MIBETA-2 and MARE

Directly measuring the neutrino mass: ^{187}Re single-beta decay experiments

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The MIBETA collaboration:

INFN sez. Milano and Università di Milano-Bicocca, Dipartimento di Fisica, ITALY
Università dell'Insubria, Dipartimento di Fisica e Matematica, ITALY
ITC-IRST and INFN, Trento, ITALY
Goddard Space Flight Center, NASA, Greenbelt, Maryland, USA
University of Wisconsin, Madison, Wisconsin, USA

The ITC-IRST "bolometers" group:

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Talk outline

- *INTRODUCTION*
- *SPECTROMETERS and CALORIMETERS*
- *MARE: Microcalorimeters Arrays for a Rhenium Experiment*
- *MIBETA2 as part of MARE. Systematic effects*
- *BEFS (Beta Environmental Fine Structure)*
- *TECHNOLOGY*

NEUTRINO MASS:
HISTORY AND FEW FACTS

Neutrino: a mass-oriented 1-minute historical introduction

~ 1920: Why electrons can't get the whole beta decay transition energy ? Conservation laws are questioned.

1930: **Pauli** postulates the existence of a new, electrically neutral, spin ½ particle. The mass is **"in any event not larger than 0.01 proton masses".**

1933: **Fermi** elaborates a first theory for the new "weak interaction". The particle is named neutrino.

1937: **Majorana** proposes that the neutrino is its own antiparticle.

1956: first direct neutrino detection.

~ 1960: Solar Neutrino Problem. Mixing and oscillations hypothesis (**Pontecorvo**).

1962: discovery of muon neutrino

1977: discovery of tau neutrino

1985: 17keV neutrino ??

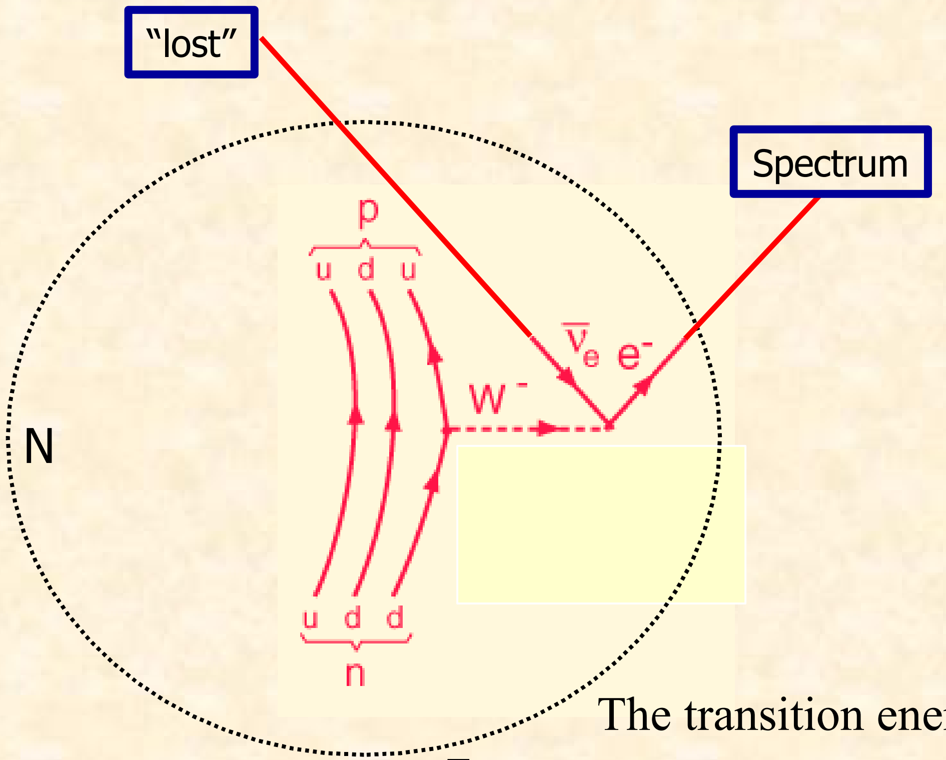
1987: neutrinos form supernova → the mass is exceedingly small (<20eV)

1998: oscillations confirmed → the mass is non-zero !!

2002: neutrinoless double beta decay observed ??

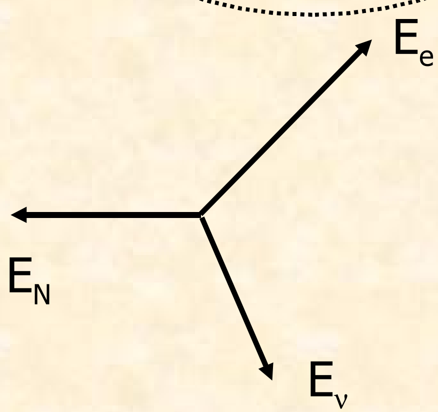
2006: refined oscillations picture, BUT **the mass absolute scale is still beyond direct experimental capabilities**

Kinematics of beta decay: "direct" approach



$$\begin{cases} P_\nu + P_e + P_N = 0 \\ E_\nu + E_e + E_N = E_{TOT} \end{cases}$$

$$E_N << E_{TOT}$$



The transition energy E_{TOT} is basically shared between the electron and the anti-neutrino, while the nucleon (nucleus) ensures the momentum conservation.

<u>*Spectrum end-point energy (Q):*</u> maximum (kinetic) energy taken by the electron.

$E_{TOT} \neq Q$ (conceptually) $E_{TOT} \approx Q$ (experimentally)

→ **NEUTRINO MASS !!**

Ideal vs. Real World

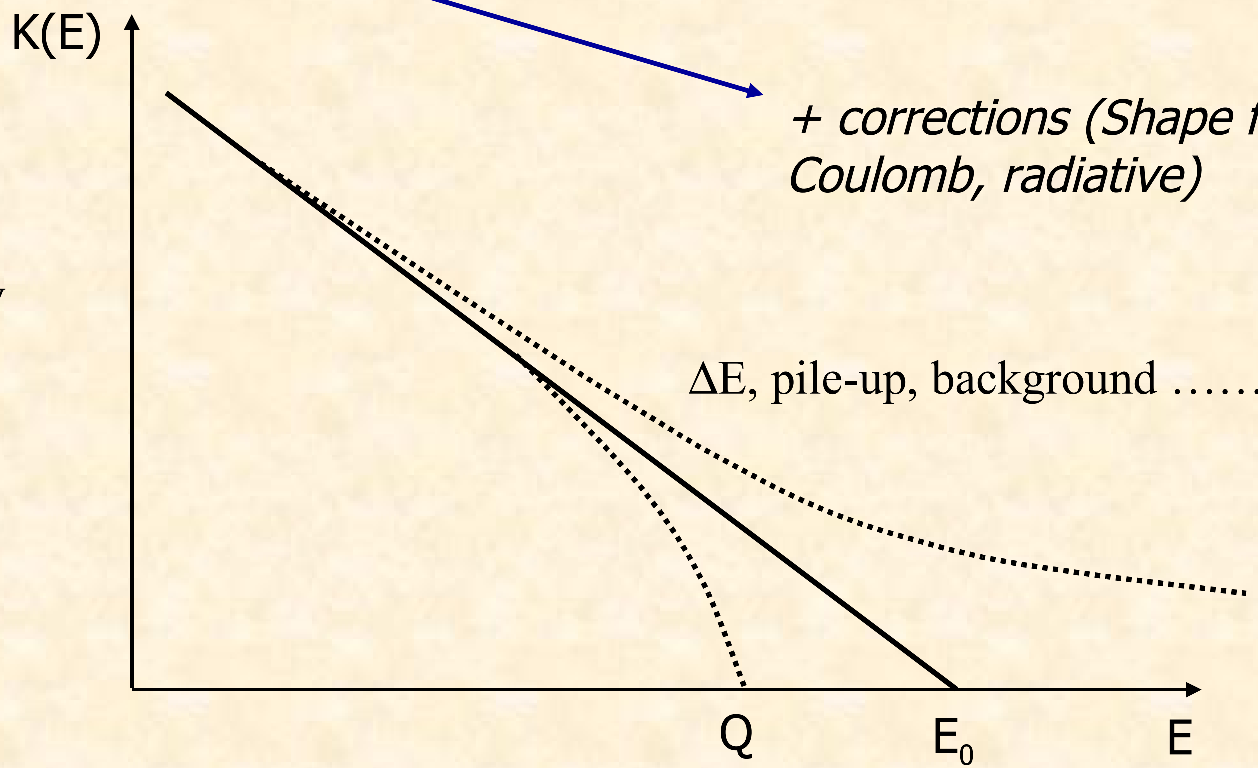
$$K(E) \equiv \sqrt{\frac{N(E)}{p \cdot E}} = (E_0 - E) \cdot \sqrt[4]{1 - \frac{m_\nu^2 \cdot c^2}{(E_0 - E)}}$$

Kurie Function → Kurie Plot

+ corrections (Shape factor, Coulomb, radiative)

~~EASY !!!~~

… not exactly



"Indirect" approaches: oscillations

$$\left|\nu_f\right\rangle = \sum_{i=1}^{3} M^*_{f\,i} \left|\nu_i\right\rangle$$

<u>At the beginning it was:</u>
the SOLAR NEUTRINO PROBLEM

<u>HYPOTHESIS:</u> a **pure flavour** (f=e,μ,τ) state is produced or detected according to whatever reaction. The state is a coherent superposition of defined **mass states** (i=1,2,3).
→ By evolving the flavour state between production and detection a flavour change is statistically predicted according to the details of the mixing matrix M_{fi}.
→FLAVOUR OSCILLATIONS possible in principle if at least one of the three masses is non-zero and the masses are not exactly degenerate.

$$P(\nu_l \rightarrow \nu_k) = \sin^2(2\theta) \cdot \sin^2\left(1.27 \cdot \Delta m^2 \cdot \frac{L}{E_\nu}\right)$$

In vacuum, 2 flavours

Solar neutrinos → ν_e **deficit** (Homestake to SNO)
Atmospheric neutrinos → upward going ν_μ **deficit** (SK)
Reactor neutrinos → ν_e **deficit** (KamLAND), ν_e OK (CHOOZ)
Accelerator neutrinos → ν_μ **deficit** (K2K)

Well established, but still few problems and work in progress to completely fix M_{fi}

“Indirect” approaches: $0\nu\beta\beta$

Double Beta Decay is observed, as an extremely rare event ($T_{1/2}>10^{18}$y), in a few, mainly neutron-rich isotopes (e.g. ^{48}Ca, ^{76}Ge, ^{128}Te, ^{130}Te). In “normal” double beta decay ($2\nu\beta\beta$) two electrons are emitted together with two anti-neutrinos. The spectrum of the electron(s) energies is, again, continuous and exhibits an end-point like in single beta decay

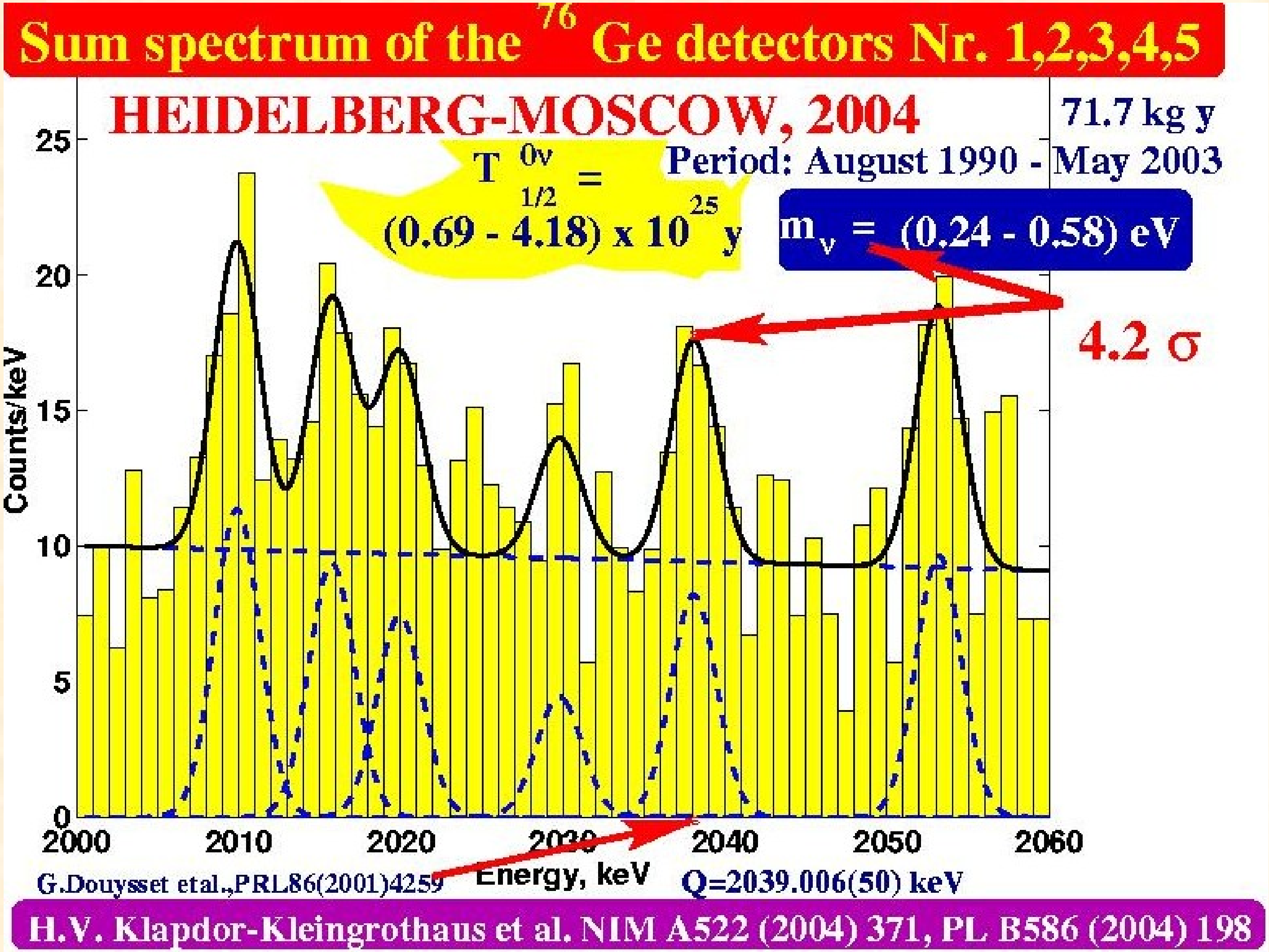
If ($m_\nu \neq 0$ && $\nu \equiv \underline{\nu}$ (MAJORANA)) the process is expected to present a largely minority branch with no neutrinos emitted → **$0\nu\beta\beta$**. The lifetime is proportional to an effective “Majorana mass” that is a coherent combination of the three ν_i states. The process might also be activated by alternative channels, all requiring a non-zero neutrino Majorana mass. However, the effective mass limits/values that are given are usually calculated assuming an exchange of light Majorana neutrinos.

Experimental signature: a single $0\nu\beta\beta$ peak in the summed electrons energies spectrum corresponding to the E_0 transition energy. $T_{1/2}>10^{25}$y (!)

Major results:

- **$m_{ee} <$ 0.2÷1.1 eV** (CUORICINO, ^{130}Te, $T_{1/2}>1.8\cdot10^{24}$y)
- **$m_{ee} =$ 0.1÷0.9 eV** (sub-group of Heidelberg-Moscow, ^{76}Ge, **$T_{1/2}=(0.69\div4.18)\cdot10^{25}$y @ 4.2$\sigma$**)

$0\nu\beta\beta$ first evidence ?



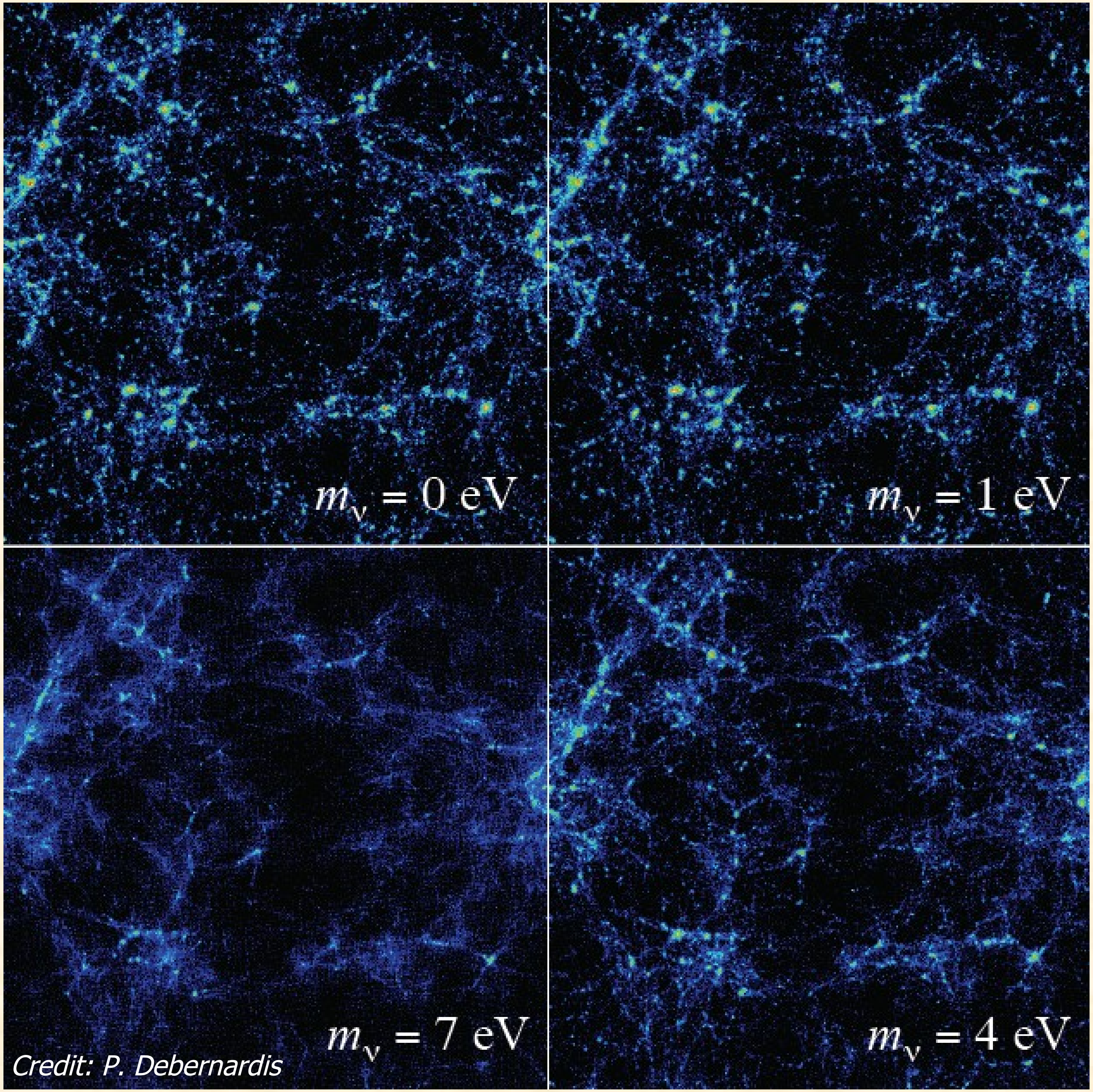
Even more indirect approaches: cosmological constrains

Massive neutrinos, in the Cosmological SM, had an important role in the shaping the Large Scale Structures (LSS) that we observe in today Universe. LSS more constraining than CMB measurements in this case.

MAJOR RESULTS:

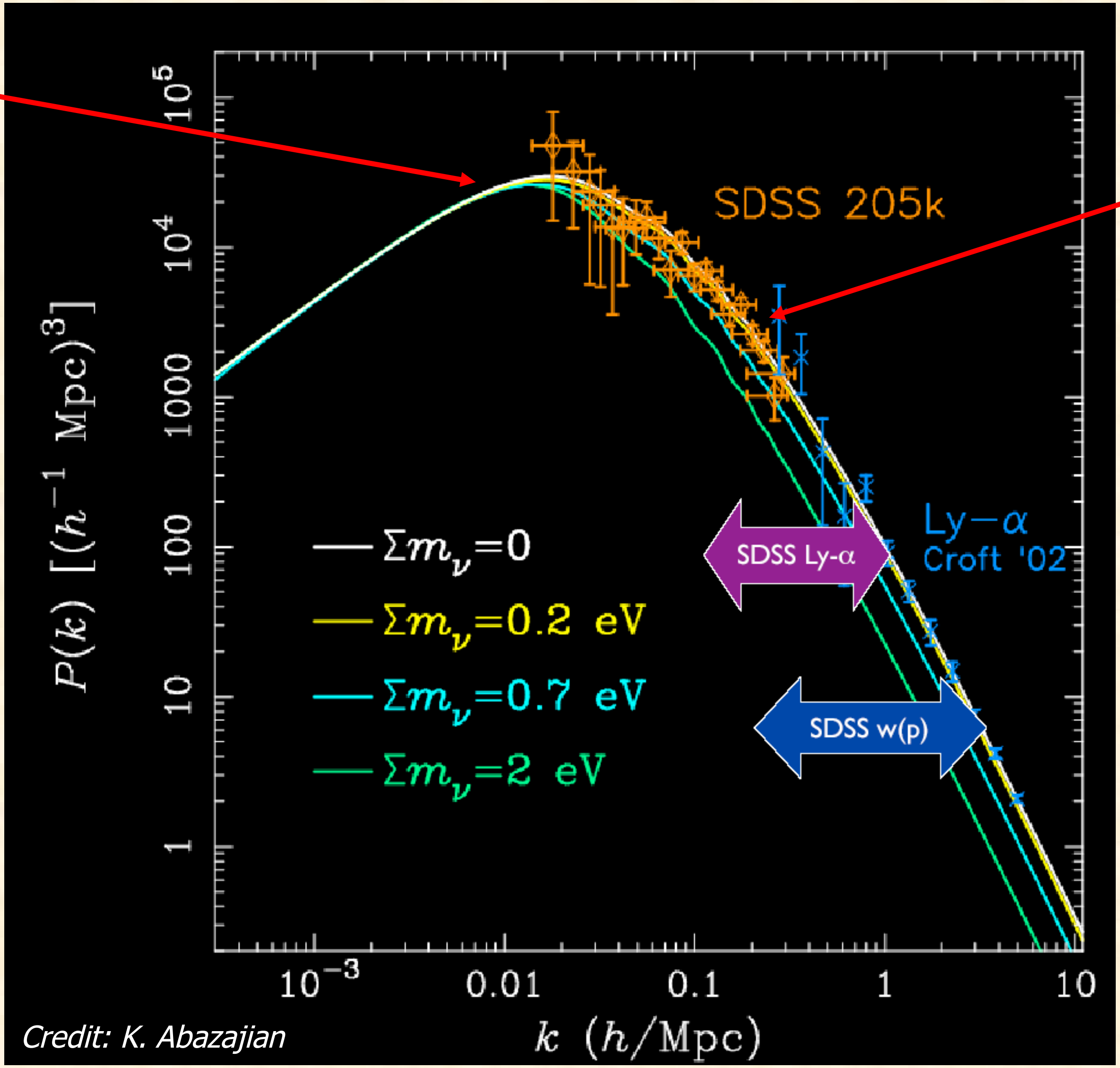
- $\Sigma m_\nu < 0.42$eV (LSS+CMB)
- weak preference for $\Sigma m_\nu > 0$

Problem: as most of the Cosmological constrains, it is quite model-dependent. In fact, in the so-called "neutrinoless universe" scenario the above limits can be pretty well evaded. By assuming a small scalar coupling the neutrinos can be either confined for a much longer time (not being able to smear the large scale structures) or almost completely annihilated (real "neutrinoless" universe). Important insights would result in case of sensitive relic neutrinos searches. But this is well beyond existing experimental reach and not foreseen in the near future.


$m_\nu = 0$ eV
$m_\nu = 1$ eV
$m_\nu = 7$ eV
$m_\nu = 4$ eV
Credit: P. Debernardis

The Cosmological Density perturbation Spectrum

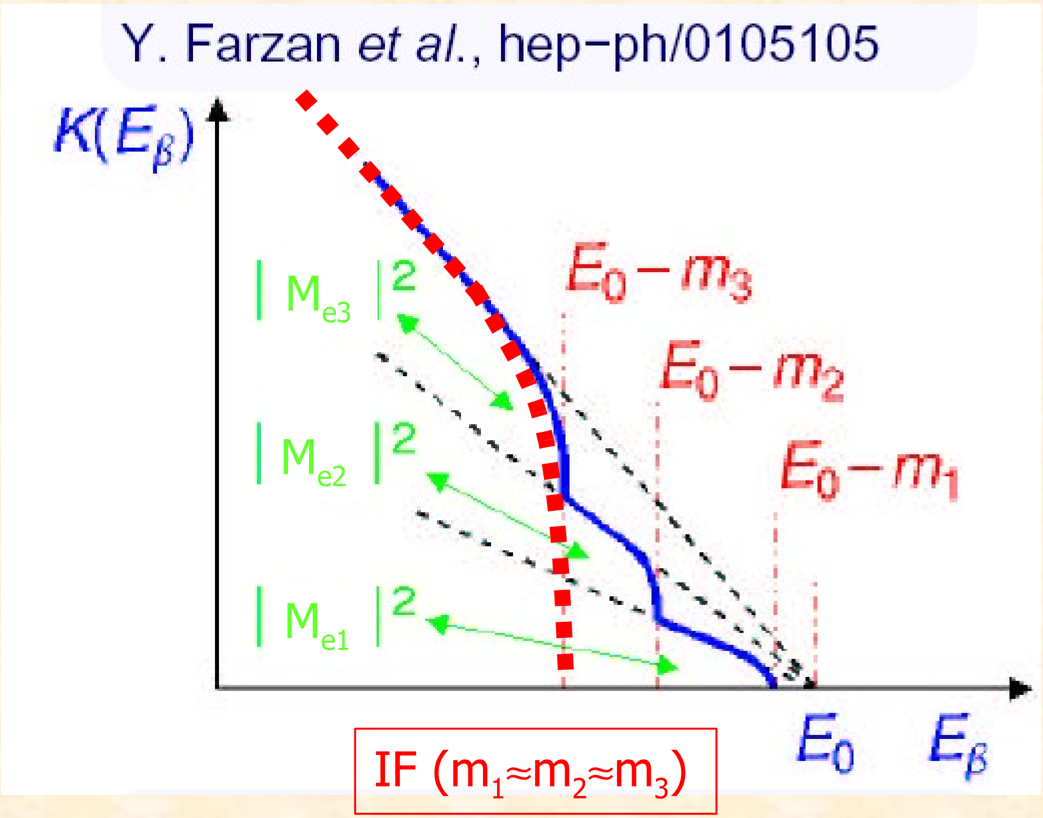
CMB (weak) constrains. not shown in figure.



LSS (strong) constrains

Beta decay experiments in the three-flavours mixing scenario 1/2

The (electron) anti-neutrino generated in the point-like beta decay is actually a mixed mass state.



The classical, simply deformed KURIE plot is out-of date. A highly structured behaviour is expected close to the end-point. With kinks corresponding to the three (?) eingestates. The mixing matrix determines the relative weights of the spectral features. Assuming a "normal hierarchy" $m_1 < m_2 < m_3$ the end-point is actually:

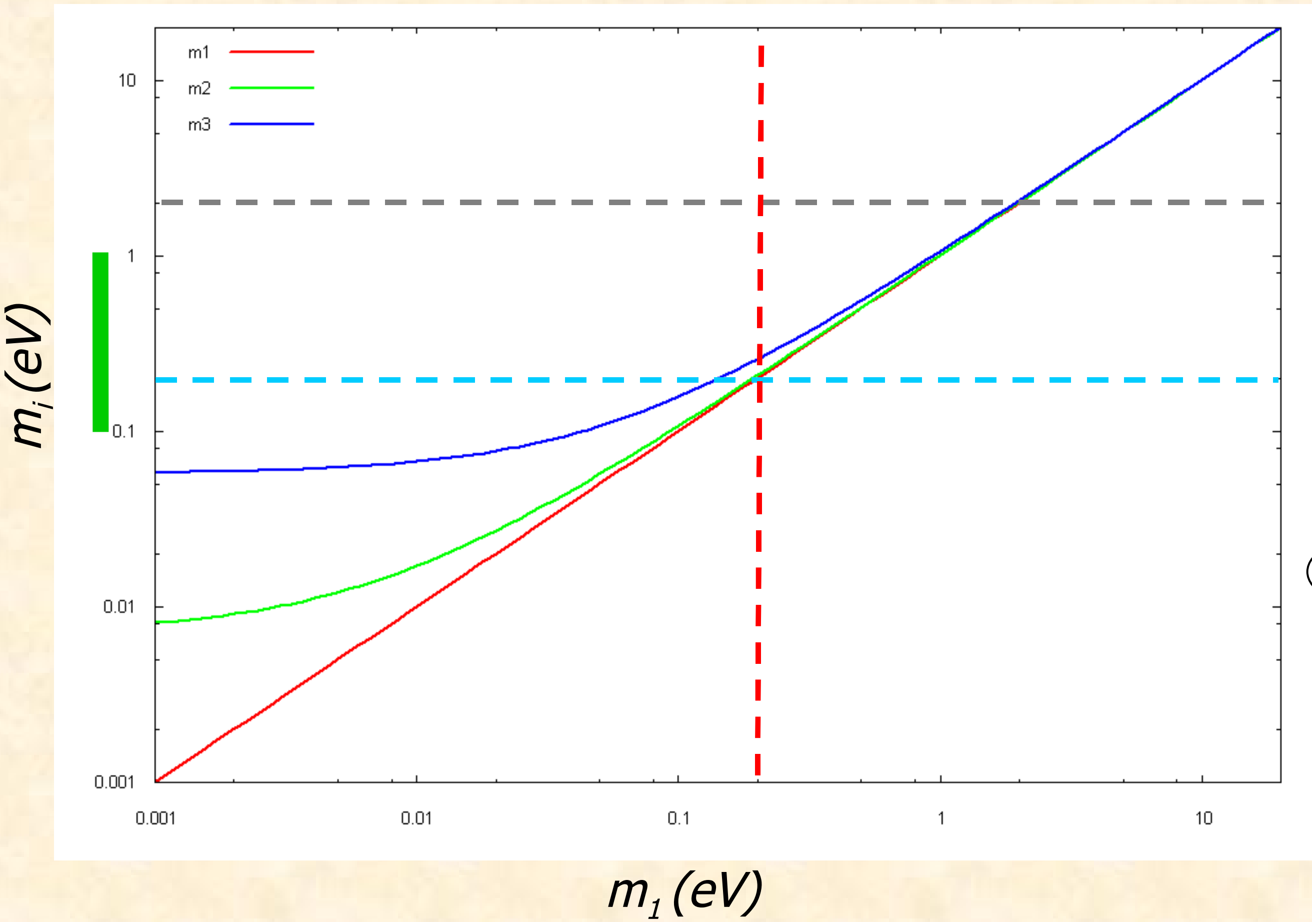
$$Q = E_0 - m_1$$

With m_1 being the lightest mass state.

Beta decay experiments in the three-flavours mixing scenario 2/2

$m_1 << m_2 << m_3$

$m_1 \approx m_2 \approx m_3$



SPECTROMETERS	***BOLOMETERS***
1980	2003
2000	2008 (?)
2012 (?)	2013 (?)
???	???

Summary: $\{m_\nu \neq 0$ && $m_\nu = ?\}$

Neutrino oscillations (Δm^2 only):

$\nu_{atmospheric}$ $\Delta m_{23}^2 \approx 2 \cdot 10^{-3}\ eV^2$ (SK evidence + CHOOZ constrains)

ν_{solar} $\Delta m_{12}^2 \approx 7 \cdot 10^{-5}\ eV^2$ (SNO + KAMland)

Neutrinoless double beta decay - $0\nu\beta\beta$ (model-dependent):

..but direct insights on the neutrino nature (Majorana ?) and access to Majorana phases

Effective Majorana mass:

$m_{ee} < 0.35$ eV (Heidelberg-Moscow ^{76}Ge)

$m_{ee} < 0.2 \div 1.1$ eV (CUORICINO ^{130}Te)

$m_{ee} = 0.1 \div 0.9$ eV (Klapdor: ^{76}Ge reanalysis)

Cosmology (indirect):

U. Seljak, Physics Review D 71 (2005) 103515

$\Sigma m_{\nu_i} < 0.42$ eV (CMB+SDSS+SN)

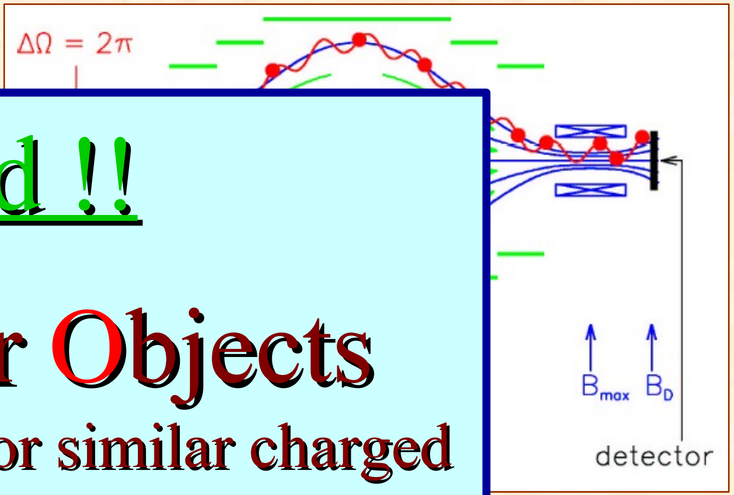
Direct (β decay) SAFE determination NEEDED !!

… deserves more than one approach (to cross-eliminate systematic effects)

SPECTROMETERS - ^{3}H
&
CALORIMETERS - ^{187}Re

Past ^{3}H spectrometers: Mainz-Troitzk

Electrostatic Spectrometers with Magnetic Adiabatic Collimator (MAC) and E-filter. High energy resolution, high luminosity, precise end-point scan.
But few problems: excited states, transport etc.



Troitzk (94-99). Gaseous windowless T_2 source.

Mainz (94-0

RESULTS:

Troitzk. m_ν

time-depen

explanation

magnitudes

Without ad-

limit no add

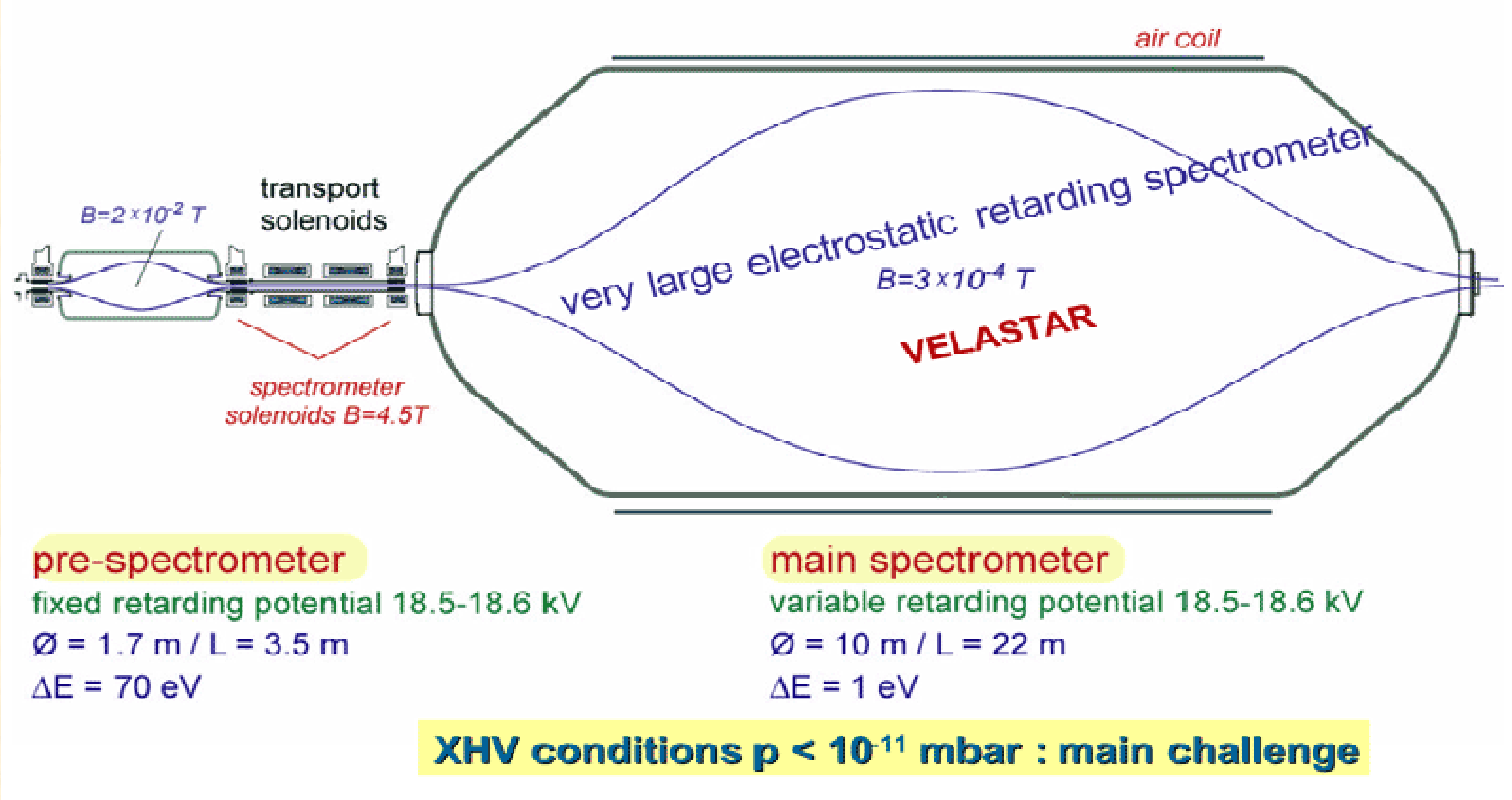
Daemons are invoked !!

DArk Electric Matter Objects

Planckian elementary black holes or similar charged (≈10e) entities interacting with the Nb coils and inducing secondary electrons. *hep-ph/0502056*

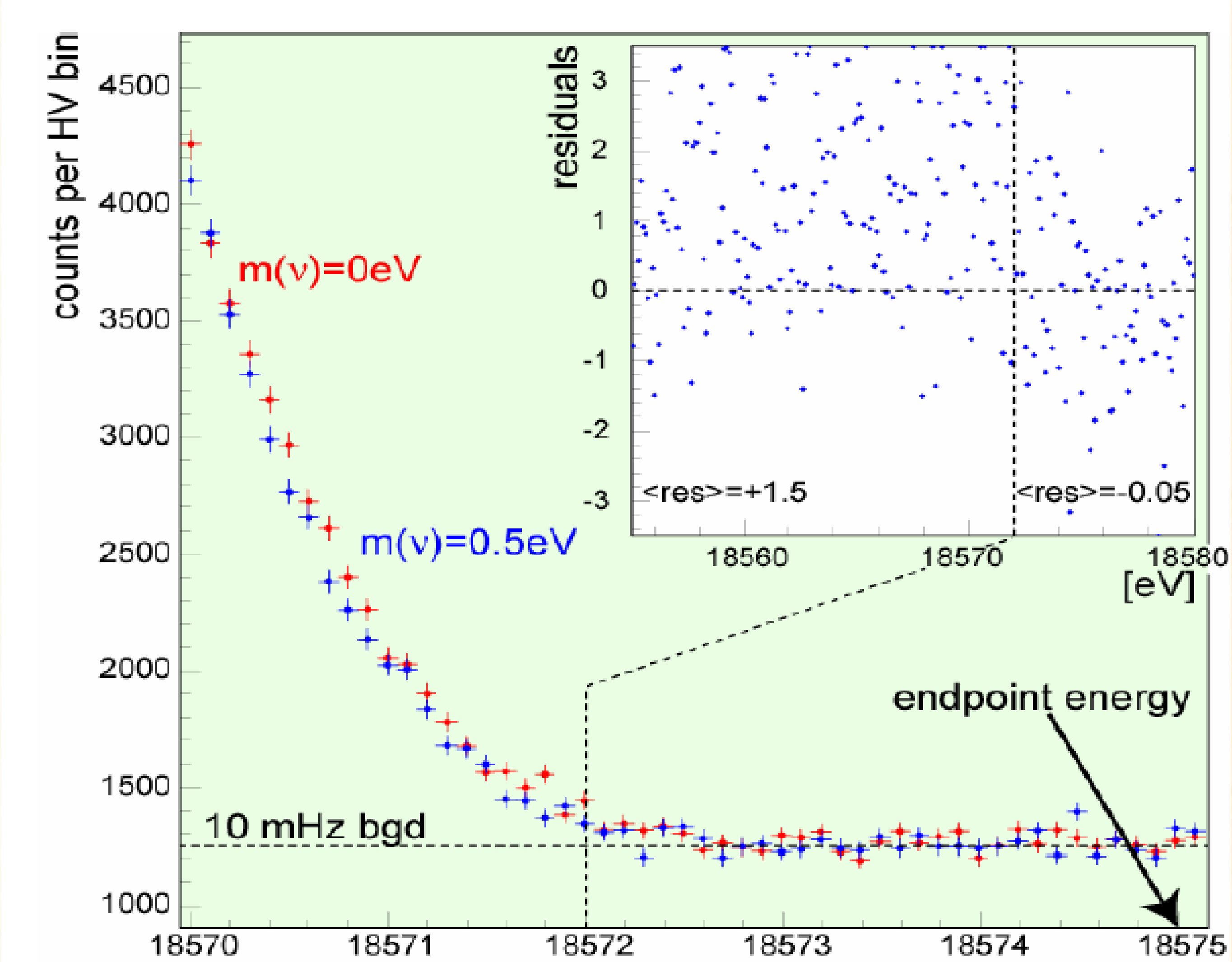
Mainz. $m_\nu < 2.3$eV (95%C.L.). A lot of work done to understand and reduce the systematics (excited final states, energy losses in the source etc.). In the final analysis, the mass squared is compatible with zero. Some datasets have been rejected. *Eur.Phys.J. C40 (2005) 447-468.*
The Troitzk end-point anomaly is NOT confirmed, even if cannot be firmly excluded.

Future ^{3}H spectrometers: KATRIN



Expected to reach a sensitivity of 0.35eV for 5σ discovery and down to 0.2eV in case of a 90% C.L. upper limit. The experiment is funded and ongoing, the first run is expected around 2010. ***Major improvements:*** energy resolution (a factor 4 better than Mainz) and luminosity. Challenging HW setup; ultimate spectrometer ?

1-year KATRIN simulated spectra



Credit: G. Drexlin

MY PERSONAL OPINION:

KATRIN is a great experiment, but the *tininess* of the signal that is possibly expected means:
"is definitely worth investing in an almost parallel experience affected by totally different systematics."

[just me]

^{187}Re: a peculiar nuclear β transition

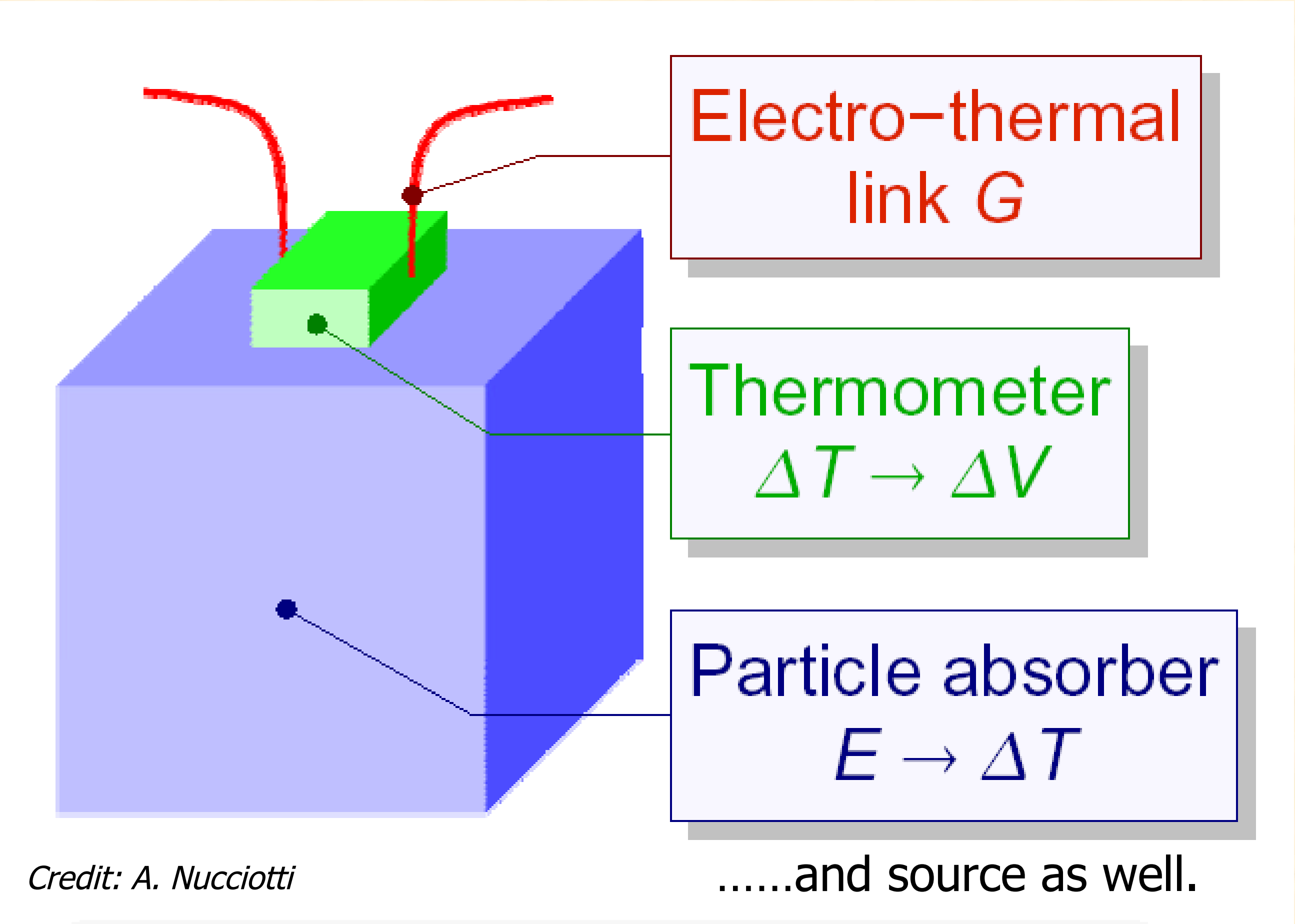
In 1984 Fiorini (Milano) and Niinikosky invented a **"true bolometric"** Low Temperature approach for rare events searches (e.g. $0\nu\beta\beta$). Following this idea, Vitale (Genova) proposed to adopt the new technique for **single-beta decay** studies applied to **^{187}Re**.

^{187}Re is the **lowest-Q** known beta transition (< 2.5keV !!), and thus the most interesting for neutrino mass measurements.

$$\left.\frac{\int_{E_0-\Delta E}^{E_0} N(E)\cdot dE}{\int_0^{E_0} N(E)\cdot dE}\right|_{m_\nu=0} \propto Q^{-3} \quad \Rightarrow \quad \frac{^{187}\mathrm{Re}}{^{3}\mathrm{H}} \approx 400$$

^{187}Re is the major isotope in natural Rhenium (62%). The transition is **forbidden**, and possible as a Gamow-Teller process in which the pair electron-antineutrino must carry at least one unit of orbital angular momentum. The resulting half-life time (**$T_{1/2}$ > 40 Gyr**) exceeds the age of the Universe. The **Re/Os** ratio is thus a potentially sensitive **Cosmochronometer** being investigated by "Galactic guys".

Calorimetric approach



The composite microbolometer

Environment:
- T < 100mK
- micro-detectors

Major Advantages:
- source ≡ detector
- affected by completely different systematics
- micro-approach (?)

Major Drawbacks:
- can't select the beta energy range. We must take the lot
- slow response even on single pulse

INFN Genova: MANU (until 2001)

MANU detector: Re single crystal (~0.06 mm^3)
NTD-Ge thermistor

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

mass spectrometer meas. indicates (4.35 ±0.13) x 10^{10} y

M.Galeazzi, F.Fontanelli, F.Gatti, S.Vitale, Phys Rew C,63 (2000) 014302

- ✓ **$m_n{}^2 = -462^{+579}_{-679}$ eV^2/c^4**
- ✓ **m_n < 26 eV/c^2 95% CL, < 19 eV/c^2 90% CL**
- ✓ **Improvement on limits for massive neutrino admixture**

M.Galeazzi, F.Fontanelli, F.Gatti, S.Vitale, Phys Rev Lett 86 (2001)1978

- ✓ **First observation of the Beta Environmental Fine Structure (BEFS)** F. Gatti et al., Nature 397, (1999) 137-139

Credit: D. Pergolesi

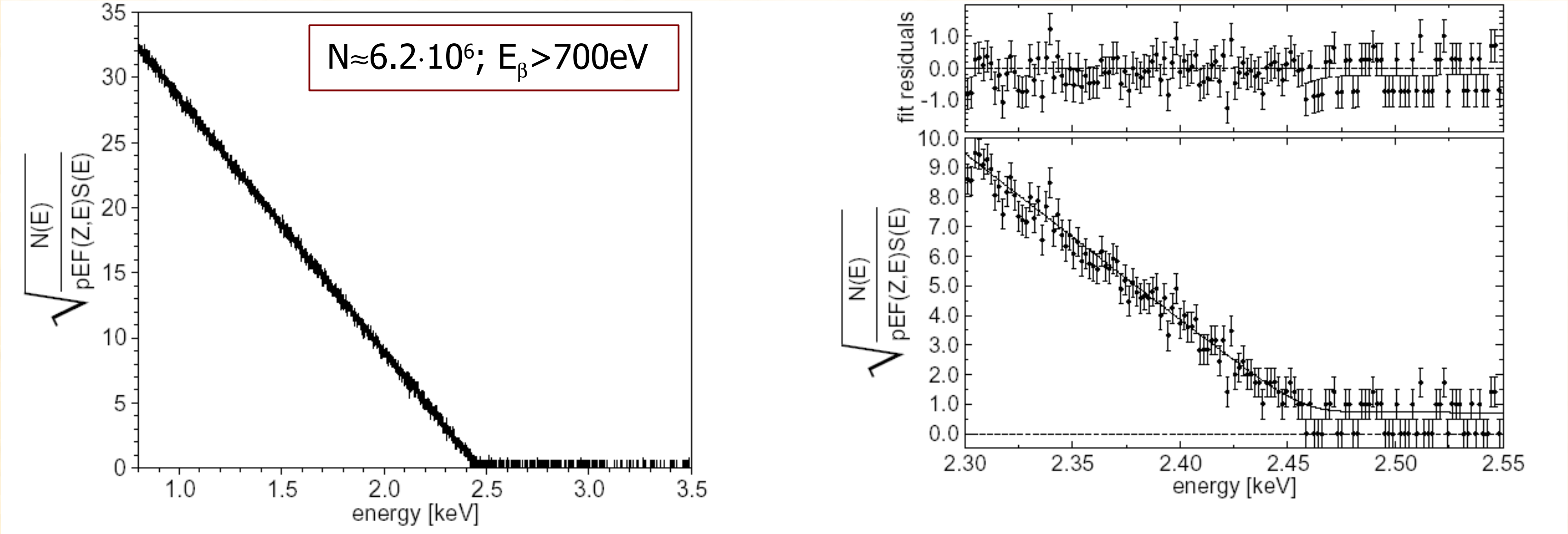
INFN Milano: MIBETA (until 2003)

Intense detectors development in Milano and IRST in the 90s.

Side-product result: first $\Delta E_{FWHM} \approx$ 5eV ever achieved on 6keV X-ray Mn K calibration lines.

Ref. PRL, 82-3, 513 (1999)

Details: small array of 8 $AgReO_4$ micro-detectors (1 year data taking, $m_{TOT} \approx 2$mg).



m_ν < 15eV (90%C.L.)

Q = 2465.3±0.5$_{stat}$±1.6$_{sys}$ eV

$T_{1/2}$ = 43.2 ±0.2$_{stat}$±0.1$_{sys}$ Gyr

+ BEFS (see next)

Thermistors: IRST doped(P)/compensated(B) silicon kept in VRH (Variable Range Hopping).

$$R(T) = R_0 \cdot e^{\left(T_0/T\right)^\gamma}$$

Calorimetric technique: status summary

Lowest-Q (2.5keV) beta decay (most sensitive to small m_ν): ^{187}Re

GOALS: - eliminate/differentiate as much systematic as possible (remember, we're talking about sub-eV!!)
- scaling (in principle) possible up to the n[th] generation

→ Source ≡ Detector (neutrino is the only allowed to escape from the bulk)

→ Published results: < 15 eV (90% C.L.) Milano MIBETA (AgReO$_4$)
< 19 eV (90% C.L.) Genova MANU (metallic Re)

PRESENT STATUS: still about one order of magnitude worse than spectrometers.

Some pros in principle: micro vs. macro approach (scalability to a further generation?) and systematic effects (but to be studied carefully… see next talk sub-sections).


MARE
Microcalorimeters Arrays for a
Rhenium Experiment

COLLABORATION

INFN sez. Genova and Università di Genova, Dipartimento di Fisica, ITALY

NASA Goddard Space Flight Center, USA

Universität Heidelberg, Kirchhoff-Institut für Physik, GERMANY

Università dell'Insubria, Dipartimento di Fisica e Matematica, ITALY

INFN sez. Milano and Università di Milano-Bicocca, Dipartimento di Fisica, ITALY

ITC-IRST, Trento, ITALY

University of Wisconsin, Physics Department, USA

NIST, Colorado

University of Miami

University of Cardiff (TBD)

... STILL OPEN TO NEW IDEAS/CONTRIBUTIONS

MARE: a two stages effort

Two orders of magnitudes (to 0.2eV) is a (too) big task for a single step.

Phase I: (2005-2009)
- Present technology detectors
- Optimization of the single channel
- Scaling up to hundreds of devices (MIBETA2, MANU2)

Goals: - m_ν < 2eV before KATRIN
- phase II preliminary (systematics, technology..)

Phase II: (2010-2015)
- R&D during the phase I data taking
- New approach (multiplexed TES, MMC, MKIDs)
- More than 10^4 fast (~μs) devices with ≈ 5eV resolution

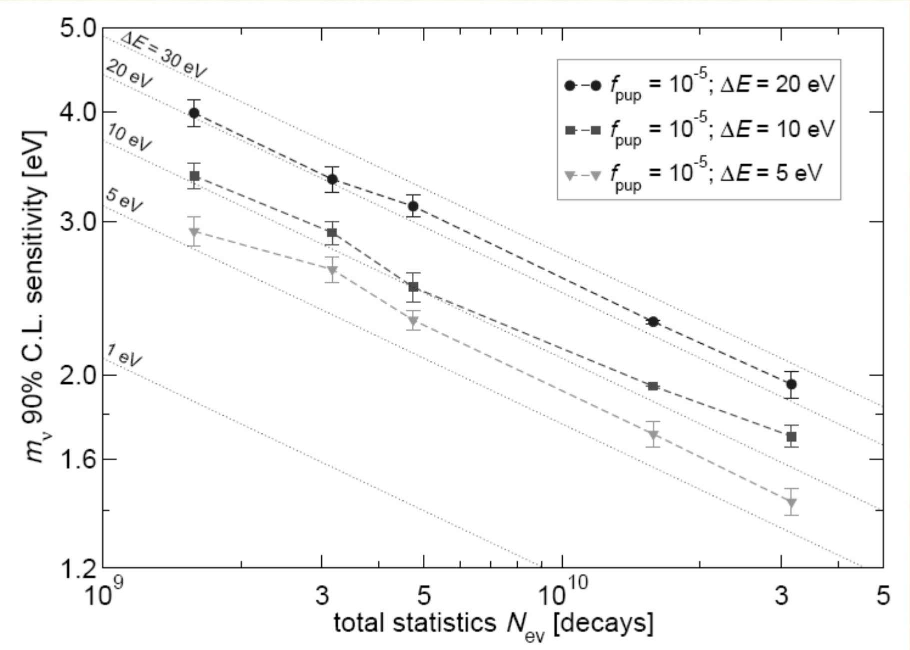
Goals: - 0.2eV sensitivity in 2015
- still upper limits (e.g. hierarchical pattern) ?

→ Starting point for a 4^{th} generation ($N_{DET} > 10^6$)

* Consistent with MIBETA experimental results

Montecarlo results*

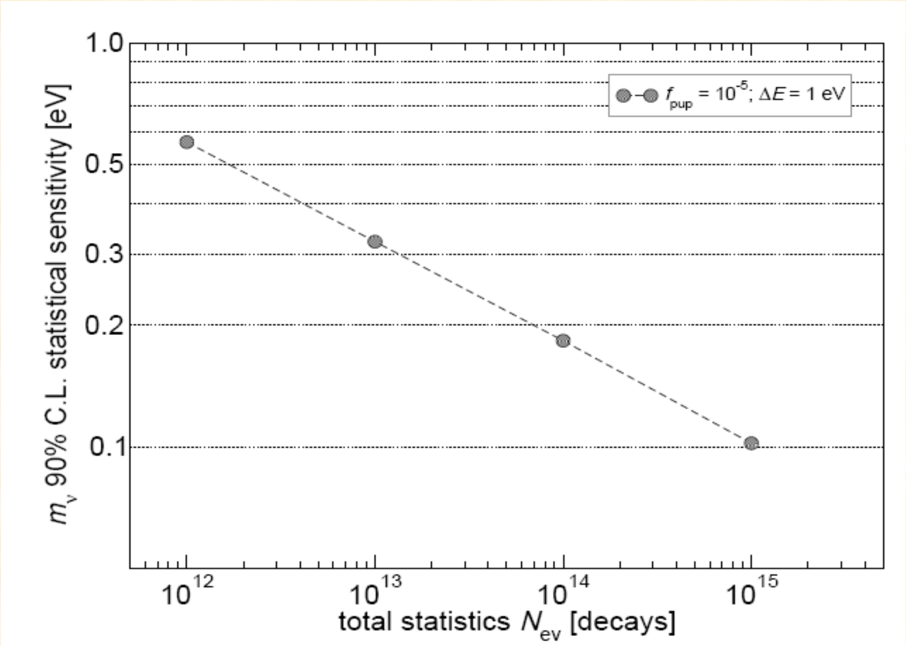
Phase I



- ~ 10^{10} beta decays required
- ΔE and f_{pup} achievable

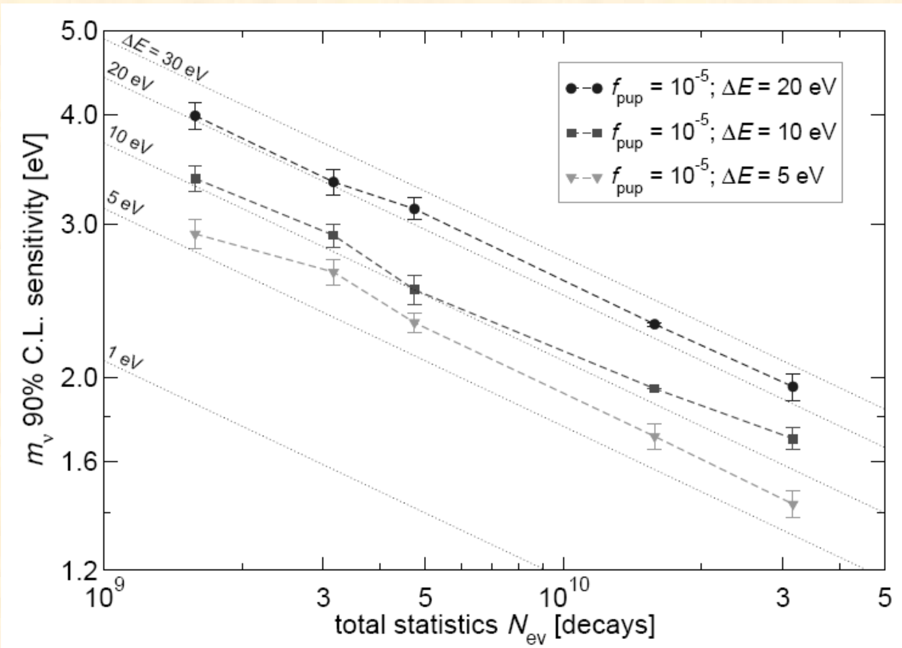
$f_{pup} \sim A_\beta \cdot \tau_R$

Phase II



- ~ 10^{14} beta decays required
- $f_{pup} \sim 10^{-5}$ is required
- ΔE < 5eV is enough

MIBETA 2 brief description



- $\sim 10^{10}$ beta decays required
- ΔE and f_{pup} achievable

$f_{pup} \sim A_\beta \cdot \tau_R$

STARTING POINT: MIBETA

GOAL: significantly increase the statistics

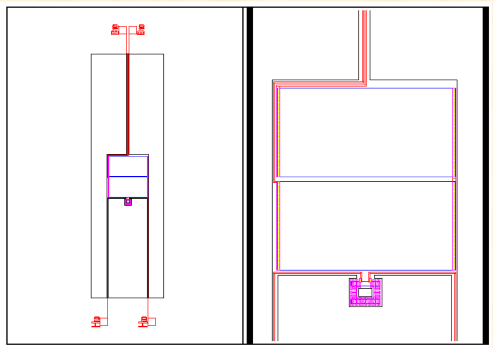
SOLUTION: scaling up to 200 detectors the MIBETA concept

ABSORBER: $AgReO_4$

THERMISTOR: semiconductor (Si or Ge)

Single absorber mass ≈ 500μg

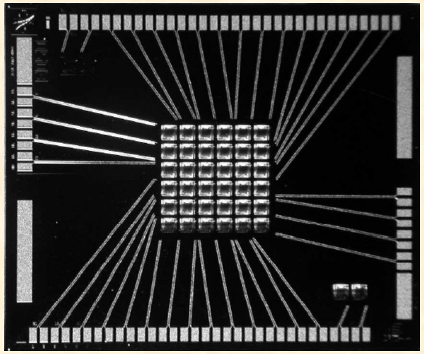
MARE phase I: MIBETA2 options



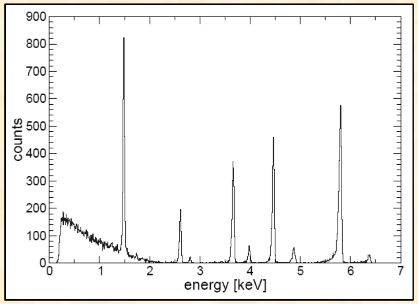
ITC-IRST TMAH micromachined arrays with SU8 supports for the absorbers. Implanted silicon with the technology developed for the MIBETA single devices.

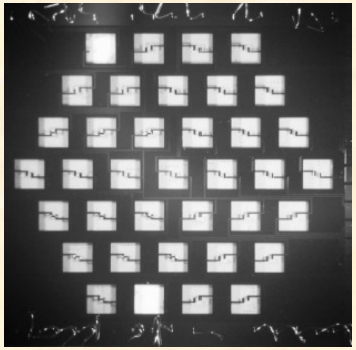
STATUS: 10 devices arrays fabrication ongoing.

IRST process BL12 (ongoing)

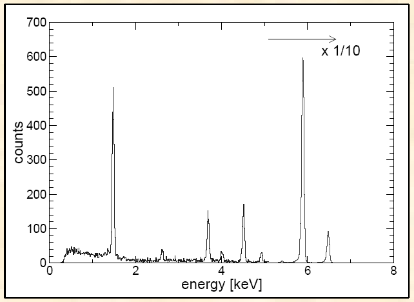


NASA 6×6 silicon array (XRS2).
STATUS: encouraging first results with 450μg $AgReO_4$.
Coupling and electronics to be optimized.

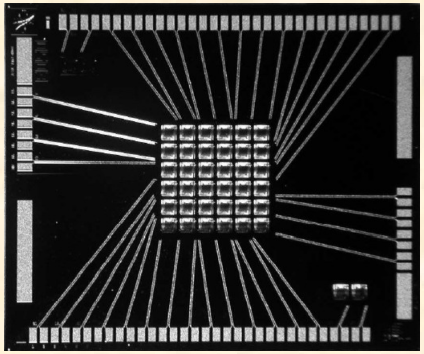


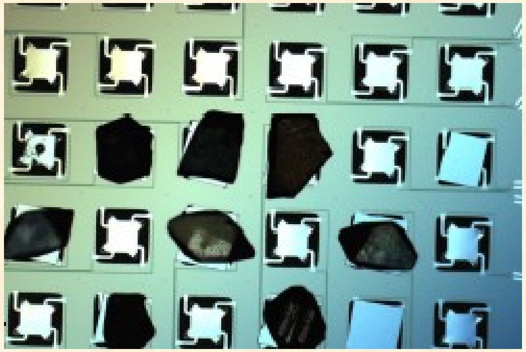


NTD Ge array (**LBL+Bonn**).
STATUS: preferred for the larger e-ph thermal coupling. Reproducibility to be demonstrated.



NASA array results





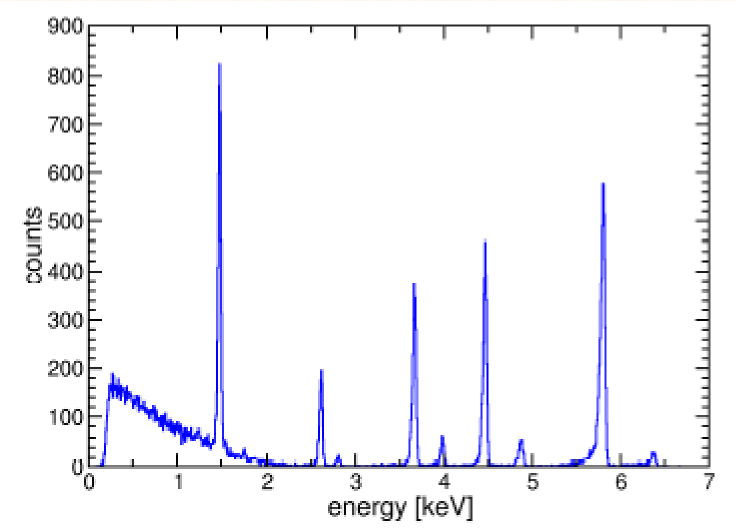
- 6×6 array (XRS2)
- $T_0 \approx 7$ K
- $AgReO_4$ (**450μg**) either mounted on Si platforms glued to the four SU8 spacers or directly to the thermistor (with the help of a silicon spacer)

Best results obtained with the spacers:

- ΔE_{FWHM} (@ 1.5keV) = 35eV
- τ_{RISE} = 220μs

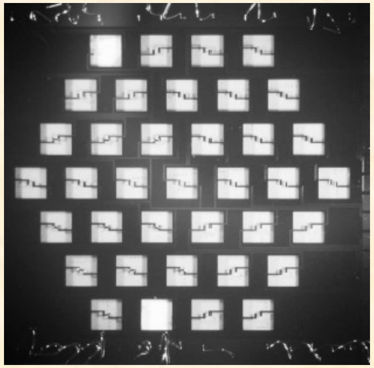
Problems:

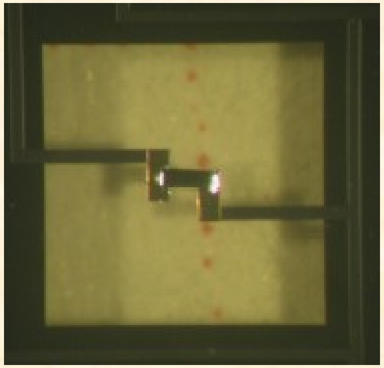
- MIBETA electronics not well matched yet
- coupling of $AgReO_4$ to be optimised.

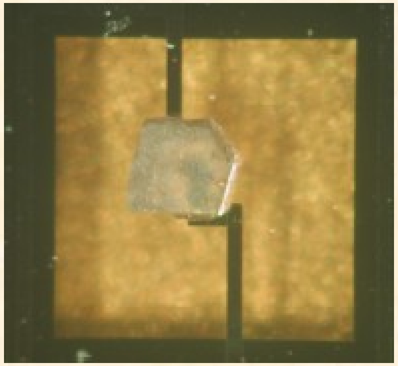


But…… good baseline choice in any case.

Germanium NTD results



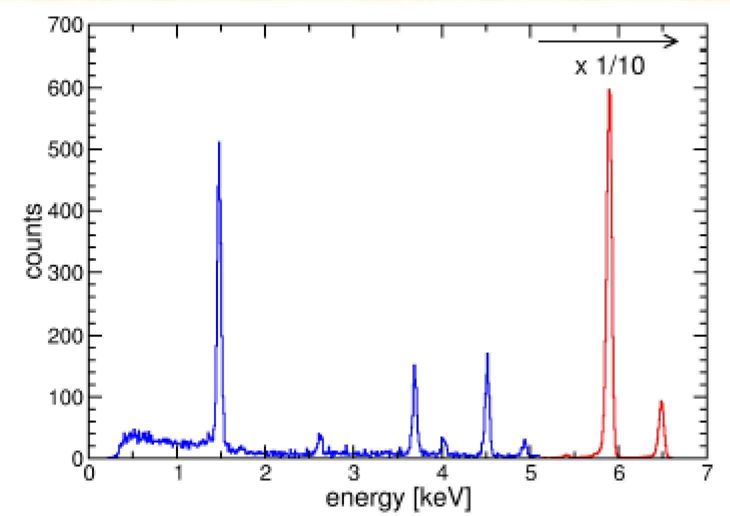




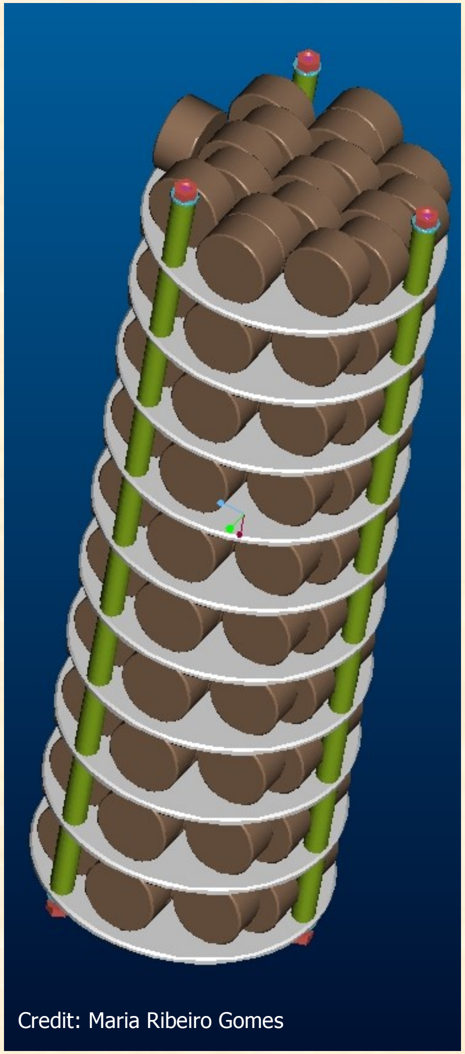
- 37 devices array originally built for astronomical purposes
- Ge NTD bump bonded on SiN thin (0.8µm) membranes
- Nb wiring to the pads
- $AgReO_4$ (**450µg**) glued on the NTD (ST2850FT)

Among 10 actually bonded NTDs, the best result is summarized here:
- ΔE_{FWHM} (@ 1.5keV) = 50eV
- τ_{RISE} = 270µs

Problems: - NTD mechanical stress



INFN Genova: MANU2



Detectors: about 300 Transition Edge Sensors (TES). Ir-Au (bilayer) or γ Ag-Al (hcp intermetallic alloy)

Absorbers: metallic Rhenium ($m_{Re}\approx 1mg$)

Readout: no-SQUID. Home-made 100mK transformers feeding Room-Temperature low-noise JFETs.

Single channel preliminary results:
ΔE=11eV FWHM at 6keV (with SQUID read-out and m_{Re}=215μg).

Should start data taking before MIBETA2. Expected final sensitivity **m_ν=1.5÷1.7eV** in 1÷2 years.

Systematic effects

Under investigation using "old" MIBETA data:

- theoretical spectral shape of the 1st forbidden ^{187}Re decay;
- solid state BEFS effect;
- internal detector response function calibration;
- unidentified pile-up spectrum;
- external radioactive background;
- energy scale calibration;
- surface electron escape;
- data reduction.

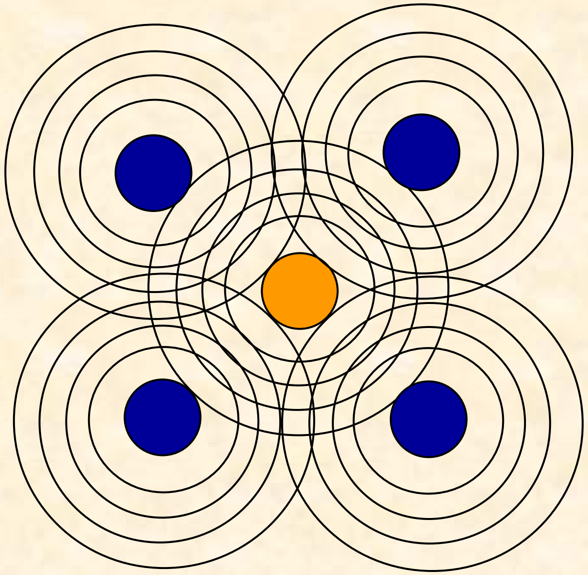
Briefly discussed here

Briefly discussed here

…. plus more that we still don't know about

Beta Environmental Fine Structure (BEFS)

..OR, how to transform a potentially annoying systematic effect into a new, independent, multidisciplinary research line.

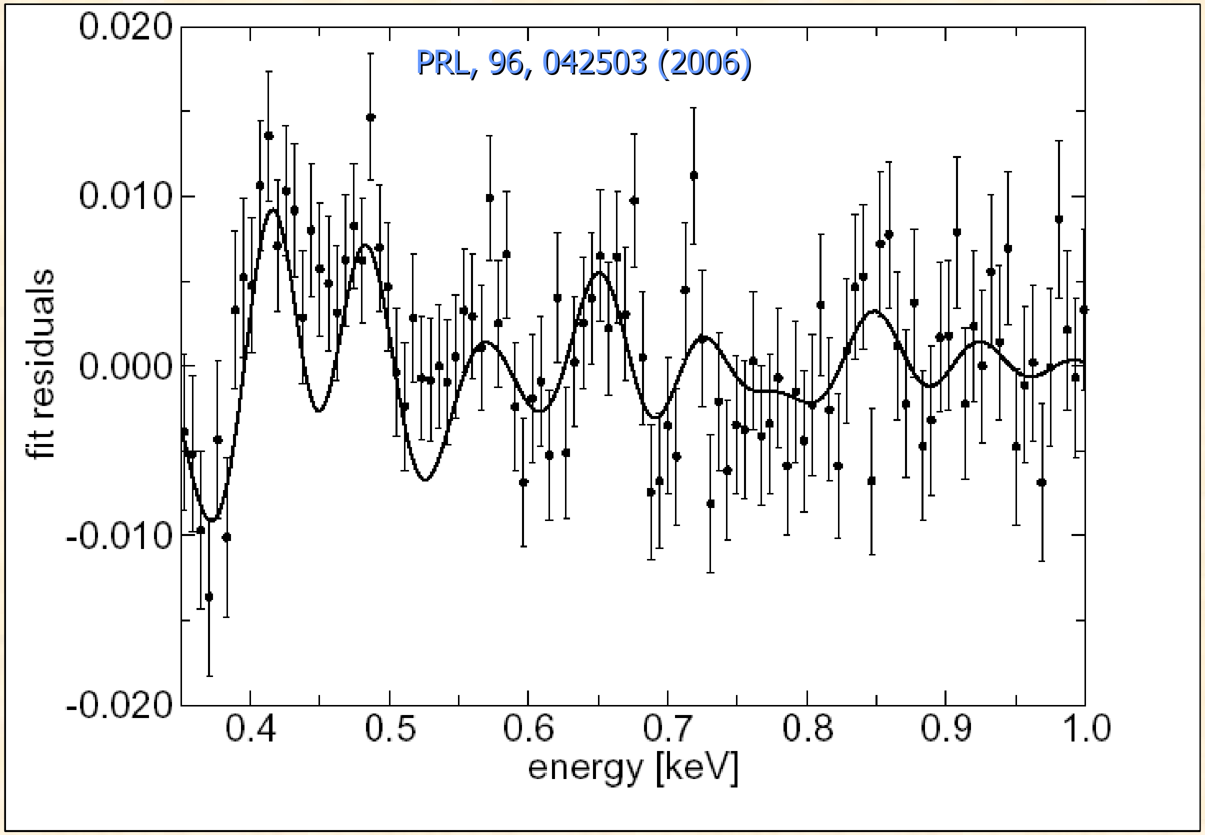


Theoretically predicted by Koonin (**1991**) in analogy with XAFS (X-ray Absorption Fine Structure). **Oscillatory modulation** superimposed on the beta decay spectrum due to the **electron wave reflections** on the surrounding atoms.

- **1998.** We (MIBETA) integrated the Koonin theory to include the electron orbital angular momentum (e.g. ^{187}Re).
- **1999.** First BEFS evidence; metallic rhenium (MANU).
- **2003.** BEFS evidence on $AgReO_4$ (MIBETA)
- **2006.** BEFS effect is used to extract novel structural and nuclear information (MIBETA).

Ongoing activities: ESRF proposal submitted in March to further investigate the XAFS-BEFS analogies by **directly comparing experimental data** obtained on the same compounds.

Beta Environmental Fine Structure (BEFS)



A recent re-analysis of the MIBETA fit residuals with the state-of-the-art EXAFS software (GNXAS) led to a substantial improvement of our understanding of the effect.

The important result here is:

$$F_{(le=1)} = 0.84 \pm 0.30$$

Fraction of electrons emitted with l=1 (p-wave electrons).

To satisfy the overall angular momentum conservation the antineutrino is mainly emitted with null orbital momentum.

Now extrapolation to the end-point is much safer, and we know that **the effect is negligible for MARE phase I.**
→ BUT Crucial for MARE Phase II.

^{44}Ti gamma: "deeply excited" Re

A 6 keV X-ray photon can only penetrate for about 4μm in an $AgReO_4$ target, path to be compared with 300μm, linear dimensions of a typical MIBETA crystal.

QUESTION: are the asymmetric calibration line profiles due to escape effects ?

DEDICATED RUN: a ^{44}Ti gamma source (E_γ=78.4keV) has been used to uniformly excite Re K,L escape peaks throughout the absorbers.

External ^{55}Fe photons impinging onto the crystals

IDEA:

why not use BEFS as a tool for energy and response function calibration ?

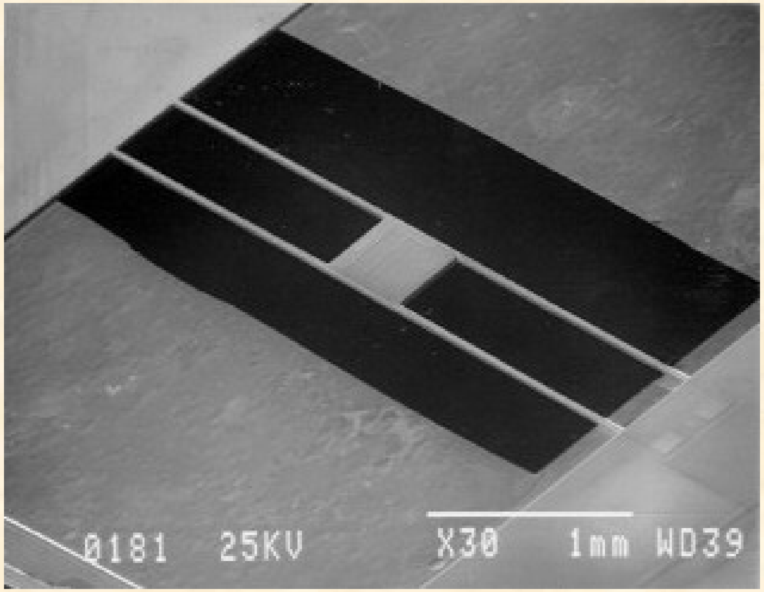
Internal Re Escape peak ($K_{\alpha 2}$) determined by an external ^{44}Ti source

Preliminary result: the symmetry seems recovered…but the large intrinsic width of the escape peaks (42eV) is annoying.

Paper in preparation

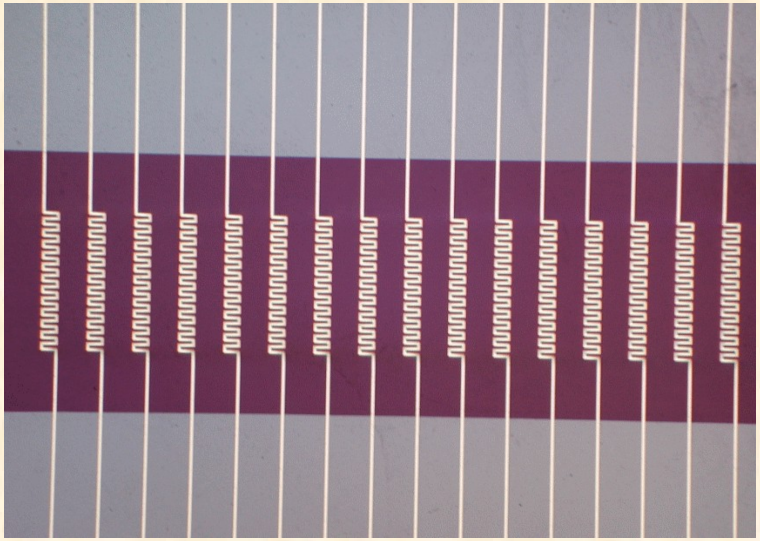
TECHNOLOGICAL DEVELOPMENTS

ITC-IRST technology for Cryodetectors



Old single devices are shown here.

New run:
- 10 detectors modular arrays;
- absorbers SU8 supports;
- heaters for calibration.

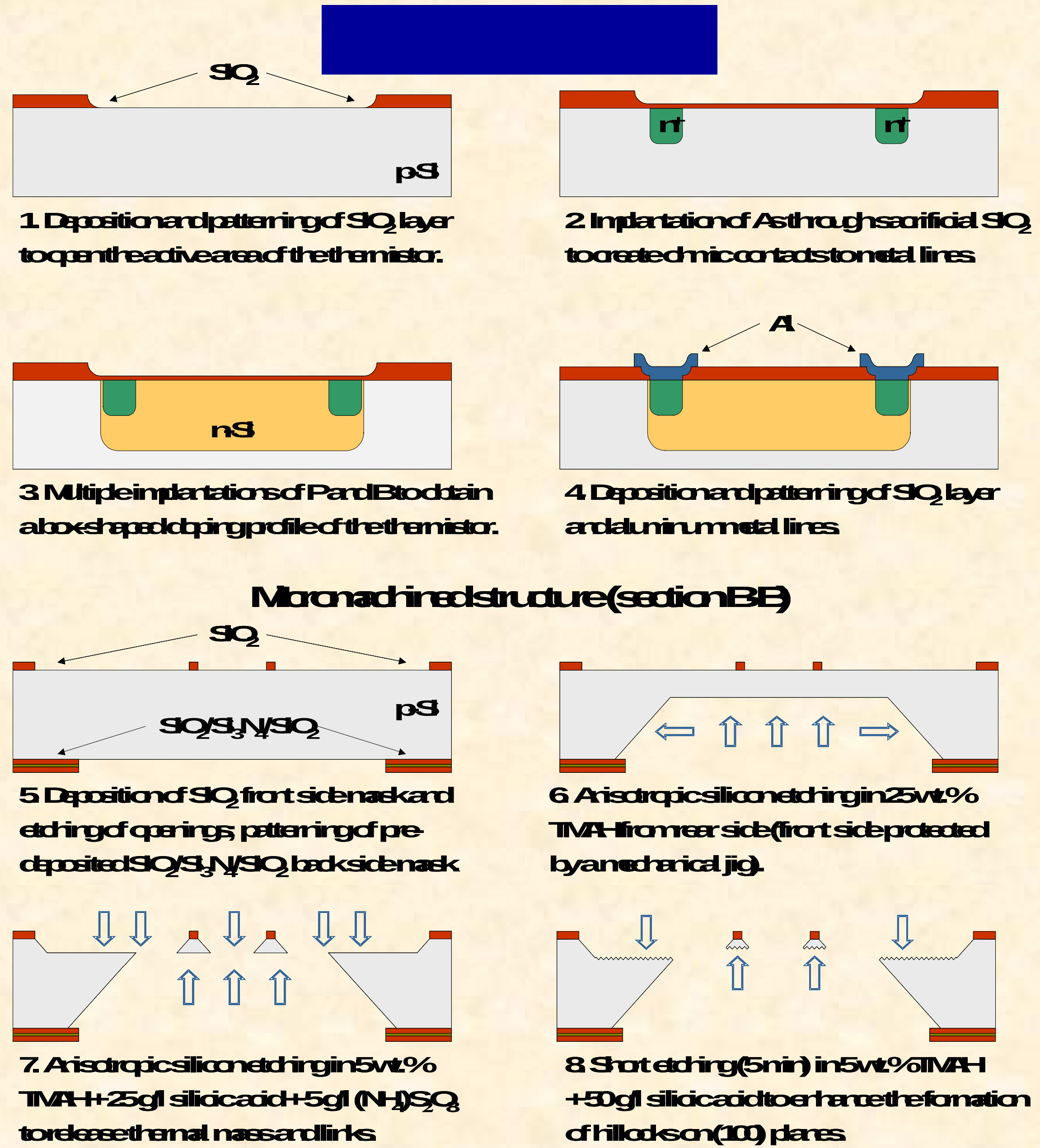


ITC-IRST capabilities applied to Cryogenics Detectors:

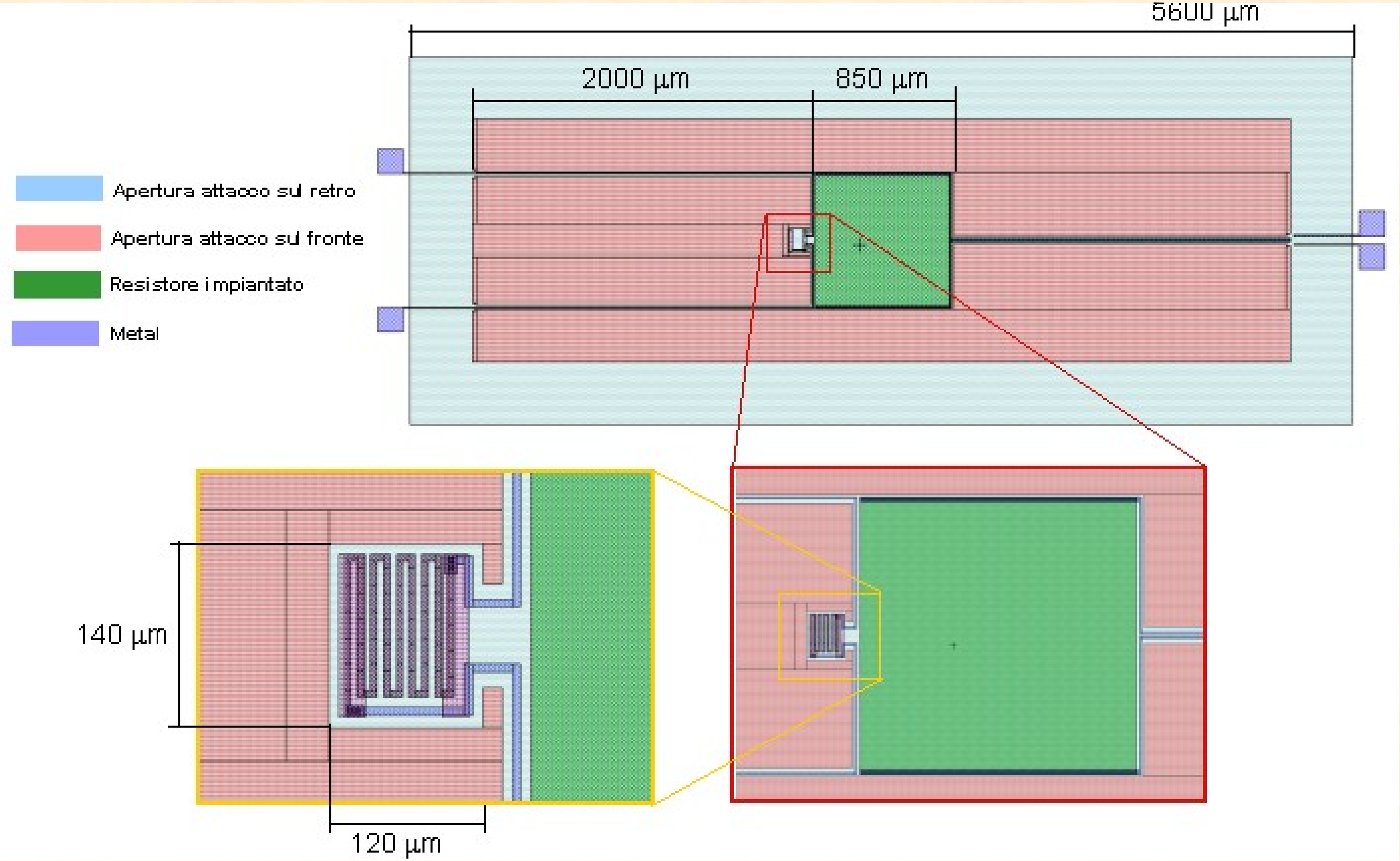
- "usual" silicon technologies (lithography down to 2μm) for the thermistor implant and heater
- surface micromachining for thermistor-to-absorber coupling
- Bulk micromachining (chemical) for the realization of the suspended structure
- Experience with thin membranes and films for other detectors concepts (e.g. MKID, IR and THz detectors)

IRST silicon arrays

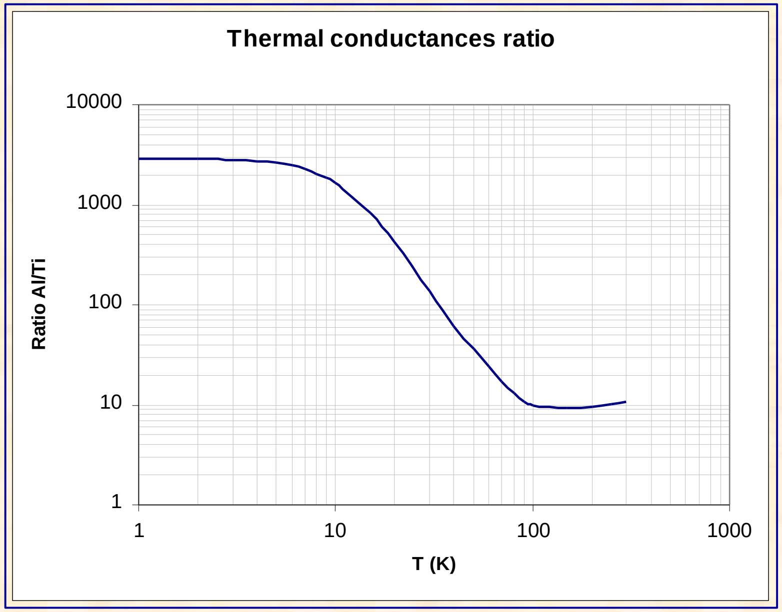
fabrication steps



A new ITC-IRST thermistor: closer view



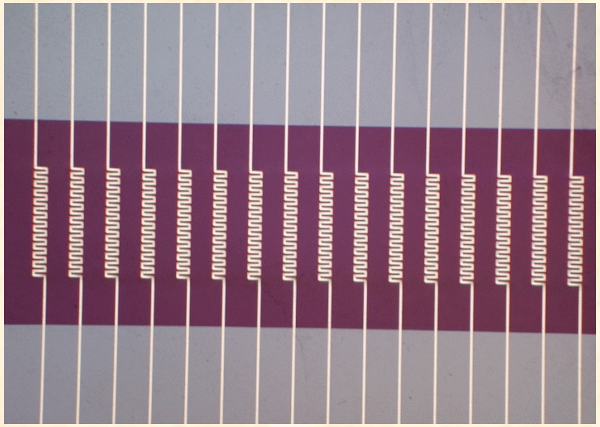
Wiring and "old" ITC-IRST Cryoflats



General problem: *COLD END WIRING*

3) detector → "cold" electronics plate 20mK → 4K
4) plate → (e.g. JFET input) 4K → 120K

In order to keep the power transmitted per wire below 10nW for usable wire lengths and sections the first connection has to be realised in Titanium.



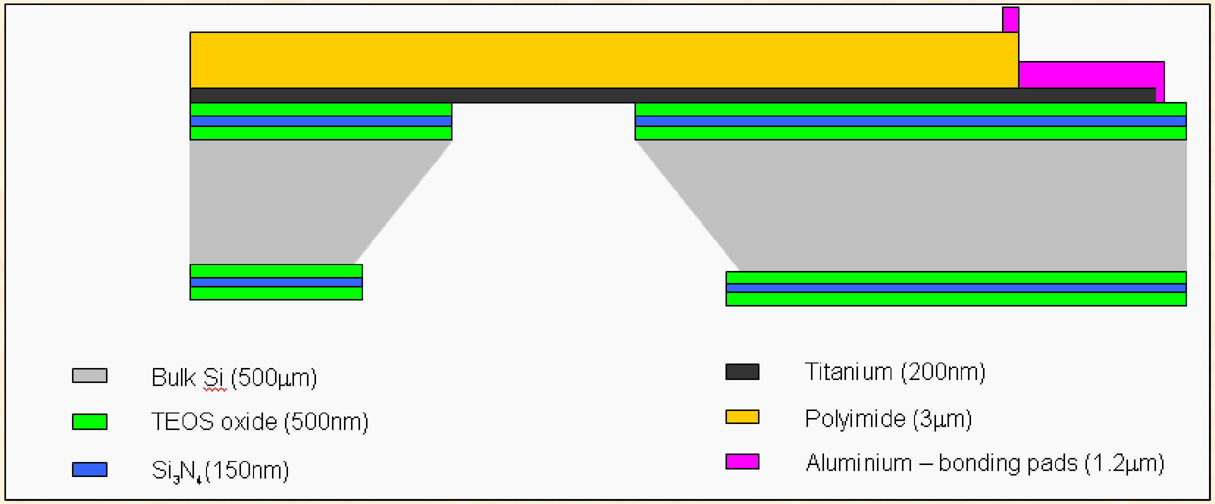
First RUN problems:

- single front mask
- aluminium
- cleaving
- bonding
- weak suspension points

Achievement:

- Micromachining process tuning

New IRST cryoflats for MIBETA

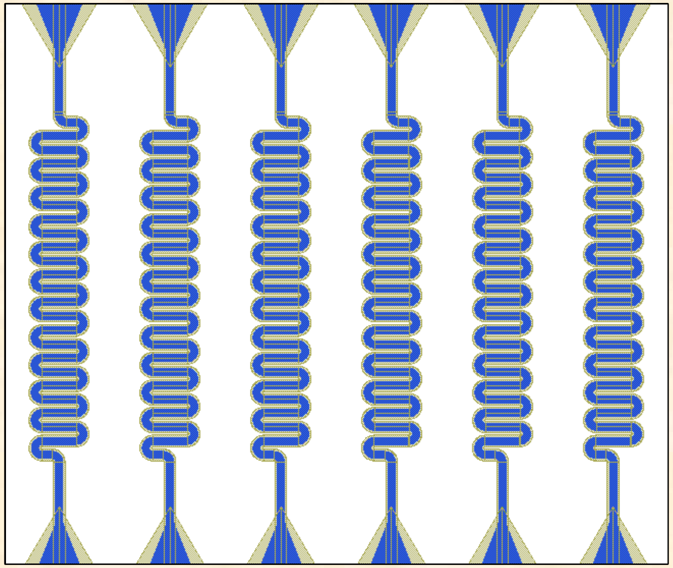


PROCESS SCHEME

Old problems:
hopefully all understood and solved with the new layout/process

Present Status:
Ongoing run

SINGLE MEANDERS LAYOUT



MARE phase II detectors options

- **Semiconductor microbolometers**

  Advantage: we have broad experience in fabricating and running them.
  Drawback: not easily multiplexable and quite slow.
  Summary: probably not useful for this application.

- **Multiplexed TES (Transition Edge Sensors)**

  Advantage: relatively mature technology. The single pixel shouldn't be a problem.
  Drawback: large number of channels. The multiplexing is still "weak".
  Summary: **baseline choice so far.**

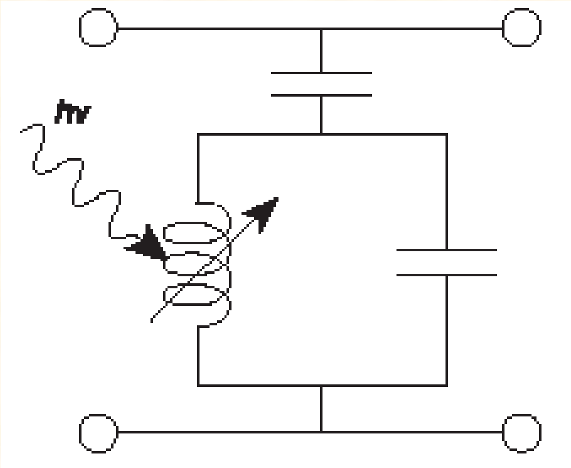
- **Multiplexed MMC (Magnetic Metallic Calorimeters)**

  Advantage: best energy resolution so far; potentially fast.
  Drawback: large number of channels. Multiplexing to be demonstrated.
  Summary: very promising.

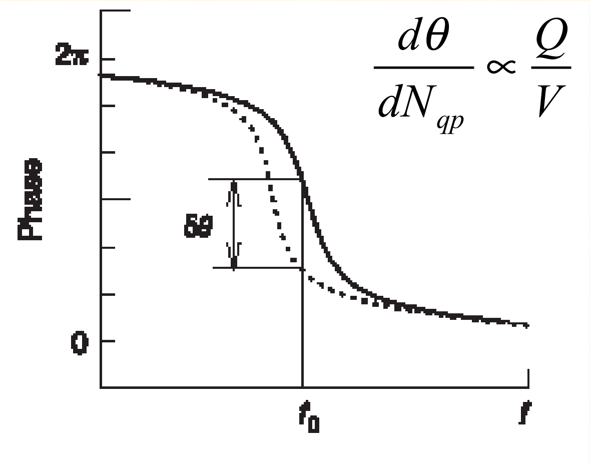
- **MKID (Microwave Kinetic Inductance Detectors)**

  Advantage: intrinsically multiplexable.
  Drawback: new technology. The single pixels still to be investigated.
  Summary: potentially the best choice in the long term (even beyond MARE II ?) as far as the number of channels is concerned.

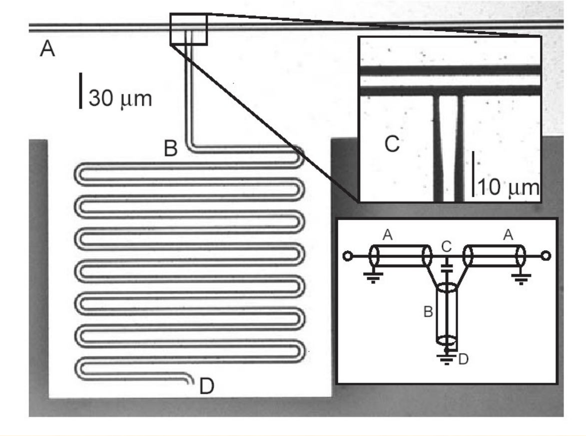
…MARE phase II: MKIDs ?



The quasi-particles generated by the radiation (or beta) determine an impedance variation in a SC Strip.
If the SC is part of a resonant circuit (e.g. 1-20GHz) this translates in a "phase pulse" on the main transmission line.



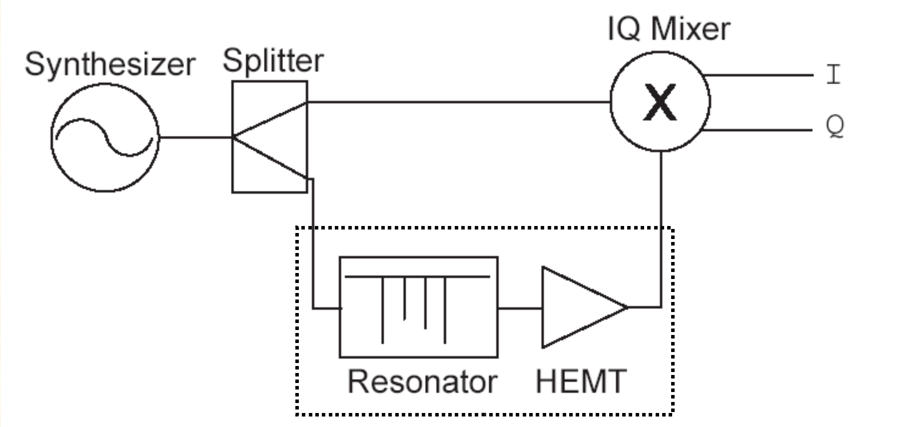
Resonators
Day et al., NATURE (2003)



A complete Detector includes:

-Resonators
-Feeding power to the resonator
- *qp trapping (quasi-optical)*
- *stripline (antenna coupling)*
- *……*

MKID detectors: intrinsically multiplexable



The only (but fundamental) MKID advantage:

INTRINSICALLY MULTIPLEXABLE

Major drawback:

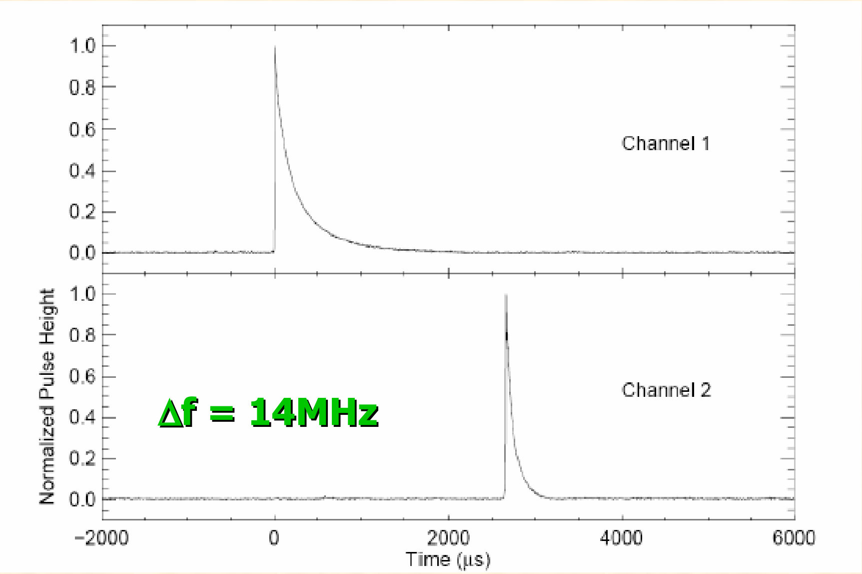
Novel detector not well developed yet.
No conceptual limitations.

Limiting the channels per single line:

- Q of the resonator (Δf > 20kHz)
- pulse bandwidth (Δf > 100kHz)
- lithography precision (Δf > 2.5MHz if $\delta L=2\mu m$)
- total power in HEMT (cold)
- amplifier bandwidth

…… theoretically up to 16000 channels assuming $\delta L=0.2\mu m$!!

MKID detectors: other groups (from LTD11)

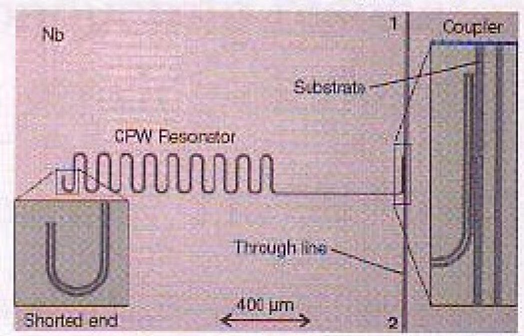


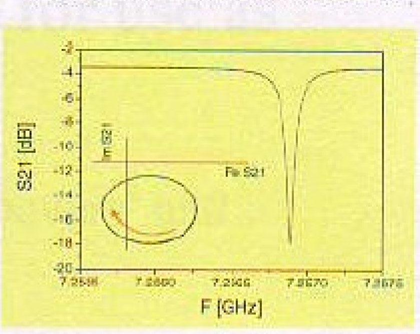
USA: JPL + NIST + Caltech

Nb and Al resonators with nominal results. Excess phase noise.
The single pixel design has still to be completely demonstrated (published).
Projects: antenna coupling, polarizers, multi-color pixels, UV-optical.

Europe: SRON + Delft

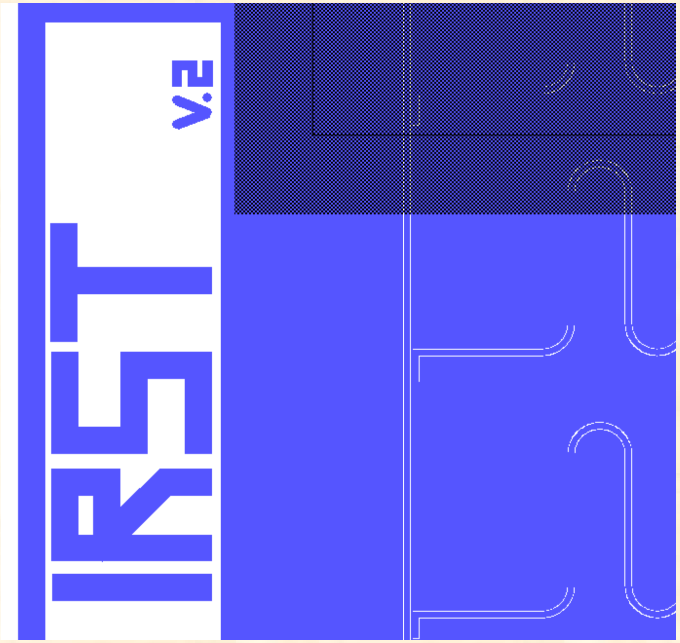
Good results on Nb resonators.
Designing the final detectors.
Projects: quasi-optical Ta absorbers coupled with λ/4 Al resonators.
Applications: space telescopes.





MKID detectors in IRST

We are part of an **Italian-British** collaboration funded in Italy by INFN to develop MKID. We've just started designing and fabricating the first prototypes.
GOAL for 2006: single pixel coupled with an antenna for 150GHz radiation detection.



Ideas:
- Explore the possibility of depositing the resonators on a membrane to minimize the substrate losses or phase noise;
-using planar micromachining to produce trenches and isolate the lines;
- new designs for the antenna.

Applications:
- CMB polarization measurements (Space, Antarctica, balloons);
- MARE phase II.

Conclusions

• The neutrino mass problem, signalling the begin of beyond-SM Physics, is being slowly solved as a result of a multi-approach effort. Oscillations, $0\nu\beta\beta$, Cosmology…. We believe that the direct single beta approach is now becoming even more important.
• A valid alternative to check and complement spectrometers results is proved to be the ^{187}Re "true" calorimetric approach.
• MIBETA2 is part of the two steps experiment MARE. The phase II is still, adopting Space Experiments terms, "in phase A".
• A number of physically interesting systematic effects are under investigation using pilot MIBETA data (e.g. BEFS, line profile). More fundamental results, neutrino mass aside, are expected as a result of the statistics increase.
• Technological development is an important part of the game. In particular, the novel MKID have a great potential for a number of highly demanding radiation detection applications (e.g. CMB, THz …).