National Institute of Nuclear Physics INFN

University of Genoa

Perspectives of direct searches of neutrino mass with very low energy beta spectroscopy of Re-187

Flavio Gatti
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Three ways for measeuring $m_{\nu i}$

- β decay: $m^2_i \neq 0$ can affect spectrum endpoint. Sensitive to the “effective electron neutrino mass”:

$$m_\beta = \left[c_{13}^2 c_{12}^2 m_1^2 + c_{13}^2 s_{12}^2 m_2^2 + s_{13}^2 m_3^2\right]^{\frac{1}{2}}$$

- $0\nu 2\beta$ decay: Can occur if $m^2_i \neq 0$ and $\nu = \nu$. Sensitive to the “effective Majorana mass” (and phases):

$$m_{\beta\beta} = \left|c_{13}^2 c_{12}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right|$$

- Cosmology: $m^2_i \neq 0$ can affect large scale structures in (standard) cosmology constrained by CMB+other data. Sensitive to:

$$\Sigma = m_1 + m_2 + m_3$$

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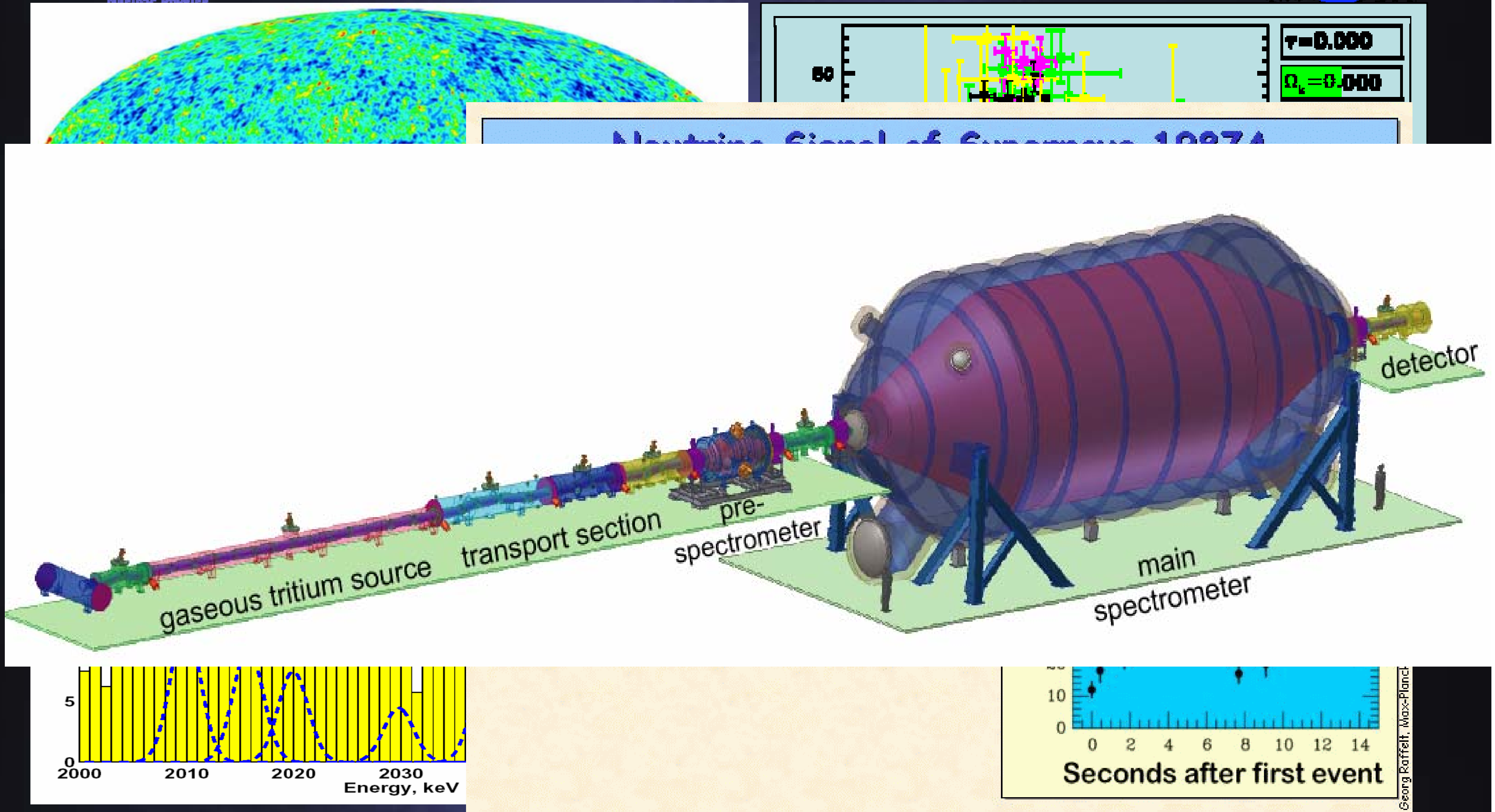


The searches via β decay

- $(A,Z) \rightarrow (A,Z+1) + e + \nu \qquad (+\,Q)$

- $dN(\varepsilon)=G^2\, F(Z,\varepsilon)\, |M|^2\, S(\varepsilon)\, p\, \varepsilon\, (\varepsilon-\varepsilon_0)^2\, d\varepsilon$

$$\Downarrow$$

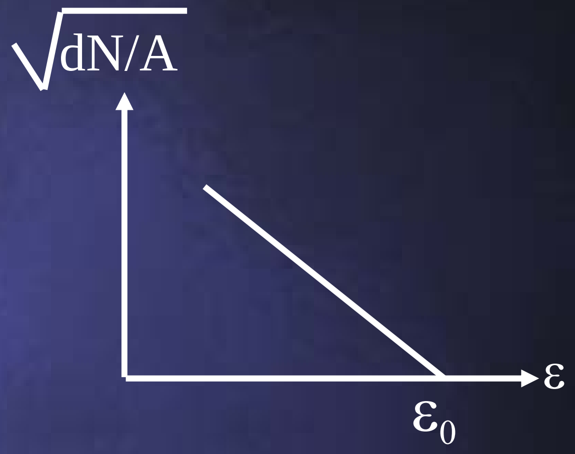
$$\varepsilon \rightarrow \varepsilon_0$$

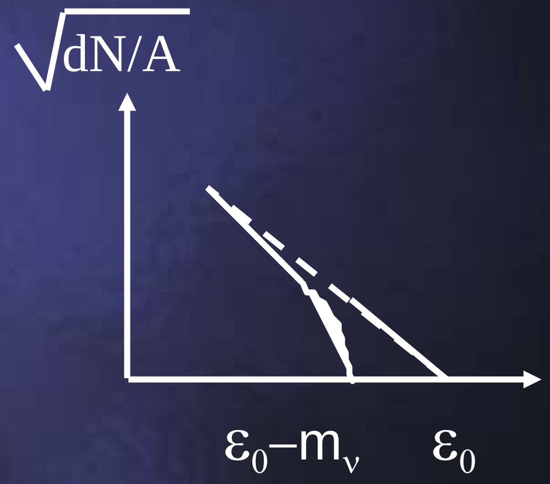
$$dN(\varepsilon)=A\,(\varepsilon-\varepsilon_0)^2\, d\varepsilon$$

- $dN(\varepsilon)=A\,(\varepsilon-\varepsilon_0)^2\,[1 - m_\nu^2c^4 / (\varepsilon-\varepsilon_0)^2]^{1/2}\, d\varepsilon$

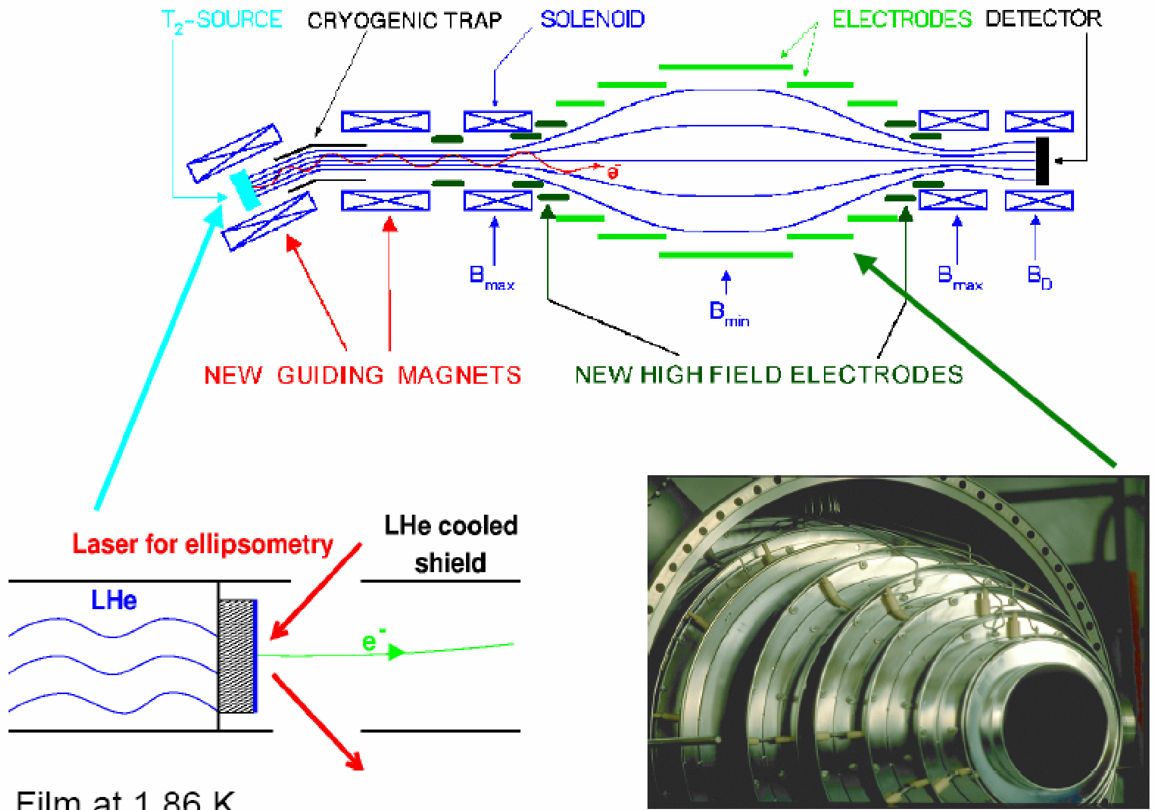
$\Rightarrow\ \varepsilon_{max}= \varepsilon_0 - m_\nu c^2$

$\Rightarrow$ deficit $\propto [\, m_\nu c^2 / \varepsilon_0\,]^3$





1^{st} method: beta impulse spectroscopy



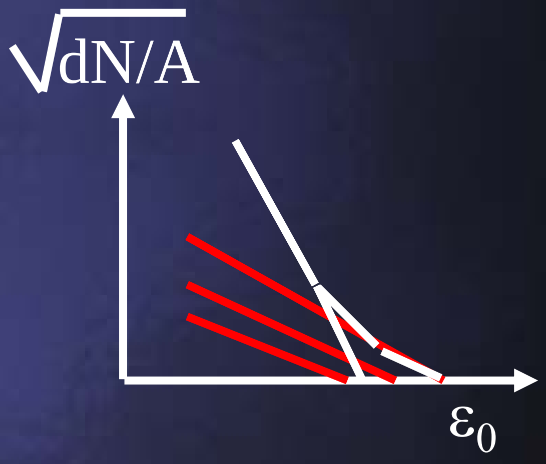
- T_2 Film at 1.86 K
- quench-condensed on graphite (HOPG)
- 45 nm thick (≈130ML), area 2cm^2
- Thickness determination by ellipsometry

Mainz
ν group
2001:

J. Bonn
B. Bornschein*
L. Bornschein
B. Flatt
Ch. Kraus
B. Müller
E.W. Otten
J.P.Schall
Th. Thümmler**
Ch. Weinheimer**

* → FZ Karlsruhe
** → Univ. Bonn

- Systematic unknown effects affect the shape at the end-point: in particular the so called “final states effect”

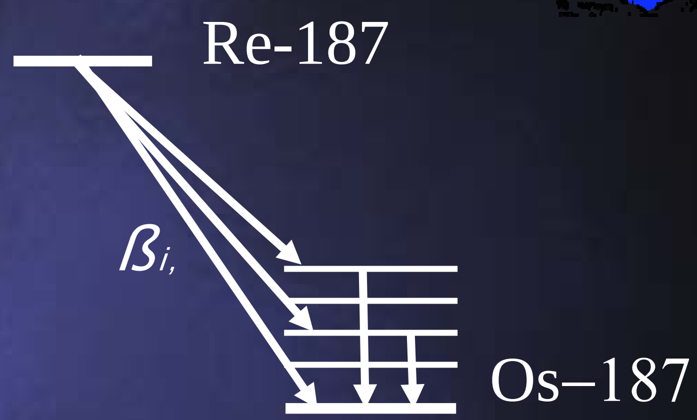


2^{nd} method: calorimetric beta spectoscopy

Advantages:

- Measurement of whole energy of the decay

$$E_i = \varepsilon_i + \Delta_i$$



$\Rightarrow$ $dN(E) = A \, \Sigma_i \, w_i \, (E_i - E_0)^2 \, dE$

$\Rightarrow$ no model dependent corrections for atomic and molecular final states.

$\Rightarrow$ no correction for nuclear recoil energy and for electron energy losses,…

Disadvantages:

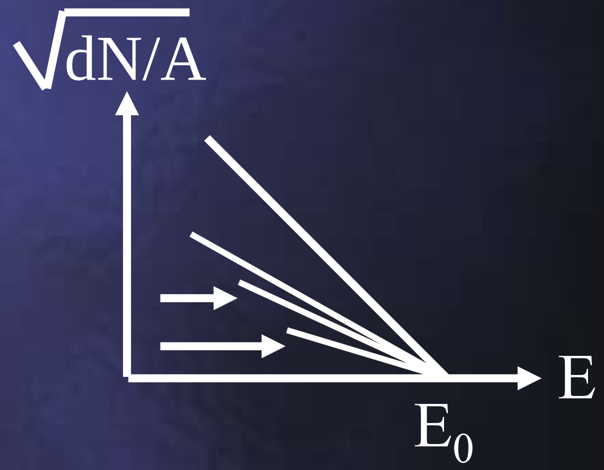
- Beta Source inside the detector

$\Rightarrow$ all spectrum must be acquired: but interesting area proportional to

$$[m_\nu c^2 / E_0]^3$$

$\Rightarrow$ Re^{187} : lowest $Q \sim 2.5$ keV.

$\Rightarrow$ Re^{187}: $[m_\nu c^2 / E_0]^3 \sim 1/400$ of H^3



Few Historical hints

- 1985 - First conceptu
  of determining neutri
  (S.Vitale)
- Re-187 properties rel
- Only two measurements
  1967

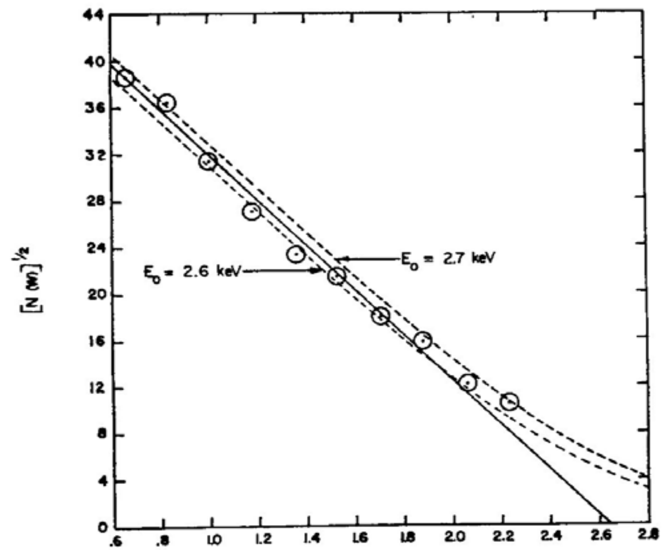
PHYSICAL REVIEW VOLUME 138, NUMBER 6B 21 JUNE 1965

Decay of Rhenium-187

R. L. BRODZINSKI AND D. C. CONWAY*
Department of Chemistry, Purdue University, Lafayette, Indiana

(Received 21 September 1964; revised manuscript received 23 February 1965)

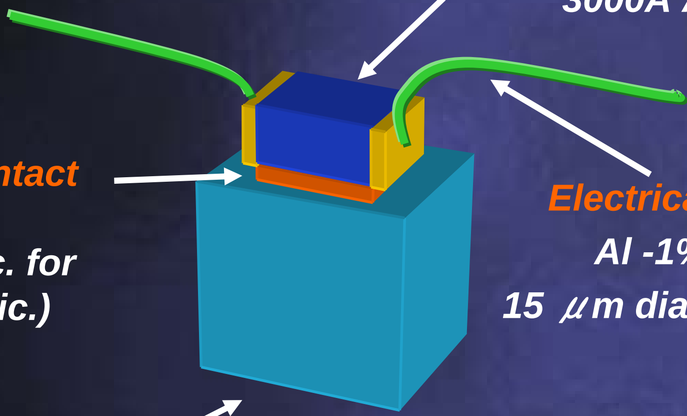
The end-point energy for ^{187}Re has been determined to be 2.62±0.09 keV by use of $(C_5H_5)_2ReH$ vapor in a proportional-counter spectrometer. The ^{187}Re half-life determined from the proportional-counting experiments is $(6.6\pm1.3)\times10^{10}$ year. This is identified as the β^- half-life for decay to continuum states only. When this is combined with the total half-life of $(4.3\pm0.5)\times10^{10}$ year obtained from $^{187}Re/^{187}Os$ ratios in geologically dated minerals, the ratio of bound-state to continuum-state decays is found to be 0.5±0.3.



Cryogenic microcalorimeter for ß decay

Thermistor

Ge-NTD (#19) 50x100x240 µm with 3000Å Au pads



$\Delta E \ FWHM = 2.35\zeta(kT^2C)^{1/2}$

Thermal contact

High purity epoxy (spec. for optical applic.)

Electrical & Heat link

Al -1% Si wires

15 µm diam., 1mm length

Absorber

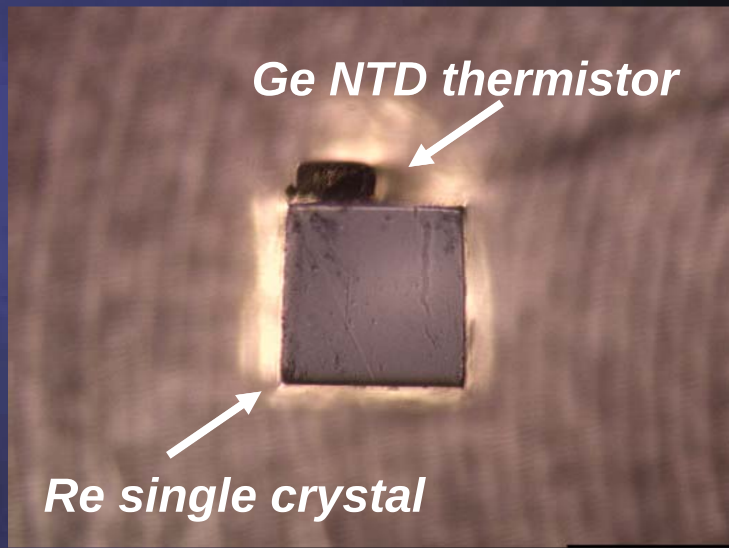
Re single crystal (99.99% purity)

typical dim. 500x500x500 µm

surfaces cleaned to optical level

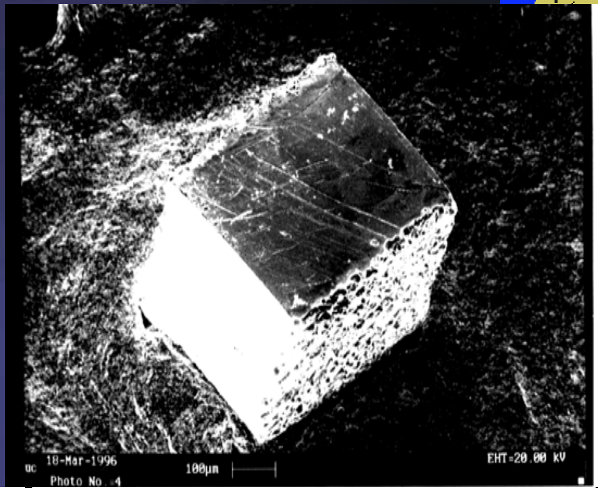
annealed at 1300ºC in UHV

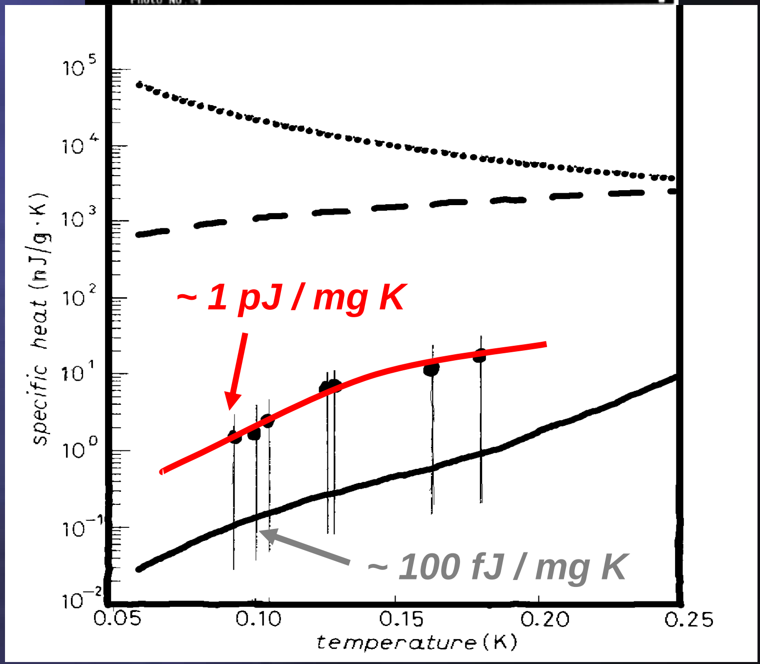
63% of 187- Re



Re properties

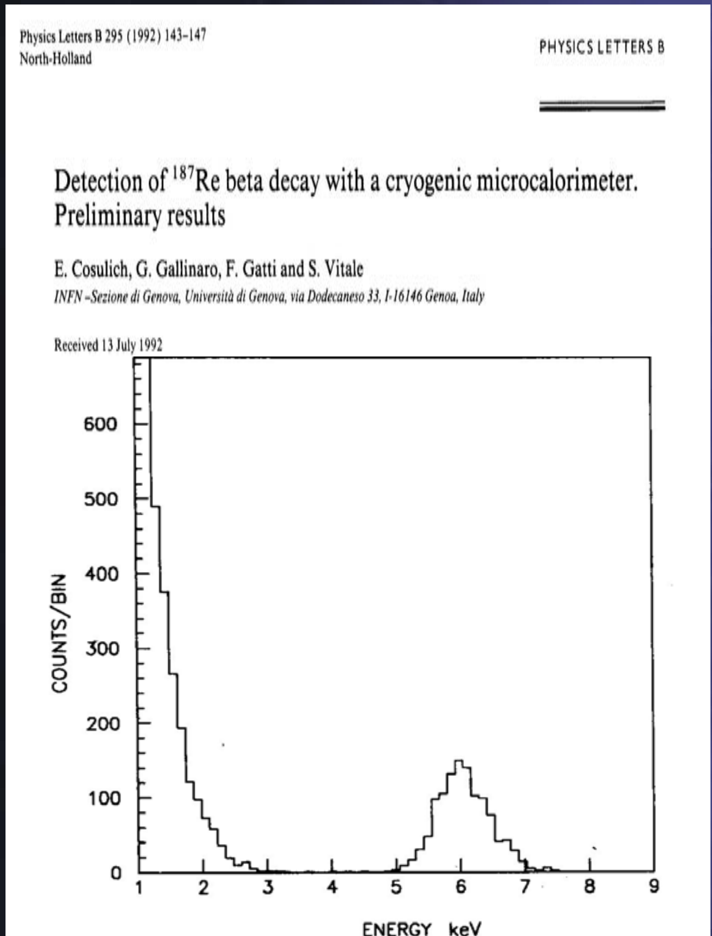
- Re metallic superconductor
  - HCP lattice
  - T_c=1.69 K
  - ρ = 21 g/cm^3
  - T(Debye)= 460 K
  - M.P.=3000 K
  - Z=75
  - A=185(37%), 187(63%)
  - τ(1/2) Re-187=4x10^{10} y
- Specific heat has a Shottky term $1/T^2$, not measured for short thermal pulses in superconducting state
- Specific heat seems contains a small contribution of normal electrons (about 1/1000) measured exciting with ionizing particles.
- Very small electron escape depth L (Ex: L < 100 Å @ 1.6 keV) $\Rightarrow$ negligible corrections for energy escape





First steps

- 1992 (660 eV FWHM)



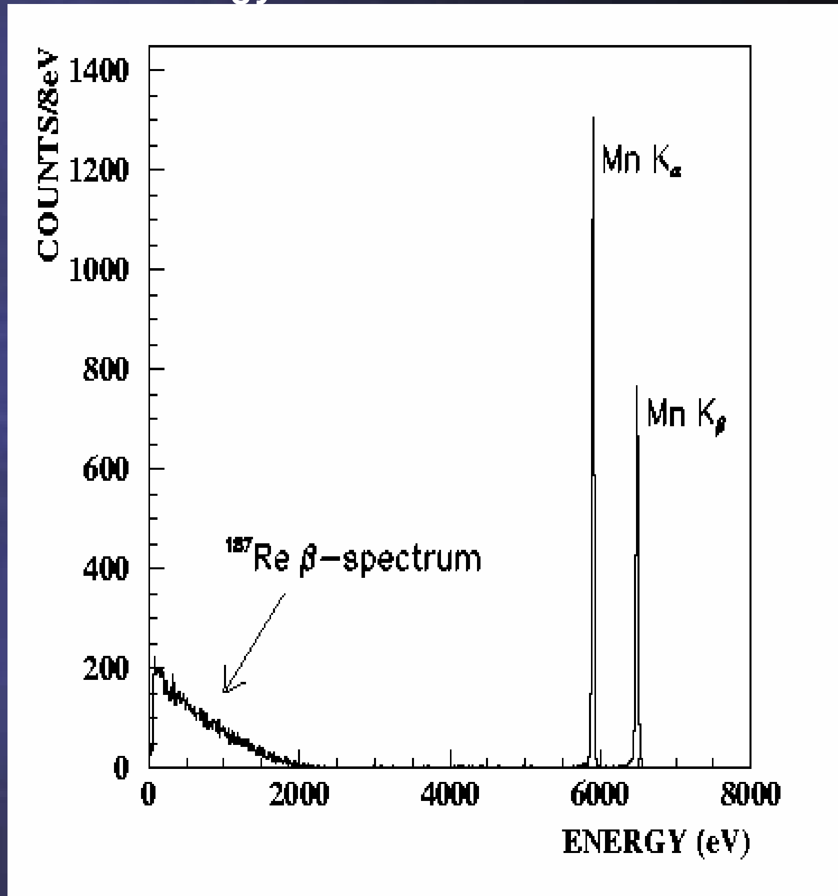
Physics Letters B 295 (1992) 143-147
North-Holland
PHYSICS LETTERS B

Detection of ^{187}Re beta decay with a cryogenic microcalorimeter. Preliminary results

E. Cosulich, G. Gallinaro, F. Gatti and S. Vitale
INFN - Sezione di Genova, Università di Genova, via Dodecaneso 33, I-16146 Genoa, Italy

Received 13 July 1992

- 1996 (30 eV FWHM)
  Energy Threshold = 50 eV



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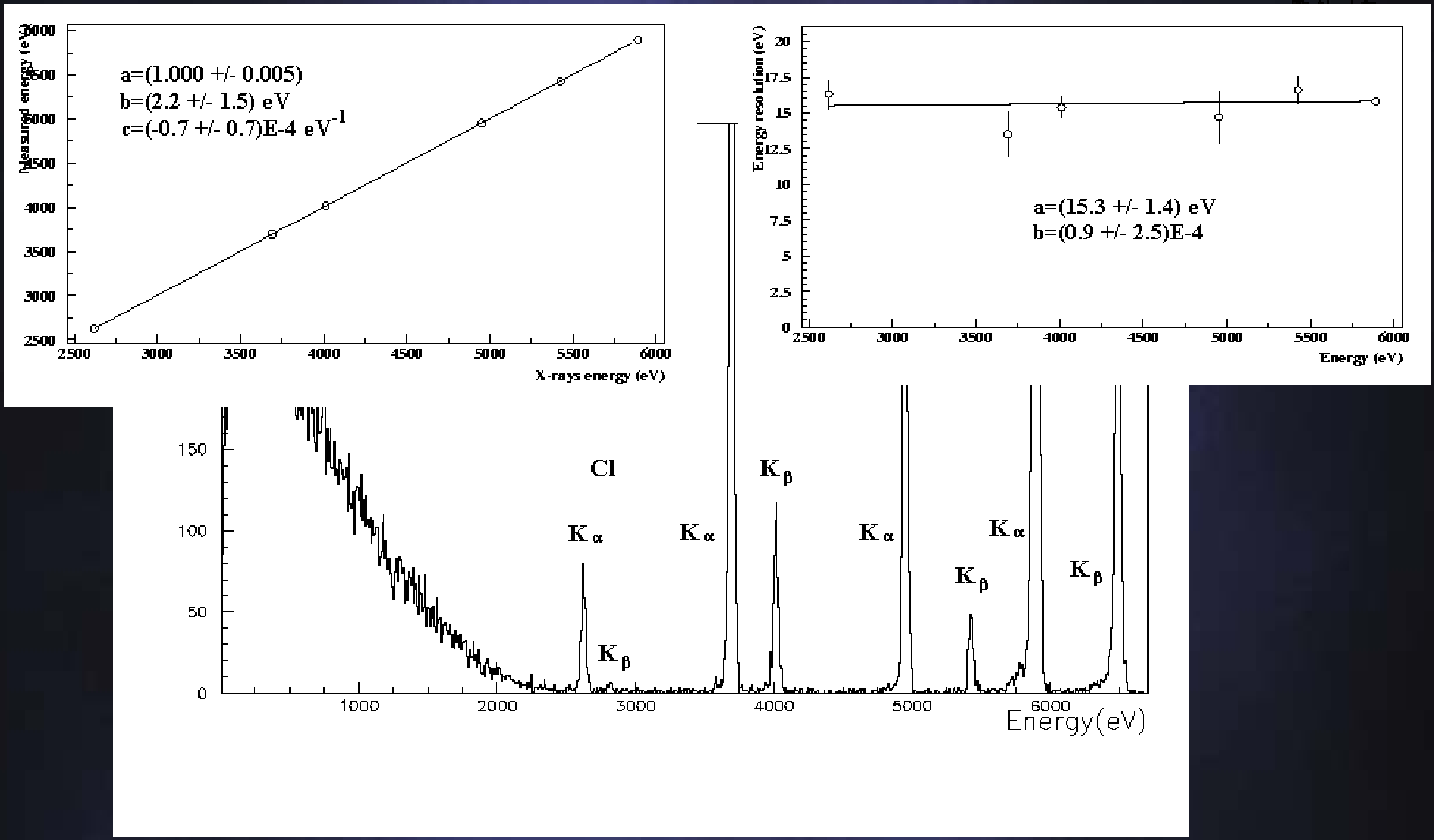
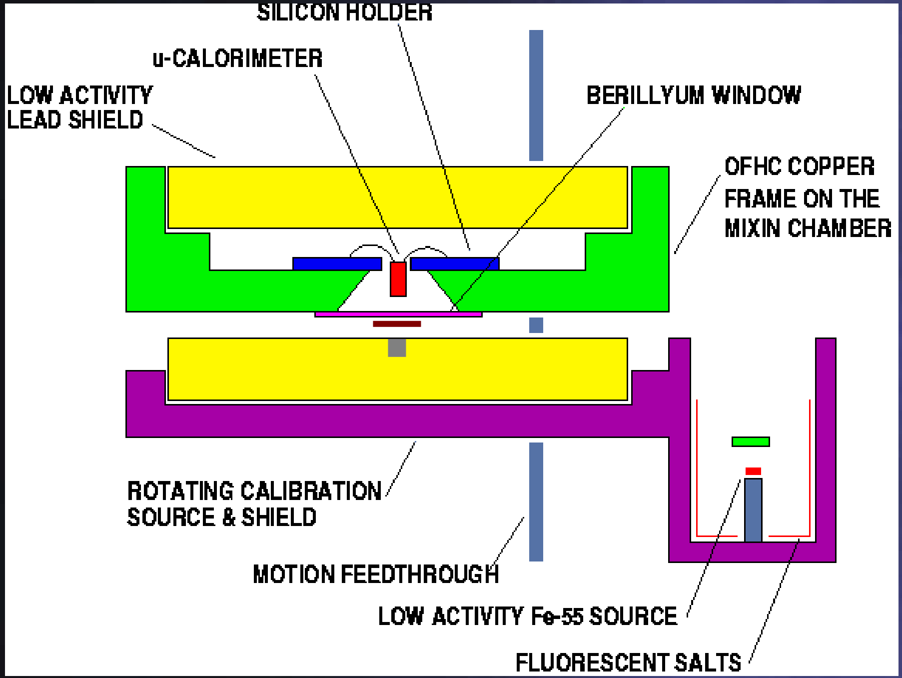
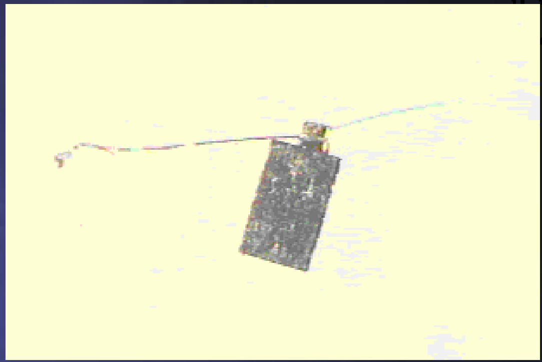
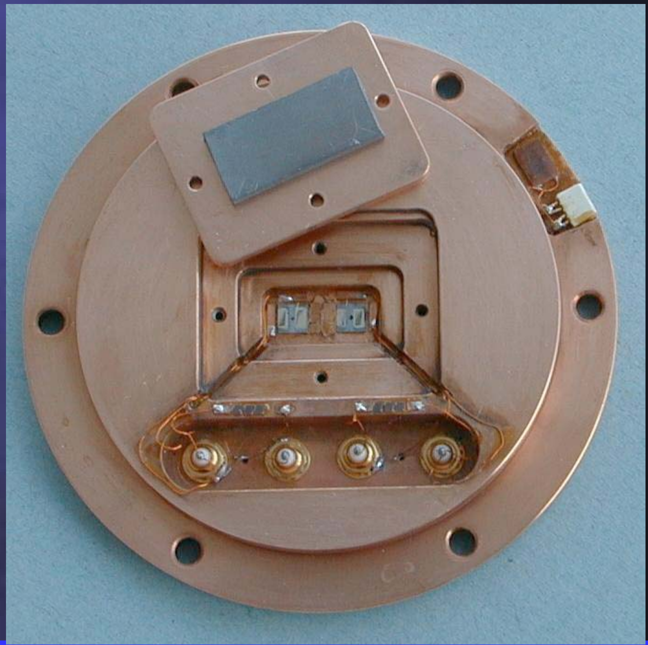
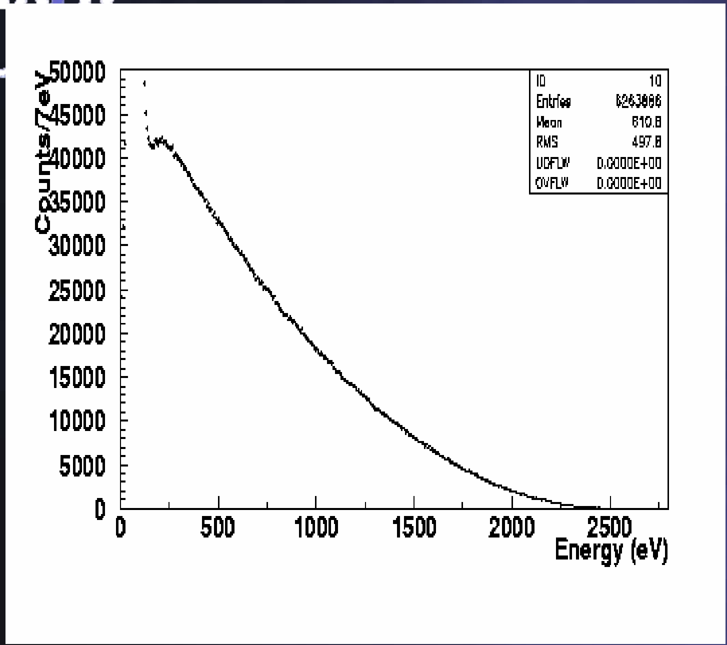


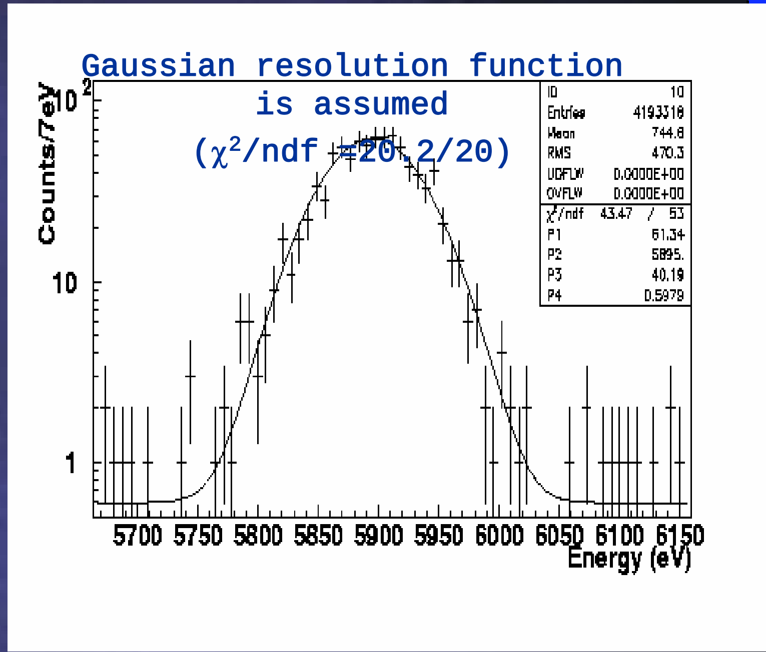
First pilot experiment ('99)











- End point =(2470 ± 1 stat ± 4 sys) eV
- Half life = (4.12 ± 0.02stat ± 0.11sys) 10^{10}y

M.Galeazzi, et al. Phys Rev C,63 (2000)014302.

- $m_\nu^{\,2} = -462^{+579}_{-679}$ eV^2/c^4
- $m_\nu < 26$ eV/c^2 95% CL, 19 eV/c^2 95% CL

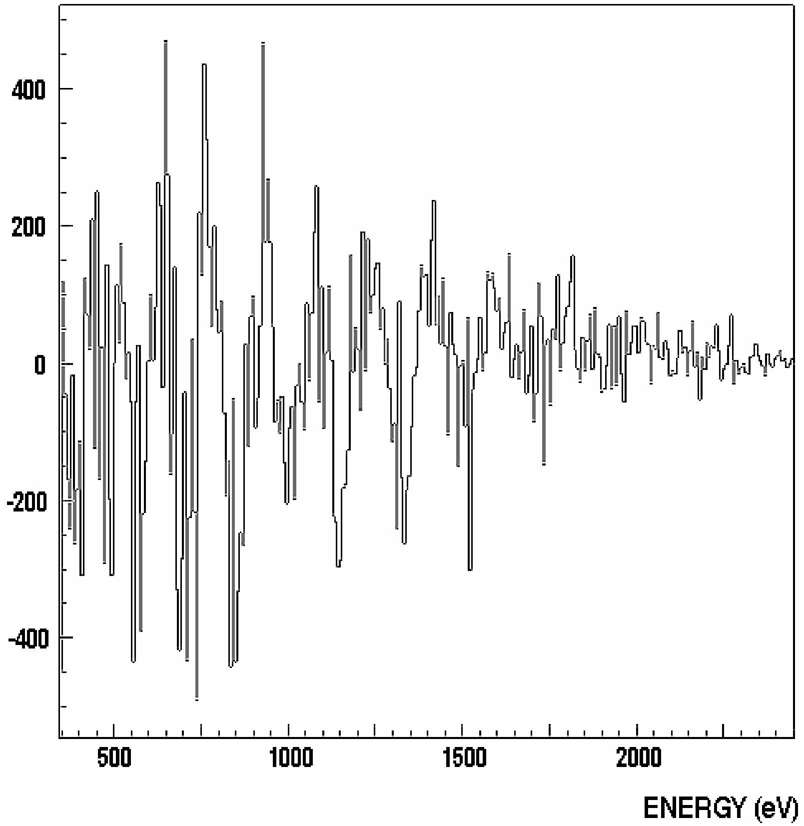
F.Gatti, Nucl Phys B,

- Improvement of the present limits on massive neutrino admixture

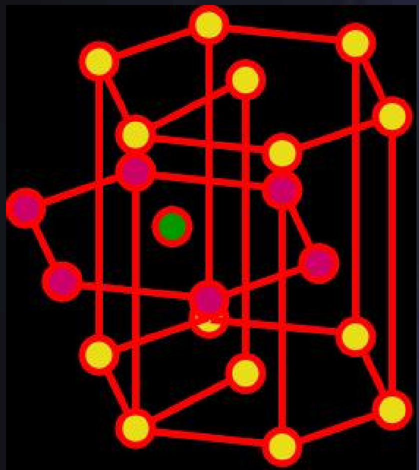
M.Galeazzi, et al. Phys Rev Lett 86 (2001) 1978.

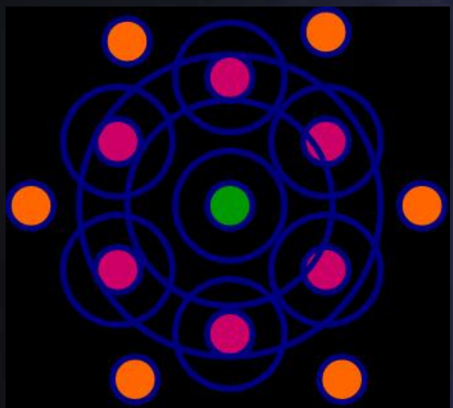
But something unexplained

- The residuals of the beta spectra fit with the theoretical function show correlation well beyond the admitted statistic fluctuation.
- This has been found to be caused by a physical effect



Why the Beta Spectrum Oscillates





- E(β) >>E(Fermi) ⇒ beta electrons interacts with atomic cores.
- $k^2=2m(E(\beta)-V)/h^2$, V ~ -15 eV ,

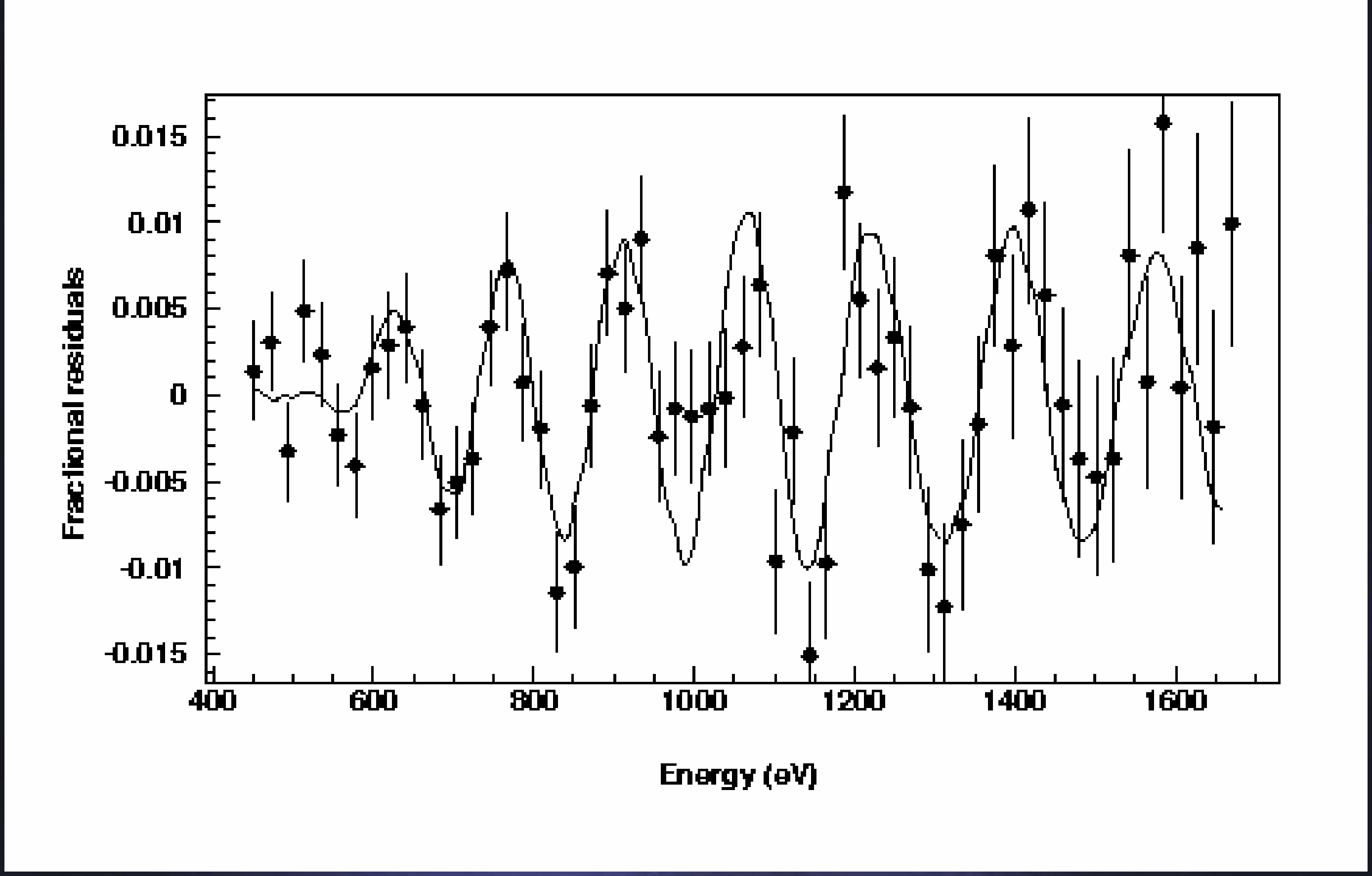
  λ(100) ~ 0.2A, λ(1000) ~0.04A

  a=2.76A, c=4.45 A, c/a=1.61A (1.63 A).
- Self interference of outgoing and reflected waves from atomic shells:

  ⇒ (backscattering amplitude) x (self-interference amplitude on Re nucleus from each atomic shell) x (number of atoms of shell)
- Thermal motion energy: T->0 ~ exp($2k^2 / M\Theta_D$)
- β wave attenuation (“range”): exp(-γR), γ(ε)~3-20 A
- First hypothesis: S.E.Koonin in 91(Nature 354,486), never observed.

$$\chi(T_e) = \sum_i \frac{N_i |f_i(\pi)|}{kR_i^2} \sin(2kR_i + \phi_i + 2\delta_0) e^{-\gamma \cdot R_i} e^{-2\sigma_i^2 k^2}$$

Fine Structure of the Beta Decay



F.Gatti et. Al, NATURE,VOL 397, 14, jan, 1999

BEFS as probe of the crystal structure

BEFS	th. phase ampl.	exp. phase ampl.
R_1 (Å)	2.76±0.02	2.75±0.02
R_2 (Å)	2.78±0.02	

- The BEFS spectroscopy … r
  studing hydrogen-charg
  new interest in the la
  researches of efficien
- Indeed, the atomic sit
  efficiently investigat
  esperiments using the
  Actually this informat
  EXAFS spectroscopy, be
  electron binding energ
  recording of an EXAFS
  the tiny cross section
  hundreds of eV coming
  rise in general to a n

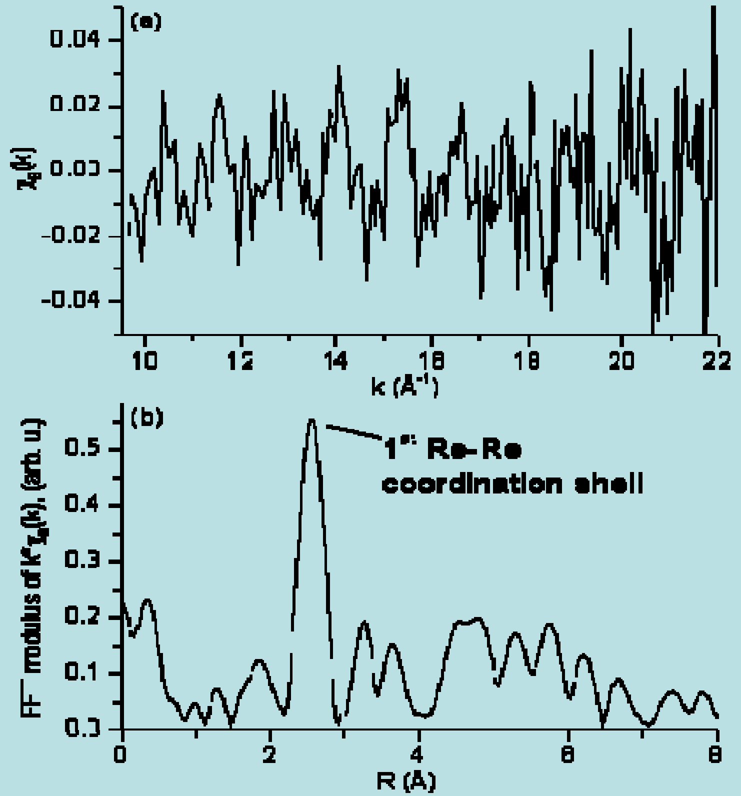
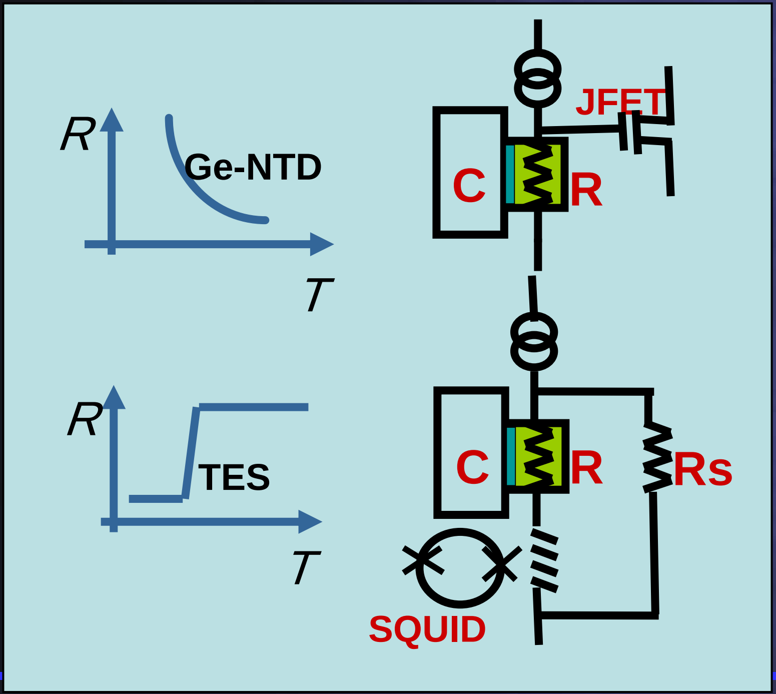
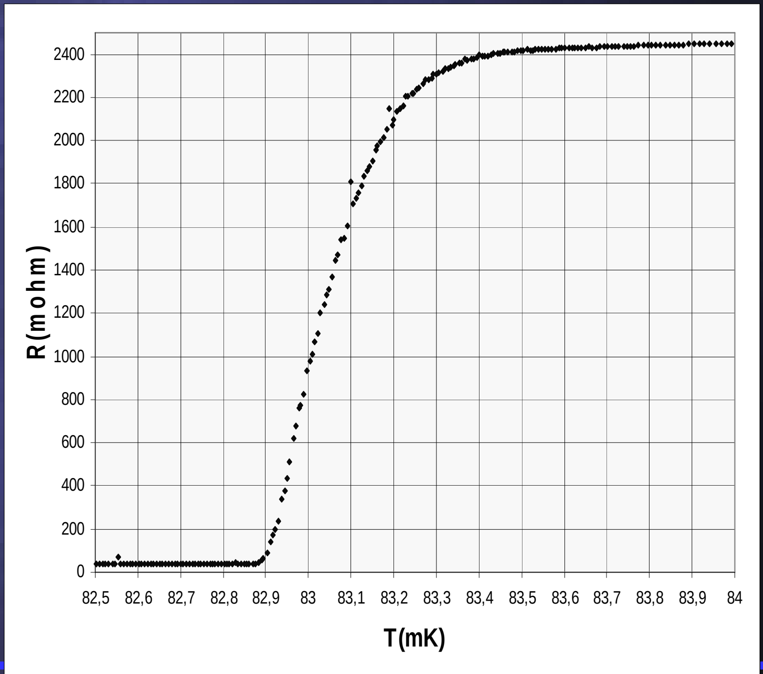


Fig. 1

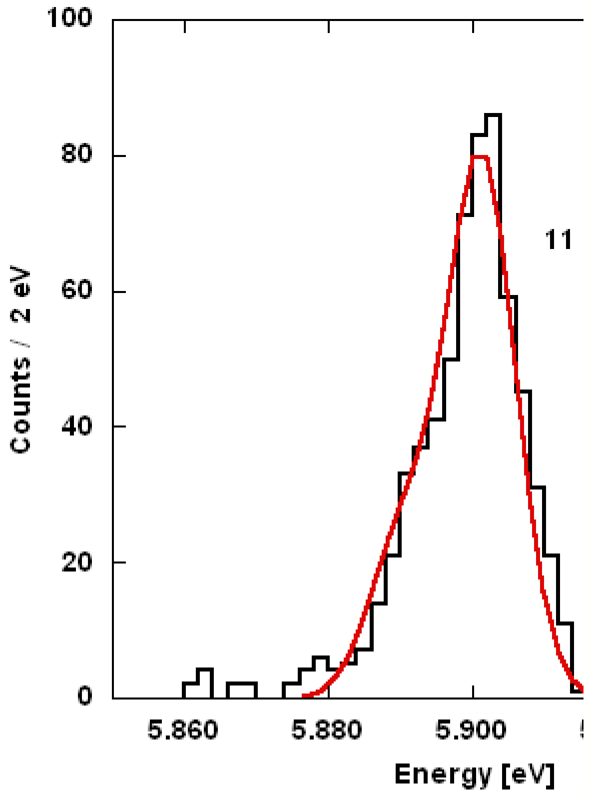
A second generation experiment for neutrino mass search

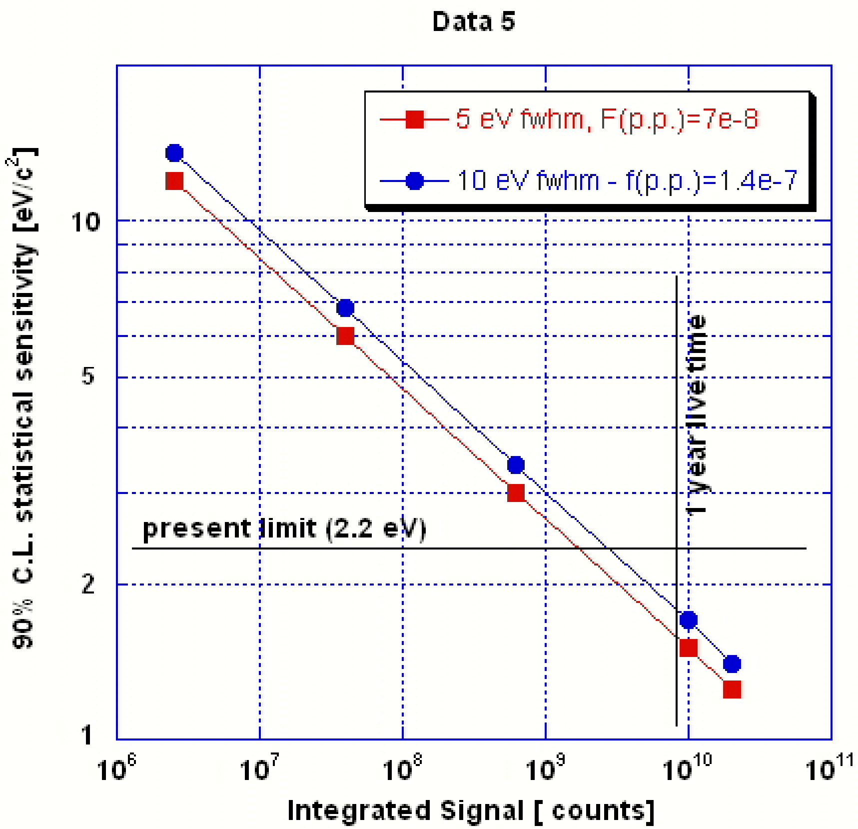
- New Technology for sensor we have been developed in the last years allow to perform an experiment with about 1 eV/c^2 sensitivity.
- The result of Mainz & Troistzk can be reproduced with a different methodology and hopefully improved.





A 300 Re detectors experiment





Next Generation Experiment (proposal MARE) down to 0.1 eV7c²