Superluminal νs

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Superluminal

νs

OPERA –

September 2011

Neutrinos travel faster than light

OPERA (cont)

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

The Media

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Einstein was wrong!

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Time Travel Possible

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GPS no longer works

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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

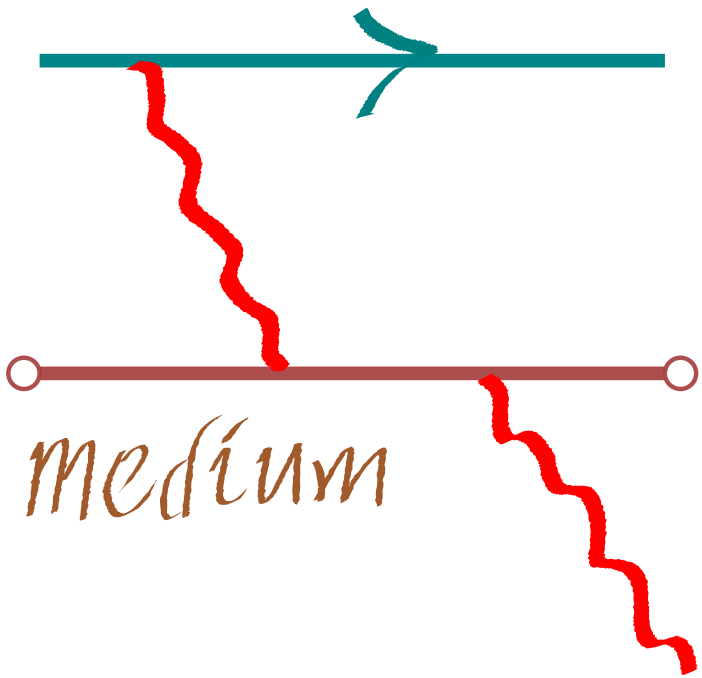
$E \sim 10s$ of GeV

OTHER LIMITS

$$|\delta_e| \lesssim \begin{cases} 10^{-16} \\ 10^{-9} \end{cases}$$ ECNGS

from Cerenkov-like processes

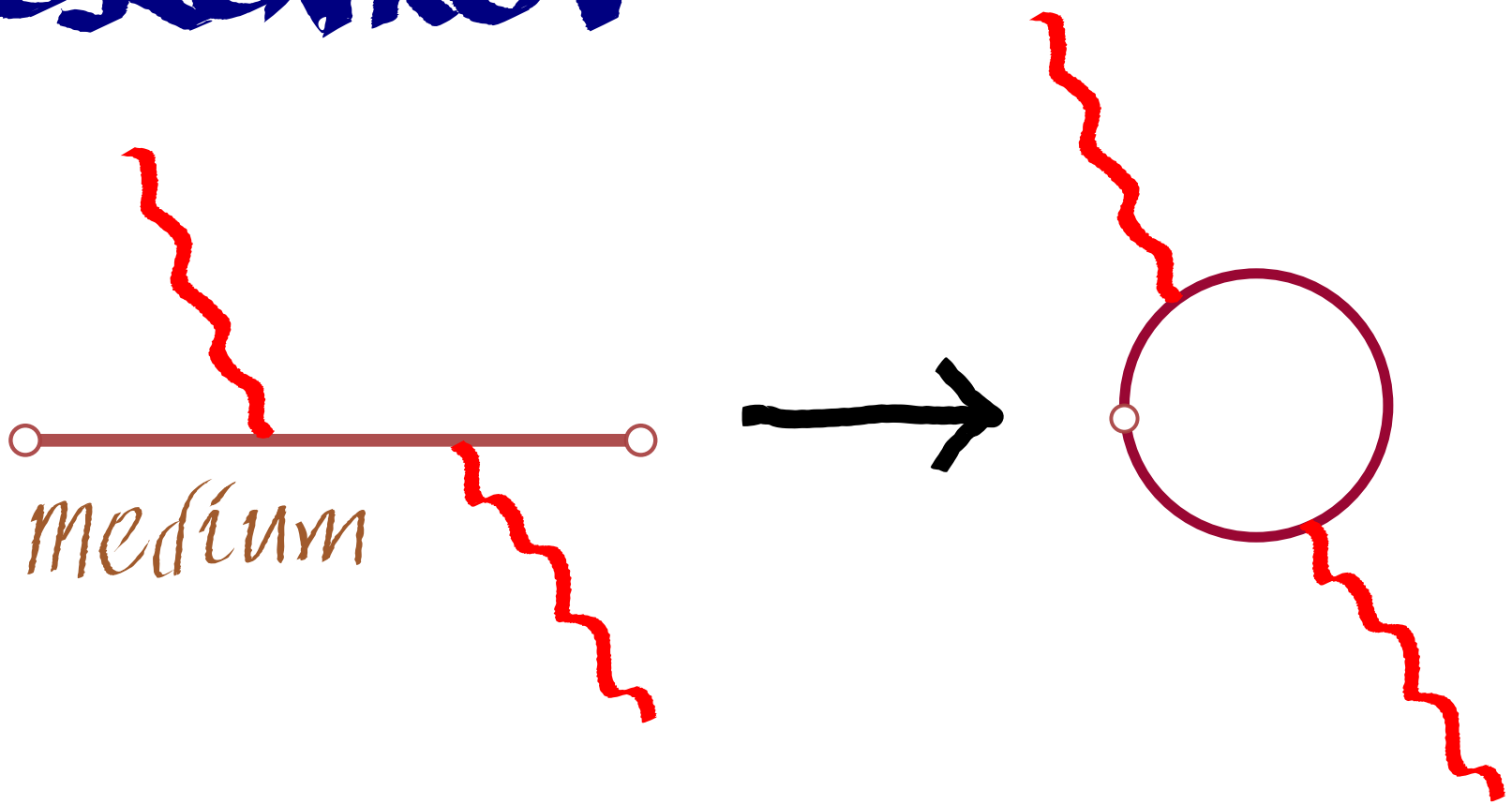
CERENKOV



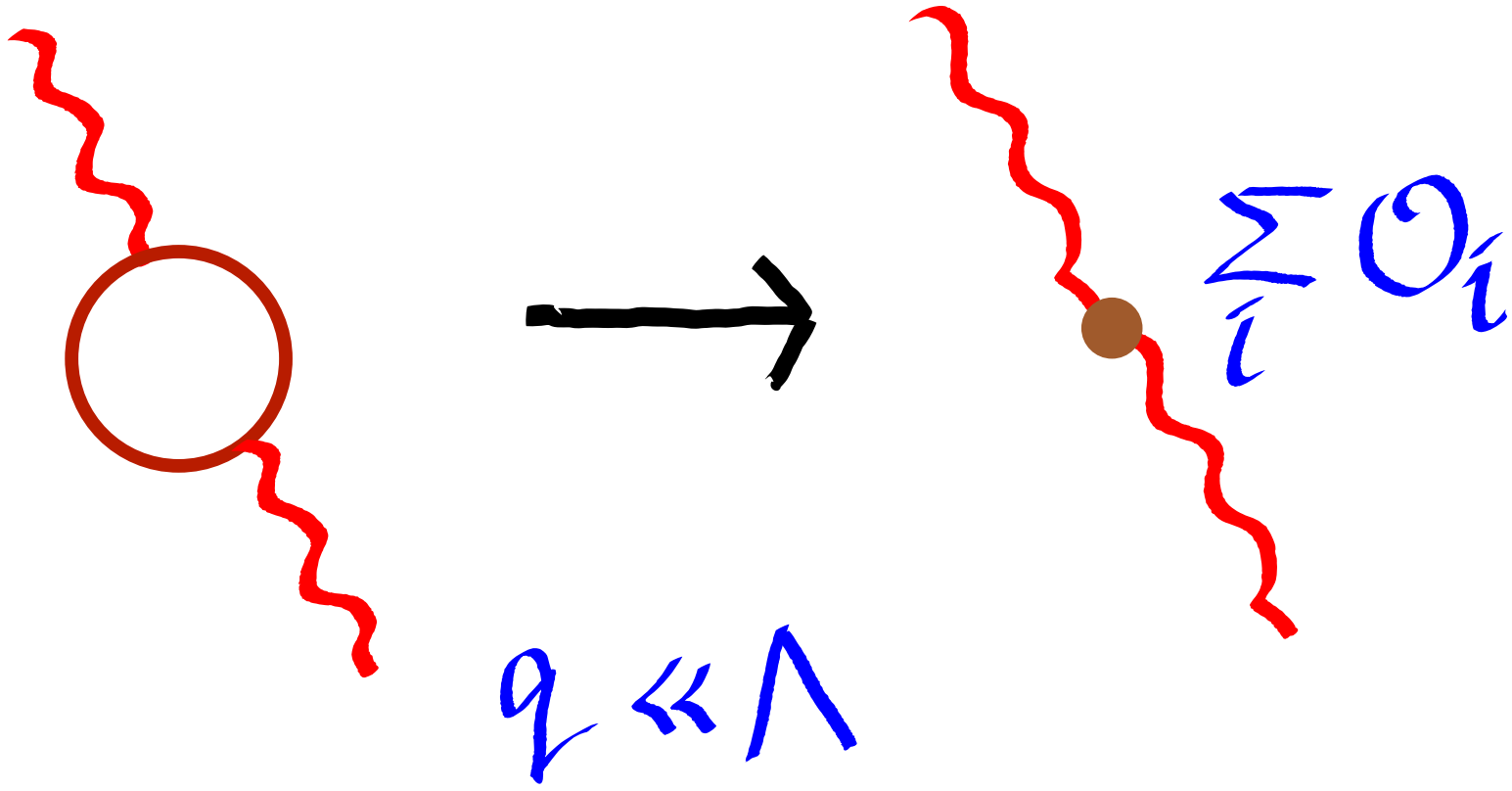
$$e \rightarrow e + \gamma$$

$$v > c$$

CERENKOV



CERENKOV



CERENKOV

$$0 \supset \frac{\delta_\varepsilon}{2}\vec{E}^2 - \frac{\delta_B}{2}\vec{B}^2 + \cdots$$

CERENKOV

$$0 \supset \frac{\delta_\varepsilon}{2}\vec{E}^2 - \frac{\delta_B}{2}\vec{B}^2 + \cdots$$

Electric & Magnetic Permeability

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

SPEED OF WHAT

Rescale $A_\mu ; t ; x$

$c_\gamma \longrightarrow 1$

Other particles have different 'maximal' velocities

ASSUMPTIONS

Conserved Generators of spacetime translations

$$(E, \vec{P}): \quad x \to x + a$$

Small departures from Lorentz

$$L = L_0 + \delta L$$

VACUUM CERENKOV

$$e^- \rightarrow e^- + \gamma \qquad v_e > 1$$

$$\gamma \rightarrow e^+ + e^- \qquad v_e < 1$$

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

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

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

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

NEUTRINOS

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

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

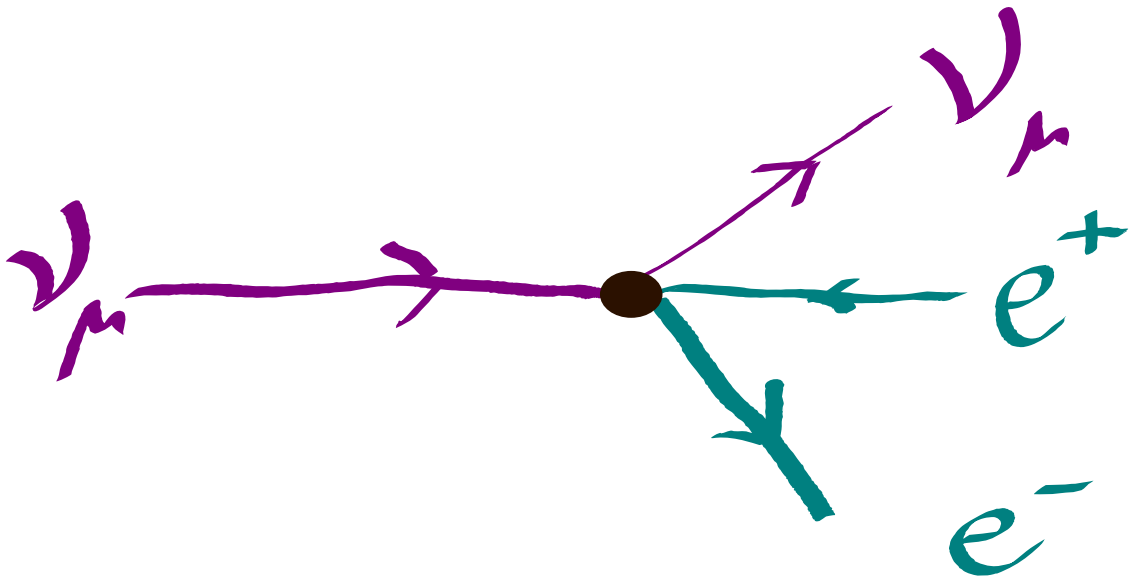
NEUTRINOS

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

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

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

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

$\delta < 2\ 10^{-8}$ 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

→ Highest Energy Distant Source

NEUTRINO TELESCOPES

Observation of neutrinos of energy E at low zenith angle

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

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

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