Superluminal νs

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GGI Invisibles/*Imaginaries*—What is ν?

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Superluminal

νs

CERN hosts the report

PRESS RELEASE:

OPERA experiment reports anomaly in flight time of neutrinos from CERN to Gran Sasso

Geneva, 23 September 2011. The OPERA experiment, which observes a neutrino beam from CERN 730 km away at Italy's INFN Gran Sasso Laboratory, will present new results in a seminar at CERN this afternoon at 16:00 CEST. The seminar will be webcast at `http://webcast.cern.ch`. Journalists wishing to ask questions may do so via twitter using the hash tag `#nuquestions`, or via the usual CERN press office channels.

OPERA –

September 2011

Neutrinos travel faster
than light

OPERA (con't)

$$\delta \equiv \frac{v^2 - 1}{v^2} \simeq 5 \; 10^{-5}$$

THE MEDIA

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Einstein was wrong!

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Time Travel Possible

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Time Travel Possible
GPS no longer works

THE MEDIA

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Time Travel Possible
GPS no longer works

Einstein is right!

THE MEDIA

Einstein was wrong!

Time Travel Possible

GPS no longer works

Einstein is right!

He's so smart

SKEPTICISM
(Physicists)

$$\delta = 5 \ 10^{-5}$$

is *enormous!*

SKEPTICISM (con't)

Supernova 1987a

ν_e and γ

$t \sim 168,000$ lightyears

$\Delta t \sim 3$ hours

SUPERNOVA

$$\delta_{\nu_e} \lesssim 5 \ 10^{-9}$$

MeV energies
Electron - type neutrinos

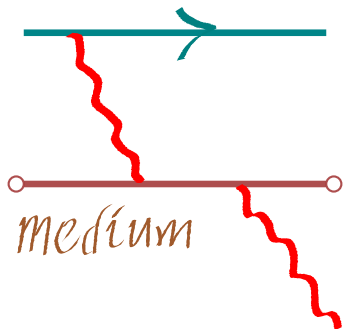# CNGS BEAM

Muon neutrinos

$$\mathcal{E} \sim 10s \text{ of } GeV$$

OTHER LIMITS

$$|\delta_e| \lesssim \begin{cases} 10^{-16} \\ 10^{-9} \end{cases} \quad \text{EC(NGS)}$$
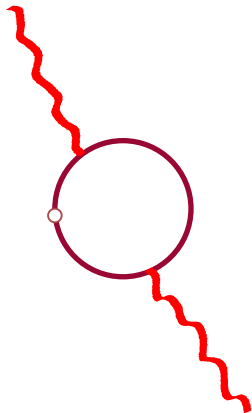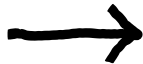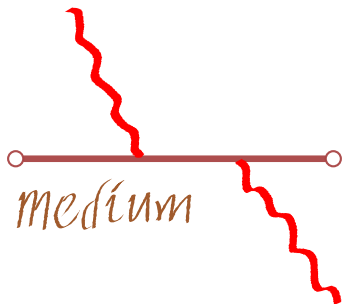
from Cerenkov-like processes

CERENKOV

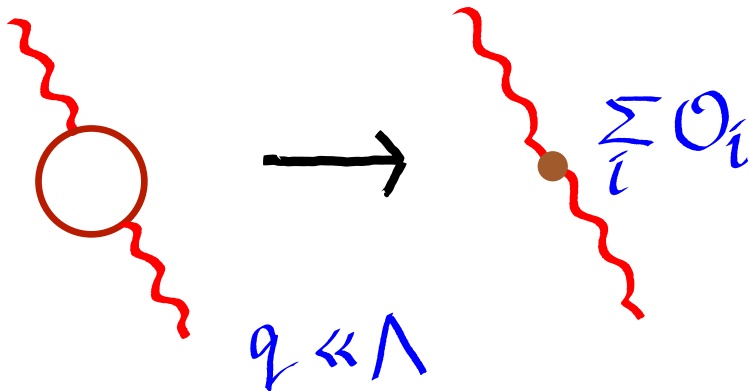$$e \longrightarrow e + \gamma$$

$$v \quad > \quad c$$

medium

CERENKOV

medium

CERENKOV

CERENKOV

$$\mathcal{O} \supset \frac{\delta_\varepsilon}{2} \vec{E}^2 - \frac{\delta_B}{2} \vec{B}^2 + \cdots$$

CERENKOV

$$O \supset \frac{\delta_\varepsilon}{2} \vec{E}^2 - \frac{\delta_B}{2} \vec{B}^2 + \cdots$$

Electric & Magnetic
Permeability

$$c^2 = \frac{1 + \delta_B}{1 + \delta_\varepsilon}$$

SPEED OF WHAT

Rescale A_μ ; t ; x

$$c_\gamma \longrightarrow 1$$

Other particles have
different 'maximal'
velocities

ASSUMPTIONS

Conserved Generators of
spacetime translations

$$(E, \vec{P}): \quad \chi \longrightarrow \chi + a$$

Small departures from Lorentz

$$L = L_0 + \delta L$$

VACUUM CERENKOV

$$e^- \longrightarrow e^- + \gamma \qquad \upsilon_e > \Lambda$$

$$\gamma \longrightarrow e^+ + e^- \qquad \upsilon_e < \Lambda$$

NEUTRINOS

$$\nu_x \longrightarrow \nu_x + \gamma$$

$$\nu_x \longrightarrow \nu_x + \nu_y + \bar{\nu}_y$$

$$\nu_x \longrightarrow \nu_x + e^+ + e^-$$

NEUTRINOS

$\times$ $\nu_x \longrightarrow \nu_x + \gamma$

$\nu_x \longrightarrow \nu_x + \nu_y + \overline{\nu}_y$

$\nu_x \longrightarrow \nu_x + e^+ + e^-$

NEUTRINOS

$\times$ $\quad \nu_x \longrightarrow \nu_x + \gamma$

$\times$ $\quad \nu_x \longrightarrow \nu_x + \nu_y + \bar{\nu}_y$

$\nu_x \longrightarrow \nu_x + e^+ + e^-$

NEUTRINOS

✗ $\nu_x \longrightarrow \nu_x + \gamma$

✗ $\nu_x \longrightarrow \nu_x + \nu_y + \overline{\nu}_y$

✓ $\nu_x \longrightarrow \nu_x + e^+ + e^-$

WEAK INTERACTION
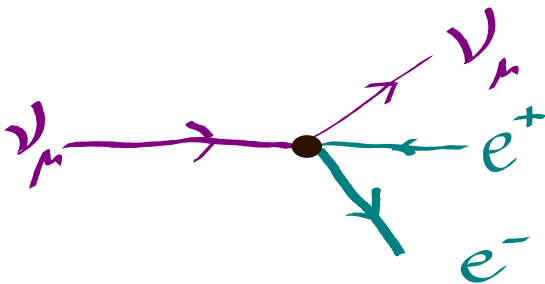
$$\frac{G_F}{\sqrt{2}} \, \tilde{J}^{\alpha}_{(\nu_\mu)} \, J_{(e)\,\alpha}$$

WEAK INTERACTION

$$\Gamma = k \frac{G_F^2}{192\pi^3} E^5 \delta^3$$

$$\frac{dE}{dx} = -k' \frac{G_F^2}{192\pi^3} E^6 \delta^3$$

$$k = 2/35 \qquad k' = 5/112$$

OPERA IMPLICATION

With $\delta \sim 5 \, 10^{-5}$

neutrinos from CERN

with $E > 13 \, GeV$

rarely reach the

Gran Sasso

ICARUS & NOMAD

Limit δ from absence

of e^+e^- pairs

$$\delta < 2 \; 10^{-8} \quad \text{ICARUS}$$

ICARUS & NOMAD

Limit δ from absence of e^+e^- pairs

Nomad Emulsions would be black from pairs!

THE FAT LADY SINGS

An improperly attached cable introduced timing anomaly

No significant departure from speed of light

NEW CONSTRAINTS

Absence of Cerenkov-like energy loss constrains δ

NEW CONSTRAINTS

Absence of Cerenkov-like energy loss constrains δ

$\longrightarrow$ Highest Energy Distant Source

NEUTRINO TELESCOPES

Observation of neutrinos of energy E at low zenith angle

$$\delta < \text{few } 10^{-3} \left(\frac{GeV}{E} \right)^{5/3}$$

NEUTRINO TELESCOPE

$$\delta < 10^{-12}$$

from observation of
few hundred TeV
neutrinos

CONCLUSIONS

- No evidence for superluminal neutrinos

- **Strong** new constraints on neutrino Lorentz violation

$$\delta < 10^{-12}$$