NSTX

Recent Experimental Results
ET1: Ohmic Plasma Optimization

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Scientific Goals of ET1 from 1999 NSTX Research Forum

- Establish wall conditioning techniques.
- Plasma startup.
- Establish controlled plasma discharge at significant I_p and flattop duration.
- Explore range of operating space.
- Perform initial global confinement scans, access to H-mode.

Approved XPs for ET1

XP001- Optimization of Volt-Second Consumption

XP002- Establishing Reproducible Wall Conditions

XP003- Control System Response

XP004- Investigation of Equilibrium Domain

XP005- Exploration of Operational Limits

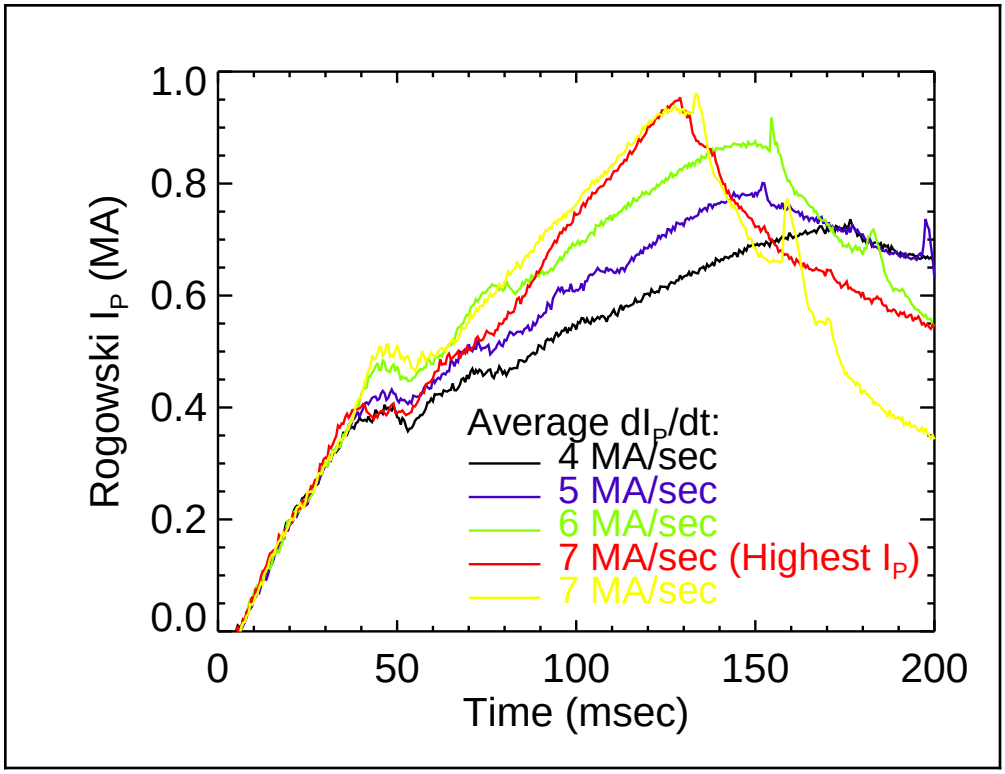
XP010- Edge Turbulence Measurements

XP001 Optimization of Volt-second Consumption

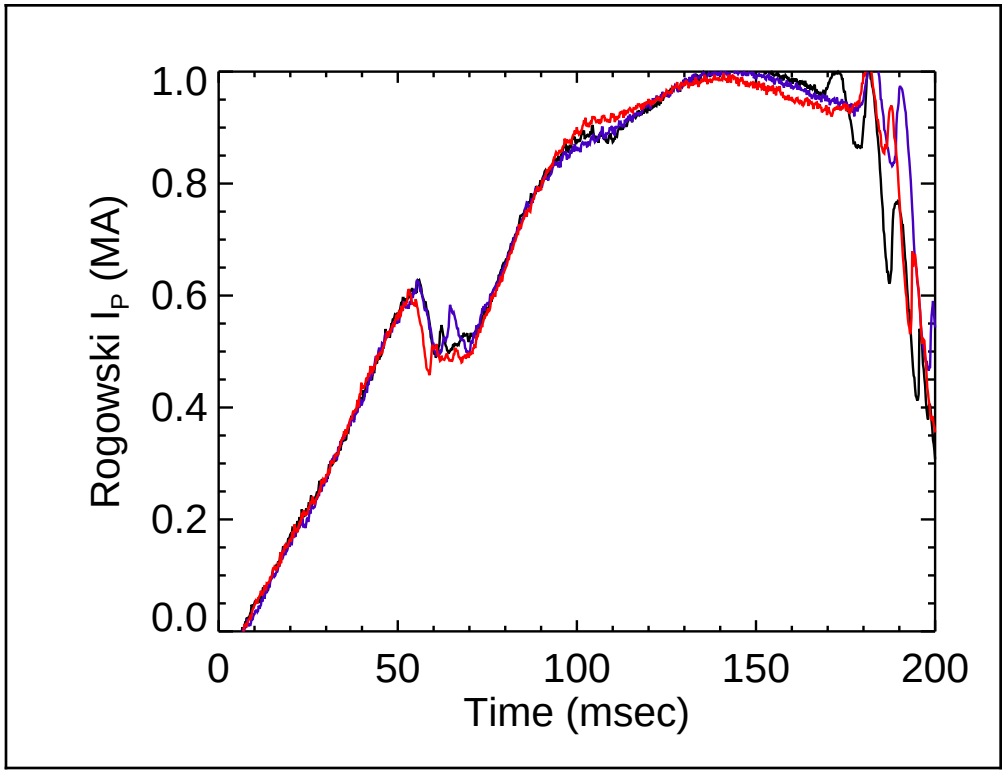
(J. Menard, *et al.*)

- Achievements
  - Finished systematic scans of I_P ramp rate pre and post-bake: 5-7MA/sec is maximum sustainable
  - Optimized shape for each ramp-rate to achieve maximum stable elongation
  - Computed Ejima coefficients and energy balance evolution from EFITs: Best $C_E = 0.4$.
  - Achieved I_P=1MA discharges with long periods of high current ($I_P > 800$kA for $t > 70$msec)
- Outstanding issues:
  - Density (or P_{rad}) dependence of C_E has not been characterized.
  - We have not gotten to high current ($I_P > 800$kA) with a tightly controlled I_P ramp and flat-top because of poorly understood MHD events.
  - Actually, MHD events typically impact discharges of all current levels $\Rightarrow$ we should try slowing the discharge ramp-rate early ($t < 30$msec), modify the fueling, or change the shape evolution early to try to suppress the MHD.
- **1-2 days of run-time to complete**

Optimization of V-sec consumption- I_p Ramp Rate Scan



Optimization of V-sec Consumption- High I_p Operation



XP002 Establishing Equilibrium Wall Conditions
(R. Maingi, H. Kugel, *et al.*)

- Goals:
  - Assess short term and long term evolution of wall conditions and impact on plasma discharges
  - Use glow discharge cleaning in deuterium (D_2 GDC) and/or helium (He GDC) to achieve reproducibility
- Specific Questions:
  - How many discharges to short-term equilibrium?
  - Is there a measurable change in discharges and how long does it last after GDC of 'n' minutes ($2<n<720$)?
  - Is (shorter) GDC between discharges more or less effective than longer duration, less frequent GDC ?
  - How long to recover after events (e.g. vent, CHI)?

Establishing Equilibrium Wall Conditions

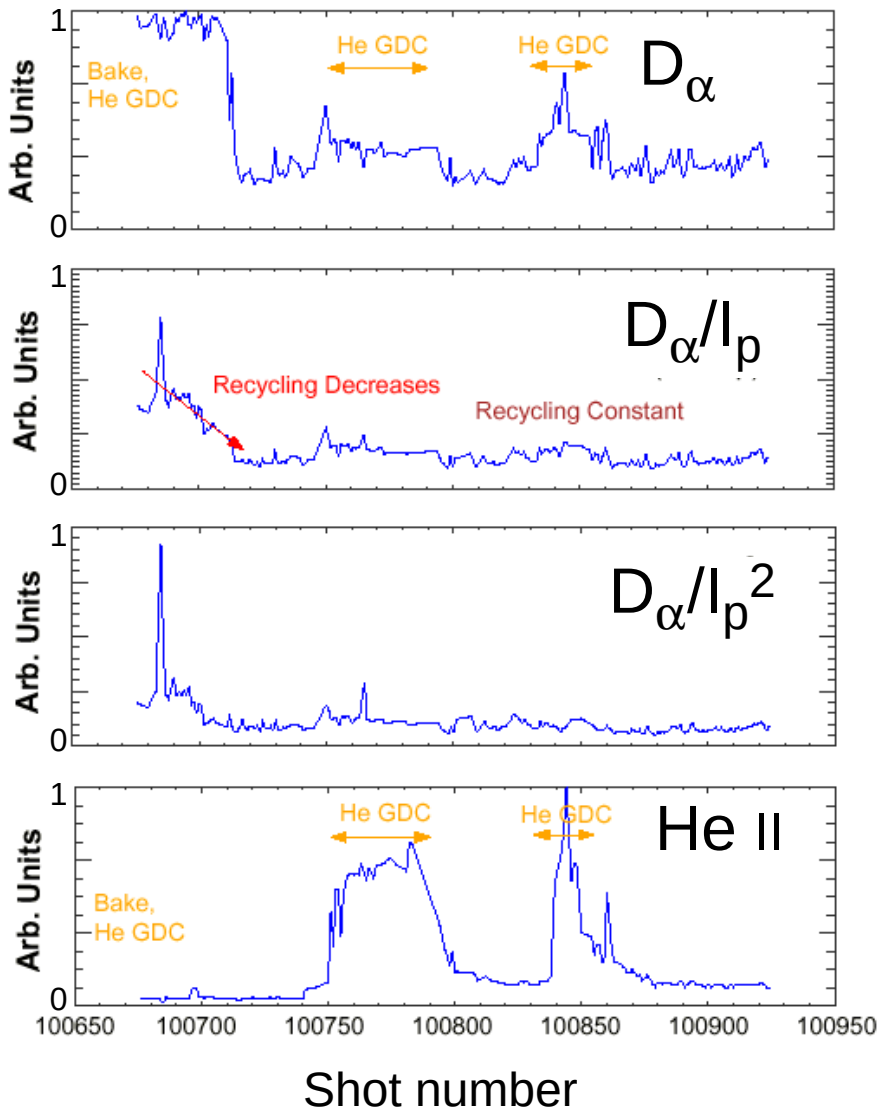
- Measureables:
  - D_α , C-II, C-III, O-II, and He-II visible light emission √
  - Edge visible light emission survey √-
  - Core VUV impurity line emission ×
  - Line-average density √-
  - Radiated power profile √-
  - Neutral pressure, fast time response ×
  - Stored energy √

Establishing Equilibrium Wall Conditions

- Results and Observations:
  - OPS in summer 1999 required 40 discharges to achieve reproducible edge light emission
  - 10-20 discharges required to recover normal "low" edge line emission levels after a vent or CHI
  - Post-CHI cleanup requires 30 minutes HeGDC before OPS
  - Machine base pressure increases during run day with 10 minute rep. rate
  - GDC coats windows - shutters required
  - Between shot HeGDC shows not effect on plasma performance
  - In discharges before 10/99, $(H_\alpha)/(H_\alpha+D_\alpha)$ ratio was 95%; now less than 10% in gas fueled discharges
  - Metallic impurities are copper and stainless steel components; HeGDC most effective for carbon/oxygen

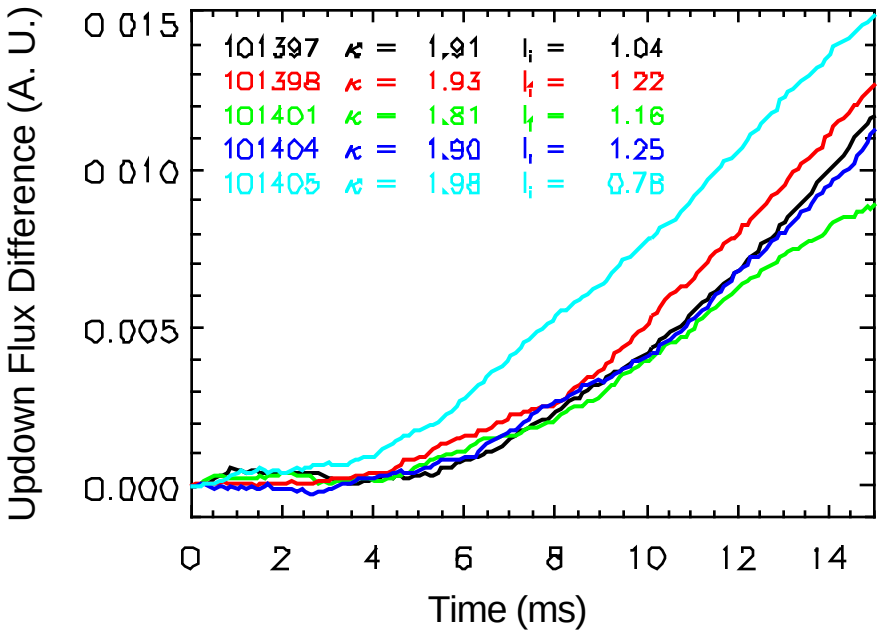
Establishing Equilibrium Wall Conditions

- Many Discharges Required for D_α Light to Come Down



XP003 Control System Response (D. Gates)

- Goals:
  - Measure vertical growth rate as a function of internal inductance and elongation
  - Measure step function responses of vertical, radial and I_p control loops
  - Compare response with TSC simulation
- Results:
  - Growth rates measurements taken for a range of inductances and κ's (1 day of run time)
  - Radial and Ip step function response indirectly available as a result of frequent MHD spikes



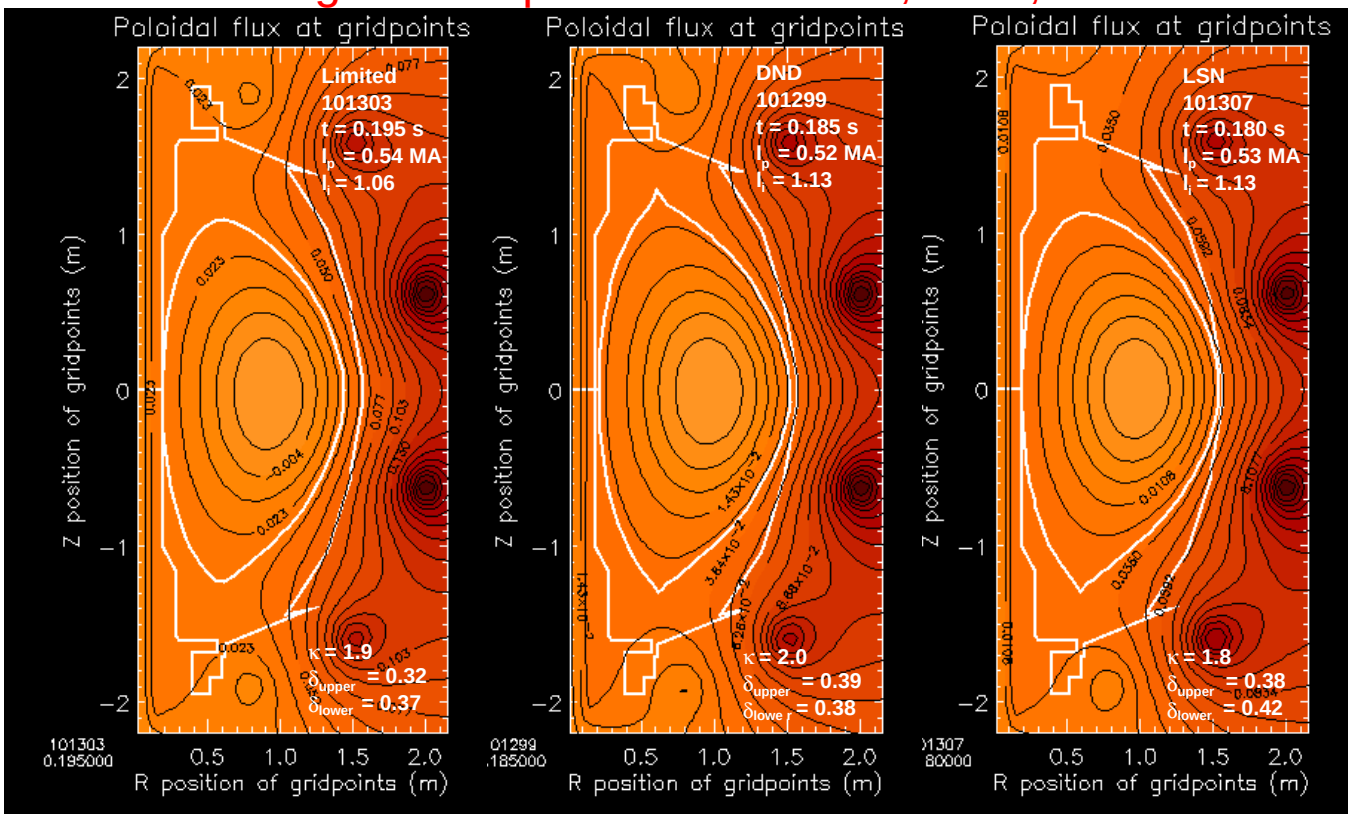
- **2 days of run-time to complete**

XP004 Investigation of Equilibrium Domain
(S. Sabbagh, *et al.*)

- Goals and Status:
  - Establish plasma shape domain
    - Inner wall limited, DND, and LSN plasmas have been successfully created
    - Elongation ≤ 2.5 (transient), 2.0 flattop; $\delta \leq 0.6$; 0.26 - 0.46 flattop
  - Operate with $I_p \geq 500$ kA with long pulse
    - I_p flattop for ≥ 100 ms ($3 - 5 \times \tau_E$) at 600 kA; (XP01: $2 - 3 \times \tau_E$ at 1 MA)
  - Establish various plasma current profiles
    - ℓ_i varies from 0.3 to ≤ 1.3 during a shot
  - Document the MHD characteristics
    - IREs observed; vertical instability & global kink modes induced
  - Create optimal targets for Phase II high-β, CHI, and HHFW operation
    - $I_p = 0.8$ MA target ($2 - 3 \times \tau_E$) for NBI; LSN target produced for CHI

Investigation of Equilibrium Domain

Configurations produced: Limited, DND, LSN



- Present Results:
  - Limited, DND, and LSN plasmas have similar characteristics
    - No configuration is immune to MHD
    - W_{tot} is similar in all configurations so far
    - Greatest W_{tot} is attained in high I_p, volume, and density
    - Maximum I_p attained at high κ and relatively low ℓ_i

Investigation of Equilibrium Domain

- Tasks to Complete:
  - Increase triangularity at high Ip (0.8 MA)
  - Vary current profile shape: Increase / decrease ℓ_i by ramping I_p down / up
    - Determine effect on MHD
    - Ramp-down has reduced H-mode power threshold in NBI heated tokamaks

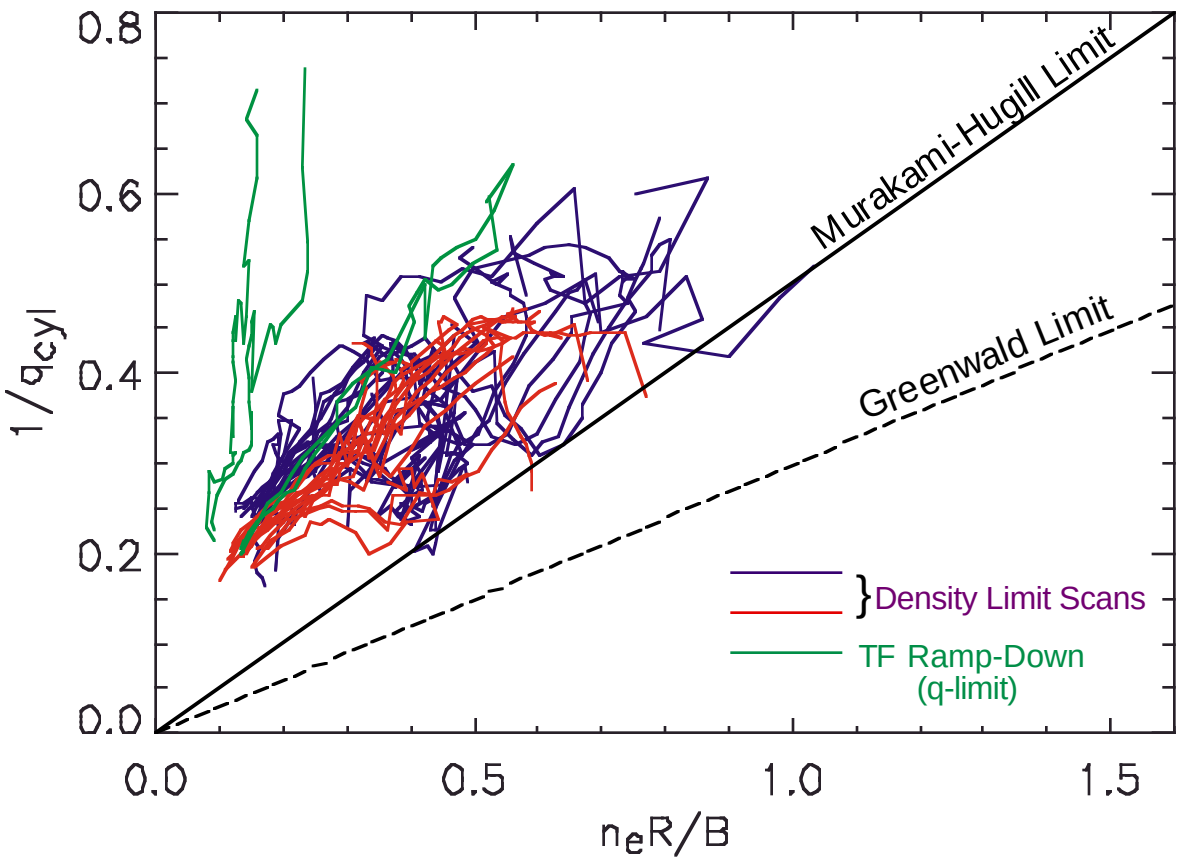
- **< 1 day of run-time to complete**

XP005 Exploration of Operational Limits
(S. Kaye *et al.*)

- **Goals:**
  - Explore operational range of density and q
  - Identify mechanisms limiting the accessible range of these variables
  - Use gas puff to explore density limit, TF ramp down to probe q limit

- **Results:**
  - Density limit explored in I_p = 300-600 kA range
    - Limit consistent with Murakami-Hugill Limit
    - Limit manifest as MHD (oscillatory or catastrophic)
    - Radiated power fraction ≤ 40% at the limit
  - q limit characterized by MHD that severely distorts plasma
    - q limit ≈ 1.4 ($q_{cyl} = 2.5a^2B_T(1+\kappa^2)/RI_p$)

Exploration of Operational Limits

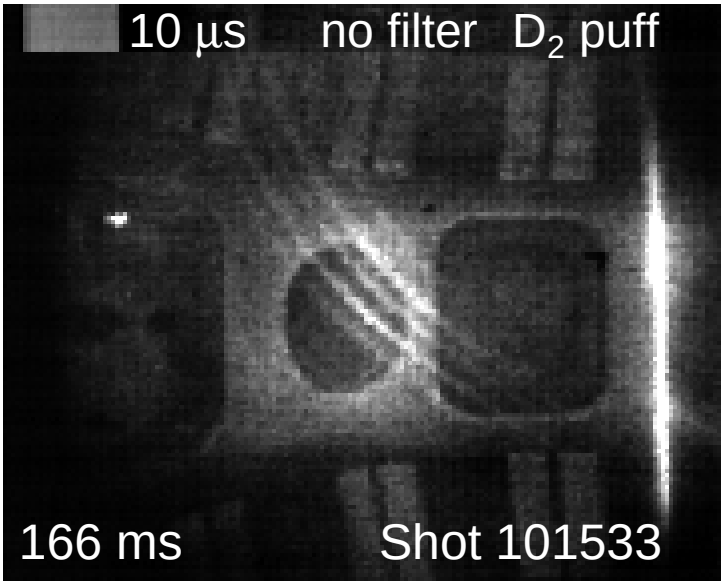


- Future Work:
  - Determine if impurities are an issue in observed limit
  - Extend density and q scans to higher I_p ($I_p \geq 800$ kA)
  - Perform additional q-limit scans

- **2 days of run-time to complete**

XP010 Edge Turbulence Measurements
(R. Maqueda, S. Zweben, H. Kugel, *et al.*)

- Goals:
  - Characterize the cross-field scale lengths and frequency spectrum of turbulent filaments at the plasma edge.
  - Filaments correspond to density fluctuations at the edge well aligned with the magnetic field.
  - The Los Alamos fast framing visible camera (1-4kHz) and the fast chords (200 kHz) are used to look at edge gas puffs or at high recycling regions (e.g. HHFW antenna) with high spatial resolution.
  - Turbulent structure is viewed either along the field line ("end on") or transverse to the field ("side on").



Edge Turbulence Measurements

- Progress:
  - Edge turbulence have been observed during D_2 and He puffs ("side on"), in natural recycling ("side on") and in He puffs ("end on").
  - During a 1/2-day-long run, a dedicated gas puff line introduced a Helium "plume" which was imaged during 3 discharges with the Los Alamos fast framing camera.
- Analysis:
  - Data analysis is underway. More data, particularly "end-on" observations required.
  - Plan:
    - Map Location of visible emission ("end on") based on magnetic field profiles.
    - Model atomic physics of neutrals
    - Analyze spatial structure of edge turbulence from fast camera images
    - Analyze time series of fast chords for frequency spectrum, coherence, and zonal flows.
- Resources needed:
  - New Gas Puff Imaging (GPI) system with "end on" and "side on" capablilites.
- **> 2 days of run-time to complete**

ET1 Summary

- Established feedback controlled plasmas in a variety of configurations
- Attained long I_p flattop
- Reached I_p = 1 MA
- Evaluated wall conditioning techniques
- Began documentation of operational range and limits

Remaining ET1 Effort

- Estimated run time to complete present XPs: **8-10 days**
- New XPs to address practical limits
  - MHD events
  - IREs
- New diagnostic capabilities will improve data quality
  - Thomson scattering
  - UCLA interferometer chords
  - Locked mode coils