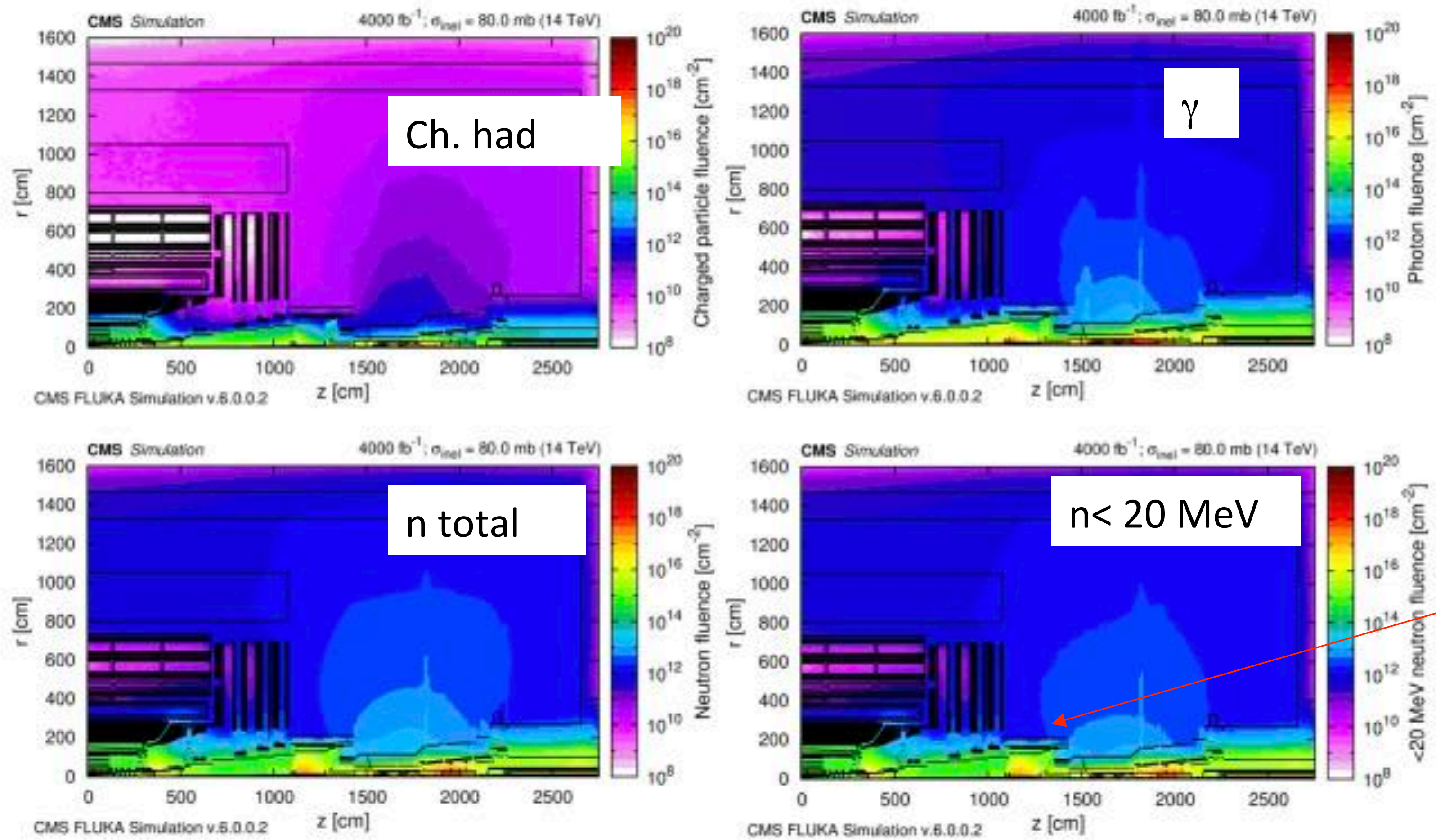
"TetraBall"
A Single moderator neutron spectrometer proposal for PHASE 2 BRIL NMR

Roberto Bedogni, Marco Costa
on behalf of INFN Frascati (LNF) and INFN Torino

Nov. 7th 2023

The contribution to the radiation field of the cavern from different particle types from 4000 fb^{-1} of luminosity, as derived from FLUKA simulations,7 TeV per beam, is detailed in Fig. 3.1, which shows that neutrons are the primary component of radiation outside of the CMS main structure, and neutrons with energy below 20 MeV dominate. [BRIL TDR]

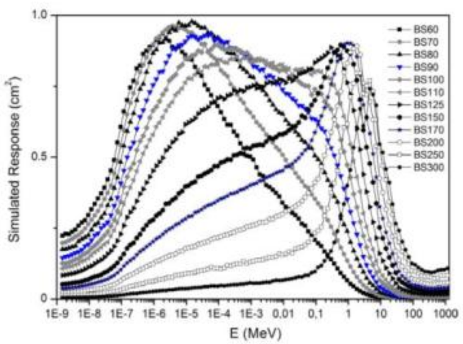


Mixed field. Neutrons dominates

At nominal UXC loca
Neutron's Integrate
fluence ~10^{13} n/cm^2

Transition from Bonner spheres to TetraBall

960 to date: Bonner spheres



hermal to GeV

sotropic response

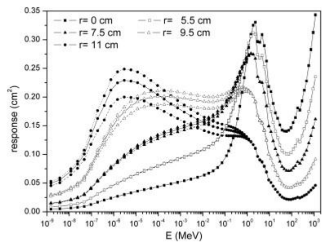
lultiple polyethylene spheres
vith single thermal neutron
etector (TND)

ead insert for high-Energy

Jnfolding process

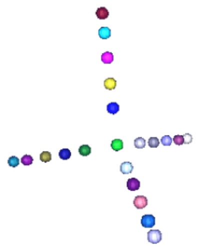
equential exposure

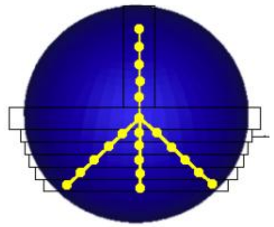
2010s @ INFN
From BS to Single moderator spectrometers



- Thermal to GeV
- Isotropic response by combining radial positions
- Single polyethylene sphere with multiple Silicon-TND in 31 positions along 3 axes
- Lead insert for high-Energy
- Unfolding process
- Single exposure

TetraBall

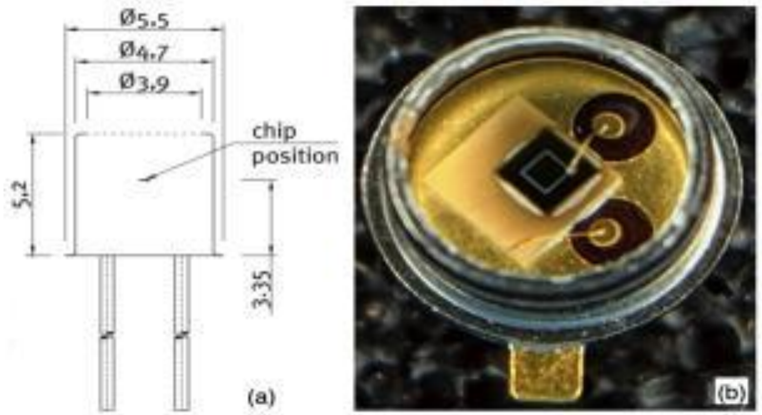


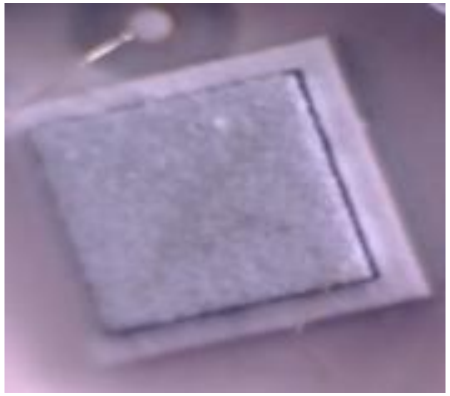


- Thermal to GeV
- Isotropic response by combining radial positions
- Single polyethylene sphere with rad hard SiC-TND in 2 tetrahedral positions
- Lead insert for high-Energy
- Unfolding process
- Single exposure

Rad-hard Silicon Carbide thermal neutron detectors

Sensitive area to be chosen from 1 mm^2 up to 8 mm^2 (different field intensity)
Slightly biased to reduce noise without increasing gamma response
Dual detector: Thermal n signal = ^{6}LiF Covered SiC - **bare SiC**
Radiation hardness: tested @ TRIGA reactor (LENA Pavia) up to 1E+14 cm^{-2}



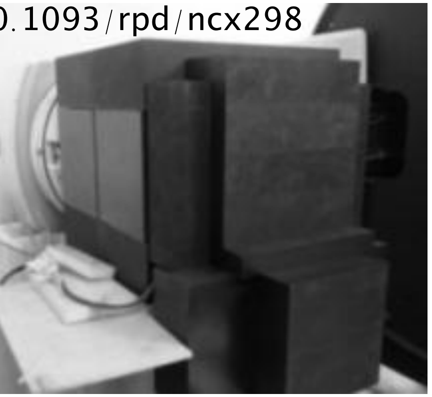


	Thermal Response (cm^2) (3% s.d.)	Rad damage beyond approx 10^{12} cm^{-2}	
		Left shift ?	Integral Response decrease
1 cm^2 Si + ^{6}LiF	3.0E-2	✔	-5% per 10^{12} cm^{-2}
1 mm^2 SiC + ^{6}LiF	3.0E-4	✔	constant within 3% up to $5.6 \cdot 10^{13}$ cm^{-2}

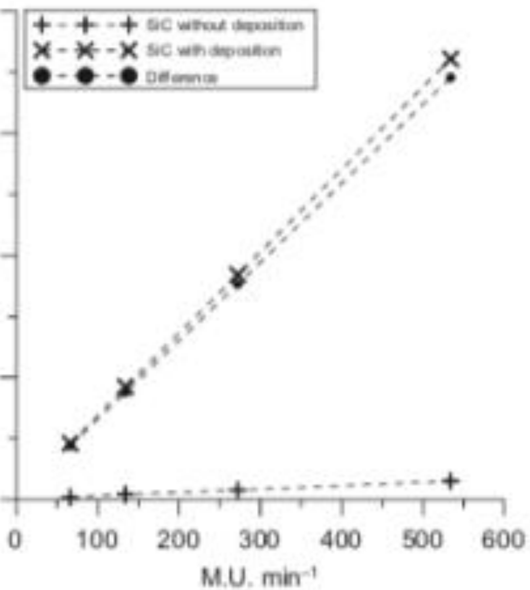
Eur. Phys. J. Plus (2022) 137:1358

Testing the Dual detector
Thermal n signal = ^{6}LiF Covered SiC - bare SiC

0.1093/rpd/ncx298



The Gamma rejection: very good, measured at Torino e-Linac neutron facility



^{6}LiF Covered – bare
Spectrum integrated
nearity Vs. fluence rate

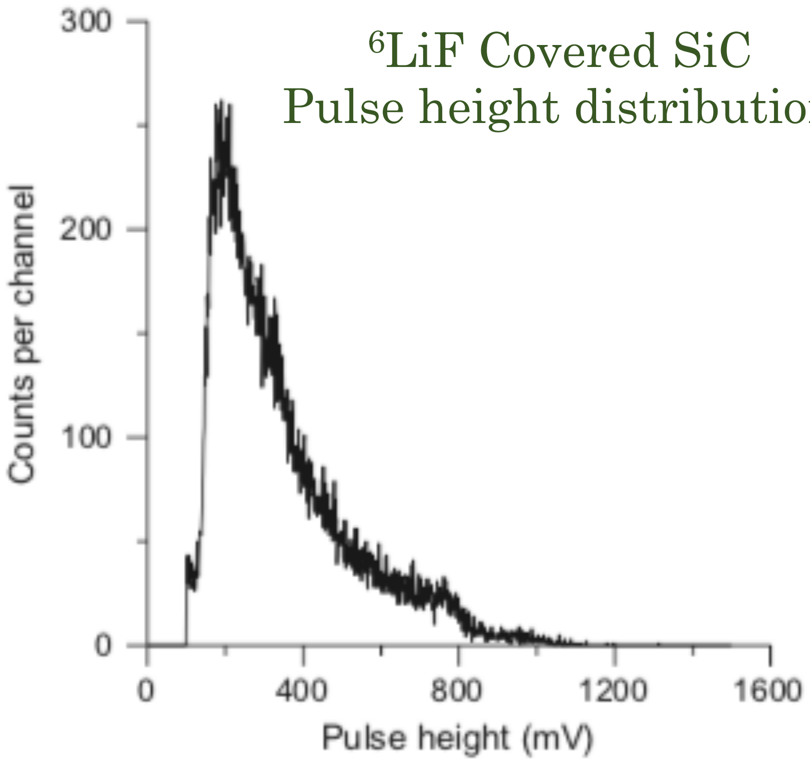


Figure 5. Spectrum obtained during a measurement in the center of the E_LiBANS cavity (size 20 cm × 20 cm × 5 cm) with a SiC + ^{6}LiF (measurement time: 180 s).

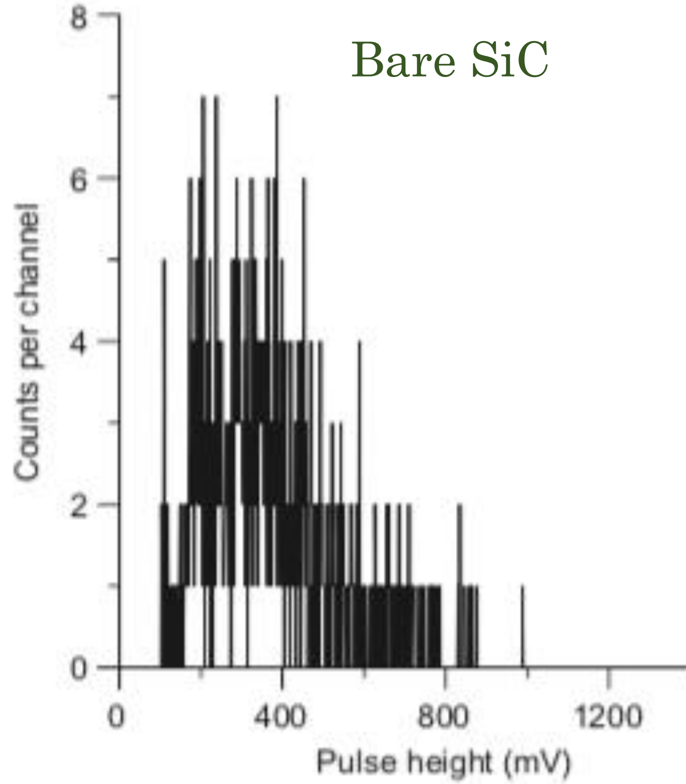
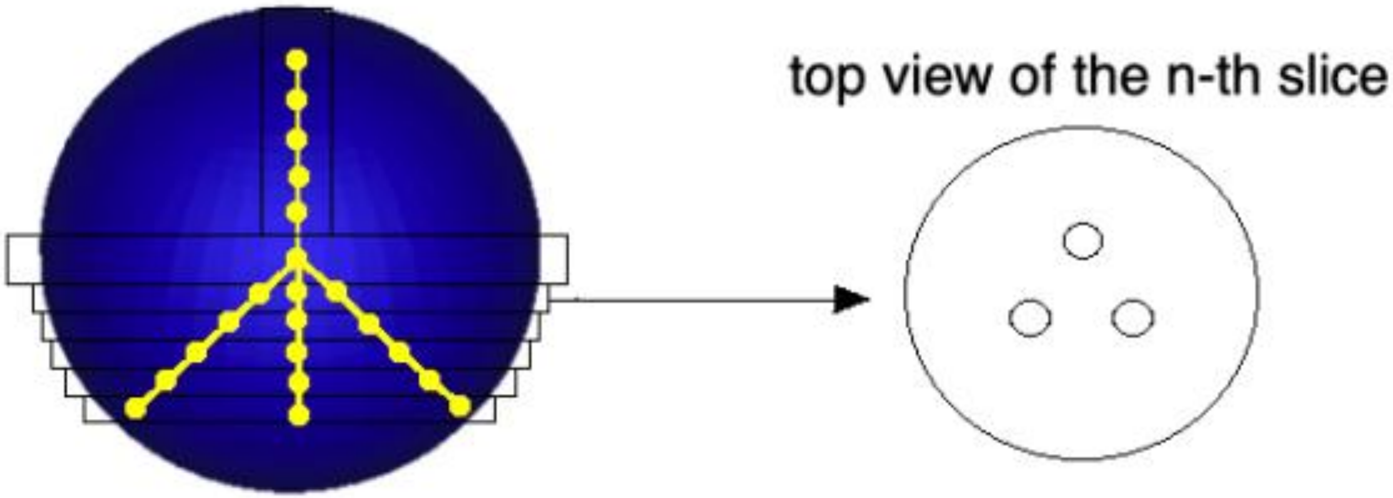


Figure 6. Spectrum obtained during a measureme center of the cavity the E_LiBANS cavity (size 20 cm × 5 cm) with a bare SiC detector (measurement tim

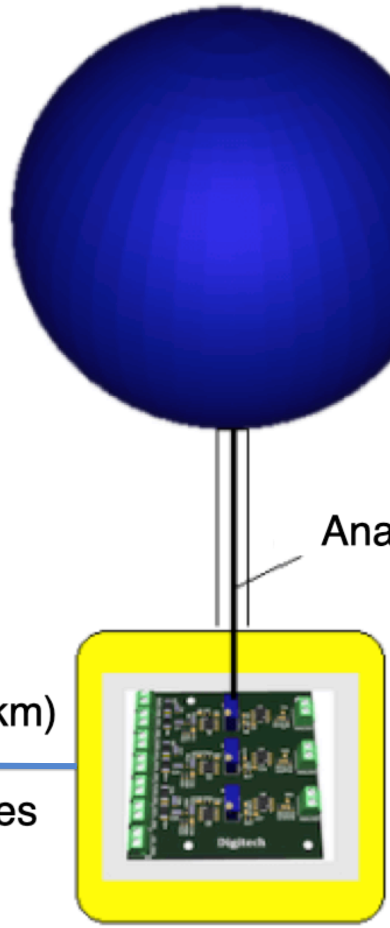
TetraBall design



- Tetrahedral arrangement of detectors covers all directions
- Overall diameter 23 cm
- Radial positions: 3 cm, 5 cm, 7 cm, 9 cm, 10.5 cm **(to be tuned with simulation)**
- (1 central detector + 5 detectors x 4 axes = 21 detectors) x 2 (**covered + uncovered**) = 42 SiC
- High-E component accessed by introducing lead inserts using (n,xn) reactions
- Calibrated to allow neutron monitoring across the whole energy spectrum

TetraBall design

Front-end
UXC



Analog lines: about 50 cm

Digital data:
RS 485 (up to 1.2 km)

using existing cables

PE + boron shield fo
- frontend shielding
- Tetraball “holder”

Possibility of using existing medipix cables and infrastructures under investigation (23-24 Nov on site)

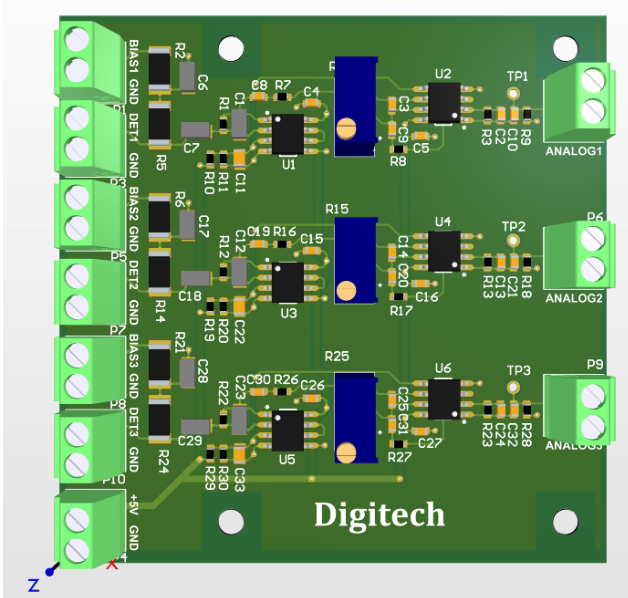
Back-end
USC

ngle acquiring PC

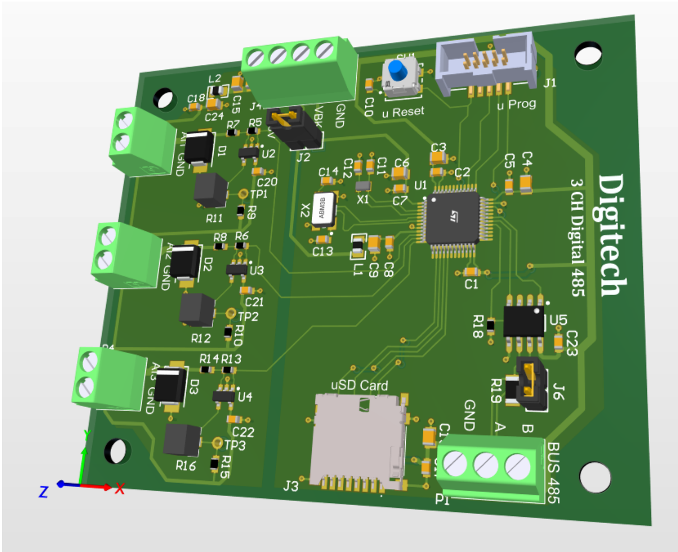
TetraBall design

ectronics being developed

NALOG part (*Through-hole prototype working in lab*)
- SMD technology (surface about 2-3 cm^2 per channel)
- Charge pre-amplifier + Gaussian shaper amplifier with adjustable gain
- 3 channels/board



GITAL part (DIGITECH SRL)
- Digitalisation, thresholding, counting and data formatting for RS485
- 3 channels/board



<u>Prototypes under productions – expected by Dec23</u>

TetraBall proposal based on a technology developed and demonstrated @INFN

INFN Projects:
NESCOFI (2011-2013)
NEURAPID(2014-2016)
e_LiBANS (2016-2018)
ANET(2019-2022)
Enter_BNCT(2020-2023)

People involved on INFN side:

INFN LNF

R. Bedogni

L. Russo Post graduate (100%)

M.A. Caballero post-doc (25%)

A.I. Castro Campoy post-doc (25%)

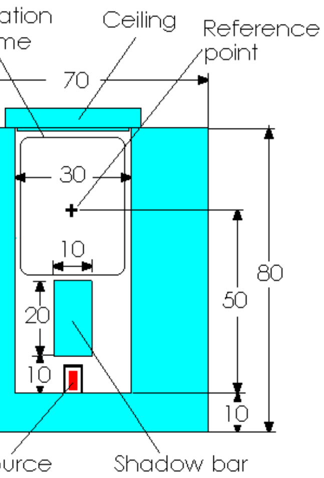
T. Napolitano Mech Ing (Staff)

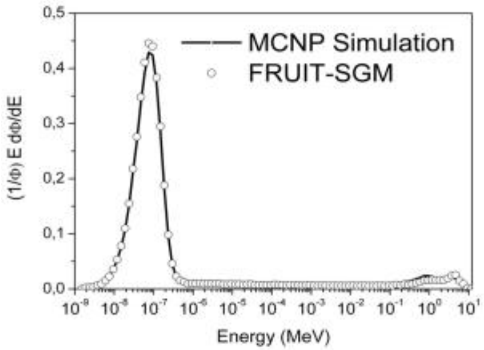
INFN TORINO

- M. Costa,
- E. Mafucci, Post-doc (100%)
- V. Monti, Research Techn (Staff)
- E. Durisi Research Techn (Staff)
- P. Mereu Mech Ing (Staff)

Detector calibration facilities at INFN

HOTNES(*)

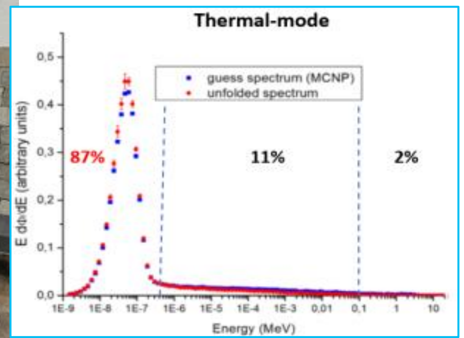


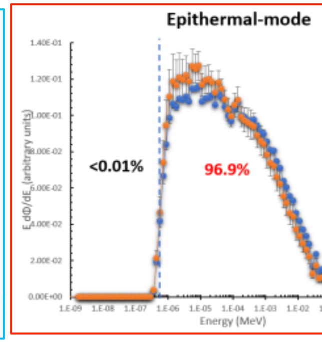


- ^{241}Am-B Neutron source ($3.5 \cdot 10^6$ s^{-1})
- Polyethylene assembly
- Large cavity volume
- High Purity thermal field
- Thermal fluence uniformity 1%
- Thermal fluence rate 700 cm-2s-1
- Calibrated wrt primary reference field

Bedogni et al., NIM-A, Volume 843, 2017, Pages 18-21

e_LiBANS(*)





- 18 MeV electron medical Linac
- Coupled to γn converter +moderator
- Large cavity volume
- High Purity thermal & epithermal fields
- Field uniformity ~5%
- Thermal fluence rate 1.5 x10^6 cm^{-2}s^{-1}
- Epithermal fluence rate 2.5 x10^5 cm^{-2}s^{-1}
- Calibrated wrt primary reference field

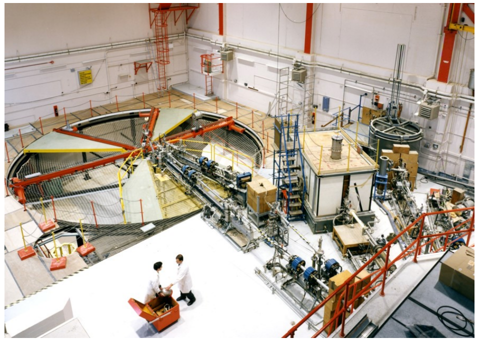
(*) M. Costa et al. Appl. Rad. Isot. 2020 Dec:166:109363

TetraBall calibration

Step1) Calibration of single channels at INFN Thermal neutron facilities

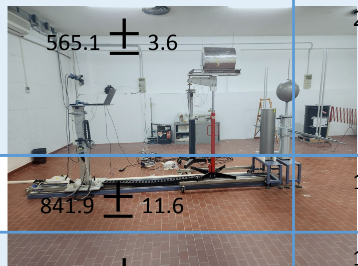
Step2) Calibration of the complete Tetraball system at :

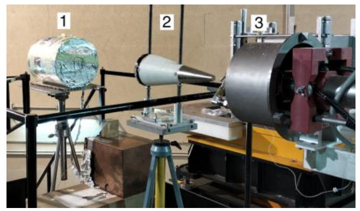
- 71 keV-1.2MeV mono-energetic beams (National Physics Lab-Teddington UK or PTB)



Neutron Energy [keV]	SSD (cm)	Reaction	Angle [°]
71.5 ± 4.5	180.7	$^7Li(p,n)^7Be$	50
144.2 ± 4.6	181	$^7Li(p,n)^7Be$	0
565.1 ± 3.6	230.8	$^7Li(p,n)^7Be$	0
841.9 ± 11.6	180.6	$T(p,n)^3He$	50
1200.4 ± 14.8	180.7	$T(p,n)^3He$	0

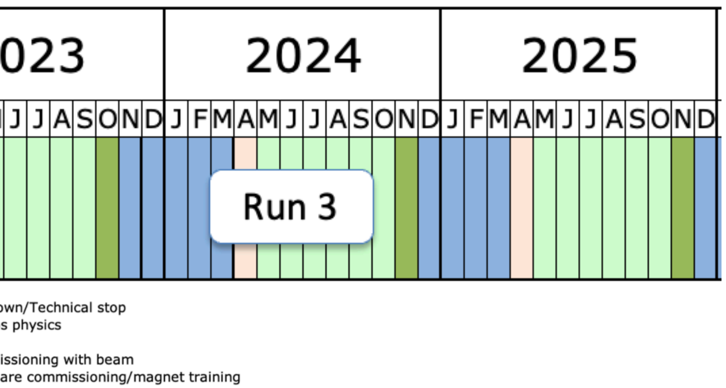
- MeV region (< 14 MeV)
  Am-Be , $^{252}C_f$ (ENEA-Bologna) D-D, D-T (FNG ENEA-Frascati)

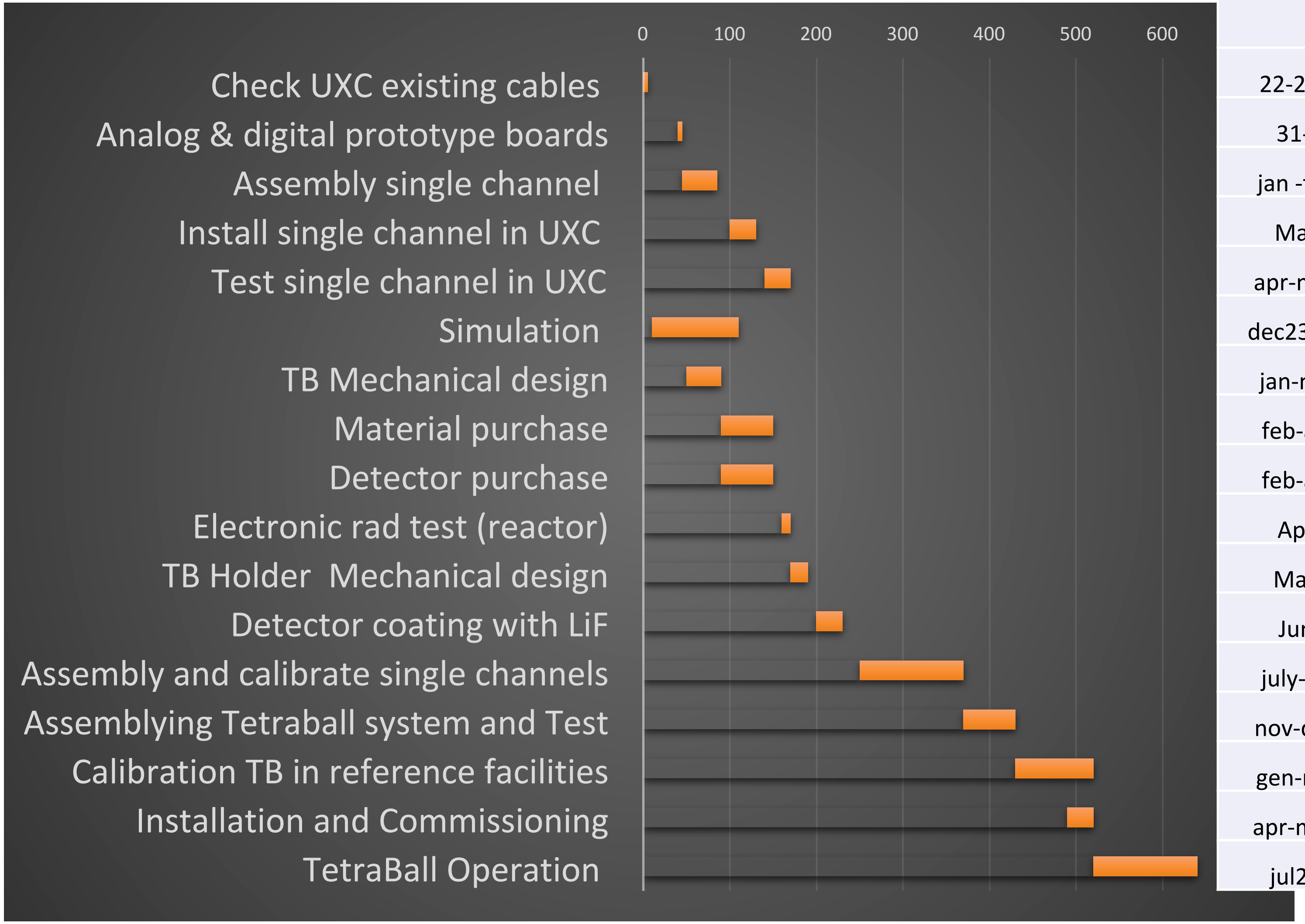




- High Energy CERF

TetraBall timeline 2024-2025





TB operational in Q2-Q3 2025

dependent from the rest of the CMS

r upgrade → we have some contingency

nediate Goal: operate single channel

mode in April-May 2024

now :

ck UXC existing infrastructure

NP simulation....

nbly and calib single channels Q3 2024

embly Q4 2024

ate TB Q1 2025

TETRABALL - Conclusions

- INFN –TETRABALL: Specific contribution for PHASE 2 BRIL –NRM
  - Single exposure, suitable for Online Monitoring
  - Isotropic Response
  - Wide energy range thermal to GeV
  - Radiation hard
  - Portable system

- INFN Frascati and Torino physicists and engineers committed to the task

- Aim to deliver the first TetraBall to be operational in Run 3 - 2025

Next steps (near future):

- TBall Simulation: energy and directional distributions of neutrons and hadrons in specific UXC locations are available → input to MCNP simulation

- TBall UXC to USC check existing BRIL –NMR infrastructure (PS, cables, connectors...)
  -November 22-24-th 2023 first inspection into the CMS Cavern with BRIL-TC

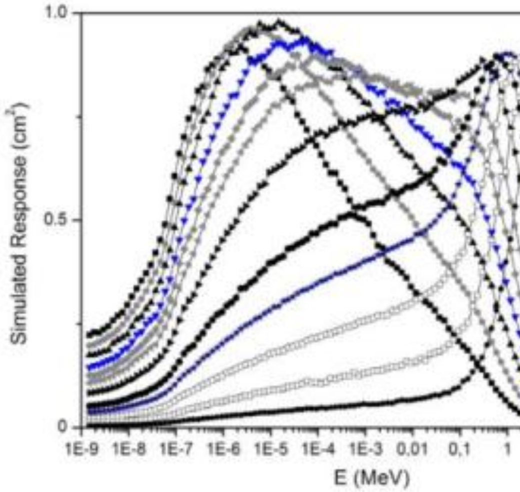
- Mixed radiation field → Dual Mode Counting: Operation of a single channel in the UXC Q1 2024
  -Analog and digital electr. prototype boards expected Dec2023

spares

From Bonner Spheres to Single Moderator Neutron Spectrometers

Bonner Spheres Spectrometer

Physics Reports 875 (2020) 1–65



Covers thermal to GeV energy range
sotropic response
Simple operation
Detector can be changed to match the field in terms of intensity and photon compon
Very accurate

the fluence in large energy intervals can be determined with <5% unc.

Unfolding still needs skill but, after 60+ years, unfolding method are better established:

- ❑ *ways to provide pre-information according to the specific problem*
- ❑ *uncertainty treatment*
- ❑ *codes became "friendly" / training material online / unfolding courses / exercise*

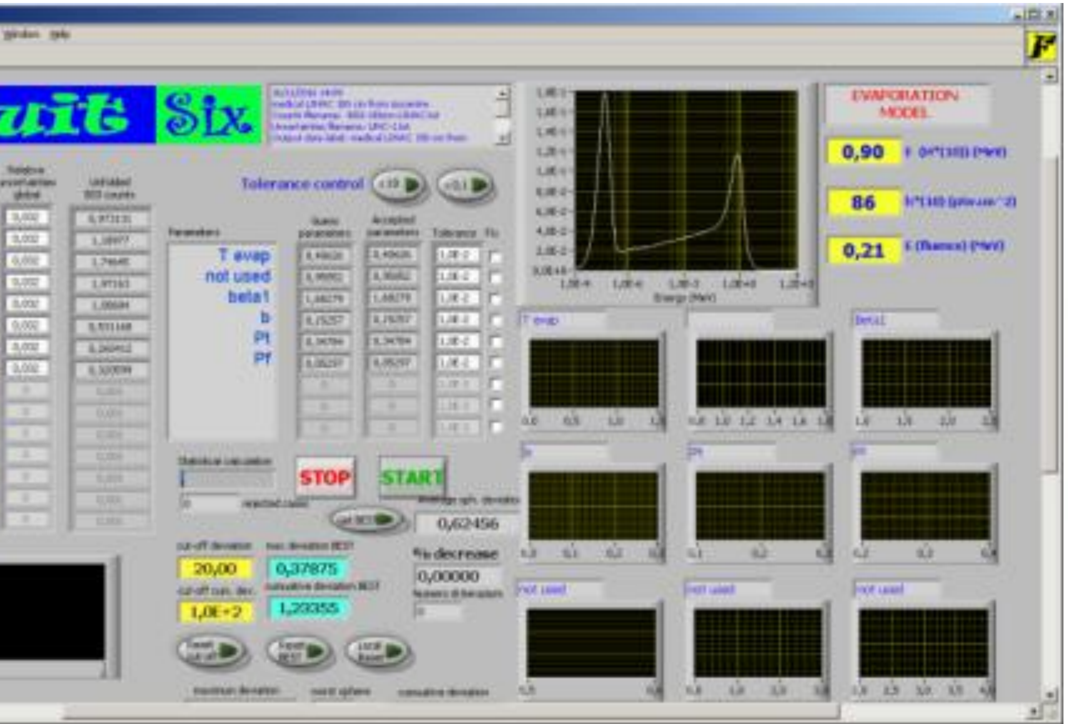
Continuous and partially superimposed response functions: limited resolving power
Sequential irradiations are needed – time consuming – <u>unsuited for real time moni</u>

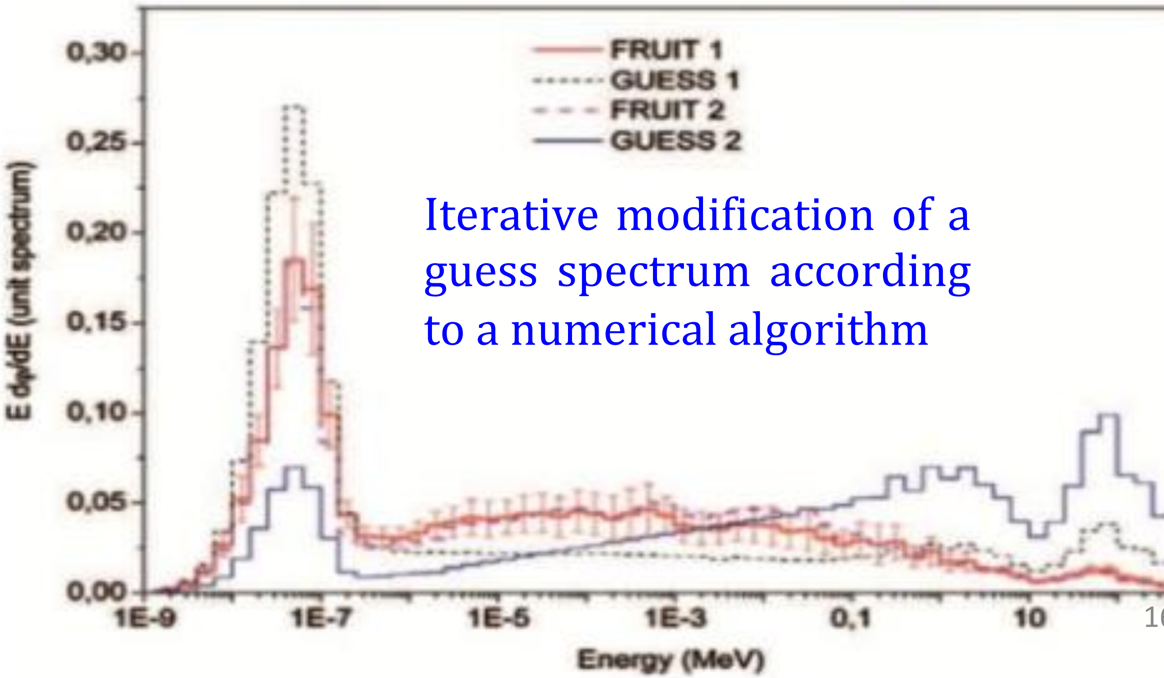
From Bonner Spheres to Single Moderator Neutron Spectrometers

Jnfolding in BSS pretends to infer a complex neutron spectrum starting from less than ten count rate

The problem is underdetermined and needs therefore some amount of pre-information from the user. C he infinite mathematical solutions, only a limited subset is physically acceptable (= the solution withi ts uncertainty boundary)

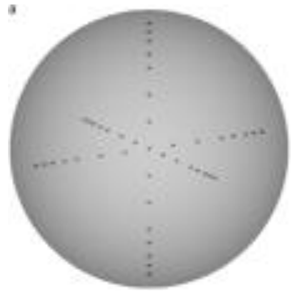
re-information is needed to identify that subset: "suggesting" an educated guess spectrum, i.e. a guess ctrum obtained with MC





History of SMNS

A sphere made of boron-loaded scintillating plastic read out by an array of light detectors (SLAC) (*IAEA proceeds.*)



2010

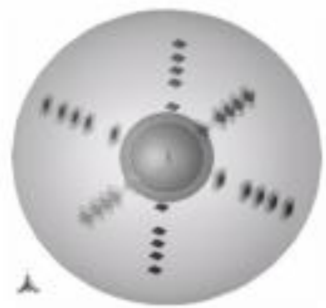
30 cm PE sphere embedding TLDs symmetrically arranged along the 3 axis. Summing up signals at same radial position gives isotropic response.
NIMA 584 (2008) 196-203; NIMA 613 (2010) 127-133

2011

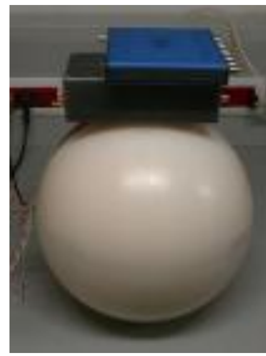
First PASSIVE prototype with Dy activation foils – 37 positions
Radiat. Meas. 46 (2011) 1712-1715

In view of the active version, design modified to 31 positions and added internal 1 cm lead layer for high-E
NIMA 677 (2012) 4-9

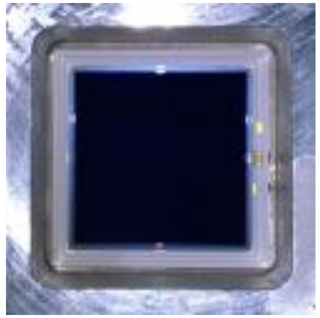
SP^2: Spherical Spectrometer – direct reading
NIMA 767 (2014) 159-162
Eur. Phys. J. Plus (2015) 130: 24



2012



SP2 Internal thermal neutron sensors


NPD – thermal neutron pulse detectors

ypical: 1-cm^2 Si-diode covered by 30 μm ^{6}LiF

Rad damage at large accumulated fluence

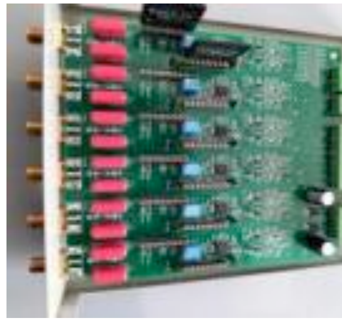
lightly biased to improve noise gamma rejection

ustom multi-detector analog board (charge preamp. + shaper amp.)

ndividually calibrated in thermal neutron fields.

0.03 cm^2 (typical fluence response to thermal neutrons)

igital elaboration using commercial digitizer and laptop



efs.: *NIM A 1018 (2021) 16585*
NIM A 780 (2015) 51-54
Radiat. Prot. Dosim. 161 1-4 (2014) 229-232

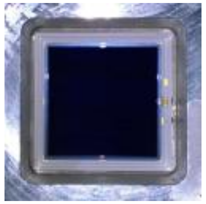
Silicon Carbides

Rad hardness tests at TRIGA reactor (LENA Pavia)

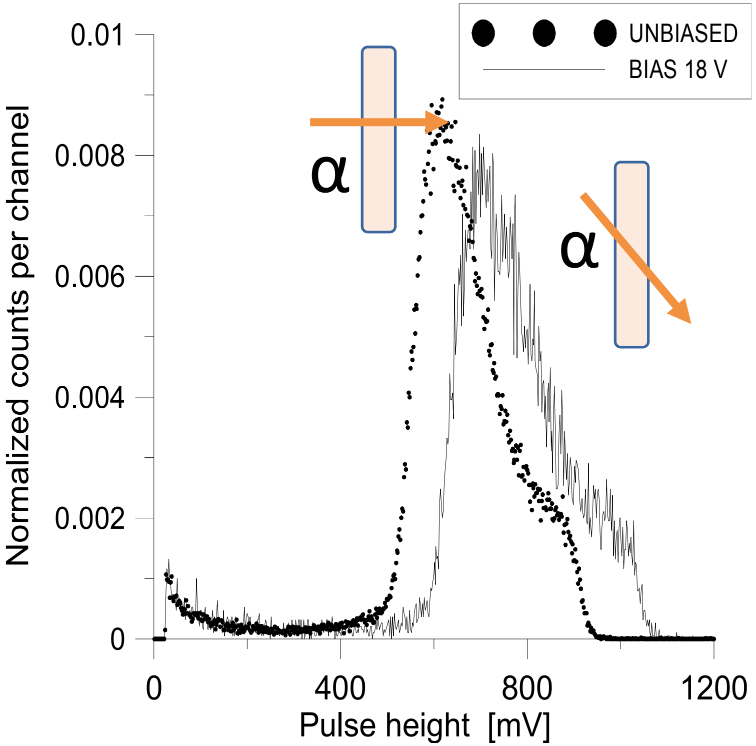
- ✓ $1.2 \bullet 10^{10}$ $cm^{-2}s^{-1}$ @ 250 kW in thermal column
- ✓ SiC irradiated up to $5.6 \bullet 10^{13}$ cm^{-2}

	Thermal Response (cm^2) (3% s.d.)	Rad damage beyond approx 10^{12} cm^{-2}	
		Left shift ?	Integral Response decrease
1 cm^2 Si + ^{6}LiF	3.0E-2	✔	-5% per 10^{12} cm^{-2}
1 mm^2 SiC + ^{6}LiF	3.0E-4	✔	constant within 3% up to $5.6 \bullet 10^{13}$ cm

Conversion reaction $^{6}Li + n = \alpha + {}^{3}H + 4.8$ MeV

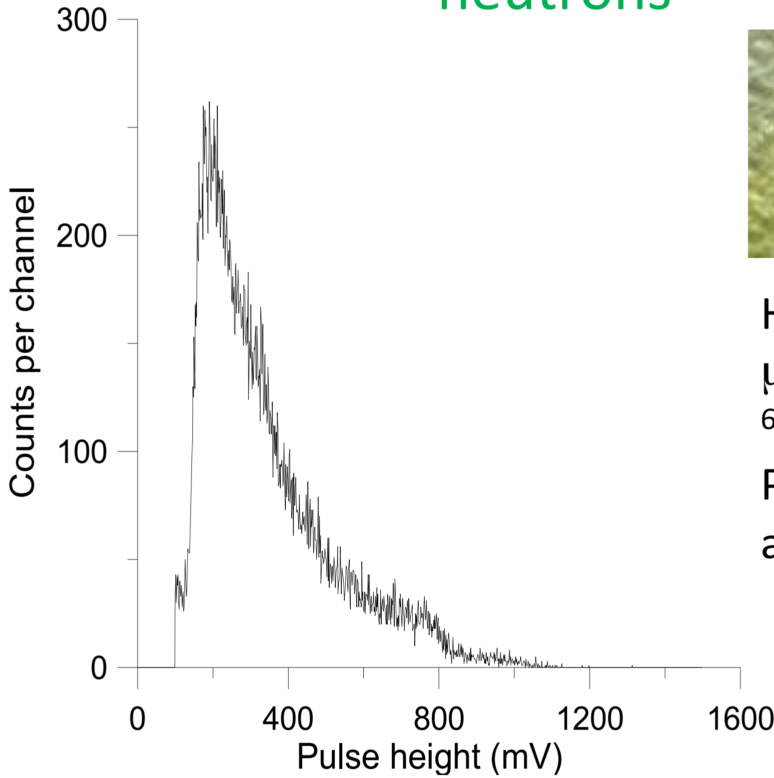


Detector uncovered exposed to α

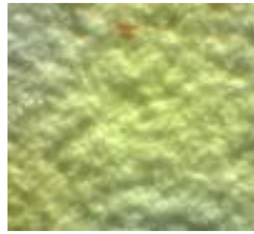


^{241}Am alpha Source

Detector 6LiF-covere exposed to thermal neutrons



LINAC ELEKTA 18MV+ThermalCavity



Homogenou
μm-thicknes
^{6}LiF deposit
Process avai
at LNF