

# Measurement and modeling of the electron pressure profiles in the Levitated Dipole Experiment (LDX)

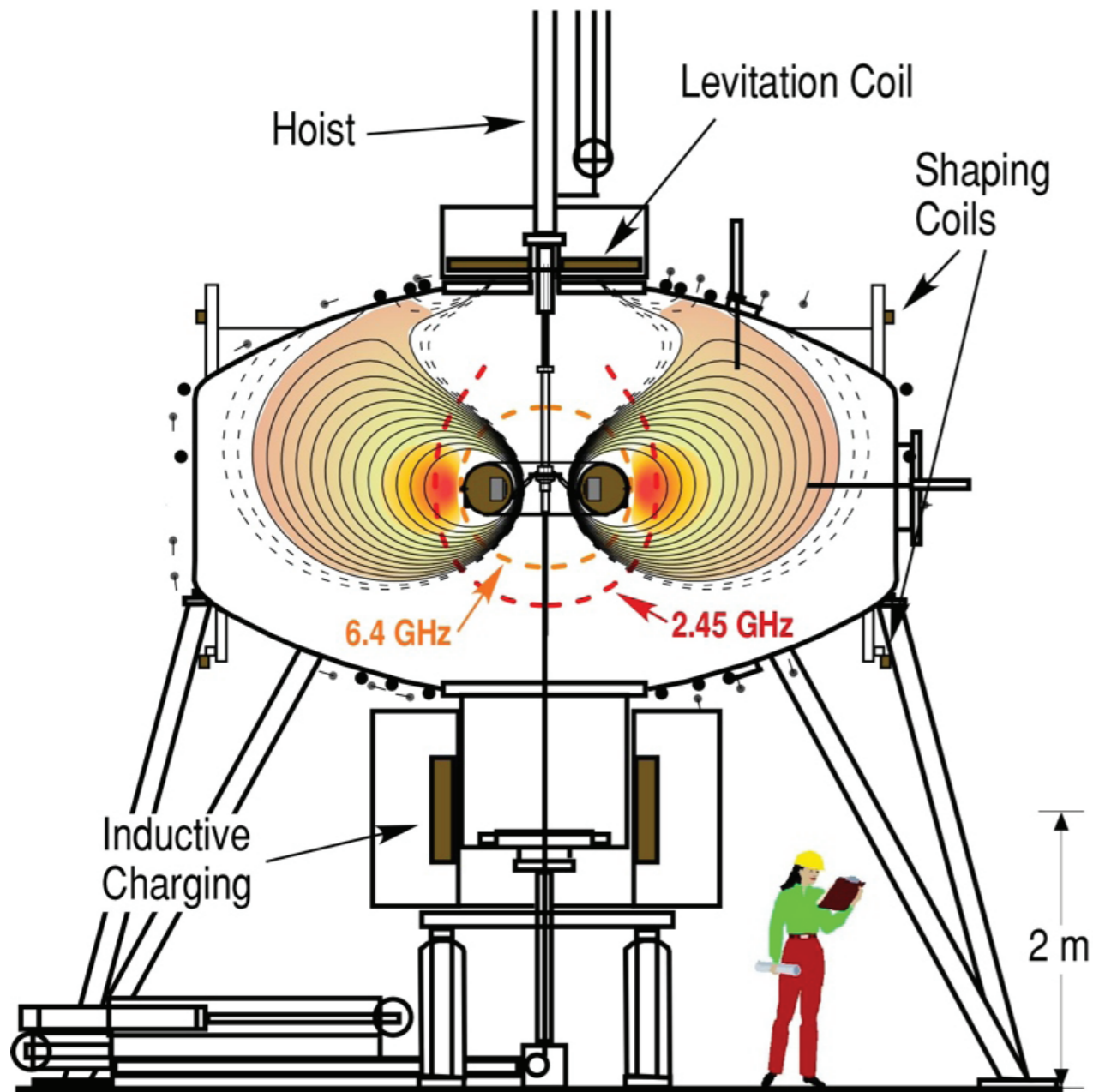
M. S. Davis, D. T. Garnier, M. E. Mael, *Columbia University*, J. Kesner, *PSFC MIT*



# Abstract

Electron pressure profiles in plasmas confined by a dipole are predicted to be centrally peaked when the dominate mode of particle loss is cross field turbulent transport. This central peaking of the pressure has been observed in planetary magnetospheres by spacecraft. LDX operates in two distinct modes: mechanically supported and magnetically levitated. When the dipole is mechanically supported particles are rapidly lost along the field to the supports. Levitation eliminates particle loss to the supports making the cross field transport the dominate mode of particle loss. We model electron pressure profiles and compare them to magnetic reconstructions and X-ray measurements made on LDX in both supported and levitated operation.

# LDX Overview



- Small coil magnetically levitated in large vacuum vessel (5 m diameter)
- 1.2 MA  $\text{Nb}_3\text{Sn}$  superconductor in floating coil
- Plasmas created and heated by 28 kW ECRH at multiple frequencies

# Invariant profiles

$$\delta (nV) = 0$$

Established by Boxer using interferometry.

$$\delta (pV^\gamma) = 0$$

Focus here:

establish constraints on the value of  $\gamma$   
using magnetics and X-rays

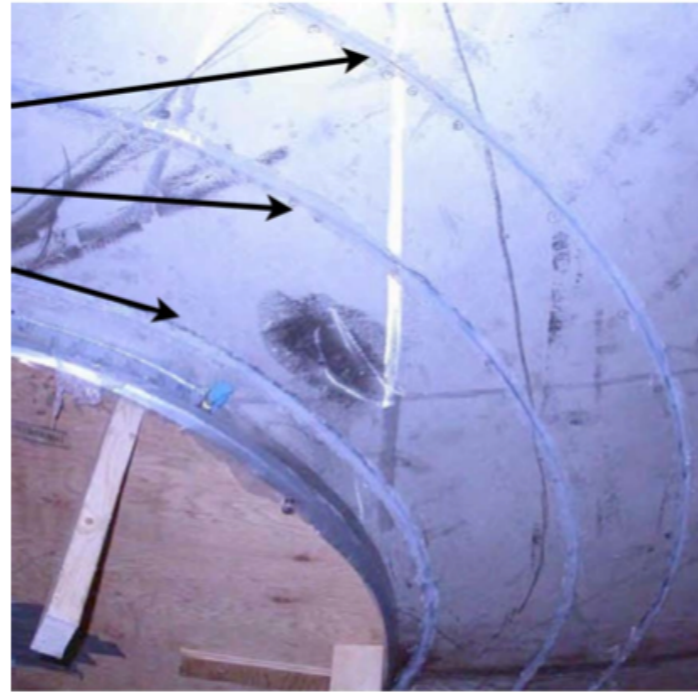
$\gamma = 1$  --> isothermal flux-tube mixing

$\gamma = 5/3$  --> adiabatic flux-tube mixing

$$V \equiv \oint \frac{dl}{B}$$

# Magnetic sensors: flux loops and poloidal field coils

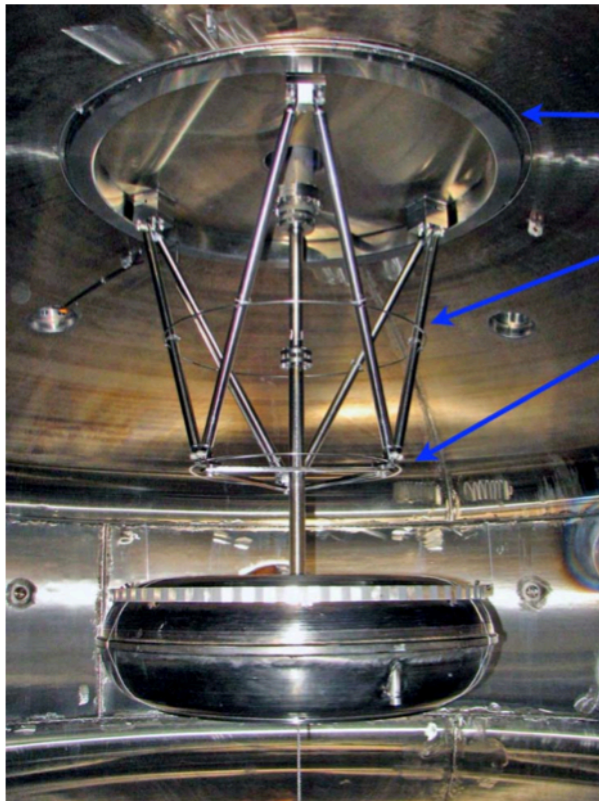
External flux loops



Poloidal field coils



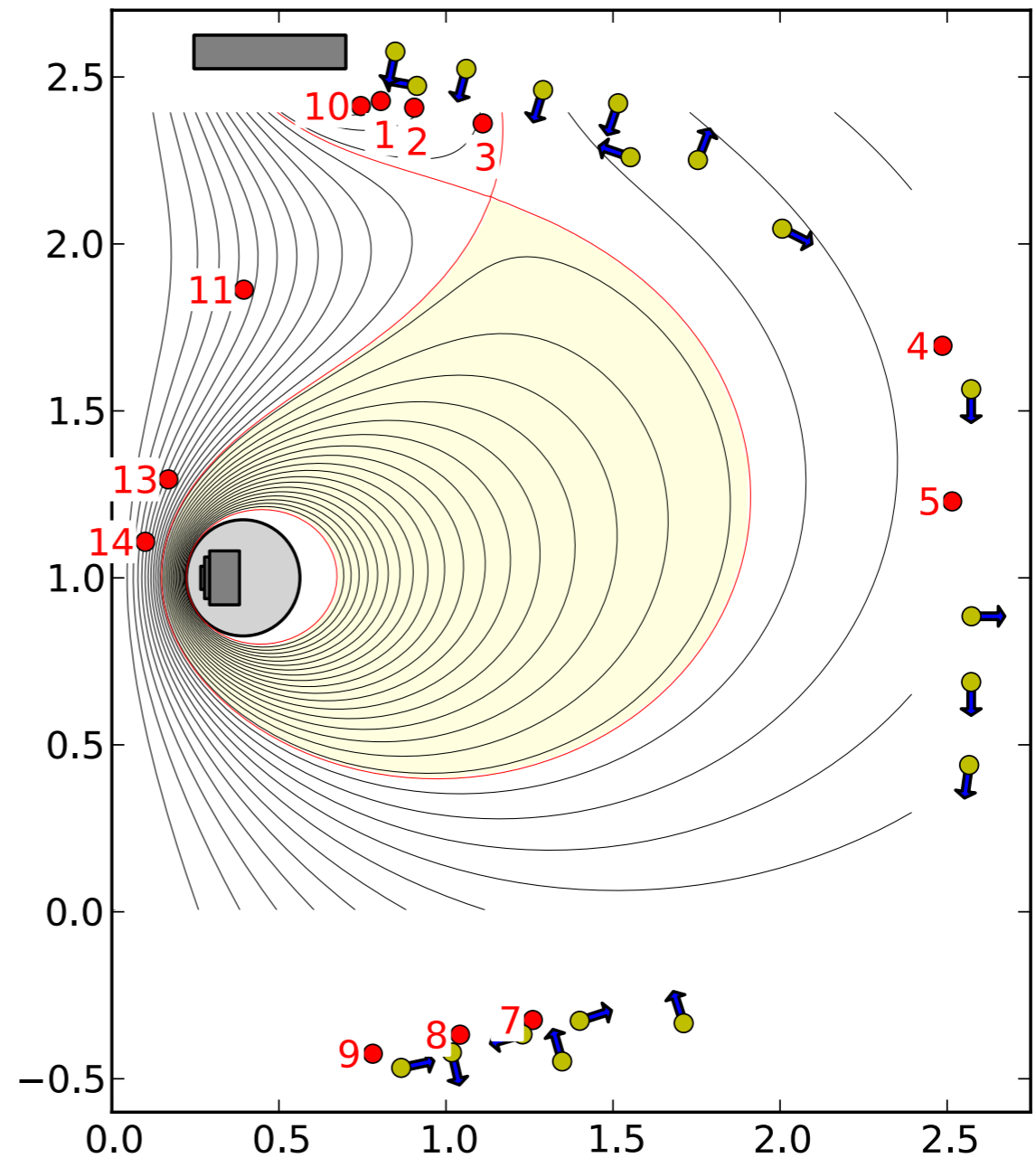
Internal flux loops



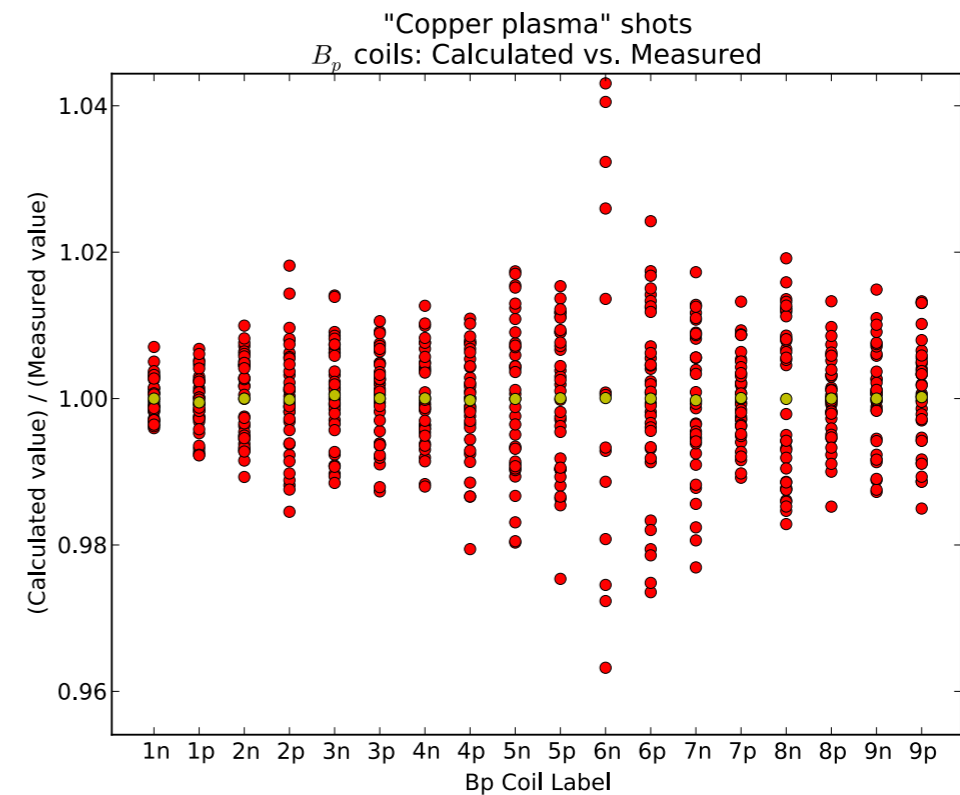
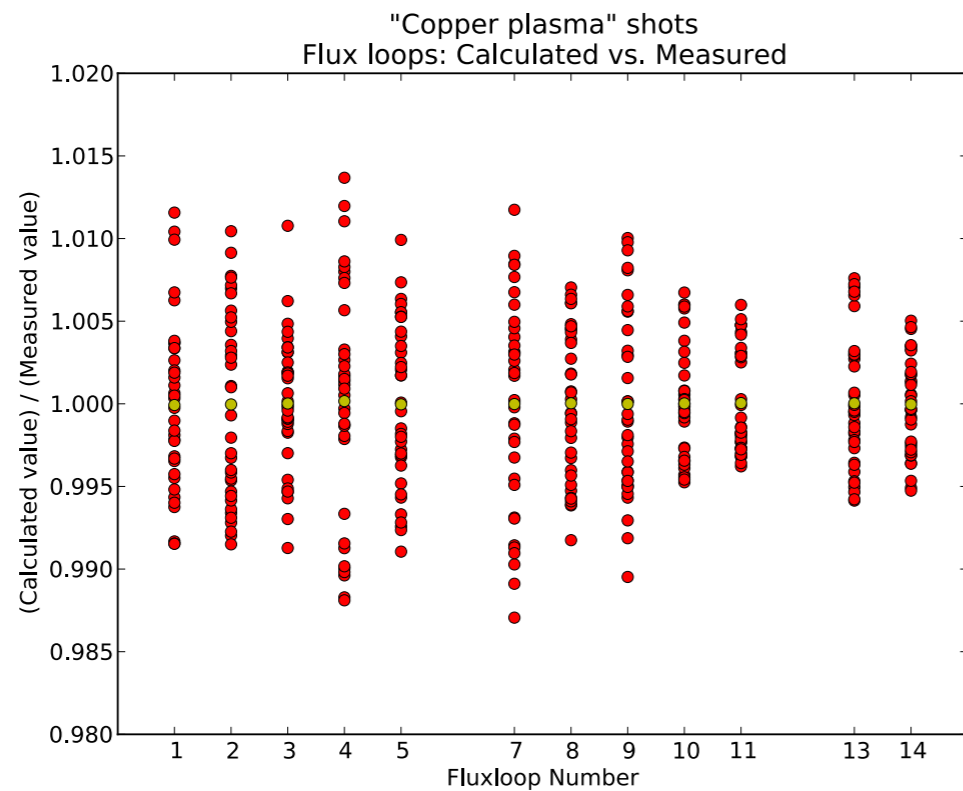


# Magnetic sensor locations

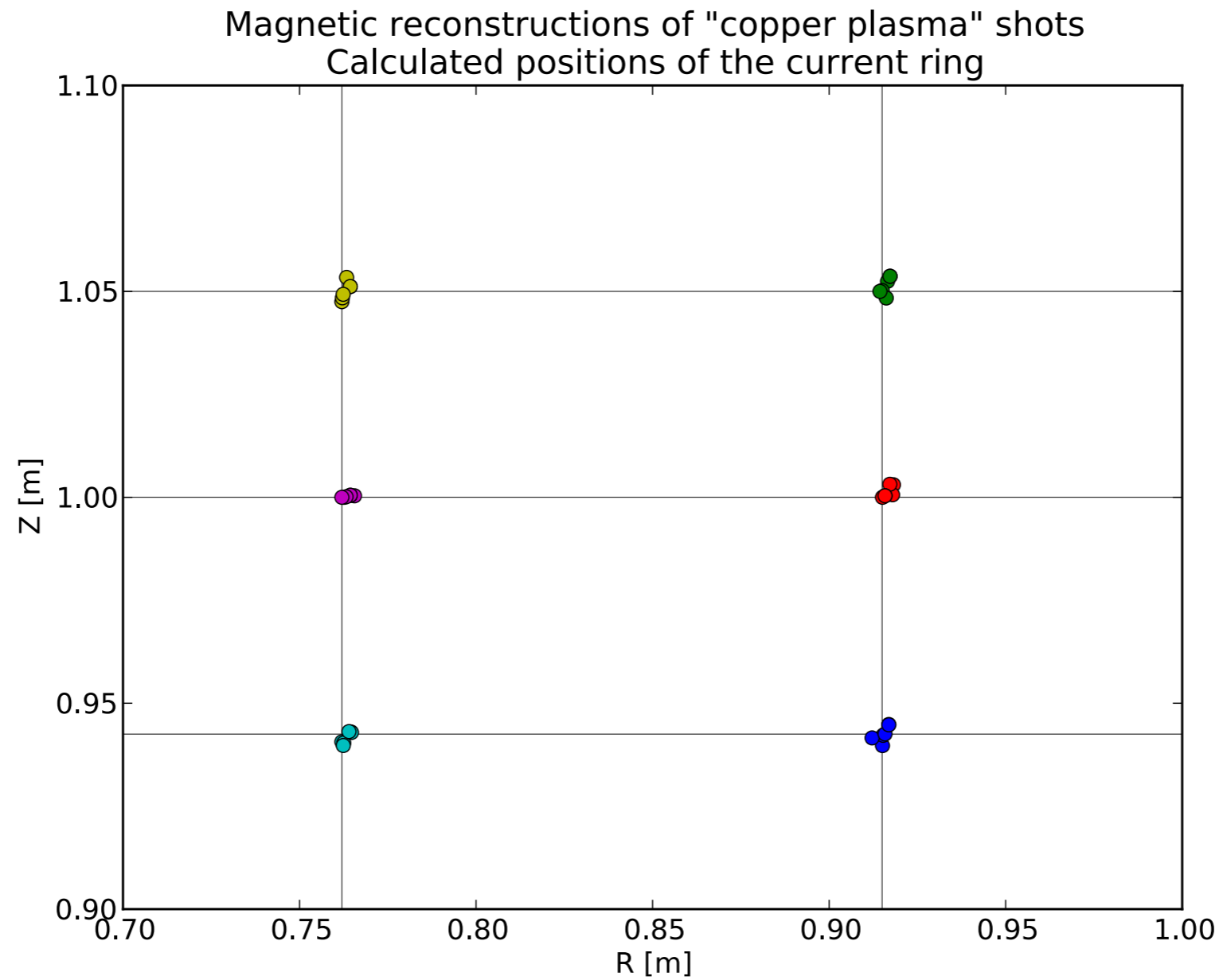
- 12 flux loops (shown in red)
- 18 poloidal field coils (shown with yellow dot and blue arrow)



# Magnetics calibrated with in vessel copper coil -- alias, the "copper plasma"



# Magnetics locate position of current ring well





Magnetics agree with vacuum shots

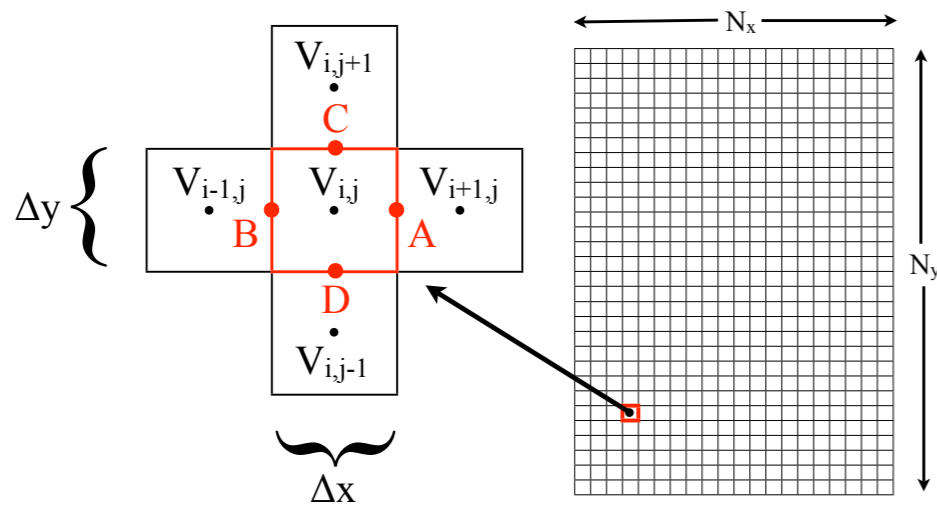
# Solve Grad-Shafranov with FiPy

$$\Delta^* \psi = -\mu_o R J_\phi$$

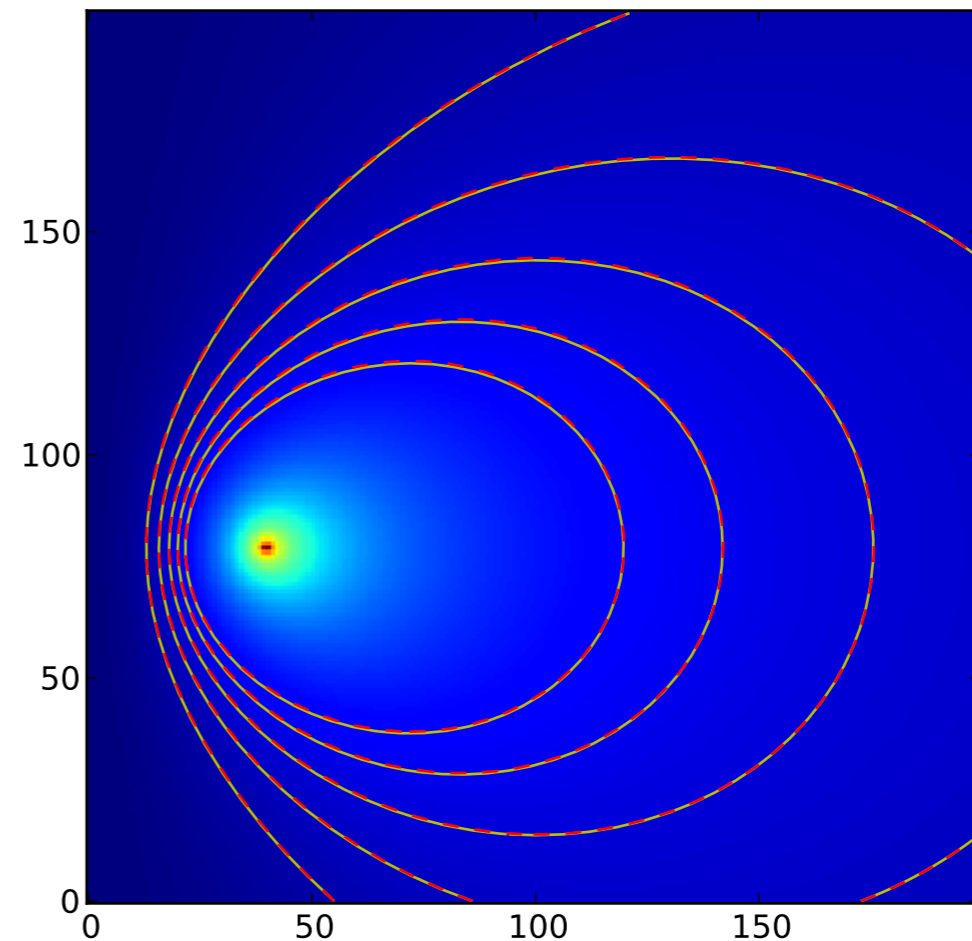
$$J_\phi = R \frac{\partial P}{\partial \psi}$$

FiPy is a PDE solver that employs the Finite Volume Method (FVM)

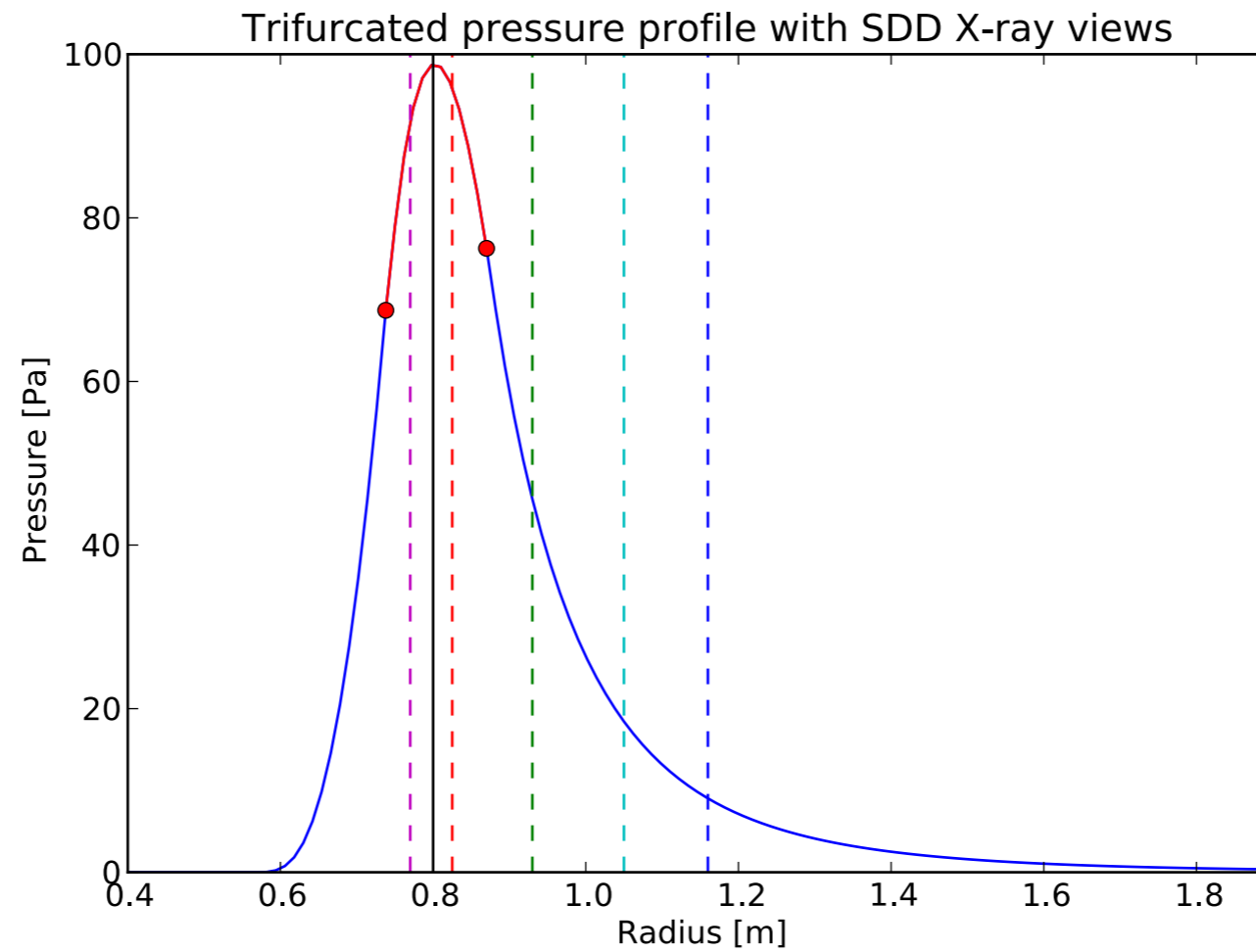
$$\Delta^* \psi \equiv R^2 \nabla \cdot \left( \frac{\nabla \psi}{R^2} \right) = R \frac{\partial}{\partial R} \left( \frac{1}{R} \frac{\partial \psi}{\partial R} \right) + \frac{\partial^2 \psi}{\partial Z^2}$$



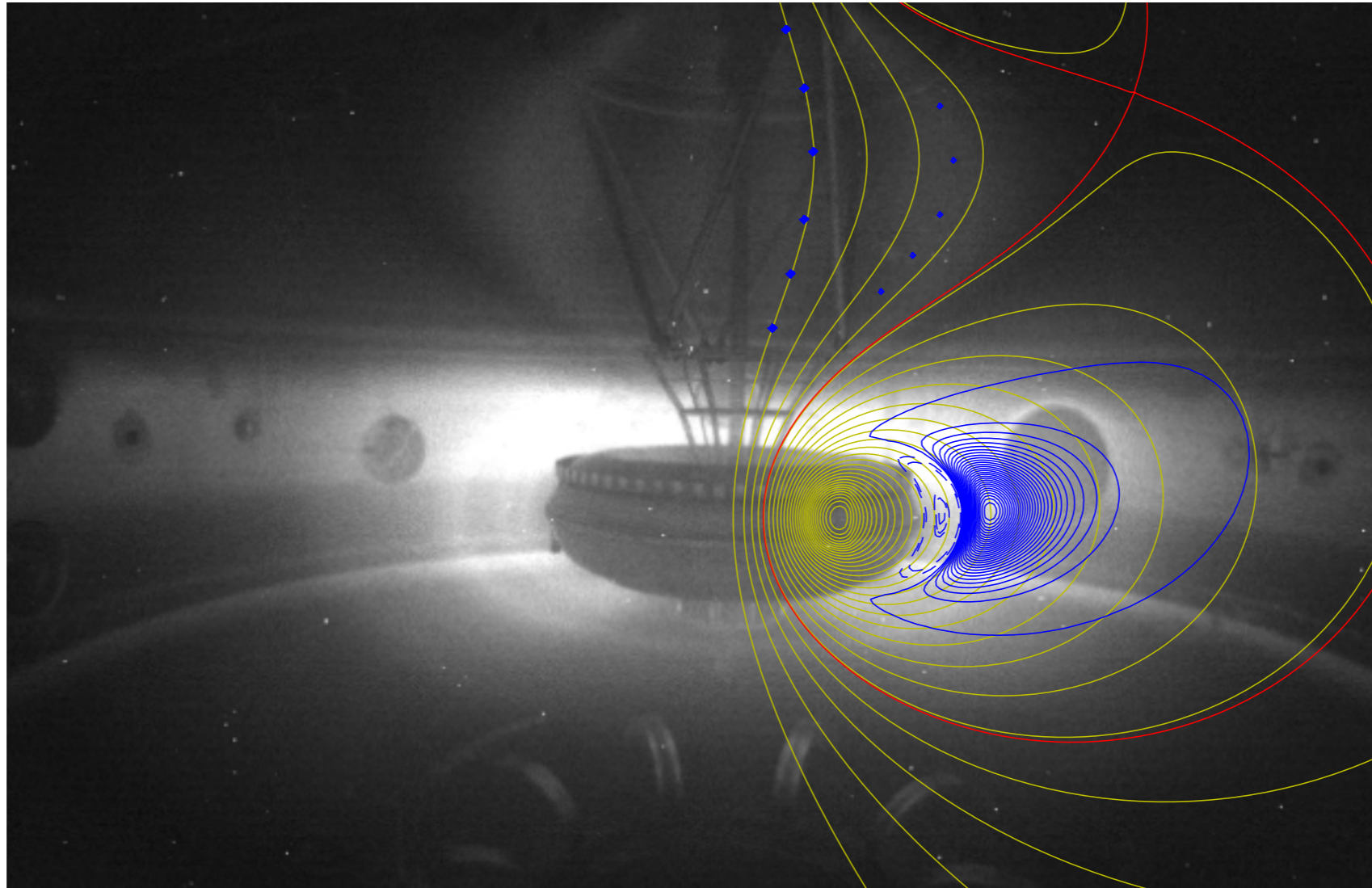
FVM example: FiPy  
 $\psi$  contours for current loop



# Pressure model for dipole plasma

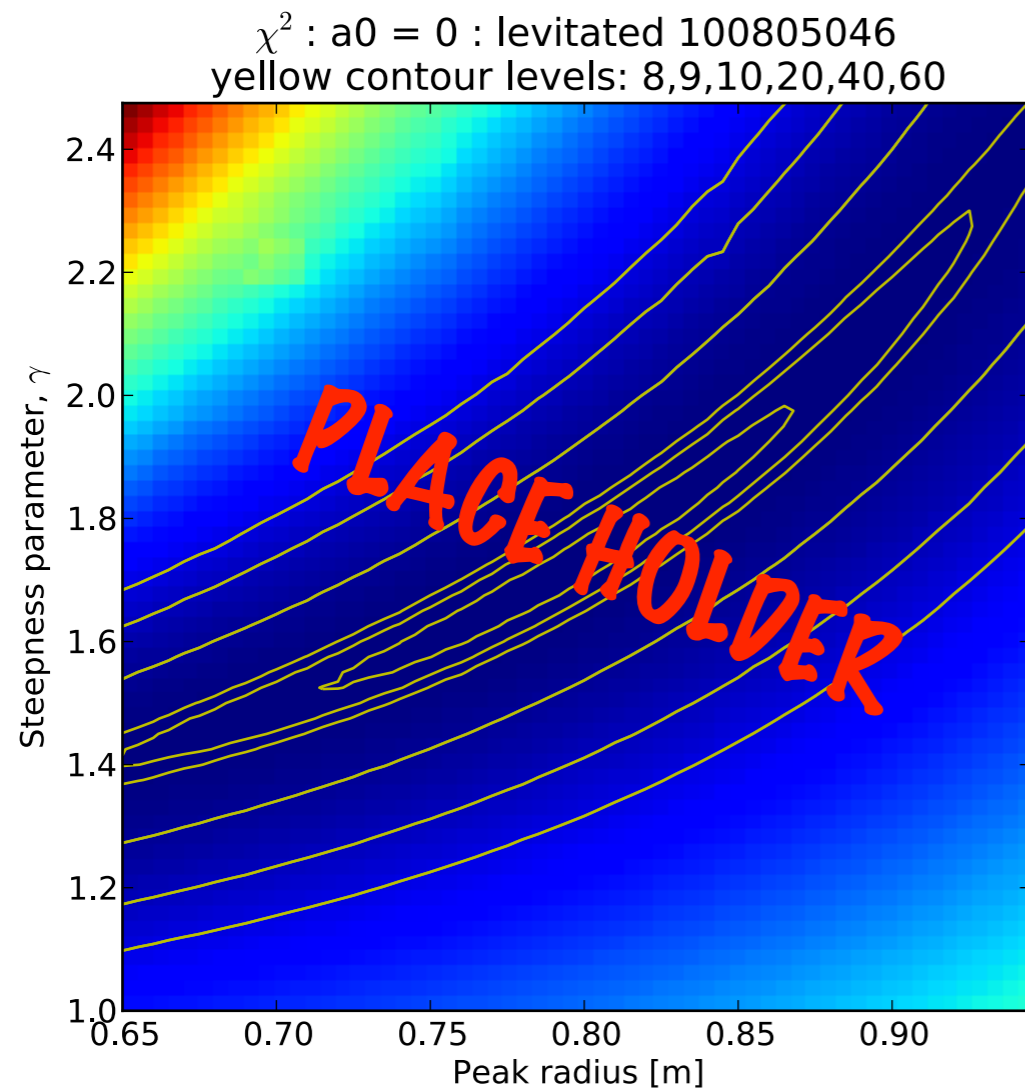


# Plasma in upper mirror region complicates pressure model

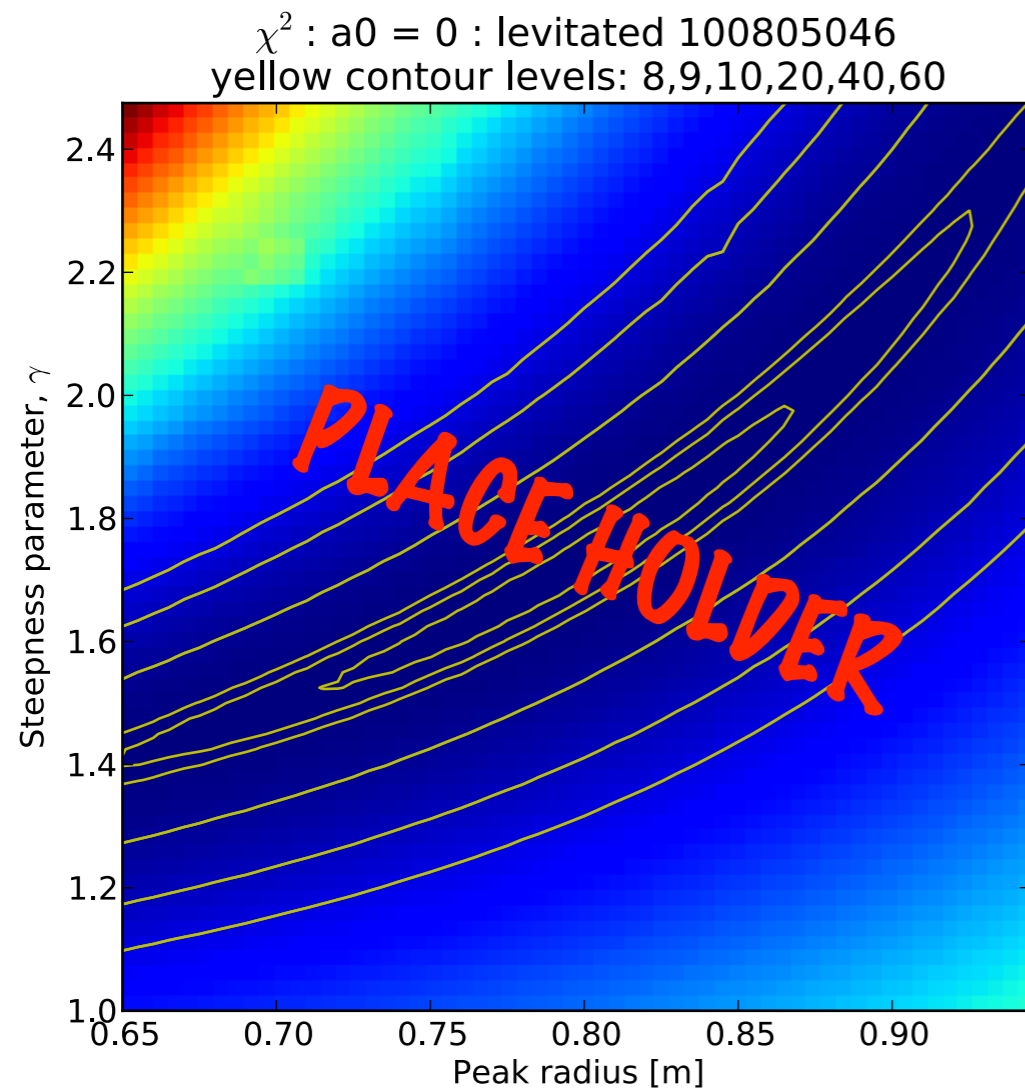


- ◎ Currents in upper mirror are large enough (kiloAmps) that they must be included in reconstruction model
- ◎ A simple baffle could be installed to eliminate this plasma

# Supported plasmas have highly peaked pressure profiles

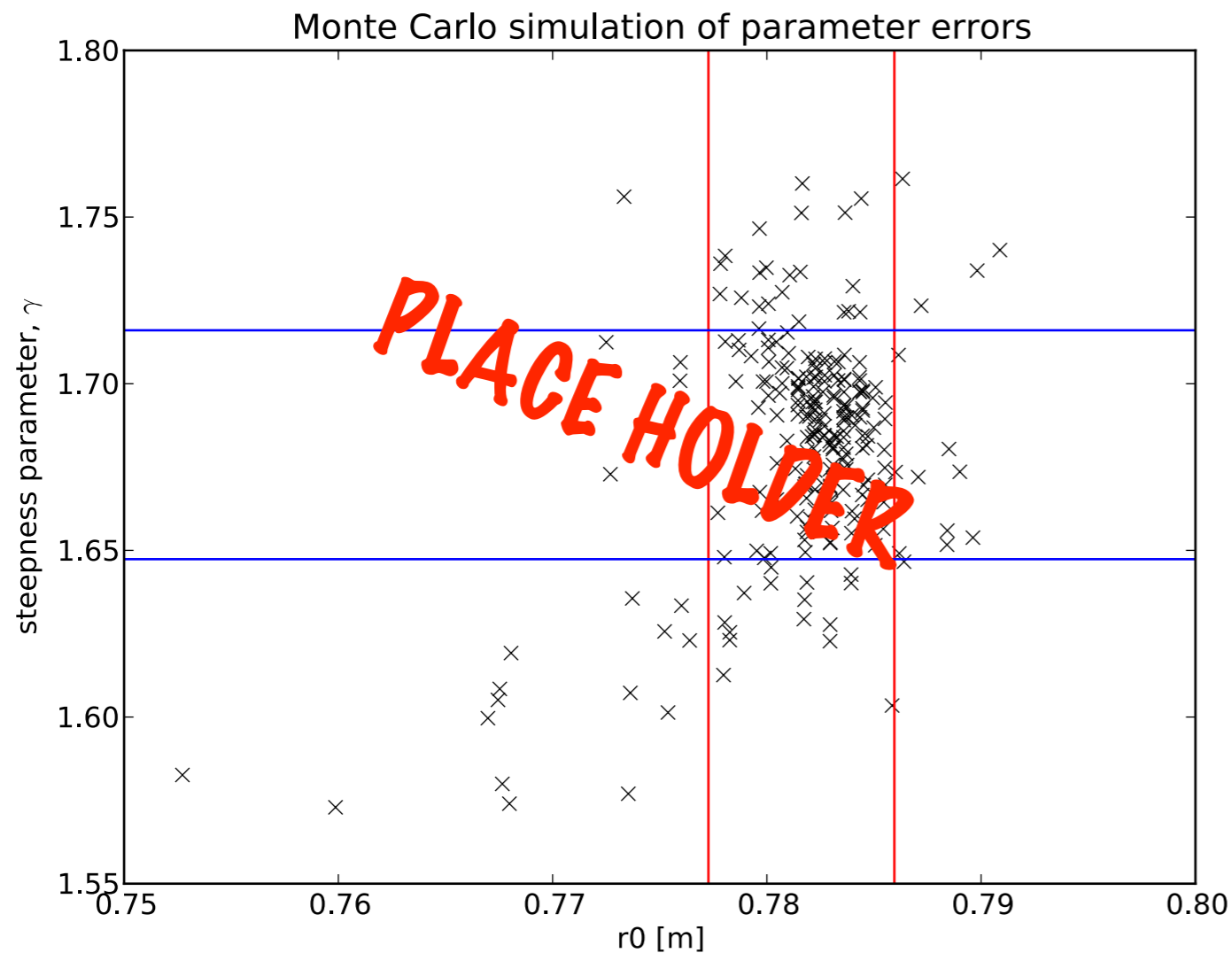


# Levitated plasmas have broader pressure profiles



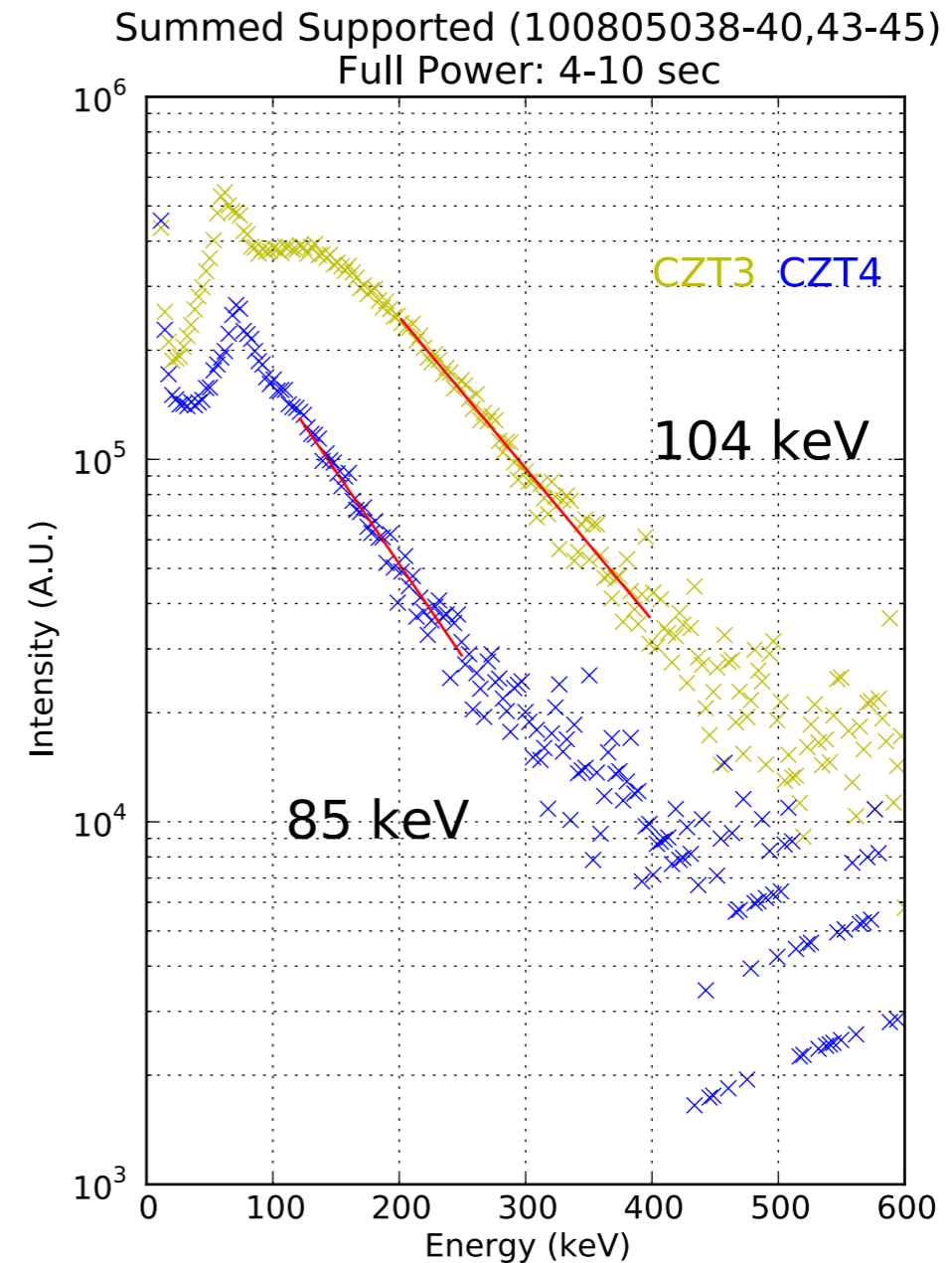
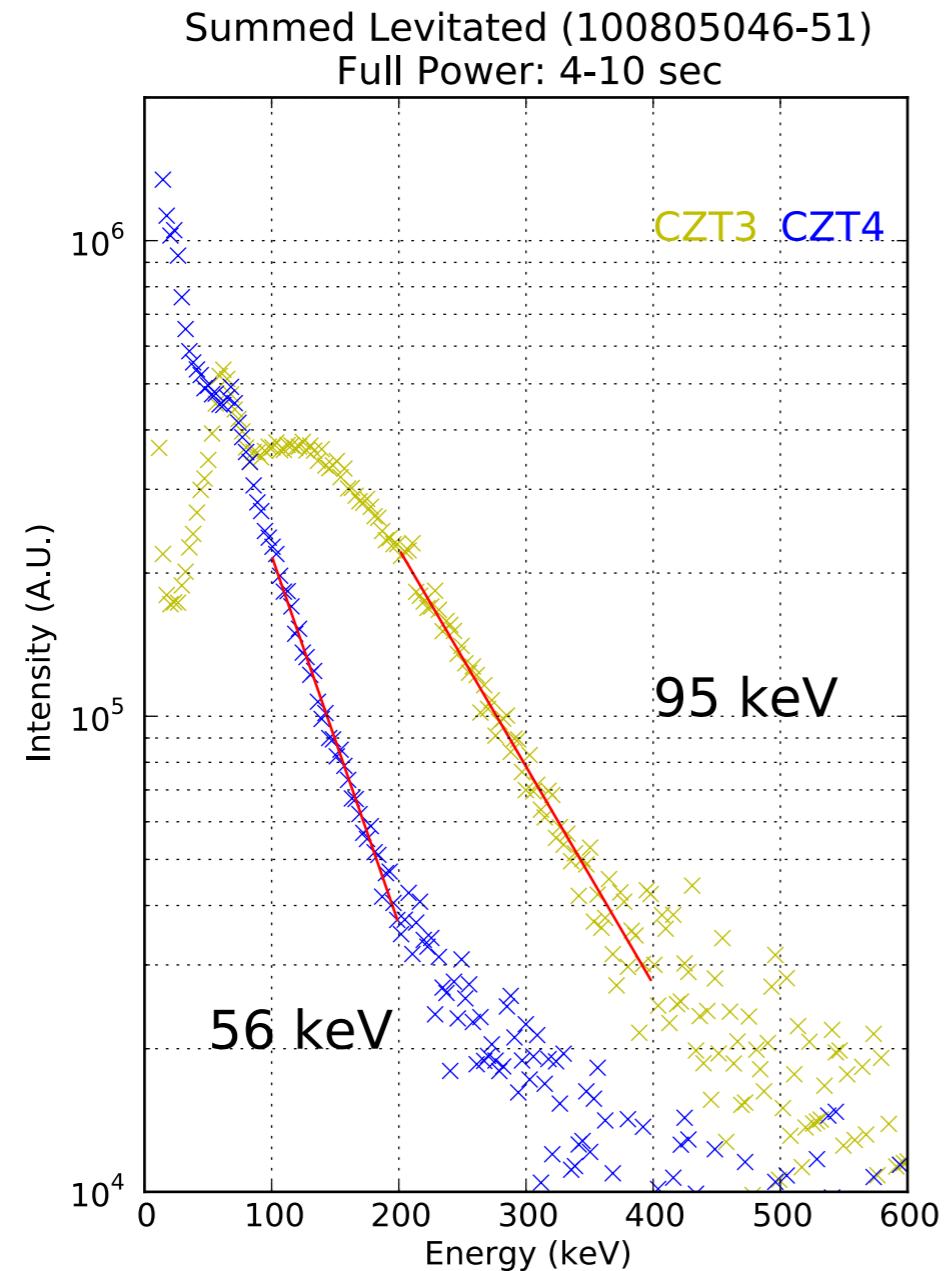


# Confidence in pressure profile parameters



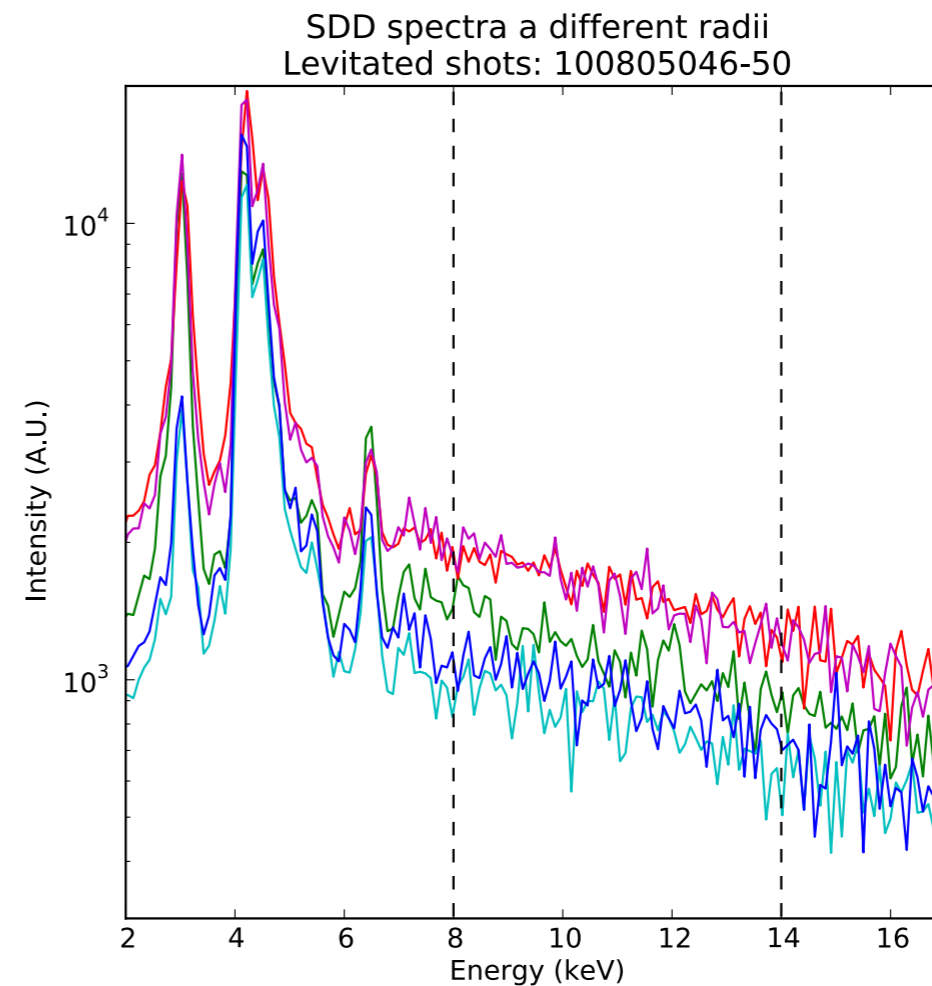
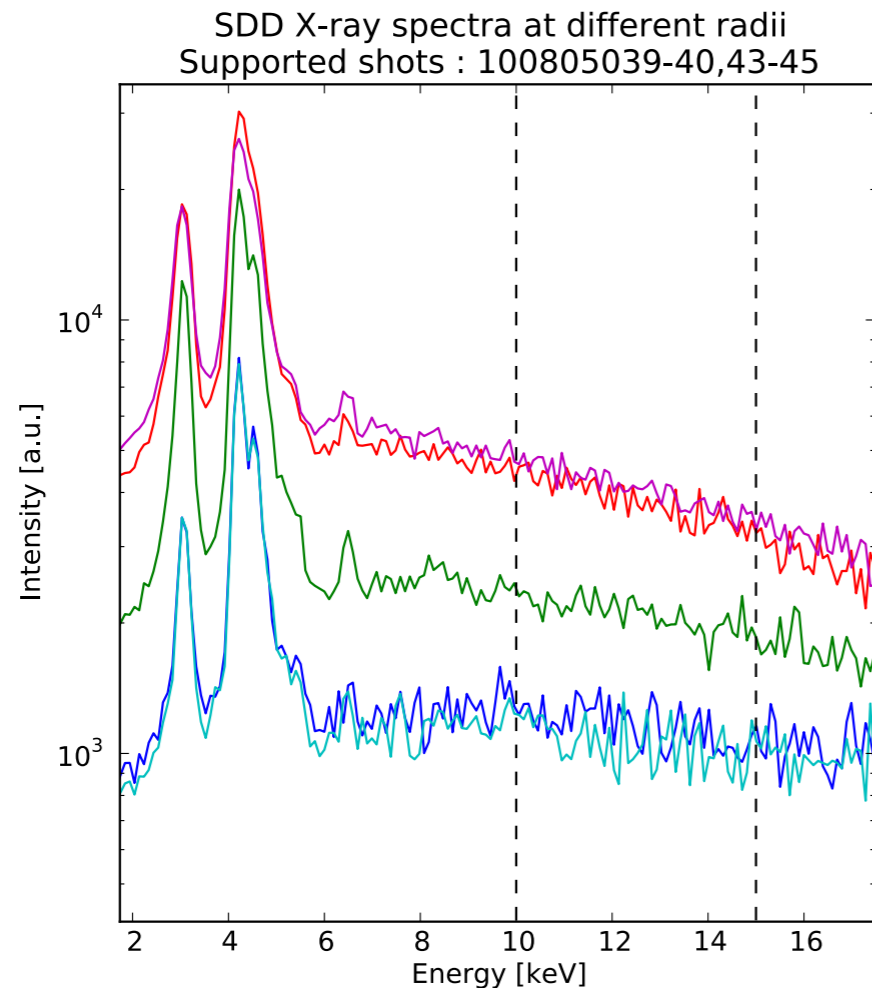
- Synthetic measurements are generated within measurement error bars and  $\chi^2$  minimization is performed to estimate the errors in the calculated pressure profile parameters

# CZT [20-600 keV]: Hot electron temperature



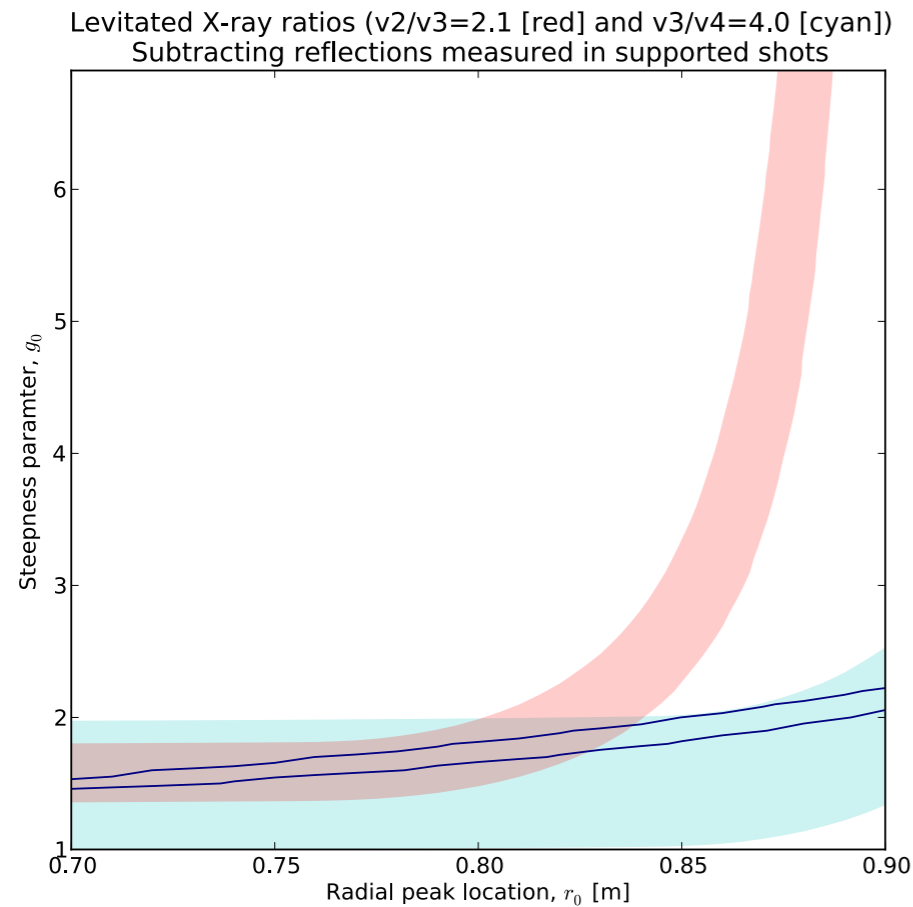
● Hot electrons have a temperature of 50-100 keV

# SDD [2-20 keV] X-rays

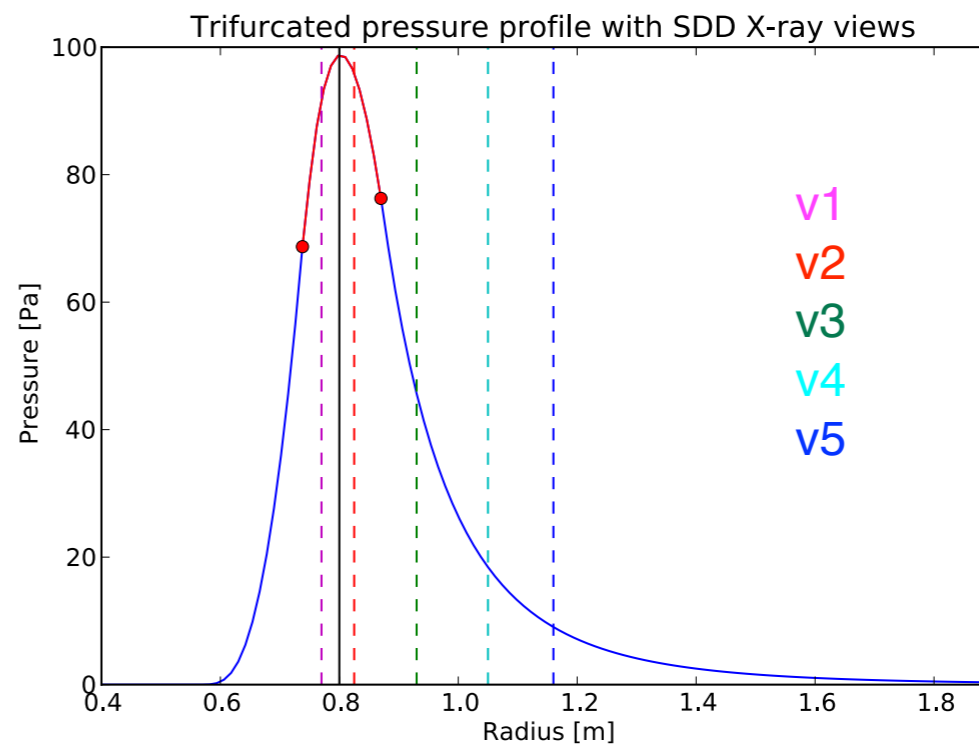


- Original intent: view the thermal bremsstrahlung spectrum of the bulk --> bulk electron temperature
- Signal dominated by the hotter electrons ( $> 10$  keV)
- Integration of continuum spectrum shows radial variation of X-ray emission

# X-ray consistency with magnetic reconstructions



- Measured ratios of the X-ray continuum intensity at different tangency radii match the expected ratios from pressure profiles derived from the magnetic reconstructions in levitated shots



# Estimating the energy in the thermal population

$$P_{\text{brem}} \sim n_{e_{\text{hot}}} n_i \sqrt{T_{e_{\text{hot}}}}$$

# Conclusion

Levitated plasmas have pressure profiles consistent with marginally stable, invariant profiles.