Calibration Strategy for ITER Neutron Spectrometers (HRNS)

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Outline

- High Resolution Neutron spectrometer System (HRNS)
- Determination of neutron flux, fuel ion ratio and ion temperature
- Calibration of individual detectors
- Calibration of spectrometers
- Conclusions

High Resolution Neutron spectrometer System (HRNS)

Operational range for a neutron spectrometer is approximately one order of magnitude in fusion power

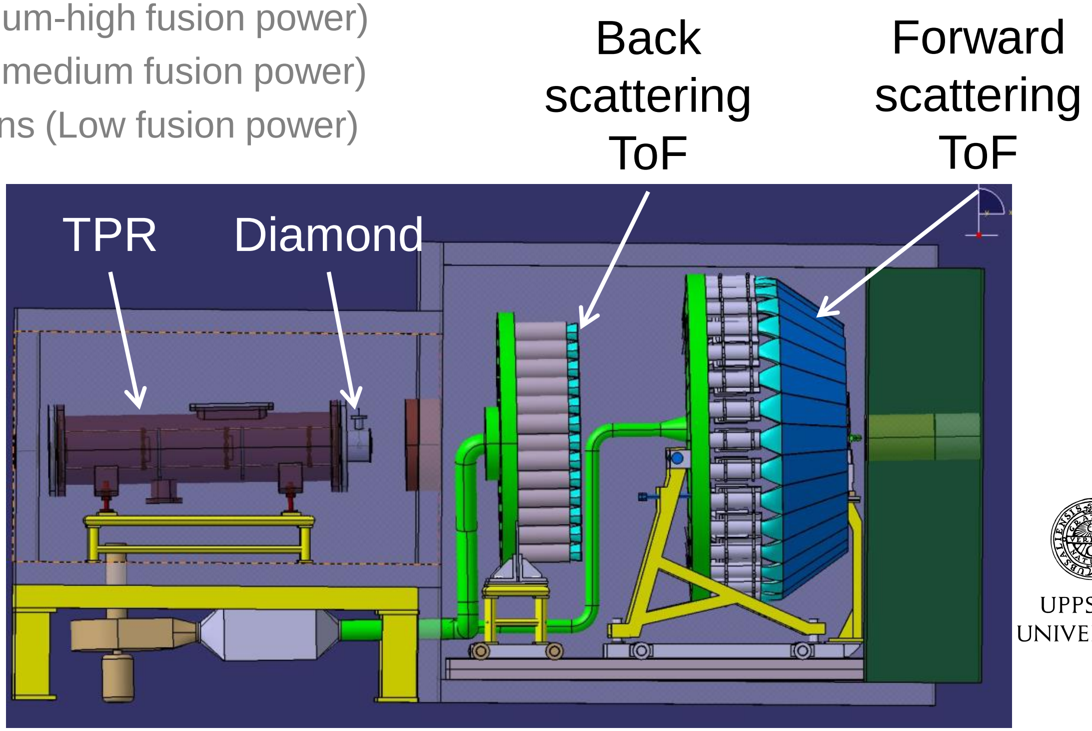
- ITER operational power in DD and DT span approximately four order of magnitude (steady state)

Different neutron spectrometer techniques

Thin-foil Proton Recoil (TPR)	DT neutrons (High fusion power)
Diamond	DT neutrons (Medium-high fusion power)
Back-scattering Time-of-Flight	DT neutrons (Low-medium fusion power)
Forward-scattering Time-of-Flight	DD and DT neutrons (Low fusion power)

Converting neutrons to charge particles (p, d and α)

- Elastic (n,p) scattering in polyethylene foil
- C (n,α) scattering
- Elastic (n,d) and (n,p) scattering in organic scintillators
- Elastic (n,p) scattering in organic scintillators



Determination of neutron flux, fuel ion density ratio and ion temperature

Neutron flux, F_n, determination

- $F_n = \frac{C_n}{\varepsilon}$
- Neutron detection efficiency, $\varepsilon\ (m^2)$
- Spectrometer count rate or coincidence count rate C_n
- Reaction cross sections
- Geometry of spectrometer sub systems

Fuel ion density ratio, $\frac{n_t}{n_d}$, and ion temperature, T_i

- Spectrometer energy resolution $\frac{\Delta E}{E}$
- Geometry of spectrometer system
- Energy scale and energy resolution of individual detectors (TPR, Diamond and ToF systems)
- Time resolution of individual detectors (ToF systems)

Spectrometer neutron detection efficiency and energy resolution

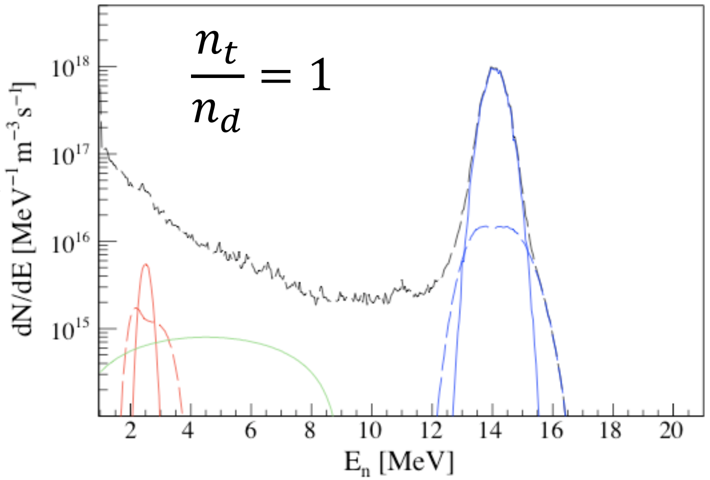
Monte-Carlo simulations (neutron transport)

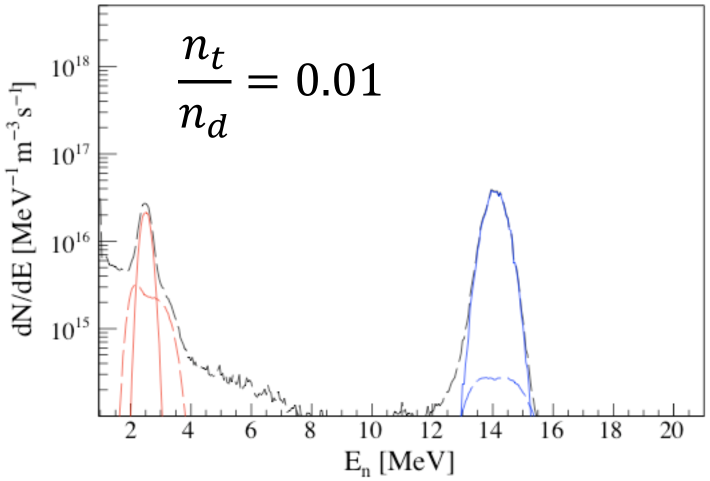
- First principles, neutron cross sections
  - ○ Elastic (n,p) scattering
  - ○ Elastic (n,d) scattering
  - ○ ^{12}C(n,α) reaction
- Geometry of spectrometer

Calibration of individual detectors

- For all spectrometers
  - Accelerator beam measurements for particle energy calibration and resolution
    - Proton beams in an energy range 1 to 18 MeV
    - Deuteron beams in an energy range of 4 to 14 MeV
    - ^{4}He beams in an energy range of 7 to 12 MeV
  - Monitoring particle energy calibration with gamma and alpha sources
  - Count rate capability of data acquisition system
  - Stray magnetics field effect

- For ToF system
  - Particle energy dependent time resolution
    - Artificial light sources, fibre optics and light attenuator
    - Gamma sources
  - Time alignment detector pairs
    - Gamma sources or fusion gammas





Calibration of spectrometers

Calibration for neutron flux determination

TPR (proton telescope), Diamond (direct nuclear reaction) and Back-scattering ToF (coincidence elastic scattering in organic scintillators)

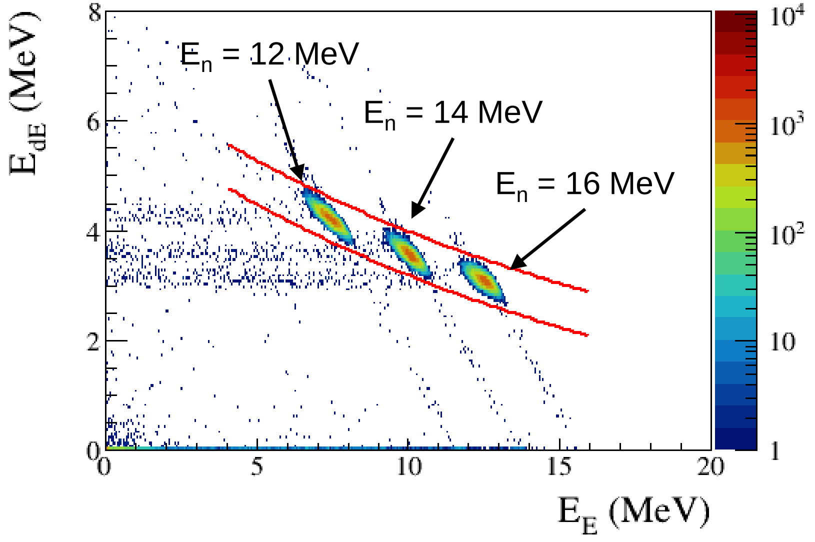
- Detection hardware thresholds low impact on detection efficiency ε
- Larger uncertainties in detector energy calibration acceptable

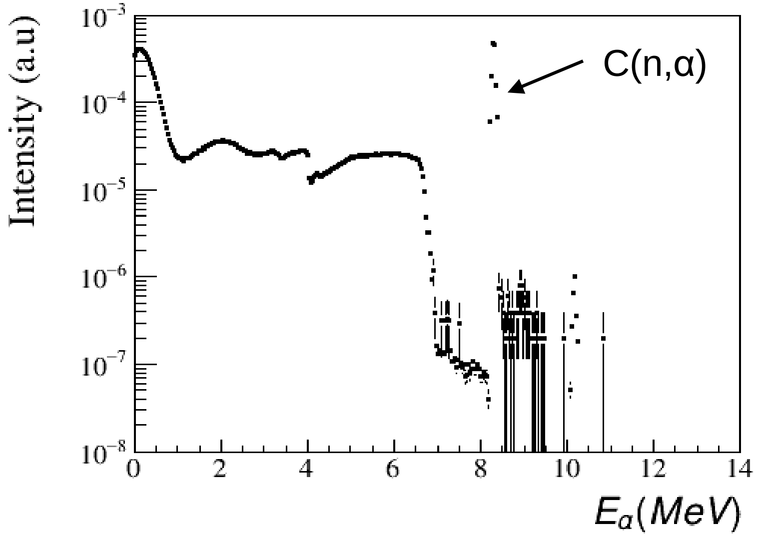
Forward-scattering ToF (coincidence elastic scattering in organic scintillators)

- Detection hardware thresholds high impact on detection efficiency ε
- Small uncertainties in detector energy calibration needed

DD and DT neutron generators for calibration measurement of neutron detection efficiency

- Activation measurements for neutron source strength
- Monitoring neutron source stability
- A few neutron calibration energies based on kinematics of neutron production in neutron generators
- Confirmation of spectrometer response function based on Monte-Carlo simulations including calibration results of individual detectors





Calibration of spectrometers

Fuel ion ratio and ion temperature

Relative measurements of different DT neutron components for TPR, Diamond and Back-scattering ToF

- Absolute energy calibration not necessary
- TPR
  - $\frac{\Delta E}{E}$ dominated by spectrometer geometry
  - Larger uncertainties on detector energy calibration acceptable
- Diamond
  - $\frac{\Delta E}{E}$ dominated by detector energy resolution
  - Small uncertainties on detector energy calibration needed
- ToF
  - $\frac{\Delta E}{E}$ combination of spectrometer geometry and detector time resolution
  - Small uncertainties in detector energy and time calibration needed
  - Small uncertainty in time alignment between detector pairs

Relative intensity of DD and DT neutron components for Forward-scattering ToF

- ToF
  - $\frac{\Delta E}{E}$ combination of spectrometer geometry and detector time resolution
  - Very accurate detector energy calibration needed
  - Small uncertainties in detector time calibration needed
  - Small uncertainty in time alignment between detector pairs

Conclusions

HRNS primary task

- Deduce fuel ion density ratio, $\frac{n_t}{n_d}$

HRNS secondary task

- Deduce thermal ion temperature, T_i

Primary and secondary task require relative measurements of neutron components

Calibration tasks required for primary and secondary tasks and neutron flux determination

- Accelerator beam experiments for calibration of energy scale and resolution of individual detectors
- Artificial light and gamma sources for detector time calibration and time alignment of detector pairs
- Well known geometry and alignment between spectrometer systems
- Good alignment with HRNS line-of-sight
- Monitoring of calibration long and short term
- Count rate capability of data acquisition system

Addition calibration required for neutron flux determination

- Absolute calibration of neutron detection efficiency
  - Neutron measurements using DD and DT neutron generators
  - Confirmation of Monte-Carlo calculations based on neutron cross sections

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