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Reconstruction of NSTX Equilibria including MSE data

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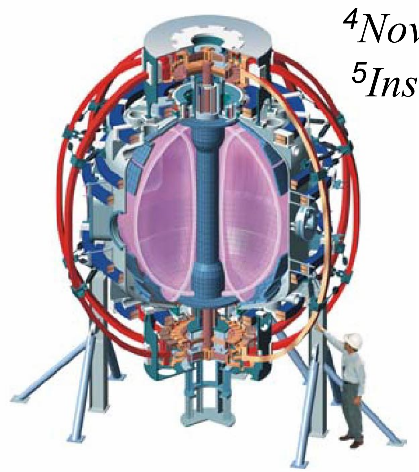

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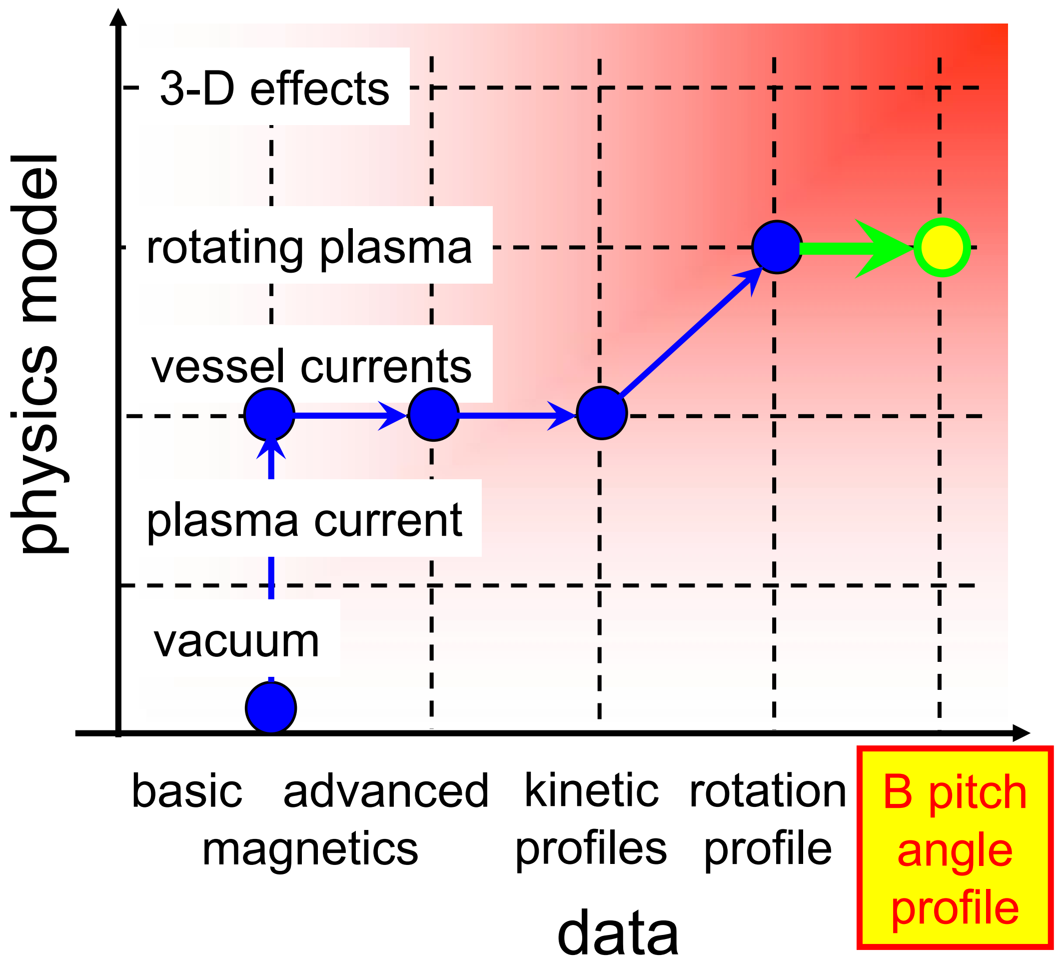
NSTX

Motional Stark Effect data is a natural addition to NSTX EFIT reconstructions

- Approach
  - "Best" model
    - for a given physics model / data set, reliably fit all data within error
    - improved physics/data set reduces artificial constraint
  - "Rapid" reconstruction
    - between-shots
    - find one constraint set for a given (data,model)
  - "Levels" of reconstruction
    - based on available data
    - seamlessly switch levels during shot if needed



MSE can be included in all levels of EFIT

- NSTX EFIT "Levels"
  - Level 1: external magnetics data alone
  - Level 2: partial kinetic profile data added
  - Level 3: toroidal rotation added

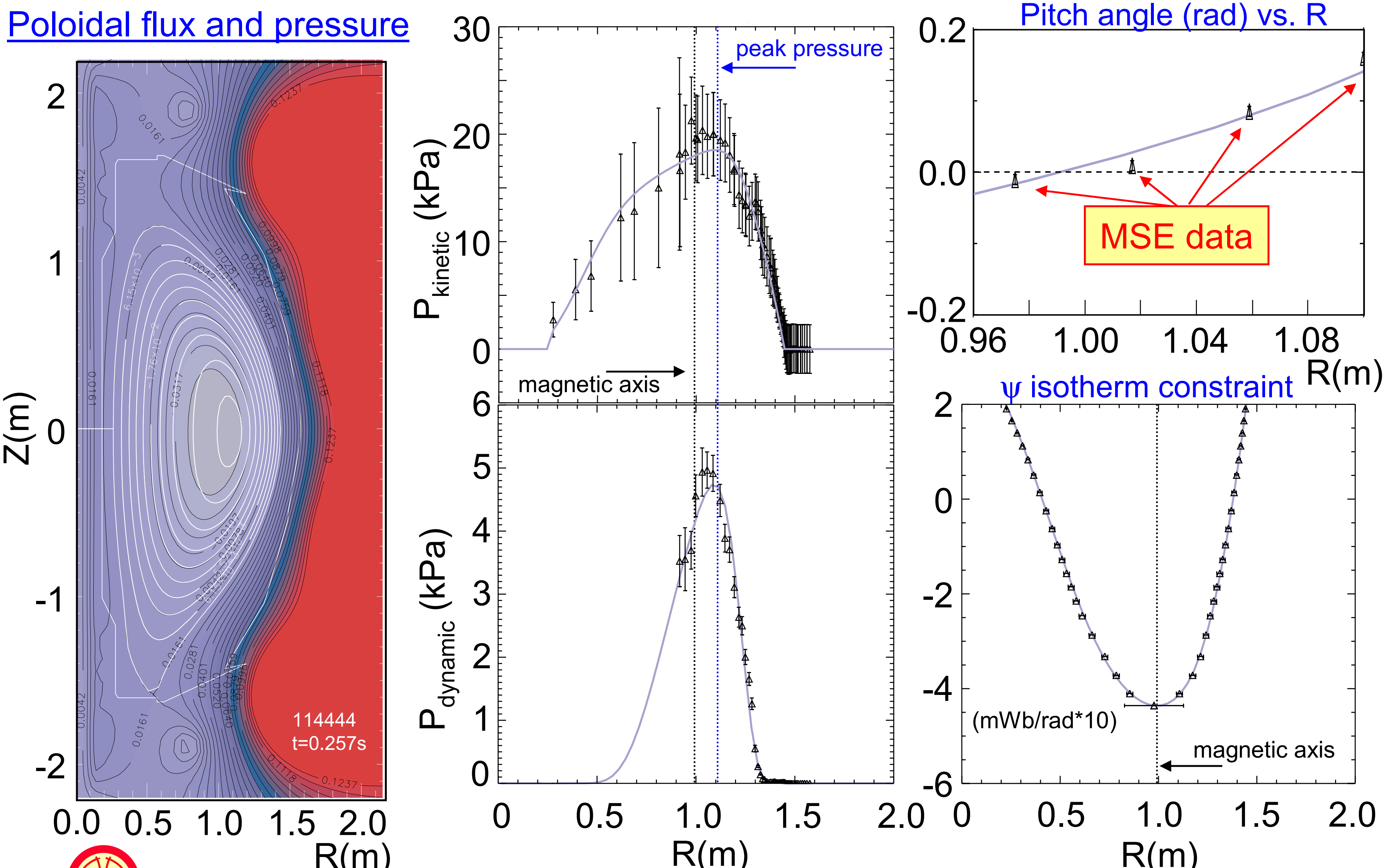
	fitted parameters	artificial constraints
Level 1	4	strong
Level 2	10	3 weak
Level 3	20	none

- Statistics on MSE fits so far:
  - Four channels span typical magnetic axis position; 0.3 degree error
  - MSE data for 58 shots available on data tree
  - All 58 shots reconstructed with NSTX EFIT and written to NSTX database
    - More than 7,500 equilibria available to the group
    - More than 11,000 equilibria run in MSE testing so far

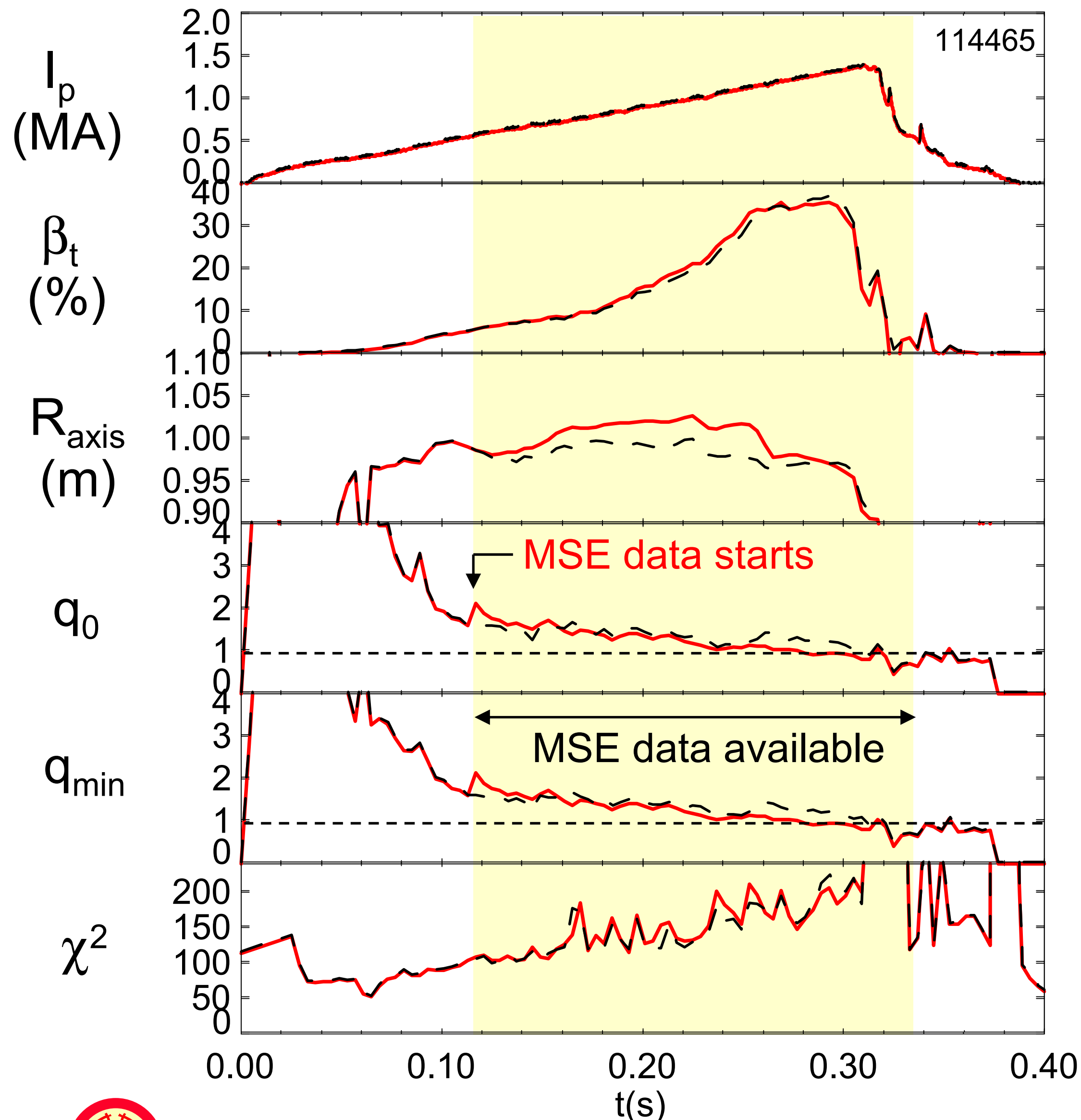
MSE data adds further constraint to present rotating, high β ST equilibrium reconstructions

Physics constraints	Data points
Internal magnetic field pitch angle (MSE)	4
Plasma rotational pressure (CHERS)	51
Flux surfaces are electron temperature isotherms	20
• $T_e = T_e(\psi(R)\|_{z=0})$ *directly* from Thomson data - rapid analysis	
❑ required to insure self-consistent solution with toroidal rotation	
Plasma kinetic pressure	
• Ion pressure (CHERS)	51
• Electron pressure (Thomson)	20
External magnetics / plasma current	119
Plasma diamagnetism	1
Vacuum vessel current (includes “3-D” vessel effects)	25
Shaping coil / TF currents	9
Total (per time point)	300

B field pitch angle profile added to reconstruction



Fits with / without MSE confirm high β results

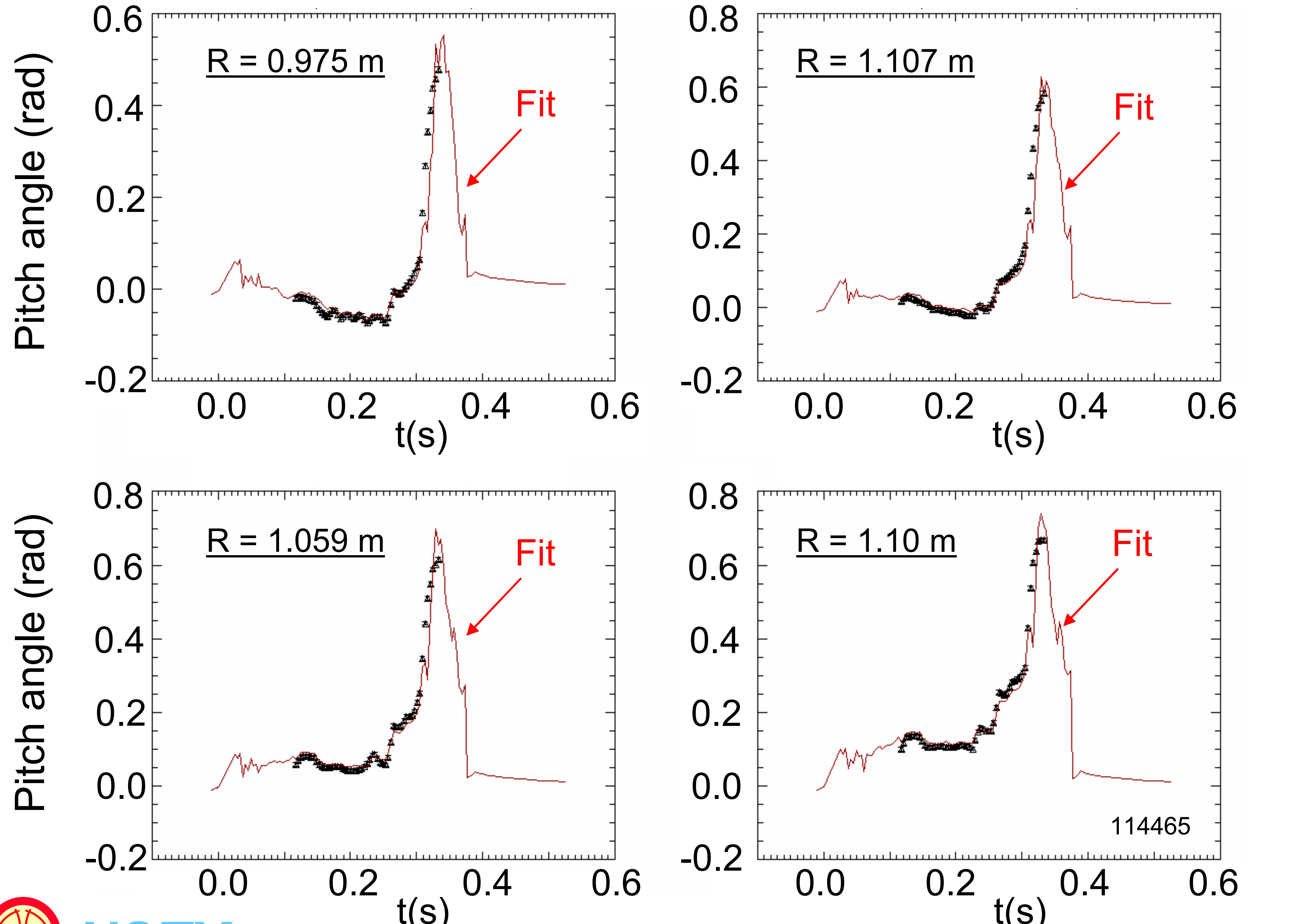


Partial kinetic fits

solid (red) – with MSE
dashed (black) – w/o MSE

- Few % change in stored energy
- Fits without MSE give good q_0 values
  - "calibrated" constraint set (using sawtooth onset, rational surface position from USXR in selected shots)
  - can now use MSE for "calibration"
- Correlation with crossing $q_0 = 1$ and β collapse

Fitted pitch angle evolution follows MSE data



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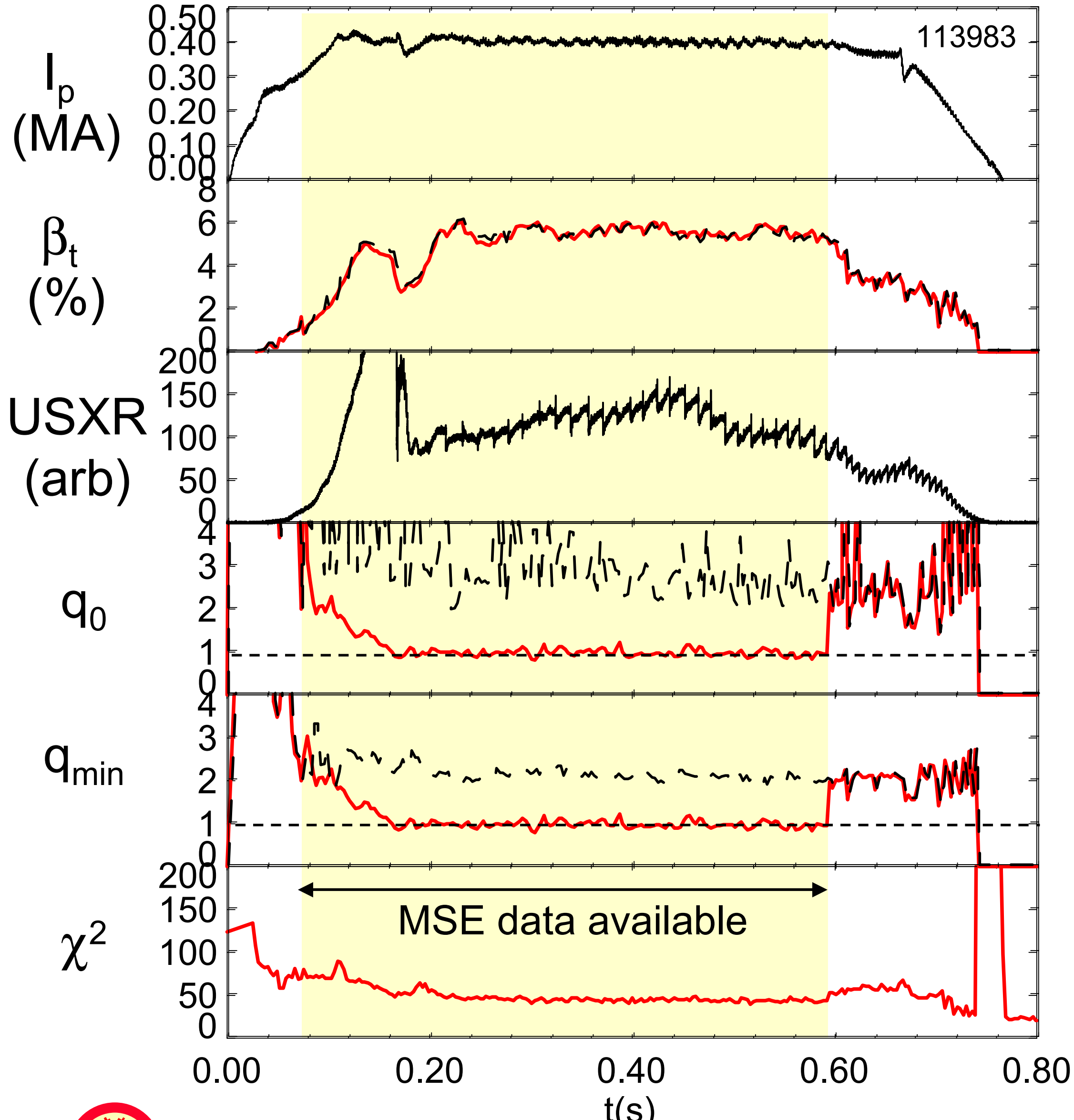
MSE finds q_0 ~ 1 in plasmas with sawteeth

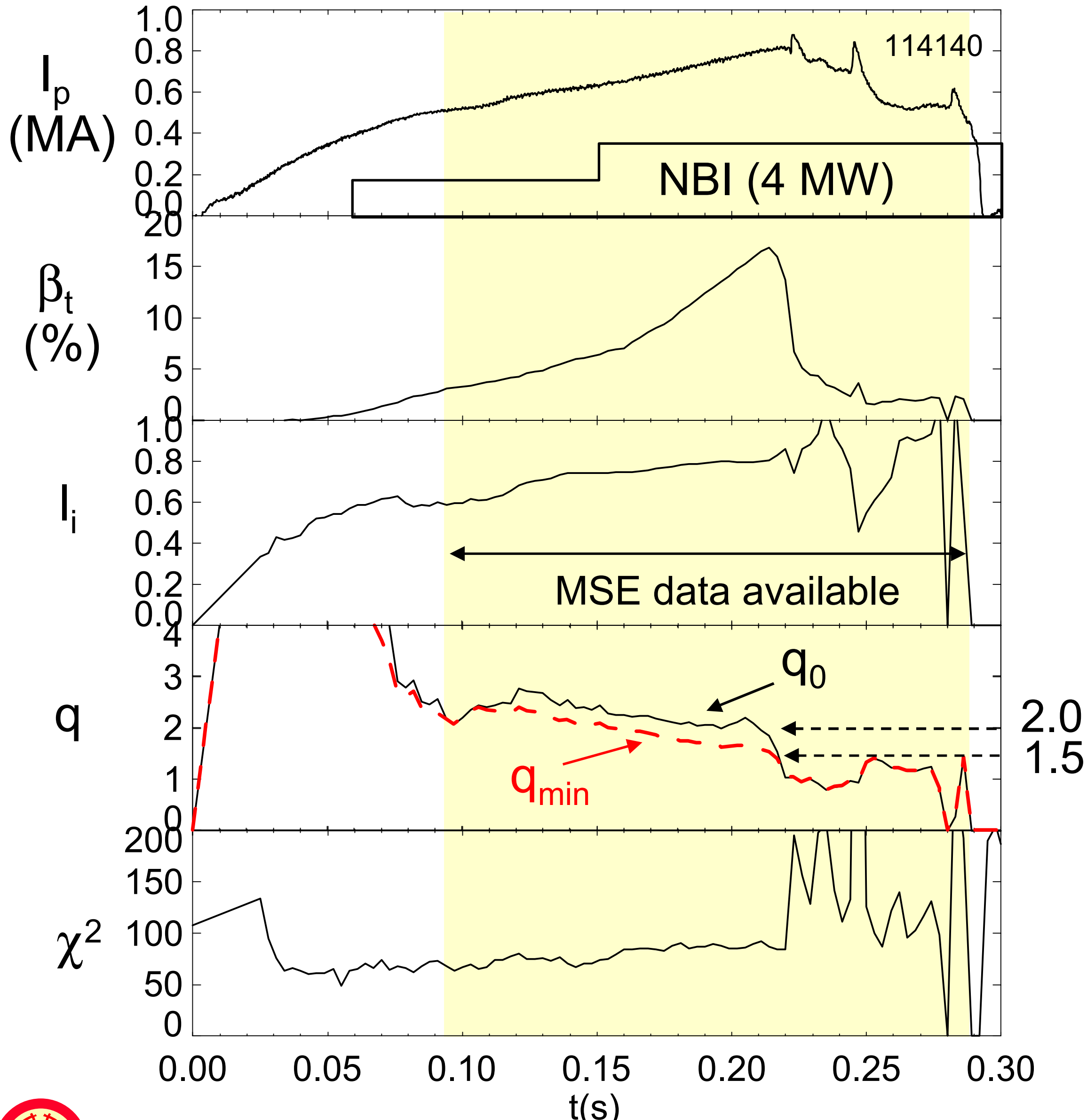


Partial kinetic fits

solid (red) – with MSE
dashed (black) – w/o MSE

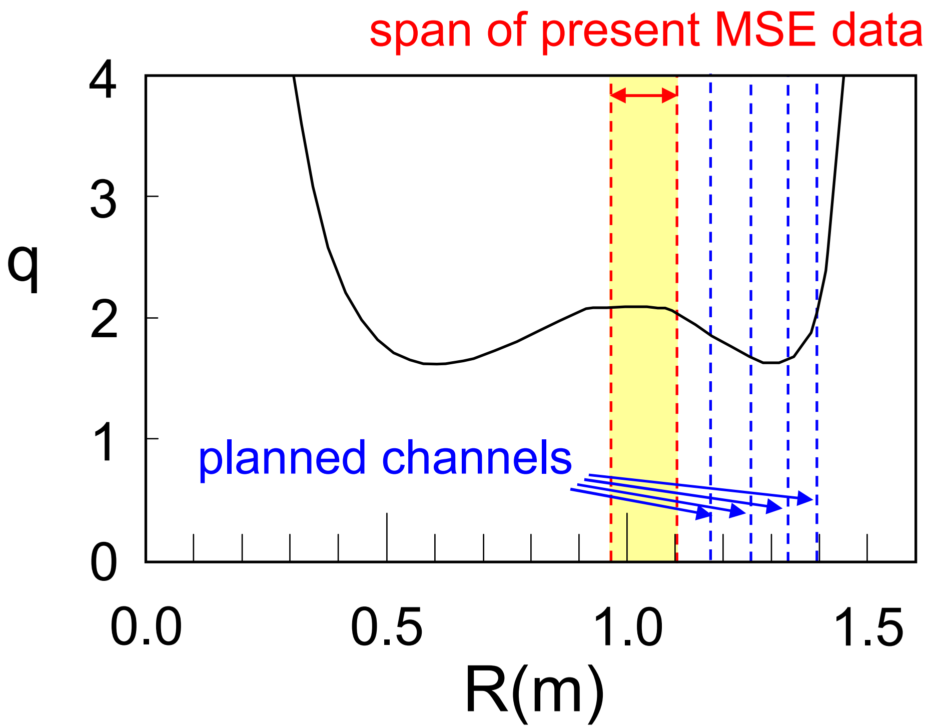
- External magnetics-only fit has q_0 = 1.1
- Partial kinetic fit does not give q_0 ~ 1 at low stored energy
  - MSE required to find reasonable q_0

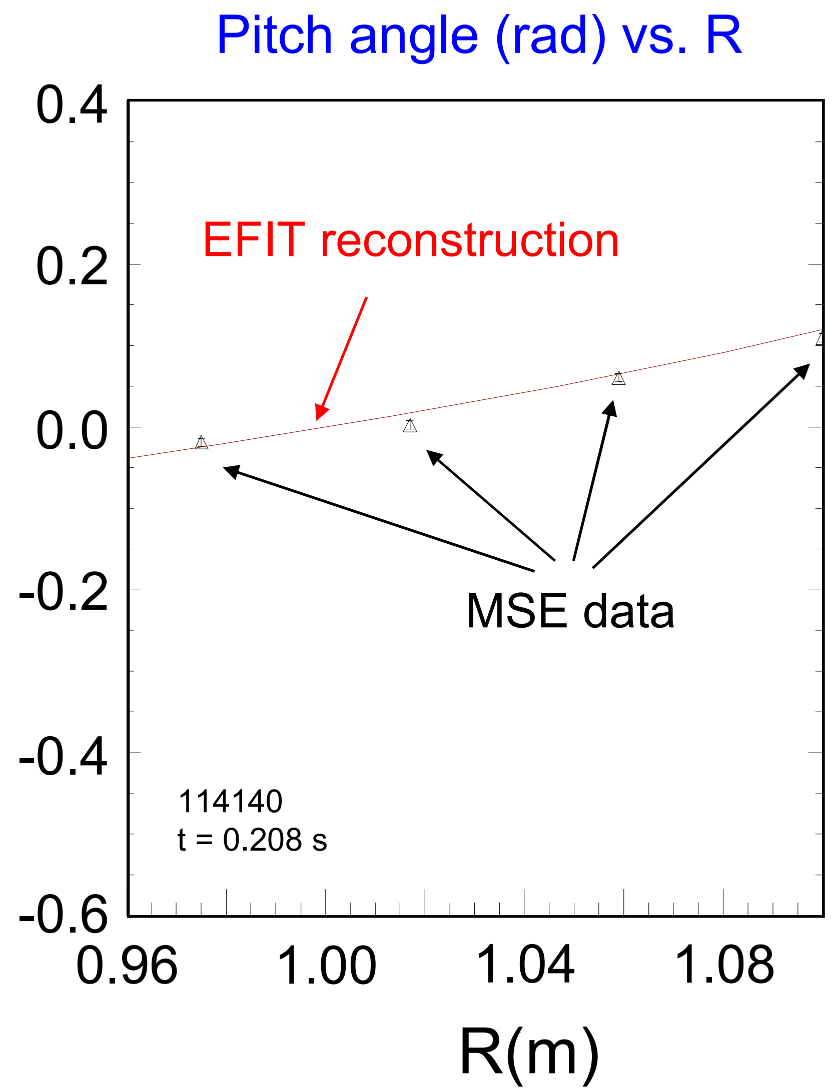
MSE fits indicate shear reversal in some equilibria



- Shear reversal not seen in reconstruction for this shot without MSE
- Shear reversal not apparent in l_i evolution
- Collapse in β when $q_0 = 2$, $q_{min} = 1.5$

CY05 MSE channels will provide additional q constraint





- Present MSE measurements do not span q_{min} position in shear reversed equilibrium

Diagnostic input / code interaction continues to expand

- Add new MSE channels
  - 8 channels start of FY05 run
  - Up to 14 channels by end of FY05 run
- Include computed fast-ion profiles directly from TRANSP
  - Understand possible role of MHD on fast-ion diffusion/loss
  - Include beam pressure anisotropy and flow of fast ions
- Use EFIT to help benchmark other reconstruction codes
  - LRDFIT: time-evolved circuit model of vessel included in fit
    - Reconstruction of 20kA PF-only start-up plasmas
  - ESC: reconstruction version built around fixed-boundary code
    - Used on JET for current holes, being developed for CDX-U (LTX)

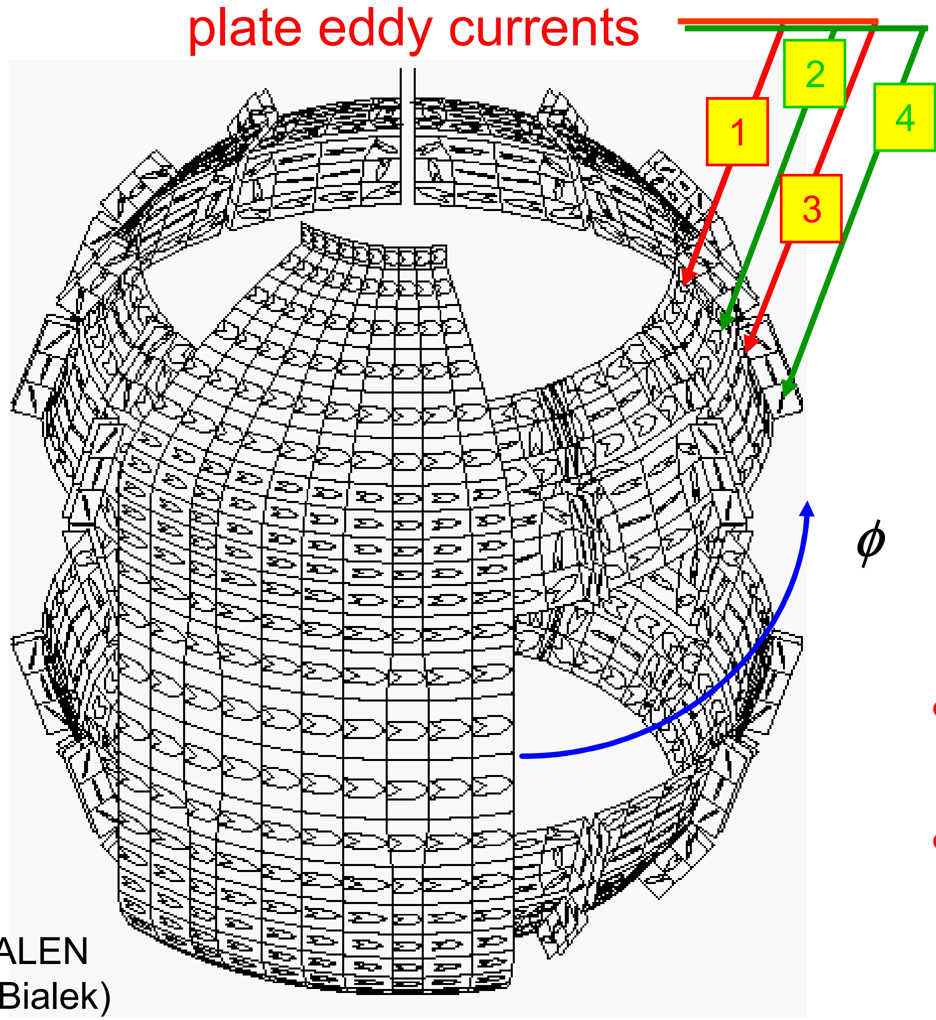
NSTX EFIT with MSE is ready for the 2005 run

- Pre-run testing / analysis
  - Greater basis function flexibility, constraint optimization
  - Radial electric field correction to MSE data (using toroidal flow)
  - Further consistency checks with other diagnostics
  - More tests of rotating equilibria – comparison to static case
  - Physics analysis
    - effects of reversed shear
    - low-order rational surfaces and β collapse

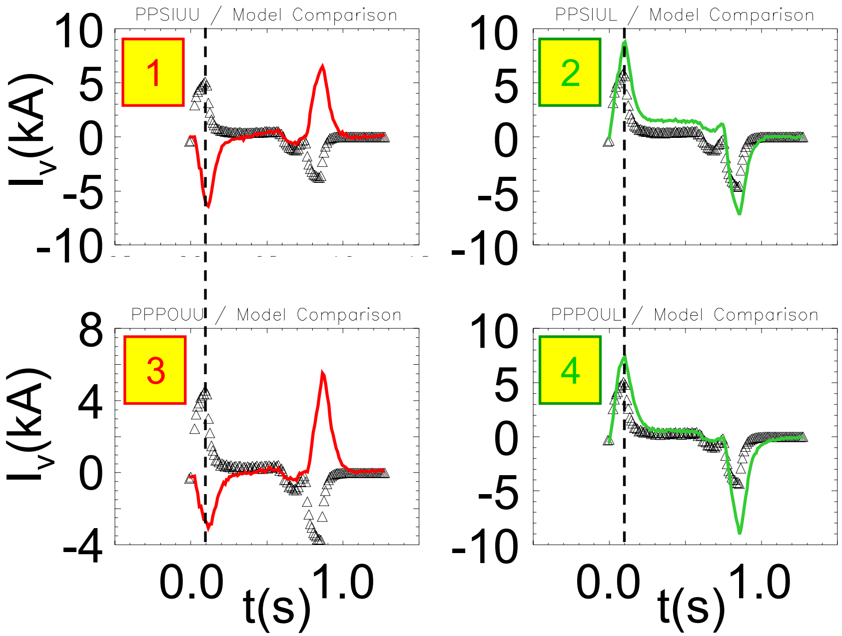
- Between-shots EFIT reconstructions with MSE will improve analysis including present control room MHD stability calculations

Supporting slides follow

Expanded magnetics set reproduces 3-D eddy currents as axisymmetric currents during OH ramp



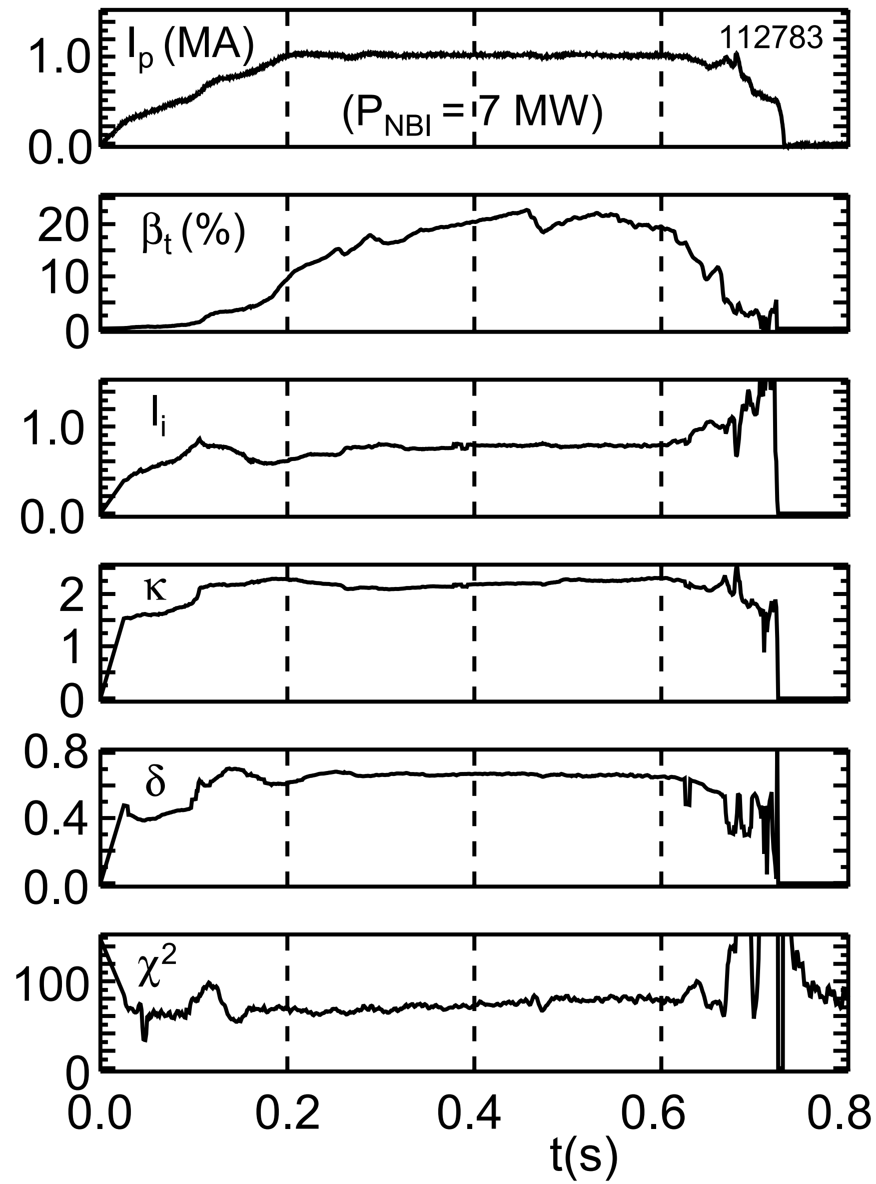
VALEN
(J. Bialek)



- Black points: plate current approximated from V_{loop} sensors
- Solid lines: EFIT reconstructed plate currents using all magnetics data
  - Fitted currents match 3-D eddy currents as a 2-D analog

External magnetics data allow basic reconstruction

- Over 60 attempted variations to find model
- Profile constraints: $p'(0) = 0$, $(ff')'(1) = 0$
  - constraints reproduce $q_0 = 1$ appearance, rational surface position from USXR
  - allows finite edge current (to model current transients)
- 4 profile variables (1 p', 3 ff'; 2nd order polynomial in p', 3rd order in ff')
- Goodness of fit $\chi^2 \sim 70$ over majority of pulse for 108 measurements



$\beta_t = 2\mu_0 \langle p \rangle / B_0^2$

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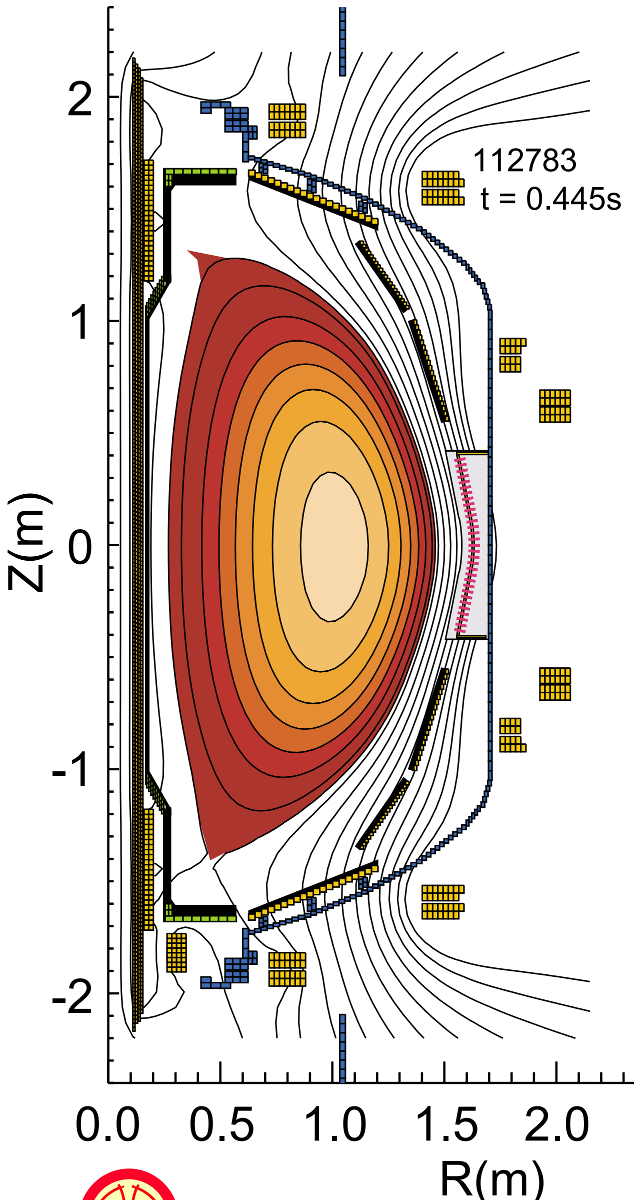
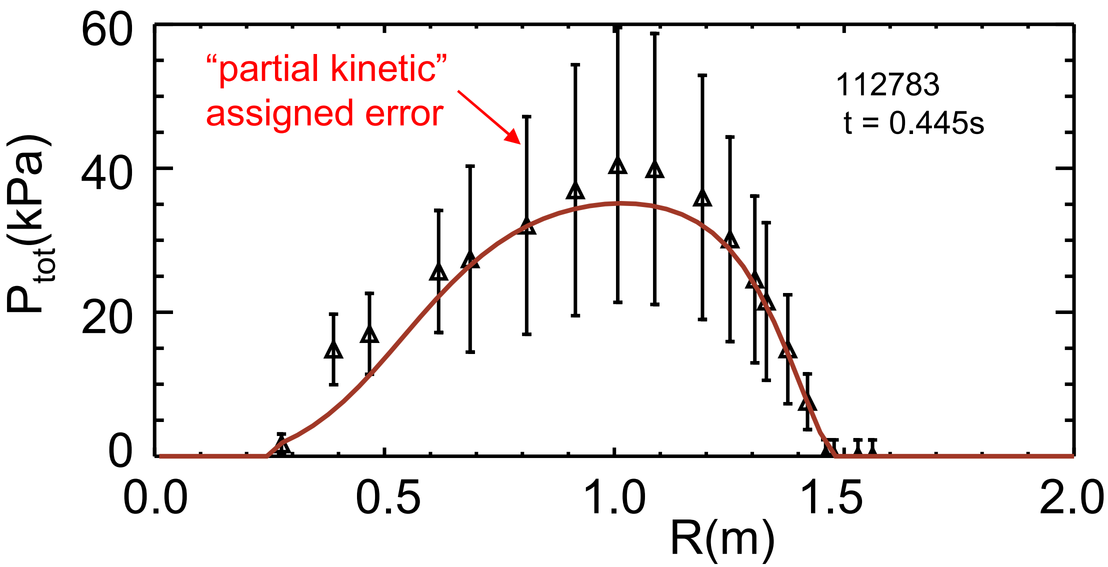
"Partial kinetic" prescription reduces artificial constraint

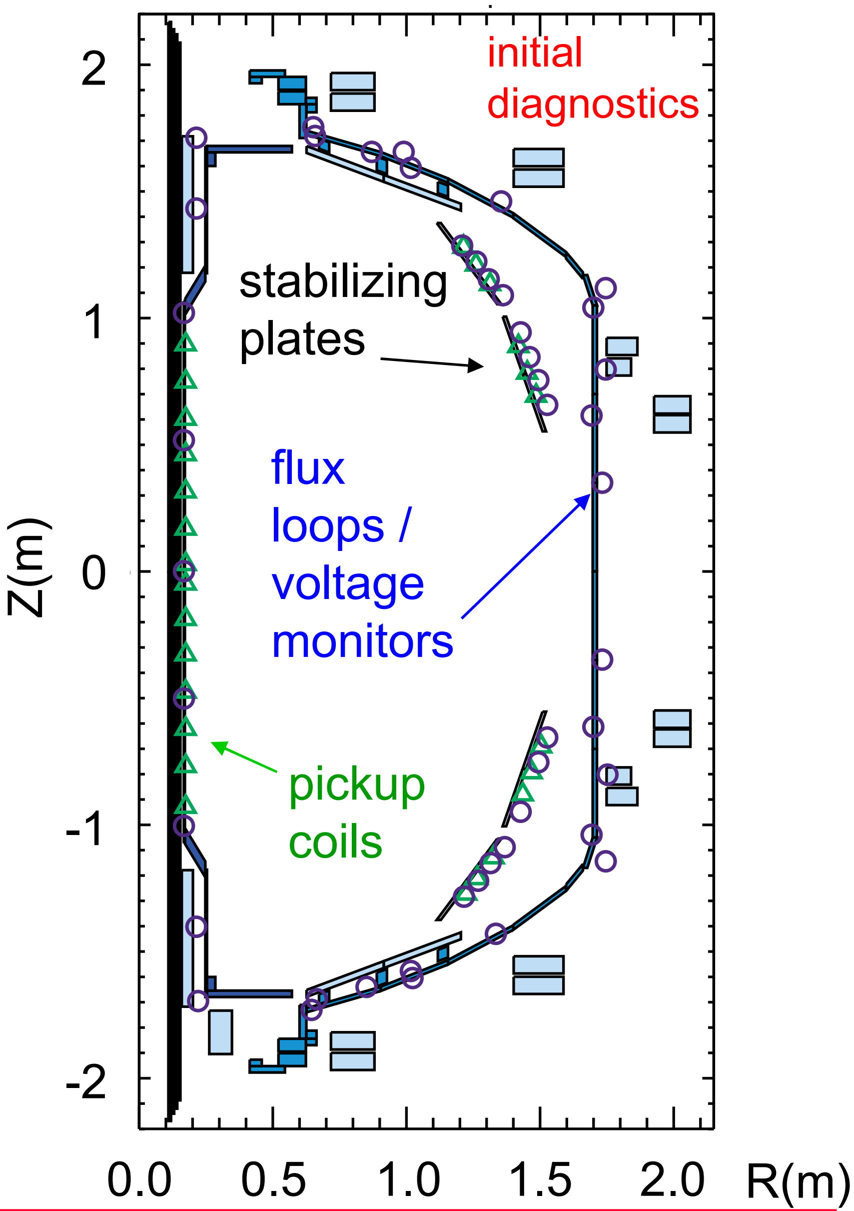


- Over 110 attempted model variations used to find model
- 10 profile variables (5 p', 5 ff'); allows finite edge current
- External magnetics plus 20 Thomson scattering P_e points to constrain P profile shape
  - $P_{tot} = P_e$ + "P_i" + "P_{fast}"; errors summed in quadrature (large total error)
- Diamagnetic flux to constrain stored energy
  - Greater freedom in ff' basis function for good fit over full discharge evolution and for various shots
- Weak constraints on p'(0), ff'(0) yield "reasonable" q(0)



NSTX EFIT* alterations required for low A geometry

- Uniform discretization of elements at low aspect ratio
- Vessel currents required
  - Lower A components have lower resistance
  - Total vessel currents ~ 0.3 MA; plasma current ~ 1.0 MA
  - Vessel / plates broken into 30 groups (poloidally)
  - Wall currents determined by local loop voltage data (9 loops)
  - Vessel element resistances matched against independent model of vacuum field shots
- Stabilizing plates / divertor plates included (~5 kA)
  - plate currents not well-diagnosed

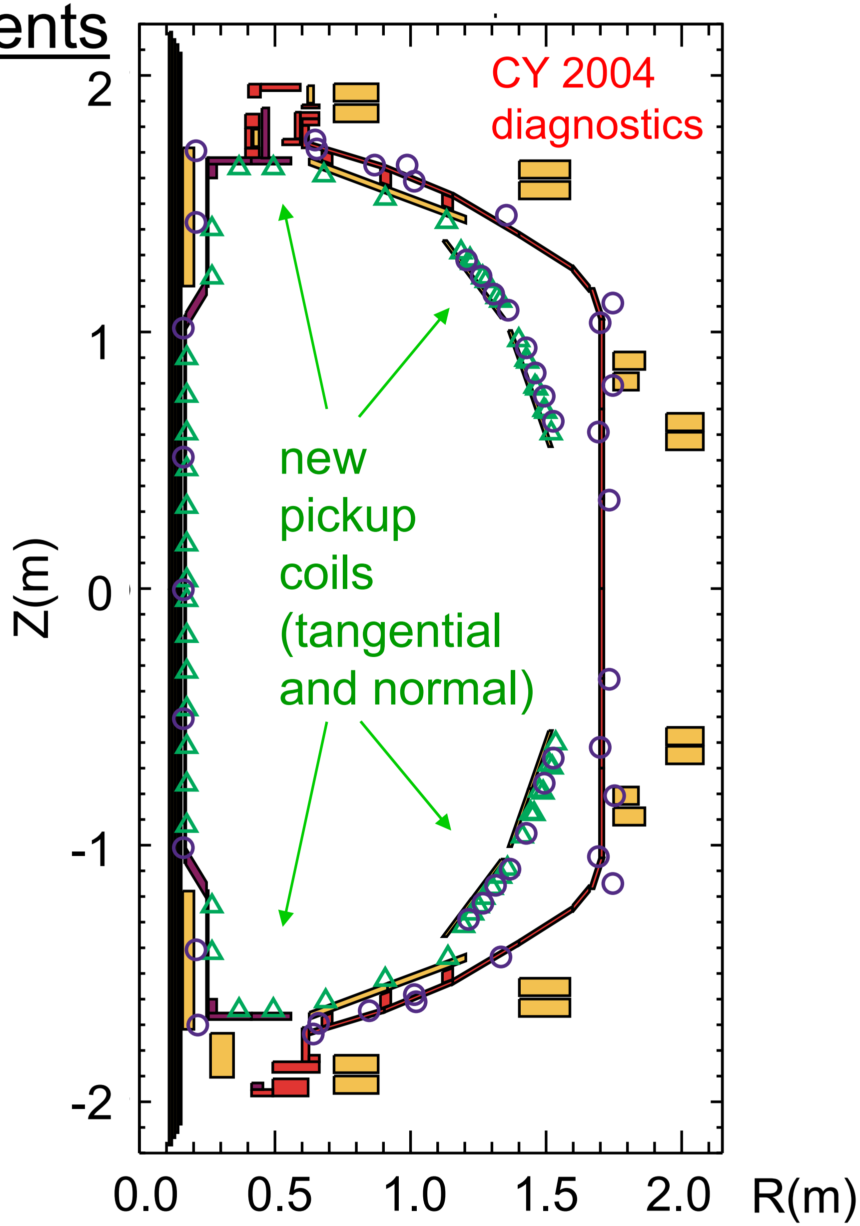


*S.A. Sabbagh, et al., Nucl. Fus. **41** (2001) 1601.

NSTX

Expanded magnetics to yield more accurate X-point and plate currents

- Significant upgrade to magnetics set
  - 57 pickup coils vs. 23
  - 25 local loop voltage data vs. 9 for wall current distribution
  - Compensation for stray field from TF leads
- Stabilizing plates / divertor plates currents now better resolved



Pure toroidal flow allows a tractable equilibrium solution

- Solve $\nabla\phi$, $\nabla\psi$, ∇R components of equilibrium equation
  - MHD: $\rho\mathbf{v}\bullet\nabla\mathbf{v} = JxB - \nabla p$; ρ = mass density
    - $\nabla\phi$: $f(\psi) = RB_t$
    - ∇R: $2P_d(\psi,R)/R = p'(\psi,R)|_\psi$; $P_d \equiv \rho(\psi,R)\omega^2(\psi)R^2/2$ (Bernoulli eq.)
    - $\nabla\psi$: $\Delta^*\psi = -\mu_0 R^2 p'(\psi,R)|_R - \mu_0^2 ff'(\psi)/(4\pi^2)$ (G.S. analog)
  - Pure toroidal rotation and $T = T(\psi)$ yields simple solution for p
    - $p(\psi,R) = p_0(\psi)\exp(m_{fluid}\,\omega^2(\psi)(R^2 - R_t^2)/2T(\psi))$
- Constraints for fit
  - EFIT reconstructs two new flux functions: $P_w(\psi)$, $P_0(\psi)$
    - $P_w(\psi) \equiv \rho(\psi)\,R_t^2\omega^2(\psi)/2$; $P_0(\psi)$ defined so that:
    - $p(\psi,R) = P_0(\psi)\exp(P_w(\psi)/P_0(\psi)\,(R^2 - R_t^2)/R_t^2)$
  - Standard input: $P_w(\psi)$, $P_0(\psi)$ from approximation or transport code
  - New approach:
    - Solve for $P_w(\psi)$, $P_0(\psi)$ in terms of measured $P(\psi,R)|_{z=0}$, $P_d(\psi,R)|_{z=0}$