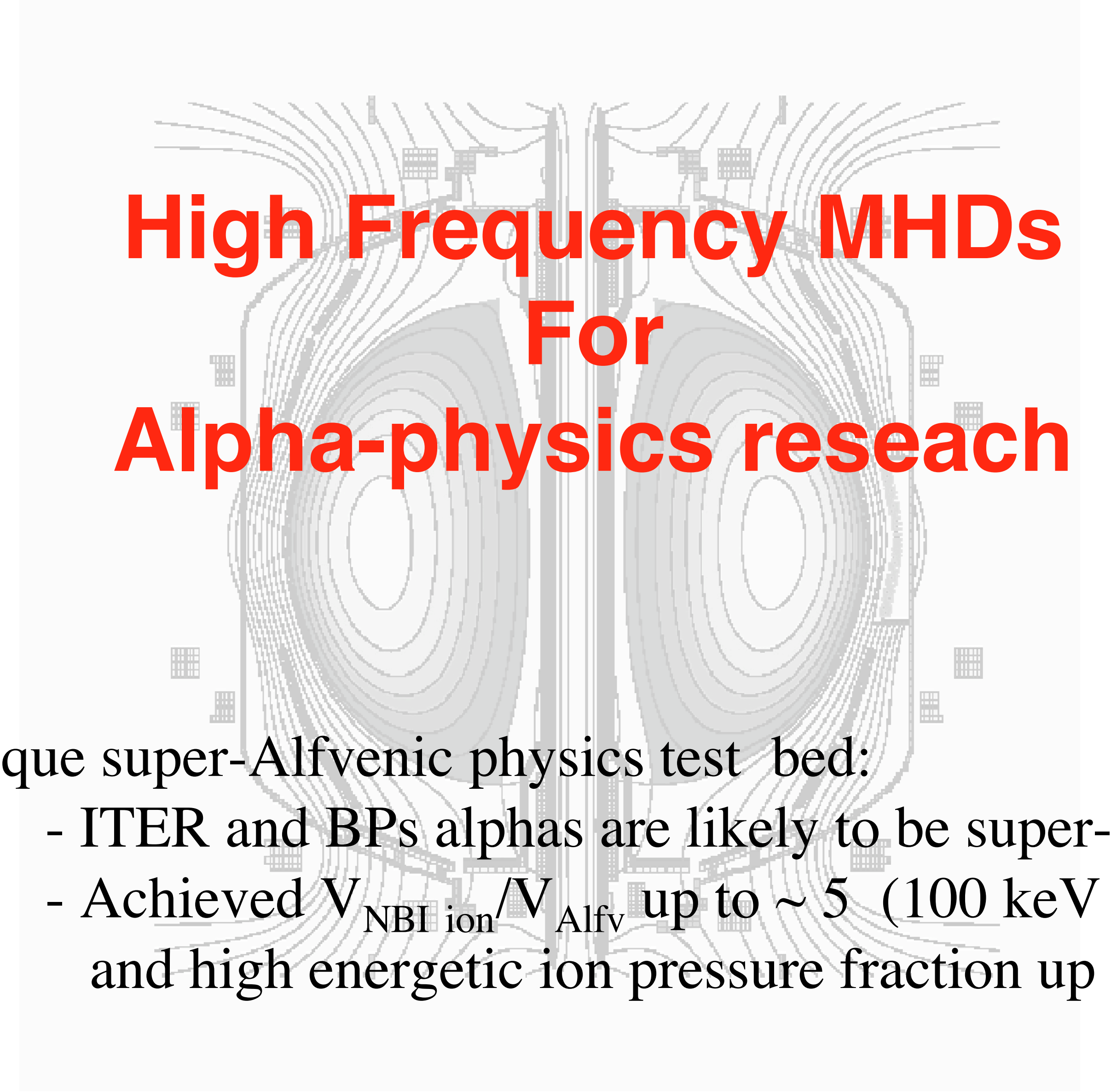


Pump at
30 MHz

IBW Side-bands
separated by ~ fci

- An innovative edge ion temperature and rotation diagnostic revealed strong edge ion heating and rotation
- Parametric instability consistent with decay into IBW and Ion Quasi-mode observed - lower power threshold and robust
- Edge ion can drain a significant fraction of wave power ~ 30%

T. Biewer

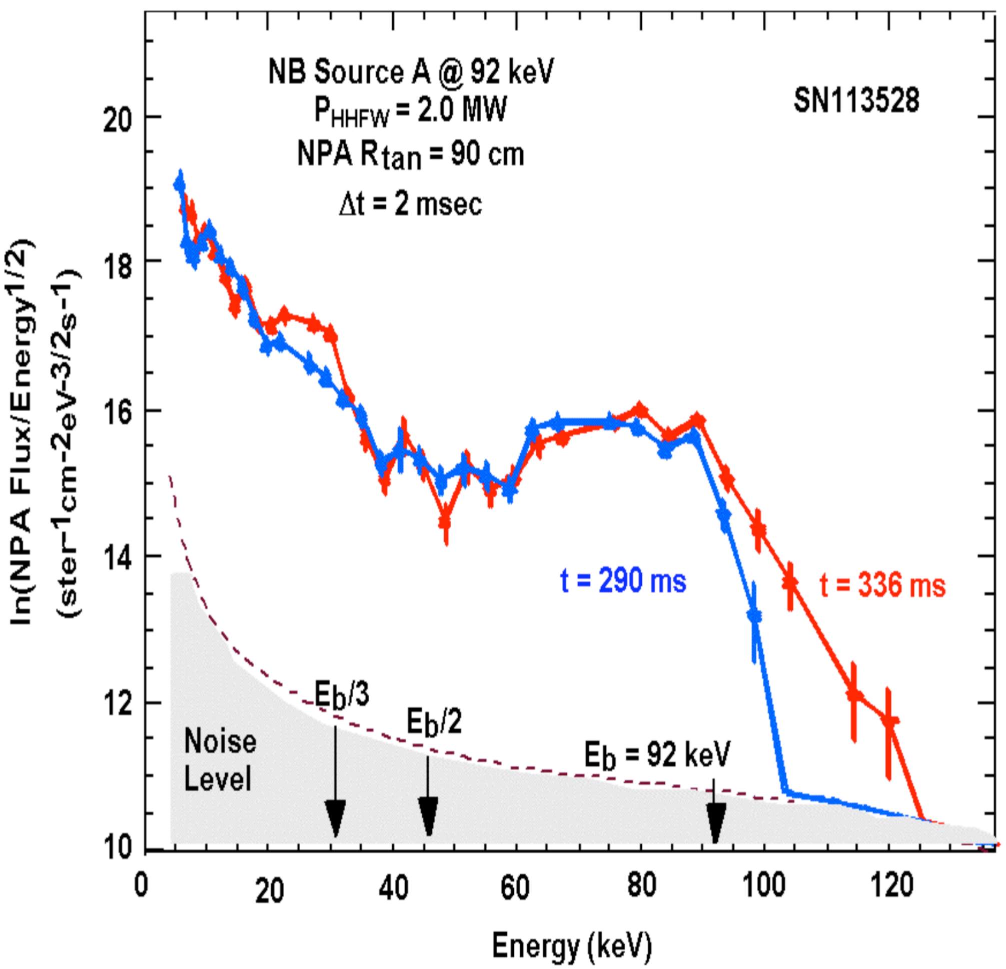


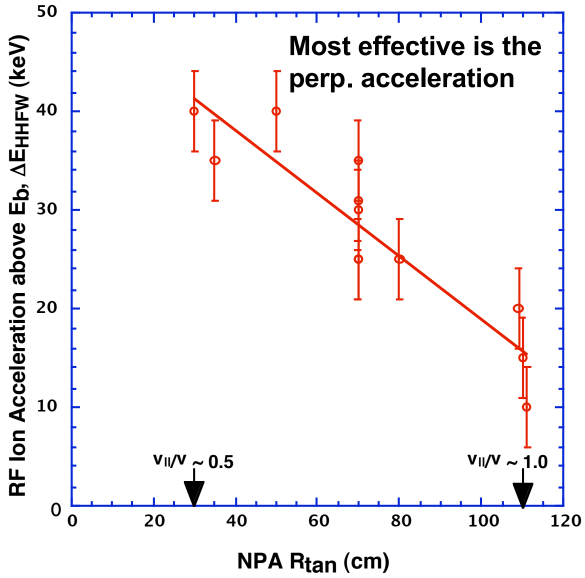
High Frequency MHDs For Alpha-physics reseach

A unique super-Alfvenic physics test bed:

- ITER and BPs alphas are likely to be super-Alfvenic
- Achieved $V_{\mathrm{NBI\ ion}}/V_{\mathrm{Alfv}}$ up to ~ 5 (100 keV NBI) and high energetic ion pressure fraction up to 50%

NPA data proves that HHFW accelerates beam ions



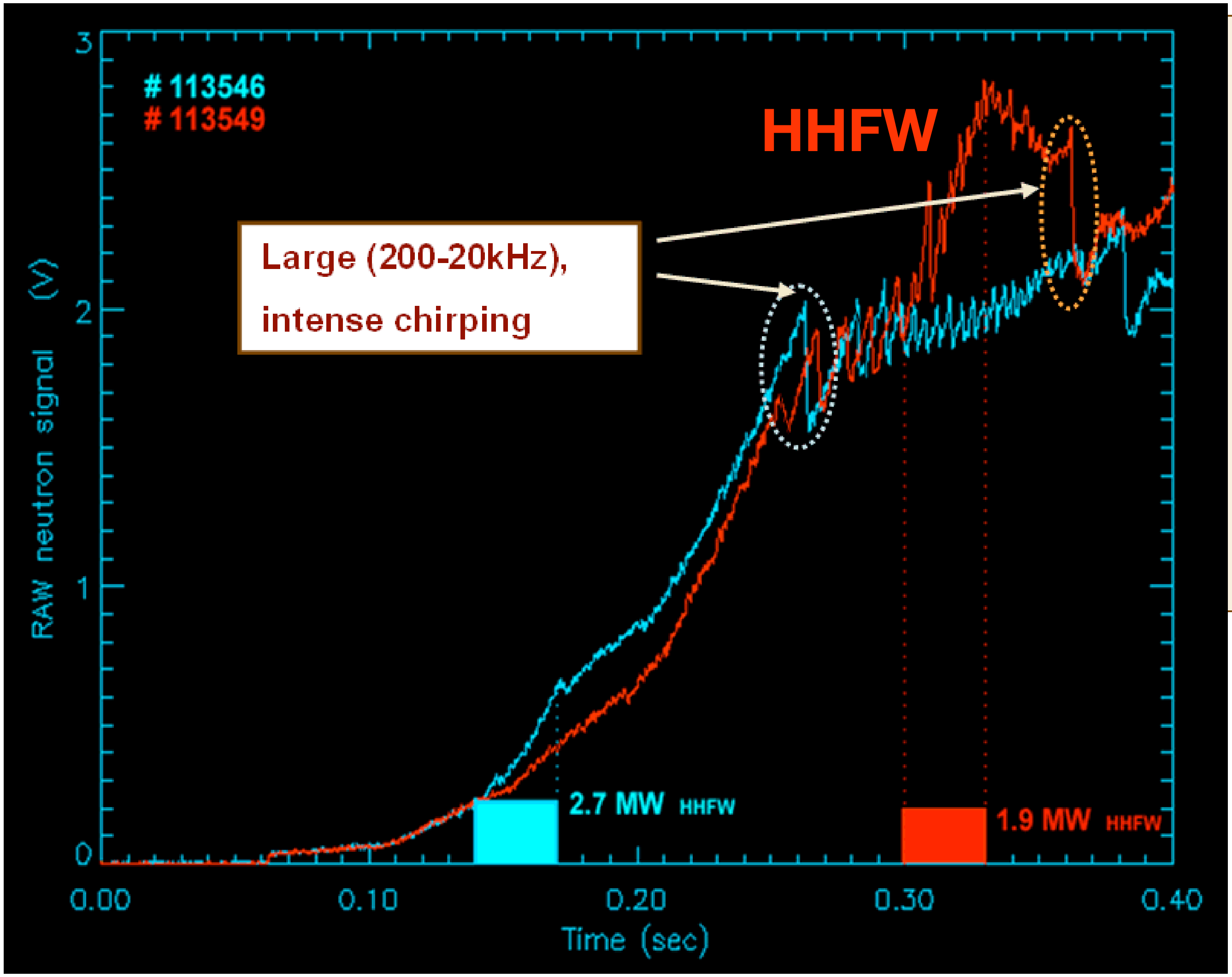


- **Comparable RF acceleration of neutral beam ions observed at E_b ~ 65 keV and E_b ~ 90 keV for all NB sources.**

- **The energetic ion tails form in < 15 ms for P_{HHFW} ~ 2 MW.**
- **Tail decay time ~ 12 ms**

S. Medley

HHFW increases the neutron rate. Chirping causes rapid 5-25% drops

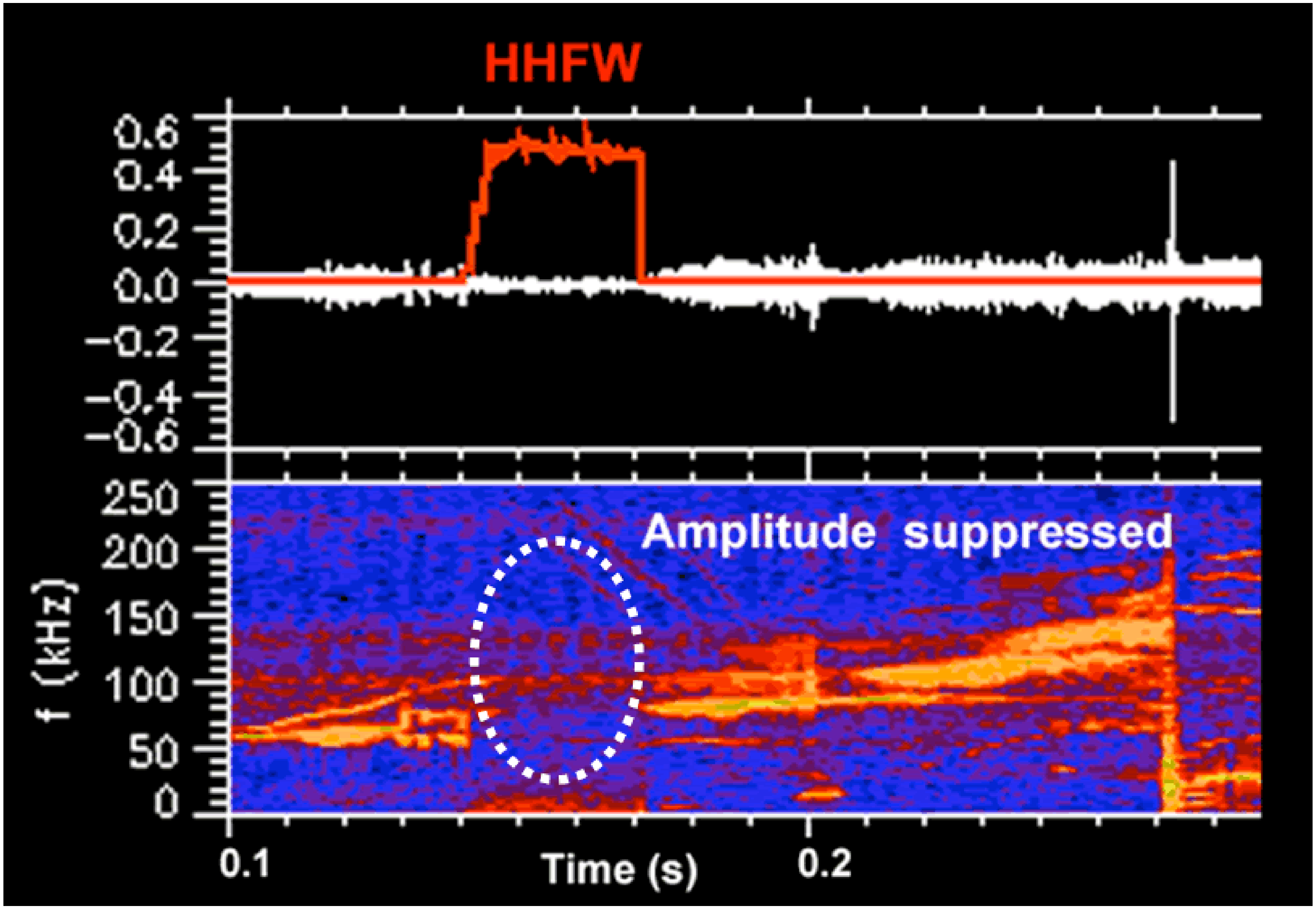


Large (200-20kHz), intense chirping

- **Successfully developed our target helium L-mode plasma**
- **Early chirping** ***(during current ramp-up)*** **seen only for the most tangential full energy beam injection (source A, 2MW / 90 keV).**
- **Late chirping seen in all shots.**

Ruskov, UCI

HHFW suppresses MHD modes: early chirping TAEs
Shows delicate dependence on velocity distribution function



__Note:__ **These two shots use beams B and C with 1MW / 60KeV, and have nearly identical plasma parameters.**

Power and Particle Handling

Gas Puff Imaging

Divertor Camera*

Fast Probe

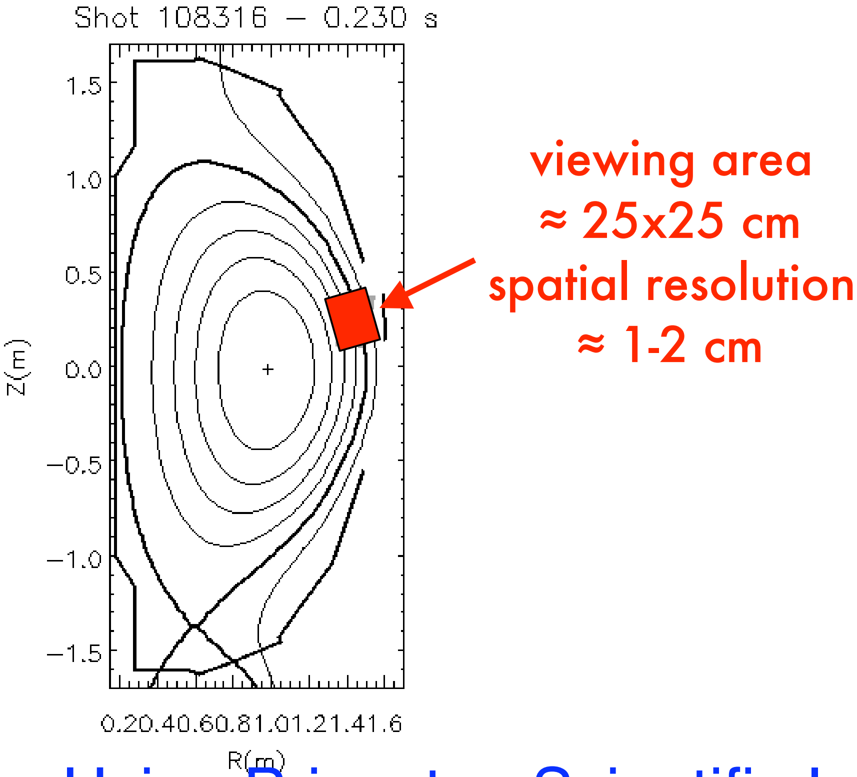
Divertor Spectroscopy

Lithium Pellet

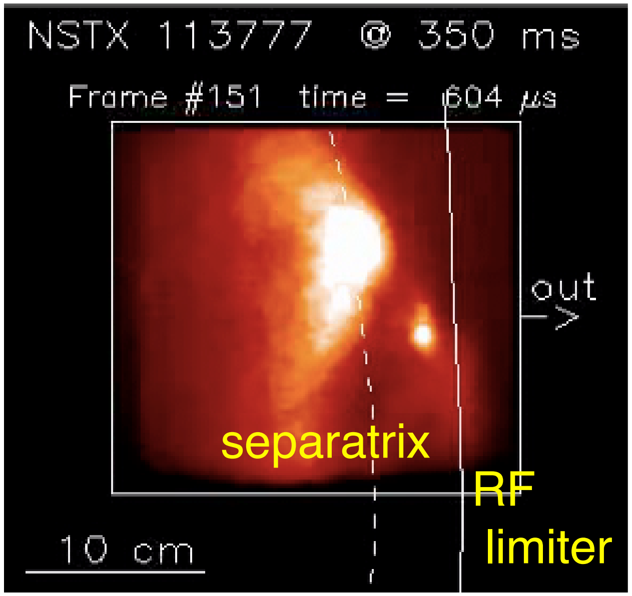
Supersonic Gas Injector

* N. Nishino

GPI Image Orientation



viewing area
≈ 25x25 cm
spatial resolution
≈ 1-2 cm



Typical image

Using Princeton Scientific Instruments PSI-5 camera

250,000 frames/sec @ 64 x 64 pixels/frame
300 frames/shot, 14 bit digitizer, intensified

S. Zweben

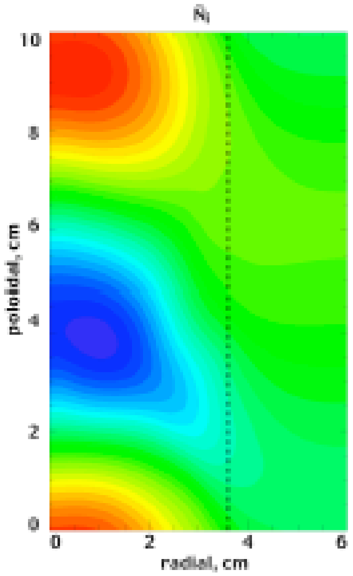
Simulation of NSTX Edge Shows “Blob-like” Structures

BOUT fluctuations from NSTX case appear to have reasonable spatial and temporal scales

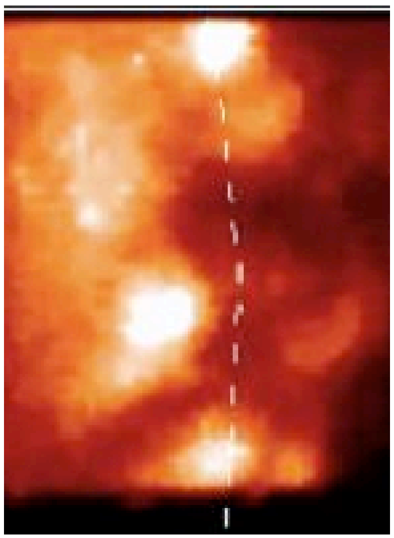
Preliminary results

- δN_i at the level ~10%
- δT_{ei} at the level a few eV
- $\delta\phi$ at the level ~10 V
- Spatial scale ~ 2 cm
- Frequency f ~ 1e5 s^{-1}

BOUT



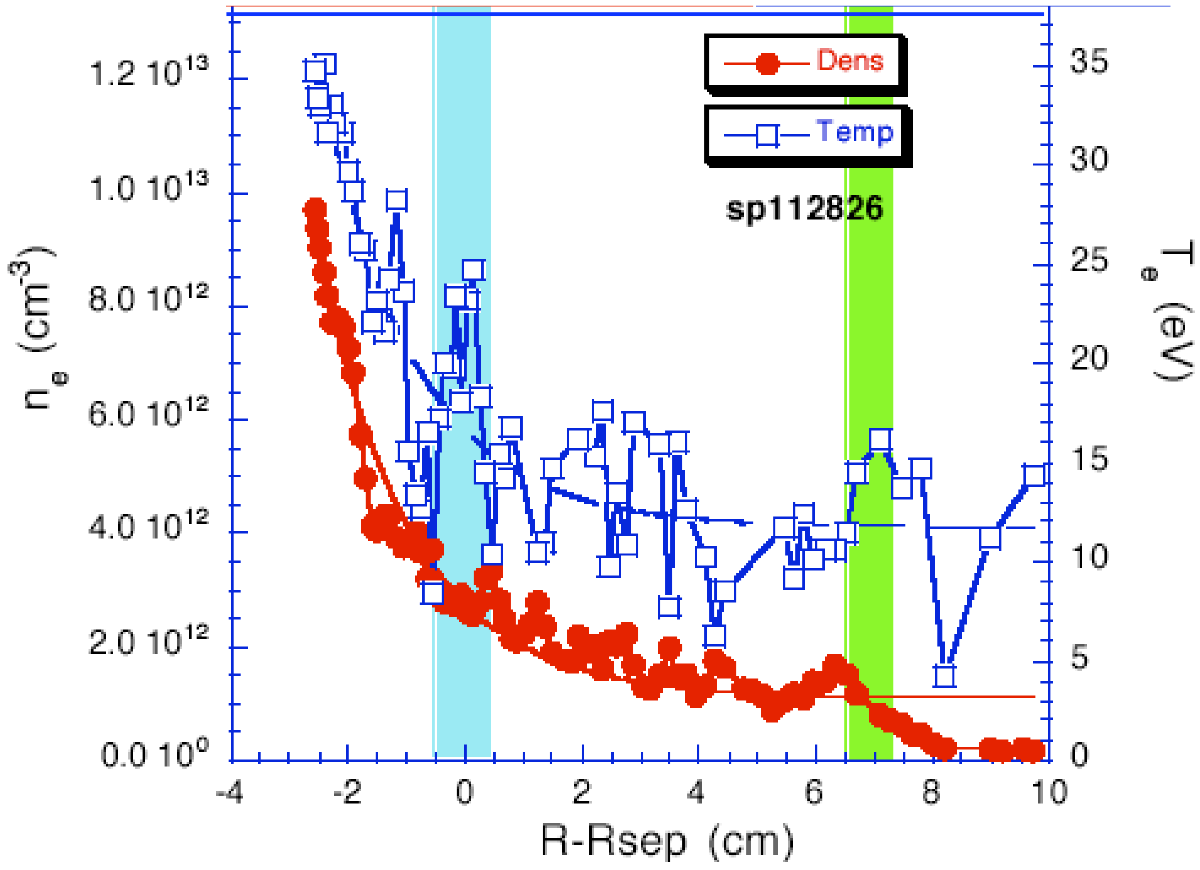
SZ data



M.V. Umansky, LLNL

Fast probe provided edge density and temperarure profile

n_e rises faster than T_e



J. Boedo, UCSD

Profiles with high (~2 mm) spatial resolution

3 ms time resolution

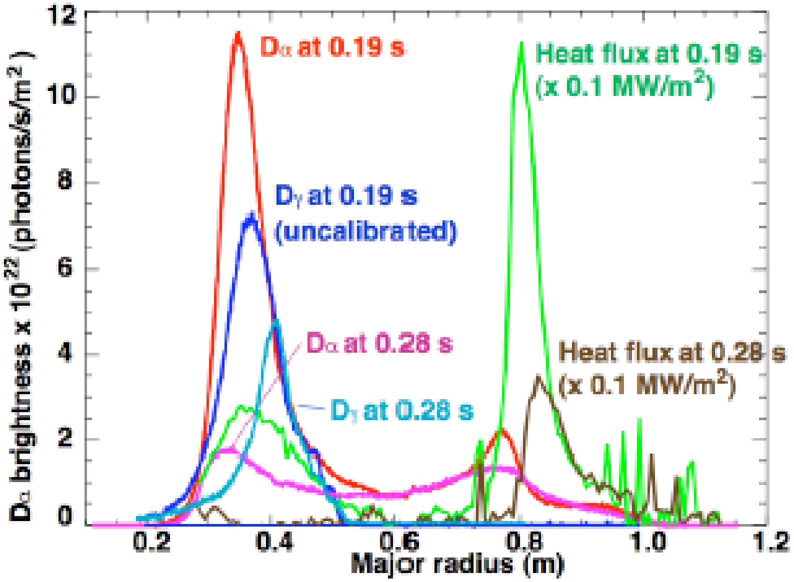
Upgrading to 2 μs resolution

Data well inside the LCFS

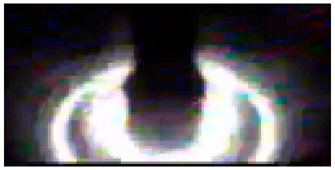
Plasma exists far into the SOL

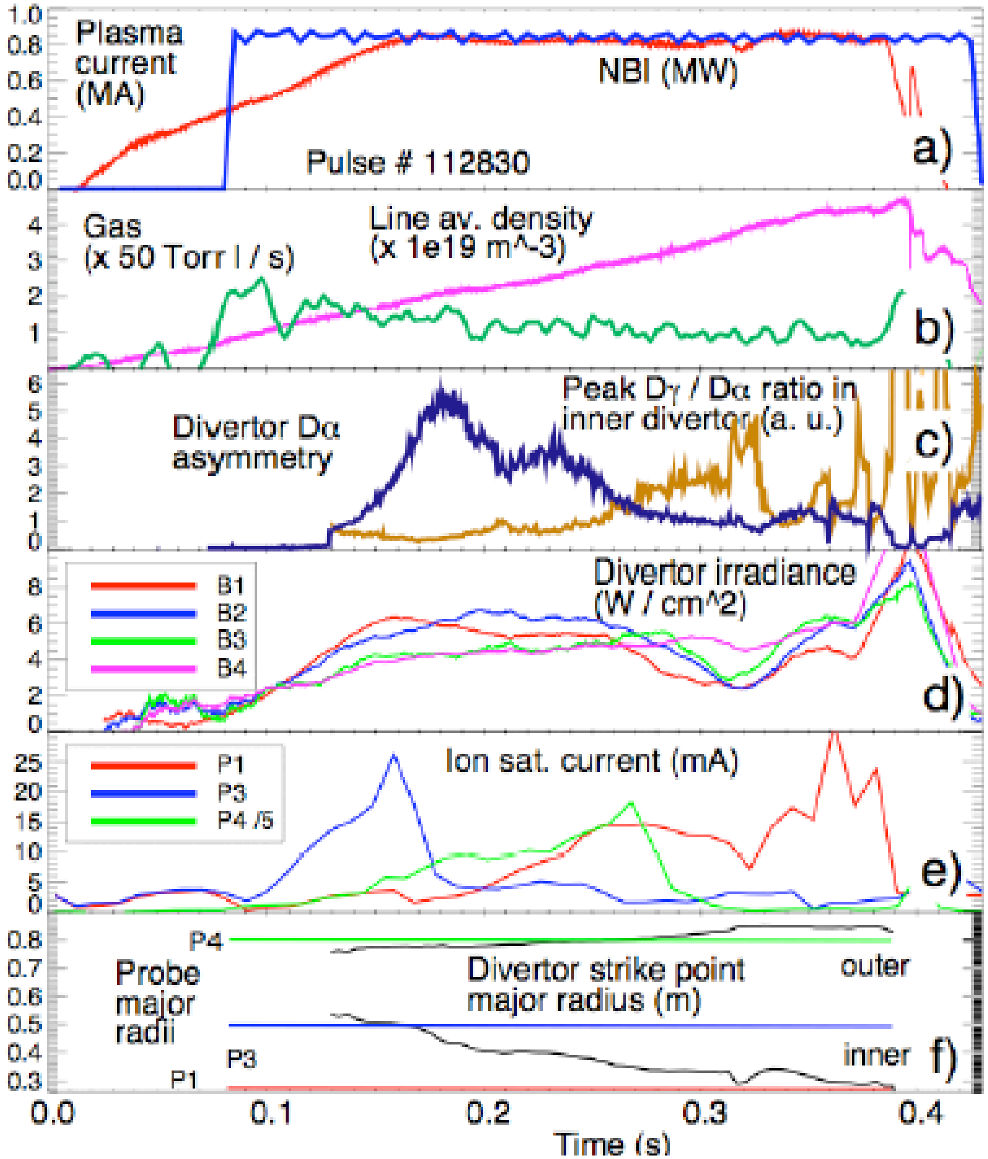
An offset is needed for fits

Inner divertor cold / detached in LSN plasmas



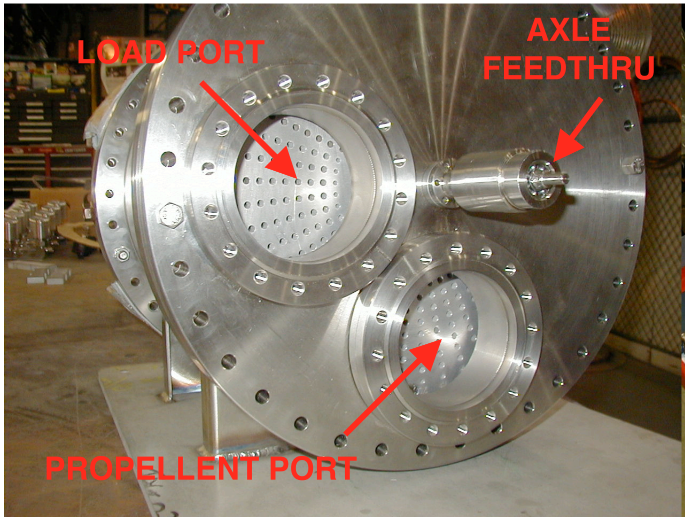
- 1 NBI src L-mode
- Inner divertor detached at $\langle n_e \rangle$ = 2.5-3 x 10^{19} m^{-3}



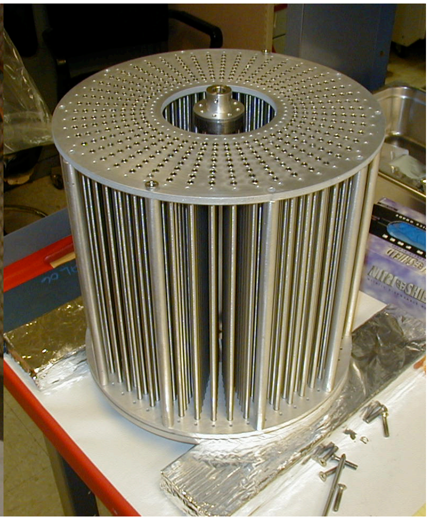


Outer divertor not detached yet

Lithium Pellets Injection to Control Particle Recycling



OUTBOARD VIEW



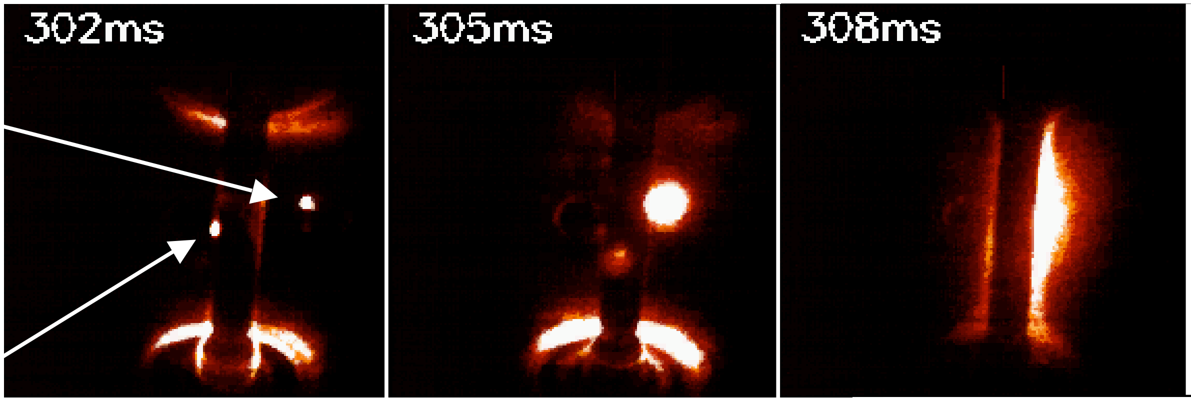
400 BARREL TURRET

- Capability for injecting solid pellets (<1 – 5 mg) & powder (micro-pellets)
- 10 – 200 m/s radial injection
- 1 – 8 pellets per discharge
- 400 pellet capacity
- Develop optimized scenarios

Lithium vapor spreading along the center-stack

Lithium Pellet moving through plasma after entering at 296ms

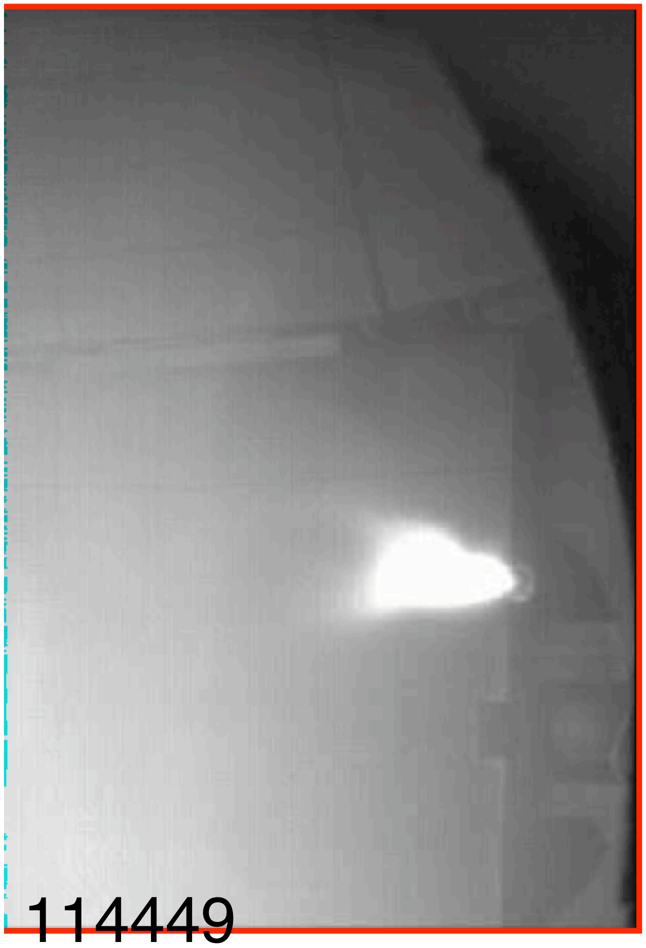
In-board gas injector

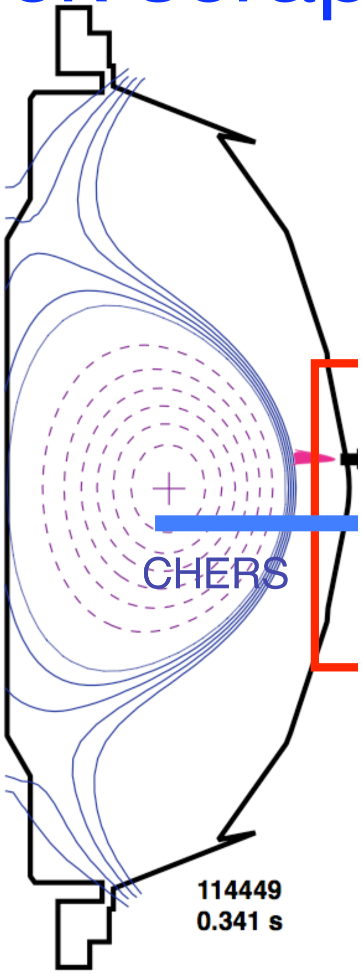


Lithium “vapor ball” surrounding pellet as it approaches the center-stack

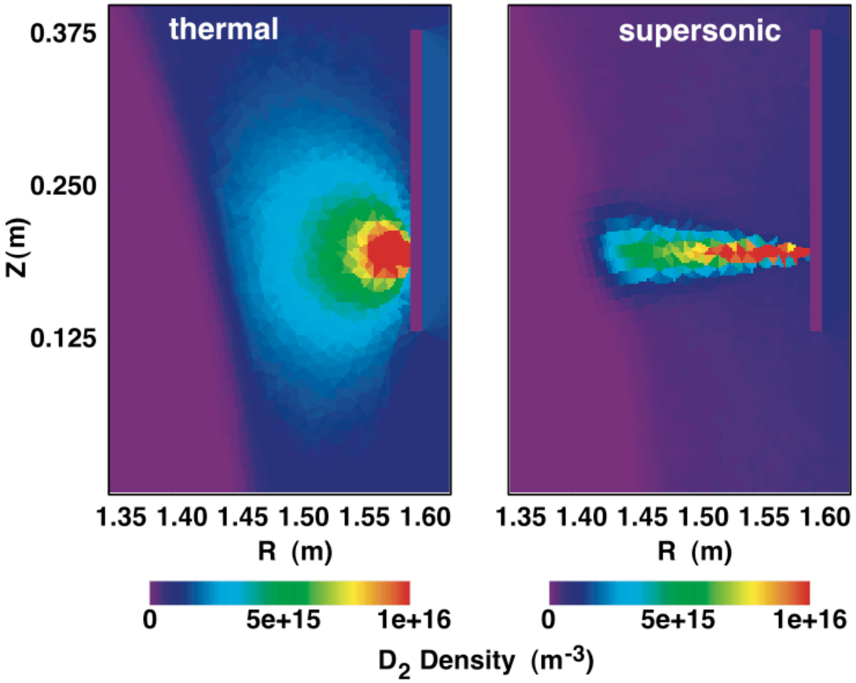
H. Kugel

Supersonic gas jet penetrates well through a thick scrape-off layer





Preliminary fueling efficiency estimate shows ~ 3 - 4 times improvement over gas puff



DEGAS 2 Neutral transport modeling reproduces observed features (D. P Stotler)

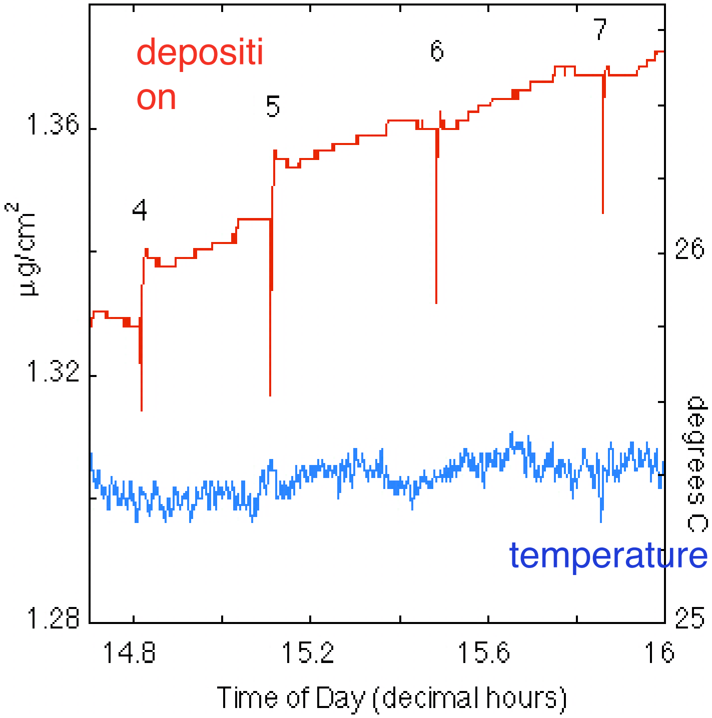
V. Soukhanoskii, LLNL

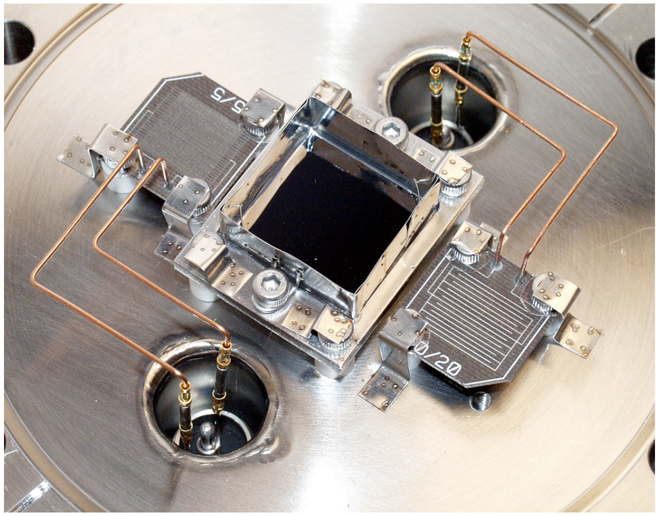
NSTX is developing ITER/BP relevant time resolved surface deposition monitors

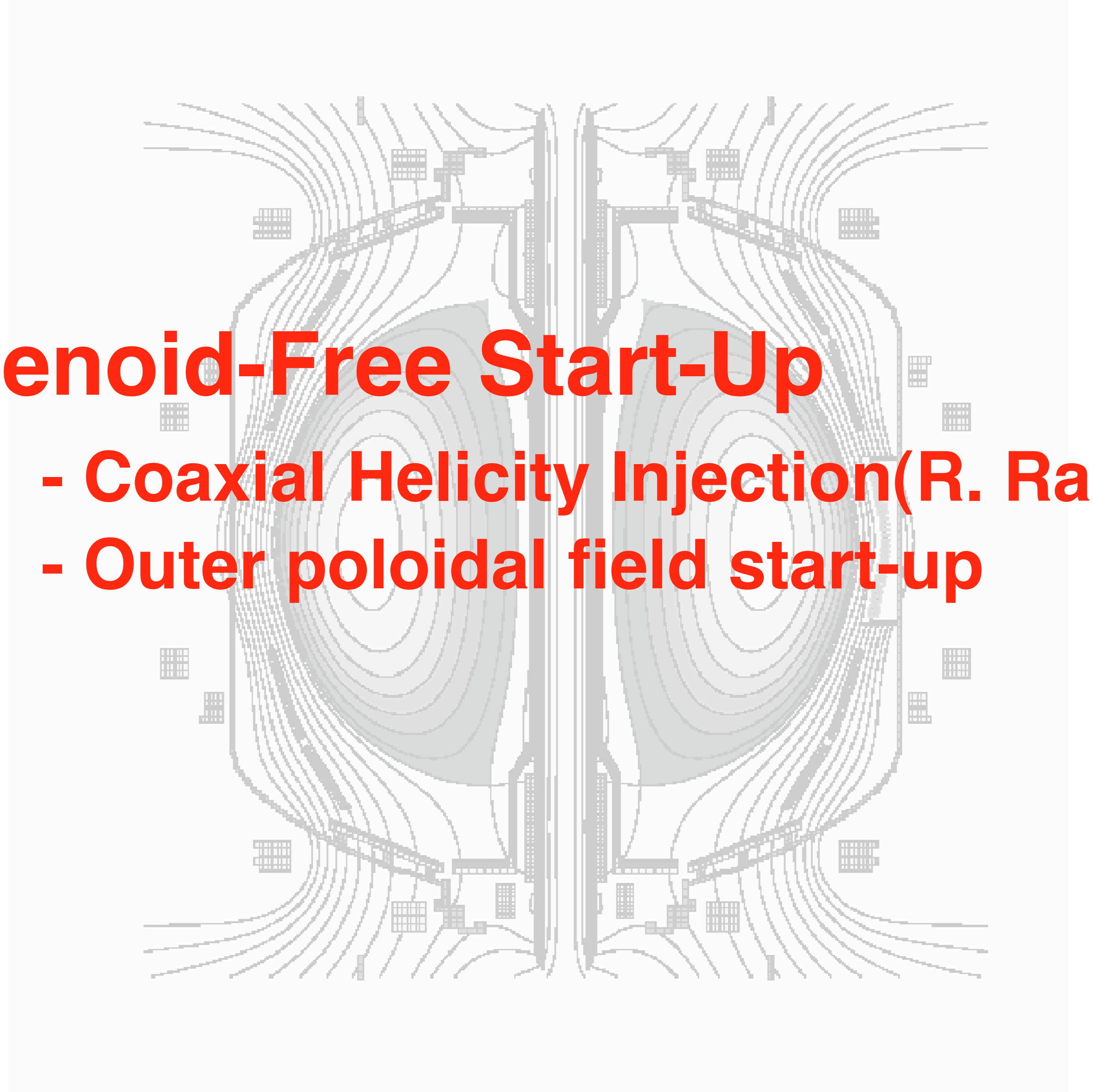
- Quartz microbalance shows time resolved deposition on NSTX in geometry typical of a diagnostic mirror - results show significant deposition after plasma discharge.
- Novel electrostatic surface particle detector works well in air and vacuum environments.
- First time-resolved measurements of surface dust in tokamaks.

C. Skinner

Deposition over 4 shots 112014-017.





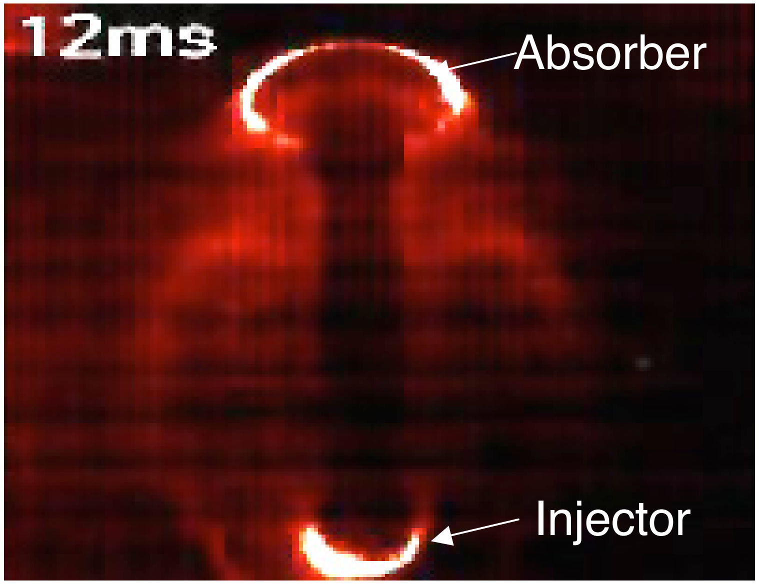


Solenoid-Free Start-Up

- Coaxial Helicity Injection(R. Raman)
- Outer poloidal field start-up

Possible Improvements to the Transient CHI System

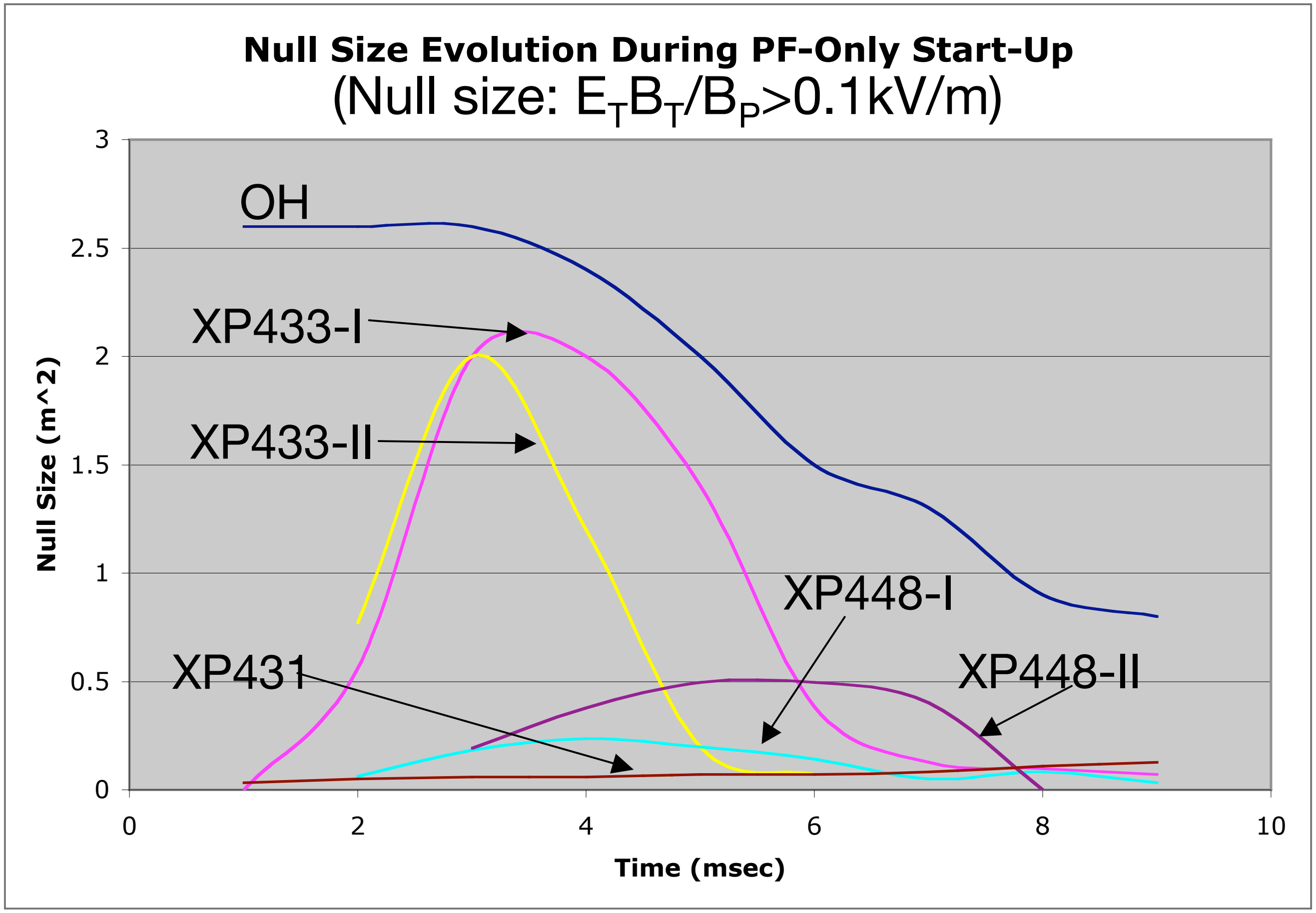
- Operated reliably up to 1 kV
- Produced reliable breakdown with lower gas pressure
- Generated $I_p \sim 140$ kA with $I_{inj} \sim 4$ kA in a few milliseconds
- Measured peaked profiles $T_{e0} \sim 16$ eV



Roger Raman in this meeting

Solenoid-Free Start-Up Research on NSTX Begun

Plasma initiation has been identified an important issue

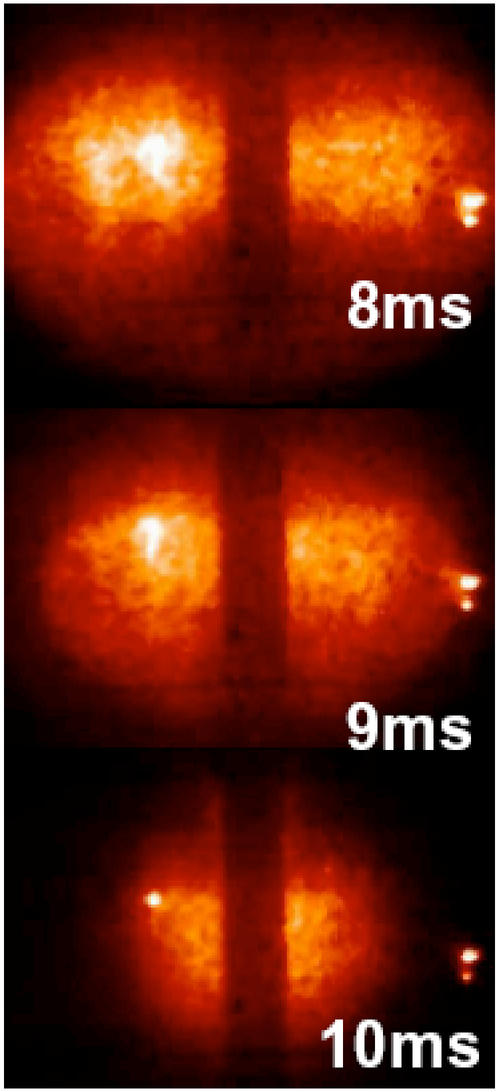


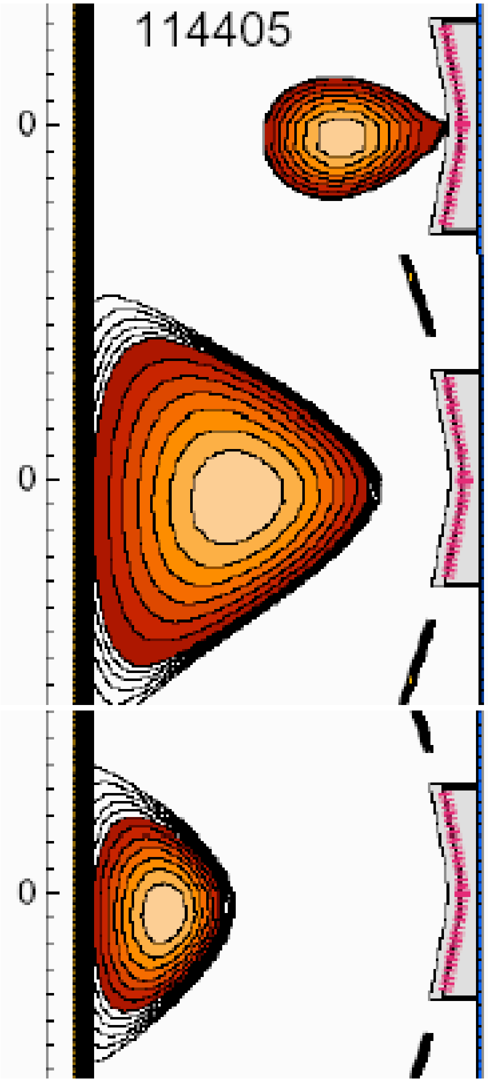
Successful initiations:
OH:112152, 4.5 kG
XP433-I: 113612, 3.5 kG
XP433-II:114405, 3 kG

Not successful initiations:
XP431: H:11293, 4.5 kG
XP448-I: 113609, 3.5 kG
XP448-II:114484, 3 kG

J. Menard
Y. Takase
M. Ono
W. Choe

Camera images and reconstructions show plasmas are born on LFS and have an inward radial trajectory





- LRDFIT code used for reconstructions
  - $I_{Vessel} \approx 10 \times I_P$
- Careful control of B_Z after breakdown helped raise I_P from 10kA to 20kA
- More B_Z evolution optimization possible

J. Menard

Future Plan for the PF-Only Start-Up

Broadening initiation parameter space is a crucial near term issue:
  - Smaller null tends to yield more flux opportunities
  - Earlier initiation makes more flux available for current ramp up

- Possible approach for improving initiation :
  - More HHFW power or mixed phasing with more antennas
  - More readily ionizing gas such as deuterized methane
  - 8 -10 GHZ ECH to directly heat the null region (a source needed)
  - CT injection to eliminate the need for ionization (longer term)

- Develop scenarios maximizing available flux for a given null

- Refurbish PF4 to enable opposite polarity operation with respect to PF-5.

Research Tool Development on NSTX Supports Fusion and Plasma Science

NSTX

- Expand MHD operation space: RWM and PF 1A coil systems
- Understand confinement: Current Profile, X-rays, Fluctuation diagnostics
- Explore super-Alfvenic energetic ion physics: HHFW as a new tool
- Gain understanding of HHFW heating and current drive
- Develop new efficient edge current drive tool: EBW
- Arrays of research tools for heat and particle control
- Develop practical solenoid-free start-up tools: CHI and outer PF coils

NSTX Welcomes Collaborations