MURMUR: a new low-noise experiment for the search of neutron-hidden neutron transitions in the context of braneworld scenarios

Stasser Coraline for the MURMUR collaboration

ICHEP ● Operation, Performance and Upgrade of Present Detectors ● 2020

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Context of the research

Hidden sector

Hidden sector: extension of both the Standard Model of particles and the ΛCDM cosmological model.

Purpose: addressing some shortcomings as questions of dark matter and dark energy, hierarchy problems, unification problems, etc.

Hidden sector

Duplication of the SM content: Mirror partners

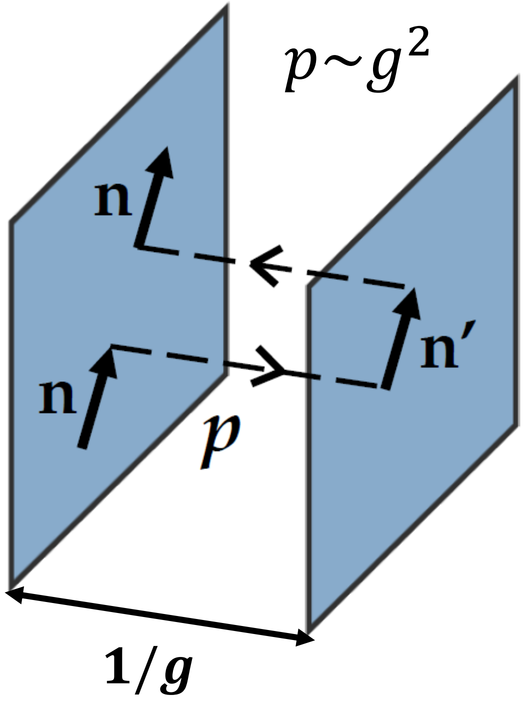
Geometrical sense: Braneworld hypothesis

Subclass of hidden sector models: fermions could exist in both the visible and the hidden states. In particular, a neutron n would have a sterile hidden state n'. Mixings between the two states could lead to $n \rightarrow n$' transitions.

Passing-through-wall neutron

Braneworld models are often considered in the literature!

Neutrons could undergo fast oscillations between the two braneworlds!



M. Sarrazin, F. Petit, Phys. Rev. D81 (2010).

→ Phenomenological way to probe braneworld scenarios with $n \to n' \to n$ transitions

Parameter of interest:

$$g \sim \frac{m^2}{M_B}$$

With $M_B = \frac{1}{\xi}$ the energy scale of the brane (TeV or Planck scale?) and m the mass of a constituent quark (340 MeV)

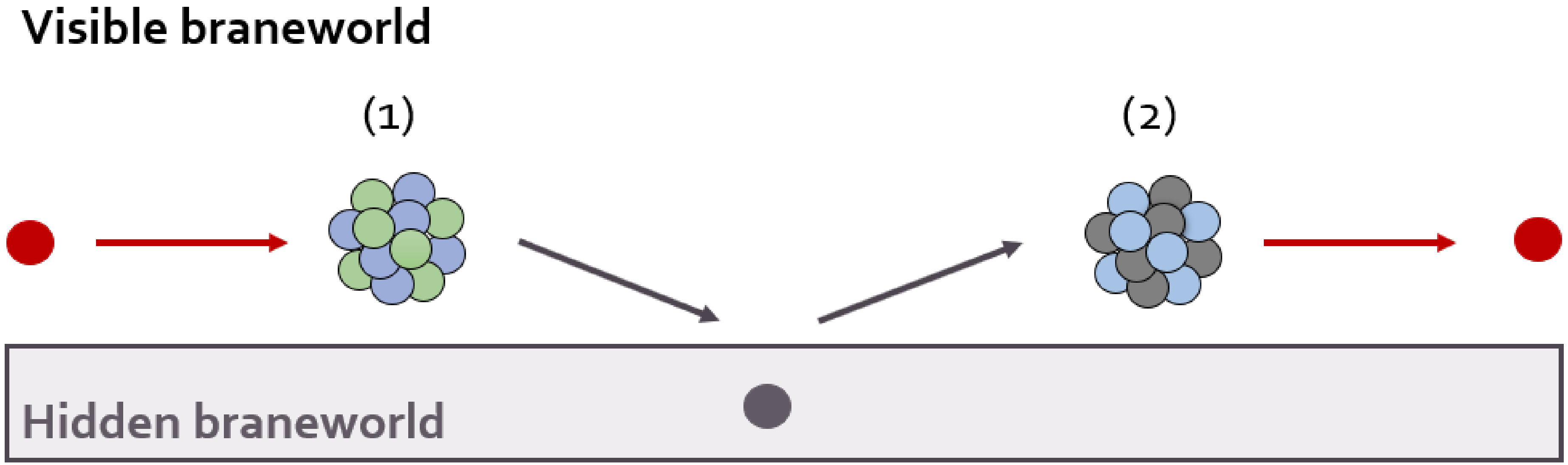
→ New physics reachable even at the Planck scale!

C. Stasser, M. Sarrazin, Int. J. Mod. Phys. A34 (2019) 1950029.

Neutron passing-through-wall experiment

Neutron passing-through-wall experiment

Neutron disappearance/reappearance toward/from a hidden brane can be induced thanks to nuclei with high scattering cross section.



(1) $\sigma\,(\text{vis. } n + \text{vis. nucleus} \longrightarrow \text{hid. } n) = \sigma_E\ (\text{vis. } n + \text{vis. nucleus} \longrightarrow \text{vis. } n) \cdot \text{p}/2$

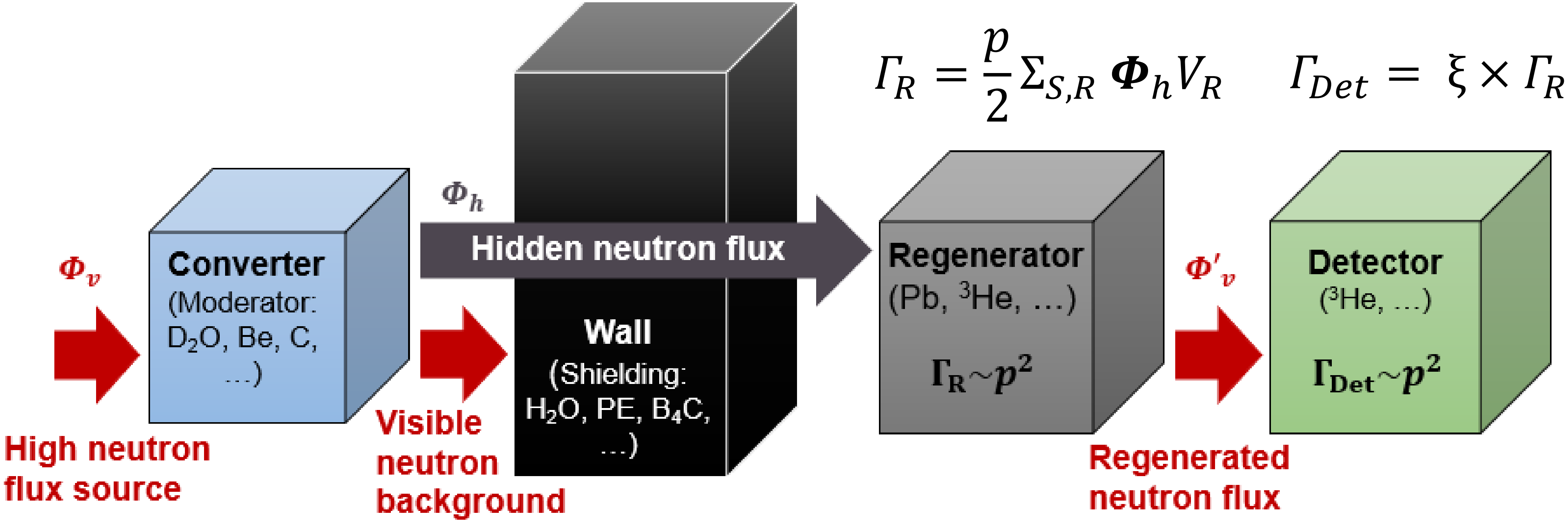
(2) $\sigma\,(\text{hid. } n + \text{vis. nucleus} \longrightarrow \text{vis. } n) = \sigma_E\ (\text{vis. } n + \text{vis. nucleus} \longrightarrow \text{vis. } n) \cdot p/2$

C. Stasser, M. Sarrazin, G. Terwagne, EPJ Web Conferences (2019).

Neutron passing-through-wall experiment

Neutron disappearance/reappearance toward/from a hidden brane can be tested with high-precision experiments.

$$\Gamma_R = \frac{p}{2} \Sigma_{S,R}\, \boldsymbol{\Phi}_h V_R \qquad \Gamma_{Det} = \xi \times \Gamma_R$$



C. Stasser, G. Terwagne, J. Lamblin, M. Méplan, G. Pignol, B. Coupé, S. Kalcheva, S. Van Dyck, M. Sarrazin, arXiv:2007.11335, submitted paper

$$\boldsymbol{\Phi}_h(\boldsymbol{r}) = \frac{p}{8\pi} \int_C \frac{1}{|\boldsymbol{r} - \boldsymbol{r}'|^2} \Sigma_{S,C}(\boldsymbol{r}')\, \boldsymbol{\Phi}_v(\boldsymbol{r}')\, d^3 r'$$

M. Sarrazin, G. Pignol, J. Lamblin, F. Petit, G. Terwagne, V. V. Nesvizhevsky, Phys. Rev. D91 (2015).

Neutron passing-through-wall experiment

First experiment of this kind at the ILL (France) in 2015: regenerator = detector (^3He counter).

$$p < 4.6\ 10^{-10} \text{ at } 95\% \text{ CL.}$$

M. Sarrazin, G. Pignol, J. Lamblin, F. Petit, G. Terwagne, V. V. Nesvizhevsky, Phys. Rev. D91 (2015).

M. Sarrazin, G. Pignol, J. Lamblin, J. Pinon, O. Méplan, G. Terwagne, P.L. Debarsy, F. Petit and V. V. Nesvizhevsky, Phys. Lett. B758 (2016).

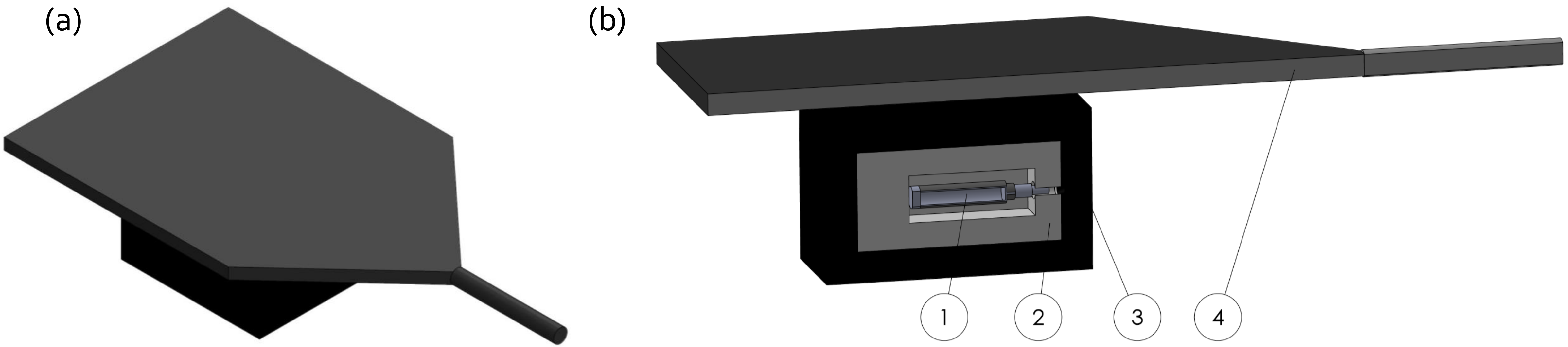
<u>MURMUR:</u> improved detector placed near the BR2 nuclear core at Mol in Belgium to constrain braneworld cosmological scenarios.

- Noise substraction thanks to ON/OFF reactor measurements
- Regenerator made of 50 kg of lead
- PSD
- Active veto

C. Stasser, M. Sarrazin, G. Terwagne, EPJ Web Conferences (2019).

The MURMUR detector

MURMUR detector



Design of the MURMUR detector: (a) complete view and (b) sectional view. 1. ^{3}He proportional counter, 2. Regenerator: $23.6 \times 17.7 \times 11.5\ cm^3$ of lead (50 kg), 3. Boron carbide box of $3.6\ cm$ of thickness, 4. plastic scintillator acting as a veto.

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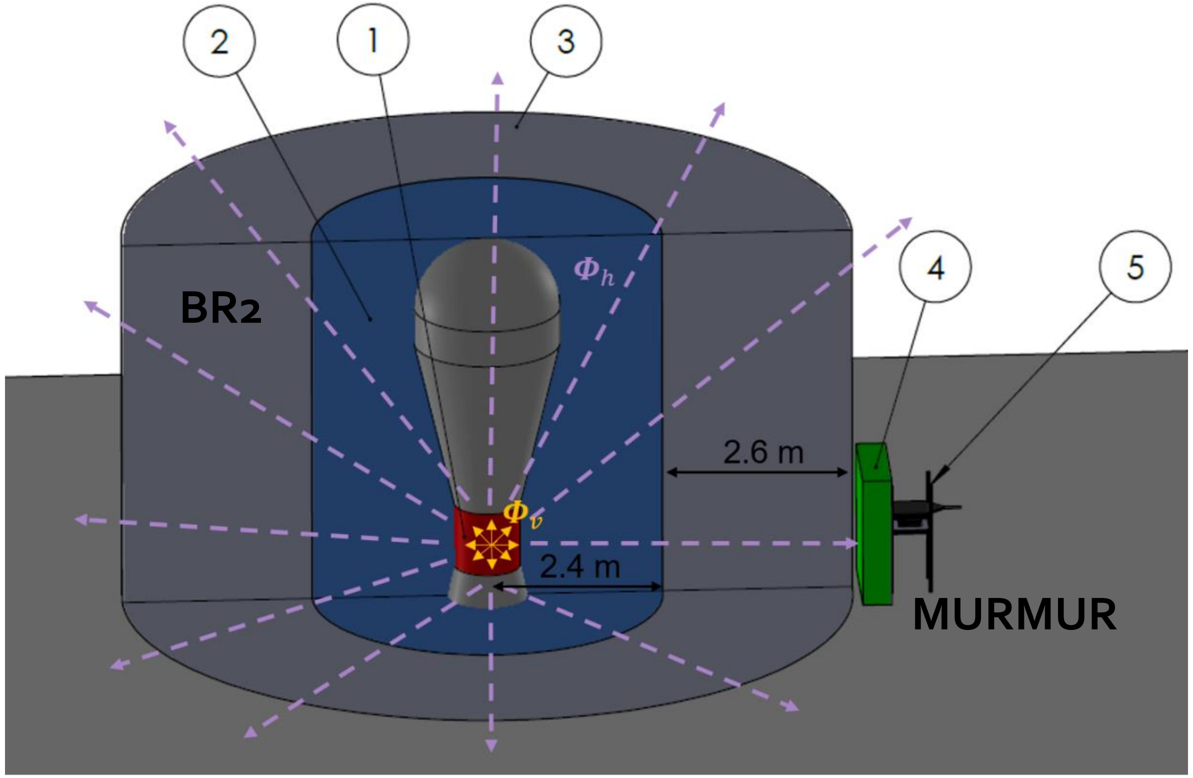
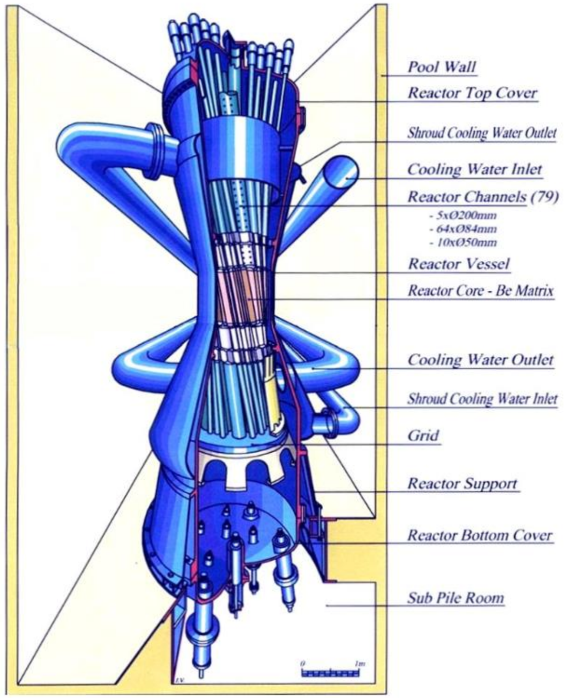
$$^{3}_{4}He + ^{1}_{0}n \rightarrow ^{1}_{1}p + ^{3}_{1}H + 764\ keV$$

MURMUR near the BR2 core

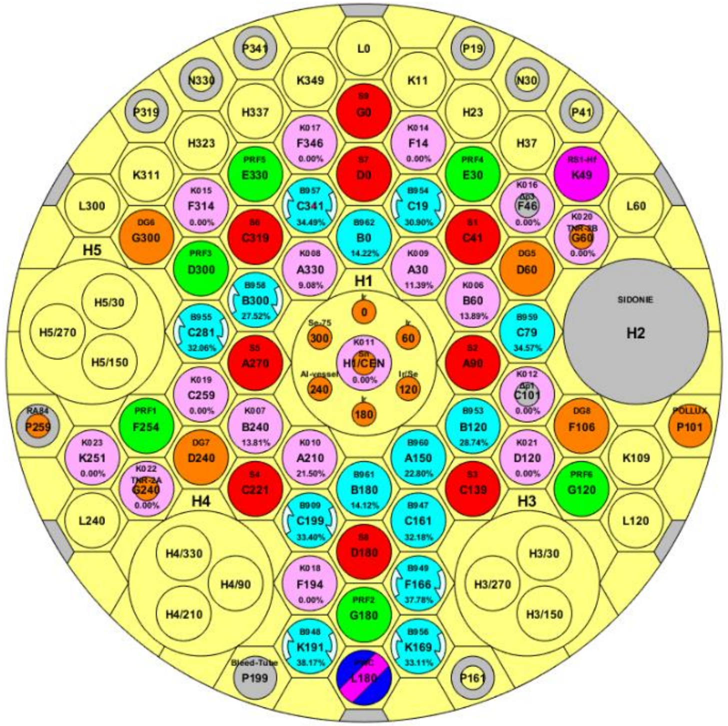


MURMUR experiment near the BR2 core in the SCK·CEN at Mol in belgium. 1. BR2 core which has a beryllium moderator, 2. light water pool, 3. concrete wall, 4. paraffin wall, 5. MURMUR detector.

(a)



(b)



(a) Geometry of the BR2 nuclear core of the SCK·CEN at Mol in belgium. (b) Mid-plan of the BR2 core for the Cycle02/2019A. Orange: Fuel. Red: control roads in cadmium or hafnium.

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First results

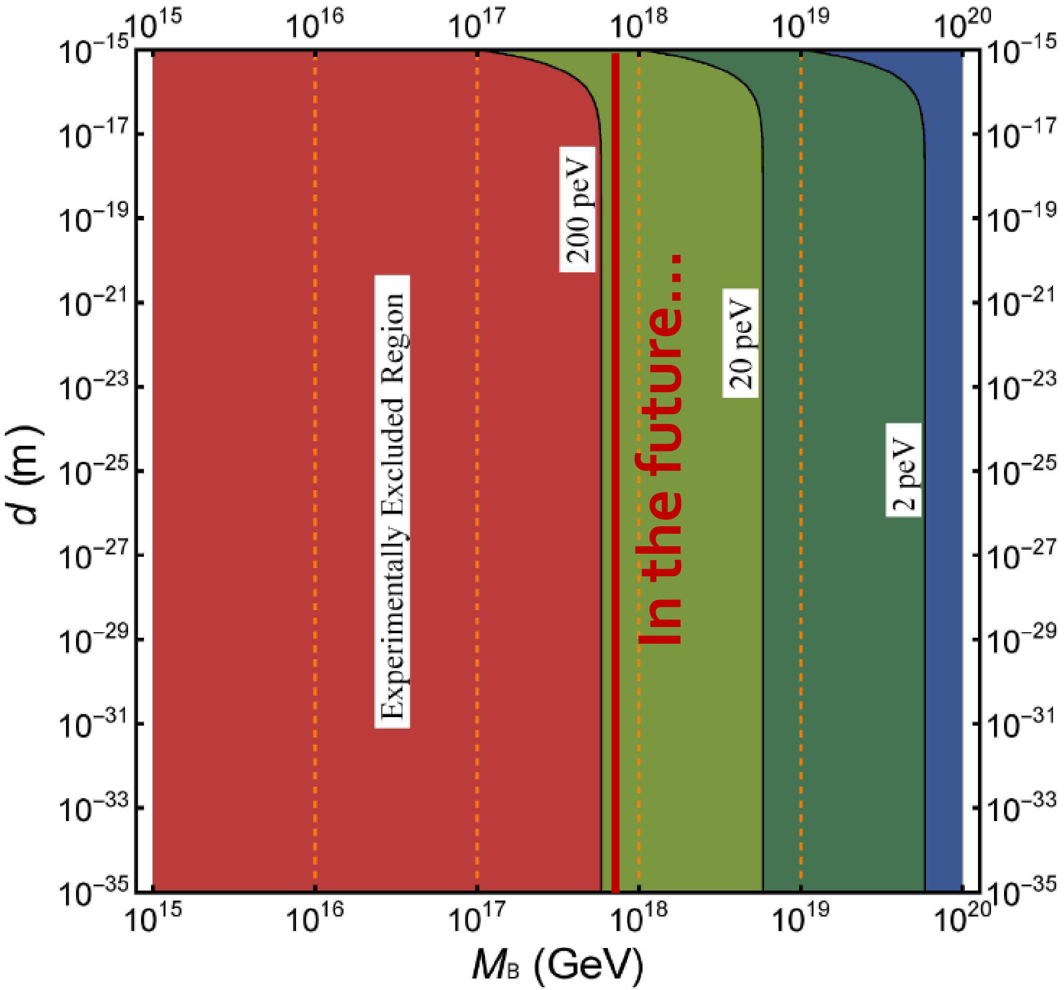
New constraint on *p*

$\Gamma_{Det} < 3.3 \times 10^{-5}\ s^{-1}$ at 95% CL

$p < 4.0 \times 10^{-10}$ at 95% CL

- The BR2 efficiency to produce hidden neutron flux is weaker than the ILL by a factor 7.4.

- Lead as regenerator material and noise substraction both make possible to give a similar constraint than the previous one found at the ILL depiste a moderator less efficient to produce hidden neutrons.



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Perspectives

Prospects for the futur…

- Improvements of the experimental setup:

  - Addition of cadmium as shielding to reduce the epithermal neutron background.
  - Addition of PE to reduce the fast neutron background.
  - Addition of plastic scintillators by the sides of the experiment to reduce neutron background due to muons in lead.

- Test of the detector near the high flux nuclear core of the ILL.

Thank you! ☺

My room on zoom: Link: kkzefizanazf, Pass:

Braneworld

<u>Our visible world</u>: 3+1 hypersurface (a 3-brane) embedded in a hyperspace (the bulk) of more than 3+1 dimensions.

Many braneworlds could coexist in the bulk!

V.A Rubakov and M.E Shaposhnikov, Phys. Lett. 125B (1983) 126.

G. Dvali, G. Gabadadze, M. Shifman, Phys. Lett. B 497 (2001) 271.

D.J.H Chung and K. Freese, Phys. Rev. D62 (2000) 063513.

P. Horava and E. Witten, Nucl. Phys. B460 (1996) 506.

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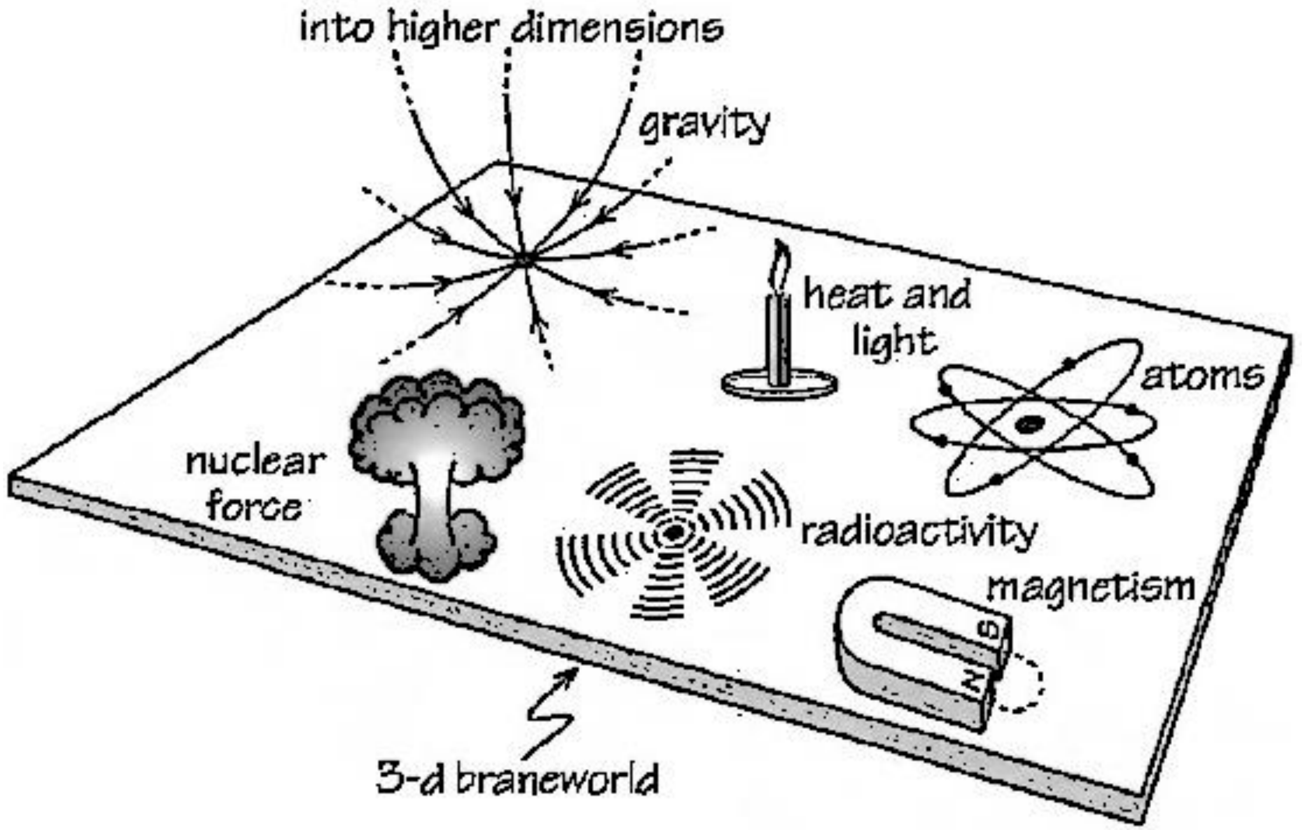
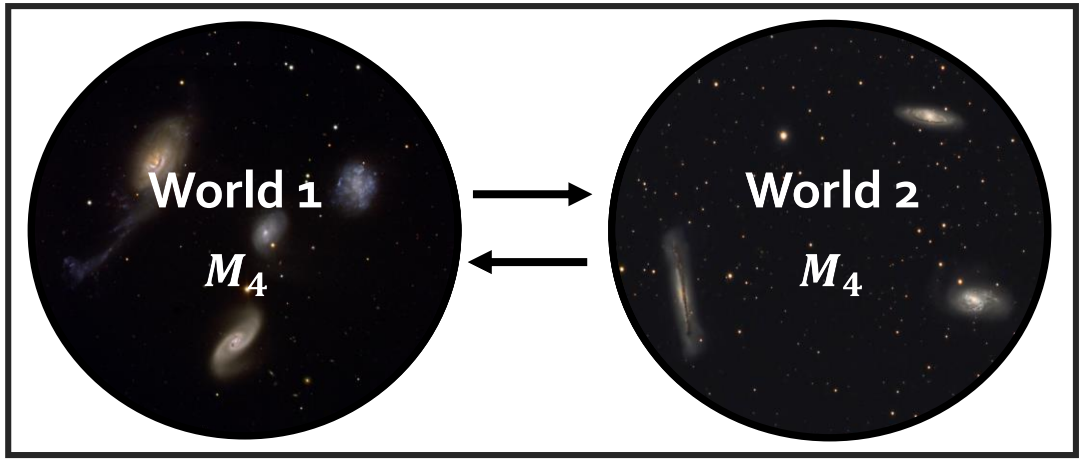


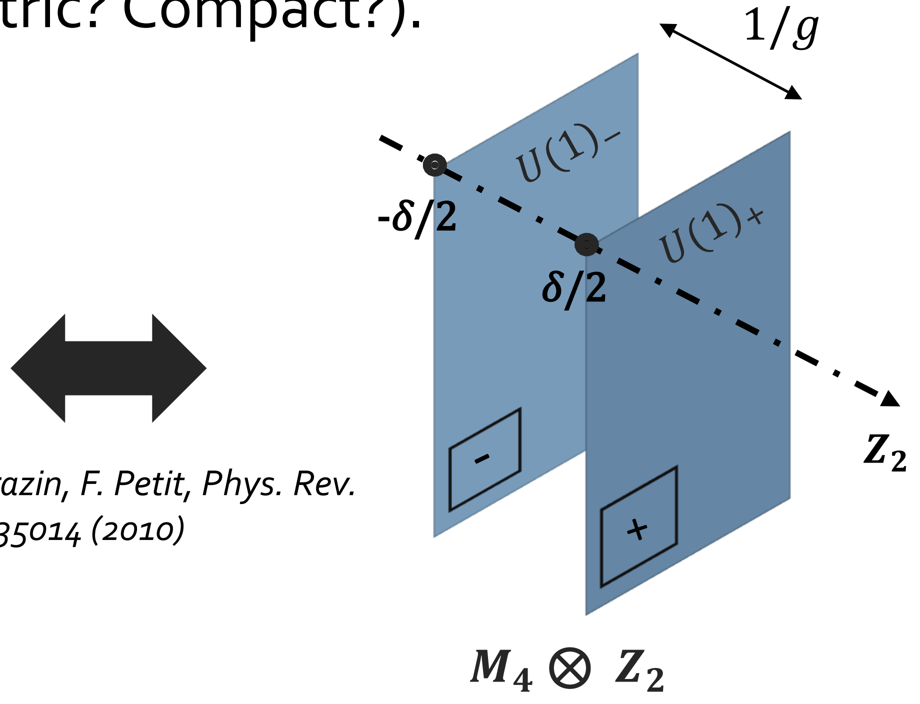
Framework

<u>Problem</u>: Many complex braneworld models to probe, ignoring which is the right one!

<u>Solution:</u> A two-brane universe is naturally described at low energy by a noncommutative two-sheeted system, whatever the nature of the branes (strings? Domain walls?) and the properties of the bulk (number of dimensions? Metric? Compact?).

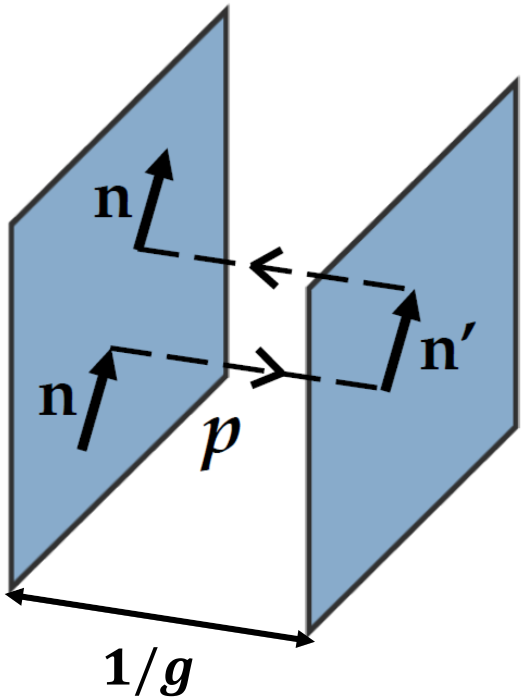


M. Sarrazin, F. Petit, Phys. Rev. D 81, 035014 (2010)



Passing-through-wall neutron

Neutrons could undergo fast oscillations between the two braneworlds!



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Mean value of the probability p:

$$p = \frac{2\,{\Omega_P}^2}{{\Omega_0}^2} \text{ with } \Omega_0 = \frac{V_+ - V_-}{\hbar} \text{ and } \Omega_P = \frac{\mu g A}{\hbar}, \text{ where}$$

$V_\pm$ is the energy of the particle in each brane.

→ Phenomenological way to probe braneworld scenarios with $n \to n' \to n$ transitions

Parameter of interest:

$$g \sim \frac{m^2}{M_B} \sim 10^{-4}\, m^{-1} \sim 0.01\, neV$$

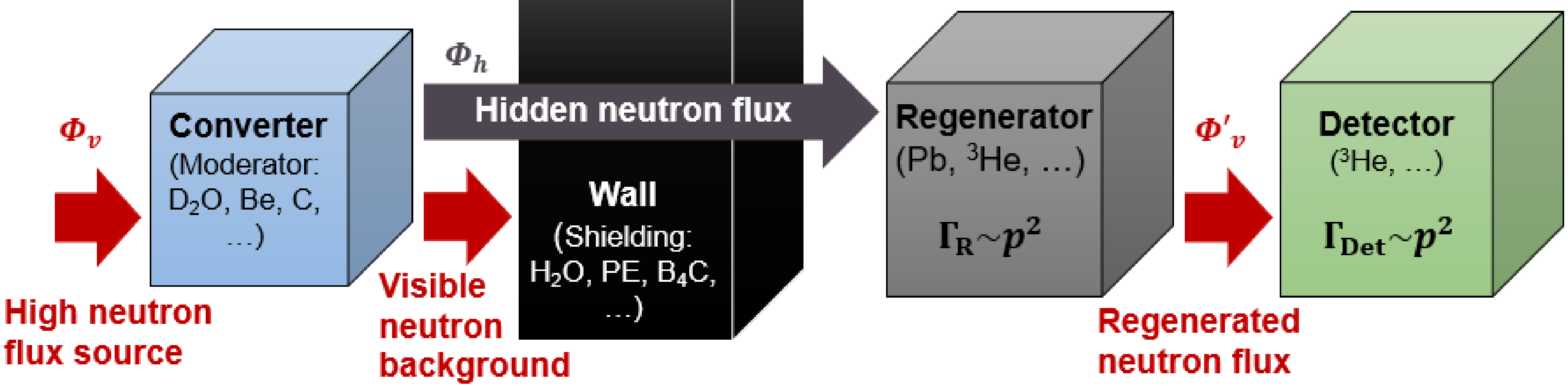
→ New physics reachable even at the Planck scale ($M_B = \frac{1}{\xi} = M_{Planck}$)

MURMUR

Neutron passing-through-wall experiment

Neutron disappearance/reappearance toward/from a hidden brane can be tested with high-precision experiments.

$$\Gamma_R = \frac{p}{2}\Sigma_{S,R}\,\boldsymbol{\Phi}_h V_R \qquad \Gamma_{Det} = \xi \times \Gamma_R$$



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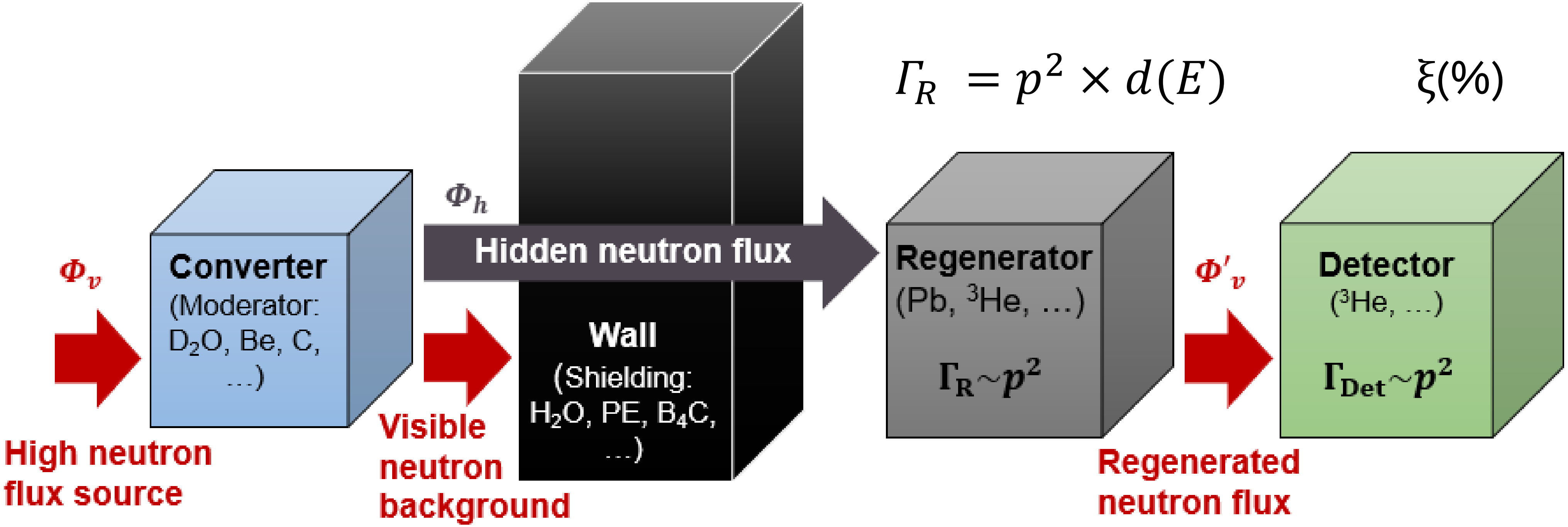
Numerical computations

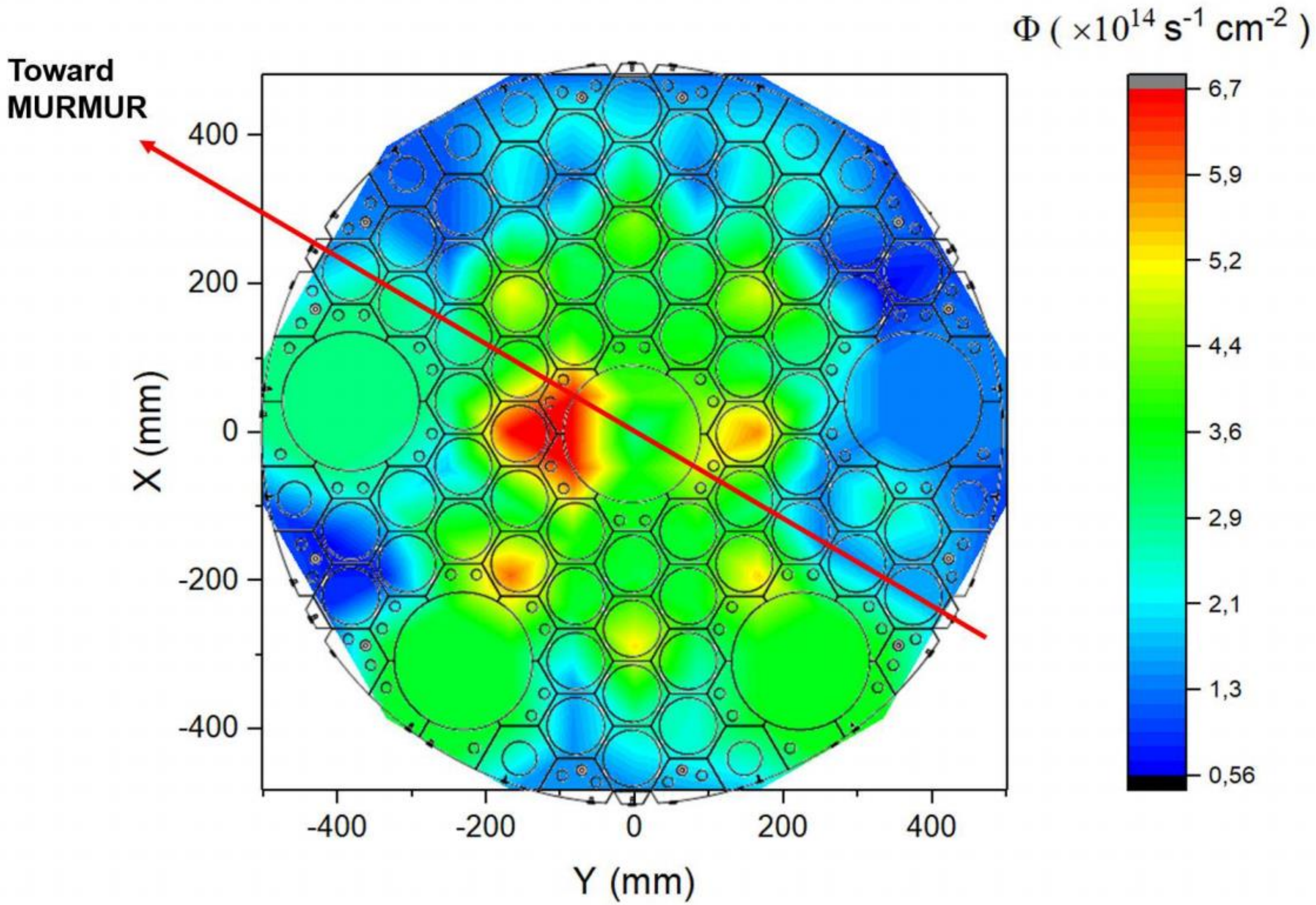


$$d = \frac{\Sigma_{S,Pb}}{16\pi} \int_C \frac{\Sigma_{S,C}(\mathbf{r}')\boldsymbol{\Phi}_v(\mathbf{r}',E)d^3\,r'}{|\mathbf{r}-\mathbf{r}'|^2}$$

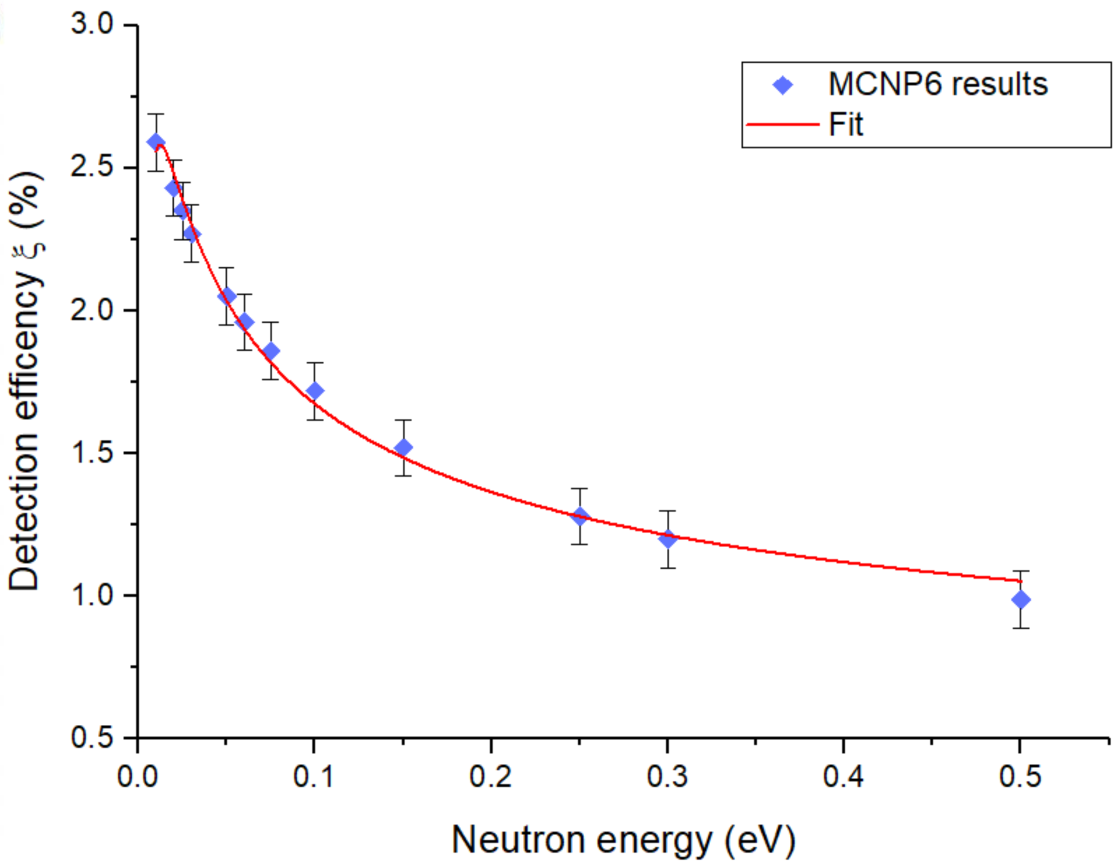
$$p < \sqrt{\frac{\Gamma_{Det}}{\xi(E) \times d(E)}}$$

First results

Numerical computations



Map of the thermal neutron flux Φ in the mid-plan of the BR2 core calculated thanks to MCNP6 simulations.

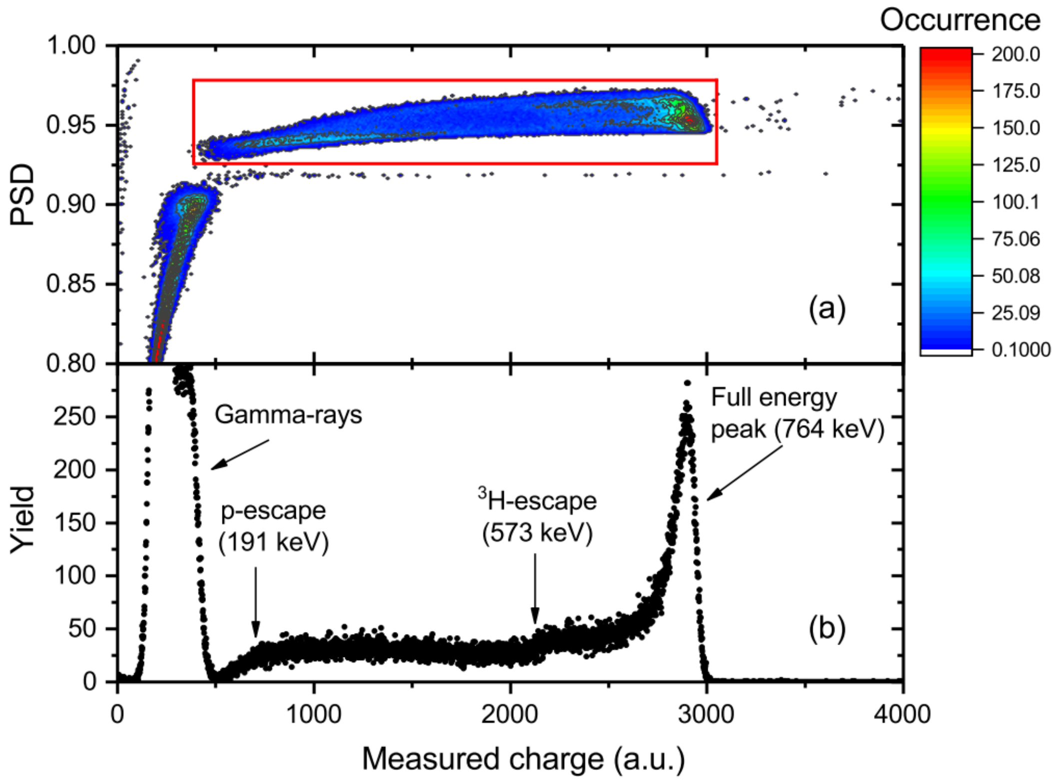


Regenerated neutron detection efficiency ξ(%) in function of the neutron energy calculated with MCNP6. Fit function in red: $\frac{A}{E} + \frac{B}{\sqrt{E}} + C$.

Neutron counting rate

(a) OFF1 ($\times 10^{-4}\ s^{-1}$)	(b) ON ($\times 10^{-4}\ s^{-1}$)	(c) OFF2 ($\times 10^{-4}\ s^{-1}$)
$3,09^{+0,17}_{-0,16}$	$3,10^{+0,18}_{-0,17}$	$2,88^{+0,15}_{-0,15}$

Neutron counting rate in the ^{3}He counter. (a) 831 hours of acquisition during the shutdown period (OFF) of the BR2 nuclear core of December 2018/January 2019. (b) 760 hours of acquisition during the Cycle02/2019A of April 2019. (c) 998 hours of acquisition during the shutdown period of May/June 2019.



(a) PSD quantity in function of the measured charge in the ^{3}He counter. (b) ^{3}He counter charge spectrum.

$\Gamma_{Det} < 3.3 \times 10^{-5}\ s^{-1}$ **at 95% CL**

C. Stasser, G. Terwagne, J. Lamblin, M. Méplan, G. Pignol, B. Coupé, S. Kalcheva, S. Van Dyck, M. Sarrazin, arXiv:2007.11335, submitted paper

New constraint on p

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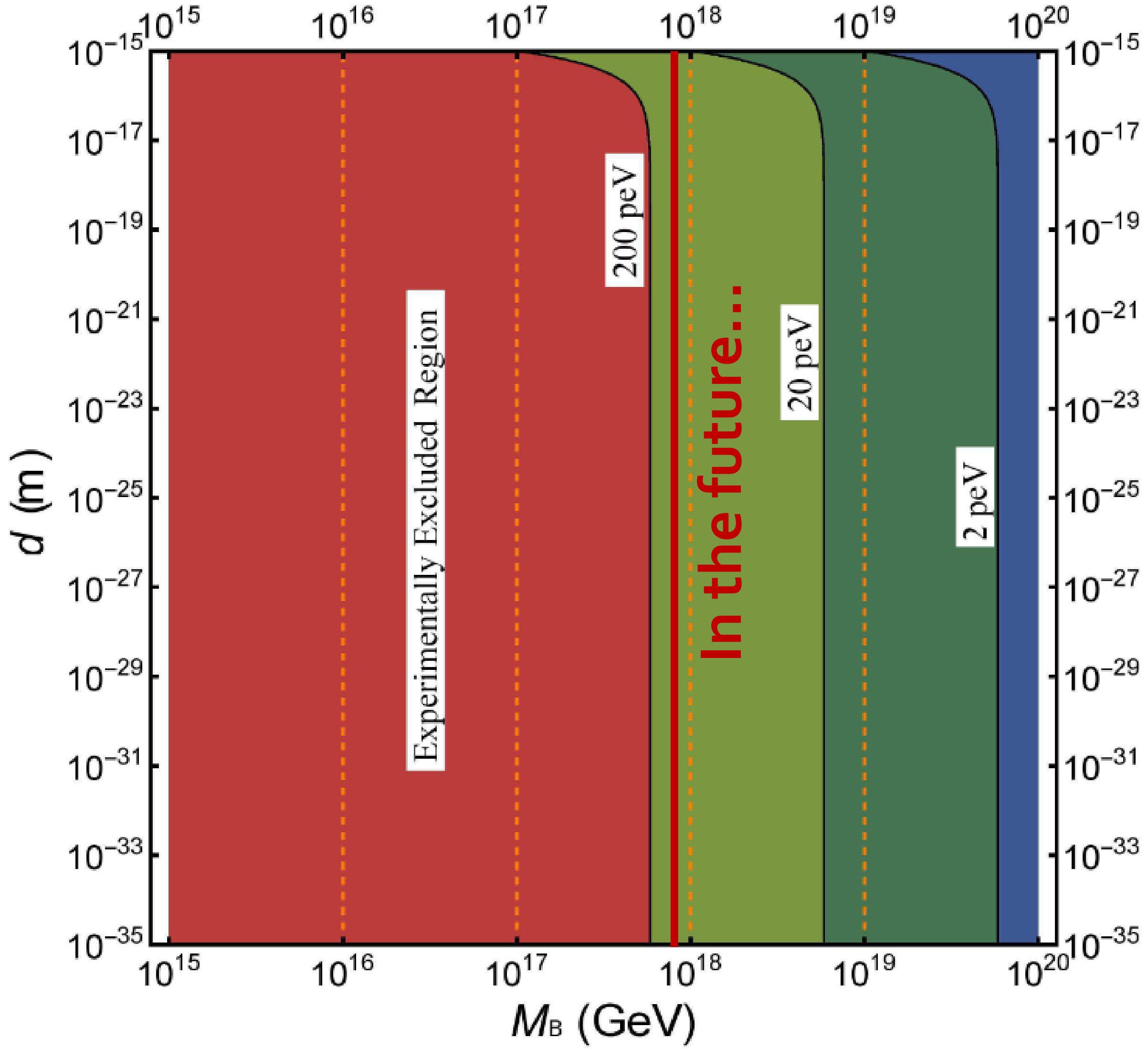

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