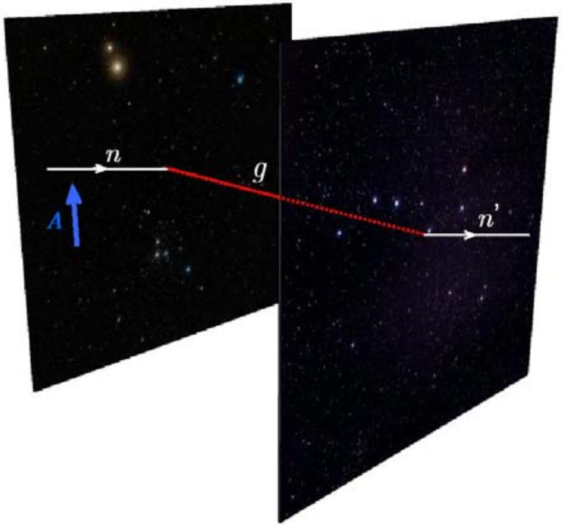
Testing baryon number conservation in braneworld models at ESS



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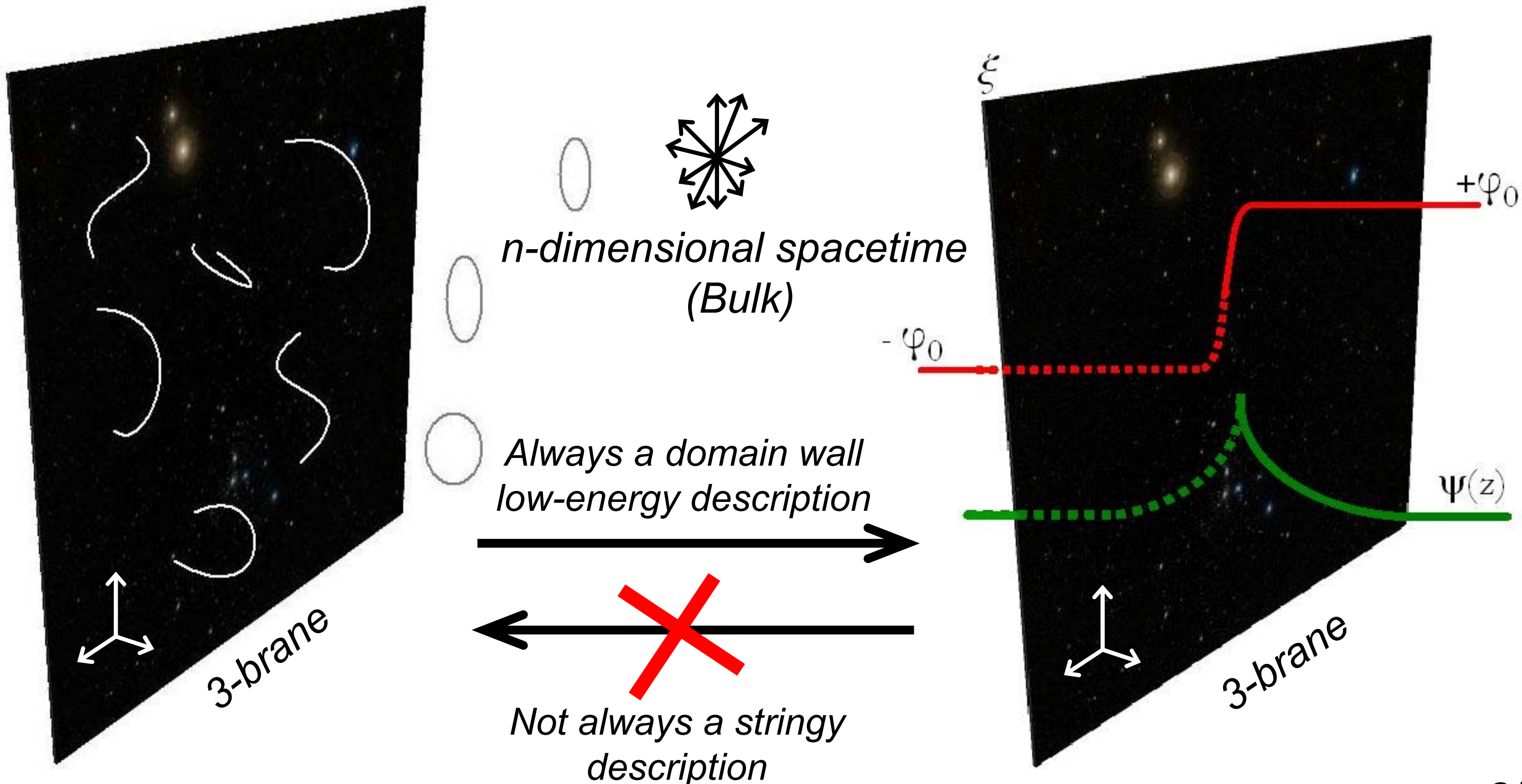
ESS Science Symposium on Particle Physics at Long-Pulse Spallation Sources
25-27 March 2013

Context: Braneworld, a product from ToE attempts

Our world as a sheet embeded in a hyperspace: An « old » and rich idea !

- *1996, P. Horova & E. Witten*: Brane as boundary conditions of superstrings

-*1983, V.A. Rubakov & M.E. Shaposhnikov*: SM particles as bounded excitations on a domain wall



Context: Braneworld, a product from ToE attempts

Our world as a sheet embeded in a hyperspace: An « old » and rich idea !

⇒ A productive topic with many published works

⇒ Lead to attractive solutions for Dark Matter, Hierarchy, …

But, are extra dimensions and/or branes

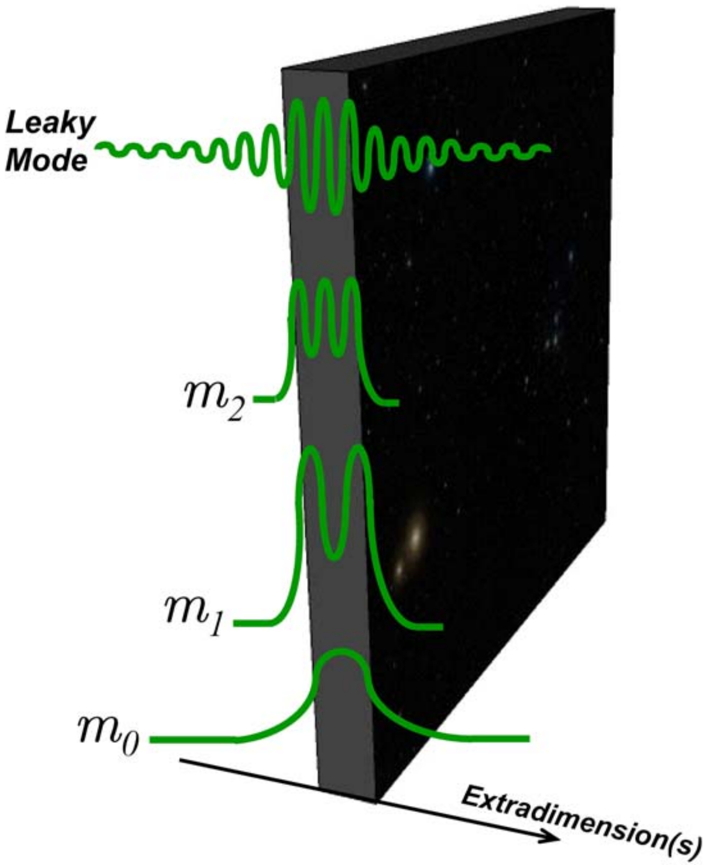
a <u>real</u> viable track for physics?

⇒ Need for prompt experimental evidences of extra dimensions or braneworlds!

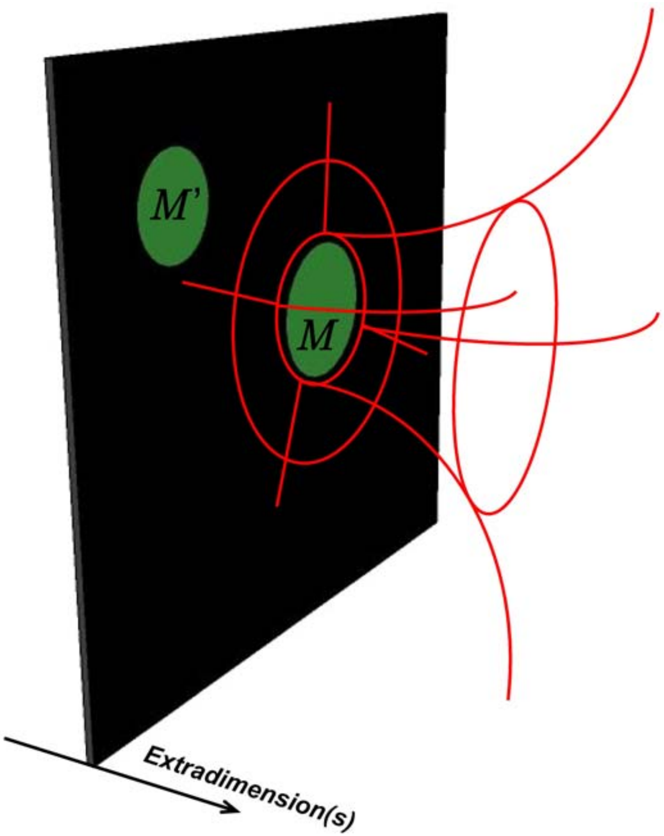
Prospecting for new physics

Prospecting for braneworld phenomenology: One-brane system

- High Energy Physics: KK states at LHC

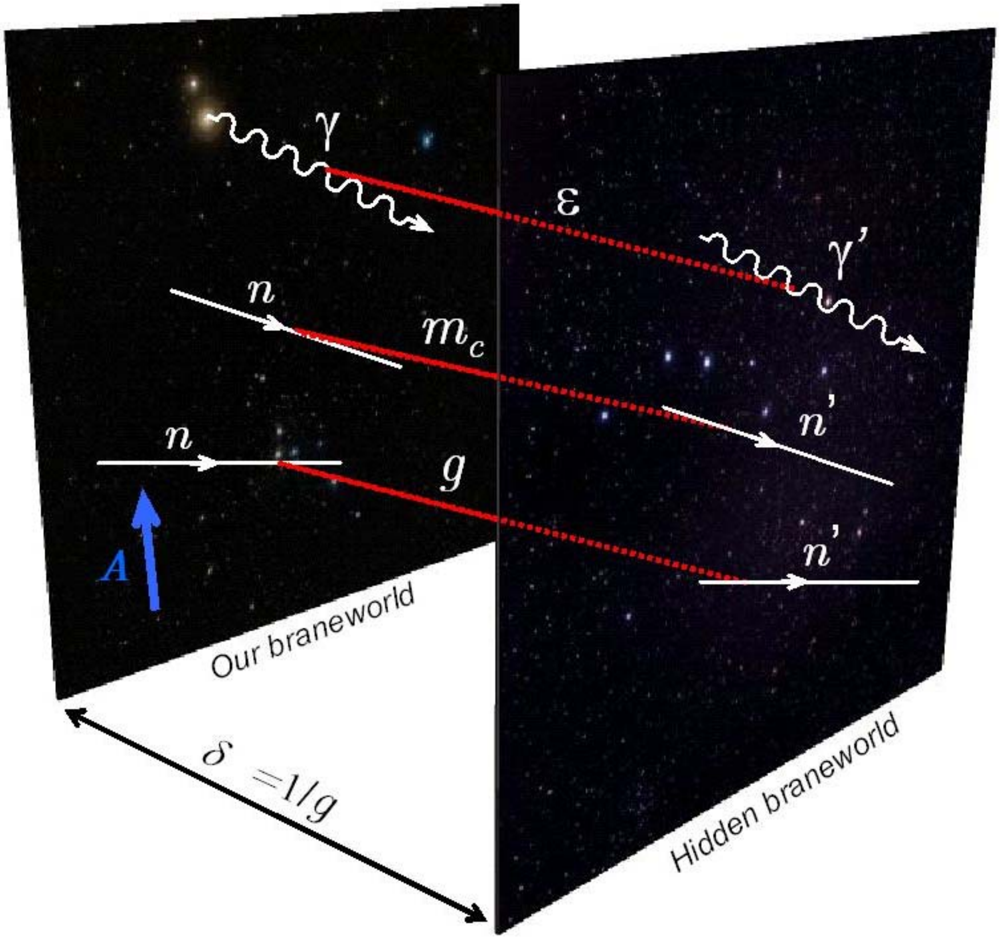


- Low Energy Physics: Deviations of Newton Law with gravitation metrology



Prospecting for new physics

Prospecting for braneworld phenomenology: Two-brane system



As for one-brane + many new effects:

M. Sarrazin, F. Petit, Eur. Phys. J. C ***72*** *(2012) 2230*

- Photon-hidden photon kinetic mixing

See A. Ringwald, S. Abel, …

- Fermion-hidden fermion mass mixing

See Z. Berezhiani, …

- Fermion-hidden fermion geometrical mixing

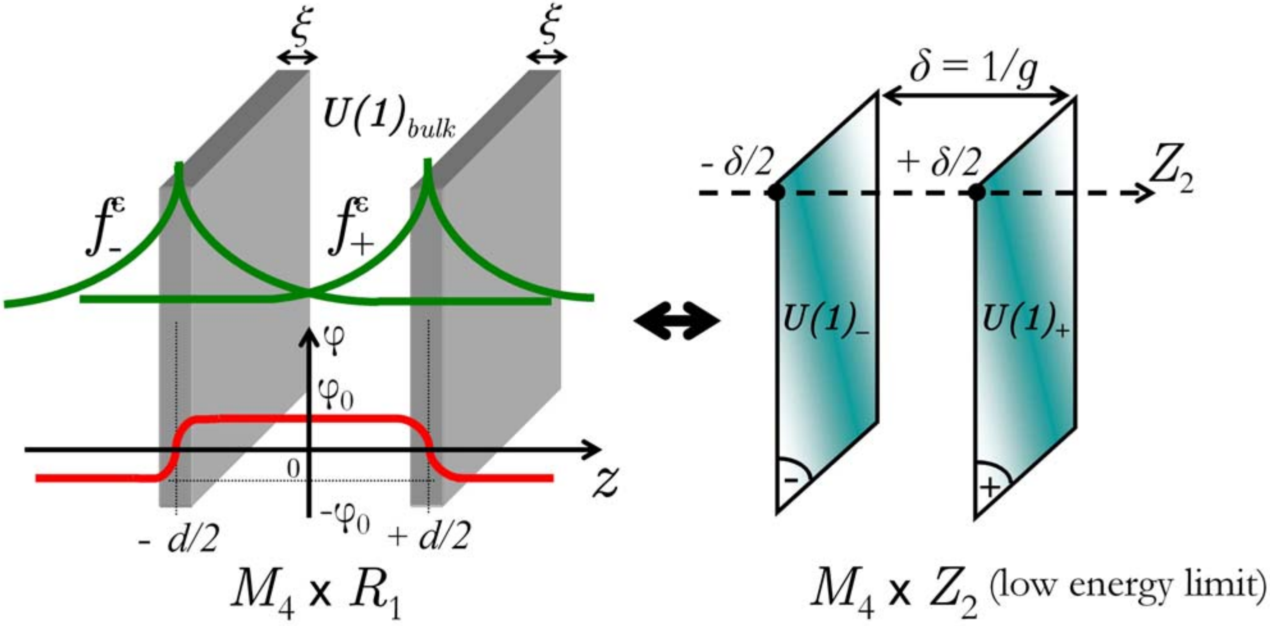
Prospecting for new physics

Describing the effects of interactions between two branes

⇒ At low energy, any multidimensional setup with two branes can be described by a two-sheeted spacetime in the formalism of the noncommutative geometry.

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

⇒ A tool for a model-independent phenomenology of braneworlds!



With g ∂ (1/ξ) exp(-*d*/ξ) in the simplest approach

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⇒ Two-brane Dirac equation:

$$(i\not{D}_A - M)\Psi = \begin{pmatrix} i\gamma^\mu(\partial_\mu + iqA_\mu^+) - m & ig\gamma^5 - m_c + i\gamma^5\Upsilon \\ ig\gamma^5 - m_c^* + i\gamma^5\bar{\Upsilon} & i\gamma^\mu(\partial_\mu + iqA_\mu^-) - m \end{pmatrix}\begin{pmatrix} \psi_+ \\ \psi_- \end{pmatrix} = 0.$$

+ *E.M. terms*

Contains:
- Photon-hidden photon kinetic mixing
- Fermion-hidden fermion mass mixing
- Fermion-hidden fermion geometrical mixing

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Contains:

Dominant effect relatively to the two others

- Fermion-hidden fermion geometrical mixing

Prospecting for new physics

Why two-brane physics is so interesting?

$\Rightarrow$ Because it allows low-energy experiments
to probe a new physics invisible in colliders !

- Roughly speaking brane thickness ξ is probed in colliders at energy E = 1 / ξ

- In two-brane physics, the relevant parameter is: $g \; \partial \; (1/\xi) \, \exp(-d/\xi)$

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- But what if we get branes at Planck scale? e.g. if $d \approx 87\ \xi$ then $g \approx 10^{-3}\ m^{-1}$!

⇒ New physics at ILL or ESS but not in colliders !

Prospecting for new physics

A two-brane Pauli equation

$$i\hbar\frac{\partial}{\partial t}\begin{pmatrix}\psi_+\\ \psi_-\end{pmatrix} = \{\mathbf{H}_0 + \mathbf{H}_{cm} + \ldots\}\begin{pmatrix}\psi_+\\ \psi_-\end{pmatrix}$$

- Two times the usual Pauli Hamiltonian for each brane:

$$\begin{cases}\mathbf{H}_0 = \begin{pmatrix}\mathbf{H}_+ & 0\\ 0 & \mathbf{H}_-\end{pmatrix}\\ \mathbf{H}_\pm = -\frac{\hbar^2}{2m}\left(\nabla - i\frac{q}{\hbar}\mathbf{A}_\pm\right)^2 + g_s\mu\frac{1}{2}\sigma\cdot\mathbf{B}_\pm + V_\pm\end{cases}$$

g coupling constant between branes

- A new term appears that couples the branes.
- The coupling depends of the magnetic vector potential.

$$\mathbf{H}_{cm} = igg_s\mu\frac{1}{2}\begin{pmatrix}0 & -\sigma\cdot\{\mathbf{A}_+ - \mathbf{A}_-\}\\ \sigma\cdot\{\mathbf{A}_+ - \mathbf{A}_-\} & 0\end{pmatrix}$$

*M. Sarrazin, F. Petit, Phys. Rev. D **81**, 035014 (2010)*
*F. Petit, M. Sarrazin, Phys. Lett. B **612**, 105-114 (2005)*

Rabi oscillations between branes: Matter swapping effect

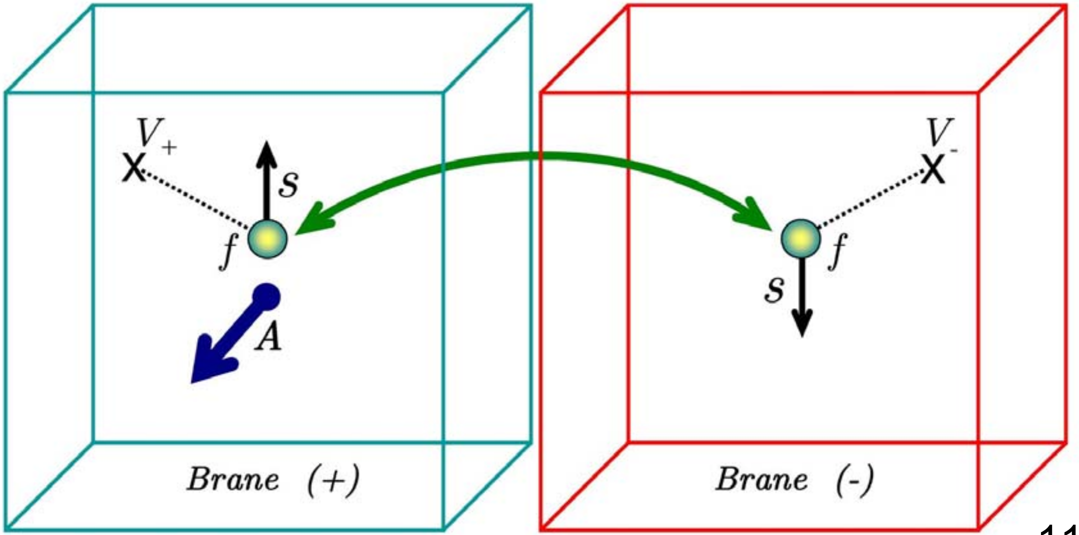
- A neutron undergoes gravitational potentials $V_{\leq}$ in each brane + and -

- Under the influence of a magnetic vector potential,
  the neutron presents Rabi oscillations between both branes

$$P = \frac{4\Omega^2}{\eta^2 + 4\Omega^2} \sin^2\left((1/2)\sqrt{\eta^2 + 4\Omega^2} t\right)$$

with $\Omega = (1/2) g g_s \mu A_{amb}/\hbar$ and $\eta = (V_+ - V_-)/\hbar$

- Spin state modification in the second brane: unobservable effect!



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- Magnetic vector potential dependence of the phenomenum:

  • Allows to expect an artificial control of the effect (stimulated swapping… later)

M. Sarrazin, F. Petit, Phys. Rev. D ***83****, 035009 (2011)*

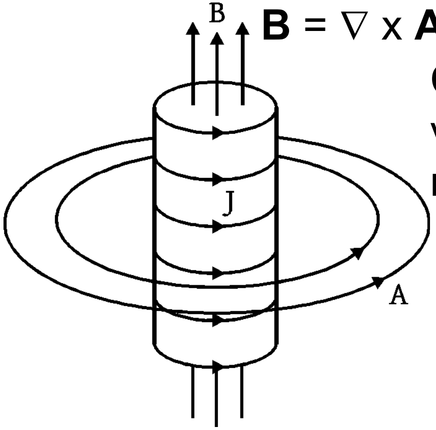
  • But also a spontaneous effect (astrophysical magnetic vector potential)

M. Sarrazin, F. Petit, Eur. Phys. J. C ***72*** *(2012) 2230*
*M. Sarrazin, G. Pignol, F. Petit, V.V. Nesvizhevsky, Phys. Lett. B****712*** *(2012) 213*

- Can be discriminated from neutron-mirror neutron oscillation

M. Sarrazin, F. Petit, Eur. Phys. J. C ***72*** *(2012) 2230*

Origin of the ambient magnetic vector potential

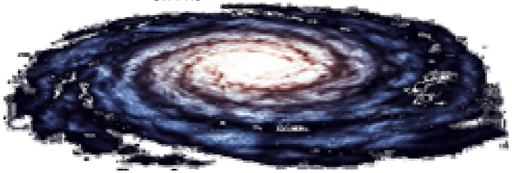


B = ∇ x **A**

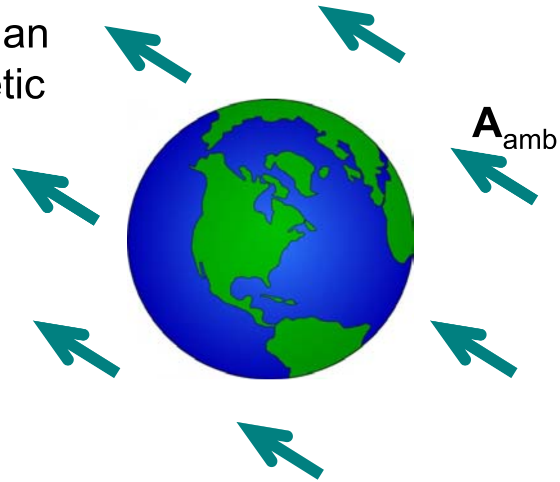
Currents induce magnetic vector potentials from which magnetic fields result

R. Lakes, Phys. Rev. Lett. 80 (1998) 1826
J. Luo, C.-G. Shao, Z.-Z. Liu, Z.-K. Hu, Phys. Lett. A 270 (2000) 288

Astrophysical sources imply an ambient magnetic vector potential $\mathbf{A}_{amb}$



Earth is surrounded by an almost constant magnetic vector potential $\mathbf{A}_{amb}$



A_{amb} ~ 200 T.m in relation to Earth's magnetic field

A_{amb} ~ 2.10^9 T.m in relation to Milky Way core

*M. Sarrazin, F. Petit, Eur. Phys. J. C **72** (2012) 2230*
*M. Sarrazin, G. Pignol, F. Petit, V.V. Nesvizhevsky, Phys. Lett. B**712** (2012) 213*

Environmental interactions and η

Gravitational contributions

- Gravitational interaction between neutron and environment

$V_{grav,+}$ = 500 eV from Milky Way core's grav. field

$V_{grav,+}$ = 9 eV from Sun's grav. field

$V_{grav,+}$ = 0.65 eV from Earth's grav. field

$V_{grav,+}$ = 0.1 meV from Moon's grav. field

- Gravitational contribution $V_{grav,-}$ from another brane: unknown !

$\Rightarrow$ We can fairly assess that $|V_{grav,+} - V_{grav,-}| = \eta < 10^3$ eV

N.B.: If the other brane is dense enough $|V_{grav,+} - V_{grav,-}| = \eta \sim 1$ eV

*M. Sarrazin, F. Petit, Eur. Phys. J. C **72** (2012) 2230*
*M. Sarrazin, G. Pignol, F. Petit, V.V. Nesvizhevsky, Phys. Lett. B**712** (2012) 213*

Matter swapping probability between two branes

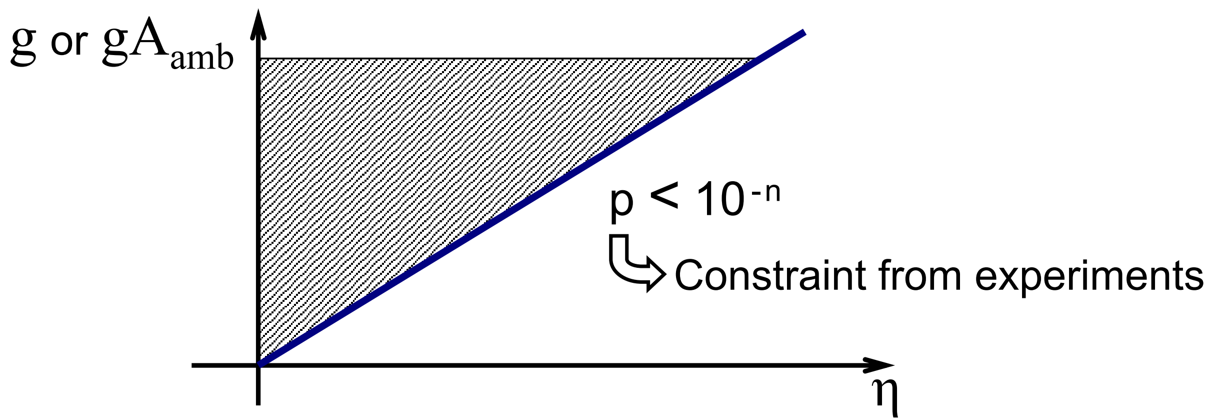
As justify hereafter $\eta >> \Omega$

$$P = \frac{4\Omega^2}{\eta^2 + 4\Omega^2} \sin^2\left((1/2)\sqrt{\eta^2 + 4\Omega^2}t\right)$$

- High oscillation frequency between branes: averaged probability p = <P>

- But: weak amplitude of the oscillations

Then: $p = \langle P \rangle \sim \frac{2\Omega^2}{\eta^2}$ with $\Omega \partial gA_{amb}$

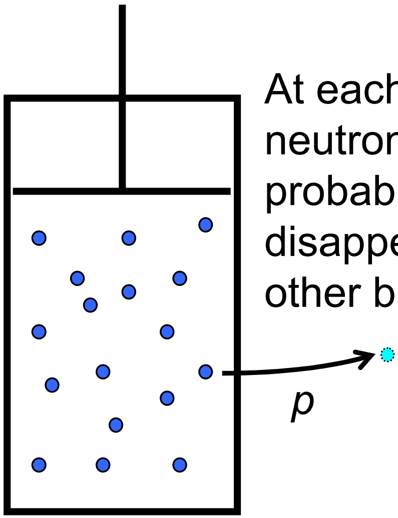


*M. Sarrazin, G. Pignol, F. Petit, V.V. Nesvizhevsky, Phys. Lett. B**712** (2012) 213*

First constraints from Storage time Vs. Collision rate

Experimental limits on neutron disappearance into another braneworld

*M. Sarrazin, G. Pignol, F. Petit, V.V. Nesvizhevsky, Phys. Lett. B**712** (2012) 213*



At each collision, neutron has a probability *p* to disappear into the other brane

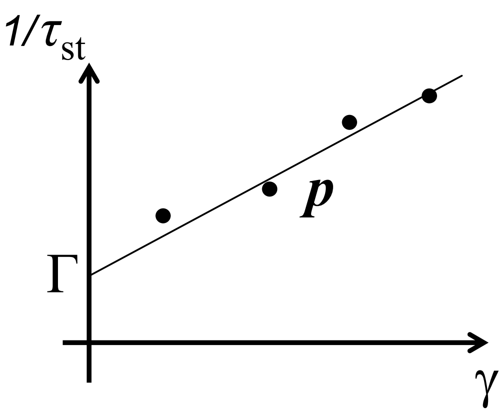
Neutron decay rate

Collisional losses

$$\frac{1}{\tau_{st}} = \Gamma_\beta + \Gamma_{loss} + \gamma p$$

Storage time — *Normal losses* — *Swapping probability*

γ ***Collision rate frequency***



$p < 7 \times 10^{-6}$ at 95% C.L.

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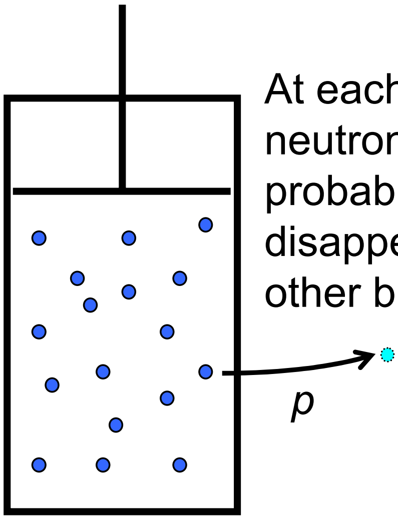
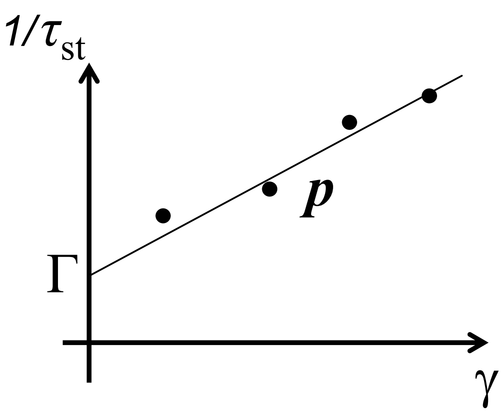
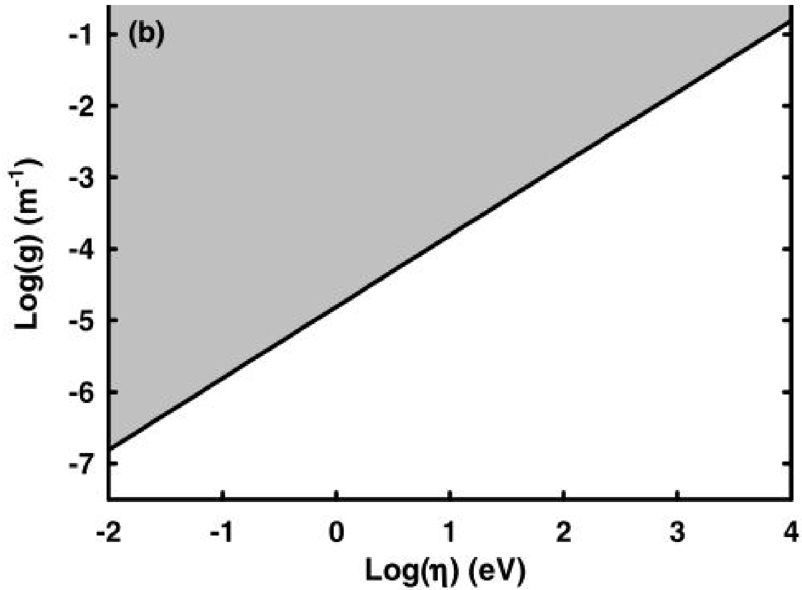




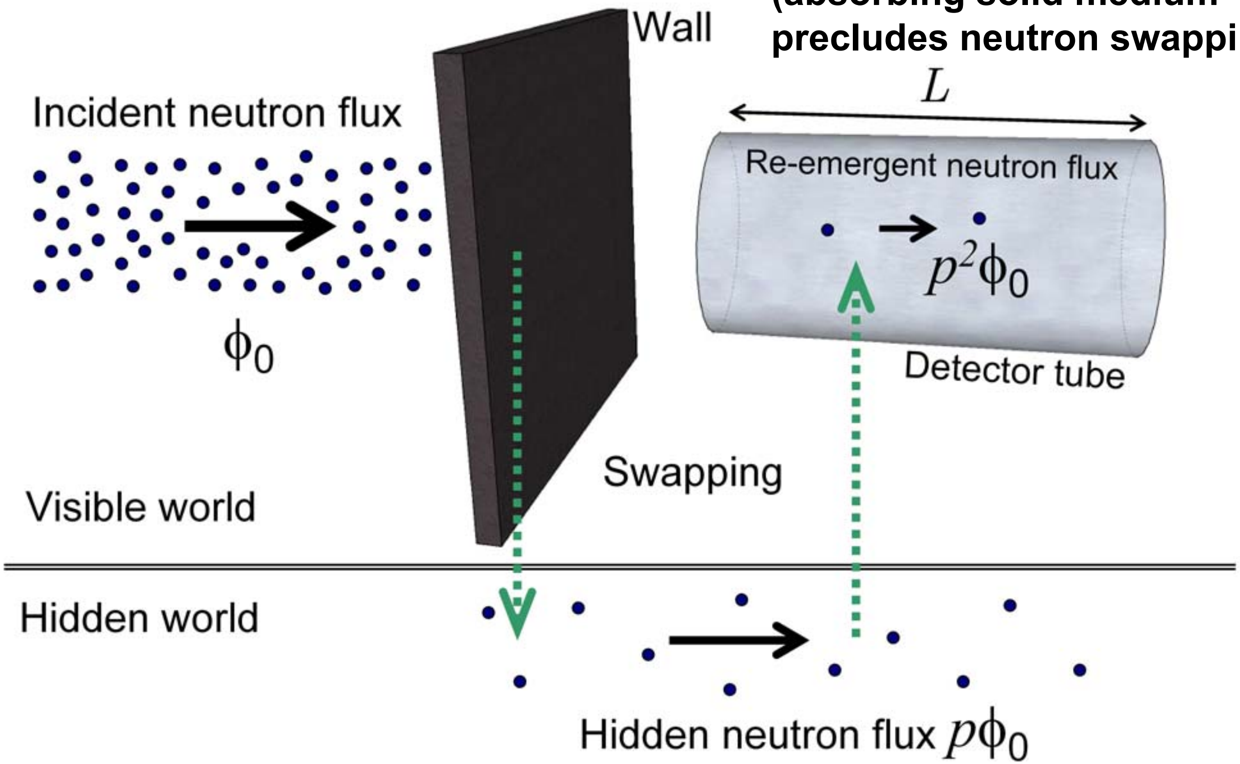


$g < 1.6 \times 10^{-2}\ m^{-1}$ *at* $\eta = 1$ keV

New experimental approach at ESS

Neutrons shining through a wall

He-3 gaseous detector (P = 4 atm) (absorbing solid medium precludes neutron swapping)



Various wall thickness: to discriminate with an unexpected solid state or nuclear effect

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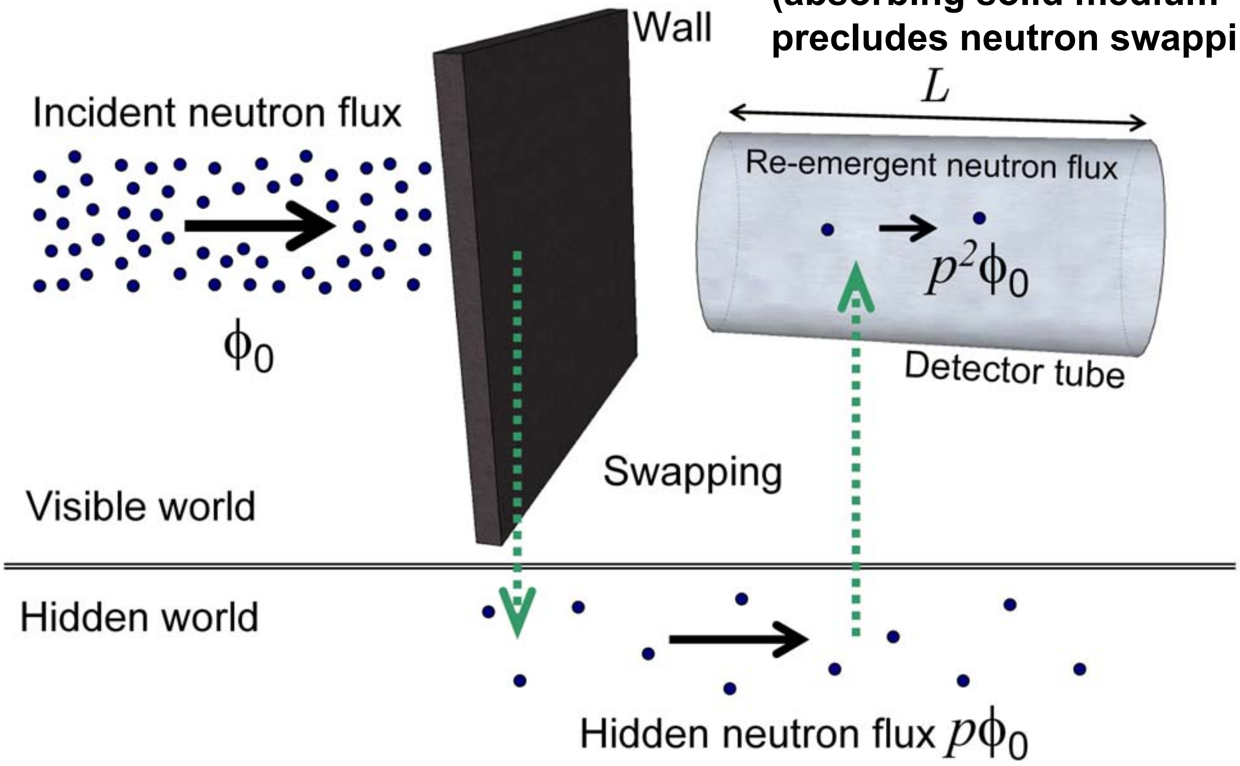

$\phi_0 \sim 10^9$ n/s (2×10^7 n/s/cm^2) $L \sim 10$ cm $\Rightarrow$ Signal < 1 hit per second if $p < 7 \times 10^{-6}$

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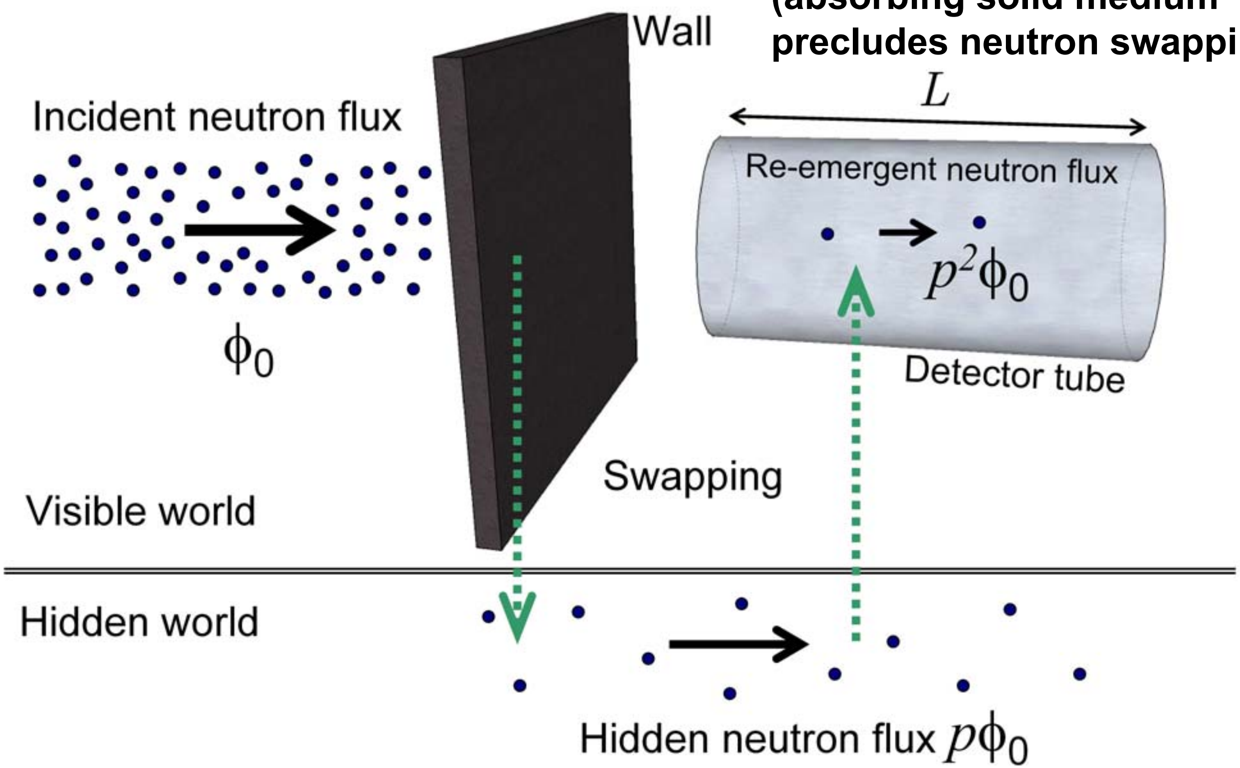


$\phi_0 \sim 10^9$ n/s (2×10^7 n/s/cm^2) $L \sim 10$ cm $\Rightarrow$ Signal < 1 hit per second if $p < 7 \times 10^{-6}$

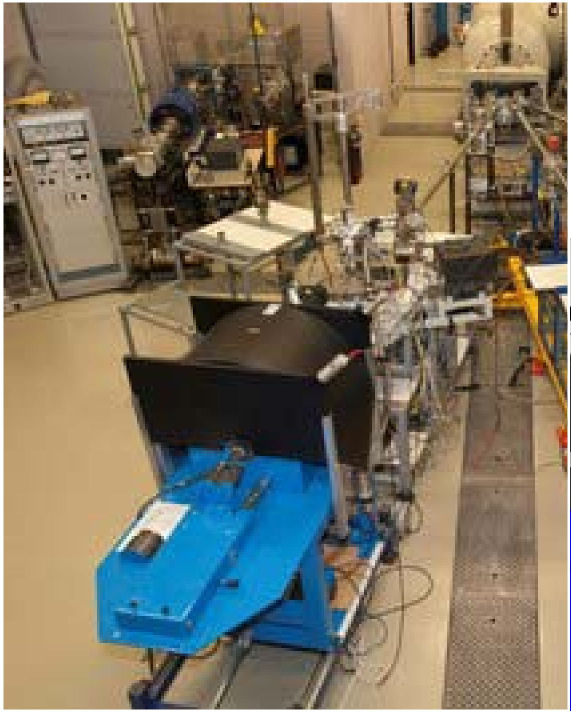
With a 14h time acquisition we could reach $p < 3 \times 10^{-7}$

New experimental approach at ESS

Neutrons shining through a wall: Minimal required conditions

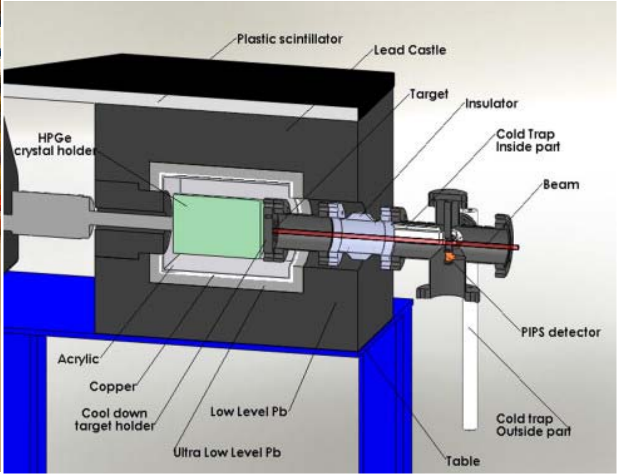
- The very weak expected signal needs optimal conditions

  - Low noise device



LARN device:

Cylindrical detector size: Ø = 86 mm, L = 88 mm
Low noise chamber : 50 x 50 x 50 cm^3
Stand about 1.50 x 1.50 x 1.00 m^3



G. Genard, V. Nuttens, V. Bouchat, G. Terwagne, Phys. Res. B ***268*** *(2010) 1523*
G. Genard, M. Yedji, G. Ross, G. Terwagne, Nucl. Instrum. Meth. B ***264*** *(2007) 156*

New experimental approach at ESS

Neutrons shining through a wall: Minimal required conditions

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$\Rightarrow$ *Prospecting for the future:* Long detector: up to 200 cm?

What is the available place?

New experimental approach at ESS

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What is the available place?

- On-Off source: On-Off signal correlations

A large period range can be considered: Many hours up to milliseconds

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- Cold neutrons for a better cross-section (4 Å < λ < 9 Å)

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What is the available place?

- On-Off source: On-Off signal correlations

A large period range can be considered: Many hours up to milliseconds

- Cold neutrons for a better cross-section (4 Å < λ < 9 Å)

- Intense neutron flux: Enhances measured signal

For instance if $\phi_0 \sim 10^9$ n/s/cm^2 with $L \sim 10$ cm

$\Rightarrow$ *with a 14h time acquisition we could reach $p < 4 \times 10^{-8}$*

(175 times better than today)

Summary

$\Rightarrow$ Braneworld is a concept inherited from High Energy Physics, which needs to be tested

$\Rightarrow$ Many Universe models consider two coexisting branes

$\Rightarrow$ New model-independent phenomenological consequences:
Matter swapping between branes under magnetic vector potential constraint

$\Rightarrow$ The effect can be discriminated from other oscillations

$\Rightarrow$ Testing the braneworld hypothesis at low energies with cold neutrons

$\Rightarrow$ A fully relevant experiment at ESS: Neutrons shining through a wall

UNIVERSITÉ DE NAMUR

FACULTÉ DES SCIENCES

PMR

Thank you for your attention

Why neutrons?

- Proton or electron:

$$\mathbf{H}_{\pm} = -\frac{\hbar^2}{2m}\left(\nabla - i\frac{q}{\hbar}\mathbf{A}_{\pm}\right)^2 + g_s\mu\frac{1}{2}\sigma\cdot\mathbf{B}_{\pm} + V_{\pm}$$

For charged particles, this term considerably inhibits off-diagonal terms

$$\mathbf{H}_{cm} = igg_s\mu\frac{1}{2}\begin{pmatrix} 0 & -\sigma\cdot\{\mathbf{A}_+ - \mathbf{A}_-\} \\ \sigma\cdot\{\mathbf{A}_+ - \mathbf{A}_-\} & 0 \end{pmatrix}$$

- He-3 or Xe-129, Li-6:

Spin-1/2, infinite lifetime, high-magnetic moment (Li-6) but…

Quantum-induced instantaneous electric dipole (required for London dispersion force)

$\Rightarrow$ Long enough to have the same consequences as a charge

- Neutron: ideal benchmark matter particle