ELI Beamlines facility: Heading towards operations

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ELI ERIC

The **Extreme Light Infrastructure (ELI)**

- Research Infrastructure
  part of the European ESFRI Roadmap.

- 1. 1. 2011 start of
  parallel implementation of 3 sites
- 30.4.2021 ELI ERIC founded
- Founding members: CZ, HU, IT, LT
- Founding observers: DE, BG

- Countries interested in
  joining:
  CH, ES, PL, PT

ELI sites

- International, civilian, laser-driven user facility.
- Open-access, single-interface user-facility

ELI Beamlines

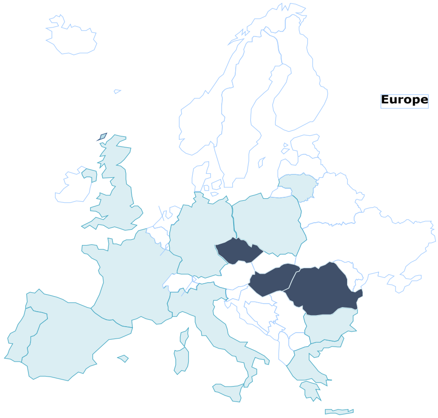
New generation of secondary sources for interdisciplinary applications in physics, medicine, biology and material sciences

ELI Attosecond

Physics of ultrashort attosecond pulses

ELI Nuclear Physics

Photonuclear physics, nuclear spectroscopy



ELI ALPS

www.eli-alps.hu

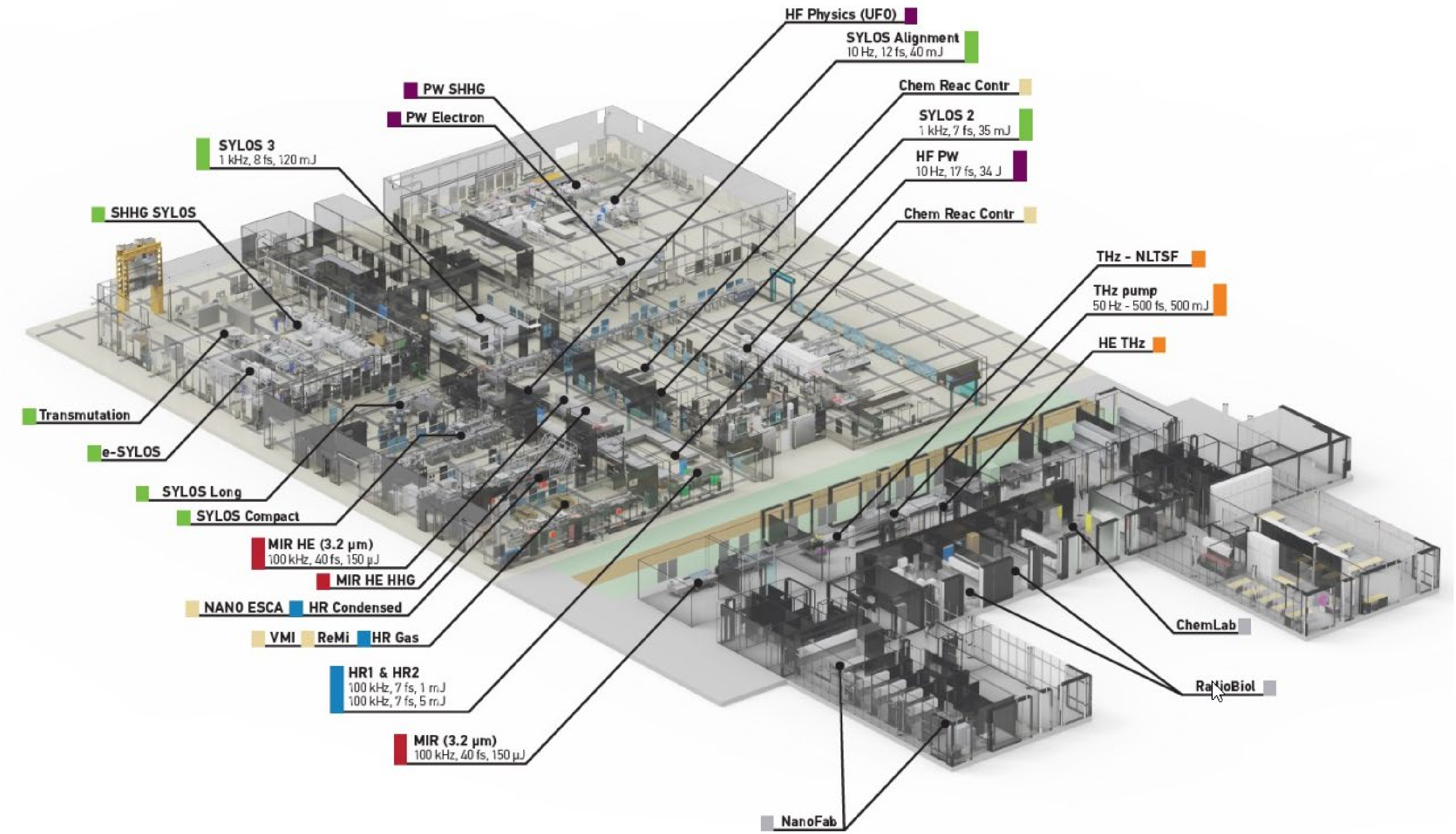
- "Attosecond Light Pulse Source"
- Szeged, Hungary
- Light sources between THz (10^{12} Hz) and X-ray (10^{18} - 10^{19} Hz) frequency range
- 5 laser systems
- 8 experimental stations

Applications:

- Attosecond studies in atomic and molecular dynamics
- Nanophysics, materials science
- Plasma physics
- Radiobiology
- THz spectroscopy

ELI ALPS

www.eli-alps.hu



ELI ALPS Virtual tour: https://www.youtube.com/watch?v=zIxsgJHqiq0

ELI NP

www.eli-np.ro

Magurele, Romania

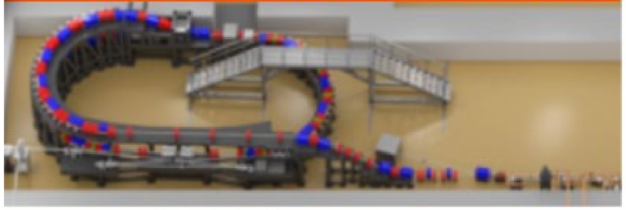
- 2 laser systems
- Intensities 10^{23}-10^{24} W/cm^2

Applications:

- Photonuclear reactions
- Exotic nuclear physics
- Astrophysics
- Characterization of laser – target interaction

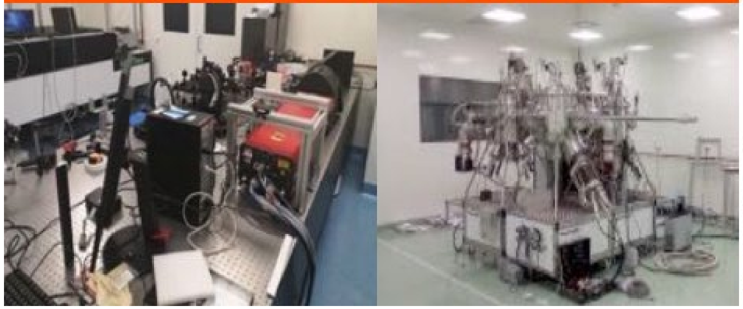
Largest geothermal system in Europe ~ 6 MW

2 x 10 PW High-Power Laser System



Variable Energy Gamma System

2 x 10 PW + 1 x 1 PW Laser Beam Transport System



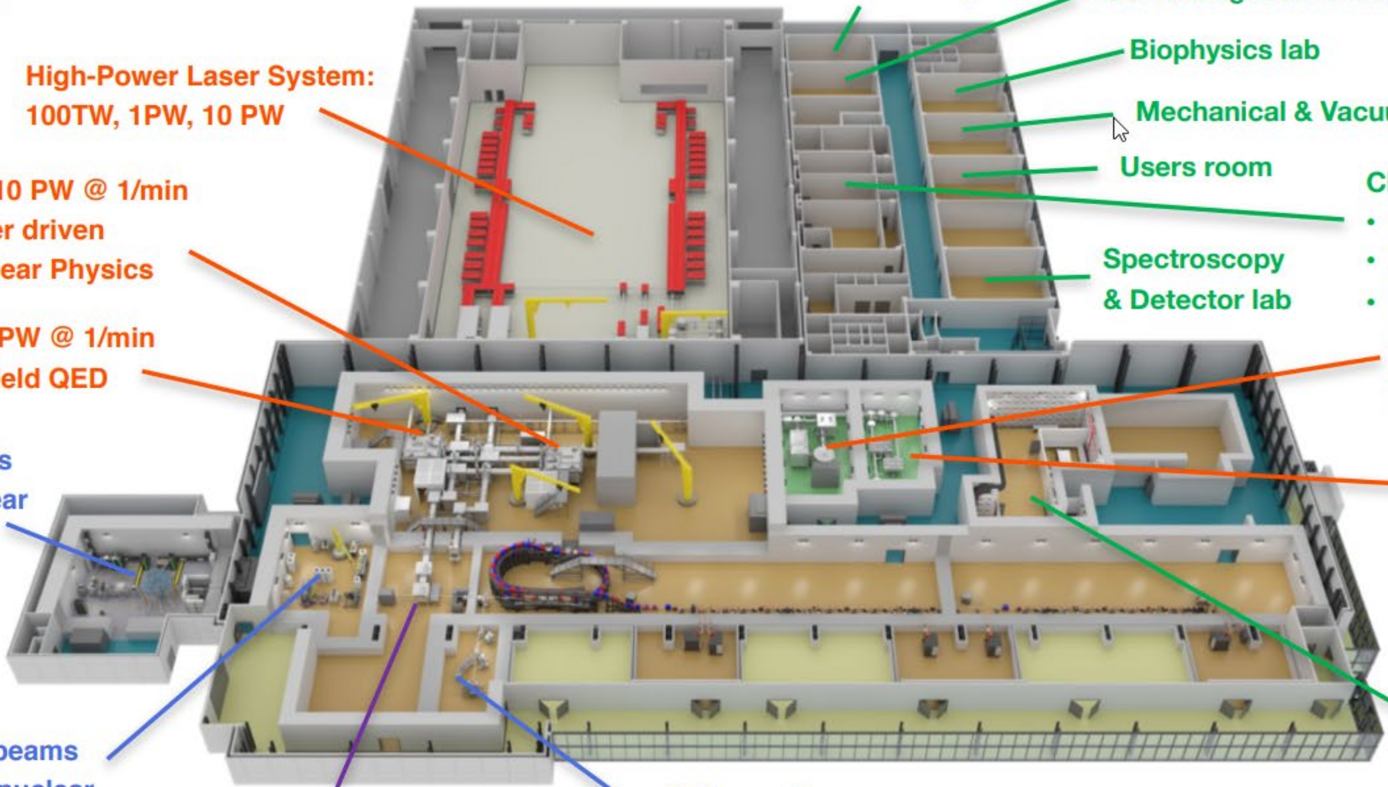
Laboratories and workshops

9 Experimental areas

ELI NP

www.eli-np.ro

Experimental building



Dosimetry lab

Plasma diagnostics lab

Biophysics lab

Mechanical & Vacuum workshop

Users room

Clean rooms
- Optics lab
- Laser lab
- Target lab

Spectroscopy
& Detector lab

High-Power Laser System:
100TW, 1PW, 10 PW

E1: 10 PW @ 1/min
Laser driven
Nuclear Physics

E6: 10 PW @ 1/min
High Field QED

E9: γ beams
Photonuclear
Reactions

E5: 1 PW @ 1 Hz
Material Studies

E4: 0.1PW@10 Hz
Photon-photon
int., LWFA, X-ray
imaging

E3: X rays
Test/develop
instrumentation
and technology

E8: γ beams
Photonuclear
Reactions

E7: 10 PW + 1 PW + γ/e^-
High Field QED

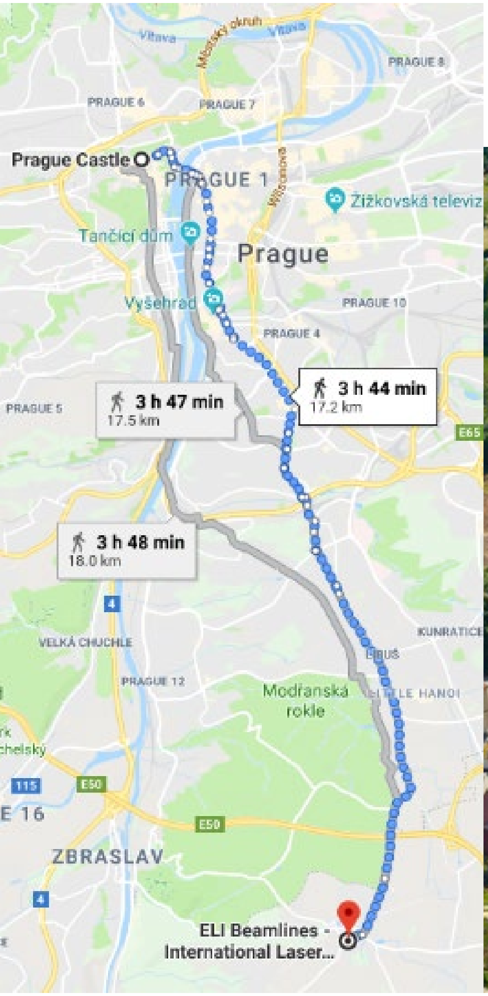
ERA: positrons
Material Studies

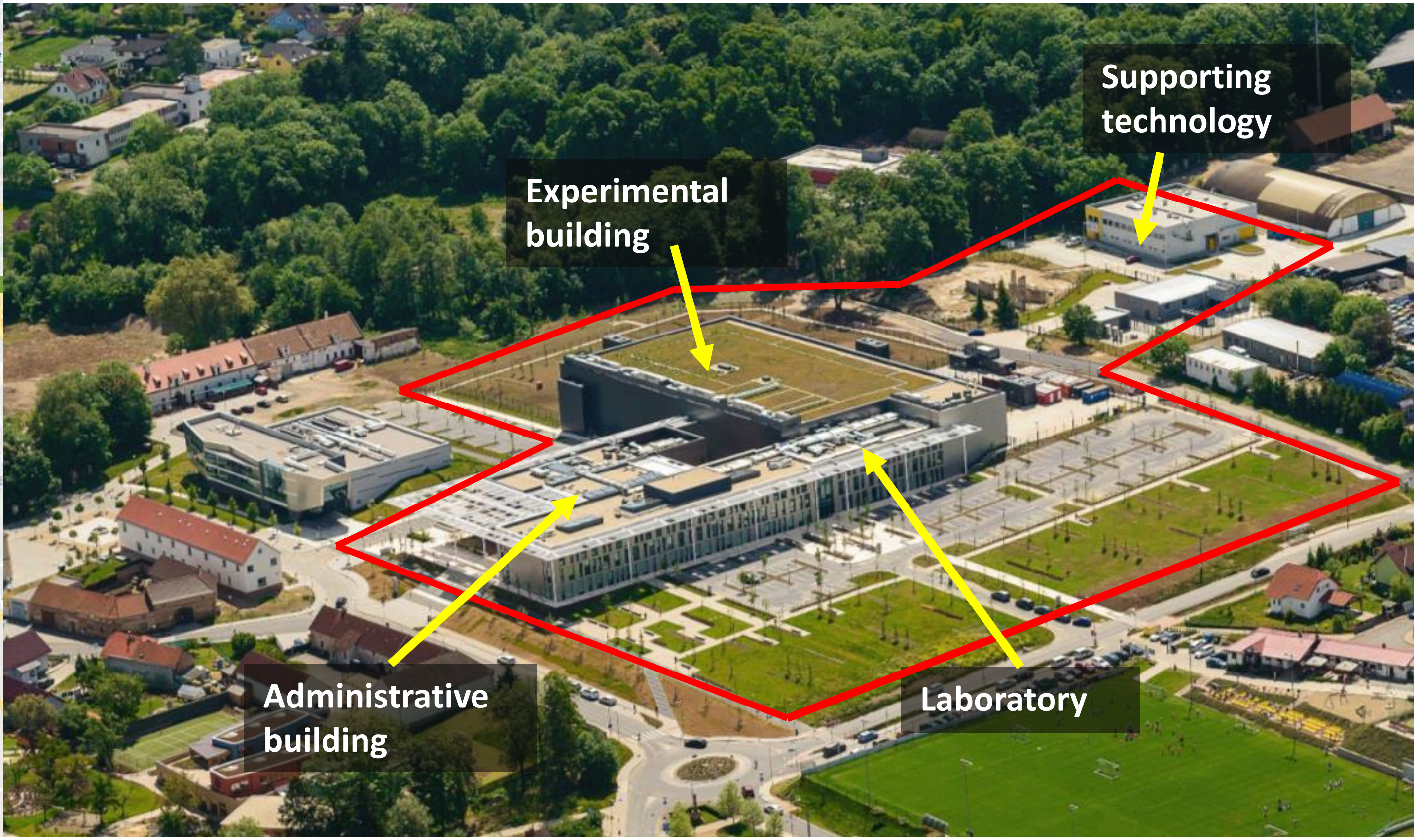
Videos from ELI NP: https://www.youtube.com/channel/UC8_QtgJqMppmfJF3rxgwAHA

ELI Beamlines

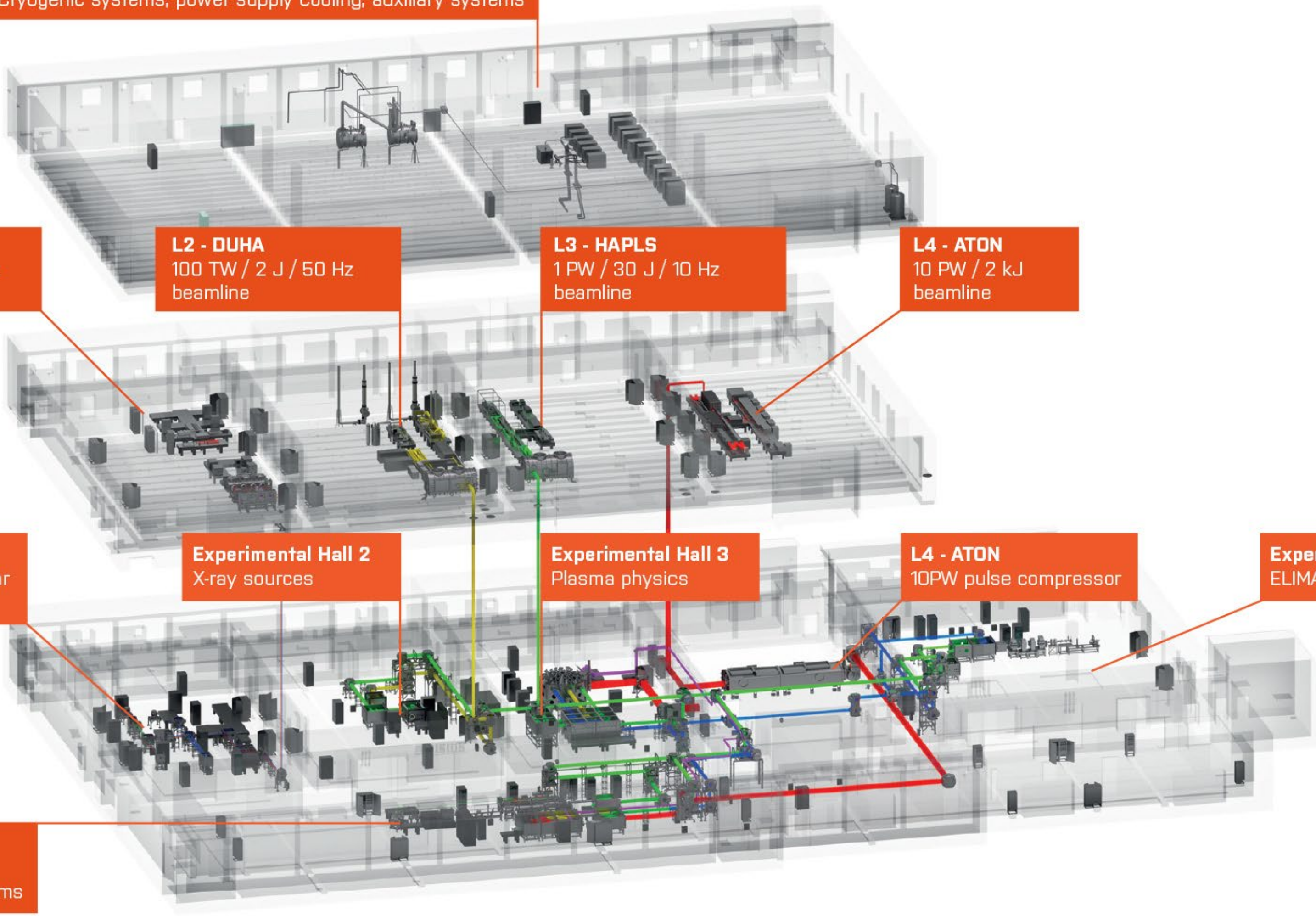
Integrated in the ERIC from 1.1.2023

Located on the outskirts of Prague





ELI Beamlines



Support Room
Cryogenic systems, power supply cooling, auxiliary systems

First Floor

L1 - ALLEGRA
5 TW / 100 mJ / 1 kHz
beamline

L2 - DUHA
100 TW / 2 J / 50 Hz
beamline

L3 - HAPLS
1 PW / 30 J / 10 Hz
beamline

L4 - ATON
10 PW / 2 kJ
beamline

Ground Floor
Laser Systems

Experimental Hall 1
Material & biomolecular applications

Experimental Hall 2
X-ray sources

Experimental Hall 3
Plasma physics

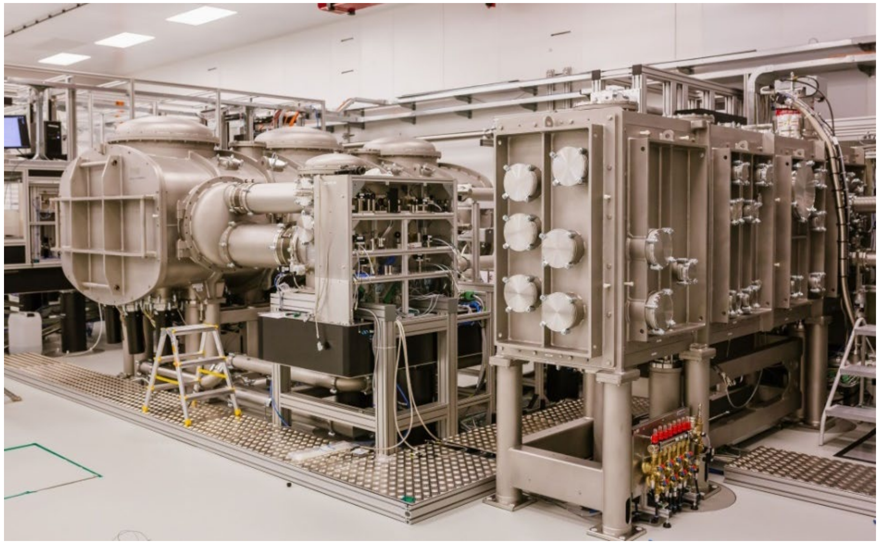
L4 - ATON
10PW pulse compressor

Experimental Hall 4
ELIMAIA - ion acceleration

Basement
Experimental Halls

Experimental Hall 5
Electron acceleration
LUX and HELL platforms

L1-Allegra: 10 TW, 100 mJ, 1 kHz

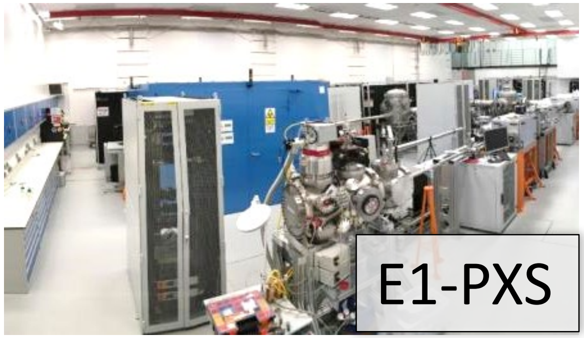


L2-Duha: 100 TW, 2 J, 50 Hz

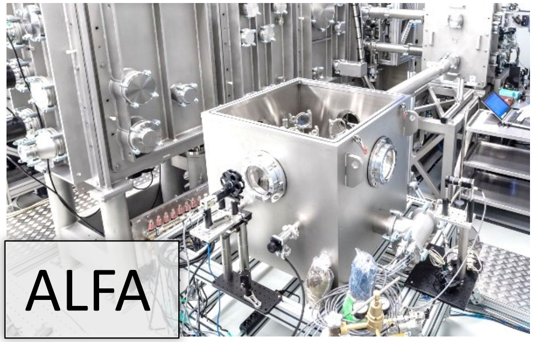
L3-HAPLS: 1 PW, 30 J, 10 Hz

L4-Aton: 10 PW, 1,5 kJ, 0,016 Hz

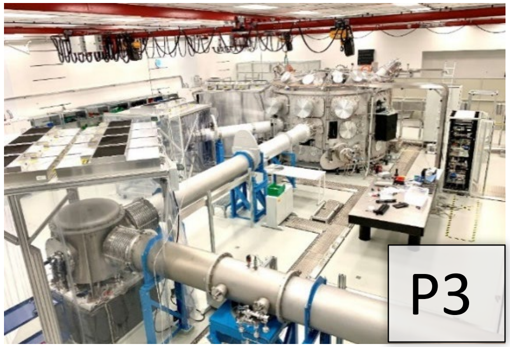
Experimental stations

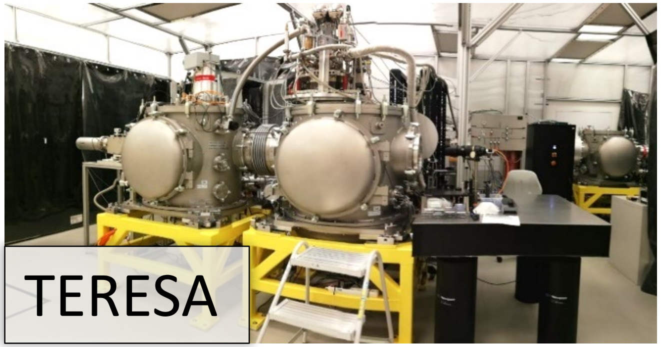

E1-PXS


E1-HHG

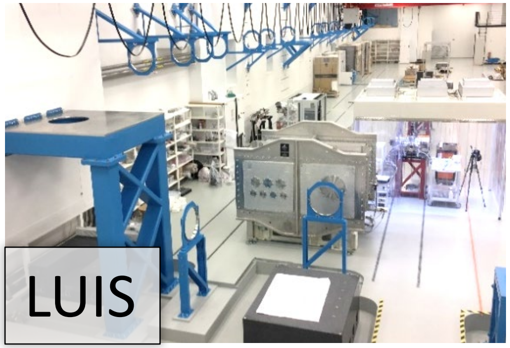

ALFA


ELBA


P3

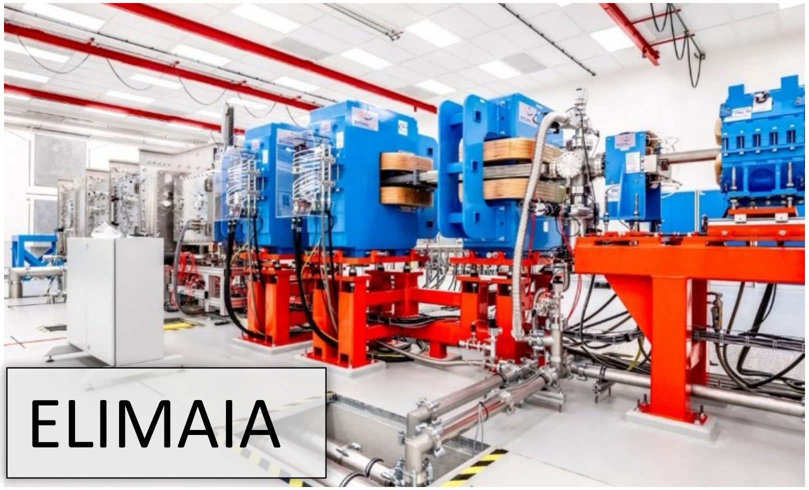

TERESA


E2


LUIS


ELIMAIA

Experimental stations


ELIMAIA

Ion acceleration

- Commissioning started in 2020
- 1st phase: protons up to 60 MeV
- Later 200-300 MeV


P3

Plasma physics

- Commissioning started in 2020
- Mixed source
  at large emission angles

Experimental stations

LUIS

From spontaneous to coherent electron radiation

- Commissioning started 05/2022
- Up to 600 MeV electron, 1% spread
- λph ~ 2-5nm (water-window)

ELBA

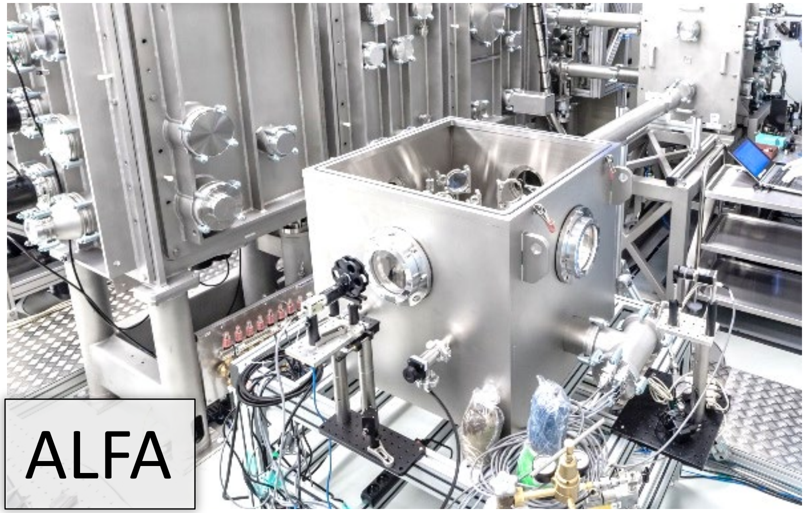
Electron acceleration

- Commissioning started 05/2023
- 1st phase: multi-GeV
  - 600 MeV last week ☺

Experimental stations

E2

- Installations ongoing
- Commissioning to start late 2023
- Electrons up to 2 GeV
- X rays used for experiments



ALFA Testbed

- Commissioning started in 2021
- Electron acceleration proof of concept
- ~150 MeV in spring 2022

Source term: General

Character of generated fields

- Pulsed – length of primary pulse ~10^{-14}s
- Low repetition rate: 0.1 Hz – 1 kHz
- Mixed – e-, p+, n, μ
- Wide spread of energies (10^0 eV to 10^9 eV)
- Extremely high dose rate in a single pulse
- Strong magnetic field (10^2 kV/m)

Source term not well known

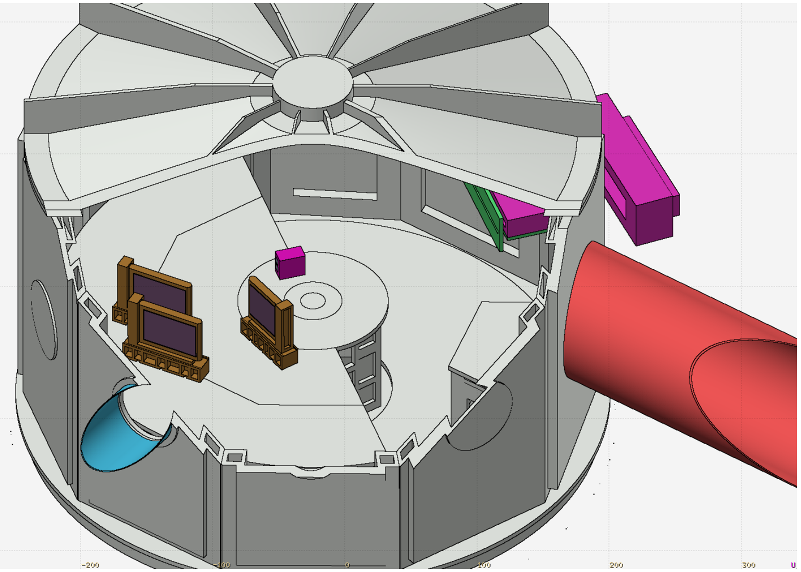
- Subject of research
- Strongly dependent on the experiment

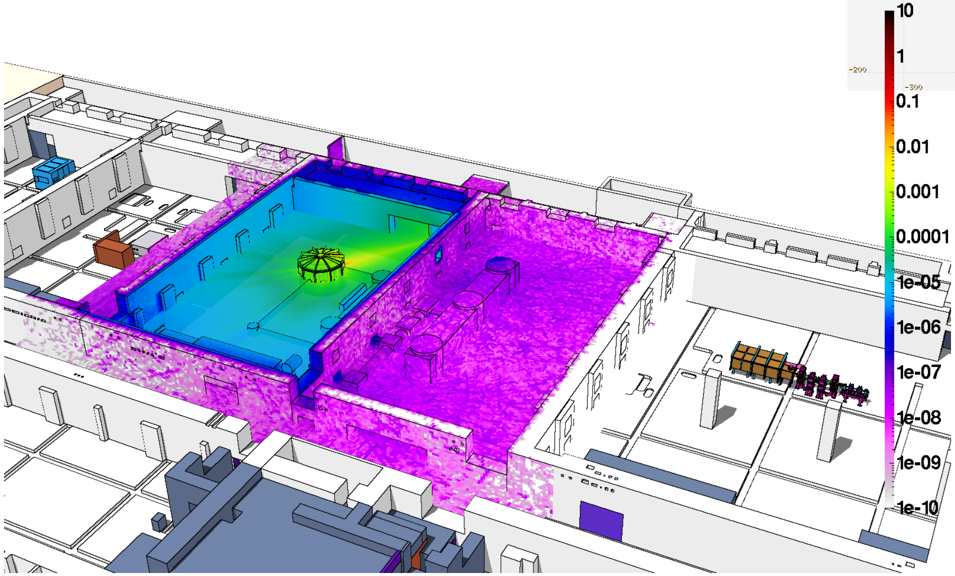
Monte Carlo simulations

Code FLUKA.CERN

Studies for model experiments:

- Dose rate maps
- Activation
- Radiation damage
- Shielding





Results as solid
as the knowledge of
the initial conditions

Monte Carlo simulations

Code FLUKA.CERN

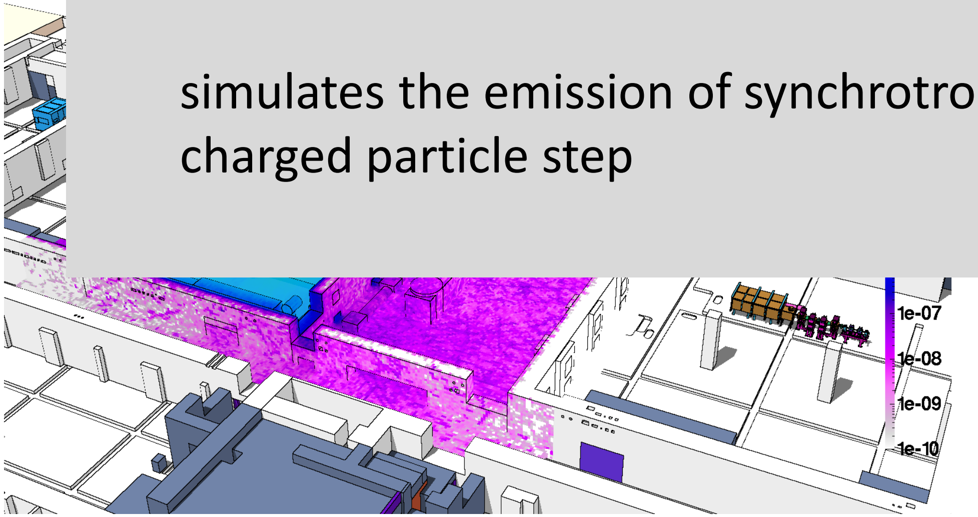
Studies for model experiments:

- Dose rate maps
- Activation
- Radiation damage

version 4-3.0 released in 09/2022

SYRASTEP card

simulates the emission of synchrotron radiation photons along charged particle step



the initial conditions

Personal safety systems

Interface between laser and experimental halls – gate valve in the BT

Laser halls

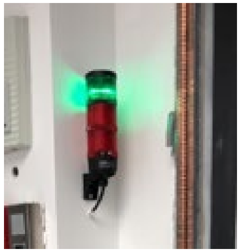
- LSS
- Laser hazard only
- Inhouse
- Running since 2018

Experimental halls: Temporary solution

- TPSS
- Laser and radiation hazards
- Allows operation with defined limitations
- Complemented with administrative measures
- Inhouse
- Running since 2020
- 2 halls (as of 2023)

Experimental halls: Targeted solution

- PSI
- Laser, radiation, vacuum, HV, gas…
- Rockwell automation
- Running:
  1 hall (2020)
  2 hall (2022)
  2 halls to install (2023)



Beam transport

- PSI
- Laser, vacuum hazard
- 1 BT – running (2022)
  1 BT installed
  1 BT to be done (2023)

RP standard measures

- People not allowed in the experimental area
  - laser and IR safety (covered by personal safety interlock)
- Monitoring system of ionizing radiation
  - For RP purposes – in the control room (γ, n)
  - In the experimental area (γ , n)
    - to benchmark simulations
    - to understand behaviour of the system
- Monte Carlo assessment

First experience (RP viewpoint)

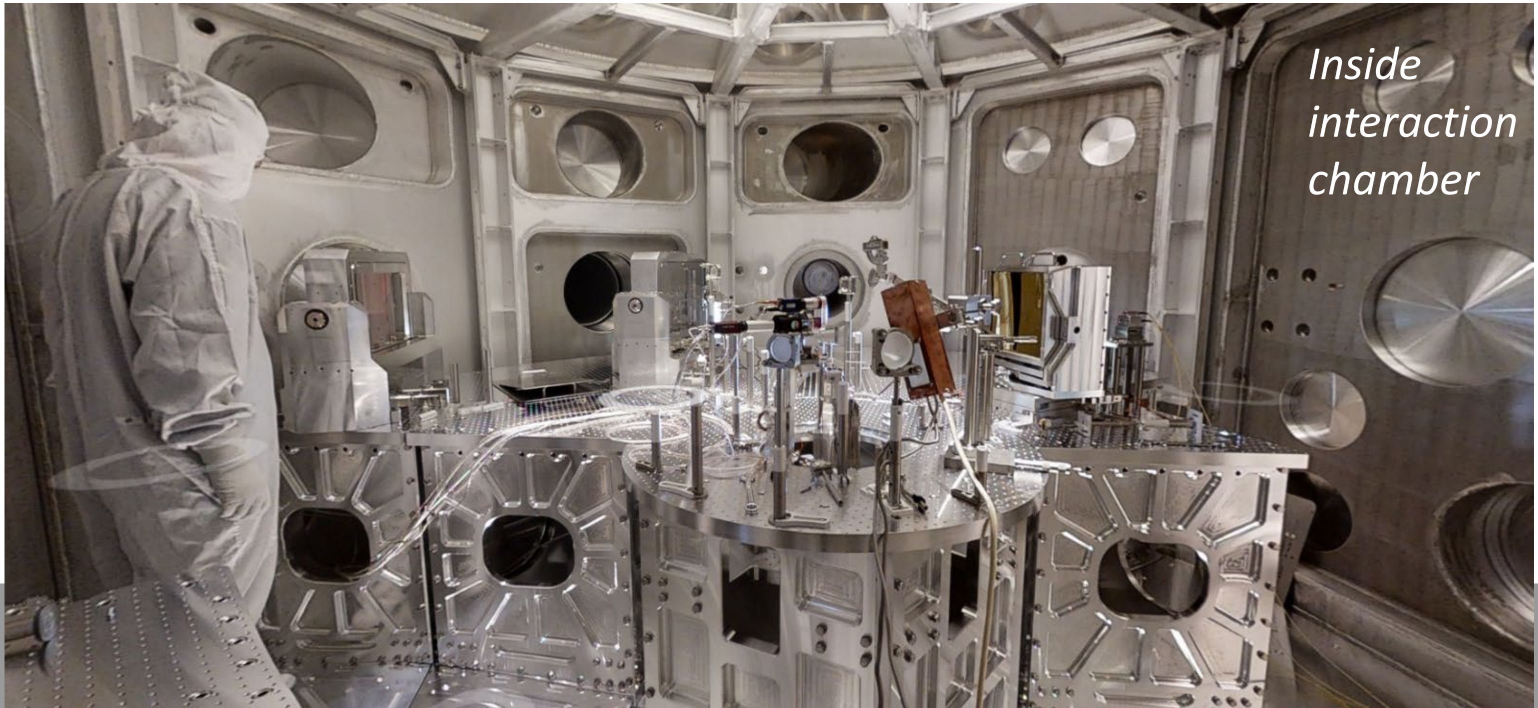
- Do not blindly trust your measurements!
- Tiny change in experimental setup can lead to very different radiation fields.
- No source term is weak enough to be neglected.

Do not blindly trust your measurements!

Do not trust measurements: SFL campaign

Goal of “Short Focal Length“ experiment

- Test of target systems
- L3 laser HAPLS, gradual ramp up to 12J, 3.10^{-14} s laser pulse length
- Single shots to sequences at 3.3 Hz for 20 s
- Production of X-rays and of low energy electrons
- Expected source term:
  10^{-7}C of electrons/shot, Maxwell-Boltzmann T=1.4 MeV



Inside interaction chamber

Do not trust measurements: SFL campaign

Given the

- expected source term
- total number of shots
- geometry (chamber wall 5 cm of Al)

NO radiation above background level **expected**

(avg bg <0.1 µSv/h)

The reality…

Do not trust measurements: SFL campaign

Given the

- expected source term
- total number of shots
- geometry (chamber wall 5 cm of Al)

NO radiation above background level **expected**
(avg bg <0.1 µSv/h)

The reality…

within first day of shooting:

~3 µSv/h – of neutrons
above 20 MeV!

Do not trust measurements: SFL campaign

Given the

- expected source term
- total number of shots
- geometry (chamber wall 5 cm of Al)

NO radiati ha

Oh wait…

Indeed?

The r

within first day of shooti

~3 μSv/h – of neutrons

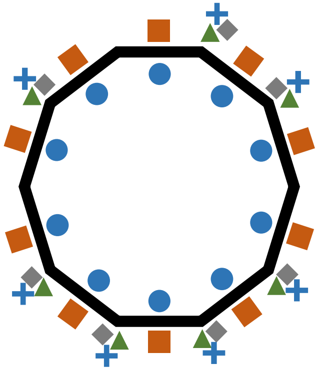
above 20 MeV!

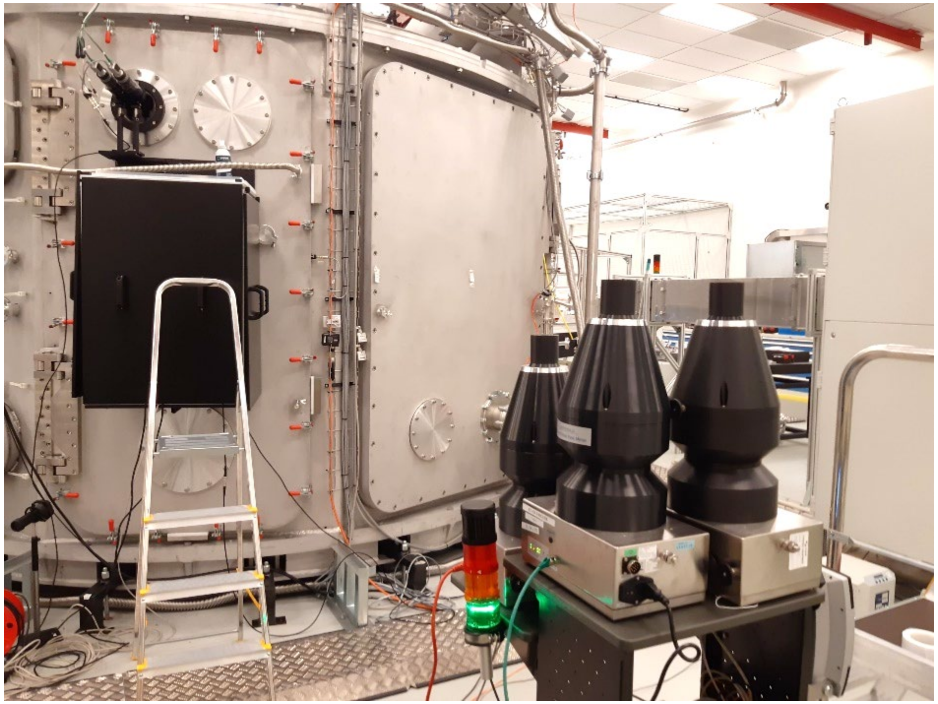
Do not trust measurements: SFL campaign

- Active systems:
  - LB6419-PANDORA
  - EPDn
  - Sensitive to γ only: EPDg, CryRad

- Passive systems
  - Bubble detectors
  - CR39
  - Sensitive to γ only: OSL, DIS

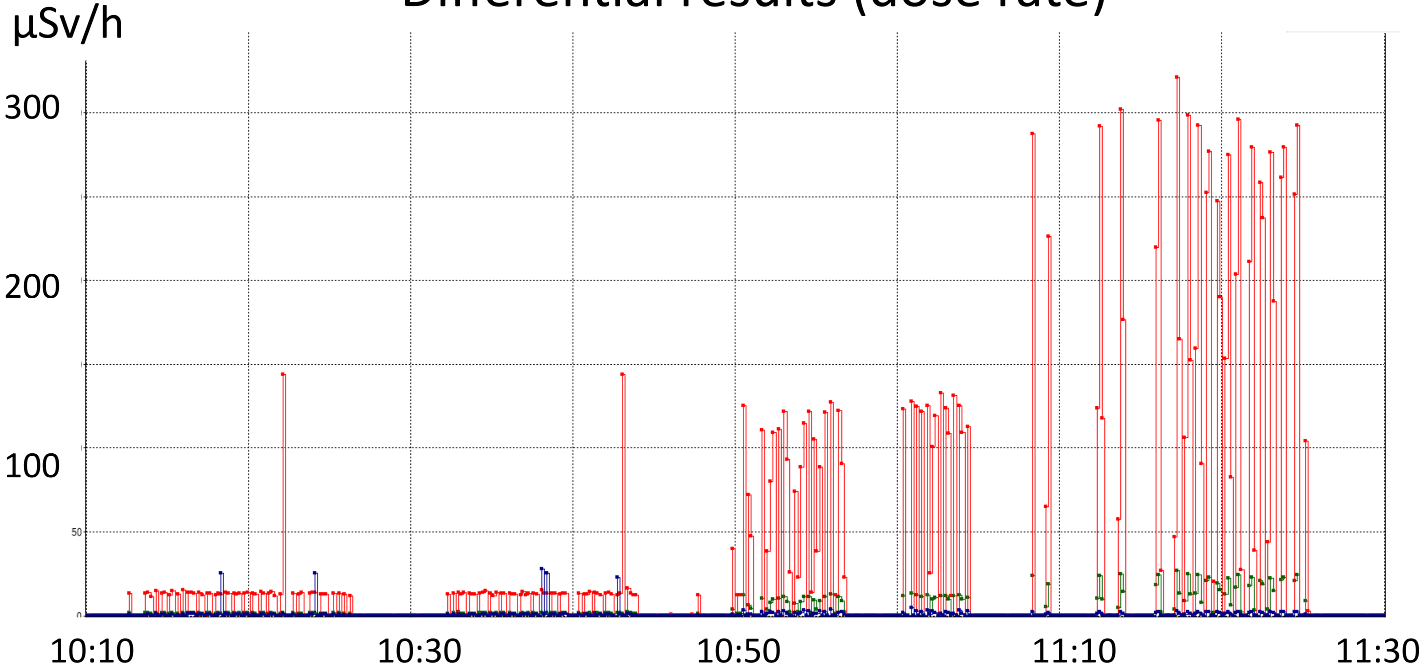
- At beam height
- Over 2π

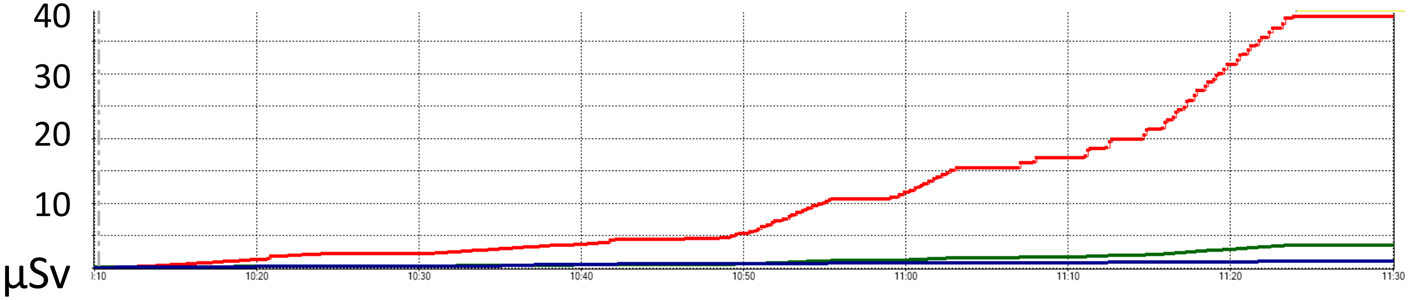




Do not trust measurements: SFL campaign

Differential results (dose rate)



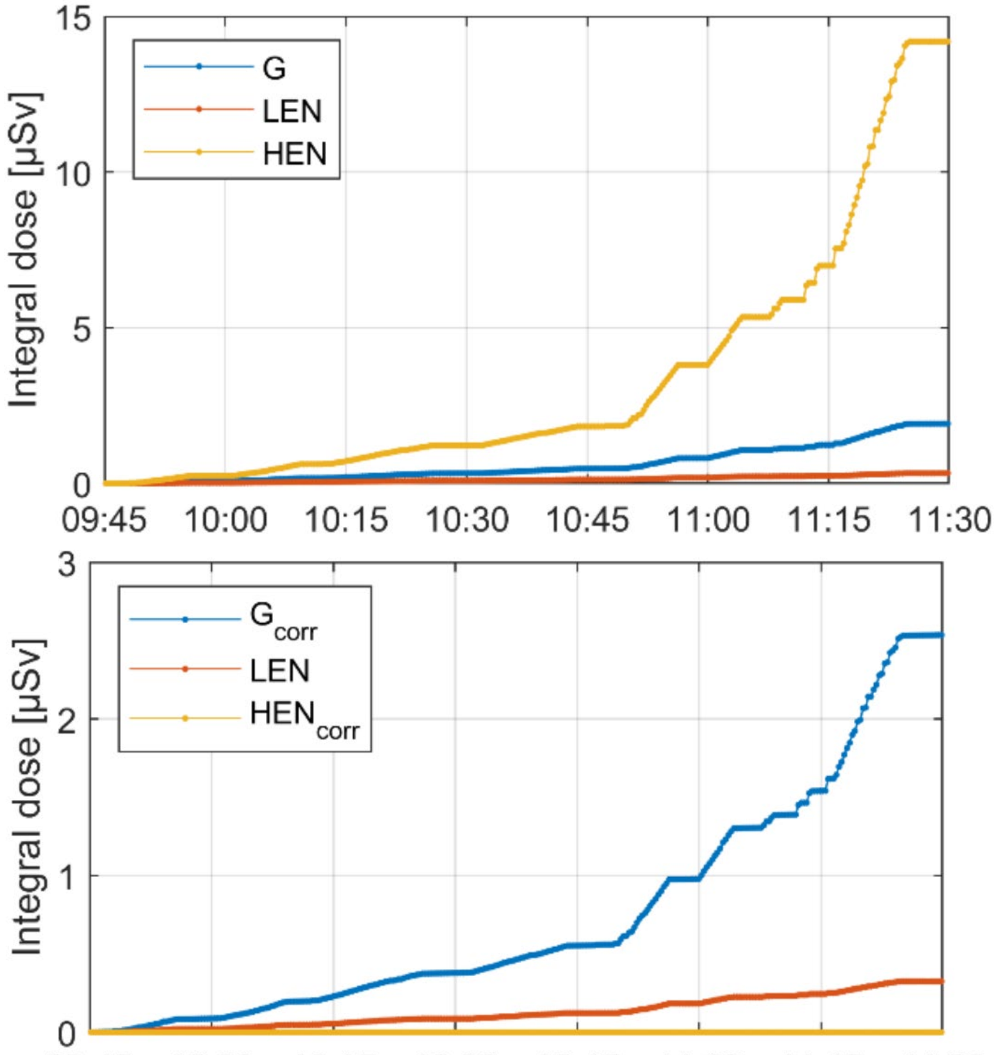


Integral results (dose)

● HE neutron
● LE neutron
● Gamma

LB6419 - Pandora

Do not trust measurements: SFL campaign



LB6419 – Pandora corrected

- ● LE neutron
- ● HE neutrons
- ● gamma

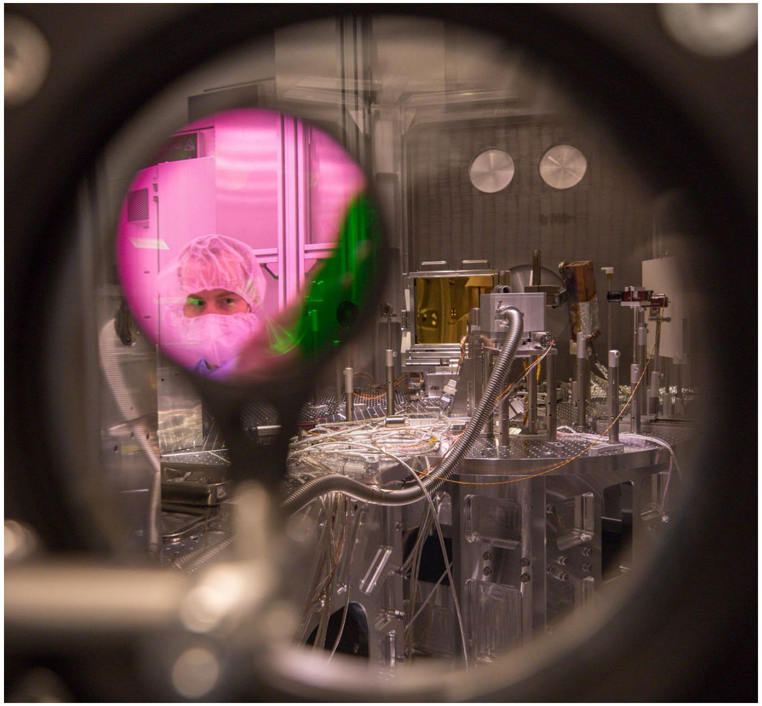
Interpretation with the fundamental help of Albrecht Leuschner (DESY)

Do not trust measurements: SFL campaign

Bubble detectors	**~0.1 microSv**/day in 200 keV – 15 MeV region
Tracked-etched (CR39)	on **background** level
EPDn	up to **17 mSv**/day

- No correlation observed with
    - Laser energy
    - Target
    - Number of shots

- No high energy neutrons
- Low energy neutrons present – origin unclear. Prepulse?



View to P3 through a port

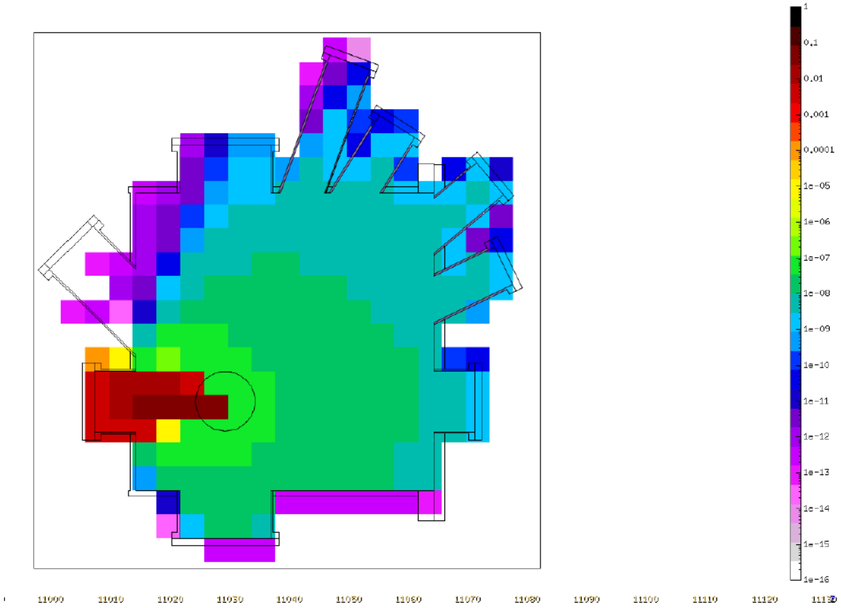
No source term is weak enough to be neglected

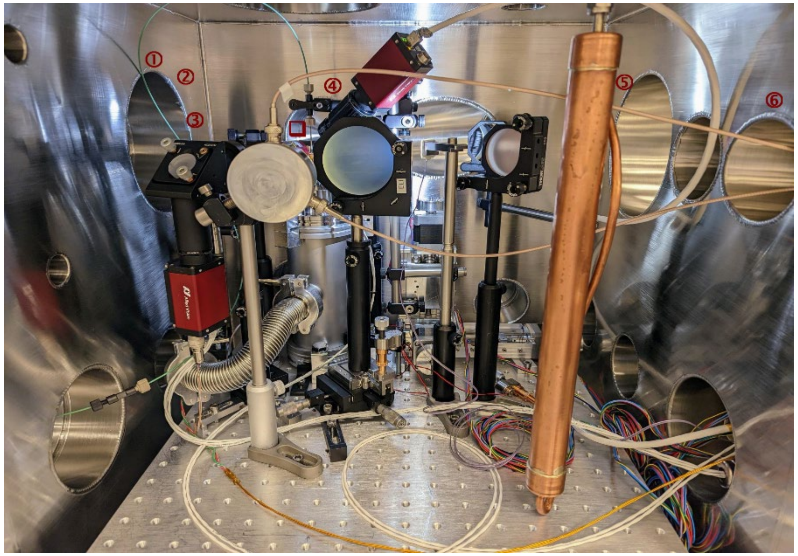
No weak source term: Astrella experiment

Small setup with a commercial Class 4 laser “Astrella“

- Rep. rate 1 kHz, water jet target
- Expected source term: protons, 1 MeV
- Wall: 1 cm thick steel

No measurable radiation expected outside the chamber





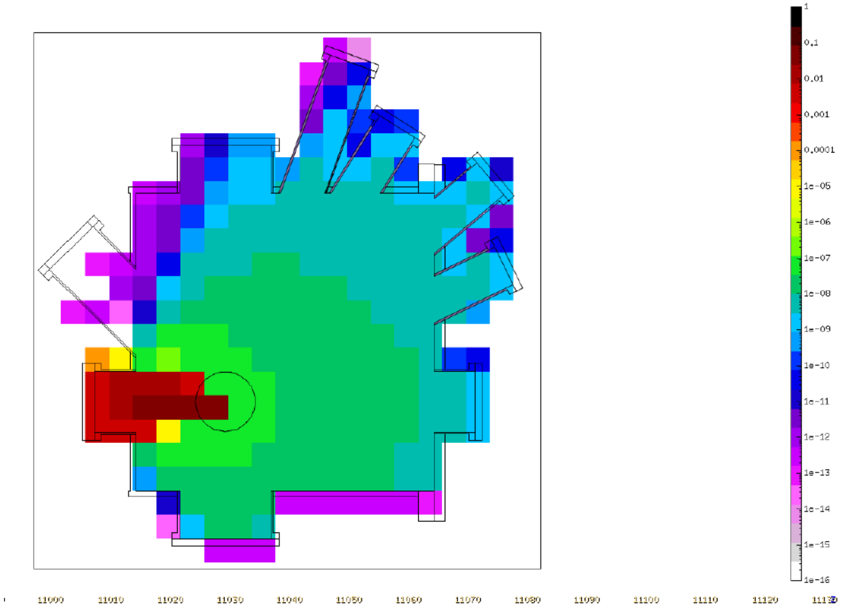
No weak source term: Astrella experiment

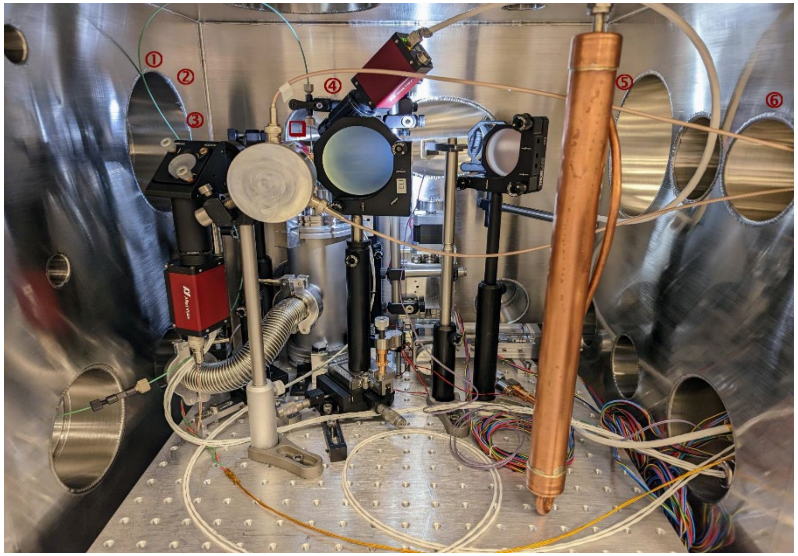
Small setup with a commercial Class 4 laser “Astrella“

- Rep. rate 1 kHz, water jet target
- Expected source term: protons, 1 MeV
- Wall: 1 cm thick steel

Reality: 12 uSv/h rate detected by EPD in close chamber vicinity

→ OSL installed, cumulative dose up to 200 uSv/over 12 hour operation



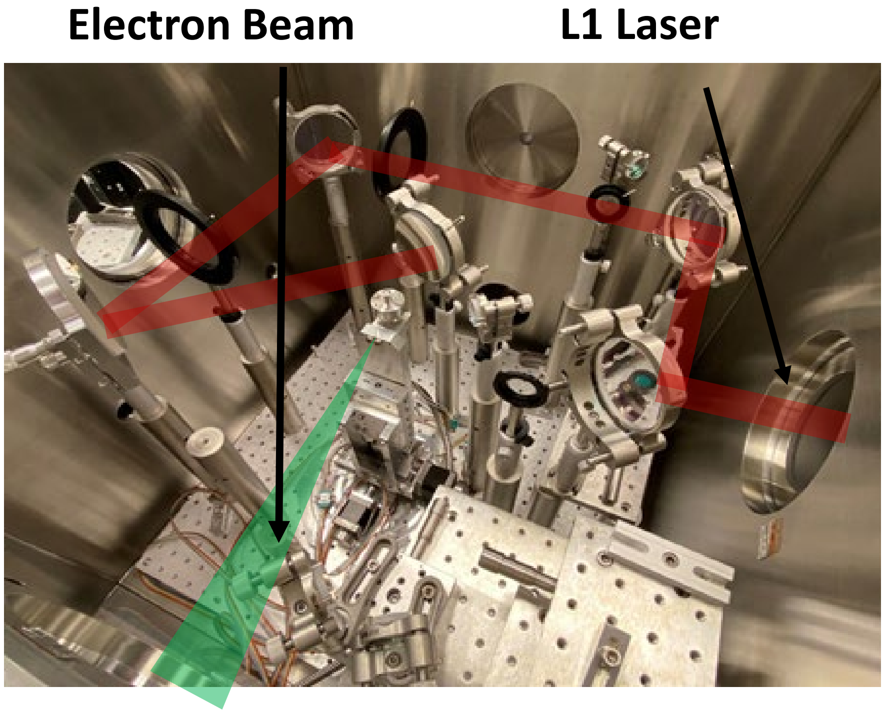


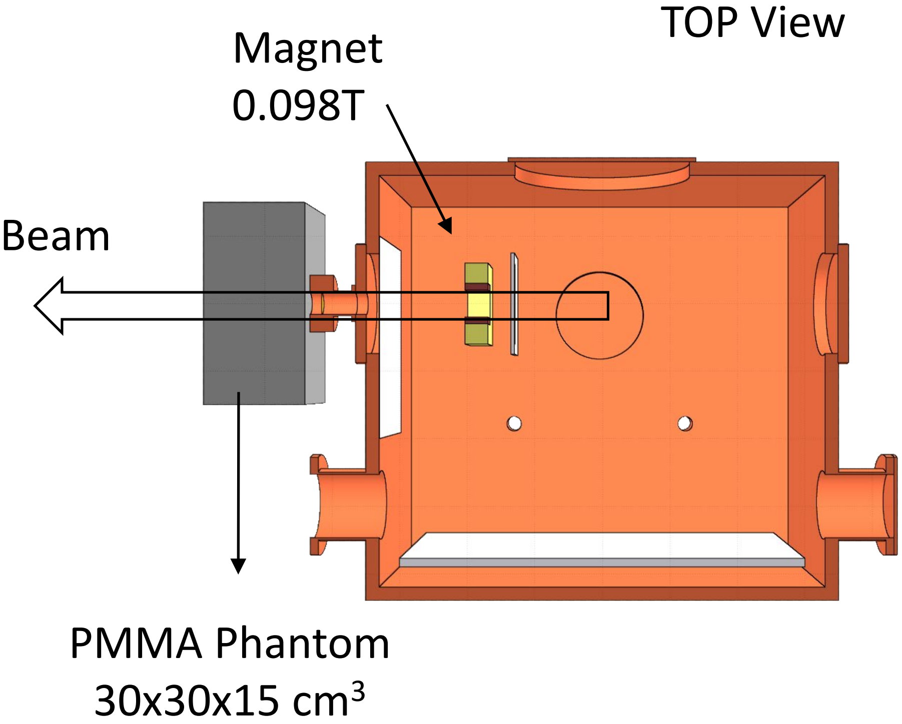
Tiny change in experimental setup can lead to **very different** radiation **fields**

Tiny change – big impact: ALFA Experiment

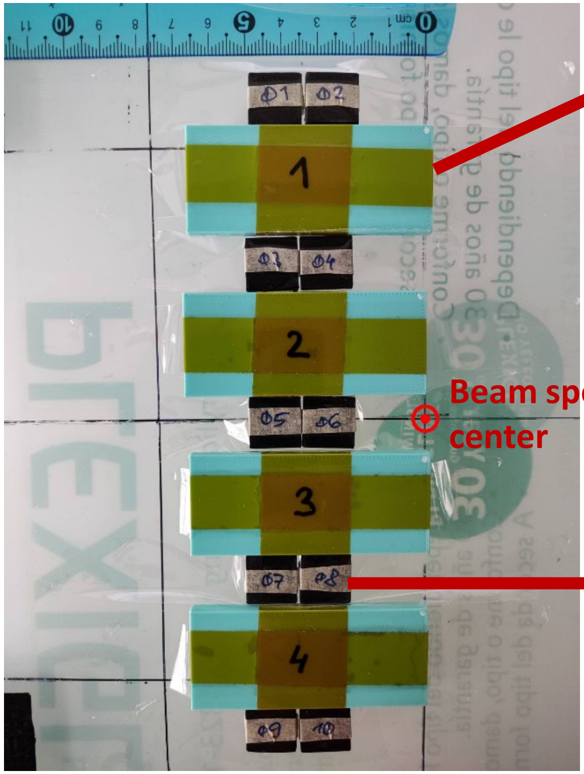
ALFA (Allegra Laser For Acceleration)

- Electron beam of energy up to 50 MeV
- Laser energy 16 mJ
- Repetition rate 550 Hz





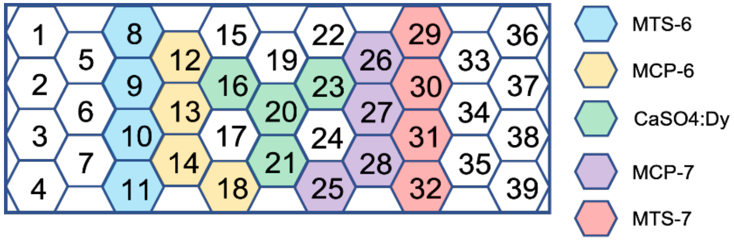
Tiny change – big impact: ALFA Experiment

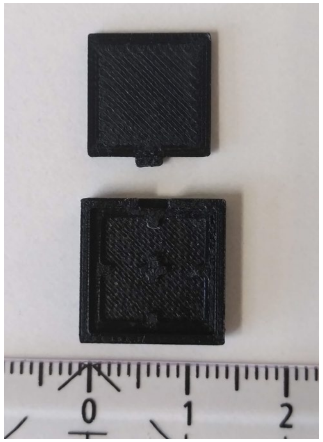


Beam spot center

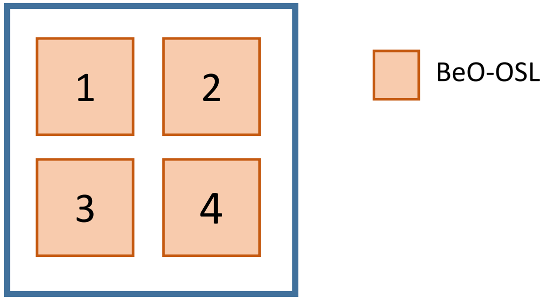
The dosimeters were placed on the front face of the PMMA phantom

Total: 80 TLDs

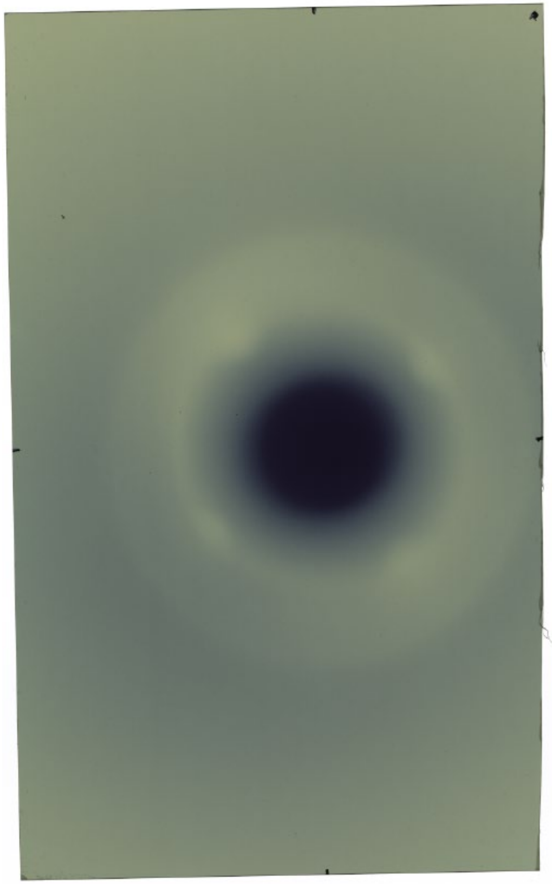




Total: 40 Be-OSLs



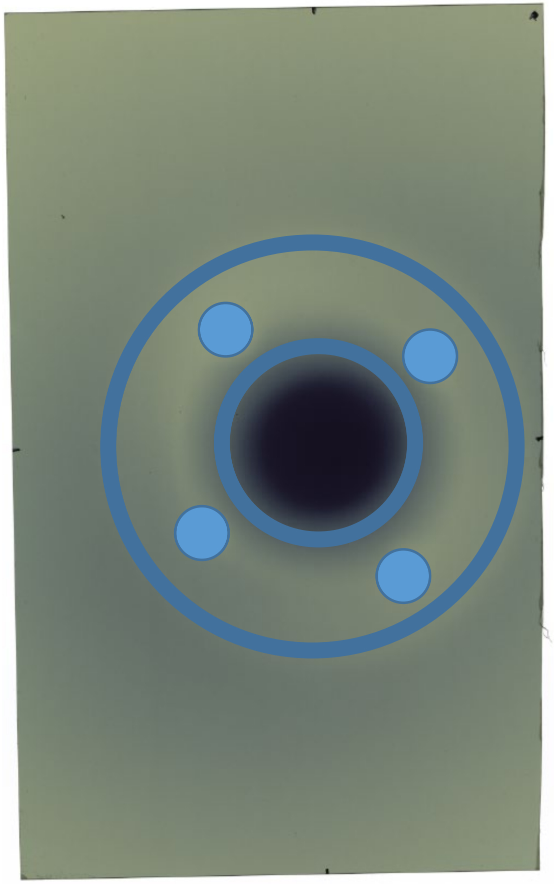
Tiny change – big impact: ALFA Experiment



GAFChromic film scan

- **Irradiation time =** 400s
- **Total pulses =** 220 000 pulses
- **Beam profile=** 1 MeV to 13 MeV
- **Divergence =** 12 mrad @ 5 MeV
- **Average energy =** 3-4 MeV
- **Average dose =** 1,45 mGy

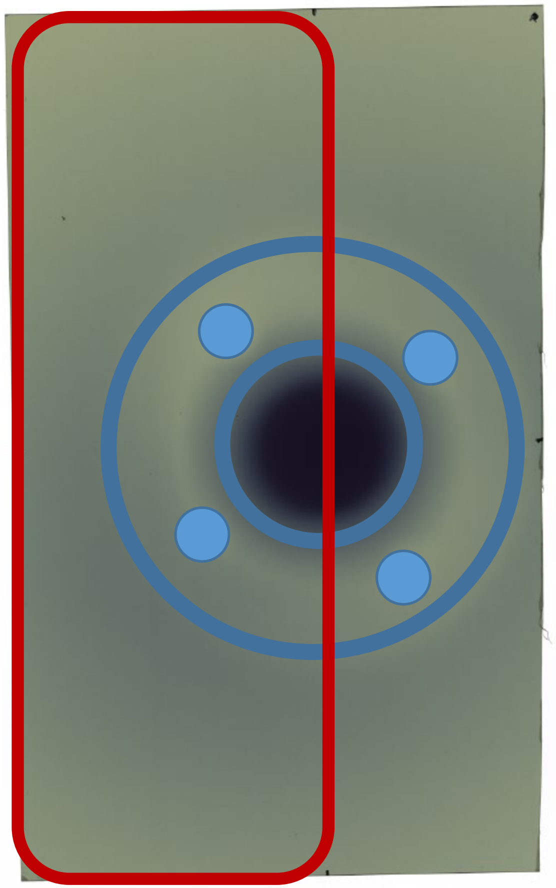
Tiny change – big impact: ALFA Experiment



GAFChromic film scan

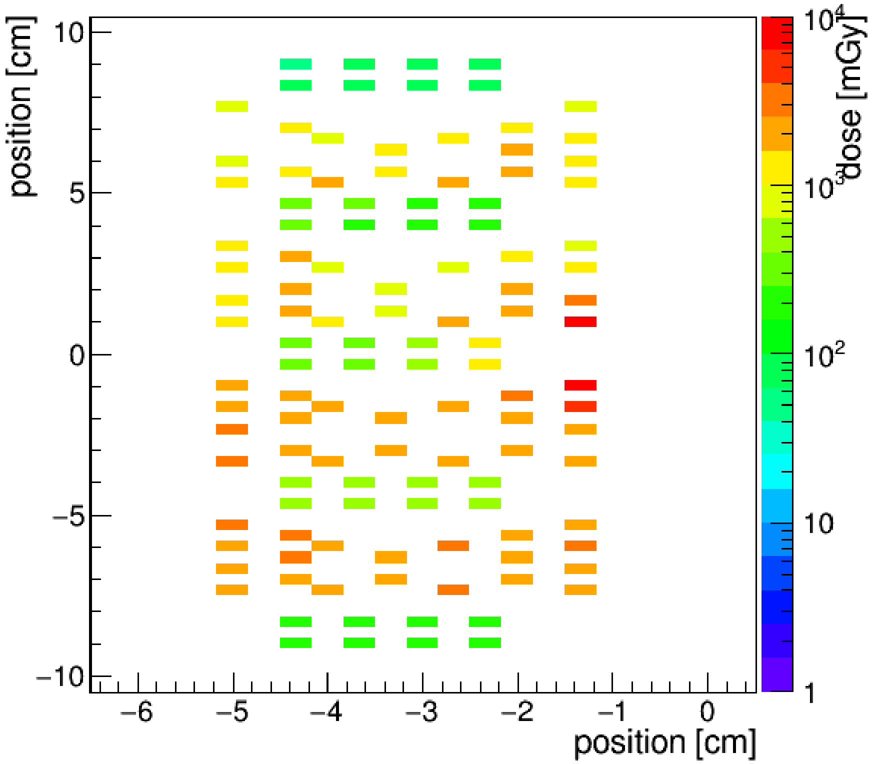
- Shadows of the flange (~4cm form beam axis) and its 4 screws

Tiny change – big impact: ALFA Experiment



GAFChromic film scan

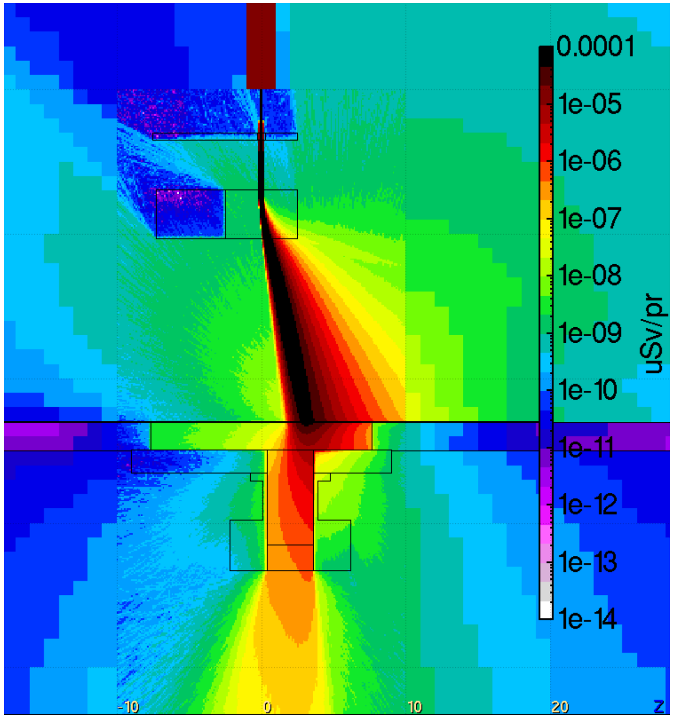
- Shadows of the flange (~4cm form beam axis) and its 4 screws
- Results from passives difficult to interpret

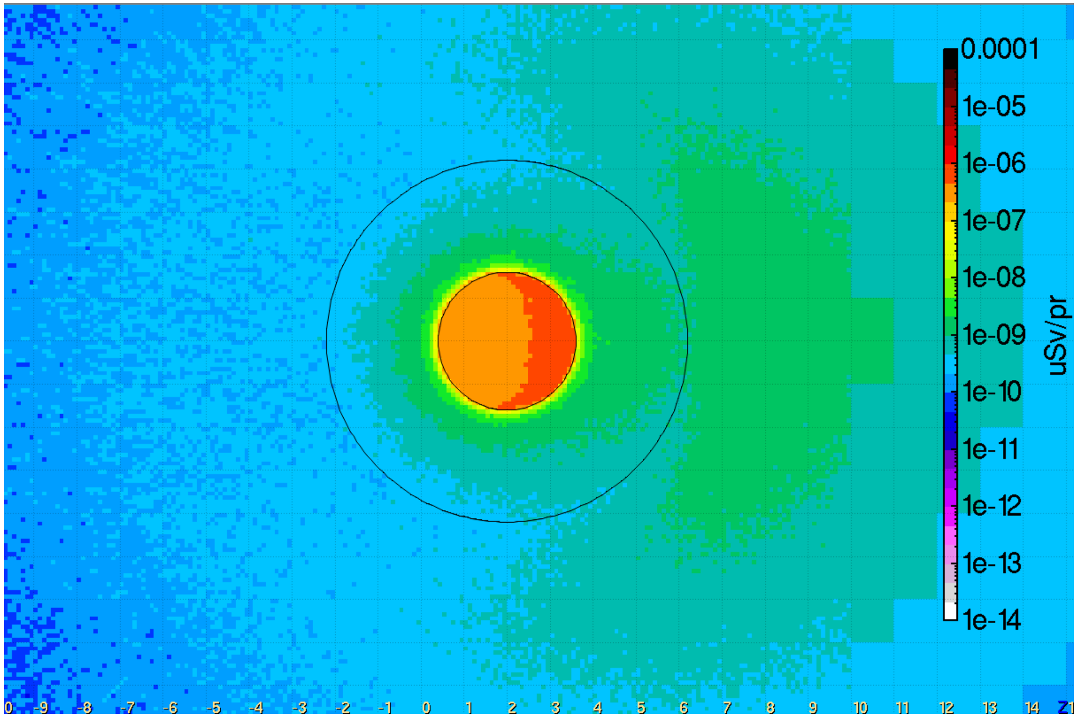


Tiny change – big impact: ALFA Experiment

FLUKA Monte Carlo

- Electrons: 3.5 MeV Average – 2.5 MeV FWHM
- 12 mrad divergence
- Magnet centered with beam axis

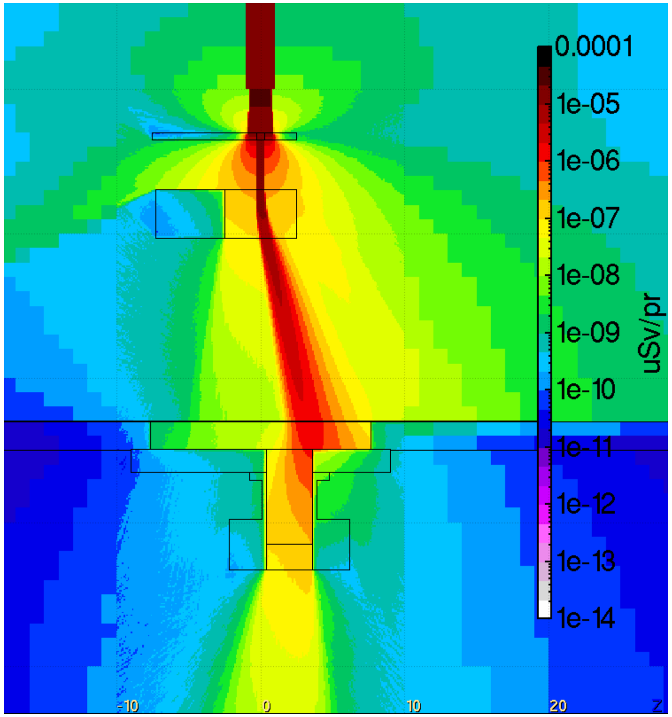


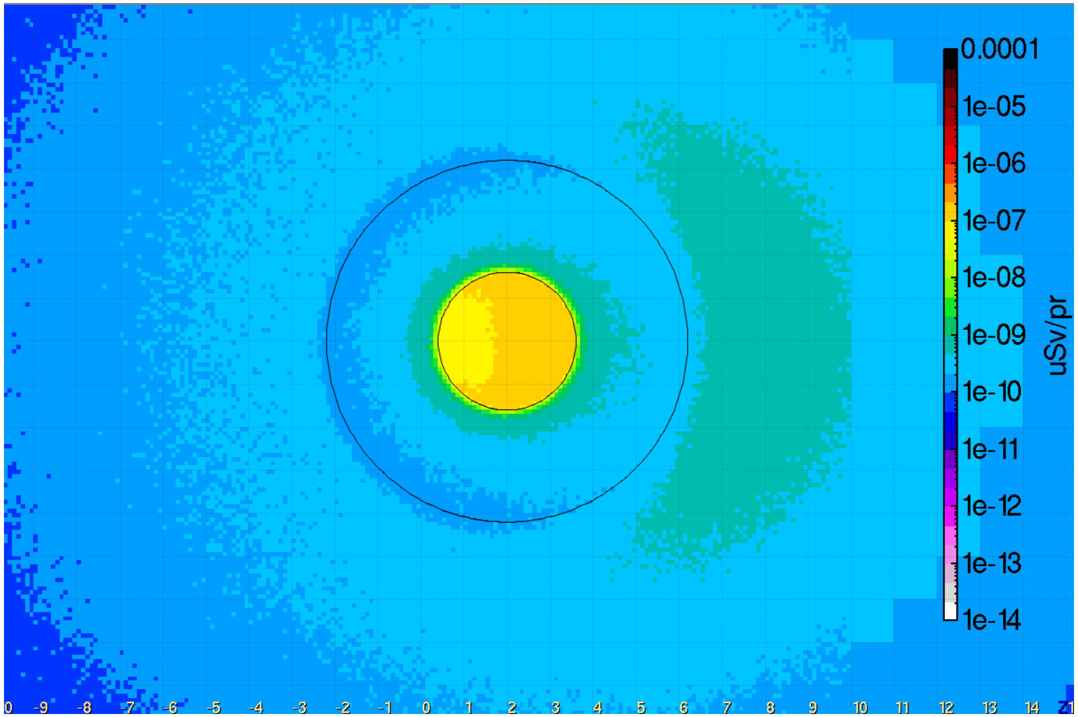


Tiny change – big impact: ALFA Experiment

FLUKA Monte Carlo

- Electrons: 3.5 MeV Average – 2.5 MeV FWHM
- 100 mrad divergence
- Magnet centered with beam axis

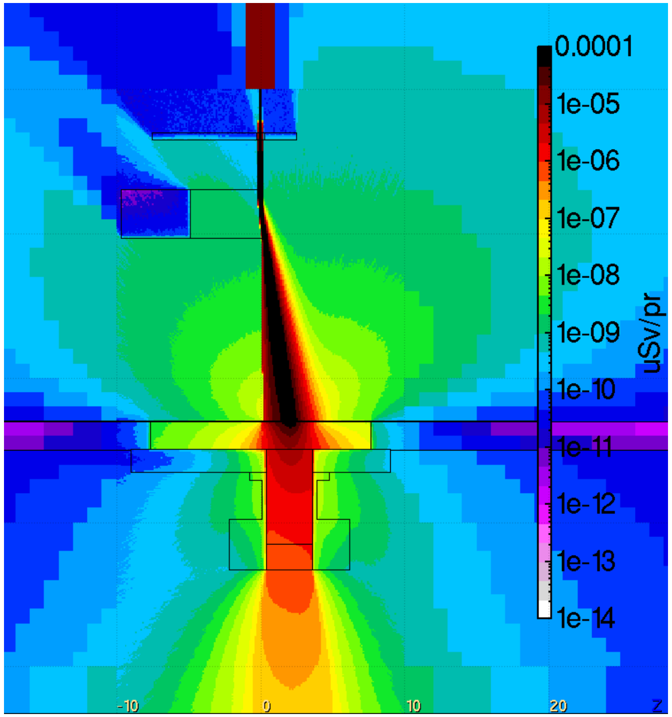


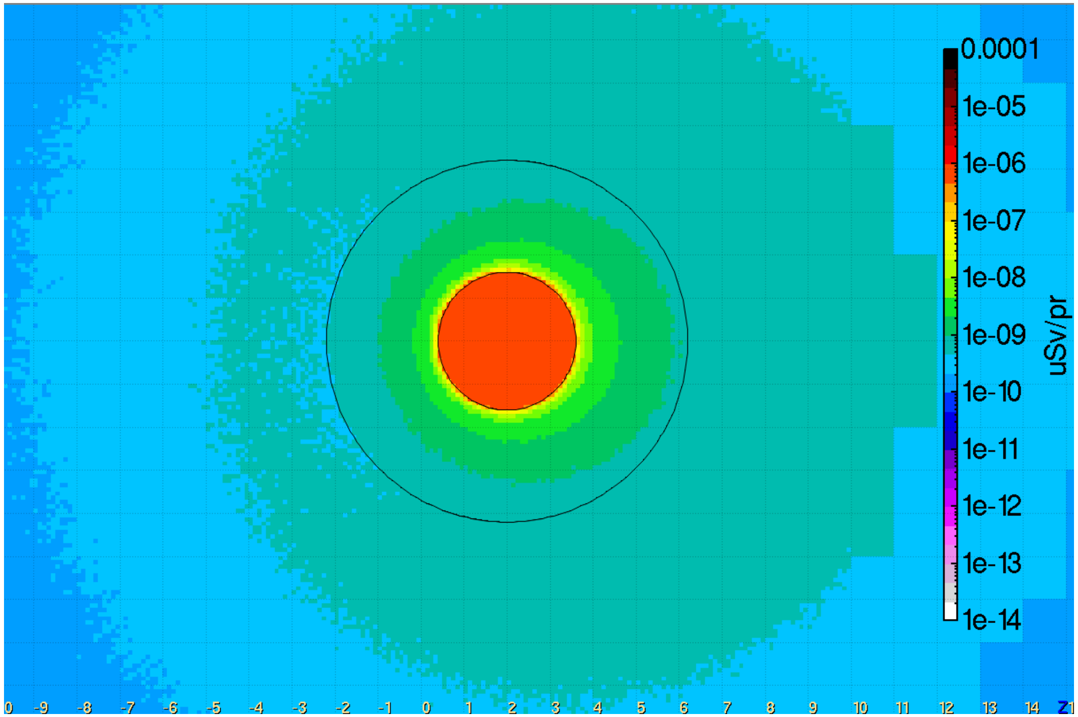


Tiny change – big impact: ALFA Experiment

FLUKA Monte Carlo

- Electrons: 3.5 MeV Average – 2.5 MeV FWHM
- 12 mrad divergence
- Magnet shifted (maximum fluence)





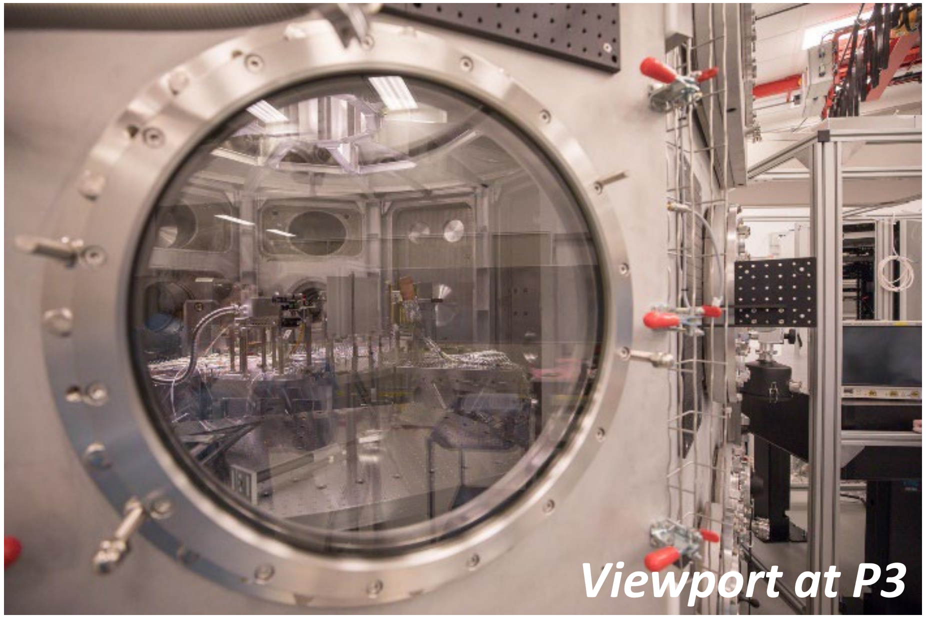
Conclusions

- The interlock and monitoring systems worked perfectly
- Ambient dose levels in populated areas compatible with background
- Designed shielding and protection measures proved adequate

Conclusions

- MC simulations:
  - As solid as the input
  - Cannot reproduce campaigns with too many unknown parameters
  - Problem: shot-to-shot differences

- Radiation generated:
  - Often more energetic than expected



Viewport at P3

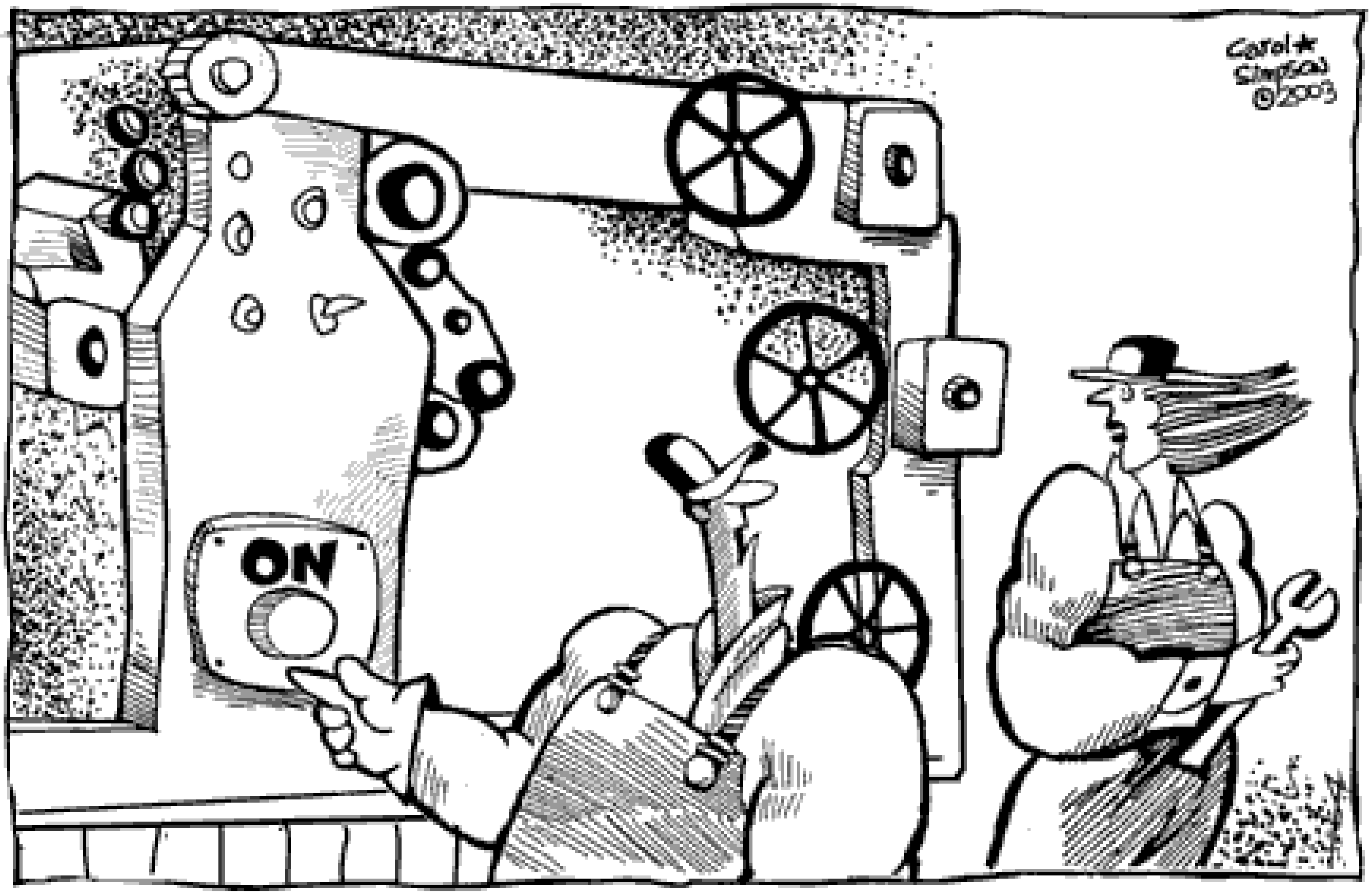
Conclusions

Be suspicious!

- Higher safety factor than in conventional facilities is needed
- Interpretation of detector readings requires critical thinking

Future plan:

- Have a dedicated campaign, with fixed laser parameters (as many as possible)



"This machine is perfectly safe...
As long as you never press this button."

THANK YOU FOR YOUR ATTENTION

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