Status and Perspective of the GERDA Neutrinoless Double Beta Decay Experiment

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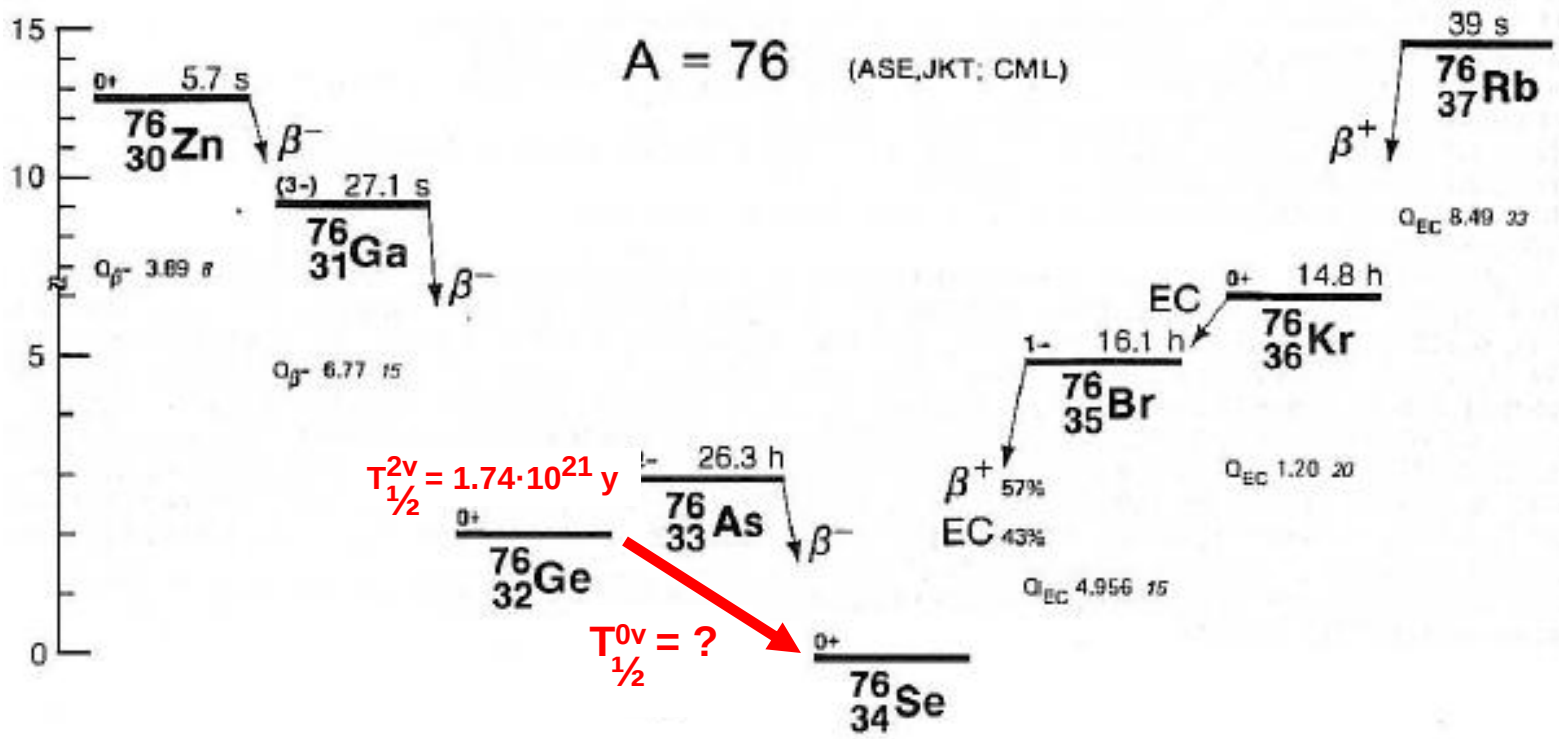
on behalf of the GERDA collaboration
http://www.mpi-hd.mpg.de/GERDA



The 19 th Particles and Nuclei International Conference (PANIC11)
Massachusetts Institute of Technology, Cambridge, July 24th – 29th, 2011

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About 100 members, 19 institutions, 7 countries

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Introduction

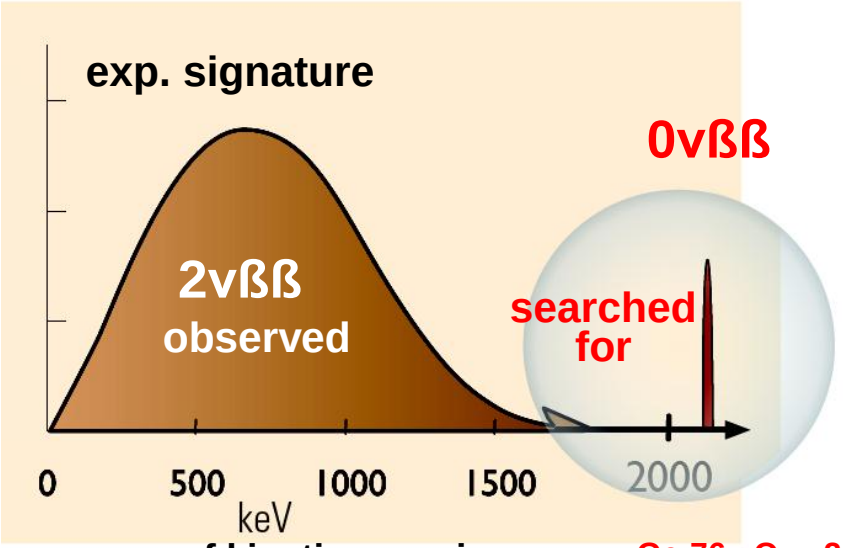
Construction and Status

Results from Commissioning Runs

Perspectives and Conclusion

Discovery of neutrinoless double beta decay would imply:

- Neutrino is its own anti-particle, has Majorana mass
- Access to absolute neutrino mass scale
- Lepton number violation ΔL = 2
- Further new physics beyond the standard model



sum of kinetic energies

Ge-76 : $Q_{\beta\beta}$=2039 keV

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2\,\langle m_{ee}\rangle^2$$

measured

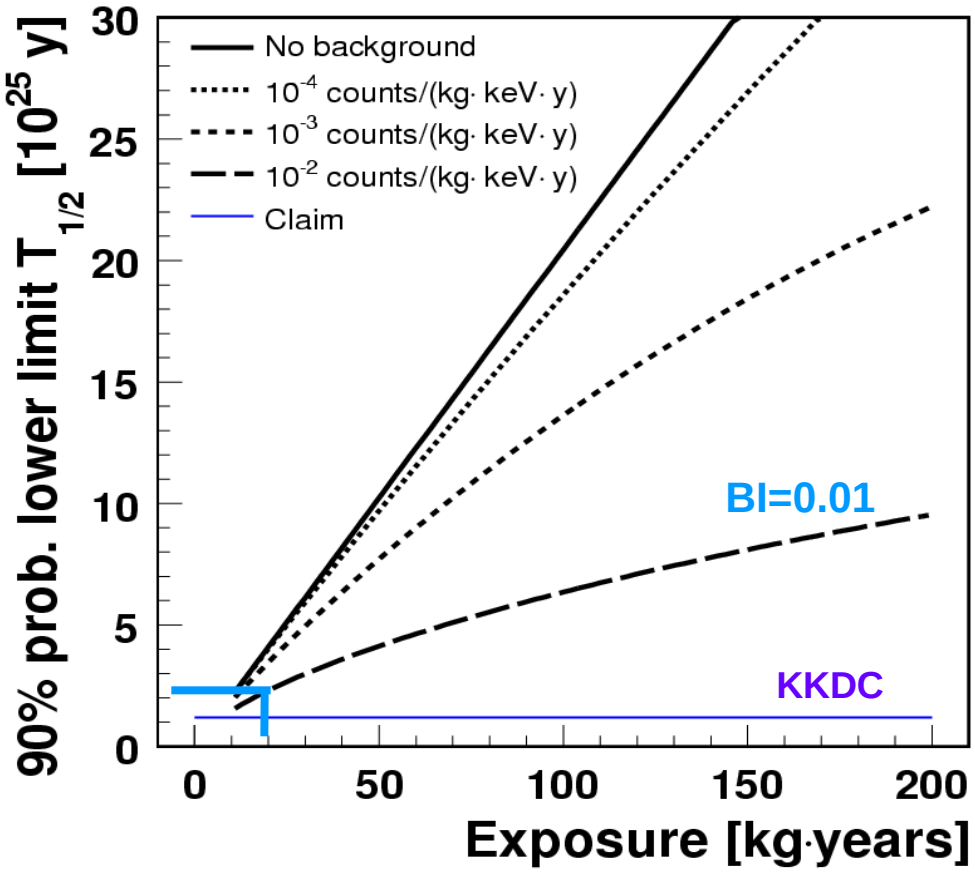
phase space

nuclear matrix element

deduced

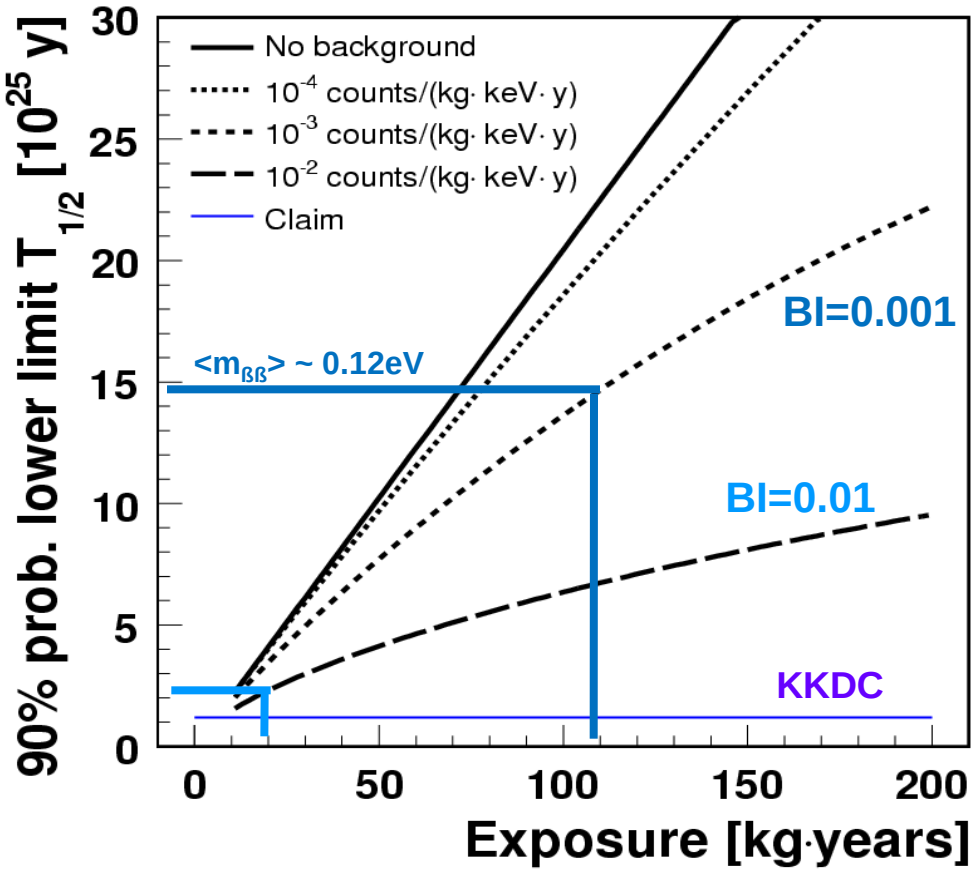
So far, best limits for neutrinoless double beta decay from Ge-76 experiments, IGEX and Heidelberg-Moscow (HdM), $T_{1/2} > 1.9 \cdot 10^{25}$ y at 90% confidence limit,
as well as claim for evidence by part of HdM collaboration KKDC, PL B586 (04) 198 (71.7 kg·y, BI ~ 0.11 cts/(keV·kg·y)

Reach background index (BI) at $Q_{\beta\beta}$ = 2039 keV of 0.01 / 0.001 cts / (keV·kg·y)



phase I :
use Ge-76 diodes of HD-Moscow & IGEX
~18 kg
BI ~ 0.01 cts / (keV·kg·y)
intrinsic background expected

Reach background index (BI) at $Q_{\beta\beta}$ = 2039 keV of 0.01 / 0.001 cts / (keV·kg·y)

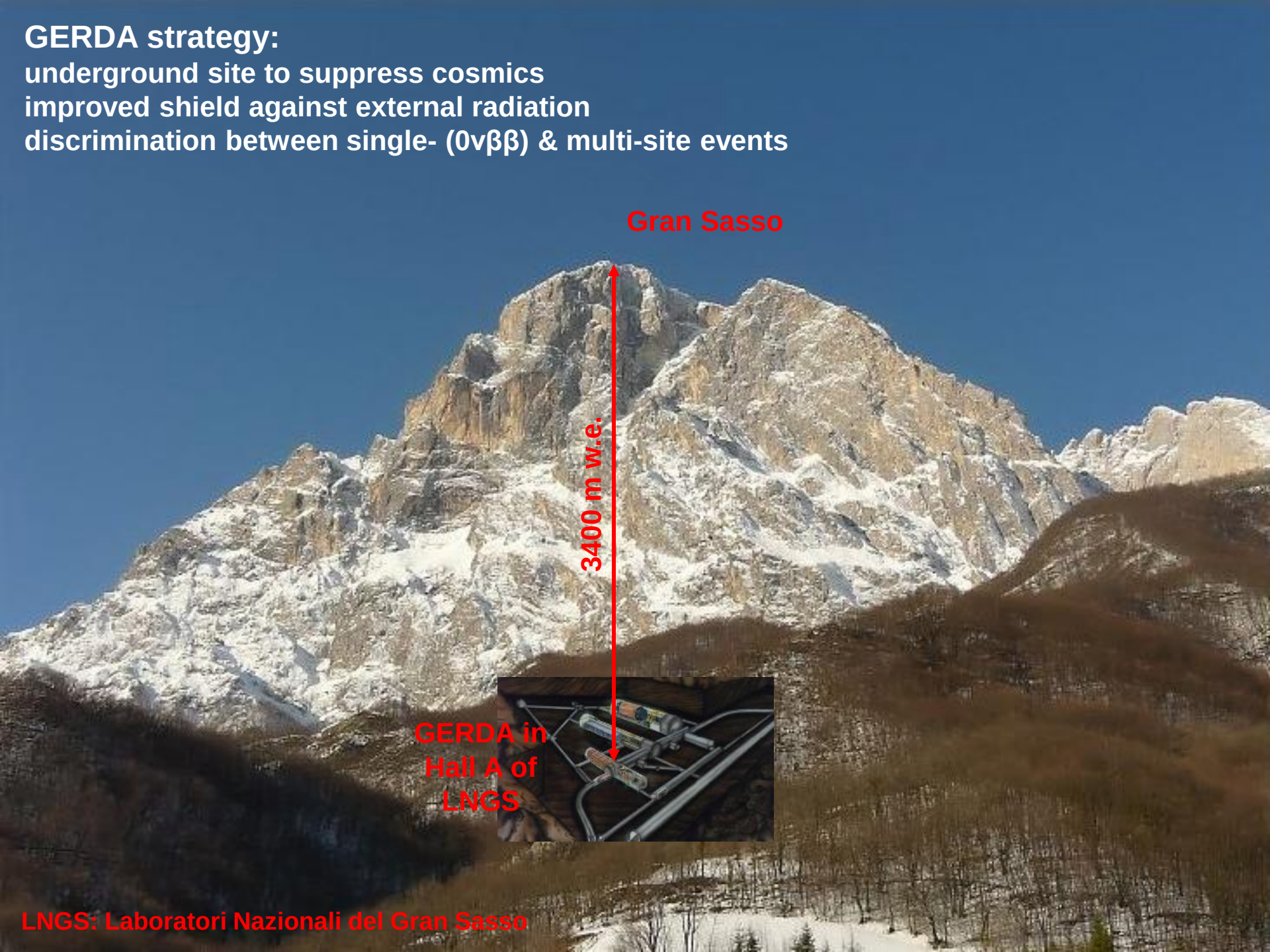


phase II :
add new enriched Ge-76 detectors, 20 kg
BI ~ 0.001 cts / (keV·kg·y)
► 37.5 kg enriched Ge-76 bought
35 kg · 3 y exposure

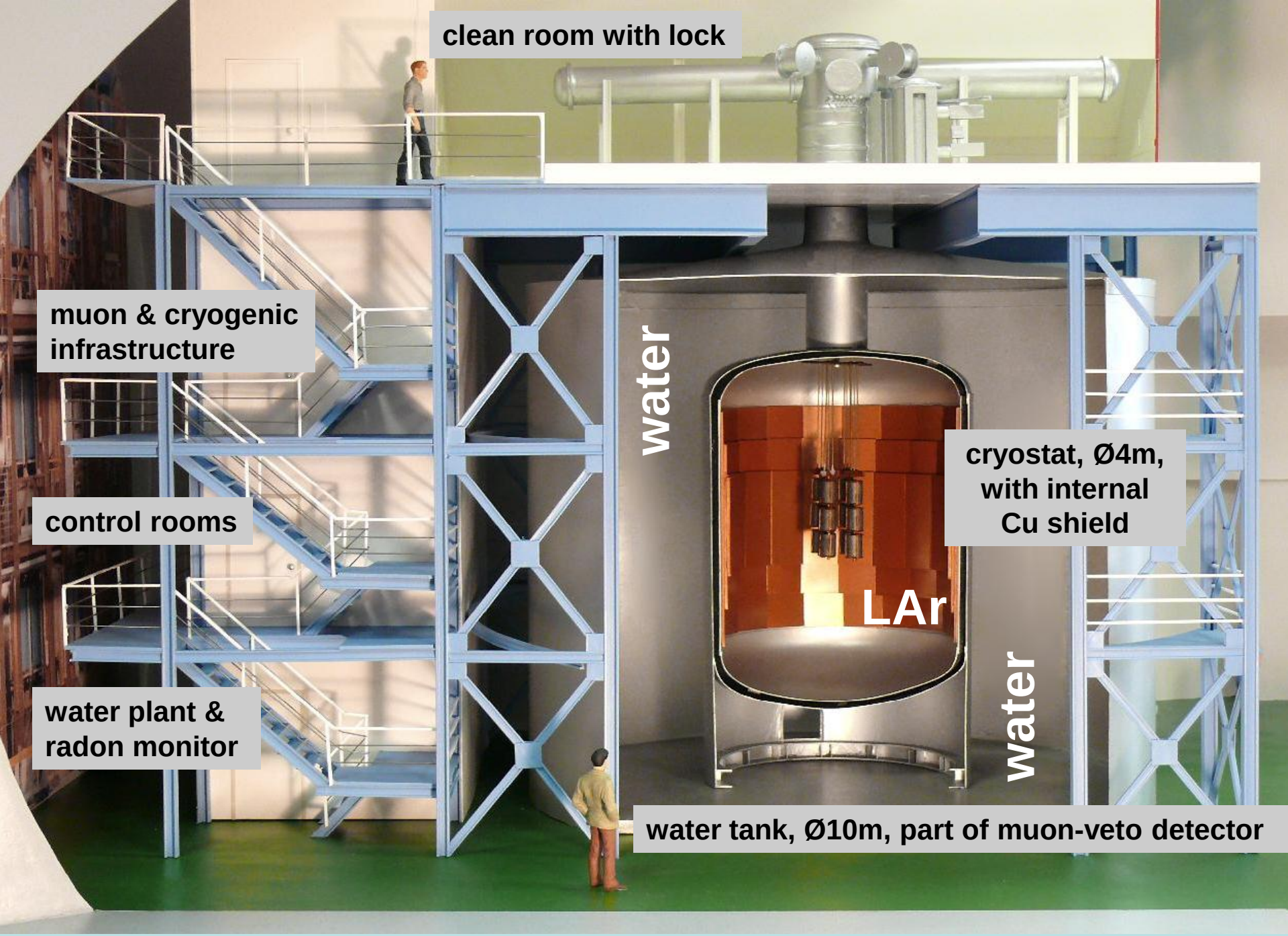
phase I :
use Ge-76 diodes of HD-Moscow & IGEX
~18 kg
BI ~ 0.01 cts / (keV·kg·y)
intrinsic background expected

phase III: depending on results worldwide collaboration for real big experiment
close contacts & MoU with MAJORANA collaboration

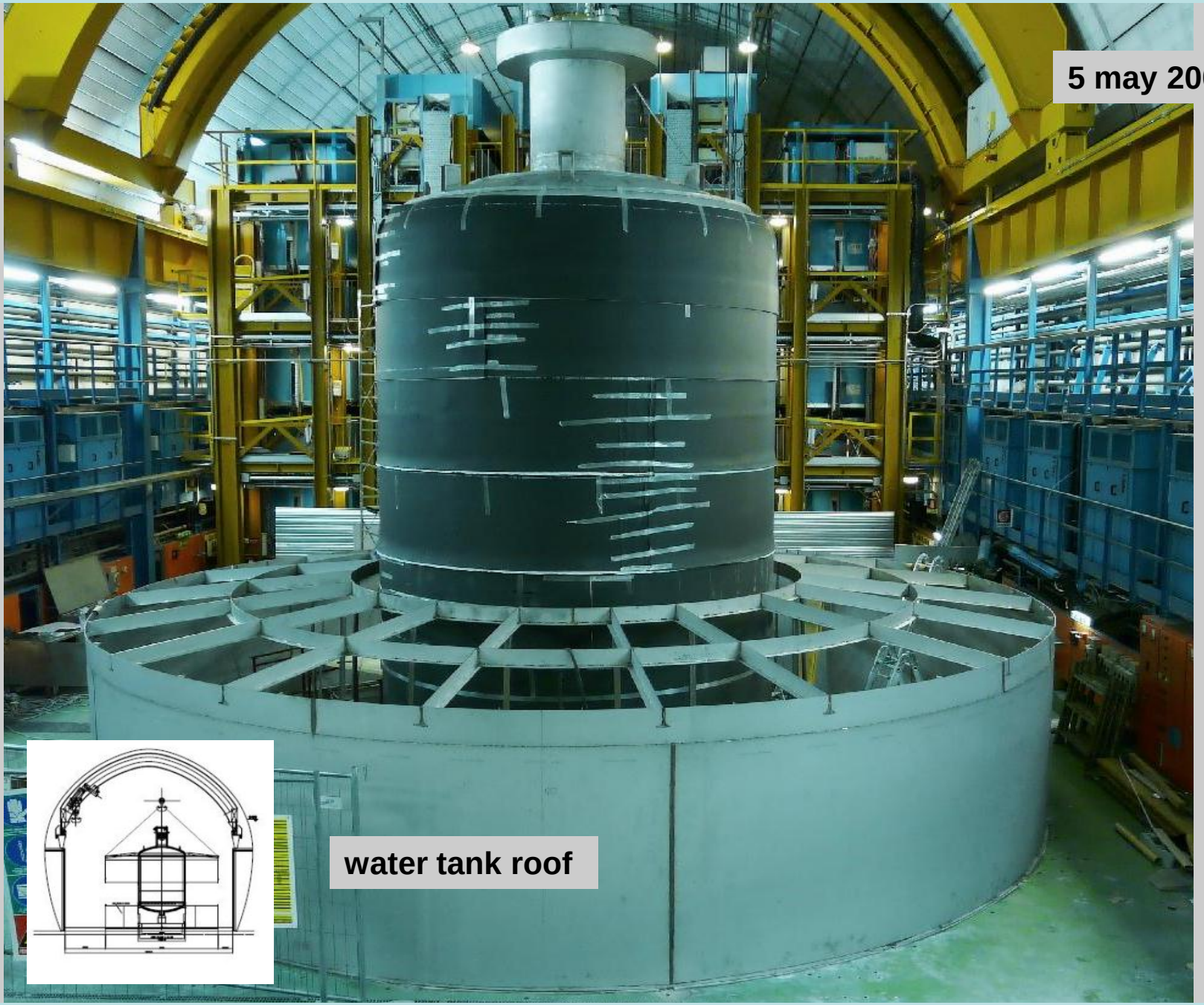
GERDA strategy:
underground site to suppress cosmics
improved shield against external radiation
discrimination between single- (0νββ) & multi-site events



LNGS: Laboratori Nazionali del Gran Sasso

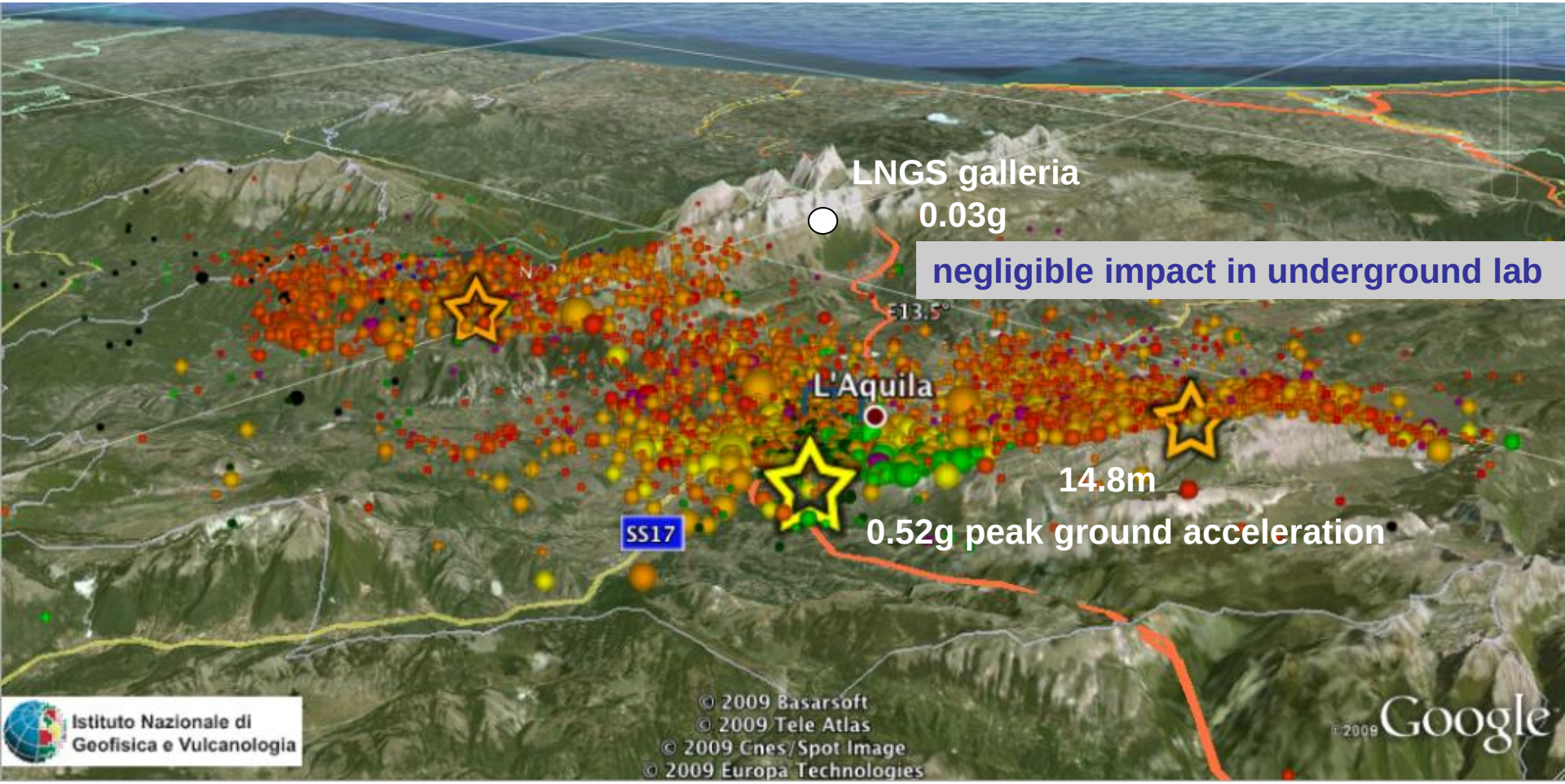

clean room with lock
muon & cryogenic infrastructure
control rooms
water plant & radon monitor
water
cryostat, Ø4m, with internal Cu shield
LAr
water
water tank, Ø10m, part of muon-veto detector

delivery of cryostat


5 may 2008
water tank roof


29 feb 2009

6 April 2009


LNGS galleria
0.03g
negligible impact in underground lab
L'Aquila
14.8m
0.52g peak ground acceleration
SS17
Istituto Nazionale di Geofisica e Vulcanologia
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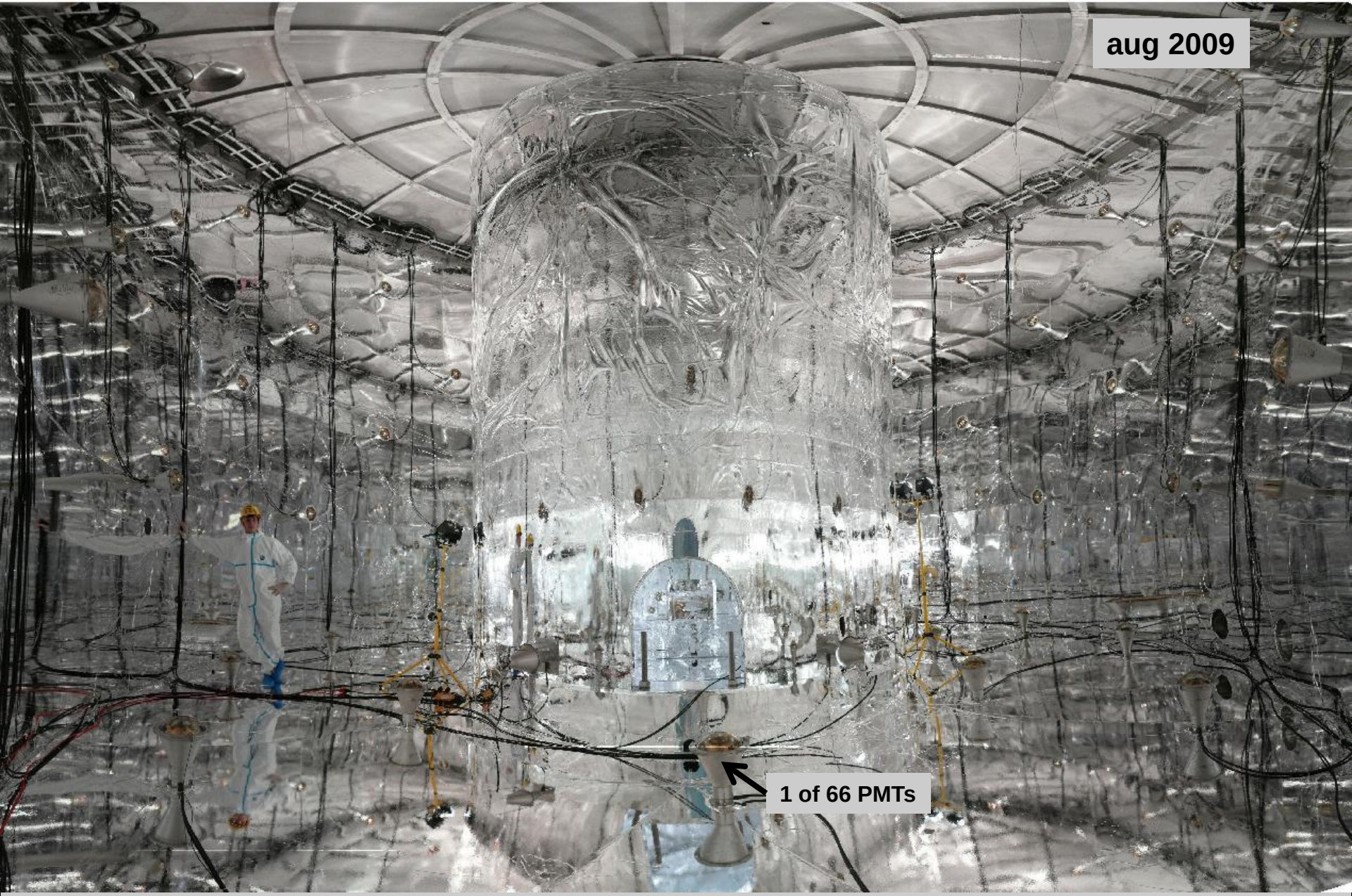
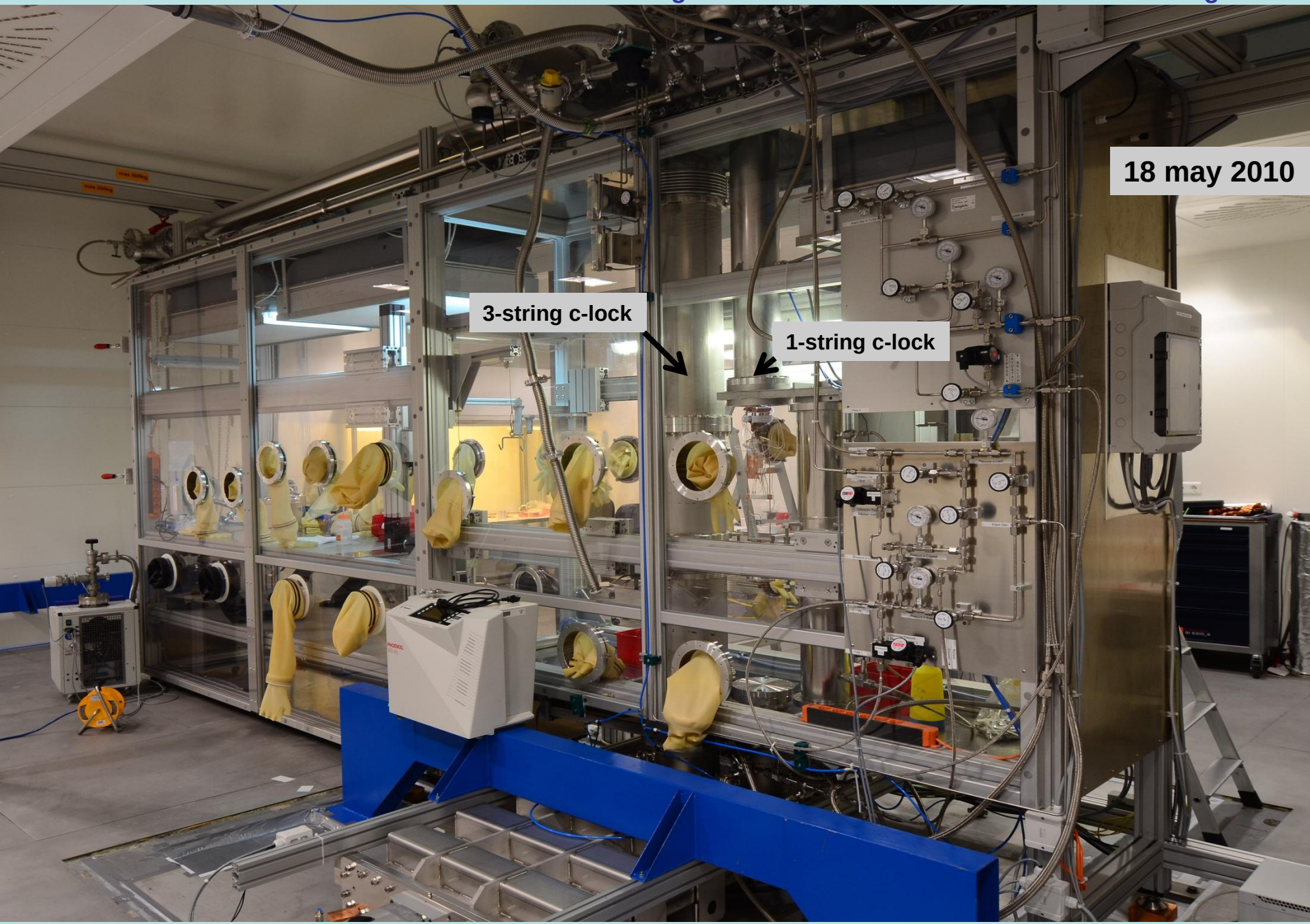
Google

heat exchanger for active cooling & radon shroud


aug 2009
1 of 66 PMTs

nitrogen flushed clean bench and commissioning locks



Cryogenic system ✓

Running smoothly since cryostat filled with LAr in December 2010.
No refill needed since thanks to active cooling.

Water plant ✓

Maintaining quality of ultra-pure water (resistivity >17MΩ·cm & TOC <20ppb) from BOREXINO.

Commissioning lock ✓

Rigorously tested above ground in 2010 – working as expected.

Cleanroom and N_2 flushed clean bench ✓

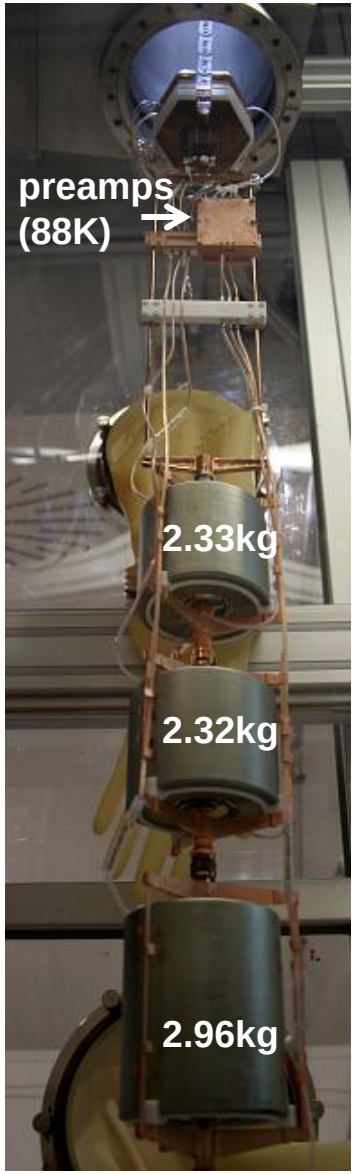
Running smoothly. Handling procedures of Ge diodes - never come in air! - well established.

Slow control ✓

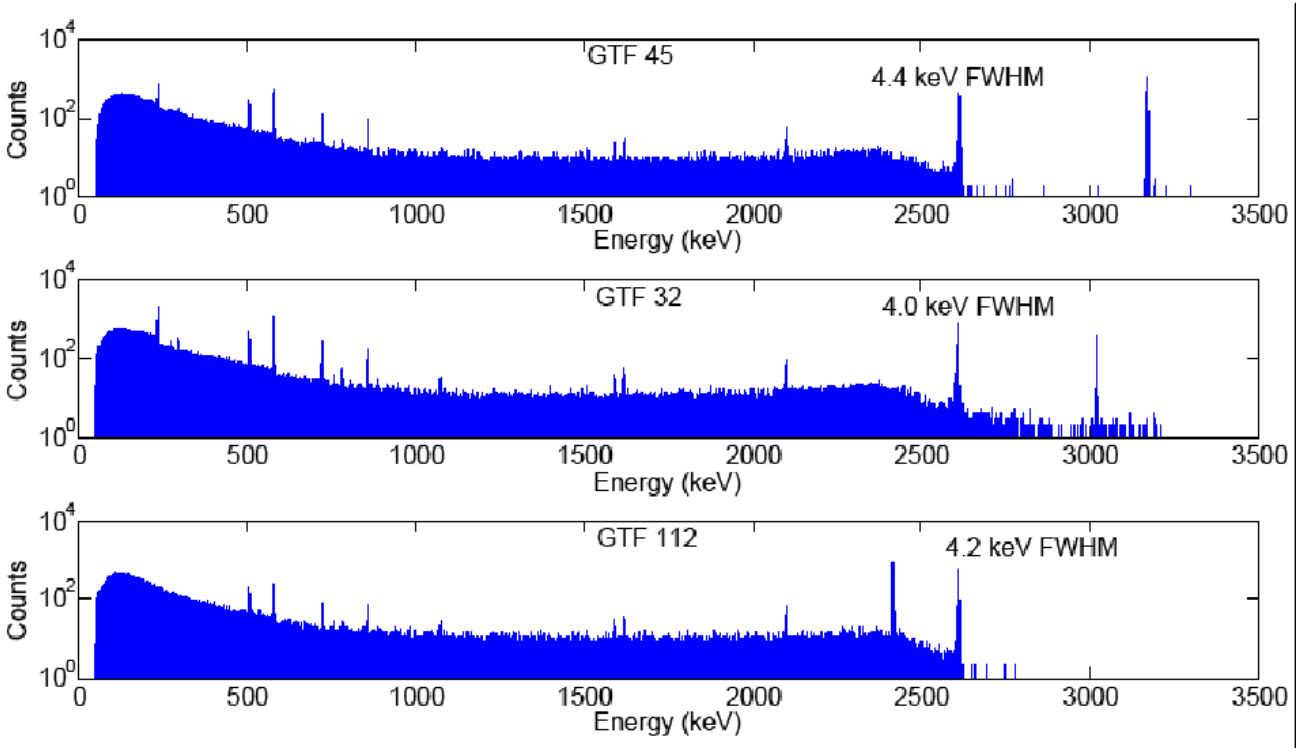
Collects data from all subsystems; web-based interface for global access.

Safety systems ✓

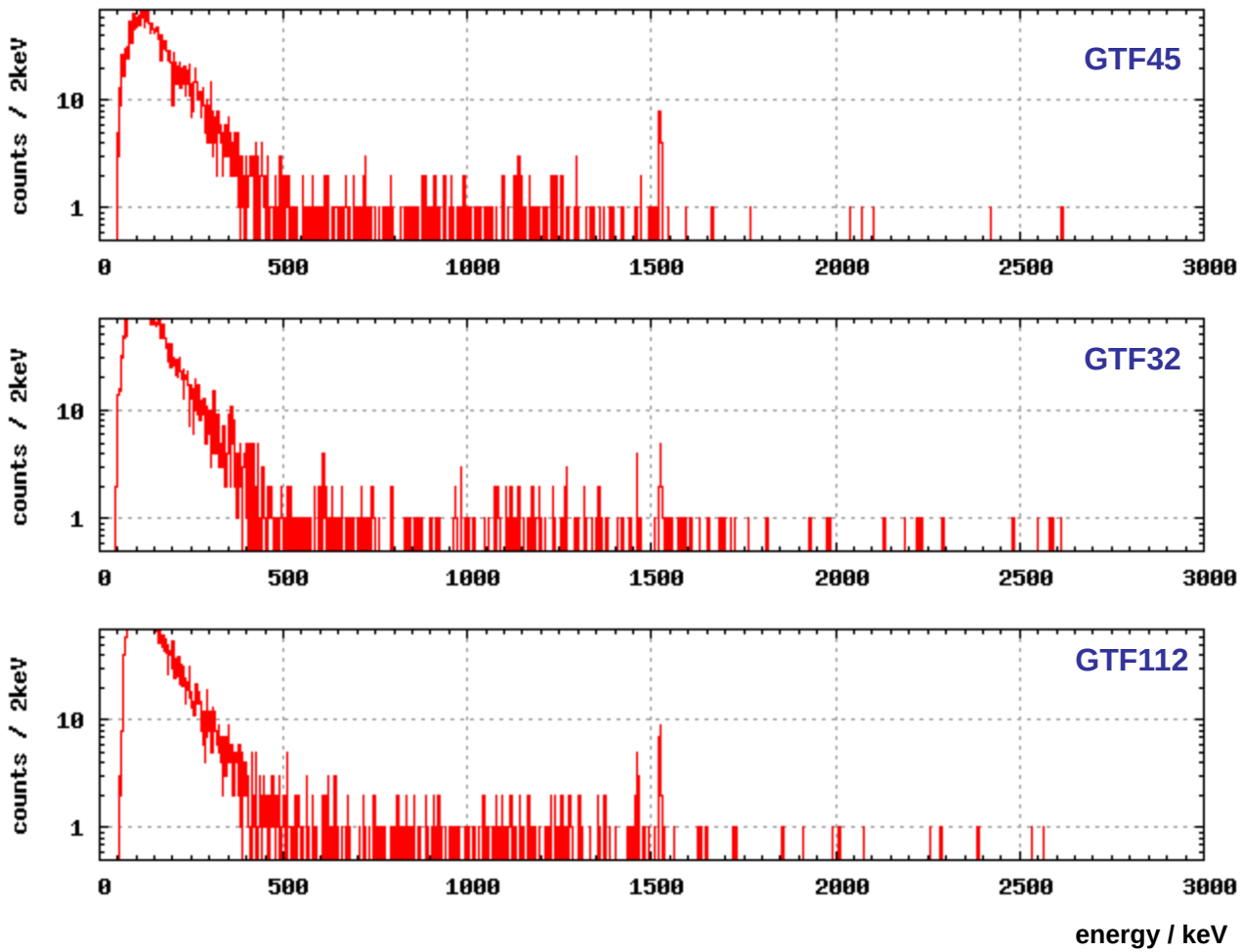
Passed several realistic tests. Fast water drainage (<2 hours) verified.



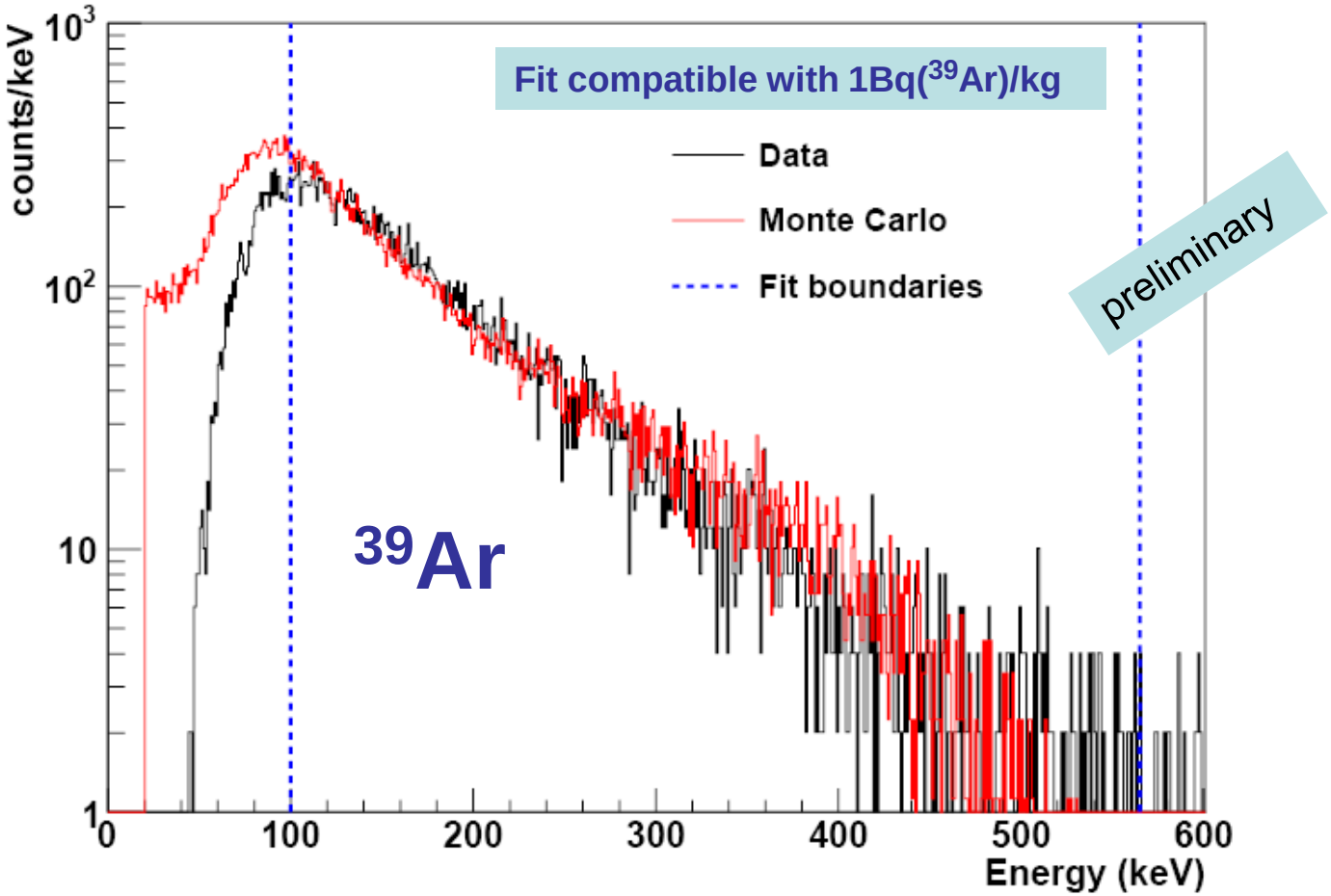
Runs started in June 2010
using 3 refurbished Genius-TF ^{nat}Ge-diodes (7.61 kg)
NB ► p-type / coaxial ► 'low background' diodes



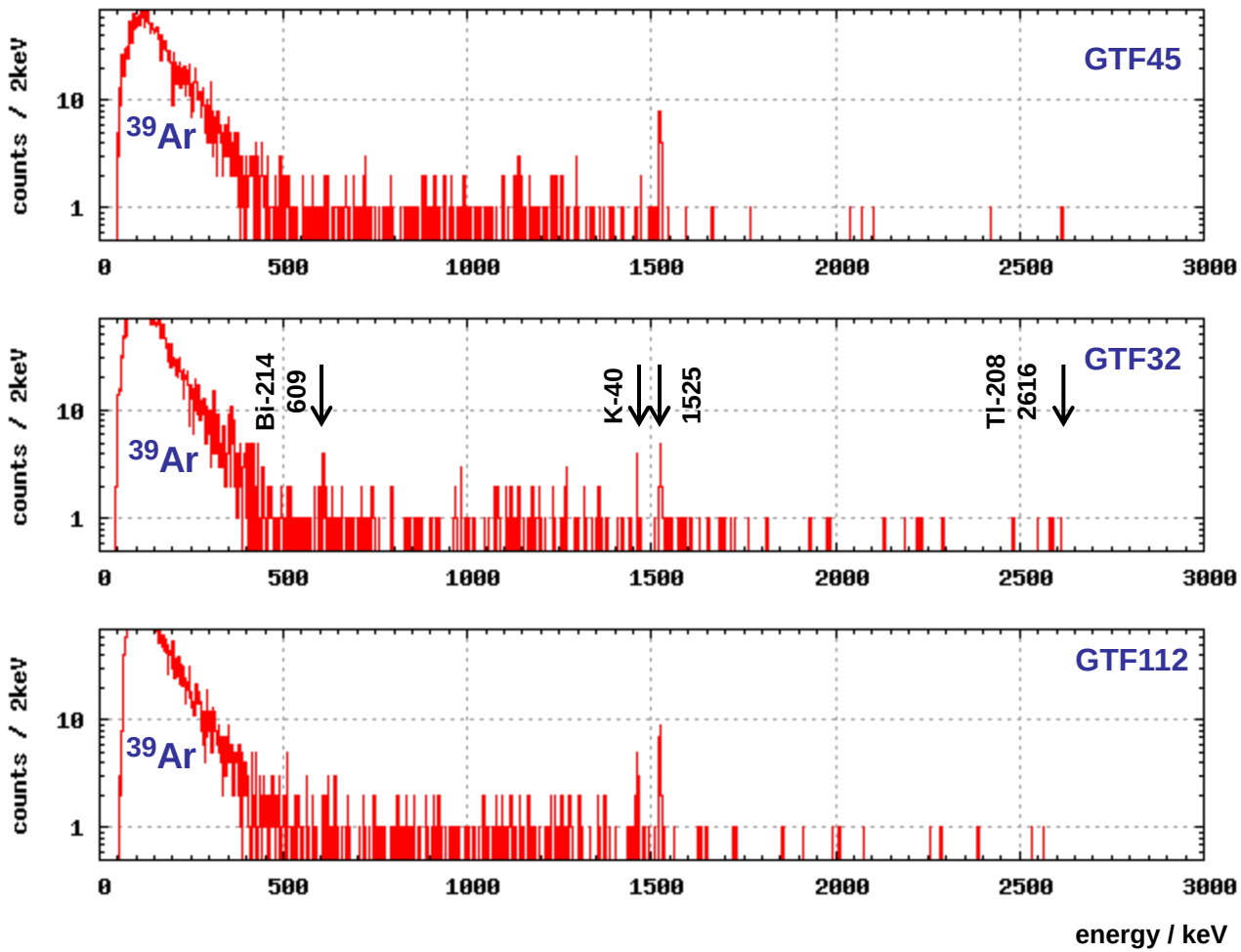
calibration: spectra with Th-228 radioactive source



run 12 (0.564 kg·y)
27 days run time


Fit compatible with 1Bq(^{39}Ar)/kg
Data
Monte Carlo
Fit boundaries
preliminary
^{39}Ar
counts/keV
10^3
10^2
10
1
0
100
200
300
400
500
600
Energy (keV)

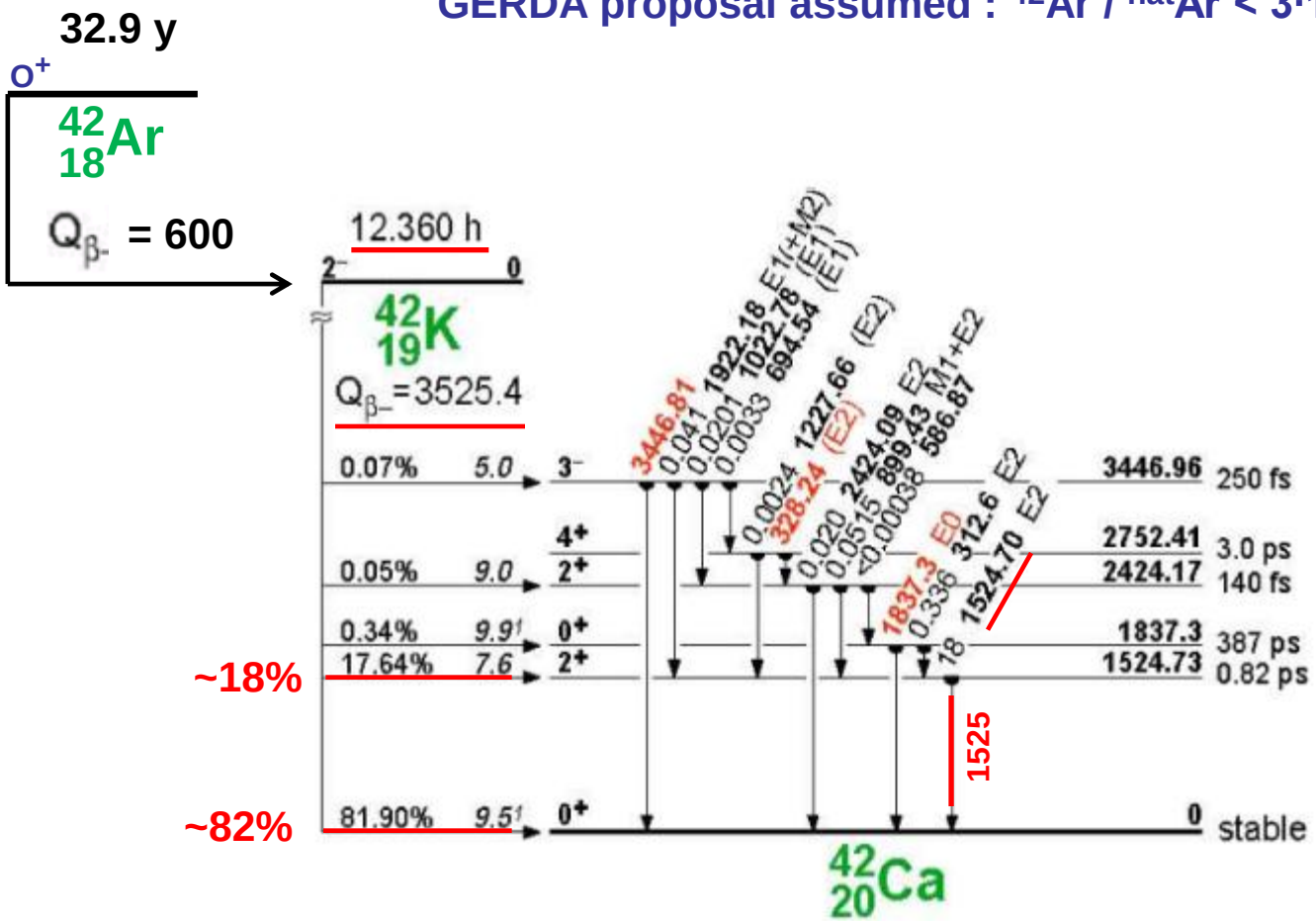
'understood'



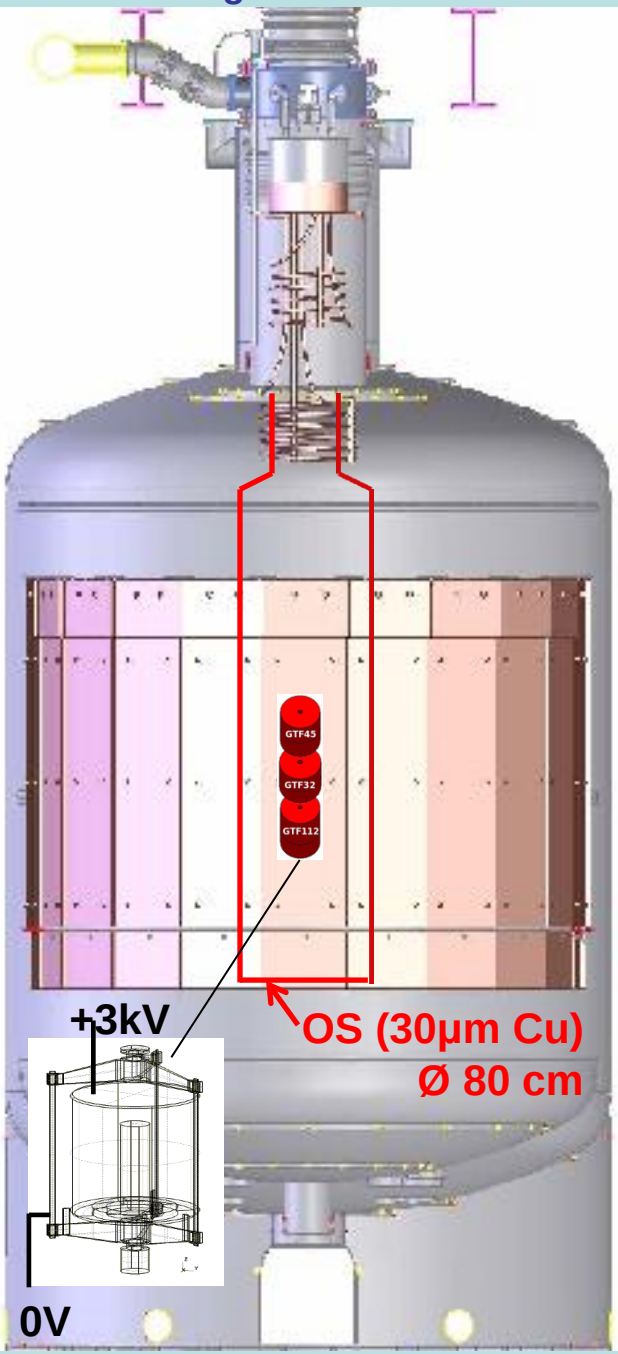
Rather weak discrete lines from Th/U background,
Th / U / ^{40}K lines suppressed by factors of ~4 / ~4 / ~20 wrt HdM.
1525 keV line much stronger than expected,

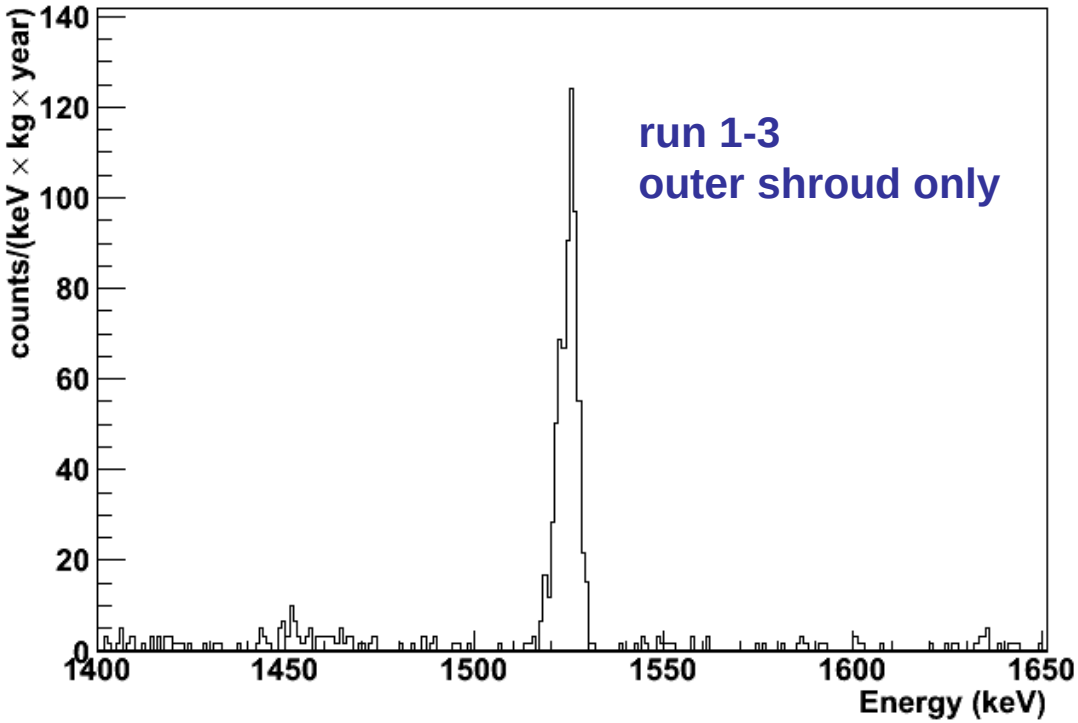
run 12 (0.564 kg·y)

GERDA proposal assumed : ^{42}Ar / $^{nat}Ar < 3 \cdot 10^{-21}$



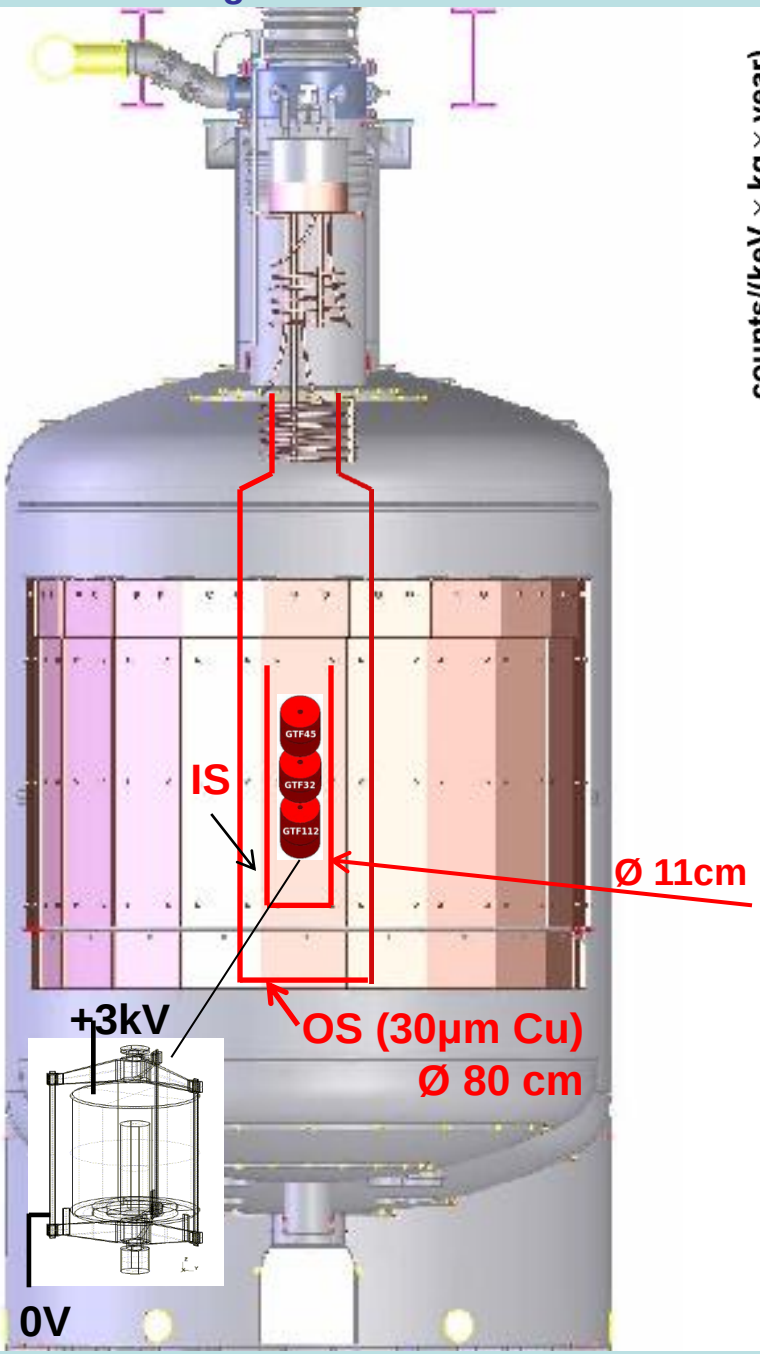
study of Ar-42/K-42 via 1525 keV line

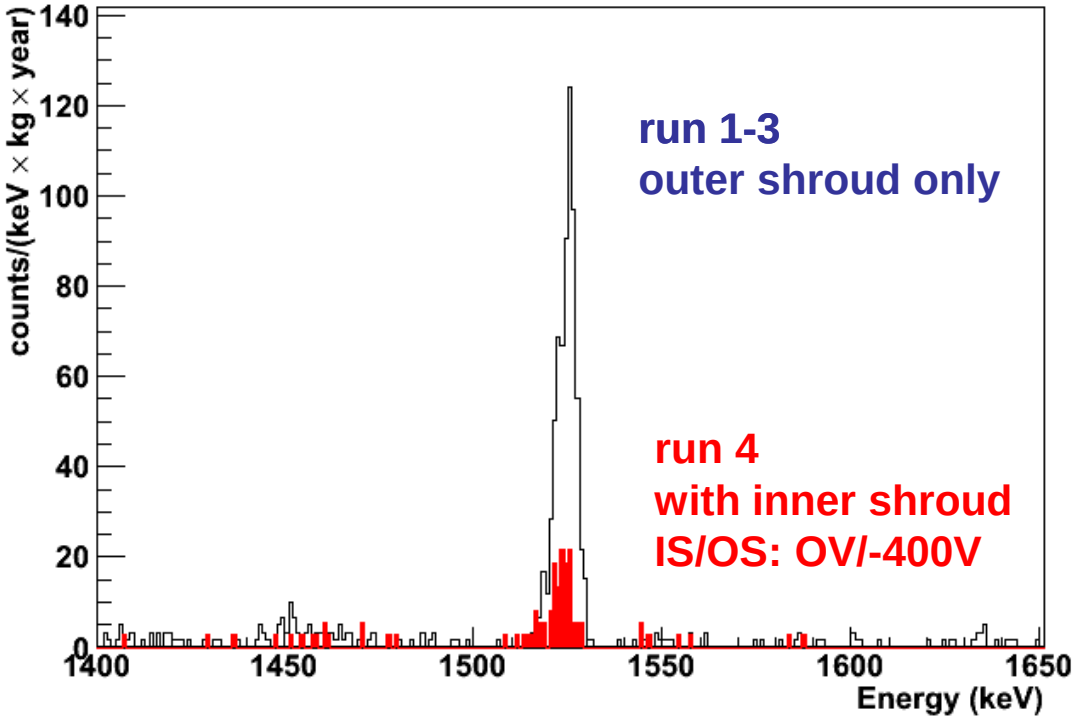




Count rate of 1525 peak factor ~14 larger than expected.

study of Ar-42/K-42 via 1525 keV line

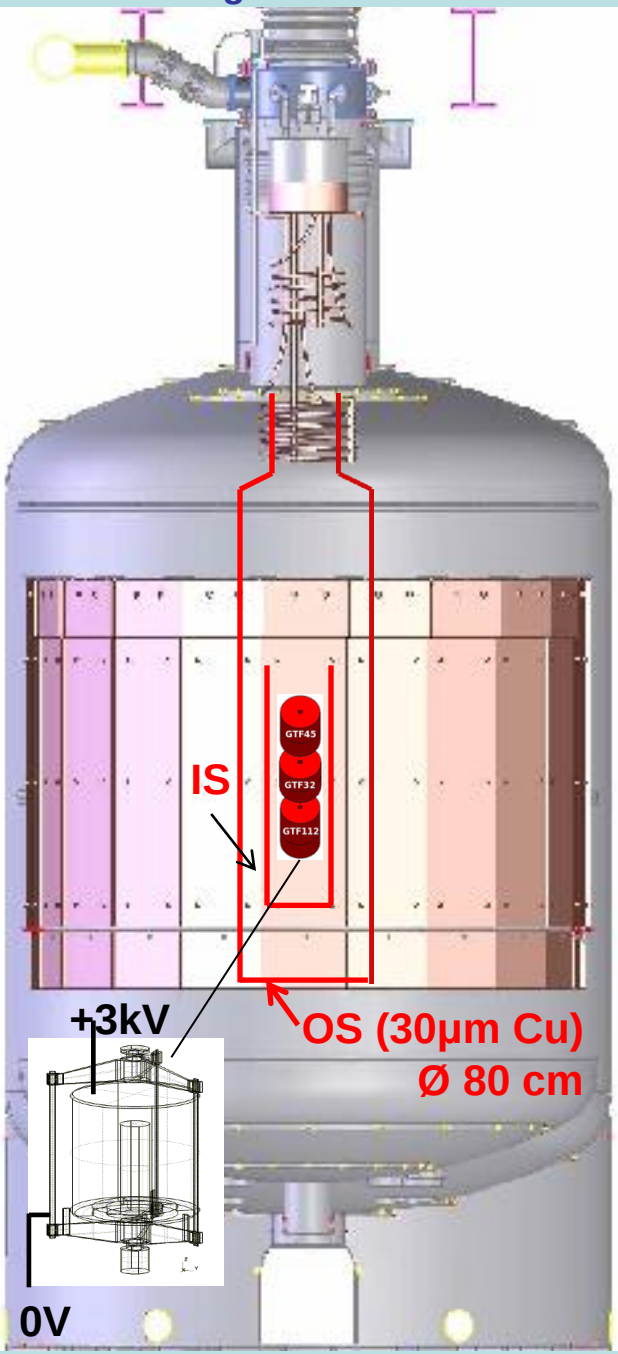


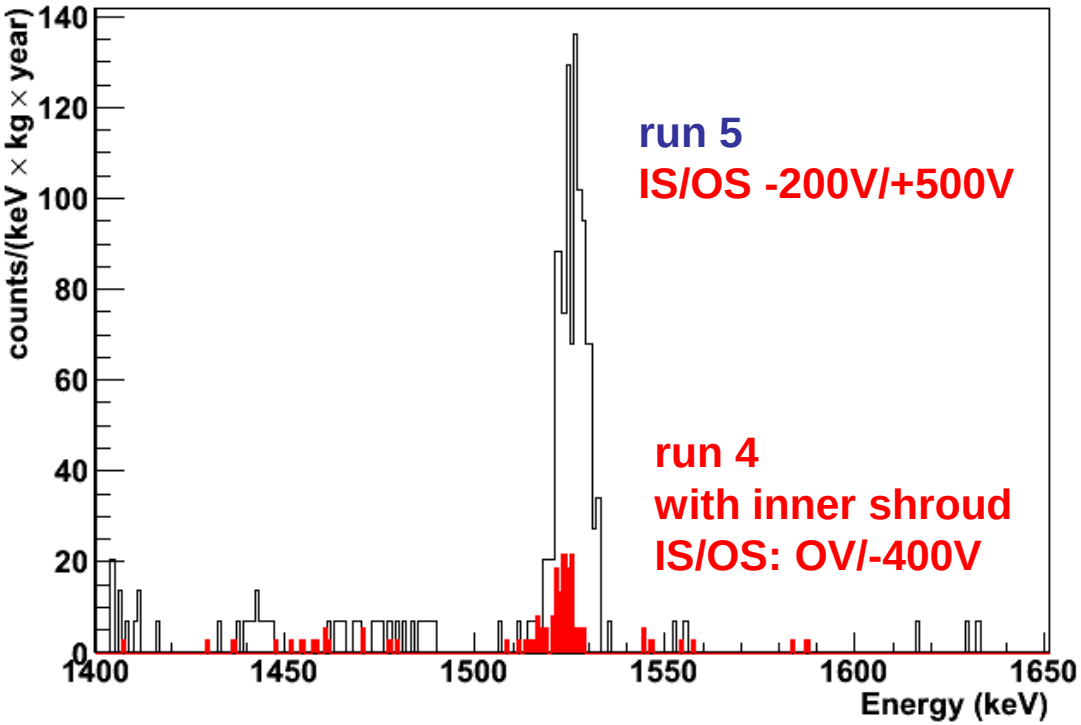


Count rate of 1525 peak factor ~14 larger than expected.

Additional inner shroud (IS) reduces counts by factor of 4-5.
Still larger than expected! IS shields E- field and convection.
NB: Similar observations at $Q_{\beta\beta}$!

study of Ar-42/K-42 via 1525 keV line





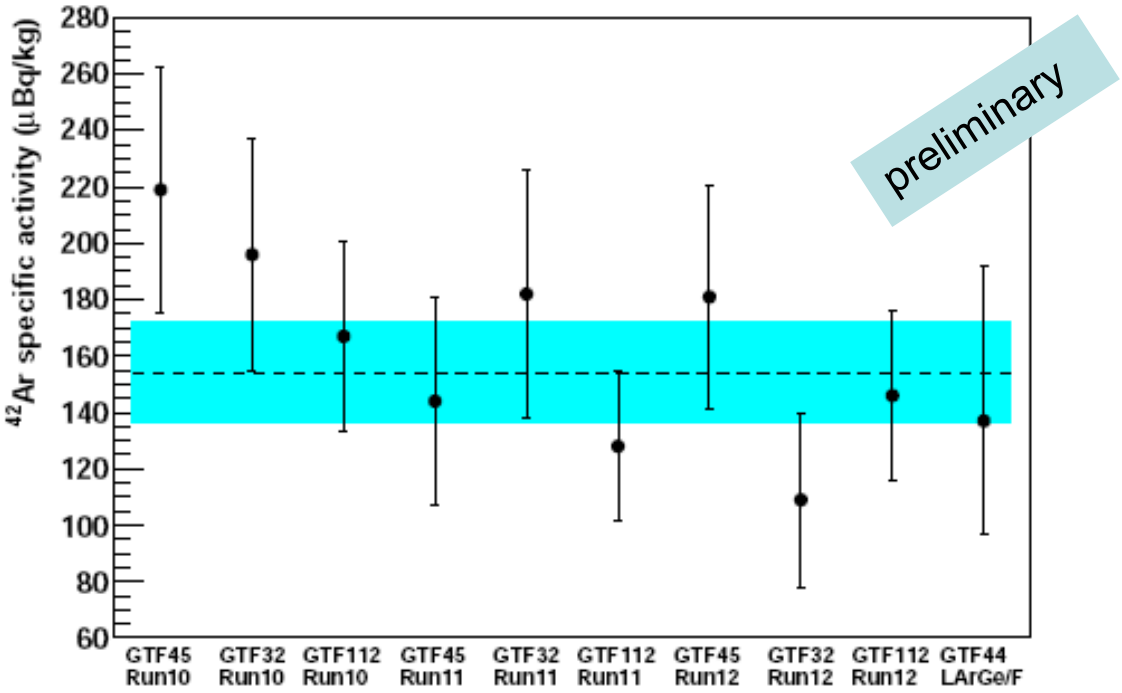
Count rate of 1525 peak factor ~14 larger than expected.

Additional inner shroud (IS) reduces counts by factor of 4-5.
Still larger than expected! IS shields E- field and convection.
NB: Similar observations at $Q_{\beta\beta}$!

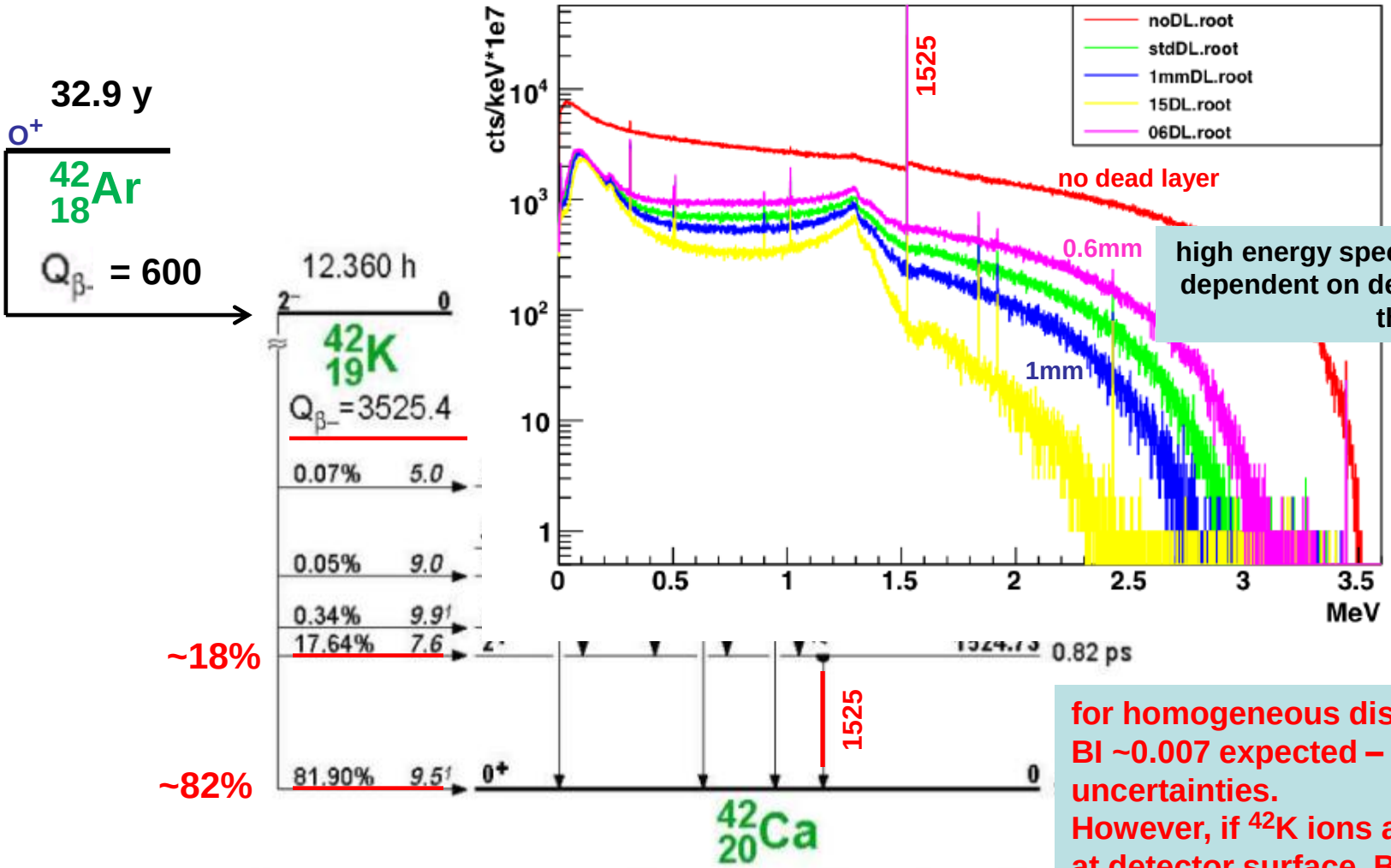
Biasing IS/OS such that positive ions are attracted by IS:
Count rate increases to about previous value.

► Clear evidence that ^{42}K-ions drift in electric field.
Potentially severe consequences for background at $Q_{\beta\beta}$!
Field-free configurations desirable!

Ar-42 specific activity deduced from almost field-free runs 10-12

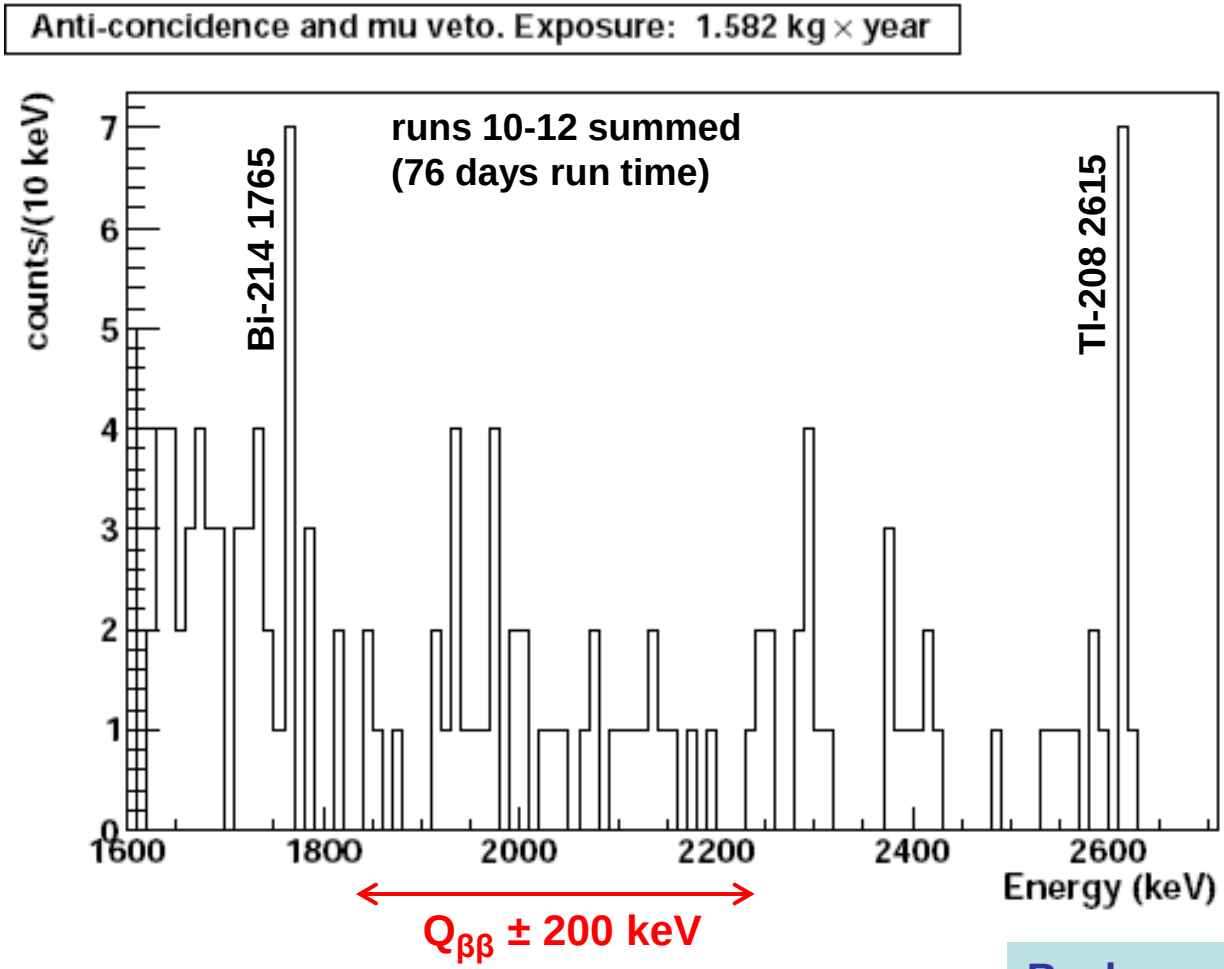


Published limit : <43 μBq/kg i.e. <4.3·10^{-21}g/g at 90% CL (Barabash et al. 2002)



high energy spectral part dependent on dead layer thickness

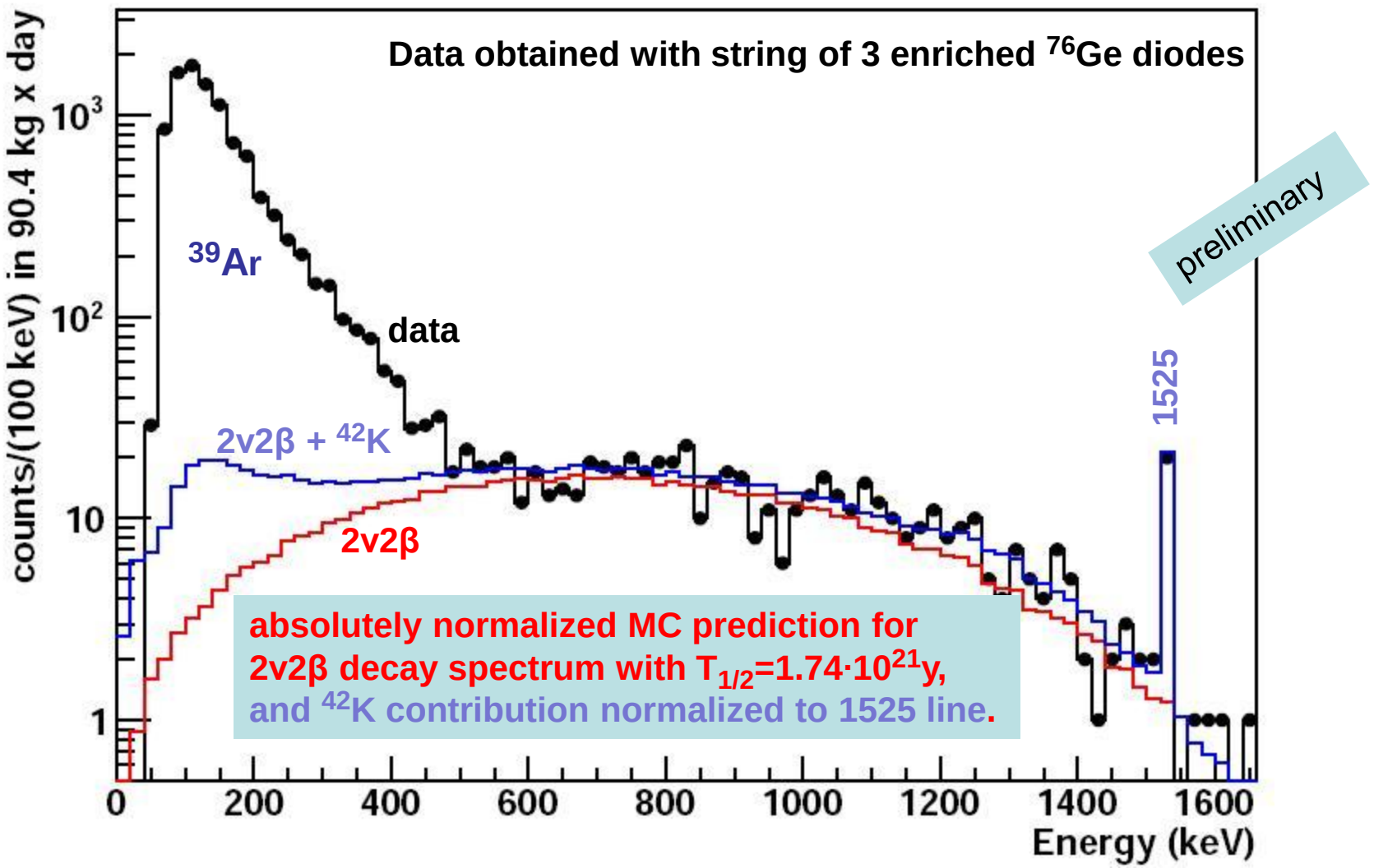
for homogeneous distribution BI ~0.007 expected – has big uncertainties.
However, if ^{42}K ions are collected at detector surface, BI increases.



Deduced background index in interval ($Q_{\beta\beta}$ ± 200) keV: 0.06 ± 0.01 cts/(keV·kg·y)

Background rate significantly lower than in previous experiments (HdM, IGEX) - but still higher than Phase I goal of 0.01.

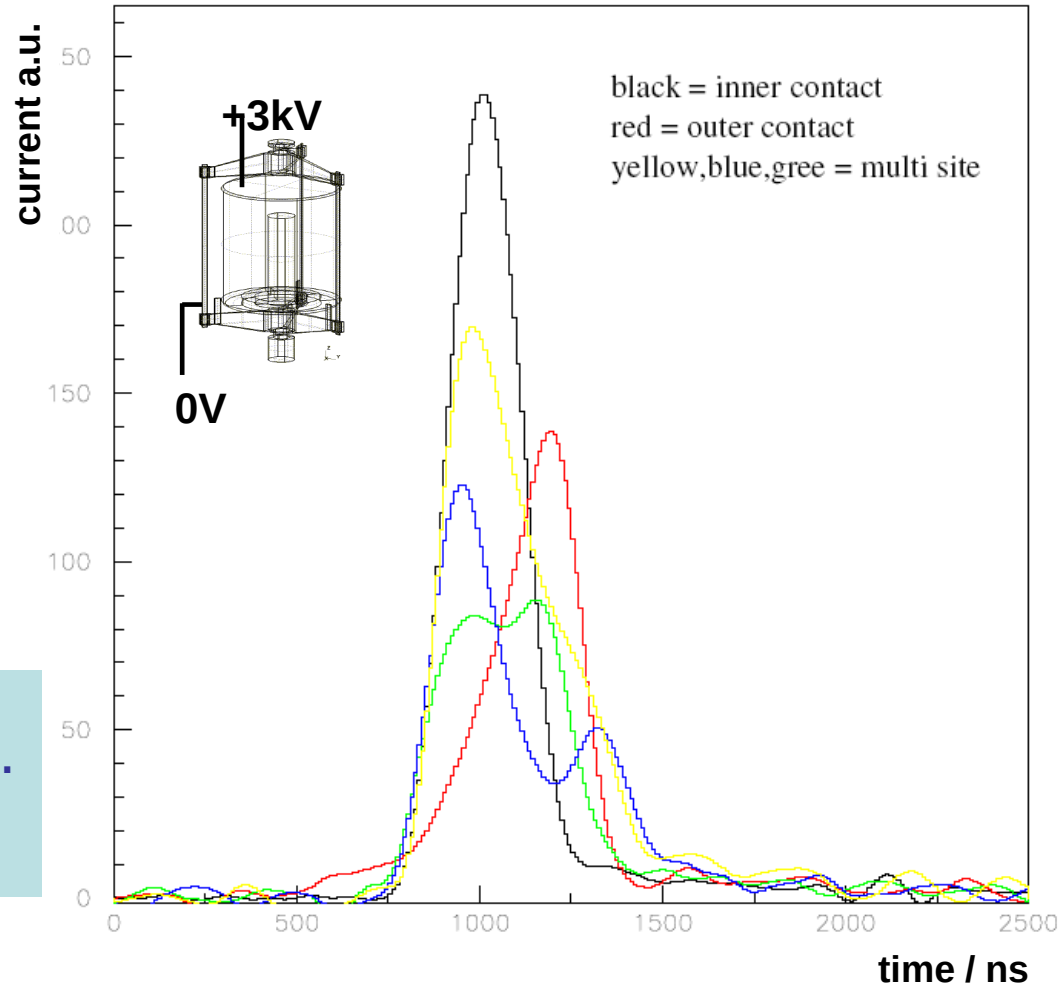
Background most probably not only due to $^{42}Ar/^{42}K$; could (partially) be due also to distant Th-232 source. ► Background at $Q_{\beta\beta}$ not yet understood - better statistics needed!



absolutely normalized MC prediction for 2v2β decay spectrum with $T_{1/2}=1.74\cdot10^{21}$y, and ^{42}K contribution normalized to 1525 line.

Most background between ^{39}Ar endpoint & 1525 keV line accounted for by 2v2β decays. (Basic background studies done better with non-enriched diodes:)

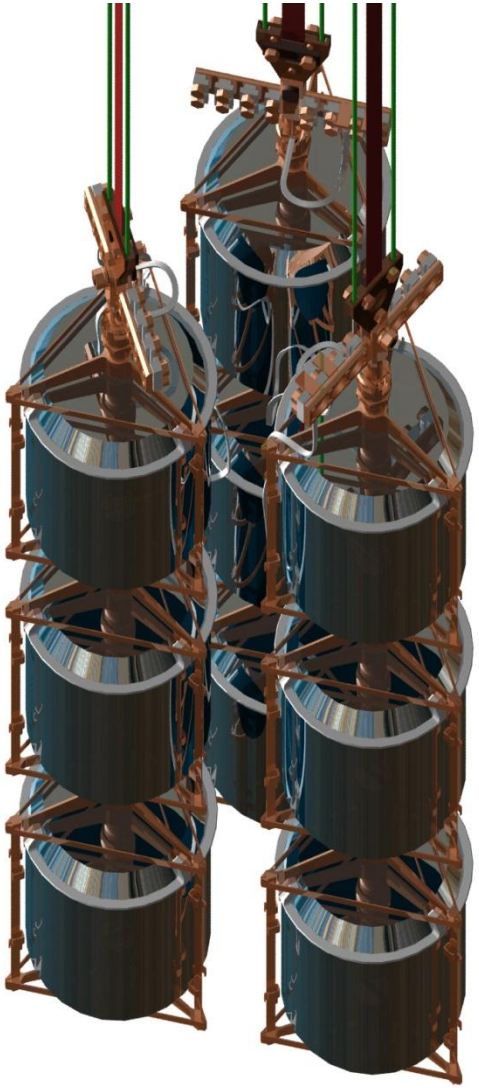
- **Exploitation of pulse shape analysis**



For Phase I detectors reduction of BI by a factor of up to 2 might be feasible.

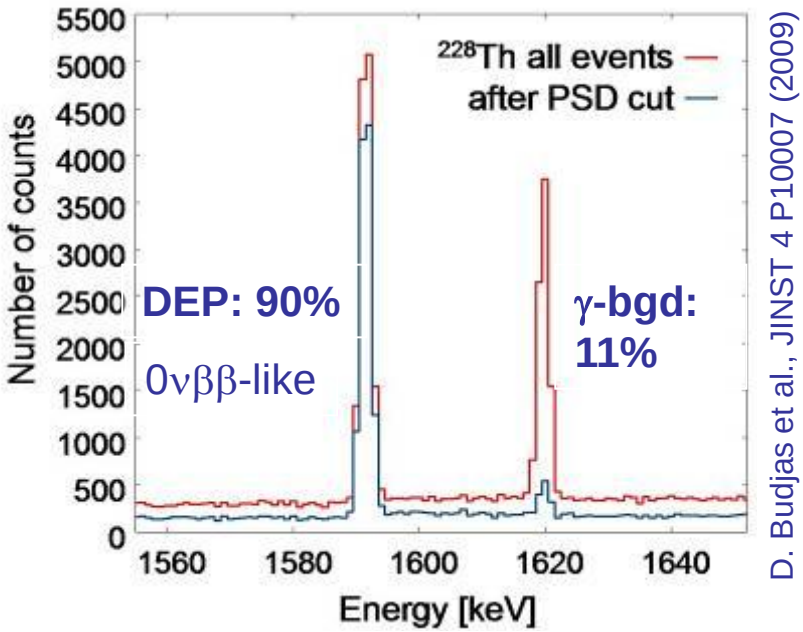
Blind analysis indispensible.

- Exploitation of pulse shape analysis
- Deployment of full array of enriched diodes



8 refurbished and tested diodes (HdM, IGEX) available
- 86% isotopically enriched in Ge-76
- 17.66 kg total mass
- 3-string lock under commissioning
- soon ready for start of Phase I physics run

- Exploitation of pulse shape analysis
- Deployment of full array of enriched diodes
- Order of phase II detectors



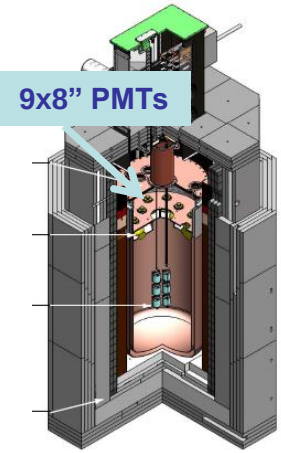
BEGe (point-contact) type of diode selected for Phase II – superb pulse shape discrimination!

Full production cycle tested with depleted material left over from enrichment process.

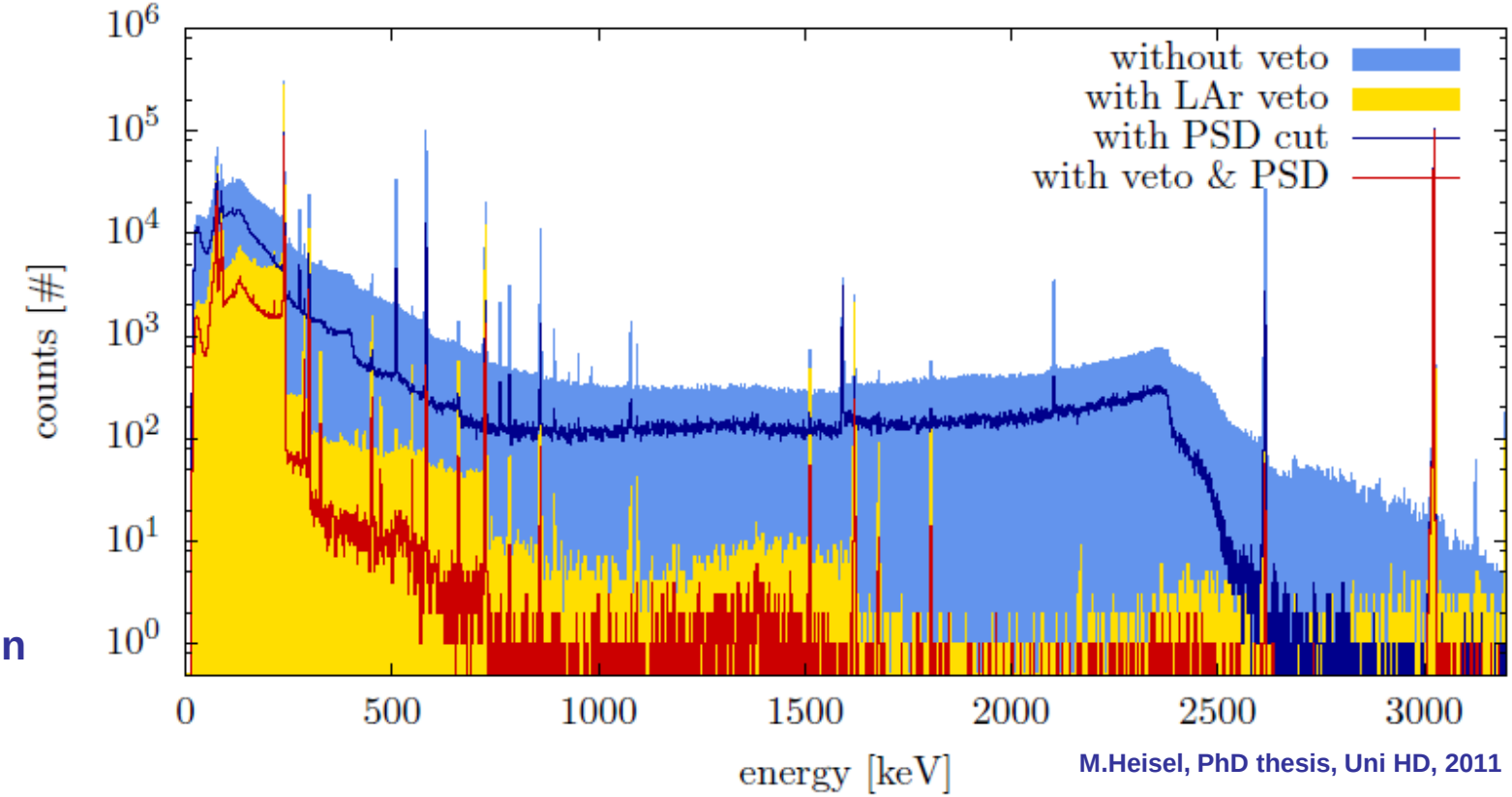
Enriched material reduced and purified. Negotiations for Phase II detector order in progress.

- Exploitation of pulse shape analysis
- Deployment of full array of enriched diodes
- Order of phase II detectors
- Instrumentation of LAr for scintillation veto

LArGe



R&D for LAr instrumentation



M.Heisel, PhD thesis, Uni HD, 2011

Suppression factor at $Q_{\beta\beta}$ of ~5000 measured with Th-228 calibration source. Alternative to scintillation light readout by PMTs: fibers coupled to SiPMs.

- Construction completed.
- All subsystems commissioned and running smoothly.
- All phase I detectors (8 pcs ,~18 kg) refurbished & ready.
- Commissioning with natural and enriched Ge diodes in progress.

► ^{42}Ar isotopic abundance found to be about factor of 4 larger than 90% limit reported previously – serious background for phase II.

► Best background index at $Q_{\beta\beta}$ of all Ge experiments so far, but still factor 6 above phase I goal - not yet fully under-stood why. LAr instrumentation might be needed already to reach goal of phase I.

- Start of phase I physics run with enriched detectors soon.
- Full production chain tested for phase II BEGe detectors.
- Phase II detectors (~20 kg) to be ordered this year.

goals: phase I : background 0.01 cts / (keV·kg·y)

► scrutinize KKDC result within ~1 year

phase II : background 0.001 cts / (keV·kg·y)

► $T_{1/2} > 1.5 \cdot 10^{26}$ y , $0.09 < \langle m_{ee} \rangle < 0.15$ eV *

* PR C81(10)028502

Backup Slides

sensitivity*

$$T^{0\nu}_{1/2}(n_\sigma) = \frac{4.16 \times 10^{26} y}{n_\sigma} \left(\frac{\varepsilon a}{W}\right) \sqrt{\frac{Mt}{b\Delta(E)}}$$

detection efficiency (=1 if source=detector)

86%

72 kg y

exposure [kg y]

3.3 keV

instrumental spectral width

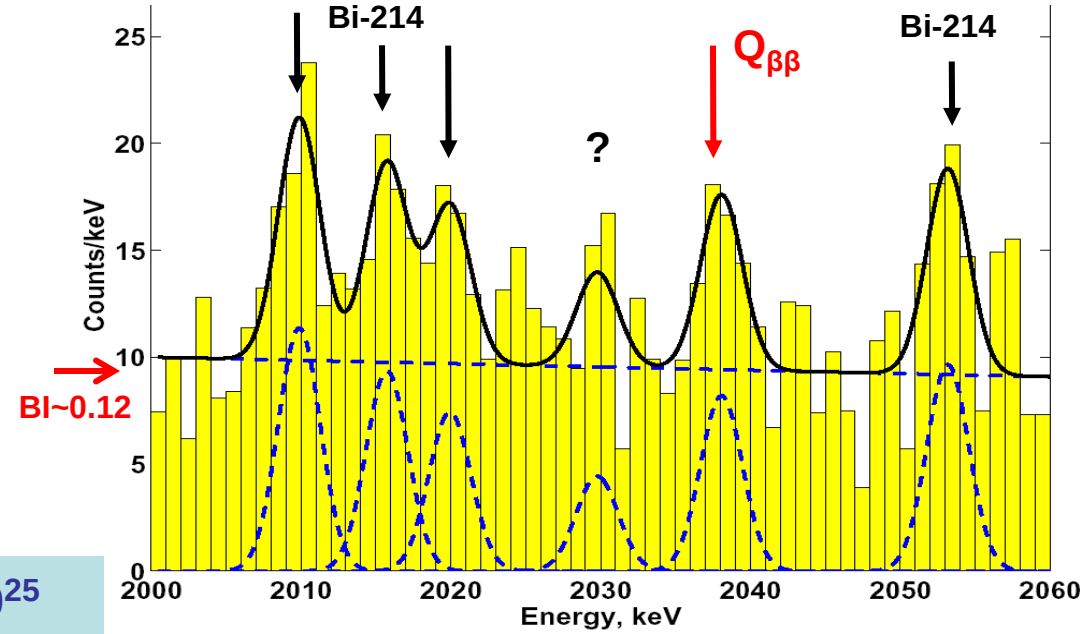
molecular weight of source

background index (BI) [cts/(keV·kg·y)]

0.1

achieved with ^{76}Ge

*RevModPhys 80(08)481

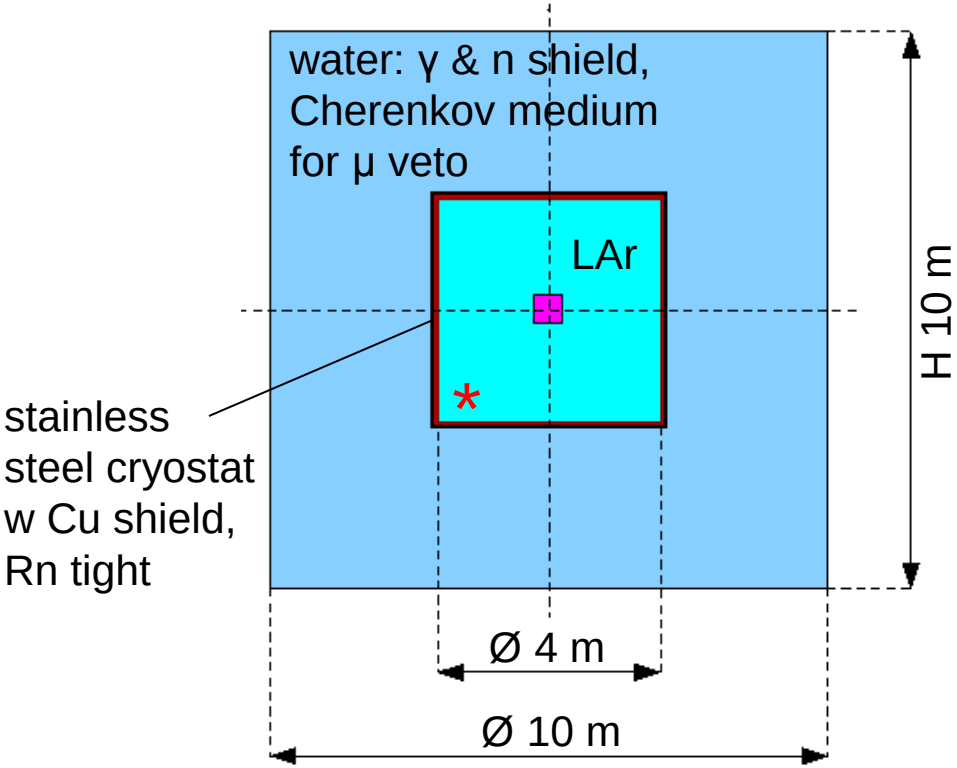


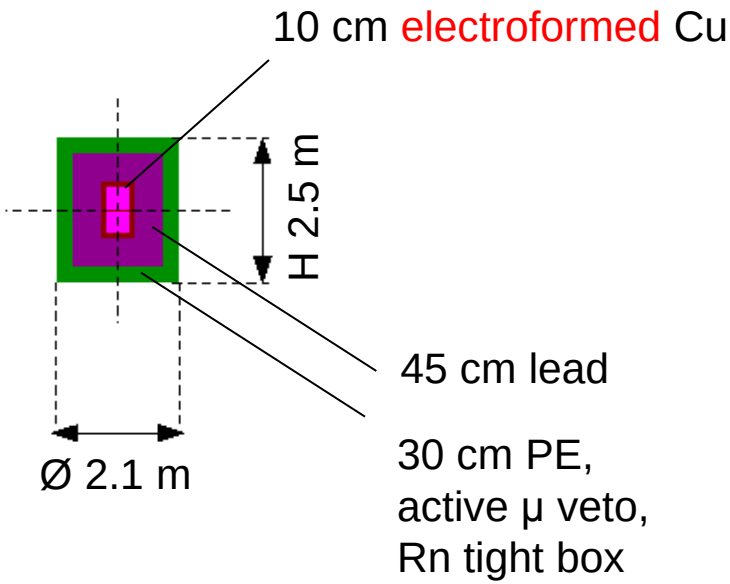
KKDC: 71.7 kg·y: $T_{1/2}$ = 1.2 (0.7-4.2)·10^{25}

$\langle m_{\beta\beta} \rangle$ = 0.44 (0.24 – 0.58) eV (3σ)

GERDA: low Z shield, underground bare Ge diodes in high-purity LAr

MAJORANA: high Z, deep underground Ge diodes housed in vacuum cryostat, ultra-high-purity electroformed Cu shield



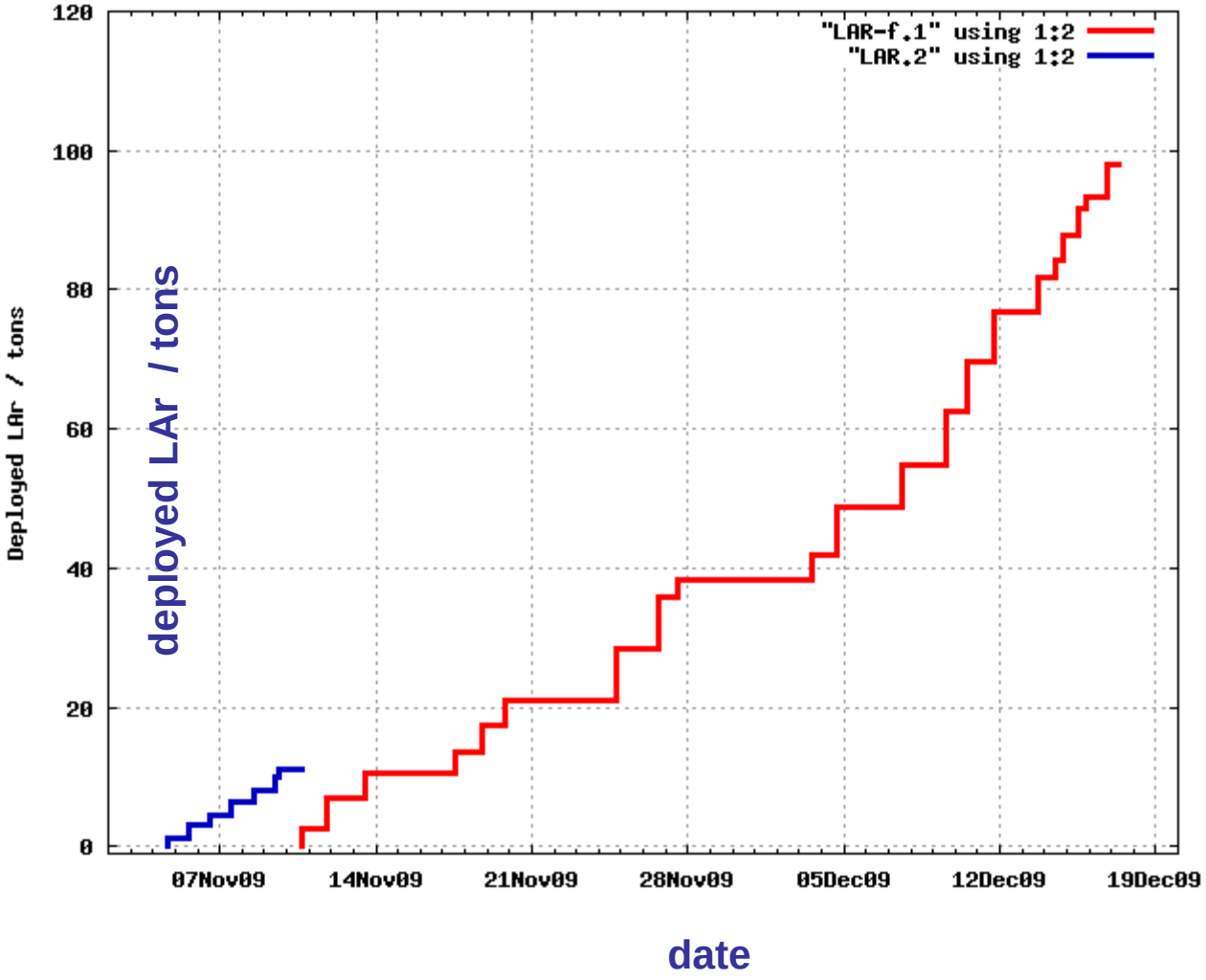


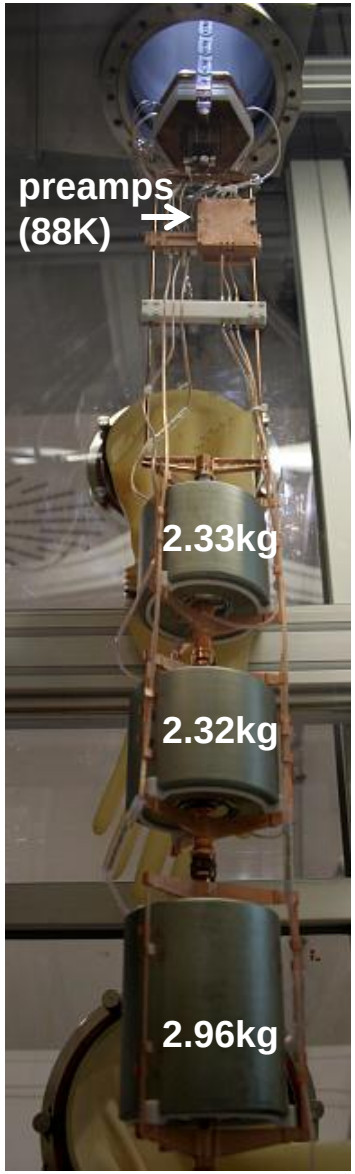
* LAr can be also active shield!

α(LAr) = 0.050/cm α(Cu) = 0.34/cm
$\alpha(H_2O)$ = 0.043/cm α(Pb) = 0.48/cm

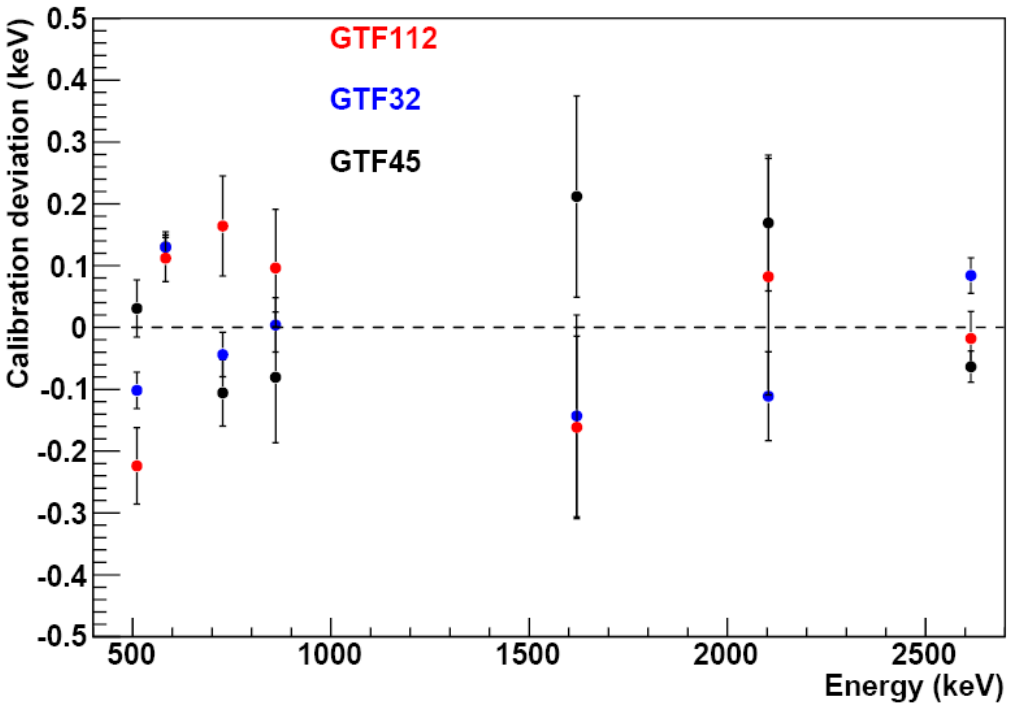
cool down and filling of cryostat

LAr for cool down and filling taken from storage tank.

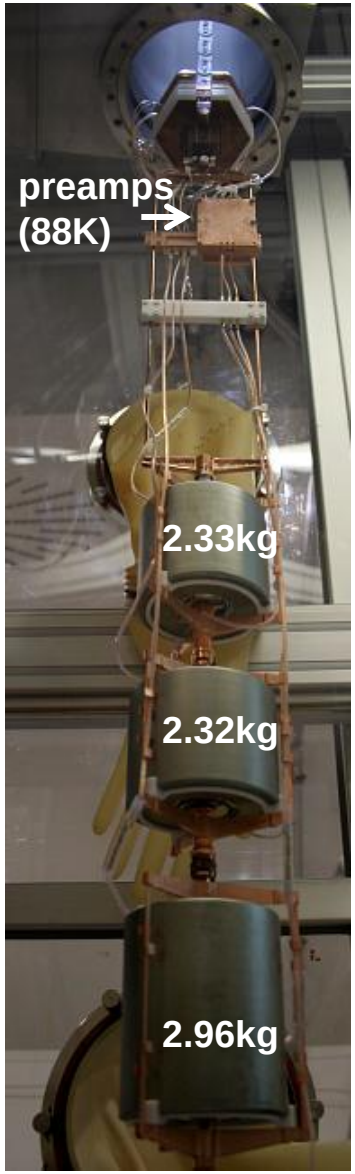




started in June 2010
using 3 refurbished Genius-TF ^{nat}Ge-diodes (7.61 kg)
NB ► p-type / coaxial ► 'low background' diodes



calibration: deviations from linearity



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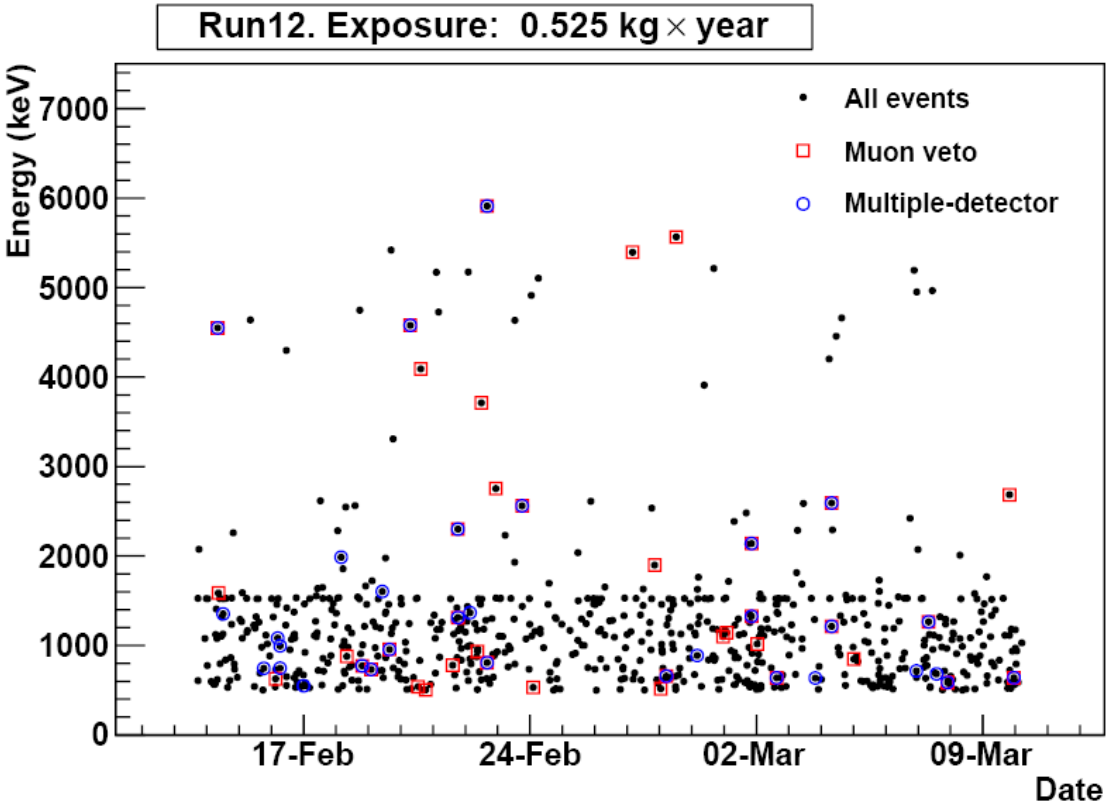

muon induced rate ~ 0.01 cts/(keV·kg·year)
veto efficiency >94% (system still incomplete)