# Silicon carbide neutron detectors for reactor monitoring in subcritical conditions

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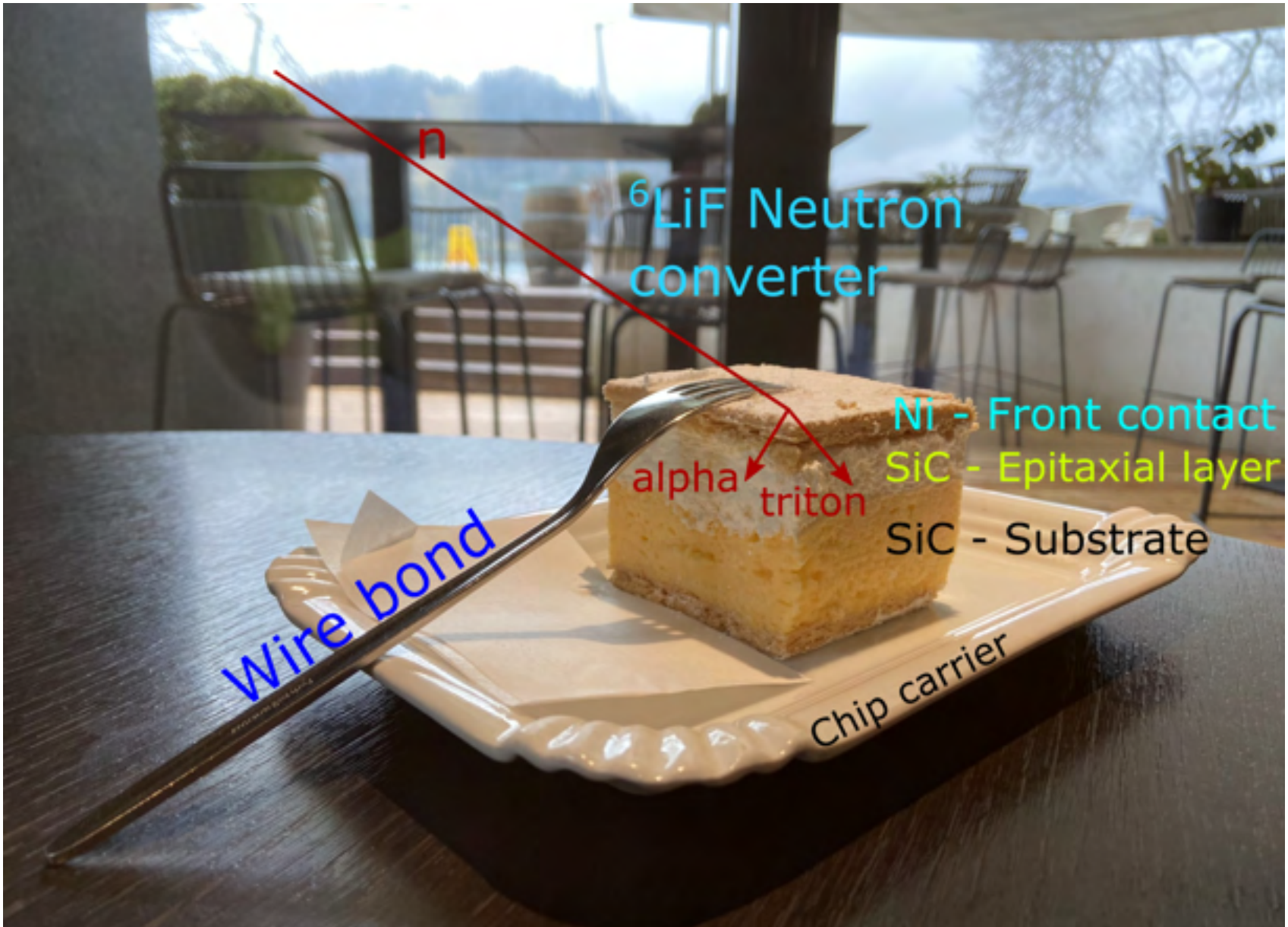
ANIMMA 2025, June 9-13, Valencia, Spain

# Motivation & Objectives

- SiC - **hot topic** in radiation detection research
  - Wide bandgap semiconductor
  - Radiation hardness
  - $\rightarrow$ high T
  - $\rightarrow$ harsh environments
- Power electronics based on SiC
- First applications of SiC are emerging
- **Our research**: sensitivity, converters, applications, education

# Bled cream cake (blejska kremšnita)

# SiC neutron detector (SBD)

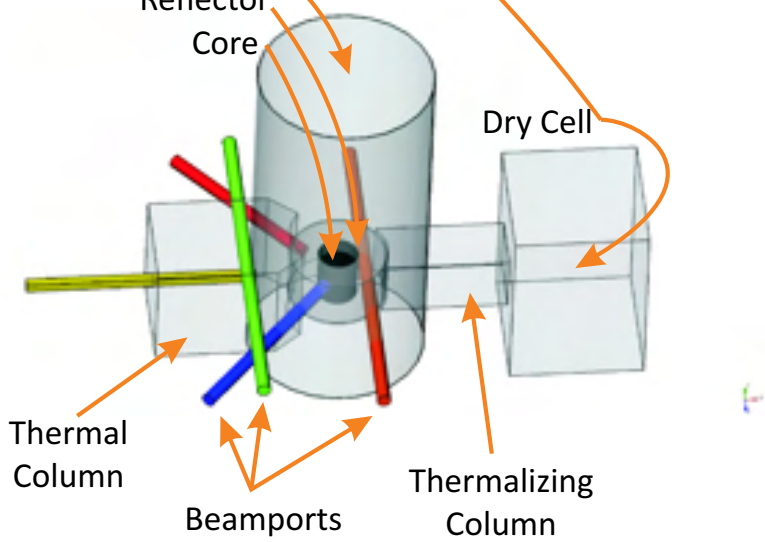


# Past research work

- 2016-2022: 2x NATO-SPS funded research projects (E-SiCure, E-SiCure2)
  - Rudjer Bošković Institute, Zagreb, Croatia
  - ANSTO, Sydney, Australia
  - QST, Takasaki, Japan
  - University of Aveiro, Portugal
  - Jožef Stefan Institute, Ljubljana, Slovenia

# JSI TRIGA reactor

- Neutron detection testing
- Power: 50 mW - 250 kW
- Max. neutron flux: $2 \times 10^{13}\ n\ cm^{-2}s^{-1}$



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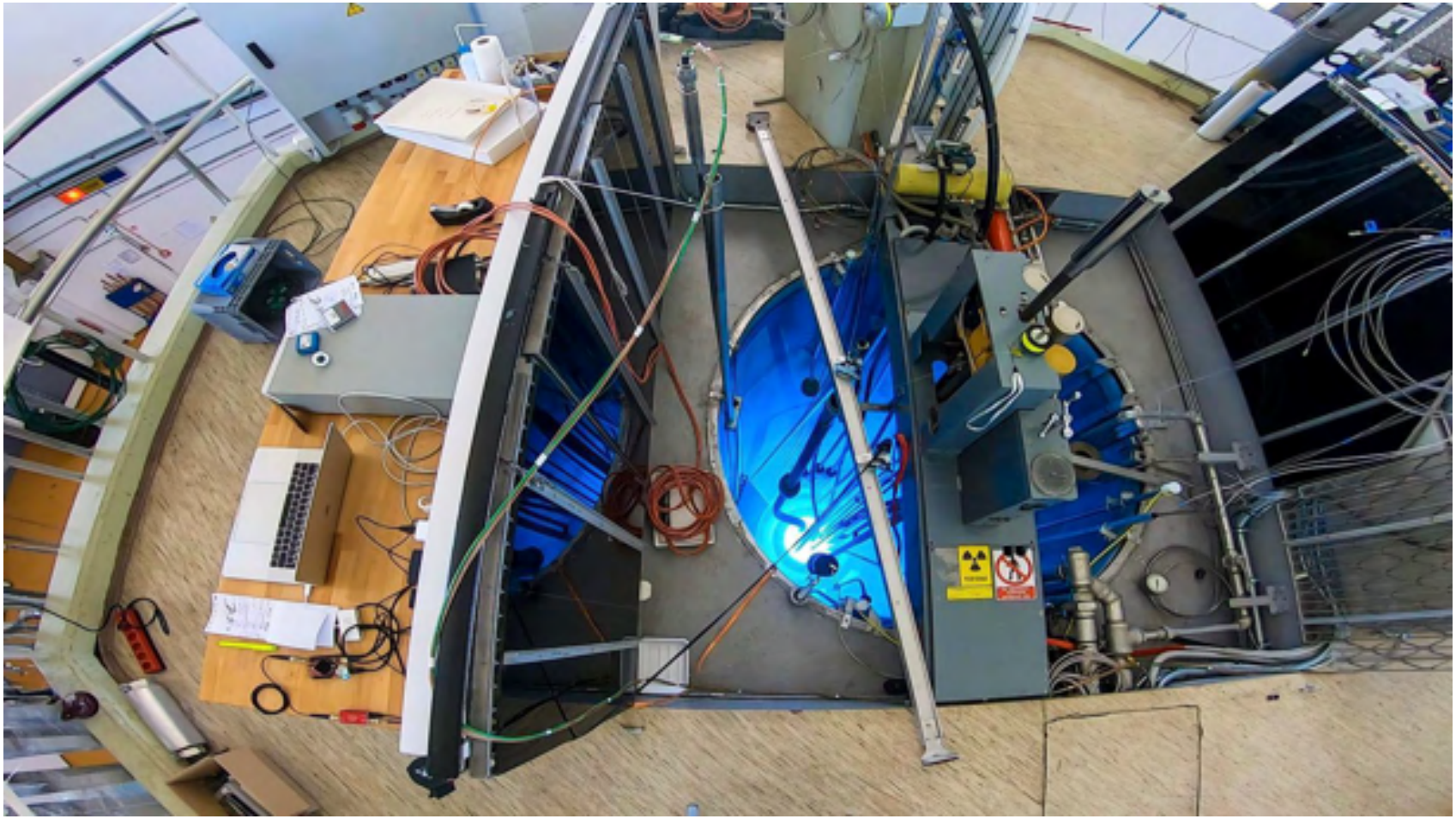

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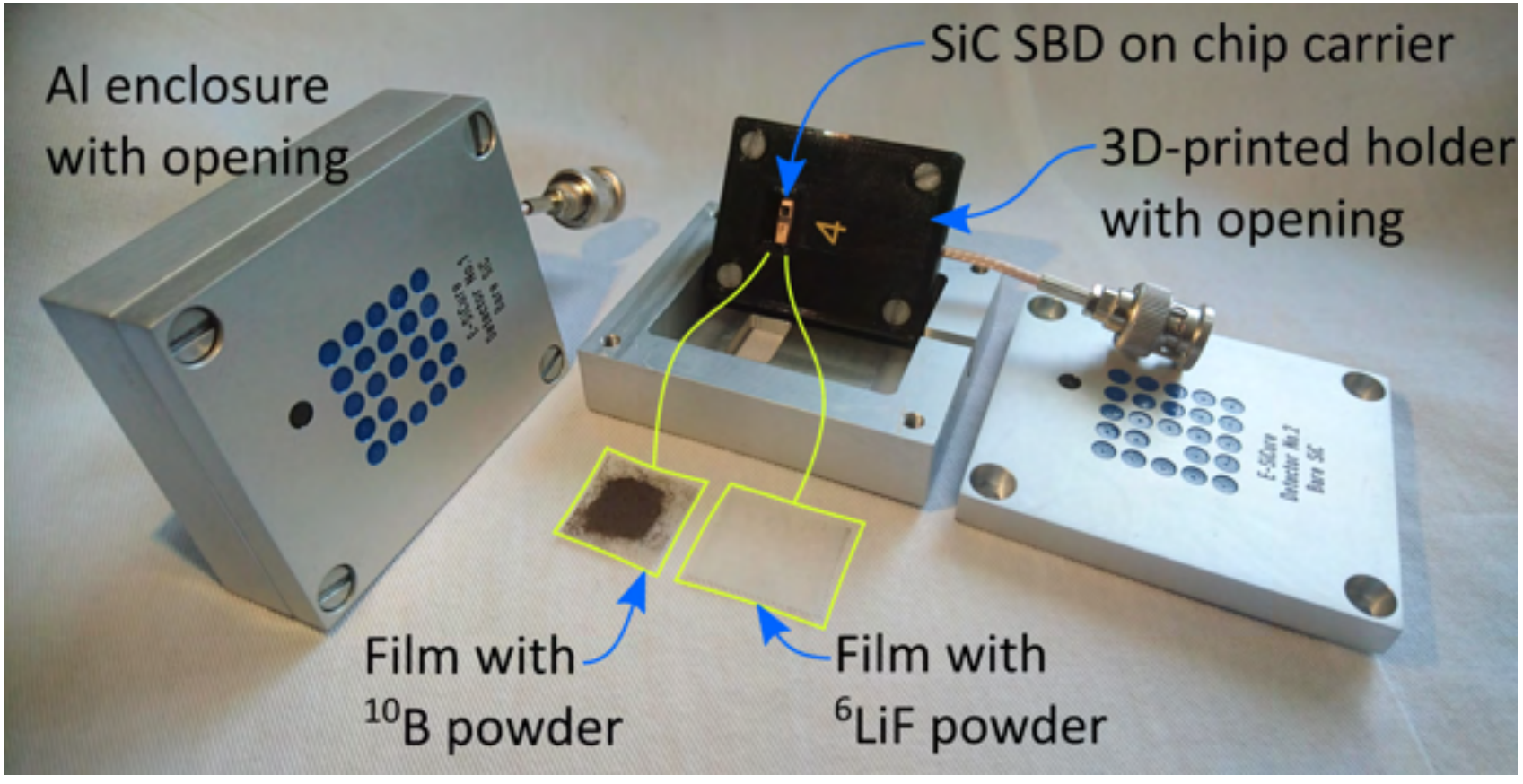


- Detector areas: 1x1 mm$^2$, 2x2 mm$^2$, 3x3mm$^2$, 4x4$^2$, 5x5mm$^2$, 10x10mm$^2$
- Converters: $^{6}$LiF, $^{10}$B / $^{10}B_4C$, $\mu$m layers
- Sensitivities (cps/nv): $10^{-5}$ (1x1), $10^{-3}$ (2x2), $10^{-2}$ (10x10)

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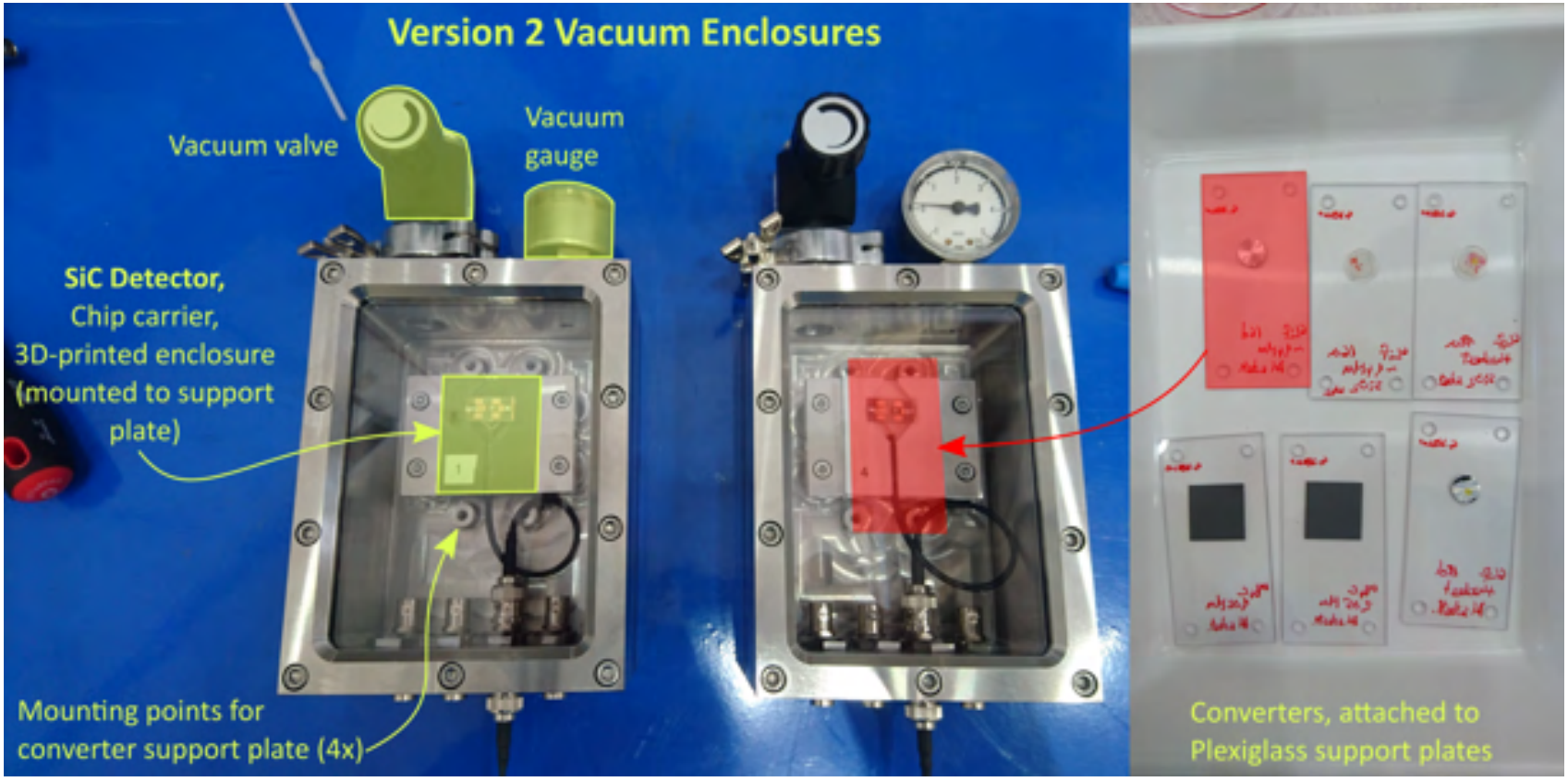

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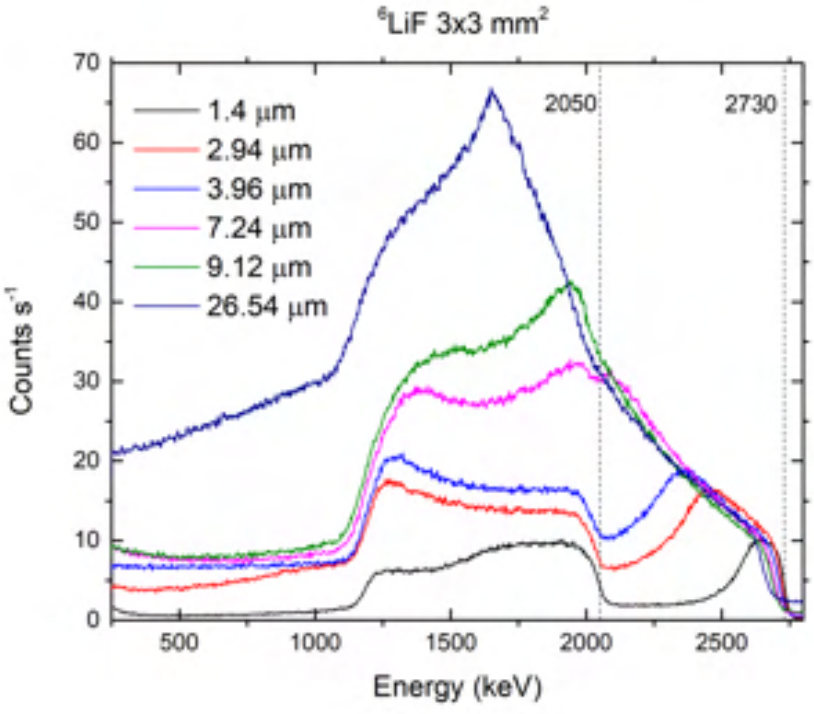


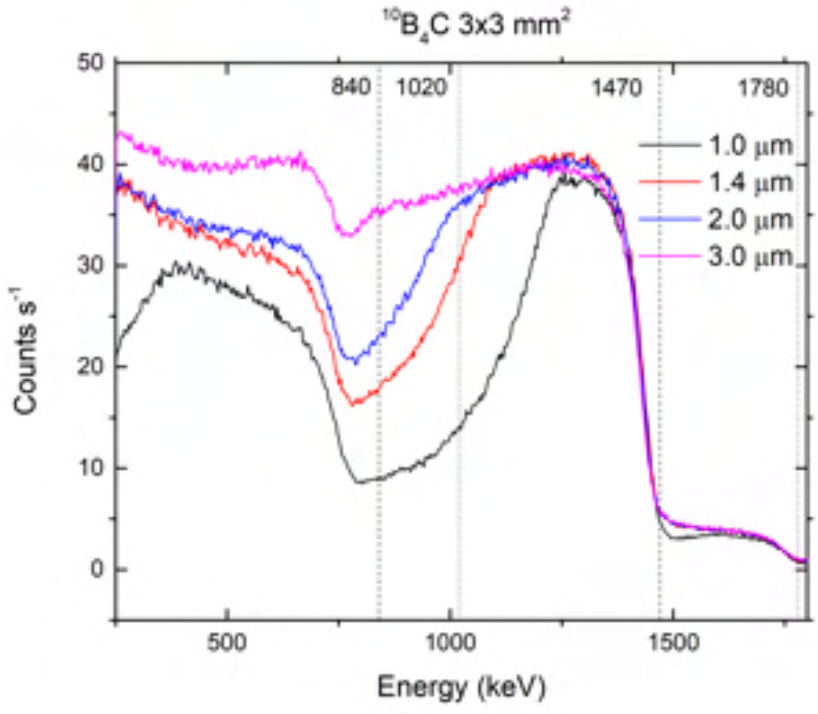


- Measurements with 1 SiC detectors and different converters / properties
- Structures / Charged particle spectra $\leftrightarrows$ Detection efficiency

# This work

- Large area SiC detectors (4x4 $mm^2$ and 5x5 $mm^2$)
- $^6$LiF converter deposited onto detector contact
- Test of detection performance in **reactor core**, in **subcritical conditions**

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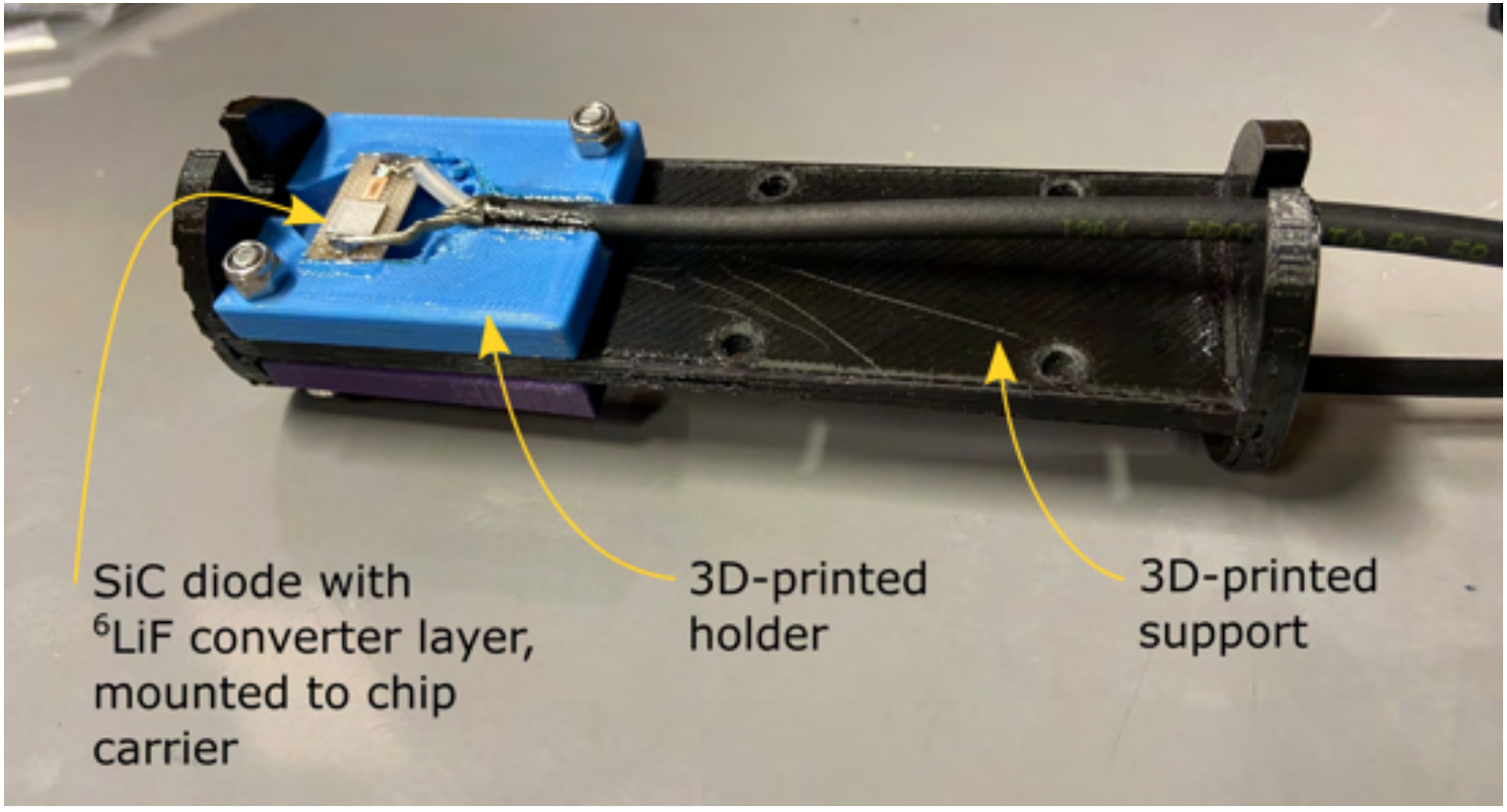
- $^6$LiF converter deposited onto detector contact
- Test of detection performance in **reactor core**, in **subcritical conditions**
- Relevance:
  - Criticality monitoring (normal operation, accident scenario)
  - Education
- Experiments:
  - Approach to criticality
  - Axial distribution

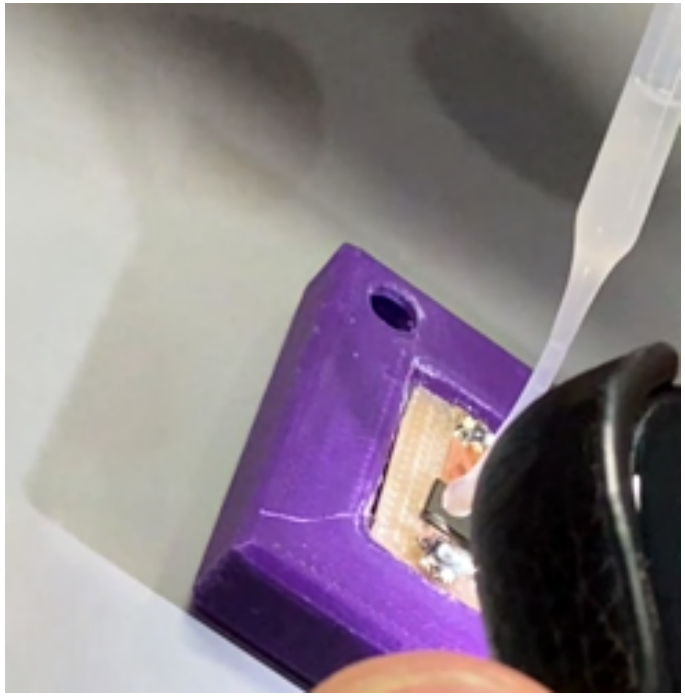
# Detector realization

- SiC diodes fabricated at QST
  - 4H-SiC, 36 $\mu$m (CVD)
  - Donor concentration: $1.7 \times 10^{14} \mathrm{cm}^{-3}$
  - Ni contact deposition and sintering in Ar (4x4 $\mathrm{mm}^2$, 5x5$^2$)



# Detector realization

- $^{6}$LiF converter prepared an deposited
- Target thickness: 20 $\mu$m (efficiency)
- Estimated thicknesses: 6 $\mu$m (5x5 mm$^2$), 17$\mu$m (4x4 mm$^2$))



# Acquisition system


- 4 channel, 3 mode acquisition system for fission chambers, developed by CEA, commercialized by I-Tech
- Presentation at Workshop no. 1 - D.Bisiach
- Presentation This afternoon - D.Bisiach, From Prototype to Production: Industrialization and Application of the Libera MONACO 3 Neutron Flux Monitoring System
- I-Tech booth

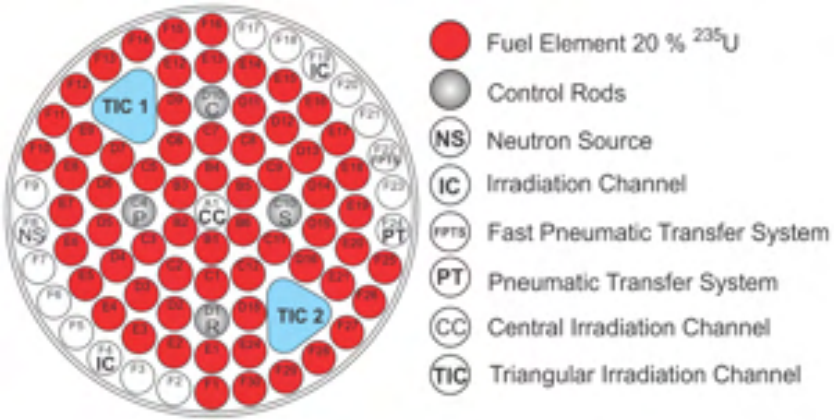
# Approach to criticality

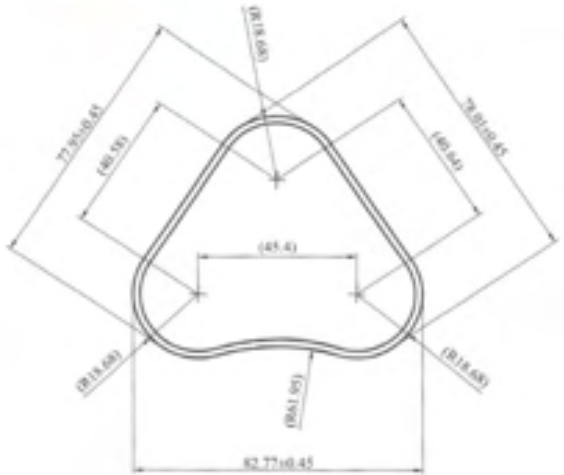
- SiC detectors located in TIC2 (fixed position)
- Centronic FC165 (165 $\mu$g of $^{235}$U) in TIC1 (fixed position)
- Start: all control rods inserted (ARI)
- Progressive w/drawal of control rods, measurement of signals (PHA / count rates)

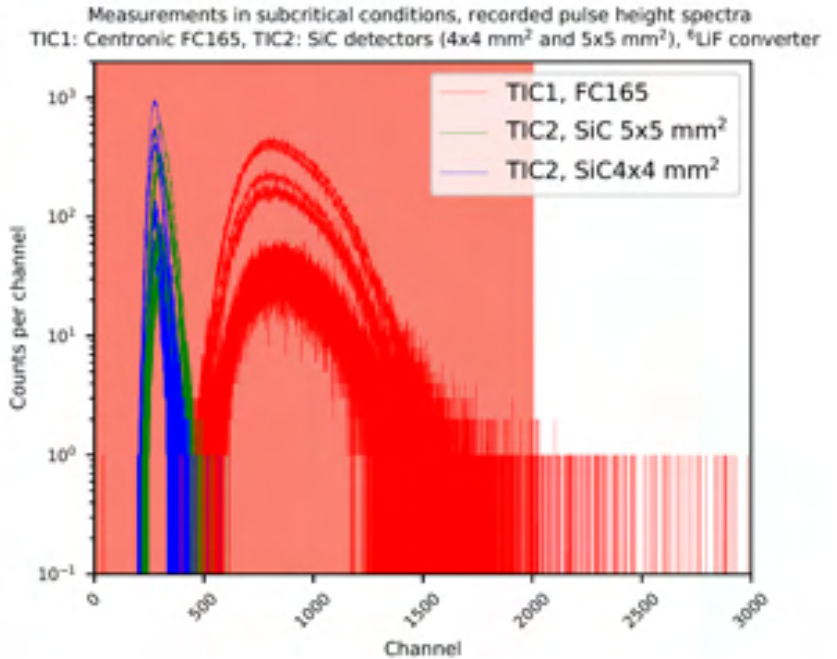
$$\begin{aligned} N &= S + k_{eff} S + k_{eff}^2 S + k_{eff}^3 S + \cdots = \\ &= S \frac{1}{1 - k_{eff}} = SM, \quad \text{if } k_{eff} < 1 \end{aligned}$$

If $I \propto N$, $I_i/I_0$ ratio ($M^{-1}$) goes from 1 to 0 as we approach criticality

# Approach to criticality





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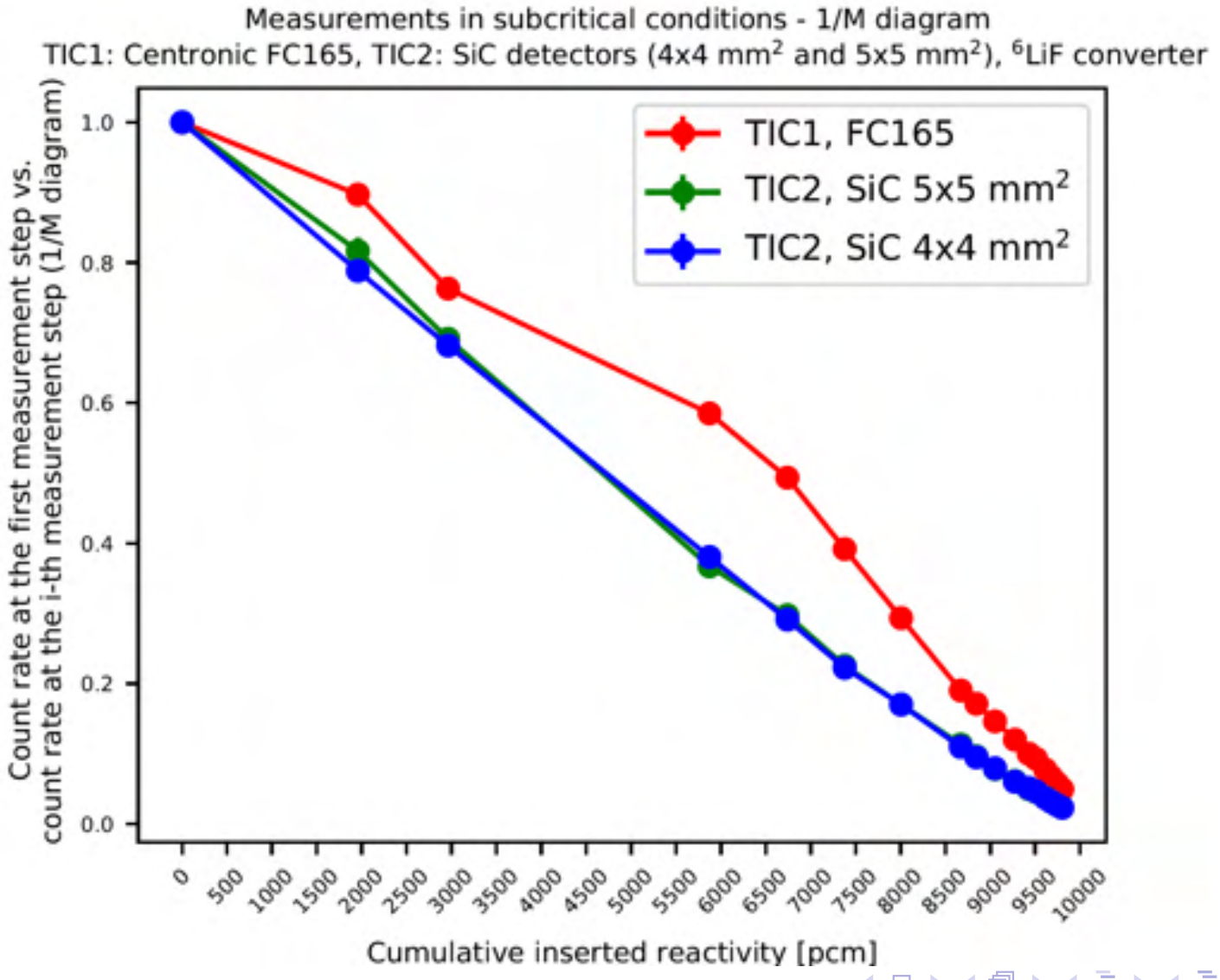

# Axial distribution

- SiC detector assembly on steel cable, lifted in steps from bottom of TIC2
- Height measurement: Pneumatic system designed and used in 2011 for miniature FC measurements (JSI-CEA collaboration, IRPhE benchmark (2017))

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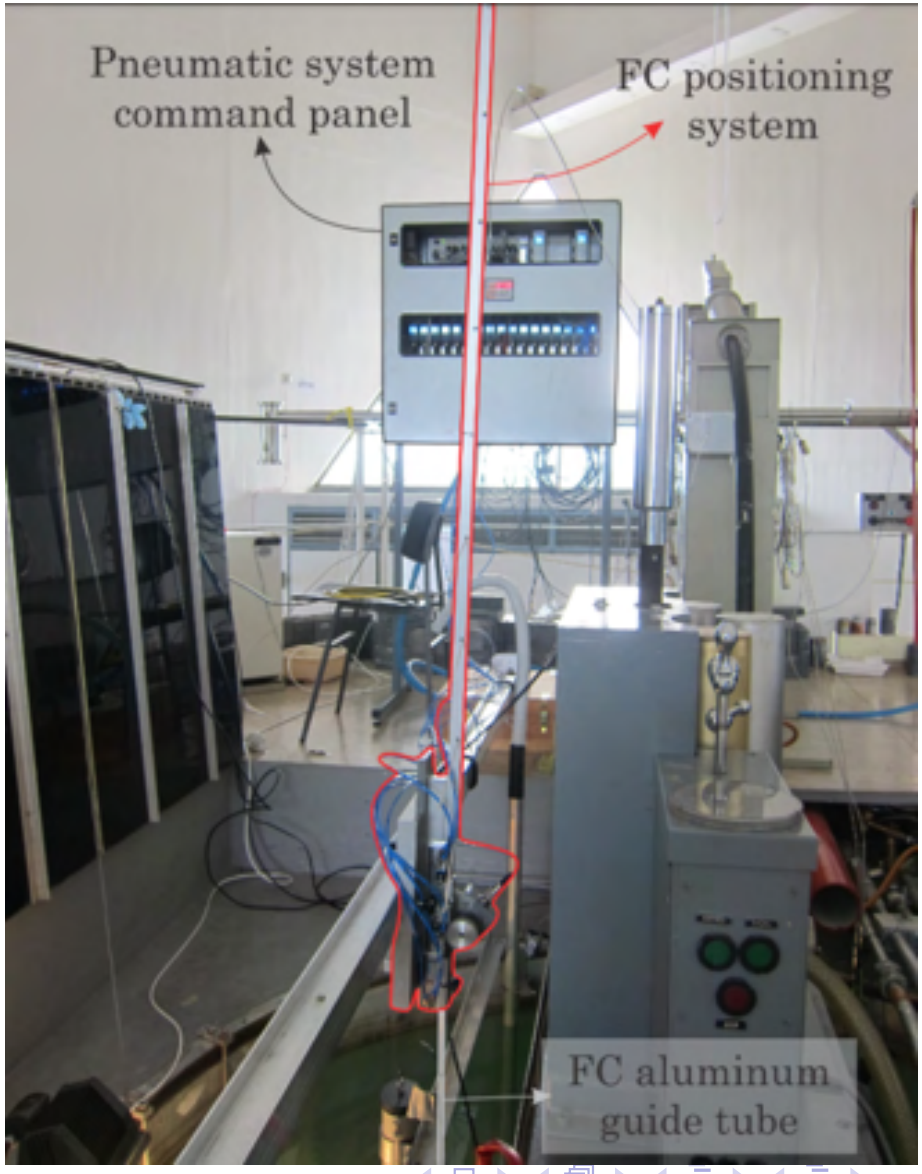
- Presentation on Wednesday by Loïc Barbot



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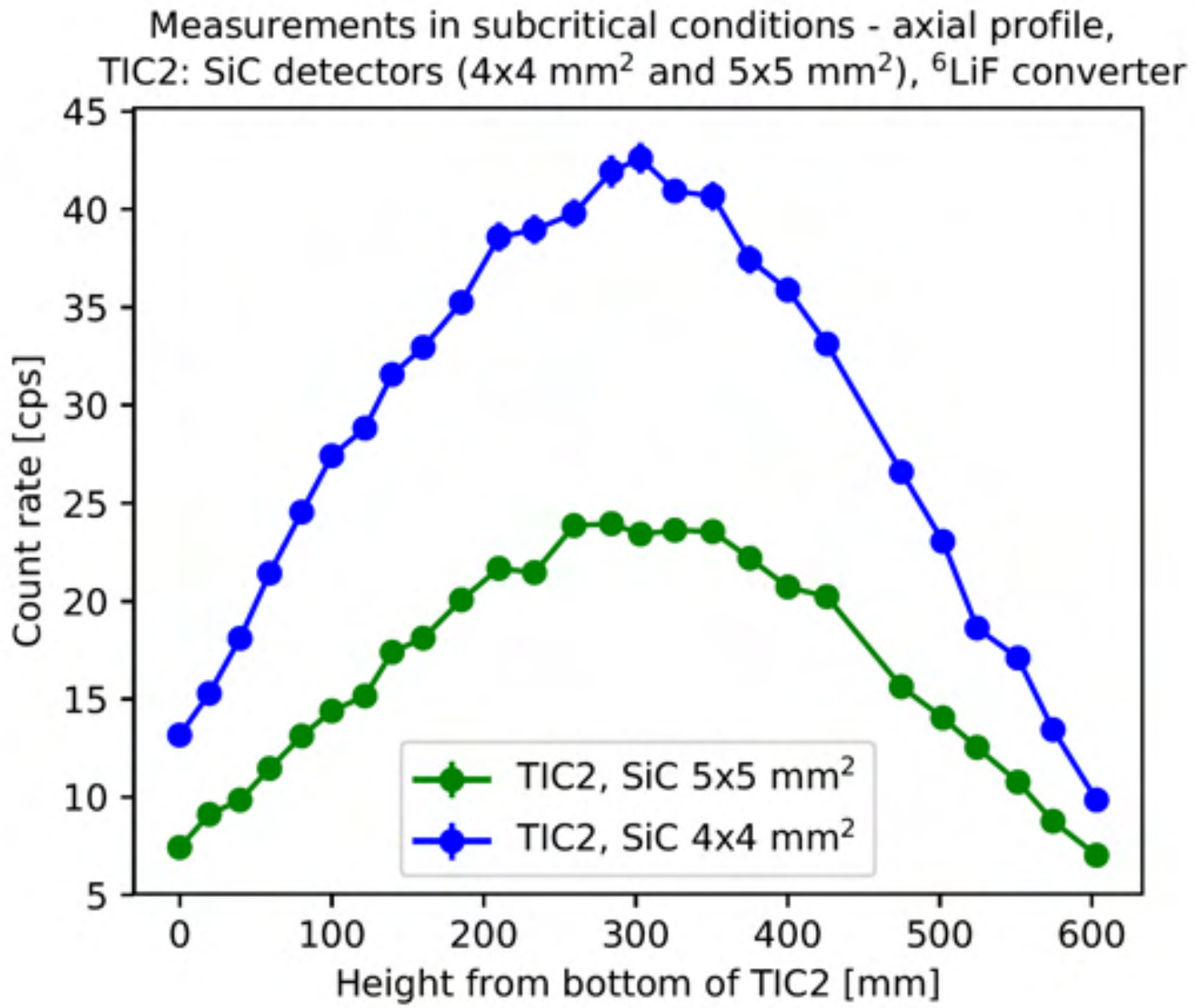

# Education

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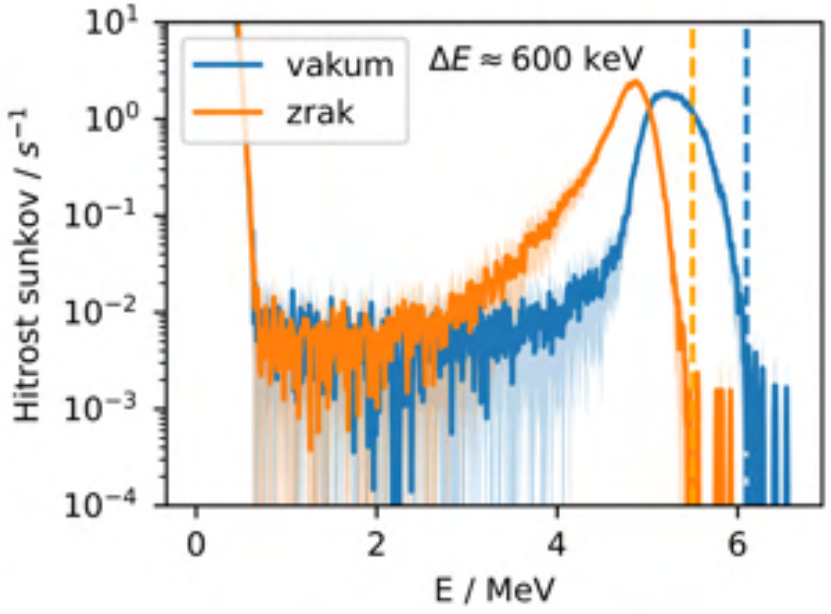
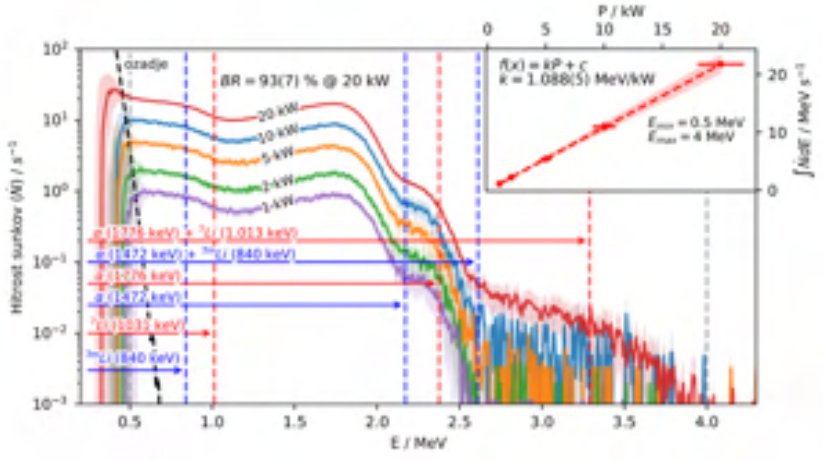
- **ENEEP** - European Nuclear Experimental Educational Platform (SI, SK, IT, CZ)

# Education

- Research, new experiments → new experiments for education
- SiC: Very visual, numerous options:
  - $\alpha$ energy loss in air
  - Different thermal neutron converters ($^6Li$, $^{10}$B)
  - Converter preparation and testing
    - Response vs. incident n. flux
    - Charged particle energies
  - Fast neutron reactions
  - Use for critical experiment, distribution measurement



# Education


**Opportunities, new courses → Visit the ENEEP Booth! :-)**

# Conclusions

- SiC neutron detectors: applications are emerging
- **This work**:
  - Performance for monitoring in subcritical conditions
  - Test of I-Tech Libera MONACO-3 with SiC
  - SiC detector applications in education (detector/reactor oriented)

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Thank you for your attention!