Multipass Absorption of ECH on DIII-D for Polarization/ Propagation Tests and High-Density Heating

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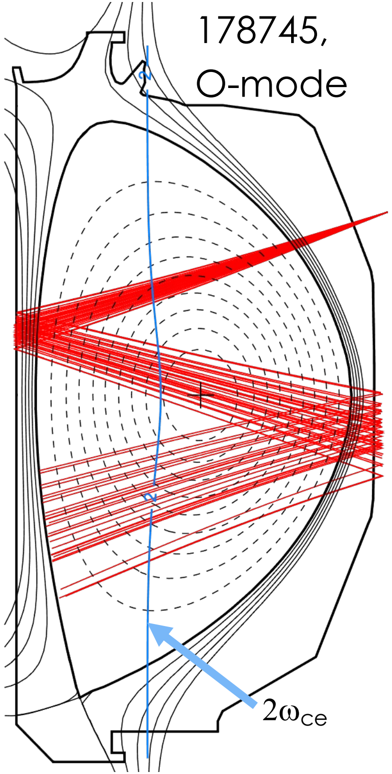

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Abstract

The suite of codes to model the ECH profile on the DIII-D tokamak has been extended to follow the EC waves (110 GHz, second harmonic) over multiple bounces, allowing quantitative comparisons with experimental measurements in low absorption regimes for a number of purposes. First, the EC wave polarization has been checked by launching the waves radially at the centerpost tiles, where the injected X-mode component is absorbed off-axis on the first pass while the injected O-mode component is damped primarily on the second pass (at smaller radius) due to the higher electron temperature and mode scrambling. Second, the injection angle for top launch ECH has been tested by placing the EC resonance so that it grazes the inboard side of the downward propagating beam on the first pass, and grazes the outboard side of the upward propagation beam after it reflects off the floor tiles. This results in a double-peaked deposition profile that can be used to constrain the poloidal launch angle by matching the multipass ray tracing code to the observed BT dependence of the two peaks. Finally, future DIII-D experiments plan to use high density plasmas (above the X-mode cut-off) for pedestal and core-edge integration experiments, and multipass ray tracing is being used to optimize second harmonic O-mode damping for central electron heating. One option that will be explored is installing polarization-conserving reflection tiles on the centerpost to give multiple passes of nearly pure O-mode polarization.

Outline

I. Extending TORAY to Multiple Passes

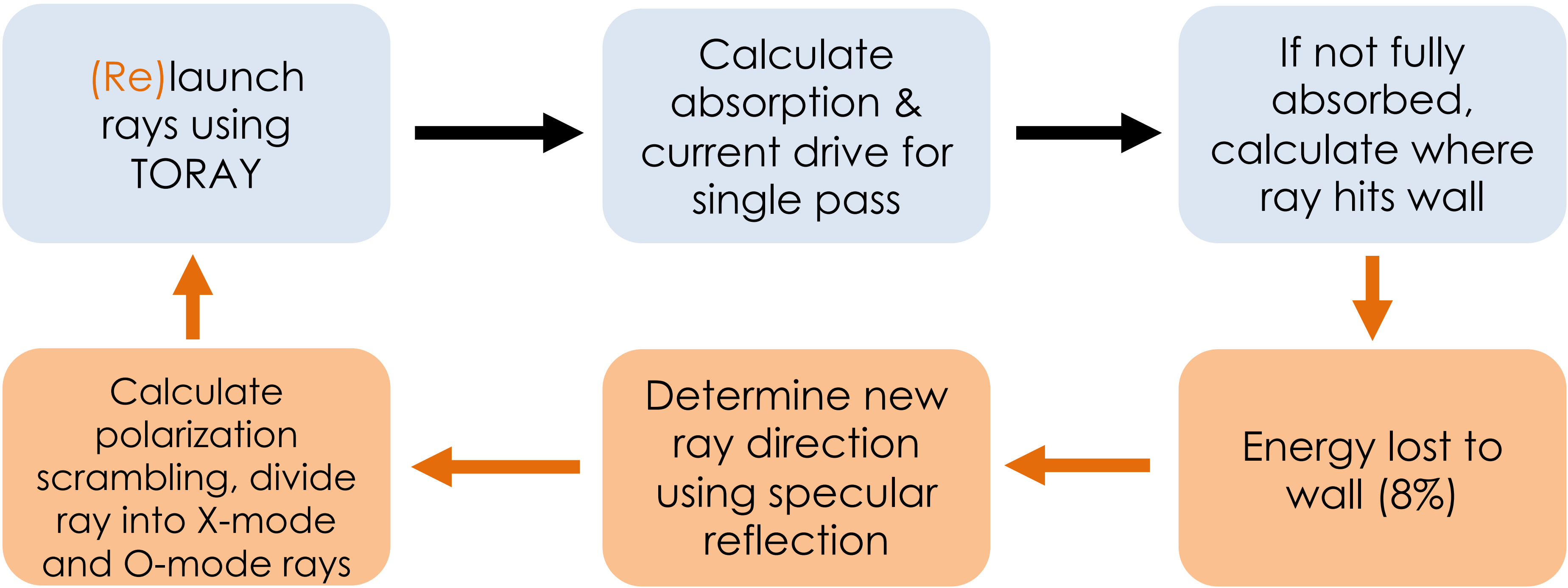
II. X-mode and O-mode Polarization Tests

III. Check of Top Launch Steering

IV. Maximizing O-mode Absorption for Outside Launch

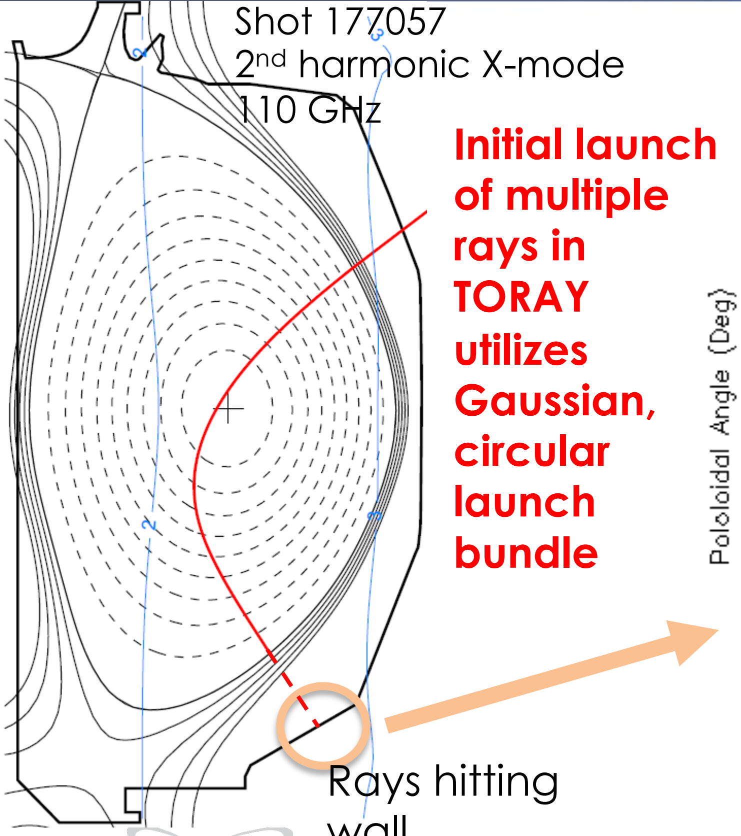
I. Extending TORAY to Multiple Passes

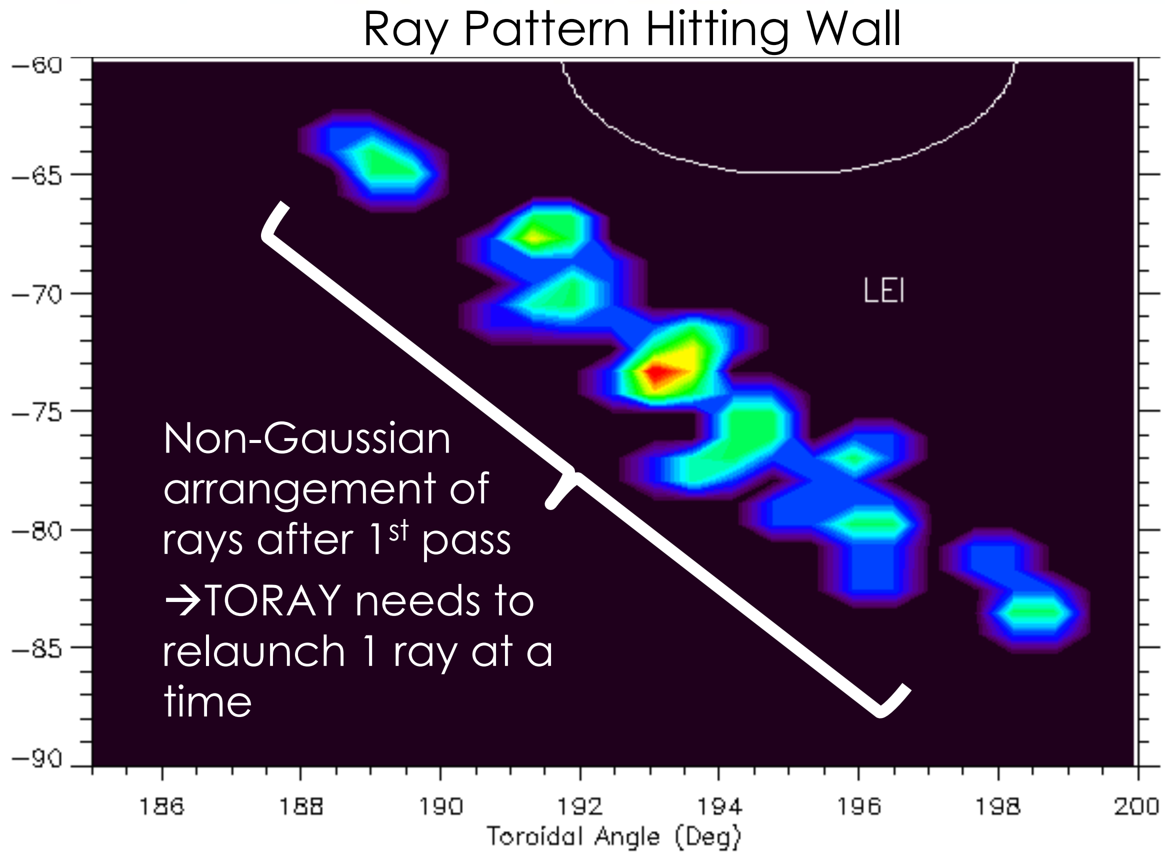
Previous ray tracing procedure (single pass)



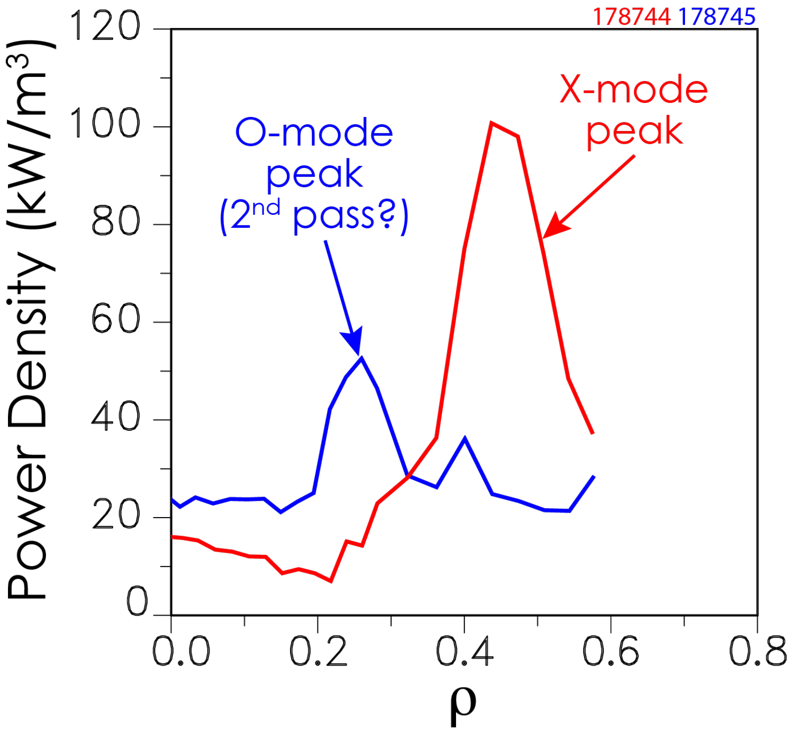
Modifications to ray tracing procedure for multiple passes

After 1st Pass, Each Unabsorbed Ray is Split into X-mode & O-mode Components, and TORAY is Relaunched for Each Ray Separately

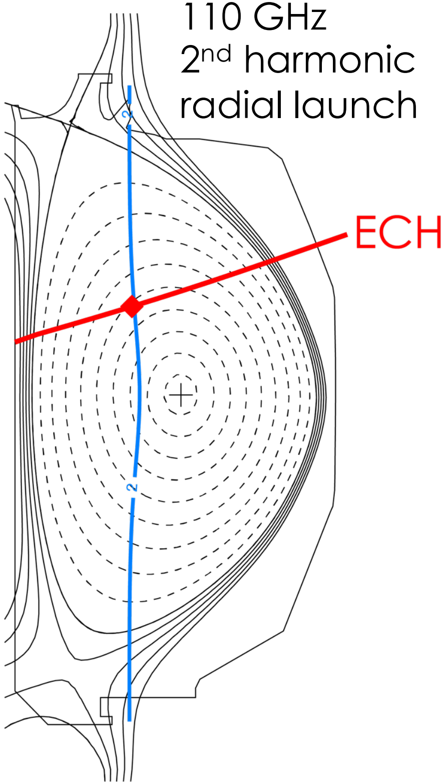




II. X-mode and O-mode Polarization Tests

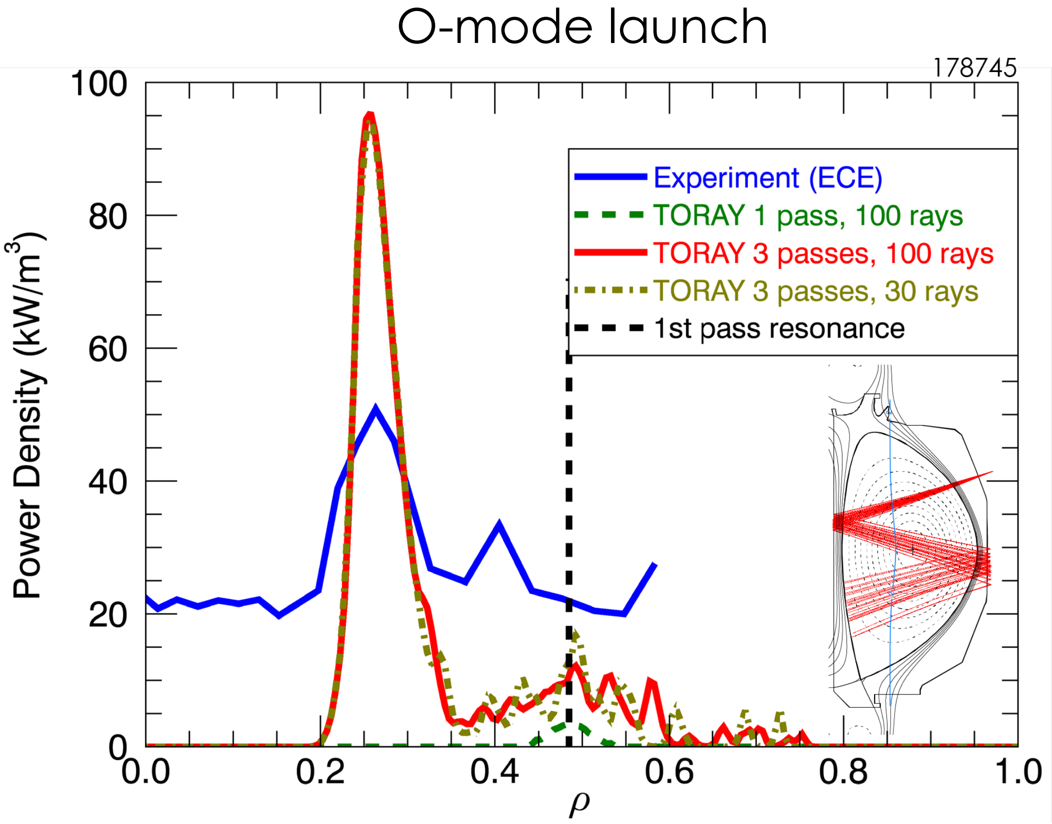


- **Large difference in ECH deposition location, measured by power modulation, between X-mode and O-mode launch can be used to test the polarization purity**
- **Since O-mode peak at small ρ cannot be explained by 1st pass absorption, multipass ray tracing is needed to model this case**



Calculated Absorption by Multipass TORAY is in Good Agreement with Experimental ECH Peak for O-mode Launch

- **Multipass TORAY deposits most 2nd and 3rd pass power at the experimental ECH peak location, which single pass TORAY doesn't do**
- **Launching 30 rays gives comparable multipass deposition profile as launching 100 rays**



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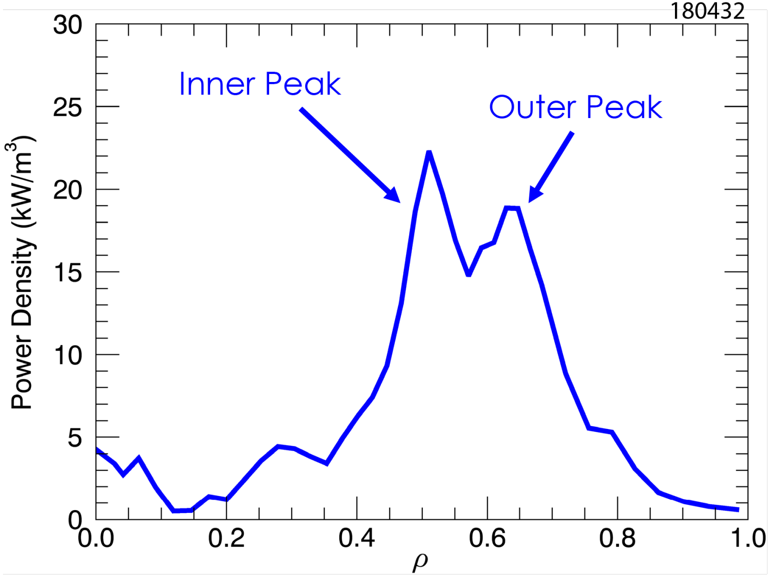
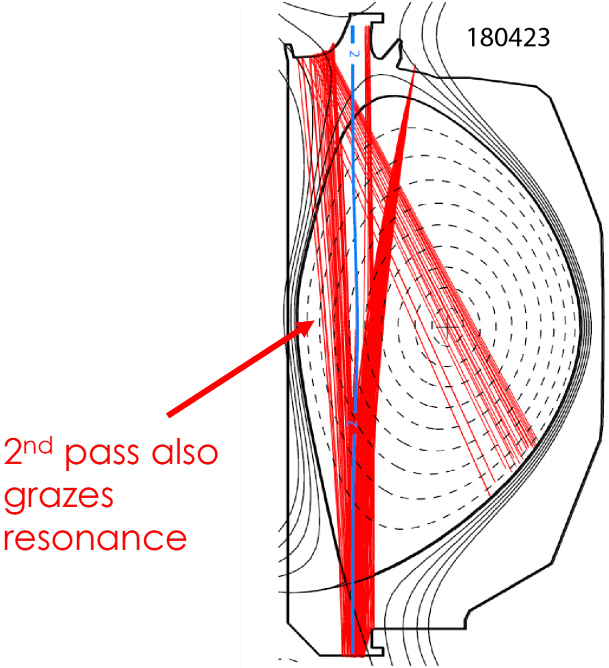
III. Check of Top Launch Steering

- **For low B_T, two separate peaks are measured in top launch power deposition profile**



- **Multiple passes could explain double-peak profile since 1st pass damping is weak at low B_T**



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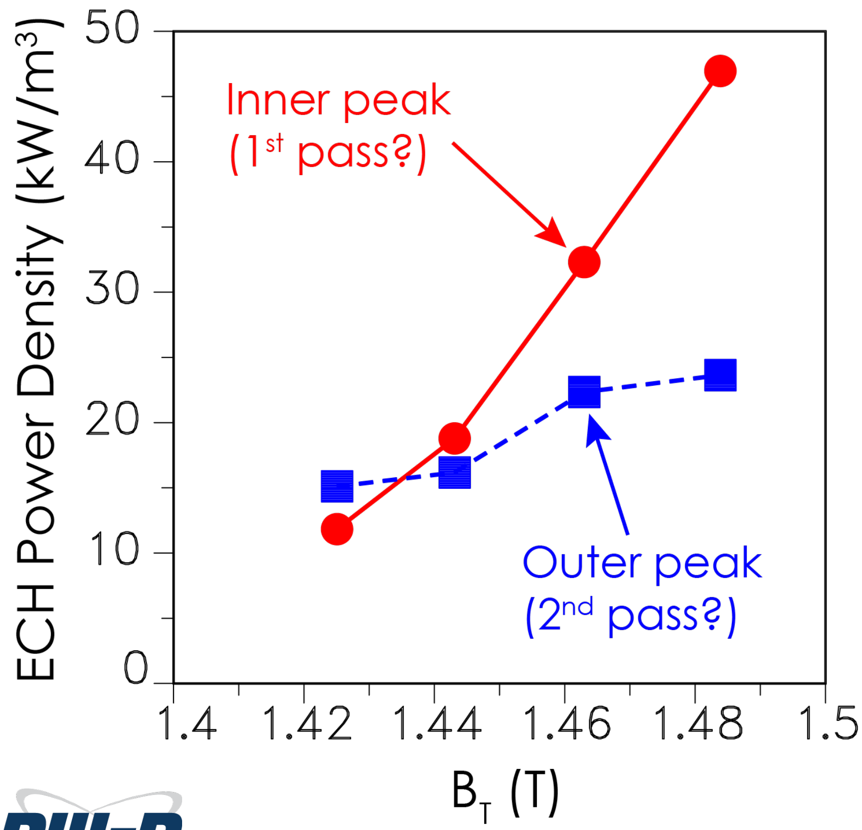
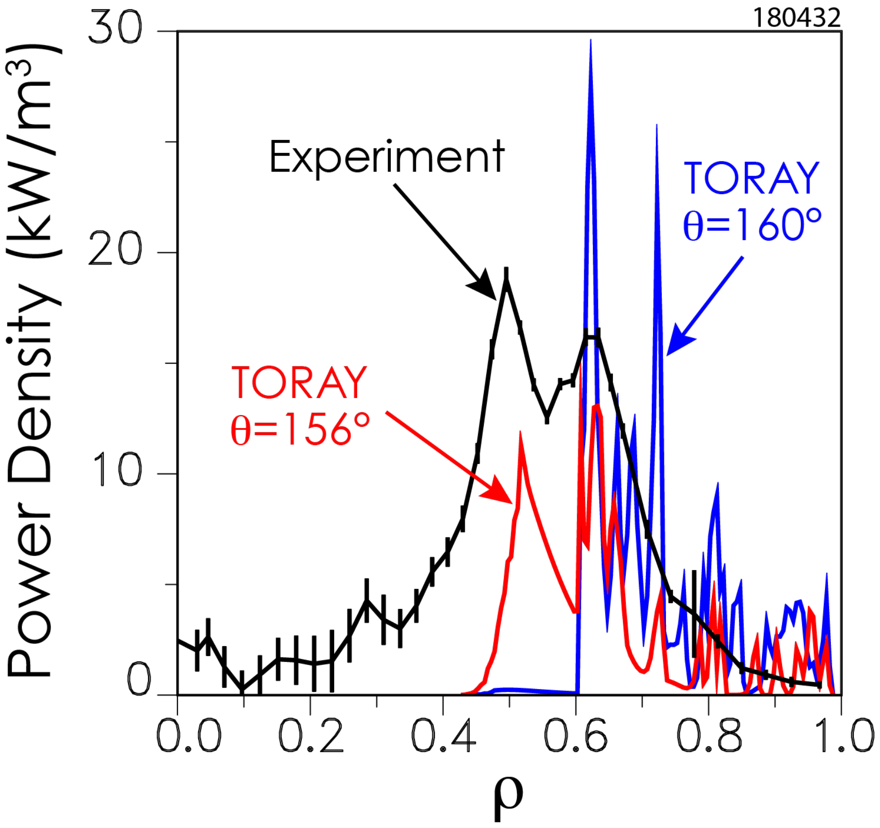
Inner Peak's Location and Stronger Response to B_T, Compared to Outer Peak, Indicates It Comes from 1st Pass Absorption



- Top launch first pass interacts with electrons on low field side of vacuum resonance
- Top launch second pass should interact with electrons on high field side of vacuum resonance and be absorbed at larger radius

Multipass TORAY can Reproduce Double-Peak Deposition Profile But Only After Adjusting Poloidal Launch Angle

- **Top launch uses a fixed mirror with poloidal launch angle of θ=160° (vertical is θ=180°)**
- **However, TORAY finds almost no deposition on 1st pass for θ=160° as ray is too far from resonance**
- **Using θ=156°, TORAY finds similar amplitudes for inner (1st pass) and outer (2nd pass) peaks**
  - Separation between inner and outer peaks is also good match between TORAY and experiment



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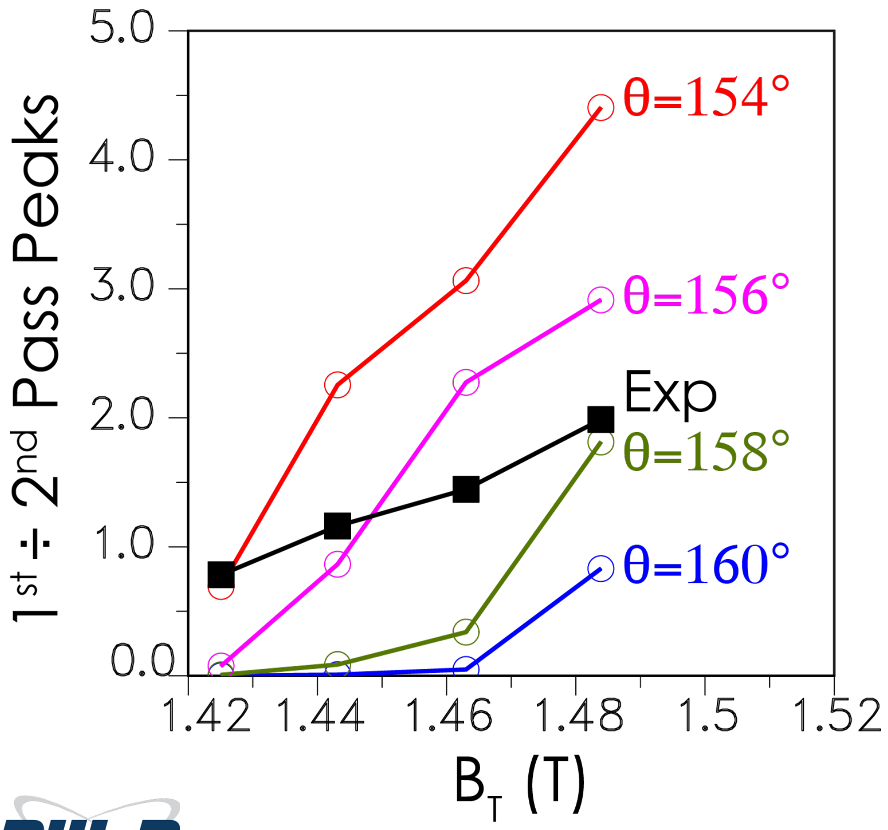
Measured Ratio of 1st and 2nd Pass Peaks During B_T Scan is Best Matched in TORAY for Poloidal Launch Angle of θ=156°-157°



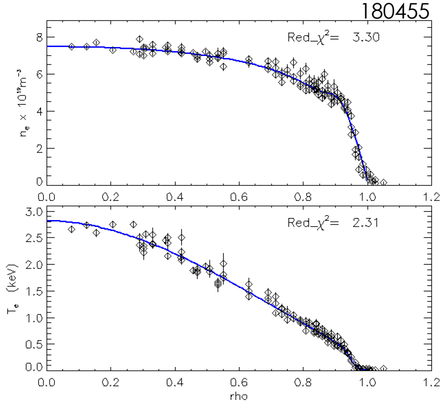
- **Measured ratio of 1st and 2nd pass peaks increases slowly with higher B_T**
- **TORAY also predicts this ratio increases with B_T but more rapidly**
- **While top launch was designed for θ=160°, a lower value of θ=156°-157° gives best match of TORAY with experiment**

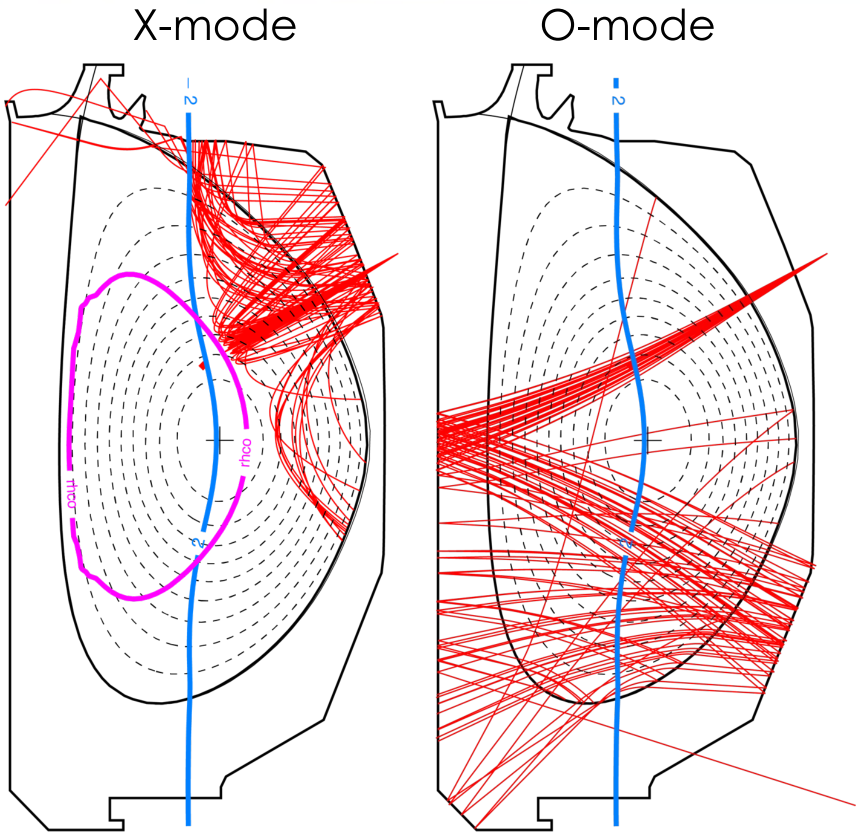
Double-peak deposition profile can be used to check poloidal injection angle for top launch

IV. Maximizing O-mode Absorption for Outside Launch

- **Core electron heating in high density plasmas is an important need for reactor-relevant studies on DIII-D**
- **X-mode polarization cannot be used in high density plasmas due to RHCO**
- **O-mode polarization has twice the density limit but weaker absorption**

Here we optimize the launcher steering for multi-pass absorption of O-mode in high density plasmas





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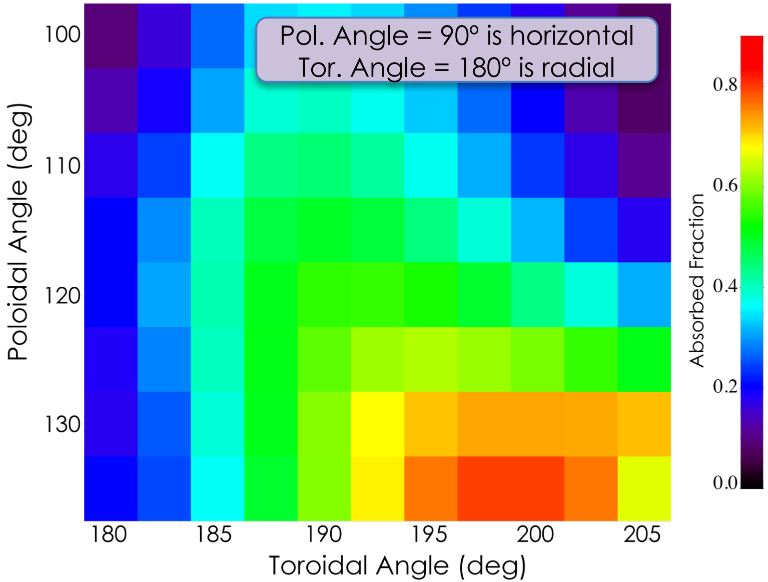
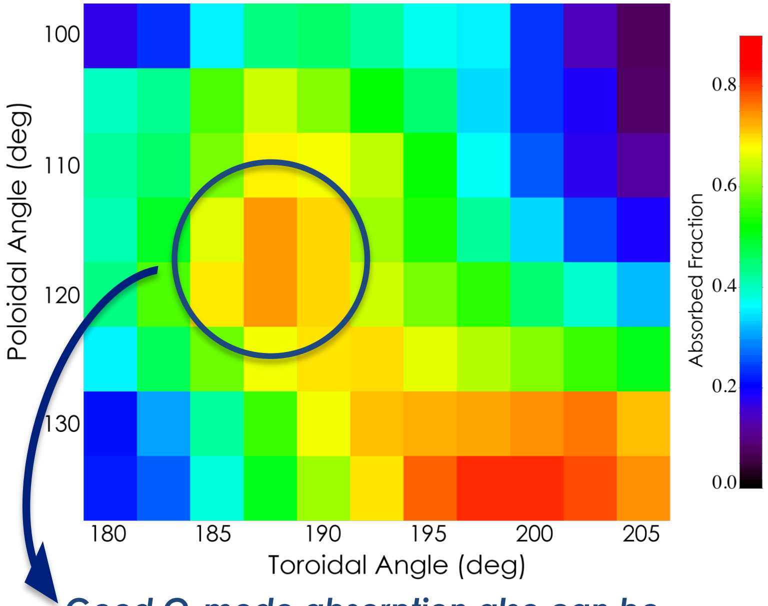
Multiple Reflections Between Centerpost and Outer Wall can Significantly Increase O-mode Absorption in High Density Plasmas

- **TORAY single pass modeling**



Good O-mode absorption (~80%) only occurs during 1st pass for oblique launch with strong downward aiming so rays pass near plasma center

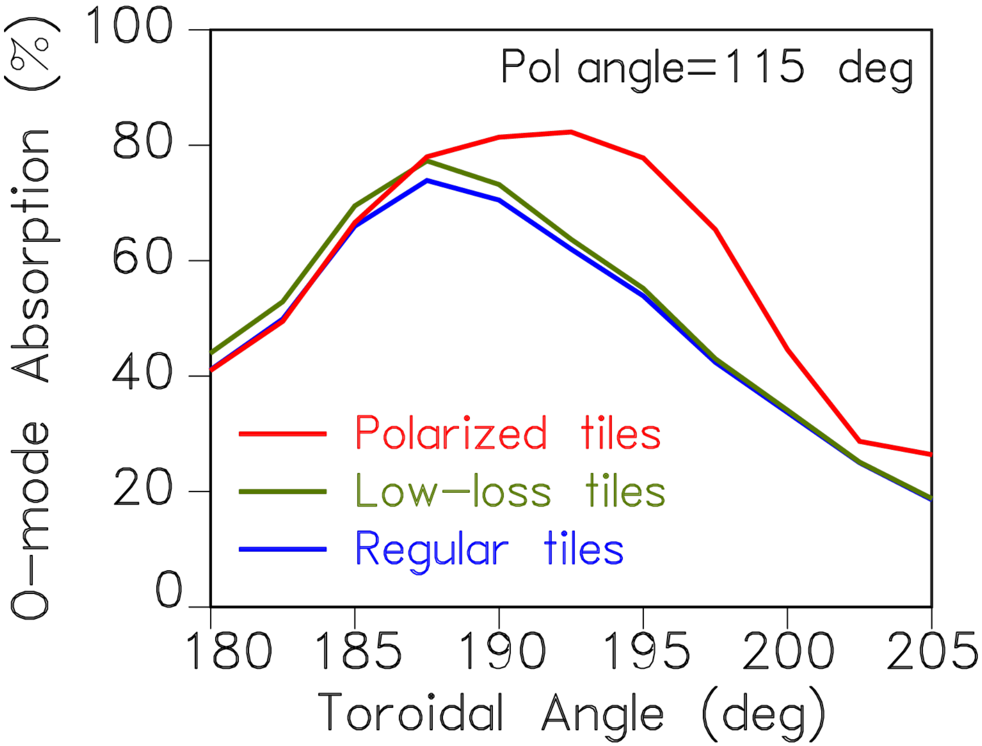
- **TORAY multipass modeling**



Good O-mode absorption also can be obtained by bouncing 1st pass off centerpost such that 2nd pass (and maybe 3rd) goes near plasma center

Polarization-Conserving Reflection Tiles to Give Multiple Passes of Pure O-mode Polarization can Modestly Increase Absorption

- **Using special tiles that prevent polarization scrambling during reflection can increase O-mode absorption for large toroidal angles but peak value is only slightly higher**
- **Replacing regular graphite tiles with low-loss (0.3%) W tiles gives little increase in absorbed power**



Conclusions

- **The suite of codes to run TORAY for DIII-D has been extended to follow launched EC rays for multiple passes through the plasma**
  - Effects of polarization scrambling and wall losses (~8%) are included
- **Multipass TORAY correctly predicts location of 2nd pass peak (after reflecting off centerpost) for weakly absorbed O-mode**
- **Double-peak deposition profile observed for top launch ECH is well modeled by multipass TORAY**
  - Two peaks are due to 1st and 2nd pass damping
  - Dependence of the two peaks on B_T is sensitive to poloidal angle of top launch
- **Multipass TORAY allows optimal poloidal and toroidal injection angles to be determined for good O-mode absorption (~80%) in high density plasmas**