How to improve the sensitivity of future neutrino mass experiments with thermal calorimeters

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While the existence of a non-vanishing neutrino mass is definitely proved by the evidence for neutrino flavour oscillations, the absolute value of this mass is still unknown.
Experiments using spectrometers have set a limit on the electron anti-neutrino mass of about 2 eV, while experiments using thermal microcalorimeters have reached sensitivities of about 10 eV. A new experiment to measure the neutrino mass with a sensitivity of about 0.25 eV using a large electrostatic retarding spectrometer (KATRIN) is planned to start taking data in 2007.
In this poster we discuss the perspectives for a new generation of neutrino mass experiments using thermal detectors to reach scientifically interesting sensitivities before and after the KATRIN experiment. By scaling the performance of the present Milano neutrino mass experiment with Montecarlo simulations, we show how a new experiment can validate the present limit of few eV set by spectrometers before the KATRIN experiment starts. We also show how such a result can be used to design a very large thermal detector experiment to reach sensitivities beyond the KATRIN expected one.

1. Montecarlo simulation

- generate 1000 simulated experiments
  - calculate total β spectrum
  - $S(E) = (N_{ev}\,(N_\beta(E) + f_{pile\text{-}up} N_\beta(E) \otimes N_\beta(E)) + b(E)) \otimes g(E)$
    - N_{ev} total β statistics
    - $N_\beta(E)$ ^{187}Re spectrum (usually for $m_\nu = 0$), normalized to 1
    - $f_{pile\text{-}up}$ fraction of unresolved β pile-up events
    - $b(E)$ background (usually constant)
    - $g(E)$ detector energy resolution function (usually gaussian)
  - generate 1000 spectra introducing Poisson fluctuations in $S(E)$
  - fit the spectra with standard technique (*see poster U12*)
- obtain **90% C.L. m_ν sensitivity** from $\sqrt{(1.64\sigma)}$ of m_ν^2 distribution

2. Montecarlo ⇔ experimental parameters

- relationships between Montecarlo input parameters and real experiment parameters
  - $N_{ev} = N_{det} \times t_M \times A_\beta$
    - N_{det} number of detectors
    - t_M measuring time
    - A_β activity of single detector
  - $f_{pile\text{-}up} \approx \Delta t \times A_\beta$
    - $\Delta t \approx 3\tau_{rise}$ time resolution for pile-up identification (*see poster U12*)
  - $g(E)$: gaussian energy resolution function
    - ΔE FWHM detector energy resolution

3. Comparison with the Milano experiment

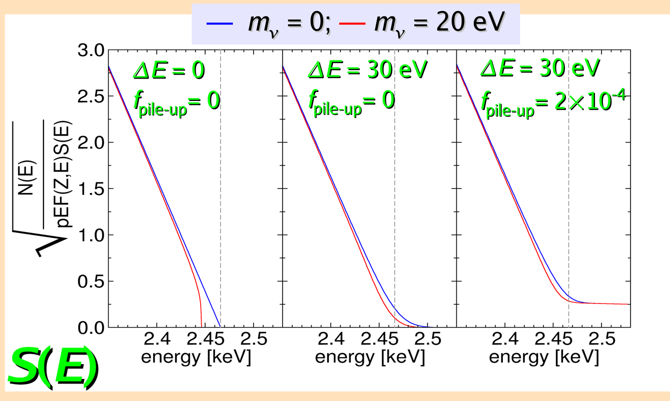
experiment

N_{det}	8
t_M [y]	0.59
$\langle A_\beta \rangle$ [dec/s]	0.15
$\langle m_{AgReO_4} \rangle$ [μg]	271
N_{ev} [$\times 10^6$]	16.7
$\langle \tau_{rise} \rangle$ [μs]	490
$\langle \Delta E \rangle$ [eV]	28.5
$\langle b \rangle$ [c/keV/det]	26.3
m_ν 90% CL limit [eV]	15

⇔

MC simulation

N_{ev} [$\times 10^6$]	17
$f_{pile\text{-}up}$	2×10^{-4}
ΔE [eV]	29
b [c/keV]	210
m_ν 90% CL limit [eV]	16±1

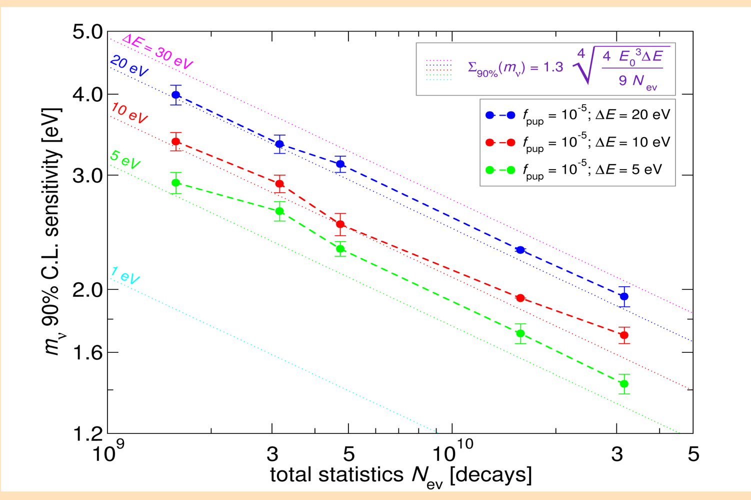


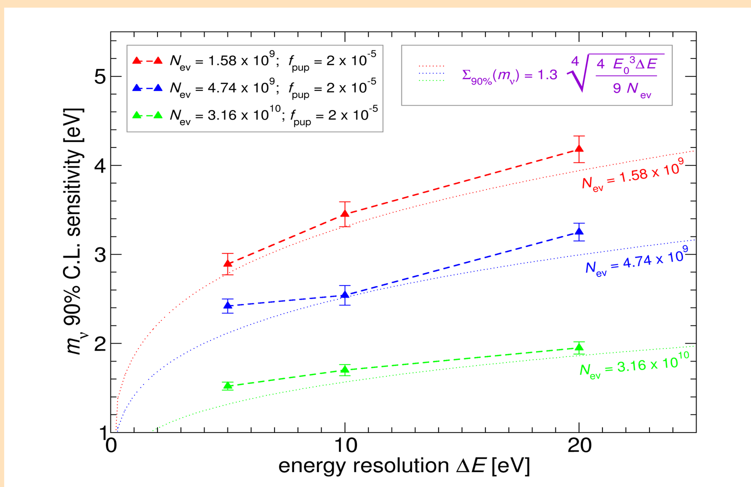
4. m_ν sensitivity

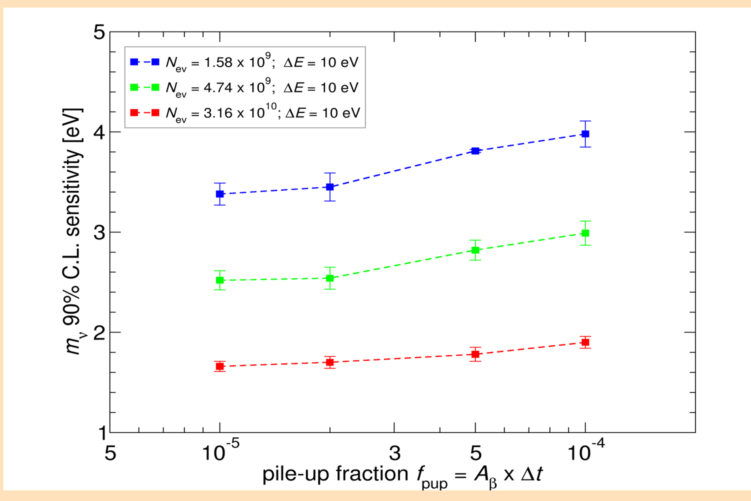
- from pure statistical considerations ⇨

$$\Sigma(m_{\bar\nu_e}) \propto \sqrt[4]{\frac{E_0^3 \Delta E}{A_\beta t_M}} \propto \sqrt[4]{\frac{1}{N_{ev}}}$$

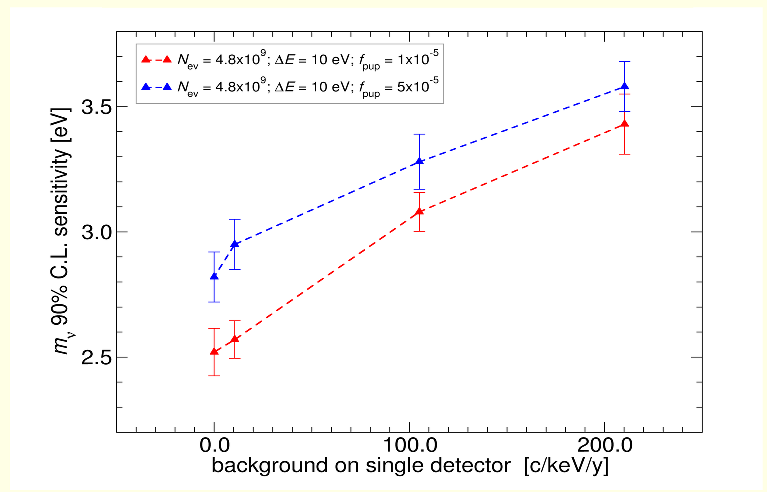
where:
- E_0: β spectrum end-point
- $\Sigma(m_\nu)$: neutrino mass sensitivity
- from Montecarlo simulations ⇩







- **if the background scales with the detector mass**
  - $N_{det} = 200$
  - $A_\beta = 0.25$ Hz
  - $t_M = 3$ y
  - $b = 105$ c/keV/y on the single detector is the scaled background of the present Milano experiment



5. A new Milano neutrino mass search: first phase

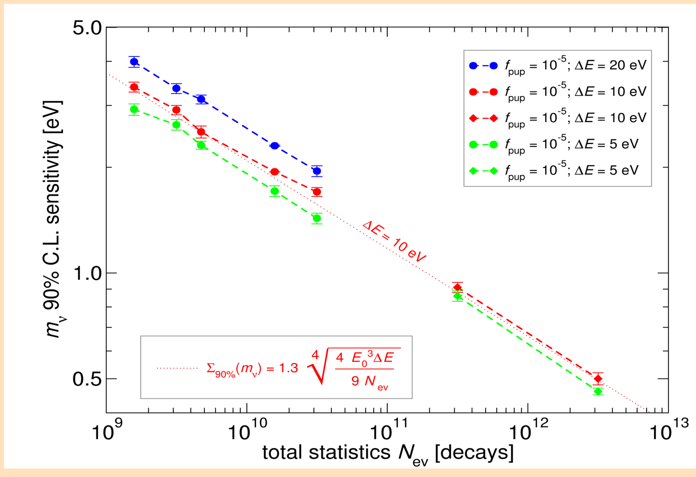
- **aim**: reach a sensitivity of about 2 eV before the KATRIN experiment ends
- possible experimental configurations (b = 0):

Montecarlo input parameters			90% CL sensitivity	Possible experimental configurations			
N_{ev} [$\times10^9$]	$f_{pile\text{-}up}$ [$\times10^{-5}$]	ΔE [eV]	m_ν [eV]	N_{det}	t_M [y]	$\langle A_\beta \rangle$ [dec/s]	$\langle \Delta t \rangle$ [μs]
1.4	2.0	10	3.5	100	2	0.20	100
3.2	2.5	10	3.0	200	2	0.25	100
4.7	2.5	10	2.5	200	3	0.25	100

- micromachined arrays of implanted silicon thermistors or Ge-NTDs
- experimental technical challenges:
  - improve energy resolution ΔE from 30 eV to 10 ÷ 15 eV
  - improve time resolution Δt from 1 ms to 100 ÷ 200 μs
  - reduce background at least a factor 10

6. Second phase: a next generation experiment

- **aim**: be an alternative to the KATRIN experiment
  - first phase must succeed...
    - no unexpected source of systematics
  - a very large collaboration is needed
  - really innovative techniques are required
- results would come much later than the KATRIN experiment
  - it could be really interesting in case KATRIN fails the target



Montecarlo input parameters			90% CL sensitivity	Possible experimental configurations			
N_{ev}	$f_{pile\text{-}up}$ [$\times10^{-4}$]	ΔE [eV]	m_ν [eV]	N_{det}	t_M [y]	$\langle A_\beta \rangle$ [dec/s]	$\langle \Delta t \rangle$ [μs]
3.2×10^{10}	1.0	5	1.7	500	2	1	100
3.2×10^{12}	1.0	5	0.5	1000	10	10	10
3.2×10^{13}	1.0	5	0.3	1000	10	100	1

7. Conclusions

- Montecarlo simulations show a feasible way to reach sensitivities similar or better than present spectrometers limits
- Further improvements maybe unrealistic

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Katrin					0.3 eV								
Phase I				2 eV									
future													0.3 eV

U10