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Paper Rehearsal:

OPTEMIST: A neutral beam for measuring quasi-omnigenity in Wendelstein 7-X

Phys. of Plasmas

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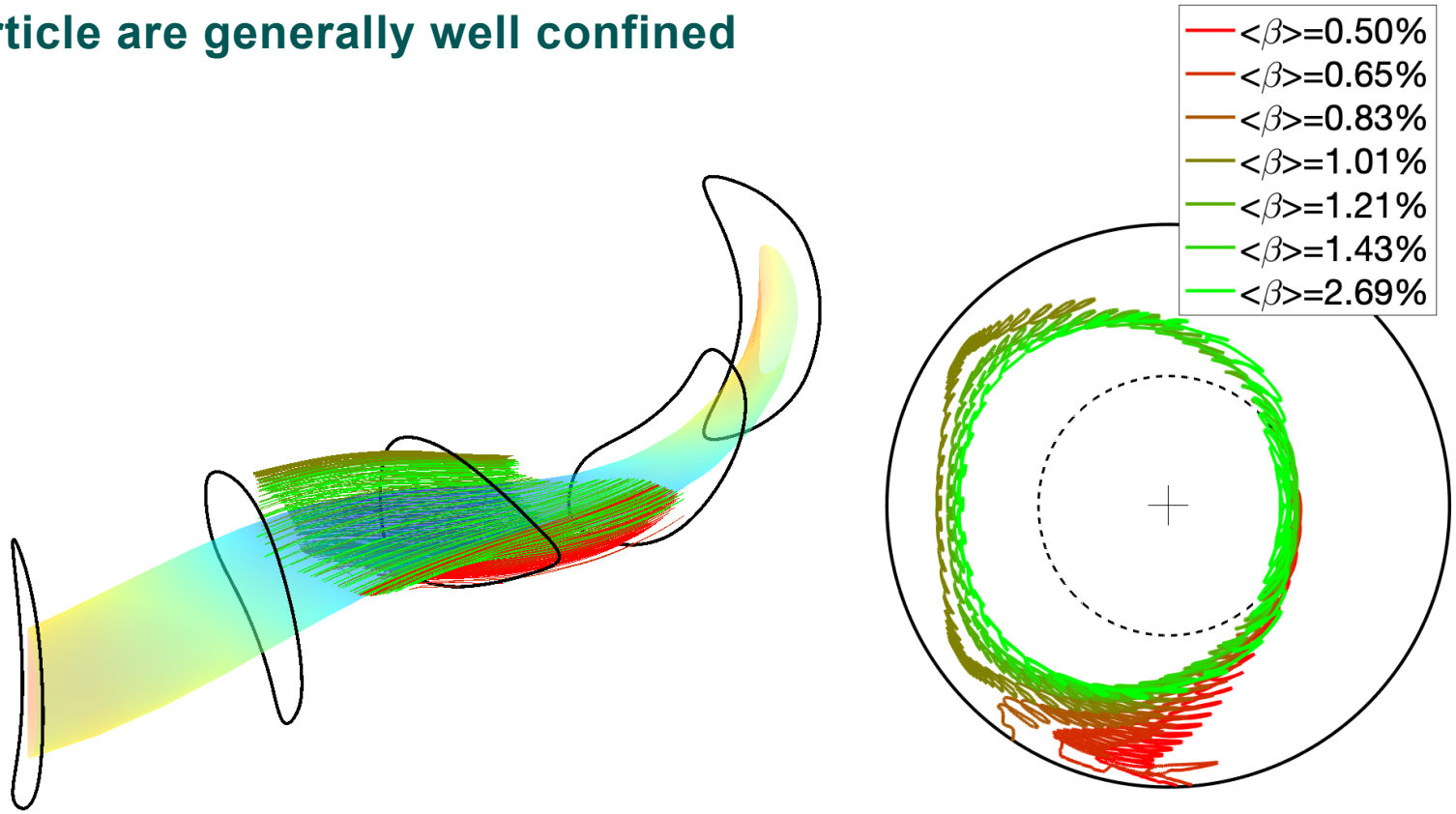
Scope of Paper (Abstract)

- Wendelstein 7-X is predicted to have improving fast ion confinement with plasma beta
- What are the necessary requirements for the fast ions to demonstrate this?
- Can this be demonstrated with the existing neutral beam system on W7-X?
- Can this be demonstrated with D-D fusion products?
- What about a new neutral beam specifically designed to do this?
- What is the minimum energy beam needed?
- What power would this beam need?

Wendelstein 7-X is predicted to have improving fast ion confinement with increased plasma beta (high mirror)

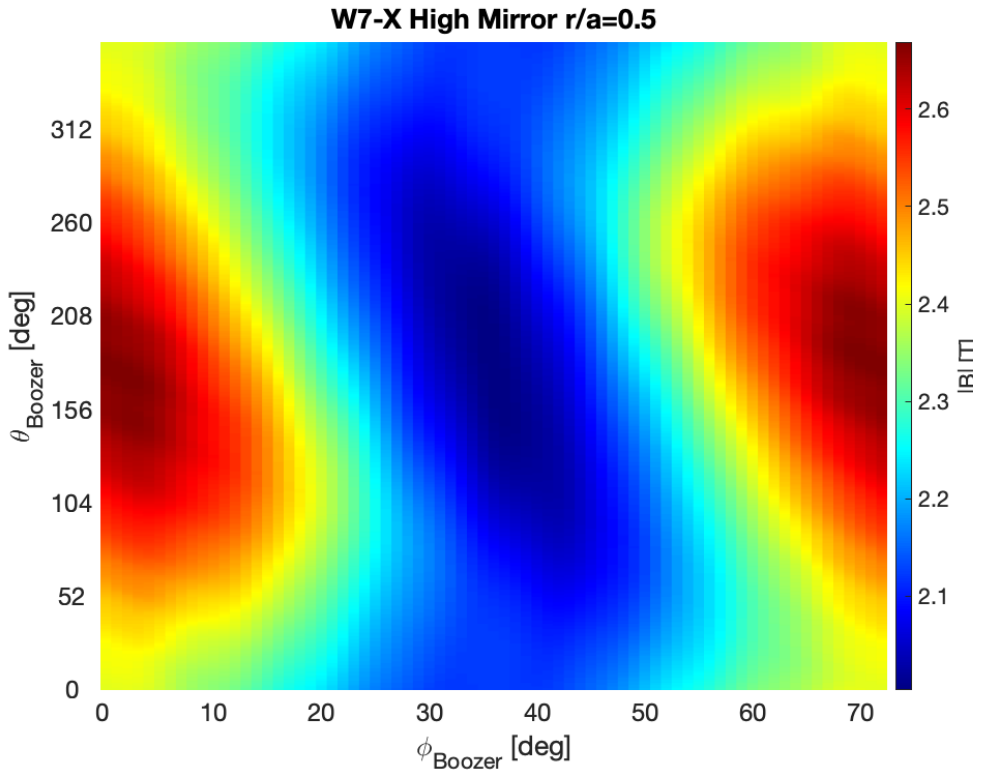
- Improvement comes from deeply trapped particles orbit precessing in the poloidal direction
- The collisionless orbits close poloidally as beta increases
- Passing particle are generally well confined

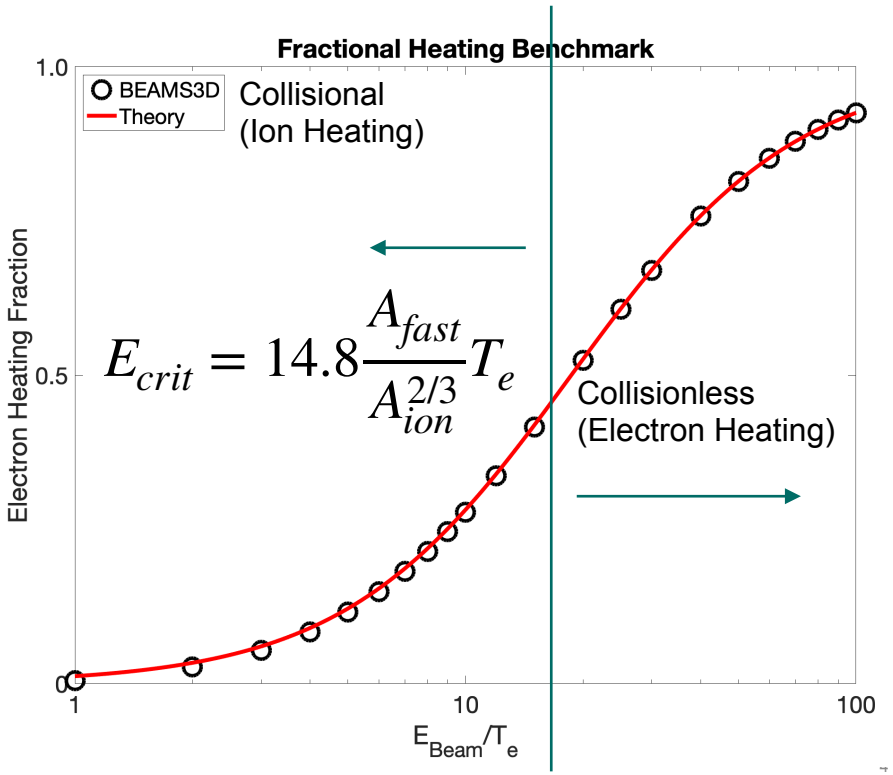


Creation and measurement of collisionless deeply trapped particles is essential

- In W7-X the toroidal variation of |B| is greater than the poloidal
- The geometry (toroidal) matters for generation of deeply trapped particles
- With electron temperatures in the 1-4 keV range collisionless implies ~100 keV proton energies

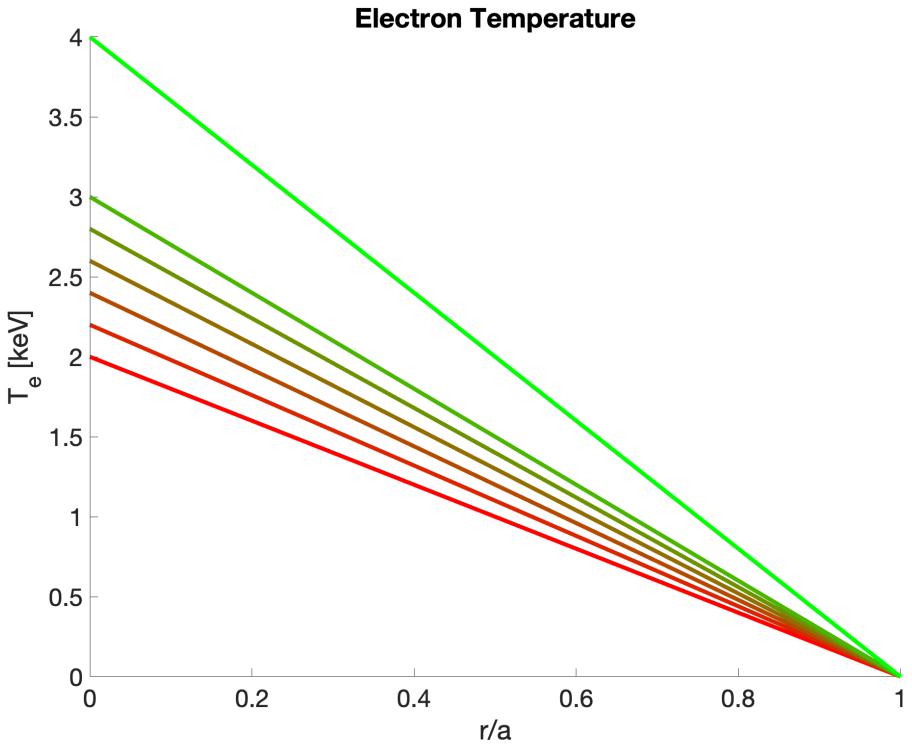
$$B_{mirror} = B_{birth}\left(1 + \frac{v_{\parallel}^2}{v_{\perp}^2}\right)$$

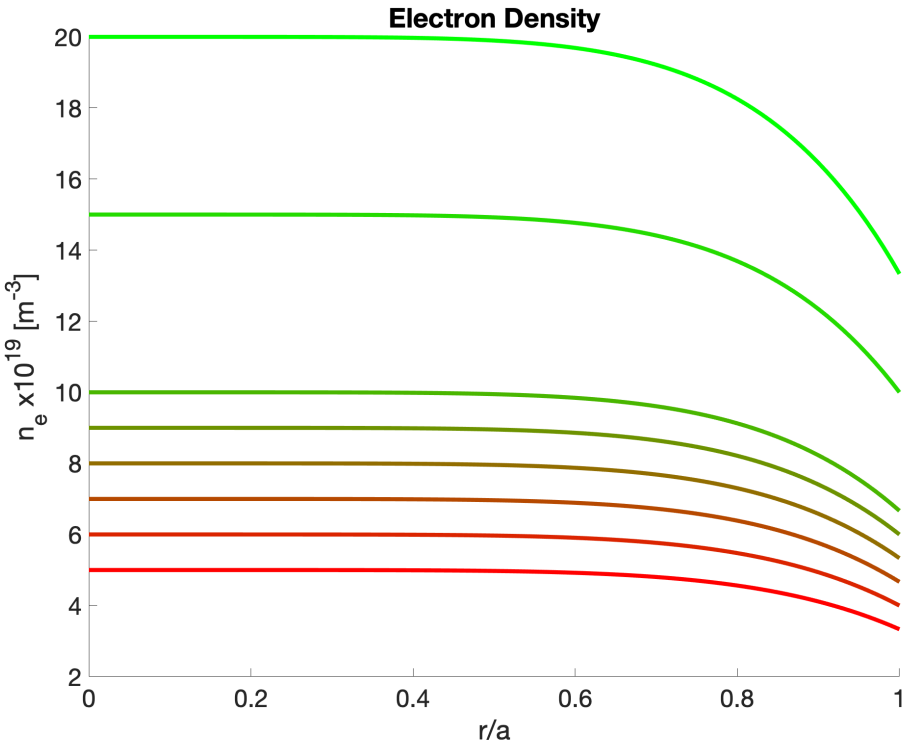




In this work we consider self-consistent plasma beta scans

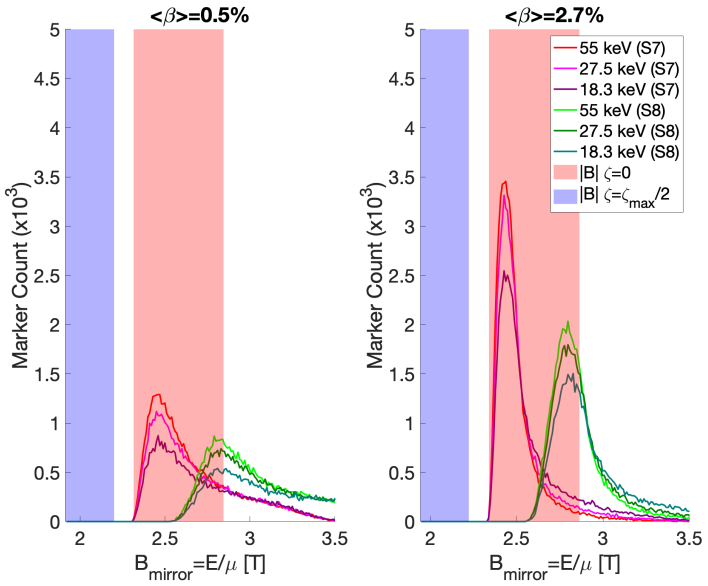
- We assume equilibrium pressure is a function of temperatures and densities
- Neoclassical estimates of the bootstrap current and radial electric field
- In W7-X plasma beta comes from increasing density

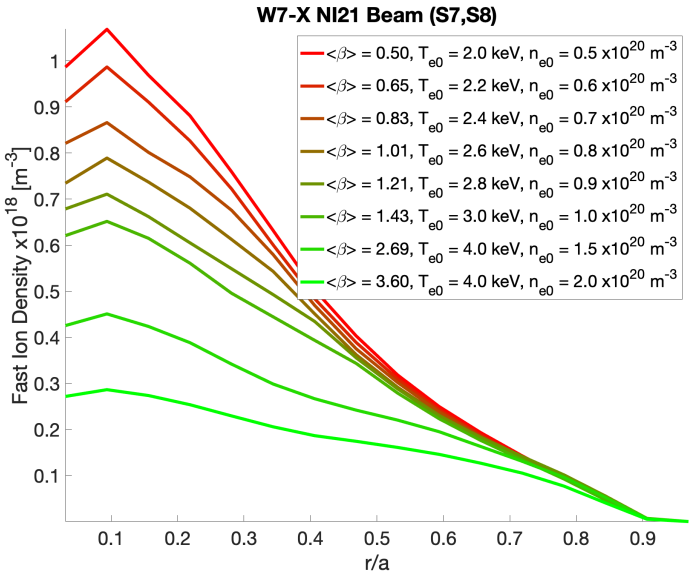


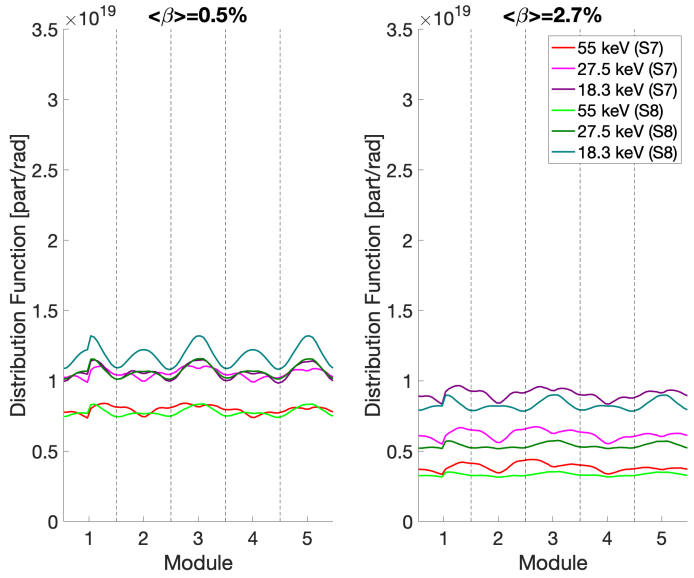


The existing NBI system on W7-X does not populate the deeply trapped orbits and injects at too low an energy

- The beams fire into a higher field region with non-trivial parallel velocity
- Collisions are significant as well (not collisionless)
- FI density decreases with increasing plasma beta (FIDA/BES would be even worse)

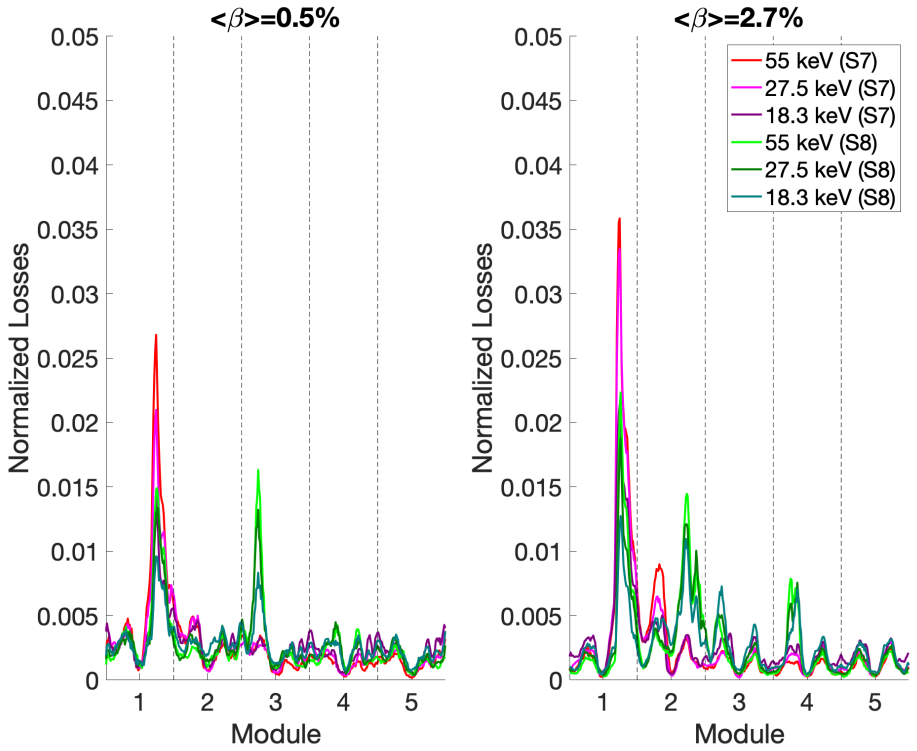


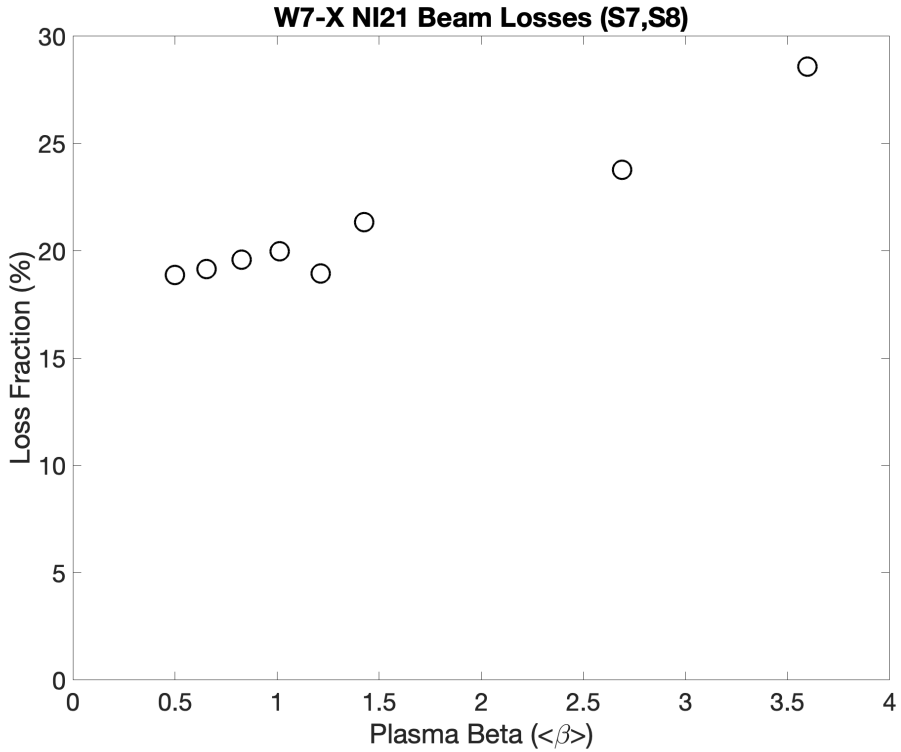




Fast ion losses from the NBI system follow the trend of the distribution functions

- Loss structure has some toroidal localization
- Toroidally localized losses increase with plasma beta (edge prompt losses)
- Generally confinement appears to decrease with plasma beta





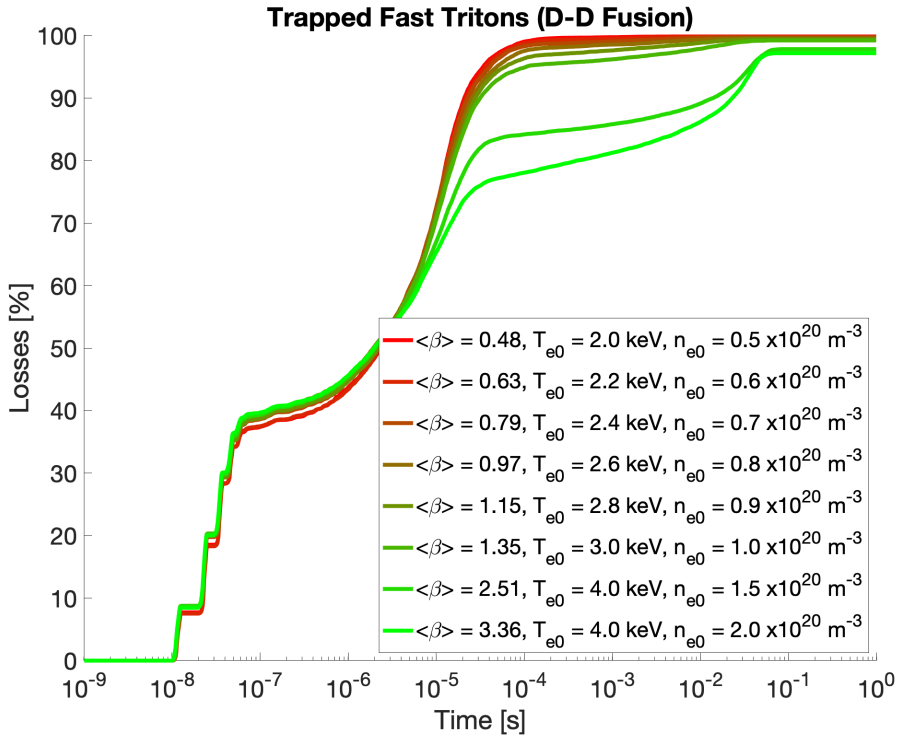
Why didn’t we see the QO nature of the high mirror with the existing NBI system

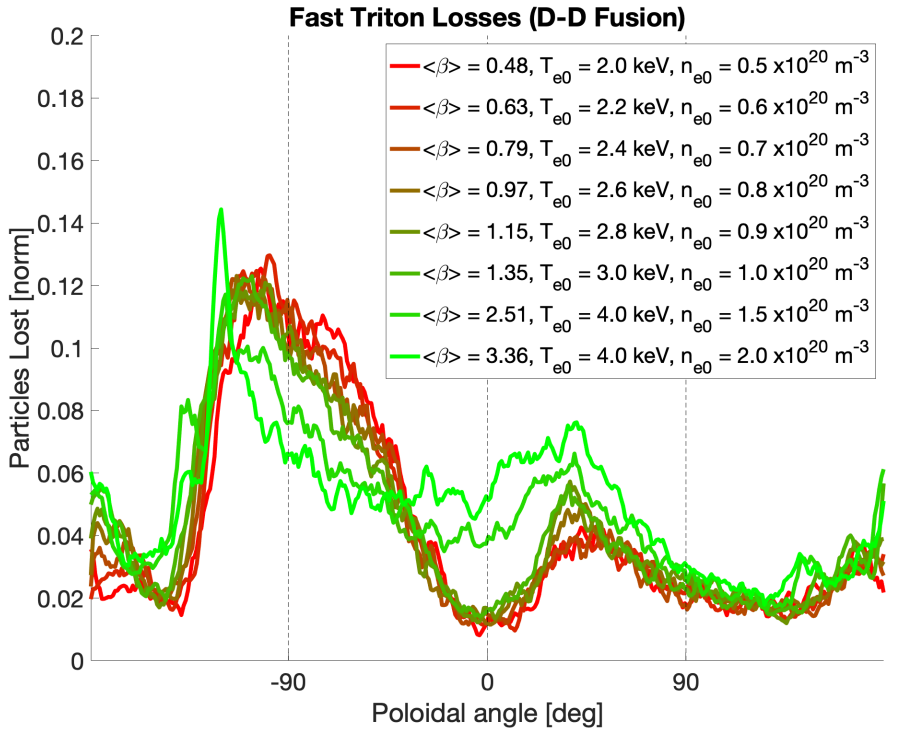
- Geometry was incorrect for this purpose
  - No deeply trapped particles generated
- Energy was too low
  - At Te=4 keV need E > 60 kV (for lifetime of particle)

Could we use D-D fusion products?

Fast tritons from D-D fusion could fulfill this role

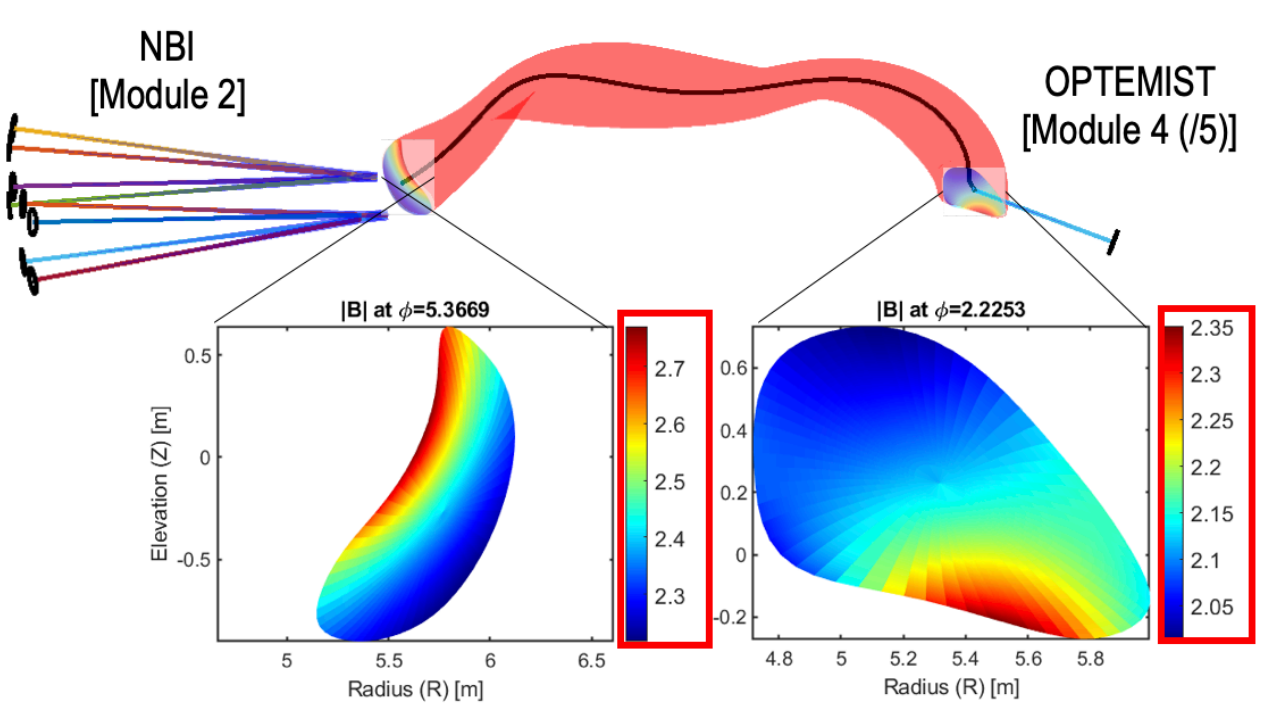
- Isotropic birth -> deeply trapped particles will be generated
- Born collisionless although perhaps at too high an energy (gyro-center approximation no longer valid)
- Measurement is challenging as the birth rate is also a function of plasma beta (profiles)

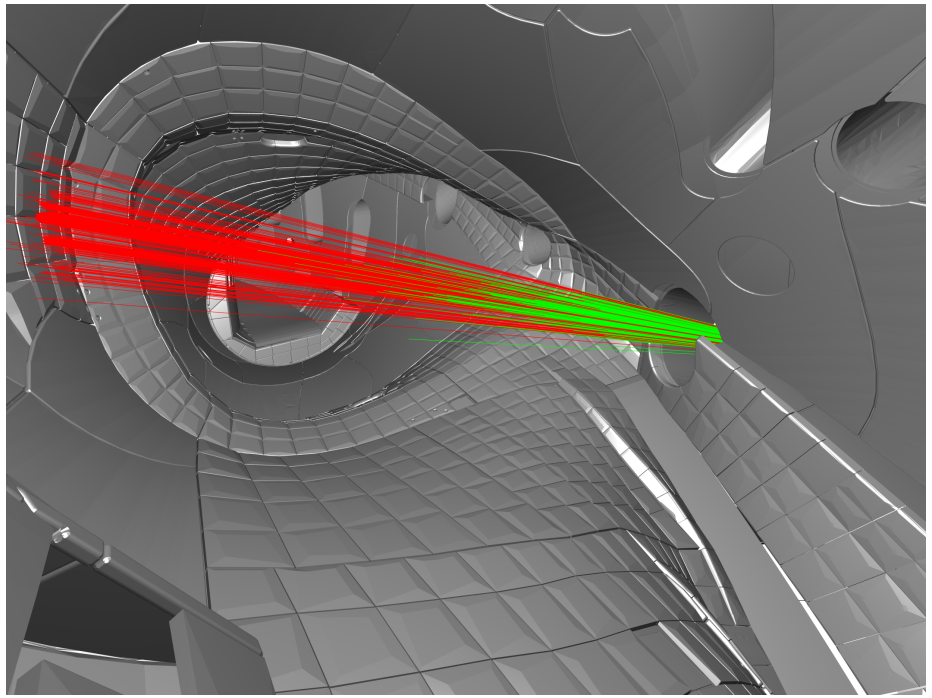




OPTEMIST: Omnigeneous Particle Test EMISsion in Triangular cross section

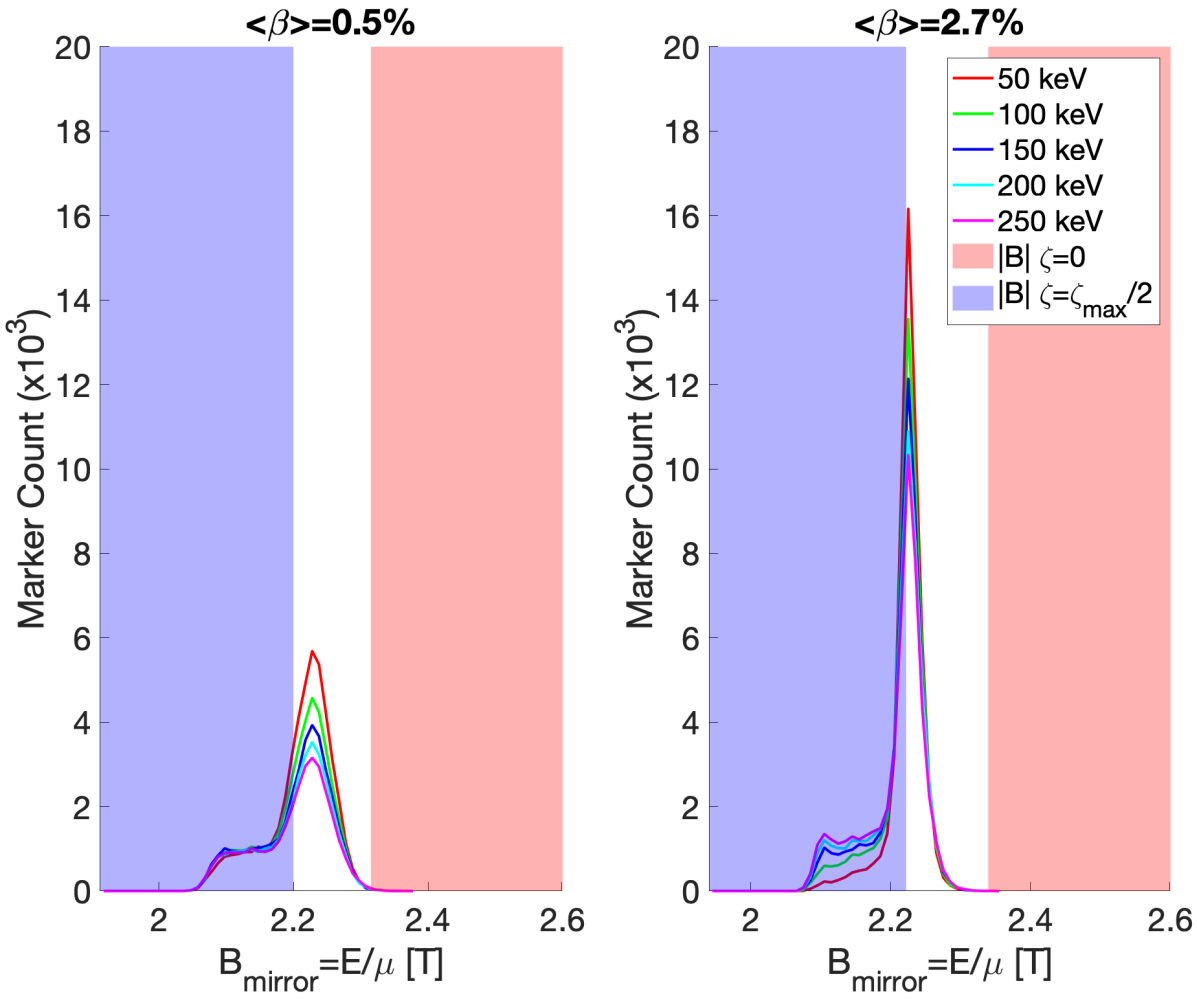
- Fire into the triangular cross section (old RuDiX port) -> deeply trapped particles
- Fire at higher energy to stay in collisionless limit
- Instrument to directly measure this effect (should be localized to module)





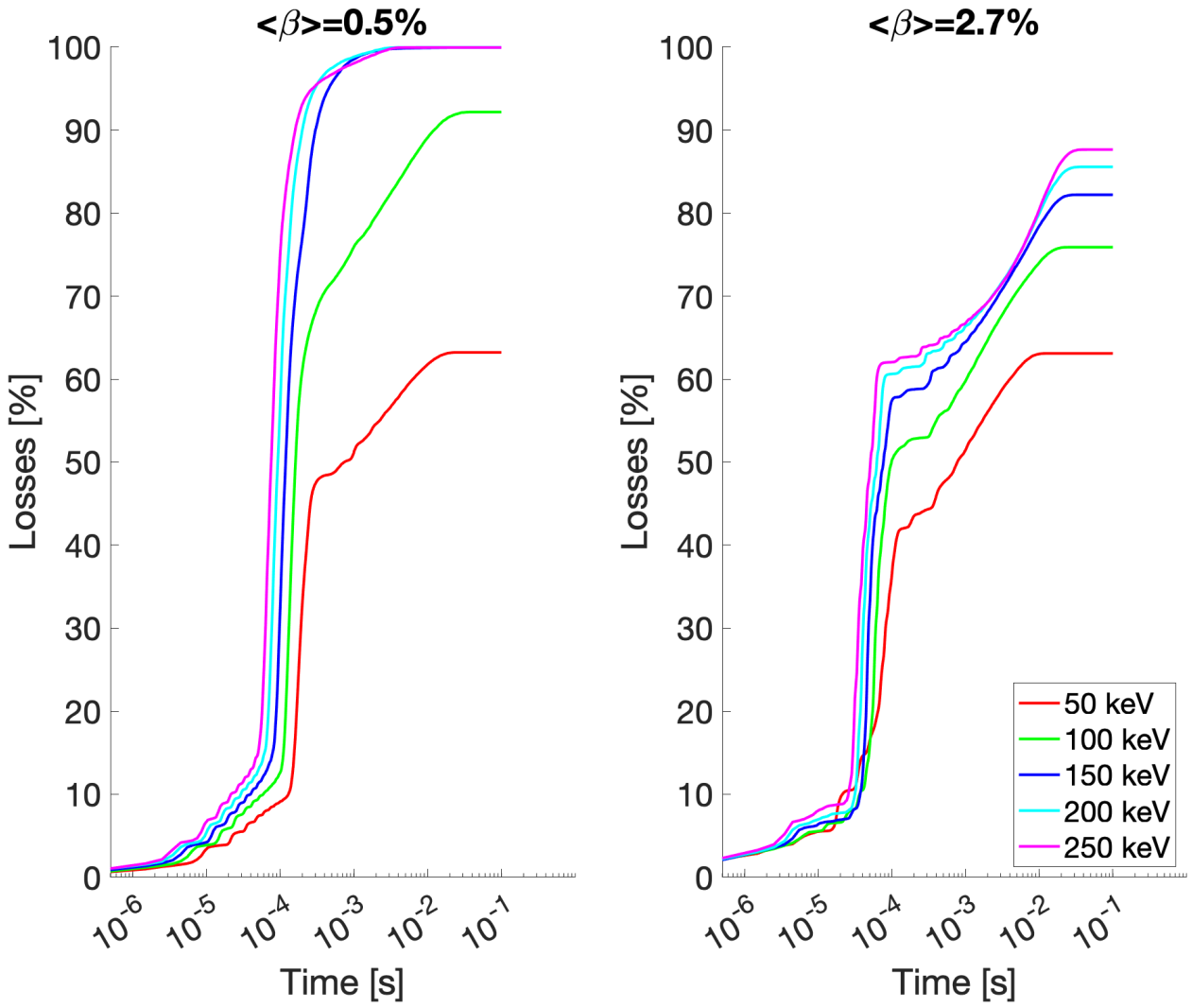
Particles from OPTEMIST are born trapped

- Fires into low field toroidal section of W7-X
- Fires nearly perpendicular to the magnetic field
- Beta actually improves the injection geometry
- Injection energy is scanned in this study



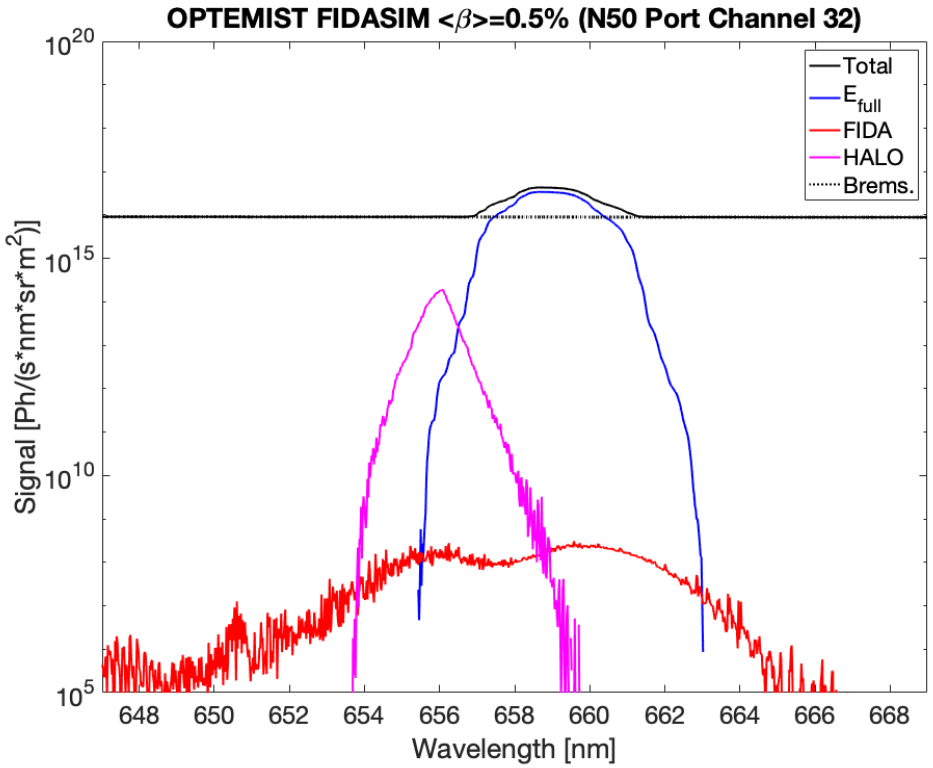
Confinement increases with increasing plasma beta

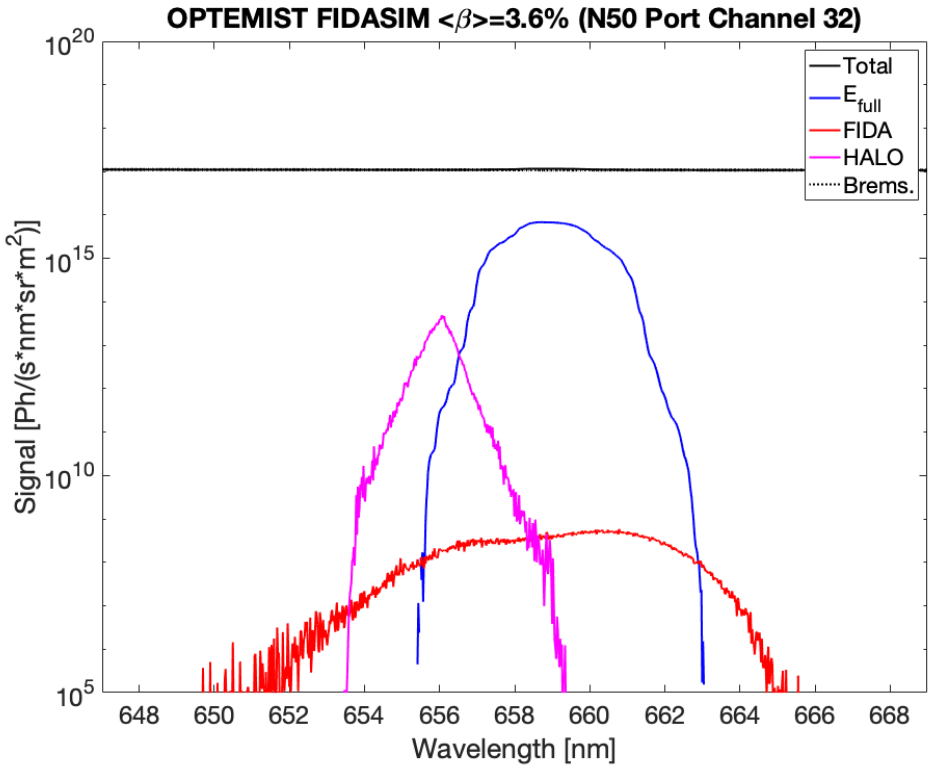
- At low beta high energy implies no confinement (as one would expect)
- As beta increases losses decrease for all but 50 keV injection energy
- No change in 50 keV losses suggests pitch angle scattering is playing large role in determining orbits
- For a mono energetic beam 120 keV is the nominal choice for demonstrating this effect.



FIDA measurement is blinded by Bremsstrahlung

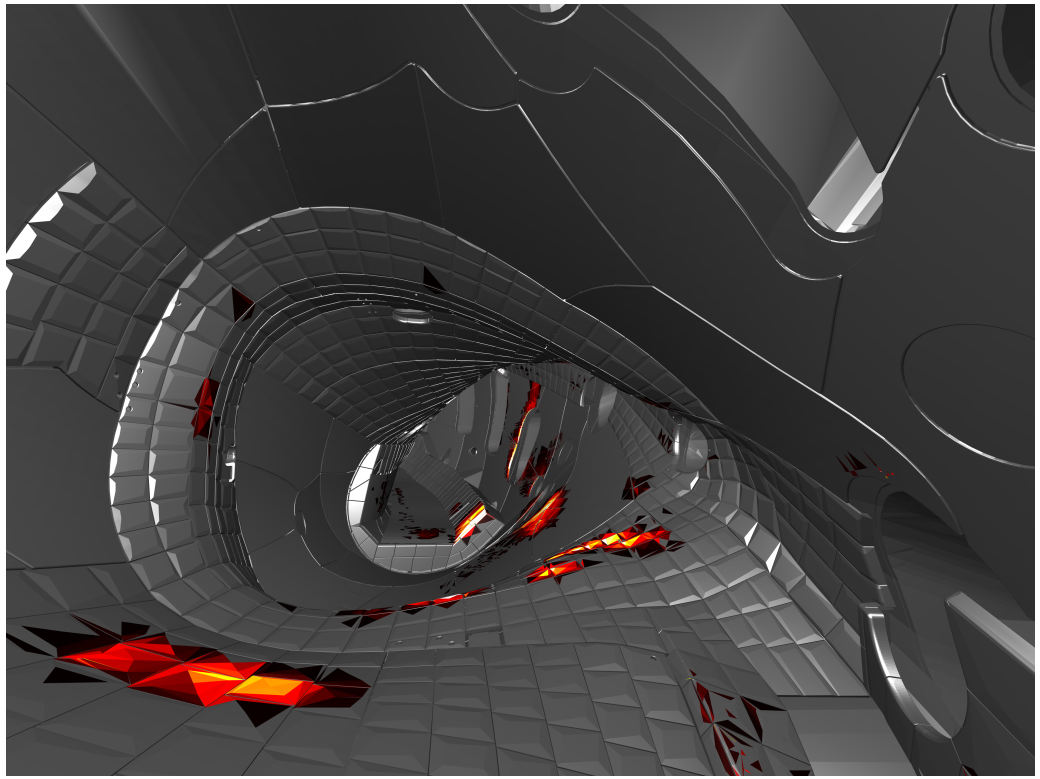
- Multi-port scan performed for possible FIDA systems
- Changes in FIDA/BES signal would show improvements in confinement with plasma beta
- Bremsstrahlung blinds the system as density goes up (beta)
- Scan of beam power from 1MW (1A) to 8 MW (70A) at 120 keV only shows modest improvement

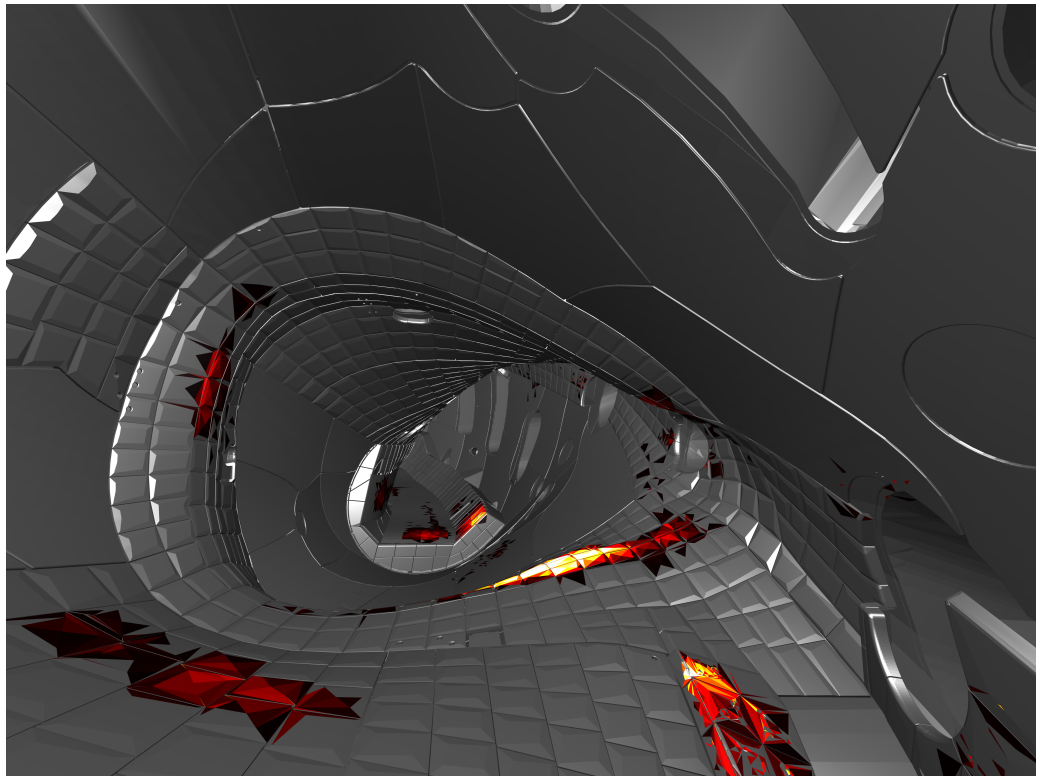




Fast ion losses provide the most direct measurement of changes in confinement

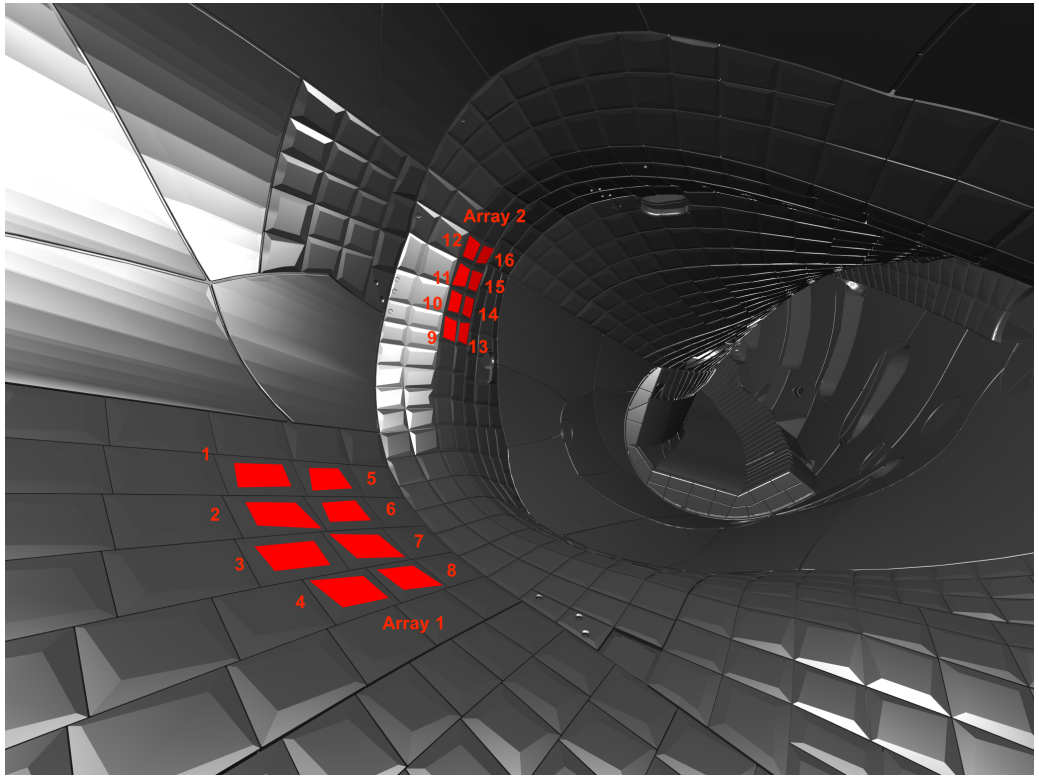
- FC-FILD sensors allow for instrumentation of wall tiles for fast ion losses
- Wall losses reduce in some areas and shift in others
- Perfect use case for the FC-FILD sensors

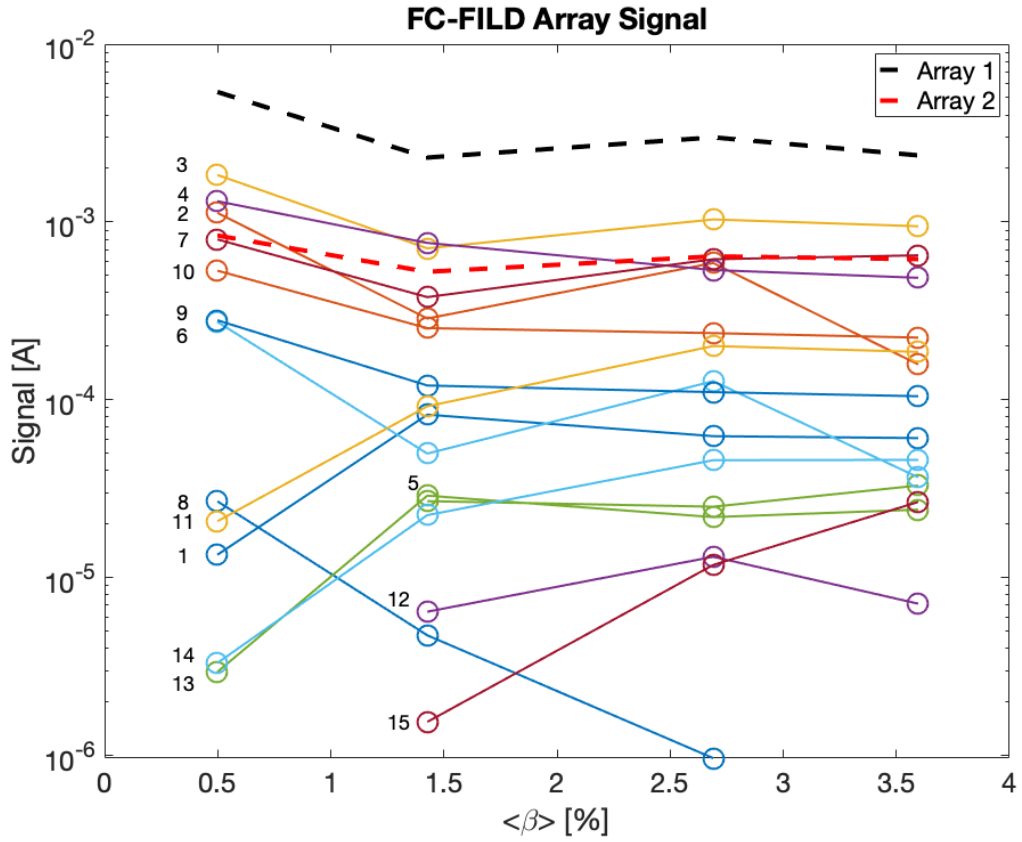




Fast ion losses provide the most direct measurement of changes in confinement

- Two arrays of 8 sensors each are selected
- Signal scaled to an aperture size 40mm x 5 mm (well within measurement capabilities)
- Losses decrease with increasing plasma beta for arrays





Discussion and future outlook

- To demonstrate the QO nature of W7-X using fast ions (improvement of confinement with beta in the high mirror) particle must be born deeply trapped and collisionless.
- The W7-X NBI system generates particles which meet neither of these conditions
- D-D fusion products could be used for this purpose
  - Measurements must be normalized to neutron rates (birth rate)
  - Deeply trapped particles must be discerned from the isotropic population
- The OPTEMIST beam line has been proposed to directly address this key goal of W7-X
  - 120 kV mono energetic beam line (or >250 keV if traditional) @ 1MW neutralized power
  - FIDA blinded by Bremsstrahlung due to high density at finite plasma beta
  - FC-FILD array proposed to measure the lost fast ion and loss pattern changes.

FIDA/NPA Geometry considered

- 8 ports considered
  - I41, K41, L41, M41, N41, N50, N41, T50
- 64 LOS each
- Scanned from one side of plasma to the other.