Stimulated Transitions in Resonant Atom Majorana Mixing

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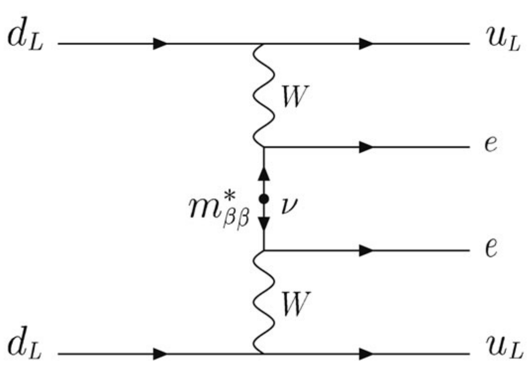
Based on:

J. Bernabéu and A. Segarra, arxiv:1706.08328 [hep-ph]

Neutrinoless double beta decay

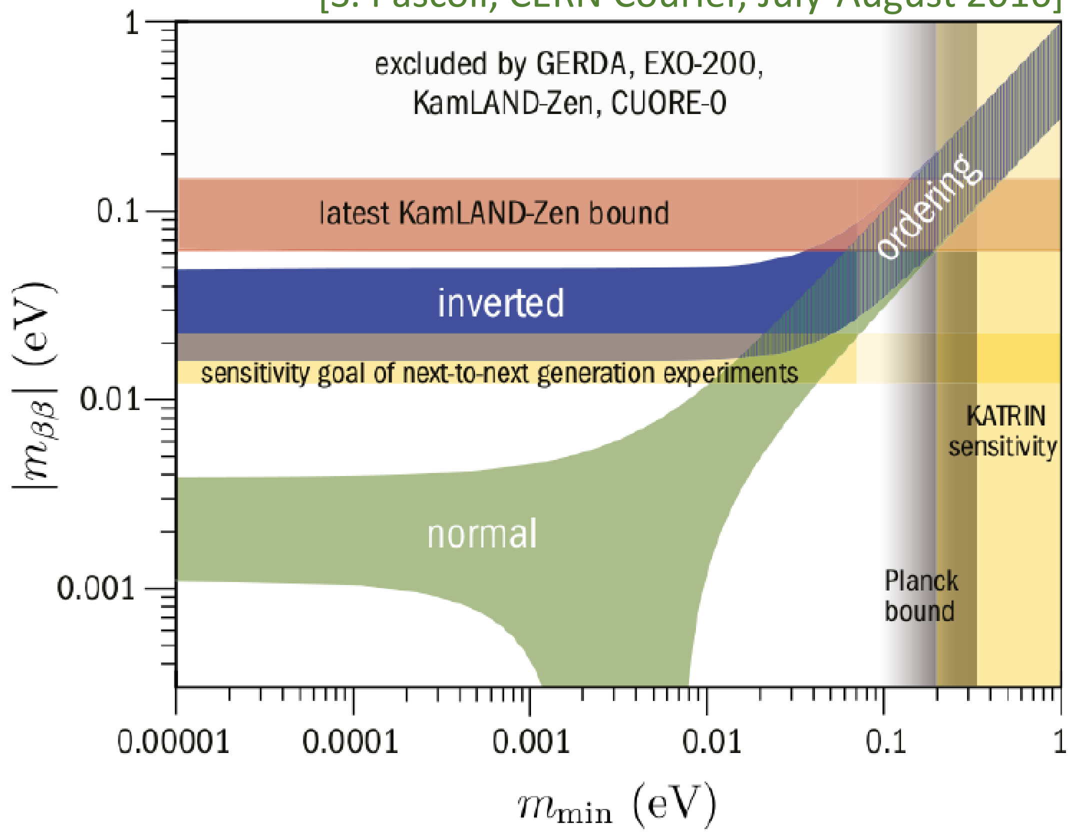
$$^{A}Z \rightarrow {}^{A}(Z+2) + 2e^{-}$$



- $\Delta L = 2$ process, only if Majorana ν
- Signature: $T_{ee} = Q$
- Background: 2ν mode with $T_{ee} < Q$

$$m_{\beta\beta} \equiv \sum_i U_{ei}^2 \, m_{\nu_i}$$

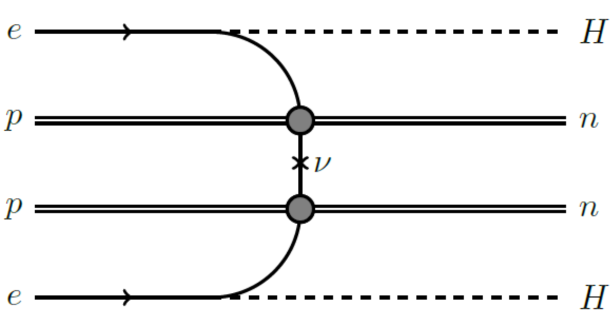
[S. Pascoli, CERN Courier, July-August 2016]



Neutrinoless double electron capture

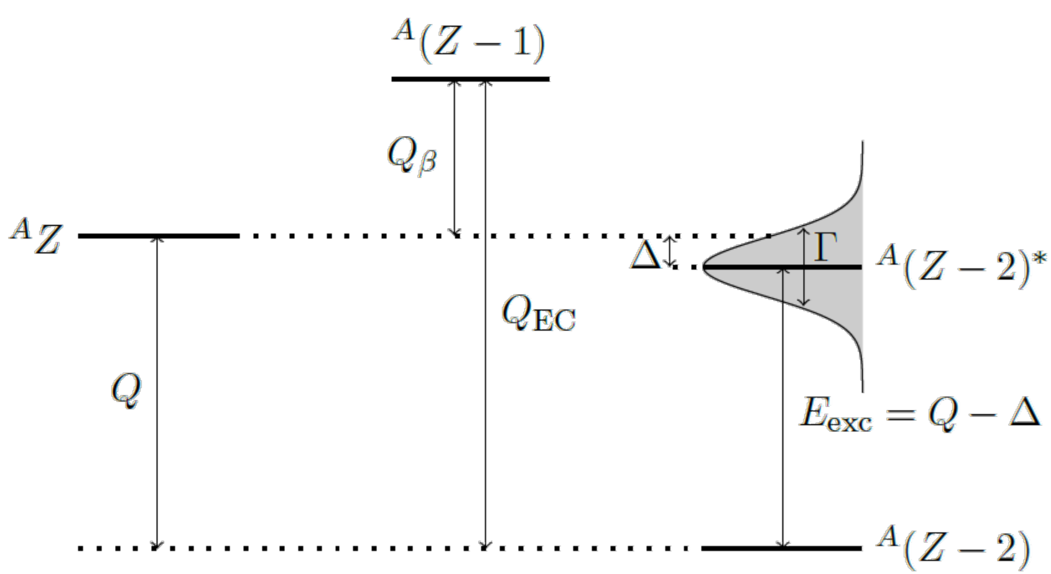
$${}^{A}Z + 2e^{-} \rightarrow {}^{A}(Z-2)^{*}$$

$$m_{\beta\beta} \equiv \sum_i U_{ei}^2 \, m_{\nu_i}$$



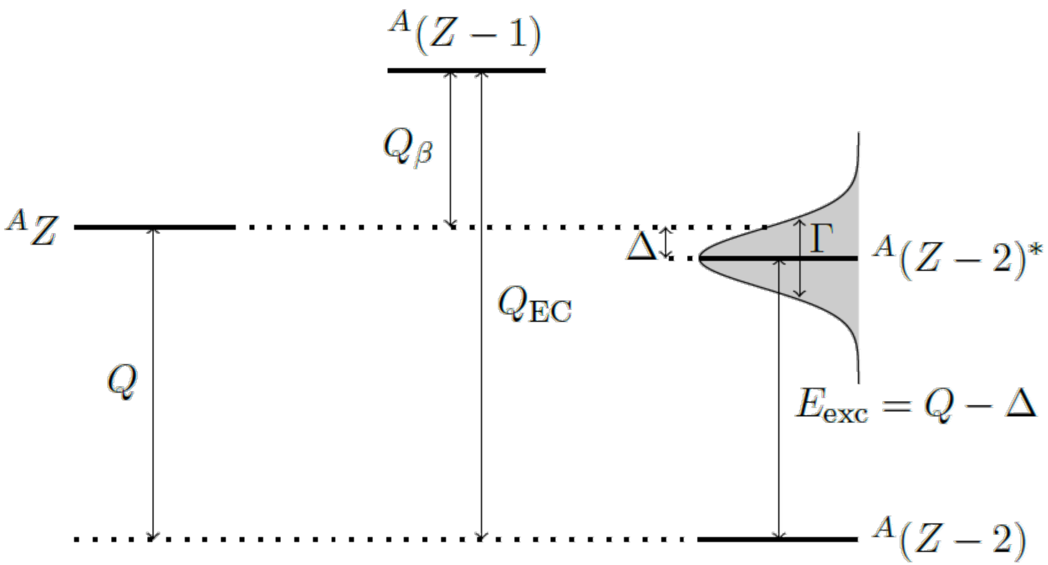
Majorana Mixing M_{21}

- $\Delta L = 2$ mixing, only if Majorana ν, followed by 2 X-ray emission
- Signature: $T_{\gamma\gamma} = Q$
- No intrinsic background on the resonance



Atom Mixing

$$\mathbb{H} = \mathbb{M} - \frac{i}{2}\mathbb{\Gamma} = \begin{bmatrix} M_1 & M_{21}^* \\ M_{21} & M_2 \end{bmatrix} - \frac{i}{2}\begin{bmatrix} 0 & 0 \\ 0 & \Gamma \end{bmatrix}$$



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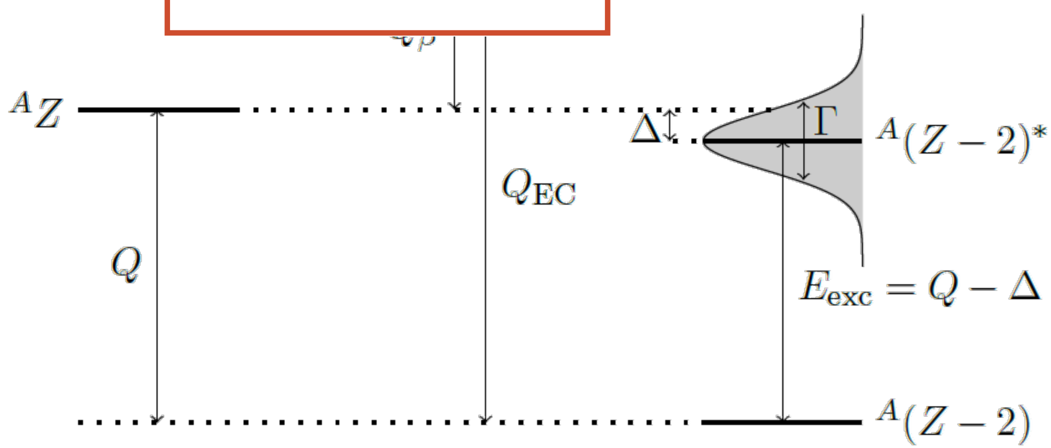
Non-orthogonal eigenstates: $[\mathbb{M}, \mathbb{\Gamma}] \neq 0$, $\langle \lambda_S | \lambda_L \rangle = \alpha - \beta$

$$|\lambda_L\rangle = |1\rangle + \alpha\,|2\rangle\,,$$
$$E_L \approx M_1\,,$$
$$\Gamma_L \approx |\alpha|^2\,\Gamma\,,$$

$$\alpha = \frac{M_{21}}{\Delta + \frac{i}{2}\Gamma}$$

$$\beta = \frac{M_{21}}{\Delta - \frac{i}{2}\Gamma}$$

$$|\lambda_S\rangle = |2\rangle - \beta^*\,|1\rangle\,,$$
$$E_S \approx M_2\,,$$
$$\Gamma_S \approx \Gamma\,.$$



Resonant enhancement

$$\Delta \sim \Gamma$$

$^{152}\mathrm{Gd} \rightarrow {}^{152}\mathrm{Sm}$

- $\Delta \sim 30\,\Gamma$
- $|\alpha|^2 = 10^{-54}\left[\frac{|m_{\beta\beta}|}{0.1\ \mathrm{eV}}\right]^2$

$$\alpha = \frac{M_{21}}{\Delta + \frac{i}{2}\Gamma}$$

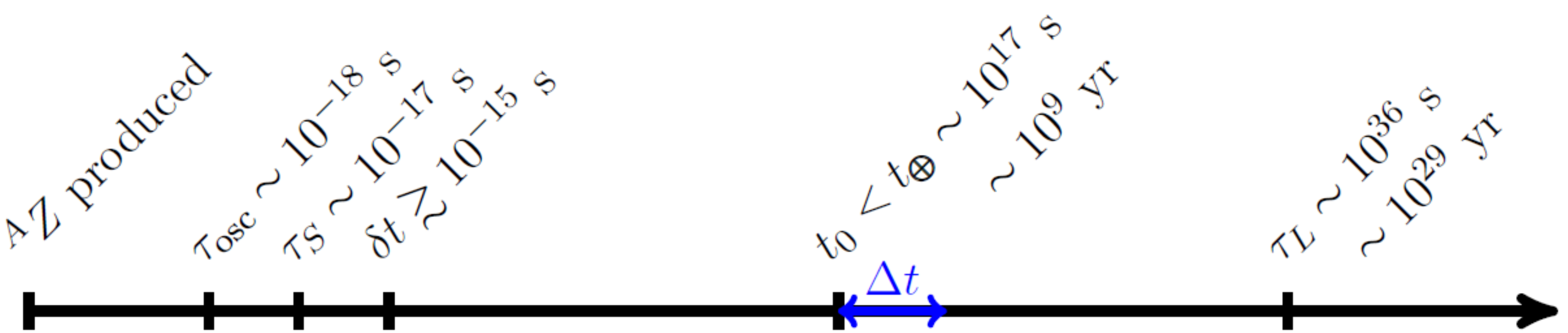
$$\beta = \frac{M_{21}}{\Delta - \frac{i}{2}\Gamma}$$

- Intense experimental searches looking for a better fulfilment of the Resonance Condition.
- Precise measurement of atomic masses achievable due to the development of atomic traps.

Time evolution

$$\left|\langle {}^{A}(Z-2)^{*}|{}^{A}Z(t)\rangle\right|^{2} = |\alpha|^{2}\left\{1+e^{-\Gamma t}-2e^{-\frac{1}{2}\Gamma t}\cos(\Delta\cdot t)\right\}$$

- Different time-scales given by $|\Delta|$, Γ and Γ_L



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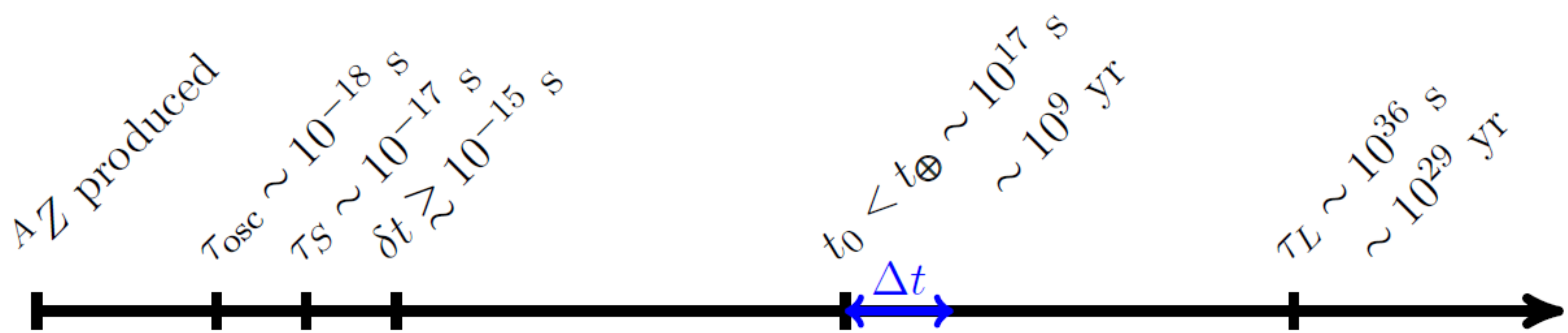
- Different time-scales given by $|\Delta|$, Γ and Γ_L

$$\tau_S \ll t \ll \tau_L \quad \Longrightarrow \quad \begin{cases} P_L(t) \approx 1 - \Gamma_L\, t \\ P_S(t) \approx 0 \\ P_{\text{g.s.}}(t) \approx |\alpha|^2\, \Gamma\, t \end{cases}$$

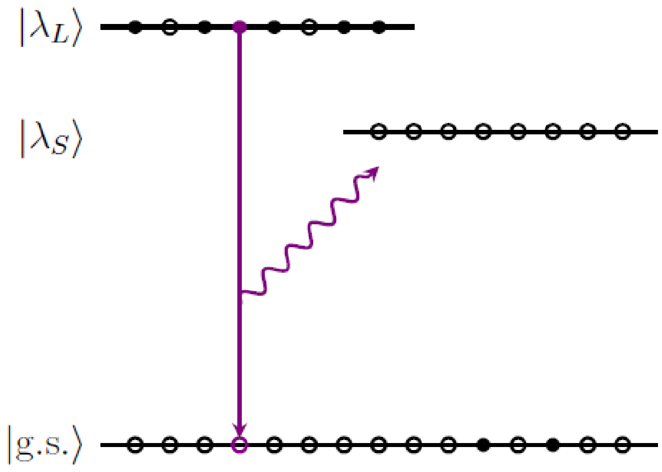


Majorana observables

- **Spontaneous emission**

$$P_L(\Delta t) \approx 1 - \Gamma_L \, \Delta t$$

$$\tau_L \sim 10^{29} \text{ yr}$$



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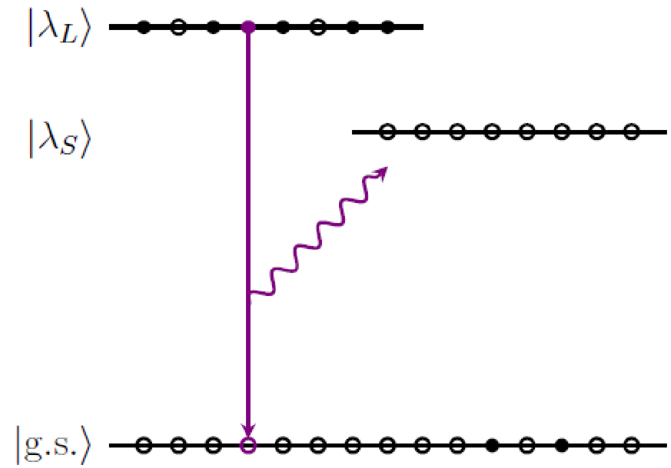
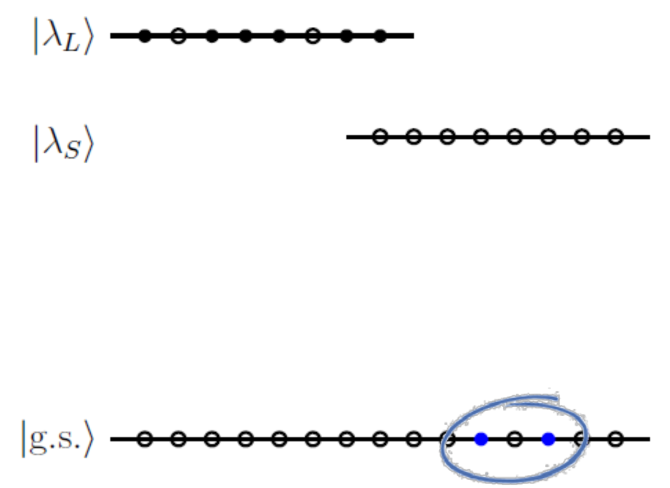


- **Daughter atom population**

$$P_{\text{g.s.}}(t) \approx |\alpha|^2 \, \Gamma \, t_0$$

1 mole Gd from T_{Earth}
includes 20 000 Sm atoms



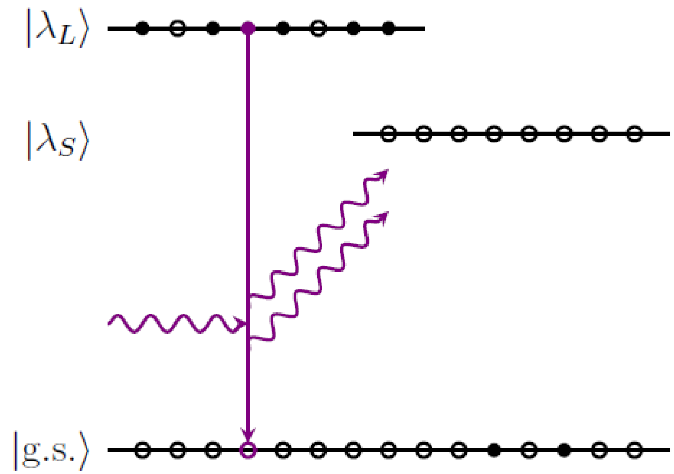
Stimulated Majorana observables

➢ **Stimulated emission**

$$\frac{\mathrm{d}N_L^{\mathrm{st}}}{\mathrm{d}t} = G\,\frac{\mathrm{d}N_L^{\mathrm{sp}}}{\mathrm{d}t}$$

$$G = \hbar\,(\hbar c)^2\,\frac{\pi^2}{(\hbar\omega)^3}\,\frac{\mathrm{d}N}{\mathrm{d}t\,\mathrm{d}S}\,\left[\frac{\mathrm{d}\omega}{\omega}\right]^{-1}$$

Natural population inversion!



$\hbar\omega \sim$ tens of keV

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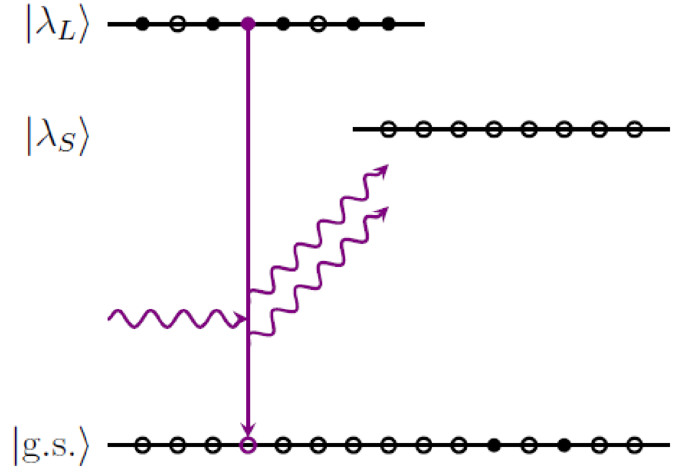

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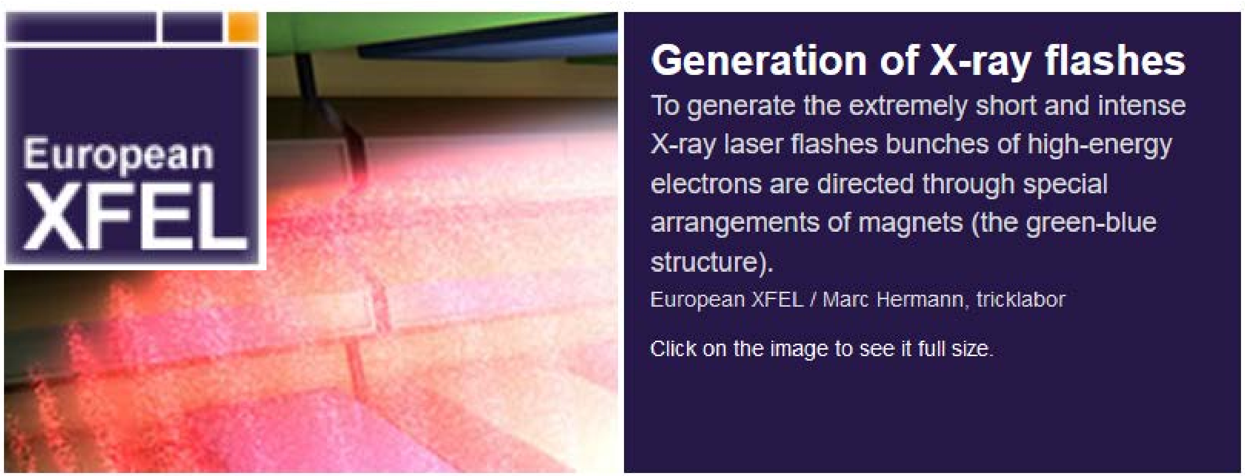
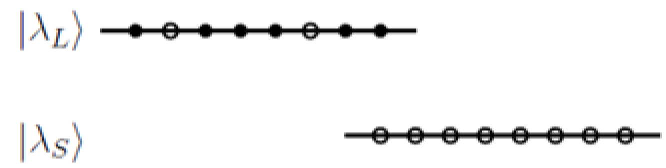


- 100 fs pulse
- 100 nm spot size
- 20W mean power

$G \sim 100$

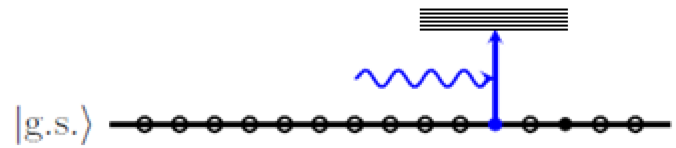
Stimulated Majorana observables (cont'd)

➢ **Daughter Atom**
Absorption Spectrum



Laser:

- 100 fs pulse
- 40 μm spot size
- 5 W mean power



$$\left.\frac{\mathrm{d}N_{\mathrm{g.s.}}}{\mathrm{d}t}\right|_{\mathrm{abs}} = -60\%\, N_{\mathrm{g.s.}} \left[\frac{100\ \mathrm{ns}}{\tau}\right] \mathrm{fs}^{-1}$$

The daughter atom can be excited to any of its atomic levels!

➢ Typical atomic lifetimes of ^{152}Sm range from 10 to 1000 ns

Conclusions and Outlook

- Neutrinoless double electron capture is a quantum Majorana Mixing between two atoms, generated by $\Delta L = 2$ Majorana mass neutrino, which provides **enhanced observables under the resonance condition**.

- Intense experimental searches looking for a better candidate. Today's best one, ^{152}Gd, is still a factor 30 away of the resonance, implying a **1000 factor** loss in any observable.

- Time evolution of these mixed states presents the phenomenon of **Atom Oscillations**. At observable times, the description is the same as any 3-level atomic system with natural **population inversion**.

- Many interesting **observables** besides spontaneous emission: probes of **daughter atom population** (both geochemical and optical) **and XFEL-stimulated X-ray emission**.