Status of the JET Faraday cup lost alpha particle diagnostic KA-2

*F.E. Cecil[1], V. Kiptily[2], D. Darrow[3], A. Murari[2], and JET-EFDA contributors**

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

1 Colorado School of Mines, Golden Colorado, USA

2 JET-EFDA, Abingdon, UK

3 Princeton Plasma Physics Lab, Princeton, New Jersey, USA

****Appendix of F. Romanelli et al., Proceedings of the 23rd IAEA Fusion Energy Conf. 2010, Daejeon, Korea***

The JET lost alpha particle diagnostic KA-2 was installed in JET in 2005 to investigate lost energetic ions in general and lost alpha particles from possible future d-t plasmas in particular. We will summarize our operational experience with this diagnostic over the past six years. In particular we will describe the response of KA-2 to ICRH, scattered UV, Langmuir type behavior and various machine magnetic fields. We will also summarize the measurement of lost energetic ions during ICRH heated deuterium/helium plasmas during the 2009 JET campaign. Finally we will discuss the theoretical and experimental evidence for the insensitivity of this diagnostic to intense fluxes of fast neutrons as the basis for the consideration of such a device as a lost alpha diagnostic for ITER and other future burning plasma experiments.

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(1) Conceptual design of KA2 Faraday Foil lost alpha diagnostic

(2) Measured and calculated responses of a set of thin Faraday foils as a lost alpha particle diagnostic for high yield d-t plasmas to:

(a) Fast neutrons
(b) Energetic gamma rays
(c) UV radiation/Langmuir
(d) ICRH
(e) Time varying magnetic fields

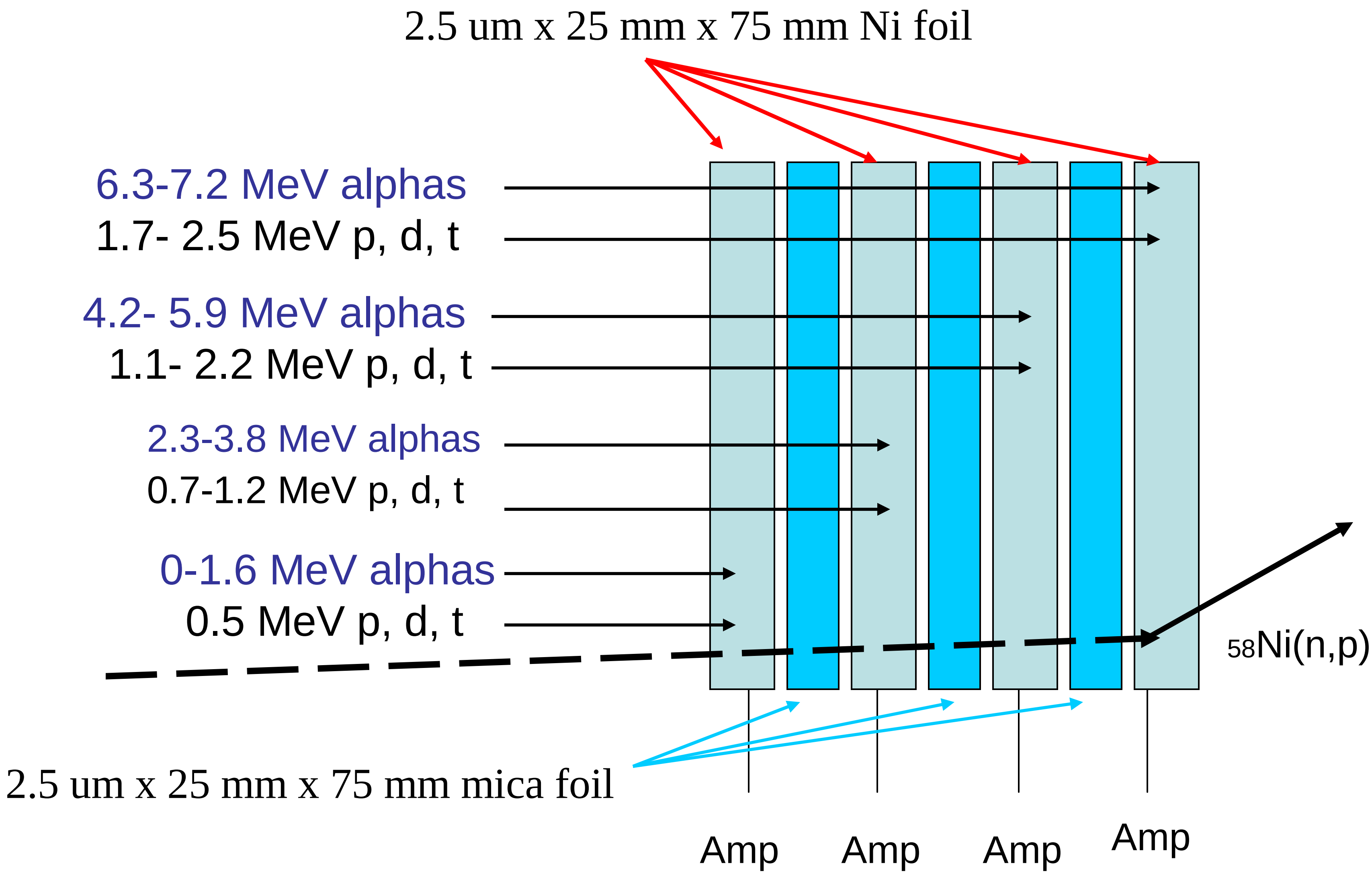
(3) Recent observations on JET

(a) Lost α's / d's with energies up to 7 MeV during ICRH ^{4}He plasmas

(b) Energetic ^{3}He/d's during mode conversion plasmas

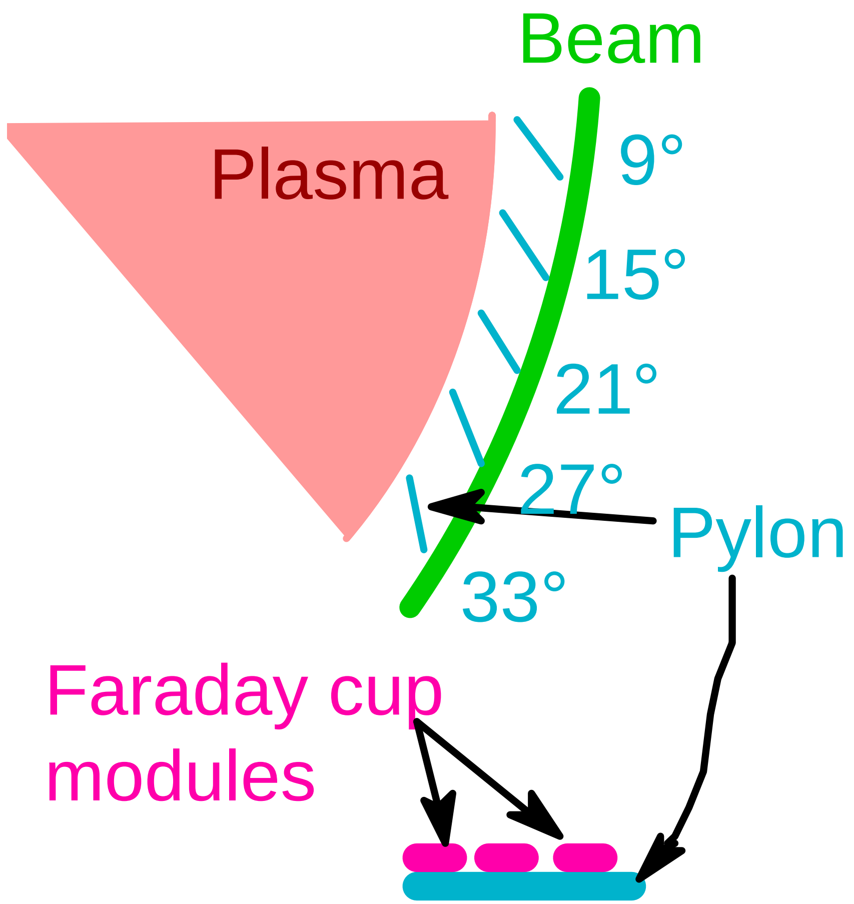
(c) Rough calibration of KA3 PMT current during ICRH ^{4}He plasmas

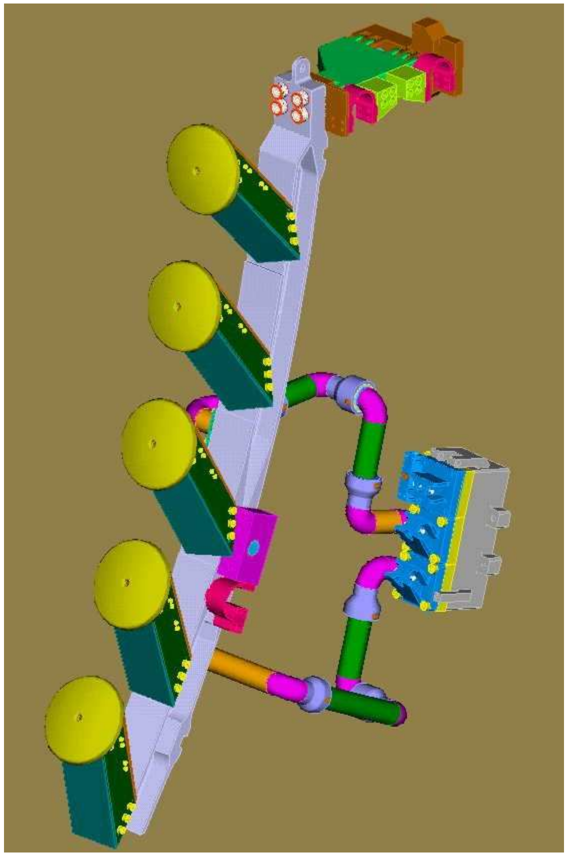
(1) Conceptual design JET Lost Alpha Diagnostic KA-2; 2005



Darrow et al.;Fus. Eng. and Design, **74**, 853, (2005)

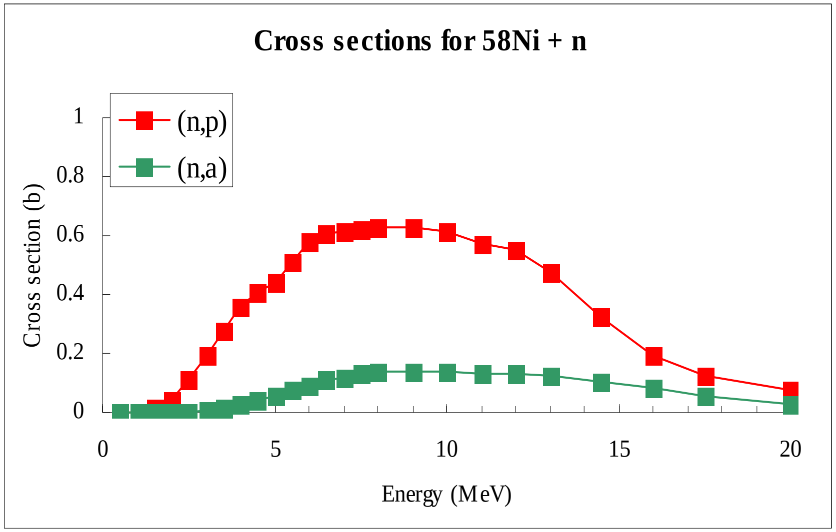
Schematic diagram of poloidal distribution of 5 sets of foils





Response (a): Fast neutrons

Calculation of fast neutron induced currents



φ = Neutron flux = 6 E13 /cm2 - s;
σ = Cross section = 6 E-25 cm2;
n = Target density = 2.1 E 19 /cm2;
reaction rate density = $\varphi * \sigma * n$ = 7.4 E 8 /cm2-s
predicted current = - 0.12 nA/cm2

Measurements of fast neutron induced currents (per cm^2 target)

Machine	Flux(n/cm2/s)	Msd current	Pred current
TFTR(95) [a]	1E12	< 100 nA	0.1 nA
JET(97) [b]	3E12	<5 nA	0.3 nA
TRIGA(03) [c]	1E13	1.2 nA	0.5 nA
JAERI(01) [d]	3E14	30 nA	n/a
ITER	6E13		6 nA

- Refs: a RSI **68**, p. 363, b RSI **70**, p. 1151, c RSI **74**, p. 1749, d FED **56**, p. 907

Response (b): Energetic gamma rays

Calculation of gamma ray induced currents (per cm^2 target)

Attenuation coefficient at 5 MeV = 0.03 cm^2/gm

Thickness of 2.5 micron Ni foil = .002 gm/cm^2

Gamma ray flux= $6\ 10^{13}\ /cm^2 - s$;

Number absorbed= $6\ 10^{13}\ (1 - e^{-\ Atten\ *\ Thk})$

= $4\ 10^{13}/cm^2$-s= 0.6 nA/cm^2

Measurement of gamma ray induced currents (per cm^2 target)

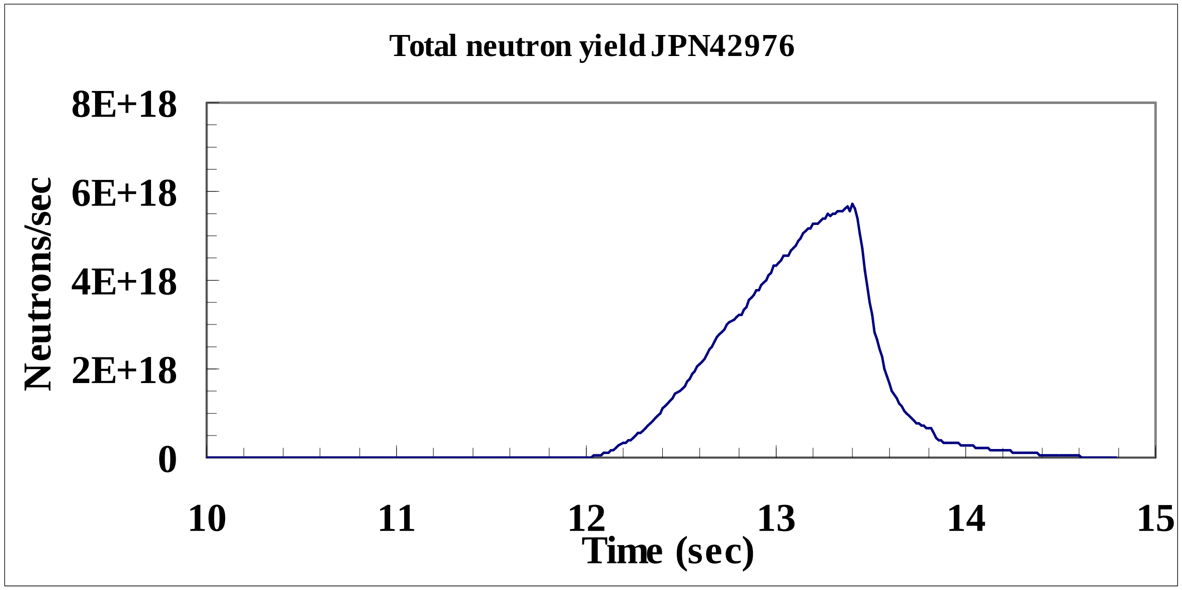
Induced charge from 2.5 micron foil ~ $2.5\ 10^{-23}$ Coulomb/ (γ/cm^2) [a]

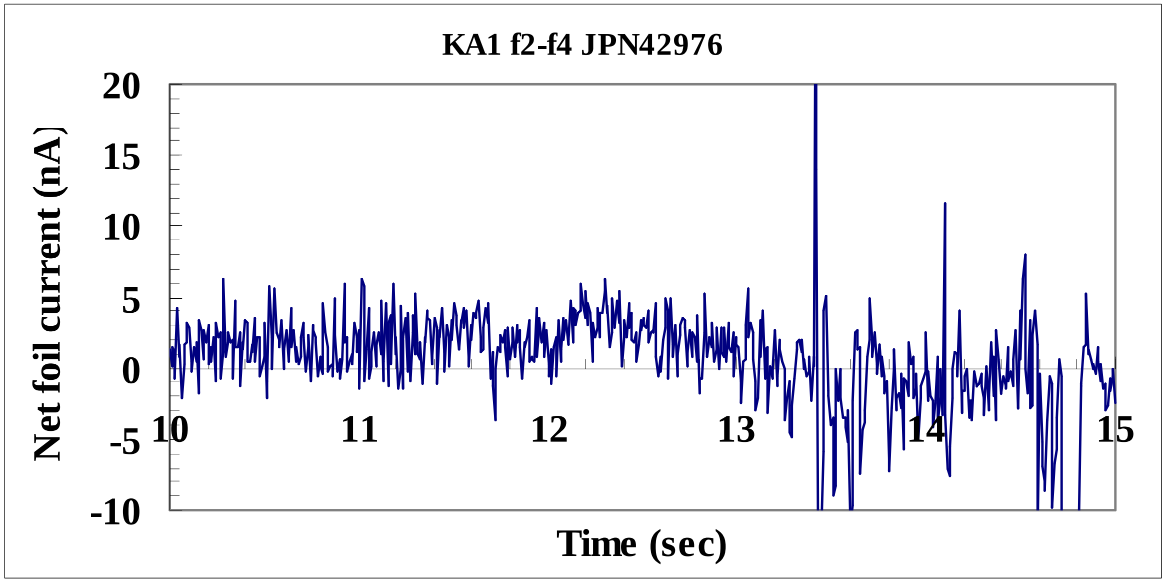
Measured current for γ flux of $6\ 10^{13}$ /cm2 - s ~ 1.2 nA/cm^2

[a] X. Ouyang et al. IEEE Trans Nucl Sci vol 54, p 1239 (2007)

Combined observed neutron/gamma insensitivity

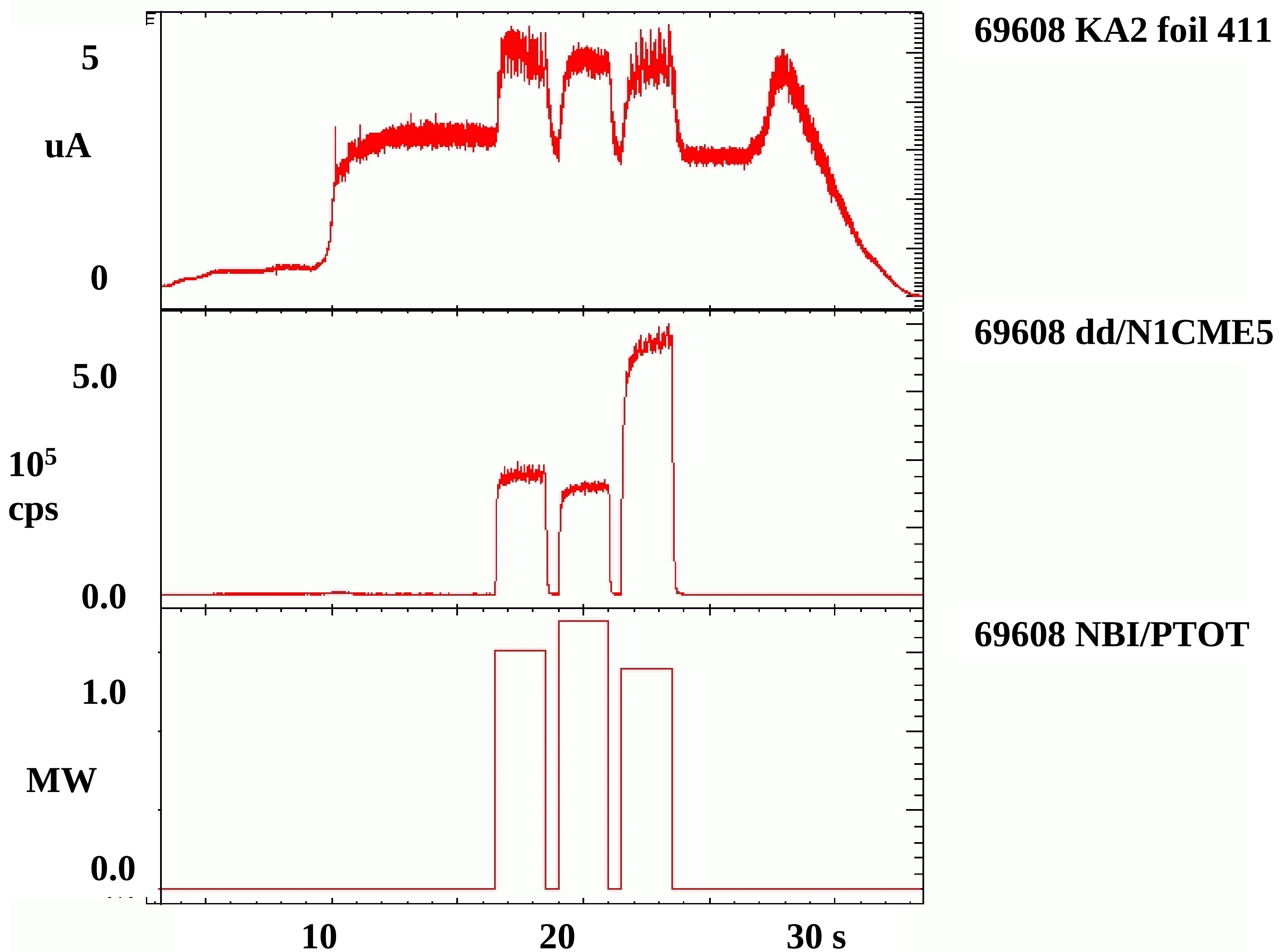
Example: KA-1 on JET for 16 MW d-t pulse



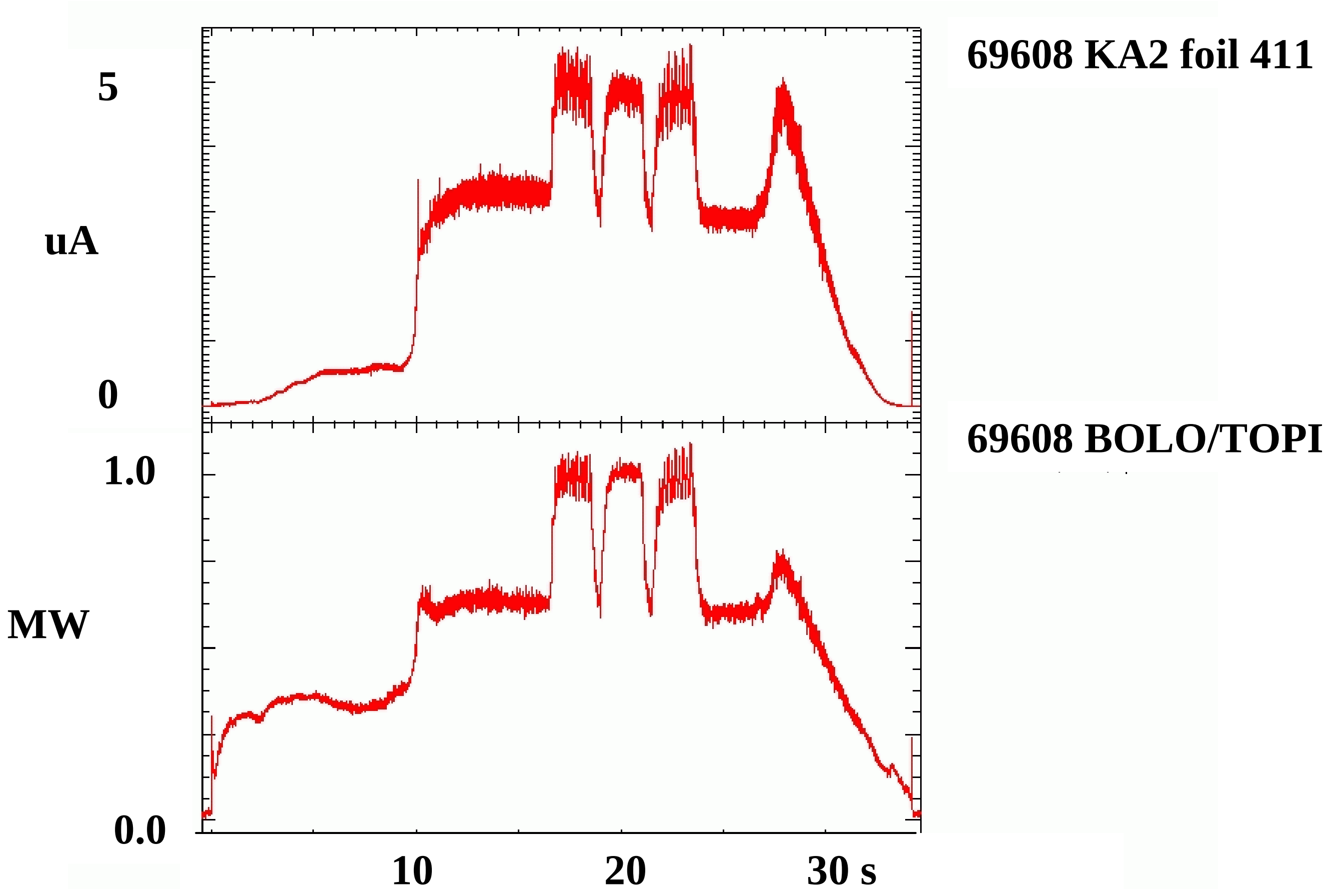


Response (c): Scattered UV/Langmuir

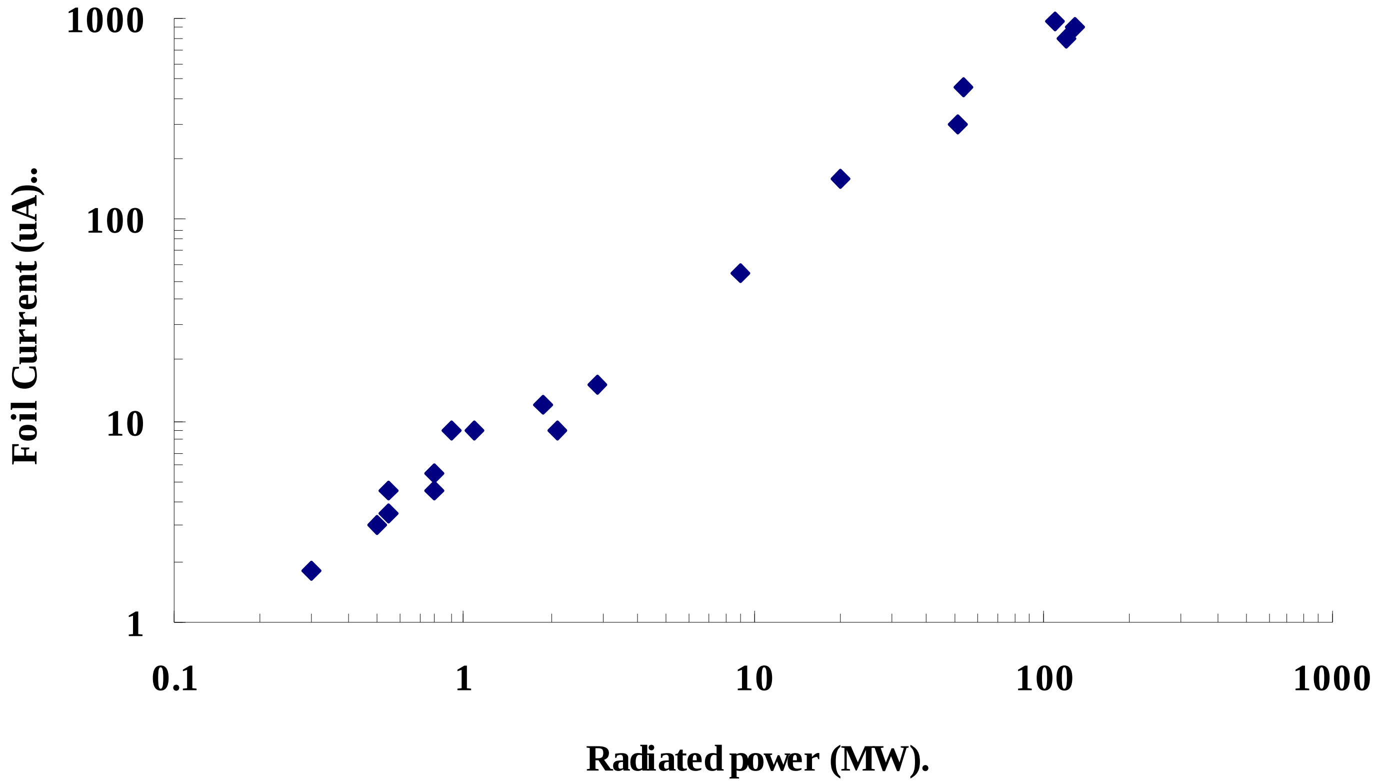
Observation of significant (μA) current during Ohmic heating



Observed strong correlation with bolometer which is good measure of UV/Langmuir



Comparison of front foil current and bolometric power

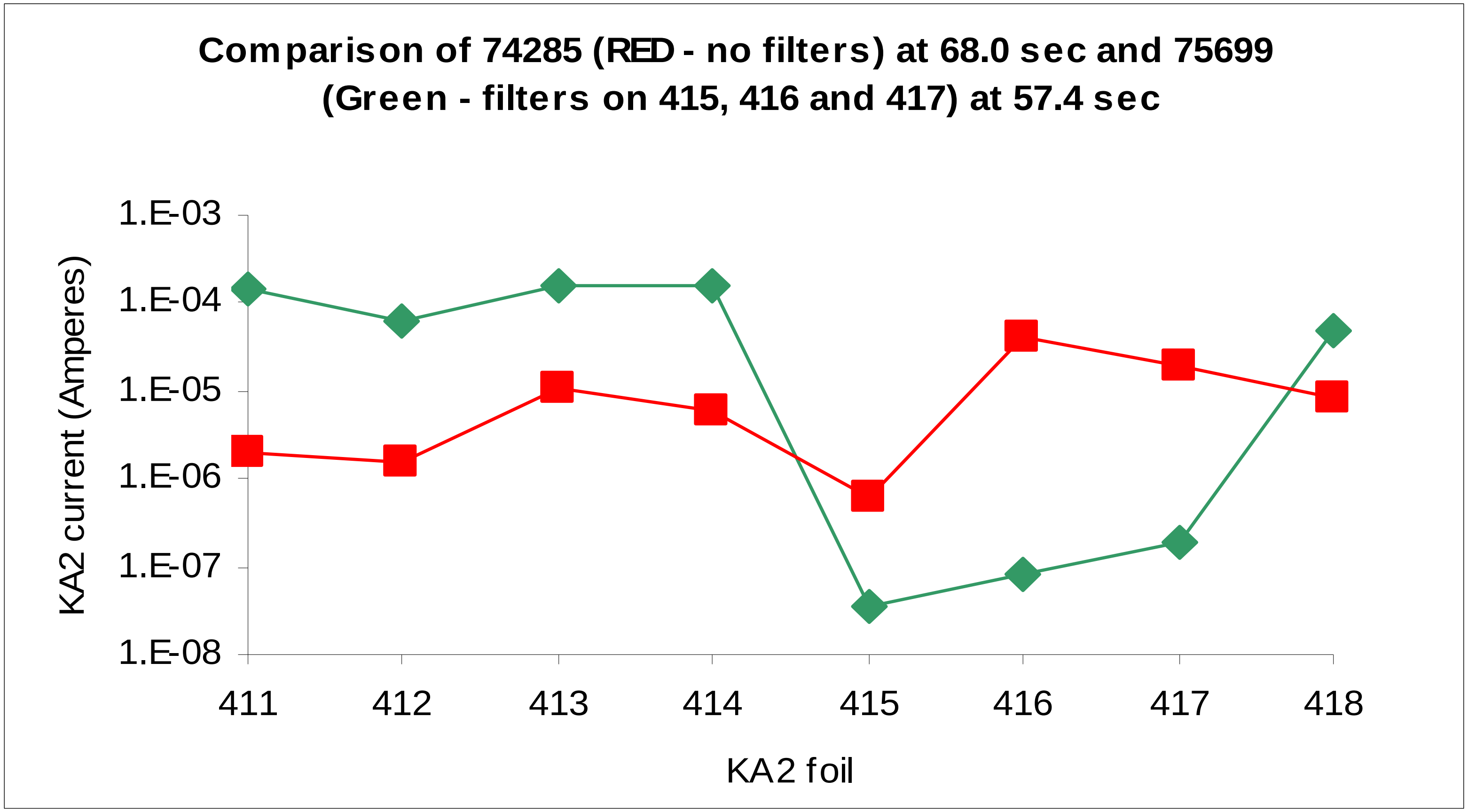


Conclusion ~ 6 μA front foil current per MW total bolometric power:

Solution: 1) Install very thin (0.1 μm) Ni foil to suppress UV/low energy ions
2) Measure BOLO and subtract using 6 μA /MW

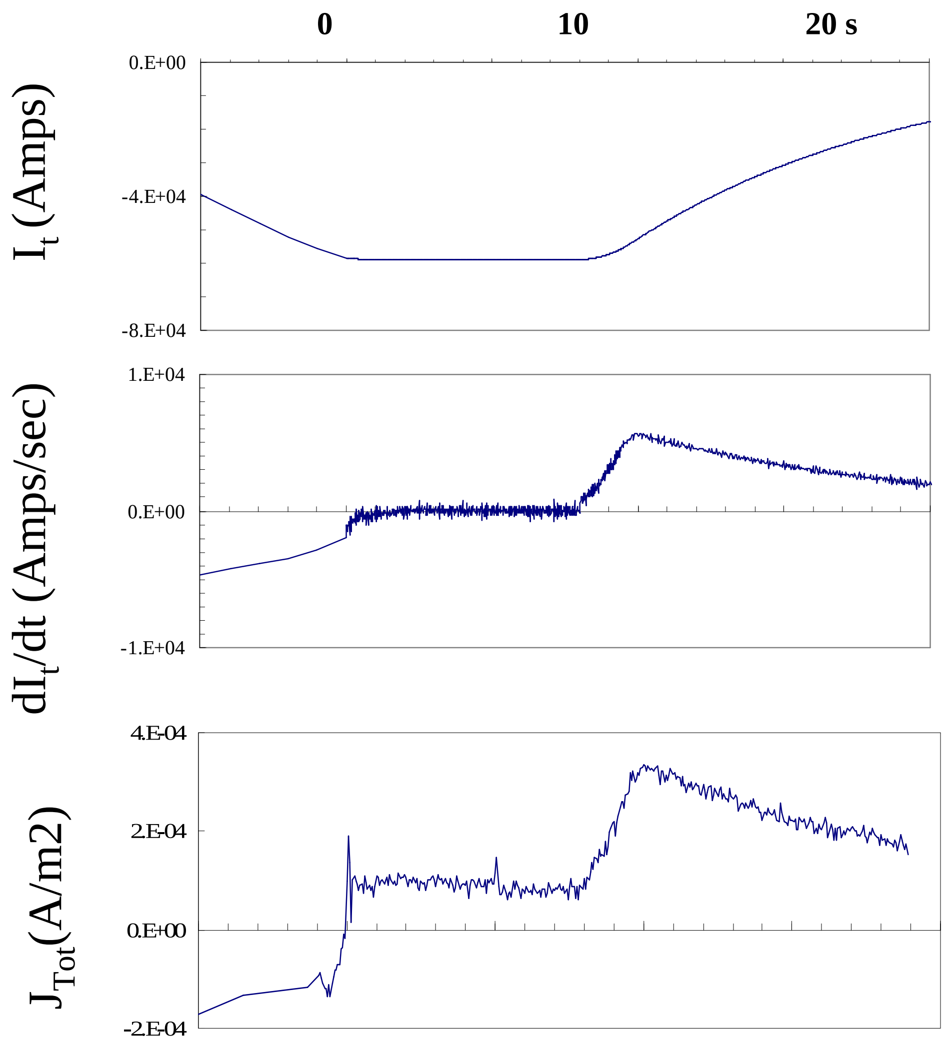
Response (d): >100 µA of noise during high power (6 MW) ICRH

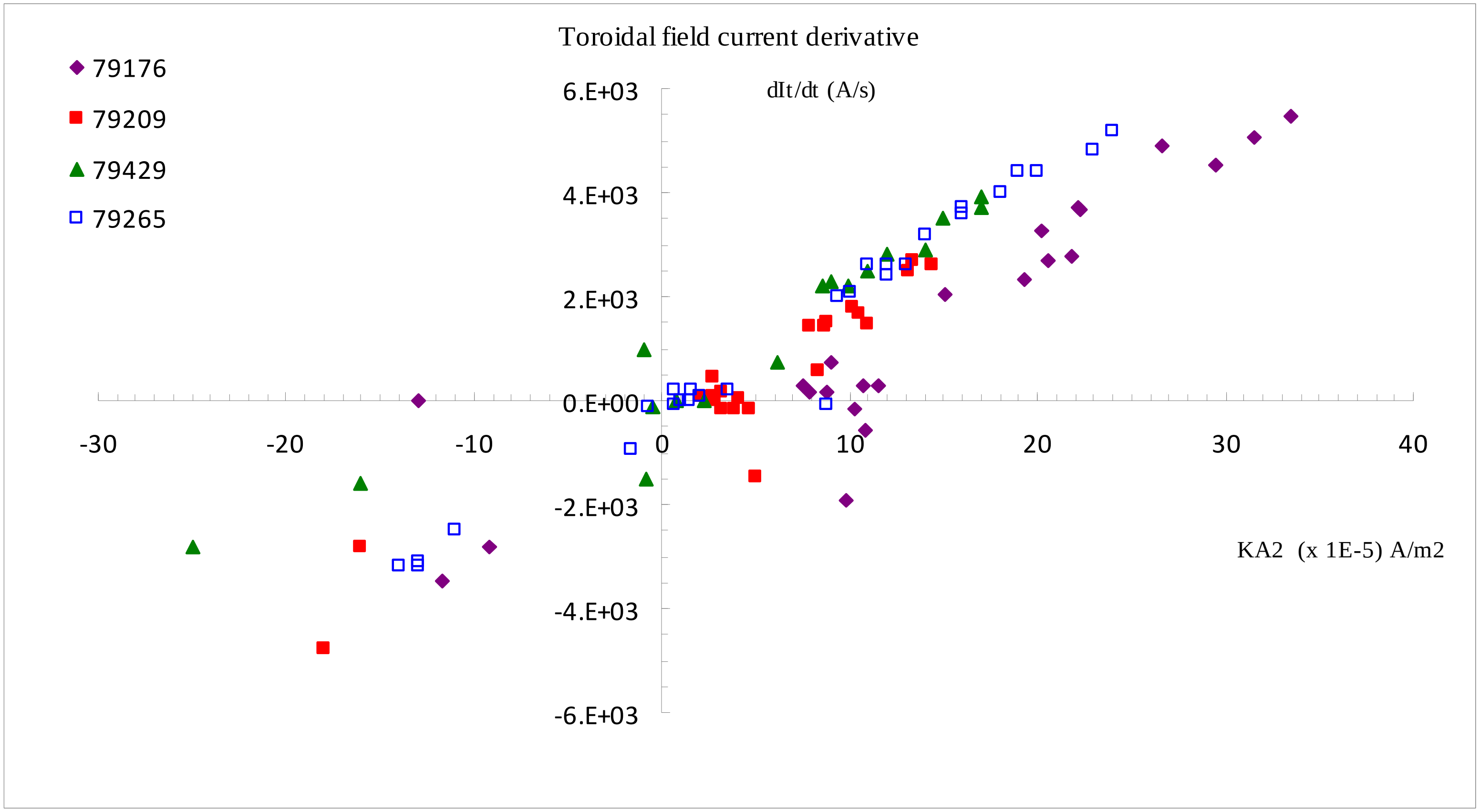
Solution: reduce noise by >100 with passive filters at amps



Comparison of foil currents for JPN 75699 (with 4.5 MW of RF power) where filters have been installed on KA2-415, 416 and 417 and JPN 74285 with no filters. Note that the currents in these three foils are at the 100 nA level whereas the currents in the unfiltered foils exceed 100 µA.

Response (e): Correlation between KA2 total current density and time derivative of Toroidal magnetic field (but NOT other magnetics)

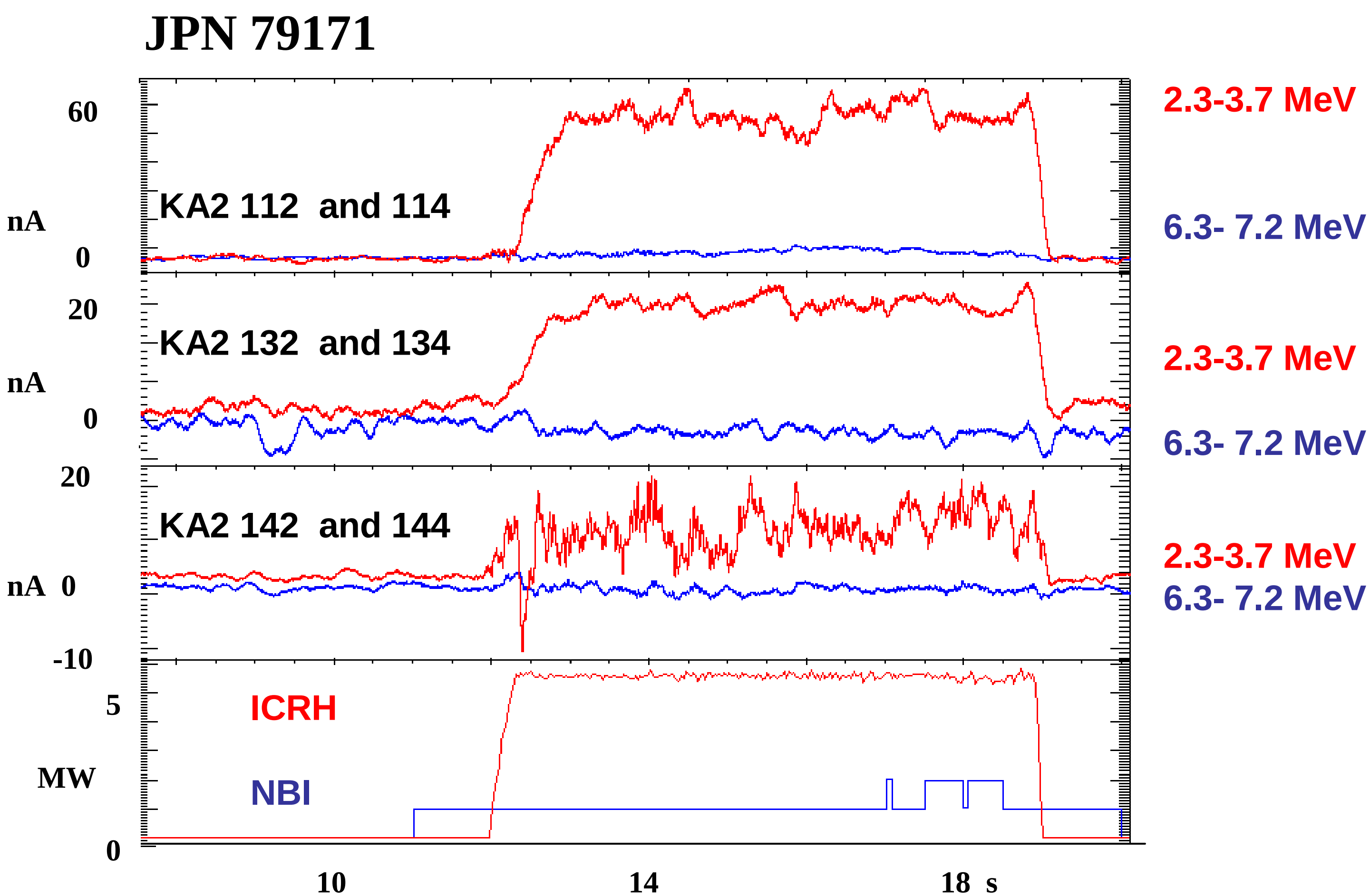




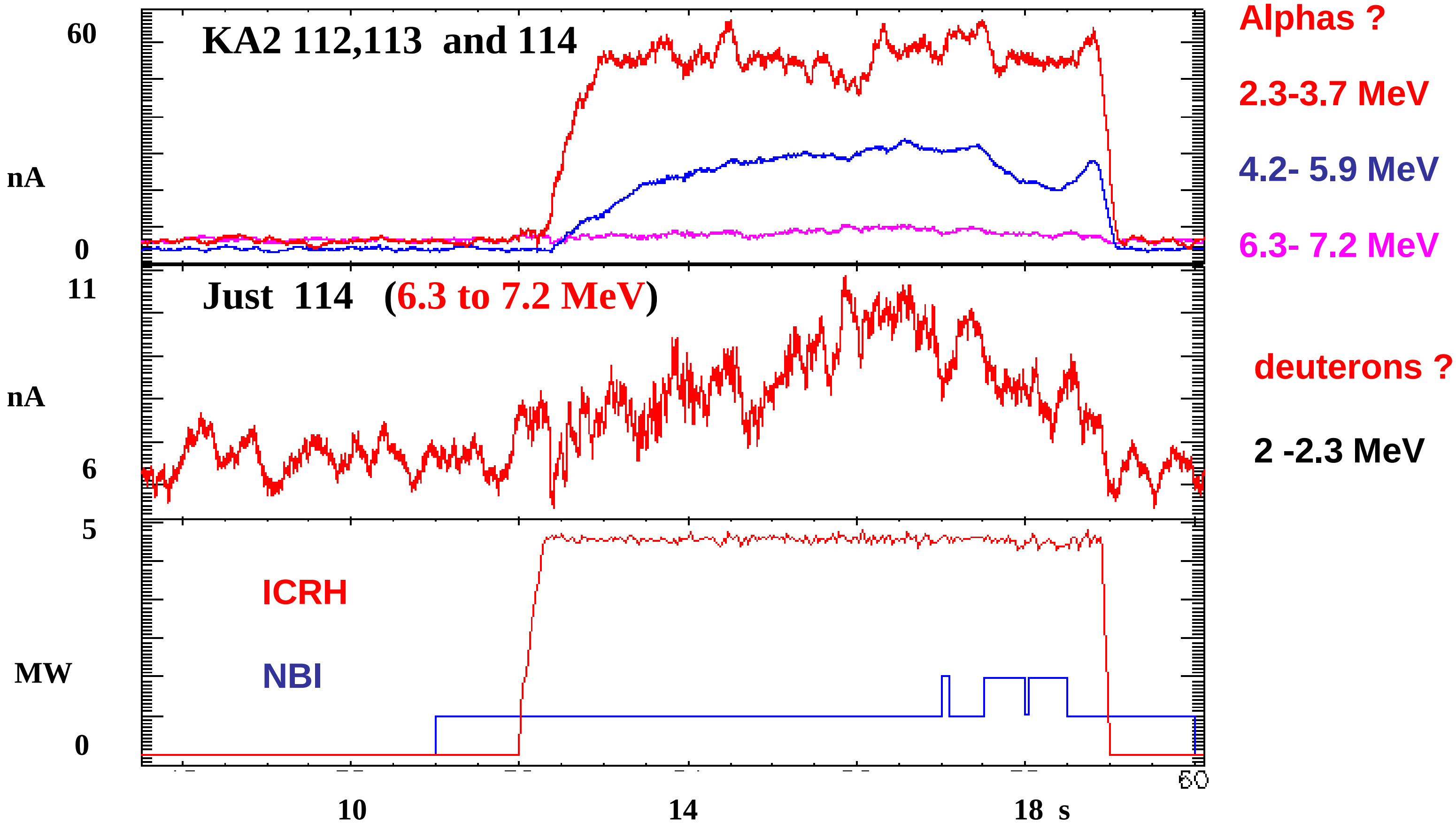
Solution: subtract induced current by measuring dI_t/dt and using approximate correlation coefficient J_{Tot} (A/m^2) ~ 4.5 10^{-8} (s/m^2) dI_t/dt (A/s)

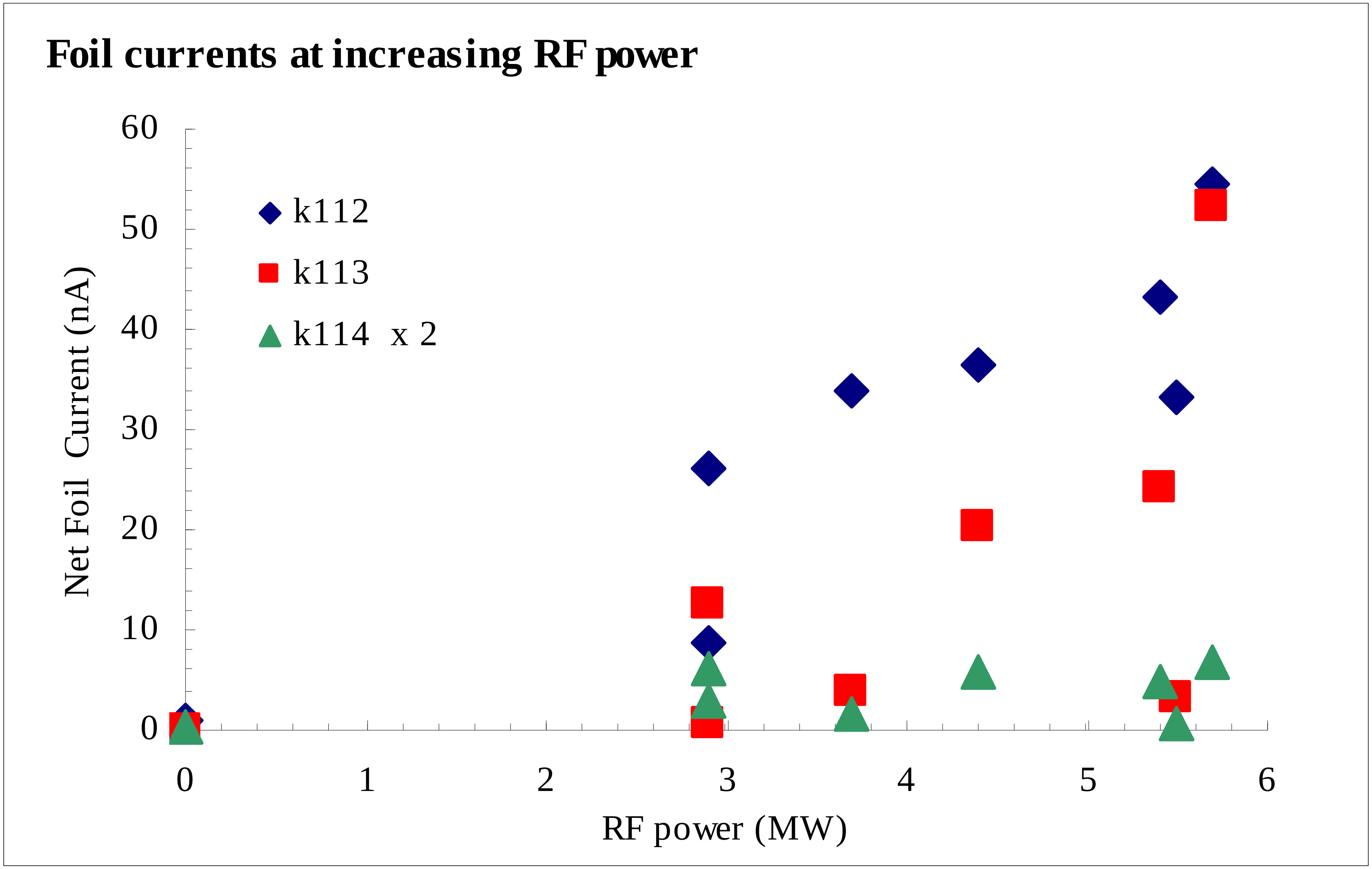
Recent observation of energetic charged particles

Observation (a): **Lost alpha particles (or deuterons) with energies up to about 7 MeV (4 MeV) generated during ICRH (up to 6 MW) $^{4}He/d$ plasmas**

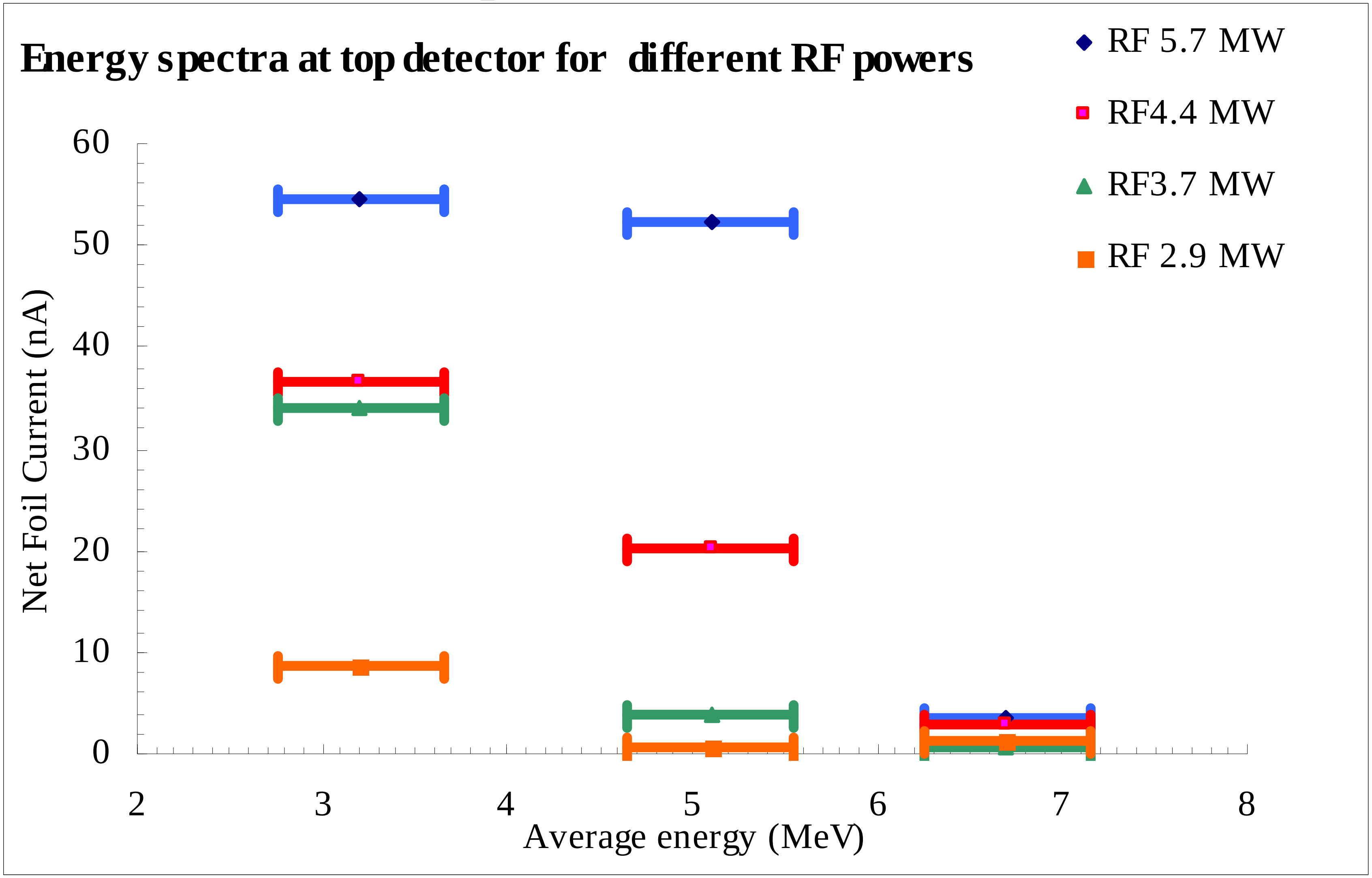


JPN 79171


KA2 112,113 and 114
60
nA
0
Just 114 (6.3 to 7.2 MeV)
11
nA
6
5
ICRH
NBI
MW
0
10
14
18 s
Alphas ?
2.3-3.7 MeV
4.2- 5.9 MeV
6.3- 7.2 MeV
deuterons ?
2 -2.3 MeV

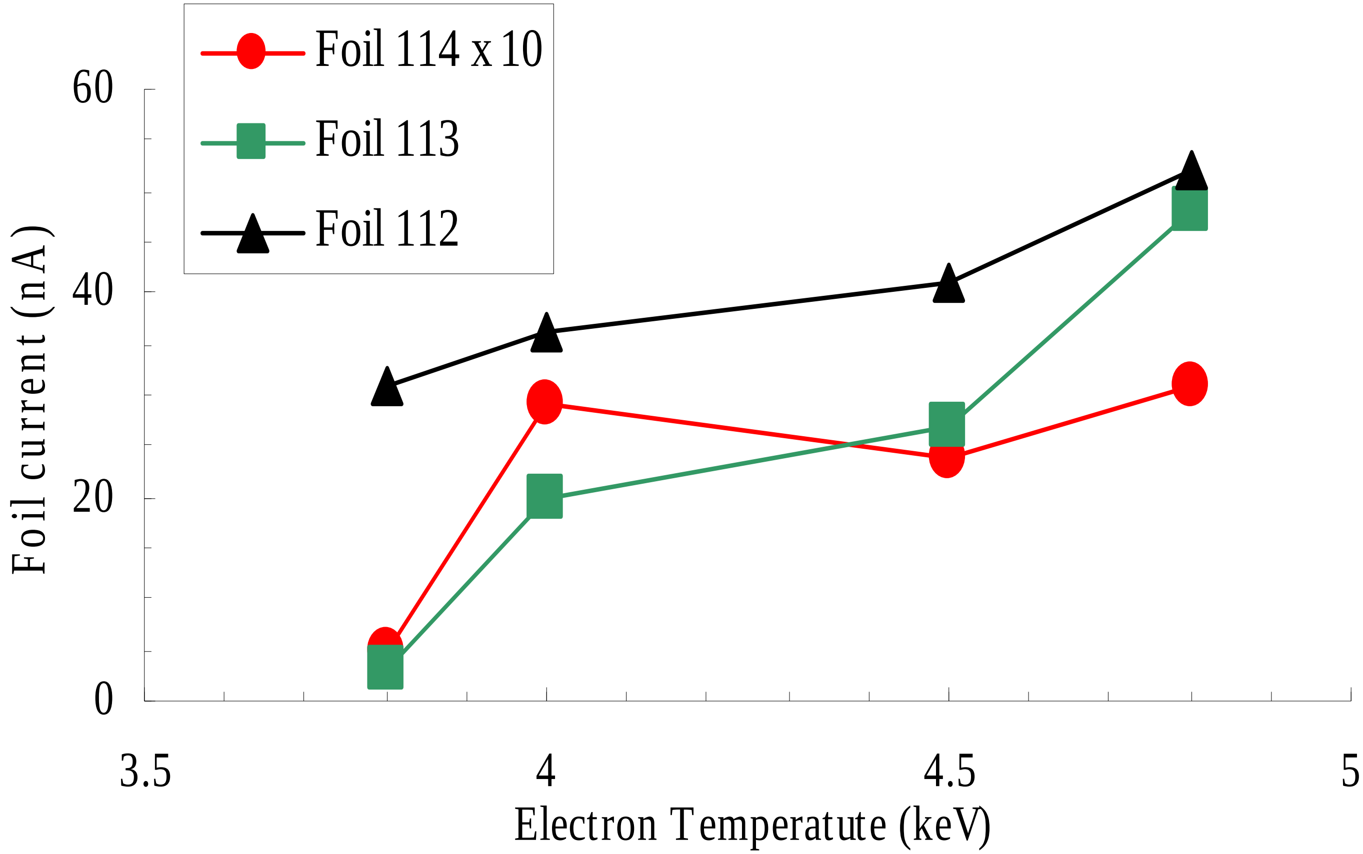

Foil currents at increasing RF power
60
50
40
30
20
10
0
Net Foil Current (nA)
k112
k113
k114 x 2
0
1
2
3
4
5
6
RF power (MW)

Alphas



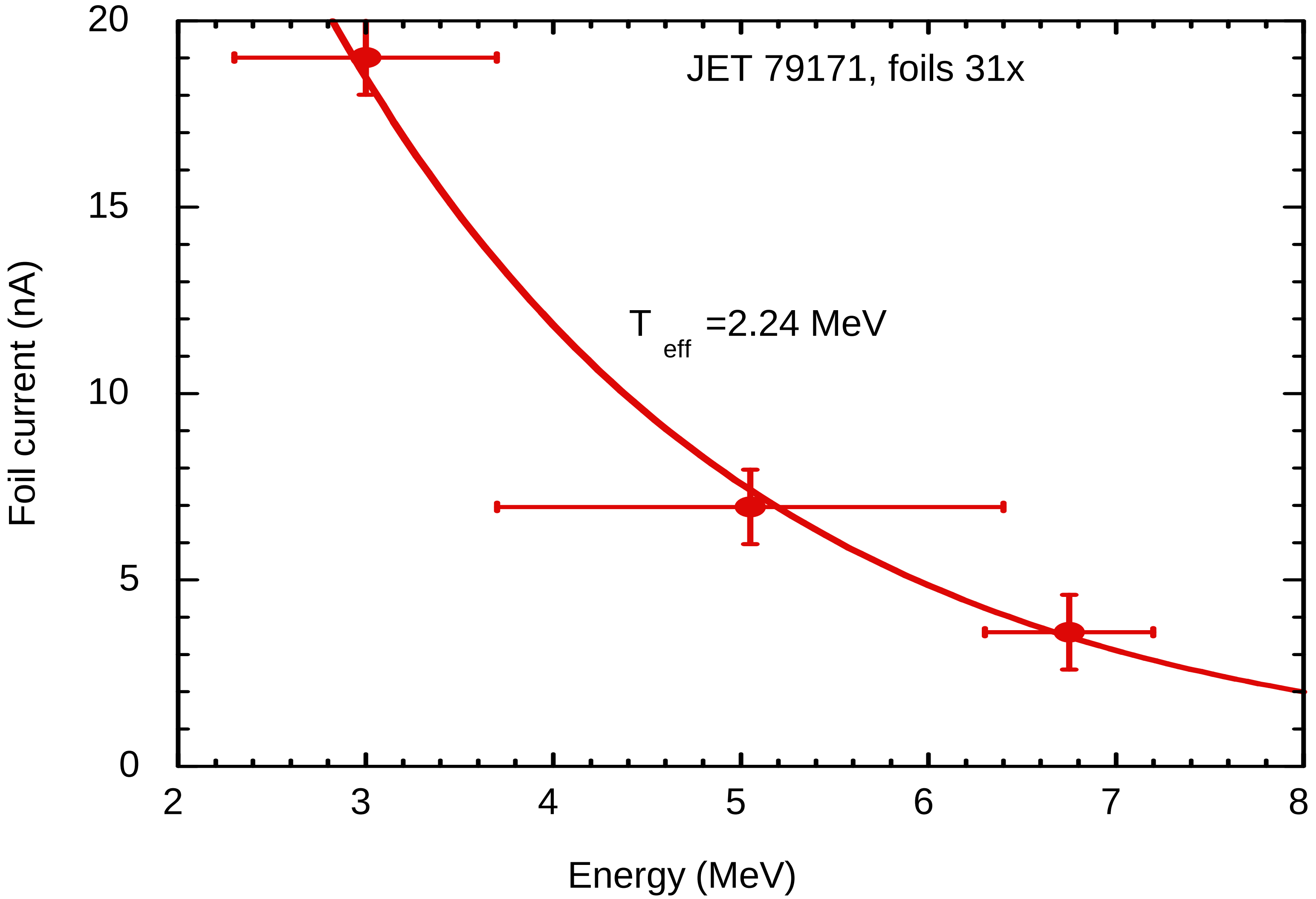
Energy spectra at top detector for different RF powers
RF 5.7 MW
RF4.4 MW
RF3.7 MW
RF 2.9 MW
60
50
40
30
20
10
0
Net Foil Current (nA)
2
3
4
5
6
7
8
Average energy (MeV)

Correlation between foil current and electron temperature



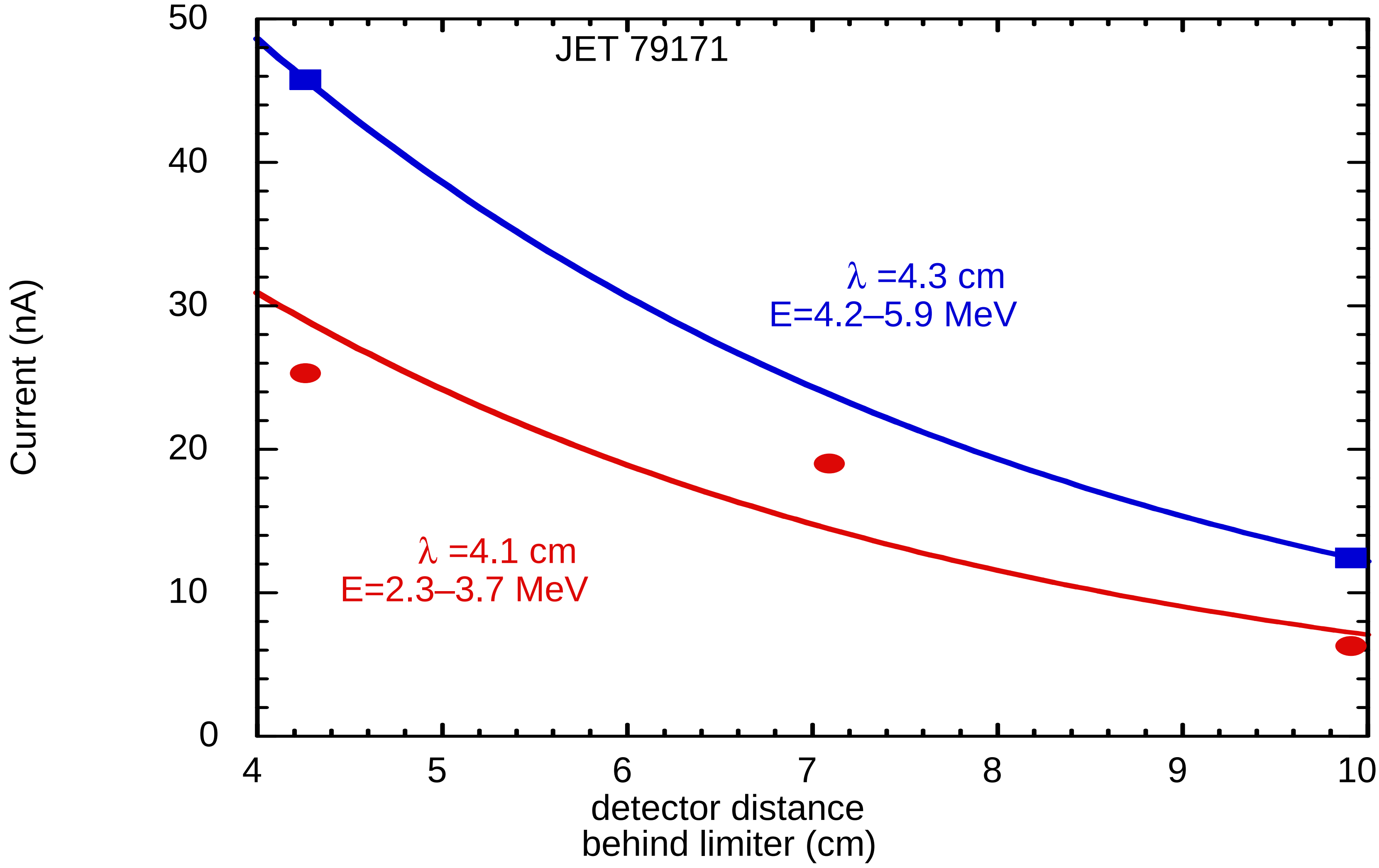
2.24 MeV tail temperature good fit to foil current vs depth

- Pylon 3, first stack; Data averaged over RF pulse duration

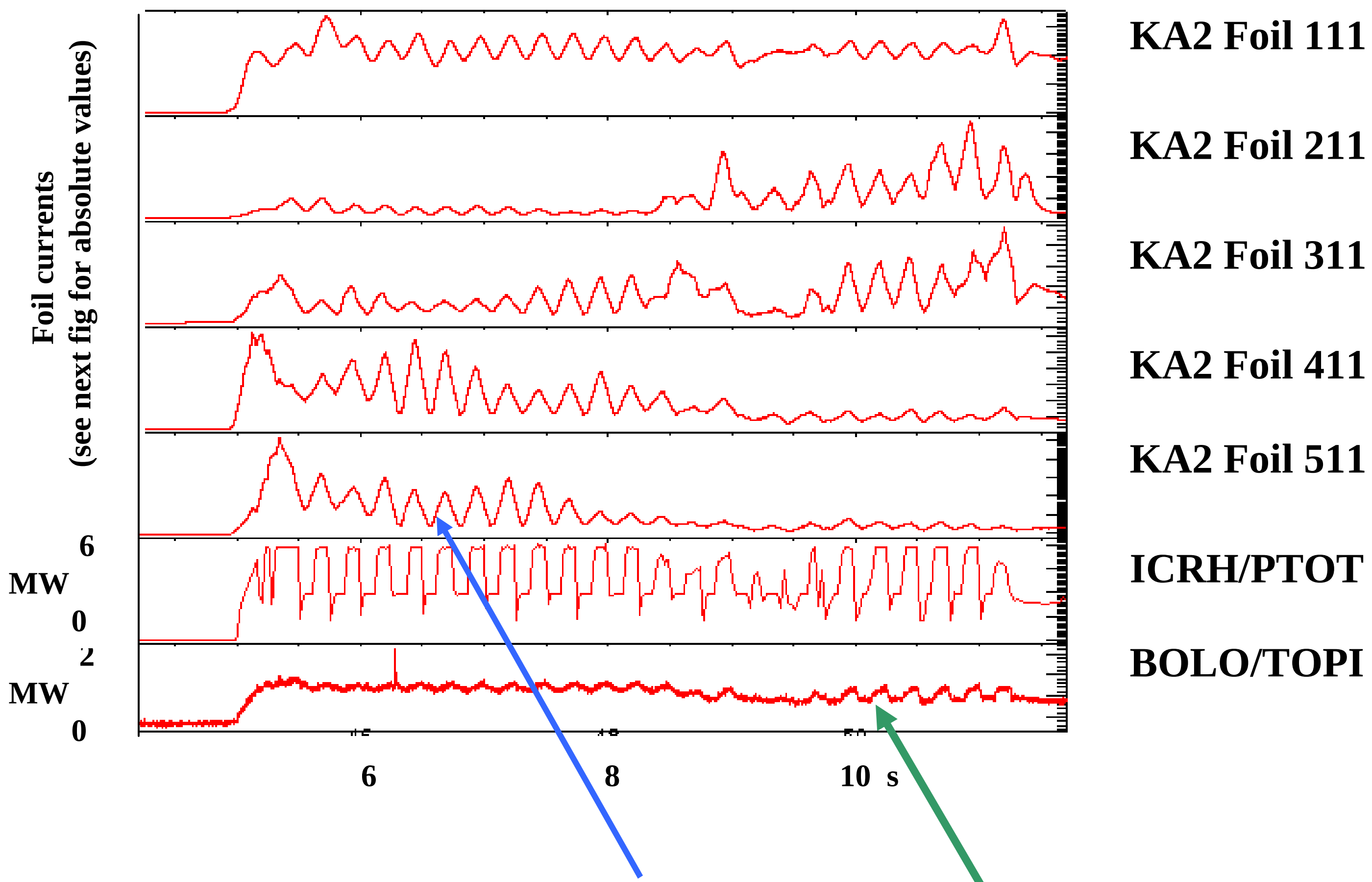


Radial scrape off length ~4 cm

- Data from top pylon (near midplane)
- Both energy ranges show similar scrape off length

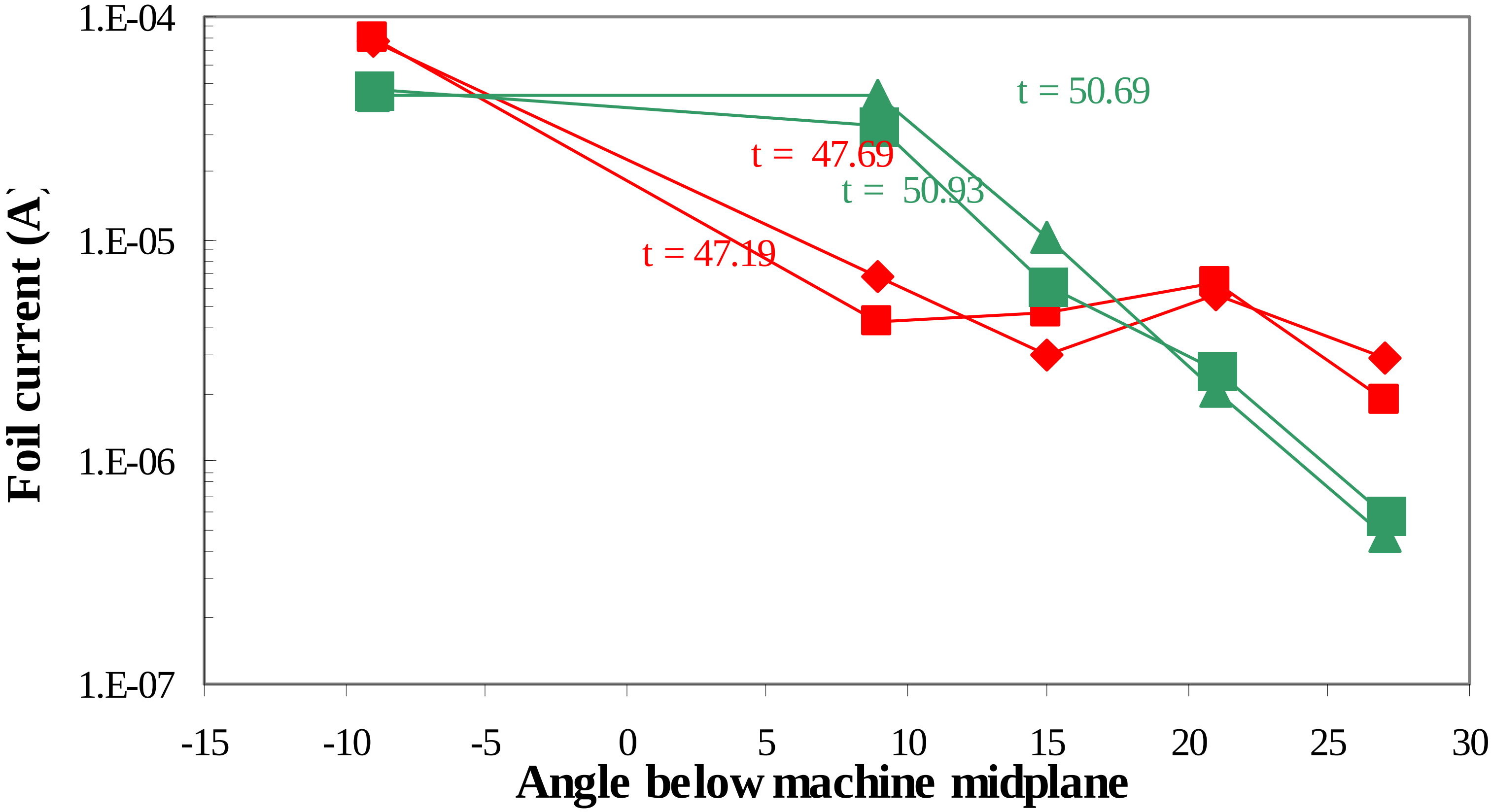


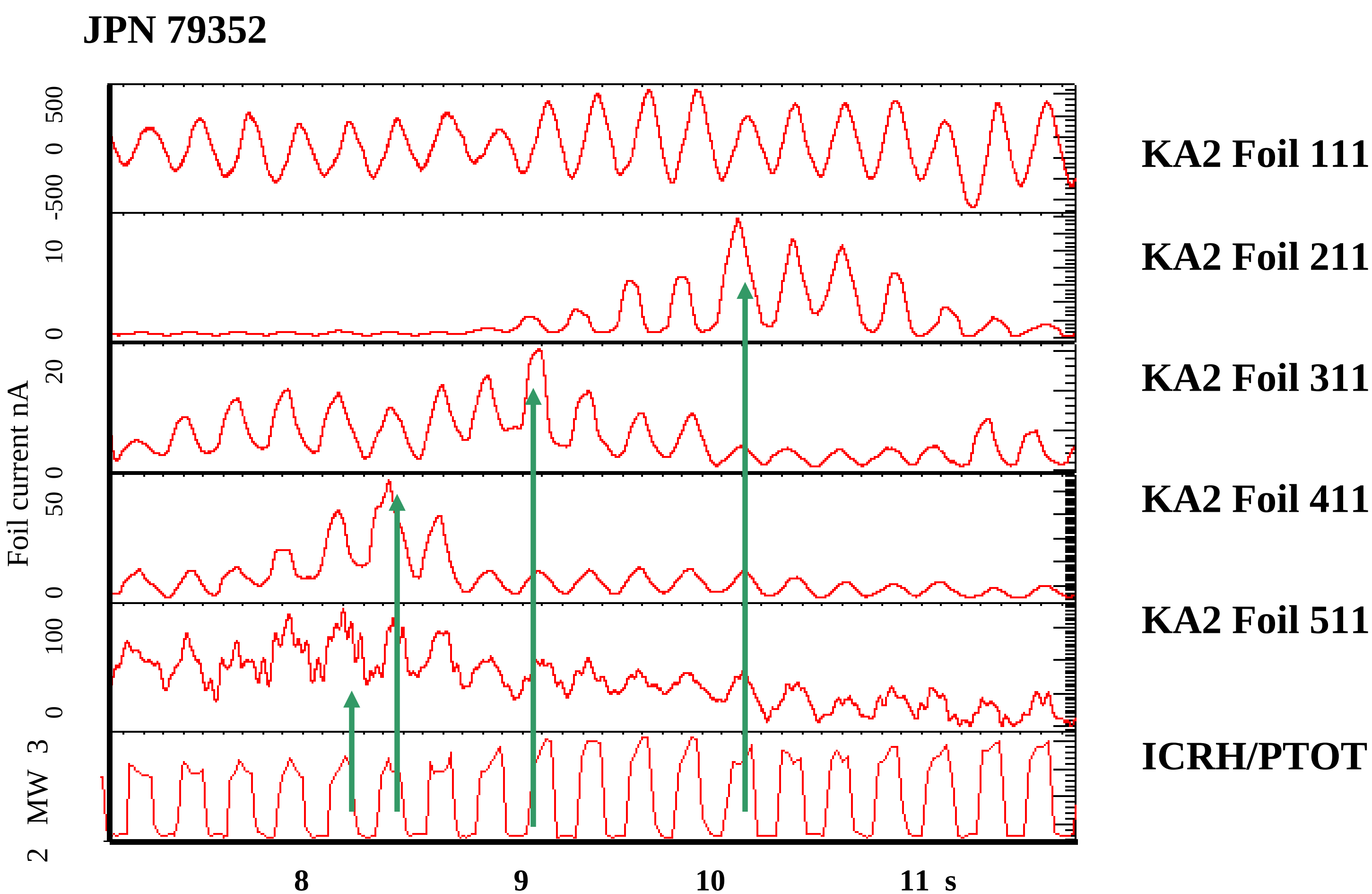
Observation (b): Poloidal distribution of lost energetic 3He during JPN 79341mode conversion plasma.



Note very weak correlation between front foil currents and bolometer (recall slide 10 above)

Poloidal distribution front foil currents JPN 79341

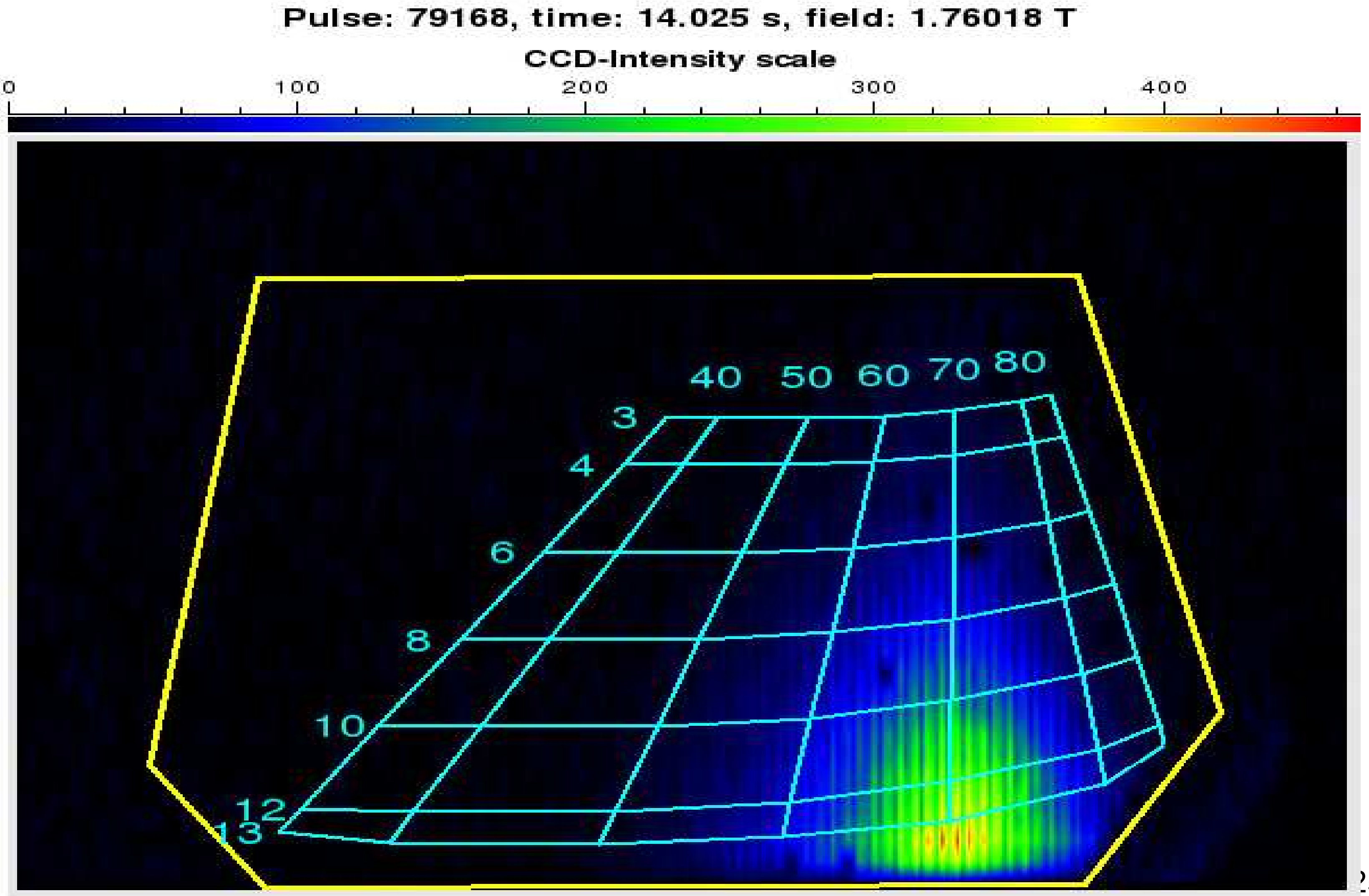




JPN79352: Note that peak current occurs at later times for foils closer to machine midplane; rising at about 9º / sec.

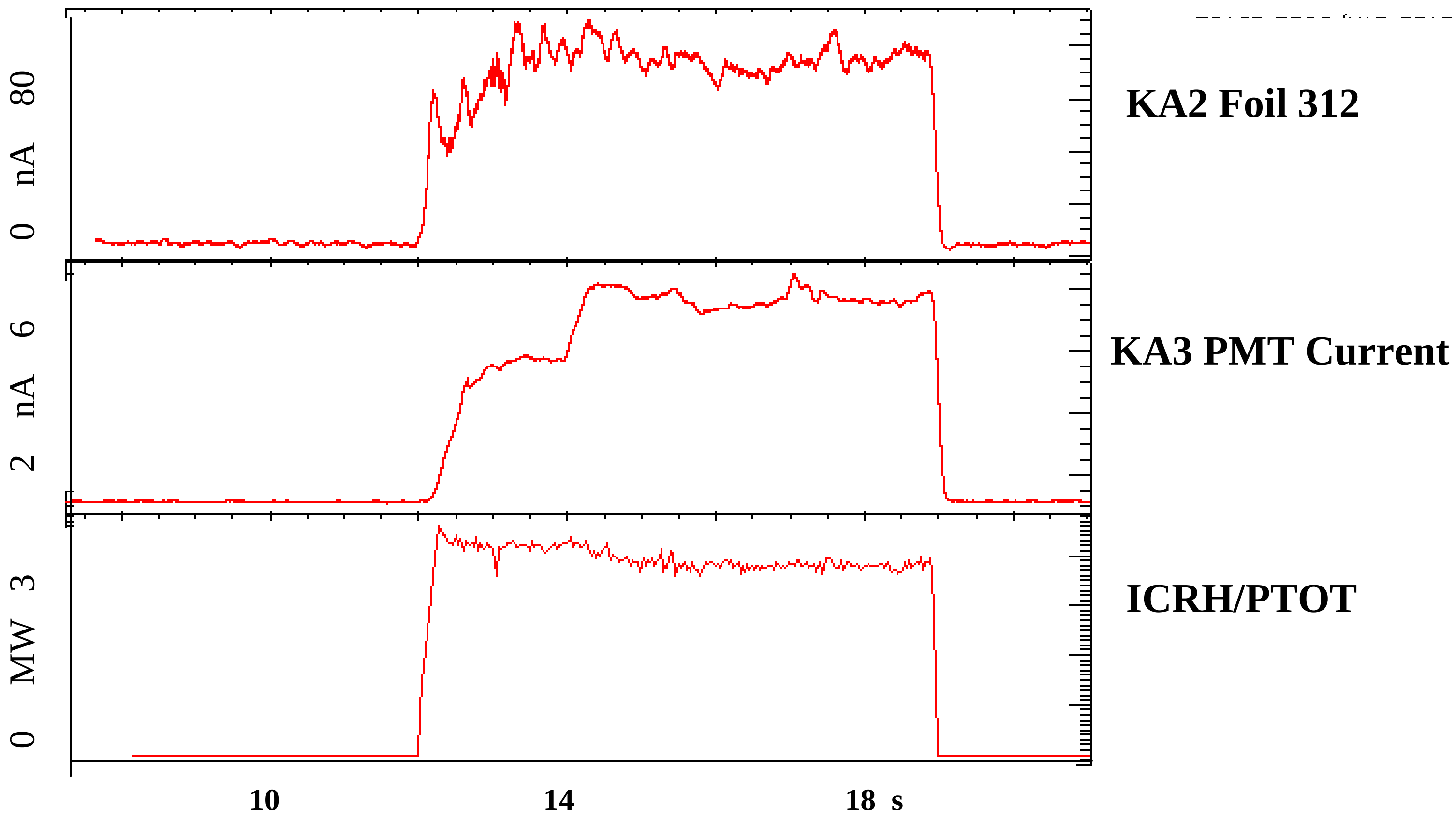
Observation (c): Calibration of KA3 PMT during ICRH ^{4}He plasmas

Focal plane image of KA3 Scintillator Probe of α's up to 3.7 MeV or d's up to 1.9 MeV

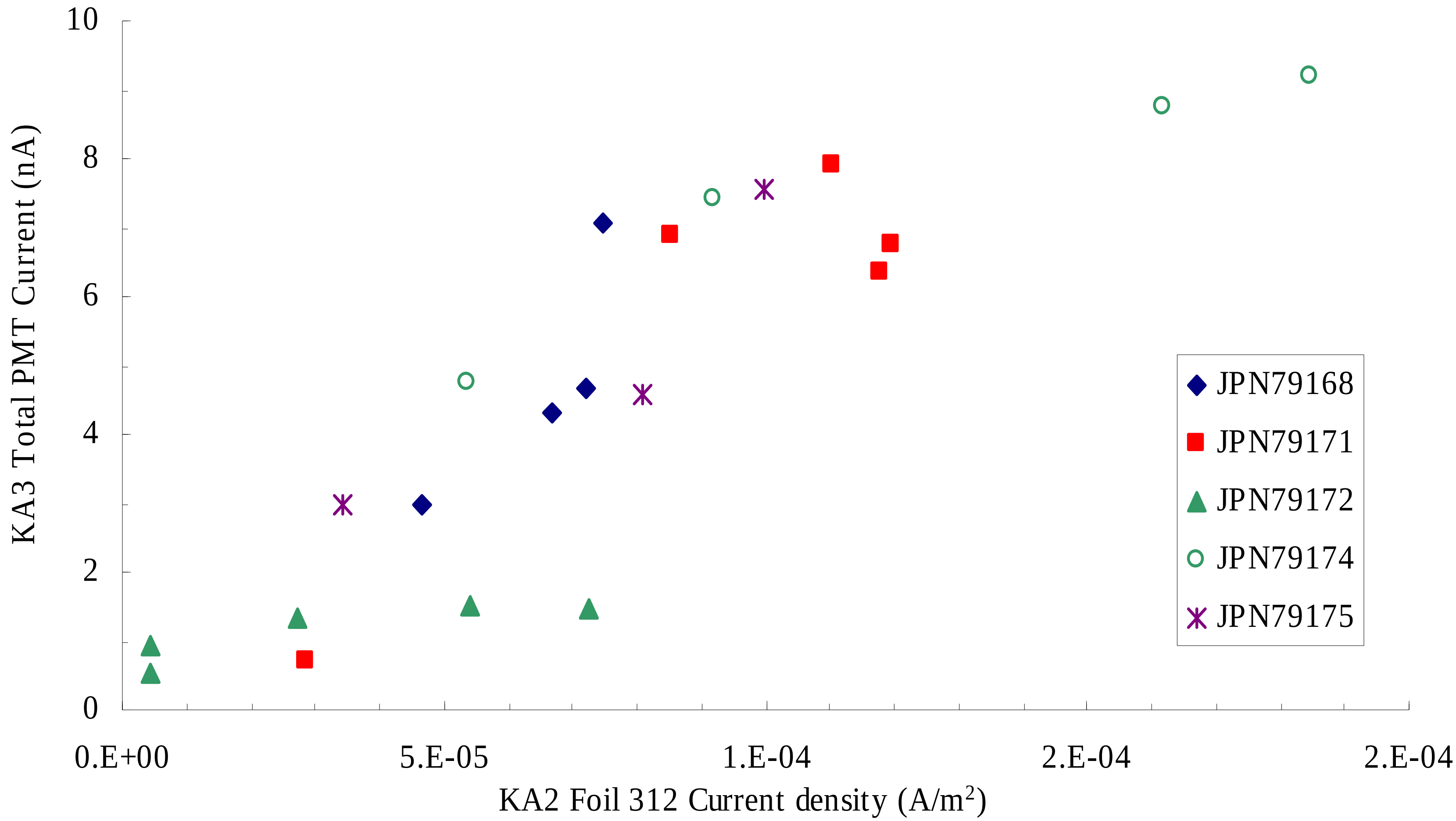


Comparison of KA3 total PMT current and

KA2 foil 312 during JPN 79168 ICRH ^{4}He plasmas



Comparison of KA2 and KA3



Conclusion: 8 nA of KA3 total PMT current corresponds to about 1E-4 A/m^2 of KA2 312 current density (same poloidal height as KA3) during ICRH ^4He plasmas

Conclusions

- Faraday cup lost ion detector capable of operating in ITER like conditions for alpha currents > 10 nA/cm2
- Lost alpha/deuteron signals measured on JET for ICRH ^{4}He d-t simulation plasmas
- Poloidal distributions measured during ^{3}He mode conversion experiment
- KA2 data (KA2-312 at same height as KA3) will allow ***<u>absolute</u>*** calibration of KA3 scintillator losses