The SuperNEMO Demonstrator:
a unique technology for high-precision measurements of ββ-decay modes

Miroslav Macko *on behalf of the* ***SuperNEMO Collaboration***

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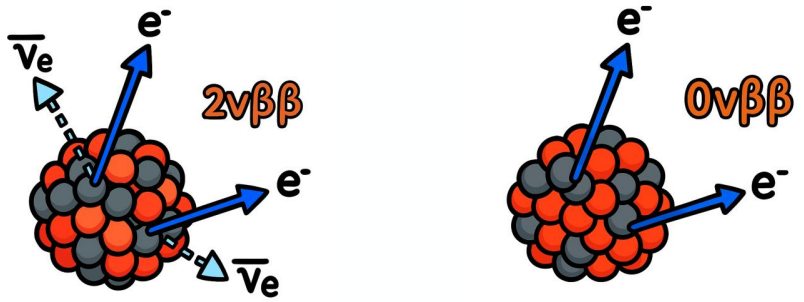
EPS-HEP conference 2025 | Marseille | 9th July 2025

Presentation plan

- Double beta decay
- SuperNEMO Demonstrator
- Background
- New physics



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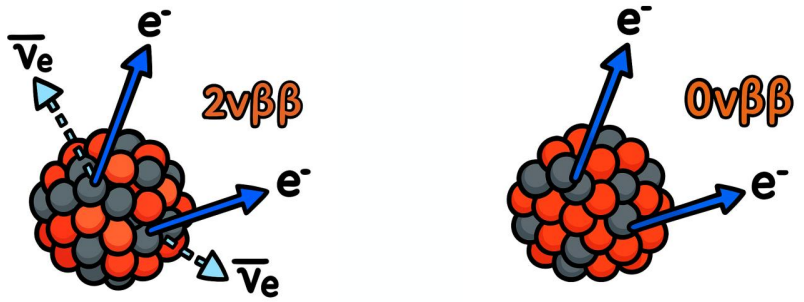

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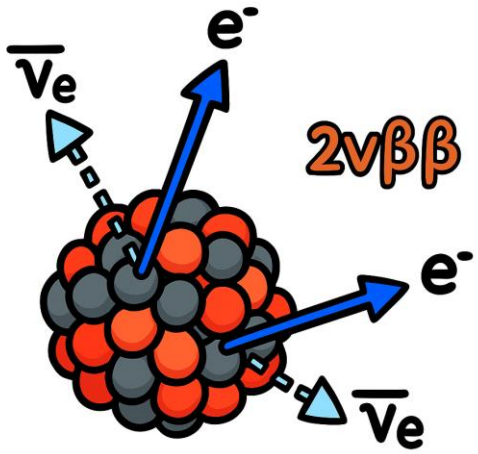

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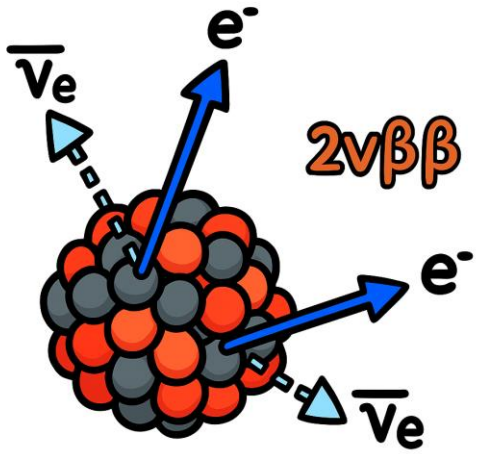

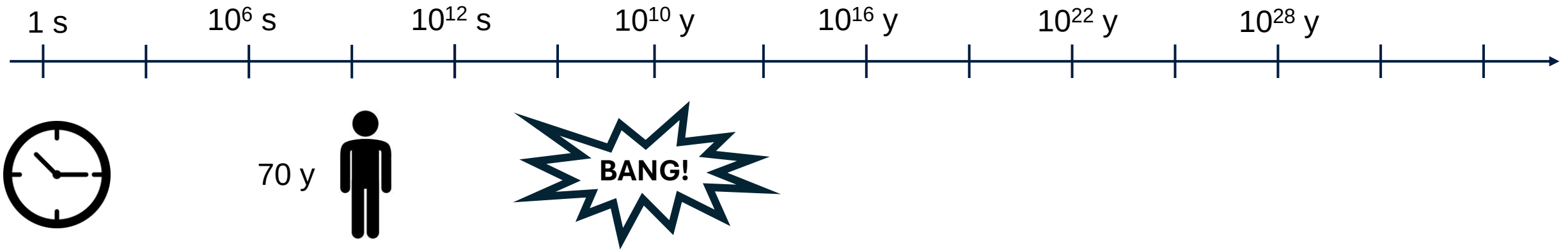

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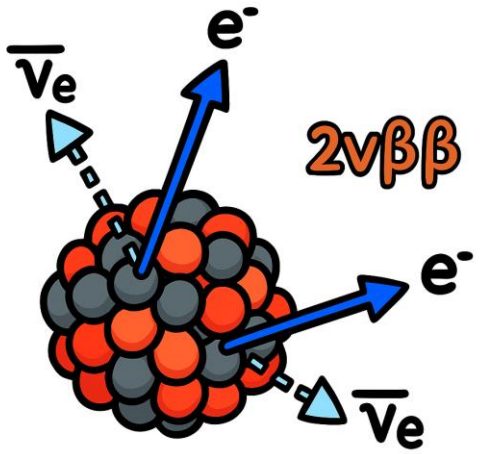

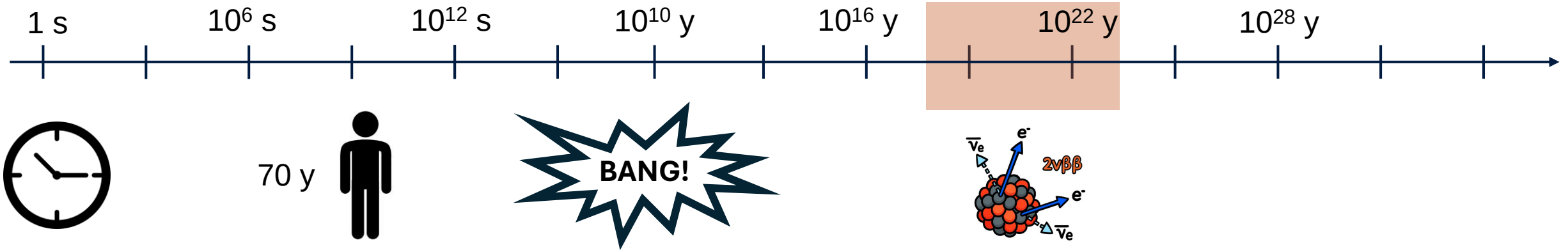

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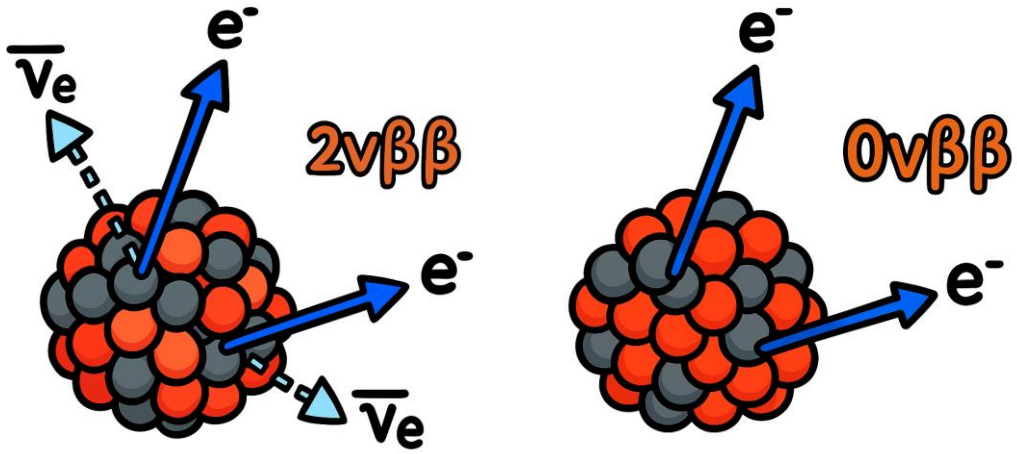

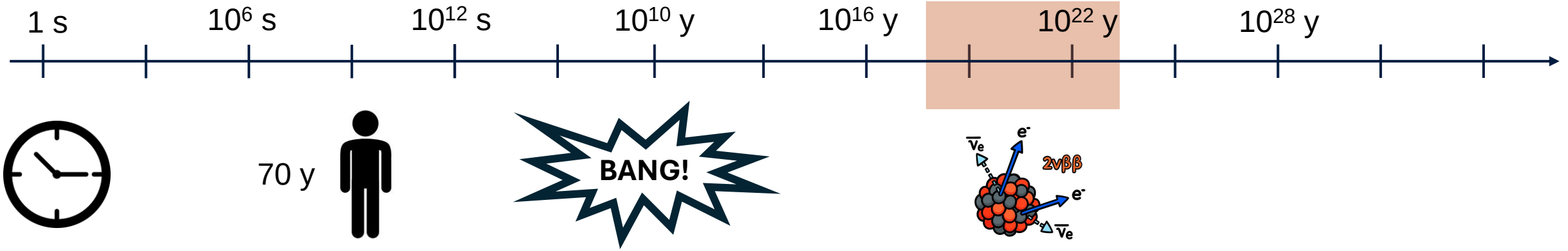

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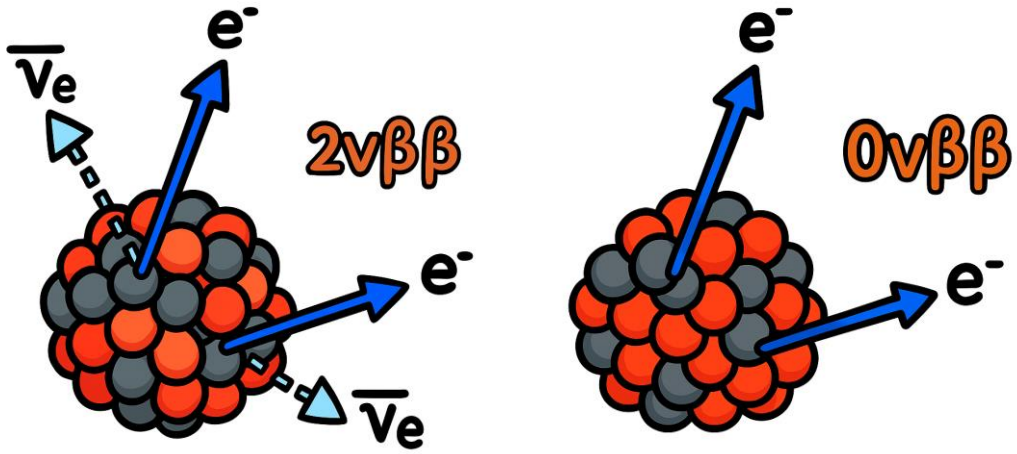
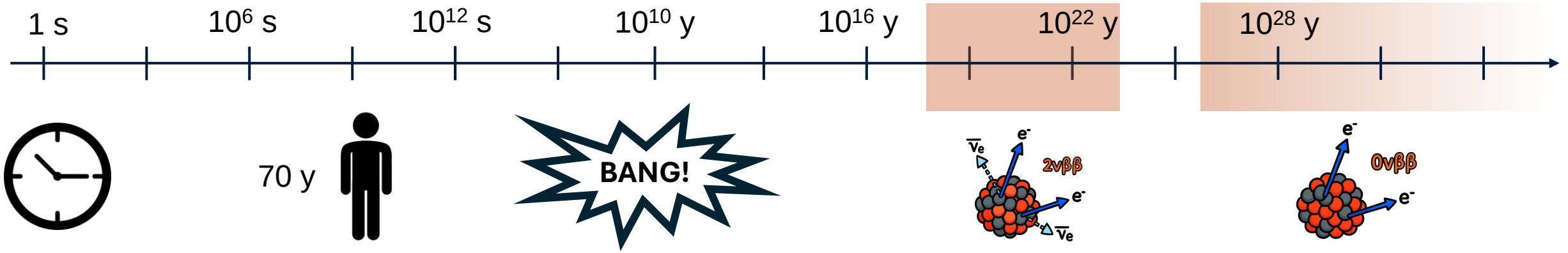
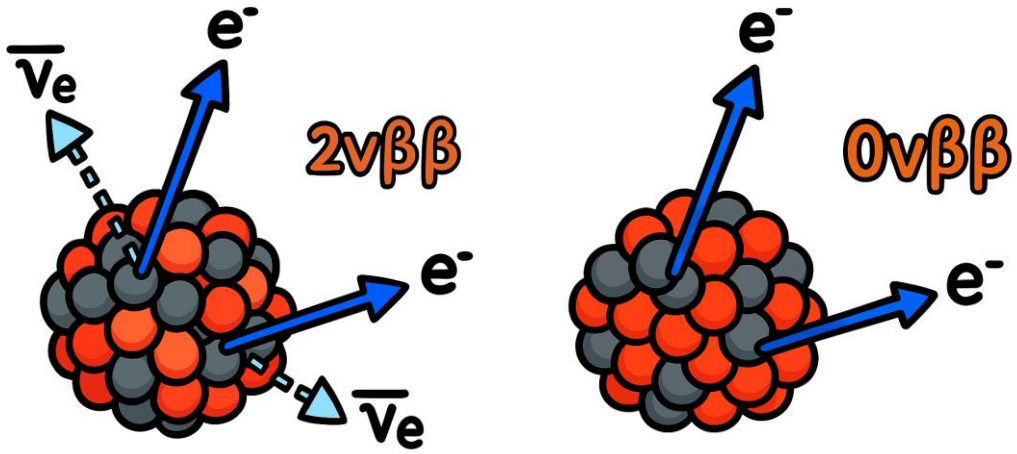


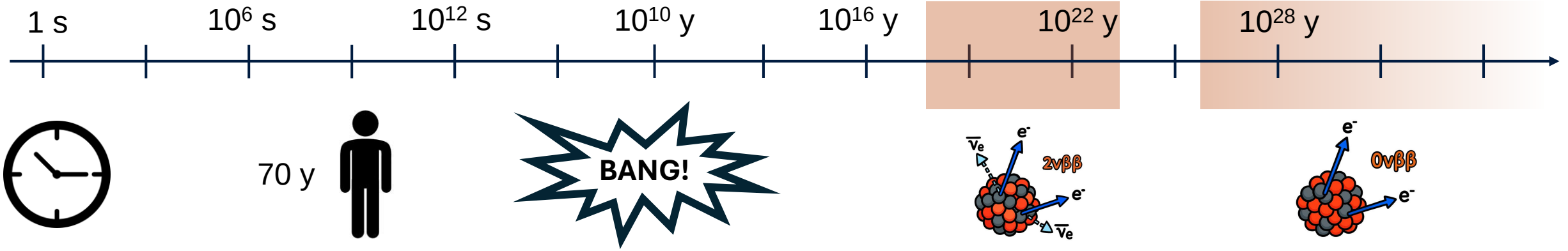


Double beta decay

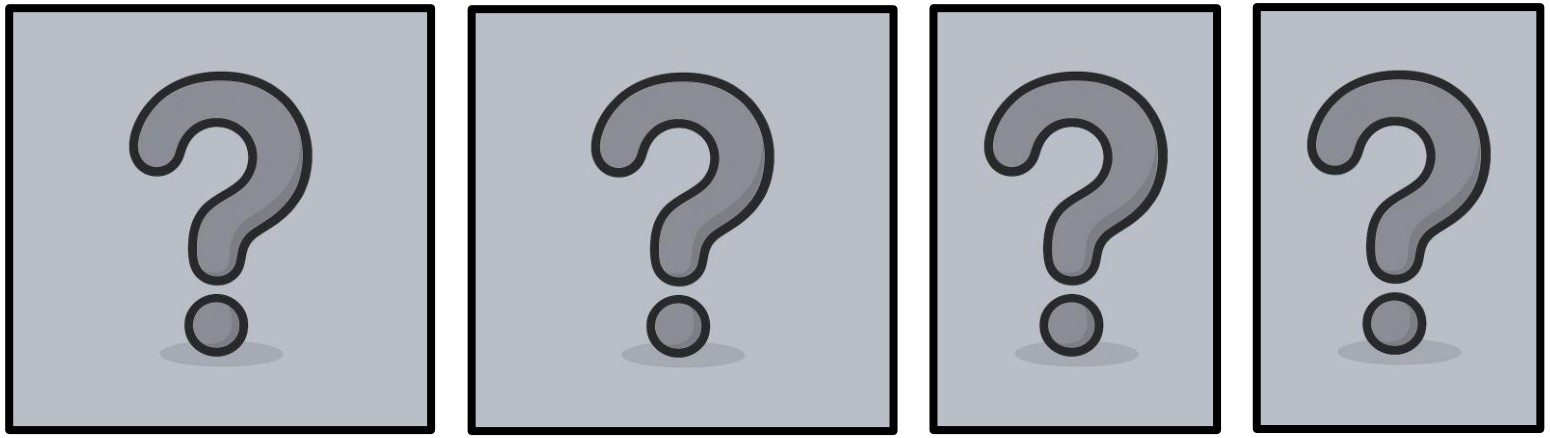
Why do we search for 0νββ?

- Measurement of absolute neutrino mass
- Lepton number violating process
- Mass ordering
- Might show a path beyond the SM



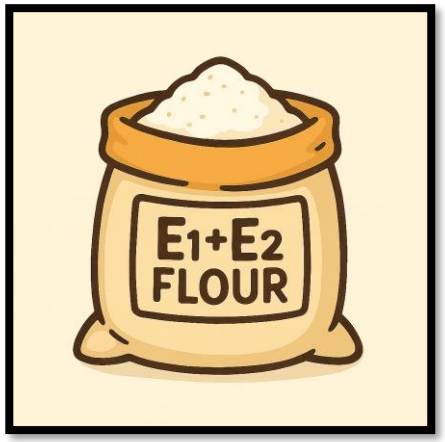


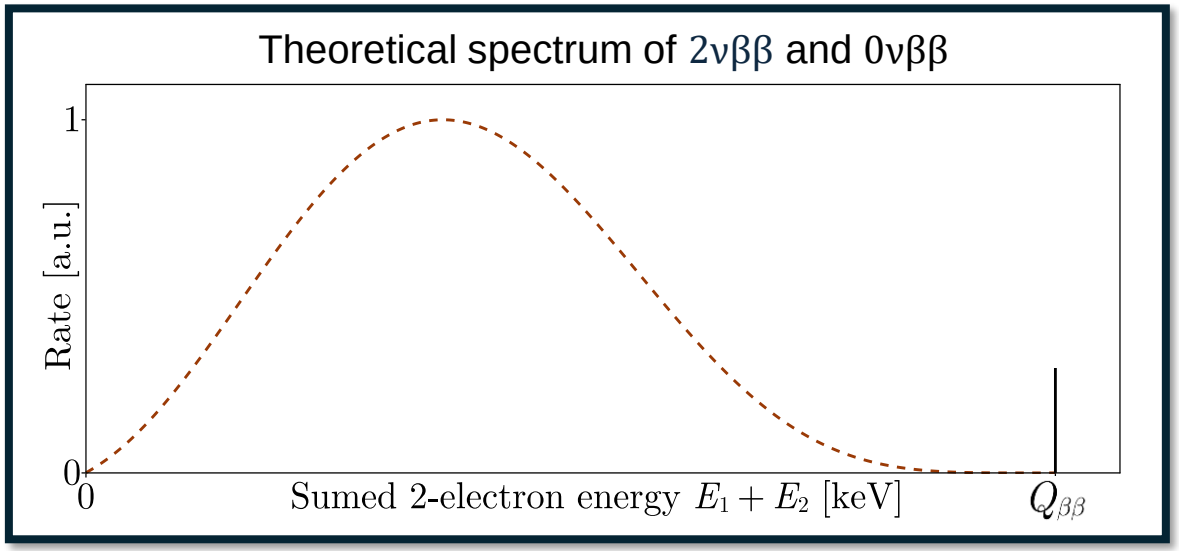
Ingredients to bake a DBD experiment



Ingredients to bake a DBD experiment

- Energy measurement (flour)
- ?
- ?
- ?





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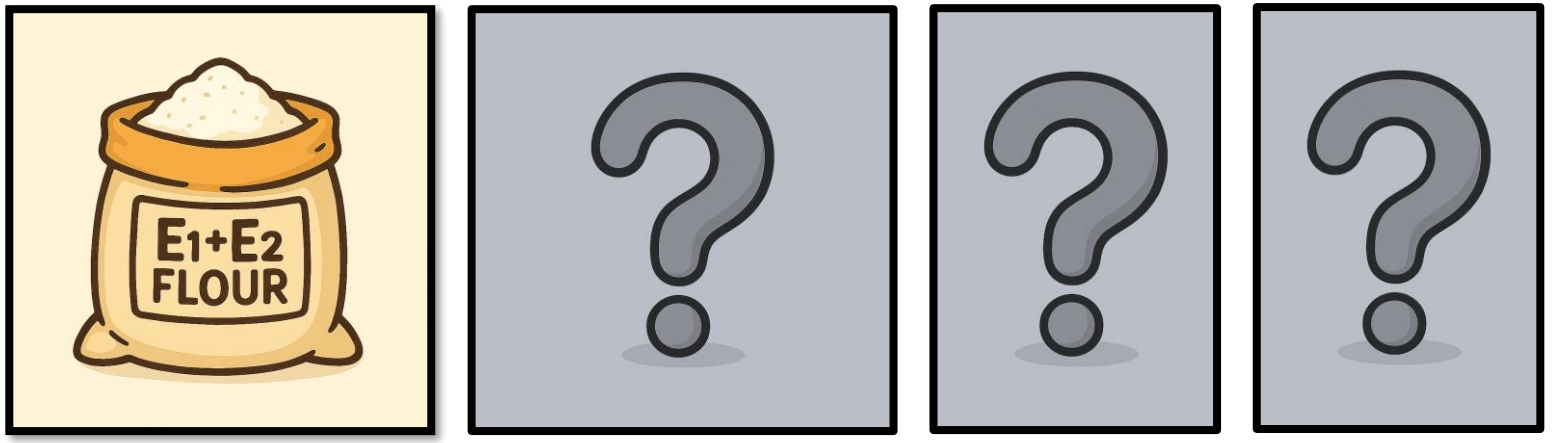

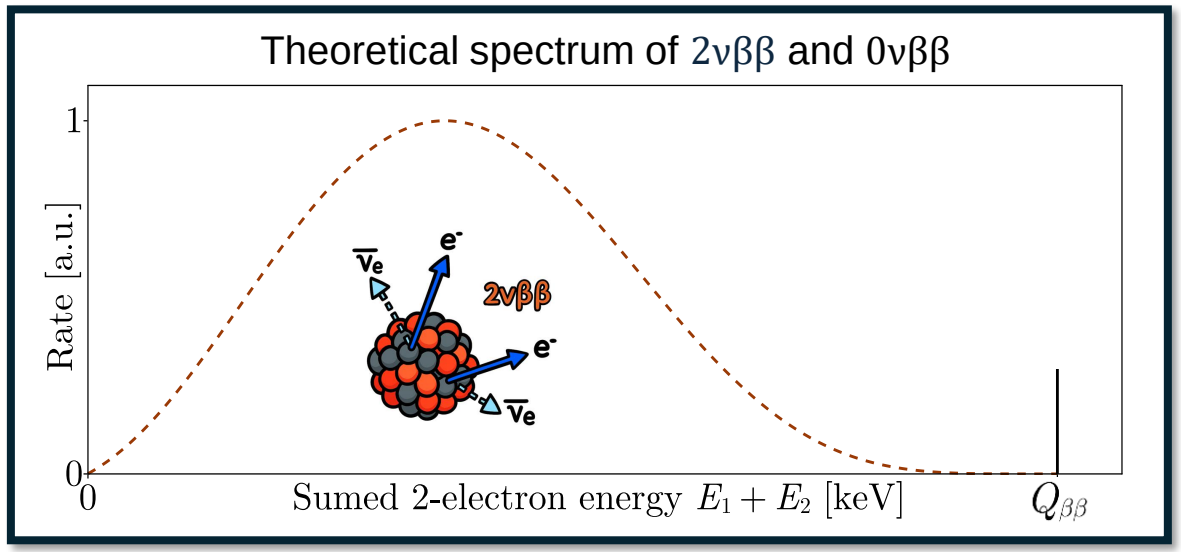

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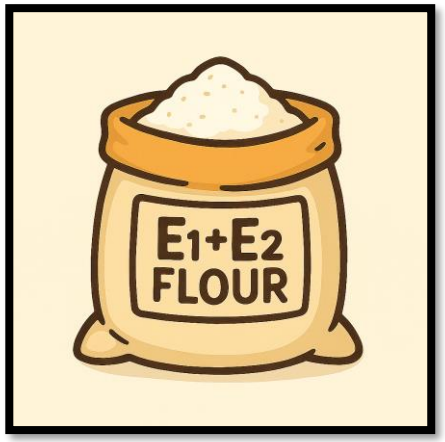

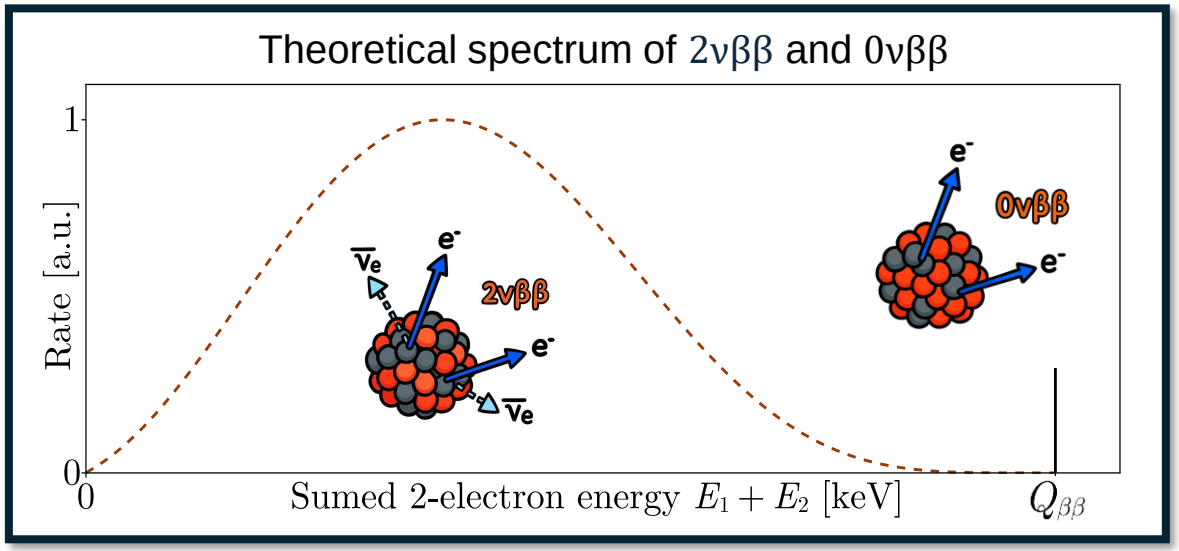

Ingredients to bake a DBD experiment

- Energy measurement (flour)
- Low background (yeast)
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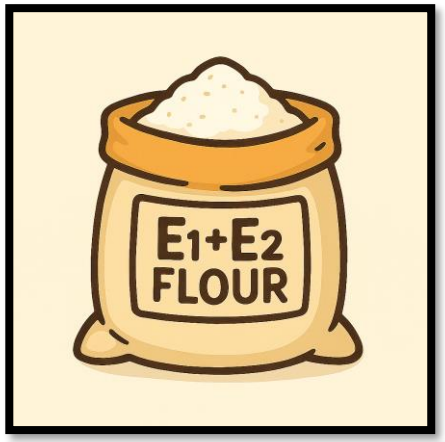
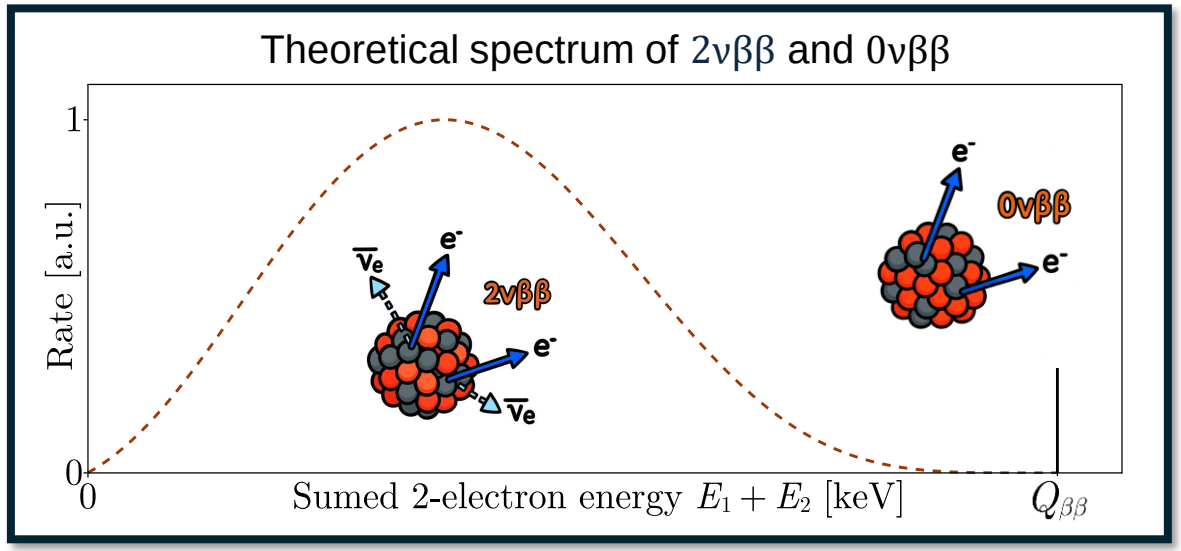
- ?



10^{-5} - 10^{-4} counts / keV.kg.yr in ROI



Ingredients to bake a DBD experiment

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- Statistical methods (water)
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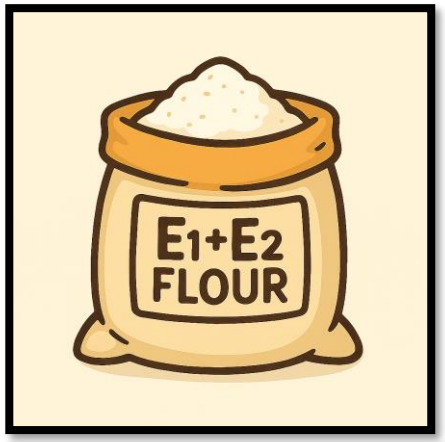

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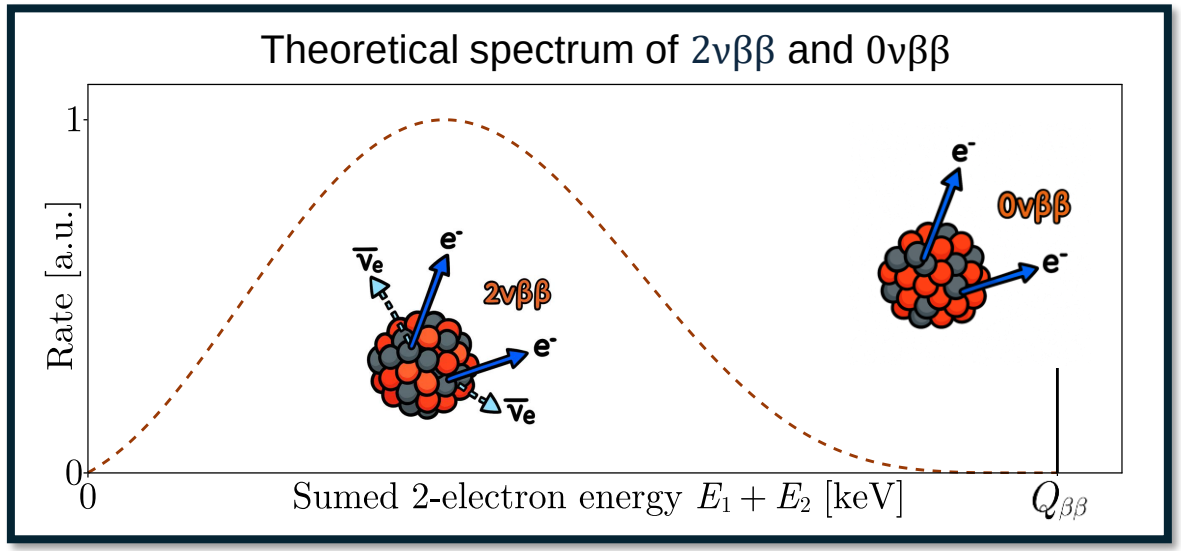
Bayes / Frequentist → $T_{1/2}$ lower limit → $|m_{\beta\beta}|$ upper limit



Ingredients to bake a DBD experiment

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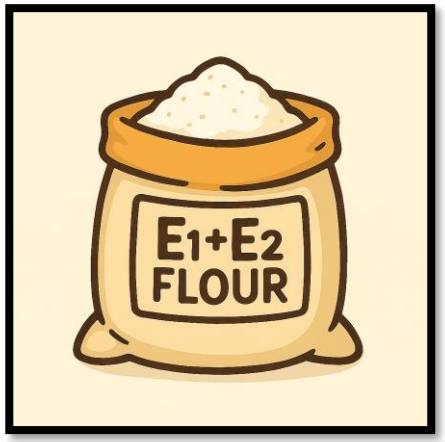
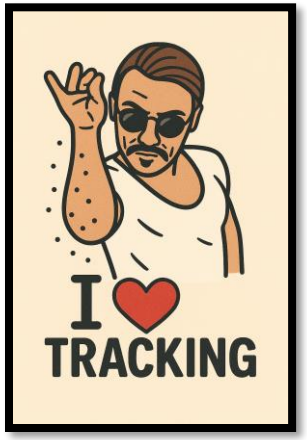
- Low background (yeast)
- Statistical methods (water)
- Track reconstruction (salt / spices)





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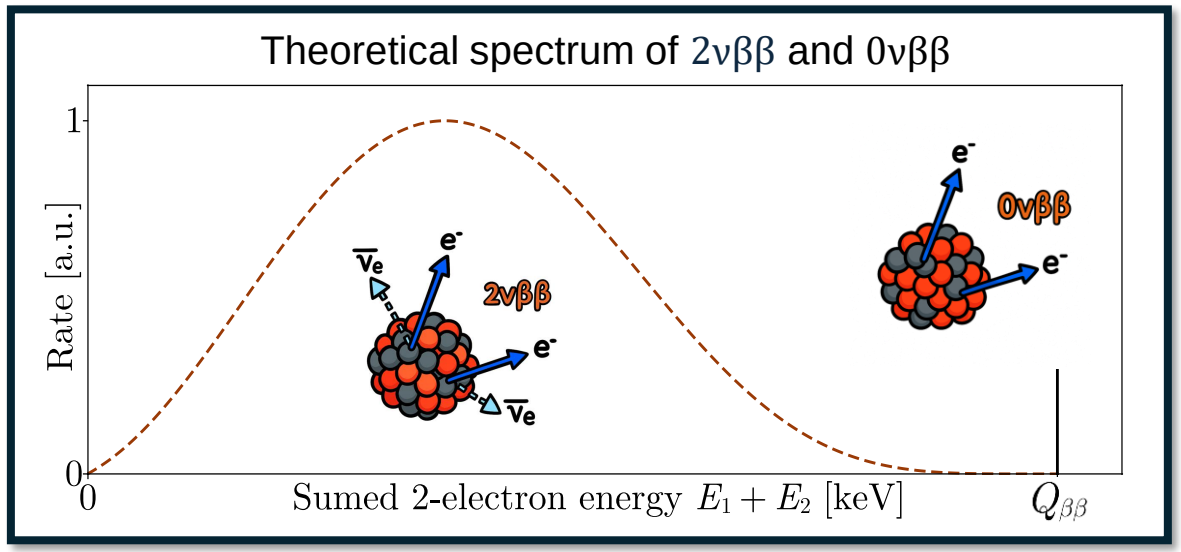

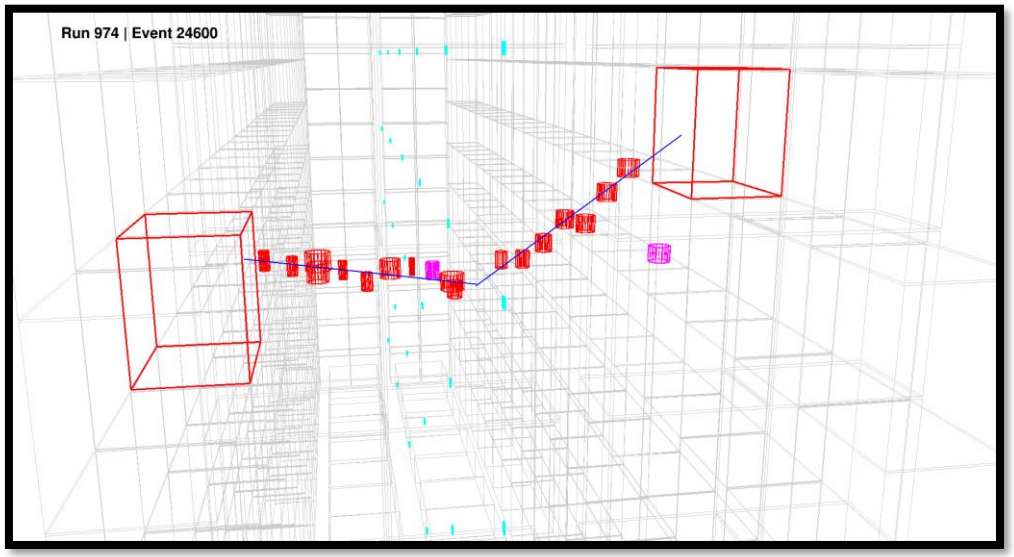

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- **SuperNEMO Demonstrator**
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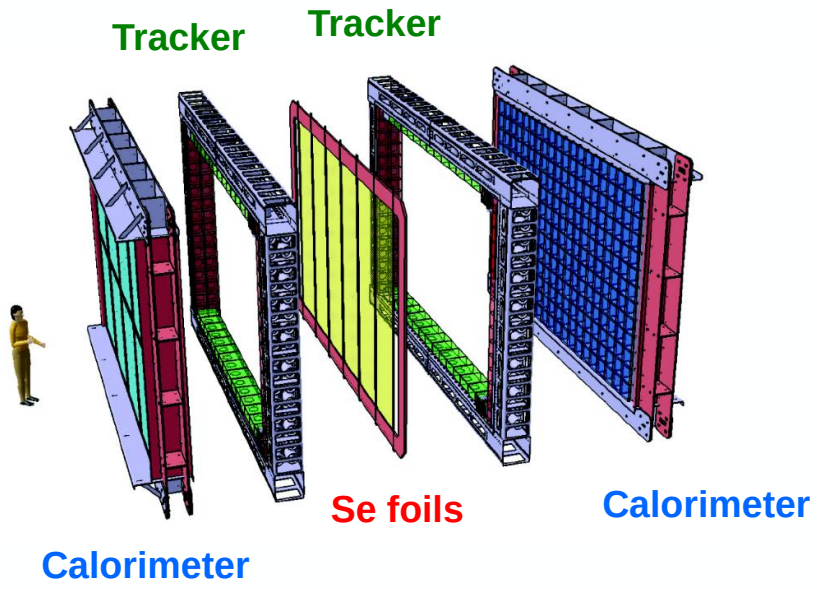
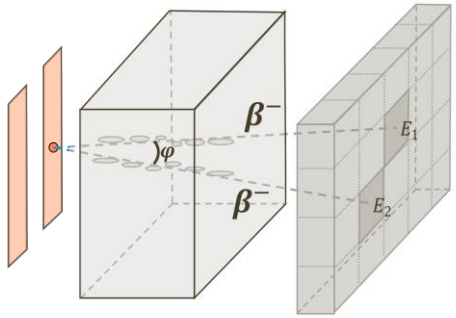
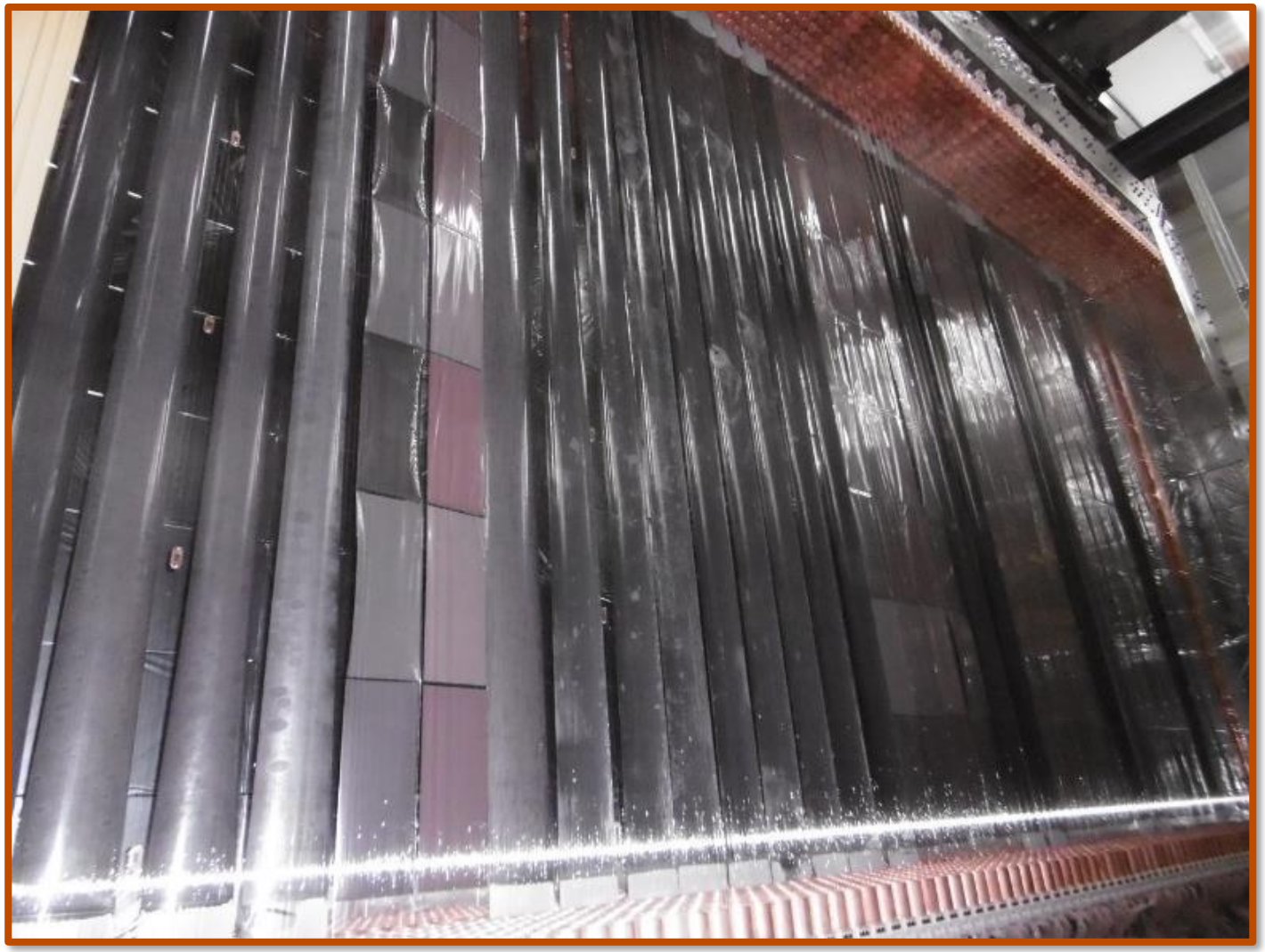


SuperNEMO Demonstrator – source foil

Source foil



- Free choice of isotope
- 34 strips of ^{82}Se
- 6.11kg mass, $\sim 50\ mg/cm^2$
- 96-99.9% enrichment
- Q ≈ 3 MeV
- If $\boldsymbol{0\nu\beta\beta}$ discovered - measure isotope



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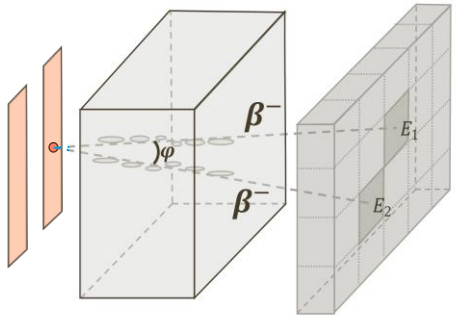

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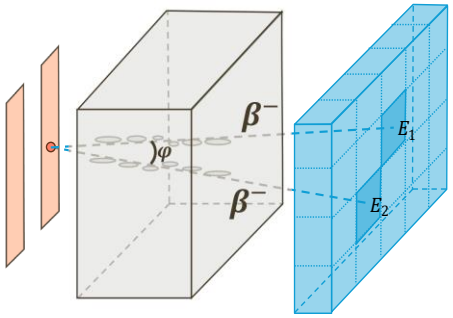
SuperNEMO Demonstrator - calorimeter



- 712 Optical Modules (OM)
- Target ~ 8% FWHM @ 1 MeV
- 8'' + 5'' PMTs
- Time-resolution ~200 ps @ 1 MeV
- Automatic calibration system
- Status: working (97.4%)!

Calorimeter main wall ($6 \times 4\ \mathrm{m}^2$)

Optical Module (OM): Polystyrene scintillator + PMT

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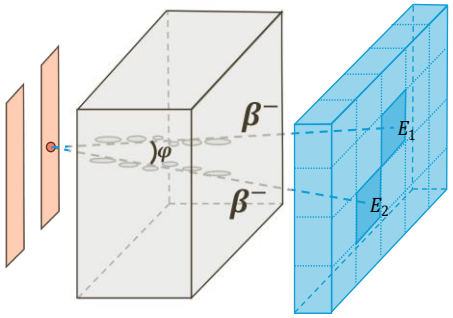

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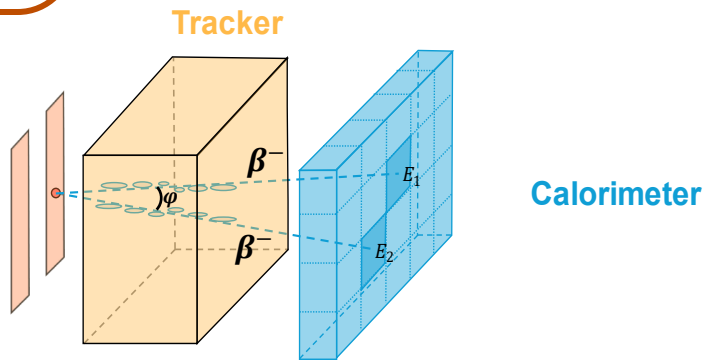
SuperNEMO Demonstrator - tracker



- 2034 drift cells (Geiger mode)
- Allows particle identification
- Full electron topology
- Single-electron spectra
- Angular distribution
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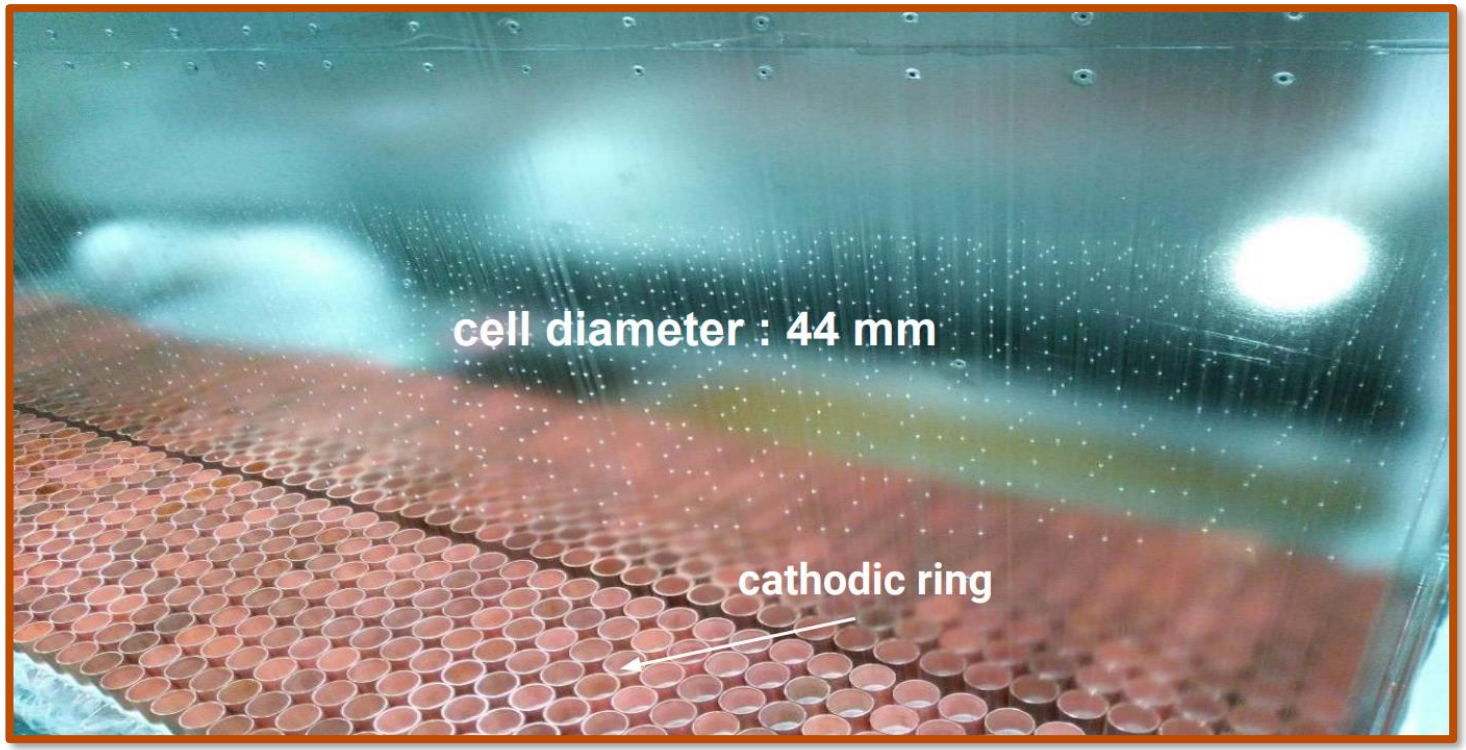

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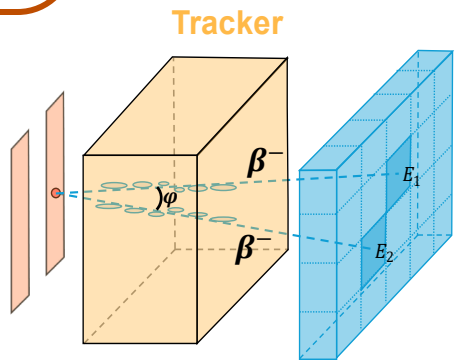

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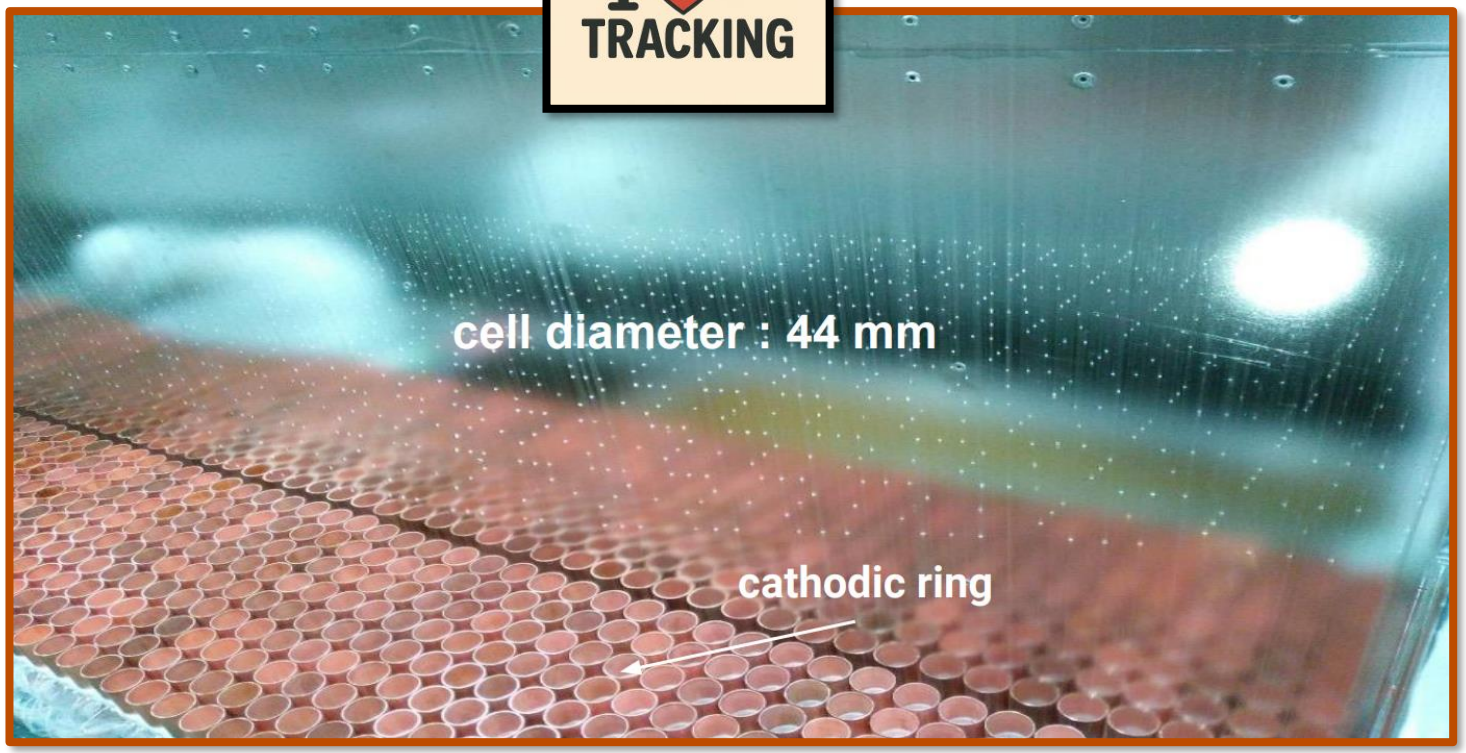
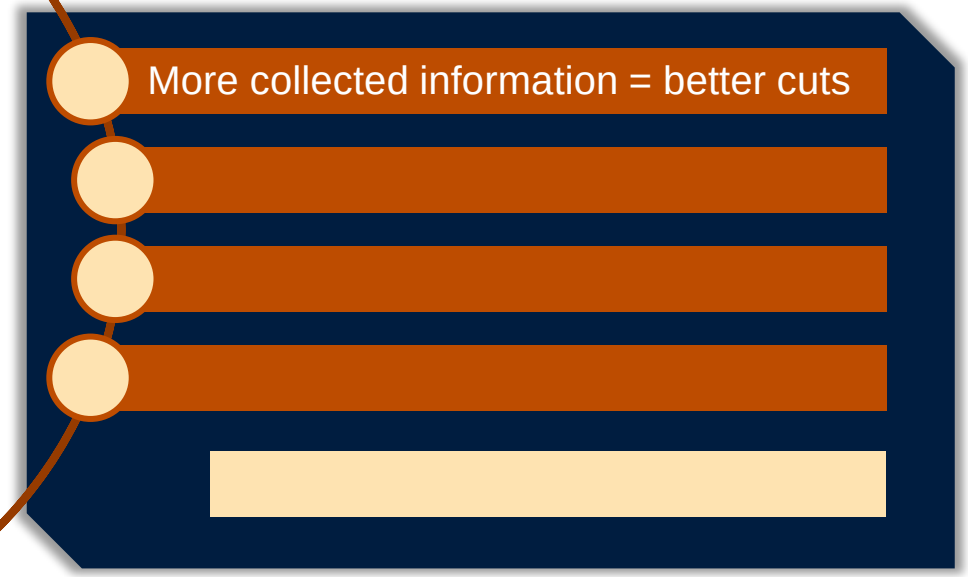
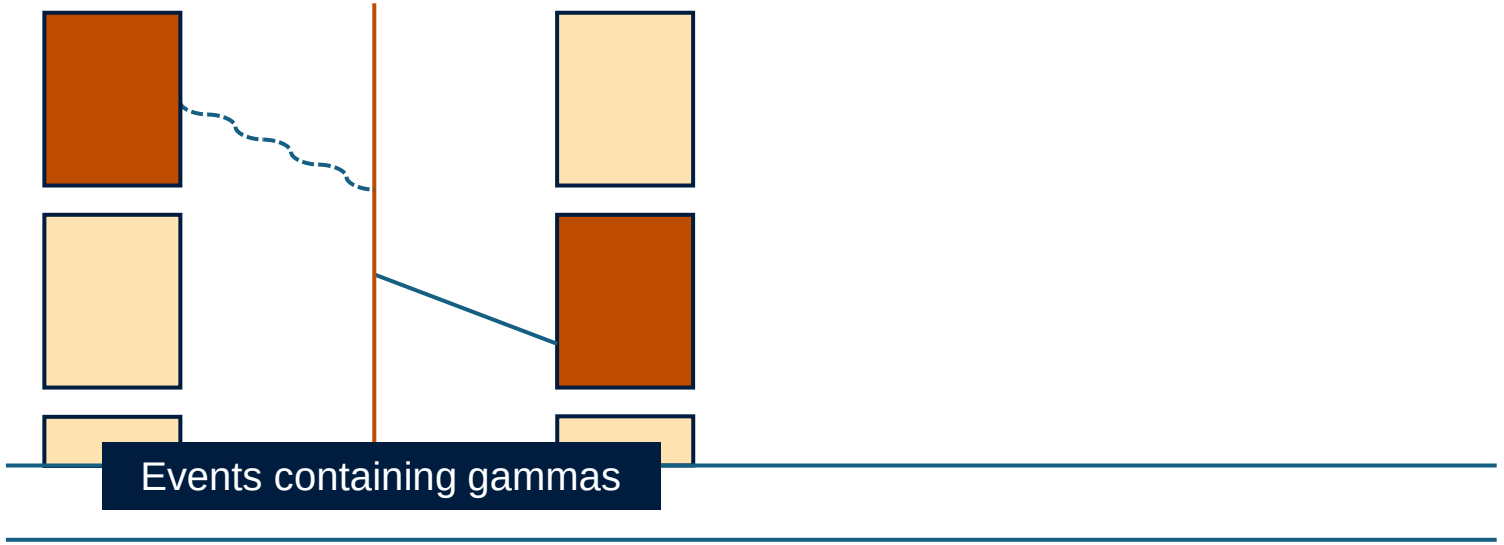


Why tracking?



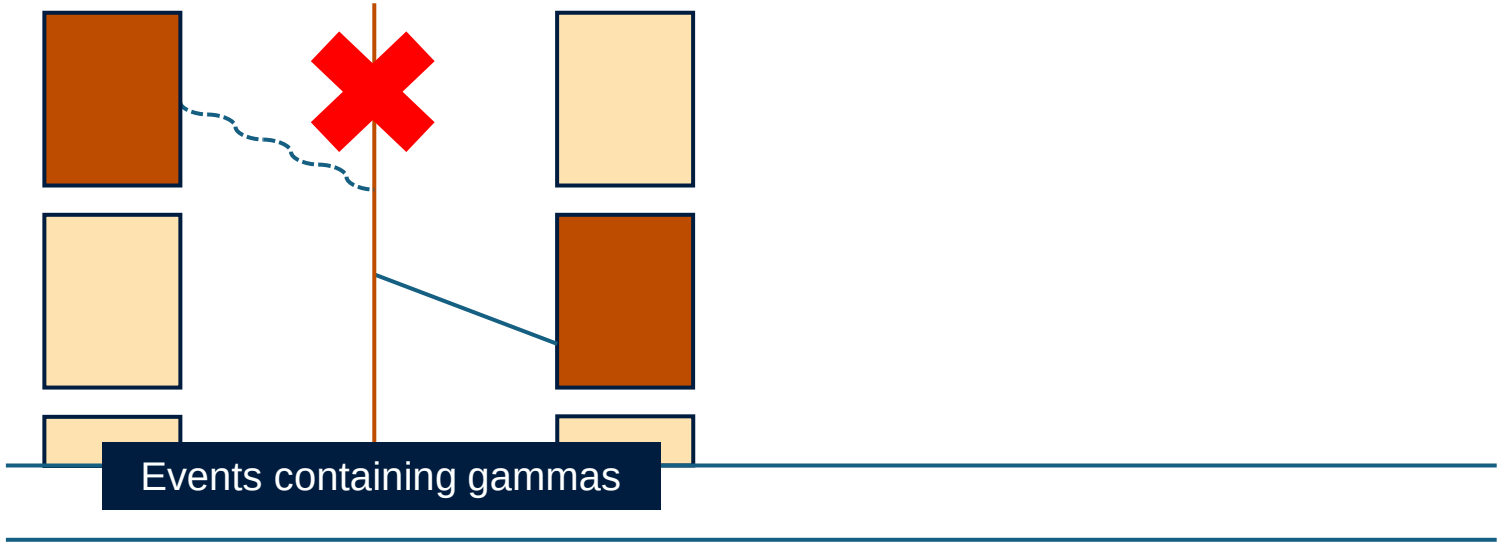
Why tracking?

- More collected information = better cuts



Why tracking?

- More collected information = better cuts
- Two electron tracks



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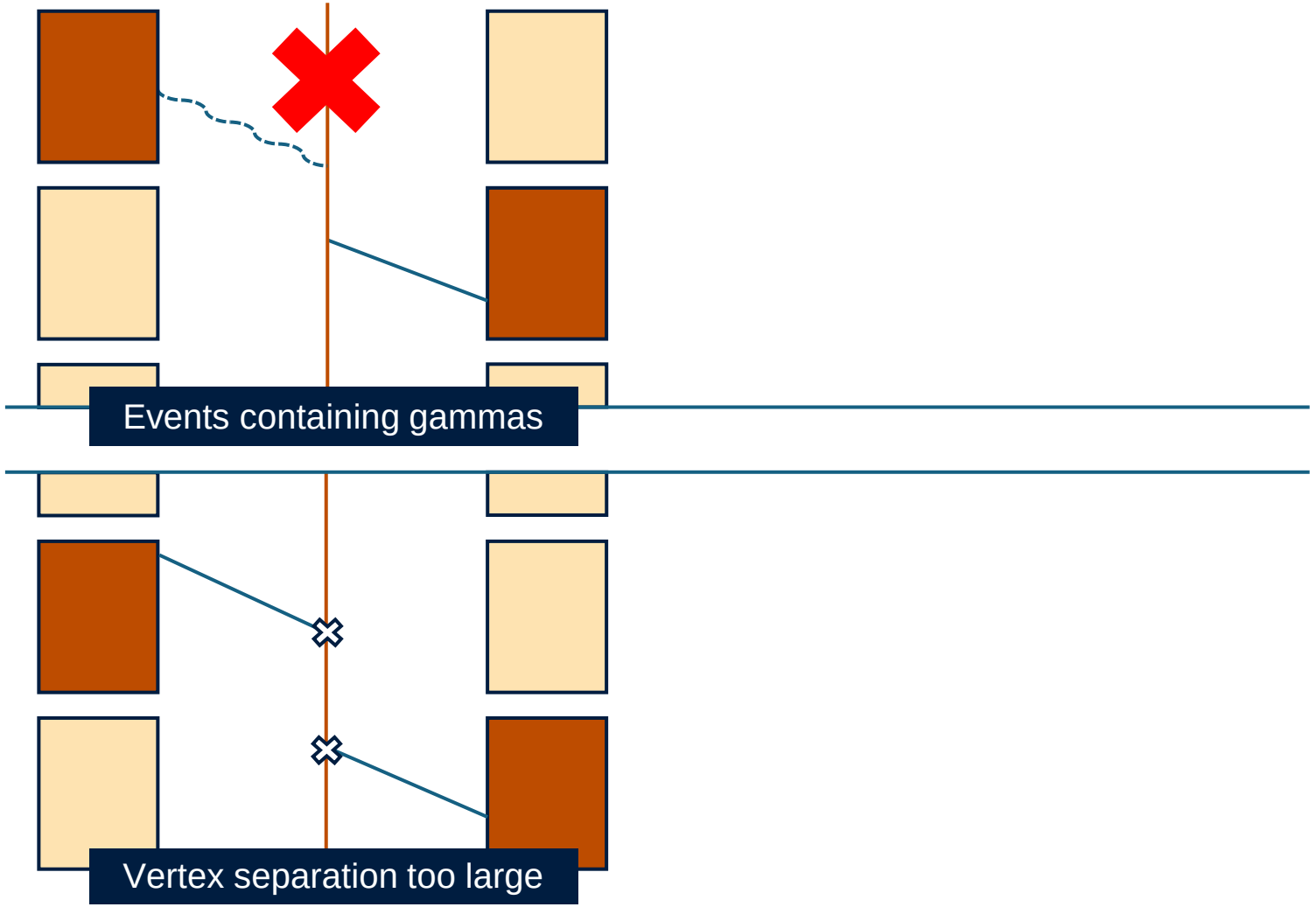

Why tracking?

- More collected information = better cuts
- Two electron tracks
- Vertex distance
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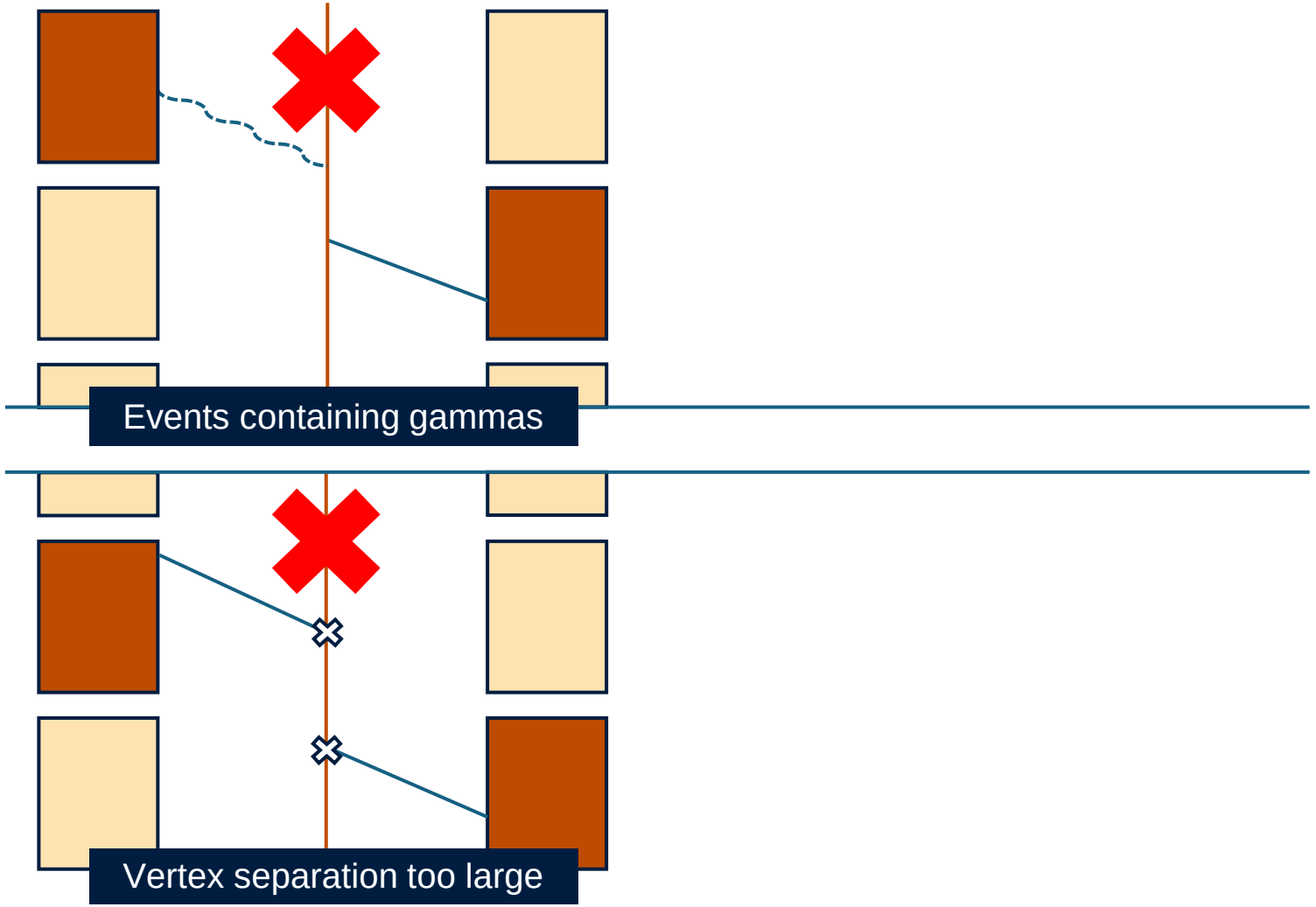

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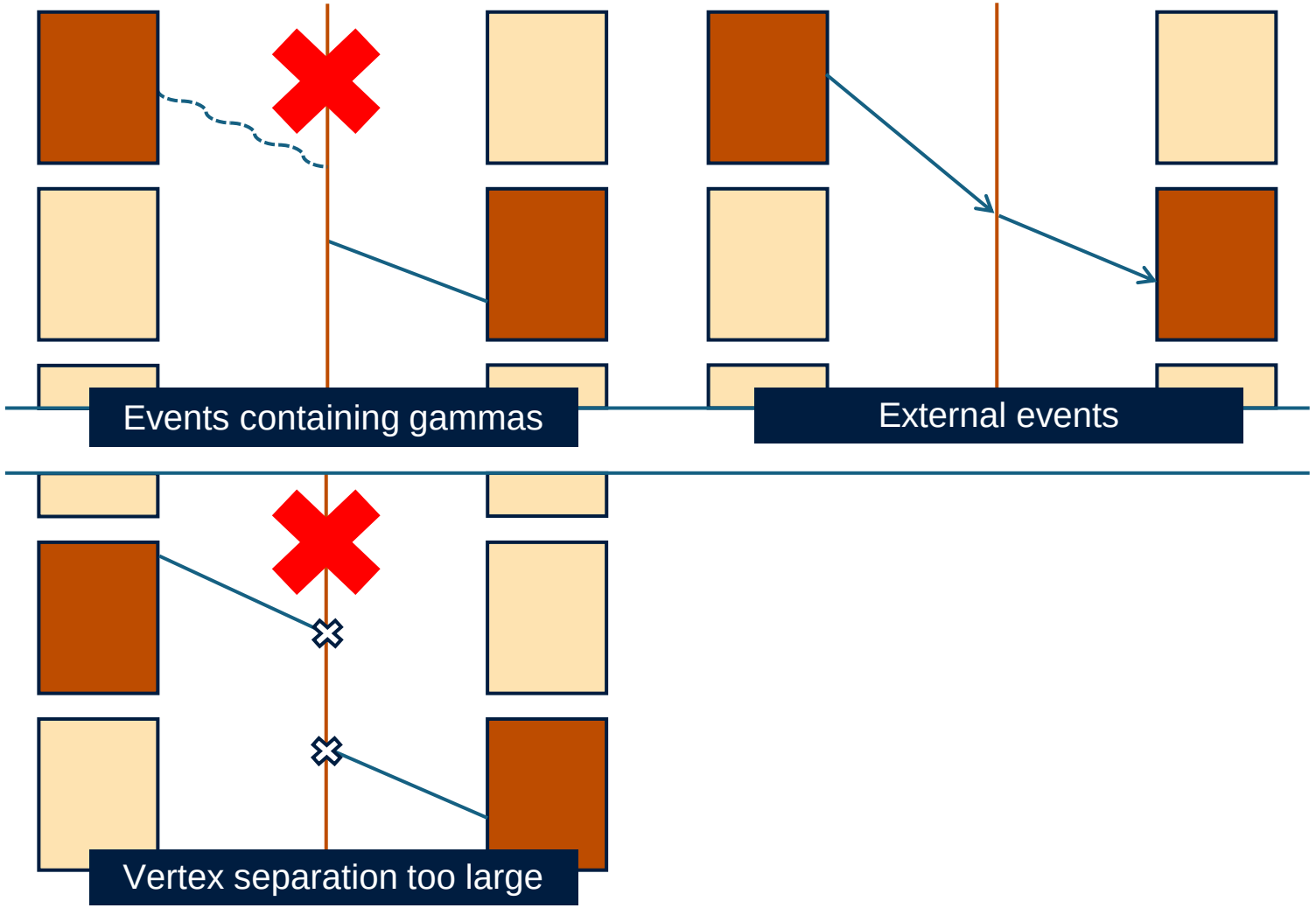

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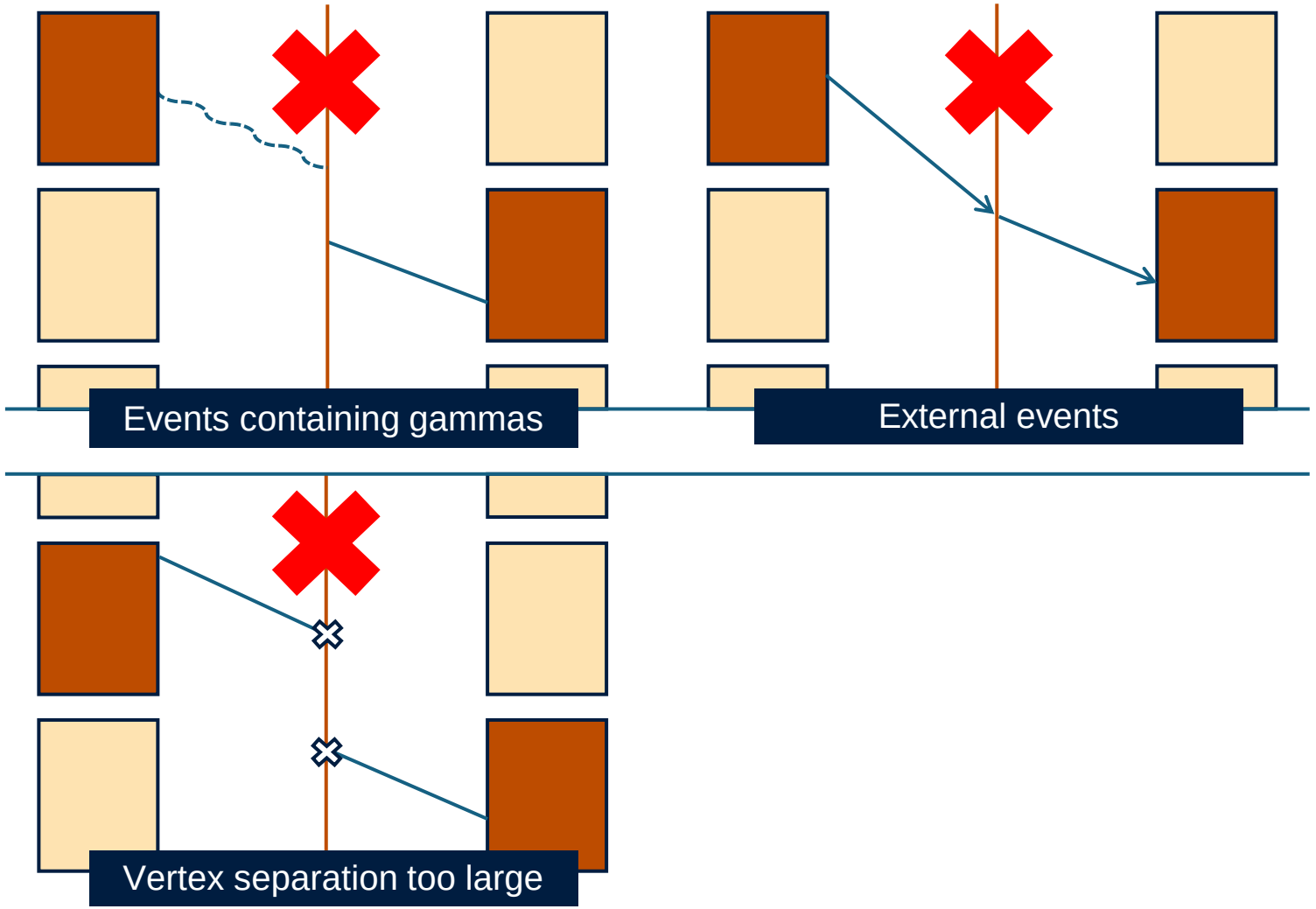

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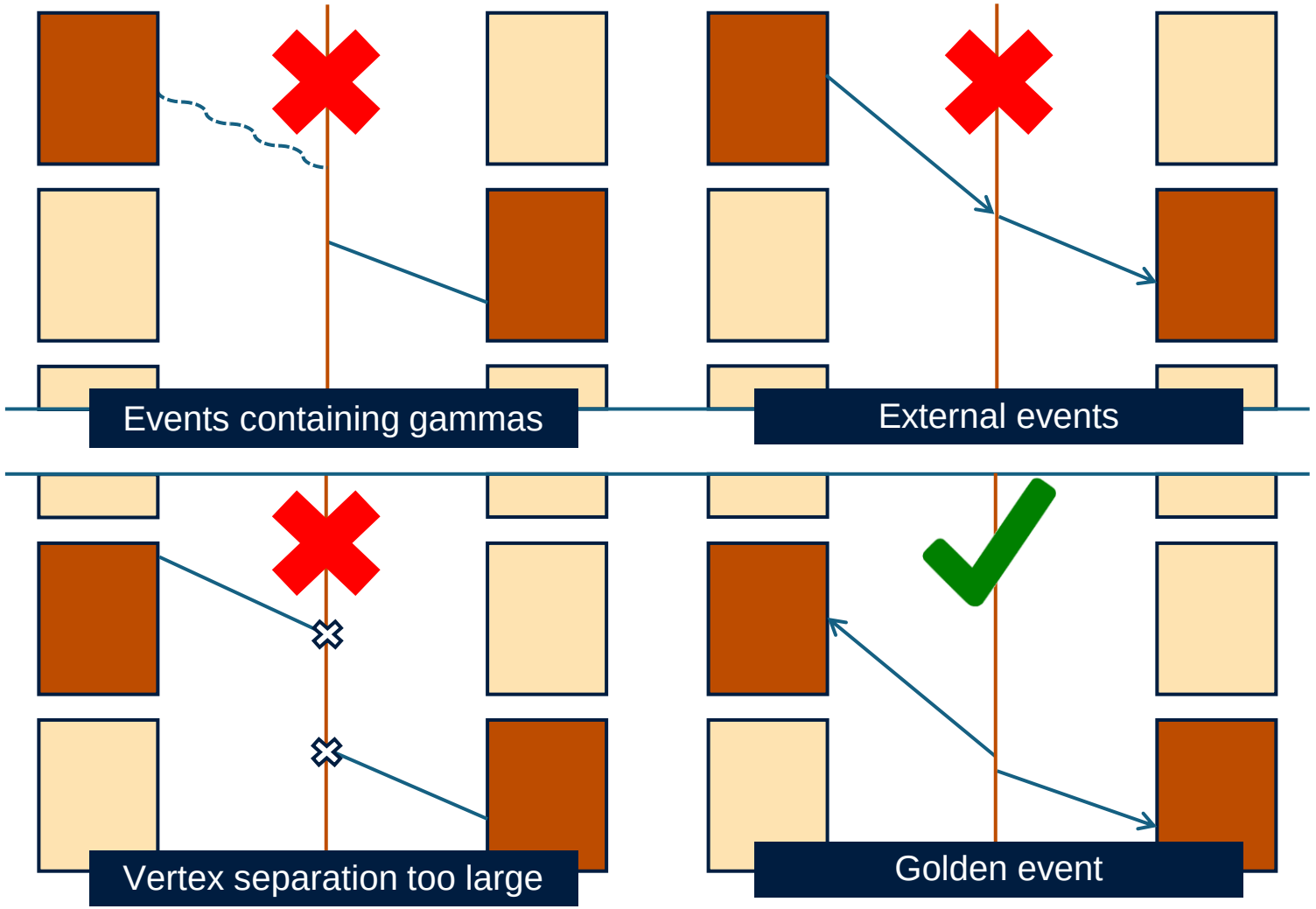
And more!



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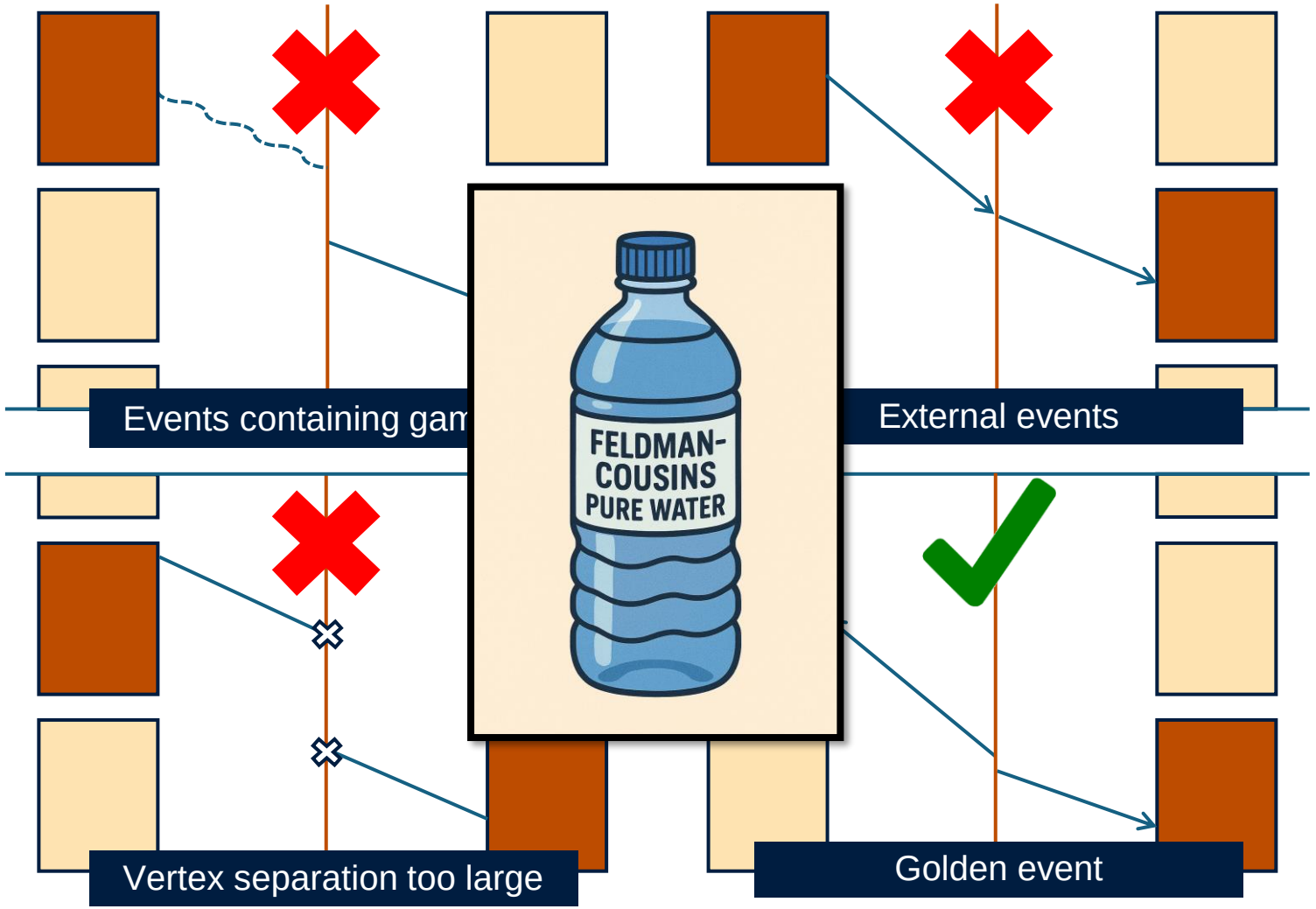
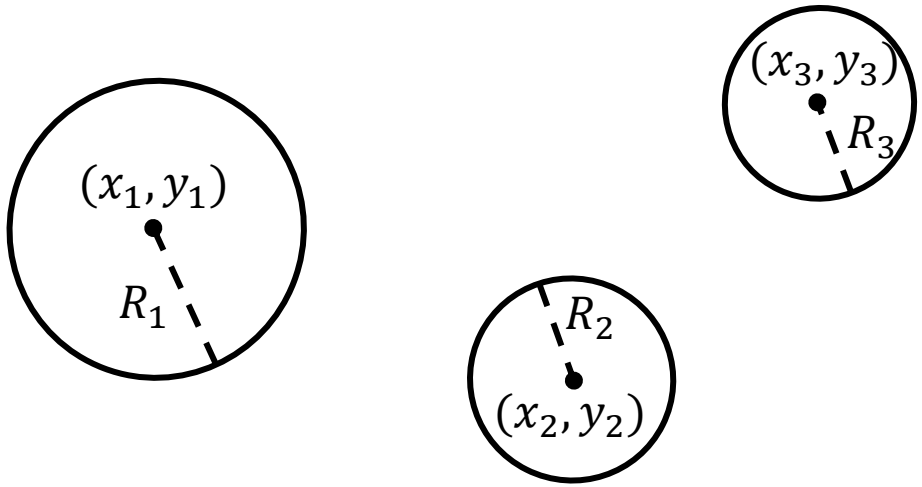


Tracking algorithm

SuperNEMO = very specific 3D tracking task



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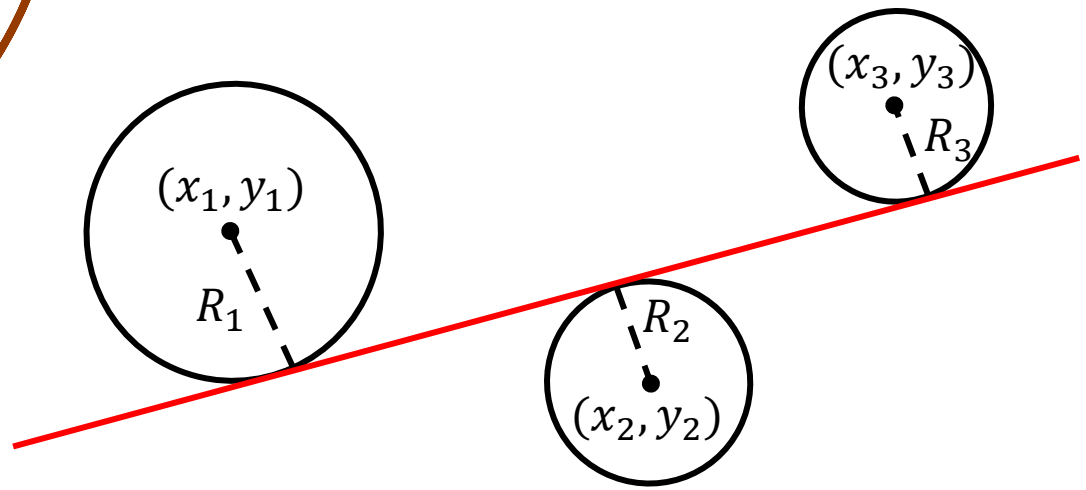
- Combination of Legendre transform and MLM
-



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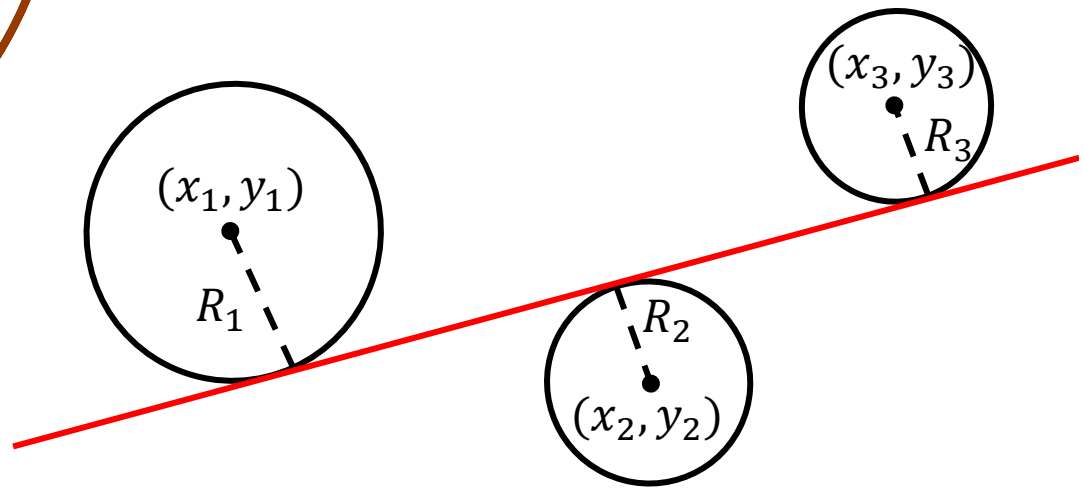
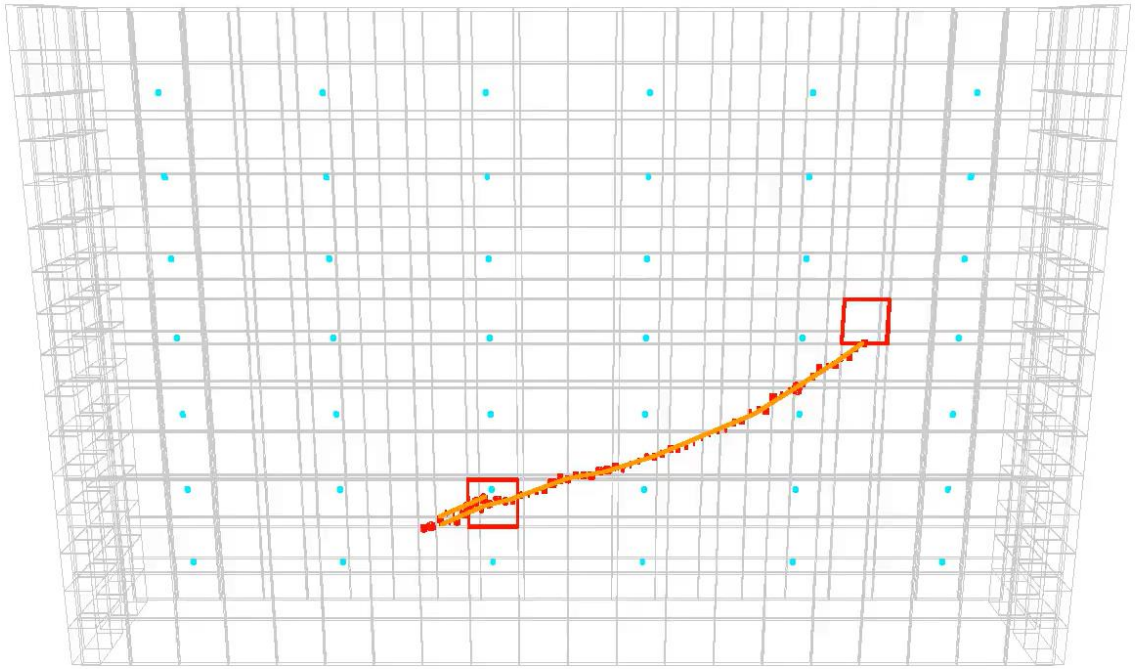
- **See poster #754 (Tomáš Křižák - today at 18:00)**

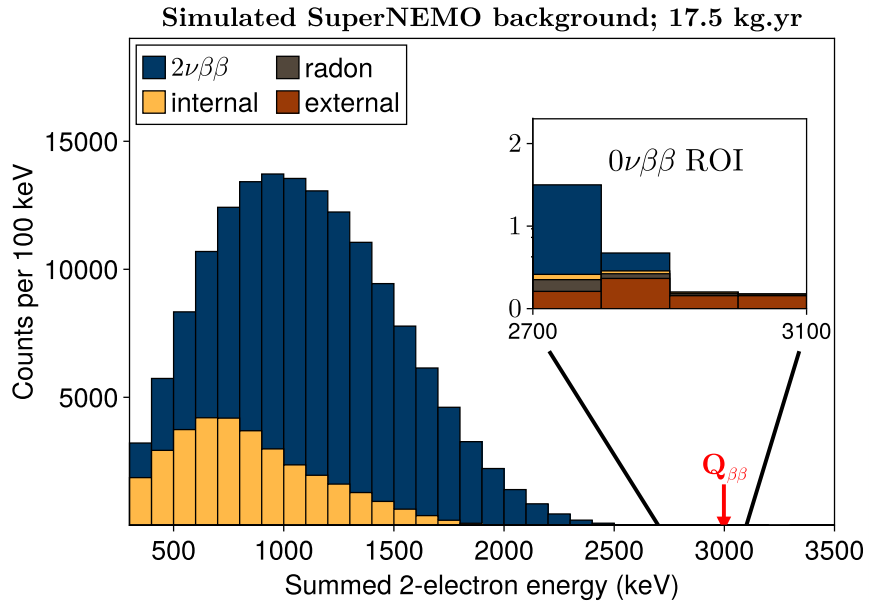




Cimrman module!

Presentation plan

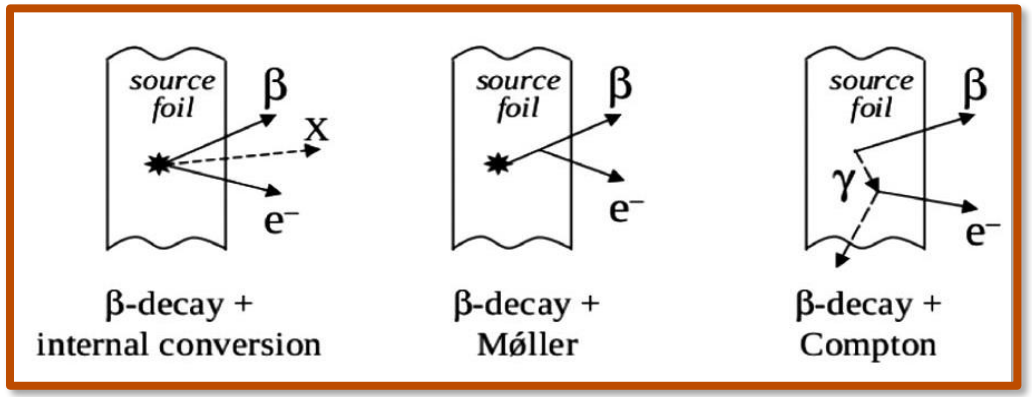
- Double beta decay
- SuperNEMO Demonstrator
- **Background**
- New physics



Background sources

Internal background

- $2\nu\beta\beta$
- Foil contamination



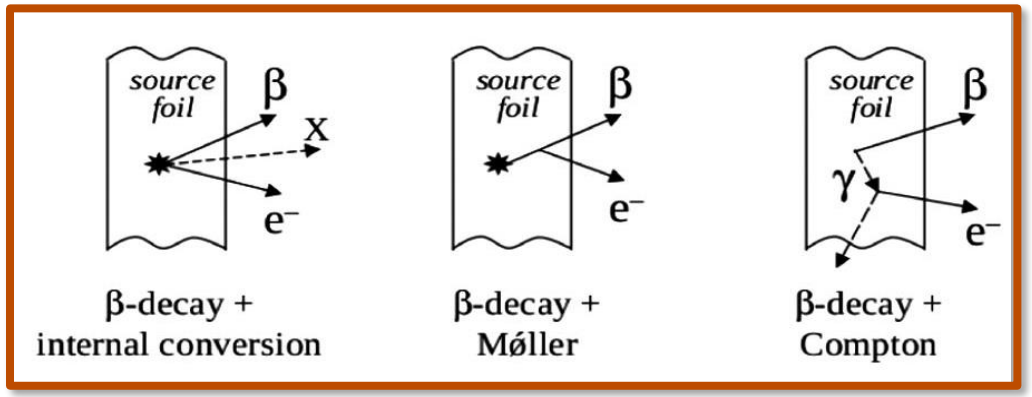
Background sources

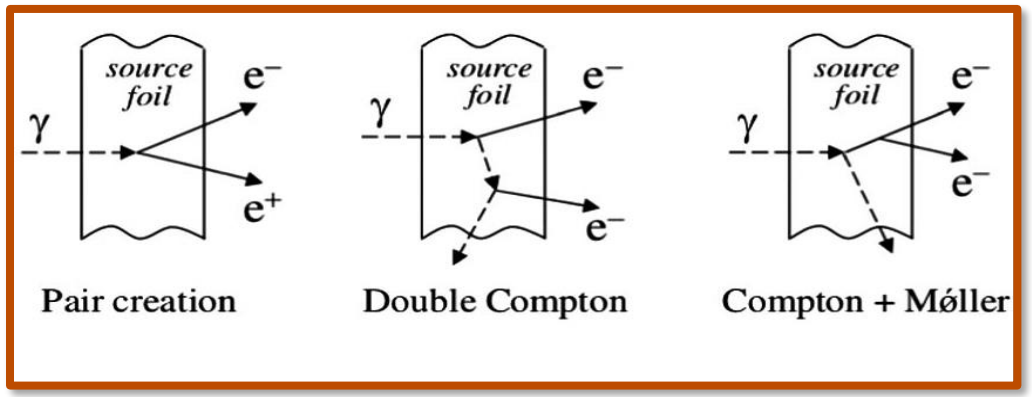
Internal background

- $2\nu\beta\beta$
- Foil contamination

External background

- Detector contamination
- Ambient (neutrons and gamma)
- Radon gas





SuperNEMO - shielding

Anti-radon tent

aim ~ 0.25 *events*
in ROI @ 17.5 kg · yr

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Iron gamma shield

aim ~ 0.07 *events*
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Anti-radon tent

aim ~ 0.25 *events*
in ROI @ 17.5 kg · yr

Iron gamma shield

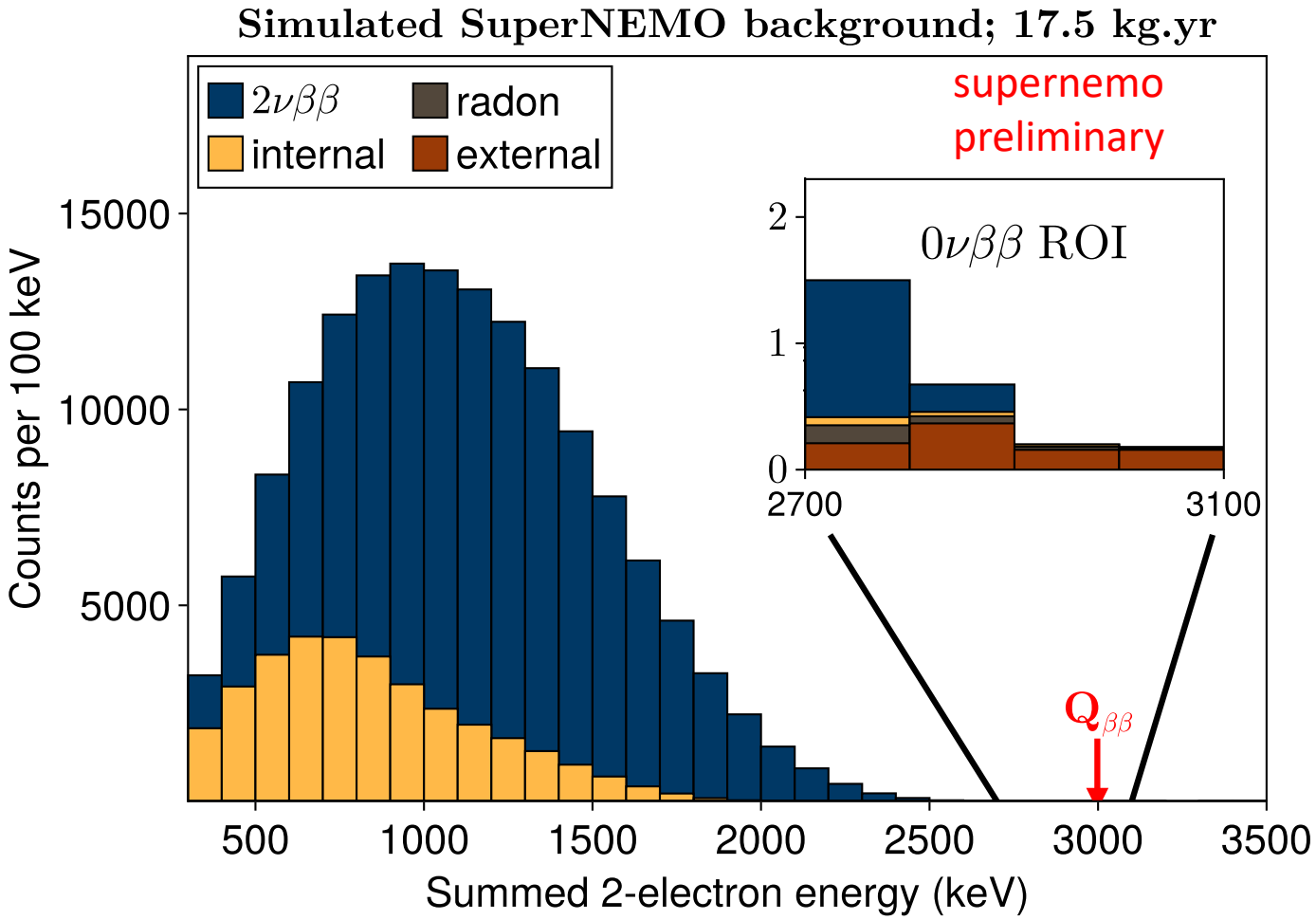
aim ~ 0.07 *events*
in ROI @ 17.5 kg · yr

PE neutron shield

aim ~ 0.65 *events*
in ROI @ 17.5 kg · yr

Background model

- Expected 100k – 200k $2\nu\beta\beta$ events
- Wide ROI for $0\nu\beta\beta$ (2700 - 3100) keV
- Largest bkg.: $2\nu\beta\beta$ and neutrons
- **Bkg. Index $\sim 2 \times 10^{-4}$ cts / (keV · yr · kg)**



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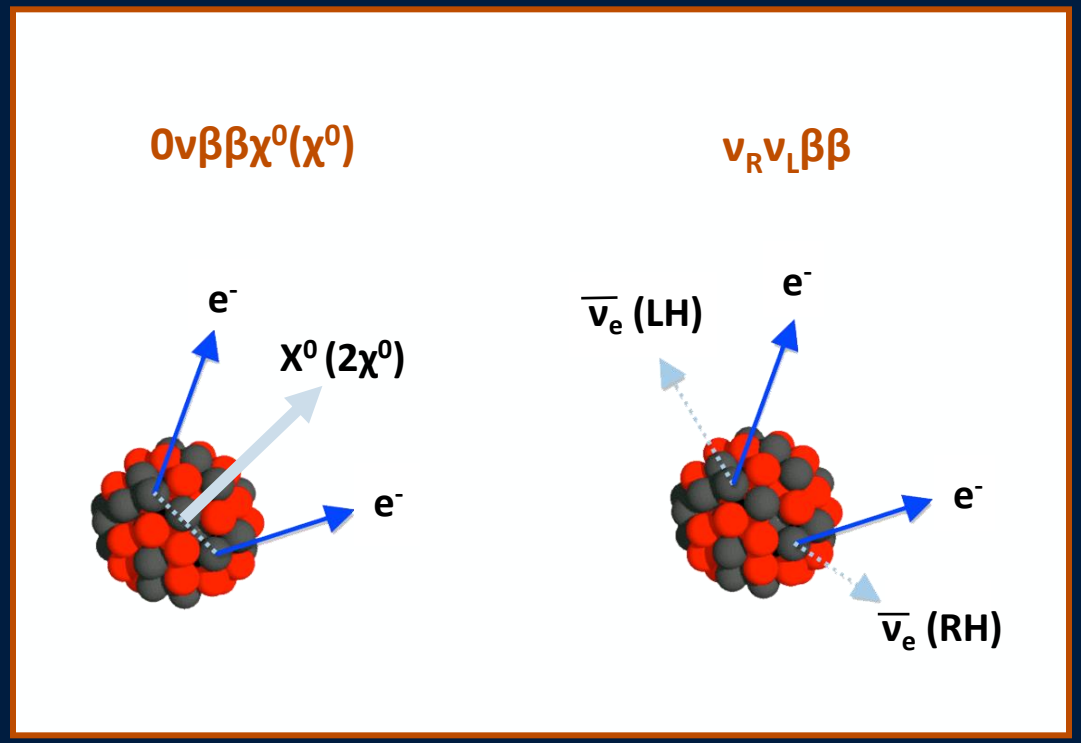
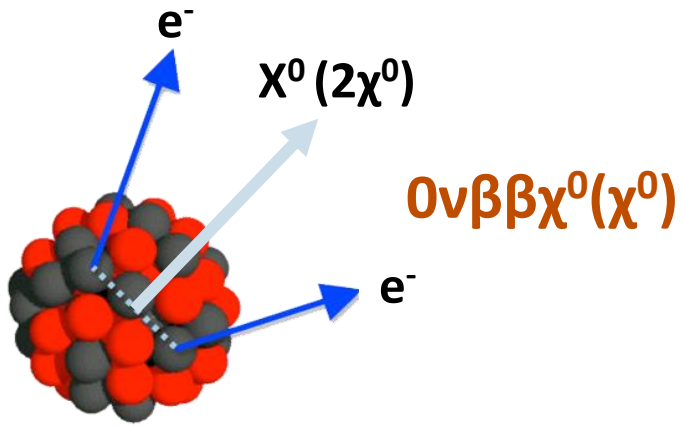
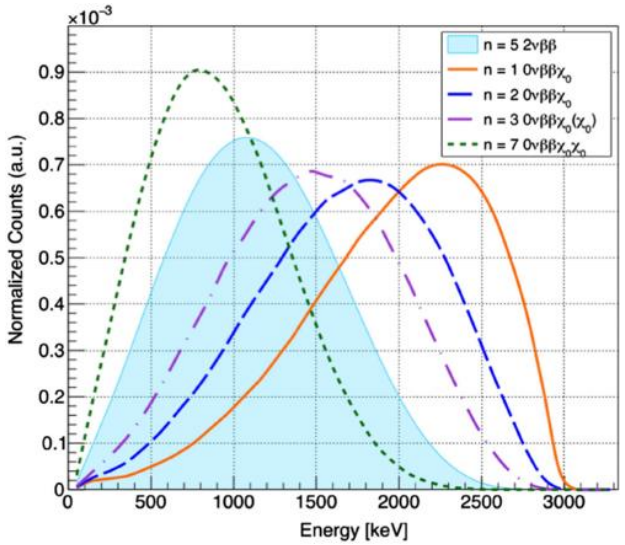


Modes beyond 0νββ





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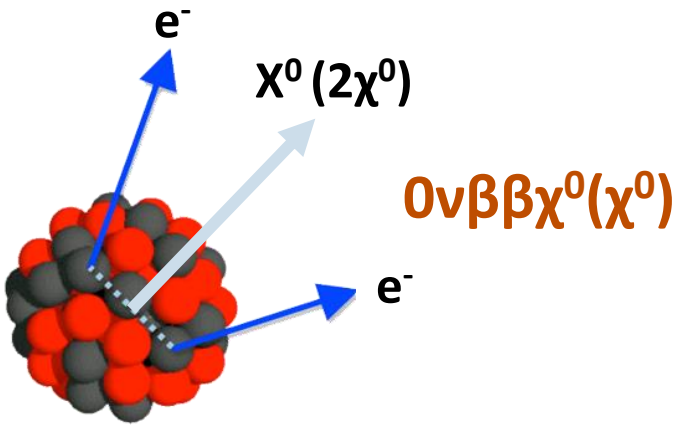
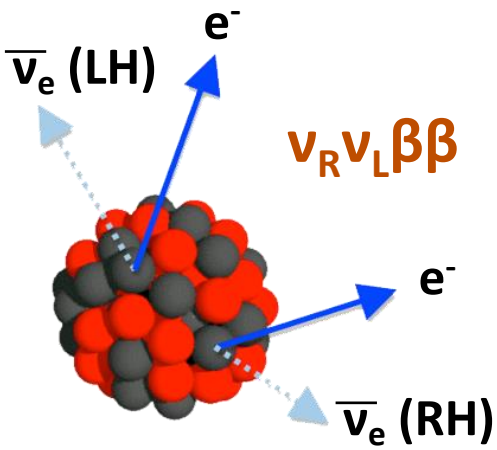
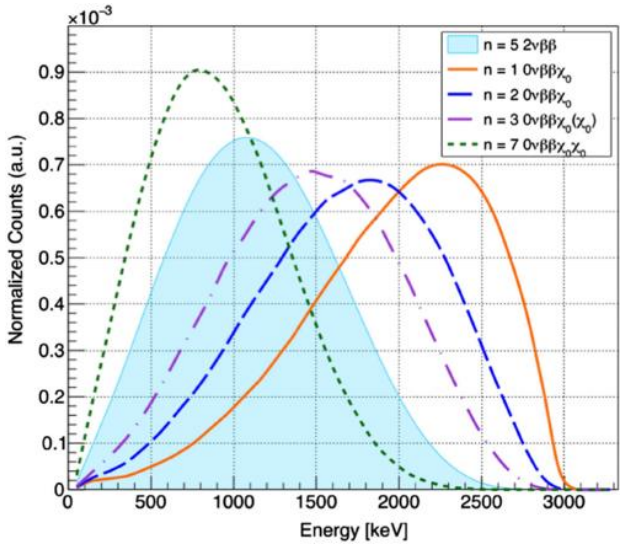
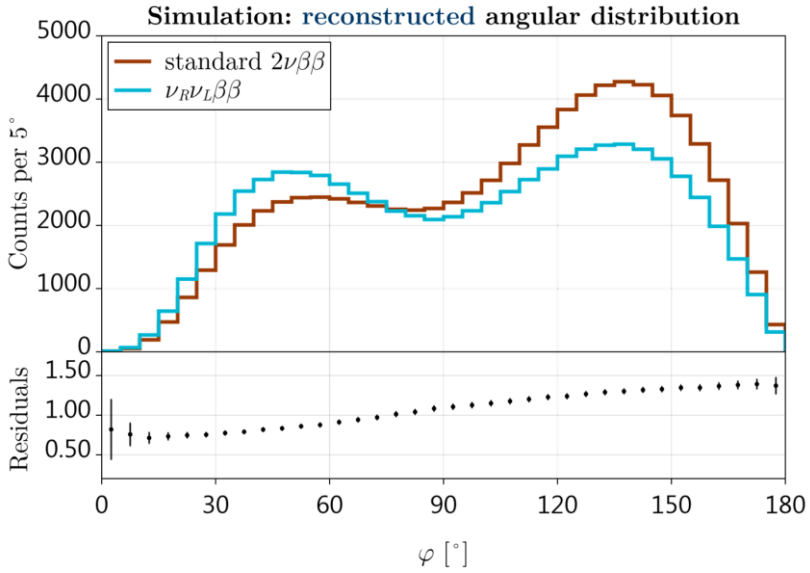
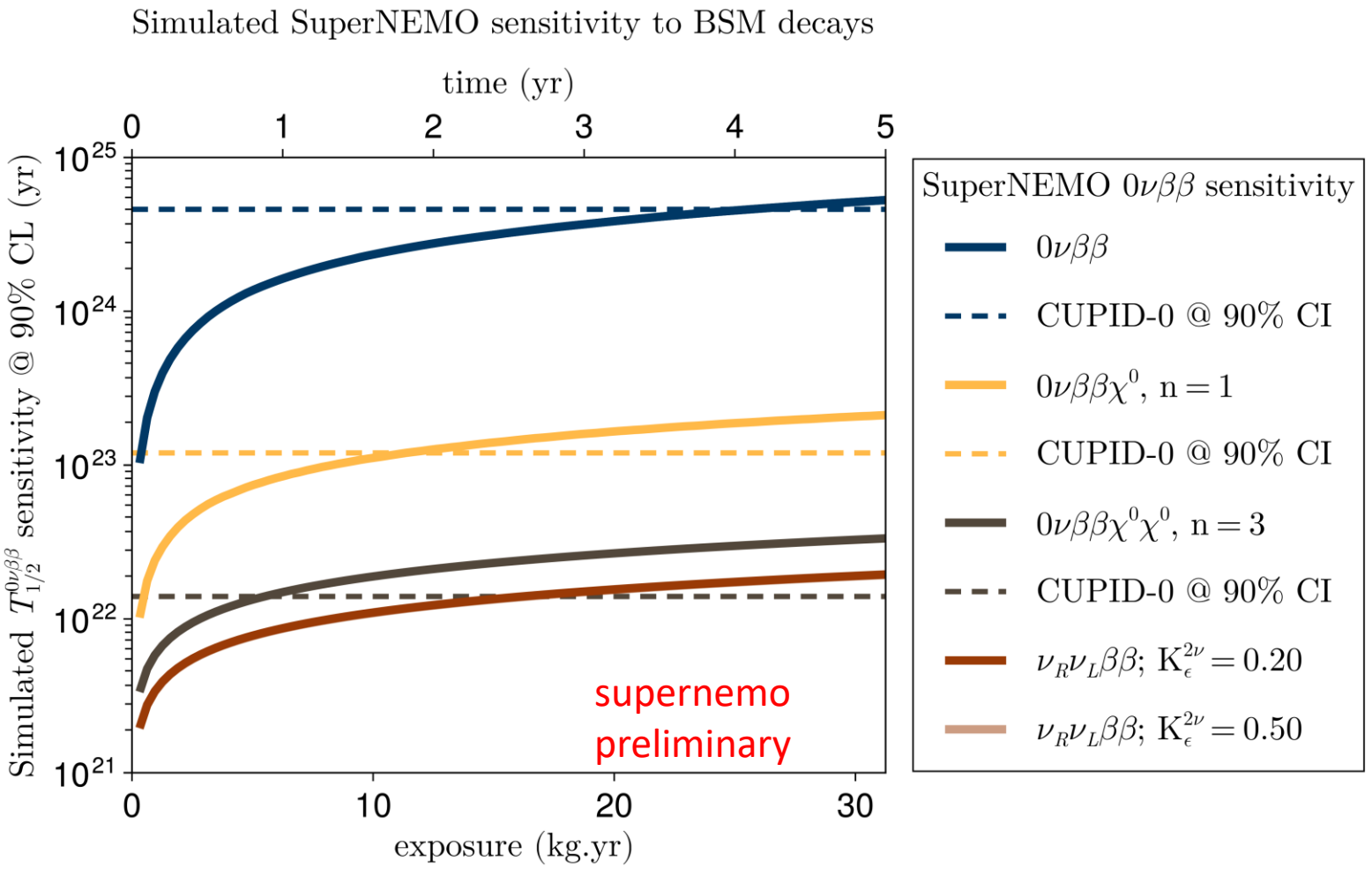








- With enough time world best $0\nu\beta\beta$
- Can achieve best for majoron (1-2 yr)
- World first $\nu_R\nu_L\beta\beta$
- **$2\nu\beta\beta$ to excited states, g_A, …**



Conclusions

SuperNEMO
- The tracking opens **very unique possibilities**
- Detector running in $\beta\beta$**-mode**!
- **Background data being assessed**
- We collected so far **~1 kg · yr** of data

Background
- Simulation expected $< 2 \times 10^{-4}$ **cts/(keV · yr · kg)**

Sensitivity
- Estimated $0\nu\beta\beta$ sensitivity $\geq 4.6 \times 10^{24}$ **yr** (Bayes, 90%)
- Possible world´s best/first limits for **0νββχ⁰(χ⁰)** and **$\nu_R\nu_L\beta\beta$**

Collaboration meeting in Marseille, February 2024

This work was supported by the Czech Science Foundation (GAČR), project No. 24-10180S.

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Thank you for your attention!

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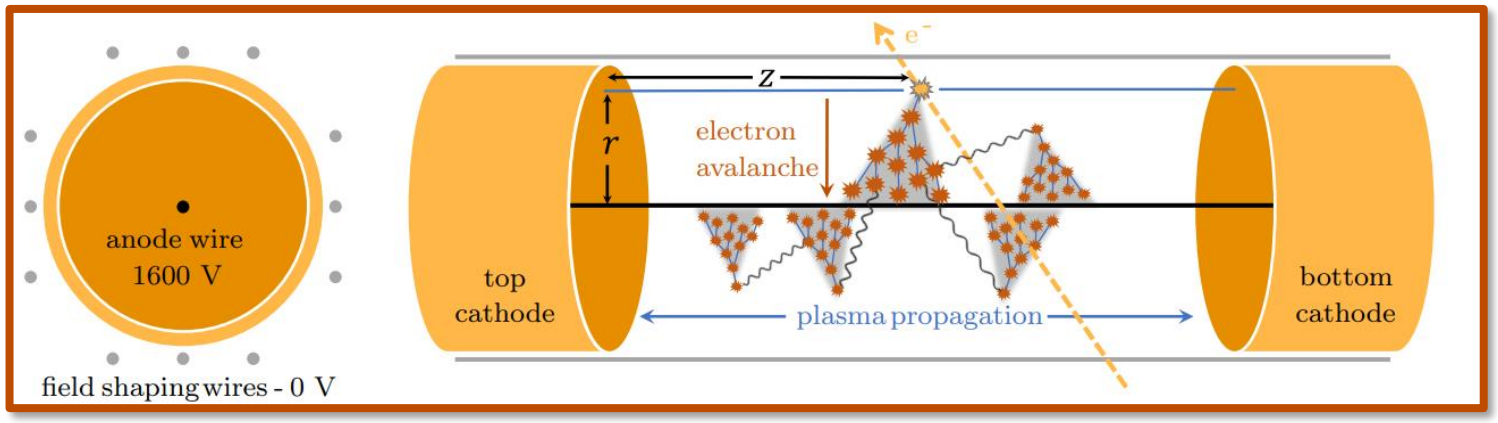
Backup slide


anode wire
1600 V
field shaping wires - 0 V
e⁻
z
r
electron
avalanche
top
cathode
plasma propagation
bottom
cathode