Extra dimensions of space and time
in the region of deeply inelastic processes

Boris Levchenko, SINP MSU

- Estimate of the speed of virtual photons from the Heisenberg's inequalities

- HERA data, superluminal photons and difficalties caused by the condition: $\boldsymbol{\beta^* \to 1}$ at $\boldsymbol{Q^2 \to 0}$ (real photons limit)

- What is the geometry of phase space?

- 2T-physics: one extra timelike and one extra spacelike dimensions

    - Interpretation and a solution of the normalization problem

- Summary

Motivation

«The effective quark radius limits», ZEUS collab., HERA

Phys. Lett. B757 (2016) 468, arXiv:1604.01280

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{\rm SM}}{dQ^2}\left(1-\frac{R_e^2}{6}Q^2\right)^2\left(1-\frac{R_q^2}{6}Q^2\right)^2$$

$$-(0.47\cdot 10^{-16}\,{\rm cm})^2 < R_q^2 < (0.43\cdot 10^{-16}\,{\rm cm})^2$$

$$\bar{r}_q = \sqrt{|\langle R_q^2\rangle|} < 0.43\cdot 10^{-3}\,{\rm fm}$$

How to evaluate the radius using HUR? $\sqrt{(\Delta R)^2 Q^2} \geq \hbar$ **?**

Is knowledge of only (x_{Bj}, Q^2) **enough ? It is not !**

Heisenberg's inequalities, reduction of degrees of freedom and new parameters

$\Delta p_x \cdot \Delta x \geq \hbar/2$

This is a secondary representation!

The primary view is as follows (**H.Weyl**):

$$(\Delta x)^2 = \int_{-\infty}^{+\infty} x^2 \bar{\psi}(x)\psi(x)\,dx, \qquad (\Delta p)^2 = -h^2 \int_{-\infty}^{+\infty} \bar{\psi}(x) \frac{d^2\psi}{dx^2} dx$$

$$\left.\begin{array}{rcl} (\Delta p_x)^2 (\Delta x)^2 & \geq & (\hbar/2)^2 \\ (\Delta p_y)^2 (\Delta y)^2 & \geq & (\hbar/2)^2 \\ (\Delta p_z)^2 (\Delta z)^2 & \geq & (\hbar/2)^2 \end{array}\right\} \longrightarrow \|(\Delta \mathbf{P})^{(2)}\| \, \|(\Delta \mathbf{R})^{(2)}\| \geq \frac{3\hbar^2}{4\cos\psi}$$

$$= (\Delta \vec{P})^{(2)} \cdot (\Delta \vec{R})^{(2)}$$

$\psi \in [0, \pi/2)$

$0 < \cos(\psi) \leq 1$

New variable

ψ

6 DoF → 3 DoF

Heisenberg's inequalities: II

In the same 1927 article, Heisenberg gives an uncertainty relation for another pair of canonically conjugate energy-time variables:

$$(\Delta E)^2 (\Delta t)^2 \geq \delta_H^2 \cdot \hbar^2 \qquad E_1 t_1 \sim h.$$

In relativistic domain $U_x \Delta p_x \Delta t \geq \delta_{LP} \cdot \hbar$ (Landay, Peierls, 1931)

U is group velocity

Similarly, adding the squares of the components with the vector $\vec{U}^{(2)} = ((U_x)^2, (U_y)^2, (U_z)^2)$, we obtain

$$\|\vec{U}^{(2)}\| \cdot \|(\Delta \vec{P})^{(2)}\| \cdot (\Delta t)^2 \sim 3 \delta_{LP}^2 \hbar^2 / \cos \psi_H$$

By taking the ratio,

$$\|U^{(2)}\| \geq A_t \frac{(\Delta E)^2}{\|(\Delta \vec{P})^{(2)}\|}$$

The speed estimate we are looked for !

Finally:

For the norm of group velocity

$$U^{*}_{lb} \sim \sqrt{\sqrt{3}\left\|U^{(2)}\right\|} = \sqrt{\sqrt{3}\, A_t \frac{(\Delta E)^2}{\left\|(\Delta \vec{P})^{(2)}\right\|}}$$

The **lower** bound !

From the Cauchy-Buniakowsky-Schwarz inequality

Finally:

For the norm of group velocity

A_t from the condition:
in the limit **$Q^2 \to 0$** GeV² **$U^* \to c$** should hold!
(a real photon limit)

$$U^*_{lb} \sim \sqrt{\sqrt{3}\,\|U^{(2)}\|} = \sqrt{\sqrt{3}\,A_t \frac{(\Delta E)^2}{\|(\Delta \vec{P})^{(2)}\|}}$$

The **lower** bound !

From the Cauchy-Buniakowsky-Schwarz inequality

$\|(\Delta \vec{P})^{(2)}\|$ and $(\Delta E)^2$ are obtained via indirect measurements.

Method of indirect measurements

Indirect measurement is a measurement in which the value of the unknown quantity sought is calculated from measurements of other quantities related to the measurand by some known relation.

For instance,

$$z = F(x, y), \quad (\Delta z)^2 = (\partial F/\partial x)^2 (\Delta x)^2 + (\partial F/\partial y)^2 (\Delta y)^2$$

In our study, we need to calculate $(\Delta E)^2$ and $\left|(\Delta \vec{P})^{(2)}\right|$

For DIS

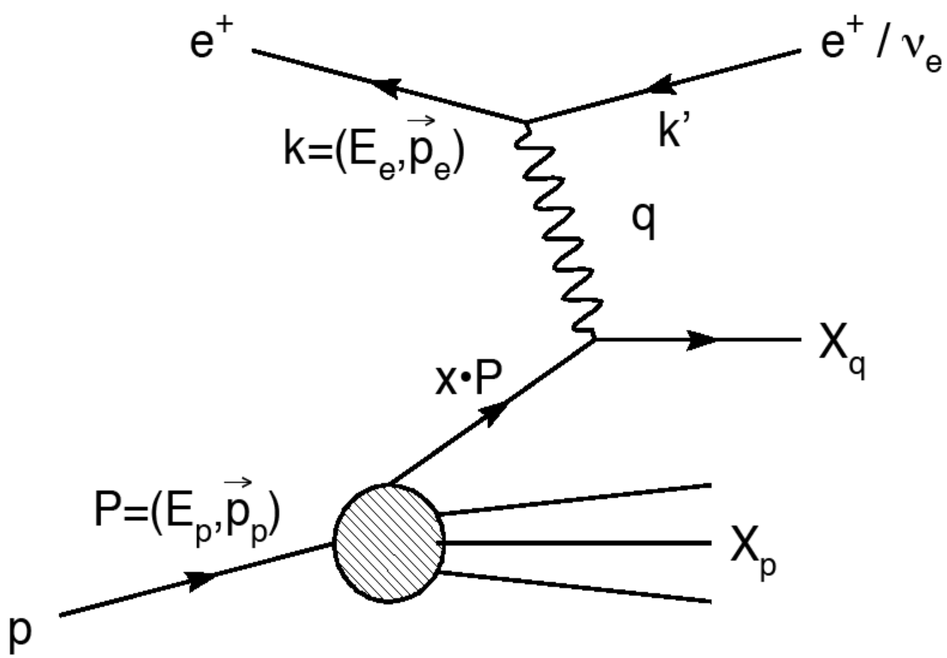
$$(\Delta E)^2 = \left(\frac{\partial E}{\partial x_{Bj}}\right)^2 (\Delta x_{Bj})^2 + \left(\frac{\partial E}{\partial y}\right)^2 (\Delta y)^2$$

$$(\Delta P)^2 = \left(\frac{\partial P}{\partial E}\right)^2 (\Delta E)^2 + \left(\frac{\partial P}{\partial Q^2}\right)^2 (\Delta Q^2)^2,$$

Chained relations

....

e±p DIS kinematics



$$Q^2 = -(k - k')^2$$

$$x_{Bj} = \frac{Q^2}{2P \cdot q}$$

$$y = \frac{P \cdot q}{P \cdot k}$$

HERA (1992-2007):
Energies
e± : 27.5 GeV
p : 820, 920, 575 and 460 GeV

At $Q^2 < 100$ GeV^2,
one-photon exchange
prevails in ep!

Data for Q^2 and X_{Bj} from Tables

«Combination of Measurements of Inclusive Deep Inelastic e± p Scattering Cross Sections and QCD Analysis of HERA Data» Eur. Phys. J. C 75 (2015) 580

Q^2 GeV^2	x_{Bj}	$\sigma^+_{r,NC}$	δ_{stat} %	δ_{uncor} %	δ_{cor} %	δ_{rel} %	
3.5	0.406×10^{-4}	0.806	6.14	4.17	1.18	1.09	-
3.5	0.432×10^{-4}	0.881	3.08	2.83	3.31	0.70	-
3.5	0.460×10^{-4}	0.965	3.05	2.99	1.10	0.35	-
3.5	0.512×10^{-4}	0.940	2.16	2.25	1.53	0.52	-
3.5	0.531×10^{-4}	0.880	3.10	2.64	0.91	0.48	-
3.5	0.800×10^{-4}	0.952	1.25	1.55	0.88	0.43	-
3.5	0.130×10^{-3}	0.918	0.66	0.86	0.80	0.45	-
3.5	0.200×10^{-3}	0.854	0.68	0.83	0.81	0.44	
3.5	0.320×10^{-3}	0.791	0.72	0.88	0.86	0.50	-
3.5	0.500×10^{-3}	0.749	0.76	1.17	0.89	0.37	-
3.5	0.800×10^{-3}	0.659	0.67	1.16	0.91	0.37	
3.5	0.130×10^{-2}	0.623	0.87	1.38	0.97	0.42	-
3.5	0.200×10^{-2}	0.568	0.51	0.87	0.85	0.44	-

Compromise combining data from the **ZEUS** and **H1** experiments

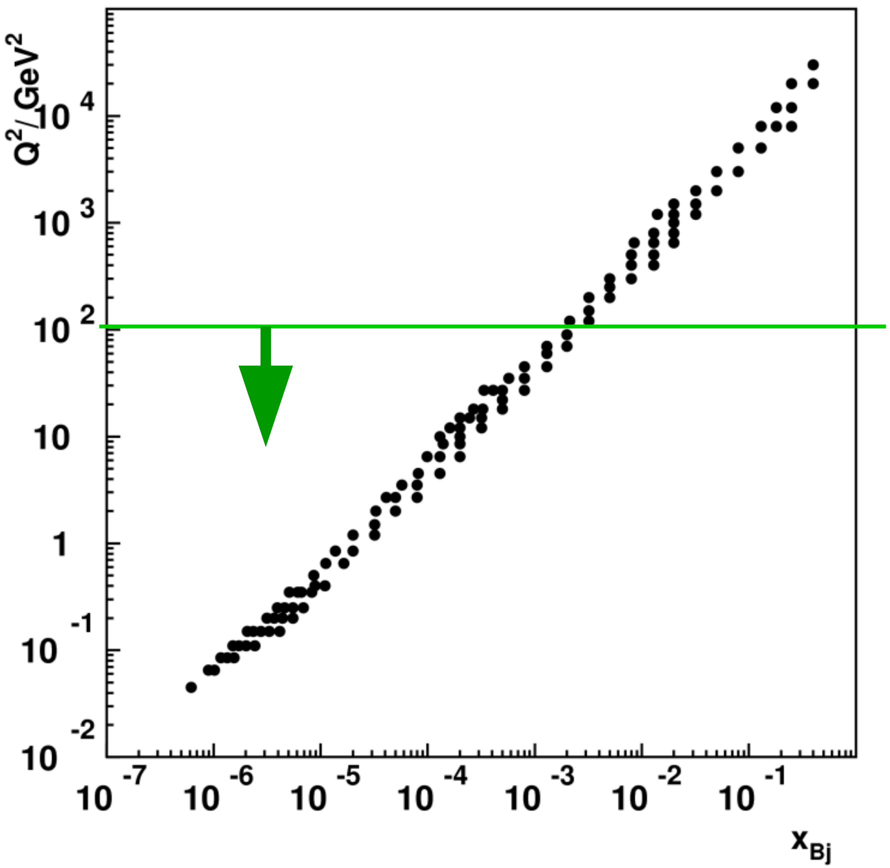
HERA data

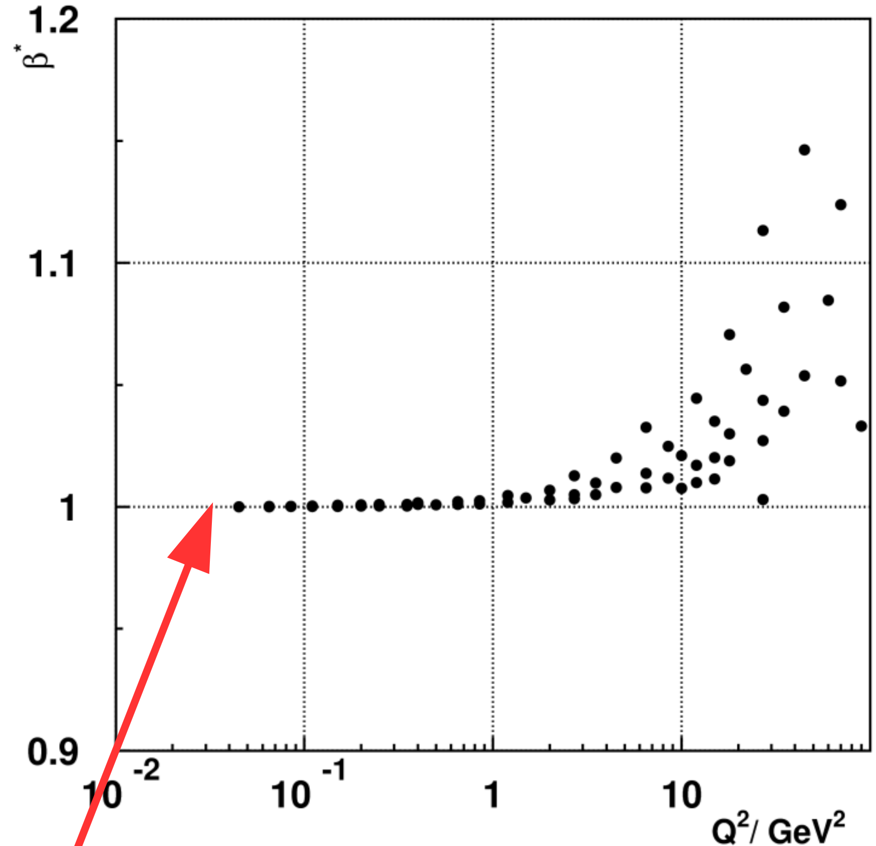
Each point (x, Q^2) is an average values in a bin on the (x, Q^2)-plane.

I present here results only for a small portion of data at Ep=820 GeV, NC, Table 11 !

Q^2 and x_Bj from Tables with the HERA data

Ep = 820 GeV, NC, table 11





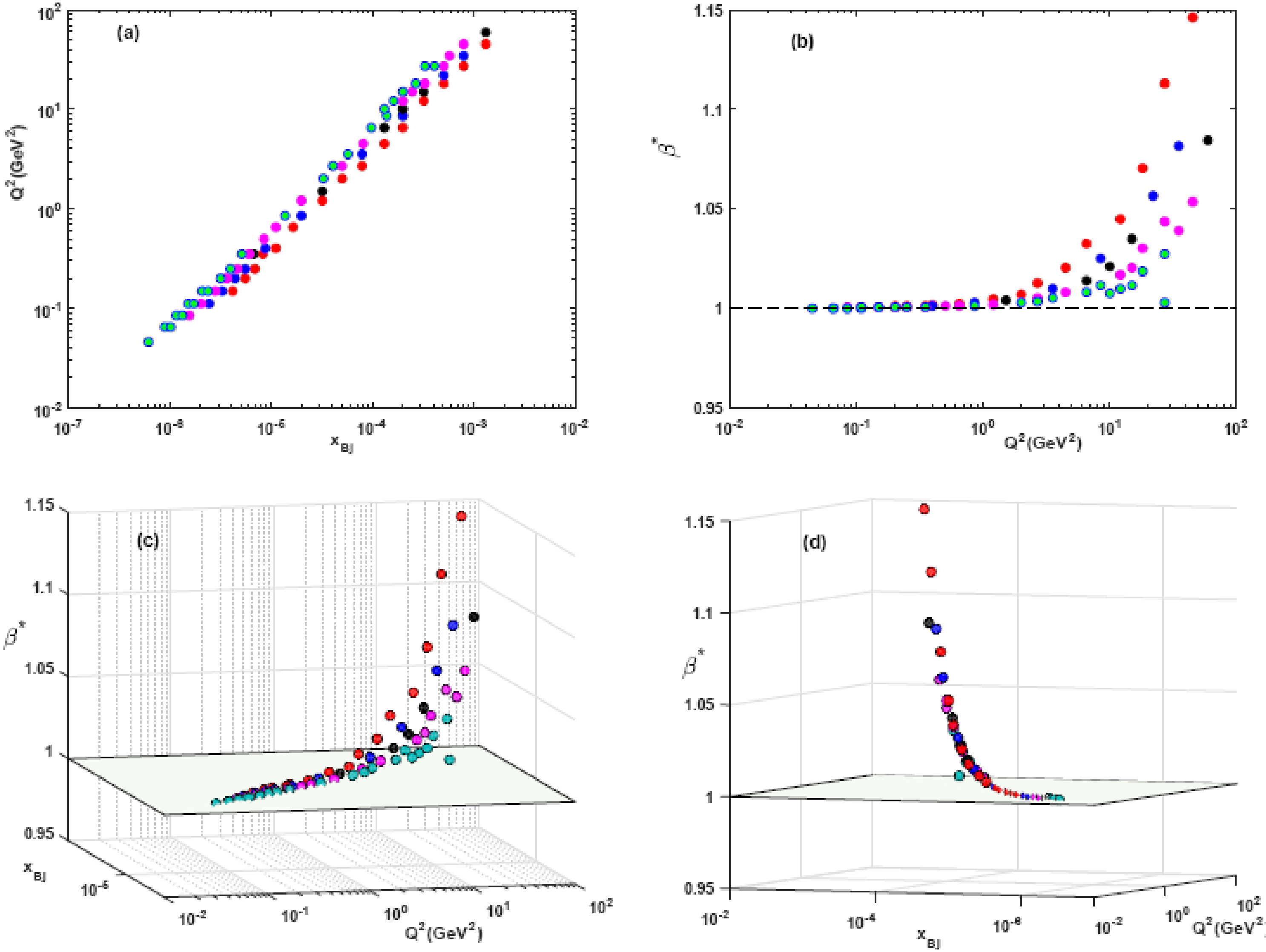
$Q^2 \to 0$ $\beta^* \to 1$ $\sqrt{3}\,A_t = 1$

$$\beta^* = \sqrt{\frac{(\Delta q_0)^2}{(c\,\Delta q)^2}}$$

Conclusion I

- Virtual photons are superluminal !

Another view



y windows
0.354−0.47 (red)
0.47−0.511 (blue)
0.511−0.598 (black)
0.598−0.676 (magenta)
0.676−0.951 (green)

Different colors indicate data with the inelasticity, y = Q2/xBj s, in the following intervals :
0.354−0.47 (red); 0.47−0.511 (blue); 0.511−0.598 (black); 0.598−0.676 (magenta); 0.676−0.951 (green)

A challenge !

$$A_t = \frac{\delta_{LP}^2}{\delta_H^2}\frac{3}{\cos\psi_H} \to A_t = \frac{3}{\cos\psi_H} \qquad \text{If} \qquad \frac{\delta_{LP}^2}{\delta_H^2} = 1$$

The normalization condition: $\sqrt{3}A_t = 1$

But $3\sqrt{3} \neq \cos\psi_H$ in Euclidean 3D part of the Minkowski space with the signature (+,-,-,-)=(1,3)!

A possible solution to this problem is
to "increase" the pseudo-Euclideanity of space,
say, a space with signature (2,2):

$$\cos\psi_H \to \cosh(\psi_H)$$

But this destroys the relativistic kinematics !

Lets look for another solution!!

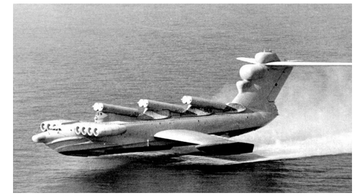
Ancient wisdom

Give me a firm spot on which to stand, and I will ....
Archimedes

Additional Dimensions of Space and Time

Kaluza–Klein (1,3+1), de Sitter (1,n), ...

«Лунь»



Доклады Академии наук СССР
1965. Том 163, № 4

РОБЕРТ ОРОС ди БАРТИНИ

НЕКОТОРЫЕ СООТНОШЕНИЯ
МЕЖДУ ФИЗИЧЕСКИМИ КОНСТАНТАМИ

(Представлено академиком Б. М. Понтекорво 23 IV 1965)

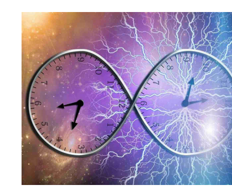
Robert Bartini (3,3)...

Superstrings: 10D ➔ M-theory, (2,10); F-theory, (2,10); S-theory , (2,11); (1,2) strings;
12D super Y-M

A lot of evidence has accumulated by now to convince oneself that the different versions of D =10 superstrings and their compactifications are related to each other nonperturbatively by duality transformations. There is evidence that the non-perturbative theory is hiding higher dimensions

The main difficalties of the T-like variable:

- **negative probabilities ("ghosts");**
- **violation of causality (paradoxes)**



"Treatment" by means of local gauge symmetry !

Additional timelike dimensions

Sakharov, Aref'eva-Volovich - The possibility of the cosmological emergence of additional time dimensions (no ghost modes in KK if T' in compact manifold, no Killing vector field), a solution Λ=0 in 4D.

Berndt Müller (hep-th/1001.2485) — HEP processes: a thermally excited T*, a small compactification radius, such a scenario is consistent with Kaluza-Klein type theories.

All above are at the Planck scale !

But our experimental data are collected at «low» energies

and

we need a theory with «large» extra timelike dimention(s) !

Symplectic properties are possessed by:

- Linear optics
- Classical mechanics
- Hydrodynamics
- Maxwell equations
- Lorentz transformations
- STR, GTR
- Quantum mechanics
- Field theory

Not well accounted by QFT !

Manifolds, phase space, symplecticity

Lagrange space: $M \oplus T_x M$

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}_j} - \frac{\partial L}{\partial q_j} = 0$$

General covariance principle

Phase space (Hamilton) $M \oplus T^*_x M$

$$\dot{q}^j = \frac{\partial H}{\partial p_j}; \quad \dot{p}_j = -\frac{\partial H}{\partial q^j}$$

Hamilton's eqs

$$Q^i = Q^i(q, p, t); P_i = P_i(q, p, t); i = 1, 2, \cdots, n$$

$$M = \begin{bmatrix} \frac{\partial Q}{\partial q} & \frac{\partial Q}{\partial p} \\ \frac{\partial P}{\partial q} & \frac{\partial P}{\partial p} \end{bmatrix}$$

Jacobian matrix

$$M J M^T = J \qquad \det M = 1$$

$$J = \begin{bmatrix} 0 & I \\ -I & 0 \end{bmatrix}$$

Almost a complex structure

$$J^2 = -I, J^T = -J$$

Geometry of the phase space is symplectic geometry.

Symplectic group Sp(2n) ---
a group of linear transformations that preserve the canonical form of the Hamilton equations, Poisson brackets and preserve the skew-symmetric 2-form.

$$\omega(a, b) = a \wedge b$$, a =(q,p), b =(q', p')

$$\omega(Ma, Mb) = \omega(a, b)$$

«symplectic diffeomorphism» ≡ Canonical transformation

In the quantum case, Sp(2n) preserves the commutation relations,

$$[\hat{a}_\alpha, \hat{a}_\beta] = i\hbar J_{\alpha\beta}$$

$Sp(2n,\mathbb{R})$ is a «big» group !!

$$\boldsymbol{Sp(2n,\mathbb{R}) \subset GL(n,\mathbb{R}) \subset O(n) \subset SO(n)}$$

$$n(2n+1) \qquad n^2 \qquad \frac{1}{2}n(n-1)$$

$$\boldsymbol{SU(n) \subset U(n) \subset Sp(2n,\mathbb{R})}$$

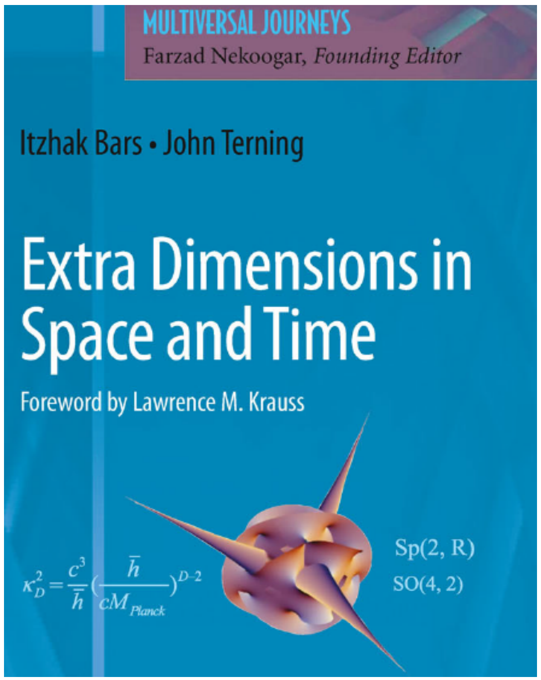
$$n^2-1 \qquad n^2 \qquad n(2n+1)$$

U(n) and SU(n) are the basics of the Standard Model : U(1)⊗SU(2)⊗SU(3)

«Two-Time Physics»: Itzhak Bars (USC)

1995-present University of Southern California, L-.A.

2010



Hints:

Superstrings: 10D ➔ M-theory, (2,10); F-theory, (2,10); S-theory , (2,11); (1,2) strings; 12D super Y-M

Ghosts and violation of causality

1T⇔ **special gauge symmetries**

The "magic" formula, "casting out ghosts" and opening the cherished box of a new theory, is

the local gauge symmetry Sp(2,R) in Ph-Sp !

Sp(2,R) makes equivalent (indistinguishable): $X^M \to P_M$ **and** $P_M \to X^M$

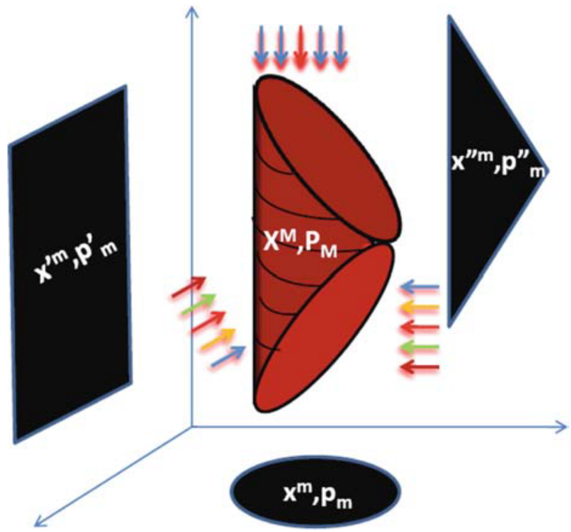
Global Sp(2, R) → Local gauge symmetry

$$p_i = \frac{\partial F_1}{\partial q_i} = Q_i,$$

$$P_i = -\frac{\partial F_1}{\partial Q_i} = -q_i$$

$$\begin{pmatrix} \tilde{X}^M(\tau) \\ \tilde{P}^M(\tau) \end{pmatrix} = \begin{pmatrix} a(\tau) & b(\tau) \\ c(\tau) & \frac{1+b(\tau)c(\tau)}{a(\tau)} \end{pmatrix} \begin{pmatrix} X^M(\tau) \\ P^M(\tau) \end{pmatrix}$$

2T - physics



PHYSICAL REVIEW D, VOLUME 62, 046007

Two-time physics in field theory

Itzhak Bars

PHYSICAL REVIEW D **74,** 085019 (2006)

Standard model of particles and forces in the framework of two-time physics

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(Received 16 June 2006; published 20 October 2006)

«there and back again»

International Journal of Modern Physics A
Vol. 25, No. 29 (2010) 5235–5252

GAUGE SYMMETRY IN PHASE SPACE CONSEQUENCES FOR PHYSICS AND SPACE–TIME*

ITZHAK BARS

PHYSICAL REVIEW D **82,** 045031 (2010)

Six-dimensional methods for four-dimensional conformal field theories

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(Received 30 June 2010; published 30 August 2010)

Allegorical representation relationship between 2T physics and 1T physics

2T physics in d+2 dimensions, spawns many "shadows/images", 1T-phenomena (physicist) in (D,1) dimension. D=d-1=3

Geometry of space-time
2T-physics: (1+1',D+1').

-The geometry of the phase space is everywhere locally symplectic.

.. both spinor and tensor Green's functions in 4D conformally-invariant field theories can be greatly simplified by six-dimensional methods.

Interpretation and solution of the problem $\sqrt{3}A_t = 1$

We postulate: Geometry of space-time is (1+1',3+1')

Minkowski, (1,3): $ds^2 = g_{\alpha\beta}\,dx^\alpha dx^\beta = \left(g_{ik}\beta^i\beta^k + g_{44}\right)dx_4\,dx_4$

The p-Euclidean part of $g_{\alpha\beta}$ is not involved in determining the speed of the particle.

Similarly, in S-T (2,4), (+,+,-,-,-,-) (Bars) $ds^2 = (c\,dt)^2 + (c\,d\tau)^2 - g_{ik}\,dx^i dx^k - dx\cdot dx$

Exta dim-s

DIS has a small spatial and temporal extent.

"Capture" of variables dx or dτ with the probability ~**α**, {dx, dτ} ~ **α²**
"Capture" of the old $\{dt, dx^i\}$ ~ **ω**.

Schematically: $\beta_H^2(t, x^1, x^2, x^3) \sim \omega \qquad \tilde{\beta}_H^2(t, x^i, x^j, x) \sim 3\alpha$

$$u_B^2(\tau, x^1, x^2, x^3) \sim \alpha \qquad \tilde{u}_B^2(\tau, x^i, x^j, x) \sim 3\alpha^2$$

In total: $\omega + 4\alpha + 3\alpha^2 = 1$ So, α=0 at ω=1.

Interpretation and solution of the problem $\sqrt{3}A_t = 1$

In this way $\beta^{*2}_{eff} = \sqrt{3}\left\langle \omega\cdot\beta^2_H\cdot A_H + 3\alpha\cdot\tilde{\beta}^2_H\cdot A_H + \alpha\cdot u^2_B\cdot A_B + 3\alpha^2\cdot\tilde{u}^2_B\cdot A_B \right\rangle$

Or at $Q^2=0$ $\quad 1 = \sqrt{3}A_{eff}, \quad \beta^2_H = \tilde{\beta}^2_H = u^2_B = \tilde{u}^2_B = 1$ $\qquad A_H = \frac{3}{\cos\psi_H}, \quad A_B = \frac{3}{\cos\psi_B}$

with $\quad A_{eff} = \omega\cdot A_H + 3\alpha\cdot A_H + \alpha\cdot A_B + 3\alpha^2\cdot A_B$

We solve equation

$$1 = 3\sqrt{3}\left\{\frac{1-\alpha-3\alpha^2}{\cos\psi_H} + \frac{\alpha+3\alpha^2}{\cos\psi_B}\right\}$$

with respect to α . Thus, in order to $\alpha \in (0,1)$

$\alpha > 0$, if $\quad \cos\psi_B > \cos\psi_H$

And, $\alpha < 1$, $\quad 3\sqrt{3} - \cos\psi_H < 12\sqrt{3}\left(1 - \frac{\cos\psi_H}{\cos\psi_B}\right)$

These are quite soft restrictions !

Conclusion II

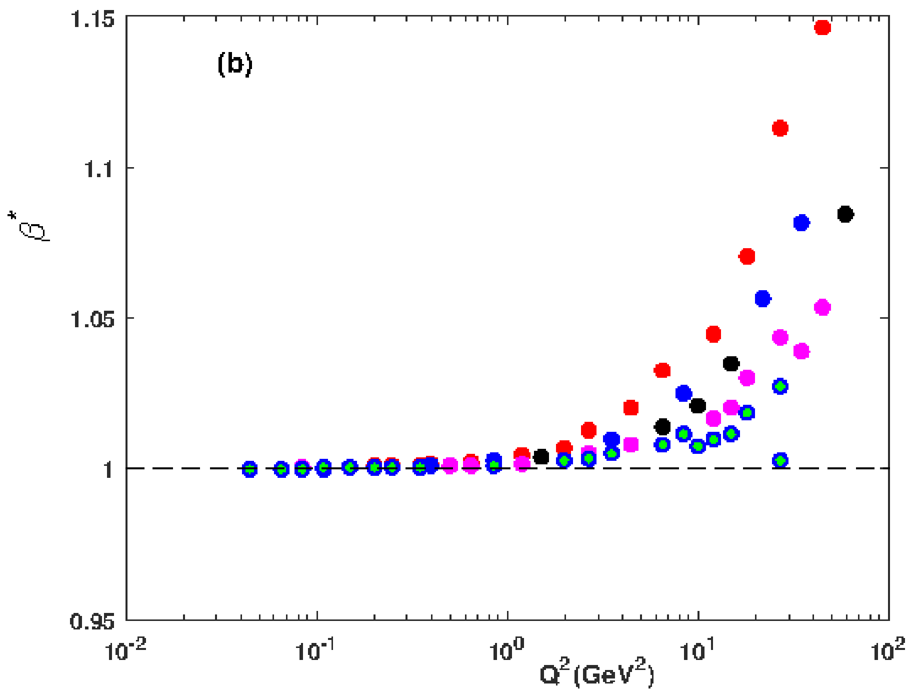
The equation $\sqrt{3}A_{eff}-1=0$ has a solution in the space-time volume with the signature (1+1',3+1').

The problem has no solution if only one extra dimension is added!

Summary I

► We have developed a general mathematical method based on quantum uncertainty relations and the theory of indirect measurements, which makes it possible to estimate the group velocity of virtual photons γ^* from the data for deep inelastic scattering processes.

► HERA data indicate that the group velocity of virtual photons, β^*, can exceed the speed of light in free space ($\beta^*>1$).



Summary II

► Superluminal speed, U*> c, means that virtual photons γ* have **tachyon-like** properties:

	Tachyon	Virtual photon
mass	$(m^*)^2 < 0$	$(m^*)^2 = -Q^2 < 0$
energy	$\epsilon < 0, > 0$	$q_0 < 0, > 0$
speed	$\beta^* \geq 1$	$\beta^* \geq 1$
	$\epsilon \to 0, \beta^* \to \infty$	$q_0 \to 0, \beta^* \to \infty$ (?)

► **The first particle from the tachyon family is identified.**

Summary III

► Within the framework of the theory of 2T-physics by I. Bars, a solution to the problem of the normalization condition, **$\beta^* \rightarrow 1$** at **$Q^2 \rightarrow 0$** GeV^2, is found.

(2T-physics: QFT in phase-space with the local Sp(2,R) gauge symmetry and the space-time of signature (1+1', 3+1'))

► It is shown that the "admixture" of extra time and extra space dimensions in DIS processes makes it possible to explain the normalization condition $\sqrt{3}A_{eff}=1$ as observed in the «Minkowski» space.

Thank's for Your Attention!

A quotation from Gell-Mann

(Once you have a consistent theory),

Anything which is not forbidden is compulsory !

Backup slides

The Cauch-Buniakowsky-Schwarz inequality is the statement

$$(a_1^2+ a_2^2 + a_3^2 + \cdots + a_n^2)\,(b_1^2+ b_2^2 + b_3^2 + \cdots + b_n^2) \geq (a_1 b_1 + a_2 b_2 + a_3 b_3 + \cdots + a_n b_n)^2$$

Now let set all b_i=1, n=3 and $a_1 = a^2, a_2 = b^2, a_3 = c^2$.
Let vectors are with components $\overrightarrow{u}$ = (a,b,c) and $\overrightarrow{V^2} = (a^2, b^2, c^2)$.

So, $(a^2+b^2+c^2)^2 \leq 3[(a^2)^2 + (b^2)^2+(c^2)^2] \rightarrow u^2 \leq \sqrt{3(\overrightarrow{V^2})^2} \rightarrow |u| \leq \sqrt{\sqrt{3}|\overrightarrow{V^2}|}$

	x1	x2	x3	x	t	τ
p1	$(\Delta p_1)^2 \cdot (\Delta x_1)^2 \geq (\frac{\hbar}{2})^2$	0	0	α	0	0
p2	0	$(\Delta p_2)^2 \cdot (\Delta x_2)^2 \geq (\frac{\hbar}{2})^2$	0	α	0	0
p3	0	0	$(\Delta p_3)^2 \cdot (\Delta x_3)^2 \geq (\frac{\hbar}{2})^2$	α	0	0
p	α	α	α	α^2 $(\Delta p)^2 \cdot (\Delta x)^2 \geq (\frac{\hbar}{2})^2$	0	0
E_t	0	0	0	0	$(\Delta E_t)^2 \cdot (\Delta t)^2 \geq (\delta_H \hbar)^2$	α
E_τ	0	0	0	0	α	α^2 $(\Delta E_\tau)^2 \cdot (\Delta \tau)^2 \geq (\delta_H \hbar)^2$

Some references

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- V.F.Perepelitsa, Looking for a Theory of Faster-Than-Light Particles, ArXiv:1407.3245v4 (2015)

E. Recami, a lot of papers

+ Search the word **«superluminal» ....** in **ArXiv**

III. Systems with an imaginary proper mass, i.e., $M^2 < 0$.

Systems of the third kind include the virtual particles of quantum theory of field.

Hence, the virtual particles appearing in the quantum theory of elementary particles can be considered as physically real particles with imaginary proper masses exchanged by ordinary elementary particles. **The introduction of such particles does not violate the second law of thermodynamics** and, consequently, we cannot violate the macroscopic Principle of Causality with their help. (**Y.P. Terletskii, 1966)**

Reinterpretation principle—interpretation of negative-energy tachyons propagating backward in time as positive-energy tachyons propagating forward in time. This reinterpretation invalidates causality objections to the possibility of existence of faster-than-light signals and permits construction of a consistent theory of tachyons.(**O. Belaniuk, E. Sudarshan)**

Stiickelberg-Feynman