Comments on new bounds on neutrino magnetic moment

"Results and Perspectives in Particle Physics"

La Thuile
28/02/2011

Alexander Studenikin
MSU, JINR

Outline

- ***Neutrino magnetic moment***
- ***Bruno Pontecorvo Centenary Council***
- ***Conclusions and greetings***

Why

magnetic moment

of  ***?***

…Why

electromagnetic properties

provide a kind of window / bridge to

NEW Physics ?

… in spite of

- *results of terrestrial laboratory experi on ν EM properties*

as well as

- *data from astrophysics and cosmology*

are in agreement with "νERO" EM

… However, in course of recent development knowl ν ge on mixing and oscilla

1 *Carlo Giunti, Alexander Studenikin :*
"Neutrino electromagnetic properties"
Phys.Atom.Nucl. 73, 2089-2125 (2009)
arXiv:0812.3646 v5, Apr 12, 2010

2 *A.Studenikin :*
"Neutrino magnetic moment: a window to new physics"
Nucl.Phys.B (Proc.Supl.) 188, 220 (2009)

3 *C. Giunti, A. Studenikin :*
"Electromagnetic properties of neutrin
J.Phys.: Conf.Series. 203 (2010) 01210(
arXiv:1006.3646 June 8, 2010

4 *C.Giunti, A.Studenikin : "Theory and phenomer of neutrino electromagnetic properties"*
Rev.Mod.Phys. (in preparation)

Carlo Giunti, Alexander Studenikin

"Neutrino electromagnetic prop

Phys.Atom.Nucl. 73, 2089-2125 (2009)
arXiv:0812.3646 v5, Apr 12, 2010

exhibits unexpected properties (p

W. Pauli, 1930

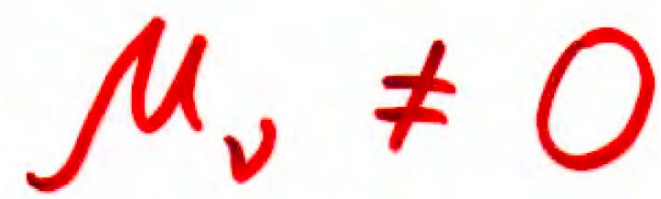
- neutral "neutron ⟹ "

E.Fermi, 1933
- probably $\mu_\nu \neq 0$!?
- Pauli himself wrote to Baade:

...recent claims f new experimenta bounds c μ_ν continue chain of puzzles..

"Today I did something a physicist shoul I predicted something which will never be experimentally...".

…the present status…

to have visible 

is not an easy task for

theoreticians

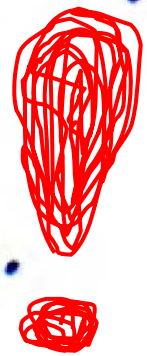
and experimentalists

In the Standard Model : $m_\nu = 0$,

there is no ν_R $\Rightarrow$

ν magnetic moment $\mu_\nu = 0$.

Thus, $\mu_\nu \neq 0$ ← beyond the SM.



$m_\nu \neq 0$

Theory (Standard Model with ν_R)

$$\mu_e^{\nu_e} = \frac{3eG_F}{8\sqrt{2}\pi^2} m_{\nu_e} \sim 3 \cdot 10^{-19} \mu_B \left(\frac{m_{\nu_e}}{1eV}\right), \quad \mu_B = \frac{e}{2m_e}$$

Lee Shrock, 1977; Fujikawa Shrock, 1980

$$a_e = \frac{\alpha_{QED}}{2\pi} \sim 10^{-3}$$

... much greater values are desired

for astrophysical or cosmology

visualization of μ_ν

Astrophysical bounds

$\mu_\nu \leq 3 \cdot 10^{-12} \mu_B$ (Red Giant lumin.) etc.

G. Raffelt, D. Dearborn, J. Silk, 1989.

Theory (Standard Model with ν_R)

$$\mu_e = \frac{3eG_F}{8\sqrt{2}\pi^2} m_{\nu_e} \sim 3 \cdot 10^{-19} \mu_B \left(\frac{m_{\nu_e}}{1eV}\right), \quad \mu_B = \frac{e}{2m_e}$$

Lee Shrock, 1977; Fujikawa Shrok, 1980

… importance μ_ν studies

If diagonal $\mu_\nu \neq 0$

were confirmed

then ν Dirac

… for ν Majorana
non-diagonal = transitional
$\mu_\nu \neq 0$

… progress in experimer μ_ν studies of ⇒

Studies of ν-e scattering - most sensitive method of experimental investigation of μ_ν

Cross-section:

$$\frac{d\sigma}{dT}(\nu + e \to \nu + e) = \left(\frac{d\sigma}{dT}\right)_{\rm SM} + \left(\frac{d\sigma}{dT}\right)_{\mu_\nu}$$

where the Standard Model contribution

$$\left(\frac{d\sigma}{dT}\right)_{\rm SM} = \frac{G_{\rm F}^2 m_e}{2\pi}\left[(g_V + g_A)^2 + (g_V - g_A)^2\left(1 - \frac{T}{E_\nu}\right)^2 + (g_A^2 - g_V^2)\frac{m_e T}{E_\nu^2}\right],$$

T is the electron recoil energy a

$$\left(\frac{d\sigma}{dT}\right)_{\mu_\nu} = \frac{\pi\alpha_{em}^2}{m_e^2}\left[\frac{1 - T/E_\nu}{T}\right]\mu_\nu^2$$

$$\mu_\nu^2 = \sum_{j=\,\nu_e,\,\nu_\mu,\,\nu_\tau} |\,\mu_{ij} - \epsilon_{ij}\,|^2$$

$$g_V = \begin{cases} 2\sin^2\theta_W + \frac{1}{2} & \text{for } \nu_e\,, \\ 2\sin^2\theta_W - \frac{1}{2} & \text{for } \nu_\mu, \nu_\tau\,, \end{cases} \qquad g_A = \begin{cases} \frac{1}{2} & \text{for } \nu_e\,, \\ -\frac{1}{2} & \text{for } \nu_\mu, \nu_\tau \end{cases}$$

for anti-neutrin

$$g_A \to -g_A$$

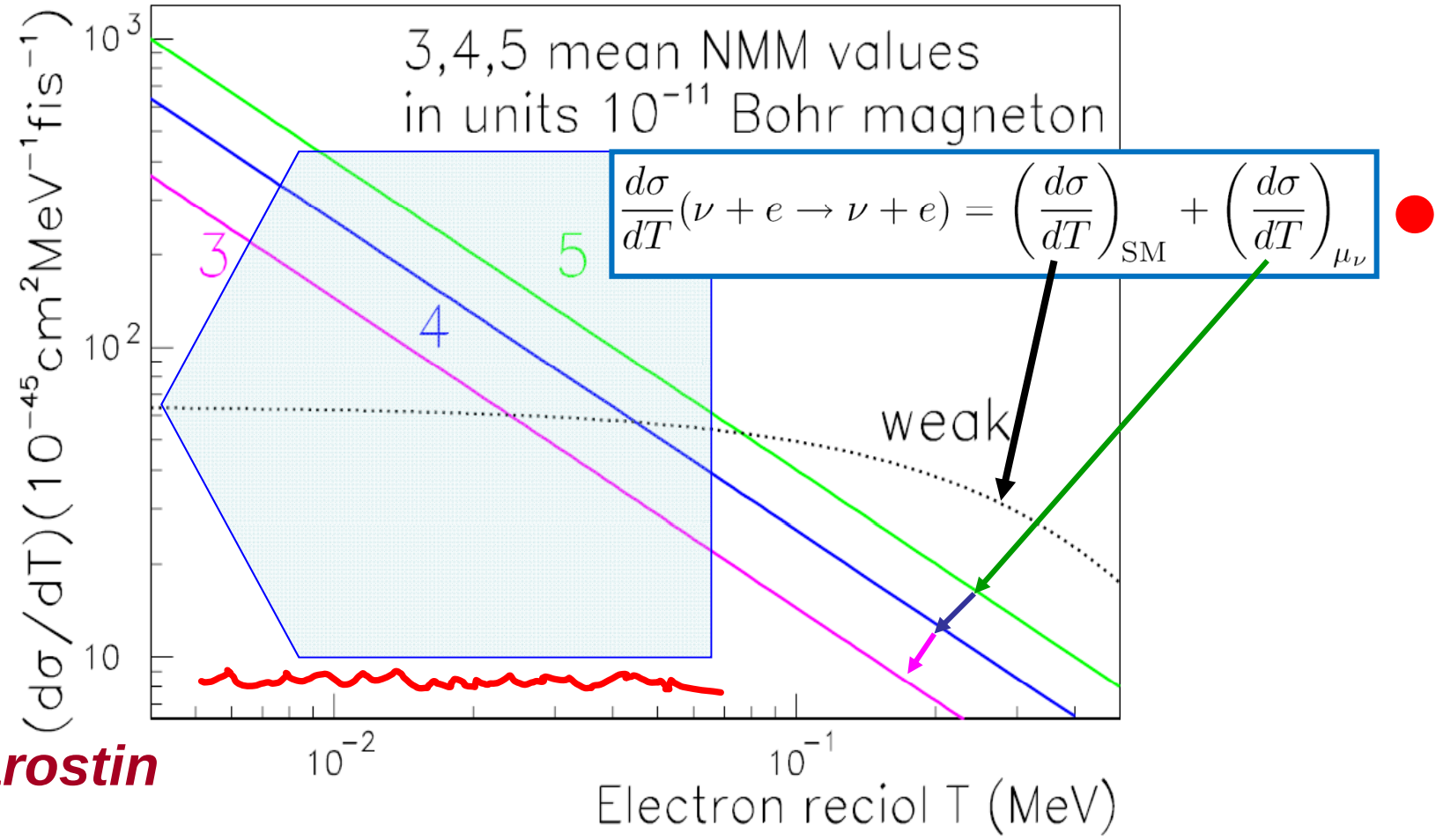
to incorporate charge ra

$$g_V \to g_V + \tfrac{2}{3} M_W^2 \langle r^2 \rangle \sin^2\theta_W$$

Magnetic moment contribution is dominated at l

recoil energies v $\left(\frac{d\sigma}{dT}\right)_{\mu_\nu} > \left(\frac{d\sigma}{dT}\right)_{SM}$ $\frac{T}{m_e} < \frac{\pi^2 \alpha_{em}}{G_F^2 m_e^4} \mu_\nu^2$ **and**

… the lower the smallest measurable electron recoil en
the smaller value μ_ν^2 f can be probed in scatterin



from A.Starostin

MUNU* experiment at Bugey reactor *(2005)

$$\mu_\nu \leq 9 \times 10^{-11} \mu_B$$

TEXONO* collaboration at Kuo-Sheng power plant *(2006)

$$\mu_\nu \leq 7 \times 10^{-11} \mu_B$$

GEMMA (2007) $$\mu_\nu \leq 5.8 \times 10^{-11} \mu_B$$

GEMMA I 2005 - 2007

BOREXINO (2008) $$\mu_\nu \leq 5.4 \times 10^{-11} \mu_B$$

…was considered as the world best const

$$\mu_\nu \leq 8.5 \times 10^{-11} \mu_B \quad (\nu_\tau,\ \nu_\mu)$$

Montanino, Picariello, Pulido, PRD 2008

based on first release of BOREXINO data

GEMMA (2005-2008)

Germanium Experiment on measurement of Magnetic Moment of Antineutrino

R (Dubna) + ITEP (Moscow) at Kalinin Nuclear Power P

$$\mu_\nu < 3.2 \times 10^{-11} \mu_B$$

…till 13 January 2010 and again since 23 August
best limit on ν magnetic moment

A.Beda, E.Demidova, A.Starostin et al,
arXiv:09.06.1926 , June 10, 2009,

A.Beda, V.Brudanin, E.Demidova et al,
in: "Particle Physics on the Eve of LHC",
ed. A.Studenikin, World Scientific (Singapore),
p.112, 2009 (13th Lomonosov Conference)
www.icas.ru

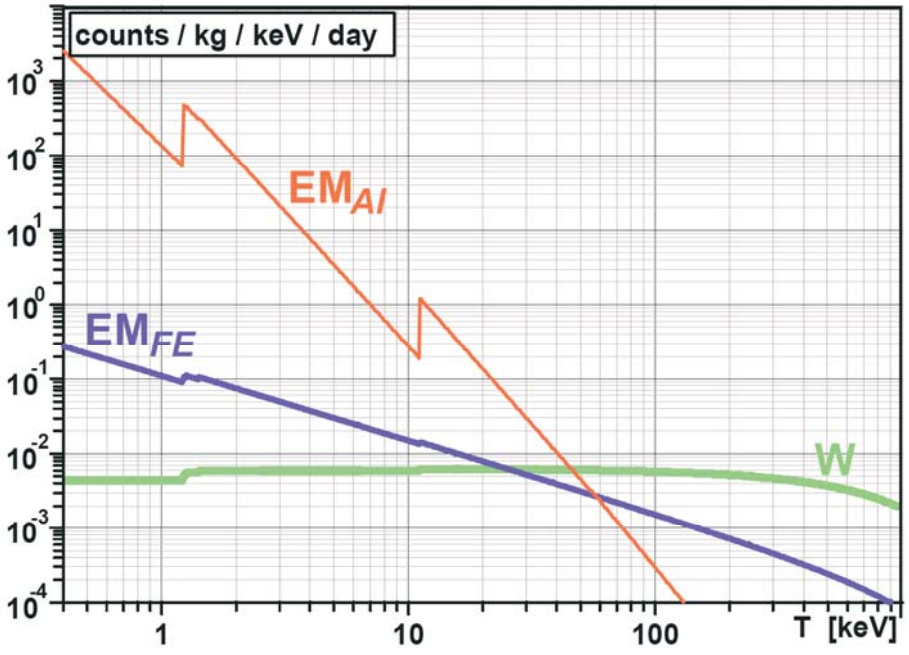
… quite recent claim that ν-e cross section should be increased by Atomic Ionization effect?

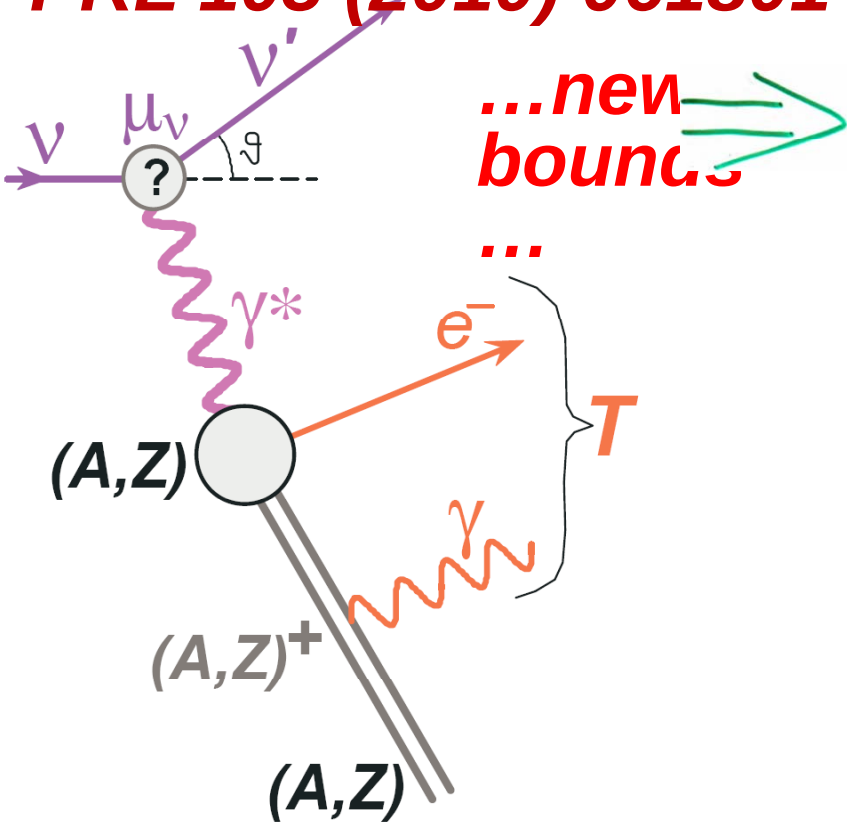
H.Wong et al. (TEXONO Coll.), arXiv: 1001.2074, 13 Jan 2010, reported at Neutrino 2010 Conference (Athens, June 2010), PRL 105 (2010) 061801

$$\nu + (A,Z) \longrightarrow \nu' + (A,Z)^+ + e^-$$

$$\downarrow \text{recombination}$$

$$(A,Z) \quad + \gamma$$





…new bounds …

…much better limit on effective magnetic

H.Wong et al., (TEXONO Coll. arXiv: 1001.2074 13 Jan 2010, PRL 105 (2010) 061801

$\mu_\nu < 1.3 \times 10^{-11} \mu_B$?

… atomic ionization effect accounted for …

Neutrino 2010 Conference, Athens

… however …

$\mu_\nu < 5.0 \times 10^{-12} \mu_B$?

A.Beda et al. (GEMMA Coll.), arXiv: 1005.2736, 16 May 2010

… atomic ionization effect accounted for …

$\mu_\nu < 3.2 \times 10^{-11} \mu_B$

… ν-e scattering on free electrons …
(without atomic ionization)

K.Kouzakov, A.Studenikin,

- **“Magnetic neutrino scattering on atomic electrons revisited”**
  Phys.Lett. B 105 (2011) 061801, arXiv: 1011.5847

- **“Electromagnetic neutrino-atom collisions: The role of electron binding”**
  to appear in
  Nucl.Phys.B (Proc.Supp.) 2011 (Proc. of Neutrino Oscillation Workshop

K.Kouzakov, A.Studenikin, M.Voloshin,

- **“Neutrino-impact ionization of atoms in search for neutrino magnetic mo**
  arXiv: 1101.4878, 25 Jan 2011, submitted to *Phys.Rev.*D

- **“On neutrino-atom scattering in searches for neutrino magnetic moment**
  arXiv: 1102.0643, 3 Feb 2011, to appear in
  ***Nucl.Phys.*B (Proc.Supp.) 2011 (Proc. of Neutrino 2010 Conference)**

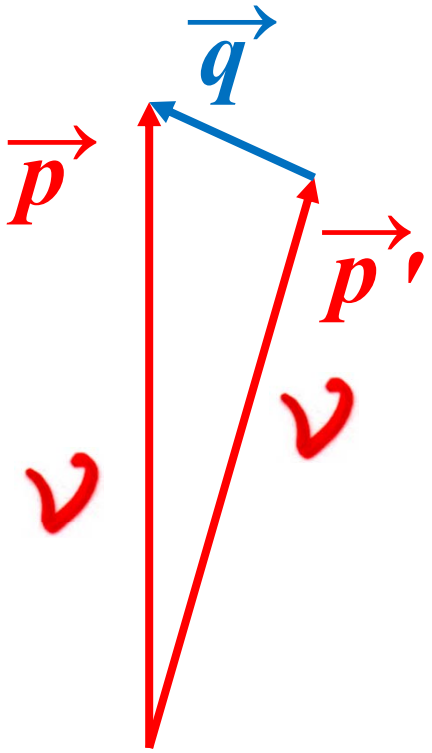
M.Voloshin,

- **“Neutrino scattering on atomic electrons in search for neutrino magnetic moment”**
  ***Phys.Rev.Lett.* 105 (2010) 201801, arXiv: 1008.2171**

No important effect of Atomic Ionization on cross section in experiments once all possible final electronic states accounted for

- ***M.Voloshin, 23 Aug 2010;***
  K.Kouzakov, A.Studenikin, 26 Nov 2010;
  H.Wong et al, arXiv: 1001.2074 V3, 28 Nov 2010

Neutrino-impact ionization of atoms in in serarch fo ν_μ



scattering on atoms (Ge) at low energy t

T ~ few keV and lower sc $\frac{T}{E_\nu} \ll 1$

Ge atom recoil en $< \frac{2E_\nu^2}{M_{Ge}} \ll T \quad M_{Ge} \to \infty$,

ν interaction with nucleus is neglec

ν scattering on atomic e is importa

Four momentum transfer

$$q = p - p'$$

$$q_\mu = (T, \vec{q}), \quad q^2 = \vec{q}^{\,2}$$

energy and spatial momentum transfer from neutrinos to atomic electrons

Kouzakov, Studenikin, 2010;
Kouzakov, Studenikin, Voloshin, 2011

Double differential ν-e cross section

$$\frac{d^2\sigma_{(\mu)}}{dT\,dq^2} = 4\pi\,\alpha\,\frac{\mu_\nu^2}{q^2}\left[\left(1-\frac{T^2}{q^2}\right)S(T,q^2)+\left(1-\frac{q^2}{4E_\nu^2}\right)R(T,q^2)\right]$$

$$\frac{d^2\sigma_{(\mu)}}{dTdq^2} = \left(\frac{d^2\sigma_{(\mu)}}{dTdq^2}\right)_{\parallel} + \left(\frac{d^2\sigma_{(\mu)}}{dTdq^2}\right)_{\perp}$$

Kouzakov, Studenikin, 201
Kouzakov, Studenikin, Voloshin, 2011

where dynamical structure factor (Van Hove, 1954)

$$S(T,q^2) = \sum_n \delta(T - E_n + E_0)\;|\langle n|\rho(\vec{q})|0\rangle|^2$$

and

$$(\vec{j}_\perp\cdot\vec{q}) = 0$$

$$R(T,q^2) = \sum_n \delta(T - E_n + E_0)\;|\langle n|j_\perp(\vec{q})|0\rangle|^2$$

summ is over all st$|n\rangle$s of electr$|0\rangle$ system,

For single-differential inclusive cross section measured

$$\frac{d\sigma_{(\mu)}}{dT} = 4\pi\,\alpha\,\mu_\nu^2 \int_{T^2}^{4E_\nu^2} S(T,q^2)\,\frac{dq^2}{q^2}$$

$$R(T,q^2) = \frac{T^2}{q^2} S(T,q^2)$$

transversal contribution practically for most q^2 is negligible

SM electroweak contribution to cross section

$$\frac{d\sigma_{EW}}{dT} = \frac{G_F^2}{4\pi}\left(1 + 4\,\sin^2\theta_W + 8\,\sin^4\theta_W\right) \int_{T^2}^{4E_\nu^2} S(T,q^2)\,dq^2$$

nonrelativistic limit $\int_{T^2}^{4E_\nu^2} \Rightarrow \int_0^\infty$

For free electron

$$S_{(FE)}(T,q^2) = \delta(T - q^2/2m)$$

$$\int_0^\infty S_{(FE)}(T,q^2)\,\frac{dq^2}{q^2} = \frac{1}{T}\,, \qquad \int_0^\infty S_{(FE)}(T,q^2)\,dq^2 = 2\,m$$

$$\frac{d\sigma_{(\mu)}}{dT} = 4\pi\,\alpha\,\mu_\nu^2\left(\frac{1}{T} - \frac{1}{E_\nu}\right) = \pi\,\frac{\alpha^2}{m^2}\left(\frac{\mu_\nu}{\mu_B}\right)^2\left(\frac{1}{T} - \frac{1}{E_\nu}\right)$$

- *… the same for electron bound in atom …* ***free electron approximation is valid***

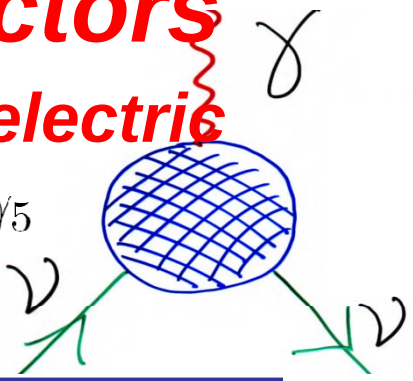
(ν-e scattering on free electrons)

ν e.m. vertex ⇒ 4 form factors function

charge dipole magnetic and electric

- $\Lambda_\mu(q) = f_Q(q^2)\gamma_\mu + f_M(q^2)i\sigma_{\mu\nu}q^\nu + f_E(q^2)\sigma_{\mu\nu}q^\nu\gamma_5$

  $f_A(q^2)(q^2\gamma_\mu - q_\mu \not{q})\gamma_5$ anapole



- EM properties ⇒ a way to distinguish Dirac ν

- Standard Model with ν_R ($m_\nu \neq 0$): $\mu_e = \frac{3eG_F}{8\sqrt{2}\pi^2} m_{\nu_e} \sim 3\cdot 10^{-19}\mu_B \left(\frac{m_{\nu_e}}{1eV}\right)$

- In extensions of SM ⇒ enhancement of ν magnetic moment, even electrically millicharg ν

- Limits from reactor ν-e scattering experiments (2009, 2010):

  $\mu_\nu < 3.2 \times 10^{-11}\mu_B$ A.Beda et al. (GEMMA Coll.)

- Limits from astrophysic star cooling (1990):

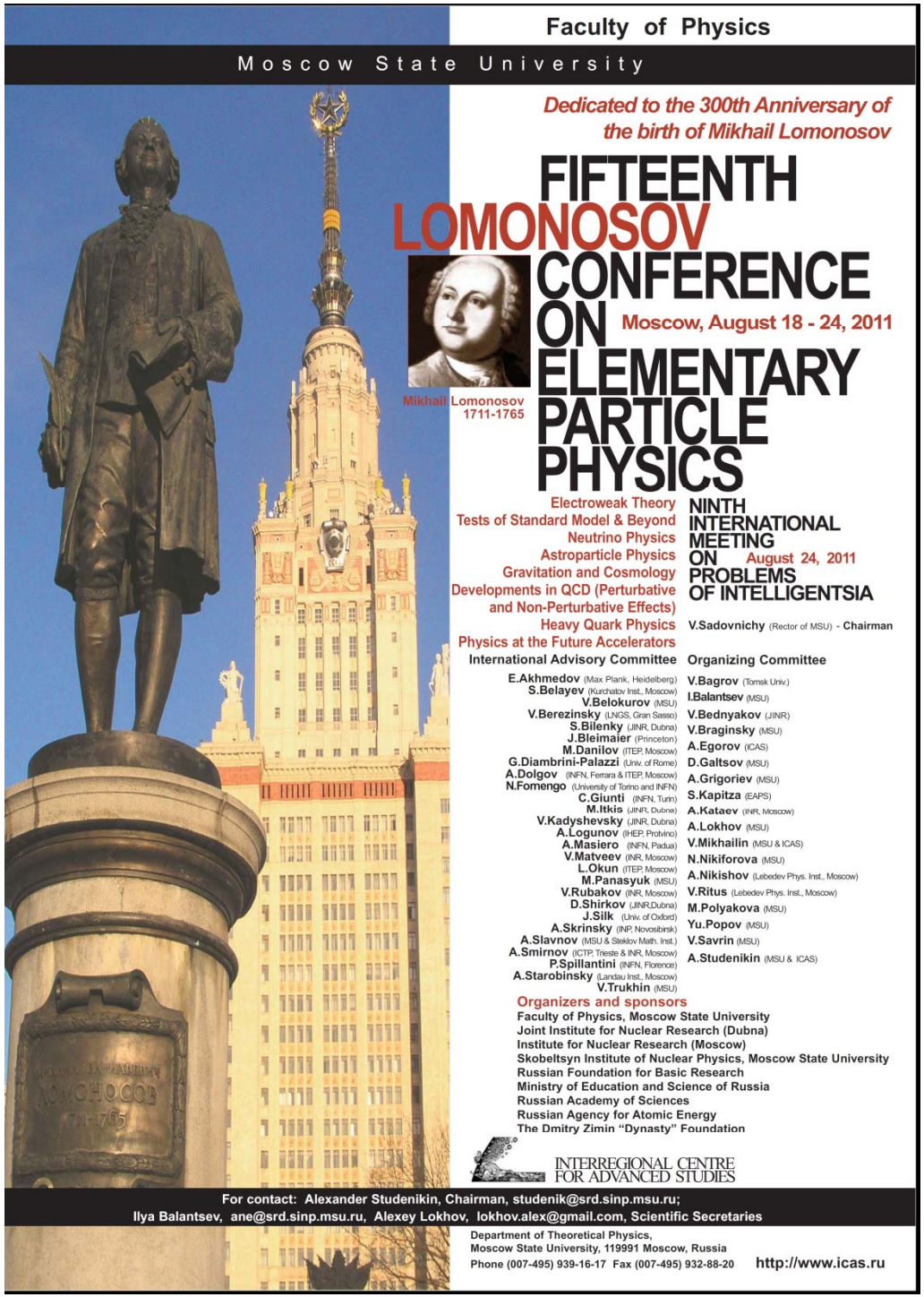
  $\mu_\nu < 3 \times 10^{-12}\mu_B$ G.Raffelt

- *Since 1950 **Bruno Pontecorvo**, outstanding Italian scientist, lived in Russia and was staff member of Joint Institute for Nuclear Research, Dubna*
- *Bruno Pontecorvo was Head of Department of Particle Physics and member of Scientific Council of Faculty of Physics of Moscow State University*
- *Bruno Pontecorvo Laboratory on Neutrino Physics and Astrophysics (PLN)*

has been recently established at Faculty of Physics of Moscow State University

… to provide continuation of long-standing traditions in teaching
and performing scientific researches of neutrinos of relat

3 proposals



15th Lomonosov Conference on Elementary Particle Physics, Moscow State University, August 18-24, 2011

www.icas.ru

16th Lomonosov Conference on Elementary Particle Physics

MSU, Moscow, August 22-28, 2013

1913-1993

August 22, 2013 is the centenary of Bruno Pontecorvo birth

… our 3 proposals:

- 16LomCon will be dedicated to the memory of Bruno Pontecorvo
- Scientific programme of 16LomCon to be devoted to neutrino physics astroparticle physics and related subjects

- ***To establish***

International Bruno Pontecorvo Centenary Council

for preparing celebrations (conferences, workshops etc)

dedicated to

Bruno Pontecorvo heritage

MEMORANDUM

2nd Round Table Italy-Russia@Dubna:

"SPACE PHYSICS and BIOLOGY"

- In the days from 19th to 23rd December 2010 at the Joint Institute for Nuclear Research (JINR), it took place the second Round Table Italy-Russia at Dubna devoted this year to the problems of Cosmo Physics and Biology. Just as the first Round Table in December 2009, the present event was co-organized by the Italian Embassy in the Russian Federation and by JINR.

- **A) Review and Perspectives of Italo-Russian collaborations in the field of Astrophysics and Cosmology.**

In this field the joint collaboration activities are already very much alive and developed. The participants supported the proposal of devoting to the memory of Bruno Pontecorvo the 16th Lomonosov Conference on Elementary Particle Physics organized for the year 2013 by the Bruno Pontecorvo Neutrino Physics Laboratory of Moscow State University and creating an International Bruno Pontecorvo Centenary Council to prepare celebrations. Similarly the outstanding figure of the Italian physicist Nicola Cabibbo who was full member of the Russian Academy of Sciences should be honored in one of the next possible meetings.

• • •

Co-presidents of the Memorandum Committee

Academician A. Grigoriev .....

Academician V. Matveev .....

Prof. G. Martinelli .....

Prof. M. Capaccioli .....

Dubna, December 22nd , 2010

RUSSIAN ACADEMY
OF SCIENCES
(RAS)

Institute for Nuclear Research
of the Russian Academy of Sciences

Учреждение Российской академии наук
ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ РАН

LXX

Dear Professor Mario Greco,

On the occasion of your seventieth jubilee I have a honour to send you warmest greetings on behalf of the Russian Academy of Sciences, the Russian scientific community and myself.

You are a world know scientist and it is a pleasure for me to emphasize your personal great contribution to different branches of high energy and particle physics.

Your brilliant scientific career started in Italy at Laboratori Nazionali di Frascati and in collaborating with Bruno Touschek, then it was continued in the world famous centers of high energy physics, in particular at CERN, SLAC and DESY. Your contribution to electroweak theory, QCD jet and heavy-quark physics are well known and highly appreciated by scientific community.

Your successful scientific research work has been accomplished with great academic teaching activity in universities of Marseille, Pavia, L'Aquila and more than for 20 years in the University of Roma Tre.

We also very much appreciate your determinative role in founding the world's prestigious series of international conference on "Results and Perspectives in Particle Physics" (Les Recontres de Physique de la Vallee d'Aoste) that is successfully running under your supervision for 25 years.

There is a long standing tradition of fruitful scientific and academic relations between Russia and Italy. It is a pleasure for me to emphasize your personal great contribution in promoting these relations and also in support of the Russian scientists during the series of Les Recontres de Physique de la Vallee d'Aoste.

Please be sure that we would be very glad to continue our contacts and collaboration in the future.

We would like to wish you new achievements in your scientific research and academic activity and prosperity to you, Mrs Halina Bilokon and all of your family.

Sincerely yours,

Victor Matveev,
Director
Institute for Nuclear Research of Russian Academy of Sciences,
Academician-Secretary, Division of Physical Sciences
Russian Academy of Sciences