



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

ITPA Meeting  
Princeton, March 2007





# Introduction



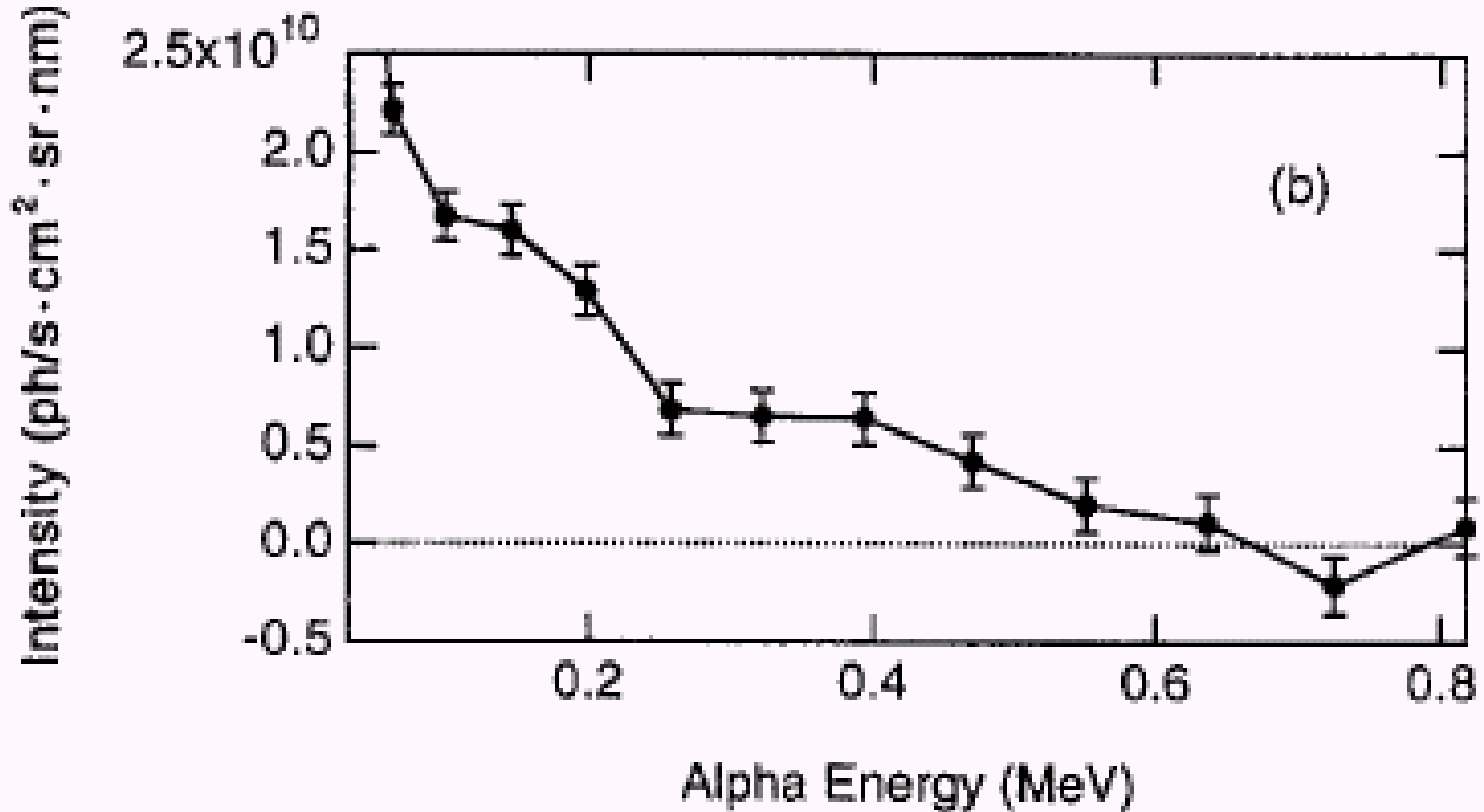
Present predictions of thermal helium ash measurement on ITER using the DNB show typical SNR values for HeII of the order 10 in the plasma core ( $r/a=0.3$ )

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 wavelength 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)**



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

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

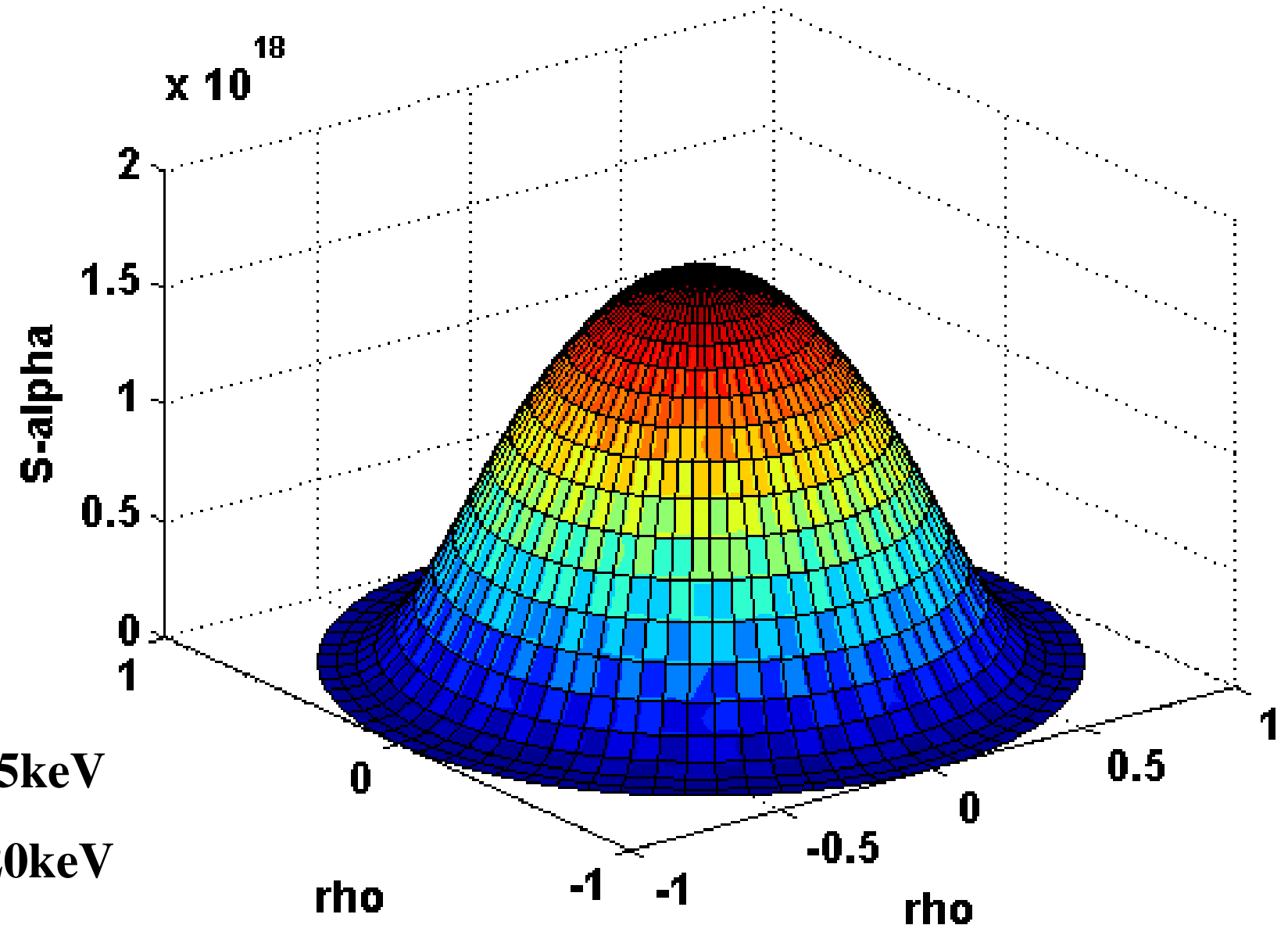
$$S_{\alpha} = \frac{1}{2} n_{\text{thermal}}^2 \sigma_{dt}(T_i)$$

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





# Thermal Alpha Source Rate



$T_i(0)=25\text{keV}$

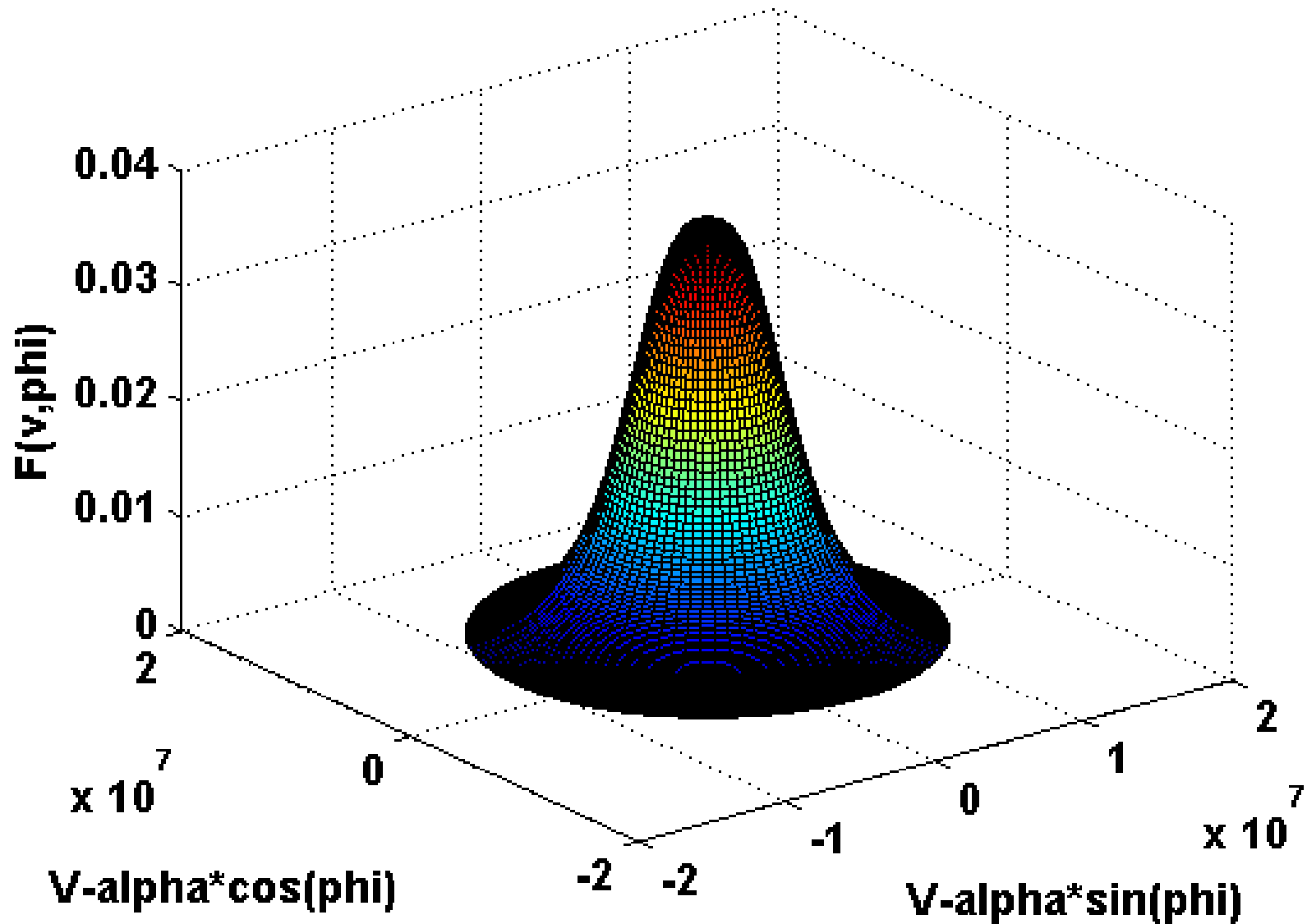
$T_e(0)=20\text{keV}$

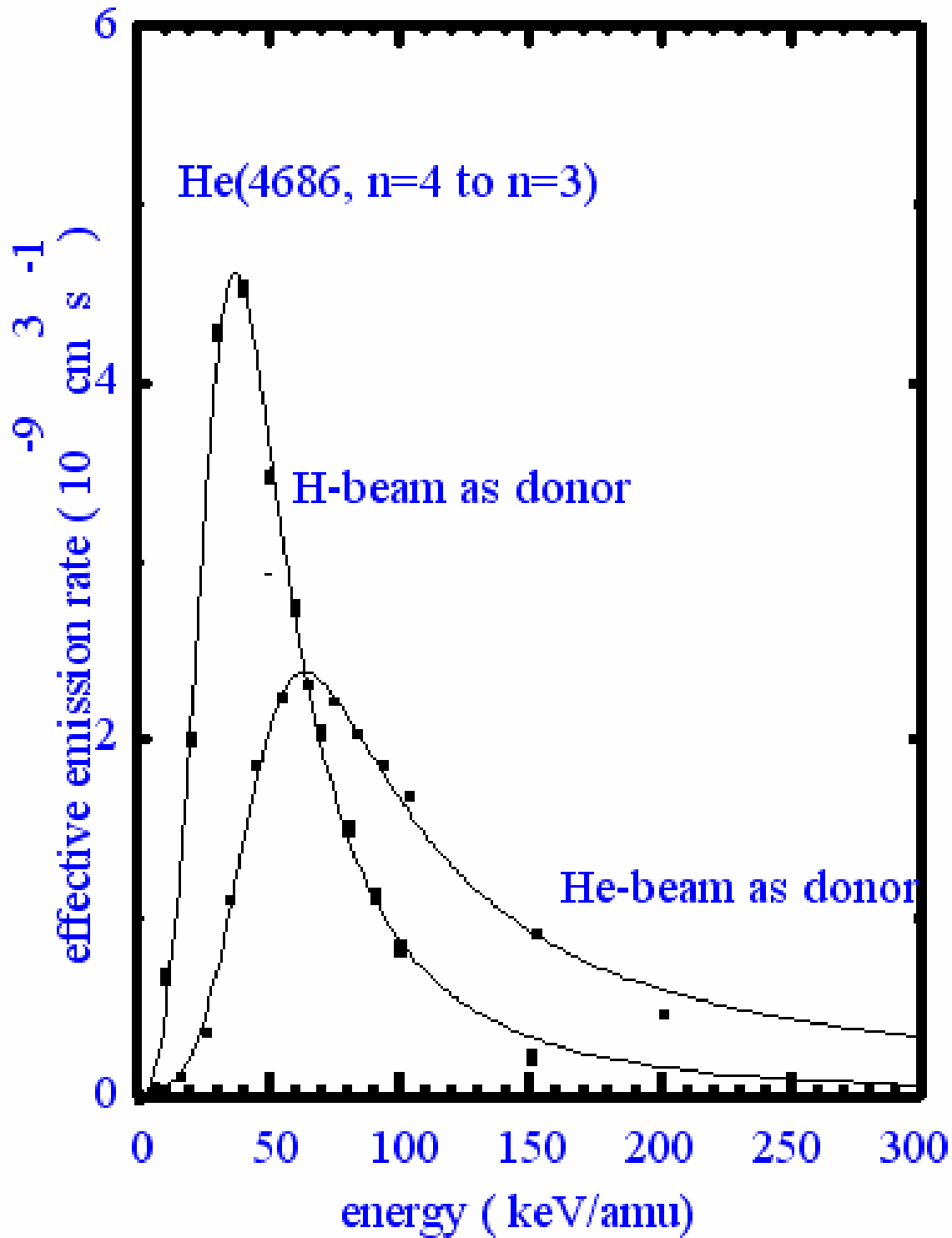
$n_d=n_t=0.5 \cdot 10^{20}\text{m}^{-3}$





# Alpha Slowing-Down







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

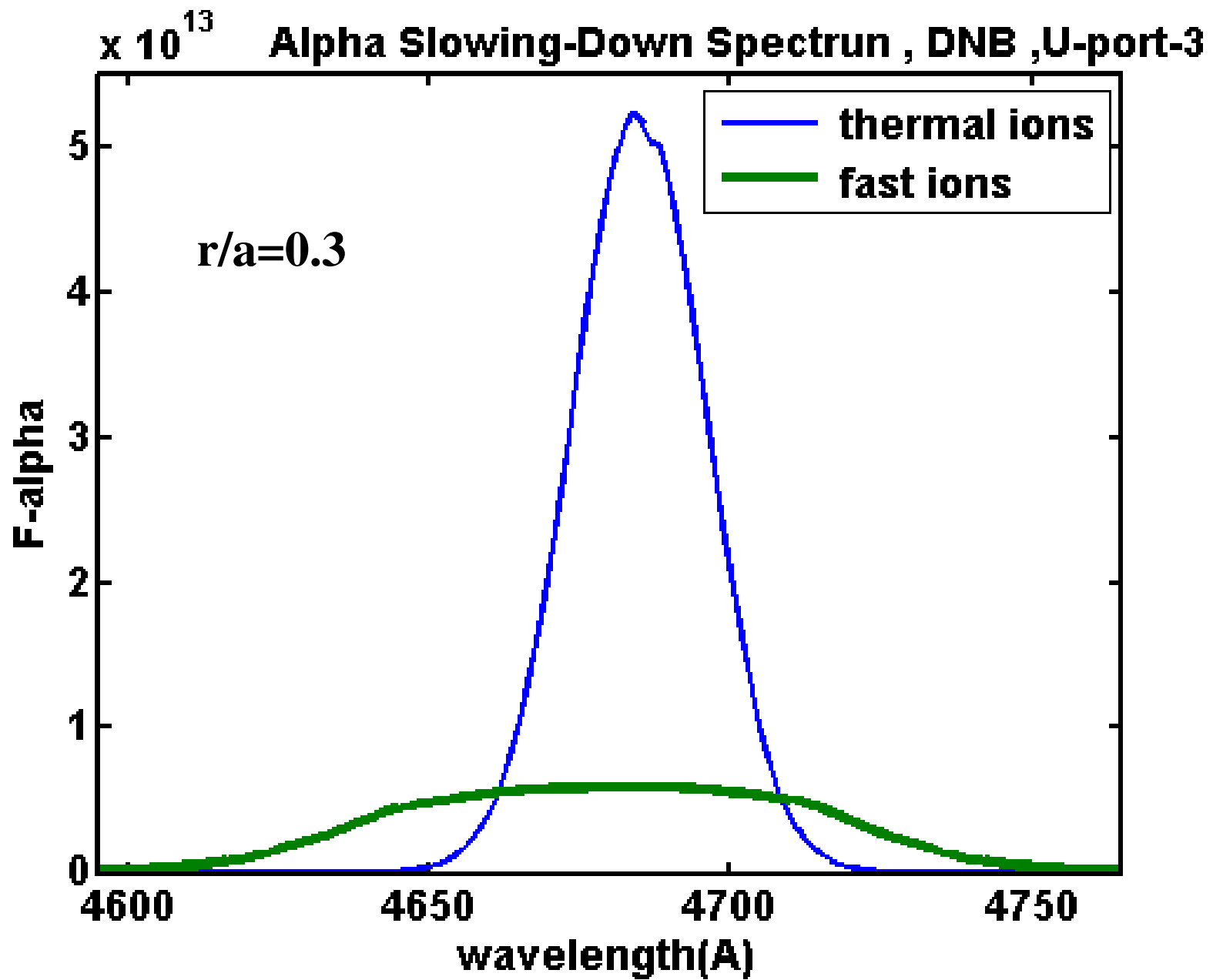
$$f_{obs}(v_z) =$$

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

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

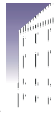
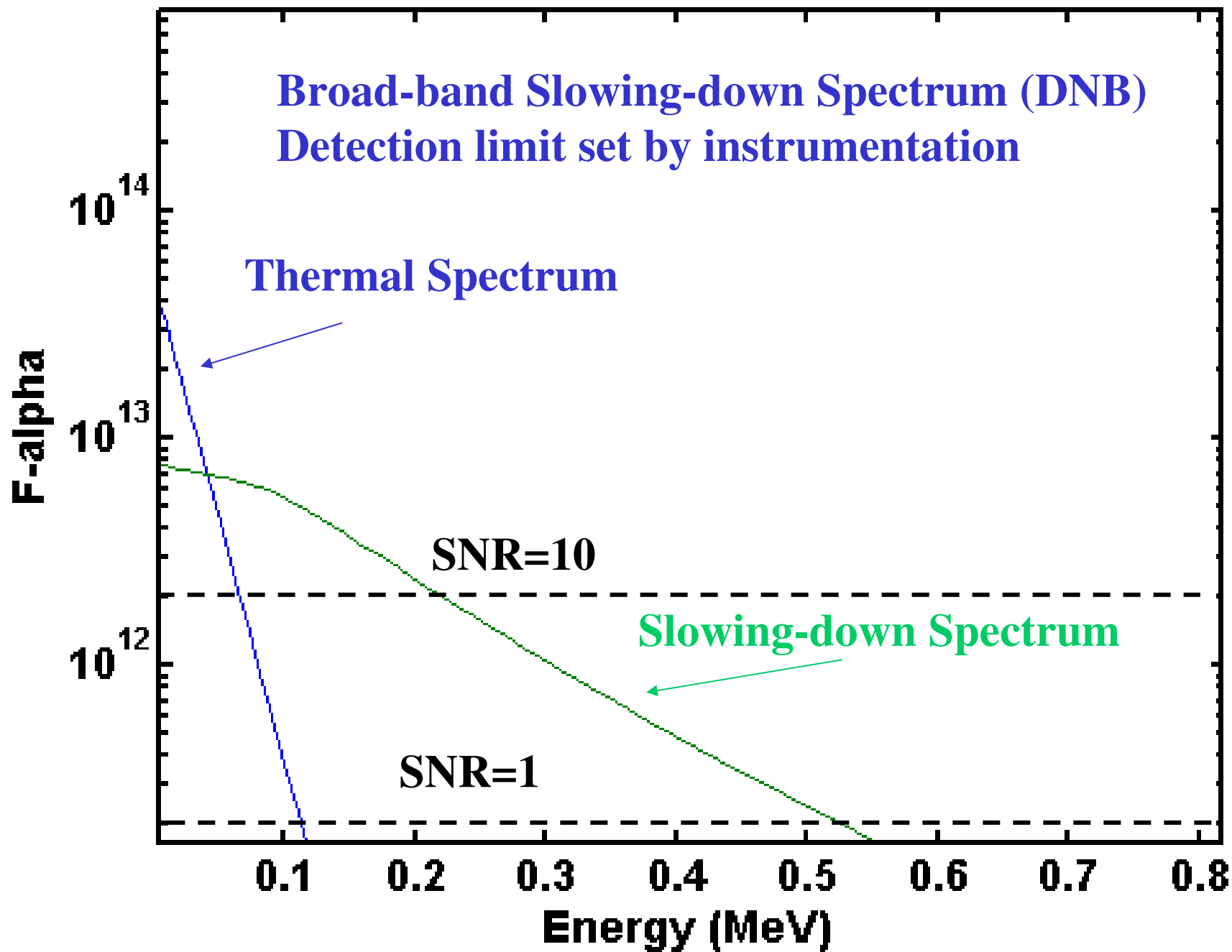








# Thermal Alpha Slowing-Down



Active ion source

Upper Port 3

Parameter Settings

efficiency 80 [%]

3

throughput 0.05

on time 0.1 [s]

1 [mm]

12 [mm]

0.056 [A/pixel]

4

1340

20 [microns]

Modulation .....No

Beam Parameters

E 100 [keV/amu] Ineut 36 [A]

div 10 [mrad]

f(E) 1 f(E/2) 0 f(E/3) 0

blanket aperture(m) H 0.25 W 0.2

Active Spectrum

CX-Line Hell (4-3)  Fix Ti & Omega

Passive components

Edge-amplitude 20 [a.u] Ti-edge 150 [eV]

PCX-component All PCX params. fixed

nd at boundary 2 [10<sup>16</sup>m<sup>-3</sup>]  Show PCX model

Plasma Parameters

Ti(0) 21 [keV]	alpha-Ti 0.8
Te(0) 25 [keV]	alpha-Te 0.5
ne(0) 1 [10 <sup>20</sup> m <sup>-3</sup> ]	alpha-ne 0.1
vrot(0) 200 [km/sec]	alpha-Om 0.5
rho 0.3	

Concentrations (%)

He+2 4	Be+4 2	C+6 1	Ar16 0
N+7 0	O+8 0	Ne+10 0	Ar18 0

Spectral Fit Results

v-rot : 1.99e+005 m/sec; error = 12.87%

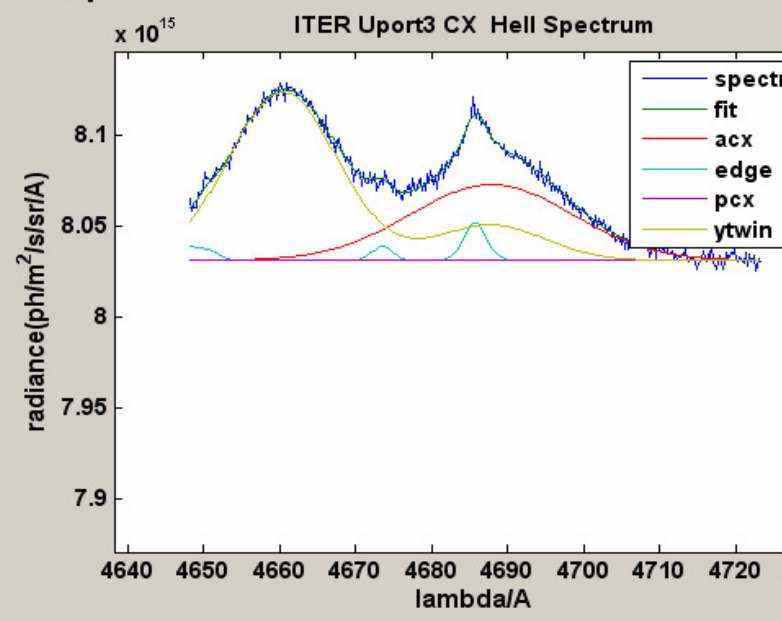
Ampl : 4.19e+013 ph/m<sup>2</sup>/sr/s/A; error= 1.20%

Base : 8.03e+015 ph/m<sup>2</sup>/sr/s/A; error= 0.01%

Ti : 19.2827 keV; error =2.39%

<SNR at half ampl> : 6.857  Show Optimisation

Calculated spectrum



Description of components

Hell-edge at 4685.73 Hell-CX at 4687.83

Hell-PCX at 4686.79 Ti-PCX: 7.46 keV

Bell 4673.5 ,BeIV-CX(6-5) 4658 (8-6) 4685

CIII-edge at 4647.42, 4650.18, 4651.37

multiplet ratio : 5:3:1

negative ion source

R Upper Port 3

Spectrometer Settings

throughput efficiency:  [%]  
 number:   
 throughput:   
 integration time:  [s]  
 slit width:  [mm]  
 slit height:  [mm]  
 dispersion:  [Å/pixel]  
 binning:   
 pixels:   
 detector size:  [microns]

Modulation .....No

start calculation

exit

**Beam Parameters**

E:  [keVamu] Ineut:  [A]

div:  [mrad]

f(E):  f(E/2):  f(E/3):

blanket aperture(m) H:  W:

**Active Spectrum**

CX-Line:   Fix Ti & Omega

**Passive components**

Edge-amplitude:  [a.u] Ti-edge:  [eV]

PCX-component:

order at boundary:  [10<sup>16</sup> m<sup>-3</sup>]  Show PCX model

**Plasma Parameters**

Ti(0):  [keV] alpha-Ti:   
 Te(0):  [keV] alpha-Te:   
 ne(0):  [10<sup>20</sup> m<sup>-3</sup>] alpha-ne:   
 vrot(0):  [km/sec] alpha-Om:   
 rho:

**Concentrations (%)**

He+2:  Be+4:  C+6:  Ar16:   
 N+7:  O+8:  Ne+10:  Ar18:

**Spectral Fit Results**

v-rot : 2.01e+005 m/sec; error = 15.28%

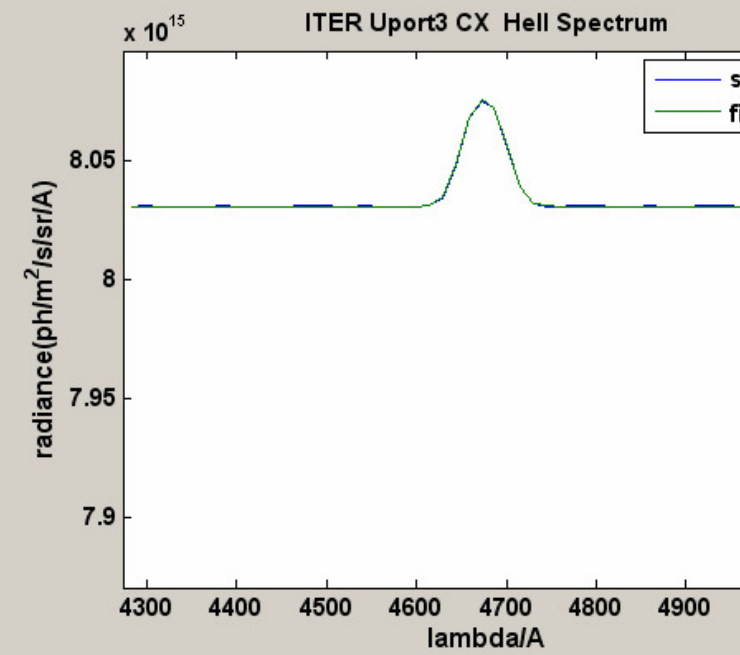
Ampl : 4.14e+013 ph/m<sup>2</sup>/sr/s/Å; error= 3.06%

Base : 8.03e+015 ph/m<sup>2</sup>/sr/s/Å; error= 0.00%

Ti : 19.8999 keV; error =4.82%

<SNR at half ampl> : 85.0623  Show Optimisation

Calculated spectrum



**Description of components**

Hell-edge at 4685.73 Hell-CX at 4687.85

Bell 4673.5 ,BeIV-CX(6-5) 4658 (8-6) 4685

CIII-edge at 4647.42, 4650.18, 4651.37  
multiplet ratio : 5:3:1

Multi-Device-CX-Spectra- Simulation (V5.09)

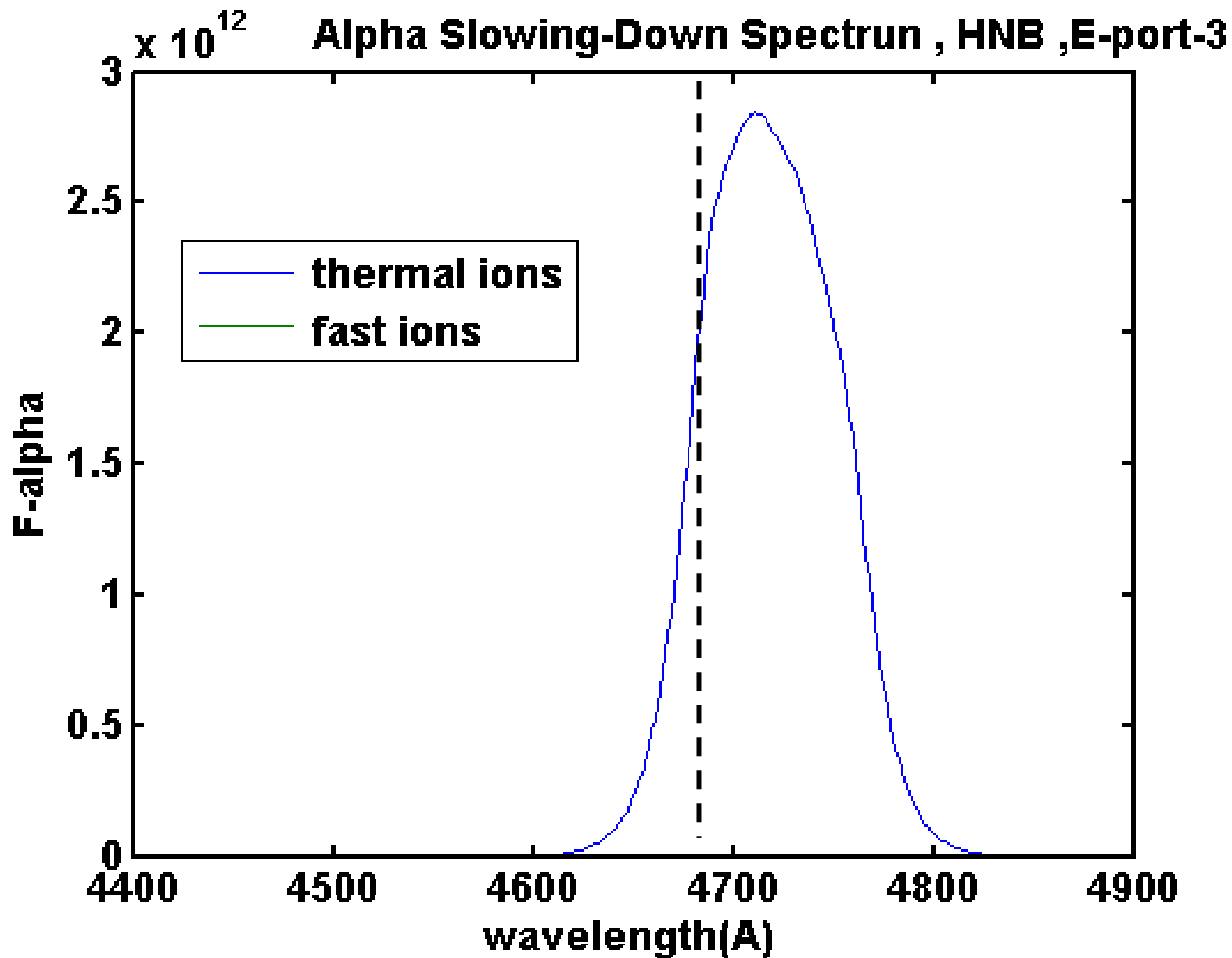
M.G. von Hellermann, FOM Institute for Plasma Physics Rijnhuizen (mgvh@rijnh.nl)

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

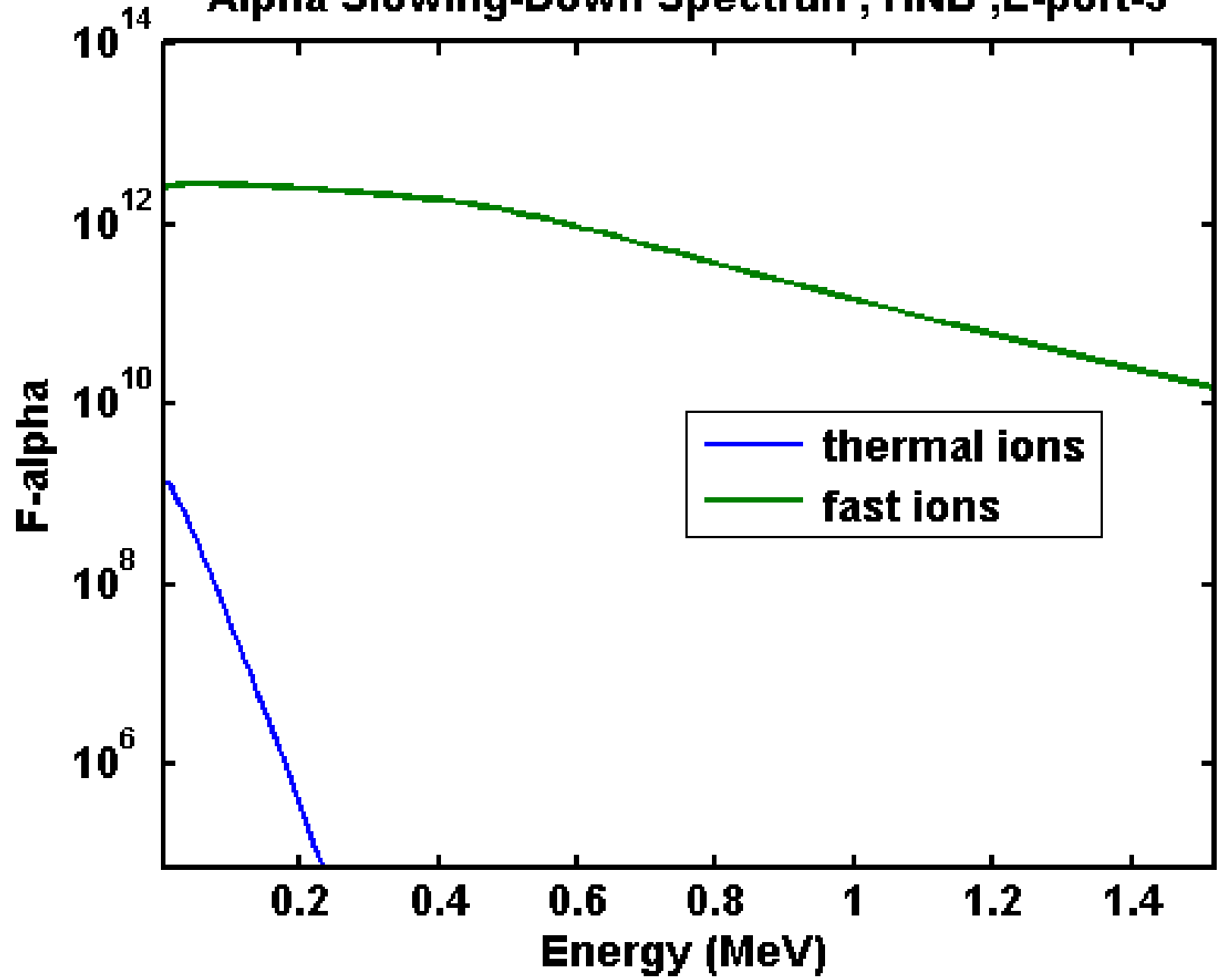




**Note: Cross-section effect leads to strong distortion and apparent Red-shift**

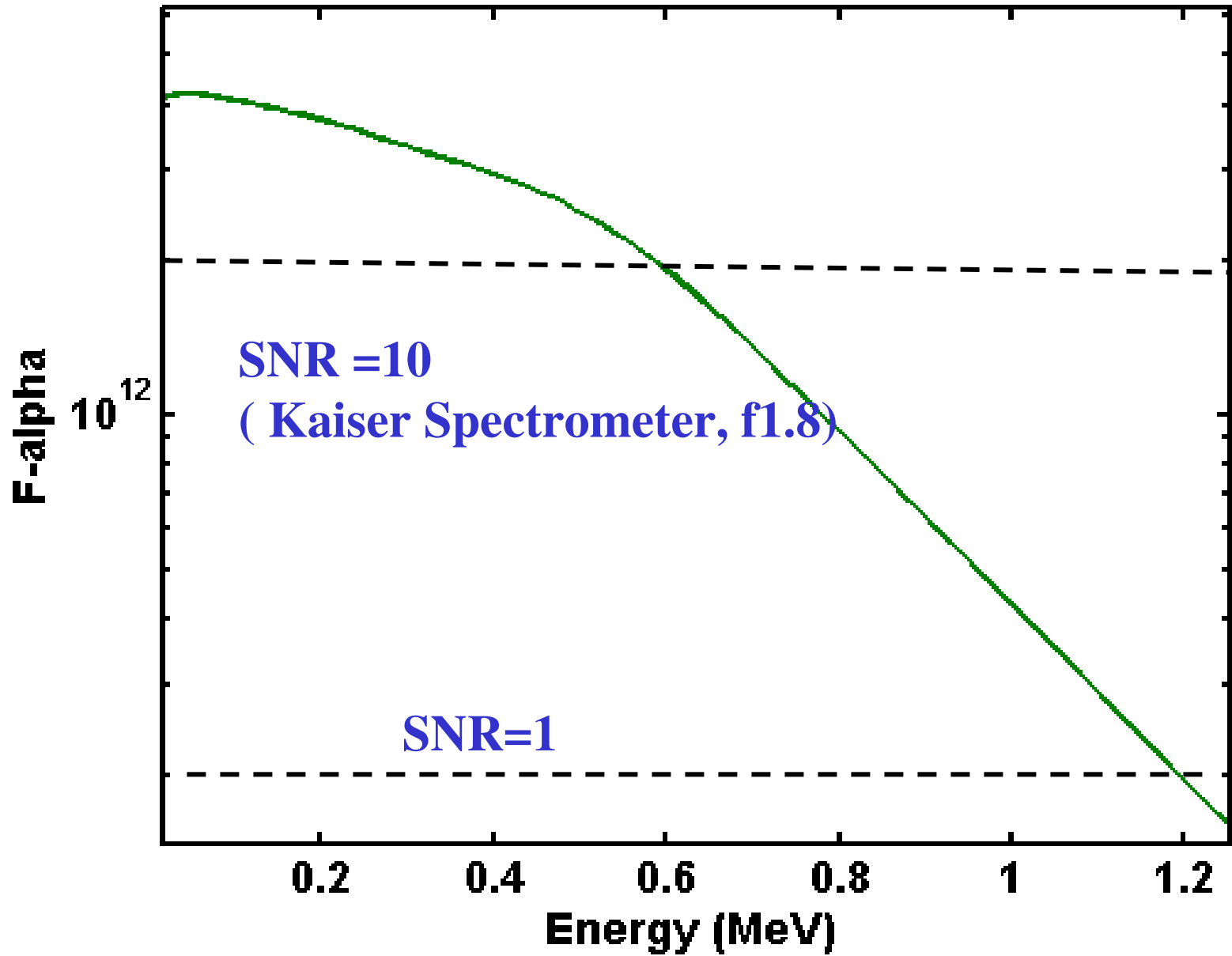


### Alpha Slowing-Down Spectrun , HNB ,E-port-3





### Alpha Slowing-Down Spectrun , HNB ,E-port-3







# Beam Slowing-Down-Spectra.....

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





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

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

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

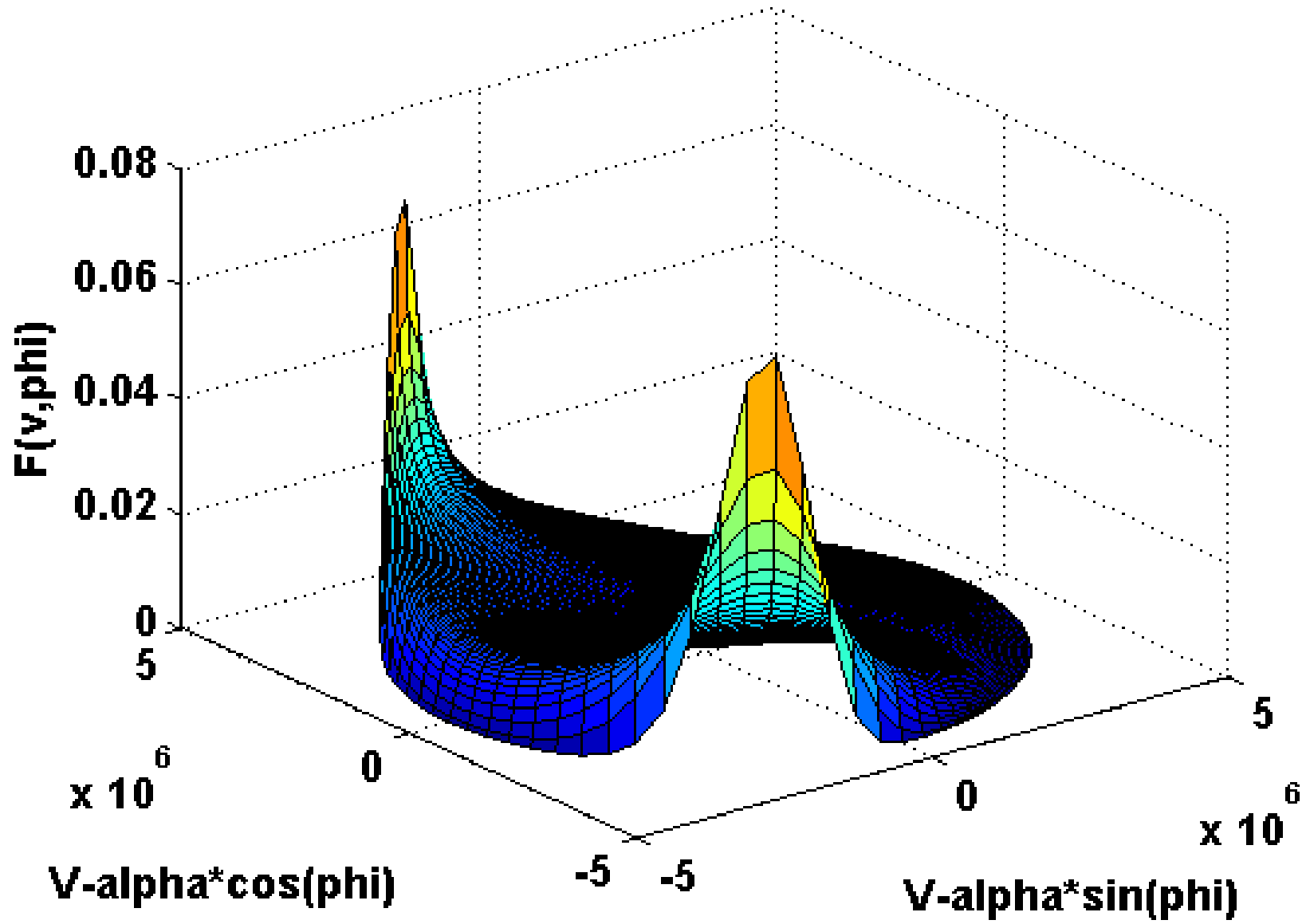
M.v.H. et al.

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



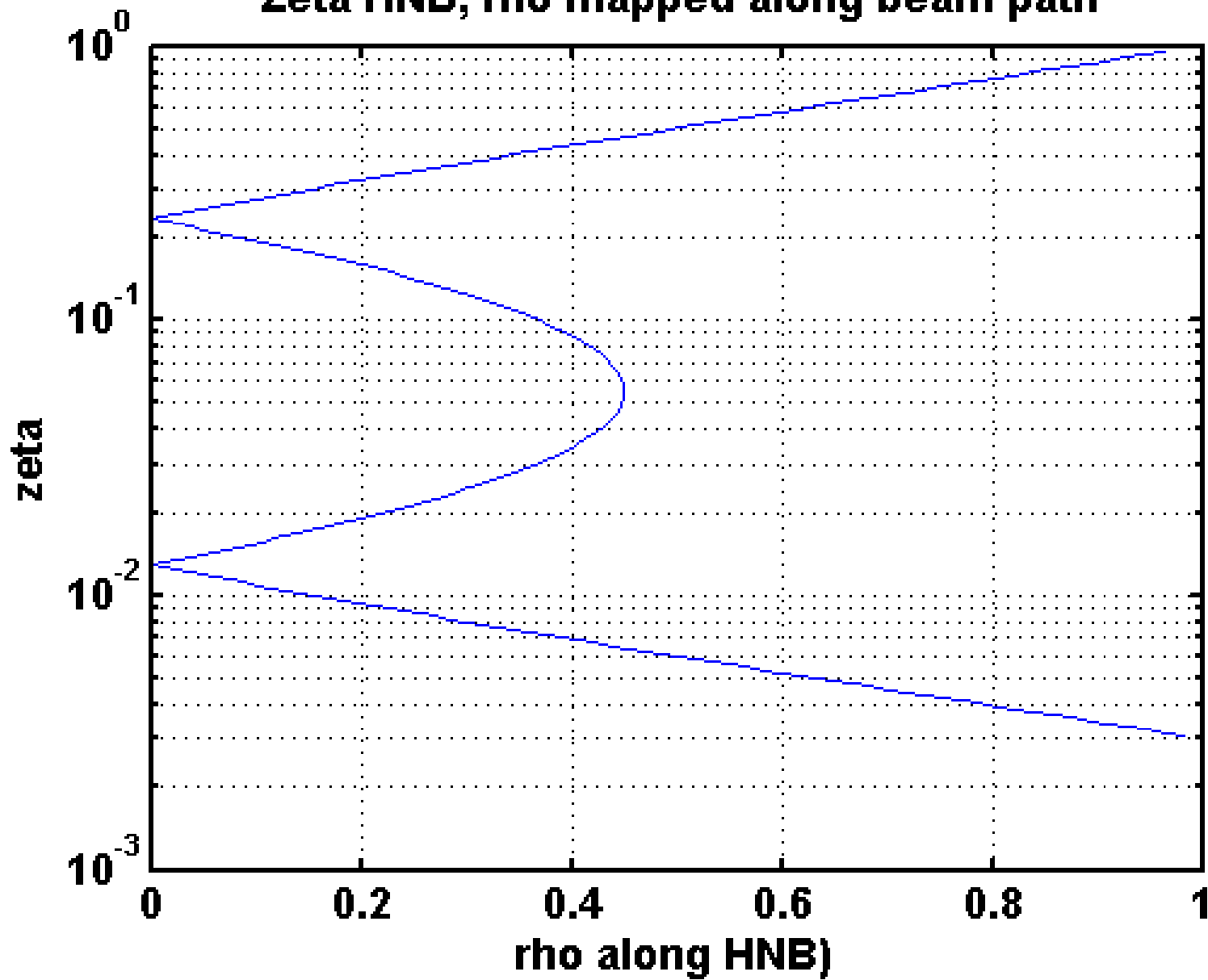


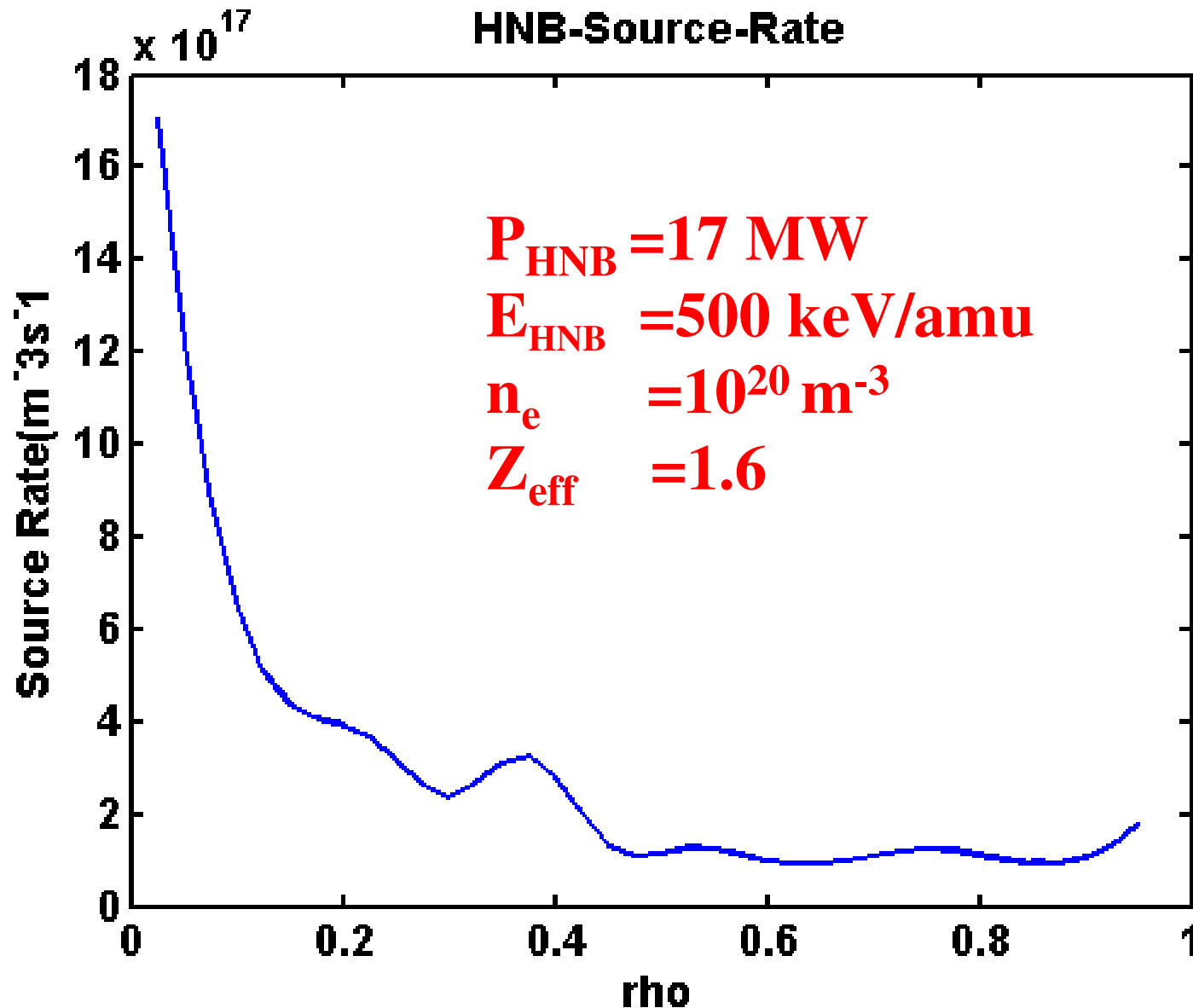
# Anisotropic Beam Slowing-Down





### Zeta HNB, rho mapped along beam path



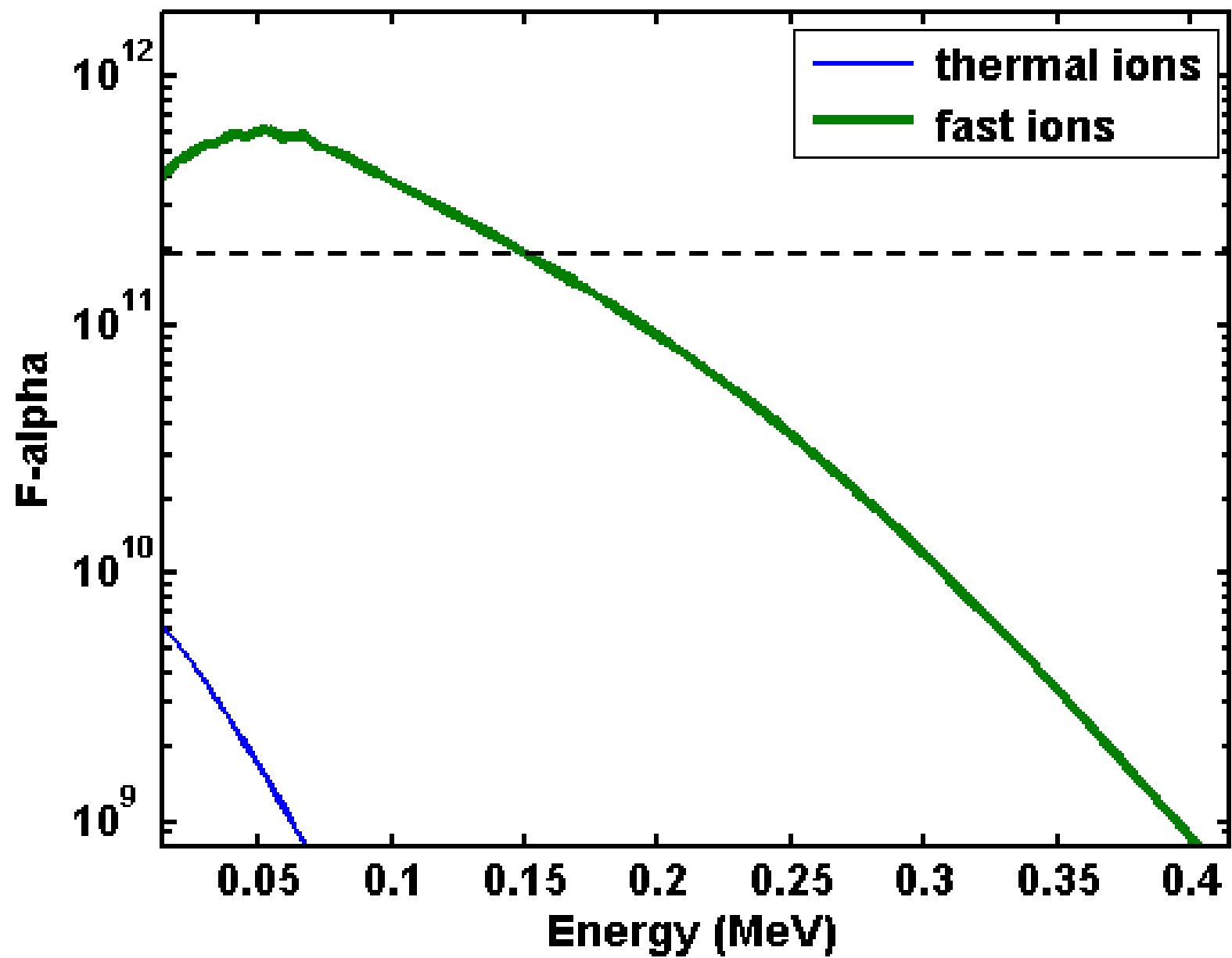


**HNB source rate deduced from attenuation along beam path**



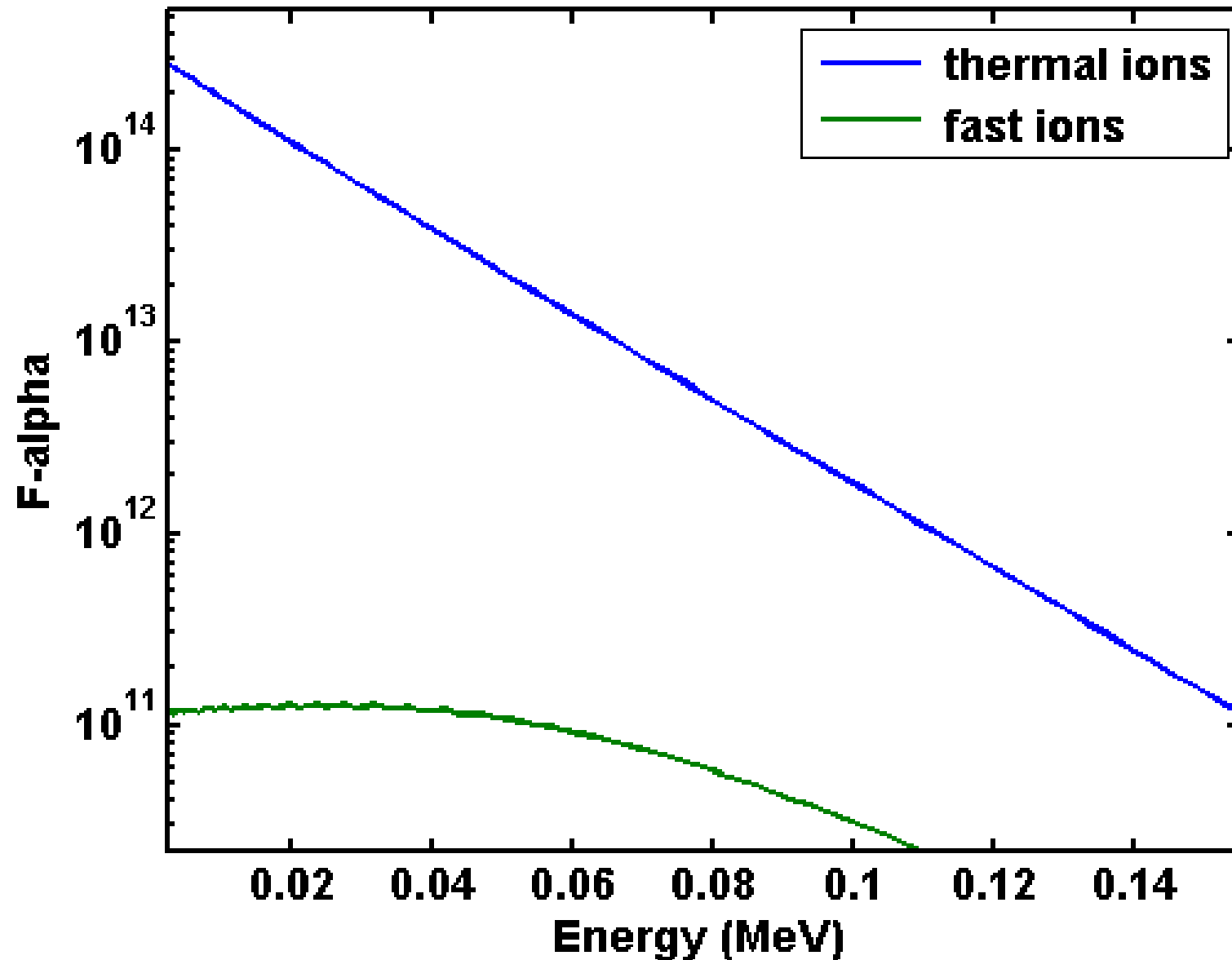


### Fast Beam Ion Slowing-Down , HNB ,E-port-3





## Fast Beam Ion Slowing-Down , DNB ,U-port-3





# 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**







## **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  $g(\lambda)$**

