SPECTRAL Project

Spectrométrie Neutronique Rapide Large Bande

L. Dioni[1], R. Jacqmin[2] ,V. Gressier[3], P. Leconte[2], B. Perot[4], C. Carasco[4], V. Lacoste[3], M. Aiche[5], L. Mathieu[5], B. Stout[1]

[1]Institut Fresnel (Aix-Marseille Université), [2]CEA-CAD/DER, [3]IRSN-CAD, [4]CEA-CAD/DTN, [5]CENBG Bordeaux

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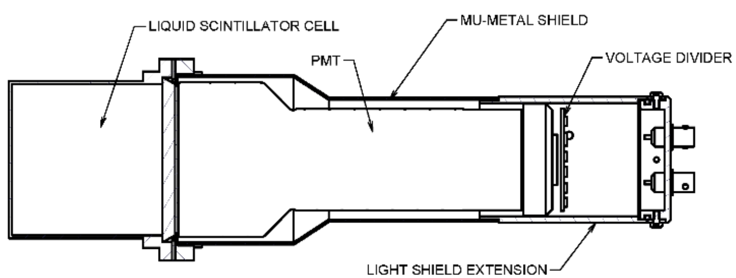
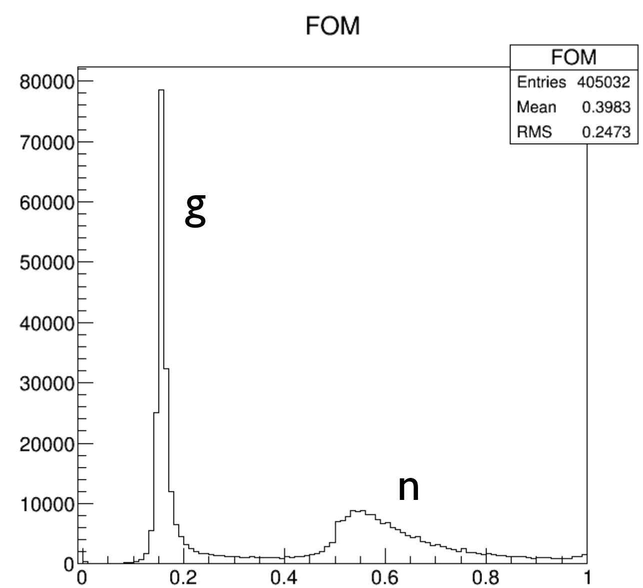
Context and Motivation

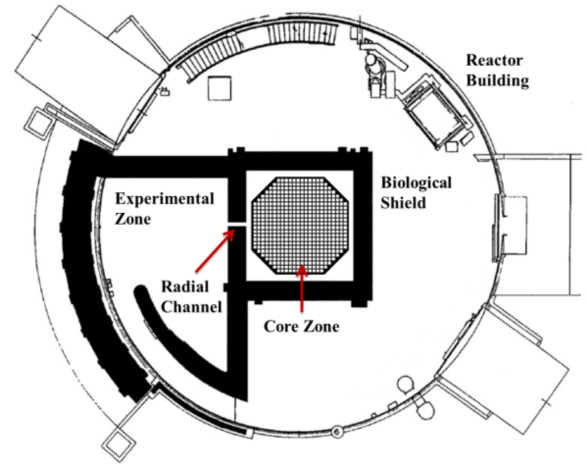
- Techniques for fast neutron spectrometry in mixed radiation fields
  - Continued and pulsed neutron beam characterization
  - In-core and out-of-core fast neutron spectra measurements: *Development of a Multi-Purpose Fast Neutron Spectrometric Capability in the MASURCA Experimental Facility* (PhD Thesis - Luca Dioni)
  - Nuclear physic measurements





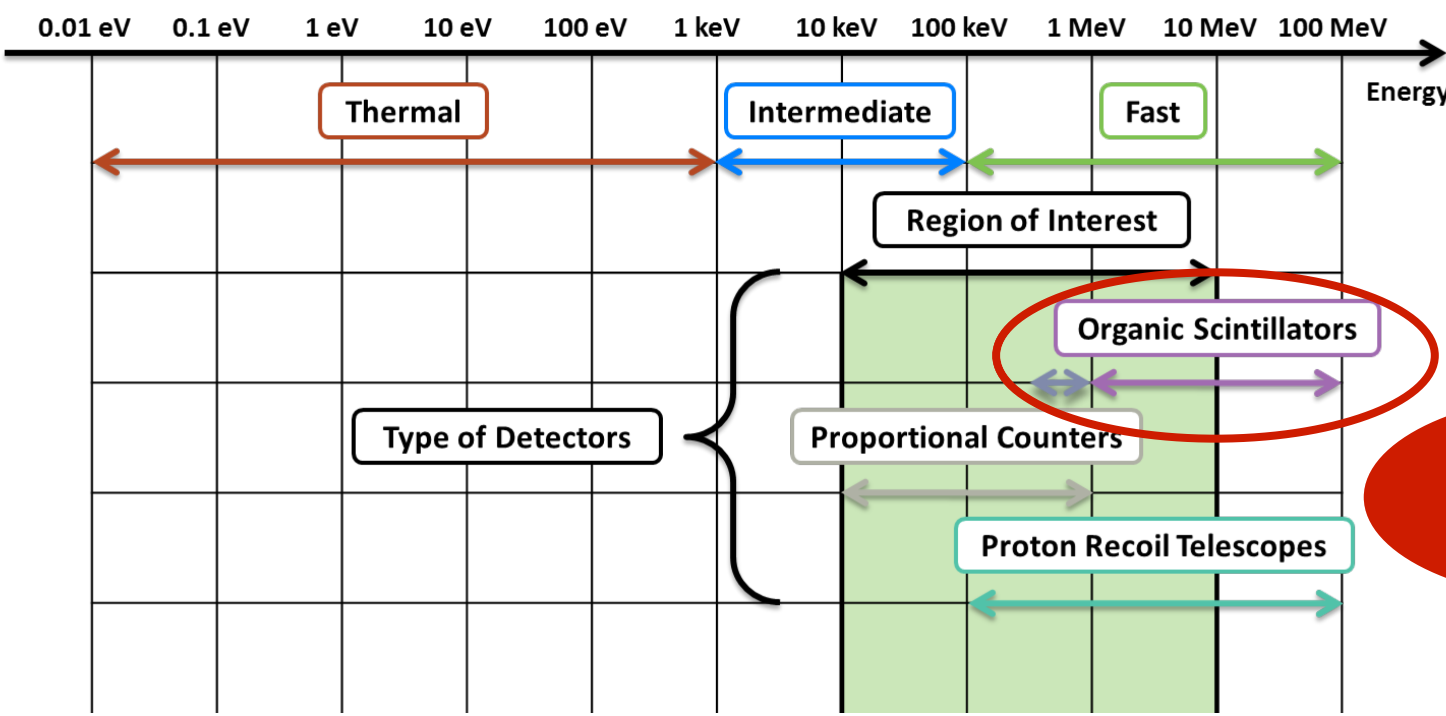
C & M: focus on MASURCA

- In-core and out-of-core fast neutron spectra measurements at the MASURCA facility
  - Zero-power air-cooled experimental critical facility
  - Built in the 60's at CEA Cadarache
  - Operate for studying the physics of fast neutron lattices and cores
  - Refurbishment phase in preparation for new programs (mainly related to ASTRID)
  - Instrumentation to be entirely renewed



Objective

- Developing a combined neutron spectrometry concept based on proportional counters, organic scintillators and proton-recoil gas telescopes for covering the neutron **intermediate-to-fast** energy range, between some keV to 10 MeV

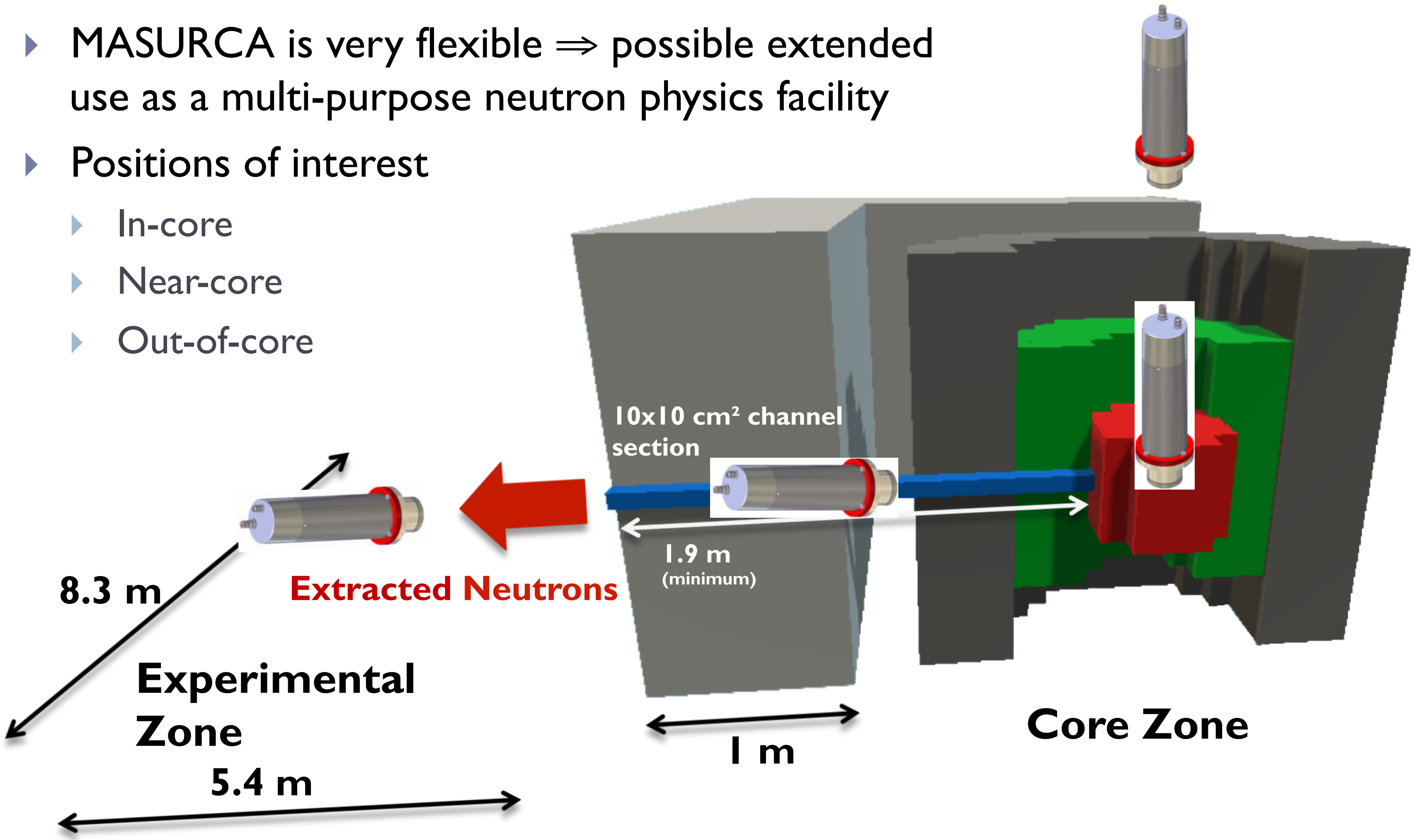


Supported by NEEDS

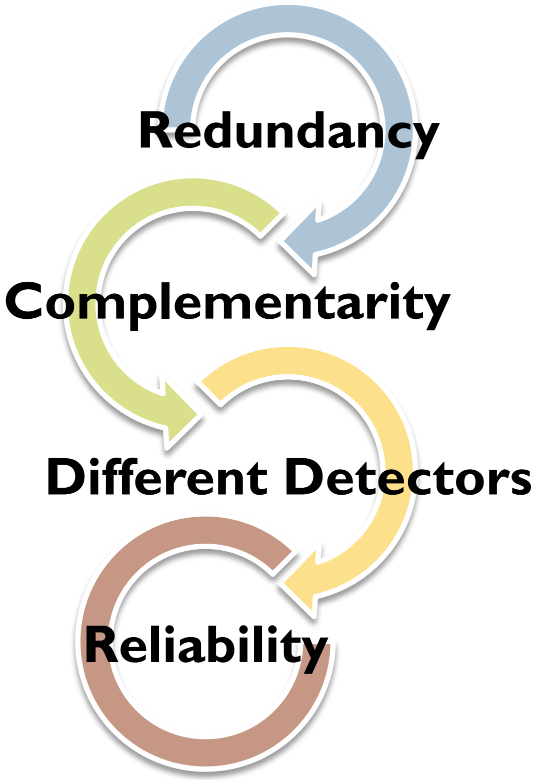
Stilbene

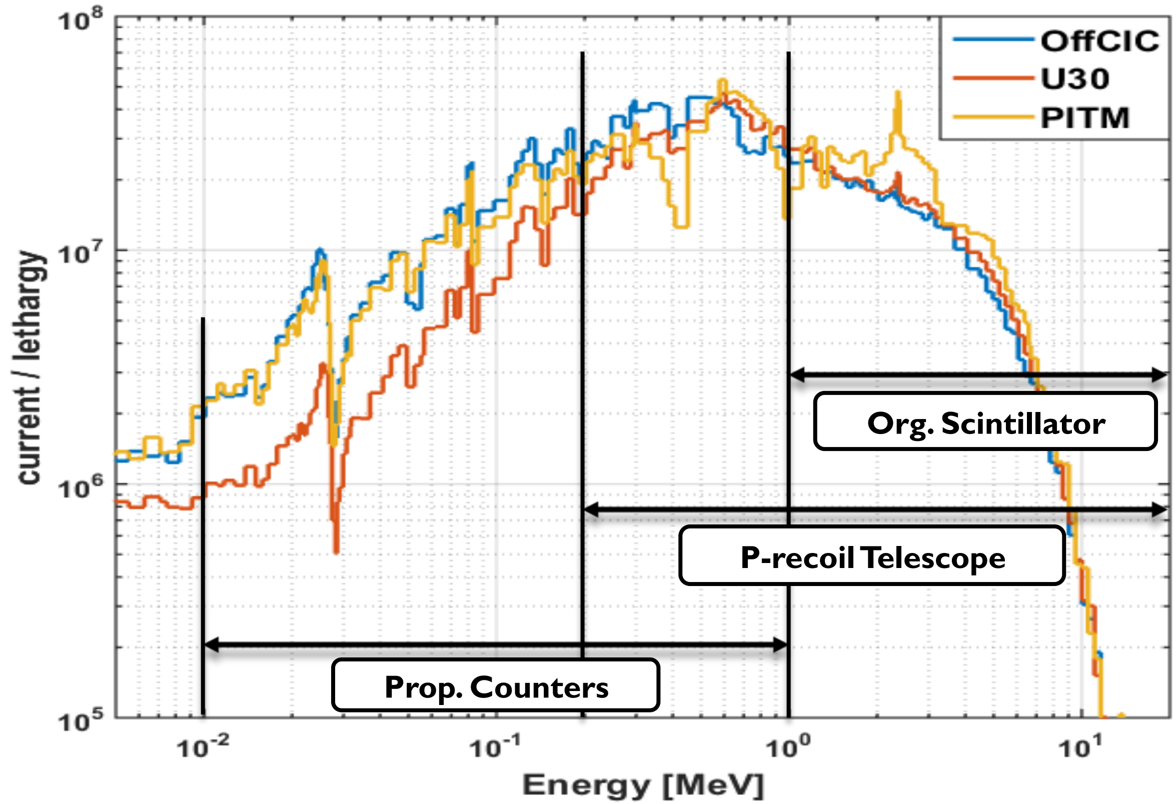
MASURCA - Introduction

- MASURCA is very flexible ⇒ possible extended use as a multi-purpose neutron physics facility
- Positions of interest
  - In-core
  - Near-core
  - Out-of-core



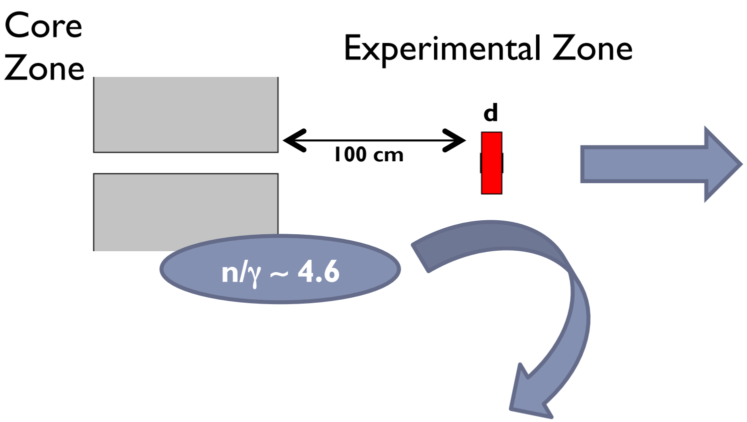
MASURCA – Neutron Spectra



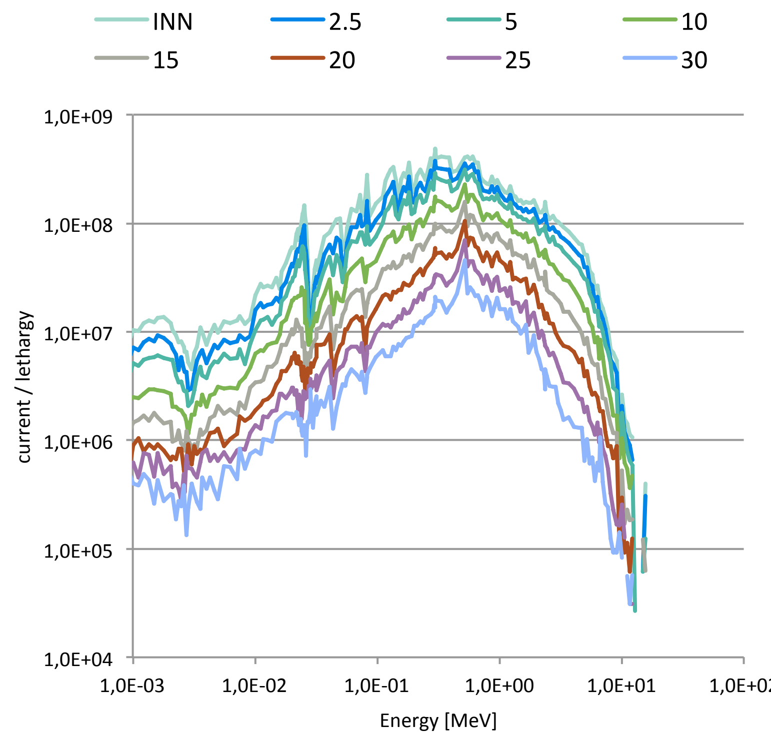


- In-core: neutron spectrum
- Near-core: neutron leakage spectrum measurements
- Out-of-core: different applications
- Variable power to match the instrumentation needs

MASURCA – Gammas



d	n/γ
2.5	3.91
5	31.96
10	87.09
15	117.02
20	126.49
25	111.63
30	103.30



	Total Neutron Intensity (n cm^{-2} s^{-1})	Fast Neutrons Fraction (>10 keV)	Total Gamma Intensity (γ cm^{-2} s^{-1})	n_{fast}/γ
OffCIC	1.32E+08	89 %	2.52E+07	4.66

- Gamma rays affect the measurements
- A 5 cm lead filter increases the n-γ ratio by about one order of magnitude
- Detection techniques capable of discriminating neutrons from gammas

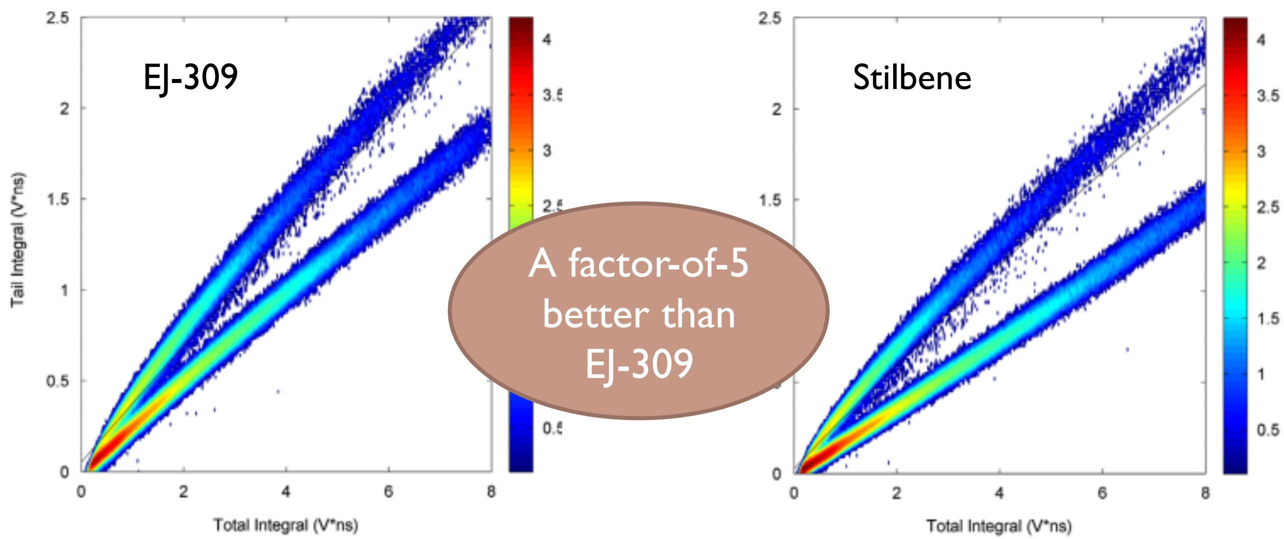
Organic Scintillators: BC501A

- Instrumentation wanted characteristics:
  1. Cover the 10 keV to 10 MeV energy domain, with overlaps
  2. Able to discriminate well neutrons from gammas
  3. Insensitive to thermal neutrons (or capable of discriminate between the two)
  4. Not based on Time of Flight techniques, the reactor operates continuously
  5. Capable of working in a harsh environment without breaking safety limitations (research reactor-type)
- BC501A:
  1. Energy domain: used as standard for neutron spectroscopy in mixed radiation fields above 1MeV
  2. Able to discriminate well neutrons from gammas in the covered energy range
  3. Insensitive to thermal neutrons
  4. Not based on Time of Flight techniques
  5. Not capable of working in a harsh environment without breaking safety limitations

Temperature sensitivity and inflammability

Organic Scintillators: Why Stilbene?

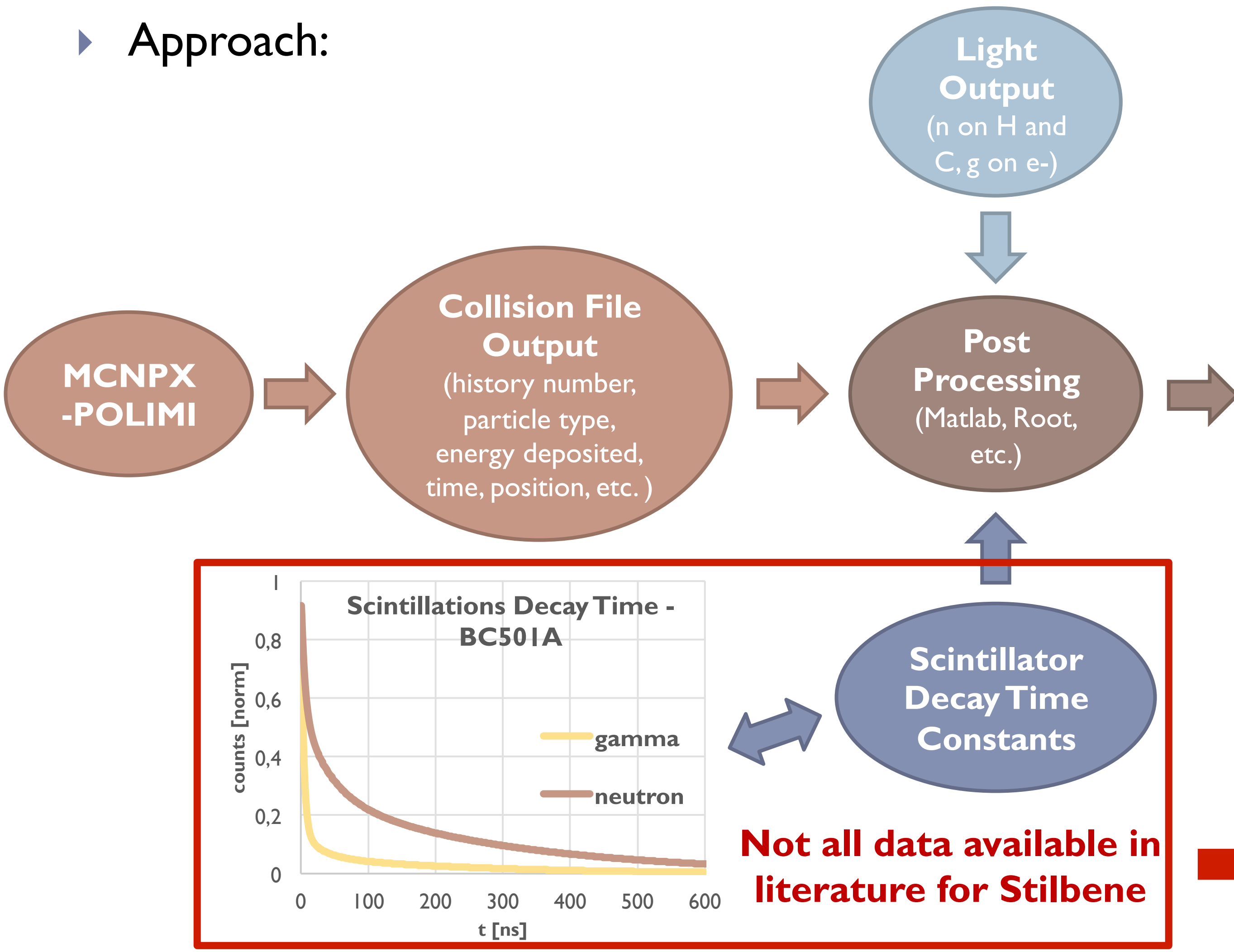
- Stilbene (solution-grown):
  i. Energy domain: over 400 keV, energy resolution from 3% (14 MeV) to 10% (0.5 MeV) [4]
  ii. Able to discriminate better than liquid scintillators neutrons from gammas [5]
  iii. Insensitive to thermal neutrons and not based on Time of Flight techniques
  iv. Capable of working in a harsh environment without breaking safety limitations [6]
  v. Sensitive to temperature changes and anisotropy response correction needed [7]

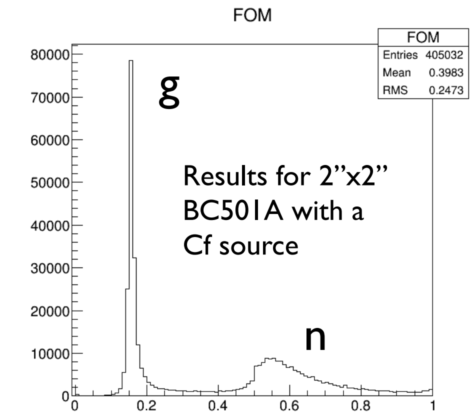


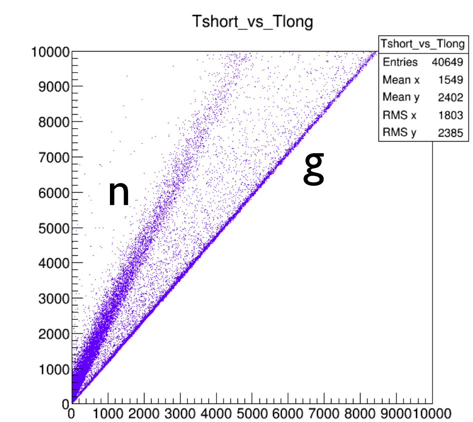
Images from [5]

Evaluating the n-γ Discrimination Capability

- Approach:







L.M. Bollinger and G.E. Thomas, THE REVIEW OF SCIENTIFIC INSTRUMENTS (1961);
N. Zaitseva et al., NIM A (2015)

Evaluating the Neutron Spectrum

- Approach:

Tripoli 4 (or other MC codes) → **Simulated Neutron Spectra** →

Measurements → **Pulse High Spectra** →

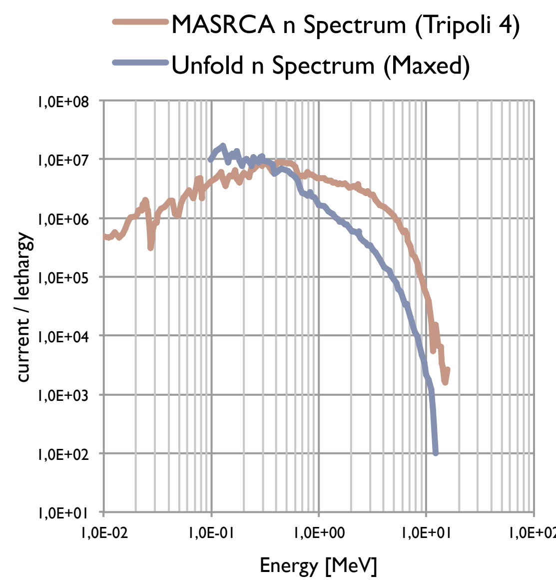
MCNPX-POLIMI

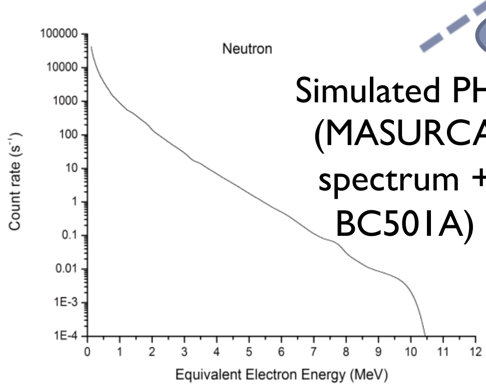
Unfold (gravel, maxed, etc.)

Detector Response Matrix

Not presents in literature for Stilbene → **Measurements in mono-energetic, <u>REFERENCE</u> neutron fields**

Preliminary Results (BC501A)

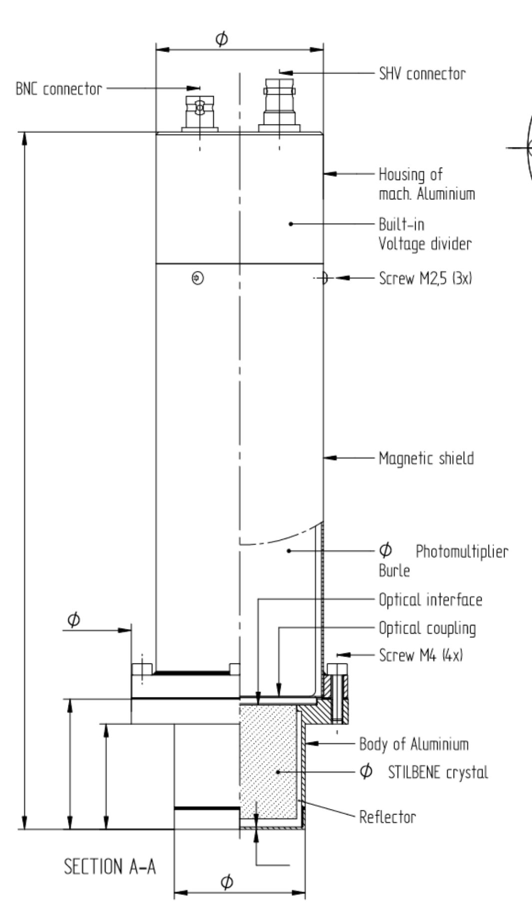


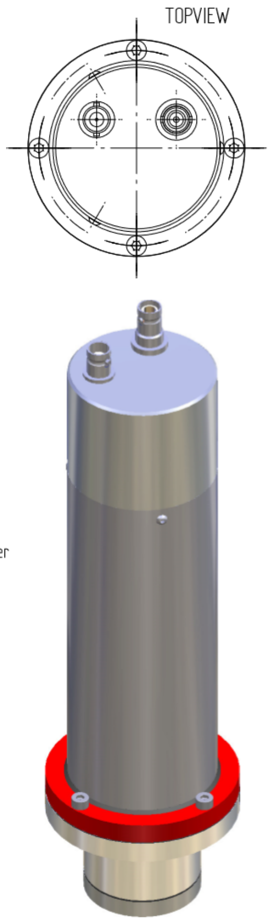


Simulated PHS (MASURCA spectrum + BC501A)

Detector

- Scintillator: 25 mm diameter, 25 mm high (cylinder) solution-grown stilbene crystal (**Inradoptics**)
- Photomultiplier: fast 12 stage ET 9214 PMT (**ET Enterprises**)
- Manufacturing phase (**SCIONIX**): stilbene mounted in aluminum housing with optical window, optically coupled in demountable assembly to the PMT surrounded by a solid mu-metal shield and transistorized voltage divider wired for negative high voltage with separate anode an dynode outputs
- Sponsored by NEEDS: stilbene + PMT + coupling + transport ⇒ ~2 k€

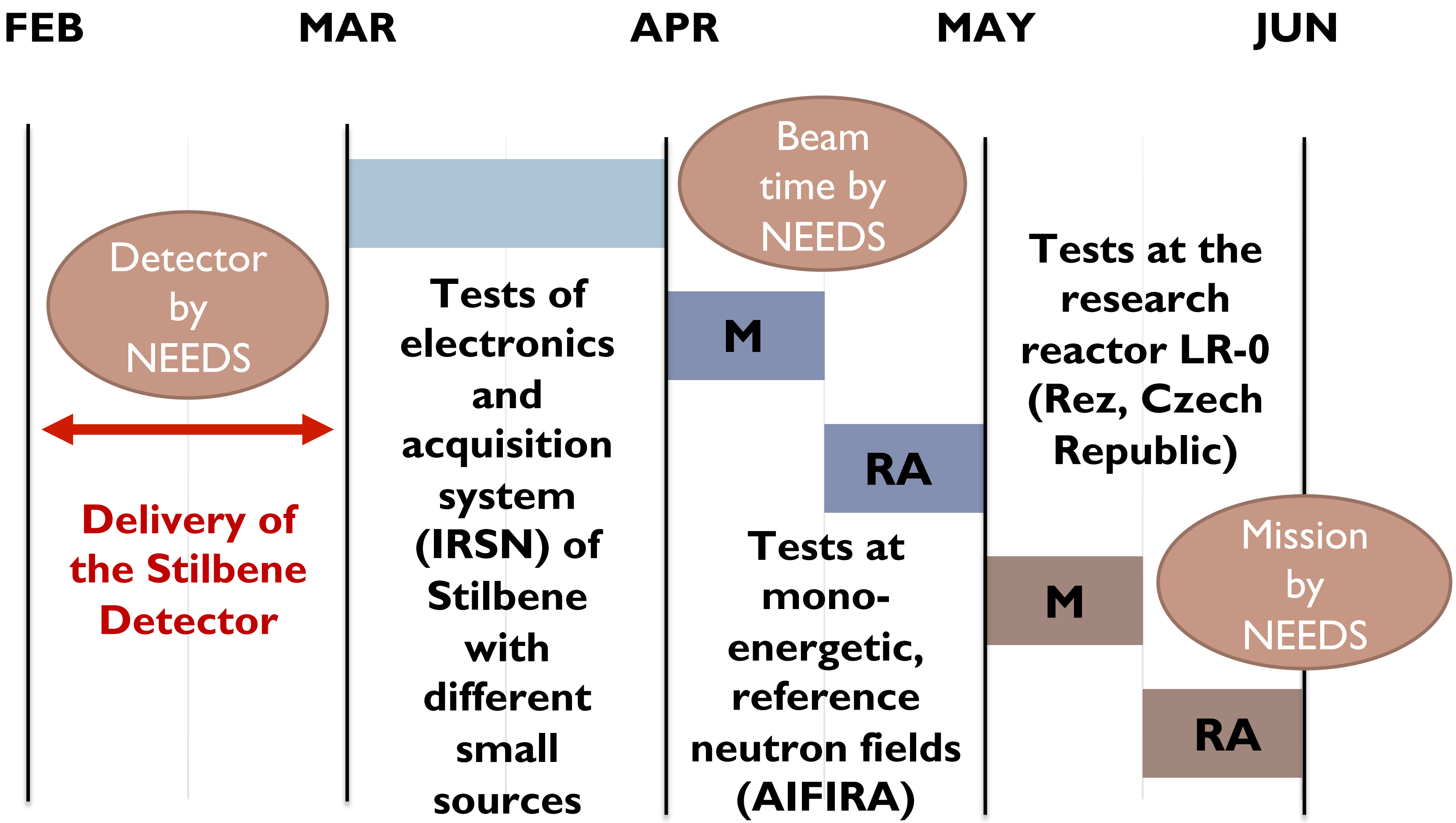




Experimental Campaign

- **Overall objective**: start a rigorous approach to a full description of Stilbene as a neutron (and gamma) spectrometer
- First tests with small neutron and gamma sources. Tests of the electronics and the acquisition system
- Calibrations at mono-energetic, reference neutron beams: define the main characteristics (efficiency, psd capabilities, etc.) of the Stilbene scintillator in well-defined mono-energetic neutron fields
  - The results will be compared to the measurements performed, under the same conditions, by IRSN reference proton recoil spectrometers, namely: BC501A liquid scintillator and SP2 proton recoil proportional counter at lower energies (the same acquisition system and electronics will be used for both scintillators)
- Measurements at the research reactor LR-0 (Rez, Czech Republic) for assessing the near/out-of-core neutron spectrum characterization capability
  - The results will be compared to the measurements performed, under the same conditions, by melt-grown stilbene crystals in use at the Rez research center

Experimental Campaign



Summary

- SPECTRAL project: develop a neutron spectrometer system based on a combination of measurement techniques for the spectral characterization of intermediate-to-fast energy neutron spectra (together with gammas)
- Main initial motivation = new measurements + extended use of MASURCA after the current refurbishment work
- Project has triggered interest among various groups
- Organic scintillators are good candidates for the measurement of the neutron spectrum above about 1MeV
- Stilbene crystal meets the requirements but lacks experimental data, there is still a need for a full characterization of the detector response
- A small prototype detector is being assembled, thanks to the support of NEEDS in 2016
- The SPECTRAL plans in 2017 are to test it in various neutron fields

Thank you for the attention

Questions?

Luca Dioni

References

- References

1. L. Dioni, R. Jacqmin, M. Sumini, B. Stout, ANIMMA 2015
2. L. Dioni, R. Jacqmin, M. Sumini, B. Stout, PHYSOR 2016
3. L. Dioni, R. Jacqmin, M. Sumini, B. Stout, ND 2016
4. V.A. Chernov et al., NIM A 476 (2002) 374-377
5. M.M. Bourne et al., NIM A 806 (2016) 348-355
6. M. Kostal et al., Applied Radiation and Isotopes 82 (2013) 193-199
7. F. Cvachovec et al., NIM A 476 (2002) 200-202
8. L.M. Bollinger and G.E. Thomas, THE REVIEW OF SCIENTIFIC INSTRUMENTS (1961)
9. N. Zaitseva et al., NIM A 789 (2015) 8-15

Potential Applications

In the Experimental Zone

- Testing of advanced neutron detection systems
- Calibration of detection systems
- Testing of equipment for neutron capture therapy or semiconductor industry
- Neutron radiography
- …

> "These requirements [in term of neutron spectrum] depend of course on the type of experiment. The problem is usually to get a high intensity of neutrons in a certain energy range with as few neutrons of other energies and gammas as possible."
> K.H. Beckurts, P.A. Egelstaff, H. Goldstein
> January 1962

In or Near the Core Zone

- Neutron leakage spectrum measurements
- Prompt and delayed fission neutron spectrum measurements
- Fast neutron (and gamma) shielding and transmission experiments
- Neutron cross section measurements in the intermediate/fast energy range
- …