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XP507: Early divertor and H-mode development for long pulse

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NSTX Results Review
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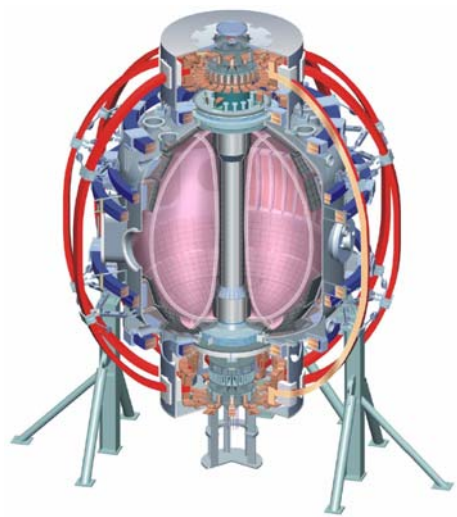

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XP507 - Goals and Progress (Part 1)

1. Re-obtain FY04 long-pulse discharges at 4.5kG
   - Try to reproduce best 0.8, 0.9, 1.0 and 1.2 MA shots **(700-900kA OK)**
   - Document q(ψ,t) of existing early H-mode scenarios - **DONE**
     - Are we close to a "hybrid scenario" in any of these discharges? **YES**

2. Develop early evolution to divert ASAP
   - Attempt in PF1B + new PF1AL – use DND if vertical control problematic
     - **PF1AL + PF1B COMBINATION WORKED WELL**
3. Find fastest sustainable early ramp to 0.5MA
   - Get to $I_P \geq 0.5$MA by 40-50ms (10-12MA/s) to help absorb beam
     - **DISRUPTS AFTER I_P PAUSE if dI_P/dt > 6-7MA/s BEFORE PAUSE**
   - Develop steady control of vertical position and X-point R,Z early in shot
     - **VERY DIFFICULT BEFORE t = 60-70ms**
   - Control inner and outer gaps > 5cm during entire ramp and flat-top
     - **DONE**
   - Open question - is error field correction useful/needed for this ?
     - **TRY IN 2006 – HAVE BETTER UNDERSTANDING OF ERROR-FIELD**

XP507 - Goals and Progress (Part 2)

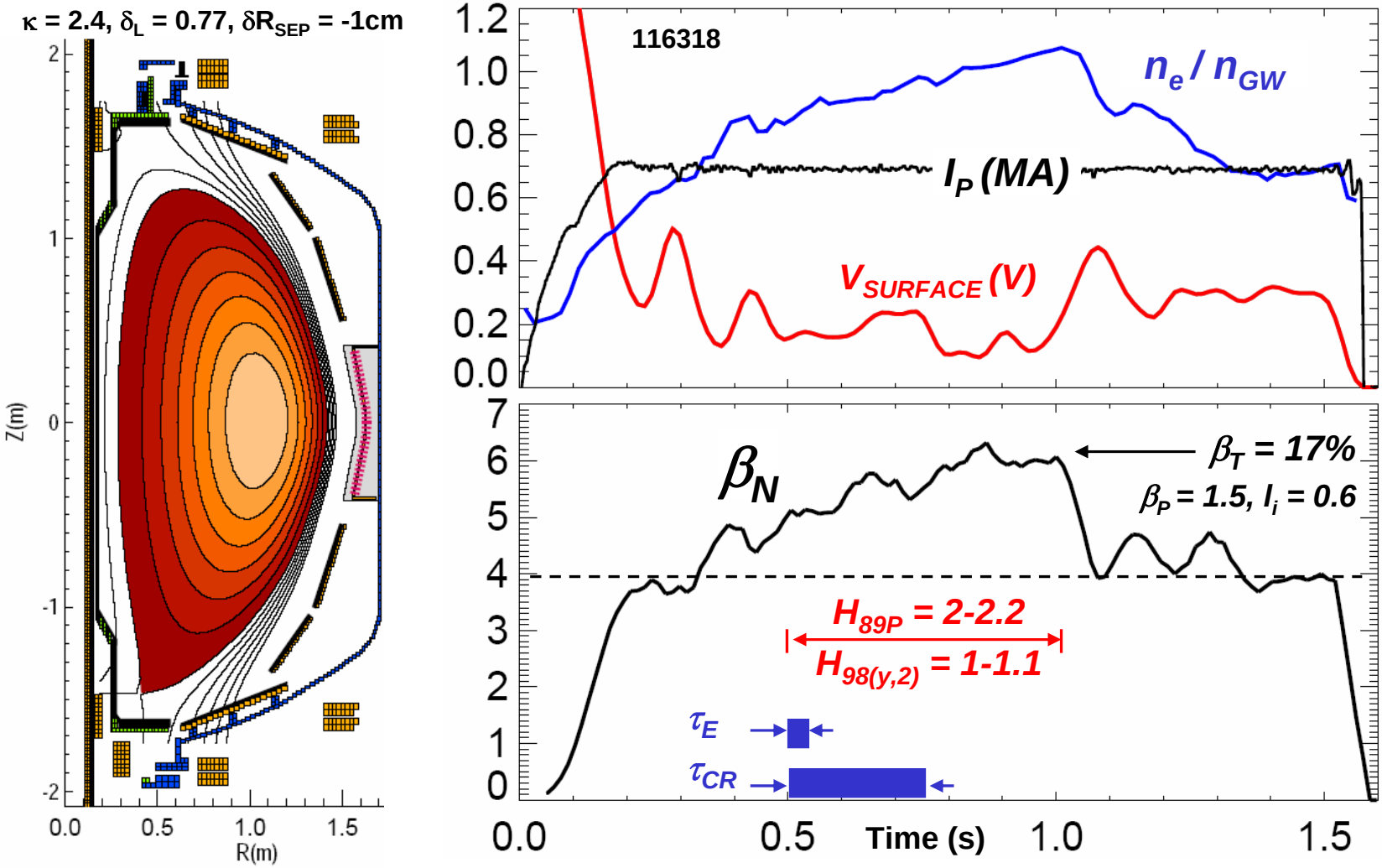
4. Attempt to induce H-mode by t=50ms – **QUITE DIFFICULT**
   - Scan current pause duration, NBI timing and power, and X-pt position
   - Early gas programming also important

5. Modify post-transition TM and ELM activity
   - Scan I_P ramp-rate after transition to avoid locking of TM
   - Scan bottom δ and squareness and assess impact on MHD
     - **RECOVERED TOLERABLE ELM REGIME AT HIGH KAPPA → 2.4**
     - **SLOW DENSITY RISE WITH THESE ELMS**

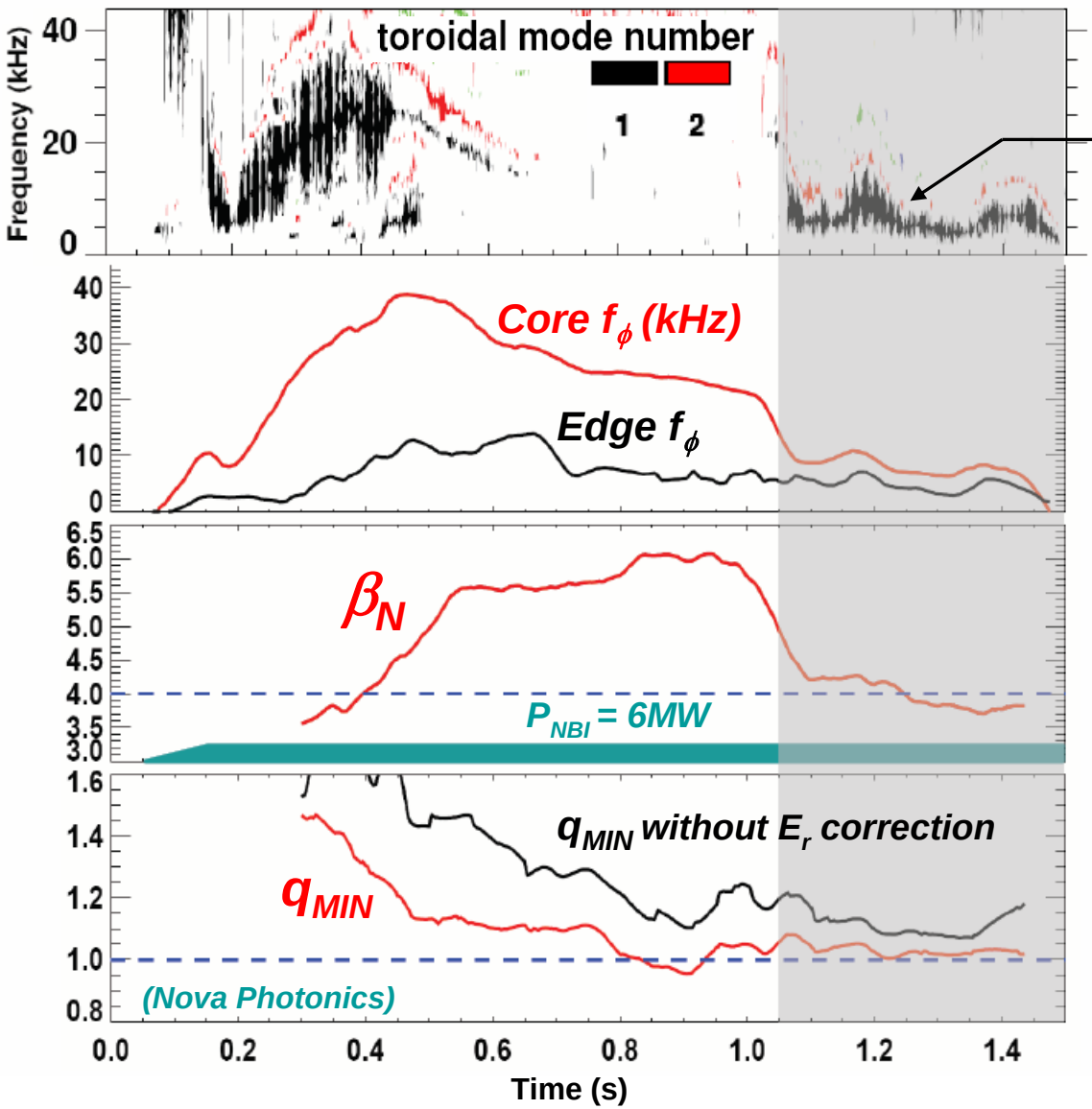
6. Maximize plasma flat-top duration
   - Goal is **Δt > 1s flat-top** at or above 800kA - as quiescent as possible
     - Need to lower B_T to < 4.5kG due to TF coil heating limit…
     - Is pulse length limit set by MHD, TF heating limit, or OH?
     - **GOT TO 1.5s at 700-750kA, IP DURATION MAXIMIZED WHEN OH AND TF HEATING LIMITS ARE REACHED SIMULTANEOUSLY**

Record discharge pulse-lengths have been achieved by operating with sustained H-mode and high β_N

- H-mode with small ELMS $\Rightarrow$ reduced flux consumption, slow density rise
- $\beta_N > 4$ for $\Delta t > 1$s at high $\beta_P > 1$ increases bootstrap fraction, lowers V_{LOOP}



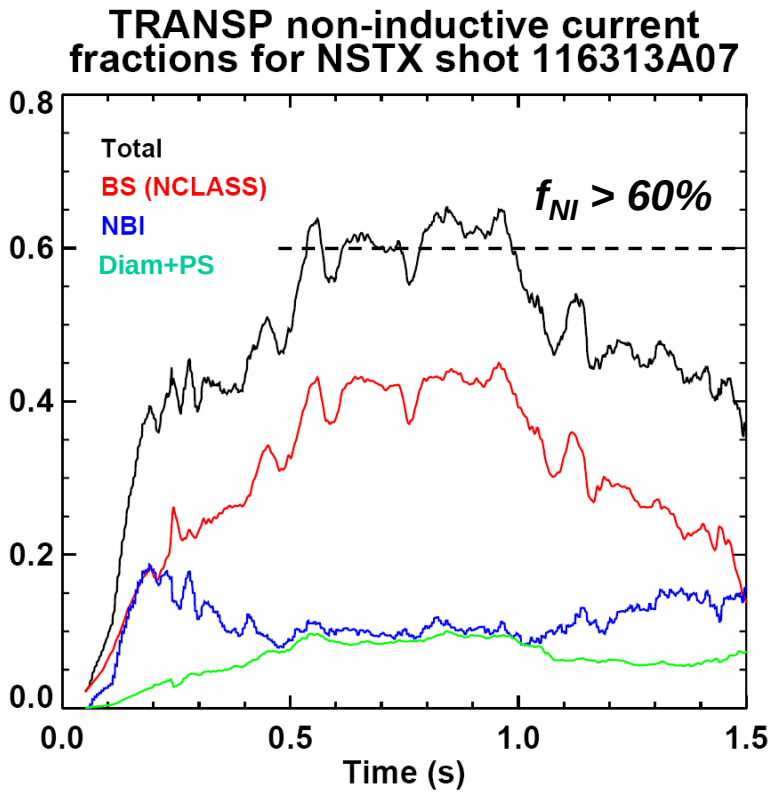
MSE data indicates low loop-voltage phase ends at onset of saturated n=1 mode when $q_{MIN} \rightarrow 1$

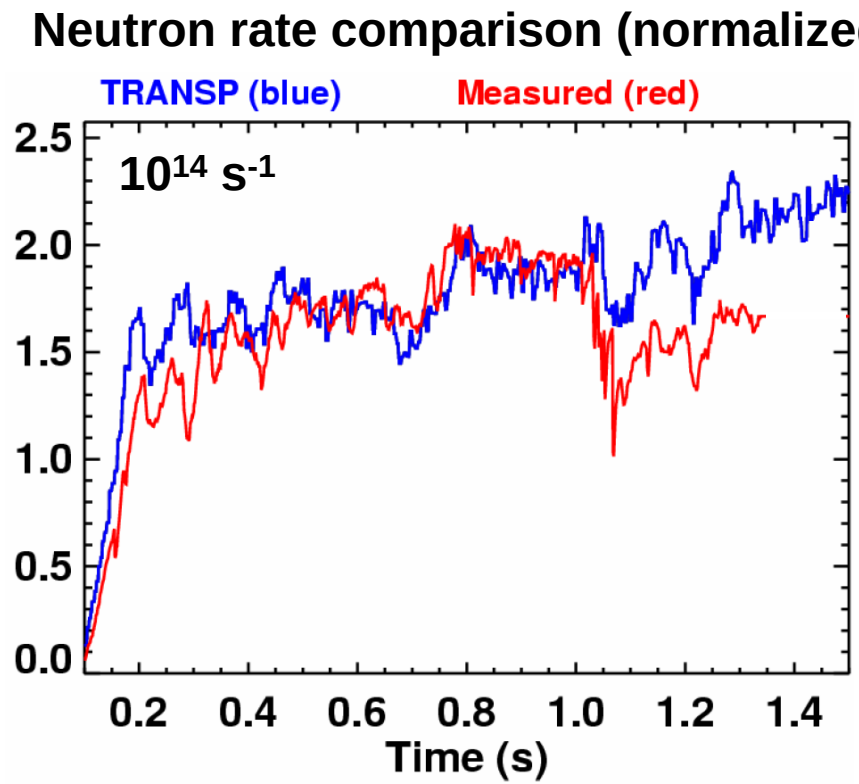


- Saturated n=1 mode persists for 0.5s late in discharge evolution
- Central rotation drops by factor of 3 at mode onset
  - Edge f_ϕ maintained
  - $T_i / T_e \rightarrow 1$ (not shown)
- $\beta_N = 6$ decreases to 4
  - $\beta_N = 6$ above no-wall limit
  - $\beta_N = 4$ near no-wall limit
    - No RWM observed…
- q_{MIN} sustained near 1
  - No sawteeth observed
  - Discharge runs out of OH flux and TF flat-top
  - Possible “hybrid” mode

Longest duration discharges exceed 60% non-inductive current fraction during high-β phase

- **85% of non-inductive current is ∇p-driven = BS + Diamagnetic + PS**



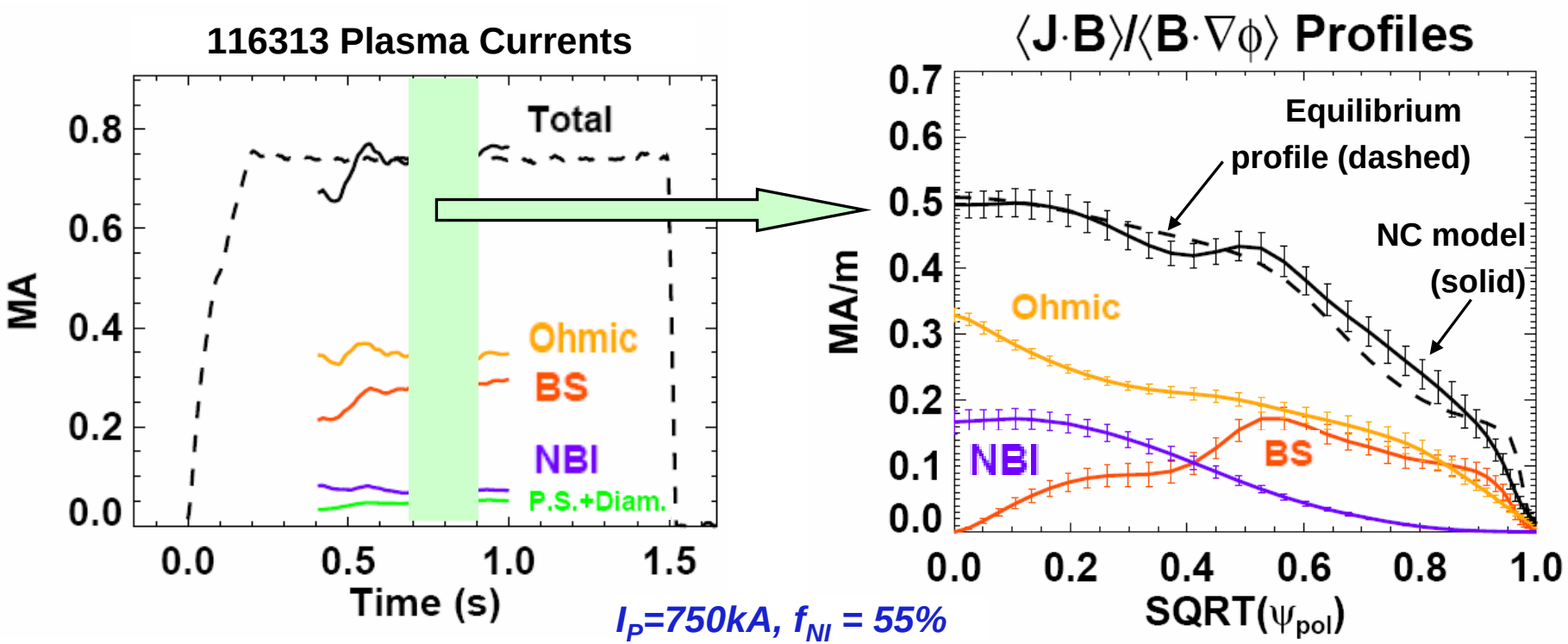


- TRANSP agrees with measured neutron rate to within ± 15% during high-β phase
- Normalize at high β ⇒ TRANSP over-predicts neutron rate early and late in shot
  - Low-f MHD is present at these times ⇒ fast-ion diffusion and/or loss likely
  - Assessing impact of MHD on J_{NBI} profile and q-profile evolution

MSE diagnostic enables testing of models of inductive and non-inductive current drive sources

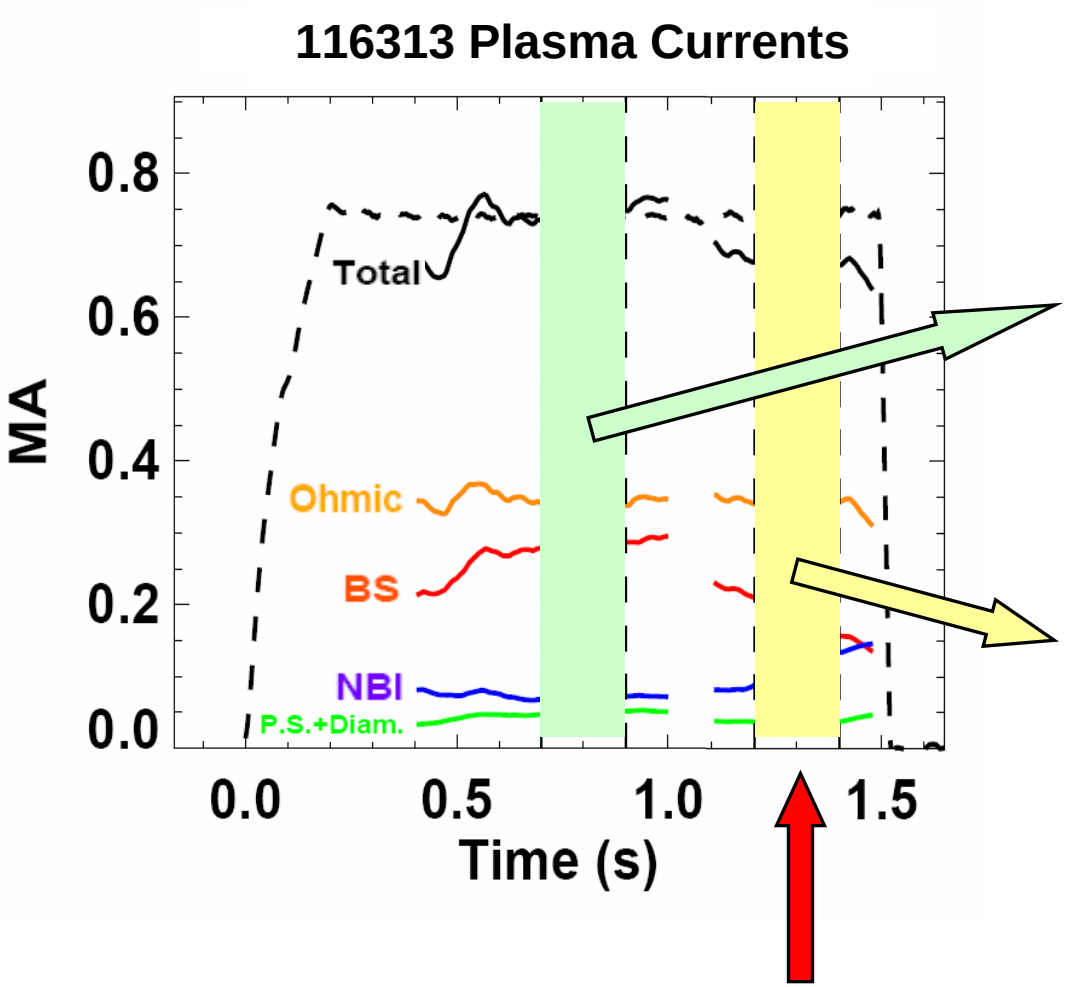
- **Compute V_{LOOP} distribution/evolution directly from MSE-constrained fits**
  - **Long pulse-length and quiescent discharges needed for analysis**
- **Fit *T*, *p*, Z_{eff} to ψ, compute σ_{NC}, J_{OH} & J_{BS} (Sauter model), add TRANSP J_{NBI}**

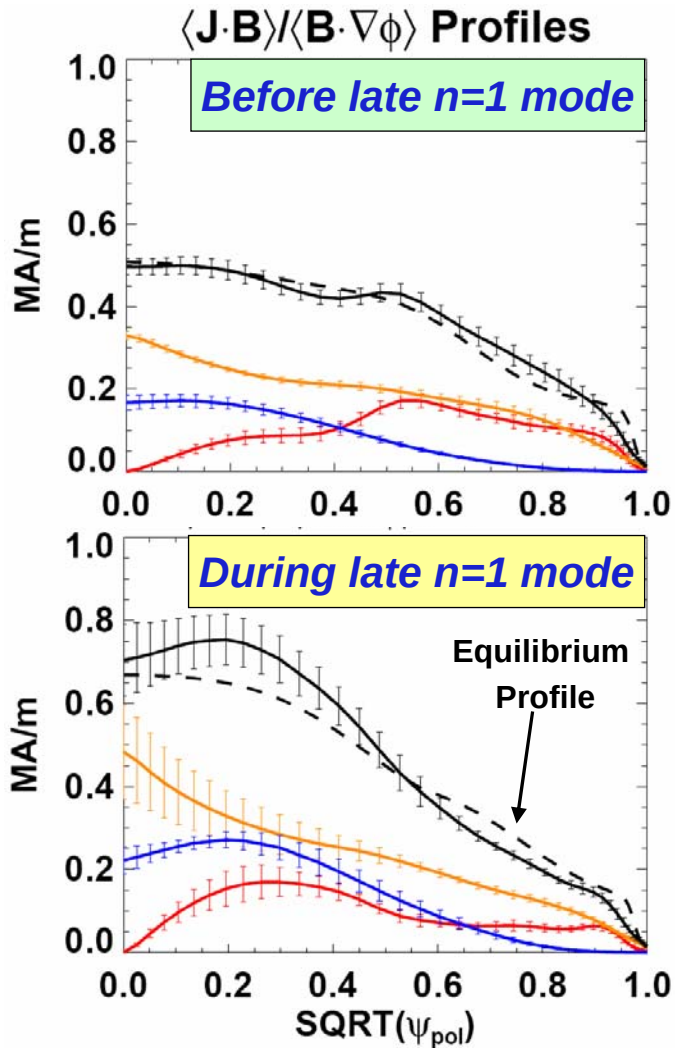
Sauter collisional NC model consistent with experimental I_P and J_{II}



Comparing Sauter to NCLASS models to assess role of aspect ratio, impurities, etc...

Neoclassical current profile analysis consistent with $J_{||}$-profile peaking and q(0) → 1 at end of discharge

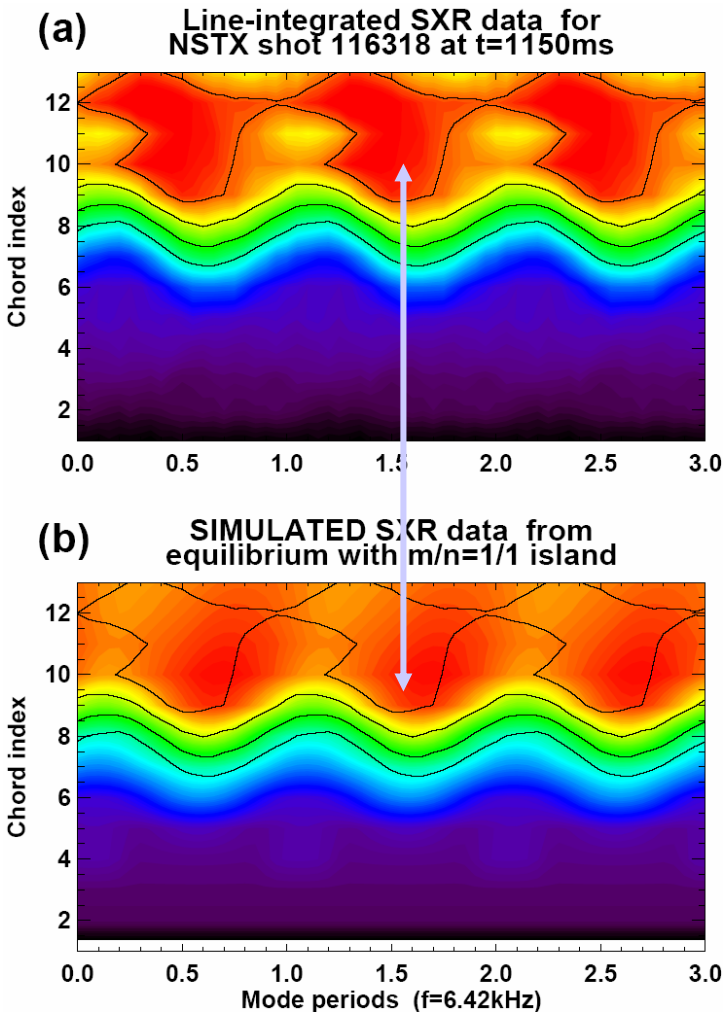




- **Under-predict total current during last 0.5s – due to model, or n=1 MHD?**

What is n=1 mode at end of shot?: USXR most consistent w/ saturated internal kink w/ m/n = 1/1 component dominant

Good fit with narrow 1/1 island w/ $\rho_{q=1}$ = 0.8, but <u>there is no q=1 surface!</u> (MSE) ➔ kink



Can fit with only 2/1 island using MSE $\rho_{q=2}$ = 0.7, but core phase match is poor