New results on rare processes by DAMA at Gran Sasso:

searches for processes violating the Pauli Exclusion Principle in Sodium and Iodine with DAMA/LIBRA

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INFN-LNGS

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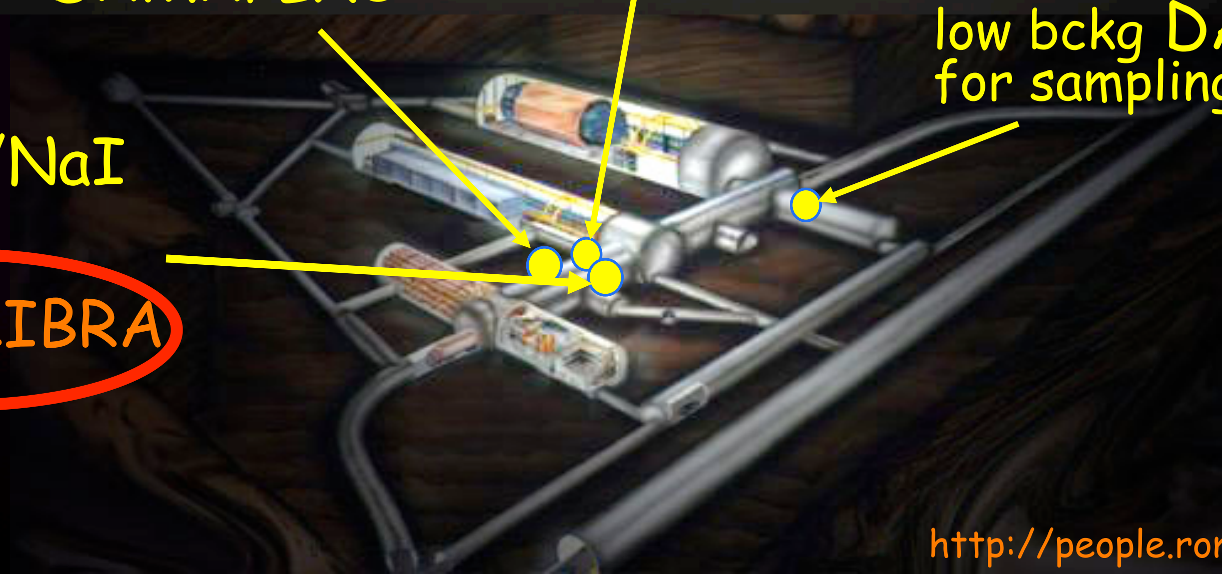
DAMA: an observatory for rare processes @LNGS



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

DAMA/LXe: results on rare processes

Dark Matter Investigation

NIMA482(2002)728

- **Limits on recoils investigating the DMp-^{129}Xe elastic scattering by means of PSD** — PLB436(1998)379
- **Limits on DMp-^{129}Xe inelastic scattering** — PLB387(1996)222, NJP2(2000)15.1
- **Neutron calibration** — PLB436(1998)379, EPJdirectC11(2001)1
- **^{129}Xe *vs* ^{136}Xe by using PSD → SD *vs* SI signals to increase the sensitivity on the SD component** — foreseen/in progress

Other rare processes:

- Electron decay into invisible channels — Astrop.P.5(1996)217
- Nuclear level excitation of ^{129}Xe during CNC processes — PLB465(1999)315
- N, NN decay into invisible channels in ^{129}Xe — PLB493(2000)12
- Electron decay: $e^- \rightarrow \nu_e \gamma$ — PRD61(2000)117301
- 2β decay in ^{136}Xe — Xenon01
- 2β decay in ^{134}Xe — PLB527(2002)182
- Improved results on 2β in ^{134}Xe, ^{136}Xe — PLB546(2002)23
- CNC decay ^{136}Xe → ^{136}Cs — Beyond the Desert (2003) 365
- N, NN, NNN decay into invisible channels in ^{136}Xe — EPJA27 s01 (2006) 35

DAMA/R&D set-up: results on rare processes

- **Particle Dark Matter search with CaF_2(Eu)**

NPB563(1999)97, Astrop.Phys.7(1997)73

- 2β decay in ^{136}Ce and in ^{142}Ce — **Il Nuov.Cim.A110(1997)189**
- $2EC2\nu$ ^{40}Ca decay — **Astrop. Phys. 7(1997)73**
- 2β decay in ^{46}Ca and in ^{40}Ca — **NPB563(1999)97**
- $2\beta^+$ decay in ^{106}Cd — **Astrop.Phys.10(1999)115**
- 2β and β decay in ^{48}Ca — **NPA705(2002)29**
- $2EC2\nu$ in ^{136}Ce, in ^{138}Ce and α decay in ^{142}Ce — **NIMA498(2003)352**
- $2\beta^+0\nu$, $EC\beta^+0\nu$ decay in ^{130}Ba — **NIMA525(2004)535**
- Cluster decay in $LaCl_3$(Ce) — **NIMA555(2005)270**
- CNC decay ^{139}La → ^{139}Ce — **UJP51(2006)1037**
- α decay of natural Eu — **NPA789(2007)15**
- β decay of ^{113}Cd — **PRC76(2007)064603**
- $\beta\beta$ decay of ^{64}Zn — **PLB658(2008)193**
- $\beta\beta$ decay of ^{108}Cd and ^{114}Cd — **EPJA36(2008)167**
- $2\varepsilon0\nu$ in ^{136}Ce; 2β in ^{136}Ce, ^{138}Ce — **NPA824(2009)101**
- 2β in ^{64}Zn, ^{70}Zn, ^{180}W, ^{186}W — **NPA826(2009)256**

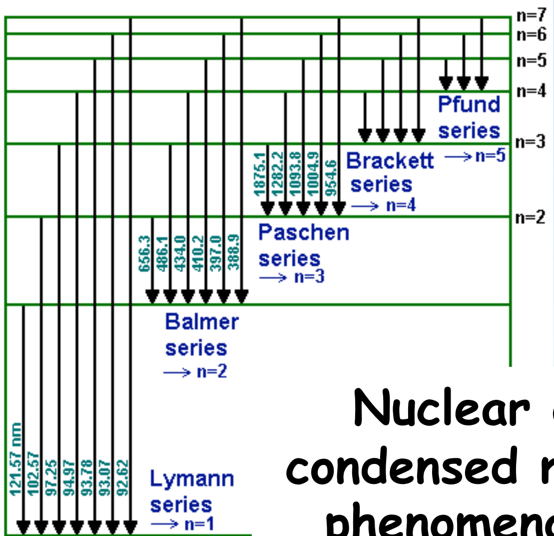
DAMA/Ge & LNGS Ge facility

- RDs on highly radiopure NaI(Tl) set-up;
- several RDs on low background PMTs;
- qualification of many materials
- measurements with a $Li_6Eu(BO_3)_3$ crystal (NIMA572(2007)734)
- measurements with ^{100}Mo sample investigating $\beta\beta$ decay in the 4π low-bckg HP Ge facility of LNGS (NPAE(2008)473)
- search for ^{7}Li solar axions (NPA806(2008)388)

+Many other meas. already scheduled for near future

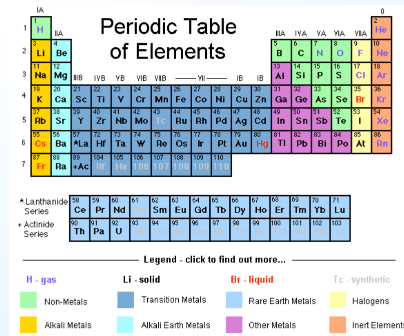
Pauli Exclusion Principle (PEP)

has a crucial role in physics



Experimental atomic spectra

Periodic table of elements

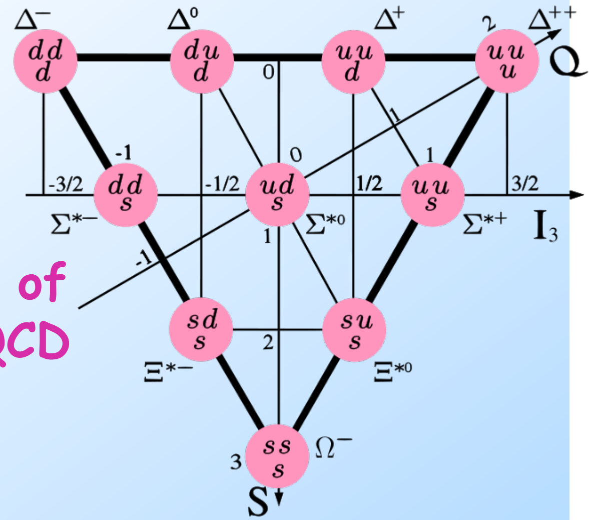


PEP

Nuclear and condensed matter phenomenology

commutation/anti-commutation relations of a and a+ in QFT

Discovery of color in QCD



Many experimental evidences/successes but a simple and easy explanation is still missing as stressed by Feynmann.

Why test Pauli Exclusion Principle (PEP)?

...many theoretical attempts to go beyond Bose and Fermi statistics ...

Phys. Rev. Lett. 64 (1990) 705
Phys. Lett. B 242 (1990) 407
Fund. Phys. 29 (1999) 397.

$$a_i a_j^\dagger - q a_j^\dagger a_i = \delta_{ij}$$

$$q = -1 + \beta^2 \qquad \beta^2 \ll 1$$

$$\rightarrow \quad \delta^2 = \frac{\beta^2}{2}$$

small probability of admixed symmetric component

BUT also possible PEP violations due to physics at higher energy scale

Phys. Rev. Lett. 68 (1992) 1826

superficial PEP violations due to possible substructure in composite models of quark and leptons

$$\delta_e^2 = \left[\frac{4}{3}\left(\frac{3}{7}\right)^5\left(\frac{Zr_0}{a_0}\right)^3\right]^2$$

composite electron size

Possible PEP violations due to extra dimensions: Phys. Rev. D 39 (1989) 2032

If something in fundamental physics can be tested, then it absolutely must be tested (Okun)

4 classes of experiments:

1) search for PEP-forbidden electronic states in atoms

Phys. Lett. B 240 (1990) 227
Phys. Rev. Lett. 74 (1995) 4787
JETP Lett. 68 (1998) 112
Phys. Rev. Lett. 85 (2000) 2701

2) search for PEP-forbidden nuclear states

J. Phys. G 17 (1991) S355.

3) search for PEP-forbidden electronic transitions

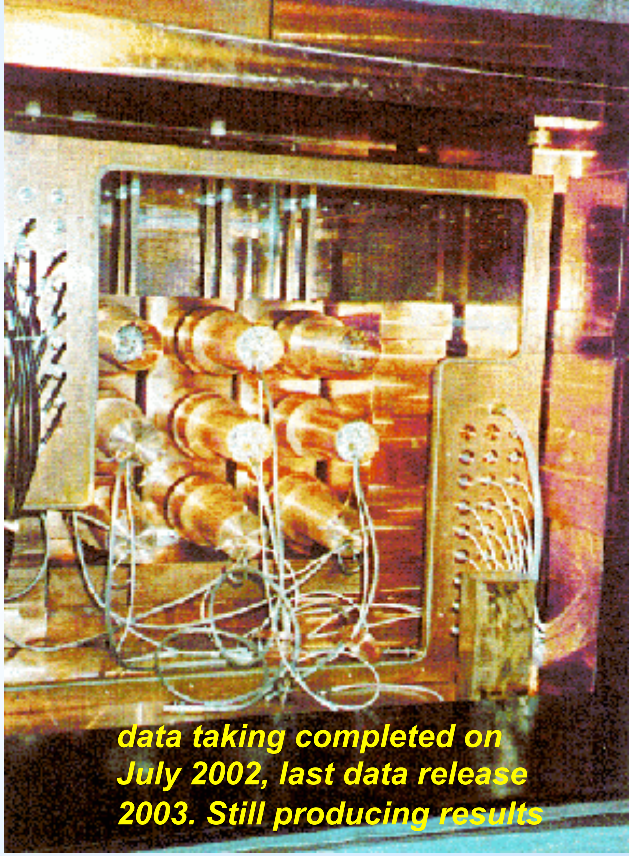
Nucl. Phys. B (Proc. Suppl.) 28A (1992) 219
Phys. Lett. B 460 (1999) 236
Phys. Lett. B 641 (2006) 18
Int. J. Mod. Phys. A 22 (2007) 242

4) search for PEP-forbidden nuclear transitions

Phys. Lett. B 306 (1993) 218
Phys. Lett. B 408 (1997) 439
Eur. Phys. J. A 6 (1999) 361
Nucl. Phys. B (Proc. Suppl.) 87(2000) 510
Eur. Phys. J. C 37 (2004) 421

Underground experiment site and high radiopurity set-up allow to reduce background due to PEP-allowed transitions induced by cosmic rays or environmental radioactivity

DAMA/NaI : ≈100 kg NaI(Tl)



Performances: N.Cim.A112(1999)545-575, EPJC18(2000)283, Riv.N.Cim.26 n. 1(2003)1-73, IJMPD13(2004)2127

Results on rare processes:

- Possible Pauli exclusion principle violation — PLB408(1997)439
- CNC processes — PRC60(1999)065501
- Electron stability and non-paulian transitions in Iodine atoms (by L-shell) — PLB460(1999)235
- Search for solar axions — PLB515(2001)6
- Exotic Matter search — EPJdirect C14(2002)1
- Search for superdense nuclear matter — EPJA23(2005)7
- Search for heavy clusters decays — EPJA24(2005)51

Results on DM particles:

- PSD — PLB389(1996)757
- Investigation on diurnal effect — N.Cim.A112(1999)1541
- Exotic Dark Matter search — PRL83(1999)4918
- Annual Modulation Signature

PLB424(1998)195, PLB450(1999)448, PRD61(1999)023512, PLB480(2000)23, EPJC18(2000)283, PLB509(2001)197, EPJC23(2002)61, PRD66(2002)043503, Riv.N.Cim.26 n.1 (2003)1, IJMPD13(2004)2127, IJMPA21(2006)1445, EPJC47(2006)263, IJMPA22(2007)3155, EPJC53(2008)205, PRD77(2008)023506, MPLA23(2008)2125.

model independent evidence of a particle DM component in the galactic halo at 6.3σ C.L.

total exposure (7 annual cycles) 0.29 ton x yr

The new DAMA/LIBRA set-up ~250 kg NaI(Tl)
(Large sodium Iodide Bulk for RAre processes)

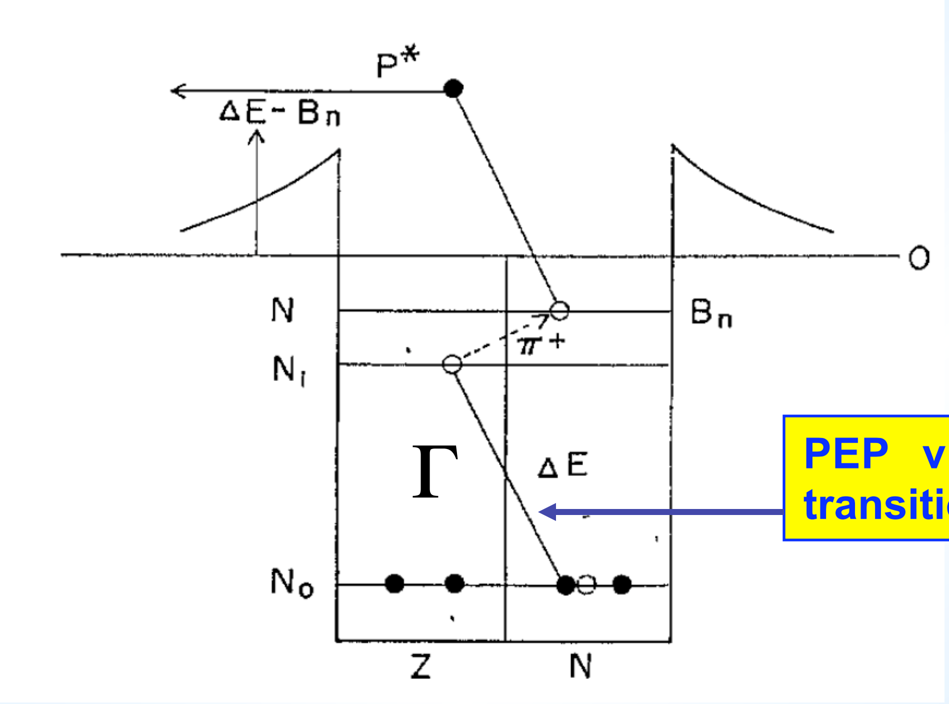
As a result of a second generation R&D for more radiopure NaI(Tl)
by exploiting new chemical/physical radiopurification techniques
(all operations involving crystals and PMTs - including photos - in HP Nitrogen atmosphere)

- **Radiopurity,performances, procedures, etc.:** NIMA592(2008)297
- **Results on DM particles:** Annual Modulation Signature: EPJC56(2008)333
  See Bernabei's talk
- **Results on rare processes:** Possible processes violating the Pauli exclusion principle in Na and I: EPJC62(2009)327

DAMA/LIBRA over 4 annual cycles (0.53 ton×yr) confirms the *model independent evidence of a particle DM component in the galactic halo* of DAMA/NaI (0.29 ton×yr); the cumulative confidence level is 8.2 σ (total exposure 0.82 ton × yr)

A) Search for non-paulian nuclear processes

Proton emission
$E_p > 10$ MeV



Example of a process violating PEP: **deexcitation** of a nucleon from the shell N_i to the N_o lower (full) shell. The energy is converted to another nucleon at shell N through strong interaction, resulting to **excitation to the unbound region**. (analogy: Auger emission)

for ^{23}Na and ^{127}I:

$$E_{max} = V - B_N$$

$$V \simeq 40 \text{ MeV}$$

$$B_N \simeq 6 - 12 \text{ MeV}$$

PEP violating transition

PEP violation parameter (mixing probability of non fermion statistics)

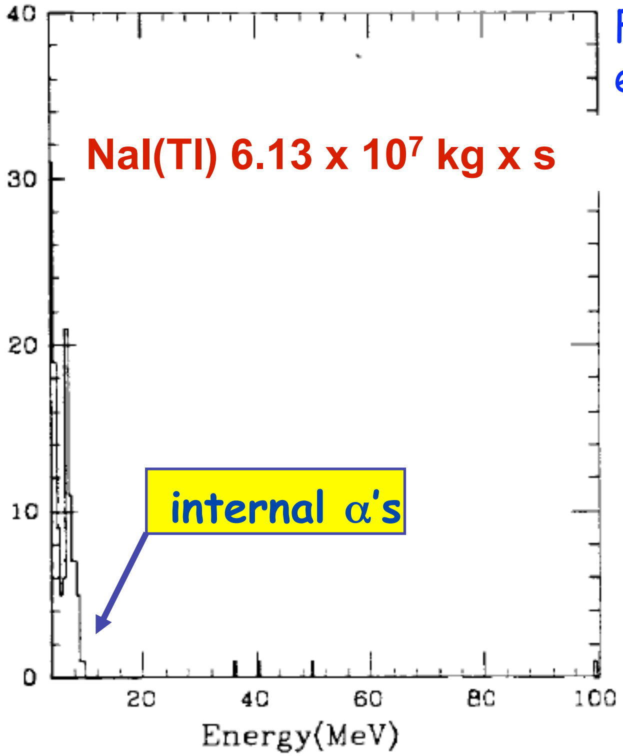
$$\Gamma = \delta^2 \tilde{\Gamma}$$

PEP violating transition width

PEP allowed transition width (as if the state N_o would be empty)

The former results obtained with 100 Kg low background DAMA/NaI

PLB 408 (1997) 439



For PEP violating nuclear processes: events where just one detector fires.

Exposure: N x t = 2.46 10^{32} nuclei x s

0 events in the 10 - 36 MeV range

$$\lambda \leq 4.6\times10^{-33}\, s^{-1} \quad (68\% \ C.L.)$$

Є proton detection efficiency ≈ 100%

$$\Gamma = \Gamma(^{23}\mathrm{Na}) + \Gamma(^{127}\mathrm{I}) = \hbar\lambda \lesssim 3.0\cdot 10^{-54}\ \mathrm{MeV}$$

Width calculated for escape and tunneling prob. of the excited proton $g_W(k) = g_c(k) = 1$

average escape prob. of the excited proton

Limits on δ^2 are strongly model dependent; a cautious approach could be to consider:

Models for momentum distribution function

Case	^AX	E_{th} (MeV)	$\bar{\Gamma}_0$ (MeV)	$\langle g_w \rangle$	$\bar{\Gamma}$ (MeV)	Upper limit for δ^2
a)	^{23}Na	10	3.90	0.42	1.65	$4.8\cdot10^{-55}$
	^{127}I	10	16.0	0.29	4.64	
a)	^{23}Na	18	0.60	0.32	0.19	$5.0\cdot10^{-54}$
	^{127}I	18	1.65	0.25	0.41	
b)	^{23}Na	10	14.2	0.32	4.59	$1.9\cdot10^{-55}$
	^{127}I	10	76.6	0.14	11.1	
b)	^{23}Na	18	8.22	0.23	1.90	$5.6\cdot10^{-55}$
	^{127}I	18	44.6	0.08	3.49	

Lower limit on the mean life for non-paulian proton emission:

τ > 0.7 x 10^{25} y for ^{23}Na

τ > 0.9 x 10^{25} y for ^{127}I

First results on PEP-violating nuclear processes with DAMA/LIBRA

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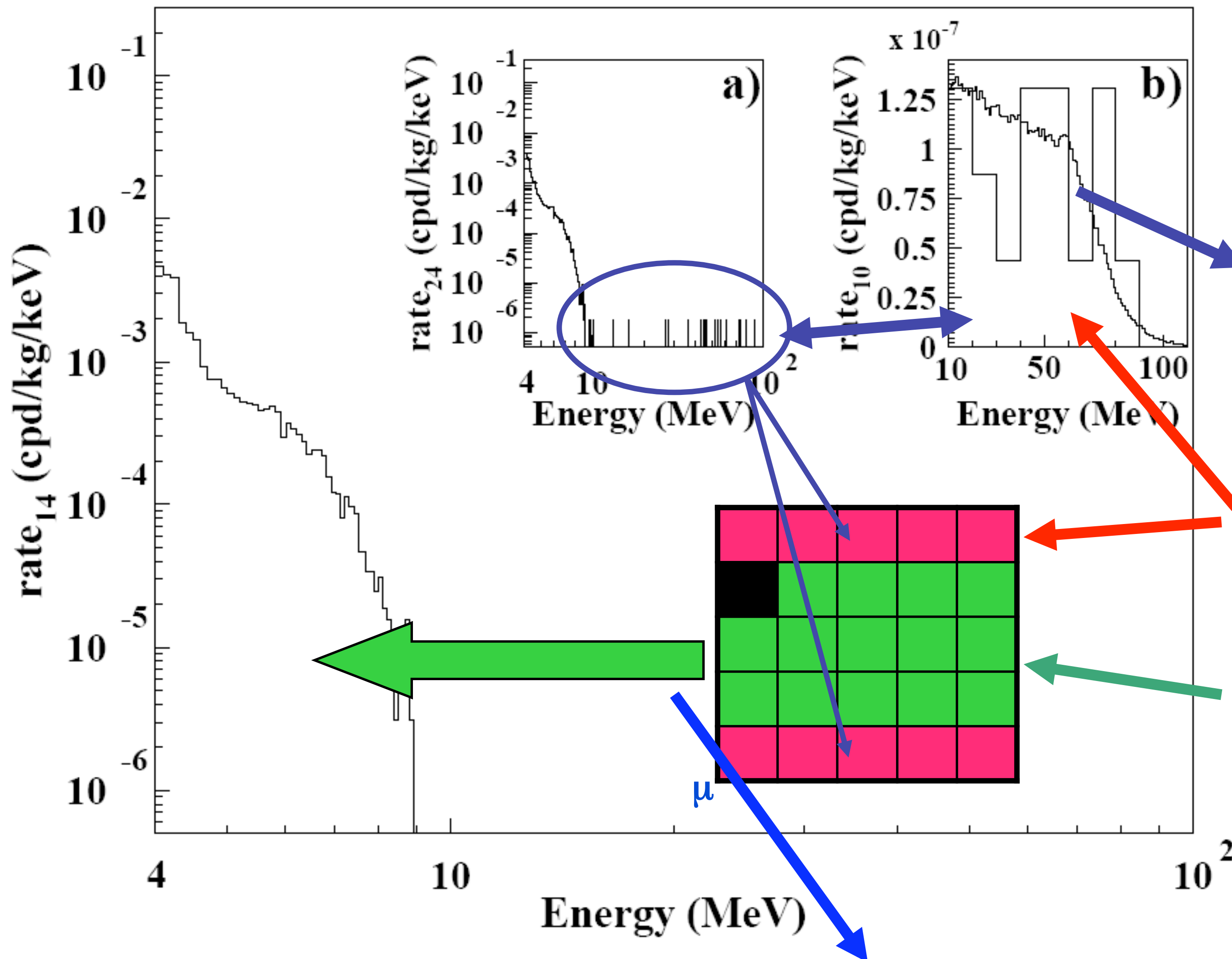
570h running time, optimized for very high energy

At very high energy (E > 10 MeV) background is due to the very high energy muons possibly surviving the mountain.

For PEP violating nuclear processes: events where just one detector fires.



BKG Muon events evaluated by MC non present in the inner core (veto)

For E > 10 MeV

17 events in the upper/lower plane of detector (10 cryst.)

0 events in the central planes of detector (14 cryst.)

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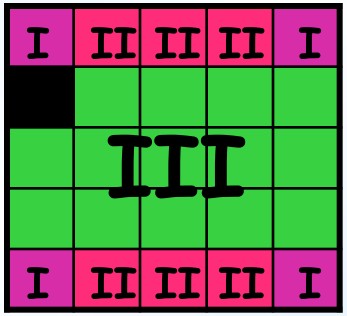
Group (J) of considered detectors	Corresponding exposure ($N_J t$) (nuclei × s)	Expected background events (b_J)	Measured events (n_J)	Upper Limit on λ (90% C.L.) (s^{-1})
Just the 4 detectors at corners (I)	3.2×10^{32}	12.1	11	1.99×10^{-32}
Just the remaining 6 detectors in the upper and lower rows (II)	4.8×10^{32}	8.7	6	9.33×10^{-33}
Just the 14 central detectors (III)	1.1×10^{33}	2.2	0	2.06×10^{-33}
Just the 9 core detectors (IV)	7.2×10^{32}	0.057	0	3.19×10^{-33}
Combined analysis (I+II+III):				1.63×10^{-33}



Case	^AX	$\tilde{\Gamma}$ (MeV)	δ^2 Upper Limit (90% C.L.)
a)	^{23}Na ^{127}I	1.65 4.64	1.7×10^{-55}
b)	^{23}Na ^{127}I	4.59 11.1	6.8×10^{-56}

$$\Gamma = \Gamma(^{23}Na) + \Gamma(^{127}I) = \hbar\lambda \leq 1.1 \times 10^{-54} MeV$$

Lower limit on the mean life for non-paulian proton emission:

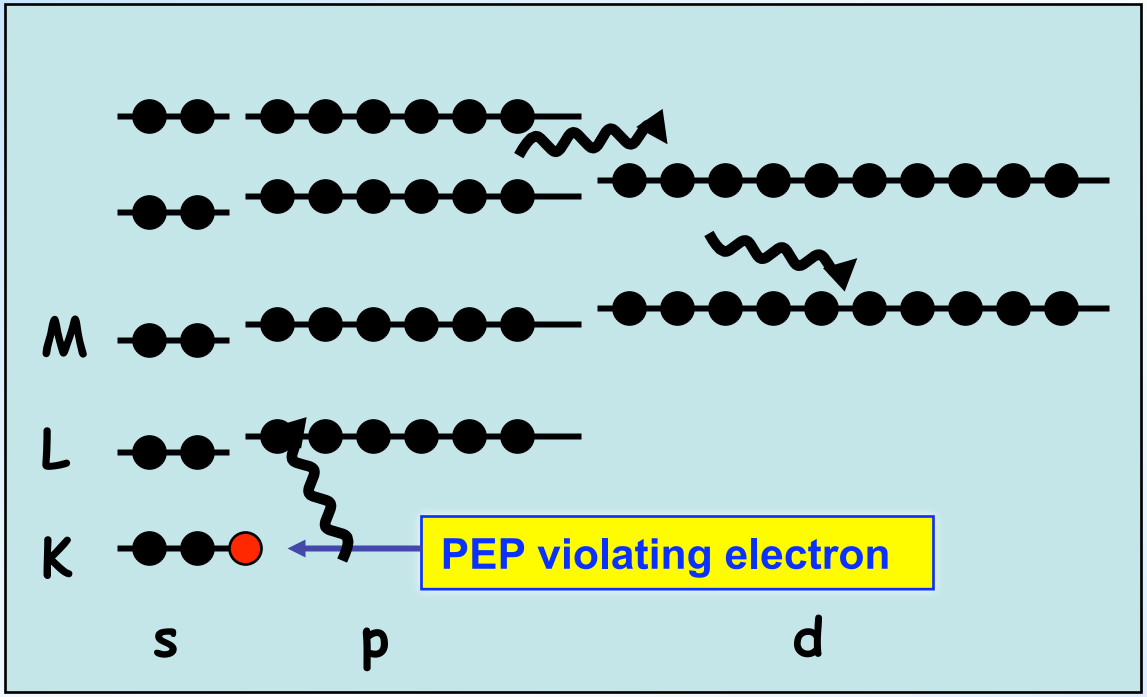
$\tau > 2 \times 10^{25}$ y for ^{23}Na, $\tau > 2.5 \times 10^{25}$ y for ^{127}I

cautious approach:

$$\delta^2 \lesssim 3 - 4 \times 10^{-55}$$

B) Search for non-paulian electronic transitions

Electronic configuration schema of I anion (54 electrons) in $Na^{+}I^{-}$ crystal



example of a PEP violating transition of Iodine electron to the full k-shell followed by the atomic shells rearrangement. The total released energy (x-ray + Auger electrons) is approximately equal to k-shell ionization potential (≈ 32 keV)

First results on PEP-violating electronic transitions with DAMA/LIBRA

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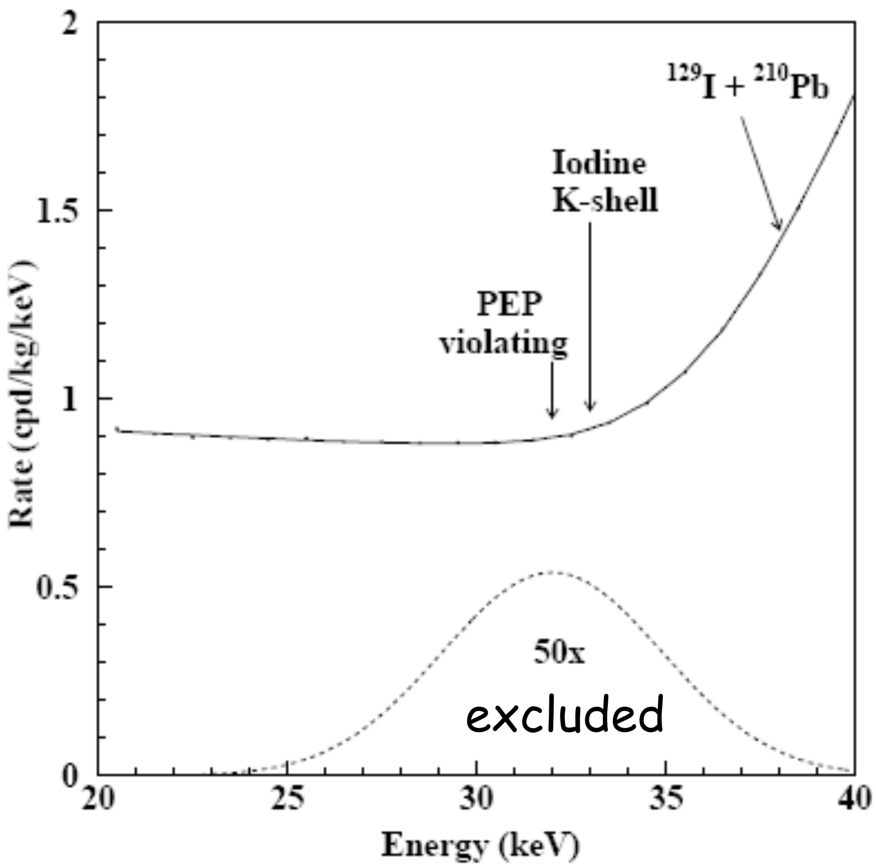
Exposure: 0.53 ton × yr



$\tau_{PV} > 4.7 \times 10^{30}$ s (90% C.L.)

$$\tau^0 = \delta_e^2 \tau_{PV}$$

normal electromagnetic dipole transition to Iodine K-shell:
$\tau^0 \approx 6 \times 10^{-17}$ s

$\delta_e^2 < 1.28 \times 10^{-47}$ (90% C.L.).

one order of magnitude more stringent than the previous one (ELEGANTS V) (VIP sensitivity with a different approach in Cu sample is 10^{-28} with final goal 10^{-31})

This limit can also be related to a possible finite size of the electron in composite models of quarks and leptons providing supercial violation of the PEP; the obtained upper limit on the electron size is: $r_0 < 5.7\times10^{-18}$ cm (energy scale of $E > 3.5$ TeV).

CONCLUSIONS-1

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PEP-violating spontaneous emission of protons:

- First DAMA/LIBRA results: $\delta^2 < (3 - 4) \times 10^{-55}$
- $\tau_{Na} > 2 \times 10^{25}$ y and $\tau_I > 2.5 \times 10^{25}$ y

PEP-violating electronic transitions in Iodine:

- First DAMA/LIBRA results: $\delta_e^2 < 1.28 \times 10^{-47}$
- Investigation of composite model of quark and leptons: $r_0 < 5.7 \times 10^{-18}$ cm (energy scale of E > 3.5 TeV).

CONCLUSIONS-2

Future perspectives: **DAMA/LIBRA expected sensitivity in case of 3 yr of data taking optimized for high energy**

MonteCarlo simulation
- vertical muon intensity distribution
- Gran Sasso rock overburden map

SpinStat08 in Foundation of Physics, to appear

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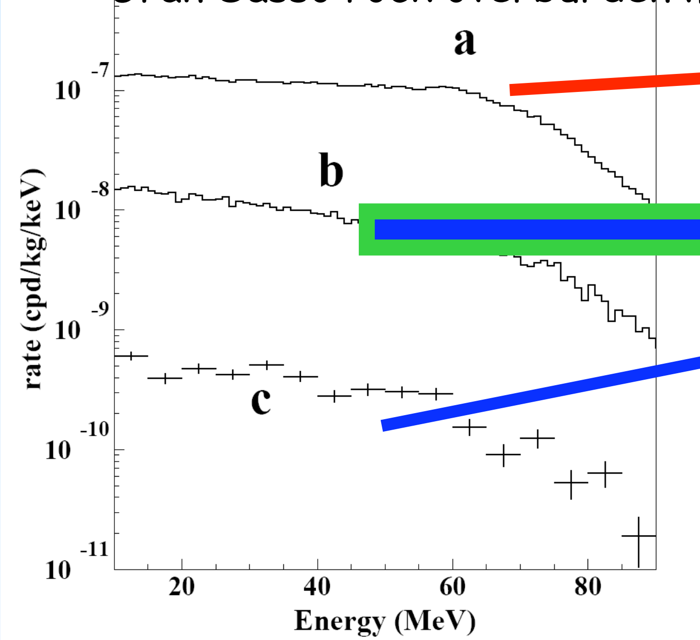

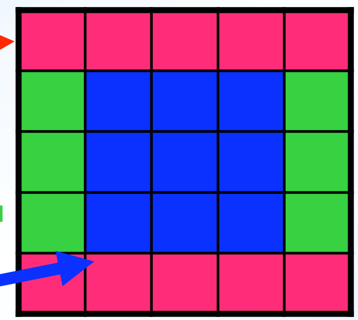

events where just one detector fires

From c): less than 1 bckg event expected in the 9 NaI(Tl) detectors in the inner core during ~ 1000 days exposure in 10 - 35 MeV region

reachable sensitivity ➔ $\delta^2 \lesssim 1 - 2 \times 10^{-56}$

> 1 order of magnitude improvement with respect to available limits for ^{23}Na and ^{127}I reachable by DAMA/LIBRA with 3 yr exposure optimized for h.e. and without any simulated muon background subtraction

- First upgrade of DAMA/LIBRA in September 2008
- Replacement of PMT achieving higher Q.E.:in preparation

+

Possible highly radiopure NaI(Tl) multi-purpose set-up DAMA/1 ton (proposed by DAMA in 1996) at R&D phase