Preliminary RAYS results for MPEX, OXB

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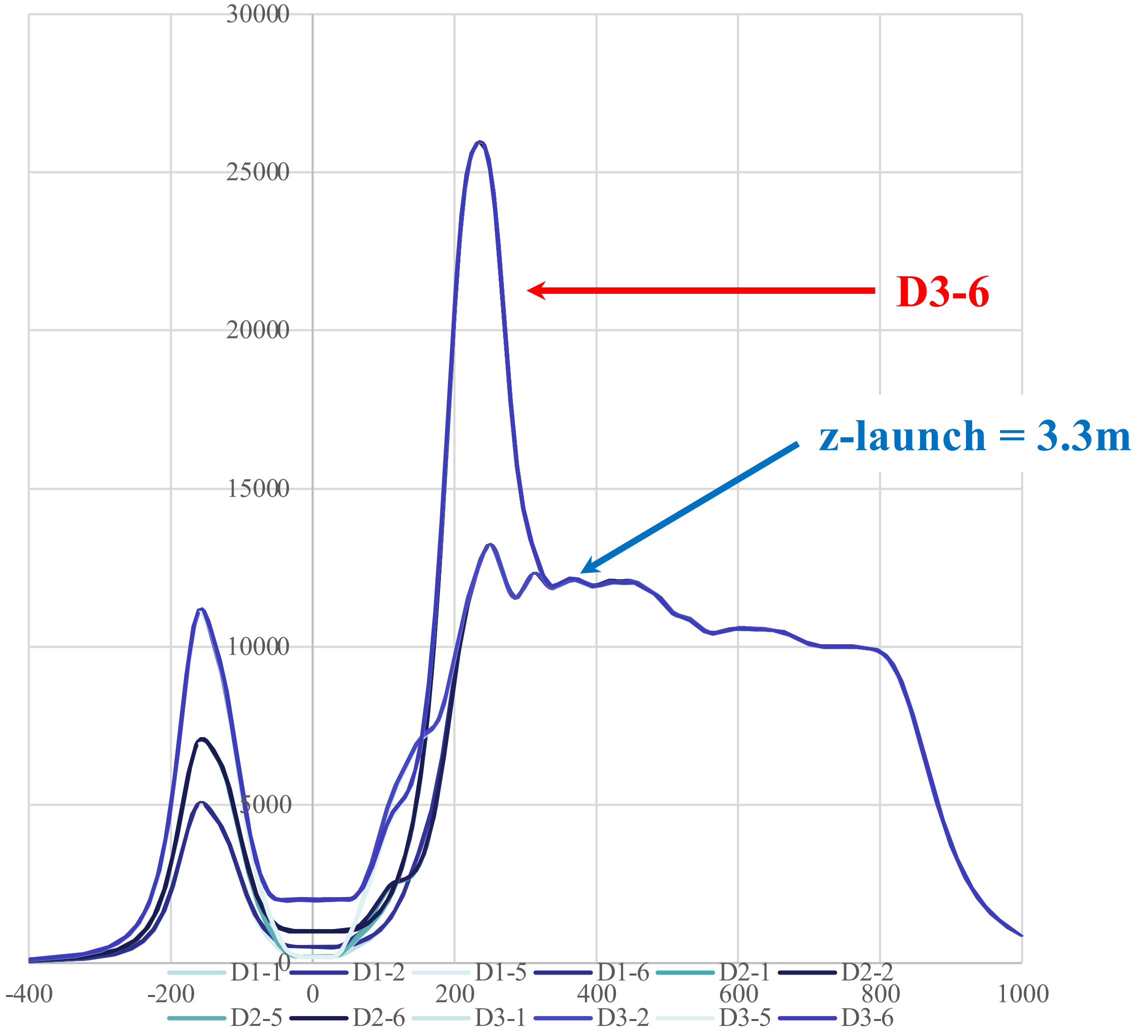
- **RAYS – added multiple mirror equilibria, post-processing and graphics, Ordinary to Extraordinary mode conversion coefficients**

⇒ **Can now trace cold-plasma rays in MPEX and calculate OX mode conversion**

- **Ran several cases for 2nd harmonic ECH OX conversion**
  - **Tried to extract parameters from various MPEX design documents**
  - **Several unknowns, uncertainties, and inconsistencies**
  - **Put together parameter sets representing what I think, that you think are representative of MPEX**
  - **Looked at rays, and conversion coefficients for off-axis launch – haven't seen any such in MPEX documentation**

- **Need more information before doing more ➔ especially a good characterization of rays launched from the antenna**

Magnetics information from Earle Burkhardt (spread sheet)



- **Case D3-6**
- **Field in RAYS is calculated using elliptic integrals (not paraxial approximation), spline fit**

Hyperbolic density model based on Marin, MPEX-03-003

$$n_e(r) = \left[n_e(0) - n_e(r_{edge})\right] \frac{\tanh\left(\frac{\psi + \psi_P}{\Delta}\right) - \tanh\left(\frac{\psi - \psi_P}{\Delta}\right)}{2\tanh\left(\frac{\psi_P}{\Delta}\right)} + n_e(r_{edge})$$

- **He takes $\boldsymbol{\psi_P = 0.6, \Delta = 0.19}$, which seems to fit Proto MPEX**

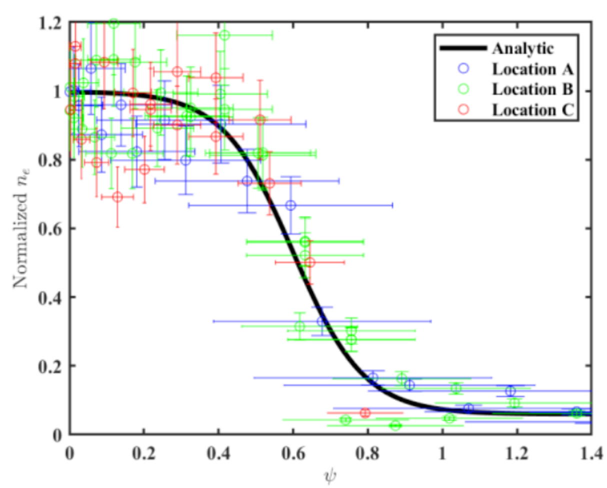
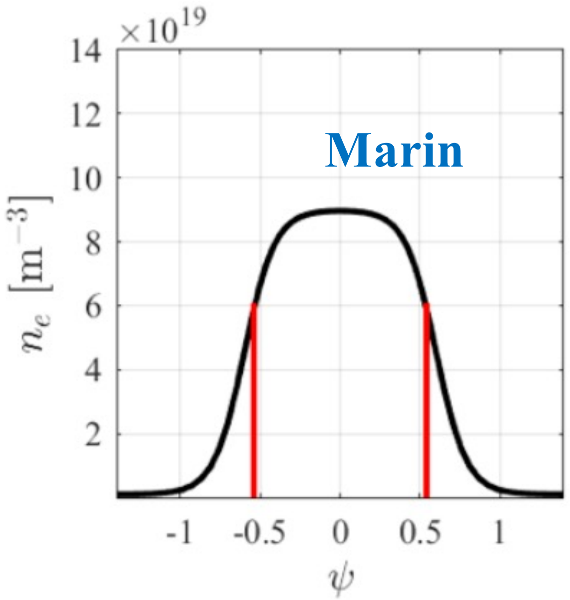


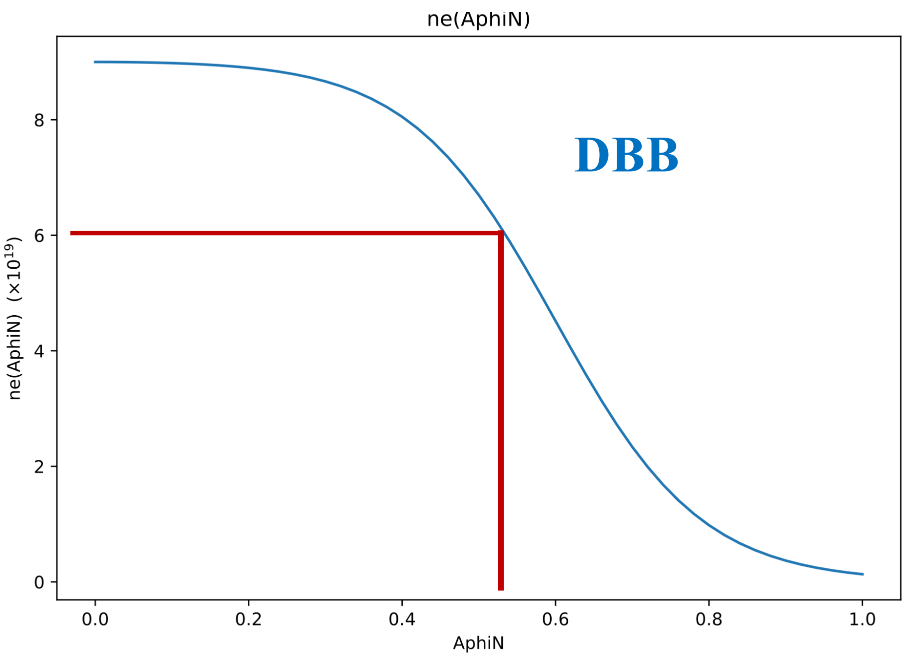
Figure 1, Experimentally measured radial electron density profiles normalized to the peak density at different axial locations along Proto-MPEX. Analytical fit to the data uses Eq. 9 with $\boldsymbol{\psi_p = 0.6}$ and $\boldsymbol{\Delta\psi = 0.19}$.

- **He apparently uses the same parameters to model MPEX**

However, I get a different radial profile from him for MPEX using these parameters

- **Density versus ψ are similar, $\psi_P = 0.6, \Delta = 0.19$**



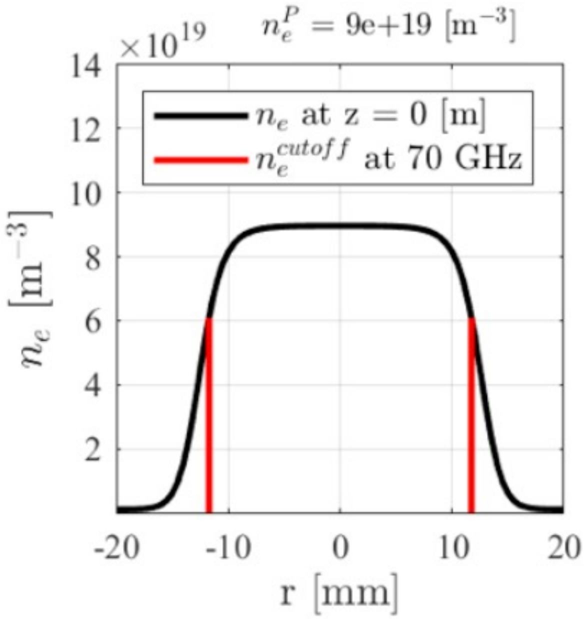


- **Cutoff density is at same location in ψ**

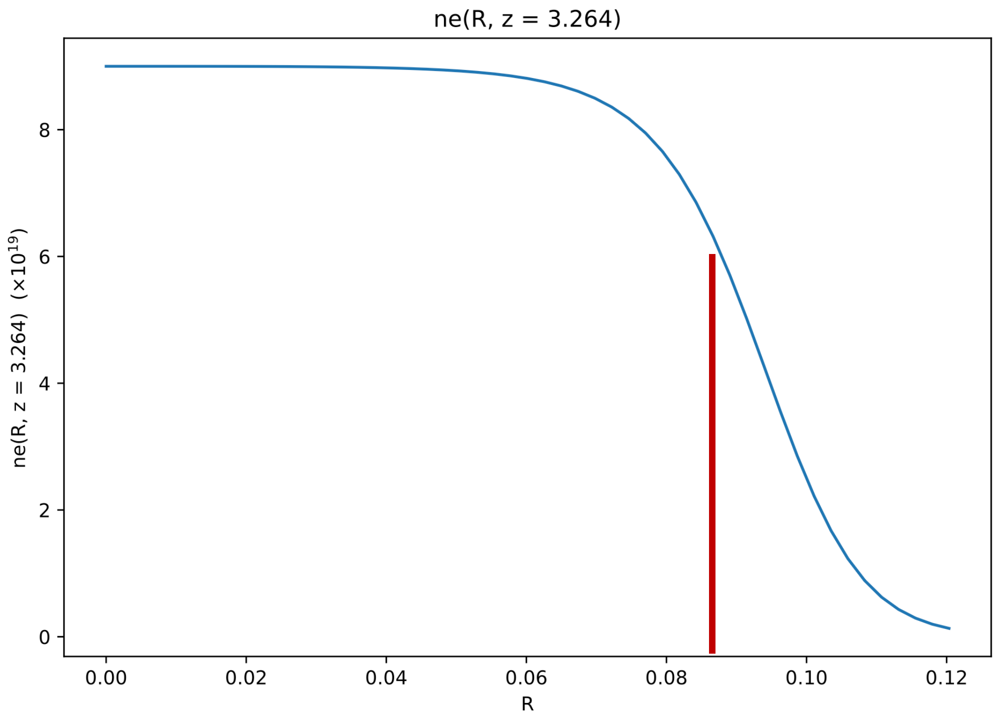
Profiles in radius are very different

- **Again $\psi_P = 0.6, \Delta = 0.19$**

Marin

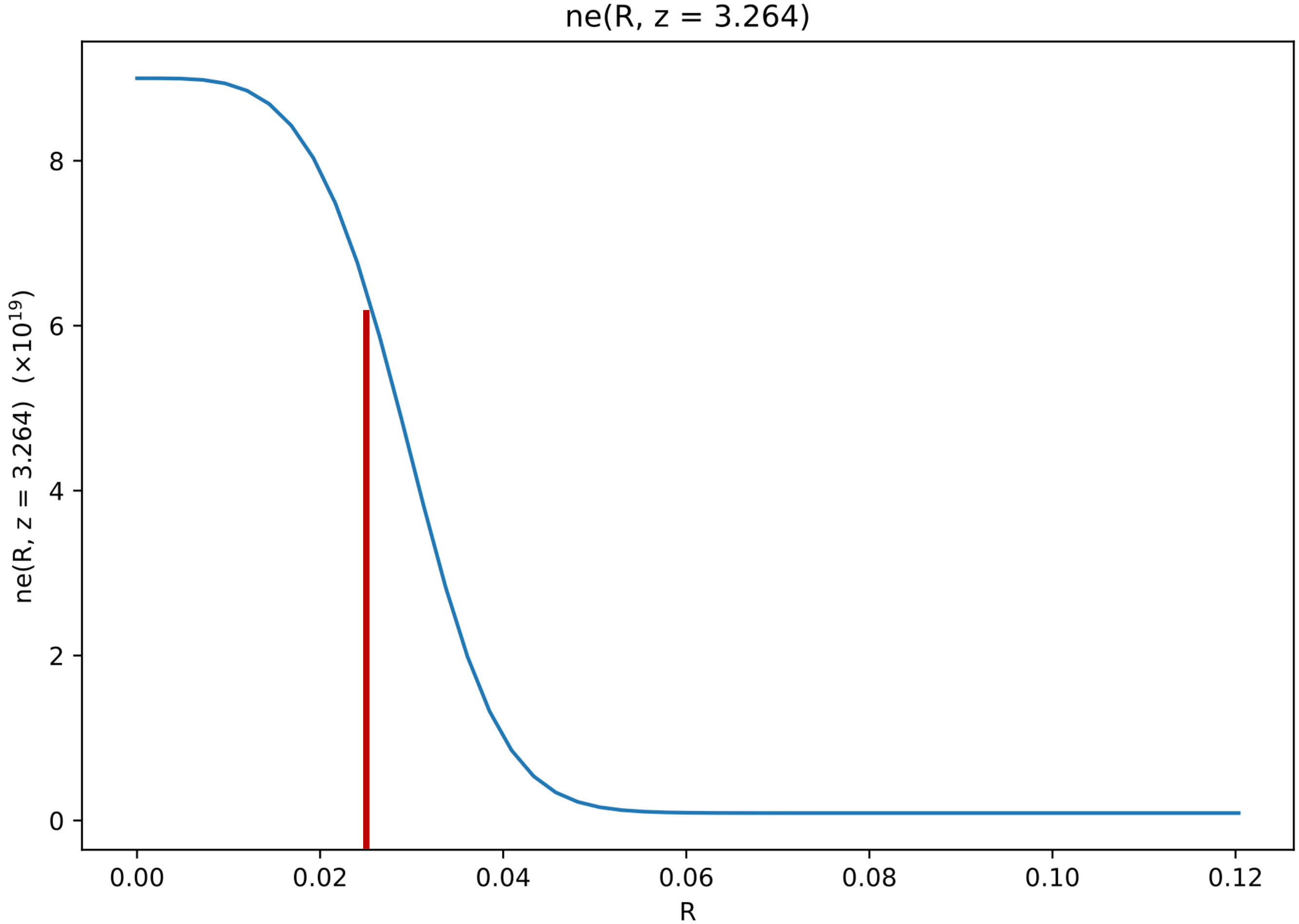


DBB



- **His plasma is about 2 cm wide, mine is about 17 cm at z = 3.3m with these profile parameters**
- **Maybe the discrepancy is the definition of LUFS. I haven't been able to find out the limiter strike point for the D3-6 case.**

Cases were run with narrower profile $\psi_P = 0.05, \Delta = 0.05$



- **Plasma is about 4 cm wide at O-mode cutoff, z = 3.3m**

There appears to be a discrepancy in the optimum launch angle

- **From Preinhalter and Kopecky (1973) the optimum value of $\boldsymbol{n}_{||}$ is given by**

$$n_{z\,opt} = \sqrt{\frac{\beta}{1+\beta}}\,, \quad \text{where} \quad \beta \equiv \frac{\Omega_{ce}}{\omega_{rf}}$$

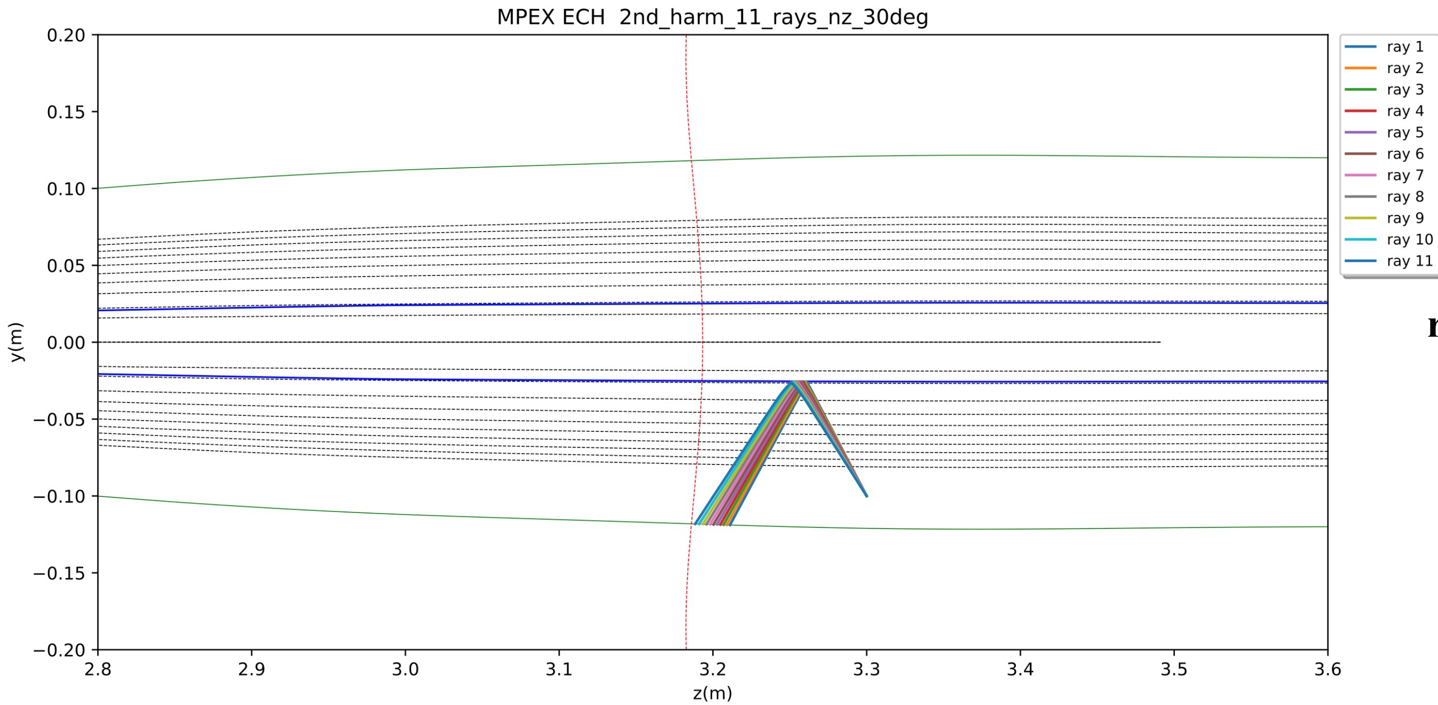
- **For 2nd harmonic i.e. $\boldsymbol{\beta = 0.5}$, $\boldsymbol{n_{z\,opt} = 0.577 \quad \Rightarrow \quad \theta_{opt} = 35.3°}$.**

- **Here $\boldsymbol{\theta}$ is the angle between the density gradient (essentially Y here) and the incident wave vector. The magnetic field is taken to be perpendicular to the density gradient (essentially Z here)**

- **The MPEX design seems to shoot for a launch angle of 30°**

- **It makes a difference**

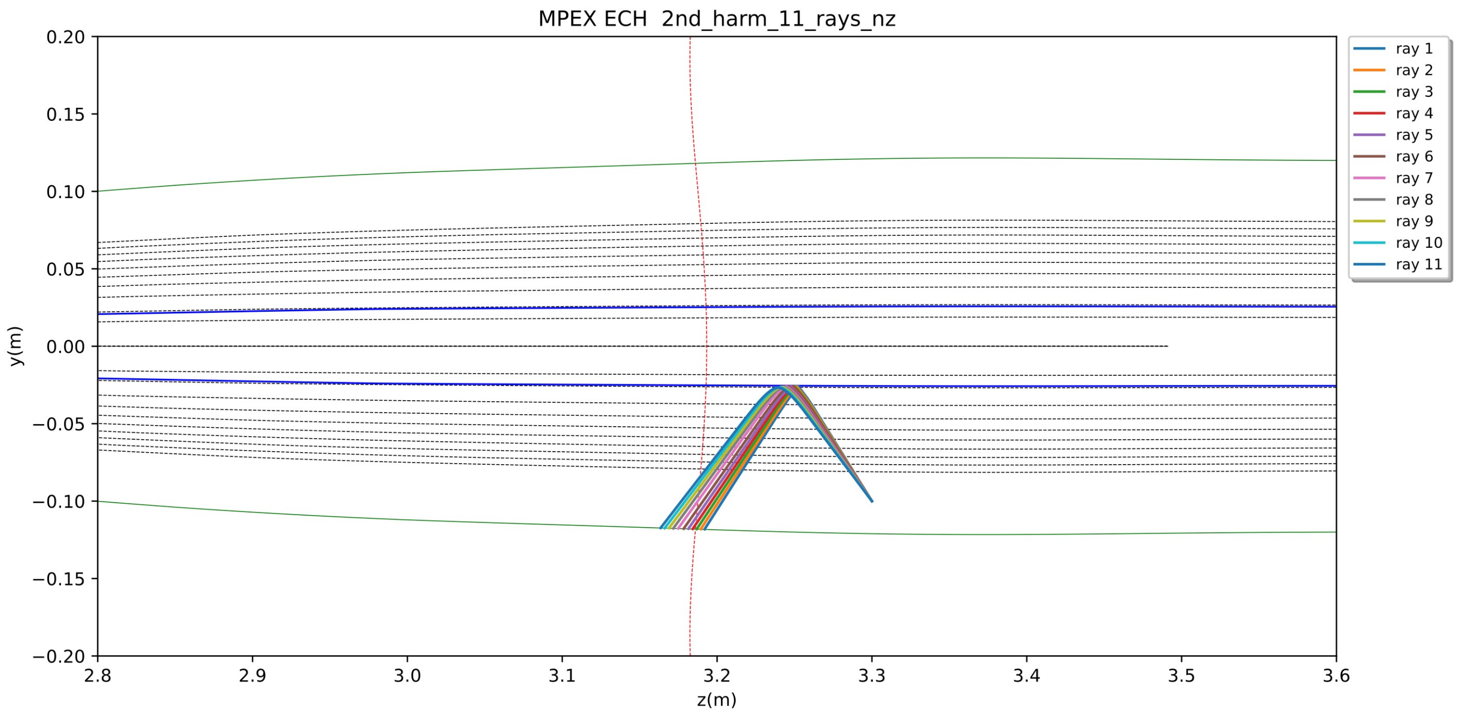
Rays launched around 30° to Y, in Y-Z plane



ray 1 conv coeff = 0.292
ray 2 conv coeff = 0.346
ray 3 conv coeff = 0.404
ray 4 conv coeff = 0.466
ray 5 conv coeff = 0.530
ray 6 conv coeff = 0.596
ray 7 conv coeff = 0.662
ray 8 conv coeff = 0.726
ray 9 conv coeff = 0.786
ray 10 conv coeff = 0.842
ray 11 conv coeff = 0.891

- **Launch angle varies from $30° \pm 2.5°$ in $0.5°$ steps**
- **Ray 6 is the 30° case, conversion is about 60%**

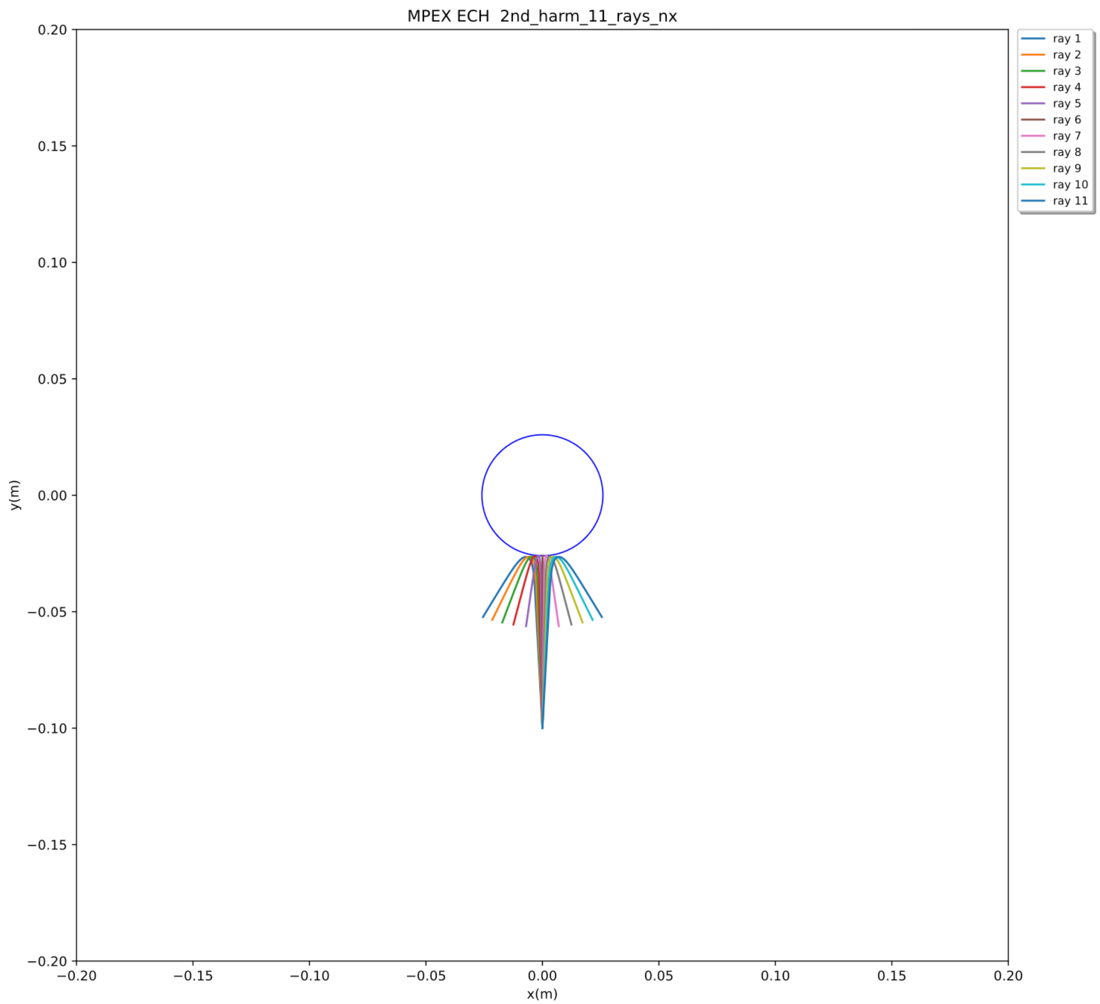
Rays launched around $35.3°$ to Y, in X-Z plane



ray 1 conv coeff = 0.842
ray 2 conv coeff = 0.891
ray 3 conv coeff = 0.932
ray 4 conv coeff = 0.964
ray 5 conv coeff = 0.986
ray 6 conv coeff = 0.998
ray 7 conv coeff = 0.999
ray 8 conv coeff = 0.989
ray 9 conv coeff = 0.971
ray 10 conv coeff = 0.945
ray 11 conv coeff = 0.913

- **Launch angle varies from $35.3° \pm 2.5°$ in $0.5°$ steps**
- **Ray 6 is the $35.3°$ case, conversion is about 100%**

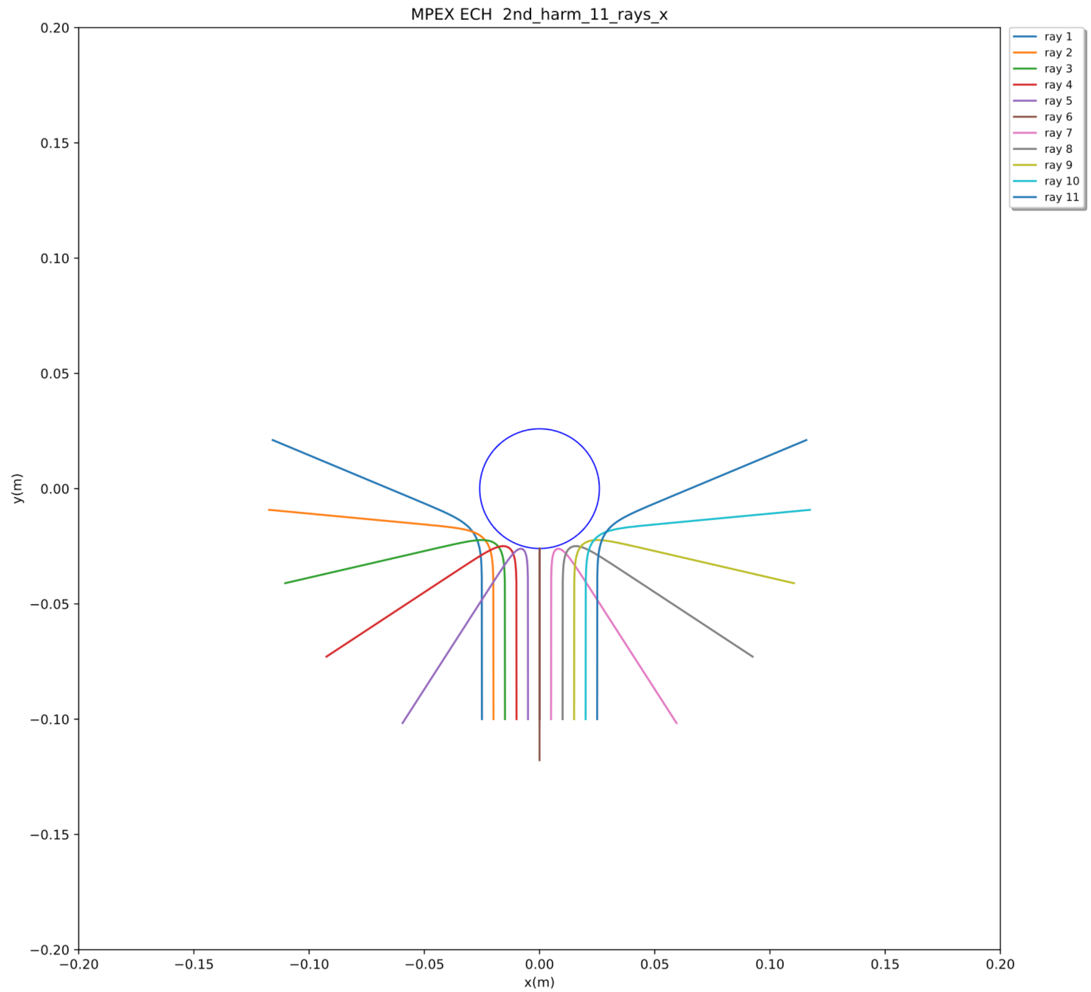
Rays launched not directly at axis, at $35.3°$ to Y in Y-Z plane, and around $0°$ in X-Y plane, $\pm 2.5°$



ray 1 conv coeff = 0.468
ray 2 conv coeff = 0.596
ray 3 conv coeff = 0.733
ray 4 conv coeff = 0.863
ray 5 conv coeff = 0.960
ray 6 conv coeff = 0.998
ray 7 conv coeff = 0.960
ray 8 conv coeff = 0.863
ray 9 conv coeff = 0.733
ray 10 conv coeff = 0.596
ray 11 conv coeff = 0.468

- **Launch angle varies from $0° \pm 2.5°$ in $0.5°$ steps**
- **Ray 6 is the 0° case, conversion is about 100%**
- **But drops off pretty fast if not aimed directly at axis**

Rays launched not directly at axis – at $35.3°$ to Y in Y-Z plane, X-launch varies $\pm 2.5cm$ about X = 0



ray 1 conv coeff = 4.135E-003
ray 2 conv coeff = 1.012E-002
ray 3 conv coeff = 3.254E-002
ray 4 conv coeff = 0.1295
ray 5 conv coeff = 0.5021
ray 6 conv coeff = 0.9981
ray 7 conv coeff = 0.5021
ray 8 conv coeff = 0.1295
ray 9 conv coeff = 3.254E-002
ray 10 conv coeff = 1.012E-002
ray 11 conv coeff = 4.135E-003

- **Ray 6 is the $X = 0$ case, conversion is about 100%**
- **But drops off really fast if not aimed directly at axis**

Final points

- **These results are preliminary. There are a number of inputs that need to be nailed down better before anything else is done. (Questions for MPEX team next slide)**
- **The calculation of O-X conversion gives an upper limit to the amount of O-X-B heating that can be obtained. Converted X-mode may not go and be absorbed where you want it, but first it has to be converted.**
- **This situation looks similar to me to what we had in Elmo Bumpy Torus (EBT). For that we developed a "power balance" model, which was essentially a three region zero-D model, supplemented with ray tracing. ("Detailed modeling of microwave energy deposition in EBT", Batchelor, Goldfinger, Rasmussen, Phys. Fluids 27, 1984). Something similar might be useful for MPEX.**
- **What I would really like to do is to turn this analysis over to an ORNL person so I can focus on adding the X-mode propagation and Bernstein mode propagation and absorption to the code.**

Questions for MPEX team

- **What are the relevant coil current cases to examine? D3-6? Are there others? What is the operational rationale for the various cases?**
- **What is the location and geometry of the limiter? Or better yet:**
- **What are the strike points on the limiter for the various coil current cases? What is the LUFS for the various cases?**
- **What is the geometry of the first wall all along the device?**
- **Is there more recent thought on expected plasma profiles than is contained in Marin's 2021 report, MPEX-03-RTP-003?**
- **What is the geometry of the ECH launcher? The design is sketched out in MPEX-03-DAC-007, 2022, But I can't find that the actual location and orientation as built are specified there.**
- **The biggest uncertainty is how to represent the launched ECH power as an initial distribution of rays. I think these RAYS calculations do show how sensitive the O-X-B performance is to details of the launched antenna spectrum. I think it would be advisable to put some effort into refining such a model, maybe to the point of revisiting the COMSOL work.**

Reality check – Are there important things that I have wrong or left out?