Runaway electron confinement modeling for DIII-D disruptions

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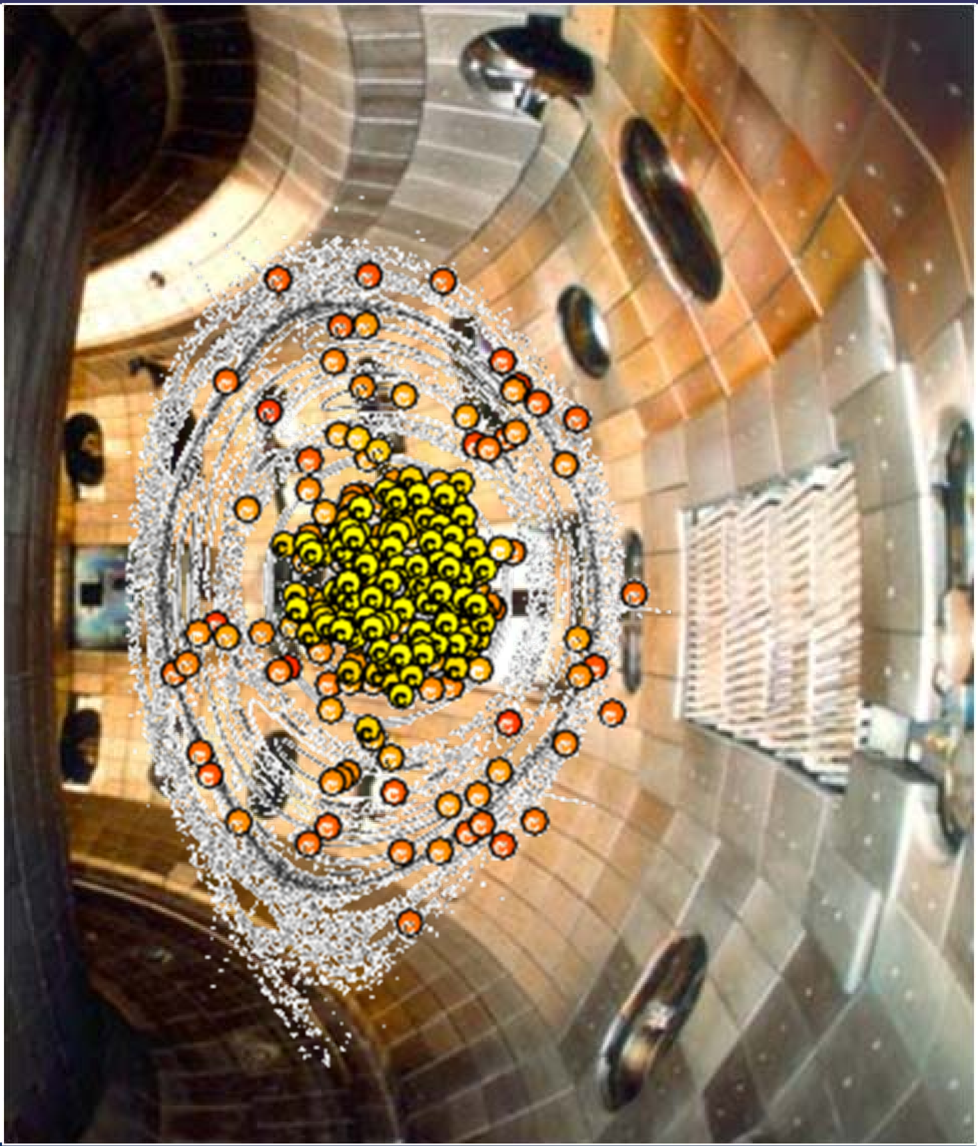
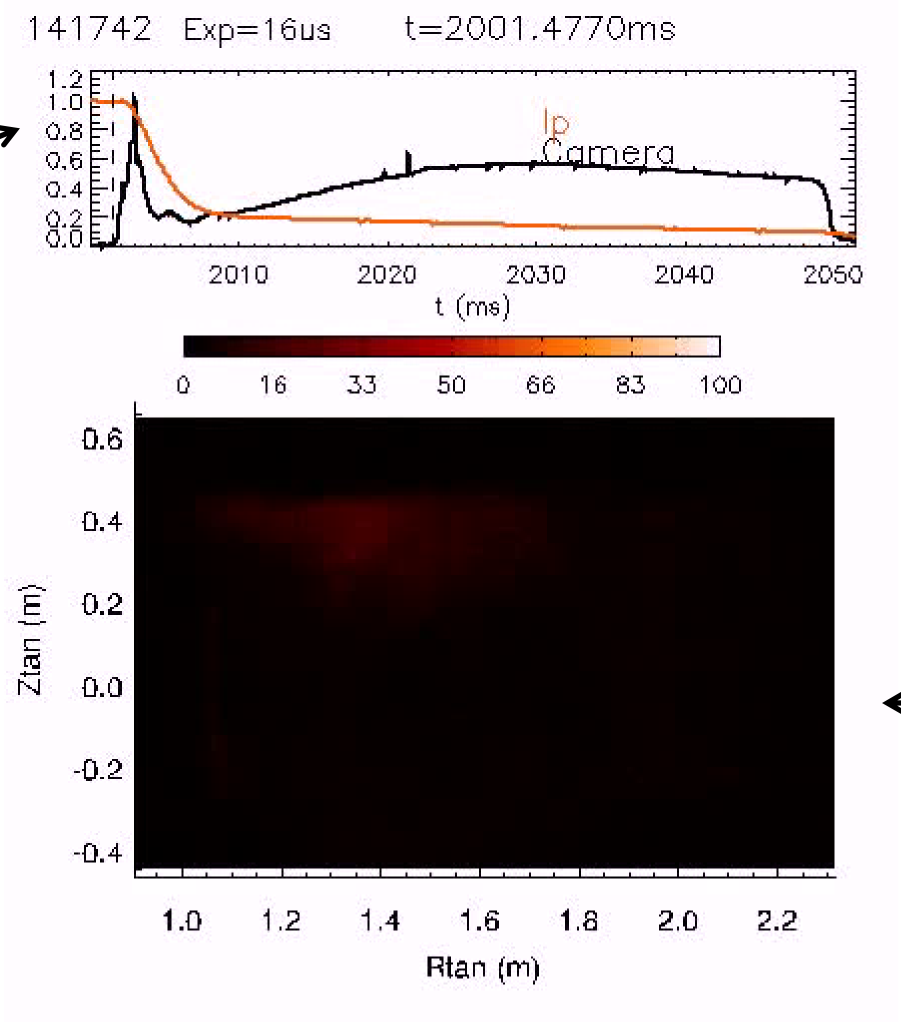


Sherwood 2010
Seattle, WA

DIII-D Ar pellet rapid shut down experiments produce 150-400 kA of runaway current

No current spike

Runaway plateaus last up to 250 ms



Mostly radiative collapse

Little vertical motion

RE beam is centered

Runaway electron orbits are integrated as NIMROD fields evolve

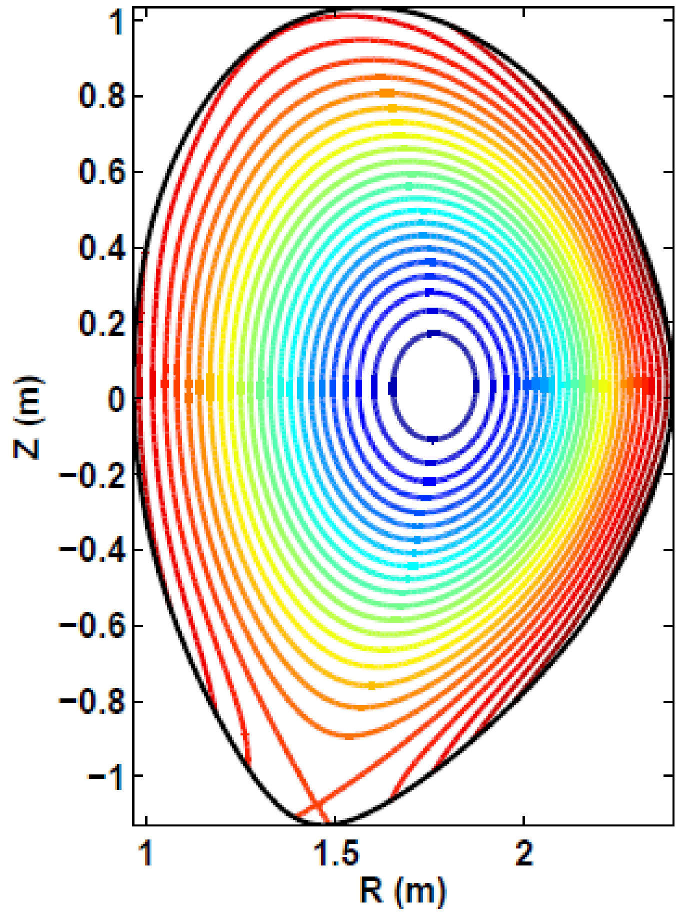
- The fast electron orbit model is a diagnostic tool that runs concurrently with NIMROD to study runaway electron *confinement*
  - →Orbits are integrated for a fixed population of randomly initialized electrons
  - →Guiding-center drift orbits + parallel velocity are calculated

The electrons are purely trace—they do not impact the NIMROD fields

- The model does not include runaway *generation*
  - →Seed and avalanche terms are not included, the population of REs is fixed based in the (random) initial conditions

Model can tell us about: runaway confinement time, strike points of escaping electrons. **The model cannot predict:** total runaway current, energy distribution of REs

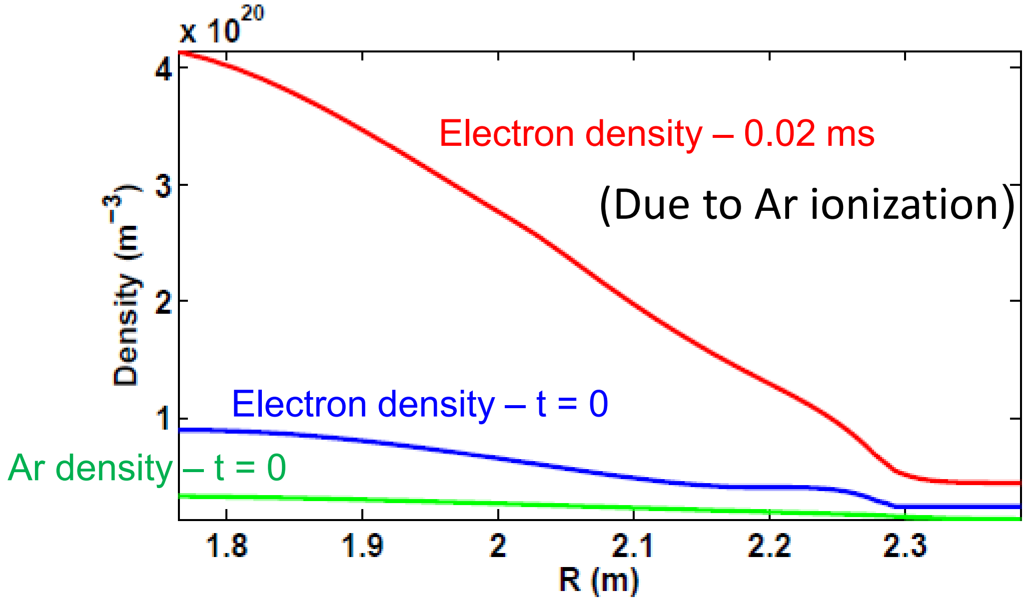
Ar induced rapid shutdown in diverted geometry is simulated



At t=0, neutral Ar is deposited over the entire plasma simultaneously (no pellet delivery/ablation model)

Total Ar quantity is same as Ar pellets in DIII-D experiments

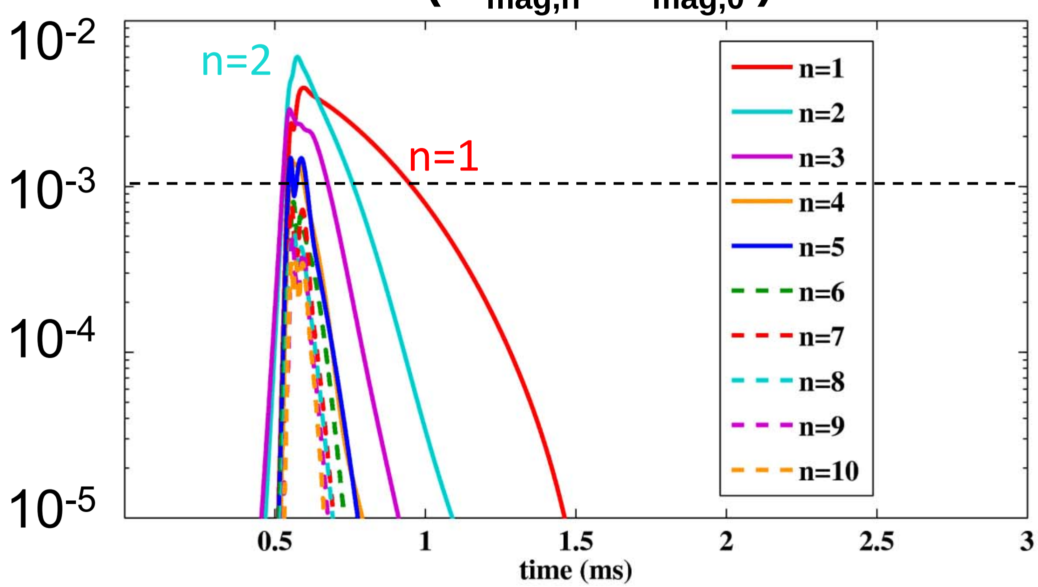
Initial electron density rise of ~4x quite similar to line averaged DIII-D measurements

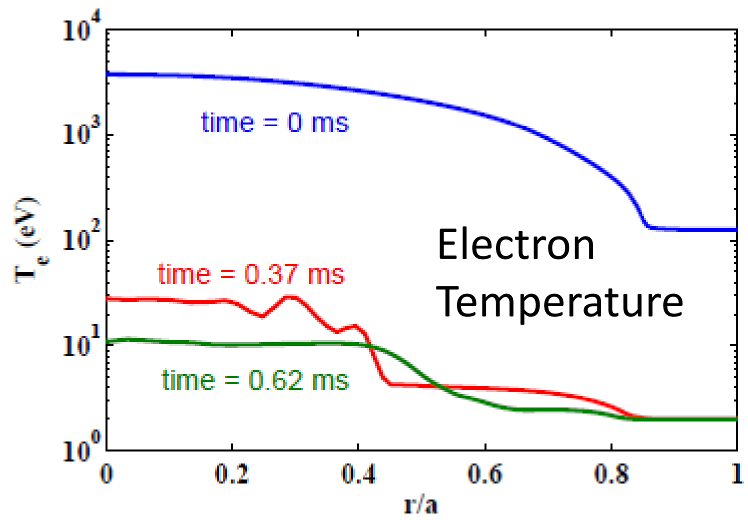


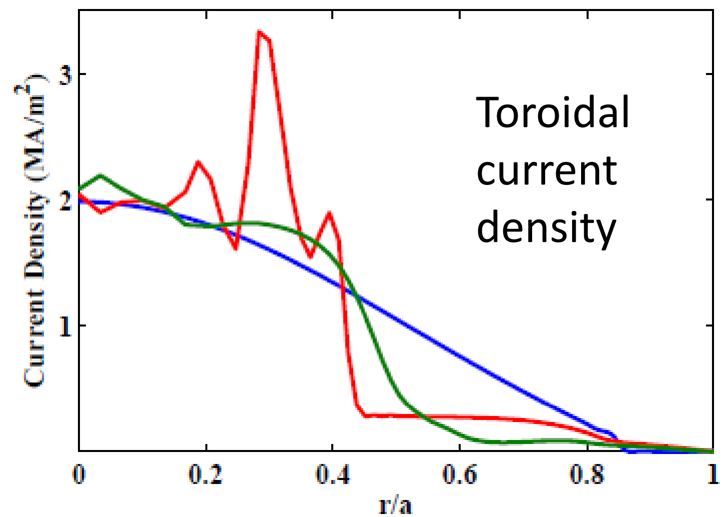
DIII-D Ar pellet simulation has accelerated TQ, realistic CQ time scale

- Plasma cools to ~30 eV in < 0.1 ms due to instantaneous delivery (Spitzer resistivity is used throughout, no artificial enhancement)
- Final phase of TQ occurs due to MHD at ~0.5 ms, core T_e drop to ~10 eV
- Current quench occurs on ~3 ms time scale

$\partial B/B \approx (W_{mag,n} / W_{mag,0})^{1/2}$







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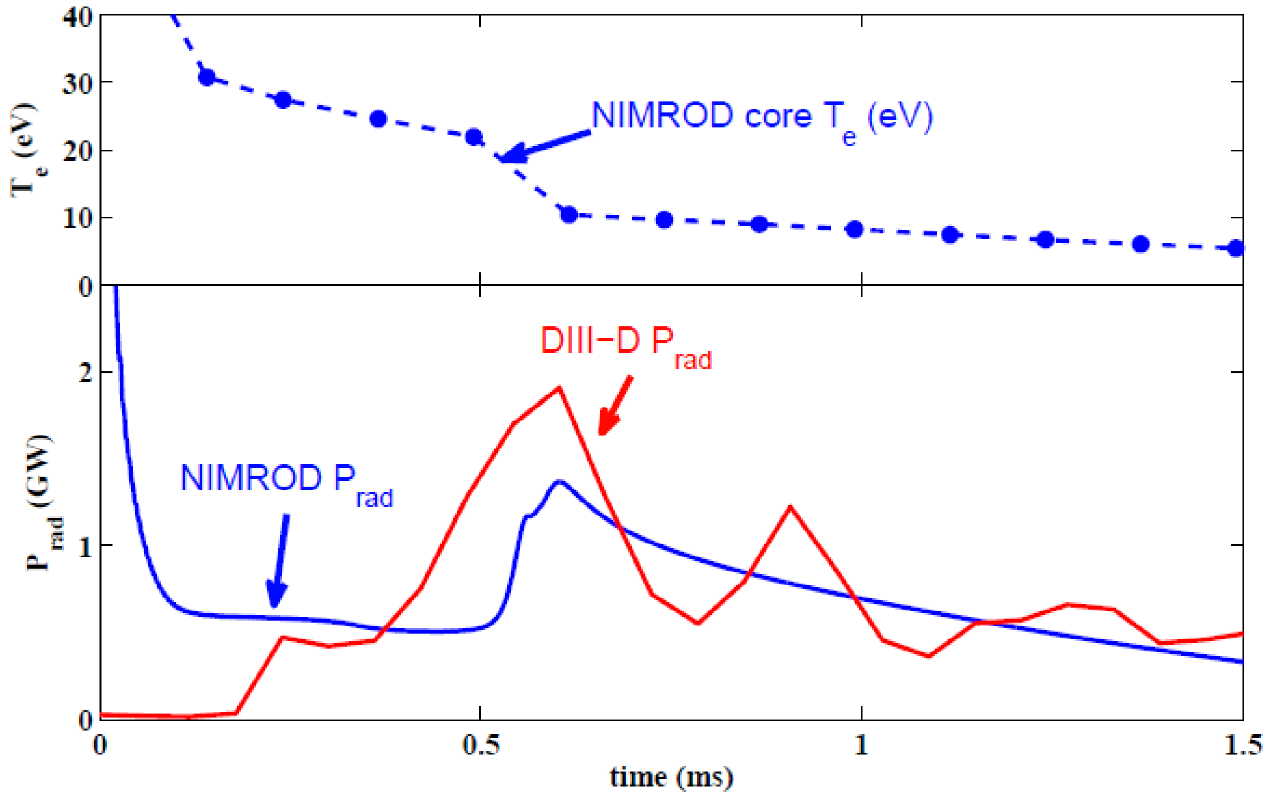
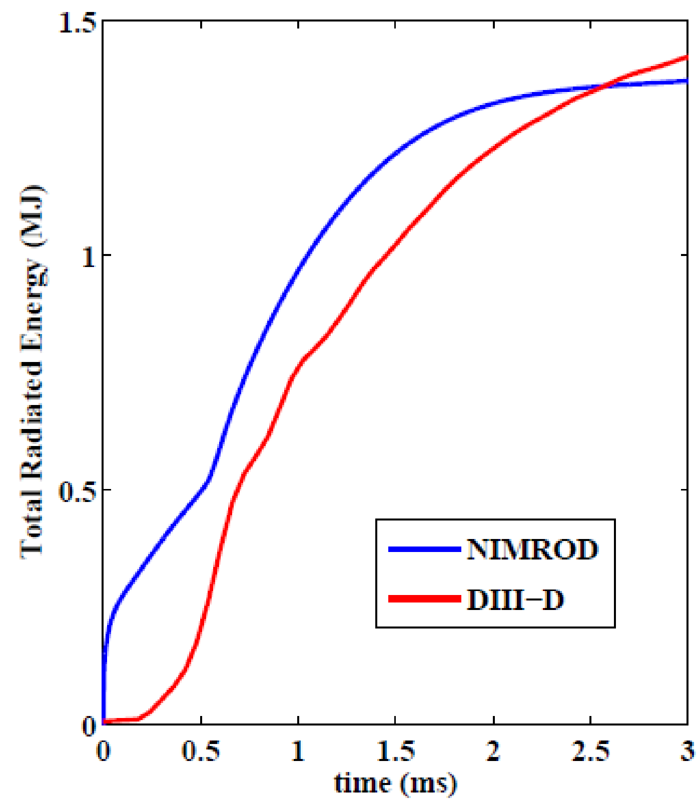
Radiated power and energy compare well to DIII-D measurements

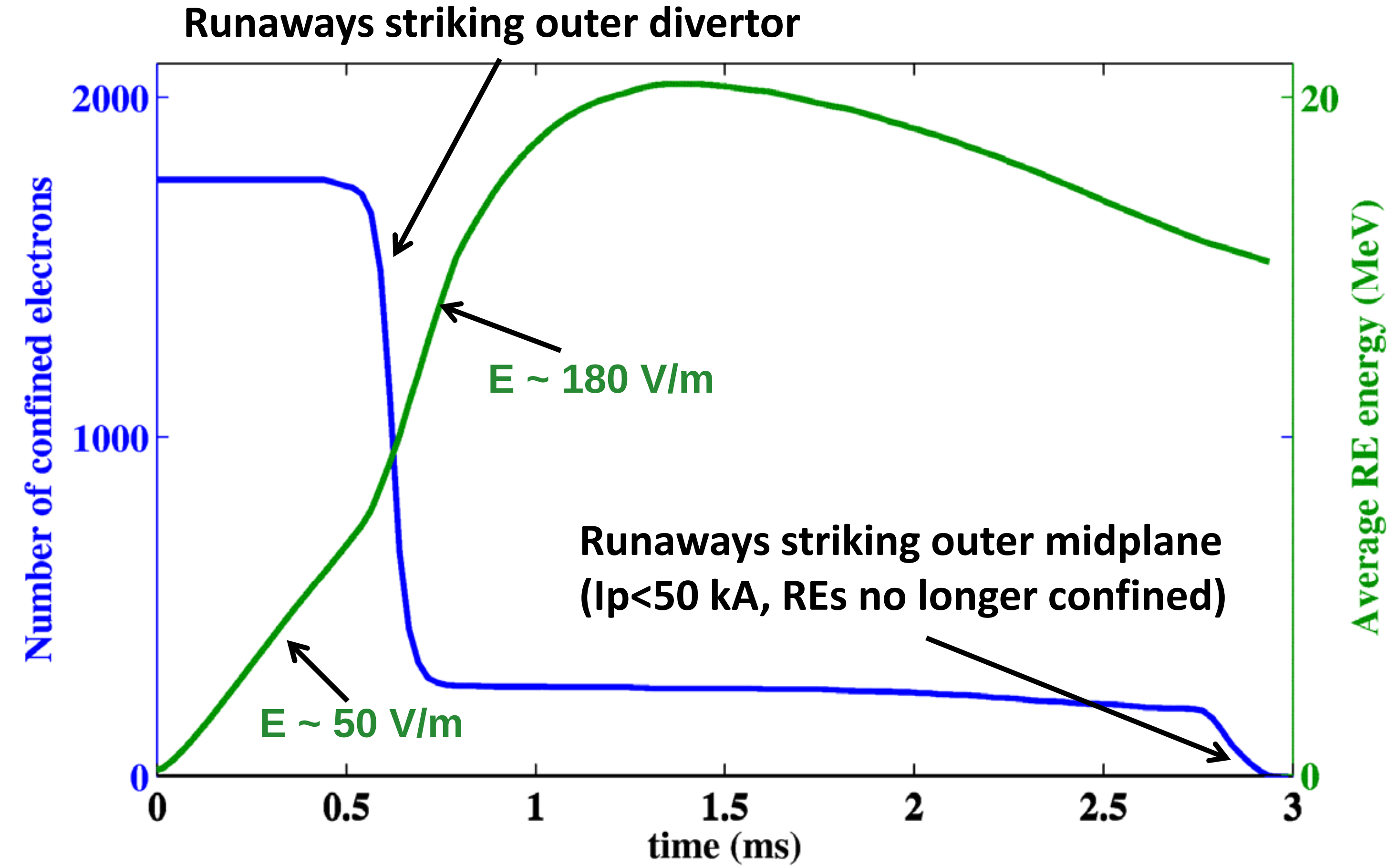
- 1.5 GW Spike in radiated power at 0.5 ms due to MHD onset corresponds to final drop in core T_e
- DIII-D measured spike is ~2 GW using toroidal uniformity assumption (P_{rad} is measured at 90°, pellet injected at 135°)





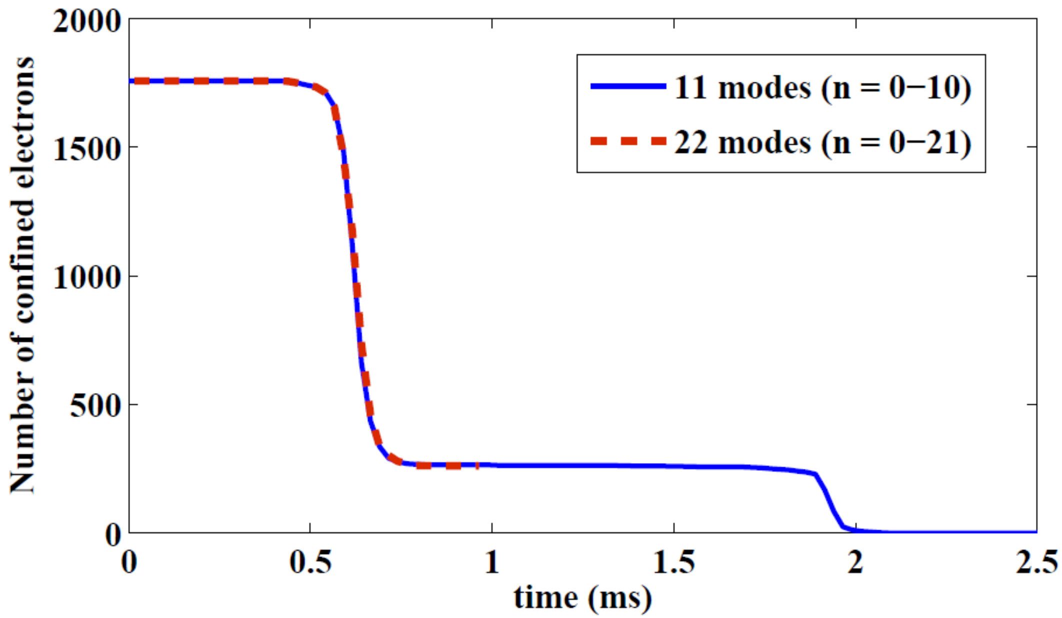
Most runaways are promptly lost due to MHD

- At t=0, 1758 electrons are launched with an energy of 150 keV

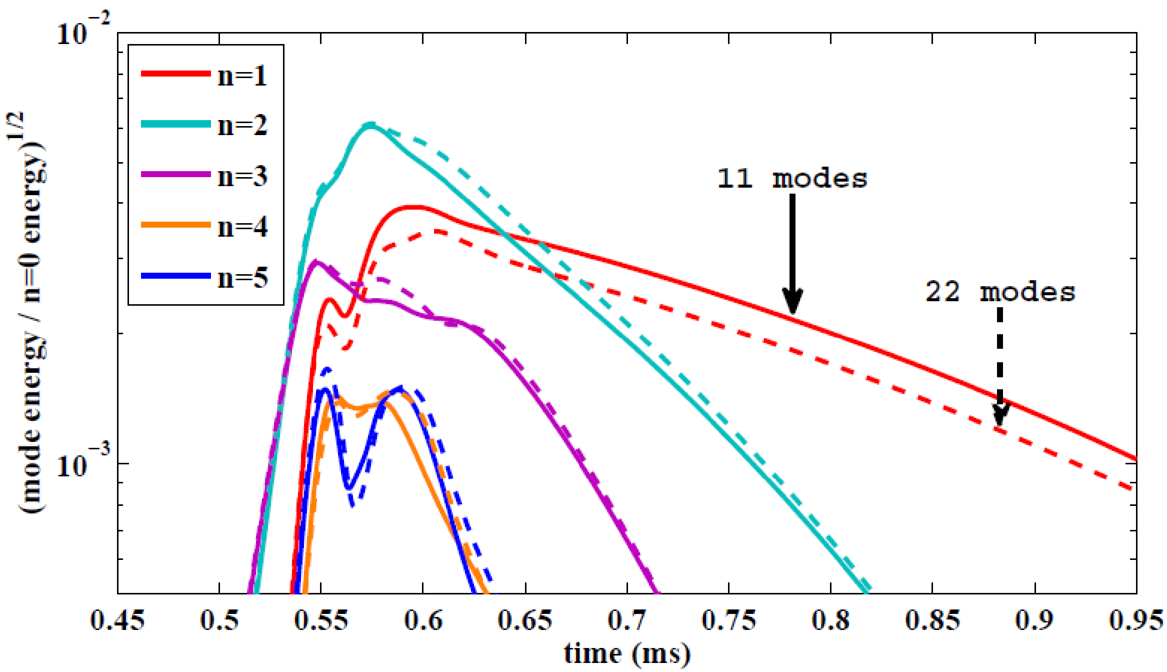


- In reality, REs carry their own current, remain confined much longer

Toroidal convergence of RE confinement

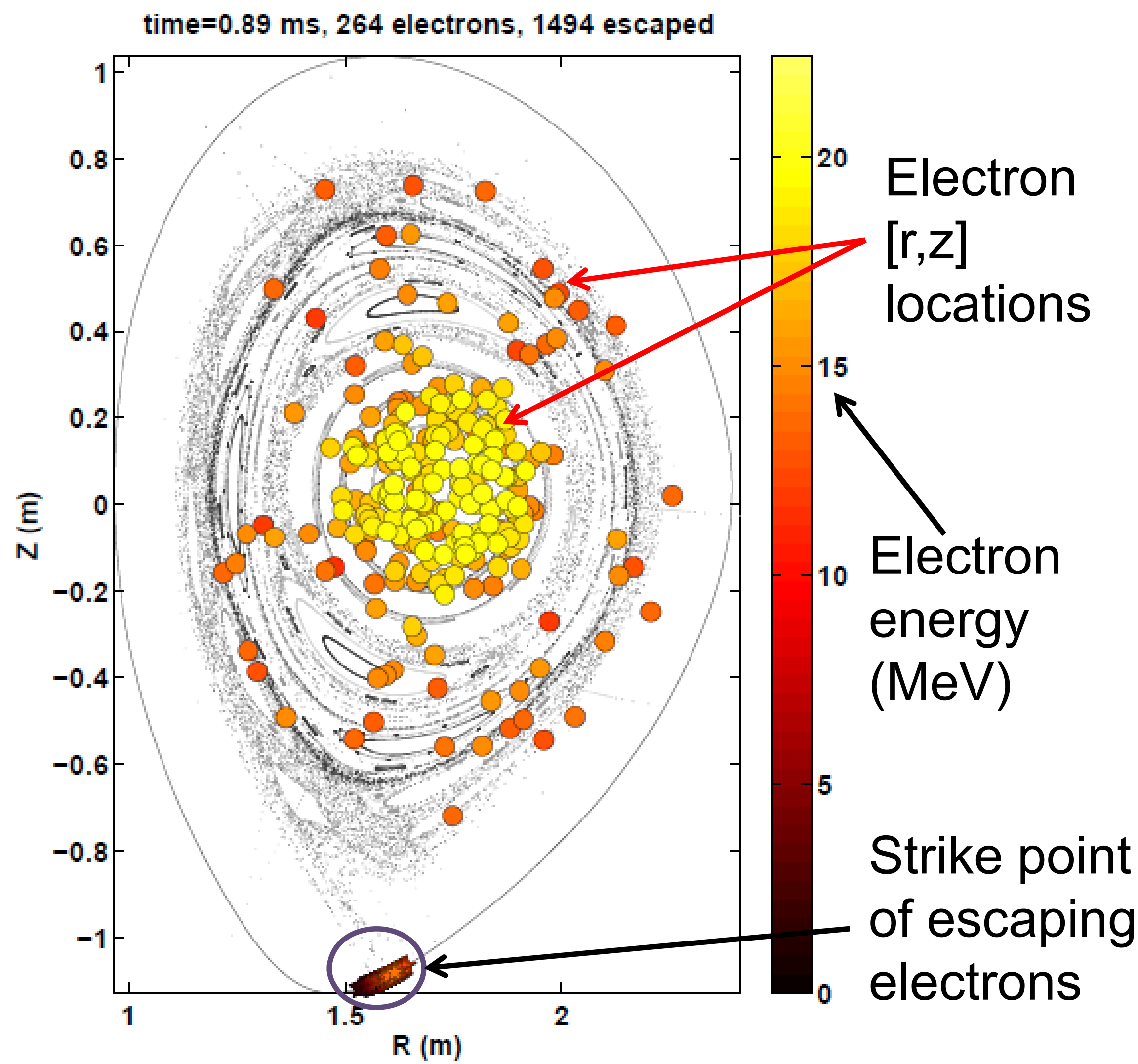


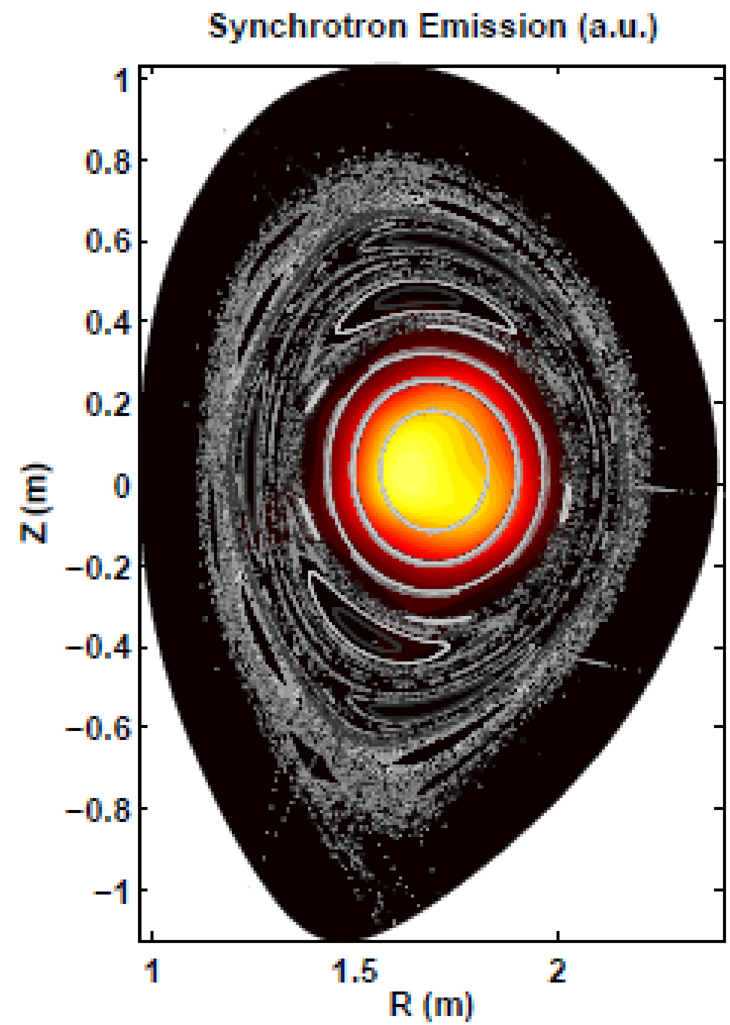
RE confinement converges at 11 toroidal modes



Comparison of mode amplitudes

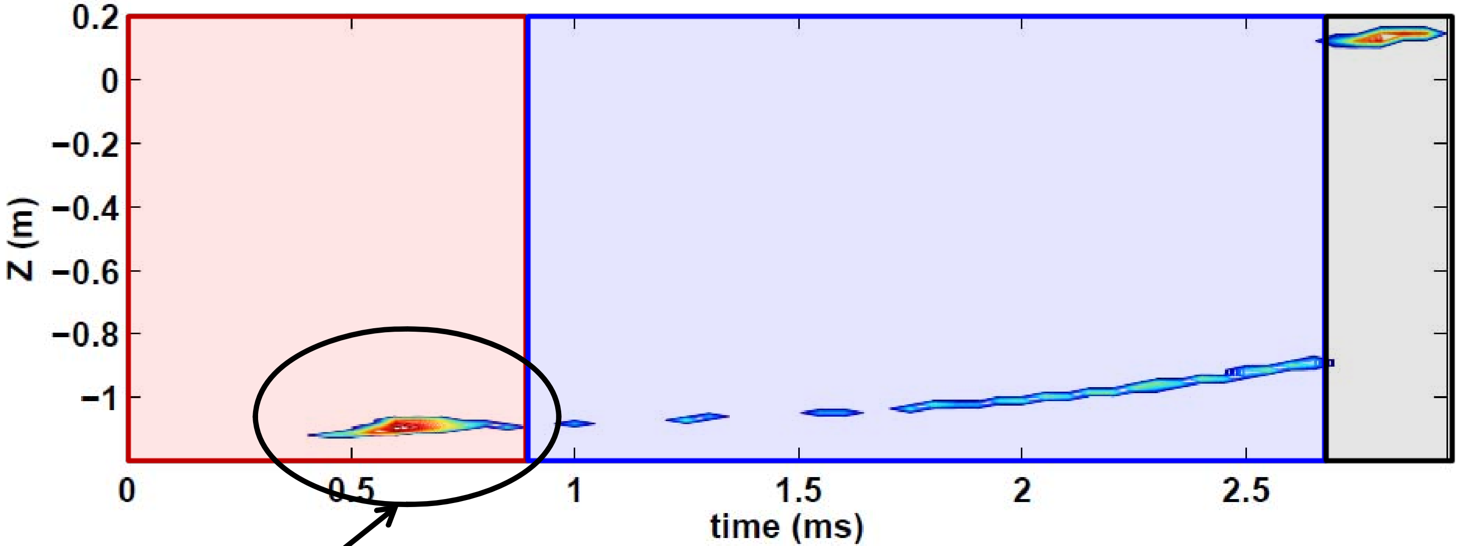
Following prompt loss, REs are concentrated in core





Prompt loss of 5-10 MeV electrons is poloidally localized, toroidally uniform

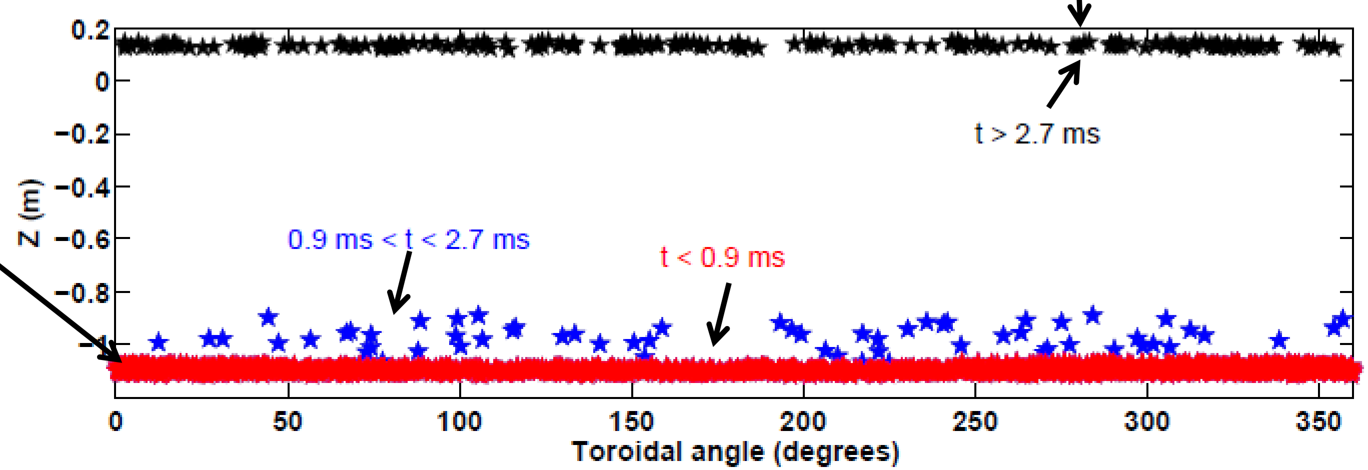
RE energy flux to wall (log-scale a.u.)



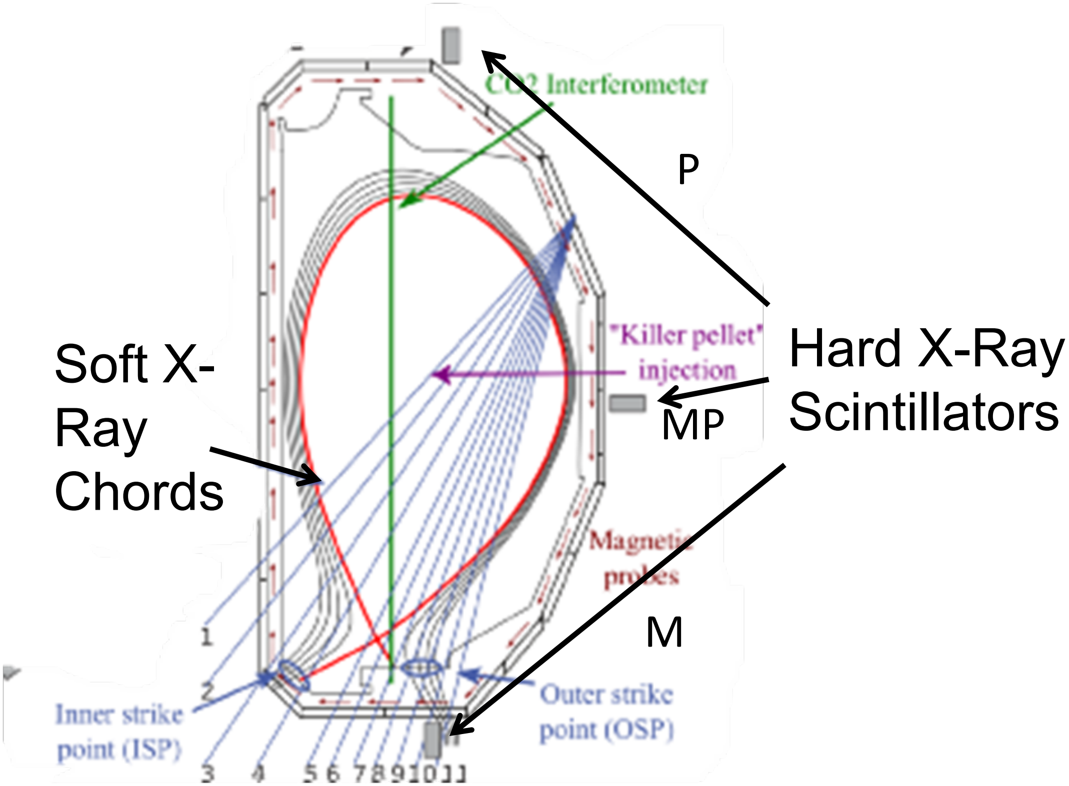
In diverted geometry, all RE losses are toroidally symmetric

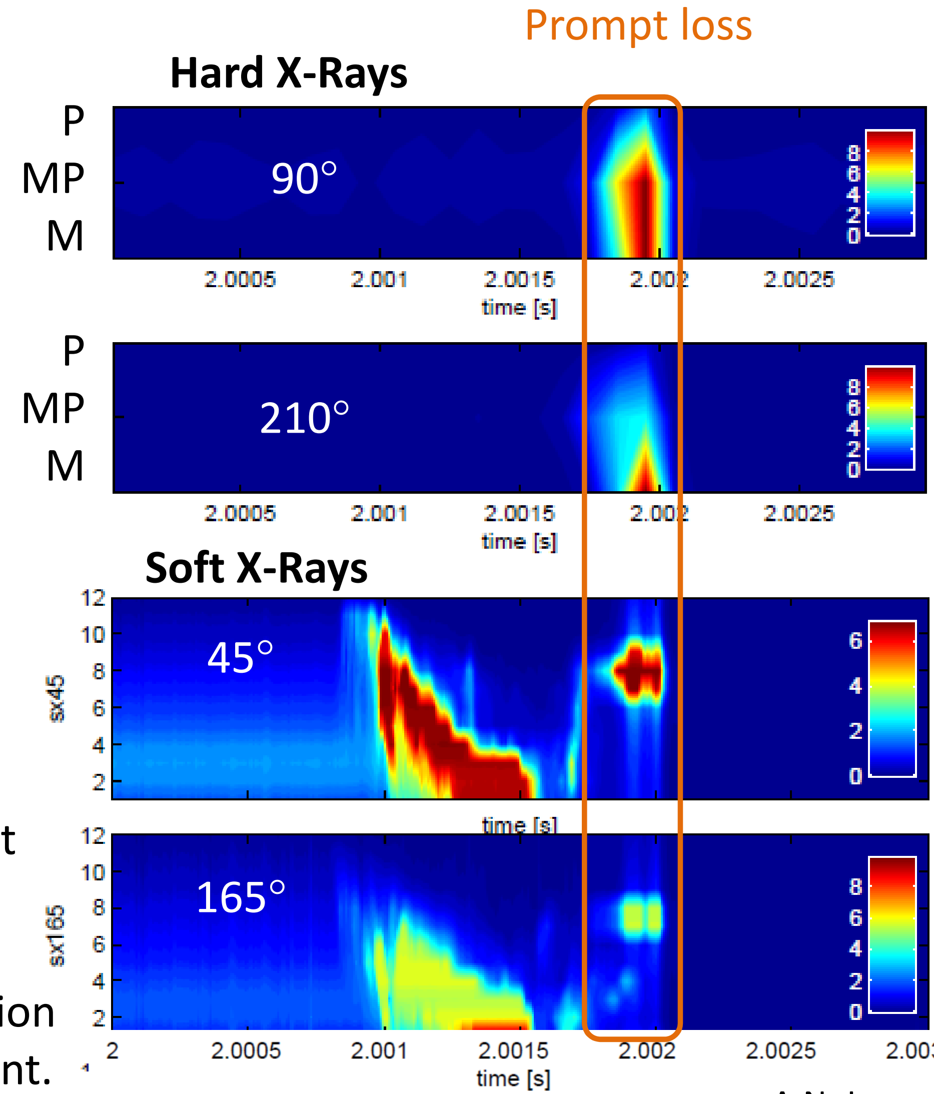
Prompt loss electrons have 5-10 MeV energies

(Later electrons losses are ~20 MeV)



Prompt loss strikes outer divertor on DIII-D





• Hard X-Ray scintillators indicate prompt loss of REs just before 2002 ms.

• Soft X-Ray measurements with better poloidal resolution indicate prompt loss location is outer divertor strike point.

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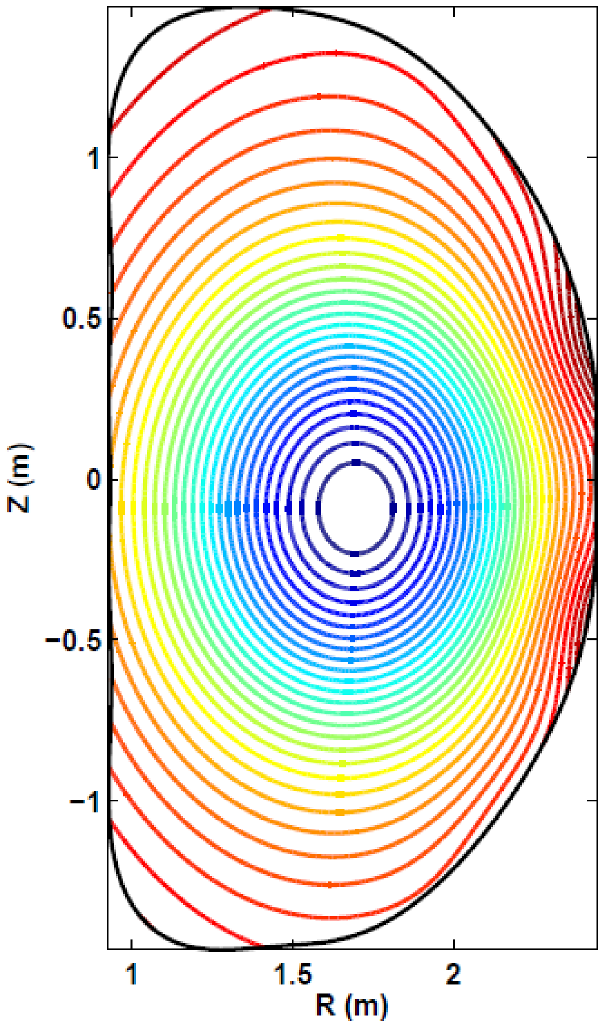
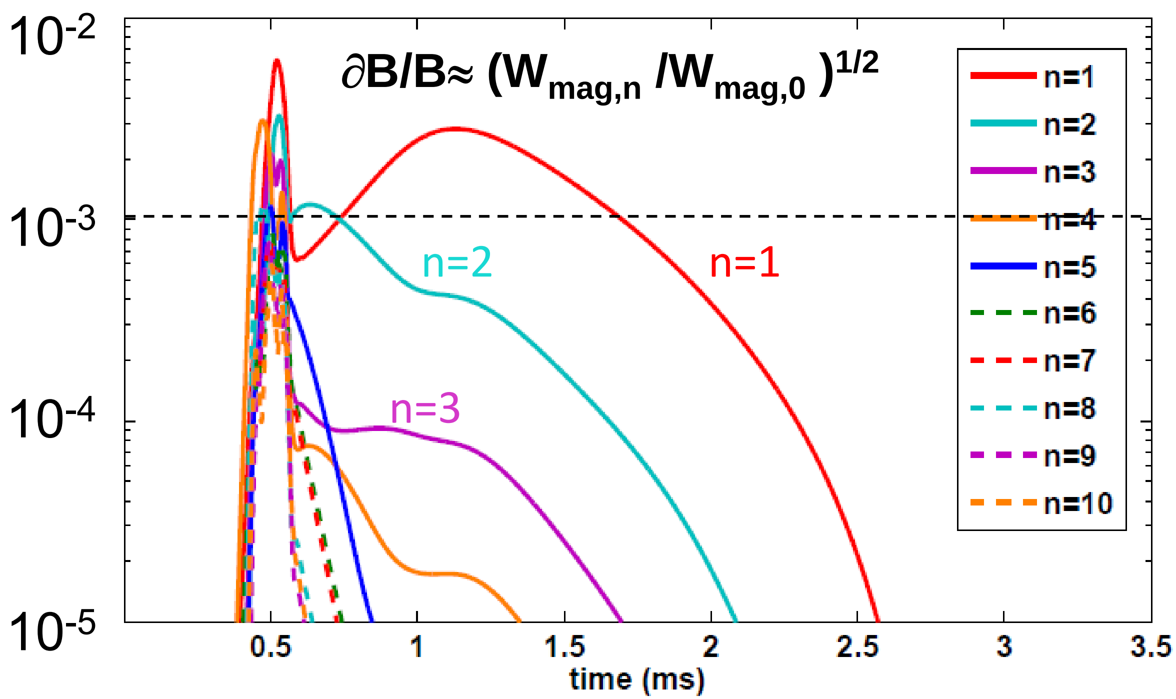
Simulation with Inner wall limited shape from DIII-D RE experiments



Two MHD events:

1st includes all toroidal mode numbers with n=1 dominant

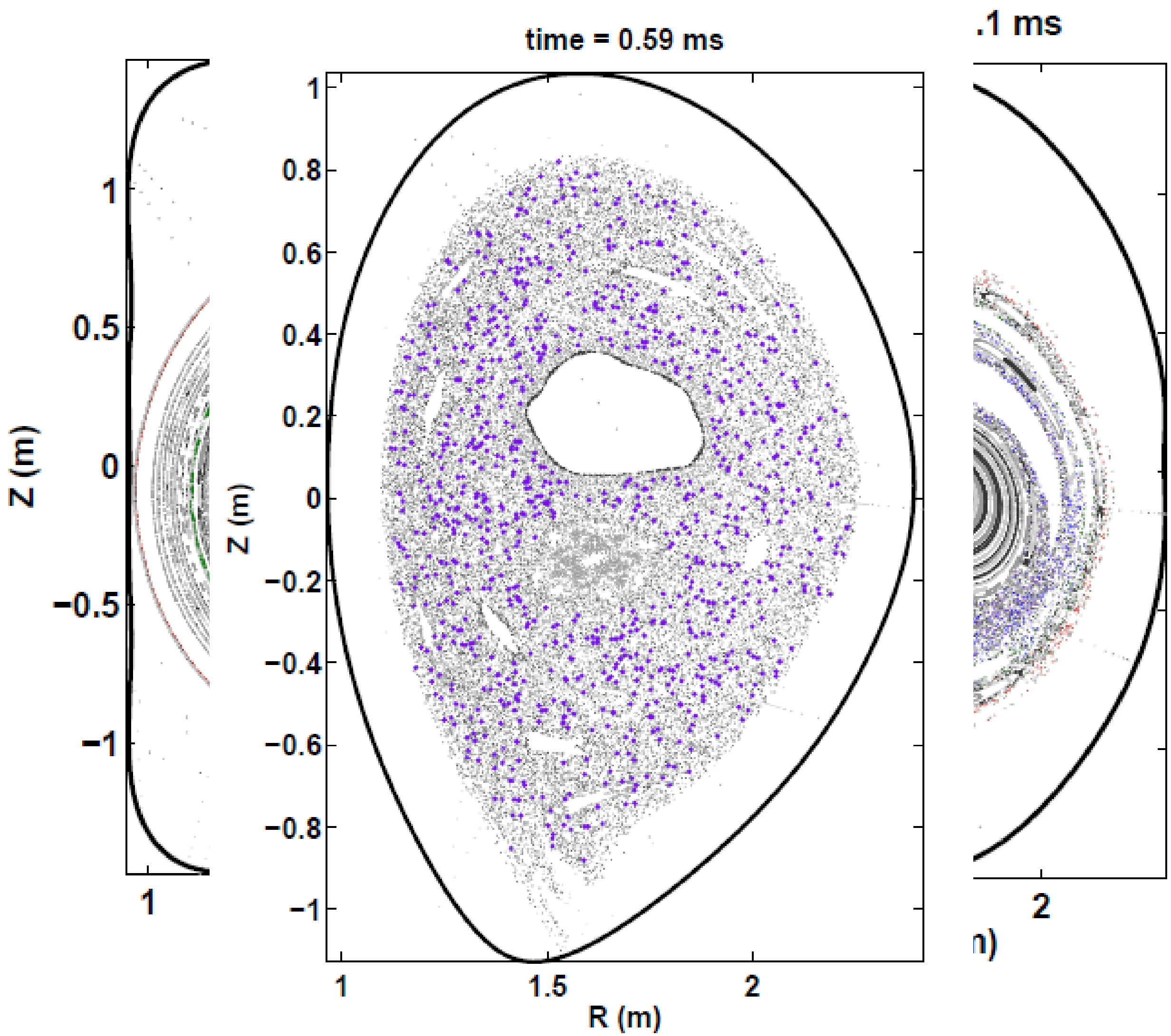
2nd is nearly pure n=1 (n=2 is ~order of magnitude smaller)



Localized flux surface destruction, isolated island chains in limited case

First MHD event involves many toroidal mode numbers …

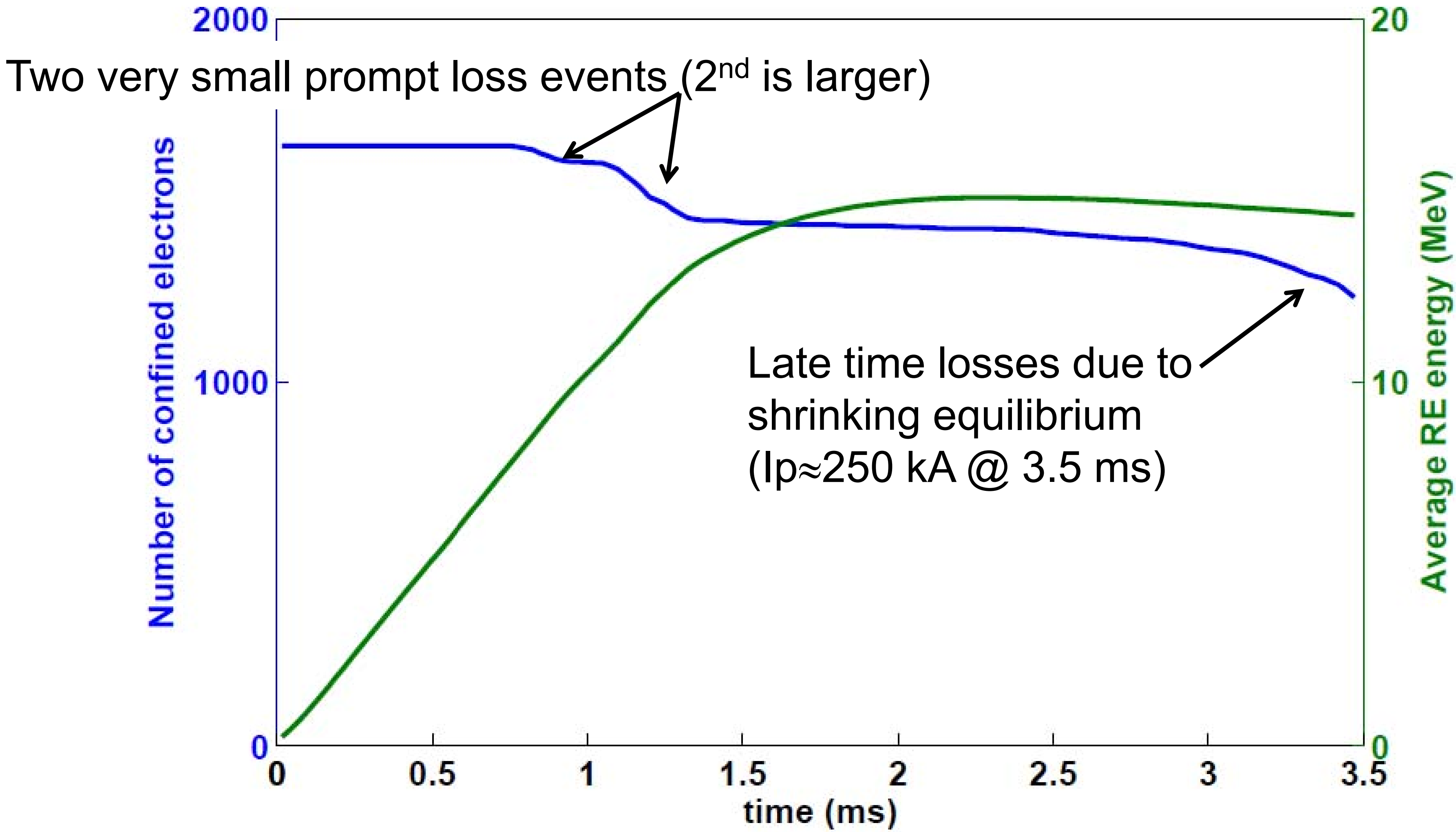
But is almost entirely localized in the core, with outer flux surfaces intact



Second MHD event affects the outer flux surfaces …

But nearly pure n=1 mode produces individual m=2-6 islands, no short connection between inner and outer islands

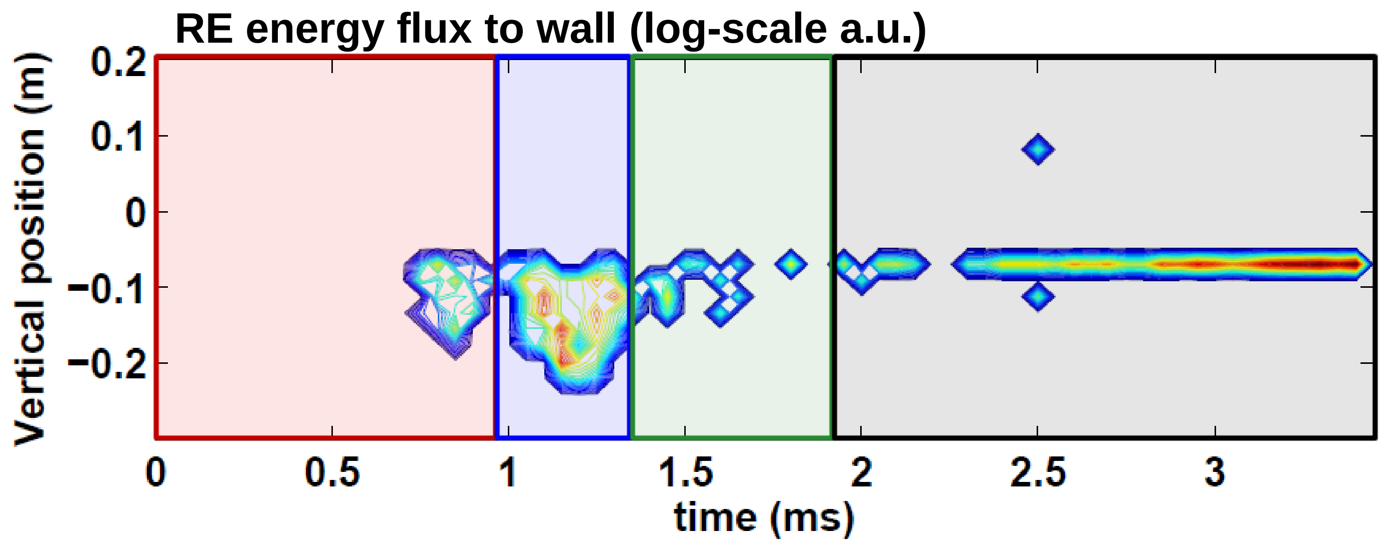
Although comparable in amplitude to diverted case, MHD produces minimal RE losses

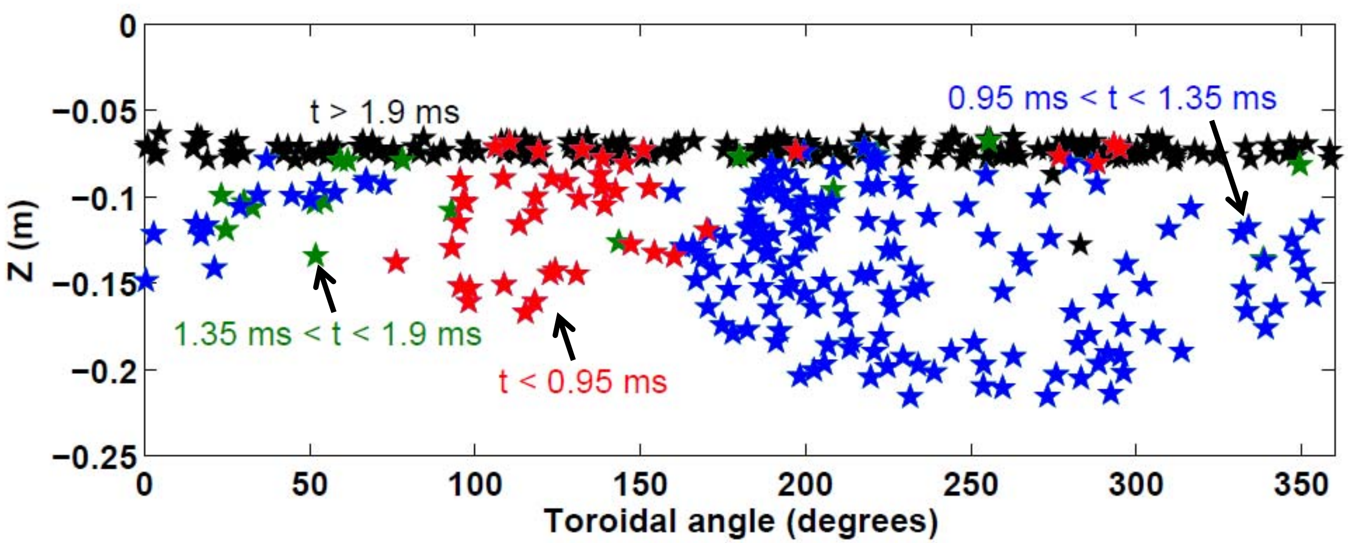


Prompt loss RE strikepoints on inner-wall midplane are toroidally localized

Two prompt loss events extend to ~20 cm below inner midplane

Late time losses concentrated on midplane strike point

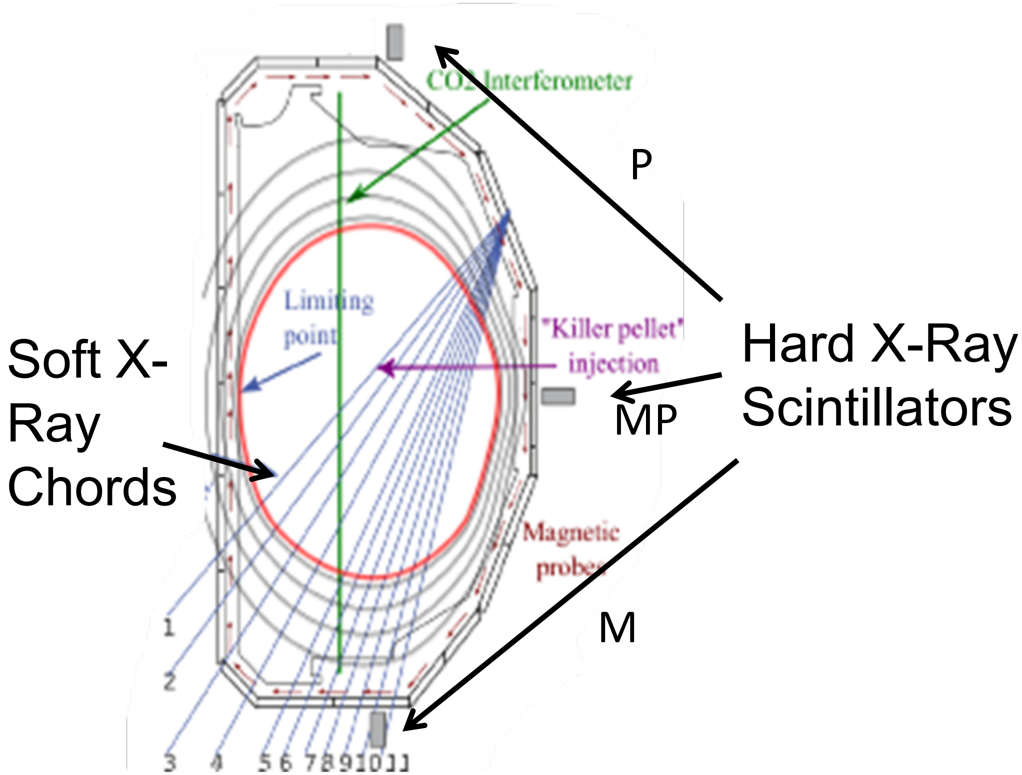


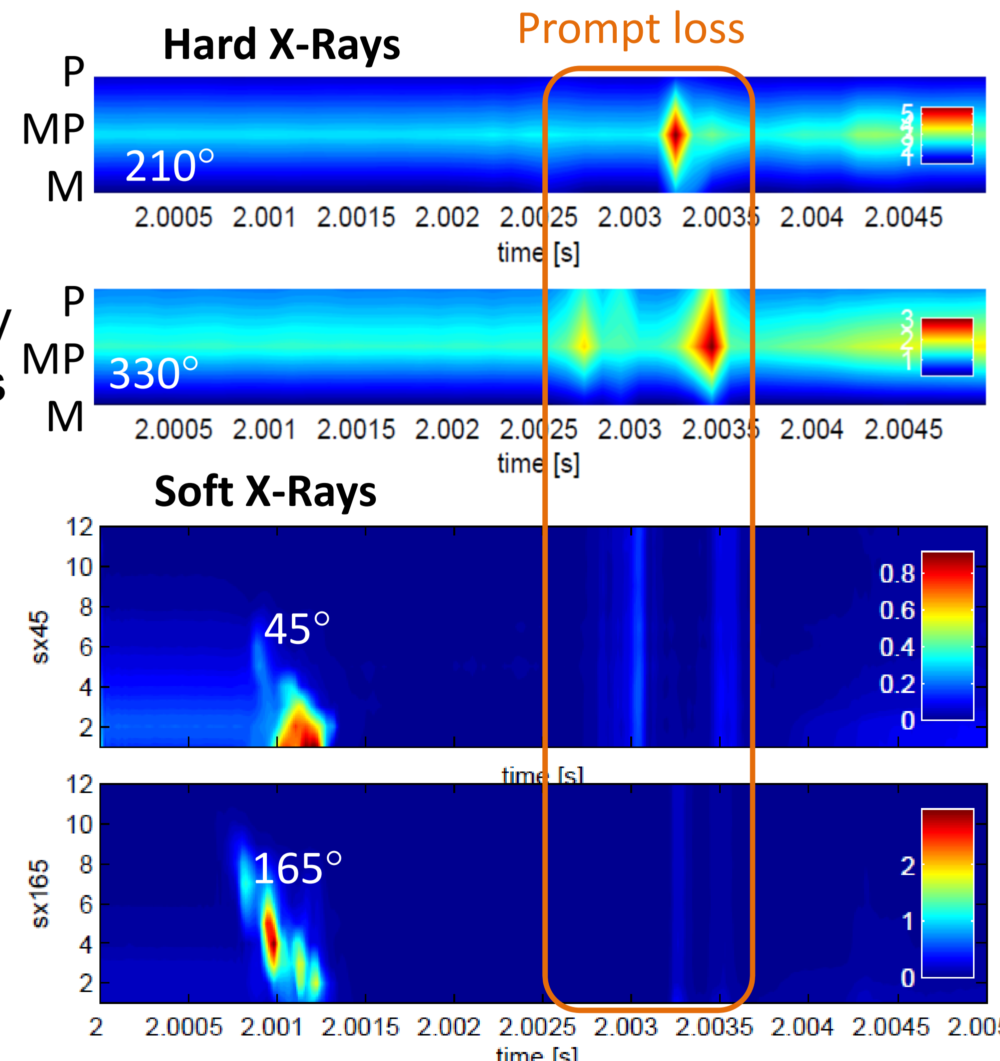


Toroidal localization seen for both prompt loss events

Consistent with shift of equilibrium into center column

HXR signals suggest midplane strike point, toroidal asymmetry for DIII-D prompt loss





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- Hard X-Ray scintillators see one or two prompt loss events between 2002.5 and 2003.5 ms. Amplitudes are smaller overall. (Outer and inner midplane can't be distinguished).
- Soft X-Ray detectors do not observe prompt loss event(s)– consistent with midplane strike point.

How to proceed

Inclusion of runaway current:
Given low particle numbers, mapping from RE population to a continuum current density should use simple functional form– i.e. assume a circular gaussian current profile, obtain only the amplitude, width, and centroid location from the RE population.

Addition of a circular gaussian, n=0 current source is already available in NIMROD

Predicting the runaway current:
Do the avalanche term first, assuming a seed. Can generate new electrons from existing using a simple formula for avalanche growth rate.
Seed terms: Have not determined how to include hot-tail without evolving a distribution function.
Benchmark these reduced models against CQL3D