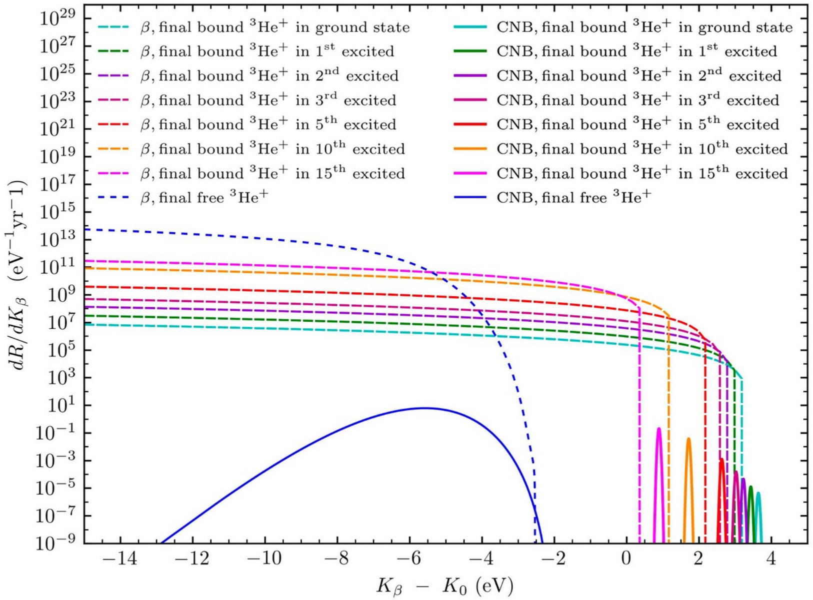
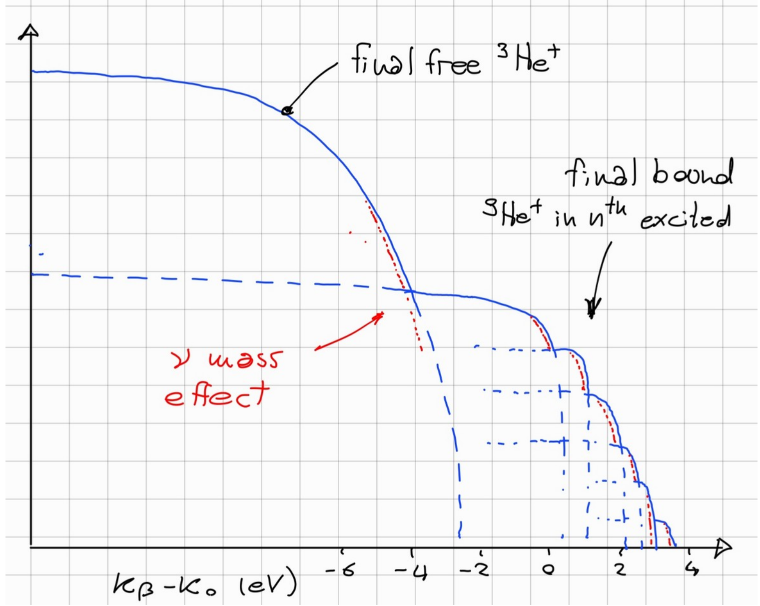
Neutrino mass sensitivity with the Ptolemy demonstrator: approach 1

Angelo Nucciotti
Physics Department, University of Milano-Bicocca
INFN Sezione Milano-Bicocca

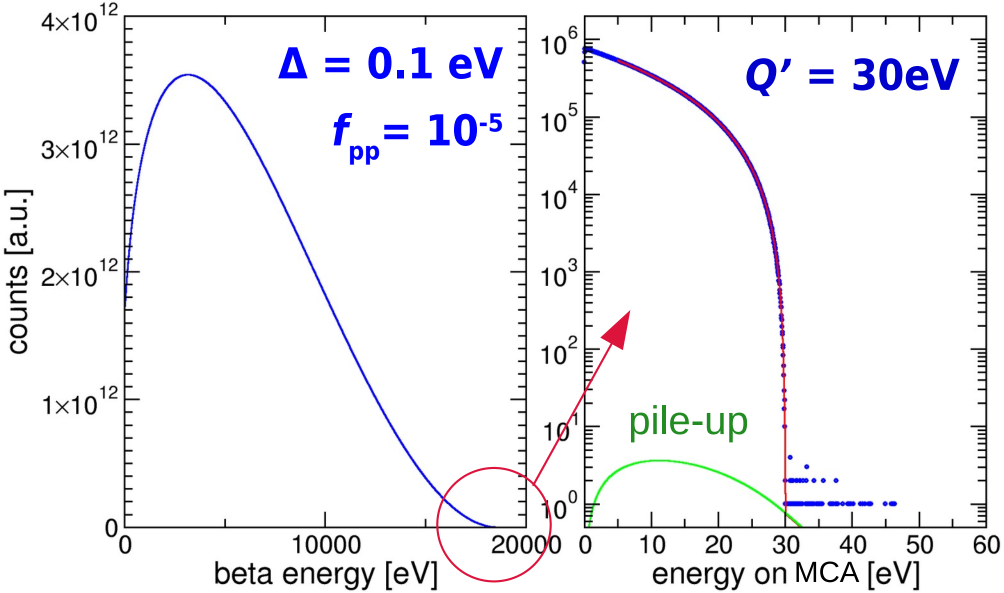
PTOLEMY meeting, Princeton 6-8 November 2023

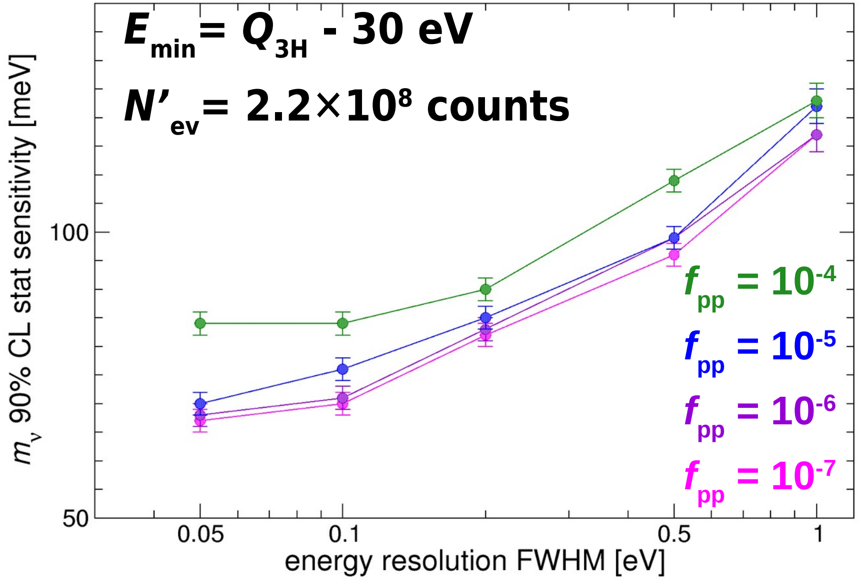
- sensitivity estimate for “bare” Tritium spectrum (i.e. in vacuum decay)
- effect on sensitivity of Heisenberg ZPF in the initial state for free $^3He^+$ decay
- **TODO**: sensitivity from analysis of end-points of bound $^3He^+$ decays





PTOLEMY demonstrator neutrino mass statistical sensitivity / 1





Simulated tritium spectrum in PTOLEMY demonstrator for

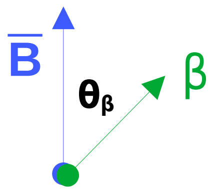
- **1 µg** of ^{3}H (≈50 cm^2 at 100% graphene loading) → $\boldsymbol{A_{3H}}$**=370 MBq**
- 3 year measurement (t_M)
- EMF selection: $\boldsymbol{E_{min}=q_e(V_{3H}-V_{TES}) \rightarrow Q'=Q_{3H} - E_{min}}$
- rate on TES microcal array (MCA) $\boldsymbol{A' \approx 3A_{3H}(Q'/Q_{3H})^{3/2}}$
- pile-up probability $\boldsymbol{f_{pp}=A'\ \tau_R\ /\ n_{pix}}$ (TES τ_R time resolution)
- for Q'=30 eV → A'=2.3 c/s → $f_{pp}=10^{-5}$ for n_{pix}=1 and τ_R=1 µs

PTOLEMY demonstrator statistical sensitivity estimated by frequentist approach

- $\boldsymbol{N'_{ev} = \eta\ A'\ t_M}$
- pitch angle acceptance η=1 (i.e. 0<θ_β≤180°)
- no background

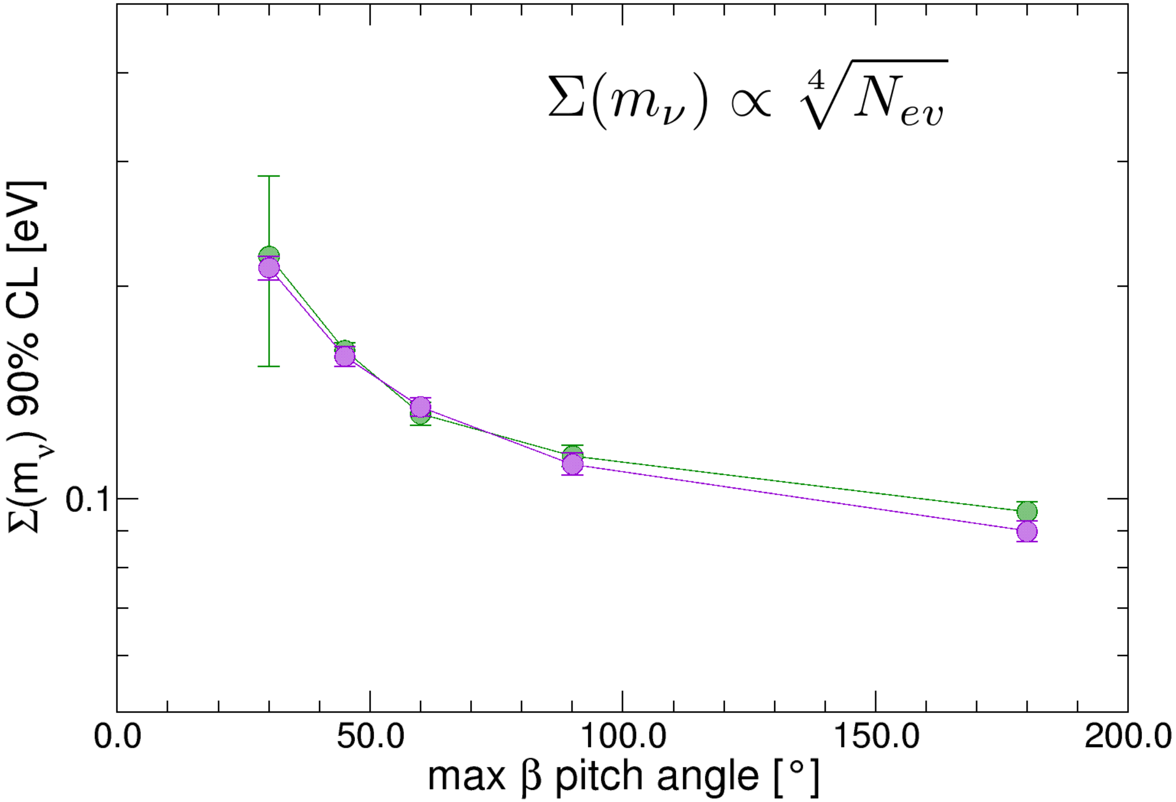
A.Nucciotti, et al., Astropart.Phys. 34 (2010) 80–89; https://doi.org/10.1016/j.astropartphys.2010.05.004

PTOLEMY demonstrator neutrino mass statistical sensitivity / 2



PTOLEMY demonstrator statistical sensitivity estimated by frequentist approach

- pitch angle acceptance η for θ_β = 30°, 45°, 60°, 90°, 180°
- geometrical TES efficiency (coverage): 0.5
- **N'_{ev} = 0.5 η A' t_M**
- **f_{pp} = 0.5 η A' τ_R / n_{pix}**
- ΔE_{FWHM}=0.1eV



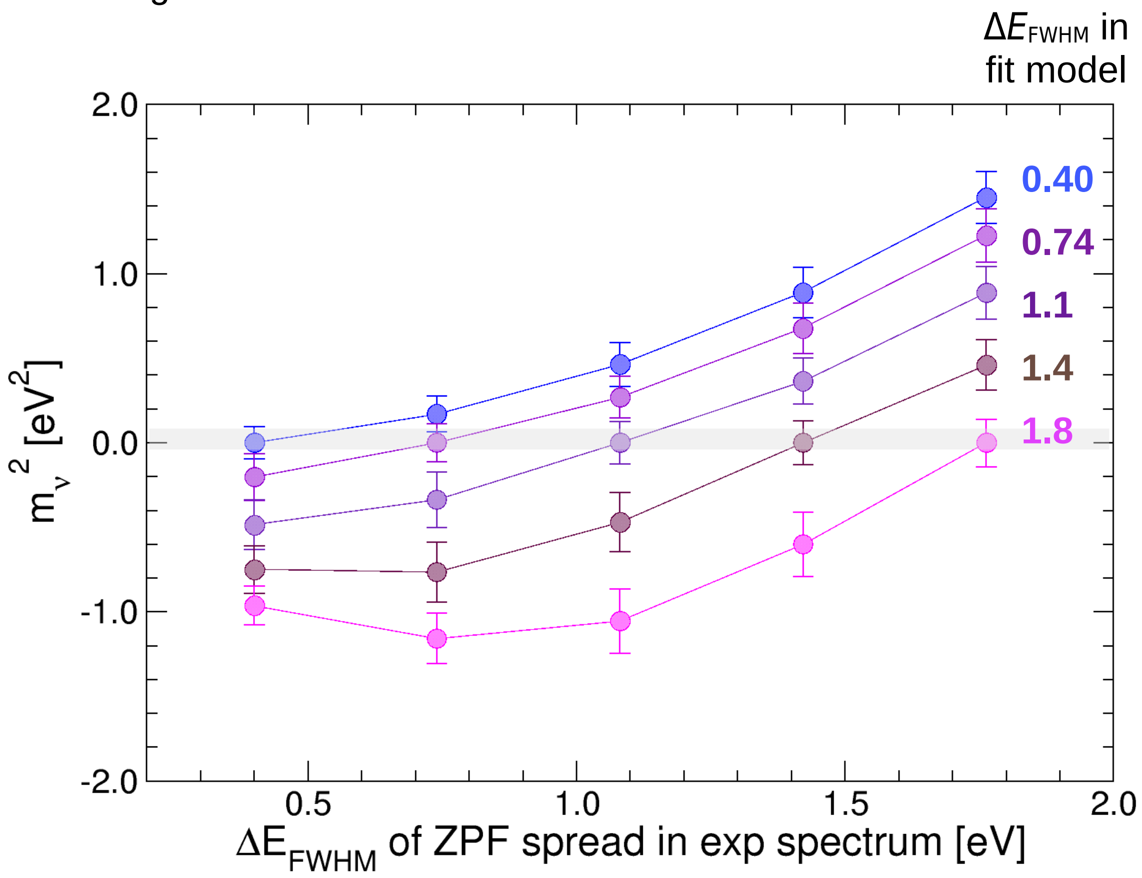
PTOLEMY demonstrator neutrino mass systematic effects / 1

Systematic uncertainty because of unknown Heisenberg ZPF broadending

- ZPF broadening with 0.17 eV $\leq \Delta E \leq$ 0.75 eV (5 values in the interval)
- ZPF broadening in “experimental spectra” vs. broadening in fit “model”
- perfectly known TES resolution ΔE_{FWHM}=0.1eV
- pitch angle acceptance η=1

Potential	Source	κ, [eV/Å^2]	λ, [Å]	ΔE, [eV]
Chemisorption	[23]	2.15	0.16	0.60
	[21], GGA	4.62	0.13	0.73
	[21], vdW-DF	4.9	0.13	0.75
Physisorption	[24]	0.08	0.37	0.26
	[23]	0.09	0.34	0.28
	[21], GGA	0.18	0.29	0.33
	[21], vdW-DF	0.13	0.32	0.3
	[22], GGA	0.04	0.43	0.22
	[22], LDA	0.01	0.55	0.17
Migration	[26]	0.283	0.264	0.37

https://doi.org/10.1103/PhysRevD.104.116004



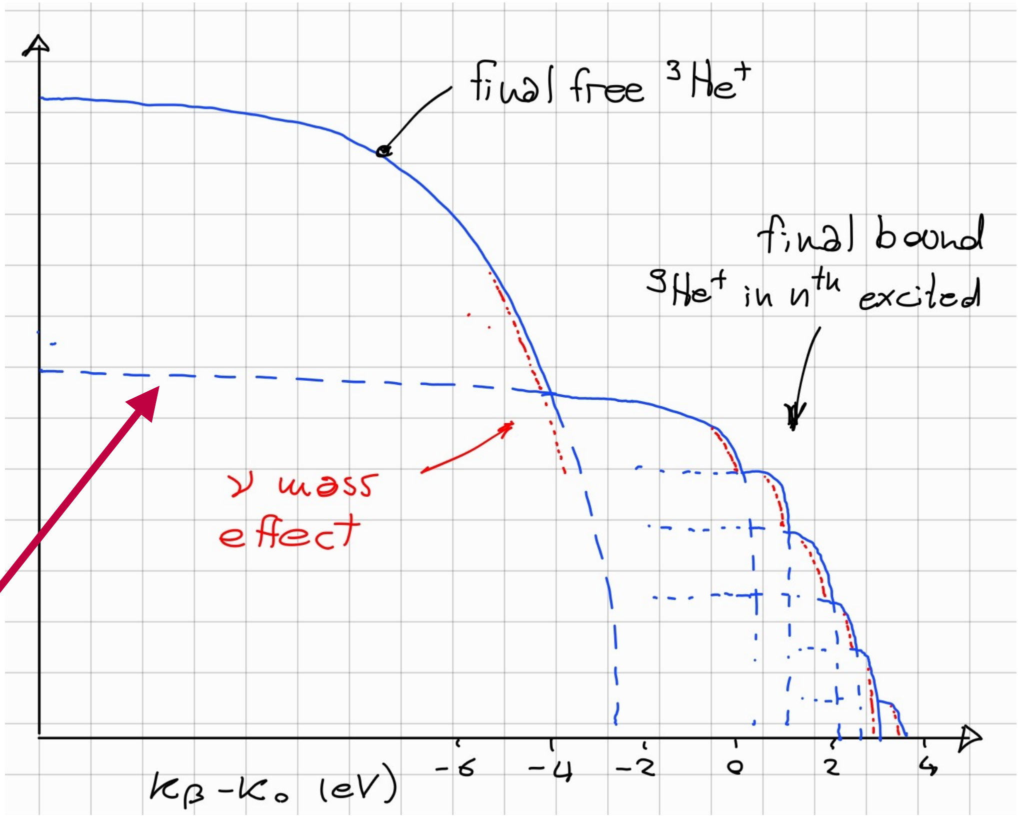
PTOLEMY demonstrator neutrino mass systematic effects / 1

Systematic uncertainty because of unknown Heisenberg ZPF broadending

- ZPF broadening with 0.17 eV $\leq \Delta E \leq$ 0.75 eV (5 values in the interval)
- ZPF broadening in “experimental spectra” vs. broadening in fit “model”
- perfectly known TES resolution ΔE_{FWHM}=0.1eV
- pitch angle acceptance η=1

Potential	Source	κ, [eV/Å^2]	λ, [Å]	ΔE, [eV]
Chemisorption	[23]	2.15	0.16	0.60
	[21], GGA	4.62	0.13	0.73
	[21], vdW-DF	4.9	0.13	0.75
Physisorption	[24]	0.08	0.37	0.26
	[23]	0.09	0.34	0.28
	[21], GGA	0.18	0.29	0.33
	[21], vdW-DF	0.13	0.32	0.3
	[22], GGA	0.04	0.43	0.22
	[22], LDA	0.01	0.55	0.17
Migration	[26]	0.283	0.264	0.37

https://doi.org/10.1103/PhysRevD.104.116004



background due
to bound state decays
not included!

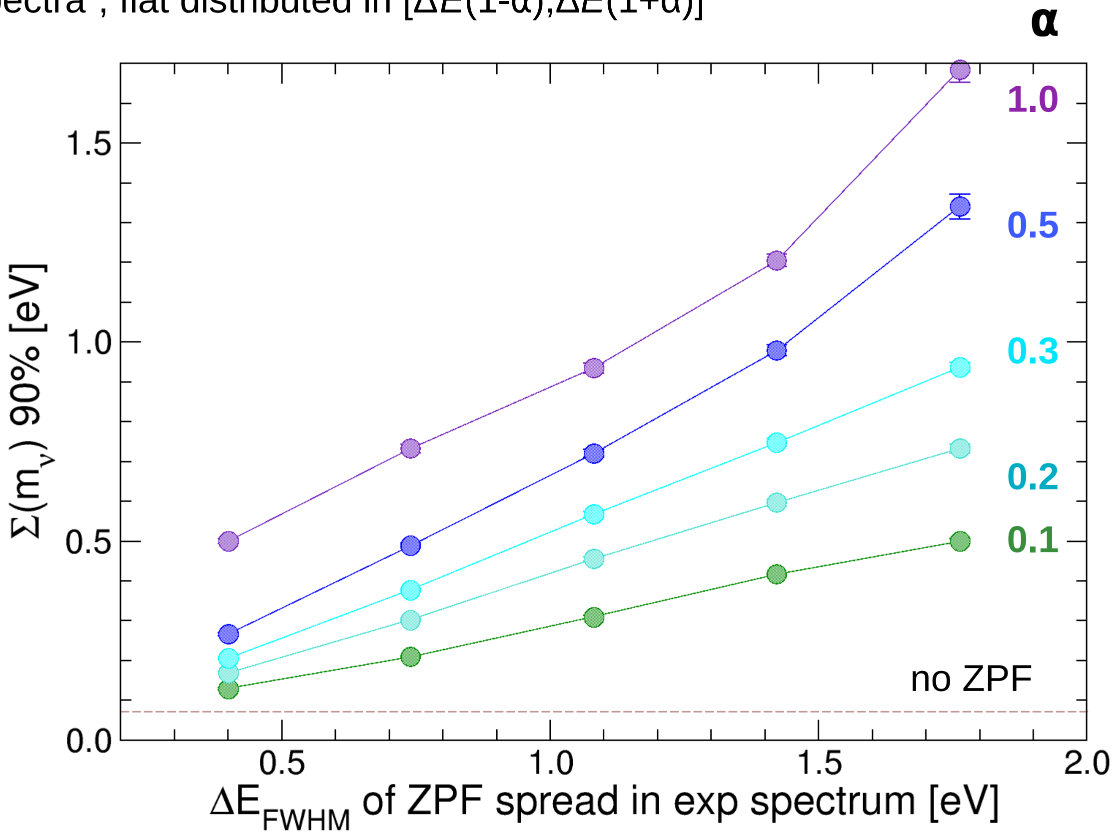
PTOLEMY demonstrator neutrino mass systematic effects / 2

Systematic uncertainty because of unknown Heisenberg ZPF broadending

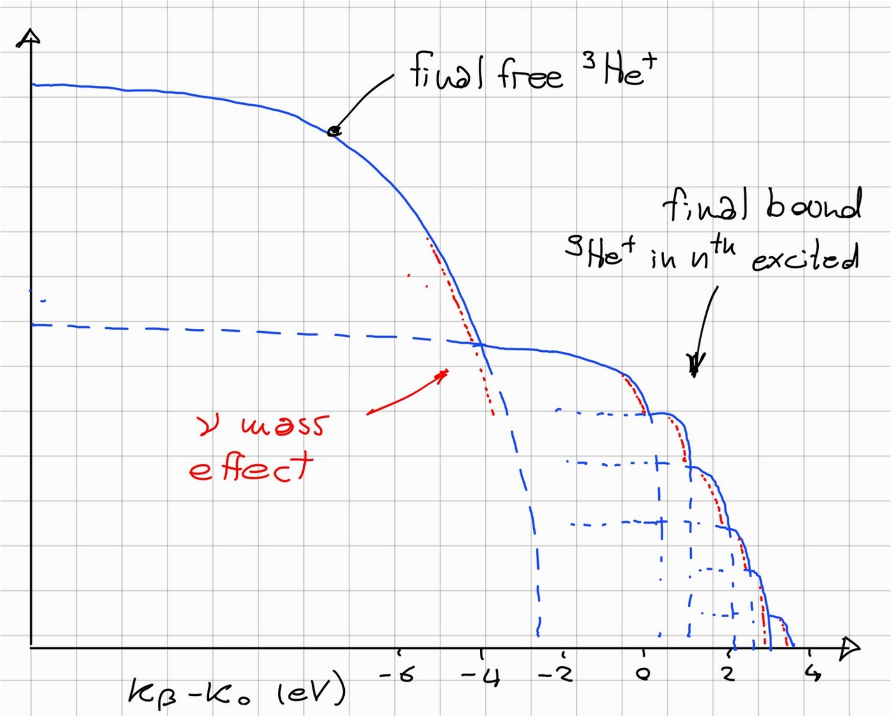
- ZPF broadening with 0.17 eV $\leq \Delta E \leq$ 0.75 eV (5 values in the interval)
- **complete ignorance**
  - uncertain ZPF broadening in "experimental spectra", flat distributed in $[\Delta E(1-\alpha), \Delta E(1+\alpha)]$
  - fit "model" with only TES resolution
- perfectly known TES resolution ΔE_{FWHM}=0.1eV
- pitch angle acceptance η=1

Potential	Source	κ, [eV/Å²]	λ, [Å]	ΔE, [eV]
Chemisorption	[23]	2.15	0.16	0.60
	[21], GGA	4.62	0.13	0.73
	[21], vdW-DF	4.9	0.13	0.75
Physisorption	[24]	0.08	0.37	0.26
	[23]	0.09	0.34	0.28
	[21], GGA	0.18	0.29	0.33
	[21], vdW-DF	0.13	0.32	0.3
	[22], GGA	0.04	0.43	0.22
	[22], LDA	0.01	0.55	0.17
Migration	[26]	0.283	0.264	0.37

https://doi.org/10.1103/PhysRevD.104.116004



PTOLEMY demonstrator neutrino mass systematic effects / 3



- **Sensitivity estimates Including intial and final states**
  - Use complete composite spectrum with neutrino mass affecting all spectra end-points
- Inputs for simulation:
  - ZPF broadening in final free $^3He^+$ decay **known** from theory
    - Resitdual theoretical uncertainties → systematic uncertainties
  - **known** branching ratios between free and bound $^3He^+$ decays
  - **known** end-points for final free and bound $^3He^+$ decays
- Expected consequences
  - ZPF ΔE≈1 eV would limit statistical sensitivity
  - Background from higher end-point spectra would limit statistical sensitivity
  - Decay on final bound $^3He^+$ in 1st excited has too low rate at end-point