Equilibrium data/parameters for strongly non-linear EP dynamics based on AUG experimental results: EGAMs, RSAEs, BAEs and TAE bursts

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‘sea’ of unstable small amplitude modes for low energy [80/60keV] on-axis NBI drive in ramp-up

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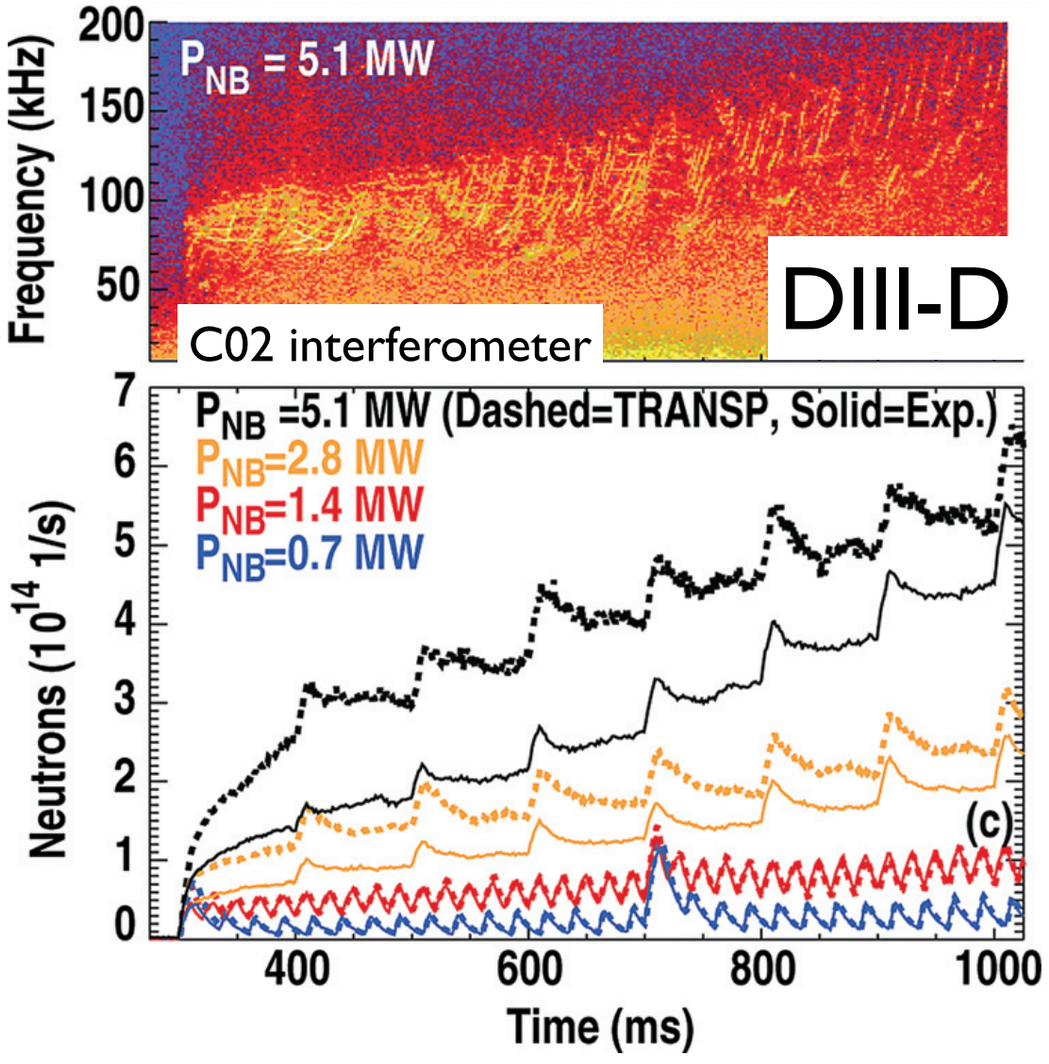
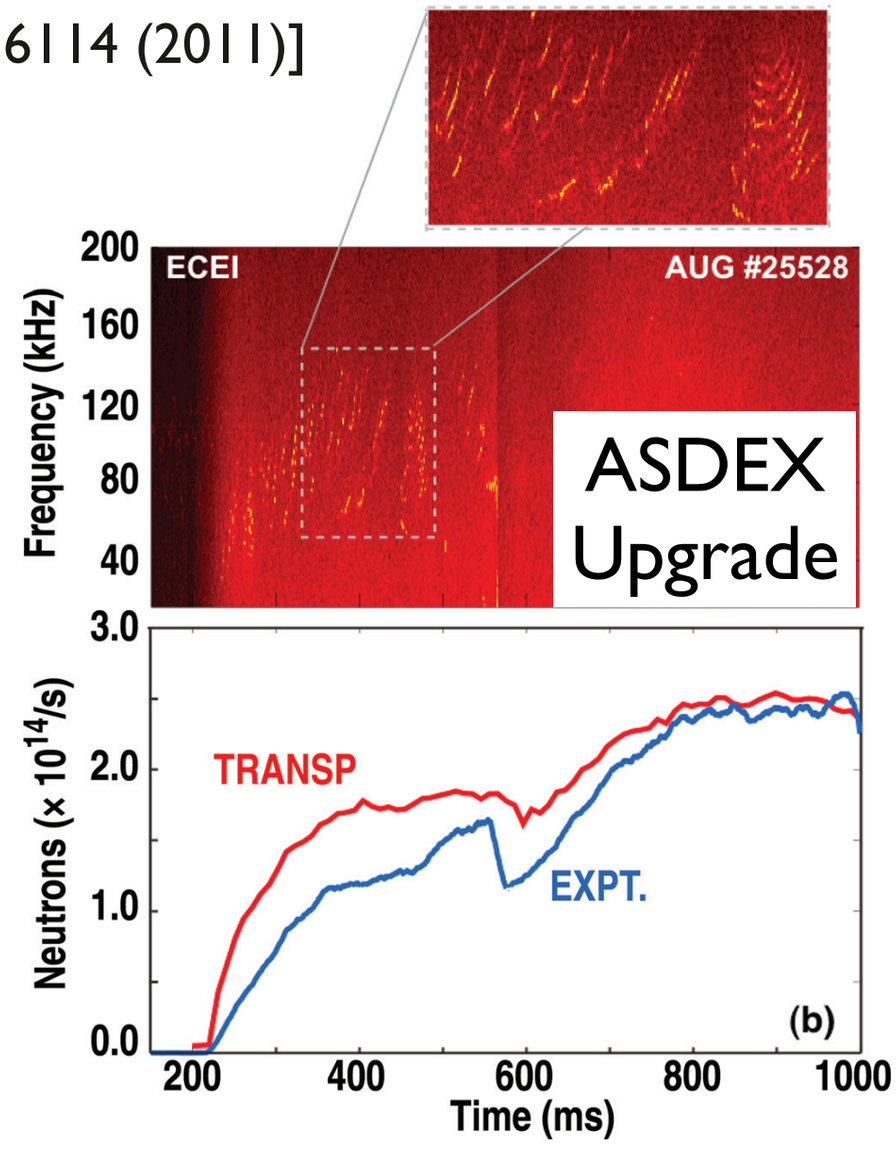
EUROfusion

[VanZeeland et al Phys. Plasmas 18, 056114 (2011)]



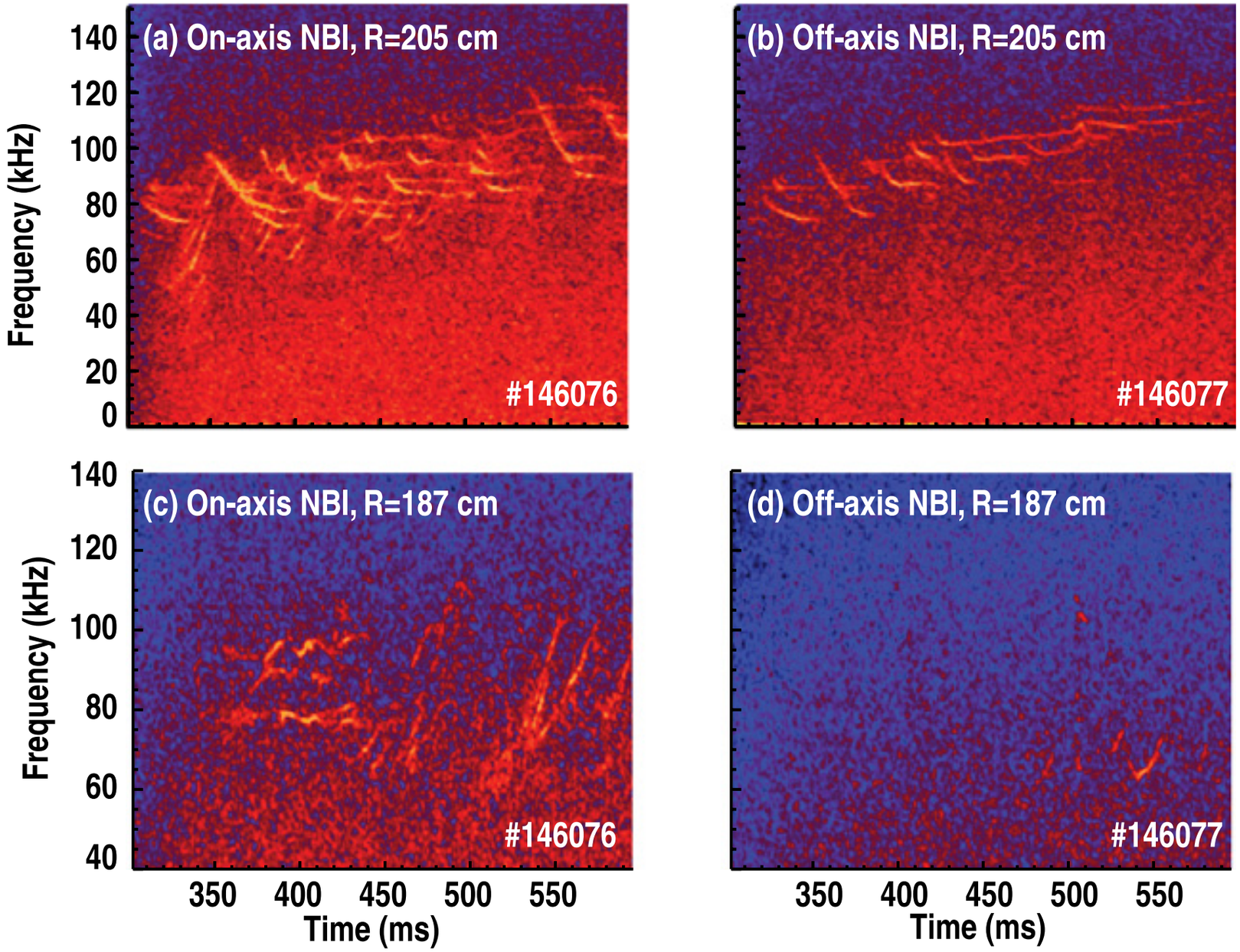


in these cases, neutron deficiency and EP transport well understood and measured (FIDA, FILD), successful comparison to quasi-linear hybrid models (amplitudes given by the experiments) [R. White et al, 2011]

similar to case studied by Vlad et al, 2009, also Todo [2013/14/15], US codes[TAEFL,GTC,GYRO] ITPA DIII-D case [Lauber 2015]

NBI off-axis heating at DIII-D [80keV, 4-4.5MW]

[B. Heidbrink et al , NF 53, 2012]



conclusions: overlap of many small amplitude modes dominates EP transport -threshold to strongly non-linear behaviour? ITER?

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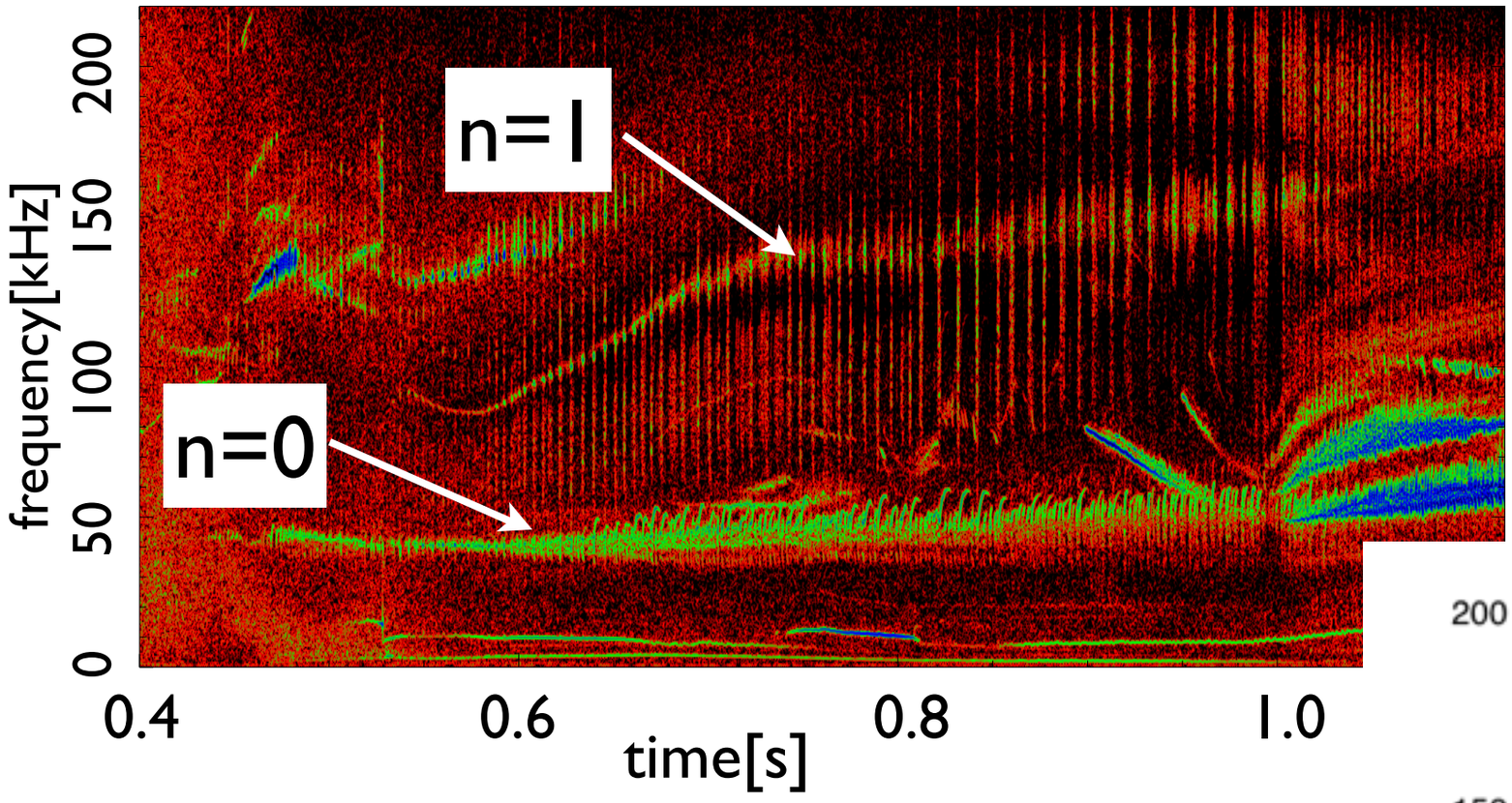
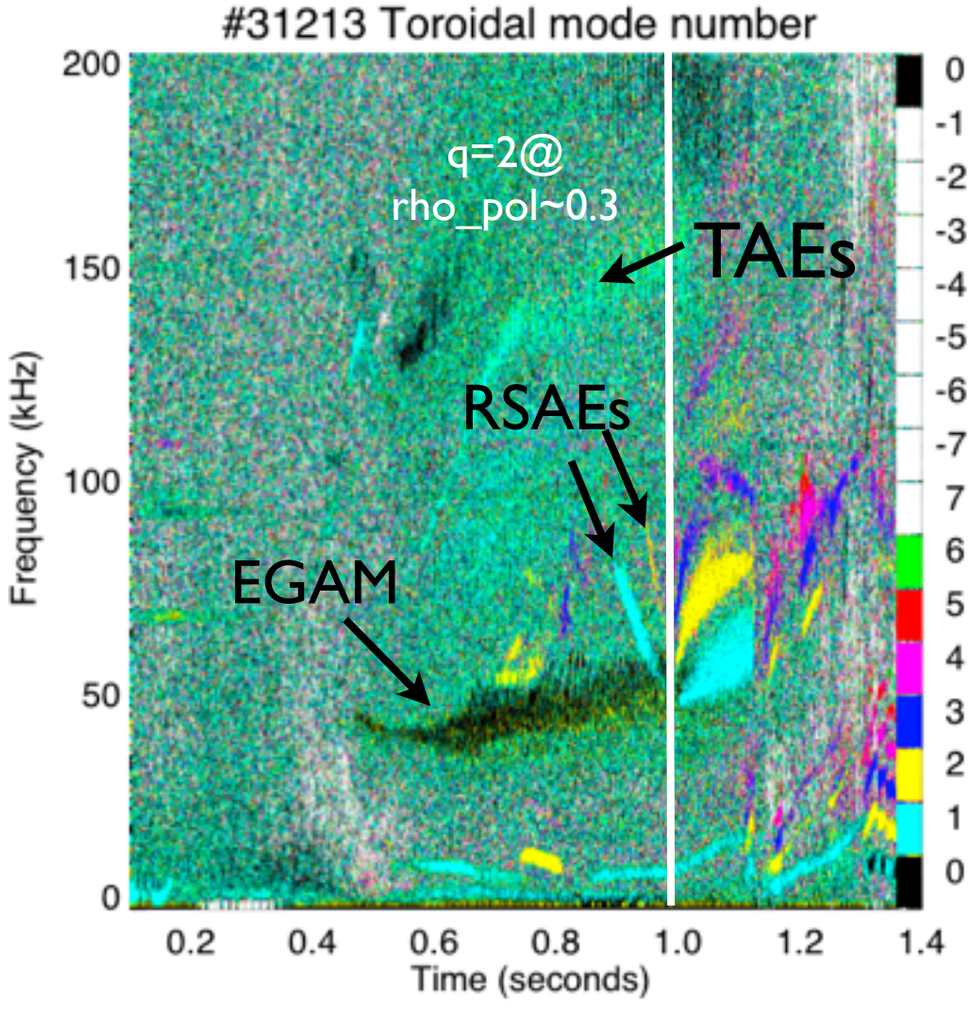


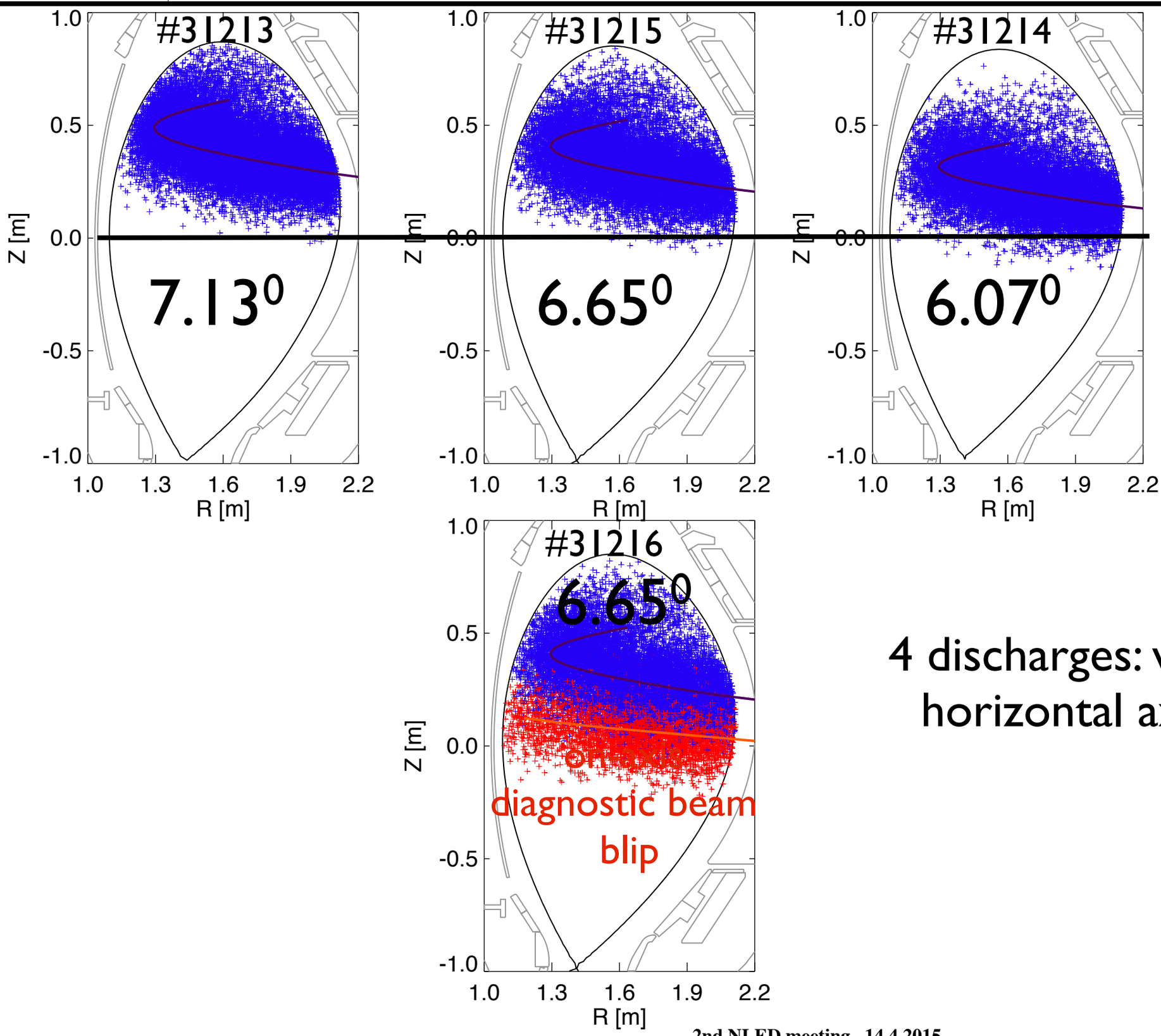
[July 2014]

B_0=2.2T
I=0.6-1.0MA
P_{beam}=2.5MW



- rather well reproducible scenario
- no 'sea' of Alfvenic modes (TAEs/RSAEs)
- but strongly chirping n=0 modes and n=1 'bursts'

beam injection geometry



4 discharges: vary angle between horizontal axis and beam-line

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normalised magnetic fluctuation spectra

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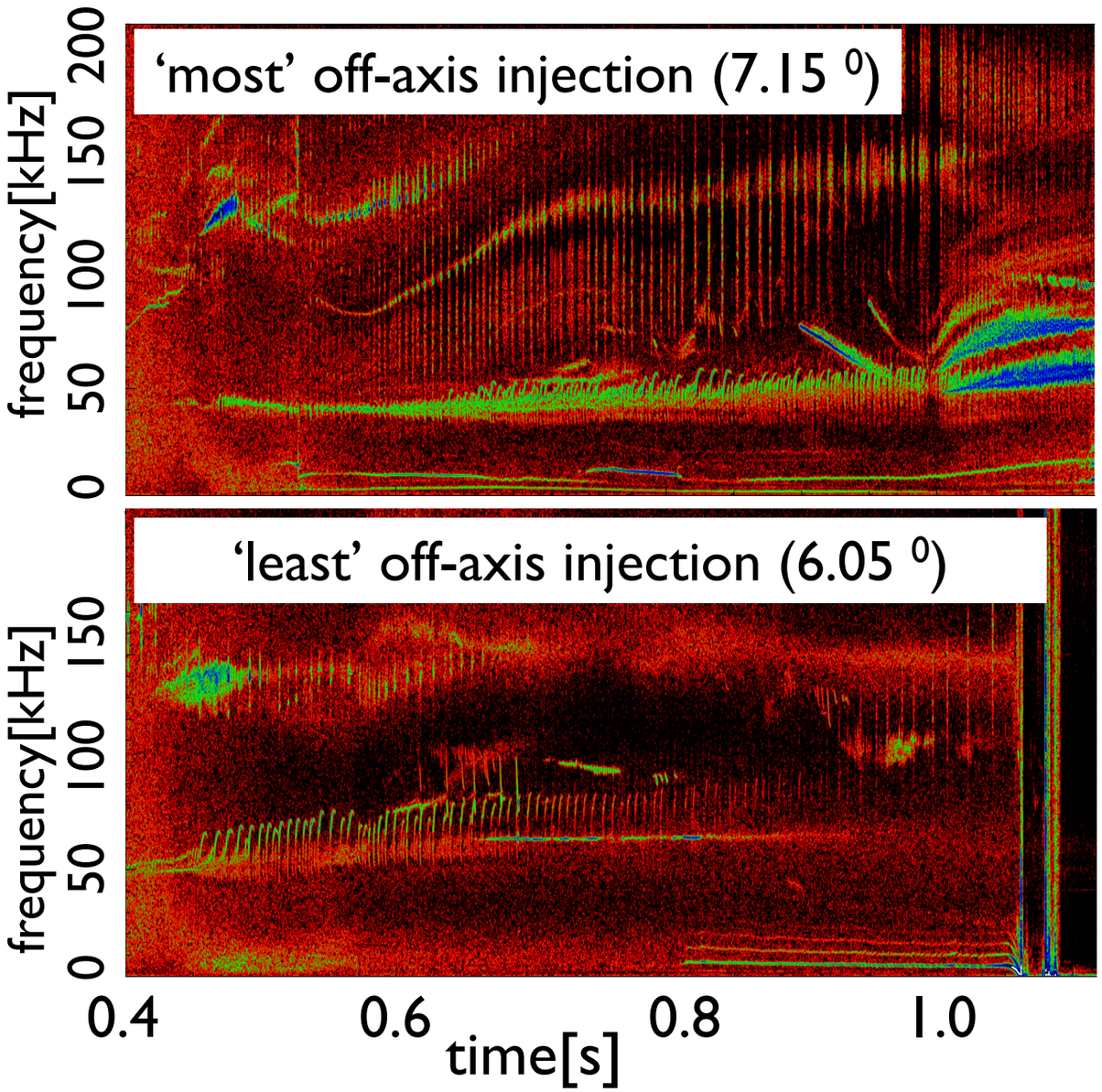

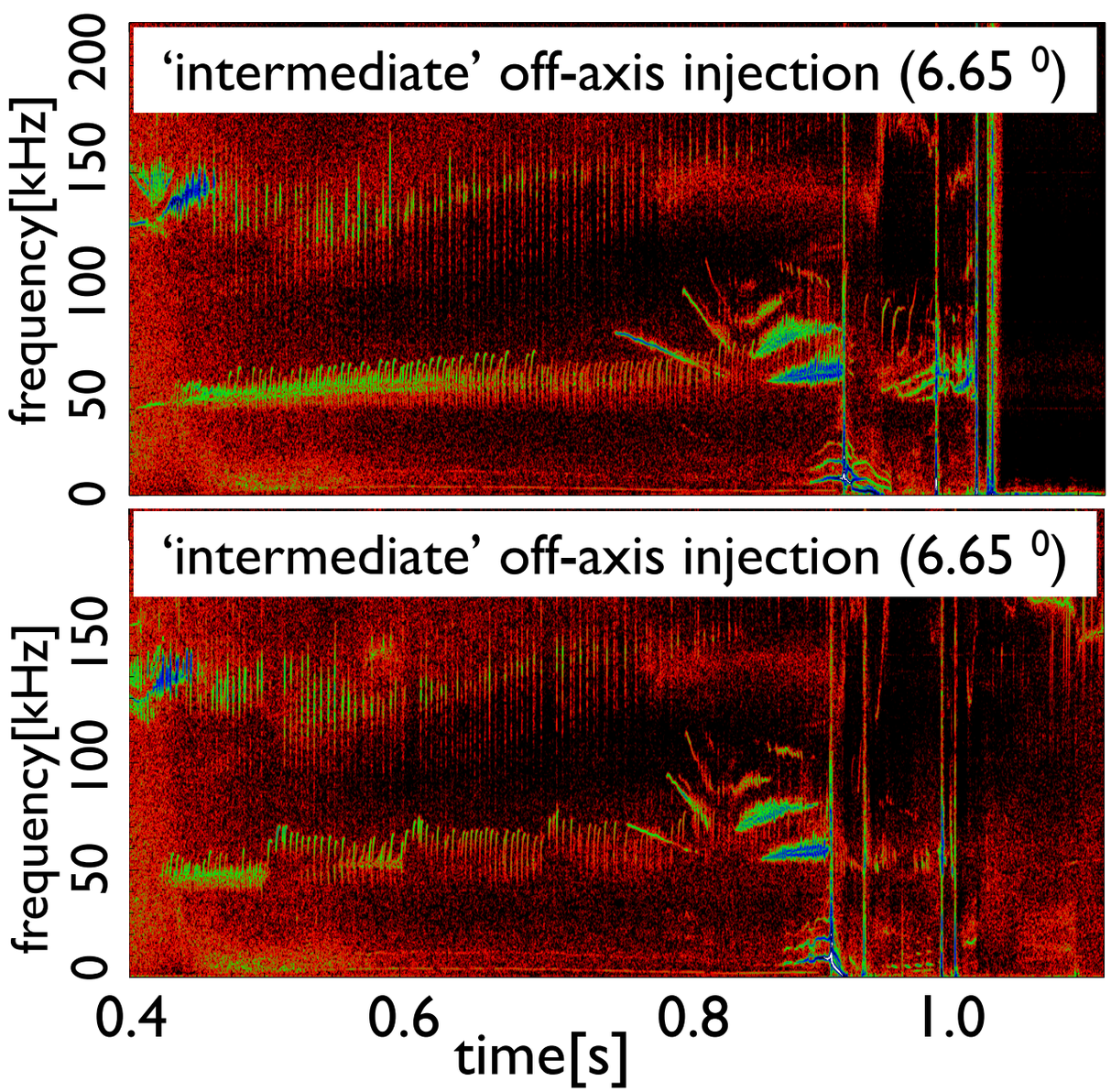

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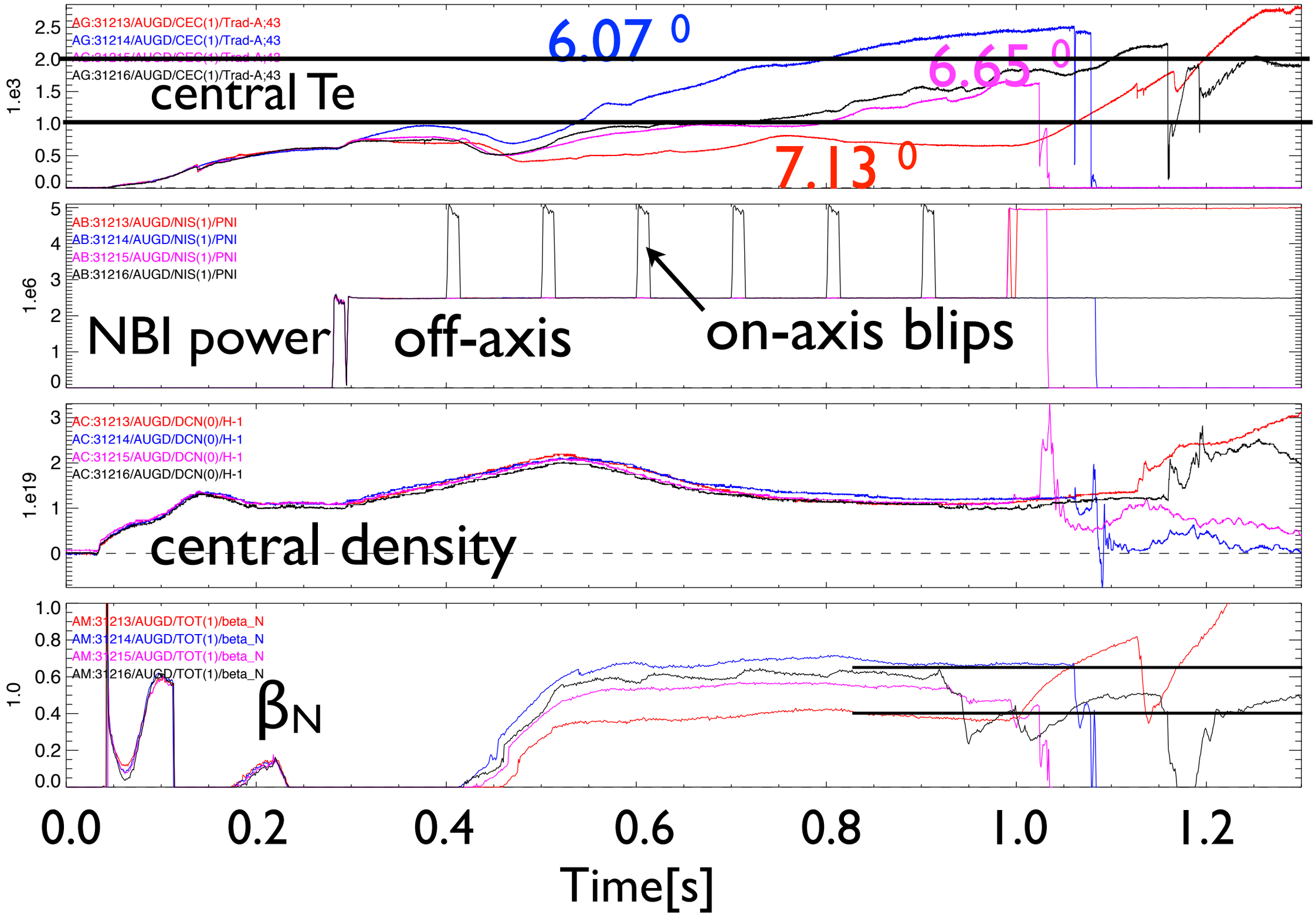
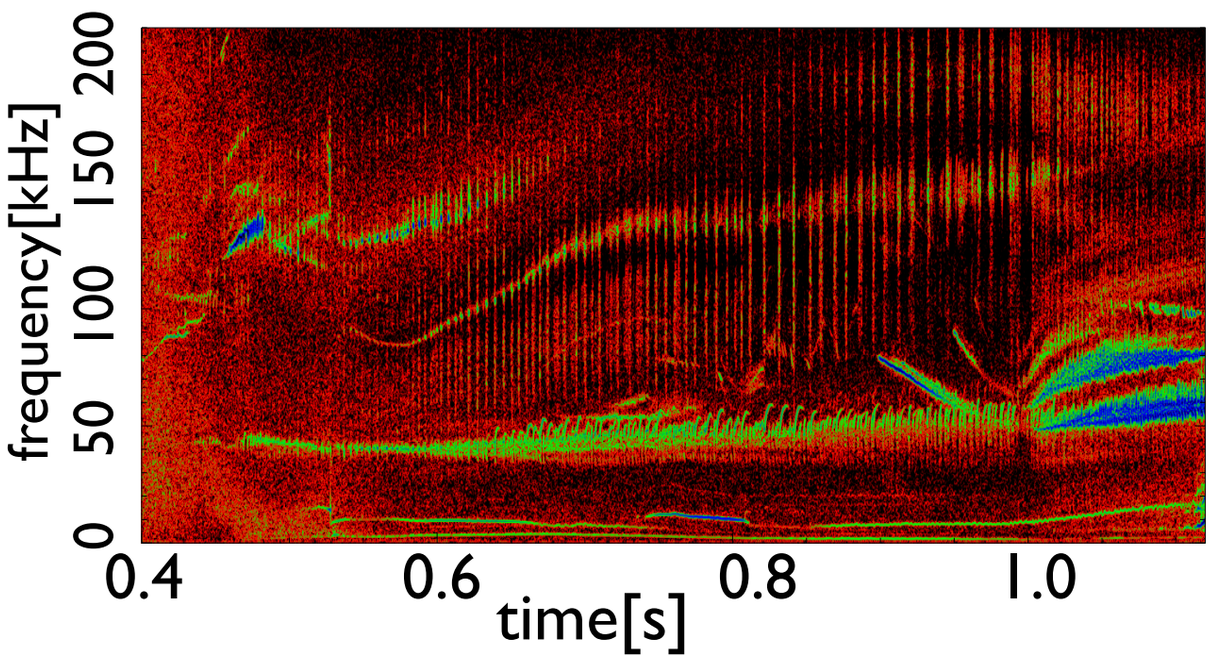
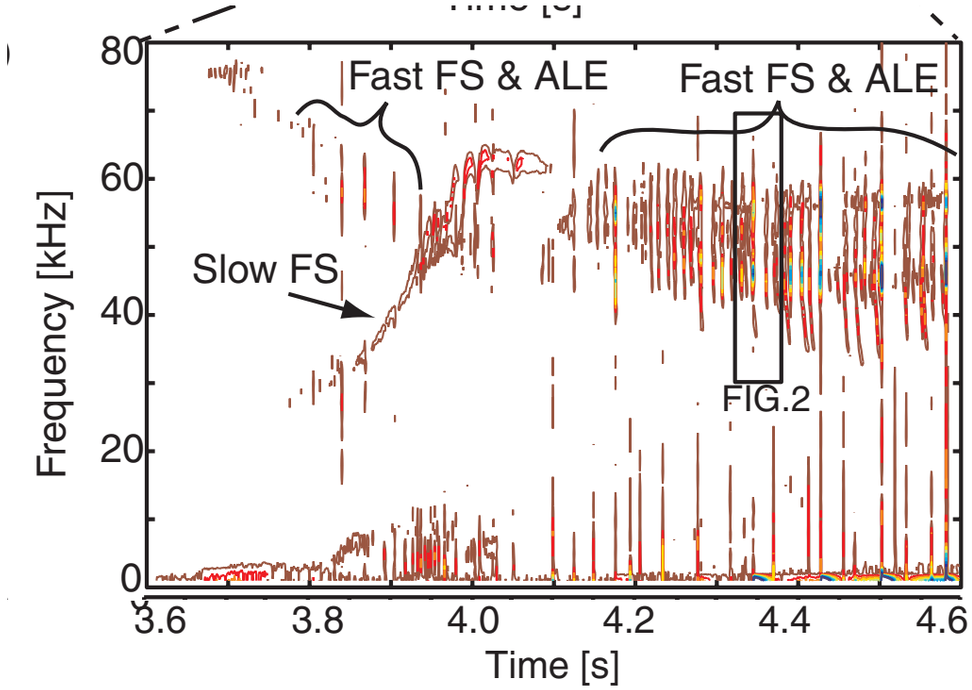
time history of 4 discharges with different NBI injection angles

EUROfusion



n=1 TAE bursts seem to have some similarity to 'fast sweeping' and 'ALE' events at JT-60U



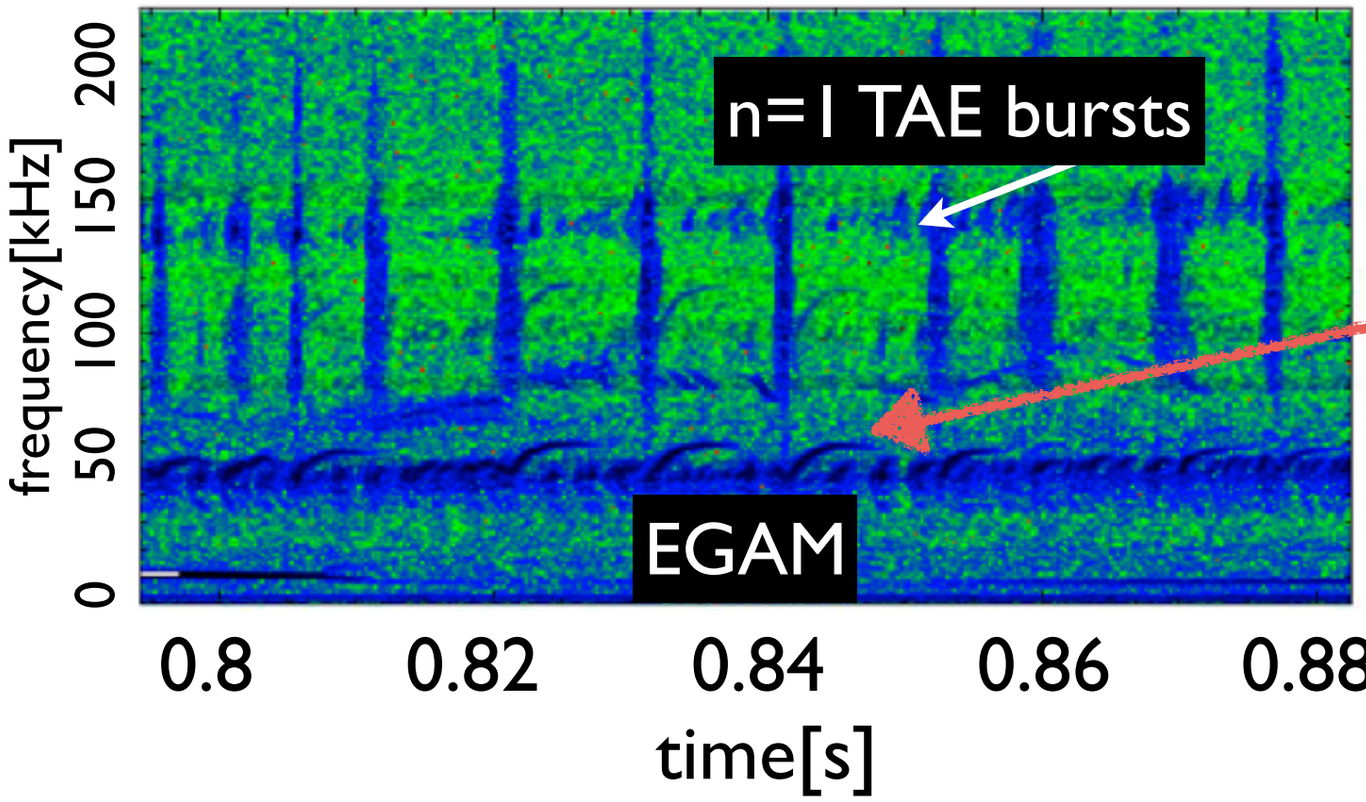


JT-60U: K. Shinohara et al, 2002-2004

JT-60U: v_f/v_{A0}~1.3 ; NB: 350keV
DIII-D: v_f/v_{A0}~0.4 ; NB: 80keV
AUG: v_f/v_{A0}~0.45; NB: 93keV

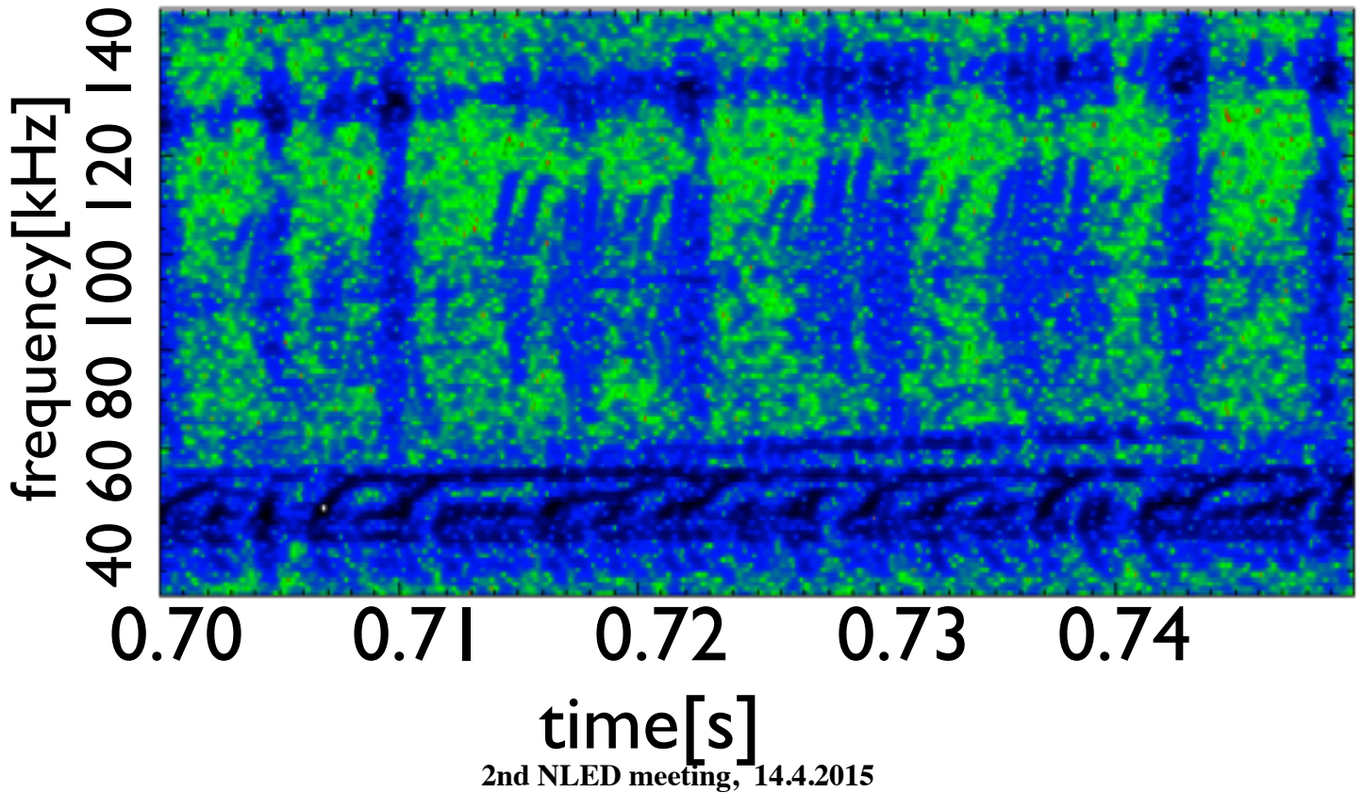
additional new physics: nl EGAM interaction, drive at $v_A/3$

phase space coupling: n=1 TAE bursts seem to trigger EGAMs



experimental evidence that EGAMs change radial width during nl evolution [L Horvath, master thesis 2015]

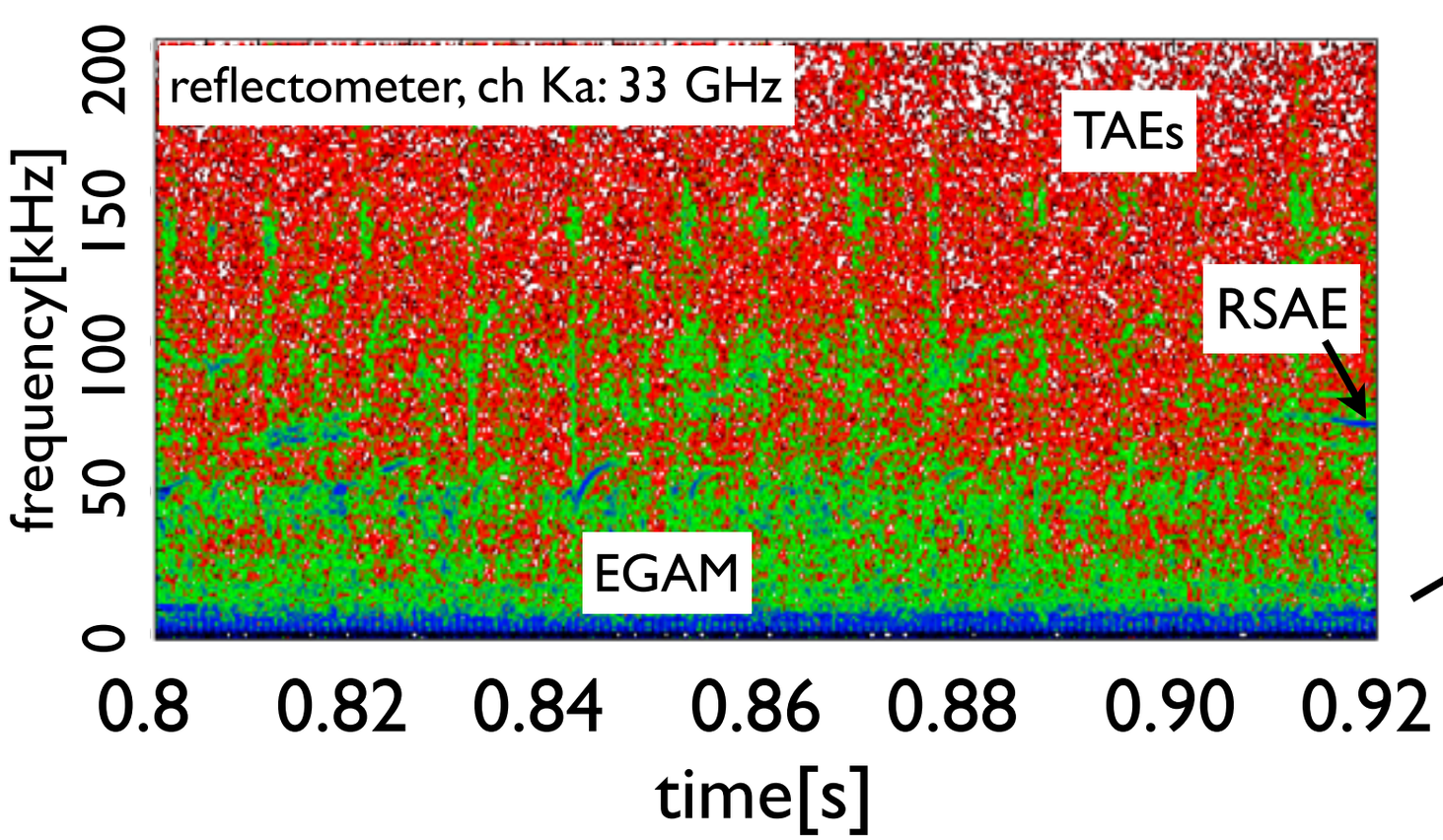
modes around 100kHz: probably modes propagating in the electron diamagnetic direction (2 f_{rot})



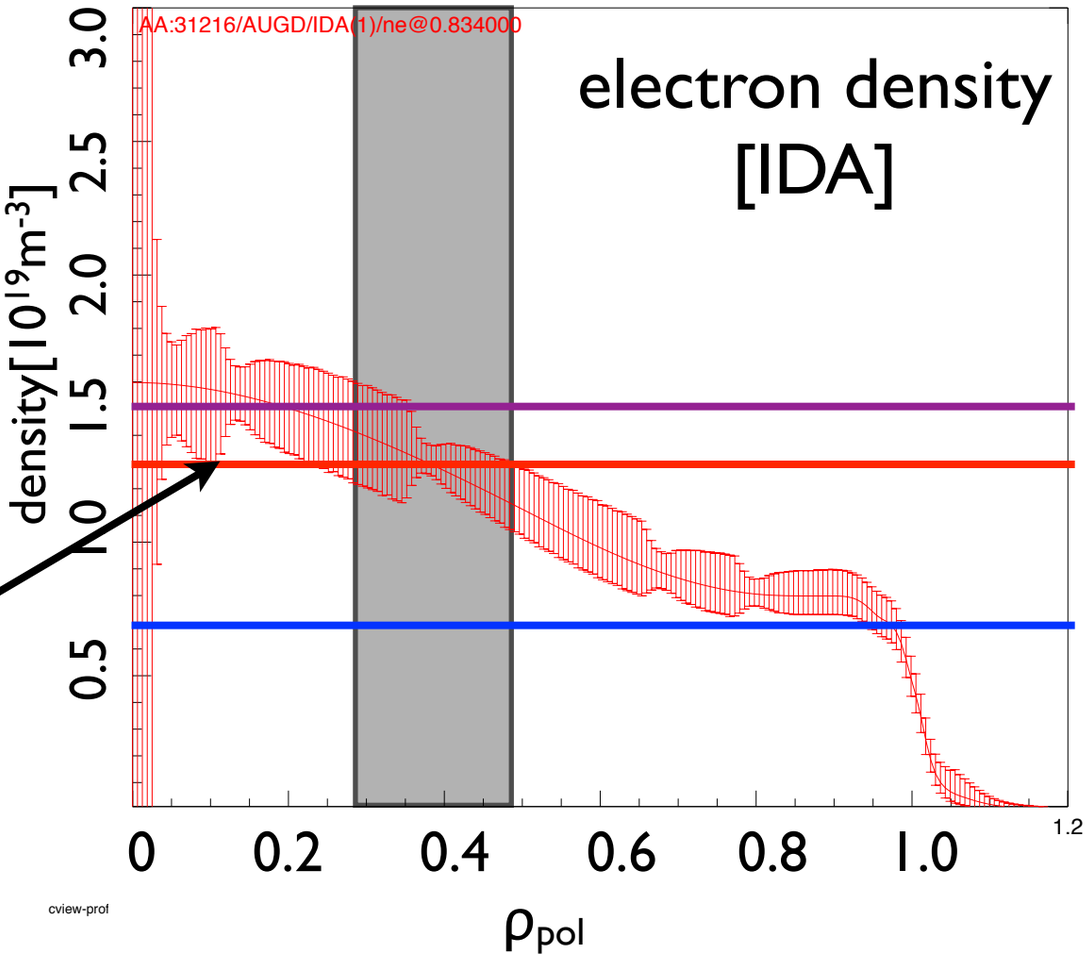
radial mode localisation

from reflectometry (hopping frequency) and soft-X-ray measurements: EGAMs, TAEs RSAEs and intermediate frequency modes are visible in the same channels ⇒ similar radial location at ρ_{pol} ~0.2-0.5,

EGAMs more core localised (0.1-0.5), TAEs more outside (0.3-0.7)



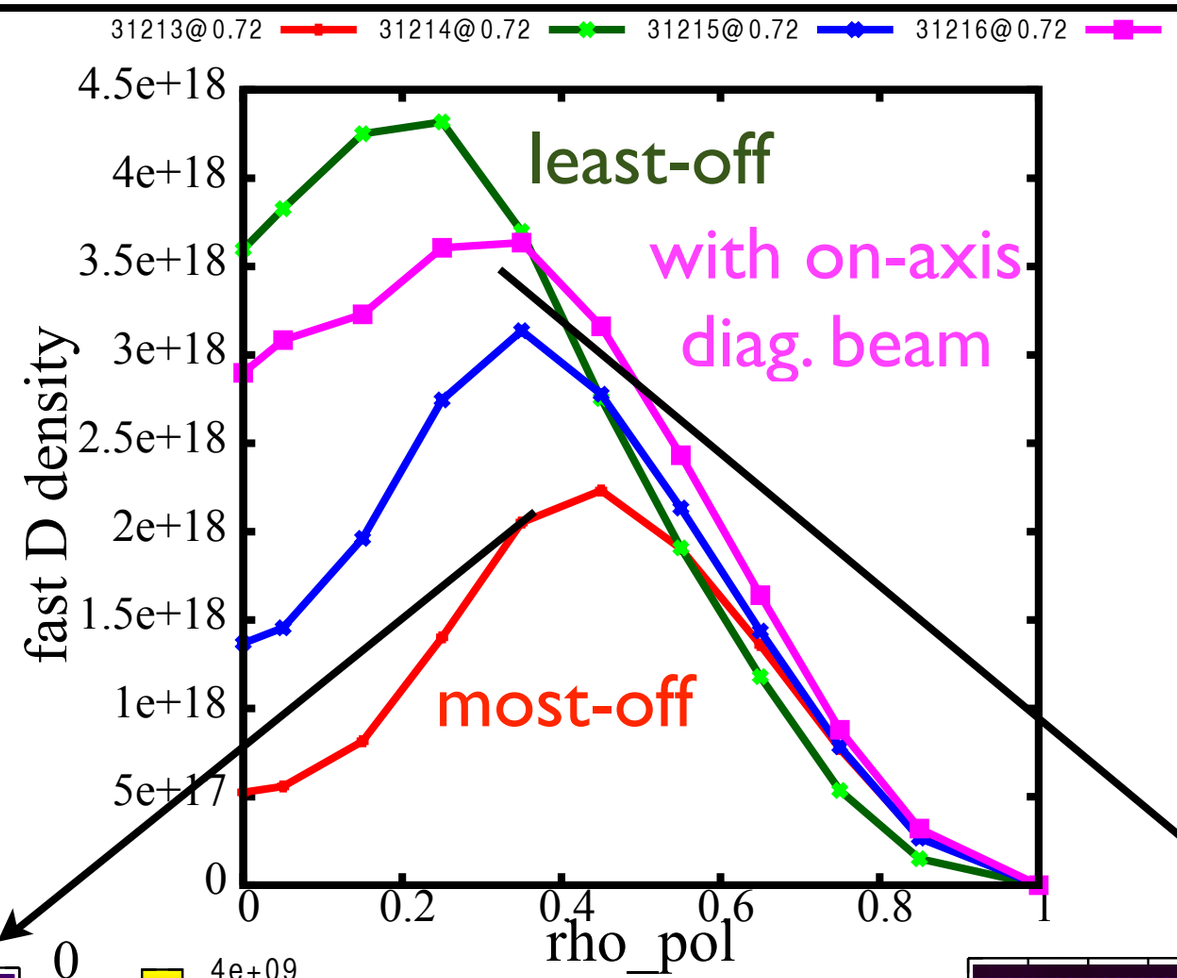
[V. Nikolaeva, L Guimares]

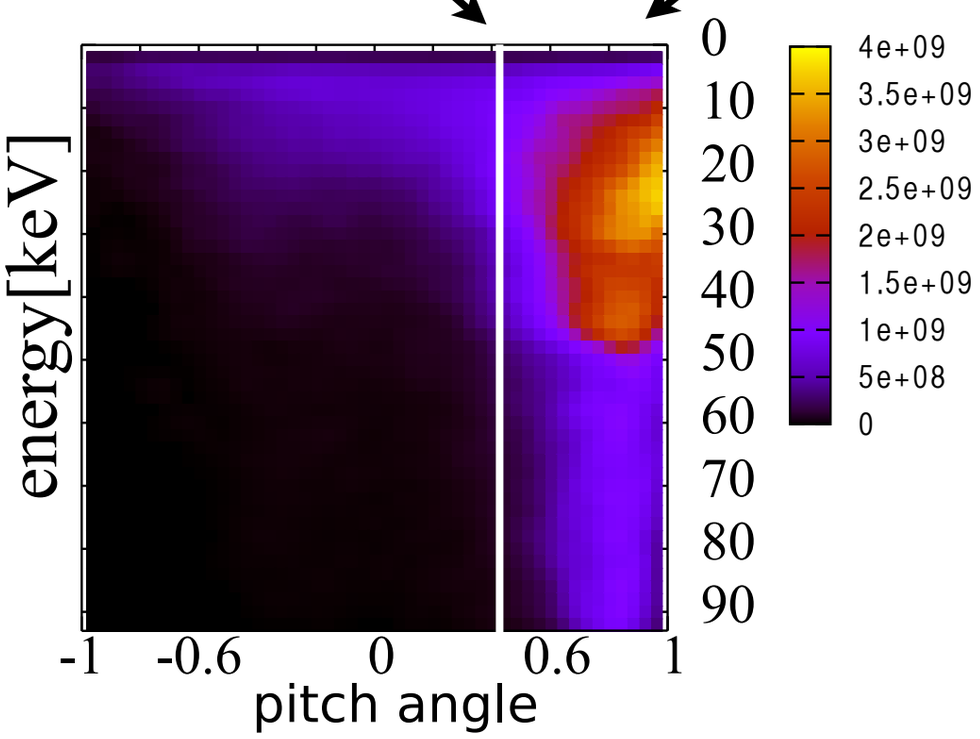


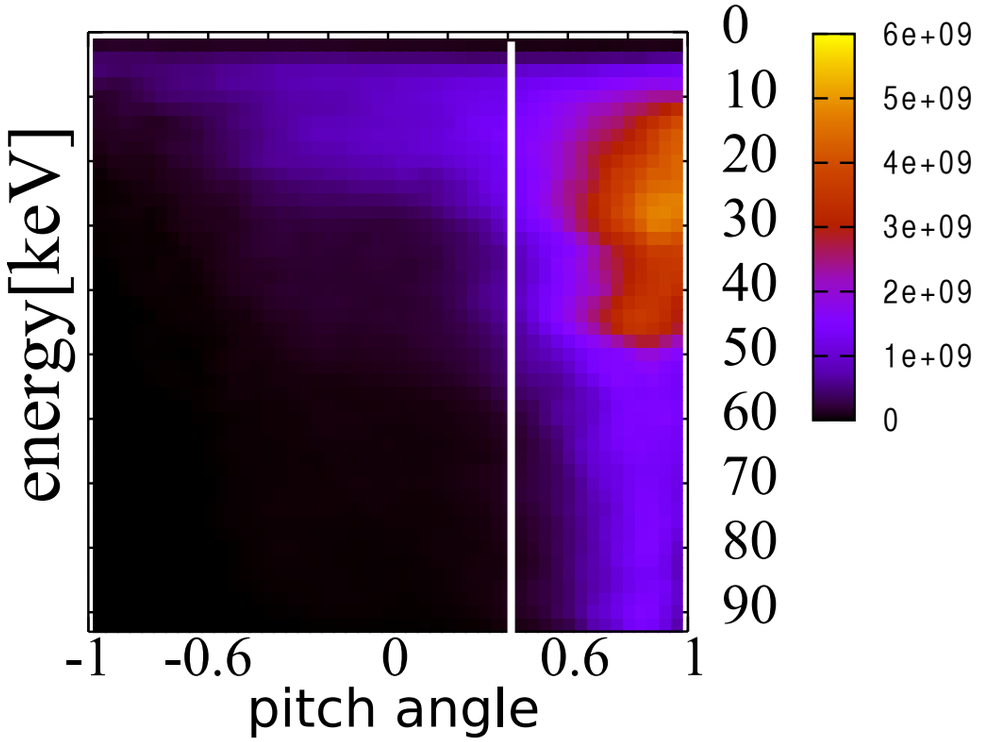
NBI distribution function

radial dependence: off-axis maximum

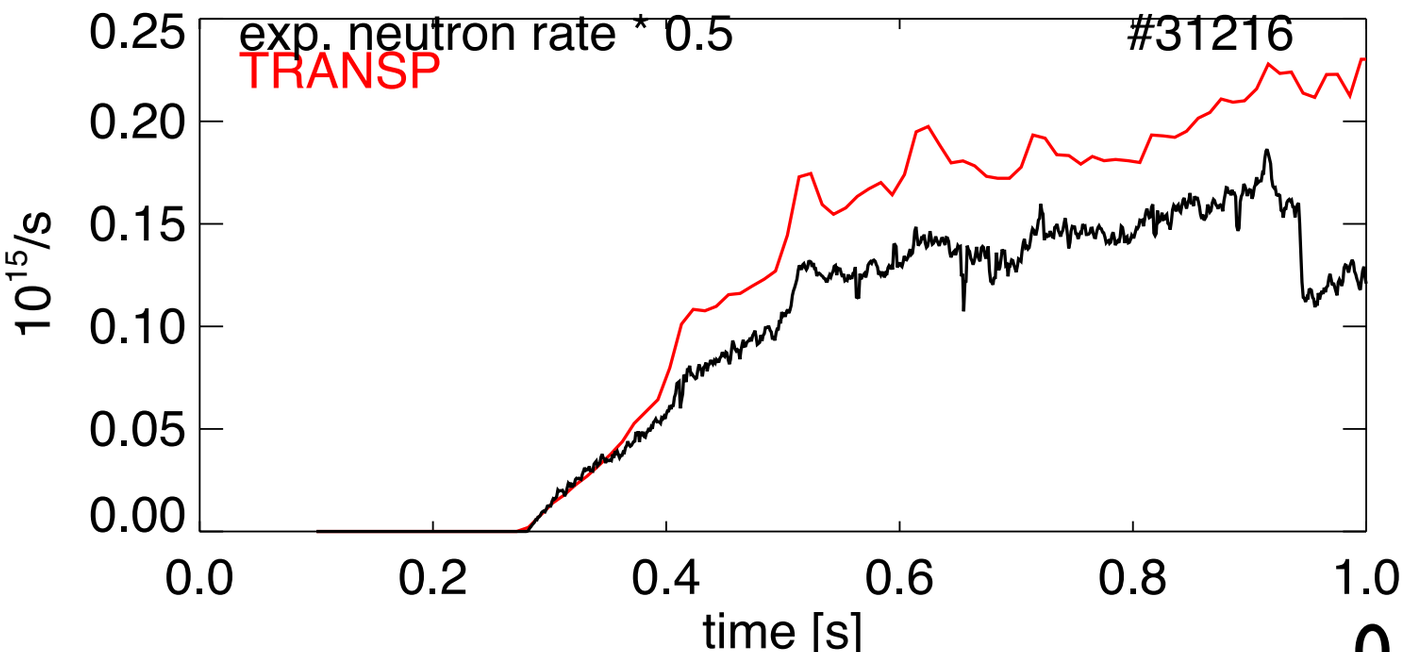
trapped/ passing boundary



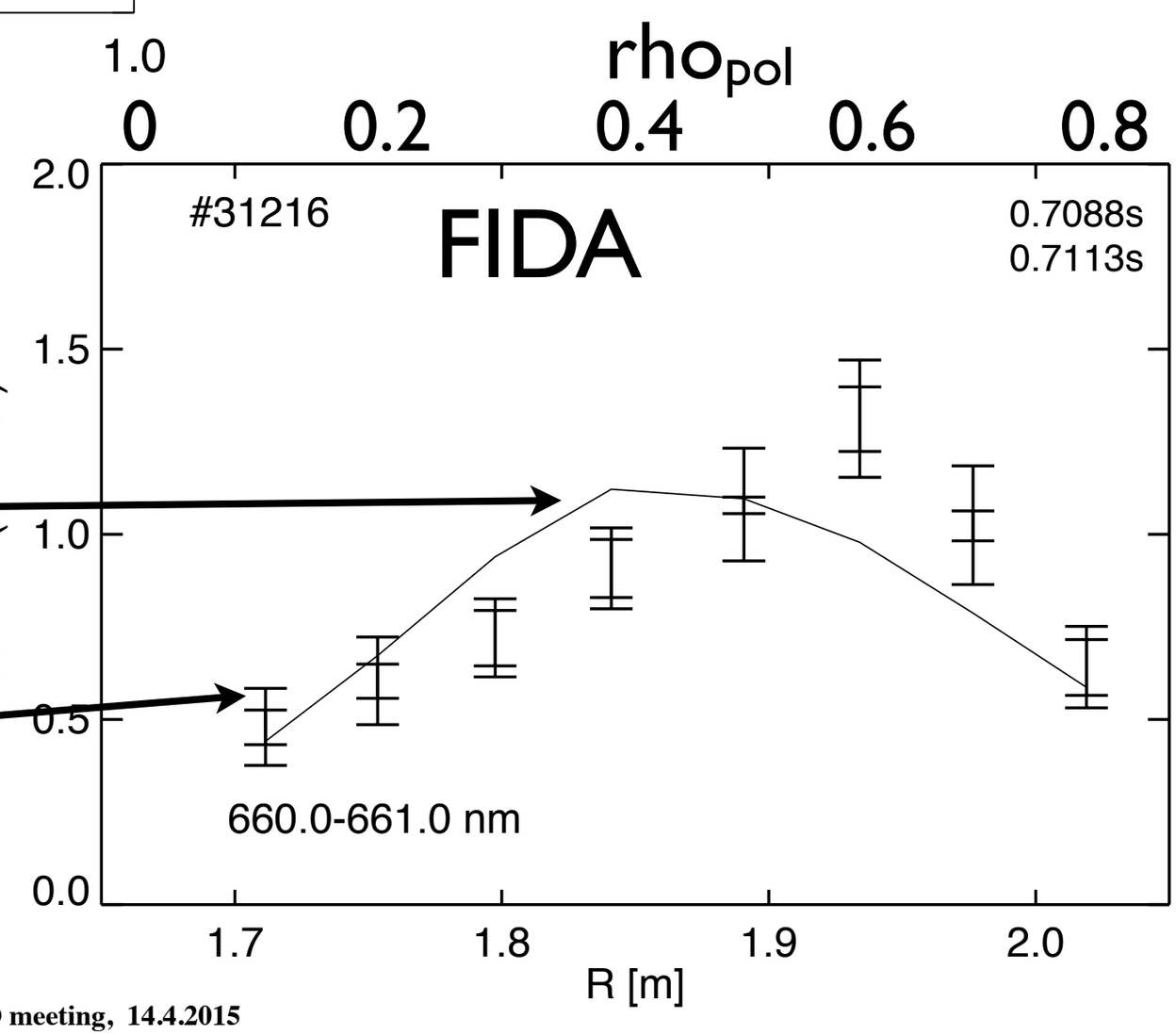




experimental EP transport



[B Geiger]



forward simulation

measurements

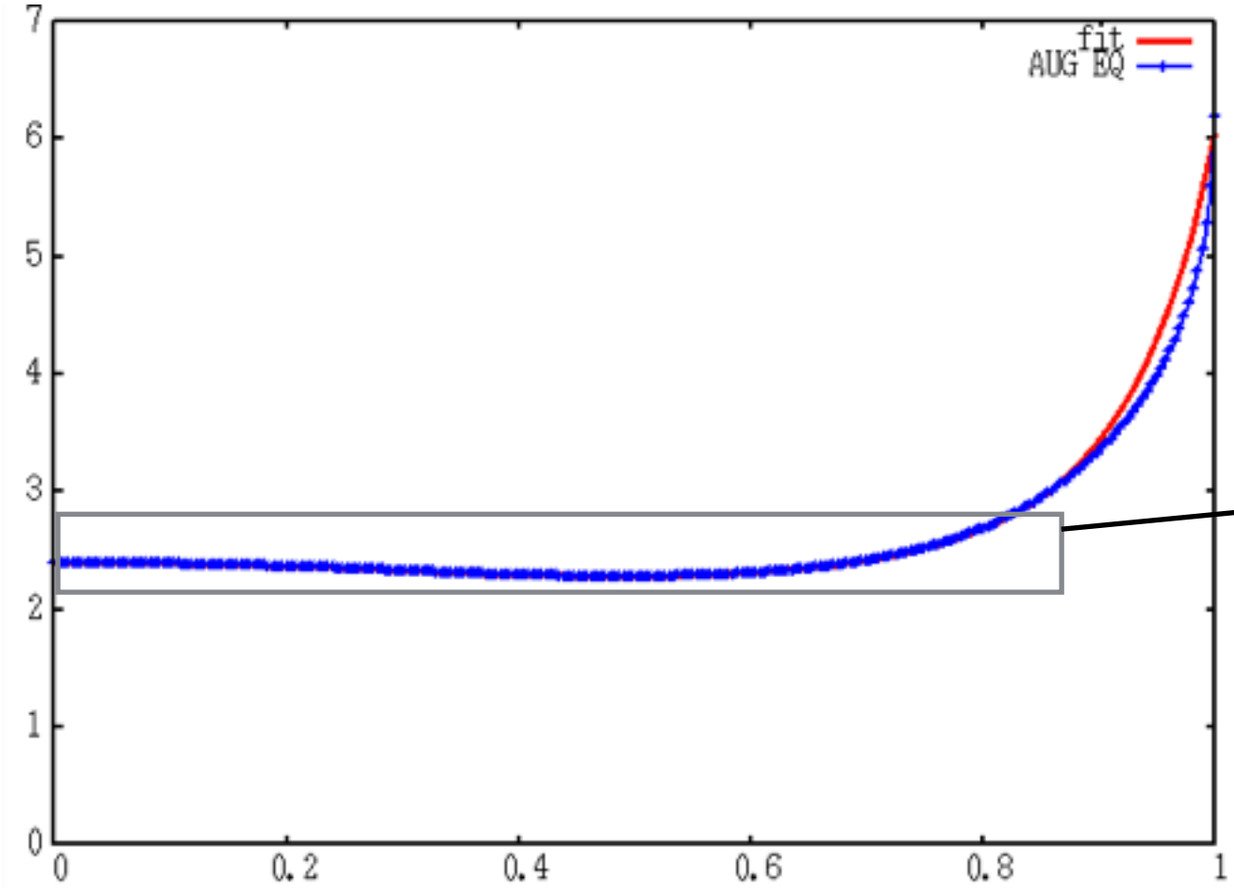
synthetic test case: q-profile

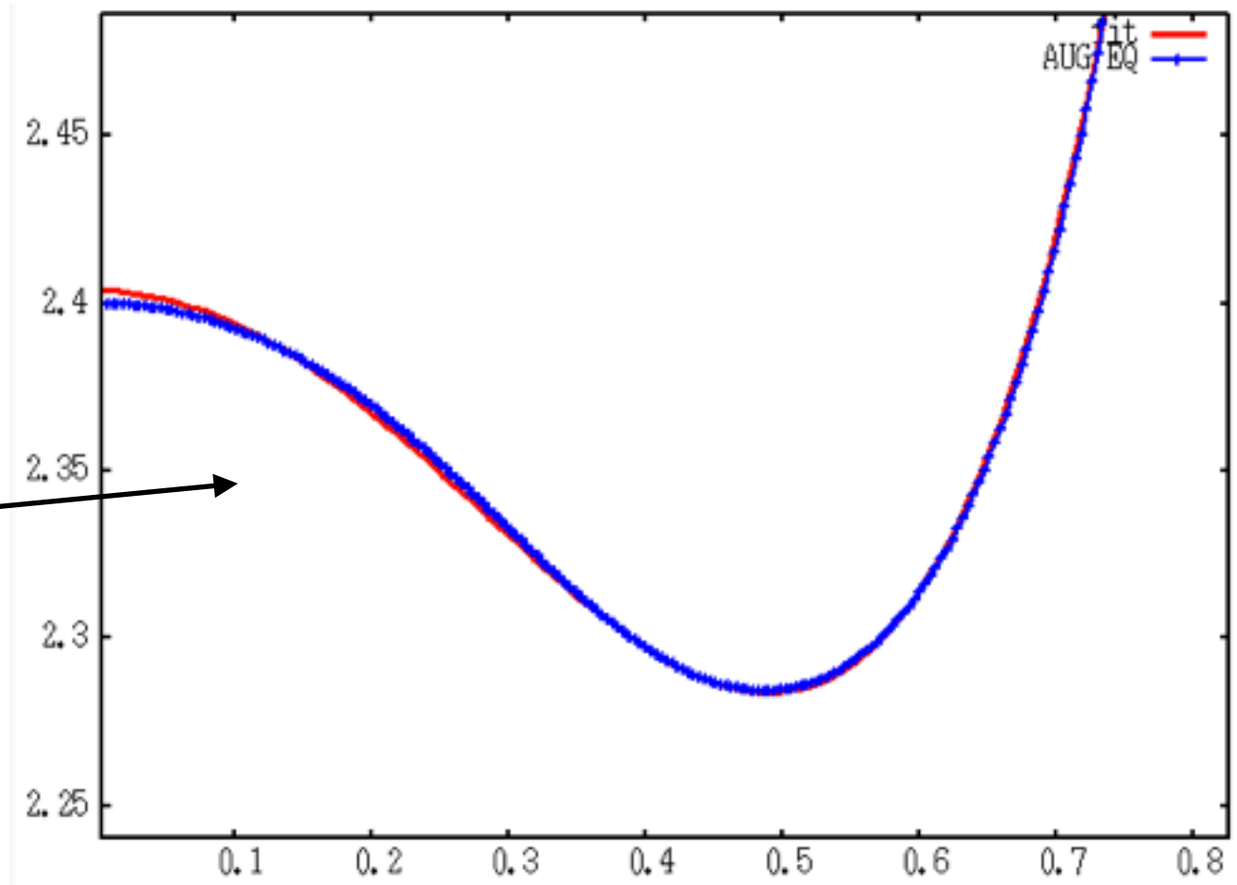
x: sqrt (normalised poloidal flux)

$$q(x)=a+b\,x^2+c\,x^4+d\,x^{16}$$

a= 2.40367; b = -0.994915; c = 2.06782; d = 2.61738

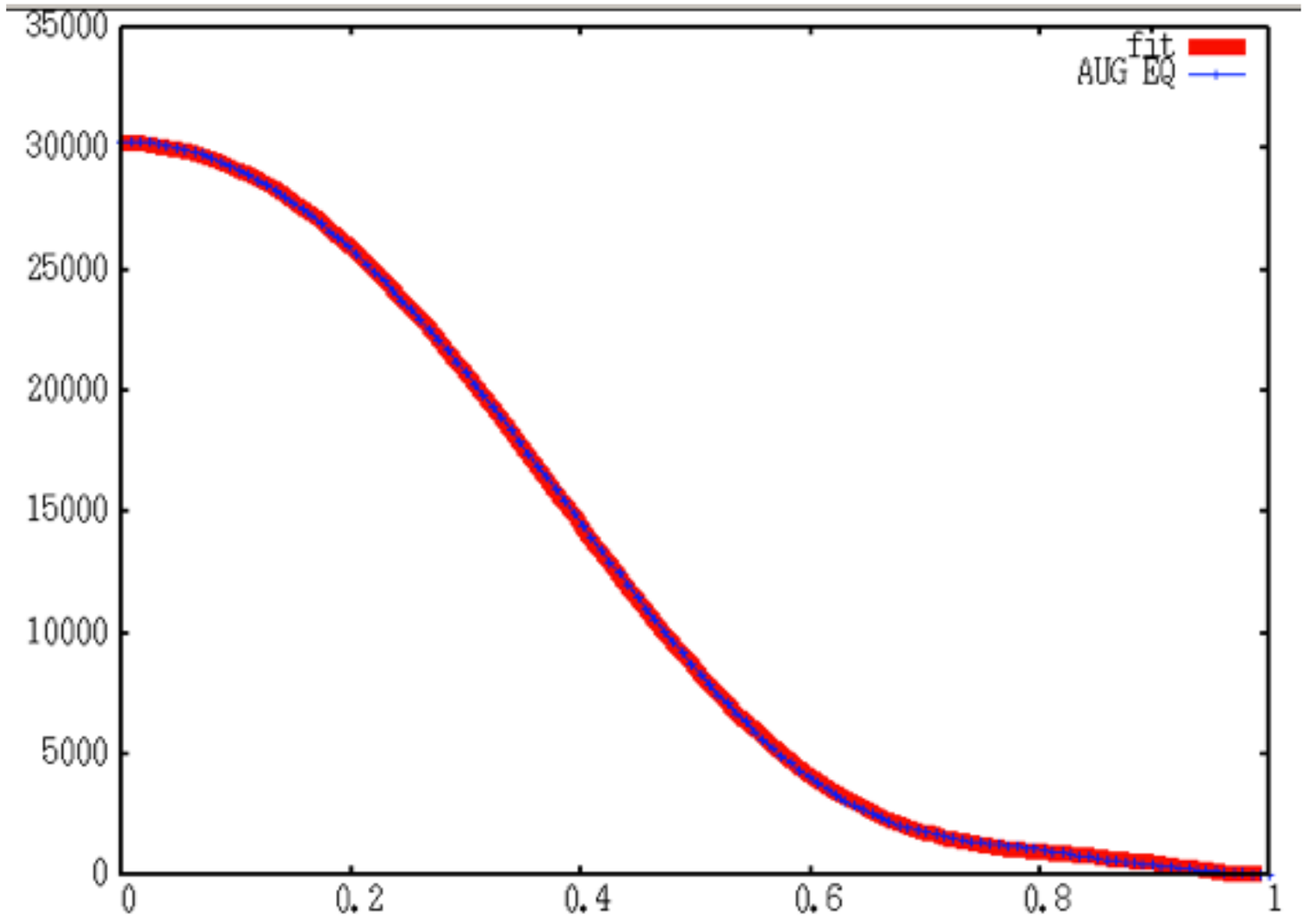
simplify?





total equilibrium pressure

[kPa]



sqrt (normalised poloidal flux)

$$f(x)=a+b\,x^2+c\,x^4+d\,x^5+g\,x^6+h\,x^7$$

a = 30195.9
b = -102303
c = -381943
d = 1.65216e+06
g = -1.85843e+06
h = 660312

equilibrium quantities

R_geo = 1.620m
B_geo = 2.248T
R_mag = 1.666m
B_mag = 2.208
a [m] = 0.482m
$\varepsilon = a/R_{geo} = 0.297$
$\beta_{tot,axis} = 1.3\%$

1.step: take mid-radius values for background $T_{i,e}$; on axis flat density
2.step: use density profile
3.step: use profile for Ti=Te
4.step: use different profiles for Ti, Te

step 1:

use parameters at mid radius:

$n_e=n_D=1.265\ 10^{19}m^{-3}$

Te=Ti=1.6keV

f_{A0} = 909.209 kHz

va0 = $9.54 * 10^6$ m/s

dimensionless parameters: $v_{th}^2=2T/m$

$a/\rho_D=115$

$a/\rho_{fast\ D}=15$ [93 keV]

$\beta_{kin,back,on\text{-}axis}=0.3\%$

$v_{th,e}/va0=$ 2.49

$v_{th,D}/va0$ = 0.04

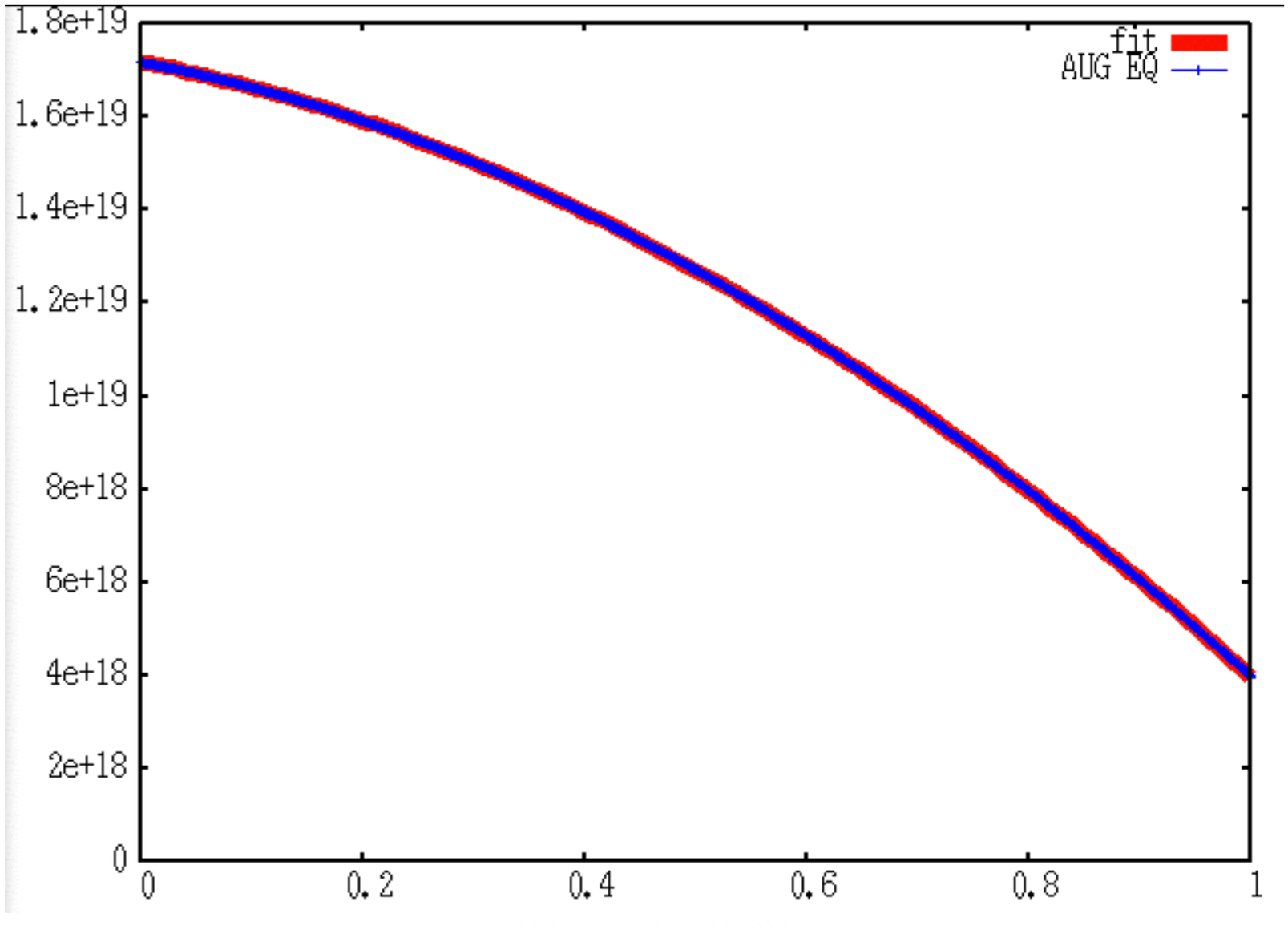
$v_{th,fast\ D}/va0$ = 0.312 [93keV]

electron density:

x: sqrt (normalised poloidal flux)

electron density [m^{-3}]: $n_e(x)=a+b\,x+c\,x^2+d\,x^4$

a = 1.71587e+19 b = -4.52225e+18; c= -8.85926e+18 d= 1.98778e+17



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deuterium temperature:

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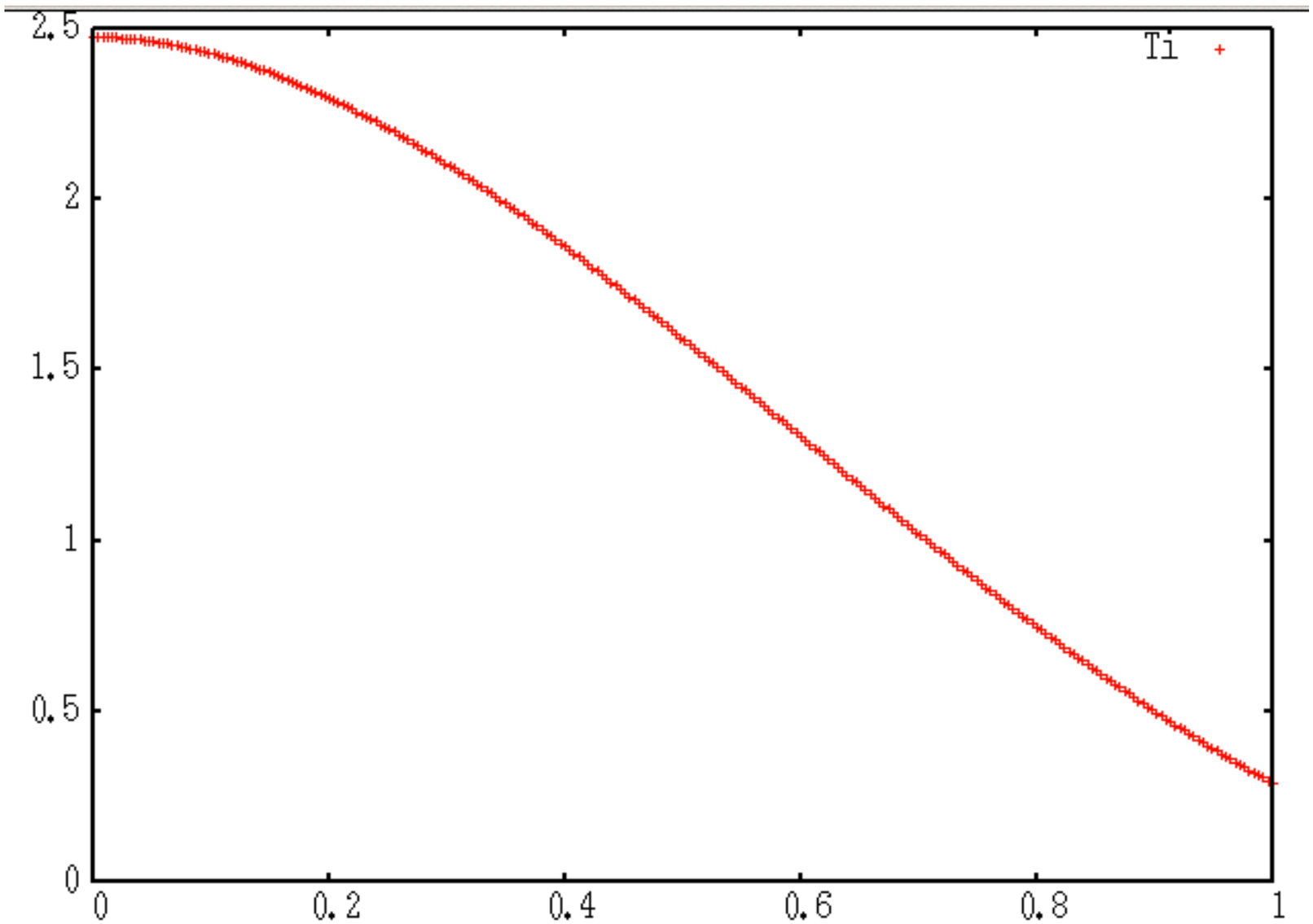
x: sqrt (normalised poloidal flux)

deuterium temperature[eV]: $Ti(x)=a+b\,x^2+c\,x^3+d\,x^4$

a=2474.1; b=-5128.7;c=3417.9,d=-473.3

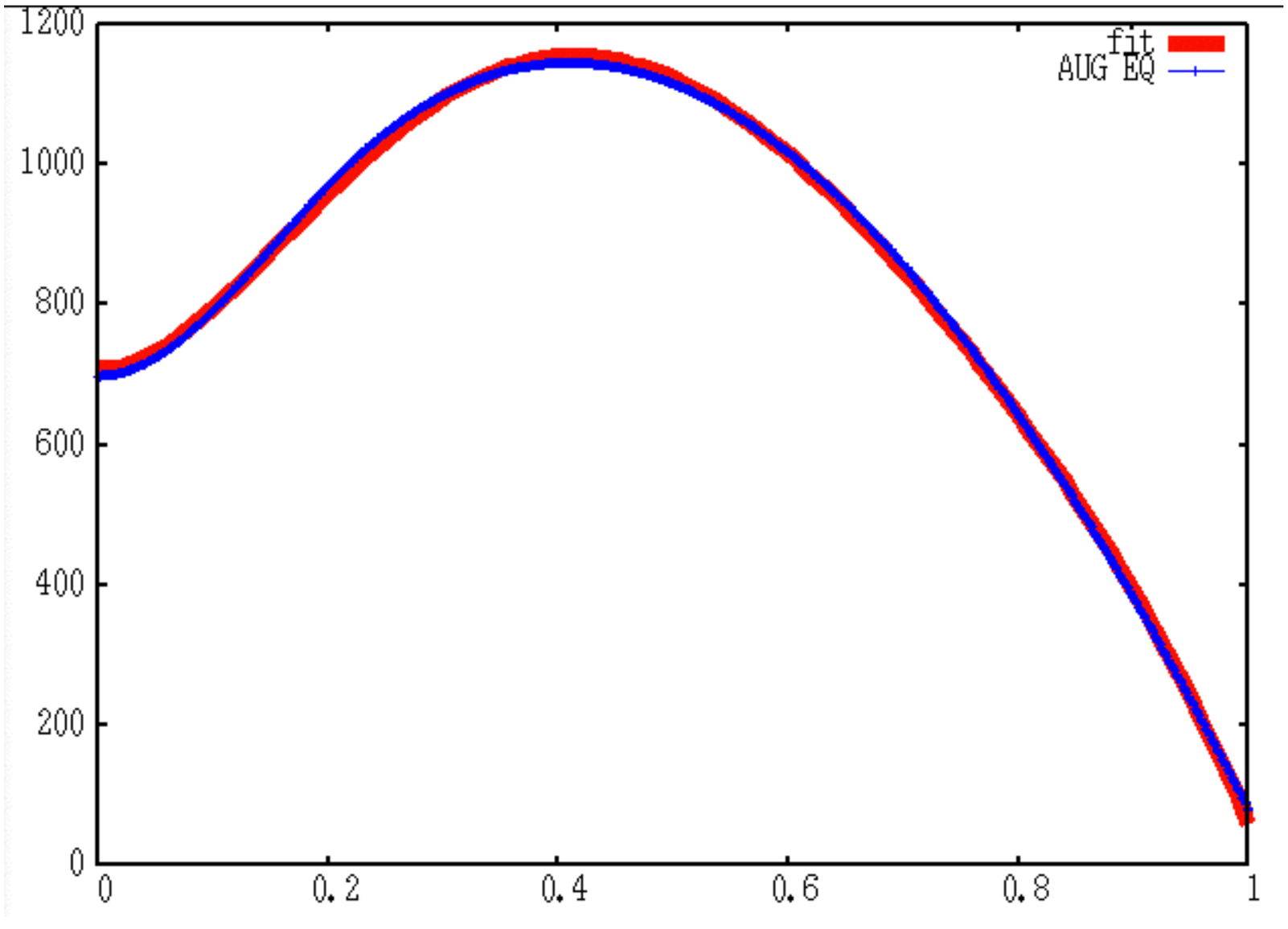


electron temperature:

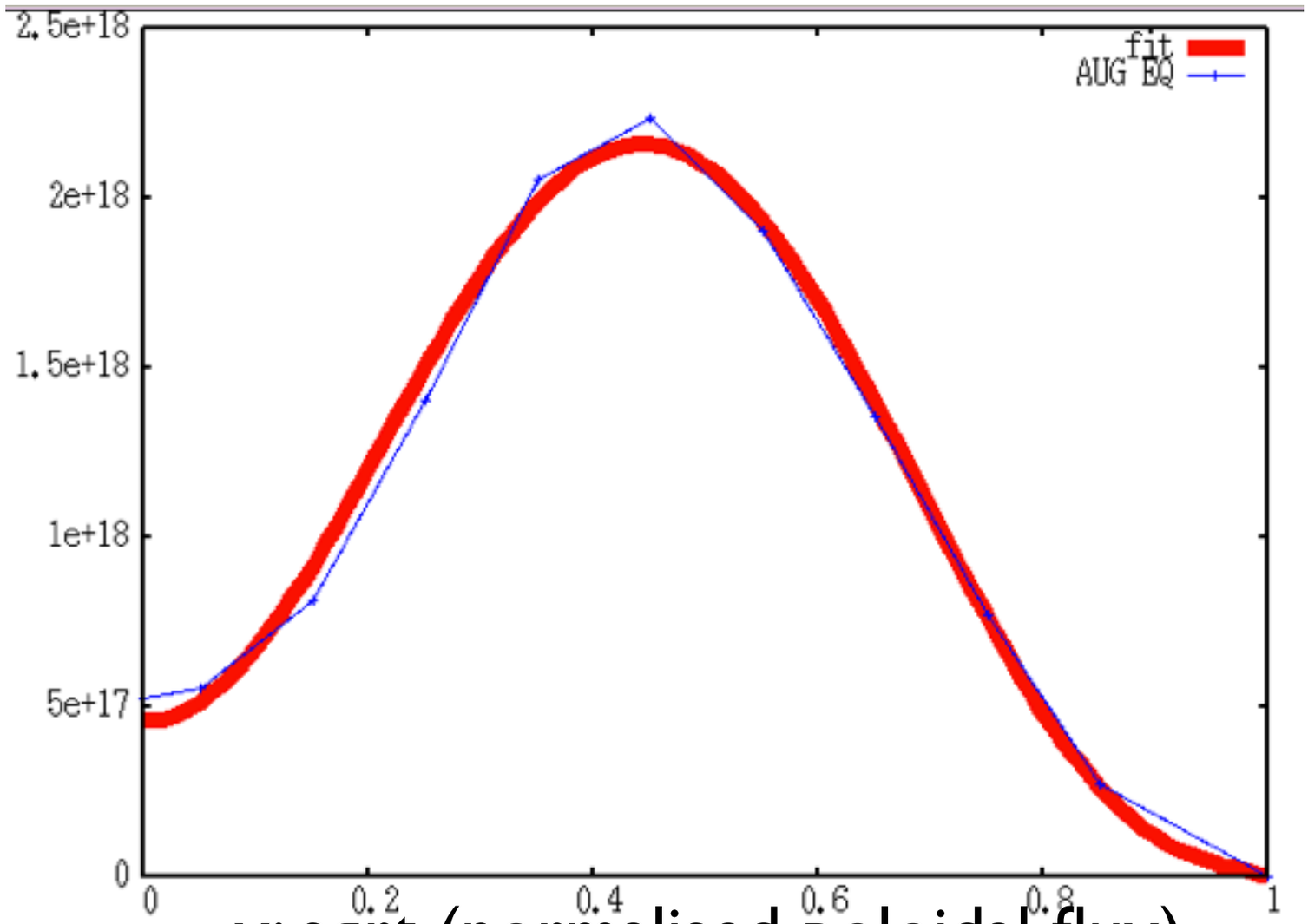
x: sqrt (normalised poloidal flux)

electron temperature [eV]: $Te(x)=a+b\,x^2+c\,x^3+d\,x^4+e\,x^5$

a = 707.419; b = 11909.8; c = -34439.8; d = 33868.6; e = -11986.6



TRANSP NBI distribution function

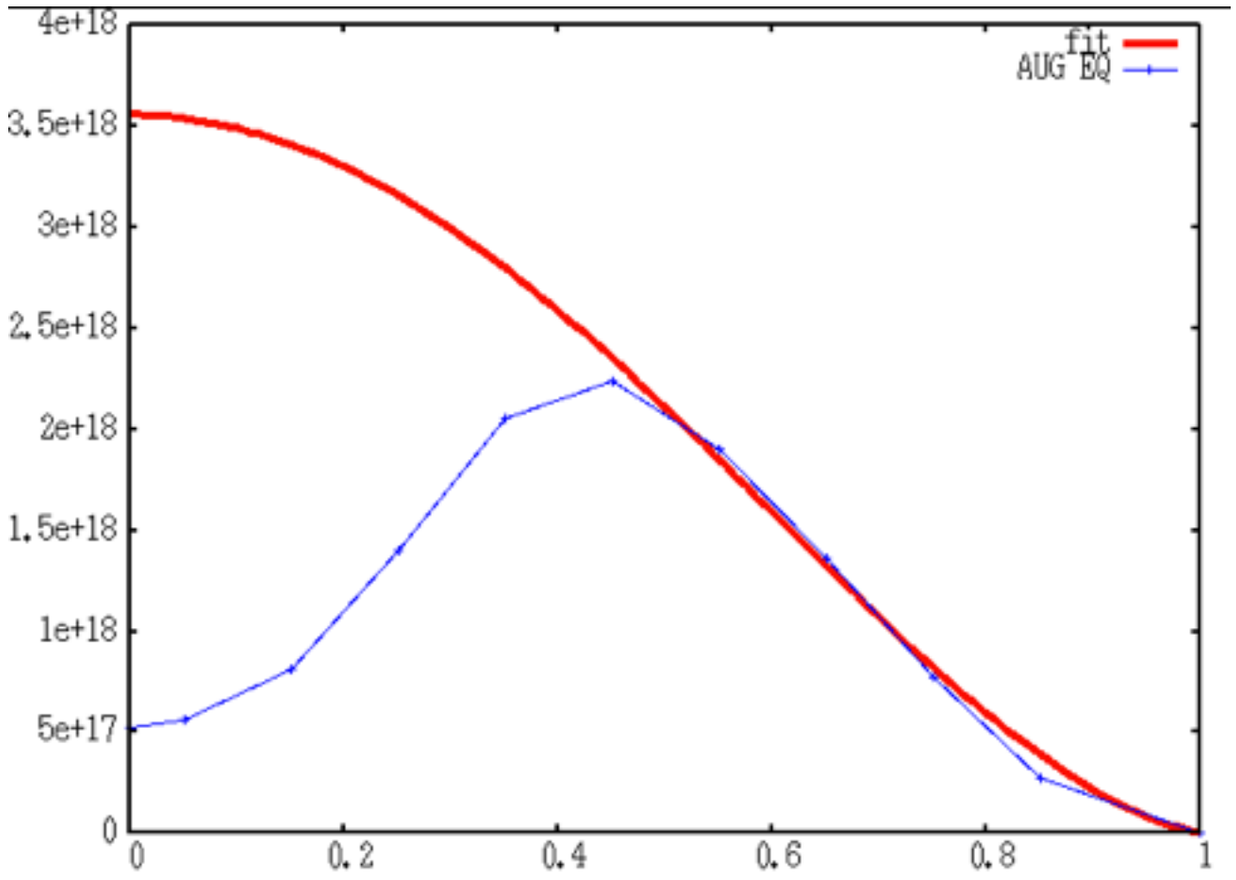


x: sqrt (normalised poloidal flux)

$nf(x)=a+b\,x^2+c\,x^6+e\,x^4+g\,x^5$

a = 4.58182e+17; b = 2.30149e+19 ;
c = -7.56176e+19; e= -1.4614e+20; g= 1.98287e+20

simplified NBI distribution function



$$n_{fD}(x)=a+b\,x^2+c\,x^4$$

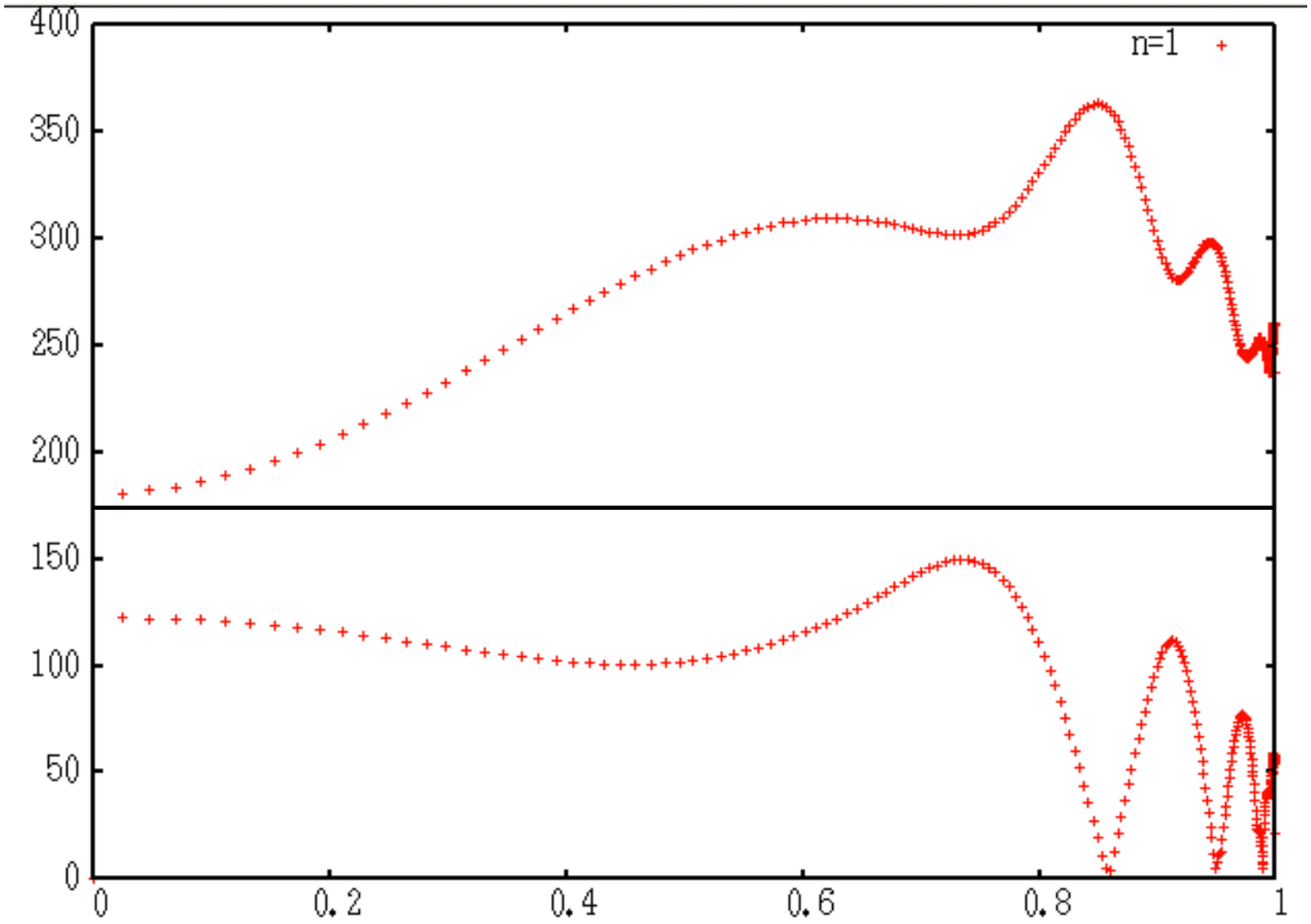
a = 3.552e+18;
b = -6.52986e+18;
c= 2.97864e+18

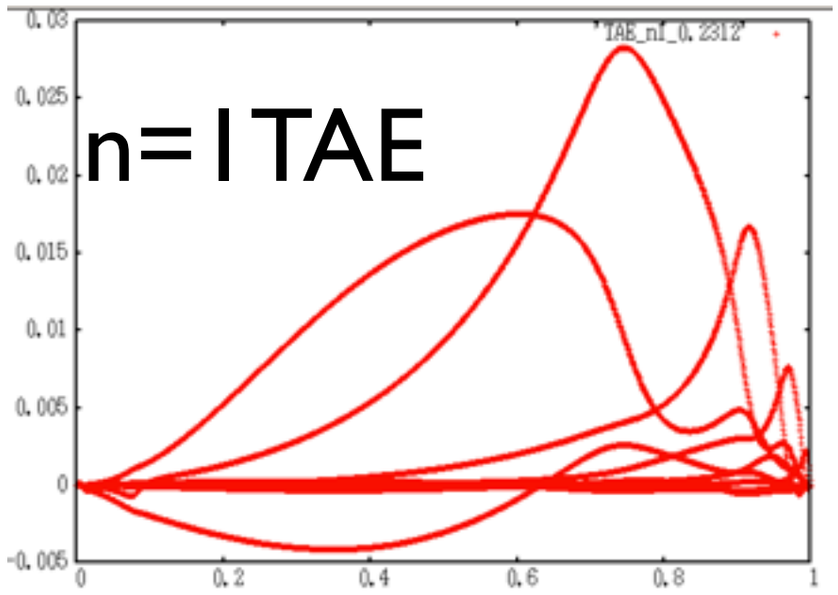
suggestion for starting point (TAE,RSAE,BAE):
change (Maxwellian) temperature; 'effective' $T_{fast,D}$ ~ 30keV (T_f/T_D=18.75)

representation of anisotropy (EGAM) to be determined together with Claudio
is Claudio's representation [PPCF, 54, (2012) 105017] ok?

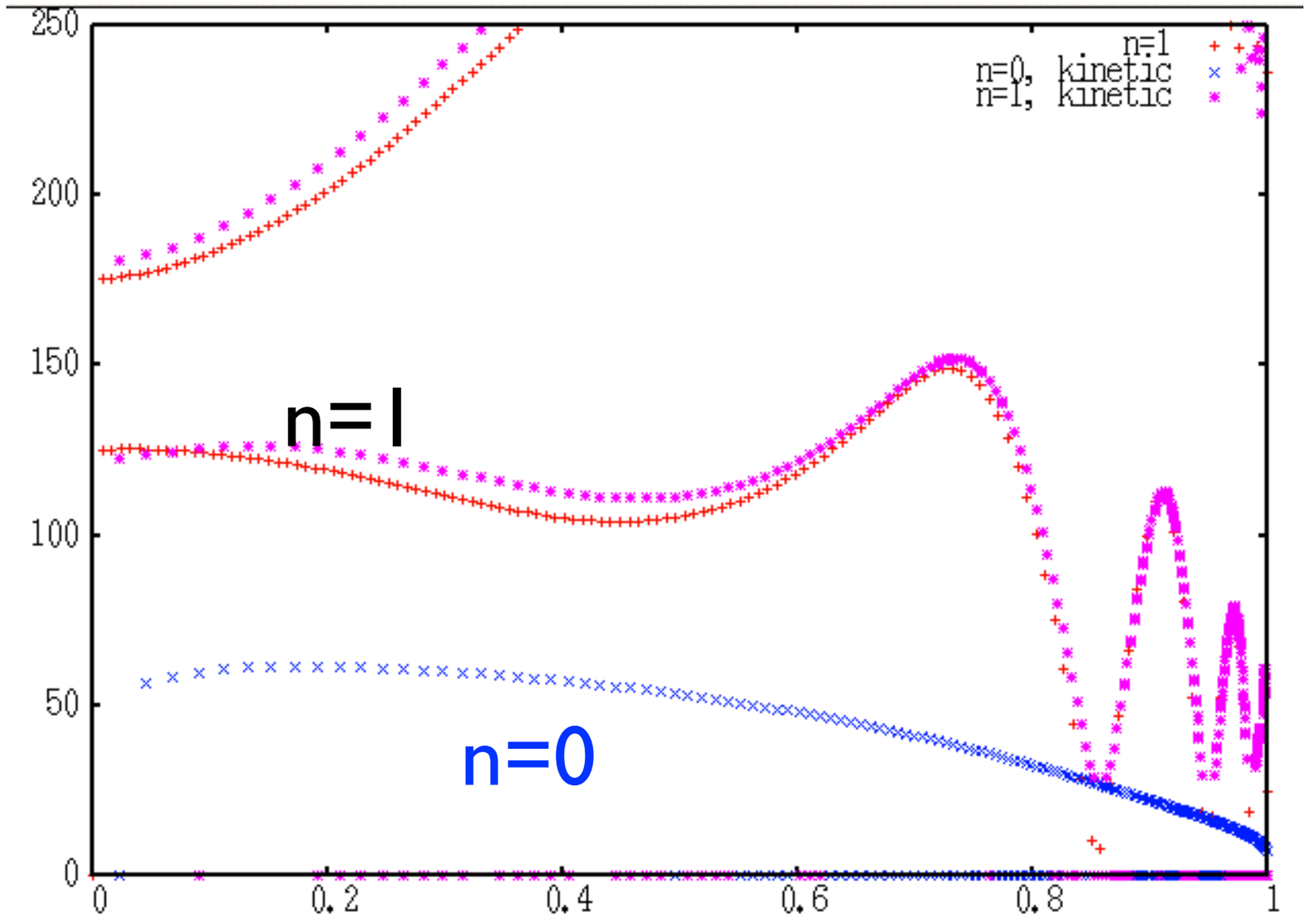
$$f_{eq}=\frac{\mathcal{N}\left(w/T_w\right)^{\alpha_w}}{\sqrt{2\pi}w^{3/2}}\exp\left[-\left(\frac{\mathcal{P}_\phi-\mathcal{P}_{\phi 0}}{\Delta_{P_\phi}}\right)^2\right]\exp\left\{-\frac{w}{T_w}\left[1+\left(\frac{\lambda-\lambda_0}{\Delta_\lambda}\right)^2\right]\right\}$$

ideal n=1 SAW spectrum





kinetic spectra



summary & discussion

- AUG (and DIII-D?) seem to be close to regimes with strongly nonlinear EP dynamics (like spherical Tokamaks or JT-60U)
- TAE/EPM bursts instead of several marginally stable modes - where is the transition?
- experimentally: reduced beam voltage and NBI power scans to be performed in 2015

- are proposed parameters possible for NLED codes? simplifications needed? different representation?
- EP parametric distribution function to be determined (next weeks)
- scale to burning plasmas: change ρ^* - mode numbers