

The High-Resolution Neutron Spectrometer at ITER

8th International Conference on Frontier in Diagnostic

A. Hjalmarsson¹, L. Hägg¹, S. Conroy¹, J. Eriksson¹, P. Ollus¹, A. Jardin², M. Rebai³, F. Scioscioli³, J. Koning⁴, B. Coriton⁵ and A. Kovalev⁵

1. Department of Physics and Astronomy, Uppsala University, Lägerhyddsvägen 1, 75237 Uppsala, Sweden

2. Institute of Nuclear Physics Polish Academy of Sciences, Radzikowskiego 152, PL-31342 Krakow, Poland

3. Istituto per la Scienza e Tecnologia dei Plasmi, via Cozzi 53, Milano, Italy

4. Heemskerk Innovative Technology, Rotterdamseweg 183C, 2629 HD, Delft, The Netherlands

5. ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul Lez Durance Cedex, France



UPPSALA
UNIVERSITET



THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES



Consiglio Nazionale delle Ricerche

Outline:

- HRNS: requirements and measurement parameters
 - HRNS
- Methodology
 - Plasma neutron source
 - Collimated neutron source (line-of-sight)
 - HRNS response
 - HRNS performance analysis
 - Fuel ion ratio uncertainty
- Scaling of ITER baseline 15MA/5.3T scenario
- Results: HRNS performance analysis
- Summary and conclusion





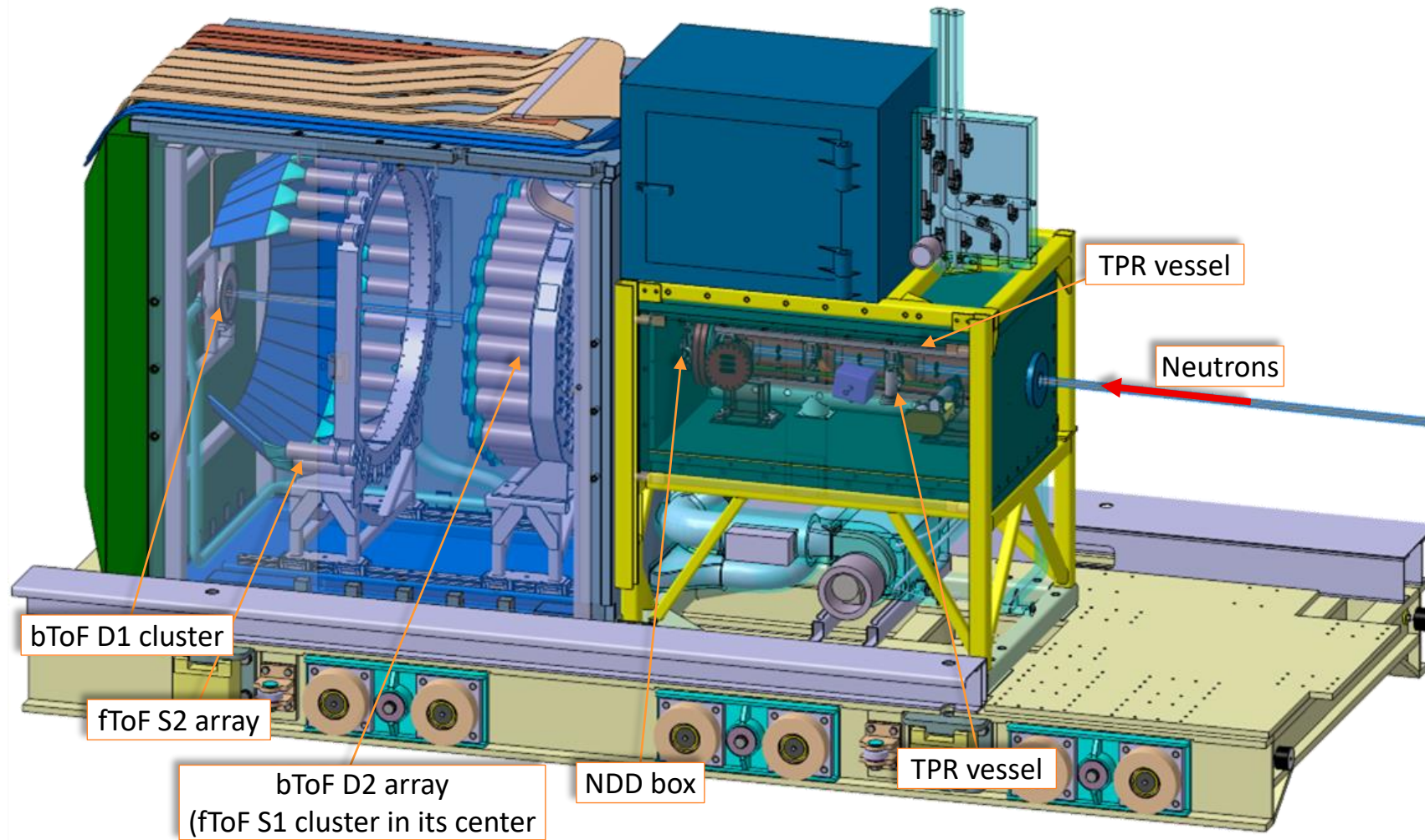
HRNS: requirements and measurement parameters

MP	Range	Time res.	Accuracy	Role
MP020 n_T/n_D	0.01-10	100 ms	20%	1a.2 BC (primary)
MP064 Core T_i	0.5-40 keV	100 ms	10%	1b.AC backup
MP069 Alpha	0.1-3.5 MeV	100 ms	20%	PHY suppl.
MP070 p,D,T, ^3He	0.1-1.0 MeV	-	20%	PHY suppl.

- Fusion power range 0.5-500 MW

Spectrometer	Power range	Detection principle
Forward-scattering ToF	0.5 - 5 MW	Coincidence ToF n-p scattering
Back-scattering ToF	1 - 25 MW	Coincidence ToF n-d scattering
Diamond detector	5 - 200 MW	n + C nuclear reaction
Thin-foil proton recoil	40 - 500 MW	n-p scattering in thin foils

HRNS



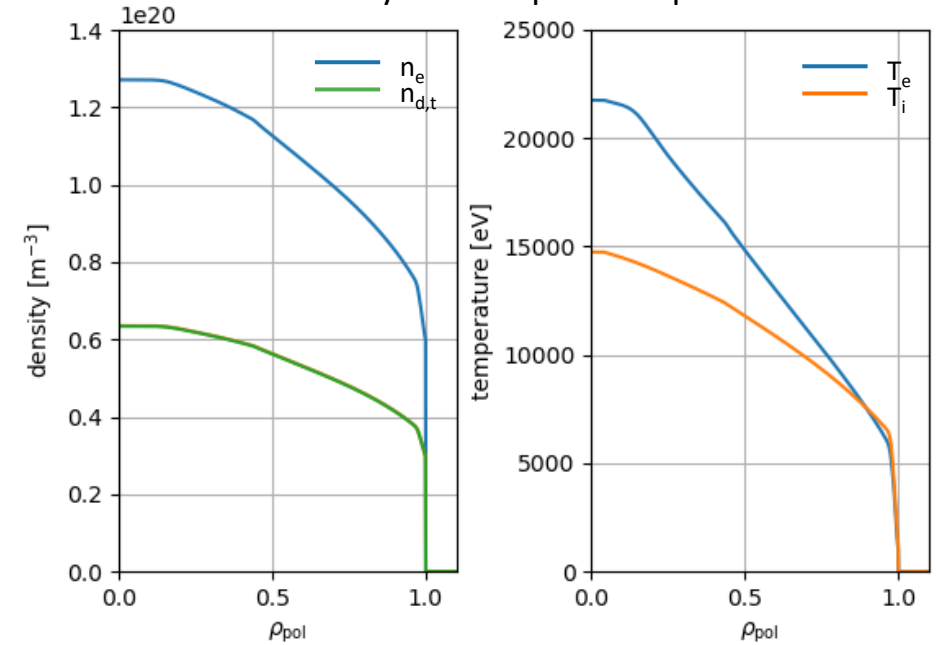
A. Hjalmarsson

8th International Conference on Frontier in Diagnostic

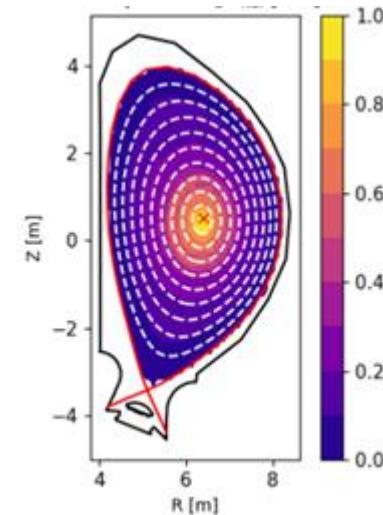
Plasma neutron source

- Plasma equilibrium
- Fuel ion density profiles
- Temperature profiles T_e and T_i
- Neutral beam power and injection geometry
- Thermal ion distributions in (R,Z)
 - Temperature profiles
 - Density profiles
 - Plasma equilibrium
- NBI fast ion energy-pitch distribution in (R,Z)
 - Plasma transport codes (TRANSP, ASCOT)

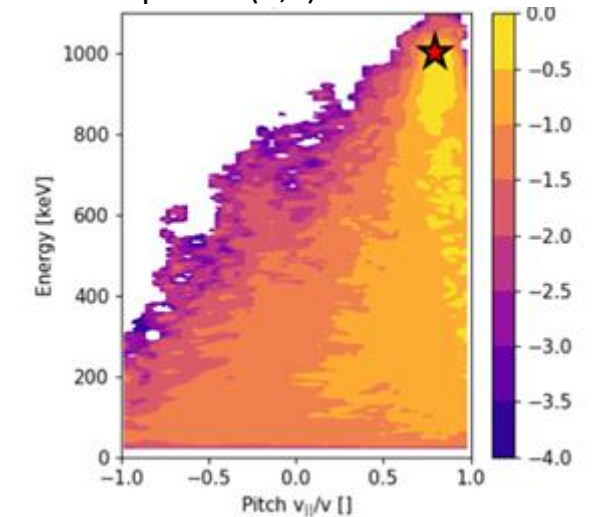
Density and temperature profiles



Normalized fast ion density in (R,Z)



Fast ion energy-pitch distribution for specific (R,Z) coordinate



HRNS neutron source

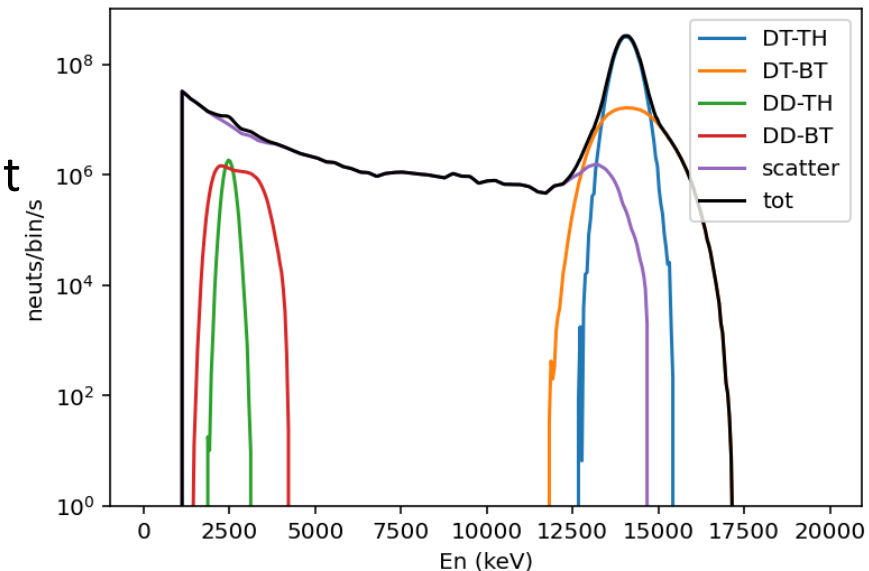
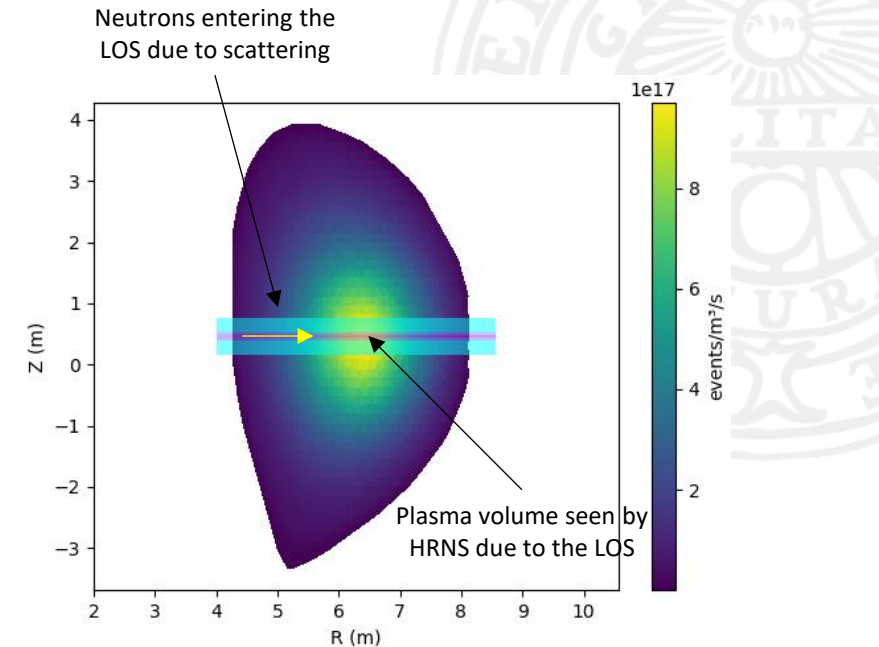
Directional Relativistic Spectrum Simulator (DRESS) calculates the neutron emissivity for any two energy-pitch ion distributions as function of the poloidal plane coordinates (R,Z).

- For the HRNS neutron source model three fuel ion distribution functions were considered
 - Thermal deuterium
 - Thermal tritium
 - Fast deuteron ions due to neutral beam slowing-down

The effect of instrumental line-of-sight (LOS) on the neutron emissivity is implemented and corrected for within the DRESS code

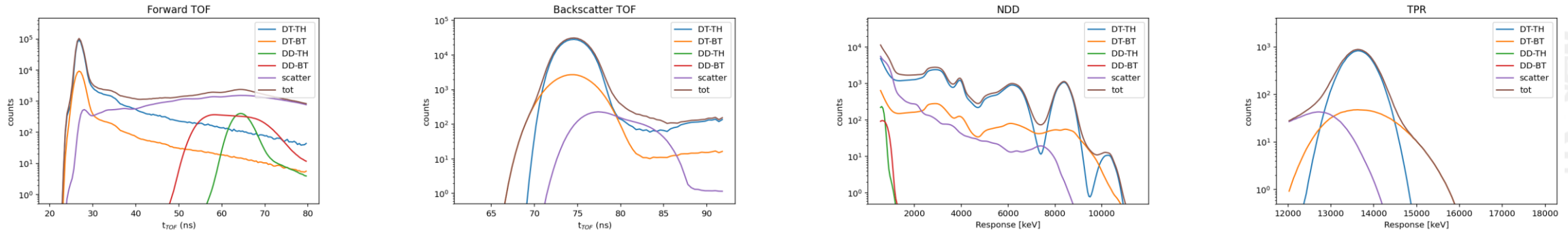
Additional neutron component due to neutron scattering into the instrumental LOS is estimated using ITER MCNP modelling and LOS geometry

- The neutron energy distribution reaching the HRNS system is built up by five neutron components
 - Thermal D ions (DD-TH)
 - Thermal D and T ions (DT-TH)
 - Thermal D and beam slowing-down deuterons (DD-BT)
 - Thermal T and beam slowing-down deuterons (DT-BT)
 - Neutron scattering component (scatter)
 - Sum of all neutron components (tot)



HRNS response

Spectroscopy model for each instrument



HRNS instrumental response functions are modeled using Monte-Carlo methods

Spectral component intensities

$I_{DD,TH}^0$: given by thermal deuterium density, $n_{D,TH}$ and thermal ion temperature profiles

$I_{DD,BT}^0$: given by thermal deuterium density, $n_{D,TH}$ and thermal ion temperature profiles and modeled fast ion slowing down distribution, $n_{D,Beam}$

$I_{DT,TH}^0$: given by thermal density, $n_{D,TH}$ and $n_{T,TH}$ and thermal ion temperature profiles

$I_{DT,BT}^0$: given by thermal tritium density, $n_{T,TH}$ and thermal ion temperature profiles and modeled fast ion slowing down distribution, $n_{D,Beam}$

$I_{scatter}^0$: given by MCNP neutron transport calculations

I_{tot}^0 : Sum of $I_{DD,TH}^0$, $I_{DD,BT}^0$, $I_{DT,TH}^0$, $I_{DT,BT}^0$ and $I_{scatter}^0$

HRNS performance analysis DT plasmas

Normalize the total intensity I_{tot}^0 to correspond to a data collection time of 100 ms: $I_{tot,100ms}^0$

Perturbing $I_{tot,100ms}^0$ using Poisson statistic to simulate “measurement data” of a specific ITER plasma scenario

Generate trial intensities $I_{DT,TH}$, $I_{DT,BT}$ and $I_{scatter}$

The intensity, $I_{DT,TH}$, of the thermal component scales to model intensities, $I_{DT,TH}^0$, with the density scaling factors k_D and k_T

$$I_{DT,TH} = k_D k_T I_{DT,TH}^0$$

The intensity, $I_{DT,BT}$, of the beam component scales to model intensity, $I_{DT,BT}^0$, with scaling factor k_T

$$I_{DT,BT} = k_T I_{DT,BT}^0$$

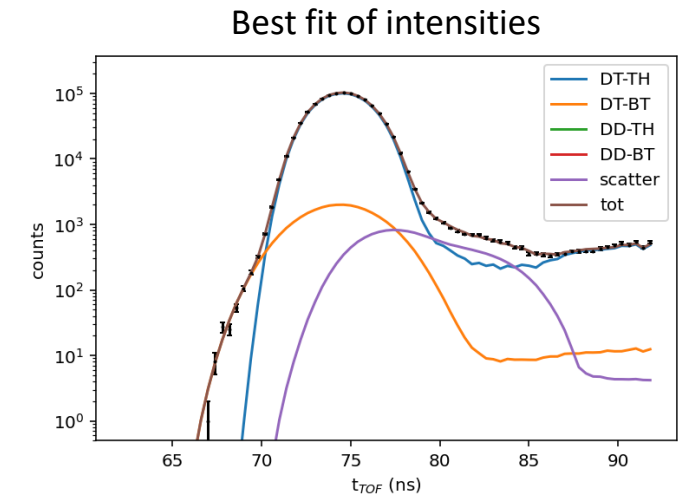
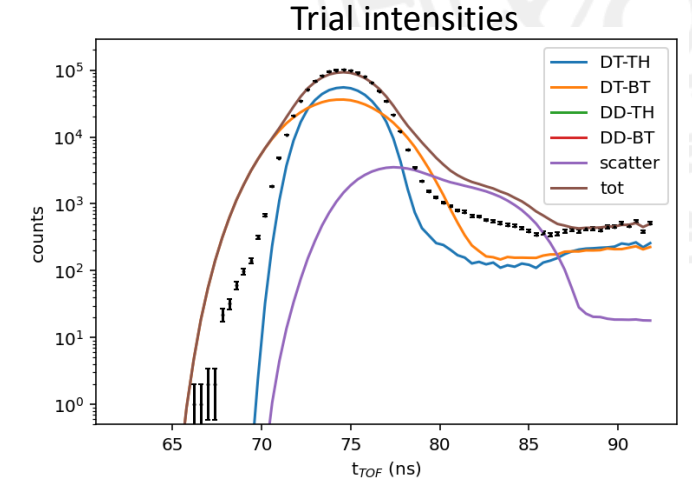
From fits to “measurement data” one obtains the intensity ratio

$$I_{DT,TH} / I_{DT,BT}$$

From the intensity ratio together with the total neutron rate, R_{tot} , k_D and k_T are determined and the fuel ion ratio is given by

$$\frac{n_T}{n_D} = \frac{k_T n_T^0}{k_D n_D^0}$$

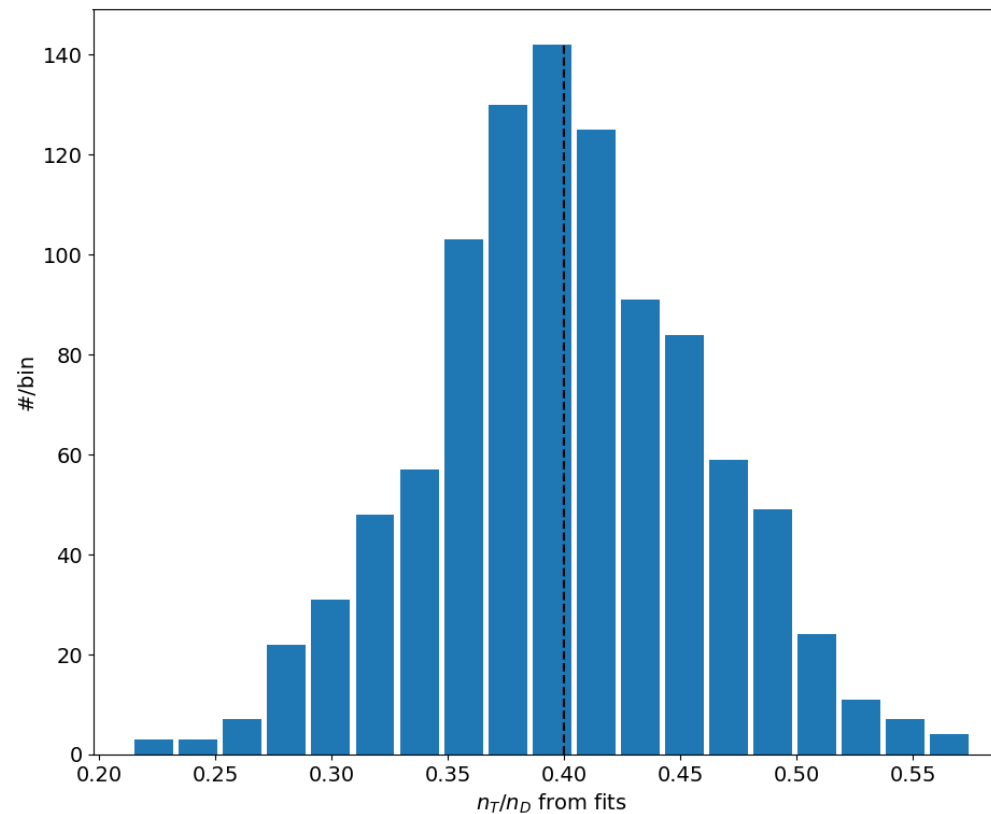
In the performance analysis an uncertainty of 10 % is used on R_{tot} , and the ion temperature, T_i is assumed provided by another diagnostic.



Uncertainty of fuel ion ratio

Generate a n_T/n_D distribution by simulating a set of “measurement data” and perform intensity fits to determine k_D and k_T and calculate n_T/n_D

The uncertainty in n_T/n_D is given by 1σ of the produced n_T/n_D distribution



A. Hjalmarsson

8th International Conference on Frontier in Diagnostic

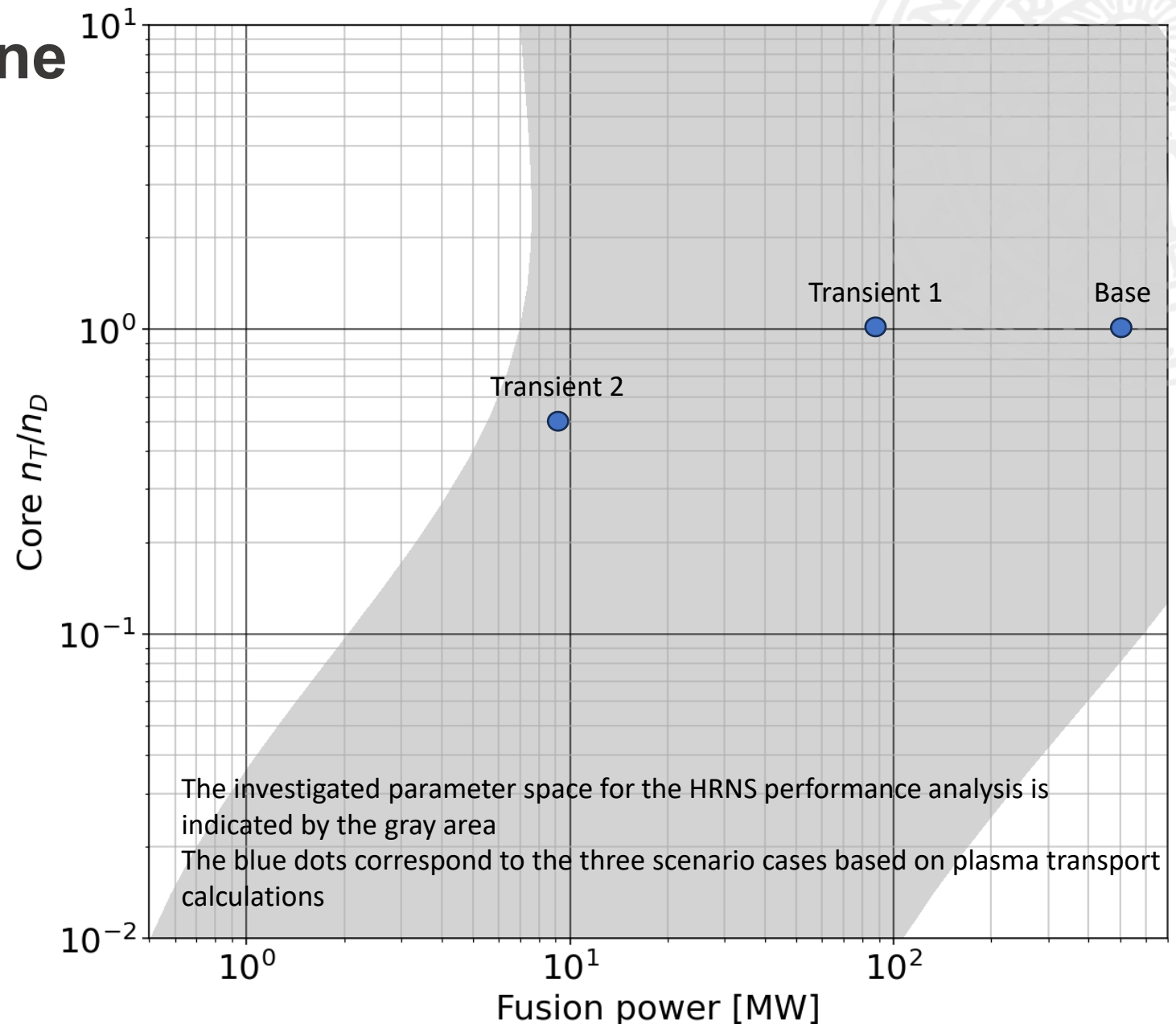
Scaling of ITER baseline 15MA/5.3T scenario

The total ion density, $n_T + n_D$, was always kept constant to have confidence in a correctly modeled fast ion slowing down distribution

The fuel ion ratio, n_T/n_D , was scaled in the range 0.01 to 10

The ion temperature, T_i , was scaled in the range 5 keV to 40 keV

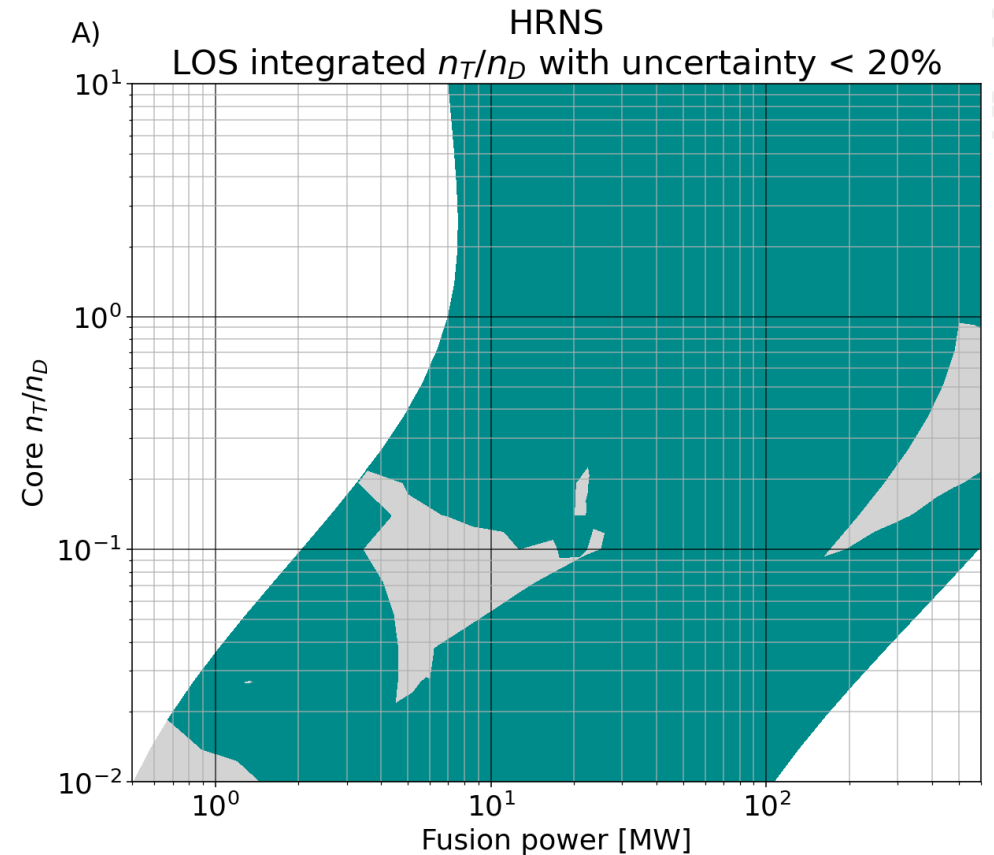
The total density of beam-slowing down ions was scaled with $T_e^{3/2}$



Results: HRNS performance analysis

$$n_T/n_D$$

- HRNS fulfills ITER's requirement on n_t/n_d in most of the investigated parameter space, except for:
 1. A small region at very low fusion power $P_{\text{fus}} < 1.5$ MW and tritium fraction $n_T/n_D < 0.02$;
 2. A triangular region located at low/intermediate fusion power $3 \text{ MW} < P_{\text{fus}} < 20$ MW and tritium fraction $0.02 < n_T/n_D < 0.2$;
 3. A last region located at high fusion power $P_{\text{fus}} > 200$ MW and tritium fraction $0.1 < n_T/n_D < 1.0$
- The region representing low/intermediate fusion power are possibly an operational area of interest for ITER
- Region with high fusion power and low n_T/n_D is possibly an unphysical operational area for ITER
- Information from plasma transport calculations needs to be investigated to assess ITER's operational regions in terms of n_T/n_D and T_i



Summary and conclusion

The HRNS performance analysis is based on realistic

- Fuel ion density profiles
- Temperature profiles
- Thermal ion distributions
- Fast ion energy-pitch distribution (plasma transport calculations)

To cover an extended HRNS operational range, scaling of plasma transport calculation results was performed

- Fuel ion ratio scaled between 0.01 and 10
- Ion temperature scaled between 5 keV to 40 keV
- Total density of beam slowing-down ions was scaled with $T_e^{3/2}$

The performance analysis was based on individual instrument

In the current investigation, HRNS fulfill ITER's requirements on n_T/n_D for most of the investigated parameter space if T_i is provided by other diagnostics

To perform a more accurate HRNS performance analysis in a correct parameter space:

- Plasma transport calculations for other ITER DT scenarios, including fast-ion distributions, are necessary.
- Scaling of plasma transport calculations should be avoided.
- Alpha heating effects should be considered.