Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

On-target neutron flux monitoring with Self Powered Neutron Detectors

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Neutron fluxes in fusion power Tokamak

Neutron flux in ITER will be a first of its kind:

10^{14} n/cm^{2}s on the first wall surface, slowly decreasing with penetration depth

Monitoring the **neutron flux** is one of the **key diagnostics** to understand plasma burning conditions in the tokamak

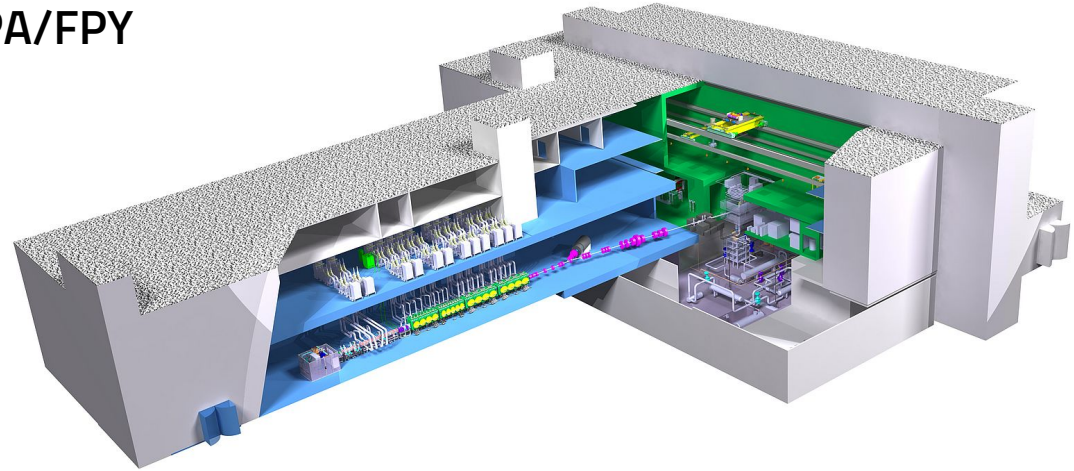
with such intensity, **monitoring is a great challenge** considering also environmental conditions: temperature **above 200 degrees C**, **maintainability** of any detector in those areas **limited** to long shutdown periods

Radiation damage to structures and devices is one of the main challenges of future fusion reactors: **several DPA** are foreseen on most exposed materials including structural ones

DONES: Demo Oriented NEutron Source

In order to evaluate the damage to structural materials for the DEMO reactor, the next step to commercial fusion electricity after ITER, the **Roadmap to Fusion Energy** has foreseen a **dedicated test facility: IFMIF-DONES**

Plasma-facing materials radiation hardness will be tested under realistic fusion irradiation conditions and validated to be used in the harsh conditions of a fusion power plant. **Goal: 15 DPA/FPY**



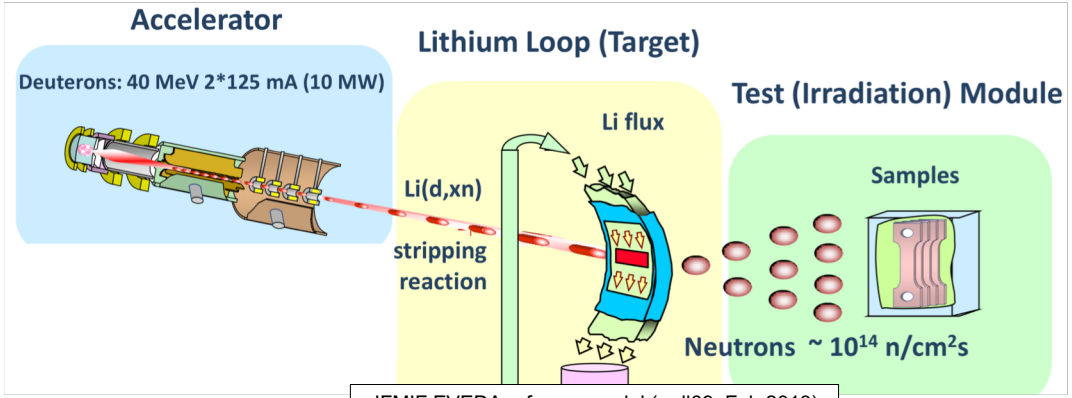
DONES to be built in Granada

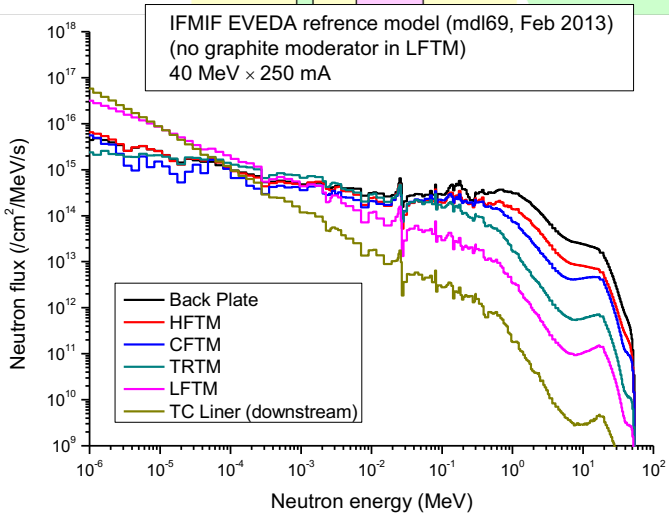
In 2018 the site **for the construction of DONES** has been chosen in Escuzar, 30 km from **Granada** (Spain)

DONES: 10^{14} n/cm^{2}s production by D-Li stripping

IFMIF-DONES is based on a **40 MeV, 125 mA in continuous wave mode (CW) deuteron accelerator** (5 MW beam average power) hitting with a rectangular beam size (approx. 20 cm x 5 cm) a **liquid Li screen target** flowing at 15 m/s to dissipate the beam power

and generating a flux of **neutrons of 10^{14} cm^{-2} s^{-1}** with a broad peak at 14 MeV through stripping nuclear reactions, close to the expected conditions of fusion power plants.



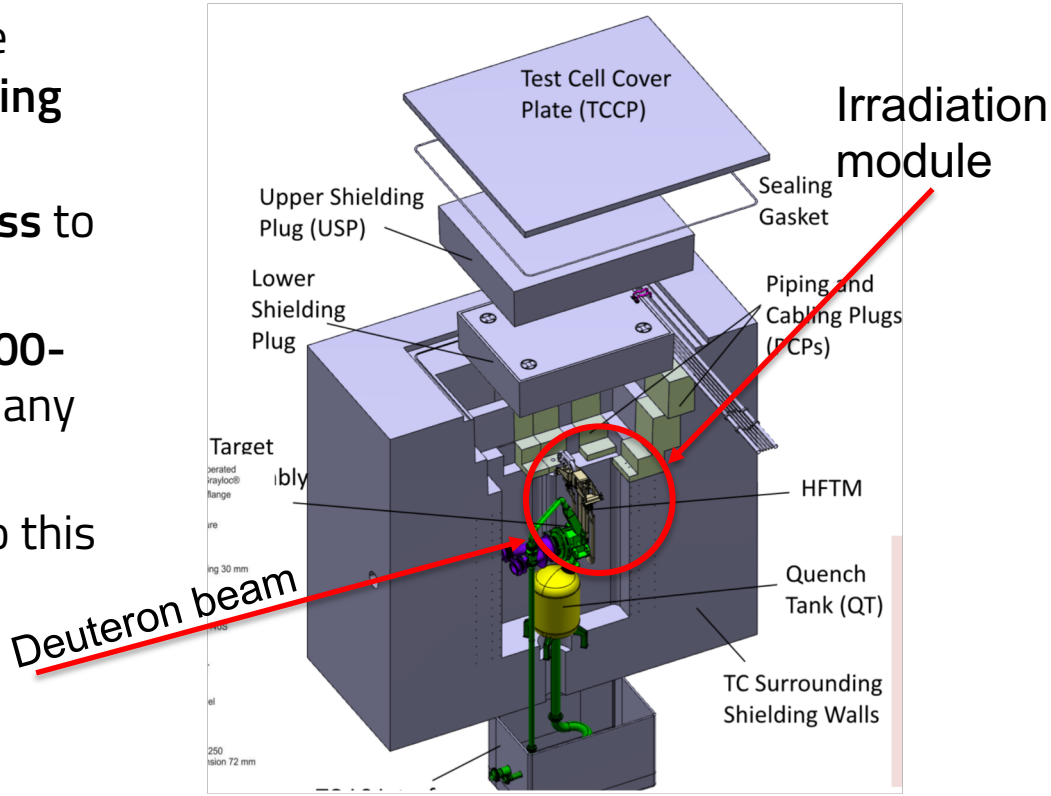


Neutron flux in the DONES Test Cell

Monitoring the neutron flux during the irradiation in the Test Cell is a **challenging** task:

- **year-long irradiations with no access** to the cell are foreseen
- **10^{14} n/cm^{2}s** on the samples with **200-400° C** pose a seriuos challenge for any kind of detector

New detectors should be developed to this pourpose

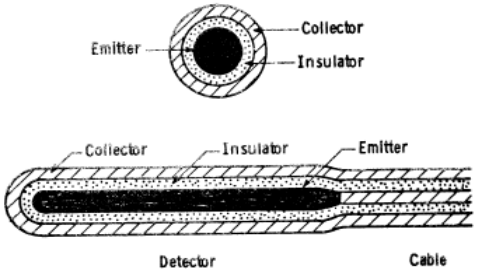


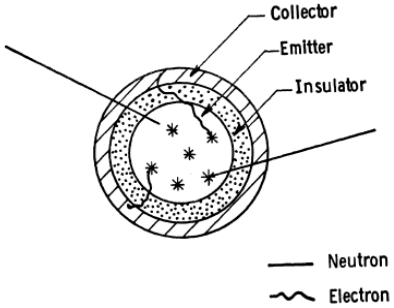
Self Powered Neutron Detectors for Fast Neutrons

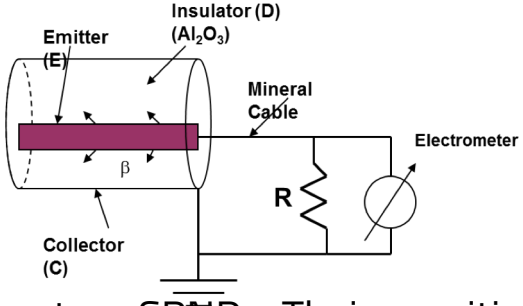
Self Powered (Neutron) Detectors (SPNDs) are **rugged miniature** devices used for **fixed in-core reactor monitoring** both for safety purposes and neutron and gamma flux mapping.

operate **without any bias voltage**

usually constructed in a **coaxial configuration** with a **central emitter characteristic of each device** type. The other electrode or metallic sheath is called collector and the two are separated by a coaxial insulator. Typical **diameter is 3mm**



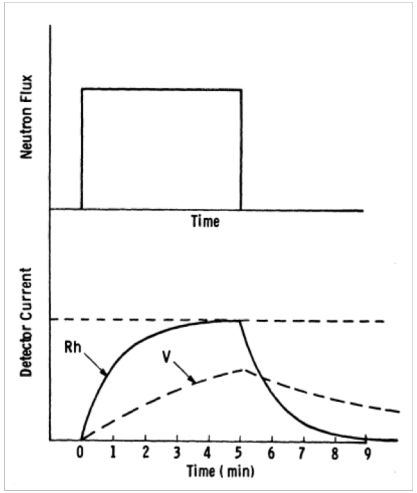




V, Co, Rh are common elements used as emitter in the thermal neutron SPNDs. Their sensitivity for fast neutron is rather low due to limited cross section of these elements. Alternative materials should be used to cover fast neutron energy range.

Contributions to signal formation

Different reactions can take place in the electrodes and the insulator, inducing a current through the emission of electrons



- (n,γ, β): the nuclei of the emitter are activated by a neutron capture and decay with β electron emission
  $\rightarrow$ **delayed** response
- (n,γ): photons from a radiative capture interact through Compton and photoelectric effect
  $\rightarrow$ **prompt** response
- (γ,e^-): external photons interact through Compton and photoelectric effect
  $\rightarrow$ **prompt** response

Note that electrons coming from the emitter that stop in the collector give a **positive** signal; electrons coming from the collector that stop in the emitter give a **negative** signal

$\rightarrow$ The **net current is the algebraic sum of all the contributions**

Test environment for DONES candidate SPND: CERN nTOF

Working environment on DONES Target for the SPND:

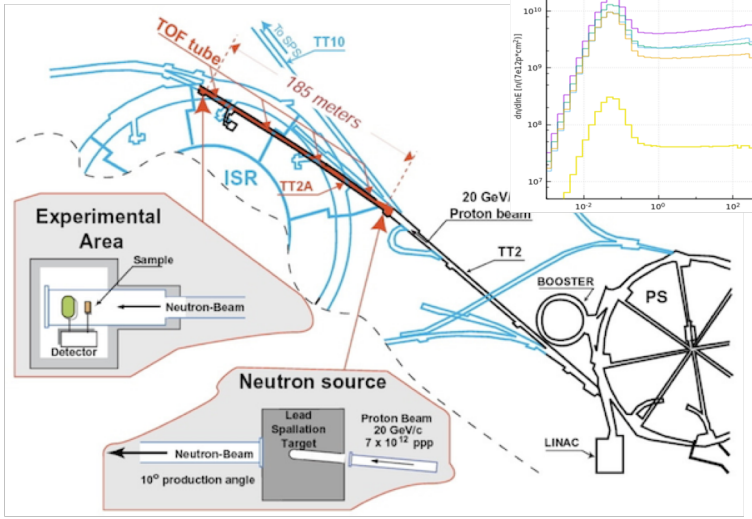
mixed neutron and gamma field, wide energy range neutron spectrum up to 40 MeV

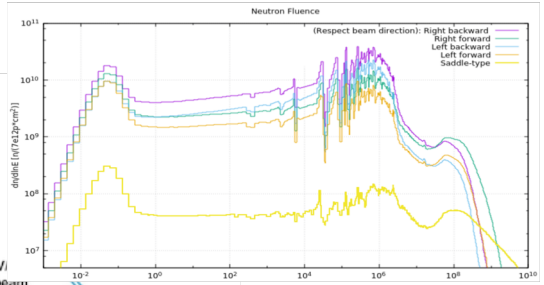
Looked for a **Particle accelerator facility beam on target neutron production to face with similar conditions** including background (particle and EMI)

The **nTOF experiment at CERN**

exploits the 20 GeV PS proton beam interaction with a **lead target**, to produce neutrons by **spallation**.

Neutron spectrum close to the target has a wide **energy spectrum up to hundred MeV** and a long tail down to thermal neutrons





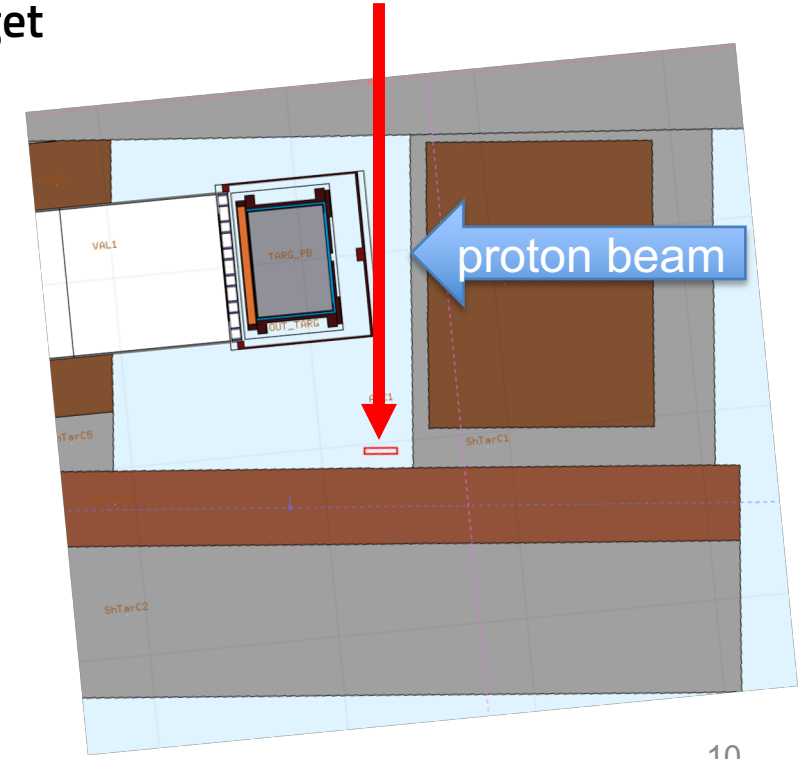
SPND @ nTOF test setup

In order to get ~**10^{11} n/cm^2 s** with high fraction in the energy range 1-10 MeV, we **installed SPNDs in the area surrounding the target**

Two readout systems:

- one with the **Keithley picoammeters**
- one using a **4-channels CAENels picoammeter with10 ms time resolution**
- **100 m cable between SPND and DAQ**

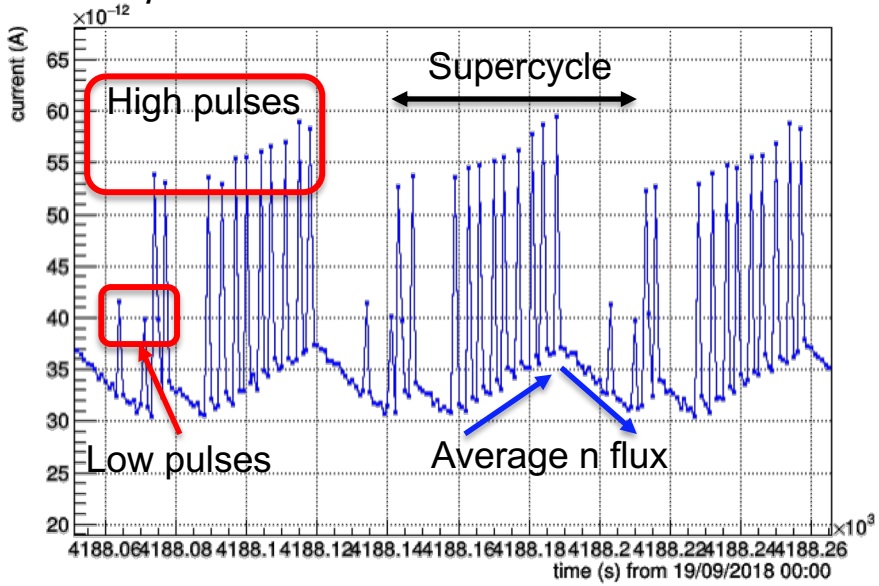
The test beam lasted over **~50 days**

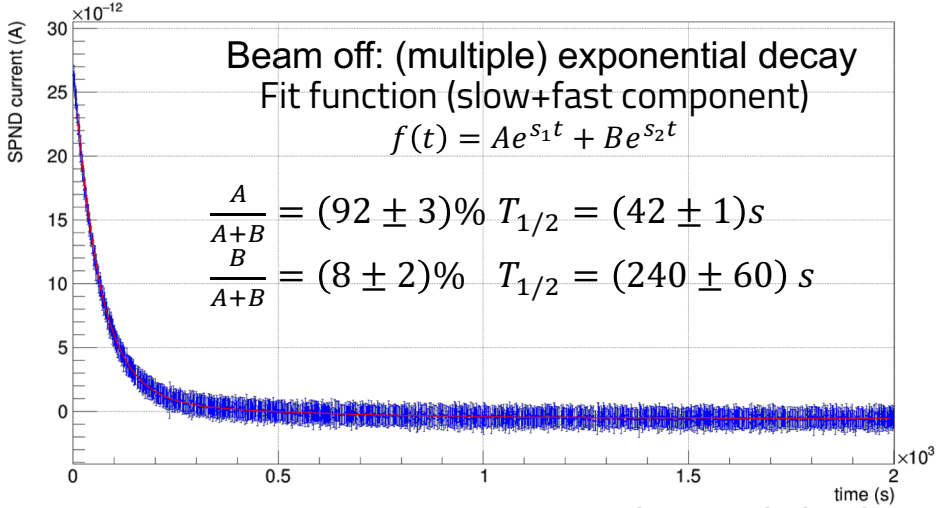


Rhodium SPND signal shape

Proton bunches hit target **every 1.2 s or multiple -> discrimination between prompt and delayed signal possible**

Rh SPND response has a sharp peak due to prompt target emission, proportional to pulse intensity, and a **slow drift of the baseline due to neutron activation** of the emitter



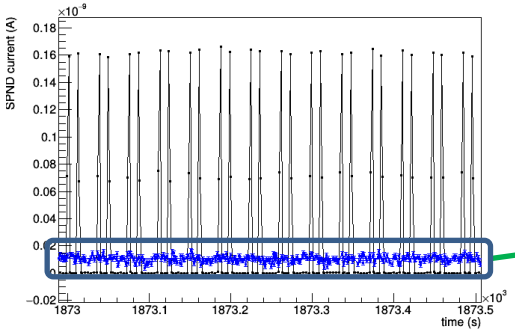


consistent with the expected values of the half life of ^{104}Rh and ^{104m}Rh

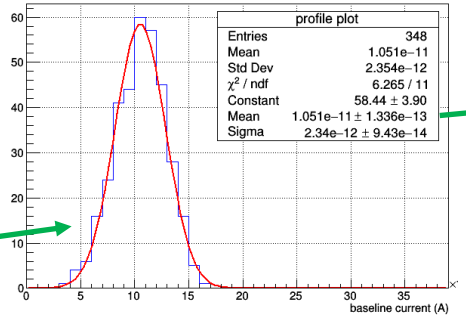
Rh SPND signal linearity

The intensity of the baseline current of Rh SPND is proportional to the average proton current on target → it's **proportional to the neutron flux** on the detector

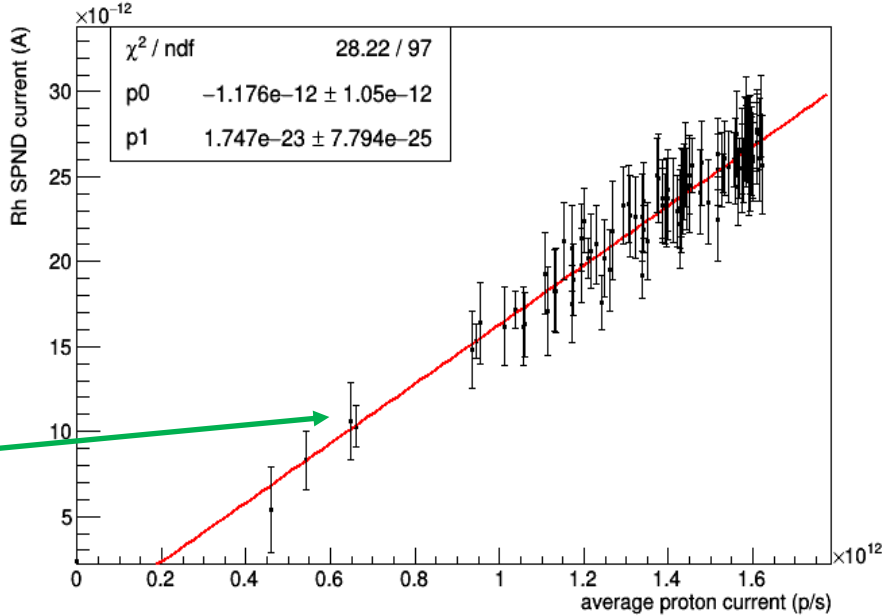
The points sample a time window of ~50 days



baseline is isolated from the prompt signal



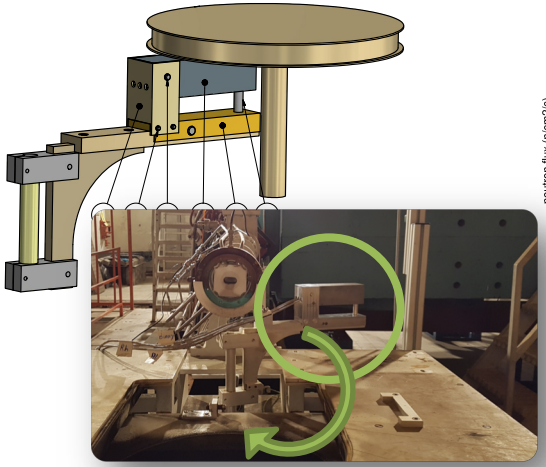
profile plot is fit with gaussian function and central value is added to the linearity plot

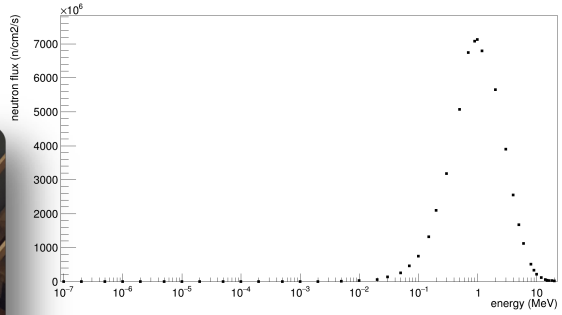


Consistent also with Warren analytical model which predicts 10^{-11} A in this flux range

Second test: GELINA neutron time-of-flight facility

GELINA neutron time-of-flight facility (JRC Geel, Belgium) provides a fast neutron spectrum close to the target, with a yield up to **$2x10^{13}$ n/s exploiting neutron photoproduction** from an electron beam of 110 MeV average energy interacting with a rotating uranium target.





SPND placed 5 cm far from the target hotspot, on a support structure which substituted the moderator used for TOF experiments: **first experiment with such setup at GELINA** thanks to JRC colleagues

GELINA – Al SPND in Pb support (fast neutrons)

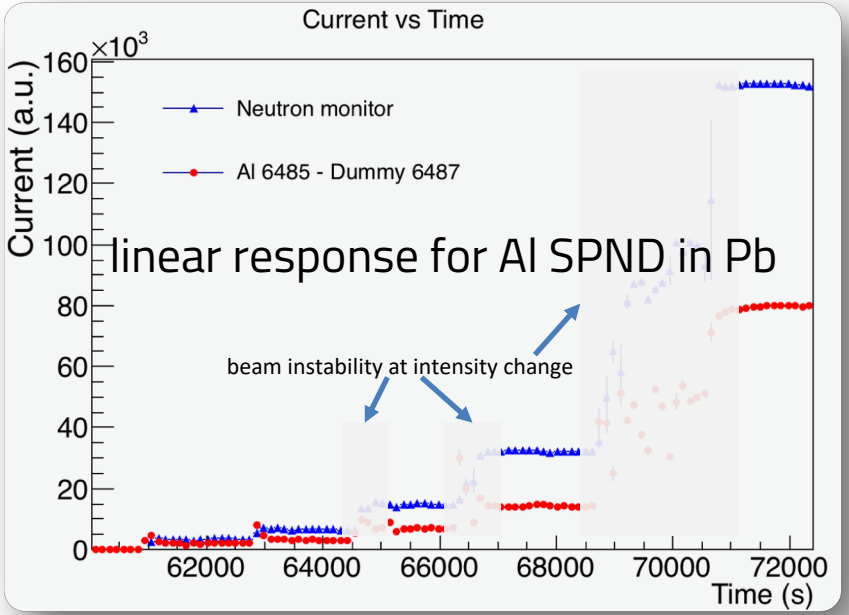
Current from a Dummy SPND has been subtracted as a background from the Al SPND

Beam variations in steps of factor 2: wide range of neutron fluxes (1:16)

SPND/neutron monitor ratio constant over the full range

Ni activation foils to measure neutron flux on the support structure:

5.9×10^{10} n/cm^{2}s at the maximum beam intensity – consistent with MCNP (6.0×10^{10})



n_TOF and GELINA target monitoring with SPND:

Experiment at n_TOF with SPNDs has **successfully taken data across almost 50 days**

- ✓ **SPND response tested under several operation conditions** including variable neutron flux, flux interruptions from minutes to days, all in severe, real-life hadron accelerator EMI conditions
- ✓ Very **low noise** considering detectors position and cable length
- ✓ **Rh SPND** delayed signal consistent with model and linear with average neutron flux
- ✓ Rh SPND decay time consistent with expected activation processes

in GELINA: first experiment on the modified target moderator arm, thanks to JRC colleagues

- ✓ simulated neutron flux fully consistent with measured one
- ✓ Al SPND signal proportional to beam intensity in hard n flux

Outlook

The performances of the SPNDs and the experience of the first on-target experiment at GELINA and nTOF opened new scenarios:

- SPNDs **will be installed in the new nTOF Target#3 assembly to monitor the neutron production independently from PS data during next 10 years operation**
- **New tests of** SPND prototypes with different emitter materials are foreseen in research reactors and beam target (with different setup to reduce background)
- **Detailed signal generation Monte Carlo models** are needed to fully understand the response in such mixed fields: **comparisons and new development are foreseen**

Looking forward for new target neutron sources to host SPNDs for test purposes and long-term monitoring of the neutron yield

Thank you

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