Feasibilty study for the measurement of Slowing-Down Alpha Particles on ITER using DNB and HNB
A review

ITPA Meeting
Princeton, March 2007

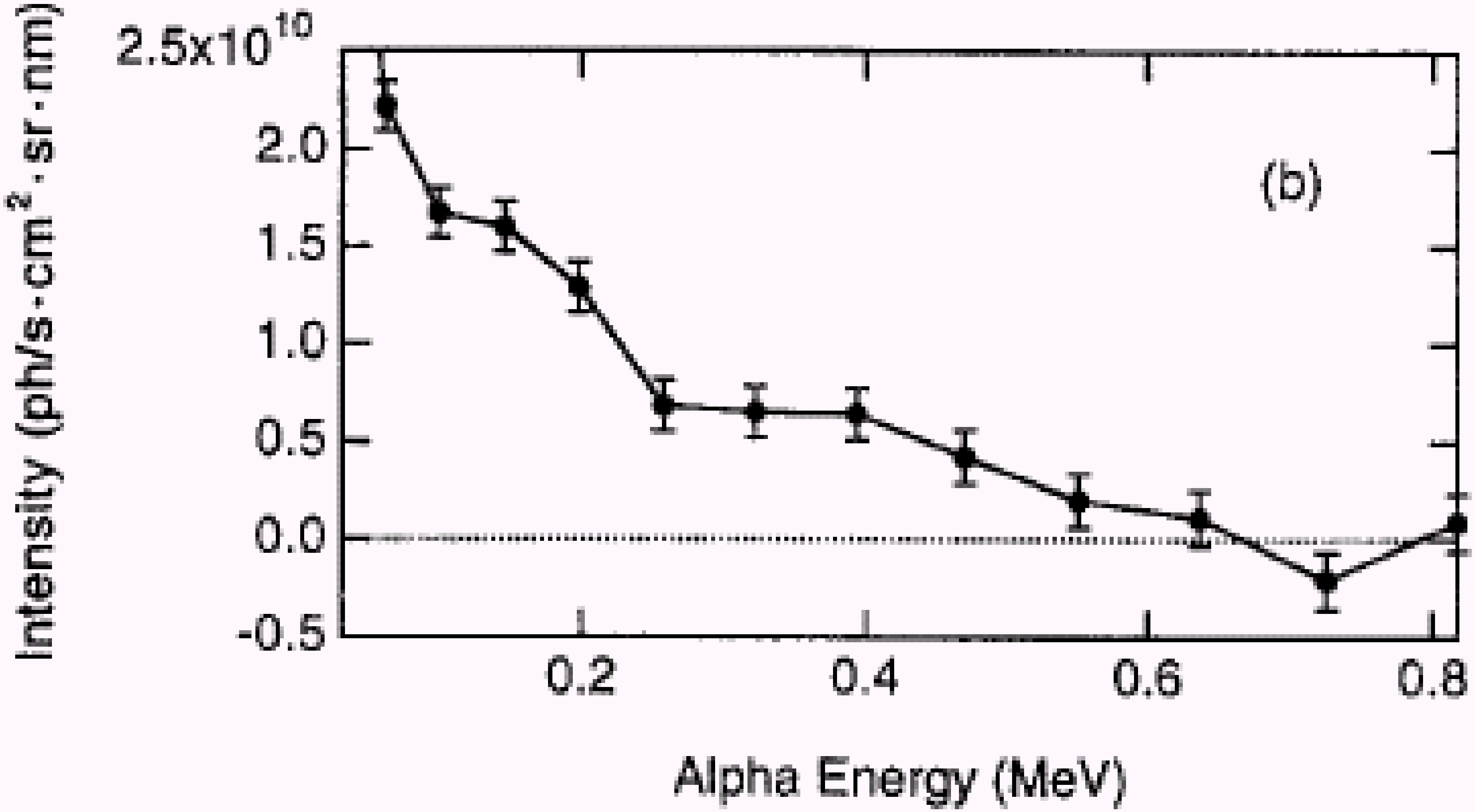
Introduction

Present predictions of thermal helium ash measurement on ITER using the DNB show typical SNR values for HeII of the order 10 in the plasma core (r/a=0.3)

Modelling of alpha source rate profiles and calculation of isotropic slowing-down features and their representation in velocity space are needed for the prediction of broad-band CXRS features in the wave-length region around 486 nm.

A peaked CXRS emission rate function acts as a filter in velocity space.

A goal post set by George McKee in 1997 , can we do this at ITER ?



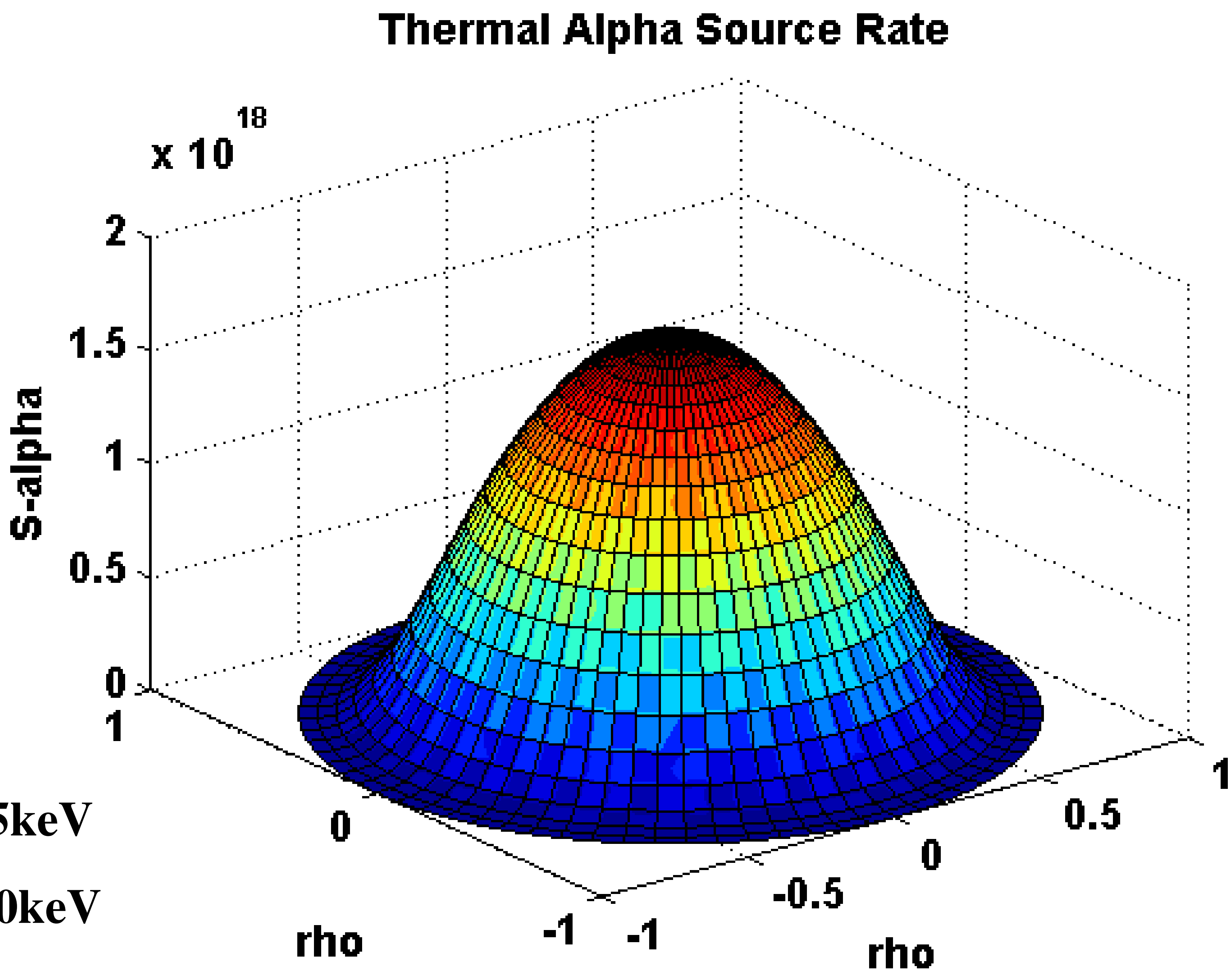
G.R.McKee et al. Nuclear Fusion, 37,501(1997)

$$g_{alpha} = \frac{S \cdot \tau_s}{v_c^3 + v^3}$$

$$\tau_s = \frac{3 v_e^3 m_e m}{16\sqrt{\pi} e^4 Z^2 n_e \ln \Lambda}$$

$$S_{alpha} = \frac{1}{2} n_{thermal}^2 \sigma v_{dt}(T_i)$$

$$v_c^3 = \frac{3}{4}\sqrt{\pi}\left(\frac{2T_e}{m_e}\right)^{3/2} \sum_j \frac{n_j}{n_e} Z_j^2 \frac{m_e}{m_j}$$

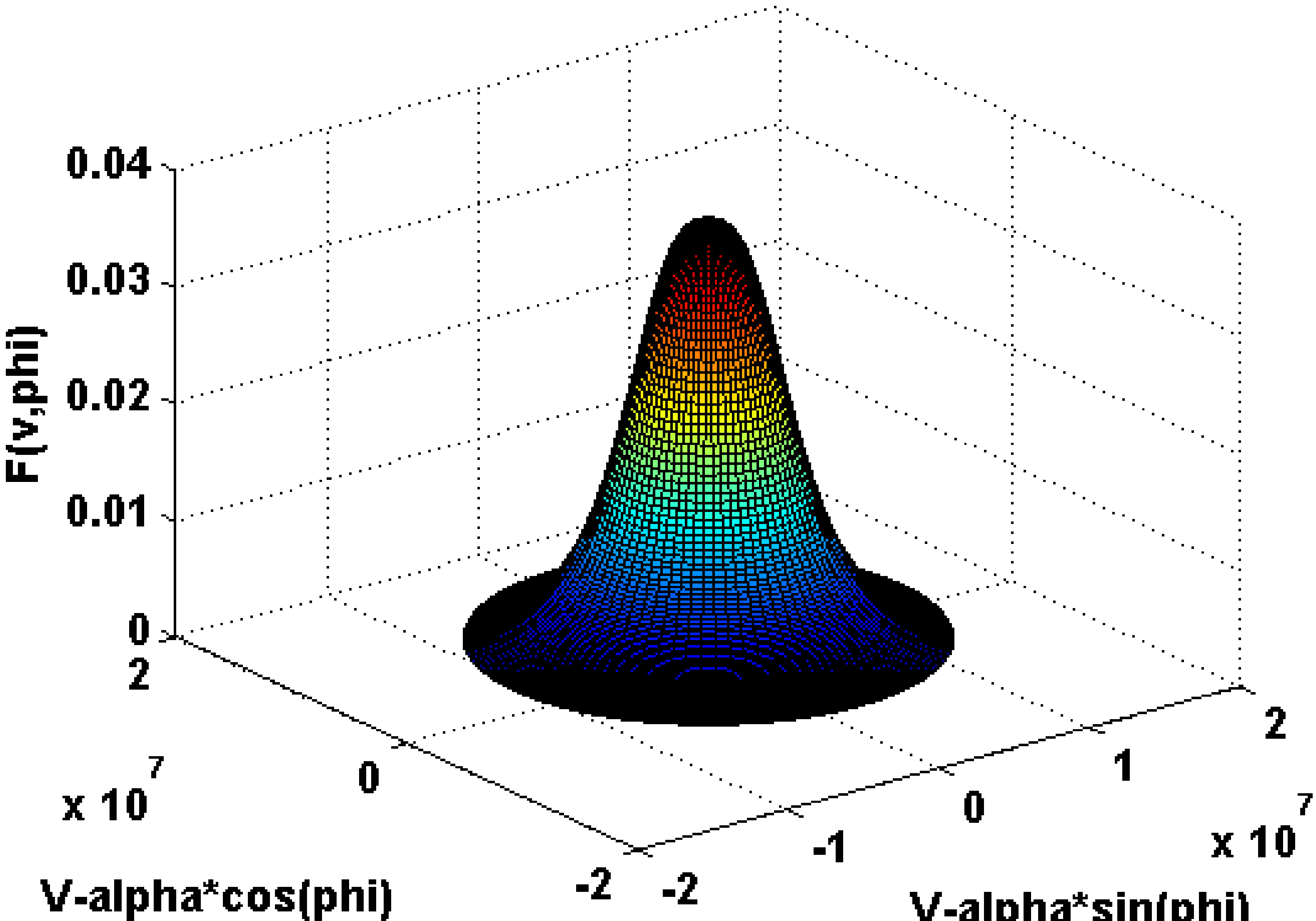


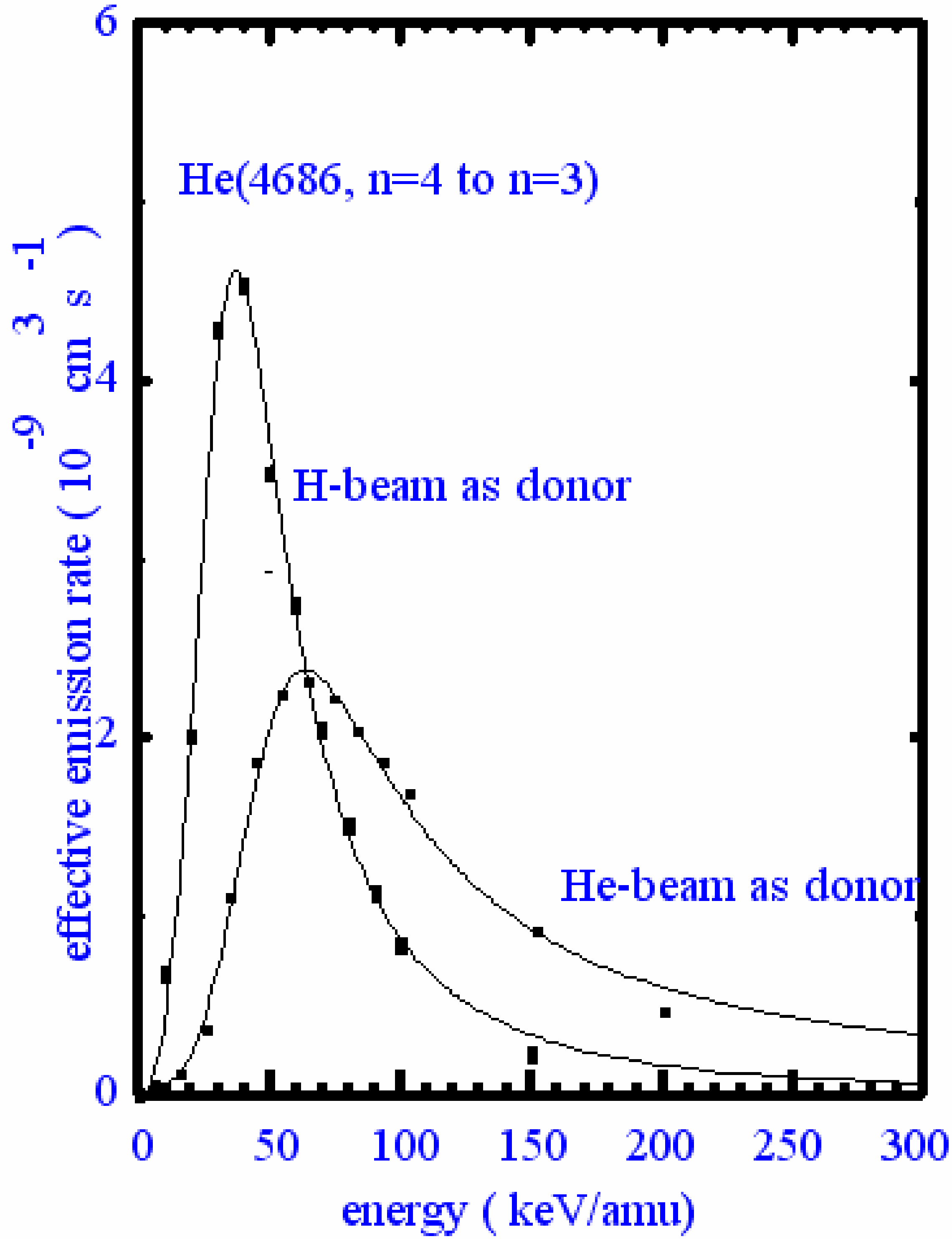
Ti(0)=25keV

Te(0)=20keV

$n_d=n_t=0.5\cdot10^{20}m^{-3}$

Alpha Slowing-Down




He(4686, n=4 to n=3)
H-beam as donor
He-beam as donor
effective emission rate (10 -9 cm 3 s -1)
0
2
4
6
0
50
100
150
200
250
300
energy (keV/amu)

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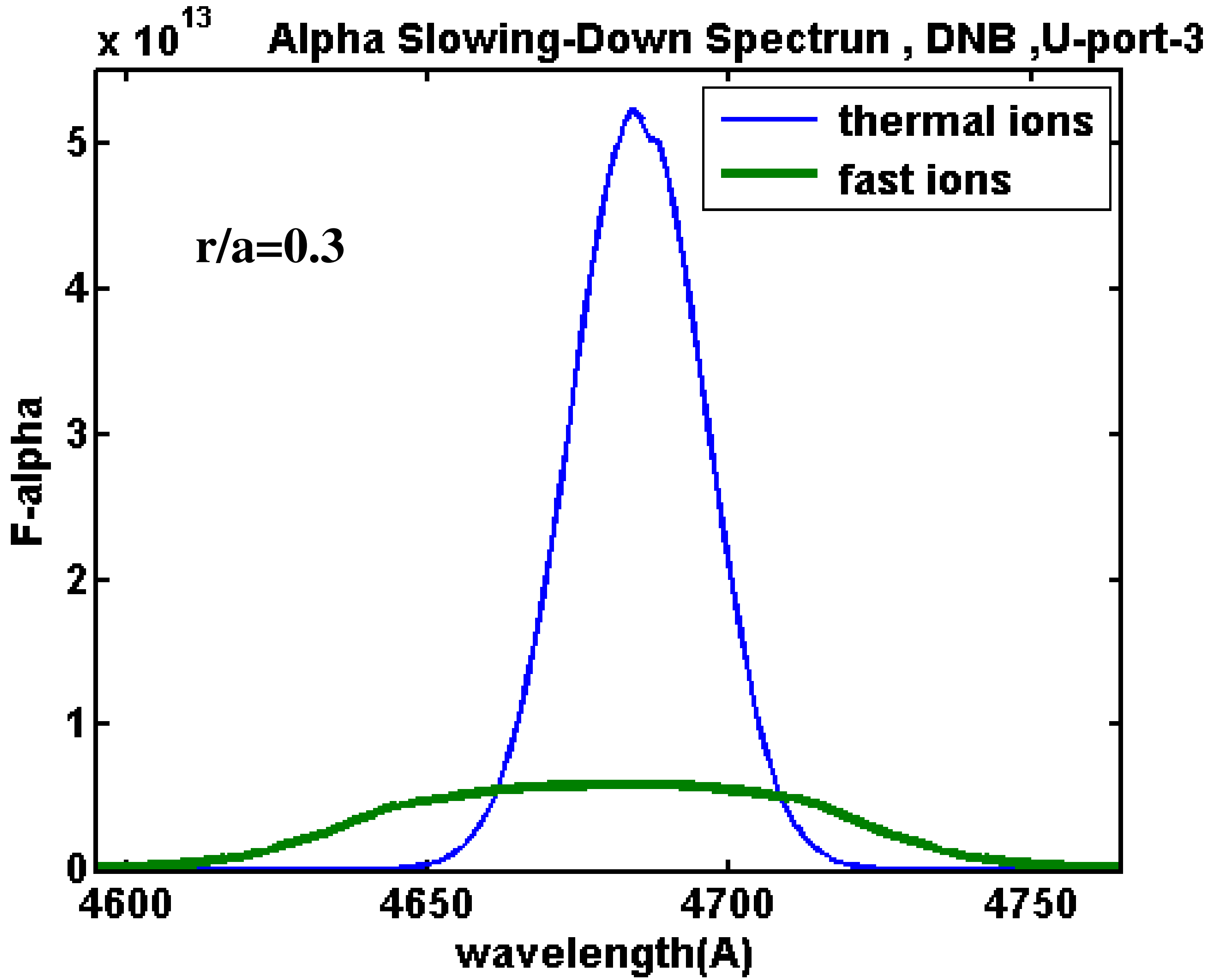
Calculation of observed CX spectrum taking into account collision velocity dependence of effective emission rate

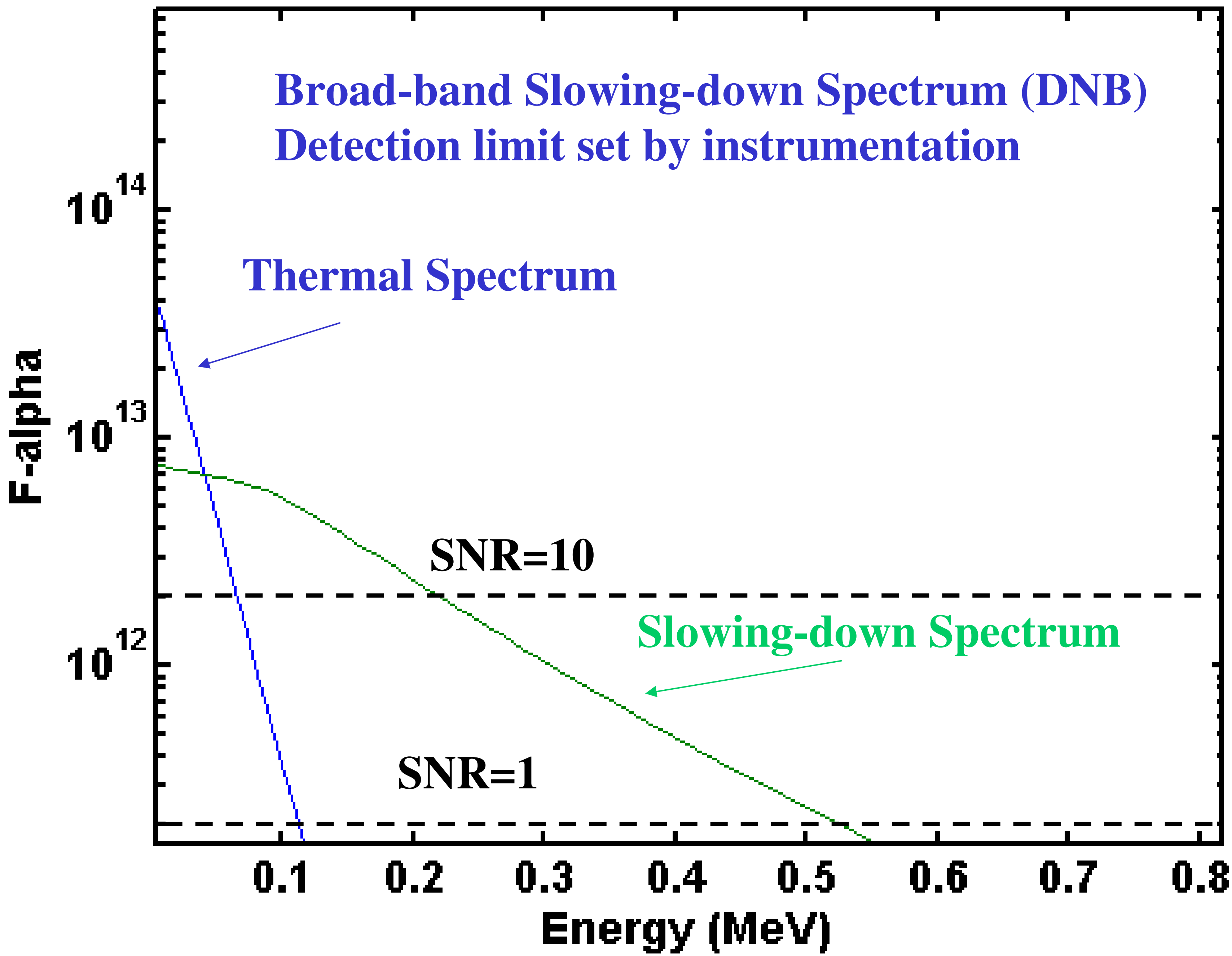
$$f_{obs}(v_z) =$$

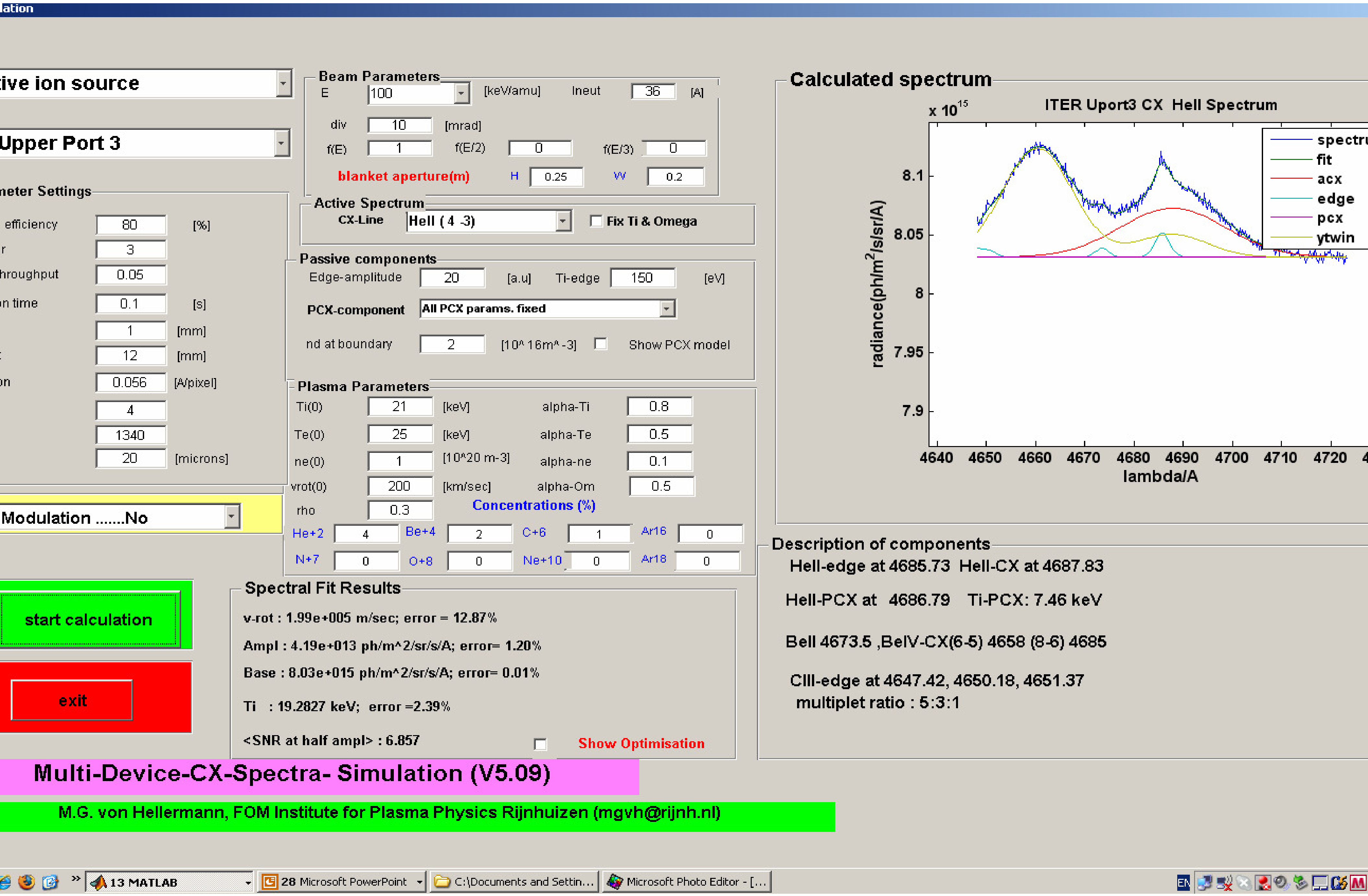
$$\int_0^\infty v'^2\, dv' \int_0^\pi d\theta' \sin\theta' \int_0^{2\pi} d\varphi'$$

$$g_{slow}(v', \theta', \varphi') Q_{cx}(v_r) \delta(v_z - v' \cos\theta')$$

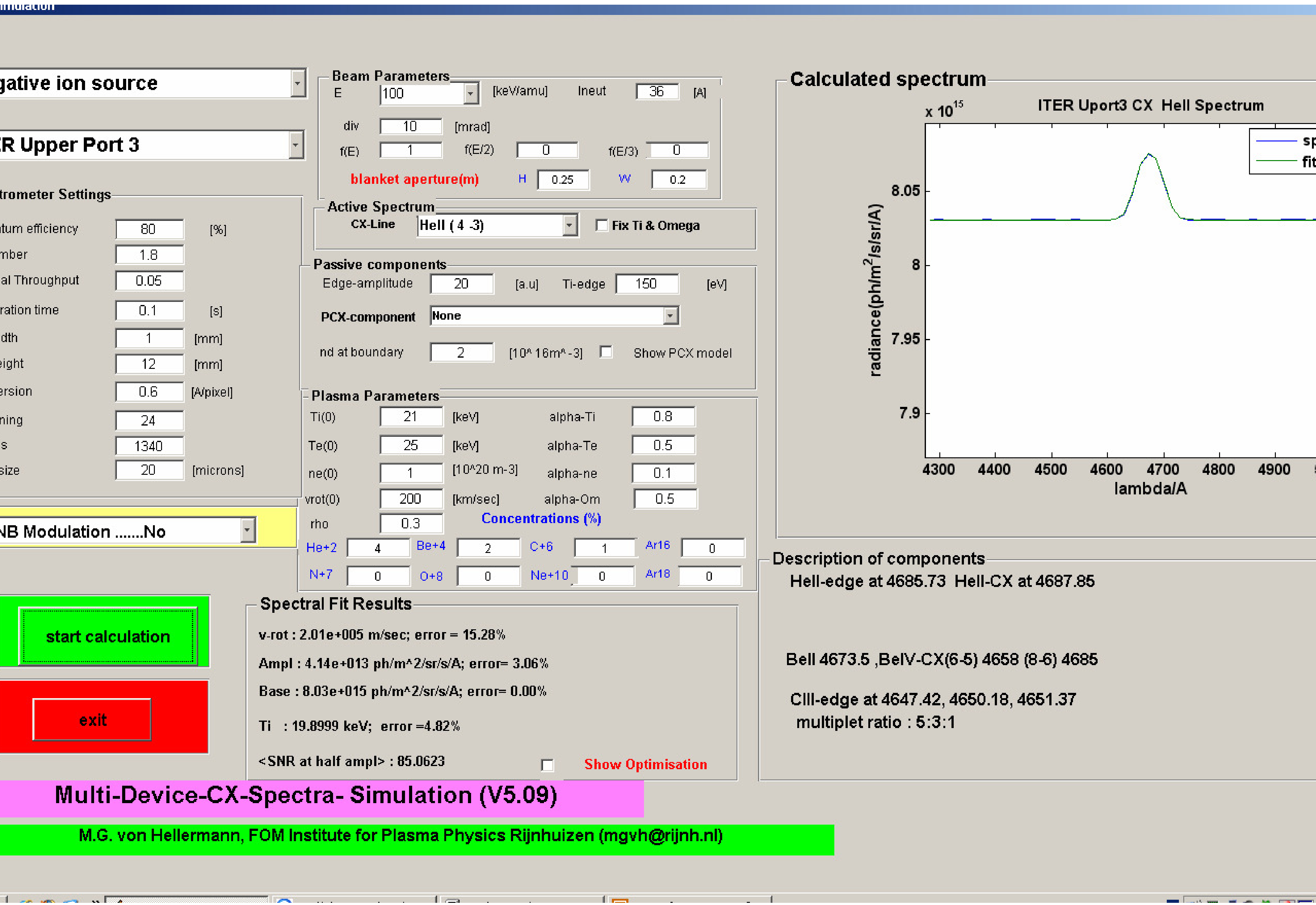

x 10^13
Alpha Slowing-Down Spectrun , DNB ,U-port-3
thermal ions
fast ions
r/a=0.3
F-alpha
5
4
3
2
1
0
4600
4650
4700
4750
wavelength(A)

Thermal Alpha Slowing-Down



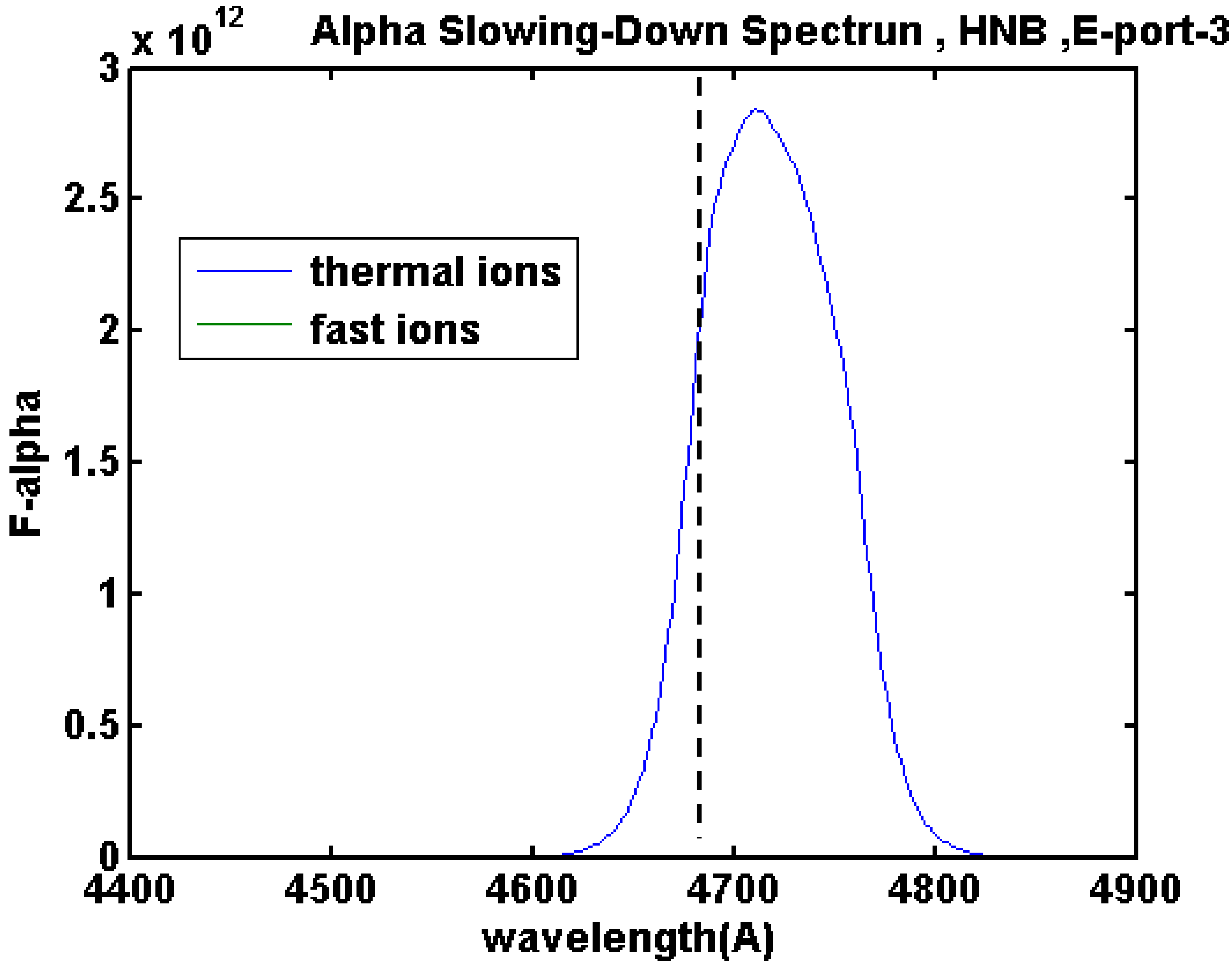


Standard scenario using HRS TRINITI spectrometer, f/3, 0.25nm/mm, SNR=1

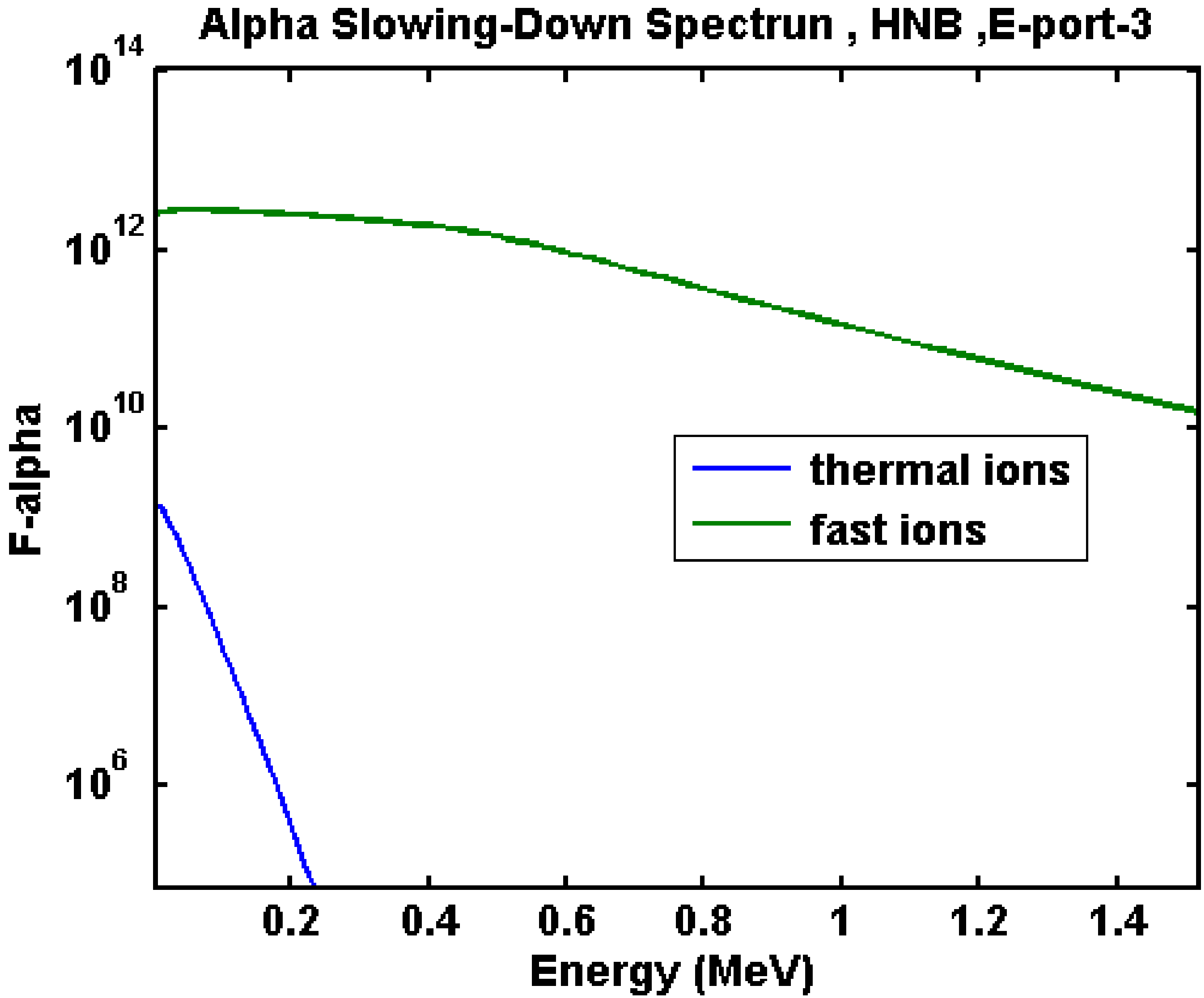


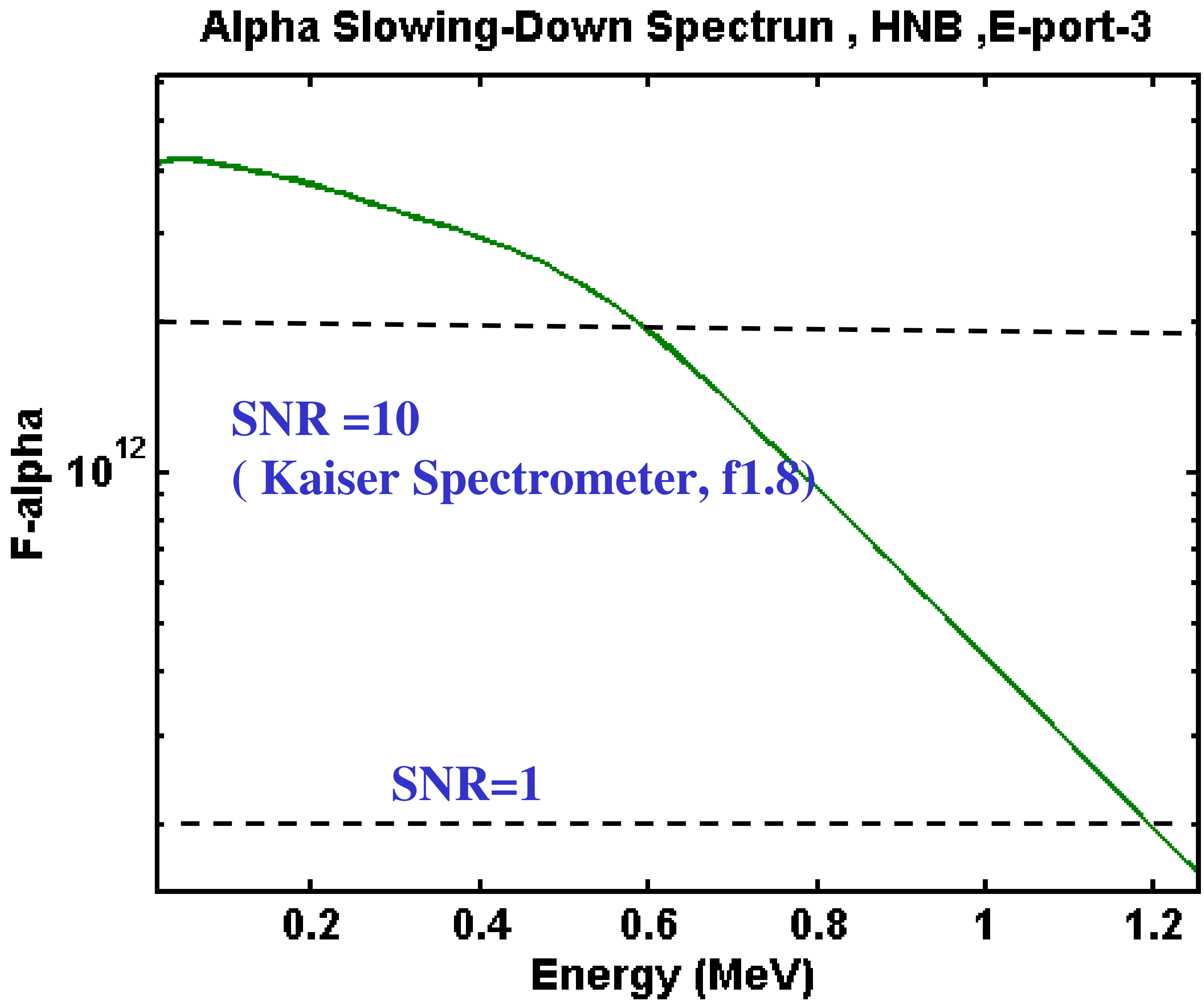
Conjectured broad band spectrometer (e.g. Kaiser), f/1.8, 3nm/mm, SNR=170

Using the HNB as potential source for Slowing-Down alphas and Broad-band CXRS spectra



Note: Cross-section effect leads to strong distortion and apparent Red-shift


Alpha Slowing-Down Spectrun , HNB ,E-port-3
10^14
10^12
10^10
10^8
10^6
F-alpha
thermal ions
fast ions
0.2
0.4
0.6
0.8
1
1.2
1.4
Energy (MeV)


Alpha Slowing-Down Spectrun , HNB ,E-port-3
F-alpha
10^{12}
SNR =10
(Kaiser Spectrometer, f1.8)
SNR=1
0.2
0.4
0.6
0.8
1
1.2
Energy (MeV)

Beam Slowing-Down-Spectra…..

c.f. Bill Heidbrink et al. DIII-D , PPCF,46,1855(2004)
"Hydrogenic fast-ion diagnostic using Balmer-alpha light"

$$g_{slow}(v,\xi) = \frac{S\tau_s}{v^3 + v_c^3} \frac{1}{\sqrt{4\pi\alpha}} \exp\{-\frac{(\xi - \xi_0)^2}{4\alpha}\}$$

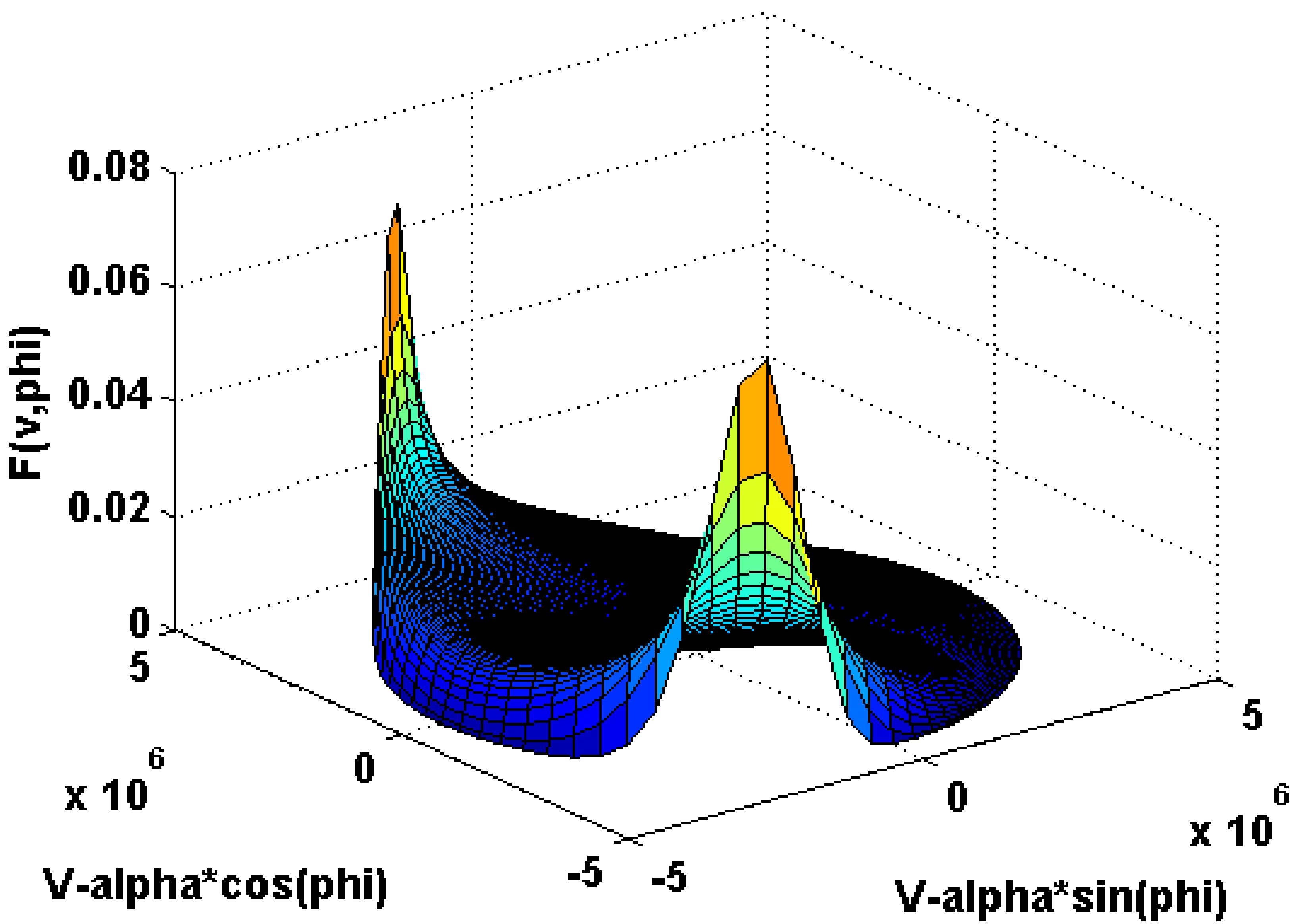
$$\alpha(\mathbf{v}) = \frac{\beta}{3}(1 - \xi_0^2)\log\frac{[1 + (\mathbf{v_c}/\mathbf{v})^3]}{[1 + (\mathbf{v_c}/\mathbf{v_b})^3]}$$

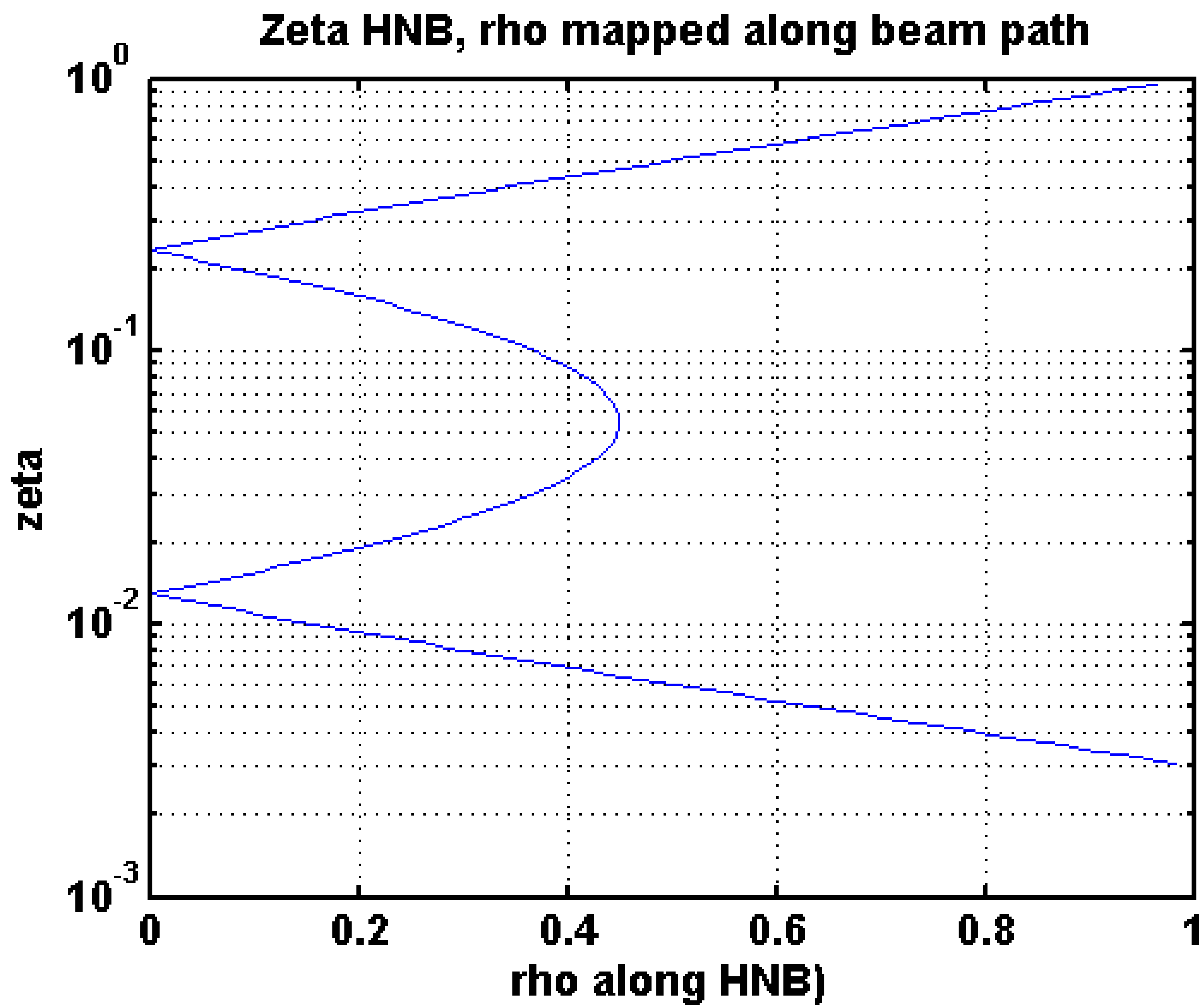
$$S = \frac{P_{beam}}{e \cdot E_{beam}} \cdot \frac{\partial \zeta}{\partial V}$$

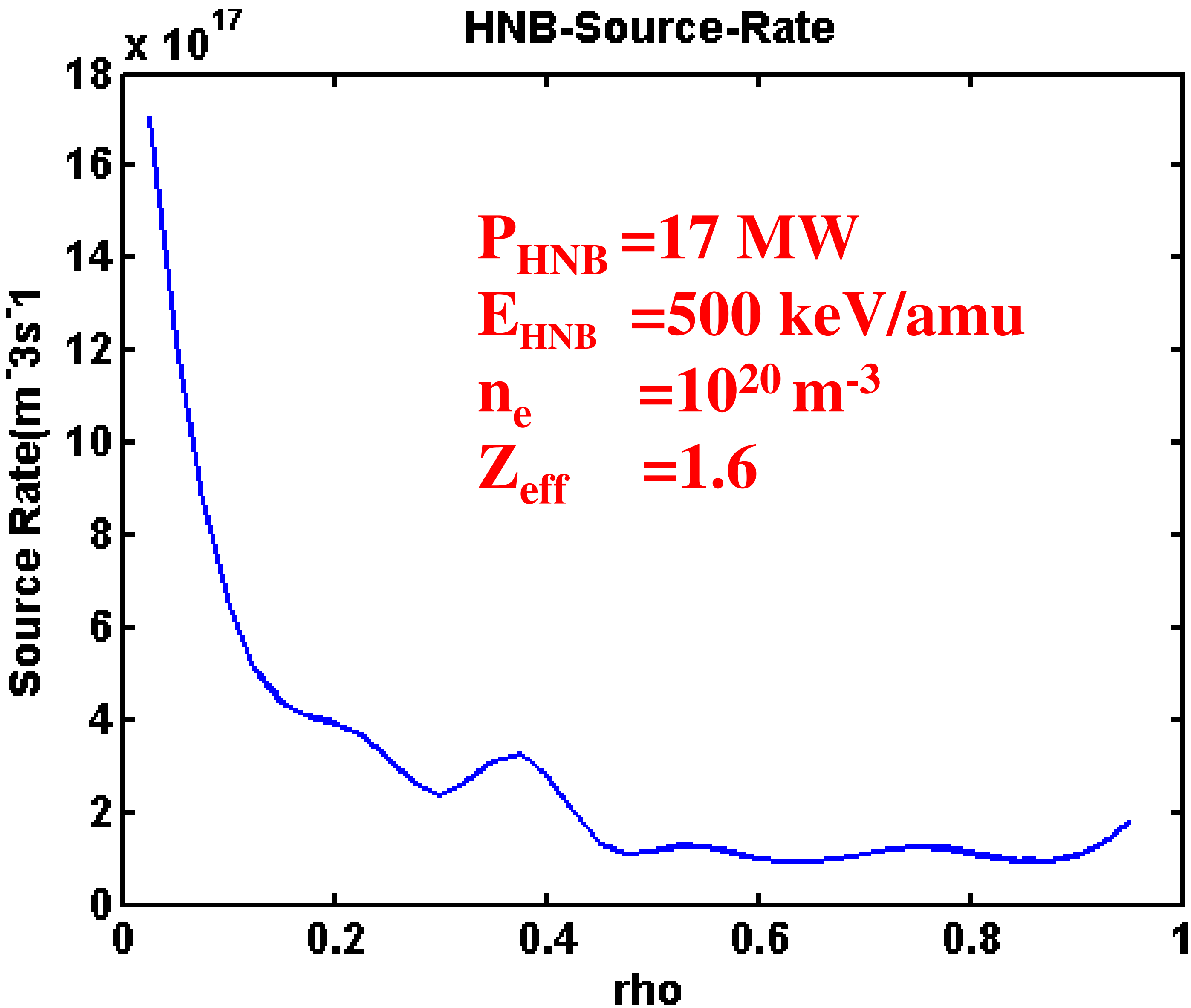
M.v.H. et al.

“Observation of Alpha Particles Slowing-DownSpectra in JET Helium Beam Fuelling Experiments”, PPCF, 35,766(1993)

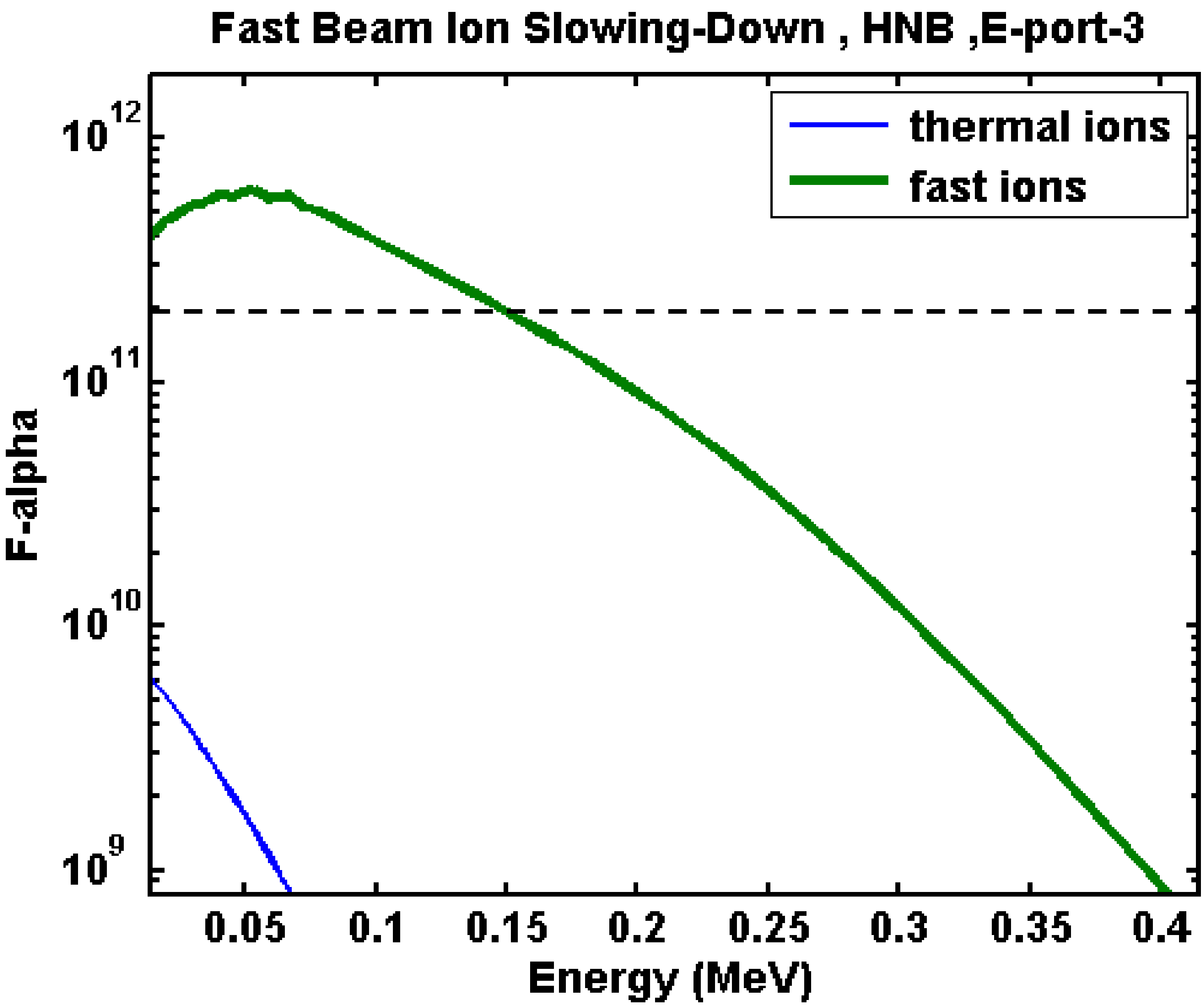
Anisotropic Beam Slowing-Down

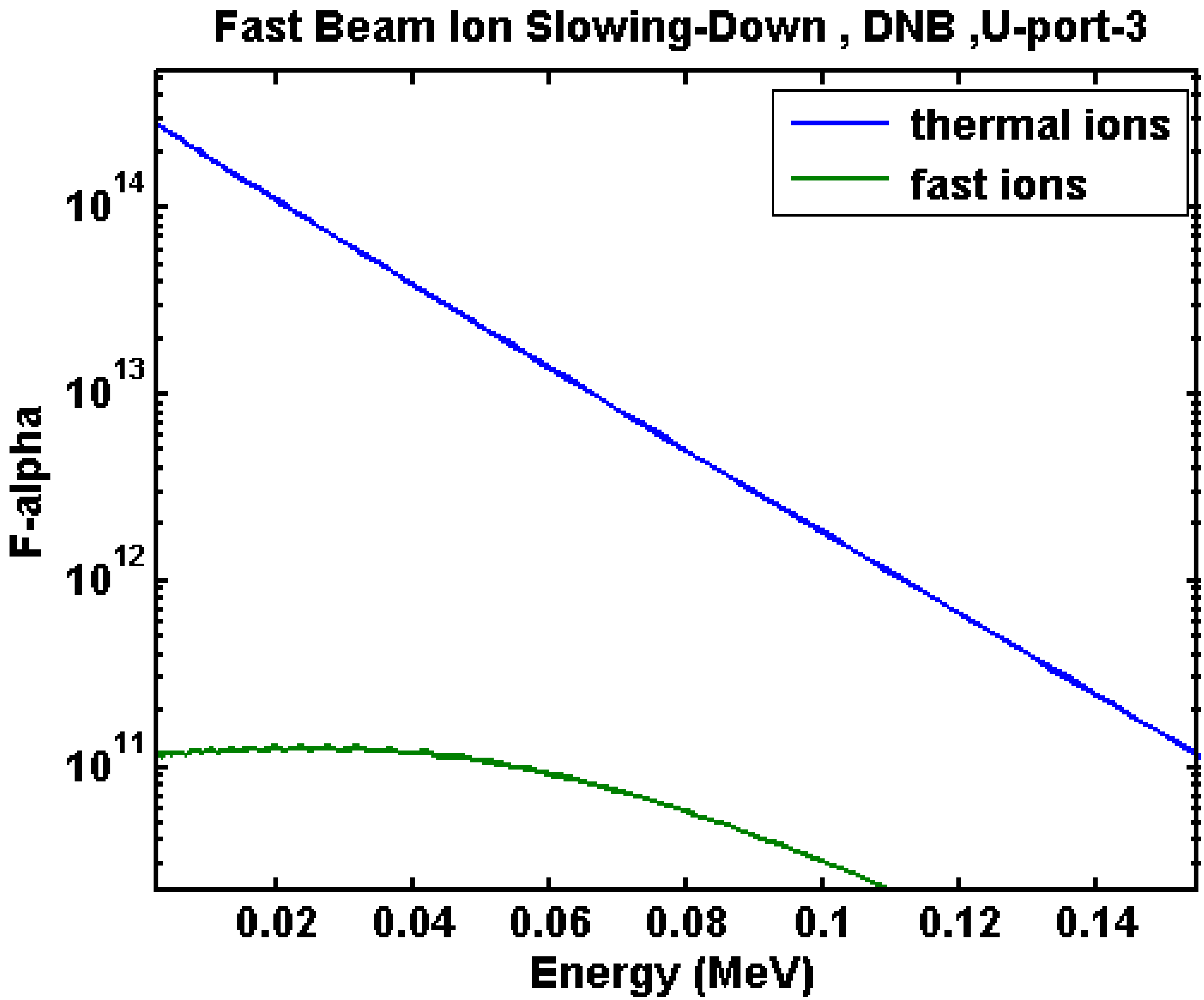



Zeta HNB, rho mapped along beam path
zeta
rho along HNB)
10^0
10^-1
10^-2
10^-3
0
0.2
0.4
0.6
0.8
1



HNB source rate deduced from attenuation along beam path


Fast Beam Ion Slowing-Down , HNB ,E-port-3
thermal ions
fast ions
F-alpha
Energy (MeV)
10^{12}
10^{11}
10^{10}
10^{9}
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4


Fast Beam Ion Slowing-Down , DNB ,U-port-3
thermal ions
fast ions
10^{14}
10^{13}
10^{12}
10^{11}
F-alpha
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Energy (MeV)

Conclusions

CXRS on Slowing-Down alpha particles appears to be feasible in the energy range up to 0.5 MeV using DNB or 1.2 MeV using HNB

Dedicated broad-band instrumentation will be required (30 A/mm, delta lambda 30A, Kaiser ,f1.8)

By contrast, the observation of beam fast ion features will be slightly (not) possible

No interference of HNB induced features expected and MSE features undisturbed by fast ion presence

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R&D work

1) Confirm broad-band detection limits
2) Hijack US MSE HNB periscope for Alpha Studies ??
3) Implement additional fibres for passive background
4) Theoretical Modelling on anisotropic alpha losses making use of DNB and HNB features
5) Develop evaluation tools deconvolving f(v) from g(λ)