IFIC simulations using Geant4 for the BRIKEN neutron counter

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Outline

- **Introduction.**
- Compact configuration.
- Hybrid configuration.
- Flexible configuration.
- Evaluation of the performance for compact and hybrid configurations.
- Summary and remarks.

Some facts to consider:

- According to our previous experience, the **<u>rate of failure of ^{3}He tubes is around 10%</u>**. Therefore, an estimation of the safe amount of counters at the experiment in RIKEN is 90% of the available counters within the BRIKEN Collaboration.

- **Concerns about the shipment of the counters to RIKEN**. An agreement between institutions is required. This process slows down the shipment of the counters. It is possible that some groups of the collaboration will not be able to send the counters on time for the experiment. Present status of shipment (to be updated during this meeting):

Group	Diameter (inch/cm)	Eff. Length (inch/mm)	Number of counters	Status
UPC	1 / 2.54	23.62 / 600	**42**	Starting bureaucratic steps
GSI	1 / 2.54	23.62 / 600	**10**	
ORNL	1 / 2.54	24 / 609.6	**17**	Agreement already signed. Some counters shipped for tests to RIKEN
ORNL	2 / 2.54	24 / 609.6	**67**	
RIKEN	1 / 2.54	118.1 / 300	**26**	@ RIKEN
JINR	1.18 / 3.0	19.69 / 500	**20**	Not known
Probably around 160 counters at RIKEN for the second half of this year.				

- The proposed experiments for BRIKEN will benefit from an hybrid setup (neutron counter + clovers), which includes two HPGe clover detectors of the EXOGAM type.

The IFIC approach for the design of the BRIKEN detector

- We study configurations using **138 counters (~90% of each detector type)**. 138 tubes is a “realistic” amount of counters regarding the rate of failure and the shipment status.

- We focus our attention to an hybrid configuration **using two clovers**. Therefore, the **polyethylene** geometry is constrained to a fixed size **($90x90x90cm^3$)** and includes holes for the two clovers.

- In this study, we focus on a geometry using AIDA as implantation detector. Therefore, a squared central hole in the PE matrix with 11cm side length is considered.

- We study a compact geometry (without clovers) and a hybrid geometry (including clovers).

- We approach the problem of finding a flat neutron response counter as a *constrained minimization problem*. A figure of merit for the flatness of the neutron efficiency can be minimized from numerical simulation constrained to the moderator geometry and properties, counters geometry, clovers geometry, a constant number of counters and a high value on the neutron efficiency.

- The solution of the problem requires the parametrization of the distribution of counters inside the moderator.

Some definitions for the analysis of the simulations

- For the choice of proposed configurations and the comparison of the two kind of detector (with and without clovers), four reference values are used:

  - Two F-factor values constrained to the highest average efficiency:

    F ~ 1.12 and ***F ~ 1.15***

  - The **maximum average efficiency** calculated for the detector.

  - The **maximum flatness** calculated for the detector.

Average efficiency:

$$\langle\eta\rangle = \Sigma_i\ \eta(E_i) / 9$$

Flatness:

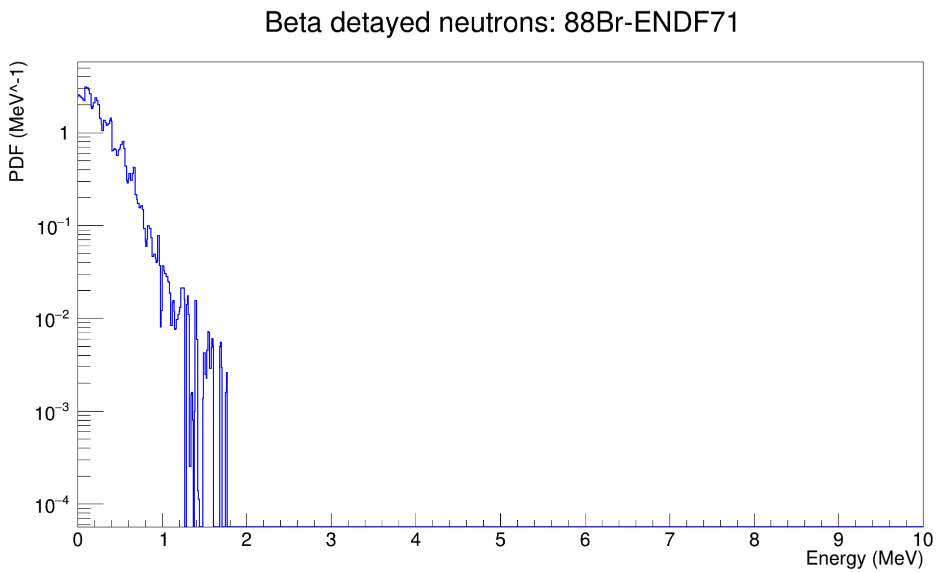
$$F = Max(\eta(E_i)) / Min(\eta(E_i))$$

$$E_i(MeV) = \{0.0001, 0.001, 0.01, 0.1, 1.0, 2.0, 3.0, 4.0, 5.0\},$$

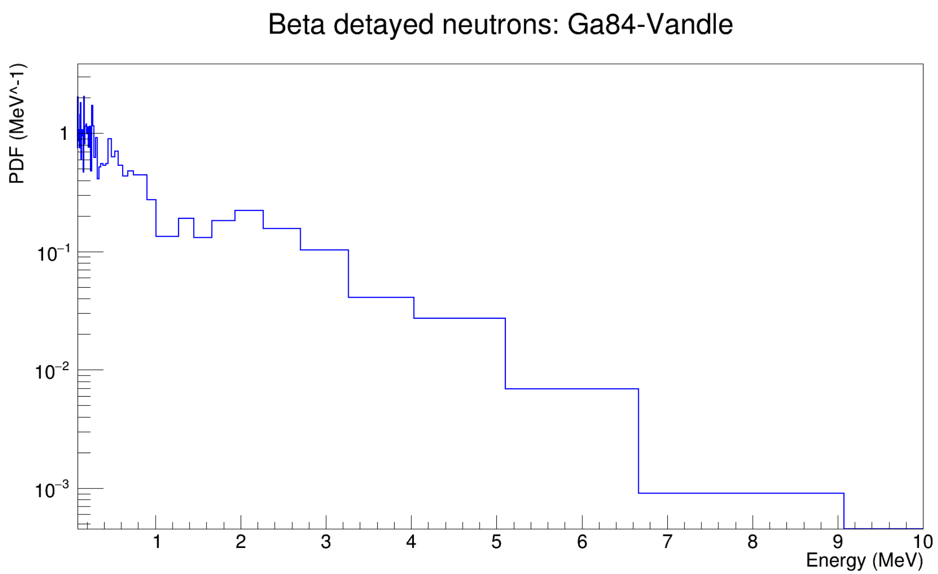
Some definitions for the analysis of the simulations

- An evaluation of the performance of the proposed configurations is considered in the analysis. For this purpose, the calculation of the efficiency for two reference beta-delayed neutron spectra is carried out:

    - ***"Soft spectrum"***: Which corresponds to the beta delayed neutron spectrum for isotope 88Br (from ENDF71).



    - ***"Hard spectrum"***: Which corresponds to the beta delayed neutron spectrum for isotope 84Ga. The spectra was taken from unpublished results from VANDLE.



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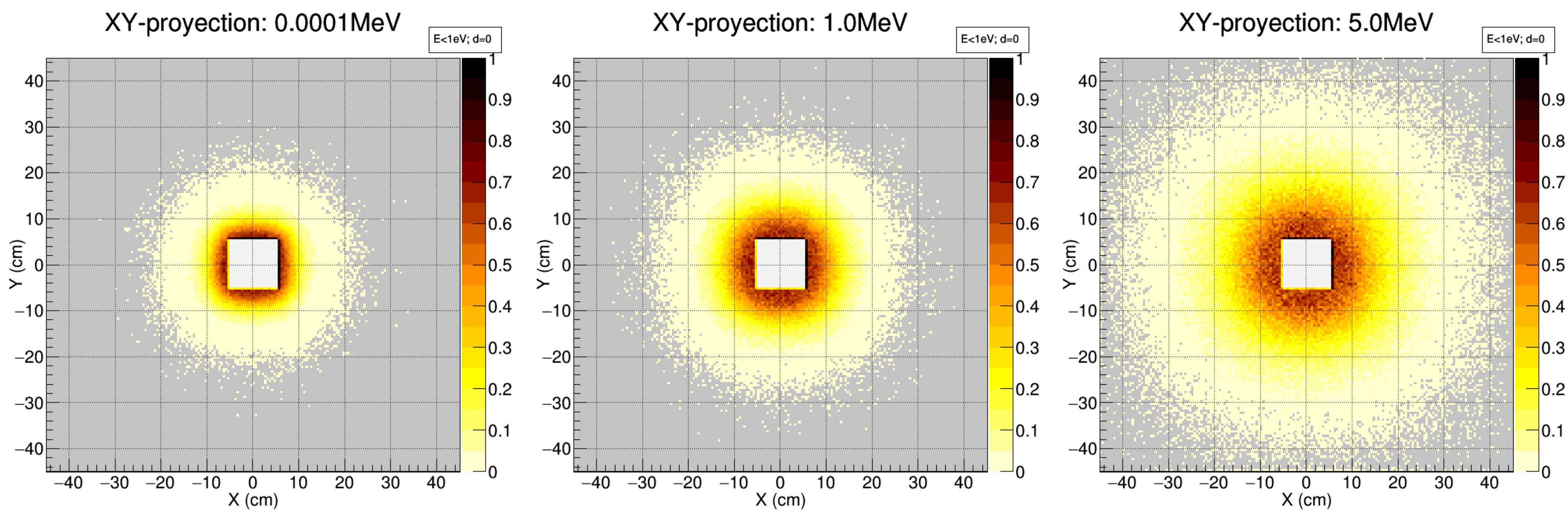
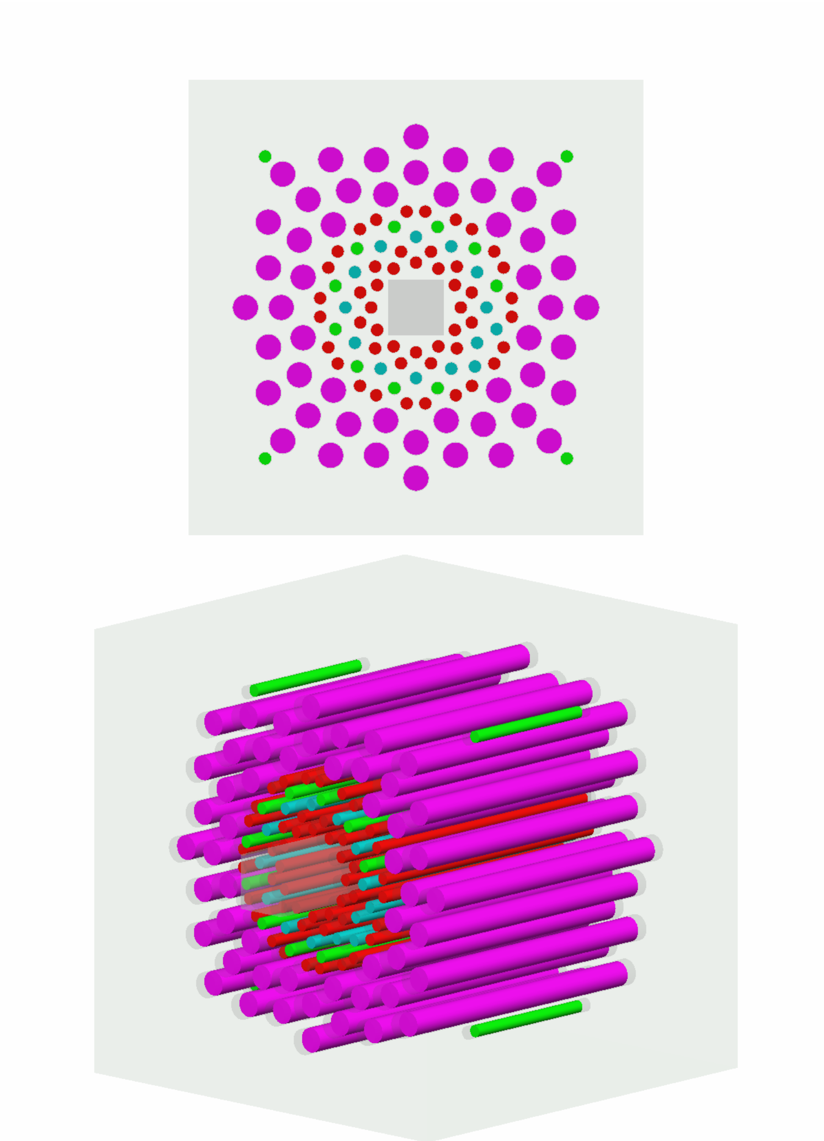
Compact configuration: Thermal flux inside the empty moderator



- The thermal flux is cylindrically symmetric around the hole for AIDA.
- Deformations to this symmetry are observed close to the boundary of the hole (~ 4cm beyond of the border) and predominantly for low energies.
- Because of the symmetry, it is reasonable to distribute the counters along rings with different radii around the AIDA hole.
- Because of the high density of thermal neutrons close to the hole, the position of the first ring with respect to the hole will be important.

Compact configuration: Parametrization of the counter distribution



Geometry parameters:
h_0=2.0cm, f_r=0.325

Briken detector geometry without clovers						
Owner group	**Diameter (inch/cm)**	**Eff. Length (inch/mm)**	**Total counters**	**Used counters**	**Available**	**Color code**
UPC + GSI	1 / 2.54	23.62 / 600	52	48	4	
ORNL	1 / 2.54	24 / 609.6	17	14	3	
ORNL	2 / 2.54	24 / 609.6	67	52	15	
RIKEN	1 / 2.54	118.1 / 300	26	24	2	
TOTAL			**162**	**138**	**24**	

Parametrization description:
Counters are symmetrically distributed along eleven consecutive rings which encircle the AIDA hole.

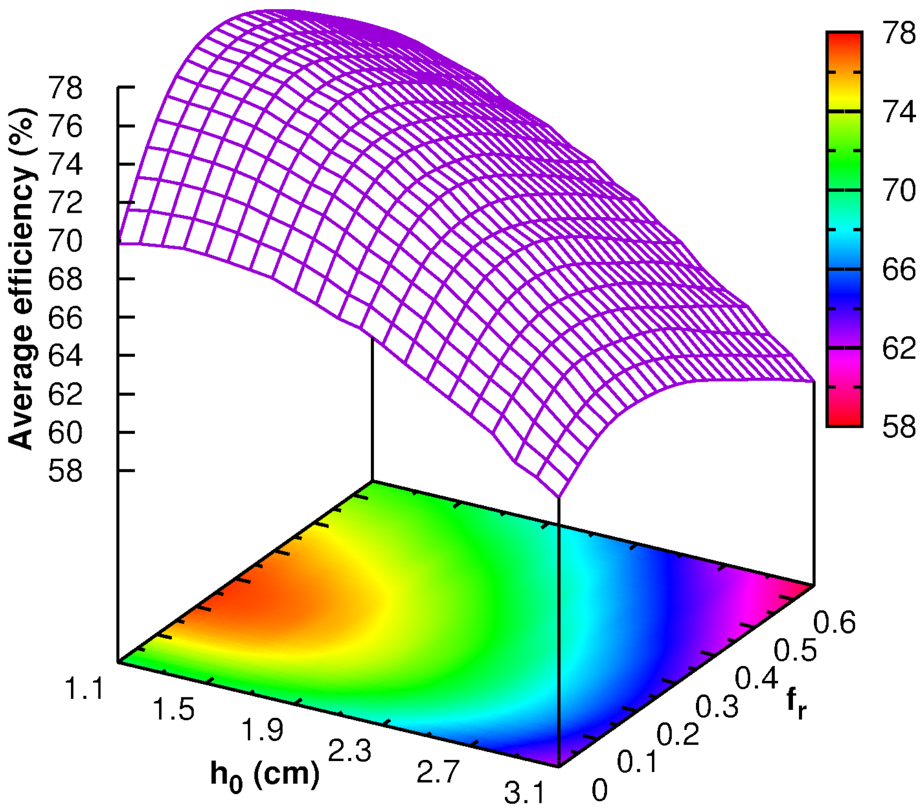
Two parameters define the counter distribution:
***h_0* : Define the radial distance from the center of the moderator to the first ring.**

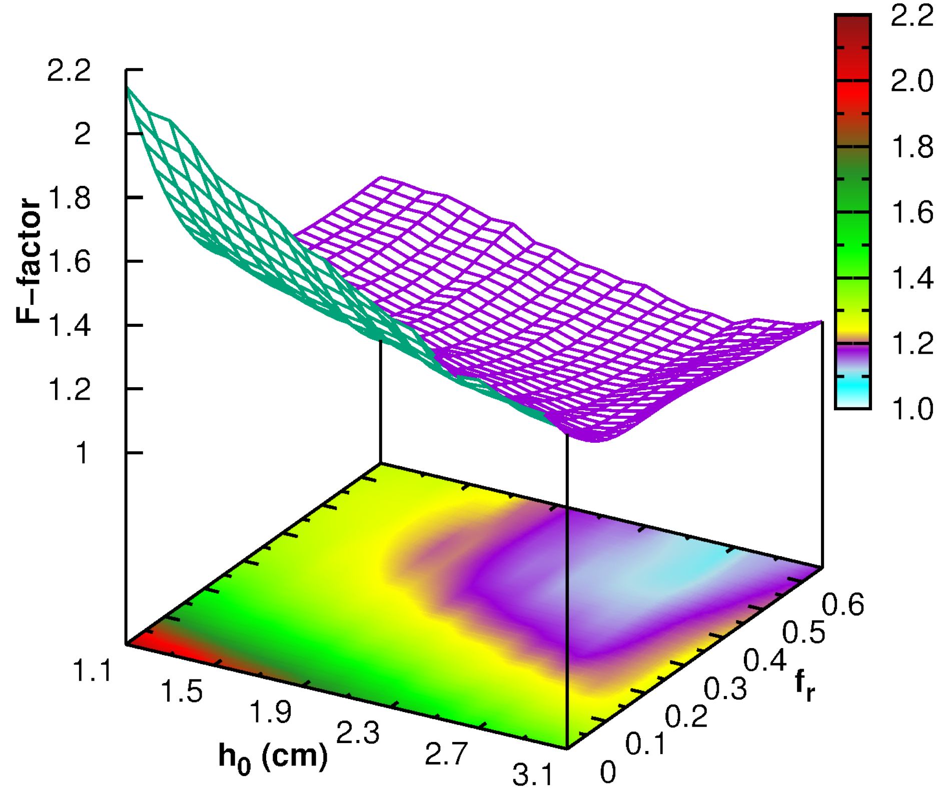
***f_r* : Parameter related to the radial separation between consecutive rings.**

Small diameter tubes (1”) are used until the ring five and for ring eleven. Big diameter tubes (2”) are use for rings six to ten. The number of tubes per ring is 12, with exception of ring five (24) and ring ten and eleven (4).
Ranges of the parameters for calculations:

h_0 : 1.1 – 3.1 cm
f_r : 0 – 0.65

Compact configuration: Simulation results





- A compromise between efficiency and flatness is observed. Roughly speaking, **the greater the flatness, the lower the efficiency.**

Compact configuration: Proposed configurations

A map of the possible configurations:

- Color density for the flatness.
- Solid lines for the average efficiency.

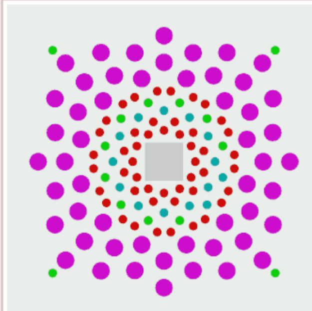
Proposed configurations according to four reference values:

(1) Maximum calculated flatness.

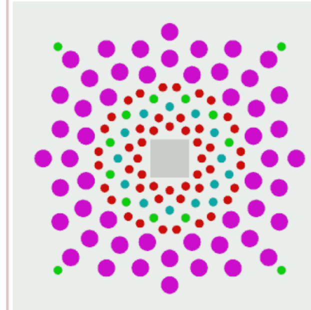
(2) F ~ 1.12

(3) F ~1.15

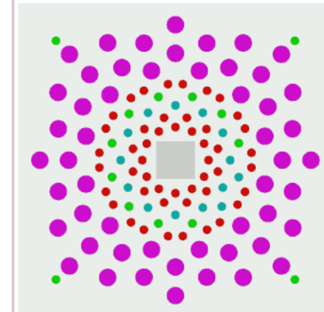
(4) Maximum calculated average efficiency.



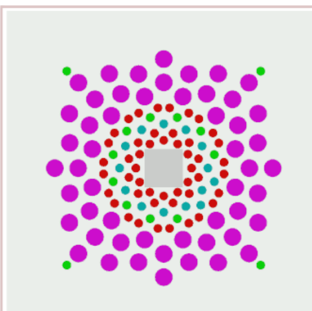
Flatness around 1.15:
F = 1.145 ± 0.02
<η> = 70.9% ± 0.8 %



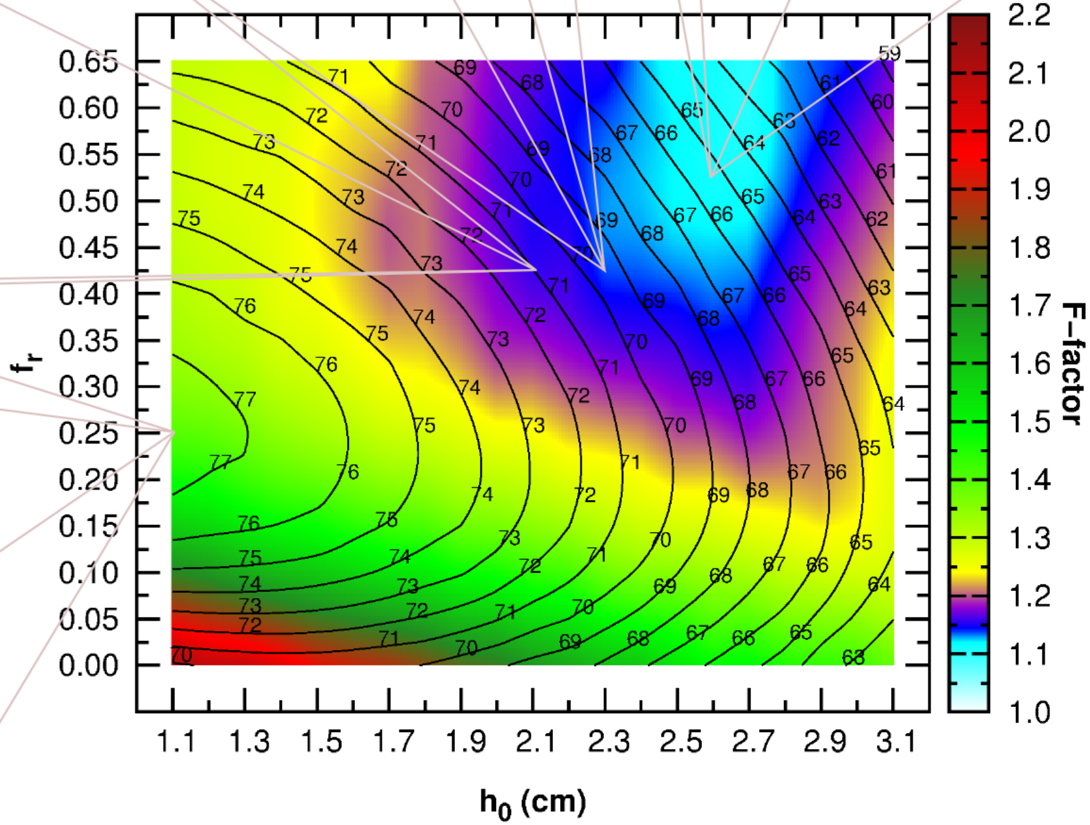
Flatness around 1.12:
F = 1.116 ± 0.02
<η> = 69.4% ± 0.8 %



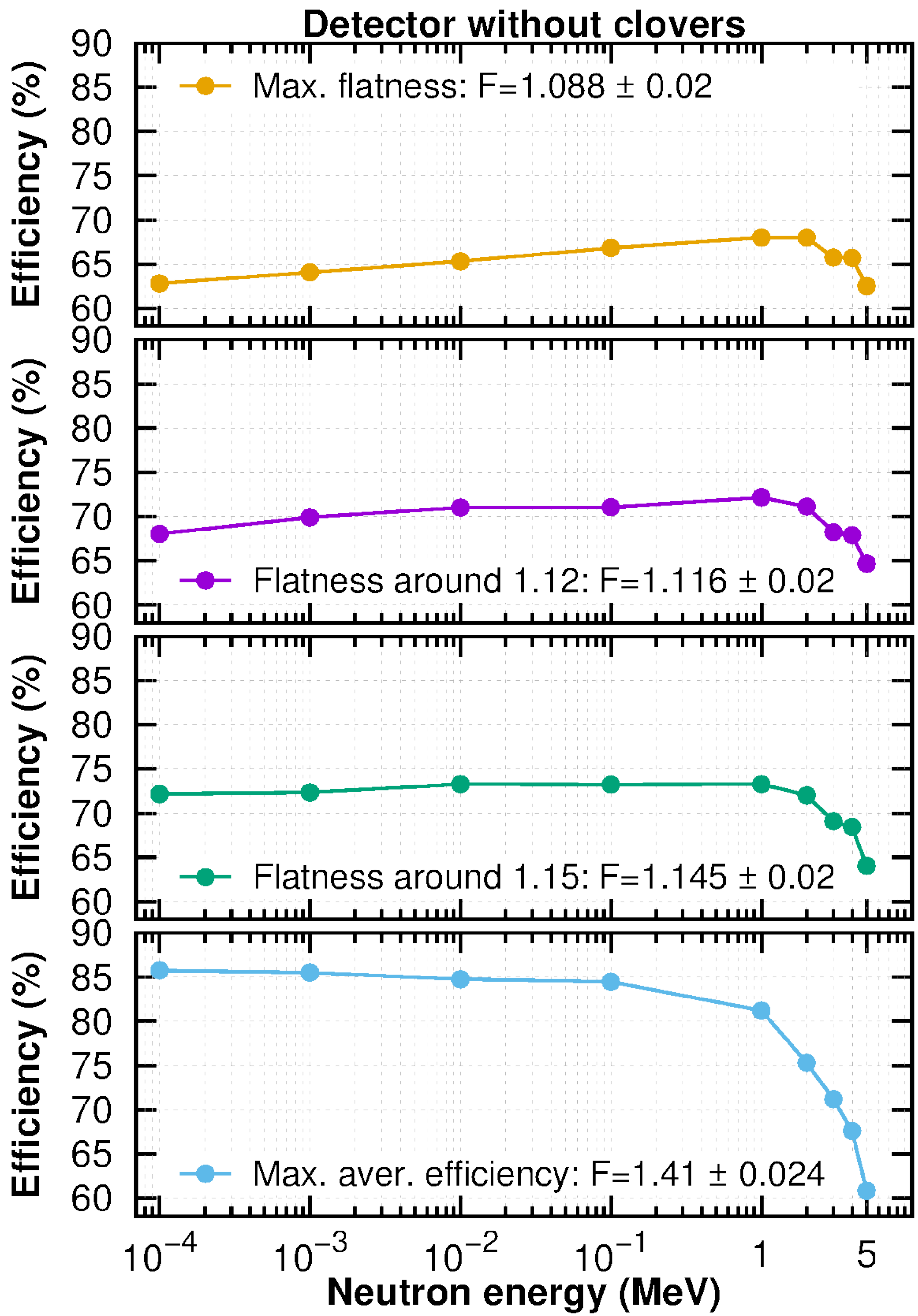
Maximum flatness:
F = 1.088 ± 0.019
<η> = 65.5% ± 0.7 %



Max. aver. efficiency:
F = 1.409 ± 0.024
<η> = 77.4% ± 3 %



Compact configuration: Proposed configurations



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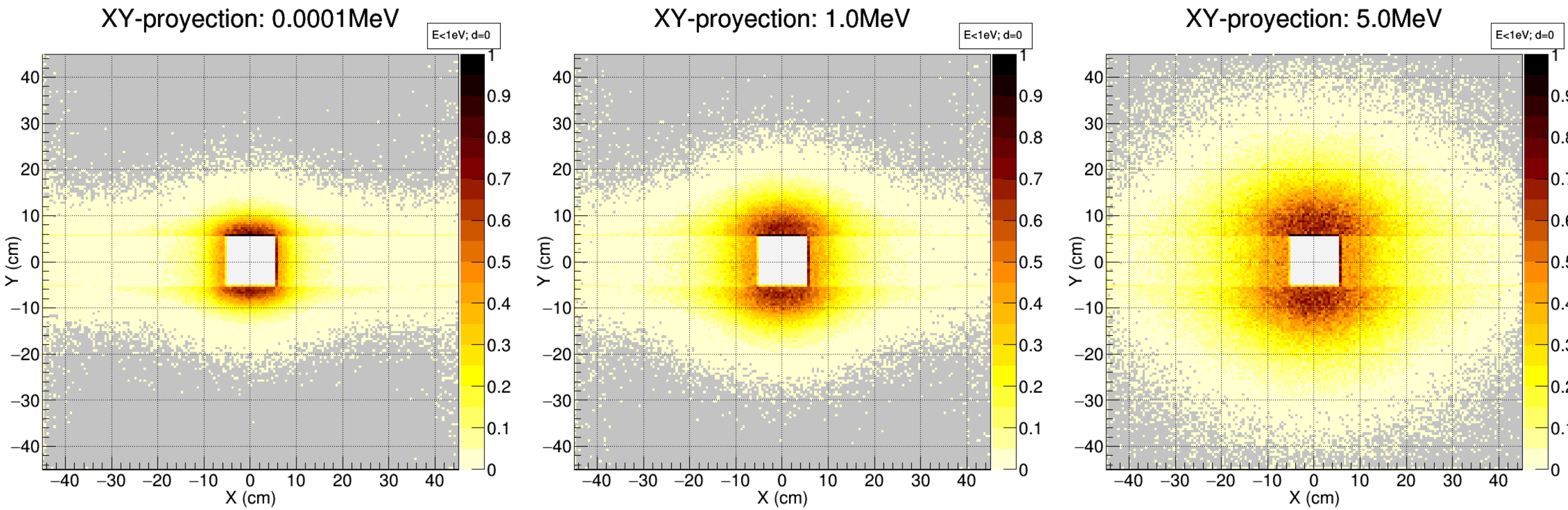
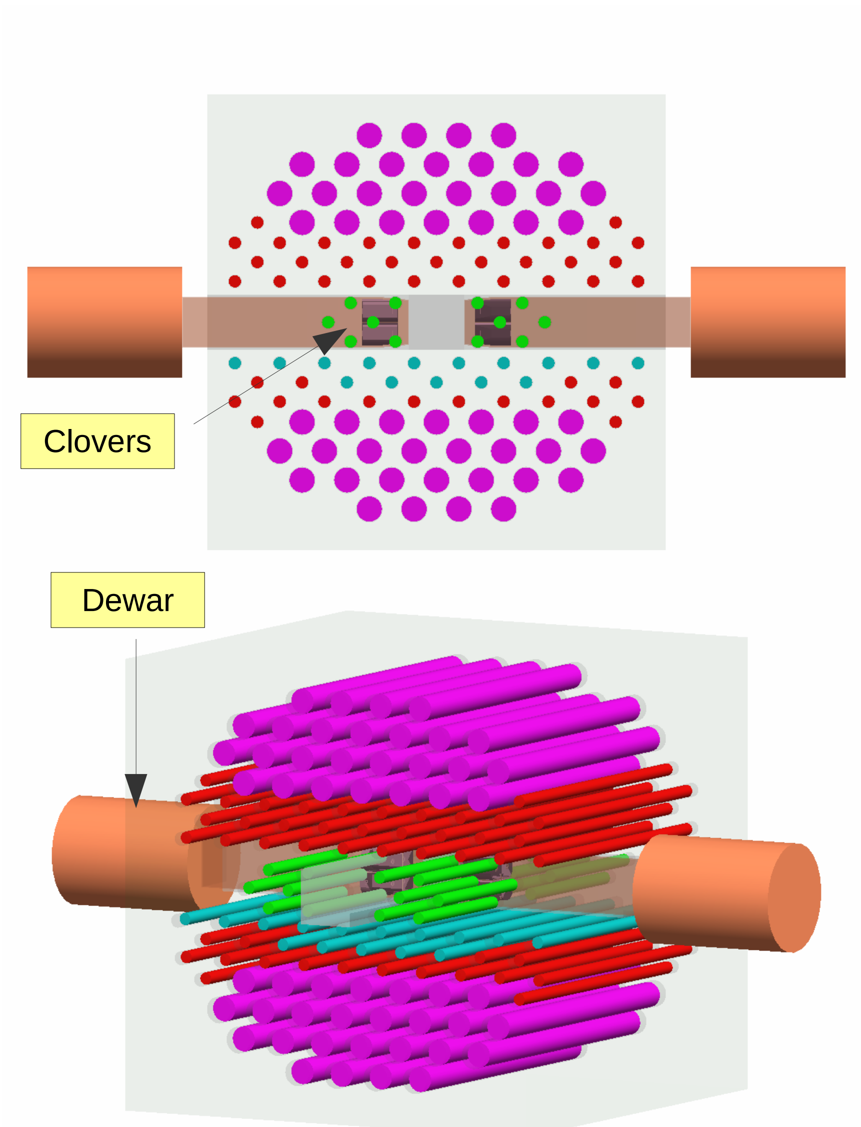
Hybrid configuration: Thermal neutron flux inside empty moderator with two holes for clovers



- With holes for the clovers in the moderator, the cylindrical symmetry of the thermal flux is broken.
- Two symmetric regions are clearly distinguish:
  - I) The middle part of the moderator, adjacent to the holes.
  - II) The top and bottom of the moderator.
- Because of the moderator size, BRIKEN counters are more suitable for the middle part.
- An oval shape distribution should be achieved for the top and bottom of the moderator.
- Because of the high density of thermal neutrons close to the holes, the position of the counters in this area (close to AIDA and clovers hole) will play a role.

Hybrid configuration: Parametrization of the counter distribution



Geometry parameters:
h_0=1.2cm, f_x=2.2, f_y=1.6

Briken detector geometry with two clovers						
Owner group	**Diameter (inch/cm)**	**Eff. Length (inch/mm)**	**Total counters**	**Used counters**	**Available**	**Color code**
UPC + GSI	1 / 2.54	23.62 / 600	52	47	5	
ORNL	1 / 2.54	24 / 609.6	17	15	2	
ORNL	2 / 2.54	24 / 609.6	67	52	15	
RIKEN	1 / 2.54	118.1 / 300	26	24	2	
TOTAL			**162**	**138**	**24**	

Parametrization description:
Roughly speaking, the counters are placed along seven rows on the top/bottom of the moderator and along three columns at each side of the middle part of the moderator.

Three parameters define the counter distribution:
***h_0* : Define the distance from the border of the hole to the counters on the first column in the middle part or the first row in the top/bottom of the moderator.**

***f_x* : Parameter controlling the counters separation in the X-direction.**

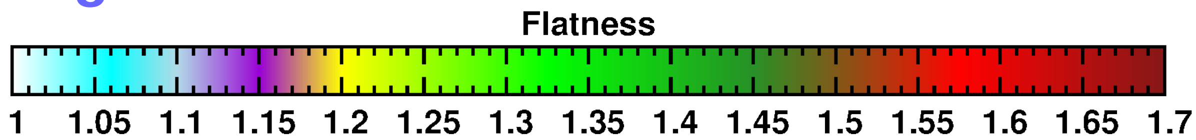
***f_y* : Parameter controlling the counter separation in the Y-direction.**

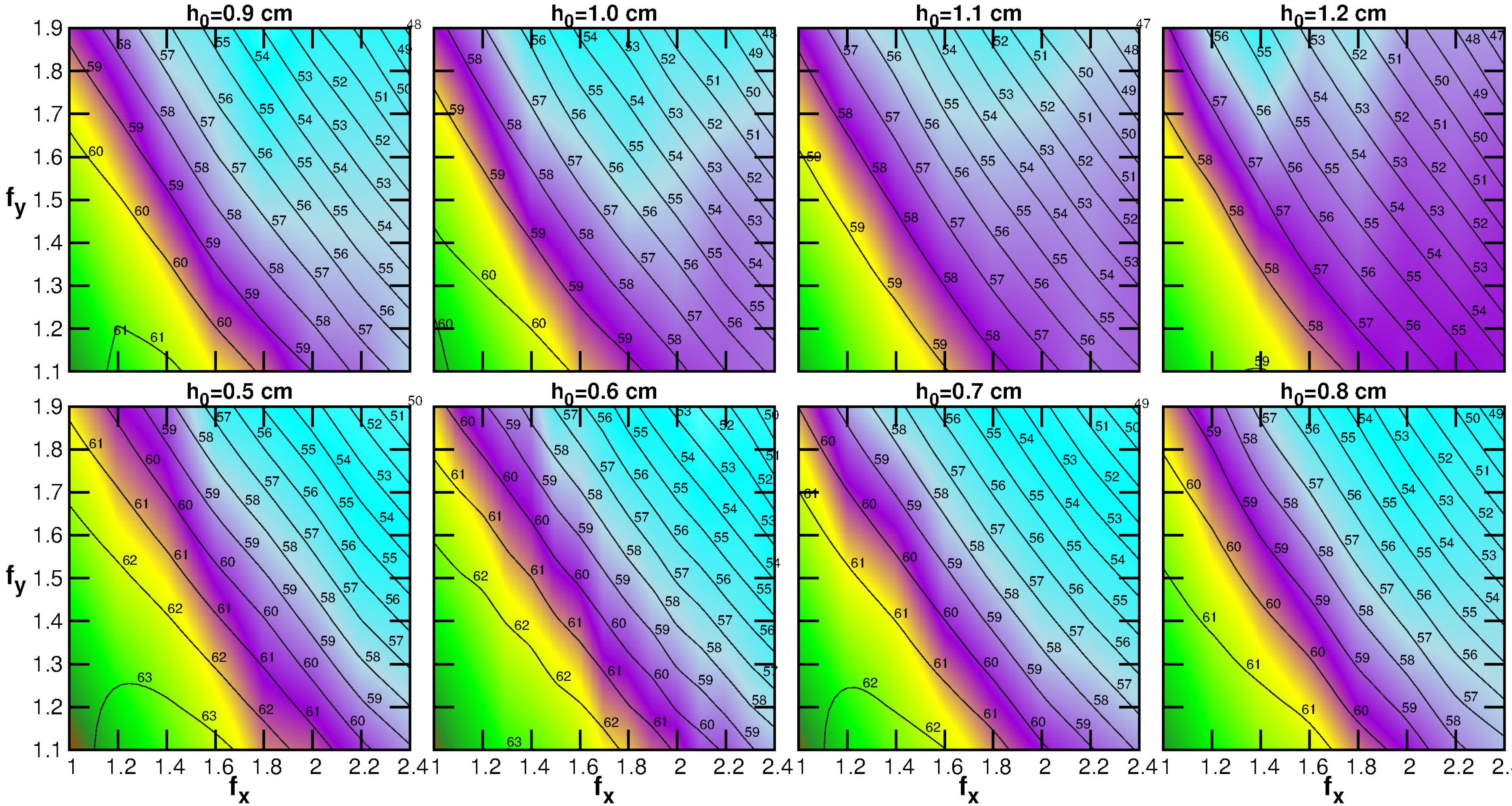
Ranges of the parameters for calculations:

h_0 : 0.5 – 1.2 cm
f_x : 1.0 – 2.4
f_y : 1.0 – 1.9

Hybrid configuration: Simulation results

- Color density for the flatness.
- Solid lines for the average efficiency.

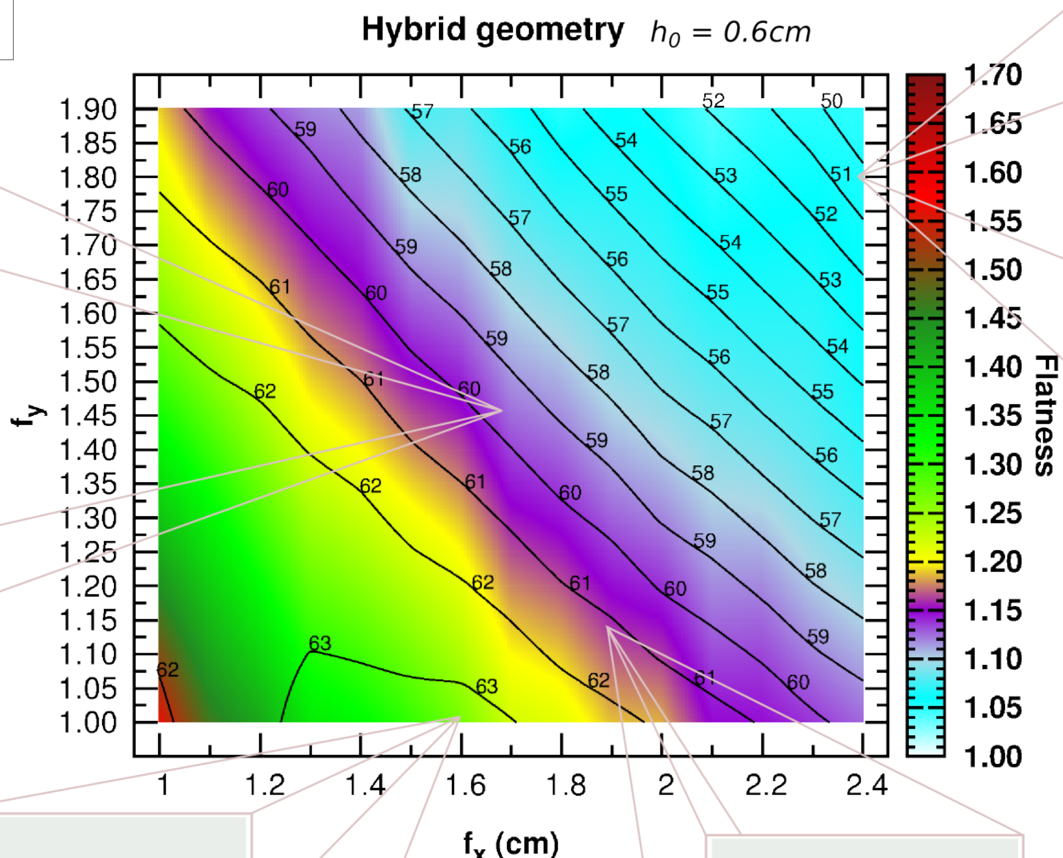


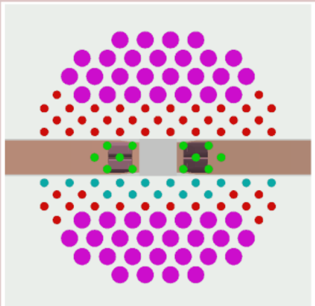


Similarly as in the detector without clovers case, **a compromise between efficiency and flatness is also found for the hybrid detector**.

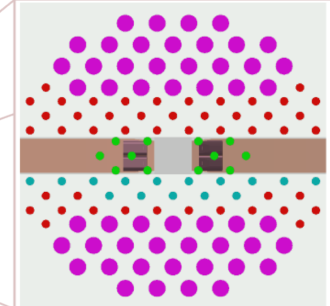
Hybrid configuration: Proposed configurations for h_0=0.6cm

With two clovers!!!!

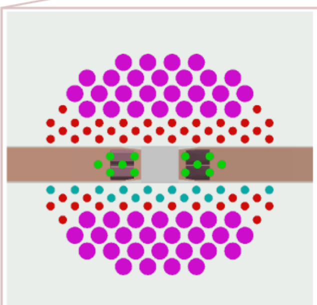




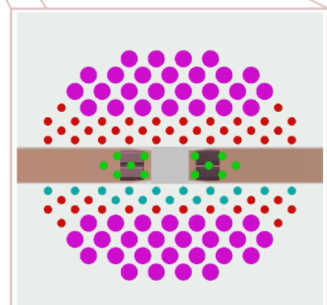
Flatness around 1.12:
F = 1.125 ± 0.02
<η> = 59.8% ± 0.7%



Maximum flatness:
F = 1.037 ± 0.021
<η> = 50.3% ± 0.2%



Max. aver. efficiency:
F = 1.3 ± 0.024
<η> = 63.2% ± 1.6%



Flatness around 1.15:
F = 1.152 ± 0.021
<η> = 61.3% ± 0.9%

Proposed configurations according to four reference values:

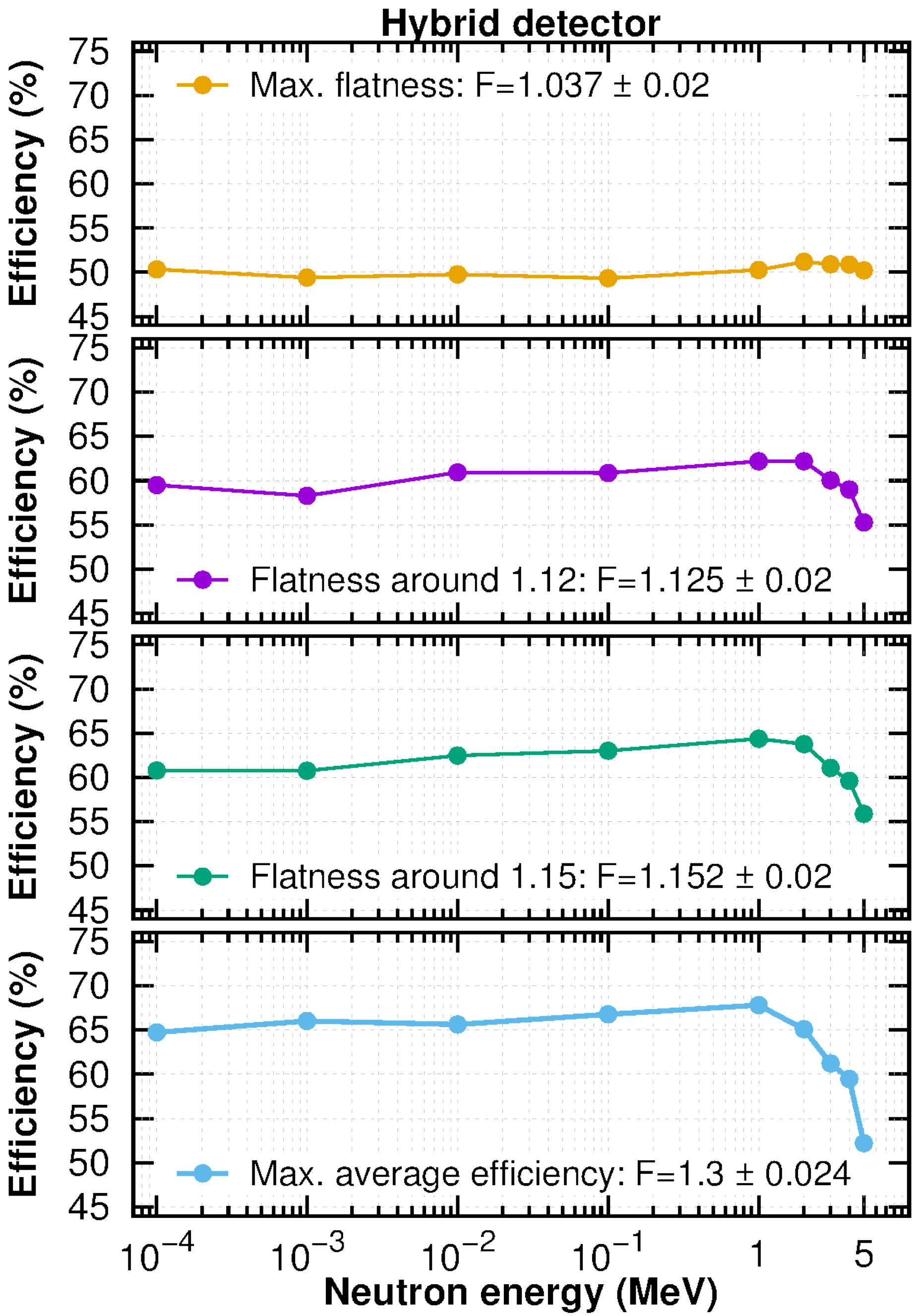
(1) Maximum calculated flatness.

(2) F ~ 1.12

(3) F ~1.15

(4) Maximum calculated average efficiency.

Hybrid configuration: Proposed configurations



Summary of the proposed configurations

Reference value	Detector without clovers		Hybrid detector	
	(h_0, f_r)	Results	(h_0, f_x, f_y)	Results
Minimum flatness	(2.6cm, 0.525)	***F = 1.088 ± 0.02*** ***<η>= 65.5 ± 0.7 %***	(0.6cm, 2.4, 1.8)	***F = 1.037 ± 0.02*** ***<η>= 50.3 ± 0.2 %***
Flatness around 1.12	(2.3cm, 0.425)	***F = 1.116 ± 0.02*** ***<η>= 69.4 ± 0.8 %***	(0.6cm, 1.7, 1.45)	***F = 1.125 ± 0.02*** ***<η>= 59.8 ± 0.7 %***
Flatness around 1.15	(2.1cm, 0.425)	***F = 1.145 ± 0.02*** ***<η>= 70.9 ± 1.0 %***	(0.6cm, 1.9, 1.15)	***F = 1.152 ± 0.02*** ***<η>= 61.3 ± 0.9 %***
Maximum average efficiency	(1.1cm, 0.25)	***F = 1.41 ± 0.024*** ***<η>= 77.9 ± 1.0 %***	(0.6cm, 1.6, 1.0)	***F = 1.3 ± 0.024*** ***<η>= 63.2 ± 1.6 %***

Roughly speaking,

- A Flatter average efficiency is obtained with the hybrid detector.
- A higher average efficiency is obtained the detector without clovers.
- For configurations with the corresponding flatness, i. e. F~1.12 and F~1.15, the inclusion of clovers has a cost of ~10% average efficiency.

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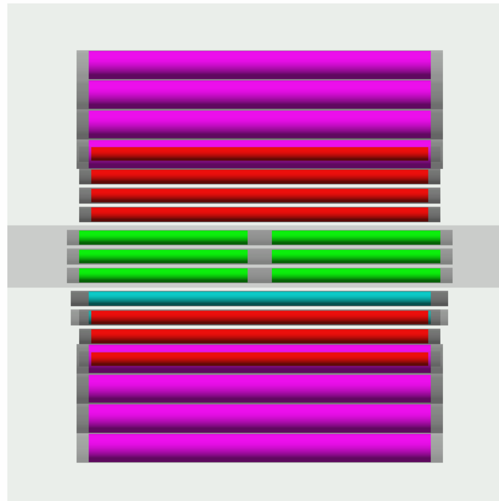
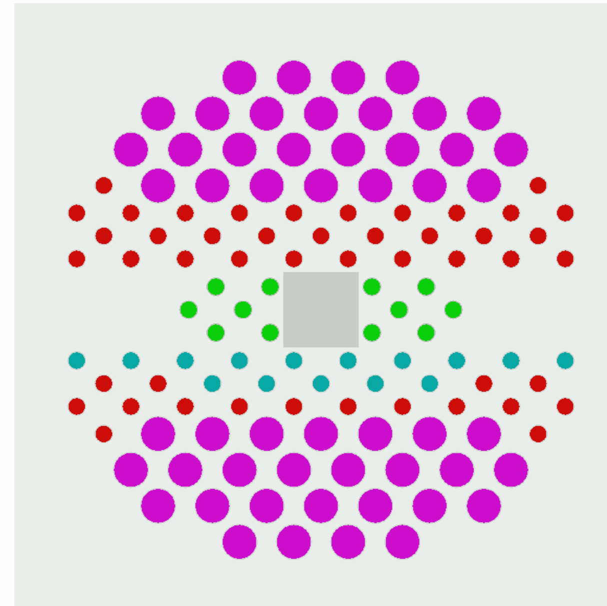
Flexible configuration

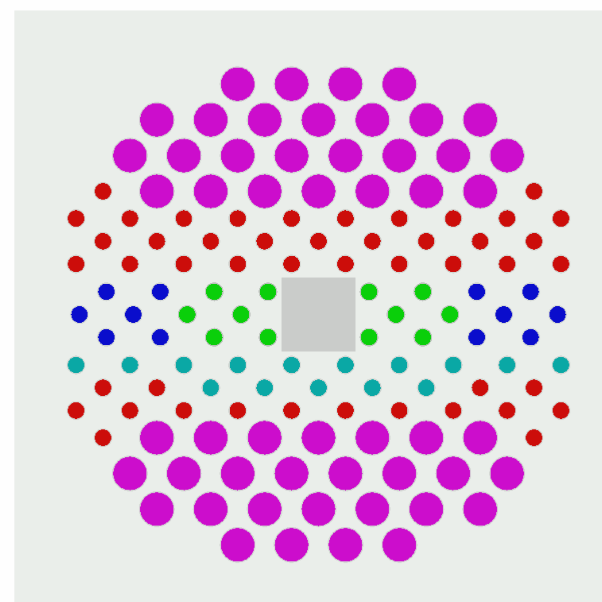
A configuration able to be converted from hybrid to compact by replacing clovers with PE, and filling with counters.





138 counters

Number of counters	Hybrid F~ 1.12		Hybrid F~ 1.15	
	<*η*>	***F***	**<*η*>**	***F***
138	63.00%	1.113	61.50%	1.116
142	63.20%	1.103	61.90%	1.1
144	63.60%	1.084	62.00%	1.072
148	63.70%	1.108	62.30%	1.068
150	63.70%	1.07	62.30%	1.068



150 counters

- By increasing the number of counters an improved flatness is obtained, while the mean efficiency remains constant.
- Not the solution to obtain higher efficiencies from the hybrid configuration when clovers are removed.

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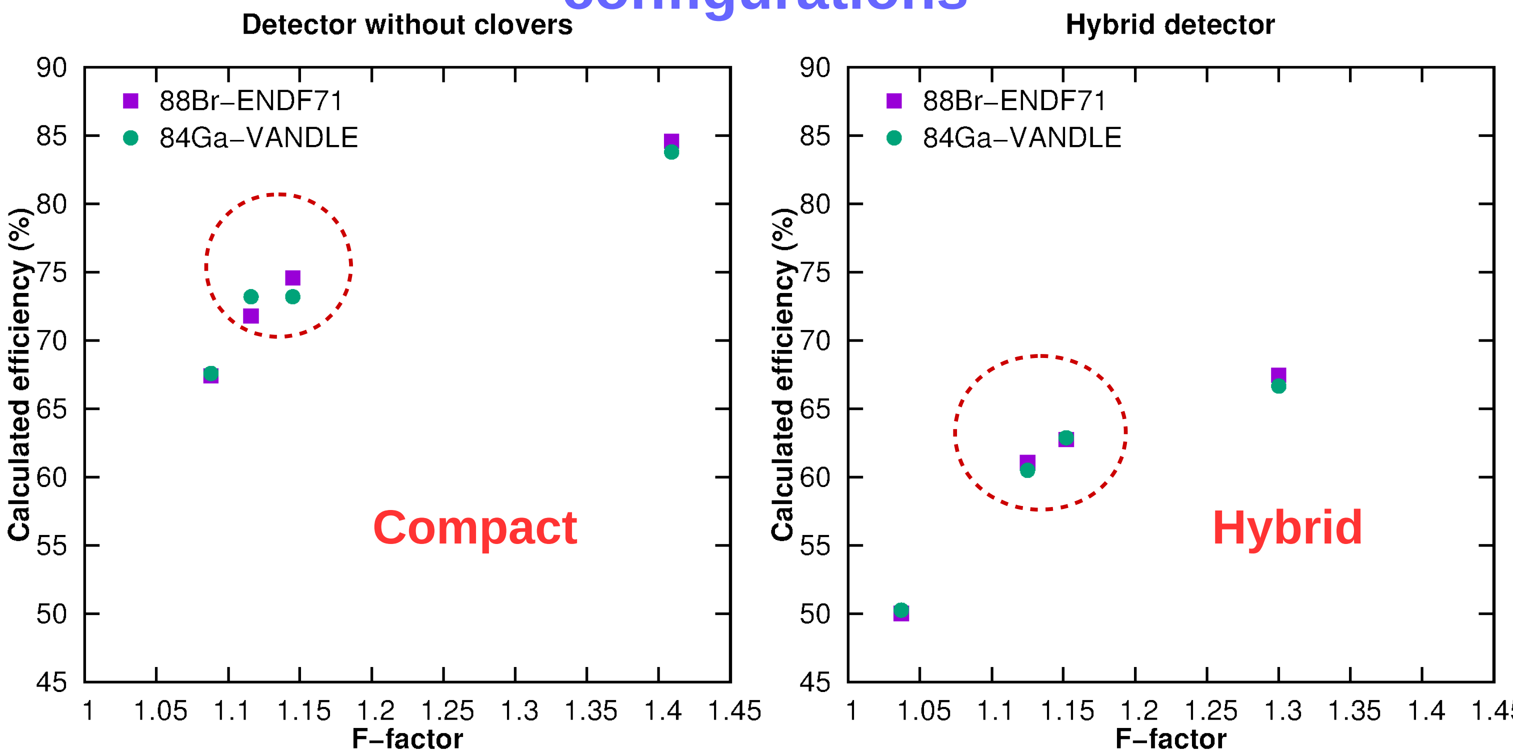
Evaluation of the performance for compact and hybrid configurations



Reference value	Detector without clovers		Hybrid detector	
	F-factor	Ratio efficiency 88Br/84Ga	F-factor	Ratio efficiency 88Br/84Ga
Maximum flatness	1.088	**0.998 ± 0.017**	1.037	**0.995 ± 0.02**
Flatness around 1.12	1.116	**0.98 ± 0.016**	1.125	**1.01 ± 0.018**
Flatness around 1.15	1.145	**1.019 ± 0.017**	1.152	**0.998 ± 0.018**
Max. average efficiency	1.409	**1.01 ± 0.016**	1.3	**1.01 ± 0.02**

- Similarly, it is found, for configurations with the corresponding flatness (F~1.12 and F~1.15), that the inclusion of clovers has roughly a cost of 12% on the neutron efficiency.

Summary of of 1n and 2n neutron efficiencies for the reference spectra

Compact detector

Reference value	F-factor	1-neutron emission efficiency			2-neutron emission efficiency		
		88Br (Low energy)	84Ga (High energy)	Mean	88Br (Low energy)	84Ga (High energy)	Mean
Maximum flatness	1.088	67.4%	67.6%	67.5%	45.5%	45.7%	45.6%
Flatness around 1.12	1.116	71.8%	73.2%	72.5%	51.5%	53.6%	52.6%
Flatness around 1.15	1.145	74.6%	73.2%	73.9%	55.7%	53.6%	54.6%
Max. average efficiency	1.409	84.6%	83.8%	84.2%	71.6%	70.2%	70.9%

Hybrid detector

Reference value	F-factor	1-neutron emission efficiency			2-neutron emission efficiency		
		88Br (Low energy)	84Ga (High energy)	Mean	88Br (Low energy)	84Ga (High energy)	Mean
Maximum flatness	1.037	50.0%	50.3%	50.1%	25.0%	25.3%	25.1%
Flatness around 1.12	1.125	61.1%	60.5%	60.8%	37.3%	36.6%	36.9%
Flatness around 1.15	1.152	62.8%	62.9%	62.8%	39.4%	39.6%	39.5%
Max. average efficiency	1.3	67.5%	66.7%	67.1%	45.5%	44.4%	45.0%

- Max. average efficiency configurations present mechanical difficulties due to a small spacing between some detectors (less than 5mm).

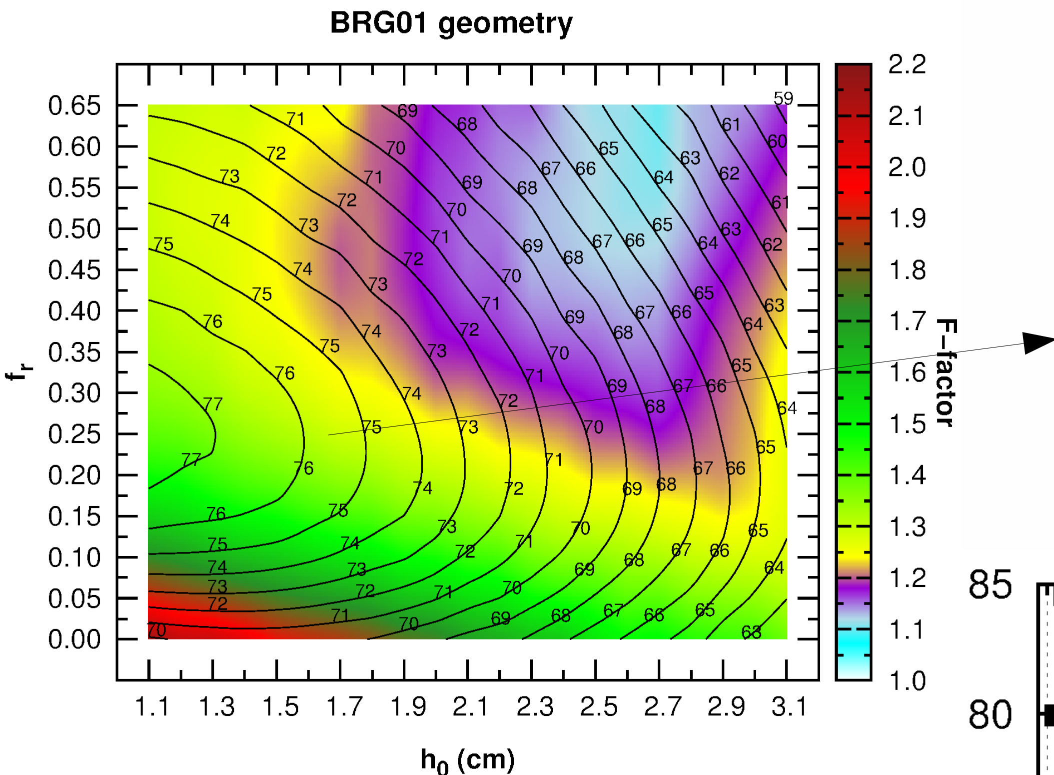
- The **configurations of flatness around 1.12 and 1.15** are the most suitable for the design of the detector. Roughly speaking, these configurations will have a neutron efficiency, for most of the nuclei of interest in RIKEN, of around 73% for the compact configuration and 62% for hybrid configuration.

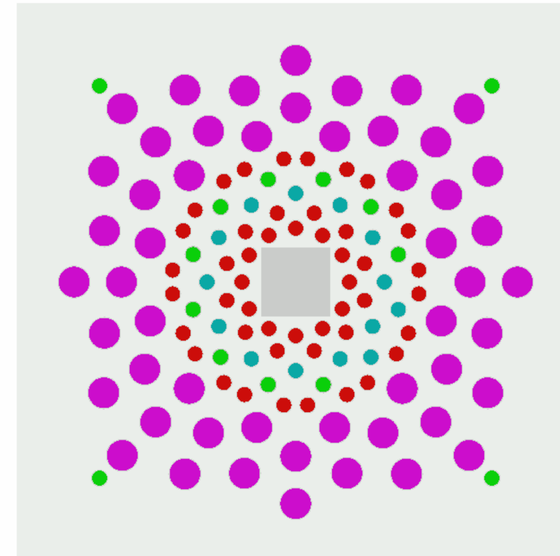
- In these configurations, the effects of high energy beta-delayed neutron spectra are minimized (~1-2% effect for 88Br/84Ga).

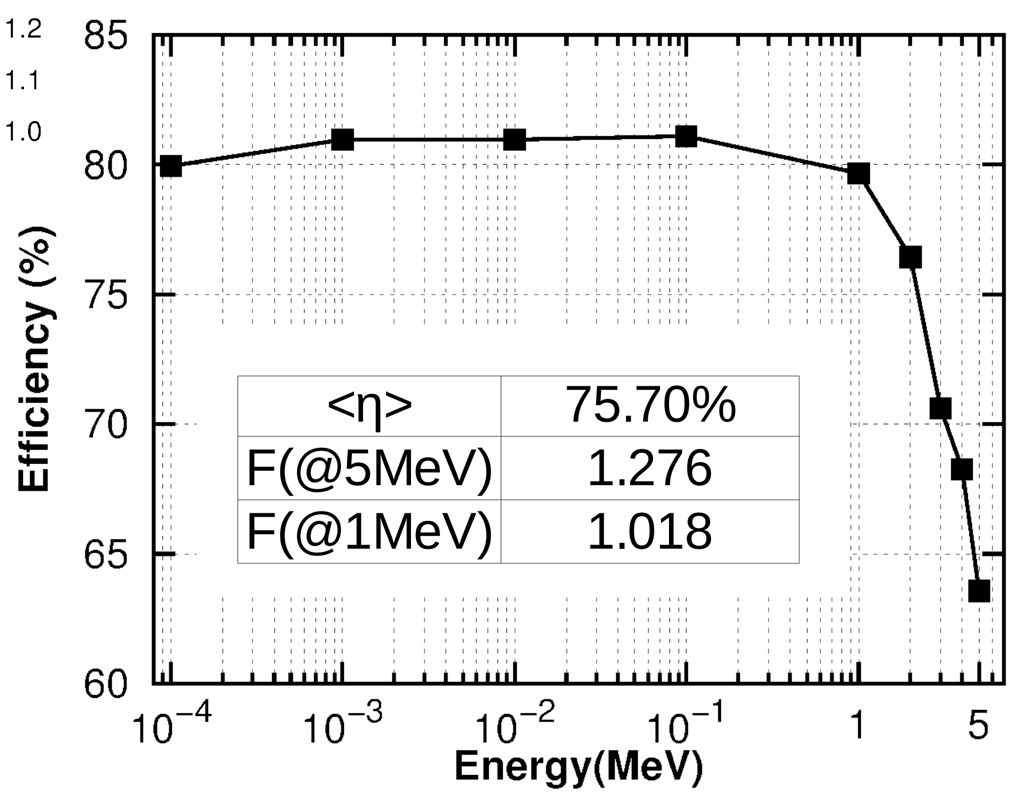
- For 2n-emission, using these proposed configurations, it is obtained a neutron efficiency of around 53% for the compact configuration and around 39% for the hybrid configuration.

- Based on these results, we conclude that clovers in the moderator do not drop significantly the efficiency, while it increases the flexibility and control capabilities for the experiments.

Achievable high efficiency compact configuration?







Space between counters and counters to moderator border is higher than 5mm. In principle possible to be constructed.

Achievable high efficiency compact configuration?

Reference value	1-neutron emission efficiency			2-n mean efficiency	3-n mean efficiency
	88Br (Low energy)	84Ga (High energy)	Mean		
Achievable high efficiency	77.0%	75.8%	76.4%	58.3%	44.6%

- Interesting for Giuseppe's proposal in order to have good counting rates for 2-n (even 3-n!!!) measurements, but giving up good flatness values above 1MeV.

<η>	75.70%
F(@5MeV)	1.276
F(@1MeV)	1.018

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Summary and remarks

- We propose new geometries for the BRIKEN neutron detector with three main advantages with respect to the compact construction proposal geometry:

    1) The new geometries requires only 138 tubes, thus keeping 10% of tubes for backup.
    2) The hybrid geometry includes two clovers (efficiency ~3% @ 1MeV), thus allowing for detection of neutrons and gammas.
    3) The performance in efficiency and flatness of the new geometries are comparable to the compact construction proposal geometry.

Reference value	Detector without clovers	Hybrid detector
Flatness around 1.12	***F = 1.116 ± 0.02***	***F = 1.125 ± 0.02***
	$\langle\eta\rangle$= 69.4 ± 0.8 %	***$\langle\eta\rangle$= 59.8 ± 0.7 %***
Flatness around 1.15	***F = 1.145 ± 0.02***	***F = 1.152 ± 0.02***
	$\langle\eta\rangle$= 70.9 ± 1.0 %	***$\langle\eta\rangle$= 61.3 ± 0.9 %***

- A high efficiency (~77% for most nuclei) compact configuration is also possible, but it means to give up good flatness above 1MeV.

- A flexible configuration will not allow to improve the efficiency from our hybrid configurations.

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BACKUP slides

Description of the Geant4 codes: Geometry

- Geant4 codes for the BRIKEN detector with and without clovers have been implemented.

- In both codes, a simple description of the counter tubes has been included. The description is based on an active ^{3}He volume and a simple geometrical description for the canning.

- The following parameters have been used for the geometry and properties of the moderator:

  Size: 90x90x90cm^3.
  Holes for AIDA and clovers: Squared shaped, size 11x11cm^2.
  Polyethylene density: 0.95 g/cm^3.
  Room temperature: 293.6 ºK.

- For the hybrid detector code, a “realistic” description of the clover geometry has been included. In our simulations, there are not detected events in the clovers, i.e. clovers are only a passive material for our calculations. Previous simulations have estimated the clover efficiency to 3% for 1 MeV gamma-ray.

Description of the Geant4 codes: Neutron source and detection

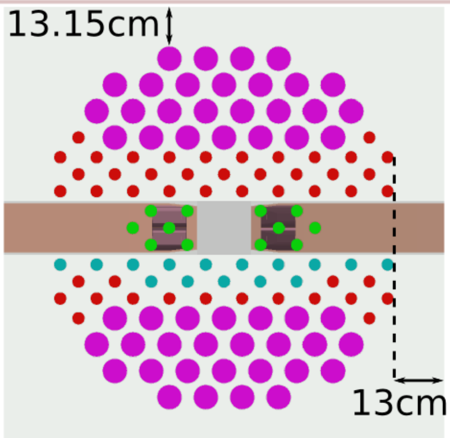
- For simplicity, a point source is used.
- The neutron source is located at the center of the polyethylene matrix.
- Neutrons are emitted isotropically from the source.
- The calculations were carried out for a set of discrete neutron energies,

$$\mathbf{E_i(MeV) = \{0.0001, 0.001, 0.01, 0.1, 1.0, 2.0, 3.0, 4.0, 5.0\},}$$

- In the simulation, detected events correspond to energy deposition in the ^{3}He active volume of the counter. Threshold for energy deposition are E_{min} = 150 keV and E_{max} = 900 keV.
- In single calculations, 10^5 events are processed.

PE Shielding

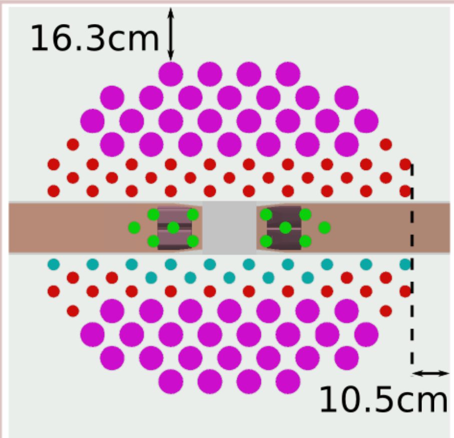
- The shielding size has not been considered as constrain in this study. This topic should be discussed by the collaboration. The configuration map for the hybrid detector allows some flexibility in selecting a configuration. It can be achieved without substantially changing the detector performance.



Flatness around 1.12:

F = 1.125 ± 0.02

<η> = 59.8% ± 0.7%



Flatness around 1.15:

F = 1.152 ± 0.021

<η> = 61.3% ± 0.9%