MULTIPURPOSE APPLICATIONS OF THE ACCELERATOR-BASED NEUTRON SOURCE GENEPI2

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OUTLINE

- The GENEPI2 facility
- Dosimetry
- GENEPI2 applications
    - Detector calibration
    - Integrated circuit irradiations
- Conclusions & perspectives

GENEPI2
FAST NEUTRON GENERATOR

THE GENEPI MACHINES (1)

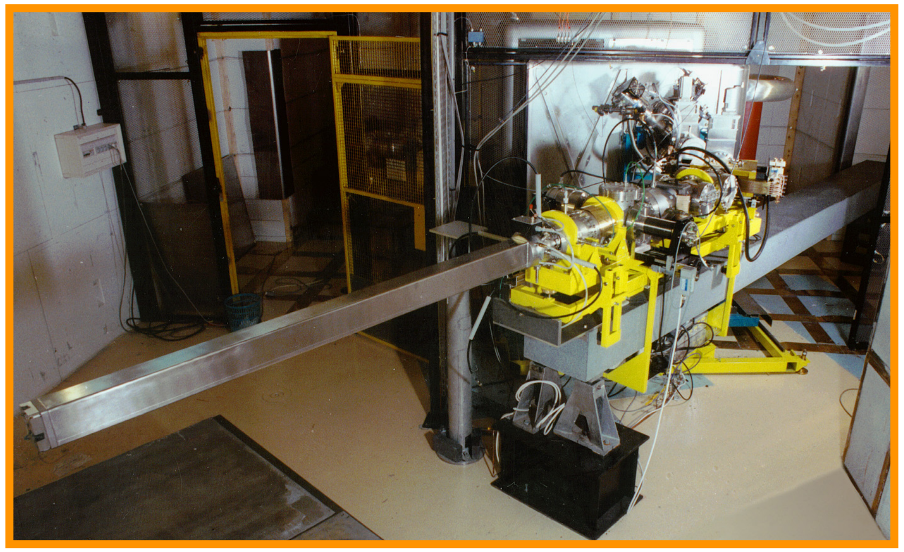
GENEPI : GEnerator of NEutrons Pulsed and Intense

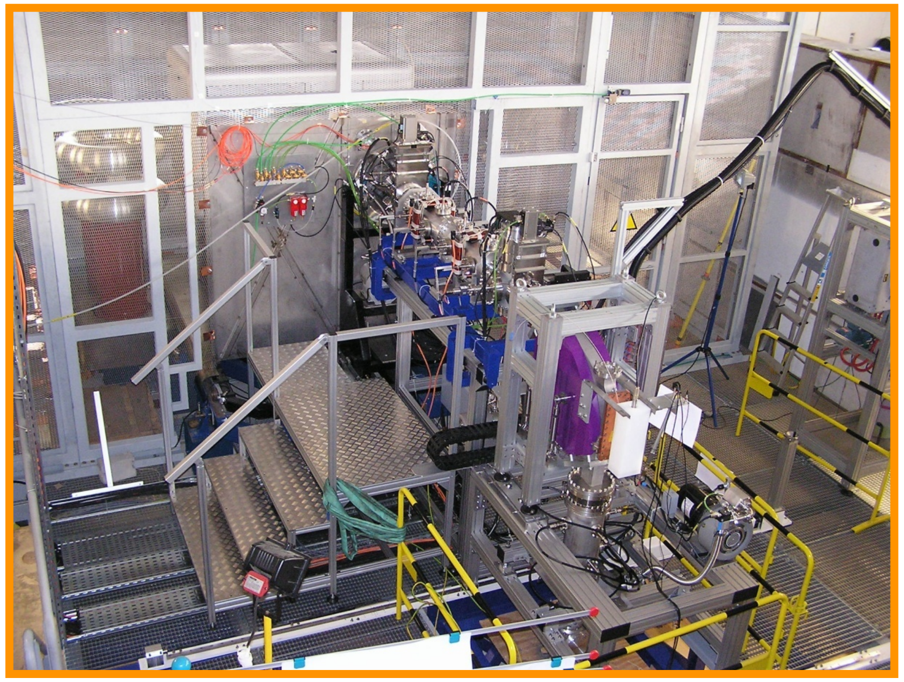
- Accelerator-based neutron source originally for studies on innovative reactors
- Electrostatic acceleration of deuterons for neutron production via dT and dD reactions:
  - $d + T \rightarrow n + \alpha$ $E^{n}_{ave} = 14.2$ MeV
  - $d + D \rightarrow n + {}^{3}He$ $E^{n}_{ave} = 2.5$ MeV
- Developed entirely by LPSC (CNRS/IN2P3)
- 3 machines built since late '90: SIMPLE, COMPACT, CHEAP and RELIABLE

GENEPI2
FAST NEUTRON GENERATOR

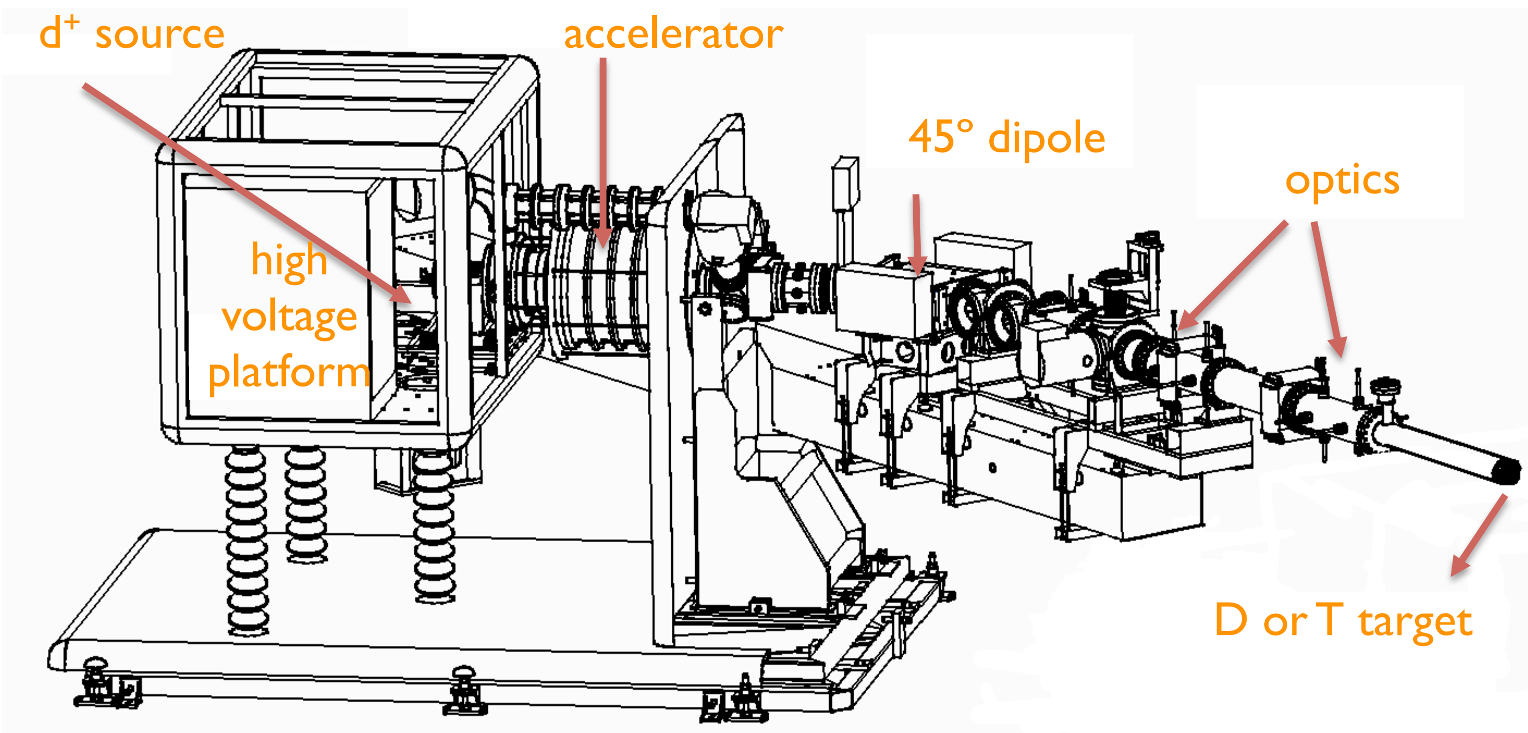
THE GENEPI MACHINES (2)

- GENEPI1 @ CEA-Cadarache (France) now dismantled
  - Developed between 1996 - 1999 and coupled to MASURCA reactor in 2000
  - MUSE-4 experiment: first to proved feasibility of Accelerator Driven System (ADS)
- GENEPI2 @ LPSC Grenoble (France)
  - Developed for precise nuclear section measurements
  - Operation started in 2003
- GENEPI3C @ SCK-CEN Mol (Belgium)
  - Development 2006-2009, first beam and reactor coupling 2010
  - ADS operating in pulsed or continuous mode





THE GENEPI2 FACILITY



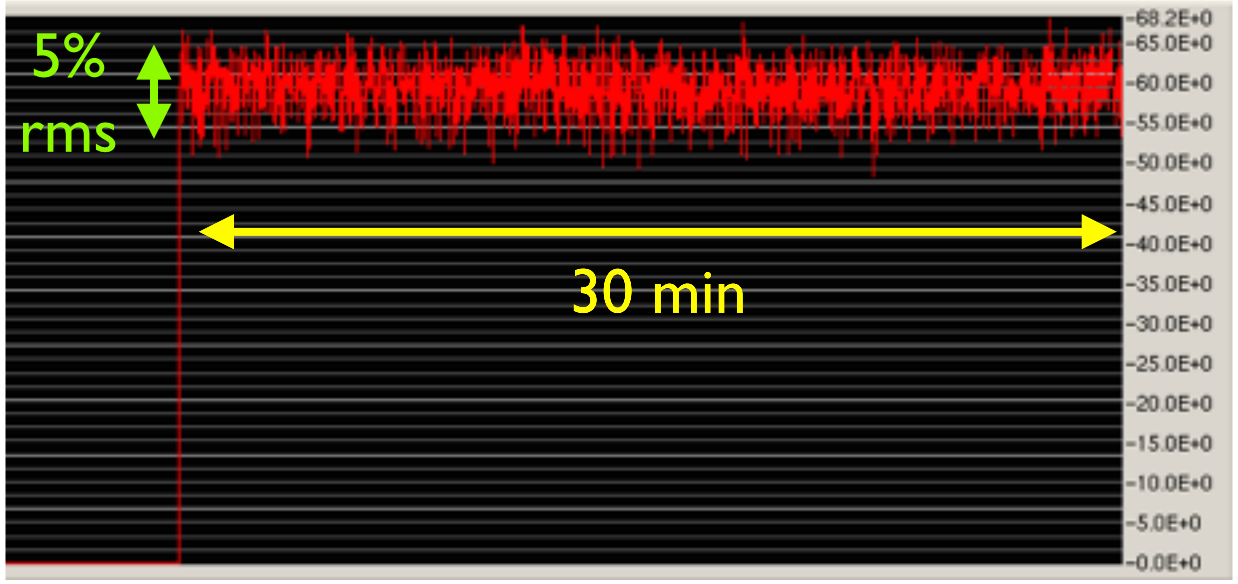
- duoplasmatron source → short and intense d^+ bunches (~65 mA, FWHM ~700 ns)
- electrostatic platform at 250 kV
- 5-stage accelerating column
- 45° dipole for magnetic separation
- electrostatic focusing (4 quadrupoles)
- Cu target with thin deposition of TiT (0.9 Ci) or TiD

GENEPI2 SPECIFICATIONS

DEUTERON ENERGY	220-250 keV
PEAK CURRENT	~ 50 mA
REPETITION RATE	from 100 Hz to 4000 Hz
AVERAGE CURRENT	from 4 μA to 140 μA
PULSE FWHM	700 ns
PULSE STABILITY	~ 5% rms
SPOT SIZE @ TARGET	20-25 mm
MAXIMAL TOTAL NEUTRON PRODUCTION	8×10^9 n s^{-1} in 4π
MAXIMAL NEUTRON FLUX	4.5×10^7 n cm^{-2} s^{-1}
AVERAGE NEUTRON ENERGY	14.2 MeV for dT, 2.5 MeV for dD

DOSIMETRY

- Real-time:
  monitoring of beam current on target → preliminary flux estimate
  current ~50 mA on target, @1000 Hz, 1cm from target: flux ~ 1,1x10^7 n cm^{-2} s^{-1}



- Off-line data treatment:

  1. PERIODIC IRRADIATIONS OF REFERENCE FOILS

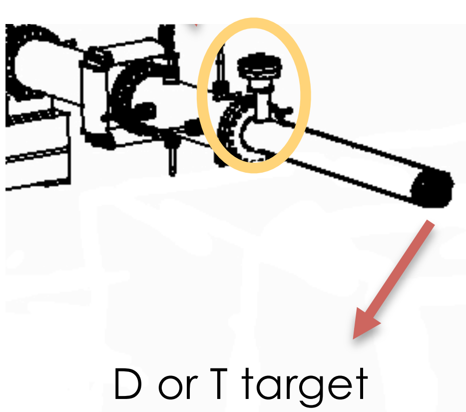
  2. DIRECT MONITORING
     for T(d,n)^{4}He reaction:
     - detection of α particle backwards
     - detection of n forward
     for D(d,n)^{3}He reaction:
     - detection of p backwards from D(d,p)T reaction ~ equiprobable

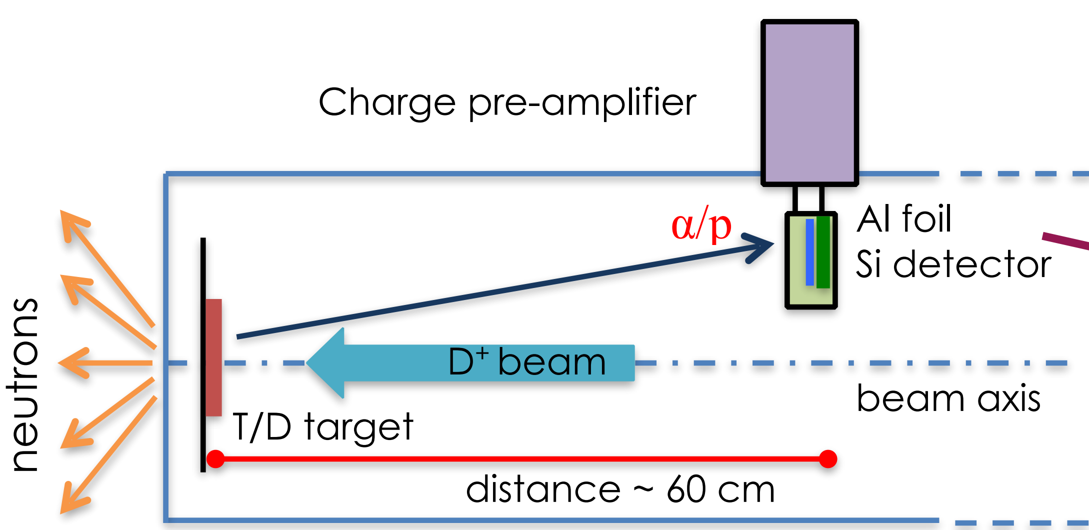
ALPHA AND P DETECTOR (I)

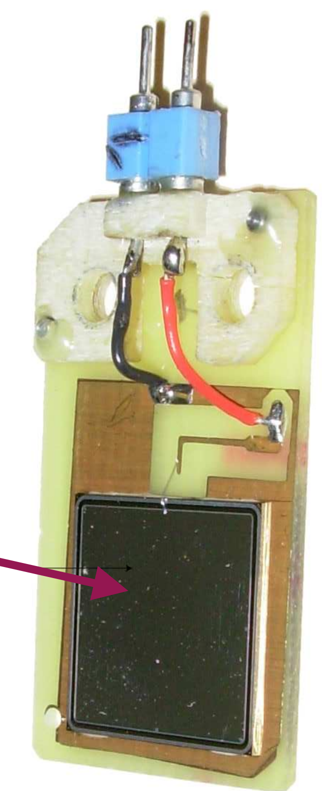
API: Alpha + Proton monItor

- Detection of the backscattered α (p) particles associated to dT (dD) reaction
- Si detector placed under vacuum in the beam pipe upstream of the target

➡ ABSOLUTE NEUTRON PRODUCTION MONITORING

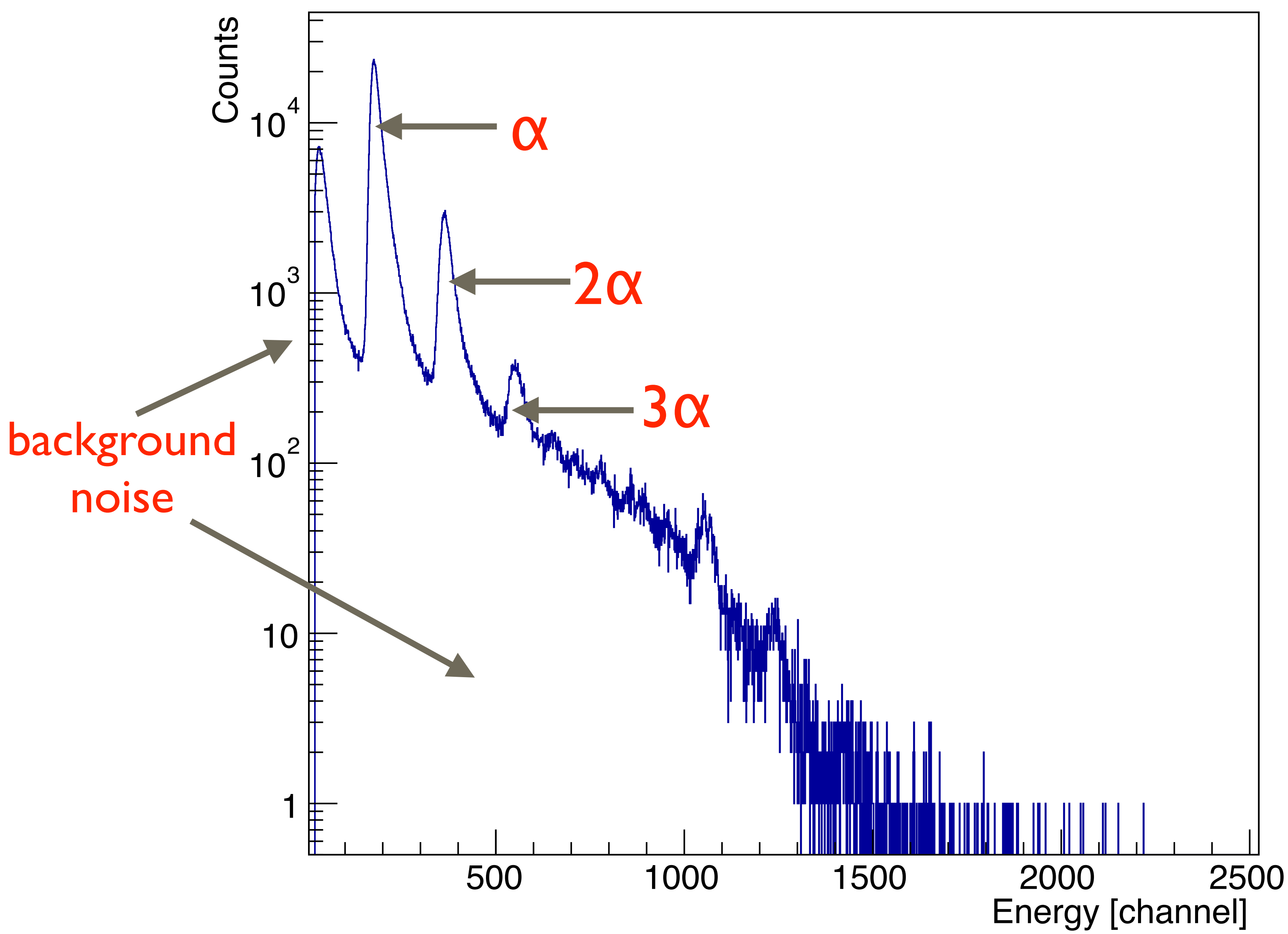






ALPHA AND P DETECTOR (2)

Measured α energy spectrum from API monitor



Total number of emitted neutrons:

$$N_{tot} = \frac{\sum_i m_i N_{\alpha i}}{\varepsilon_{geom}}$$

ε_{geom}: geometrical efficiency
m_i : i peak multiplicity
$N_{\alpha i}$: number of α in the i peak

About 95% of α in first 3 peaks

SINGE DETECTOR (1)

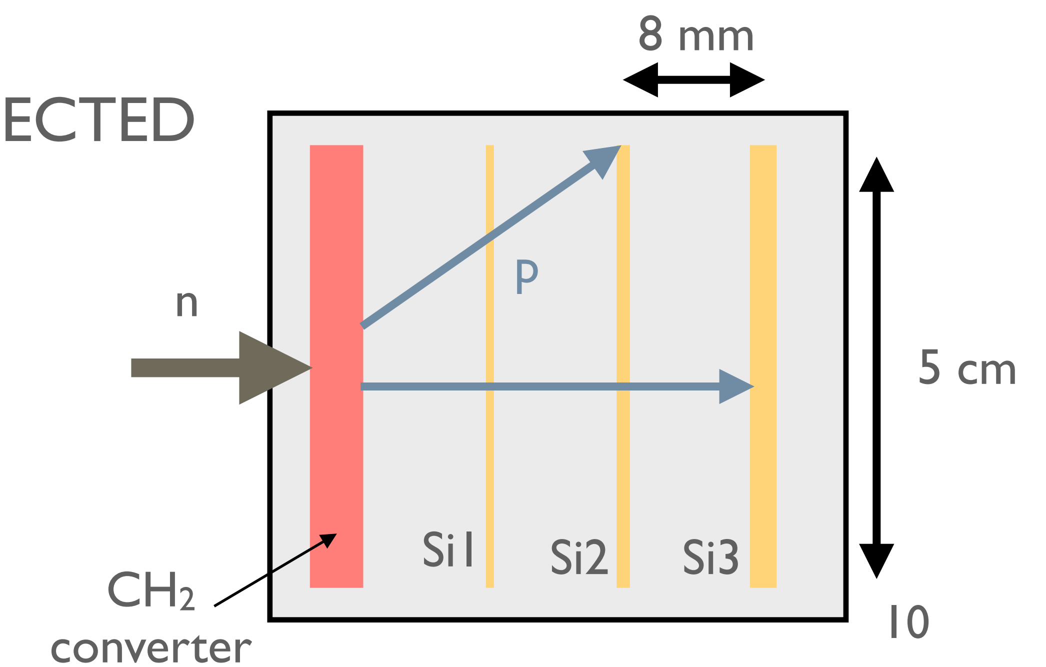
SINGE: SIlicon for Neutrons at GENEPI Experiment (<u>under commissioning</u>)

- Movable proton recoil telescope for 14 MeV neutron direct monitoring
- Hydrogenous converter (2 mm of CH_2) to induce proton conversion
- 3-stage Si detector (300, 500 and 1000µm) with triple coincidence

1 p for 10^3 incident n
false coinc. < 2%

➡ ONLY PROTONS WITH ENERGY > 9MeV ARE DETECTED

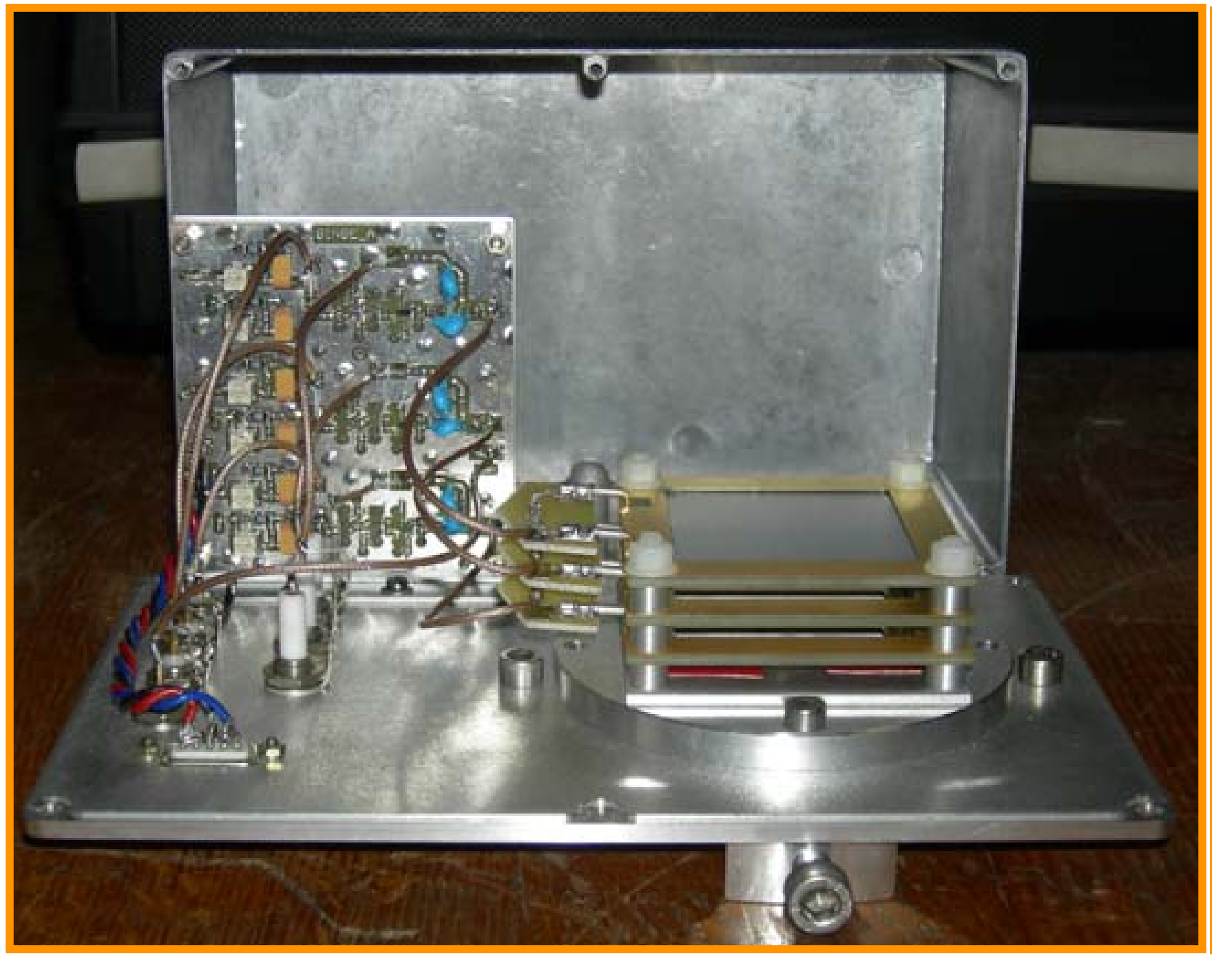
➡ RELATIVE MONITORING OF THE SOURCE

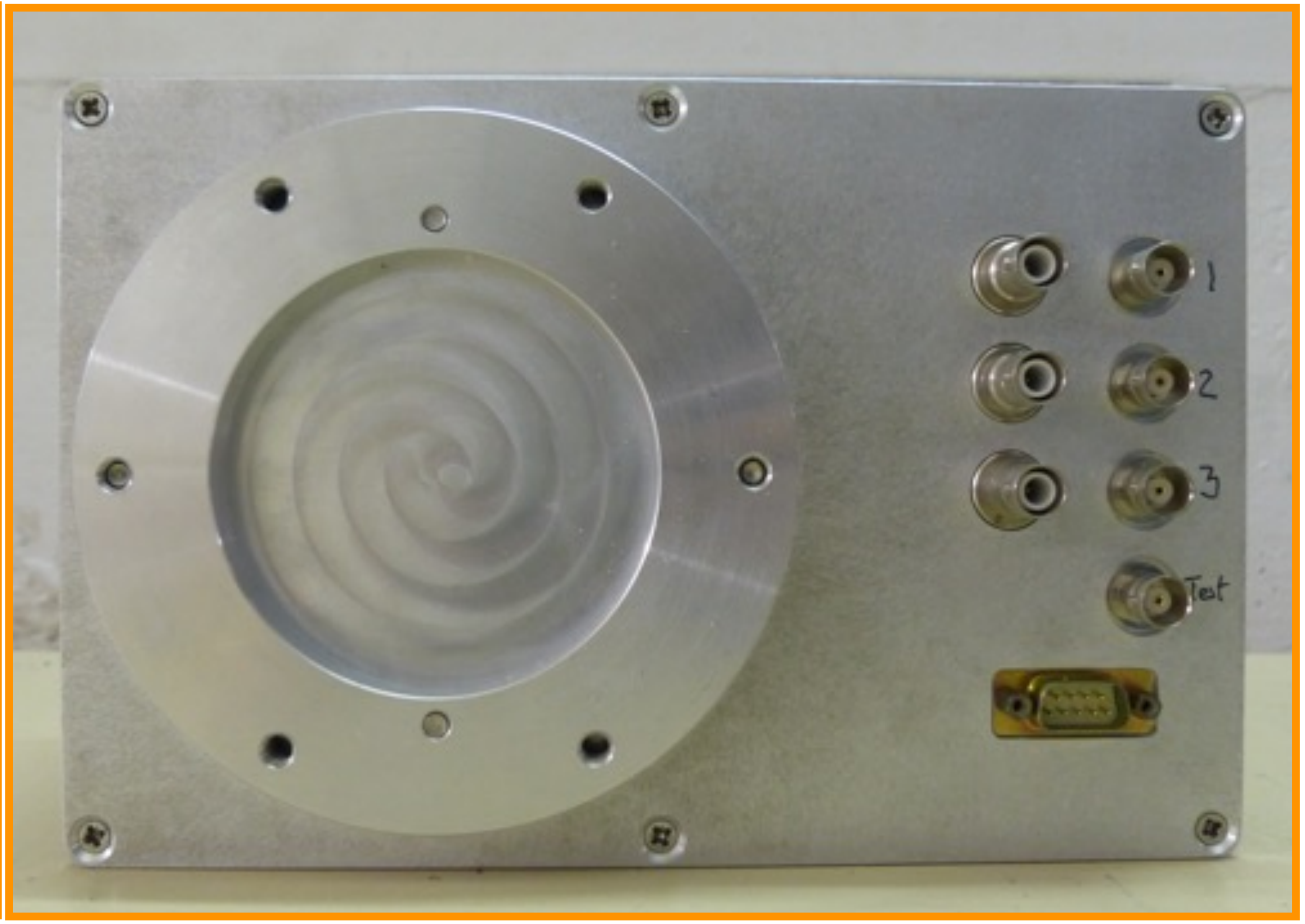


G. Ban et al., "A telescope for monitoring fast neutron sources", NIM A 577 (2007) 696-701

GENEPI2
FAST NEUTRON GENERATOR

SINGE DETECTOR (2)





SINGE: Si detectors and preamplifiers

Light-tight detector casing

ACTIVATION MEASUREMENTS

- Activation measurements of Al foils with Ge detectors once a month at low activity laboratory LBA (LPSC)

- Irradiation @ reference and sample position

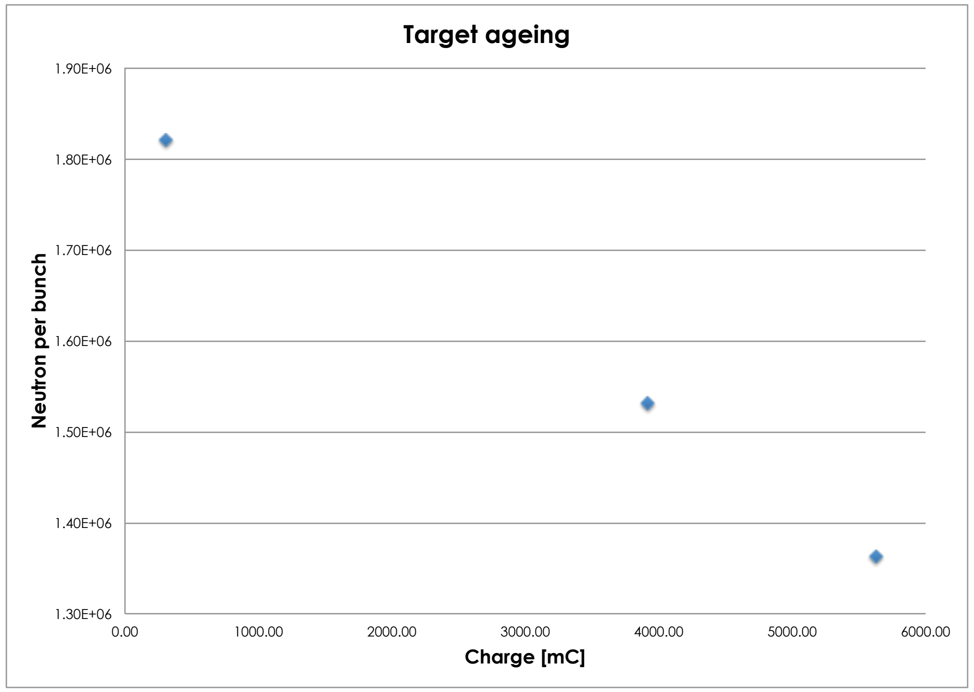
➡ ABSOLUTE MEASUREMENT OF NEUTRON FLUX

Cross-check of API monitoring

Calibration of SINGE detector (underway)

- Monitoring of target ageing

API+SINGE+ Al Foil activation:
Flux dosimetry better than 15%

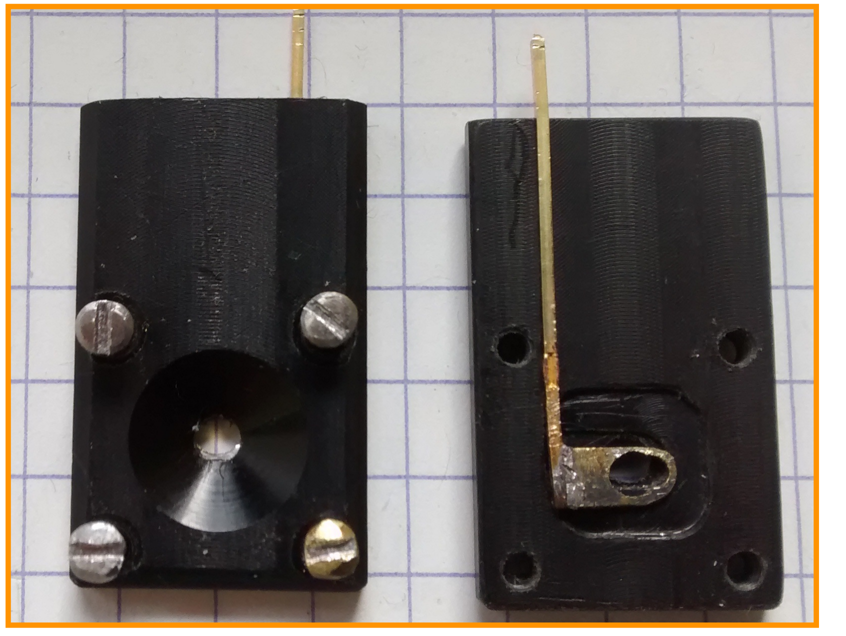


LBA:http://lpsc.in2p3.fr/index.php/fr/support-aux-activites-scientifiques/service-detecteurs-et-instrumentation/65-valorisation/lba/403-laboratoire-de-mesure-des-basses-activites-lba

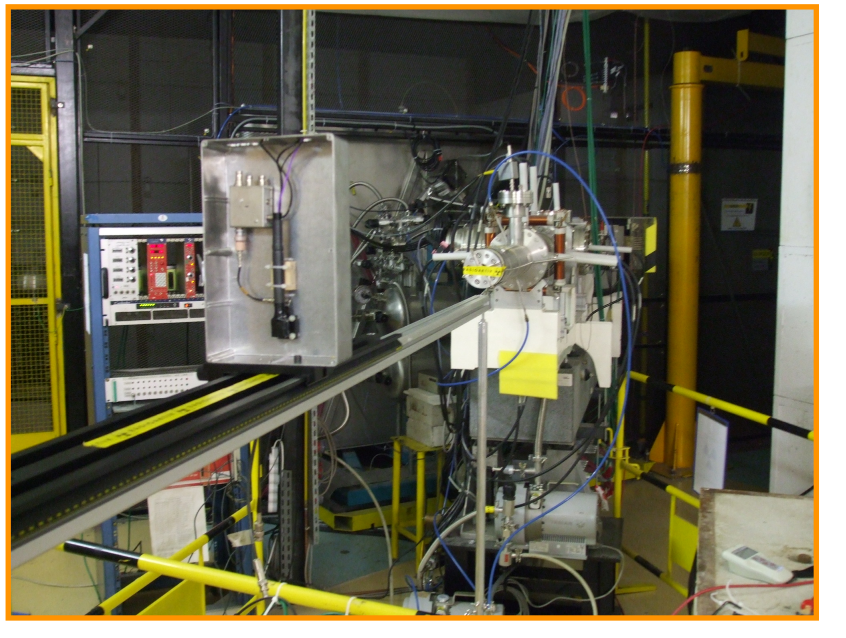
APPLICATIONS OF GENEPI2 NEUTRON SOURCE

DETECTOR CALIBRATION FOR PHYSICS

- Tests of a diamond detector dedicated to monitoring of hadrontherapy proton beam
  - CH_2 converter → mixed irradiation n+p
  - Validation of experimental set-up and DAQ chain under flux
  - comparison mono-crystal and poly-crystal diamond detectors

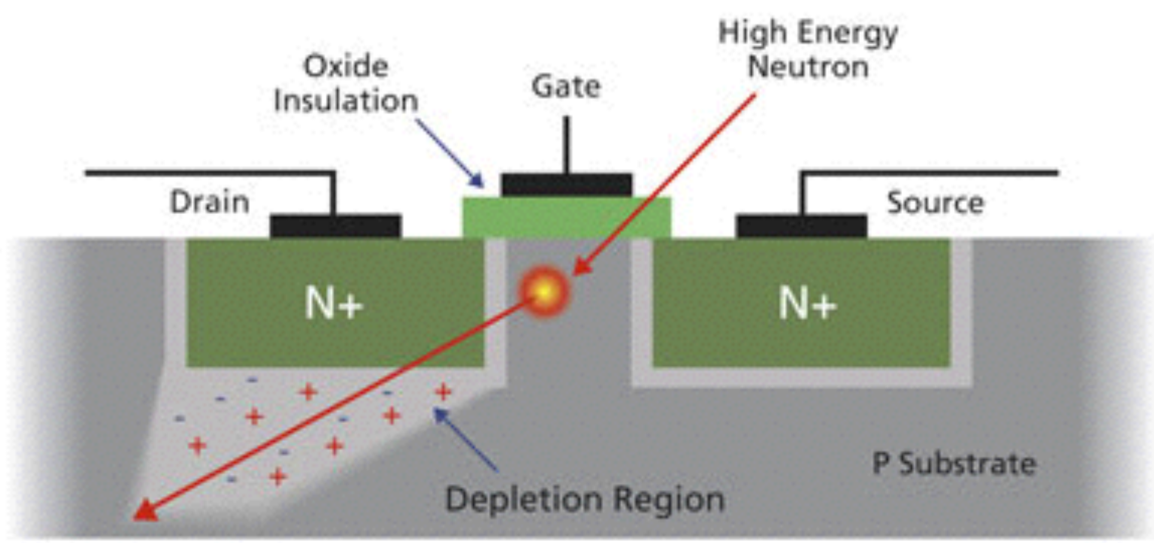


- Calibration and test of detectors for the NFS (Neutron For Science) beam line at SPIRAL2 (GANIL) scheduled for fall 2015
  - ^{238}U fission chamber for flux monitoring
  - liquid scintillator for energy spectrum determination
  - gaz detector dedicated to the measurement of $^{16}O(n,\alpha)^{13}C$ cross section



INTEGRATED CIRCUITS IRRADIATIONS (1)

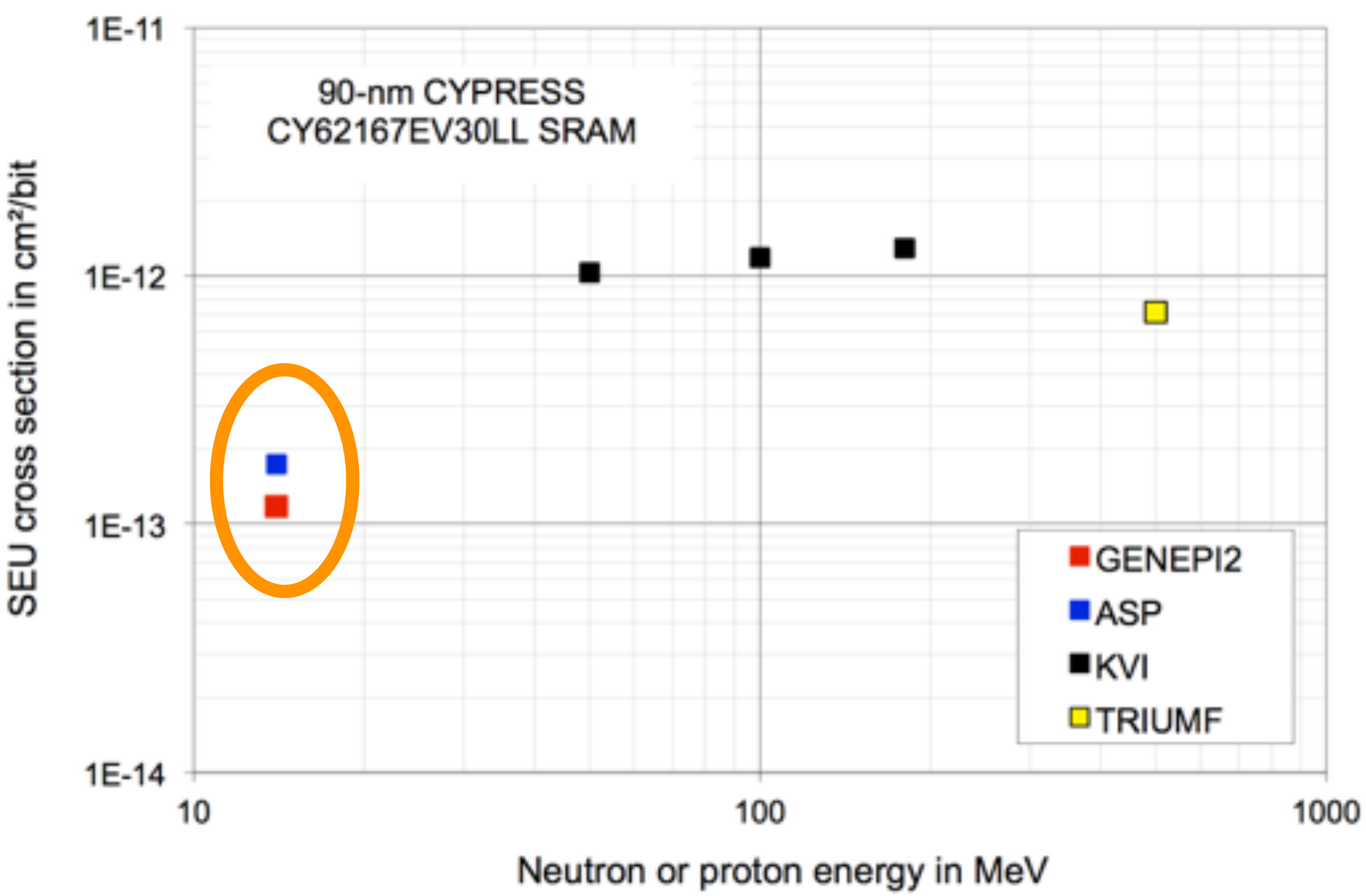
INTEGRATED CIRCUIT ACCELERATED RADIATION GROUND TESTS



- Activity started in late 2013, collaboration with TIMA laboratory (Grenoble) and French Aerospace Laboratory (ONERA, Toulouse)
- 2014 : two publications from NSREC conference, 2015: several abstracts submitted (NSREC and RADECS)

INTEGRATED CIRCUITS IRRADIATIONS (2)

Facility validation:
PRELIMINARY RESULTS: low flux and preliminary dosimetry



SEU cross-section measurements

GENEPI2 PRELIMINARY RESULT COMPATIBLE WITH ASP (UK) DATA

Data for simulation/prediction

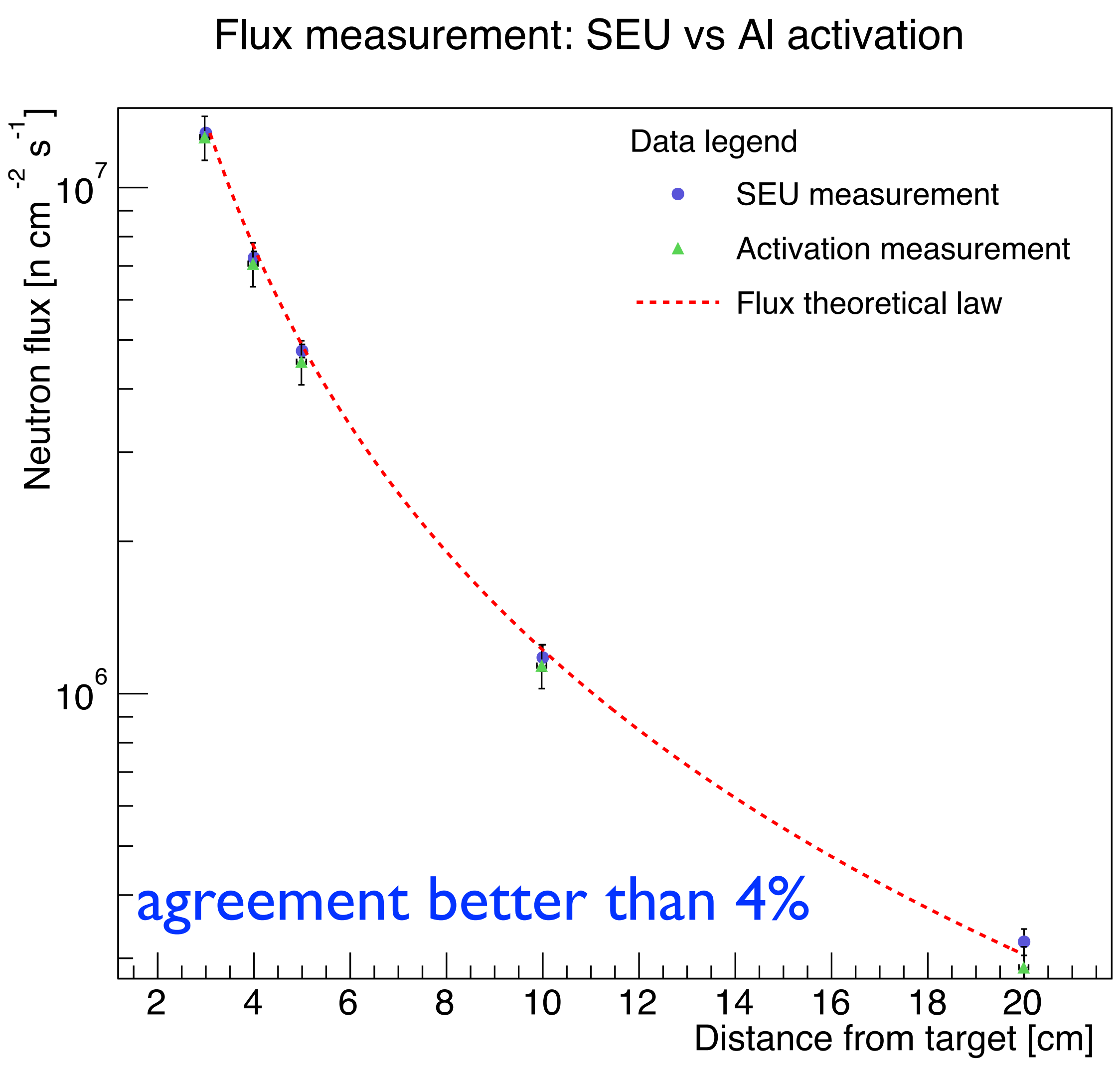
FROM GENEPI2 MEASUREMENTS EXTRAPOLATE AT HIGHER ENERGIES

"Accelerator-based neutron irradiation of integrated circuits at GENEPI2 (France)", F. Villa *et al.*, IEEE Radiation Effects Data Workshop Record, NSREC2014
"Evidence of the Robustness of a COTS Soft-Error Free SRAM to Neutron Radiation", R. Velazco *et al.*, IEEE Transactions on Nuclear Science, vol. 61 issue 6, 1(2014)

FLUX MEASUREMENTS

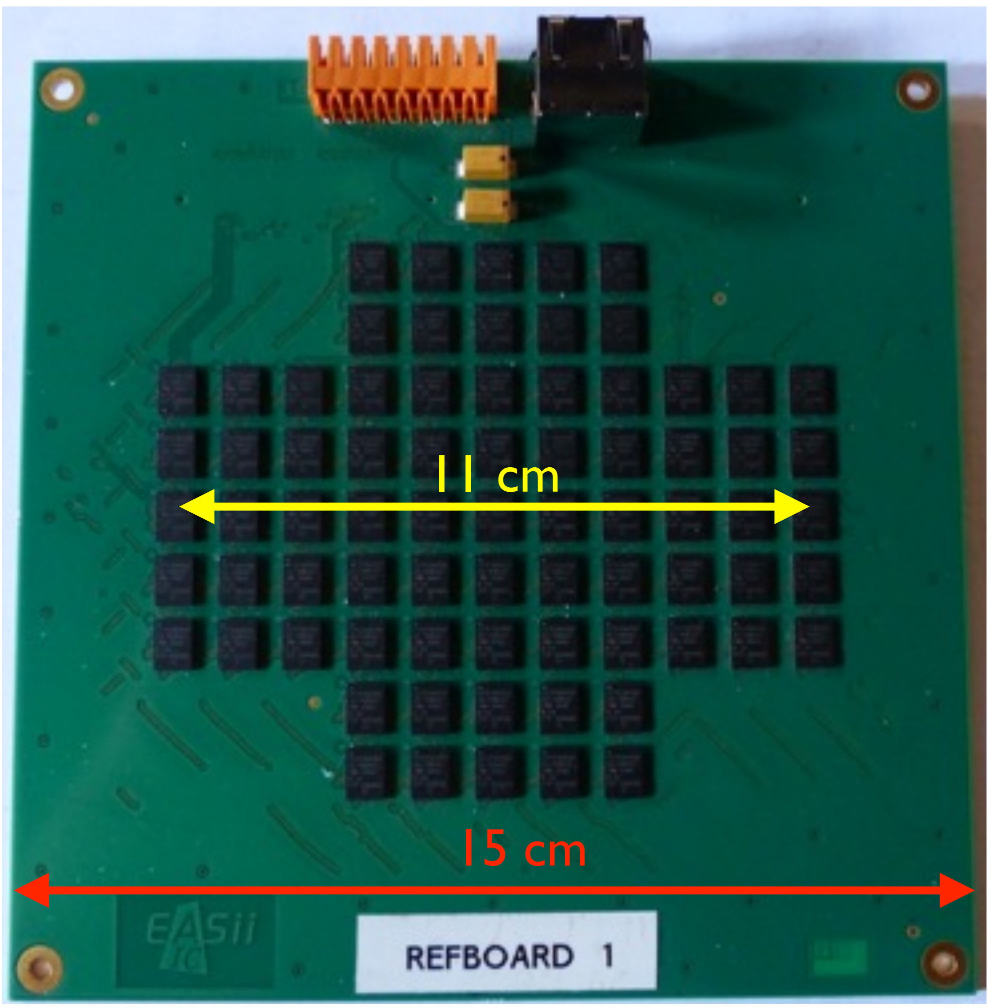
Characterisation of GENEPI2 flux counting SEU of a well-known SRAM (tested with NUCLETUDES)

SAMSUNG KM 68 4000
low power SRAM → highly sensitive to neutrons
Tested since 1996 (NSREC paper)
Used for flux calibration @ 14-MeV facilities (CEA Valduc France SAMES and ALVAREZ, Frascati, SODERN tube)



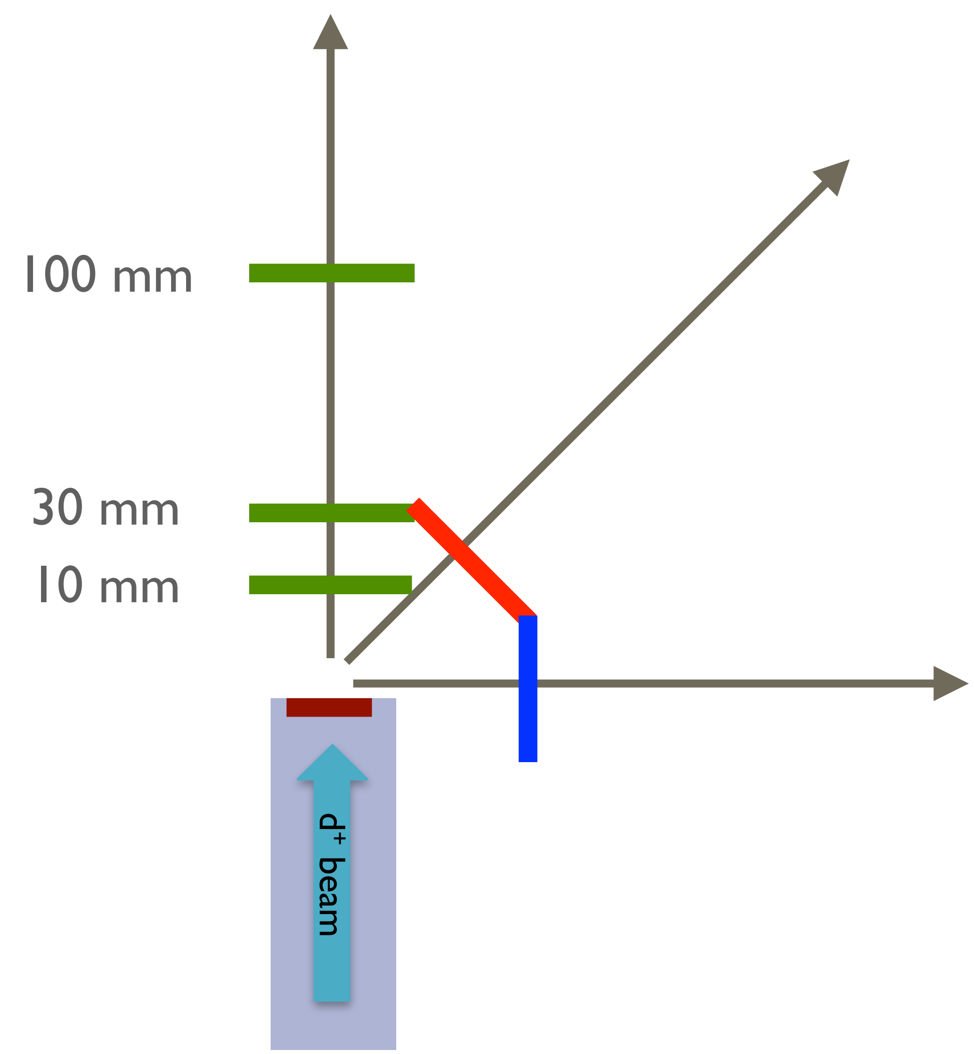
“"Neutron Single Event Effect Test Results for Various SRAM Memories", D.Thouvenot,P.Trochet,R. Gaillard, and F. Desnoyers, Nucletudes, NSREC1997

FLUX HOMOGENEITY (1)



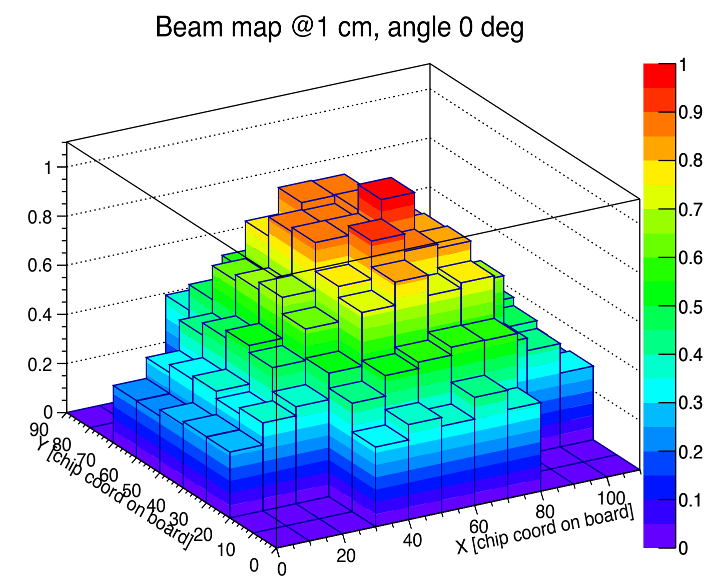
GoldenBoard developed by EASii-IC (Grenoble)
75 SRAMS 4-Mbit CY7C1041D
components sensitive to SEU
about 500 errors in 15 min (flux ~ 10^7 n/cm^2/s)

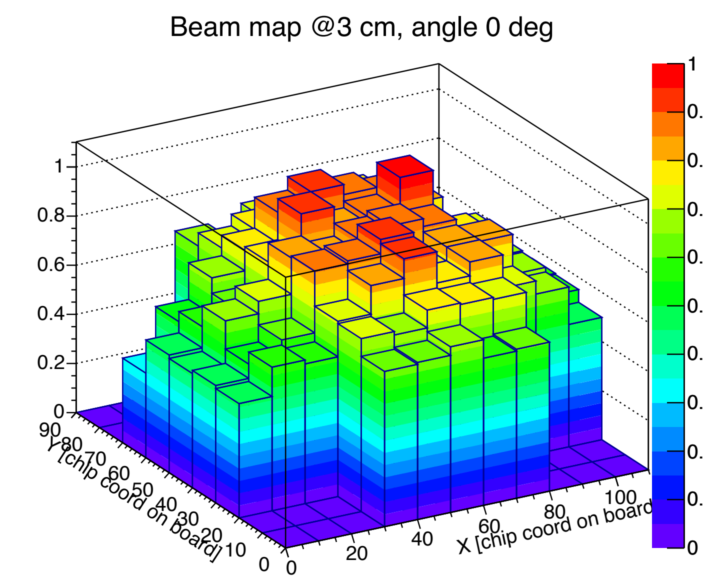
New technique: measure the SEU distribution on a matrix of well-known chips to characterise the spatial distribution of neutron flux

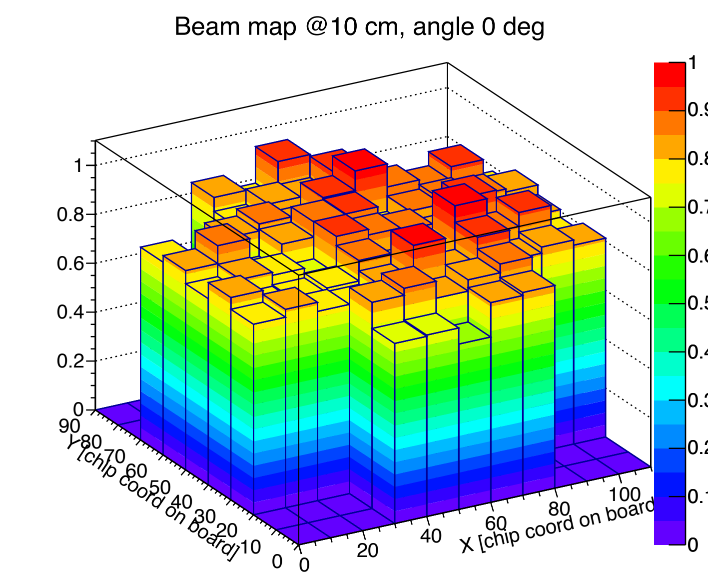


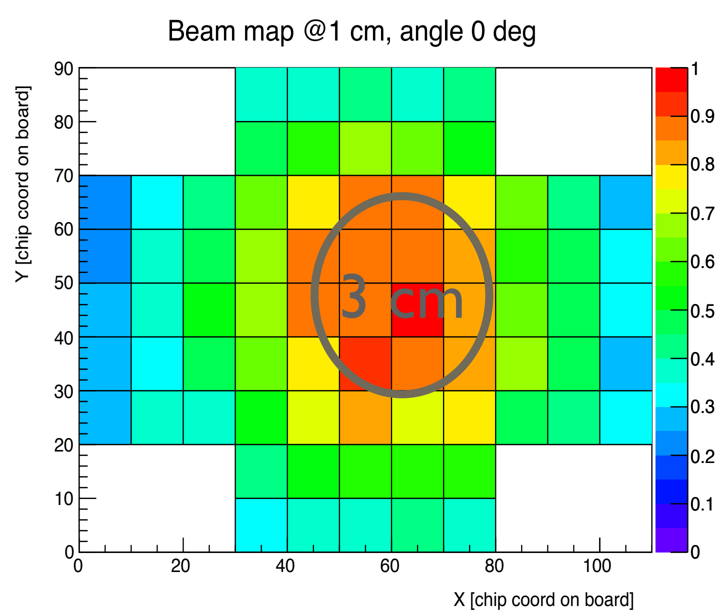
FLUX HOMOGENEITY (2)

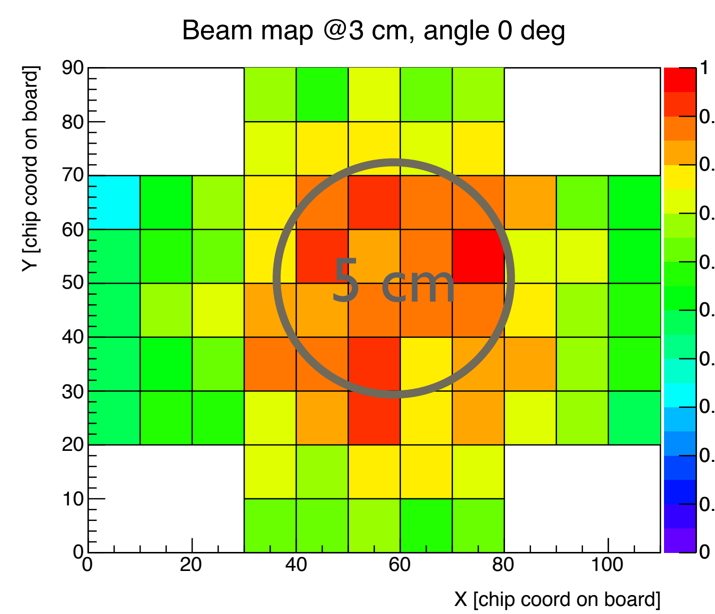
On-axis measurement: evolution of ±10 % homogeneity region with distance from the target

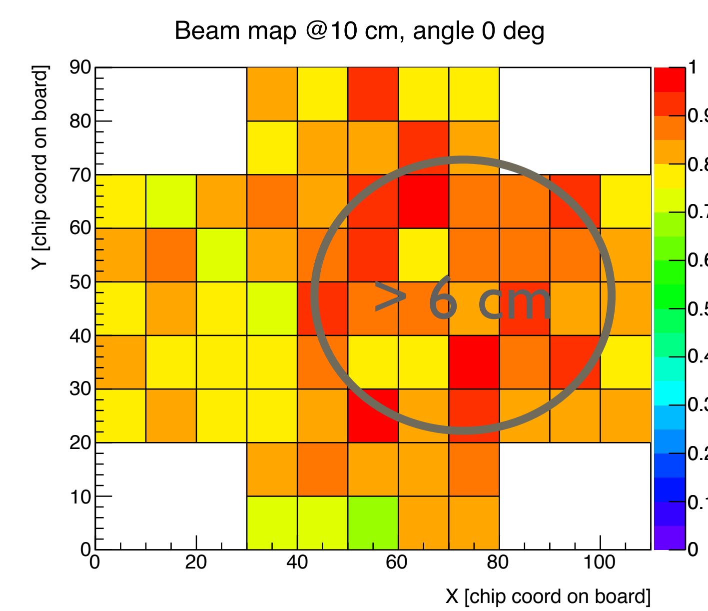






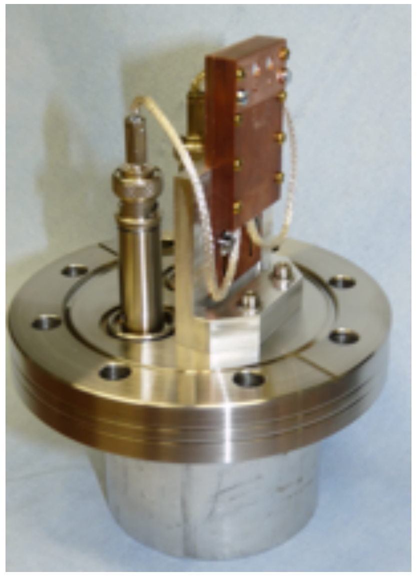






CONCLUSIONS & PERSPECTIVES

- GENEPI2 proved to be a robust and reliable machine open to physics and industrial applications
- An UPGRADE of the facility is scheduled:
  - new ECR source for deuteron production will be installed by the end of 2015
    - neutron production increased by a factor > 3 with improved shielding
  - dosimetry improvement:
    - SINGE monitor commissioning
    - new PI + API detector
    - possible purchase of fission chamber for 2.5MeV neutrons



- Small and flexible facility (no program committee) + support of local neutron physics experts → VARIETY OF PROGRAMS to ensure machine operation and scientific production

THANK YOU FOR YOUR ATTENTION

BEAM HOMOGENEITY (3)

Off-axis measurement: evolution with angle