“Andean School on Nuclear Physics
in the 21st Century ”.

“Relativistic Radiactive Decay and the Opera's Neutrinos ”

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arXiv 1112.0815

- In march 2012, OPERA team finally announce that they mistakenly reported faster than light neutrinos in September 2011. They also recognize that a second experiment, with ultrashort (3 ns) neutrino's beam pulse announced in November 2011 was wrong. They blame a loose cable that produce a delay in the clocks and time tag of the detection events.

- It is possible that an alternative error was made?

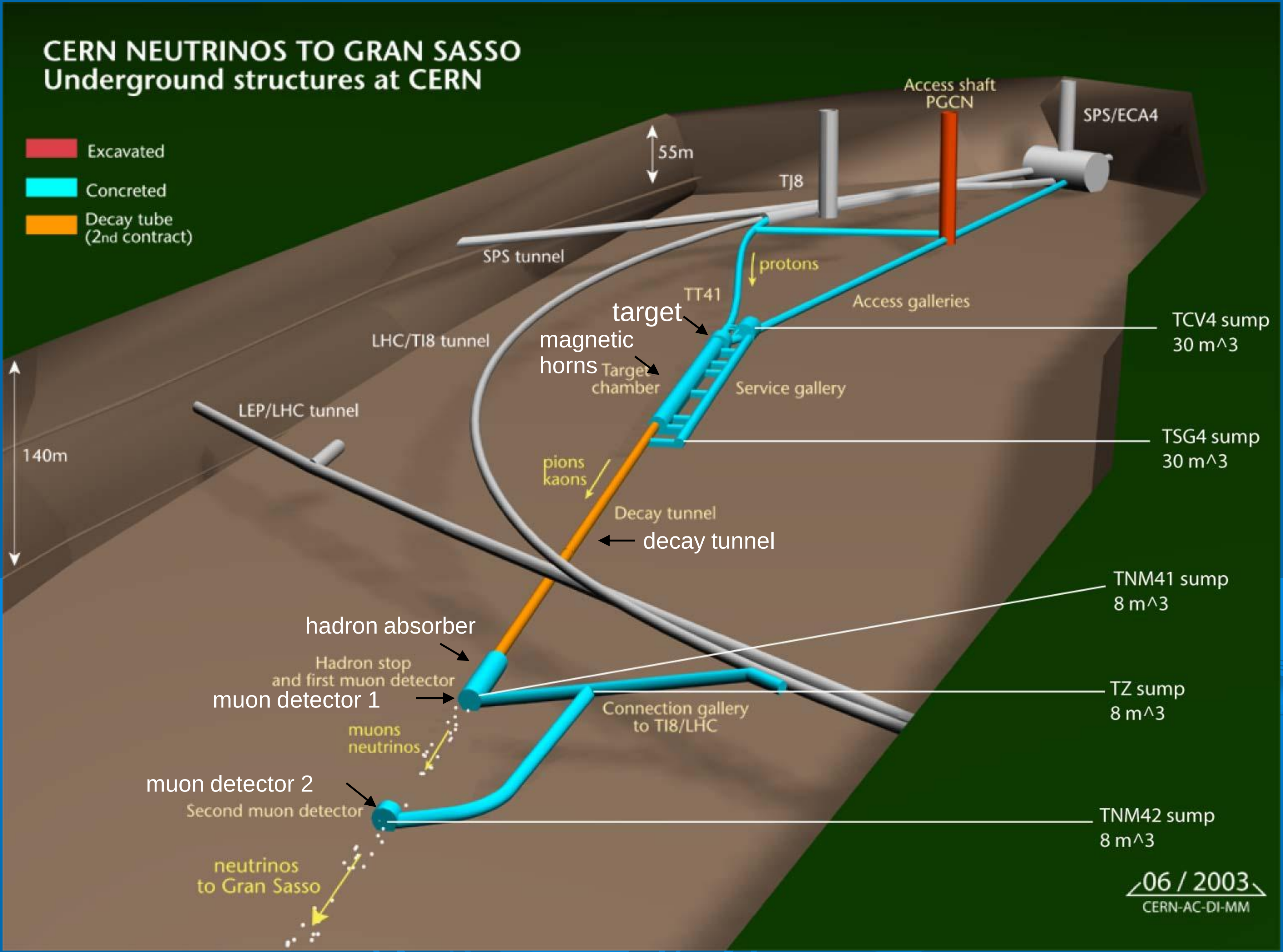
- Here we review the classical radiactive decay in the context of special relativity, for decaying particles (pions) moving close to the speed of light.

- It is shown, that for the short 3 ns neutrino pulses, a relativistic shape deforming effect of the neutrino distribution function produces an apparent earlier arrival of 65.8ns in agreement with the reported 62.1ns, within the experimental error (3.7ns), explaining the apparent superluminal effect.

“Explaining OPERA neutrinos speed experiment”

OPERA collaboration report 15223 neutrinos:

57.8 ns within 6 σ Faster than light !



target

magnetic horns

decay tunnel

hadron absorber

muon detector 1

muon detector 2

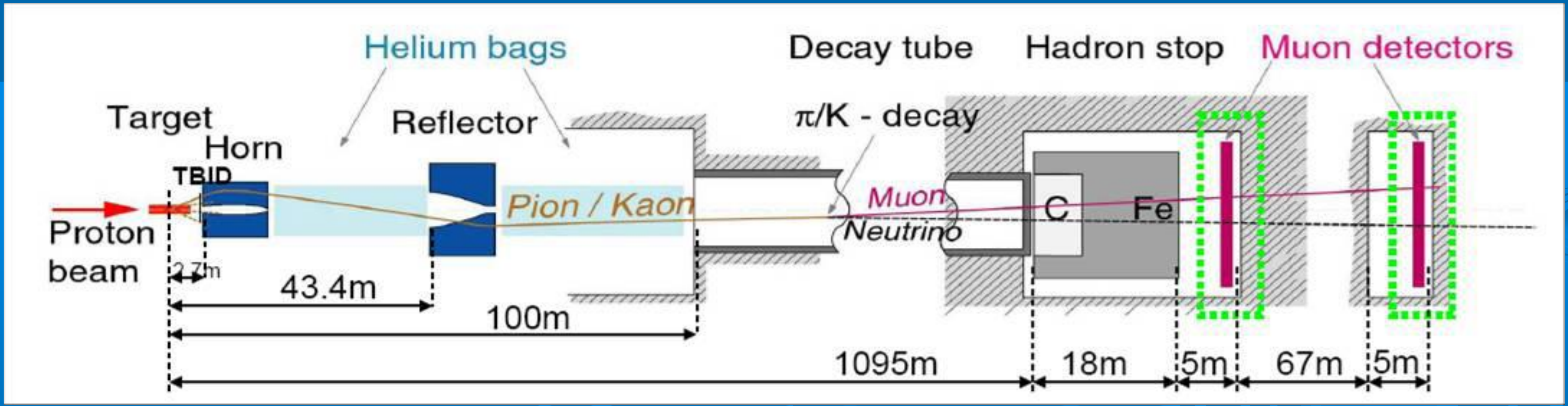
How neutrinos are produced?

A kicker magnet send “POT”

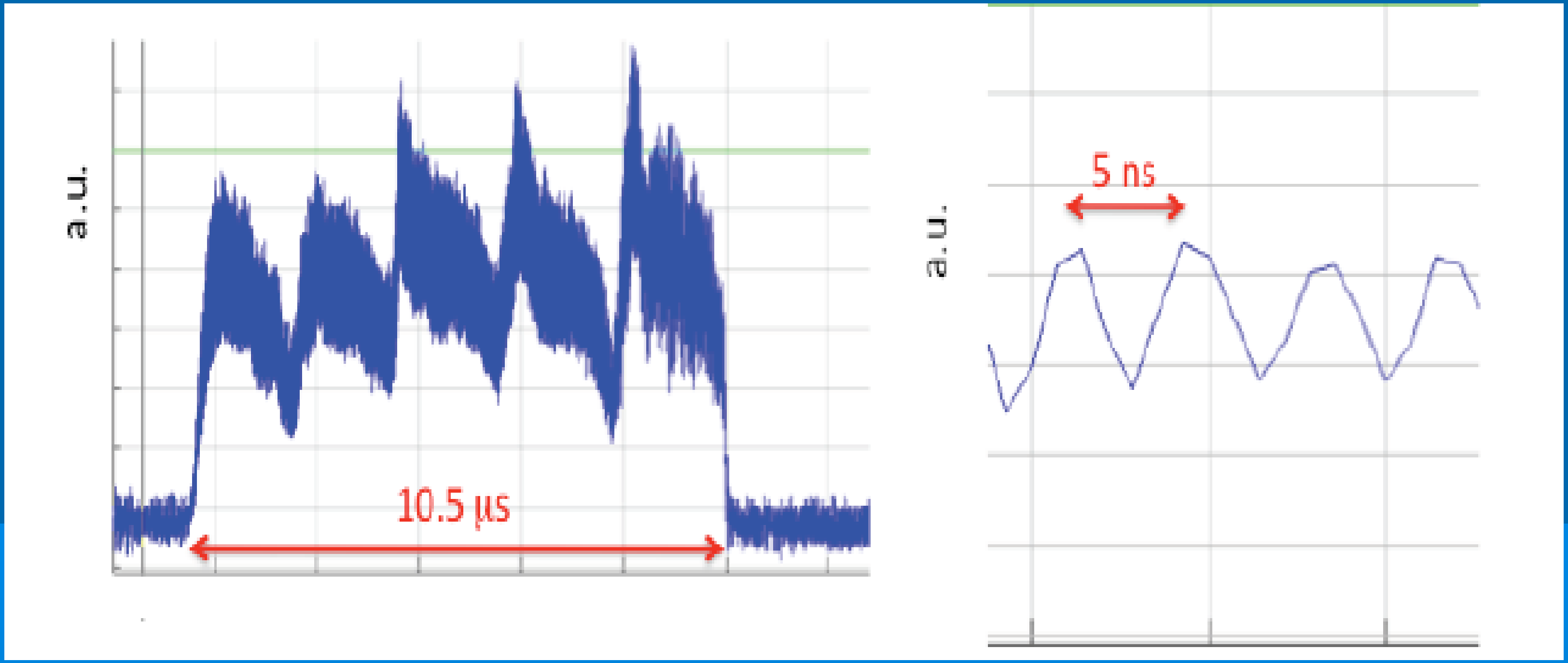
That produces “mesons”

That decays into “neutrinos”

That are detected at Gran Sasso

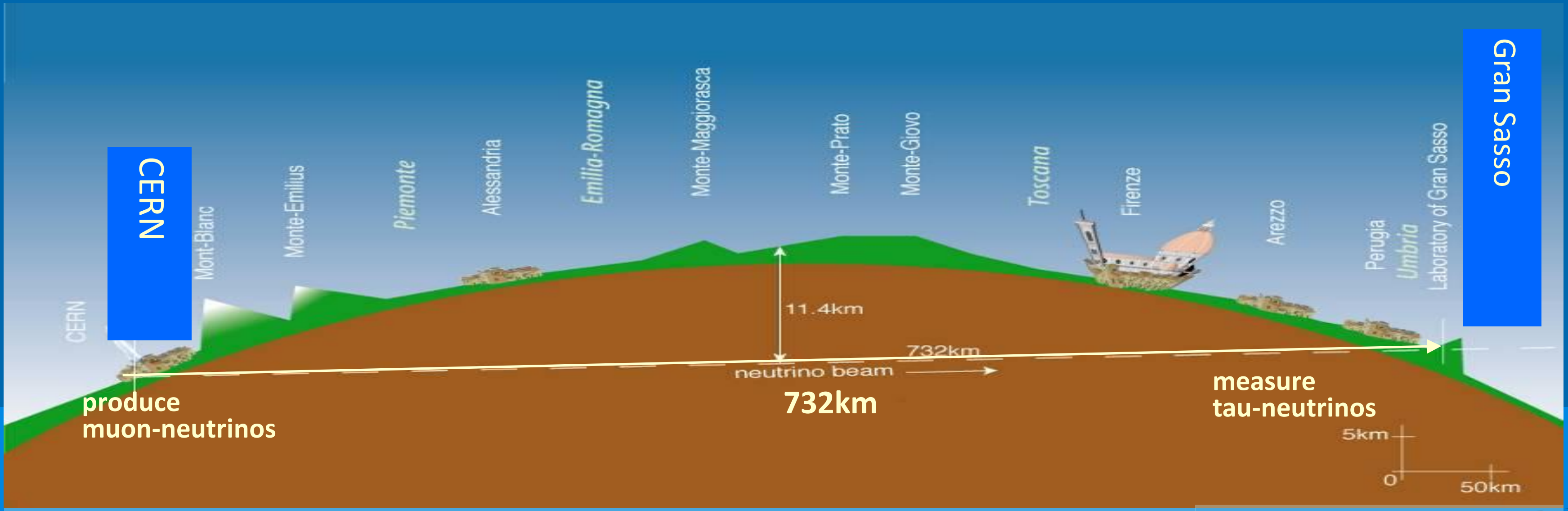


How looks Proton extraction waveform?



Note 200 Mhz CERN proton synchrotron

Travel from CERN to Gran Sasso



~$4 \cdot 10^{19}$ p/year ~$2 \cdot 10^{19}$ ν_μ/year

~2 ν_τ/year

(~$1 \cdot 10^{17}$ ν_μ/year)

Actually 730534.6 m error 0.2 m

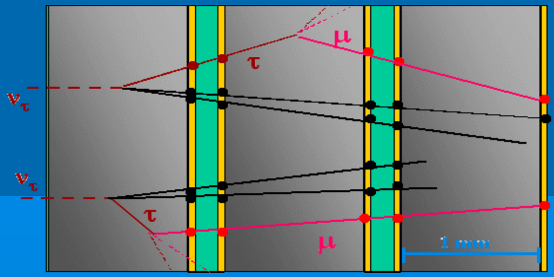
About 1.97 x E13 protons each extraction

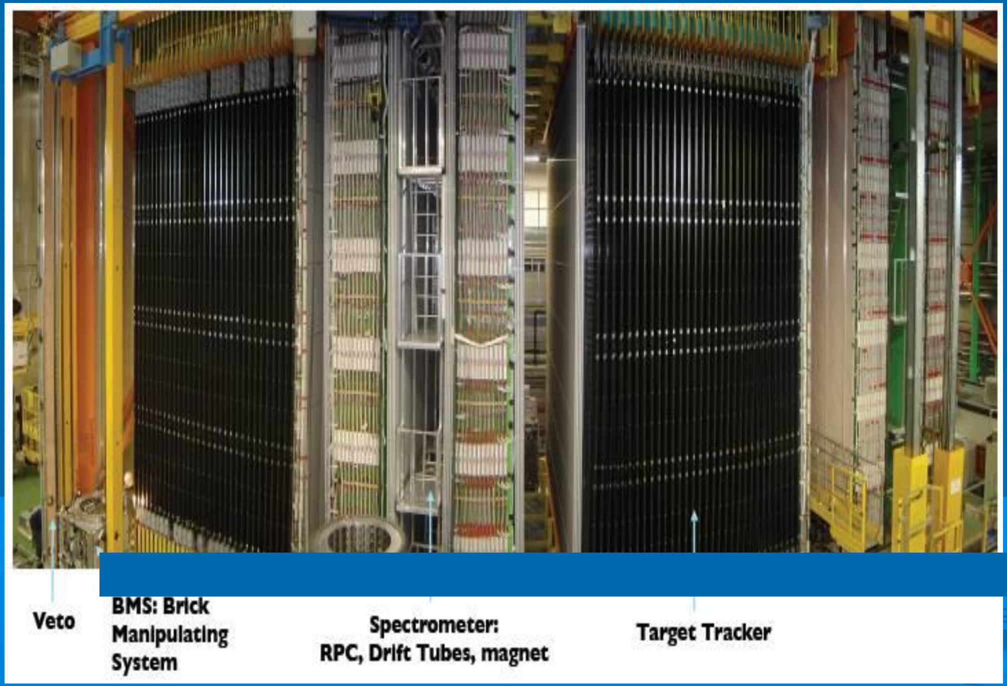
OPERA detector

OPERA

1.2 kton emulsion target detector

~146000 lead emulsion bricks



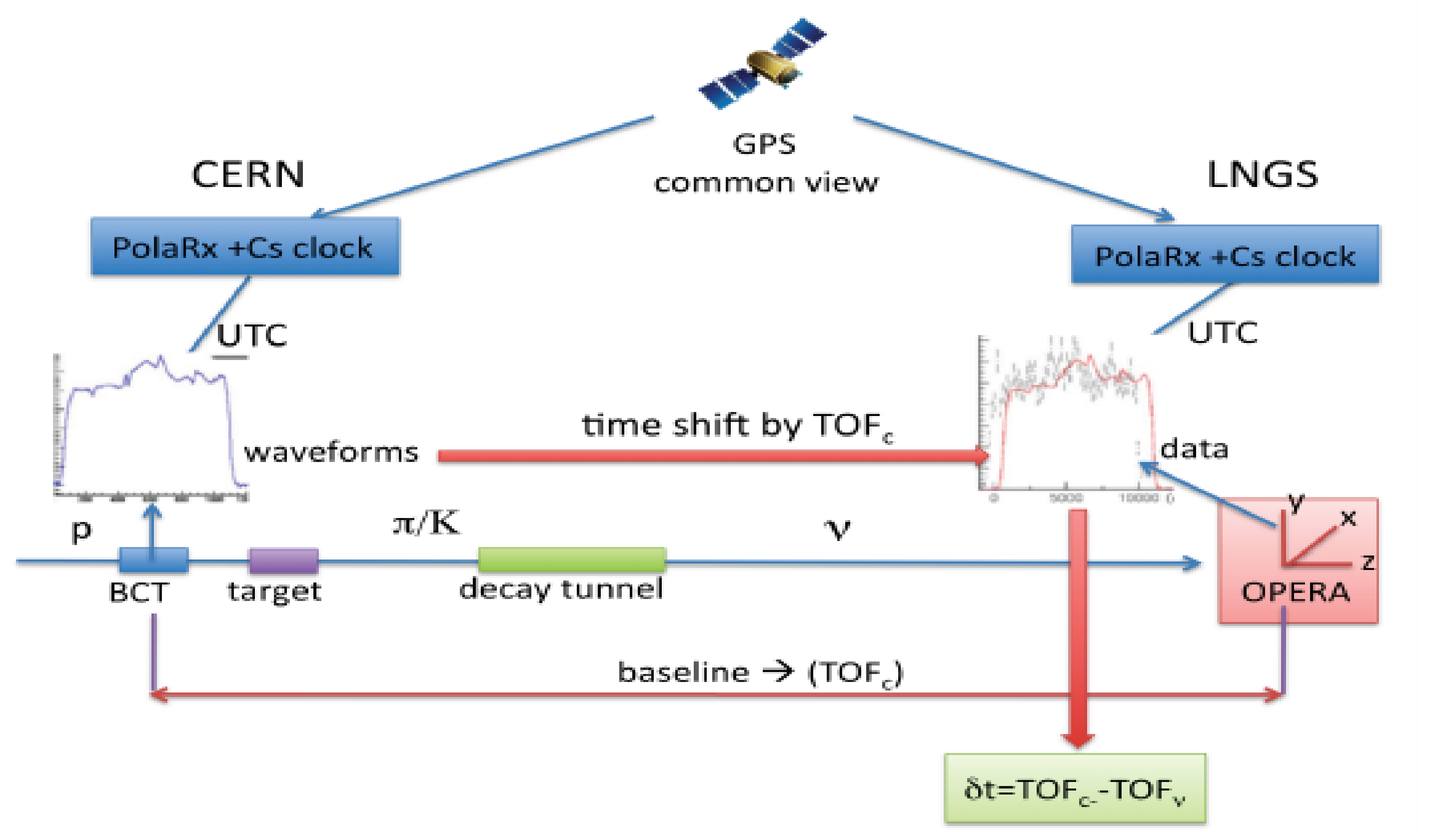


CC and NC distinguish

External and Internal

Cosmic rays not at time

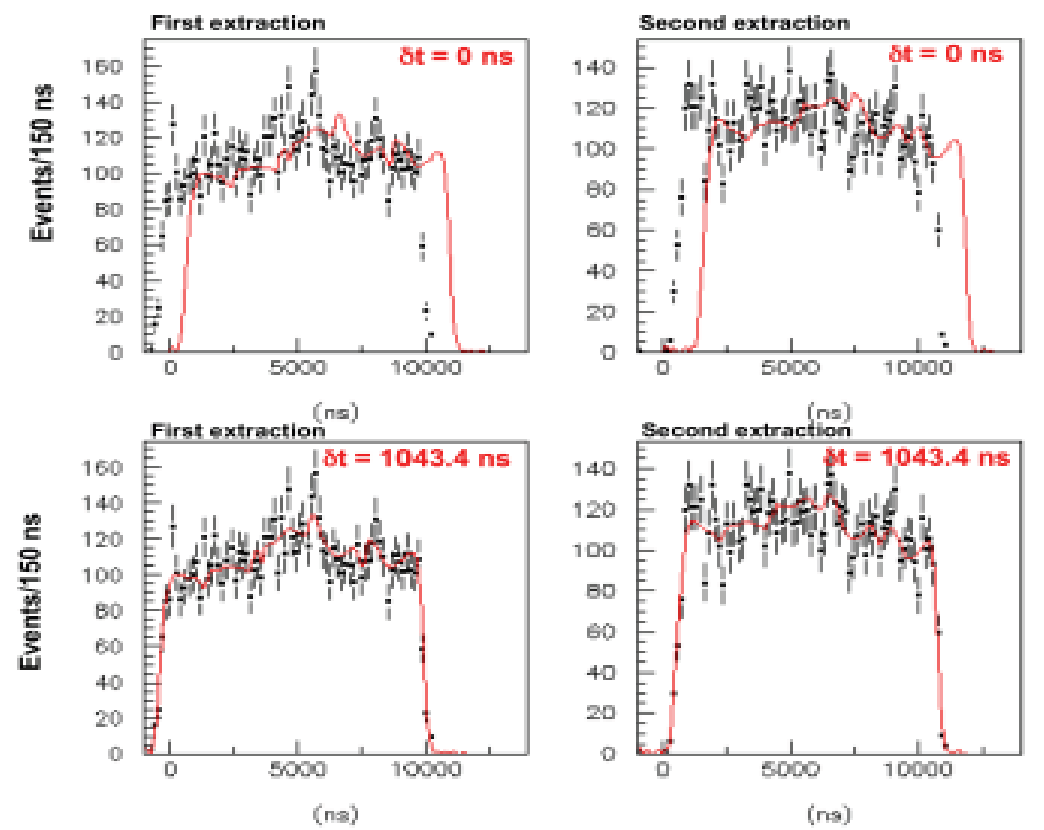
High precision GPS time compared

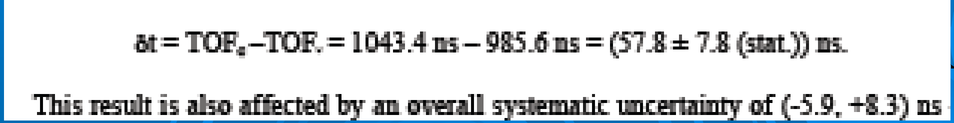


Here PDF= $\prod_j w_k\left(t_j+\delta t_k\right)$ k = 1,2 extractions

Faster than light neutrinos OPERA-1?

arXiv 1109.4897V1



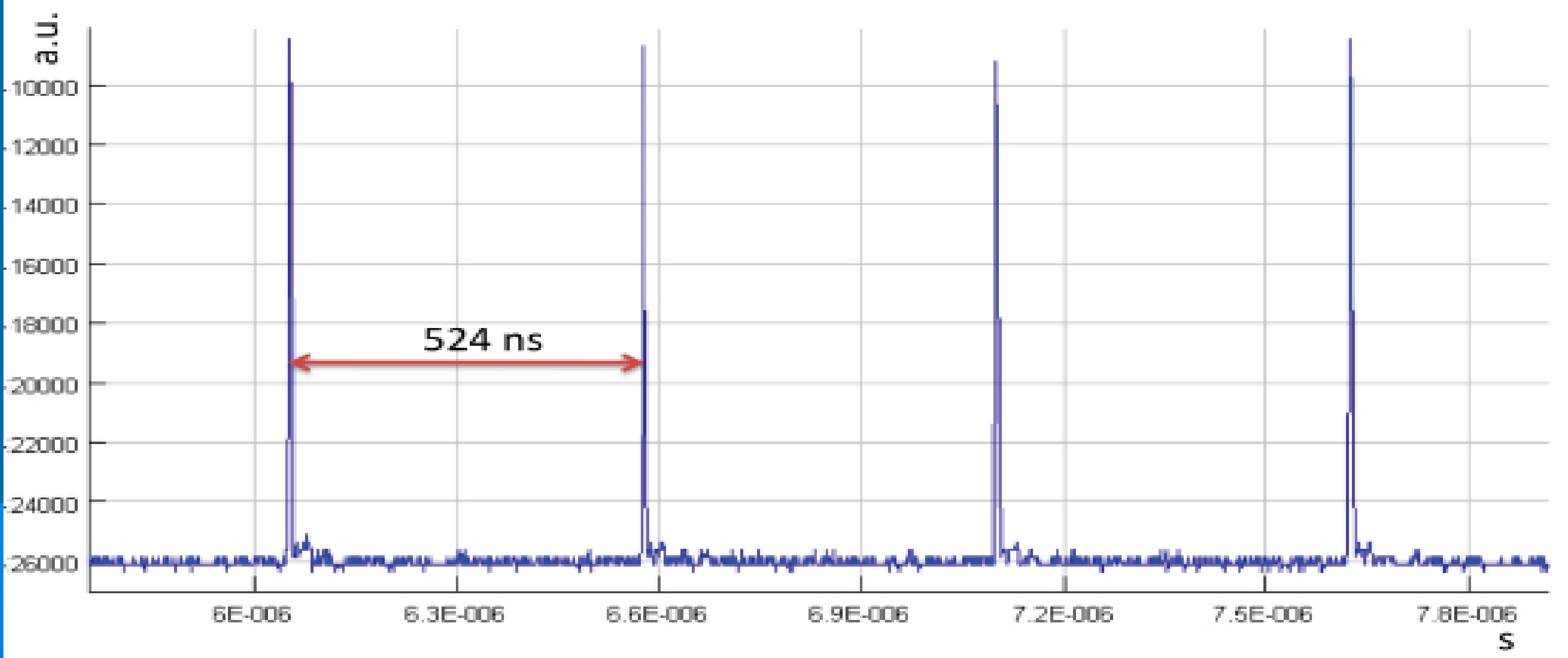


$\delta t = TOF_c - TOF_\nu = 1043.4$ ns – 985.6 ns = (57.8 ± 7.8 (stat.)) ns.

This result is also affected by an overall systematic uncertainty of (-5.9, +8.3) ns

November 2011: OPERA – 2

arXiv 1109.4897V2&3



Ultrashort bunch beam 3 ns

Low intensity E11 pot but isolated packages

20 neutrinos detected

November 2011: OPERA - 2

20 neutrinos detected

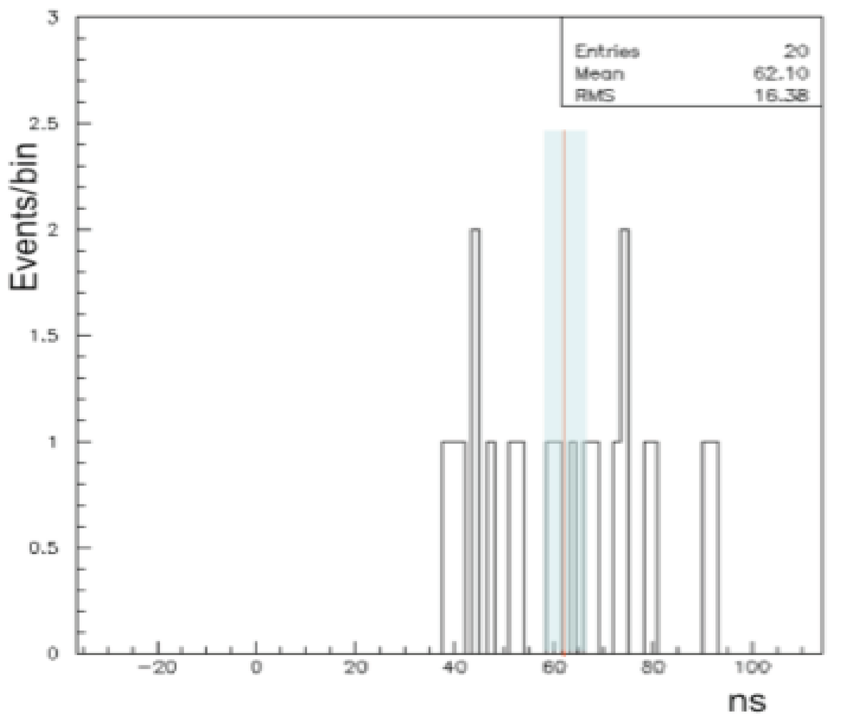


Fig. 18: Distribution of the δt values obtained from the events taken with the bunched neutrino beam. The mean value, indicated by the red line and the blue band, is (62.1 ± 3.7) ns.

Relativistic Radioactive Decay

arXiv 1112.0815

Consider the equations of radioactive decay for pions (creation of meson/neutrino) but including the in and out moving particles inside a control volume for a differential time interval.

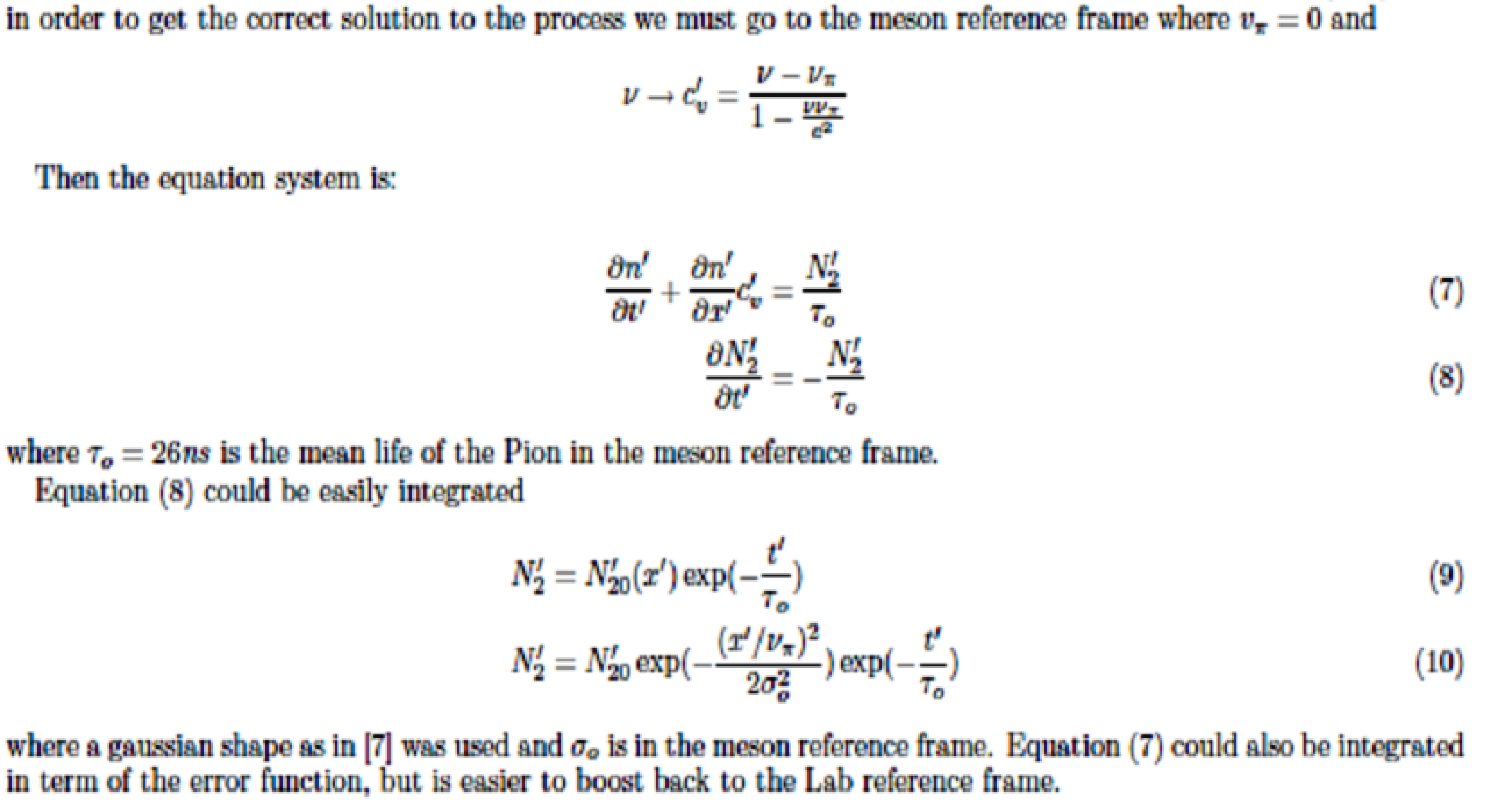
$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x} . \nu = N_2 \, A_{21} \qquad (5)$$

$$\frac{\partial N_2}{\partial t} + \frac{\partial N_2}{\partial x} . v_\pi = -N_2 \, A_{21} \qquad (6)$$

This is a conservative covariant equation, like a flux continuity equation.

Control volumes for the pion and neutrino are velocity dependent, but both speeds are close to c

Solving Relativistic Decay Equations



in order to get the correct solution to the process we must go to the meson reference frame where $\nu_\pi = 0$ and

$$\nu \to c'_v = \frac{\nu - \nu_\pi}{1 - \frac{\nu\nu_\pi}{c^2}}$$

Then the equation system is:

$$\frac{\partial n'}{\partial t'} + \frac{\partial n'}{\partial x'} c'_v = \frac{N'_2}{\tau_o} \tag{7}$$

$$\frac{\partial N'_2}{\partial t'} = -\frac{N'_2}{\tau_o} \tag{8}$$

where $\tau_o = 26ns$ is the mean life of the Pion in the meson reference frame.

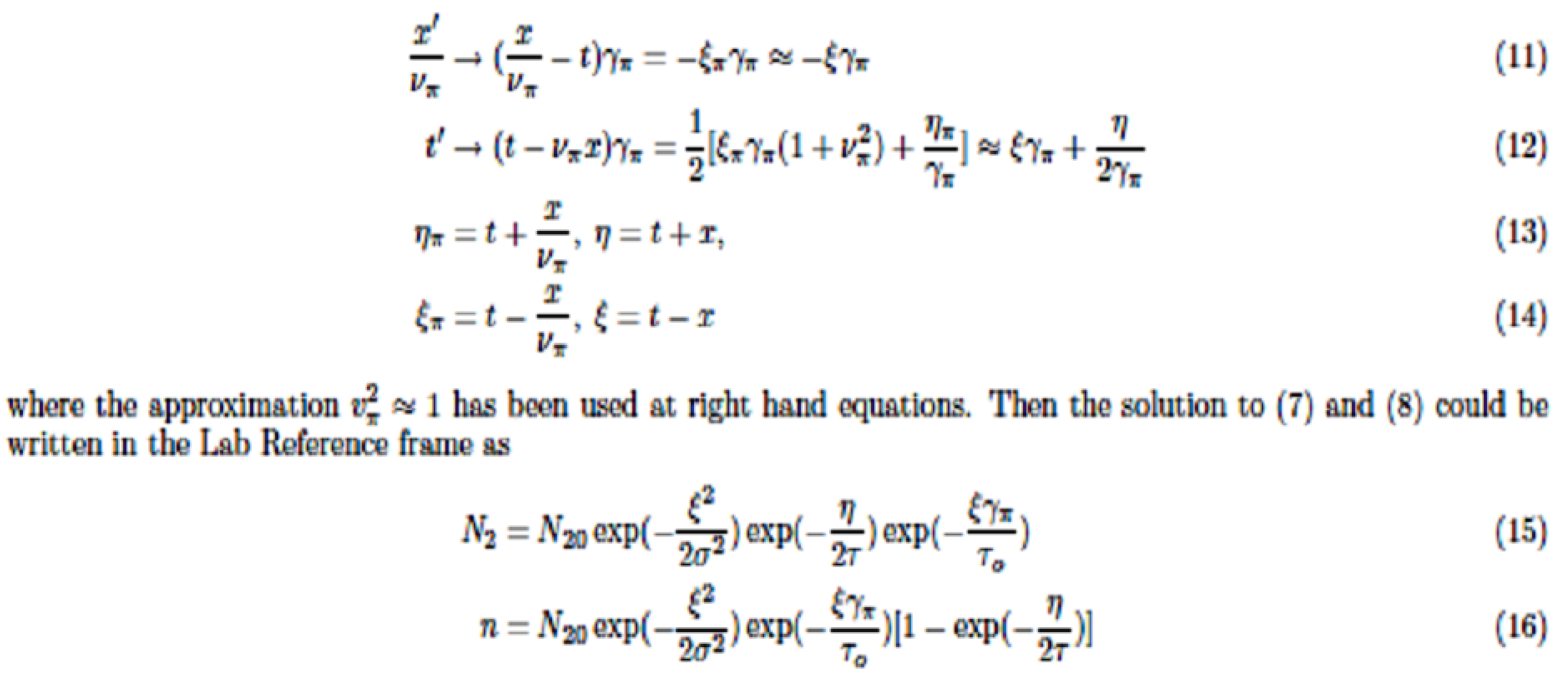
Equation (8) could be easily integrated

$$N'_2 = N'_{20}(x')\exp(-\frac{t'}{\tau_o}) \tag{9}$$

$$N'_2 = N'_{20}\exp(-\frac{(x'/\nu_\pi)^2}{2\sigma_o^2})\exp(-\frac{t'}{\tau_o}) \tag{10}$$

where a gaussian shape as in [7] was used and σ_o is in the meson reference frame. Equation (7) could also be integrated in term of the error function, but is easier to boost back to the Lab reference frame.

Back to Lab Reference Frame



$$\frac{x'}{\nu_\pi} \rightarrow (\frac{x}{\nu_\pi} - t)\gamma_\pi = -\xi_\pi\gamma_\pi \approx -\xi\gamma_\pi \tag{11}$$

$$t' \rightarrow (t - \nu_\pi x)\gamma_\pi = \frac{1}{2}[\xi_\pi\gamma_\pi(1 + \nu_\pi^2) + \frac{\eta_\pi}{\gamma_\pi}] \approx \xi\gamma_\pi + \frac{\eta}{2\gamma_\pi} \tag{12}$$

$$\eta_\pi = t + \frac{x}{\nu_\pi},\ \eta = t + x, \tag{13}$$

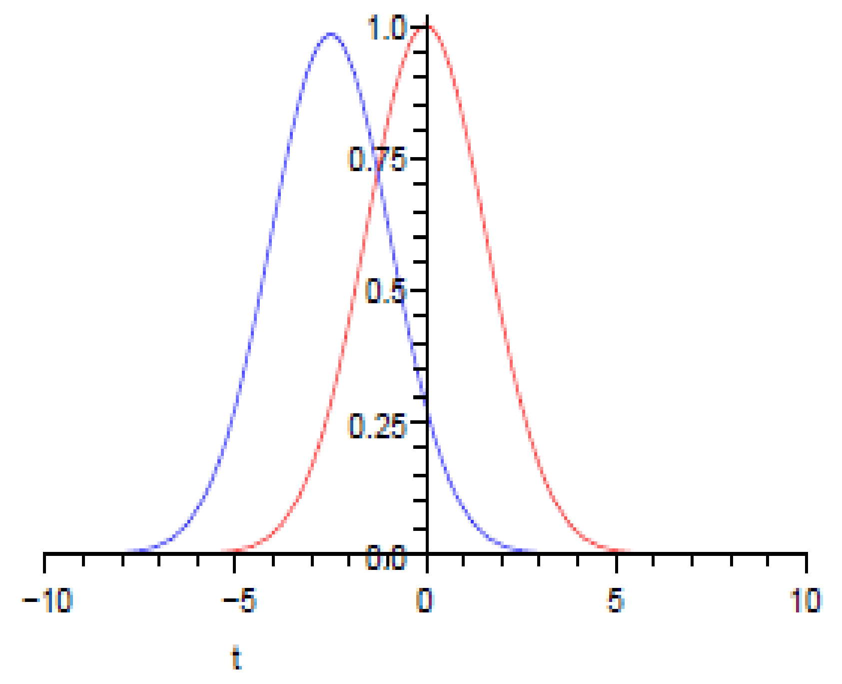
$$\xi_\pi = t - \frac{x}{\nu_\pi},\ \xi = t - x \tag{14}$$

where the approximation $v_\pi^2 \approx 1$ has been used at right hand equations. Then the solution to (7) and (8) could be written in the Lab Reference frame as

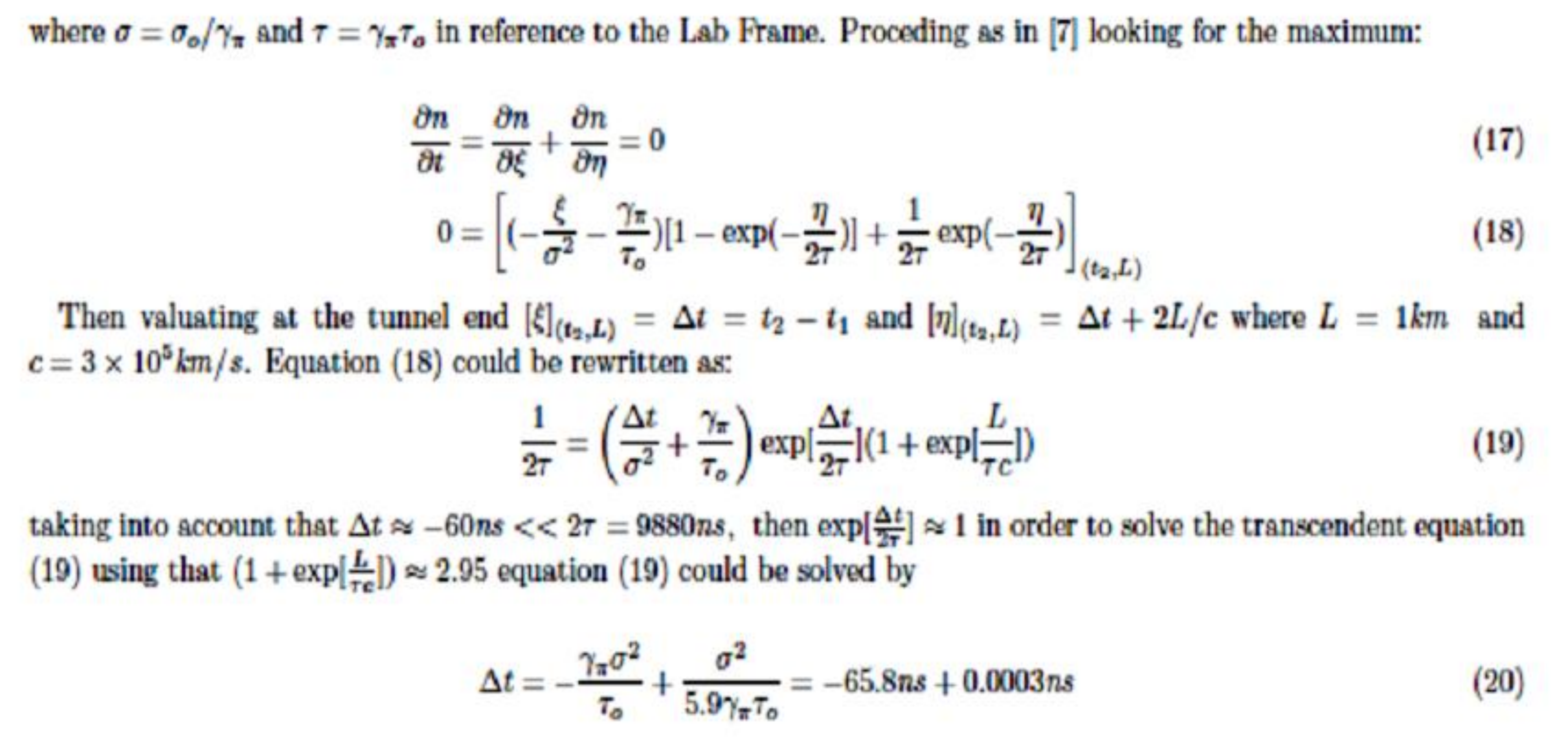
$$N_2 = N_{20}\exp(-\frac{\xi^2}{2\sigma^2})\exp(-\frac{\eta}{2\tau})\exp(-\frac{\xi\gamma_\pi}{\tau_o}) \tag{15}$$

$$n = N_{20}\exp(-\frac{\xi^2}{2\sigma^2})\exp(-\frac{\xi\gamma_\pi}{\tau_o})[1 - \exp(-\frac{\eta}{2\tau})] \tag{16}$$

Lab Reference Frame: Wave Shifting



OPERA-2 superluminal neutrinos Relativistic Shifting?



where $\sigma = \sigma_o/\gamma_\pi$ and $\tau = \gamma_\pi \tau_o$ in reference to the Lab Frame. Proceding as in [7] looking for the maximum:

$$\frac{\partial n}{\partial t} = \frac{\partial n}{\partial \xi} + \frac{\partial n}{\partial \eta} = 0 \tag{17}$$

$$0 = \left[\left(-\frac{\xi}{\sigma^2} - \frac{\gamma_\pi}{\tau_o}\right)\left[1 - \exp\left(-\frac{\eta}{2\tau}\right)\right] + \frac{1}{2\tau}\exp\left(-\frac{\eta}{2\tau}\right) \right]_{(t_2,L)} \tag{18}$$

Then valuating at the tunnel end $[\xi]_{(t_2,L)} = \Delta t = t_2 - t_1$ and $[\eta]_{(t_2,L)} = \Delta t + 2L/c$ where $L = 1km$ and $c = 3 \times 10^5 km/s$. Equation (18) could be rewritten as:

$$\frac{1}{2\tau} = \left(\frac{\Delta t}{\sigma^2} + \frac{\gamma_\pi}{\tau_o}\right) \exp\left[\frac{\Delta t}{2\tau}\right]\left(1 + \exp\left[\frac{L}{\tau c}\right]\right) \tag{19}$$

taking into account that $\Delta t \approx -60ns << 2\tau = 9880ns$, then $\exp[\frac{\Delta t}{2\tau}] \approx 1$ in order to solve the transcendent equation (19) using that $(1 + \exp[\frac{L}{\tau c}]) \approx 2.95$ equation (19) could be solved by

$$\Delta t = -\frac{\gamma_\pi \sigma^2}{\tau_o} + \frac{\sigma^2}{5.9\gamma_\pi \tau_o} = -65.8ns + 0.0003ns \tag{20}$$

65.8 ns = (62.1 + 3.7) ns !!

SUPERLUMINIC NEUTRINOS ERRORS

6 December 2011

14 December 2011

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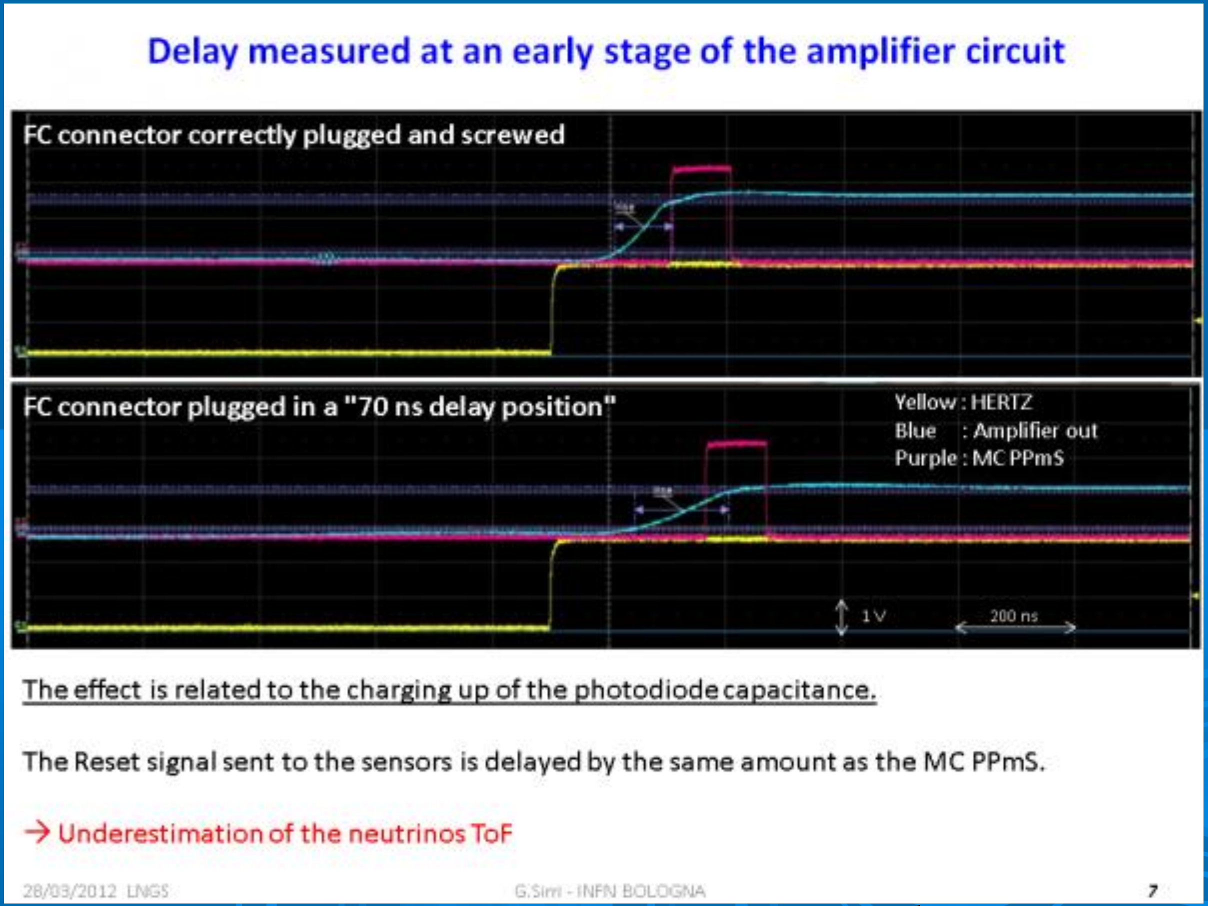
First Mistake

Opera´s Master Clock tag CERN beam at a later time, because photodiode needs more time to charge and “trigger” the clock: delay~ 120 ns.



Delay measured at an early stage of the amplifier circuit

FC connector correctly plugged and screwed

FC connector plugged in a "70 ns delay position"

Yellow : HERTZ
Blue : Amplifier out
Purple : MC PPmS

The effect is related to the charging up of the photodiode capacitance.

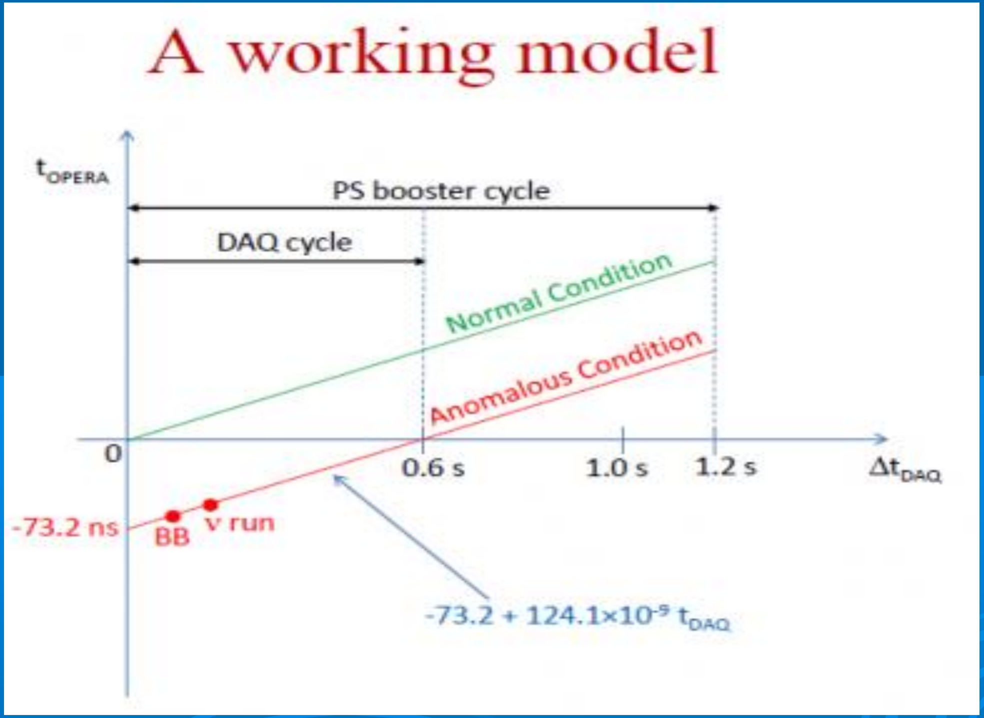
The Reset signal sent to the sensors is delayed by the same amount as the MC PPmS.

→ Underestimation of the neutrinos ToF

28/03/2012 LNGS G.Sirri - INFN BOLOGNA 7

Second mistake:

Drifting of Gran Sasso Master Clock, beetween
-73.2 and + 73.2 ns, data read only from 0 to 0.6 s
Cannot compensate first 124ns mistake (Scioli's talk)



End of the OPERA Story (http://profmattstrassler.com)
Posted on June 8, 2012 | 29 Comments

So the news from the Neutrino 2012 conference in Kyoto, on new data from May 2012 taken by OPERA and three nearby experiments, is no surprise to anyone who was paying attention back in March and early April; it’s *exactly* what we were expecting.

Neutrinos arrive at a time that differs from expectation by, compatible with zero:

○ Borexino: δt = 2.7 ± 1.2 (stat) ± 3 (sys) ns

○ ICARUS: δt = 5.1 ± 1.1 (stat) ± 5.5 (sys) ns

○ LVD: δt = 2.9 ± 0.6 (stat) ± 3 (sys) ns

○ OPERA: δt = 6.5 ± 7.4 (sys) [-1.9 ± 3.7 (sys) BB] ns
○ OPERA: δt = 1.6 ± 1,1 (sta) ± [6.1,-3.7] ns

Modifing the decay equation

(LASER inspired)

$$\begin{aligned}
\frac{\partial N_2}{\partial t} + \frac{\partial N_2}{\partial x}.v_\pi &= -N_2\ A_{21} - D_{21}N_2N_1 -\ B_{21}\ N_2 n + \ C_{12}\ N_1 n \\
\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x}.\nu &= -\frac{\partial N_2}{\partial t} - \frac{\partial N_2}{\partial x}.v_\pi \\
\frac{\partial N_1}{\partial t} + \frac{\partial N_1}{\partial x}.v_\mu &= \frac{\partial n}{\partial t} + \frac{\partial n}{\partial x}.\nu
\end{aligned}$$

$$\begin{aligned}
\frac{\partial N_2}{\partial t} + \frac{\partial N_2}{\partial x}.v_\pi &= -N_2\ A_{21} - D_{21}N_2N_1 \\
\frac{\partial N_1}{\partial t} + \frac{\partial N_1}{\partial x}.v_\mu &= -\frac{\partial N_2}{\partial t} - \frac{\partial N_2}{\partial x}.v_\pi \qquad N_1(x,t) \simeq n(x,t) \\
B_{21} \longrightarrow 0, &\qquad C_{21} \longrightarrow 0
\end{aligned}$$

New Intensity dependent shape-coherence effects ?

$$\Delta t \simeq 57.8ns_{\pm 7.8} \qquad (\text{Wrong OPERA}) \Longrightarrow D_{12} = \frac{\Delta t\ vol}{N_1 \sigma_o^2} \simeq 75barn$$

$$\Delta t \simeq 1.6ns_{\pm 7} \qquad (\text{corrected OPERA}) \Longrightarrow D_{12} = \frac{\Delta t\ vol}{N_1 \sigma_o^2} \leq 1.5barn$$

$$vol = \pi R_m L = 0.013m^3 \qquad L = 1000m \qquad \sigma_o = 3ns \qquad N_1 = 10^{20}$$

$$Rm = \frac{1}{\int_{1mm}^{1m} \frac{1}{r^2} dr} \int_{1mm}^{1m} r * \frac{1}{r^2} dr = 3.6mm$$

Too Big: must be less than 1mbarn (next fig.), but….

LHC about 10^8 times more Luminosity than SPS

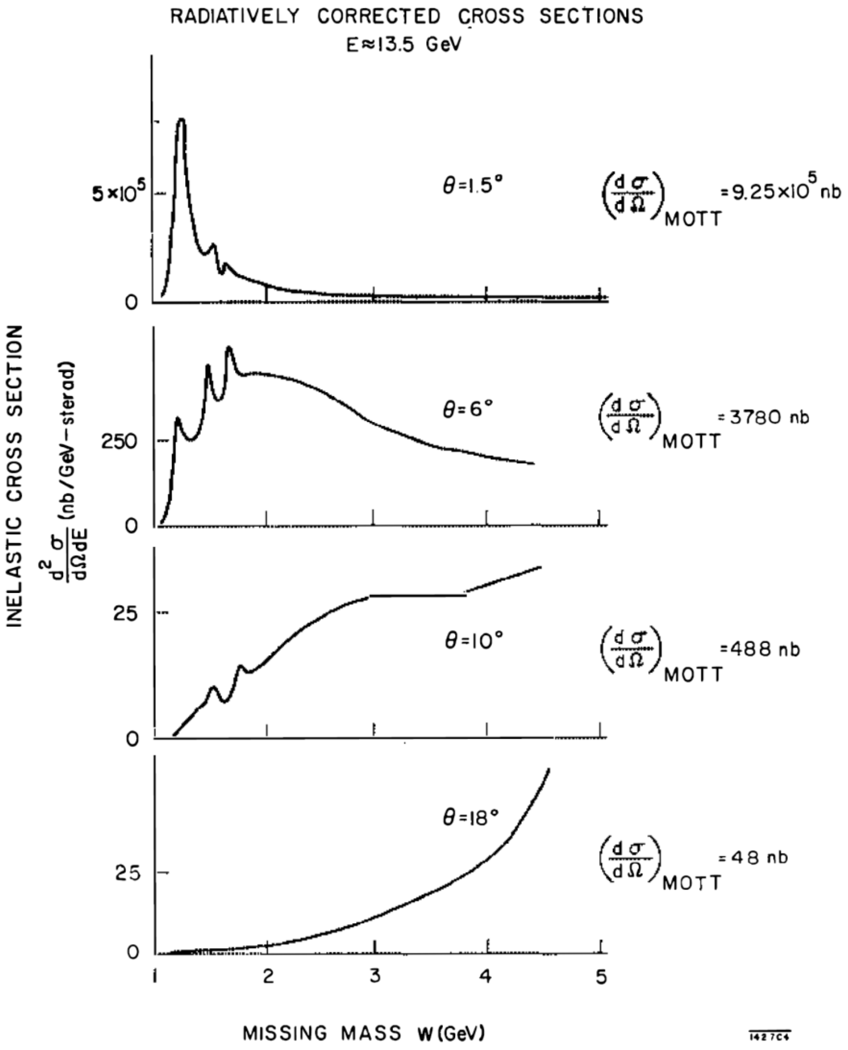


FIGURE 8. Visual fits to spectra showing the scattering of electrons from hydrogen at a primary energy *E* of approximately 13.5 GeV, for scattering angles from 1.5° to 18°. The 1.5° curve is taken from the MIT-SLAC data, (18), used to obtain photoabsorption cross sections.

- Annu.Rev.Nucl.Sci(1972) 22: 203-254

¿Future experiments?

- Muchas Gracias