

Possible explanation of the neutrino signal from SN1987A

detected using the LSD (speculation)

Authors:

Agafonova N.*, Fulgione W.**, Malgin A.* , Manukovskiy K.* , Ryazhskaya O.* , Yen S.***,
Yudin A.*

* Institute for Nuclear Research RAS

** INFN, Torino, Italy, *** Sudbury, Canada

The International Seminar "Quarks-2018", 27/05 – 02/06 2018, Valday, Russia

Outline:

❑ Introduction

- ✓ signal from SN1987A detected with LSD
- ✓ signal from SN1987A detected with IMB, Kamiokandell, BUST
- ✓ contradictions

❑ Supernova explosion models

- ✓ Standard model
- ✓ Two-stage collapse

❑ Some speculation

- ✓ neutrino interaction with Fe and rock nuclei
- ✓ Monte-Carlo simulation (available crosssection)
- ✓ energy spectrum of detected events (gammas from neutron captures)

❑ Conclusion

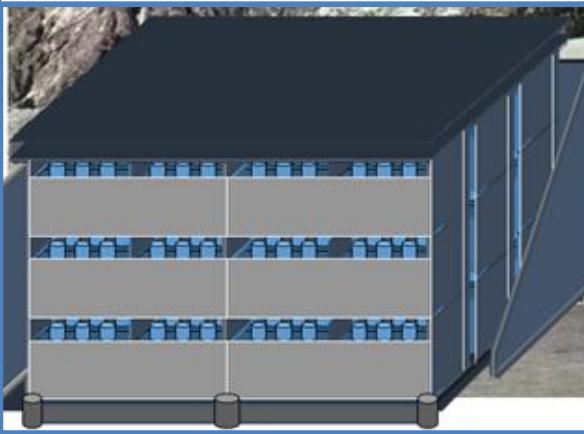
main theses

what is the second signal?

Signals from SN1987A on 23 Feb.1987:

LSD

- 90 tons liquid scintillator
- 220 tons Fe
- threshold ~ 5 MeV
- 5 events in 7 sec – 2:52
- 2 ev. In 18 sec. – 7:36



Baksan

- 330 tons liquid scint
- threshold ~10 MeV
- 5 events in 9.1 sec.



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

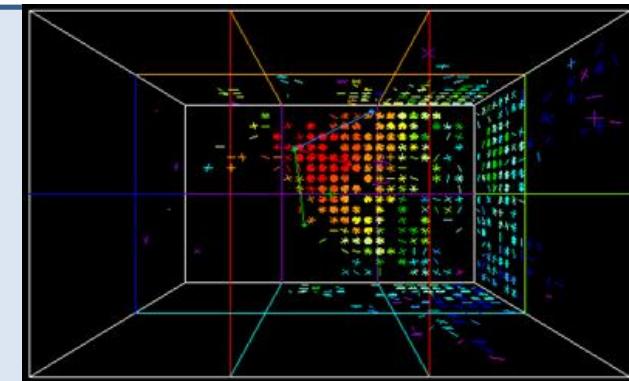
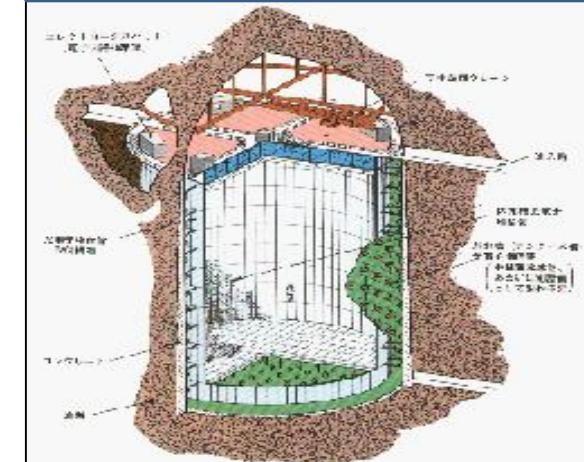
IMB,KII, BUST, LSD
detected ν by IBD

IMB

- water Cerenkov
- 5000 tons fiducial
- threshold 20 MeV
- 8 events in 6 seconds

Kamioka

- water Cerenkov
- 2140 tons fiducial
- threshold ~6 MeV
- 12 events in 12.4 sec.



On line print of five pulses on 23 February
1987 at 2 hr, 52 min,
detected at LSD experiment

The first !

23 59 52.80/7 22 02 1987/CN 051 A 158/ S
*** PDP-11 DATE/TIME WAS : 87/02/23 00:00:07:24
*** INEGF CLOCK DATE/TIME IS : 23 00:00:00:
CLOCK -- STOP

LSDMON -- 23-FEB-87 00:12:59 *** HIST.UPDATE AT EV

LSDM02 -- 23-FEB-87 01:28:10 *** UPDATE HIST. FILE

LSDMON -- 23-FEB-87 01:33:52 *** HIST.UPDATE AT EV

LSDMON -- 23-FEB-87 02:12:48 *** EMPTY/ERRORED EVE

LSDMON -- 23-FEB-87 03:17:08 *** HIST.UPDATE AT EV

LSDM02 -- 23-FEB-87 03:37:47 *** UPDATE HIST. FILE

LSDM02 -- 23-FEB-87 03:52:47 !!!!!!! BURST OF 4

3:52:42.696 23- 2-87 TIME = 5.904 SEC. EV.ATI
EV 994 TANK 31 ADC 33 L.E.P. 0
EV 995 TANK 14 ADC 37 L.E.P. 0
EV 996 TANK 25 ADC 46 L.E.P. 1
EV 997 TANK 35 ADC 32 L.E.P. 0

LSDM02 -- 23-FEB-87 03:52:56 !!!!!!! BURST OF 4

3:52:43.800 23- 2-87 TIME = 3.151 SEC. EV.ATI
EV 995 TANK 14 ADC 37 L.E.P. 0
EV 996 TANK 25 ADC 46 L.E.P. 1
EV 997 TANK 35 ADC 32 L.E.P. 0
EV 998 TANK 33 ADC 40 L.E.P. 0

LSDM02 -- 23-FEB-87 03:53:04 !!!!!!! BURST OF 5 EVENTS

3:52:43.800 23- 2-87 TIME = 7.008 SEC. EV.ATIESI = 0.08 FREQ.IMIT. = 0.178E-02 /DAY

EV 994 TANK 31 ADC 33 L.E.P. 0

EV 995 TANK 14 ADC 37 L.E.P. 0

EV 996 TANK 25 ADC 46 L.E.P. 1

EV 997 TANK 35 ADC 32 L.E.P. 0

EV 998 TANK 33 ADC 40 L.E.P. 0

CLOSTR -- 04 52 52.90/1 23-02 1987/CN 052 A 158/ SCR 0000100 REL 0000

LSDMON -- 23-FEB-87 04:53:22 *** HIST.UPDATE AT EVENT 1062 RUN 1328

LSDM02 -- 23-FEB-87 05:28:53 *** UPDATE HIST. FILE 2 ***

Circ
I. A

EYELEX TELEEX EYELEX TELEEX

28/02 14:37
ASTROGRAM CAM
*
224379 COSMOT

TO DIRECTOR

IN THE MONT BLANC NEUTRINO OBSERVATORY ~~AS~~
FEB. 23RD AT 2:58 UT. THE NEUTRINO TELESCOPE
AT 5000 M.W.E. UNDERGROUND, IN COLLABORATION
COSMOGEOFISICA CNR, TORINO (ITALY) AND ACADEMIA
MOSCOW (ZATSEPIN GROUP), CONSISTS OF 90 TON
IN 72 COUNTERS SHIELDED WITH 200 TONS OF FL
THE RECORDED SIGNAL IS MADE BY 5 PULSES, AT
THRESHOLD, DURING 7 SEC. THIS IS IN AGREEMENT
COLLAPSING FE-CORES STANDARD MODELS AT 50 T
AND IN TIME DURATION.
THE PROBABILITY OF A RANDOM COINCIDENCE WI
ABOUT EVERY 10000 YEARS.
DETAILS WILL BE SEND SOON BY TELEFAX (PLEAS
NUMBER).
BEST WISHES

CARLO CASTAGNOLI
DIRECTOR OF ISTITUTO COSMOGEOFISICO
TORINO - ITALY

* ASTROGRAM CAM
224379 COSMOT INNNNN

**Circular No. 4323
I. A. U. 2/28/1987**

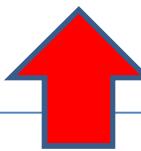
**EX-
EYELE**
0025+
0257103206842
NA
0025+
0257103206842+
28/02 14.37
ASTROGRAM CAM

224379 COSMOT
TO DIRECTOR

IN THE MONT BLANC NEUTRINO OBSERVATORY A SIGNAL HAS BEEN DETECTED ON FEB. 23RD AT 2:58 UT. THE NEUTRINO TELESCOPE, RUNNING SINCE OCT. 1984, AT 5000 M.W.E. UNDERGROUND, IN COLLABORATION BETWEEN OUR ISTITUTO DI COSMOGEOFISICA CNR, TORINO (ITALY) AND ACADEMY OF SCIENCES OF USSR MOSCOW (ZATSEPIN GROUP), CONSISTS OF 90 TONS OF LIQUID SCINTILLATOR IN 72 COUNTERS SHIELDED WITH 200 TONS OF FE SLABS. THE RECORDED SIGNAL IS MADE BY 5 PULSES, ABOVE THE 7 MEV ENERGY THRESHOLD, DURING 7 SEC. THIS IS IN AGREEMENT WITH THE PREDICTIONS OF COLLAPSING FE-CORES STANDARD MODELS AT 50 KPC FARAWAY, BOTH IN ENERGY AND IN TIME DURATION. THE PROBABILITY OF A RANDOM COINCIDENCE WITH SUPERNOVA SN 1987 A IS 1 ABOUT EVERY 10000 YEARS. DETAILS WILL BE SEND SOON BY TELEFAX (PLEASE, LET US KNOW YOUR NUMBER). BEST WISHES.

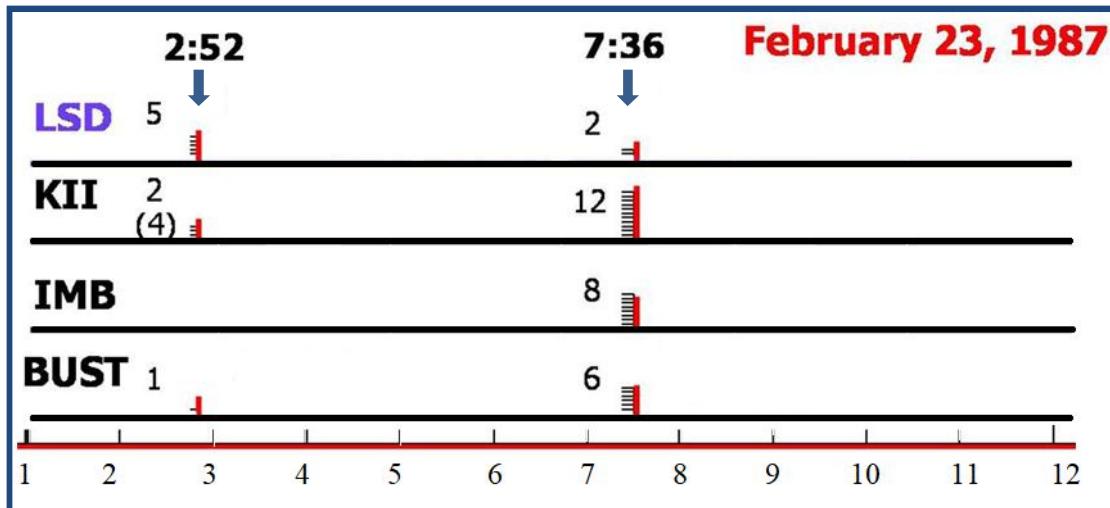
CARLO CASTAGNOLI
DIRECTOR OF ISTITUTO COSMOGEOFISICO
TORINO - ITALY

ASTROGRAM CAM
224379 COSMOT JNNNNN



International Astronomical Union

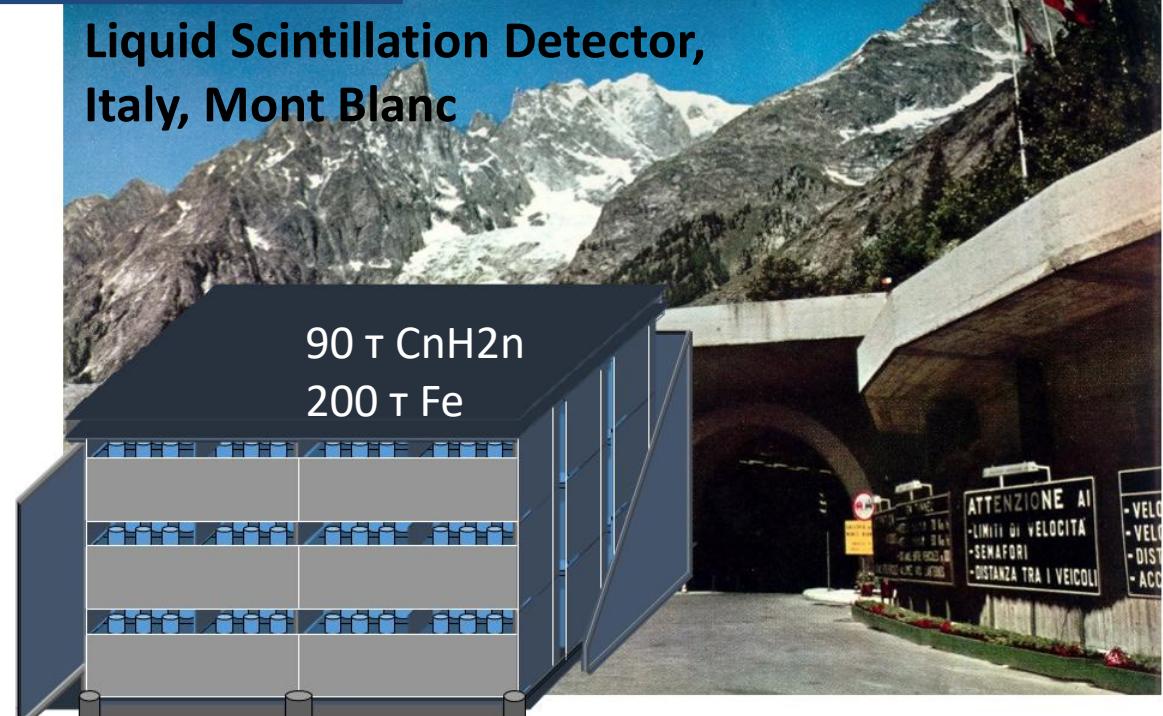
Detected signals with LSD, KII, IMB, BUST on 23/2/1987:



On the Event Observed in the
Mont Blanc Underground
Neutrino Observatory during
the Occurrence of Supernova
1987A M. Aglietta, et all.,
EuroPhys. Lett. **3** (1987) 1315

LSD events

Nº	Time, UT \pm 2ms	Energy, MeV
1	2:52:36,79	6,2 – 7
2	40,65	5,8 – 8
3	41,01	7,8 – 11
4	42,70	7,0 – 7
5	43,80	6,8 – 9
1	7:36:00,54	8
2	7:36:18,88	9



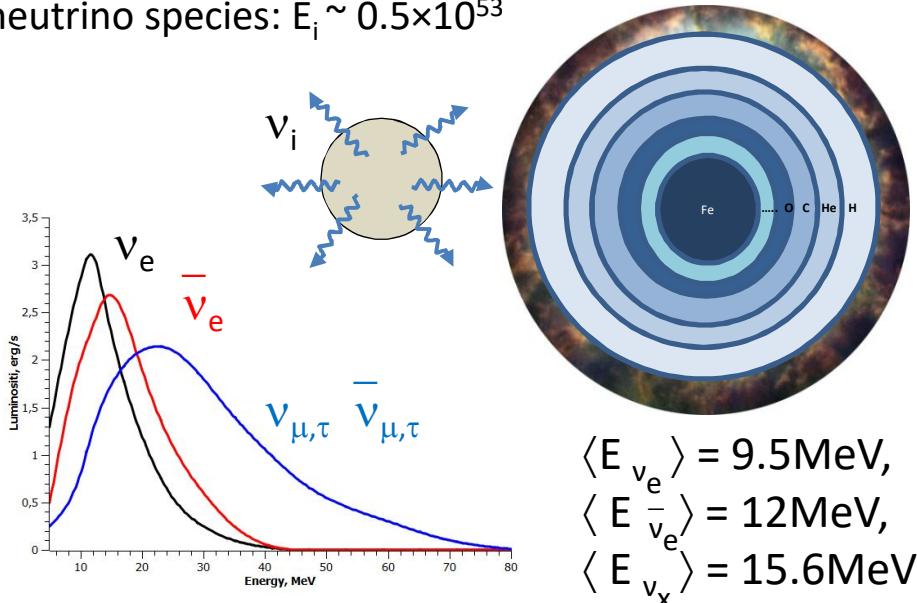
3 of them in the 16 internal tanks, 2 in the 56 external tanks

Models of SN explosions:

Standard Collapse Model

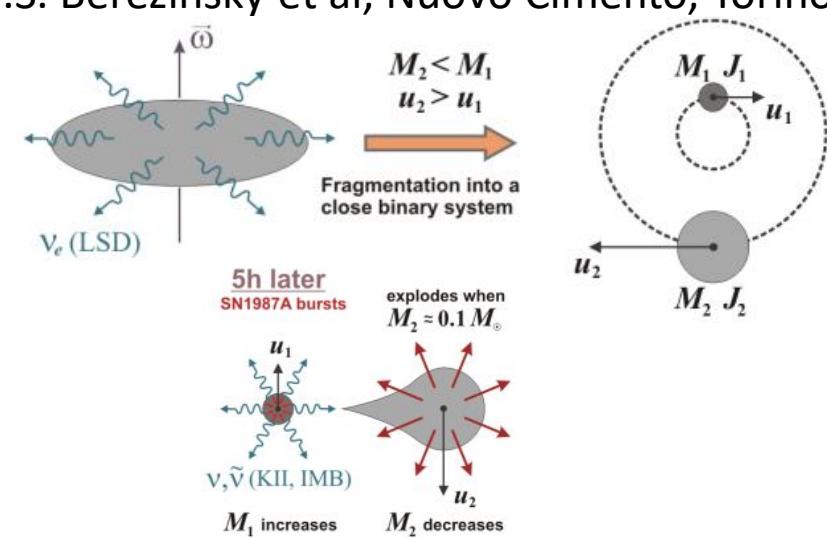
Two-stages Collapse Models

The SN outburst is triggered by the gravitational collapse of the “iron” core of a mass $M_{Fe}=1.2\pm 2 M_c$ into a neutron star. About $(10 \pm 15)\% M_{Fe}c^2$ is radiated in the form of ν and $\bar{\nu}$ of all the flavors (e, μ, τ): $E_{\nu} \bar{\nu} = (3 - 5) \times 10^{53}$ erg. The total energy is assumed to be equally distributed among the six neutrino species: $E_i \sim 0.5 \times 10^{53}$



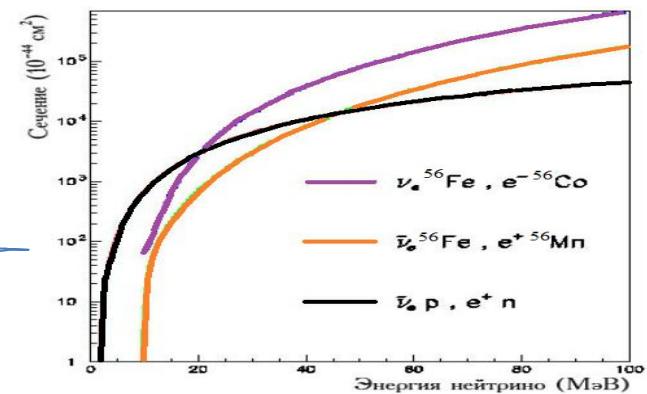
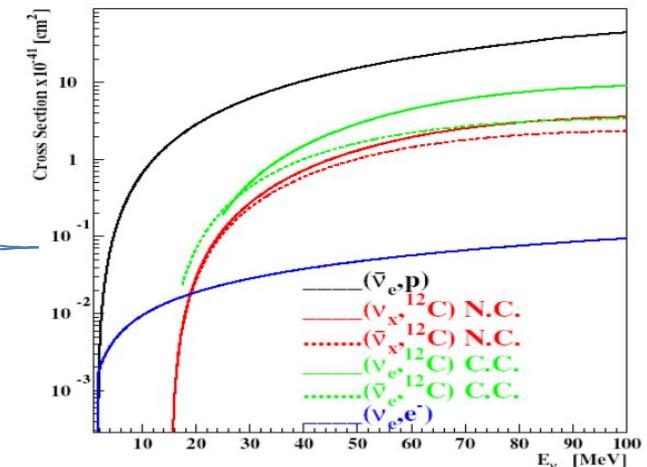
Neutrino spectra, 100ms after bounce

- A. DeRujula (Phys.Lett.B 1987, CERN)
- A. Burrows' group (Arizona); E. Müller, T. Janka (MPA, Garching)
- G.S. Bisnovatyi-Kogan's group (ICR, Keldysh IPM, Moscow)
- V.S. Imshennik (Alikhanov ITEP, Moscow)
- V.S. Berezinsky et al, Nuovo Cimento, Torino



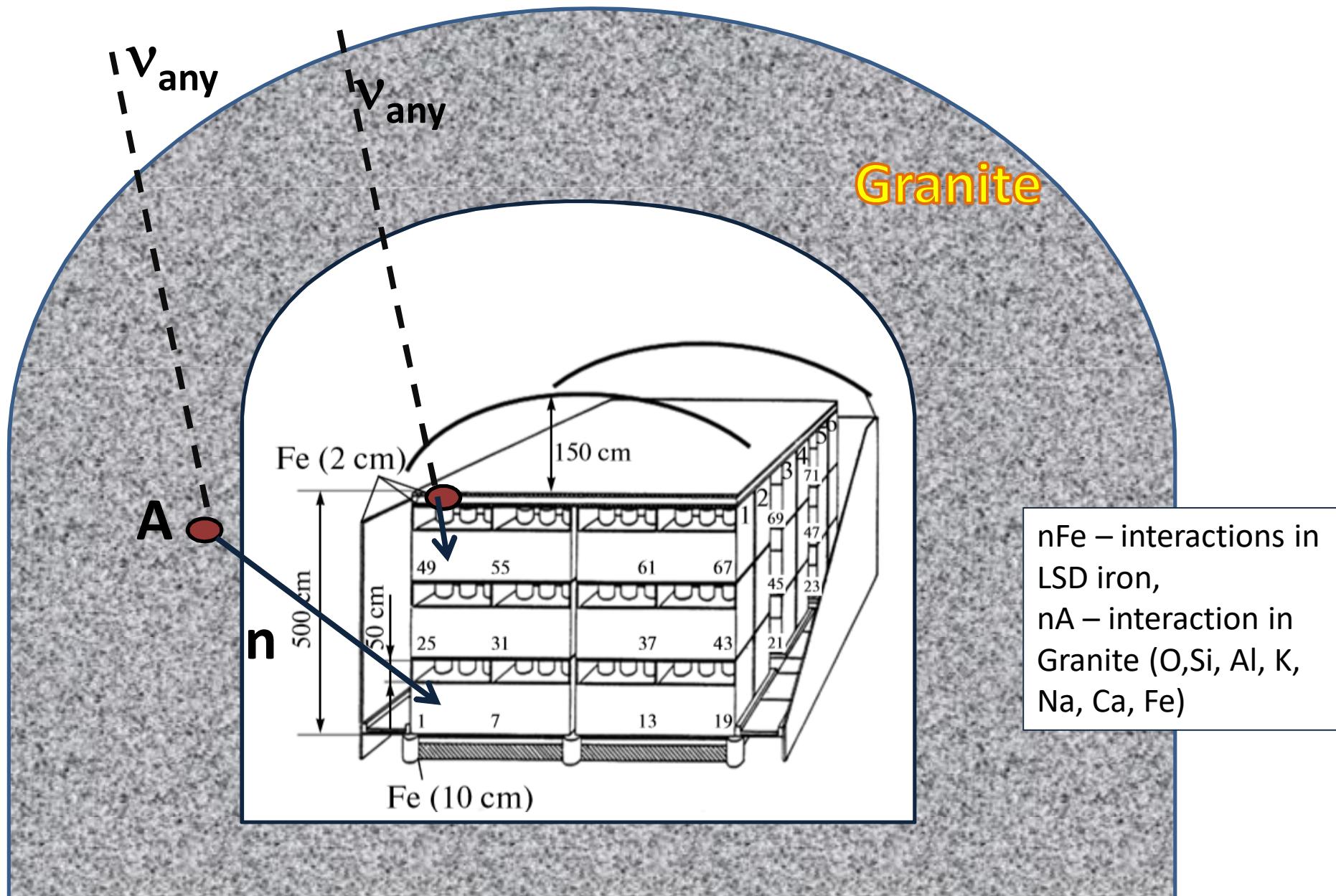
Neutrino interactions in LSD material

$\bar{\nu}_e + p \rightarrow e^+ + n$	The main reaction	$E_{th} = 1.8 \text{ MeV}$
$n + p \rightarrow d + \gamma$		$E_\gamma = 2.2 \text{ MeV}$
$n + \text{Fe} \rightarrow \text{Fe} + \Sigma\gamma$		$\langle E_\gamma \rangle \approx 7 \text{ MeV}$
$\nu_e + {}^{12}\text{C} \rightarrow e^- + {}^{12}\text{N}$		$E_{th} = 17.3 \text{ MeV}$
${}^{12}\text{N} \rightarrow {}^{12}\text{C} + e^+ + \bar{\nu}_e$		
$\bar{\nu}_e + {}^{12}\text{C} \rightarrow e^+ + {}^{12}\text{B}$		$E_{th} = 14.4 \text{ MeV}$
${}^{12}\text{B} \rightarrow {}^{12}\text{C} + e^- + \bar{\nu}_e$		
$\nu_i + {}^{12}\text{C} \rightarrow \nu_i + {}^{12}\text{C}^*$		$E_{th} = 15.1 \text{ MeV}$
${}^{12}\text{C}^* \rightarrow {}^{12}\text{C} + \gamma$		$E_\gamma = 15.1 \text{ MeV}$
${}^{12}\text{C}^* \rightarrow {}^{11}\text{C} + n$		$E_n = 8 - 9 \text{ MeV}$
${}^{12}\text{C}^* \rightarrow {}^{11}\text{B} + p$		$E_p = 8 - 9 \text{ MeV}$
$\nu_i + e^- \rightarrow \nu_i + e^-$		-
$\nu_e + {}^{56}\text{Fe} \rightarrow e^- + {}^{56}\text{Co}^*$		$E_{th} = 10 \text{ MeV}$
${}^{56}\text{Co}^* \rightarrow {}^{56}\text{Co} + \Sigma\gamma$		$E_\gamma = 7 - 11 \text{ MeV}$
${}^{56}\text{Co}^* \rightarrow {}^{55}\text{Co} + n$		
${}^{56}\text{Co}^* \rightarrow {}^{55}\text{Fe} + p$		
$\bar{\nu}_e + {}^{56}\text{Fe} \rightarrow e^+ + {}^{56}\text{Mn}^*$		$E_{th} = 12.5 \text{ MeV}$
${}^{56}\text{Mn}^* \rightarrow {}^{56}\text{Mn} + \gamma$		
${}^{56}\text{Mn}^* \rightarrow {}^{55}\text{Mn} + n$		
${}^{56}\text{Mn}^* \rightarrow {}^{55}\text{Cr} + p$		
$\nu_i + {}^{56}\text{Fe} \rightarrow \nu_i + {}^{56}\text{Fe}^*$		$E_{th} = 15.0 \text{ MeV}$
${}^{56}\text{Fe}^* \rightarrow {}^{56}\text{Fe} + \gamma$		$E_\gamma \approx 7.6 \text{ MeV}$
${}^{56}\text{Fe}^* \rightarrow {}^{55}\text{Fe} + n$		
${}^{56}\text{Fe}^* \rightarrow {}^{55}\text{Mn} + p$		

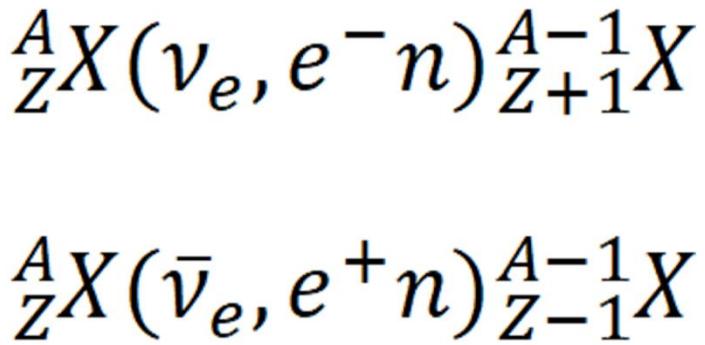


Recently, Stanly Yen (Sudbury) suggested to take into account the role of surrounding LSD rock.

Monte-Carlo simulation neutrino interactions



Reactions with neutron productions



PHYSICAL REVIEW C, VOLUME 63, 025802

Role of ν -induced reactions on lead and iron in neutrino detectors

E. Kolbe^{1,*} and K. Langanke²

¹Institut für Kernphysik I, Forschungszentrum Karlsruhe, Germany

²Institute for Physics and Astronomy, University of Aarhus, Aarhus, Denmark

(Received 17 March 2000; revised manuscript received 26 October 2000; published 25 January 2001)

We have calculated cross sections and branching ratios for neutrino-induced reactions on ^{208}Pb and ^{56}Fe for various supernova and accelerator-relevant neutrino spectra. This was motivated by the facts that lead and iron will be used on the one hand as target materials in future neutrino detectors and, on the other hand, have been and are still used as shielding materials in accelerator-based experiments. In particular we study the inclusive $^{56}\text{Fe}(\nu_e, e^-)^{56}\text{Co}$ and $^{208}\text{Pb}(\nu_e, e^-)^{208}\text{Bi}$ cross sections and calculate the neutron energy spectra following the decay of the daughter nuclei. These reactions give a potential background signal in the KARMEN and LSND experiment and are discussed as a detection scheme for supernova neutrinos in the proposed OMNIS and LAND detectors. We also study the neutron emission following the neutrino-induced neutral-current excitation of ^{56}Fe and ^{208}Pb .

DOI: 10.1103/PhysRevC.63.025802

PACS number(s): 23.40.Bw, 13.10.+q, 25.30.Pt, 26.65.+t

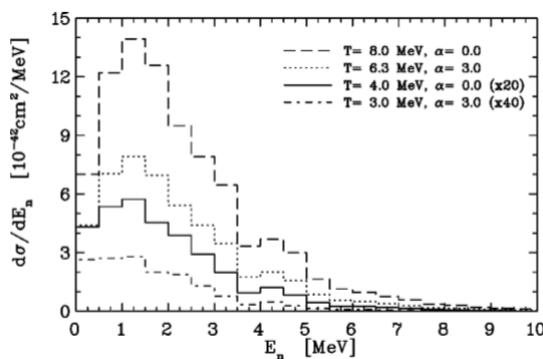


FIG. 4. Neutron energy spectrum produced by the charged-current (ν_e, e^-) reaction on ^{56}Fe .

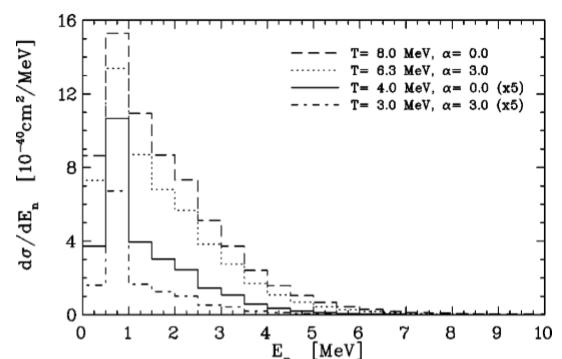


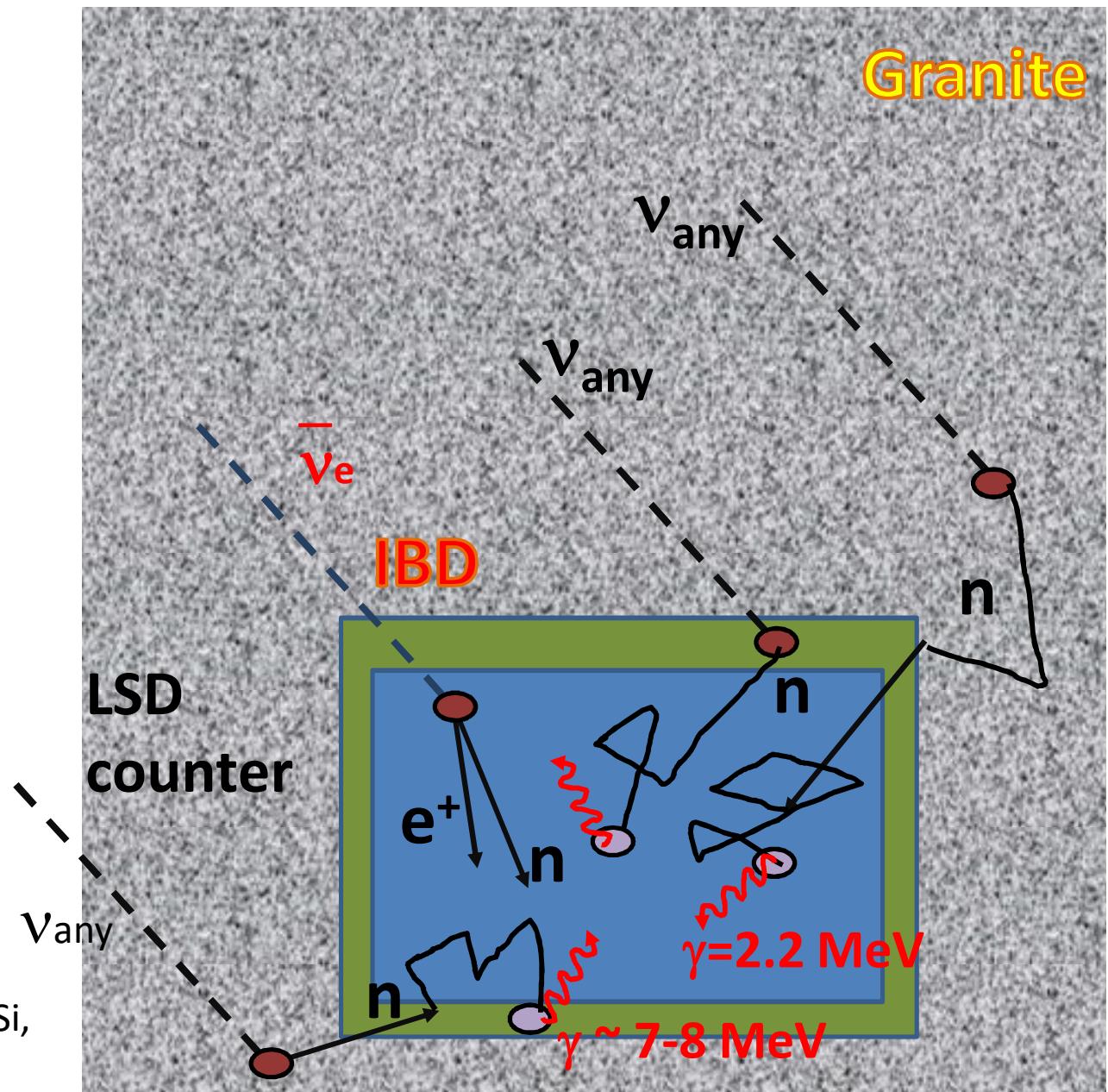
FIG. 6. Neutron energy spectrum produced by the charged-current (ν_e, e^-) reaction on ^{208}Pb .

Monte-Carlo simulation neutron interactions

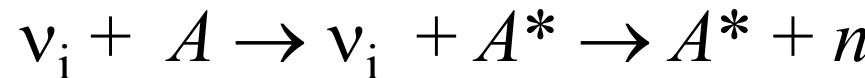
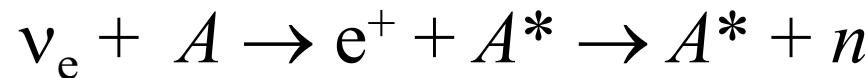
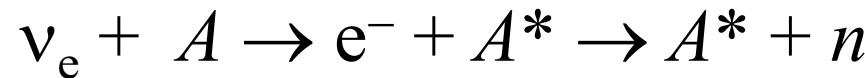
Chemical composition
of Mont Black rock

element	Mass fraction %
SiO ₂	75.4
AlO	13.7
FeO	0.99
NaO	3.73
KO	5.66
CaO	0.74
MgO	0.24

nFe – interactions in LSD iron,
nA – interaction in Granite (O, Si,
Al, K, Na, Ca, Fe)



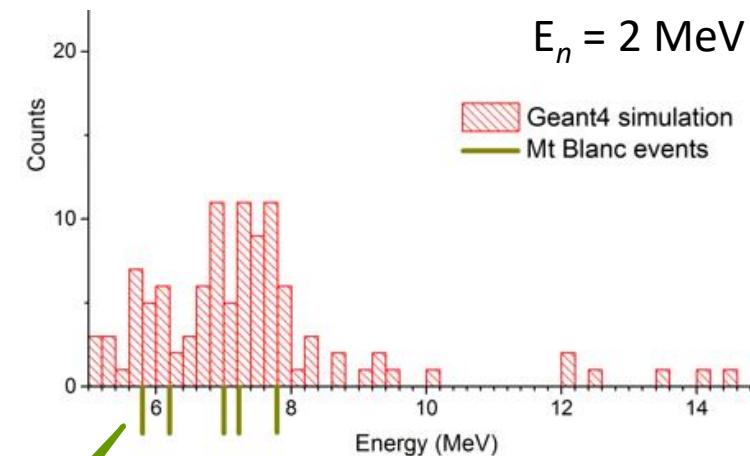
Possible explanation of LSD signal



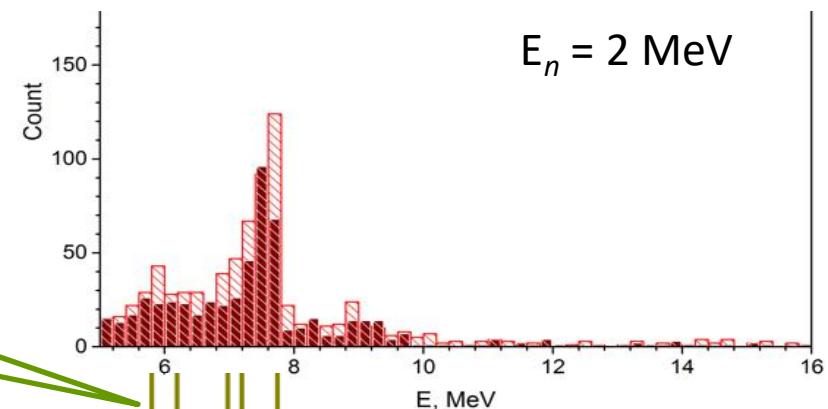
Несмотря на то, что сечения меньше, чем $\bar{\nu}_e p$, но железа в конструкции установок много и есть тяжелые ядра в окружающем грунте.

Предполагается, что учет этих нейтронов может объяснить сигнал SN1987A даже в рамках Стандартной модели взрыва сверхновых.

Simulations of neutrons produced in rock, captured in LSD material and had energy $E > 5$ MeV



Simulations of neutrons produced in LSD iron, captured in LSD material and had energy $E > 5$ MeV



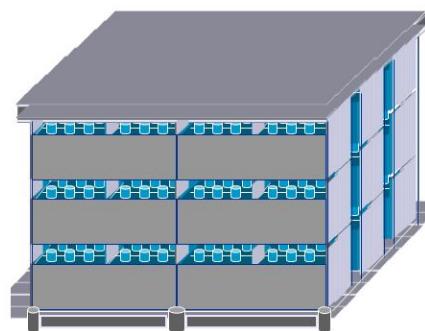
Distribution of 5
LSD pulses

Conclusion

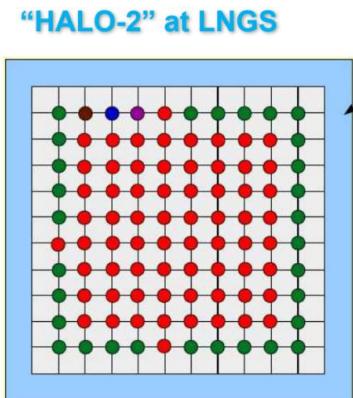
1. Our estimates show that the energy distribution of the LSD signal pulses is very similar to the distribution of gamma-quanta from neutron capture by the iron nuclei.
2. Thus, the LSD events can be associated with the capture of neutrons by the iron that is part of the detector design.
3. Neutrons can be produced by a neutrino flux from SN1987A in the rock surrounding LSD and iron in reactions : ${}_{Z}^{A}X(\nu_e, e^- n) {}_{Z+1}^{A-1}X$ ${}_{Z}^{A}X(\bar{\nu}_e, e^+ n) {}_{Z-1}^{A-1}X$



LSD was a neutron
bunch detector



Future:



References:

1. S. Yen, TRIUMF Vancouver, Canada (talk 18-Apr 2017)
2. M. Aglietta et all. *EuroPhys. Lett.* 3 (1987) 1315;
3. R. M. Bionta, et al., *Phys. Rev. Lett.* 58, 1494 (1987).
4. K. Hirata, et al., *Phys. Rev. Lett.* 58, 1490 (1987).
5. E.N. Alekseev et al., *Sov. Phys. JETP Lett.* 45 (1987) 461
6. V. S. Imshennik and O. G. Ryazhskaya, *Astron. Lett.* 30, 14 (2004);
7. P. Vogel, *Phys. Rev. D* 29, 1918 (1984);
8. P. Vogel and J. F. Beacom, *Phys. Rev. D* 60, 053003 (1999);
9. A. Strumia and F. Vissani, *Phys. Lett. B* 564, 42 (2003);
10. W. Kretschmer (KARMEN Collab.), *Nucl. Phys. A* 577, 421 (1994);
11. Ya. B. Zel'dovich and O. Kh. Guseinov, *Dokl. Phys.* 10, 524 (1965);
12. W. D. Arnett, *Can. J. Phys.* 44, 2553 (1966);
13. V. S. Imshennik and D. K. Nadezhin, *Itogi Nauki Tekh., Ser.Astron.* 21, 63 (1982);
14. V. S. Imshennik and D. K. Nadezhin, *Sov. Sci. Rev., Ser. E: Astrophys. Space Phys.* 7, 75 (1989).
15. E. Kolbe and K. Langanke, *Phys. Rev. C* 63, 025802 (2001).
16. Väänänen and Volpe, *JCAP* **1110** (2011) 019
17. V.V. Boyarkin, PhD Tesisis (2009) INR RAS - Moscow, Russia

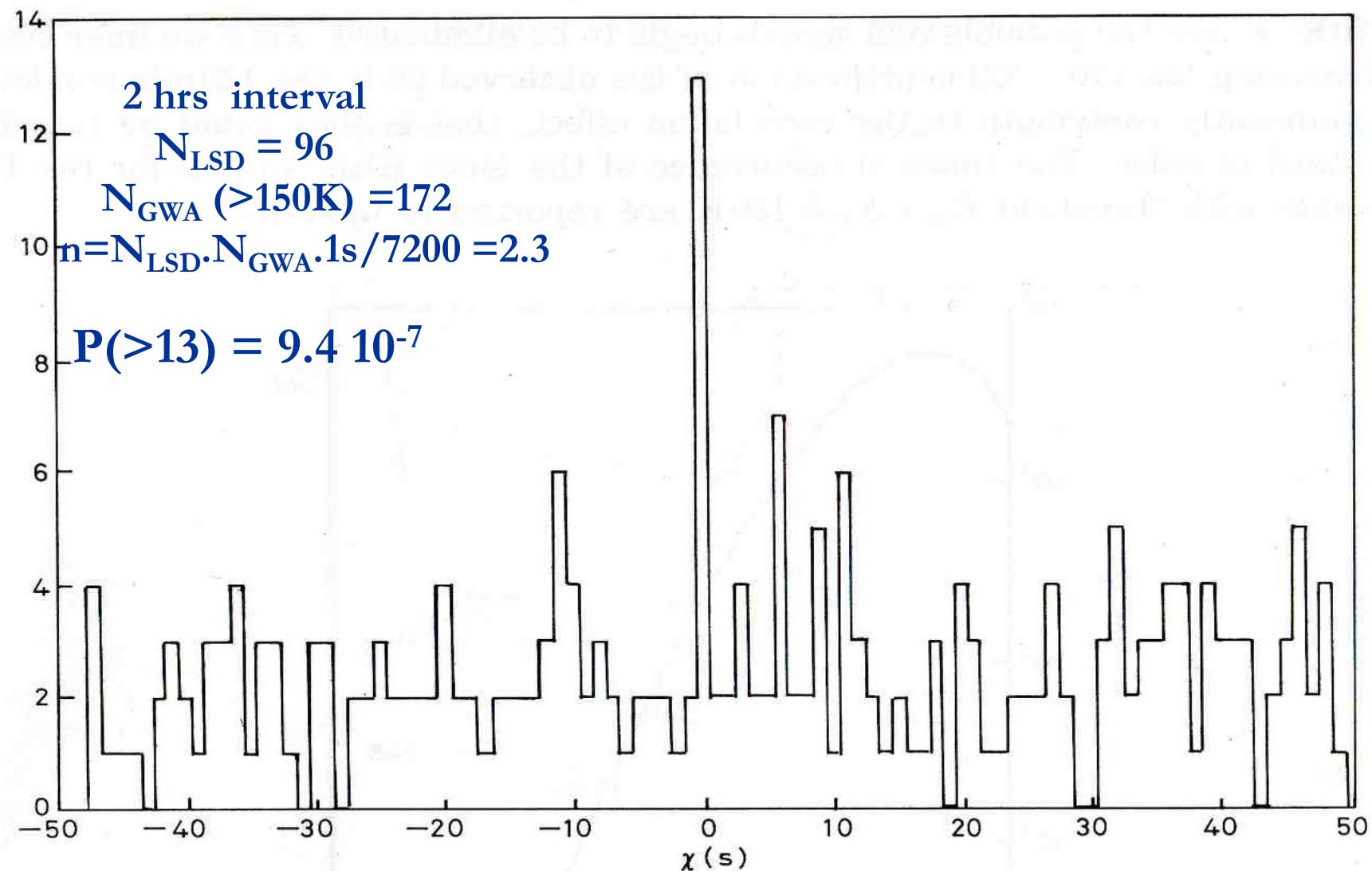


Fig. 14. – The coincidences for the period of fig. 12 between the neutrinos ($N_\nu = 96$) and the g.w. sum events above 150K ($N_{g.w.} = 172$).

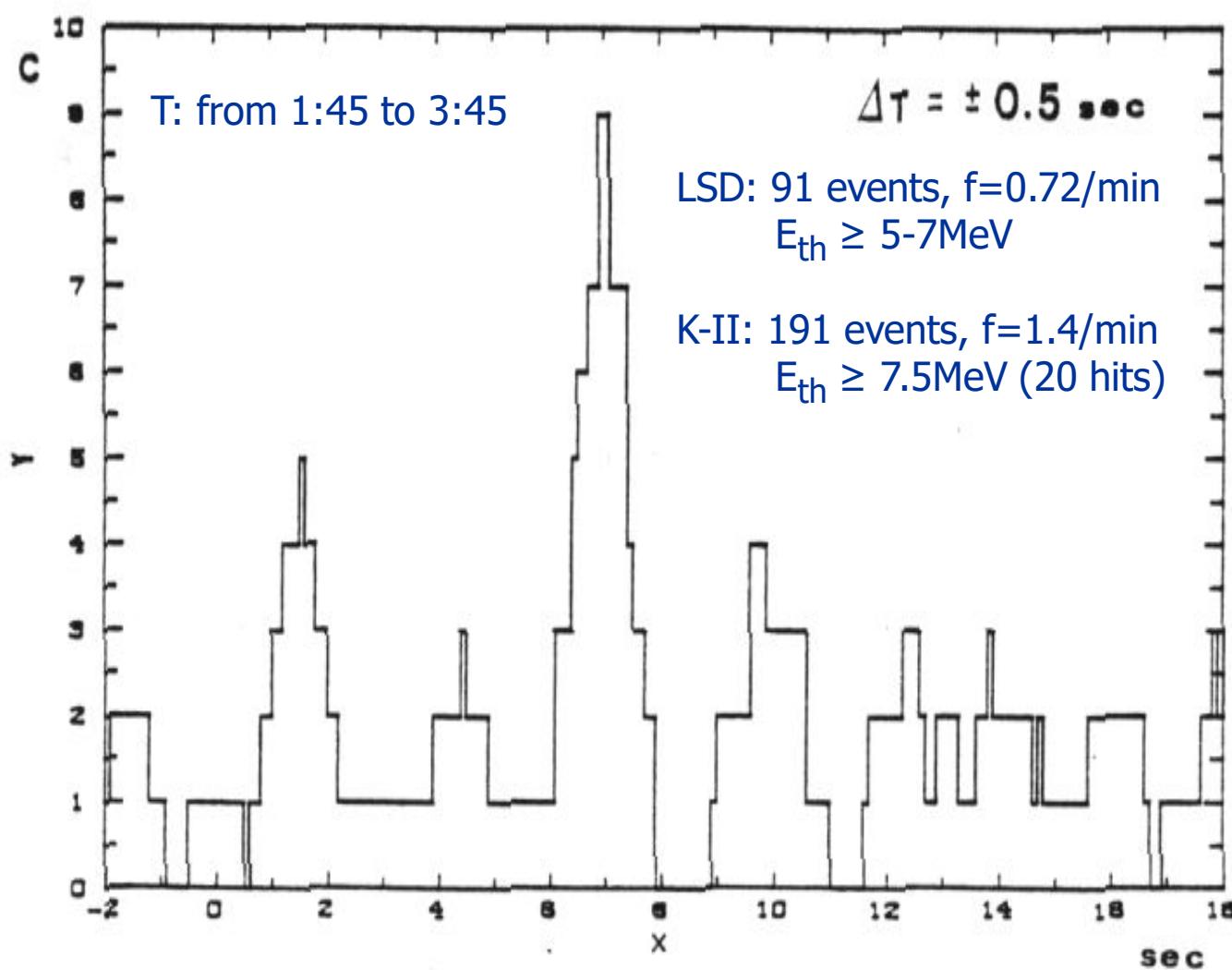
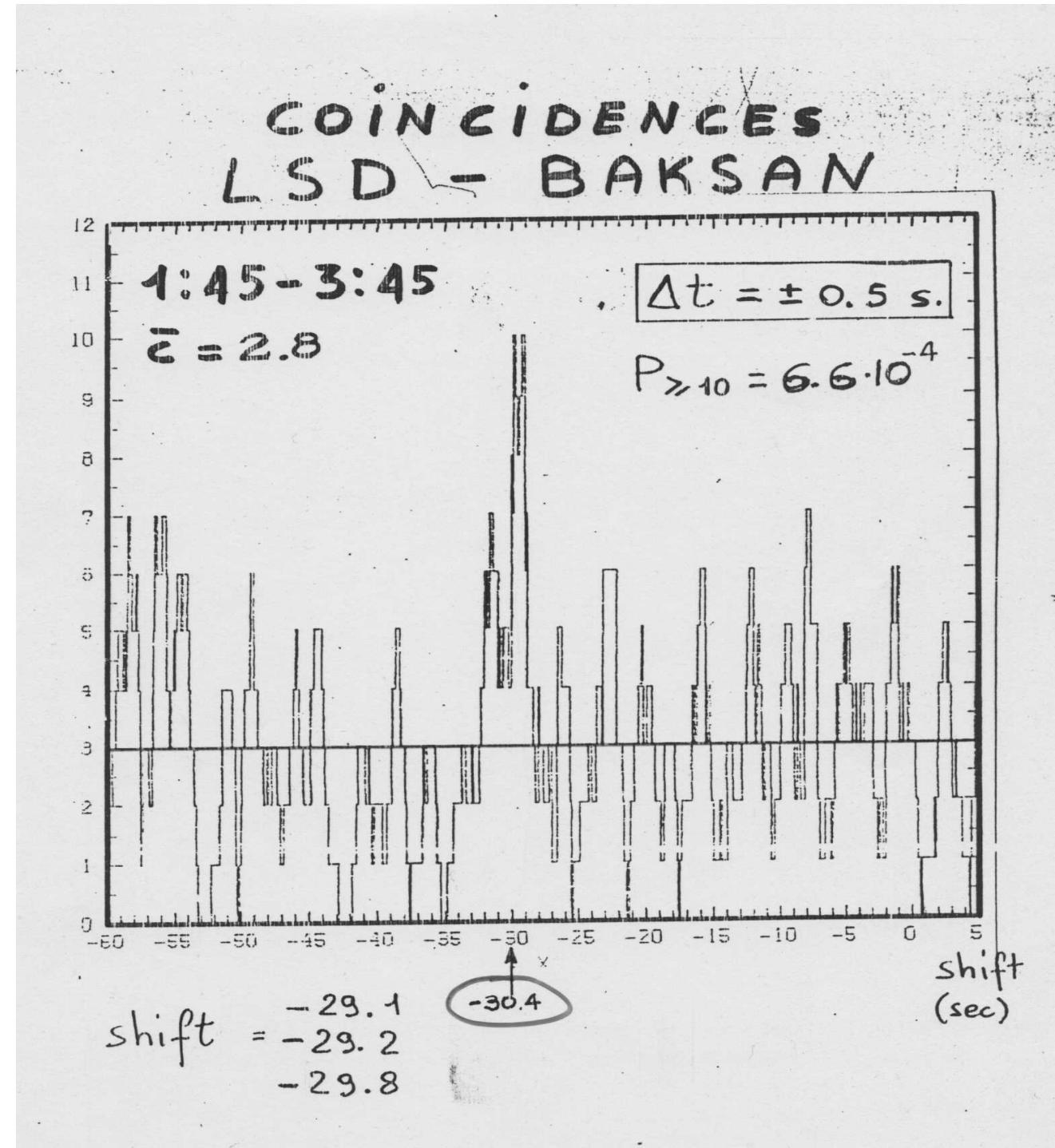


FIGURE 2. Distribution of the number of coincidences between K2 and LSD in the period from 1:45 to 3:45 U.T. on 23 February 1987 as a function of the time shift in the K2 absolute time.

91 Mt. Blanc events
240 Baksan events



LSD events Mt. Blanc
IMB events

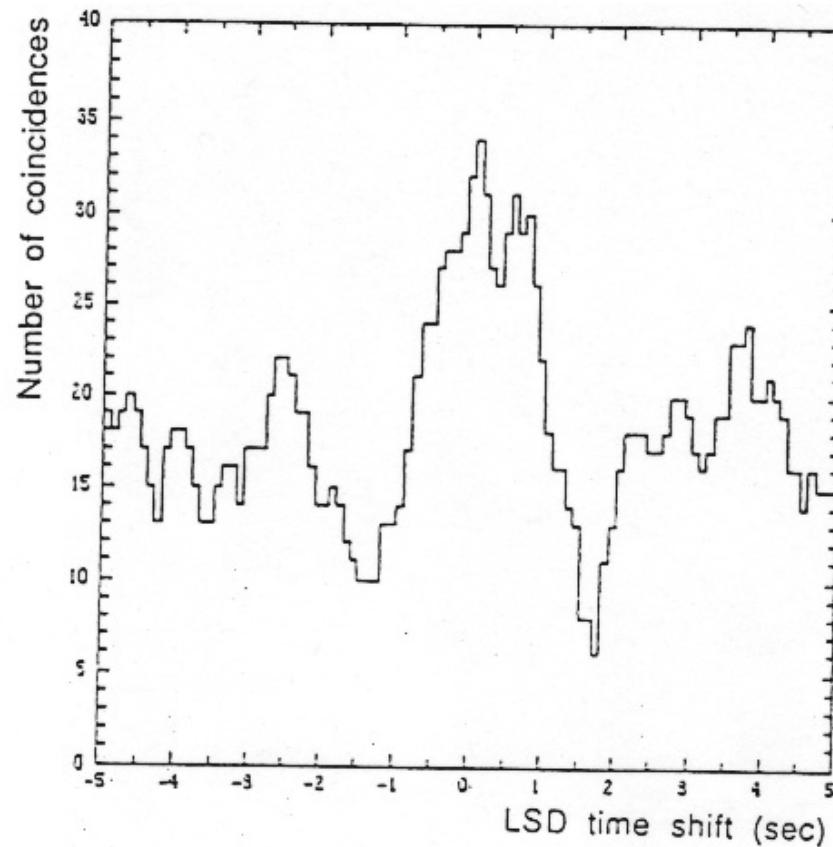


Fig.1

Coincidences between LSD neutrino candidates and IMB muons with zenith angle $\vartheta > 60^\circ$, versus LSD time shift, from 1:45 to 3:45 UT on Feb.23 1987, using a coincidence window of ± 0.5 sec.

Событие, зарегистрированное детектором LSD 23 февраля 1987 года во время вспышки Сверхновой SN1987A, не находило объяснения в рамках стандартной модели гравитационного коллапса, так как при оценках обнаруженных сигналов не принимались во внимание взаимодействия нейтрино с железом детектора и окружающим его грунтом.

События LSD могут быть ассоциированы с взаимодействием нейtronов в веществе детектора.

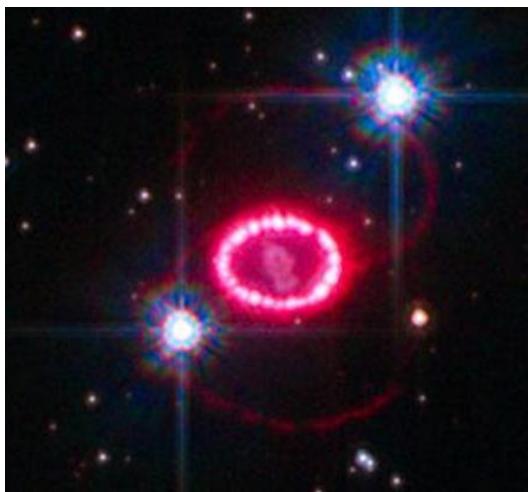
Наши оценки показывают, что энергетическое распределение импульсов сигнала в LSD очень похоже на распределение от захватов нейtronов в материале детектора.

Если предположить, что от SN1987A поток нейтрино был небольшим и их энергия вблизи порога 5-7 МэВ, то другие установки не могли увидеть сигнала.

LSD же имел преимущества из-за грунта вокруг установки и железа в самом детекторе.

LSD мог зарегистрировать 5 событий, в то время как в других экспериментах IMB, и KII не было возможности зарегистрировать нейтроны.

- ❑ The event detected by the LSD on February 23, 1987 during the supernova explosion SN1987A, could not be explained within the framework of the standard gravitational collapse model, since the neutrino interactions with the detector iron and the surrounding soil were not taken into account when estimating the detected signals.
- ❑ LSD events can be associated with neutron interaction in the detector material.
- ❑ Our estimates show that the energy distribution of the signal pulses in the LSD is very similar to the distribution from neutron capture in the detector material.
- ❑ If we assume that the SN neutrino flux was small and their energy was close to the 5-7 MeV threshold, then other installations could not see the signal.
- ❑ LSD also had advantages due to the ground around the setup and iron in the detector itself.
- ❑ LSD could detect 5 events, while in other IMB and KII experiments it was not possible to detect neutrons.



What is the second signal?