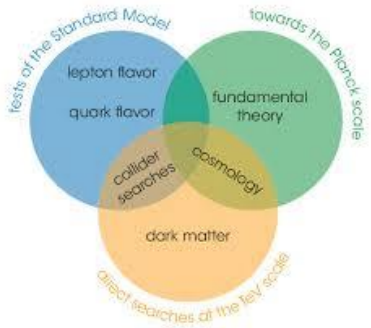
KATRIN Latest Results On the Neutrino Mass



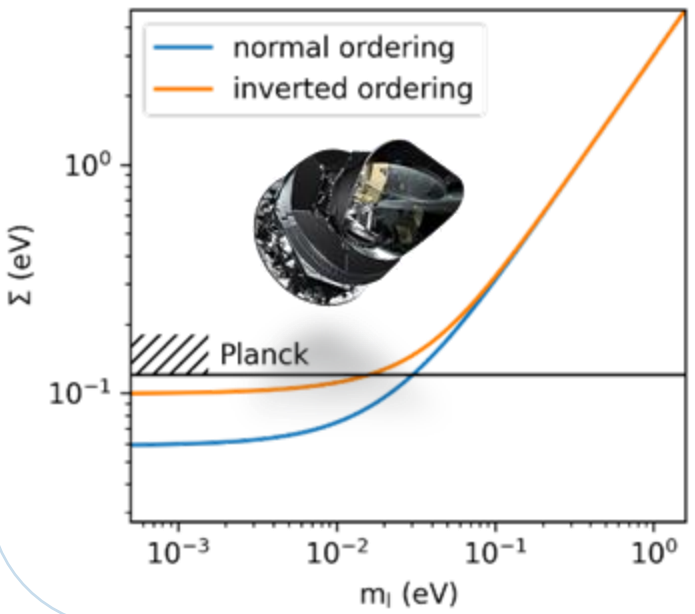
IRN neutrino meeting , Paris, 10/10/2024

T. Lasserre, CEA & TUM

Neutrino mass(es)

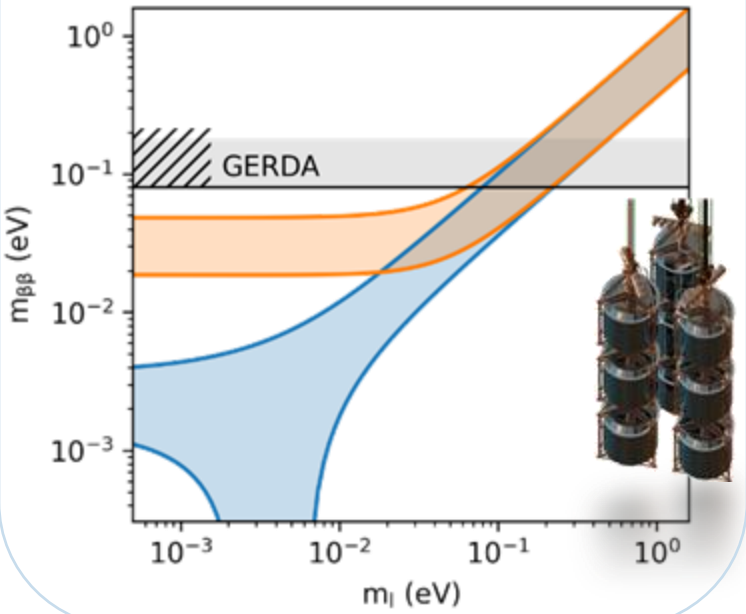
Cosmology

$$\Sigma = \sum_i m_i$$



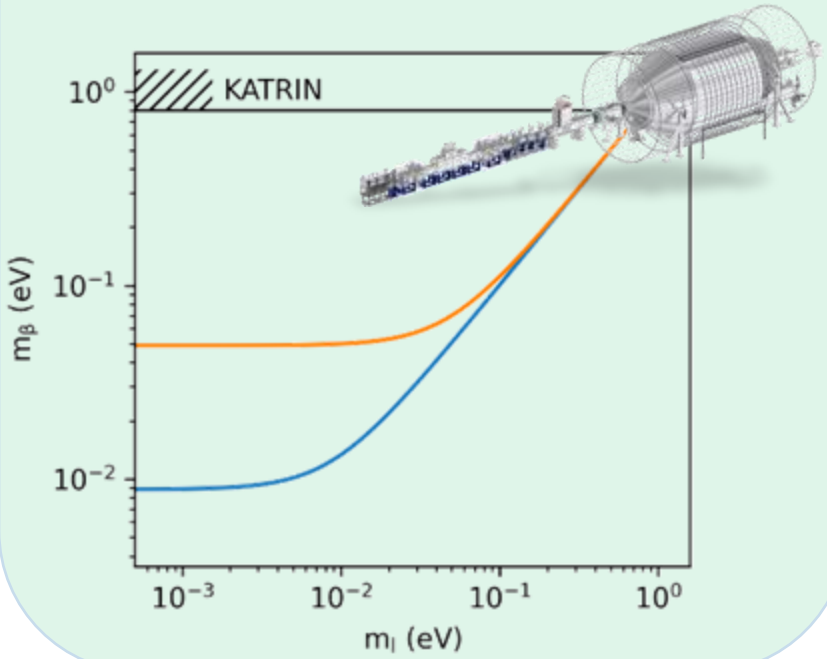
Neutrinoless ßß decay

$$m_{\beta\beta} = \sum_i U_{ei}^2 \cdot m_i$$

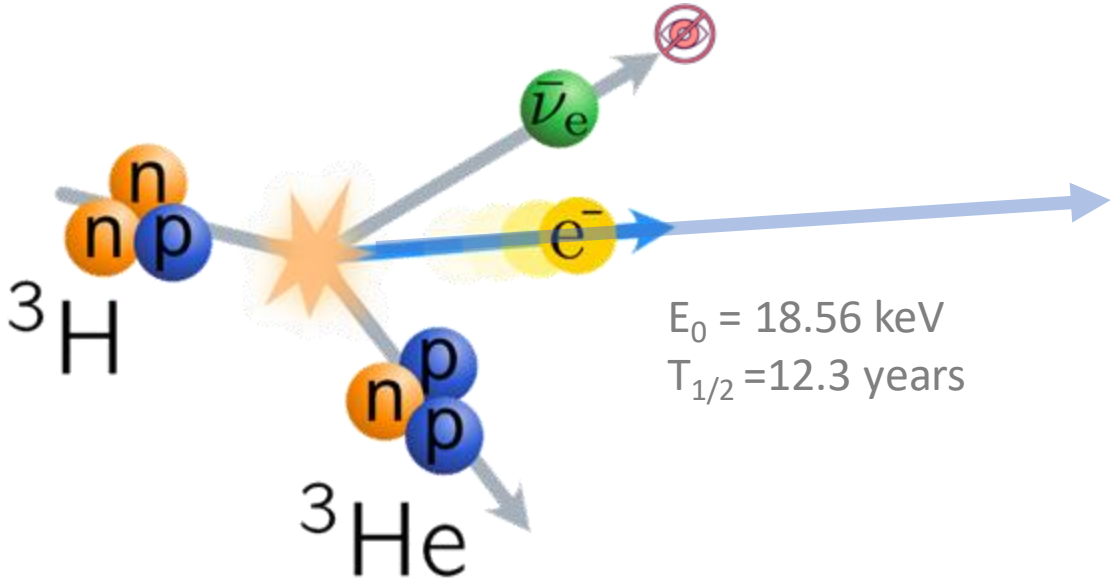


ß-decay kinematics

$$m^2_{\nu/\beta} = \sum_i |U_{ei}|^2 \cdot m_i^2$$



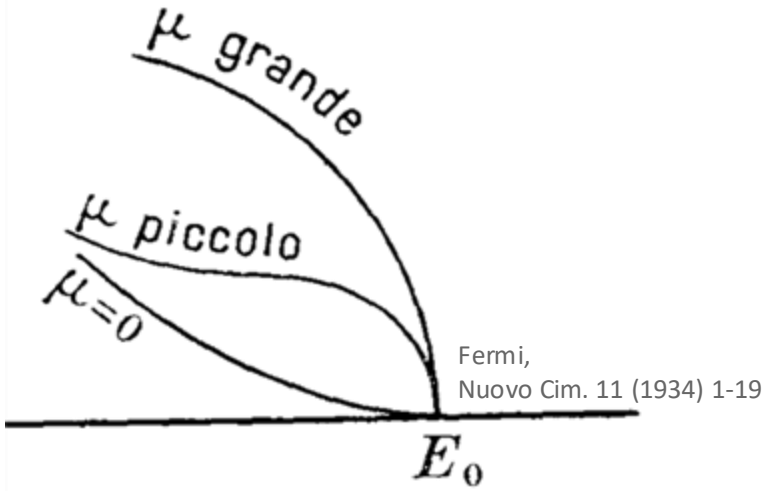
Kinematic neutrino mass measurement



E_0 = 18.56 keV
$T_{1/2}$ =12.3 years

- ✓ based on kinematics and energy conservation
- ✓ m_ν^2 spectral distortion, maximal at endpoint energy E_0
- ✓ incoherent neutrino mass : $m_\nu^2 = \sum_i |U_{ei}|^2 \cdot m_i^2$

- ✓ measurement of the electron β −spectrum
  - independent of cosmology
  - independent of neutrino nature

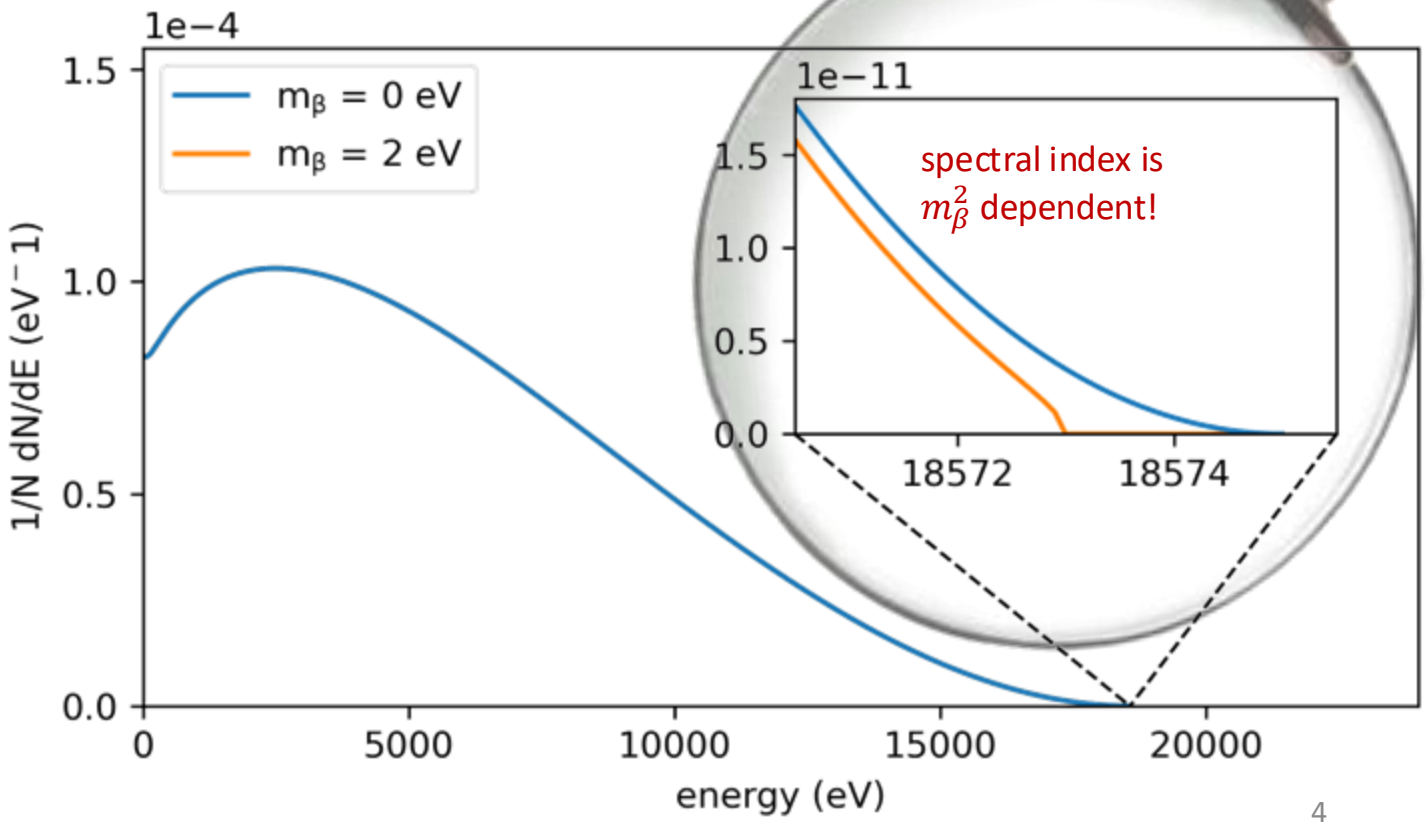


Fermi,
Nuovo Cim. 11 (1934) 1-19

KATRIN experimental challenges

- ✓ strong tritium source: 10^{11} decays/s
- ✓ < 0.1 cps background
- ✓ ~1 eV resolution
- ✓ 0.1% understanding of the spectrum shape
- ✓ 0.1% hardware stability controlled over the years

10^{-8} of all decays in last 40 eV



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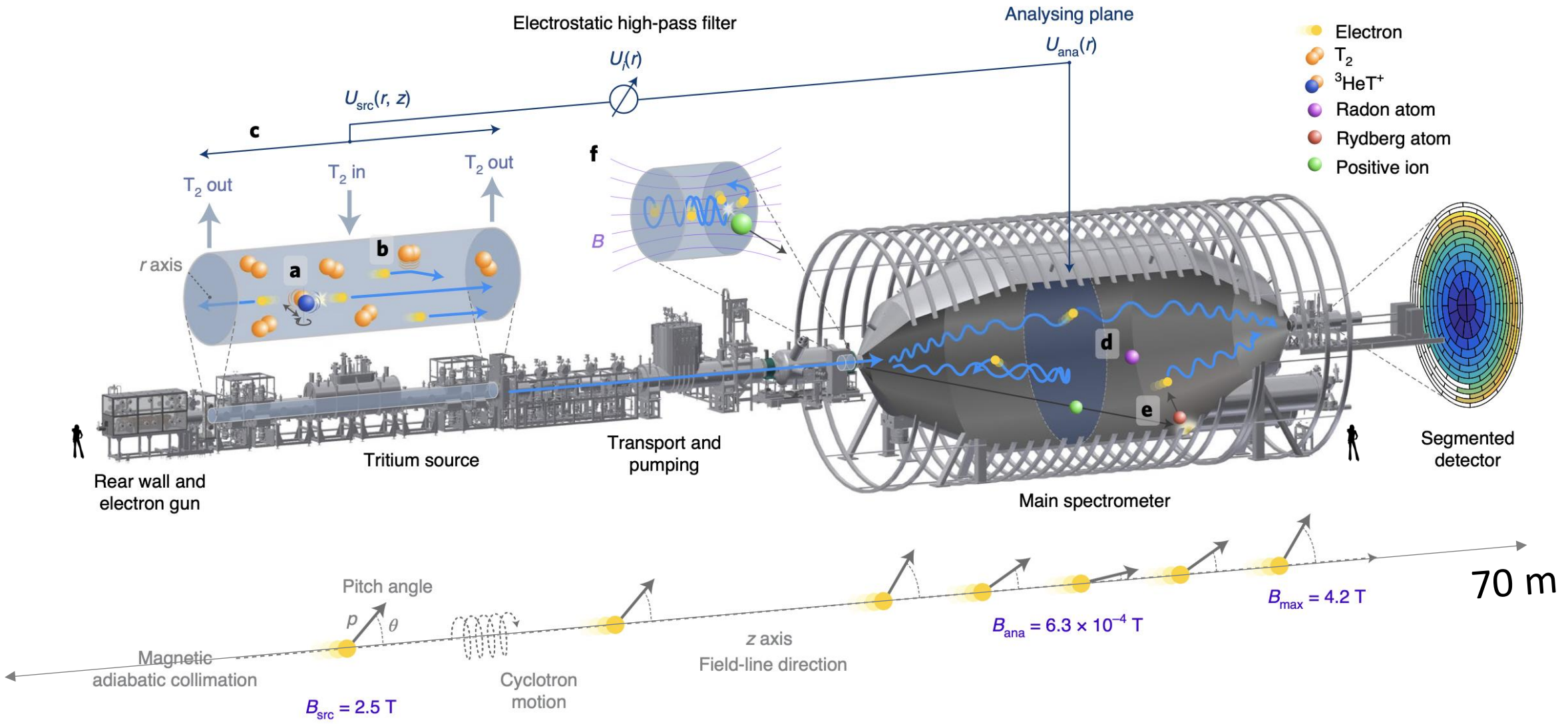
Working Principle

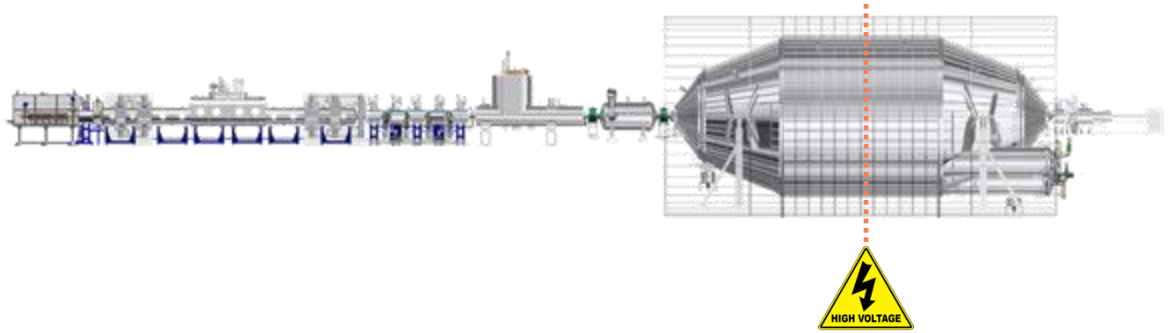


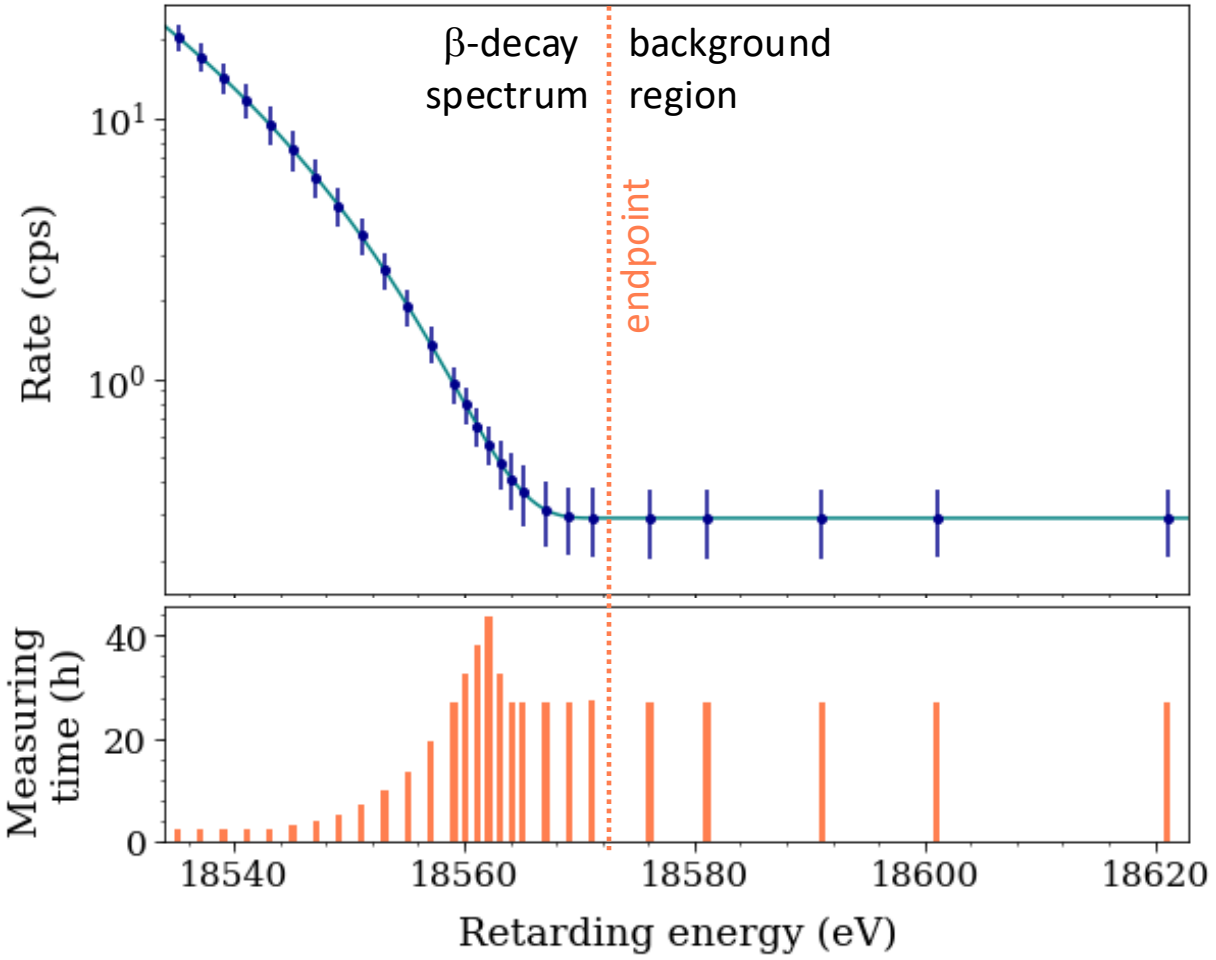
Measurement strategy

Integral spectral measurement !

β-scans illustration:

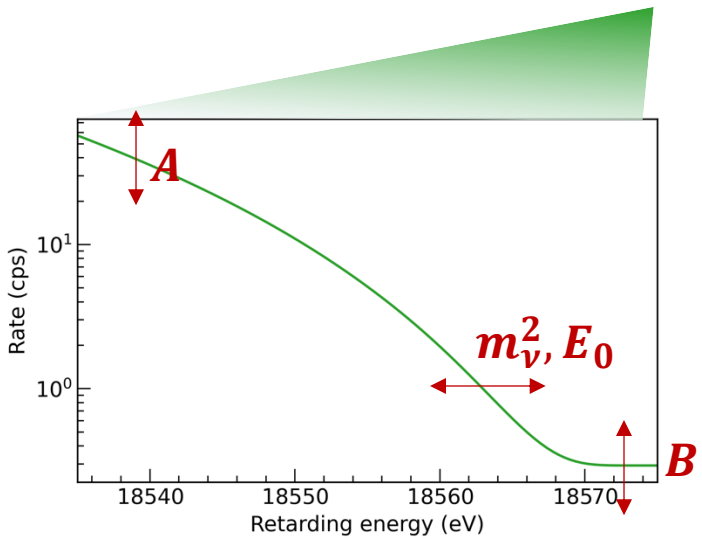
- ✓ scan points: ~30 HV set points
- ✓ scan interval: $E_0 - 40$ eV , $E_0 + 135$ eV
- ✓ scan time: ~2 hours

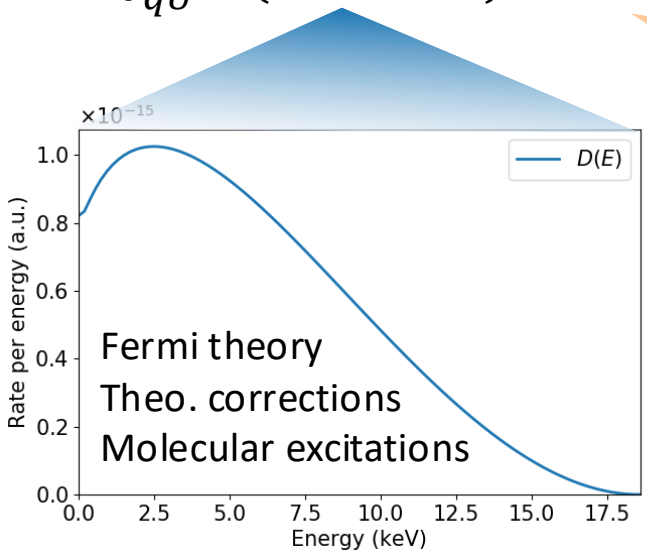


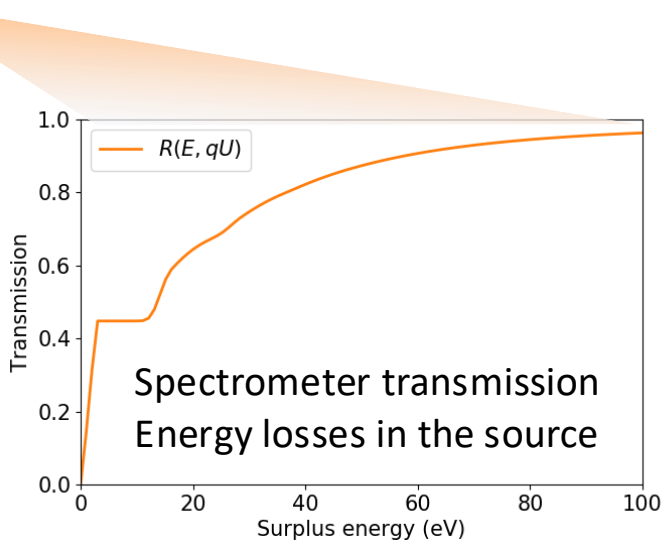


Analysis strategy

✓ fit of theoretical prediction: $\Gamma(qU) \propto \boldsymbol{A} \cdot \int_{qU}^{\boldsymbol{E_0}} D\left(E; \boldsymbol{m_\nu^2}, \boldsymbol{E_0}\right) \cdot R(qU, E)\, dE + \boldsymbol{B}$





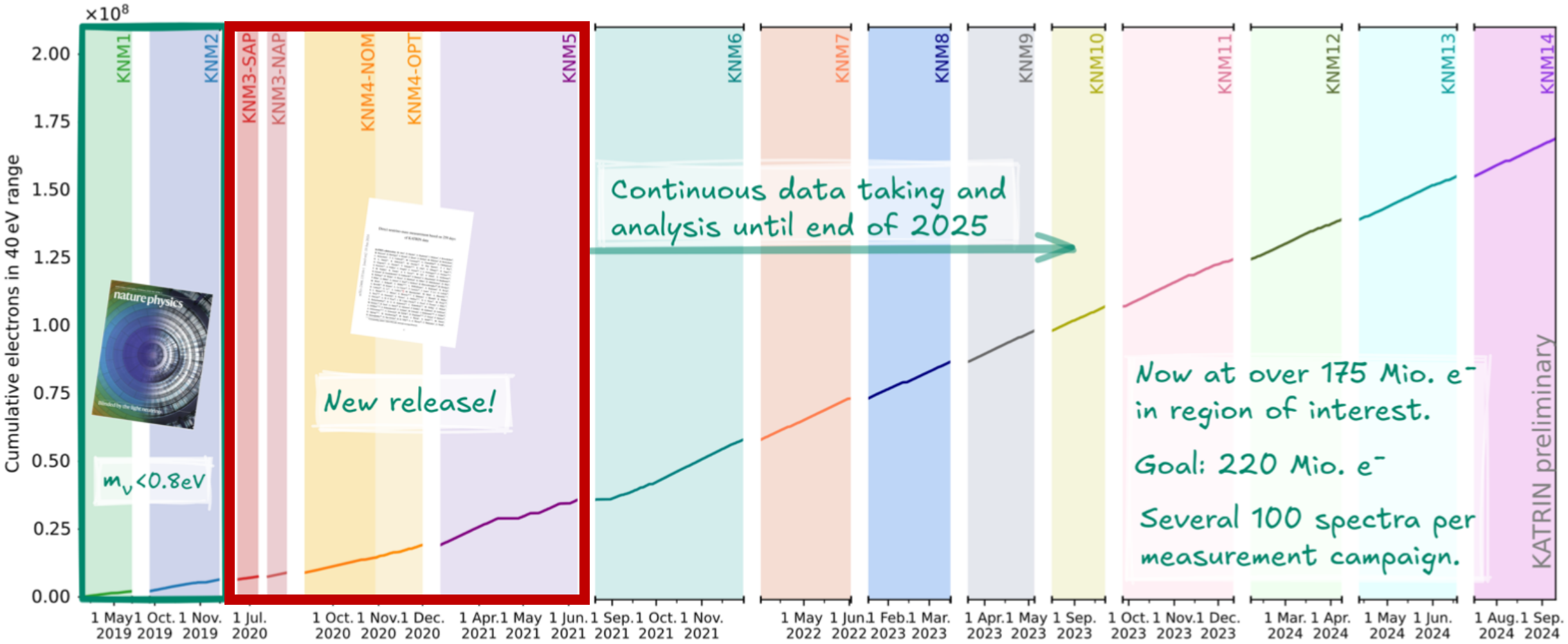


✓ neutrino mass fit parameters: $\boldsymbol{m_\nu^2}, \boldsymbol{E_0}, \boldsymbol{B}, \boldsymbol{A}$

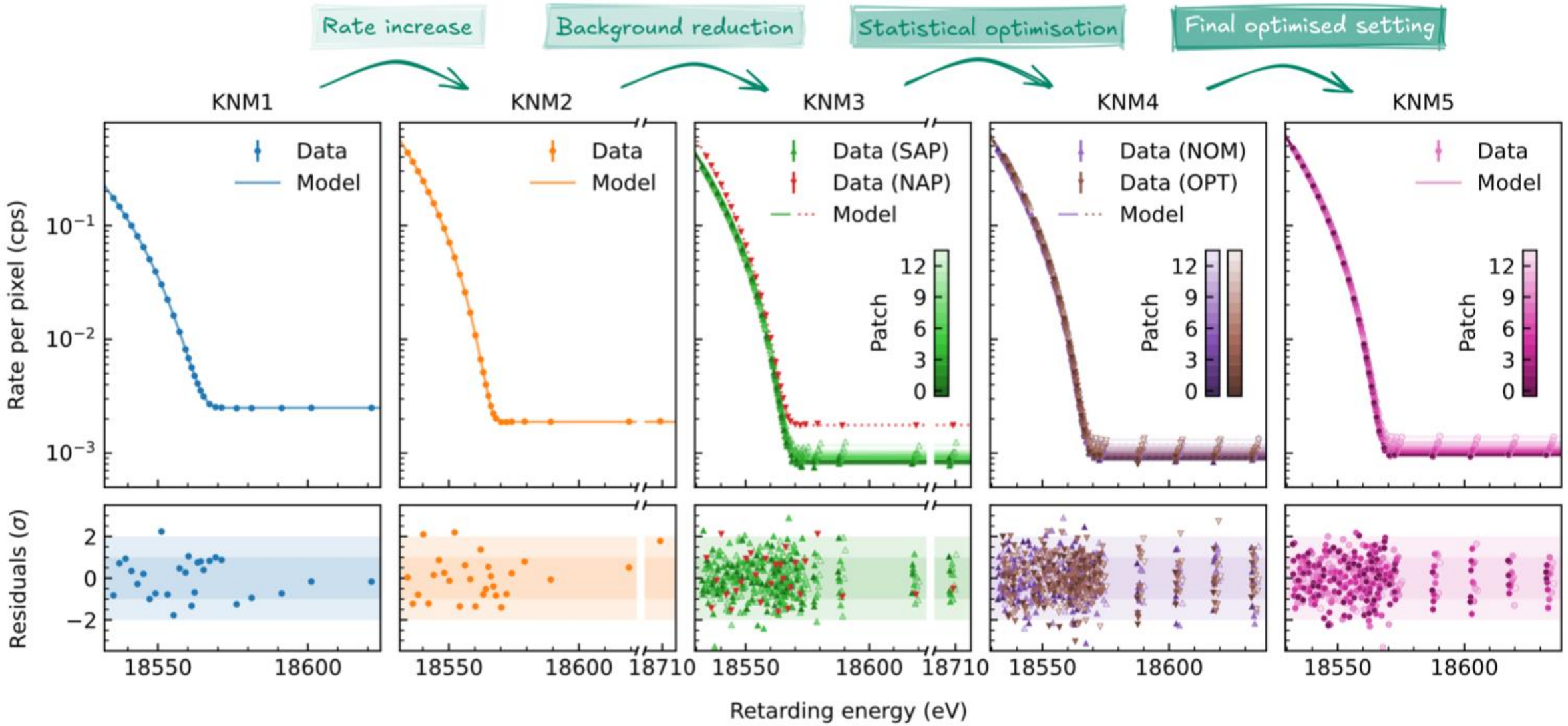
✓ fit model informed by **theoretical** and **experimental** inputs (e-gun, krypton, monitoring, …)

Data Taking & Released Dataset

6 10^6 e^- **36 10^6 e^- (2024 release)** 175 10^6 e^-



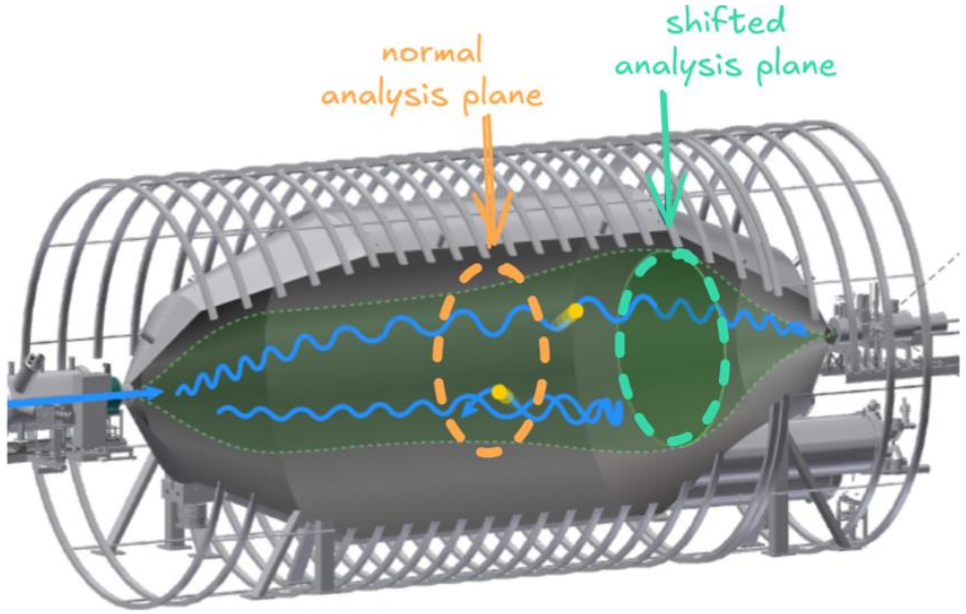
Tritium Beta Decay: Spectral Fits

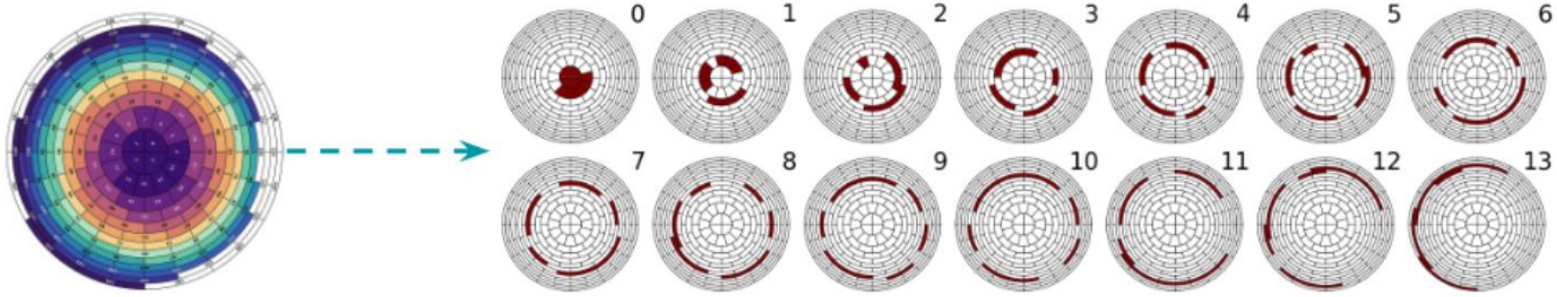


Experimental improvements: Background

Factor 2 lower background using "*shifted analysing plane*" configuration

- Smaller volume mapped onto detector
- Inhomogeneous EM-fields
  - 14 times more segmented data
  - Calibration of fields needed





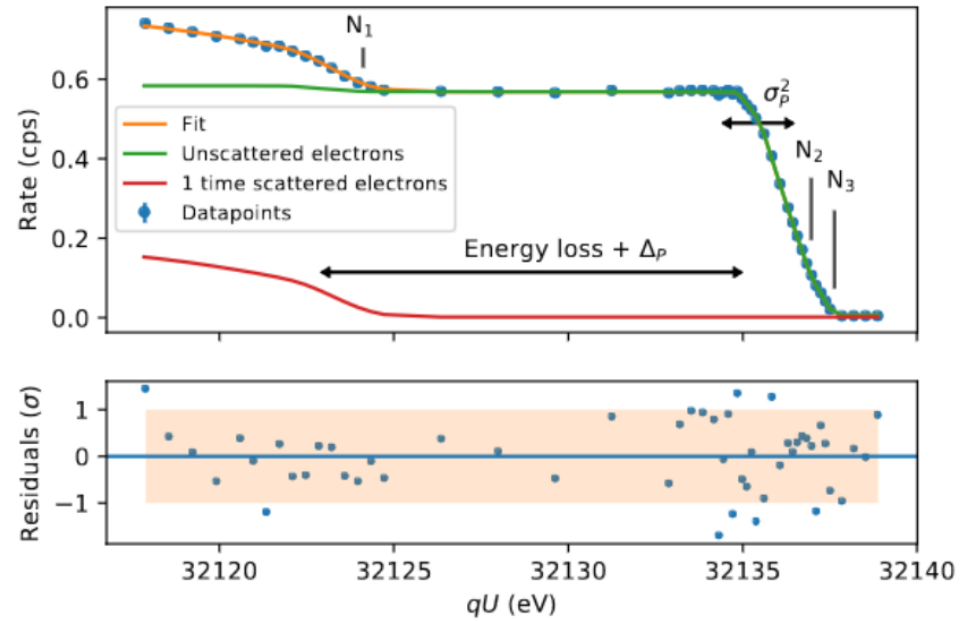
Experimental improvements: Source

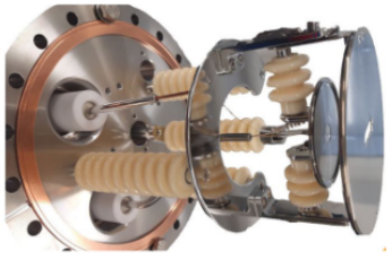
Precise calibration measurements with ^{83m}Kr co-circulation

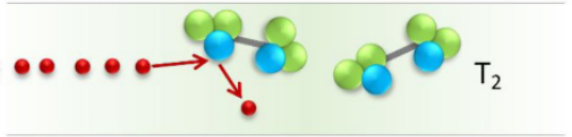
- Probe of electric potential variation in the source
- Field mapping in the spectrometer
- Source temperature: 30 K to 80 K

With electron gun:

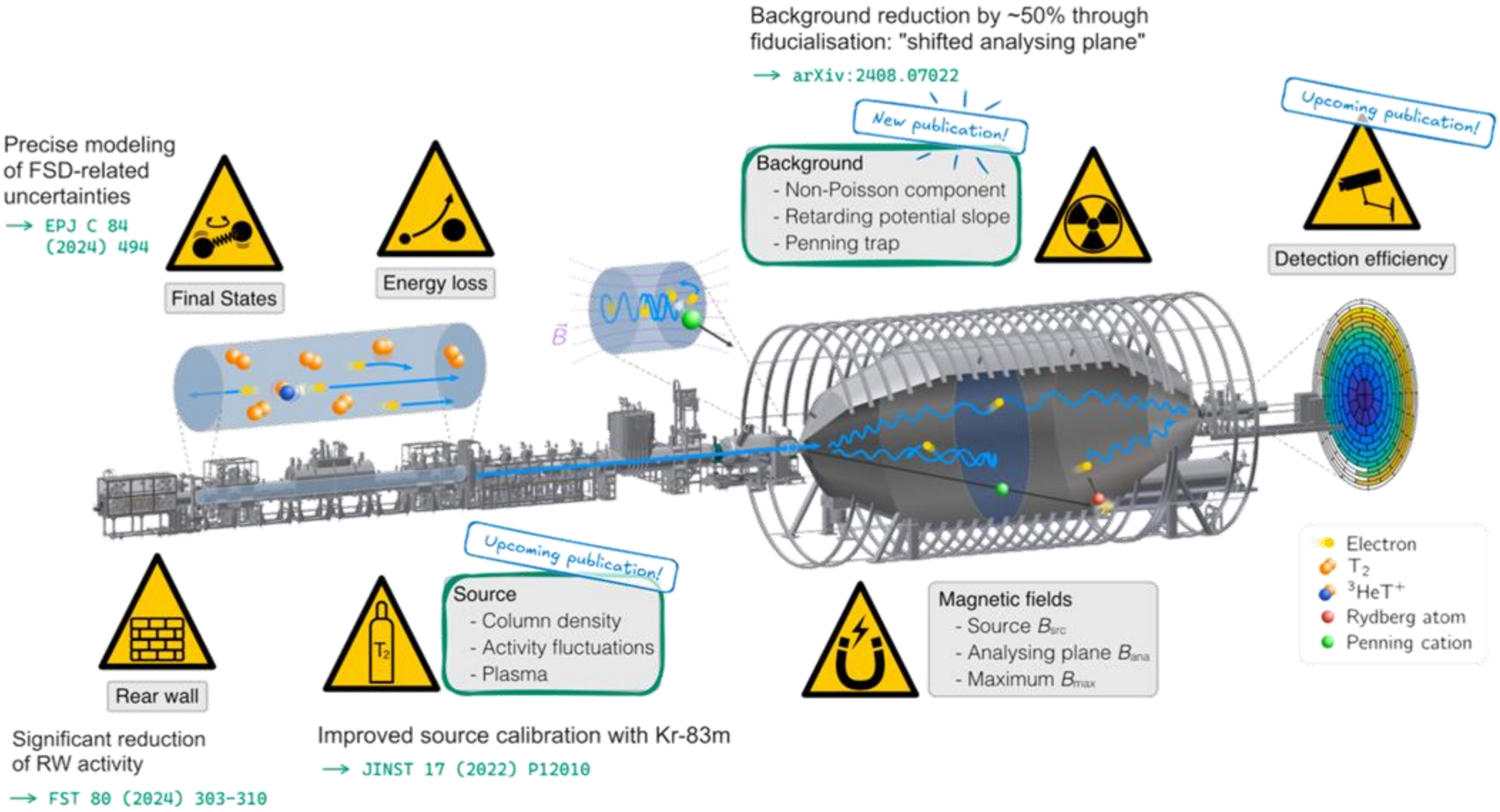
- Energy loss determination through scattering
- Tritium gas density





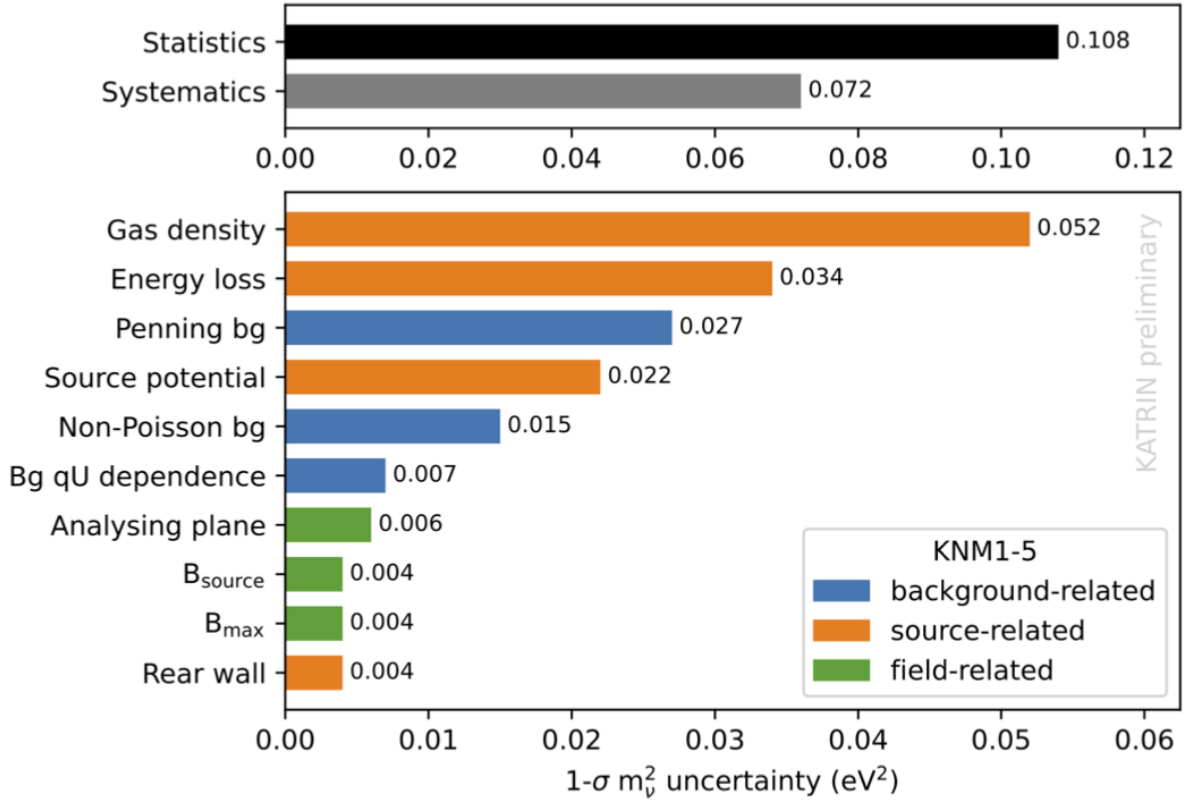


Systematic Effects



Systematic Uncertainties

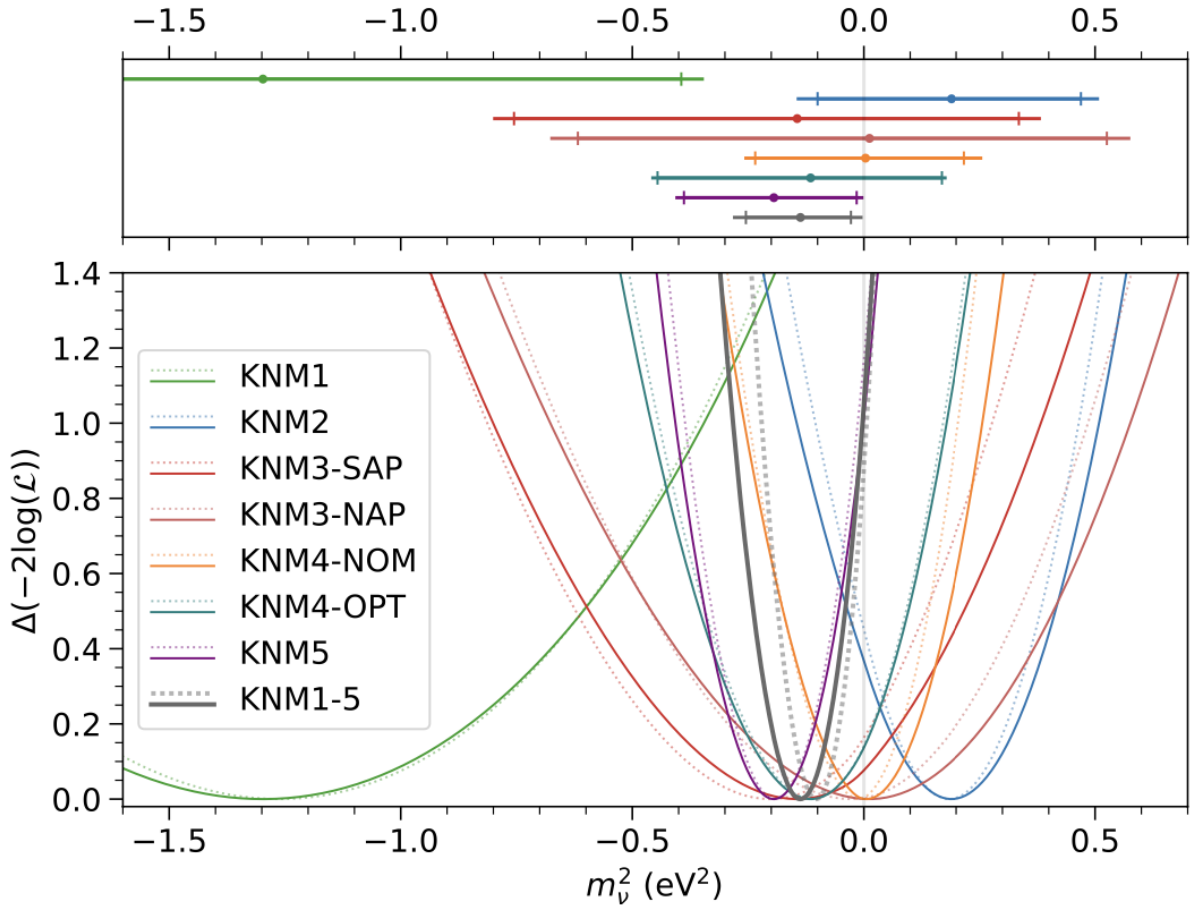
- Sensitivity dominated by statistical uncertainties
- Significant reduction of background-related systematics
- Better control over source scattering
- Reduction of molecular final-states uncertainties by theoretical reassessment



New Neutrino Mass Results: Best Fit

- Simultaneous maximum likelihood fit with common m_ν^2 parameter.
- Excellent goodness-of-fit: p-value=0.84
- Best-fit value: $m_\nu^2 = -0.14^{+0.13}_{-0.15}\ \mathrm{eV}^2$

  → Negative m_ν^2 estimates allowed by the spectrum model to accommodate statistical fluctuations.

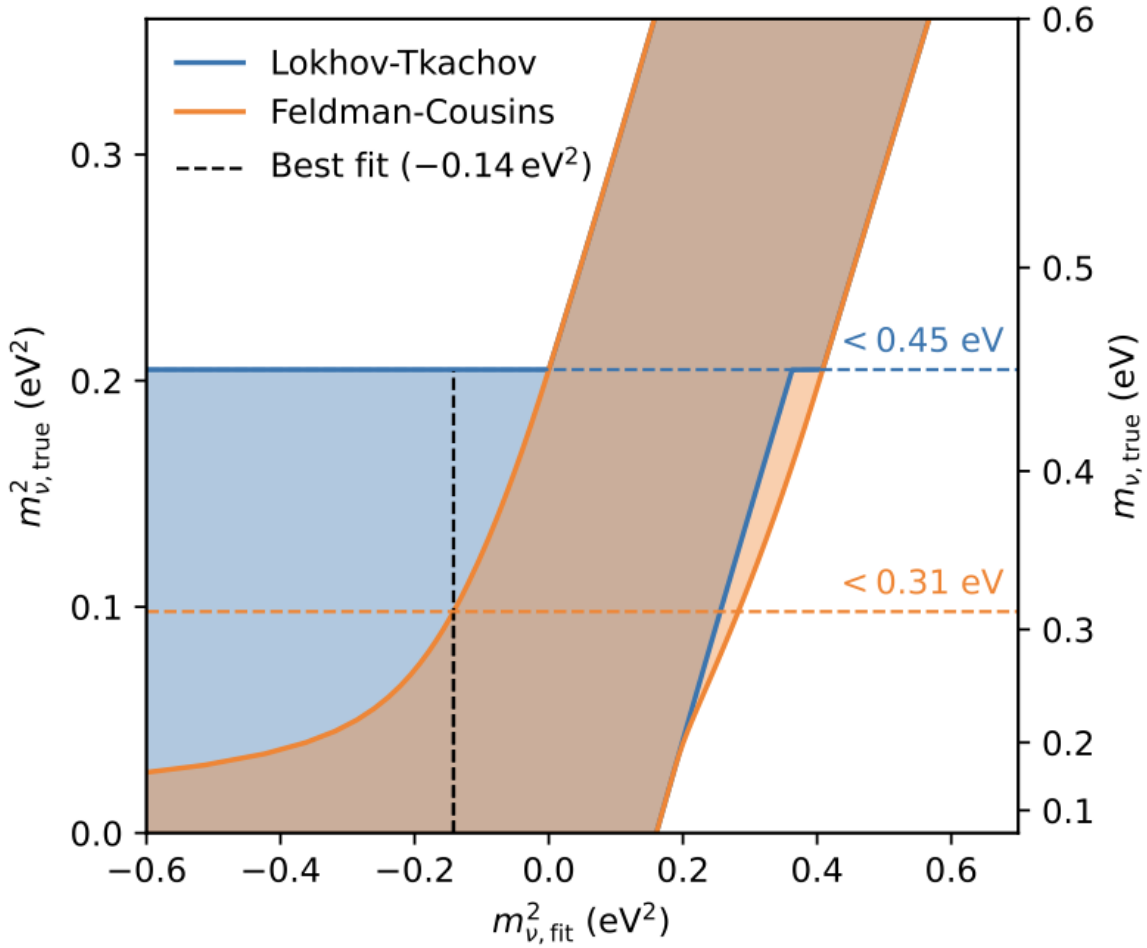


New Neutrino Mass Results: Upper Limit

- Sensitivity of result dominated by statistics.
- Simultaneous maximum likelihood fit with common m_ν^2 parameter.
- Excellent goodness-of-fit: p-value=0.84
- Best-fit value: $m_\nu^2 = -0.14^{+0.13}_{-0.15}\ \mathrm{eV}^2$

  → Negative m_ν^2 estimates allowed by the spectrum model to accommodate statistical fluctuations.
- KATRIN's new upper limit:

$$m_\nu < 0.45\ \mathrm{eV}\ (90\,\%\ \mathrm{CL})$$



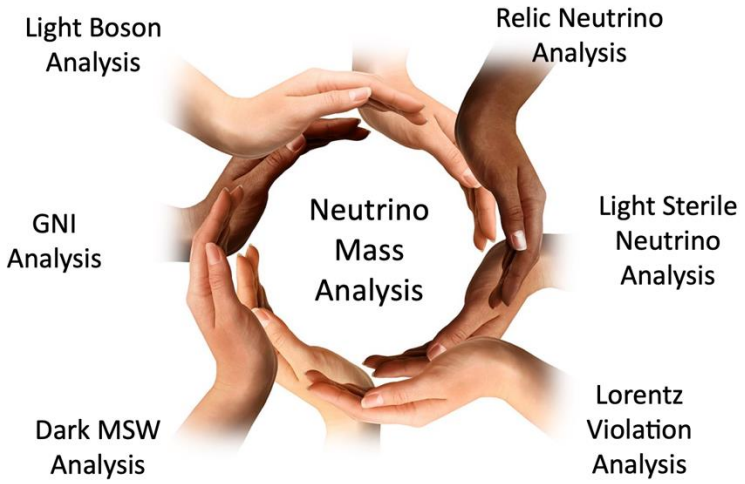
Conclusion and Outlook

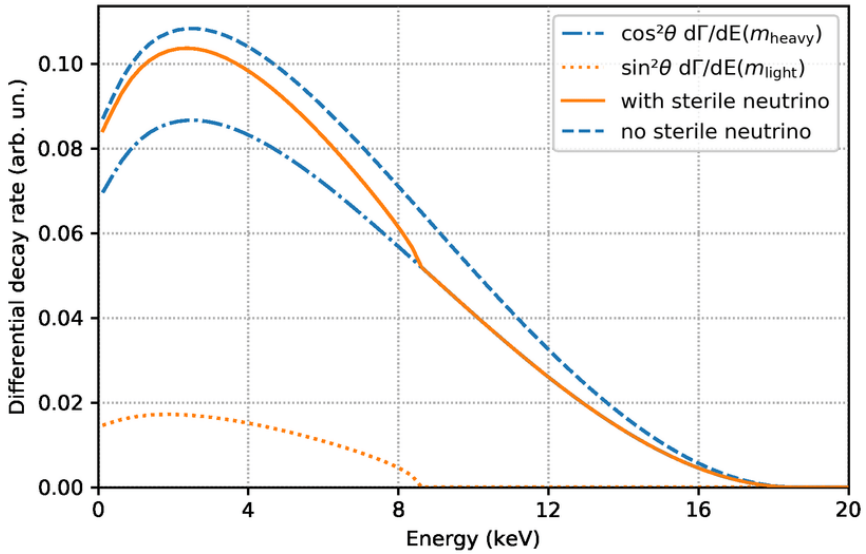
2025: neutrino mass

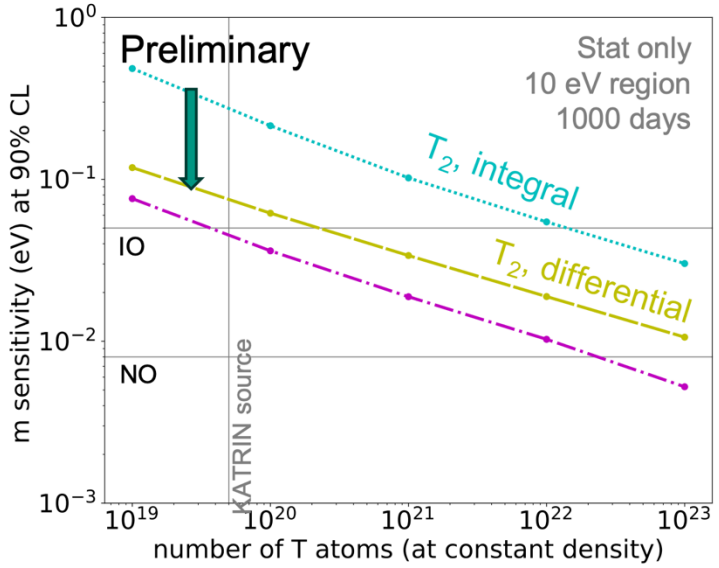
2026- 2027: keV-sterile neutrinos (TRISTAN)

KATRIN ++

+







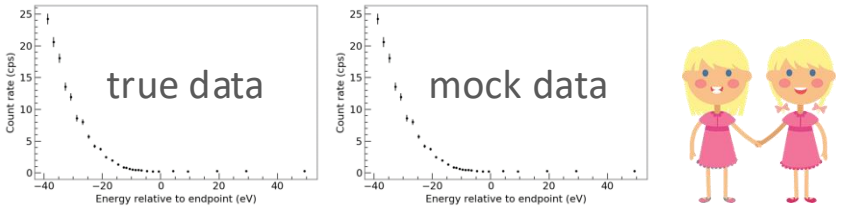
Thank you!

C. Goupy

3-tiered blind analysis

Freeze analysis on MC-twin data

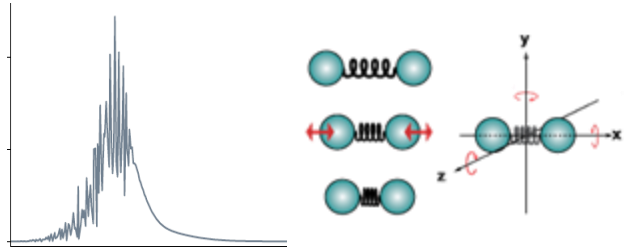
- mock data mimicking each scan



m_ν^2

Blinded model

- modified molecular final state dist.



Three independent analysis teams

- different strategies and codes