1)

International conference
“P.A. Cherenkov and modern physics”
Moscow, June 22, 2004

WHAT ONE CAN EXPECT FROM HIGH ENERGY PHYSICS IN XXI

S.S. GERSHTEIN

2)

Preparing this talk I realized that I faced with the risky and equivocal problem.

Sharp 100 years ago, in 1904, A. Puankare in his talk "The present and future of the mathematical physics" at the Congress of Art and Scienece in Sant Luis has noticed that

It is easy to raise these questions, but it is difficult to answer, having in mind all those nonsenses that could be said by prominent scientists in the beginning of last century, had one asked them about the physisc of the XIX century. They could consider themselves to be too daring in their predictions, but how humble could we find them now!

The physics of the XIX century has succeded in so many remarkable results that many thought that physics had "come to an end close" and it had "finalized" as the geometry, and only several unresolved "clouds" remains. By the way, now we know that the geometry itself has not "finalized", and now it takes up the problems of the topology of multidimensional partly compactified spaces in the hope that it will help physics.

Indeed, could one predict in the beginning of the XX century:

- atomic nucleus, protons, neutrons, abundance of other unstable particles, and ,finally, quarks;
- quantum mechanics, existence of the weak and strong interactions, unification of the weak and electromagnetic interactions;
- evolution of stars, expansion of the Universe and so on...

It was also impossible to predict the great progress in the techniques that has favoured many fundamental discoveries, and then, using them, led to the scientific and technological revolution, which has changed our world and provided new observation tools and facilities, which, in turn, has led to new fundamental results:

- use of atomic energy;
- development of the high-speed electronics and computers;
- construction of modern accelerators, colliders and detectors
- human going into the outer space, possibility of the cosmic research of the Universe beyond the Earth atmosphere...

A. Puankare, analyzing the most important experiments, upholded the main principles: principle of relativity and energy-momentum conservation law. He has divined the direction of the further development of physics.

1. Analyzing the Mikelson experiment he has showed that it agrees with the relativity principle if the observer in motion will perform measurments with the clock, synchronized by light signals; and the longitudinal scales will be shortened. In other words it was a portent of the special theory of relativity.
2. Analyzing the energy emitted by radium he explained the radiation phenomenon by the transformations, yet unknown at that time, which happens with radium.
3. Analyzing the dependence of the particle masses on the velocity, which was discovered in experiments with the cathode rays, he has concluded that had these experiments be confirmed it would lead to *"absolutely new mechanics, which would characterized by the fact that none of the velocities could be higher than the speed of the light"*.
4. Discussing unsuccessful attempts to explain the laws of the black body radiation and spectrum appropriateness in the framework of classical theory A. Puankare said that *"this is not awared of yet, but I think that namely here one of the most important secrets of the nature is contained"*. Puankare was right – this mistery was the quantum mechanics.

Can we forecast now the development of the physics in XXI?

The summit of our firmly tested knowledge is the Standard Model. It includes three generations of quarks

$$\begin{vmatrix} \mathrm{u} \\ \mathrm{d} \end{vmatrix} \quad \begin{vmatrix} \mathrm{c} \\ \mathrm{s} \end{vmatrix} \quad \begin{vmatrix} \mathrm{t} \\ \mathrm{b} \end{vmatrix}$$

three generations of leptons

$$\begin{vmatrix} \nu_e \\ e^- \end{vmatrix} \quad \begin{vmatrix} \nu_\mu \\ \mu^- \end{vmatrix} \quad \begin{vmatrix} \nu_\tau \\ \tau^- \end{vmatrix}$$

gauge vector bosons γ, $W^\pm$, Z, which transmit the electroweak interaction and 8 gluons, which transmit the strong interaction.

This achievement became possible in the second half of the XX century due to the appearance of

- high energy accelerators and colliders,
- detectors of the new type,
- high-speed electronics and computers.

One of the leading parts was played by the Cherenkov counters.

Let me remind, for instance, that antiproton was discovered namely due to the Cherenkov counters.

Cherenkov counters allow one to

- separate particular particles, which are needed for the experiment, in the intensive beams containing different charged particles with equal momenta,
- indentify secondary particles produced in reactions,
- detect with the high accuracy the direction and energy of γ-quanta via the Cherenkov radiation of the electromagnetic showers caused by the high energy γ-quanta. This led to significant results in the hadron spectroscopy (GAMS).

Without the high resolution Cherenkov counters it would not be possible to detect in IHEP the beginning growth of the effective cross-section in K^+p, as well as to discover the scale invariance.

The crucial role was played by the Cherenkov radiation in the discovery of reactions induced by neutrinos and dicovery of the neurtino oscillations. But we discuss this a little bit later.

7)

Why the Standard Model is considered as the effective model, rather than real theory?

What the problems are there in SM?

Let's start from the first problem (but not the most important). Up to now there is no explanation for the quark confinement. First of all it is explained by the nonapplicability of the perturbation theory technique for this matter. This also explains a number of unsolved problems of the hadron spectroscopy (in particular, existence of the exotic states, glueballs, hybrids, multiquark objects etc.).

1 think that one does not need new fundamental theories to solve these problems. The analogous situation took place with the superconductivity. The important hint was obtained there from the experiment, which discover the isotopic effect for the temperature of the transition into the superconducting state.

Now we can say that the similar hint was provided by the comparison of the Ginzburg-Landau theory with the experiment, that has showed the closeness of the carrier effective charge to the value of 2 (from the point of view of the gradient invariance it should be integer). This could serve as an indication that carrier are the Cooper pairs.

1 hope that the study of the hadron spectroscopy could help to solve the confinement problem.

The experiments can be carried out on the accelerators of intermediate energies, and in Russia as well. Of course, one need to improve the methods (registration of polarization, use of the polarized beams, polarized targets etc.). The important role can be played by the high energy colliders, since there is the possibility to probe the spectroscopy of hadrons with heavy quarks, to study the reactions of the $\gamma\gamma \to hadrons$ type and production in the central region.

Now let's turn to the principal problems of SM

1. The generation mechanism for the mass of vector bosons ($W^{\pm}$, Z) and fermions remains unknown. The most popular idea here is the existence of the Higgs boson. Account for the radiation corrections in the electroweak theory allowed one to indicate the expected range for its mass, and for narrowing this range the precise measurement of the W-mass is vitaly needed. The search for the Higgs boson is one of the main tasks of Tevatron and LHC. Even if the Higgs boson will be discovered the problem of the mechanism stabilizing its mass below 1 TeV will remain unsolved. Such stabilization of the Higgs mass can take place if the supersymmetry is realized in the nature. Thus, the search for the superpartners along with the search for Higgs itself are the main task of future colliders.

   From theoretical point of view the attractiveness of the supersymmetry is that along with the homogeneity of the space-time and the space isotropy the supersymmetry is an additional (quantum) symmetry of the space. Basing on the supersymmetry it is possible to unify gravitation with all other interactions. However, the question is how is it strongly broken. The masses of the quark and lepton superpartners are, in any case, heavier than 70-90 GeV. Supersymmetry involves additional Higgs bosons, including charged ones.

2. The shortcoming of SM is an nonuniversality of the Yukawa sector of theory. Different quarks and leptons are connected with the Higgs condensate in nonuniversal way: proportionally to their masses.

3. SM contains 19 free parameters (quark and lepton masses, mixing angles). There is a hope that some of these parameters can be determined in the Grand Unification Theory (as it was done for the $\sin^2\theta_W$ value). Minimal SM extension with superpartners leads to the unification of the electromagnetic , weak and strong interactions on the scale of $\sim 10^{15}$ GeV.

4. The problem of CP-violation. Experiments on the K_L^0 decay (ϵ') have proved that the violation of CP-symmetry occurs in a direct way and can be described in terms of the complex phase in the CKM matrix.

   The results by BELLE and SPEAR confirm the CP-violation in decays of mesons with b-quarks.

   However, the question of the complex phase origin still remains unsolved. Why the strong CP-violation does not observed in QCD? Does one need the axion for this purpose?

The problem of the neutrino mass

Experiments on the neutrino oscillations indicate that neutrinos have masses. But why these masses are so small?

See-saw mechanism

Neutrinos are the superposition of two Majorana neutrinos:

$$m_\nu = \frac{m_l^2}{M_{large}}$$

In this case the extension beyond SM is also needed.

It will be hardly possible to construct colliders oriented to the Grand Unification energy (even having the ungovernable fantasy). But at colliders with the energy of $1 \div 100$ TeV one can check a lot of different consequences of Grand Unification models (beyond cosmology).

After all, the electroweak theory and existence of neutral currents could be proved experimentally even if the energy would not be sufficient to produce $W^{\pm}$ and Z-bosons.

But the situation can be much more interesting. For instance, in the theories with dimensional gravity the intrigue phenomena can arise even at TeV energy.

NLC with e^+e^-, $e\gamma$, and $\gamma\gamma$ options will open extremely interesting possibility. The progress in technics (in particular, the lasers on free electrons) allow one to dream about it.

The most important discovery – oscillation of the neutrinos of different flavors

Important role was played by the Cherenkov counters

Lepton number ("neutrino" charge). Ya. Zeldovich (1952), E.Konopinski, M.Mahmoud,G.Marx

$$l = 1 \qquad e^-,\ \mu^+,\ \nu$$

$$\mu^\pm \to e^\pm + \gamma; \quad 2\beta$$

$$l = -1 \qquad e^+,\ \mu^-,\ \bar{\nu}$$

Remark by Zeldovich: the difference with electric charge (there is no long interacting forces. As well as for baryon number). Possibility to violate L and B.

B. Pontekorvo (1957) pointed out that oscillations are the most sensitive way to test the lepton number conservation:

1) the oscillation length is proportional to the transition amplitude, rather than the probability

2) the presence of oscillations → nonzero mass.

$\nu \to \bar{\nu}_{sterile}$ (two Majorana ν_1, ν_2)

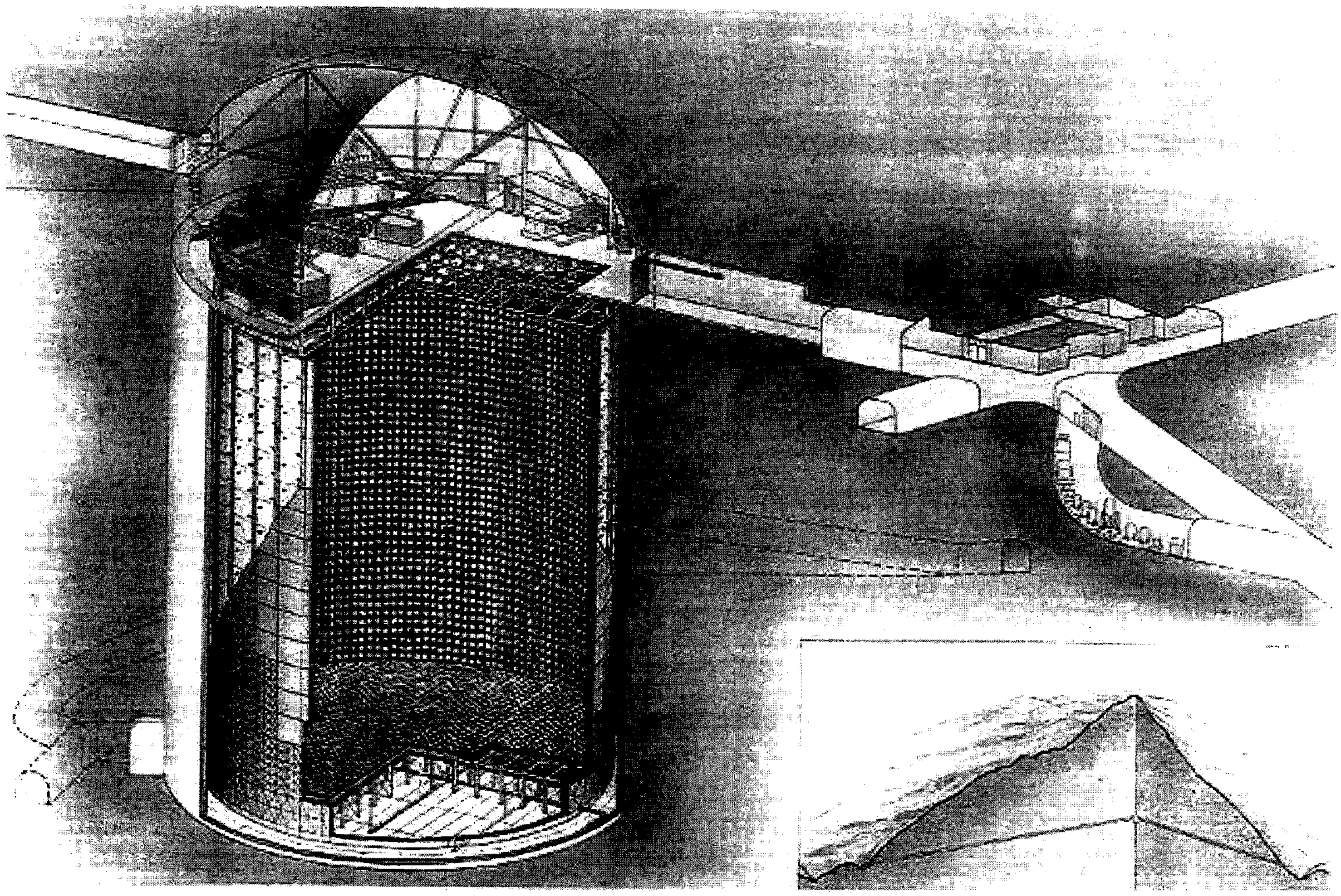
After discovery that ν_μ, ν_e, ν_τ are different → oscillation of flavors. ν_e, ν_μ, ν_τ are superpositions of ν_1, ν_2, ν_3 states with particular masses.

Neutrino is unique object: it is possible that $\bar{\nu} \equiv \nu$ (Majorana ν). Oscillation of flavors is uniformly described for both Dirac and Majorana neutrinos. In the case of Dirac neutrino there is a full analogy with quarks:

$$L = L_e + L_\mu + L_\tau$$

In the case of Majorana neutrino L is not conserved, 2β is possible, it is also possible to have $\nu_{sterile}$.

M. Nakagawa, H.Onogi, S.TAKATA, A.Tojoda



SUPERKAMIOKANDE INSTITUTE FOR COSMIC RAY RESEARCH UNIVERSITY OF TOKYO NIKKEN SEKKEI

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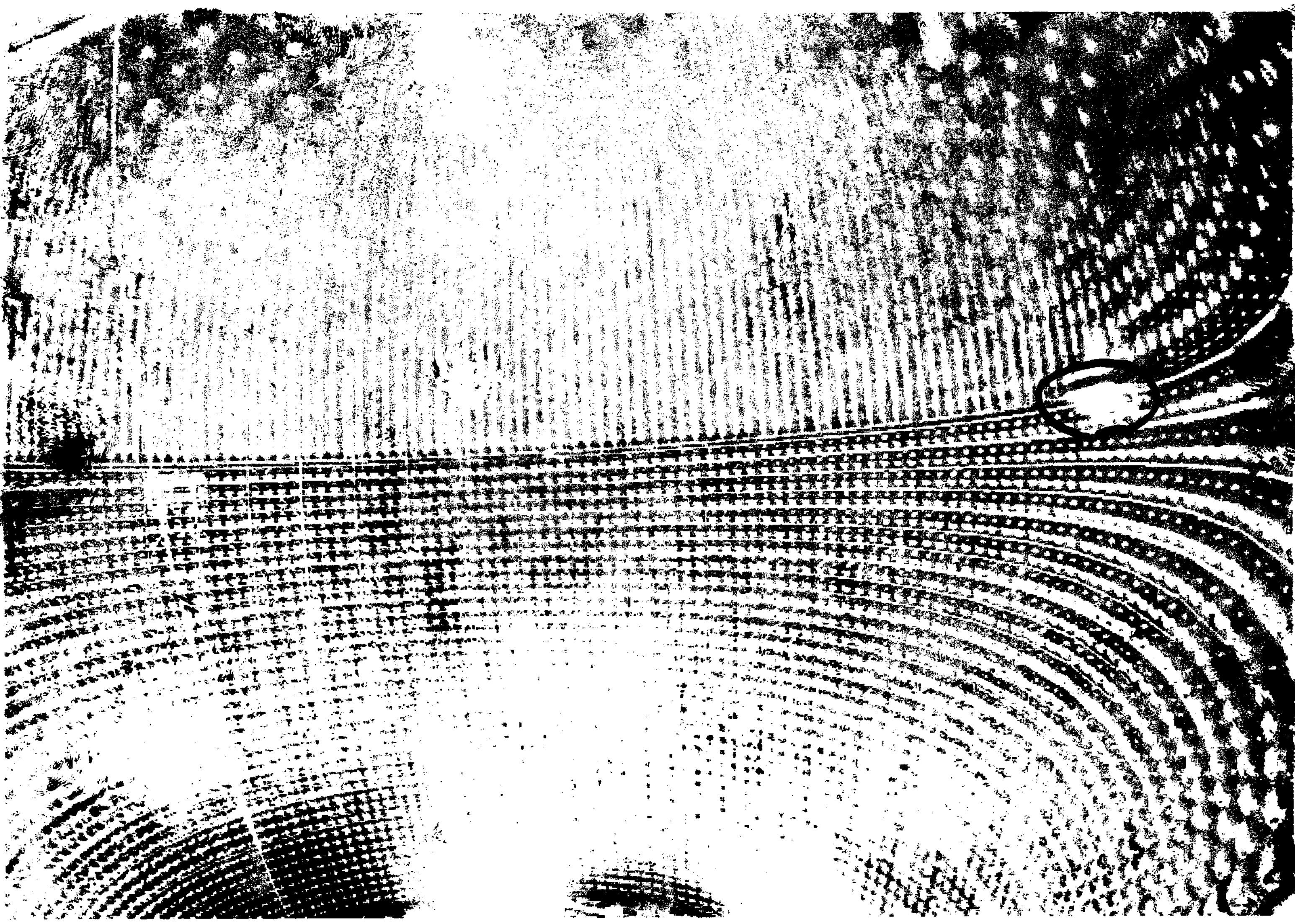

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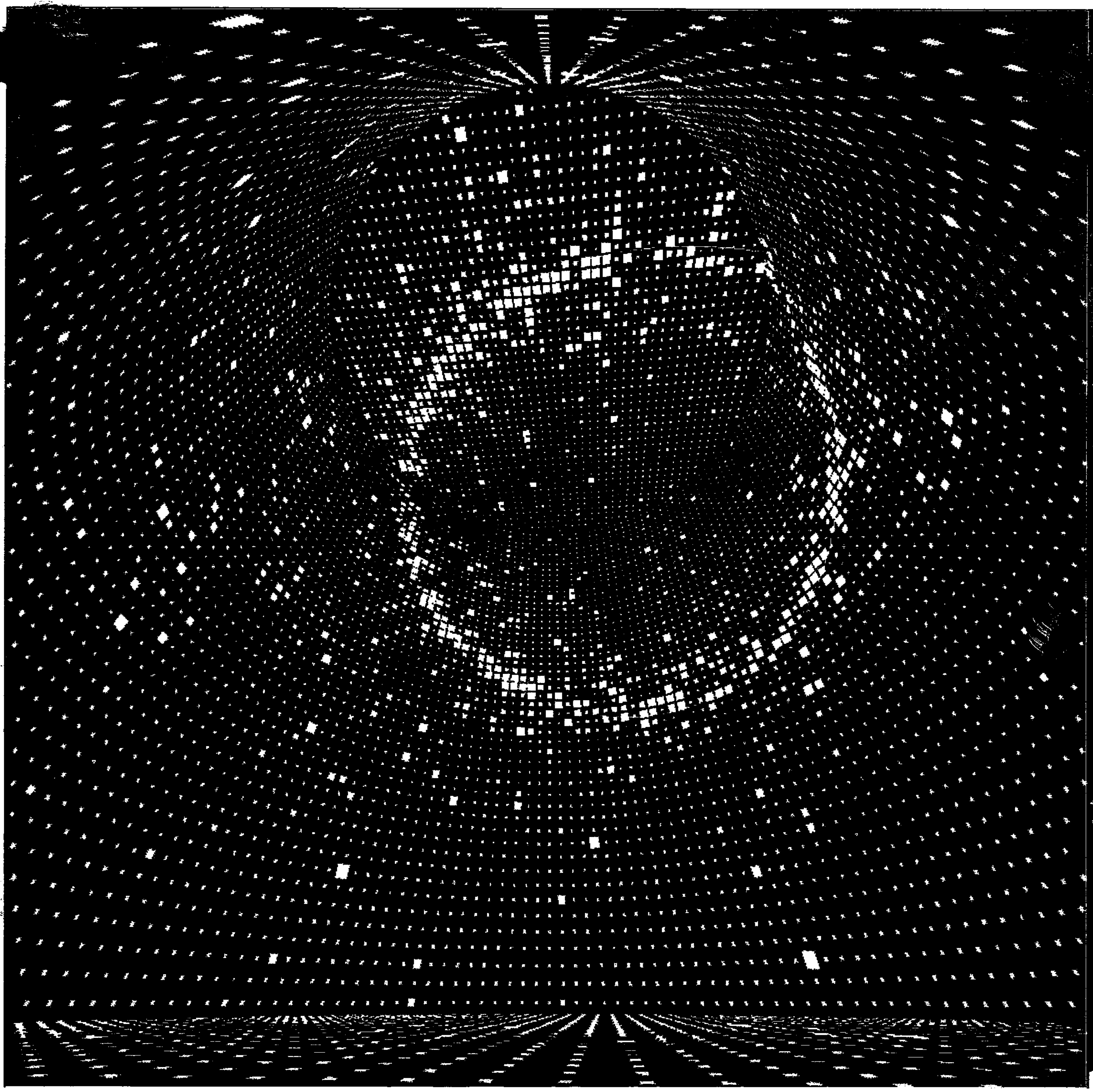

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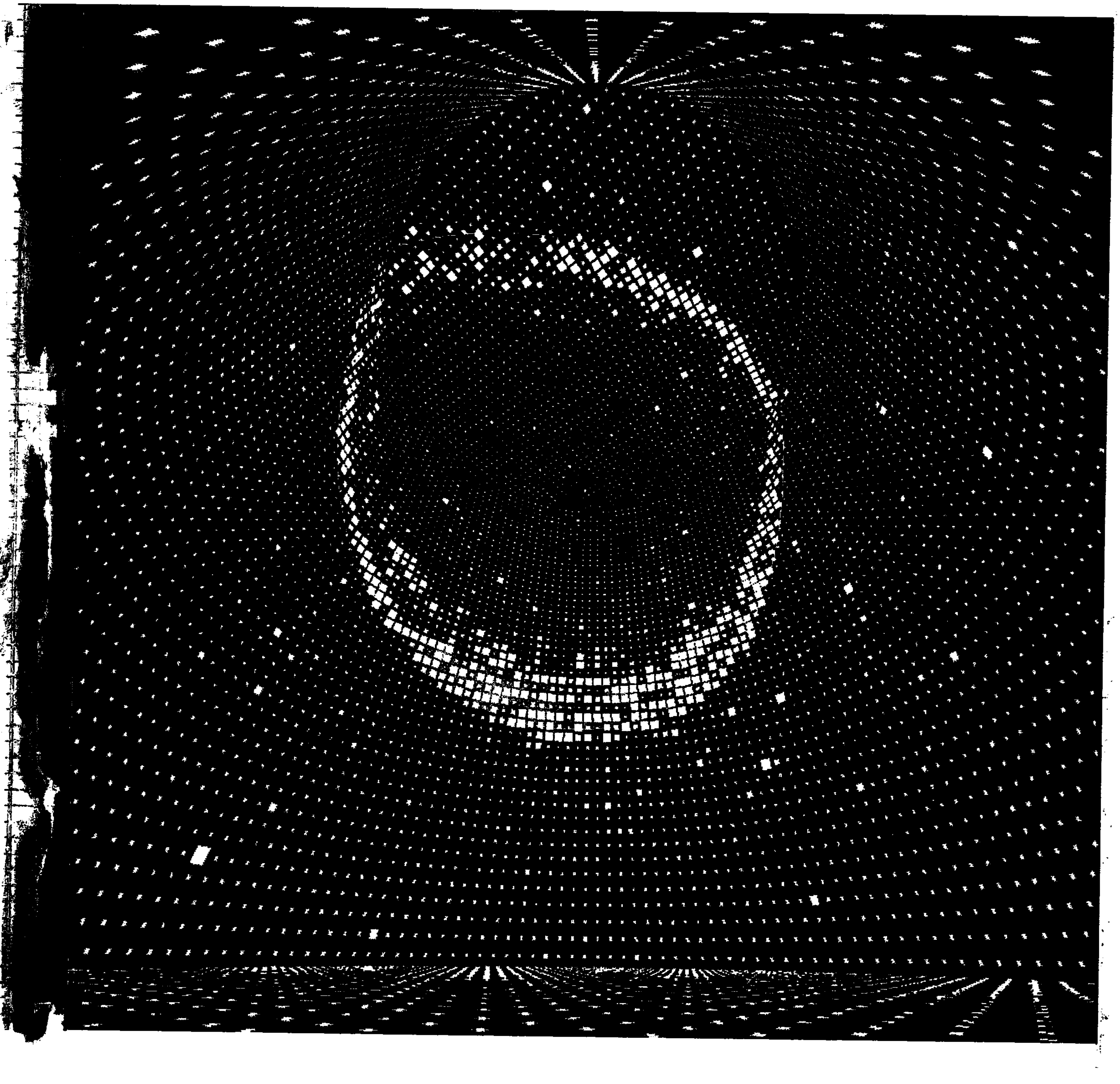
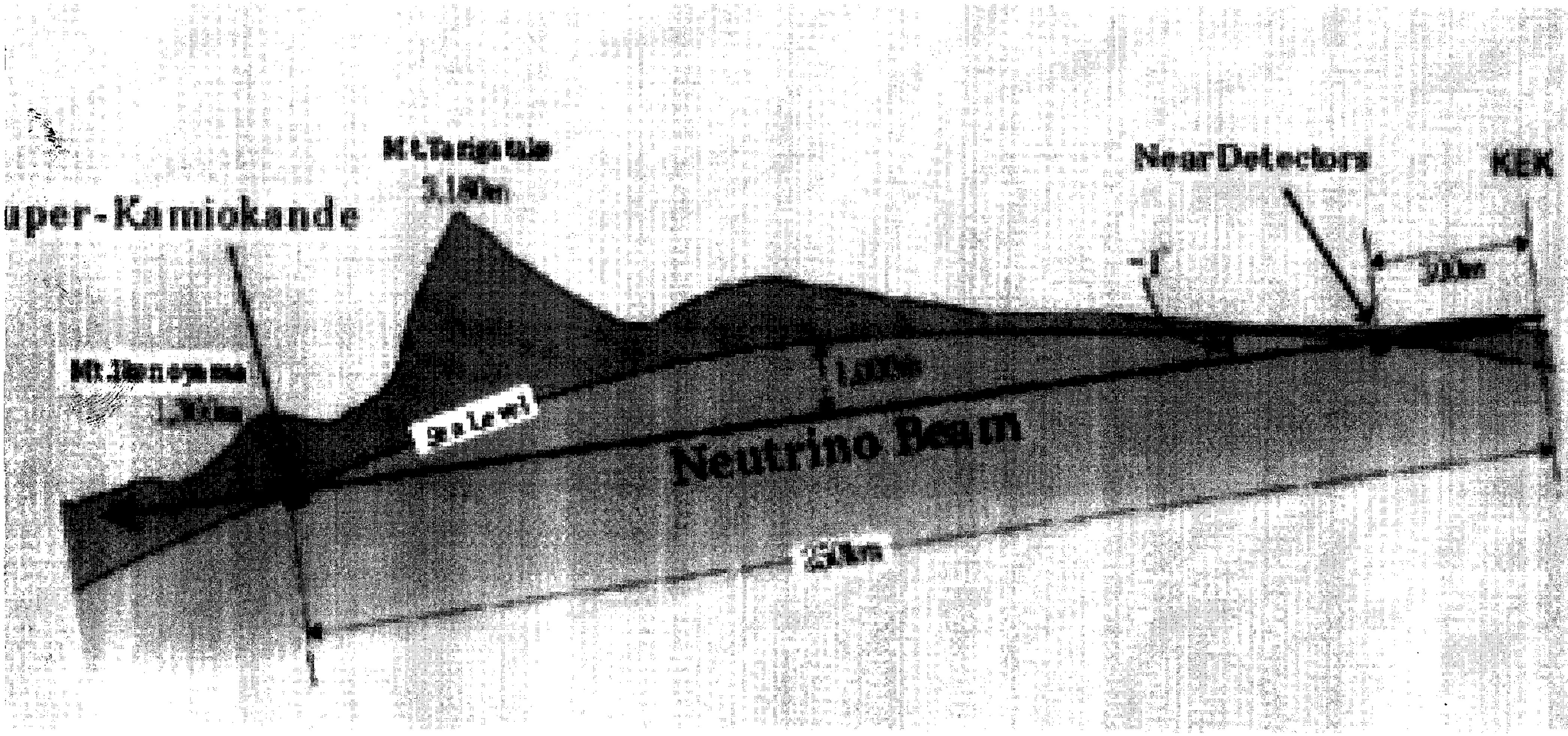



uper-Kamiokande
Near Detectors
KEK
Neutrino Beam

To detect neutrino it is necessary to have target with a large mass.

SuperKamiokande: Diameter $\simeq$40 m, height $\simeq$ 40 m. In such volumes the detection becomes possible by means of Cherenkov radiation.

The possibility to detect $\nu e \to \nu e$ at $E_\nu \geq 5 - 7$ MeV.

Solar neutrinos ($^8B \to ^8 Be + e^+ + \nu$).

The experiments have shown that mainly two-particle mixing takes place. For example:

$$\nu_e = \nu_1 \cos\theta + \nu_2 \sin\theta$$

$$\nu_\mu = -\nu_1 \sin\theta + \nu_2 \cos\theta$$

$$P_{\nu_e \to \nu_\mu} \equiv \sin^2 2\theta \sin^2(\frac{\pi}{2} \cdot \frac{L}{L_0})$$

$$L_0 = \frac{2\pi|\vec{p}|\hbar}{|m_2^2 - m_1^2|c^2} \simeq 2.5 \text{ m } \frac{|\vec{p}|(MeV/c)}{\Delta m^2(ev^2)}$$

All the data are selfconsistent (within arrow bars):
1) Solar neutrino (with an account for LAM MSW)
2) Atmospheric neutrino ($\pi \to \mu\nu$, $K \to \mu\nu$, $\mu \to e\nu\nu$)
3) Reactor antineutrino
4) Accelerator neutrino

$$\begin{aligned} |m_3^2 - m_2^2| &\simeq 2.5 \cdot 10^{-3} ev^2 & \sin^2 2\theta_{23} &\simeq 1 \\ |m_2^2 - m_1^2| &\simeq 7 \cdot 10^{-5} ev^2 & \sin^2 2\theta_{12} &\simeq 0.7 \\ & & \sin^2 2\theta_{13} &\leq 0.004 \end{aligned}$$

$$\begin{aligned} L_{\mu\to\tau} &\simeq L_{e\to\tau} \simeq 1km \cdot p(MeV/c) \\ L_{e\to\mu} &\simeq 35km \cdot p(MeV/c) \end{aligned}$$

Atmospheric neutrino:
1) Deficit of ν_μ from under the Earth
2) Absence of the ν_e deficit
$E_{\nu_\mu} \simeq$1 GeV

$$\begin{aligned} L_{\nu_\mu\to\nu_\tau} &\simeq 1000km \cdot p_nu(GeV/c) & \sin^2 2\theta_{23} &\simeq 1 \\ L_{\nu_e\to\nu_\mu} &\simeq 35000km \cdot p_nu(GeV/c) & & \\ L_{\nu_e\to\nu_tau} &\simeq 1000km \cdot p_nu(GeV/c) & \text{but } \sin^2 2\theta_{13} &< 0.04 \end{aligned}$$

Reactor neutrino:

Confirmation of the fact that $\sin^2 2\theta_{13} < 0.04$: for reactor CHOOZ at distances $L = 1$ km $\bar{\nu}_e \to \bar{\nu}T$ is not observed ($E_{\nu_e} \simeq 5$ MeV).

Reactor KamLAND ($E_{\bar{\nu}_e} \simeq 5$ MeV).

$$L_{\bar{\nu}_e\to\bar{\nu}_\mu} \simeq 35 \cdot 5 = 175km$$

The effect was observed namely at this distance.

Accelerator data:

$\bar{E} \simeq 1.3$ GeV K2K, $L = 250$ km baseline. 56 events with ν_μ were detected. According to measurements on the nearest detector one expected 80 events. It agrees with atmospheric neutrino.

Solar neutrinos

Radiochemical methods

$\nu_e +^{37}\mathrm{Cl} \rightarrow^{37} \mathrm{Ar}^* + e^-$ (mainly ^{8}B, $\sim 2 \cdot 10^{-4}$; Be, CNO admixture)
$\nu_e + \mathrm{Ga} \rightarrow \mathrm{Ge}^* + e^-$ (main cycle $pp \rightarrow de^+\nu$, + Be + CNO)
The proof that flow deficit is not related with solar activity.

Super K

$\nu + e \rightarrow \nu + e \qquad \Phi_e + \frac{1}{6}\Phi_{\mu,\tau}$

SNO

$\nu_e + d \rightarrow 2p + e \qquad \Phi_e$
$\nu + e \rightarrow \nu + e \qquad \Phi_e + \frac{1}{6}\Phi_{\mu,\tau}$
$\nu + d \rightarrow p + n + e \qquad \Phi_e + \Phi_{\mu,\tau}$!
Full agreement with the standard solar model.
The important significance for stars evolution theory.

Reaction:
$t \rightarrow^3 \mathrm{He} + e^- + \bar{\nu}_e$
$m_\nu < 2.5$ eV (Troitsk, Mainz)
KATRIN project $\qquad m_i \simeq 0.5$ eV
Neutrinos are not responsible for dark matter existence.
Wilkinson Microvawe Anisotropy Probe (WMAP)
$\Sigma m_i < 0.7$ eV

CP and CPT tests

$\Delta P^{CP}_{\alpha\beta} = P(\nu_\beta \rightarrow \nu_\alpha) - P(\bar{\nu}_\beta \rightarrow \bar{\nu}_\alpha) \neq 0$?
$(\alpha, \beta = e, \mu, \tau)$

$\Delta P^{T}_{\alpha\beta} = P(\nu_\beta \rightarrow \nu_\alpha) - P(\nu_\alpha \rightarrow \nu_\beta) \neq 0$?
$\Delta P^{CP}_{\alpha\beta} = \Delta P^{T}_{\alpha\beta}$?
$\Delta P^{CP}_{\alpha\beta} \sim [sin^2 2\theta_{13}]^{\frac{1}{2}}$ $\qquad$ few percent level.

PROBLEMS

- How many neutrinos are there? Do sterile neutrinos exist?
- Majorana ($\bar{\nu}_i \equiv \ni_i$) or Dirac (ν_i nonequal $\ni_i$)? Conservation L?
- Masses of eighenstates. Why are they small? Why are the mixing angles large?
- CP violation in ν-oscillation?
- Elements of leptonic mixing matrix. $\sin^2 \theta_{13}$! → MNS (Maki-Nakagawa-Sakata)
- The electromagnetic properties of ν. Dipole moments?
- CPT invariance
- Was baryogenesis in early Universe made possible by leptogenesis (leptonic CP-violation)?
- Baryon symmetry of the Universe

The discovery of the oscillations led to the blossom of the neutrino studies. To resolve the problems arisen one needs new powerful neutrino sources (factories) with different energies, new big setups, new registration methods (photoemulsion). Such projects are in progress now. Many problems can be solved by means of new high-speed electronics via the method of the neutrino "marking" system (IHEP) even for experiments with long base.

The synthesis of particle physics and cosmology – one of the most important achievements of the science in the XX century

Ya. Zeldovich, L.Okun, S. Pikelner, estimate for the concentration of relic free quarks → confinement

Estimate for upper limit on neutrino mass

Estimate for the number of neutrino species (before Γ_Z measurements)

Estimate for monopole concentration → transformation of the Universe evolution scenario

Estimates for limits on values of electric and magnetic impulse of neutrino (Sun, white dwarfs)

The role of the Higgs boson in early Universe

Baryogenesis etc.

Cosmology and astrophysics raise the problems of the fundamental importance

1. The nature of dark matter in galaxies and clusters. Motion of stars at periphery, macrolensing. It was proved that dark matter has nonbaryon nature (primary nucleosynthesis, $D, {}^3He$, anisothropy of relic radiation, "'Boomerang", WMAP)

   Possible candidate – stable neutralino ($M > 37$ GeV). The searches on colliders and in the environment. Dark matter density distribution

   ~~[illegible]~~ $\rho \sim 1/R^2$?

   Are the gravitational laws correct?

2. Dark energy? The discovery of acceleration in expanding Universe (SNI-candles of teh Universe). $\ddot{a}/a = -\frac{4\pi G_N}{3}(\rho + 3P)$

   ~~[illegible]~~)

   It was shown that acceleration has substituted the deceleration.

   Negative pressue! $(\rho + 3P) < 0$

   Vacuum energy (cosmological constant)?

   $$p = -\epsilon$$

   Quintessence?

   $$p = \mu\epsilon \qquad \mu < -2/3$$

SN1 → Eur. project. N(SN1) × 100. !

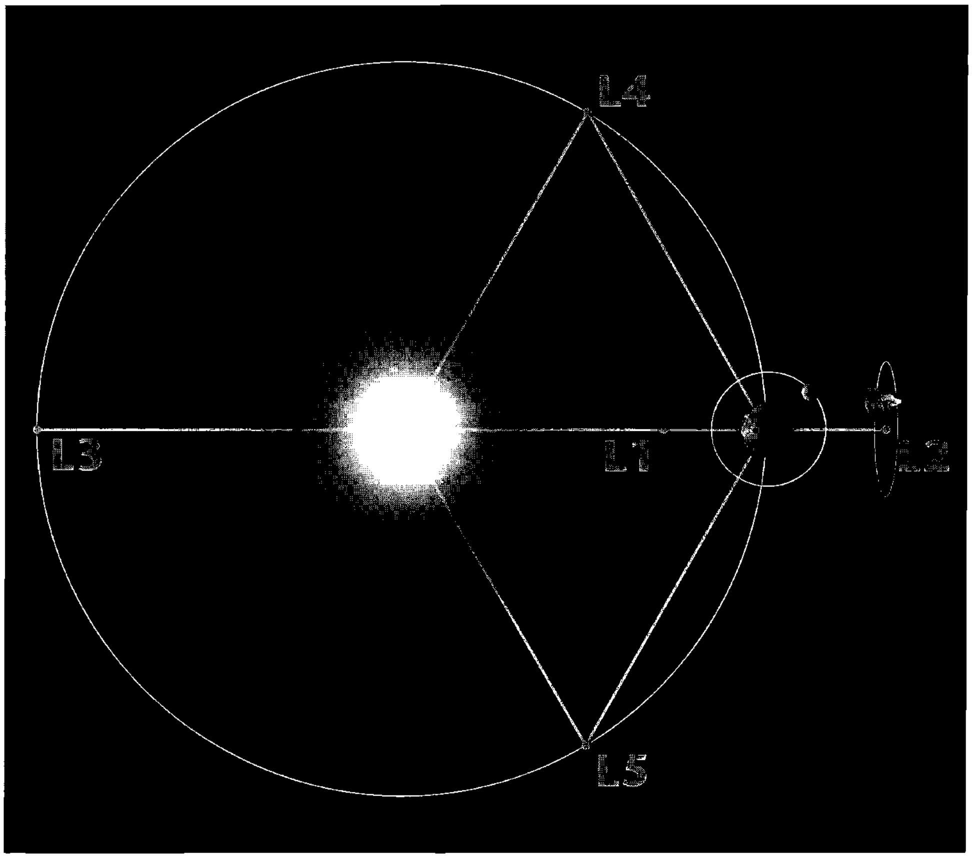
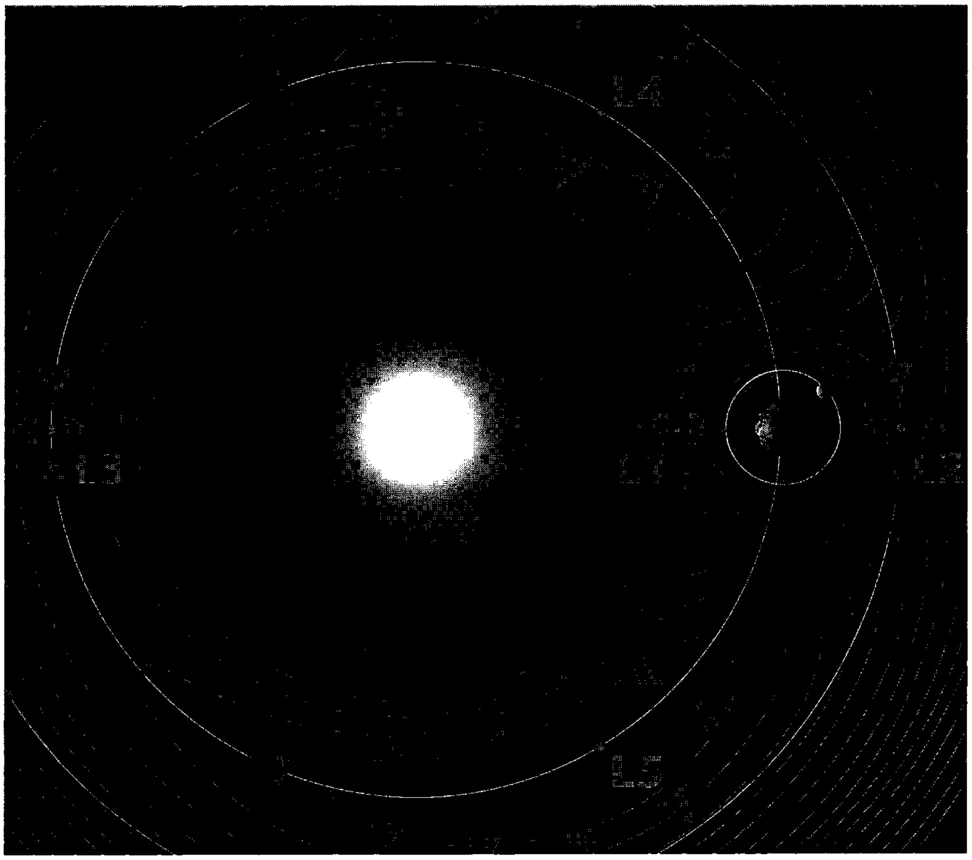
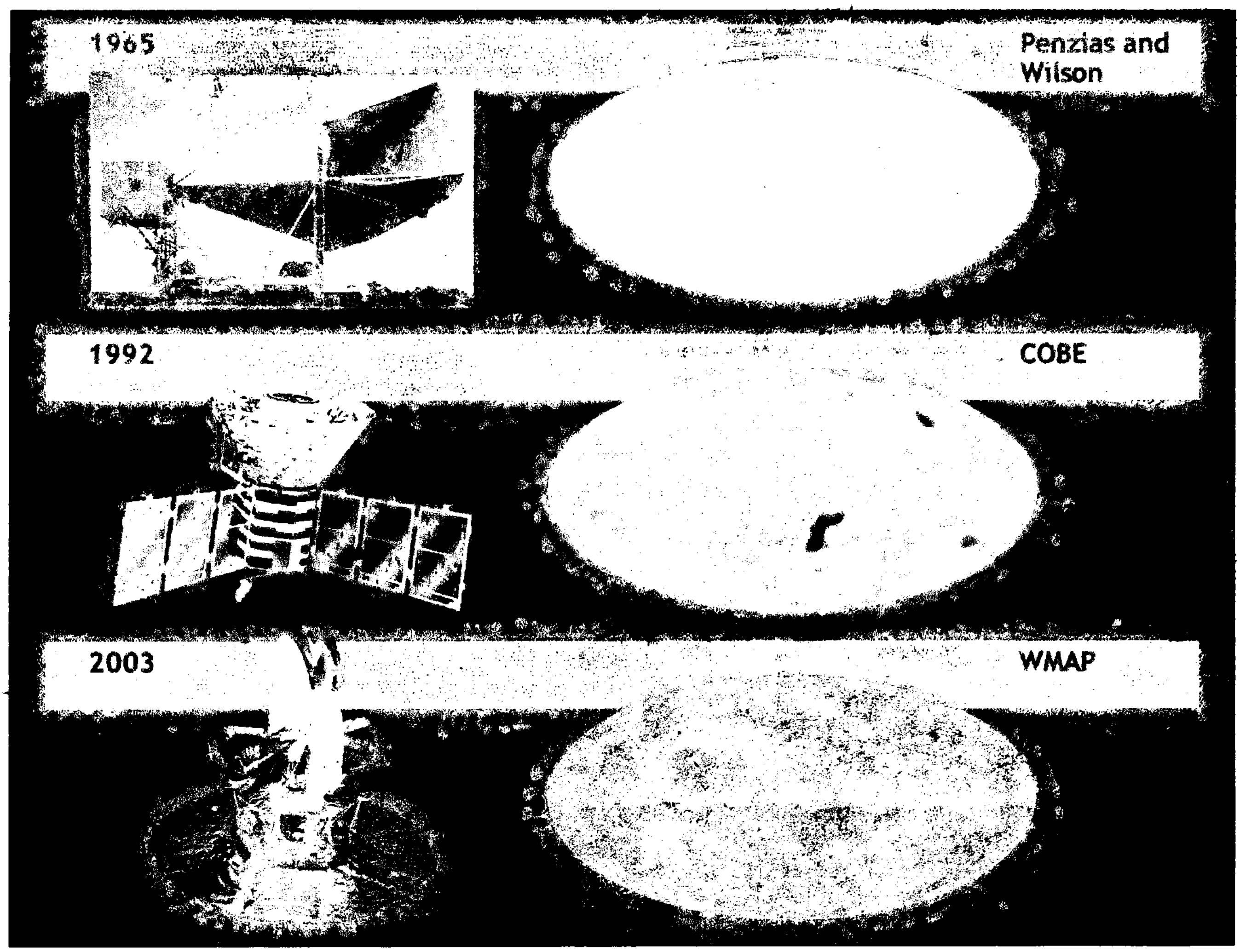


Diagram of the Lagrange Points associated with the Sun-Earth system. WMAP orbits <u>around L2</u>, which is about 1.5 million km from the Earth. Lagrange Points are positions in space where the gravitational forces of a two body system like the Sun and the Earth produce enhanced regions of attraction and repulsion. These can be used by spacecraft to reduce fuel consumption needed to remain in position.




1965
Penzias and Wilson
1992
COBE
2003
WMAP

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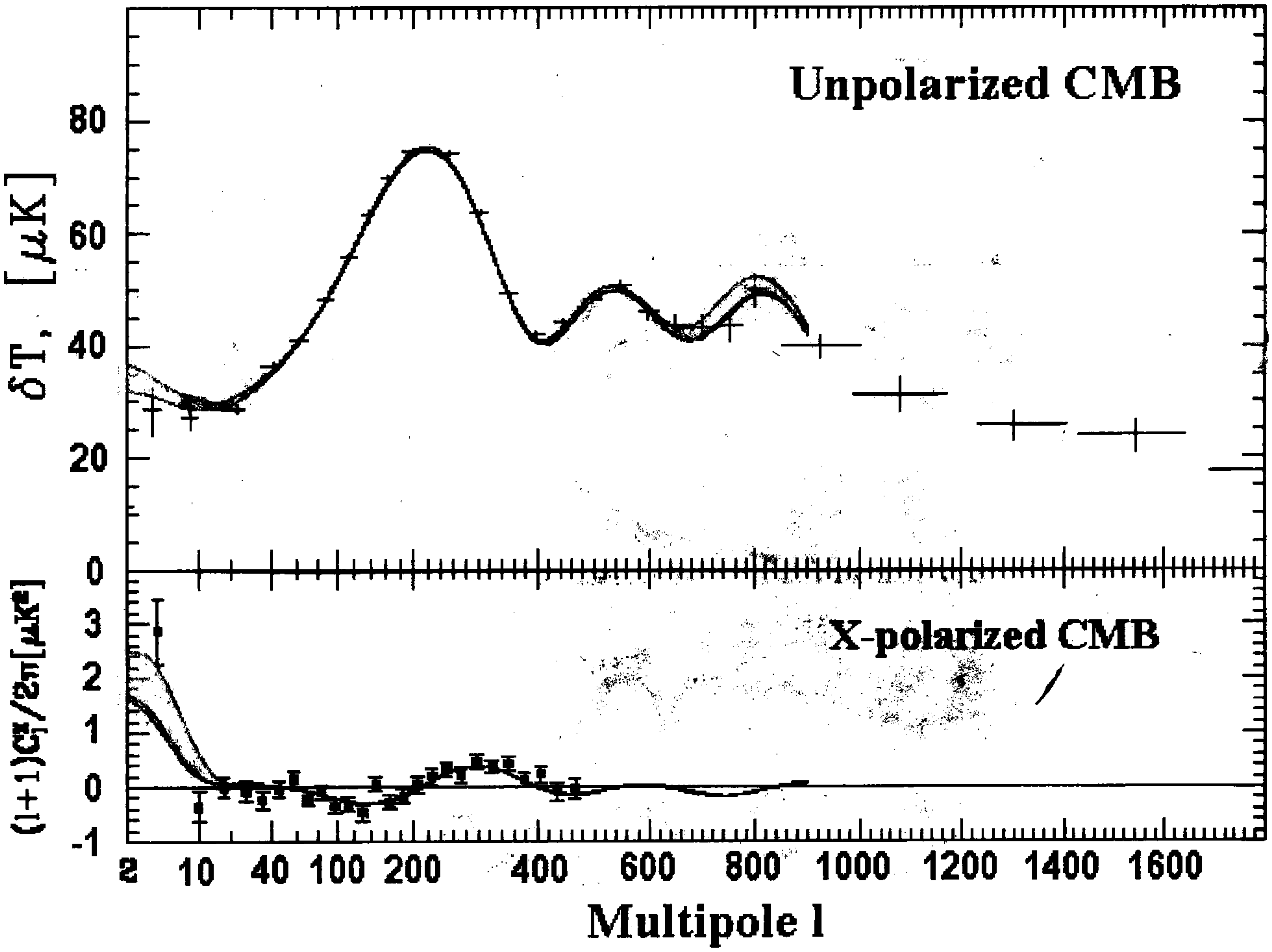
Unpolarized CMB
X-polarized CMB
δT, [μK]
(l+1)C$_l^X$/2π[μK^2]
80
60
40
20
0
3
2
1
0
-1
2
10
40
100
200
400
600
800
1000
1200
1400
1600
Multipole l

Description	Symbol	Value	+ uncertainty	− uncertainty
Total density	Ω_{tot}	1.02	0.02	0.02
Equation of state of quintessence	w	< -0.78	95% CL	—
Dark energy density	Ω_Λ	0.73	0.04	0.04
Baryon density	$\Omega_b h^2$	0.0224	0.0009	0.0009
Baryon density	Ω_b	0.044	0.004	0.004
Baryon density (cm^{-3})	n_b	2.5×10^{-7}	0.1×10^{-7}	0.1×10^{-7}
Matter density	$\Omega_m h^2$	0.135	0.008	0.009
Matter density	Ω_m	0.27	0.04	0.04
Light neutrino density	$\Omega_\nu h^2$	< 0.0076	95% CL	—
CMB temperature (K)[a]	T_{cmb}	2.725	0.002	0.002
CMB photon density (cm^{-3})[b]	n_γ	410.4	0.9	0.9
Baryon-to-photon ratio	η	6.1×10^{-10}	0.3×10^{-10}	0.2×10^{-10}
Baryon-to-matter ratio	$\Omega_b \Omega_m^{-1}$	0.17	0.01	0.01
Fluctuation amplitude in $8h^{-1}$ Mpc spheres	σ_8	0.84	0.04	0.04
Low-z cluster abundance scaling	$\sigma_8 \Omega_m^{0.5}$	0.44	0.04	0.05
Power spectrum normalization (at $k_0 = 0.05$ Mpc^{-1})[c]	A	0.833	0.086	0.083
Scalar spectral index (at $k_0 = 0.05$ Mpc^{-1})[c]	n_s	0.93	0.03	0.03
Running index slope (at $k_0 = 0.05$ Mpc^{-1})[c]	$dn_s/d\ln k$	−0.031	0.016	0.018
Tensor-to-scalar ratio (at $k_0 = 0.002$ Mpc^{-1})	r	< 0.90	95% CL	—
Redshift of decoupling	z_{dec}	1089	1	1
Thickness of decoupling (FWHM)	Δz_{dec}	195	2	2
Hubble constant	h	0.71	0.04	0.03
Age of universe (Gyr)	t_0	13.7	0.2	0.2
Age at decoupling (kyr)	t_{dec}	379	8	7
Age at reionization (Myr, 95% CL))	t_r	180	220	80
Decoupling time interval (kyr)	Δt_{dec}	118	3	2
Redshift of matter-energy equality	z_{eq}	3233	194	210
Reionization optical depth	τ	0.17	0.04	0.04
Redshift of reionization (95% CL)	z_r	20	10	9
Sound horizon at decoupling (°)	θ_A	0.598	0.002	0.002
Angular size distance (Gpc)	d_A	14.0	0.2	0.3
Acoustic scale[d]	ℓ_A	301	1	1
Sound horizon at decoupling (Mpc)[d]	r_s	147	2	2

52)

Mesurements of the angle anisothropy of relic radiation (Boomerang, WMAP). The nature of anisothropy at angles $\leq 1^o$. (R. Sunaev, Ya. Zeldovich, 1970)

3.

Oscillation of the hot (e^-, p) plasma up to hydrogen recombination and appearance transparency $(Z \sim 1000)$

$$\frac{\Delta T}{T} \qquad \Delta T \sim 10^{-5} K$$

$$f(\theta) = \sum_l a_l P_l(\cos\theta)$$

The Sakharov oscillations (named by Zeldovich)

By peak locations and their heights one can determine many cosmological parameters (model dependence)

Relative density of the baryon matter is determined by the scattering of relic photons on electrons in the final stage of recombination. There is an agreement with the data on primary nucleosynthesys.

Thus, all we did before is about 3-5% of Universe mass. Dark matter together with baryon one is about 30%. Dark energy is about 70%.

Reciting A. Puankare: “But not all realize this” etc.

This is a problem of the XXI century to solve this puzzle. The methods are the combination of accelerator and non-accelerator experiments with the data from cosmology.

Previously we used to say that the Universe is an accelerator for poor people. Now it becomes the accelerator for reach ones. The task for physicists is to provide the cosmological research with adequite and precise technique.

Cosmic Rays

D.W. Skobelzin

$\mathcal{E} \simeq 10^{20}$ ev ?! If is?

ZKG - Cut !

$L \simeq 20-50$ Mps. ?

Isotropy ?

Kuzmin, Rubakoff: $M \gtrsim 10^{22}$!

—*—

② Baikal

Amanda

$n \to \bar{n}$ oscil. (Ampl.)

Sun expl. ~ 10^{33} n, SN → n

$n \to \bar{n}$

$\quad\hookrightarrow \bar{p} + e^{+}\nu$

$\qquad\hookrightarrow$ stable.

$\bar{p}$ $\quad\varepsilon \approx 50 \div 100$ MeV ?

A.E. Chudakov