Recent NEMO-3 results

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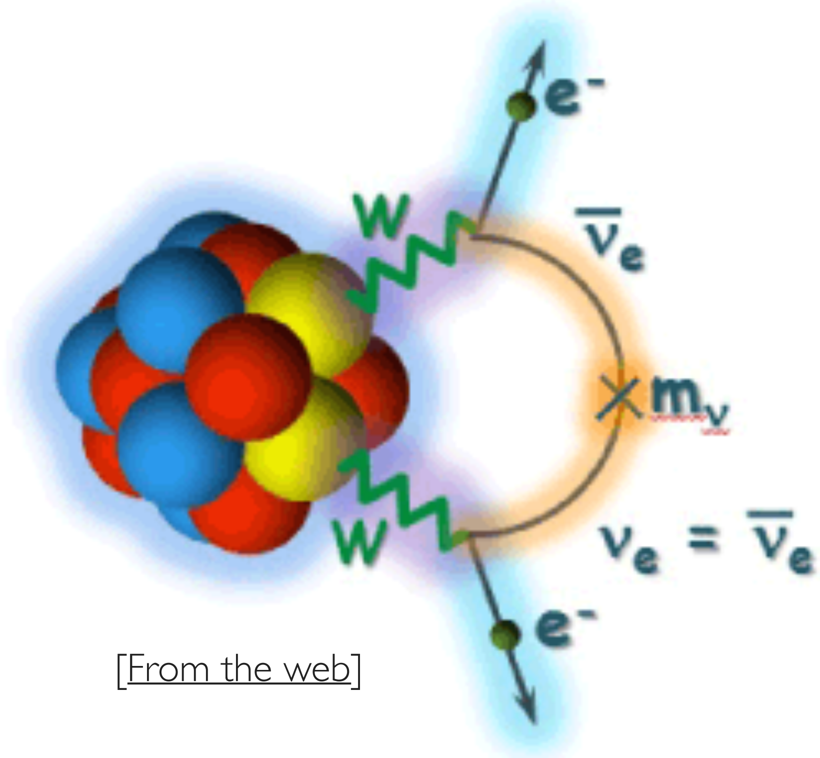
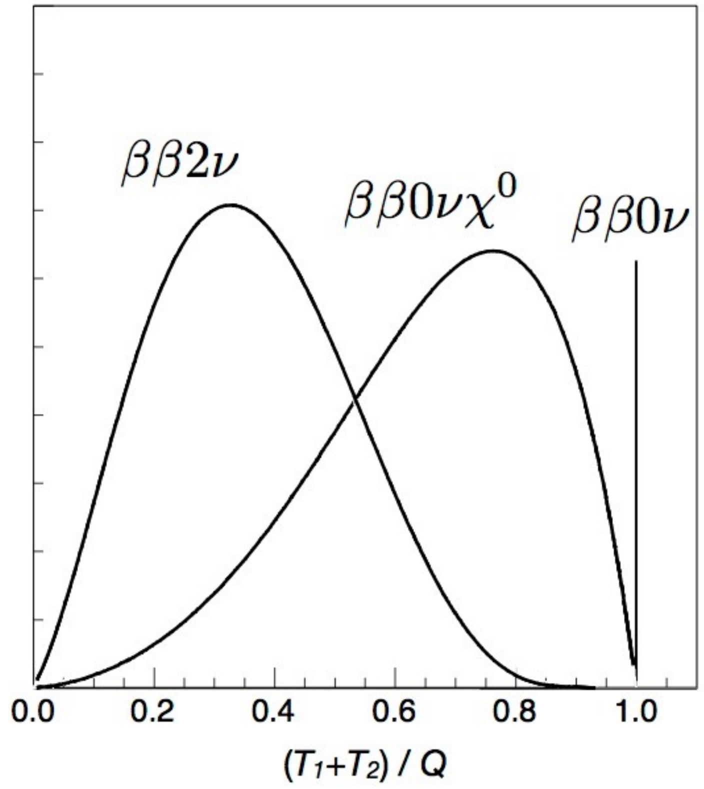
Neutrino-less double beta decay in a nutshell

- Process forbidden in the SM
- Test Dirac/Majorana nature of neutrinos
- Half-life strongly suppressed

$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)|M_{0\nu}|^2\eta^2$$



[From the web]

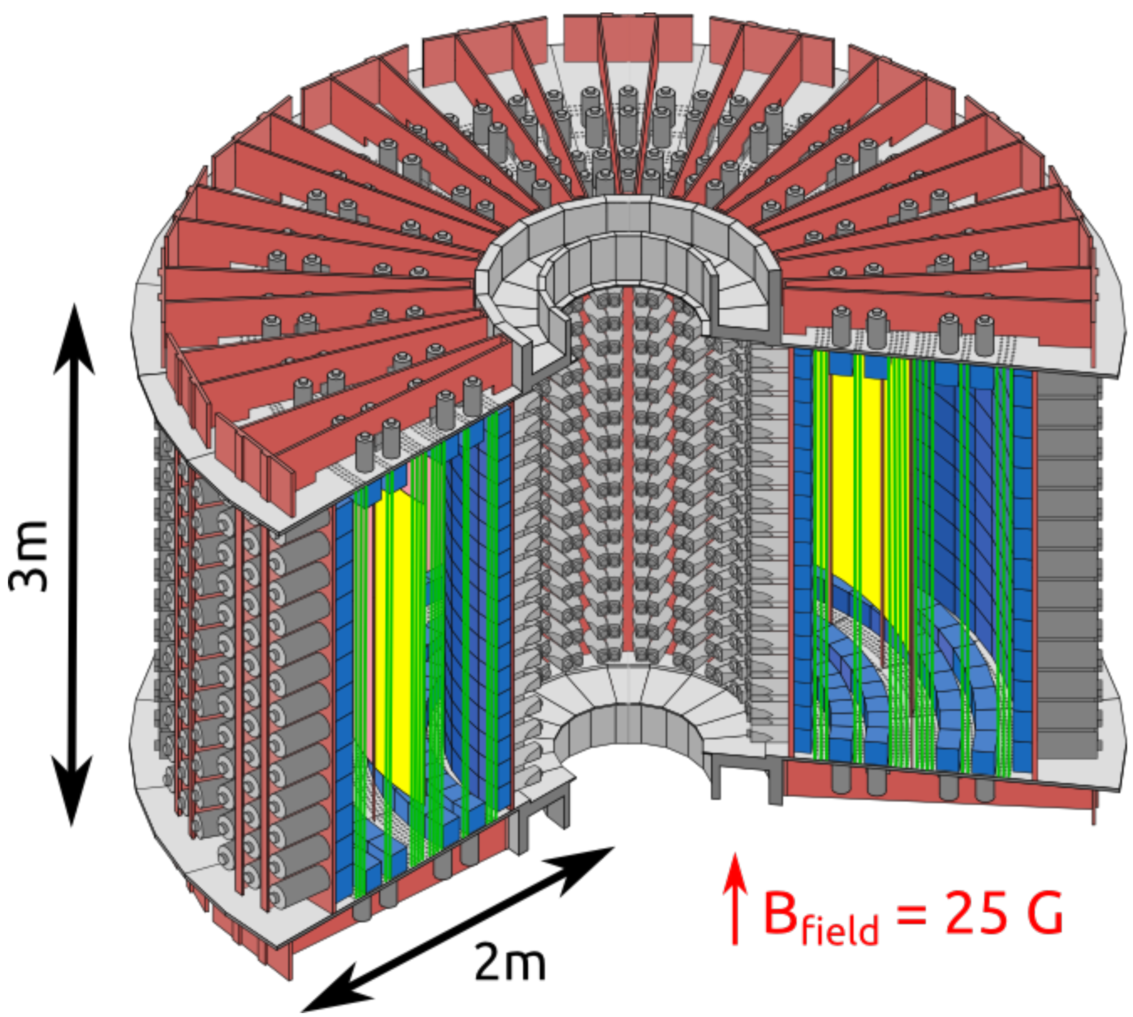


Few different mechanisms may induce 0νββ

- Light Majorana neutrino exchange
- Right-handed current (V+A), SUSY, Majoron(s), etc.

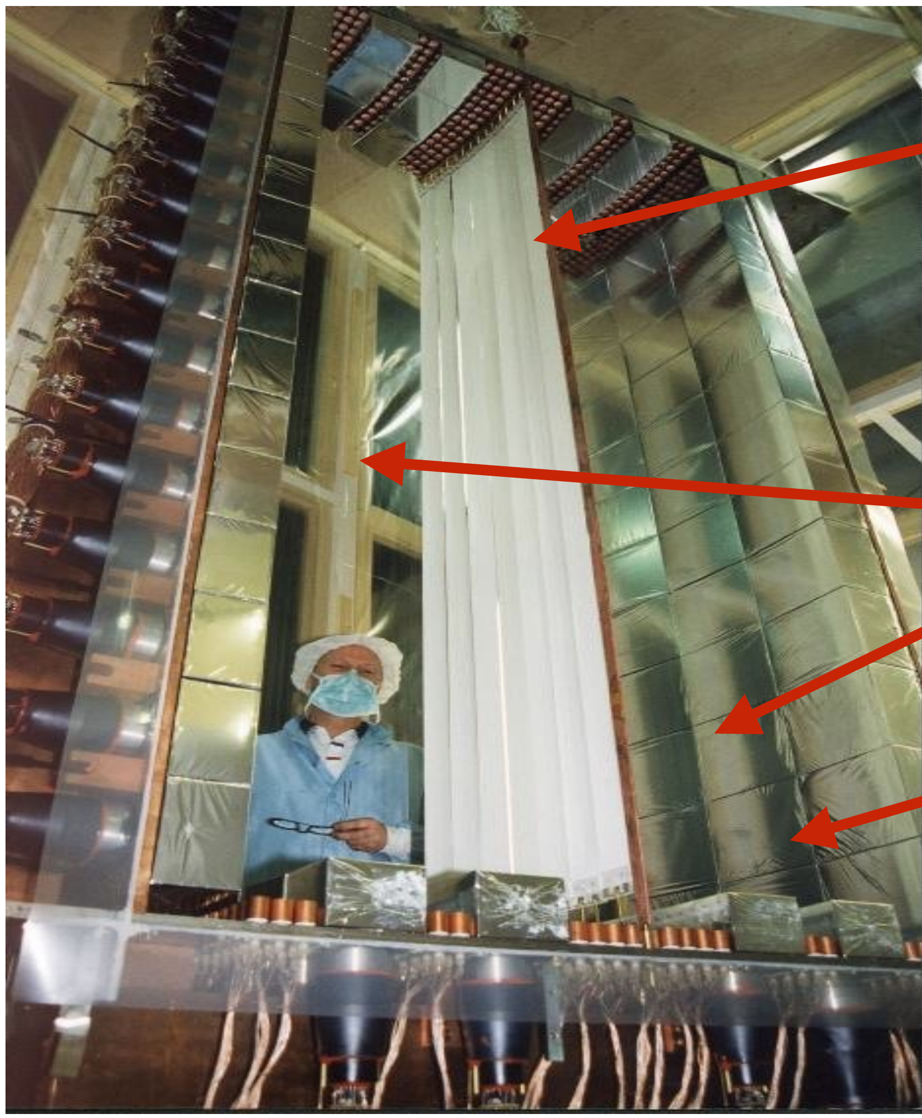
Different topology in the final state

Once upon a time: NEMO-3



- ββ decay experiment combining tracker and calorimetric measurement
- Allows reconstruction of the final state topology and particle identification
- Located in the Modane underground laboratory (LSM) in the Frejus tunnel at ~4800 m.w.e.
- Measured 10 kg of different ββ isotopes
- Taking data from February 2003 to January 2011

The detector



- Central ββ source plane made of 7 different isotopes: mainly ^{100}Mo (7 kg) and ^{82}Se (1 kg)
- Cu & ^{Nat}Te blank foils: Cross-check background measurements
- Wire drift chamber made of 6180 Geiger cells: σ_{Vertex} ~ 3 mm (xy) , 10 mm (z)
- 1940 polystyrene scintillators coupled with low radioactivity PMTs: FWHM ~15 % @ 1 MeV
- 25 Gauss magnetic field: charge identification
- Gamma & Neutron shield, anti-Radon tent

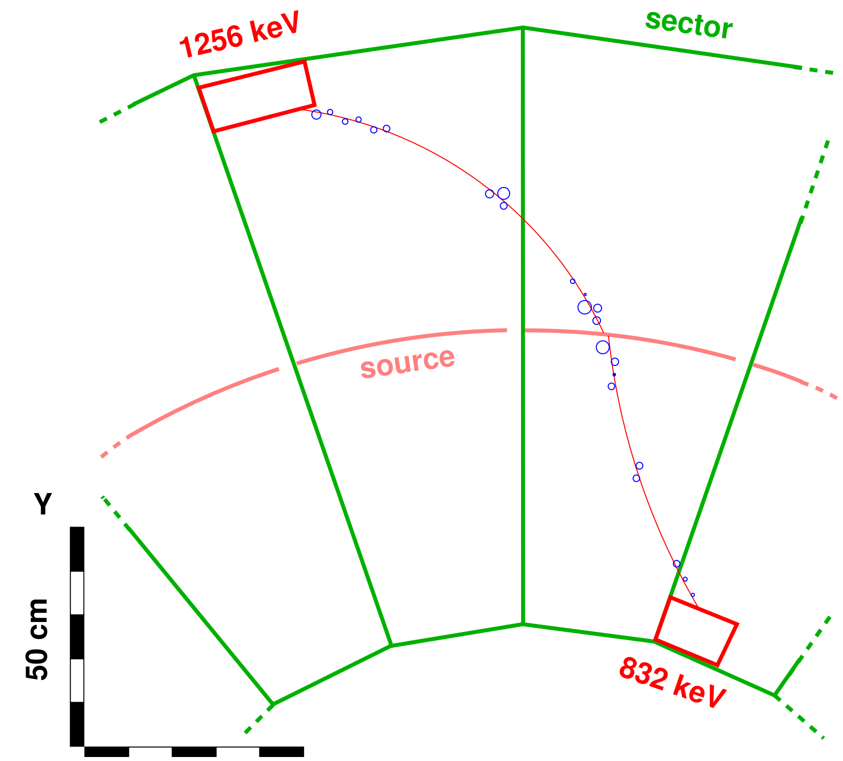
Unique features

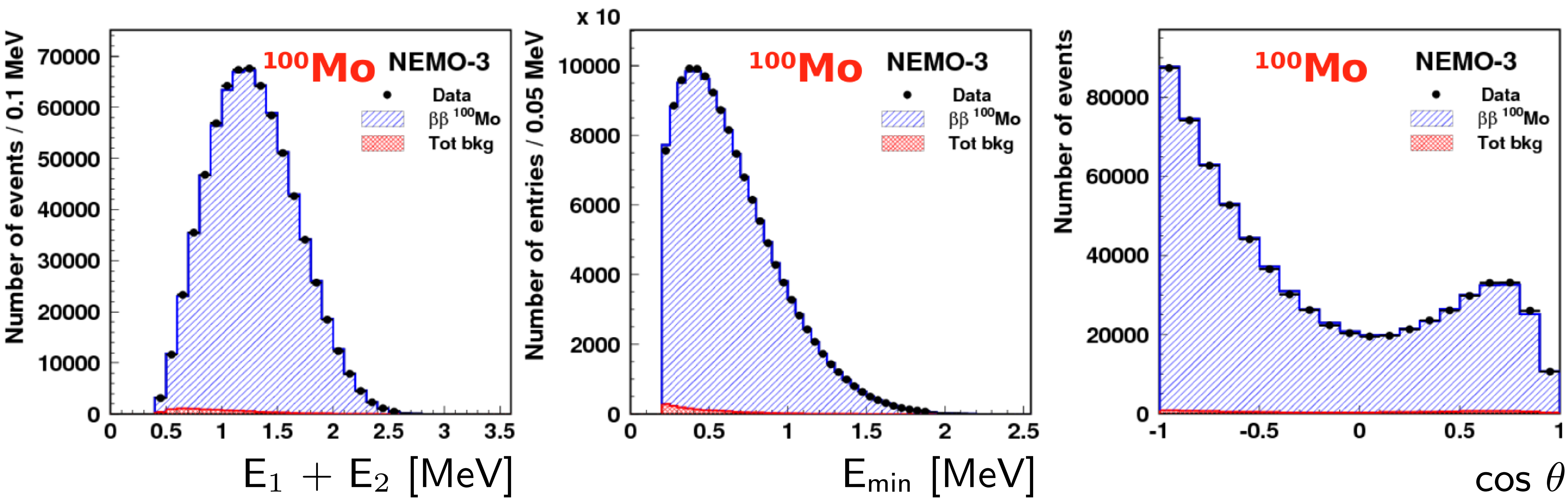
Full reconstruction of $2e^-$ kinematics: unique!

Potential discrimination of mechanism behind 0νββ decay: angular distribution, single electron spectra

Reconstruction of different final state topologies: excellent background rejection

High S/B is achieved: ~70 for ^{100}Mo 2νββ

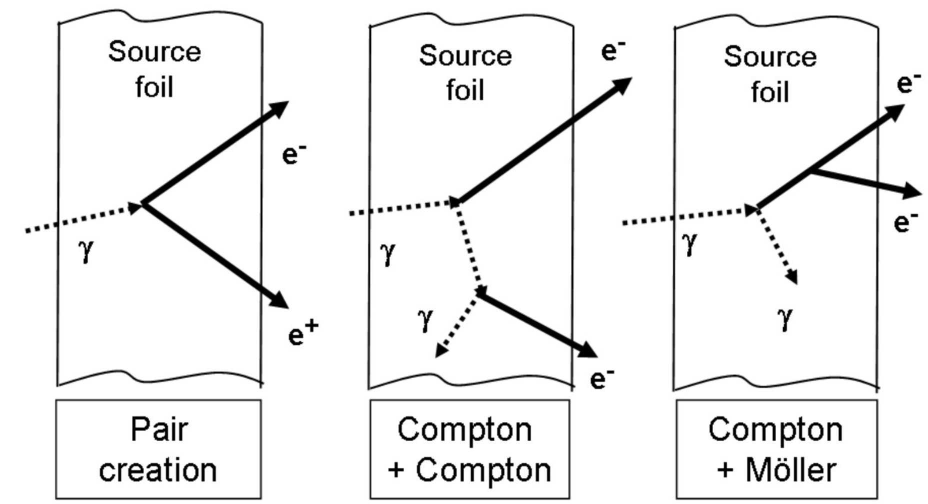




The backgrounds

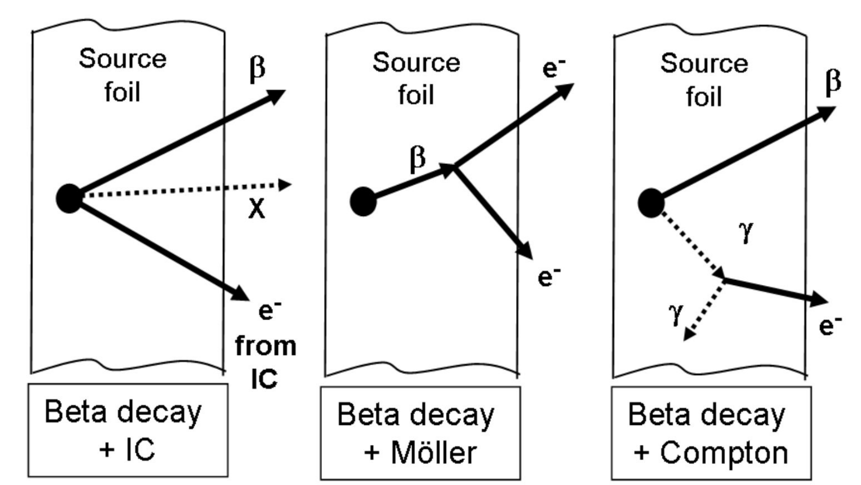
Radio-impurities in material, γ from (n,γ) and μ bremsstrahlung

- γ from ^{208}Tl at 2.6 MeV
- (n,γ) up to 10 MeV



^{208}Tl (from ^{232}Th) and ^{214}Bi (from ^{238}U) contamination in foil source and ^{214}Bi from Rn decay in tracker volume

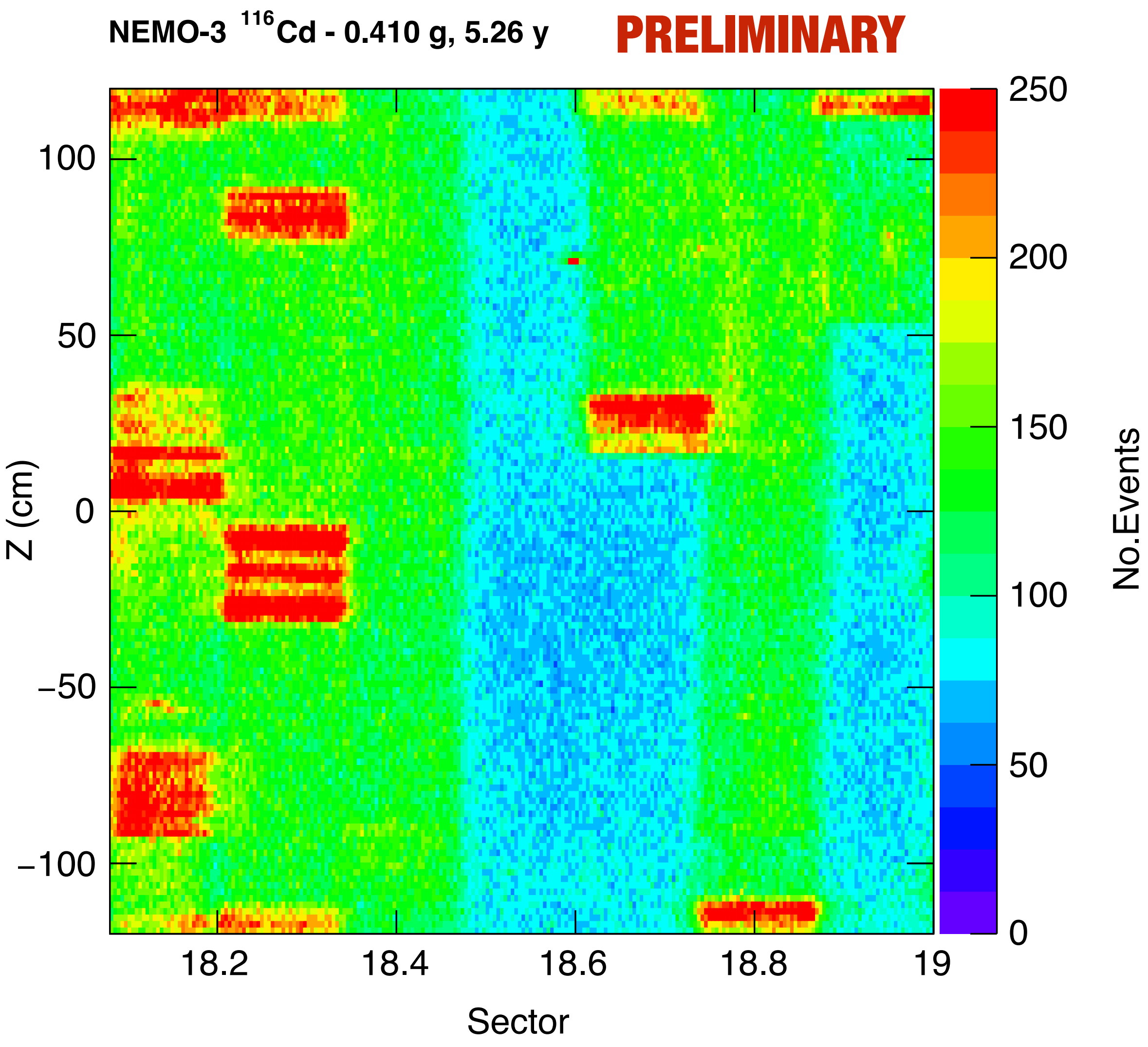
- ^{208}Tl Q_β at 5 MeV
- ^{214}Bi Q_β at 3.27 MeV



Take advantage of PID capabilities of NEMO-3: e^-, e^+, γ, α and TOF measurement

Hot spots identification

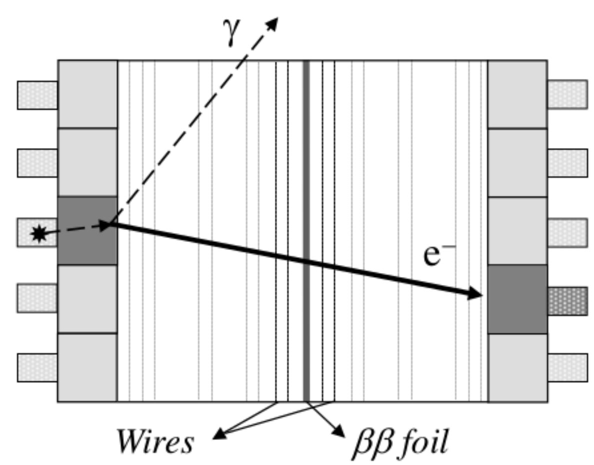
- Source foil production might introduce spot-like contamination of various isotope
- Reconstruct activity map of the foil surface in different channel
- Reduce backgrounds removing hot spots from the foils surface

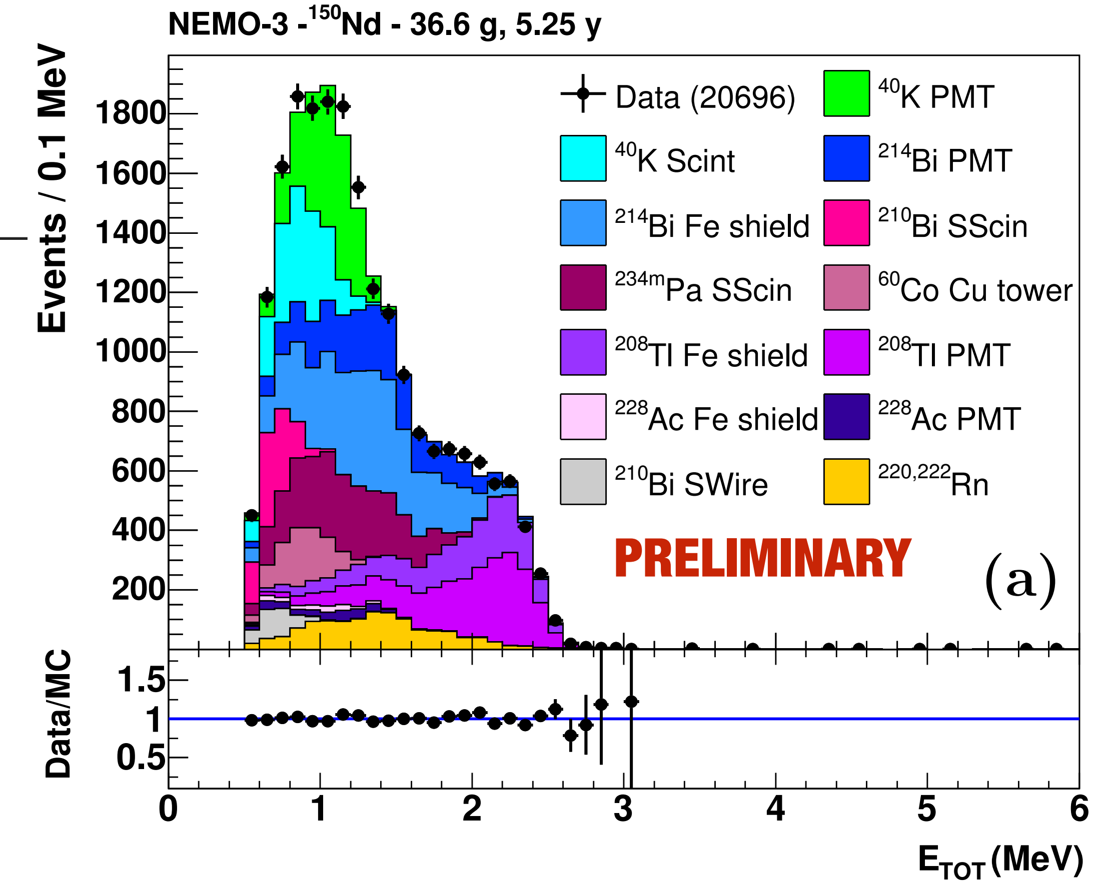


External backgrounds

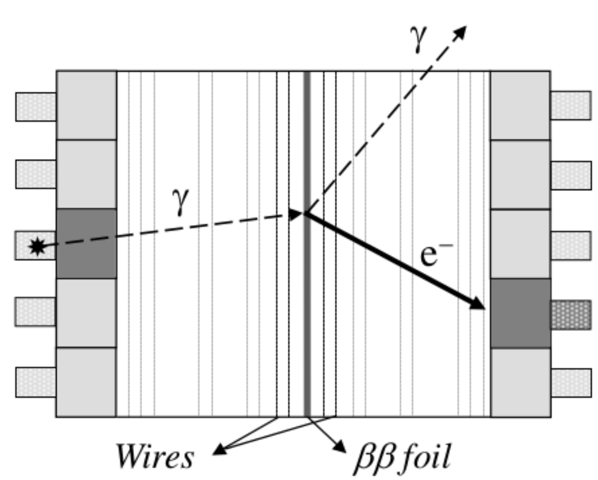
- Modelled as combination of various isotopes from different part of the detector
- Measured in 2 main channels

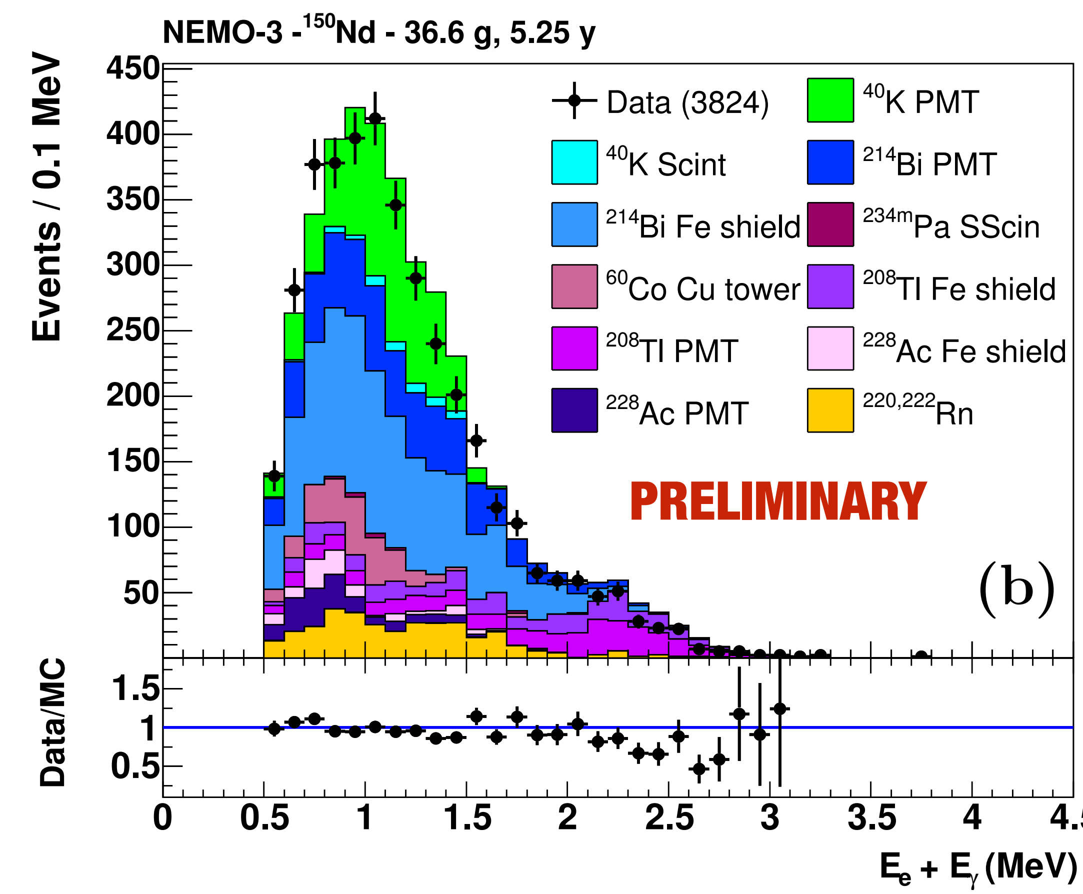
External Crossing e$^-$



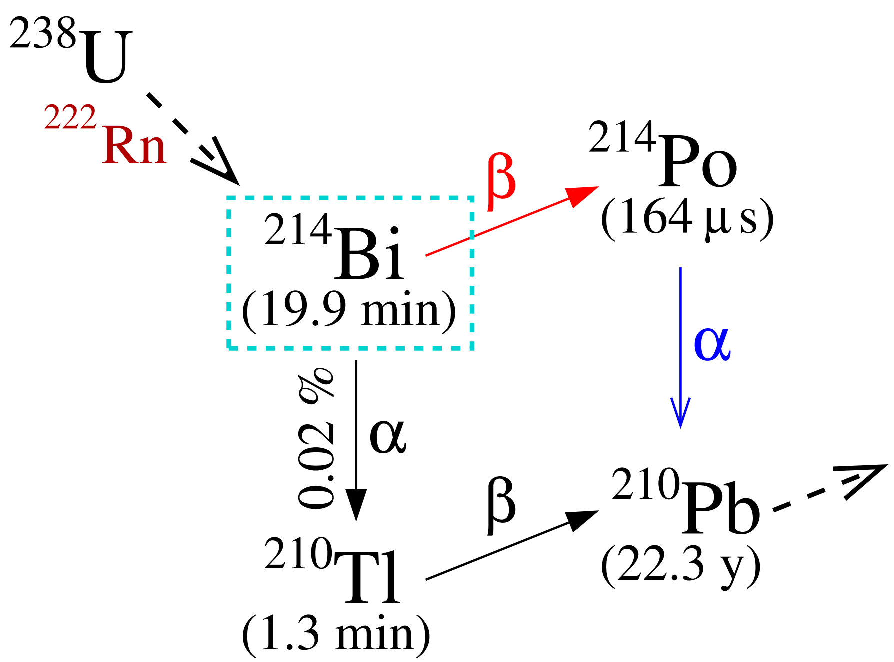


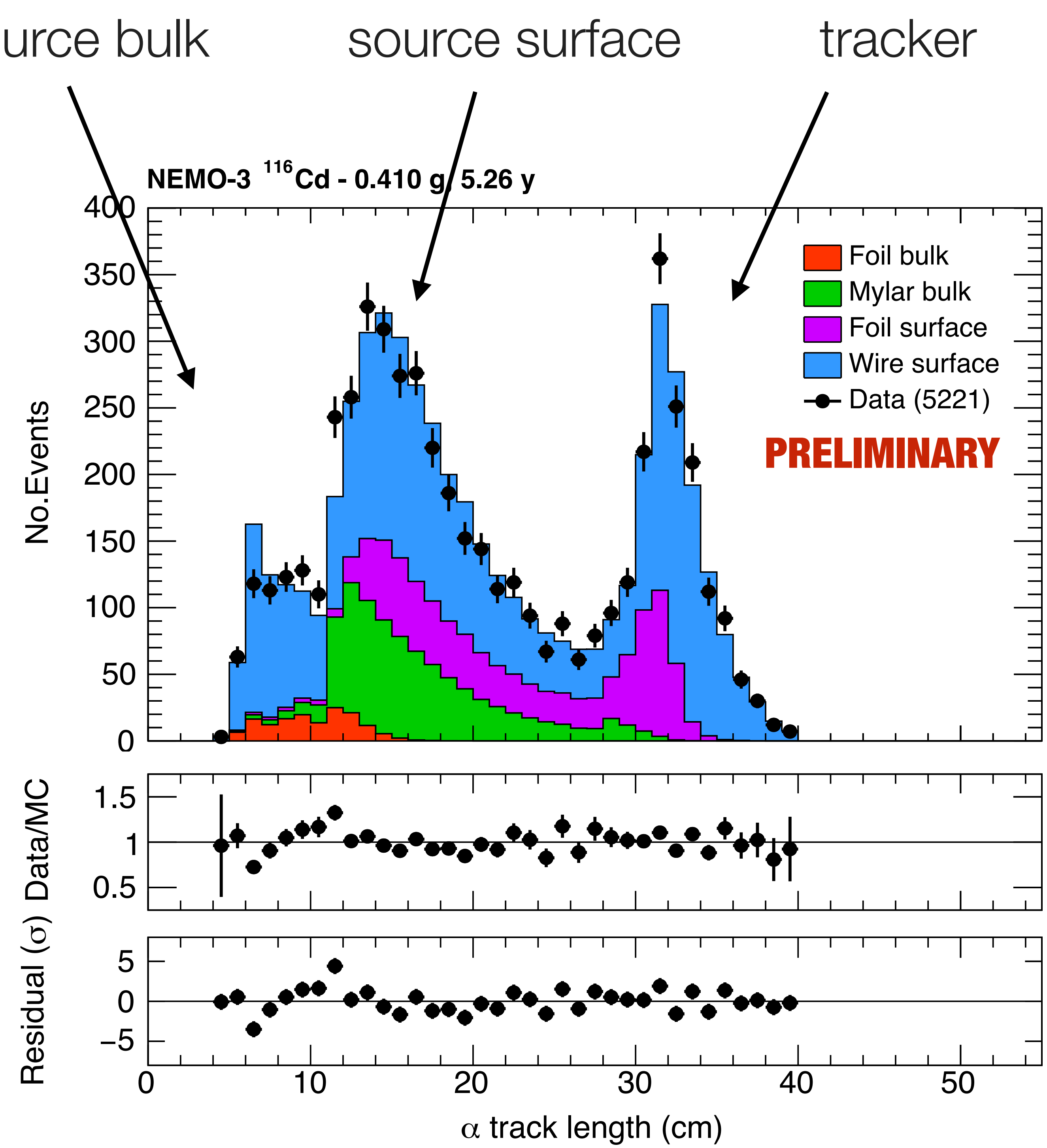
External γ → e$^-$





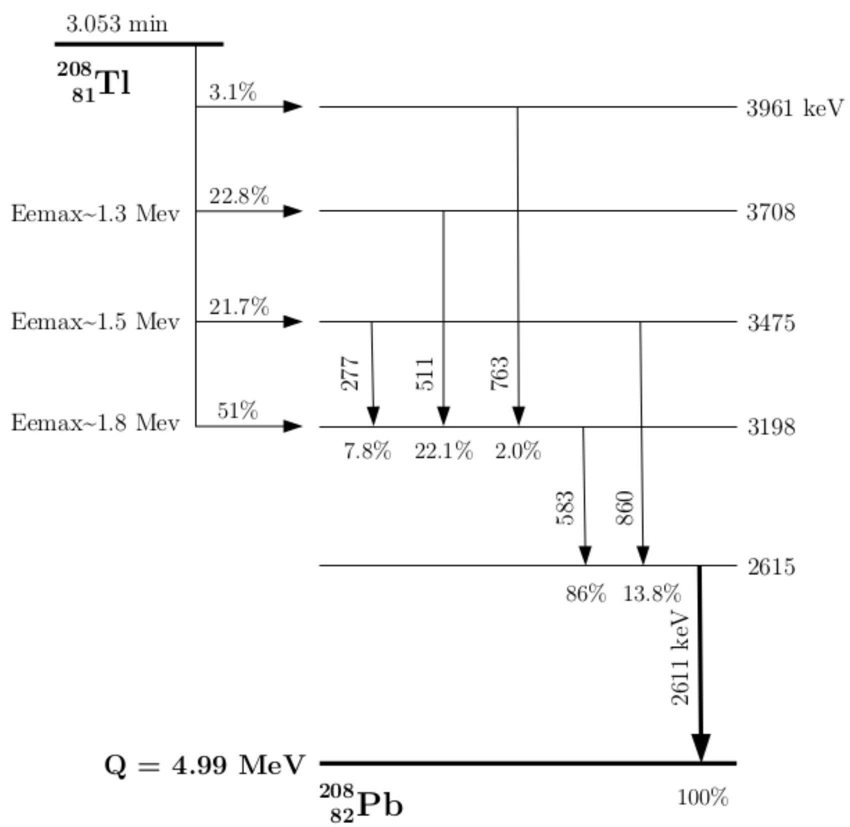
Bi-214 through delayed Bi-Po coincidence

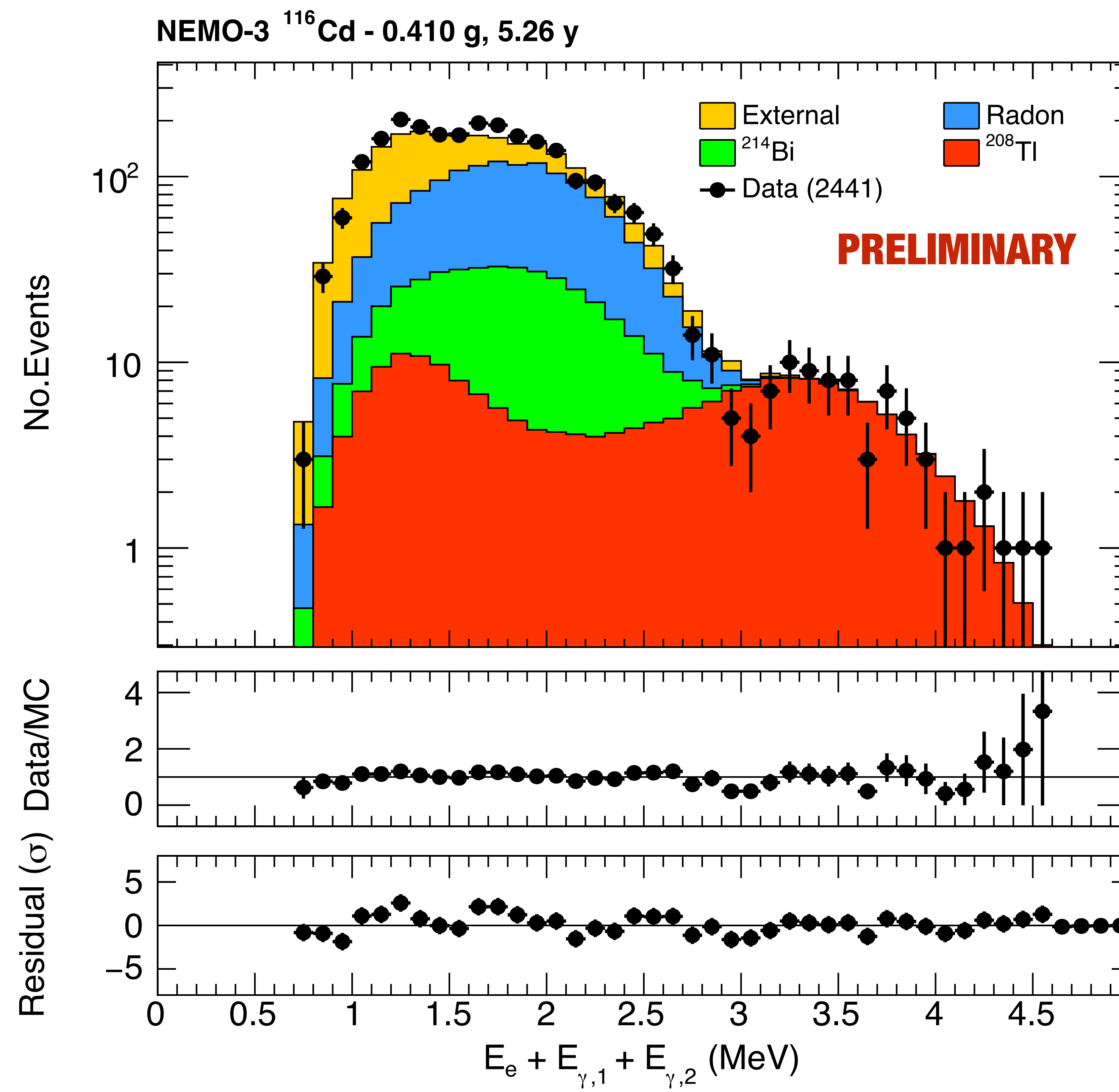




- Background-free measurement
- alpha track length sensitive to different contamination origin

Tl-208 through 1eNγ channel

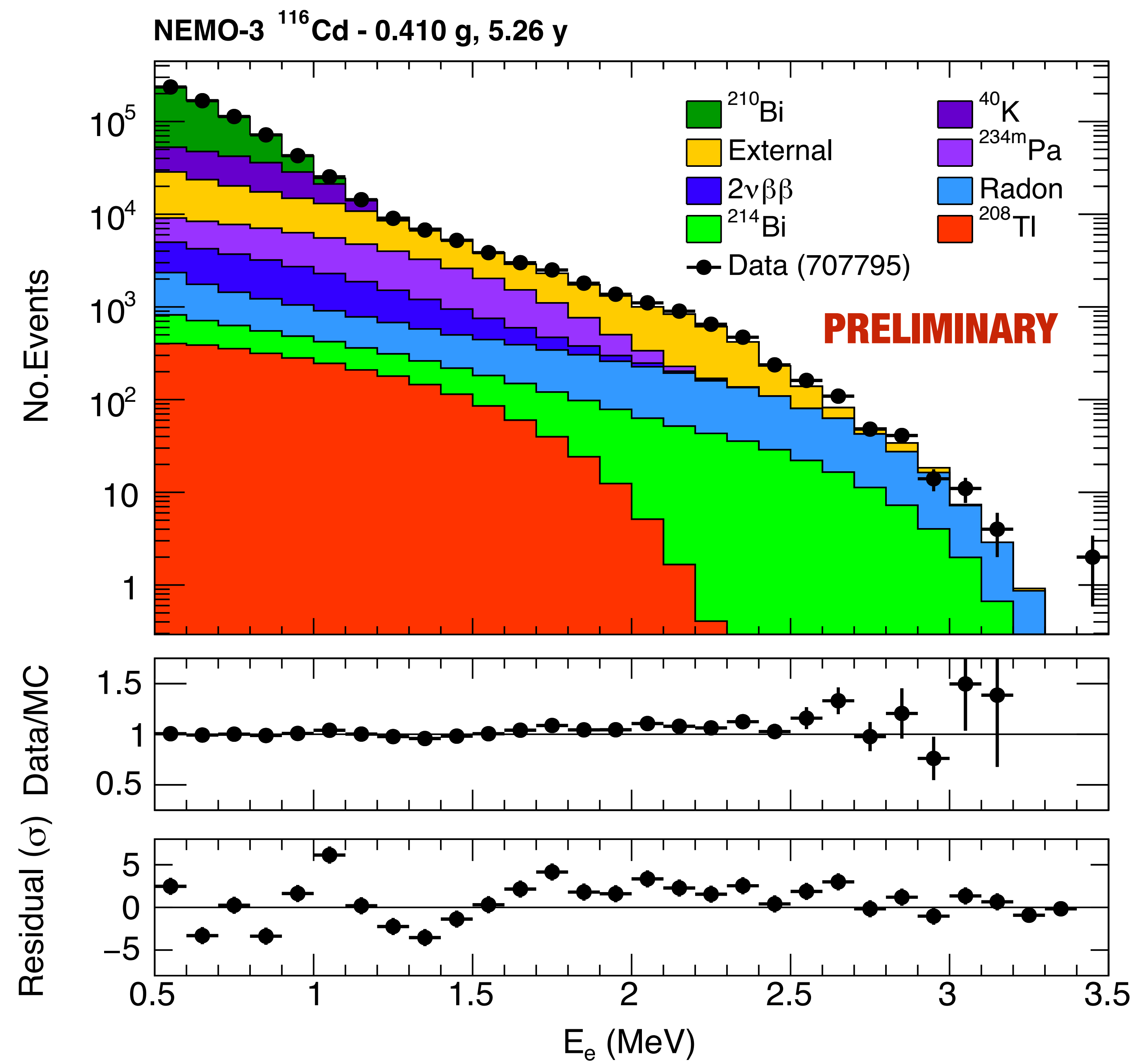




- Clean measurement requiring 1e⁻ in coincidence with 1 or more γ

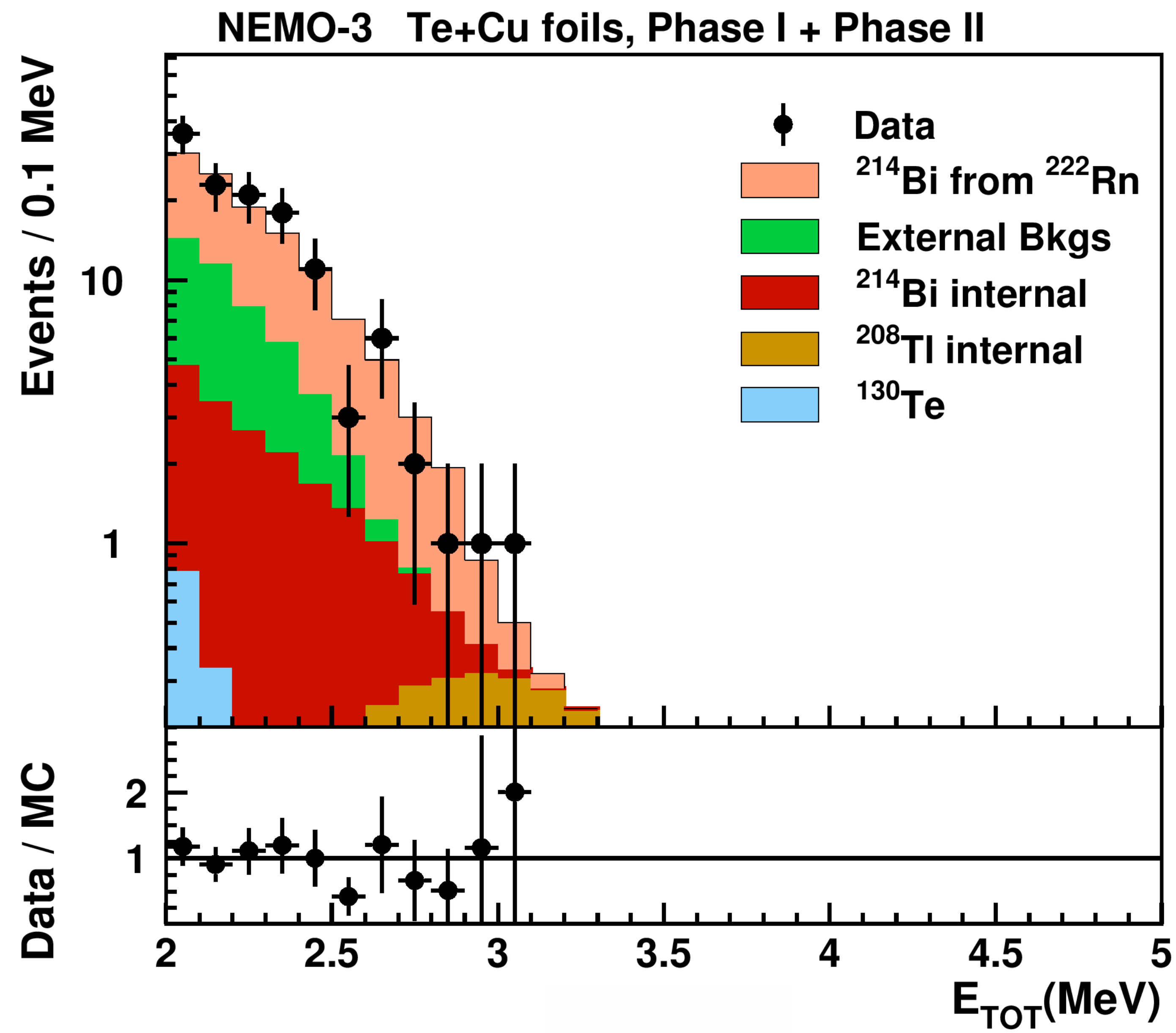
Single beta emitter on the foil

- Single electron originating from the source foils surface
- Different ββ sources have different contamination
- Develop dedicated background model for each ββ source



Background validation

- Model validated in the 2e channel
- Cu & ^{Nat}Te sectors
- No events for E > 3.1 MeV after 13.5 kg×y

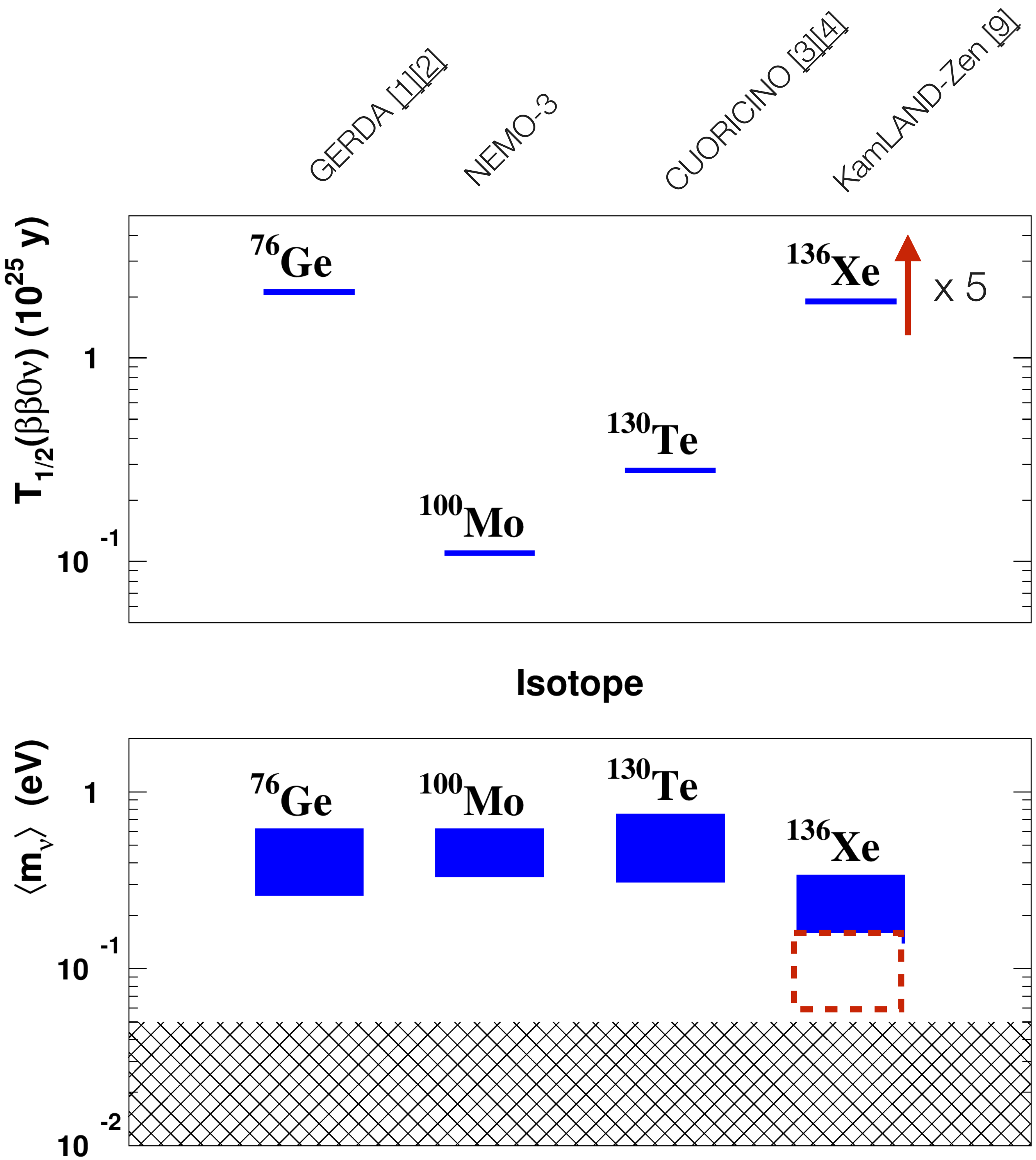


Promising background free technique for high $Q_{\beta\beta}$ isotopes

^{48}Ca (4.272 MeV), ^{150}Nd (3.368 MeV) or ^{96}Zr (3.350 MeV)

^{100}Mo 0νββ result

[Phys. Rev. D. 92 072011 (2015)]



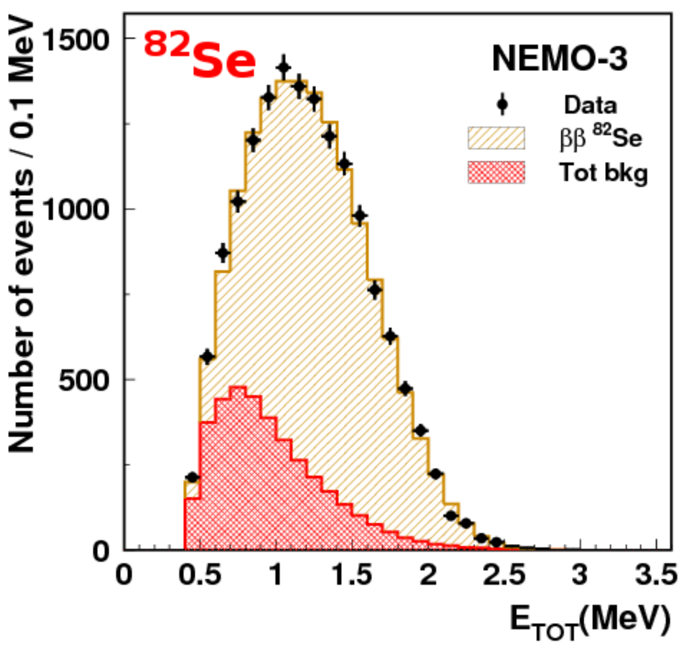
- No event excess after 34.3 kg×y
- $T^{0\nu}_{1/2} > 1.1\times10^{24}$ y (90 % C.L.)
- $\langle m_\nu \rangle < 0.33 - 0.62$ eV
- Bkg: 1.3×10^{-3} cts / (keV×kg×y)

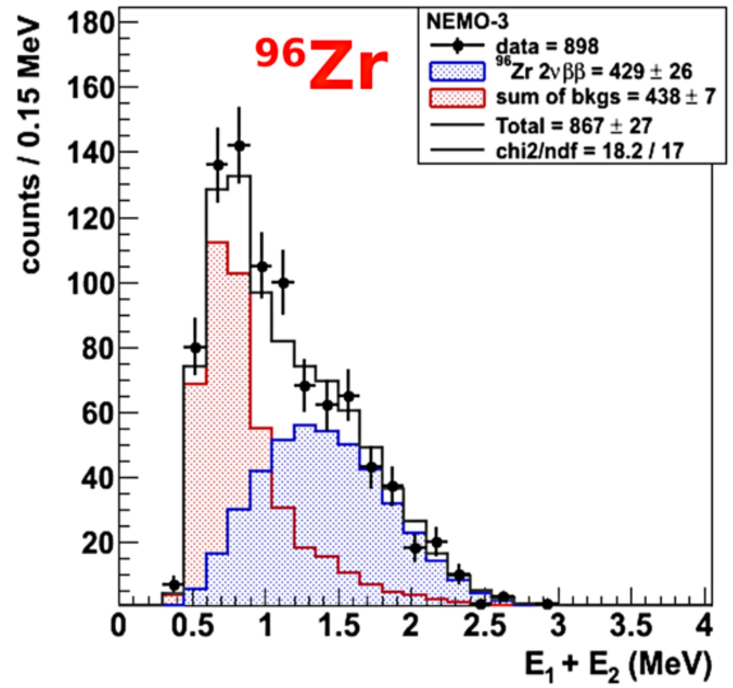
Limits at the 90% C.L. on half-lives and lepton number violating parameters. Published experimental constraints on ⟨mν⟩ and recalculated values with NMEs from Refs. [17, 19–22, 40] and recent phase space calculations from Refs. [23, 24] are also given.

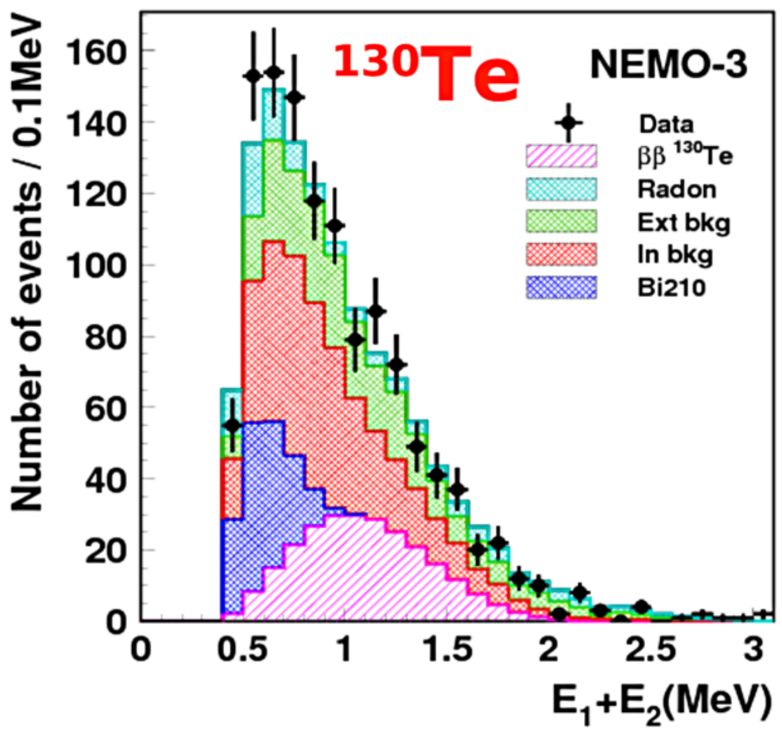
[17] J. Hyvarinen and J. Suhonen, Phys. Rev. C 91, 024613 (2015).
[19] F. Šimkovic, V. Rodin, A. Faessler, and P. Vogel, Phys. Rev. C 87, 045501 (2013).
[20] J. Barea, J. Kotila, and F. Iachello, Phys. Rev. C 91, 034304 (2015).
[21] P.K. Rath et al., Phys. Rev. C 88, 064322 (2013).
[22] T.R. Rodriguez and G. Martinez-Pinedo, Phys. Rev. Lett. 105, 252503 (2010).
[23] J. Kotila and F. Iachello, Phys. Rev. C 85, 034316 (2012).
[24] S. Stoica and M. Mirea, Phys. Rev. C 88, 037303 (2013);
[40] J. Menendez, A. Poves, E. Caurier, and F. Nowacki, Nucl. Phys. A 818, 139 (2009).

Other results

Only partial exposure published







Isotope	Mass [g]	Exposure [days]	$T_{1/2}$ (2ν) [x 10^{19} y]	$T_{1/2}$ (0ν) [y] @ 90% C.L.	⟨m_ν⟩ [eV] @ 90% C.L.	Reference
^{82}Se	932	389	9.6 ± 1.0	> 1.0 x 10^{23}	< 1.7 - 4.9	Phys.Rev.Lett. 95 (2005) 182302
^{96}Zr	9.4	1221	2.35 ± 0.21			Nucl.Phys.A 847(2010) 168
^{130}Te	454	1275	70 ± 14			Phys. Rev. Lett. 107, 062504 (2011)

^{100}Mo 0νββ decay to the ^{100}Ru excited states [Nuclear Physics A781 (2007) 209-226]

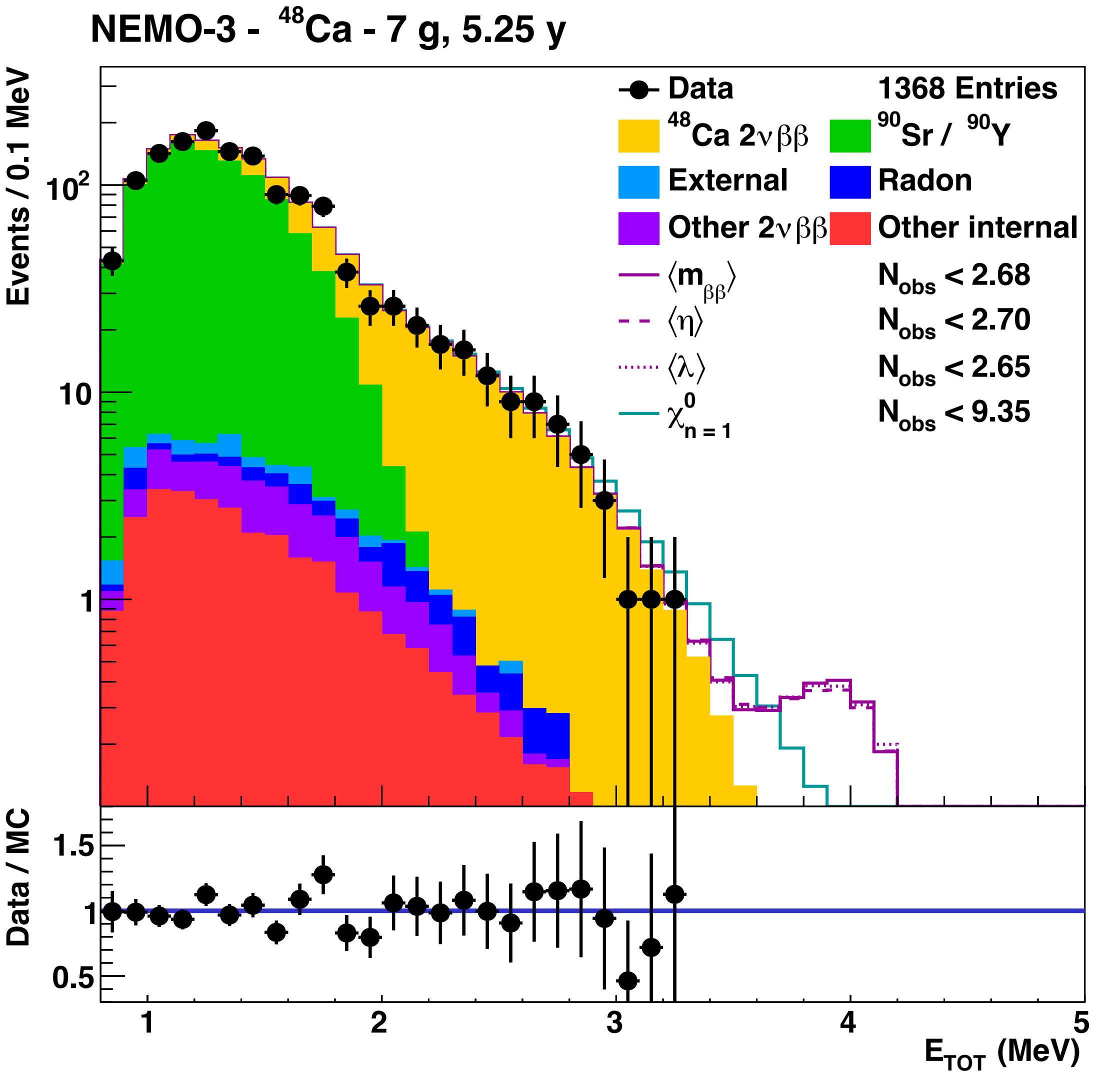
Recent results

Finalising analyses with full detector exposure:

- $2\nu\beta\beta$ measurements and $0\nu\beta\beta$ searches
- Study of the $\beta\beta$ to the excited states
- Other “exotic” studies

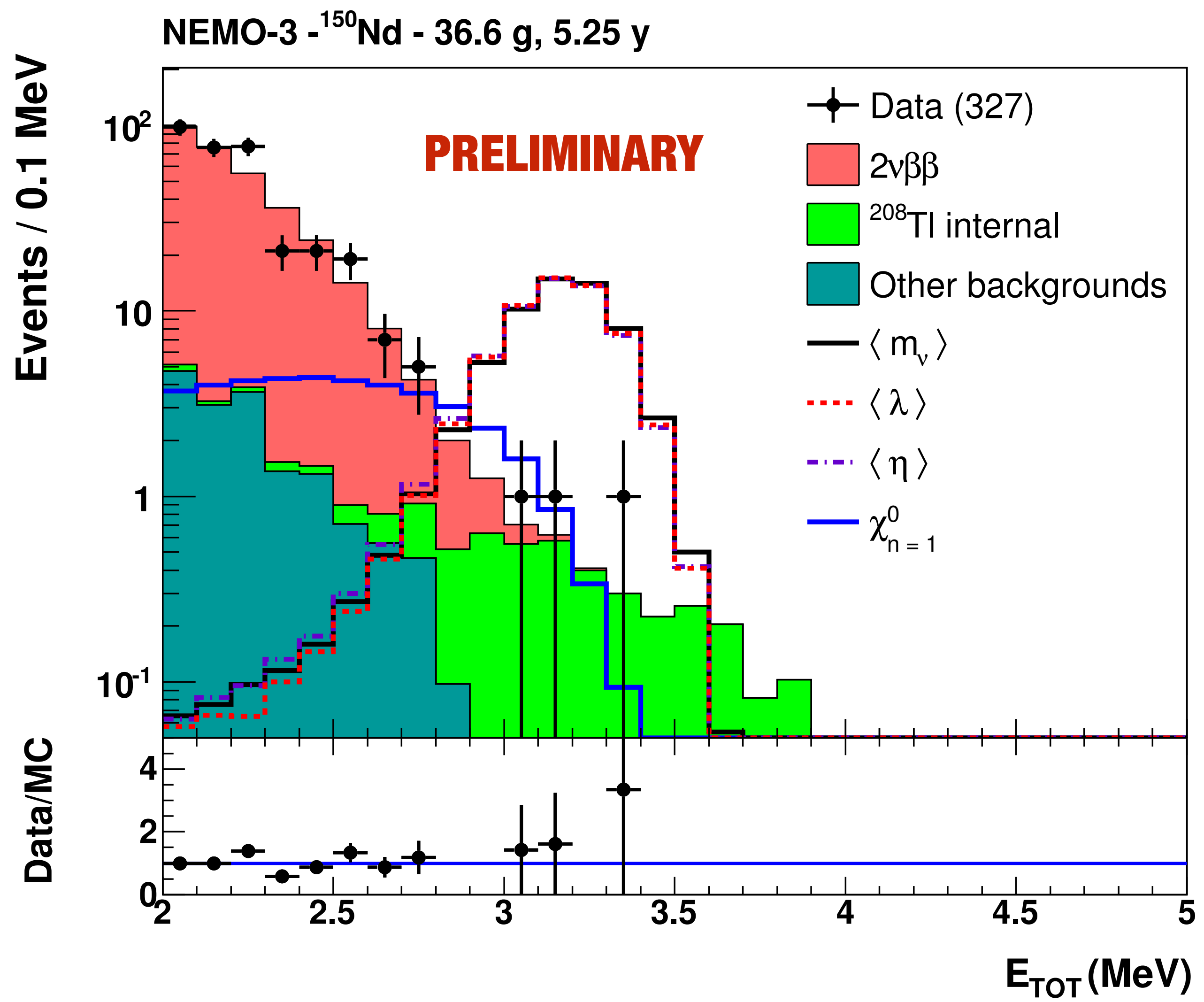
Ca-48 results in a nutshell

- 7g of ^{48}Ca
- No events observed for E > 3.4 MeV, 0.1 bkg. expected
- Potential background free for x10 exposure
- 2νββ measurement
  - S/B = 3.7
  - Best half-life measurement to date
- 0νββ searches
  - Limits set for different mechanism
- Accepted in Phys Rev D



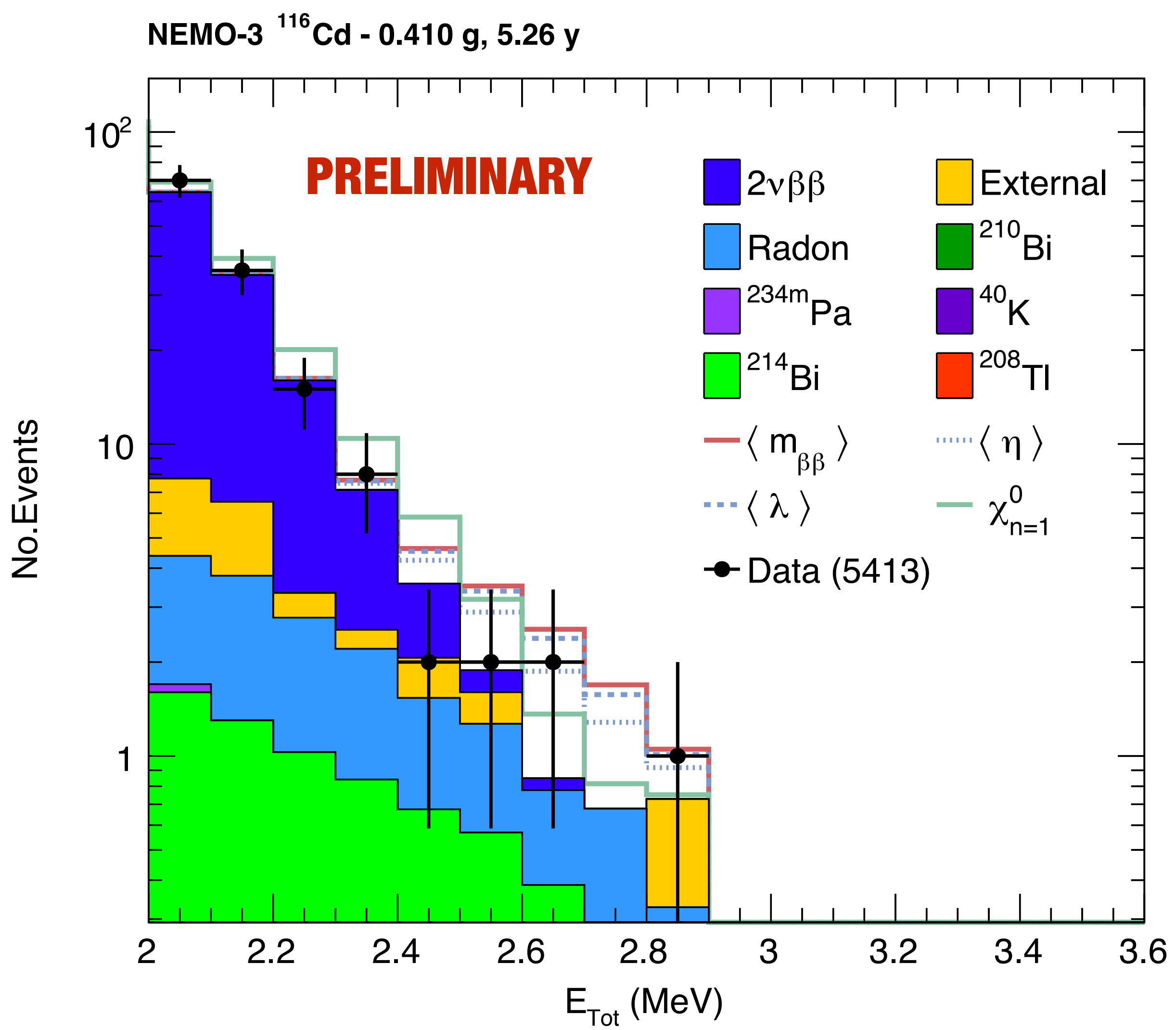
Nd-150 results in a nutshell

- $2\nu\beta\beta$ measurement
  - S/B = 3.9
  - Best half-life measurement to date
- $0\nu\beta\beta$ searches
  - First use of BDT to enhance background separation
  - Increase sensitivity by 10%
  - Limits set for different mechanism
- Paper under internal review



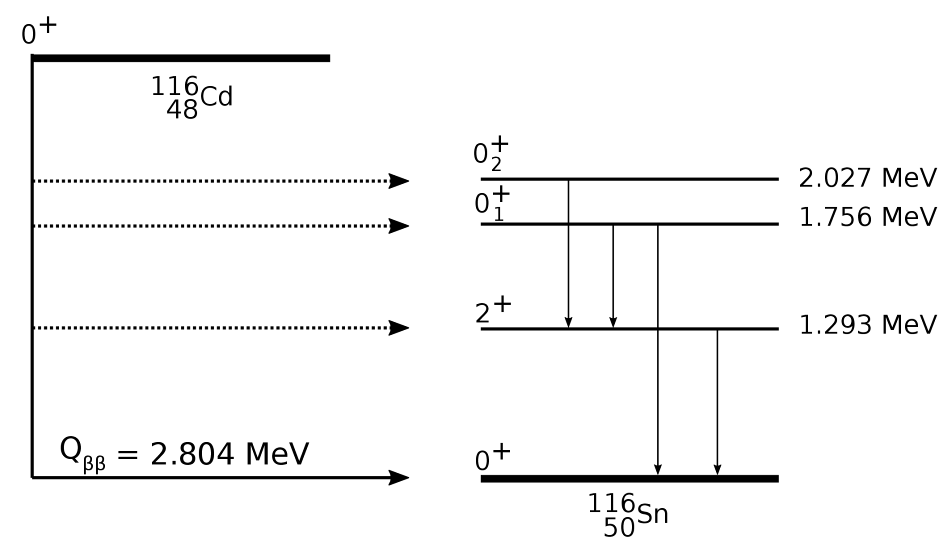
Cd-116 results in a nutshell

- 2νββ measurement
  - S/B = 12.7
  - High precision half-life measurement
  - Some sensitivity to discriminate Single State vs Higher State dominance
- 0νββ searches
  - Use BDT increase sensitivity by ~10%
  - Limits set for different mechanism
- Paper under internal review

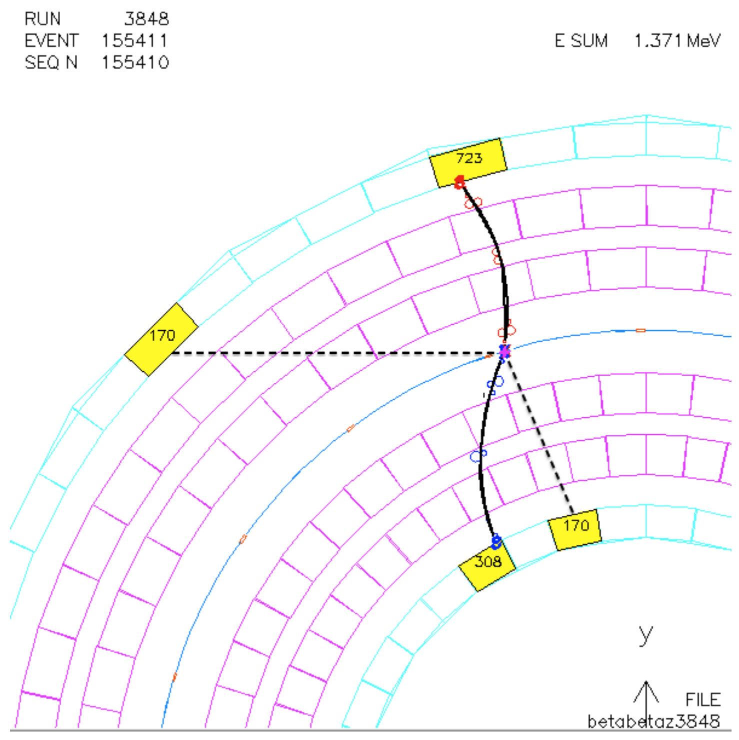


Study of the ββ decay to the excited states

- Require 2e in coincidence with γ of defined energy
  - Multivariate selection optimisation
- Provide additional handle for NME calculation



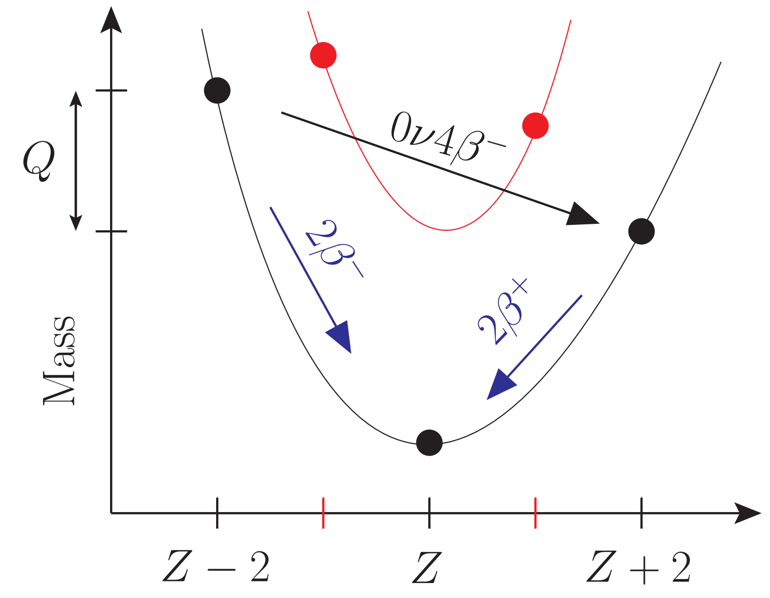
- Nd-150 (S. Blondel Ph.D. thesis 2013)
- Zr-96 (G. Eurin Ph.D. thesis 2015)
- Se-82 (B. Soulé Ph.D. thesis 2015)
- Cd-116 (T. Le Noblet Ph.D. thesis ongoing)



Other analysis

Neutrino-less quadruple beta decay:

- Proposed by J. Heeck and W. Rodejohann, Europhys. Lett. 103, 32001 (2013)
- Introduce new scalar fields coupling to RH neutrinos
- Neutrinos are Dirac particle and 0vββ is forbidden
- Only 3 candidates, 2 in NEMO-3 — Analysis ongoing



	$Q_{0\nu4\beta}$
${}^{96}_{40}\mathrm{Zr} \to {}^{96}_{44}\mathrm{Ru}$	0.629
${}^{136}_{54}\mathrm{Xe} \to {}^{136}_{58}\mathrm{Ce}$	0.044
${}^{150}_{60}\mathrm{Nd} \to {}^{150}_{64}\mathrm{Gd}$	2.079

Lorenz violation:

- First search for periodic modulation of 2vββ decay rate
- NEMO-3 data span over ~5 year exposure
- Use Mo-100 sample which provide largest and cleanest ββ sample in NEMO-3
- Analysis ongoing

Conclusions

- After 5 years from detector dismantling, NEMO-3 analysis is still very active!
- Final search for 0νββ in the pipeline (Ca-48, Nd-150 and Cd-116)
  - First (and unique!) use of multivariate techniques ~10% sensitivity enhancement
  - Not competitive with most recent result but proof of concept for the future experiment: SuperNEMO
- Most precise 2νββ half-life for almost all the isotopes (Mo-100, Ca-48, Nd-150)
- Unique handle to SSD/HSD and ββ decay toward the excited state
  - Important to improve the understanding of ββ decay at nuclear physics level
- Few unique and interesting analysis ongoing:
  - Searches for neutrino-less quadruple beta decay and Lorentz violation

Backups