The GERmanium Detector Array for the search of neutrino-less double beta decay of Ge-76

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~ 70 physicists
13 institutions
5 countrys

in memoriam

Michael Altmann

Nicola Ferrari

† 31 July 2006

Outline

Introduction & Motivation

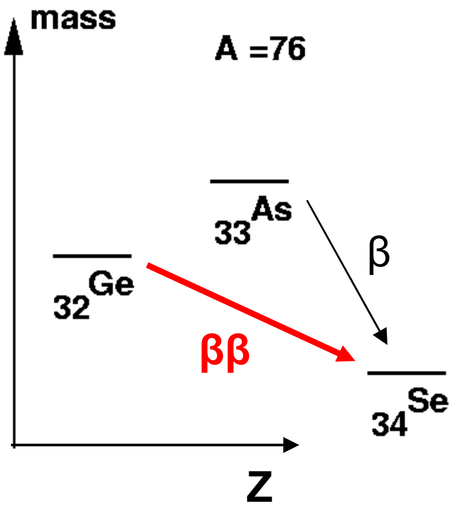
GERDA Sensitivity

Suppression of External & Internal Background

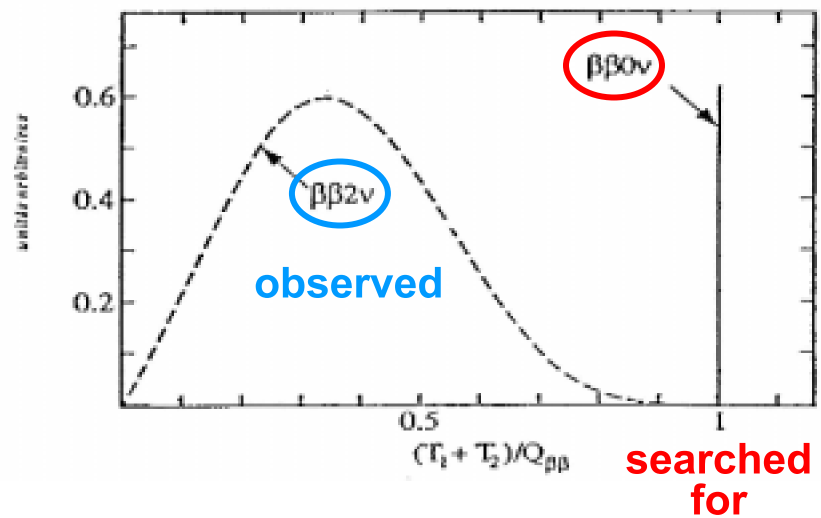
More on R&D

Status & Schedule

Summary



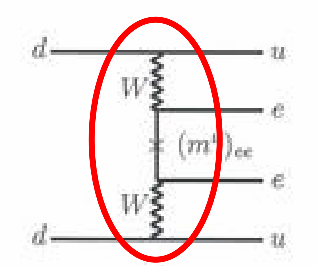
Ge-76 (source AND detector): $Q_{\beta\beta}$=2039 keV



2νββ : (A, Z) → (A, Z+2) + $2e^-$ + $2\bar{\nu}_e$

2nd order process, observed, $T_{1/2} \sim 10^{19}$-10^{21} yrs

0νββ : (A, Z) → (A, Z+2) + $2e^-$



physics beyond SM
if observed ($T_{1/2} > 10^{25}$ yrs) :

- $\nu = \bar{\nu}$: Majorana particle
- ν massive
- ΔL = 2

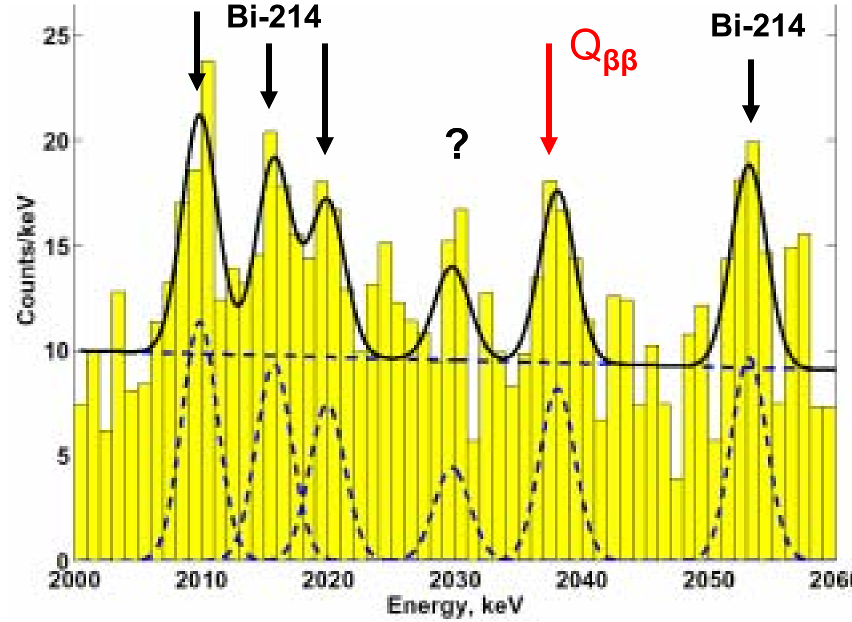
$$T^{0\nu}_{1/2} = 1 / [\ \Gamma(Q_{\beta\beta}^5)\ |M_{nucl}|^2 <m_{ee}>^2\ ]$$

phase space factor ↑ nuclear matrix element ↑

$$<m_{ee}> = |\ \Sigma_i\ \ U_{ei}^2 m_i\ |$$

<m_{ee}> best limits / value

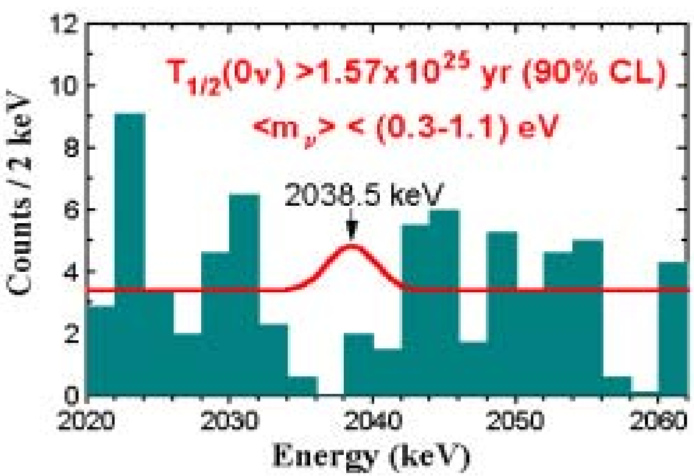
KKDC: H.V.Klapdor-Kleingrothaus, I.V.Krivoshina, A.Dietz, O.Chkvorets, Phys.Lett. B586 (2004) 198



5 enriched Ge-76 diodes (10.9 kg / 71.7 kg·y)
B = ~0.1 cts / (keV·kg·y)

$T^{0\nu}_{1/2}$ = (0.69 - 4.18)·10^{25} y (3σ range)

IGEX : **Gonzales et al., NP B87(2000)278**

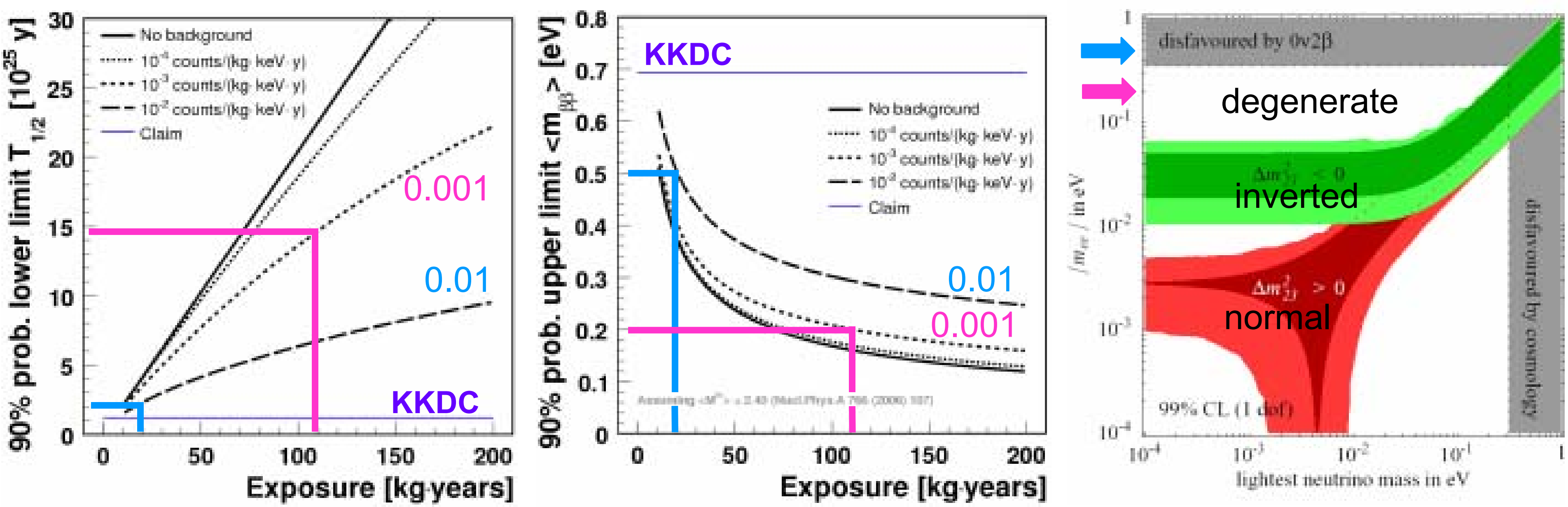


► confirmation needed with same & different isotopes
key: reduce background by *O*(100) for better sensitivity

GERDA goals & sensitivity

GERDA's goal : reach background index at $Q_{\beta\beta}$ = 2039 keV of 0.01 / 0.001 cts / (keV·kg·y)

measured → deduced → mass hierarchy



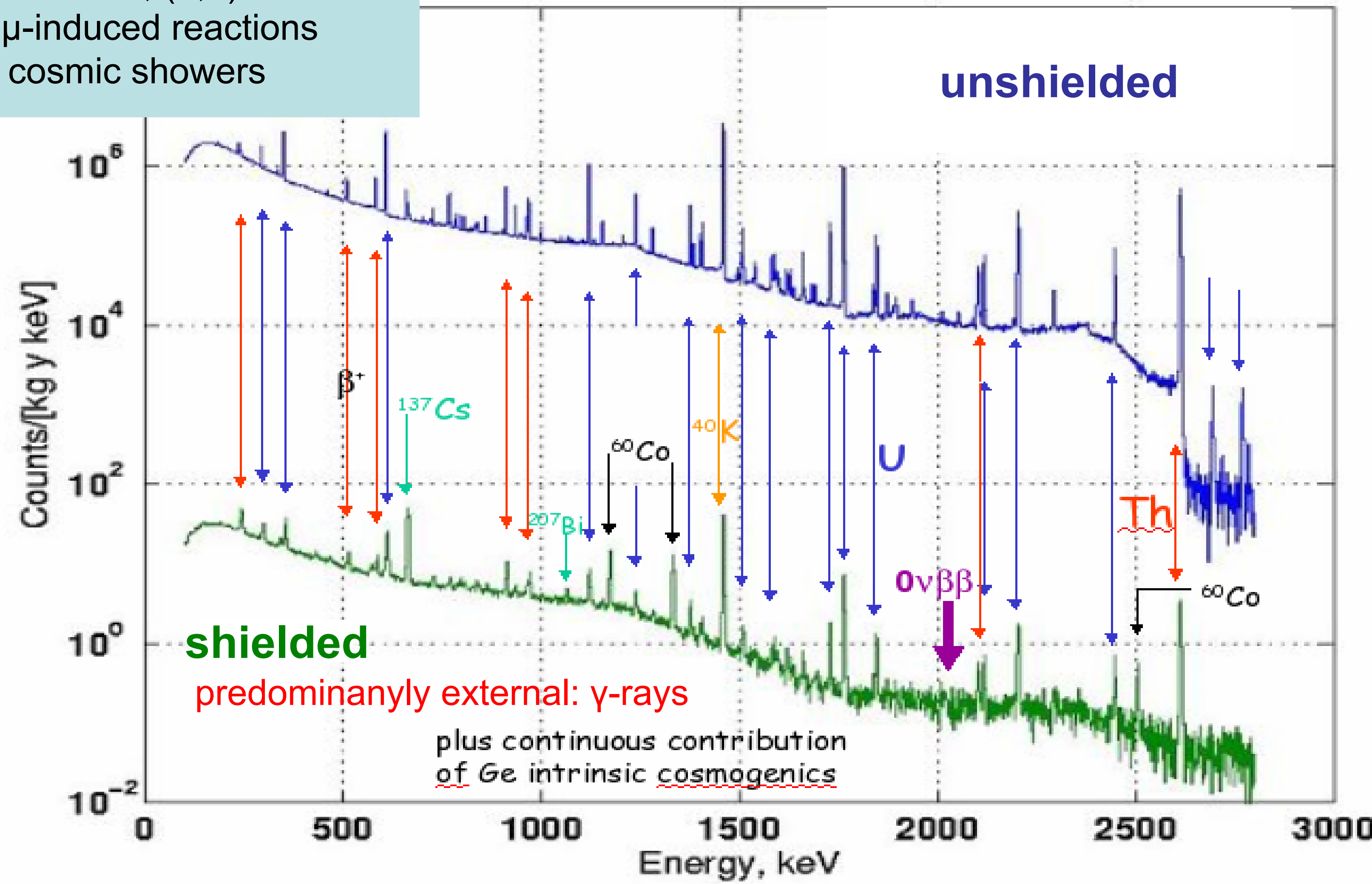
A.Strumia & F.Vissani, hep-ph / 0503246

- phase I : use existing Ge-76 diodes of Heidelberg-Moscow experiment & IGEX (~15 kg)
  ~ 0.01 cts / (keV·kg·y) intrinsic background expected
- phase II : add new enriched Ge-76 detectors, ~20 kg , (37.5 kg enriched Ge-76 bought)
  ~ 0.001 cts / (keV·kg·y) background expected ► 3 y·35 kg
- phase III: depending on results worldwide collaboration for real big experiment
  close contacts & MoU with MAJORANA collaboration established

EXTERNAL BACKGROUND:

- γ-rays from primordial decay chains
  - ►Th-232 chain: 2.615 MeV Tl-208
- neutrons from fission, (α,n) reactions in rock, and μ-induced reactions
- muons from cosmic showers

spectrum measured with Ge diode

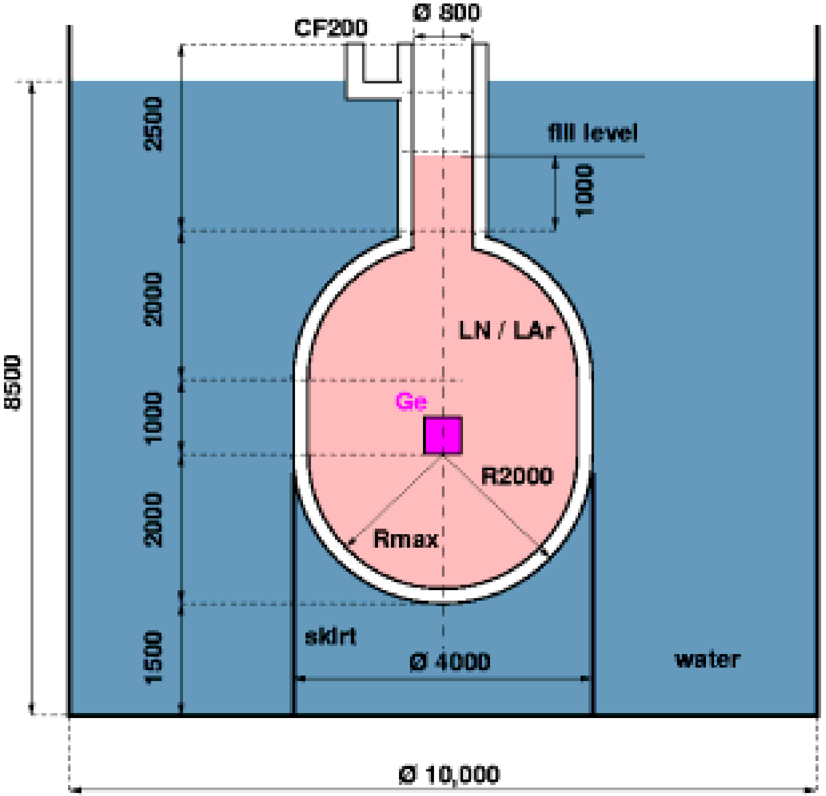


STRATEGY: reduce all impure materials close to Ge diodes as much as possible:

► operate Ge-diodes in ultra clean environment and (active) shield ► LN2/LAr best solution
(G.Heusser, Ann.Rev.NPS 45(1995) 54

Activity of Tl-208	(µBq/kg)
rock, concrete	3000000
stainless steel	~ 5000
Cu(NOSV), Pb	<20
water, purified	< 1
LN2, LAr	~ 0

Shield against 1) Tl-208 2.6 MeV γ-rays,
2) neutrons, 3) muons !



similar to GEM design

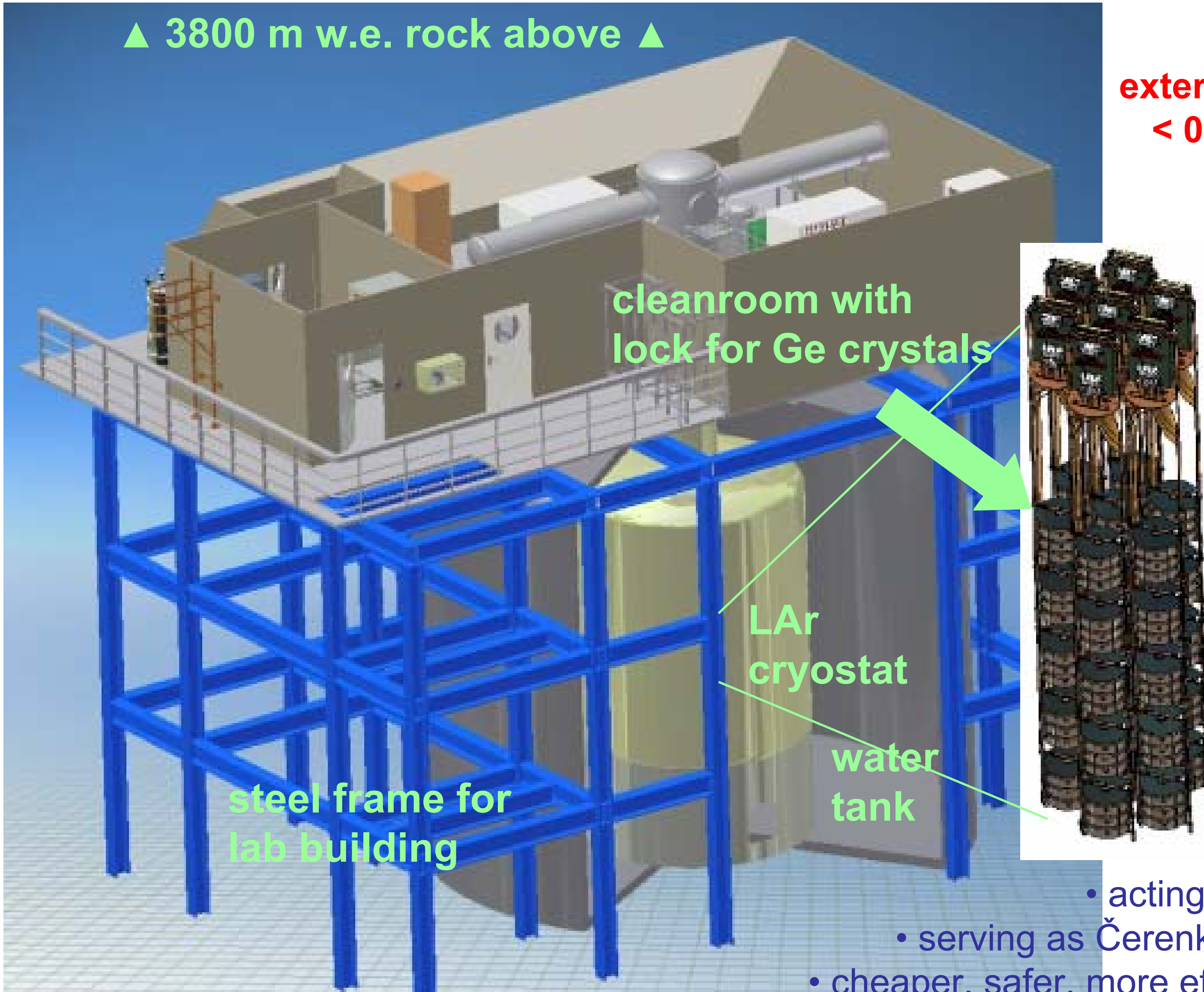
Yu.G.Zdesenko, O.A.Ponkratenko,V.I.Tretyak
J.Phys. G, Nucl.Part.Phys. 27 (2001) 2129

REALIZATION: cryostat for LN2/LAr immersed in water tank.

original plan: superinsulated cryostat made from ultra-pure copper – tripled in cost, abandonned

now: superinsulated stainless steel cryostat with internal ultra-pure copper shield – use LAr only.

proposed GERDA installation in LNGS Hall A



designed for
external γ,n,μ background
< 0.001 cnts /(keV·kg·y)

Ø 10 m water vessel
Ø 4.2 m LAr cryostat
internal Cu liner

70 m^3 of LAr
650 m^3 of water

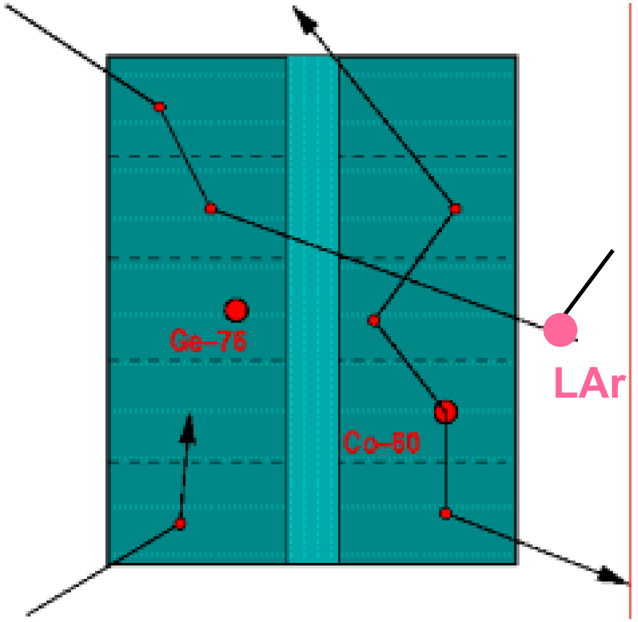
up to five diodes arranged in strings, total of 16 strings

water:

- acting as neutron moderator
- serving as Čerenkov medium for μ veto
- cheaper, safer, more effective than LN2 (LAr)

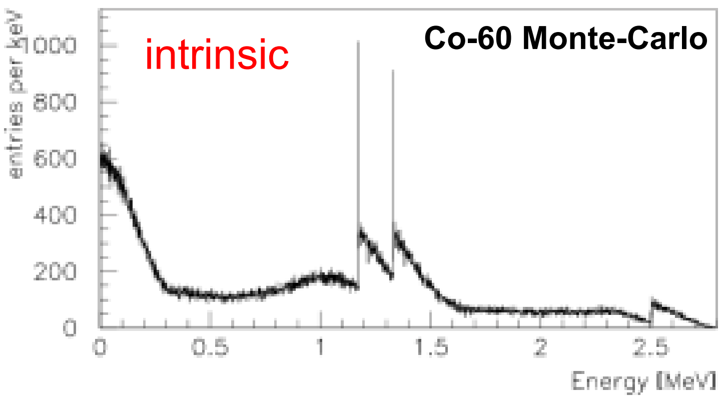
INTRINSIC BACKGROUND:
- cosmogenic isotopes (Ge-68, Co-60) due to spallation reactions above ground and $T_{1/2}$~yrs.

SUPPRESSION OF INTRINSIC BACKGROUND:
avoid it – keep enriched material underground
► discriminate between SSE and MSE events ◄



SSE Single Site Events:
energy deposition within a few mm
e.g. ββ events, double escape peak

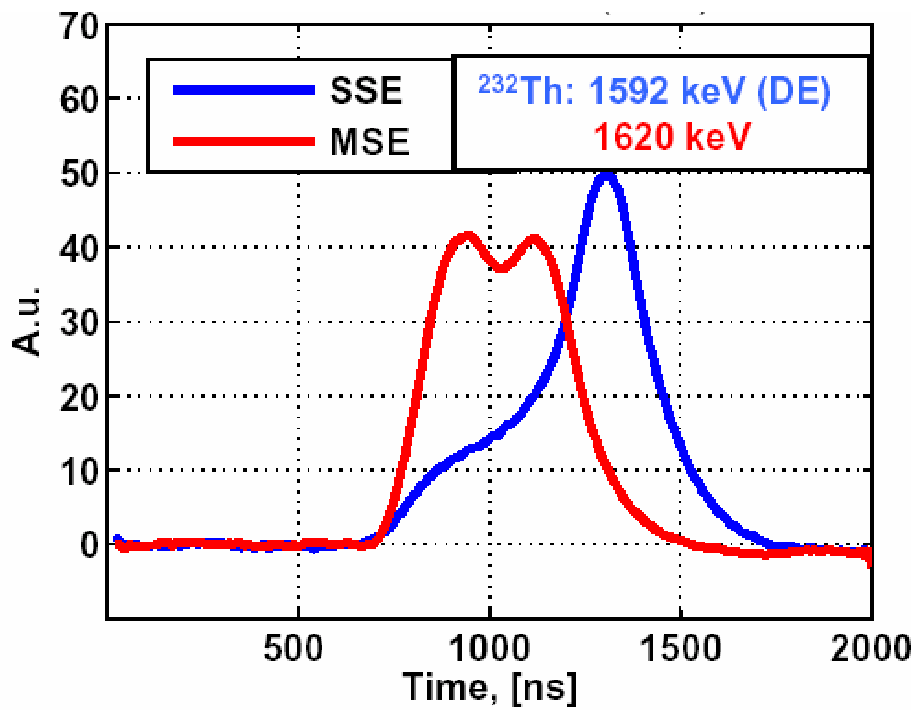
MSE Multi Site Events:
energy deposition in full detector volume
e.g. Compton scattering



Discrimination methods:
- pulse shape analysis
- anti-coincidence of detectors, detector segments, detectors and LAr

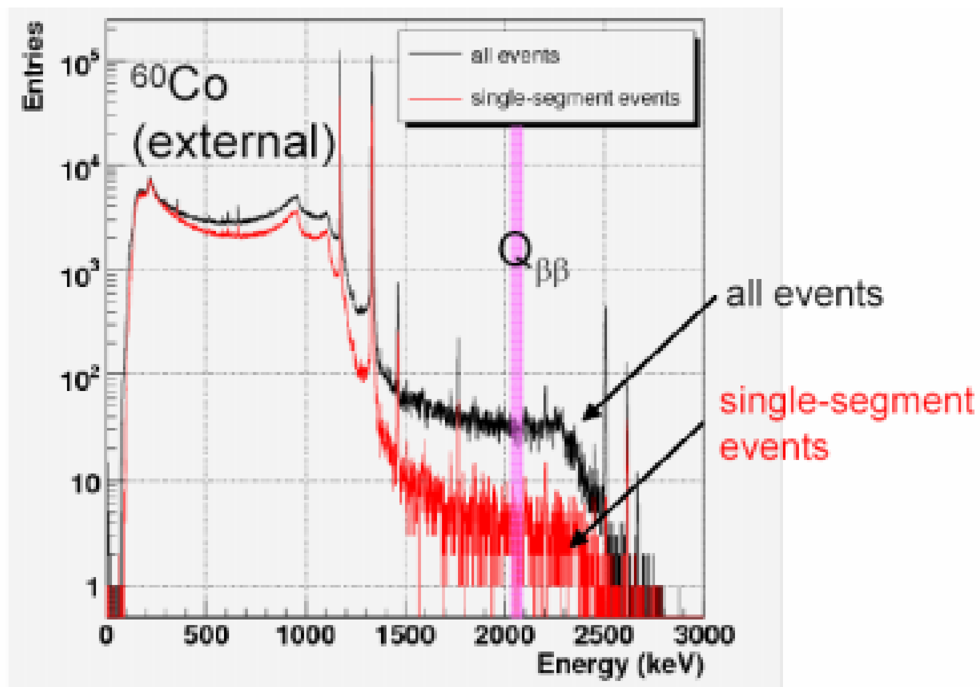
examples for background suppression

pulse shapes from SSE and MSE events



measured with ANG5 of HdM and old
i.e. slow front end electronics

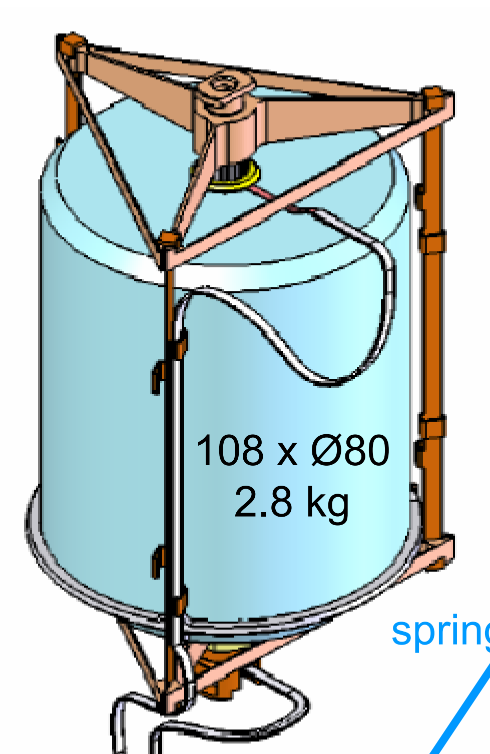
vetoing MSE in segmented Ge diode



measured with 3x6 segmented true-coaxial
n-type prototype crystal for phase II

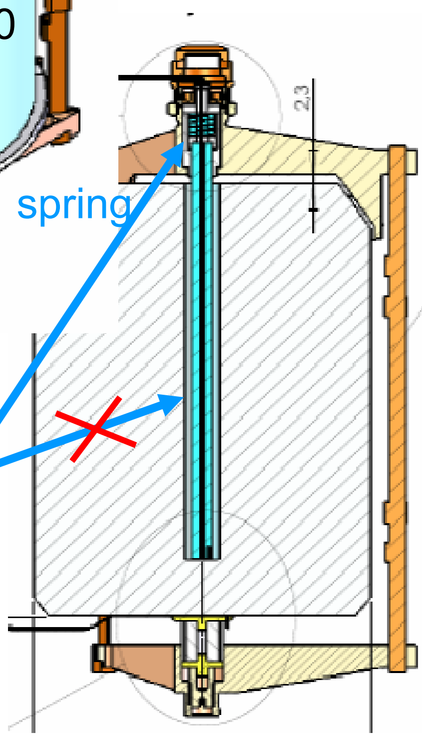
► large suppression factors,
O(5-50) depending on source & geometry

R&D: low mass diode supports and contacts



phase I

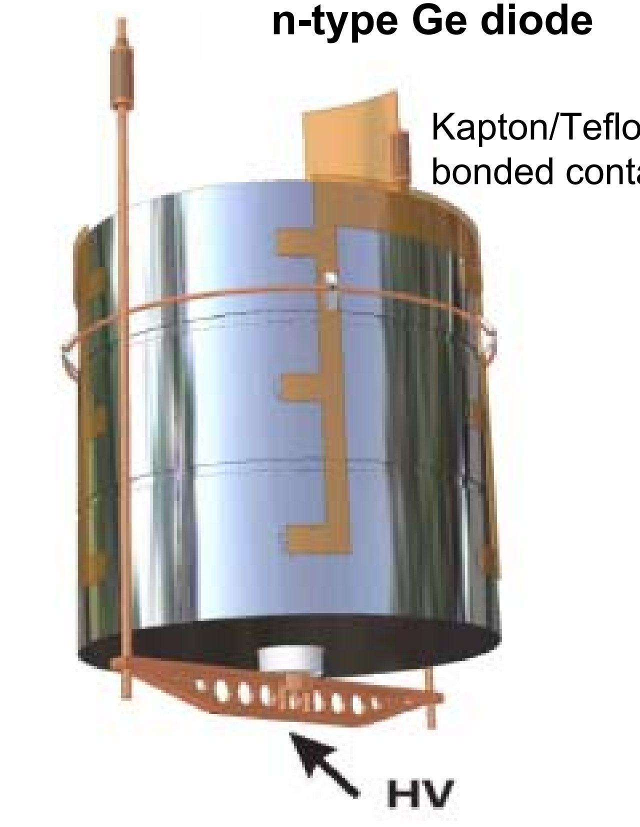
HdM & IGEX
p-type Ge diodes



Cu	80.8 g
Si	4.5 g
PTFE	6.4 g

phase II

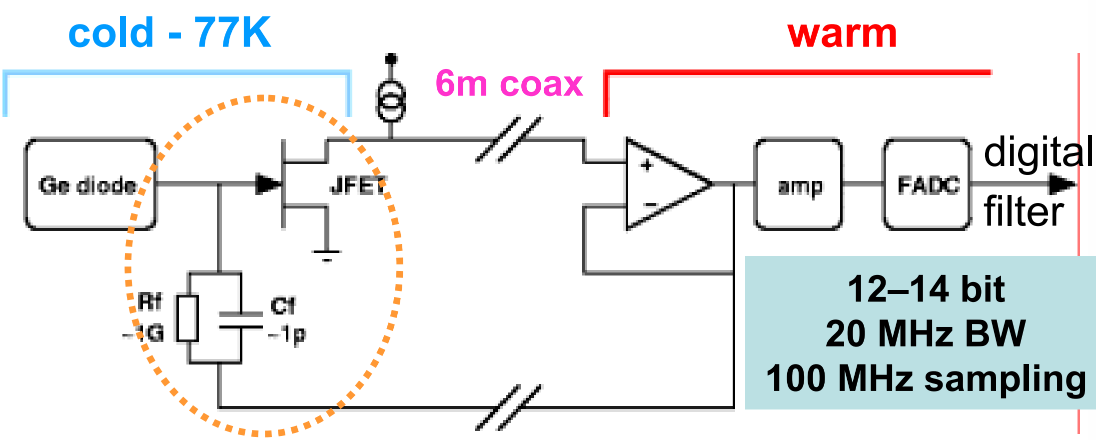
true-coaxial 3x6 segmented
n-type Ge diode



Kapton/Teflon cable
bonded contacts

total of ~30g mounting material

R&D: low mass frontend electronics(1&2)

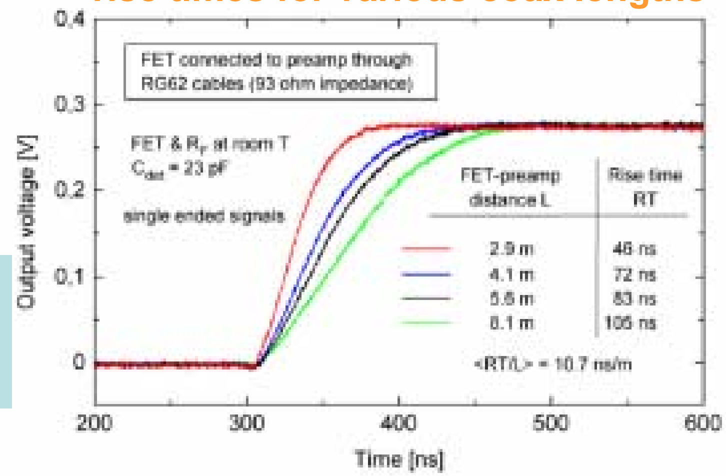


Aalseth et al., IEEE NSS-MIC, 2004

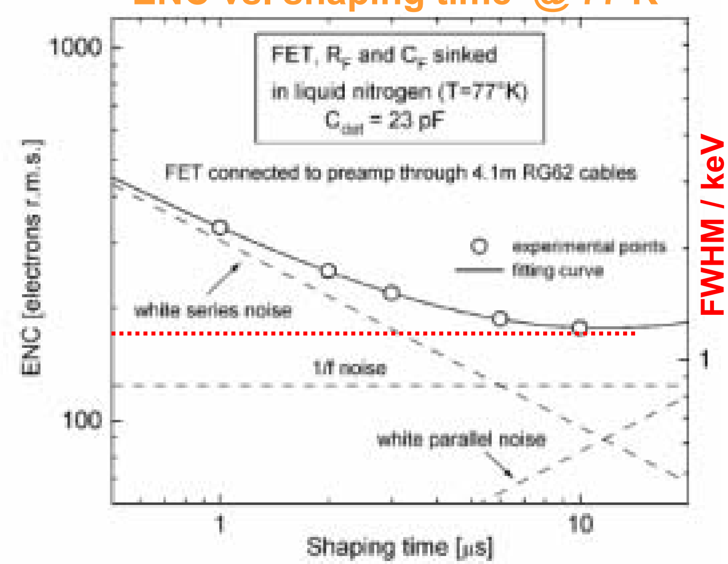
+ available & working
  ► phase I
- increased rise time
- potential for noise pickup

2nd solution: cold monolithic JFET preamp IPA4
► present solution for phase I
+ available & exc. noise: ENC ~ 150e$^-$ rms
- external FET, Rf, Cf, bias supplies

rise times for various coax lengths



ENC vs. shaping time @ 77 K



R&D: low mass frontend electronics (3)

WANTED: ASIC frontend indispensable for phase II with segmented detectors!

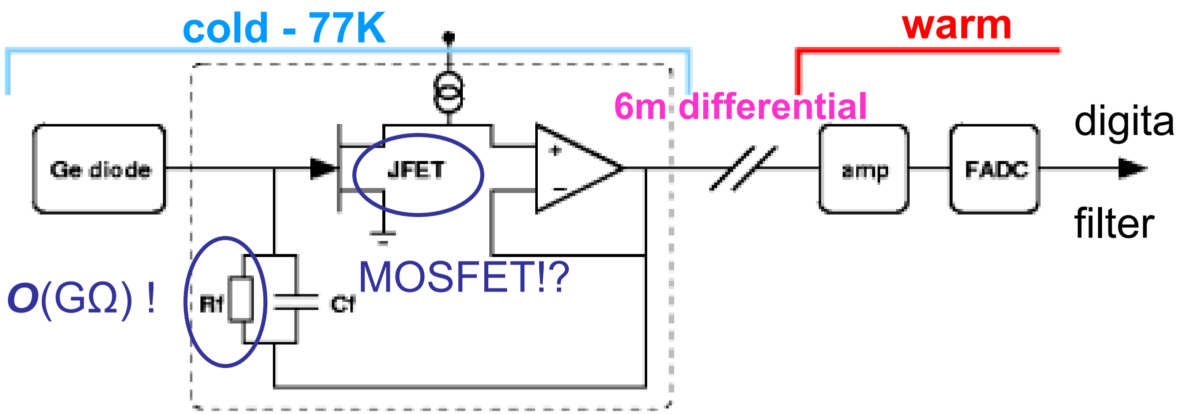
Specs for 77K ASIC

gain	200 mV/MeV
dyn. range	2000
BW	20-30 MHz
ENC	<100e @ 30 pF
output	differential

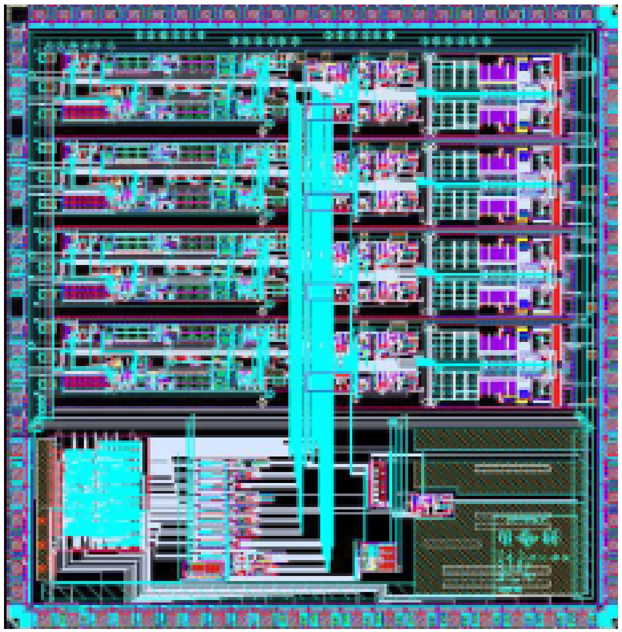
► ASIC development in CMOS
challenges: Rf, 1/f noise of MOSFET

i) ASIC in 0.8µ AMS process,
w / wo integrated input FET,
Rf and Cf not integrated,
very good results

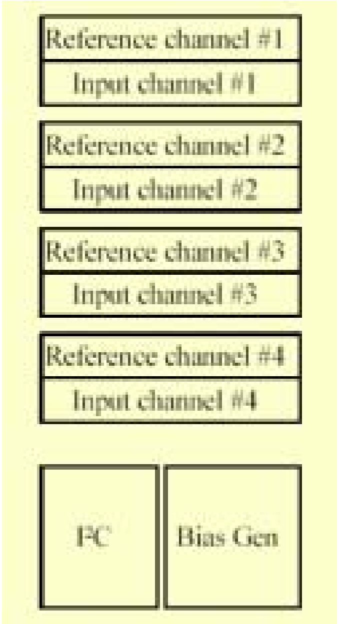
ii) ASIC in 0.6µ, 5V XFab process,
w / wo integrated input FET,
integrated Rf, Cf and bias supplies,
tests in progress



CSA104, 4 channels, 5.6x5.5mm²



floor plan



R&D: material screening / purification

Ge γ spectrometers

- Baksan 600 m w.e. (soon → 4900 m w.e.) 4-fold spectrometer
- Hades 500 m w.e. Ge-2 – Ge-9
- MPI-K 15 m w.e. 3 diodes
- LNGS 3500 m w.e. GeMPI 1,2,(3) S : ~ *O*(10[100]) μBq/kg for heavy [light] samples

Rn-222 diagnostics / monitoring

- emanation technique S : 0.5 μBq / m^2 , 10 μBq / kg
- gas purity analysis
- electrostatic chamber : 0.1 – 1 mBq / m^3

α spectrometer

- Baksan (ionization chamber) S : 10 Bq/m^3 (quick), background: 0.002 / ($cm^2 \cdot h$)
- Krakow

ICPMS **(inductively coupled plasma mass spectrometry)**

- Frankfurt U S : U/Th ~ 1 μBq / kg > secular equilibrium? <
- LNGS & commercial

(measured materials: Kapton, Teflon, Torlon, MLI, PMT glass, Cu, steel, Cu/P granulate)

►Challenge: screening of plastic materials at required Th sensitivity

Cu surface purification studies **(cryostat > 100 m^2)**

- Cu disks radiated with strong Rn source S : 1 μBq / m^2

... and still more R&D for phase II

- optimization of purification of enriched Ge-76 oxide to 6N grade metal
- optimization of production of new enriched Ge-76 diodes
- commissioning of test stands for the characterization of Ge-diodes
- study of segmented n- and p-type true-coaxial Ge-diodes

- detailed Monte-Carlo simulations

example

phase II background index
for available materials
in 10^{-4} cts / (keV·kg·y)

detector	5
holder (copper)	4
holder (Teflon)	8
cabling	6
electronics	3
infrastructure	4
muons, neutrons	2
sum	32

to be improved!

- study of active LAr shield
- and more

2004

	• Feb	Letter of Intent to LNGS, **hep-ex/0404039**
	• Sep	formation of collaboration
	• Oct	funding requests approved by MPG
	• Oct	Proposal to LNGS, www.mpi-hd.mpg.de/GERDA/proposal.pdf

2005

	• Feb	GERDA approved by LNGS, location in Hall A in front of LVD
	• May / Jun	funding requests approved by INFN / BMBF
	• Jul	FMECA & HAZOP safety studies for GERDA with copper cryostat
	• Dec	electron beam welding certification for copper cryostat

2006

	• Feb	delivery of 37.5 kg enriched Ge-76
	• Apr	all HdM & IGEX detectors fully functional at LNGS
	• May	contract for water tank concluded, decision for stainless steel cryostat
	• Jun	successful test of 3x6 segmented true-coaxial n-type Ge diode
	• Jul	safety review for GERDA with stainless steel cryostat started
	• Aug	LNGS hall A ready for installation, tender for cryostat published
	• Sep	contract for cryostat to be concluded

2007

	•	installation, commissioning

Summary

- approved by LNGS with its location in hall A,
- substantially funded by BMBF, INFN, MPG, and Russia in kind
- construction to start in LNGS Hall A end of 2006
- parallel R&D for phase II
- in 2007 ► finish installation, ► start commissioning

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

► scrutinize KKDC result within ~1 year

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

► $T_{1/2} > 1.5 \cdot 10^{26}$ y , $\langle m_{ee} \rangle < 0.2$ eV *

* with nucl. m.e. from Rodin et al.

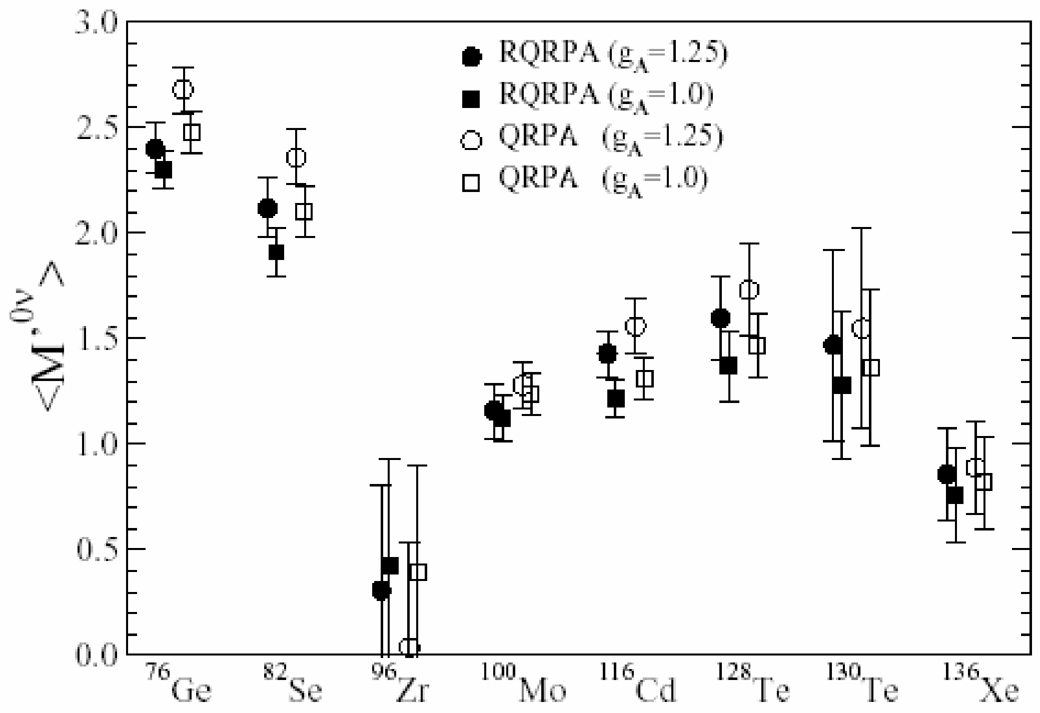


FIG. 2: Average nuclear matrix elements $\langle M'^{0\nu} \rangle$ and their variance (including the error coming from the experimental uncertainty in $M^{2\nu}$) for both methods and for all considered nuclei. For ^{136}Xe the error bars encompass the whole interval related to the unknown rate of the $2\nu\beta\beta$ decay.

V.A.Rodin, A.Faessler, F.Simlovic & P.Vogel, NP A766 (2006) 107-131

stainless steel cryostat with internal Cu shield