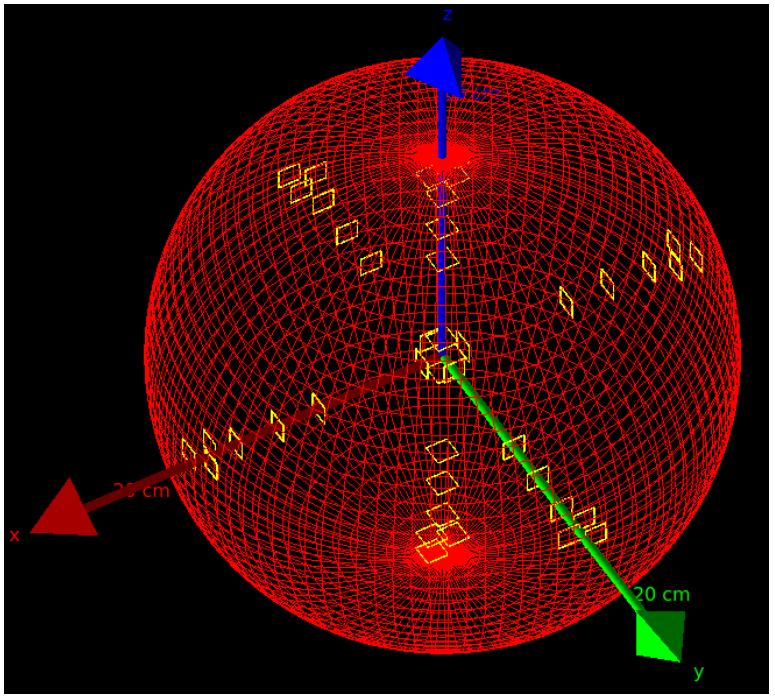
# Deconvolution methods used for the development of a neutron spectrometer

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# Introduction

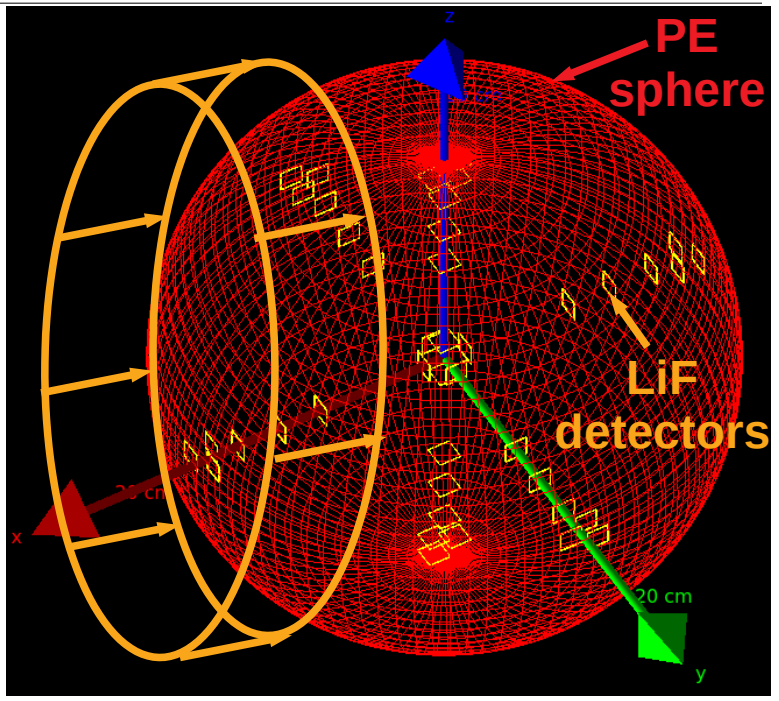
- **« Ratemeter / spectrometer »:**
  - Detection threshold : H*(10) = 1 µSv/h – 10 mSv/h in <5-10 minutes
  - 0 – 20 MeV neutron spectrometer
  - Transportable < 15 kg

- **Optimize a unique multi-detectors Bonner sphere:**
  - Simulations with GEANT4
  - Unfolding methods to pre-validate the model

# Introduction

- **Idea : multi-detectors Bonner sphere**
  - PE sphere to moderate neutrons (Ø = 25 cm)
  - LiF Detectors at different depths to be sensitive to different energies:
    - $^{6}Li(n,\alpha)^{3}H$, Q = +4,78 MeV, σ = 937 barns
    - 1.0 cm x 1.0 cm x 0.04 cm
    - $\rho_{liF}$ = 2.64 g.cm$^{-3}$
    - 14.3% $^{6}Li$ ($8.8 \cdot 10^{21}$ cm$^{-3}$) and 85.7% $^{7}Li$

**→ Select the most appropriate geometry and unfolding method**



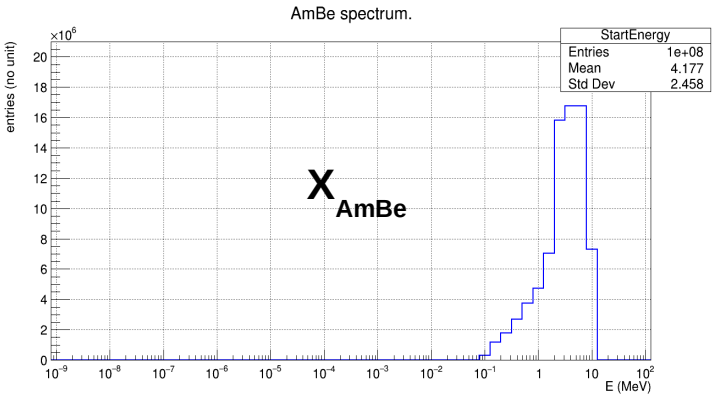

Beam of monoenergetic neutrons from $10^{-9}$ to $10^{2}$ MeV

# Introduction: unfolding, general idea

**Matrix equation RX=M, with vector X unknown.**

- X : neutron source vector to be retrieved ($cm^{-2}$) : m energy groups
- M : measure vector (no unit) : n detectors
- R response matrix, obtained with GEANT4 ($cm^2$) : size : n x m
  - **n : number of detectors** or groups of detectors
  - **m : number of groups of energies**

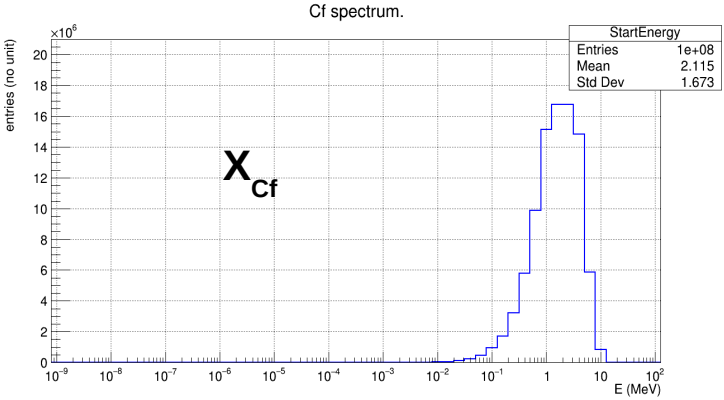
# 1. GEANT4 simulations

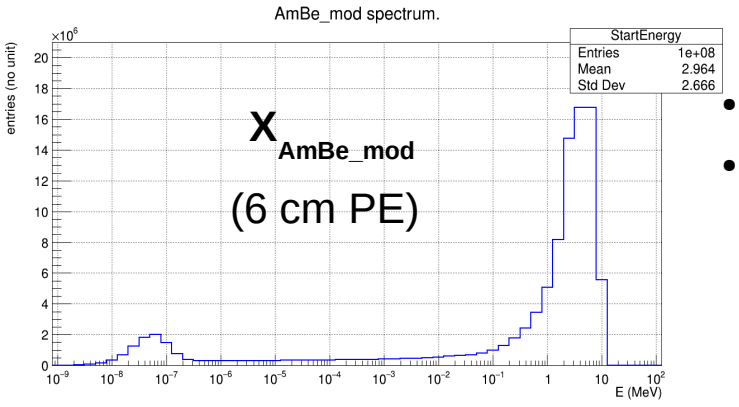



**To build the measure vectors M :**

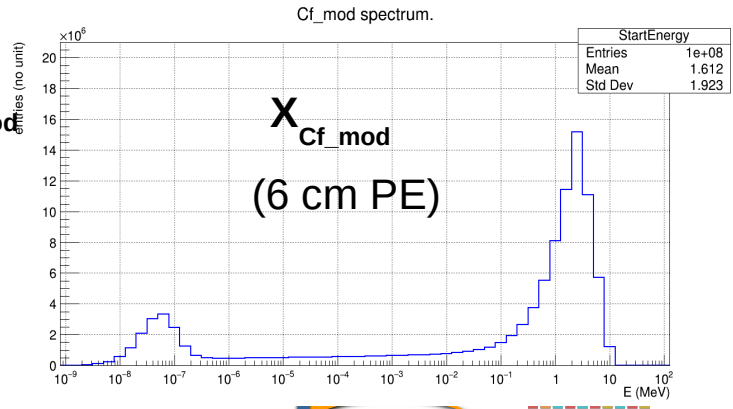
- 4 reference spectra
- 4 x $10^8$ neutrons
- Surf. Fluence Φ = 141 471 $cm^{-2}$

- $X_{AmBe}$ (bare $^{241}$AmBe) ➔ $M_{AmBe}$
- $X_{Cf}$(bare $^{252}$Cf) ➔ $M_{Cf}$

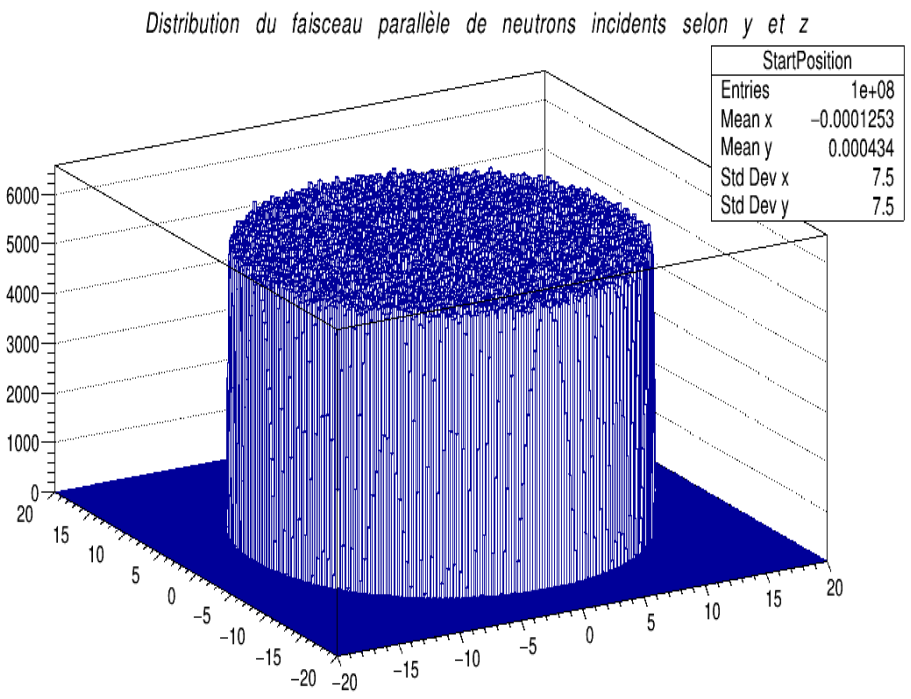



- $X_{AmBe\_mod}$(mod. AmBe)➔ $M_{AmBe\_mod}$
- $X_{Cf\_mod}$(mod. Cf) ➔ $M_{Cf\_mod}$



# 1. GEANT4 simulations

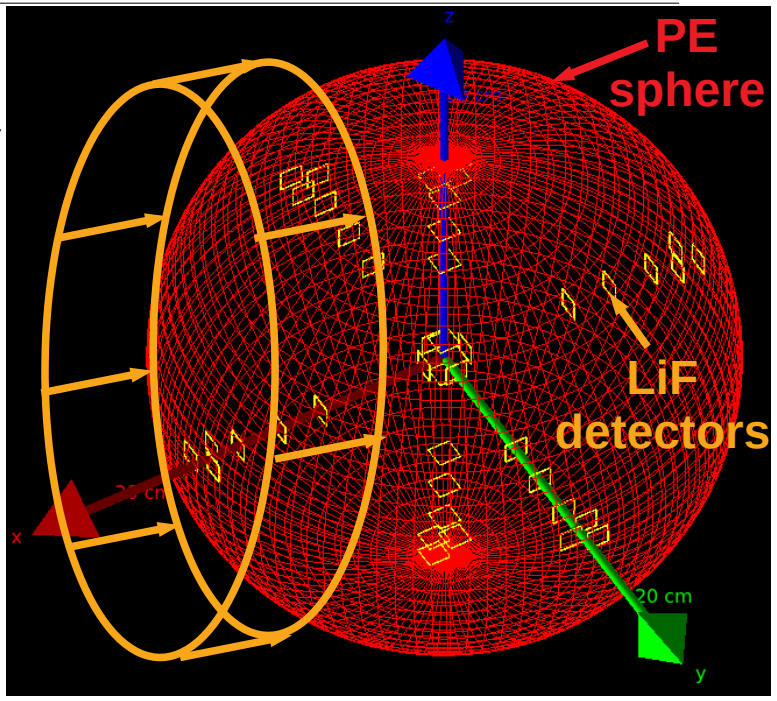



## To build the response matrix R :

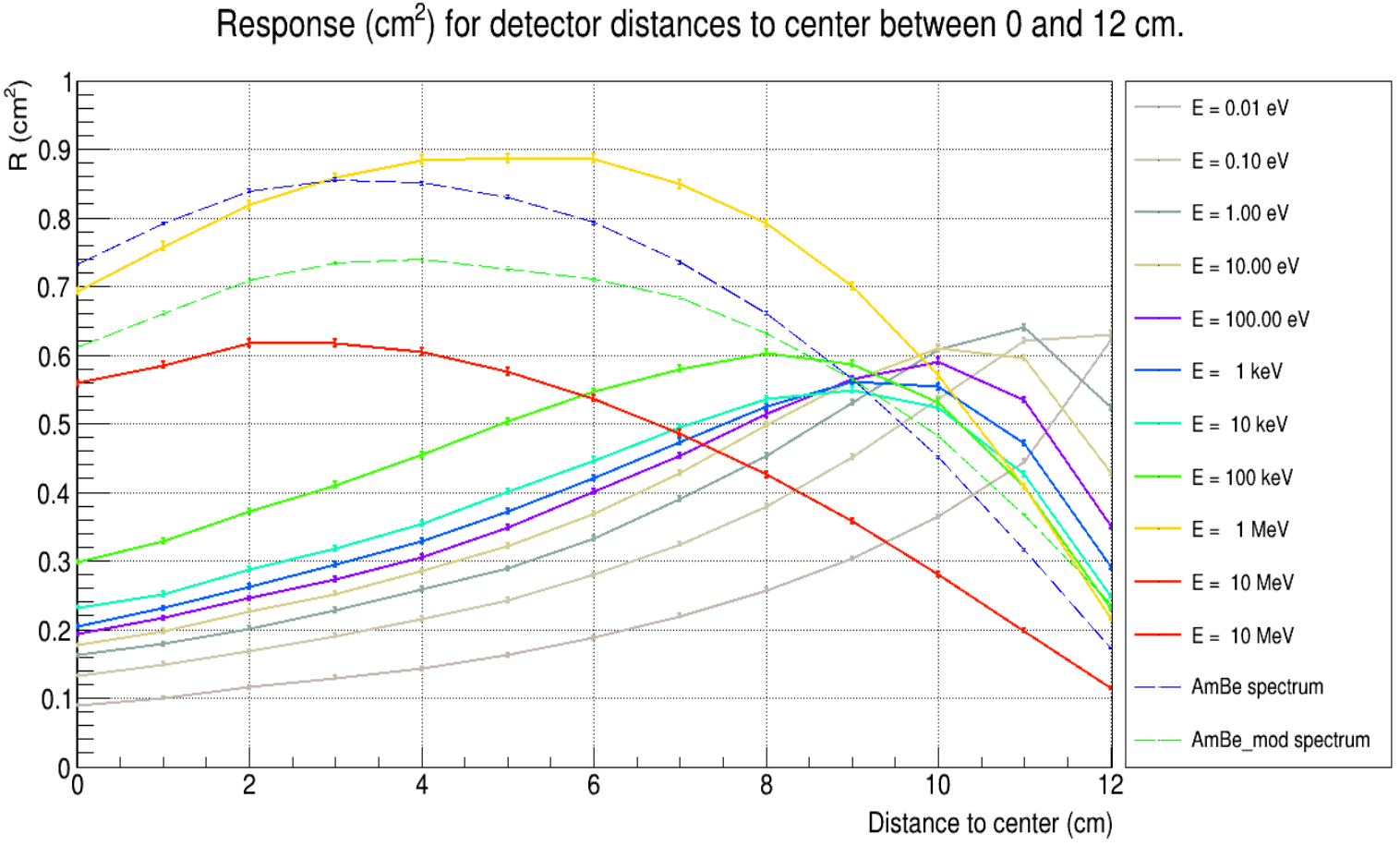
- 56 x $10^8$ neutrons from $10^{-9}$ to $10^2$ MeV
- Surface fluence : $\Phi$ = 141 471 $cm^{-2}$
- Simulation n°j with j from 0 to 55 :
  - → Neutrons energy : $E_j = 10^{(-9+0,2.j)}$ MeV
  - → Parallel monoenergetic neutrons : $R_{parallel}$ (done)
  - → Isotropic monoenergetic neutrons : $R_{isotropic}$ (to do)

# 1. R matrix construction

- **Multi-detectors Bonner sphere**
  - Parallel monoenergetic beams : $10^{-9}$ to $10^{2}$ MeV
  - Start with one detector each cm along x, y, z
  - Then : try to optimize the layout of the detectors
    ➔ new R matrix



# 1. Responses (r constant)



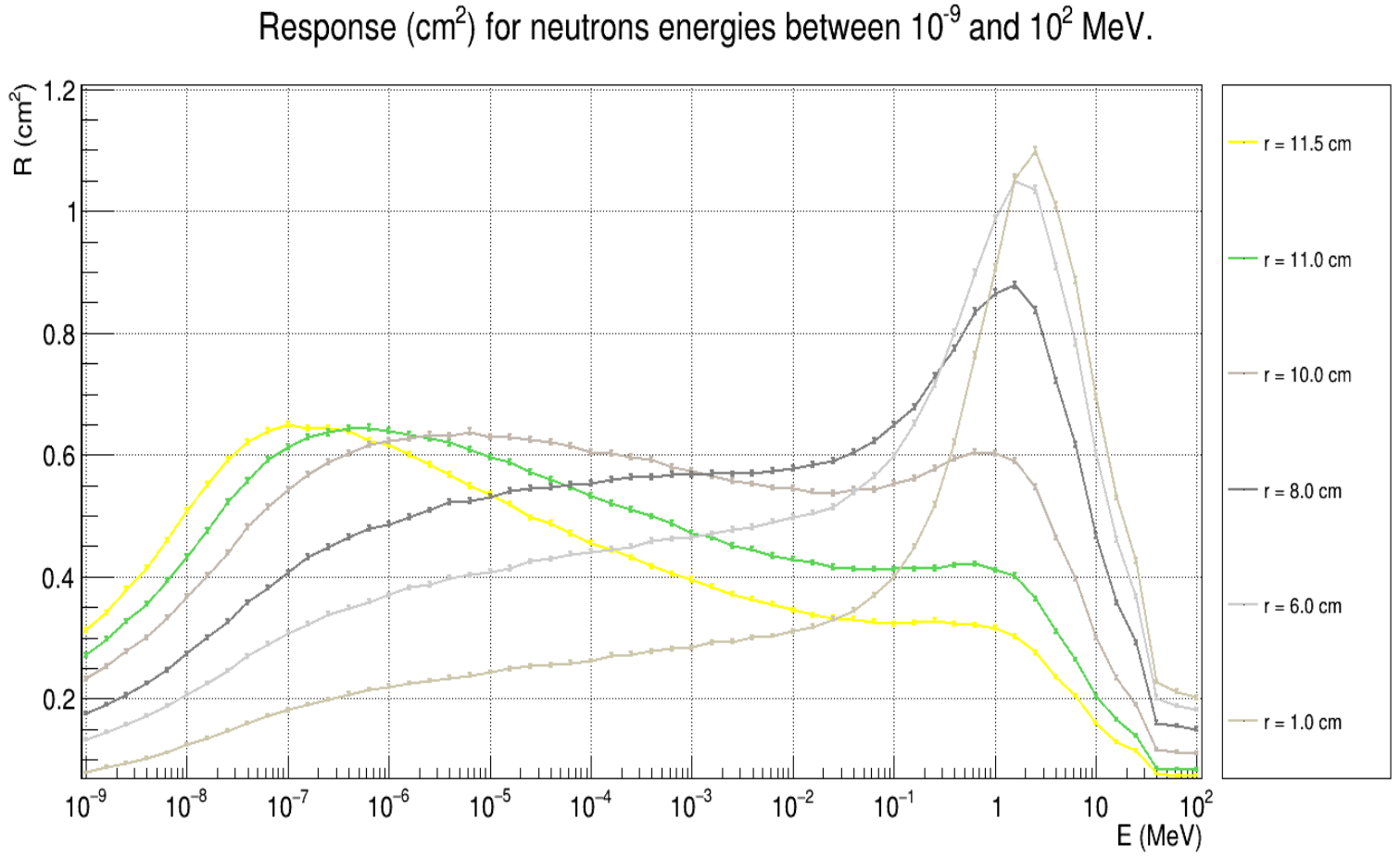

**Position optimization :**

- Simulations to determine responses, function of depth
- Very sensitive next to the surface

➔ More detectors to put next to the surface

➔ Less detectors to put next to the center

# 1. Responses (r constant)




**From the previous histogram:**

- 6 selected depths

➔ 6 groups of detectors

(Still to be optimized)

# 2. Unfolding methods

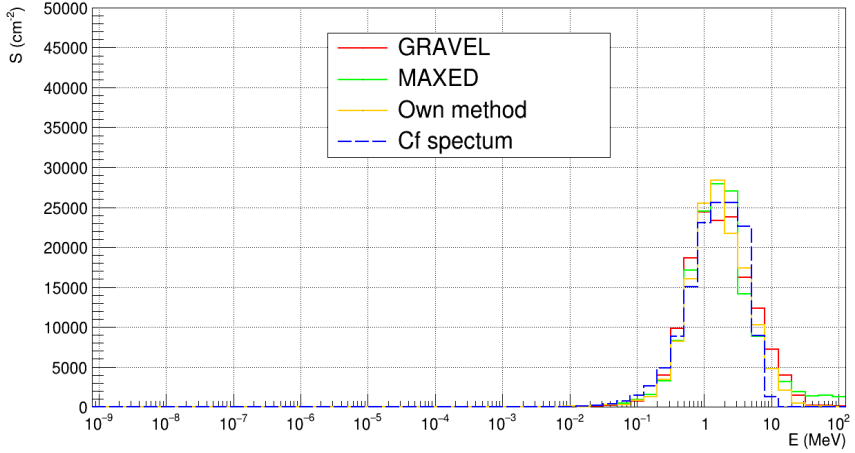
- **UMG 3.3 (NEA):**
  - GRAVEL : iterative algorithm (SAND-II modified)
  - MAXED : maximum of entropy algorithm
  - 6 groups of 6 equidistant detectors (= 36 detectors)
- **1 “personal”* method:**
  - Maximum of {likelihood and entropy}
    - Detectors taken one by one

*Inspired from the publication « Neutron Spectra Unfolding with Maximum Entropy and Maximum Likelihood », Shikoh ITOH & Toshiharu TSUNODA : https://doi.org/10.1080/18811248.1989.9734394.

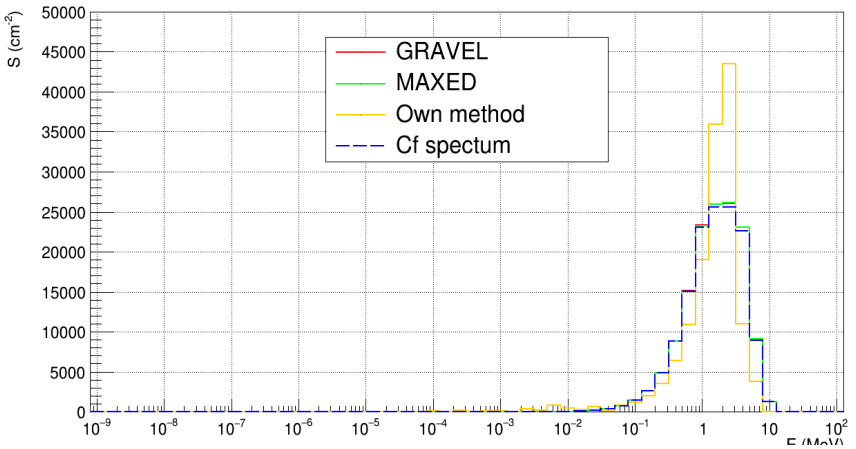
# 3. Unfolding results for Cf (H*(10)~50 µSv)

**For the first iteration of the algorithm, it is important to define a guess spectrum : Flat, bare or moderated spectrum, etc.**

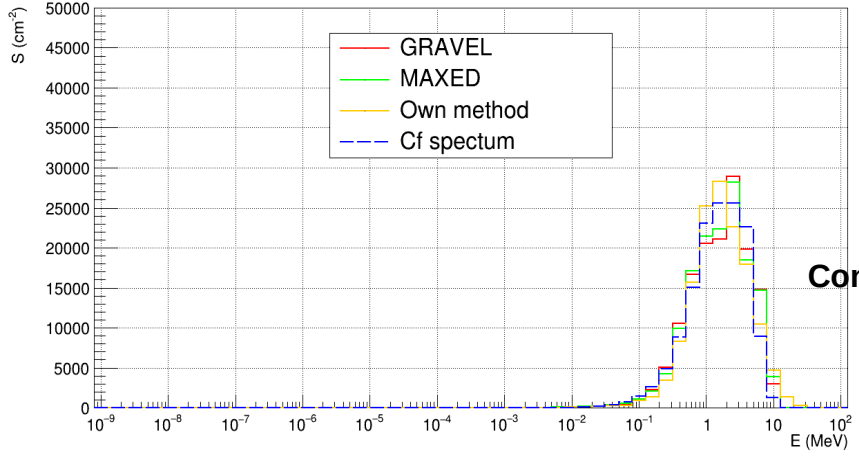
Awaited spectrum : Cf. Guess spectrum : Flat.




Awaited spectrum : Cf. Guess spectrum : Cf.

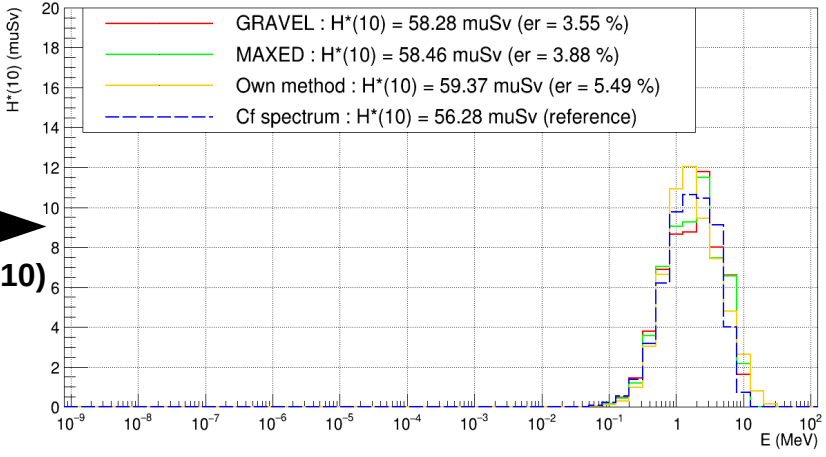



Awaited spectrum : Cf. Guess spectrum : AmBe_mod.

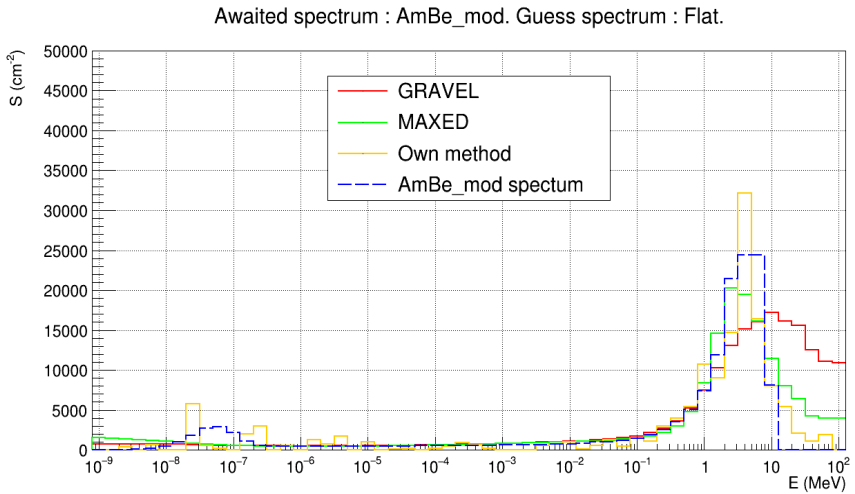


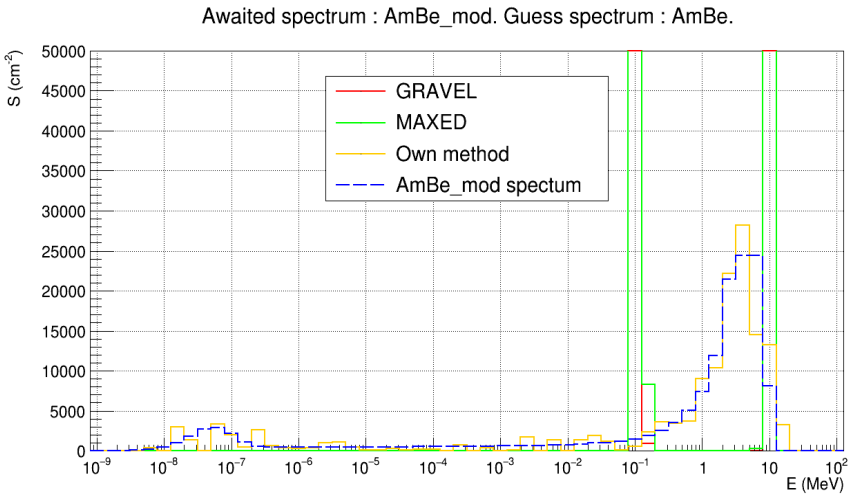

**Conversion into H*(10)**

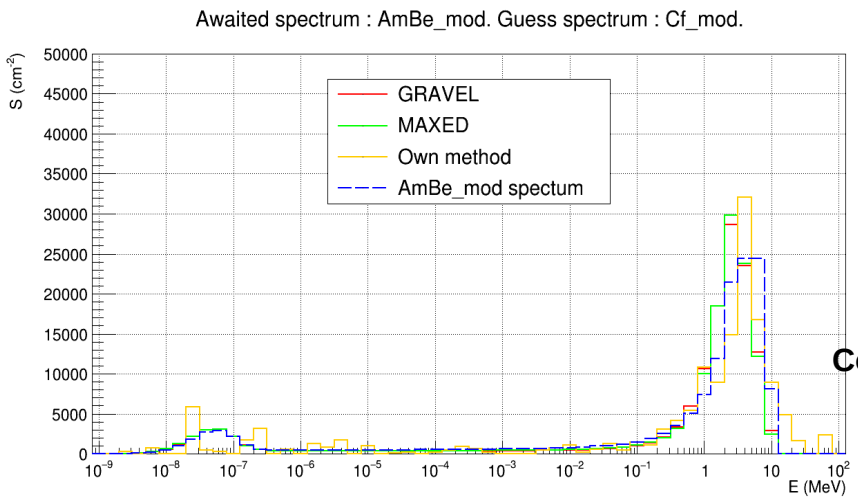
Awaited spectrum : Cf. Guess spectrum : AmBe_mod.



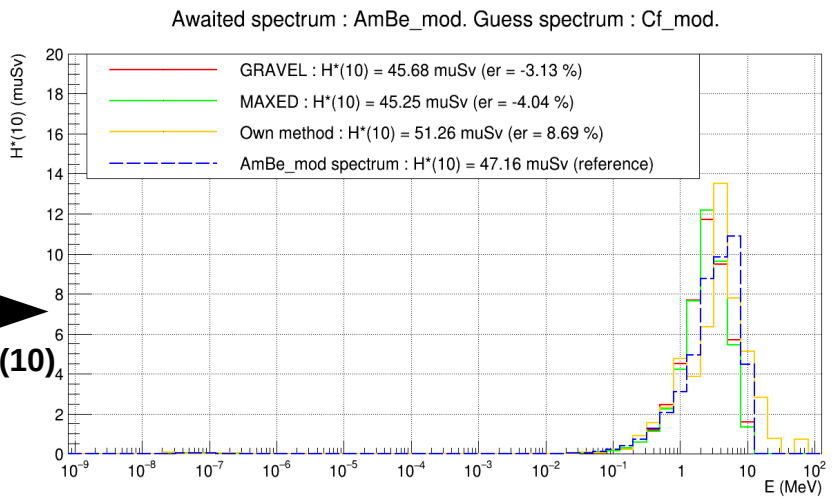
# 3. Results for moderated AmBe (H*(10)~50 µSv)



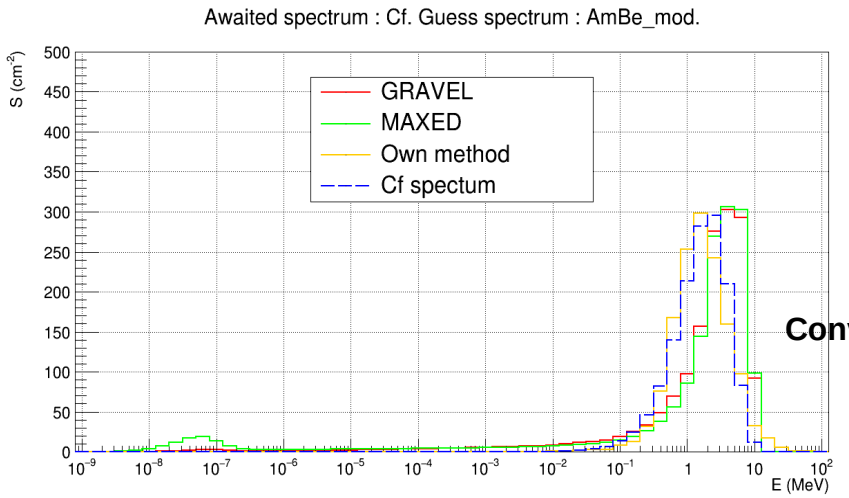




**Conversion into H*(10)**

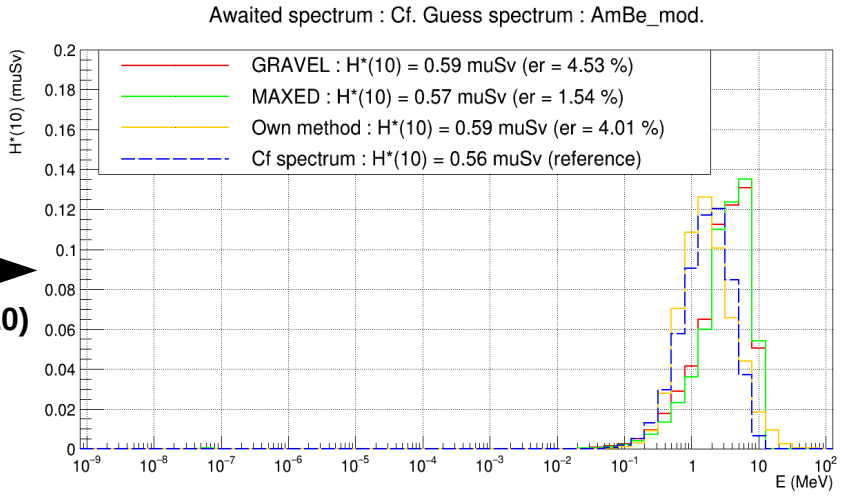


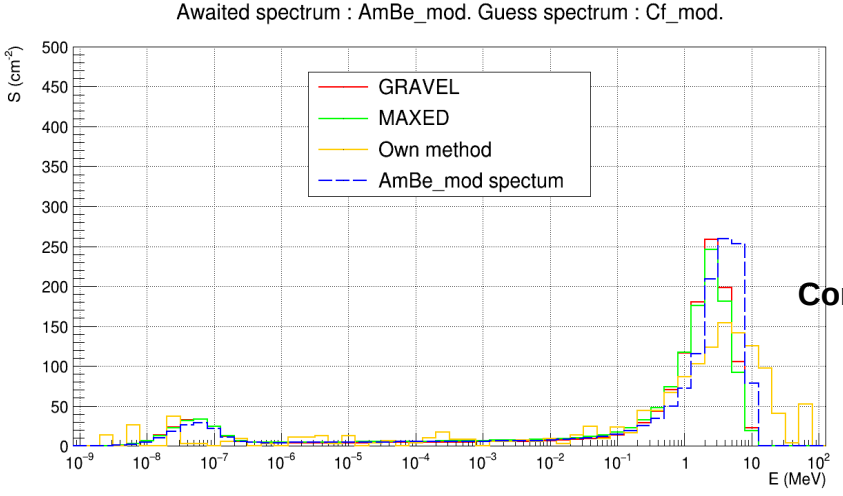

**If moderated awaited spectrum, it is very important to have at least a moderated guess spectrum.**

# 3. Results of unfolding (H*(10)~0.5 μSv)

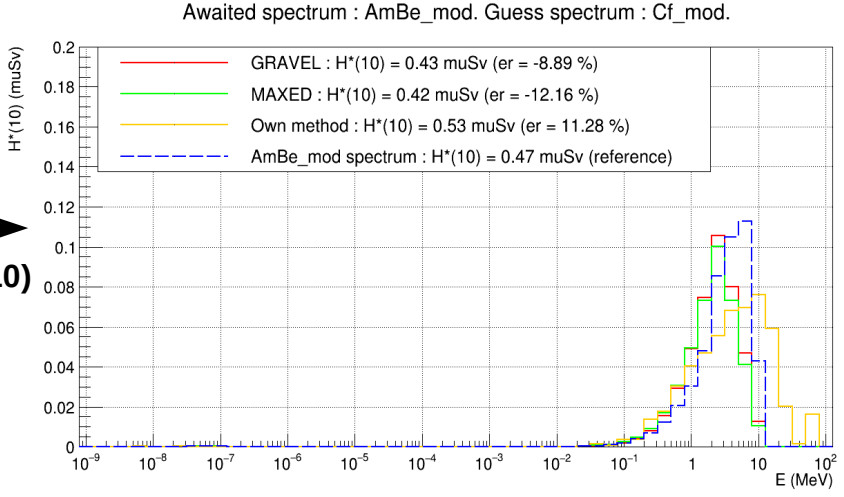



**Conversion into H*(10)**

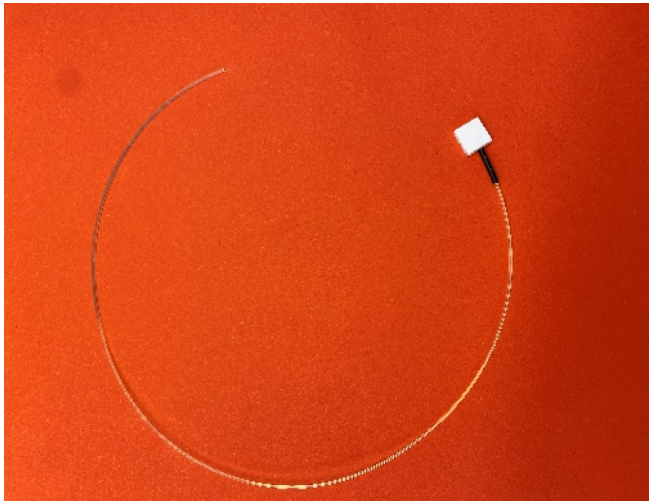


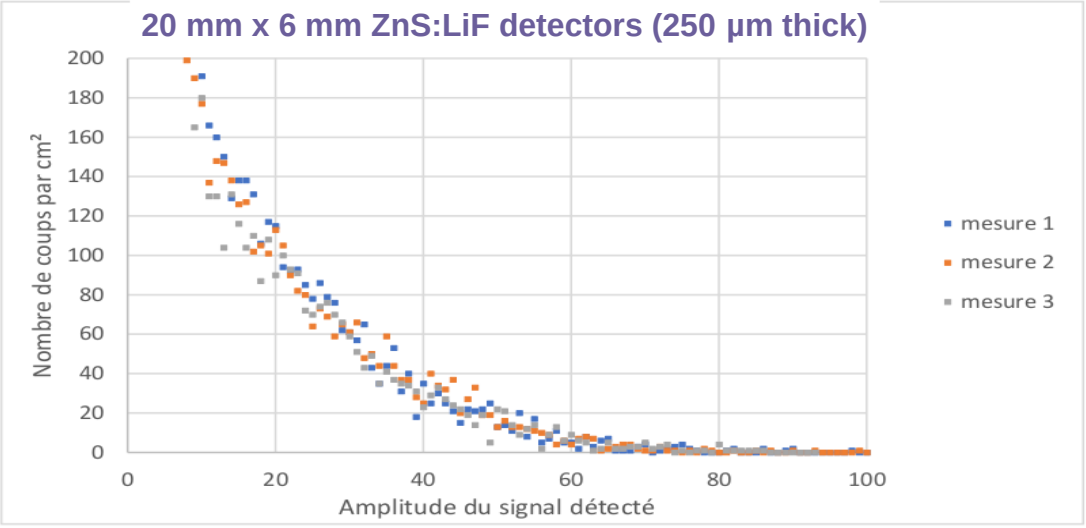




**Conversion into H*(10)**



# 4. Preliminary tests on ZnS:LiF detectors






**AmBe source : ~3muSv/h**
Detectors behind 3.6 cm of paraffine
~0,4 detected neutrons / cm²

**First encouraging results**
Could give sufficient statistics
→ tests behind different thicknesses of paraffine to try to unfold

# Conclusion

- **Better to have a guess of the spectrum before unfolding**
- **If not, it is better to pre-define**
  - A rapid component
  - An epithermal component?
  - A thermal component
- **One can imagine an automatisation**
  - Comparison of the $\chi^2$ of many different guess spectra at the first iteration
  - The spectrum which gives the minimum $\chi^2$ could be adopted
  - Then, the algorithm could start
- **Why a personal unfolding method?**
  - For a faster acquisition on a PC (MAXED/GRAVEL on older versions of Windows)
  - But some convergence parameters are still to optimize

# Conclusion

- **General simulation results with 36 detectors:**
  - < 15% from reference spectra
  - **Even with low ambient dose equivalent H*(10) ≈ 1 µSv/h in ~10 minutes**
- **To validate the multi-detectors  Bonner sphere concept:**
  - More accurate modelization of LiF detectors : ZnS(Ag) + epoxy to add to the material composition
  - 45 degrees parallel-beam + isotropic-beam-response matrices to build
- **Next steps :**
  - prototype to develop and test
  - perhaps machine learning could help