Special Relativity and Strong Fields

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(with input from A-team: Martin Formanek and Chris M Grayson)

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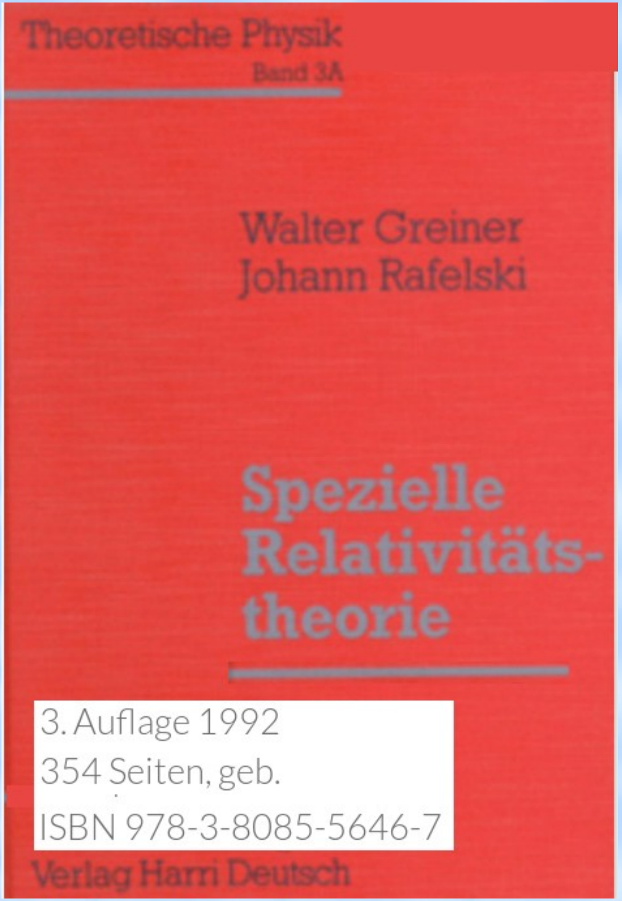
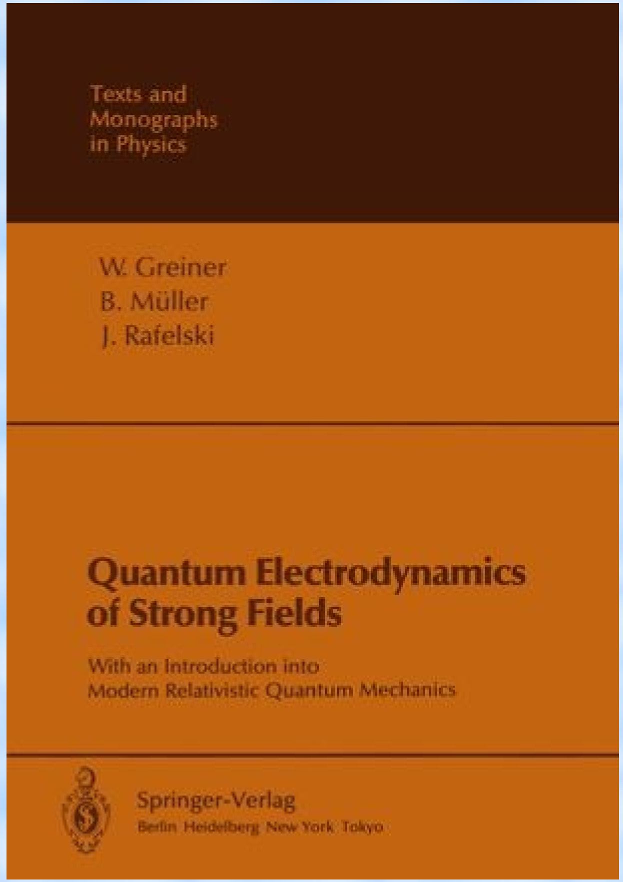
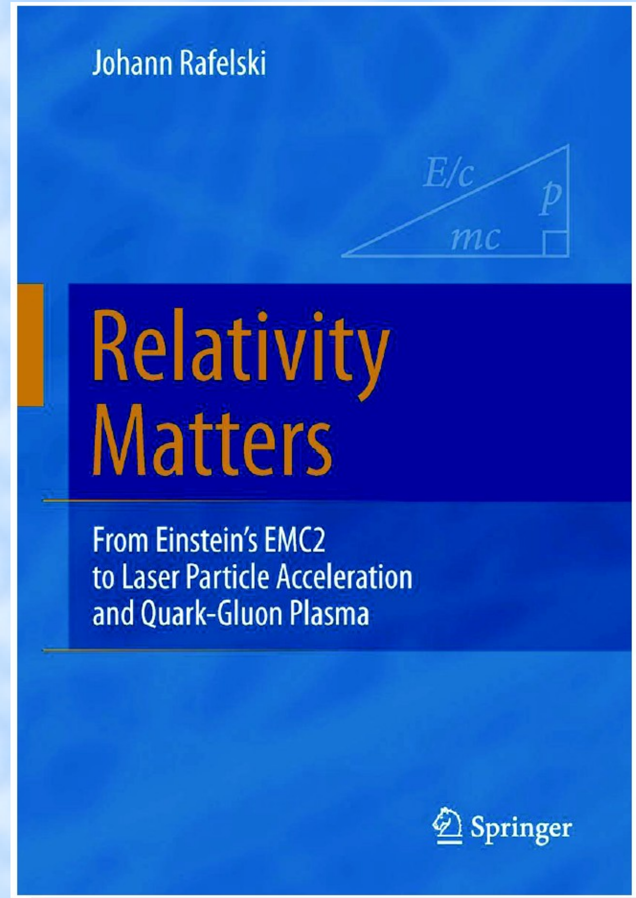
Special Relativity (SR) is the foundation of modern physics. SR is treated as a necessary insert, often omitted in the classroom or worse, misrepresented in books or lectures. Many do not correctly understand SR and related elementary physics phenomena. Examples will be given. The unfinished formulation of SR when forces are not gravity will be explained. *Strong EM fields will be introduced*

My QUALIFICATION: Long Interest in SR and StrongFields & illustrous teacher (Greiner)







EINSTEIN 1905 EXTENDED RELATIVITY PRINCIPLE TO BE VALID FOR EM (ONLY INERTIAL MOTION) AND LIGHT

Time recognized as a 4th coordinate

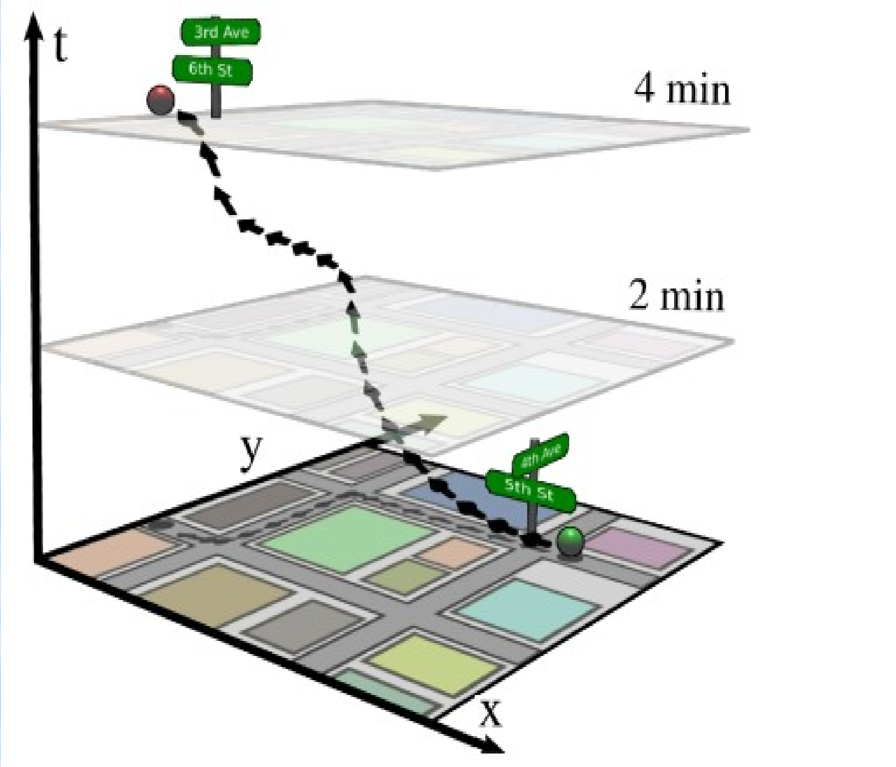


Fig. 1.2 A world line, shown here, of a four-minute walk from the corner of 4th Ave and 5th St to the corner of 3rd Ave and 6th St. Motion in the x, y, and time t dimensions is shown, with the z dimension suppressed (except for the street signs)

$$x' = \frac{x - vt}{\sqrt{1-(v/c)^2}}, \quad t' = \frac{t - (v/c^2)x}{\sqrt{1-(v/c)^2}} \, .$$

Lorentz Coord. Transformation

Set t=0: $$\boxed{x = \sqrt{1-(v/c)^2}\, x'}$$ x<x'

Observer measuring at their equal time report event separation consistent with 'contraction'

$$x' = x\sqrt{1-(v/c)^2} - t'v, \quad t' = t\sqrt{1-(v/c)^2} - \frac{x'v}{c^2} \, .$$

Larmor's form of the Lorentz transformation

Set x'=0: $$\boxed{t' = t\sqrt{1-(v/c)^2}}$$ t'<t

Clock sticking to a body measures shorter time: time dilation

Each body has its proper time

Teaching SR ask students about body contraction: I offer a choice

What is "Lorentz contraction":

Some say space is contracted. Can this be true? NO

Other say this is distance contraction. What is this?

A few claim this is "apparent" body contraction. Apparent?

Einstein wrote a "response" in 1911 explaining that his and Lorentz views in this matter **agree**: body contraction is real (*in the same way kinetic energy and momentum of a car is real even if it is zero for the driver).*

Before Gravity Relativity (GR) in 1911 nobody would confound properties of material body with space-time. GR changes space time and confounds thinking about the real "S" relativity theory!

Issues in teaching & learning Special Relativity

- A claim of a "paradox", or "not real", *means lecturer does not understand SR*
- Students: choose SR sources carefully, *lots of bad stuff around (many false internet prophets)*
- Remember: "S" R is a **bigger unfinished theory** compared to GravityR; *GR does not supersede but complements SR (bad name choice)*

SR in 1905 format is "incomplete": *allows inertial motion only*

Beware of qualitative arguments: **SR is very subtle.**

SR is evolving: we use it daily in situations where *strong forces are relevant and are trying fix-ups.*

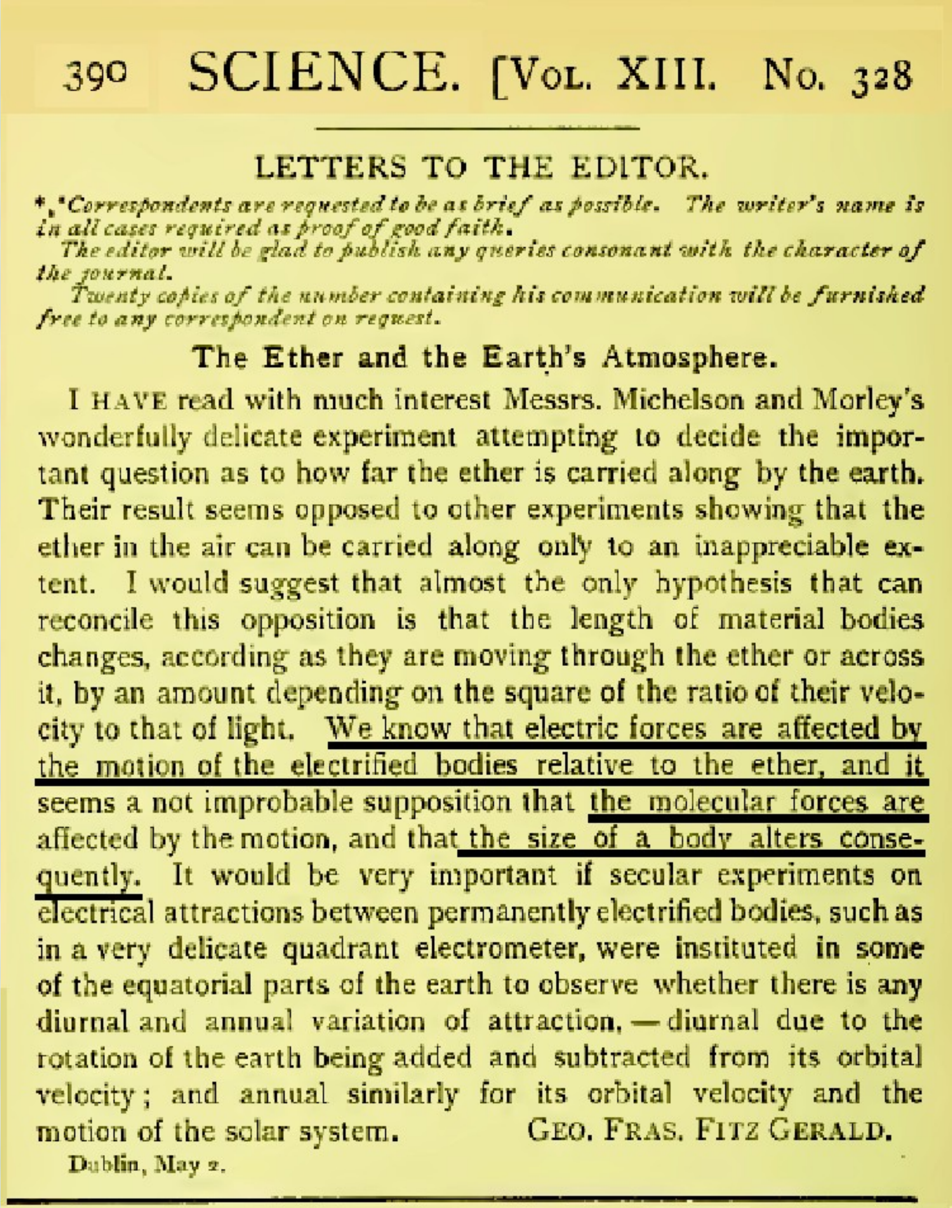
LIST OF challenges->

1: WHAT IS CONTRACTED?

Q: Is the "Lorentz contraction" that of space or of a body? Frequent wrong reply ***space is contracted -- WRONG***! *SR does not address the properties of the space-time in which we live. Gravity Relativity (GR) looks at this question generalizing Newton's law of gravity to strong field and relativistic context.* The fact that one inertial observer (IO) measures event coordinates that are different from those measured by another IO does not mean that there is a change of the space-time manifold.

A: The Lorentz-Fitzgerald (LFG) body contraction cannot be a contraction of space – *nor is it correct to speak of "distance" contraction:* space and time are not impacted in any way in SR; in particular, they are not impacted by the inertial motion of particles or extended material bodies.

It is better to always speak of "**body contraction**," rather than simply "contraction" and to include **Lorentz-Fitzgerald (LFG) to avoid confusion with Lorentz this and that**



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LETTERS TO THE EDITOR.

*** Correspondents are requested to be as brief as possible. The writer's name is in all cases required as proof of good faith.*

The editor will be glad to publish any queries consonant with the character of the journal.

Twenty copies of the number containing his communication will be furnished free to any correspondent on request.

The Ether and the Earth's Atmosphere.

I HAVE read with much interest Messrs. Michelson and Morley's wonderfully delicate experiment attempting to decide the important question as to how far the ether is carried along by the earth. Their result seems opposed to other experiments showing that the ether in the air can be carried along only to an inappreciable extent. I would suggest that almost the only hypothesis that can reconcile this opposition is that the length of material bodies changes, according as they are moving through the ether or across it, by an amount depending on the square of the ratio of their velocity to that of light. We know that electric forces are affected by the motion of the electrified bodies relative to the ether, and it seems a not improbable supposition that the molecular forces are affected by the motion, and that the size of a body alters consequently. It would be very important if secular experiments on electrical attractions between permanently electrified bodies, such as in a very delicate quadrant electrometer, were instituted in some of the equatorial parts of the earth to observe whether there is any diurnal and annual variation of attraction, — diurnal due to the rotation of the earth being added and subtracted from its orbital velocity; and annual similarly for its orbital velocity and the motion of the solar system. GEO. FRAS. FITZ GERALD.

Dublin, May 2.

First was FitzGerald

Since practically all books attribute body contraction to Lorentz I keep Lorentz name but factually FitzGerald was way ahead in 1889 and **Lorentz** once aware renamed the body contraction as **FitzGerald body contraction**. The problem was and is: names stick. Lorentz also gets the credit for coordinate transformation he never derived (it was correctly and independently obtained by Larmor, Einstein, Poincare…..)

Is a passenger on a relativistic rocket aware s/he is "body contracted"?

A. Einststein 1911: *No - there is no absolute reference frame in the Universe, s/he cannot know against what she contracts.*

J. S. Bell 1976 of “Bell inequality fame”: *adapts Lorentz-Janossy reality point of view: using acceleration he transports IO from one to another reference frame. First attempts to allow for acceleration effects in SR are discussed by Langevin*

CERN 1985 March 12

Dear Johann, the only thing I can thoroughly recommend on relativity is my own paper. I enclose a copy. I refer there to the book of Janossy. But it is very long, and insufficiently explicit that the Einstein approach is perfectly sound, and very elegant and powerful, (but pedagogically dangerous, in my opinion).

best wishes

John

Bell rockets: Spatial distance vs body length

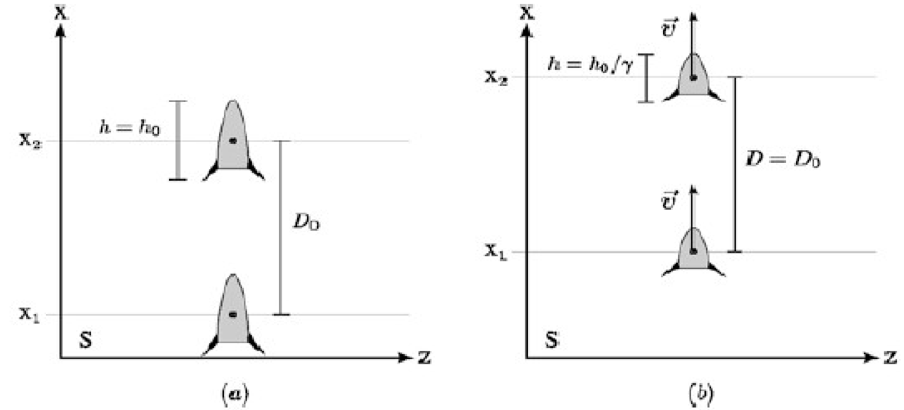

Fig. 10.2 Two rockets of length h separated by distance $D = x_2 - x_1 = D_0$. (a) at rest, and in case (b) moving at velocity $\vec{v}$ acquired at a later time

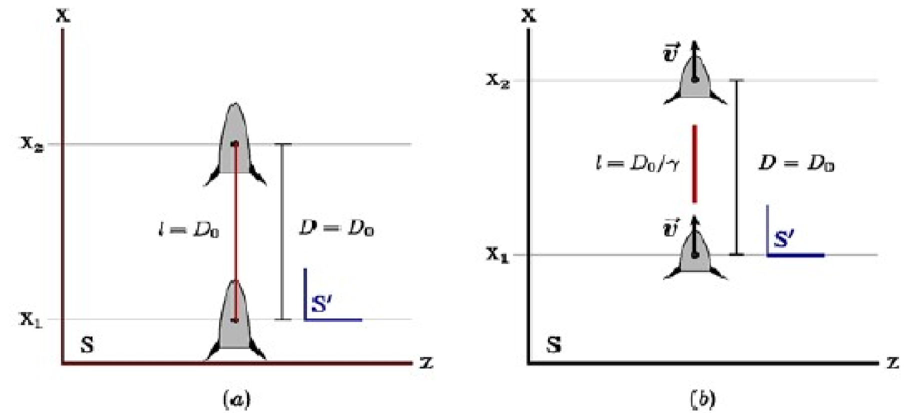

Fig. 10.3 Two rockets separated by distance $D = x_2 - x_1 = D_0$ and connected by a thin thread of (a) at rest, and in case (b) moving at velocity $\vec{v}$ acquired at a later time

Building a clock for LFG body contraction

J. S. Bell 1976 moves using acceleration the finite size rod connecting rockets from one to another inertial frame of reference. Spatial distance between rockets is preserved, so if rod is replaced by thread, the spool releases and winds up the thread.

As we move rockets between different inertial frames of reference we can wind and unwind rocket connecting thread creating a “clock” for LFG body contraction.

2: The LFG body contraction is real

Even if today the LFG body contraction has not been measured directly it is very real. While LFG body contraction “clock” does not exist today, it can be build based on Bell “rockets”. This assures that, like time dilation, the body contraction is real and can be measured. In fact we can measure LFG body contraction “tomorrow”:

Footnote remarks: Sometimes it is argued that the Michelson-Morley interferometer does not allow to measure absolute motion due to LFG body contraction and thus it is a measurement of LFG. However: MM experiment proves the principle of relativity for EM phenomena of which LFG body contraction is a consequence, and not an explanation.

Eur. Phys. J. A (2018) 54: 29
DOI 10.1140/epja/i2018-12370-4

Letter

THE EUROPEAN PHYSICAL JOURNAL A

Measurement of the Lorentz-FitzGerald body contraction

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Dedicated to Walter Greiner; October 1935 – October 2016.

Published online: 20 February 2018

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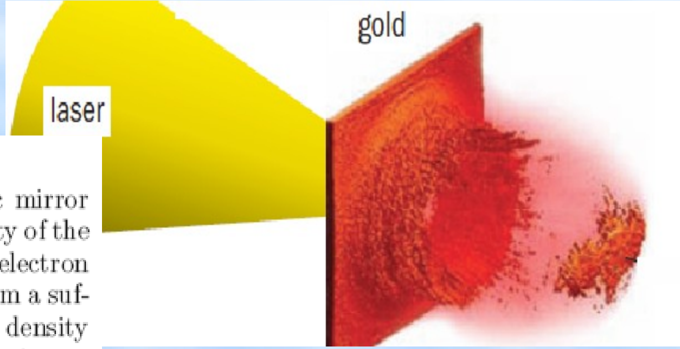
Abstract. A complete foundational discussion of acceleration in the context of Special Relativity (SR) is presented. Acceleration allows the measurement of a Lorentz-FitzGerald body contraction created. It is argued that in the back scattering of a probing laser beam from a relativistic flying electron cloud mirror generated by an ultra-intense laser pulse, a first measurement of a Lorentz-FitzGerald body contraction is feasible.

The moving electron cloud mirror is body compressed.



Body contraction experiment. — To accomplish our goal to build a laboratory-sized experiment we consider an ultra-intense ultra-short laser pulse shot at a thin (micron) foil. Such a pulse in its focal point can act as a micron-sized hammer pushing out of the foil an electron cloud accelerated to ultrarelativistic motion with a high value of Lorentz-factor γ_e. The emerging electron cloud compared to the original foil thickness will be Lorentz-FitzGerald compressed by γ_e.

A moving electron cloud acts as a relativistic mirror for a low intensity laser light bounce. The capability of the ultrarelativistic mirror to function depends on the electron cloud density; laser light can scatter coherently from a sufficiently high density cloud – what is low and high density is determined by comparing mean electron separation to the light wavelength.

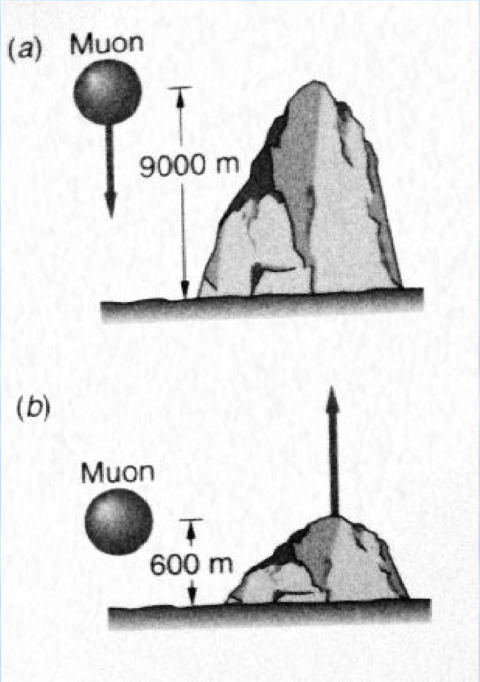
two Lorentz transforms, first into the rest-frame of the mirroi and upon reversal of the propagation direction of the ligl motion, transform back to the laboratory frame.

MU 3: The LFG body contraction and time dilation confirm each other??

In SR both the Lorentz-FitzGerald (LFG) body contraction, and time dilation are **unrelated body property phenomena** (unlike energy and momentum which are related). That they are unrelated is easily recognized by remembering that an elementary point particle (*e.g.* a muon) can experience time dilation but cannot experience a LFG body contraction.

Footnote remarks: A finite size body is often introduced in a discussion of time dilation to facilitate concurrent observation of some evidently unrelated LFG body contraction: Since an unstable particle (e.g. muon) experiences time dilation irrespective of another finite size material body being present, this motivates a frequently made claim that the two effects, body contraction and time dilation, confirm each other. This is a logically incorrect line of argument: this claim depends on a material body that is not required in the study of *e.g.* the unstable particle flight distance.

NO»NO»NO»



UNSTABLE PARTICLE TRAVEL RANGE

Imagine you perform muon range measurement in intergalactic empty space so there is no LFG body contraction of anything. Using time dilation:

$$c^2\tau^2 = (1 - v^2/c^2)\ c^2 t^2$$

AND LORENTZ-INVARIANCE OF PROPER TIME:

$$c^2\tau^2 = c^2 t^2 - x^2$$

$$x^2 = c^2 t^2 - c^2\tau^2$$

$$x^2 = v^2\tau^2 / (1 - v^2/c^2)$$

Which is to be read: for an inertial observer seeing the muon travel at velocity v the the muon travels the Lorentz extended distance x.

4: LFG BODY CONTRACTION IS NOT REVERSIBLE

"Contraction reversal paradox" does not exist but is created as follows: we look at a long train starting to accelerate at a station entering a shorter tunnel. Contacted rain will fit, the mountain in same inertial reference frame as station observer does not change size. But not so for a passenger on the train the mountain is approaching and is contracted, so train is too long!

What went wrong? The "station" observer measures at equal time in her frame of reference, the moving "train" observer in her frame of reference. Equal time is = simultaneity can only be maintained for one observer. The observer measuring at equal time ("equal time observer") always sees a moving object contracted. The correct way to argue is to note that a measurement at equal observer time reports two event separation consistent with the LFG body contraction.

5: Time dilation is NOT observer-reversible (no twin paradox)

Lorentz invariant quantities including the proper time of a body, are measured to be the same by all IO. Therefore, for each body only its proper time is a meaningful measure of time flow. The time measured by a clock at relative rest with that body:

$$c^2\tau^2 = c^2t^2 - x^2 = c^2t'^2 - x'^2 .$$

We see above: time measurement process must include a definition of how both space and time are measured. We are specifically not allowed to exchange the two twin time measurements without adjusting for associated difference in measurement of space coordinates.

Result: a returning space traveler is younger compared to his twin on Earth since it traveled a distance **x**. The twin paradox is created by claims that the relativity principle allows "exchange" of the argument allowing the laboratory twin that is younger. However, such exchange is not possible since only the laboratory twin was inertial, not the traveler.

6: Never explain Relativistic Doppler (RD) effect: like sound in air + time dilation

Time dilation of the source cannot be part of the RD effect since the relative speed with respect to the yet undetermined observer is not known at the time of light emission. Moreover, different time dilation effects would be needed, depending on the motion state of several different observers of the same light emission process.

Einstein paper works in the following way: the light wave carries to the observer the information about the source allowing the determination of the RD shift in frequency and wavelength at the actual observation of the light signal. All results are stated without derivation and the argument is very terse, leading to numerous misreads if you do not read and understand the original German manuscript (translations misleading), von Laue book easily misunderstood.

~~Beobachter untersucht werden.~~ — Durch Anwendung der in § 6 gefundenen Transformationsgleichungen für die elektrischen und magnetischen Kräfte und der in § 3 gefundenen Transformationsgleichungen für die Koordinaten und die Zeit erhalten wir unmittelbar:

$$X' = X_0 \sin \Phi', \qquad L' = L_0 \sin \Phi',$$

$$Y' = \beta\left(Y_0 - \frac{v}{V} N_0\right) \sin \Phi', \qquad M' = \beta\left(M_0 + \frac{v}{V} Z_0\right) \sin \Phi',$$

$$Z' = \beta\left(Z_0 + \frac{v}{V} M_0\right) \sin \Phi', \qquad N' = \beta\left(N_0 - \frac{v}{V} Y_0\right) \sin \Phi',$$

$$\Phi' = \omega'\left(\tau - \frac{a'\,\xi + b'\,\eta + c'\,\zeta}{V}\right),$$

wobei

$$\omega' = \omega\,\beta\left(1 - a\frac{v}{V}\right), \qquad a' = \frac{a - \frac{v}{V}}{1 - a\frac{v}{V}},$$

$$b' = \frac{b}{\beta\left(1 - a\frac{v}{V}\right)}, \qquad c' = \frac{c}{\beta\left(1 - a\frac{v}{V}\right)}$$

gesetzt ist.

Aus der Gleichung für ω' folgt: Ist ein Beobachter relativ zu einer unendlich fernen Lichtquelle von der Frequenz ν mit der Geschwindigkeit v derart bewegt, daß die Verbindungslinie „Lichtquelle–Beobachter" mit der auf ein relativ zur Lichtquelle ruhendes Koordinatensystem bezogenen Geschwindigkeit des Beobachters den Winkel φ bildet, so ist die von dem Beobachter wahrgenommene Frequenz ν' des Lichtes durch die Gleichung gegeben:

$$\nu' = \nu \frac{1 - \cos\varphi \frac{v}{V}}{\sqrt{1 - \left(\frac{v}{V}\right)^2}}.$$

Dies ist das Doppelersche Prinzip für beliebige Geschwindig-

In current language:

Einstein postulates Lorentz-invariance of light phase

$$\Phi = \omega t - \boldsymbol{x}\cdot\boldsymbol{k} = \omega t - \boldsymbol{x}\cdot\boldsymbol{n}|\boldsymbol{k}|$$
$$= \omega/c(ct - \boldsymbol{x}\cdot\boldsymbol{n})$$

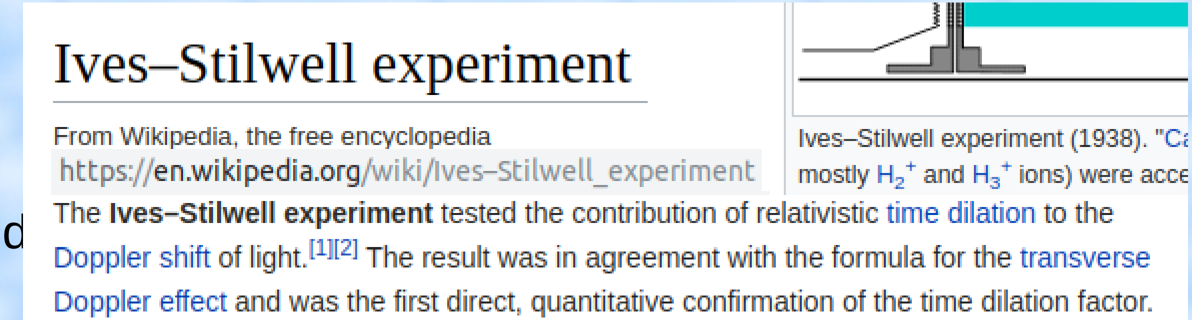
Doppler Shift

Not to be confounded with cosmological redshift (which has nothing to do with motion of stars) or gravitational (red) shift which describes the work done escaping the gravity potential.

Einstein postulated (in our language) the Lorentz invariance of light wave phase. This suffices to obtain the SR Doppler formulas for both shift and direction abberation (he states results only).

$$\Phi = \omega t - \mathbf{x}\cdot\mathbf{k} = \omega t - \mathbf{x}\cdot\mathbf{n}|\mathbf{k}| = \omega/c(ct - \mathbf{x}\cdot\mathbf{n}) = \Phi' = \omega'/c\,(ct' - \mathbf{x}'\cdot\mathrm{n}')\ .$$

After that it is slowly downhill. Ives and Stilwell 1938 experiment measuring (transverse)Doppler shift, report states they measure time dilation. Resnick around 1960 leans on text of von Laue SR without knowing German so relies on language of Ives-Stilwell. This is copied in all English language books and all over the Internet. Dark ages of relativity???


Ives–Stilwell experiment

From Wikipedia, the free encyclopedia

https://en.wikipedia.org/wiki/Ives–Stilwell_experiment

The **Ives–Stilwell experiment** tested the contribution of relativistic time dilation to the Doppler shift of light.[1][2] The result was in agreement with the formula for the transverse Doppler effect and was the first direct, quantitative confirmation of the time dilation factor.

Ives–Stilwell experiment (1938). "Ca

mostly H_2^+ and H_3^+ ions) were acce

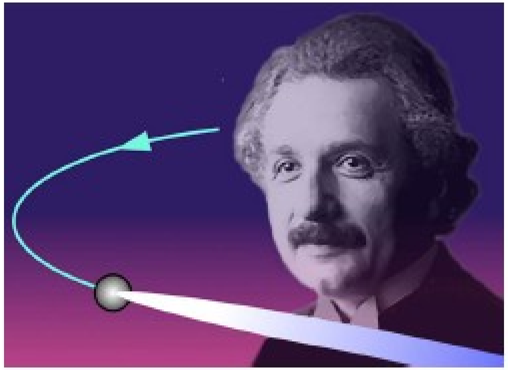
JOURNAL OF SYNCHROTRON RADIATION

ISSN 1600-5775

Received 4 April 2017
Accepted 24 May 2017

Edited by M. Eriksson, Lund University, Sweden

Keywords: special relativity; Doppler; time dilation; Lorentz transformation.



The relativistic foundations of synchrotron radiation

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Special relativity (SR) determines the properties of synchrotron radiation, but the corresponding mechanisms are frequently misunderstood. Time dilation is often invoked among the causes, whereas its role would violate the principles of SR. Here it is shown that the correct explanation of the synchrotron radiation properties is provided by a combination of the Doppler shift, not dependent on time dilation effects, contrary to a common belief, and of the Lorentz transformation into the particle reference frame of the electromagnetic field of the emission-inducing device, also with no contribution from time dilation. Concluding, the reader is reminded that much, if not all, of our argument has been available since the inception of SR, a research discipline of its own standing.

MU 7: Extended bodies have no place in SR

Not true! In SR we strive to comprehend what happens to extended material bodies. It is in this context that the LFG body contraction emerges as a pivotal concept. A cohesive extended body is naturally different from a cloud of non-interacting particles. Since space does not contract, a free particle cloud does not either (assuming a density well below some interaction range). All cohesive material bodies are contracted.

Between a non-interacting cloud and a rigid stick are many other complicated structures. This does not mean that SR is somehow not applicable to such objects or that it could not with success be used in their study.

Part II:

Strong field=strong acceleration Frontier

How big is usually "a" in laboratory?

Small acceleration approximation

Ultra-relativistic electron in a magnet of 4.41Tesla at CERN

$a_{MAX}=(e/M_e)\ \mathbf{v x B}$

$=1.6\ 10^{-19}\ 3\ 10^{8}\ 4.41\ /(9.11\ 10^{-31})=\mathbf{2.33x10^{20}m/s^{2}=nano\ a_{cr}}$

Compare: Natural "unit-1" acceleration

$\mathbf{a_{cr}}=M_e c^2\ c/(h/2\pi)=9.11\ 10^{-31}\ 27\ 10^{24}/1.05\ 10^{-34}=\mathbf{2.33\ 10^{29}m/s^2}$

This is also the acceleration generated by "critical" or Schwinger EM fields": $E_{cr}=(M_e c^2)^2/(ehc/2\pi)=1.323\ 10^{18}$ V/m

$B_{cr}=(M_e c^2)^2/(ehc^2/2\pi)=4.414\ 10^{9}$ T

Classical Electromagnetism is incomplete!

We have two separate theories:

•One which from given sources of charges and currents calculates the fields

•The other which from prescribed fields calculates the motion of charged particles.

J.D. Jackson, *Classical Electrodynamics 3rd edition*, John Wiley & Sons, (1999).

Today: empirically postulated equations of motion.

There is a disconnect – accelerated charges radiate and loose energy and momentum which should reflect on their motion! Radiation reaction / friction force term is needed.

We don't have (but we work on this)
an action principle which would describe this process!

- So far experimental ways of probing such situations are limited: Relativistic heavy ion collisions are very promising today.
- Physics effects become progressively more important with approach the "Acceleration frontier of physics"
- Another future way forward: A new generation of short pulse laser systems

Lienard Wiechert field of a moving charge

- Each point particle in the ion contributes a Lienard Wiechert field to the overall field.

$$e\mathbf{E}(\mathbf{r},t) = Z\alpha\hbar c\left(\frac{(\mathbf{n}-\beta)}{\gamma^2(1-\mathbf{n}\cdot\beta)^3|\mathbf{r}-\mathbf{r}_s|^2} + \frac{\mathbf{n}\times((\mathbf{n}-\beta)\times\dot{\beta})}{c(1-\mathbf{n}\cdot\beta)^3|\mathbf{r}-\mathbf{r}_s|}\right)_{t_r}$$

$$ec\mathbf{B}(\mathbf{r},t) = \frac{\mathbf{n}(t_r)}{c}\times\mathbf{E}(\mathbf{r},t)$$

Where, $t_r + \frac{1}{c}|\mathbf{r}-\mathbf{r_s}(t_r)| = t$

  - **Lienard-Wiechert field: Fields of an arbitrarily moving relativistic point particle derived by assuming a current density,**
  - **Often it is assumed that the ions travel in straight line motion, or that $\dot{\beta} = 0$ *which is not always a good argument to neglect* the acceleration term in the Lienard wiechert field**
  - **When acceleration is strong, radiation field dominated the velocity field and it radiates energy**

Covariant Radiation Friction
(We do not belive is right)

Framework: Lorentz-Abraham-Dirac (LAD):

see *e.g.* P. A. M. Dirac, *Classical theory of radiating electrons*, Proc. Roy. Soc. A **167**, 148 (1938).

$$m\dot{u}^\mu = eF^{\mu\nu}u_\nu + m\tau_0\left(g^{\mu\nu} - \frac{u^\mu u^\nu}{c^2}\right)\ddot{u}_\nu$$

- So called "Schott term"
- Added ad-hoc to ensure orthogonality

$$u^2 = c^2$$

- Introduces intrinsic higher order (beyond acceleration) derivative
- Creating issues with initial condition
- And "runaway" solutions
- Causality issues for small times

Provides the radiated power from Liénard-Wiechert solution of Maxwell equations

$$P = m\tau_0\dot{u}^2$$

The time scale τ_0 is

$$\tau_0 = \frac{2}{3}\frac{e^2}{4\pi\varepsilon_0 mc^3} = 6.3\times10^{-24}\mathrm{s}$$

Another vacuum friction model: Landau-Lifshitz

L. D. Landau and E. M. Lifshitz, *The Classical Theory of Fields*, (Pergamon, Oxford 1962).

"First order" approximation of LAD. Repeatedly substituting the Lorentz Force for the derivatives in the right hand side of LAD:

$$\dot{u}^\mu = \frac{e}{m} F^\mu_\alpha u^\alpha$$

Reduces the order of the differential equation:

$$m\dot{u}^\mu = eF^{\mu\nu} + e\tau_0 \left\{ u \cdot \partial(F^{\mu\nu})u_\upsilon + \frac{e}{m}\left(g^{\mu\nu} - \frac{u^\mu u^\nu}{c^2}\right) F_{\nu\alpha}F^{\alpha\beta}u_\beta \right\}$$

- Solves the issues arising from the higher order derivative term!
- Introduces problem of its own – linearly accelerated particle in constant electric field (*hyperbolic motion*) – the curly bracket disappears and there is no radiation reaction.
- That's despite the fact that Liénard-Wiechert Maxwell solution contains radiation field and the energy should dissipate.

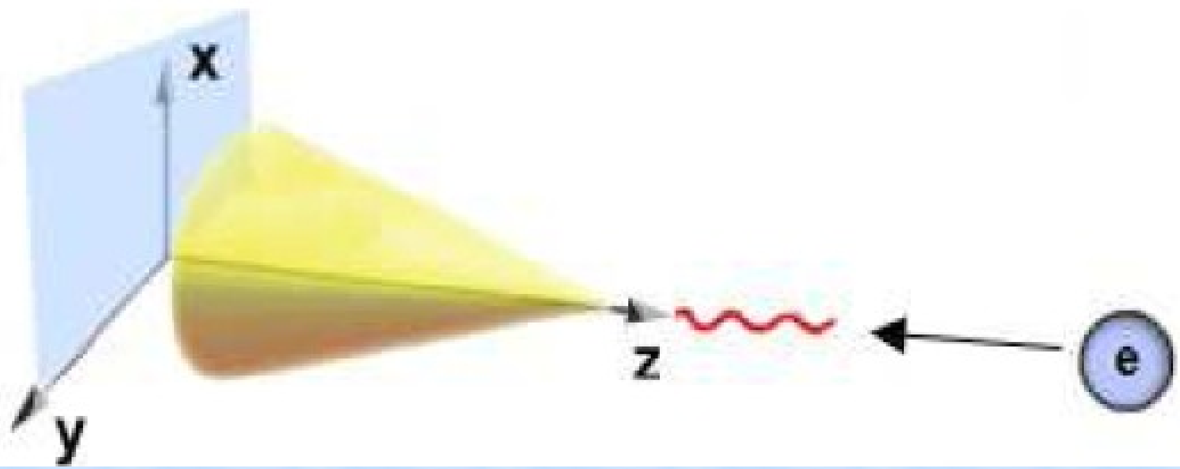
Many more models – Mo & Papas (1971), Bonnor (1974), Caldirola (1979), Cook (1984), Rohrlich (1999-2001) and lots of others. Landau-Lifshitz is considered to be the golden standard for practical calculations.

Probing super-critical (Planck) acceleration

$$a_c = 1(\rightarrow m_e c^3/\hbar = 2.331 \times 10^{29}\mathrm{m/s}^2)$$

Plan A: Directly laser accelerate electrons from rest, requires Schwinger scale field and may not be realizable – backreaction and far beyond today's laser pulse intensity technology.

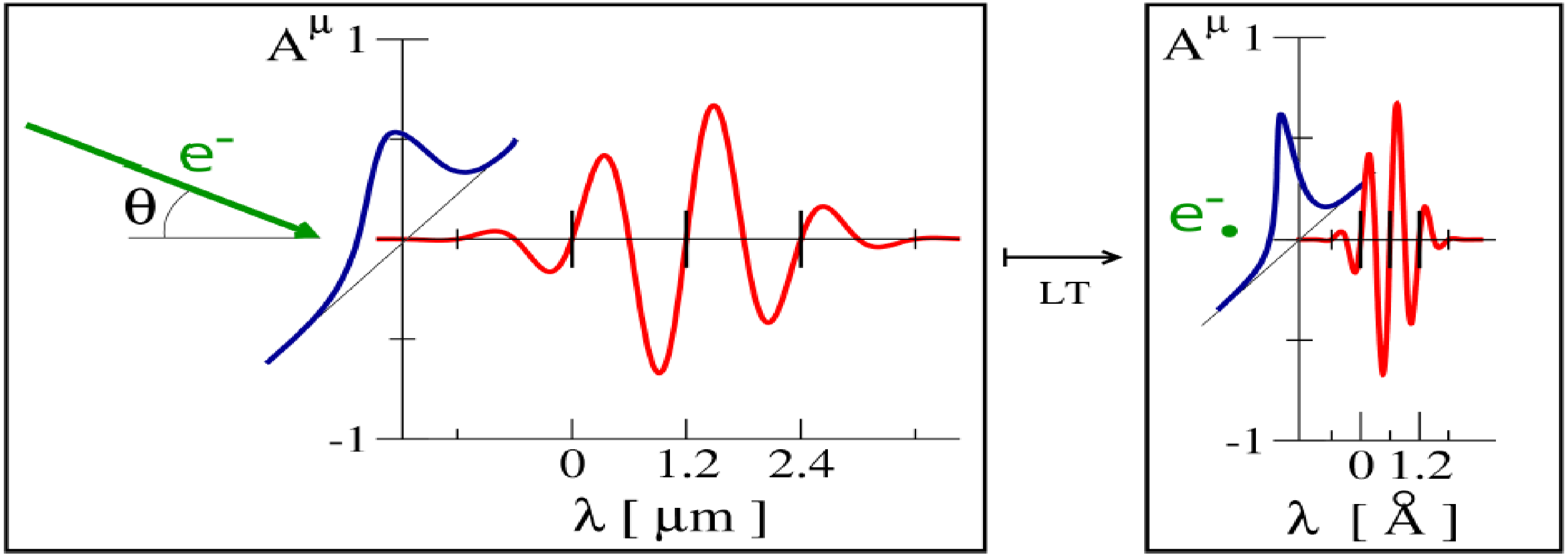
Plan B: Ultra-relativistic Lorentz-boost: we collide counter-propagating electron and laser pulse.



Puls Lorentz Transform (LT)

Relativistic electron-laser pulse collision

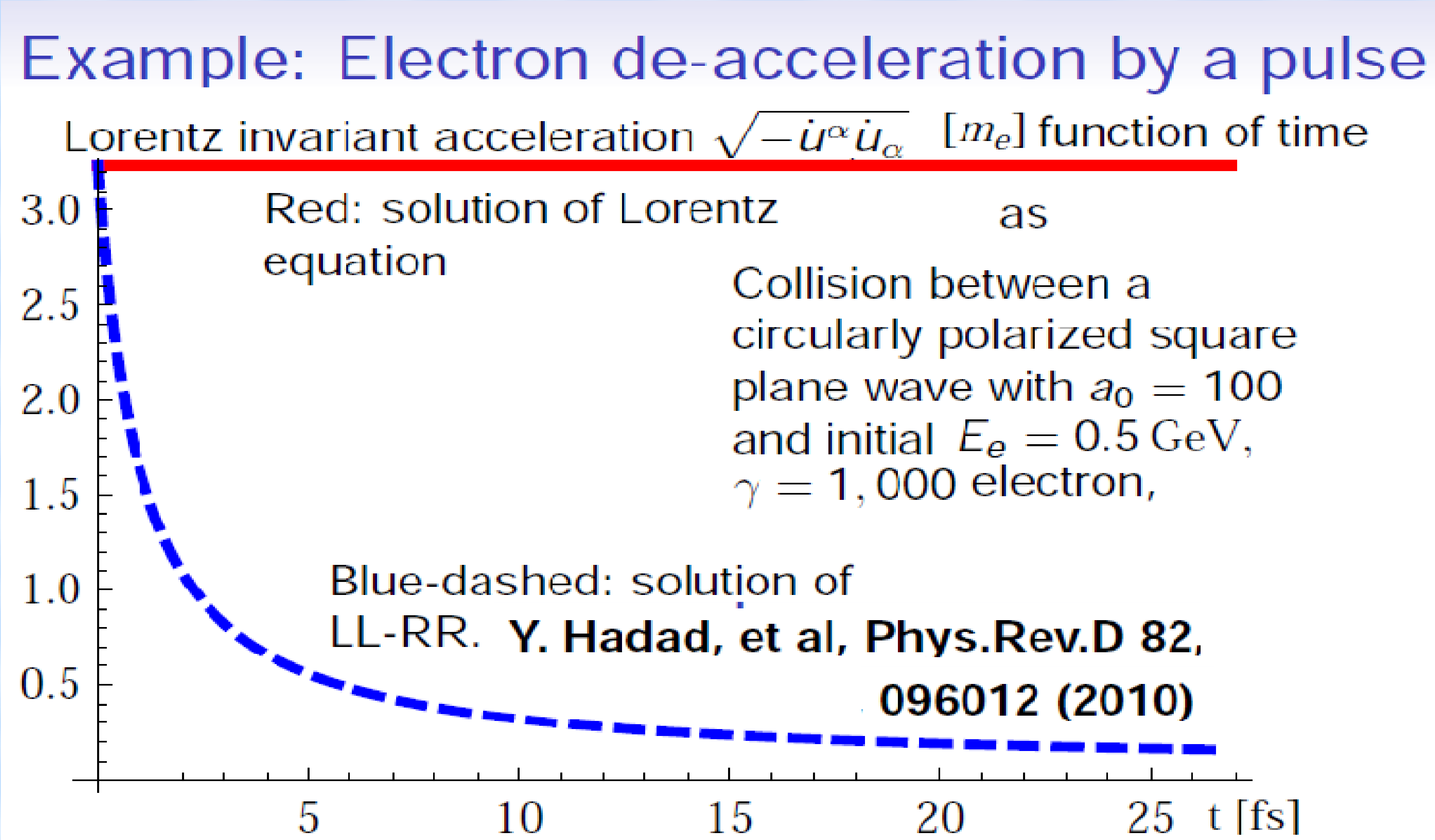
$u^\beta = \gamma(1, \vec{v}) \rightarrow$ In electron's rest frame: $u'_\beta = (1, \vec{0})$



Doppler shift: $\omega' = \gamma(1 + \vec{n} \cdot \vec{v})\omega$

$$\boxed{\text{Unit acceleration condition: } a_0 \frac{\omega'}{m_e} \simeq 2\gamma\, a_0 \frac{\omega}{m_e} \rightarrow 1}$$

Solving LL Equation for a-crit



„Absolute" Acceleration (Langevin)

Only relative velocity in SR, but not everything is „relative“
The case of body acceleration is here relevant:

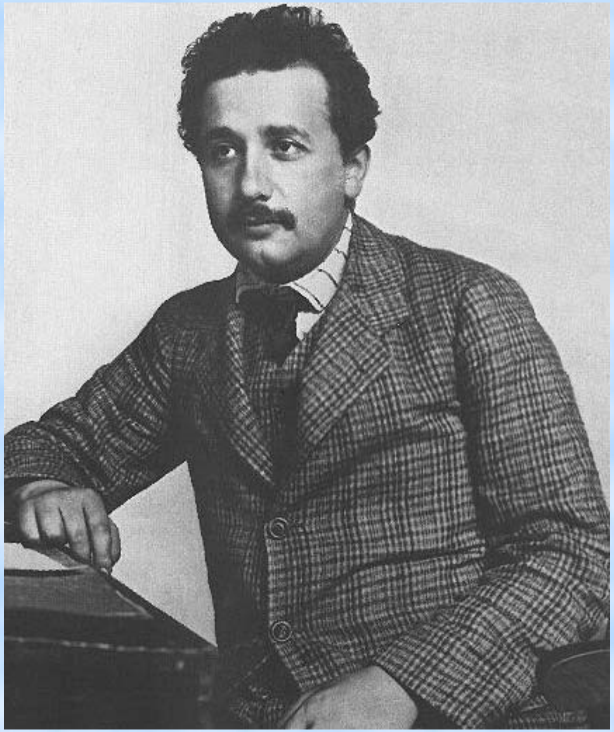
In presence of strong acceleration: An important question: how does a body "know" that it is accelerated *(and subject to radiation reaction friction force)*?

Here we meet the **strong acceleration – strong fields physics frontier** of classical and quantum physics where the quantum vacuum, *a.k.a* Einstein's non-material ether, can be probed.

New aether emerges 1919/20

After GR: the space-time metric is the new aether, allows local measurement of absolute acceleration – Langevin proposal of 1911.

Einstein 1920: “But this aether may not be thought of as endowed with the quality characteristic of ponderable media, as consisting of parts which may be tracked through time. The idea of motion may not be applied to it.”



Mach's Principle

Ernst Mach
1838-1916

Measurement of acceleration requires a reference frame: what was once the set of fixed stars in the sky is today CMB photon freeze-out reference frame.

To be consistent with special relativity: all inertial observers with respect to CMB form an equivalence class, **we measure acceleration with reference to the CMB inertial frame,** some say the structured QuantumVacuum.

Quantum vacuum structure
(replaces relativistic invariant Aether)
defining locally the class of inertial observers

Quantum vacuum defines structure of physical laws – see Higgs field, clarifies meaning of inertia and allows us to locally recognize acceleration (no need to study the stars light years away).

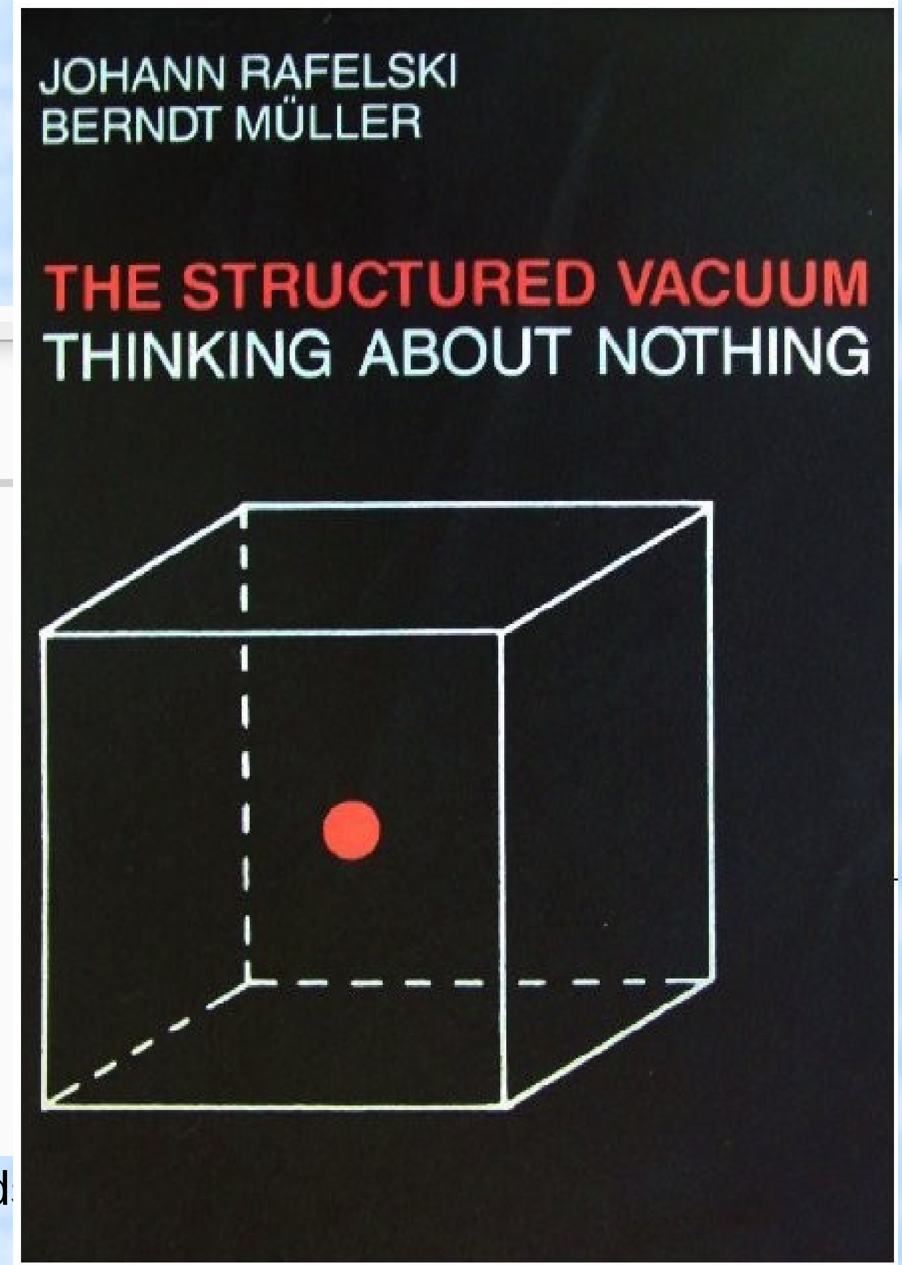
Nonmaterial aether differs from material aether: for example objects falling in material atmosphere are subject to friction resulting in a constant fall speed. Difference to (nonmaterial) Einstein aether: acceleration related friction leads to constant maximum critical acceleration

Long-standing interest in quantum vacuum structure: 1985 book and a chain of 20 papers over 40 years

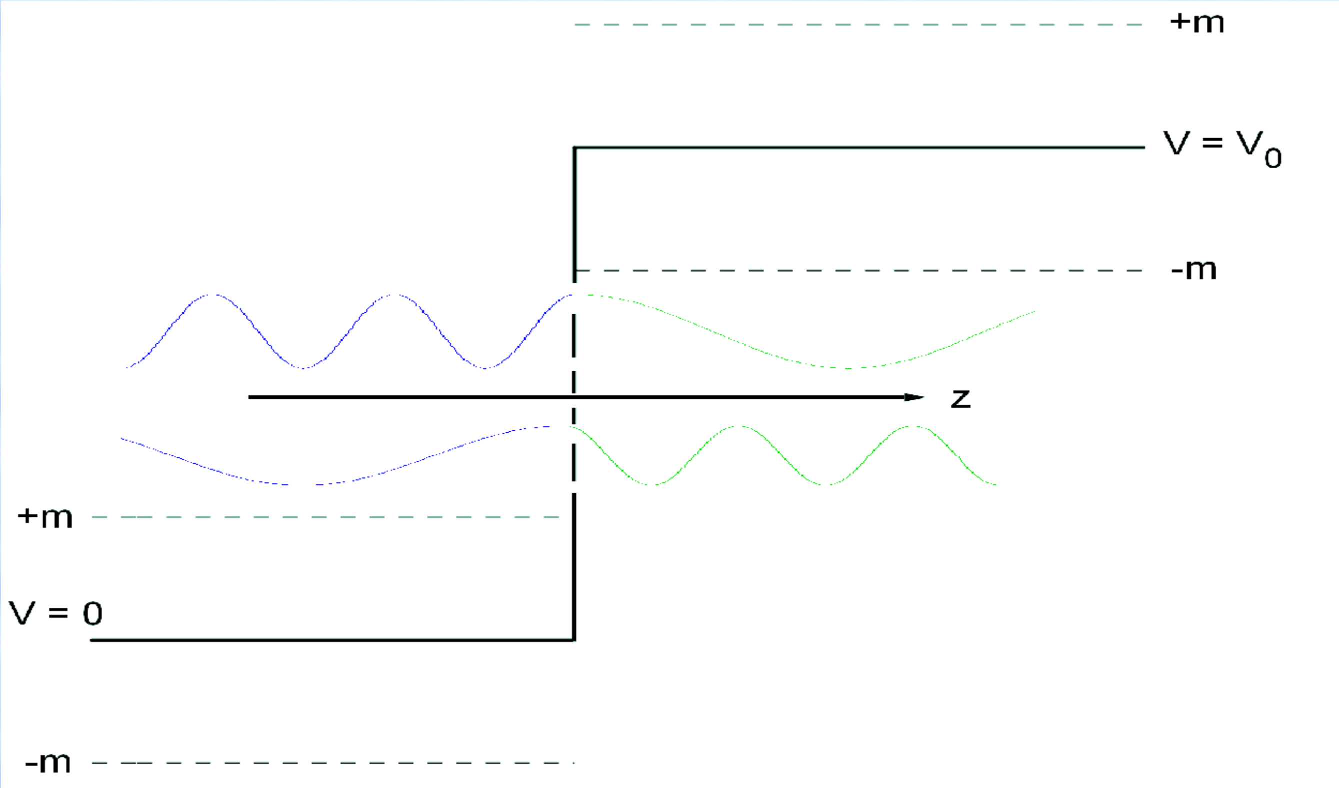
https://searchworks.stanford.edu/view/1629119

The structured vacuum : thinking about nothing

RESPONSIBILITY	J. Rafelski, B. Müller.
IMPRINT	Thun : H. Deutsch, 1985.
PHYSICAL DESCRIPTION	181 p. : ill. ; 21 cm.
ISBN	3871448893 (pbk.)
QC166 .R33 1985	9783871448898 (pbk.)
SUBJECT	Vacuum > Miscellanea.
	Physics > Philosophy > Miscellanea.

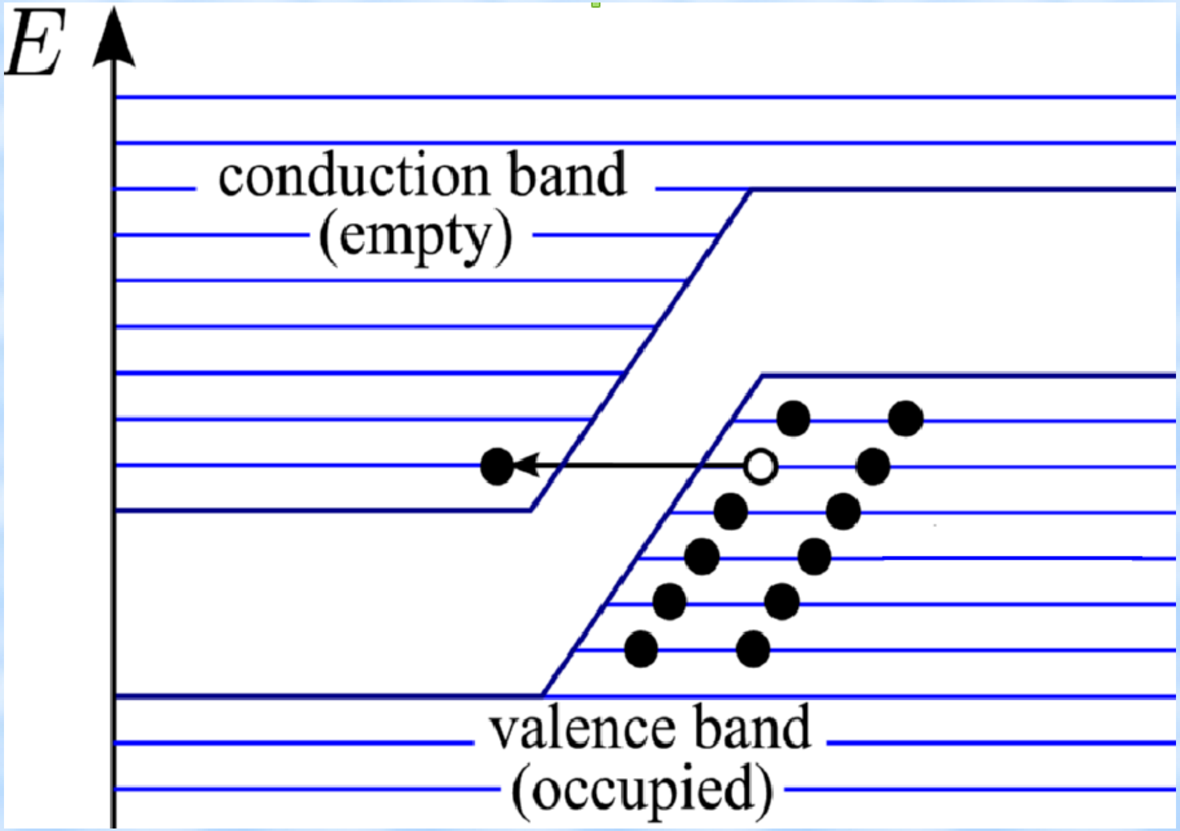


KLEIN'S "PARADOX": PAIR PRODUCTION IN STRONG FIELDS



The Dirac equation uses energy, mass and momentum of special relativity $E^2 = p^2c^2 + m^2c^4$, taking root we find in quantum physics two energy (particle) bands. A potential mixes these states!

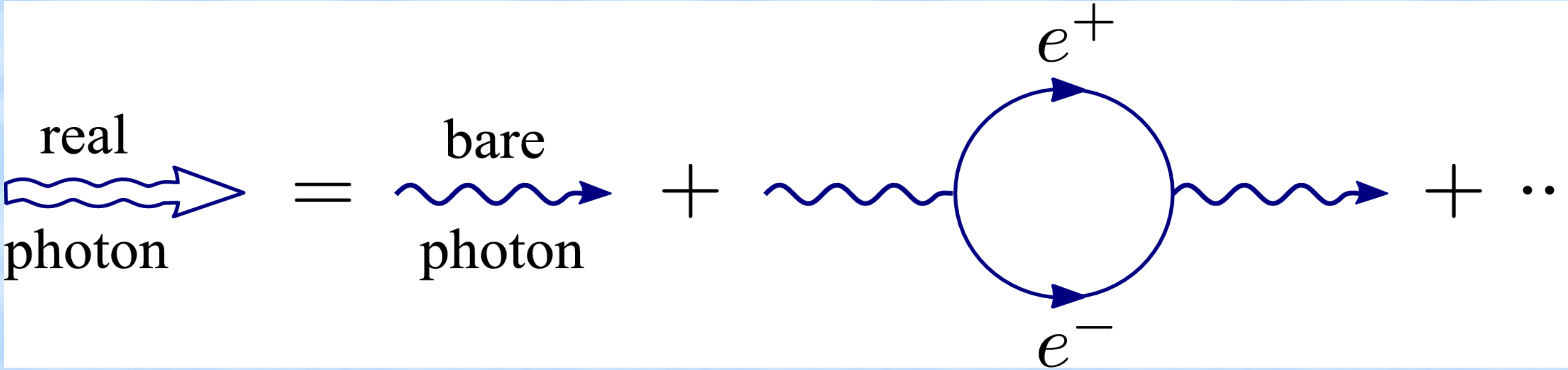
Tunneling pair production instability: Explanation of Klein's paradox



Relativistic Dirac quantum physics predicts antimatter and allows formation of pairs of particles and antiparticles.

The relativistic gap in energy reminiscent of insulators, where conductive band is above the valance (occupied) electron band

Virtual Pairs: The quantum vacuum is a dielectric



The vacuum is a dielectric medium: a charge is screened by particle-hole (pair) excitations. In Feynman language the real photon is decomposed into a bare photon and a photon turning into a "virtual" pair. The result: renormalized electron charge smaller than bare, Observable Coulomb interaction stronger (0.4%) at distance 1/m

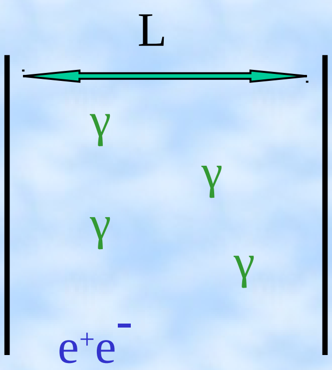
This effect has been studied in depth in atomic physics, is of particular relevance for exotic atoms where a heavy (muon) charged particle replaces an electron.

Matter influences quantum vacuum

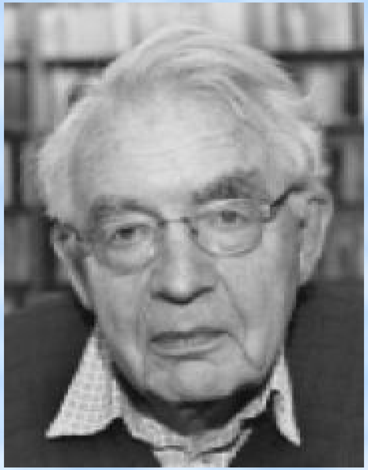
Photons fluctuations altered by matter, Casimir effect can be measured:

Attractive force between two adjacent metal plates
(Casimir force, 1948)

$$F = \frac{\pi^2}{240} \frac{\hbar c}{L^4} A$$



More fluctuations outside the plates compared to the space between: outside pressure, plates attract

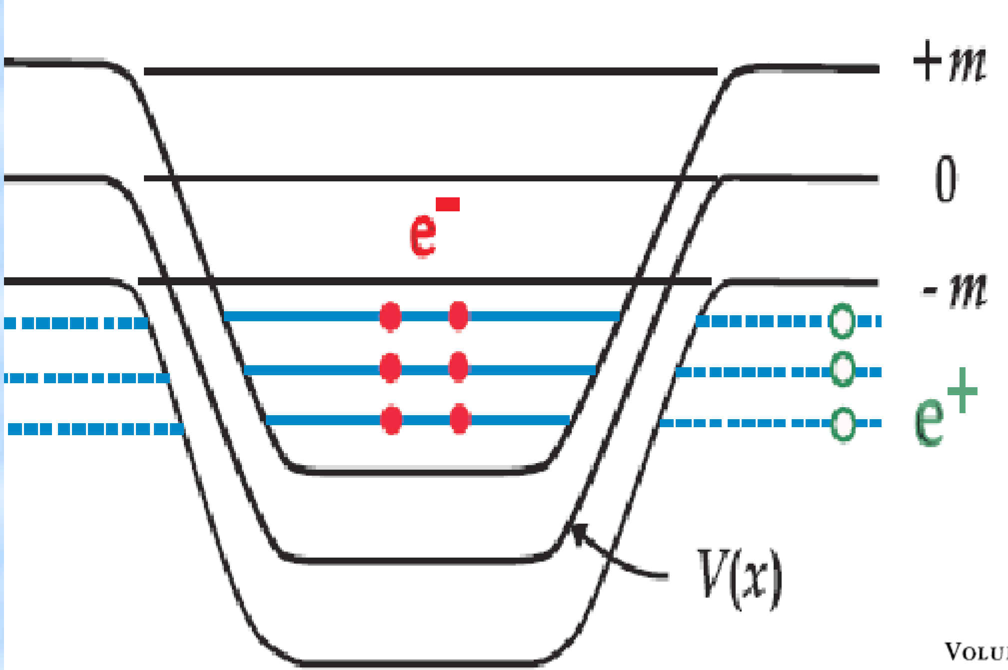


Hendrik B.G. Casimir

NOTE: Each ‘elementary’ particle, each interaction adds a new “fluctuation” to vacuum structure.

Stabilization of local vacuum state

Speed of decay of false vacuum controlled by (Heisenberg-Schwinger mechanism) E-field strength



There is localized charge density in the vacuum, not a particle of sharp energy. Formation of the charged vacuum ground state observable by positron emission: which fills any vacancies among 'dived' states in the localized domain.

SCIENTIFIC AMERICAN
DECEMBER 1979
VOL. 241, NO. 6 PP. 150–159

The Decay of the Vacuum

by Lewis P. Fulcher, Johann Rafelski and Abraham Klein

Near a superheavy atomic nucleus empty space may become unstable, with the result that matter and antimatter can be created without any input of energy. The process might soon be observed experimentally

VOLUME 34, NUMBER 6 PHYSICAL REVIEW LETTERS 10 FEBRUARY 1975

Stabilization of the Charged Vacuum Created by Very Strong Electrical Fields in Nuclear Matter*

Berndt Müller and Johann Rafelski

(Received 2 December 1974)

The expectation value of electrical charge in charged vacuum is calculated utilizing the Thomas-Fermi model. We find almost complete screening of the nuclear charge. For any given nuclear density there is an upper bound for the electrical potential. For normal nuclear densities this value is -250 MeV. This suggests that the vacuum is stable against spontaneous formation of heavy, charged particles.

W Heisenberg

Rate of surface pair production in “constant” fields

J Schwinger

The sparking of the QED dielectric

Effect large for Field

E_s=1.323 10^{18} V/m

$$P \sim exp\left(-\pi \frac{m^2 c^3}{eE\hbar}\right)$$

Probability of pair production can be evaluated in WKB description of barrier tunneling: All E-fields are unstable and can decay to particles if energy is available and rate is large enough – footnoted by Heisenberg around 1935, in 1950 Schwinger's article as an visibly after finish-point (*my idea how this happened: invited by referee=Heisenberg*?).

In strong fields: local unstable vacuum, hence vacuum decay in Strong Fields

Nuclear Physics B68 (1974) 585–604. North-Holland Publishing Company

THE CHARGED VACUUM IN OVER-CRITICAL FIELDS*

J. RAFELSKI, B. MÜLLER and W. GREINER
Institut für Theoretische Physik der Universität Frankfurt, Frankfurt am Main, Germany

Received 4 June 1973
(Revised 17 September 1973)

Abstract: The concept of over-critical fields, i.e. fields in which spontaneous, energy-less electron-position pair creation may occur, is discussed. It is shown that only a charged vacuum can be a stable ground state of the overcritical field. The time-dependent treatment confirms previous results for the cross sections for the auto-ionizing positrons. The questions in connection with the classical Dirac wave functions in over-critical fields are extensively discussed in the frame of the self-consistent formulation of QED including the effects of vacuum polarization and self-energy.

1974 first local vacuum structure model of quark confinement inside hadrons

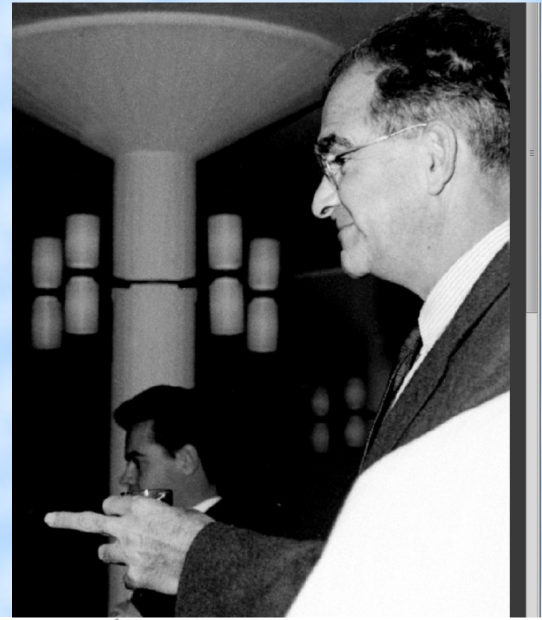
New extended model of hadrons

A. Chodos, R. L. Jaffe, K. Johnson, C. B. Thorn, and V. F. Weisskopf
Phys. Rev. D **9**, 3471 – Published 15 June 1974 Received 25 March 1974

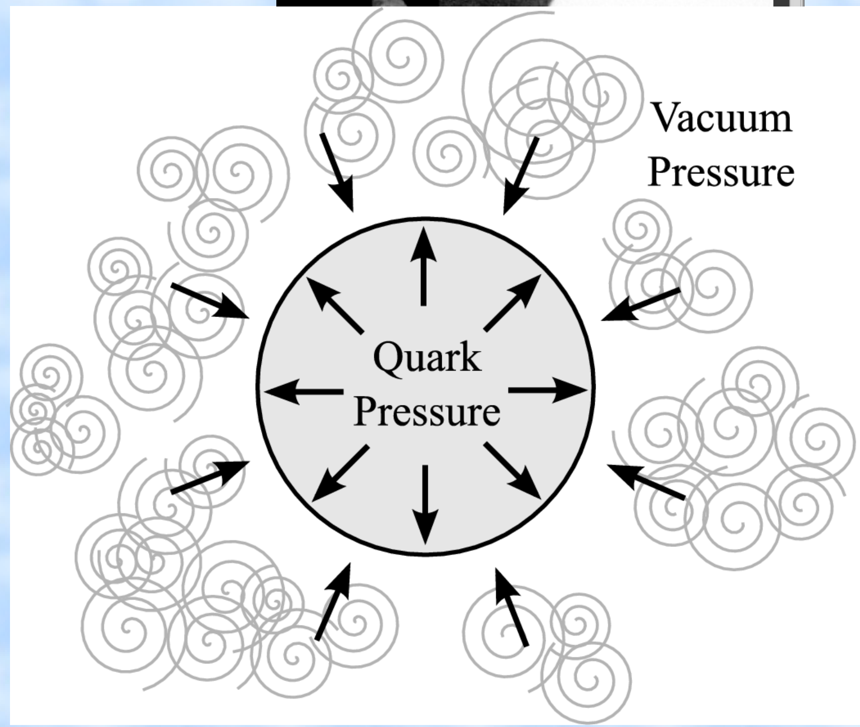
DOI: https://doi.org/10.1103/PhysRevD.9.3471

ABSTRACT

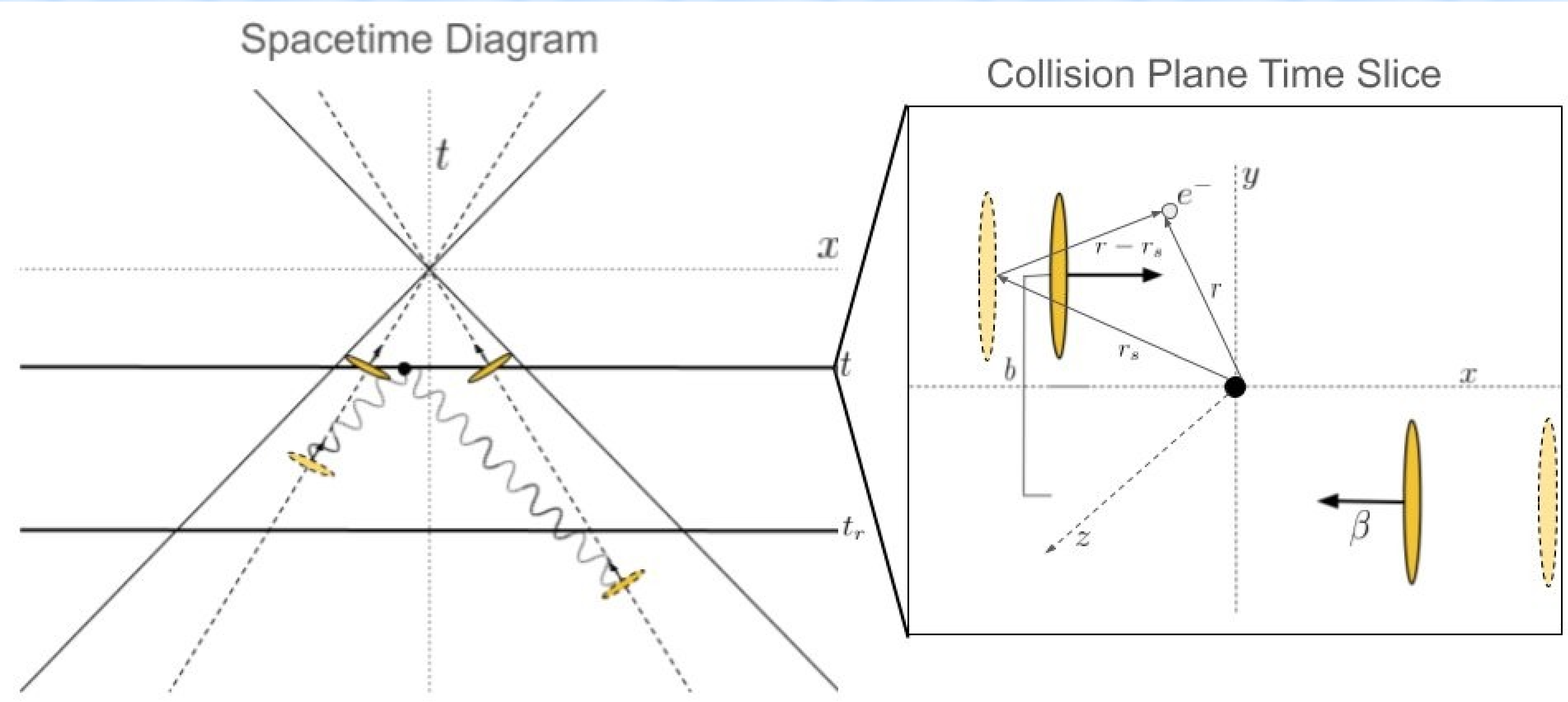
» endowing the finite region with a constant energy per unit volume »



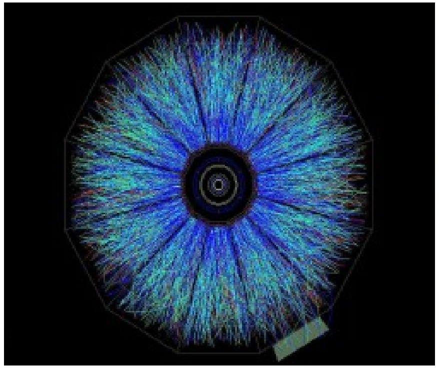
- Quarks live inside a domain where the (perturbative) vacuum is without gluon fluctuations. This outside structure wants to enter, but is kept away by quarks trying to escape.
- The model assumes that the energy density E/V=0 of the true vacuum is lower than that inside of a hadron.



Retarded EM-Field in RHI collisions



Unit Acceleration in Strong Interactions

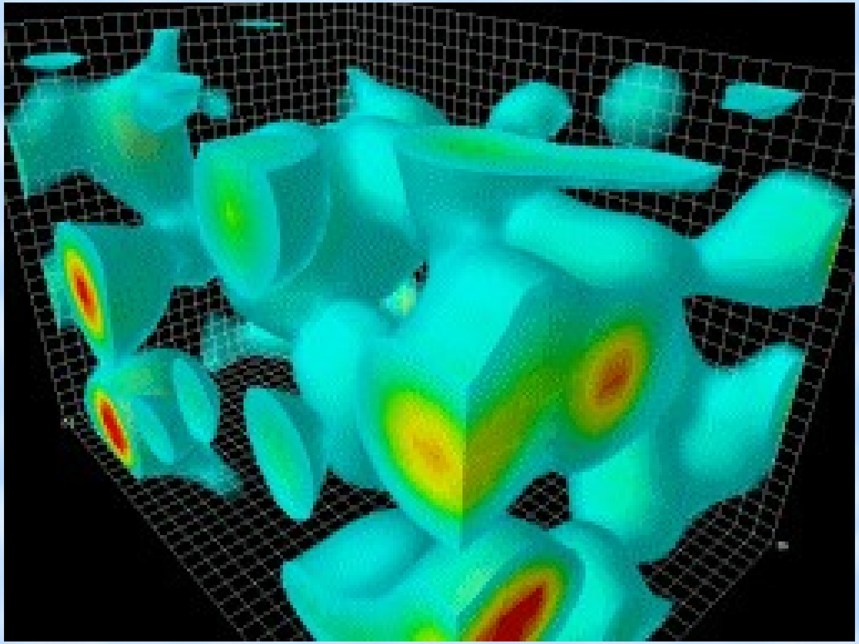


Two nuclei smashed into each other at highest achievable energy: components can be stopped in CM frame within $\Delta\tau \simeq 1$ fm/c. Tracks show multitude of particles produced, as seen at RHIC (BNL) and at CERN.

- The acceleration a required to stop some/any of the components of the colliding nuclei in CM: $a \simeq \frac{\Delta y}{M_i \Delta\tau}$. Full stopping: $\Delta y_{\rm SPS} = 2.9$, $\Delta y_{\rm RHIC} = 5.4$, larger at CERN. Considering constituent quark masses $M_i \simeq M_N/3 \simeq 310$ MeV we need $\Delta\tau_{\rm SPS} < 1.8$ fm/c and longer times at colliders to exceed critical a.

- The soft electromagnetic radiation in hadron reactions (*A. Belognni et al. [WA91 Collaboration], "Confirmation of a soft photon signal in excess of QED expectations in π–p interactions at 280-GeV/c," Phys. Lett. B* **408**, *487 (1997) [arXiv:hep-ex/9710006].*) and heavy ion reactions exceeds the perturbative QED predictions significantly

Color confinement due to gluon fluctuations



- QCD induces chromo-electric and chromo-magnetic fields throughout space-time – the vacuum is in its lowest energy state, yet it is strongly structured. Fields must vanish exactly everywhere $\langle H \rangle = 0$
- This is an actual computation of the four-d (time +3-dimensions) structure of the gluon-field configuration. The volume of the box is 2.4 by 2.4 by 3.6 fm, big enough to hold a couple of protons.
- Derek B. Leinweber's group (U Adelaide)

Numerical Method used: lattice in space time

Square of fields does not average out: "condensates

$$\langle \bar{q}q \rangle = (235\ \mathrm{MeV})^3, \left\langle \frac{\alpha_s}{\pi} G_{\mu\nu} G^{\mu\nu} \right\rangle = (335\ \mathrm{MeV})^4$$

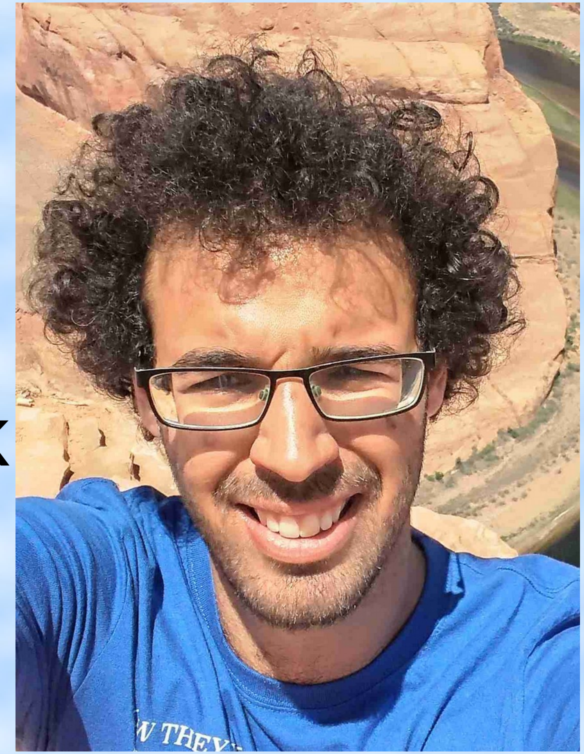
WE ARE THE ARIZONA ACCELERATION-TEAM

In S-Relativity we want to figure out what to do with acceleration in general and all non-G forces (EM overdue!). S-Relativity is still incomplete. We are here to rescue it.

The A-Team

Stefan
Evans

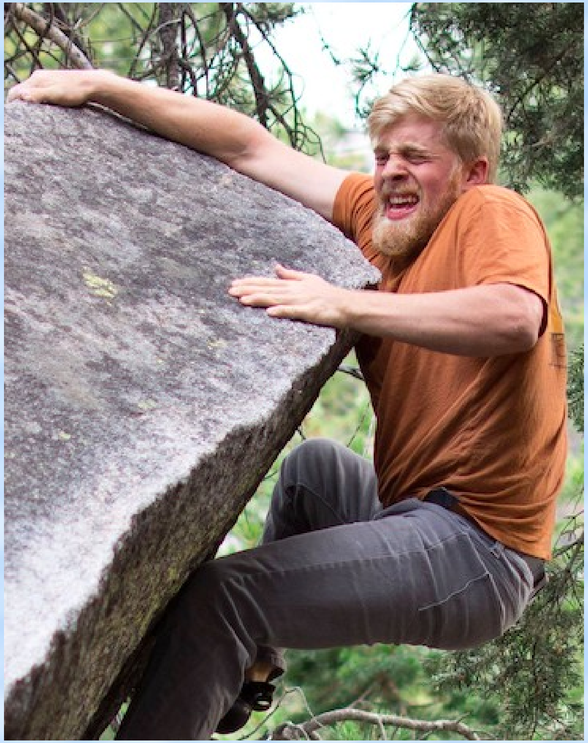
Martin
Formanek



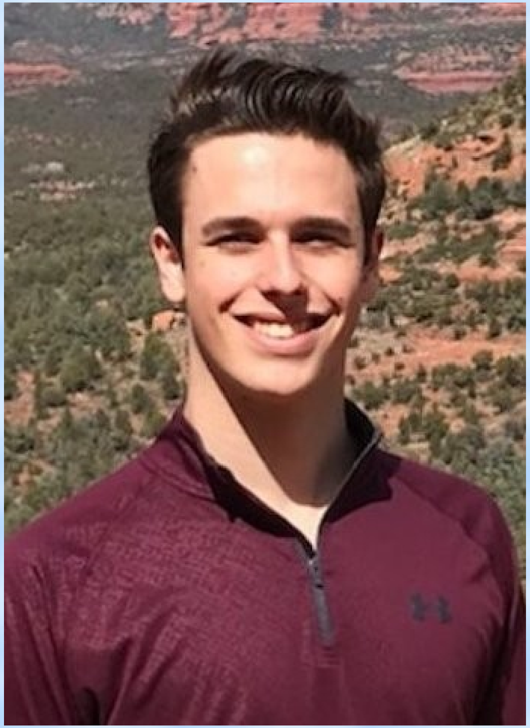
How EM strong fields modify vacuum structure and stability: fields turning into particles. Continues work of Lance Labun (PhD Dec. 2011)

How forces influence dynamical relation between proper time and laboratory time

Chris Grayson



Blake Lee



Relativistic Electro-magnetic Field Dynamics of Particle Collisions: ripping up the vacuum with relativistic strong fields.

Motion/radiation in periodic and random wiggled systems. *Undergraduate student*

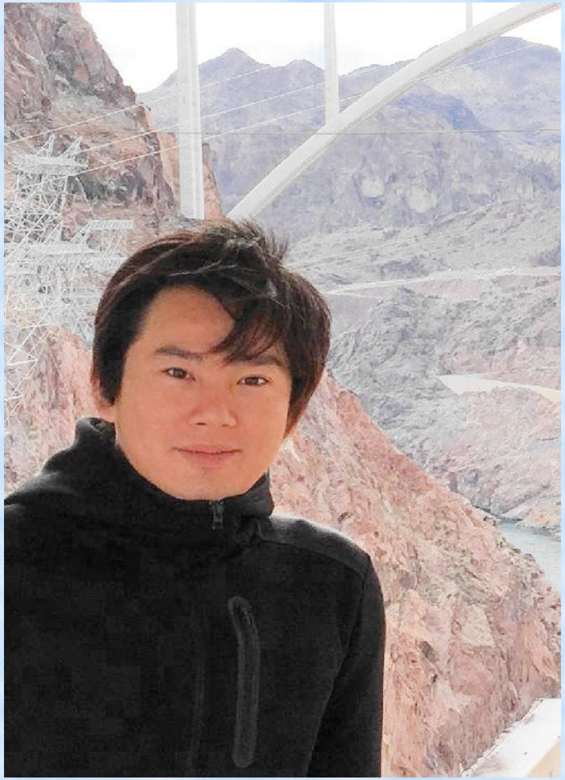
Will Price

Andrew Steinmetz

Classical dynamics of relativistic charged particle collisions, including radiation reaction in strong fields. Started in the group as an undergrad

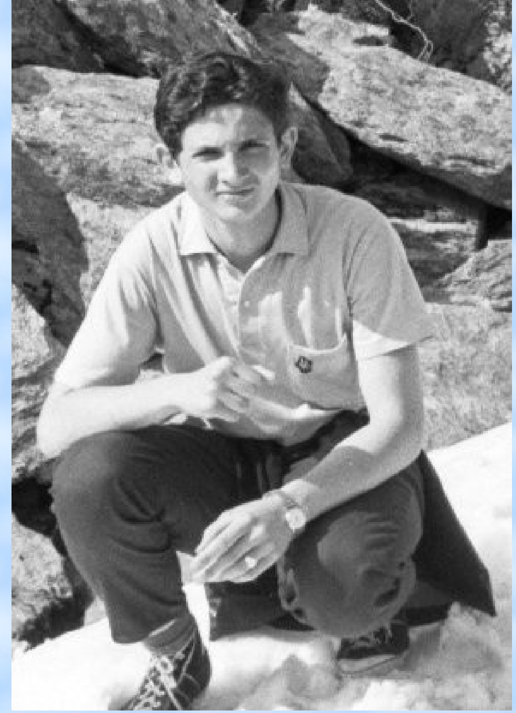
Relativistic dynamics of particles with anomalous magnetic moment and connection with quantum dynamics

Cheng
Tao
Yang



Relativistic Thermodynamics in expanding primordial Universe: from quarks to BBN. Continues work of Jeremey Birrell, PhD May,2014

Dt. R:



48 years of work in relativistic everything.
Current passion: SR, Strpng/critical acceleration phenomena.

VOLUME 27, NUMBER 14 PHYSICAL REVIEW LETTERS 4 OCTOBER 1971

Superheavy Elements and an Upper Limit to the Electric Field Strength

Johann Rafelski, Lewis P. Fulcher,† and Walter Greiner
Institut für Theoretische Physik der Universität Frankfurt, Frankfurt am Main, Germany
(Received 9 August 1971)

An upper limit to the electric field strength, such as that of the nonlinear electrodynamics of Born and Infeld, leads to dramatic differences in the energy eigenvalues and wave functions of atomic electrons bound to superheavy nuclei. For example, the $1s_{1/2}$ energy level joins the lower continuum at $Z = 215$ instead of $Z = 174$, the value obtained when Maxwell's equations are used to determine the electric field.

Some of the answers are here:

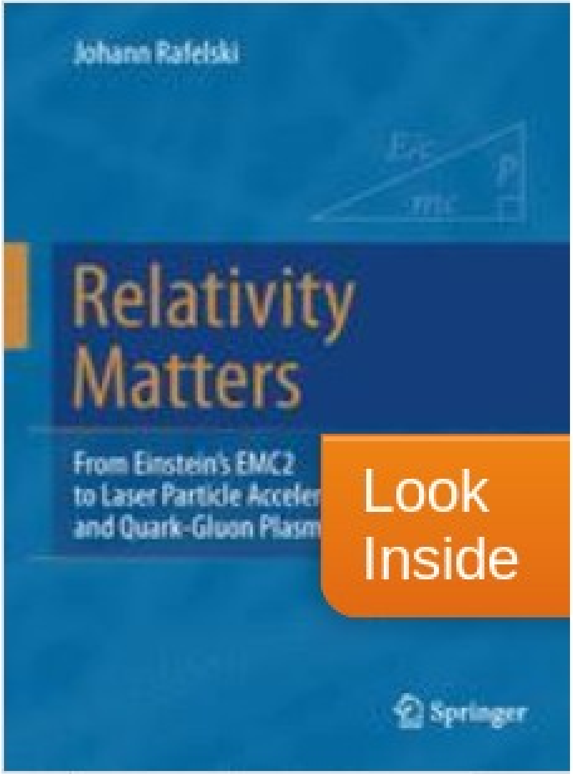
Book 2017 link.springer.com/book/10.1007%2F978-3-319-51231-0

Relativity Matters

From Einstein's EMC2 to Laser Particle Acceleration and Quark-Gluon Plasma

Authors: Johann Rafelski

ISBN: 978-3-319-51230-3 (Print) 978-3-319-51231-0 (Online)



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Conclusions

After many years of neglect we find ourselves probing the acceleration/strong field frontier in RHI experiments at CERN and RHIC and thinking ahead to very high intensity laser-particle interaction. Challenge: Teaching relativity to future researchers in this field.