EUROfusion

Simulations in Support of Planning and Execution of JET Neutron Yield Calibrations

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*See the author list of "X. Litaudon et al 2017 Nucl. Fusion 57 102001"

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Overview

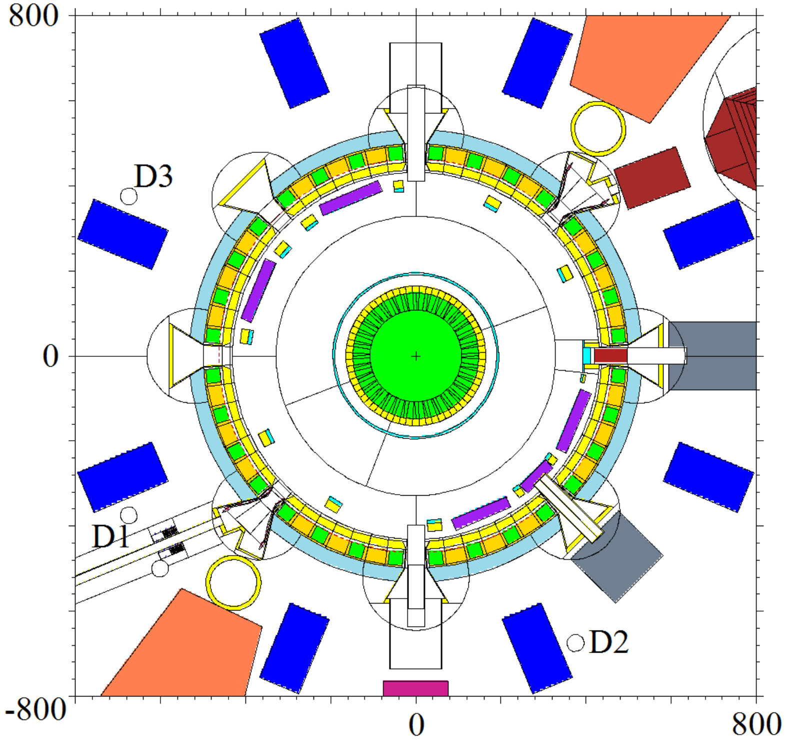
- Neutron yield detectors at JET

- Calibration procedure
- DD and DT calibration neutron sources
- Simulations in support of the calibration
- Calibration factors

- Lessons learned

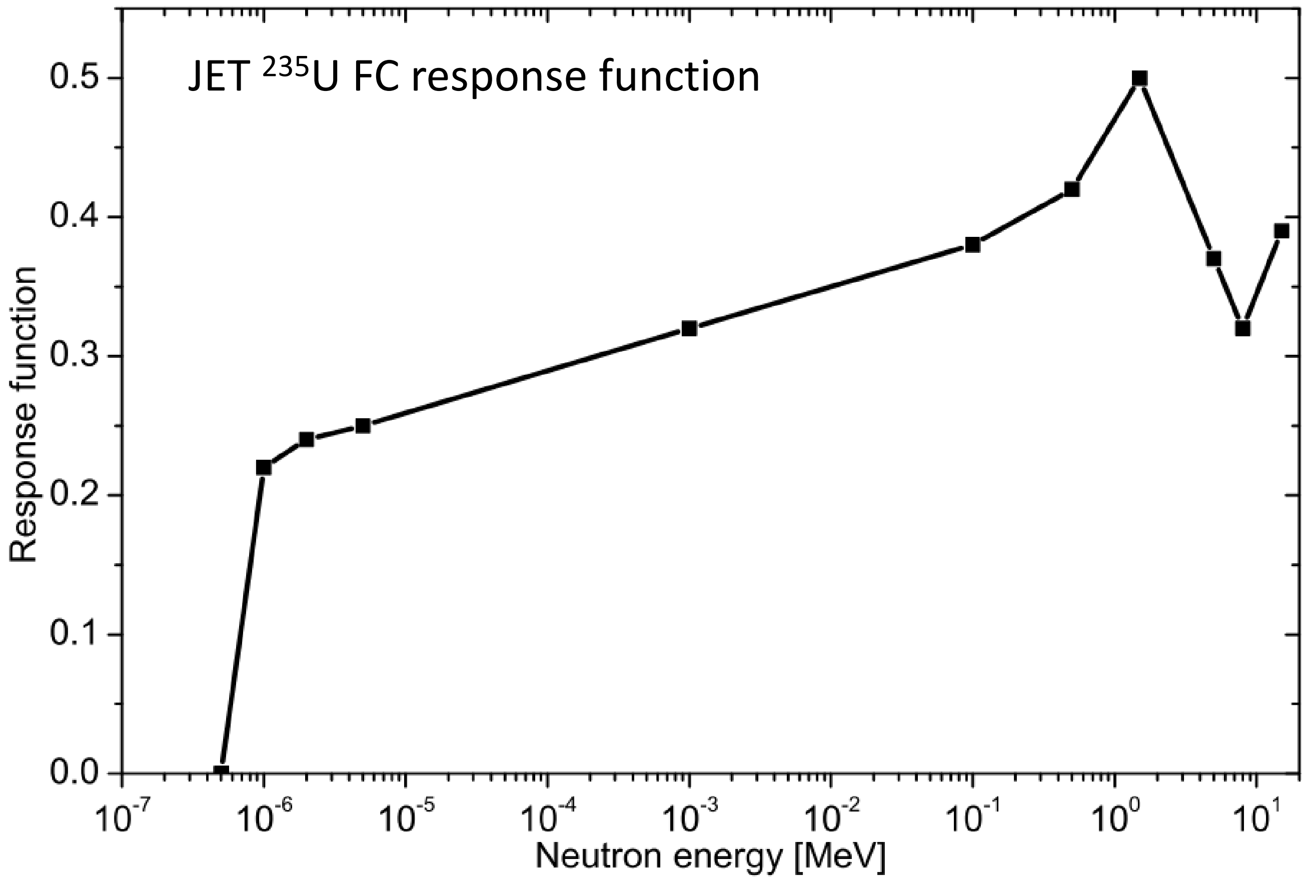
Neutron yield detectors at JET

- Fission chambers



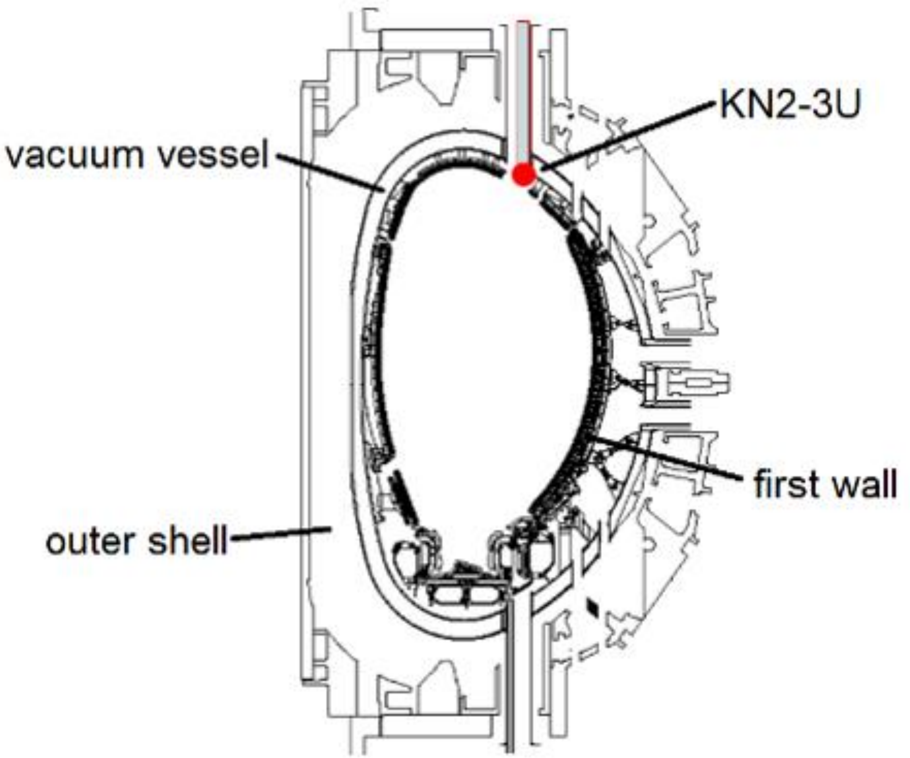
Neutron yield detectors at JET

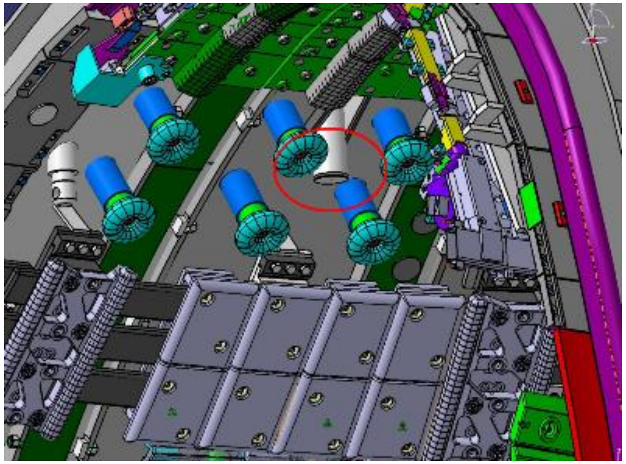
- Fission chambers

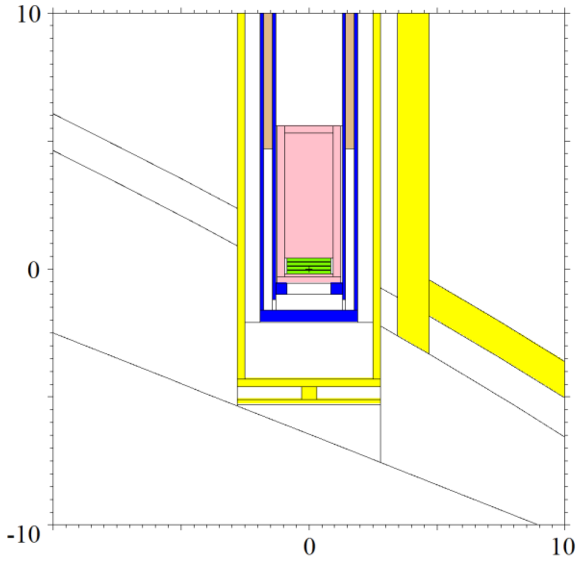


Neutron yield detectors at JET

- Activation system
  - Detailed local model
  - Threshold reactions







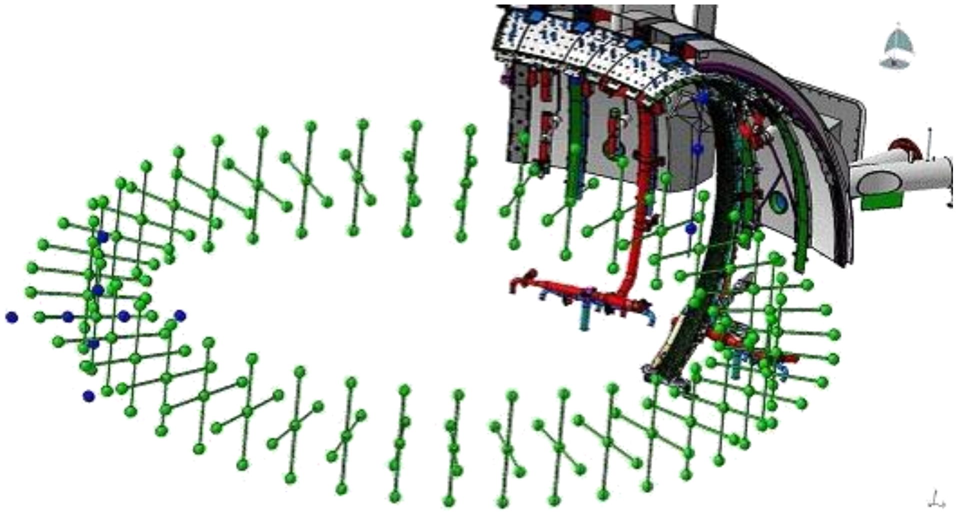
Calibration procedure

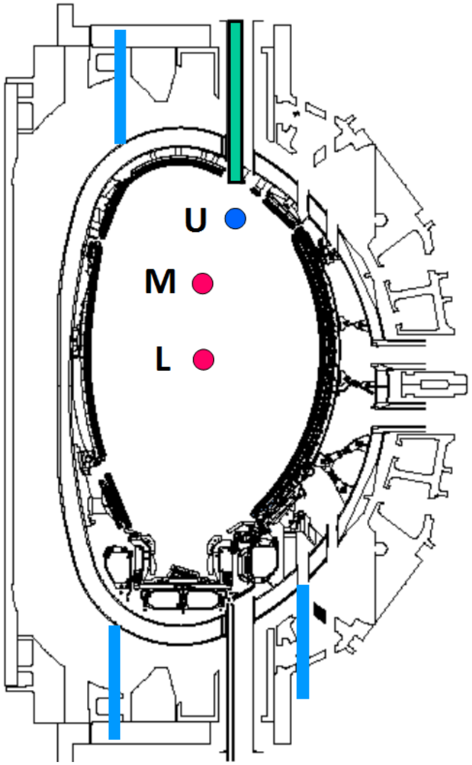
- Goal
  - Calibrate fission chambers and activation system
  - Detector sensitivity to typical plasma neutron source
  - Target uncertainty: ±10 % (ITER-relevant)

- Procedure
  - Measured detector response to a calibration source
  - Neutronic simulations

Calibration procedure

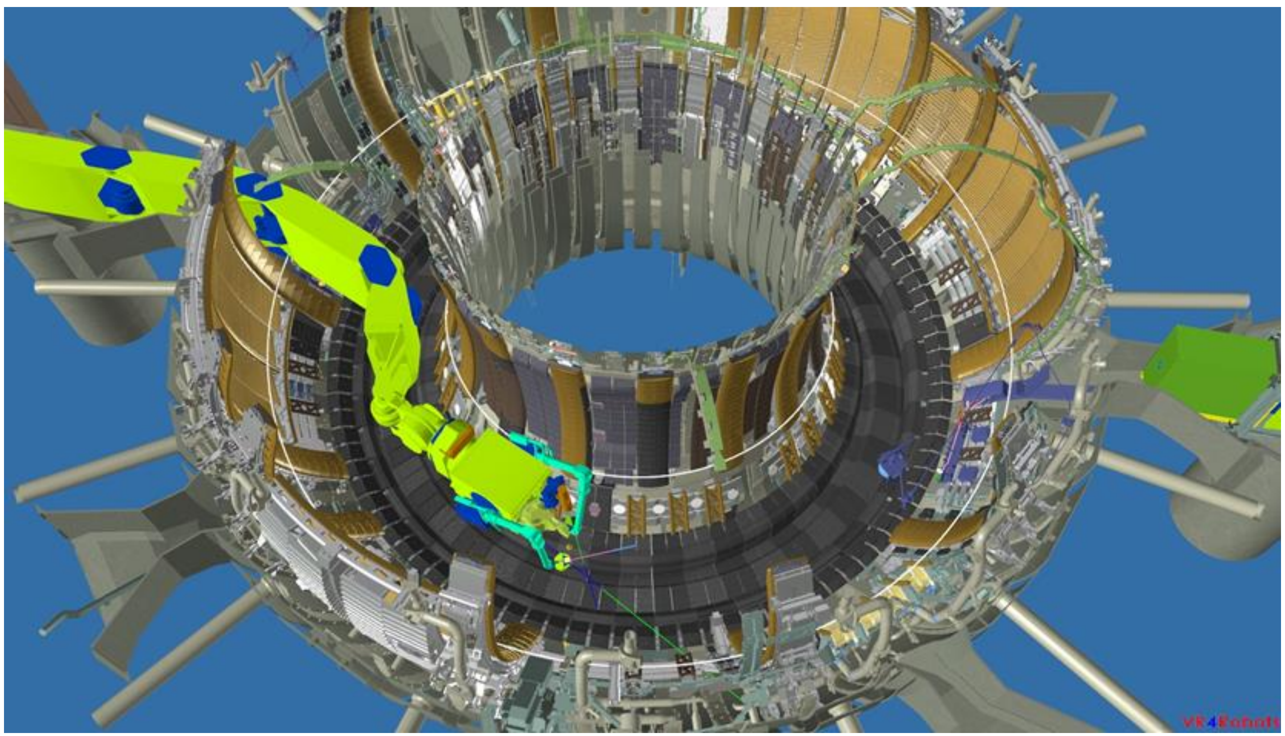
- Measured detector response to a calibration source
  - Ring scan
  - Scan near activation system





Calibration procedure

- Measured detector response to a calibration source
  - Ring scan
  - Scan near activation system



Calibration procedure

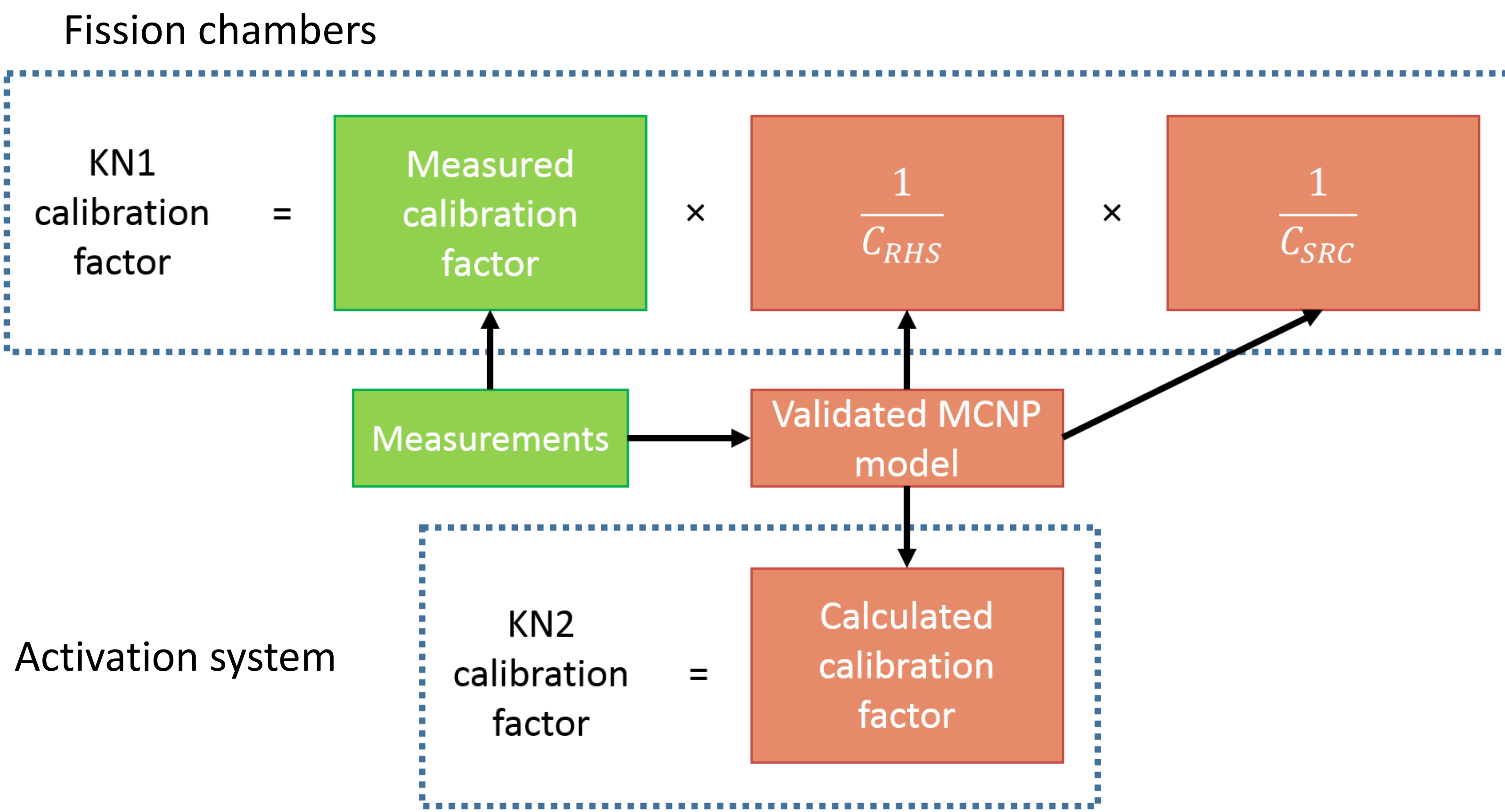
Fission chambers (ex-vessel)

- Measurements
  - Ring scan
  - Validate computational model
- Simulated corrections
  - Differences in geometry (C_{RHS})
  - Differences in source (C_{SRC})

Activation system (in-vessel)

- Measurements
  - Validate computational model
- Simulations
  - Calibration factors

Calibration procedure



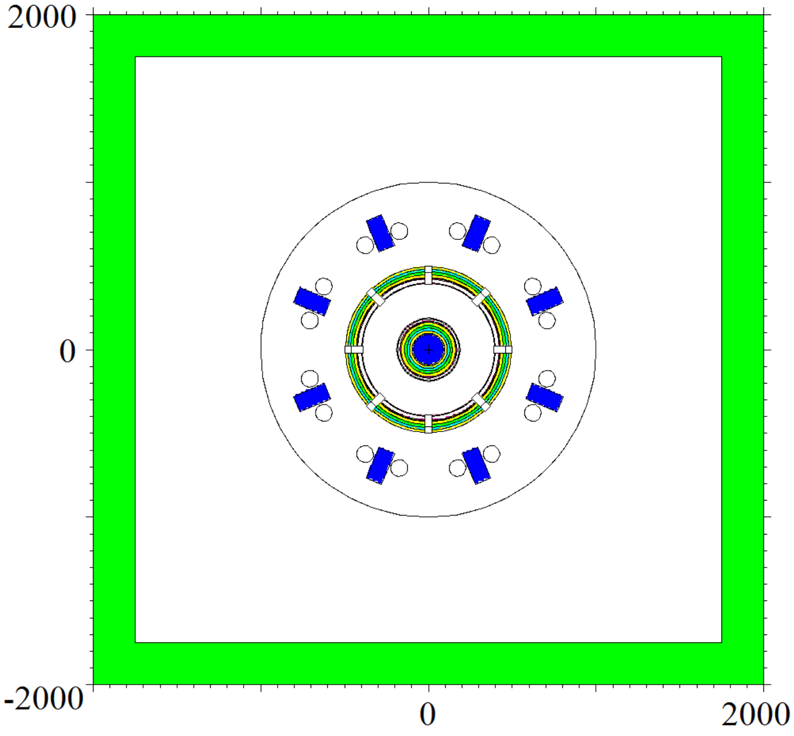
First things first

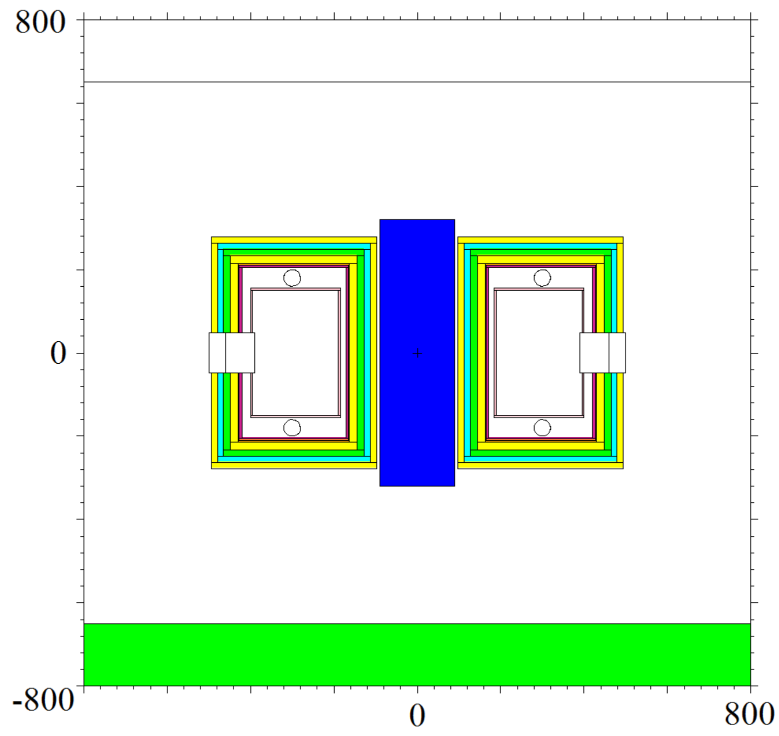
- Need to understand the system

- Build simple model
  - As simple as possible
  - Main features
  - Relevant behaviour

Simplified model

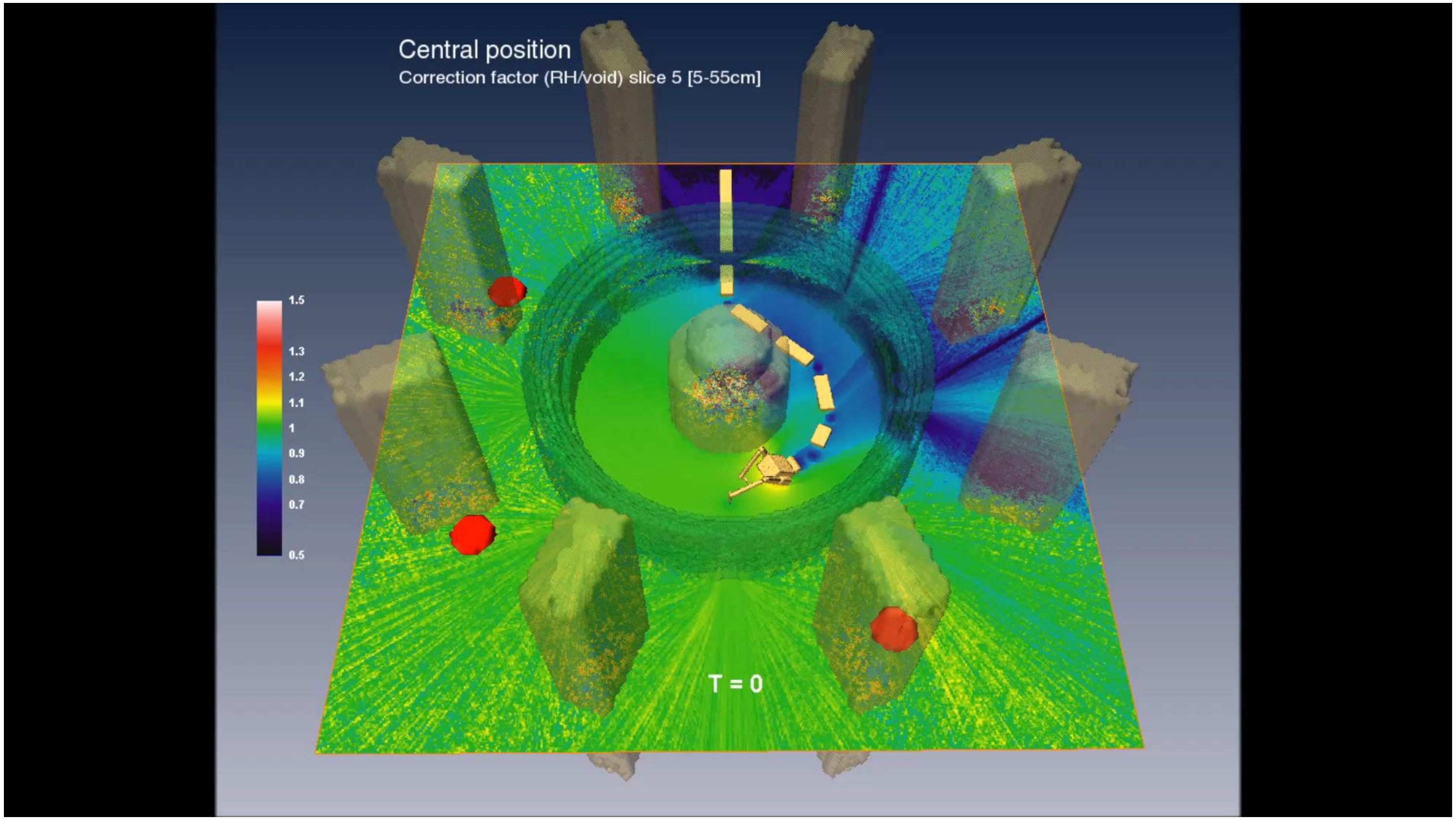
- Simple, easy to understand but representative
- General studies – quantify important contributions
- First approximation for the correction factors





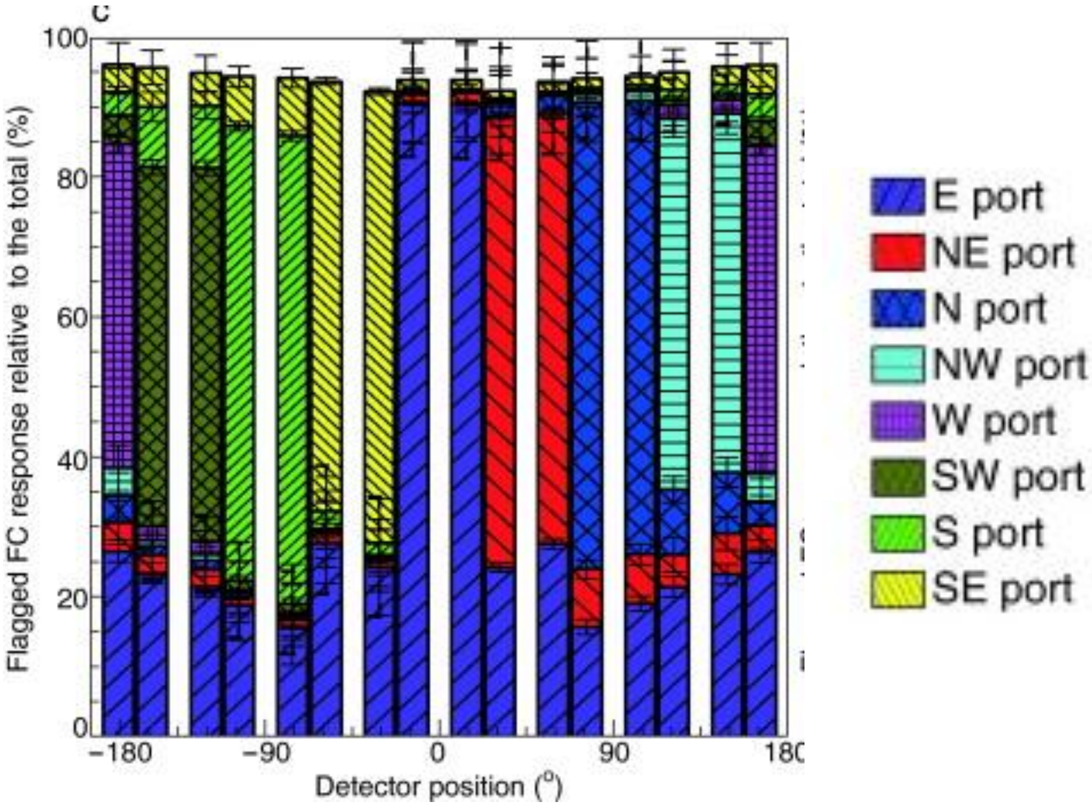
Simplified model

- First approximation for the correction factors



Simplified model

- General studies – quantify important contributions
  - Most neutrons come through ports
  - “Room return” represents 10% – 50%



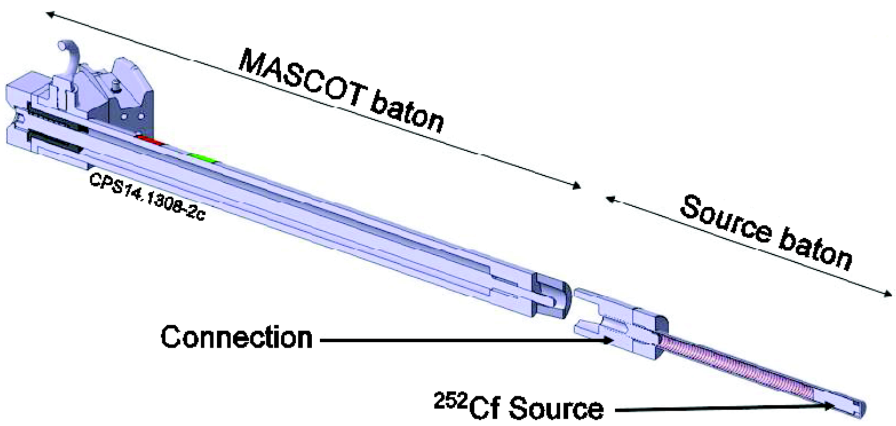
[1] L. Snoj et al.

Back to calibration procedure

Calibration neutron sources

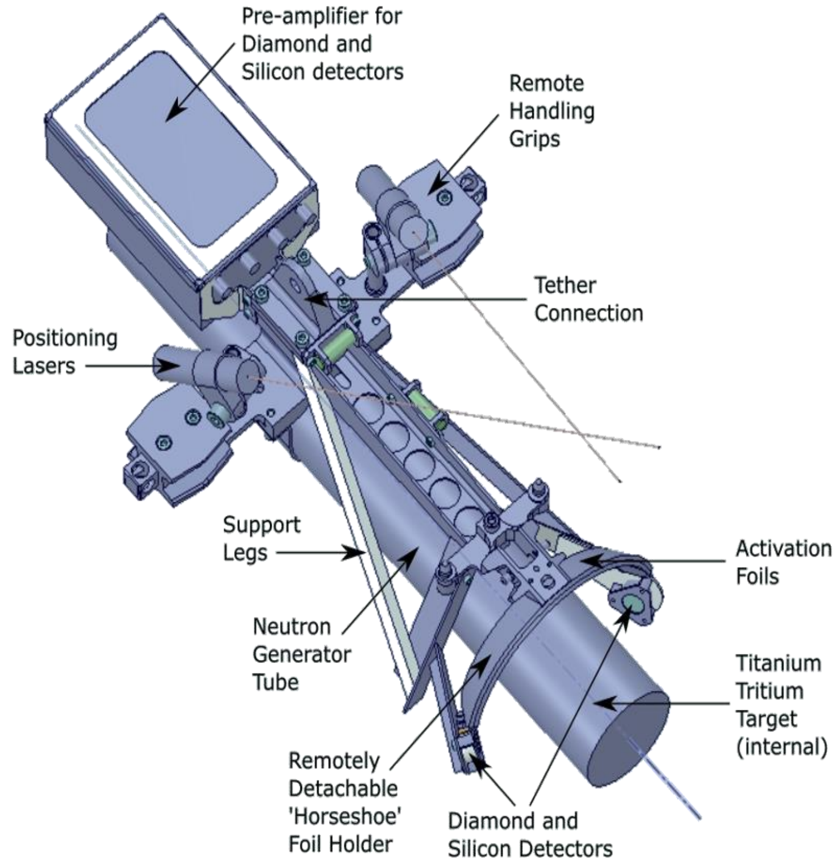
DD calibration 2013

^{252}Cf spontaneus fission source



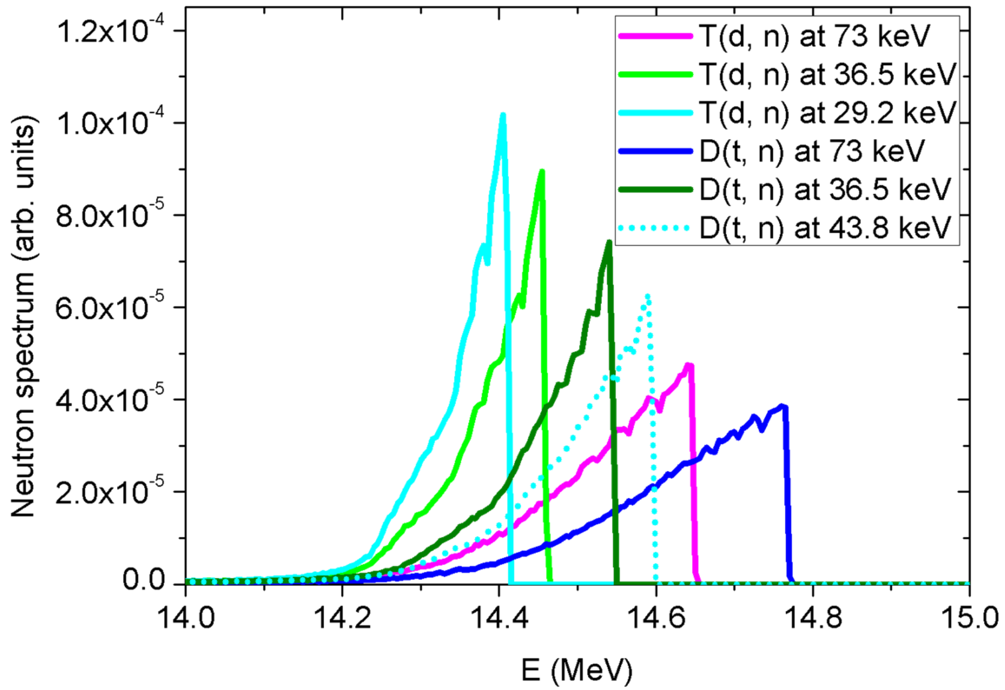
DT calibration 2017

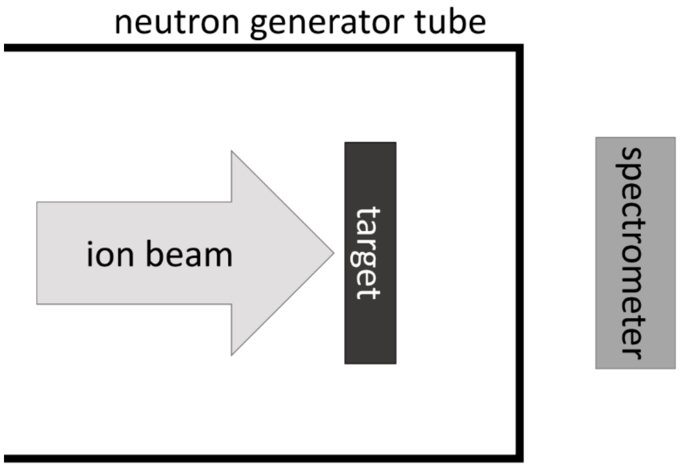
Compact DT neutron generator



Calibration neutron sources

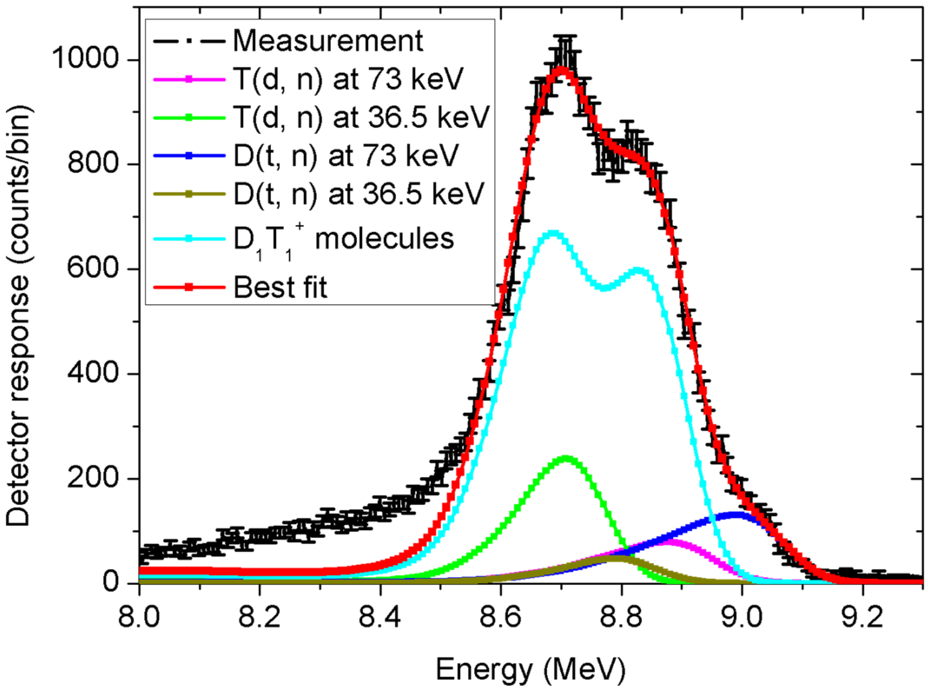
- Compact DT neutron generator
  - Mixed beam (D^+, T^+, D^{2+}, T^{2+}, D^1T^{1+}) and target (Ti, D, T)
    - 6 DT components + DD and TT

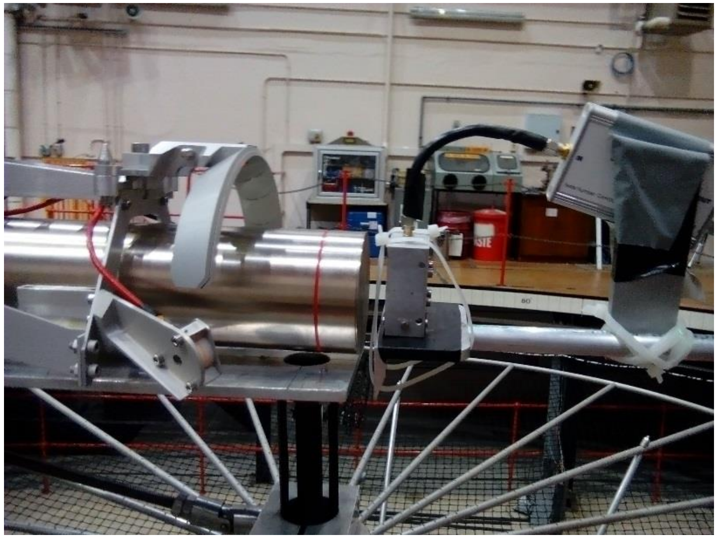




Calibration neutron sources

- Compact DT neutron generator
  - Detailed reproduction of the neutron source





[2] P. Batistoni et al.

Calibration neutron sources

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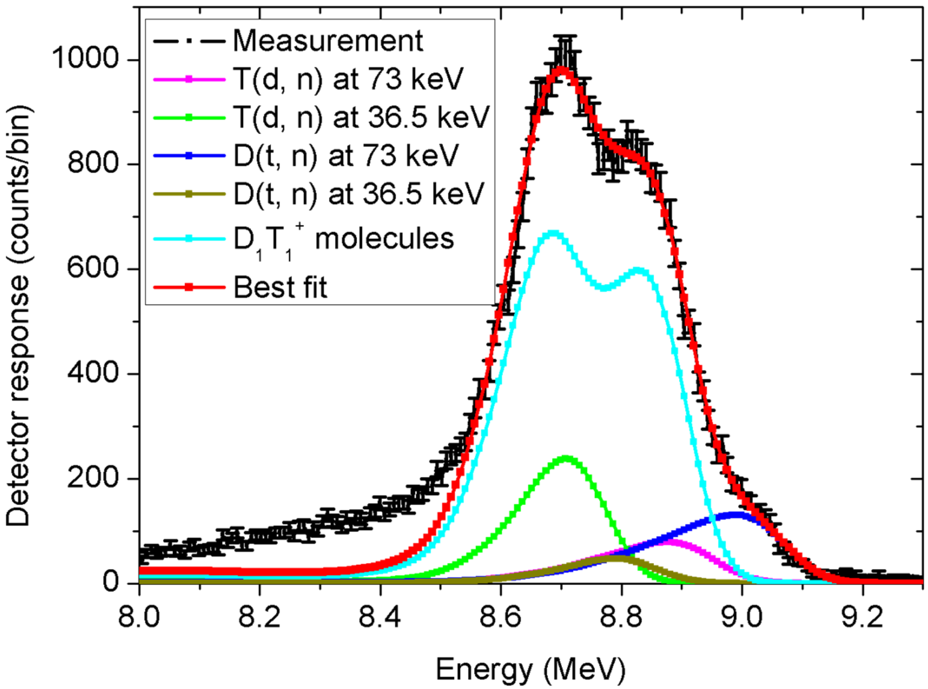
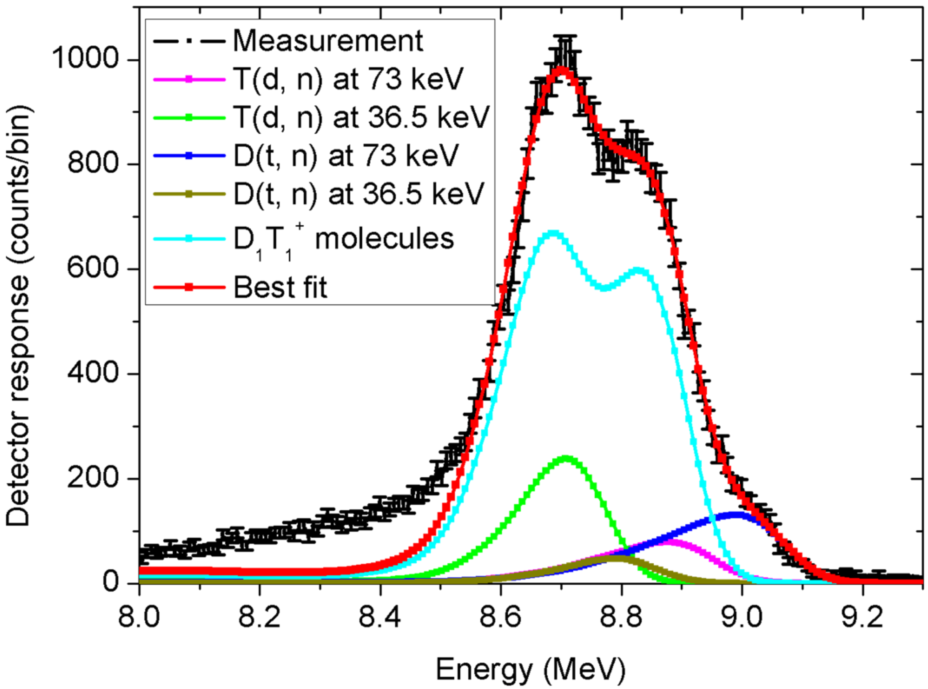


Ion beam	Neutron source component	Cont. [%]
D^+	T(d, n) at 73 keV	7.3
D_2^+	T(d, n) at 36.5 keV	15.1
T^+	D(t, n) at 73 keV	11.1
T_2^+	D(t, n) at 36.5 keV	2.9
$D_1T_1^+$	T(d, n) at 29.2 keV	25.0
	D(t, n) at 43.8 keV	38.6

[3] D. Rigamonti et al.

Calibration neutron sources

- Compact DT neutron generator
  - Detailed reproduction of the neutron source



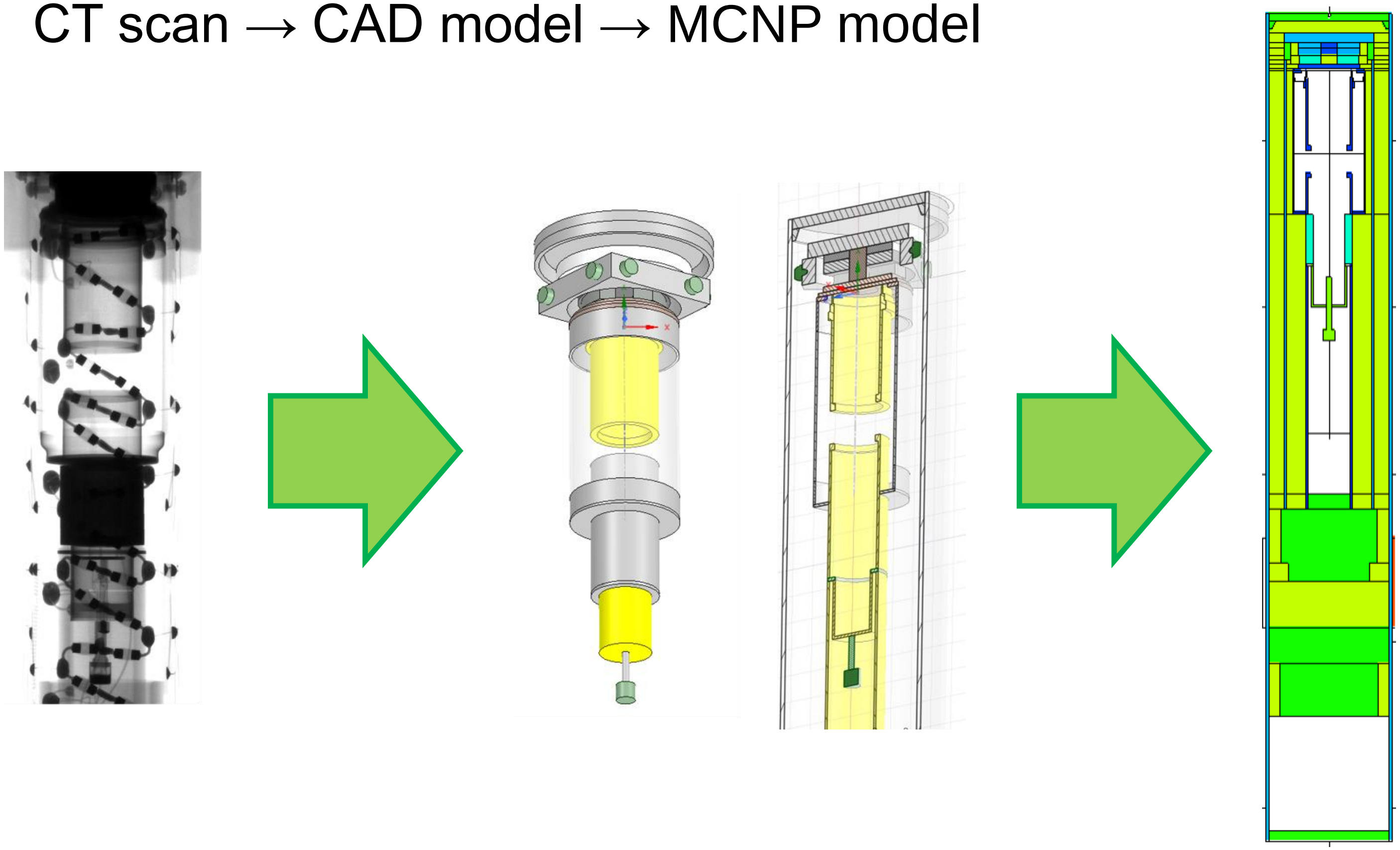
Ion beam	Cont. [%]
D^+	0.6
D_2^+	9.0
T^+	2.7
T_2^+	7.3
$D_1T_1^+$	80.4

[4] A. Čufar et al.

DD and TT contribute approximately 1 % and can be neglected

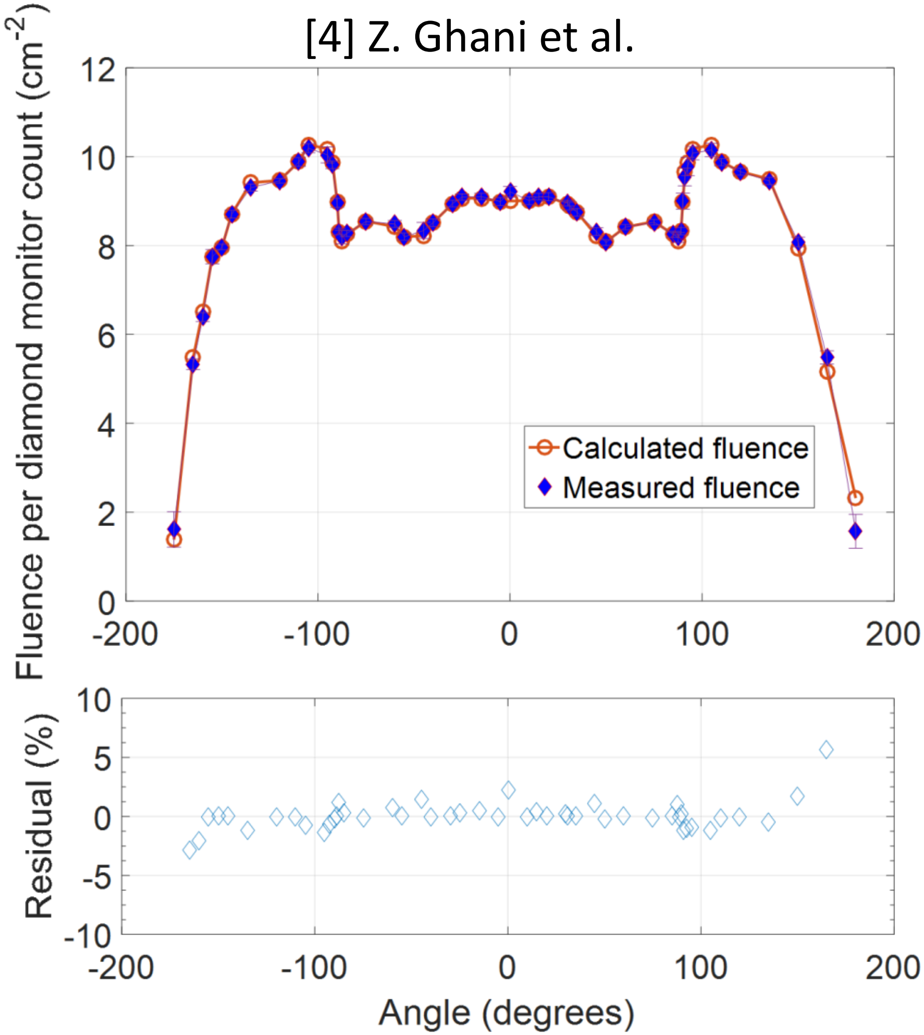
Calibration neutron sources

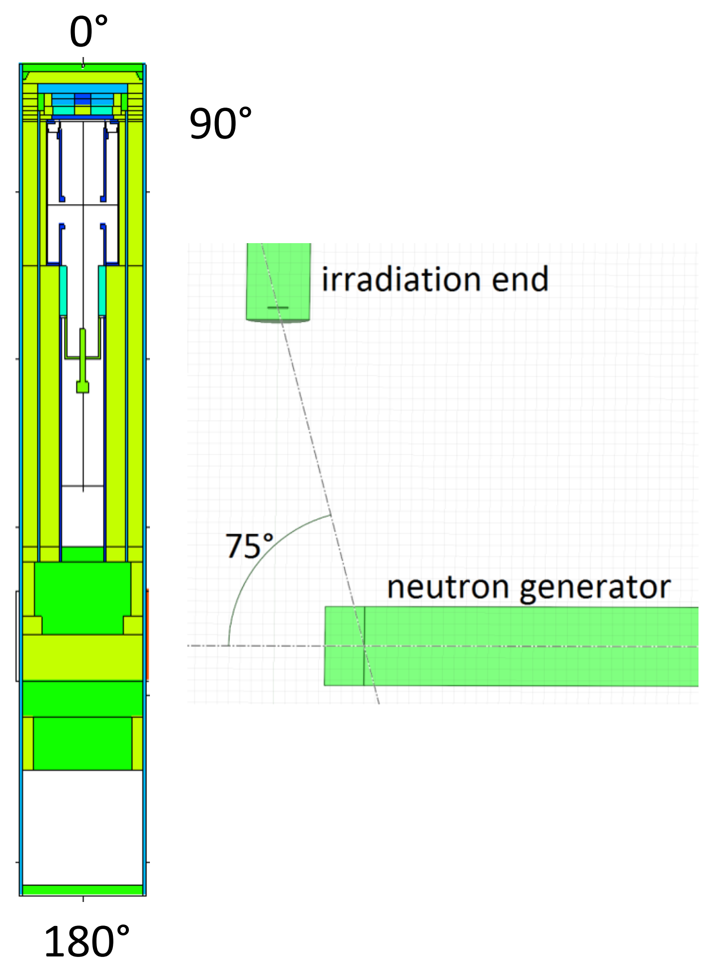
- Detailed model of the neutron generator
  - CT scan → CAD model → MCNP model



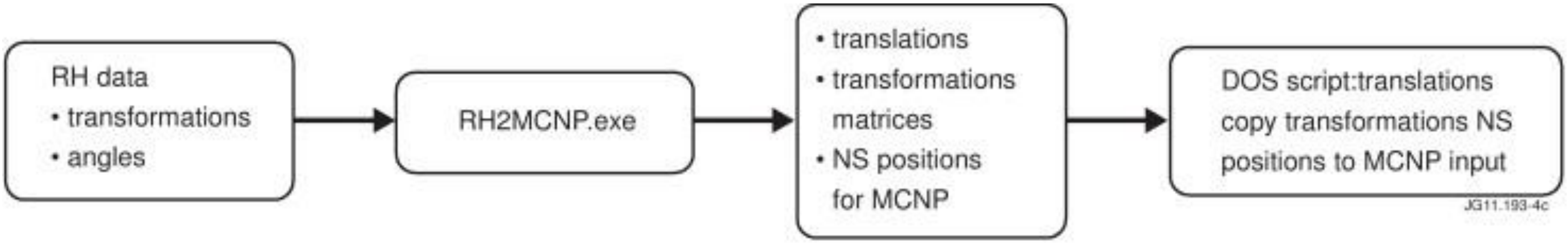
Calibration neutron sources

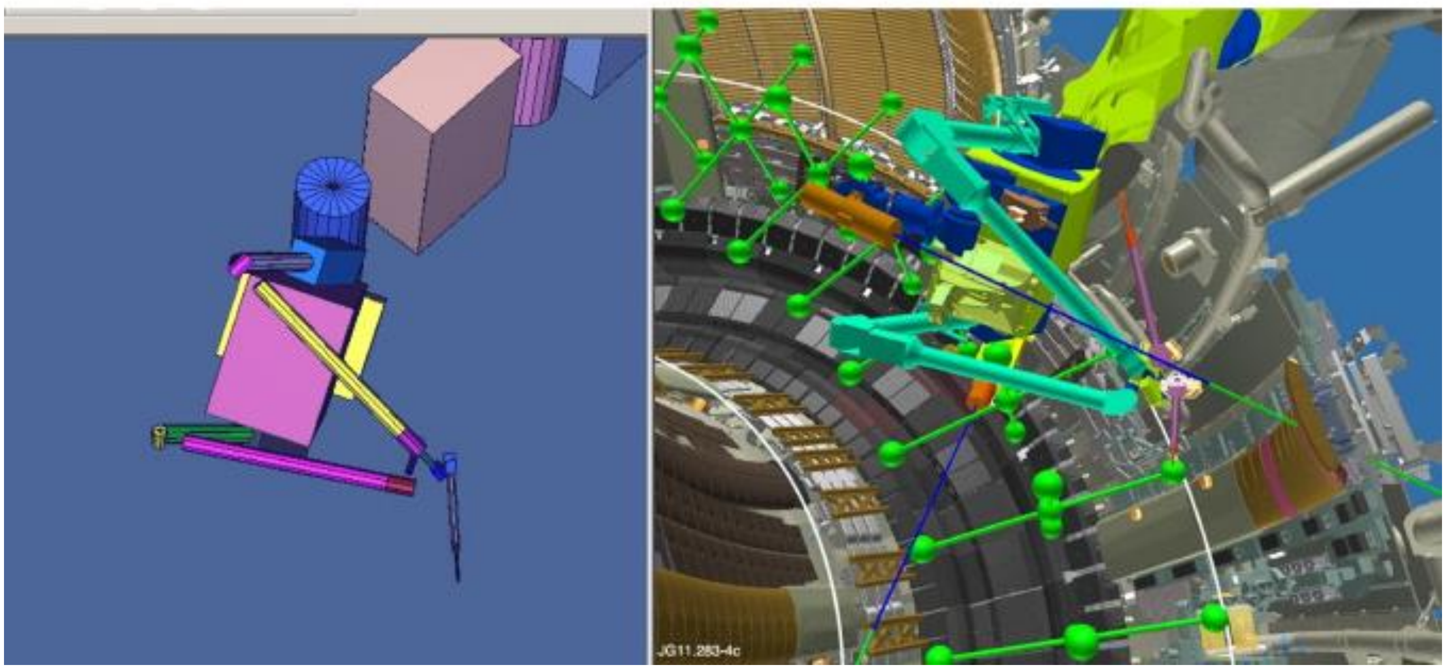
- Neutron generator – measurements vs simulations





Remote handling system



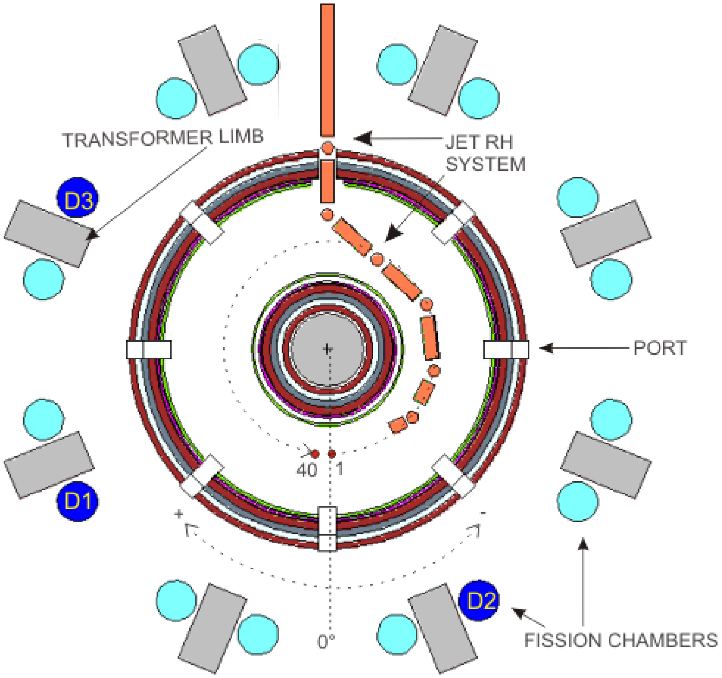


Simulations in support of the calibration – fission chambers

„Ring integral“ = response to a ring of point sources

- Measured ring integral
- Corrections
  - Uncharacteristic geometry (C_{RHS})
    - Effect of the RHS
    - Reactor configuration
  - Differences in neutron source (C_{SRC})
    - Ring vs plasma
    - Difference in neutron energy

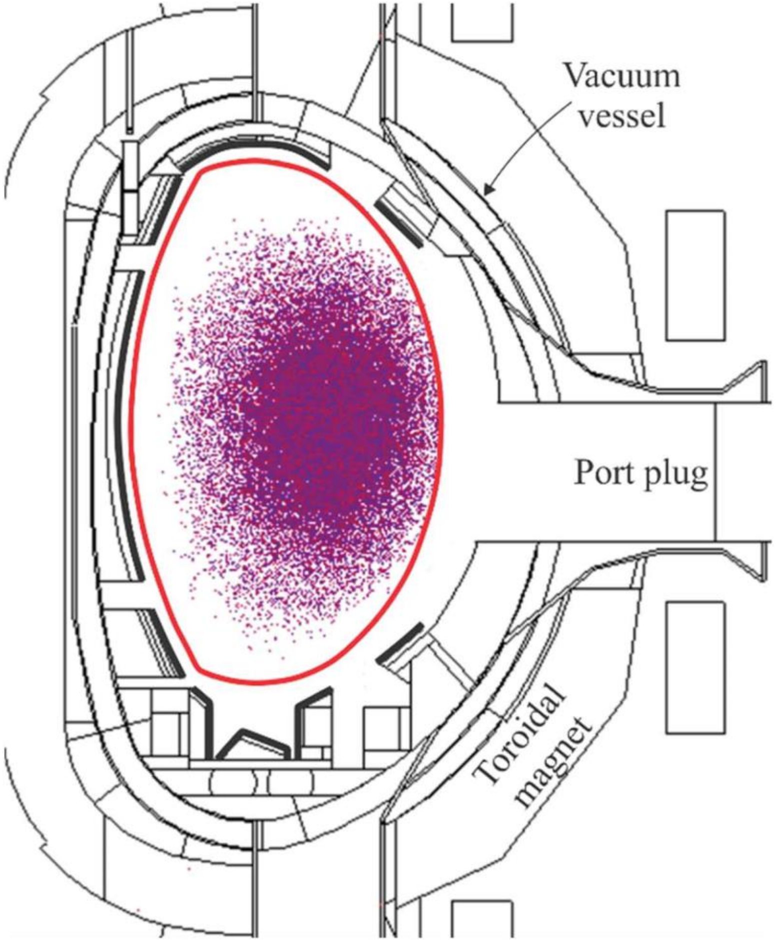
[6] A. Čufar et al.



Plasma neutron source

- Simple plasma source description
- “Representative” plasma

- Later more detailed source description was developed
  - More on this by Andrej Žohar et al.



Simulations in support of the calibration – fission chambers

„Ring integral“ = response to a ring of point sources

- Measured ring integral
- Corrections
  - Uncharacteristic geometry (C_{RHS})
  - Differences in neutron source (C_{SRC})

Detector response [counts/n]:

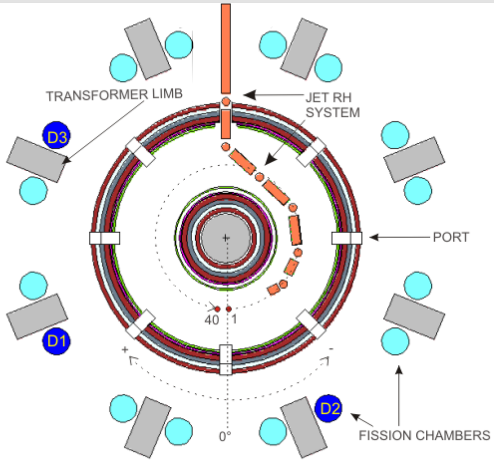
$$P_{plasma} = P_{ring\ measurement} \times C_{RHS} \times C_{SRC}$$

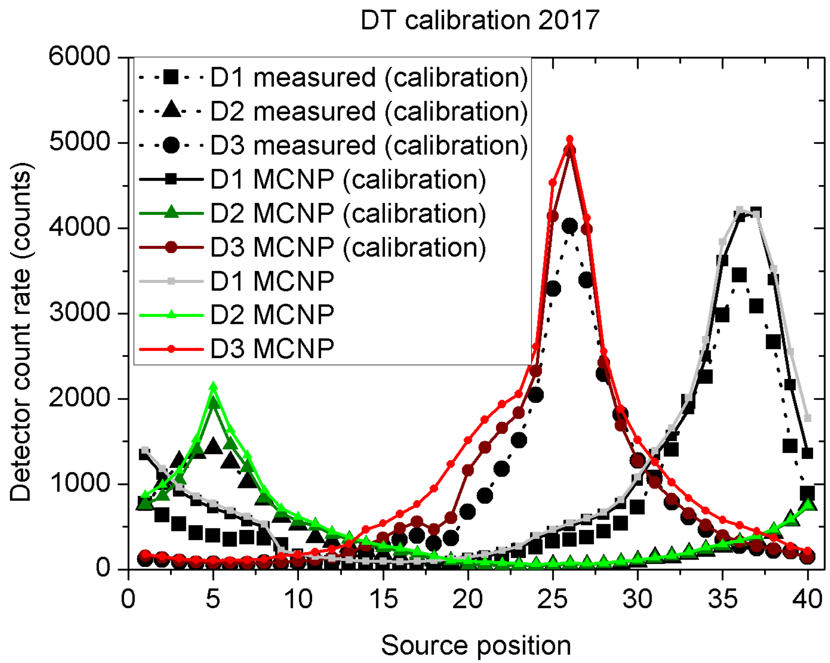
Calibration factor [n/count]:

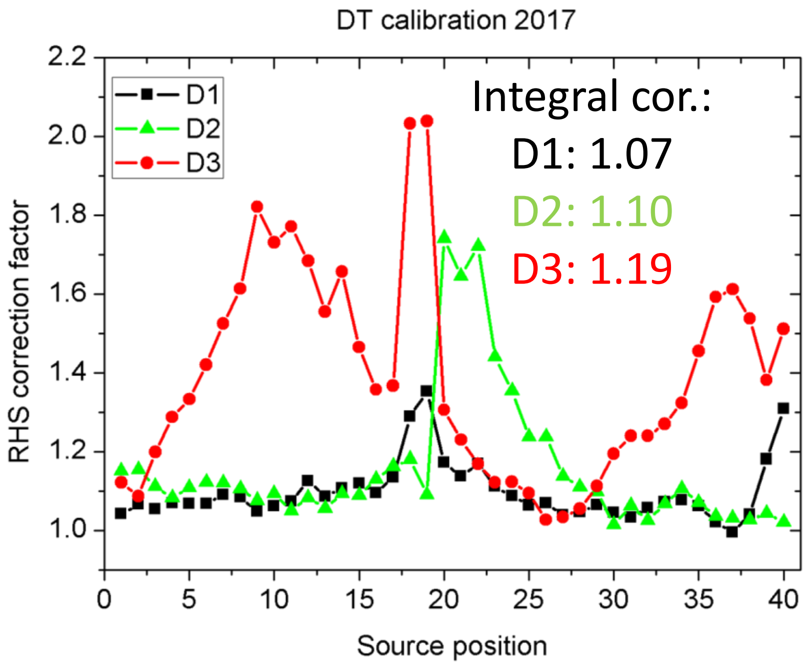
$$F_{plasma} = F_{ring\ measurement} \times \frac{1}{C_{RHS}} \times \frac{1}{C_{SRC}}$$

Simulations in support of the DT calibration – fission chambers

$$C_{RHS} = \frac{MCNP}{MCNP\ (calibration)}$$

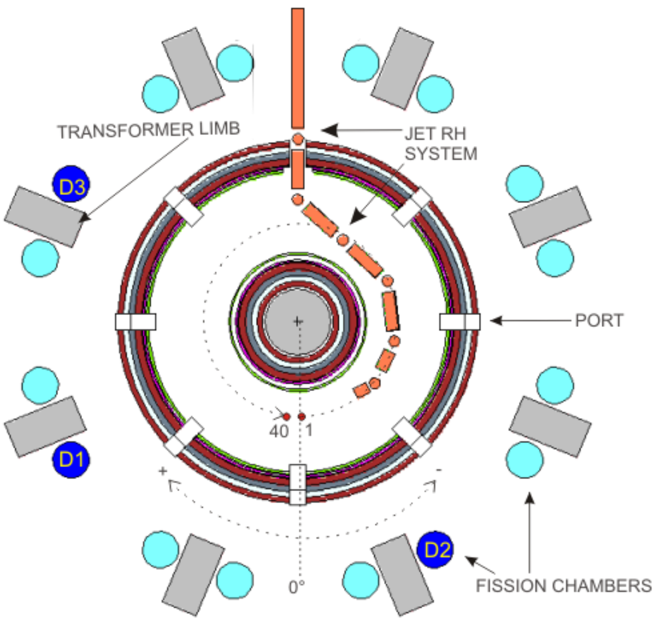






Simulations in support of the DT calibration – fission chambers

	D1	D2	D3
Measured ring integral [counts/n]	2.52×10^{-9}	1.37×10^{-9}	2.70×10^{-9}
C_{RHS}	1.07	1.10	1.19
C_{SRC}	0.98	1.00	1.00
$C_{total}=C_{RHS}\times C_{SRC}$	1.04	1.10	1.19
Calibration factor [n/count]	3.8×10^{8}	6.6×10^{8}	3.1×10^{8}



[7] P. Batistoni et al.
[8] A. Čufar et al.

Calibrations

- DD calibration experiment performed in 2013
  - Measurements from different detectors cross-validated in DD campaign – agreement within ±3%
- DT calibration experiment performed in 2017
  - To be cross-validated in the next DT campaign
- Uncertainty in both cases within ±10%
- Fission chamber (^{235}U) sensitivity to DD and DT neutrons roughly equal
- Further work includes modelling of realistic plasma neutron source (A. Žohar, later in the afternoon)

Lessons learned

- Simple models useful to understand physics
- Calibration within target ±10% achievable
- Machine time
  activation system < fission chambers
- Sensitivity to changes in reactor geometry
  activation system < fission chambers
- Geometrically simple irradiation end close to plasma is a valuable detector
- Scan for ex-vessel detector calibration valuable for model improvement/validation
- It is valuable to have multiple independent
  - Models
  - Calibration procedures

References

[1] L. Snoj et al., “Calculations to support JET neutron yield calibration: Contributions to the external neutron monitor responses,” Nuclear Engineering and Design, 246, (2012).

[2] P. Batistoni et al., “14 MeV Calibration of JET neutron detectors – Phase 1: calibration and characterization of the neutron source,“ Nuclear Fusion, 58, (2017).

[3] D. Rigamonti et al., “Neutron spectroscopy measurements of 14 MeV neutrons at unprecedented energy resolution and implications for deuterium–tritium fusion plasma diagnostics”, Meas. Sci. Technol. 29, (2018).

[4] A. Čufar et al., “Calculations to support JET neutron yield calibration: Modelling of neutron emission from a compact DT neutron generator,” NIMA, 847, (2017).

[5] Z. Ghani et al., “Characterisation of neutron generators and monitoring detectors for the in-vessel calibration of JET”, Fusion Engineering and Design, (2018), In press.

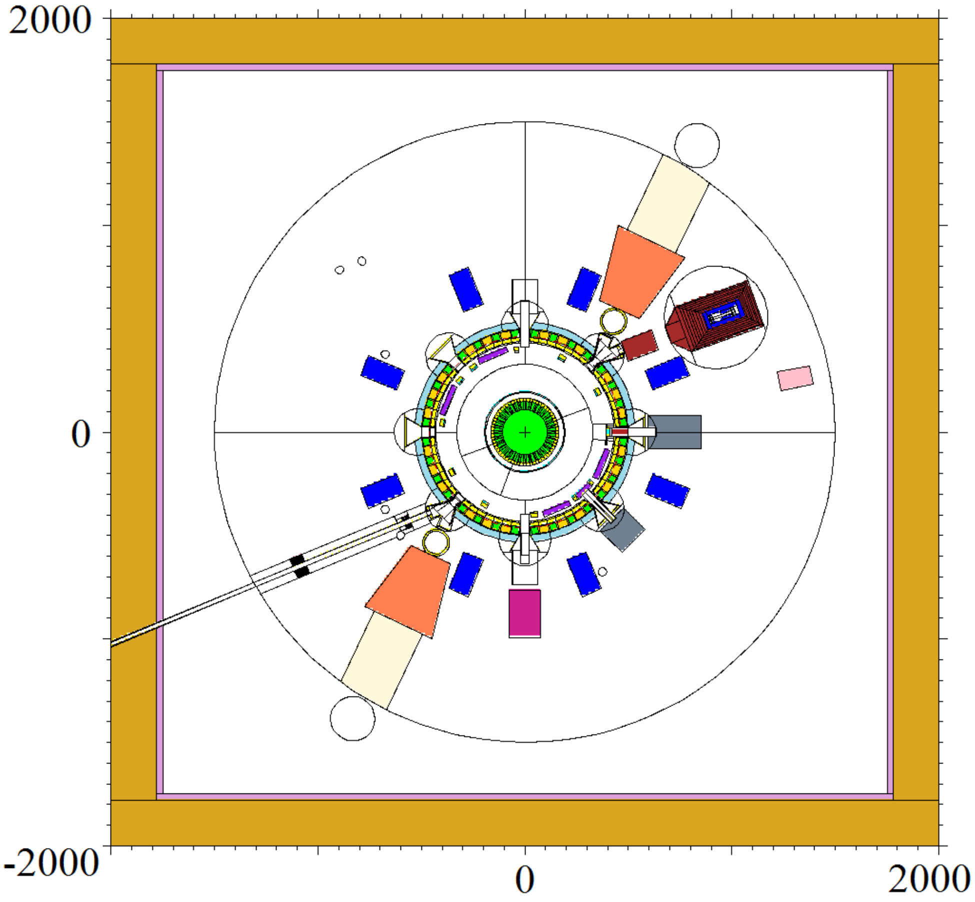
[6] A. Čufar et al., “Calculations to Support In Situ Neutron Yield Calibrations at the Joint European Torus”, Fusion Science and Technology, Special issue on fusion neutronics (2018), In press.

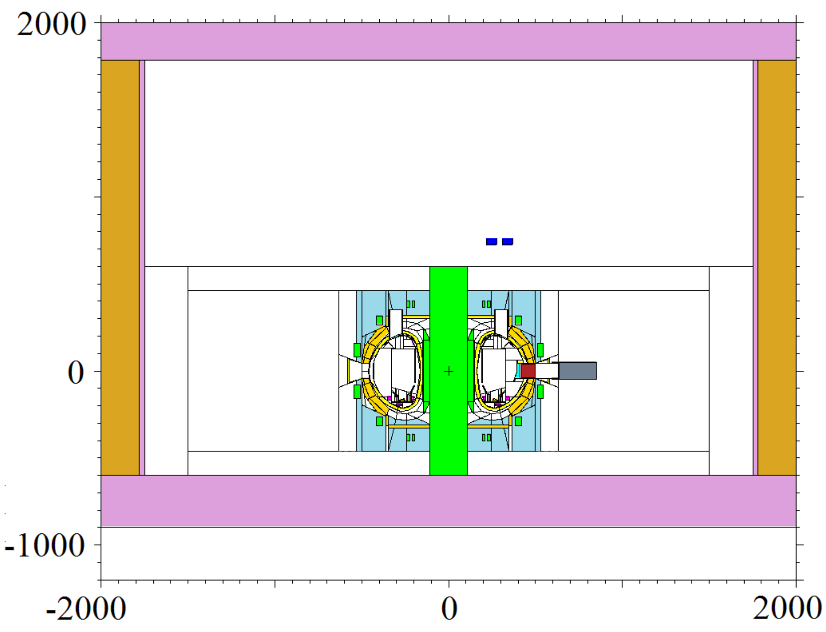
[7] P. Batistoni et al., “14 MeV calibration of JET neutron detectors – phase 2: in-vessel calibration“, Nuclear Fusion, 58, (2018).

[8] A. Čufar et al., “Calculations to Support In Situ Neutron Yield Calibrations at the Joint European Torus”, Fusion Science and Technology, 74, (2018).

Joint European Torus (JET)

- MCNP model





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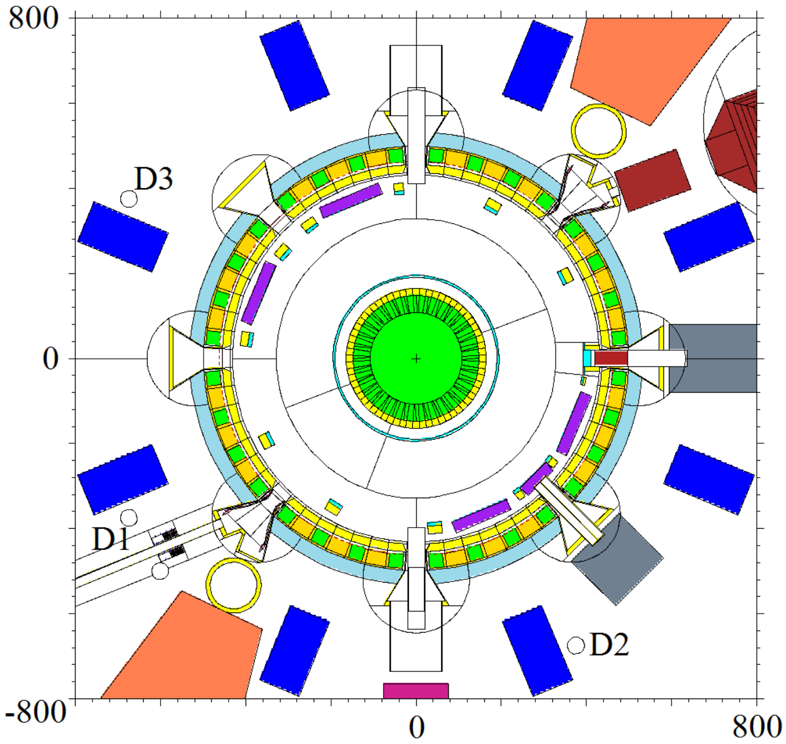

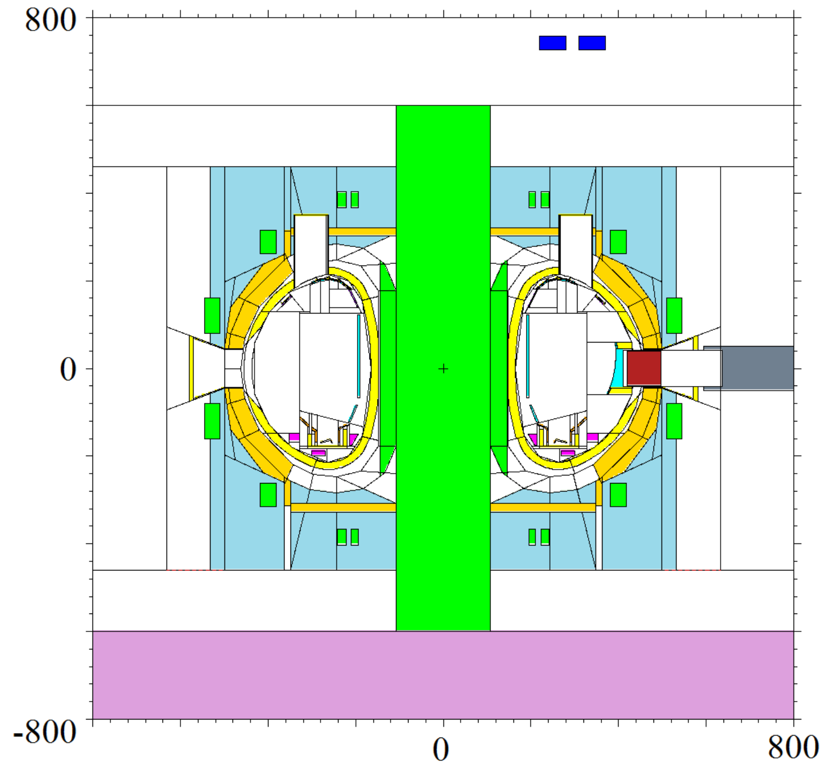

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