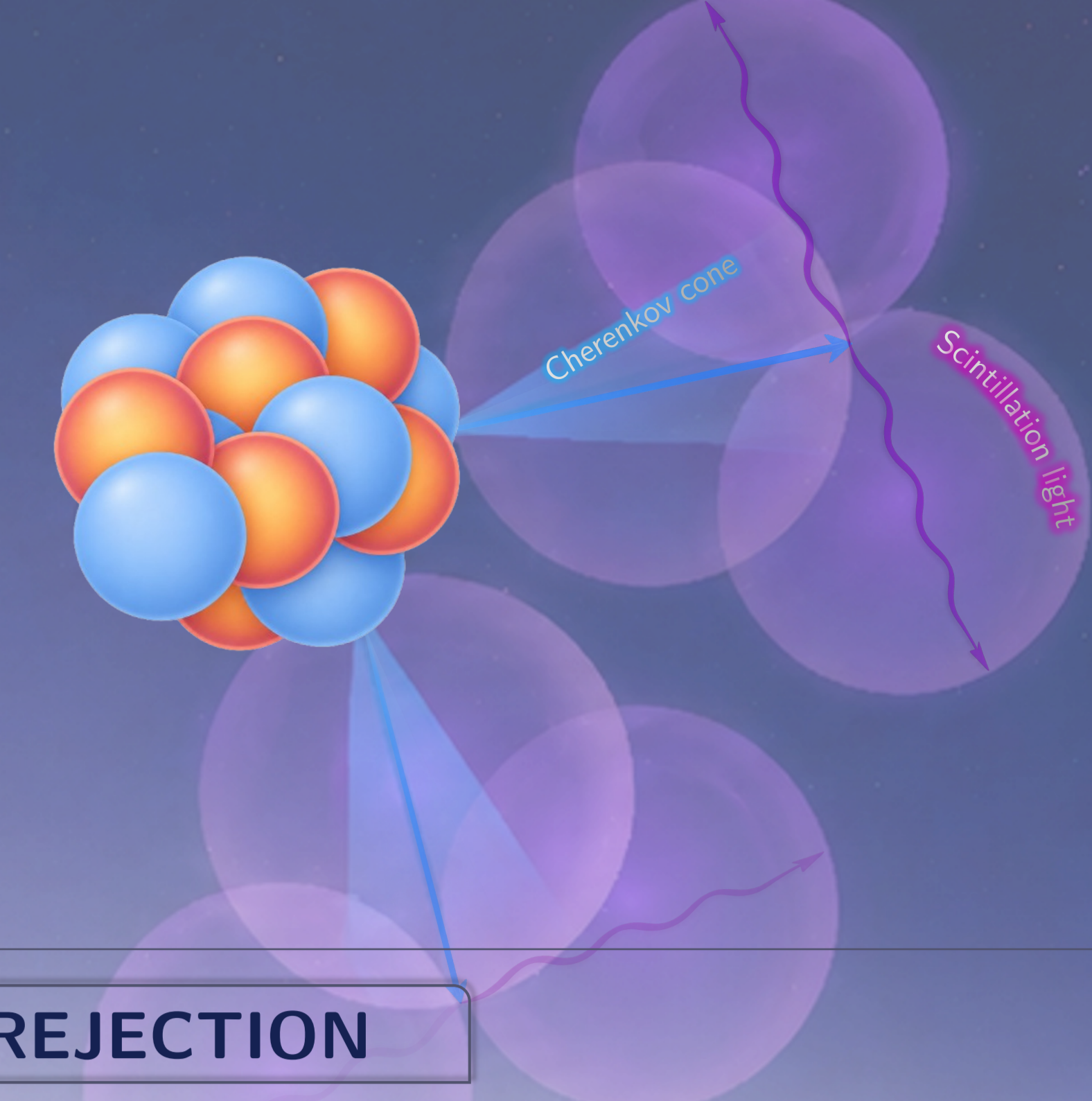


Search for Double Beta Plus Decays with Hybrid Opaque Scintillator

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1. DOUBLE BETA PLUS DECAYS (DBD+)

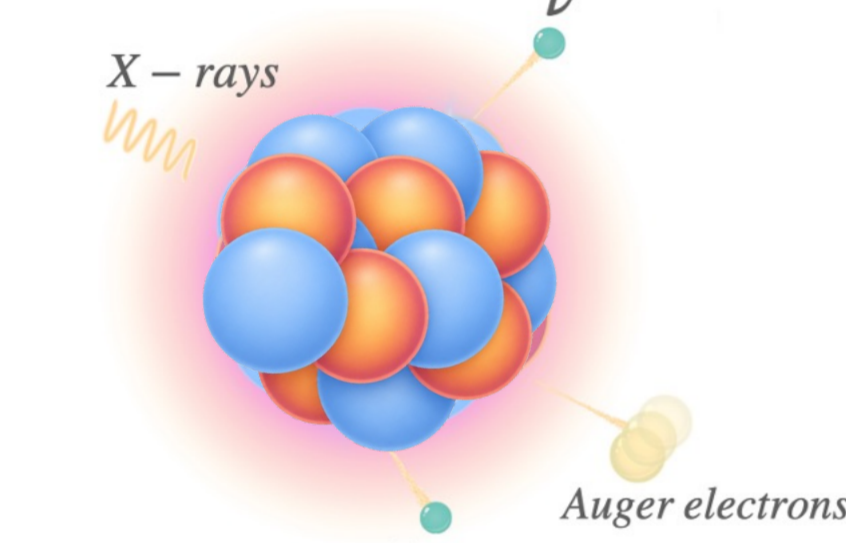
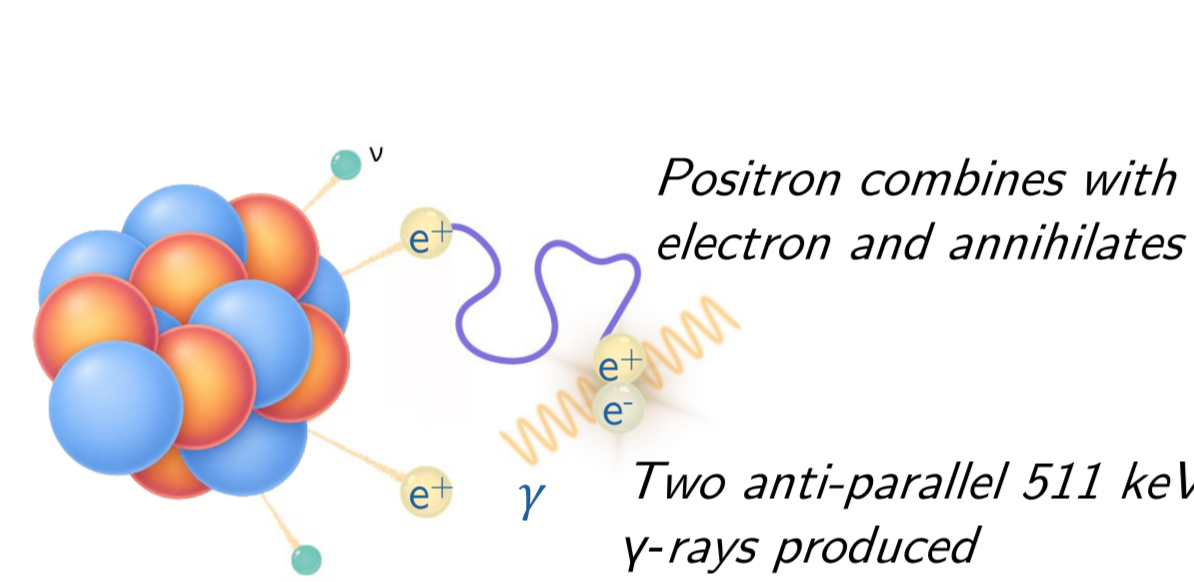
Primary Decay Mode



Modes of $\beta\beta$ that decrease the nuclear charge:

- Double positron decay ($\beta^+\beta^+$): $(A, Z) \rightarrow (A, Z - 2) + 2e^+ + 2\nu$
- Double electron capture (2EC): $(A, Z) + 2e^- \rightarrow (A, Z - 2) + 2\nu$
 - Mixed mode (β^+EC): $(A, Z) + e^- \rightarrow (A, Z - 2) + e^+ + 2\nu$

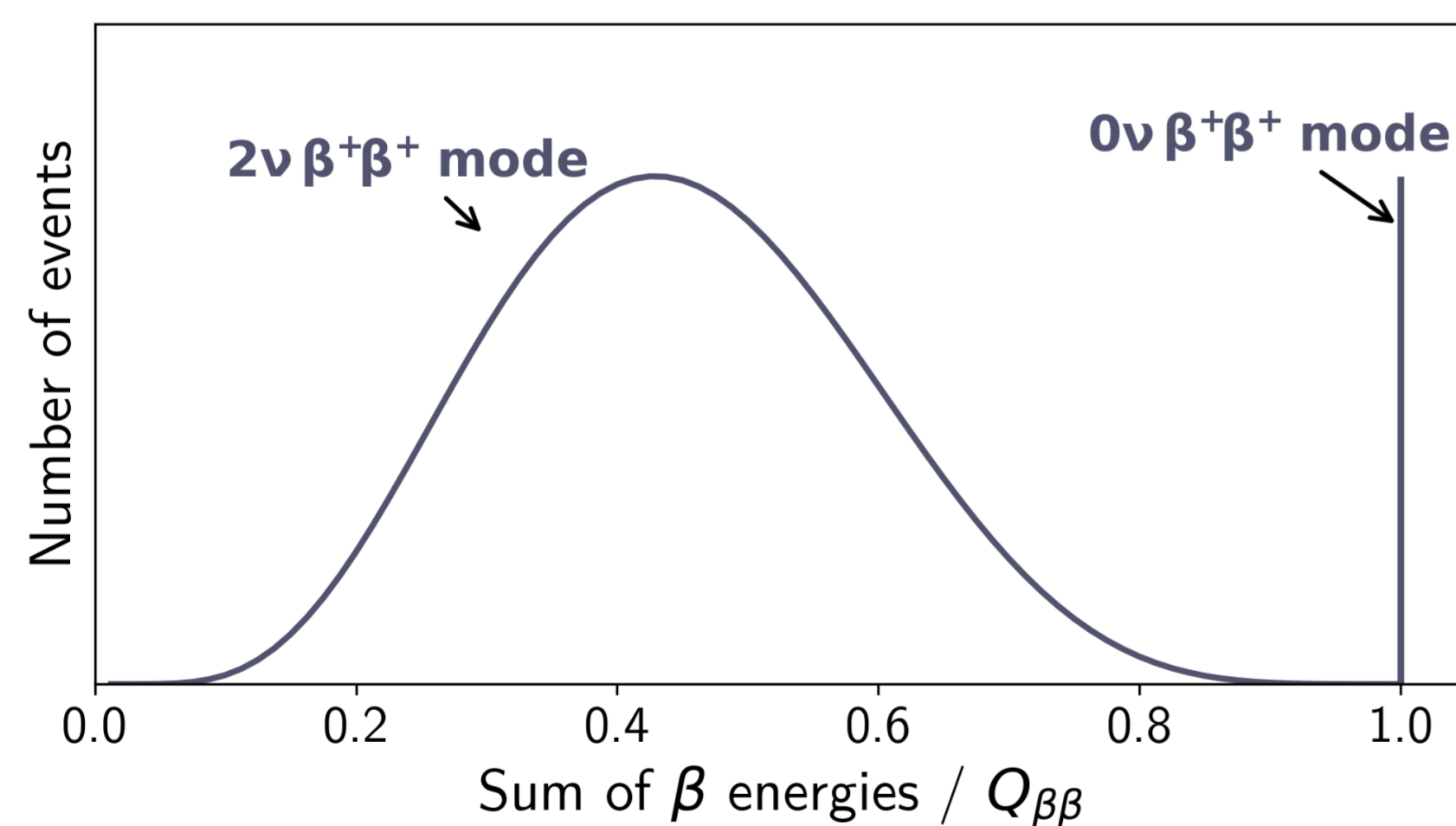
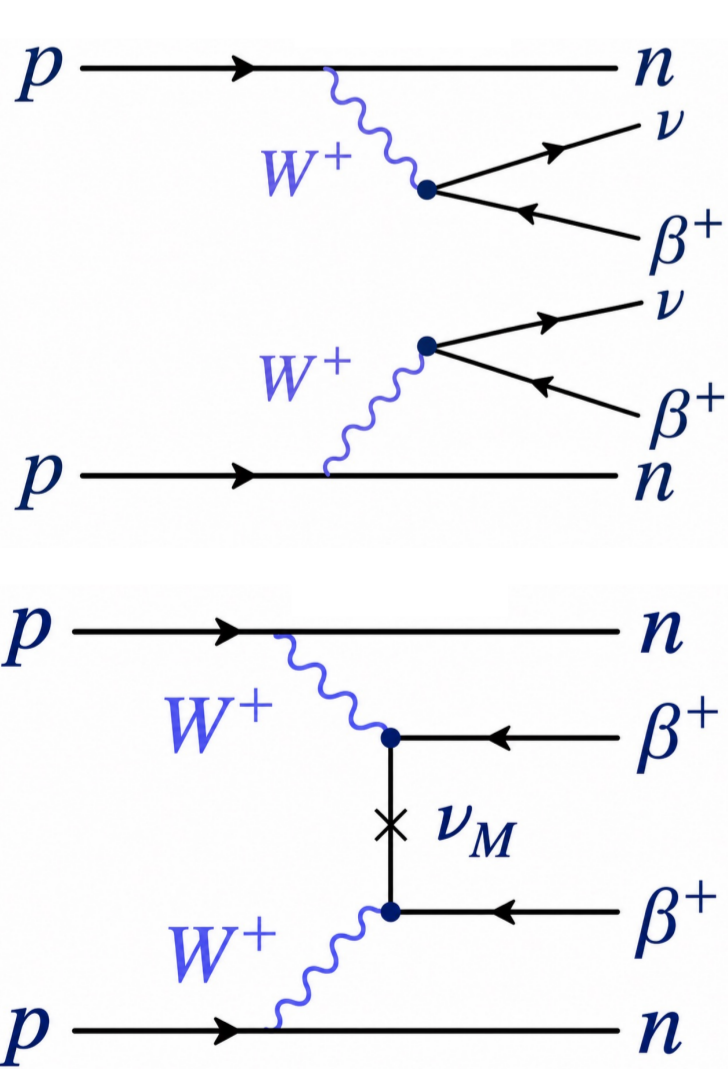
Final-state signatures



β^+EC / $\beta^+\beta^+$: Positron(s) + annihilation γ 's

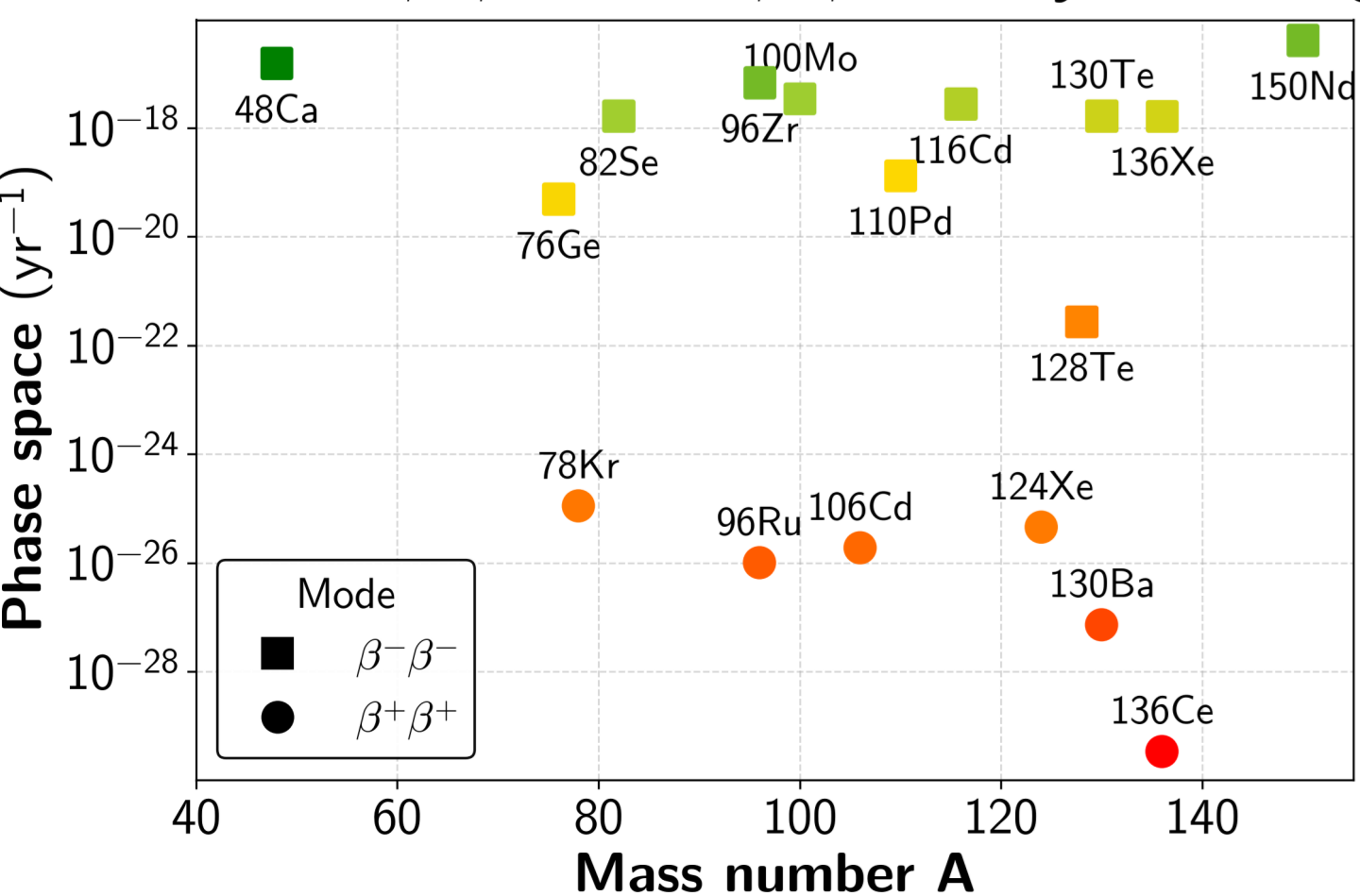
2EC: Atomic de-excitation only

Lepton-number conserving vs lepton number violating mode



Detection challenge: suppressed decay probabilities

PSF for $2\nu\beta^+\beta^-$ and $2\nu\beta^+\beta^+$ decays to final g.s.

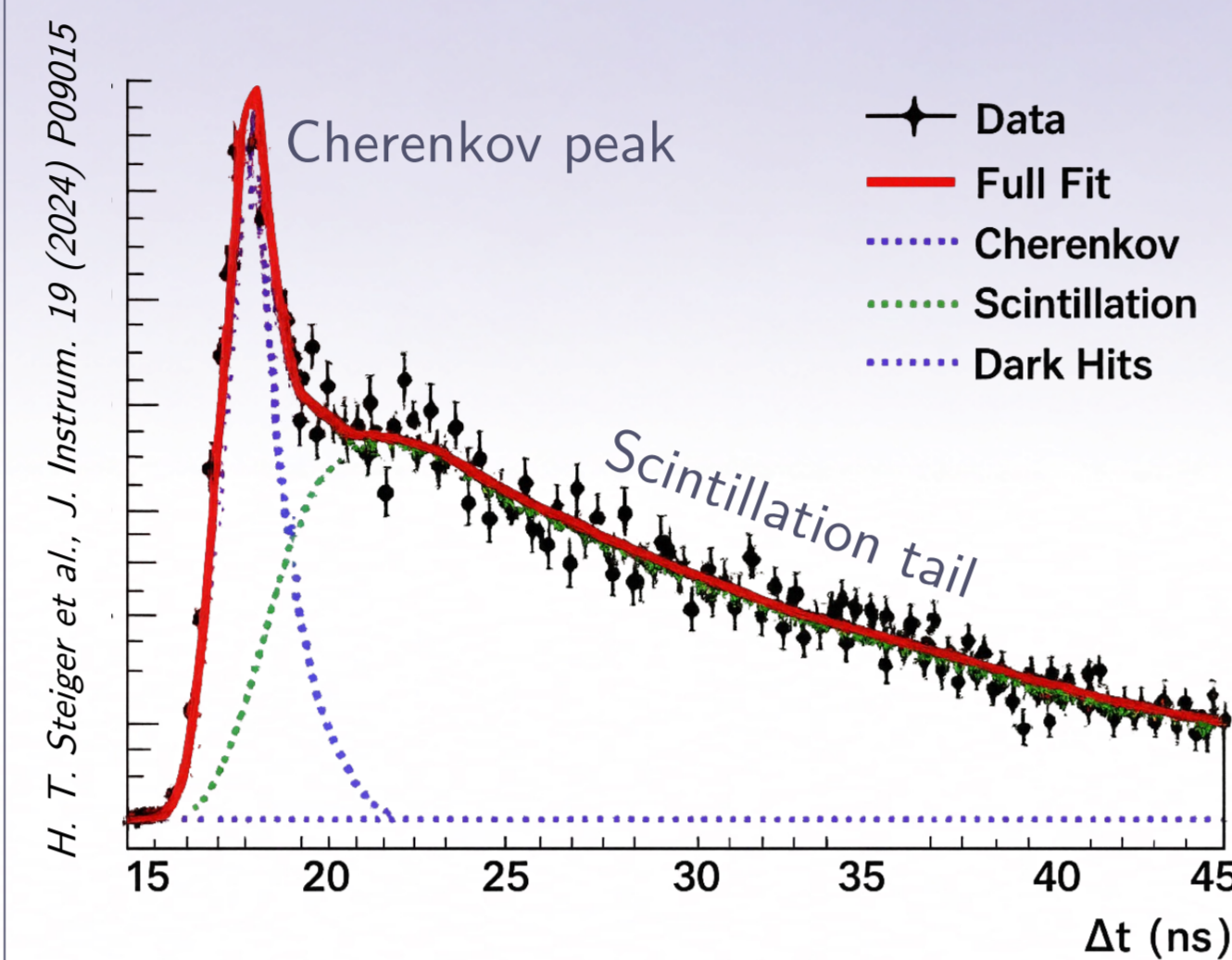


DBD+ modes have reduced available kinetic energy - $2m_e c^2$ per emitted positron.

Phase space is lower for $\beta^+\beta^+$ \rightarrow corresponding $T_{1/2}$ is higher.

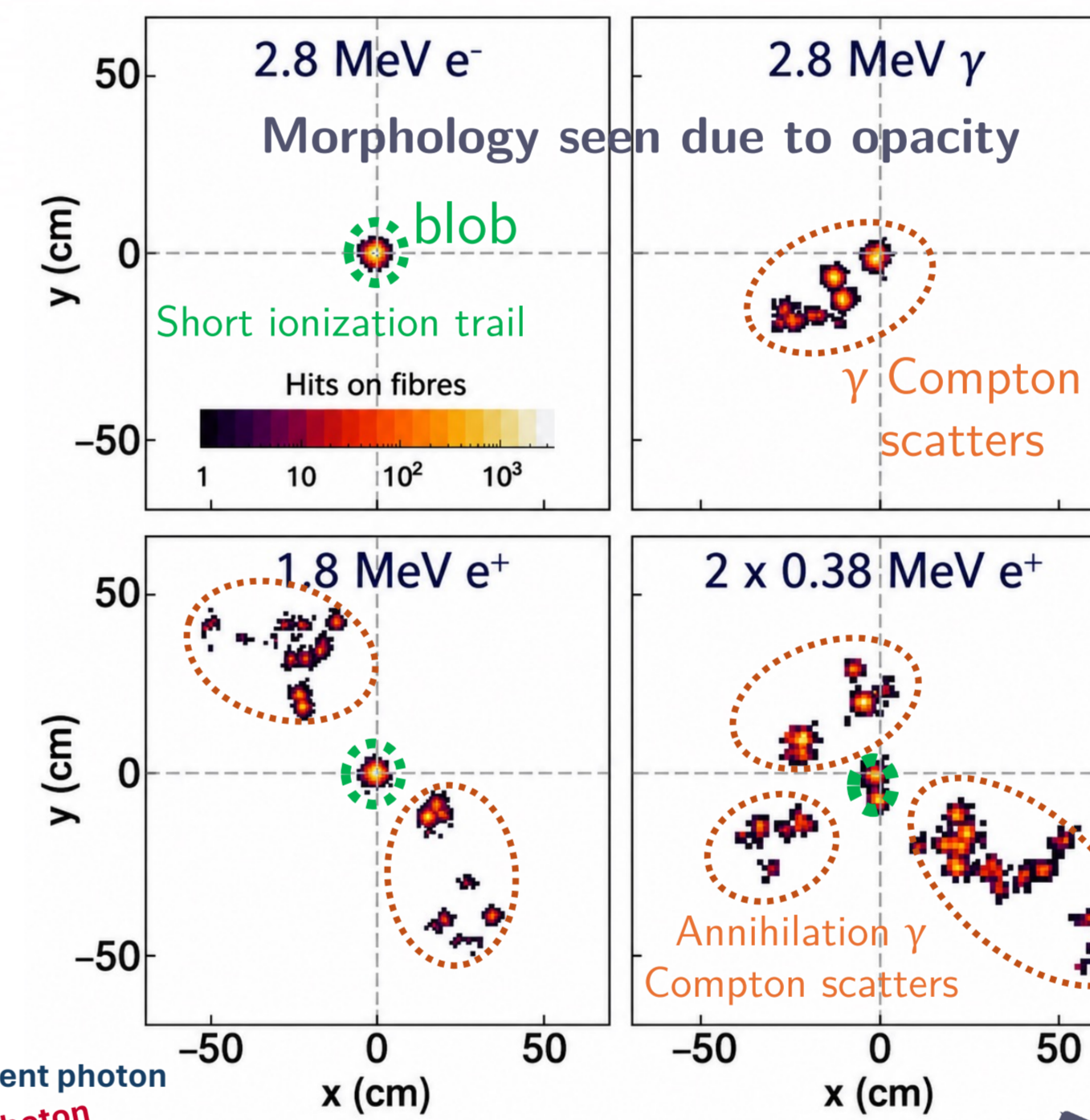
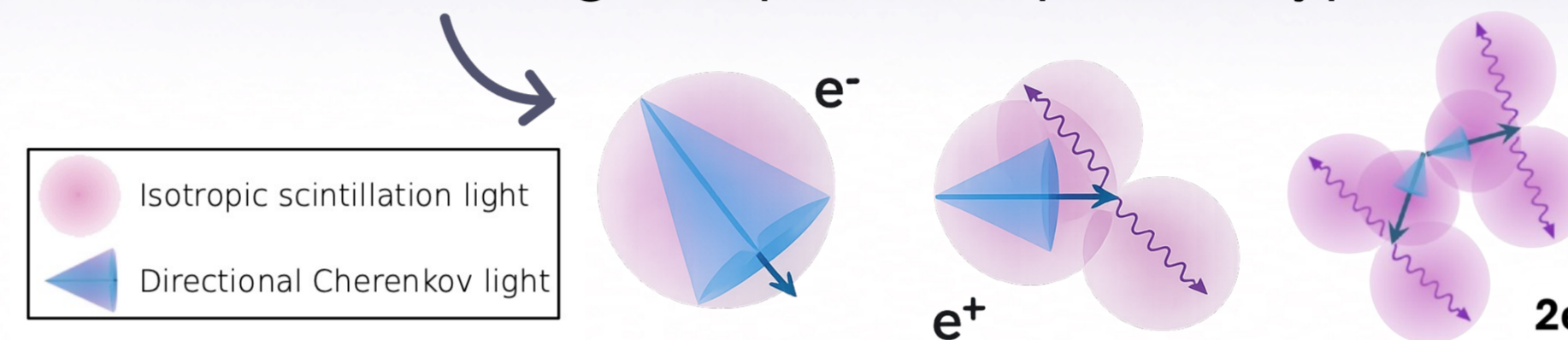
2nu beta+ EC & 2nu beta+ beta+ not yet observed!

2. HYBRID OPAQUE LIQUID SCINTILLATOR



Hybrid slow scintillator separates Cherenkov and scintillation signals.

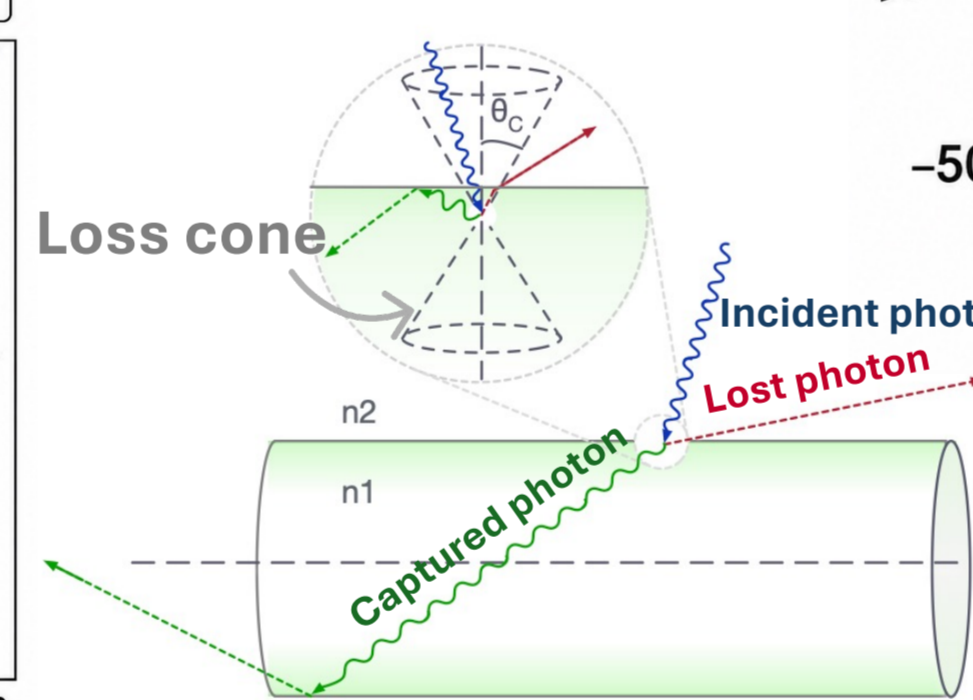
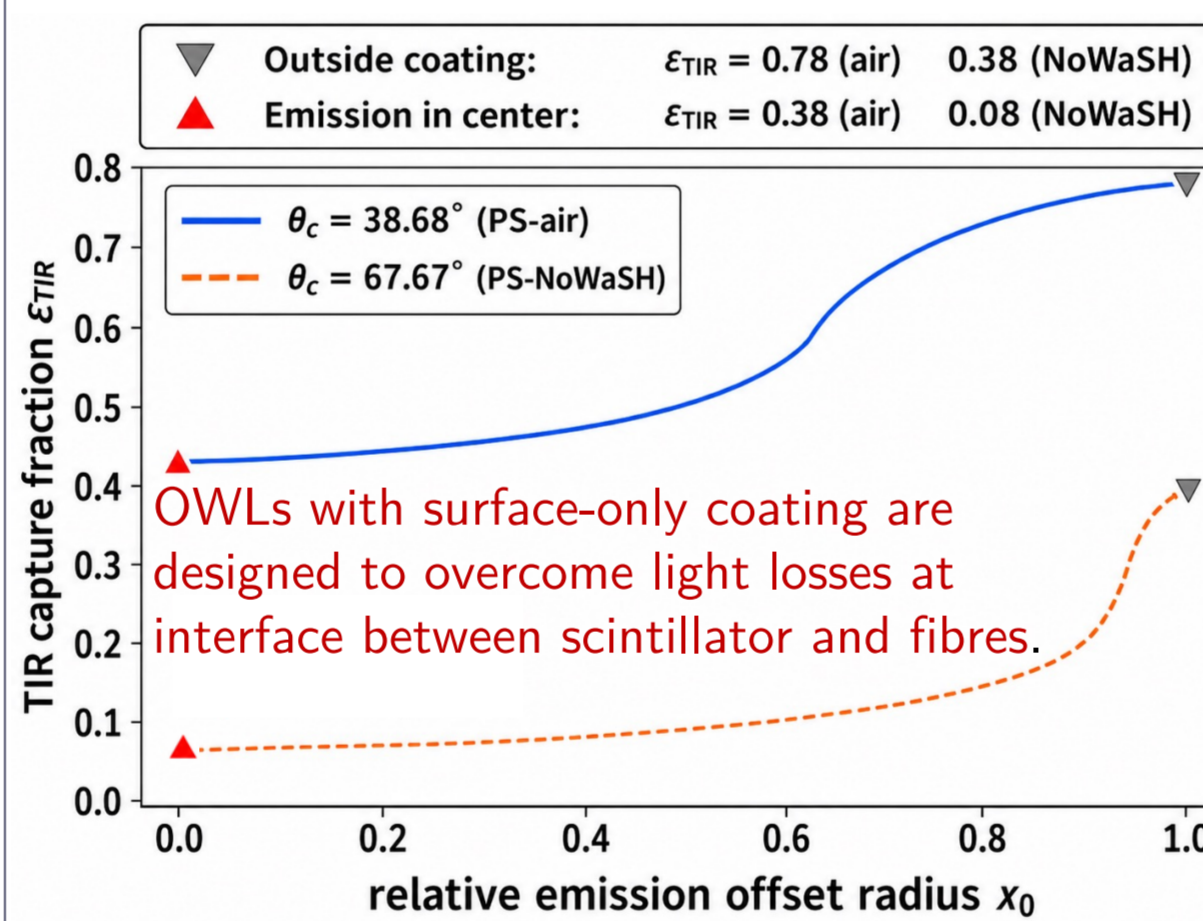
Particle ID: Ratio of Cherenkov to scintillation light depends on particle type.



Opaque scintillator retains topological information through stochastic light confinement.

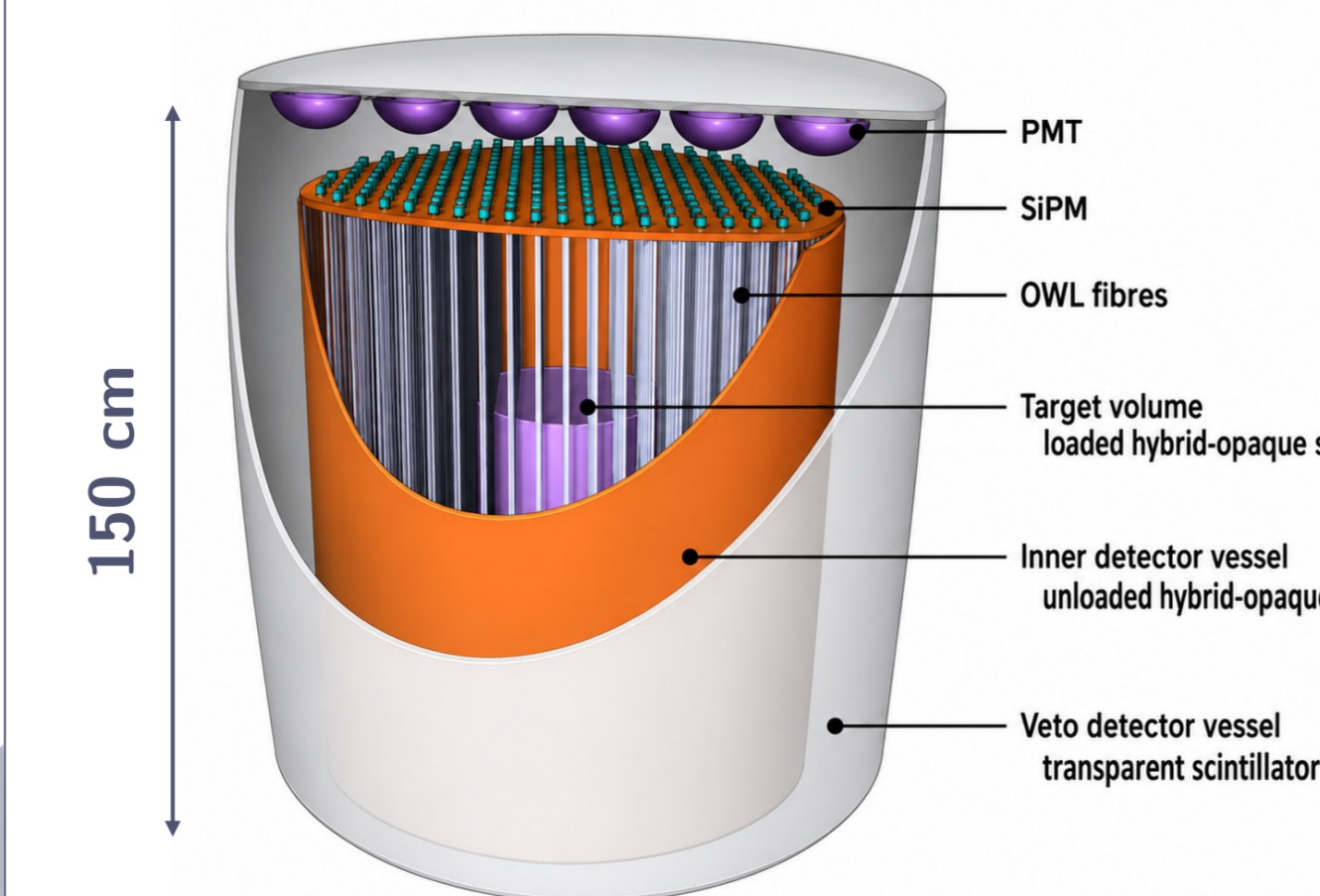
\rightarrow Light-readout via grid of wavelength-shifting fibres.

Optimised WLS light-guides (OWL) with surface WLS coating capture nearly four times more photons than conventional fibres with central emission points.



3. THE NuDoubt++ EXPERIMENT

- Combining hybrid slow and opaque scintillator techniques paired with novel light read-out (OWLs) in the search for DBD+
- Suitable for detecting positrons \rightarrow sensitive to: $2\nu 2\beta^+$ ($0\nu 2\beta^+$) & $2\nu\beta^+EC$ ($0\nu\beta^+EC$)



First prototype:

- 50% enriched Kr-78 gas at 5 bar over-pressure
- LAB/DIN/wax + PPO mixture designed for high light yield and strong scattering
- $LY \approx 9000$ photons/MeV, expected readout yield 800 PE/MeV with OWLs
- Expected energy resolution $\sim 2\%$ in ROI for 0ν mode

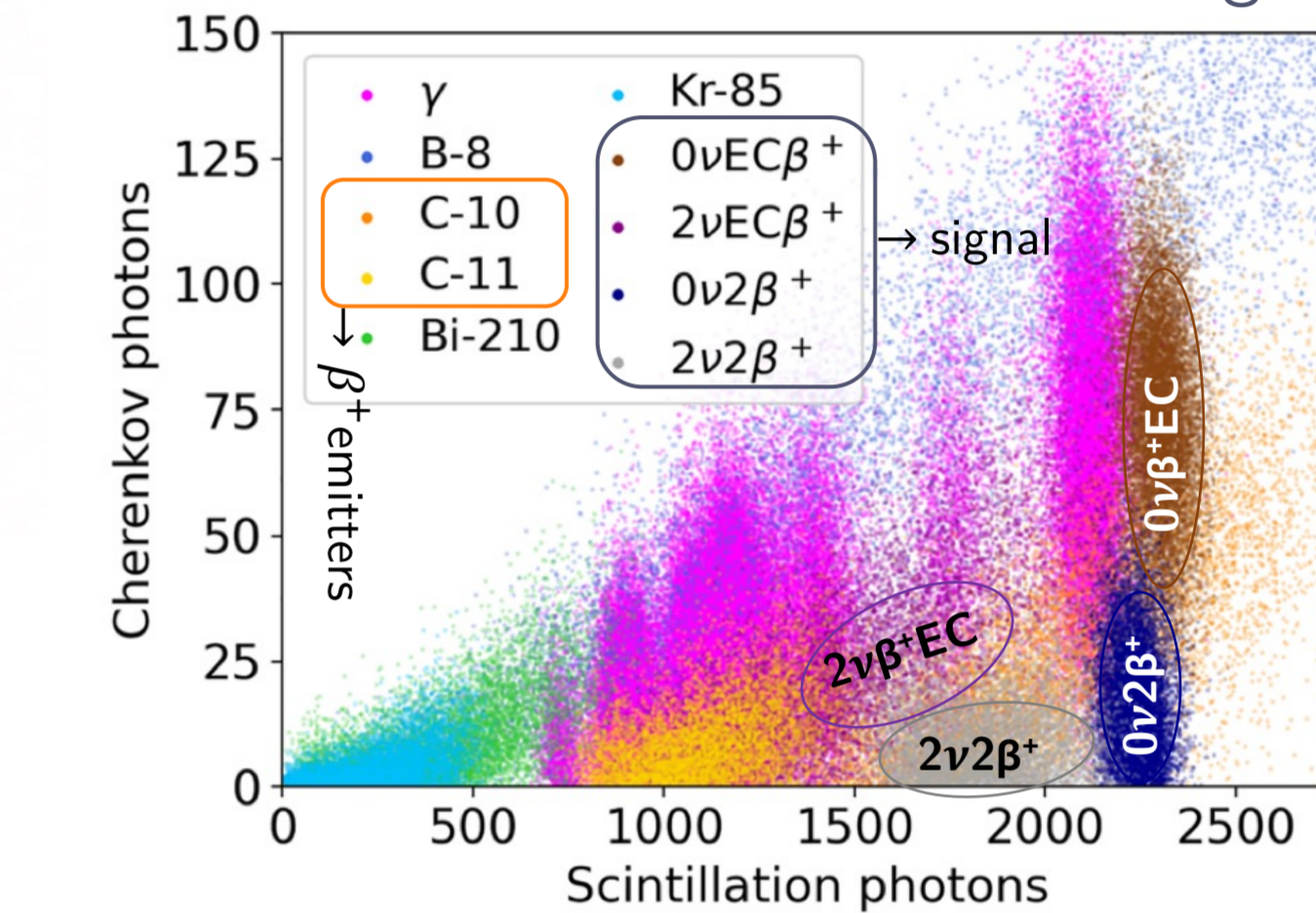
High detectable energy of the final state signature including annihilation γ 's: $E_{max} \approx Q_{2\beta^+} + 4m_e \approx Q_{\beta^+EC} + 2m_e \approx \Delta M$

Transition	ΔM (MeV)	Natural Abundance (%)
$^{78}\text{Kr} \rightarrow ^{78}\text{Se}$	2.85	0.355

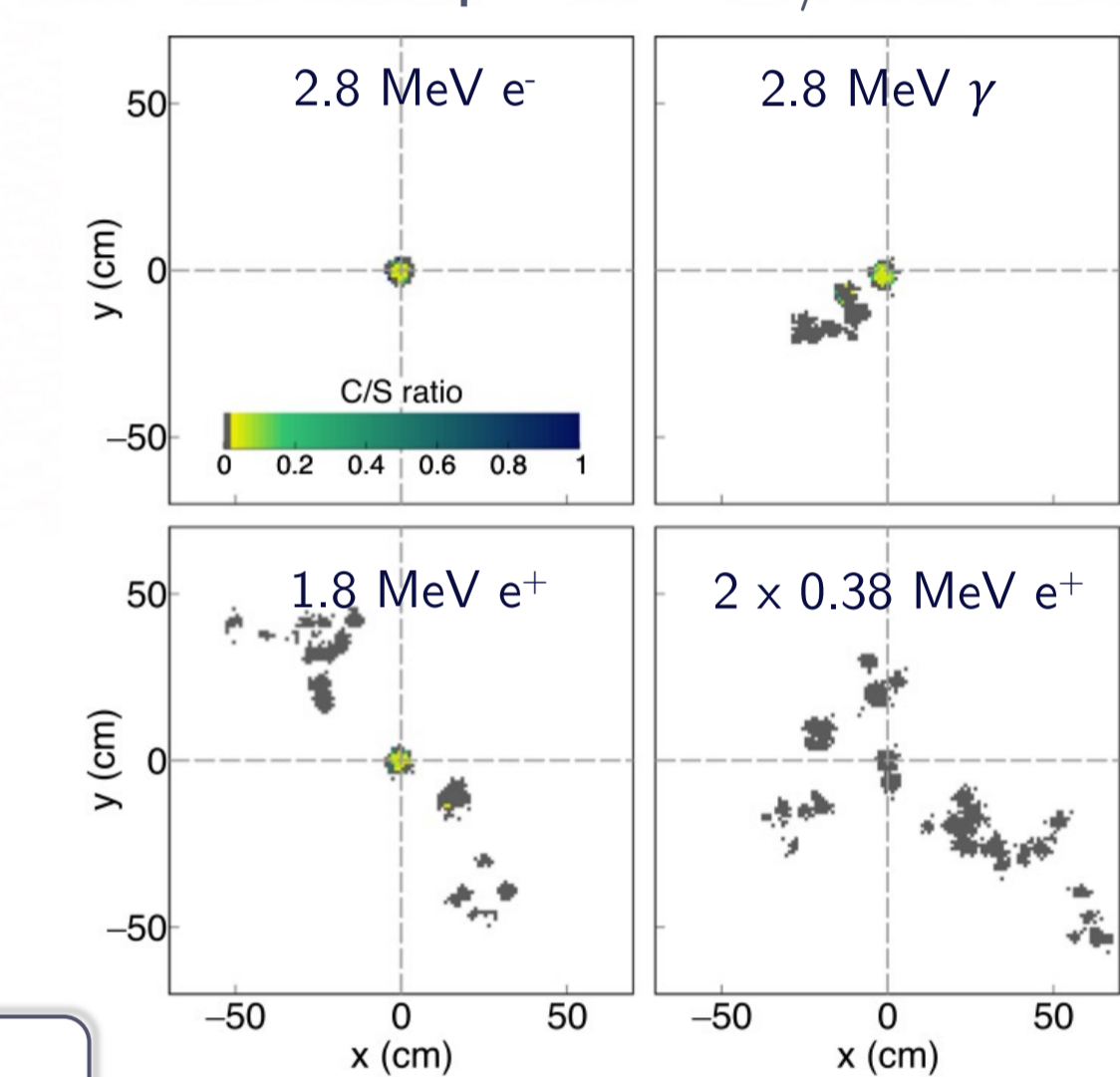
4. BACKGROUND REJECTION

Complementary background rejection capabilities of hybrid and opaque detector technologies – background suppression based on counting blobs and separation of events based on Cherenkov to scintillation light ratio.

Separation of the event categories based on Cherenkov and scintillation light



Event topologies based on the blob-dependent \check{C}/S ratio

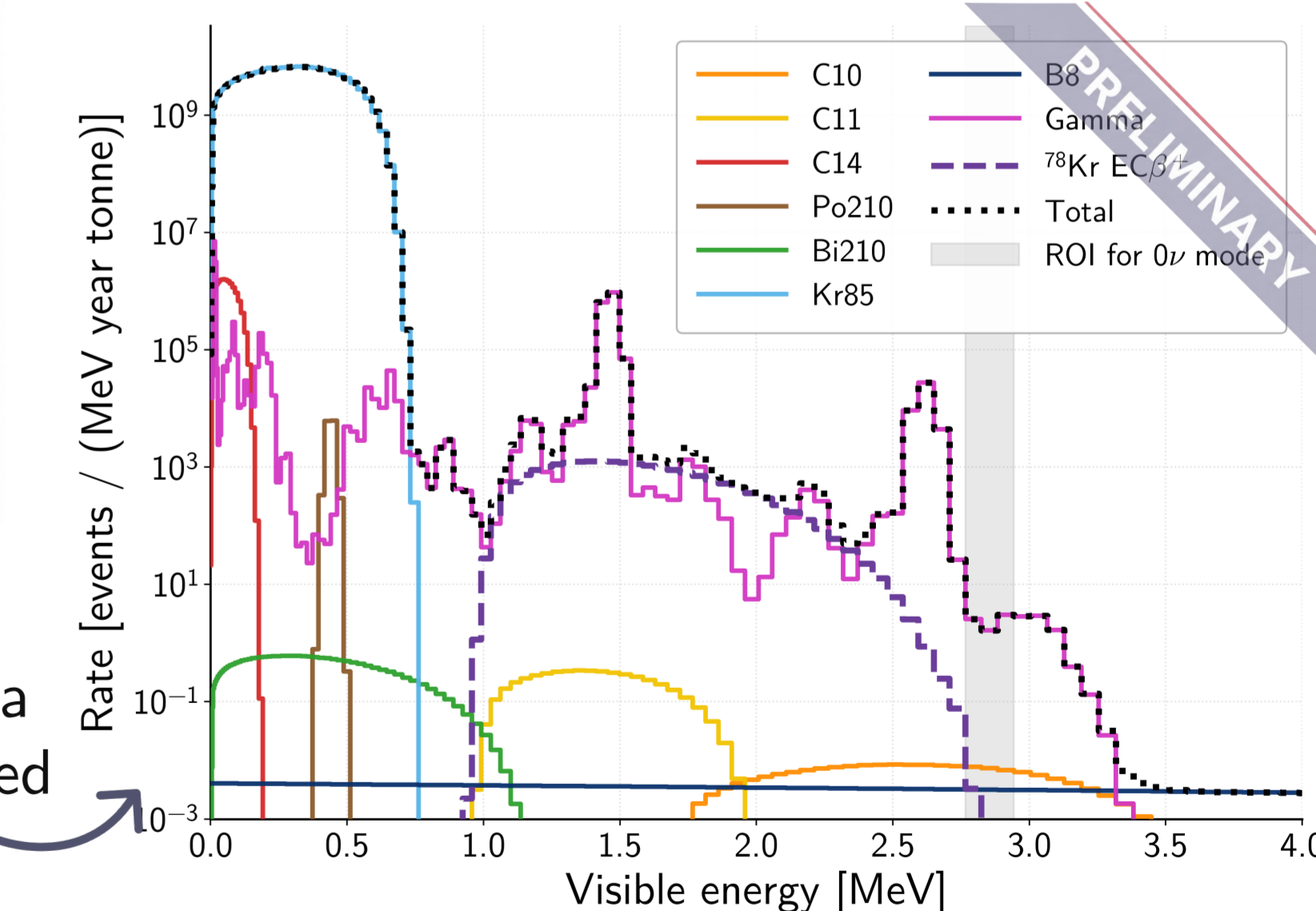


5. NuDoubt++ AT SNOLAB

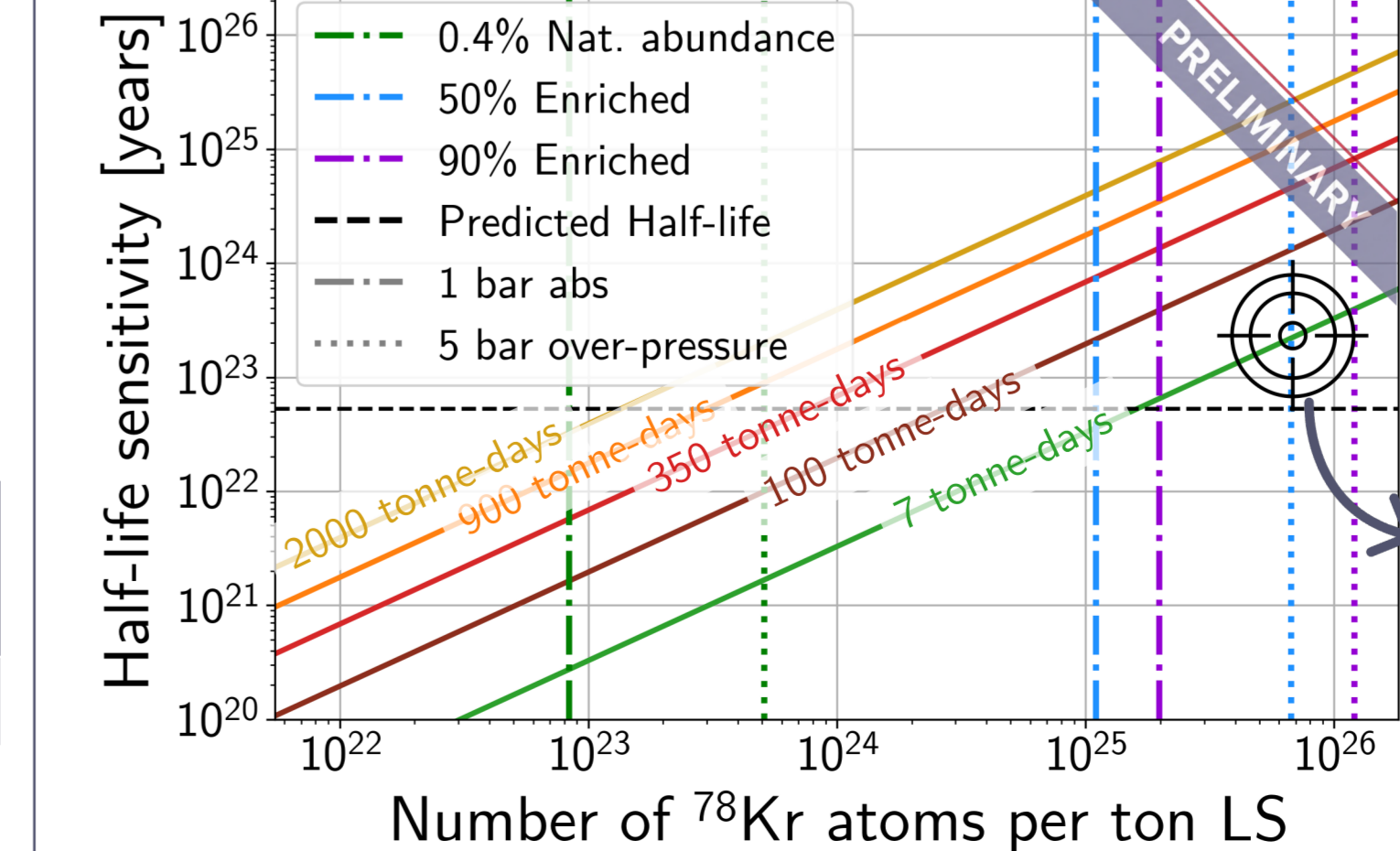


- Located at a depth of 2 kilometres in Vale's Creighton Mine near Sudbury
- Low-background environment for rare-event searches
- Low muon flux $\sim 0.27 \mu\text{m}^2/\text{day}$, reducing cosmogenic ^{10}C and ^{11}C production

Expected background and $2\nu\beta^+EC$ signal spectra for a NuDoubt++ prototype located at SNOLAB.



$2\nu EC\beta^+$ sensitivity



A binned Poisson profile-likelihood study shows how krypton loading, exposure, detector backgrounds, and SNOLAB's reduced cosmogenic rate affect the discovery sensitivity to $^{78}\text{Kr} 2\nu\beta^+EC$.

Discovery potential of the prototype at 5σ significance.