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# Preliminary dosimetry measurements within high power laser-driven experiments at ELI-NP

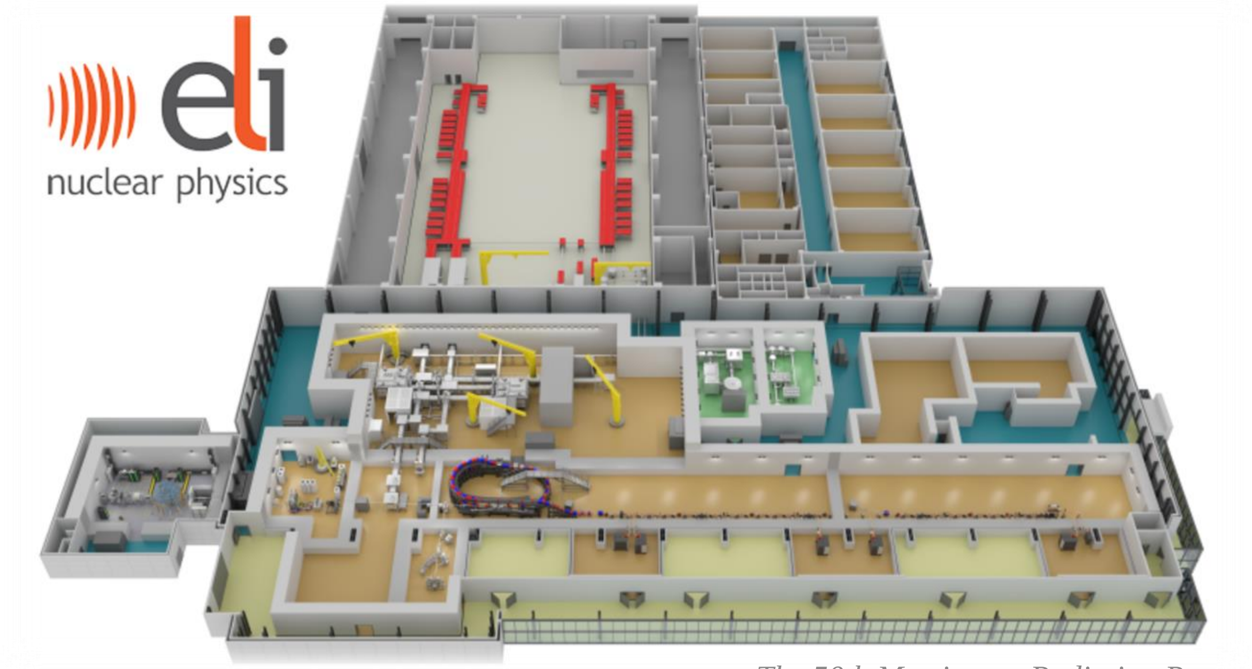
*The 50th Meeting on Radiation Protection, Hajdúszoboszló, Hungary, 7-9 of April, 2025*

# Content

- ELI-NP - cutting-edge laser technology meeting advanced NP
- Radiation Safety and Dosimetry for ELI-NP
- Measurements from ELI-NP experiments
- Conclusions and future perspectives

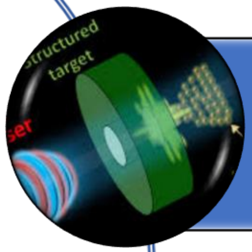
# *ELI-NP in a Nutshell*

- **HIGH-POWER LASER SYSTEM 2 x 10 PW ultra-short pulse laser arms**
  (Chirped Pulse Amplification method by Nobel Prize Winners **Gerard Mourou and Donna Strickland**)
- **BRILLIANT ENERGY TUNABLE GAMMA-RAY BEAM SYSTEM**

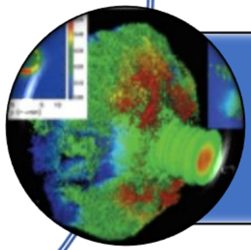



- The most advanced research facility in the world in the field of photonuclear physics, pioneering the first-ever integration of high-power lasers with nuclear physics;
- Hosting two laser arms able to deliver laser pulses @ 100 TW, @1 PW, @10 PW;
- 5 departments and 7 research laboratories providing support for laser-driven experiments;

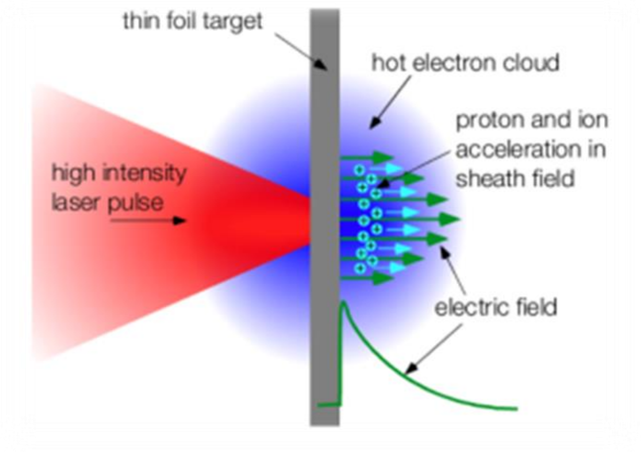
# *Generating radiation fields, source terms and scenarios considered for RP simulations*



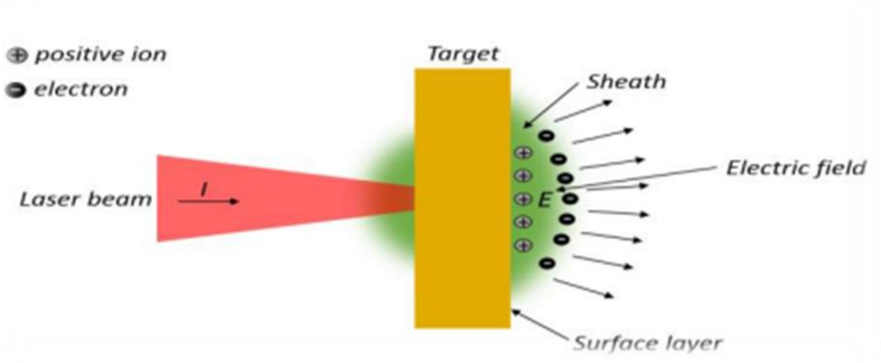

Target Normal Sheath Acceleration (TNSA)



Advanced mechanisms:
-Radiation Pressure Acceleration (RPA)
-Break-Out After – burner (BOA)
- Collisionless Schock Acceleration (CSA)




**Principle of laser driven acceleration**
***Louise Willingale**, Laser driven acceleration of protons and ions, Wakefield Accelerators Sesimbra, Portugal, 18th February 2019*




**Visual repres. of Target Normal Sheath Acceleration (TNSA)**
*(**Lucian Tudor**, Methods for characterization of particle pulses generated by high power laser interaction with matter)*

### *Current status and challenges:*

- The most powerful laser in the world hitting various target materials for acceleration of multiple types of particles, all in the same time with different spatial and energy distribution;
- Broadband spectra of the generated radiation fields (from keV up to GeV);
- Mixed complex and ultra-short radiation fields:
- Intense electromagnetic pulse – the need for shielding (e.g. Faraday cages) for every electronics inside, including detection systems;

# *Radiation protection and dosimetry approach during design, building, installation and commissioning phases*

1

2

3

4

**Dose constraints (self imposed as 1/10 of the legal dose limits)**

- Hp(10) < 2 mSv/year ;
- Equivalent dose to the lens of the eye, to the skin, to the extremities < 15 mSv/year;
- H*(10) rate outside of cold walls – 1µSv/h;

**Monte Carlo Simulations**

- Primary accelerated particles as radiation Sources terms;
- Working Scenarios / pulse frequency;
- Shielding and beam dumps design;

**Shielding & Working Scenario**

- Up to 2m thick concrete walls;
- Customized beam dumps with magnetite, Al, Pb insertions;
- Initial scenario: 10 Hz @100TW, 1Hz @1PW and 0.017 Hz @10PW;

**Dosimetry Monitoring**

- Active monitoring (Radiation Monitoring System, B-RAD Spectrometers, Bonner Spheres System)
- Passive dosimetry (BeOSL, PADC detectors);

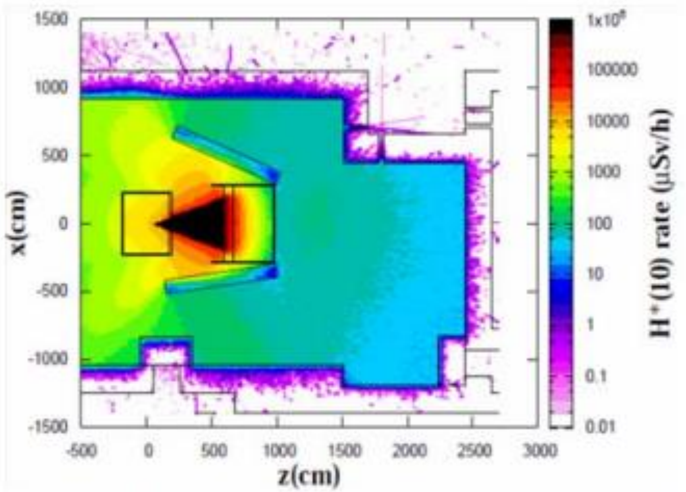
# *Radiation sources & scenarios considered for RP simulations*

| Experimental area & pulse frequency | Target Type | Source Term Carachteristics | Highest expected DR/ pulse values based on simulations, in different places of the building [µSv/h] – most of the time on the roof |
|---|---|---|---|
| **E6 @ 10PW, 0.0.17 Hz** | Gaseous | Electrons, 8.61E+10, 38 GeV – and associated bremstrahlung | 0.5<br>9200 |
| | | Photon (synchrotron), 1E+14 part/pulse, 10 MeV | 52700 |
| | Solid | Protons (TNSA), 6E+12 part/pulse, 40 MeV | - |
| | | Protons (RPA/BOA), 1.2E+12 part/pulse, 0.5 GeV | 483 |
| | | Electrons 10E+12, 0.145 MeV | 13300 |
| **E5 @ 1PW, 1 Hz** | Solid | Protons, 7.57E+12 part/pulse, 2-60 MeV –average of 20 MeV | 33500 |
| | | Electrons, 3.08E+07 | |
| | Gaseous | Electrons, 8.05E+7, 2 GeV | 40 |
| | | 8.34E+13 for 0.035 MeV, 7.6E+12 for 0.58 MeV, 6.8E+10 for 8.8 MeV, | 577000 |

**Radiation source terms considered in Fluka simulations for E6 (10 PW) and E5 (1 PW) areas**

* *I.O. Mitu et al, **RADIATION PROTECTION AND SAFETY AT ELI-NP***

- Hot spots: roof and walls (hot side) – > customized beam dumps have been designed; control access has been implemented.
- Secondary fields generated following the interaction of the primary field with the beam dumps have been seriously considered ;

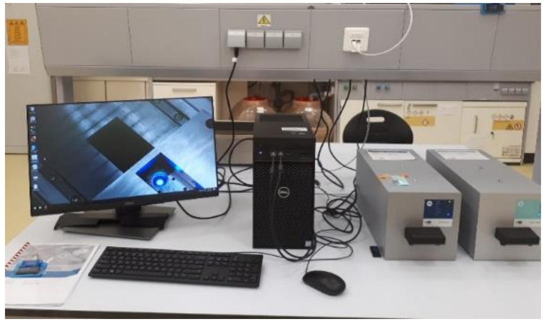



**Map representation of the dH*(10)/dt rate in µSv/h given by the proton source term in the horizontal section and neighboring areas, at the beam height level**

* *M.A. Popovici et al, **RADIOLOGICAL PROTECTION CALCULATIONS OF THE ELI-NP 10 PW LASER EXPERIMENTAL AREA USING FLUKA CODE***

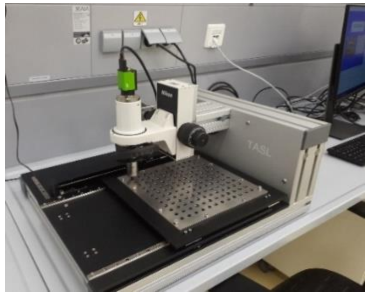
# *Dosimetry equipment foreseen for ELI-NP fields and personnel monitoring*

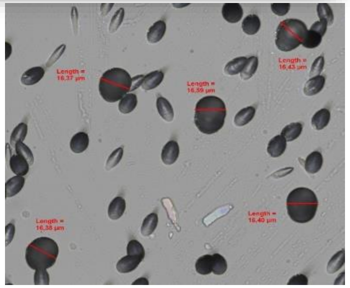
BeOSL dosemeters for gamma and X-rays dose monitoring



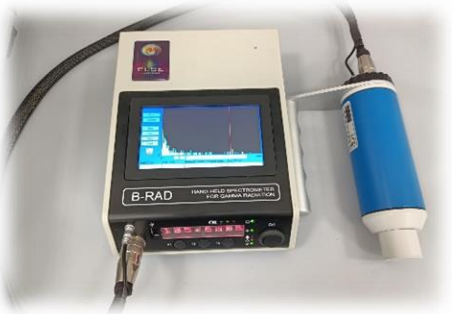

PADC detectors foreseen for neutron passive dosimetry

TASL System for
PADC detectors analysis



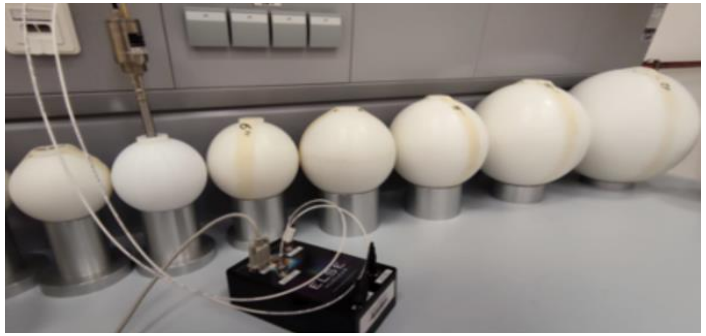
Hand-held radiation survey meter for gamma radiation and DMC 3000 DR-meters

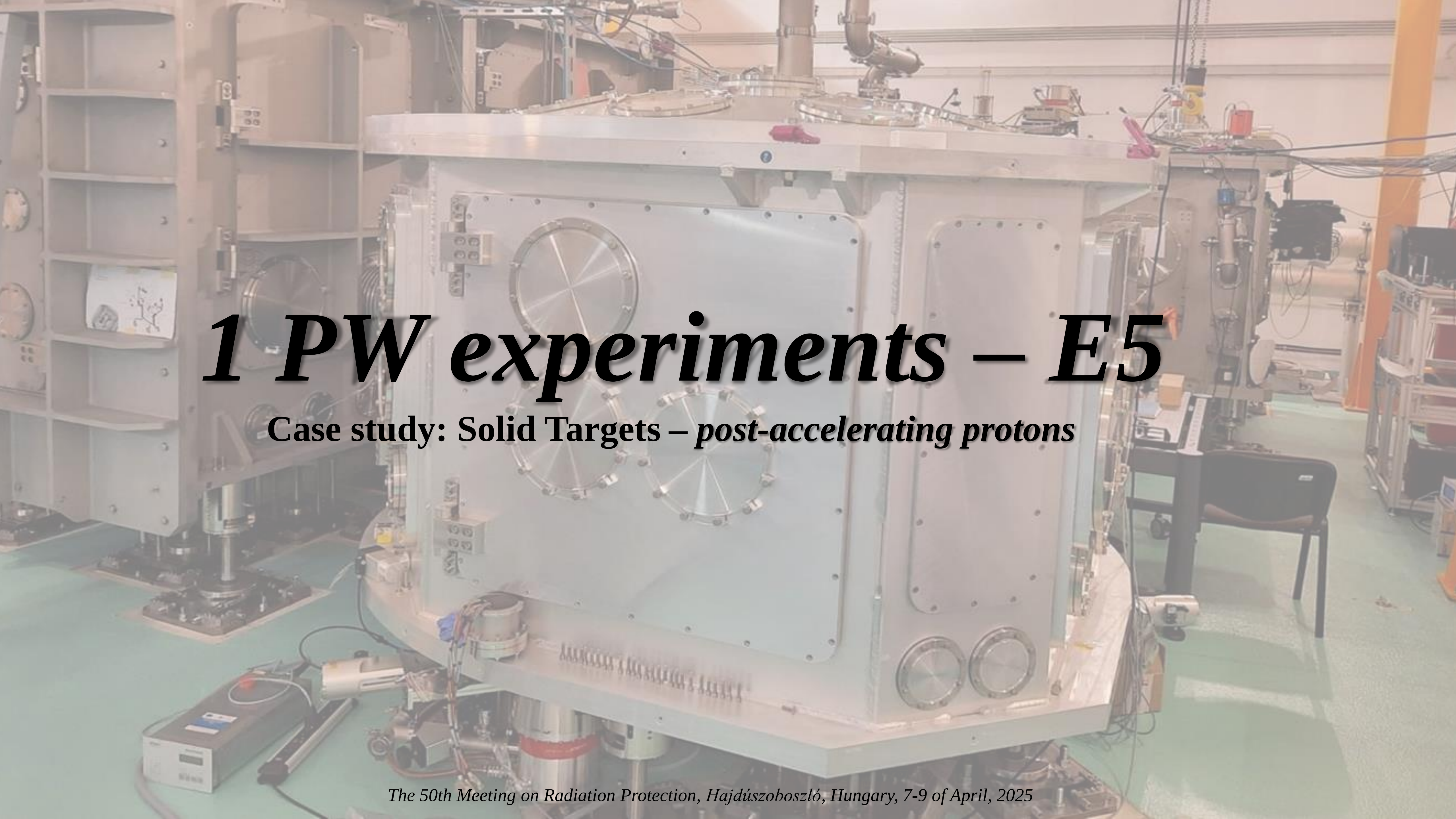




SATURN 5702 - mobile station - two detectors for gamma and neutron dose rate monitoring.

Bonner Spheres Spectrometer



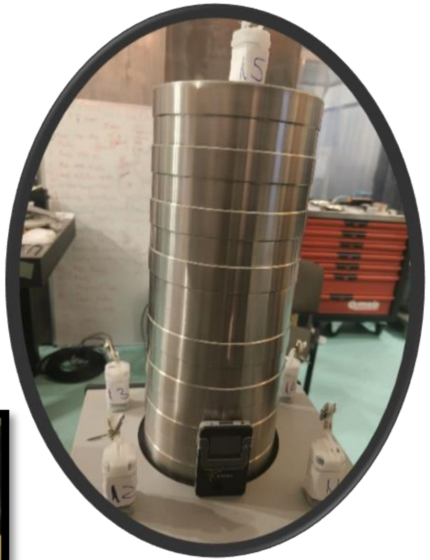


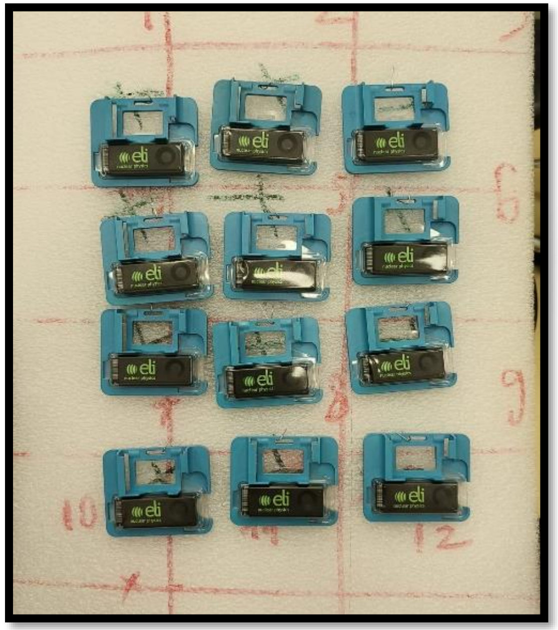
# *1 PW experiments – E5*

## Case study: Solid Targets – *post-accelerating protons*

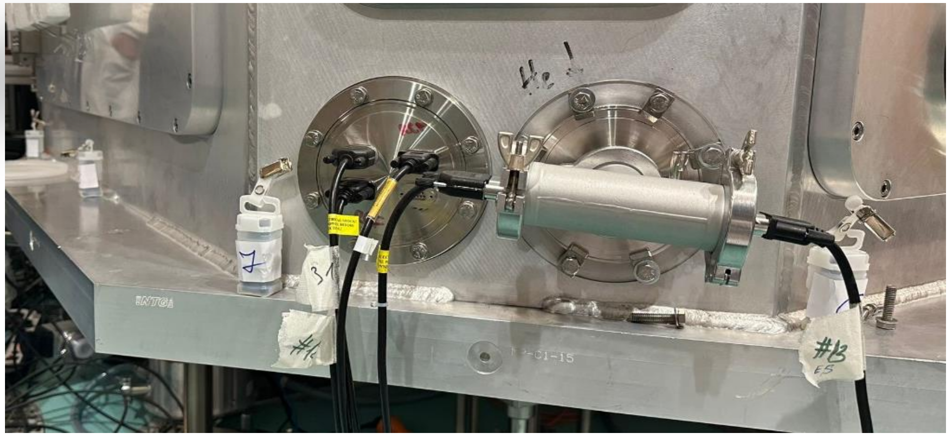
# Detection setup

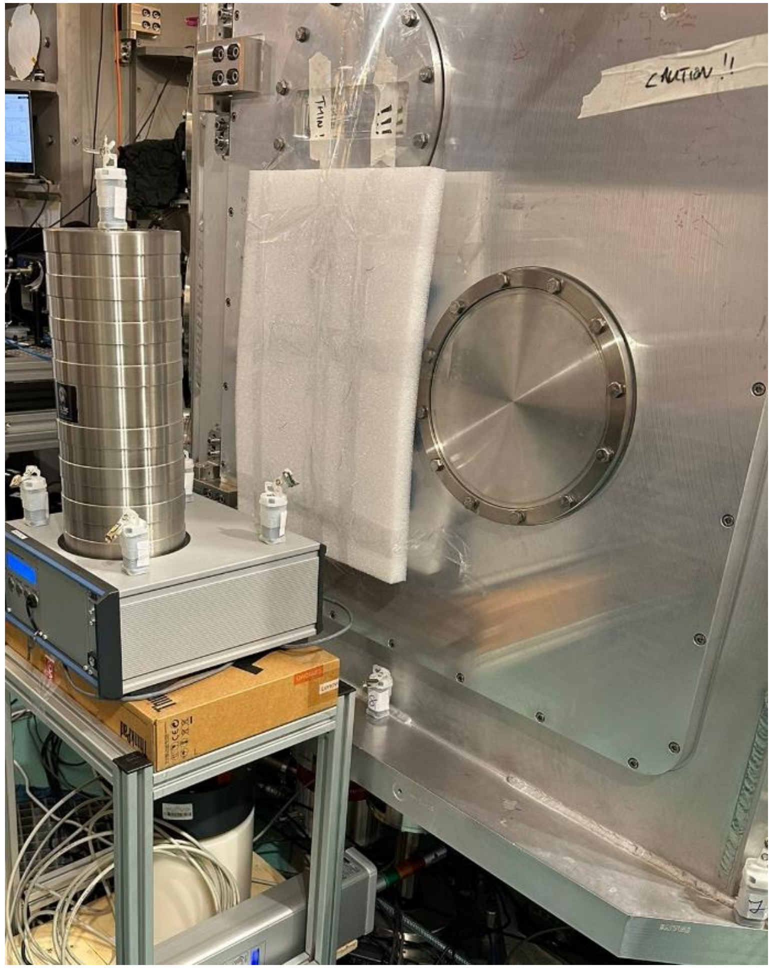
- ❖ ***BeOSL:***
- \- **12 keV ÷ 7 MeV;**
- \- **0.05 mSv ÷ 10 Sv;**
- ❖ ***NAUSICAA Ion Chamber:***
- \- **30 keV ÷ 10 MeV;**
- \- **10 nSv/h ÷ 10 Sv/h;**
- ❖ ***Lupin Proportional Counter*:**
- \- **Thermal ÷ 20 MeV;**
- \- **10 nSv/h ÷ 100 mSv/h;**





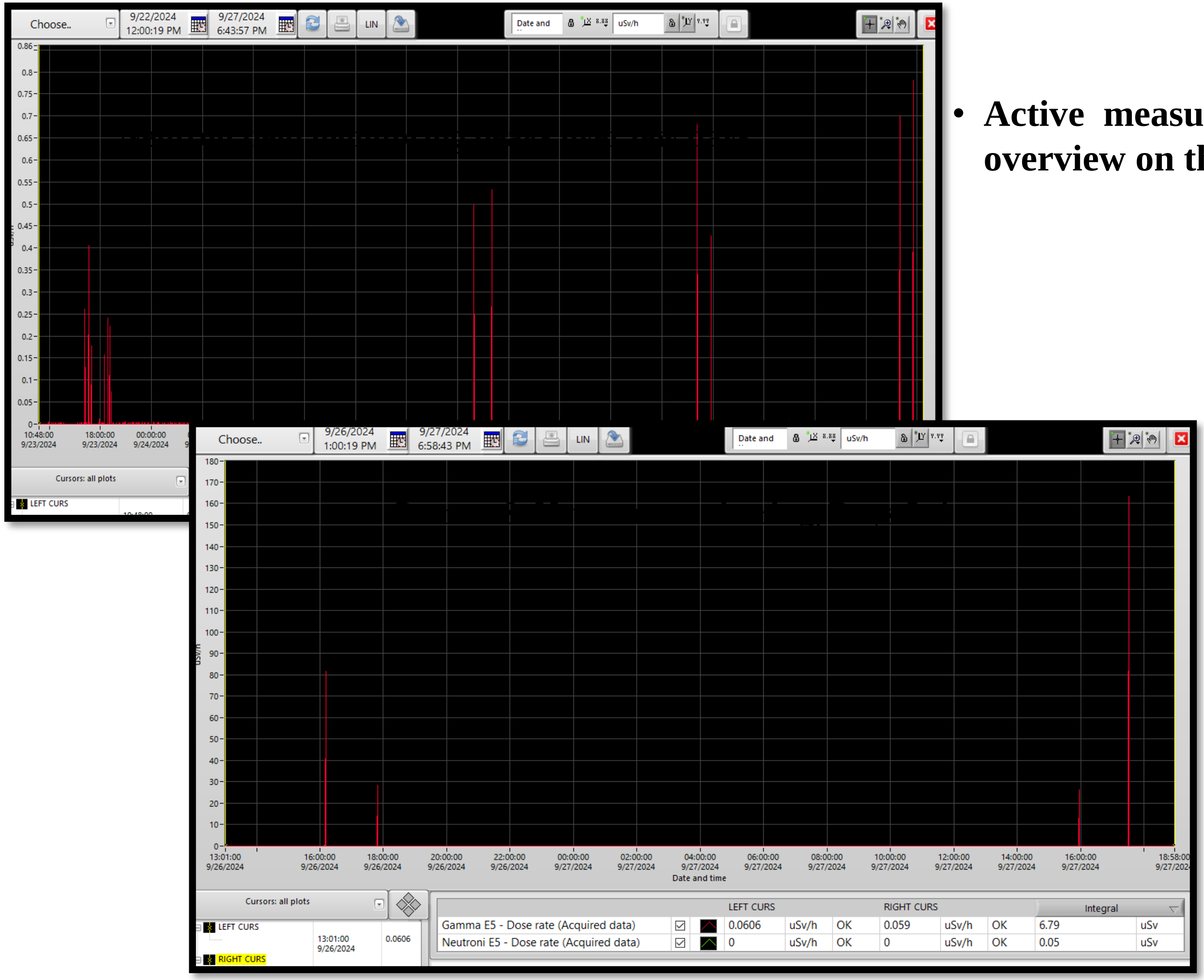
- ❖ **12 dosemeters placed in front of the flange;**
- ❖ **22 dosemeters placed in the E5 experimental area, surrounding the interaction chamber; 5 of them on and around the Ion Chamber;**
- ❖ **NAUSICAA Ion Chamber and LUPIN Proportional Counter placed in front of the main flanche, along the beam axis / radiation field preferred / main direction;**





# Proportional Counter and Ion Chamber Results

## *Active Measurements*

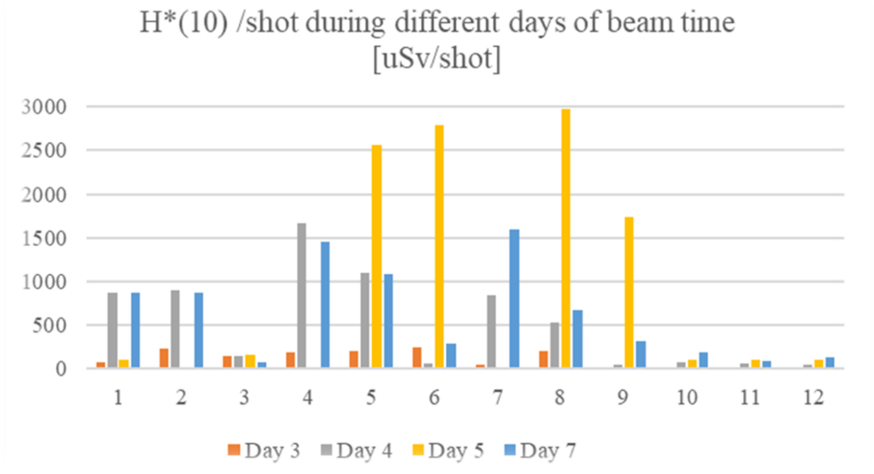



- **Active measurements provide an in-real-time visual and numerical overview on the differences between consecutive shots**

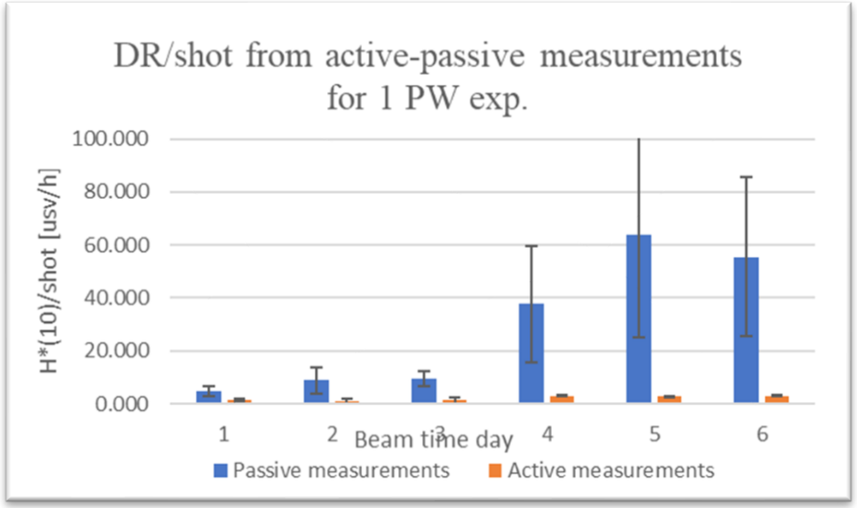
| Gamma Ion Chamber | | Neutrons Prop. Counter | | |
|---|---|---|---|---|
| **Dose rate [µSv/h]** | **Max Dose rate [µSv/h]** | **Dose rate [µSv/h]** | **Max Dose rate [µSv/h]** | |
| 58.9948 | 3530 | 0.2616 | 5.233 | **Average gamma H*(10) rate = 1.29 µSv/shot<br>Average neutron H*(10) rate = 1.17 nSv/shot<br>Day 1** |
| 99.4843 | 5960 | 0.405 | 8.1 | |
| 93.4305 | 5600 | 0.178 | 3.567 | |
| 41.6308 | 2490 | 0.011 | 0.113 | |
| 108.145 | 6470 | 0.158 | 3.163 | |
| 71.1173 | 4250 | 0.242 | 4.833 | |
| 68.4183 | 4090 | 0.223 | 4.4 | |
| 40.47 | 2400 | 0.498 | 9.967 | **Average gamma H*(10) rate = 0.9 µSv/shot<br>Day 2** |
| 13.091 | 662 | 0.0081 | 0.0326 | |
| 159.916 | 6640 | 0.533 | 10.667 | |
| 81.695 | 4890 | 0.682 | 13.633 | **Average gamma H*(10) rate = 1.25 µSv/shot<br>Day 3-4** |
| 28.464 | 1700 | 0.427 | 8.533 | |
| 26.2743 | 1570 | 0.7 | 14 | |
| 163.441 | 9790 | 0.782 | 15.633 | |
| 186.88 | 11200 | 0.3 | 6 | **Average gamma H*(10) rate = 3.06 µSv/shot<br>Average neutron H*(10) rate = 2.06 nSv/shot<br>Day 5** |
| 185.436 | 11100 | 0.302 | 6.033 | |
| 181.398 | 10800 | 0.365 | 7.3 | |
| 185.628 | 11000 | 0.447 | 8.933 | |
| 187.054 | 11200 | 0.463 | 9.2 | |
| 178.829 | 10700 | 0.6483 | 12.967 | |

# BeOSL Dosemeters Results
## ***Passive Measurements***

**Dose rate per pulse in front of the flange for different days of beamtime[µSv/pulse]**



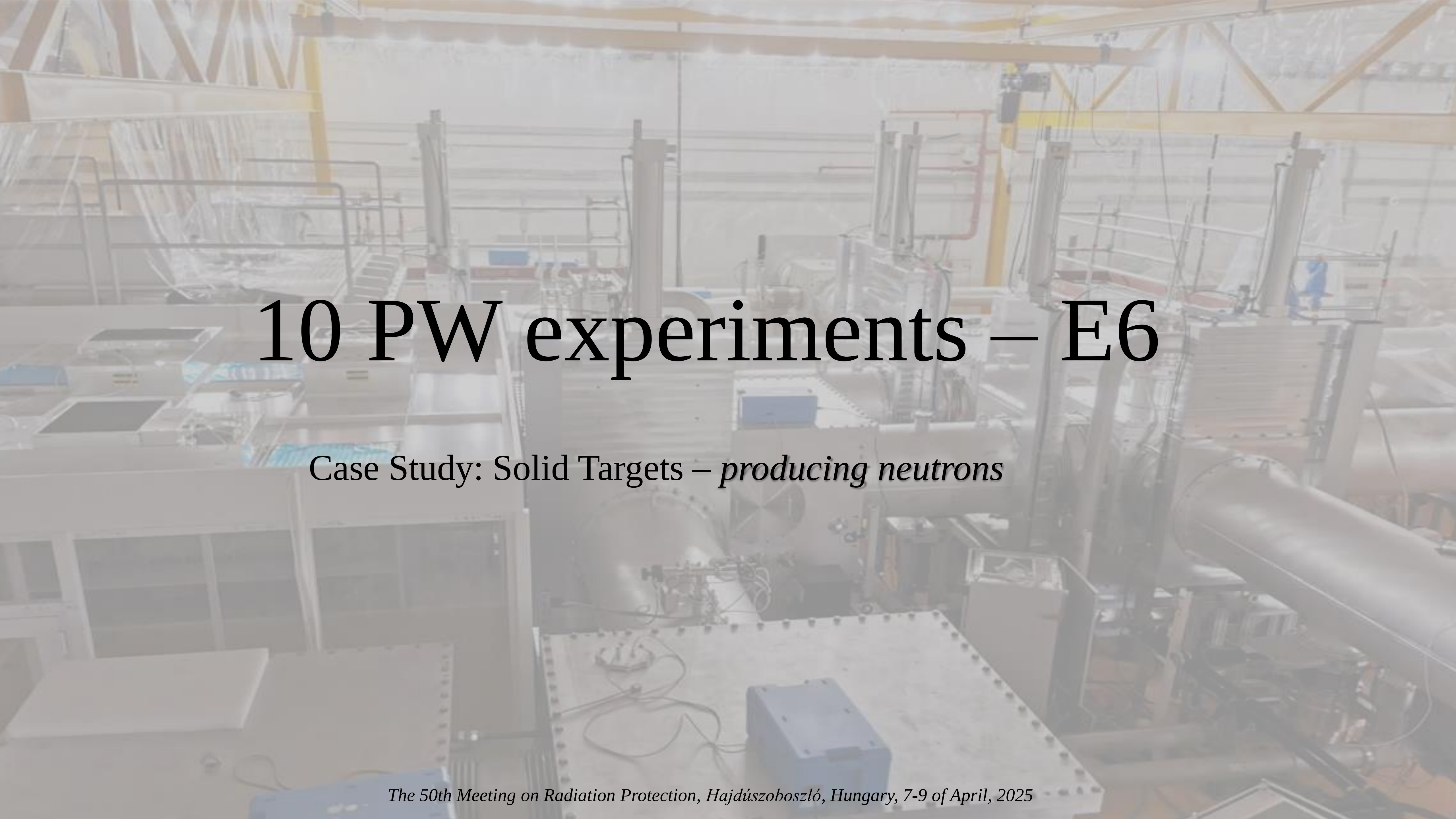

**DR Intercomparison between active and passive measurements**




**Dose rate per pulse around the interaction chamber on different days of beamtime[µSv/pulse]**

| Av. DR Day 1 [µSv/pulse] | Av. DR Day 2 [µSv/pulse] | Av. DR Day 3 [µSv/pulse] | Av. DR Day 4 [µSv/pulse] | Av. DR Day 5 [µSv/pulse] |
|---|---|---|---|---|
| 2.315 | 1.596 | 1.268 | 3.573 | 5.218 |
| 3.429 | 2.118 | 1.274 | 0.678 | 4.689 |
| 4.316 | 0.033 | 2.054 | 3.128 | 6.755 |
| 2.762 | 2.638 | 2.056 | 2.460 | 4.156 |
| 0.041 | 0.556 | 1.264 | 2.239 | 4.162 |
| 1.156 | 0.555 | 2.445 | 2.460 | 4.167 |
| 0.489 | 0.035 | 1.265 | 2.014 | 4.682 |

- **Passive measurements results of DR/pulse are made on the approximation of a congruence of the pulses during a daily beamtime;**
- **Passive measurements results are characterized by 13% uncertainty, for a confidence interval of k=1;**
- **Change in value for a dosimeter on the same position from a day to another are justified by the experimental set-up change, the variation of pulses characteristics, or targets used;**
- **The considerable underestimation – the lower energies represent the main component of the generated radiation field spectra + saturation effects;**



# 10 PW experiments – E6

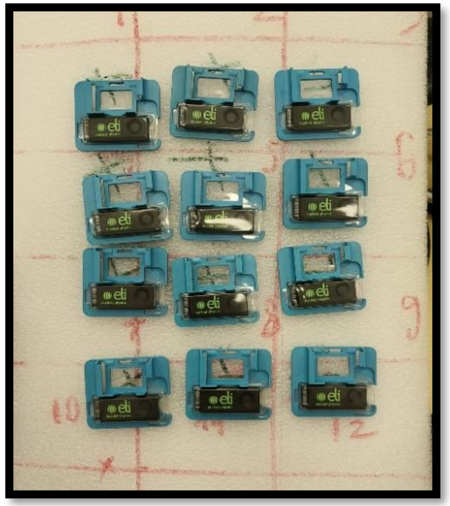
Case Study: Solid Targets – *producing neutrons*

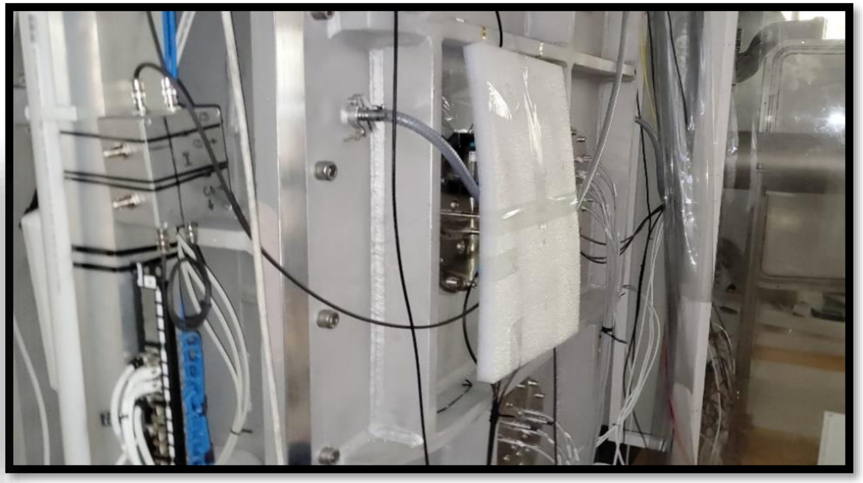
# Detection setup

**Active Detectors and Dosemeters surrounding the interraction chamber**

- 2 x 12 dosemeters placed in front of the flanges;
- 20 – 24 dosemeters placed in the E6 experimental area, surrounding the interaction chamber;
- NAUSICAA Ion Chamber and LUPIN Proportional Counter placed in front of the main flanche, along the beam axis;
- CR-39 (PADC) detectors with 11-12 mm Al layer placed inside of the interaction chamber;

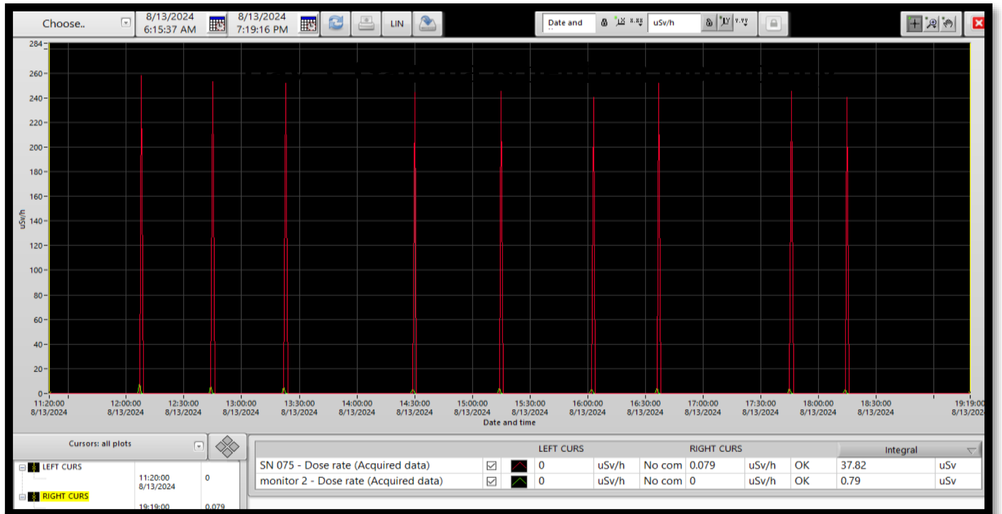
**Dosemeters placed in front of the flanges ($0^o$ and $90^o$ compared to the beam direction)**

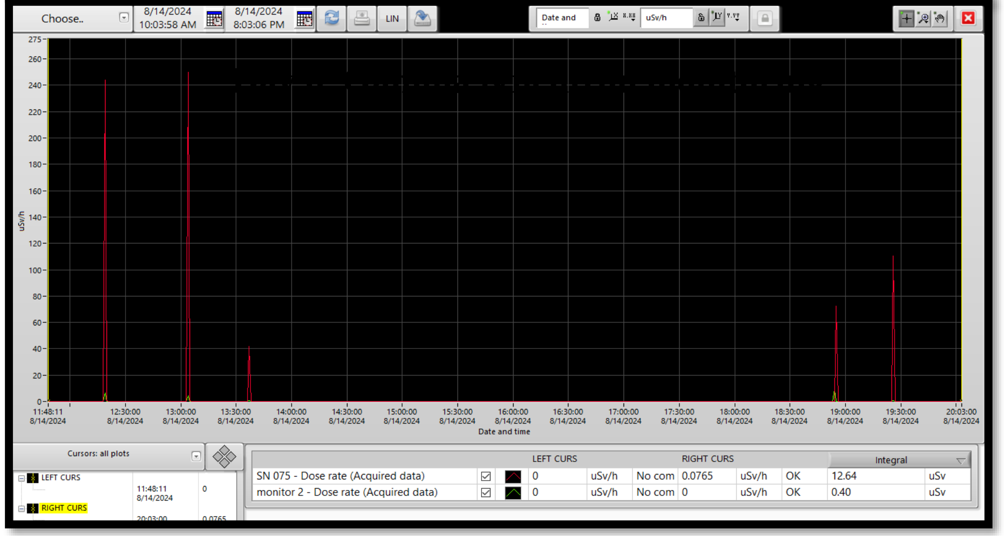




# Proportional Counter and Ion Chamber Results

## *Active Measurements*





| Gamma – NAUSICAA Ion Chamber | | Neutrons – LUPIN Proportional Counter | |
|---|---|---|---|
| Dose rate [µSv/h] | Max Dose rate [µSv/h] | Dose rate [µSv/h] | Max Dose rate [µSv/h] |
| Day 2 | | | |
| 185.315 | 11100 | 7.217 | 433 |
| 208.723 | 12500 | 6.782 | 402 |
| 181.988 | 10900 | 7.05 | 423 |
| 203.712 | 12200 | 7.25 | 435 |
| 212.078 | 12700 | 6.833 | 410 |
| 213.751 | 12800 | 6.217 | 373 |
| 218.796 | 13100 | 9.261 | 554 |
| Day 5 | | | |
| 258.342 | 15400 | 8.683 | 521 |
| 253.278 | 14800 | 6.05 | 363 |
| 252.27 | 13300 | 5.767 | 346 |
| 244.066 | 14300 | 3.667 | 220 |
| 245.567 | 14700 | 5.2 | 312 |
| 240.536 | 14400 | 3.7 | 222 |
| 252.291 | 15100 | 5.25 | 315 |
| 245.583 | 14700 | 4.167 | 250 |
| 240.549 | 14400 | 3.15 | 189 |
| Day 6 | | | |
| 244.259 | 13800 | 6.233 | 374 |
| 250.105 | 9540 | 4.444 | 265 |
| 42.0728 | 2200 | 0.708 | 14.167 |
| 72.445 | 4220 | 9.233 | 554 |
| 110.522 | 5910 | 0.8901 | 15.267 |

**Day 2:**
**Average gamma H*(10) rate = 3.38 µSv/shot**

**Average neutron H*(10) rate = 0.12 µSv/shot**

**Day 5:**
**Average gamma H*(10) rate = 4.05 µSv/shot**

**Average neutrons H*(10) rate = 0.08 µSv/shot**

**Day 6:**
**Average gamma H*(10) rate = 1.98 µSv/shot**

**Average neutrons H*(10) rate = 0.07 µSv/shot**

***Targets combination leading to neutrons field production?***

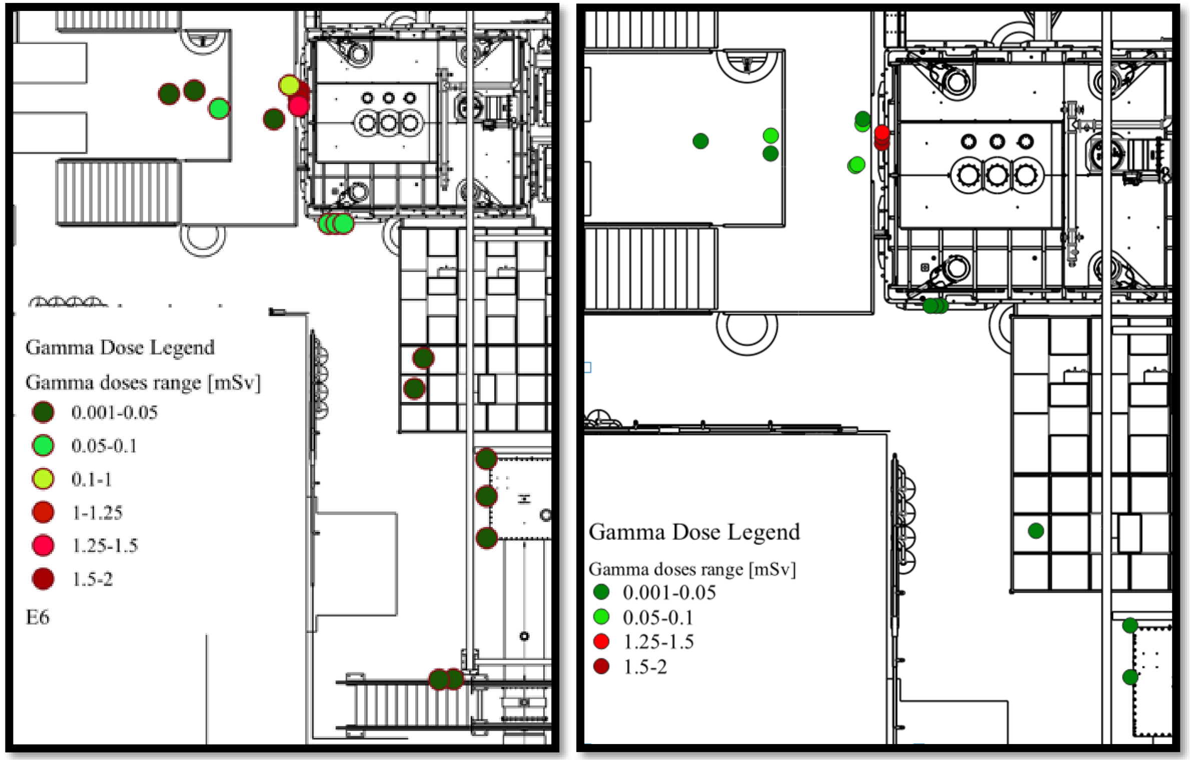
- **Average laser beam energy = 243J; almost 70% of the energy is reaching the target (after compression and plasma mirrors);**
- **Changing targets or using different targets combination led to radiation level variations;**
- **Neutron field is mostly generated by the (p,n) reaction on $^{27}$Al and/or other secondary sources;**
- **The average gamma DR/shot from passive measurements ∈ (5.98, 16.98) µSv/shot;**
- **The ratio between the DR/shot passive – active ∈ (2.78, 4.0)!**

# BeOSL Dosemeters Results
## ***Passive Measurements***

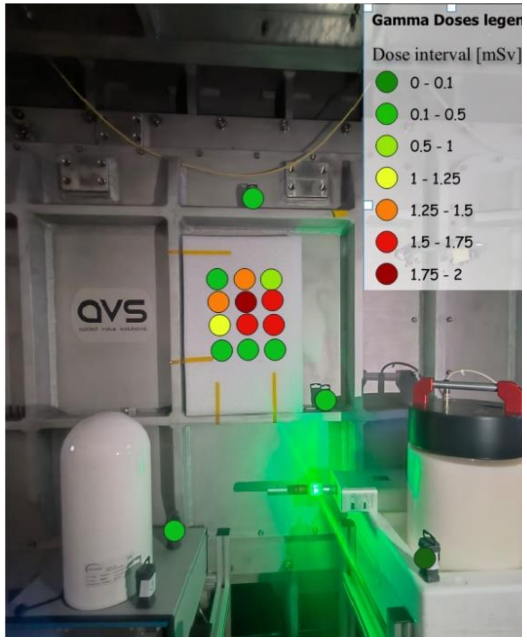
**Average dose rate H*(10) per shot from passive measurements (in front of the flange) [µSv/shot]**

| Pos. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | **Avg.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day 2 | 72.22 | 148.93 | 52.04 | 167.60 | 203.60 | 154.27 | 176.00 | 176.93 | 128.53 | 21.20 | 32.67 | 26.72 | **113.39** |
| Day 4 | 307.90 | 328.90 | 82.06 | 457.90 | 397.90 | 346.90 | 418.90 | 442.90 | 245.68 | 67.60 | 70.30 | 61.00 | **268.99** |
| Day 6 | 55.28 | 66.08 | 38.88 | 66.88 | 57.68 | 57.08 | 55.88 | 77.48 | 49.88 | 11.00 | 16.28 | 13.28 | **47.14** |

**Top view of E6 area dosimetry mapping (Day 2, 9 shots and Day 4, 4 shots)**




**H*(10) values map in front of the flange**




**H*(10) for 9 shots (Day 2) @10PW**


**H*(10) for 4 shots (Day 4) @10PW**

# Conclusions and future perspectives

Active detectors are able to detect ultra-short pulsed radiation fields, but provide measurements of huge underestimation; specific tests need to be performed to accurately explain the underestimation. Can the working scenario can be gradually improved according to this data?

Even traceable to classical continuous radiation fields, in SSDL conditions, OSLs response is not dependent on the pulse duration, therefor they are a suitable technology to properly perform dosimetry characterization of ELI-NP generated pulsed fields; their response to high energy fields needs to be studied.

To have a better knowledge about the neutron component in active measurements, accurate passive measurements need to be performed. SSNTD system foreseen to be used in the upcoming experimental campaigns. Diamon spectrometer already integreted in the recent beamtimes.

Correlation can be improved by performing MC based simulations for each specific study case. More effort needs to be involved in accurately describing radiation source terms. This needs to be further confirmed/adjusted by the experimental results in the early phases, to enhance Fluka simulations and accuracy in fields estimations.

# *Thank you for your attention!*

***“Let there be light!”***