



# Secondary Neutrons in Particle Therapy

**Nicolas Arbor**  
[\(nicolas.arbor@iphc.cnrs.fr\)](mailto:nicolas.arbor@iphc.cnrs.fr)

IN2P3/CNAO – 26/11/2021

**CNAO**  
Centro Nazionale di Adroterapia Oncologica

# Out-of-field (neutron) dose

- Secondary neutrons lead to a whole body dose exposure in particle therapy ( $\Leftrightarrow$  important contribution to out-of-field dose)
- Neutron absorbed dose is small (< 1% of total dose), but with still large uncertainties on precise neutron RBE estimate
- Important issue for childhood cancer (radiation-induced cancer risk ?)

Review on out-of-field (neutron) dose:

[1] AAPM TG 158: Measurement and calculation of doses outside the treated volume from external-beam radiation therapy, SF. Kry et al., AAPM TG 158, 2017

[2] Neutron dose and its measurement in proton therapy— current state of Knowledge, RA. Hälg and U. Schneider, Br. J. Radiology, 2020

# Out-of-field (neutron) dose

- Low doses (generally) not routinely calculated during treatment planning
- Complete radiation exposure is important for epidemiological studies (2<sup>nd</sup> cancer risk estimate, treatment techniques comparison, ...)
- Our interest in :
  - understanding how to better estimate out-of-field (neutron) dose during treatment planning (based on beam and patient parameters)
  - developing Monte Carlo simulation tool dedicated to particle therapy out-of-field dose calculations
  - validating calculations/tools using innovative neutron measurement systems

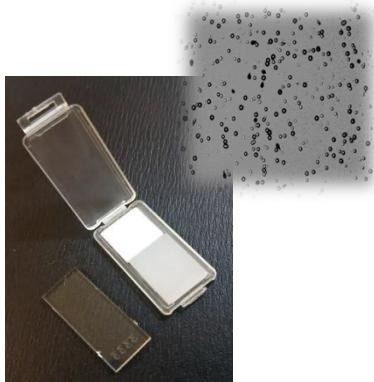
# Neutron measurements

- Most widely used spectrometer: Bonner Spheres System (BSS)



- ✓ neutron energy range
- ✓ neutron energy resolution
- ✗ cumbersome
- ✗ offline (complex) spectra deconvolution
- ✗ maximum neutron flux (saturation)

- Most widely used counter: Solid Nuclear Track Detector (SNTD)



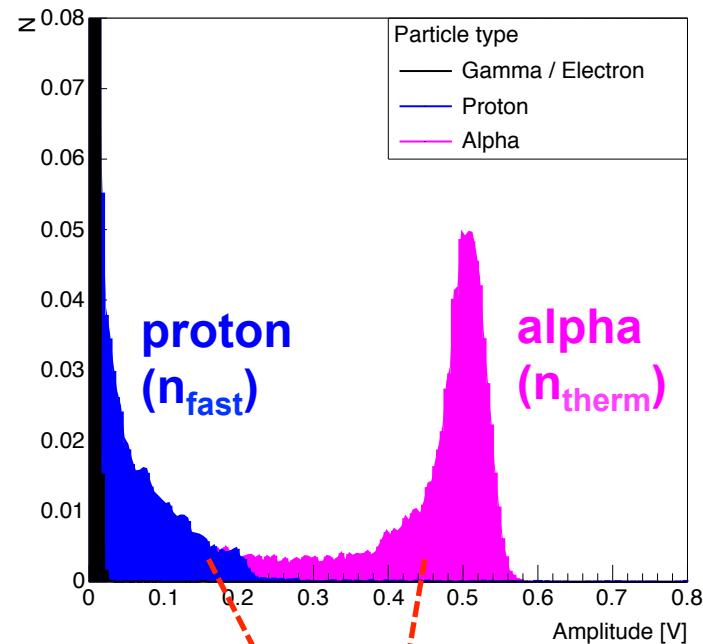
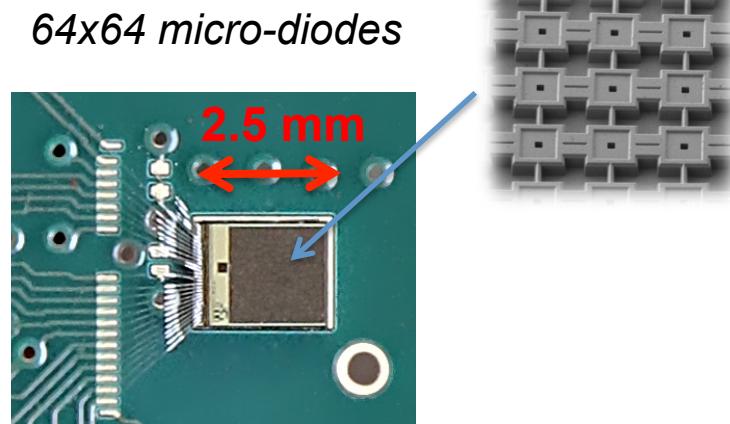
CR-39

- ✓ gamma transparent
- ✓ small size (in phantom measurements)
- ✗ thermal/fast neutrons separation (mixed field measurements)
- ✗ calibration (tracks  $\Leftrightarrow$  dose) dependent on neutron spectrum
- ✗ chemical etching (time consuming, no reuse)

⇒ new detectors to facilitate neutron measurements in treatment room

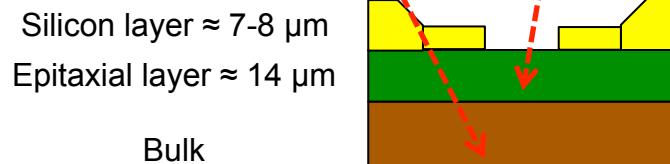
# CMOS-based neutrons counter

- Specially designed CMOS sensor for parallel detection of thermal and fast neutrons
- Compact and easy to use (real-time, integrated electronic, low power consumption)



## Neutron detection

- Neutrons are converted into:
  - protons ( $n_{\text{fast}}$ , PE)
  - 1.4 MeV alpha particles ( $n_{\text{therm}}$ ,  $^{10}\text{B}$ )



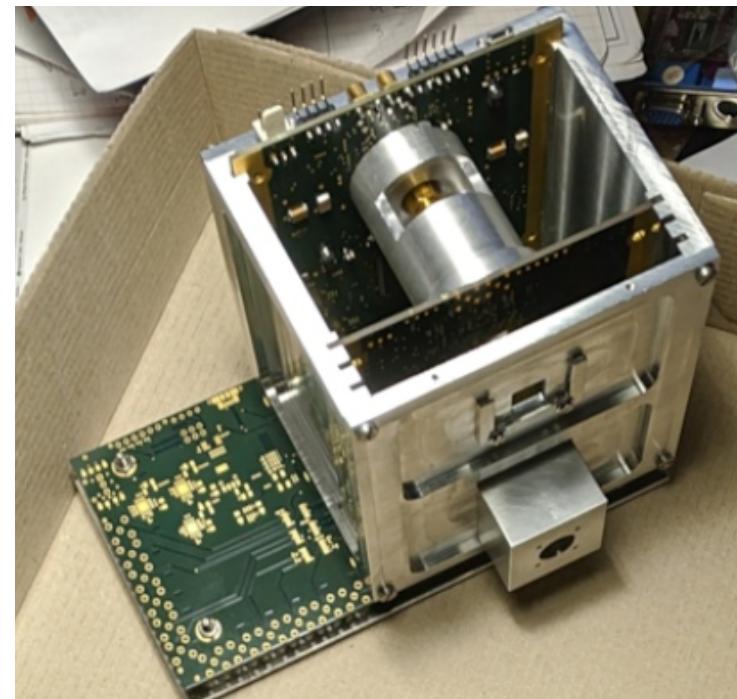
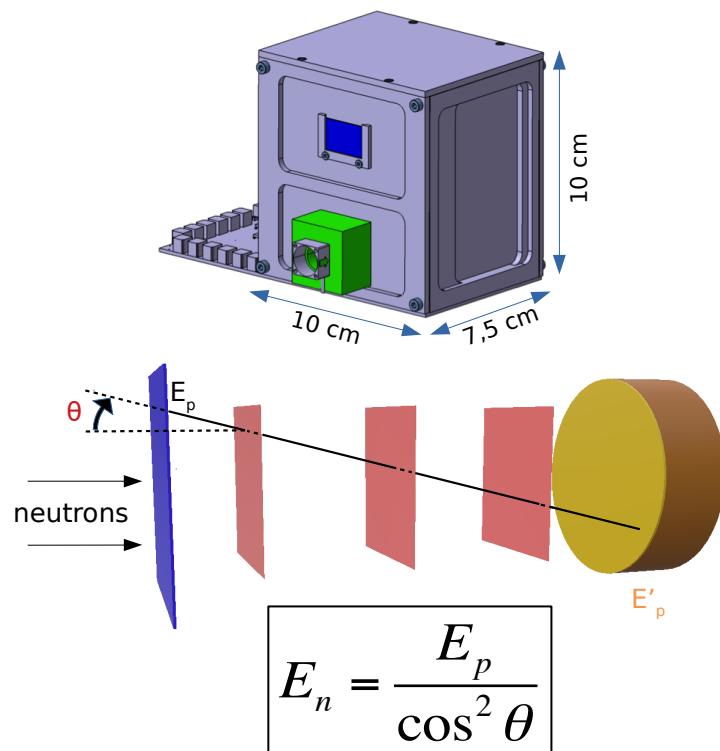
N. Arbor et al., Nuclear Instrument and Methods A 888 (2018)

# Neutron spectrometry

- Fast neutron spectrometer 4-50 MeV (recoil proton telescope):
  - compact system, real-time reconstruction
  - high-flux ( $\approx 10^8$  n/s/cm $^2$ )
- Recoil protons trajectography using 3 pixelated CMOS sensors (FastPIX) designed at the IPHC laboratory

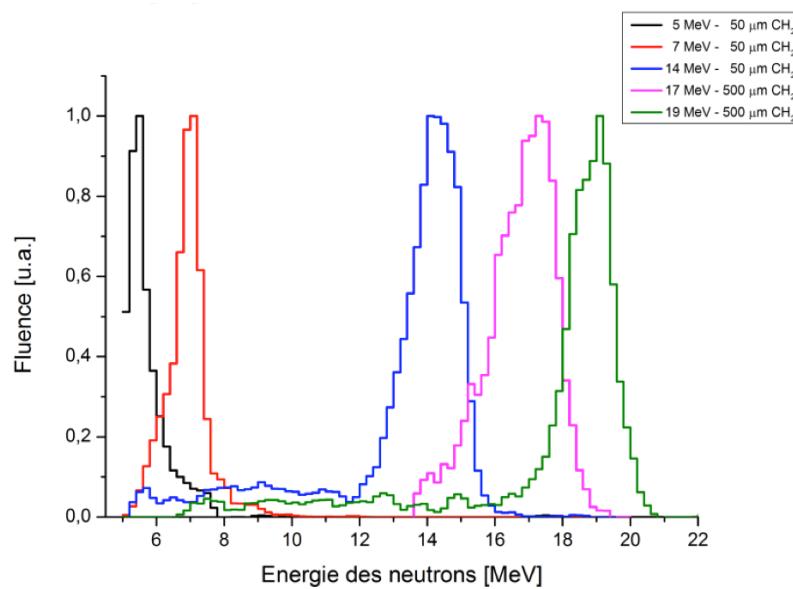
**IRSN**  
INSTITUT  
DE RADIOPROTECTION  
ET DE SÛRETÉ NUCLÉAIRE

**IPHC**  
Institut Pluridisciplinaire  
Hubert Curien  
STRASBOURG

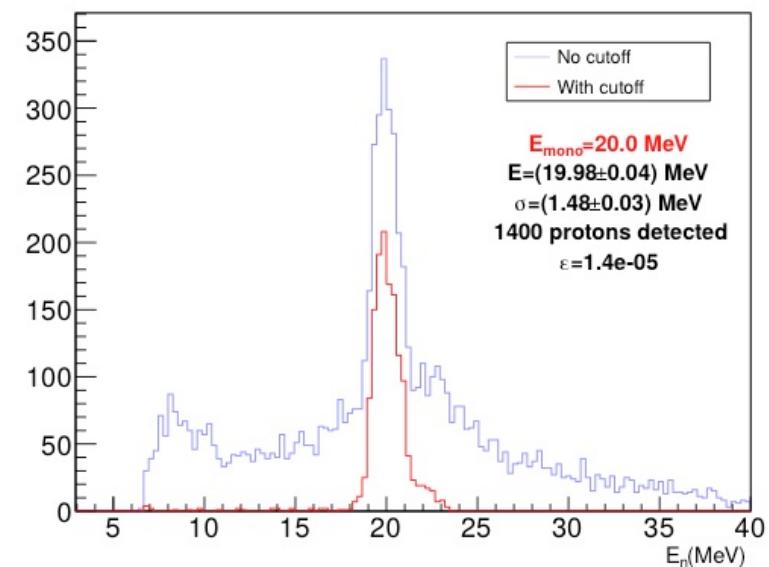


# Neutron spectrometry

- Fast neutron spectrometer 4-50 MeV (recoil proton telescope):
  - compact system, real-time reconstruction
  - high-flux ( $\approx 10^8$  n/s/cm $^2$ )
- Recoil protons trajectography using 3 pixelated CMOS sensors (FastPIX) designed at the IPHC laboratory



Mono-energetic neutron measurements (RPT v1)



Monte Carlo simulation for 20 MeV neutrons (RPT v2)

# Monte Carlo simulation

- Importance of validating nuclear models of secondary neutron production (experimental measurements) for hadrontherapy applications
- Monte Carlo simulations of secondary particles production and 3D dose distributions are done with GATE/Geant4 softwares



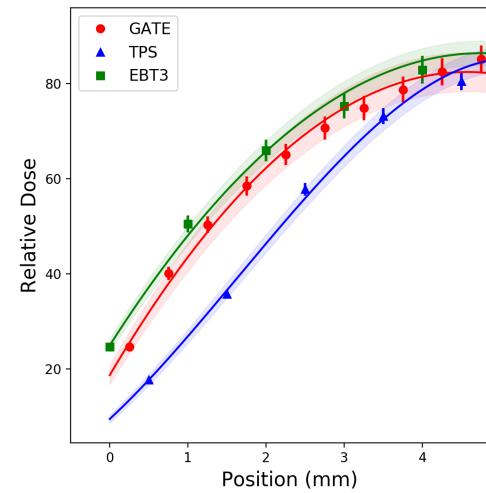
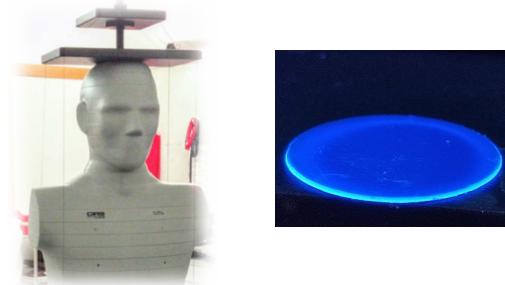
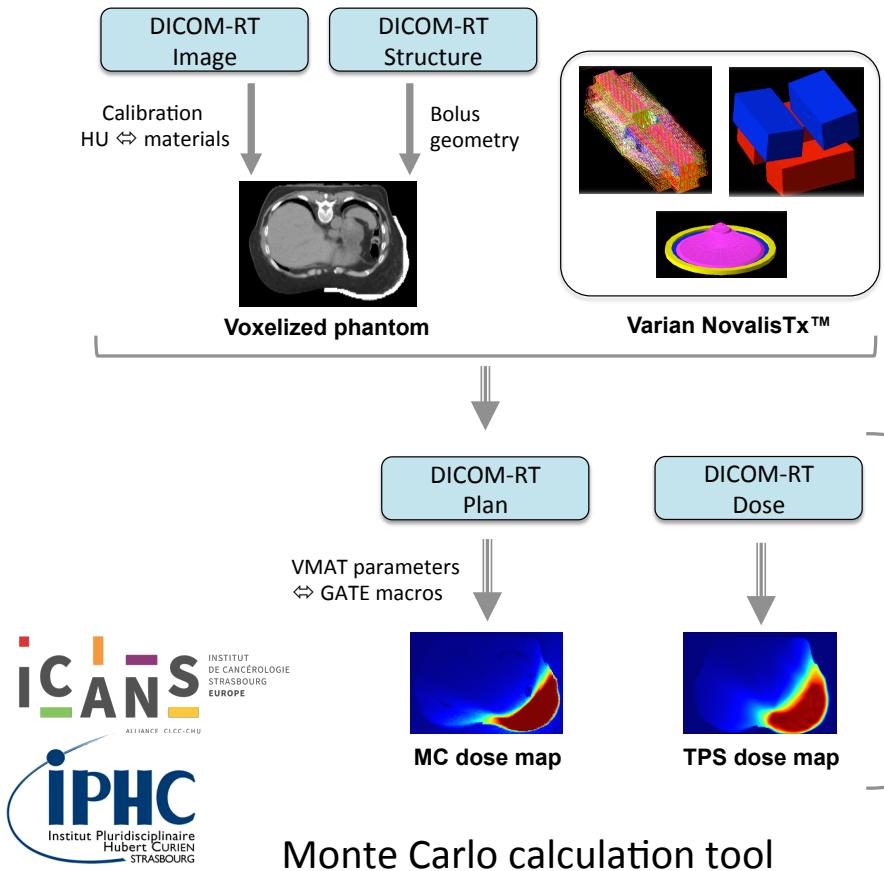
- Dedicated tool available in GATE for clinical dose calculations in particle therapy

**Technical Note: GATE-RTion: a GATE/Geant4 release  
for clinical applications in scanned ion beam therapy**  
L. Grevillot, D.J. Boersma, H. Fuchs, A. Aitkenhead, A. Elia, M. Bolsa, C.  
Winterhalter, M. Vidal, S. Jan, U. Pietrzyk, et al.

⇒ see talk from Lydia Maigne (GATE)

# Future collaboration?

- Example of on-going collaboration with ICANS (RT) on skin-dose evaluation



Experimental measurements

⇒ Same idea for the neutron (out-of-field) dose?