Mode conversion heating in JET plasmas with multiple mode conversion layers

D. Van Eester, E. Lerche
and JET-EFDA Collaborators

RF Power in Plasmas, Newport (USA), June 1-3

Mode conversion heating in JET plasmas with multiple mode conversion layers

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JET-EFDA Culham Science Centre, Abingdon, OX14 3DB, UK

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[*]See the Appendix of F. Romanelli et al., Proceedings of the 23rd IAEA Fusion Energy Conference 2010, Daejeon, Korea

In Memoriam

Zijn vriendin
Liselotte De Waele
Zijn ouders
Lucas en Dorine Leemans – Durand
Zijn broer en zus
Koen Leemans en vriendin Fanny
Annelies Leemans en vriend Tom
Zijn grootouders
Jozef(†) en Julia Leemans – Van Eester
André(†) en Kristiane Durand – Reniers
Zijn ooms, tantes, neven, nichten en vele vrienden.

Samen met familie en vrienden nemen we afscheid van Bart
in de parochiekerk van Sleidinge
op zaterdag 4 juni 2011 om 9.30 uur.

Gelegenheid tot condoleren vanaf 9.00 uur achteraan in de kerk.

U kan Bart een laatste groet brengen in het funerarium De Piramide,
Hoeksken 17 te Evergem op woensdag en vrijdag van 14 tot 18 uur.

Keizersdreef 22, 9940 Sleidinge Bloemen, noch kransen

Uitvaartcenter De Piramide - Pisman, Evergem

Bart Leemans

13/07/1985 – 29/05/2011

Speler van KFC Sleidinge

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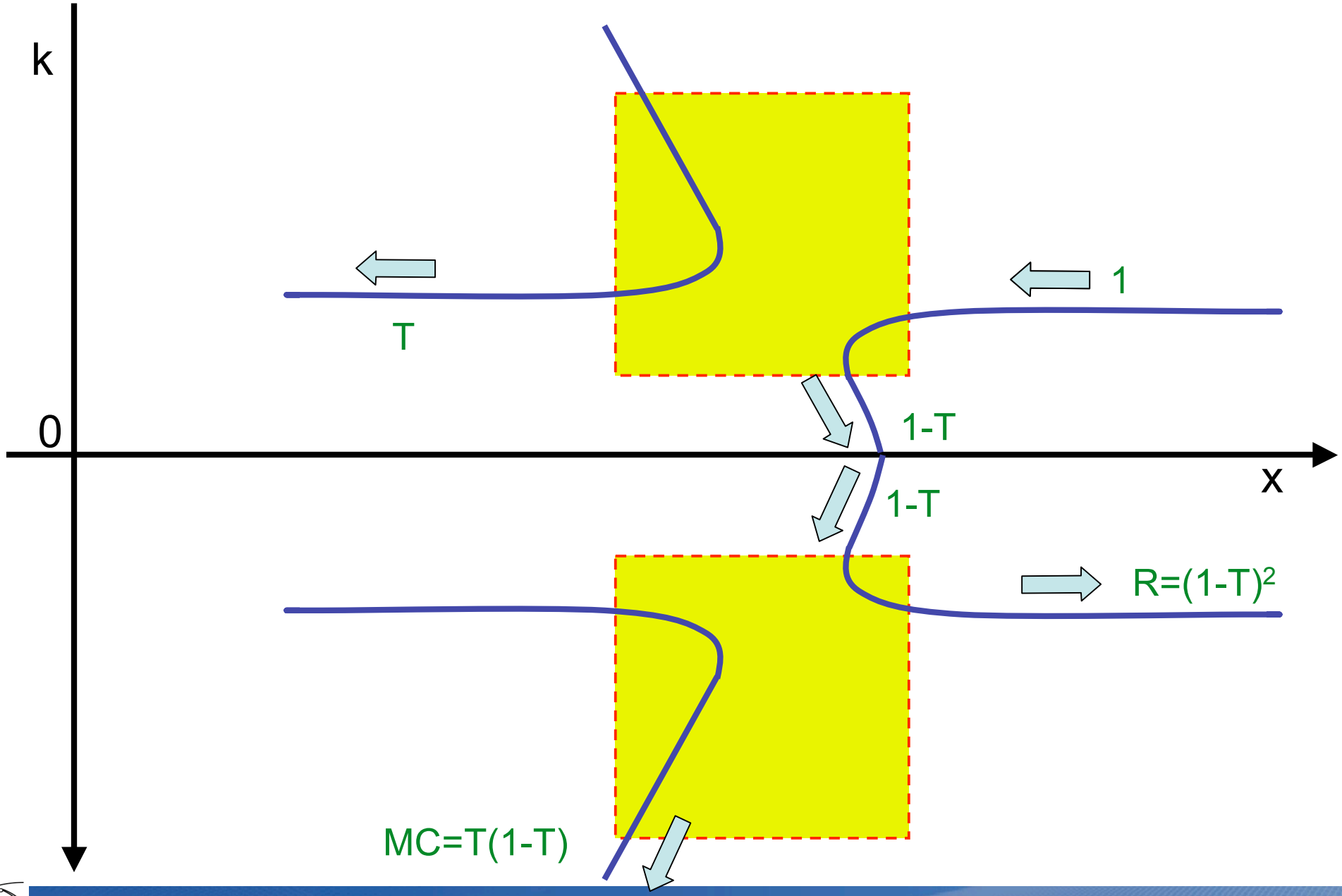
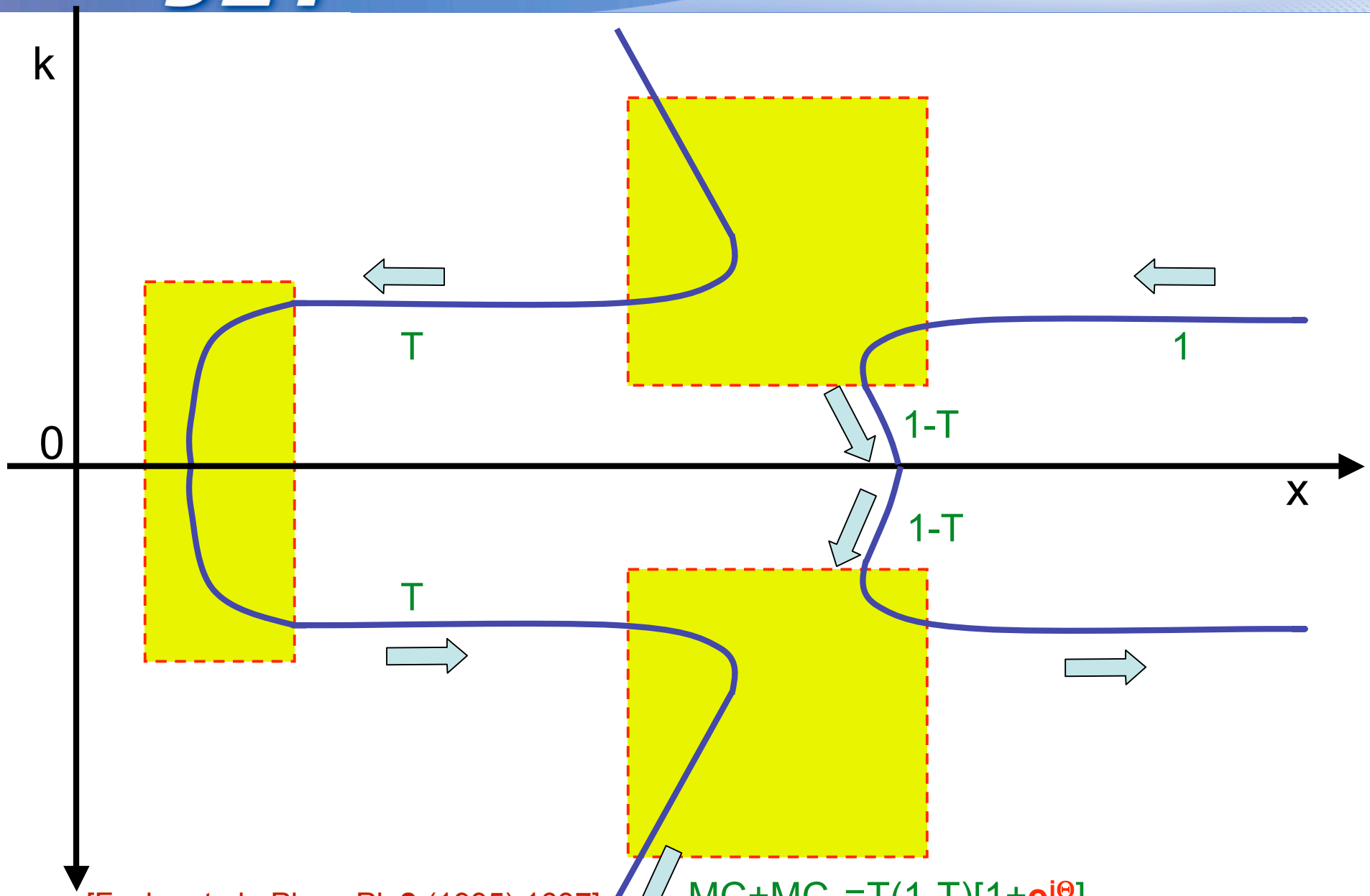
MC physics: the basics



MC physics: HFS FW cut-off & the Fuchs effect



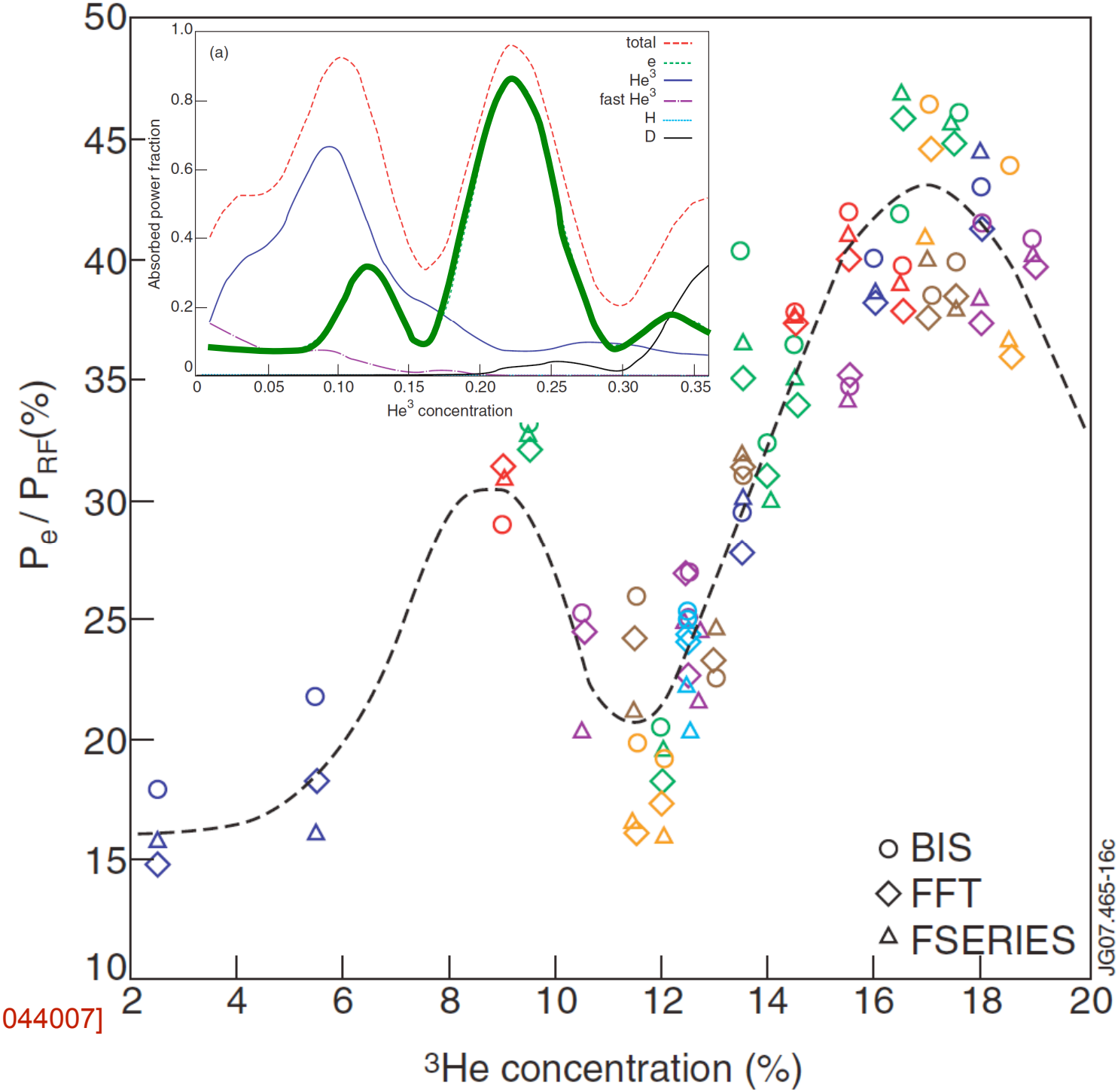
[Fuchs et al., Phys. Pl. **2** (1995) 1637]

$MC+MC_2=T(1-T)[1+e^{i\Theta}]$

Fuchs effect:

(^{3}He)-D

JET expts.



[Van Eester et al, PPCF **51** (2009) 044007]

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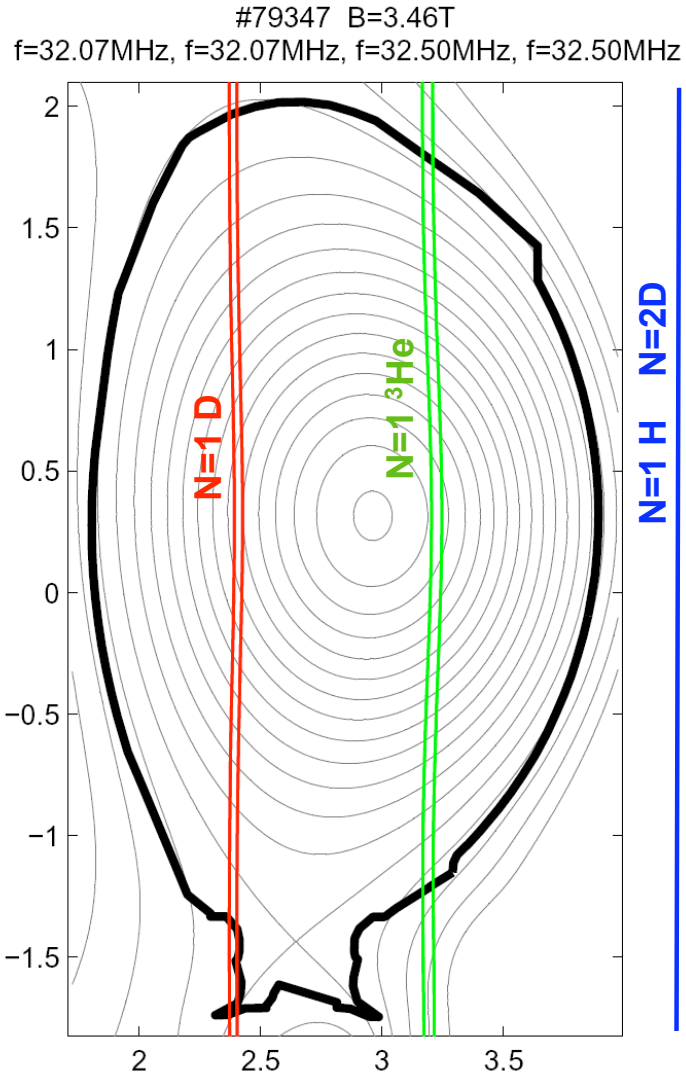
Global shot analysis

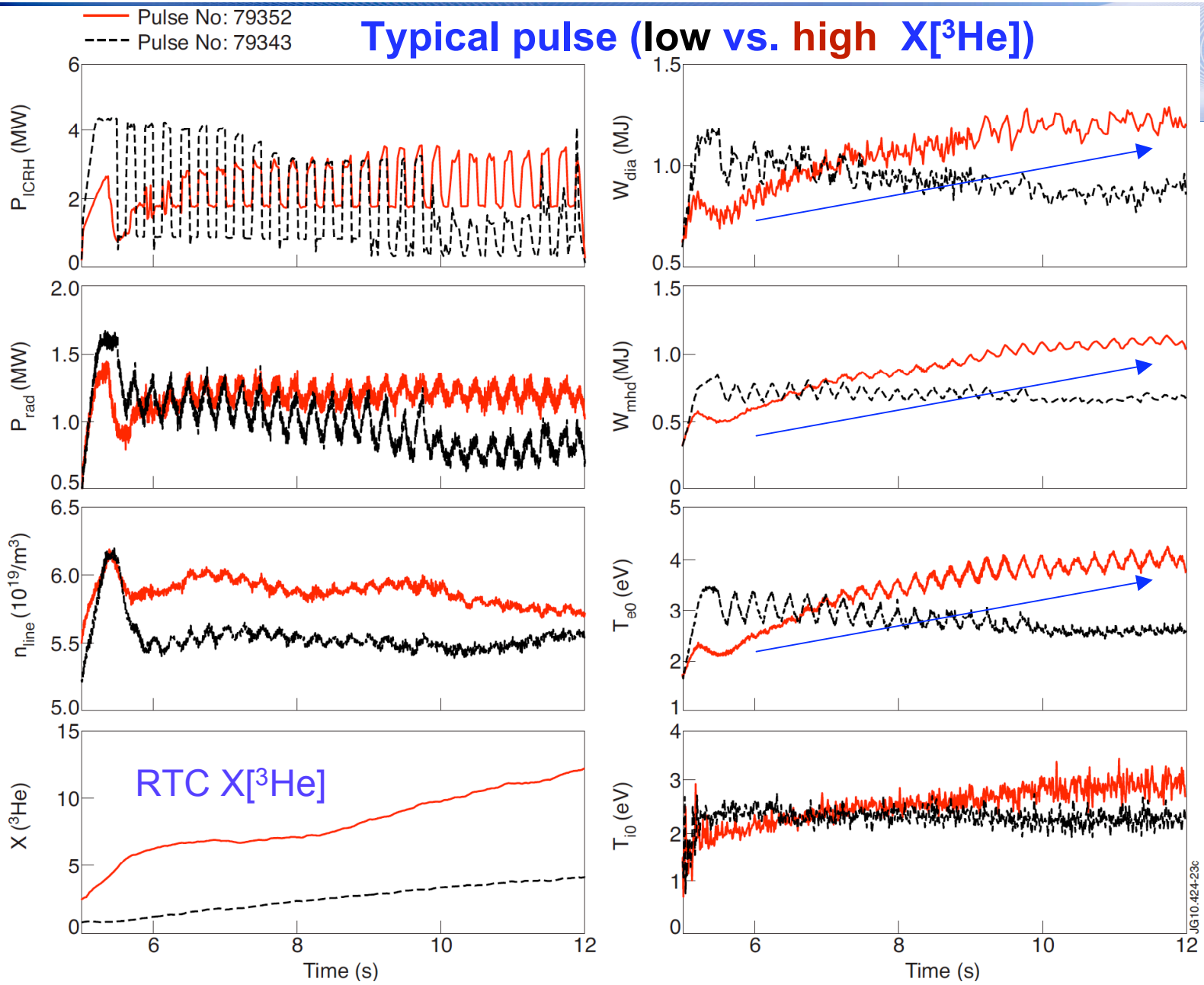
MC in (^{3}He)-H plasmas with D beams



- ITER early phase (low activation) plasmas
- Core N=1 (cyclotron) ^{3}He heating
- N=0 (ELD/TTMP) electron heating at MC layer(s)

- INVERTED scenario (MC at lower X[^{3}He])
- Low X[^{3}He]: Mayoral et al.
  [Mayoral, NF 46 (2006) S550-S563]
- Behavior at high X[^{3}He]?
  - Dominant heating?
  - RF induced toroidal/poloidal rotation?
    [Lin, EPS, Dublin, P5-164]

Typical pulse (low vs. high X[^{3}He])

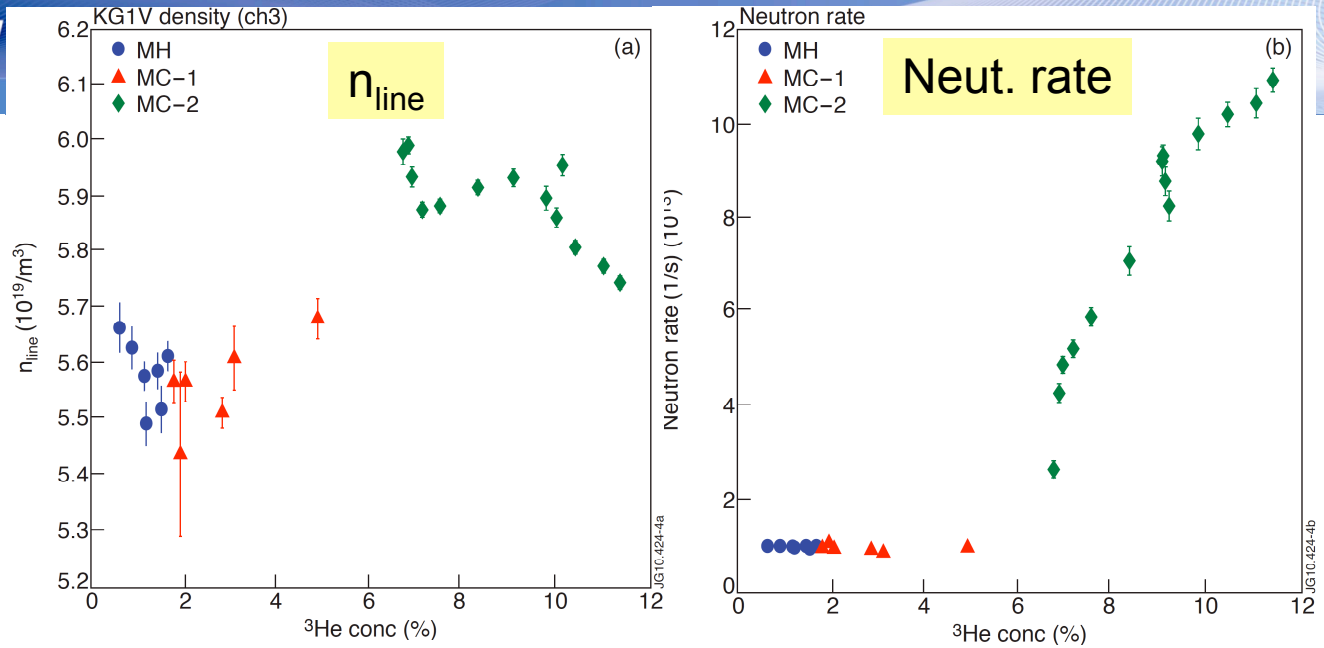


- W_{mhd} modulation throughout; (Hints of W_{dia} modulation for low X[^{3}He])
- Electron response throughout; ~ no ion response;

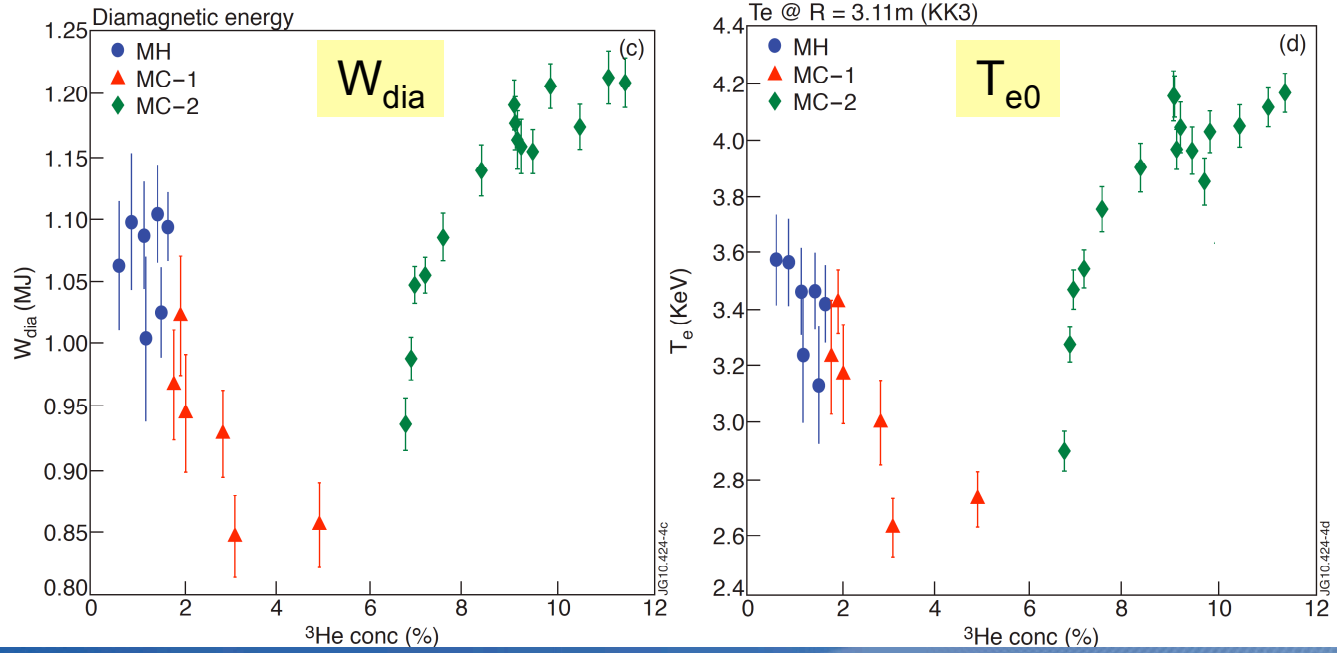
Global X[^{3}He] Dependence

P_{RF}~2.5MW

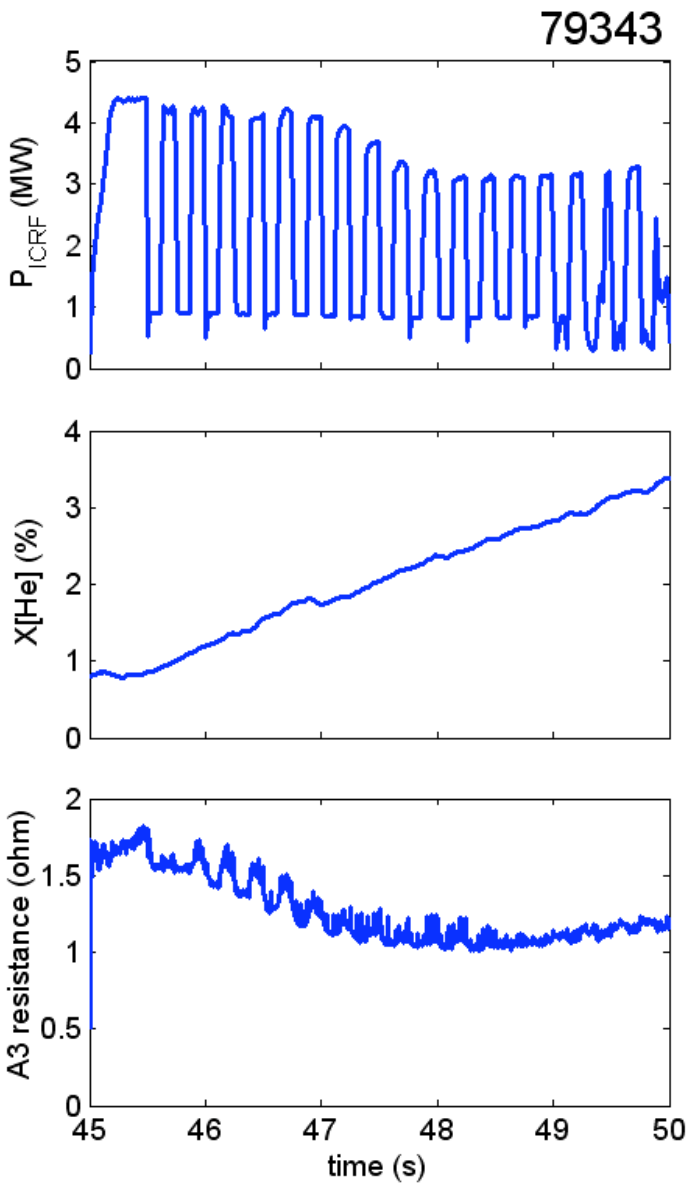
(during modulation)

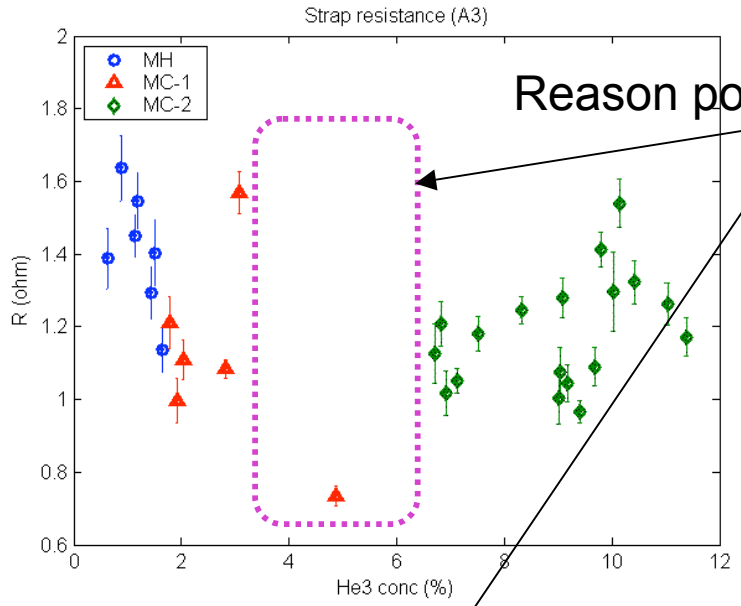


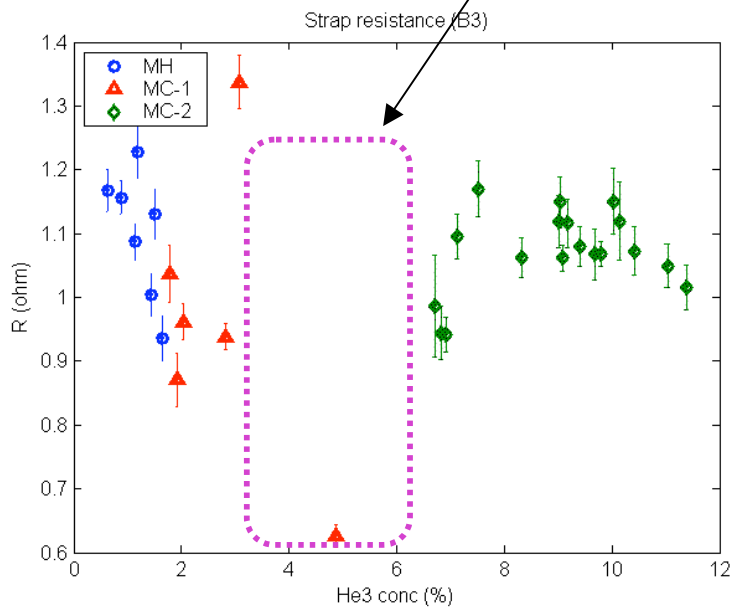
o MH: 0<X[^{3}He]<1.8% Δ MC-1: 1.8%<X[^{3}He]<5% ◊ MC-2: X[^{3}He]>6%



Antenna coupling



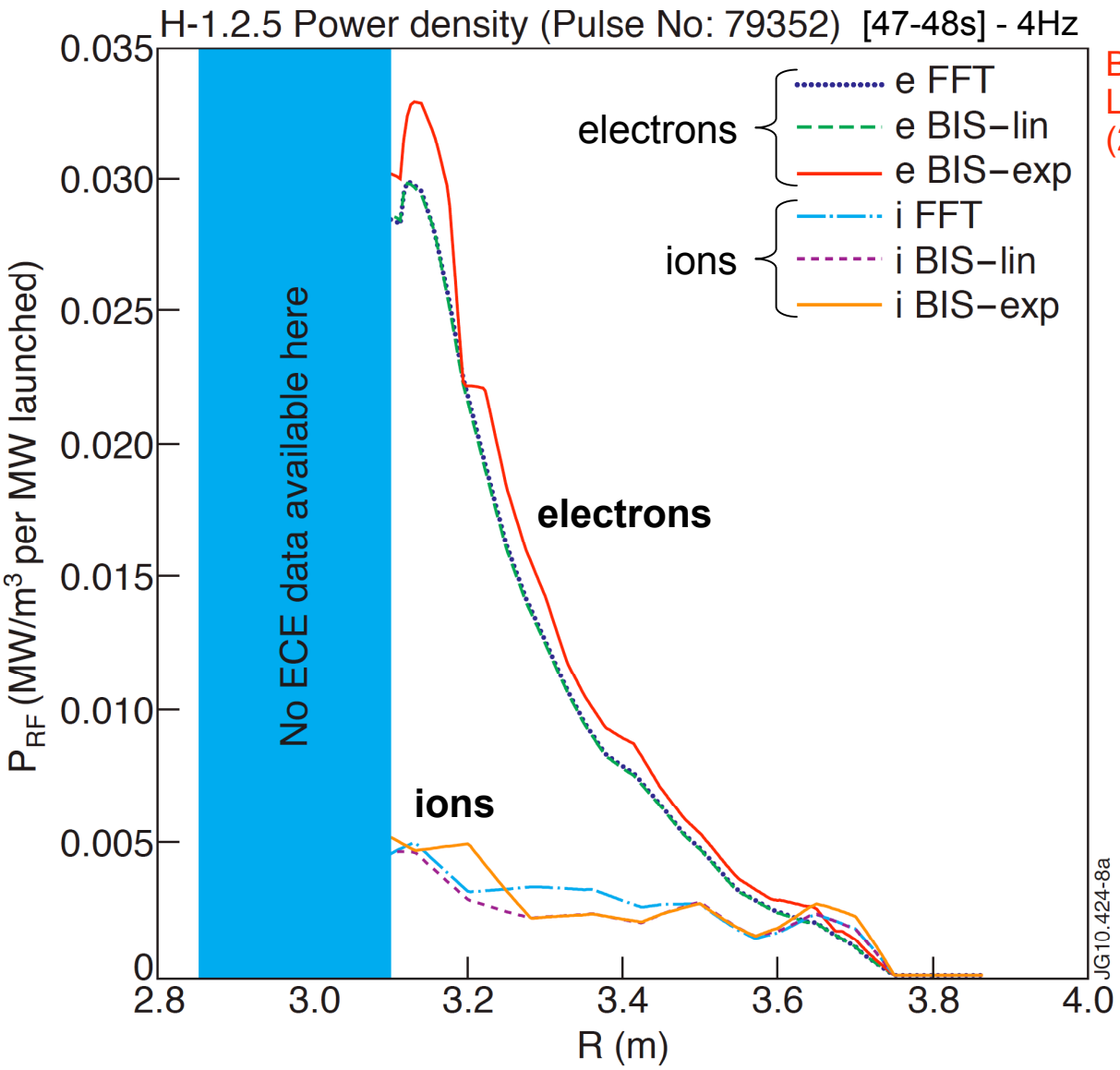




Reason poor coupling?

Power deposition discussion

RF Power Deposition (low X[^{3}He])



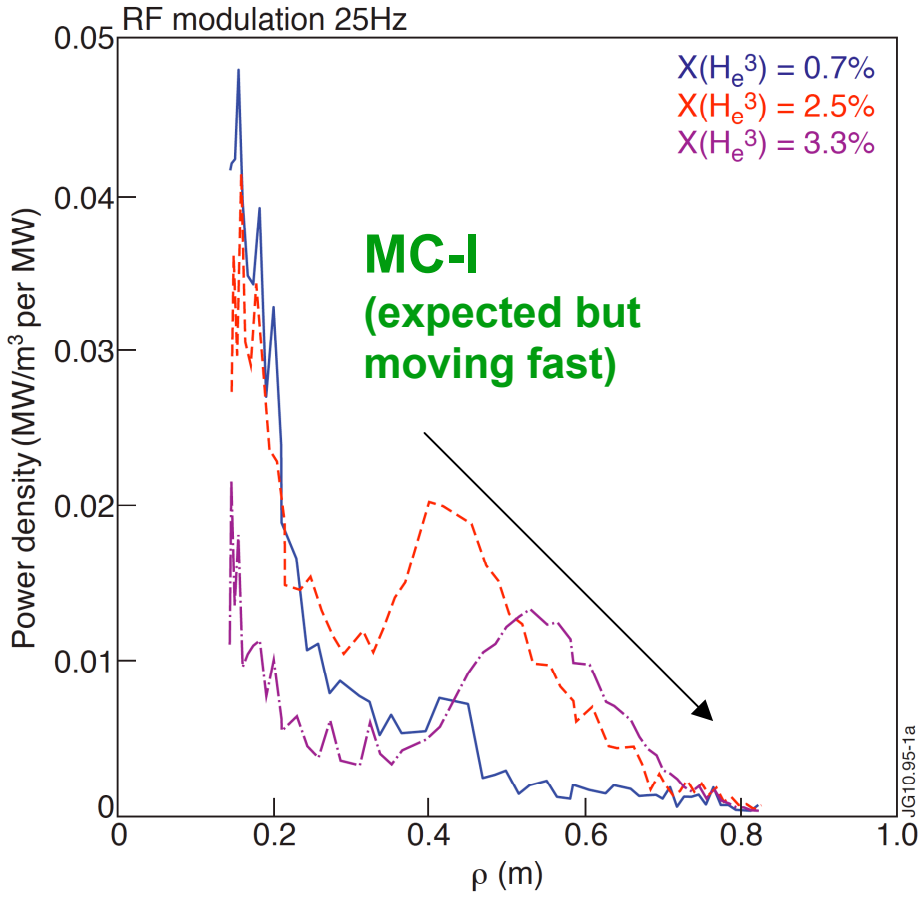
BIS:
Lerche et al., PPCF 50 (2008) 035003

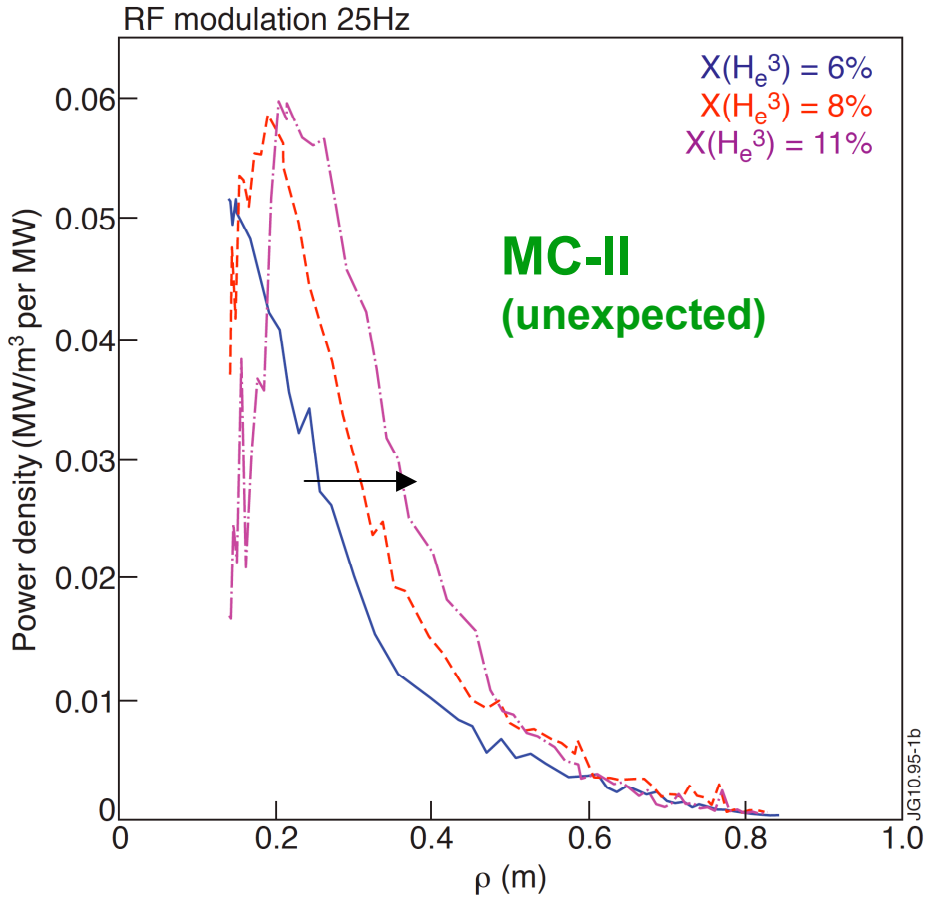
P_e~40%

P_i~12%

Clear e response; less clear i response

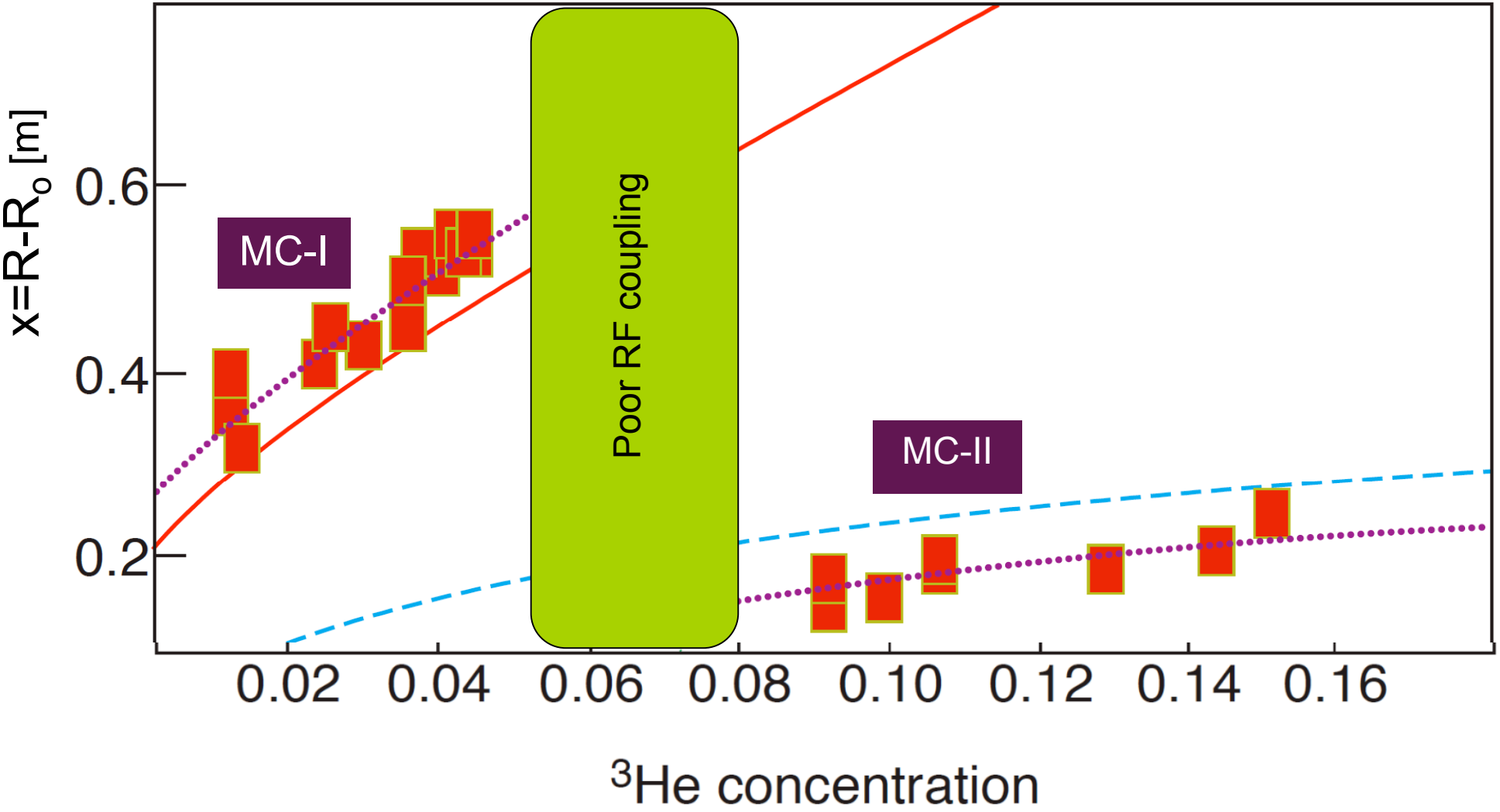
Power deposition : X[^{3}He] scan



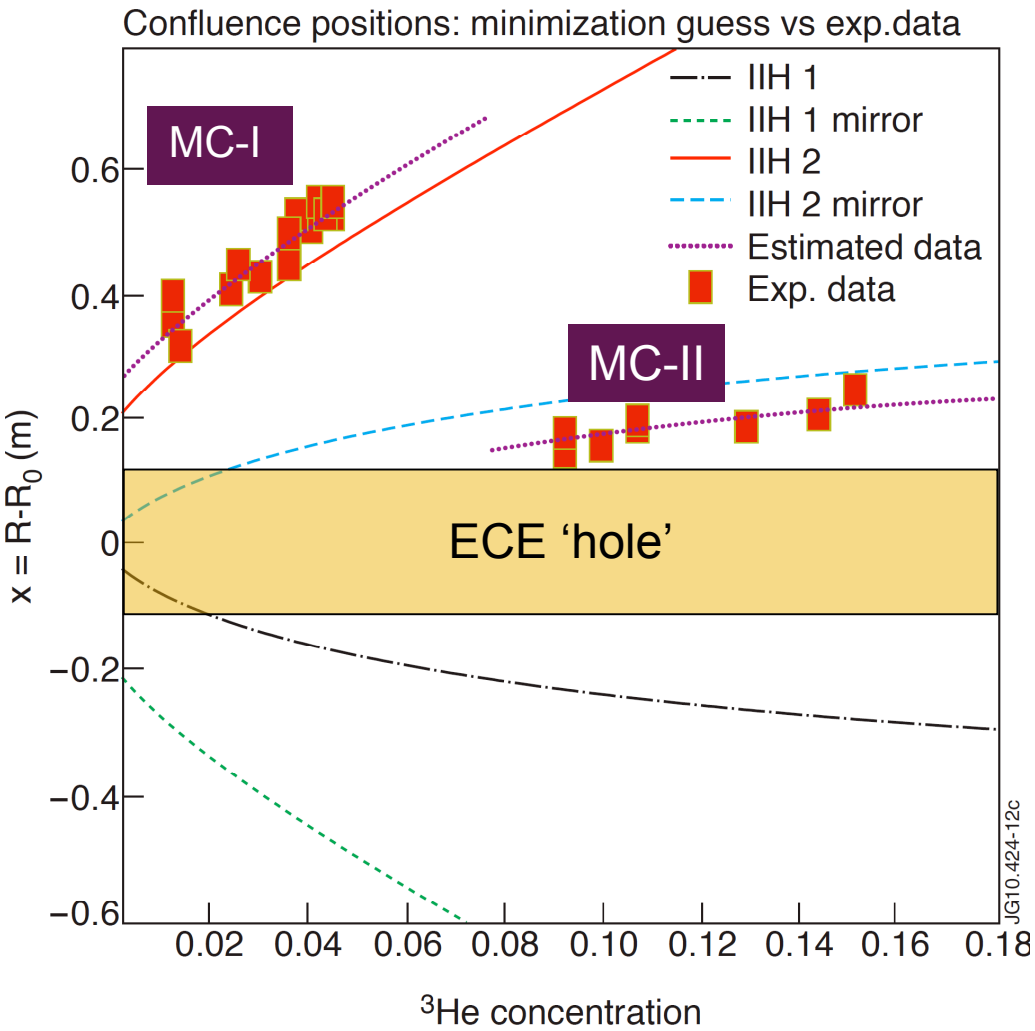


Note: @ 25Hz modulation negligible effect transport but ion dynamics not captured

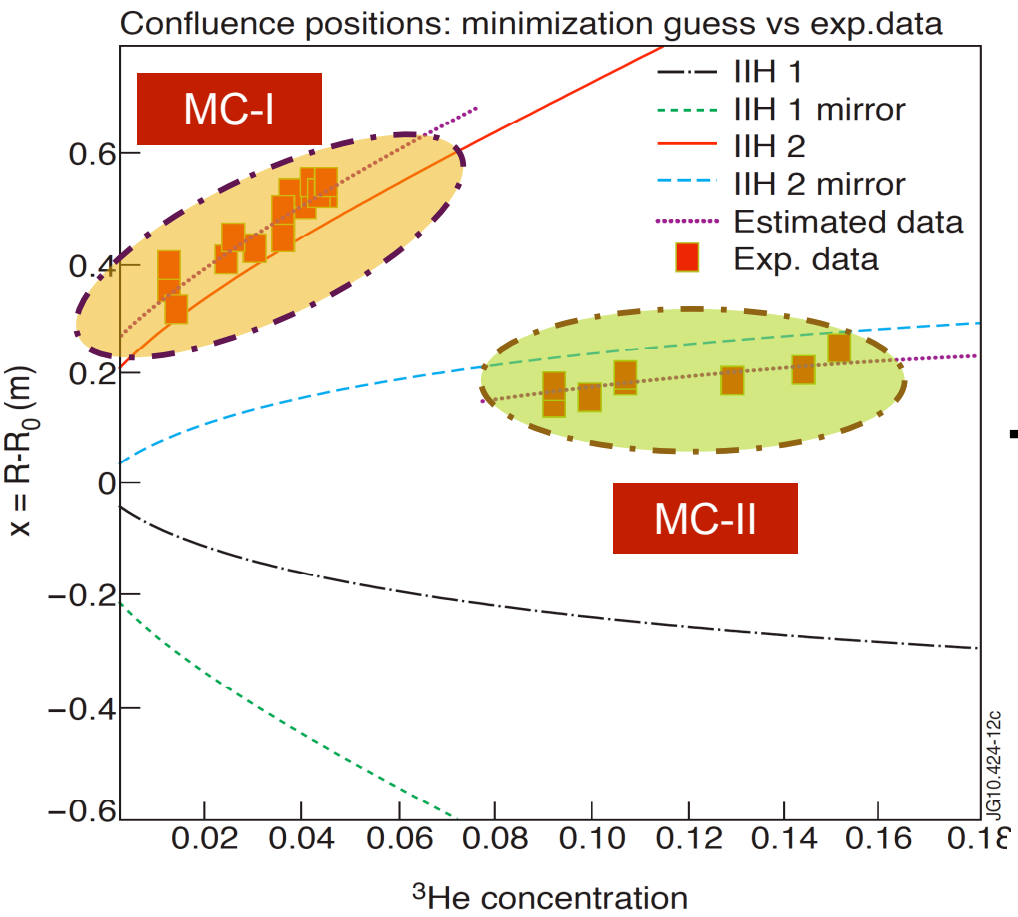
MC locations summary

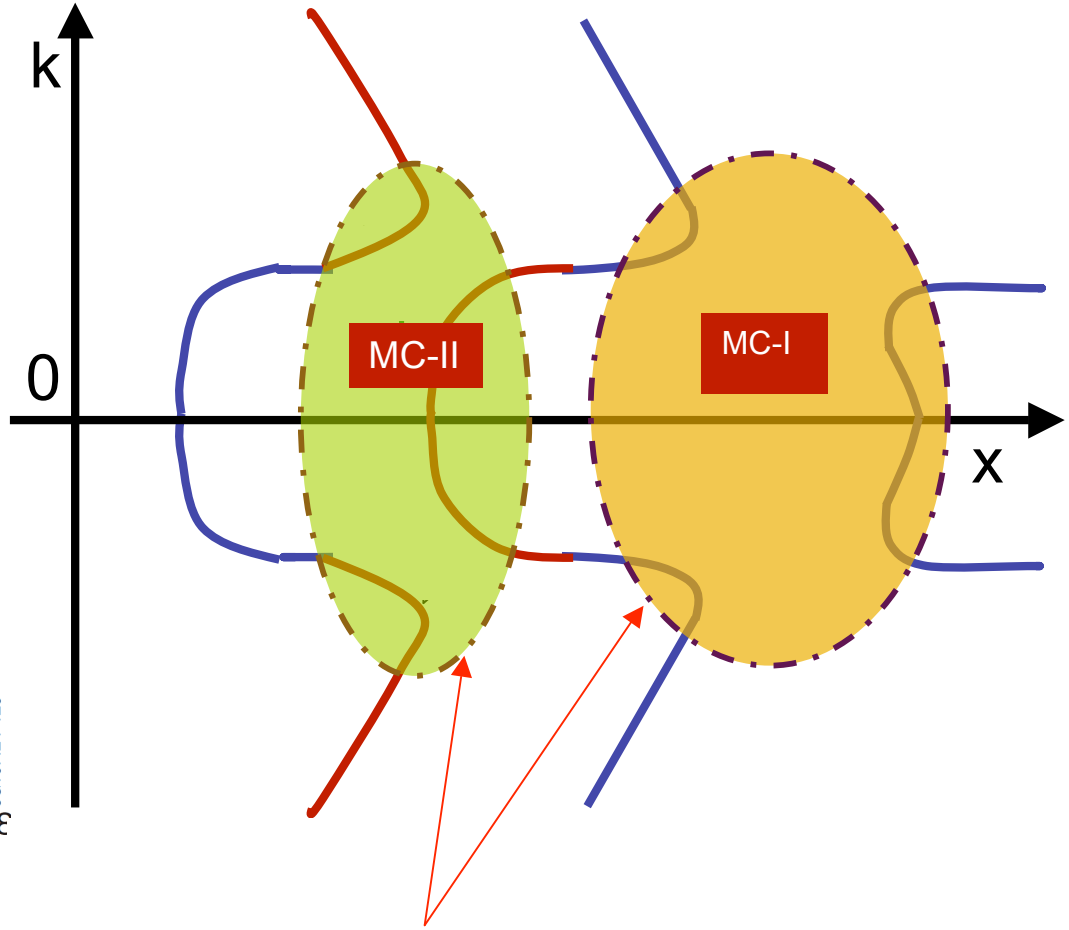


MC Location & Plasma Composition



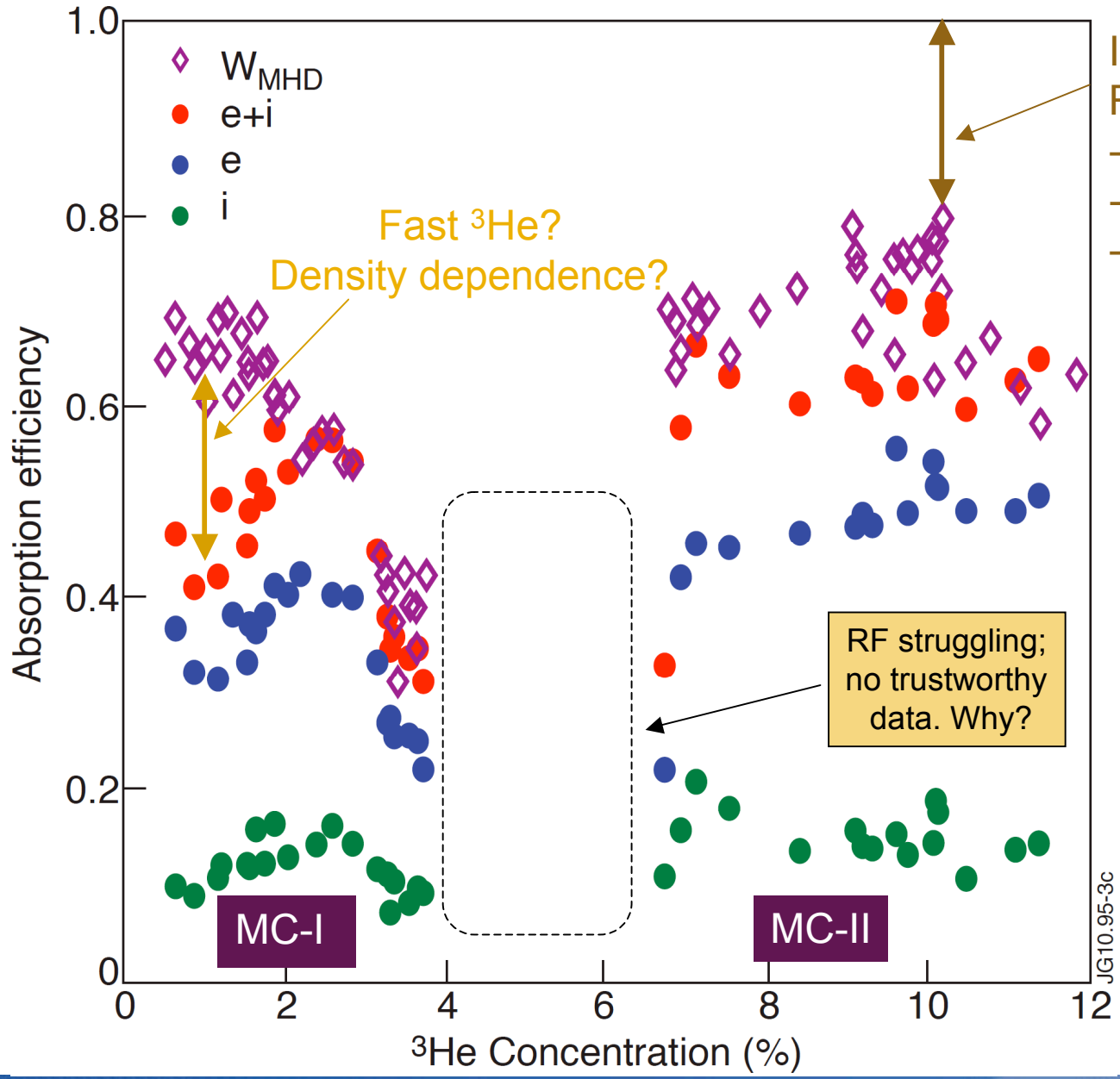
- X[D], X[C], X[^{4}He] unknown
- RTC formula results from divertor light so X[^{3}He (IIH)] ≠ X[^{3}He (RTC)] but ***correlated***; assume X[^{3}He (IIH)] = a X[^{3}He (RTC)] + b
- Minimization set up to find X[D], X[C], X[^{4}He], a, b for which experimental $P_{e,max}$ locations fall on the theoretically predicted locations for the MC positions for *both* MC-I and MC-II.
- Result: X[D-like]~20-25%, a~1.3-1.6, b~0.
- X[D]~7-8% consistent with TOFOR prediction; X[C]~2-3% in agreement with expected X[C] in carbon-wall machine





2 mode conversion layers

Power Deposition : Summary



Incomplete RF absorption
- Fast D
- ΔN
- P_{loss} (radiation, …)

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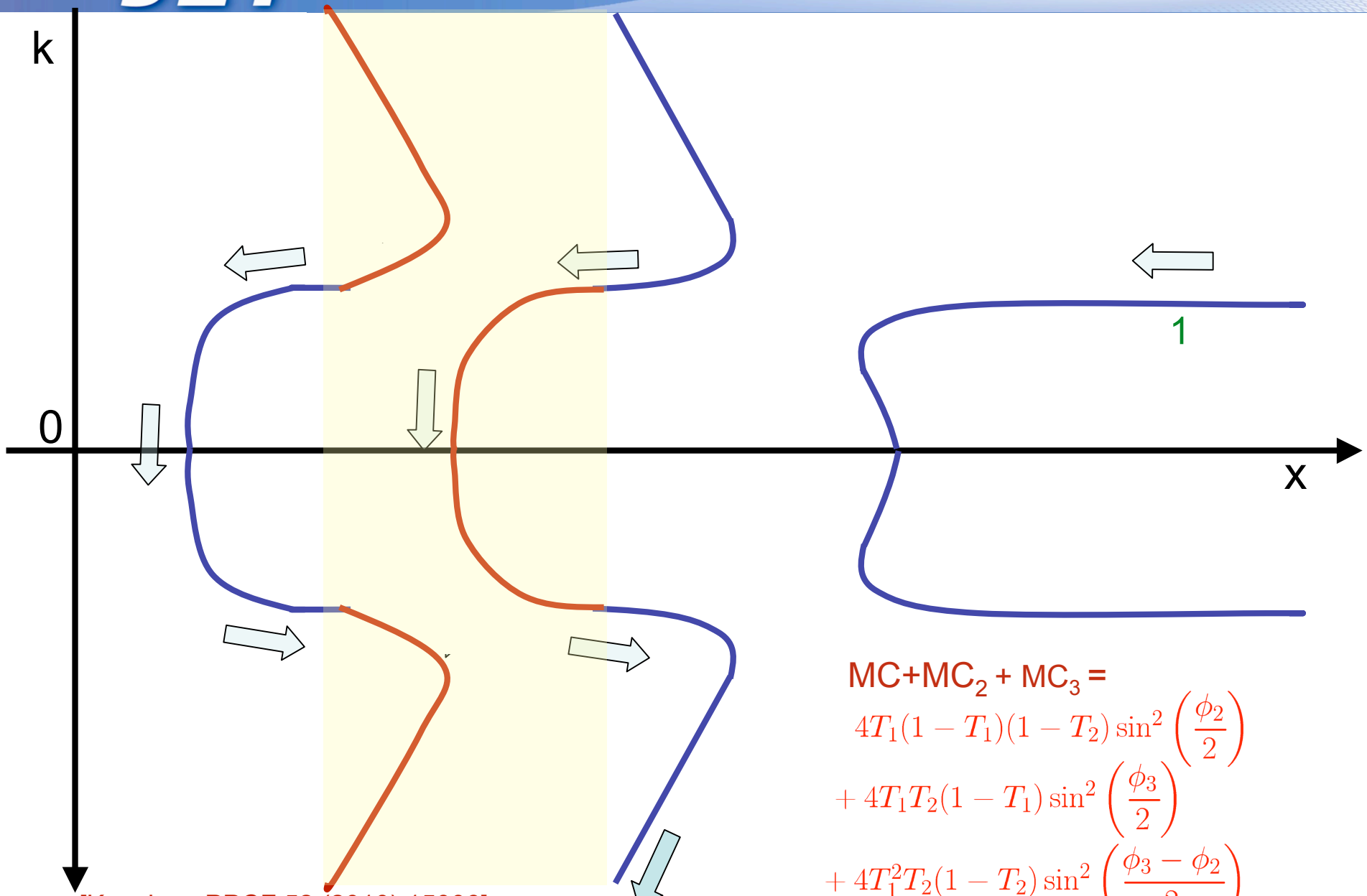
MC physics extended: the Fuchs-Kazakov effect



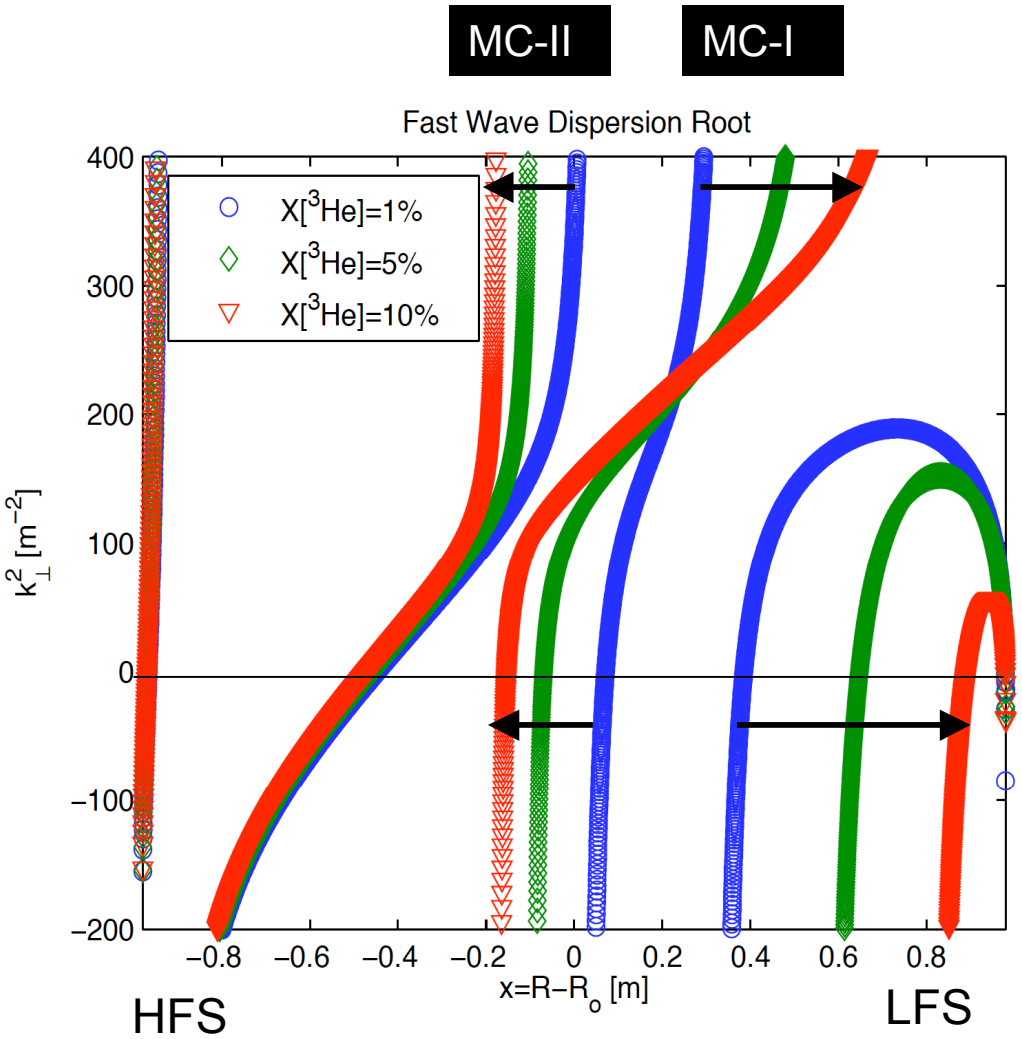
MC+MC$_2$ + MC$_3$ =

$$4T_1(1-T_1)(1-T_2)\sin^2\left(\frac{\phi_2}{2}\right)$$
$$+\,4T_1T_2(1-T_1)\sin^2\left(\frac{\phi_3}{2}\right)$$
$$+\,4T_1^2T_2(1-T_2)\sin^2\left(\frac{\phi_3-\phi_2}{2}\right)$$

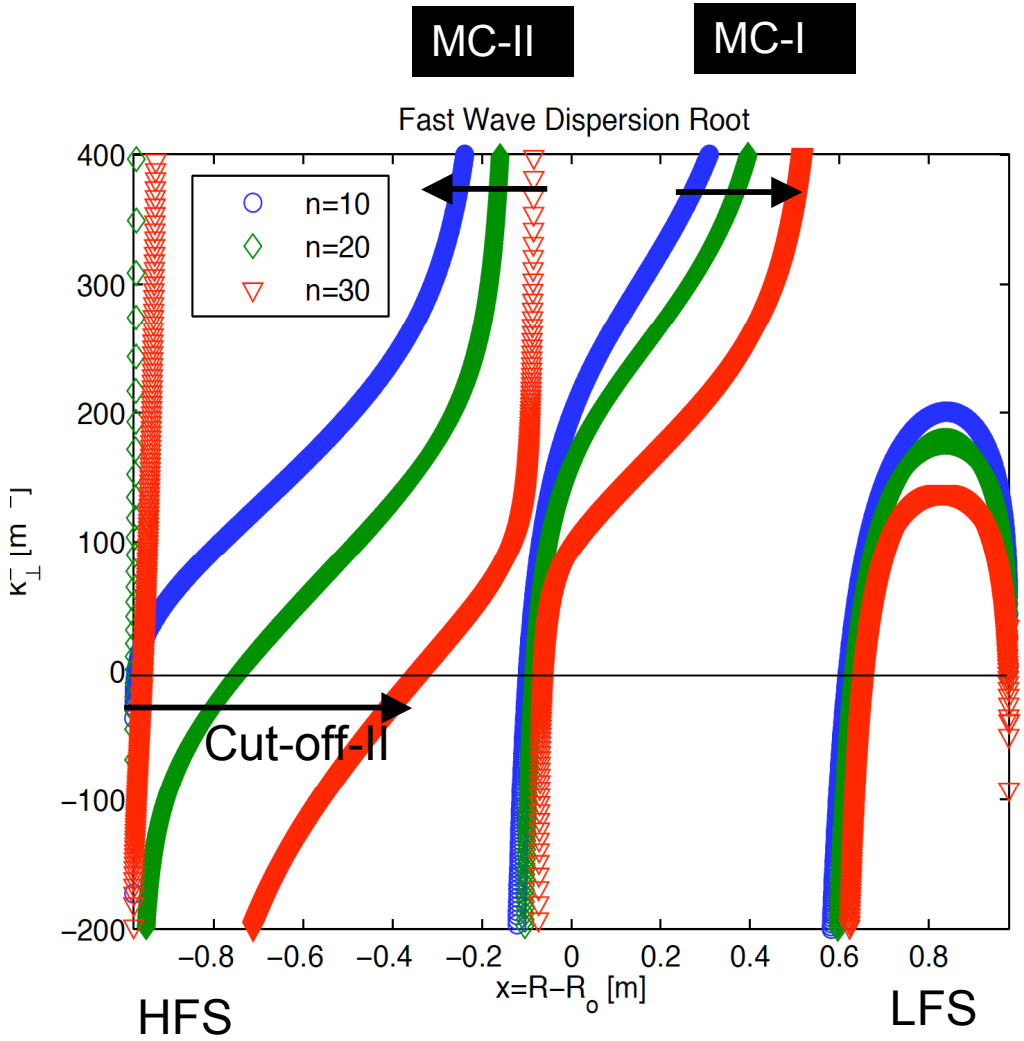
[Kazakov, PPCF 52 (2010) 15006]

Dependence MC/cut-off location on …

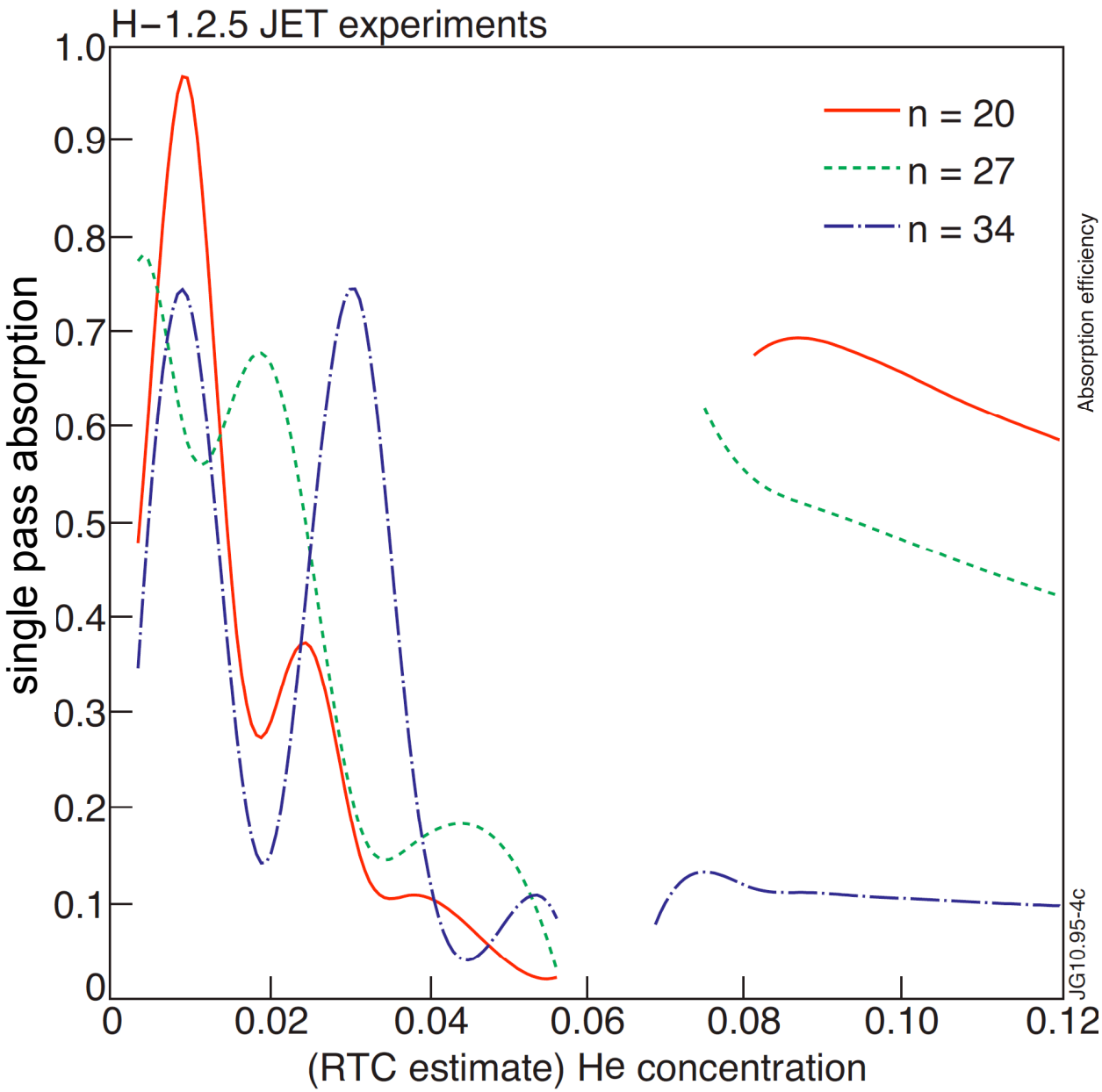
Dependence on X[^{3}He]

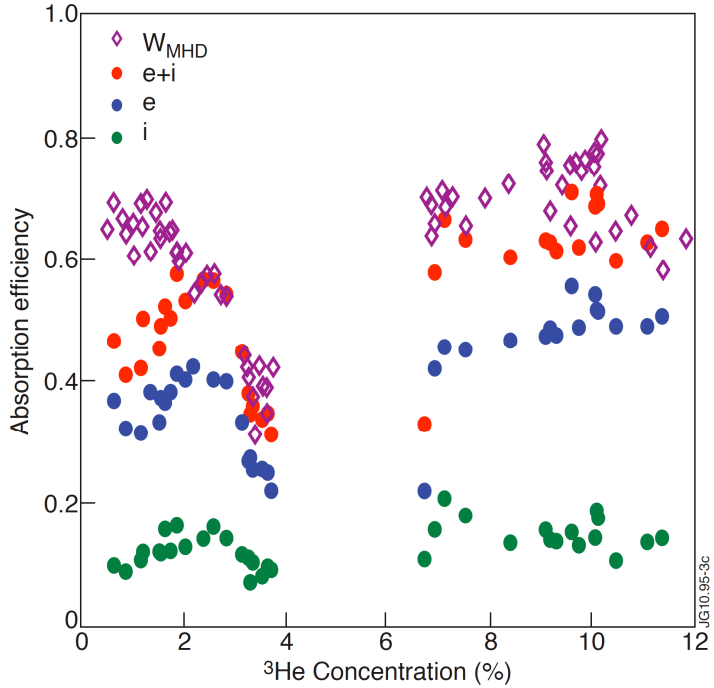


Dependence on n_{tor}



Absorptivity





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Conclusions/Summary

- plasma contamination ⇒ **multiple confluences in plasma**:
  - MC & FW cut-off sensitive to various parameters (α_n, X[…], n_{tor})
  - interplay ≠ confluences: Fuchs effect → Fuchs-Kazakov effect
  - low efficiency region at X[^{3}He]~4-6%: MC/cut-off in front of antenna

- ~ efficient heating up to ~70% (in MC regime) in (^{3}He)-H

- stronger e than i response (P_e/P_{tot}~0.4-0.5; P_i/P_{tot}~0.1-0.15) from very low X[^{3}He]

Had no time to mention but:

- high rotation velocities: ~8krad/s (comparable to (^{3}He)-D expts.)

- evidence of fast particles
  - RF enhanced NBI D tail similar to (^{3}He)-D expts. @ high X[^{3}He]
  - fast ^{3}He particles @ low X[^{3}He]

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Related work at this conference

A-42: Y. Lin

Flow drive analysis on Alcator C-Mod (with a side-glance at JET)

B-23: M.-L. Mayoral

ICRH in the 'new' JET with Be wall and W divertor

I-17: E. Lerche

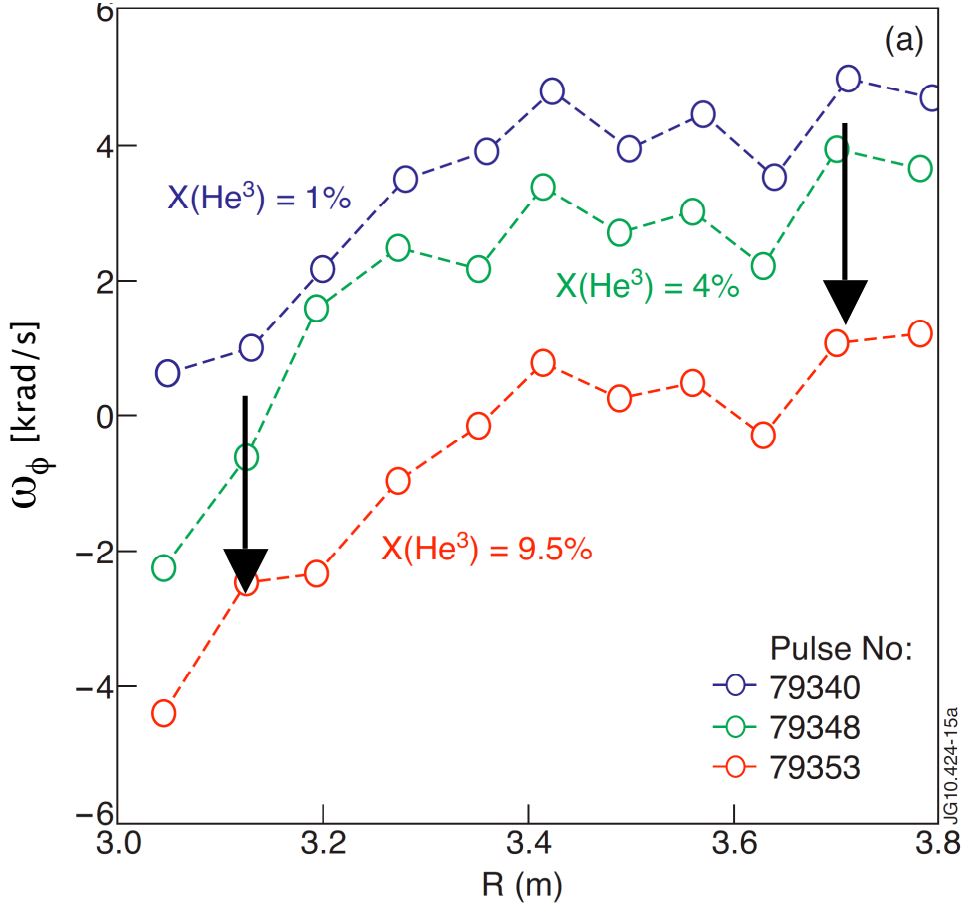
ICRH scenario's for ITER half-field phase tested in JET

EXTRA slides

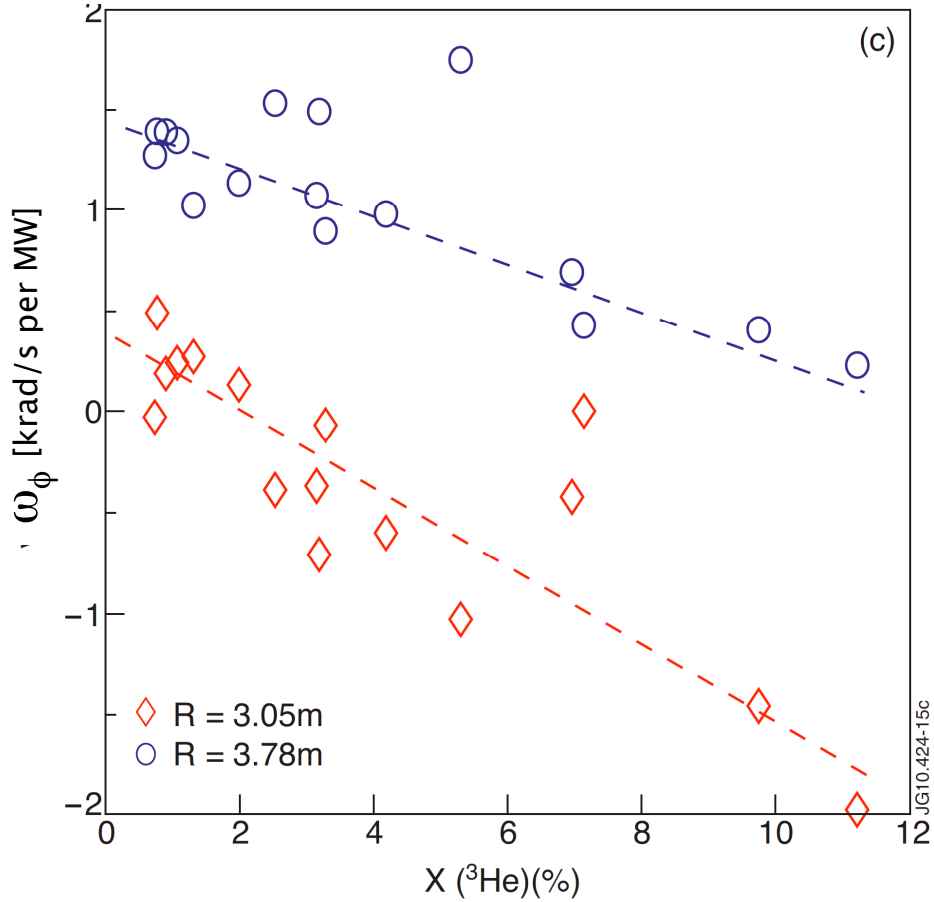
ICRF induced rotation: profiles

- 33MHz, dipole
- B_o = 3.41T
- P_{RF}~4MW

toroidal rotation



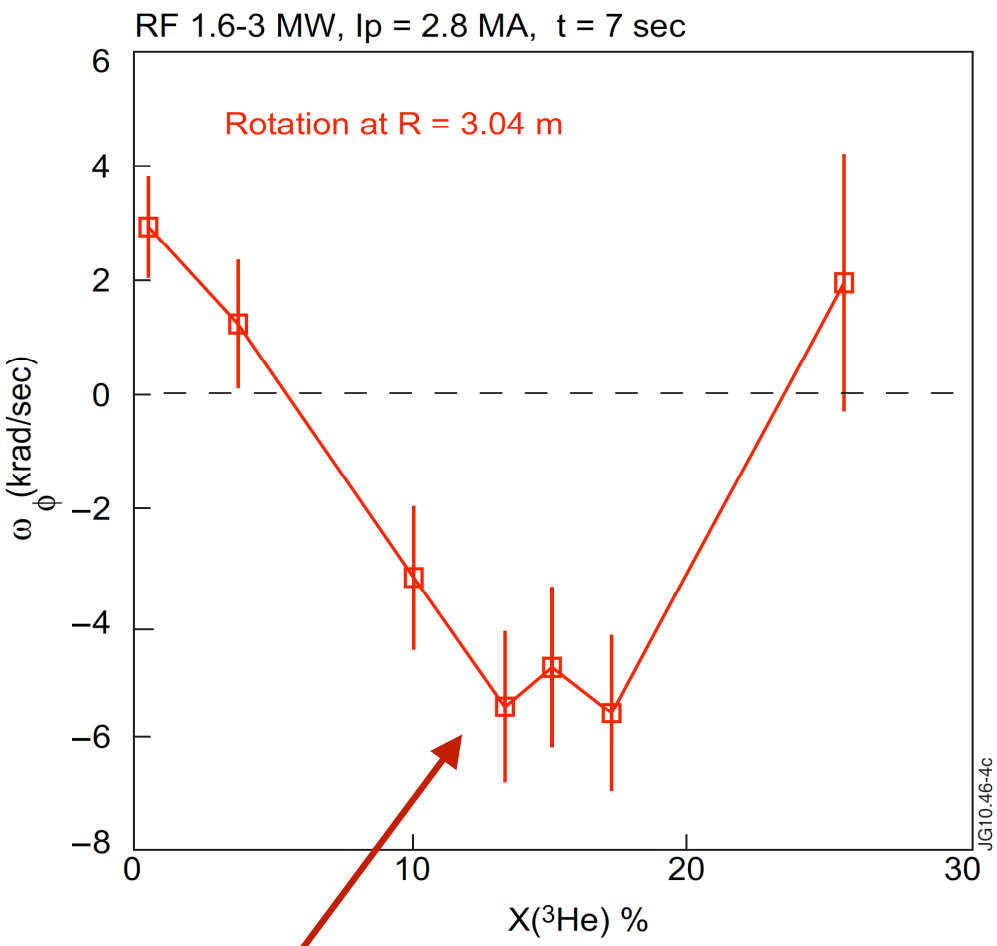
toroidal rotation



In (^{3}He)-D only central torque observed (~central MC).
Can overall drag come from multiple MC?

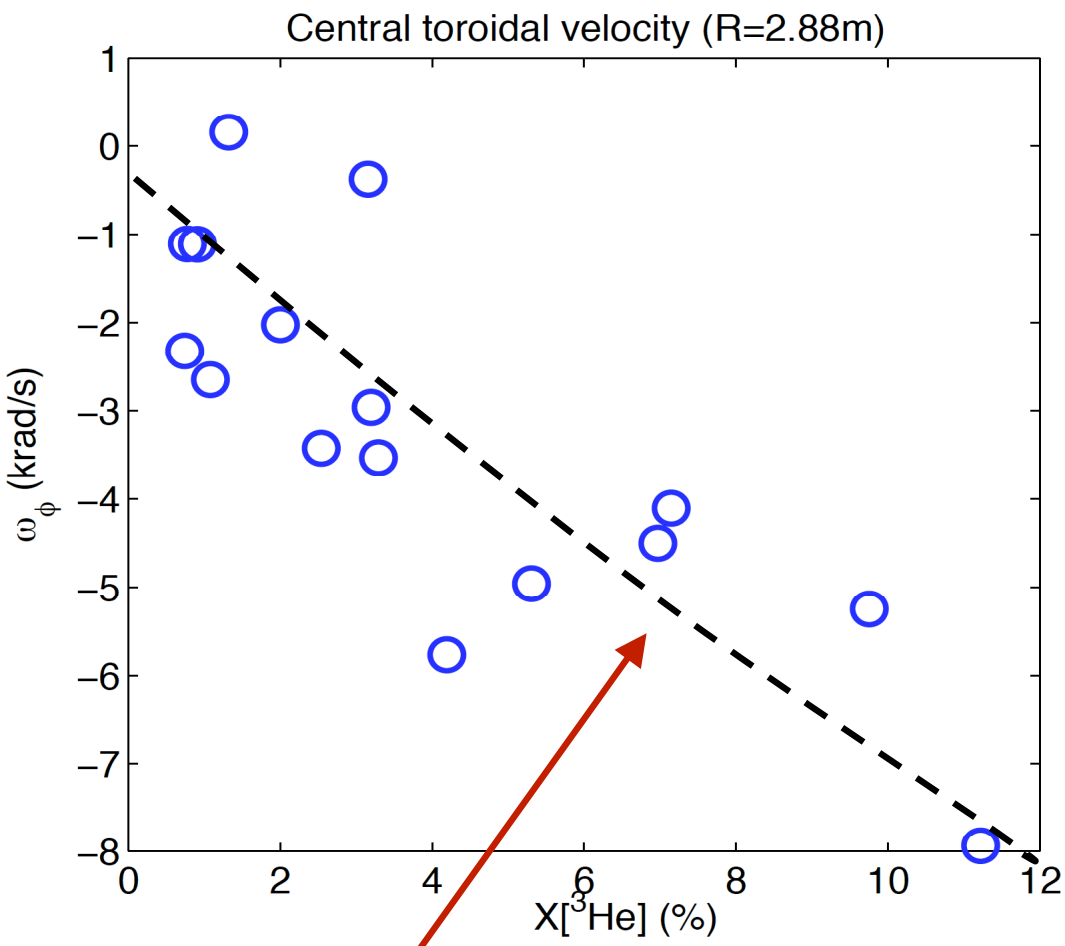
ICRF induced rotation: correlation with X[^{3}He]

(^{3}He)-D



Clear maximum observed
when MC is efficient

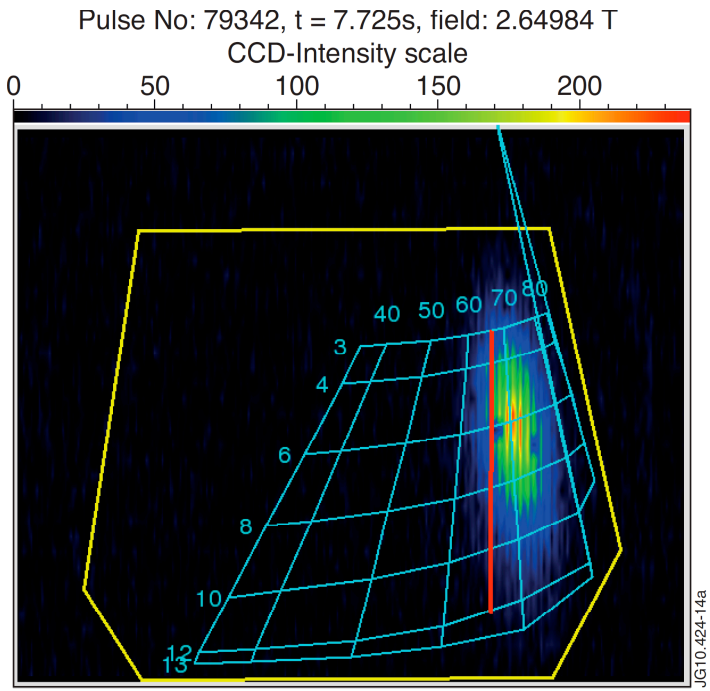
(^{3}He)-H



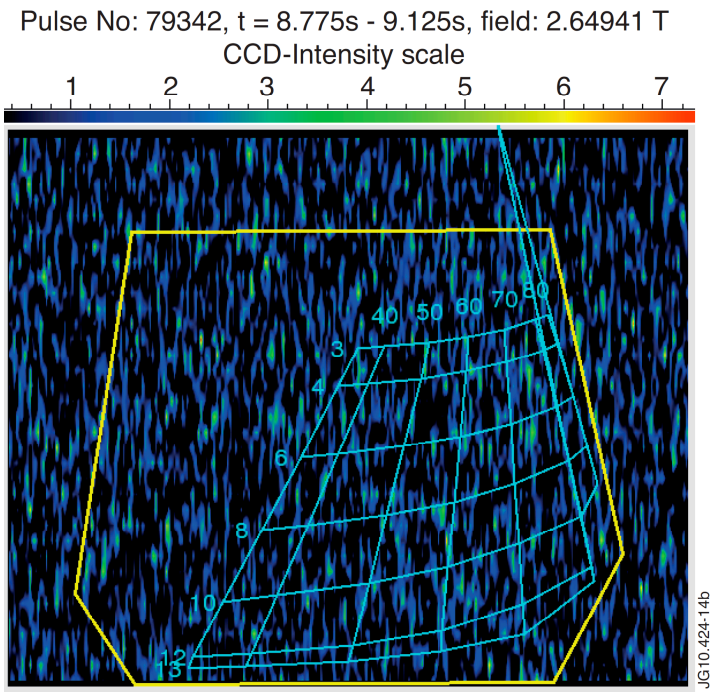
No clear maximum observed
… but very different MC + high X[^{3}He] not reached

See also
Y.Lin: Poster A-42

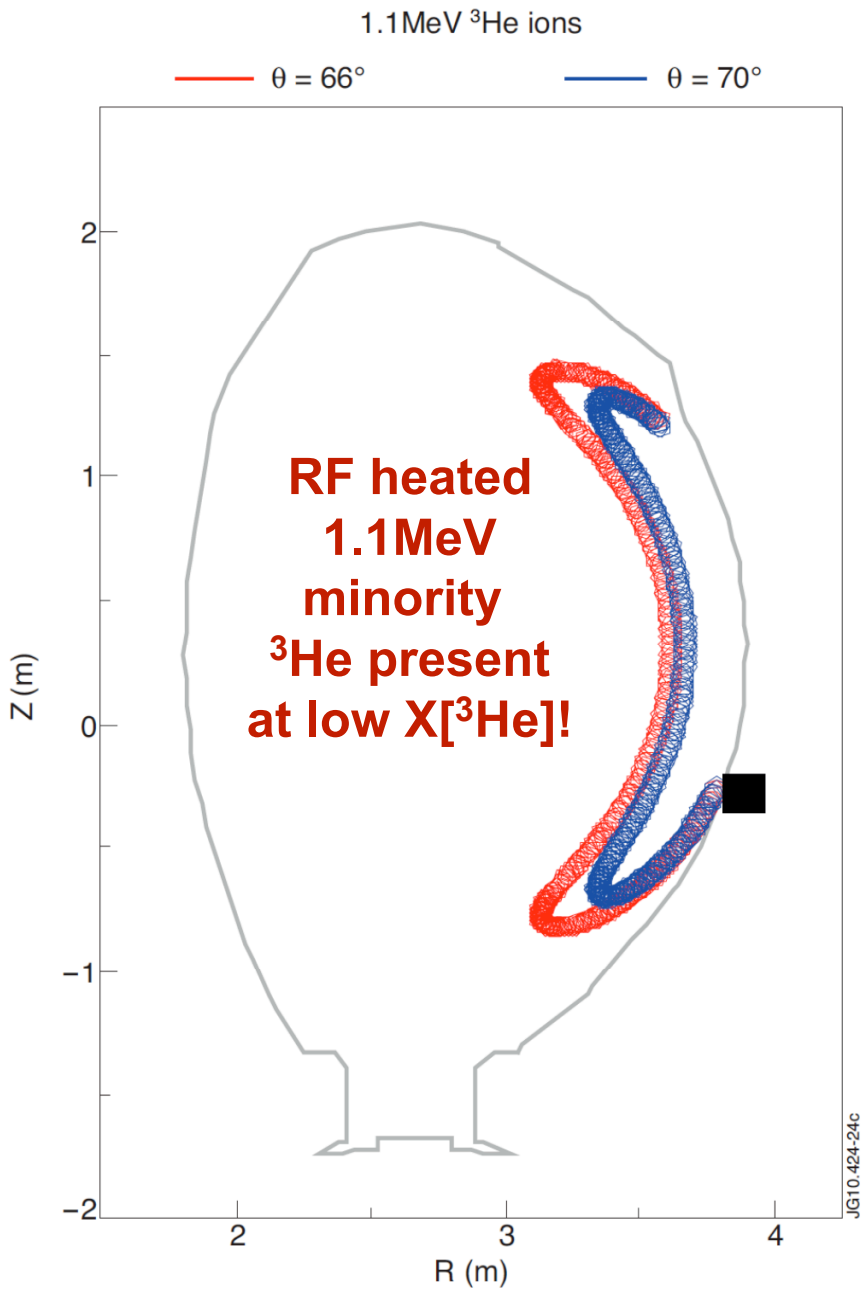
Evidence of fast ^{3}He particles: scintillator probe



P_{RF}~4MW
X[^{3}He]=2%

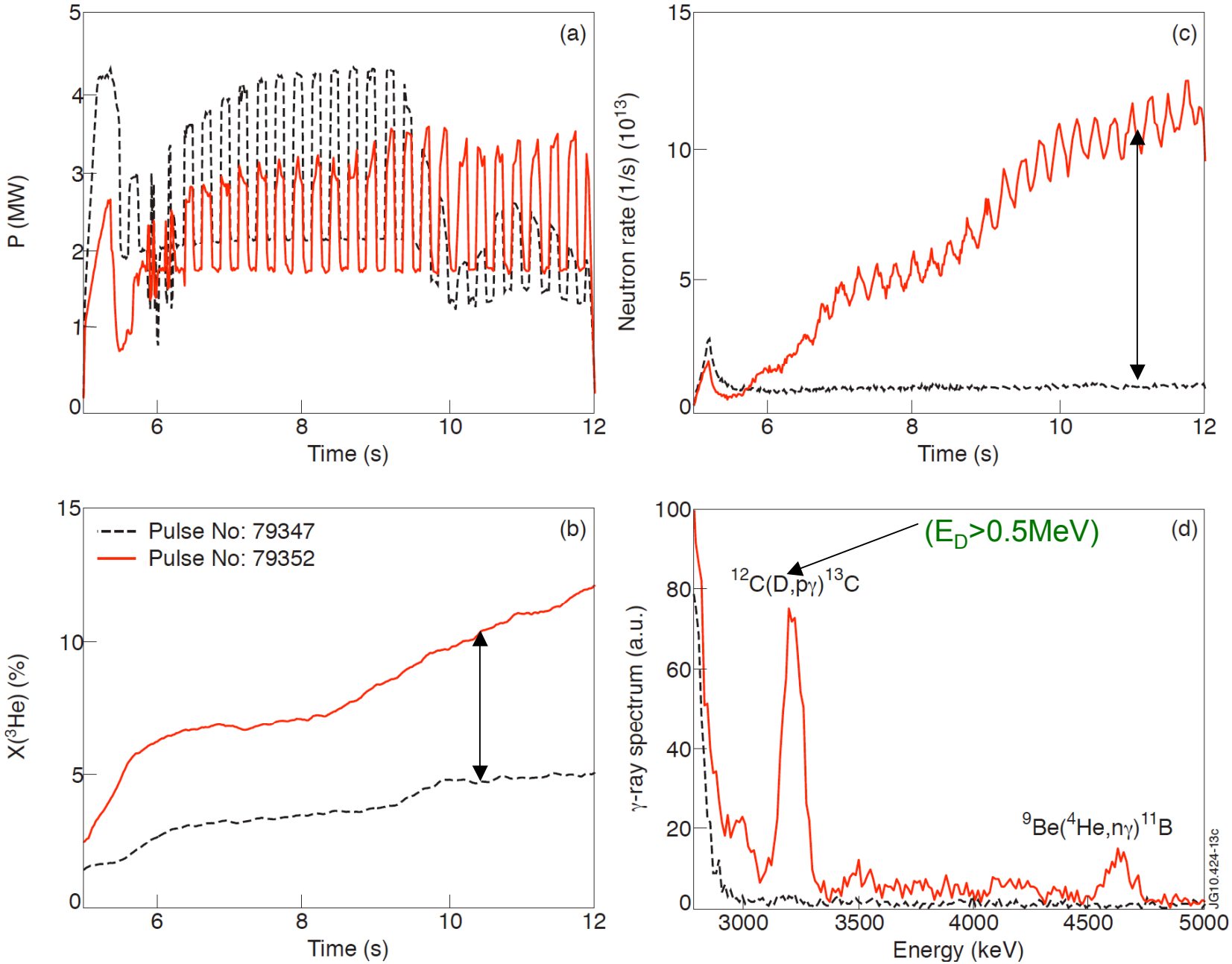


P_{RF}~2MW
X[^{3}He]=2.5%



[Kiptily, to appear in PPCF]

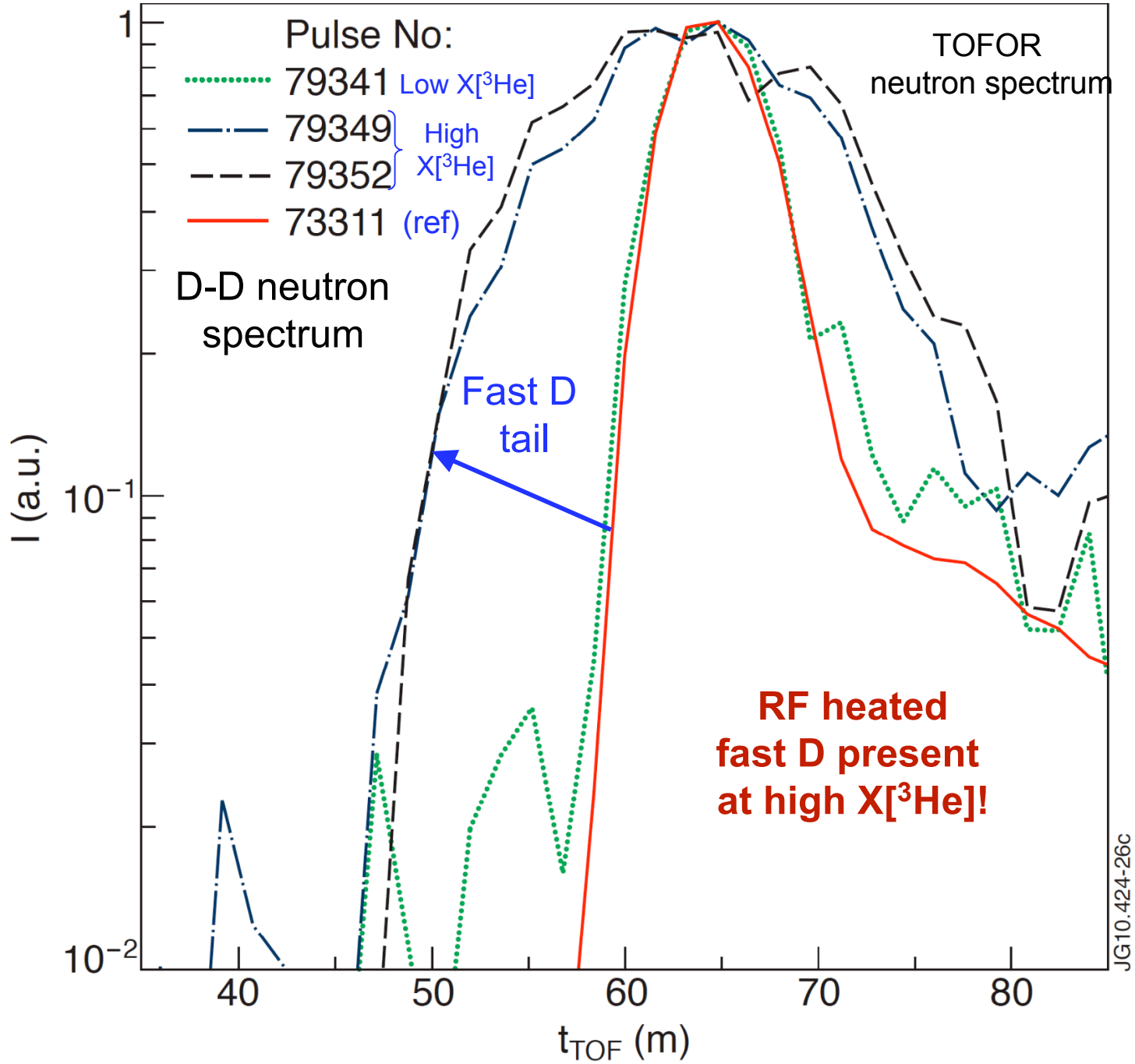
Evidence of fast particles at high X[^{3}He]: gamma rays



Fast D present!

Doppler shifted N=1 D resonance inside plasma (cf (^{3}He)-D expts)

Evidence of fast D at high X[^{3}He]: TOFOR



[Giacomelli L. et al., Rev. *Sci. Instr.*, ***79***, (2008), 10E514]

[M. Gatu Johnson et al., Rev. Sc. Instr. **81**, (2010) 10D336]