Session of the Department of Nuclear Physics, Novosibirsk,
March 10-12, 2020

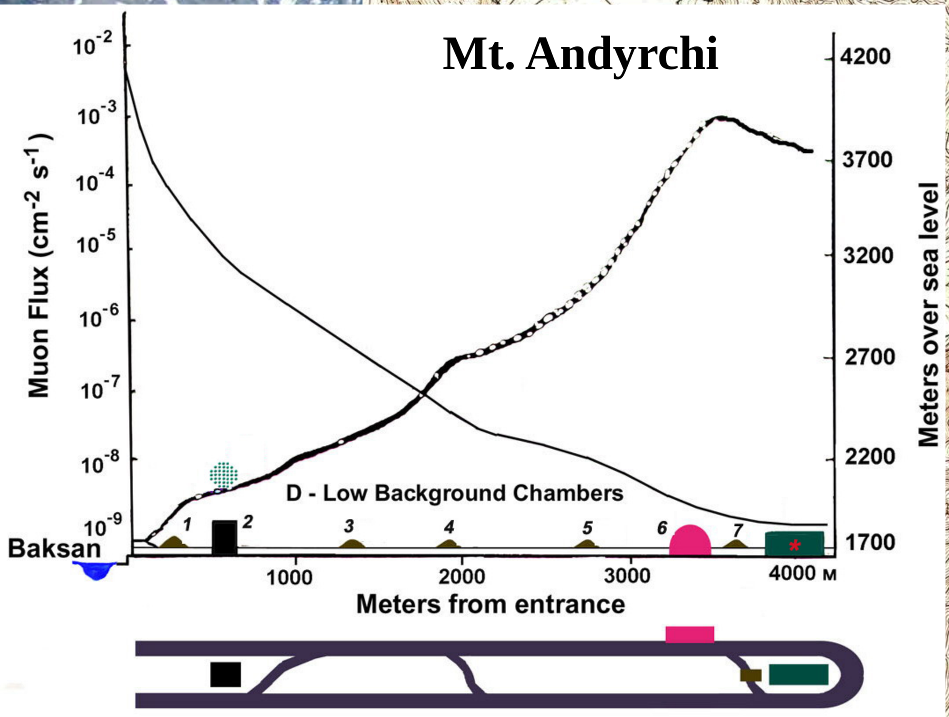
BNO INR RAS
V.N. Gavrin

# BEST
# (Baksan Experiment on Sterile Transitions)
# current status

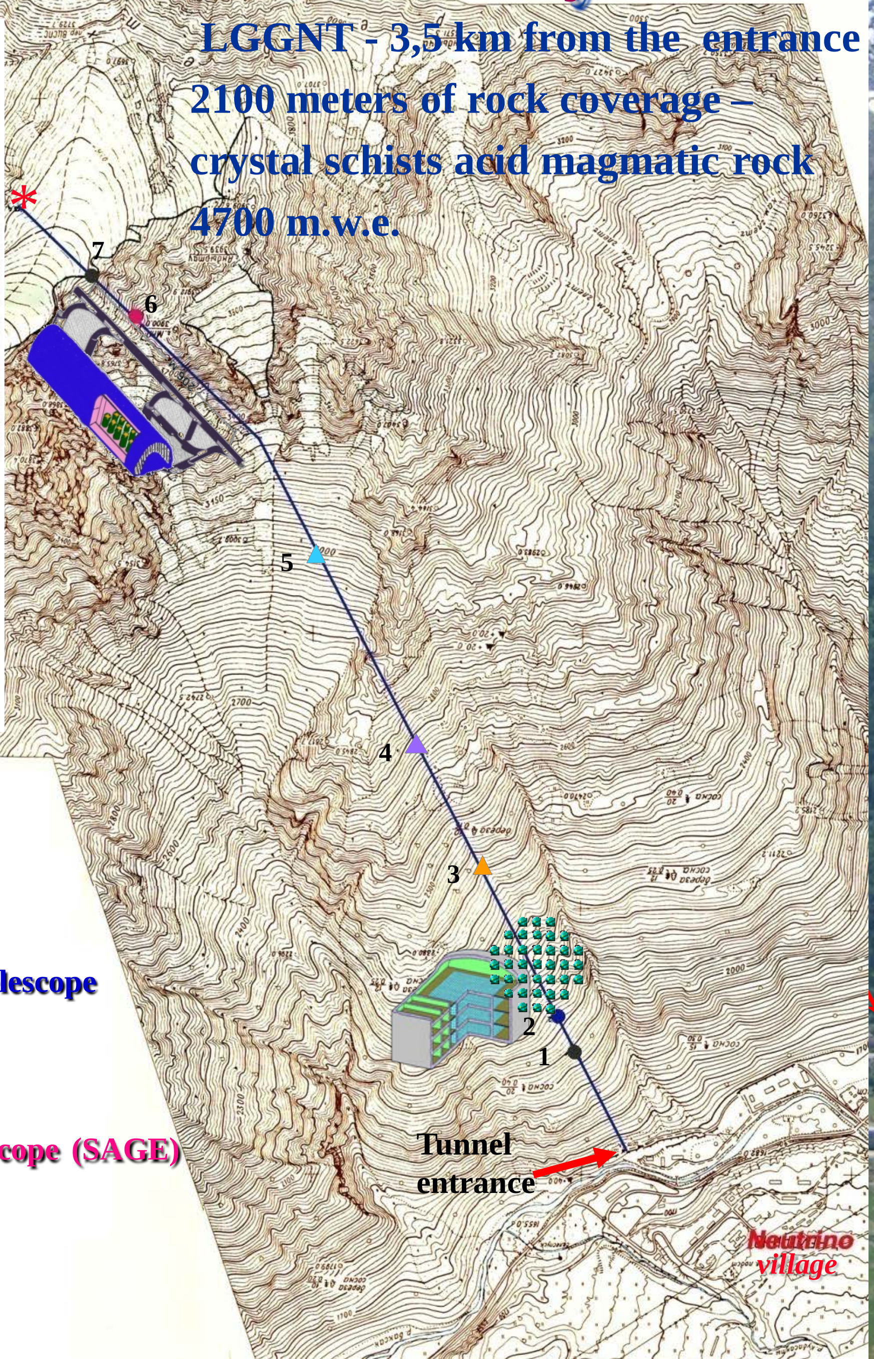
*V. N. Gavrin*
*on behalf of BEST collaboration*

**Institute for Nuclear Research of
the Russian Academy of Sciences
Moscow**

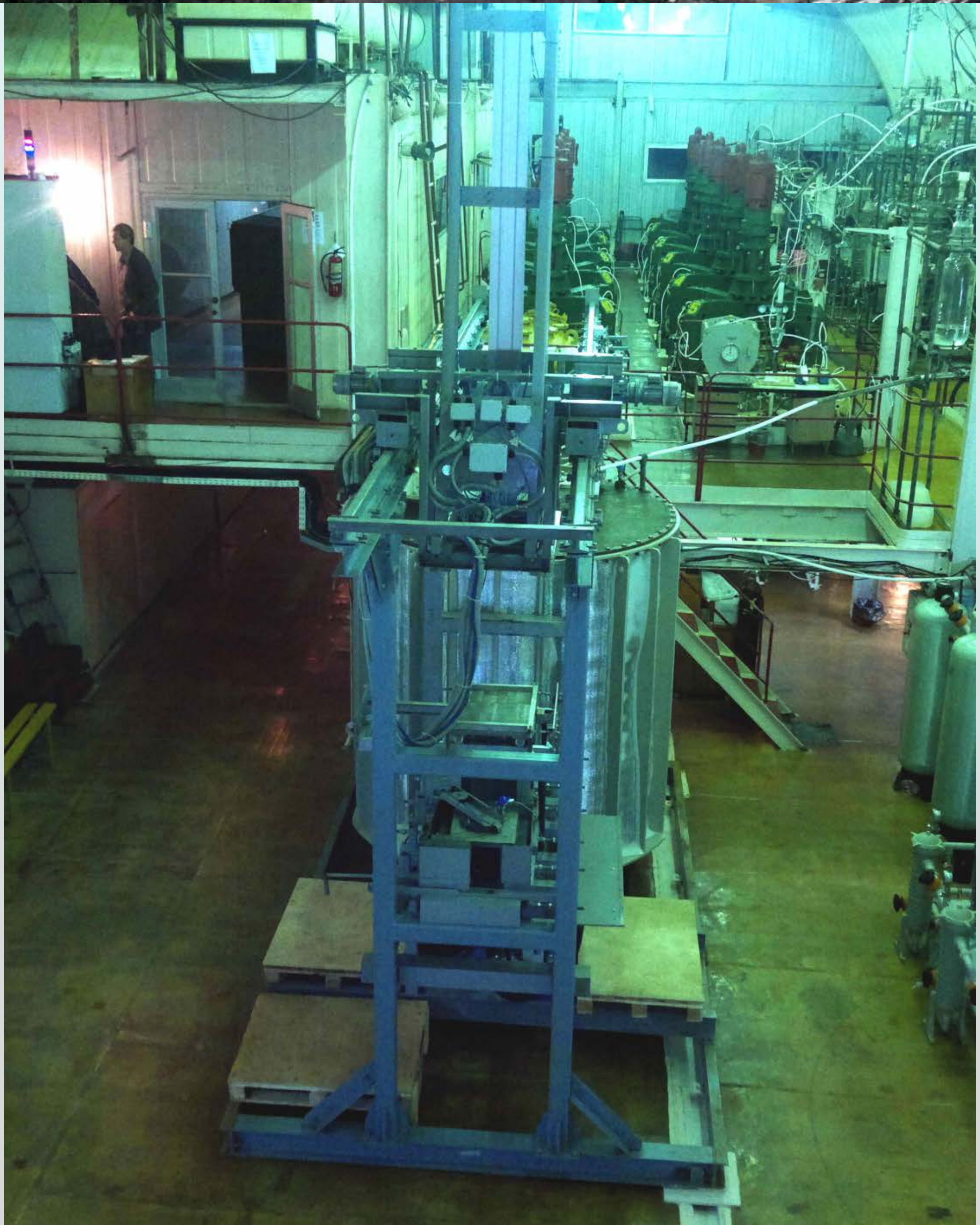
# Baksan Neutrino Observatory




**LGGNT - 3,5 km from the entrance**
**2100 meters of rock coverage – crystal schists acid magmatic rock**
**4700 m.w.e.**




1,7 - Low-background Chamber
2 - Baksan underground scintillation telescope
3 - Laser interferometer
4 - Acoustic gravitational antenna
5 - Geophysics laboratory
6 - Gallium-Germanium Neutrino Telescope (SAGE)
* - for the further projects
- EAS array "Andyrchy"



## BEST installation

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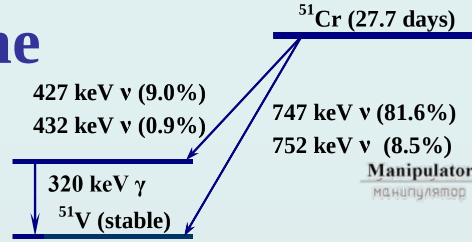
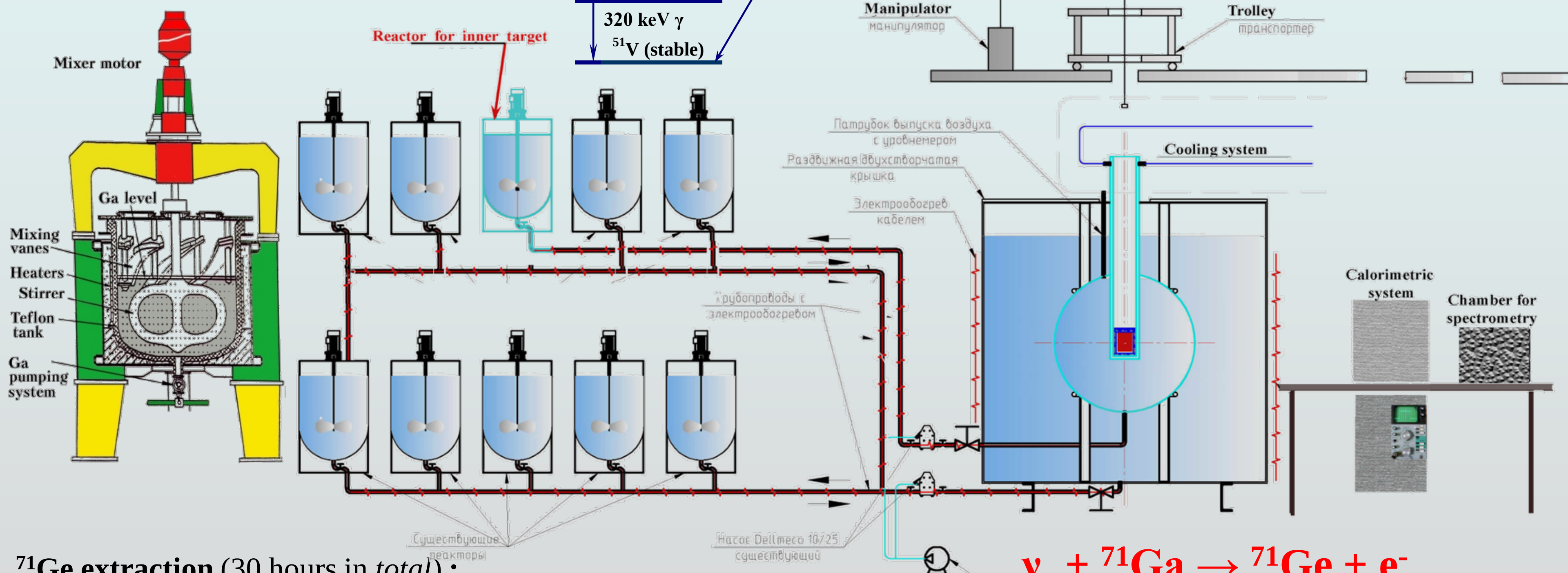
# BEST installation scheme




$$\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^-$$

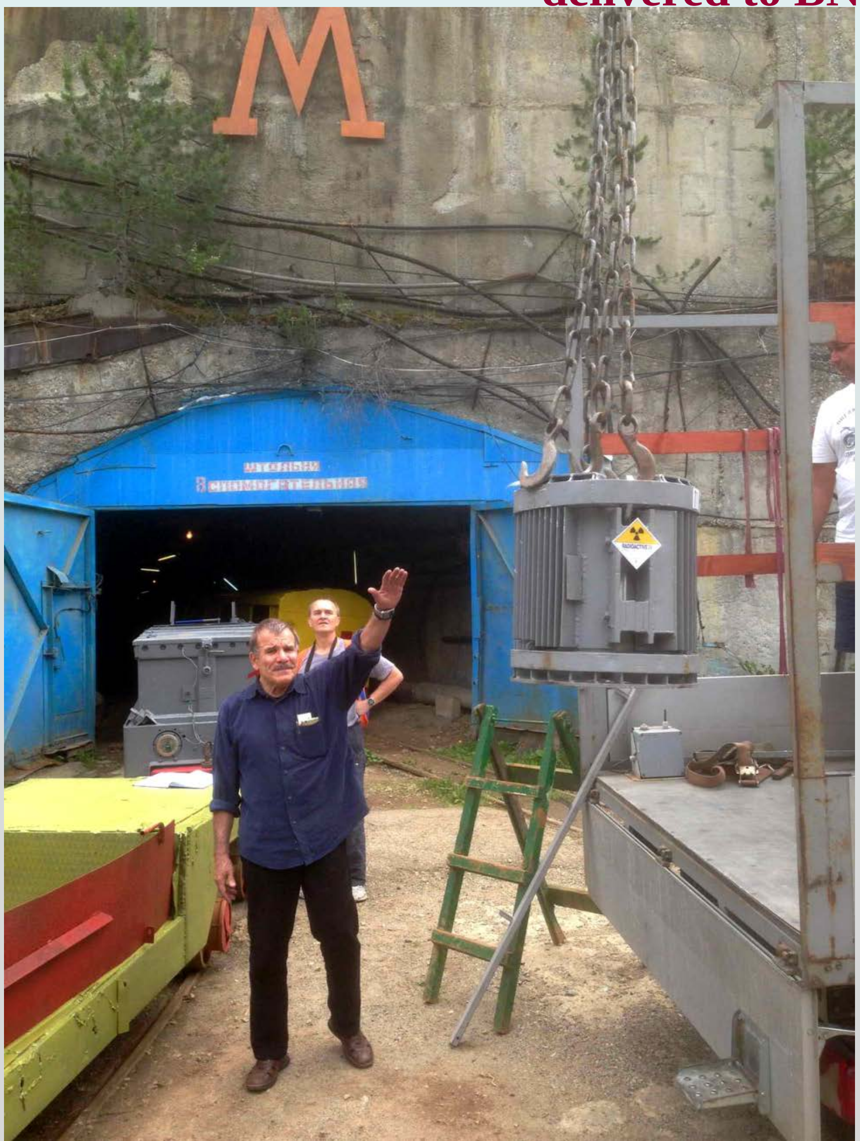
**$^{71}$Ge extraction** (30 hours in *total*) **:**

1) Pumping gallium from the target into chemical reactors: inner zone → 1 reactor, outer zone → 6 reactors. *( 4.5 h)*
2) In each reactor the germanium carrier in the form of GeCl4 is extracted from the metal into aqueous phase.
3) Concentration of the aqueous solution by evaporation. *(16h)*
4) Synthesis of GeH4 and placing it into a proportional counter.
5) $^{71}$Ge decays are counted.*( 60 – 150 days)*

**Source activity measurement:**

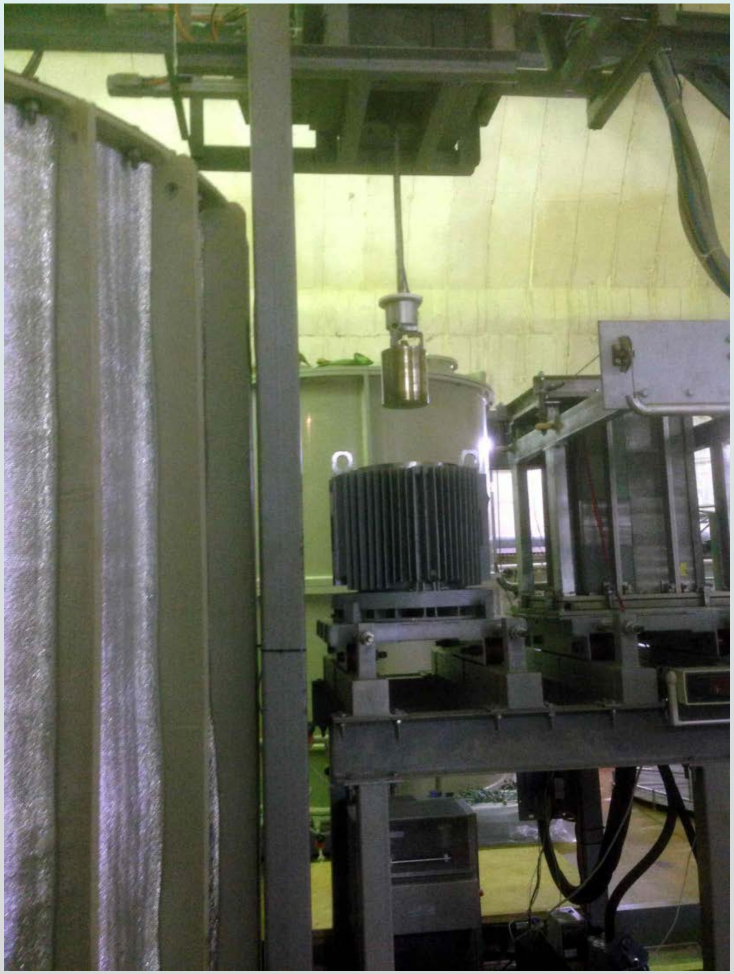
1) Moving the source into a lead container
2) Measuring gamma spectrum at 21.65 m distance with a semiconductor detector *( 1h)*
3) Moving the source into a calorimeter
4) Measuring the heat emitted by the source *( 20-21 h )*

## The $^{51}$Cr electron neutrino source with an estimated activity of 3.28 MCi was delivered to BNO on July 5, 2019.

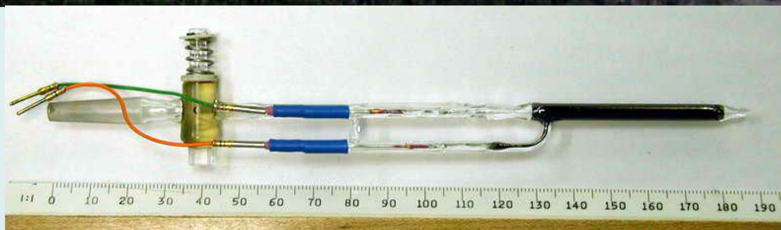


The source was immediately placed at the center of the two-zone target of liquid gallium.

**First stage of the BEST experiment began.**

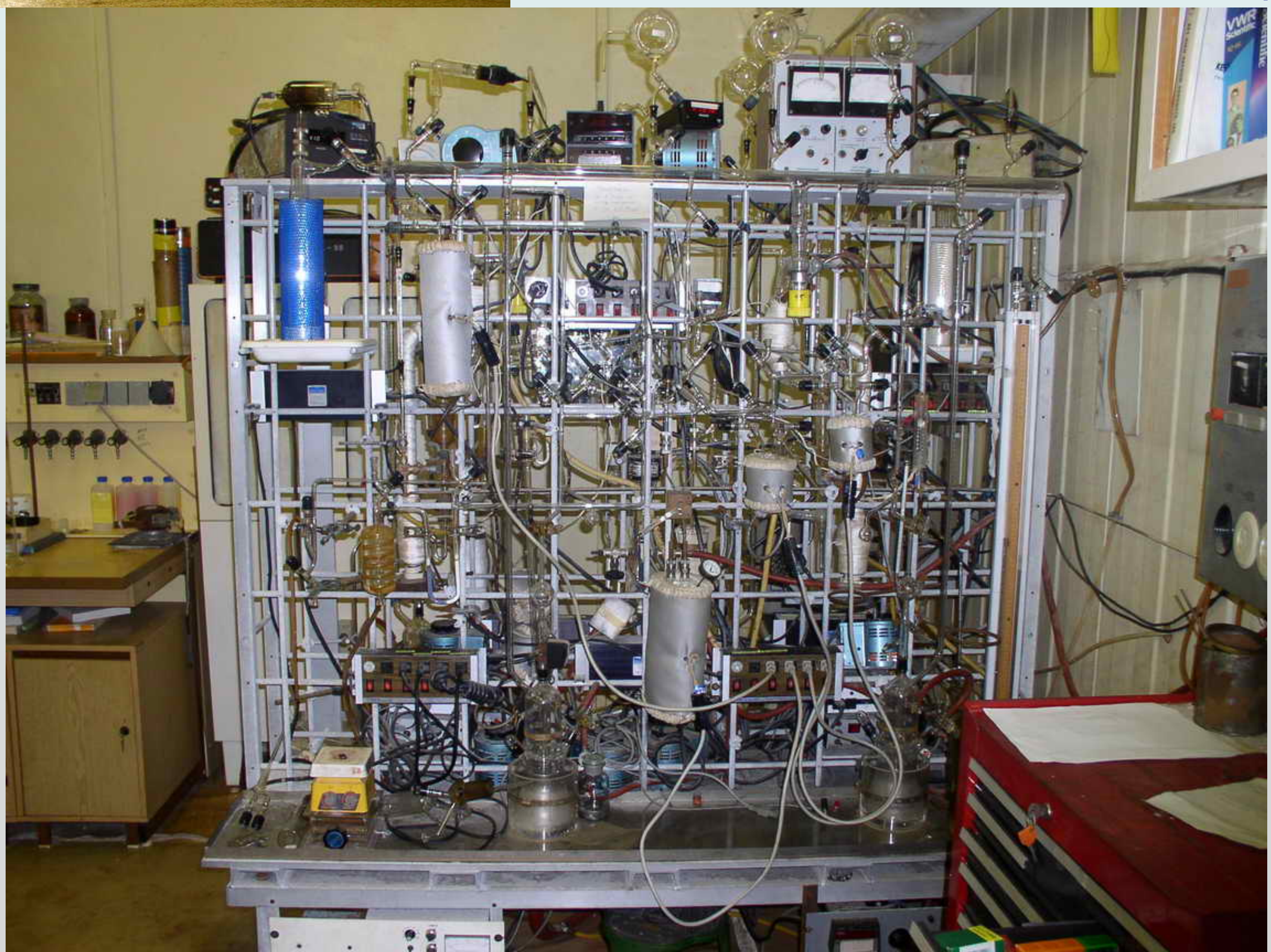


**At 14:02 Moscow time the first irradiation of the two-zone gallium target has started.**



Counter

Installation for synthesis of $GeH_4$



# Extraction schedule and related parameters

The times of exposure are given in days of year 2019

| Source exposure | | | | Extraction from cylindrical target | | Massa Ga (tons) | Extraction efficiency | | Extraction from spherical target | | Massa Ga (tons) | Extraction efficiency | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Begin | | End | | | | | | | | | | | |
| Dayyear | Mo Da Hr Mn | Dayyear | Mo Da Hr Mn | Name | Date (2019) | | from Ga | into GeH4 | Name | Date (2019) | | from Ga | into GeH4 |
| 186.59 | 07.05 14:02 | 196.376 | 07.15 09:02 | Cr1 | 15 Jul 13:59 | 40.09 | 0.97 | 0.94 | Cr11 | 15 Jul 16:01 | 7.4 | 0.98 | 0.95 |
| 197.36 | 07.16 08:41 | 206.372 | 07.25 08:56 | Cr2 | 25 Jul 13:51 | 40.09 | 0.97 | 0.95 | Cr21 | 25 Jul 16:32 | 7.4 | 0.97 | 0.95 |
| 207.28 | 07.26 06:47 | 216.374 | 08.04 08:59 | Cr3 | 04 Aug 12:47 | 40.09 | 0.98 | 0.98 | Cr31 | 04 Aug 16:37 | 7.4 | 0.97 | 0.95 |
| 217.29 | 08.05 06:52 | 226.371 | 08.14 08:54 | Cr4 | 14 Aug 12:51 | 40.09 | 0.98 | 0.96 | Cr41 | 14 Aug 15:35 | 7.4 | 0.97 | 0.94 |
| 227.26 | 08.15 06:12 | 236.458 | 08.24 11:00 | Cr5 | 24 Aug 14:35 | 40.09 | 1.00 | 0.97 | Cr51 | 24 Aug 17:17 | 7.4 | 0.99 | 0.97 |
| 237.34 | 08.25 08:13 | 246.37 | 09.03 08:51 | Cr6 | 03 Sep 12:35 | 40.09 | 1.00 | 0.96 | Cr61 | 03 Sep 15:18 | 7.4 | 1.00 | 0.98 |
| 247.24 | 09.04 05:50 | 256.368 | 09.13 08:50 | Cr7 | 13 Sep 12:29 | 40.09 | 1.00 | 0.99 | Cr71 | 13 Sep 15:11 | 7.4 | 1.00 | 0.98 |
| 257.24 | 09.14 05:47 | 266.37 | 09.23 08:52 | Cr8 | 23 Sep 12:32 | 40.09 | 1.00 | 1.00 | Cr81 | 23 Sep 15:17 | 7.4 | 1.00 | 1.00 |
| 267.24 | 09.24 05:46 | 276.369 | 10.03 08:51 | Cr9 | 03 Oct 12:27 | 40.09 | 0.95 | 0.93 | Cr91 | 03 Oct 15:00 | 7.4 | 0.97 | 0.95 |
| 277.20 | 10.04 04:49 | 286.367 | 10.13 08:48 | Cr10 | 13 Oct 12:26 | 40.09 | 0.99 | 0.96 | Cr101 | 13 Oct 14:59 | 7.4 | 0.99 | 0.95 |

10 targets irradiations:
Mean exposure time - 9.18 d;
Masses : 7.4 t and 40.09 t;
Mean extraction eff. from Ga - 98%;

**2,5 -2,9 μmol $^{72}$Ge, $^{76}$Ge**

# Counting parameters


For Outer cylindrical target — preliminary

| Counter filling | | | | | Counter efficiency | | | | Time start of counting |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | K -peak | | L -peak | | |
| Extraction name | Counter name | Pressure | GeH4 fractio | Channel | Before cuts | After cuts | Before cuts | After cuts | mo.da hr:mn |
| Cr 1 | YCN113 | 635 | 9.5 | 3.4 | 0.3959 | 0.373 | 0.3769 | 0.3551 | 07.16 15:52 |
| Cr 2 | YCT3 | 635 | 9.5 | 3.1 | 0.3955 | 0.373 | 0.377 | 0.3548 | 07.26 14:57 |
| Cr 3 | YCNA9 | 640 | 10.5 | Z.4 | 0.3959 | 0.373 | 0.377 | 0.3551 | 08.05 16:38 |
| Cr 4 | YCT9 | 635 | 9.6 | 3.6 | 0.3954 | 0.373 | 0.377 | 0.3548 | 08.15 15:27 |
| Cr 5 | YCN41 | 635 | 10.0 | Z.1 | 0.3954 | 0.373 | 0.377 | 0.3554 | 08.25 18:58 |
| Cr 6 | YCT4 | 630 | 9.0 | 3.3 | 0.3954 | 0.373 | 0.377 | 0.3555 | 09.04 14:19 |
| Cr 7 | YCN113 | 630 | 10.3 | 3.4 | 0.3942 | 0.371 | 0.3781 | 0.3562 | 09.14 14:49 |
| Cr 8 | YCT3 | 640 | 9.5 | 3.1 | 0.3964 | 0.374 | 0.3759 | 0.3542 | 09.24 15:13 |
| Cr 9 | YCNA9 | 635 | 9.9 | Z.4 | 0.3955 | 0.373 | 0.3772 | 0.3554 | 10.04 16:16 |
| Cr 10 | YCT9 | 645 | 9.5 | 3.6 | 0.3974 | 0.374 | 0.3752 | 0.3536 | 10.14 15:00 |


For Inner spherical target — preliminary

| Counter filling | | | | | Counter efficiency | | | | Time of start of counting |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | K -peak | | L -peak | | |
| Extraction name | Counter name | Pressure | GeH4 fractio | Channel | Before cuts | After cuts | Before cuts | After cuts | mo.da hr:mn |
| Cr 11 | YCT92 | 630 | 8.8 | 3.5 | 0.3615 | 0.341 | 0.3622 | 0.3413 | 07.16 15:52 |
| Cr 21 | YCT2 | 640 | 9.5 | 3.2 | 0.3968 | 0.374 | 0.376 | 0.3545 | 07.26 14:57 |
| Cr 31 | YCN43 | 650 | 9.3 | Z.3 | 0.3989 | 0.376 | 0.375 | 0.3532 | 08.05 16:38 |
| Cr 41 | YCT97 | 640 | 9.2 | 3.7 | 0.3971 | 0.374 | 0.376 | 0.3544 | 08.15 15:27 |
| Cr 51 | YCN46 | 650 | 9.5 | Z.8 | 0.3988 | 0.376 | 0.375 | 0.3533 | 08.25 18:58 |
| Cr 61 | YCN42 | 640 | 9.8 | 3.8 | 0.3966 | 0.374 | 0.377 | 0.3547 | 09.04 14:19 |
| Cr 71 | YCT92 | 640 | 9.3 | 3.5 | 0.3629 | 0.342 | 0.3612 | 0.3404 | 09.14 14:49 |
| Cr 81 | YCT2 | 645 | 9.5 | 3.2 | 0.3991 | 0.376 | 0.3768 | 0.3550 | 09.24 15:13 |
| Cr 91 | YCN43 | 640 | 9.1 | Z.3 | 0.3972 | 0.374 | 0.3760 | 0.3543 | 10.04 16:16 |
| Cr 101 | YCT97 | 650 | 9.1 | 3.7 | 0.3991 | 0.376 | 0.3747 | 0.3531 | 10.14 15:00 |


Channel name: (3 – SYS3, Z -2Z)+num. slot (1-8); HV:1080-1150V

## On December 5, 2019, the source was sent for storage to the RIAR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# The BEST stages

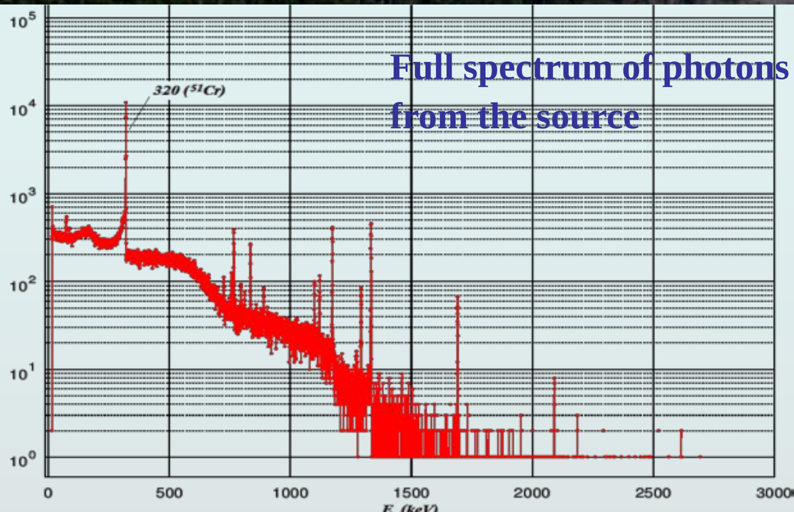
**1. Work with the $^{51}$Cr source (stage completed on October 25):**
- 10  2-zone target exposures by the source from 5 July to 23 October 2019,
- 20 extractions from 2-zone gallium targets,
- 10 calorimetric measurements to measure the source activity,
- 11 spectrometric measurements of $^{51}$Cr source gamma-ray spectrum,
- 20 syntheses and fillings of counters,
- installation of filled counters into counting systems for measurements

**2. Measurements of $^{71}$Ge decay (completion of the stage – March 2020):**
- primary data collection and processing,
- preliminary data analysis
- comparative crosscheck analysis of data by the BEST collaborators

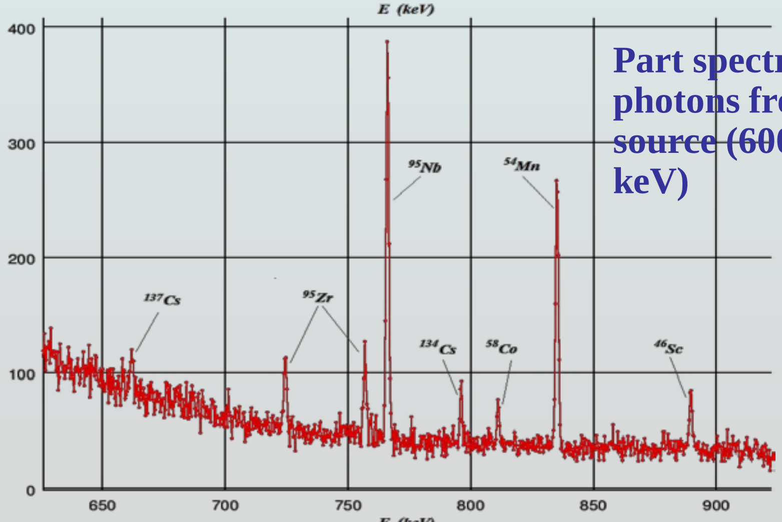
**3. Tests and checks (February-March 2020):**
- production of $^{37}$Ar, $^{71}$Ge and $^{69}$Ge isotopes
- verification of counting systems,
- measurement of the counters volumetric and peak efficiencies with using of $^{37}$Ar, $^{71}$Ge and $^{69}$Ge isotopes,
- estimation of all systematic uncertainties

**4. Interpretation and presentation of results (May 2020)**

# Gamma-ray spectroscopy




Full spectrum of photons from the source




Part spectrum of photons from the source (600-900 keV)

Measured nuclide impurities in the $^{51}$Cr source and their contribution to the source activity measurement at the reference time 14:02 on 05.07.2019

| | Isotope, $T_{1/2}$ | Energy in the line, keV | Output lines, % | $n_s$ | $n_f$ | Activity on July 5, MCi | W, mW |
|---|---|---|---|---|---|---|---|
| 1 | $^{137}$Cs, 30.05y | 662 | 85 | 229 | 1268 | 8.5×(1±0.23) | 0.06 |
| 2 | $^{95}$Zr, 64d | 724<br>757 | 11.1<br>54.38 | 356<br>334 | 768<br>748 | 60×(1±0.12) | 2.1 |
| 3 | $^{95}$Nb, 35d | 766 | 99.8 | 1313 | 682 | 87×(1±0.04) | |
| 4 | $^{134}$Cs, 2.06y | 796 | 85.5 | 217 | 626 | 3.3×(1±0.18) | 0.041 |
| 5 | $^{58}$Co, 70.85d | 811 | 99.44 | 141 | 632 | 6.0×(1±0.27) | 0.08 |
| 6 | $^{54}$Mn, 312d | 835 | 100 | 963 | 570 | 13×(1±0.05) | 0.10 |
| 7 | $^{46}$Sc, 83.8d | 889<br>1120 | 100<br>100 | 254<br>346 | 569<br>400 | 5.2×(1±0.10) | 0.07 |
| 8 | $^{59}$Fe, 44.5d | 1099<br>1291 | 57<br>43.2 | 403<br>383 | 401<br>97 | 23×(1±0.07) | 0.22 |
| 9 | $^{60}$Co, 5.27y | 1173<br>1332 | 100<br>100 | 1863<br>2300 | 286<br>85 | 6.6×(1±0.03) | 0.11 |
| 10 | $^{124}$Sb, 60.2d | 1690<br>2091 | 47.5<br>5.5 | 341<br>49 | 16<br>3 | 5.8×(1±0.06) | 0.10 |
| 11 | $^{154}$Eu (?), 8.6y | 1274<br>1595 | 34.9<br>1.8 | 88<br>13 | 114<br>13 | 0.86×(1±0.18) | 0.010 |
| Σ | | | | | | | **2.9** |

(V.V. Gorbachev, Poster session at XXXV International Conference on Equations on State for Matter, *Elbrus, KBR, March 1-6, 2020)*

From 11 spectrometric measurements of gamma radiation of the source was obtained:

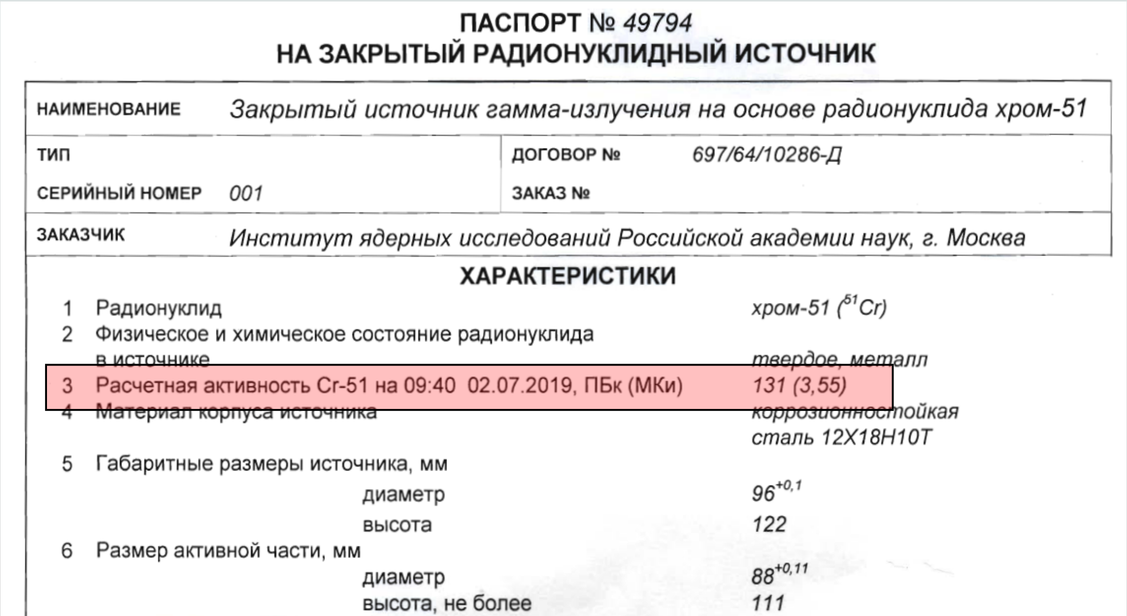
- the total amount of heat release from impurity radionuclides is **2.9 ± 0.5 mW** , which is ~ $4 \cdot 10^{-6}$ of the initial $^{51}$Cr source power, and can be neglected;
- confirmation of a high purity of the material used to produce the $^{51}$Cr source



## Source power measurements with the calorimeter system. (afternoon talk Yu. Kozlova)

**The source activity was measured by its heat release in the calorimetric system.**
**10 measurements of the $^{51}$Cr neutrino source activity were done.**
**The obtained value of the neutrino source activity on 05.07.2019 at 14:02 is**
**3.4099 ± 0.008 MCi (total uncertainty includes the uncertainties of heat release (0.015%) and energy release (0.23%) added in quadrature).**
(Using a conversion factor of 217.857 W/MCi $^{51}$Cr the heat power of the $^{51}$Cr source was **742.87 W** on July 5, 2019)
**For the first time, an artificial neutrino source of such high intensity was produced and for the first time so high accuracy in measuring such high activity was achieved.**

According to the passport from RIAR an estimated source activity was **3.55 MCi** on July 2, 2019 at 09:40 (*which corresponds **3.28 MCi** at the delivered time to BNO on July 5, 2019)*

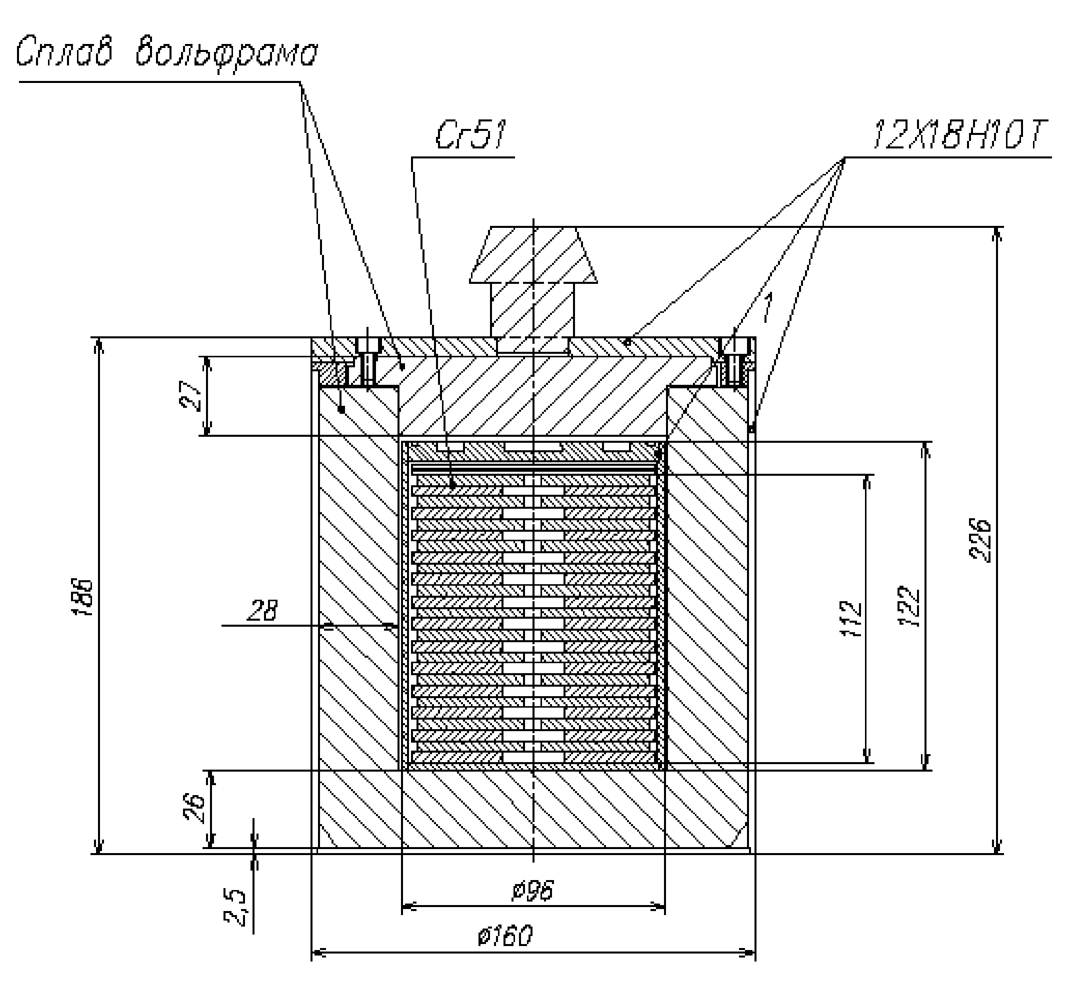


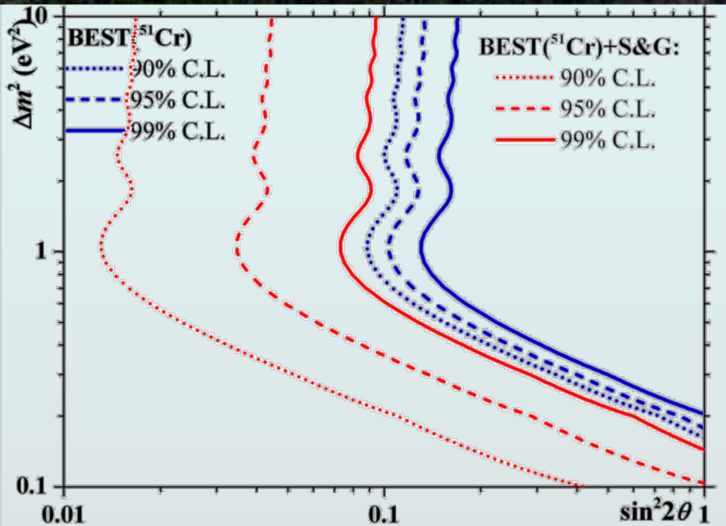
ПАСПОРТ № 49794
НА ЗАКРЫТЫЙ РАДИОНУКЛИДНЫЙ ИСТОЧНИК

| | | | |
|---|---|---|---|
| НАИМЕНОВАНИЕ | Закрытый источник гамма-излучения на основе радионуклида хром-51 | | |
| ТИП | | ДОГОВОР № | 697/64/10286-Д |
| СЕРИЙНЫЙ НОМЕР | 001 | ЗАКАЗ № | |
| ЗАКАЗЧИК | Институт ядерных исследований Российской академии наук, г. Москва | | |

ХАРАКТЕРИСТИКИ

| | | |
|---|---|---|
| 1 | Радионуклид | хром-51 ($^{51}$Cr) |
| 2 | Физическое и химическое состояние радионуклида в источнике | твердое, металл |
| 3 | Расчетная активность Cr-51 на 09:40 02.07.2019, ПБк (МКи) | 131 (3,55) |
| 4 | Материал корпуса источника | коррозионностойкая сталь 12Х18Н10Т |
| 5 | Габаритные размеры источника, мм | |
| | диаметр | $96^{+0,1}$ |
| | высота | 122 |
| 6 | Размер активной части, мм | |
| | диаметр | $88^{+0,11}$ |
| | высота, не более | 111 |


Сплав вольфрама
Cr51
12Х18Н10Т
1
27
186
28
26
2,5
ø96
ø160
112
122
226




The region in $\Delta m^2$ - $\sin^2(2\theta)$ space to which BEST($^{51}$Cr) will be sensitive

The region in $\Delta m^2$ - $\sin^2(2\theta)$ space to which BEST($^{51}$Cr) experiment combined with 4 Ga source experiments will be sensitive

# BEST ($^{51}$Cr) 3.4 MCi source

## Statistics of the experiment

Expected ν capture rates from the source in each zone in the absence of oscillation for 10 exposures from 3.4 MCi source :

| № | Source exposure (day) | | | Decay factor | Production rate at the End (at/day) | Total number of the captures (atoms) | Production rate at the End (at/day ) | Total number of the captures (atoms) |
|---|---|---|---|---|---|---|---|---|
| | Begin | End | Duration | | in Outer target | | in Inner target | |
| 1 | 186.59 | 196.38 | 9.79 | 1.0000 | 73.0 | 472.3 | 70.0 | 452.9 |
| 2 | 197.36 | 206.37 | 9.01 | 0.7636 | 55.7 | 342.9 | 53.5 | 328.8 |
| 3 | 207.28 | 216.37 | 9.09 | 0.5958 | 43.5 | 269.0 | 41.7 | 258.0 |
| 4 | 217.29 | 226.37 | 9.09 | 0.4638 | 33.9 | 209.4 | 32.5 | 200.8 |
| 5 | 227.26 | 236.46 | 9.20 | 0.3614 | 26.4 | 164.4 | 25.3 | 157.6 |
| 6 | 237.34 | 246.37 | 9.03 | 0.2808 | 20.5 | 126.2 | 19.7 | 121.1 |
| 7 | 247.24 | 256.37 | 9.13 | 0.2192 | 16.0 | 99.2 | 15.3 | 95.1 |
| 8 | 257.24 | 266.37 | 9.13 | 0.1707 | 12.5 | 77.3 | 11.9 | 74.1 |
| 9 | 267.24 | 276.37 | 9.13 | 0.1329 | 9.7 | 60.2 | 9.3 | 57.7 |
| 10 | 277.20 | 286.37 | 9.17 | 0.1036 | 7.6 | 47.0 | 7.2 | 45.1 |

$^{51}$Cr ~3.4 MCi source, expected production rate $^{71}$Ge at the start of the first exposure:
70 (inner) and 73(outer) at/d

> Total number of the captures in zones (outer,inner) ≈ 1870, 1790

> Total number of $^{71}$Ge pulses in zones (outer,inner) ~ 934, 896

**Production rate from solar ν :** [~0.0197 atoms $^{71}$Ge/(day – 1 tonne Ga)]
1.18 at. $^{71}$Ge in 8 tonne of Ga,
6.20 at. $^{71}$Ge in 42 tonne of Ga

> Statistical uncertainty: ±3.7% in 1 zone
> Total systematic uncertainty : ±2.6% (preliminary)

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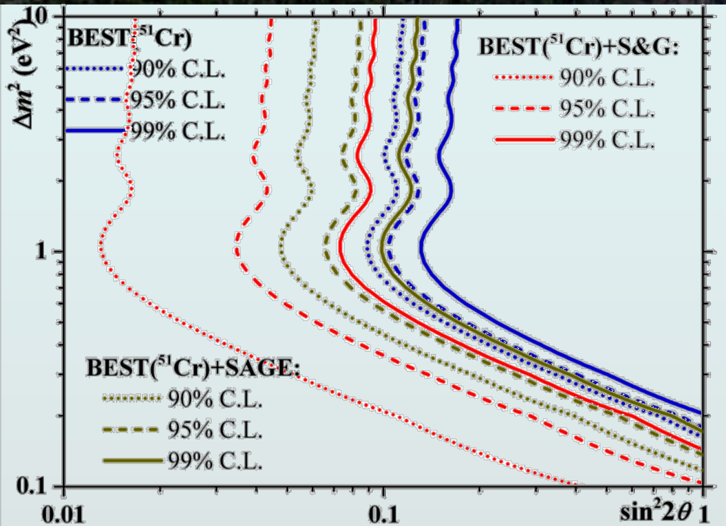
# BEST ($^{51}$Cr) 3.4 MCi source

## Statistics of the experiment




The region in $\Delta m^2$ - $\sin^2(2\theta)$ space to which BEST($^{51}$Cr) will be sensitive

The region in $\Delta m^2$ - $\sin^2(2\theta)$ space to which BEST($^{51}$Cr) experiment combined with SAGE source experiments will be sensitive

The region in $\Delta m^2$ - $\sin^2(2\theta)$ space to which BEST($^{51}$Cr) experiment combined with 4Ga source experiments will be sensitive

**Expected ν capture rates from the source in each zone in the absence of oscillation for 10 exposures from 3.4 MCi source :**

| № | Source exposure (day) Begin | End | Duration | Decay factor | Production rate at the End (at/day), in Outer target | Total number of the captures (atoms), in Outer target | Production rate at the End (at/day), in Inner target | Total number of the captures (atoms), in Inner target |
|---|---|---|---|---|---|---|---|---|
| 1 | 186.59 | 196.38 | 9.79 | 1.0000 | 73.0 | 472.3 | 70.0 | 452.9 |
| 2 | 197.36 | 206.37 | 9.01 | 0.7636 | 55.7 | 342.9 | 53.5 | 328.8 |
| 3 | 207.28 | 216.37 | 9.09 | 0.5958 | 43.5 | 269.0 | 41.7 | 258.0 |
| 4 | 217.29 | 226.37 | 9.09 | 0.4638 | 33.9 | 209.4 | 32.5 | 200.8 |
| 5 | 227.26 | 236.46 | 9.20 | 0.3614 | 26.4 | 164.4 | 25.3 | 157.6 |
| 6 | 237.34 | 246.37 | 9.03 | 0.2808 | 20.5 | 126.2 | 19.7 | 121.1 |
| 7 | 247.24 | 256.37 | 9.13 | 0.2192 | 16.0 | 99.2 | 15.3 | 95.1 |
| 8 | 257.24 | 266.37 | 9.13 | 0.1707 | 12.5 | 77.3 | 11.9 | 74.1 |
| 9 | 267.24 | 276.37 | 9.13 | 0.1329 | 9.7 | 60.2 | 9.3 | 57.7 |
| 10 | 277.20 | 286.37 | 9.17 | 0.1036 | 7.6 | 47.0 | 7.2 | 45.1 |

> Total number of the captures in zones (outer,inner) ~ 1870, 1790

> Total number of $^{71}$Ge pulses in zones (outer,inner) ~ 934, 896

**Production rate from solar ν :** [~0.0197 atoms $^{71}$Ge/(day – 1 tonne Ga)]

1.18 at. $^{71}$Ge in 8 tonne of Ga,

6.20 at. $^{71}$Ge in 42 tonne of Ga

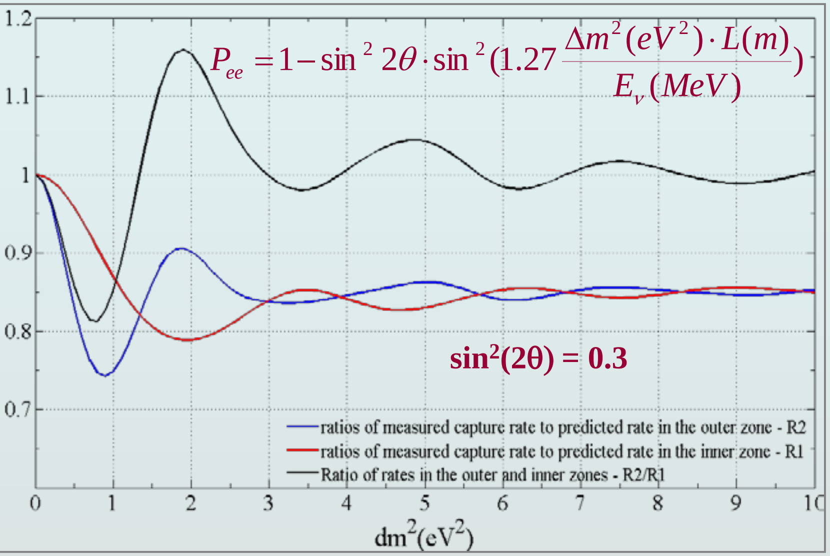
> Statistical uncertainty: ±3.7% in 1 zone

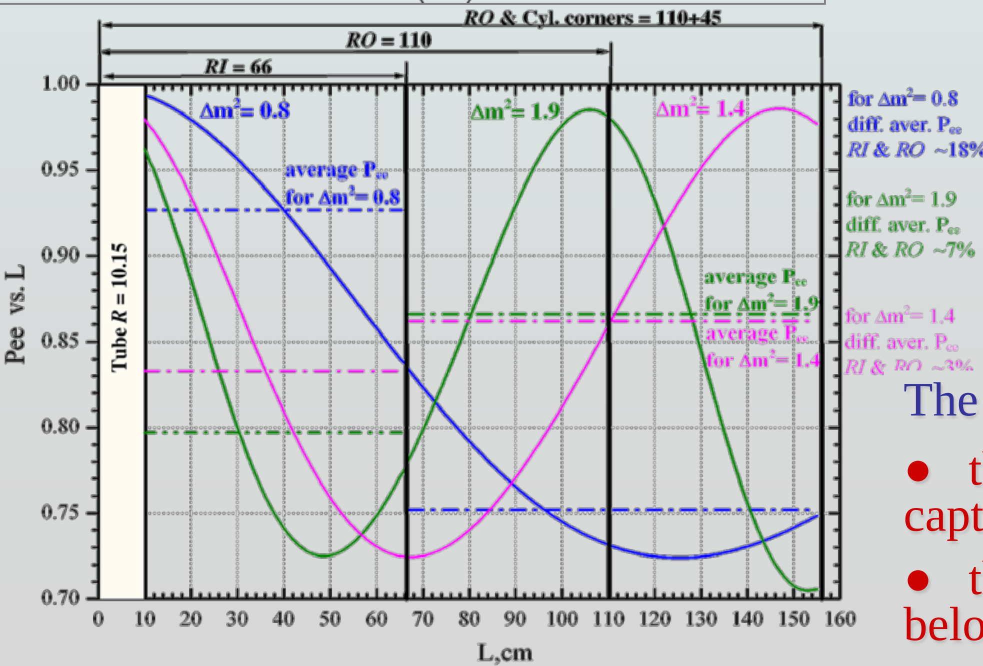
> Total systematic uncertainty : ±2.6% (preliminary)

$^{51}$Cr ~3.4 MCi source, expected production rate $^{71}$Ge at the start of the first exposure:

70 (inner) and 73(outer) at/d

# Main features of the BEST




- A Search for Electron Neutrino disappearance via charged-current (CC) reaction only:
  $\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^-$
- Monochromatic spectrum of compact source – observation of the pure sinusoid of oscillation transitions:
  $$P_{ee} = 1 - \sin^2 2\theta \cdot \sin^2(1.27 \frac{\Delta m^2(eV^2) \cdot L(m)}{E_\nu(MeV)})$$
- Precisely known intensity of the source.
- Possibility to study the dependence of the rate on the distance to the source.
  Average path length in each zone: <L> = 53 & 55 cm
- Very Short Baseline.
- Almost zero background. Mainly from the Sun.
- Very well known experimental procedures developed in SAGE.
- Simple interpretation of results.

The evidence of nonstandard neutrino properties:

- there is a significant difference between the capture rates in the two zones
- the average rate in both zones is considerably below the expected rate

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# Summary

● The BEST experiment - first direct search for neutrino oscillations into 4-th flavor with radioactive source has started 5 July 2019 in BNO INR RAS

● The first stage of BEST is finished and the second stage is nearing completion. Currently preparatory works have begun for the implementation of the third final one.

● Spectrometric measurements of gamma radiation of the source shown a high purity of the material used to production the $^{51}Cr$ source and therefore a negligible contributions (~ $10^{-6}$) from impurity radio nuclides to the calorimetric source activity measurements

● Obtained a precise value of the source activity from the calorimetric measurements which is **3.4099 ± 0.008 MCi on 05.07.2019 at 14:02**

For the first time in the world, an artificial neutrino source of such high intensity was produced and for the first time so high accuracy in measuring such high activity was achieved.

● $^{51}Cr$ results expected in June 2020

**Thanks to Rosatom**

The authors express their sincere gratitude for the comprehensive support and fruitful cooperation in the implementation of the BEST experiment to:

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Deputy Director General for Innovation Management at “Rosatom” **Yu.A. Olenin,**

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Director of JSC “SSC RIAR” **A.A. Tuzov,**

and General Director of Electrochemical Plant JSC **S.V. Filimonov.**

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# Thank you for your attention

# BACKUP SLIEDS

## Reassessment of the gallium anomaly

arXiv:1906.10980v1 26 Jun 2019

Table 5: Gallium cross sections (in units of $10^{-45}$ cm$^2$) for $^{51}$Cr and $^{37}$Ar neutrinos and their ratios with the central value of the corresponding Bahcall cross section [35] in the first line. The other lines give the cross sections corresponding to the BGT's of Haxton [8, 9], Frekers et al. [5, 9], and the JUN45 calculation presented in this paper.

| | $\sigma^{^{51}\mathrm{Cr}}$ | $\sigma^{^{51}\mathrm{Cr}}/\sigma_{\mathrm{B}}^{^{51}\mathrm{Cr}}$ | $\sigma^{^{37}\mathrm{Ar}}$ | $\sigma^{^{37}\mathrm{Ar}}/\sigma_{\mathrm{B}}^{^{37}\mathrm{Ar}}$ |
|---|---|---|---|---|
| Bahcall | $5.81 \pm 0.16$ | | $7.00 \pm 0.21$ | |
| Haxton | $6.39 \pm 0.65$ | $1.100 \pm 0.112$ | $7.72 \pm 0.81$ | $1.103 \pm 0.116$ |
| Frekers | $5.92 \pm 0.11$ | $1.019 \pm 0.019$ | $7.15 \pm 0.14$ | $1.021 \pm 0.020$ |
| JUN45 | $5.67 \pm 0.06$ | $0.976 \pm 0.011$ | $6.80 \pm 0.08$ | $0.971 \pm 0.011$ |

The new theoretical estimates for $^{51}$Cr and $^{37}$Ar cross sections are $6.80 \pm 0.12 \cdot 10^{45}$ cm$^2$ and $5.67 \pm 0.10 \cdot 10^{45}$ cm$^2$ respectively which are 2.5-3.0% lower than the Bahcall predictions

Table 7: Ratios of measured and expected $^{71}$Ge event rates in the four radioactive source experiments, their correlated average, and the statistical significance of the gallium anomaly obtained with the cross sections in Table 5.

| | GALLEX-1 | GALLEX-2 | SAGE-1 | SAGE-2 | Average | Anomaly |
|---|---|---|---|---|---|---|
| $R_{\mathrm{Bahcall}}$ | $0.95 \pm 0.11$ | $0.81 \pm 0.11$ | $0.95 \pm 0.12$ | $0.79 \pm 0.08$ | $0.85 \pm 0.06$ | $2.6\sigma$ |
| $R_{\mathrm{Haxton}}$ | $0.86 \pm 0.13$ | $0.74 \pm 0.12$ | $0.86 \pm 0.14$ | $0.72 \pm 0.10$ | $0.76 \pm 0.10$ | $2.5\sigma$ |
| $R_{\mathrm{Frekers}}$ | $0.93 \pm 0.11$ | $0.79 \pm 0.11$ | $0.93 \pm 0.12$ | $0.77 \pm 0.08$ | $0.84 \pm 0.05$ | $3.0\sigma$ |
| $R_{\mathrm{JUN45}}$ | $0.97 \pm 0.11$ | $0.83 \pm 0.11$ | $0.97 \pm 0.12$ | $0.81 \pm 0.08$ | $0.88 \pm 0.05$ | $2.3\sigma$ |

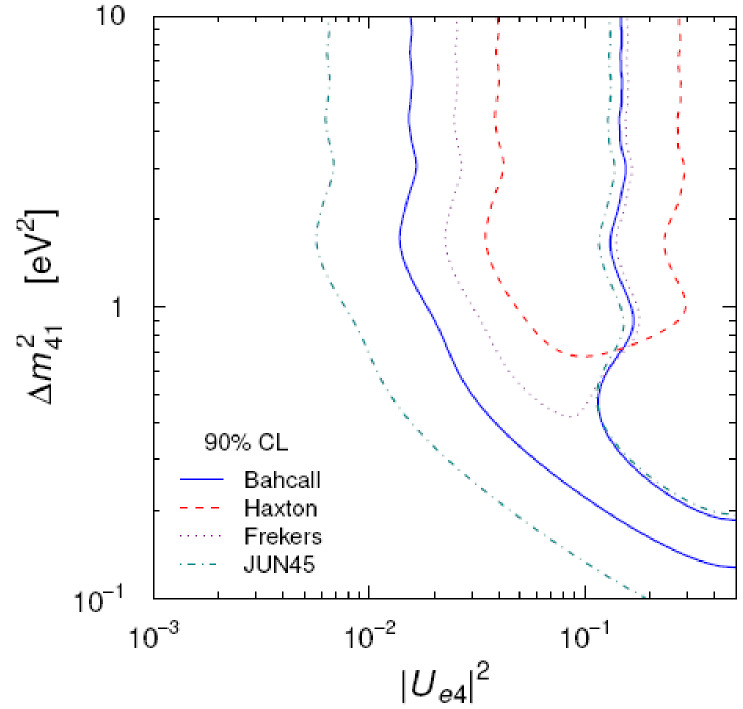



Figure 3: Comparison of the 90% allowed regions in the $|U_{e4}|^2$–$\Delta m^2_{41}$ plane obtained with the cross sections in Table 5. The Bahcall and JUN45 allowed regions are between the two corresponding curves. The Haxton and Frekers allowed regions are enclosed by the corresponding curves, without an upper limit on $\Delta m^2_{41}$.

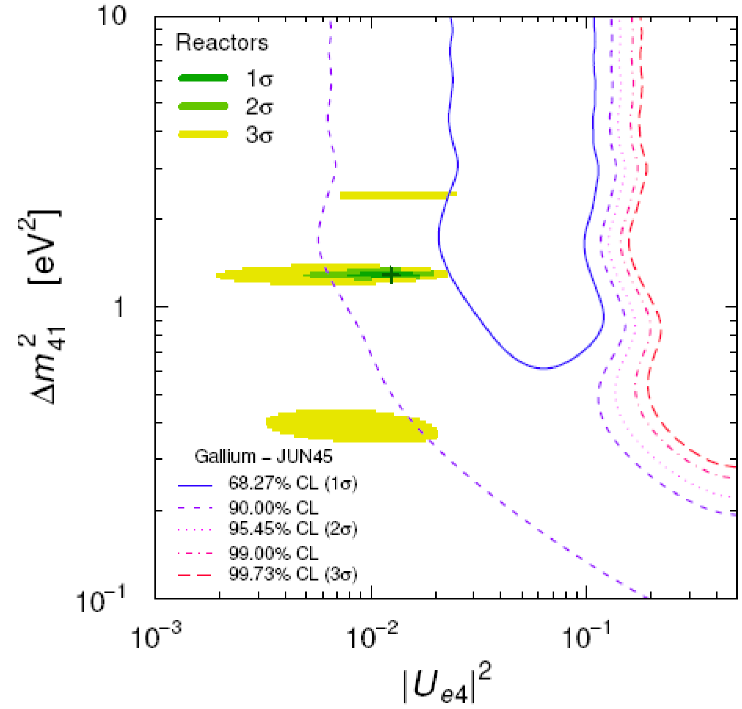
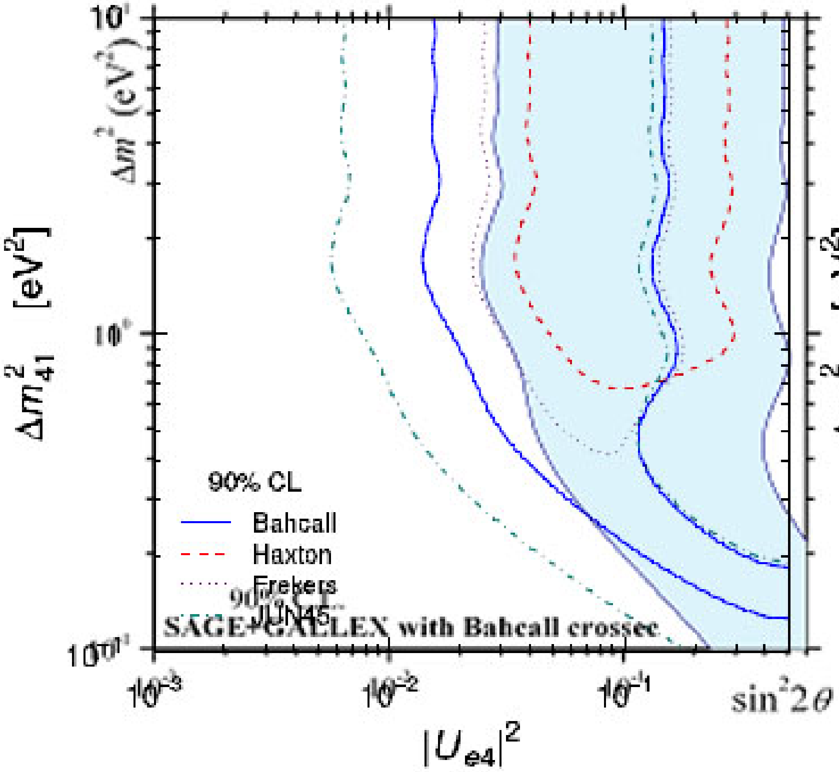



Figure 4: Comparison of the allowed regions in the $|U_{e4}|^2$–$\Delta m^2_{41}$ plane obtained from the Gallium data with the JUN45 cross sections and the allowed regions obtained from the analysis of the data of the NEOS, DANSS and PROSPECT reactor experiments.

"According to JUN45 shell-model calculation of the cross sections of the interaction of $\nu_e$'s produced by $^{51}$Cr and $^{37}$Ar radioactive sources with $^{71}$Ga, the gallium anomaly related to the GALLEX and SAGE experiments is weaker than that obtained in previous evaluations, decreasing the signicance from 3.0 to 2.3.

Our result is compatible with the recent indication in favor of short-baseline $\nu_e$ disappearance due to small active-sterile neutrino mixing obtained from the combined analysis of the data of the NEOS and DANSS reactor experiments."



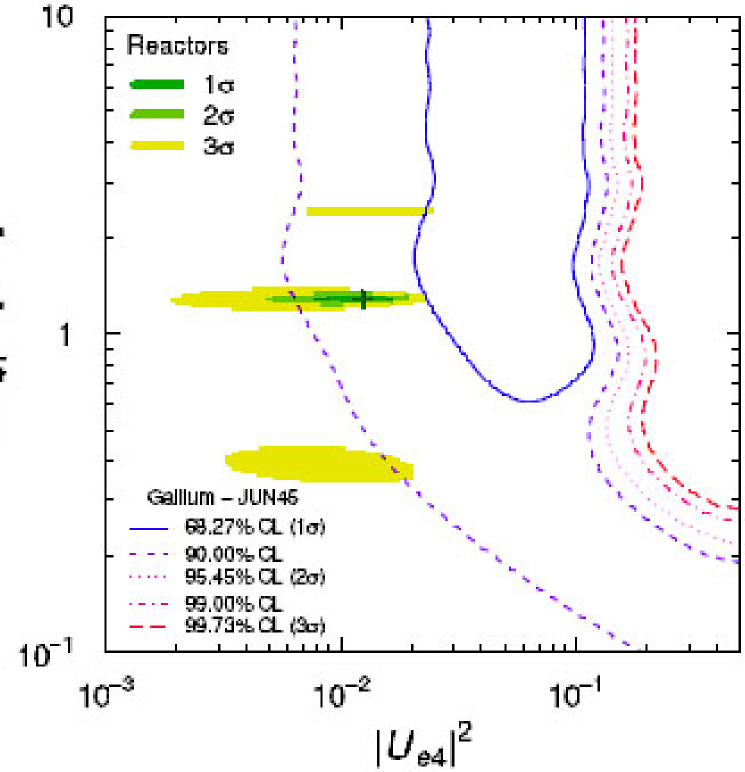




Figure 3: Comparison of the 90% allowed regions in the $|U_{e4}|^2$–$\Delta m^2_{41}$ plane obtained with the cross sections in Table 5. The Bahcall and JUN45 allowed regions are between the two corresponding curves. The Haxton and Frekers allowed regions are enclosed by the corresponding curves, without an upper limit on $\Delta m^2_{41}$.

Figure 4: Comparison of t
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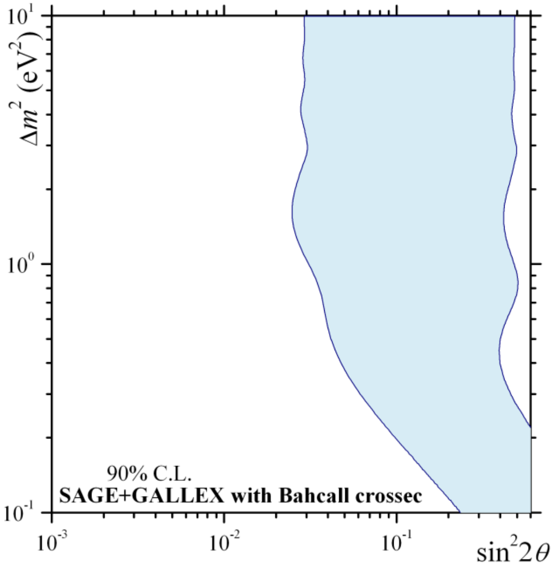
PROSPECT reactor experime

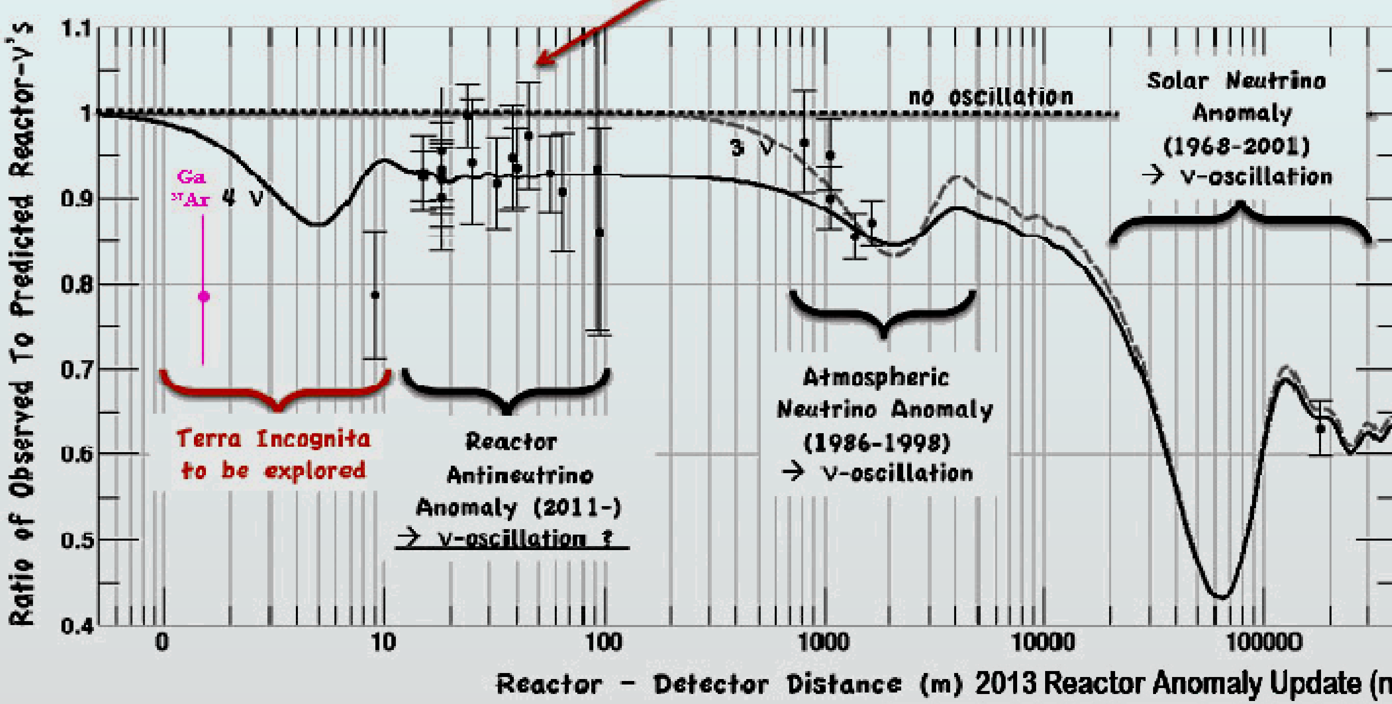



**There are some differ in the presented 90%CL Bahcall regions from our previous presented contur**

# Reactor Antineutrino Anomaly

Th. Lasserre – TAUP 2013

- Observed/predicted averaged event ratio: R=0.927±0.023 (3.0 σ)




2013 Reactor Anomaly Update (new)