Present status of LVD

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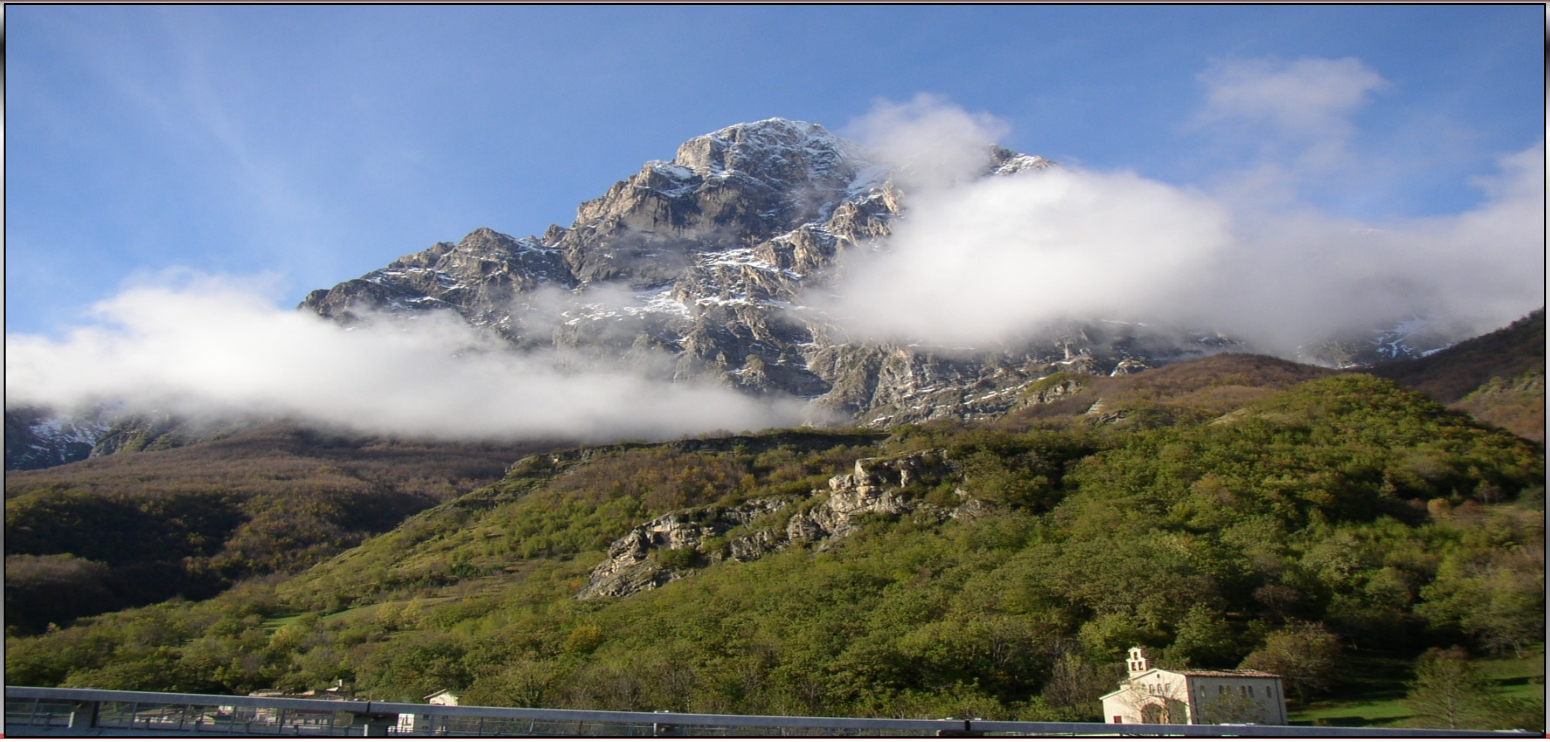
(for LVD Collaboration)

SIXTEENTH LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS

Outline

- Gran Sasso National Laboratory
- LVD experiment
- Search for neutrino bursts from Supernova with LVD
- Study of cosmic ray (CR) muons and neutrinos
- Detection of neutrons produced by CR muons and neutrinos with LVD
- CNGS project
- LVD-OPERA horizontal events
- Neutrino velocity measurements with LVD

Gran Sasso National Laboratory



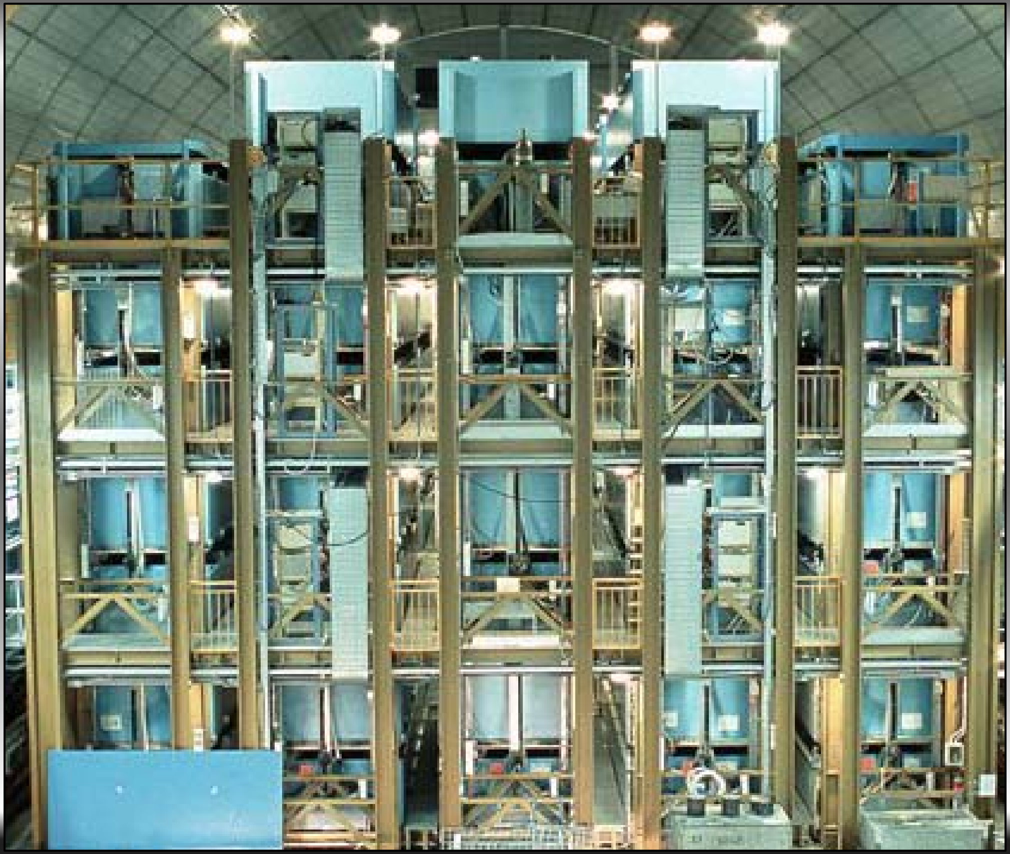
- The Gran Sasso National Laboratory (LNGS) is the largest underground laboratory in the world for experiments in particle physics, particle astrophysics and nuclear astrophysics.
- It is located between the towns of L'Aquila and Teramo, about 120 km from Rome. The underground facilities are located on a side of the ten kilometers long freeway tunnel crossing the Gran Sasso Mountain. They consist of three large experimental halls, each about 100 m long, 20 m wide and 18 m high and service tunnels, for a total volume of about 180,000 cubic meters.
- The average 1400 m rock coverage gives a reduction factor of one million in the cosmic ray flux; moreover, the neutron flux is thousand times less than on the surface, thanks to the smallness of the Uranium and Thorium content of the dolomite rocks of the mountain.

Gran Sasso National Laboratory

Underground part of LNGS

Outside part of LNGS

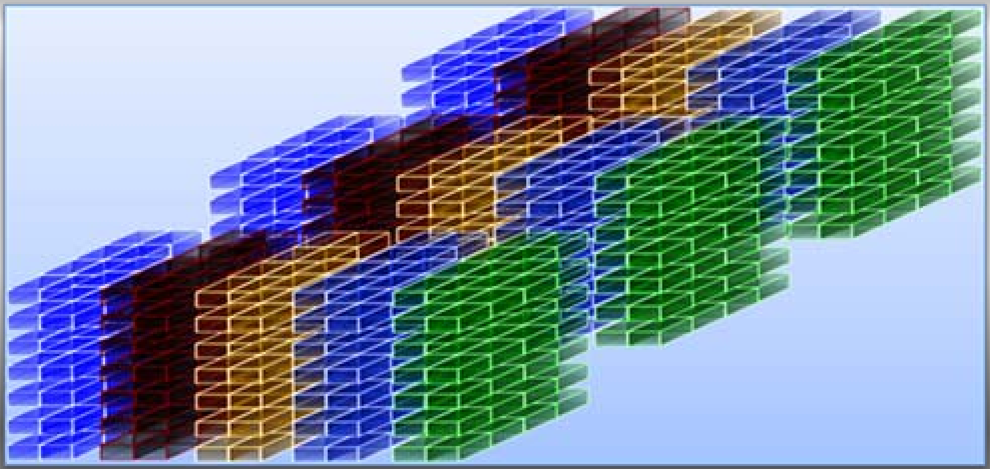
Large Volume Detector (LVD). Main goals.



The main goal is to search for ν bursts from collapsing stars

Study & important results in:
- neutrino physics
- astrophysics
- cosmic ray physics
- search for rare processes

Large Volume Detector (LVD). Structure.



✓The largest iron-scintillation telescope in the world

✓3 towers, 7 levels, 5 columns:

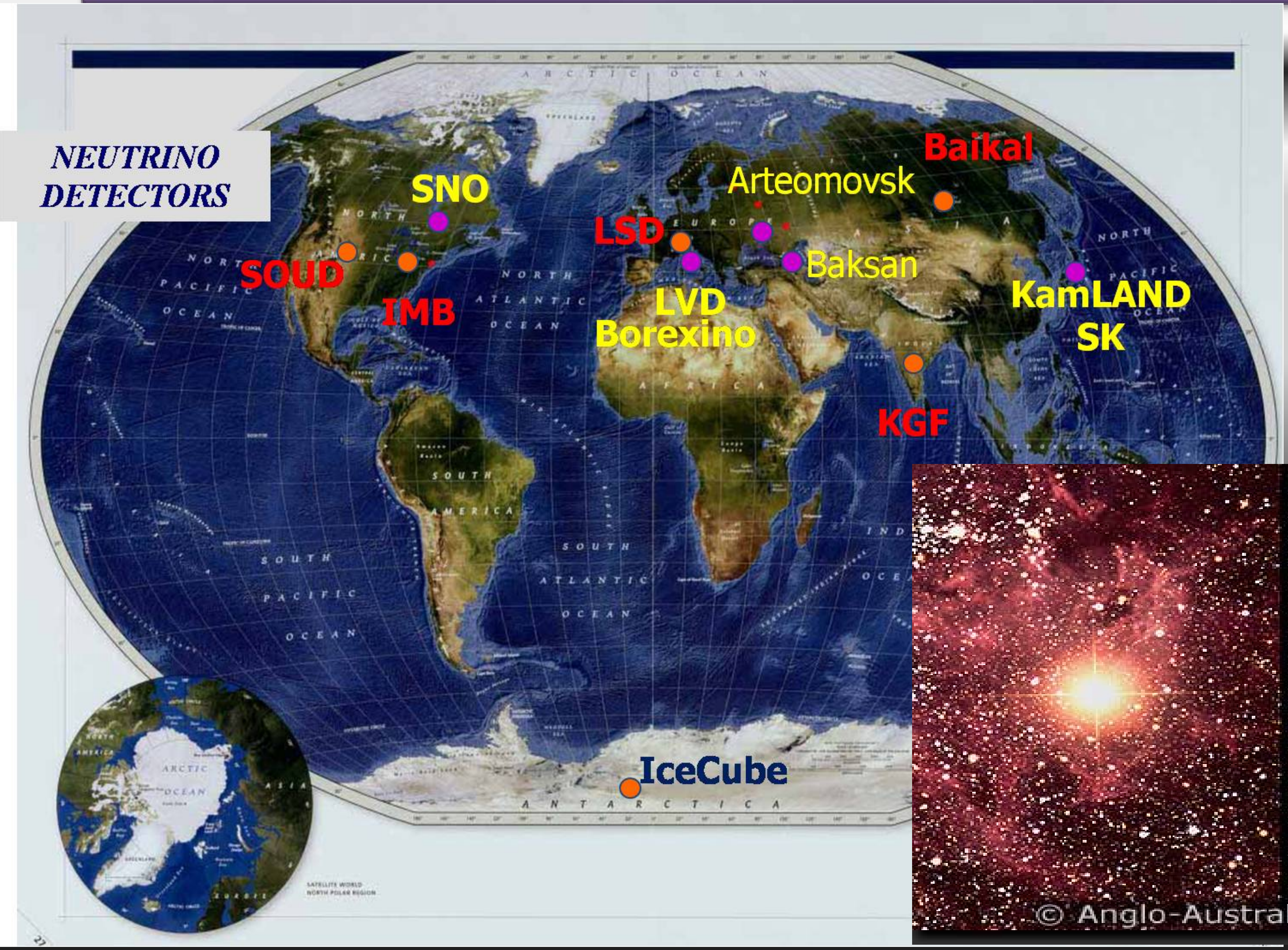
- ✓840 scintillation counters situated in 105 portatanks (1010 tons of scintillator, 1000 tons of iron)

✓Each portatank contains 8 counters

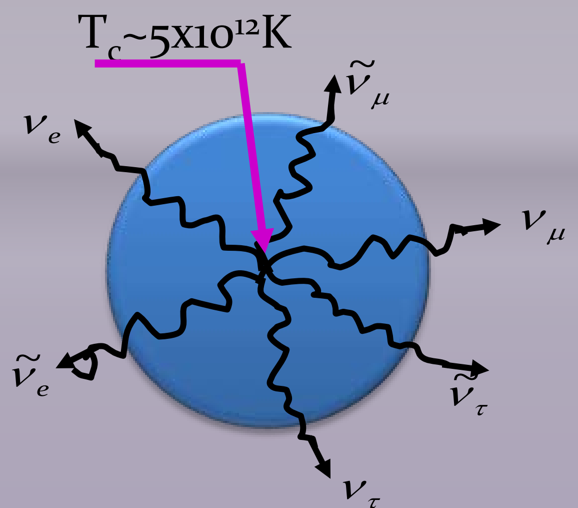
✓Counter size is
1 m x 1 m x 1,5 m:

- ✓Total mass: 1020 kg of C_nH_{2n} scintillator
- ✓3 PMT of Russian production

Supernova on LVD



1. **Standard collapse model – spherically symmetric, nonrotating, nonmagnetic star (All types of neutrinos are emitted in equal energy parts)**



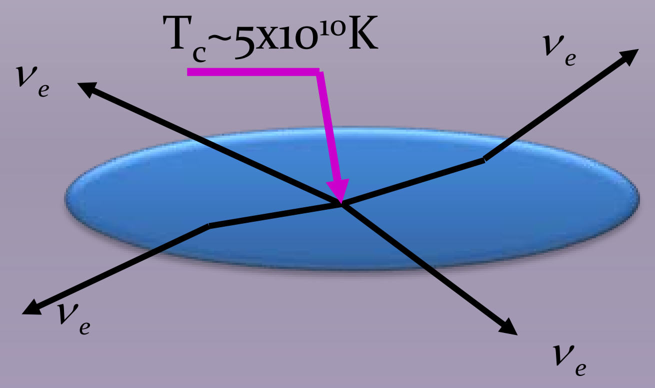
$$\overline{E}_{\tilde{\nu}_e} = 12 MeV$$

$$\varepsilon_{\nu,\tilde{\nu}} = 5.3 \cdot 10^{53} erg$$

$$\overline{E}_{\nu_e} = 10 MeV$$

$$\overline{E}_{\nu_\mu,\tilde{\nu}_\mu,\nu_\tau,\tilde{\nu}_\tau} = (20-25) MeV$$

2. **Model of rotating collapsar (V.S. Imshennik).**



The main reaction – URCA-process:

$$p + e^- \rightarrow n + \nu_e$$

$$\overline{E}_\nu = (30-50) MeV$$

$$\varepsilon_{\nu_e,\tilde{\nu}_e} \approx \varepsilon_{\nu_e} = 8.9 \cdot 10^{52} erg$$

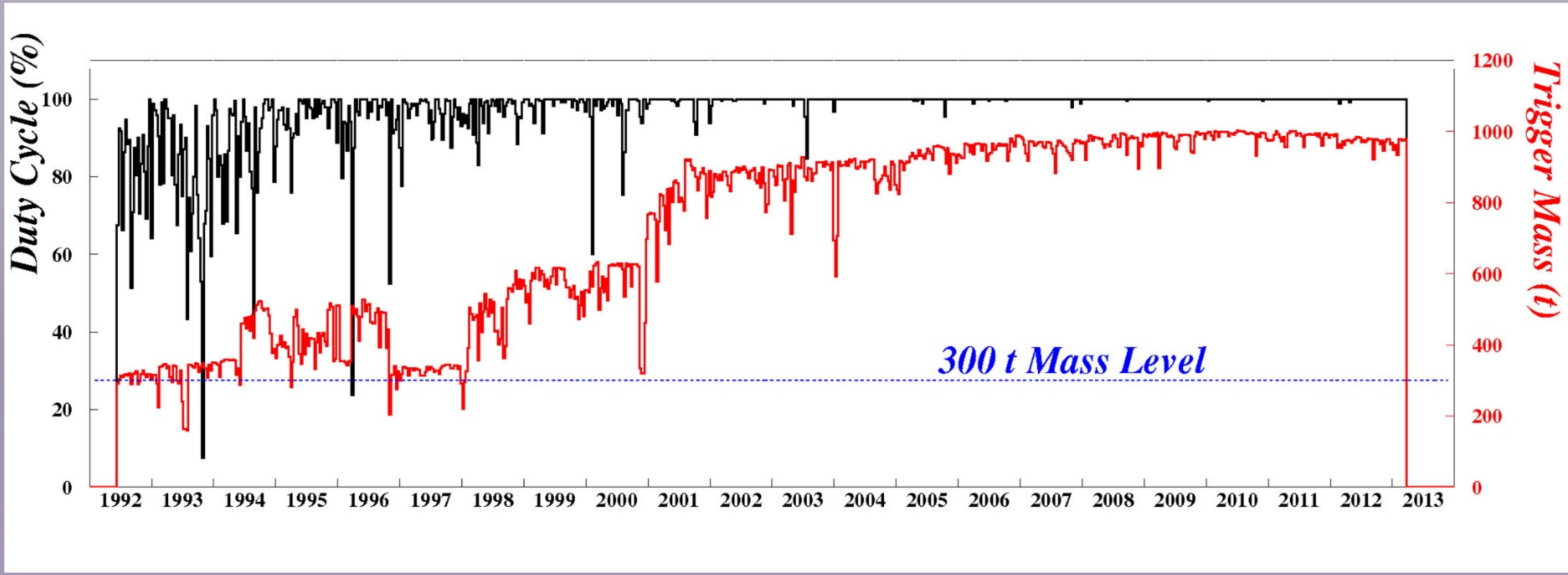
1). At first stage mostly ν_e are emitted

2). Star divides into 2 parts (small and large)

3). At the second stage all types of neutrinos are emitted (like in the Standard collapse model)

But how is it possible to detect neutrino signal in LVD detector?

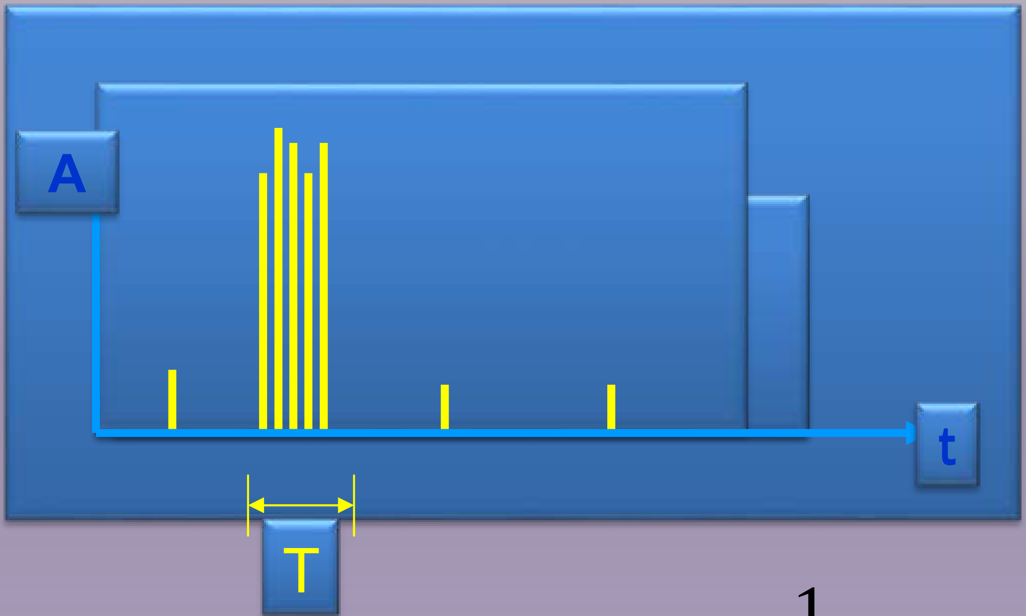
Long and stable work of detector



Module structure allows to reach high duty cycle performance (≥ 99%since 2001)

But how is it possible to detect neutrino signal in LVD detector?

Signature of signal in LVD



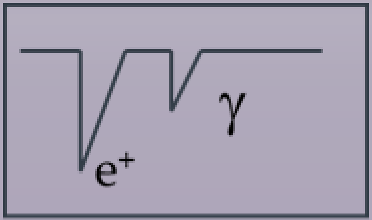
Registration of supernovae explosion with N pulses in the short period of time T

$$N \sim \frac{1}{4\pi R^2} \cdot \sum_i \int_{E_{thr}}^{\infty} I_{\nu_i}(E_{\nu_i}) \cdot \sigma(E_{\nu_i}) dE \cdot M$$

Signature of signal in LVD in the case of $\tilde{\nu}_e$ detecting

$$\tilde{\nu}_e + p \rightarrow e^+ + n$$

The energy threshold for first signal from event in counter is 5 MeV



$$\left.\begin{array}{l} n + H \rightarrow d + \gamma \ (E_\gamma = 2.2 MeV) \\ n + {}^{56}Fe \rightarrow {}^{57}Fe + \sum \gamma \ (E_\gamma = 10.16 MeV) \end{array}\right\} \tau \approx 185 \mu s$$

Signature of signal in LVD in the case of ν_e detecting

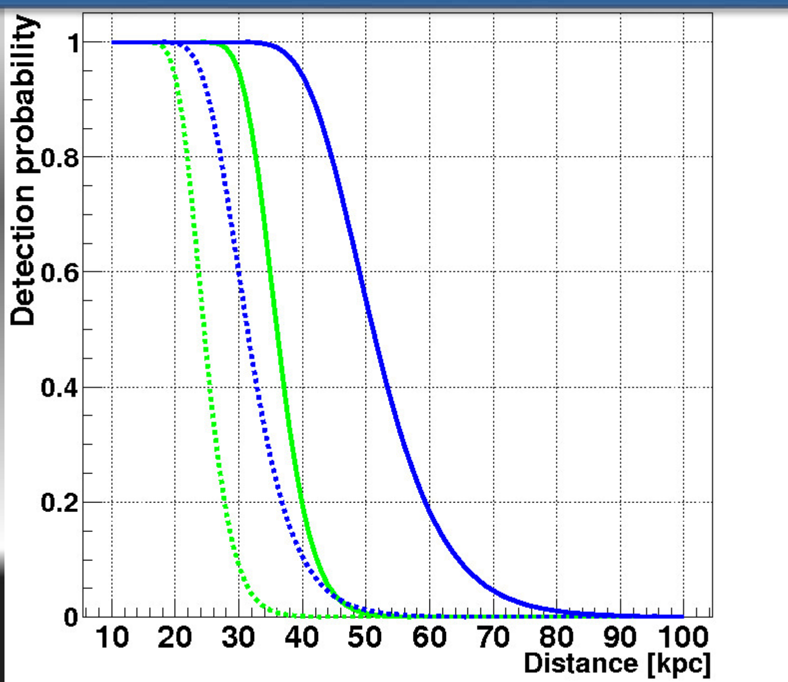
$$\nu_e + {}^{56}_{26}Fe \rightarrow {}^{56}_{27}Co^* + e^-, \quad {}^{56}Co^* \rightarrow {}^{56}Co + \Sigma\gamma, \ E_\gamma = 7 \div 11 MeV$$

and $\nu_i + {}^{12}C \rightarrow {}^{12}C^* + \nu_i, \ (i = e, \mu, \tau); \ {}^{12}C^* \rightarrow {}^{12}C + \gamma, \ E_\gamma = 15.1 \ MeV$

Detector	Depth m.w.e	Mass, ktons	Thre-shold, MeV	Efficiency			Number of events					Back-ground s^{-1}
							Standard model			Collapsar Rotation model		
				η_{e+}	η_n	η_γ	$\bar{\nu}_e p$	$\nu_i e^-$	$\nu_i C$	$\nu_e A$	$\nu_e C$	
LVD Italy, Russia	3300	1.0 C_nH_{2n} 0.95 Fe	4 – 6	0.9	0.6	0.55 0.45	500	22	55	250* 100**	110* 50**	< 0.1

* - E=40 MeV
** - E=30 MeV

In the case of Standard collapse model



Detector is ready to search for neutrino radiation from the collapsing stars, but the nature is miserly for the presents.
LVD is possible to detect not only electron antineutrino via the inverse beta decay reaction but also electron neutrinos due to their interaction with iron and other types of neutrinos via interaction on carbon nuclei.

Limit on the rate of gravitational stellar collapses in our Galaxy:
0.12 *events* · *year* $^{-1}$ at 90% c.l.

Study of cosmic ray muons and neutrinos

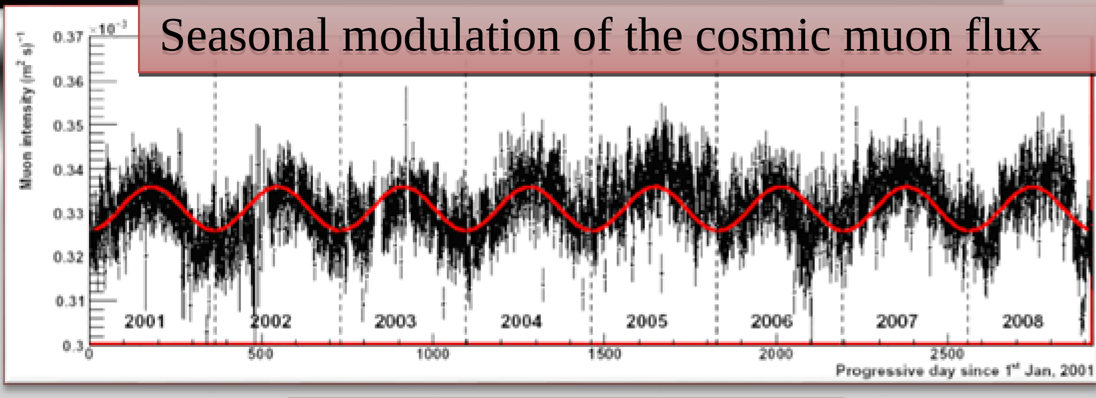
Muon selection in LVD:

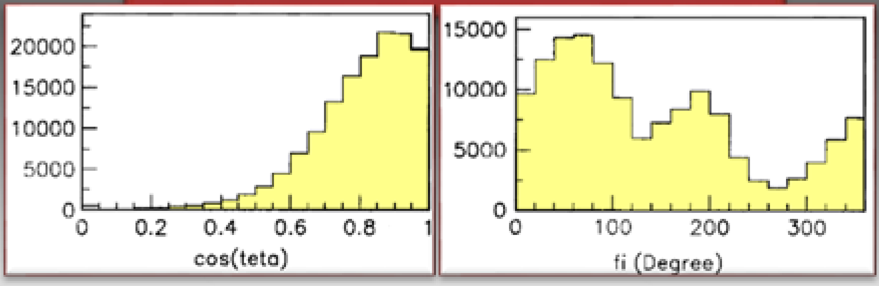
✓ Signal is measured at least with 2 counters

✓ The energy loss in the first counter is >50 MeV, in the second one is >5 MeV

✓Both signals are measured in the time range <250 ns

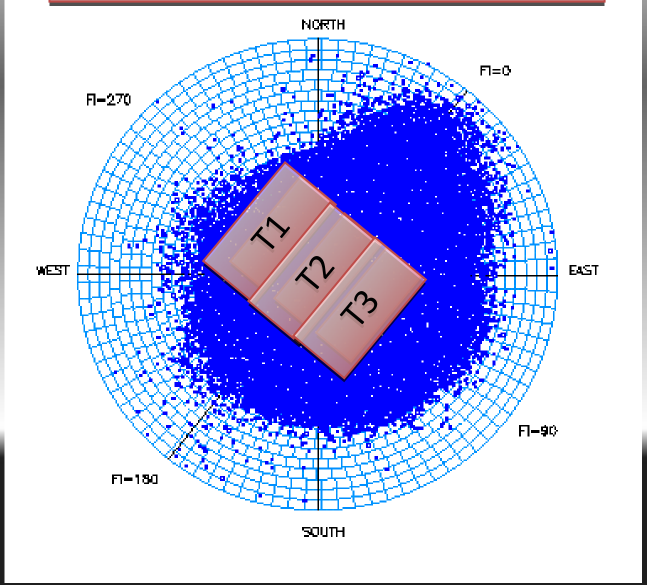
Seasonal modulation of the cosmic muon flux





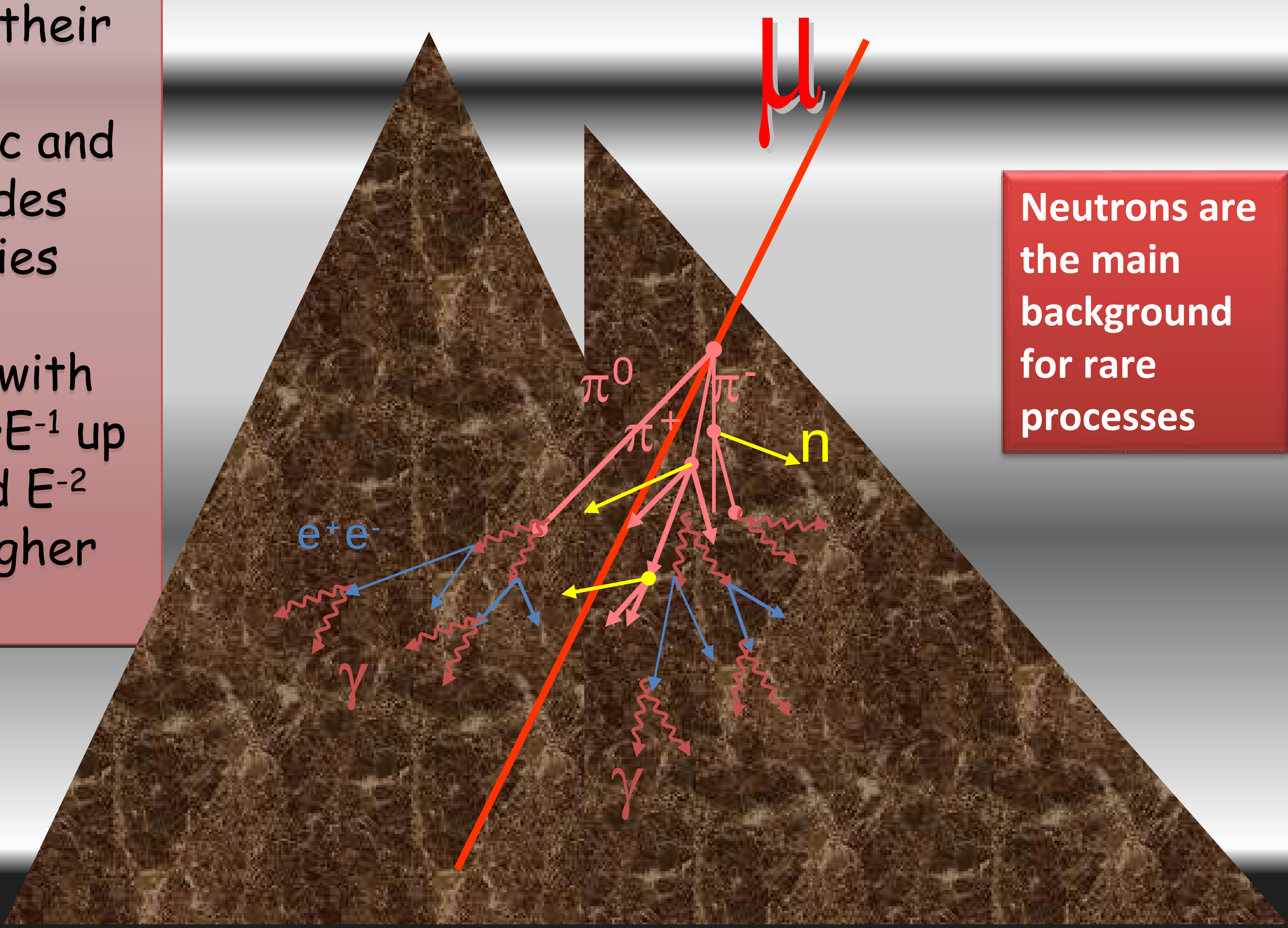
Muon cosθ and φ distribution

Muon spatial distribution

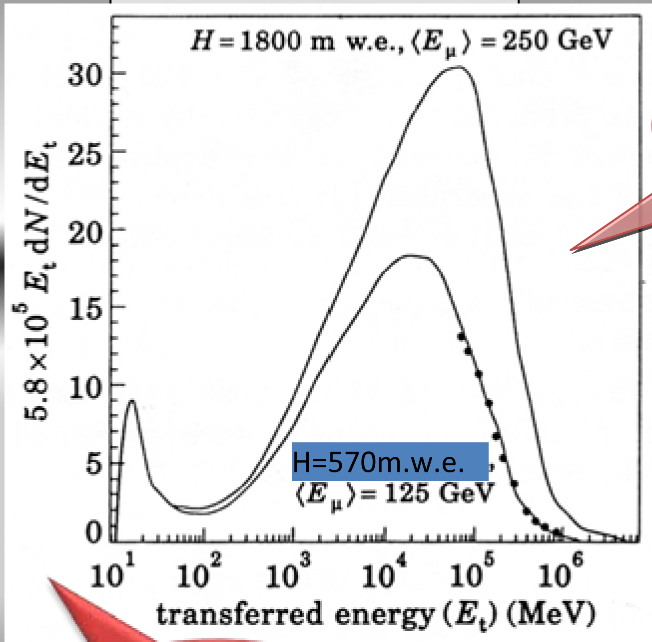


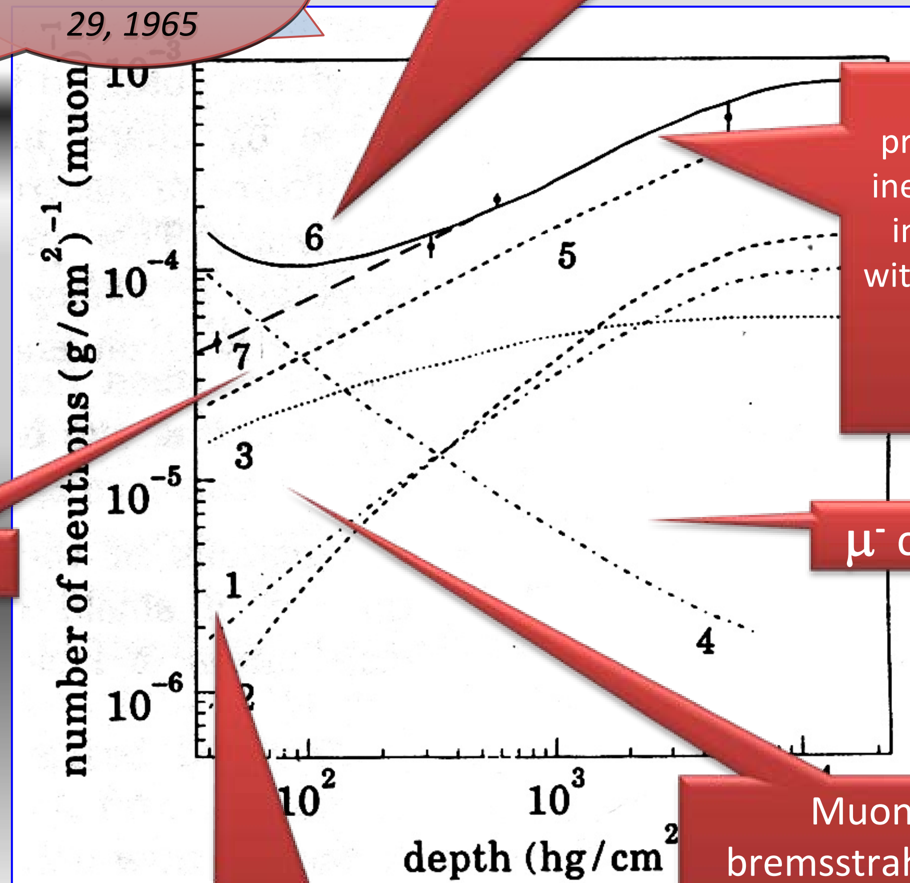
Neutron generation

The neutrons generated by muons as well as by products from their interactions in electromagnetic and hadronic cascades have the energies from keV to hundreds MeV with the spectrum ~E^{-1} up to 100 MeV and E^{-2} for energies higher than 100 MeV



Neutrons are the main background for rare processes

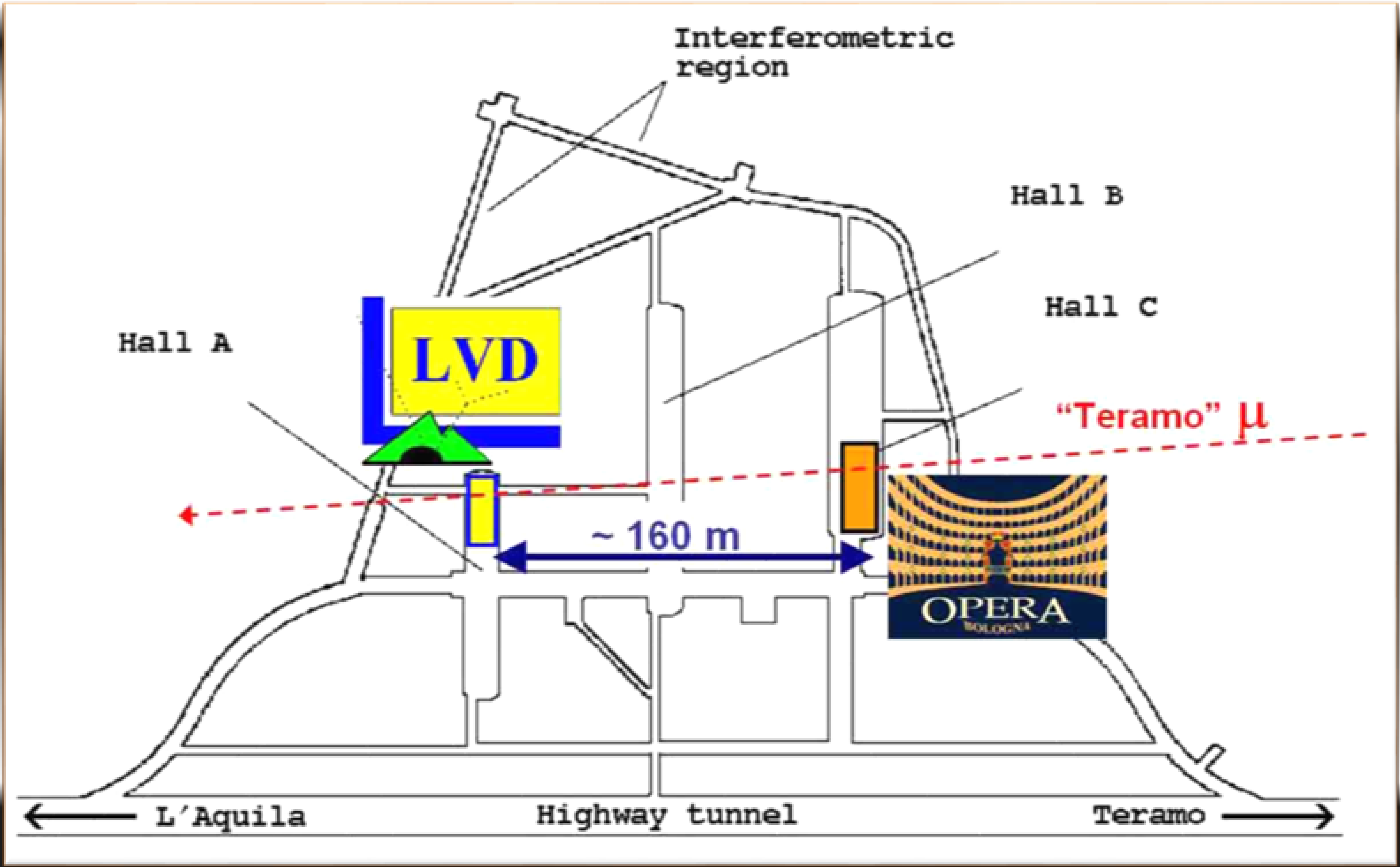




Dependence of the contribution of neutrons, produced in inelastic muon interactions, on the energy transfer in the interaction E_t

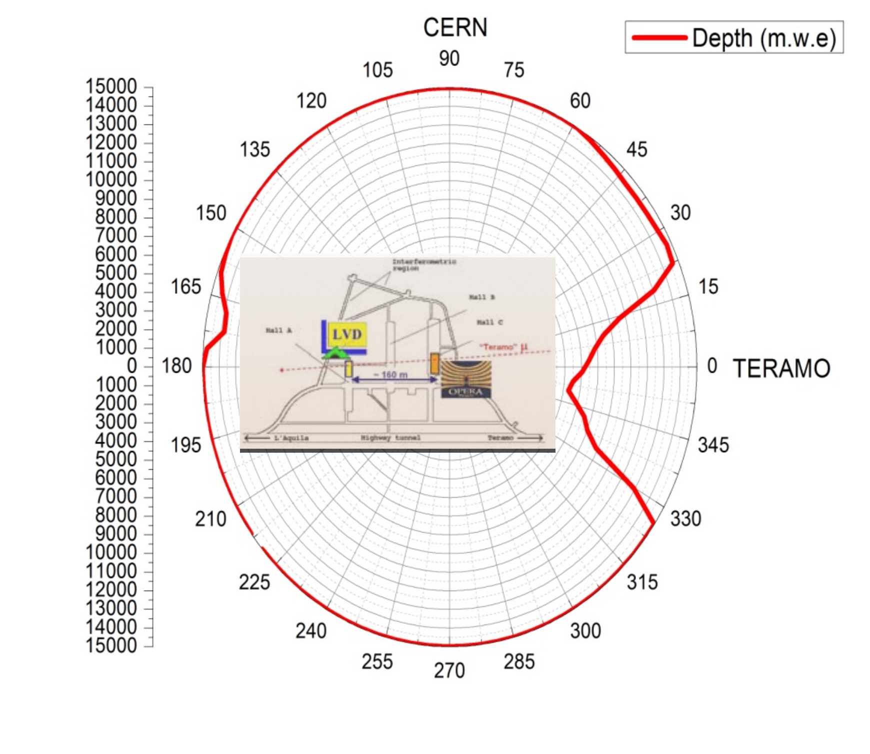
The number of generated neutrons per 1 muon per 1 g/cm^2 vs the depth from the top of the atmosphere. Curves are normalized to the results of the experiment performed at a depth of 25 m.w.e. with the aid of an LS detector.

LVD-OPERA horizontal events

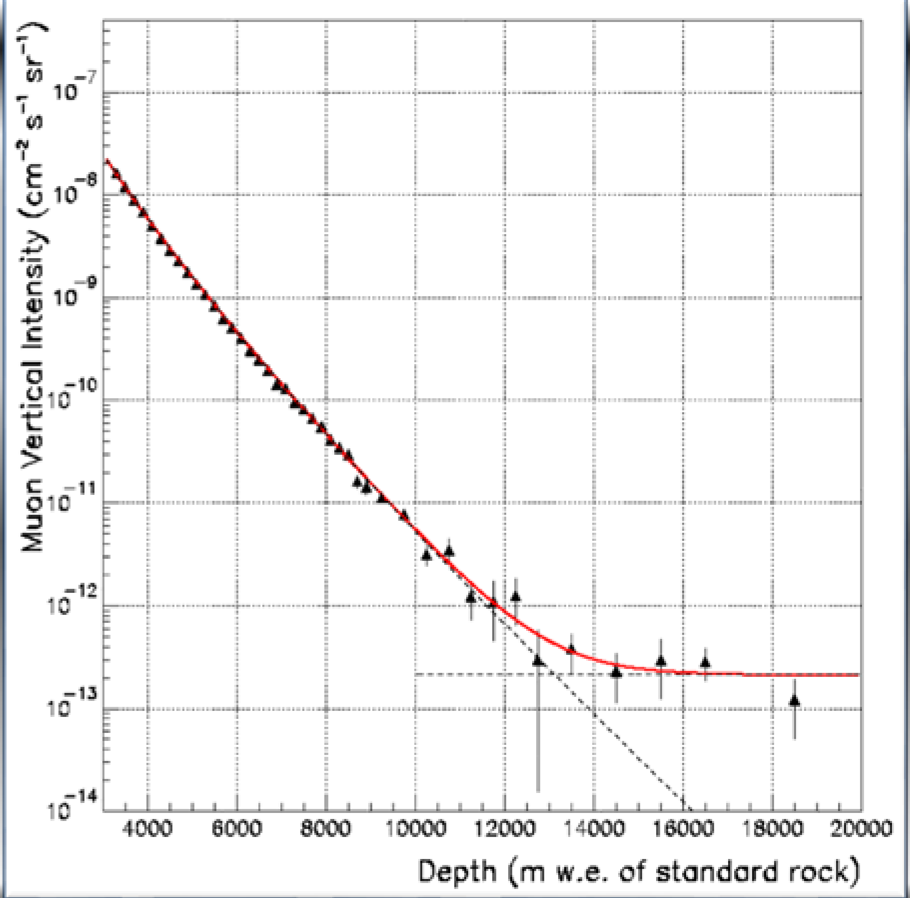


LVD-OPERA horizontal events

Gran Sasso depth distribution for θ >87º

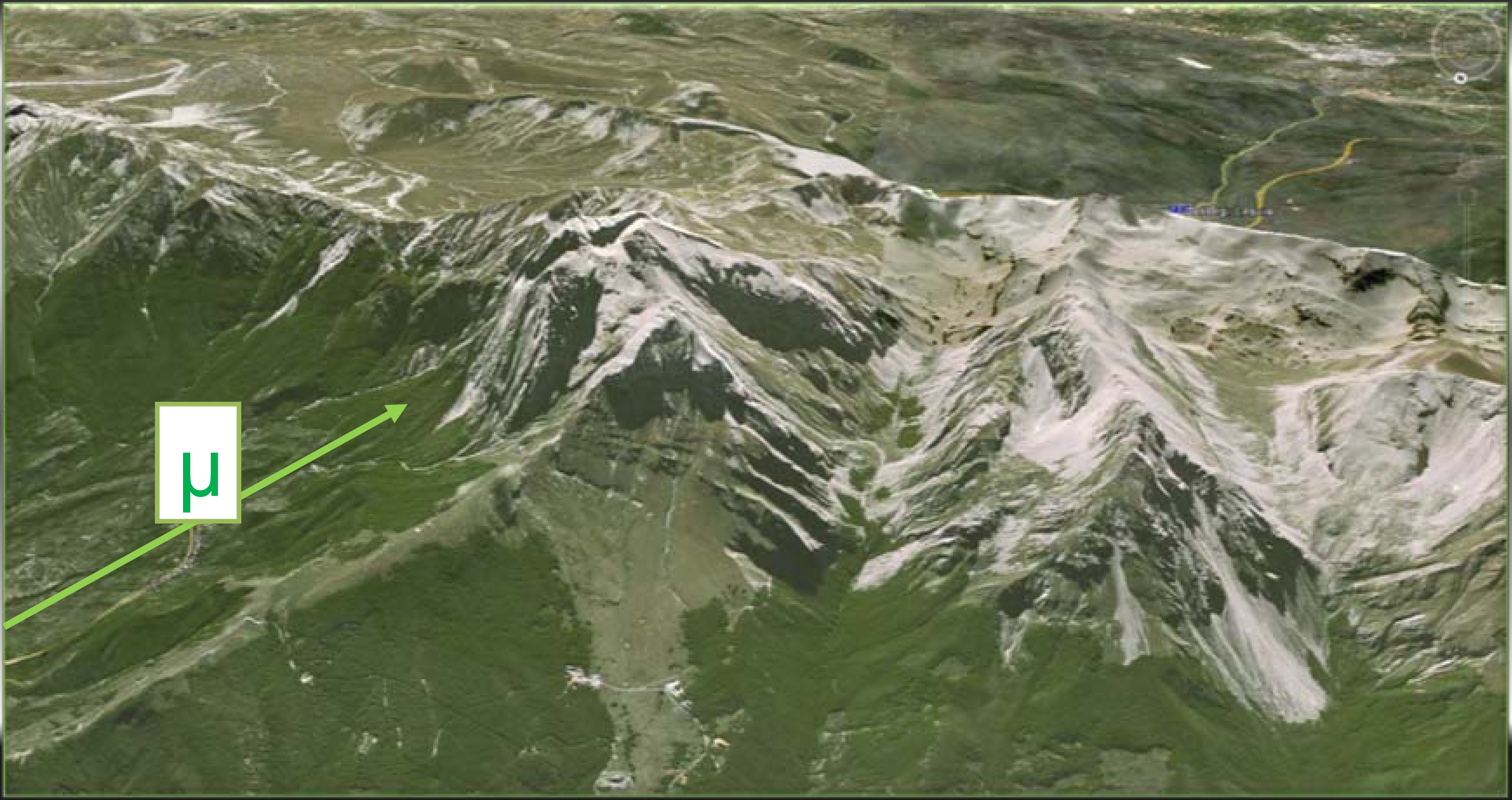


Depth-intensity curve

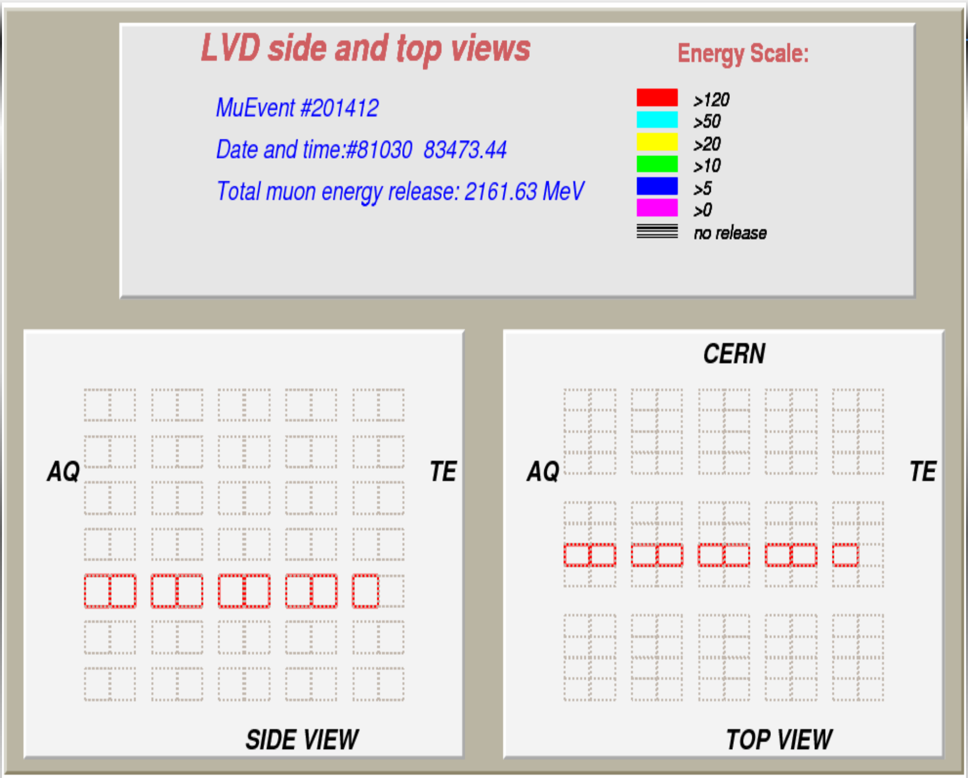


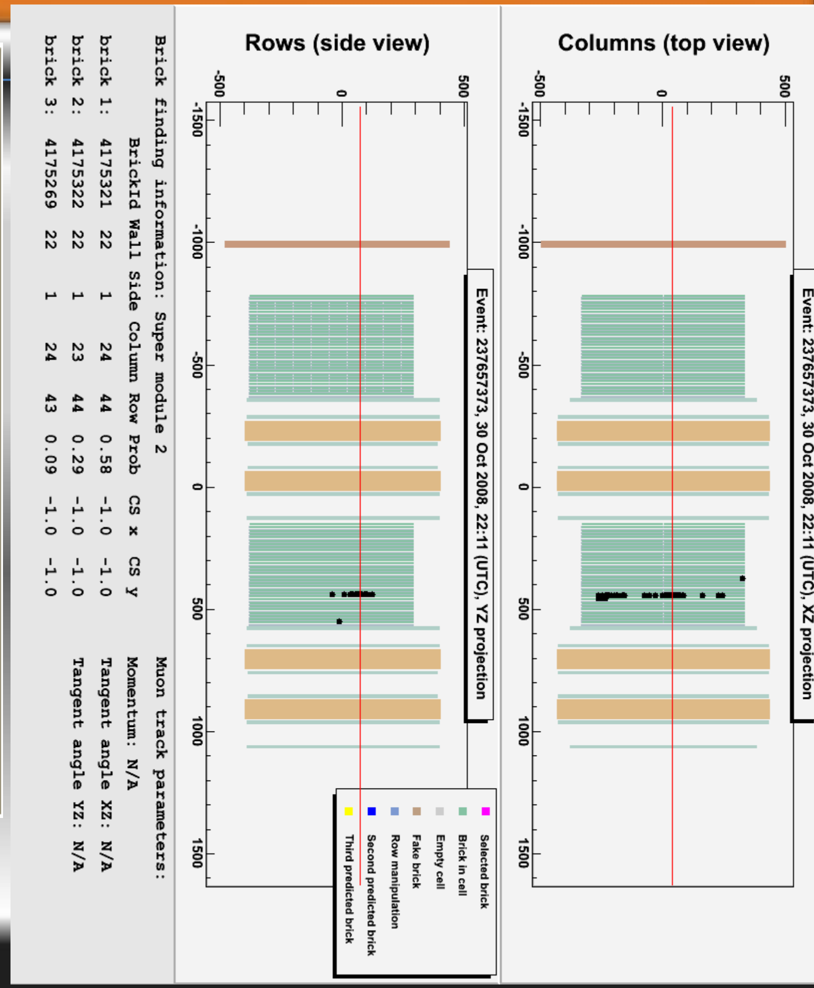
Depth from the Teramo side is about 8000 m.w.e., L'Aquila side more than 15000 m.w.e. "L'Aquila" muons are muons from neutrinos.

LVD-OPERA horizontal events

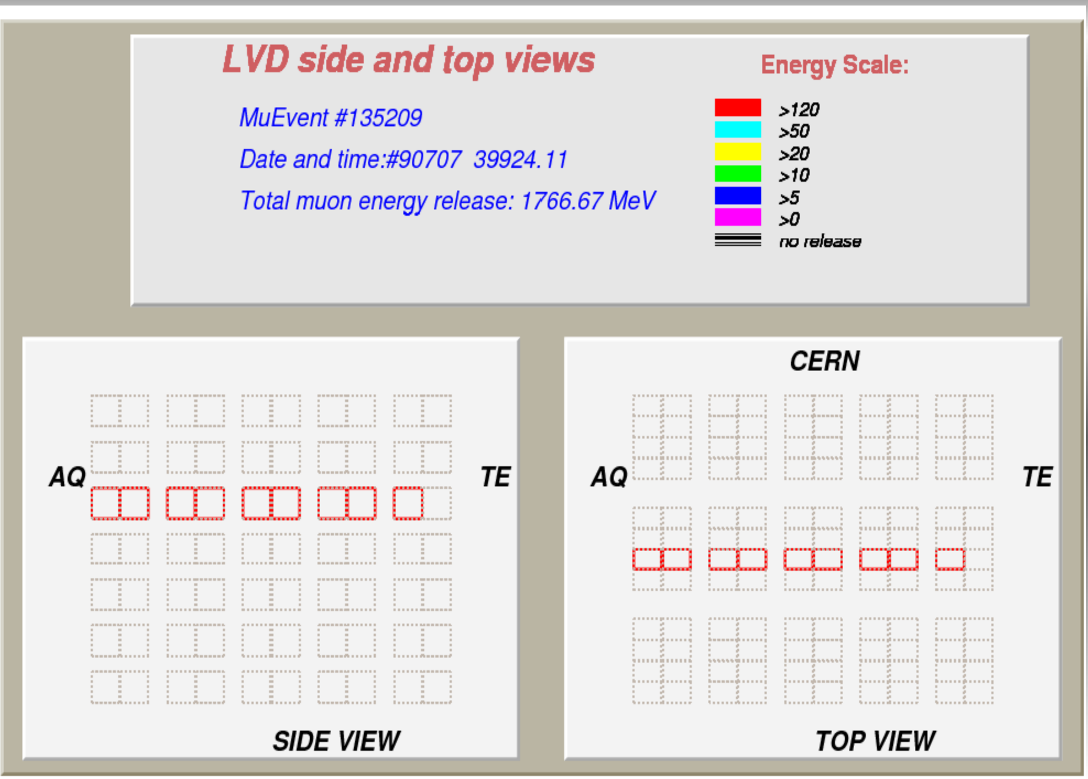


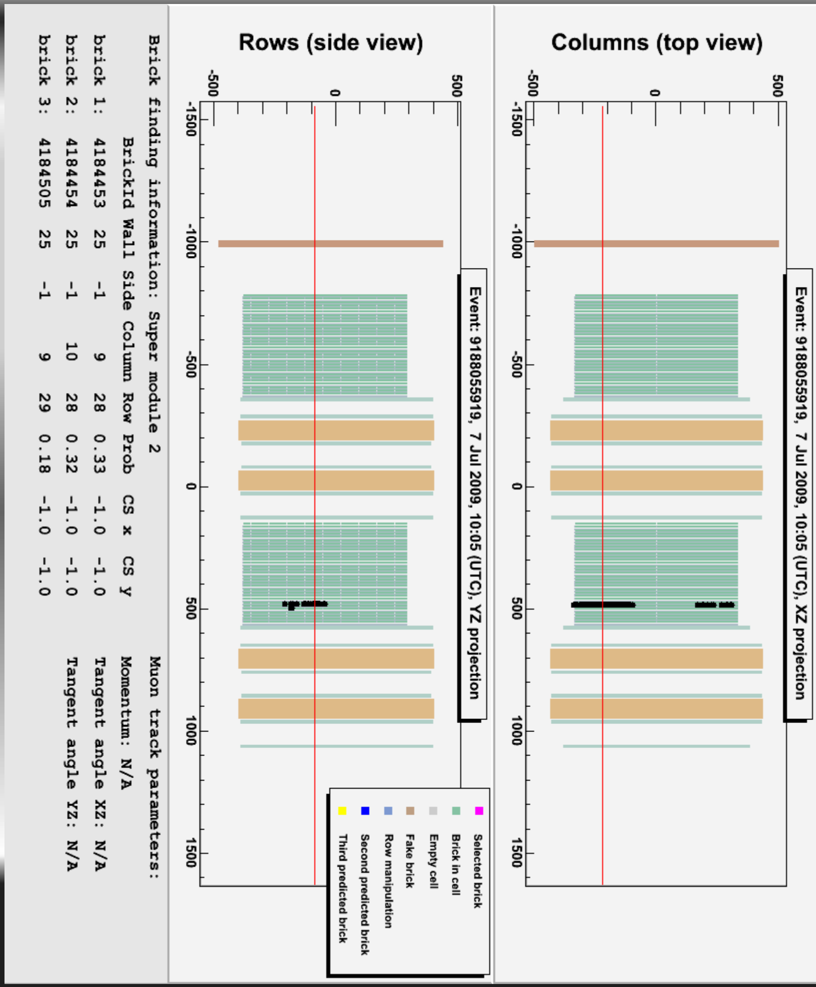
LVD-OPERA horizontal events. Example of events.





LVD-OPERA horizontal events. Example of events.



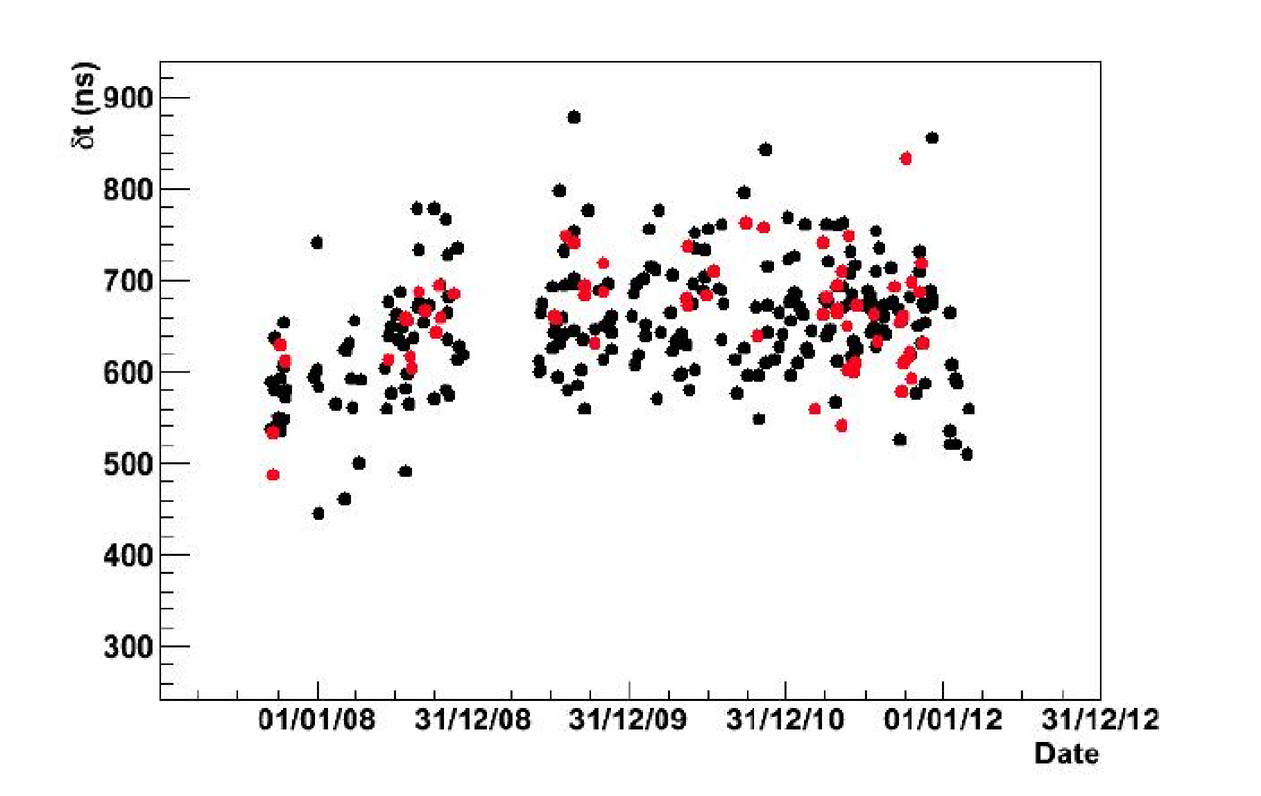


LVD-OPERA horizontal events.

Period	OPERA		LVD		Days in common	Random coincidences				Signal	
						Rate OPERA (Hz)	Rate LVD (Hz)	Expected in ±1 ms	Observed in ±1 ms	Expected Teramo m	Observed Teramo m
2007	28/08/2007	31/12/2007	27/08/2007	31/12/2007	58.2	0.184	0.095	177.1	162	15.7	21
2008	01/01/2008	05/12/2008	01/01/2008	07/12/2008	263.7	0.073	0.095	314.2	323	71.2	64
2009	01/06/2009	23/11/2009	31/05/2009	01/12/2009	171.1	0.124	0.098	359.0	351	46.2	49
2010	31/12/2009	31/12/2010	01/01/2010	01/01/2011	326.5	0.063	0.097	346.3	369	88.2	63
2011	31/12/2010	07/12/2011	01/01/2011	01/01/2012	336.9	0.063	0.098	360.6	395	91.0	109
2012	09/01/2012	02/03/2012	01/01/2012	03/03/2012	50.8	0.051	0.094	41.9	37	11.1	9
					1207.2			**1599.1**	**1637**	**323.3**	**315**

After manual analysis were selected **306** OPERA-LVD events

LVD-OPERA horizontal events.



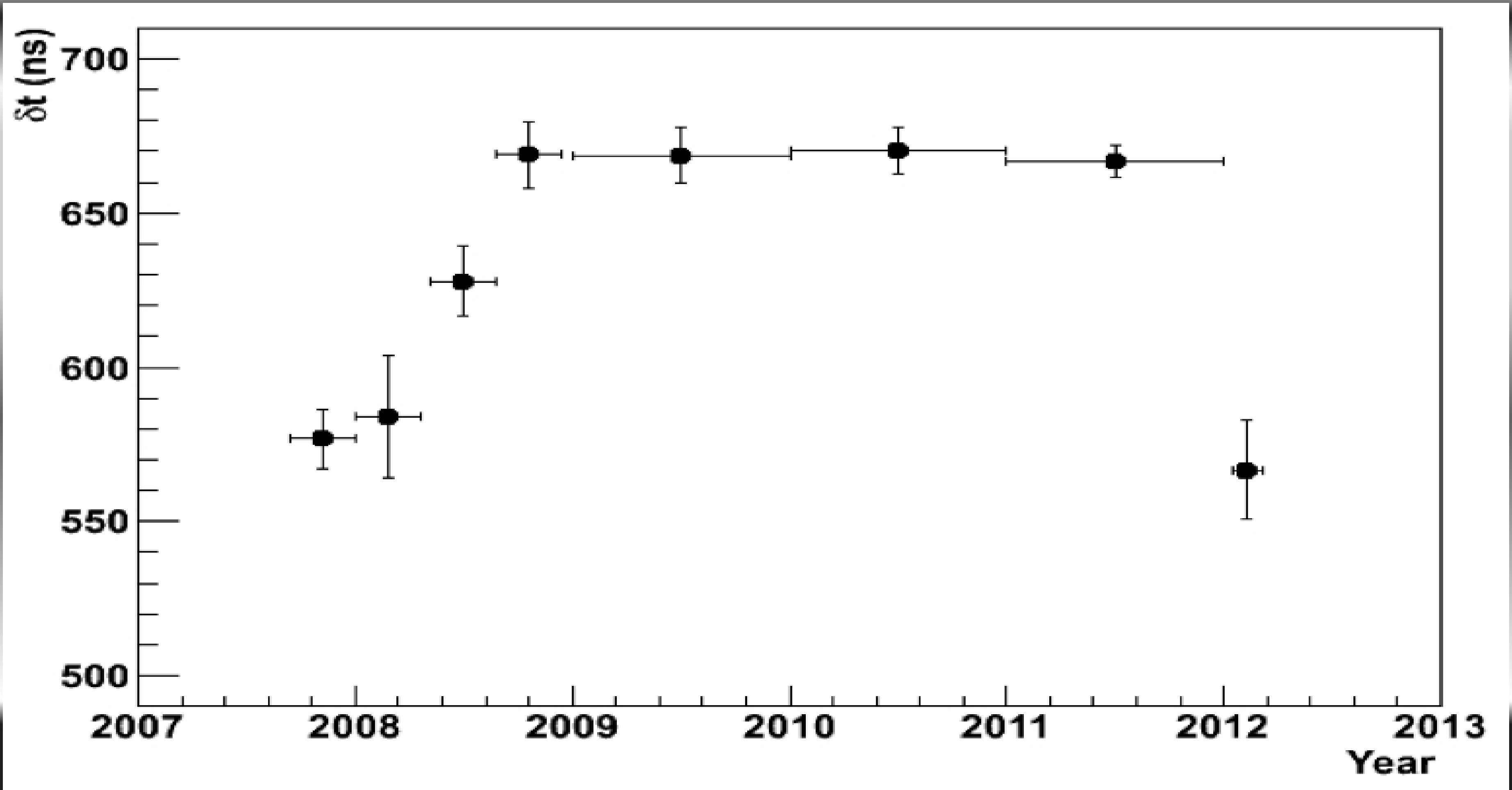
Red dots – events in the RPC OPERA sub-system, black dots – events in the Target Tracker OPERA sub-system.

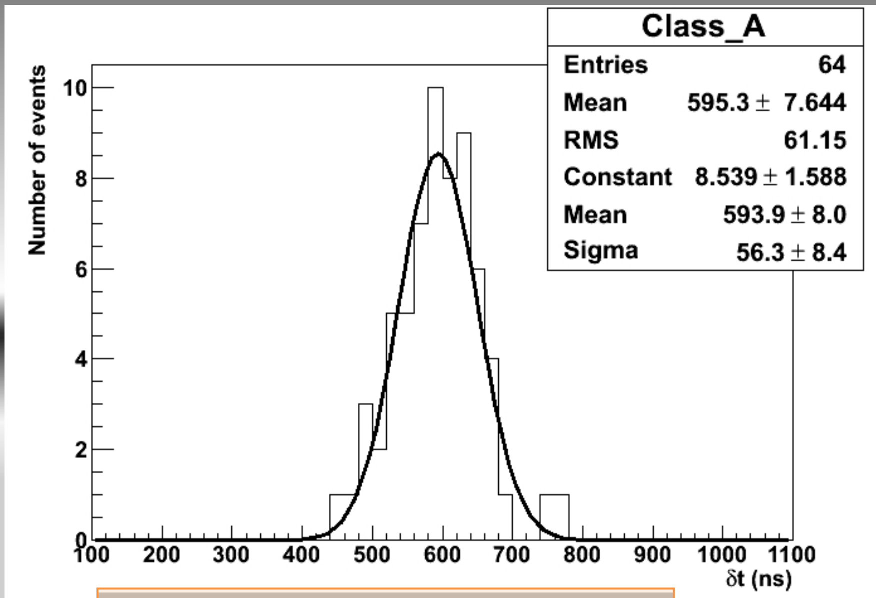
Eμ >70 ГэВ

LVD-OPERA horizontal events.

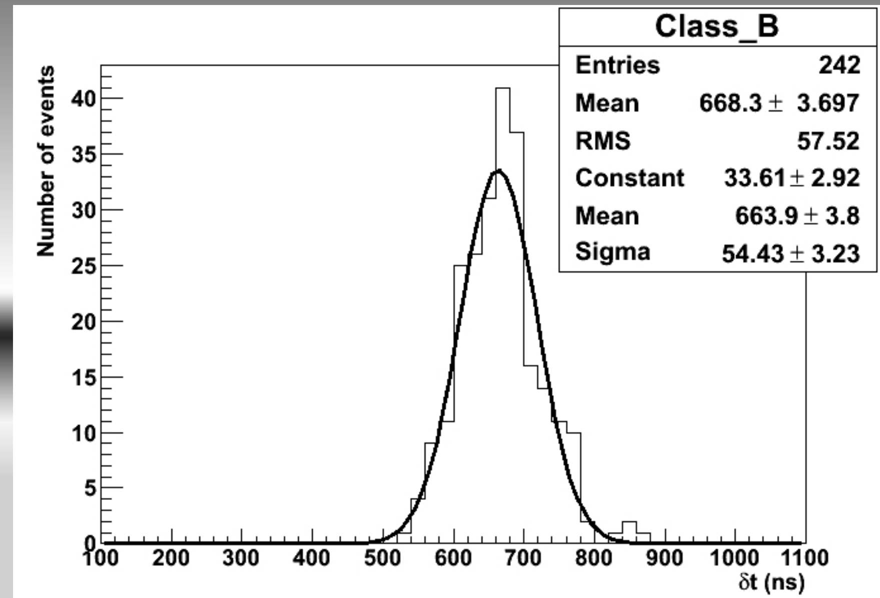
TOTAL NUMBER OF EVENTS = 306					
Class	Year	Since	To	Nb. of events	<δt> (ns)
A	2007	Aug	Dec	18	577± 10
A	2008-1	Jan	Apr	14	584 ± 20
A	2008-2	May	Aug	23	628 ± 11
A	2012	Jan	Mar	9	567 ± 16
B	2008-3	Sep	Dec	25	669 ± 11
B	2009	Jun	Nov	47	669 ± 9
B	2010	Jan	Dec	63	670 ± 8
B	2011	Jan	Dec	107	667 ± 5

LVD-OPERA horizontal events.

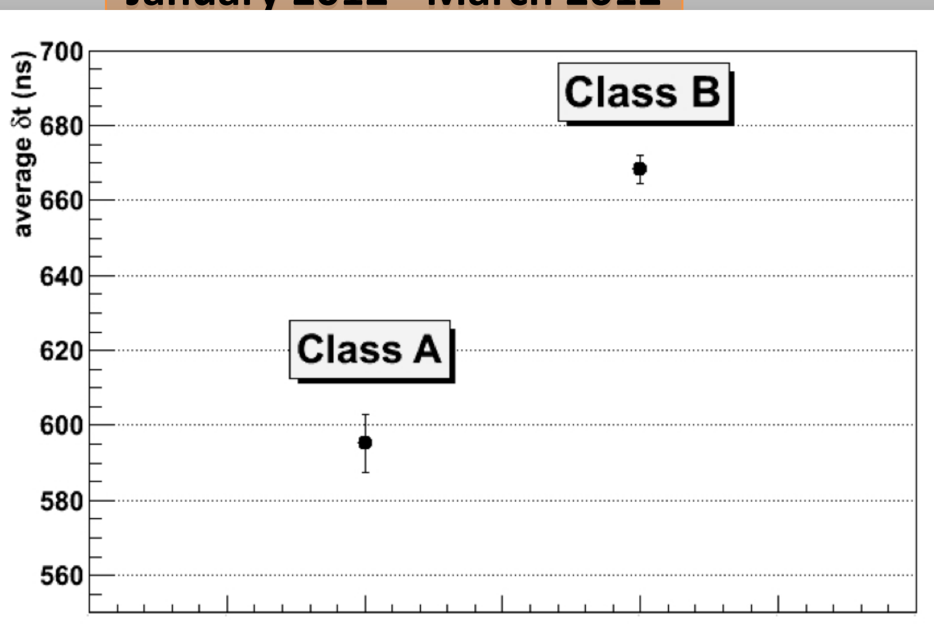




August 2007 - August 2008
January 2012 - March 2012

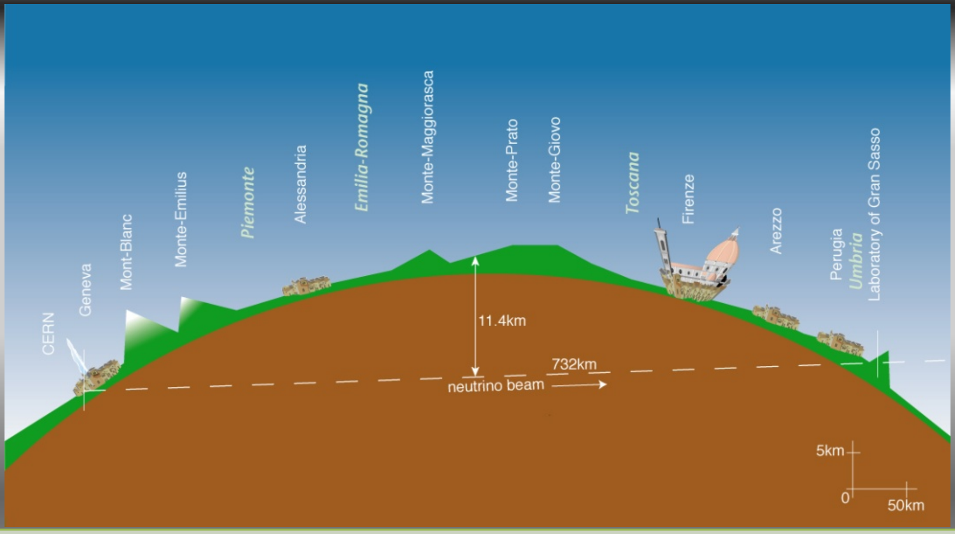


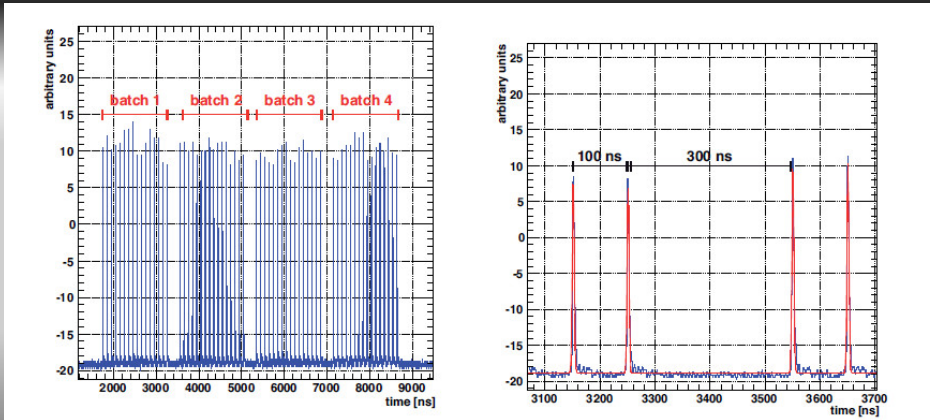
August 2008 – December 2011



Class A: δt = (595 ± 8) ns
Class B: δt = (668 ± 4) ns
Taking into account LVD and OPERA horizontal muon data OPERA time shift was detected
ΔAB = <δtA> - <δtB> = (–73 ± 9) ns

Neutrino velocity measurements





$\langle E\nu \rangle$ = 17 GeV, $L_{CERN\text{-}LVD}$ = 731291.87 ± 0.04 m

Beam structure from 10.05.2012 up to 24.05.2012

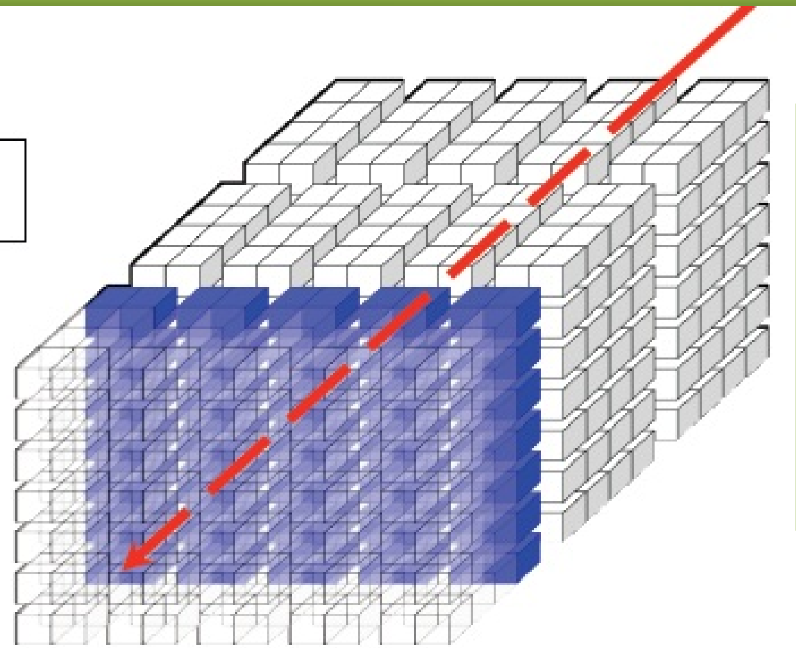
- 4 batch mode
- Time between modes is 300 ns
- Time inside one mode between signals is 100 ns
- Total it was $1.89 \cdot 10^{17}$ protons on target (p.o.t.)

Neutrino velocity measurements

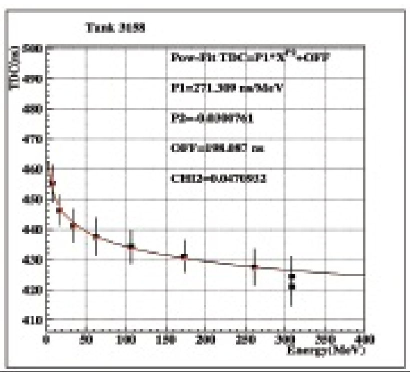
LVD SUPER-SET

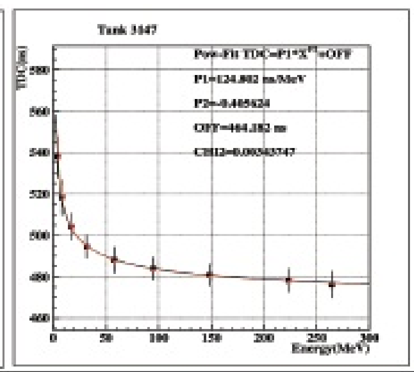
< 7% of the whole array (58/840 counters)
~40% geometrical efficiency

- all counters are equipped with a calibrated fast LED
- central PMTs in each counter are equipped with longer cables to determine the 3-fold coincidence
- a new trigger has been implemented in parallel with the standard one and a new time interval counter has been provided



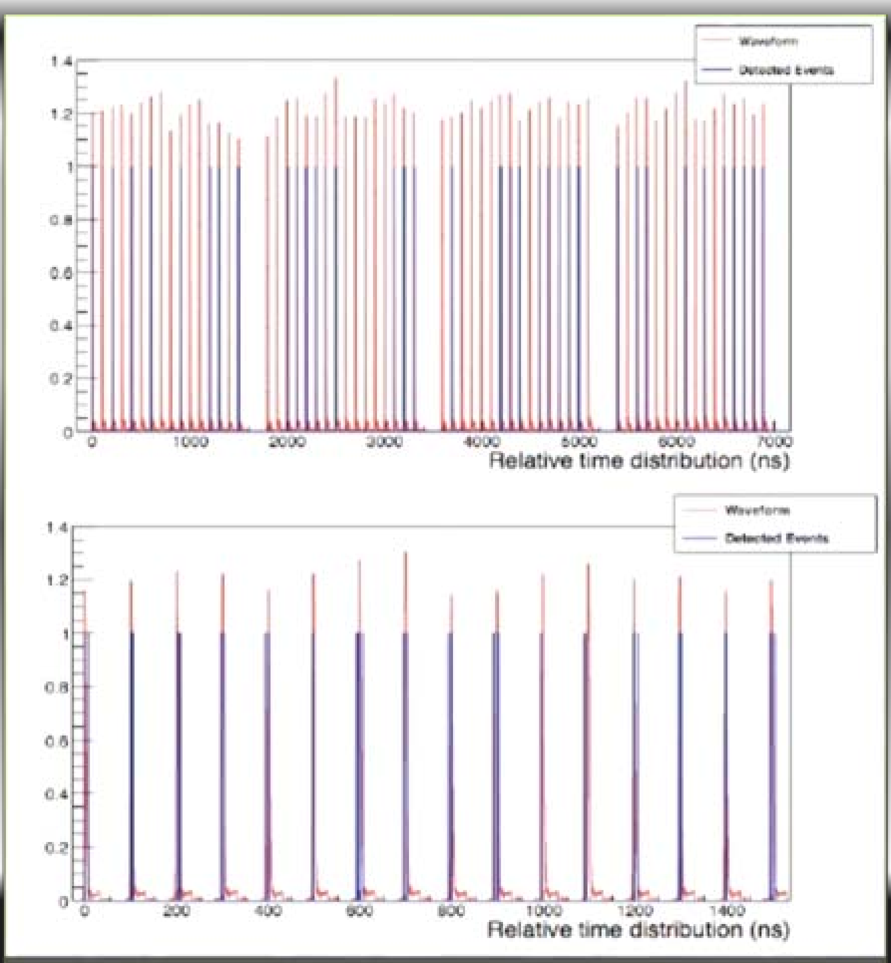
- better time performance
- direct measurement of the transit time and its dependence on the energy released
- independent and faster electronics

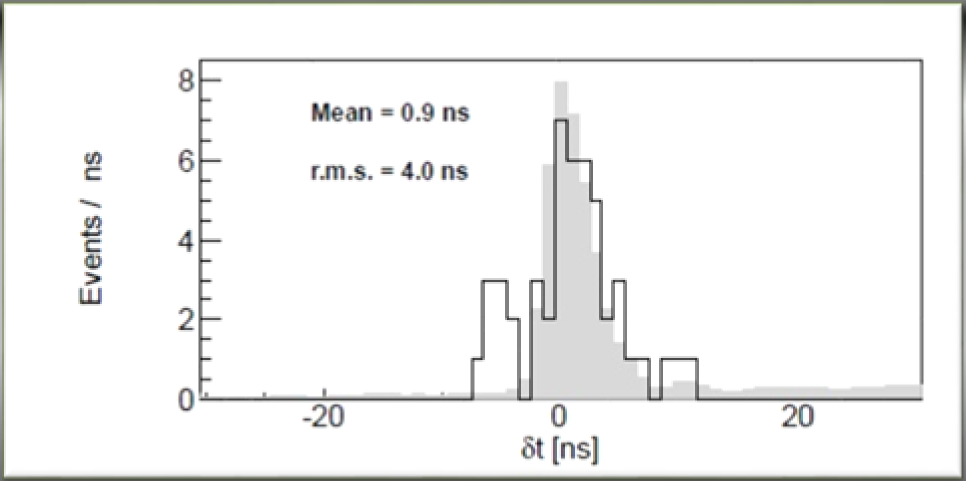




- Total was detected **190** events
- **48** events go through LVD Super-Set system

Neutrino velocity measurements





δt = -0,3 ± 0.6 (stat.) ± 3.2 (syst.) ns

$-3.3 \times 10^{-6} < (v - c)/c < 3.5 \times 10^{-6}$
$m_{\nu} < 44$ MeV/c^2 (99% confidence level)

Conclusion

- **LVD is possible to detect not only electron antineutrino via the inverse beta decay reaction but also electron neutrinos due to their interaction with iron and other types of neutrinos via interaction on carbon nuclei.**
- **Limit on the rate of gravitational stellar collapses in our Galaxy: 0.12 events · year $^{-1}$ at 90% c.l.**
- **Taking into account LVD and OPERA horizontal muon data OPERA time shift was detected**

$$\Delta AB = \langle \delta tA \rangle - \langle \delta tB \rangle = (-73 \pm 9)\ \text{ns}$$

- **Neutrino velocity limit is:**

$$-3.3 \times 10^{-6} < (v - c)/c < 3.5 \times 10^{-6}$$

$$m_{\nu} < 44\ \text{MeV}/c^2\ (\text{99\% confidence level})$$

Thank you for your attention!

Detector	Depth m.w.e	Mass, ktons	Thre-shold, MeV	Efficiency			Number of events					Back-ground s^{-1}
							Standard model			Collapsar Rotation model		
				η_{e+}	η_n	η_γ	$\bar{\nu}_e p$	$\nu_i e^-$	$\nu_i C$	$\nu_e A$	$\nu_e C$	
Arteomovsk ASD Russia	570	0.1 C_nH_{2n} 1 NaCl	5	0.97	0.8	0.85 0.05	57	2.1	9.5	25	19* 9**	0.16
Baksan BUST Russia	850	0.2 C_nH_{2n}	10	0.6	-	0.2	67	2.2	4.3		8* 4**	0.033
KamLAND USA, Japan	2700	1. C_nH_{2n}	~ 4				500	22	85		180* 80**	
BOREXINO Gran Sasso	3300	0.3 C_nH_{2n}	0.8	0.97	0.8		171	6.3	27		57* 27**	
LVD Italy, Russia	3300	1. C_nH_{2n} 0.95 Fe	4 – 6	0.9	0.6	0.55 0.45	500	22	55	250* 100**	110* 50**	< 0.1
Kamioka Super-K Japan,USA	2700	22.5 H_2O	5.5	0.9	-	-	9400	400	-	650* <160**		

* - E=40 MeV
** - E=30 MeV