GERDA

The Germanium Detector Array for the study of 0v2β decay of Ge-76

Introduction and Status

Karl Tasso Knöpfle

MPI Kernphysik, Heidelberg

GERDA FE Meeting at Milano Bicocca/INFN
16 April 2010

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The GERmanium Detector Array Collaboration

http: //www.mpi-hd.mpg.de/GERDA

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[d]) Joint Institute for Nuclear Research, Dubna, Russia
[e]) Institute for Reference Materials and Measurements, Geel, Belgium
[f]) Max Planck Institut für Kernphysik, Heidelberg, Germany
[g]) Dipartimento di Fisica, Università Milano Bicocca, Milano, Italy
[h]) INFN Milano Bicocca, Milano, Italy
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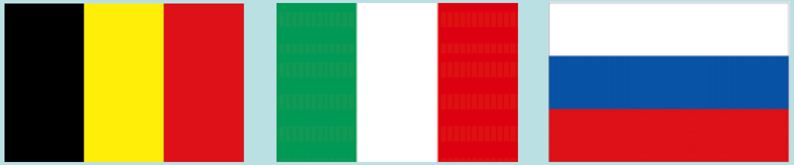
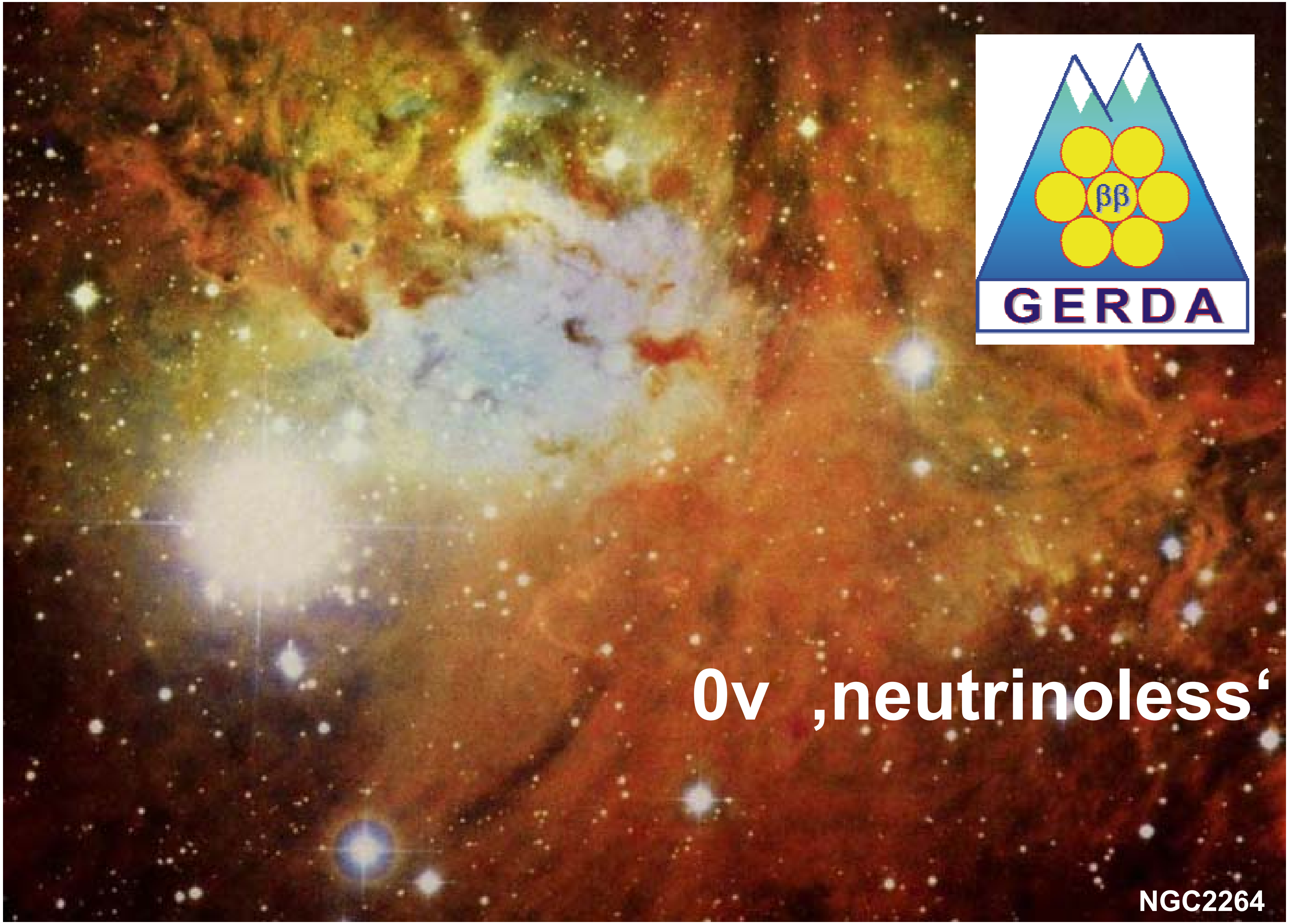
[k]) Institute for Theoretical and Experimental Physics, Moscow, Russia
[l]) Russian Research Center Kurchatov Institute, Moscow, Russia
[m]) Max-Planck-Institut für Physik, München, Germany
[n]) Dipartimento di Fisica dell'Università di Padova, Padova, Italy
[o]) INFN Padova, Padova, Italy
[p]) Physikalisches Institut, Eberhard Karls Universität Tübingen, Tübingen, Germany
[q]) Physik Institut der Universität Zürich, Zürich, Switzerland



~ 95 physicists from 17 institutions


ββ
GERDA
NGC2264



ββ

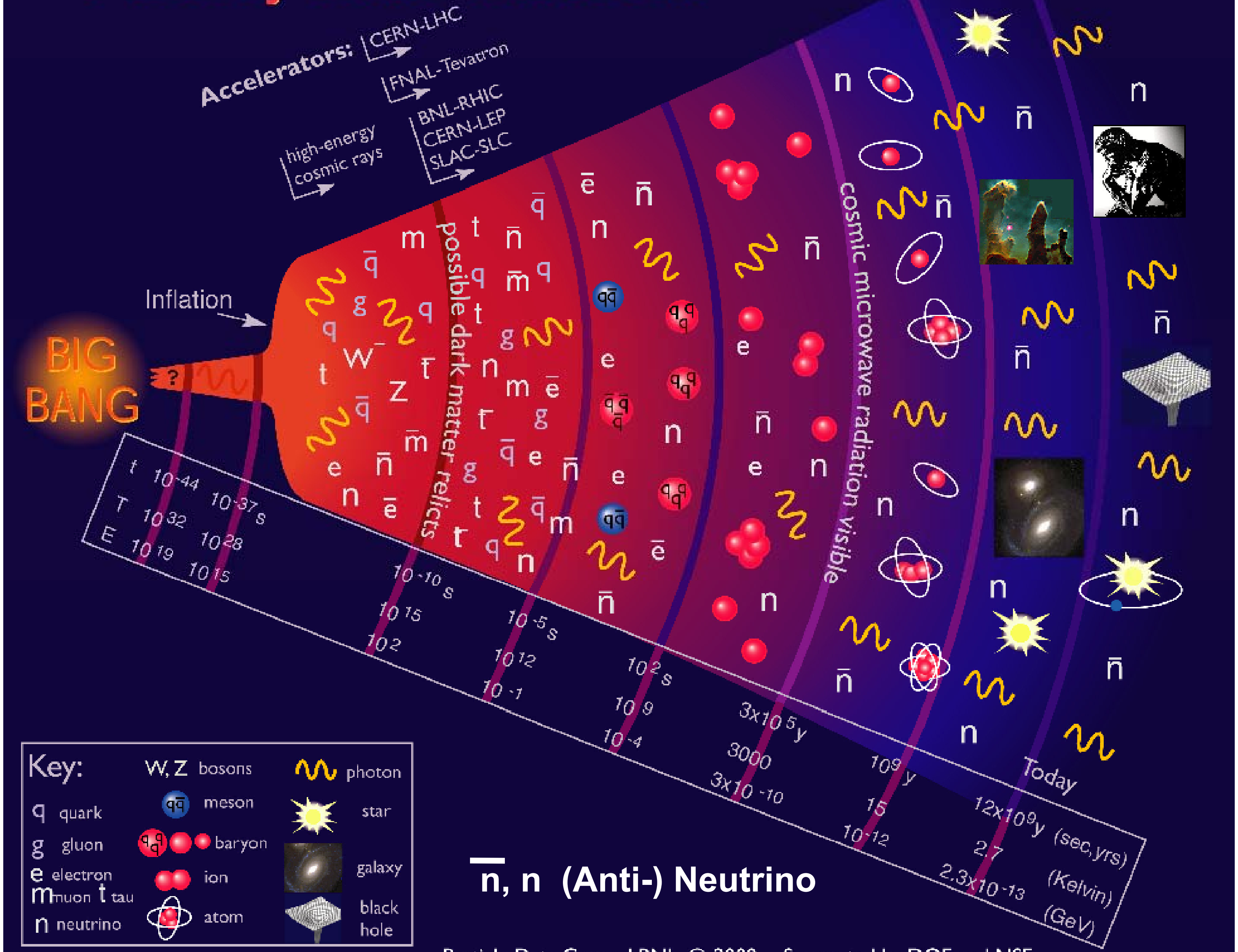
GERDA

0ν ‚neutrinoless‘

NGC2264

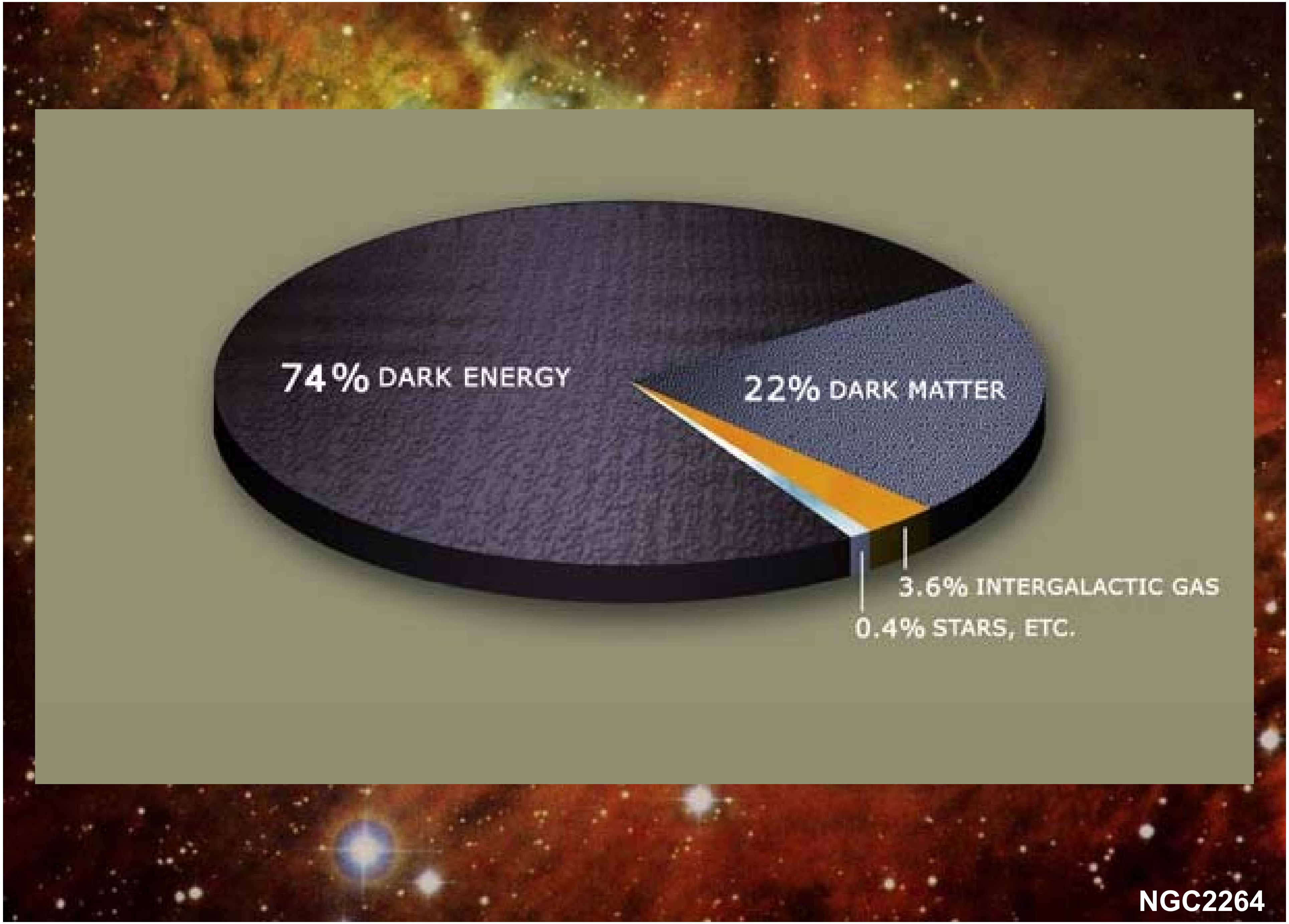
History of the Universe

13.9±0.5 Mrd y



n̄, n (Anti-) Neutrino

Particle Data Group, LBNL, © 2000. Supported by DOE and NSF


74% DARK ENERGY
22% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.
NGC2264

Two fundamental questions:

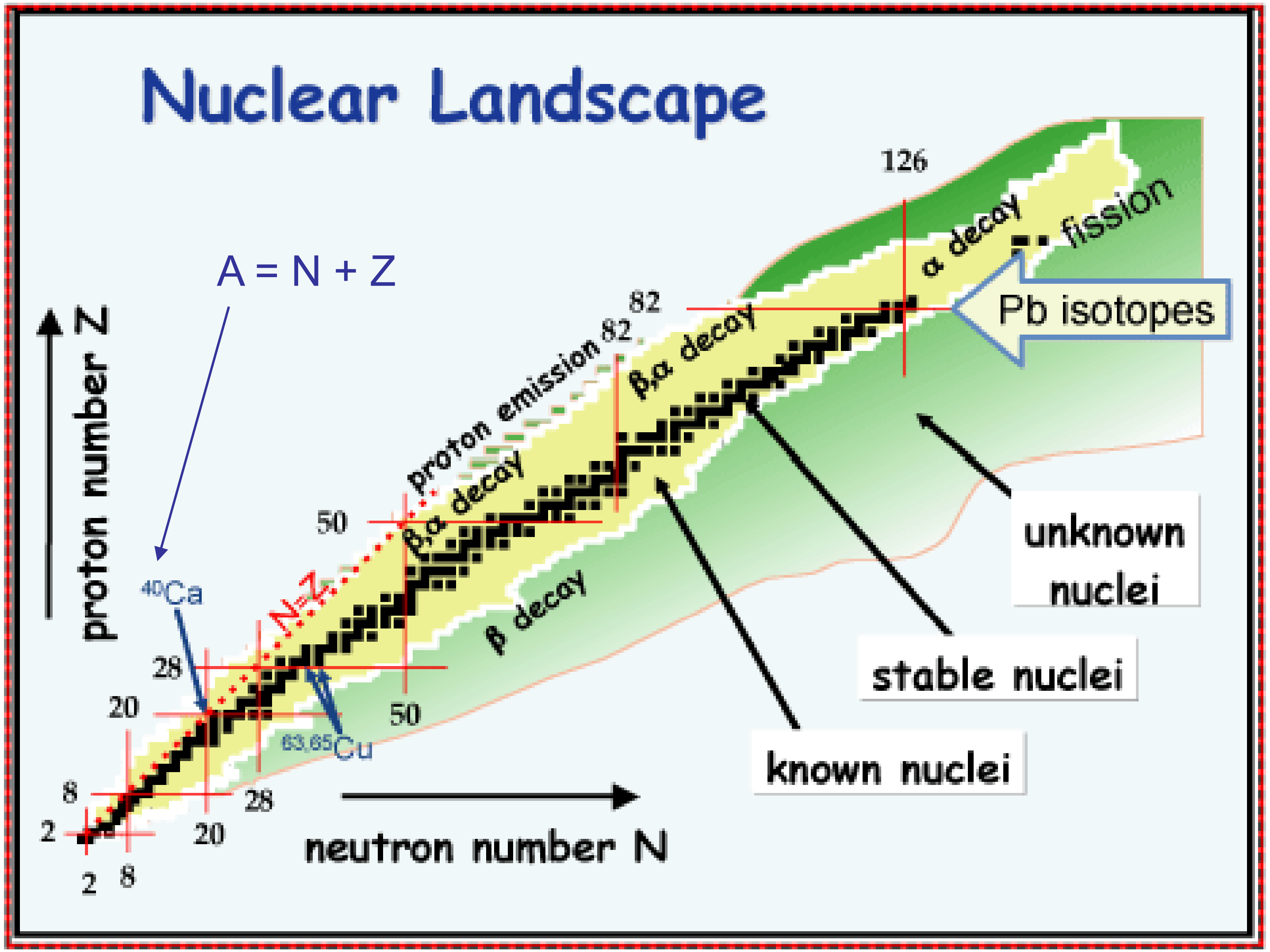
Why / how has the anti-matter produced in the big bang disappeared?

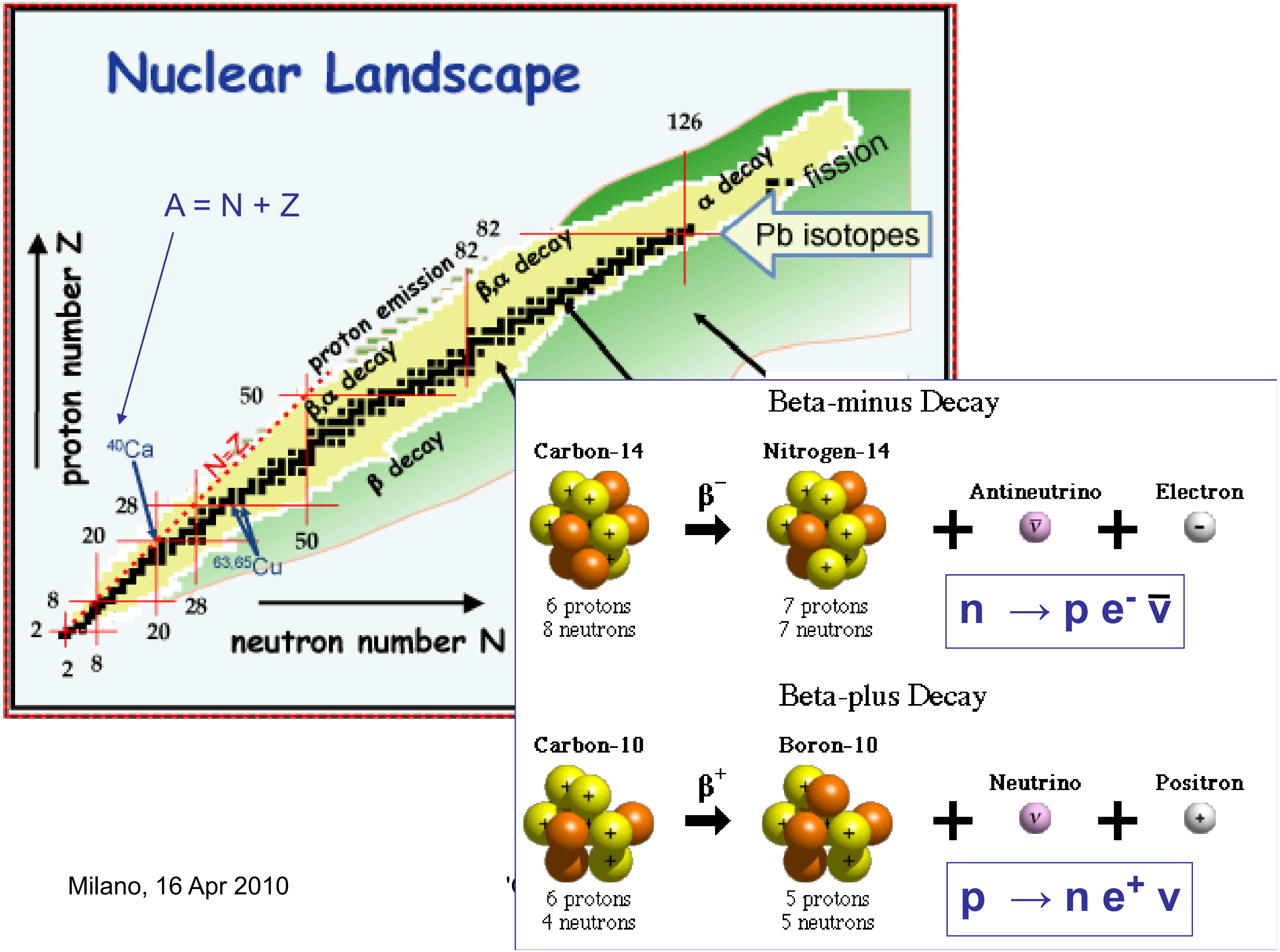
What is the stuff the universe is made from?
or What is ‘Dark Matter’ and ‘Dark Energy’?

Possible key:

NEUTRINOproperties !

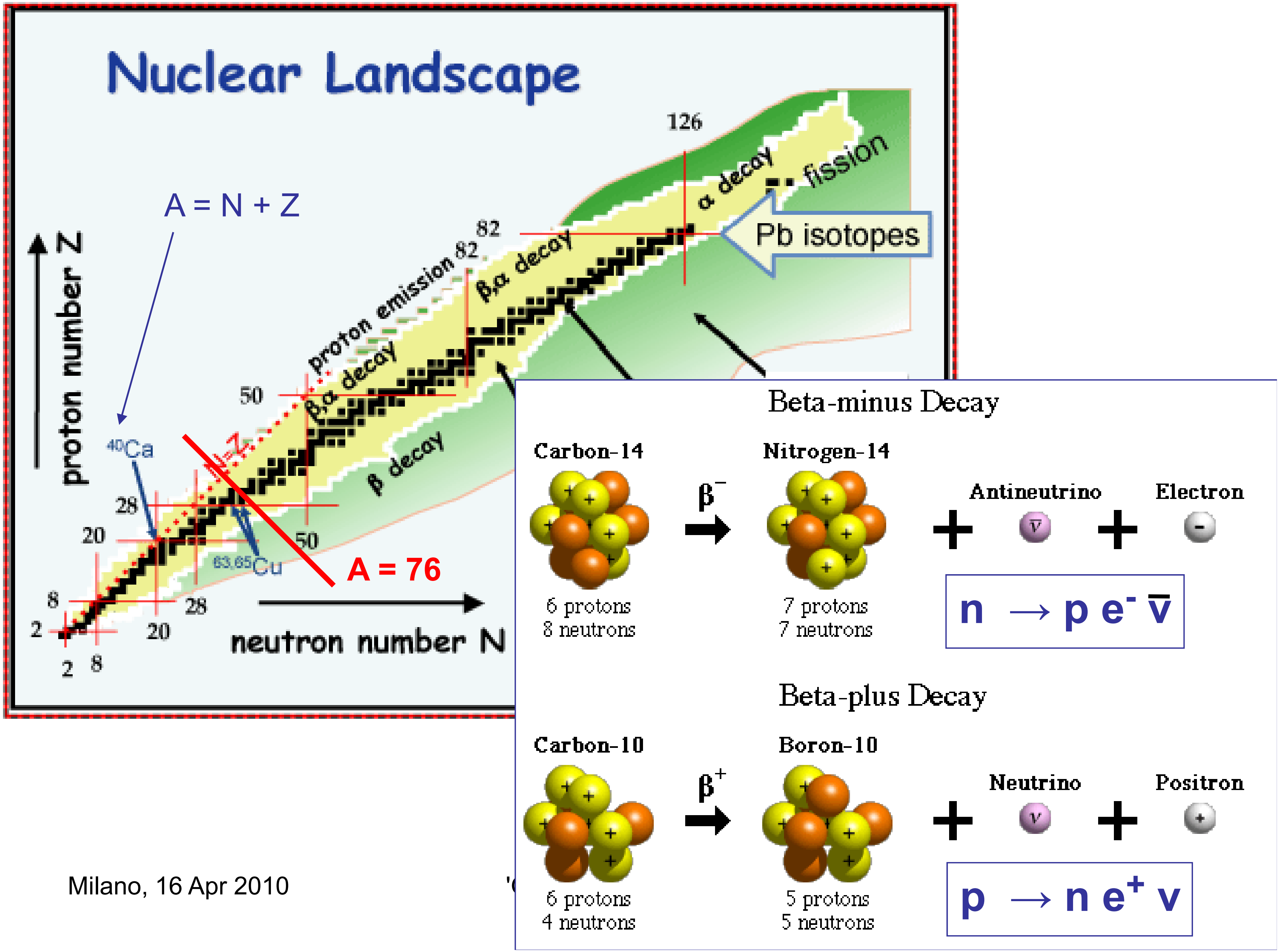
► Is the neutrino its own anti-particle ?! ◄


Nuclear Landscape
A = N + Z
proton number Z
neutron number N
^{40}Ca
^{63,65}Cu
N=Z
proton emission
β,α decay
β,α decay
β decay
α decay
fission
Pb isotopes
unknown nuclei
stable nuclei
known nuclei
126
82
82
50
50
28
28
20
20
8
8
2
2



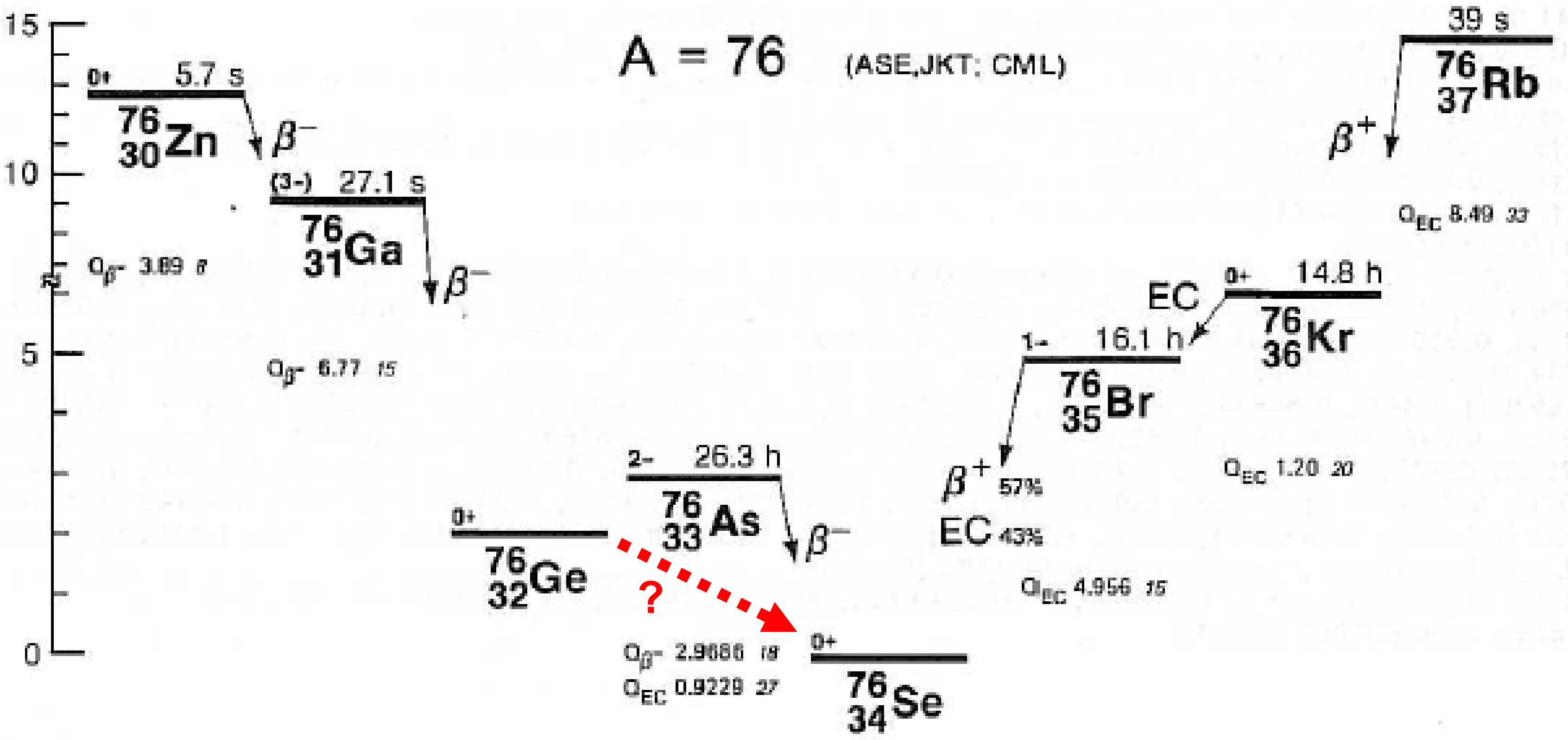
$n \rightarrow p\, e^{-}\, \bar{\nu}$

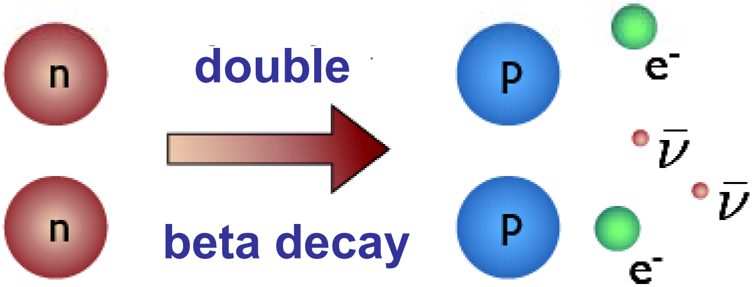
$p \rightarrow n\, e^{+}\, \nu$



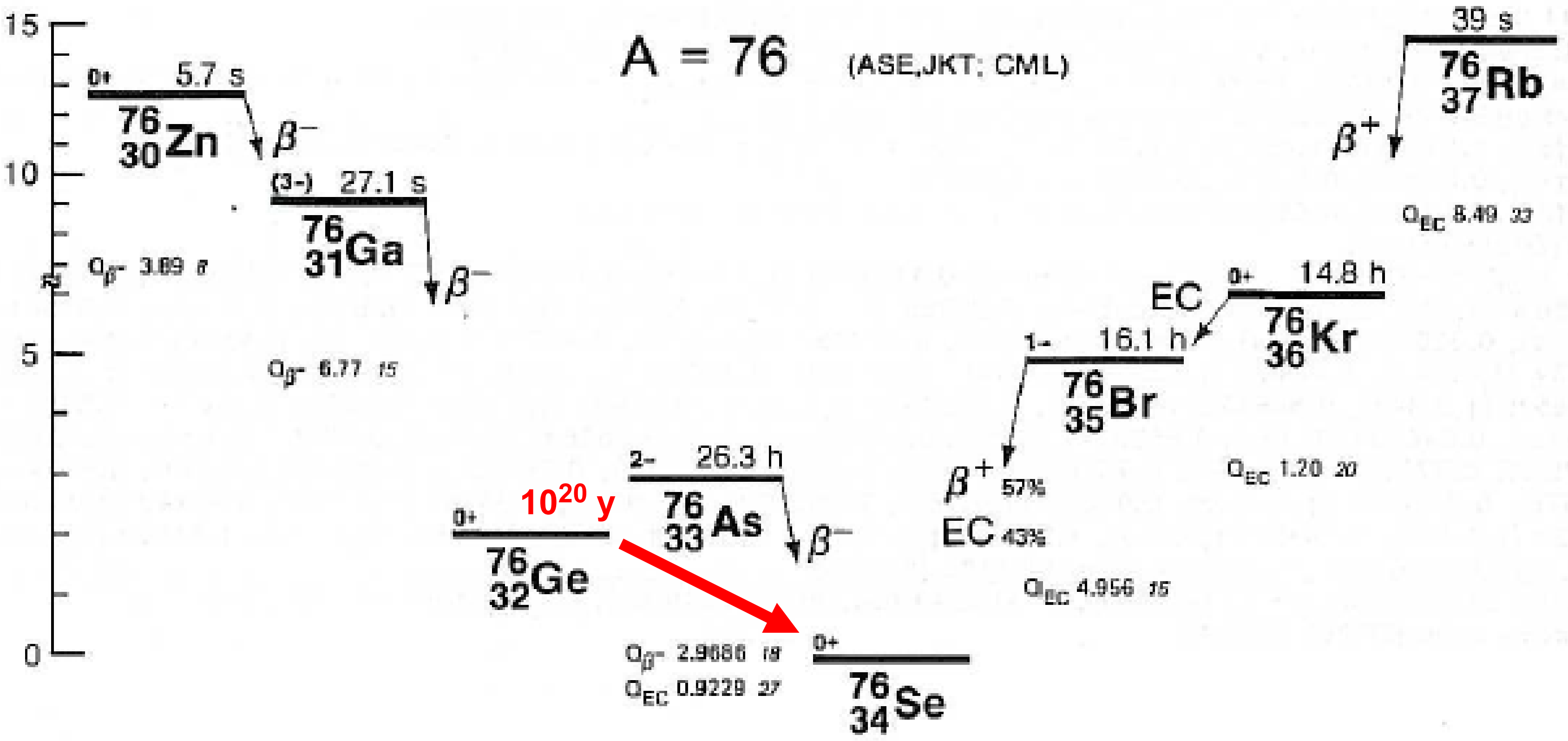
$$n \rightarrow p\, e^- \bar{\nu}$$

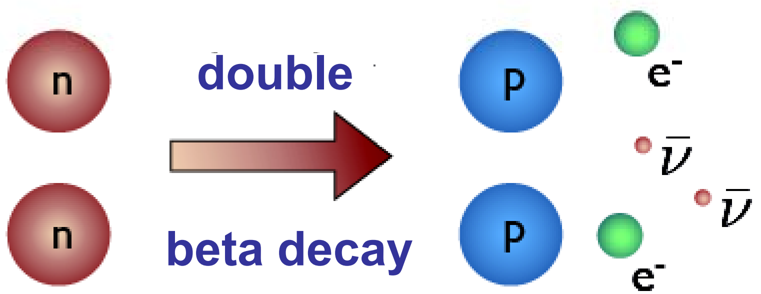
$$p \rightarrow n\, e^+ \nu$$


15
10
5
0
A = 76 (ASE,JKT; CML)
0+ 5.7 s
76 30 Zn
β⁻
Qβ⁻ 3.89 8
(3-) 27.1 s
76 31 Ga
β⁻
Qβ⁻ 6.77 15
0+
76 32 Ge
?
2- 26.3 h
76 33 As
β⁻
Qβ⁻ 2.9686 18
QEC 0.9229 27
0+
76 34 Se
1- 16.1 h
76 35 Br
β+ 57%
EC 43%
QEC 4.956 15
EC
0+ 14.8 h
76 36 Kr
QEC 1.20 20
39 s
76 37 Rb
β+
QEC 8.49 33

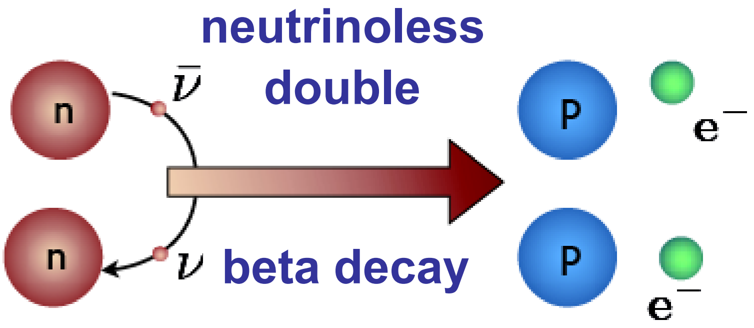

n
n
double
beta decay
p
p
e$^-$
$\bar{\nu}$
$\bar{\nu}$
e$^-$

2v2β

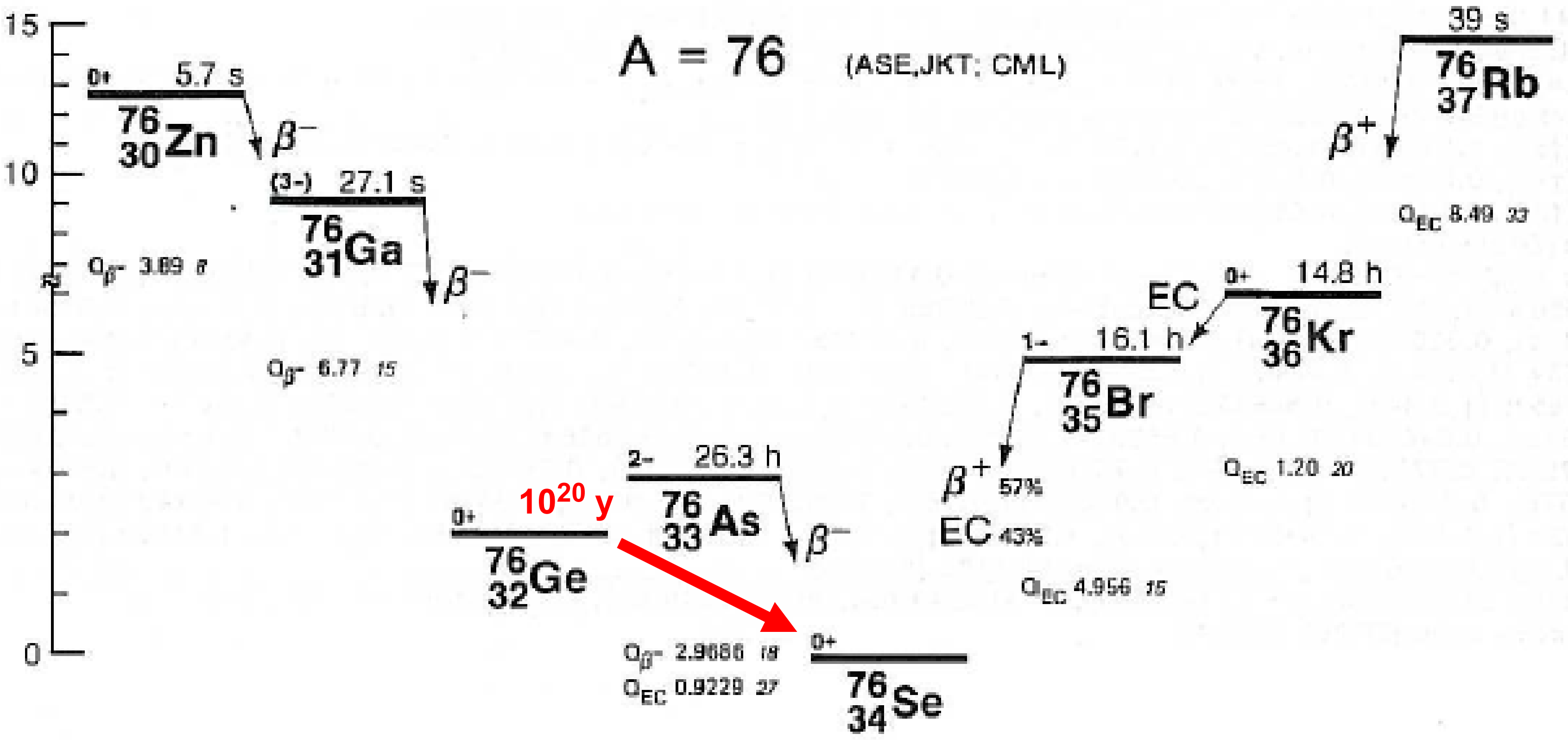

A = 76
(ASE,JKT; CML)
15
10
5
0
0+ 5.7 s
$^{76}_{30}$Zn
β⁻
Q$_{β^-}$ 3.89 8
(3-) 27.1 s
$^{76}_{31}$Ga
β⁻
Q$_{β^-}$ 6.77 15
0+
10^{20} y
$^{76}_{32}$Ge
2- 26.3 h
$^{76}_{33}$As
β⁻
Q$_{β^-}$ 2.9686 18
Q$_{EC}$ 0.9229 27
0+
$^{76}_{34}$Se
1- 16.1 h
$^{76}_{35}$Br
β⁺ 57%
EC 43%
Q$_{EC}$ 4.956 15
EC
0+ 14.8 h
$^{76}_{36}$Kr
Q$_{EC}$ 1.20 20
39 s
$^{76}_{37}$Rb
β⁺
Q$_{EC}$ 8.49 33


n
n
double
beta decay
p
p
e-
ν̄
ν̄
e-

2v2β


neutrinoless
double
beta decay
n
n
ν̄
ν
p
p
e−
e−

0v2β


A = 76
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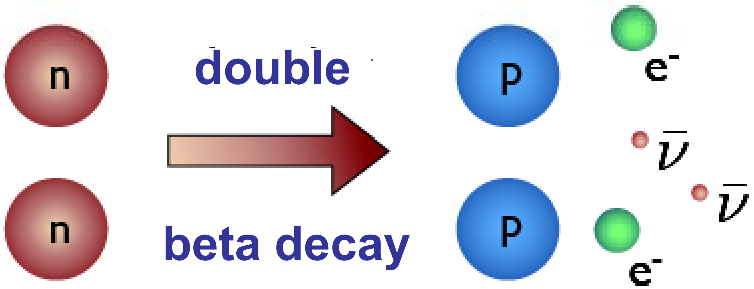
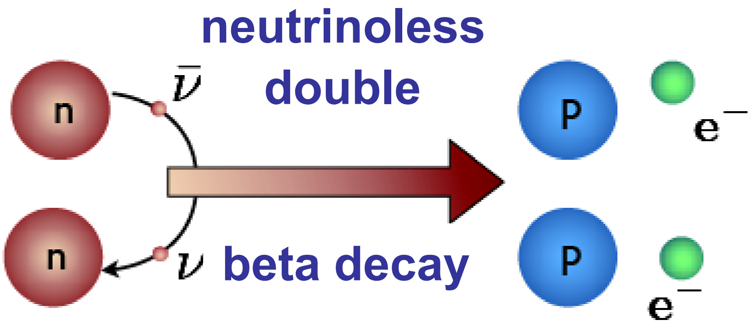


double beta decay

2v2β



neutrinoless double beta decay

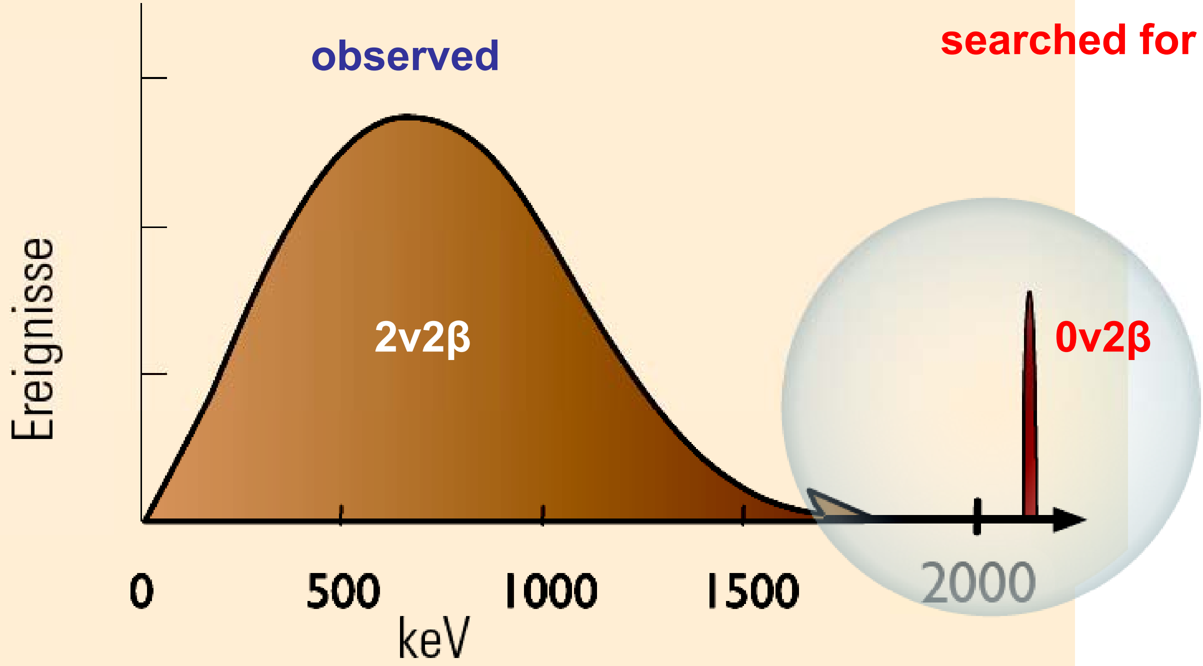
0v2β

$T \sim 10^{20}$ y

$T > 10^{25}$ y

searched for

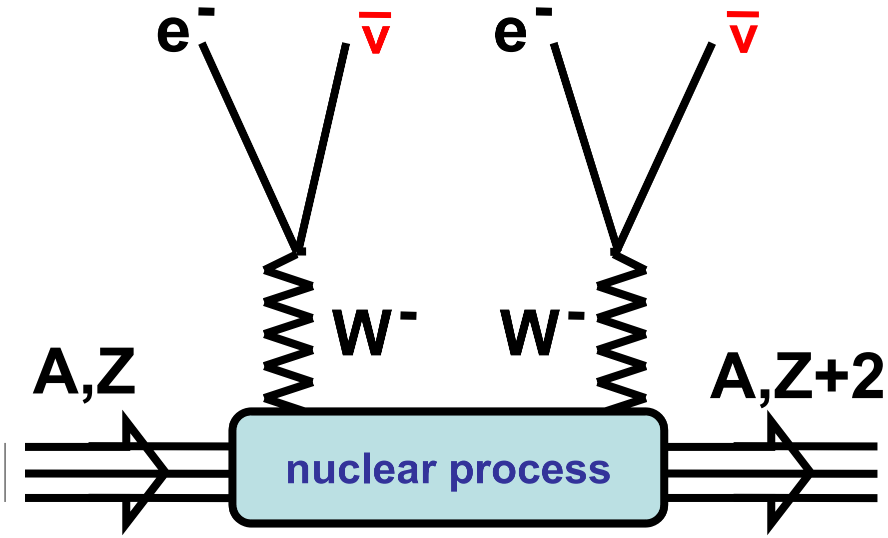
observed



spectrum of sum energy of both electrons

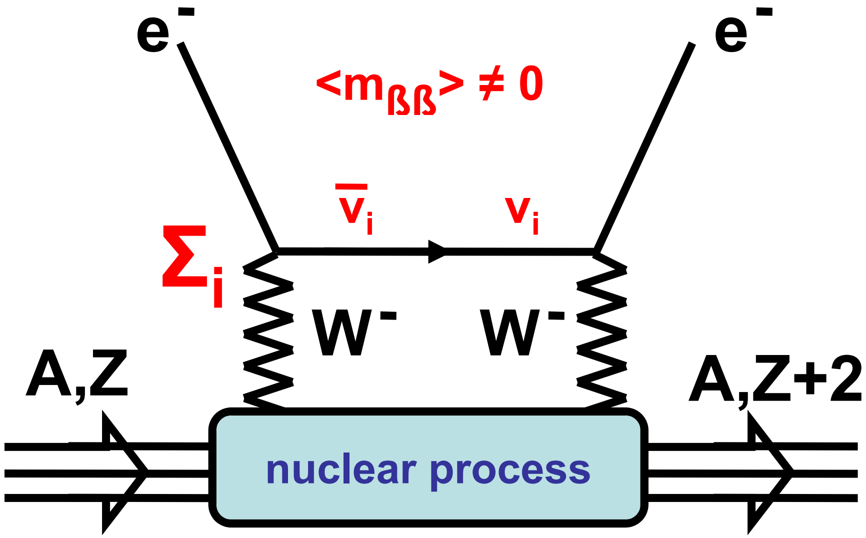
double beta decay

2νββ



conventional 2nd order process
observed in various nuclei
$T_{1/2} \sim 10^{19} – 10^{21}$ yrs

0νββ



hypothetical process , $T_{1/2} > 10^{25}$ yrs,
only possible if
neutrinos have Majorana masses

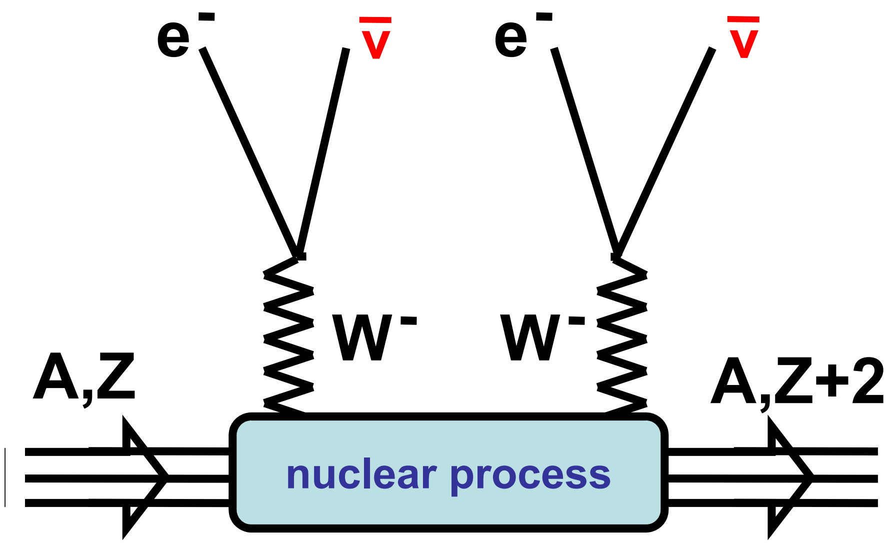
► lepton number violation ΔL=2

► access to absolute ν mass scale

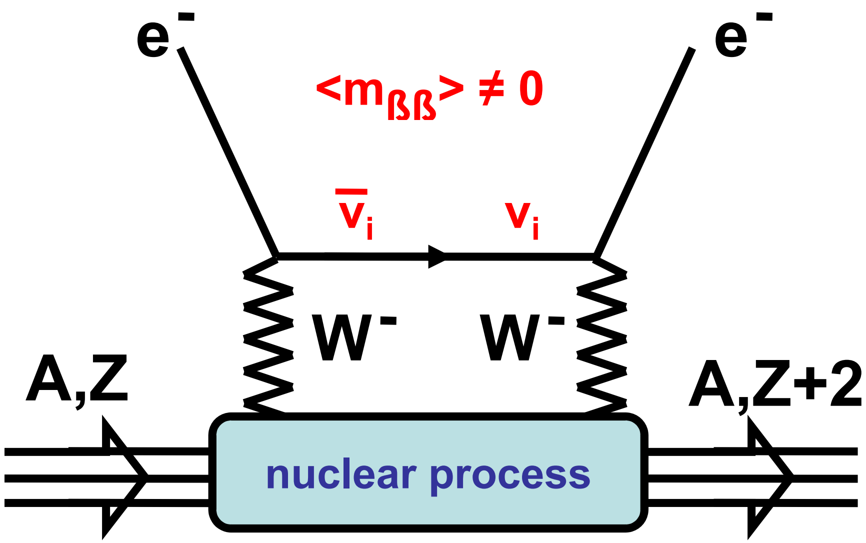
► physics beyond s.m.

double beta decay

2vßß



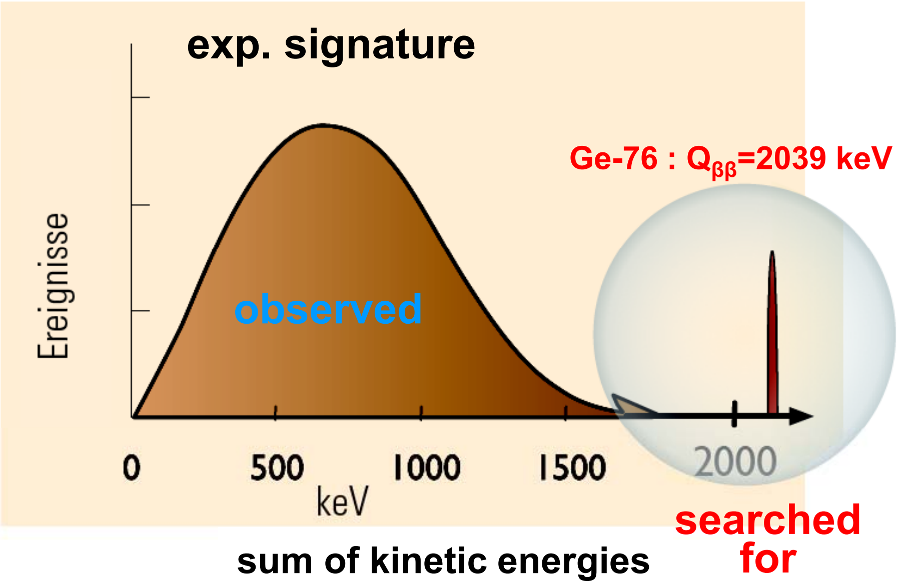
0vßß



conventional

observed in v

$T_{1/2} \sim 10^{19}$ – 1



v

cess , $T_{1/2} > 10^{25}$ yrs,

lajorana masses

r violation ΔL=2

lute v mass scale

d s.m.

halflife – effective mass relation

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

$<m_{\beta\beta}>$ best limits* / value

Heidelberg – Moscow Experiment

5 enriched Ge-76 diodes (EPJ A12 ('01) 147)

background index ~0.1 cts/ (kev ·kg ·y)

35.5 kg y : $T_{1/2} \geq 1.9 \cdot 10^{25}$ y (90% CL)

$<m_{\beta\beta}> < 0.3 – 1$ eV

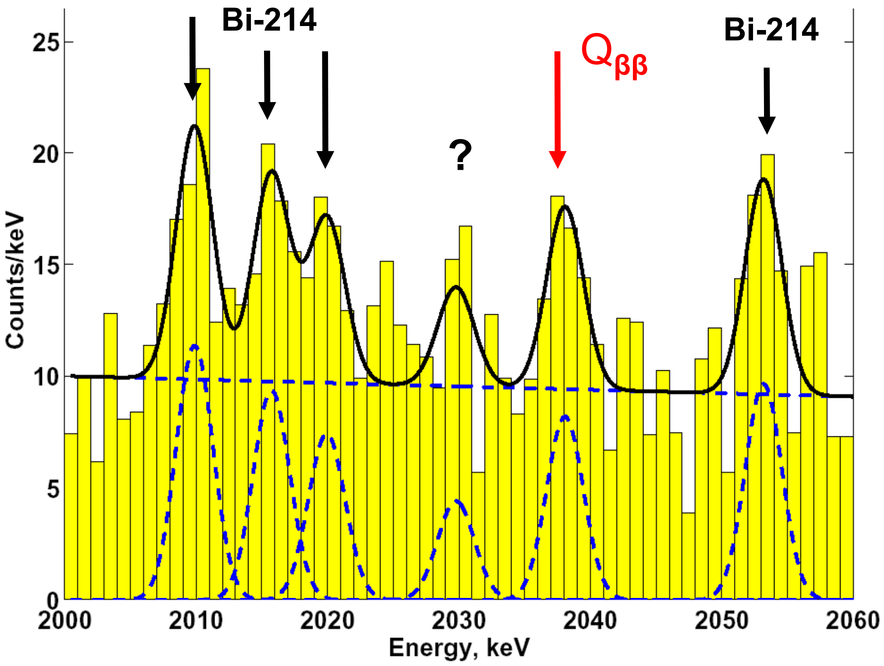
(similar limit by **IGEX**, NP B87 ('00) 278)

part of collaboration claims signal (PL B586 ('04) 198)

71.7 kg y : $T_{1/2} = 1.2\ (0.7\text{-}4.2) \cdot 10^{25}$ (3σ range)

$<m_{\beta\beta}> = 0.44\ (0.24 – 0.58)$ eV

Claimed 4σ significance dependent on background model (Strumia&Vissani '06, O. Chkvorets, PhD th. '08)



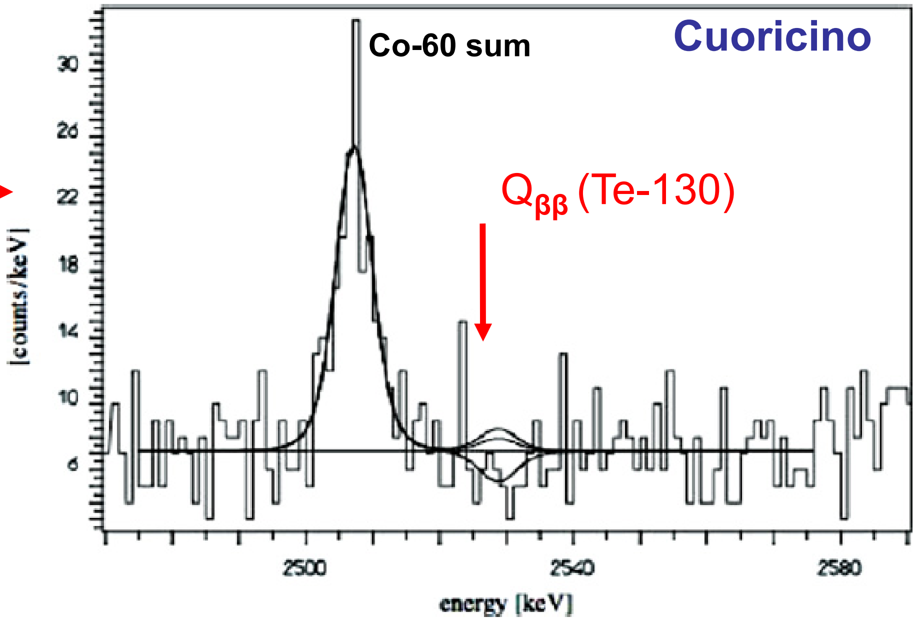
Cuoricino

62 TeO_2 bolometers (PR C7 ('08) 035502)

background index ~0.2 cts/ (kev ·kg ·y)

11.8 kg y : $T_{1/2} \geq 3.0 \cdot 10^{24}$ y (90% CL)

$<m_{\beta\beta}> < 0.19 – 0.68$ eV



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71.7 kg y : $T_{1/2} = 1.2\ (0.7\text{-}4.2)\cdot 10^{25}$ (3σ range)
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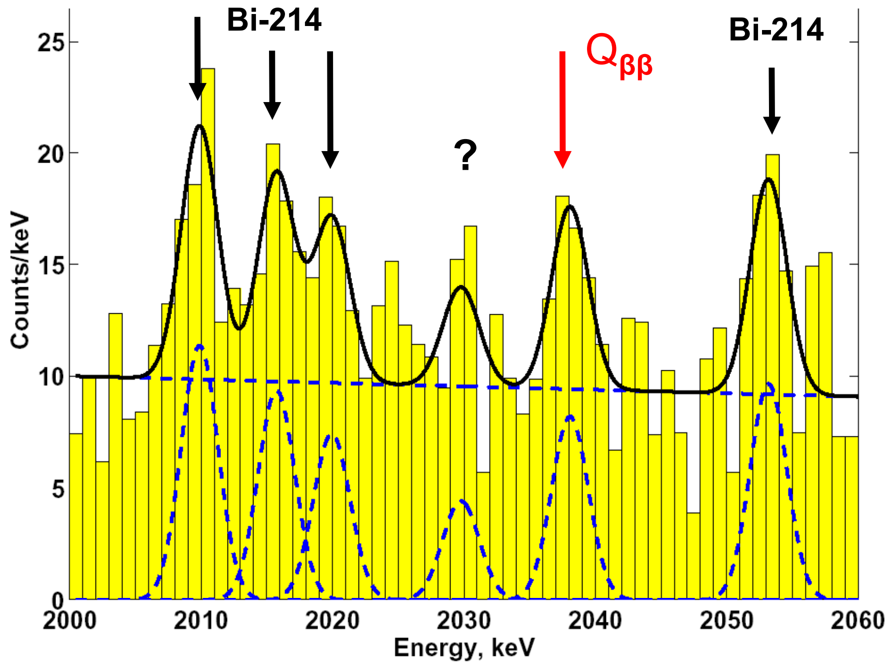

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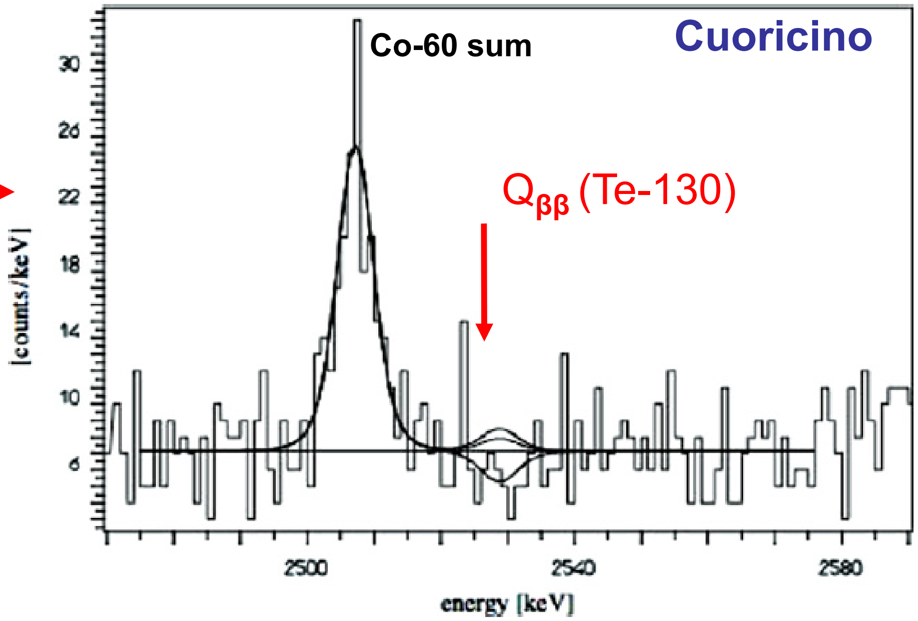
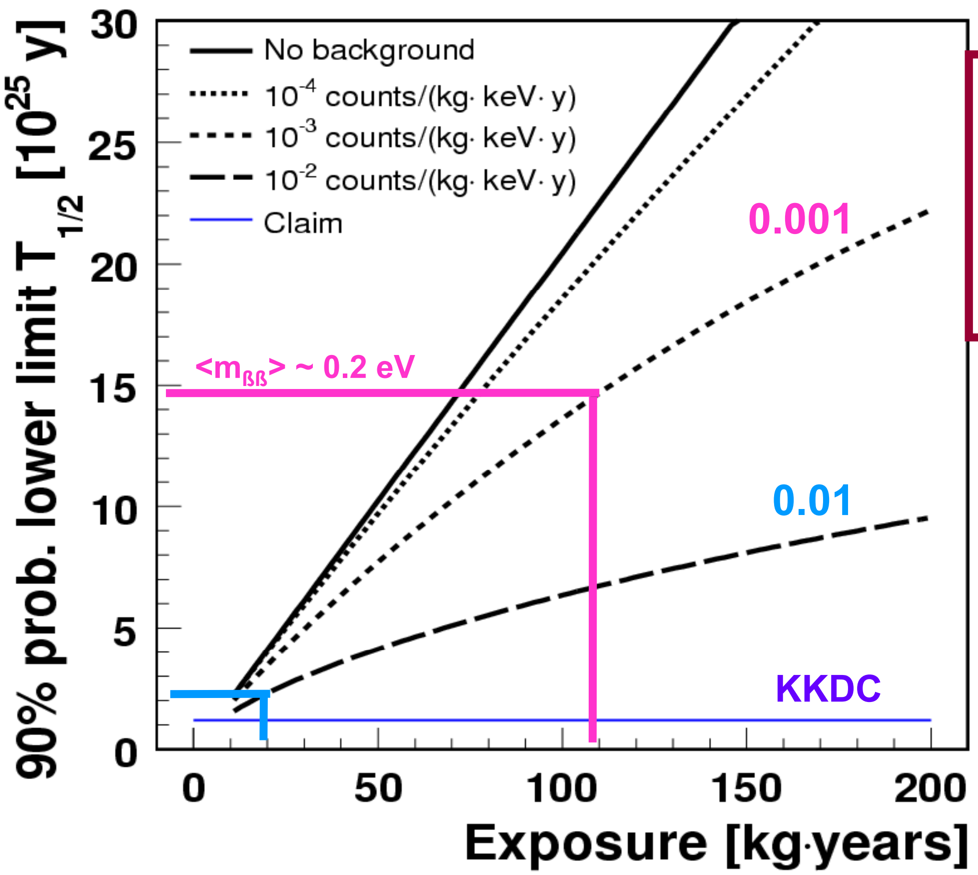
$<m_{\beta\beta}> < 0.19 – 0.68$ eV

Evidence remains unclear - confirmation needed with same & different isotopes
► 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)



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

phase I :
use Ge-76 diodes of HD-Moscow & IGEX
~18 kg
B ~ 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 background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

INTRINSIC or VERY CLOSE bgnds :
cosmogenic - ^{60}Co (5.3 a), ^{68}Ge (270 d)-
contaminated holders, FE, cables …

GERDA background reduction

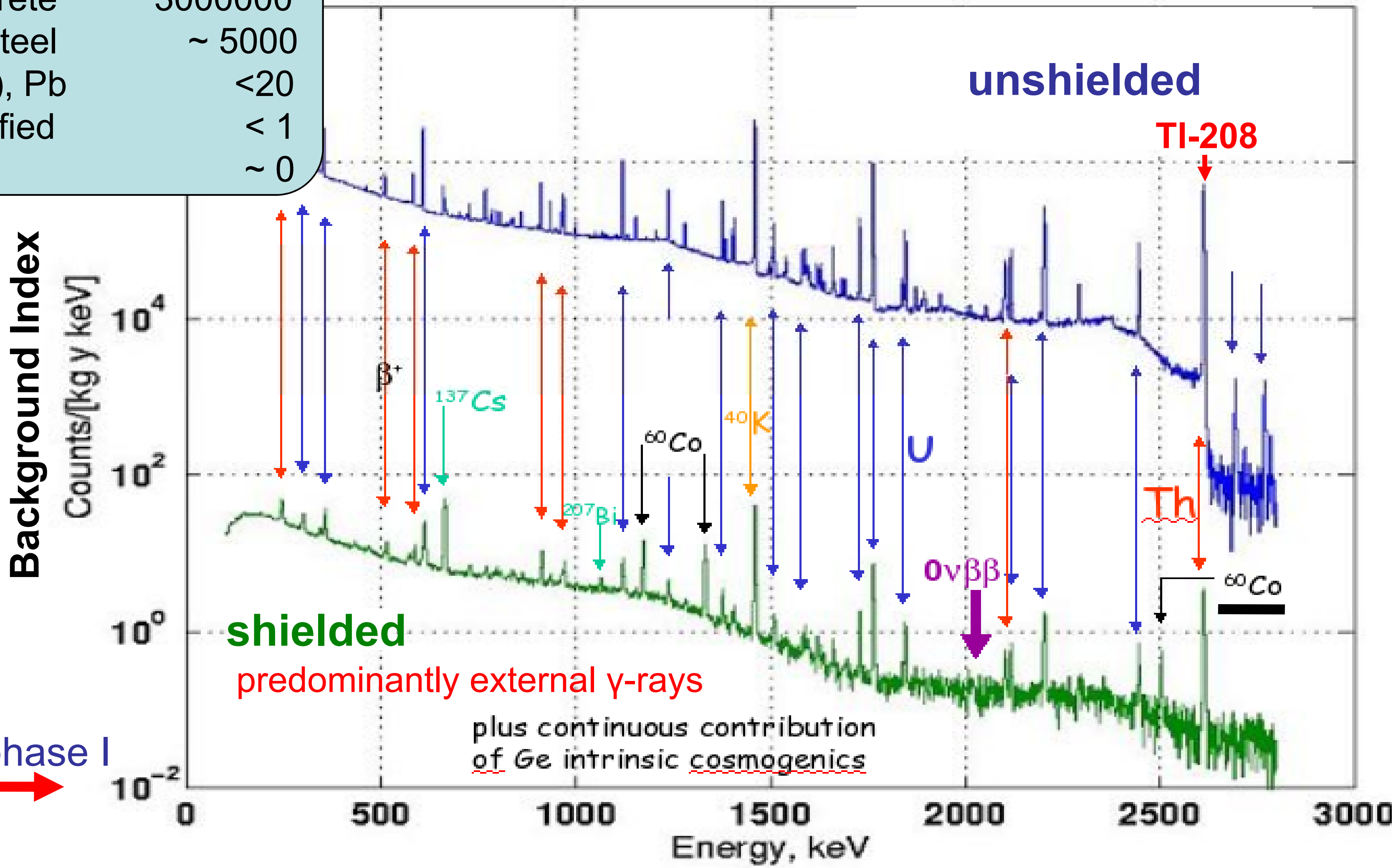
EXTERNAL bgnds: γ(Th, U), n, μ

LNGS: Laboratori Nazionali del Gran Sasso

background seen with Ge diode

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

spectra measured at LNGS with Ge diode



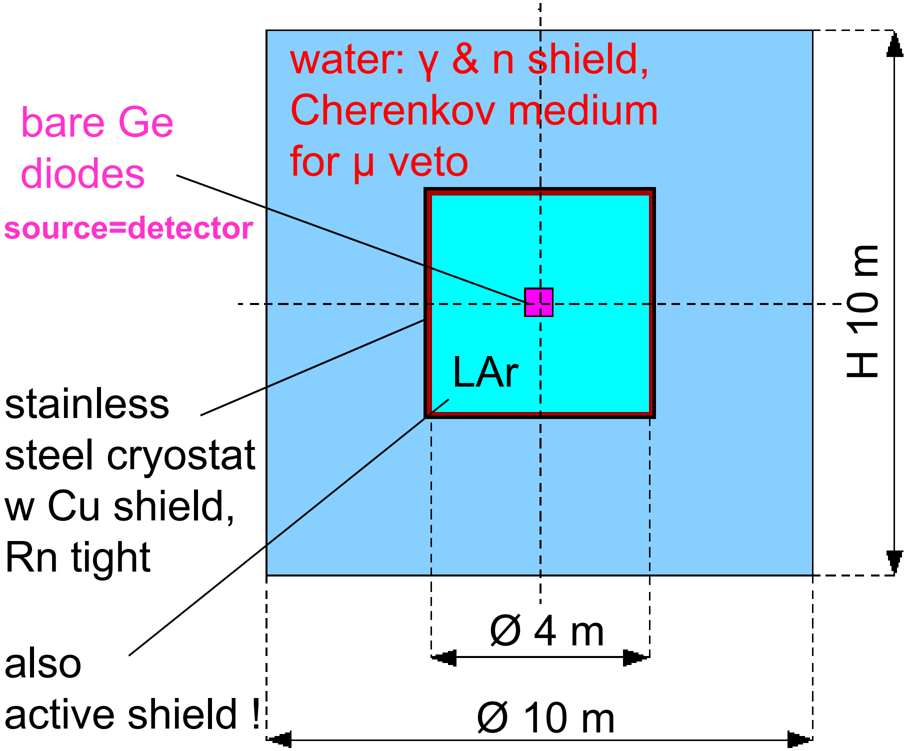
GERDA phase I

GERDA background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

Shielding possible

INTRINSIC or VERY CLOSE bgnds :
cosmogenic - ^{60}Co (5.3 a), ^{68}Ge (270 d)-
contaminated holders, FE, cables …

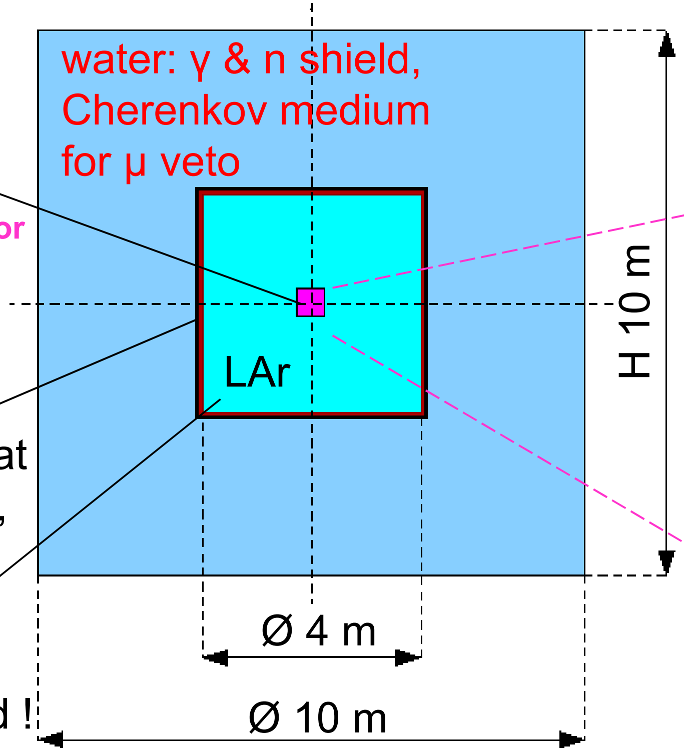


α(LAr) = 0.050/cm   α(Cu) = 0.34/cm
α(H_2O) = 0.043/cm   α(Pb) = 0.48/cm

GERDA background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

Shielding possible



bare Ge diodes

source=detector

stainless steel cryostat w Cu shield, Rn tight

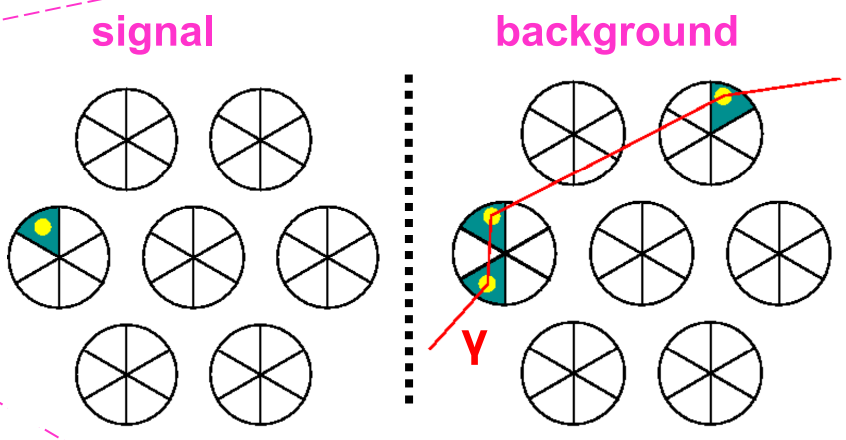
also active shield !

$\alpha(\mathrm{LAr}) = 0.050/\mathrm{cm}$ $\alpha(\mathrm{Cu}) = 0.34/\mathrm{cm}$

$\alpha(H_2O) = 0.043/\mathrm{cm}$ $\alpha(\mathrm{Pb}) = 0.48/\mathrm{cm}$

INTRINSIC or VERY CLOSE bgnds :
cosmogenic - ^{60}Co (5.3 a), ^{68}Ge (270 d)-
contaminated holders, FE, cables …

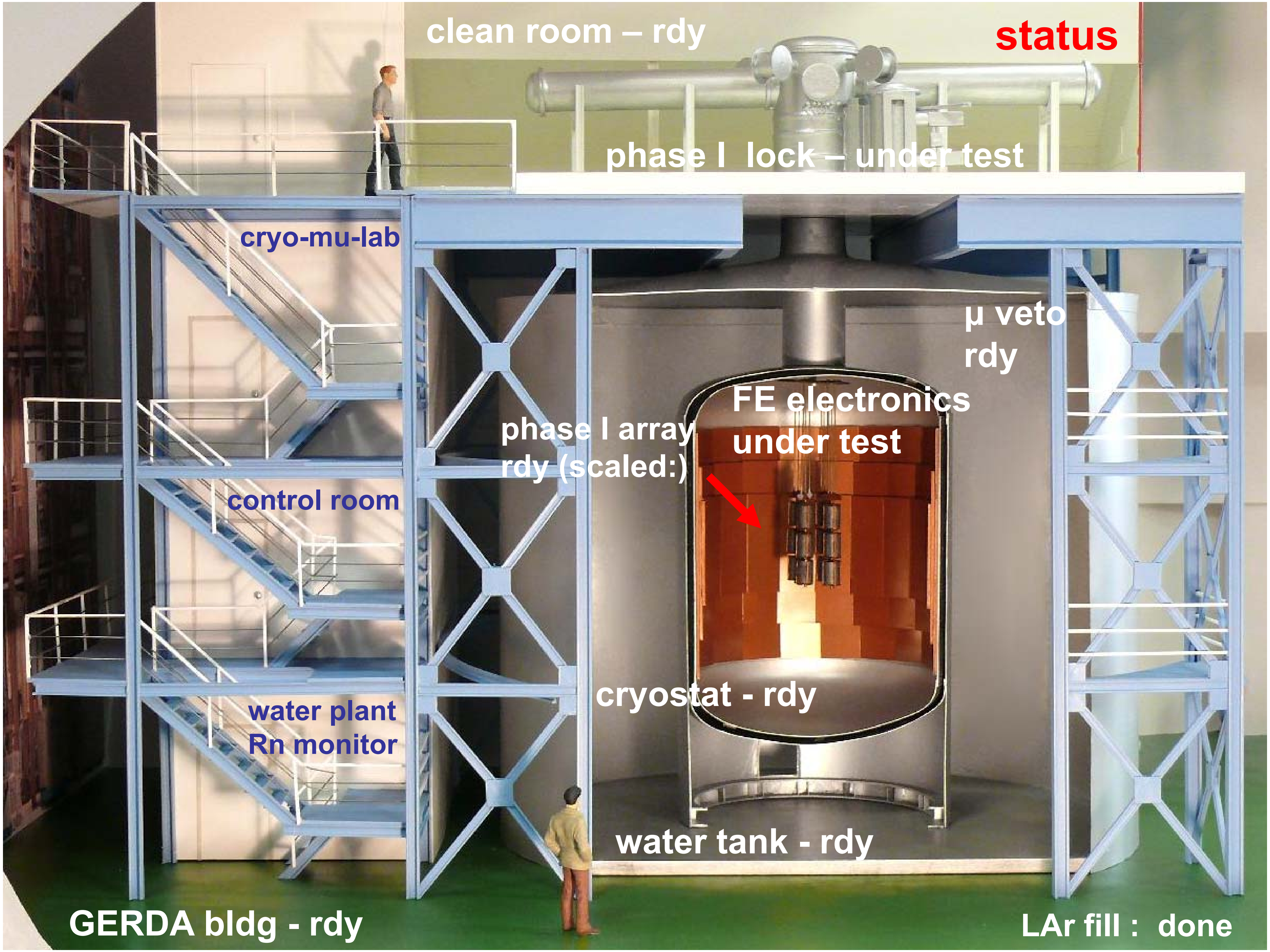
Discriminate single & multi site events !
► SSE: ßß, DEP ►MSE: Compton



array of segmented Ge detectors

- **► anti-coincidence of detectors & detector segments**
- **► pulse shape analysis (PSA)**

status



clean room – rdy

phase I lock – under test

cryo-mu-lab

control room

water plant
Rn monitor

μ veto
rdy

FE electronics
under test

phase I array
rdy (scaled:)

cryostat - rdy

water tank - rdy

GERDA bldg - rdy

LAr fill : done

GERDA area in front of LVD – bottom of WT

07 aug 07

2004	
feb	**Letter of Intent**
sep	**formation of collaboration**
oct	**funding requests approved by MPG**
oct	**proposal to LNGS**
2005	
feb	**GERDA approved by LNGS, loc Hall A**
may/jun	**funding requests approved by LNGS/BMBF**
jul	**first safety studies for copper cryostat**

GERDA area in front of LVD – bottom of WT

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2006	
apr	all HDM & IGEX detectors functional at LNGS
may	contract for water tank – decision for stainless steel cryostat
jul	safety reviews continued for stainless steel cryostat
aug	LNGS Hall A ready for installation
dec	safety review available – cryostat ordered

all HdM & IGEX diodes at refurbishment company

GERDA area in front of LVD – bottom of WT

07 aug 07

unloading of cryostat

6 mar 08

water tank:

Ø 10 m
h = 9.5 m
V = 650 m^3

designed for external
γ,n,μ background
~10^{-4} cts /(keV · kg · y)

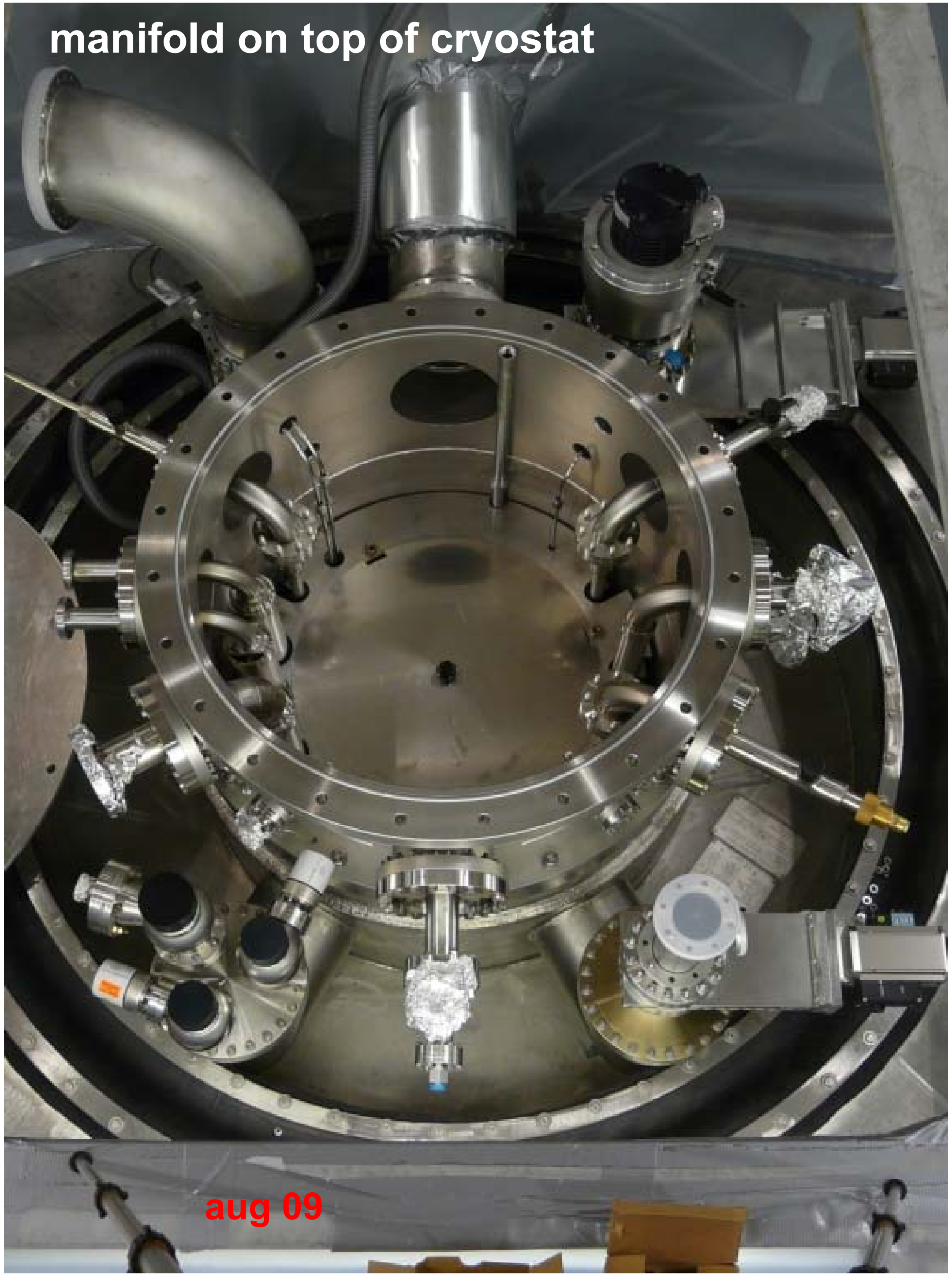
construction of clean room

27 feb 09

clean room, active cooling device getting prepared for installation

muon veto in water tank

12 aug 09



manifold on top of cryostat

aug 09

control & safety valves
heater

aug 09

transfer of clean bench
from Hall di Montaggio
to cleanroom in Hall A

29 nov 09

clean bench in clean room

29 nov 09

R&D of GERDA Task Groups

TG01	**Modification & test of existing Ge diodes**
TG02	**Design & production of new Ge diodes**
TG03	**Front end electronics**
TG04	**Cryostat and cryogenic infrastructure**
TG05	**Clean room and lock system**
TG06	**Water tank and water plants**
TG07	**Muon veto**
TG08	**Infrastructure & logistics**
TG09	**DAQ electronics & online software**
TG10	**Simulation & background studies**
TG11	**Material screening**
TG12	**Calibration**

‘LArGe’ R&D - active LAr veto - topic of TG01
► JINST 3 (2008) P08007

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phase I detectors

p-type coaxial detectors

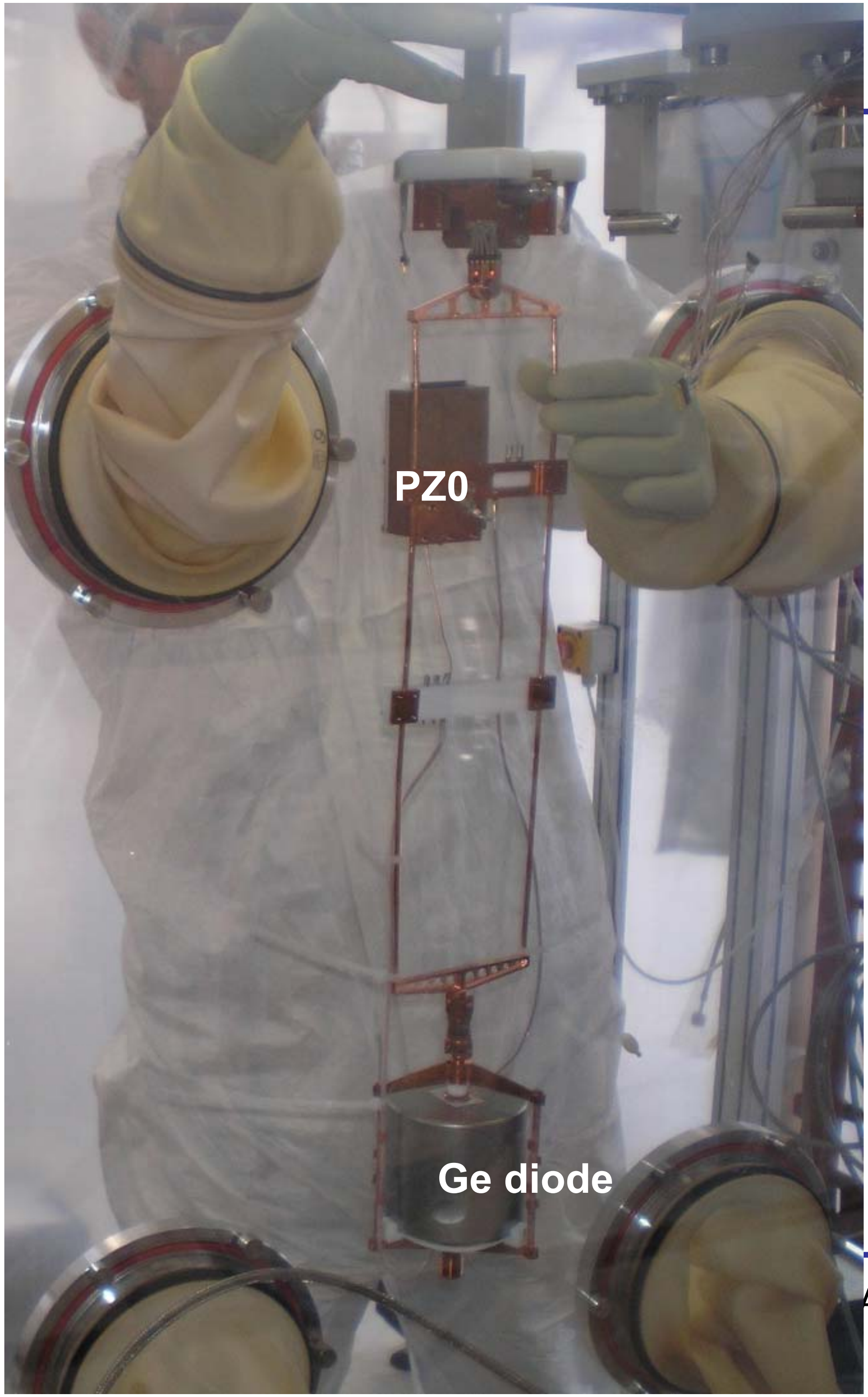
8 diodes (from HdM, IGEX) – total of 17.9 kg ^{76}Ge

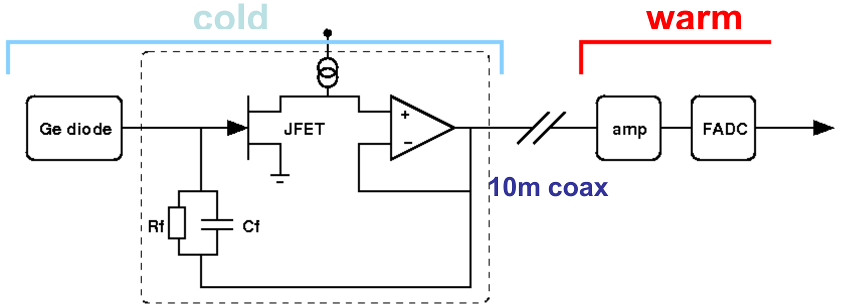
- **all diodes refurbished, changed contacting scheme for improved operation in LN/LAr**
- **well tested procedures for mounting & handling**
- **FWHM at 1.33 MeV ~ 2.5 keV**
- **long term stability in LAr established**

in addition:

6 former Genius-TF ^{nat}Ge diodes

test of full readout chain





3-channel PZ-0 ASIC for cryogenic operation

- **built in AMS HV 0.8 µm CZX**
- **input JFET, R_f & C_f discrete**

set up in Hall di Montaggio of LNGS:
clean bench for Ge handling
phase I lock prototype
test dewar with active cooling
prototype Ge-diode with final
mount, cabling & electronics

achieved: 2.9 keV with Co-60 source
successful test of 2 diode string

phase II detectors

Two technologies pursued: 1) n-type segmented 2) p-type BEGe

enriched & depleted Germanium

- 37.5 kg of 86% ^{enr}Ge (in form of GeO_2) in hand, stored underground at IRRM
- 84 kg of $^{dep}GeO_2$ acquired (relict of enrichment) and in use for tests

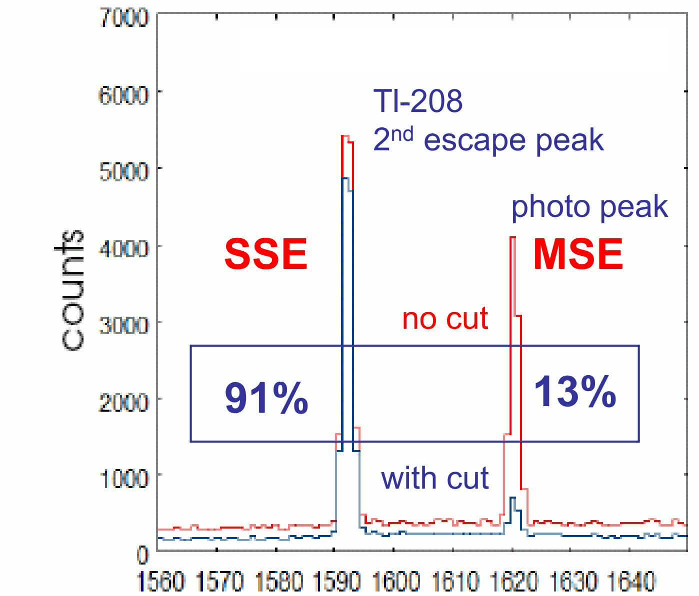
purification

- a solved problem (PPM Pure Metals, GmbH)
- no isotopic dilution
- total yield >90% for >6N quality
- total exposure at sea level < 3 days per purification
- negotiations for purification of enriched material started

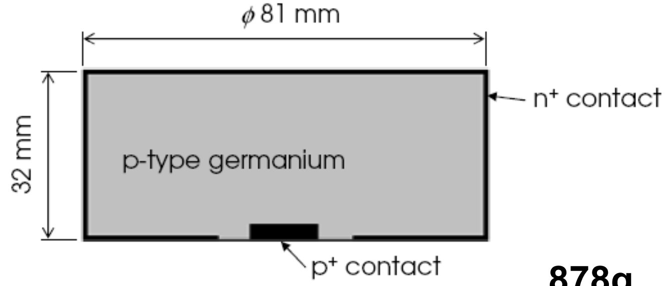
crystal growing (n-type)

- natural Ge crystals pulled from 6N material by Institut für Kristallzüchtung, Berlin
- impurity density ~ 10^{11} to 10^{13} cm^{-3}, 10^{10} cm^{-3} needed
- too high As concentration, to be reduced by refurbishing Czochralski puller
- recent alternative: p-type BEGe diodes from Canberra Belgium

R&D: **Single / Multi Site Event** discrimination



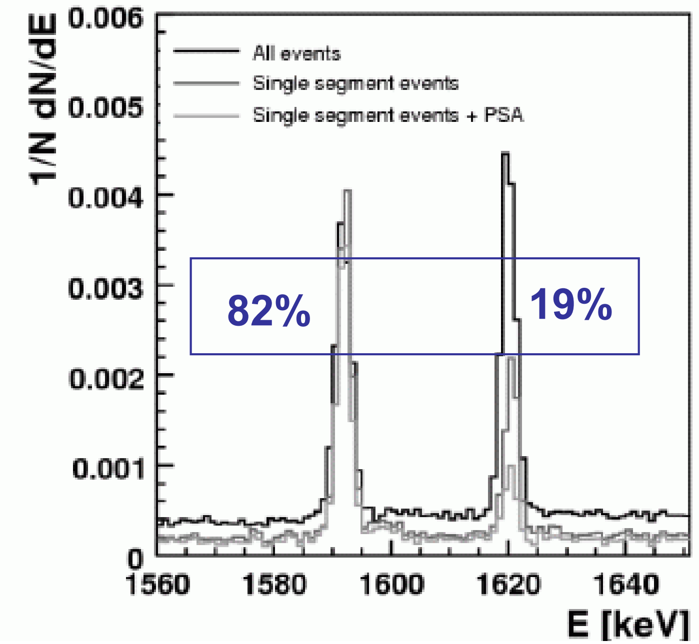
BEGe point-contact detector – p-type (COTS of Canberra)



878g

fractions after PSA cut

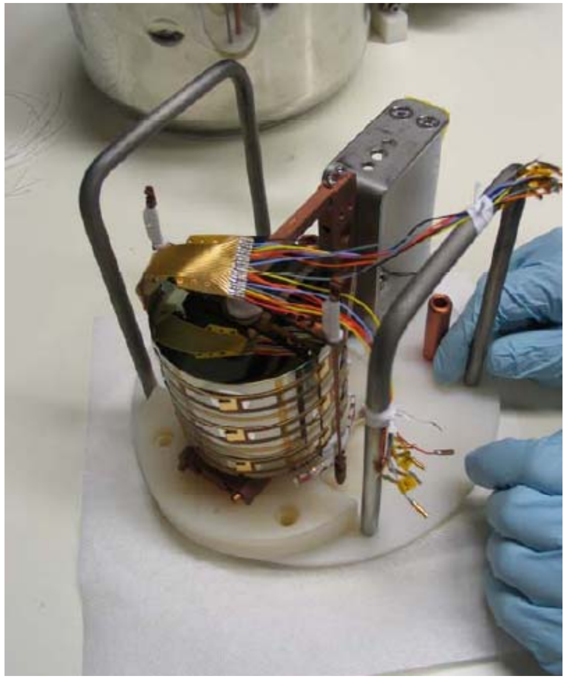
D..Budjas, PhD thesis '09
arXiv:0812.1735 [nucl-ex]
JINST, in press



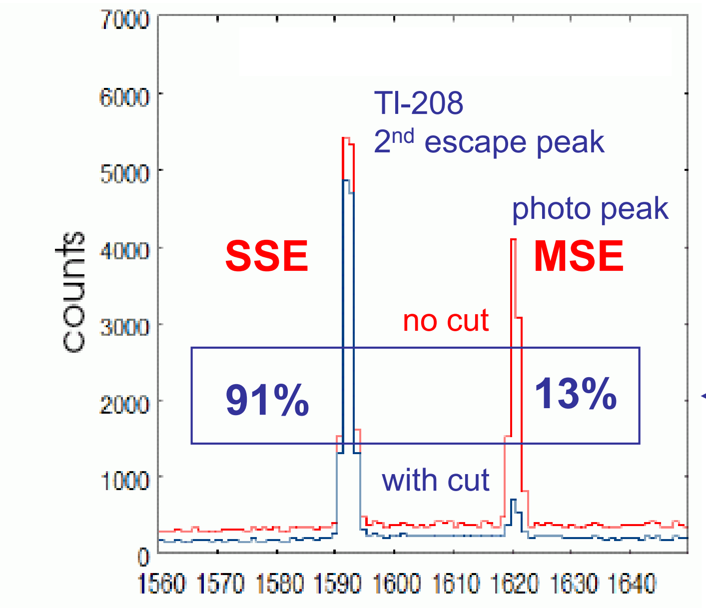
3x6-fold segmented coax detector - n-type

fractions after single-segment & PSA cut

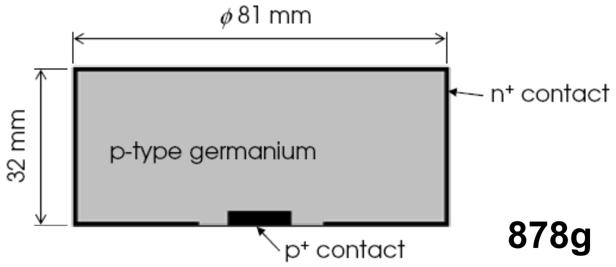
Abt etal NIM A583 (2007),
Eur.J.Phys. C52 (2007)



R&D: Single / Multi Site Event discrimination



**BEGe point-contact detector
(COTS of Canberra)**



878g

**fractions after
PSA cut**

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similar / better suppression obtained for K-40, Co-60 & Ra-226 contaminations

Results so convincing that GERDA collaboration has ordered at Canberra US/Belgium several crystals/ BEGe detectors made from the depleted Ge
► test of complete production chain

first BEGe detectors delivered – stable operation in LAr since several weeks with resolution of better than 1.9 keV.

conclusion

- approved in 2005 by LNGS with its location in hall A,
- funded by BMBF, INFN, MPG, and Russia in kind
- construction completed in LNGS Hall A
- all phase I detectors (8 pcs ,~18 kg) refurbished & ready

► Cryostat filled with LAr in in Dec '09 – plan to immerse first Ge diodes ~~March~~ May / parallel R&D for phase II

goals: 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 , $<m_{ee}> < 0.2$ eV *

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