Absolute Scale of the Neutrino Mass and the Search for Neutrinoless Double Beta Decay

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- **Introduction**
- **Search for neutrinoless double beta decay:**
- **Direct neutrino mass search**
- **Some remarks on sterile neutrinos**
- **Conclusions**

Photo: M. Zacher

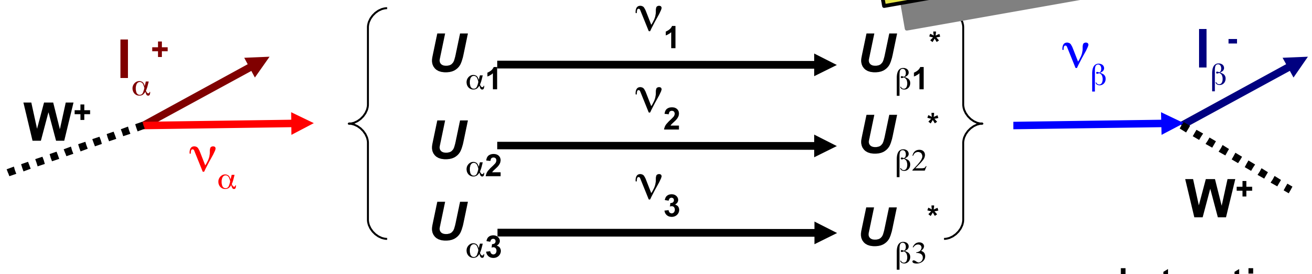
Neutrino (vacuum) oscillations

Incredients: 1) non-trivial ν mixing (matrix *U*, compare V_{CKM}) between flavor states (ν_e ν_μ ν_τ) and mass states (ν_1, ν_2, ν_3):

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

2) $m(\nu_i)$ differ ⇒ at least one $m(\nu_i)$0

Double (triple) slit experiment



creation of a ν_α via weak interaction

propagation as coherent superposition of mass states

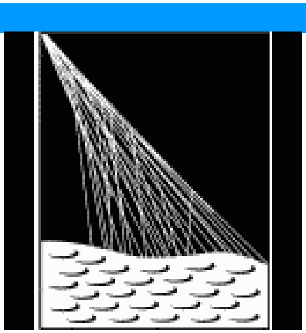
detection of a ν_β via weak interaction

$$P(\nu_\alpha \rightarrow \nu_\beta) = \left| \sum_i U_{\alpha i}\, e^{-iE_i t}\, U_{\beta i}^* \right|^2 = \underbrace{\sin^2(2\theta) \cdot \sin^2 \frac{|m_2^2 - m_1^2| \cdot L}{4E}}_{\text{2 flavor mixing}}$$

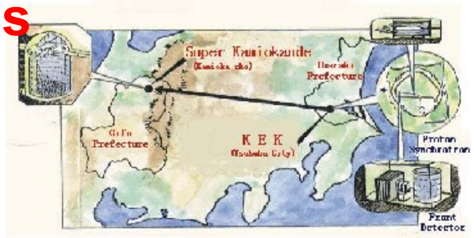
.Formula is correct,
but correct derivation
needs QFT
(Guinti, Lindner et al.)
with matter: Smirnov et al

Positive results from ν oscillation experiments

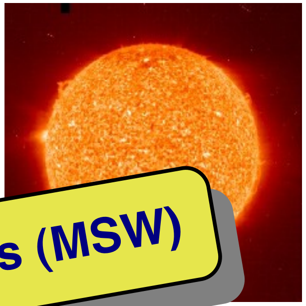
atmospheric neutrinos
(Kamiokande,
Super-Kamiokande, ...)



accelerator neutrinos
(K2K, T2K, MINOS,
OPERA, MiniBoone)

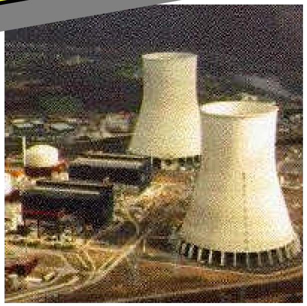


solar neutrinos
(Homestake, Gallex,
Sage, Super-Kamiokande
SNO, Borexino)



Matter effects (MSW)

reactor neutrinos
(KamLAND, CHOOZ, ...)



⇒ non-trivial ν-mixing

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}U_{e1} & U_{e2} & U_{e3}\\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3}\\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3}\end{pmatrix}\cdot\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

with:

$\sin^2(2\theta_{13}) < 0.15$ (90% CL) $\neq 0$?

$\sin^2(2\theta_{12}) = 0.87 \pm 0.03$ large !

$\sin^2(2\theta_{23}) > 0.92$ (99.7% CL) max !

$7.39\ 10^{-5}\ \text{eV}^2 < \Delta m_{12}^2 < 7.79\ 10^{-5}\ \text{eV}^2$

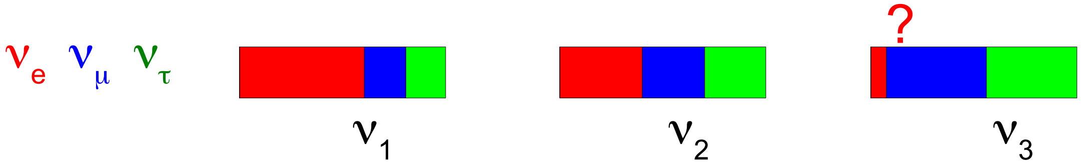
$2.30\ 10^{-3}\ \text{eV}^2 < |\Delta m_{23}^2| < 2.56\ 10^{-3}\ \text{eV}^2$

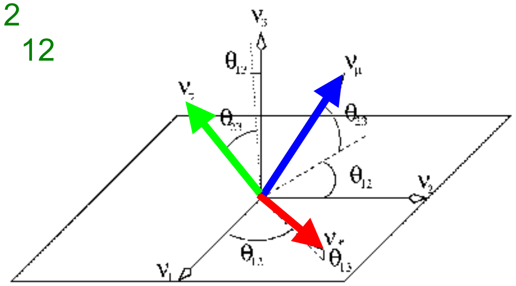
⇒ $m(\nu_j) \neq 0$, but unknown !

up to now: description by
2-flavour oscillation sufficient

Need for the absolute ν mass determination

Results of recent oscillation experiments: Θ_{23}, Θ_{12}, Δm^2_{23}, Δm^2_{12}





degenerated masses

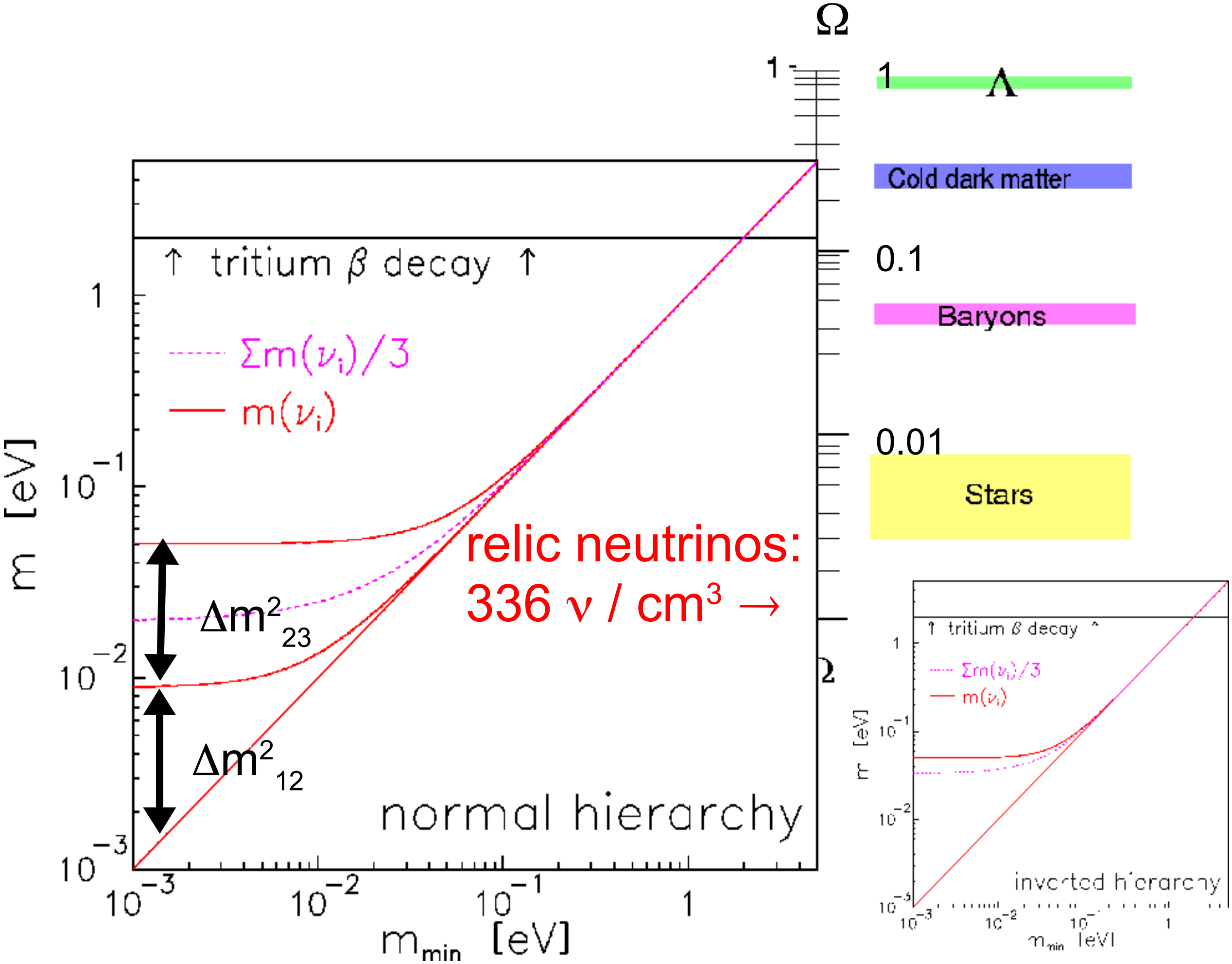
cosmological relevant

e.g. seesaw mechanism type 2

hierarchical masses

e.g. seesaw mechanism type 1

explains smallness of masses, but not large (maximal) mixing



relic neutrinos: 336 ν / cm^3 →

Three complementary ways to the absolute neutrino mass scale

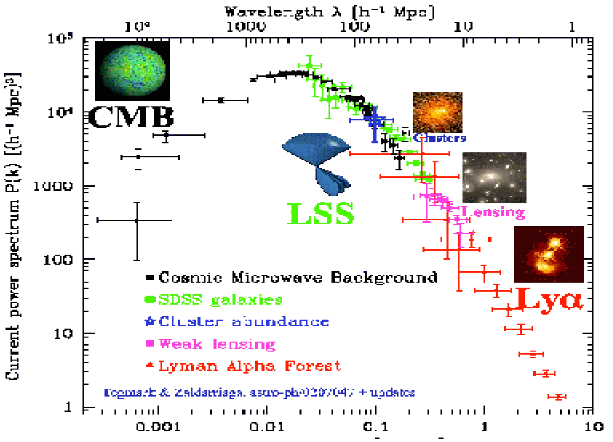
1) Cosmology

very sensitive, but model dependent

compares power at different scales

current sensitivity: $\Sigma m(\nu_i) \approx 0.5$ eV

e.g. S. Hannestad, Prog.Part.Nucl.Phys.65 (2010) 185

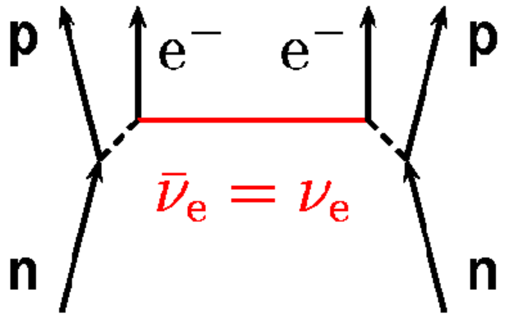


2) Search for 0νββ

Sensitive to Majorana neutrinos

Evidence for $m_{ee}(\nu) \approx 0.4$ eV ?

GERDA commissioned !

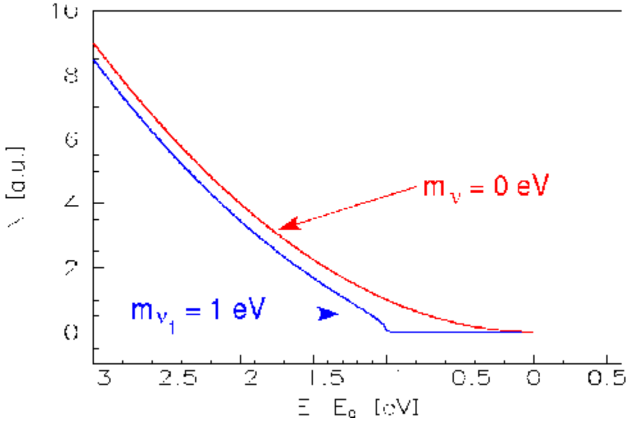


3) Direct neutrino mass determination:

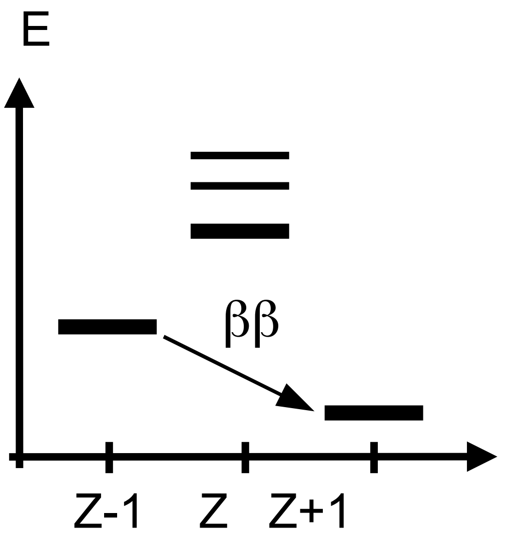
No further assumptions needed. no model dependence

use $E^2 = p^2c^2 + m^2c^4 \Rightarrow m^2(\nu)$ is observable mostly

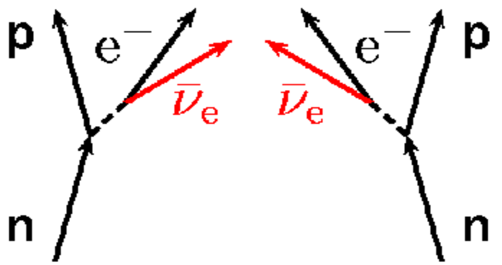
most sensitive methode: endpoint spectrum of β-decay



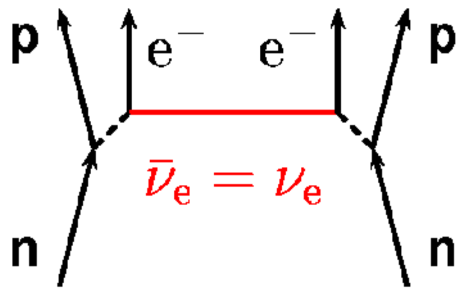
Double β decay



normal (2νββ)



neutrinoless (0νββ)

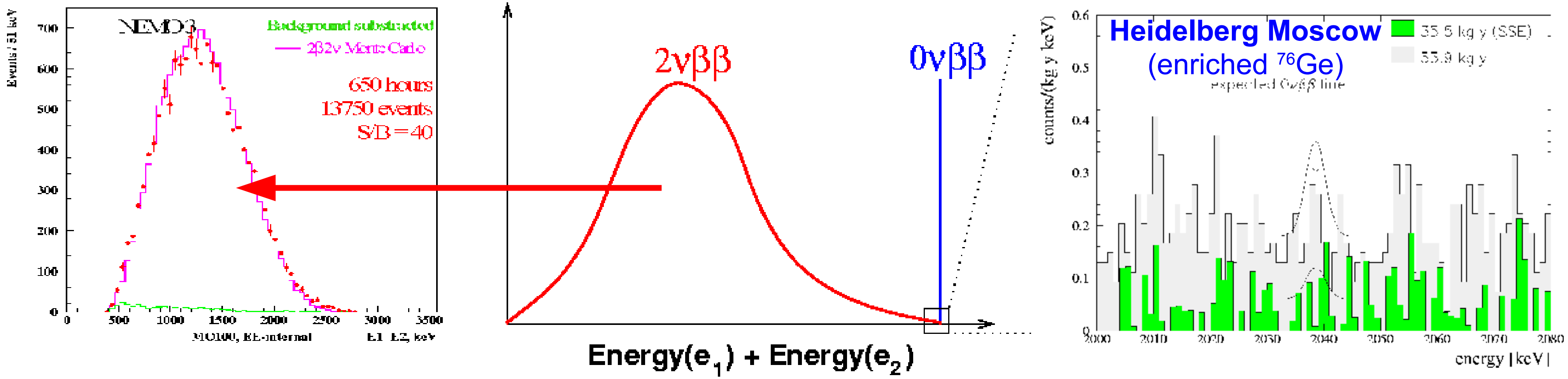


needed: a) $\bar{\nu} = \nu$ (Majorana)

b) helicity flip: $m(\nu) \neq 0$

or other new physics

$m_{\beta\beta}(\nu) = | \Sigma |U_{ei}{}^2| e^{i\alpha(i)} m(\nu_i)|$ (coherent)



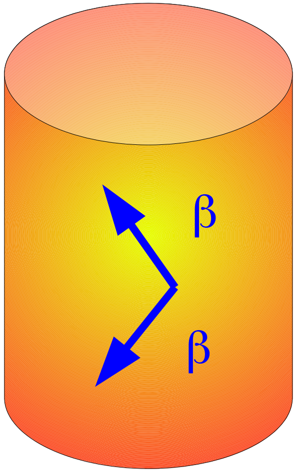
Current and future double β decay experiments

$m_{ee} \sim (1/\text{enrichment})^{1/2} \cdot (\Delta E \cdot bg/M \cdot t)^{1/4}$

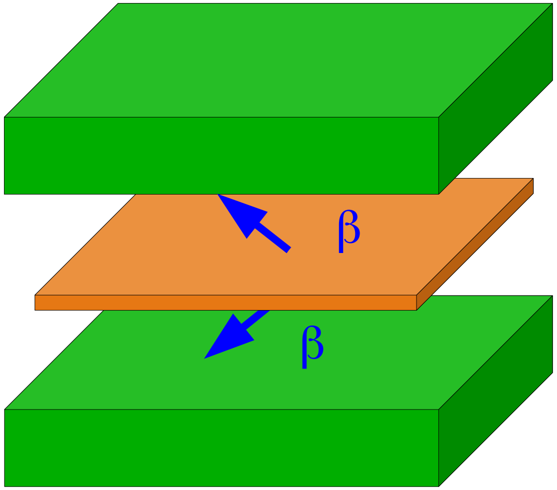
⇒ mass → 1t, high enrichment, very low background *bg*

2 ways to measure both β-electrons:

semiconductor,
cryogenic bolometer
liquid scintillator



tracking calorimeter

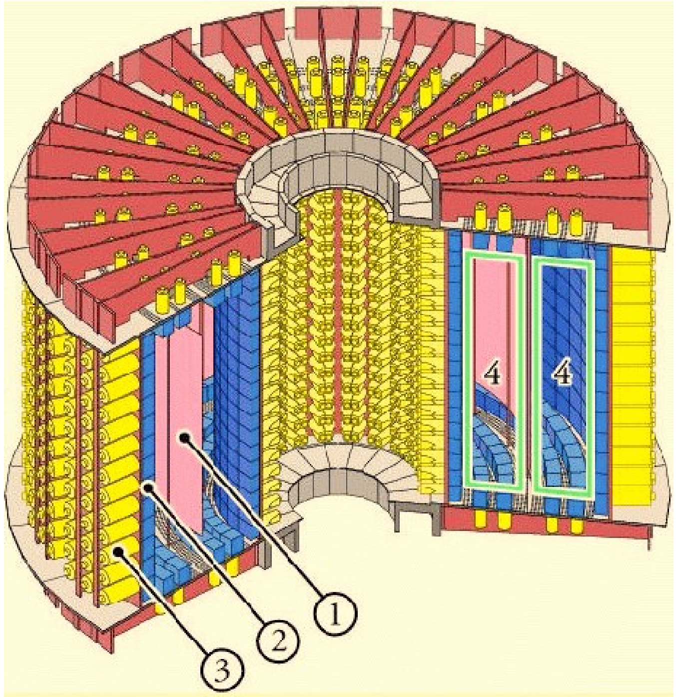


running: GERDA
setting up: CUORE, EXO-200, SNO+
planned: Majorana, KamLAND-Zen, COBRA, Luzifer

just finished (Jan 11): NEMO-3
setting up: SuperNEMO
planned: MOON

Searching for $0\nu\beta\beta$: NEMO3 → SuperNEMO

NEMO3: tracking calorimeter
with several isotopes
(finished Jan 2011)

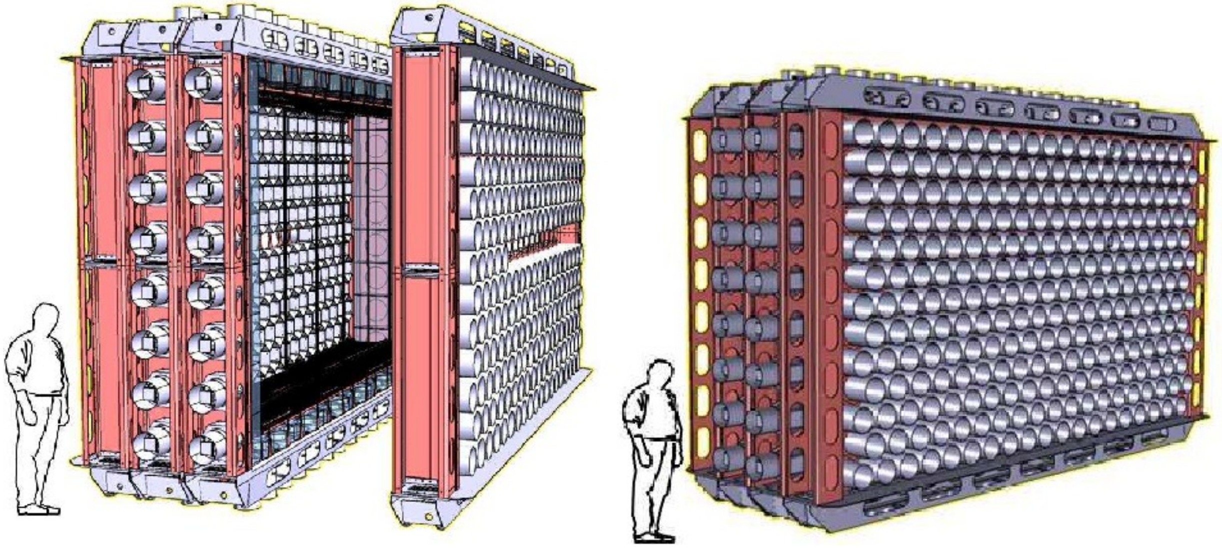


^{100}Mo: $T_{1/2}$ $(0\nu\beta\beta) > 1.1 \times 10^{24}$ y

$\Rightarrow m_{ee} < (0.45 – 0.93)$ eV

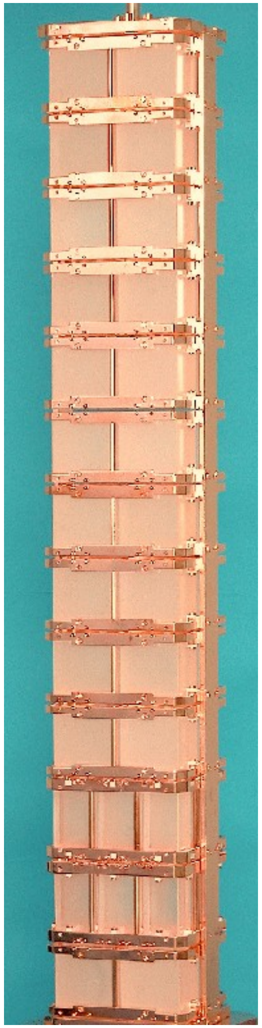
F Mauger, TAUP09

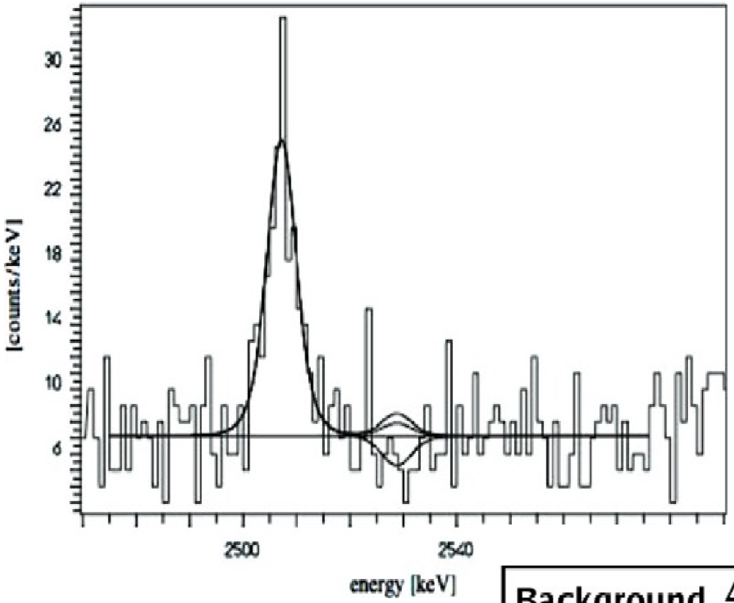
SuperNEMO:
tracking calorimeter modules
enriched ^{82}Se, ^{150}Nd



expect sensitivity: $T_{1/2}$ $(0\nu\beta\beta) > 10^{26}$

Searching for $0\nu\beta\beta$: TeO_2 cryobolometers: CUORICINO → CUORE





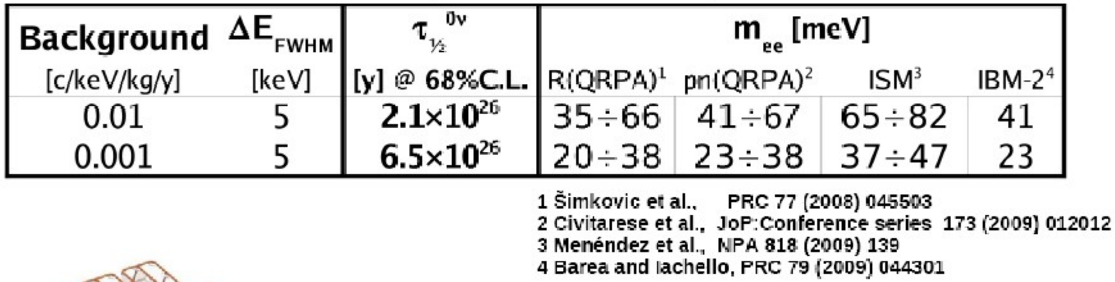
CUORICINO:

^{130}Te: $T_{1/2} > 3 \cdot 10^{24}$ y

$\Rightarrow m_{ee} < 0.19 – 0.68$ eV

PRC 78 (2008) 35502

In 5 years of live running time



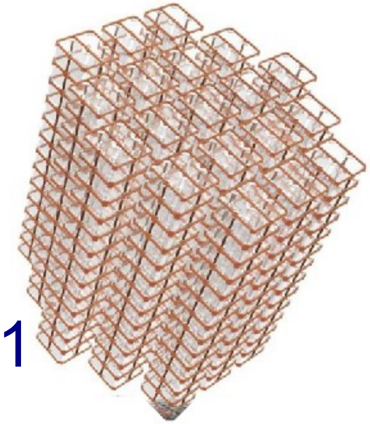
Background	ΔE_{FWHM}	$\tau^{0\nu}_{½}$	m_{ee} [meV]			
[c/keV/kg/y]	[keV]	[y] @ 68%C.L.	R(QRPA)^1	pn(QRPA)^2	ISM^3	IBM-2^4
0.01	5	**2.1×10^{26}**	35÷66	41÷67	65÷82	41
0.001	5	**6.5×10^{26}**	20÷38	23÷38	37÷47	23

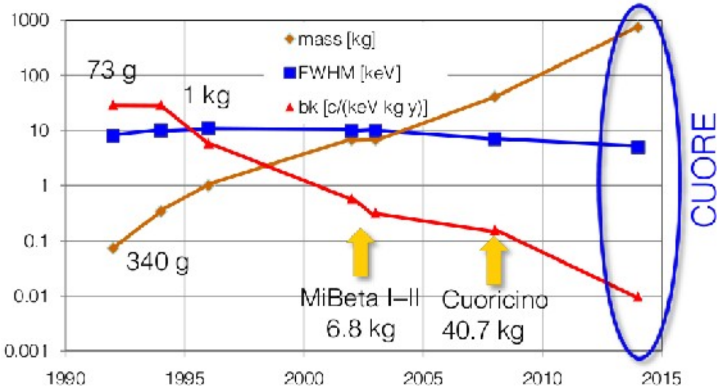
1 Šimkovic et al., PRC 77 (2008) 045503
2 Civitarese et al., JoP:Conference series 173 (2009) 012012
3 Menéndez et al., NPA 818 (2009) 139
4 Barea and Iachello, PRC 79 (2009) 044301

starting:

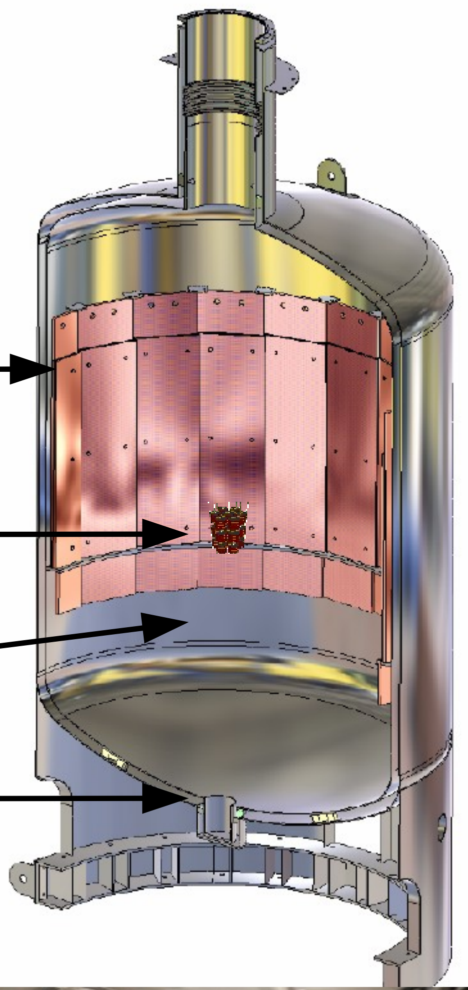
CUORE: 741 kg TeO_2

CUORE-0 will start in 2011





The GERDA experiment



inner copper shield

enriched ^{76}Ge detector array

liquid argon

stainless steel cryostat

New background reduction methods:

- naked Germanium detectors in noble liquid
- phase 2: point contact detectors p-type (BEGe) to identify multi-side events
- maybe use scintillation of LAr shield as veto

Phases of GERDA:

Phase 1: reuse old det. (Hd-Moscow, IGEX (18 kg)

1st test string with 3 non-enriched detectors
problem $^{42}Ar \rightarrow {}^{42}K \rightarrow {}^{42}Ca$, seems to be solved

since June 2011: test string with 3 enriched det.
all enriched detectors will come after summer

Phase 2: new enriched BEGe detectors (+18 kg)
delivery in 2012 expected

Opt. phase: many detectors (with MAJORANA, 500 kg)

GERDA inauguration

© Jan Hattenbach

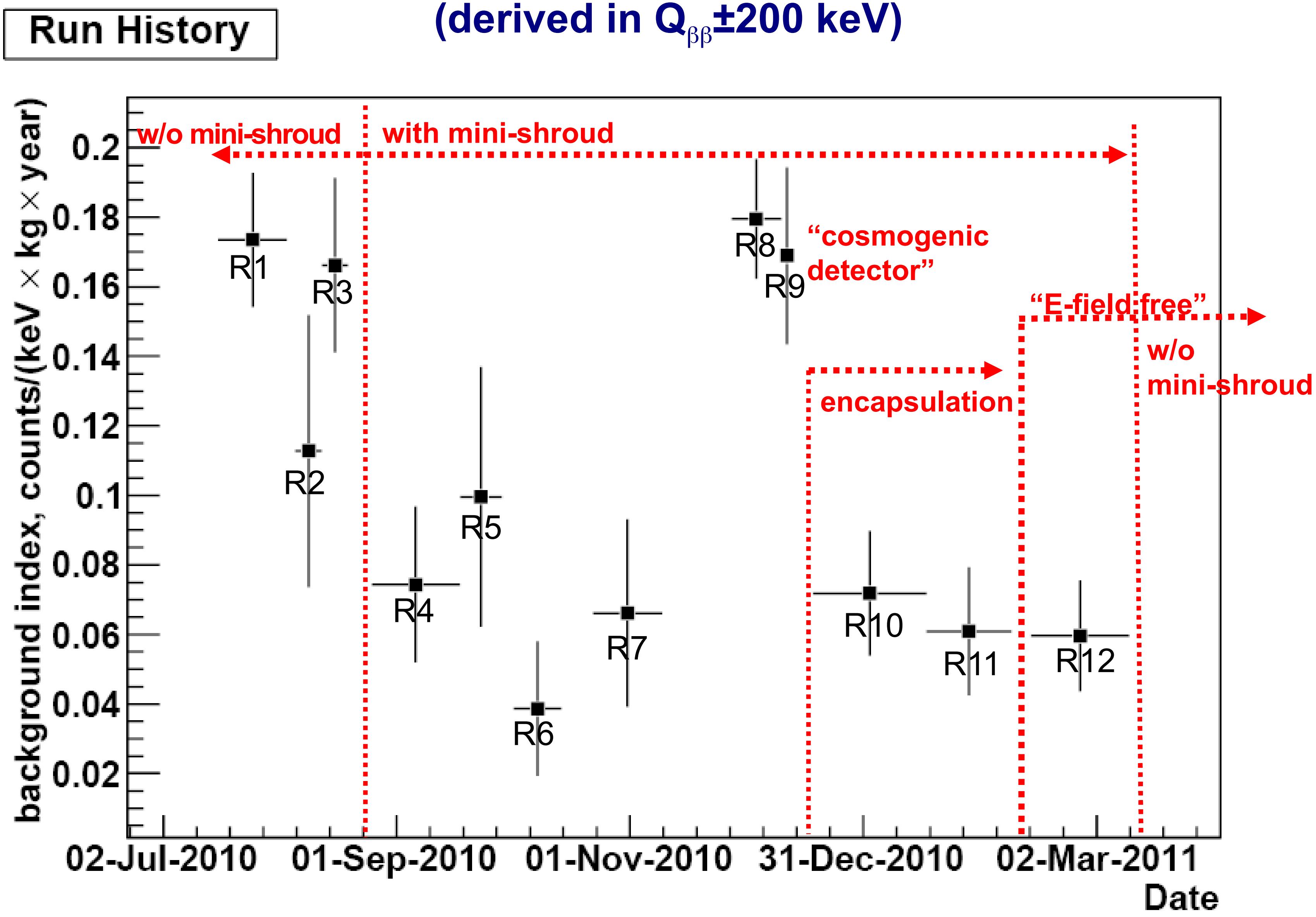
Inauguration of the GERDA experiment at the LNGS
9. November 2010

- **Nov/Dec.’09**: Liquid argon fill
- **Jan ’10:** Commissioning of cryogenic system
- **Apr/Mai ’10:** emergency drainage tests of water tank
- **Apr/Mai ’10:** Installation c-lock
- **May ’10:** 1st deployment of FE&detector mock-up (27 pF) - pulser resolution 1.4 keV (FWHM); first deployment of non-enriched detector
- **June ‘10:** Start of commissioning run with ^{nat}Ge detector string
- **Soon**: start of Phase I physics data taking

Summary of GERDA commissioning runs with non-enriched detectors

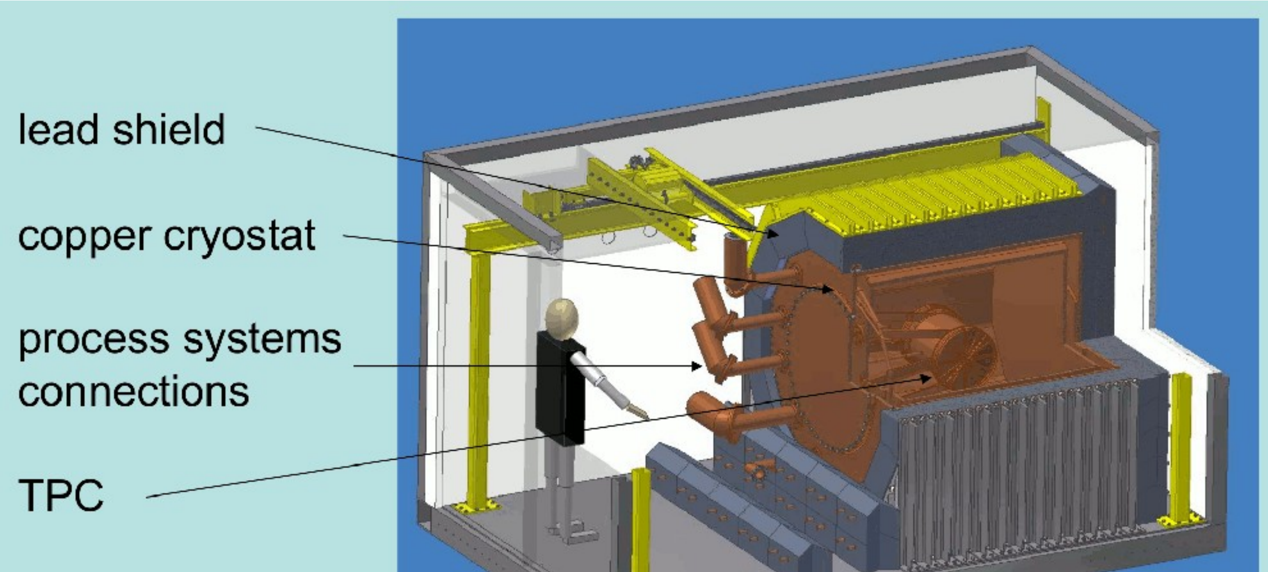
background indices for different operational conditions

(derived in $Q_{\beta\beta}\pm200$ keV)



Under Commissioning: EXO 200:

200 kg enriched ^{136}Xe at WIPP/New Mexico

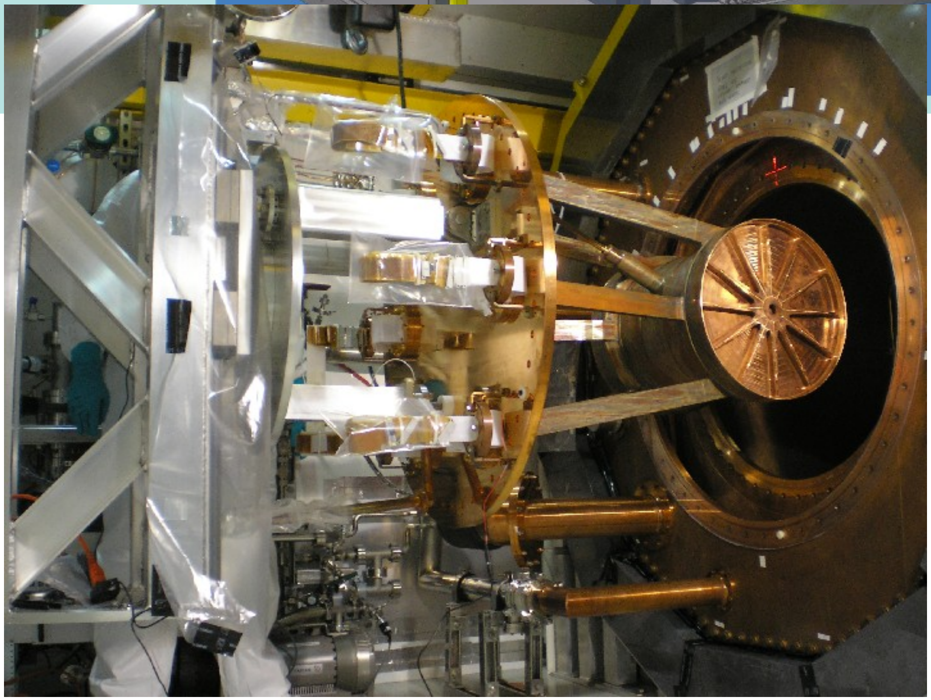


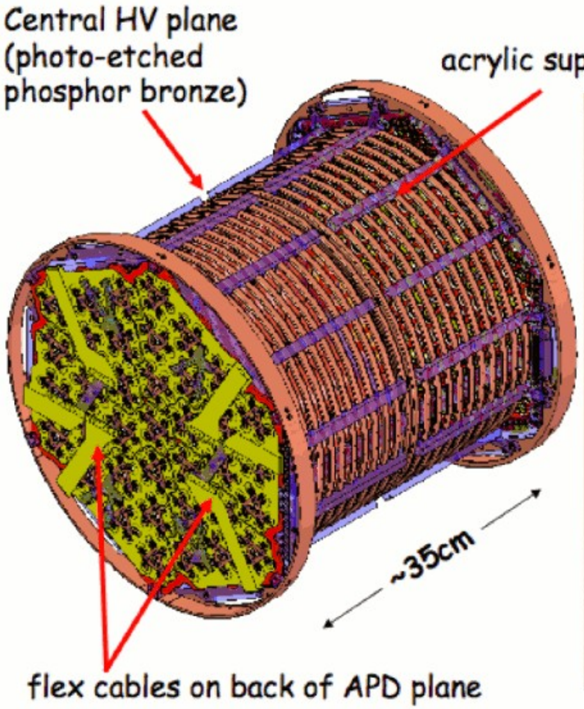
lead shield

copper cryostat

process systems connections

TPC



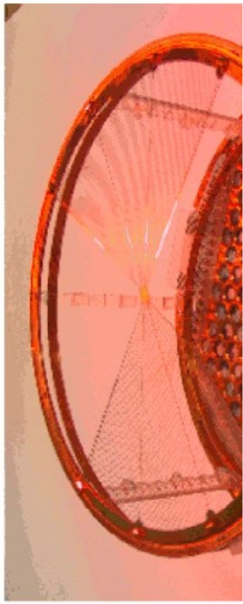


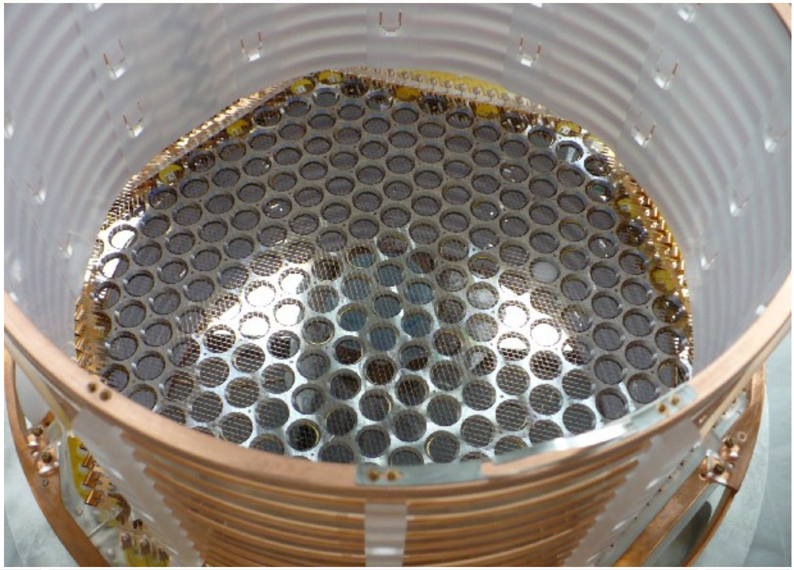
Central HV plane (photo-etched phosphor bronze)

acrylic supports

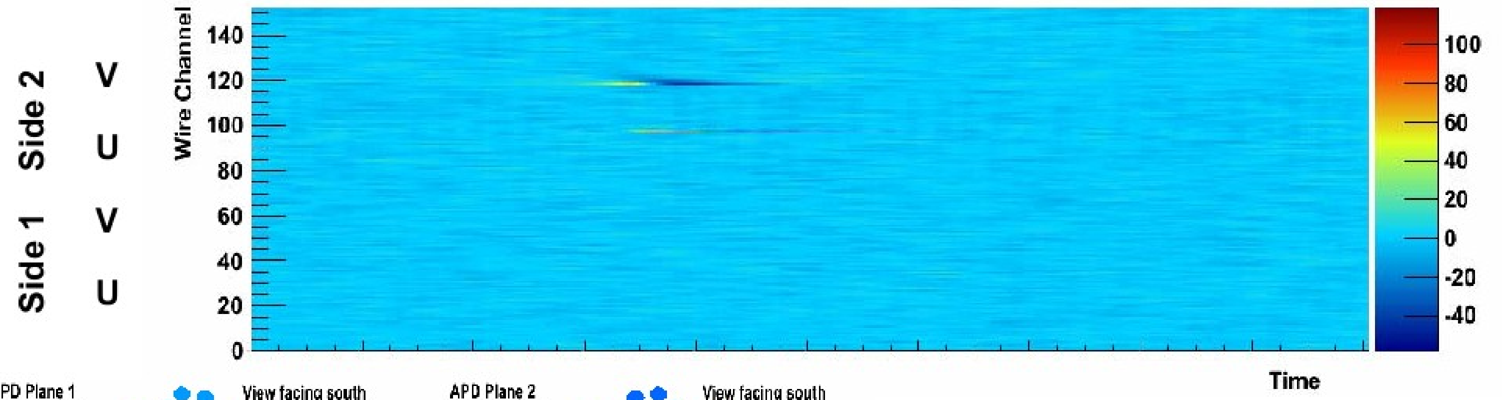
~35cm

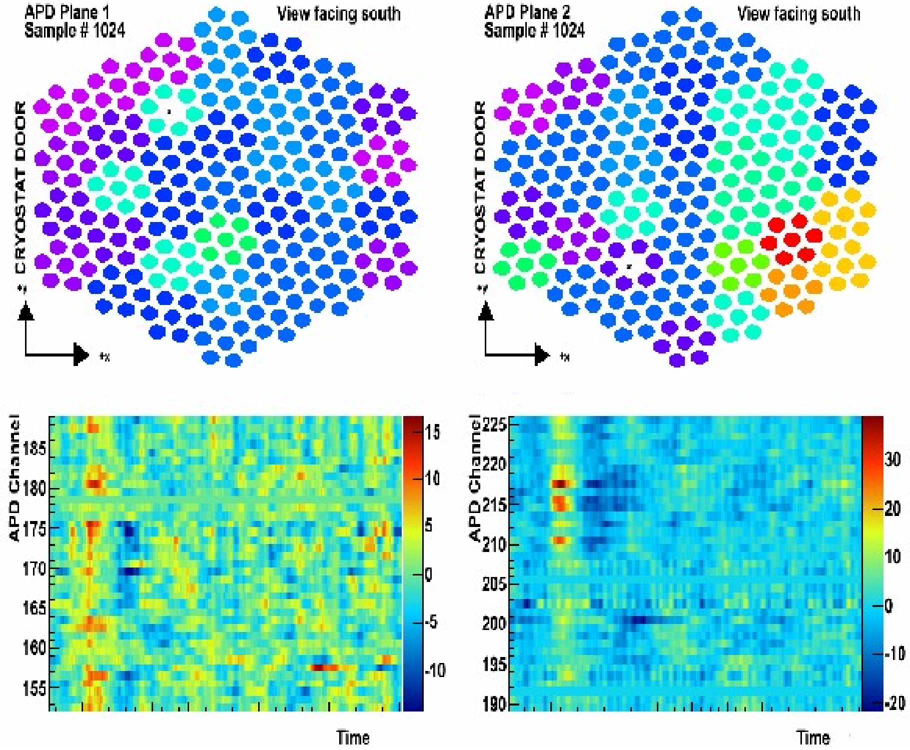
flex cables on back of APD plane





Under Commissioning: EXO 200





A single-site energy deposition in EXO-200.

Top display is charge readout (V are induction wires and U are collection wires)

Left display is light readout. APD map Refers to the sample with max signal.

Scintillation light is seen from both sides, although more intense and localized on side 2, where the event occurred.

Small depositions produce induction signals on more than one V wires but are collected by a single U wire.
V signal always comes before U.

Light signals precede in time the charge ones

Futher experiments under R&D and commissioning: Majorana, KamLAND-Zen, Lucifer, SNO+, Cobra

Direct determination of $m(\nu_e)$ from β decay

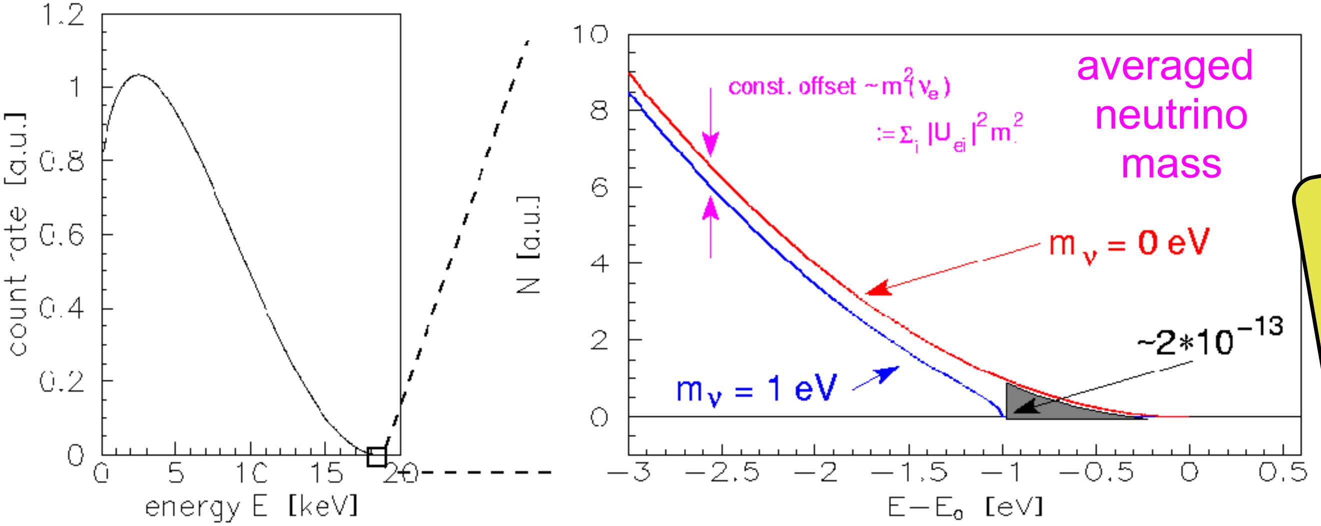
β decay: $(A,Z) \rightarrow (A,Z+1)^{+} + \boxed{e^{-}} + \bar{\nu}_e$

$$m^2(\nu_e) = \Sigma\,|U_{ei}^2|\, m^2(\nu_i)$$
(incoherent)

β electron energy spectrum:

$$dN/dE = K\ F(E,Z)\ p\ E_{tot}\ (E_0-E_e)\ \Sigma\,|U_{ei}|^2\ \sqrt{(E_0-E_e)^2 - m(\nu_i)^2}$$

(modified by electronic final states, recoil corrections, radiative corrections)

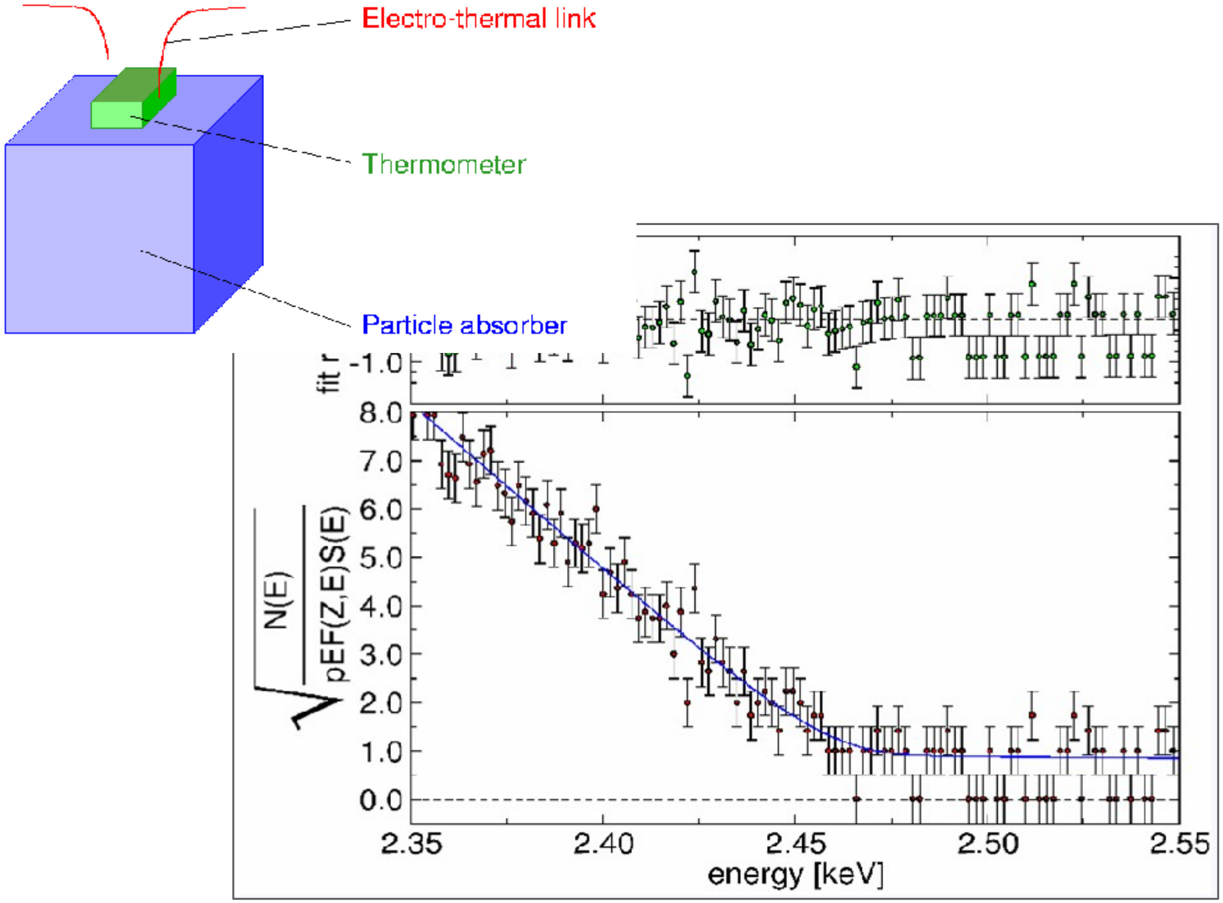


E.W. Otten & C. Weinheimer
Rep. Prog. Phys.
71 (2008) 086201

Need: **low endpoint energy** ⇒ **Tritium ^{3}H, (^{187}Re)**

very high energy resolution &
very high luminosity &
very low background
} ⇒ **MAC-E-Filter**
(or bolometer for ^{187}Re)

Cryogenic bolometers with ^{187}Re MIBETA (Milano/Como)



Parameters

detectors:	10 ($AgReO_4$)
rate each:	0.13 1/s
energy res.:	ΔE = 28 eV
pile-up frac.:	1.7 10^{-4}

$M_\nu^2 = -141 \pm 211_{stat} \pm 90_{sys}$ eV^2

$M_\nu < 15.6$ eV (90% c.l.)

(M. Sisti et al., NIMA520 (2004) 125)

MANU (Genova)

- Re metalic crystal (1.5 mg)
- BEFS observed (F.Gatti et al., Nature 397 (1999) 137)
- sensitivity: $m(\nu) < 26$ eV (F.Gatti, Nucl. Phys. B91 (2001) 293)

MARE (Microcalorimeter Arrays for a Rhenium Exp.)

Genova, Goddard Space Fligth Center/NASA, Heidelberg,
Como, Milano, Trento, U Wisconson

MARE I:

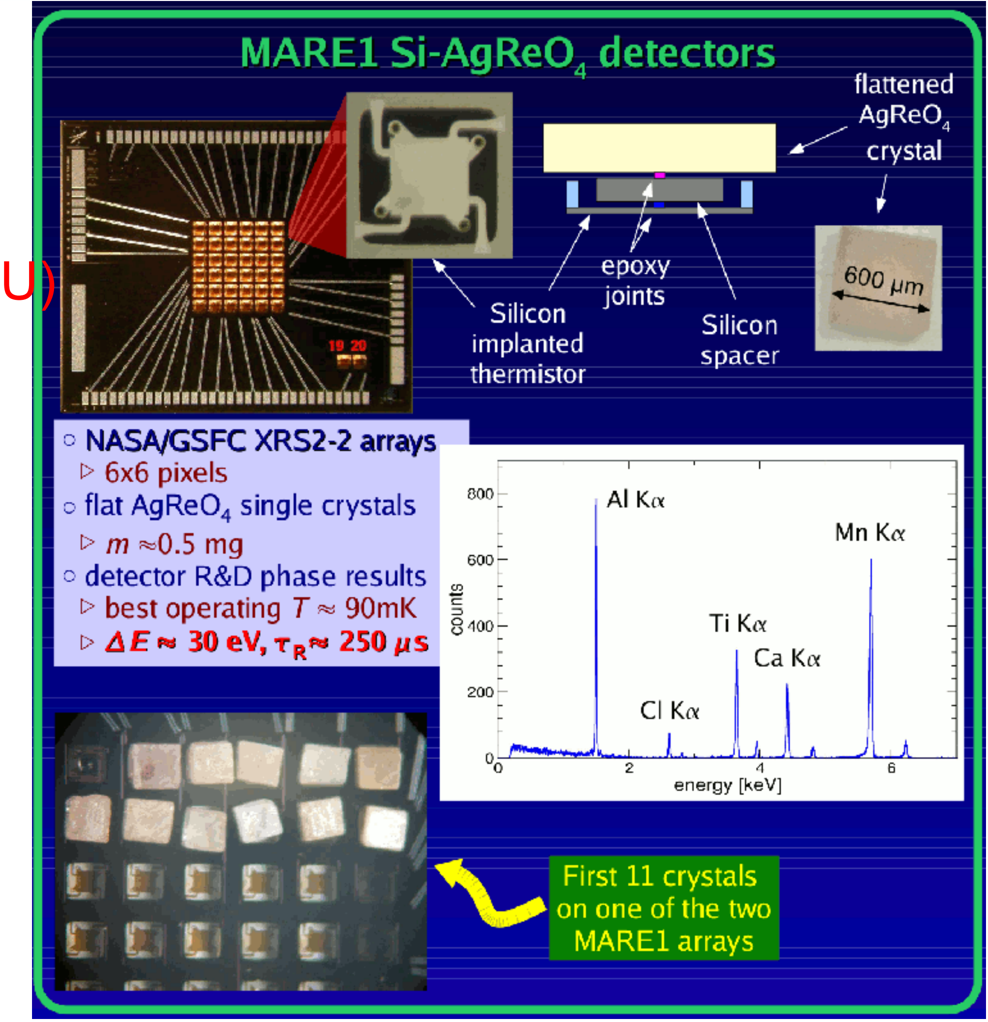
300 detectors (MIBETA: 10)

ΔE = 10 eV (MIBETA: 28 eV)

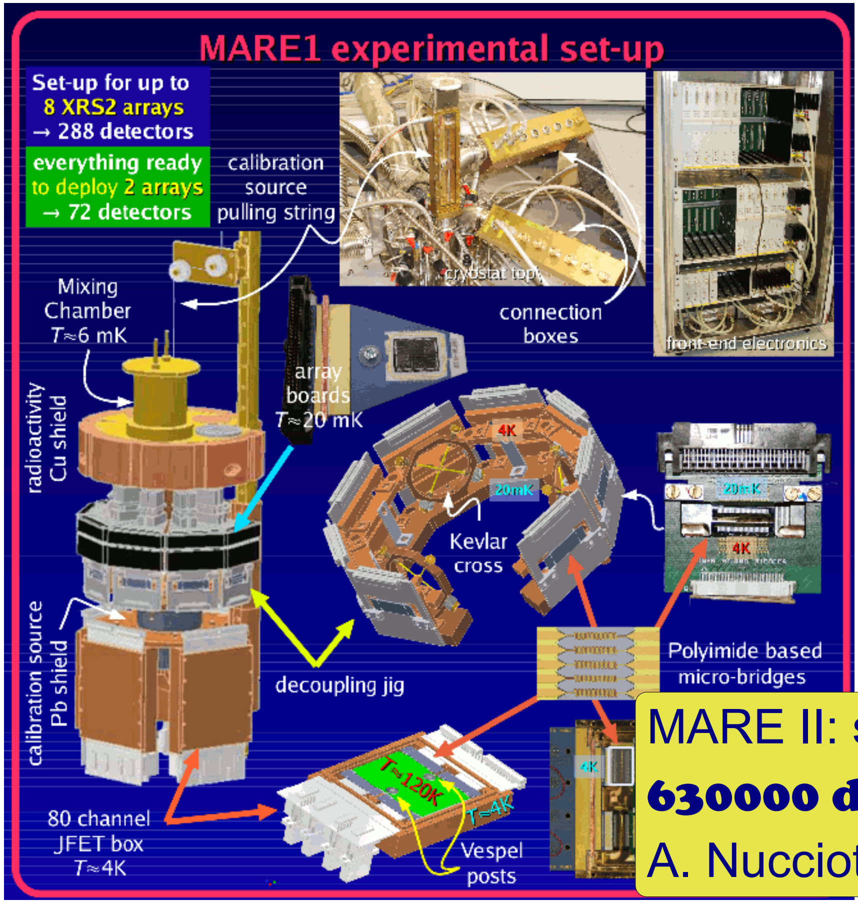
$\tau = 10^{-4}$ s (MIBETA: 10^{-3} s)

with semiconductor sensors (like MIBETA/MANU)

expected sensitivity on $m(\nu_e)$: 2-3 eV



- NASA/GSFC XRS2-2 arrays
  - 6x6 pixels
- flat $AgReO_4$ single crystals
  - $m \approx 0.5$ mg
- detector R&D phase results
  - best operating $T \approx$ 90mK
  - $\Delta E \approx$ 30 eV, $\tau_R \approx$ 250 μs

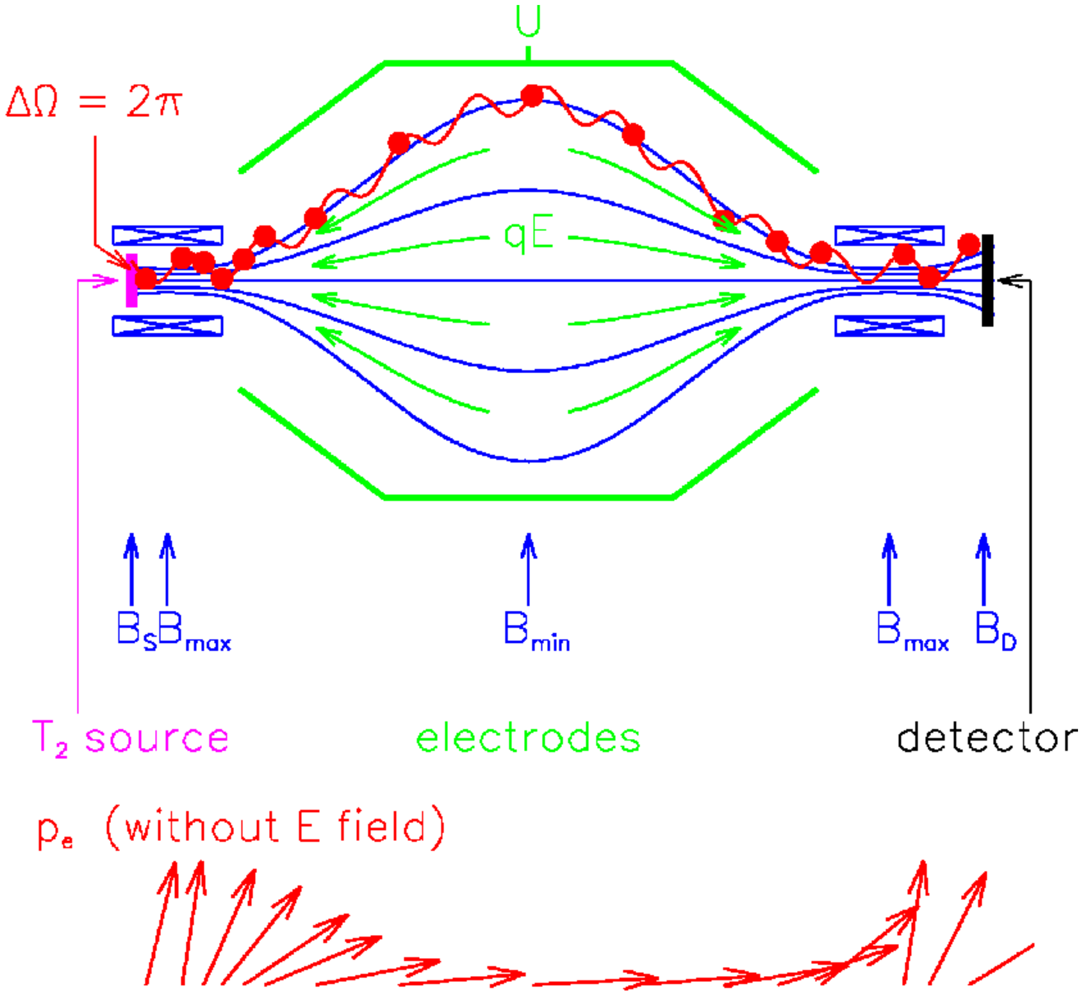


pictures from A. Nucciotti/Milano

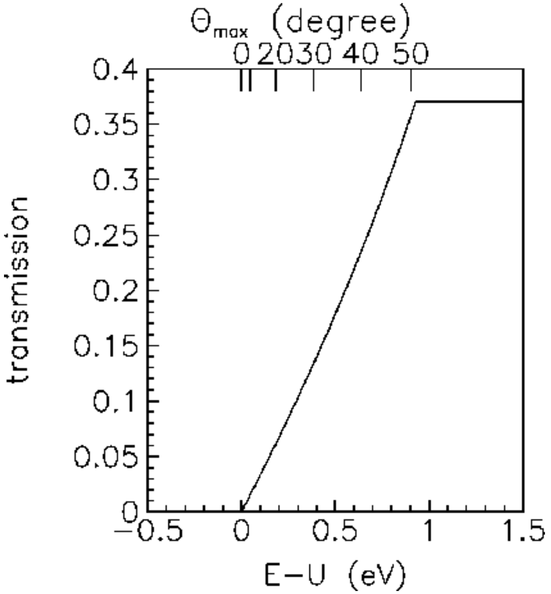
MARE II: sensitivity of 0.2 eV with 90% C.L. with about **630000 detector years** assuming an activity of 5 Bq per pixel.

A. Nucciotti et al., Astroparticle Physics vol. 34 2, (2010) 80

Tritium experiments: source ≠ spectrometer MAC-E-Filter



- Two supercond. solenoids compose magnetic guiding field
- adiabatic transformation:
  $\mu = E/B = \text{const.}$
  ⇒ parallel e^- beam
- Energy analysis by electrostat. retarding field
  $\Delta E = E B_{min}/B_{max}$
  $= 0.93$ eV (KATRIN)



⇒ sharp integrating transmission function without tails →

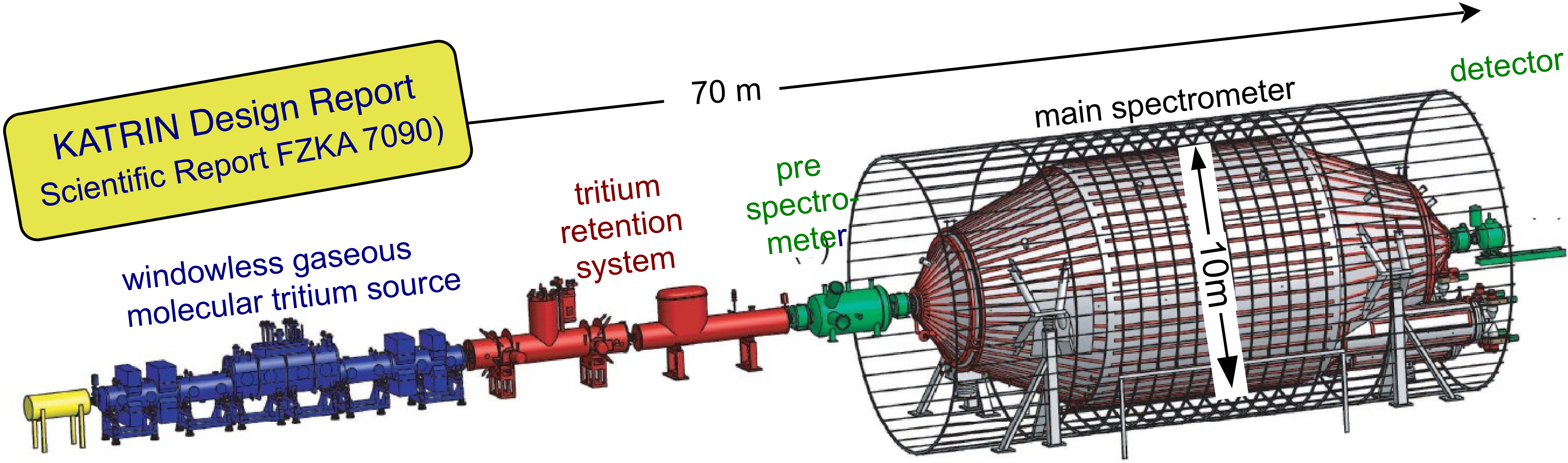
Magnetic Adiabatic Collimation + Electrostatic Filter
(A. Picard et al., Nucl. Instr. Meth. 63 (1992) 345)

The KATRIN experiment at KIT

Aim: m(ν_e) sensitivity of 200 meV (currently 2 eV)

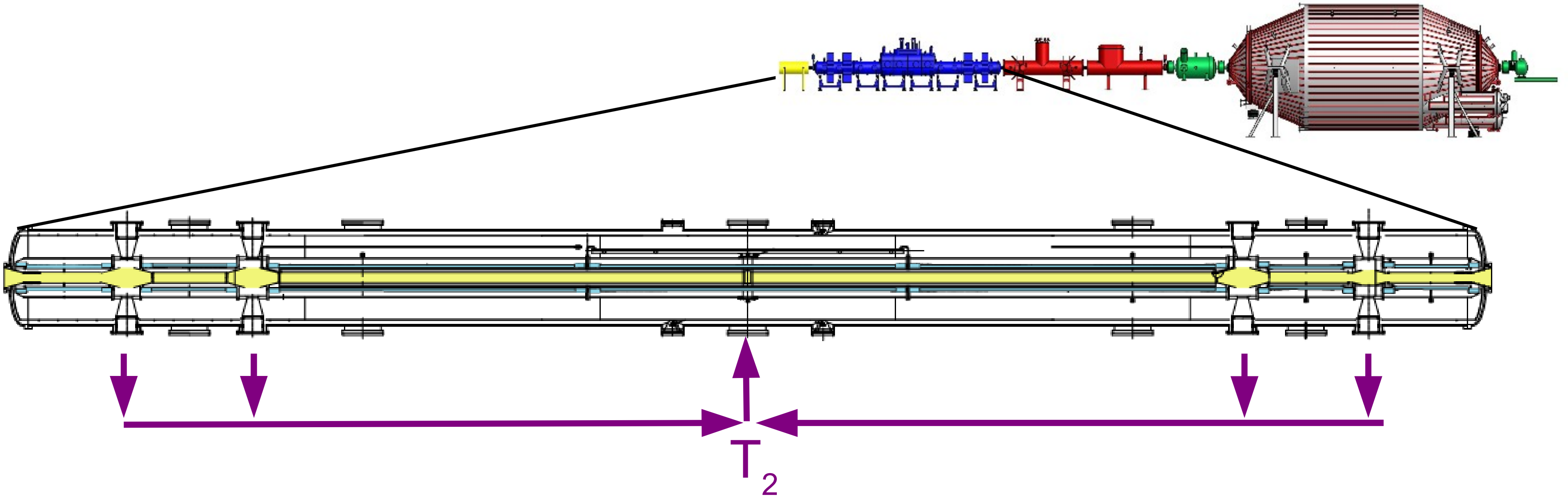
- **very high energy resolution ($\Delta E \leq$ 1eV, i.e. σ = 0.3 eV)** **⇒ source ≠ spectrometer concept**
- **strong, opaque source** **⇒ $dN/dt \sim A_{source}$**
- **magnetic flux conservation (Liouville)** **⇒ scaling law:**

$$A_{spectrometer} / A_{source} = B_{source} / B_{spectrometer} = E / \Delta E = 20000 / 1$$



KATRIN Design Report
Scientific Report FZKA 7090)

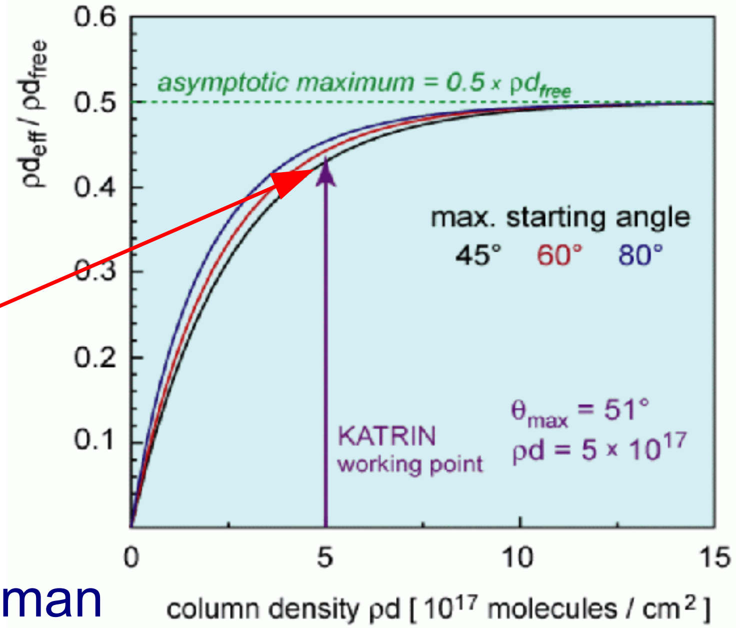
Molecular Windowless Gaseous Tritium Source WGTS



WGTS: tub in long superconducting solenoids
⊘ 9cm, length: 10m, T = 30 K

Tritium recirculation (and purification)
$p_{inj} = 0.003$ mbar, $q_{inj} = 4.7$Ci/s

allows to measure with near to maximum count rate using
$\rho d = 5 \cdot 10^{17}/\mathrm{cm}^2$
with small systematics



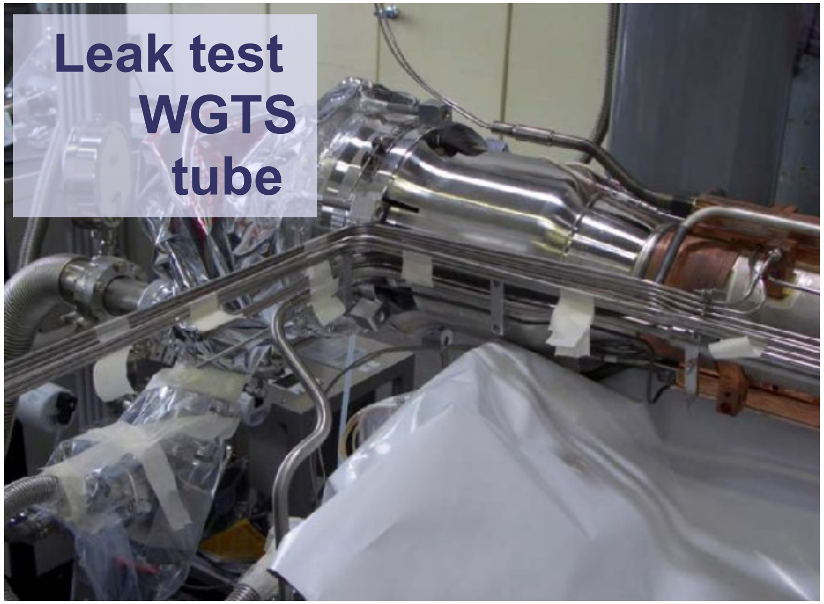
check column density by e-gun, T_2 purity by laser Raman

The windowless gaseous tritium source under construction

- WGTS demonstrator delivered in spring 2010 successfully tested
- after successful testing the demonstrator will be completed (mainly with magnets) to become the final WGTS

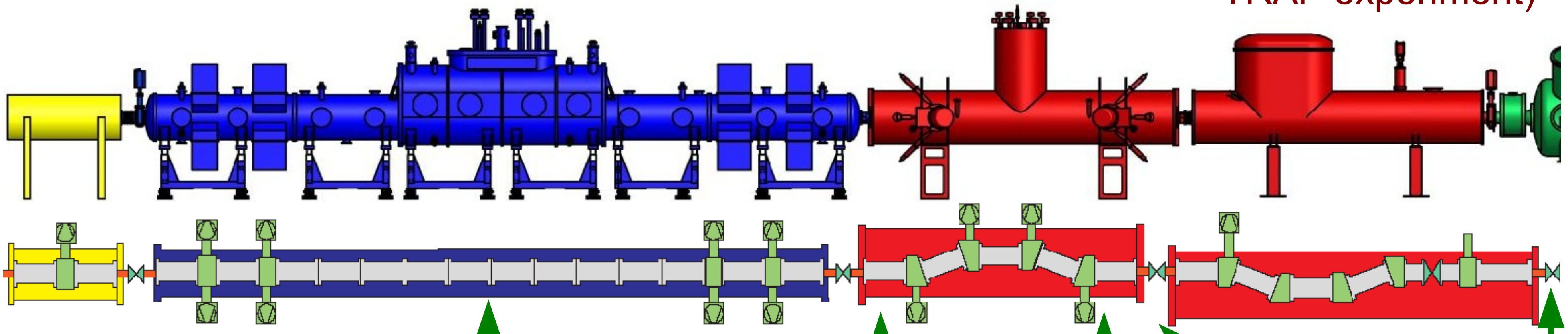
WGTS tube / inner shield assembly

April 2010: arrival of „demonstrator“ at KIT



Leak test WGTS tube

Transport and differential & cryo pumping sections



Molecular windowless gaseous tritium source

Differential pumping

Cryogenic pumping
with Argon snow
at LHe temperatures
(successfully tested with the TRAP experiment)

T_2-injection 1.8 mbar l/s (STP)
= 1.7*10^{11} Bq/s = 40 g/d

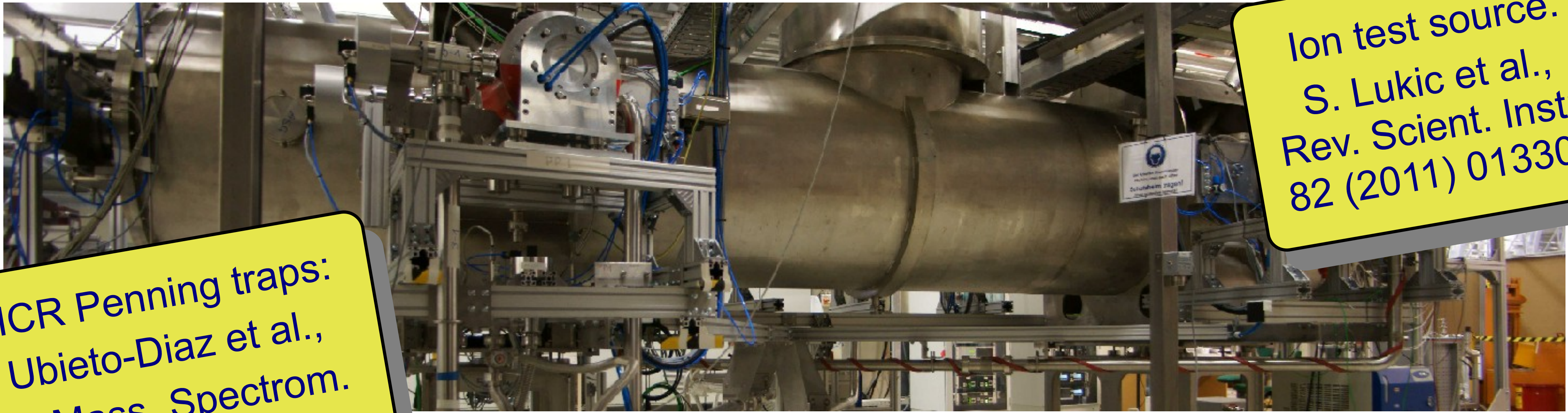
FT-ICR Penning traps to measure ions from WGTS

≈ 10^{-7} mbar l/s

< 2.5 10^{-14} mbar l/s

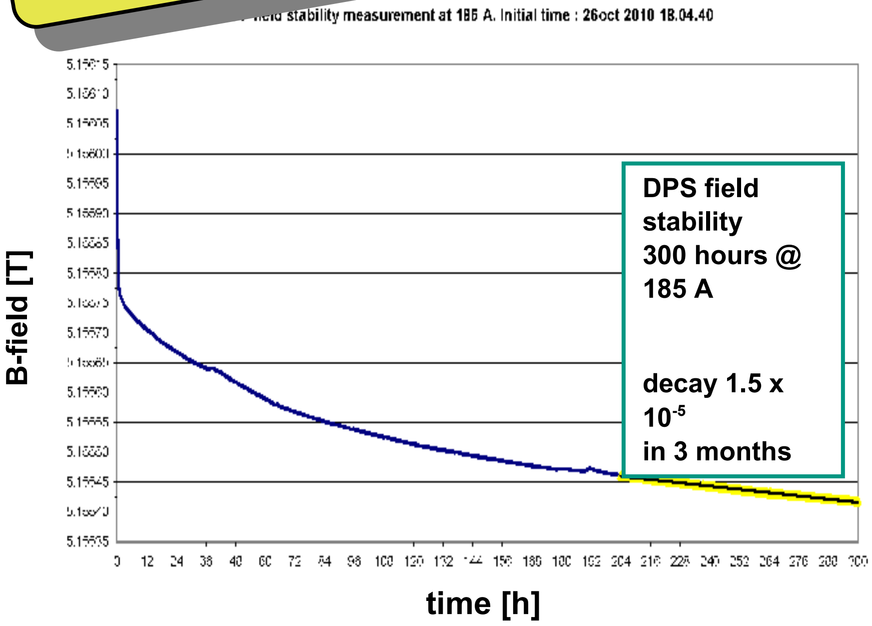
⇒ adiabatic electron guiding & T_2 reduction factor of ~10^{14}

Commissioning of DPS2-F



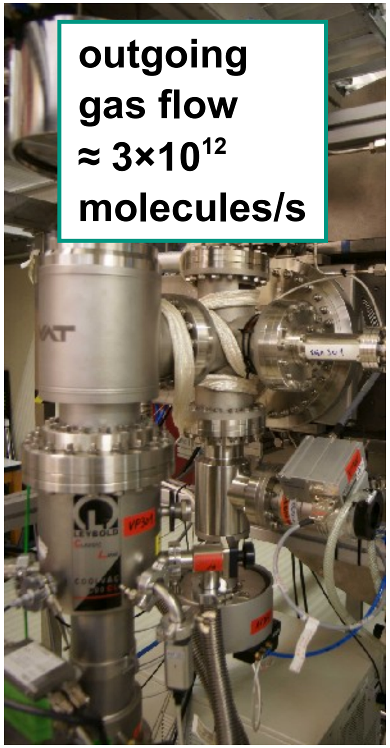
Ion test source:
S. Lukic et al.,
Rev. Scient. Instr.
82 (2011) 013303

FT-ICR Penning traps:
M. Ubieto-Diaz et al.,
Int. J. Mass. Spectrom.
288 (2009) 1-5



DPS field stability 300 hours @ 185 A

decay 1.5 x 10^{-5} in 3 months

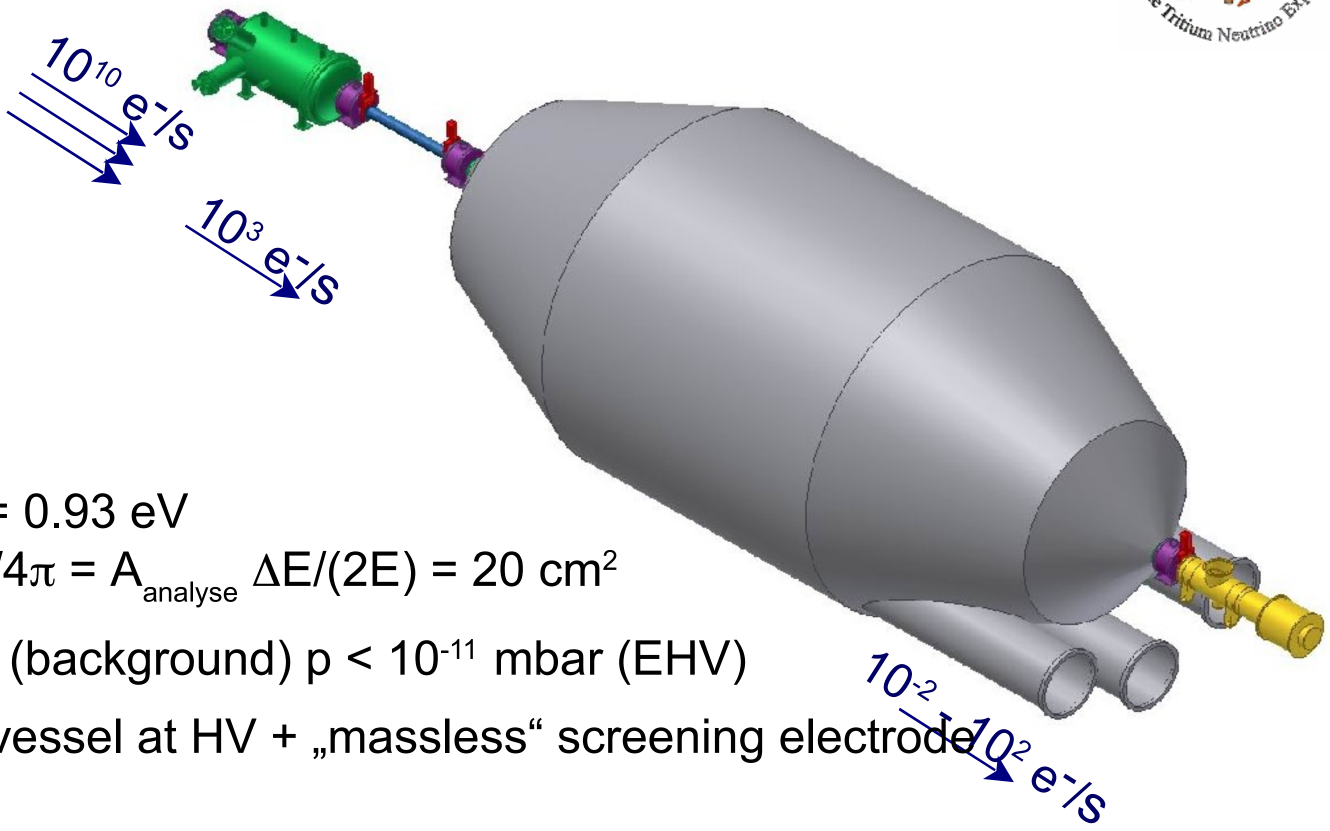


outgoing gas flow ≈ 3×10^{12} molecules/s

First gas flow reduction measurements with Ar (preliminary)

gas inlet ≈ 3×10^{17} molecules/s

Pre and main spectrometer



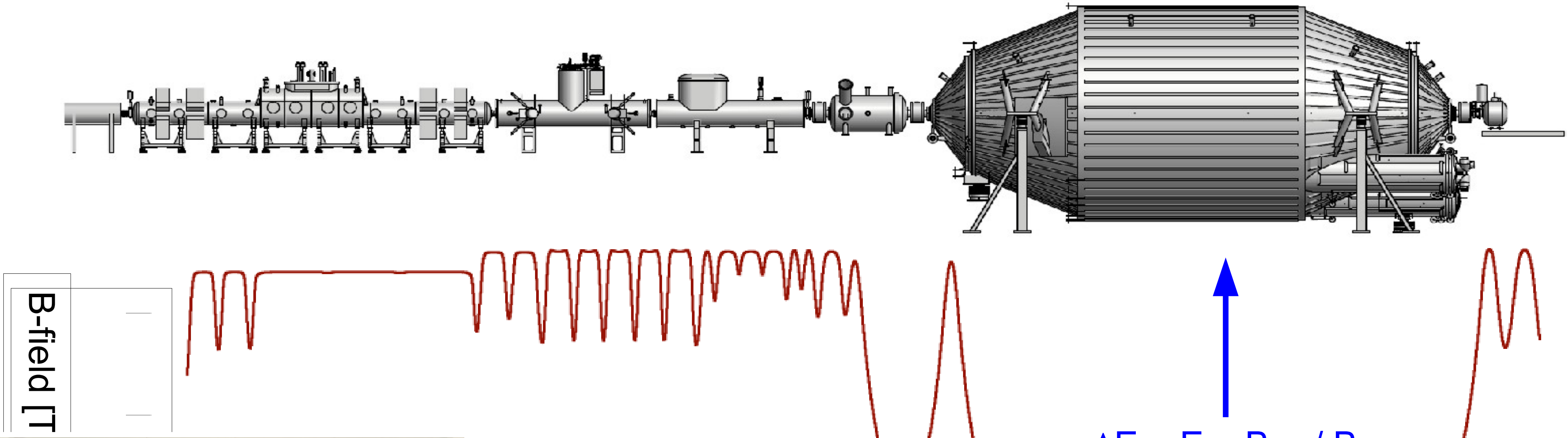
Main spectrometer:

- $\varnothing$10m, length 24m
  ⇒ large energy resolution: $\Delta E = 0.93$ eV
  ⇒ high luminosity: $L = A_{Seff}\ \Delta\Omega/4\pi = A_{analyse}\ \Delta E/(2E) = 20\ \text{cm}^2$
- ultrahigh vacuum requirements (background) $p < 10^{-11}$ mbar (EHV)
- „simple“ construction: vacuum vessel at HV + „massless“ screening electrode

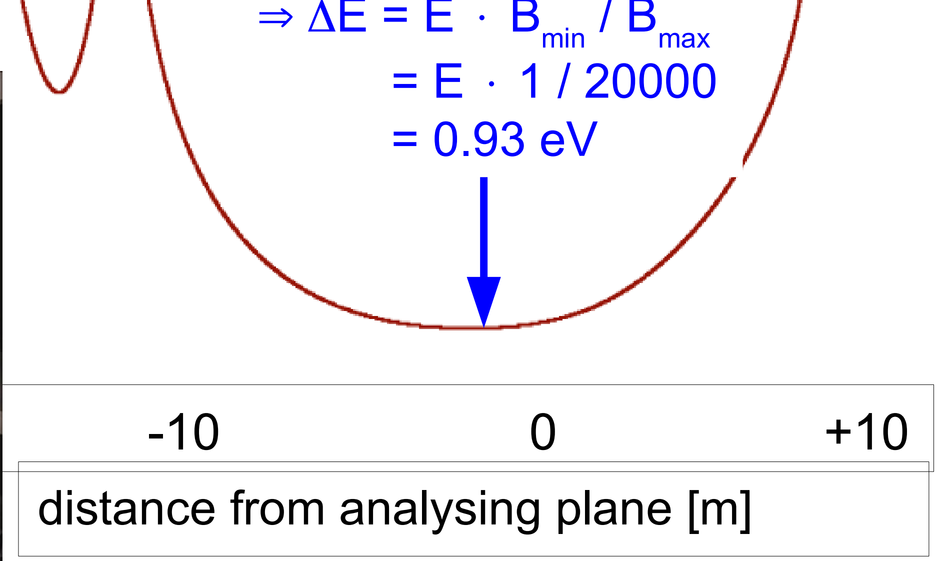
Pre spectrometer

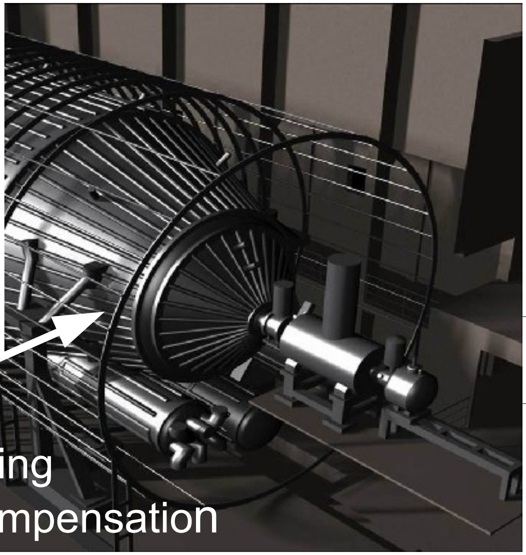
- Transmission of electron with highest energy only
  (10^{-7} part in last 100 eV)
  ⇒ Reduction of scattering probaility in main spectrometer
  ⇒ Reduction of background
- only moderate energy resolution required: $\Delta E = 80$ eV
- test of new ideas (EHV, shape of electrodes, avoid and remove of trapped particles, ...)

Electromagnetic design: magnetic fields



$\Rightarrow \Delta E = E \cdot B_{min} / B_{max}$
$= E \cdot 1 / 20000$
$= 0.93\ \mathrm{eV}$



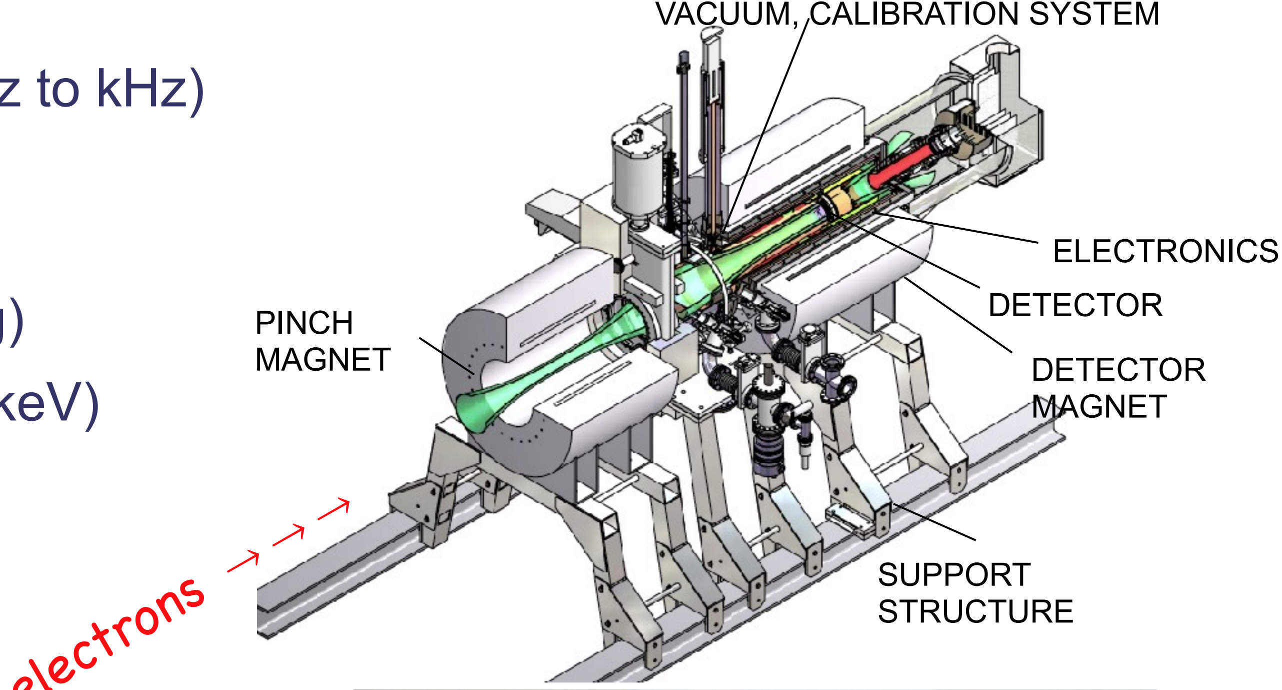


aircoils:
axial field shaping
+ earth field compensation

The detector

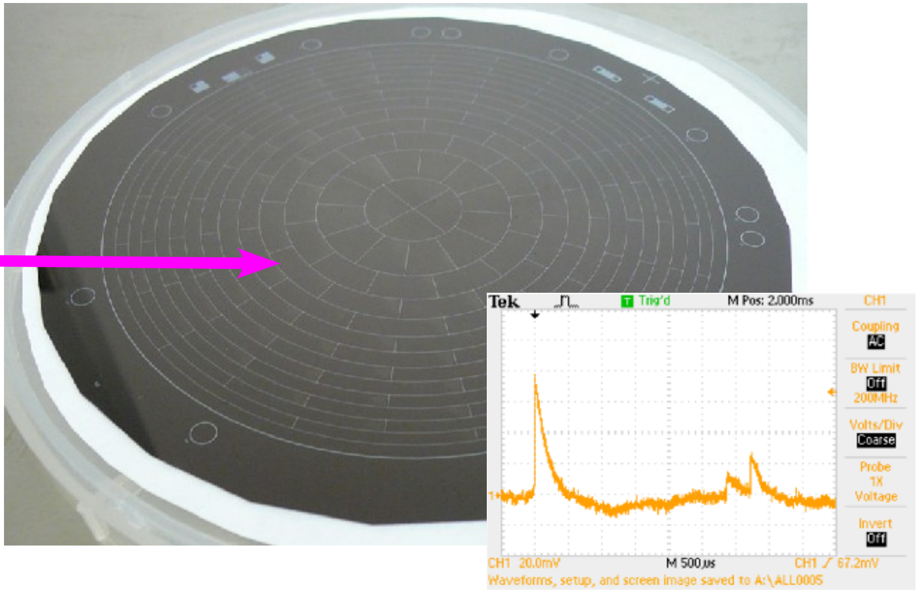
Requirements

- detection of β-electrons (mHz to kHz)
- high efficiency (> 90%)
- low background (< 1 mHz)
  (passive and active shielding)
- good energy resolution (< 1 keV)

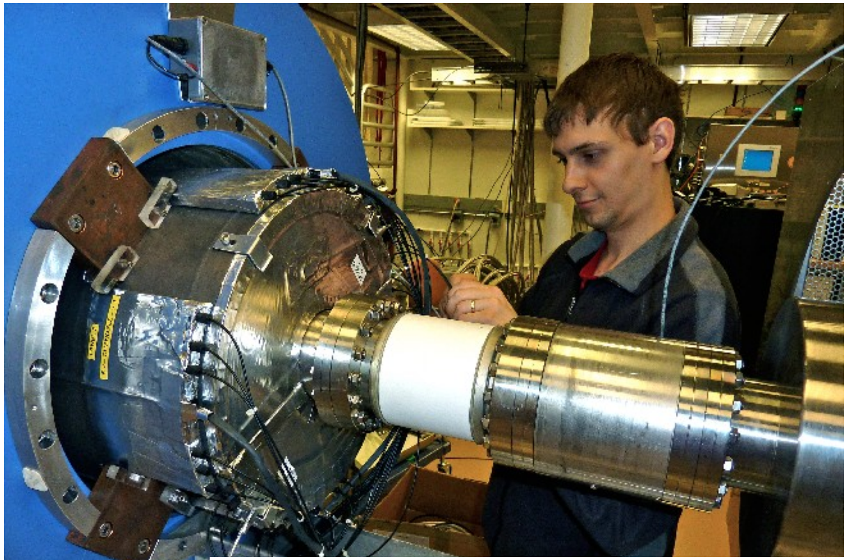


Properties

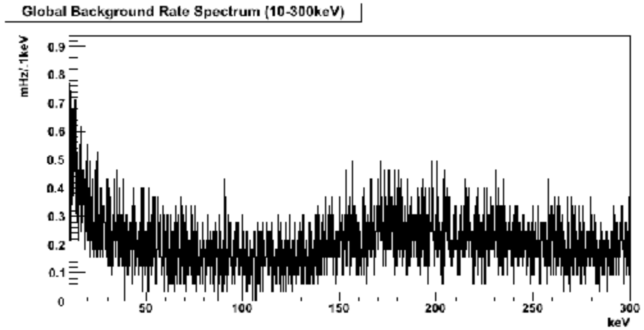
- 90 mm Ø Si PIN diode
- thin entry window (50nm)
- detector magnet 3 - 6 T
- post acceleration (30kV)
  (to lower background in signal region)
- segmented wafer (145 pixels)
  → record azimuthal and radial profile of the flux tube
  → investigate systematic effects
  → compensate field inhomogeneities



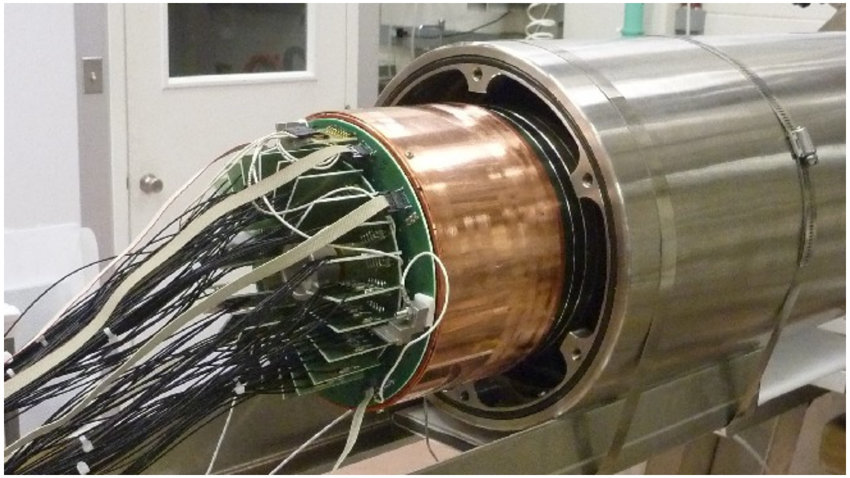
KATRIN detector

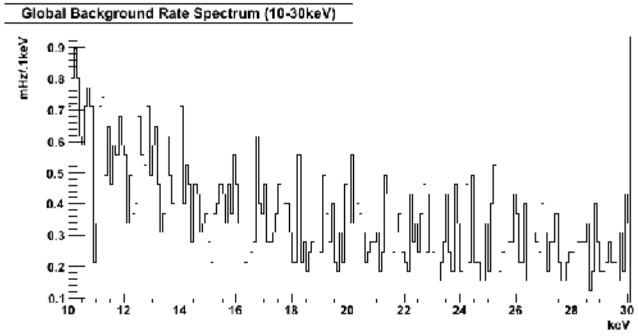


Detector at Seattle (arrival at KIT: July 11)



Global Background Rate Spectrum (10-300keV)



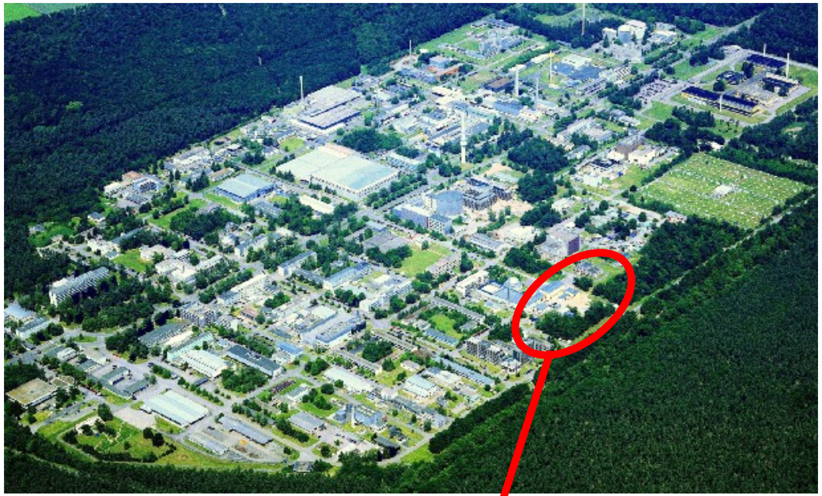


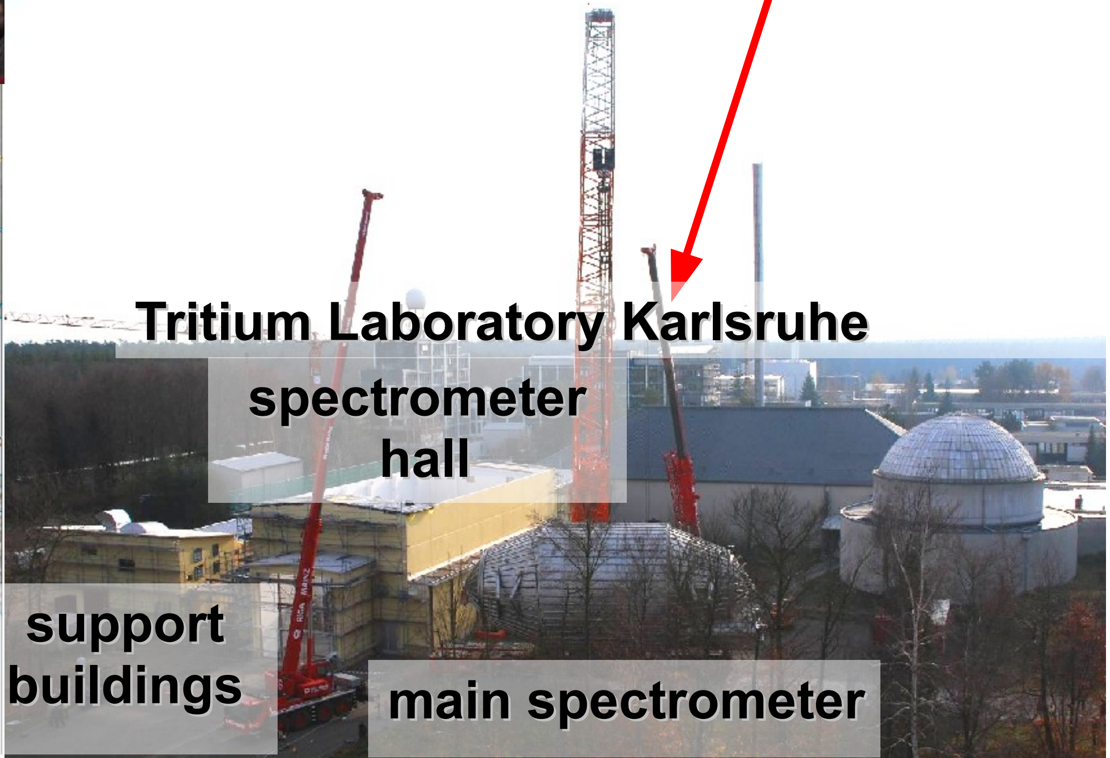
Global Background Rate Spectrum (10-30keV)

Main Spectrometer – Transport to Forschungszentrum Karlsruhe

Leopoldshafen, 25.11.06

8800 km





Tritium Laboratory Karlsruhe

spectrometer hall

support buildings

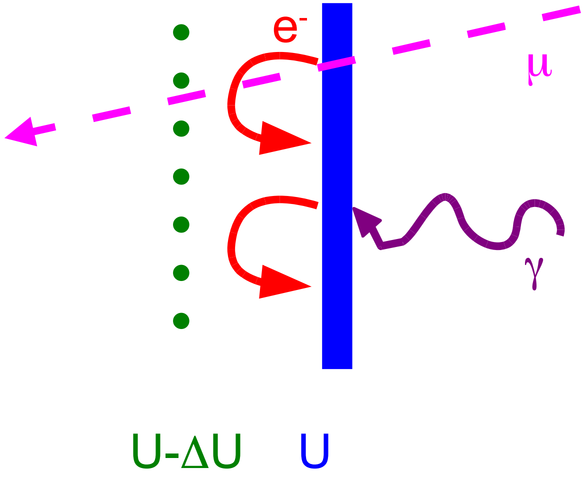
main spectrometer

Background reduction: shielding by „massless“ wire electrode

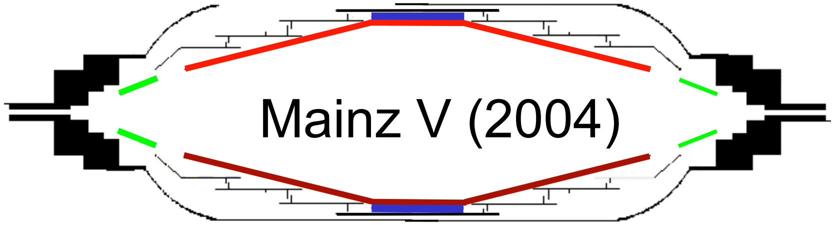
Secondary electrons from wall/electrode

by cosmic rays, environmental radioactivity, ...

wire electrode on slightly more negative potential

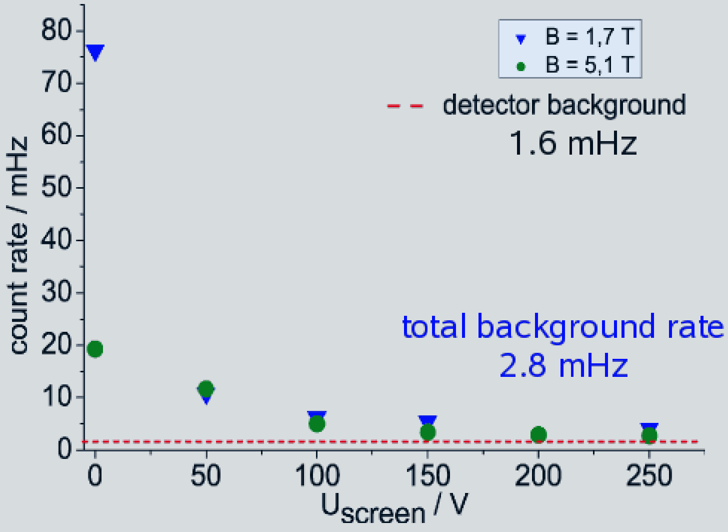


First realisation:
Mainz III

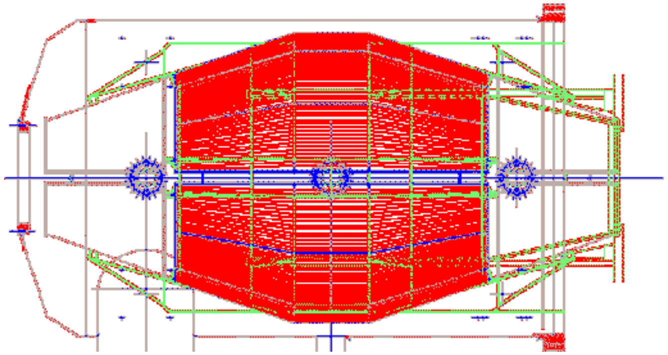

Mainz V (2004)

New record !
April 04

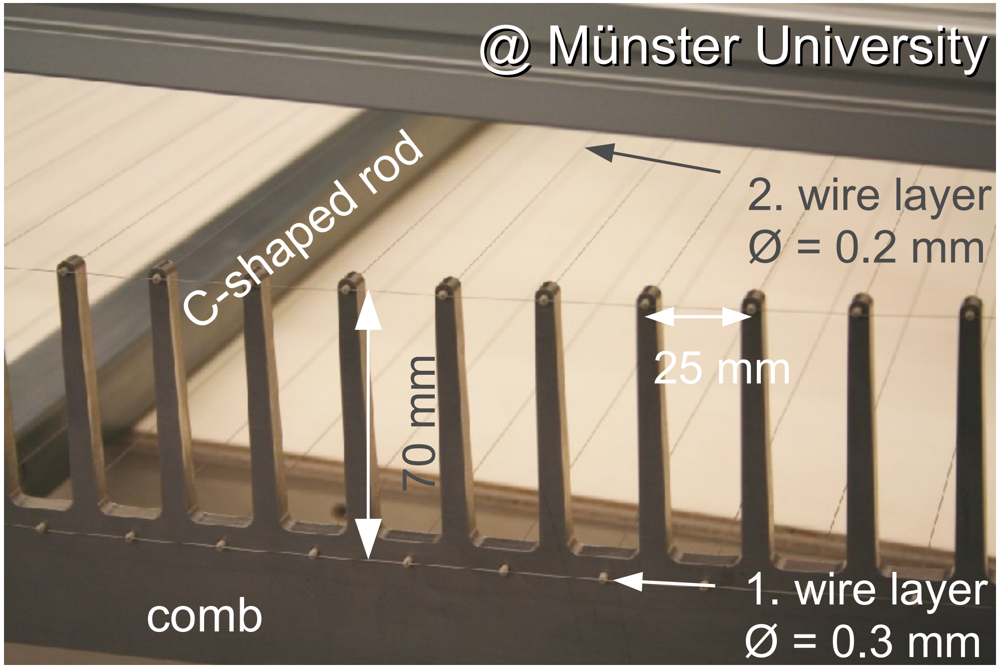
Background suppression successfully tested at the Mainz MAC-E filter:

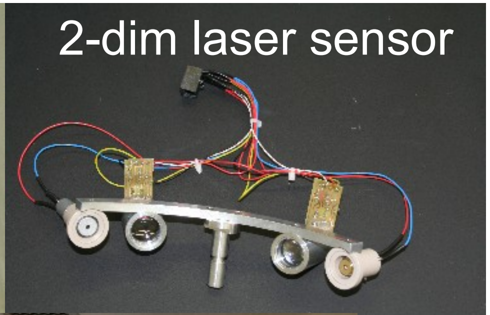


Dipl. thesis B. Ostrick (U Mainz, 2002),
PhD thesis B. Flatt (U Mainz, 2004)


KATRIN pre spectrometer

Double-wire layer electrode (690m^2) production and quality assurance

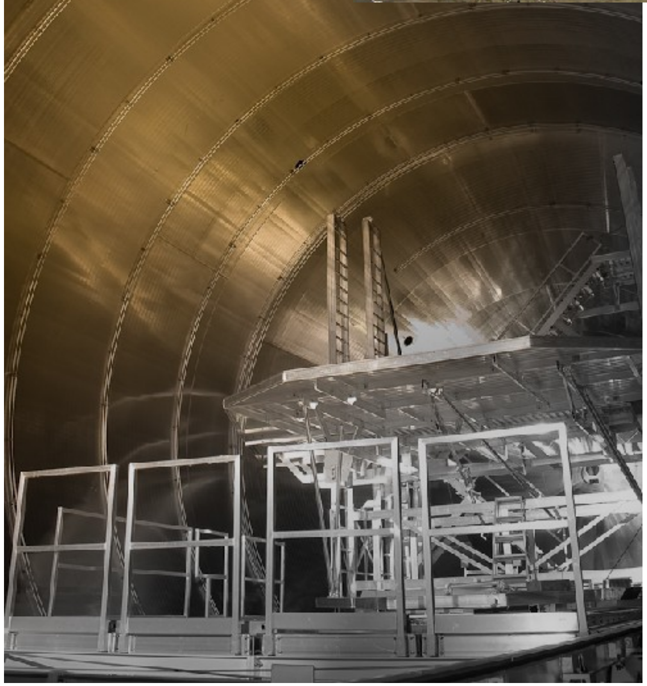




Electrode production finished in Oct. 2009

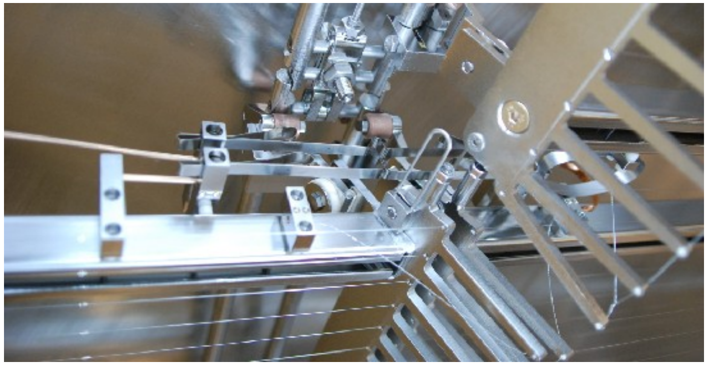
Electrode modules are being installed at the main spectrometer

Two-layer wire electrode system installation inside main spectrometer

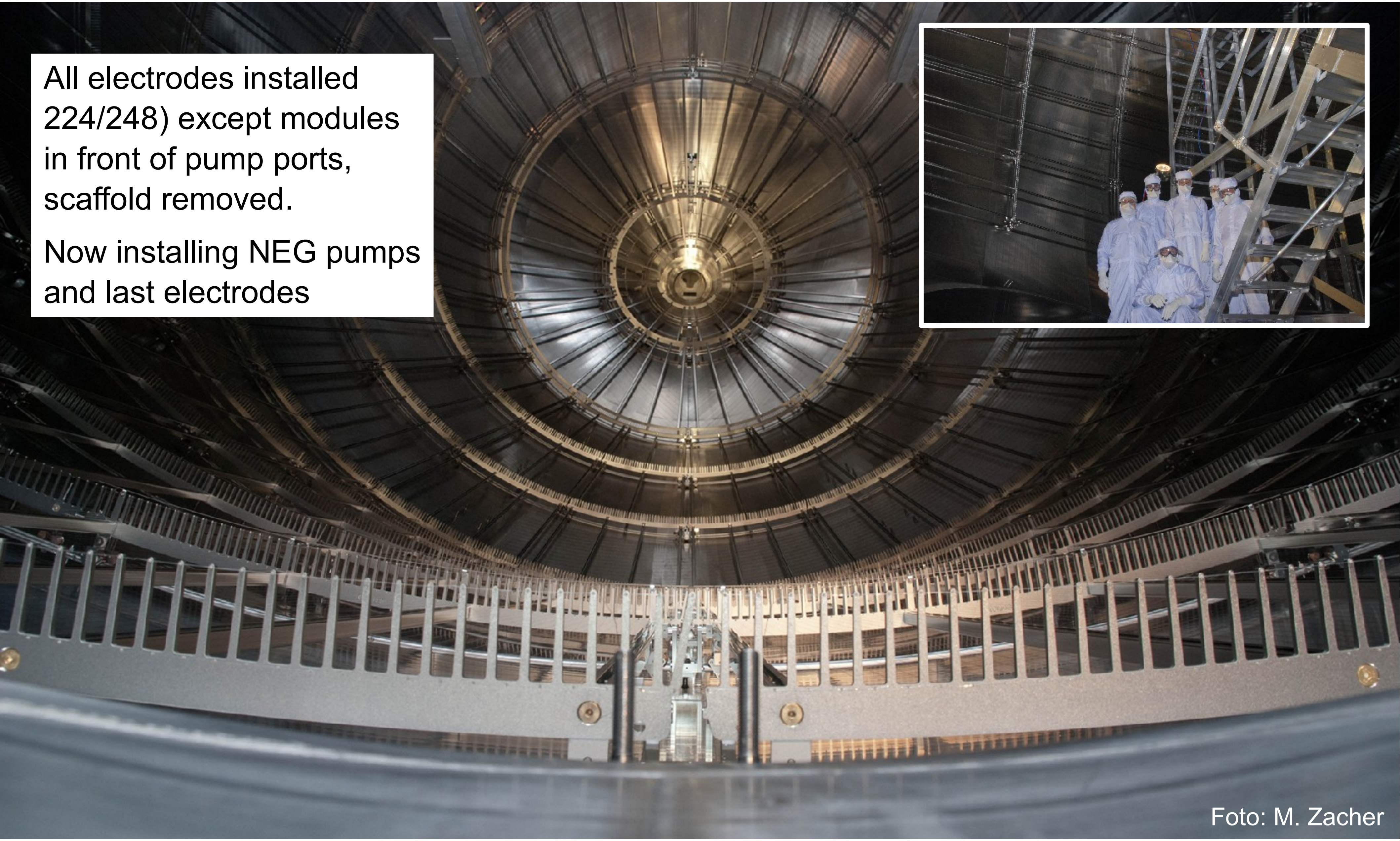


Will be finished
in August. 2011

74 modules at source side



Status of electrode installation as of July 2011



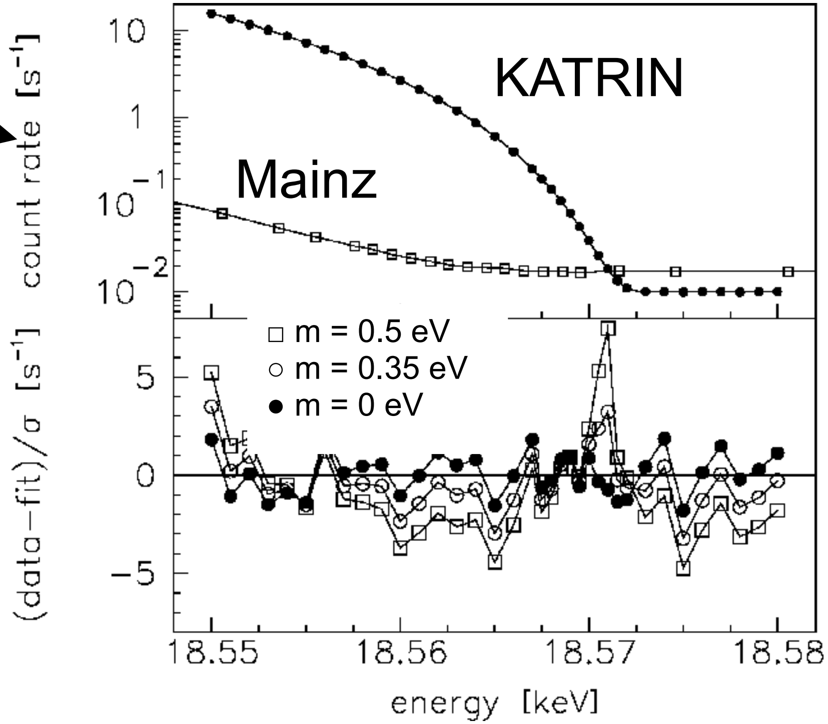
All electrodes installed 224/248) except modules in front of pump ports, scaffold removed.

Now installing NEG pumps and last electrodes

Foto: M. Zacher

KATRIN´s sensitivity

Example of KATRIN simulation & fit
(last 25eV below endpoint, reference):



sensitivity:

m_ν < 0.2eV (90%CL)

discovery potential:

m_ν = 0.3eV (3σ)

m_ν = 0.35eV (5σ)

Expectation for 3 full data taking years: $\sigma_{syst} \sim \sigma_{stat}$

Sensitivity is still statistically limited,

because with more statistics would go closer to the endpoint,

where most systematics nearly vanish

Sensitivity still has to proven, but there might be even some more improvements

KATRIN´s sensitivity

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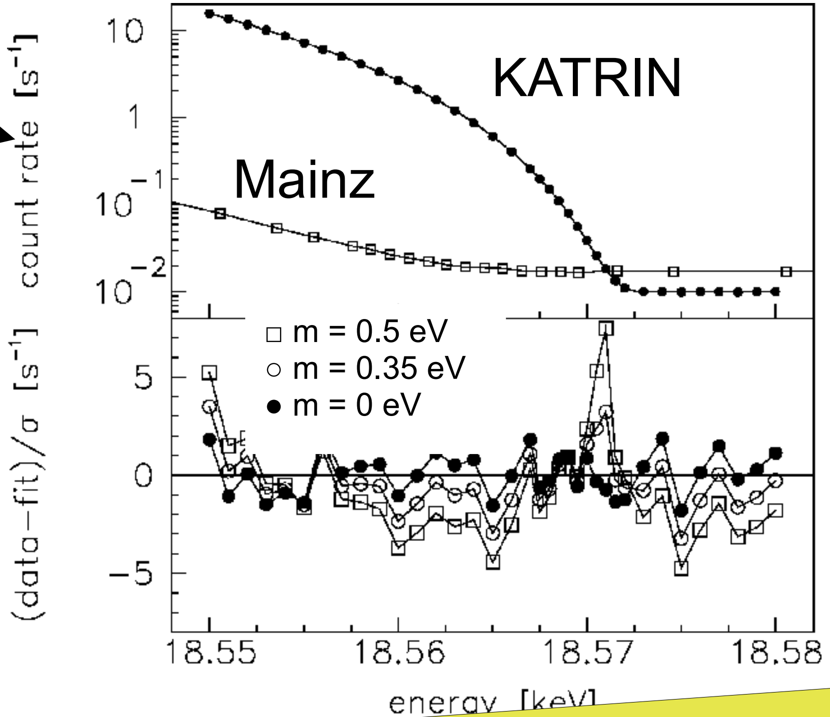


Expectation for 3 full data taking years: σ

⇒ KATRIN will improve the sensitivity by 1 order of magnitude
will check the whole cosmological relevant mass range
will detect degenerate neutrinos (if they are degen.)

Sensitivity still has to proven, but there might be even some more improvements

Complementarity of single and double β decay

Direct kinematic measurement: $m^2(\nu_e) = \Sigma |U_{ei}{}^2| \, m^2(\nu_i)$ (incoherent)

Neutrinolesss double β decay: $m_{\beta\beta}(\nu) = | \Sigma |U_{ei}{}^2| \, e^{i\alpha(i)} \, m(\nu_i)|$ (coherent)

$m(\nu_e)$ and $m_{ee}(\nu)$ could differ because of:

- Dirac neutrinos (no 0νββ)
- Non-trivial CP-phases
- Uncertainties of the nuclear matrix elements
- Other processes (right-handed currents, Susy-particles, ...)

$$T = \boxed{M_m < m_\nu >} + M_\theta < tg\vartheta > + M_{WR} < \left(\frac{M_1}{M_2}\right)^2 > \\ + M_{SUSY} \lambda'^2_{111} + M_{VR} < \frac{m_p}{M_{VR}} >$$

A. Fäßler at "Massive Neutrinos", Bad Honnef, July 2006

⇒ different neutrino masses from single and double β decay could give a unique handle on the CP phases or the Dirac/Majorana character of neutrinos

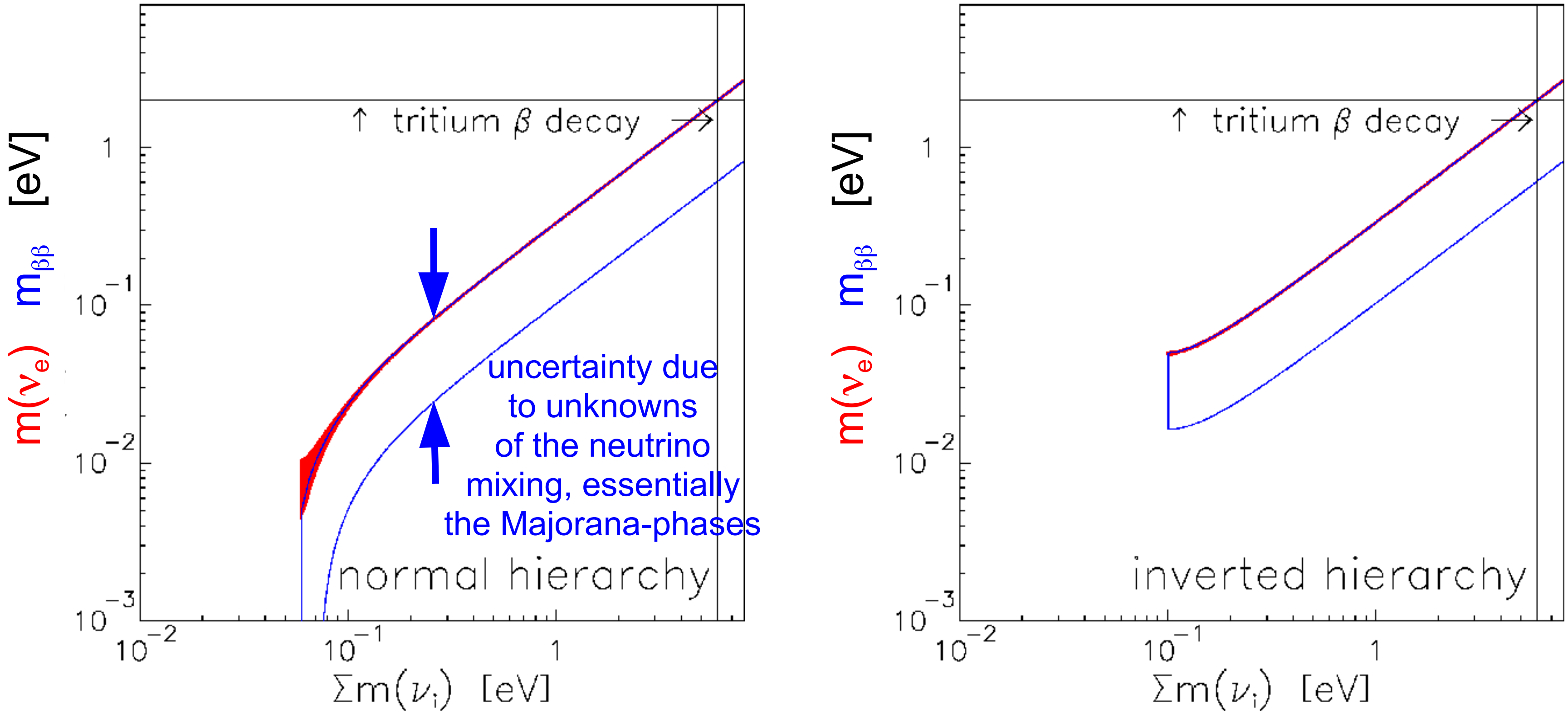
Comparison of the different approaches to the neutrino mass

Direct kinematic measurement: $m^2(\nu_e) = \Sigma |U_{ei}^2|\, m^2(\nu_i)$ (incoherent)

Neutrinolesss double β decay: $m_{\beta\beta}(\nu) = | \Sigma |U_{ei}^2|\, e^{i\alpha(i)}\, m(\nu_i)|$ (coherent)

if no other particle is exchanged (e.g. R-violating SUSY)

problems with uncertainty of nuclear matrix elements



uncertainty due to unknowns of the neutrino mixing, essentially the Majorana-phases

⇒ absolute scale/cosmological relevant neutrino mass in the lab by single β decay

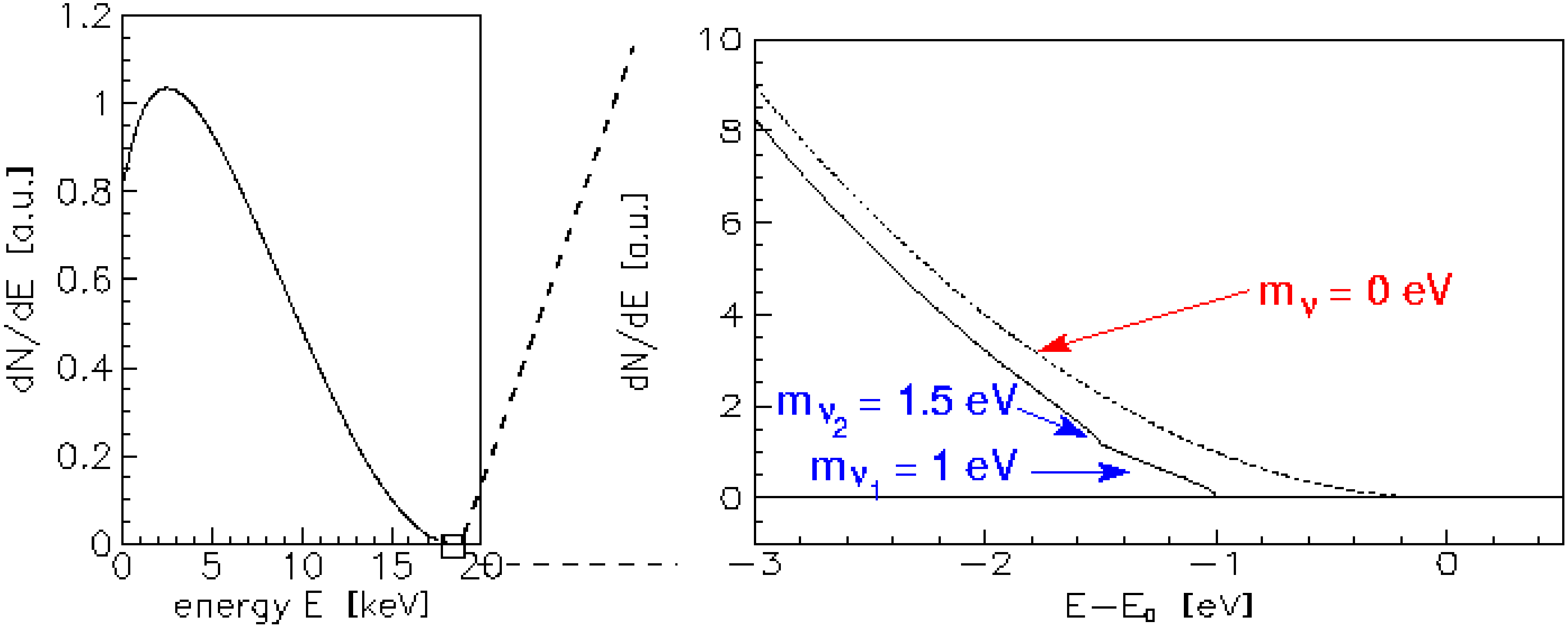
Remarks on sensitivity to sterile neutrinos

Neutrinolesss double β decay: $m_{\beta\beta}(\nu) = \left| \sum_{i=1}^{n_a+n_s} |U_{ei}^2| \, e^{i\alpha(i)} \, m(\nu_i) \right|$ (coherent)

measures only „one number“ → cannot distinguish sterile neutrinos if U_{ei} is small

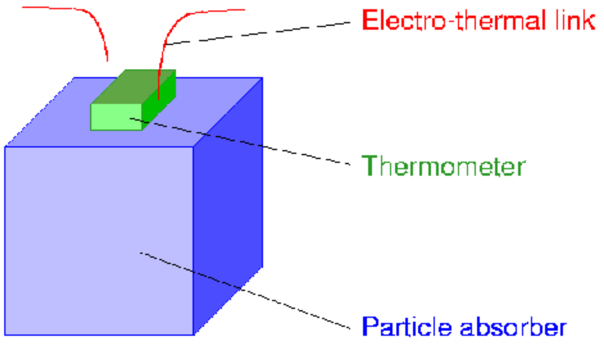
Direct kinematic measurement: $m^2(\nu_e) = \sum_{i=1}^{n_a+n_s} |U_{ei}^2| \, m^2(\nu_i)$ (incoherent)

measure spectrum → can distinguish different mass states (also sterile)
if $m(\nu_i)$ and U_{ei} are large



Sterile neutrinos: cryobolometer versus electron spectrometer (MAC-E-Filter)

Cryobolometer: source = detector

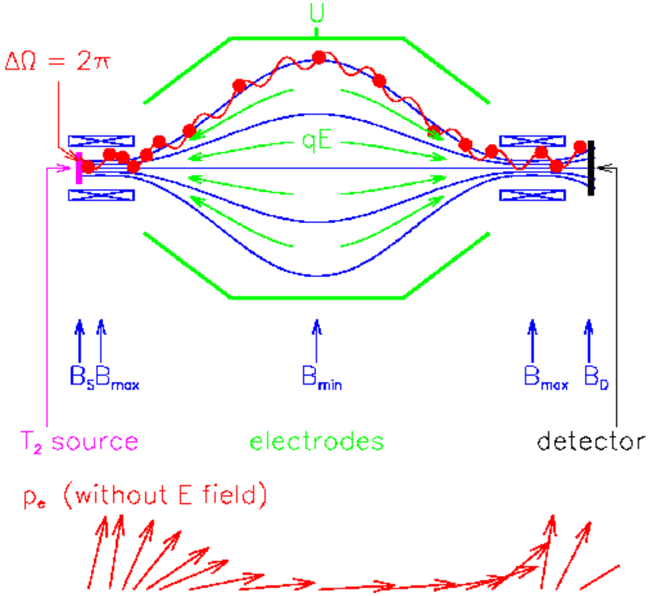


measure all energy, except that of the neutrino

→ could in principle measure large part
of the beta spectrum
without large systematics

→ large neutrino masses (up to keV) accessable

Electron spectrometer: source ≠ detector

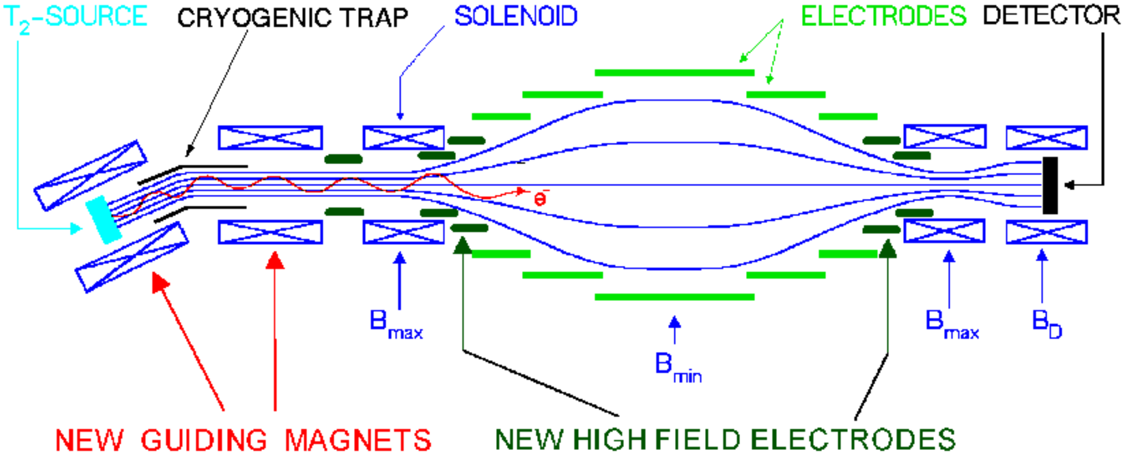


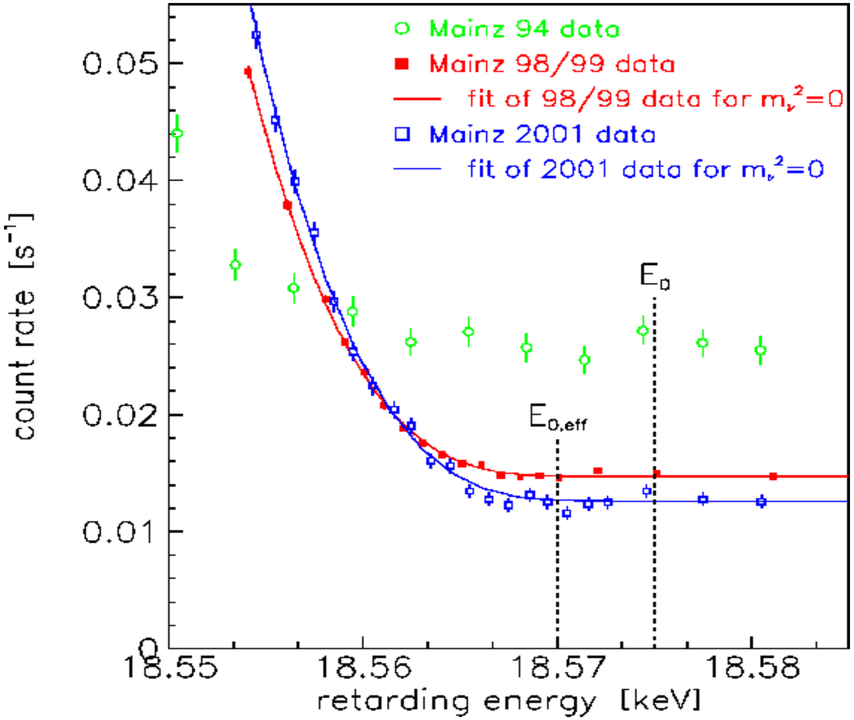
measure electron energy,
which energy losses by scattering
electronic excitations during decay (FS)
for larger intervals below endpoint ,..

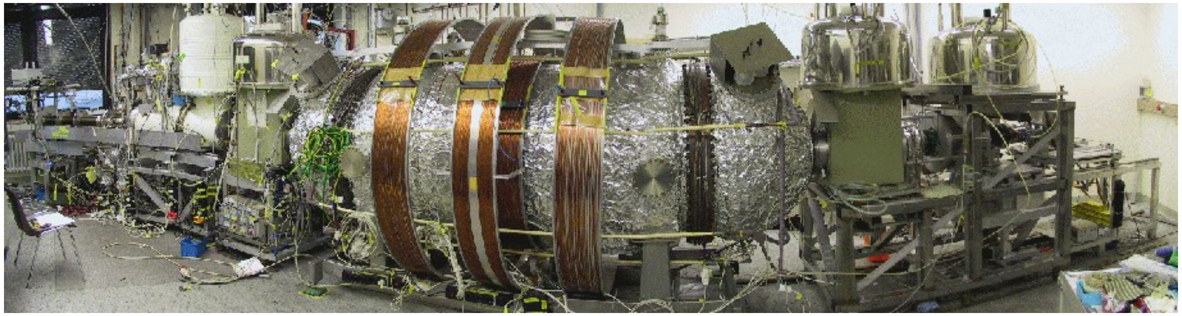
→ concentrate on endpoint region,
otherwise systematic uncertainties too large

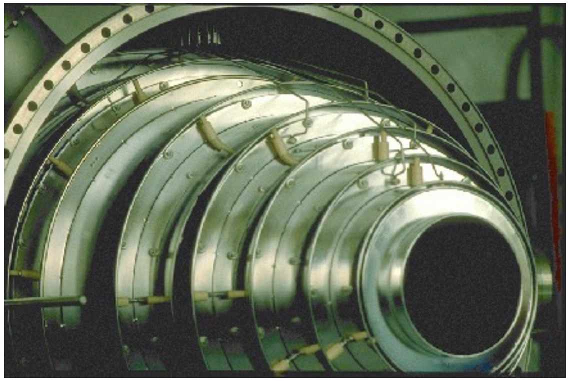
→ only medium neutrino masses (up to a few 10 eV) accessable

The Mainz Neutrino Mass Experiment
Phase 2: 1997-2001









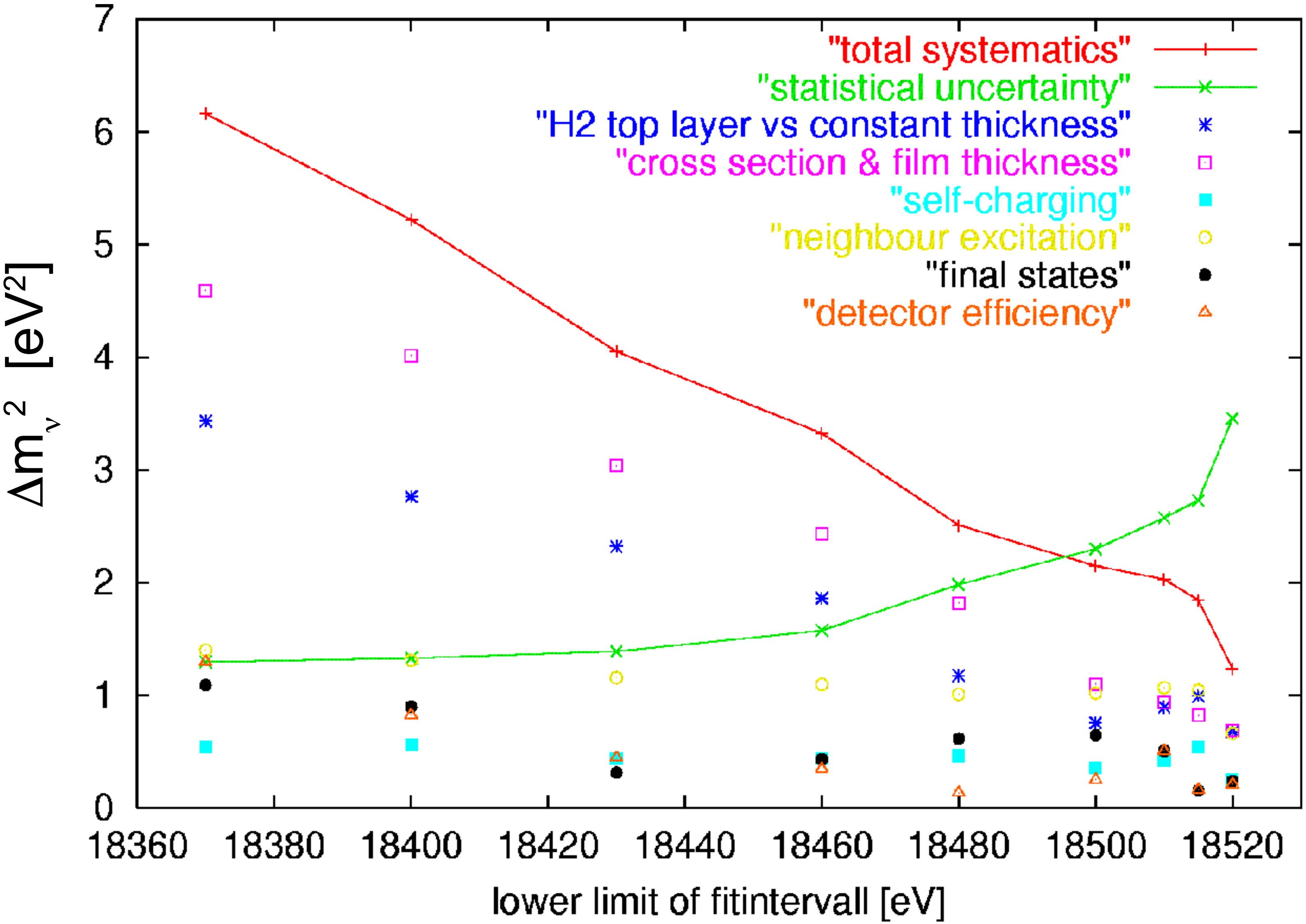
After all critical systematics measured by own experiment (inelastic scattering, self-charging, neighbor excitation):

$m^2(\nu) = -0.6 \pm 2.2 \pm 2.1\ \mathrm{eV}^2 \Rightarrow \quad m(\nu) < 2.3\ \mathrm{eV}$ (95% C.L.)

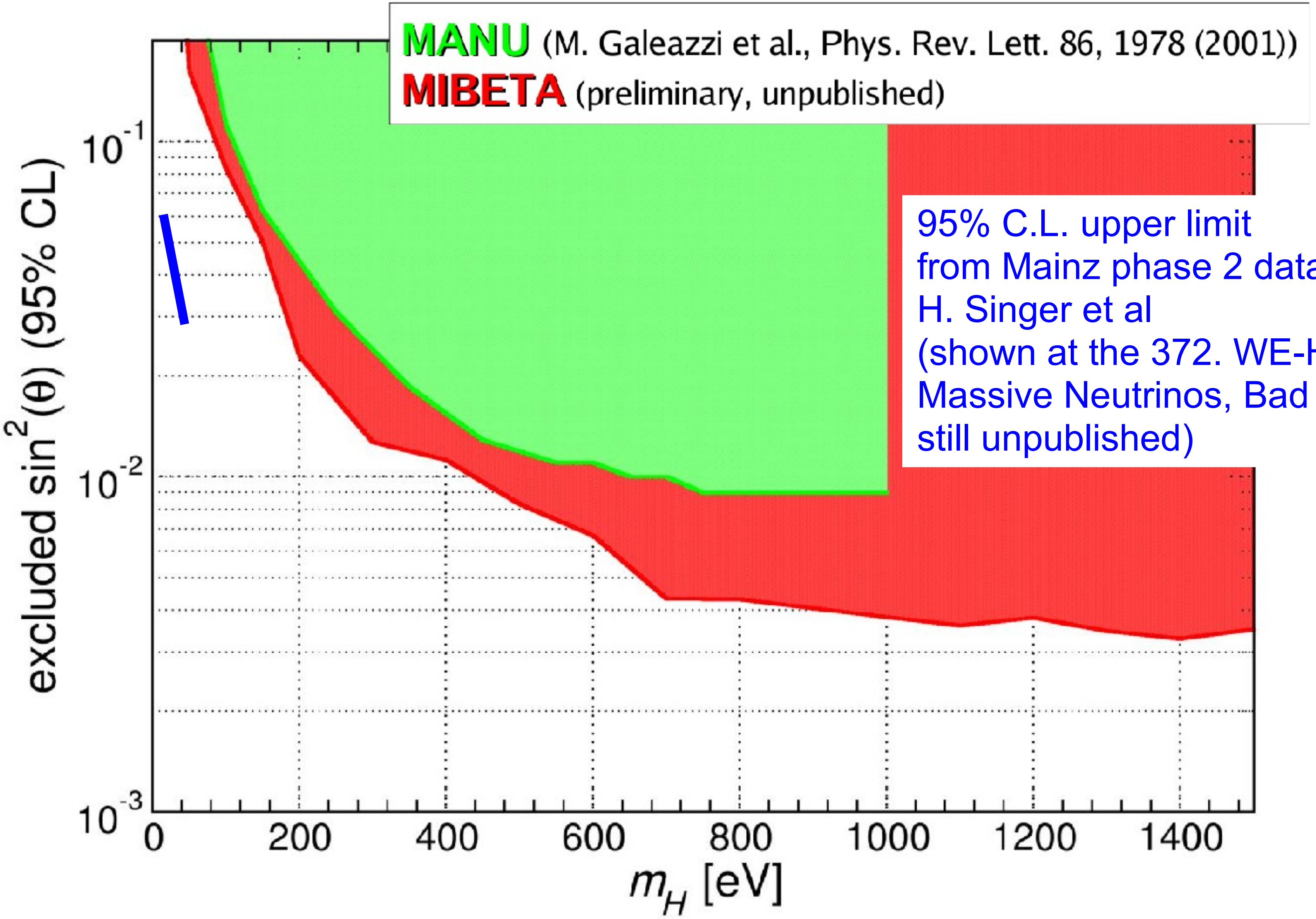
C. Kraus et al., Eur. Phys. J. C 40 (2005) 447
E.W. Otten & C. Weinheimer, Rep. Prog. Phys. 71 (2008) 086201

Statistical and systematic uncertainties of the Mainz 1998-2001 data

C. Kraus et al., Eur. Phys. J. C 40 (2005) 447



Sensivity on sterile neutrinos of previous direct neutrino mass experiments



MANU (M. Galeazzi et al., Phys. Rev. Lett. 86, 1978 (2001))
MIBETA (preliminary, unpublished)

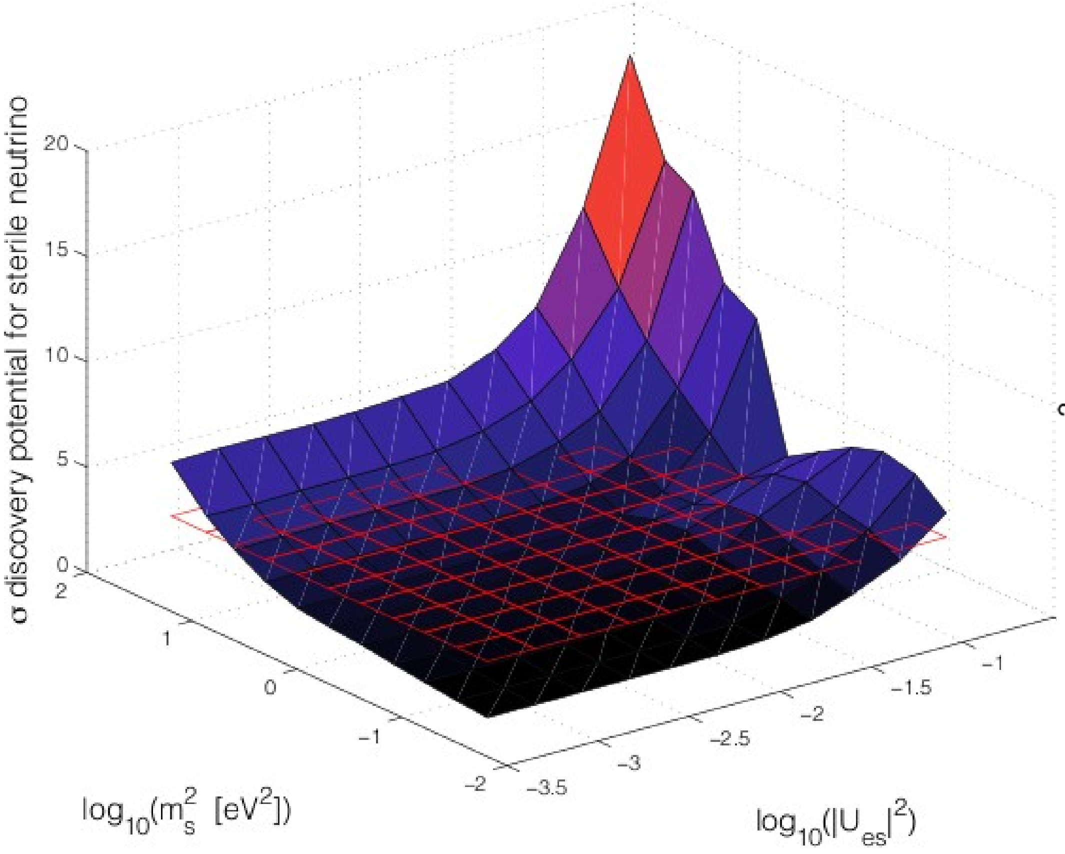
95% C.L. upper limit
from Mainz phase 2 data
H. Singer et al
(shown at the 372. WE-Heraeus seminar:
Massive Neutrinos, Bad Honnef, 2006
still unpublished)

A. Nucciotti, Meudon Workshop 2011, 8-10 JUNE 2011

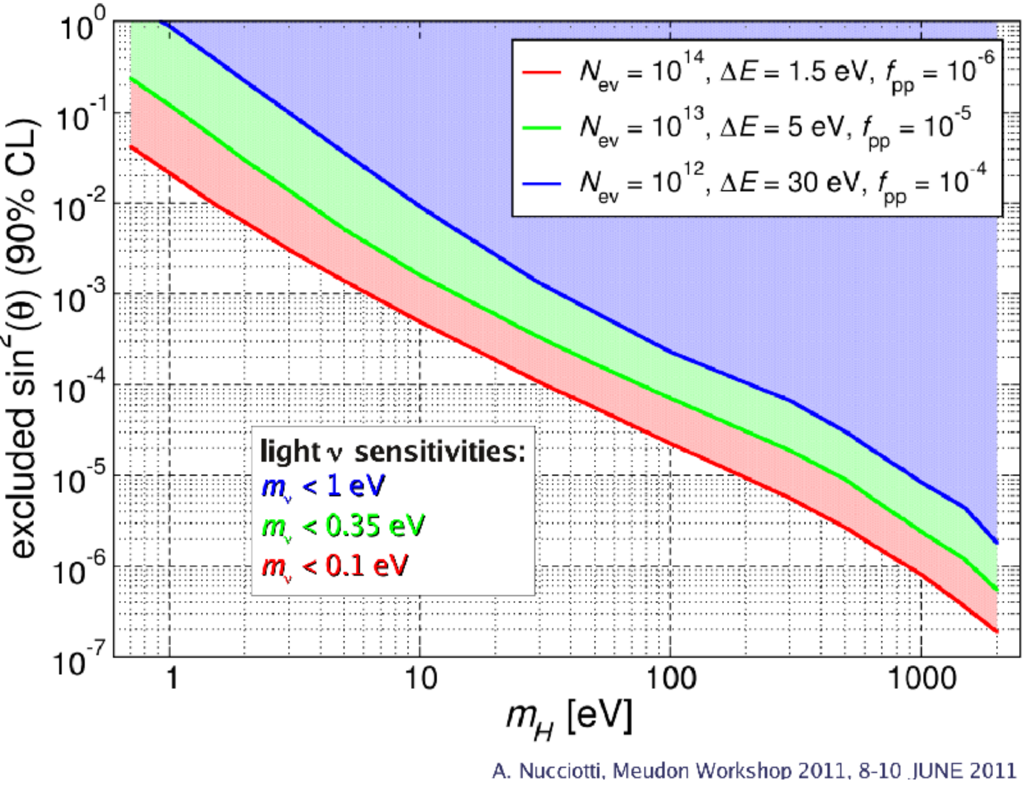
Westfälische
Wilhelms-Universität
Münster

Sensivity on sterile neutrinos of up-coming direct neutrino mass experiments

KATRIN



MARE II



A. Sejersen Riis, S. Hannestad, JCAP02 (2011) 011

A. Nucciotti, Meudon Workshop, June 2011

Conclusions

3 complementary probes of the neutrino mass:

cosmology: very sensitve, but some model-dependence

$0\nu\beta\beta$: very sensitive to Majorana neutrino masses

many experiments under way, GERDA under commissioning

direct neutrino mass determination (MARE, KATRIN):

no other assumptions, kinematics of β-decay at endpoint

KATRIN: 0.2 eV sensitivity:

2009-11 commissioning of main spectrometer and detector

2009-12 commissioning of tritium source and tritium elimination lines

2013- regular data taking for 5-6 years (3 full-beam-years)

Sterile neutrinos:

Direct neutrino mass search non neutrinoless double beta decay:

cryobolometer: for heavy masses (cosmology)

electron spectrometers for light masses (reactor neutrino anomaly, MiniBooNE)

Many thanks for providing important informations to

E. Fiorini, J. Formaggio, G. Gratta, A. Giuliani, S. Schönert, K. Zuber, ...