Alpha Particle Losses from TFTR DT Plasmas

presented by
Douglass S. Darrow
with
S. J. Zweben, S. Batha*, R. V. Budny, Z. Chang, C. Z. Cheng, J. Fang[§], N. J. Fisch, E. D. Fredrickson, G. Y. Fu, R. F. Heeter, W. W. Heidbrink[§], H. W. Herrmann, M. C. Herrmann, K. Hill, R. James[‡], E. F. Jaeger[†], R. Majeski, M. Murakami[†], C. K. Phillips, M. H. Redi, E. Ruskov[§], D. A. Spong[†], E. J. Strait[‡], G. Taylor, R. B. White, J. R. Wilson, K. L. Wong, M. C. Zarnstorff, and the TFTR Group

Princeton Plasma Physics Laboratory, Princeton, NJ
*Fusion Physics & Technology, Torrance, CA
[§]Univerisity of California, Irvine, CA
[‡]General Atomics, San Diego, CA
[†]Oak Ridge National Laboratory, Oak Ridge, TN

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Alpha particle losses can affect reactor viability

TFTR

$$D + T \rightarrow n + \alpha \ (3.5\ MeV)$$

- Alphas confinement essential for ignition:
  $\tau_{SD} \approx 10^5$ transits in ITER

- Unanticipated loss of energetic alphas may damage first wall: few % acceptable for ITER

TFTR DT experiments provide a wealth of data on alpha confinement and loss

TFTR

- Reactor-level alpha population: β_α/β_{tot}~0.1

- Set of diagnostics measures confined and lost alphas

  α-CHERS, 2F7, 9P19
  Pellet CX, 2F8
  Ω_i emission 9P26
  Loss Probe, 9P21
  μwave scattering, 9P23

Overall Result:

- Alpha loss consistent with classical models and confined alpha diagnostics results:

  >90% confined at high I_p

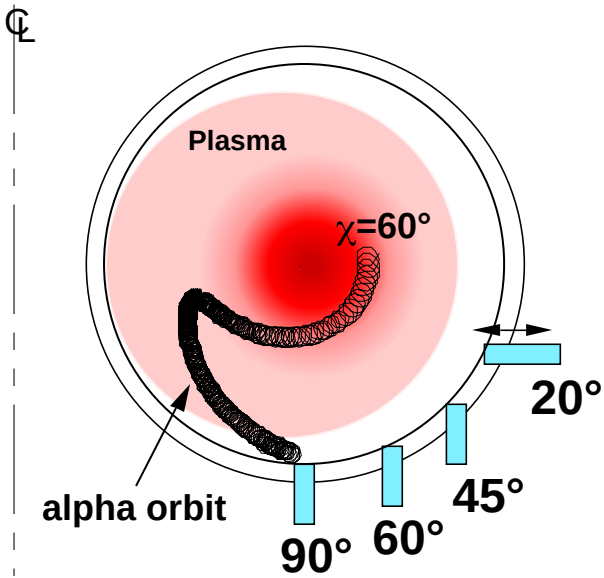
Outline

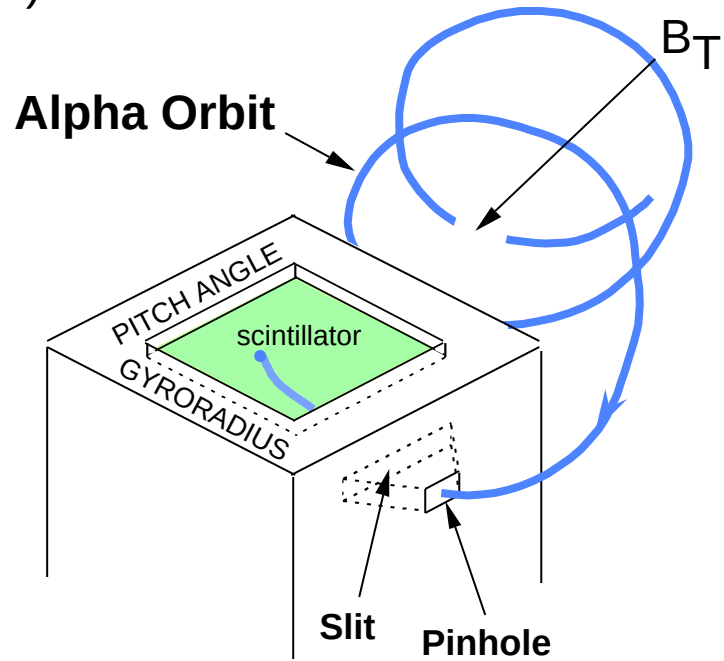
- Classical α losses
- MHD & collective α losses
- RF wave interactions with fast ions

Lost Alpha Diagnostic

TFTR

- 4 detectors
- $\rho \approx$ 2-12 cm ($\rho \approx$ 5 cm for alphas)
- $\chi = \arccos(v_T/v) = 45°\text{-}83°$





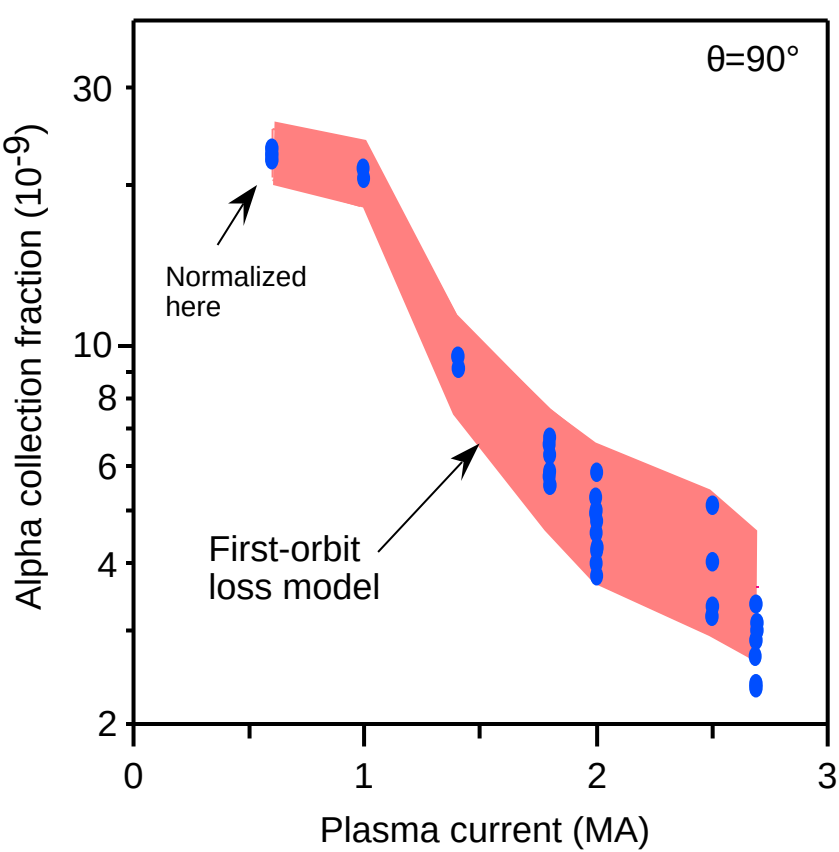
Classical Losses

TFTR

Resulting from basic magnetic structure of tokamak:

- First orbit
- Stochastic toroidal field ripple diffusion (“ripple diffusion”)
- Ripple trapping

DT alpha flux at 90° detector is consistent with classical first orbit loss

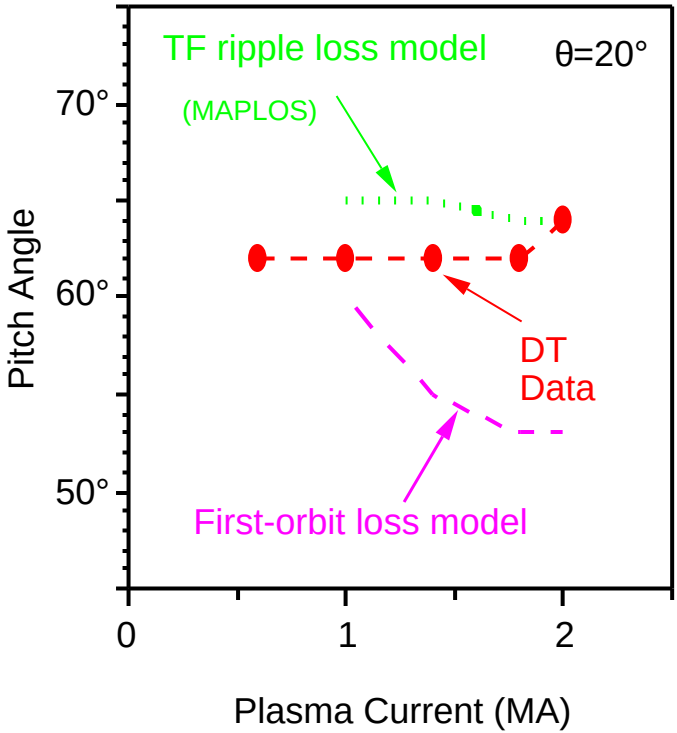


- Loss results from fat banana orbits which strike wall
- Calculated global first orbit loss: ~3% at 2.5 MA in TFTR
- First orbit loss from ITER should be <1%

S. J. Zweben *et al.*, *Nucl. Fusion* **35**, 893 (1995)

Alpha loss at 20° appears consistent with stochastic ripple diffusion

TFTR



- TF ripple causes banana orbits to diffuse & escape
- Ripple diffusion pitch angle larger than for first orbit loss
- TFTR ripple diffusion loss ≈ 10%
- ITER ripple diffusion loss ≈ 2 – 5%

S. Zweben, *et al.*, to appear in *Nucl. Fusion* (1995)
M. Redi, *et al.*, *Proc. EPS* (1995)

S. Zweben, 2F9
H. Duong, 2F10
M. Redi, 2F11

MHD & Collective Losses

TFTR

Magnetic perturbations

alphas wander out

Driven by background plasma:

- sawteeth
- kinks
- ballooning modes
- tearing modes
- locked modes
- ELMs
- disruptions

Janos, 9P24

Driven by fast ions (collective):

- fishbones
- TAEs
- BAEs

No alpha loss due to Alfvén modes seen in TFTR

TFTR

- No alpha-driven TAE, even at highest P_{fusion}

  Z. Chang, *et al.*, to appear in *Nucl. Fusion*. 9P14

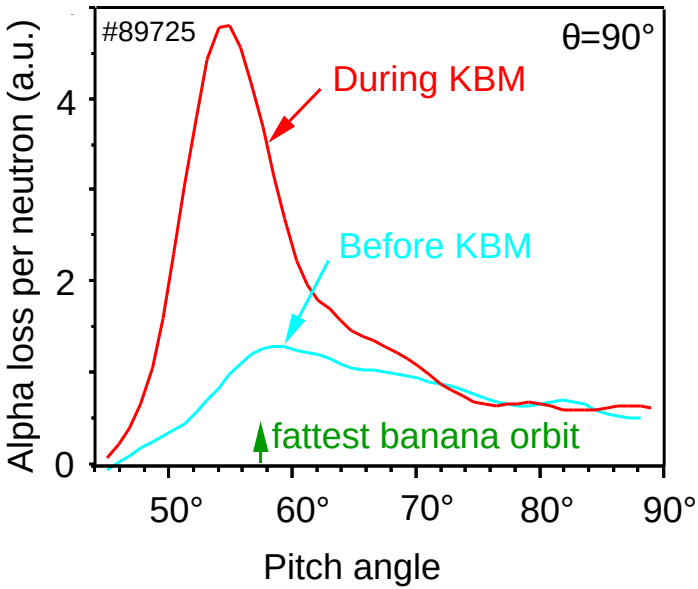
- Attempts to destabilize Alfvén modes in DT plasmas:

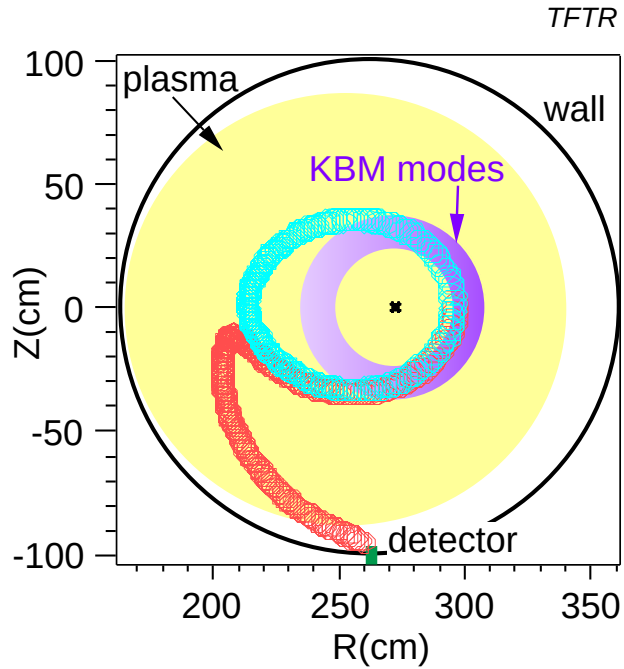
  - reduce T_i less ion Landau damping
  - increase β drive BAEs W. W. Heidbrink, 9P17
  - increase q(0) align mode with β_α
  - add ICRF tail ions increase drive K.-L. Wong, 2F6

- Tail ion loss during ICRF driven TAE caused vessel damage

- ITER has 3× larger R β_α than TFTR: predicted to be unstable

Alphas lost during KBMs through passing/banana orbit conversion





- Mode identified as kinetic ballooning mode (KBM)
- Seen at high β in D & DT pressure driven, not α-driven

Z. Chang, *et al.*, submitted to *Phys. Rev. Lett.*

R. White, 2Q22

RF Wave Interactions with Fast Ions

TFTR

Wave electric fields accelerate fast ions

- ICRF fast wave
- Ion Bernstein wave
- Lower hybrid wave

ICRF waves induce fast ion loss

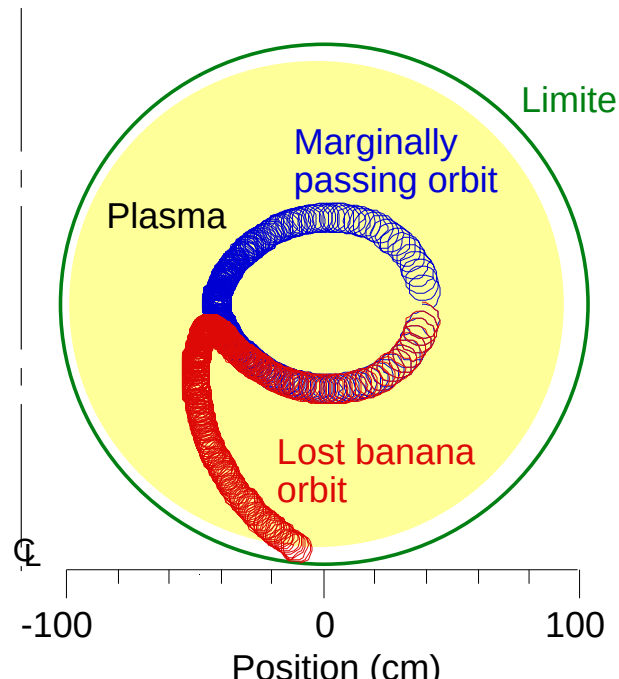
TFTR

- Fusion products interact over wide range of R due to wide range of $v_{||}$

$$\omega_{RF} = \Omega_f(R) - k_{||}v_{||f}$$

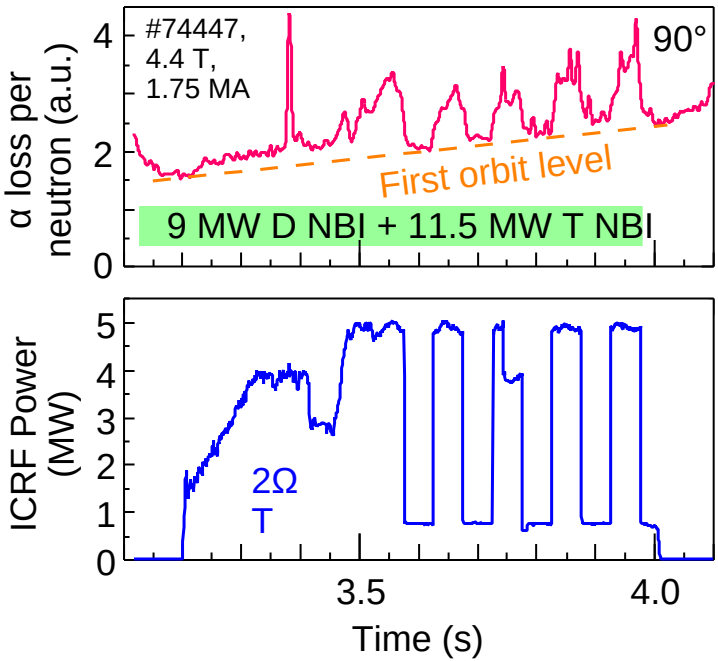
- Interaction can change E, μ, and P_φ of particles

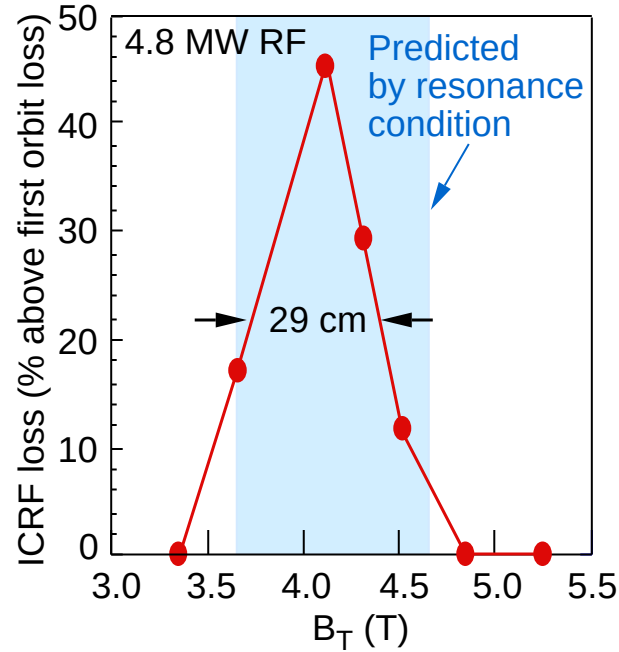
- Added v from wave moves particle from passing to lost banana orbit (as with KBMs)



ICRF fast waves expel small fraction of alphas

TFTR

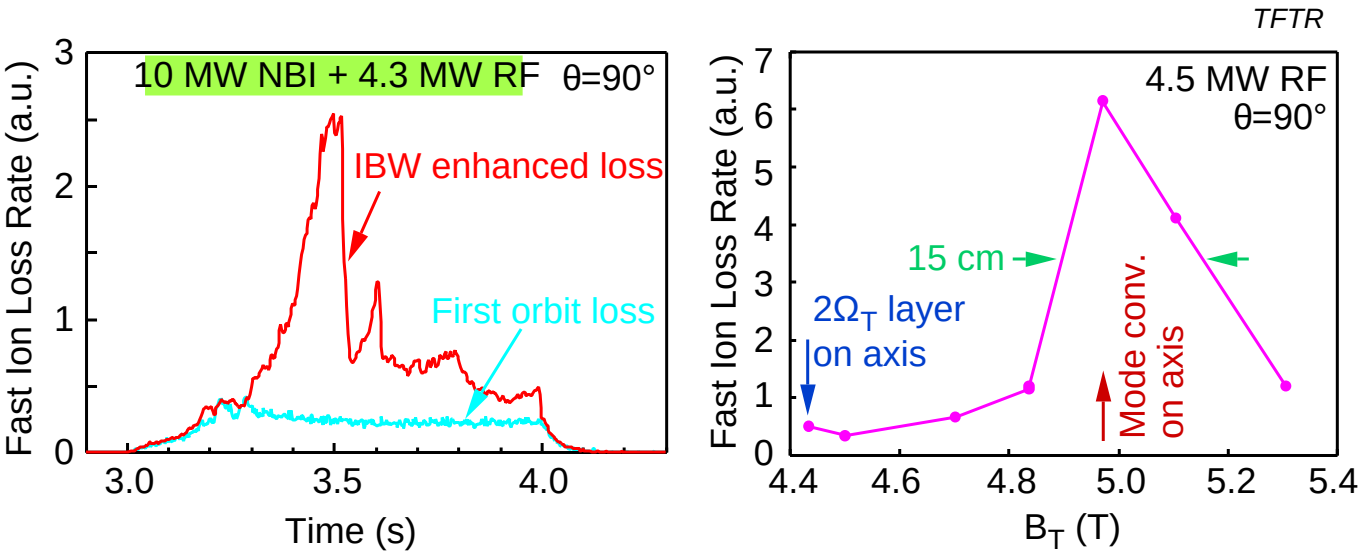




- Added loss on fattest banana orbit; ~ 2% globally
- Requires first orbit loss cone ITER losses will be small

D. S. Darrow, *et al.*, to appear in *Nucl. Fusion* (1996)

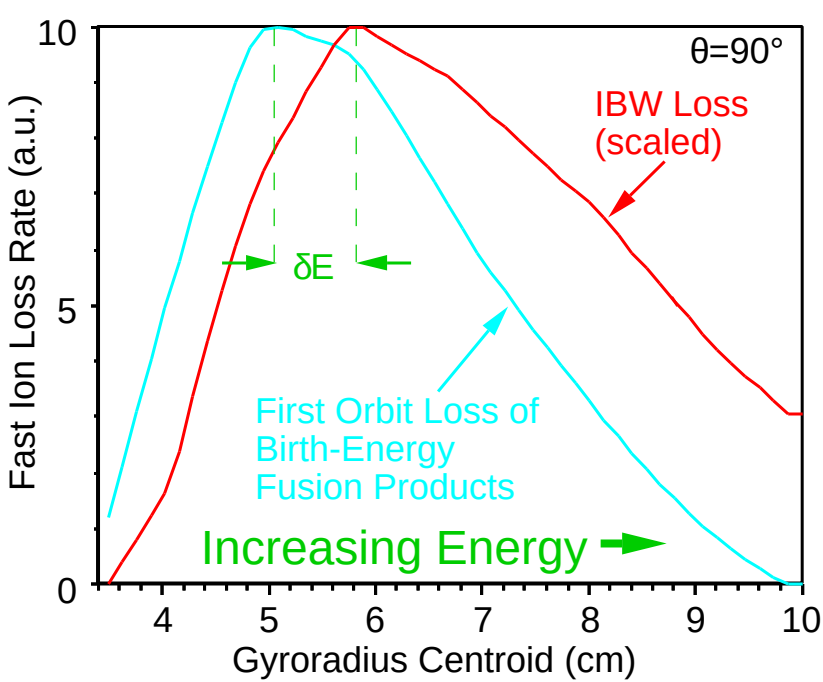
Ion Bernstein waves in D^3He plasmas expel large numbers of fast ions



- IBWs created by mode conversion of fast waves R. Majeski, 4IA2
- Vary ^3He fraction or B_T to move mode conversion layer
- Loss level depends sensitively on layer location

D. S. Darrow, *et al.*, submitted to *Phys. Rev. Lett.*

Lost fast ions strongly heated by IBW



1.0 MeV T → 1.5 MeV T
or
100 keV D beam ion → 2 MeV D

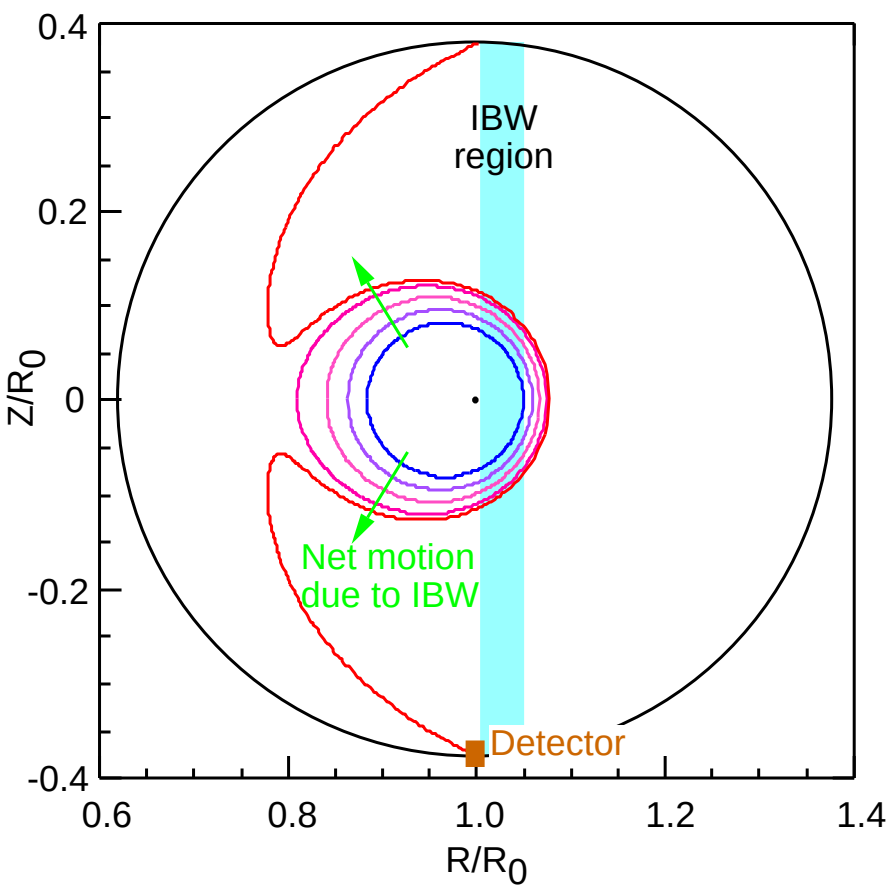
If T: D_E~ 2 MeV^2/sec
If D: D_E~25 MeV^2/sec

- Alpha energy channeling: wave extracts energy from alphas for ion heating or current drive
- Observed D_E is large enough to permit alpha channeling

Fisch & Rax, *Phys. Rev. Lett.* **69**, 612 (1992)

J. Rax, 3Q22

Numerical model predicts features of loss



- Model follows single particles
- If particle resonates with IBW in blue zone, particle is given "kick" in E & P_φ consistent with wave physics
- Orbits followed at each step
- This case: 1 MeV T heated to 1.5 MeV before loss to 90° detector

M. Herrmann, 3Q31

Future plans for TFTR alpha loss studies

- Image alpha ripple loss heating of wall with IR TV
- Push toward ITER R β_α excite alpha instabilities

  Mansfield, 4IA3; Zarnstorff, 5IA2
- Look for cooled fast ions in IBW experiments, as predicted by alpha channeling theory
- Perform IBW experiments directly with alphas: f_{RF} from 43 MHz $\rightarrow$ 30 MHz

Conclusions

- Observed alpha loss in TFTR consistent with classical model in MHD quiescent discharges
- Most losses in TFTR require first orbit loss cone, should be small in ITER
- However, ITER (20 TF coils) has significant ripple diffusion loss cone same processes may transport alphas there
- IBWs interact strongly with fast ions demonstrates one building block for “alpha energy channeling”