TEC

CXRS and BES plans for ITER

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representing
ITPA Expert Group on Active Beam Spectroscopy

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Progress & developments 2006:

- EU CXRS Consortium
- India as new ITER partner, DNB specs.
- The Indian CXRS and BES Diagnostic package
- Periscope Developments
- Software Development

a) CXRS-FIT

b) Simulation of Spectra

c) CHEAP (Charge Exchange Analysis Package)

- Spectrometer development

EU CXRS consortium established in May 2006

Association	Committed man years for these tasks	Key persons
TEC (FOM+FZJ)	8	Coordinators: R. Jaspers (FOM) and W. Biel (FZJ) Key persons: A.J.H. Donné and M. von Hellermann (FOM) A. Litnovsky and O. Neubauer (FZJ)
UKAEA	1	N. Hawkes
IPP	0.25	L. Horton, C. Maggi, E. Wolfrum
CEA	0.2	C. Fenzi
HAS	1	S. Zoletnik, O. Bede, G. Hordosy, Zs. Vizvary
IPP.CR		I. Duran

	Positive ion source	Negative ion source
Energy(keV/amu)	(80+/-10) (D^0)	(100+/-20)(D^0)
Power(MW)	3.1	2.2 (6)
Neutral Current (A)	16.6 (full E)	22 (30)
Species mix	0.85:0.08:0.07	1:0:0
Divergence(mrad)	4.3	5 (10)
Spot size (m)	<0.07	<0.1 (0.2)
modulation	yes	yes
Duty cycle	1:6	1:6

<u>Table II</u>

200 keV, 50 A D beam

Source Dimensions : Y = 1.53 m (high) and X =0.58 m Divergence of the main beam : 10 mrad

Case	Fx (m)	Fy (m)	Aperture location (m)	Aperture dimensions		Divergence (85% main beam)		Halo component (15% main beam		Fractional power transmitted	Launched power (MW)	Power at observation point (MW)	Current (A)
				X'(m)	Y'(m)	θ (mrad)	φ (mrad)	θ' (mrad)	ϕ' (mrad)				
I II III	21.5 19.2 19.2	19.2 21.5 19.2	19.2 19.2 19.2	±0.108 ±0.108 ±0.108	±0.108 ±0.108 ±0.108	10 10 10	10 10 10	30 30 30	30 30 30	0.283 0.275 0.29	6 6 6	1.7 1.65 1.74	8.5 8.25 8.7

Courtesy: Drs M.Singh, S.Mattoo, Indian Plasma Physics Research Centre

CXRS reaction:

Excitation of high-quantum shell impurity spectra following charge capture and subsequent inner-shell redistribution

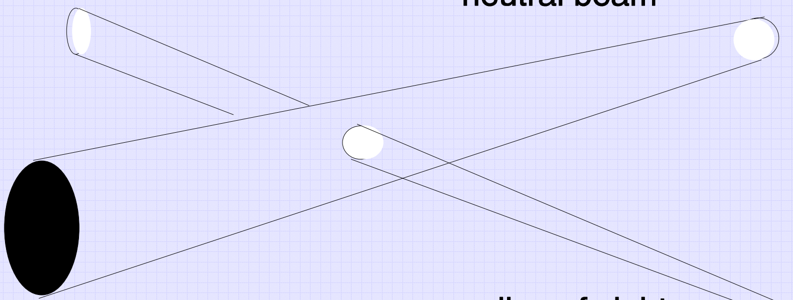
$$I_{cx} = \frac{1}{4\pi} n_z \cdot \sum_k Q_{cx}^z (E_k, n_e, T_i, Z_{eff}) \cdot \int n_b(E_k) ds$$

BES reaction:

Excitation of beam spectrum following collisions of neutral beam with plasma ions and electrons

$$I_{bes}(E) = \frac{1}{4\pi} n_e \cdot Q_{BES}(E, n_e, T_i, Z_{eff}) \cdot \int n_b(E) ds$$

Combination of CXRS and BES:



common line of sight and beam geometry

$$n_z = \frac{4\pi \cdot I_{CX}}{\sum_k Q_{cx}(E_k)\int n_b(E_k)ds} = \frac{I_{CX} \cdot n_e}{\sum_k Q_{cx}(E_k) \cdot I_{BES}(E_k)/Q_{BES}(E_k)}$$

Proposed Active Beam Diagnostic Package for Indian Partners

BES calibration

a) beam intensities for cross calibration of absolute CXRS intensities

b) power deposition profiles

c) beam imaging for shape and alignment control

d) Doppler shift measurements for precise active locations

Indian Package continued…

BES MSE

e) measurements based on line intensity ratio of pitch-angle profiles

f) measurements of total magnetic fields based on high precision Lorent split

BES – Density Fluctuations

g) density fluctuations close to plasma edge.

Indian Package continued…

CXRS on bulk ion protons, deuterons or tritons

a) absolute densities

b) isotope ratio d :t

c) fast ion distribution function of DNB produced slowing-down ions

Strategy:

Sharing of Software and its development

a) CXRS Fit

b) Simulation of Spectra

c) CHEAP

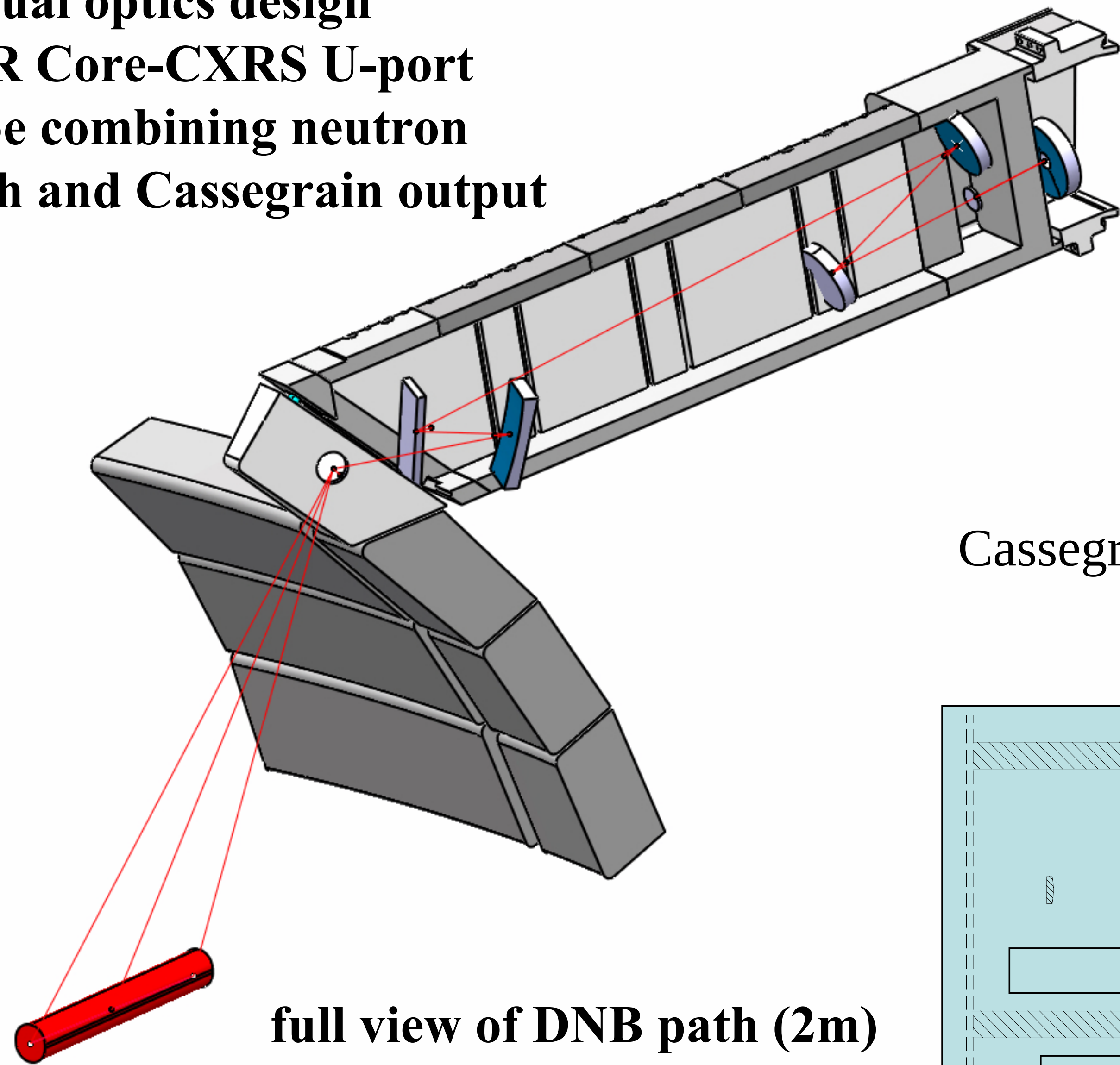
Shared Pilot Experiments

Atomic needs for Hydrogen package

Experimental and theoretical:

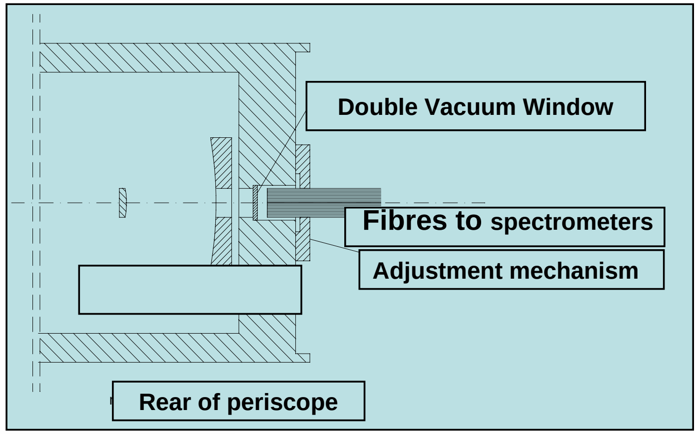
1) Dedicated Experiments bench-marking beam-emission against beam stopping
2) Review of beam emission processes
3) Bulk ion CXRS Experimental and modelling
4) Excited populations

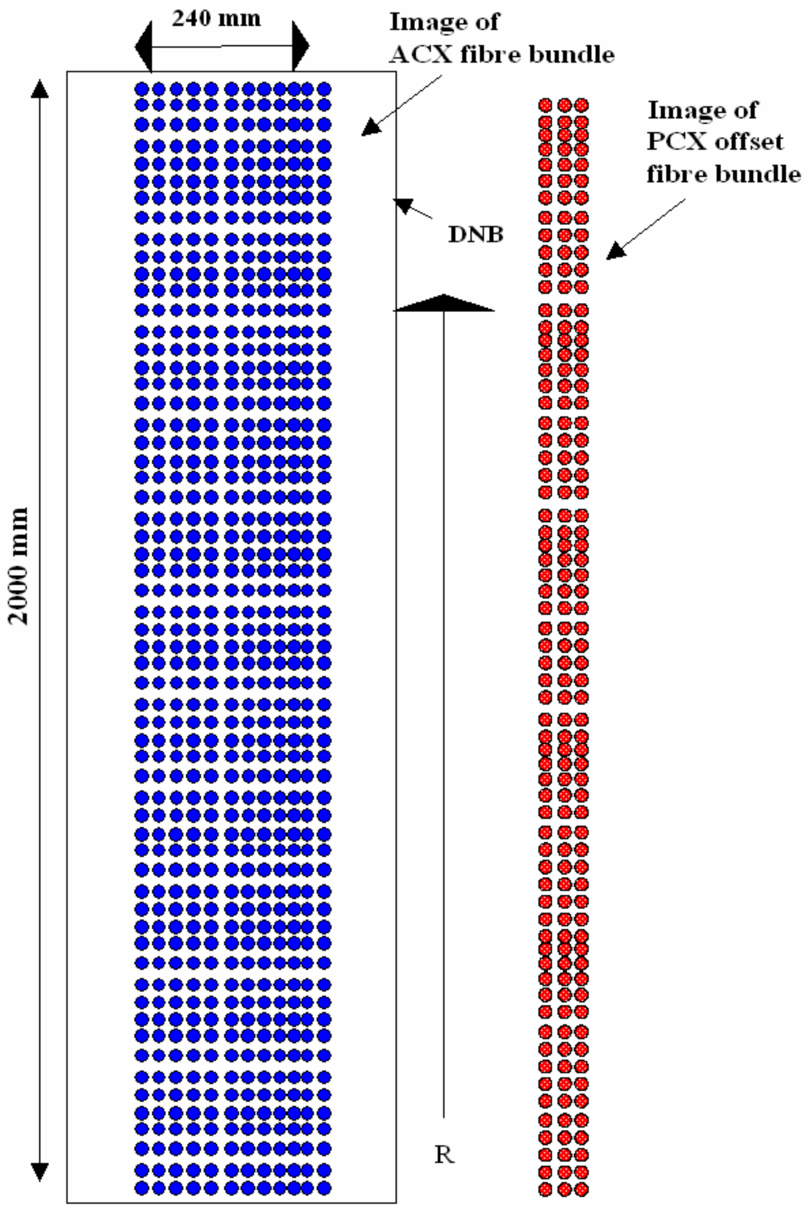
Conceptual optics design for ITER Core-CXRS U-port periscope combining neutron labyrinth and Cassegrain output optics



full view of DNB path (2m)

Cassegrain output to fibres




240 mm
Image of
ACX fibre bundle
Image of
PCX offset
fibre bundle
DNB
2000 mm
R

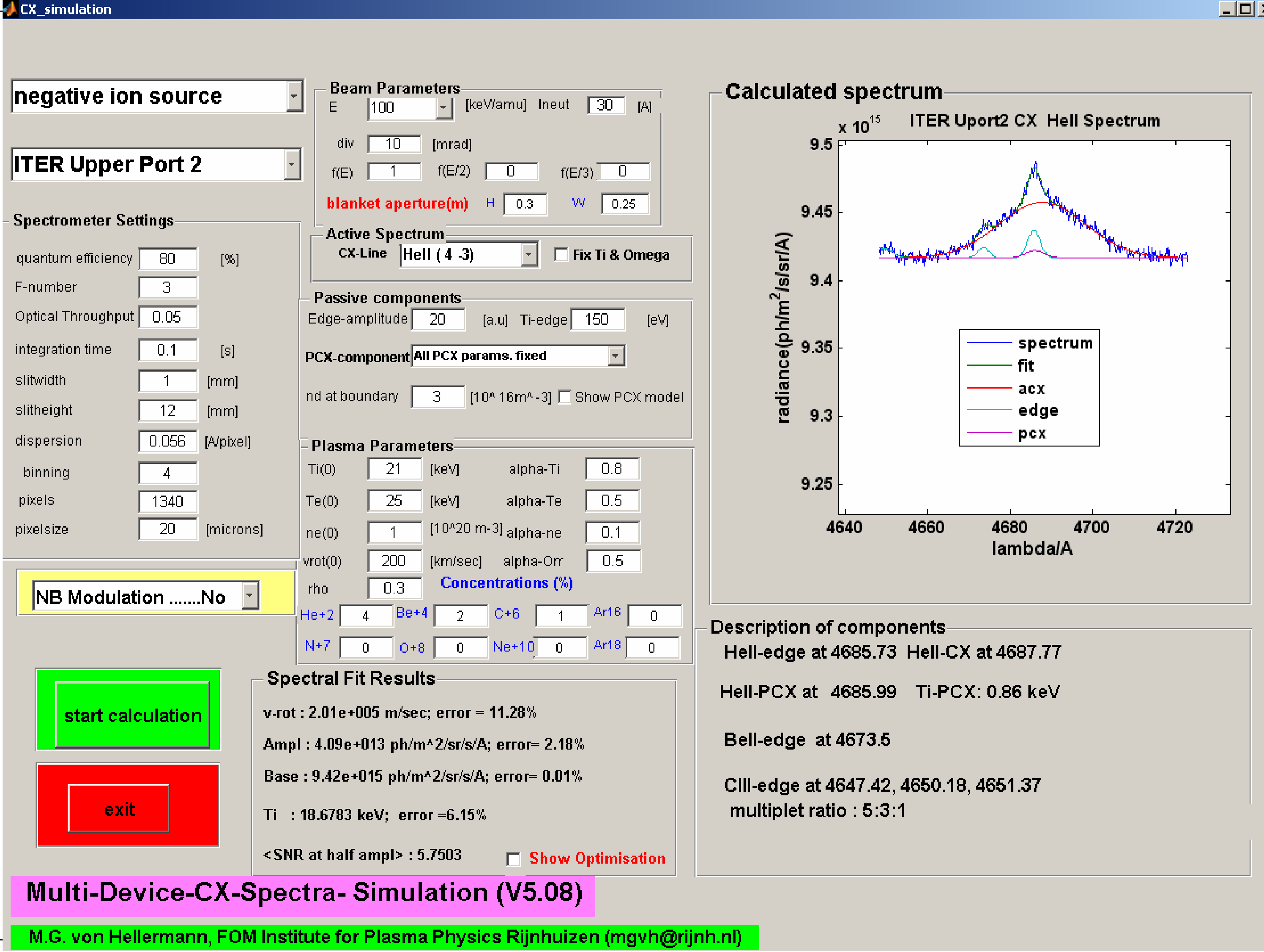
TEC

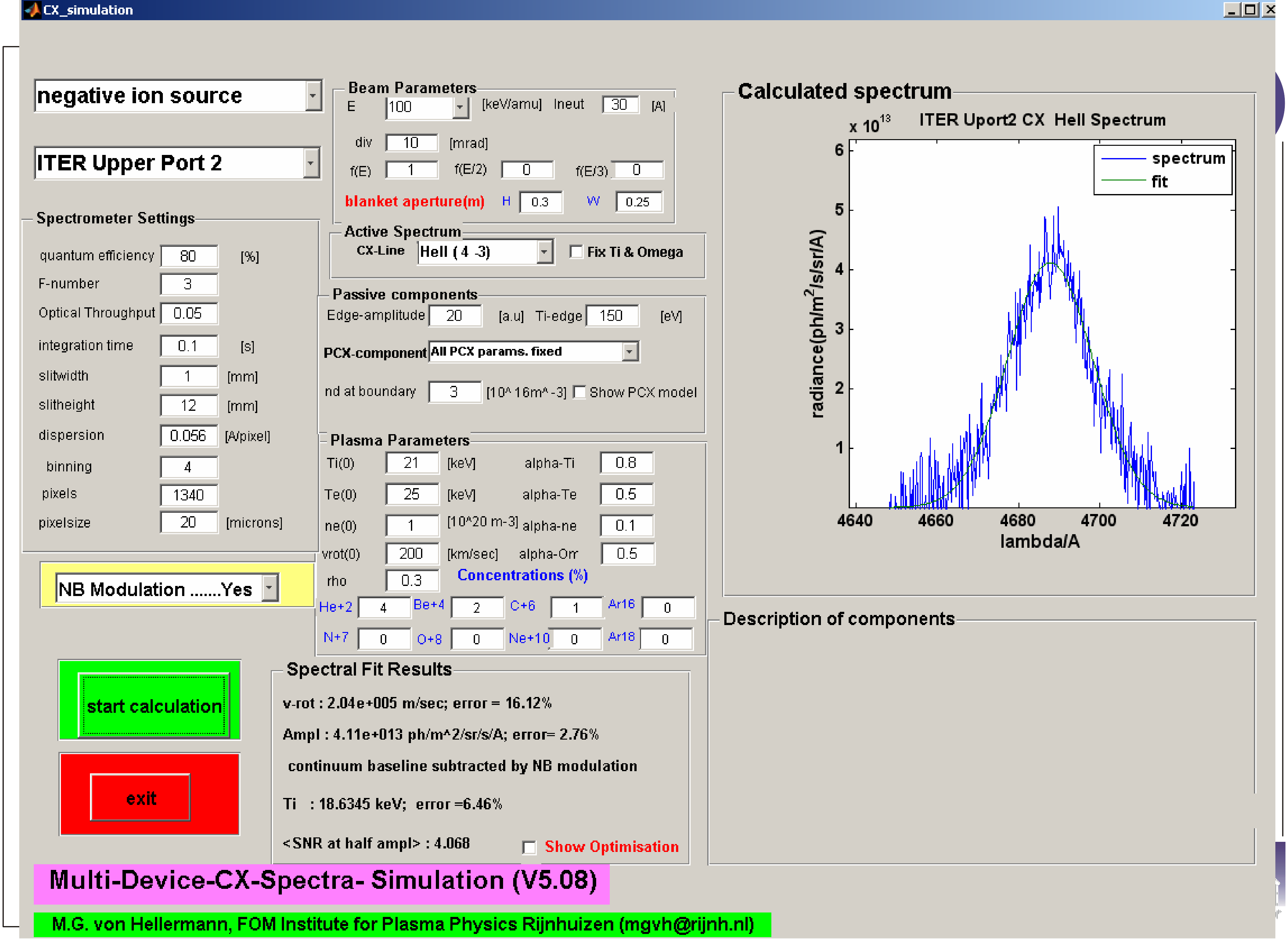
Simulation of Spectra

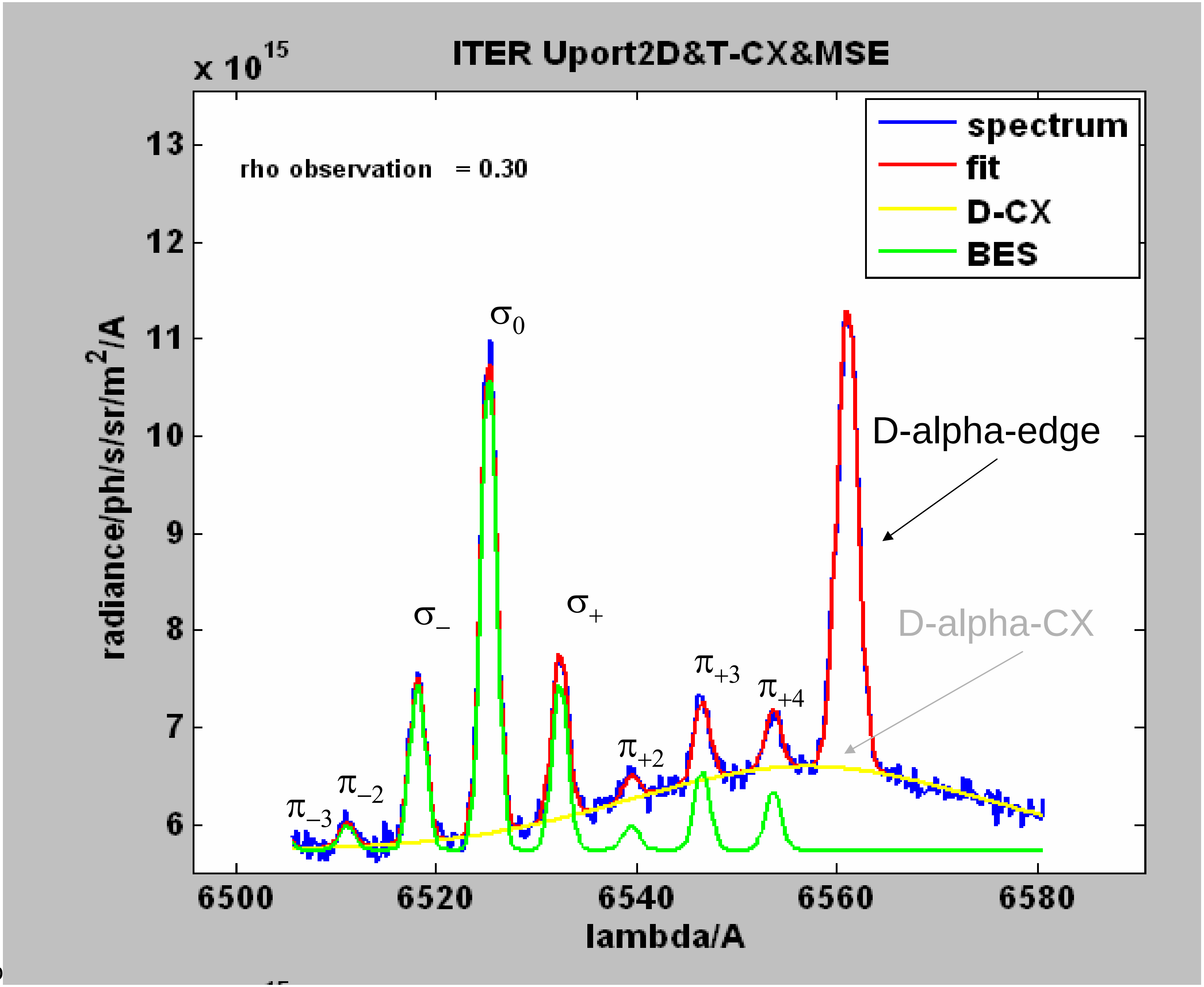
- Creation of synthetic spectra based on plasma environment and atomic data (ADAS files).
- Active features (thermal and fast ions)
- Passive features (continuum, edge lines, PCX)
- Sensitivity analysis for parameter retrieval
- Optimization of instruments
- Optimization of neutral beam specification

Simulation Structure:

1) Use CAD data for ITER geometry
   a) first-mirror coordinates (U-port-3, U-port-2, E-port-3)
   b) DNB injection coordinates
   c) Torus geometry
2) Use DNB specifications
3) Model periscope imaging properties
4) Use Spectrometer and CCD specifications
5) Model neutral beam stopping (ADAS)
6) Model DNB excited population (ADAS)
7) CXRS and BES emission rates (ADAS)
8) Model q-profile and pitch angle
9) Model continuum radiation
10) Model PCX emissivity
11) Create Synthetic spectra
12) Model DNB modulation effects
13) Assess noise performance
14) Assess parameter errors
15) Provide bench-mark data for CXRS/MSE Pilot Experiments


CX_simulation
negative ion source
ITER Upper Port 2
Beam Parameters
E 100 [keV/amu] Ineut 30 [A]
div 10 [mrad]
f(E) 1 f(E/2) 0 f(E/3) 0
blanket aperture(m) H 0.3 W 0.25
Active Spectrum
CX-Line HeII (4 -3) Fix Ti & Omega
Spectrometer Settings
quantum efficiency 80 [%]
F-number 3
Optical Throughput 0.05
integration time 0.1 [s]
slitwidth 1 [mm]
slitheight 12 [mm]
dispersion 0.056 [A/pixel]
binning 4
pixels 1340
pixelsize 20 [microns]
Passive components
Edge-amplitude 20 [a.u] Ti-edge 150 [eV]
PCX-component All PCX params. fixed
nd at boundary 3 [10^16m^-3] Show PCX model
Plasma Parameters
Ti(0) 21 [keV] alpha-Ti 0.8
Te(0) 25 [keV] alpha-Te 0.5
ne(0) 1 [10^20 m-3] 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
NB Modulation ....No
start calculation
exit
Spectral Fit Results
v-rot : 2.01e+005 m/sec; error = 11.28%
Ampl : 4.09e+013 ph/m^2/sr/s/A; error= 2.18%
Base : 9.42e+015 ph/m^2/sr/s/A; error= 0.01%
Ti : 18.6783 keV; error =6.15%
<SNR at half ampl> : 5.7503
Show Optimisation
Calculated spectrum
ITER Uport2 CX HeII Spectrum
x 10^15
9.5
9.45
9.4
9.35
9.3
9.25
radiance(ph/m^2/s/sr/A)
4640 4660 4680 4700 4720
lambda/A
spectrum
fit
acx
edge
pcx
Description of components
HeII-edge at 4685.73 HeII-CX at 4687.77
HeII-PCX at 4685.99 Ti-PCX: 0.86 keV
BeII-edge at 4673.5
CIII-edge at 4647.42, 4650.18, 4651.37
multiplet ratio : 5:3:1
Multi-Device-CX-Spectra- Simulation (V5.08)
M.G. von Hellermann, FOM Institute for Plasma Physics Rijnhuizen (mgvh@rijnh.nl)


CX_simulation
negative ion source
ITER Upper Port 2
Beam Parameters
E 100 [keV/amu] Ineut 30 [A]
div 10 [mrad]
f(E) 1 f(E/2) 0 f(E/3) 0
blanket aperture(m) H 0.3 W 0.25
Active Spectrum
CX-Line HeII (4 -3)
Fix Ti & Omega
Spectrometer Settings
quantum efficiency 80 [%]
F-number 3
Optical Throughput 0.05
integration time 0.1 [s]
slitwidth 1 [mm]
slitheight 12 [mm]
dispersion 0.056 [A/pixel]
binning 4
pixels 1340
pixelsize 20 [microns]
Passive components
Edge-amplitude 20 [a.u] Ti-edge 150 [eV]
PCX-component All PCX params. fixed
nd at boundary 3 [10^16m^-3] Show PCX model
Plasma Parameters
Ti(0) 21 [keV] alpha-Ti 0.8
Te(0) 25 [keV] alpha-Te 0.5
ne(0) 1 [10^20 m-3] 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
NB Modulation ....Yes
start calculation
exit
Calculated spectrum
x 10^13
ITER Uport2 CX HeII Spectrum
spectrum
fit
radiance(ph/m^2/s/sr/A)
lambda/A
4640 4660 4680 4700 4720
Description of components
Spectral Fit Results
v-rot : 2.04e+005 m/sec; error = 16.12%
Ampl : 4.11e+013 ph/m^2/sr/s/A; error= 2.76%
continuum baseline subtracted by NB modulation
Ti : 18.6345 keV; error =6.46%
<SNR at half ampl> : 4.068
Show Optimisation
Multi-Device-CX-Spectra- Simulation (V5.08)
M.G. von Hellermann, FOM Institute for Plasma Physics Rijnhuizen (mgvh@rijnh.nl)


ITER Uport2D&T-CX&MSE
x 10^15
rho observation = 0.30
spectrum
fit
D-CX
BES
radiance/ph/s/sr/m^2/A
lambda/A
σ0
σ−
σ+
π−3
π−2
π+2
π+3
π+4
D-alpha-edge
D-alpha-CX
13
12
11
10
9
8
7
6
6500
6520
6540
6560
6580

Spectrometer specifations for ITER CXRS and BES

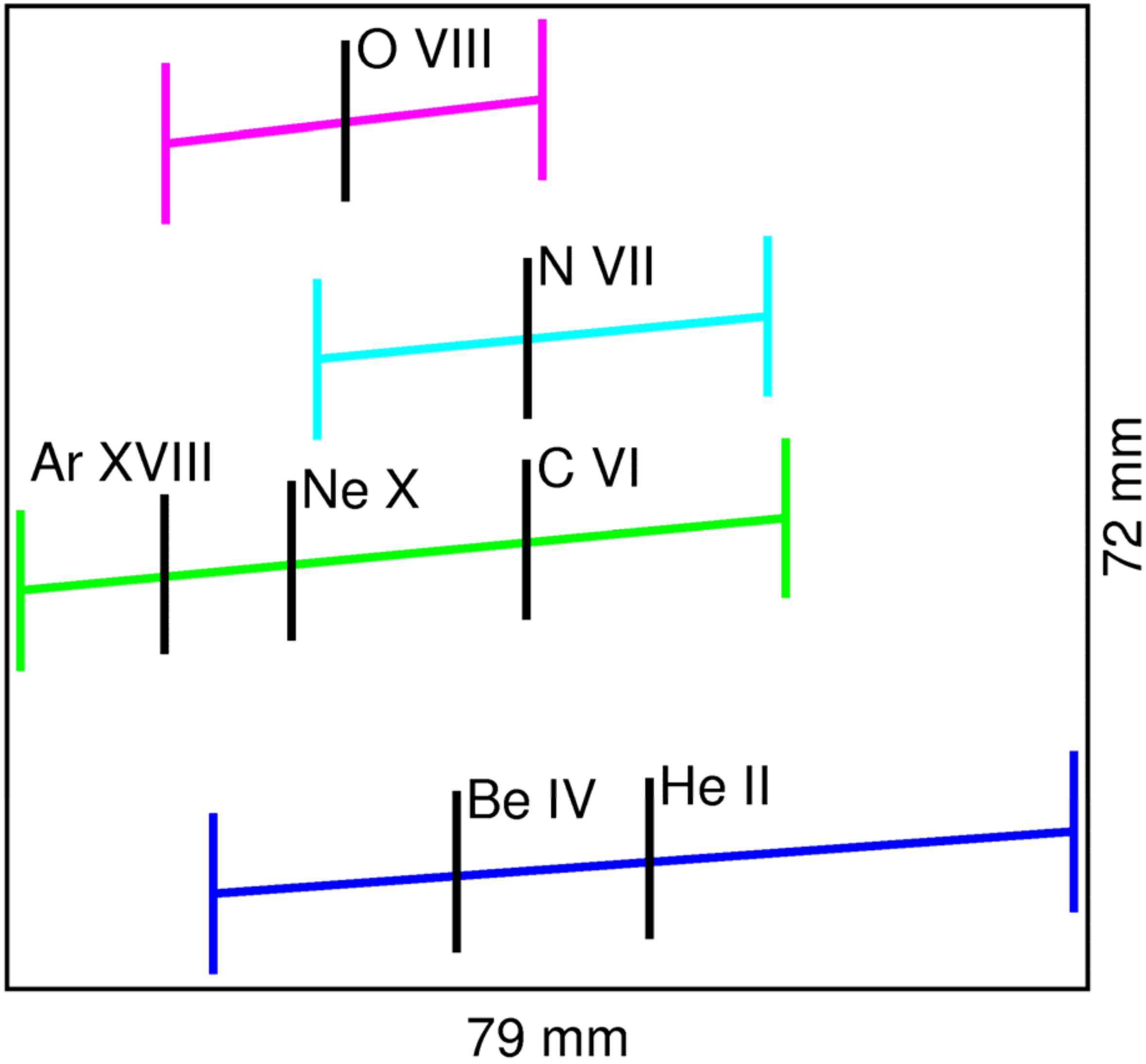
M. von Hellermann

Key specifications for the ITER CXRS special design Echelle spectrometer , W.Biel (FZJ)

1. Wavelength resolution / instrumental width <= 2.5 Å (FWHM)
2. Entrance slit width >= 1.0 mm
3. Entrance slit height >= 12 mm
4. Acceptance angle / f-number >= f/2.9
5. Table of the wavelength ranges and diffraction orders which have to be monitored simultaneously:

Impurities	λmin / Å	λmax / Å	Diffraction order m
DI, ArXVI	4320	4400	18
HeII, BeIV	4608	4736	17
ArXVIII, NeX, CVI	5194	5331	15
NVII	5629	5709	14
OVIII	6028	6108	13

W.Biel, FZJ



Combining main CX spectra on single detector making use of crossed Echelle grating technique, W.Biel FZJ