TESTING VIOLATIONS OF THE PAULI EXCLUSION PRINCIPLE INDUCED FROM NON-COMMUTATIVE SPACE-TIME

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QUANTUM GRAVITY MUST BE UV COMPLETED

- UV divergences at one-loop,

  T'Hooft & Veltman, Sagnotti & Goroff (1986)

- Realistic (N=1) Supergravity is Not enough
- Recent attempts for a “self-completion?”

  Dvali & Gomez et al. O(100) papers

  New calculations do NOT show consistency

  with DGILS (LMU) unitarity analysis.

  A. A., Massimo Bianchi, Gabriele Veneziano, 2017, JHEP

  in preparation a second analysis of Brem. ABV

“Swamplands” of long-standing ideas:

- **String theories, M-theory** (Veneziano, Nambu, Polyakov …, Witten, …, Green,...,Schwarz …)
- **Loop quantum gravity** (Ashtekar, Rovelli, …)

  Recently: **H-duality** between the two

  (A.A., Antonino Marcianò 2017)
- **Non-commutative space-time**

  (Connes, …,Susskind, ... Chamsedinne, ... Mukhanov)

  …A data desert from LHC

  until the Planck scale...

Tests of quantum gravity???

- KK resonances in proton-proton colliders.
  Arkani-Hamed/Dimopoulos/Dvali (ADD)
  and Randall-Sundrum (RS) models
- It assumes, without any motivations,
  Large extra dimensions....
  We should be
  So lucky....maybe too much lucky...

We need for new ways

We propose underground experiments!!!

Claim:

Pauli Exclusion principle violations induced from quantum gravity can be tested

i) to provide theories of quantum gravity with an experimental guidance;

ii) to distinguish, among the plethora of possible models, the ones that are already ruled out by current data;

iii) to direct future attempts to be in accordance with experimental constraints.

- **Non-commutative quantum gravity** model can induce violations of the Pauli Exclusion Principle – not all, but many
- Why? The Spin statistics theorem of Pauli in QFT is based on Lorentz invariance.

  like anyons in exotic condensed matter...

  Non-commutative geometry violates it
- CPT is **Not violated** but defomed,

  unitarity is still alive in some NC models

  (Balachandran et al.)

Examples: Theta and Kappa Poincarè

non-commutative quantum gravity models.

They induce PEP violations depending from the energy scale

(Balachandran, Amelino-Camelia, M. Arzano, A. Marcianò, …)

THIS STRONGLY MOTIVATES A MODEL INDEPENDENT ANALYS !

ABBM parametrization

an energy dependent q-algebra:

$$a_i a_j^\dagger - q(E) a_j^\dagger a_i = \delta_{ij} \,, \qquad (1)$$

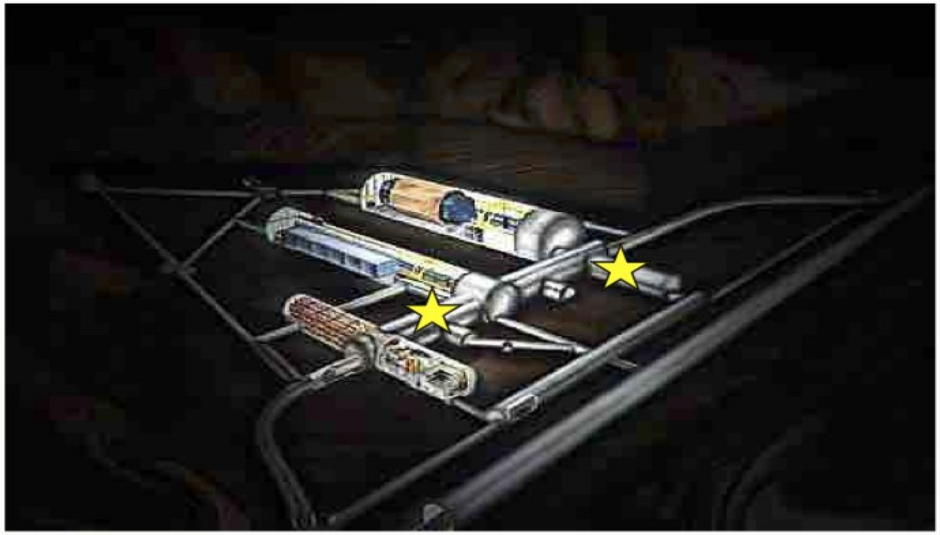
$q(E) = -1 + \beta^2(E)$, and finally $\delta^2(E) = \beta^2(E)/2$.

$$\delta^2(E) = c_k \frac{E^k}{\Lambda^k} + O(E^{k+1})$$

Forbidden transitions in DAMA

DAMA set-ups

an observatory for rare processes @ LNGS



- DAMA/LIBRA (DAMA/NaI)
- DAMA/LXe
- DAMA/R&D
- DAMA/Crys
- DAMA/Ge

sodium iodide doped with Talium

Collaboration:

Roma Tor Vergata, Roma La Sapienza, LNGS, IHEP/Beijing
+ by-products and small scale expts.: INR-Kiev + other institutions
+ neutron meas.: ENEA-Frascati, ENEA-Casaccia
+ in some studies on ββ decays (DST-MAE and Inter-Universities project): IIT Kharagpur and Ropar, India

web site: http://people.roma2.infn.it/dama

DAMA collaboration (2009)

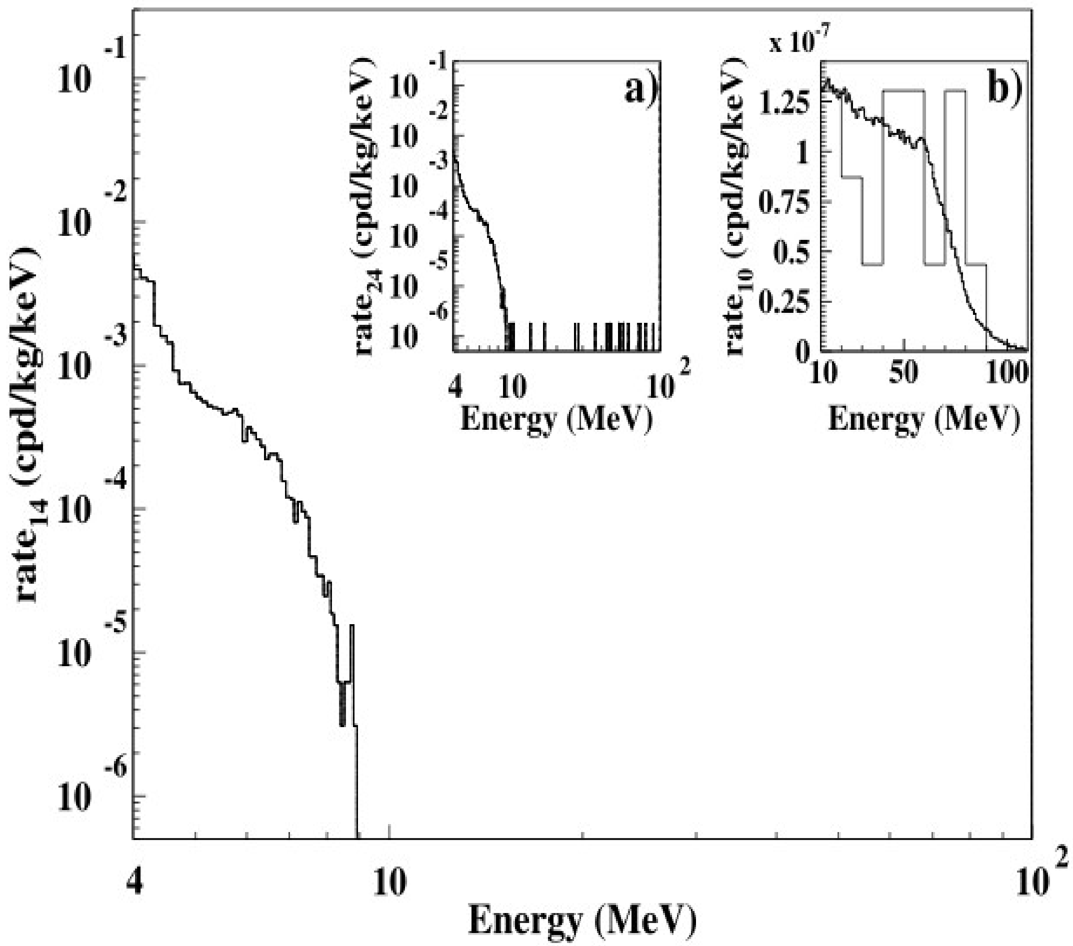


Fig. 1 Counting rate ($rate_{14}$) of the events measured by the 14 highly radiopure NaI(Tl) detectors in operation in the three central rows of the DAMA/LIBRA detectors matrix. The events in the 4–10 MeV energy region are essentially due to α particles from internal contaminants in the detectors (detailed studies are available in [34]). In inset (**a**) the counting rate measured by all the 24 working detectors ($rate_{24}$) is shown. Events with $E > 10$ MeV are present only in detectors belonging to the upper or to the lower rows in the detectors matrix. In inset (**b**) the same events as in (**a**)—with different binning—are shown above 10 MeV (histogram) with superimposed a solid line, which corresponds to the background events expected from the vertical muon intensity distribution and the Gran Sasso rock overburden map of [37]. See text

DAMA BY HAND

$$\tilde{\Gamma} = \tilde{\Gamma}(^{23}Na) + \tilde{\Gamma}(^{127}I) = \frac{\Gamma}{\delta^2}$$

Non Paulian process leading to PHOTON EMISSION

$E_p \simeq 10$ MeV

$$\tilde{\Gamma} = 2.1 \times 10^{-33}\ s^{-1}$$

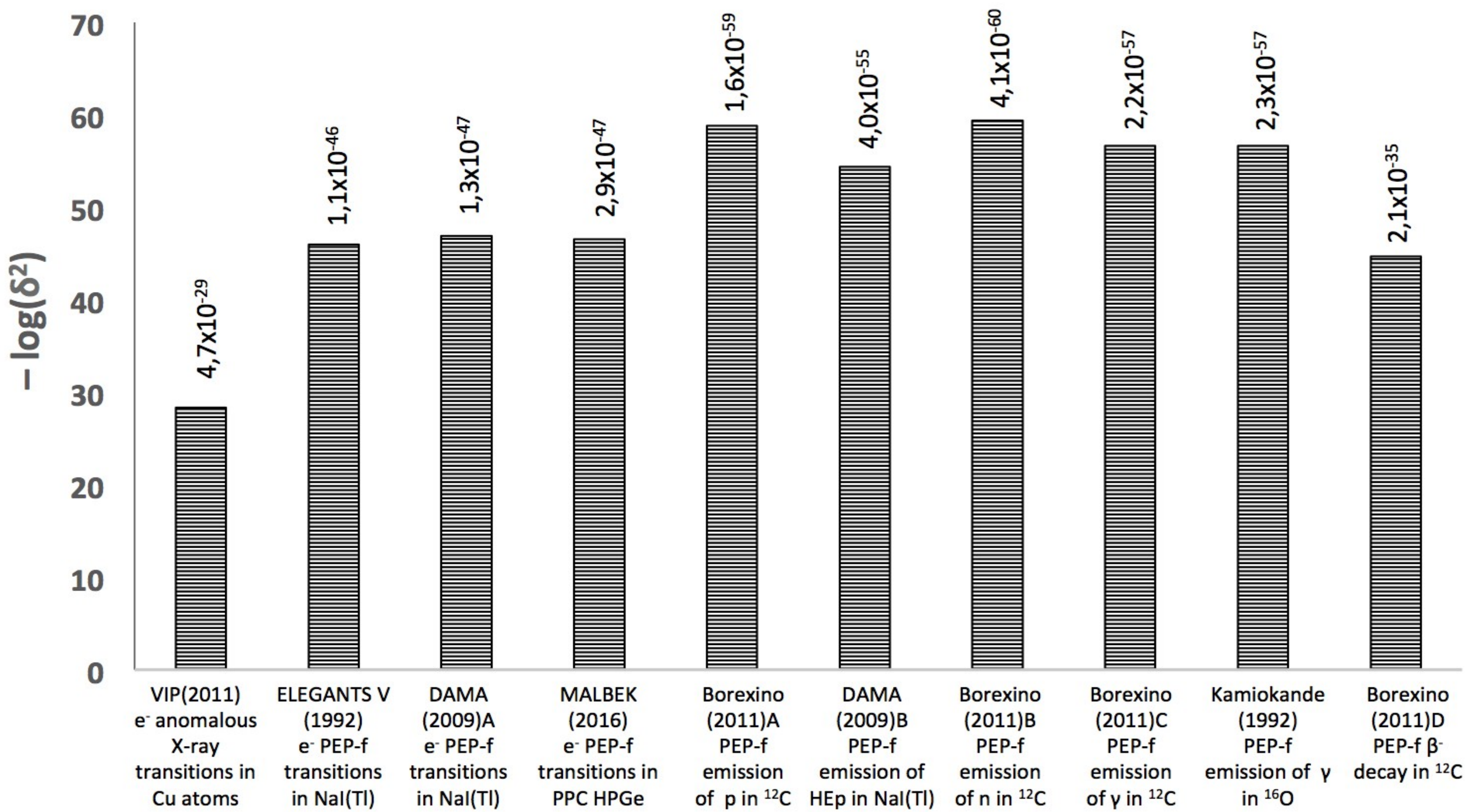
$$\Rightarrow \delta^2 < 10^{-55}$$

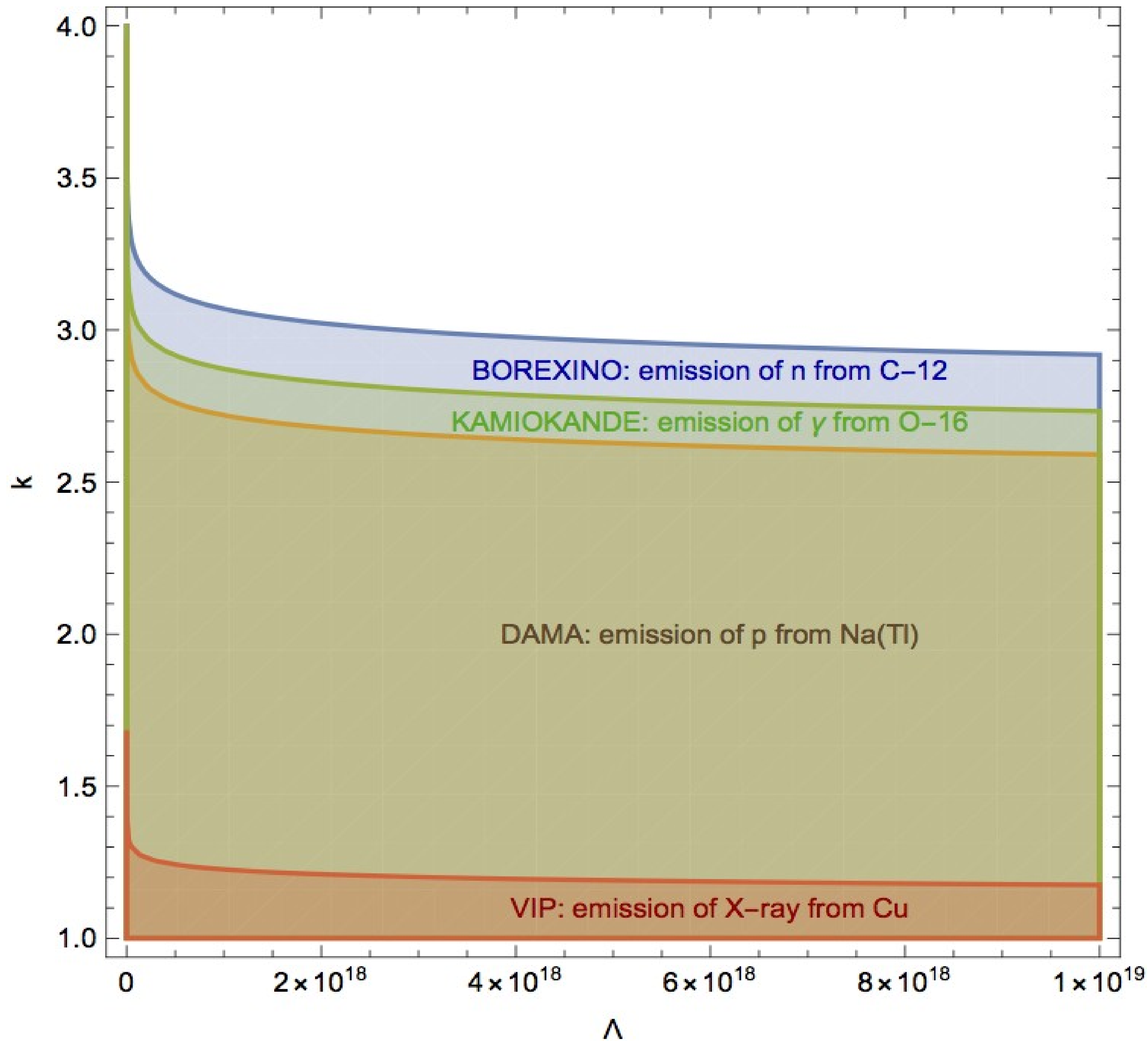
$$\Rightarrow \left(\frac{E_p}{\Lambda}\right)^2 < 10^{-55}$$

$$\Rightarrow \Lambda \gtrsim 3.3 \times 10^{25}\ \text{GeV}$$

!!!

COMPILATION





BOREXINO: emission of n from C−12
KAMIOKANDE: emission of γ from O−16
DAMA: emission of p from Na(Tl)
VIP: emission of X−ray from Cu
k
Λ
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0
2×10^18
4×10^18
6×10^18
8×10^18
1×10^19

Theta-Poincarè :in the Groenwald-Moyal arena

$$f \star g = f e^{\frac{i}{2} \overleftarrow{\partial}_\mu \theta^{\mu\nu} \overrightarrow{\partial}_\nu} g,$$

$$\theta^{\mu\nu} = -\theta^{\nu\mu} = \text{constant}.$$

$$\hat{x}^\mu(x) = x^\mu$$

$$(\hat{x}^\mu \star \hat{x}^\nu - \hat{x}^\nu \star \hat{x}^\mu) = [\hat{x}^\mu, \hat{x}^\nu]_\star = i\theta^{\mu\nu}.$$

$$\Delta_\theta(g) = e^{\frac{i}{2} P_\mu \otimes \theta^{\mu\nu} P_\nu} (g \otimes g) e^{-\frac{i}{2} P_\mu \otimes \theta^{\mu\nu} P_\nu} = \hat{F}_\theta^{-1} (g \otimes g) \hat{F}_\theta \ ,$$

Quantum fields as Groenwald-Moyal representations

$$\varphi = \int d\mu(p)\, \tilde{\varphi}(p)\, \mathbf{e}_p$$

$$\varphi = \int \frac{d^d p}{2p_0} \left(a(p)\, \mathbf{e}_p + a^\dagger(p) \mathbf{e}_{-p} \right) \ ,$$

$$\varphi \otimes \chi = \int d\mu(p)\, d\mu(q)\, \tilde{\varphi}(p) \tilde{\chi}(q)\, \mathbf{e}_p \otimes \mathbf{e}_q$$

$$\begin{aligned} \rho(\Lambda)\varphi &= \int d\mu(p)\, \tilde{\varphi}(p)\, \mathbf{e}_{\Lambda p} = \int d\mu(p)\, \tilde{\varphi}(\Lambda^{-1}p)\, \mathbf{e}_p \ , \\ \rho\left(e^{iP\cdot a}\right)\varphi &= \int d\mu(p)\, e^{ip\cdot a} \tilde{\varphi}(p)\, \mathbf{e}_p \ . \end{aligned}$$

$$\Delta_\theta(\Lambda)\, (\tilde{\varphi} \otimes \tilde{\chi})\, (p,q) = \tilde{F}_\theta^{-1} \left(\Lambda^{-1}p, \Lambda^{-1}q \right) \tilde{F}_\theta\, (p,q)\, \tilde{\varphi}(\Lambda^{-1}p) \tilde{\chi}(\Lambda^{-1}q) \ .$$

$$F_\theta = e^{-\frac{i}{2}(-i\partial_\mu)\theta^{\mu\nu} \otimes (-i\partial_\nu)}$$

$$a(p)a^\dagger(q) = \tilde{\eta}'(p,q) \tilde{F}_\theta^{-2}\, (-q,p)\, a^\dagger(q) a(p) + 2p_0 \delta^d(p-q) \ .$$

Overlap probability different from zero: PEPV

$$
\begin{aligned}
|\alpha,\alpha\rangle &= \langle a^\dagger,\alpha\rangle\langle a^\dagger,\alpha\rangle|0\rangle \\
&= \int \frac{d^dp_1}{2p_{10}}\frac{d^dp_2}{2p_{20}} e^{-\frac{i}{2}p_{1\mu}\theta^{\mu\nu}p_{2\nu}}\alpha(p_1)\alpha(p_2)c^\dagger(p_1)c^\dagger(p_2)|0\rangle \ .
\end{aligned}
$$

$$
|\beta,\gamma\rangle = \langle a^\dagger,\beta\rangle\langle a^\dagger,\gamma\rangle|0\rangle, \quad \beta\neq\gamma.
$$

We have

$$
\langle\beta,\gamma|\alpha,\alpha\rangle = \int \frac{d^dp_1}{2p_{10}}\frac{d^dp_2}{2p_{20}}(\bar\beta(p_1)\alpha(p_1))(\bar\gamma(p_2)\alpha(p_2))[1-e^{-ip_{1\mu}\theta^{\mu\nu}p_{2\nu}}]\frac{1}{N(\alpha,\alpha)} \, .
$$

Vexata quaestio: Democratic or non-democratic PEP violations???

- **Weak and Strong Equivalence Principle???**
- **B-form couplings with strings???**

IT DESERVES A TEST IN ALL POSSIBLE CHANNELS!

Conclusions

- ENERGY-DEPENDENT VIOLATIONS OF THE PAULI PRINCIPLE FROM NON-COMMUTATIVE QUANTUM GRAVITY MODEL CAN BE TESTED WITH HIGH ACCURACY IN UNDERGROUND EXPERIMENTS
- Theta-Poincarè is ruled out until the PLANCK SCALE from DAMA & BOREXINO. Kappa-Poincarè ruled out also by VIP experiment.
- Some versions of Kappa-Poincarè are already ruled-out until the Planck scale
- TeV-100 TeV scales ruled-out.

Side Slide 1: JUNO experiment

(JUNO) Jiangmen Underground Neutrino Experiment is an underground reactor antineutrino experiment under construction near Kaiping, China

Liang Zhan, Yifang Wang, Jun Cao, Liangjian Wen,
Phys. Rev. D 78, 111103 (2008)

Experiment	Day Bay	Borexino	KamLAND	JUNO
Liquid Scintillator mass	20 ton	$\sim$ 300 ton	$\sim$1 kton	20 kton
Coverage	$\sim 12\%$	$\sim 34\%$	$\sim 34\%$	$\sim 80\%$
Energy Resolution	$\frac{7.5\%}{\sqrt{E}}$	$\frac{\sim 5\%}{\sqrt{E}}$	$\frac{\sim 6\%}{\sqrt{E}}$	$\frac{\sim 3\%}{\sqrt{E}}$
Light Yield	$\sim 160\ \frac{\text{p.e.}}{\text{MeV}}$	$\sim 500\ \frac{\text{p.e.}}{\text{MeV}}$	$\sim 250\ \frac{\text{p.e.}}{\text{MeV}}$	$\sim 1200\ \frac{\text{p.e.}}{\text{MeV}}$

Side Slide 2: Nuclear models in DAMA

two possible models for the momentum distruibution functions of the nucleon:

a) Fermi momentum distribution with 255 MeV/c;
b) realistic funxtions taking into account correlation effects

Bernabei, Belli et al (DAMA collaboration) EPJC (2009)