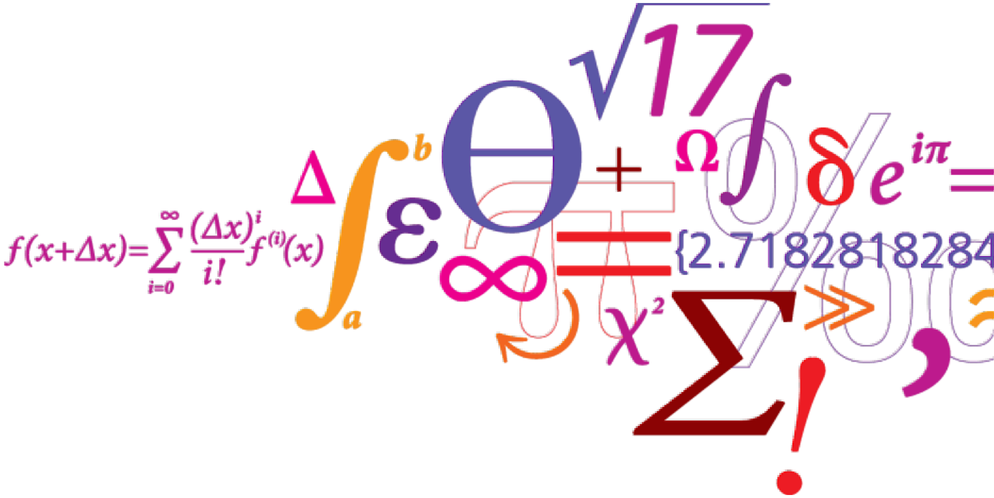
ESS Target Diagnostic Imaging System

6th October, 2016 - TAC 14

ESS, Lund



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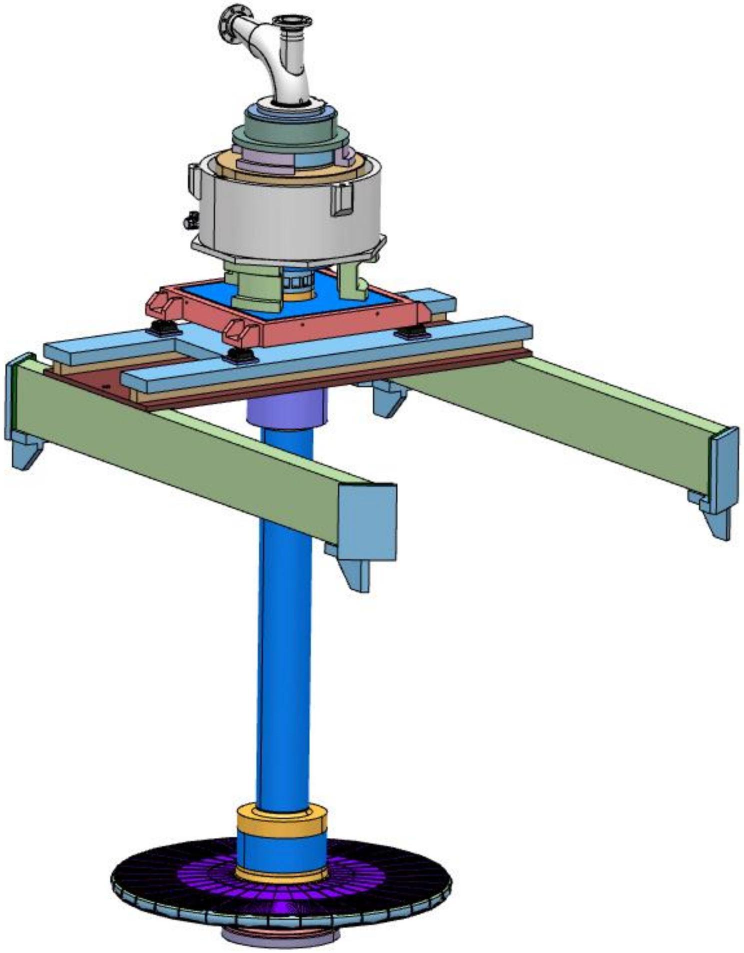
Outline

- Motivation
- Method
- Geometry and proposed realization
- MCNPX Simulation and CINDER '90 Activity calculations
- Issues and solutions
- Next steps

Motivation



The ESS Target Wheel…

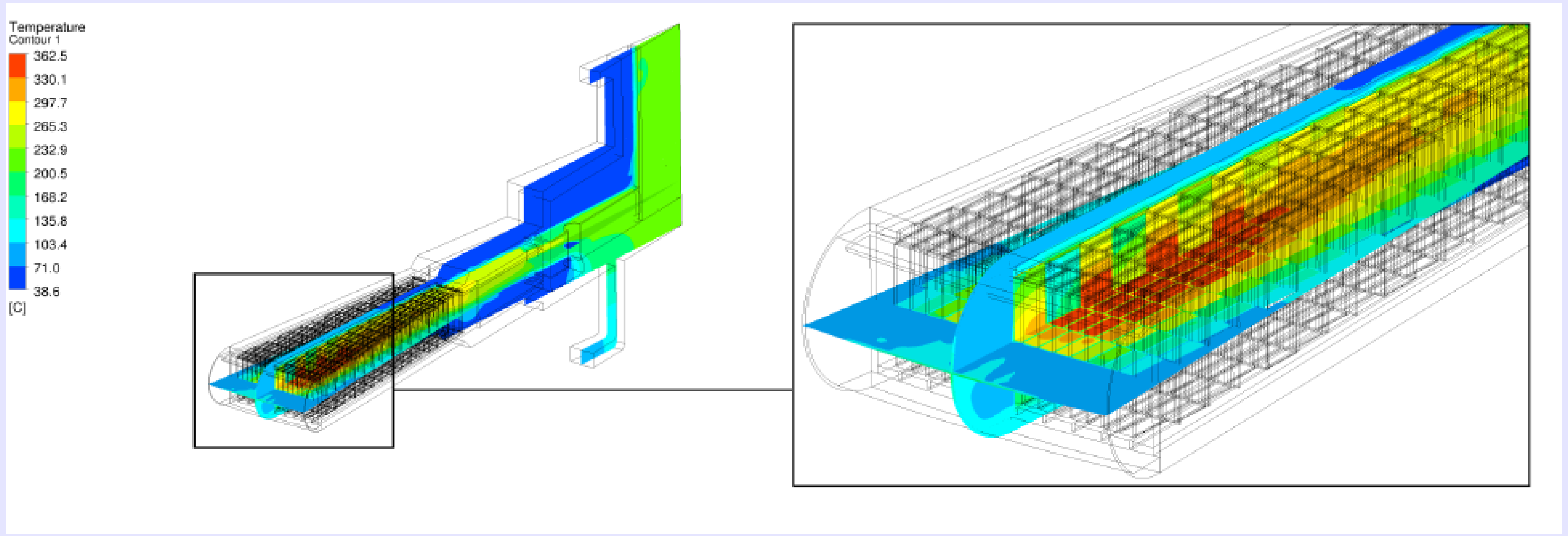
- 2.5 m diameter
- suspended on a 6 m long shaft
- 36 sectors of 10° each
- 7000 tungsten bricks (3 tons)
- 3000 tons of shielding steel around

…will operate in extreme conditions

- 3 MW heat deposit from 5 MW proton beam
- 2.86 ms long proton pulses with 4% duty cycle
- 7 million 100° C thermal cycles per year

Motivation

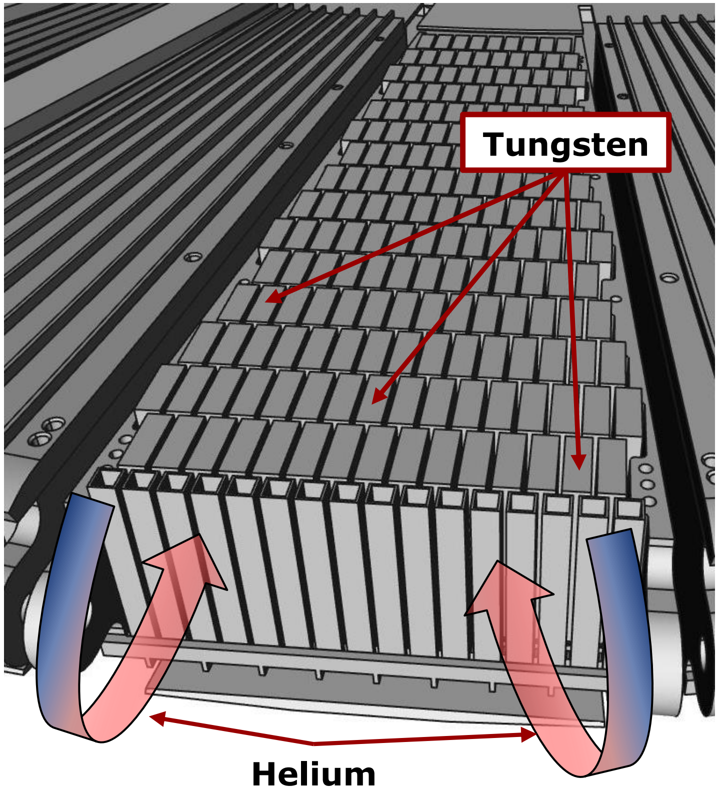
The cooling helium, **flowing at 3 kg/s**, will handle the **3 MW heat deposit**, resulting in a **200° C thermal gradient** between the hotspot and the center of the wheel.



Motivation

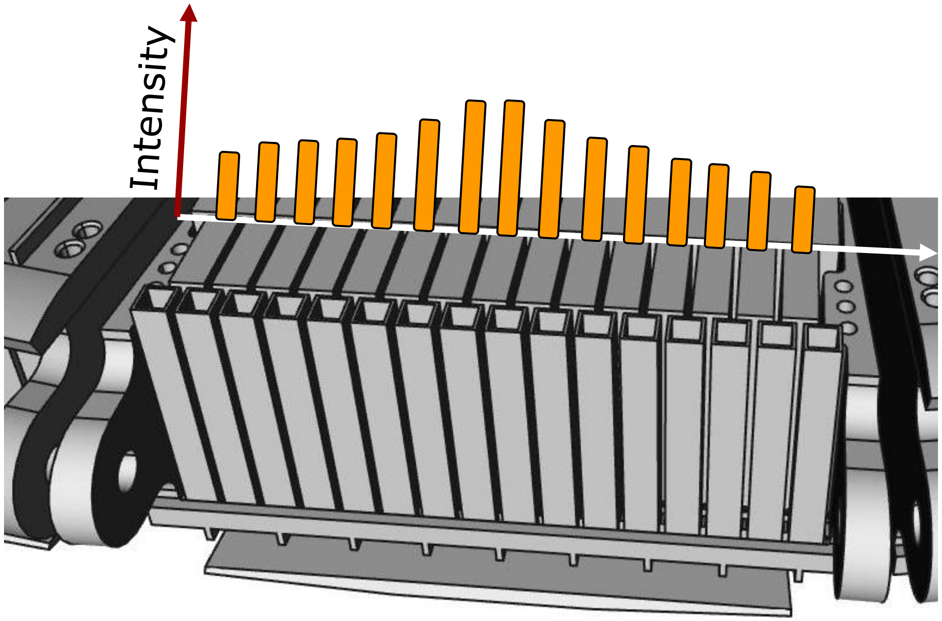
Tungsten bricks operate in a **brittle regime** after exposure to low doses of radiation

- Conditions may induce tungsten **cracking** or crack **propagation**
- Cracks could result in **cleaving** of the tungsten bricks
- Local reconfiguration may result in **local blocking** of the coolant channels
- **Thermal and pressure stresses** may not be relieved



Crucial to know from an operations perspective if the tungsten geometry is preserved over the 5 years of expected life of a target wheel

Method



The **hadrons** cause high levels of **activation** in the tungsten and, therefore, result in a large number of **decay gammas**.

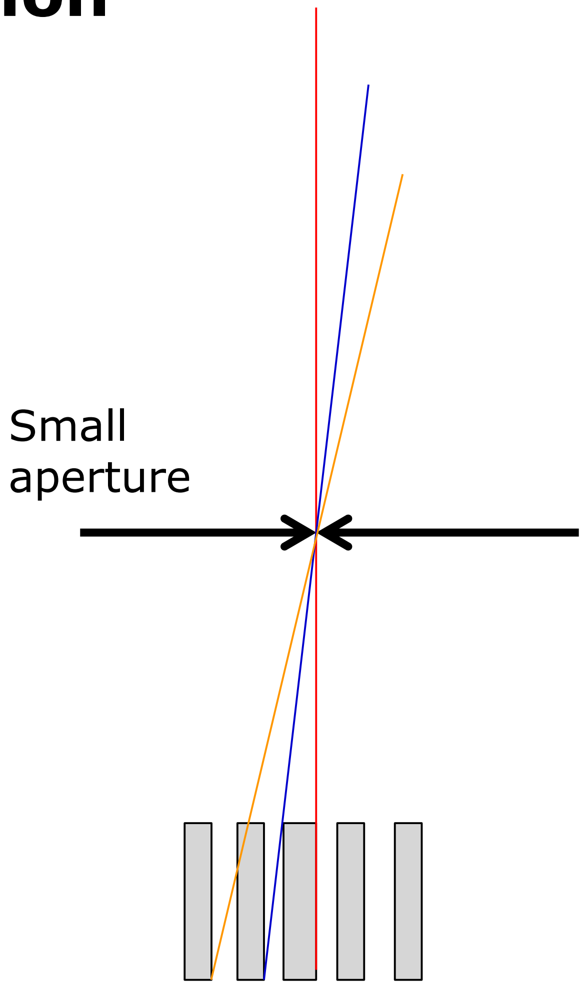
Within one sector, these gammas are emitted mainly by the **Tungsten bricks** and not by the Helium within the gaps.

Their **spatial distribution** can be imaged through the target vessel

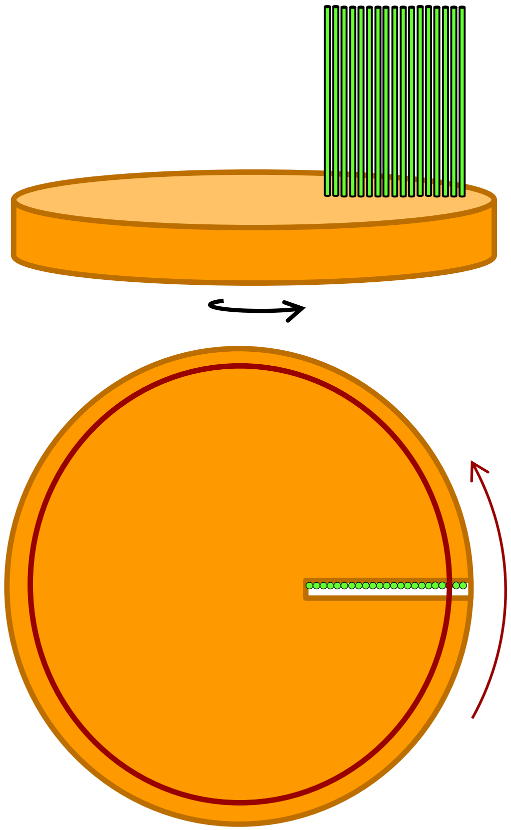
An image of the target **inner structure** can be reconstructed and used to ensure the **correct operation conditions**.

Geometry and proposed realization

- Bricks are **small**: 1x3x8 cm^3
- The **brick spacing** is only **2 mm** wide
- **High spatial resolution** (1 mm) is therefore required
- Brick height is large compared to the spacing and this results in **self-shadowing** of the blocks
- To **reduce smearing** and image quality loss, severe **angular collimation** is needed by means of a small aperture
- To attenuate the large gamma background, the **collimator** must also provide **shielding**



Geometry and proposed realization



A **2m-high** steel block suspended over the wheel with a **row of small grooves (1x1 mm^2)** spanning the entire radius is capable of providing both **attenuation** of the decay gamma background and **angular collimation**:

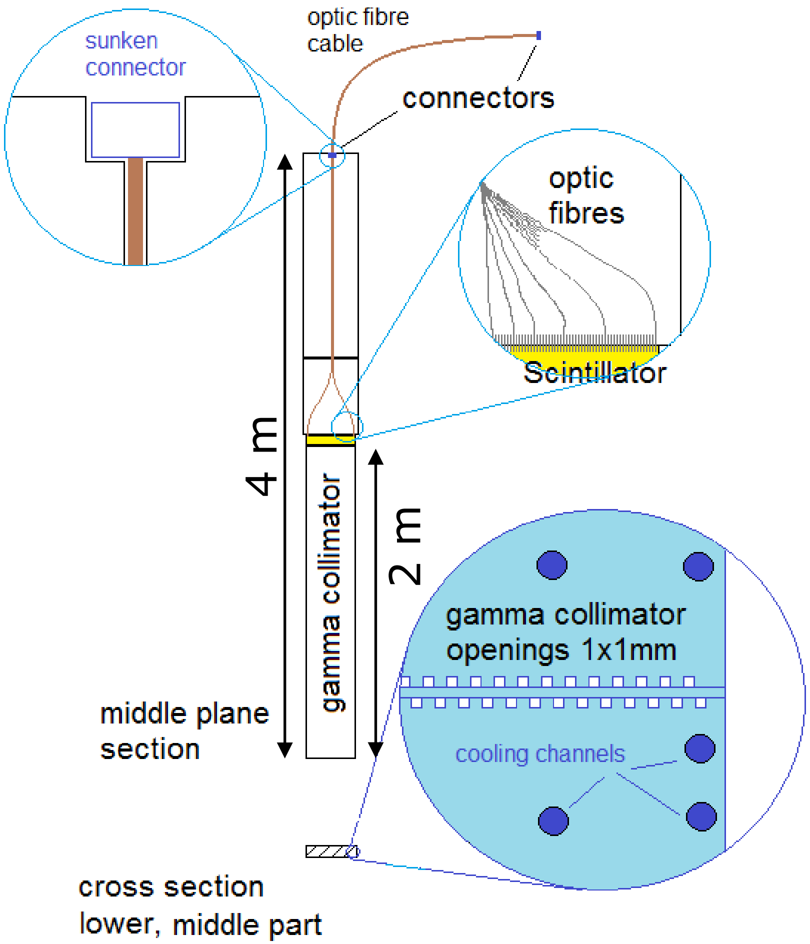
- only gammas with a direction **close to the normal to the target surface** will reach the end of the collimator.

This solution offers in principle two operation modes:

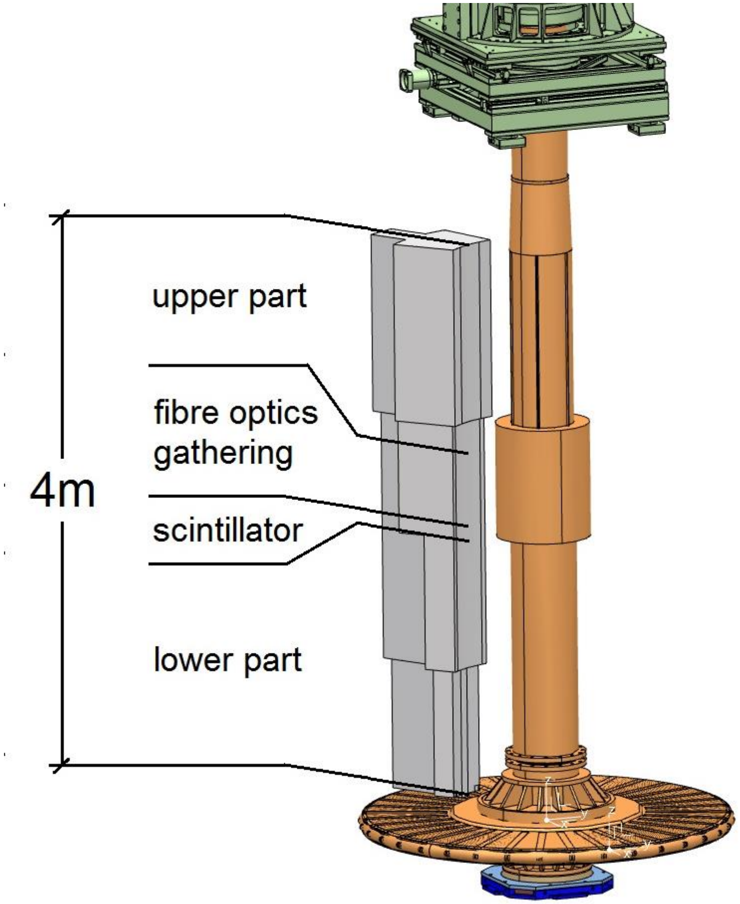
- **real time imaging** to quickly detect local modifications
- detailed wheel analysis during **maintenance stops**

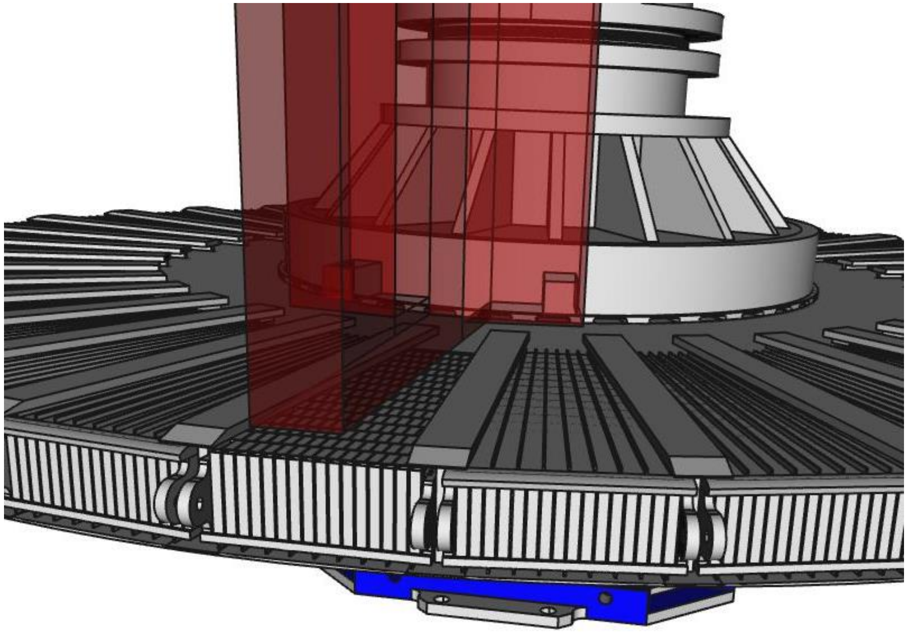
Geometry and proposed realization

- Gamma emission is collimated by means of a 2m-long steel block with **syncopated 1x1 mm^2 grooves** to ensure **complete coverage of the wheel radius**
- On top of the collimator block, an **array of scintillators** is placed to convert gammas into visible light
- The scintillator is then **coupled to optical fibers** which convey the scintillation light to a high-sensitivity **CCD camera**
- Each groove acts as a **single readout channel** and the image of the target wheel is reconstructed from an **intensity-vs-time signal**.



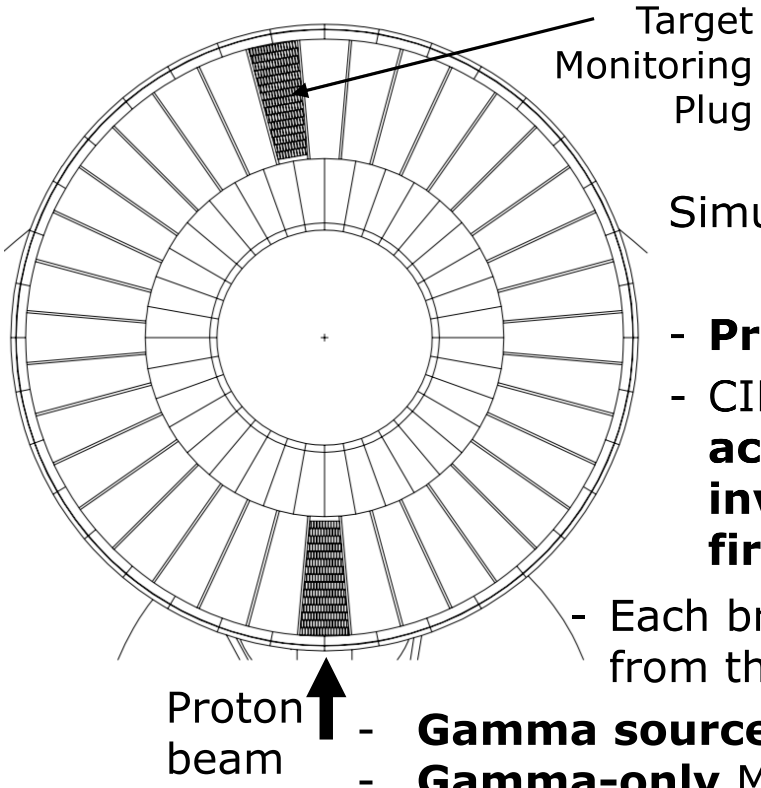
Geometry and proposed realization





CAD model of the Target Monitoring Plug positioned above the wheel

Simulation

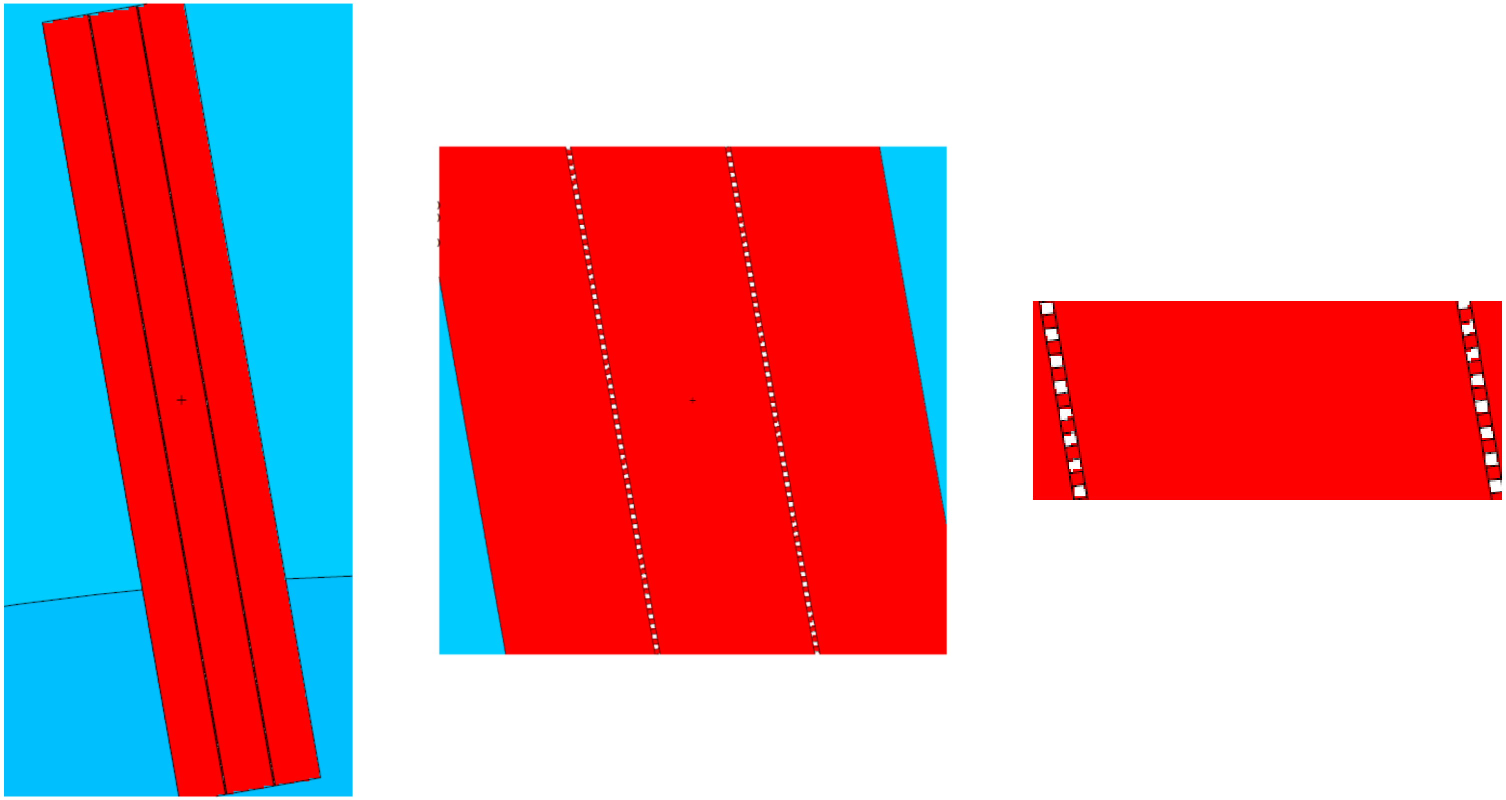


Simulation workflow:

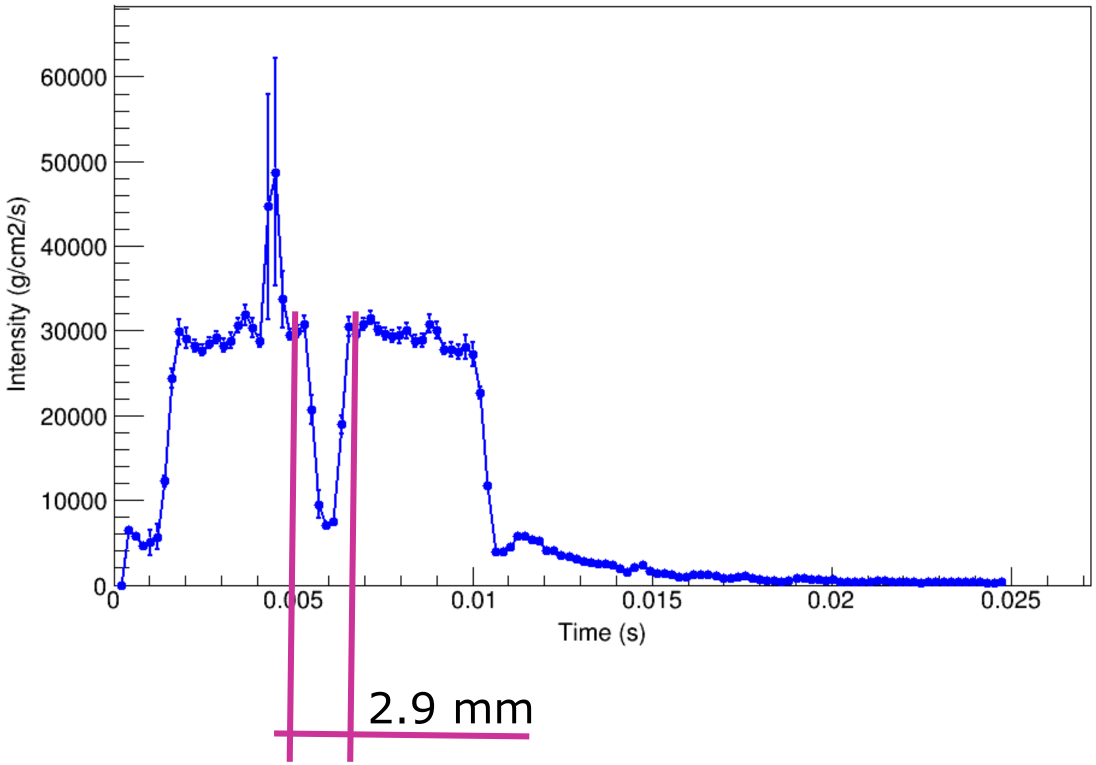
- **Protons** on the first sector
- CINDER '90 to calculate **activity and nuclide inventory after 1s** on the **first sector**
- Each brick considered independently from the others
- **Gamma source moved** to the imaged sector
- **Gamma-only** MCNPX simulation to calculate **signal**
- Independent **proton simulation** for gamma and neutron **background** evaluation

Simulation

MCNPX model of the groove collimator. Square syncopated holes (1x1 mm^2)



Simulation



2.9 mm

Wheel rotation period = 2.57 s

Distance center-straw = 1 m

Samples taken every 0.05 cm

Time steps = 204 us

Issues and solutions

The Target Monitoring Plug is a rather complex system and several conditions will affect various aspects of its operation:

- **Temperature** affects the signal **collimation** and **collection**
    - The **collimator** block can undergo **deformations** due to a **temperature gradient** along its length
    - **Scintillators** have a **temperature-dependent efficiency** for gamma-visible photon conversion
    - **PMMA optical fibers** can be **softened** and lose their geometrical properties

⬇

- **Cooling** must be provided to prevent the temperature gradient, or at least maintain it constant.

- **Temperature monitoring** is also of primary importance as it allows to detect **signal damaging gradients** in the collimator.

Issues and solutions

The Target Monitoring Plug is a rather complex system and several conditions will affect various aspects of its operation:

- Pressure (**0.01 Pa during operation**) affects the mechanical construction of the system:
    - **Surface outgassing** from steel (large surface area) requires long vacuum pumping and/or in-situ thermal treatments to reduce water content
    - **Trapped-air volumes:** require all the fixings to be vented and either bare fibers without cladding or sealed interfaces at the fiber exposed end
    - The **dimensions of the grooves** require long pumping to evacuate all the trapped air. Vent holes along the collimator length may be required to aid pumping efficiency

Issues and solutions

The Target Monitoring Plug is a rather complex system and several conditions will affect various aspects of its operation:

- **Prompt background** (10^7 n/cm^2/s and 10^5-10^6 g/cm^2/s) affects the **lifetime of components and the signal collection**:
  - **Radiation damage** to the scintillator and fibers results in reduced efficiency and lifetime.
  - **Prompt radiation** during the 2.86 ms proton pulses makes the **signal detection** very difficult, if not impossible

- **Boron-based shielding** (borated steels, such as ASTM A887-88 or ATI 3047B7, and compounds) can attenuate the neutron background and increase component lifetime

- **Intelligent gating** can be designed to limit the acquisition time to the inter-pulse time (72 ms), but background from activation decay must also be investigated by means of further simulations.

Next steps

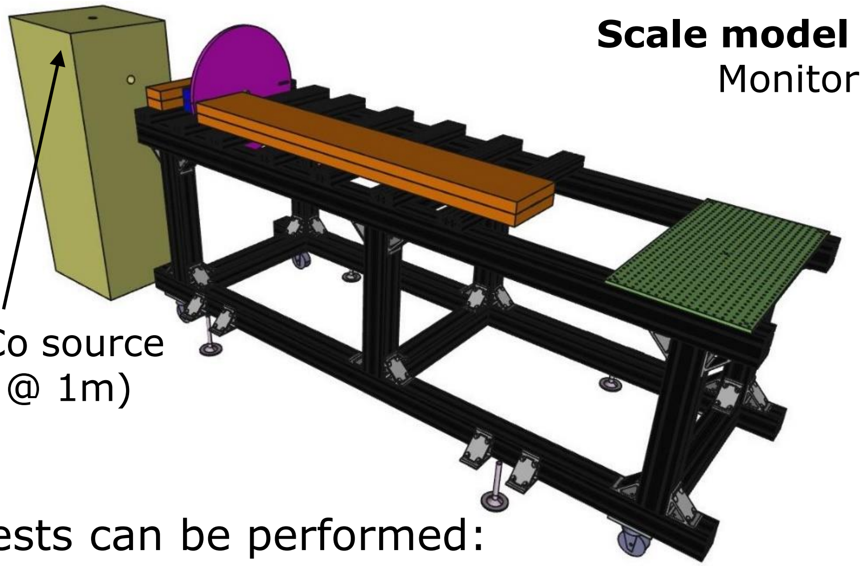
- The simulated signal is a major support to the **feasibility** of this system

- A more detailed investigation of the **sources of background** is under process:
  - **Prompt** gamma and neutron **background**
  - **Activation** of the **surrounding** materials
  - **Short-lived gamma background** in the 72 ms of beam-off, to allow gating

- The **detection system** must also be simulated both for efficiency in signal production and for radiation damage

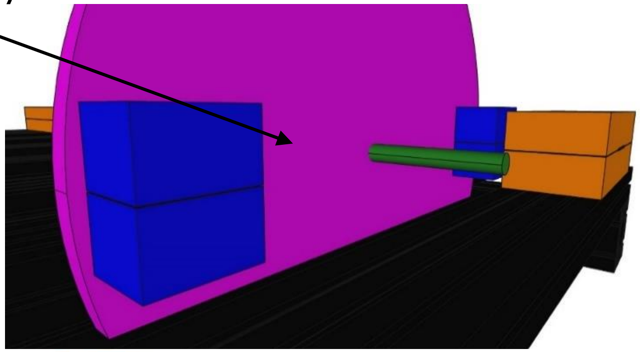
- The **mechanical feasibility** of the collimator-scintillator-fiber-CCD chain has to be studied, to provide ESS with a **proposal** of a system **significant** for the ESS **operation requirements**

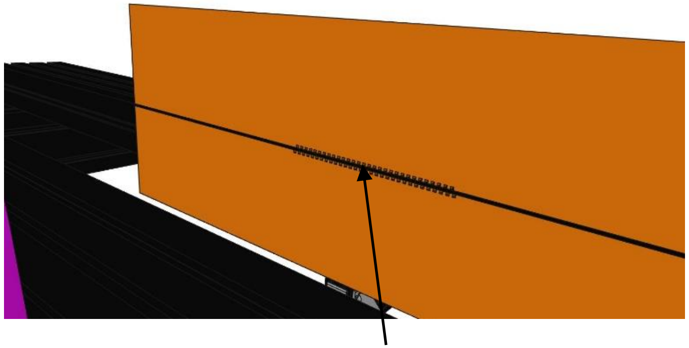
Next steps: the DTU Test Rig



455 TBq ^{60}Co source
(1.4 Gy/min @ 1m)

Scale model of the ESS Target
Monitoring System





Scale model of the collimator
(1:1 scale with reduced
number of grooves)

Several tests can be performed:

- Machining
- Accuracy
- Radiation damage
- Signal and noise evaluation
- Intelligent gating
- Image reconstruction
- Integration with other monitoring systems