Direct Neutrino Mass Measurements

Flavio Gatti, University and INFN of Genova

Introduction

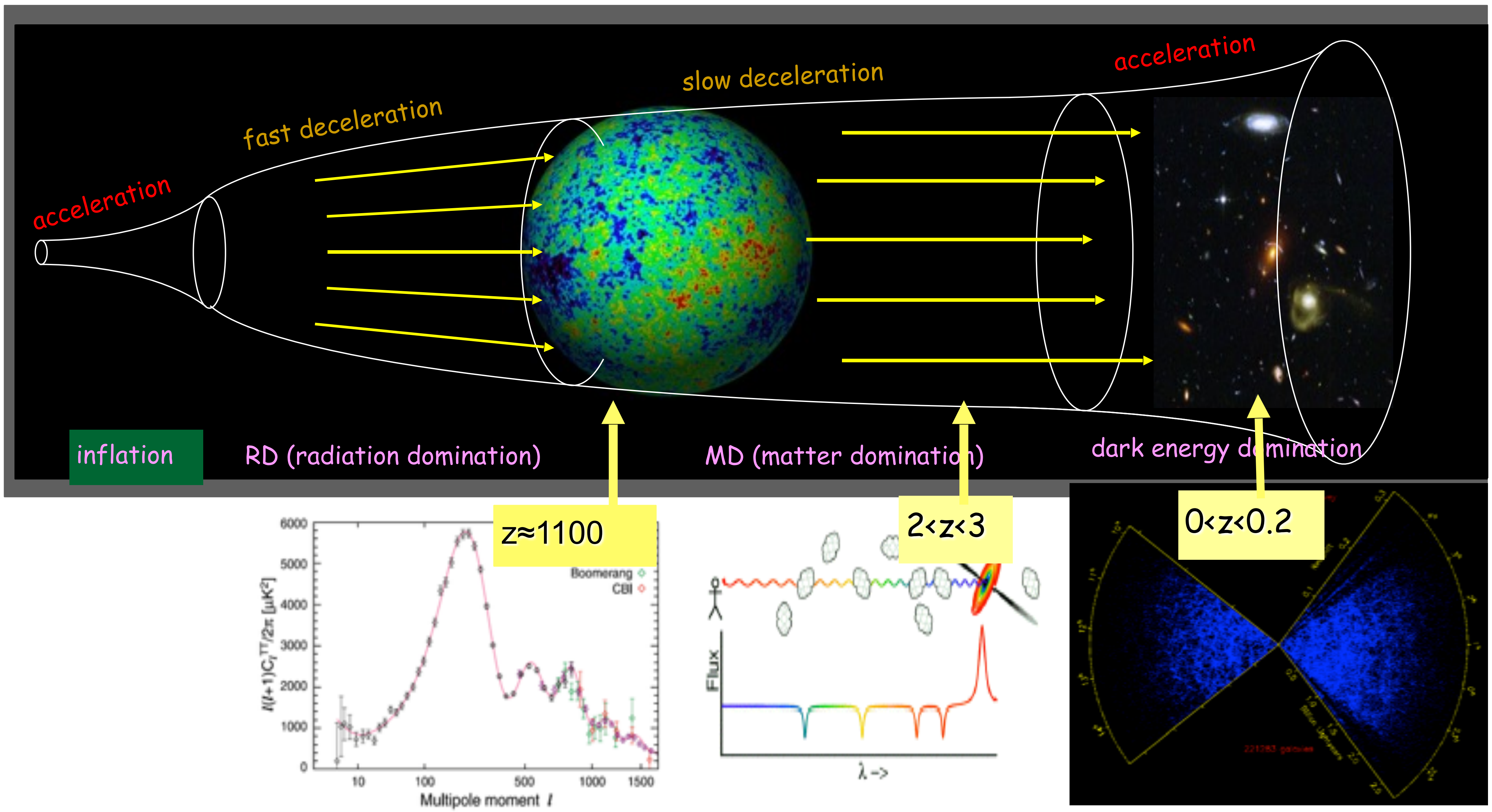
- Since the the flavour oscillations paradigm has been fully a remarkable increase of interest has in investigating directly the absolute mass scale
- The absolute mass scale of neutrinos remains today an open question subject to experimental investigation from both particle physics and cosmology.
- Over the next decade, a number of proposal/projects from both disciplines will aim to test the mass scale further to the very limits of the predictions from oscillation results → sub eV sensitivity.
- After the discovery of a finite neutrino mass Presently the main common issue is: “We need to imagine a PRECISION EXPERIMENT”
- I will focus this talk on direct experimental approach: this is a not exhaustive seminar (Apologize if many arguments are skipped)

Kinematical methods

- β decay: $m_j \neq 0$ affect β−spectrum endpoint. Sensitive to the "effective electron neutrino mass":
  $\mathbf{m}_\beta = \{ \Sigma_j m_j^2 |U_{ej}|^2 \}^{1/2}$
  Flavor-Mass Mixing Parameter
- 0ν2β decay: can occur if $m_j \neq 0$. Sensitive to the "effective Majorana mass":
  $\mathbf{m}_{\beta\beta} = \{ \Sigma_j m_j |U_{ej}|^2 e^{i\varphi_j} \}$
  Flavor-Mass Mixing parameter + imaginary phase
- Cosmology: $m_j \neq 0$ can affect large scale structures in (standard) cosmology constrained by CMB and not CMB (LSS,Lyα) data. Sensitive to:
  $\mathbf{m} = \Sigma_j m_j$
  Flavor-Mass Mixing independent

Cosmological constraints (overview)

Imprint of cosmological neutrinos upon the structure evolution of the universe is testable by cosmology observation

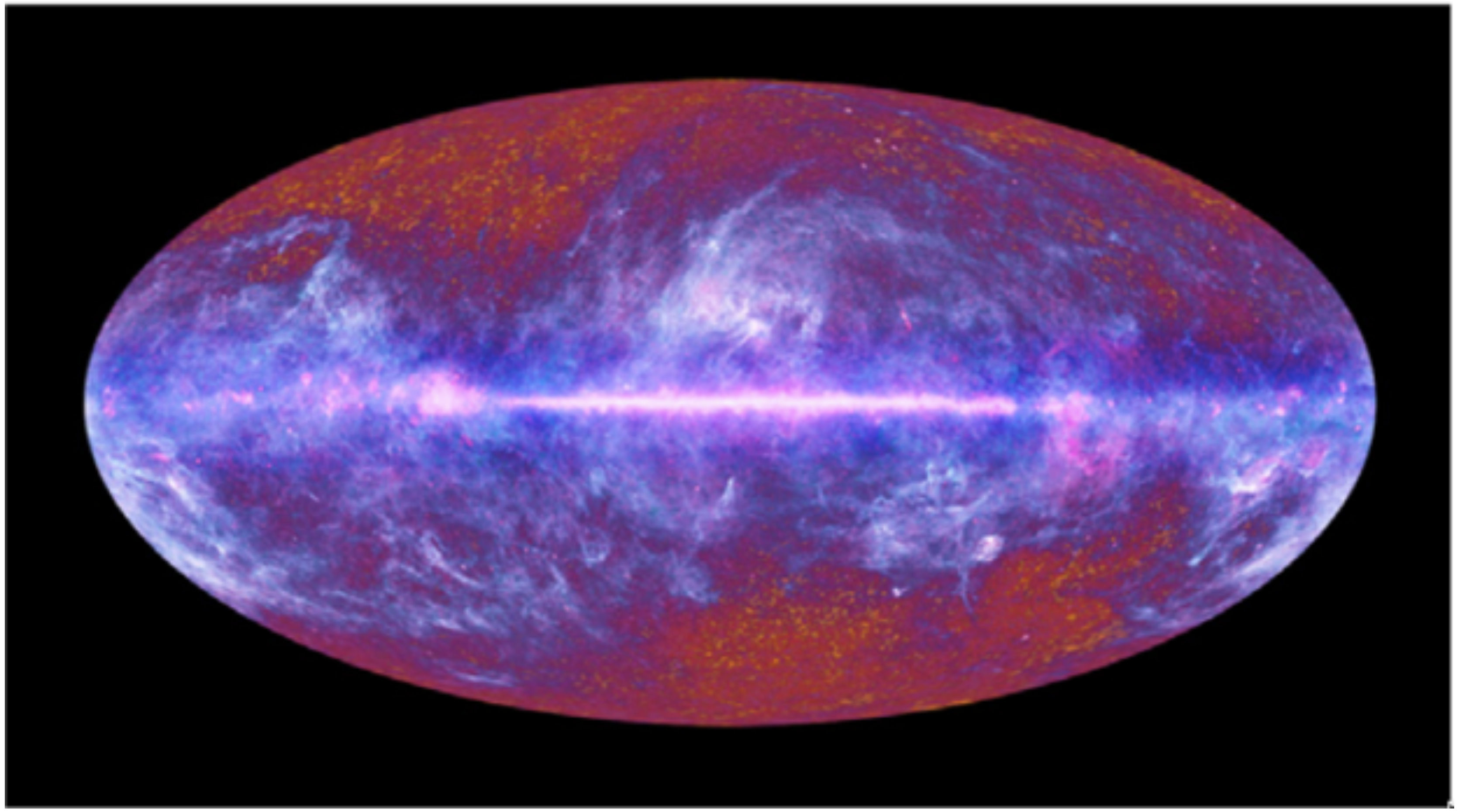


CMB temperature/polarization anisotropies

Lyman-α forests in quasar spectra

galaxy redshift surveys

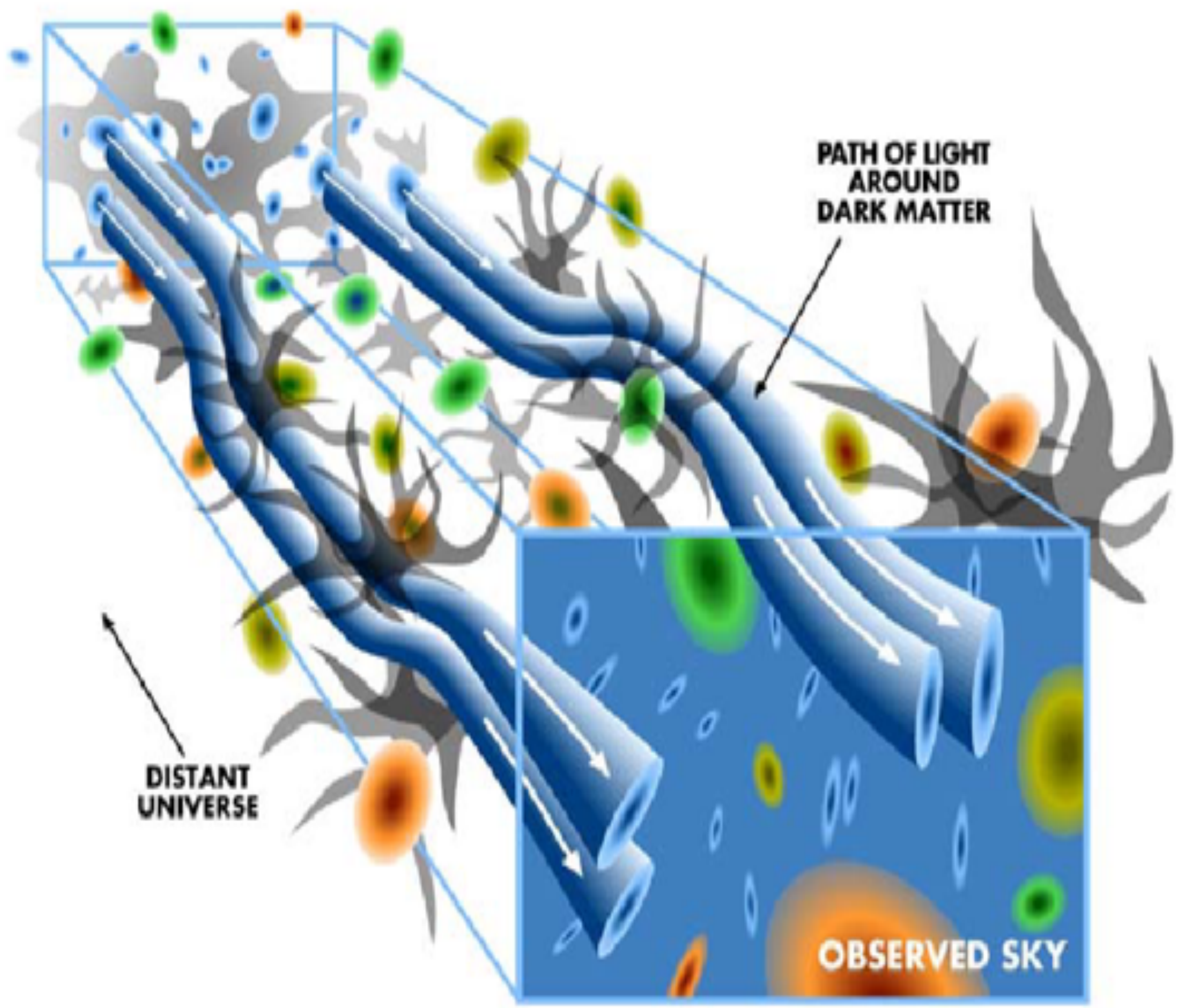
Cosmological Constraints (Planck)



Parameter	TT	TT+lensing	TT+lensing+ext	TT, TE, EE	TT, TE, EE+lensing	TT, TE, EE+lensing+ext
Ω_K	$-0.052^{+0.049}_{-0.055}$	$-0.005^{+0.016}_{-0.017}$	$-0.0001^{+0.0054}_{-0.0052}$	$-0.040^{+0.038}_{-0.041}$	$-0.004^{+0.015}_{-0.015}$	$0.0008^{+0.0040}_{-0.0039}$
Σm_ν [eV]	< 0.715	< 0.675	< 0.234	< 0.492	< 0.589	< 0.194
$N_{\rm eff}$	$3.13^{+0.64}_{-0.63}$	$3.13^{+0.62}_{-0.61}$	$3.15^{+0.41}_{-0.40}$	$2.99^{+0.41}_{-0.39}$	$2.94^{+0.38}_{-0.38}$	$3.04^{+0.33}_{-0.33}$
$Y_{\rm P}$	$0.252^{+0.041}_{-0.042}$	$0.251^{+0.040}_{-0.039}$	$0.251^{+0.035}_{-0.036}$	$0.250^{+0.026}_{-0.027}$	$0.247^{+0.026}_{-0.027}$	$0.249^{+0.025}_{-0.026}$
$dn_s/d\ln k$	$-0.008^{+0.016}_{-0.016}$	$-0.003^{+0.015}_{-0.015}$	$-0.003^{+0.015}_{-0.014}$	$-0.006^{+0.014}_{-0.014}$	$-0.002^{+0.013}_{-0.013}$	$-0.002^{+0.013}_{-0.013}$
$r_{0.002}$	< 0.103	< 0.114	< 0.114	< 0.0987	< 0.112	< 0.113
w	$-1.54^{+0.62}_{-0.50}$	$-1.41^{+0.64}_{-0.56}$	$-1.006^{+0.085}_{-0.091}$	$-1.55^{+0.58}_{-0.48}$	$-1.42^{+0.62}_{-0.56}$	$-1.019^{+0.075}_{-0.080}$

Next Possible Cosmological Constraints

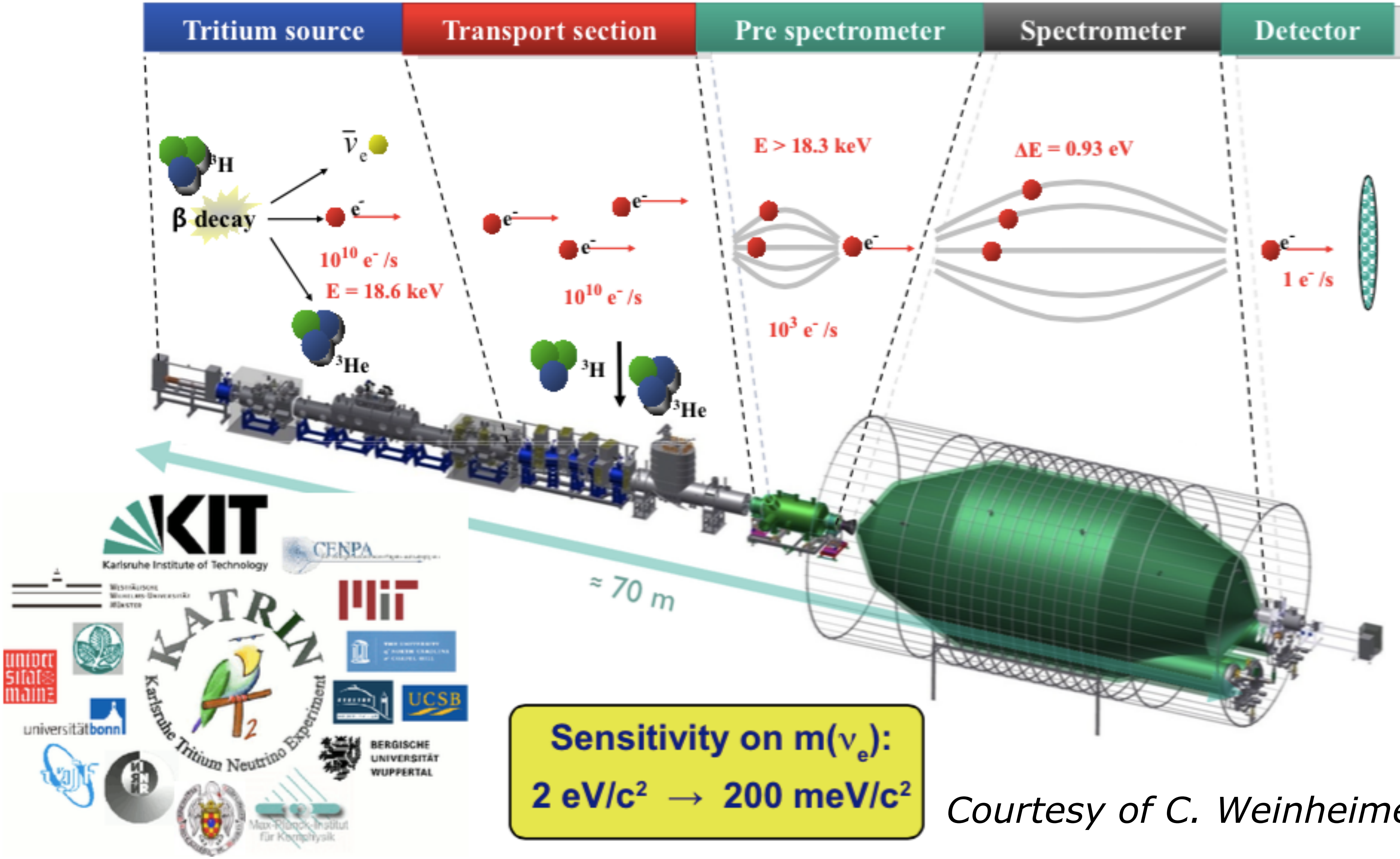
- Lensing of the CMB signal Makes CMB sensitive to smaller neutrino masses
- $\sigma(m_\nu) \rightarrow 0.01$ eV (CMBpol missions)



My considerations about Cosmological Constraints

- Neutrinos are a small fraction of the matter density of the universe → their contribution have significant effects on late-times large structure formation.
- Relativistic at the time of decoupling, they transition to non-relativistic velocities at late times
- Some tension between data sets exists.
- Possible mixing of not fully independent data (correlation well extimated?)
- The neutrino mass limits tend to vary depending on the data used and the exact model employed
- Next generation CMB missions aim to push well down into the inverted hierarchy region
- But systematic uncertainties and small order corrections become increasingly important
- → DIRECT SEARCHES IN LABORATORY ARE NEEDED

Katrin

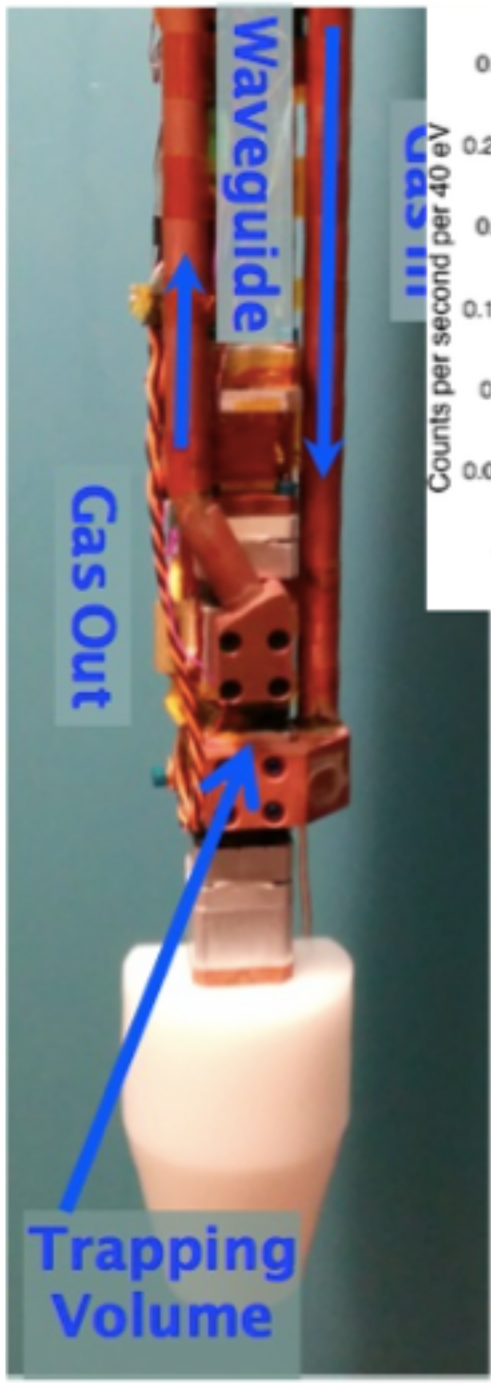


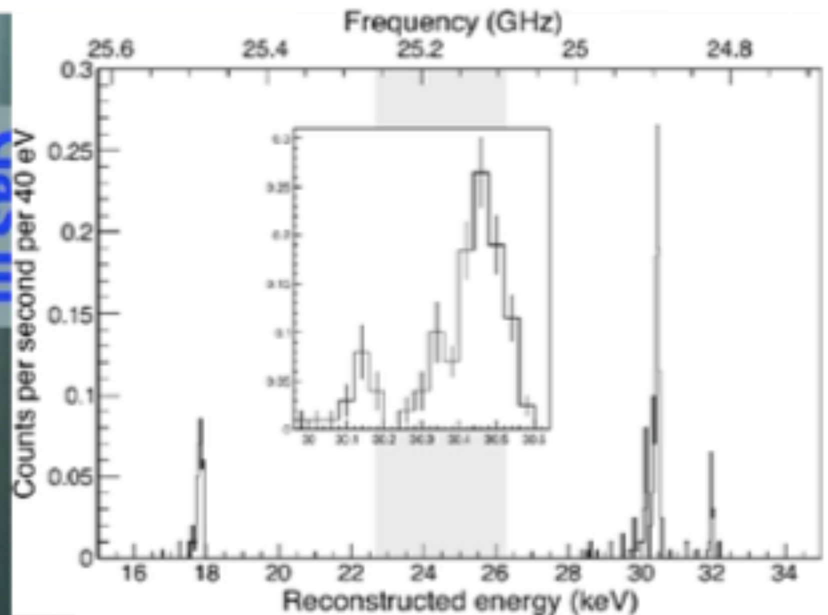
Sensitivity on $m(\nu_e)$:

2 eV/c² → 200 meV/c²

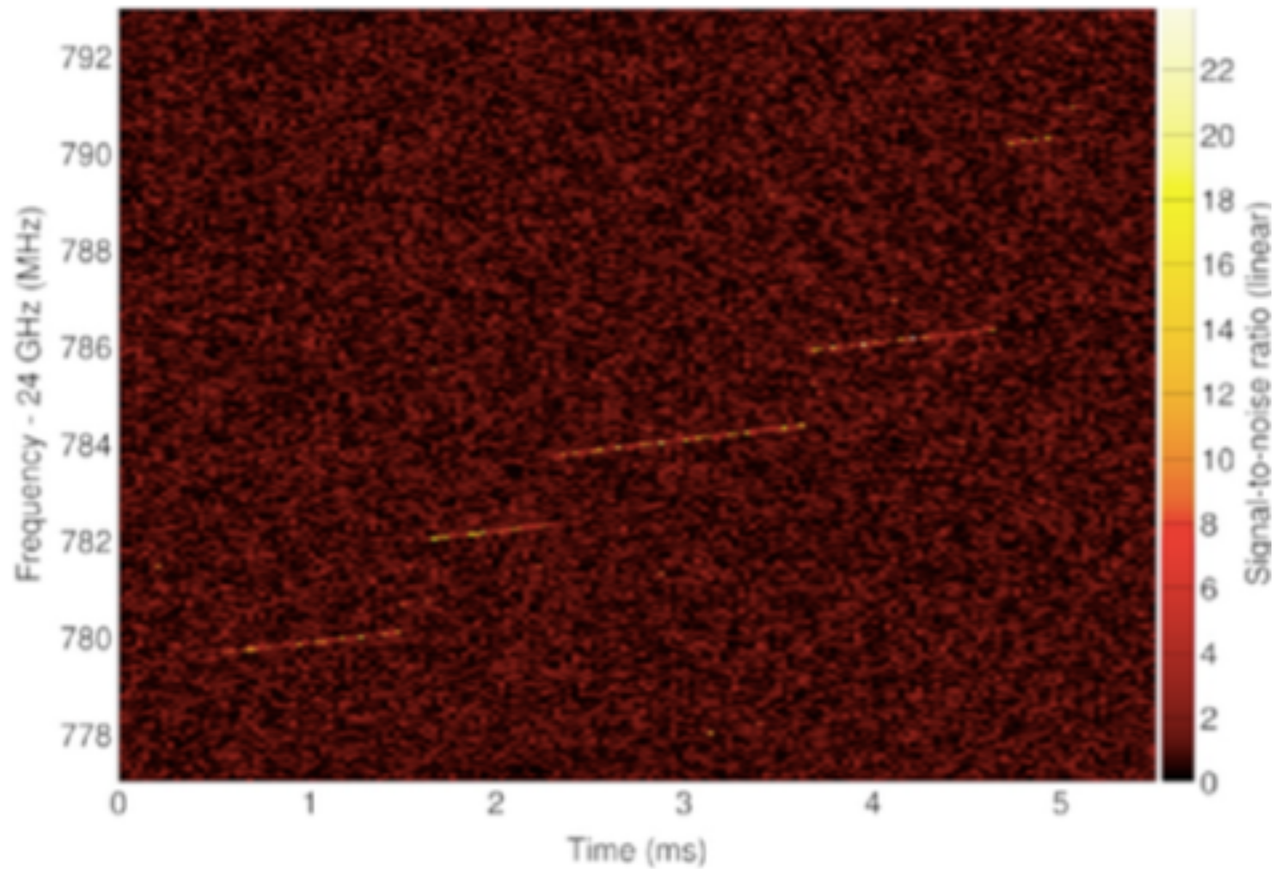
Courtesy of C. Weinheimer

Project8



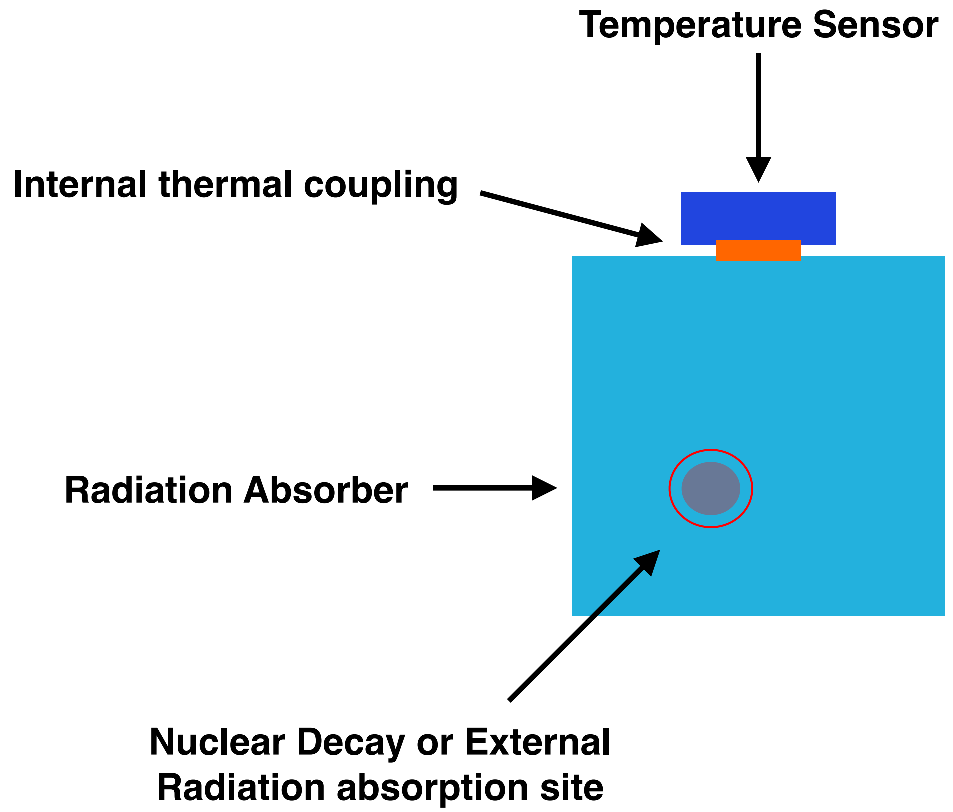


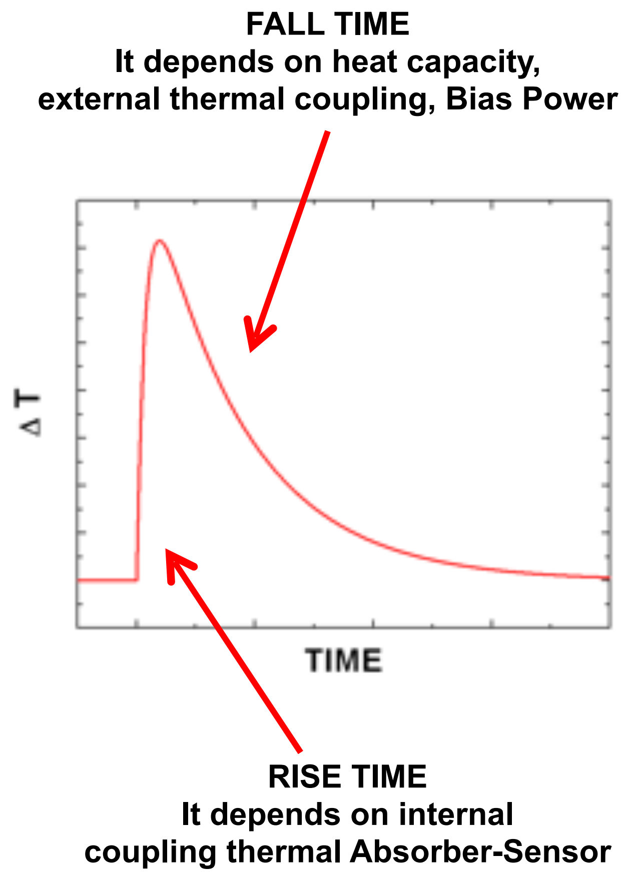
D. M. Asner et al., arXiv:1408.5362



Courtesy of J. Formaggio

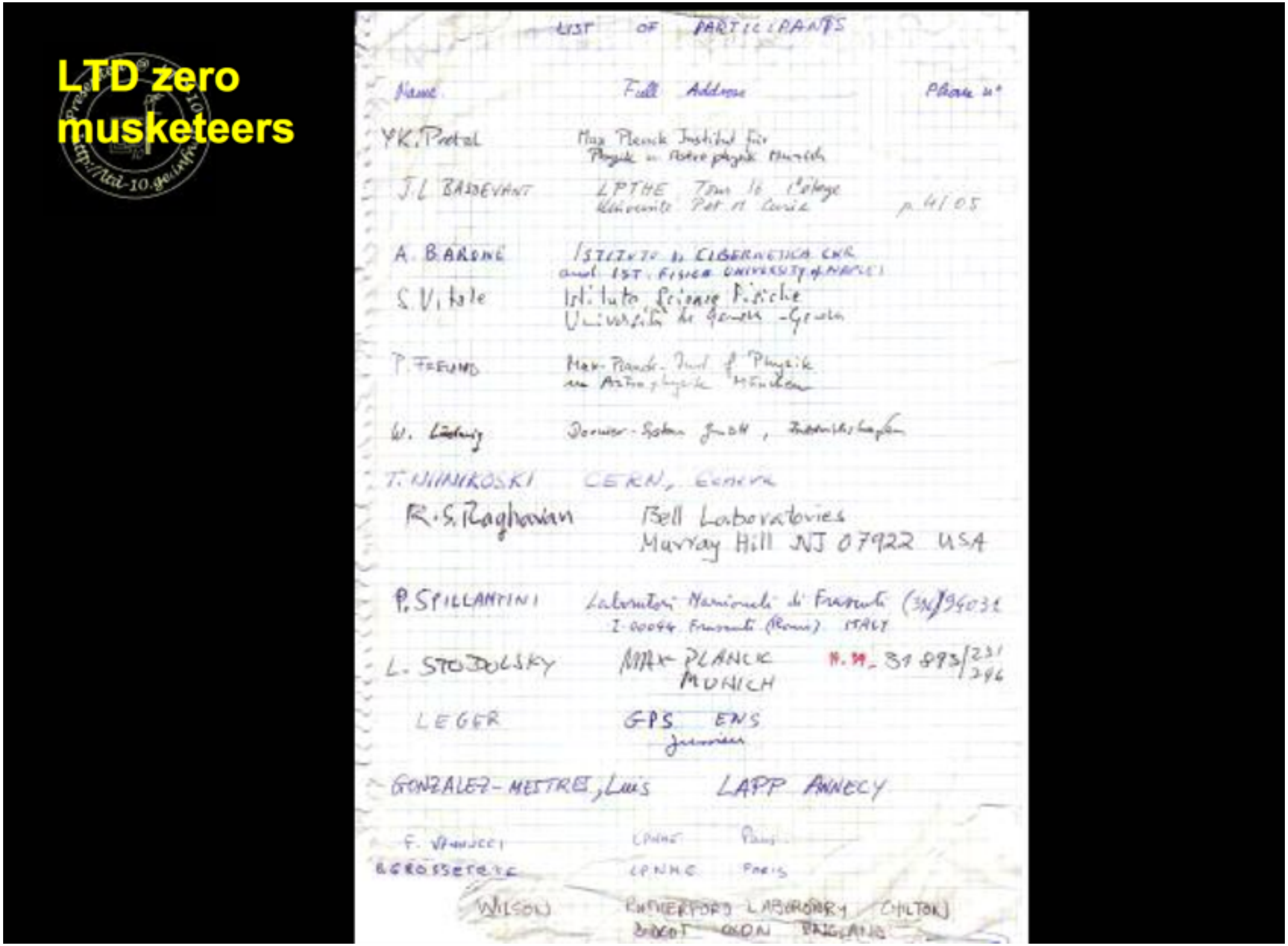
Mass measurement with cryogenic μ-calorimeter





- It's ideally an Energy Dispersive Spectroscopical Detector
- It's a fast (0.1-1 μs) true thermal calorimeter
- Energy Sensitivity at the eV scale needs very low heat capacity at the scale less than pJ/K
- The Energy Resolution Intrinsic is ultimately limited by the thermal fluctuation noise:
- Sub-K operating temperatures are needed (0.01-0.1 K) to reach eV resolutions
- IN PRINCIPLE THEY ARE A TOOL FOR VERY DEEP SEARCHES IN SUB-eV range

Pre-history of Low Temperature Technology and Community



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History of Low Temperature Technology and Community

15th International Conference on Low Temperature Detectors

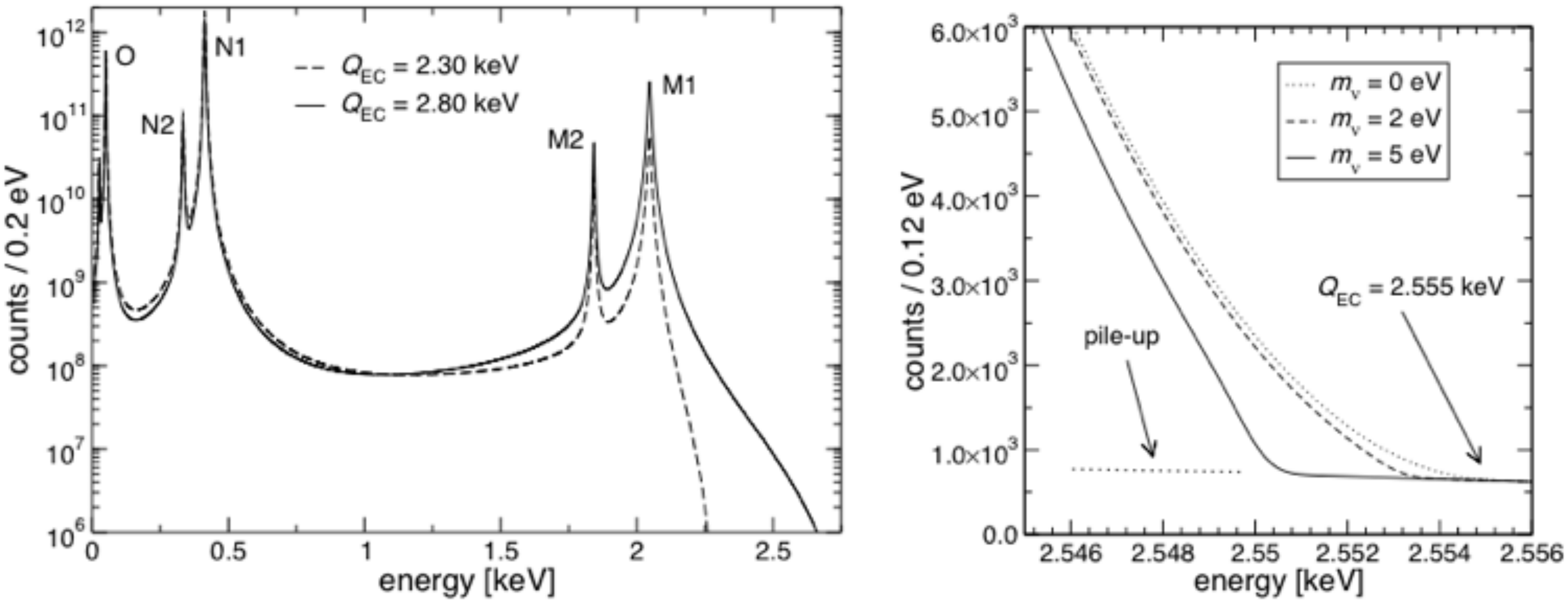
LTD15

Pasadena, California June 24 - 28, 2013

The project HOLMES

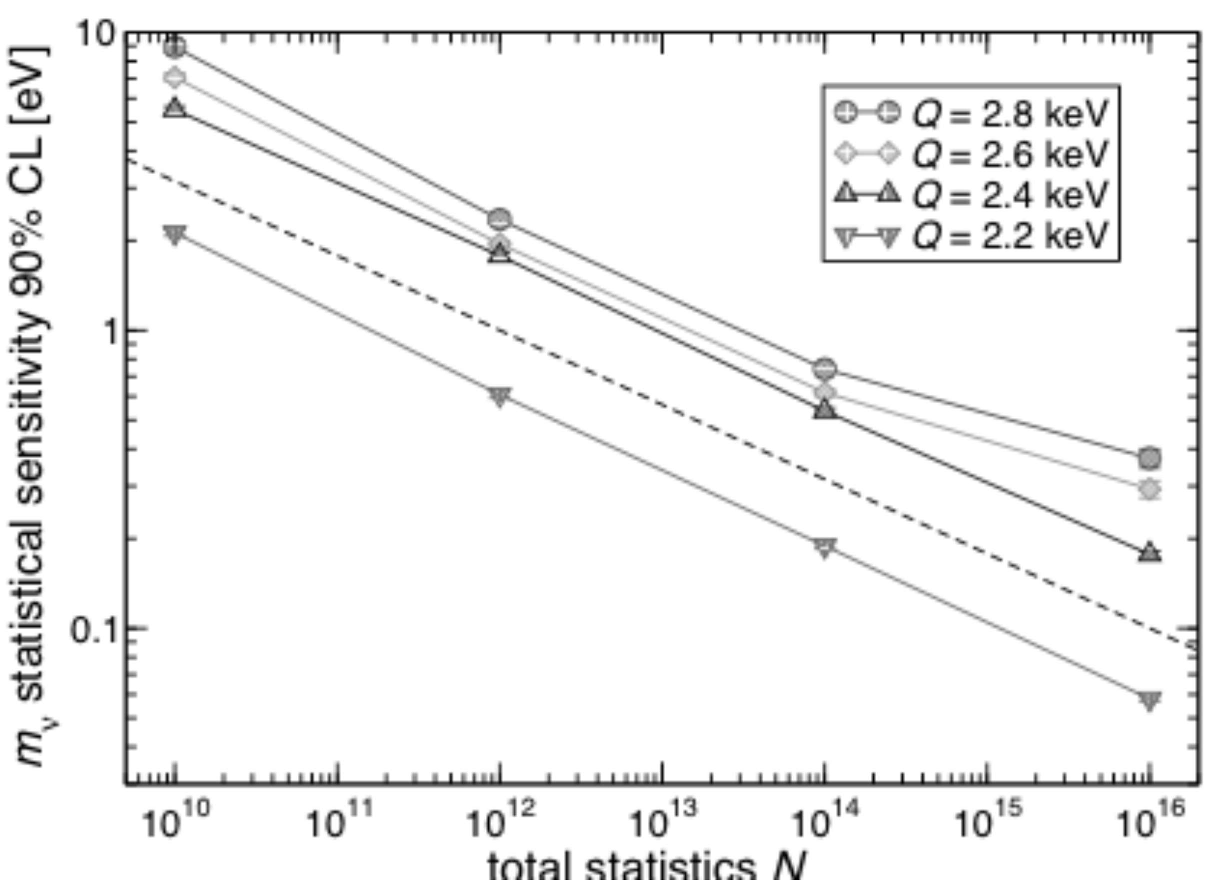
$^{163}Ho + e^- \rightarrow {}^{163}Dy^* + \nu_e$ electron capture decay

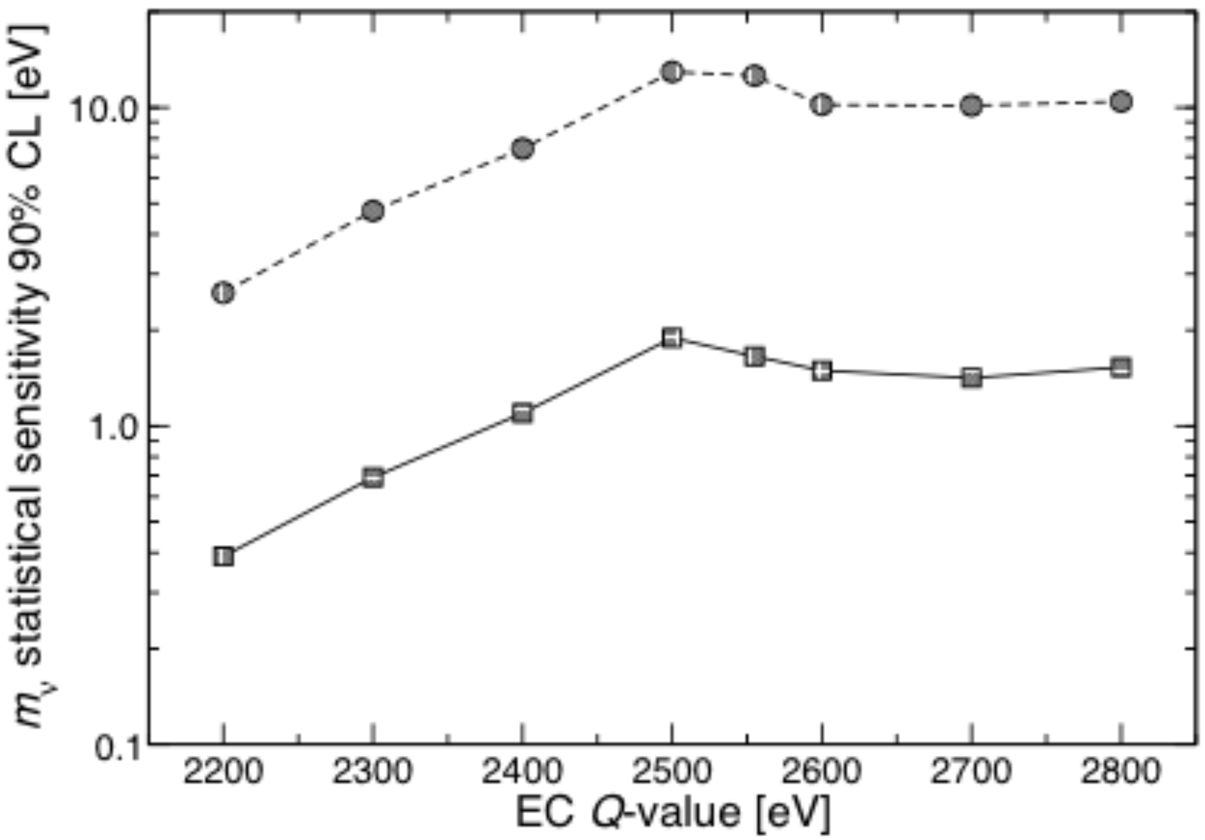
(A. De Rujula and M.Lusignoli, Phys. Lett. 9 (1982)



- First calorimetric measurement of ^{163}Ho endpoint energy: Q = 2.80 ± 0.05 keV (with Ho-oxide embedded in Sn absorber (F. Gatti, et al, Physics Letters B, 1997)

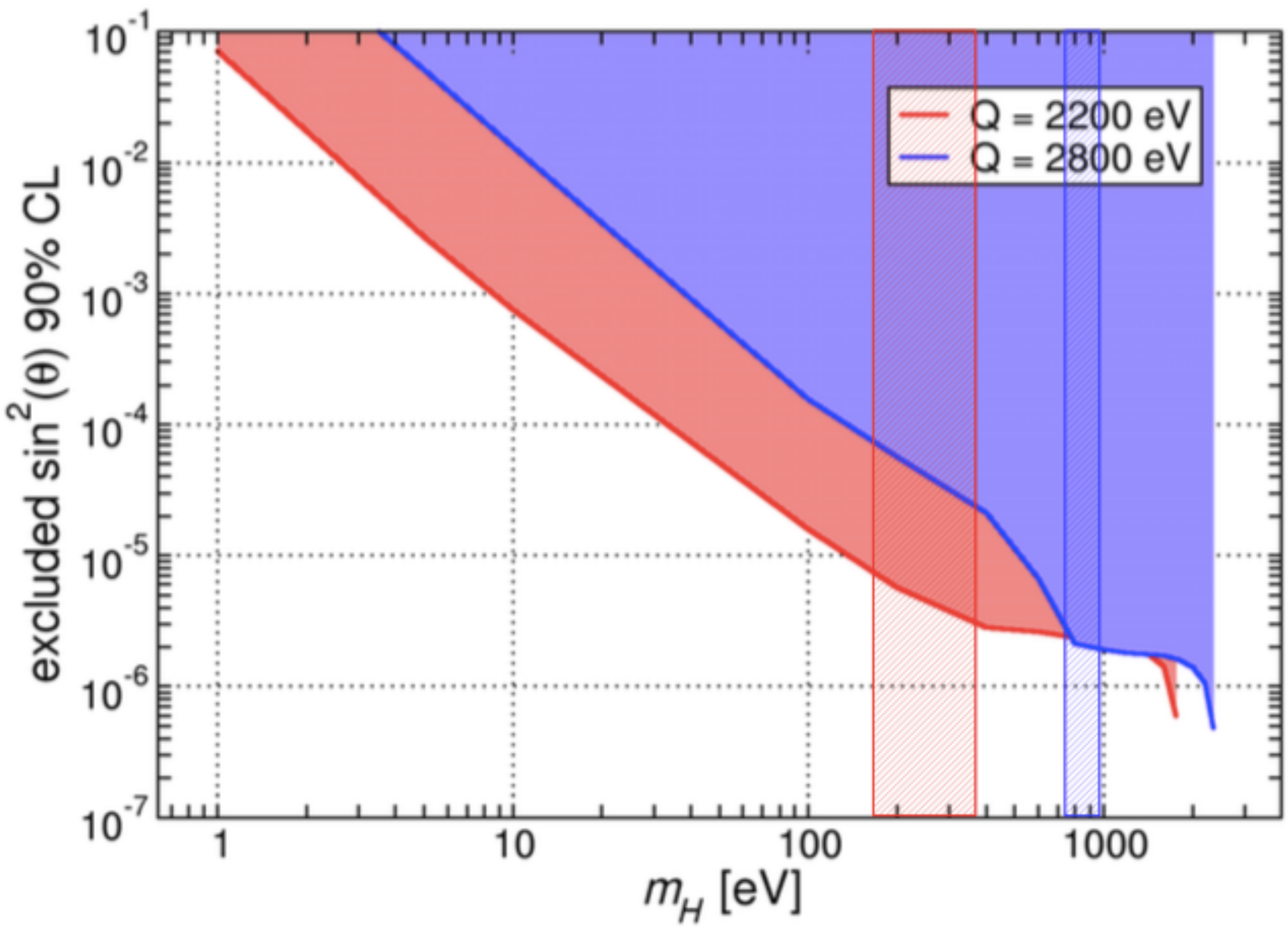
The project HOLMES





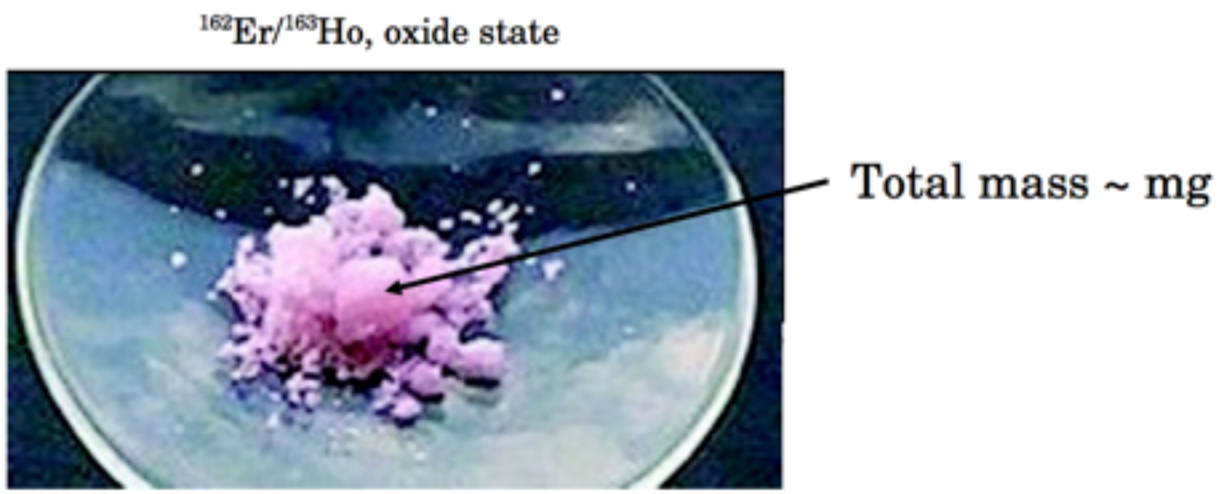
The project HOLMES

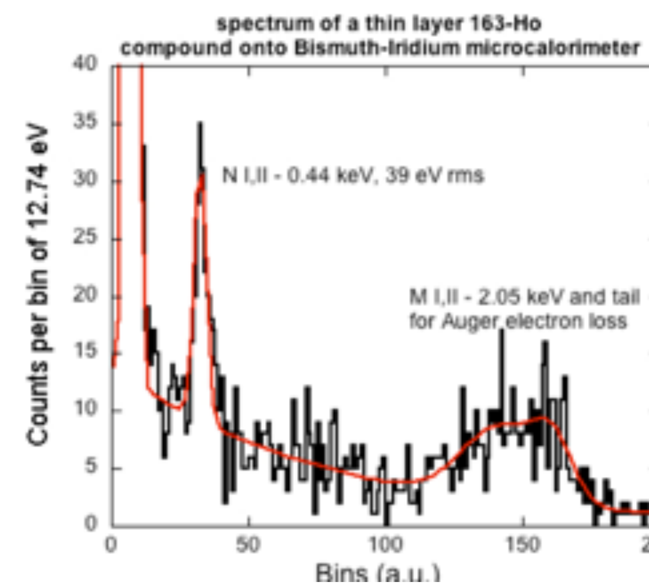
Heavy Neutrino Search in Holmes



The project HOLMES

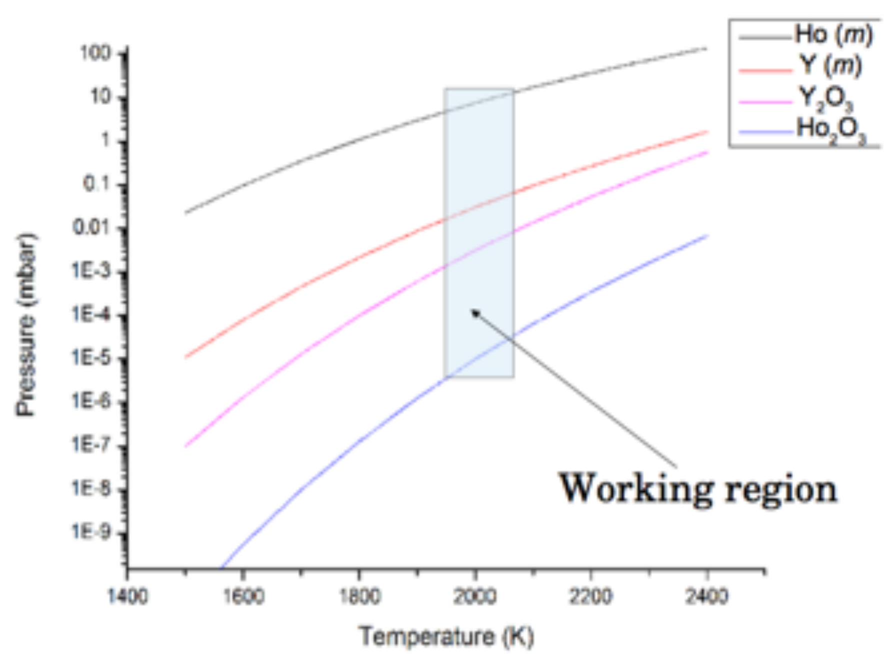
- Presently the production of ^{163}Ho is made with neutron irradiation of ^{162}Er enriched of pure Er oxide sample.
- A first spectrum has been acquired for demonstrating the production capability





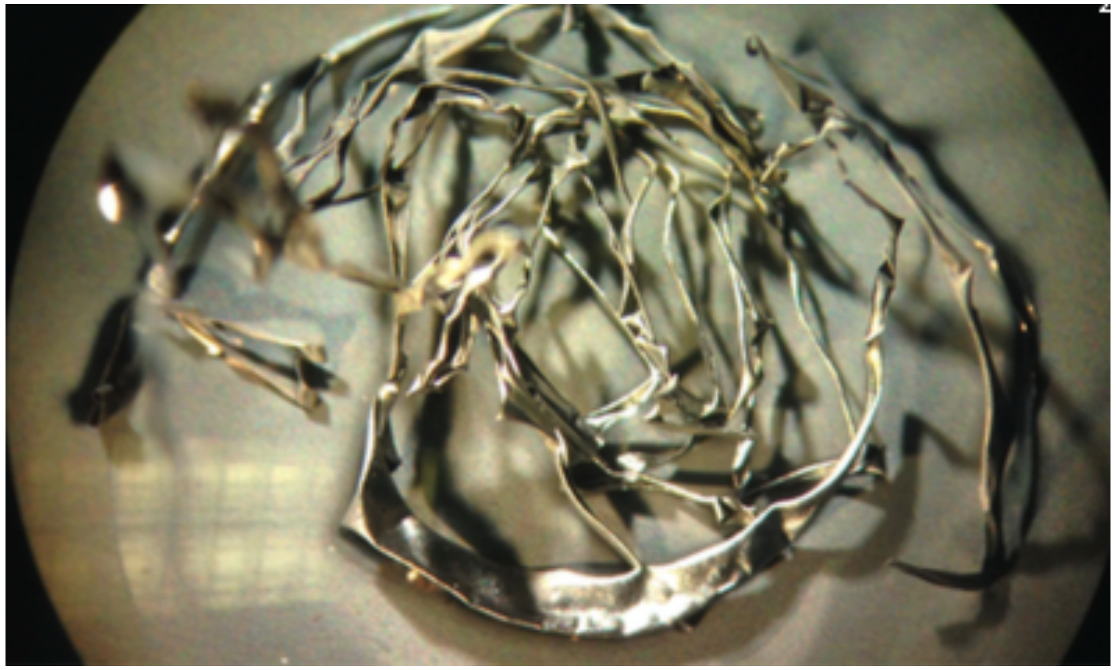
Element	ΔH oxidation (kJ/mol)
$Ho(m) \rightarrow Ho_2O_3$	-1880
$Y(m) \rightarrow Y_2O_3$	-1905

$$Ho_2O_3 + 2Y(m) \longrightarrow 2Ho(m) + Y_2O_3$$



The project HOLMES

- Er oxide enriched in 162 (30-40%) is neutron activated in reactor: the final results is Er-162/Ho-163 in Er matrix. Before embedding in the metal detector a metal Ho should be produced.
- At about 2000 C the Ho metal has a vapour pressure 10^6 times higher than Ho_2O_3 and 10^4 times the Y_2O_3. Finally, because Y oxidise reducing Ho oxide to metal, this distillates from the melted mixture.



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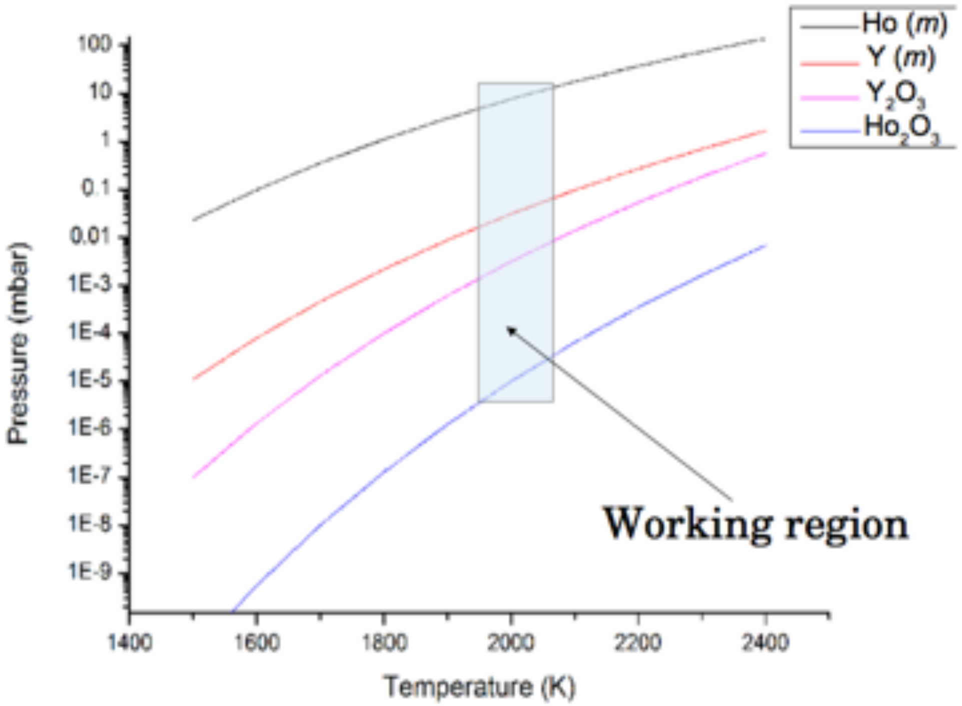
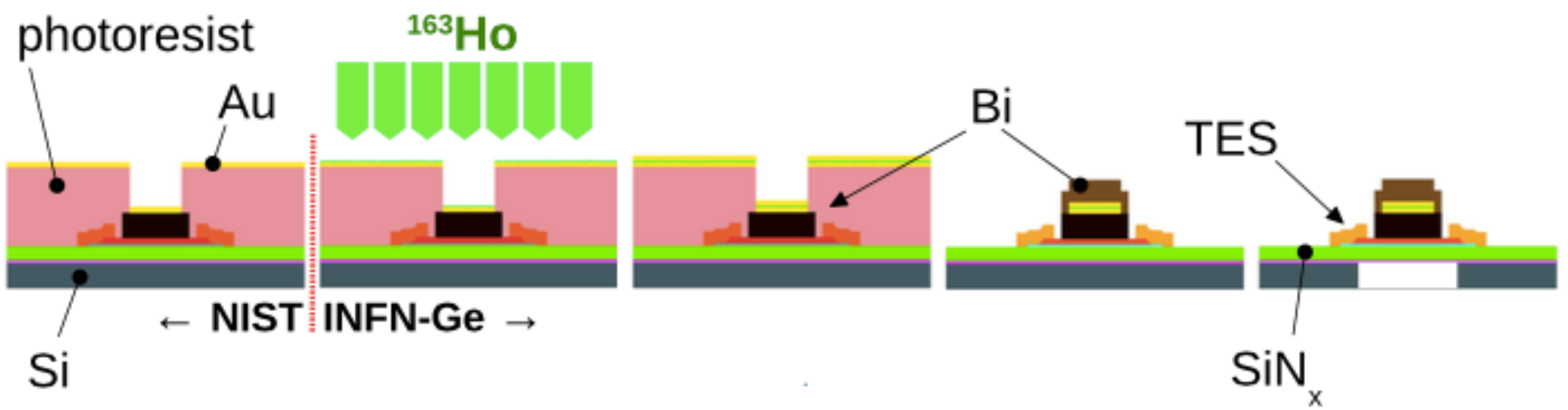
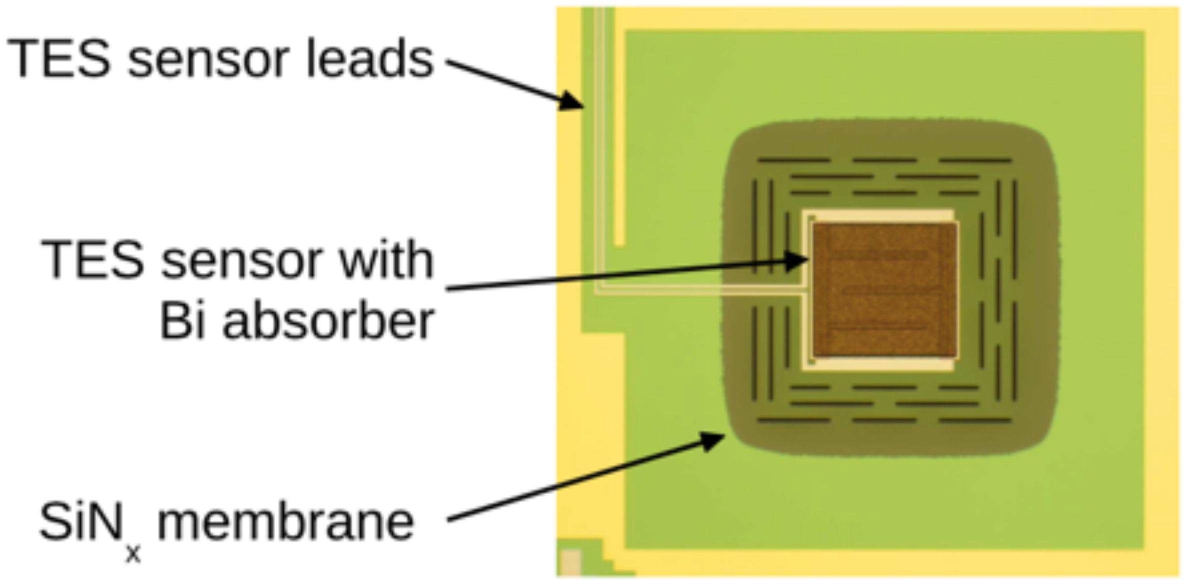


The project HOLMES

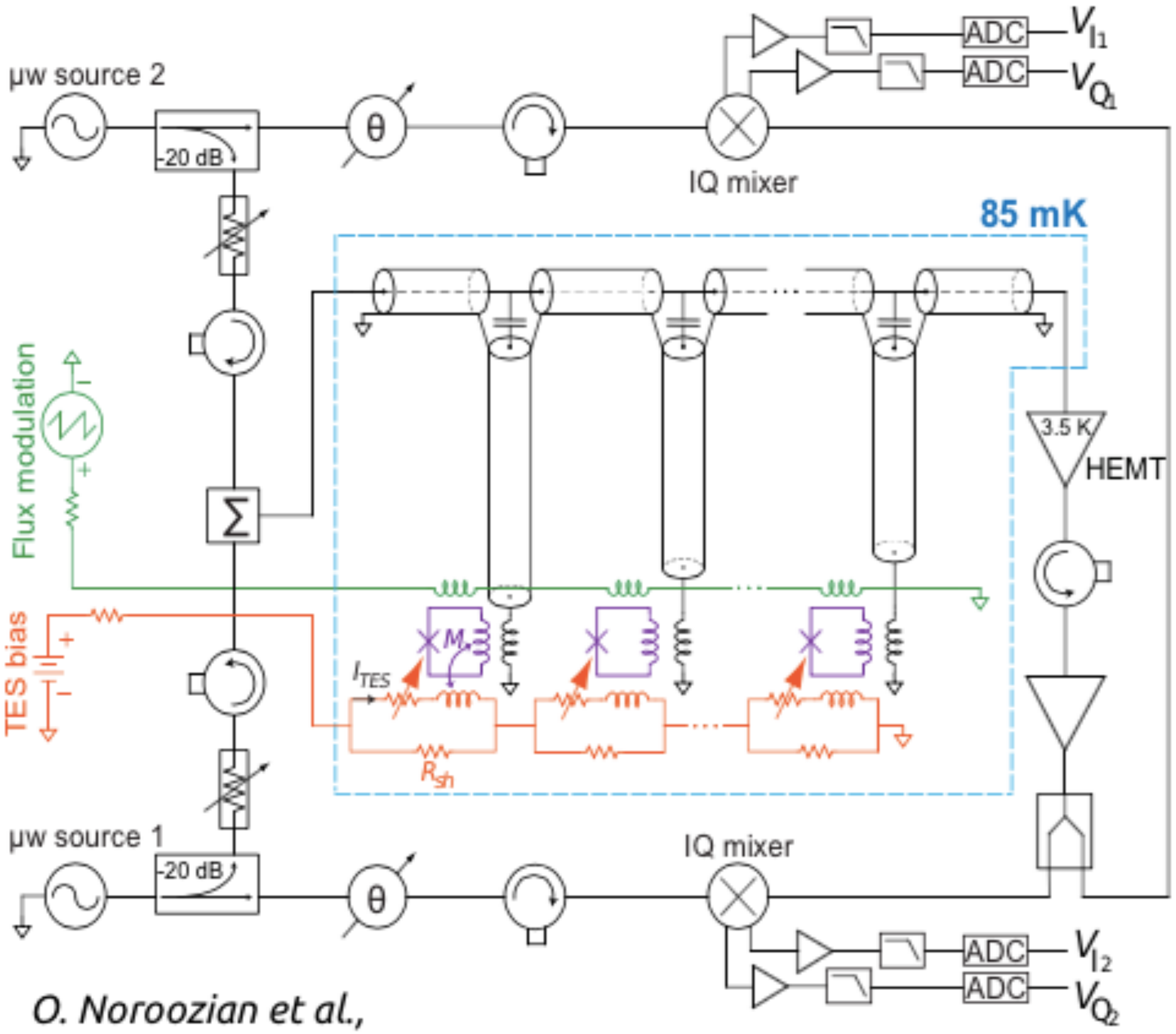
- Ho-163, produced at ILL, purified at PSI, separated magnetically and implanted in detectors a Genova

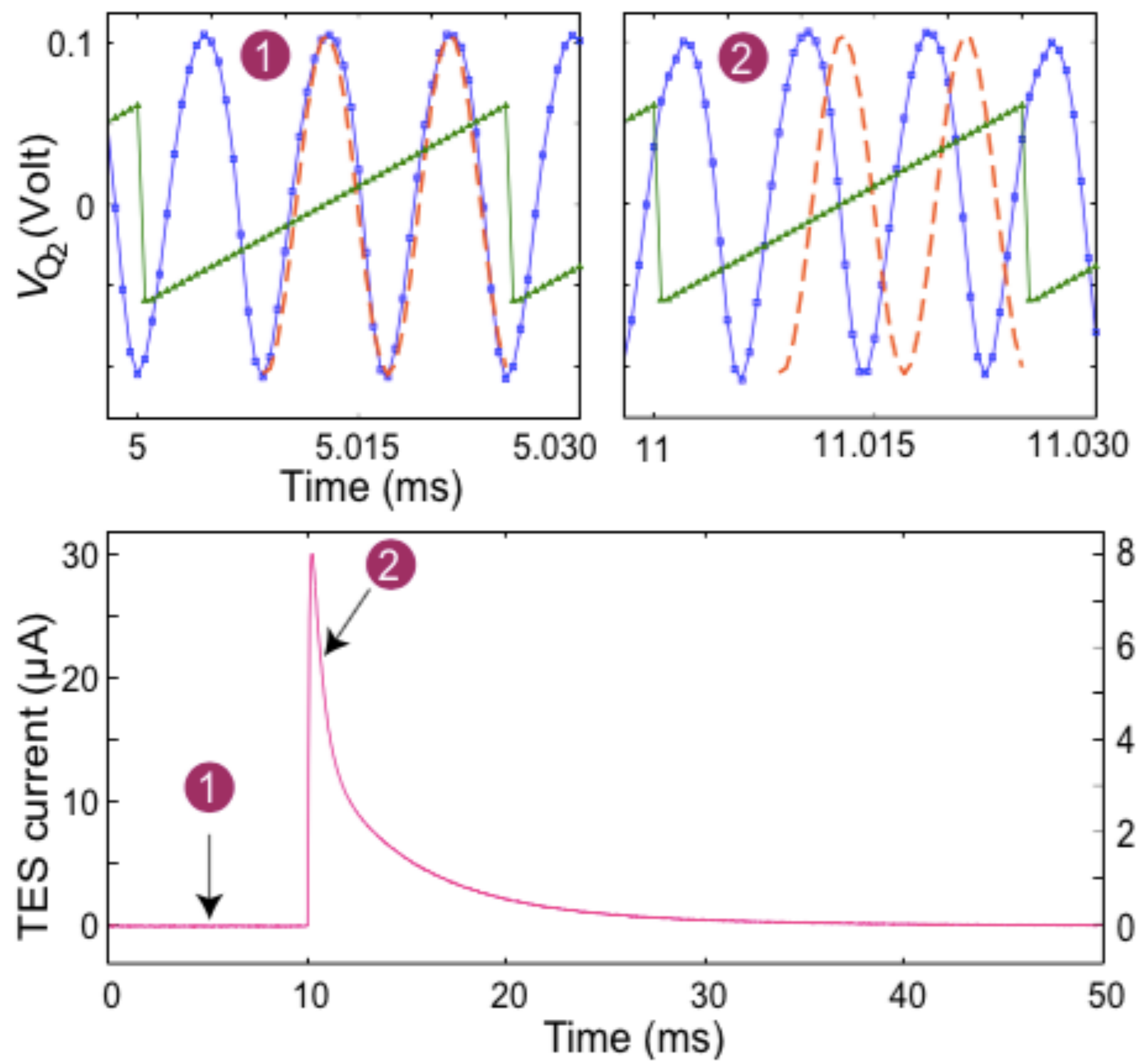




GHz FDM Multiplexing

- Fast rise-time (pile-up detection) → large band per detector
- GHz Frequency Division Multiplexing studied with NIST (Colorado-USA)

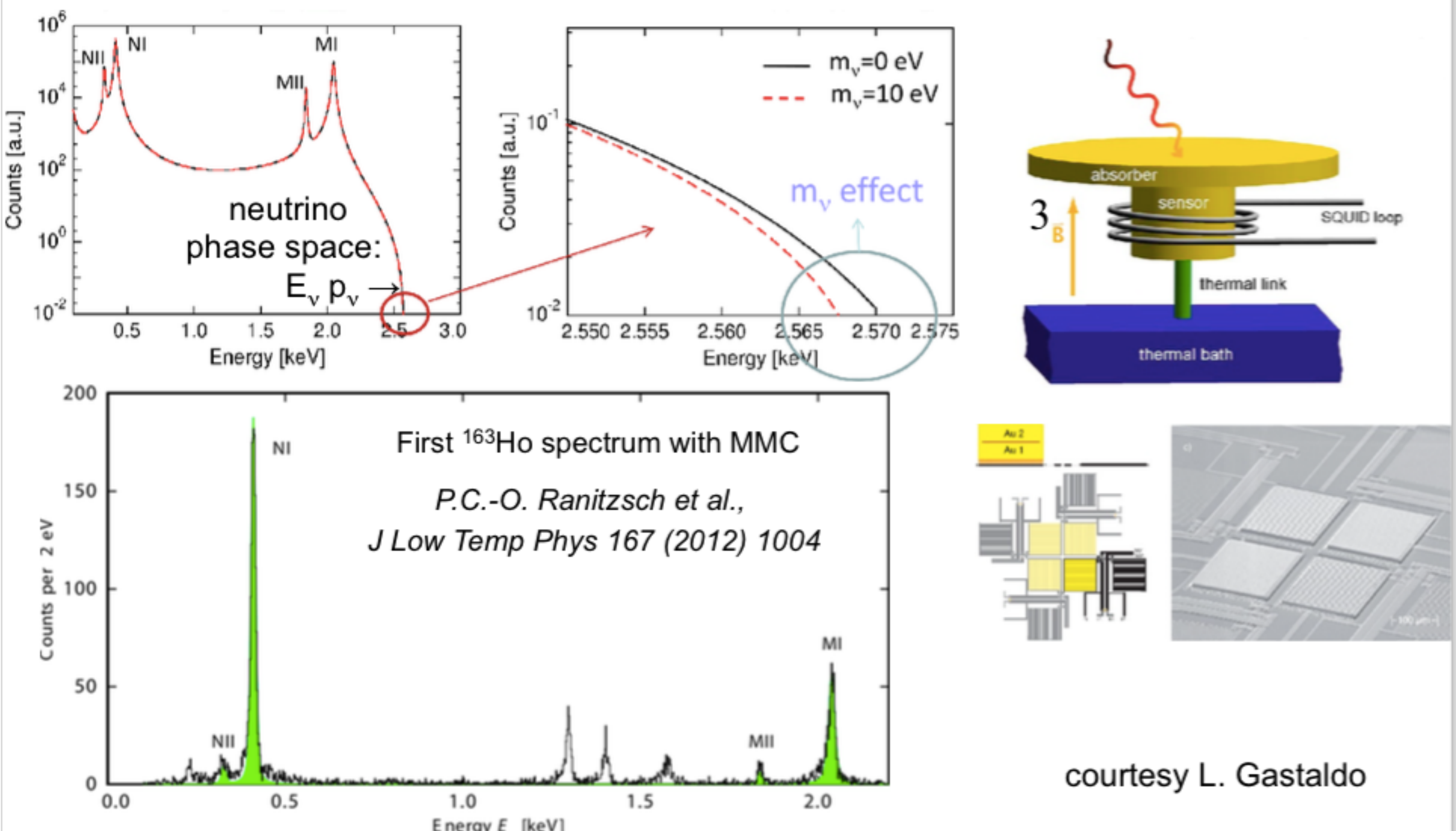




O. Noroozian et al.,
Appl. Phys. Lett. 103, 202602 (2013),
arXiv:1310.7287v1 [physics.ins-det]

ECHo Project (Heidelberg)

$$^{163}Ho + e^- \rightarrow {}^{163}Dy^* + \nu_e \rightarrow {}^{163}Dy + \gamma/e^- + \nu_e$$

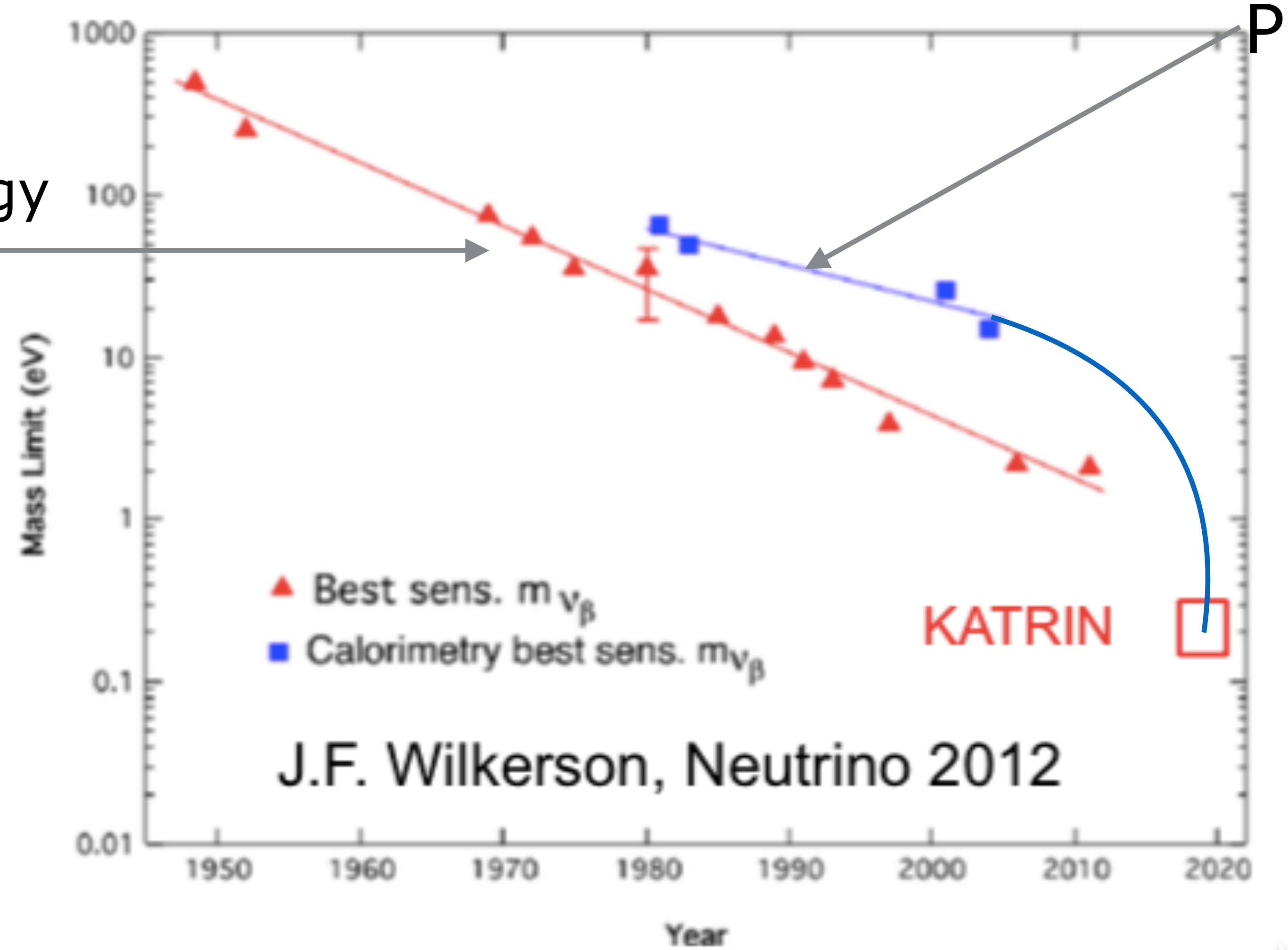


courtesy L. Gastaldo

Conclusions

Proof of Concept

Experiment with established technology



- KATRIN was the only proposal based on proved technology
- MARE was proposed as very ambitious project later after the R&D of MANU and MIbeta projects
- Now HOLMES, ECHo, US-Ho (LANL) point to a realistic goal in the sub eV range
- Project8 is a very promising technique beyond KATRIN