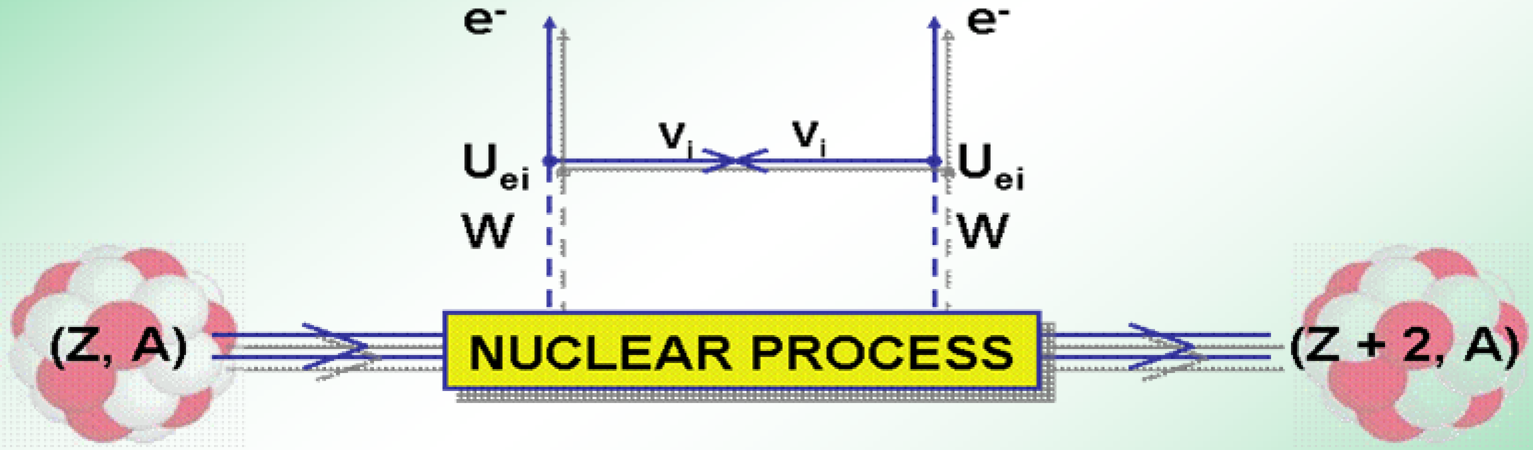
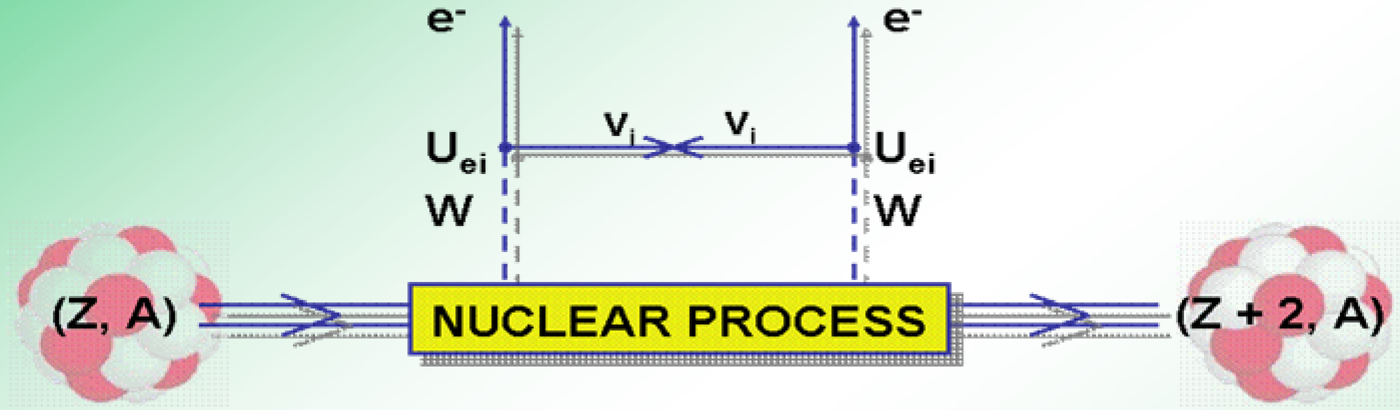
The Search for Neutrinoless Double Beta-Decay



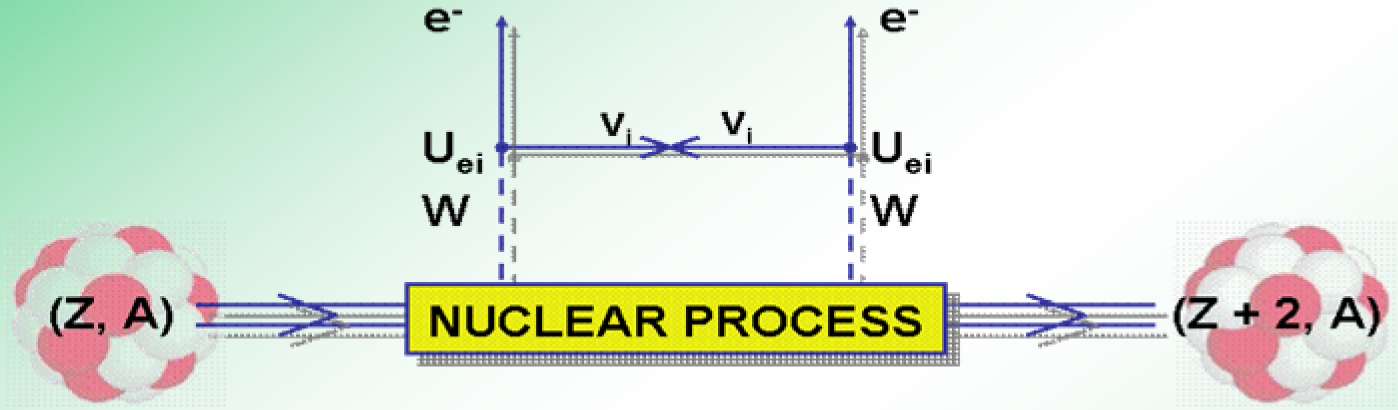
Béla Majorovits
Max-Planck-Institut für Physik, München, Germany

OUTLINE:



- Motivation: Neutrinos and their (unknown) properties
- Neutrinoless Double-Beta-Decay
- Experimental considerations and approaches
- Past 0νββ experiments
- The next generation(s) of 0νββ-experiment

OUTLINE:



- **Motivation: Neutrinos and their (unknown) properties**
- Neutrinoless Double-Beta-Decay
- Experimental considerations and approaches
- Past 0νββ experiments
- The next generation(s) of 0νββ-experiment

Motivation: Neutrinos and their (un)known Properties:

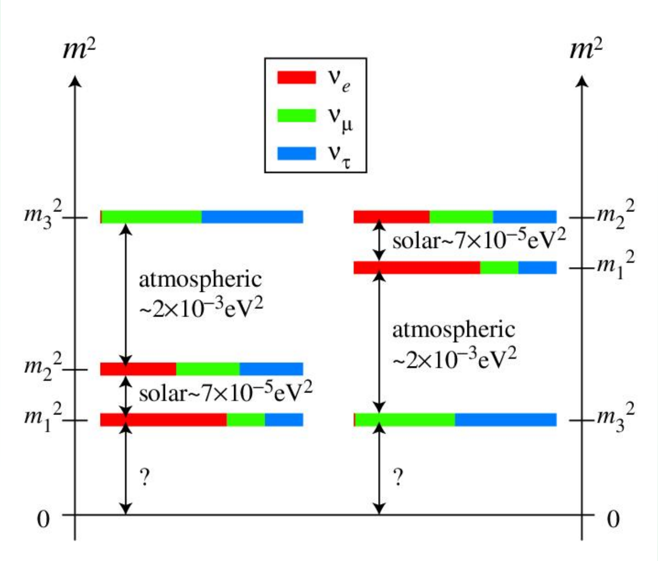
Know about neutrinos:

2^{nd} most abundant known particles in observable universe

They love to oscillate

Some neutrinos must have mass

They are generators for Nobel prizes



Unknown about neutrinos:

Is the neutrino a Majorana or Dirac particle (BAU, SeeSaw)?

Absolute mass scale?

Mass hierarchy?

Majorana-CP/ Dirac phases?

Admixture of ν_e in m_{ν_3}?

Motivation: Neutrinos and their (un)known Properties:

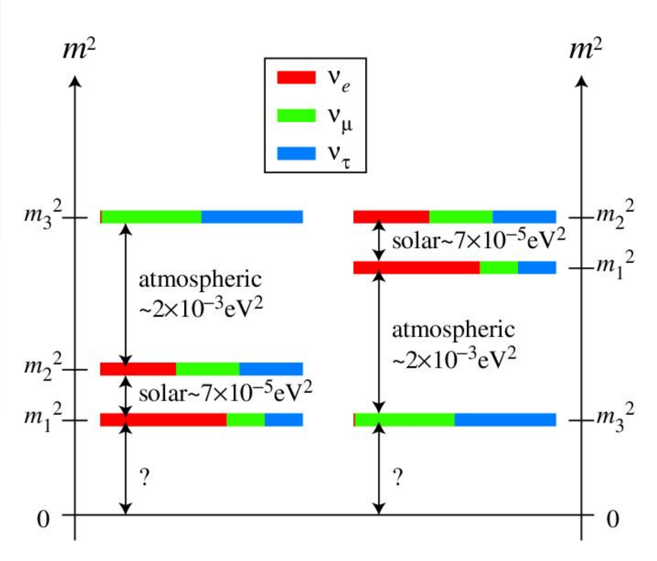
Know about neutrinos:

2^{nd} most abundant known particles in observable universe

They love to oscillate

Some neutrinos must have mass

They are generators for Nobel prizes



Unknown about neutrinos:

Is the neutrino a Majorana or Dirac particle (BAU, SeeSaw)?

Absolute mass scale?

Mass hierarchy?

Majorana-CP/ Dirac phases?

Admixture of ν_e in $m_{\nu 3}$?

DIRAC $\nu \neq \bar{\nu}$

Majorana $\nu = \bar{\nu}$

Motivation: Neutrinos and their (un)known Properties:

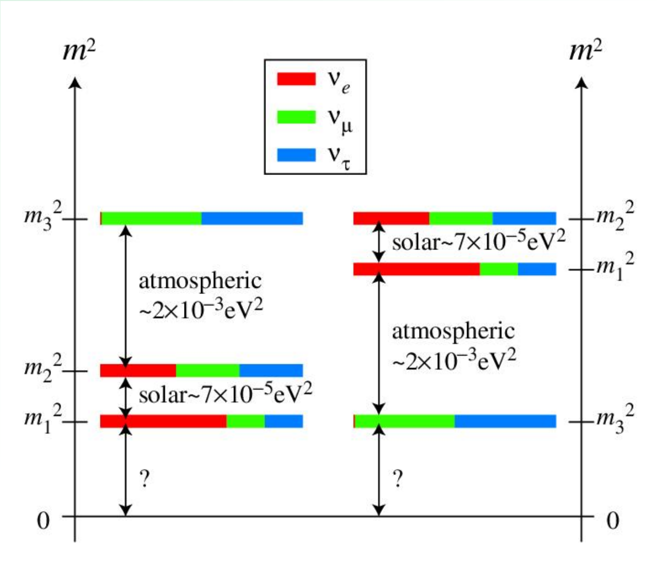
Know about neutrinos:

2nd most abundant known particles in observable universe

They love to oscillate

Some neutrinos must have mass

They are generators for Nobel prizes



Unknown about neutrinos:

Is the neutrino a Majorana or Dirac particle (BAU, SeeSaw)?

Absolute mass scale?

Mass hierarchy?

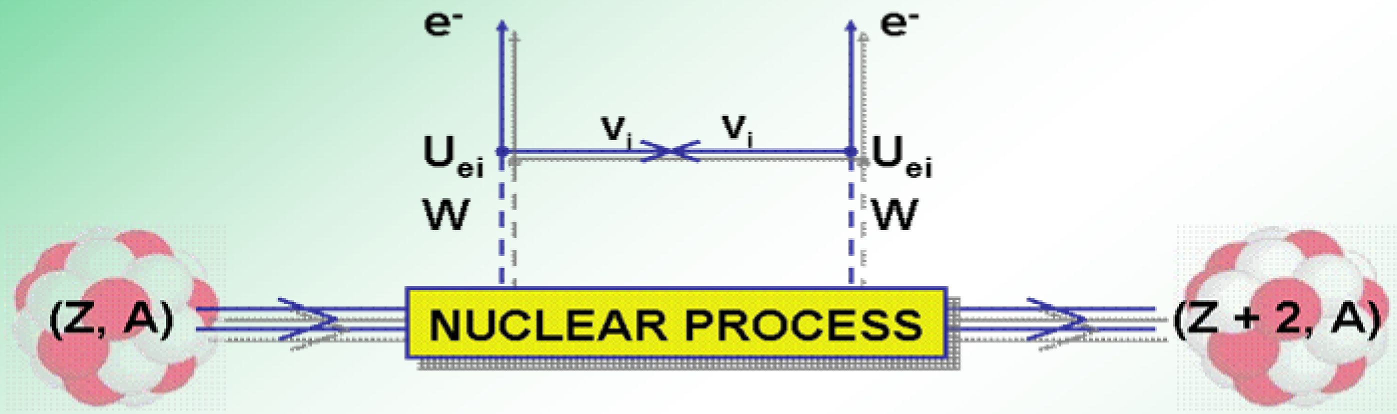
Majorana-CP/ Dirac phases?

Admixture of ν_e in m_{ν_3}?

DIRAC $\nu \neq \bar{\nu}$

Majorana $\nu = \bar{\nu}$

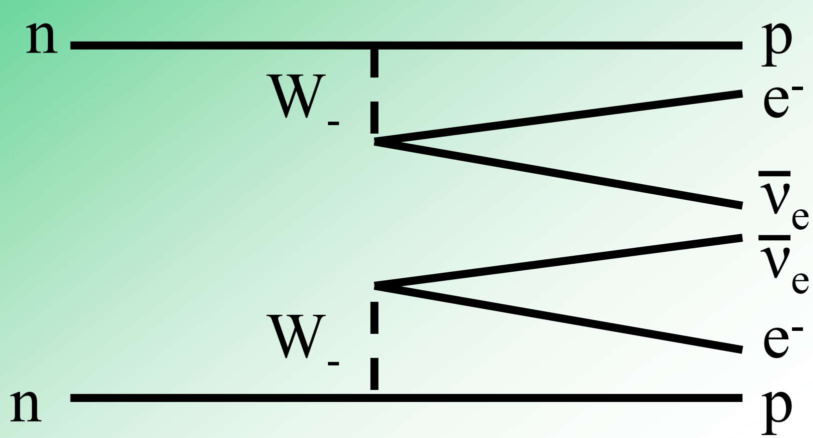
OUTLINE:



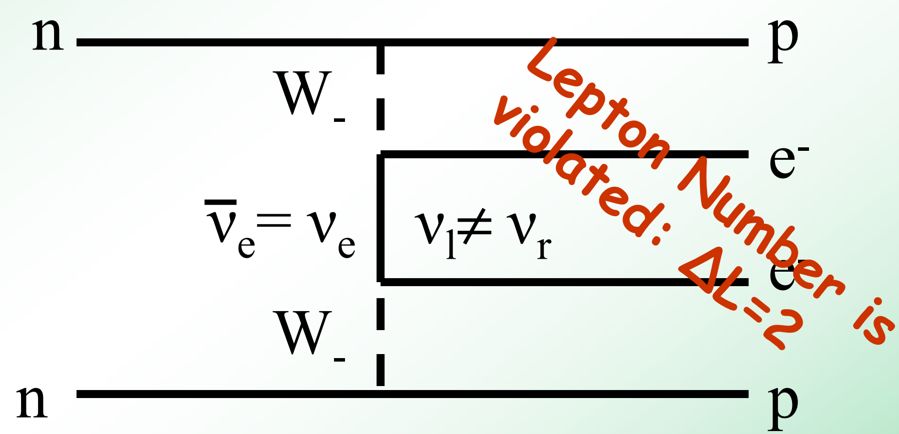
- Motivation: Neutrinos and their (unknown) properties
- **Neutrinoless Double-Beta-Decay**
- Experimental considerations and approaches
- Past 0νββ experiments
- The next generation(s) of 0νββ-experiment

Neutrinoless Double Beta-Decay:

Neutrino accompanied Double-Beta Decay:



Neutrinoless Double-Beta Decay:



Neutrinoless mode of double beta decay can only occur if:

Neutrino is a Majorana particle

Neutrino is massive (chirality flip required)

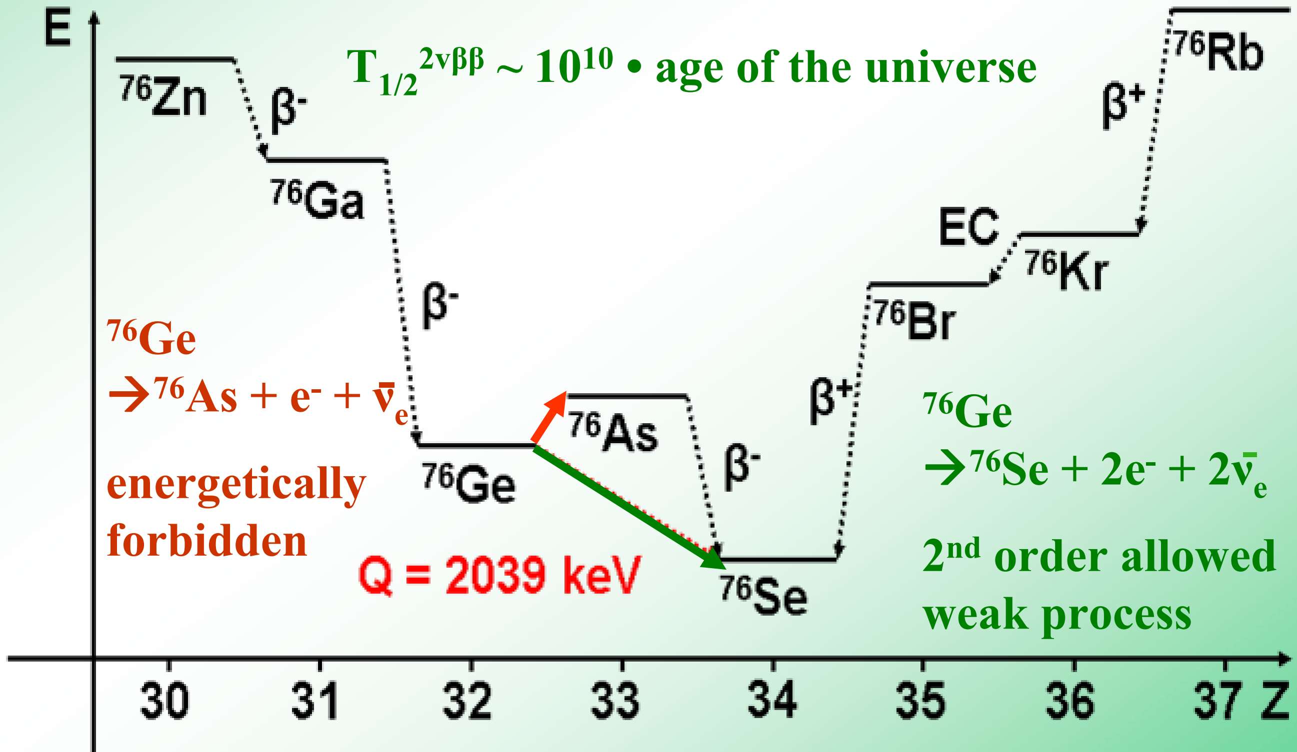
$$1/\tau = G(Q,Z)\, |M_{nucl}|^2 \, \langle m_{ee} \rangle^2$$

0νββ Decay rate	Phase space factor	Matrix element	Effective Majorana Neutrino mass

Neutrinoless Double Beta-Decay:

2νββ-decay is allowed (observed) weak process:

- Initial state nucleus bound stronger than intermediate, but less then final
- Can occur for even-even nuclei
- ~35 isotopes decay via 2νββ.

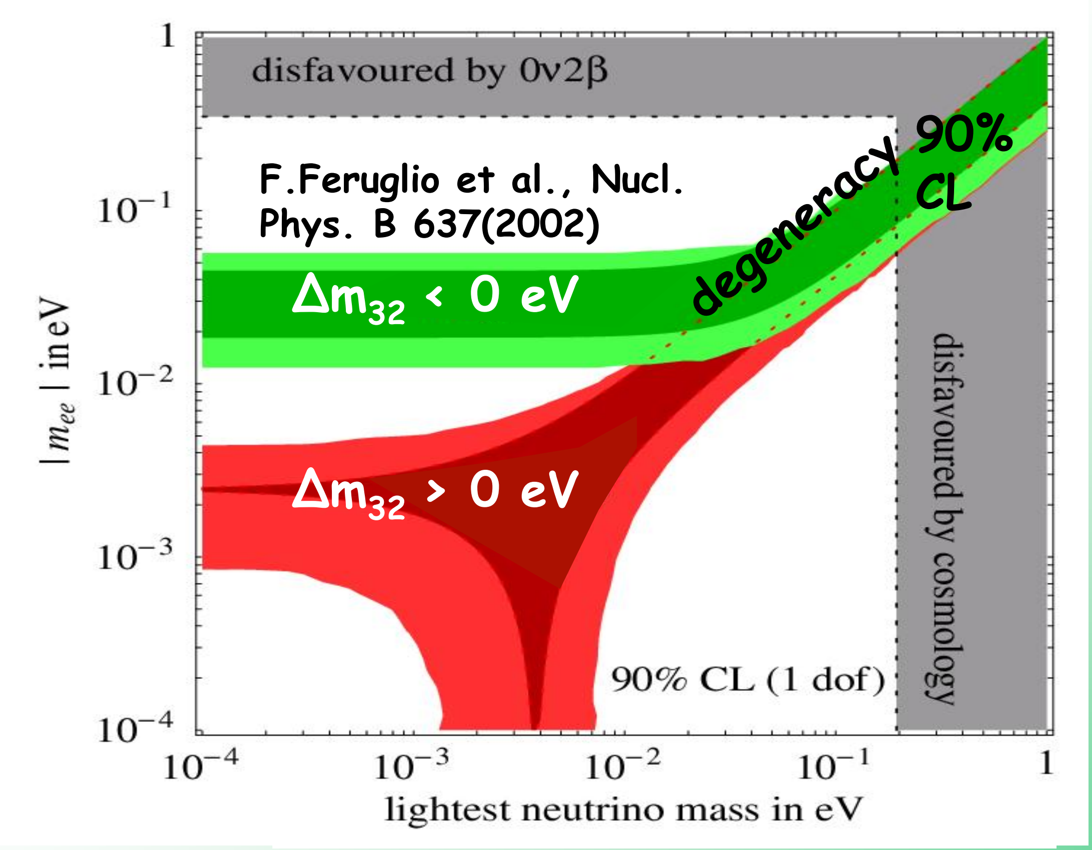


Neutrinoless Double Beta-Decay:

Neutrinoless double-beta-decay probes the effective Majorana-neutrino mass:

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

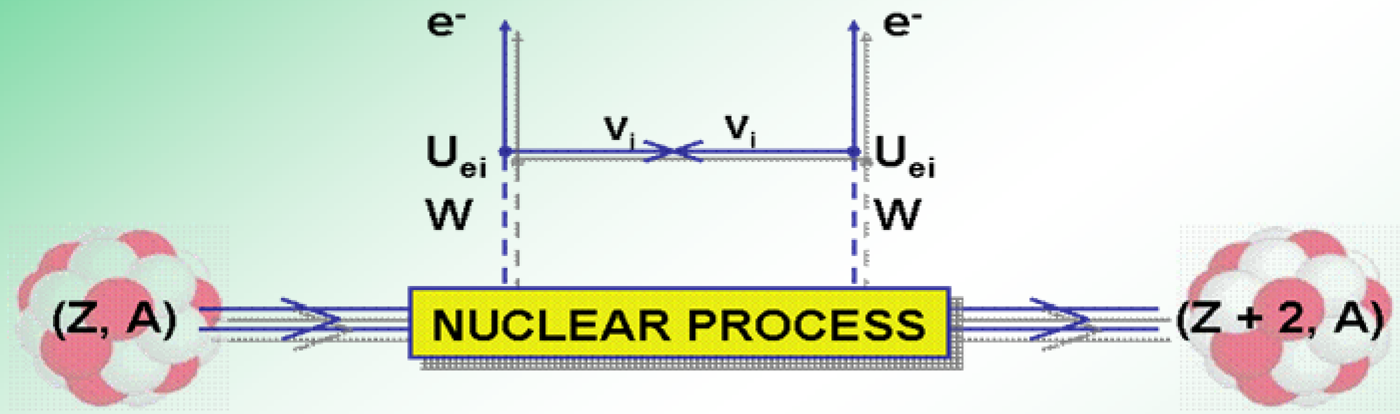
Detection of **> 10 meV** Majorana neutrino required to distinguish between normal, inverted and degenerate hierarchy.



Inverted hierarchy

Normal hierarchy

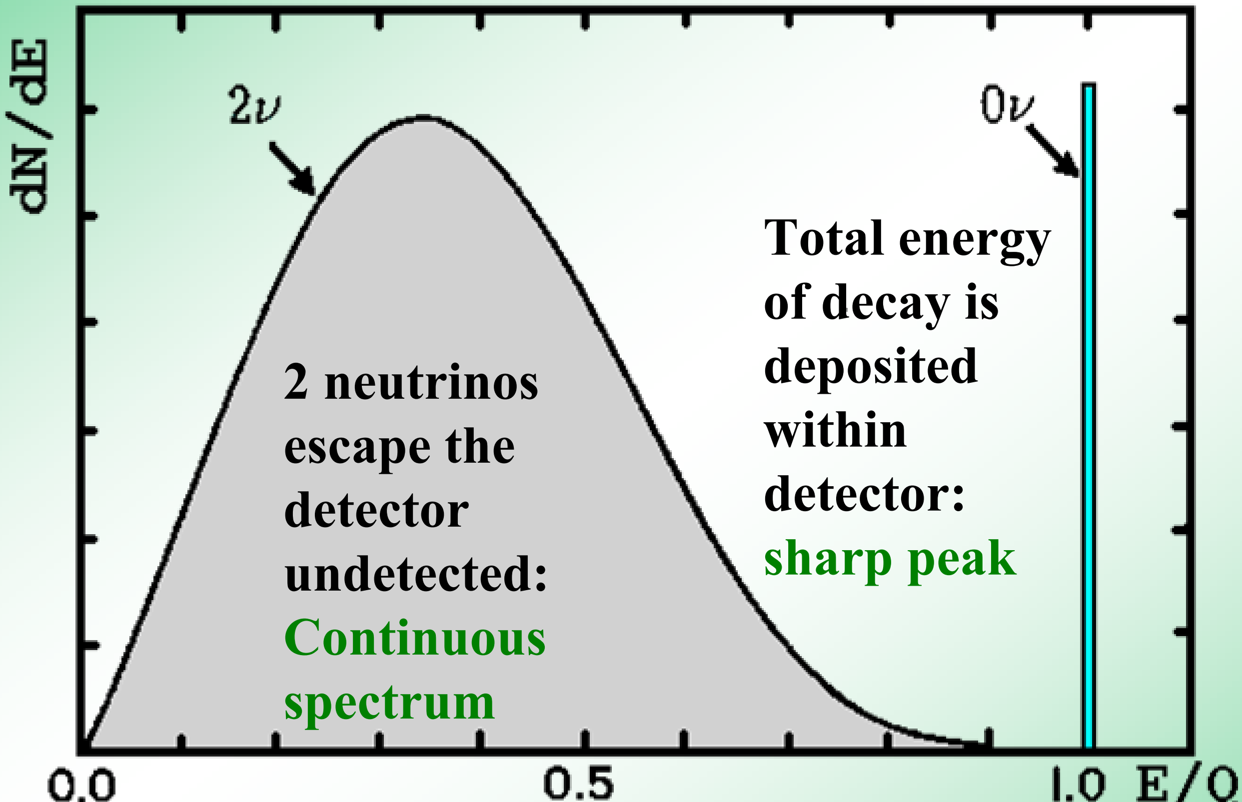
OUTLINE:



- Motivation: Neutrinos and their (unknown) properties
- Neutrinoless Double-Beta-Decay
- **Experimental considerations and approaches**
- Past 0νββ experiments
- The next generation(s) of 0νββ-experiment

Neutrinoless Double Beta-Decay:

Signature: Sharp peak at Q-value of the decay



Expected half-life: $T_{1/2}^{0\nu\beta\beta} \gtrsim 10^{15} \cdot$ **age of the universe**

Be aware: There are many sources producing mono-energetic peaks!

→ Need more than one isotope!

Experimental considerations and approaches

Figure of merit for a LIMIT sensitivity:

b>0 : $T_{1/2} \propto M_{nucl}\ a\ \varepsilon \sqrt{\frac{m\ t}{b\ \delta E}}$

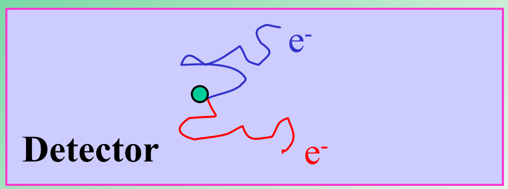
b=0 : $T_{1/2} \propto M_{nucl}\ a\ \varepsilon\ m\ t$

M_{nucl}	Nuclear matrix element	Select Isotope
b	background rate of the experiment	Minimize and select material
a	abundance of isotope under consideration (< 1.0)	Use isotope with high natural abundance or enrich material
m	active target mass of the experiment	Increase target mass
ε	signal detection efficiency (<1.0)	
δE	Energy resolution	Use high resolution spectroscopy
t	Measuring time (< 20y)	

→ Experimental approach: Improve EXPOSURE and BACKGROUND

Experimental considerations and approaches

two main experimental possibilities:

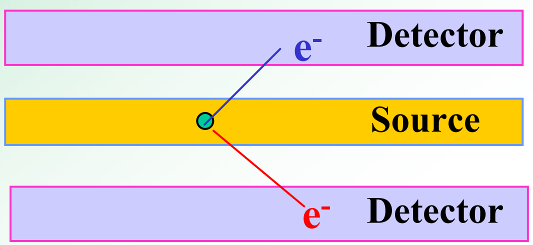


Source = Detector (Calorimetry)

Semiconductor detectors, Phonon detection
(Scintillation detectors and liquid/gas detectors)

+ High detection efficiency
+ Large target mass possible
+ Very good energy resolution
+-Reconstruction of event topologies
- Restricted number of isotopes

→ Improve on topology reconstruction



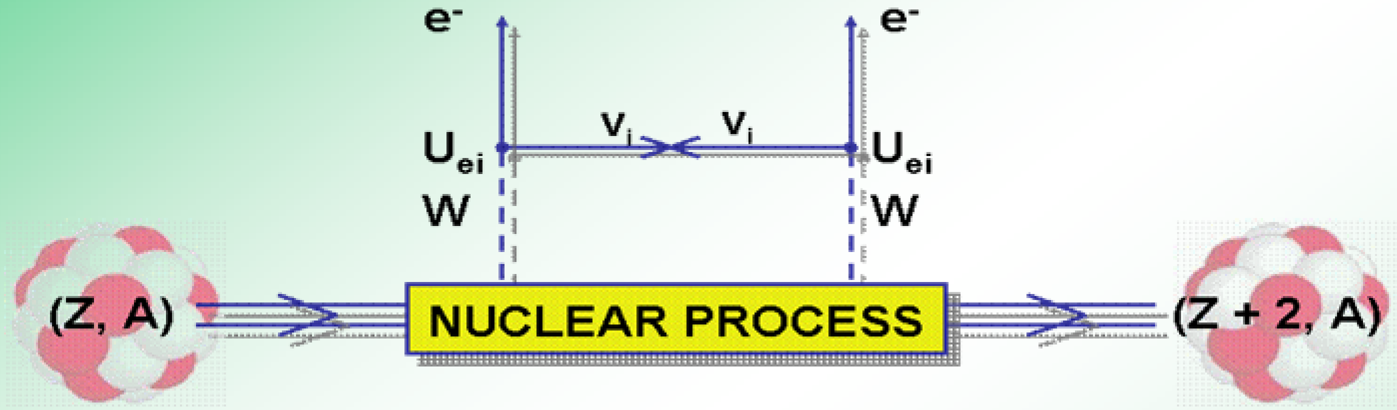
Source ≠ Detektor

Foils between Scintillation - detectors, Gas TPCs

+ Very good position resolution
  → reconstruction of event topologies
  → Except for 2νββ: zero background
+ No restriction on isotopes.
- Energy resolution → Background from 2νββ-decay
- Difficult to obtain large masses

→ Improve on energy resolution

OUTLINE:



- Motivation: Neutrinos and their (unknown) properties
- Neutrinoless Double-Beta-Decay
- Experimental considerations and approaches
- **Past 0νββ experiments**
- The next generation(s) of 0νββ-experiment

Past 0νββ experiments

Most sensitive 0vbb experiments so far: HPGe based

Heidelberg-Moscow Experiment:

11.5 kg of enriched Ge detectors
71.7 kg yrs of data
0.11 Counts/(kg keV y) around 2040 keV
$T_{1/2} \geq 1.9 * 10^{25}$ years (90% C.L.) Eur. Phys. J.A 12 (2001)147.

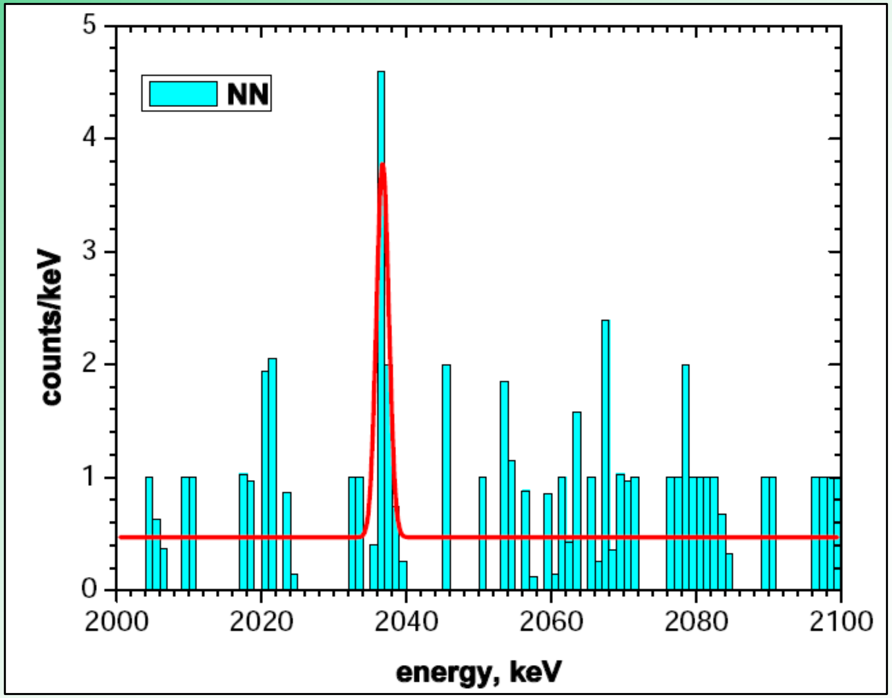
IGEX Experiment:

6.8 kg of enriched Ge detectors
8.5 kg yrs of data
0.17 Counts/(kg keV y) around 2040 keV
$T_{1/2} \geq 1.6 * 10^{25}$ years (90% C.L.) Aalseth et al., Phys.Rev.D 65 (2002)092007

Past 0νββ experiments

Most sensitive 0vbb experiments so far: HPGe based

Heidelberg-Moscow Experiment:



11.5 kg of enriched Ge detectors
71.7 kg yrs of data
0.11 Counts/(kg keV y) around 2040 keV
$T_{1/2} \geq 1.9 * 10^{25}$ years (90% C.L.) Eur. Phys. J.A 12 (2001)147.
Subgroup of HdMo:
Claim: $T_{1/2} = 2.23 * 10^{25}$ years K-K and K, Mod. Phys. Lett A 21 (2006)1547

IGEX Experiment:

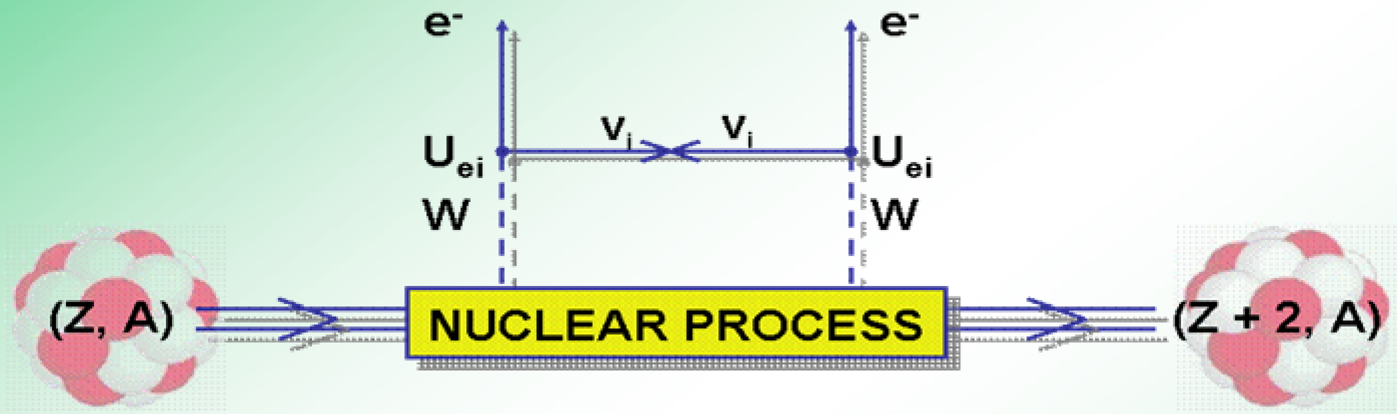
6.8 kg of enriched Ge detectors
8.5 kg yrs of data
0.17 Counts/(kg keV y) around 2040 keV
$T_{1/2} \geq 1.6 * 10^{25}$ years (90% C.L.) Aalseth et al., Phys.Rev.D 65 (2002)092007

Past 0νββ experiments

Experiment	Underground Laboratory	Isotope	Technology	$T_{1/2}$ [10^{24} y]	<m_{ee}> [*eV*]
Elegant VI	Oto (Japan)	^{48}Ca	Scintillator CaF_2	> 0.095	< 7.2 - 44.7
Heidelberg-Moscow	Gran Sasso (Italy)	^{76}Ge	HPGe	>19 evidence: $22.3^{+4.4}_{-3.1}$	< 0.35 - 1.2 $0.28^{+0.17}_{-0.11}$
IGEX	Canfranc (Italy)	^{76}Ge	HPGe	> 16	< 0.3 - 1.5
NEMO-III	Frejus (France)	^{82}Se	Foils btw.	> 0.14	< 1.7 - 4.9
NEMO-III		^{100}Mo	tracker	>1.1	< 0.45 - 0.93
$CdWO_4$ scintillator	Solotvina (Ukrain)	^{116}Cd	Scintillator	> 0.17	< 1.5 - 1.7
Cuoricino	Gran Sasso	^{130}Te	Phonons	> 2.8	< 0.3 – 0.7

Disclaimer: List represents only a few past experiments and is incomplete…

OUTLINE:



- Motivation: Neutrinos and their (unknown) properties
- Neutrinoless Double-Beta-Decay
- Experimental considerations and approaches
- Past 0νββ experiments
- **The next generation(s) of 0νββ-experiments**

The next generation(s) of 0νββ experiments

CUORE

Low temperature bolometer using TeO_2 crystals.
Te has 33.4% nat. abundance of ^{130}Te → no enrichment

New cryostat with improved radiopurity (to be delivered 2011).
Will house up to 988 TeO_2 crystals
→200kg of ^{130}Te

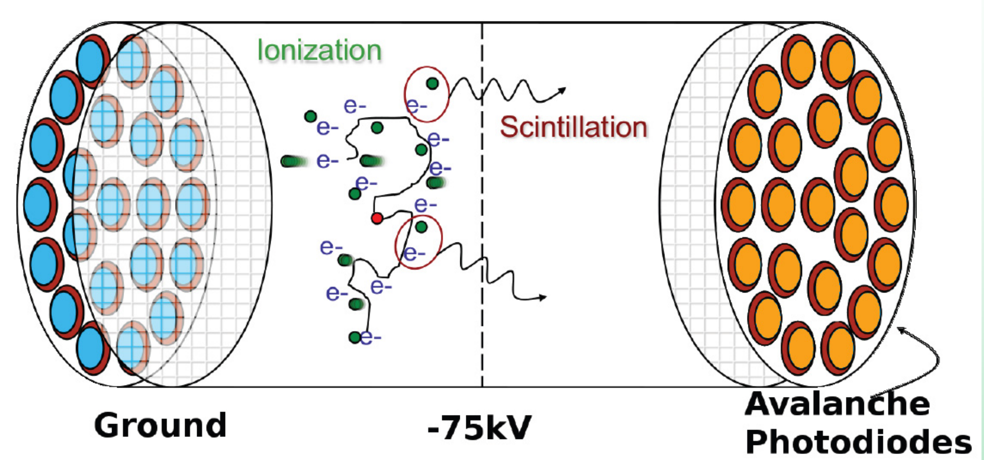
100 crystals already at LNGS

b = 0.01 cts/ (kg y keV)
Plan: Start measurements in 2013

CUORE0: use Cuoricino cryostat with first improved CUORE tower:
52 TeO_2 crystals 750g each
→~11 kg of ^{130}Te
Commissioning in 2011

The next generation(s) of 0νββ experiments

Enriched Xenon Observatory: EXO

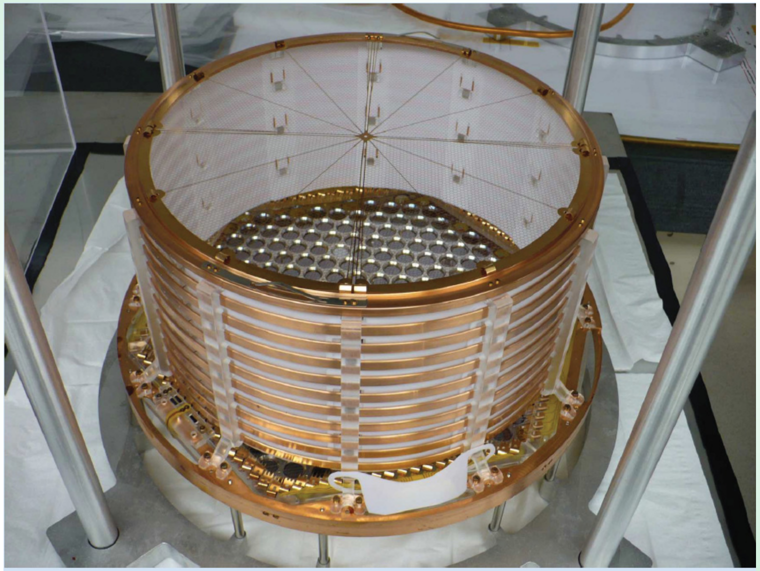


Liquid Xe TPC:

Measure scintillation light and ionization.

→Energy resolution: 1.6%@2479keV

Drift time of electrons and position on grid gives Information on decay position



200 kg of Xenon enriched in 80% with ^{136}Xe

70% fiducial volume

→112 kg ^{136}Xe target mass

Expect 20 events/year in RoI

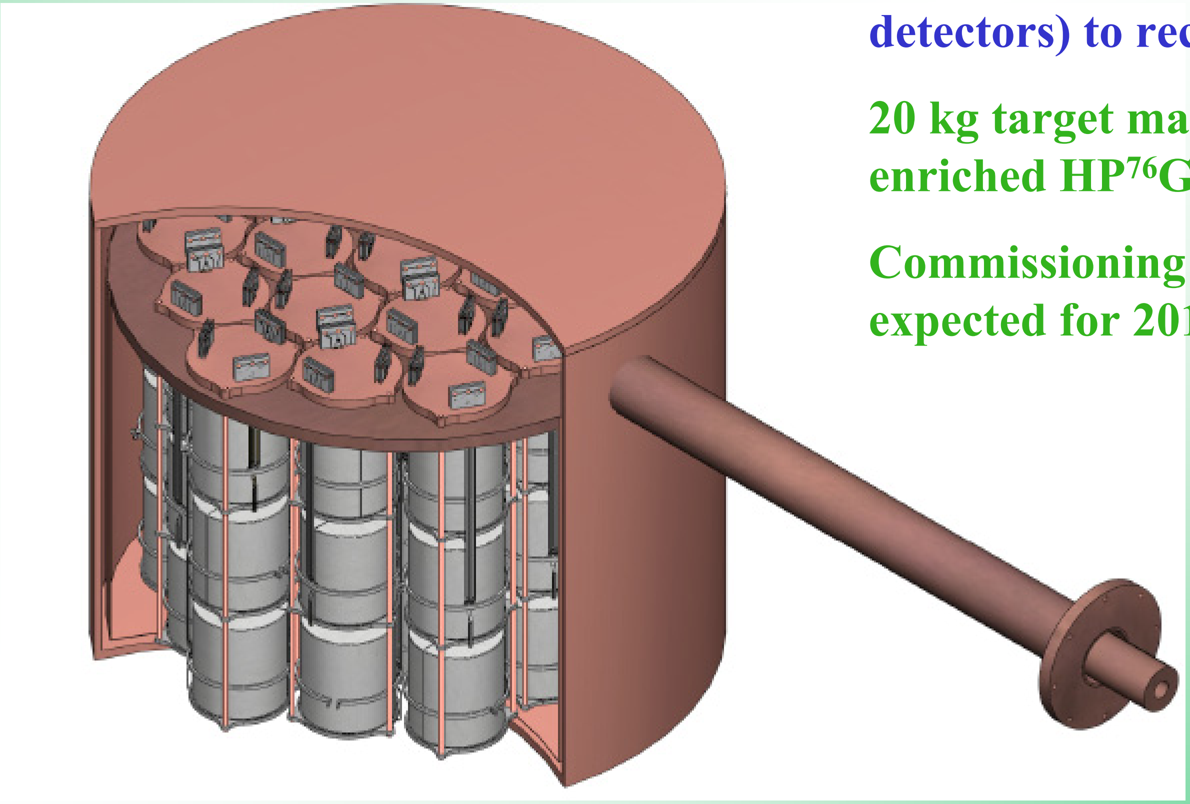
Commissioning is starting:
Cryostat filled, ramping up voltage.

First results expected 2011.

The next generation(s) of 0νββ experiments

The Majorana project

HPGe detectors operated in ultra low background cryostat.
Copper for cryostat specially electroplated

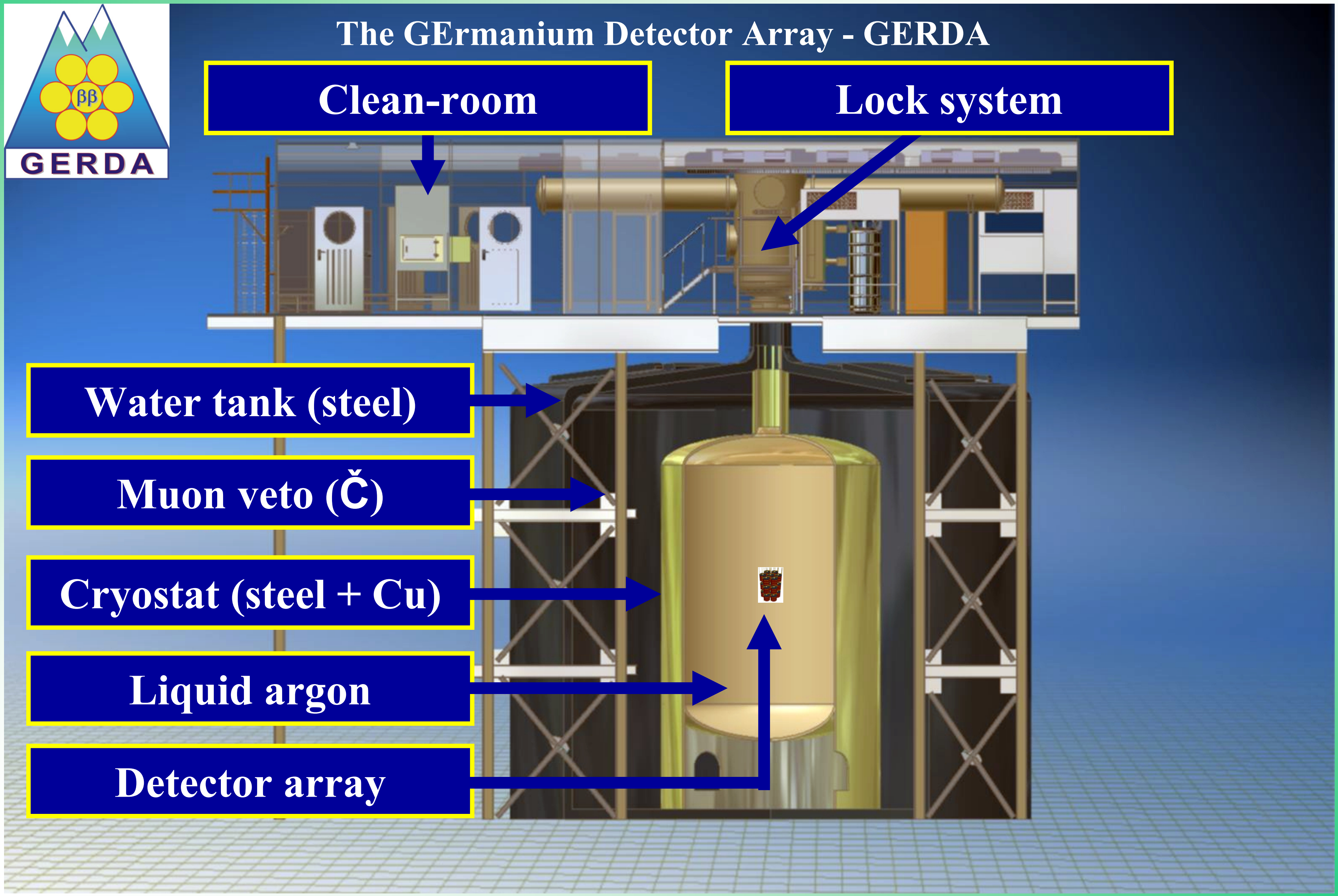


Detectors with very good PSA capabilities (point contact/BEGe detectors) to recognize background

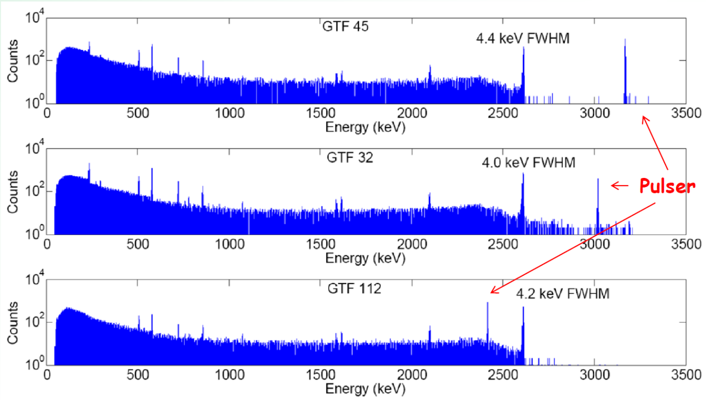
20 kg target mass in the form of enriched HP^{76}Ge detectors

Commissioning of first cryostat expected for 2012

The next generation(s) of $0\nu\beta\beta$ experiments



The next generation(s) of 0νββ experiments



First phase:

Use Heidelberg-Moscow and IGEX detectors.

Need 15 kg y with 10^{-2} cts/(kg y keV) to confirm or refute the HdMo claim.

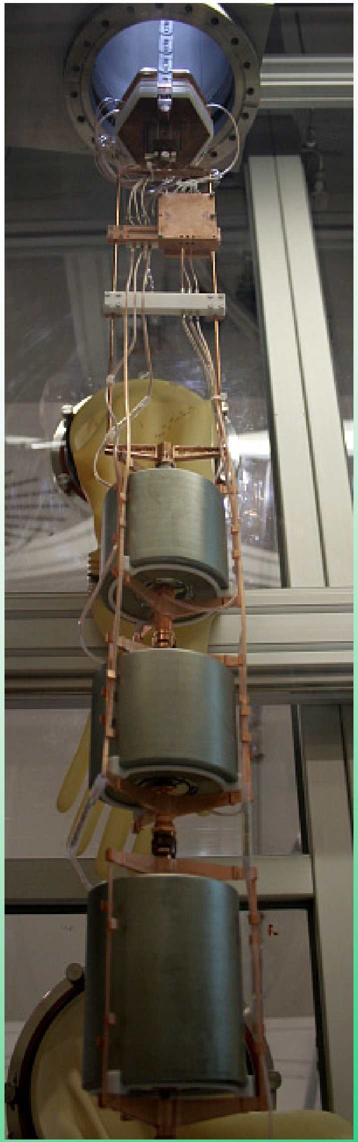
Commissioning started June 2010

Second phase:

Use additional 35 kg of enriched germanium to produce detectors. Improve background to 10^{-3} cts/(kg y keV) by Pulse Shape Analysis or segmentation.

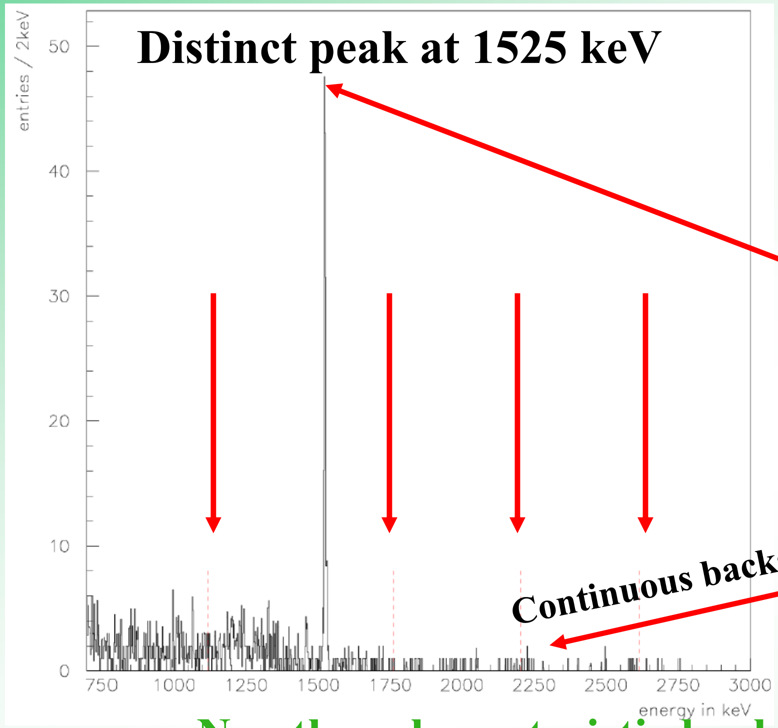
→Proof of principle for ton scale experiment (GERDA and Majorana will merge)

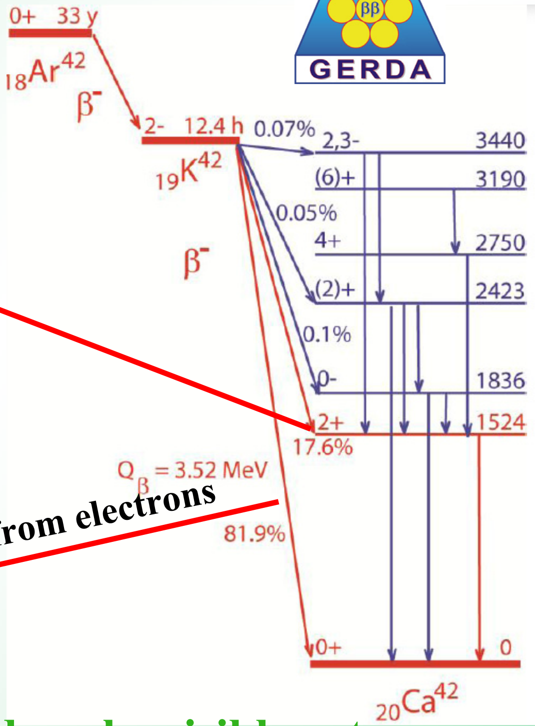
Start expected 2012



The next generation(s) of 0νββ experiments

Main GERDA background: ^{42}Ar





No other characteristic background peaks visible yet.

Background contributions due to ^{232}Th, ^{238}U (90%C.L. upper limit):

< $1.2\cdot10^{-2}$ Counts/(kg y keV)

(Background level of HdMo and IGEX experiments. Dominated by ^{42}Ar background)

Presently commissioning is ongoing to understand and reduce the ^{42}Ar background. Ions are long lived in LAr and can be drifted!

The next generation(s) of 0νββ experiments

Experiments starting data taking soon:

Experiment	Isotope	Target Mass	Technology	FWHM	Exp. Sens.[meV]	Start
GERDA I GERDA II	^{76}Ge	18 kg 40 kg	HPGe	0.2%	220 - 500 90 - 200	2011 2012
Majorana	^{76}Ge	~20 kg 40 kg	HPGe	0.2%		2012 2014
CUORE0 CUORE	^{130}Te	10 kg 200kg	$^{130}TeO_2$ bolometer	0.25%	168 - 391 41 – 96	2011 2013
EXO	^{136}Xe	100kg	LXe TPC	1.6%	130 - 190	2011

Many other experimental R&D efforts that can not be discussed in detail:

SNO+ - Doped liquid scintillator

NEXT – High pressure gas TPC

Candles, Moon, DCBA, …..

Lucifer – phonons and scintillation

COBRA – pixelized CdZnTe semiconductor detector,

SuperNEMO – Foils between tracking detectors,

CONCLUSIONS:

- Observation of 0νββ is the only known way to determine nature of neutrino (Dirac or Majorana)
- Part of Heidelberg-Moscow collaboration claims evidence for observation
- Need independent confirmation with same and different isotope
- First next generation experiments are being commissioned. Results expected next year.
- Ton scale experiments are required to disentangle neutrino-mass hierarchies