Nu_2-WP3: R&D of detectors for future high statistics, high precision experiment

(R&D for neutrinoless Double Beta Decay experiments)

Nobuhiro ISHIHARA

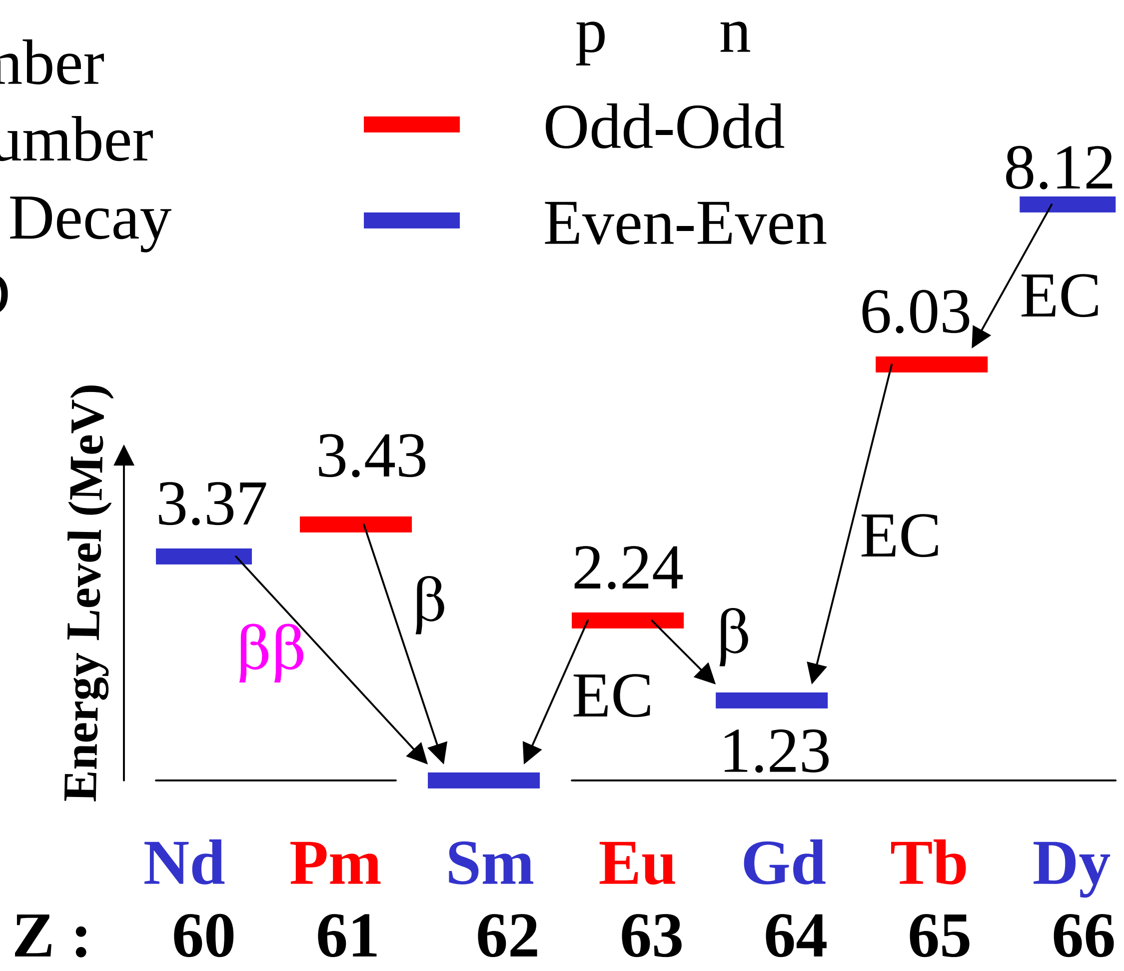
(KEK)

Double Beta Decay (DBD)

A: Mass Number
Z: Atomic Number
ΔZ = 1: Beta Decay
ΔZ = 2: DBD

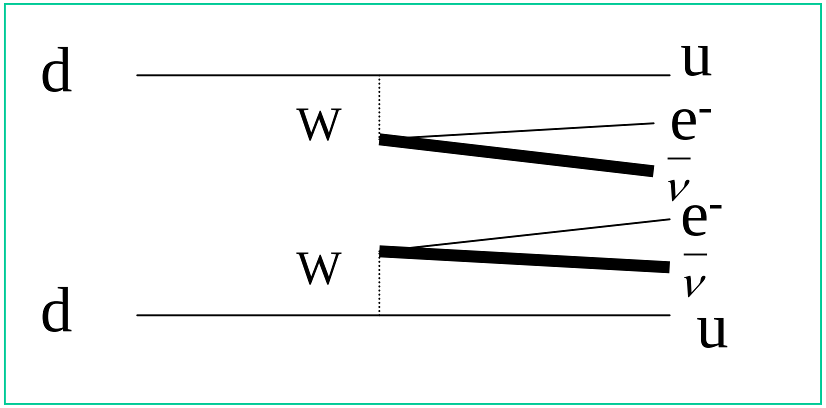
Example

A=150



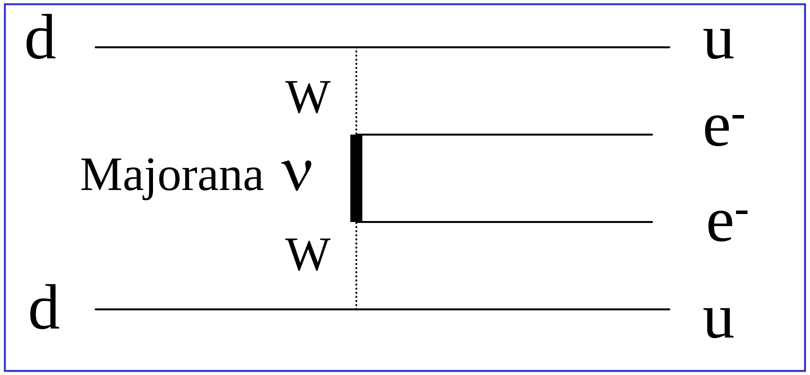
Double Beta Decay (DBD)

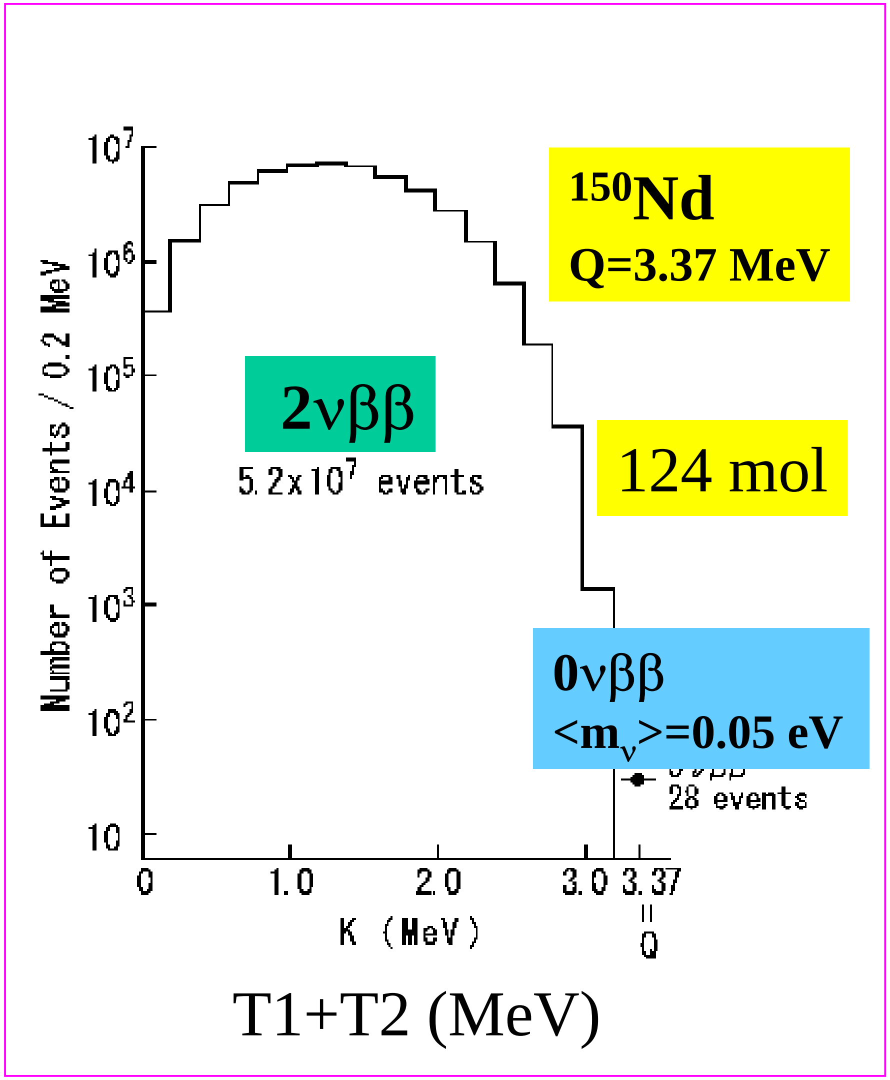
2νββ: $(Z, A) \rightarrow (Z+2, A) + 2e^{-} + 2\bar{\nu}$



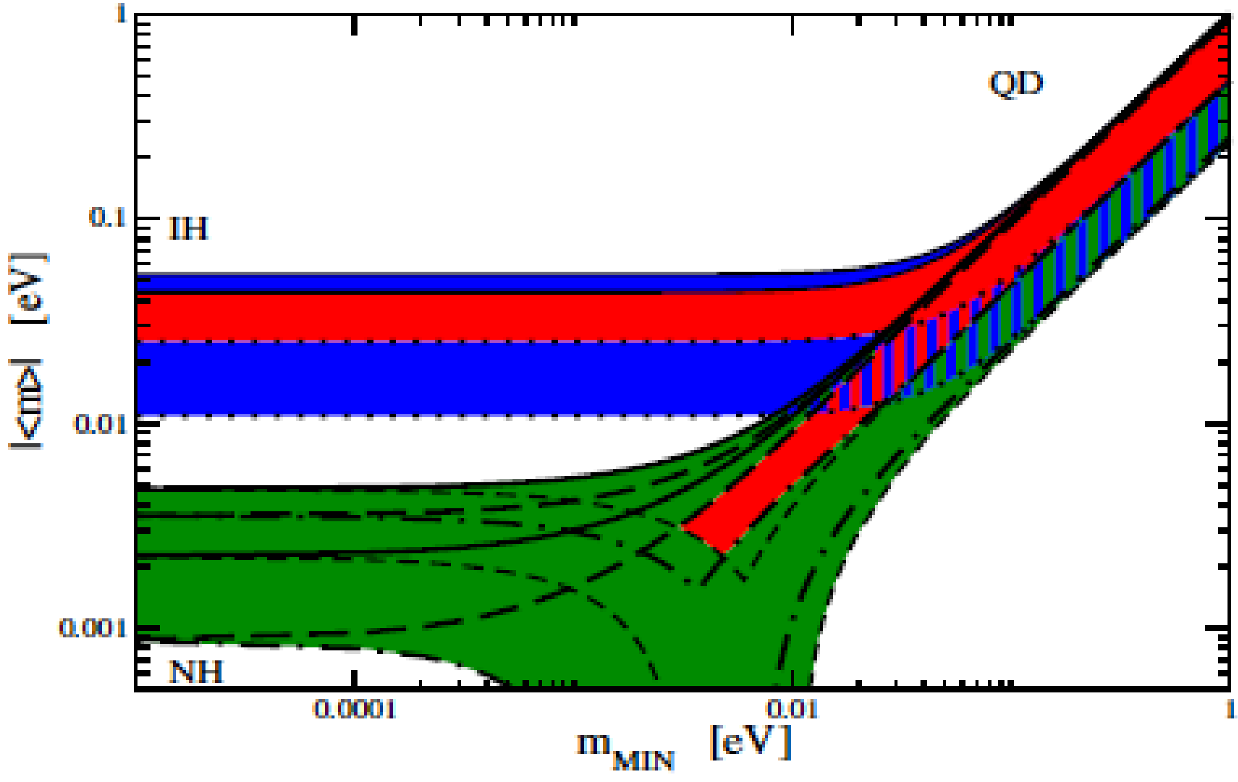
0νββ: $(Z, A) \rightarrow (Z+2, A) + 2e^{-}$

Lepton number violation process





Expected effective neutrino mass $<m_\nu>$



S. Pascoli, S.T.P., 2006
NDM06

DBD experiment and Sensitivity of Effective Neutrino Mass

Number of events (n) and Half life ($T_{1/2}$)

$$n = (\ln 2) k N_0 t / T_{1/2} > \sqrt{BG}$$

k : efficiency, N_0 : number of Nuclei, t : meas. time, BG: background

Half life ($T_{1/2}$) and Effective neutrino mass ($<m_\nu>$)

(in the case of mass term dominance)

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu} \left| M^{0\nu} \right|^2 < m_\nu >^2,$$

$G^{0\nu}$: phase space, $M^{0\nu}$: nuclear matrix element

$$< m_\nu >_{SNS} = \left(\frac{(BG)^{1/2}}{\ln 2 k N_0 t G^{0\nu} \left| M^{0\nu} \right|^2} \right)^{1/2}$$

Nuclear sensitivity for neutrinoless DBD

Isotope	A %	$Q_{\beta\beta}$ MeV	$S_N 10^{-24} y^{-1}$ (eV)$^{-2}$	Experiment/collaboration
^{48}Ca	0.187	4.276	0.11	CANDLES[a]
^{76}Ge	7.8	2.039	0.22	MAJORANA[b] GENIUS[c] GERDA[d]
^{82}Se	9.2	2.992	0.86	Super-NEMO[e]
^{100}Mo	9.6	3.034	2.02	MOON[f]
^{116}Cd	7.5	2.804	0.90	COBRA[g] CAMEO[h]
^{130}Te	34.5	2.529	0.73	CUORE[i], COBRA[g]
^{136}Xe	8.9	2.467	0.13	EXO[j], XMASS[k]
^{150}Nd	5.6	3.368	11.3	DCBA[l]

H. Ejiri, J. Phys. Soc. Jpn. 74 (2005) 2101

Status of neutrinoless DBD

Table VI. Limits on neutrino-less double β^- decays. $Q_{\beta\beta}$: Q value for the $0^+ \rightarrow 0^+$ ground state transition. $G^{0\nu}$: kinematical factor (phase space volume)^a in units of 10^{-14} y^{-1}, $T^{0\nu}_{1/2}$: half-life limits in units of 10^{24} y and $\langle m_\nu \rangle$: limit on the effective ν mass in units of eV.

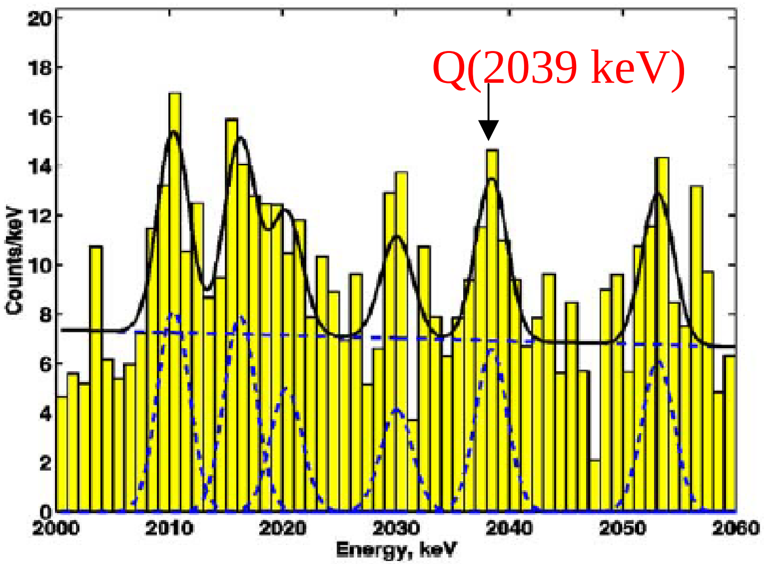
isotope	$Q_{\beta\beta}$ MeV	$G^{0\nu}$ 10^{-14} y^{-1}	$T^{0\nu}_{1/2}$ 10^{24}	$\langle m_\nu \rangle$ eV	Comments
^{48}Ca	4.276	4.46	> 0.014	< 7.2-45	b
^{76}Ge	2.039	0.44	$> 19(12^*)$	$< 0.35(\approx 0.44^*)$	$c(c')$
^{76}Ge	2.039	0.44	> 16	< 0.33-1.35	d
^{82}Se	2.992	1.89	> 0.19	< 1.3 - 3.2	e
^{100}Mo	3.034	3.17	> 0.35	< 0.7 - 1.2	f
^{116}Cd	2.804	3.24	> 0.17	< 1.7	g
^{128}Te	0.876	0.12	> 7.7	< 1.1 - 1.5	h
^{130}Te	2.529	2.86	> 0.75	< 0.3 - 1.6	i
^{136}Xe	2.467	3.03	> 0.44	< 1.8 - 5.2	j
^{150}Nd	3.368	13.4	> 0.0012	< 3	k

a: $G^{0\nu} = ln2G^{(0\nu)}$, where $G^{(0\nu)}$ is for $(T^{0\nu}_{1/2})^{-1}$ in ref,[23)] b: ref.[97)] c: ref.[81)] c': ref.[31)] *: finite values, d: ref.[30)] e: ref.[32)] f: ref.[32)] g: ref.[99)] h: geochemical method ref.[90)] i: ref.[100)] j: ref.[101)] k: ref..[85)]

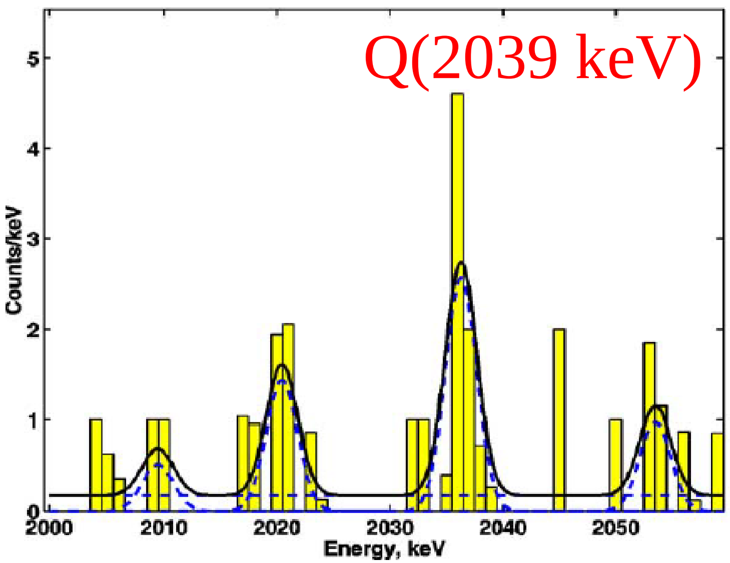
H. Ejiri, J. Phys. Soc. Jpn. 74 (2005) 2101

KKDC claim for neutrinoless DBD of ^{76}Ge from the Heidelberg-Moscow experiment with 14 collaborators

Klapdor,K,D,C, Phys. Lett. B 586 (2004) 198



Sum energy of 2 electrons



Pulse shape analysis

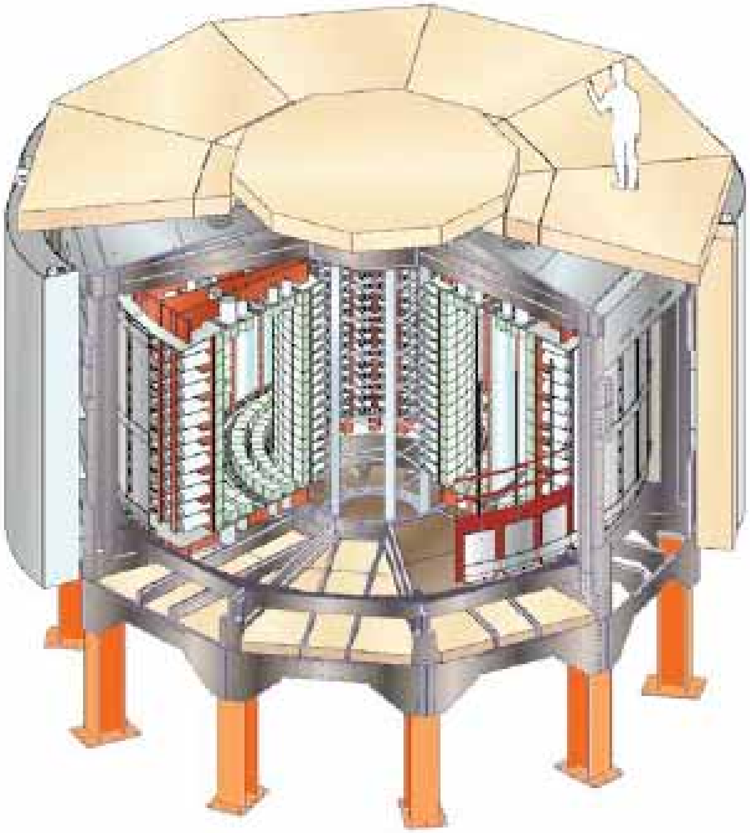
$(0.69\text{-}4.18)\times10^{25}$ yr, 1.19×10^{25} yr from data of 1990-2003

0.24 eV < $\langle m_\nu \rangle$ < 0.58 eV, best value 0.44 eV

The NEMO3 detector

(France, Finlande, Japon, Maroc, République tchèque, R-U, Russie,Ukraine, USA)

@ Freius Underground Laboratory : 4800 m.w.e.



Source: 10 kg of ββ isotopes
cylindrical, S = 20 m², 60 mg/cm²

Tracking detector:

99.5 % cells ON
Vertex resolutions :
$\sigma_\perp$ **(ΔVertex) = 0.6 cm**
$\sigma_{//}$ **(ΔVertex) = 1.3 cm** (Z=0)

Calorimeter:

97% PM+scintillators ON
TDC resolution : 250 ps @ 1MeV
FWHM (1 MeV) 14% (PM 5") **17%** (PM 3")

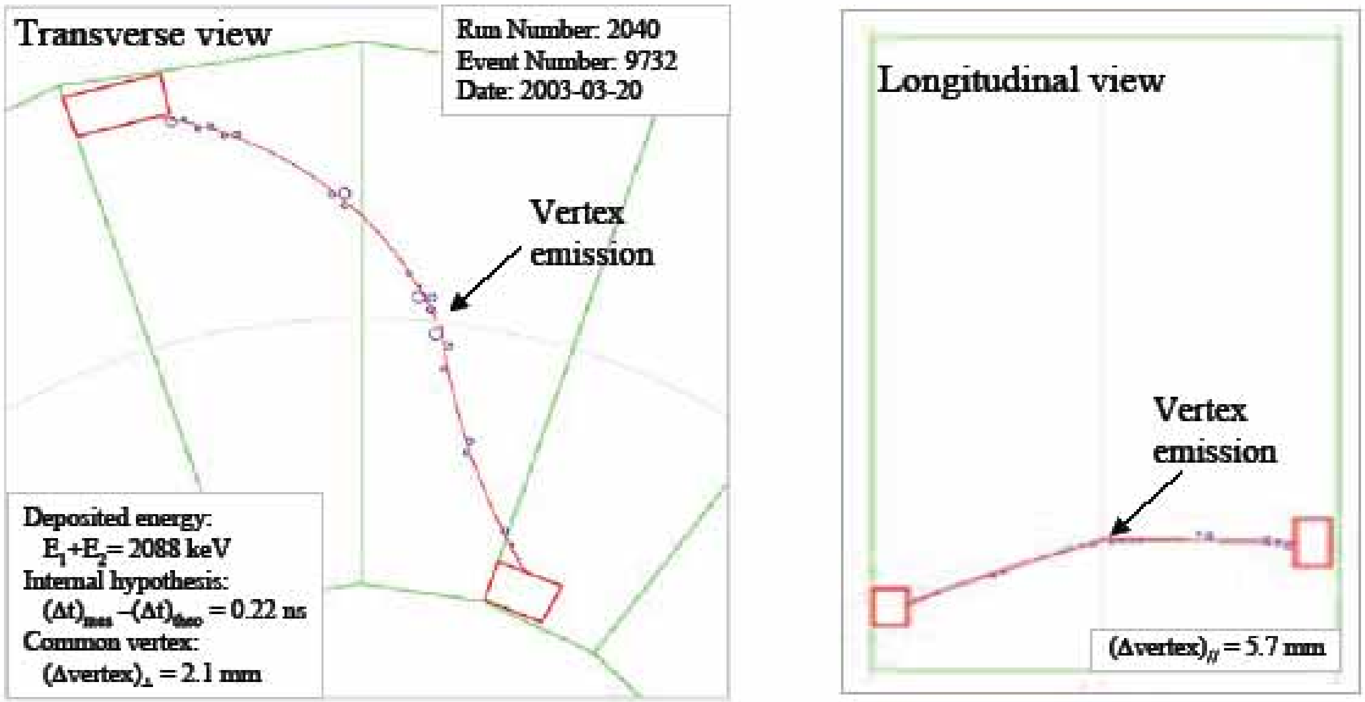
Magnetic field: 25 Gauss
Gamma shield: Iron (18 cm)
Neutron shield: borated water + wood

⇒ **Identification e⁻, e⁺, γ and α**

X. Sarazin @ NDM06

ββ events selection in NEMO3

Typical ββ2ν event observed from ^{100}Mo



Trigger: 1 PM > 150 keV

3 Geiger hits (2 neighbour layers + 1)

Trigger Rate = 5,8 Hz

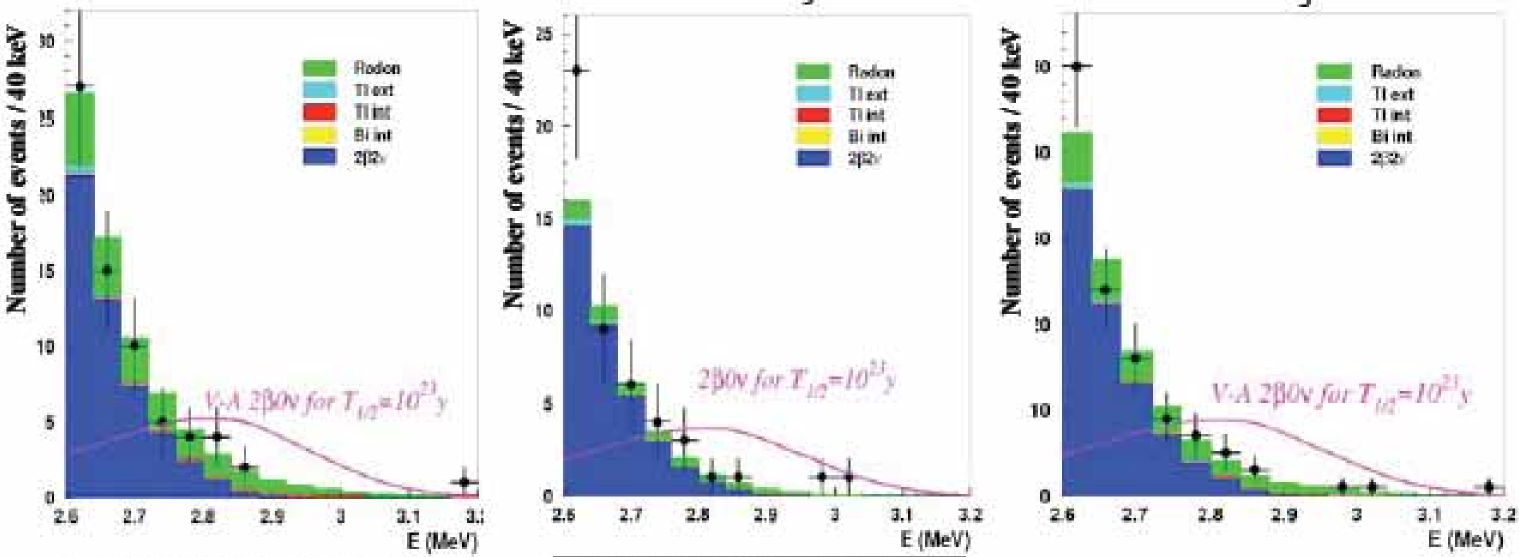
ββ evts: 1 event every 2 minutes

X. Sarazin@NDM06

ββ0ν results with ^{100}Mo

^{100}Mo, 7 kg

Phase I, High radon 394 days	Phase II, Low radon 299 days	Phase I + II 693 days



Phase I	Phase II
[2.8-3.2] MeV: ε(ββ0ν) = 8 % Expected bkg = 8.1 events $N_{observed}$ = 7 events	[2.8-3.2] MeV: ε(ββ0ν) = 8 % Expected bkg = 3.0 events $N_{observed}$ = 4 events

Phases I + II **$T_{1/2}(\beta\beta0\nu) > 5.8\ 10^{23}$ (90 % C.L.)**

Expected in 2009 $T_{1/2}(\beta\beta0\nu) > 2\ 10^{24}$ (90 % C.L.)

X. Sarazin@NDM06

Double beta decay experiments with tracking detectors

- International collaboration
  - Tracking-calorimetric / Tracking detector

    NEMO, MOON, DCBA
- Common R&D for future detectors

    Enrichment of ^{150}Nd, Energy resolution, BGD reduction
- Collaboration for LIA project

  France: F. Piquemal, Ch. Marquet, J.S. Ricol / CENBG

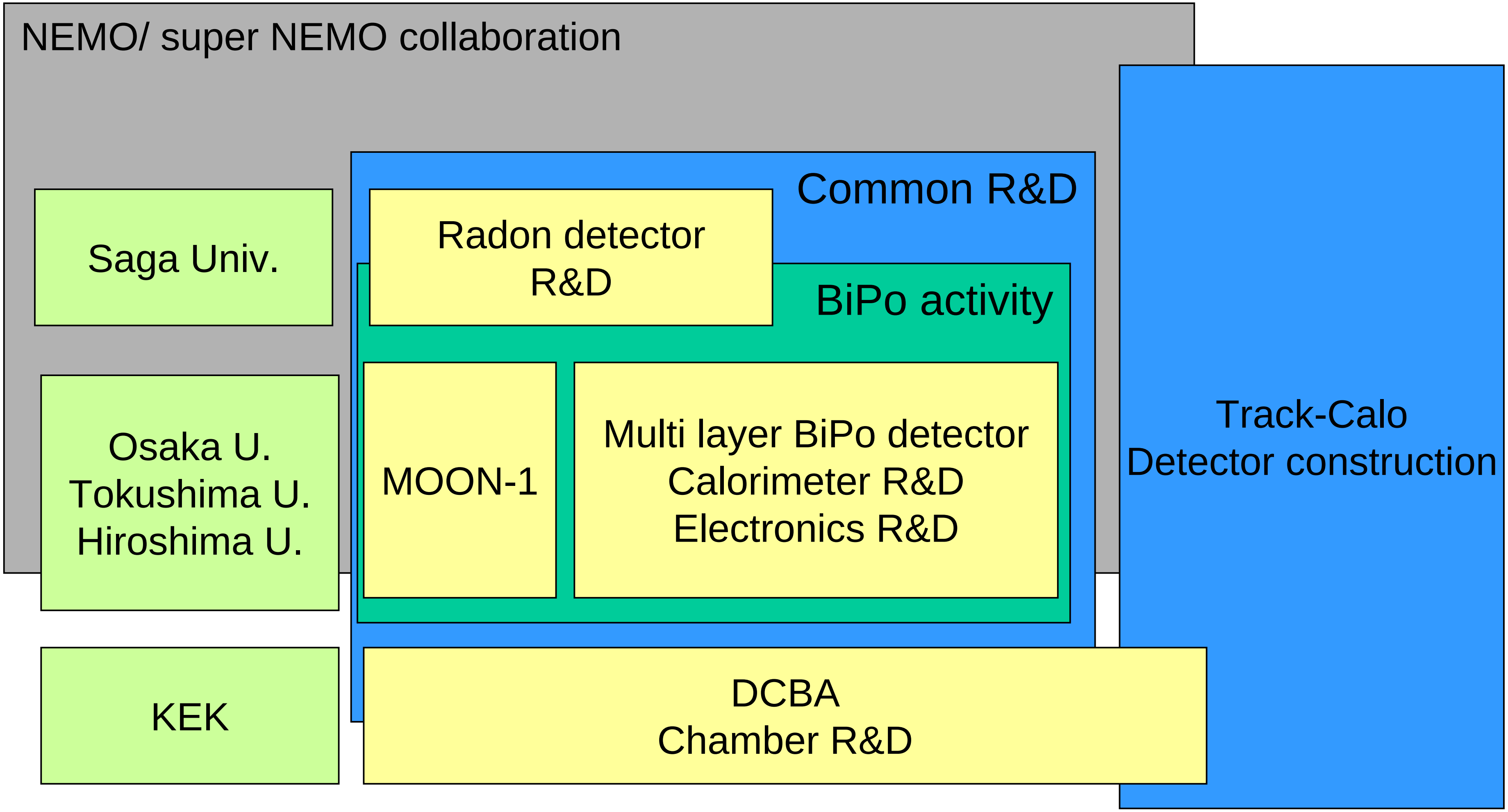
  X. Sarazin, S. Jullian, D. Lalanne, C. Augier, L. Simard,

  J. Argyriades /LAL

  Japan: N. Ishihara/KEK, M. Nomachi/Osaka-U, H. Ejiri/RCNP-Osaka U,

  H. Ohsumi/Saga-U, K. Fushimi/Tokushima-U, Hiroshima-U.

Collaborative work

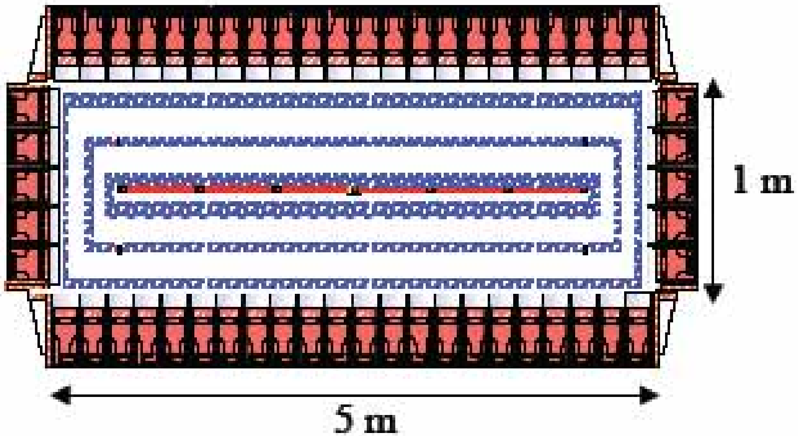


Groups interested in Track-Calo detectors in Japan.

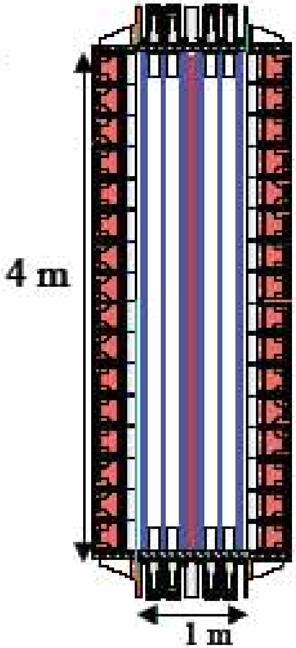
Possible SuperNEMO design

Planar and modular design: ~ 100 kg of enriched isotopes (20 modules × 5 kg)

1 module: Source (40 mg/cm^2) 4 x 3 m^2
Tracking : drift chamber ~3000 cells in Geiger mode
Calorimeter: scintillators + PM ~1 000 PM if scint. blocs
~ 100 PM if scint. bars



Top view



Side view

Ch. Marquet @ NDM06

From NEMO3 to SuperNEMO… objectives

$$T_{1/2}(\beta\beta0\nu) > \ln 2 \times \frac{N_{avo}}{A} \times \frac{M \times \varepsilon \times T_{obs}}{N_{exclu}}$$

NEMO-3		SuperNEMO
^{100}Mo	Choice of isotope	^{150}Nd or ^{82}Se
7 kg	Isotope mass M	100-200 kg
8 %	Efficiency $\varepsilon(\beta\beta0\nu)$	~ 30 %
^{208}Tl < 20 μBq/kg ^{214}Bi < 300 μBq/kg	N_{exclu} = f(BKG) *Internal contaminations* *^{208}Tl and ^{214}Bi in the ββ foil*	^{208}Tl < 2 μBq/kg *(If ^{82}Se:* ^{214}Bi < 10 μBq/kg)
8% @3MeV	Energy resolution FWHM(calorimeter)	4% @3MeV
$T_{1/2}(\beta\beta0\nu) > 2.\ 10^{24}$ y $<m_\nu> < 0.3 - 1.3$ eV	SENSITIVITY	$T_{1/2}(\beta\beta0\nu) > 10^{26}$ y $<m_\nu> < 50$ meV

Main R&D tasks:

1) ββ source production **2) Radioprurity** **3) Energy resolution**

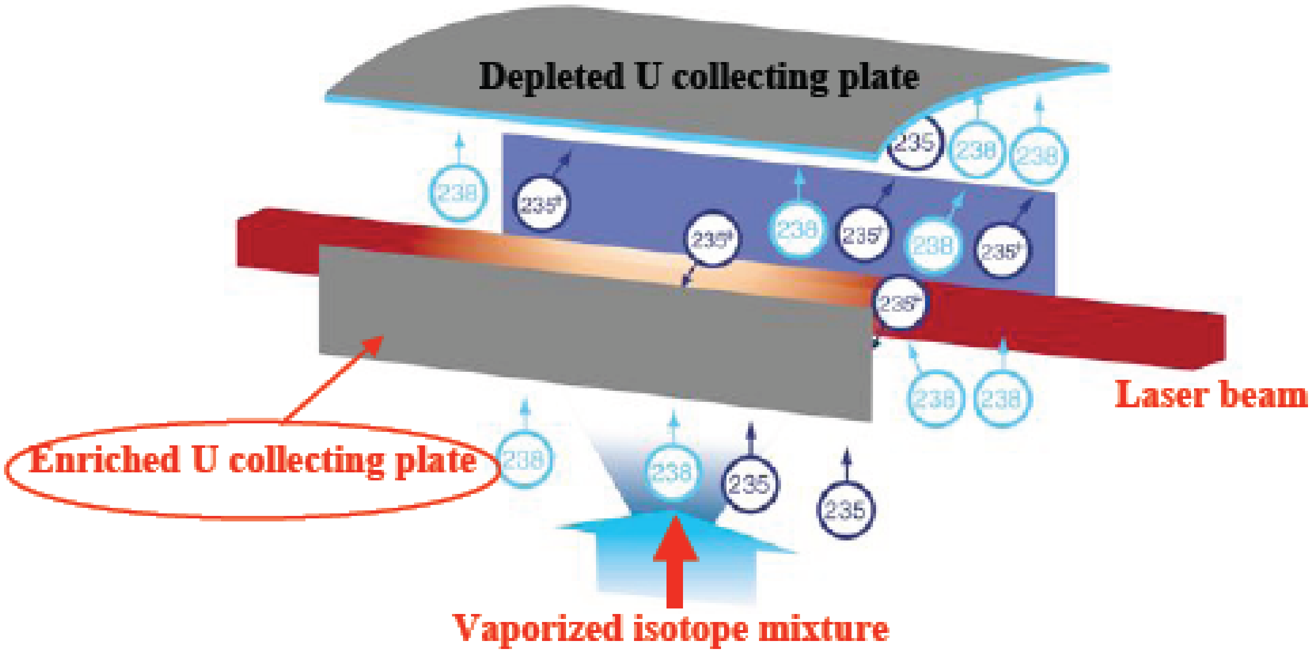
+ Tracking, Electronics, DAQ, Software, Mechanics, Theory

Ch. Marquet – NDM06 – September. 2006

^{150}Nd production: The Laser Method (AVLIS)

AVLIS: Atomic Vapor Laser Isotope Separation

Selective photoionization based on :
isotope shifts in the atomic absorption optical spectra
U + 3 selective photons → $^{235}U^{+} + e^{-}$



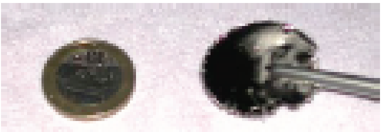
Ch. Marquet – NDM06 – September. 2006

^{150}Nd production: possibility in France ?

2000-2003: R&D with MENPHIS demonstrator facility (CEA/Pierrelatte - France)

Main results for the process :

- **204 kg of enriched uranium at ≈ 2.5 % mean (predicted) value of enrichment**
- **Production raise: few kg/h for U**

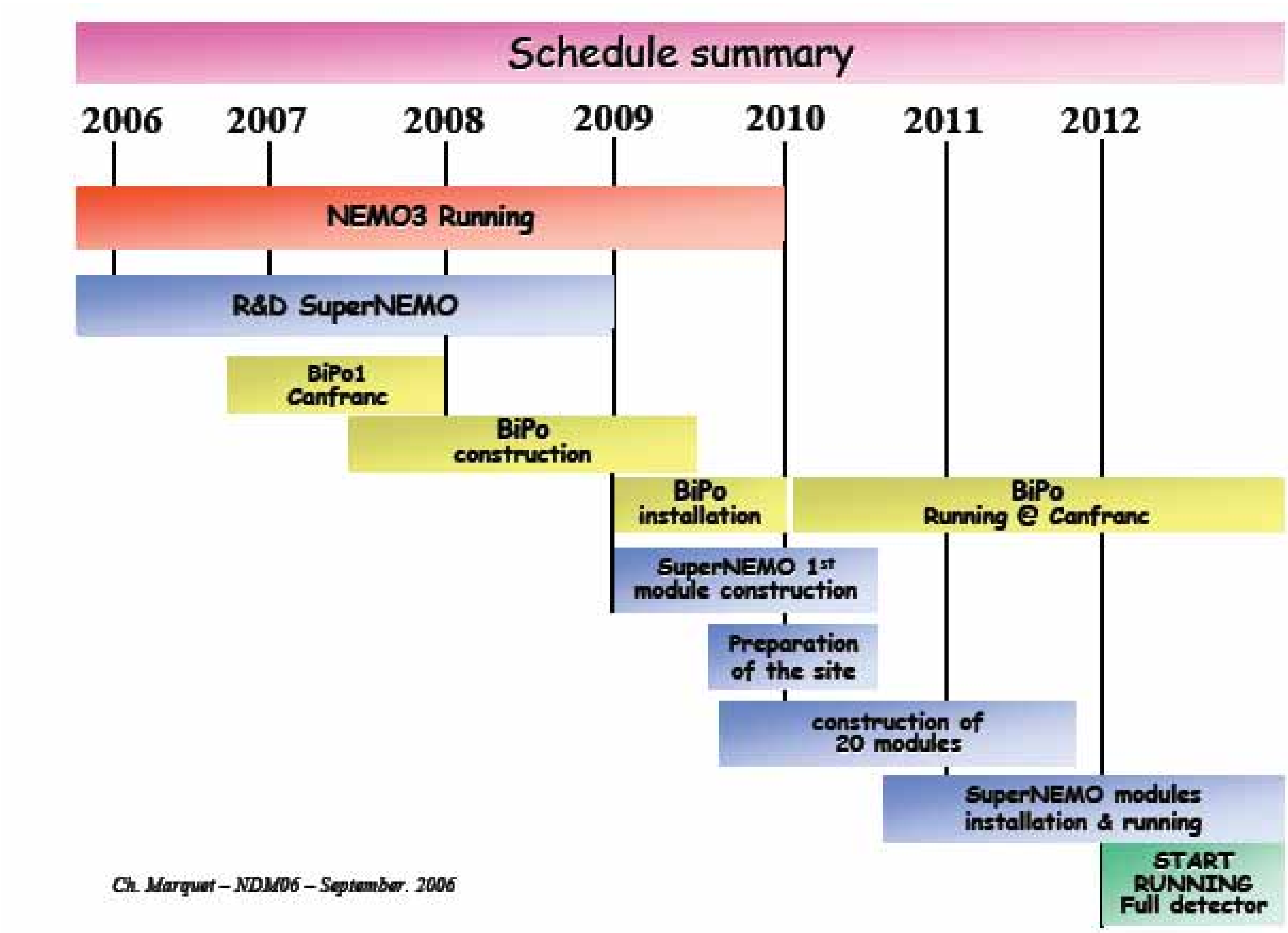


~2000kg natural U evaporated
~400 assay measurements

Restart MENPHIS… for ^{150}Nd ?

- **Technicaly possible:** Nd has been already enriched at 60% ^{150}Nd
- **Raisonable production raise:** few weeks for 100 kg
- **Several interested experiments:** SuperNEMO, SNO+, MOON, DCBA *(Letter of Interest – July 2006)*

Ch. Marquet – NDM06 – September. 2006

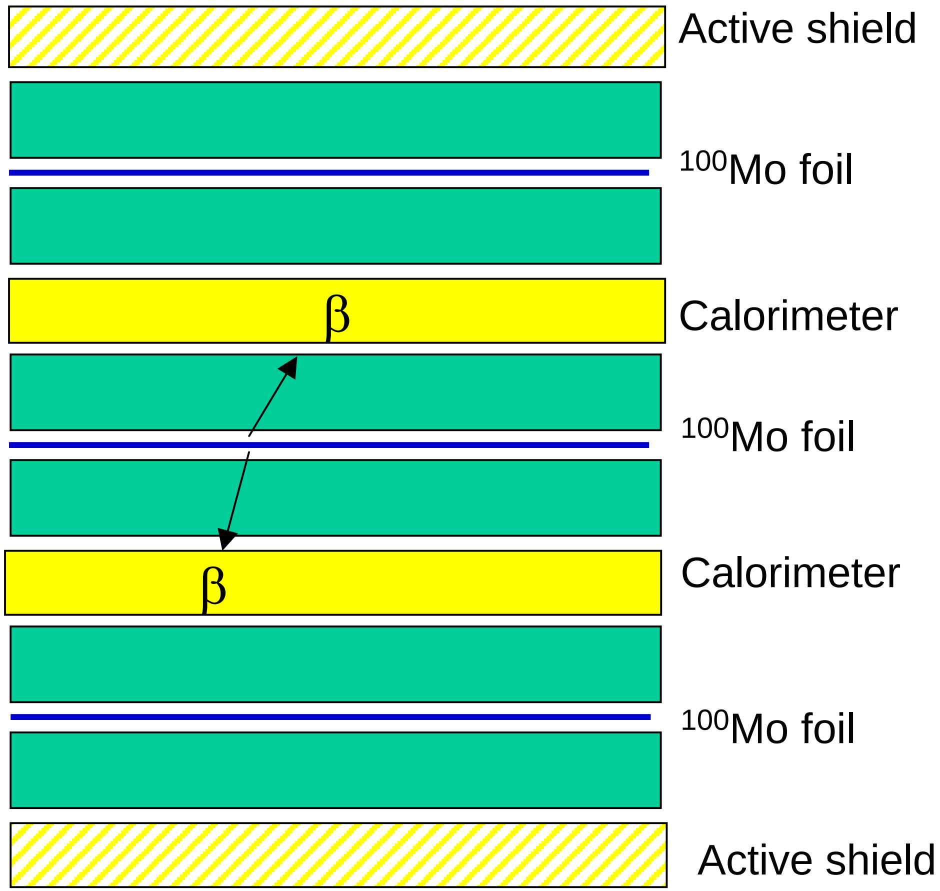

Schedule summary
2006
2007
2008
2009
2010
2011
2012
NEMO3 Running
R&D SuperNEMO
BiPo1
Canfranc
BiPo
construction
BiPo
installation
BiPo
Running @ Canfranc
SuperNEMO 1st
module construction
Preparation
of the site
construction of
20 modules
SuperNEMO modules
installation & running
START
RUNNING
Full detector
Ch. Marquet – NDM06 – September. 2006

MOON Detector

- **Multi layers module**
  - **^{100}Mo foil & Plastic scintillator**

    Mo foil is interleaved with PLs.
  - **Compact 1 t detector**

    PL works both as calorimeter and as active shield
  - **No TOF**
  - **Effective gamma veto**
  - **Particle ID.**
    - **Not in MOON-1 prototype detector**



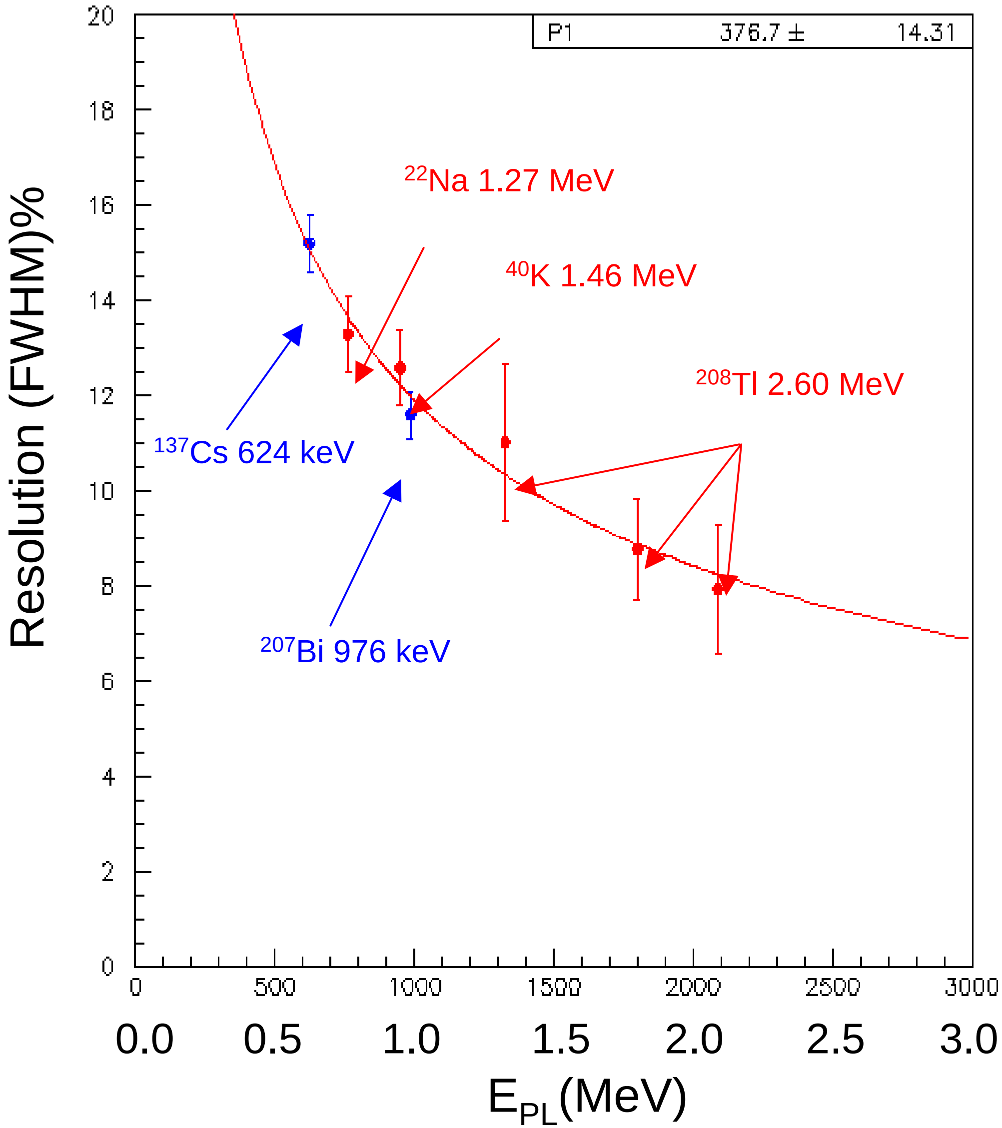
M. Nomachi

MOON-1 Energy resolution

$$R(FWHM) = \frac{(11.9 \pm 0.5)}{\sqrt{E(MeV)}}\%$$

$$R(FWHM)@3MeV = 6.8\%$$

M. Nomachi



Ultra Low Background Detector

To acieve required purity, the detector with high sensitivity

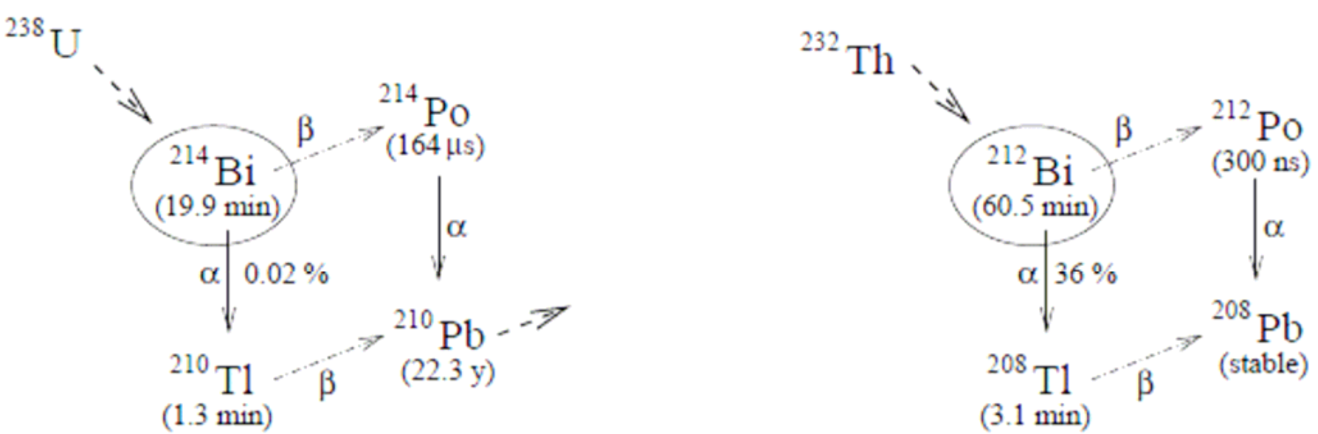
BiPo-detector (LAL,CENBG,Osaka,Tokushima)

With 5 kg of ^{82}Se source foil (~ 12 m^2, 40 mg/cm^2)

2 μBq/kg of ^{208}Tl ➡ 50 (e^-, delay α) ^{212}Bi decays / month

ε ~ 6 % ➡ 3 decays / month

Background < 1 events/month is required !



BGD measurement with Radon monitor

− R&D works at Saga Univ. (H. Ohsumi) −

Possible contributions to SuperNEMO

- **Radon detectors, (70 litters, Sensitivity 1mBq/m^3)**

  for Bi-Po experiment (@Canfranc)

- **Study of low background materials used for SuperNEMO**

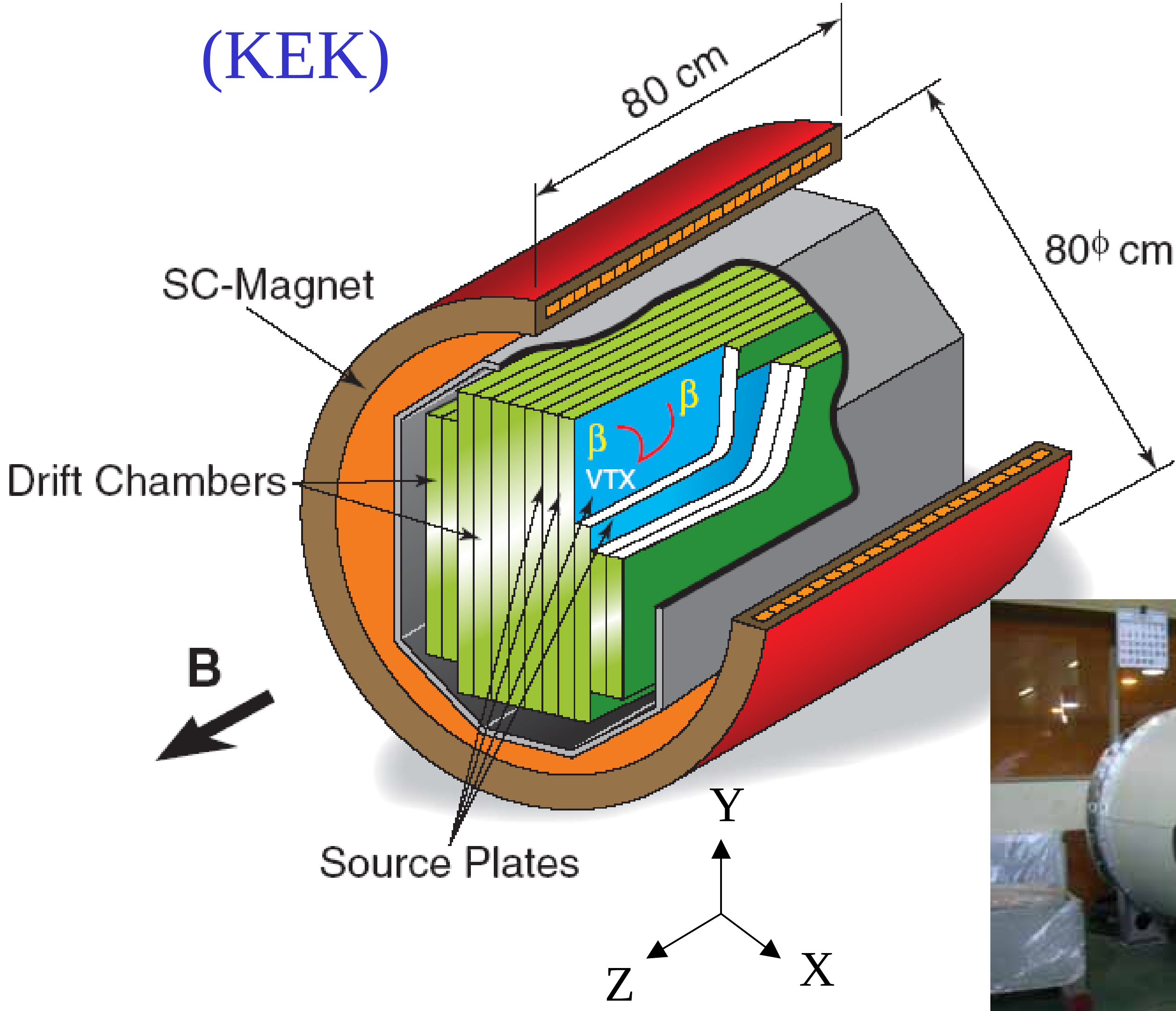
measurement of radon/thoron emanation

collaboration with CENBG Bordeaux.

- **Next generation high sensitive radon detector (Next goal -- 0.1mBq/m^3)**

  Bigger size volume, or new technique, using low background photodiode etc.

DCBA-T3 (Drift Chamber Beta-ray Analyzer)
(KEK)



Principle of DCBA

$^{150}Nd \rightarrow ^{150}Sm + 2e^-$

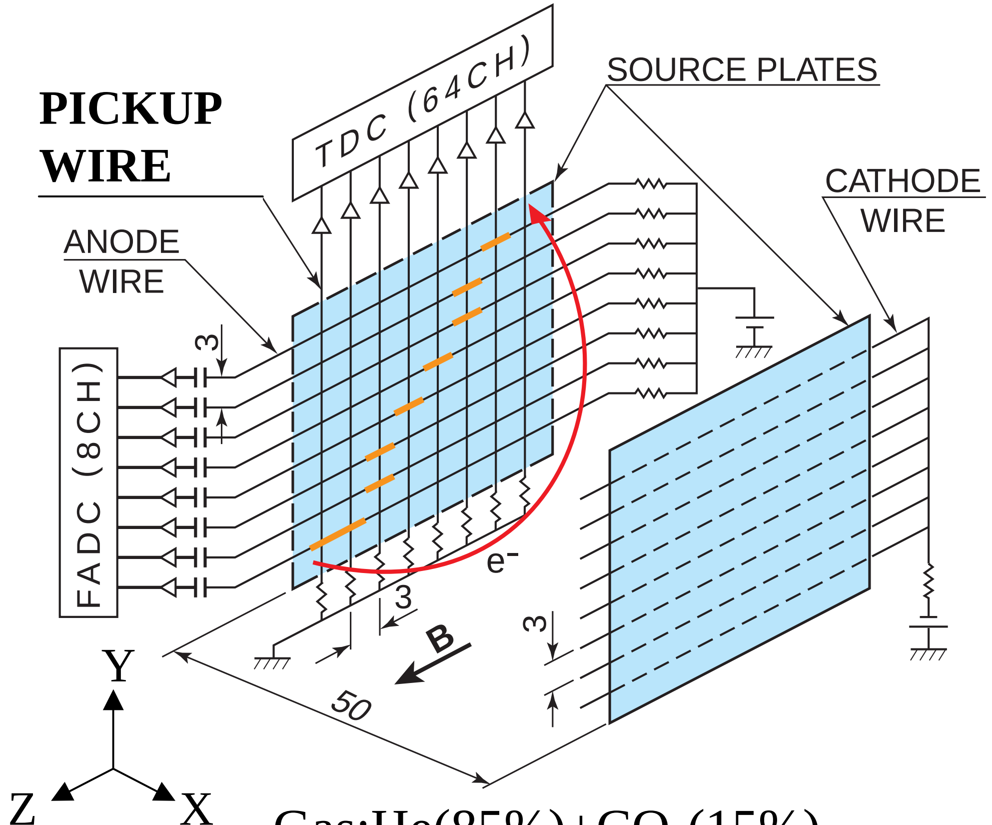
$$p\cos\lambda = 0.3rB,$$

$$T = (p^2 + m_e^2)^{1/2} - m_e$$

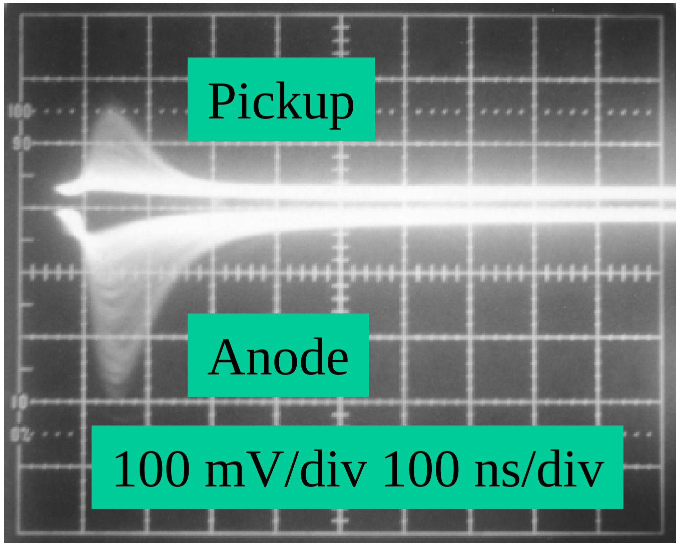
p (MeV/c): momentum, *r* (cm): radius,

λ: pitch angle, *B* (kG): magnetic field,

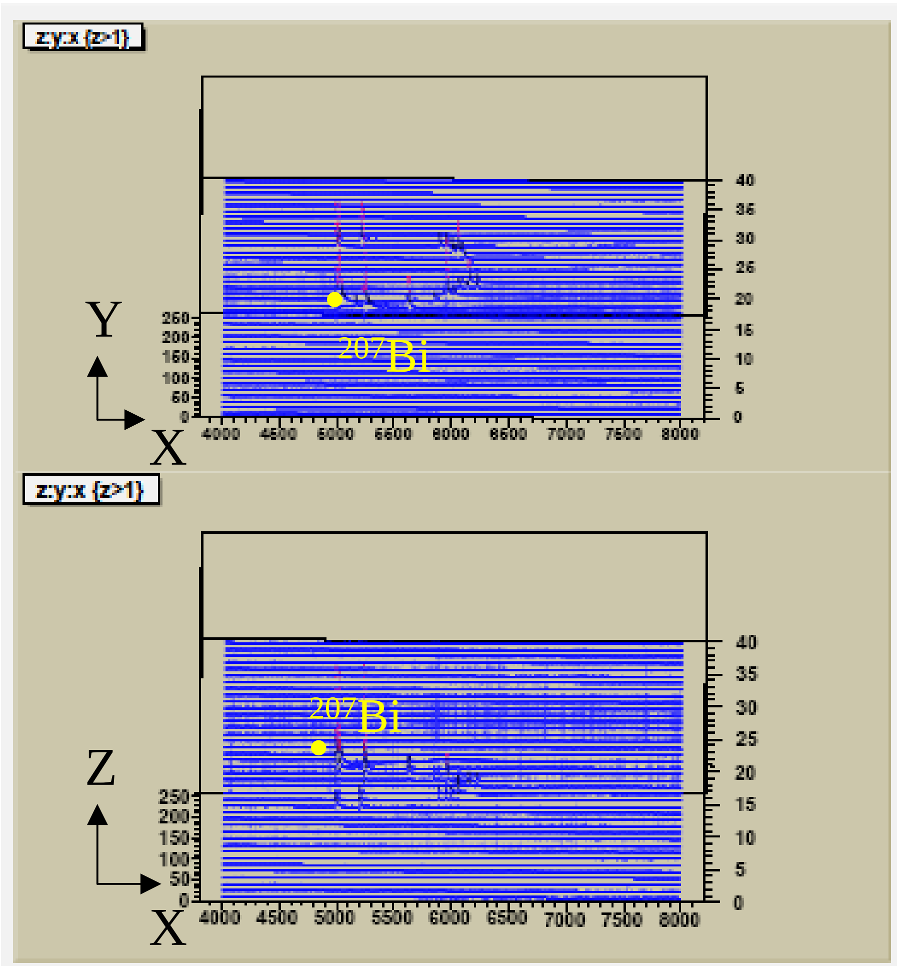
m_e (MeV/c^2): electron mass



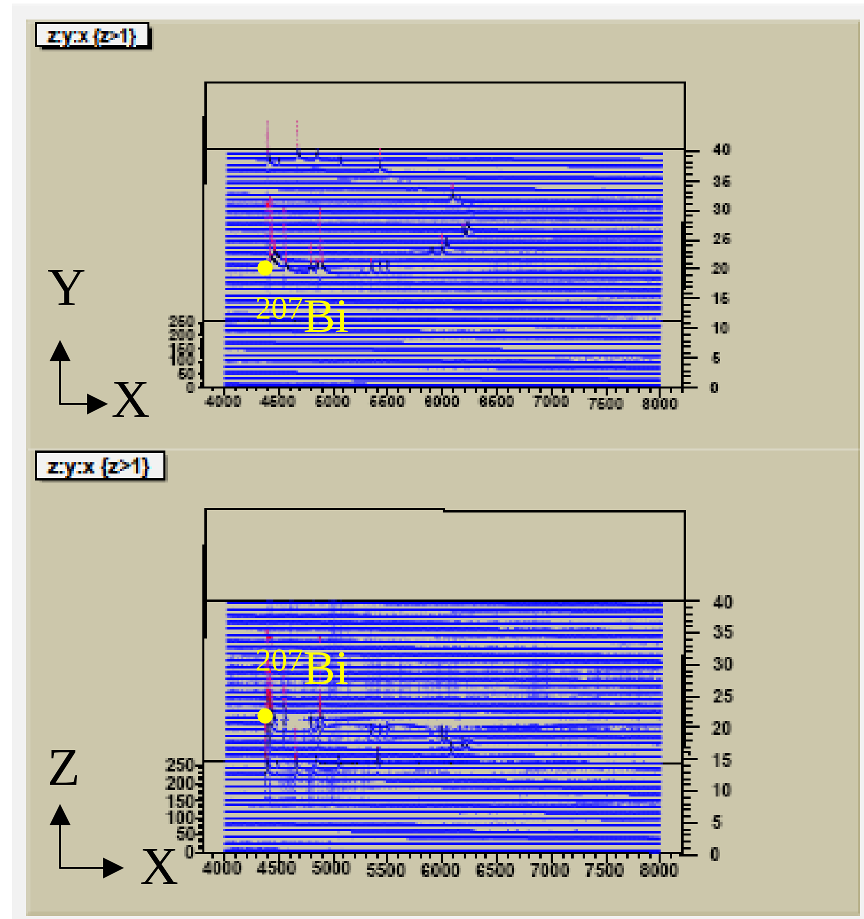
Gas:He(85%)+CO_2(15%)



Electrons from ^{207}Bi

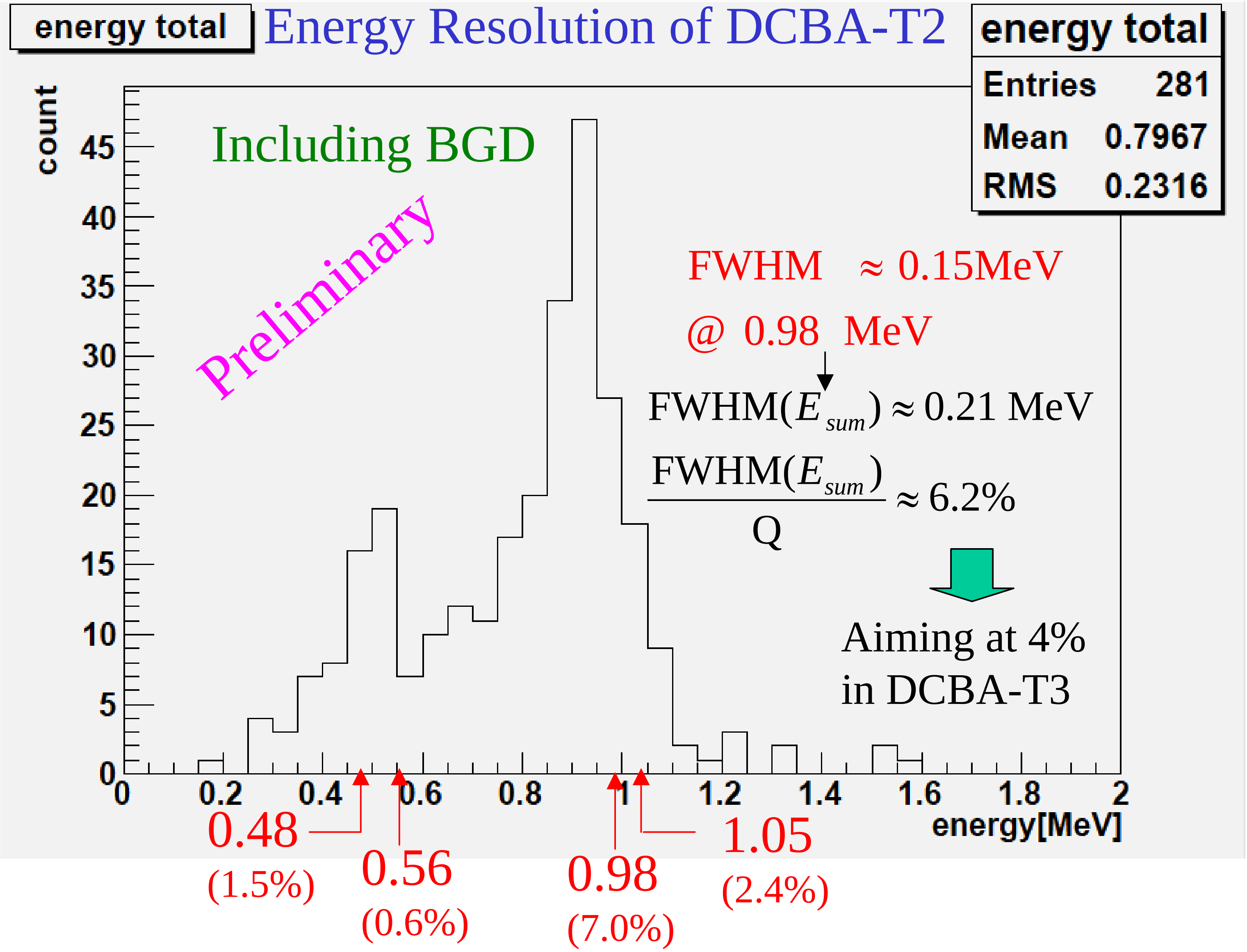


T = 458 keV



T = 971 keV

Energy Resolution of DCBA-T2



FWHM ≈ 0.15MeV

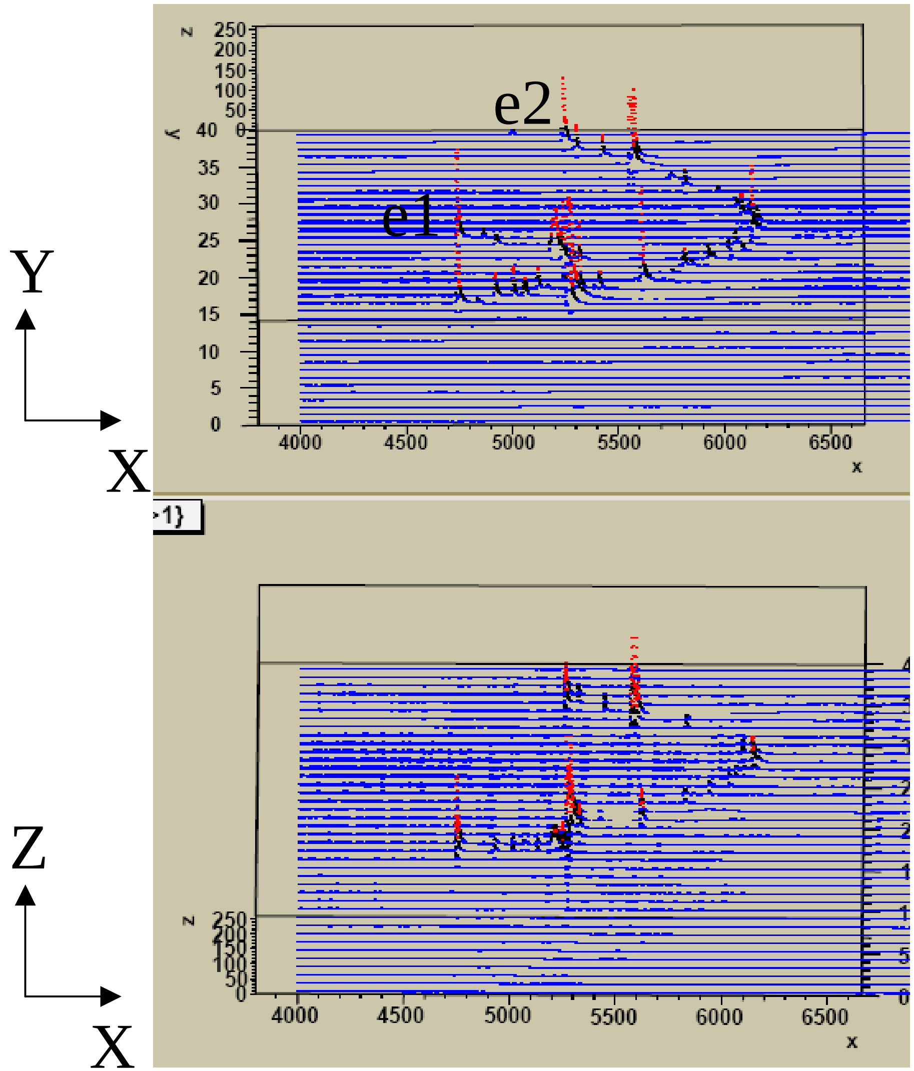
@ 0.98 MeV

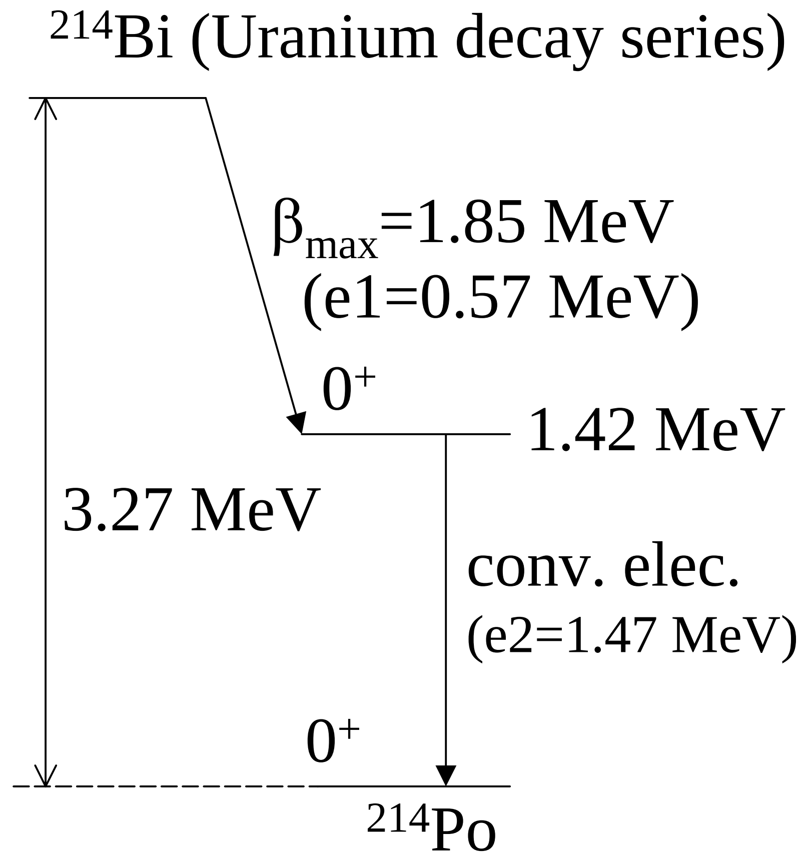
$$\mathrm{FWHM}(E_{sum}) \approx 0.21\ \mathrm{MeV}$$

$$\frac{\mathrm{FWHM}(E_{sum})}{Q} \approx 6.2\%$$

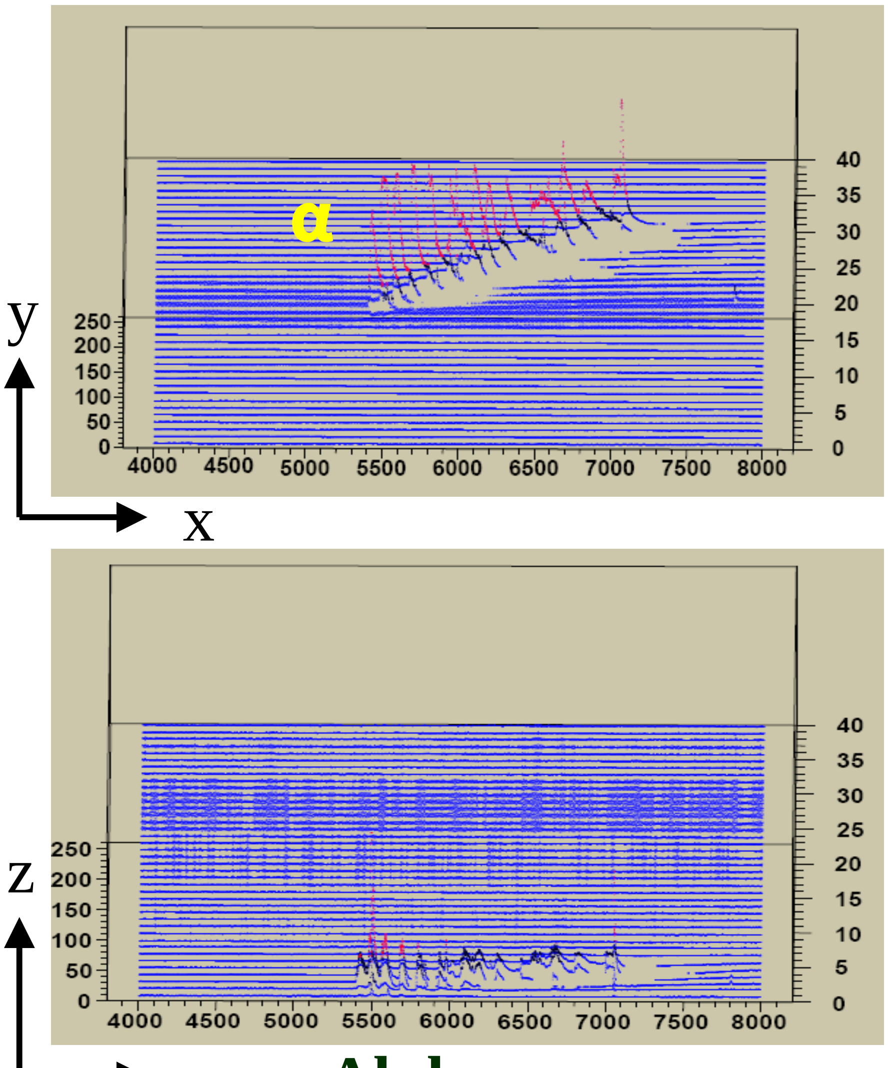
Aiming at 4%
in DCBA-T3

Background 2-electron event

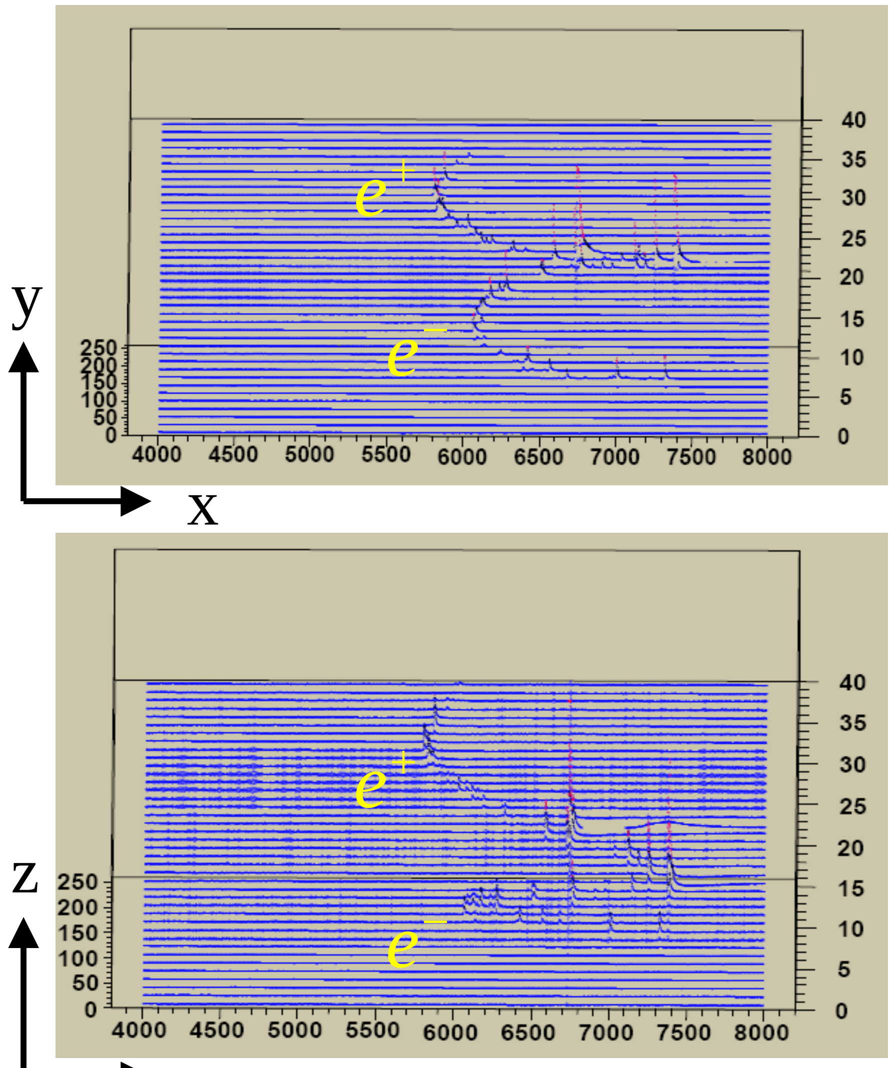




OTHER BACKGROUND EVENTS



Alpha-ray



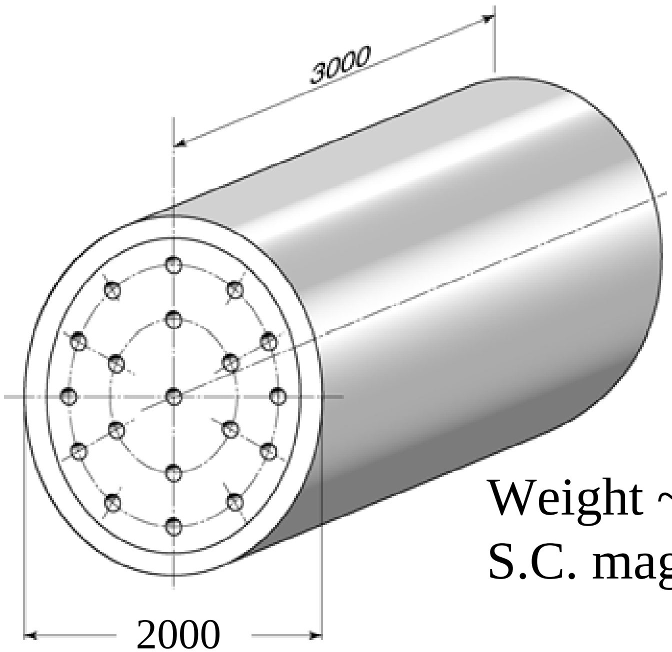
pair creation

Future plan MTD (Magnetic Tracking Detector) Temporary

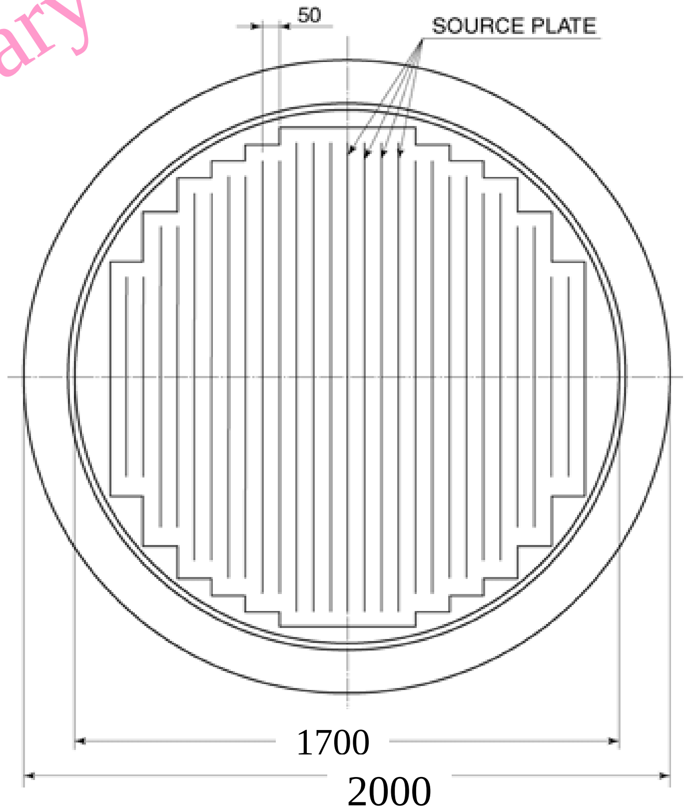
Source plate: 84 m^2/module
Thickness: 15 (40) mg/cm^2
Weight: 12.6 (33.6) kg/module

Anode wire: 10600/module
Pickup wire: 26200/module

Preliminary



Weight ~ 20 t
S.C. magnet



$< m_\nu > \approx 0.8\,\mathrm{eV}\ (0.5\,\mathrm{eV})$ for natural Nd/mod.yr

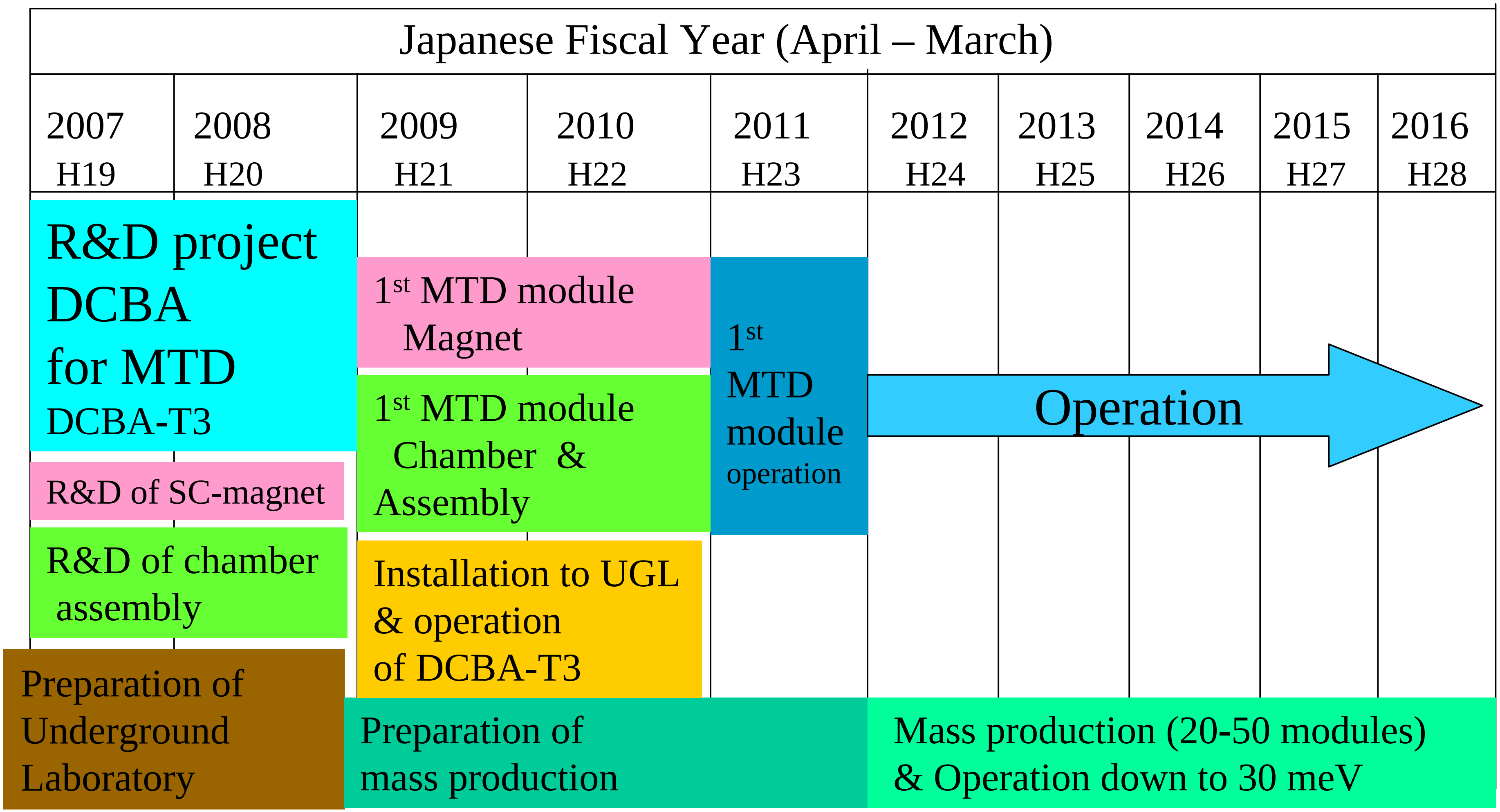
$< m_\nu > \approx 0.2\,\mathrm{eV}\ (0.1\,\mathrm{eV})$ for 60% ^{150}Nd/mod.yr

Half-life and Effective Mass Sensitivities of MTD for ^{150}Nd, ^{100}Mo and ^{82}Se (Tentative)

	Natural Nd (5.6% ^{150}Nd)	^{150}Nd (80% enr.)	^{100}Mo (90% enr.)	^{82}Se (90% enr.)
MTD Amount (mol) (600 kg : 50 modules of 15 mg/cm^2)	190	2700	5400	6600
$T^{1/2}_{0\nu}$ sens. (yr)	9×10^{24}	1×10^{26}	2×10^{26}	3×10^{26}
$\langle m_\nu \rangle$ sens. (eV)	0.06	0.02	0.07	0.04

Nucl. Matrix Element: A. Staudt et al. Europhys. Lett. 13 (1) (1990) 31

Optimistic Schedule of DCBA/MTD
(depending on financial support)



Concluding remarks

1. Observation of 0νββ events in ^{76}Ge claimed by KKDC should be confirmed by other experiments using different decay sources.

2. NEMO, MOON and DCBA can use several kinds of decay sources, such as ^{150}Nd, ^{100}Mo and ^{82}Se. They have tracking detectors which are very useful to reduce backgrounds.

3. These groups have made efforts at obtaining enriched ^{150}Nd, improving energy resolution and reducing backgrounds, in order to investigate Majorana nature and the effective mass down to 30 meV, which is predicted in the inverted hierarchy spectrum.

4. Collaboration will be made by exchange of experimental physicists between different test benches in Japanese and French Laboratories.