Max-Planck-Institut für Plasmaphysik

Calibration of neutron detectors at ASDEX Upgrade

Monika Koleva, Giovanni Tardini, Hartmut Zohm, Simppa Äkäslompolo, Jaakko Leppänen, Vitali Brack, Bernadett Wiringer, Wolfgang Zeidner

MAX PLANCK GESELLSCHAFT

EUROfusion

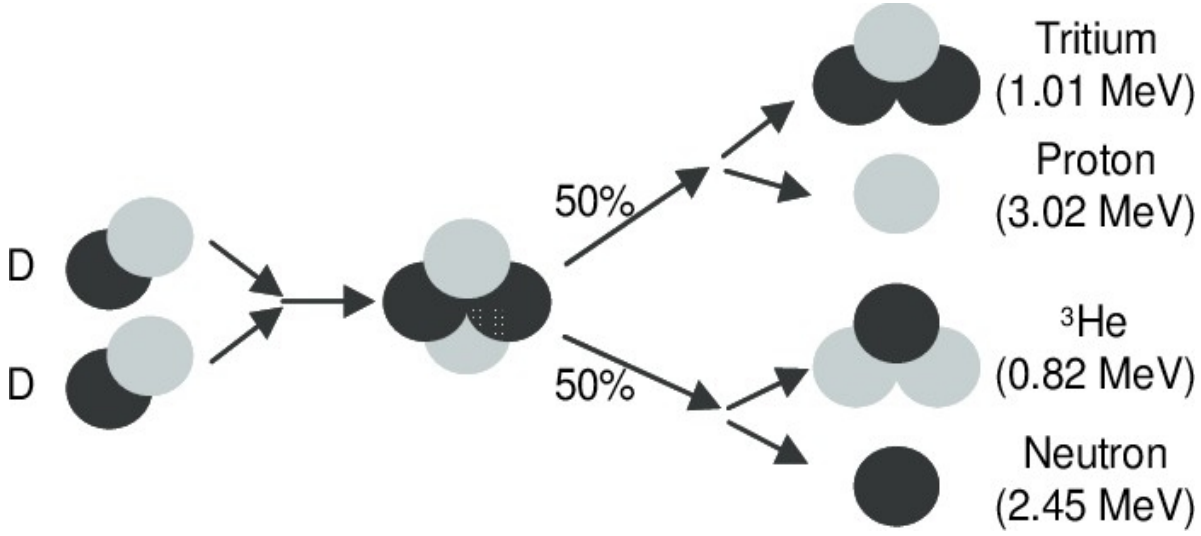
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Outline

- **Background**
  - Neutron production in ASDEX Upgrade
- **Calibration set-up**
  - Epithermal neutron diagnostics (END)
  - Overview and results
- **Monte Carlo simulation with Serpent code**
  - Geometry implementation
  - Material input
  - Point source results
- **Summary**

Background

Neutron production in ASDEX Upgrade



Tritium burn-up

$$D + T \longrightarrow {}^{4}_{2}He\ (3.5\ MeV) + {}^{1}_{0}n\ (14\ MeV)$$

Neutron rate (NR)

Present day machines

- Indicates plasma performance
- ASDEX Upgrade neutrons (3 populations)
  - Beam-target (NBI)
  - Thermal
  - Beam-Beam (NBI)
- Used to study fast particle dynamics (TRANSP/NUBEAM/RABBIT codes)

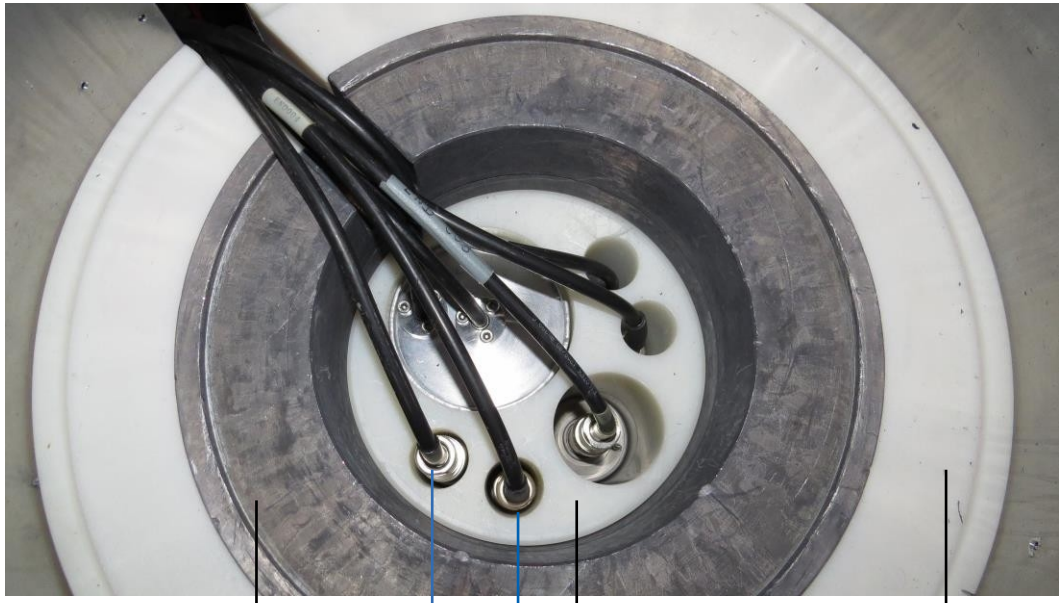
Future power plants

- Fusion power (control)
- Sustaining the fuel cycle (Li blanket walls)

Outline

- ✓ **Background**
  - ✓ Neutron production in ASDEX Upgrade
- **<u>Calibration set-up</u>**
  - Epithermal neutron diagnostics (END)
  - Overview and results
- **Monte Carlo simulation with Serpent code**
  - Geometry implementation
  - Material input
  - Point source results
- **Summary**

Epithermal neutron diagnostics (END)



Lead (gamma blocking)

^{3}He detectors

Polyethylene moderator

D-D neutrons are slowed down to thermal energies (0.025 – 0.4 eV) using a polyethylene moderator

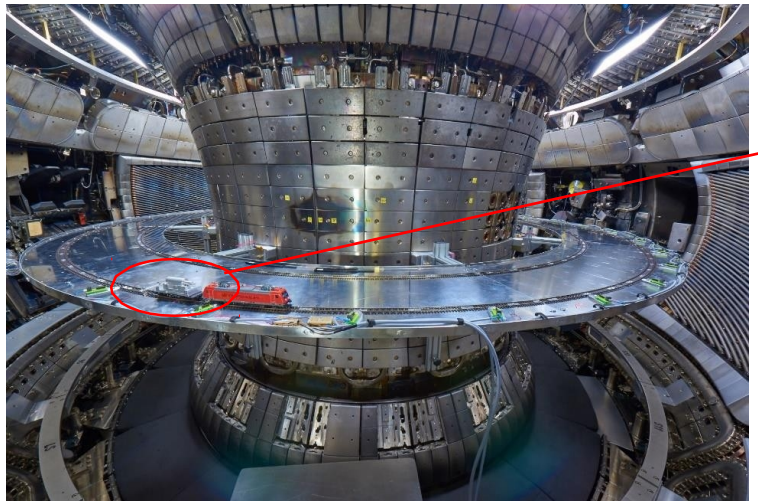
Detectors must be unresponsive to gamma emissions

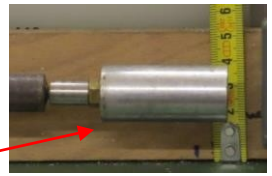
Gamma rays are blocked by a layer of lead

^{3}He detectors work through (n,p) reactions

$$^3He + {}^1n\ (thermal) \rightarrow {}^1H + {}^3H + 764\ keV$$

Calibration set-up



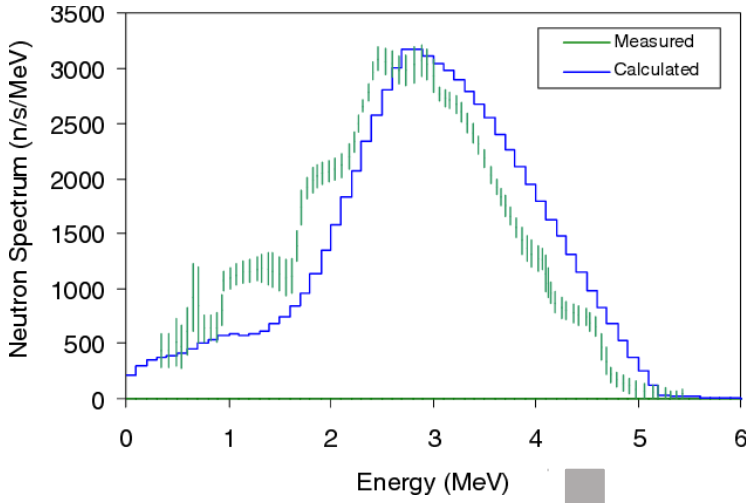


^{238}Pu/B

Works through (α, n) reactions

α-particles released by ^{238}Pu irradiate the Bor capsule thus emitting neutrons

Ian C Gauld, Robert Perry, "New neutron source algorithms in the ORIGEN-S code"

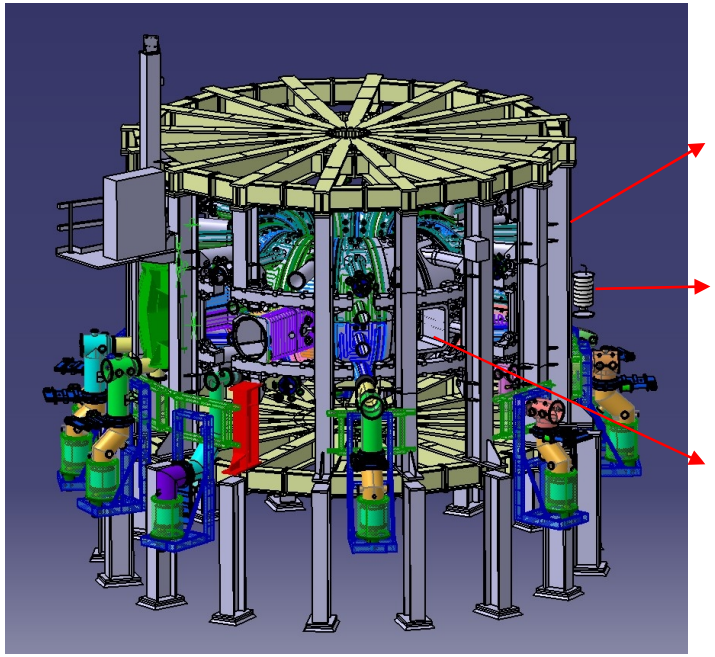


Toy train carrying radioactive source (^{238}Pu/B)

Two poloidal positions (inner/outer tracks)

Continuous calibration (1 weekend)

Easily reproducible



Support structure

Detector

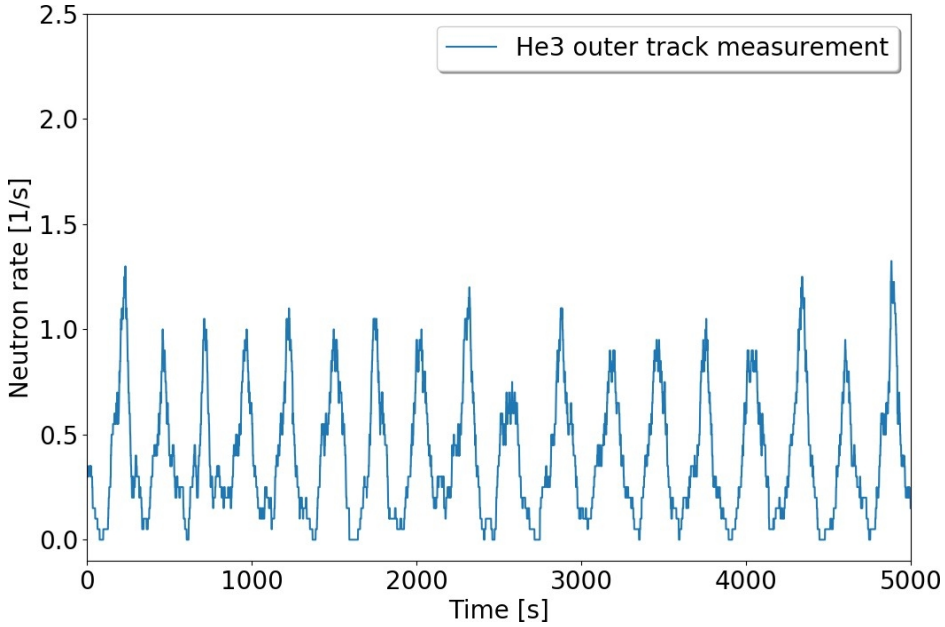
Vacuum vessel

Measured and calculated Pu/B spectrum (work by Ian C Gauld, Robert Perry) show a maximum between 2.7 and 3 MeV

In agreement with AUG data sheet (source peaked at 2.8 MeV emitting 6.10^6 n/s)

Results

Toy train measurement



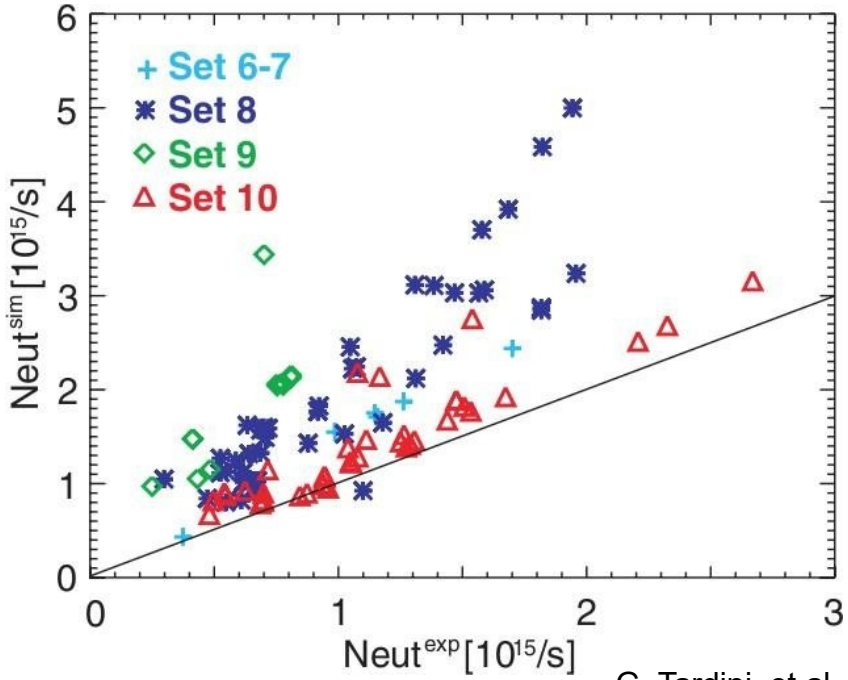
Periodical ^{3}He NR (toroidal train movement)

Average NR roughly 0.5 n/s

Longer calibration time

Better statistics

Previous calibrations



G. Tardini, et al, Simulation of the neutron rate in ASDEX Upgrade H-mode discharges

TRANSP/exp comparisons used for calibration error estimations

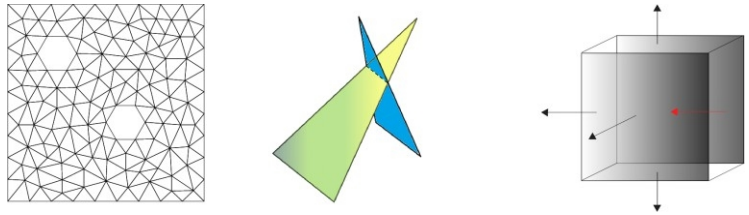
Calibrations done using fixed source positions

Outline

- ✓ **Background**
  - ✓ Neutron production in ASDEX Upgrade
- ✓ **Calibration set-up**
  - ✓ Epithermal neutron diagnostics (END)
  - ✓ Overview and results
- **<u>Monte Carlo simulation with Serpent code</u>**
  - Geometry implementation
  - Material input
  - Point source results
- **Summary**

Monte Carlo simulation with Serpent code

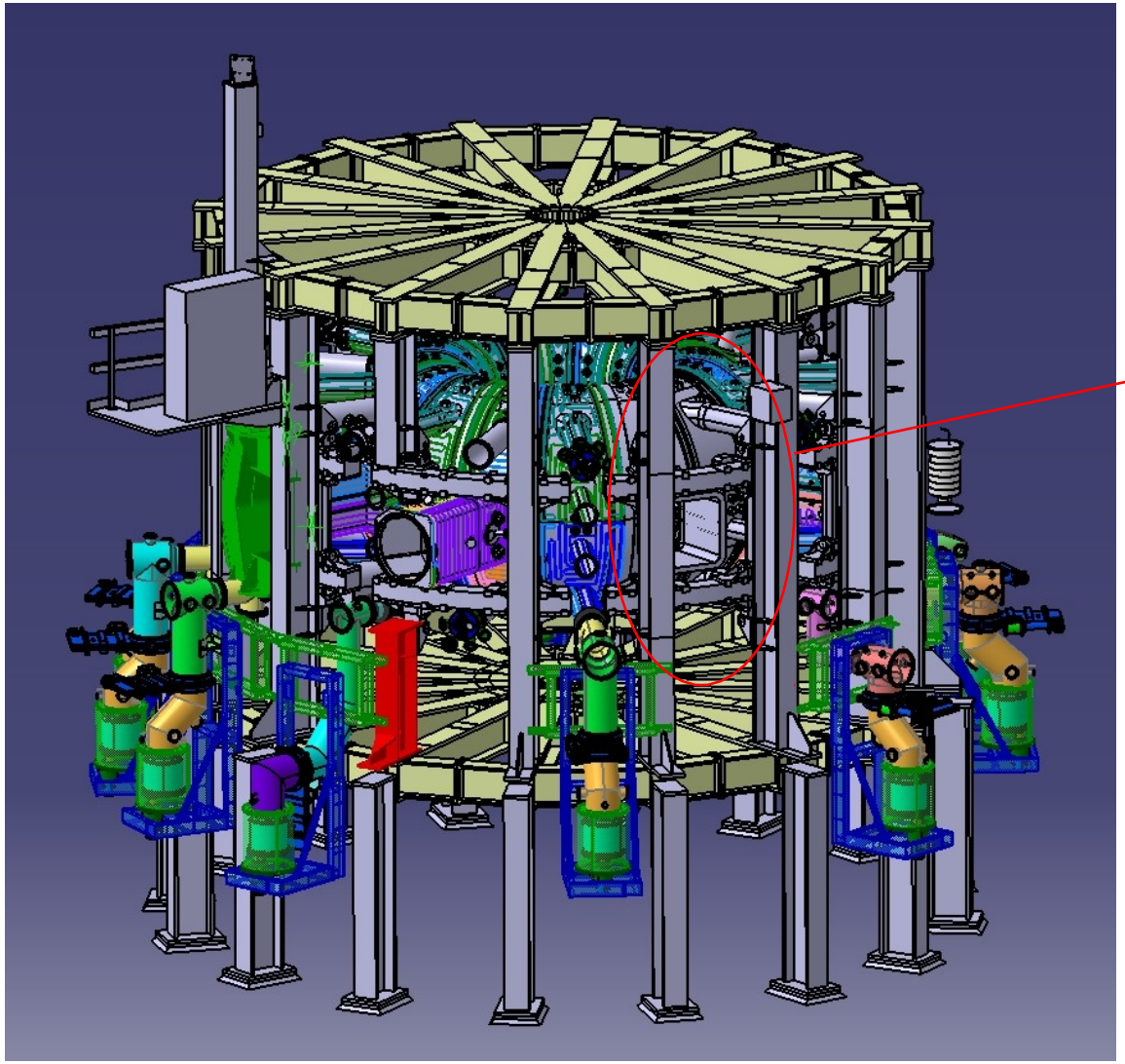
- **Geometry implementation**
  - Using stereolithography (STL) files (convenient for tokamak and stellarator geometries)
  - Whole ASDEX Upgrade, detectors and detector chamber were decomposed into smaller parts
  - Unresolved STL mesh errors can lead to poor simulation (can be checked in Serpent/the simulation might even terminate)

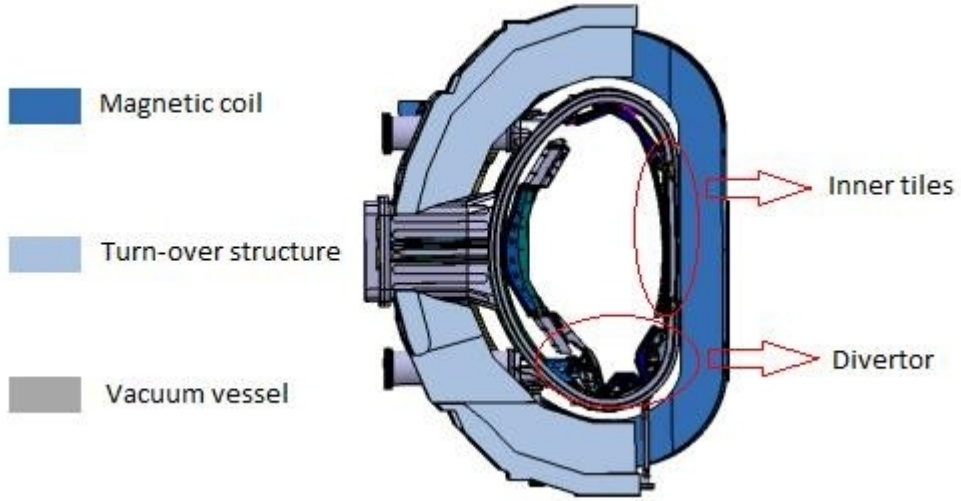


STL errors, from left to right:
holes, overlapping triangles, inverted normals

- **Material compositions**
  - Densities of components are documented and easily accessible from open web sources
  - Mass fractions of constituent nuclides additionally calculated
  - ^{3}He gas density is calculated using ideal gas law

ASDEX Upgrade decomposition

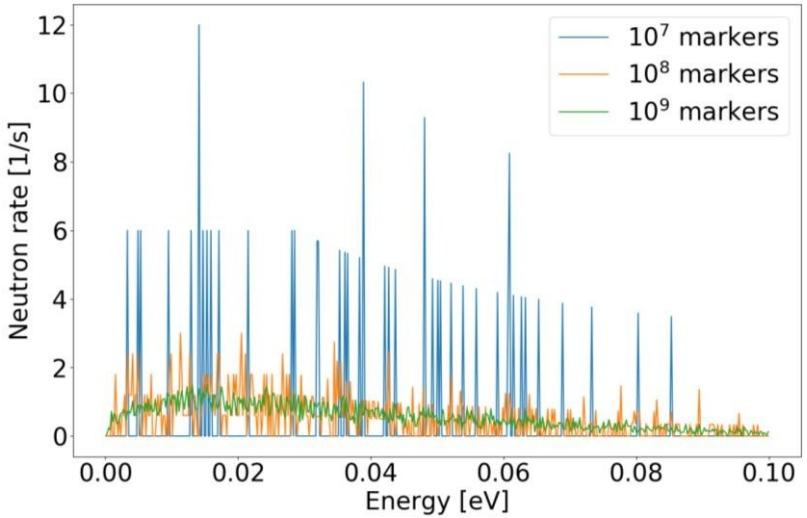


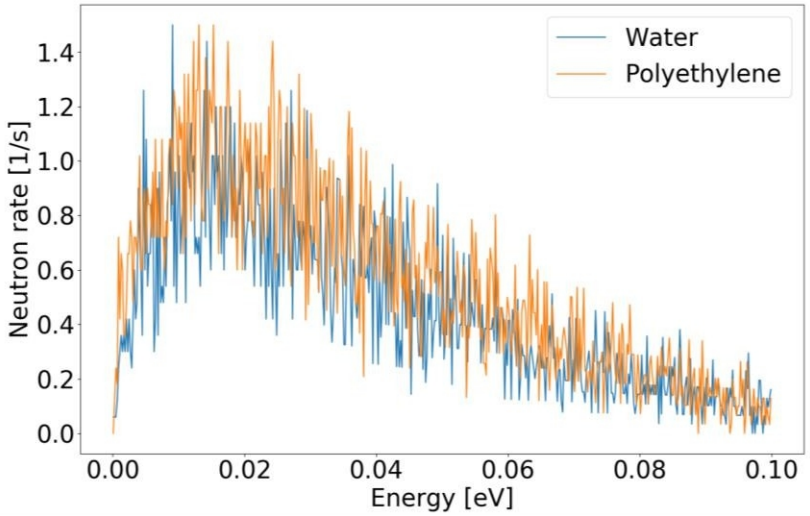


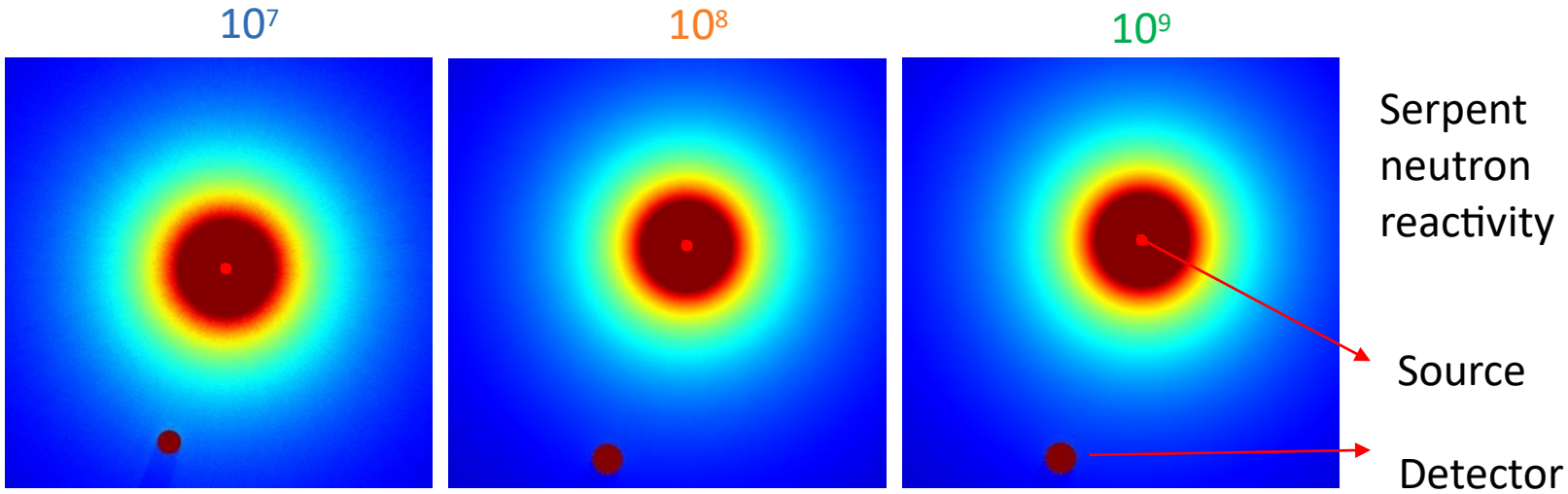
Hundreds of thousands of components

Different materials Fixing STL errors

Monte Carlo convergence





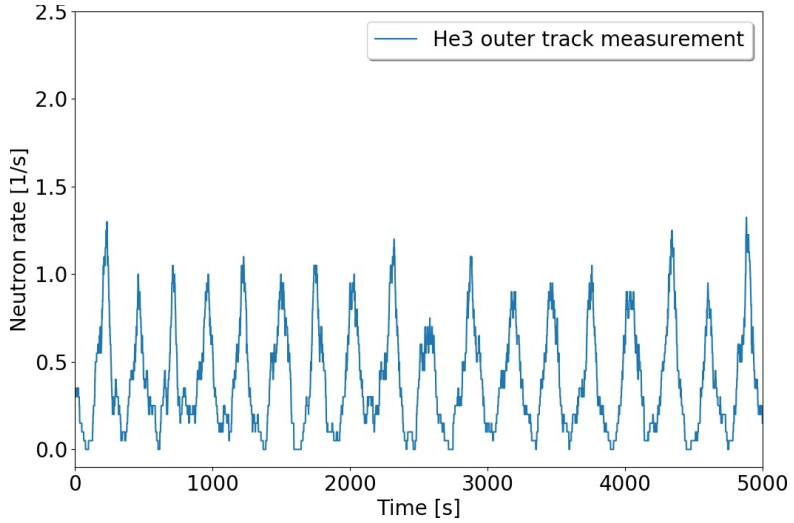


- Using point source of 3 MeV and a detector box
- Including microscopic RR (n,p) detector and converting to macroscopic using the gas atomic density
- Good convergence using 10^9 particles
- Run time varies with particle number and geometry components
- No significant difference between polyethylene and water (hydrogen is the bound scatterer in both)

Simulation results

Measurement 1: Toy train

Experiment

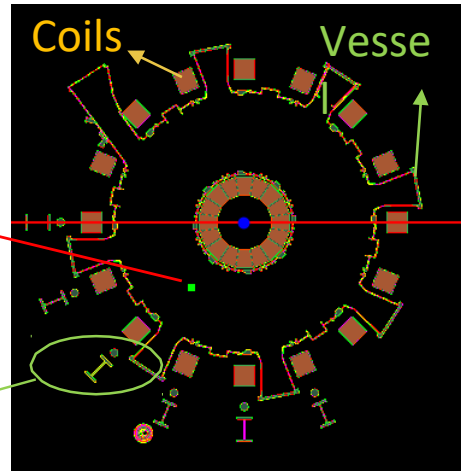


Simulation

Components	NR [n/s]
Vacuum	114.485
Sector 11	55.295
Sectors 9 and 11	57.098
All sectors	88.269
All sectors and coils	93.267
All sectors, coils and support structure	108.341

Gradually increasing with adding up components

AUG top view



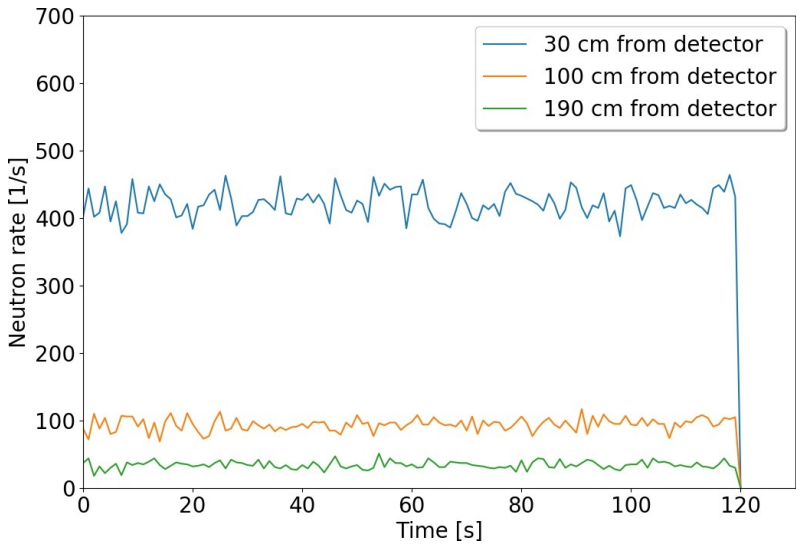
Support structure

- Simulations are performed using a point source on outer track position
- Important to have a detailed model
- Discrepancy factor reaches 100
- NR depends on included components (scattering)

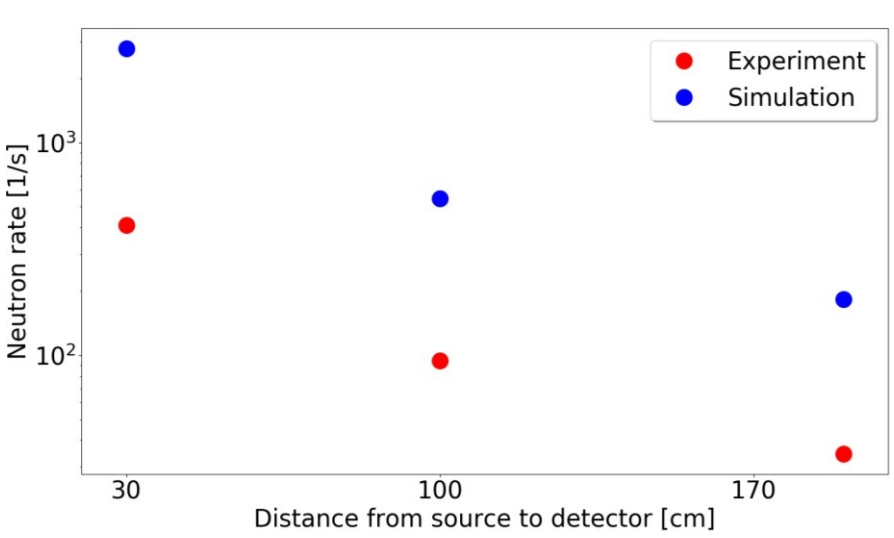
Simulation results

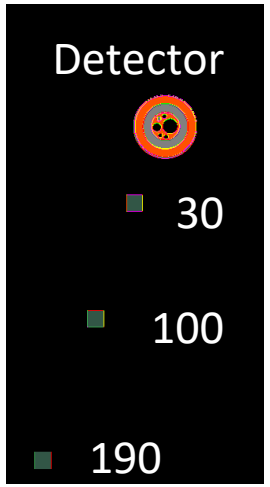
Measurement 2: Source outside vessel

Experiment



Simulation

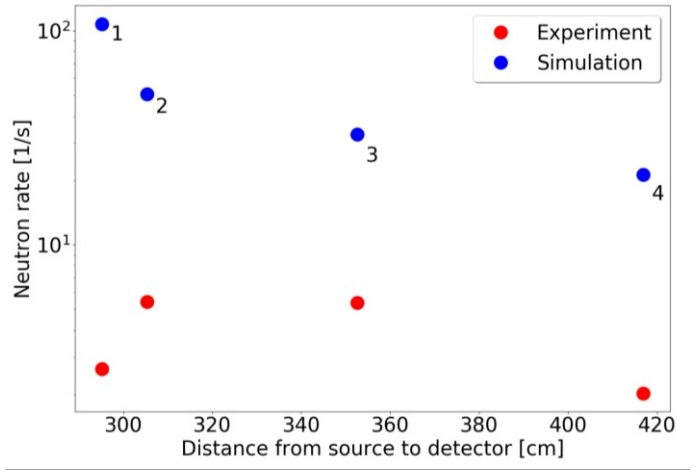


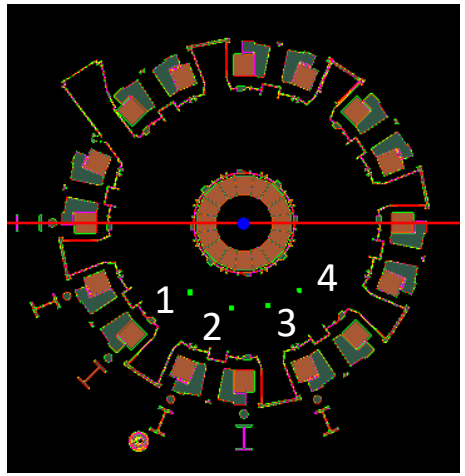


- Neutron source outside of torus on 3 different positions close to detector
- NR drops down as expected moving away from detector box
- Discrepancy factor is consistent for all three positions (≅ 6)

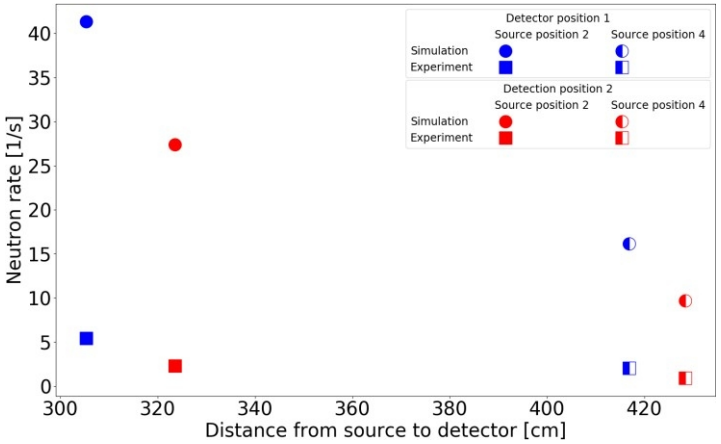
Simulation results

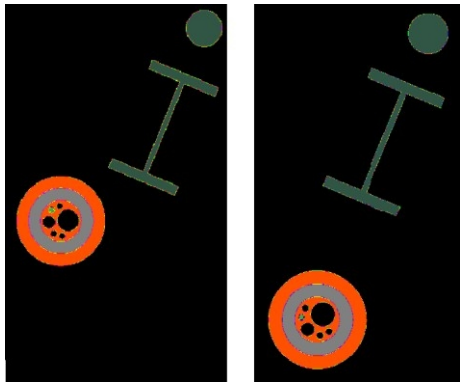
Measurement 3: Source inside vessel, fixed source positions





Serpent geometry



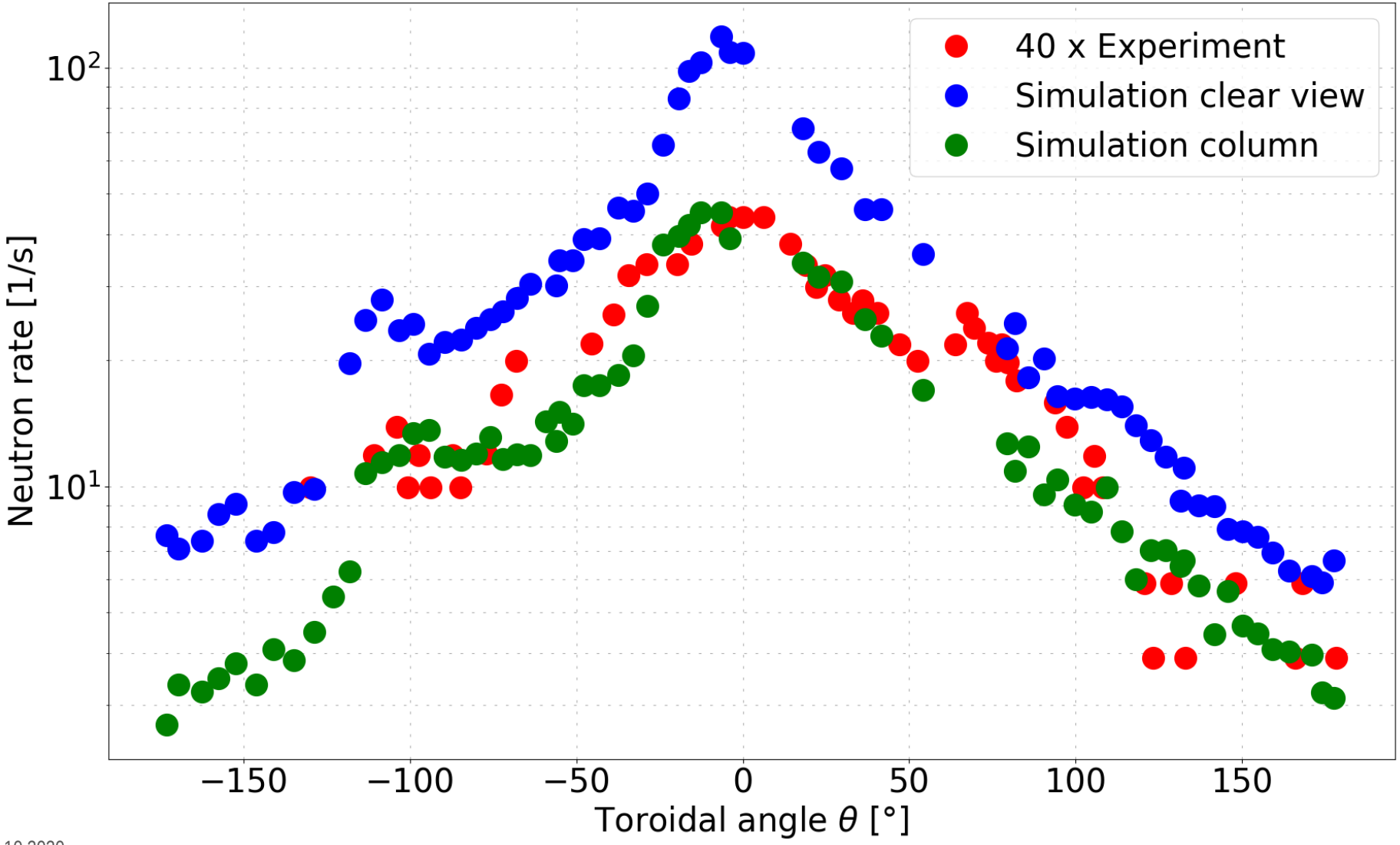


Detector position 1 Detector position 2

- Roughly consistent discrepancy factor for positions 2-4 (between 6 and 10)
- The factor is larger for position 1 (roughly 40)
- Possible explanation is a missing component on the way to the detector

- Support structure blocks neutrons for detector orientation and position 2
- Discrepancy factor varies with detector orientation (smaller/bigger moderator fraction)

Simulation results



Outline

- ✓ **Background**
  - ✓ Neutron production in ASDEX Upgrade
- ✓ **Calibration set-up**
  - ✓ Epithermal neutron diagnostics (END)
  - ✓ Overview and results
- ✓ **Monte Carlo simulation with Serpent code**
  - ✓ Geometry implementation
  - ✓ Material input
  - ✓ Point source results
- **<u>Summary and conclusions</u>**

Summary and conclusions

- Comparison using MC code Serpent showed large NR sensitivity with adding up components
- So far no absolute consistency between measurement and simulation (reasons under investigation/possible missing degree of details)
- Second NR measurement next to the detector (outside torus) showed a consistent factor of about 6 between experiment and simulation
- Third measurement for 4 positions inside torus shows a roughly consistent factor for source positions 2-4 (between 6 and 10) and a bigger discrepancy for position 1 (around 40) possibly due to missing component
- Results are sensitive to precise detector position and orientation (smaller/bigger moderator fraction)
- Code can be used to estimate relative changes
- Absolute NR value not yet confirmed

Way forward

- Investigation of the discrepancy factor (100 → 6)
- Possibly assigning a consistent factor
- Able to simulate plasma neutron sources and provide neutron map in AUG hall
- Use it for various physics applications (neutron loads on plasma diagnostics – important for electronics preservation)