Testing neutron to hidden neutron oscillations with Ultra-Cold Neutrons Beams

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1. Motivation

- Hidden matter: an extra avenue to explain dark matter [a]
- New hints on the Baryogenesis problem (n-n' violates B)
- Explanation to several anomalies in precision measurements (τ_n, ν_s, GZK cutoff, ...)

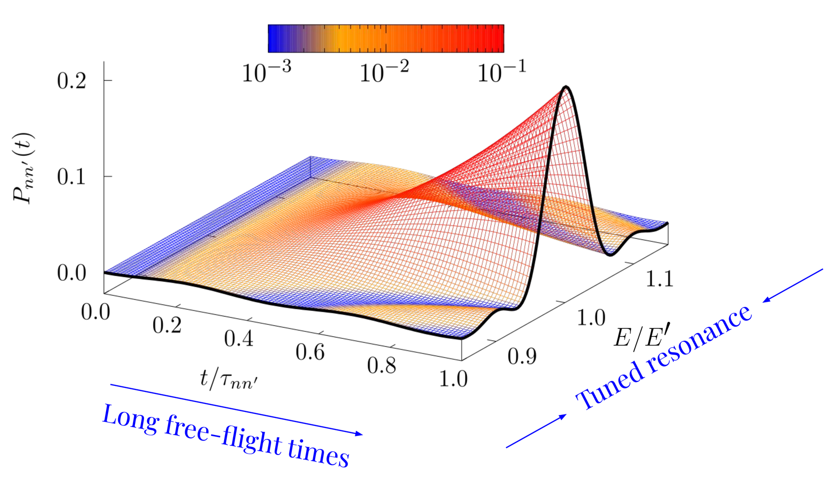
2. Measurement principle

- Simple phenomenological model

$$\hat{\mathcal{H}}_{nn'} = \begin{pmatrix} m_n + \Delta E & 1/\tau_{nn'} \\ 1/\tau_{nn'} & m_{n'} + \Delta E' \end{pmatrix}$$

- Experimental technique: **Suppress the energy degeneracy**

$$\Delta_{nn'} = (\Delta E) - (\delta m + \Delta E') \to 0$$



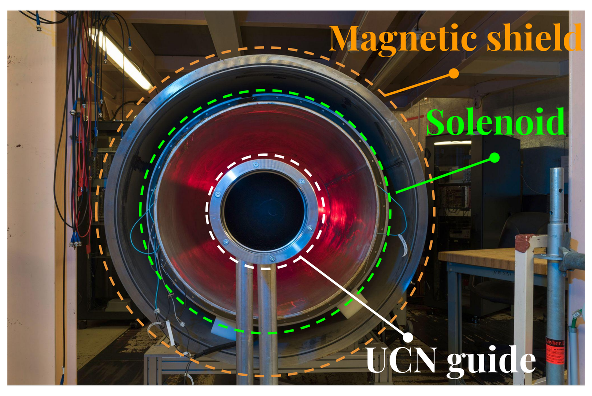
Oscillation probability for constant $\Delta_{nn'}$

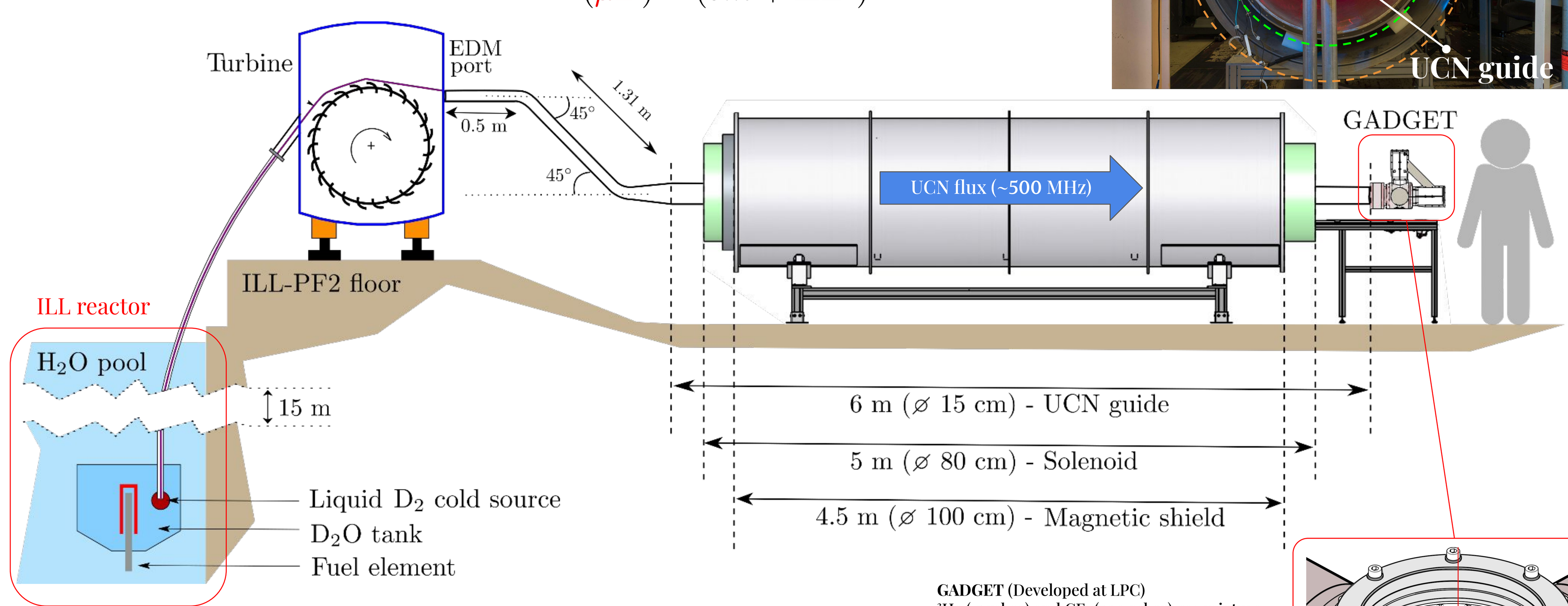
$$P_{nn'} \sim \frac{4\sin^2(\Delta_{nn'}t/2)}{(\tau_{nn'}\Delta_{nn'})^2}$$

3. Experimental setup

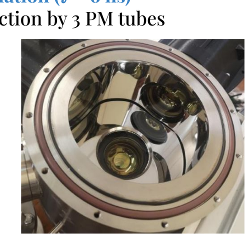
- n–n' energy degeneracy suppressed with external magnetic fields

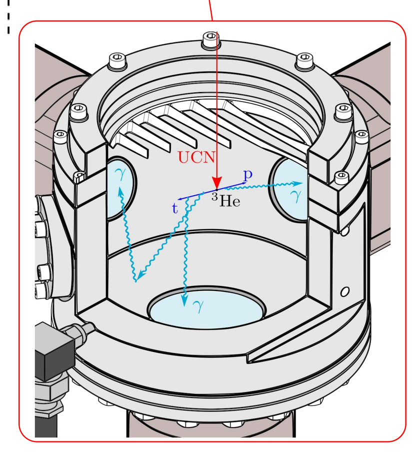
$$\Delta_{nn'} = (\Delta E) - (\delta m + \Delta E')$$
$$= (\mu B) - (\delta m + \Delta E')$$





GADGET (Developed at LPC)
- ^{3}He (15 mbar) and CF_4 (500 mbar) gas mixture
- Detection process
  1. UCN absorption $n + {}^3He \to p\ (0.57\ MeV) + t\ (0.19\ MeV)$
  2. CF_4 scintillation (r ~ 6 ns)
  3. Light collection by 3 PM tubes

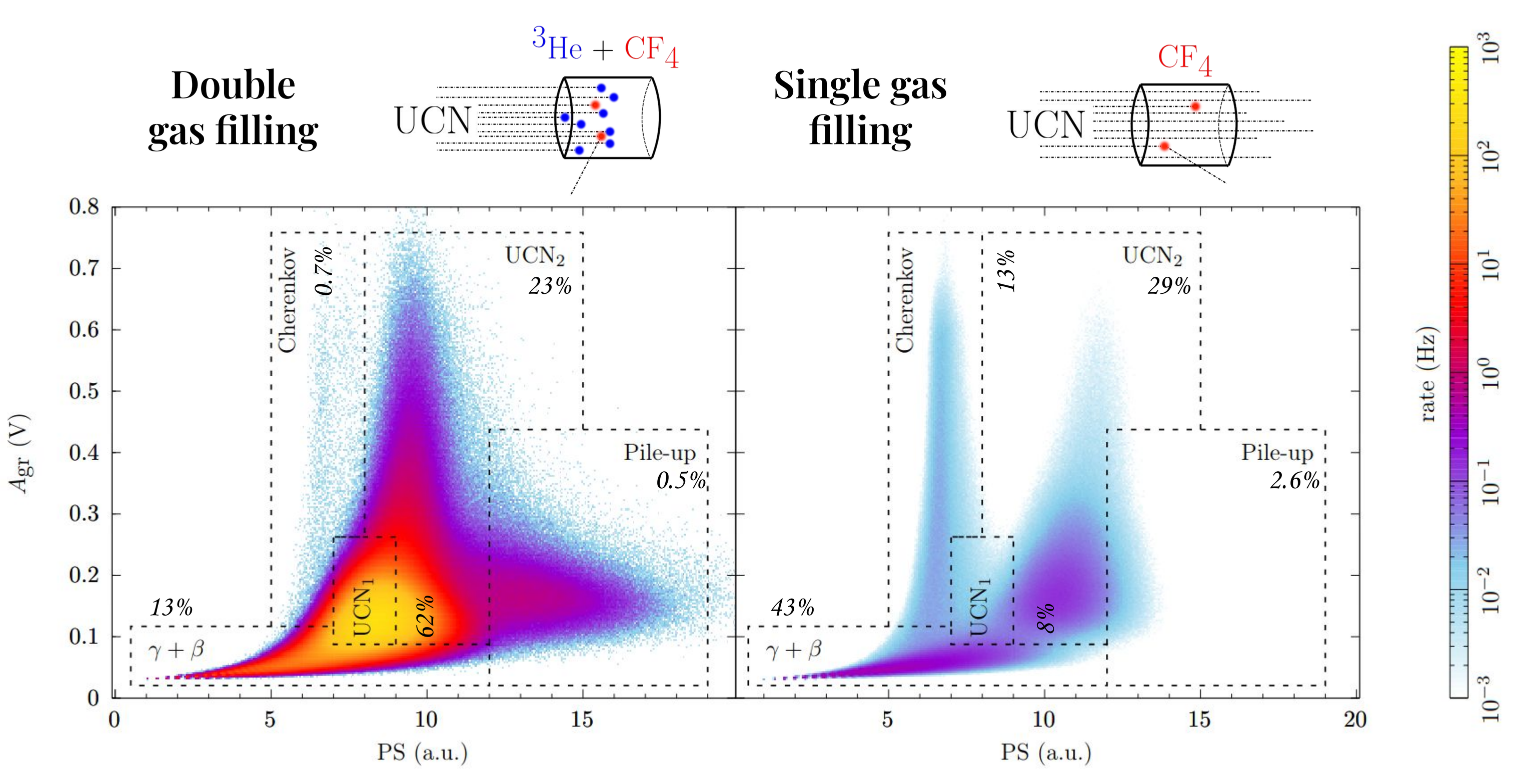




- n–n' signal: UCN flux drop at the GADGET counter
- Scanned interval [b] : $B \in [50 : 1100]\ \mu T$, i.e. $\delta m \in [2 : 69]$ peV

(Data collection: 24 days in Autumn 2020)

4. Pulse shape analysis (PSA)



Config.	Total rate (kHz)	Category contribution (kHz)				
		$\gamma+\beta$	Cherenkov	UCN$_1$	UCN$_2$	Pile-up
CF_4+^{3}He	288.5	38.8	2.3	179.4	66.6	1.4
CF_4	~1	0.43	0.13	0.08	0.29	0.3

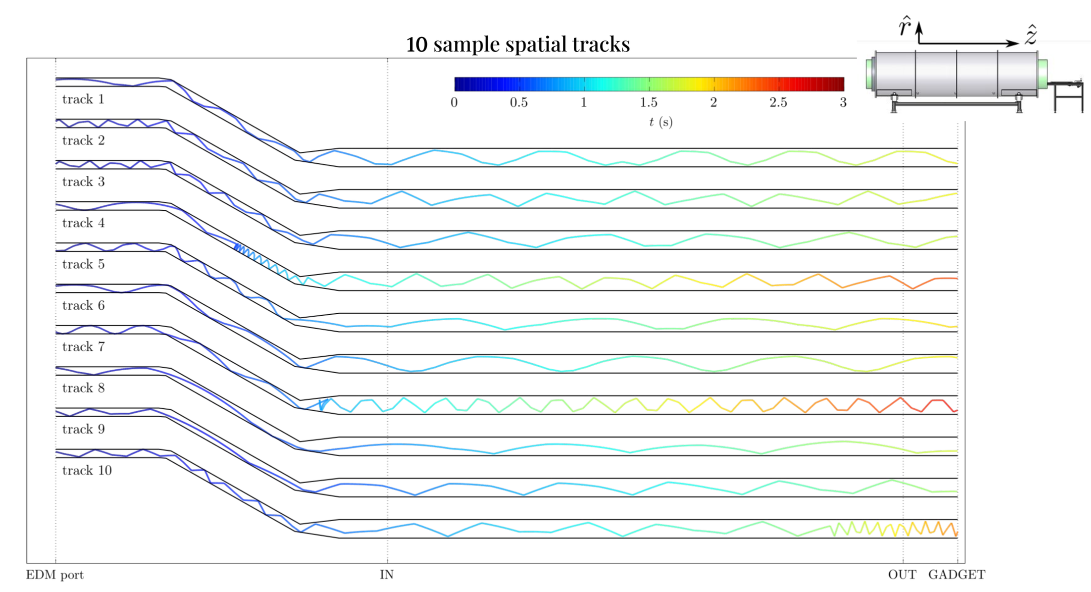
- PSA based on the total PMT voltage amplitudes (A_{gr}) and the pulse shape (PS) parameter
- Single gas filling allows characterization of background events
- Background presence in UCN$_1$ category **< 0.01 %**

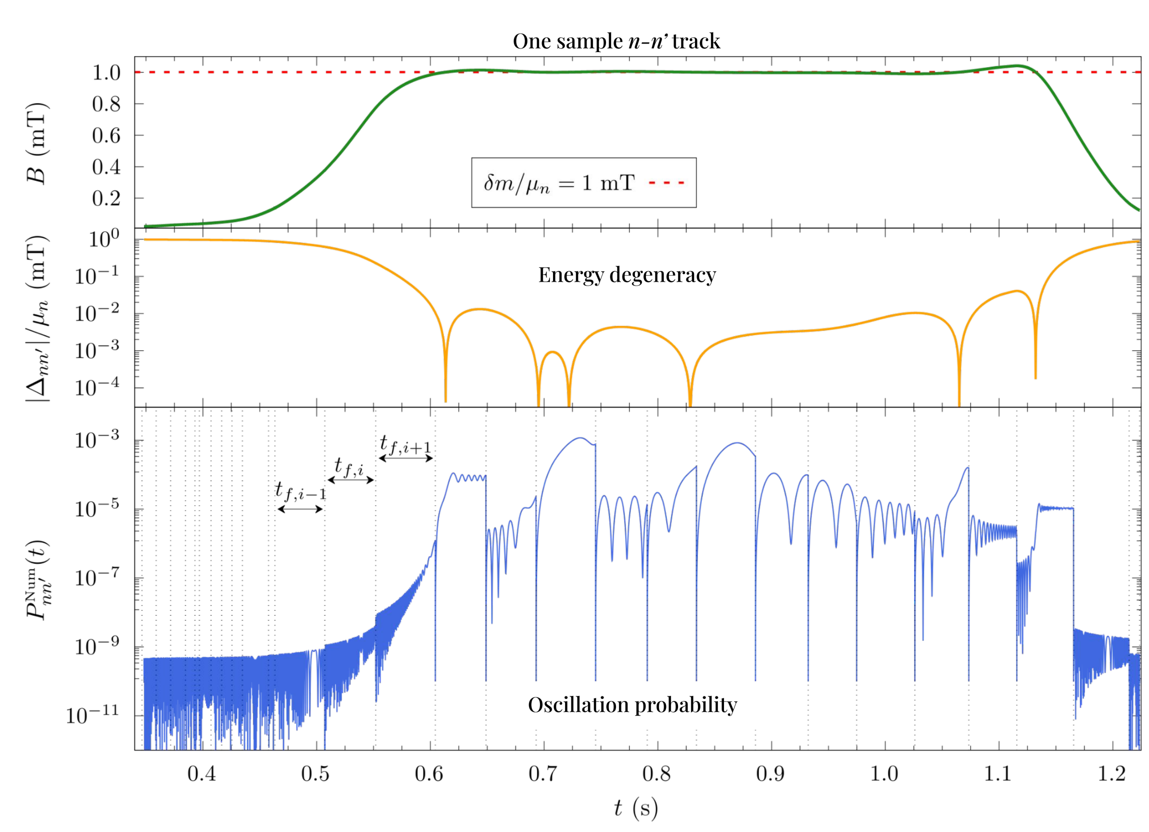
5. Magnetic field inhomogeneities

- UCN do not experience a single B-field
- Trajectories computed from MC simulations [c]
- Numerical solution of the Schrödinger equation describing n-n' oscillations

$$\frac{\partial}{\partial t}\hat{\rho} = -i[\hat{\mathcal{H}}_{nn'}, \hat{\rho}] = -i\hat{\mathcal{H}}_{nn'}\hat{\rho} + i\hat{\rho}\hat{\mathcal{H}}^{\dagger}_{nn'}$$

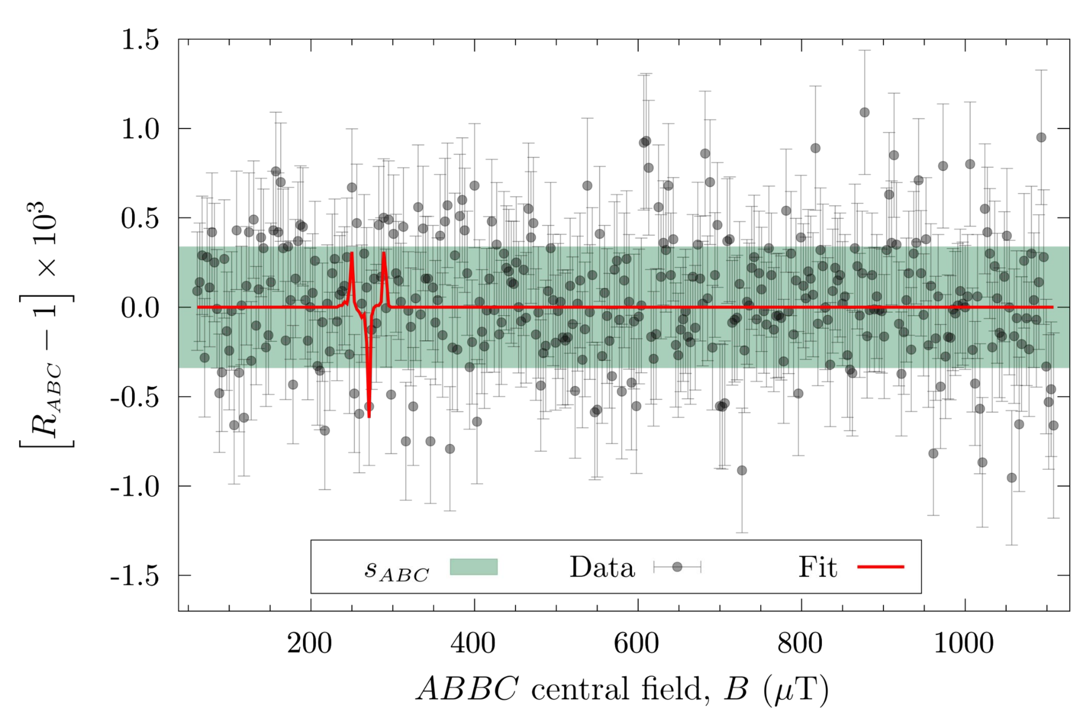
$$\hat{\mathcal{H}}_{nn'} = \begin{pmatrix} \mu_n B & 0 & \epsilon_{nn'} & 0 \\ 0 & -\mu_n B & 0 & \epsilon_{nn'} \\ \epsilon_{nn'} & 0 & \delta m & 0 \\ 0 & \epsilon_{nn'} & 0 & \delta m \end{pmatrix}$$

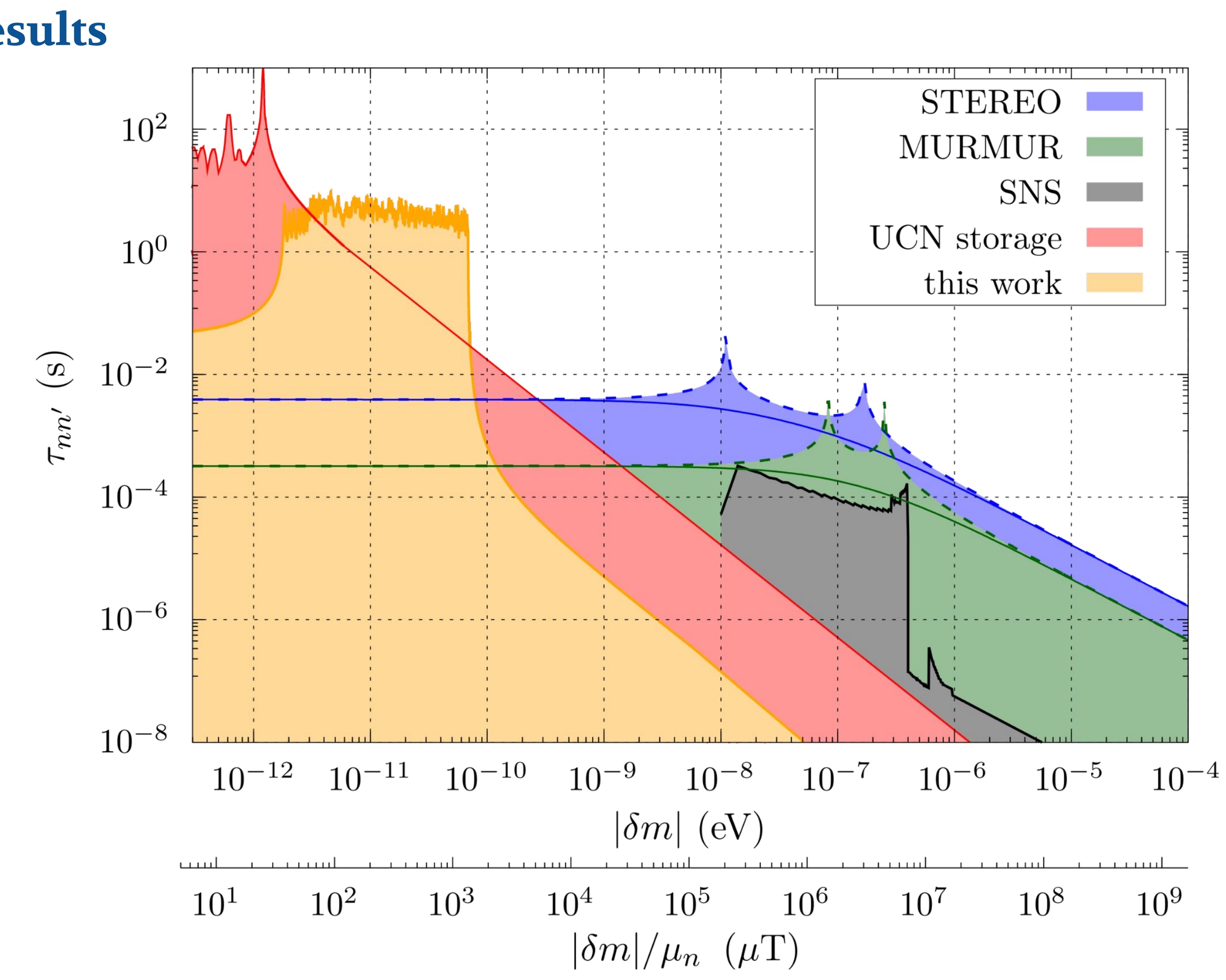




6. Results

- The normalized UCN flux (R_{ABC}) did not show a significant signal. Best fit: χ^2 / NDF = 343.2/348 (χ^2_{null} / NDF = 348.5/349)
- A new exclusion region in the (δm, $\tau_{nn'}$) parameter space was defined





7. Conclusions

- UCN beam experiments probed efficient over a wide range of mass splitting
- A new limit to the oscillations was established:

  $\tau_{nn'} > 1$ s (95 % C.L.) for $\delta m \in [6 - 72]$ peV

- There are still unexplored regions in the parameter space

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