2026.07.15 中国高能物理年会 广州

通过参量荧光效应探测宇宙中微子背景

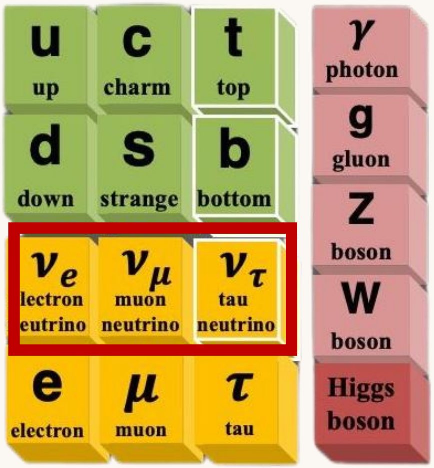
黄国远 （Guo-yuan Huang）
中国地质大学（武汉）

Based on

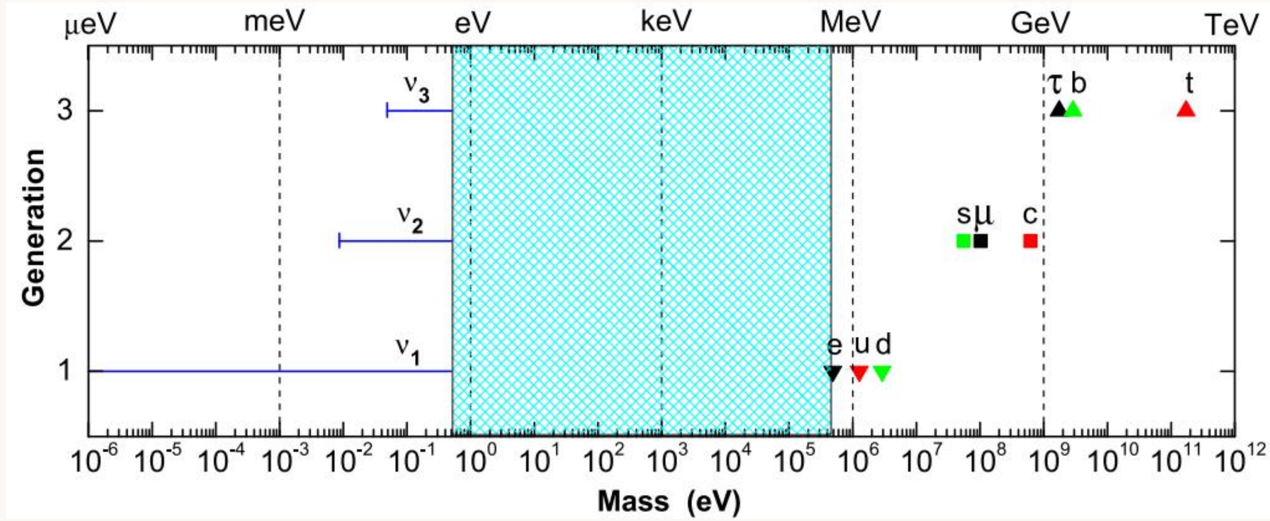
**GYH and Shun Zhou,
PRL 136 (2026) 081003**

Neutrinos

Y.-F. Li, Z.-z. Xing, PLB 695 (2011) 205
Z.-z. Xing, Physics Reports 854 (2020) 1



1897—2012 ©Fermilab

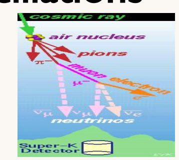


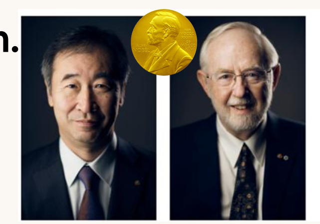
1930

Reactor neutrino discovery

1956

Solar and atm. oscillations

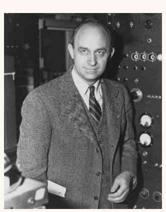




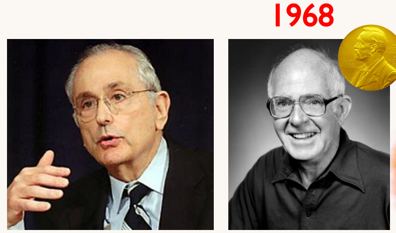
2015

1933

Weak interaction



1968

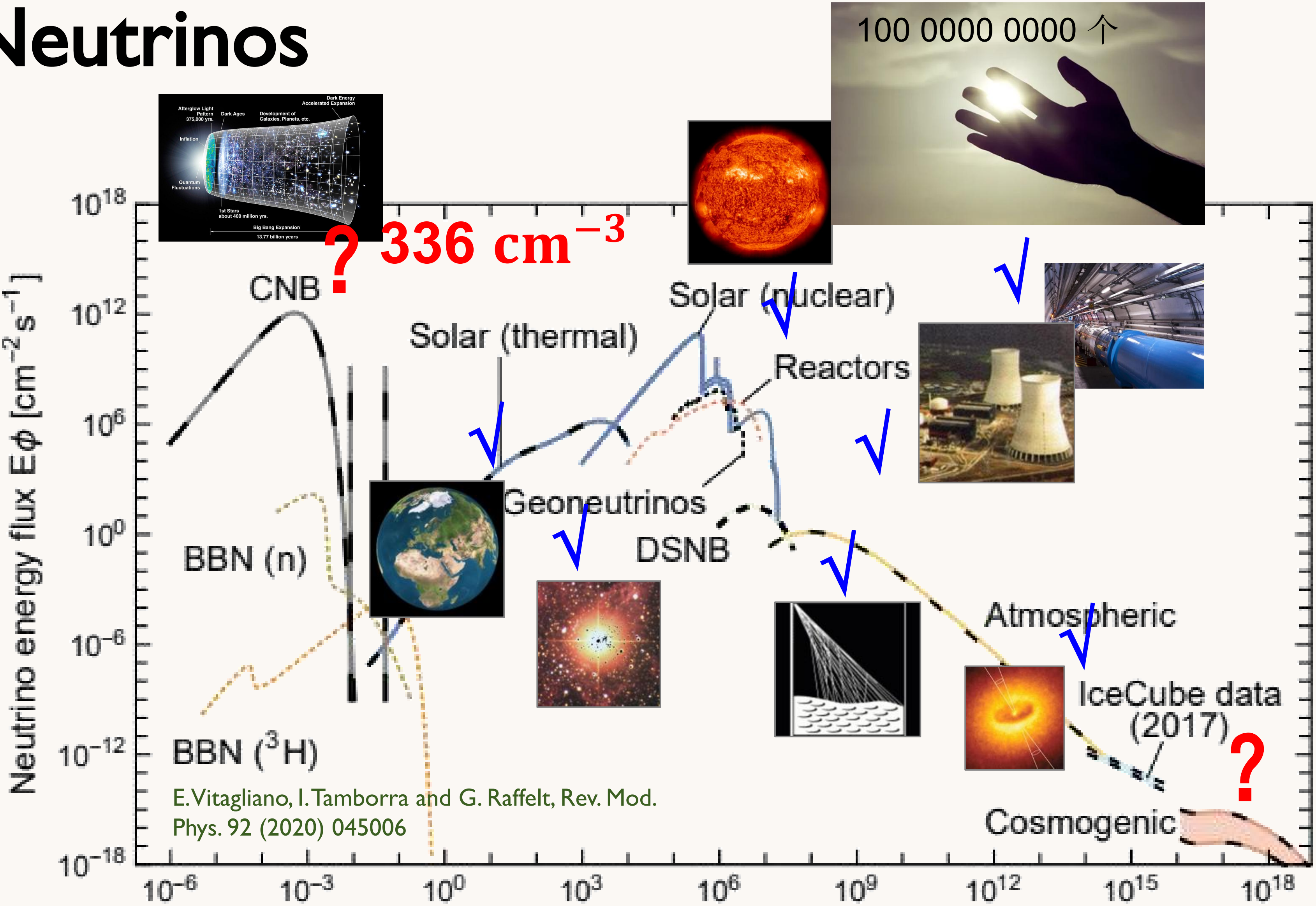


Solar nu

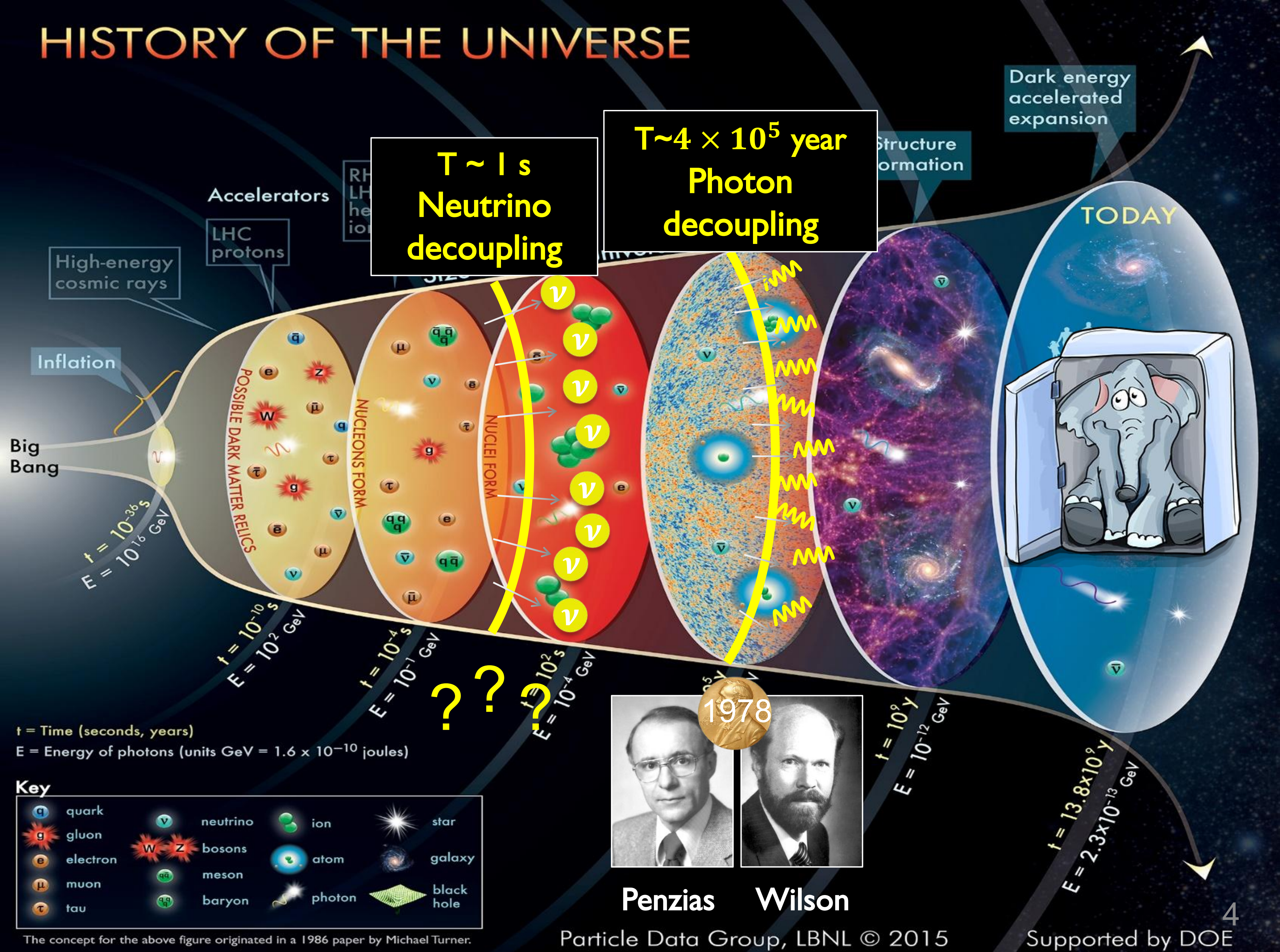
1987

SN nu

Neutrinos

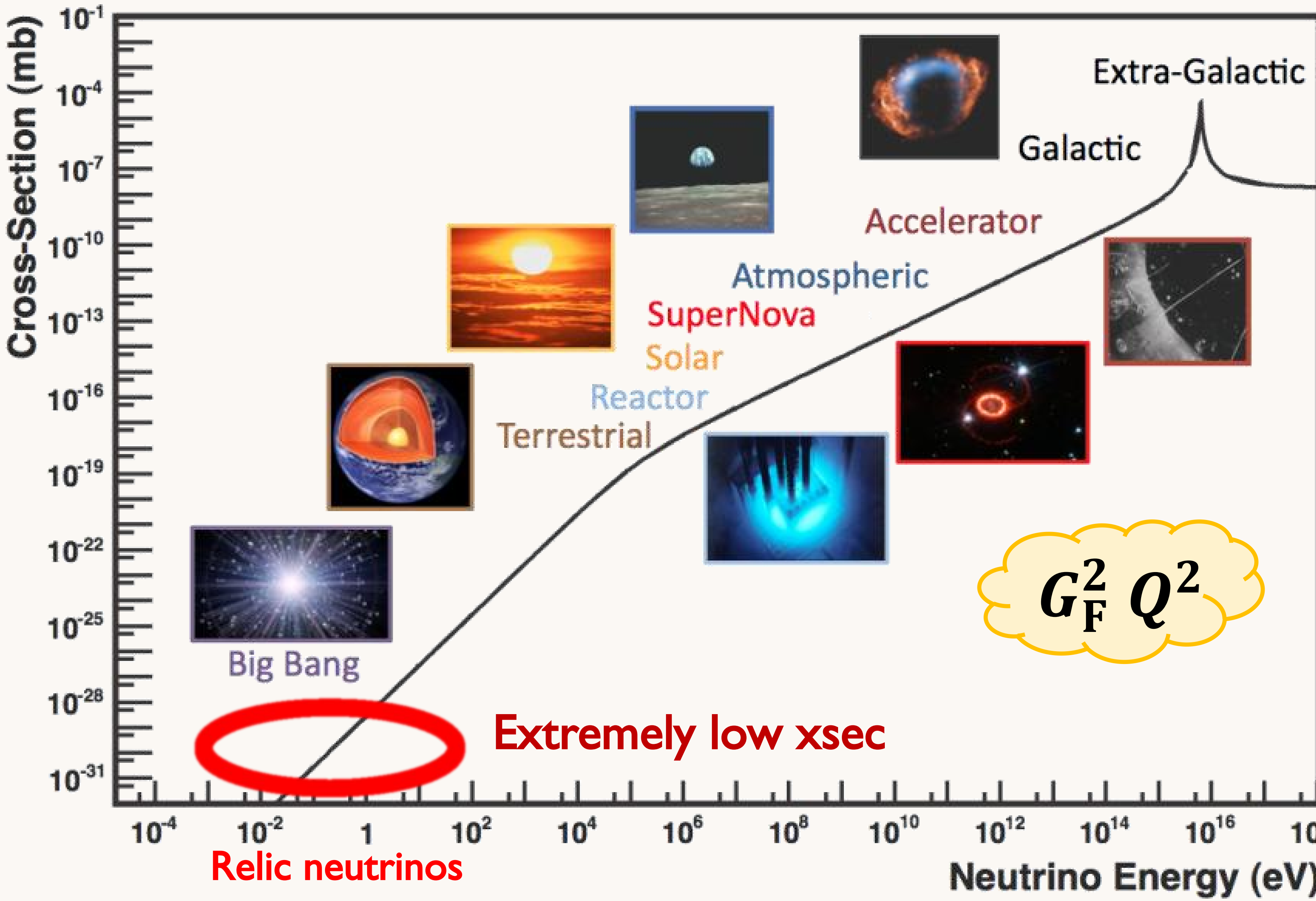


? Relic neutrinos <-------------- Energy E [eV] --------------> Cosmogenic neutrinos ?

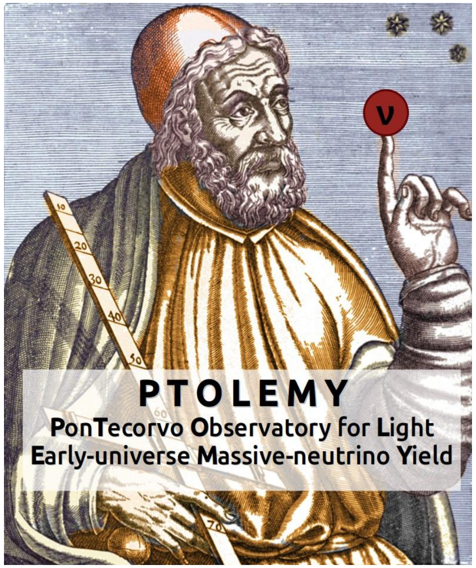

HISTORY OF THE UNIVERSE
Dark energy accelerated expansion
tructure
ormation
T~4 × 10^5 year
Photon decoupling
T ~ 1 s
Neutrino decoupling
Accelerators
LHC protons
High-energy cosmic rays
Inflation
Big Bang
TODAY
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-36 s
E = 10^16 GeV
t = 10^-10 s
E = 10^2 GeV
t = 10^-4 s
E = 10^-1 GeV
? ? ?
t = 10^2 s
E = 10^-4 GeV
1978
t = 10^9 y
E = 10^-12 GeV
t = 13.8x10^9 y
E = 2.3x10^-13 GeV
t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6 x 10^-10 joules)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
The concept for the above figure originated in a 1986 paper by Michael Turner.
Penzias
Wilson
Particle Data Group, LBNL © 2015
Supported by DOE

Neutrinos

Formaggio and Zeller, Rev. Mod. Phys. 84 (2012) 1307



Triutium capture

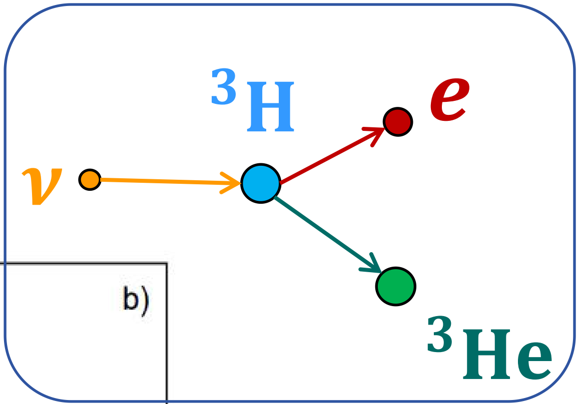


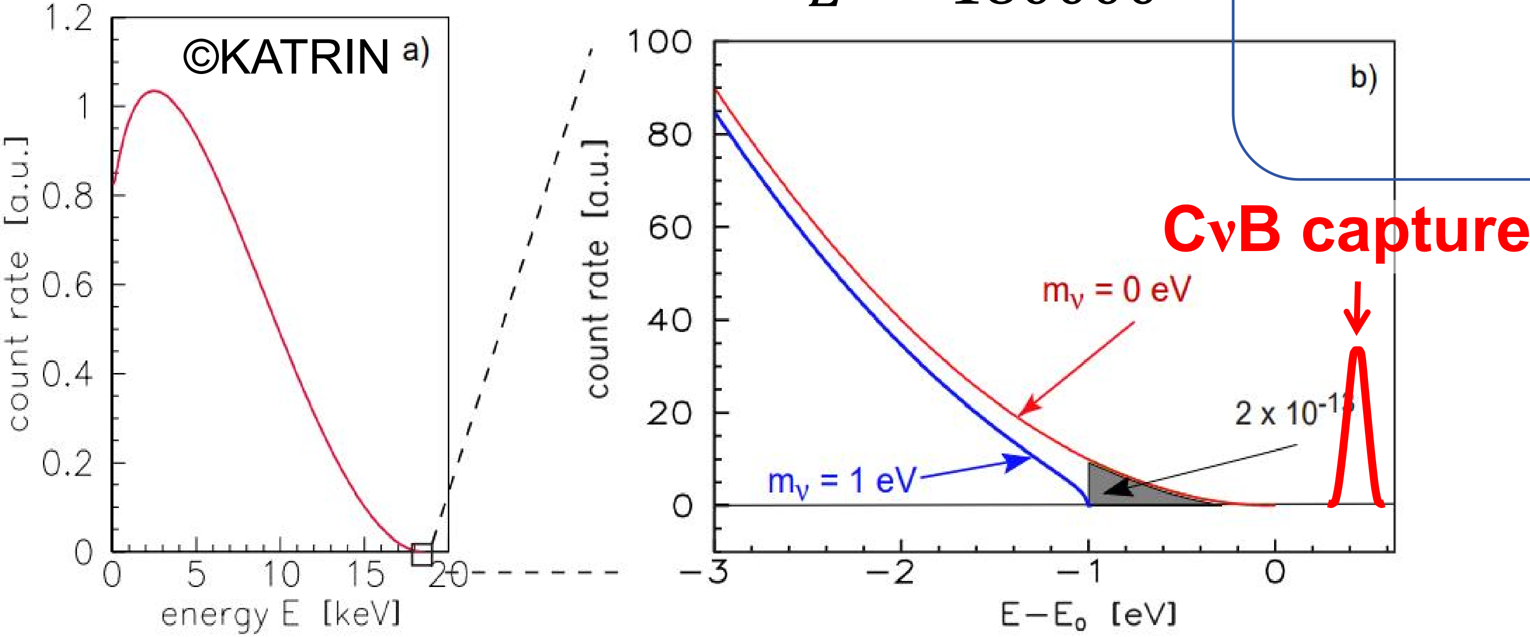
* Inverse β decay proposed by S.Weinberg.

* A direct evidence of the era when the Universe is just one second old.

* The detection can also help to pin down neutrino's properties such as absolute mass and Dirac/Majorana nature.

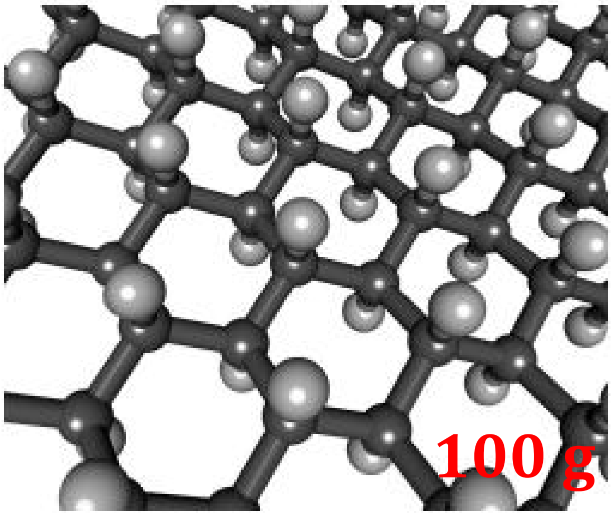
$$\frac{\Delta E}{E} \sim \frac{1}{180000}$$

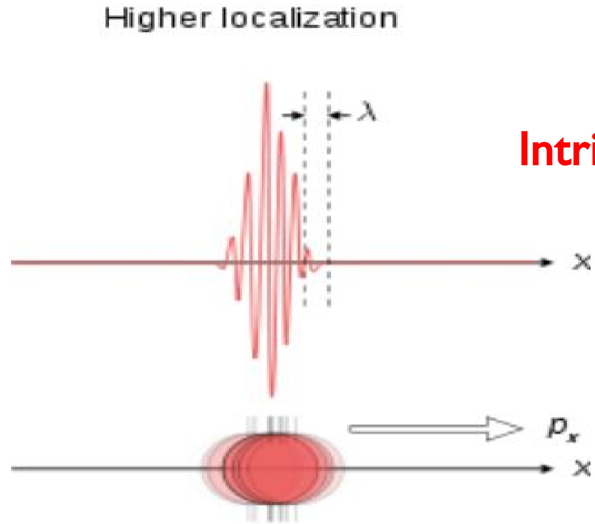




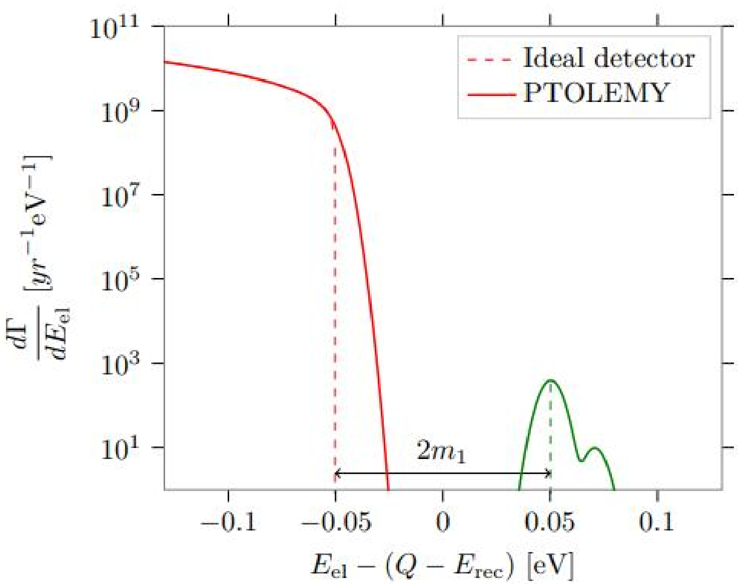
PTOLEMY: Quantum challenge

Cheipesh, V. Cheianov, and A. Boyarsky, Phys. Rev. D 104, 116004 (2021)

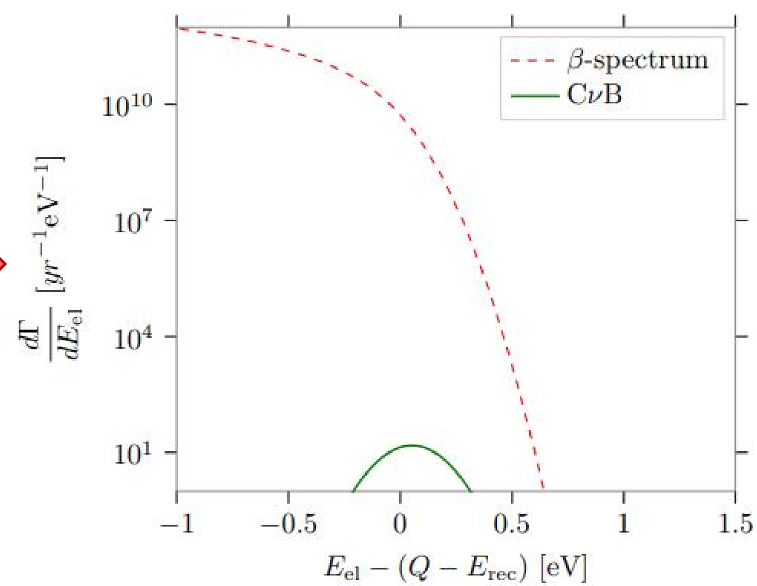




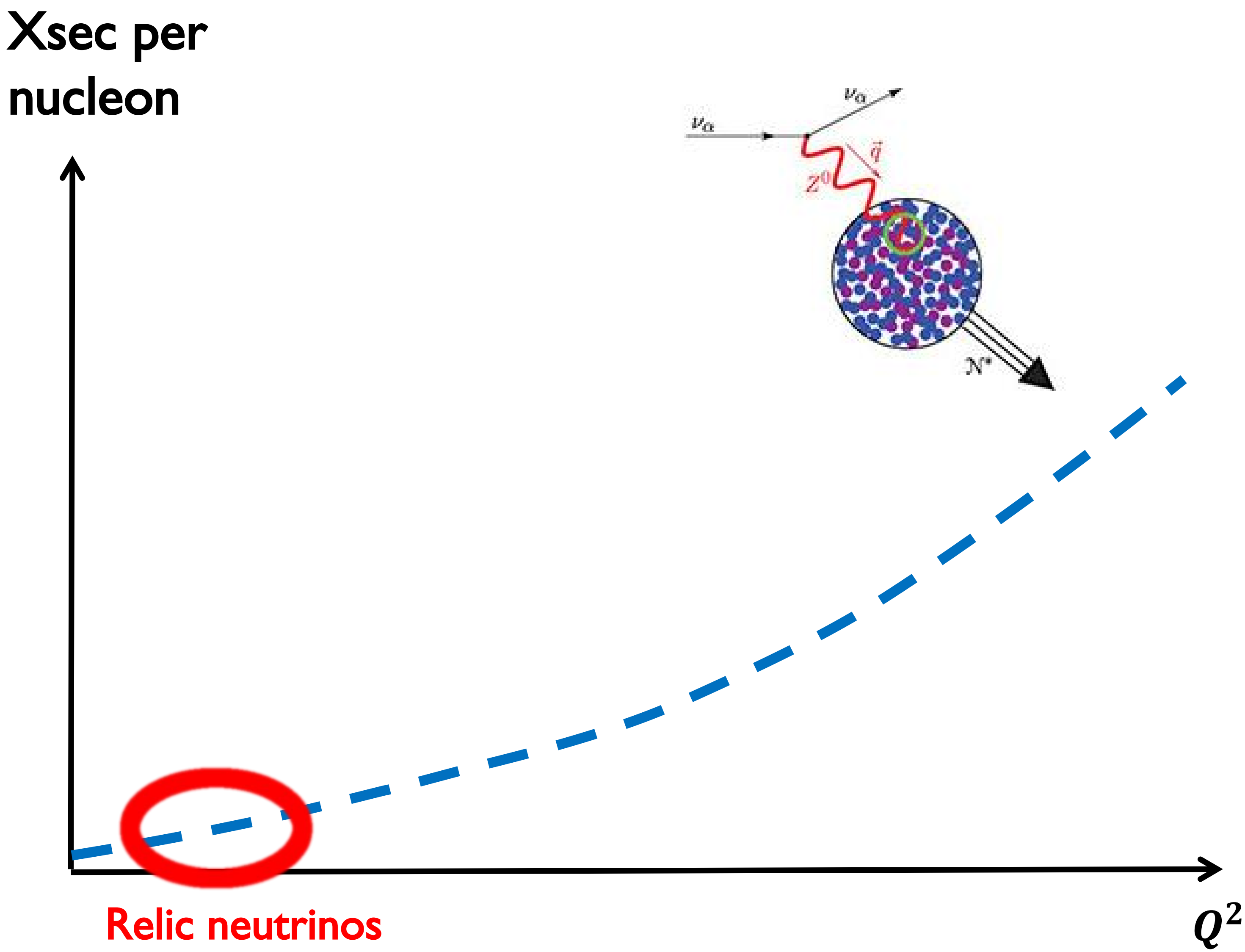
Intrinsic effect



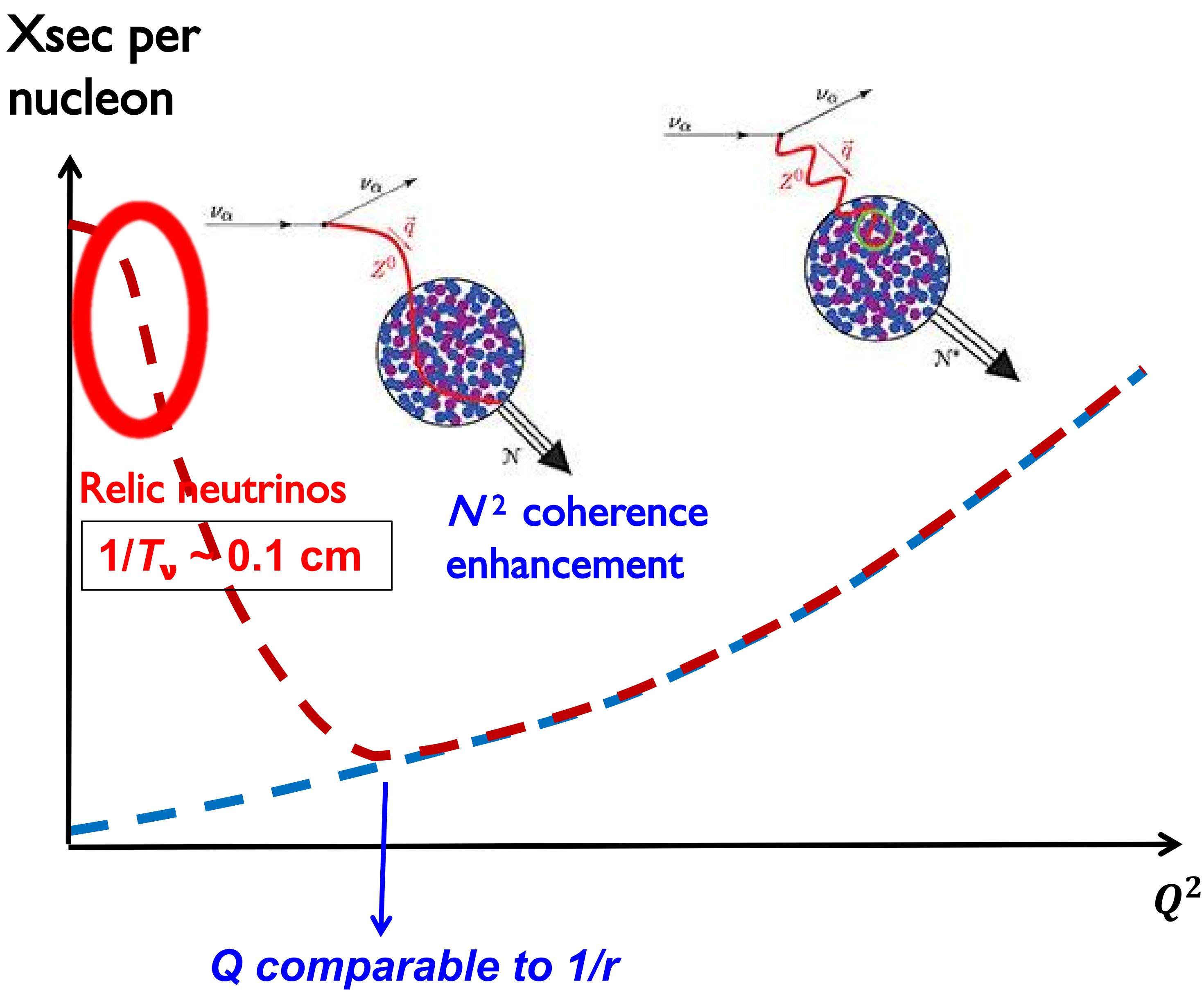
eV-scale smearing



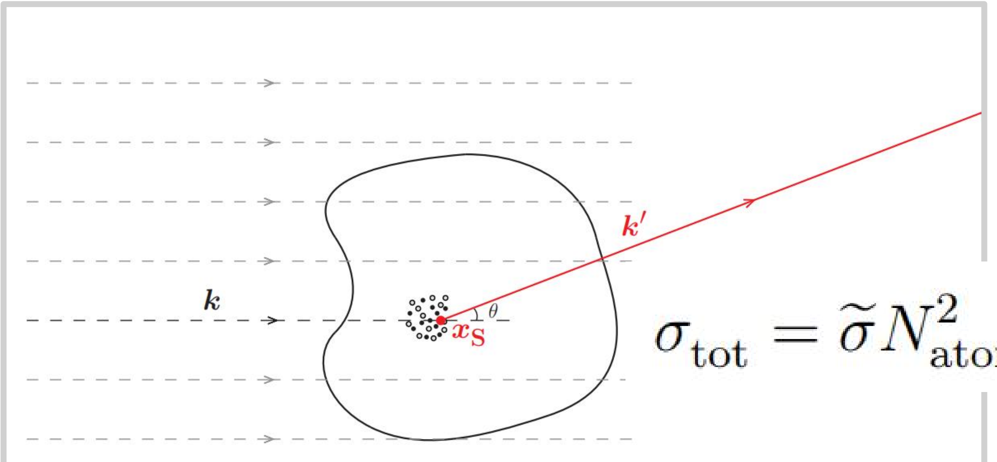
Coherent enhancement



Coherent enhancement



Coherent enhancement



$$\sigma_{\text{tot}} = \widetilde{\sigma} N_{\text{atom}}^2$$

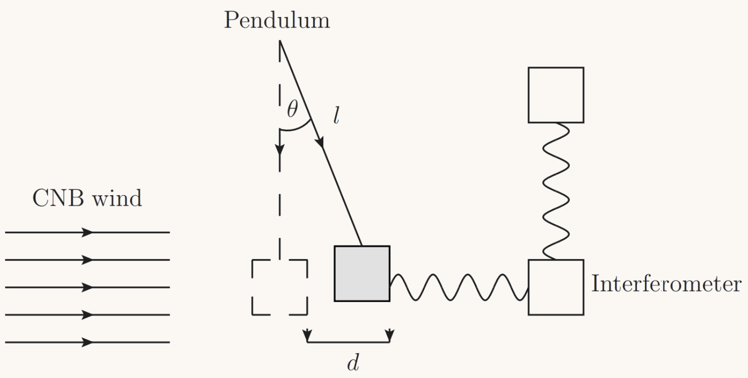
$$\frac{1}{R} = \begin{cases} 41 \text{ years} & \nu_1 \to \nu_1, \text{ relativistic} \\ 2 \text{ monthes} & \nu_2 \to \nu_2, \text{ non-relativistic, Dirac} \\ 24 \text{ years} & \nu_2 \to \nu_2, \text{ non-relativistic, Majorana} \\ 4 \text{ days} & \nu_3 \to \nu_3, \text{ non-relativistic, Dirac} \\ 56 \text{ years} & \nu_3 \to \nu_3, \text{ non-relativistic, Majorana} \end{cases}$$

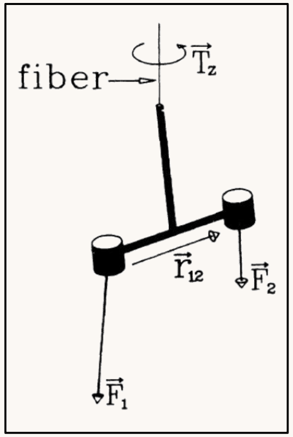
$$\widetilde{\sigma}(\nu_i/\overline{\nu}_i + {}^A_Z X) = \frac{G_F^2 \left|C_Z^A\right|^2 E_i^2}{\pi}, \qquad \text{— relativistic}$$

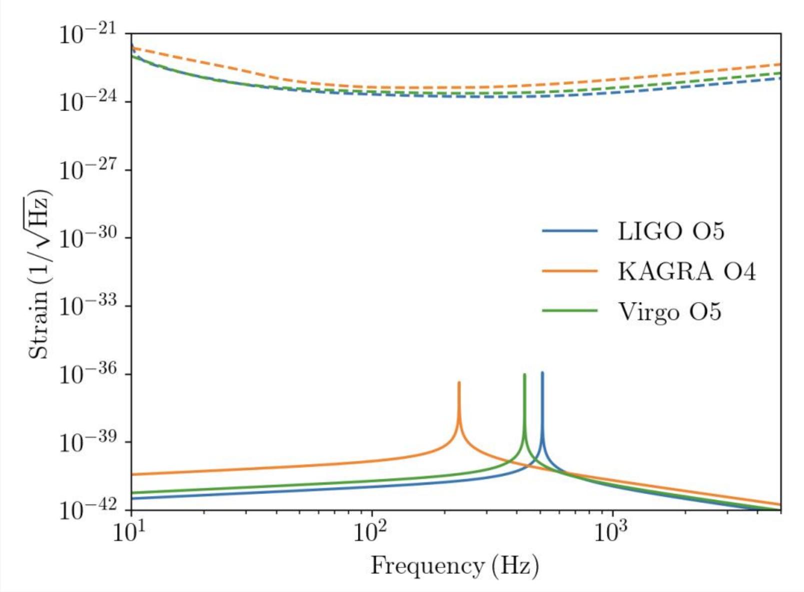
$$\widetilde{\sigma}(\nu_i/\overline{\nu}_i + {}^A_Z X) = \frac{G_F^2 \left|C_Z^A\right|^2 E_i^2}{\pi} \cdot \frac{E_i + k_i}{2E_i}, \qquad \text{— non-relativistic, Dirac}$$

$$\widetilde{\sigma}(\nu_i/\overline{\nu}_i + {}^A_Z X) = \frac{G_F^2 \left|C_Z^A\right|^2 E_i^2}{\pi} - \frac{G_F^2 \mathrm{Re}(C_Z^{A2}) m_i m_j}{\pi}. \qquad \text{— non-relativistic, Majorana}$$

Sensitivity







Acceleration in the most optimistic case

$$10^{-30}\ \mathrm{cm}\cdot\mathrm{s}^{-2}$$

Experimental sensitivity

$$a \sim 10^{-15}\ \mathrm{cm}\cdot\mathrm{s}^{-2}$$

V. Domcke and M. Spinrath, JCAP 06 (2017) 055
J. D. Shergold, JCAP 11 (2021) 052

Sensitivity

✦ We know from quantum mechanics that the recoil due to cnub is discrete

✦ Directly measuring each collision?

✦ For a mm-scale target, the rate is 1/(a few days), quite significant !

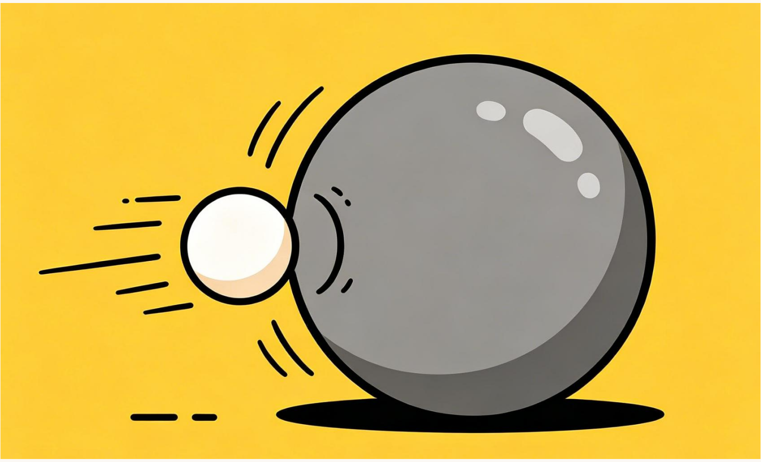
✦ However, the kinetical energy of each collision is only $2*10^{-33}$ eV for a mm target, which will be further averaged across all atoms in the target

✦ From energy-time uncertainty, an observation time of 10 billion years (~ the age of our Universe) is required.

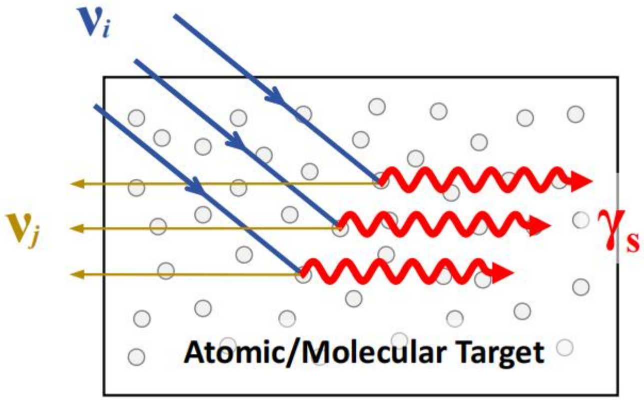
We need larger energy deposition!!!

* Superconducting current
* Softphoton emission
* Phonon emission

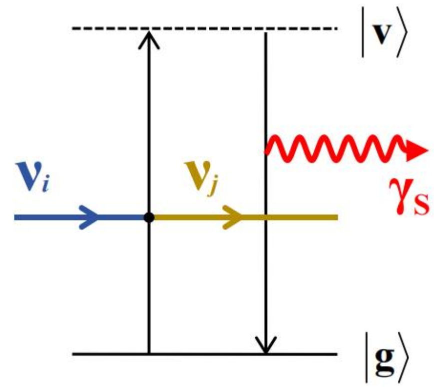
... But effects are all negligible



Coherent photon emission



Additional signal from the coherent scattering

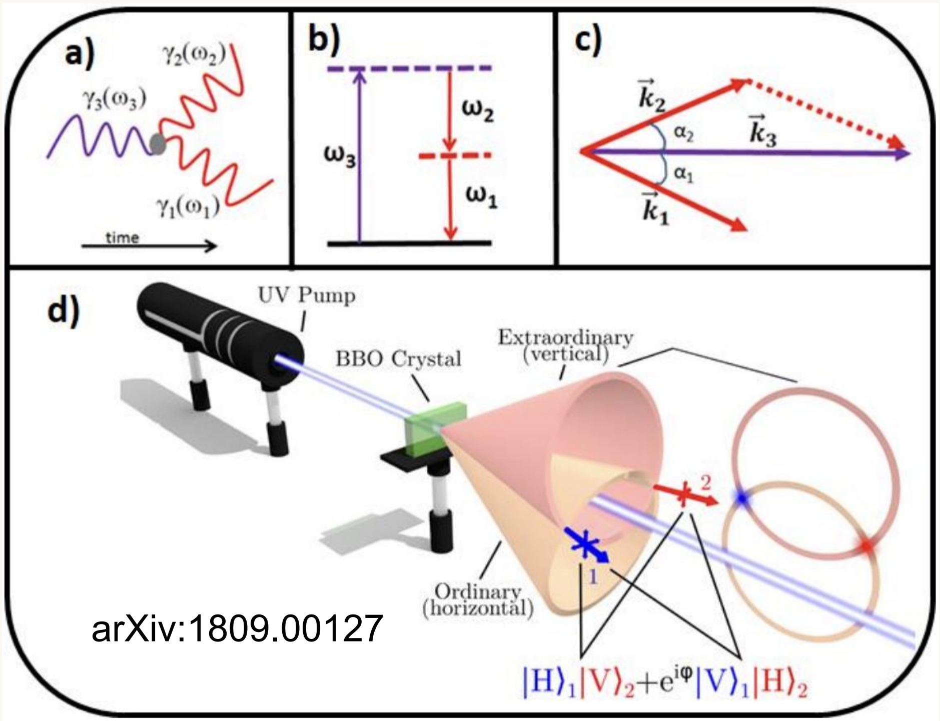


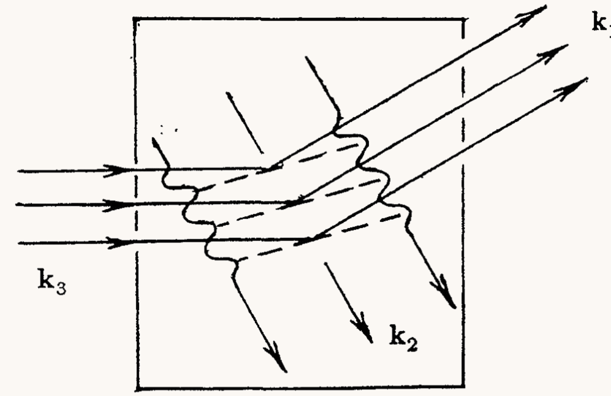
From first principles, the key for coherence may be summarized as:

1. Radiants in the medium is not altered by the scattering.
2. The quantum phases of different radiants are not averaged out.

$$\mathcal{M}_{\mathrm{tot}} = \sum_{r=1}^{N} \mathcal{M}_r \cdot \mathrm{e}^{\mathrm{i}\overbrace{\boxed{(\boldsymbol{p}_i - \boldsymbol{p}'_j - \boldsymbol{k})}}^{=0} \cdot \boldsymbol{x}_r}$$

Nonlinear optics





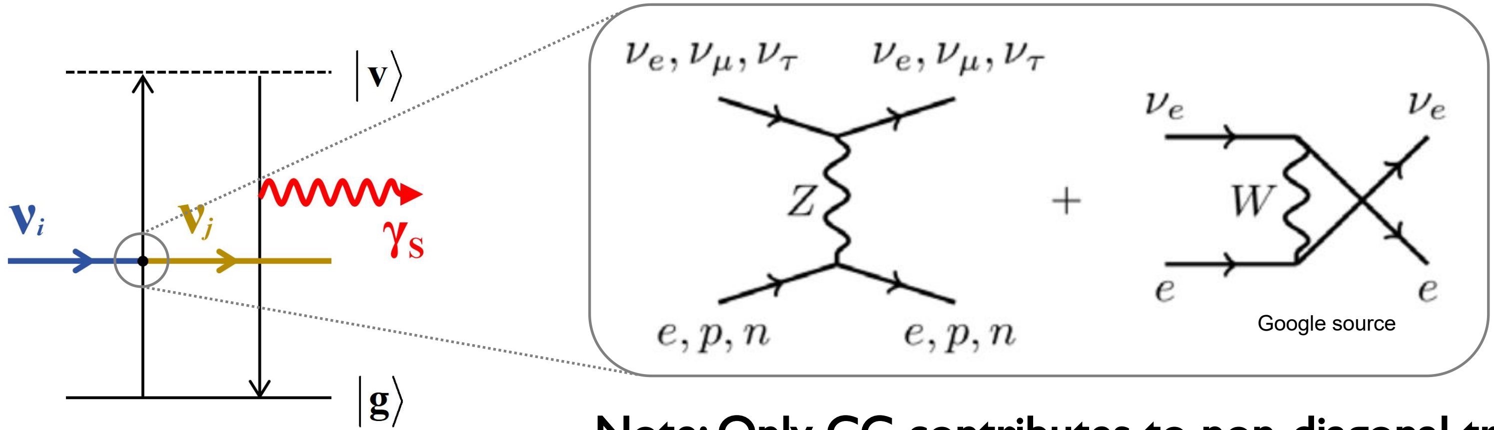
Those two outgoing parametric photons are highly entangled.
(helped to win the Nobel Prize in 2022)

SPDC process (spontaneous parametric down conversion)

Experimentally established in 1967

D. Magde and H. Mahr, PRL 18 (1967) 905
S. E. Harris, M. K. Oshman, and R. L. Byer, PRL18 (1967) 732
``Observation of Tunable Optical Parametric Fluorescence"

Fluorescence of relic neutrinos



Note: Only CC contributes to non-diagonal transitions

$$-\mathcal{L} \supset \sum_{i,j=1}^{3} \frac{G_{\mathrm{F}} C_{ij}}{\sqrt{2}} \overline{\nu}_j \gamma^\mu \left(1-\gamma_5\right) \nu_i \cdot \overline{e} \gamma_\mu \left(1-\gamma_5\right) e$$

$\overline{e}\gamma_0 e$ ⇨ the E1 transition

$\overline{e}\gamma_\alpha\gamma_5 e$ ⇨ the M1 transition

$$\int \mathrm{d}^3\boldsymbol{x}\, \Psi_{\mathrm{v}}^*(\boldsymbol{x})\Psi_{\mathrm{g}}(\boldsymbol{x})\exp[\mathrm{i}(\boldsymbol{p}_i - \boldsymbol{p}_j') \cdot \boldsymbol{x}] \longrightarrow \mathrm{i} \int \mathrm{d}^3\boldsymbol{x}\, \Psi_{\mathrm{v}}^*(\boldsymbol{x})\boldsymbol{x}\Psi_{\mathrm{g}}(\boldsymbol{x}) \cdot (\boldsymbol{p}_i - \boldsymbol{p}_j')$$

$$\langle \mathrm{v} | \boldsymbol{\sigma} | \mathrm{g} \rangle \qquad m_i^2 a_0^2 \sim 10^{-10}$$

$$-H_{\mathrm{I}}^{\mathrm{E1}}(t, \boldsymbol{x_d}) = \frac{G_{\mathrm{F}} C_{ij}}{\sqrt{2}\mathrm{i}} \hat{j}^0_{ij}(\boldsymbol{p}_i, \boldsymbol{p}_j')\, \boldsymbol{x}_{\mathrm{vg}} \cdot (\boldsymbol{p}_i - \boldsymbol{p}_j')\, \mathrm{e}^{\mathrm{i}(E_{\mathrm{vg}} + E_j' - E_i)t} |\mathrm{v}\rangle \langle \mathrm{g}| + \boldsymbol{d}_{\mathrm{vg}} \cdot \boldsymbol{\mathcal{E}}(\boldsymbol{k})\, \mathrm{e}^{\mathrm{i}(-E_{\mathrm{vg}} + \omega)t} |\mathrm{g}\rangle \langle \mathrm{v}| + \mathrm{h.c.}\,,$$

$$-H_{\mathrm{I}}^{\mathrm{M1}}(t, \boldsymbol{x_d}) = \frac{G_{\mathrm{F}} C_{ij}}{\sqrt{2}} \hat{\boldsymbol{j}}_{ij}(\boldsymbol{p}_i, \boldsymbol{p}_j') \cdot \boldsymbol{\sigma}_{\mathrm{vg}}\, \mathrm{e}^{\mathrm{i}(E_{\mathrm{vg}} + E_j' - E_i)t} |\mathrm{v}\rangle \langle \mathrm{g}| + \boldsymbol{d}_{\mathrm{vg}} \cdot \boldsymbol{\mathcal{B}}(\boldsymbol{k})\, \mathrm{e}^{\mathrm{i}(-E_{\mathrm{vg}} + \omega)t} |\mathrm{g}\rangle \langle \mathrm{v}| + \mathrm{h.c.}\,,$$

Our master Hamiltonian

Fluorescence of relic neutrinos

The key is to calculate the polarization *P*. Hamiltonian simply follows

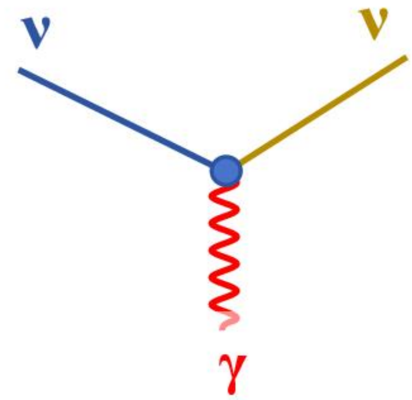
$$\mathcal{H}_{\mathrm{eff}} = -\boldsymbol{P}\cdot\boldsymbol{\mathcal{E}}$$

$$|\Psi(t)\rangle = C_{\mathrm{g}}(t)\,|\mathrm{g}\rangle + \sum_{\mathrm{v}} C_{\mathrm{v}}(t)\,|\mathrm{v}\rangle$$

$$C_{\mathrm{v}}^{(1)}(t) = \frac{G_{\mathrm{F}} C_{ij}}{\sqrt{2}\mathrm{i}} \frac{\hat{j}^{0}_{ij}\,\boldsymbol{x}_{\mathrm{vg}}\cdot(\boldsymbol{p}_i - \boldsymbol{p}'_j)}{E_{\mathrm{vg}} + E'_j - E_i} \mathrm{e}^{\mathrm{i}(E_{\mathrm{vg}}+E'_j-E_i)t}$$

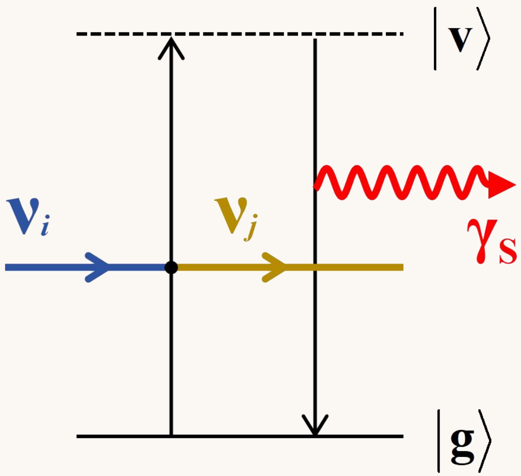
$$\mathcal{H}^{\mathrm{E1}}_{\nu\nu\gamma} = \frac{G_{\mathrm{F}} C_{ij}}{-\sqrt{2}\mathrm{i}} \frac{n_{\boldsymbol{d}}\,[\hat{j}^{0}_{ij}\,\boldsymbol{x}_{\mathrm{vg}}\cdot(\boldsymbol{p}_i - \boldsymbol{p}'_j)]\,[\boldsymbol{d}_{\mathrm{gv}}\cdot\boldsymbol{\mathcal{E}}(\boldsymbol{k})]}{E_{\mathrm{vg}} + E'_j - E_i} \times \mathrm{e}^{\mathrm{i}(\omega+E'_j-E_i)t} + \mathrm{h.c.}$$

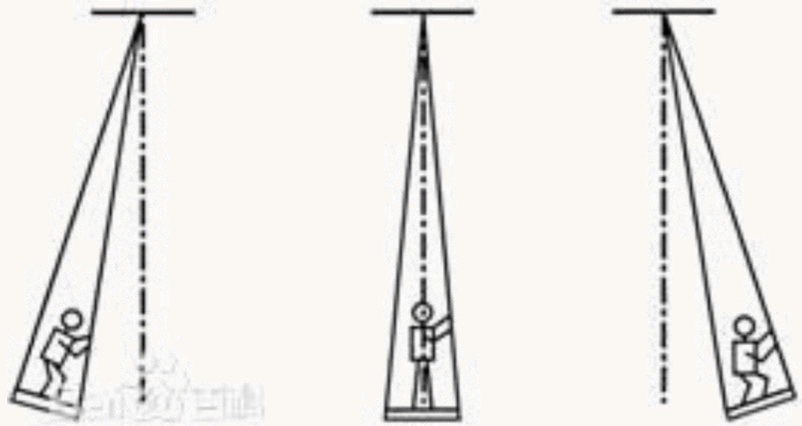
$$\mathcal{H}^{\mathrm{M1}}_{\nu\nu\gamma} = -\frac{G_{\mathrm{F}} C_{ij}}{\sqrt{2}} \frac{n_{\boldsymbol{d}}\,[\hat{\boldsymbol{j}}_{ij}\cdot\boldsymbol{\sigma}_{\mathrm{vg}}]\,[\boldsymbol{d}_{\mathrm{gv}}\cdot\boldsymbol{\mathcal{B}}(\boldsymbol{k})]}{E_{\mathrm{vg}} + E'_j - E_i} \times \mathrm{e}^{\mathrm{i}(\omega+E'_j-E_i)t} + \mathrm{h.c.}$$



- Effectively, we end up with a clean $\nu\nu\gamma$ coupling
- No new physics here. We do not require any BSM neutrino-photon couplings

Fluorescence of relic neutrinos





The E1 transition rate

$$\Gamma \approx \frac{G_F^2 |U_{ei}^* U_{ej}|^2}{2\pi e^2} \frac{f_\theta^{E1}\, n_{\boldsymbol{d}}^2\, |\boldsymbol{d}_{vg}|^4 D_k\, \omega |\boldsymbol{k}|^4}{\boxed{(E_{vg} + E_j' - E_i)^2 + \Gamma_v^2/4}}$$

Transition can be resonant when

$E_{vg} = E_i - E_j \sim 0.05$ eV

The M1 rate

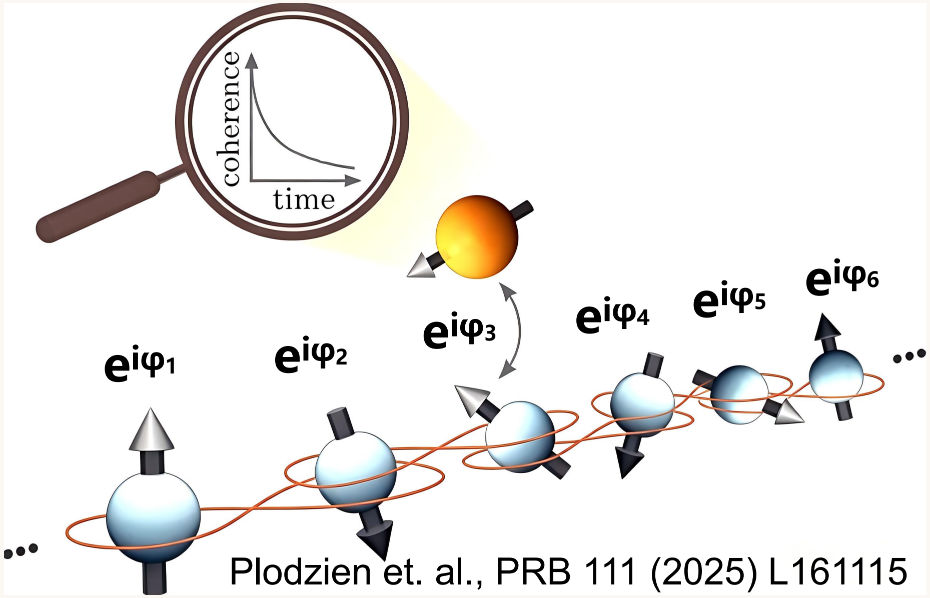
$$\Gamma \approx \frac{G_F^2 |U_{ei}^* U_{ej}|^2}{2\pi} \frac{f_\theta^{M1}\, n_{\boldsymbol{d}}^2\, |\boldsymbol{d}_{vg}|^2 D_k}{(E_{vg} + E_j' - E_i)^2 + \Gamma_v^2/4} \frac{|\boldsymbol{k}|^4}{\omega}$$

$\Gamma_v \sim 1 / T_c$

Resonance event rate

$$\Gamma \sim G_F^2 n_{\boldsymbol{d}}^2 |\boldsymbol{d}_{vg}|^2 |\boldsymbol{k}|^3 T_c^2 \qquad R_{\nu_3 \to \nu_1} \sim 1\ \mathrm{yr}^{-1} \quad (V = 5\ \mathrm{m}^3,\ T_c = 10\ \mathrm{ns})$$

Fluorescence of relic neutrinos



Decoherence time T_c accounts for all factors affecting the coherent accumulation of polarization

$$C_{\mathrm{v}}^{(1)}(t) = -\mathrm{i}\int_{-\infty}^{t} \mathrm{d}\tilde{t}\, \langle \mathrm{v}|\, H_{\boldsymbol{d}}(\tilde{t})\, |\mathrm{g}\rangle$$

$$C_{\mathrm{v}}^{(1)}(t) = \frac{G_{\mathrm{F}} C_{ij}}{\sqrt{2}} \frac{\hat{\boldsymbol{j}}_{ij} \cdot \boldsymbol{\sigma}_{\mathrm{vg}}}{\boxed{E_{\mathrm{vg}} + E'_j - E_i}} \mathrm{e}^{\mathrm{i}(E_{\mathrm{vg}} + E'_j - E_i)t}$$

$C_{\mathrm{v}} \propto t_{\mathrm{min}}$

Virtuality of $|\mathrm{v}\rangle$

$$T_c^{-1} = T_1^{-1} + T_\phi^{-1}$$

$T_1 \sim 1/(d_{\mathrm{vg}}^2 E_{\mathrm{vg}}^3)$ ~ **120 s**

T_ϕ Purely dephasing time

* Collisions
* Spin dephasing
* Phonons for solid

A coherence timescale of 10 μs is well achievable; Even 1 ms is possible in some ideal case

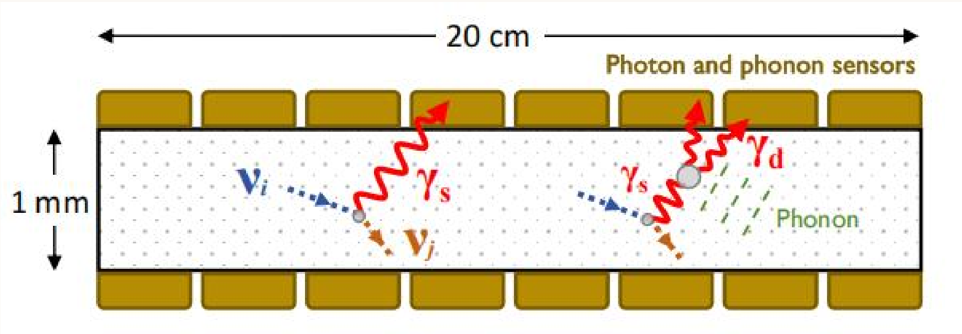
$$R_{\nu_3 \to \nu_1} \sim 1\ \mathrm{yr}^{-1} \quad (V = 5\ \mathrm{m}^3,\ T_c = 10\ \mathrm{ns})\,,$$

$$\boxed{R_{\nu_3 \to \nu_1} \sim 8\ \mathrm{yr}^{-1} \quad (V = 40\ \mathrm{cm}^3,\ T_c = 10\ \mu\mathrm{s})\,.}$$

10 ns linewidth is $6.6 * 10^{-7}$ eV

10 μs linewidth is $6.6 * 10^{-10}$ eV

Parametric Fluorescence

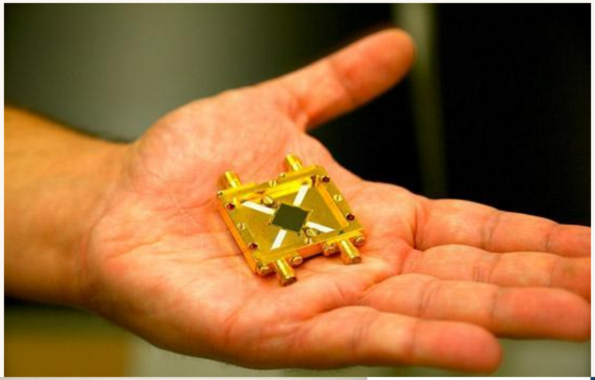


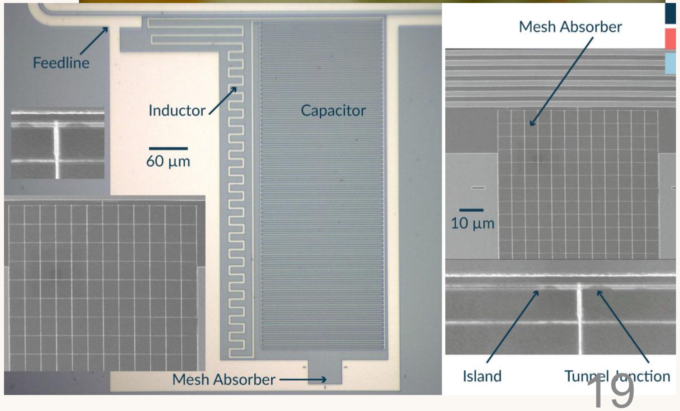
Cooper pair binding energy is 1 meV

- sc tunnel junction sensors
- kinetic inductance detectors
- quantum capacitance detectors

Possible backgrounds

- **Thermal (Blackbody) photons**. Strongly suppressed by operating at cryogenic temperatures (~1 K).
- **Cosmic Rays** (Muon Background). Underground placement ~99.9% veto efficiency makes this background manageable.
- **Radioactivity.** Shielding + vetoing, but remains a key challenge.
- **Afterglow (Luminescence).** Reduced via temporal and spatial cuts following energetic events.





Summary and prospects

🏷️ As the community becomes skeptical about the feasibility of PTOLEMY project, we revisit coherent detection of the cosmic neutrino background and explore ways around "no-go theorems."

💡 **Parametric fluorescence of the CvB may enable detection of relic neutrinos.** If achieved, it would reveal the universe about one second after the Big Bang. It would also determine neutrino properties, such as absolute mass and whether they are Dirac fermions or Majorana fermions.

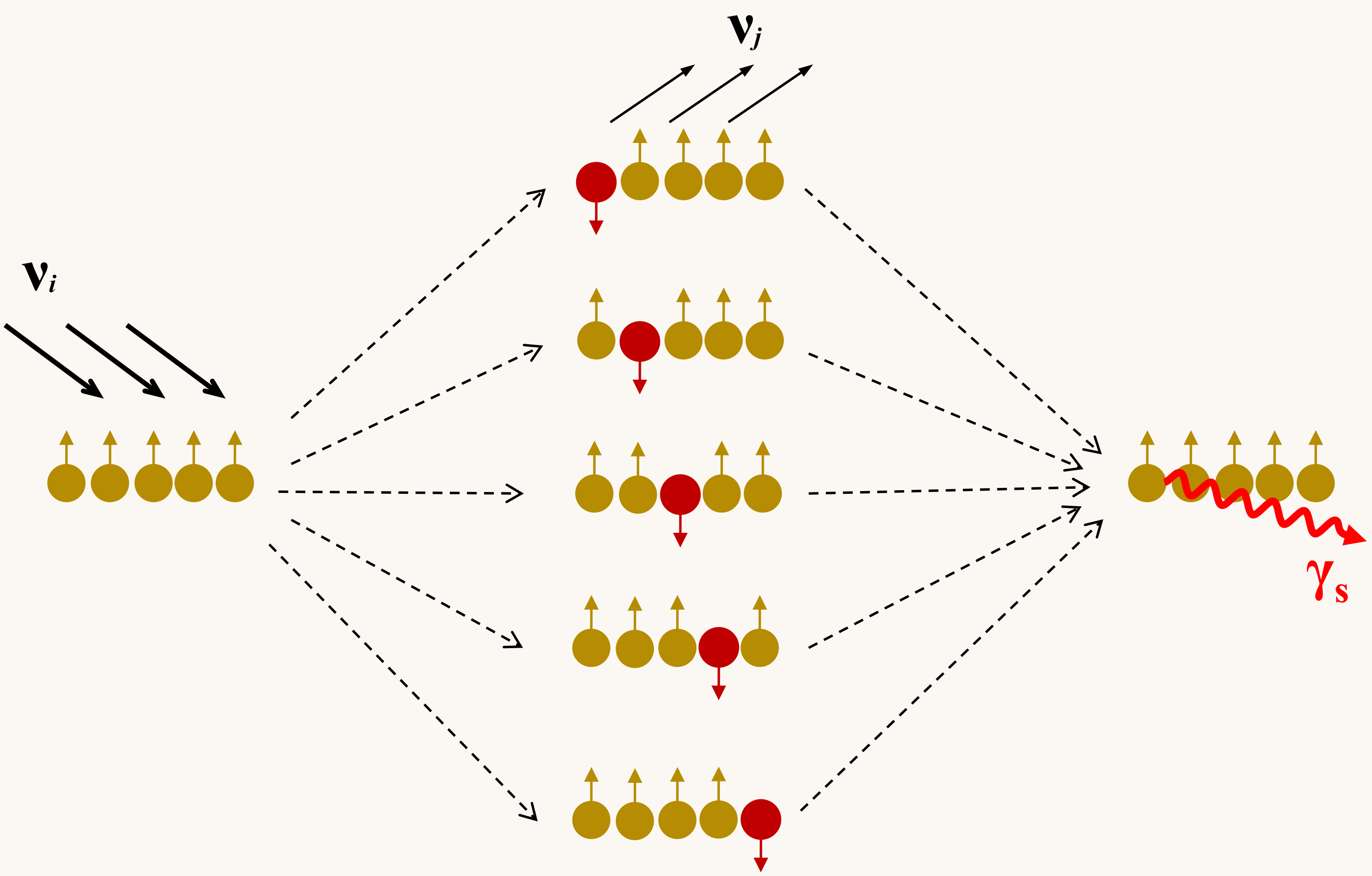
💡 **Future work requires close collaboration with experts in atomic, molecular, and optical physics, as well as solid state physics.**

Thanks for your attention!

谢谢！

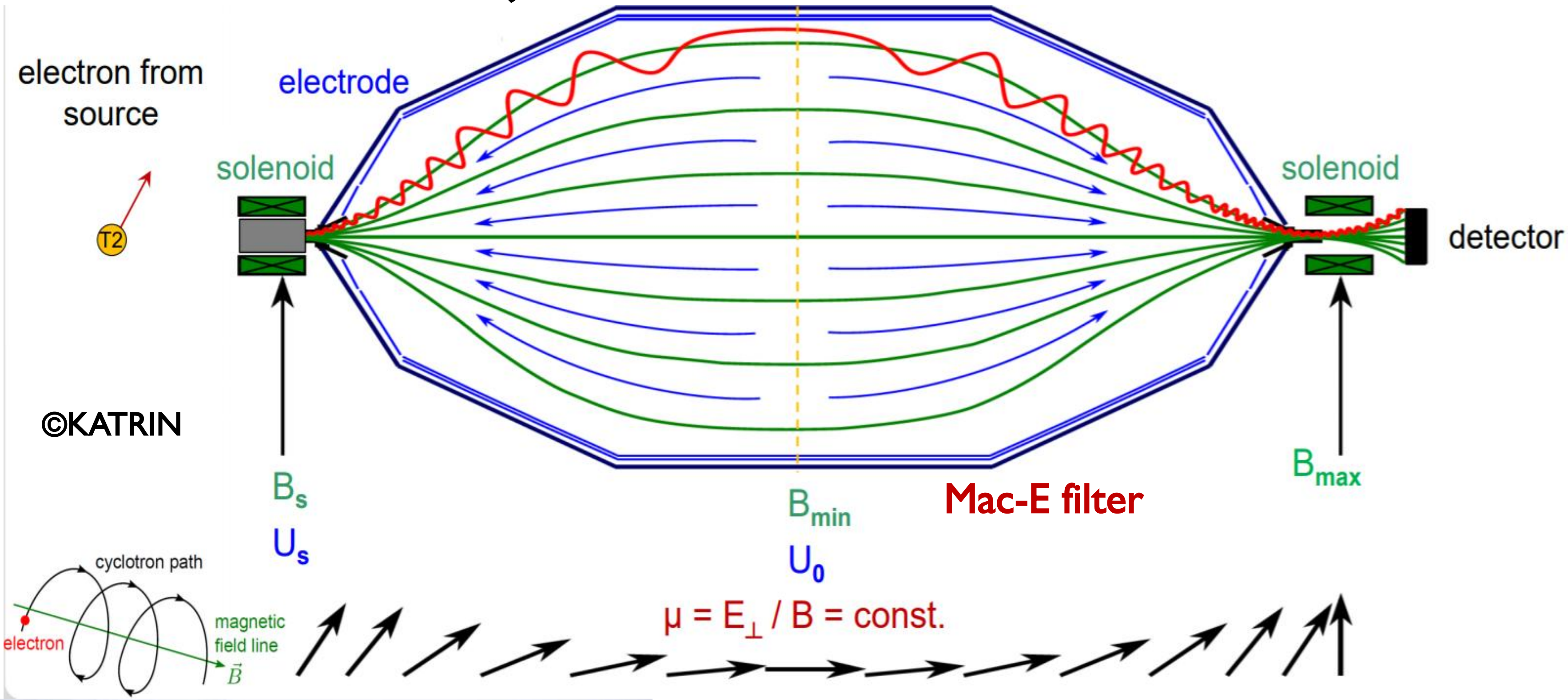
Backup slides

Fluorescence of relic neutrinos

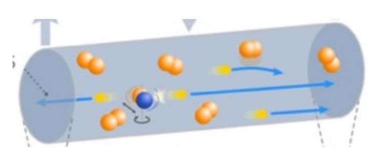


A spatial phase will be imprinted on the intermediate state

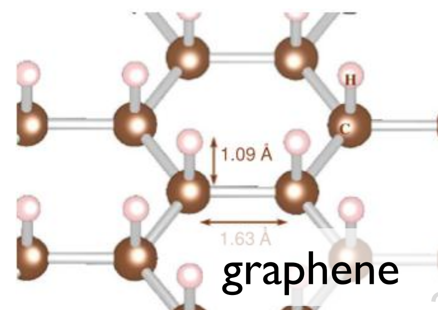
PTOLEMY Project



0.2 mg

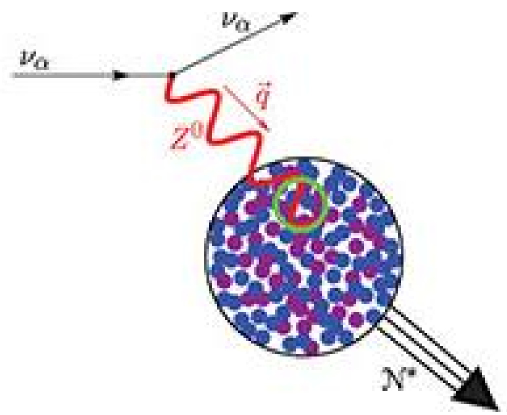


100 g



Coherent enhancement

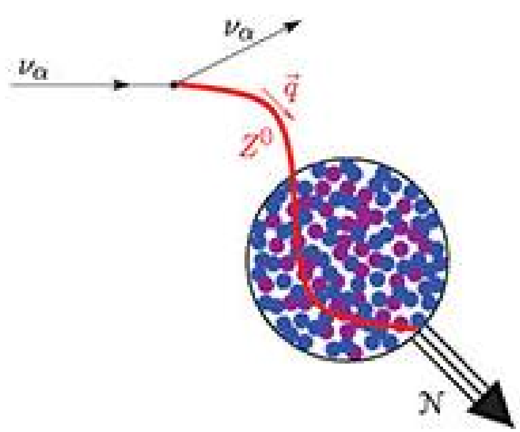
$$\Gamma \propto |\mathcal{M}_1|^2 + |\mathcal{M}_2|^2 + |\mathcal{M}_3|^2 + \cdots + |\mathcal{M}_N|^2 \propto N$$



$$\mathcal{M}_{tot} = \sum_a \mathcal{M}(x_a) \bullet e^{i\sum_l k_l \cdot x_a}$$

Quantum phases are averaged out for lengthes beyond the De Broglie wavelength

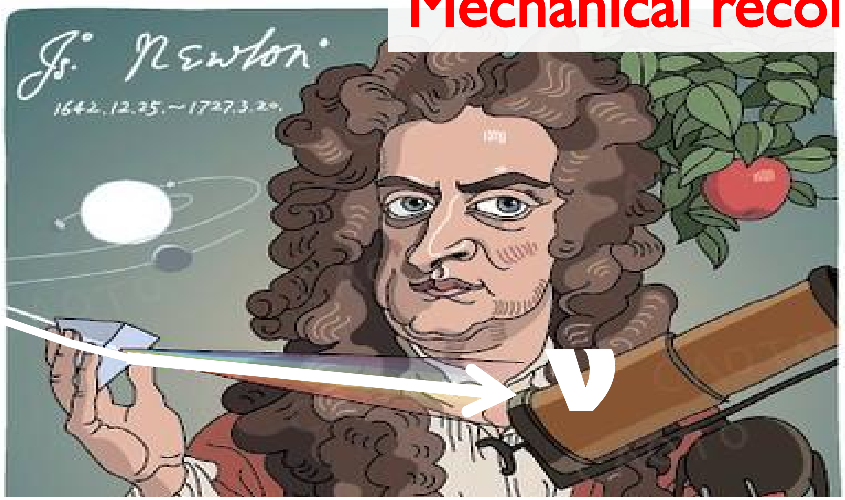
$$\Gamma \propto |\mathcal{M}_1 + \mathcal{M}_2 + \mathcal{M}_3 + \cdots + \mathcal{M}_N|^2 \propto N^2$$



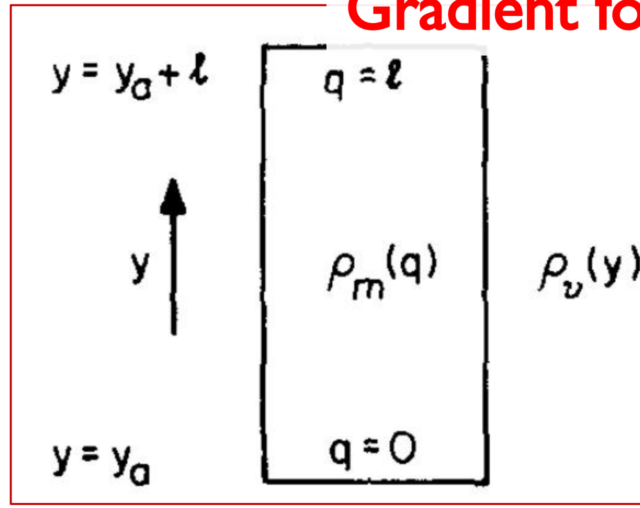
- The extreme case is just the coherent forward scattering.
- We are also clear here that coherence relies on momentum transfer (!= absolute momentum)

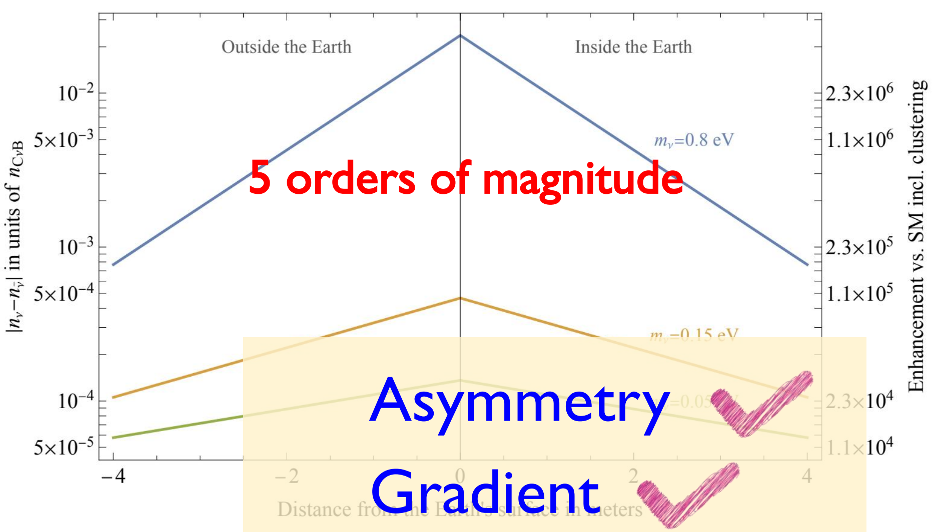
Coherent enhancement

Mechanical recoil

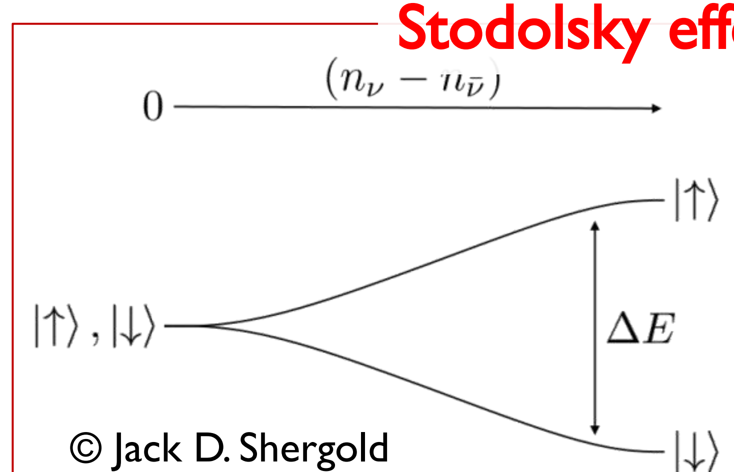


Gradient force



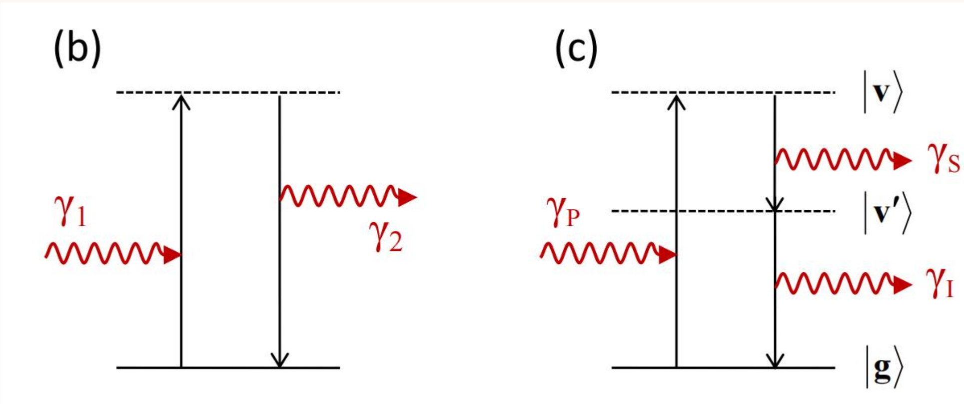


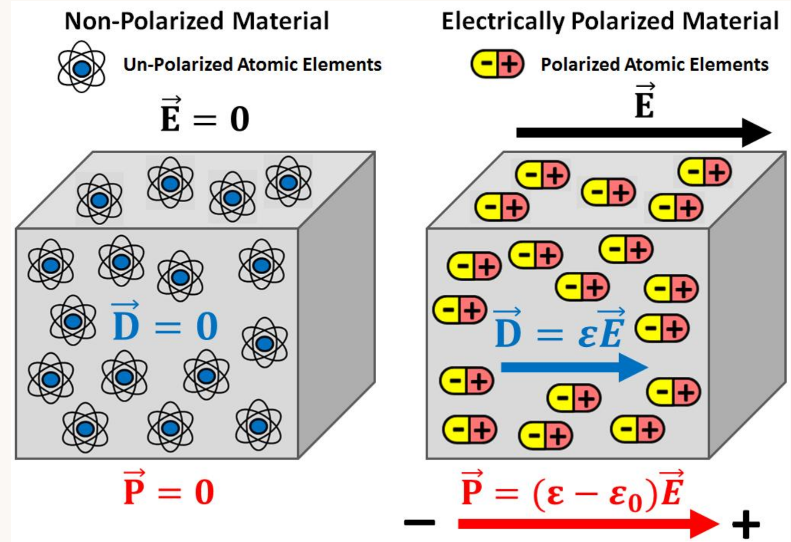
Stodolsky effect



an acceleration of order 10^{-30} cm/s^2

Nonlinear optics





A polarization modulated by external field (parametric oscillator)

$$P_i \supset \chi^{(1)}_{ij}\mathcal{E}_j + \chi^{(2)}_{ijk}\mathcal{E}_j\mathcal{E}_k + \chi^{(3)}_{ijkl}\mathcal{E}_j\mathcal{E}_k\mathcal{E}_l + \cdots$$

$$C^{(1)}_{\mathrm{v}}(t) = -\mathrm{i}\int_{-\infty}^{t} \mathrm{d}\tilde{t}\, \langle \mathrm{v}|\, H_{\boldsymbol{d}}(\tilde{t})\, |\mathrm{g}\rangle = \sum_i \frac{\boldsymbol{d}_{\mathrm{vg}} \cdot \boldsymbol{\mathcal{E}}(\omega_i)}{E_{\mathrm{vg}} - \omega_i} \mathrm{e}^{\mathrm{i}(E_{\mathrm{vg}} - \omega_i)t}$$

$$|\Psi(t)\rangle = C_{\mathrm{g}}(t)\,|\mathrm{g}\rangle + \sum_{\mathrm{v}} C_{\mathrm{v}}(t)\,|\mathrm{v}\rangle$$

$$\langle \boldsymbol{d}\rangle^{(1)} = \sum_{i,\,\mathrm{v}} \frac{\boldsymbol{d}^*_{\mathrm{vg}}\left[\boldsymbol{d}_{\mathrm{vg}} \cdot \boldsymbol{\mathcal{E}}(\omega_i)\right]}{E_{\mathrm{vg}} - \omega_i} \mathrm{e}^{-\mathrm{i}\omega_i t} + \mathrm{h.c.}$$

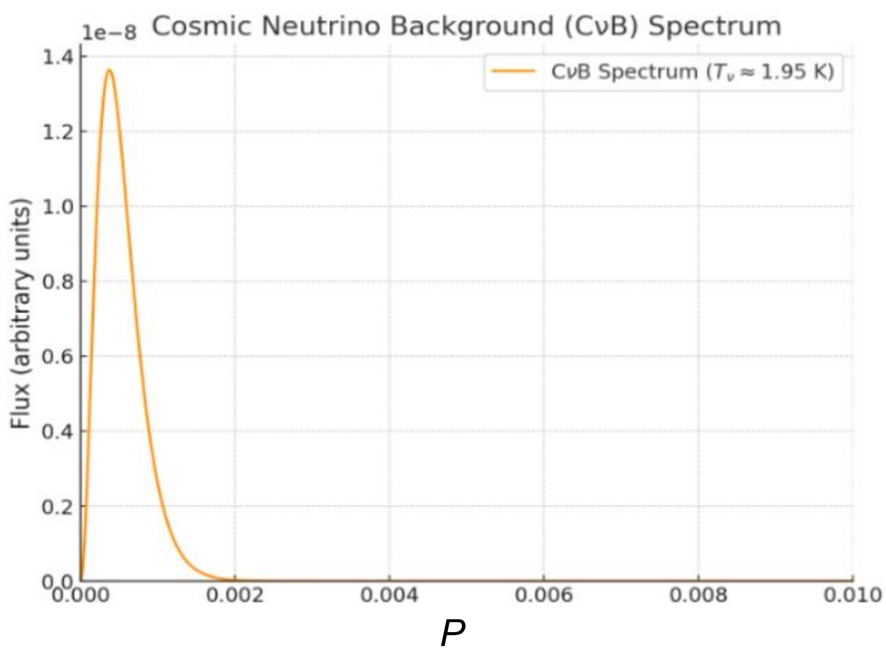
$$\boxed{\mathcal{H}^{(1)}_{2\gamma} = \sum_{i,\,j,\,\mathrm{v}} \frac{n_{\boldsymbol{d}}\left[\boldsymbol{d}^*_{\mathrm{vg}} \cdot \boldsymbol{\mathcal{E}}(\boldsymbol{k}_j)\right]\left[\boldsymbol{d}_{\mathrm{vg}} \cdot \boldsymbol{\mathcal{E}}(\boldsymbol{k}_i)\right]}{\omega_i - E_{\mathrm{vg}}} \mathrm{e}^{-\mathrm{i}(\omega_i + \omega_j)t} + \mathrm{h.c.}}$$

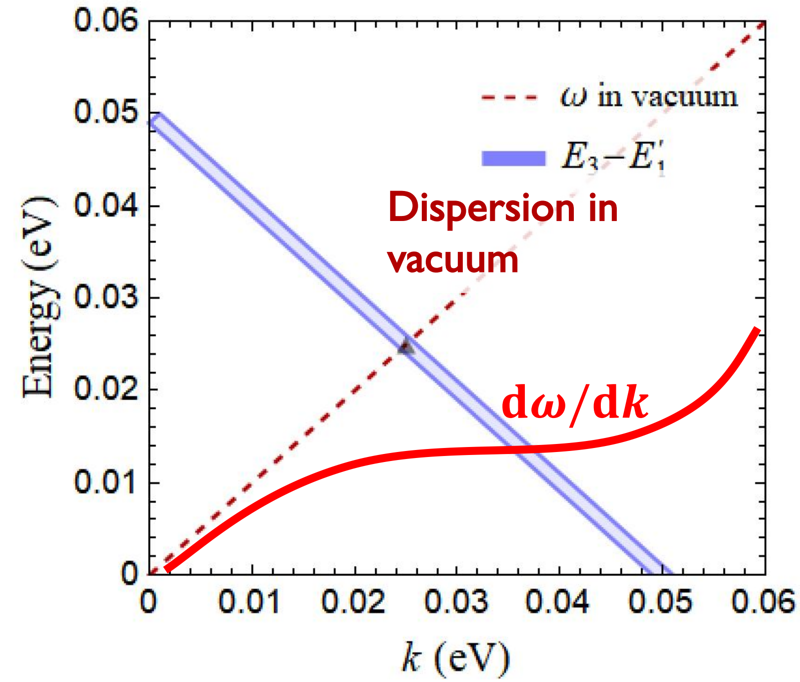
This is just the quantum origin of refractive index

$$\boxed{\boldsymbol{P}^{(2)} = n_{\boldsymbol{d}}\left(\sum_{\mathrm{v}} C^{(2)}_{\mathrm{v}}\, \langle \mathrm{g}|\, \boldsymbol{d}\, |\mathrm{v}\rangle + C^{(2)*}_{\mathrm{v}}\, \langle \mathrm{v}|\, \boldsymbol{d}\, |\mathrm{g}\rangle + \sum_{\mathrm{v},\,\mathrm{v}'} C^{(1)}_{\mathrm{v}} C^{(1)*}_{\mathrm{v}'}\, \langle \mathrm{v}'|\, \boldsymbol{d}\, |\mathrm{v}\rangle\right)}$$

This second order term just describes SPDC

Parametric Fluorescence





A momentum spread of order 10^{-3} - 10^{-4} eV

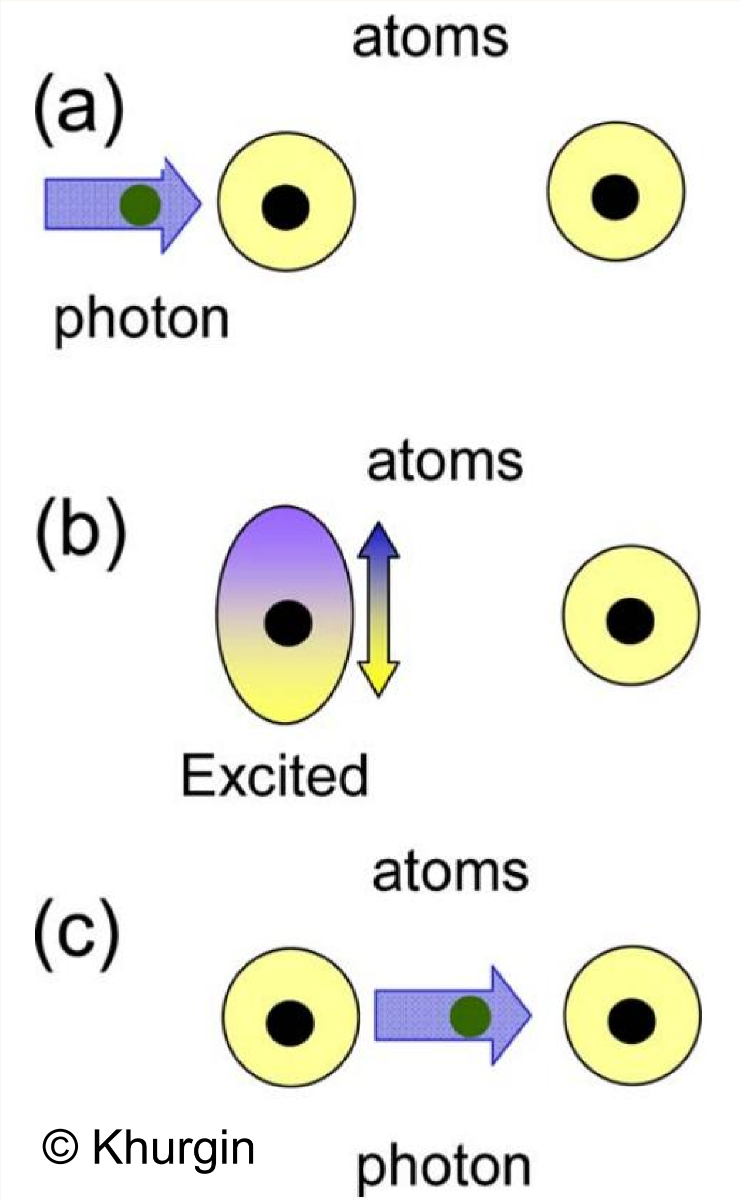
$$\Delta E_3 \approx \Delta p^2/(2m_3)$$

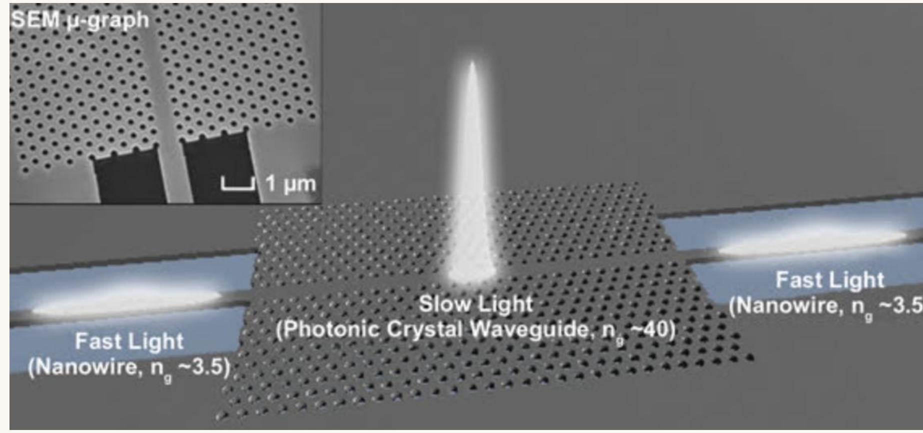
For m_ν = 0.05 eV, we have an **energy spread of < 10^{-6} eV**

- **In vacuum, the spread of $E_3 - E_1'$ is similar to momentum spread**
- **In medium, the spread is controlled by the dispersion curve**

To have 6.6 * 10^{-10} eV, we require $\frac{\mathbf{d}\omega}{\mathbf{d}k} \sim 10^{-6}$

Parametric Fluorescence



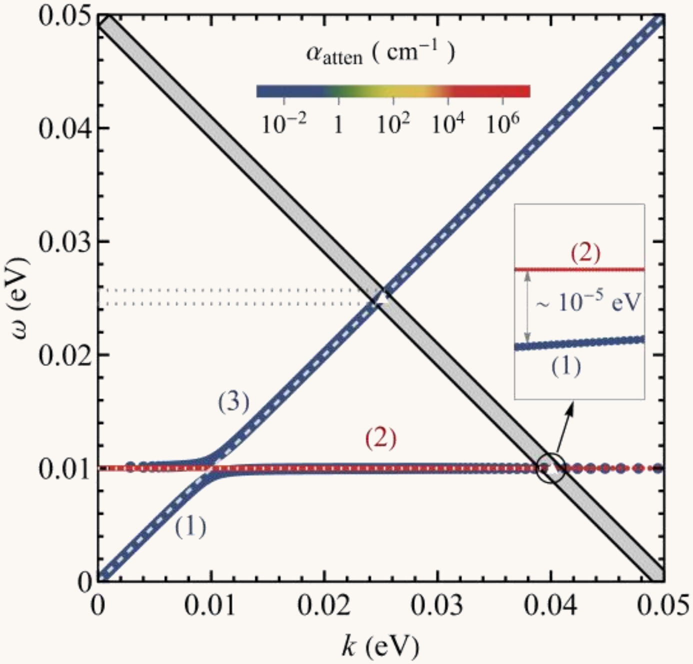


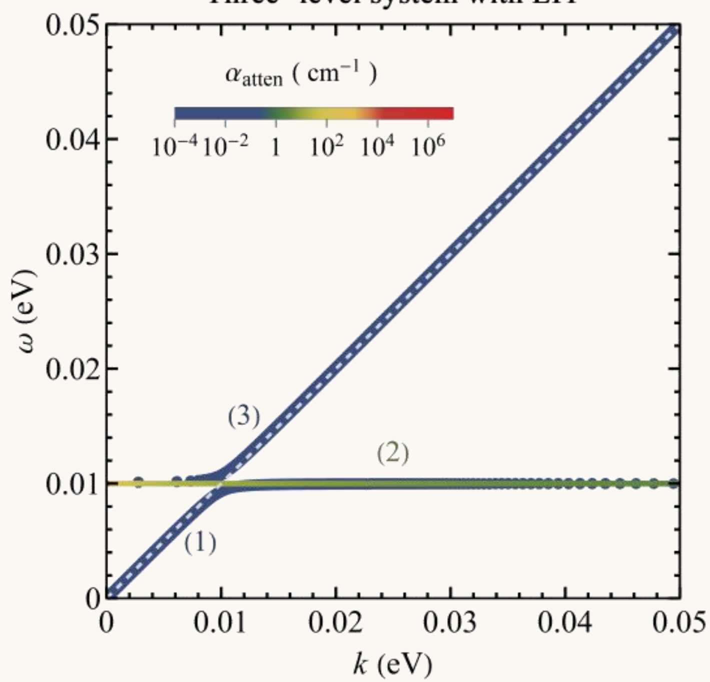
- Slight lights rely on the scattering of photons with the resonant structure of the medium.
- Intuitively, slow light arises from strong resonant absorption by some static excitations in the medium in a coherent manner.

a dressed "polariton"-like state

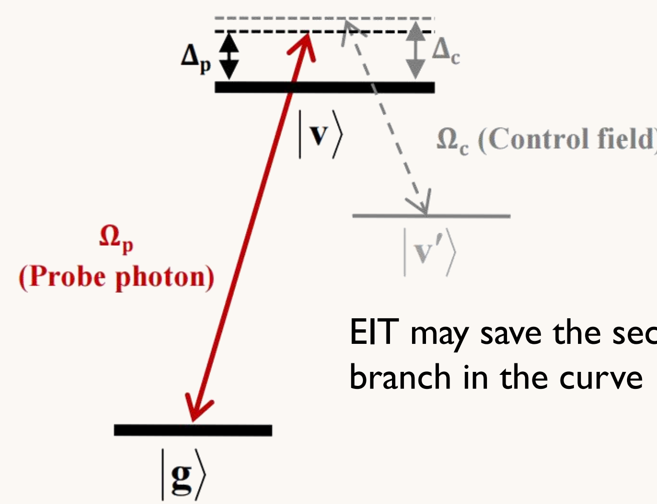
collective mixture of photon and excitation

Parametric Fluorescence





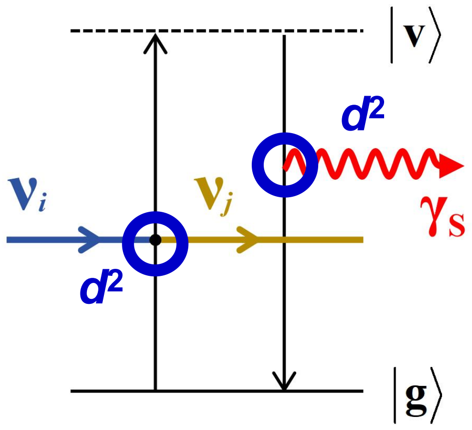
- Slow light naturally exists in the vicinity of the resonance.
- There are always resonance fluoresence mode in the phase space.



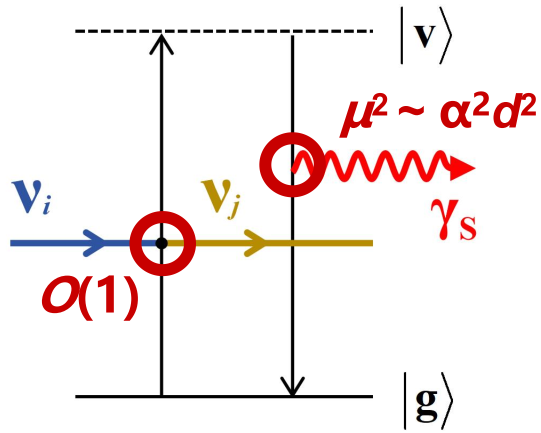
EIT may save the second branch in the curve

Further enhancement

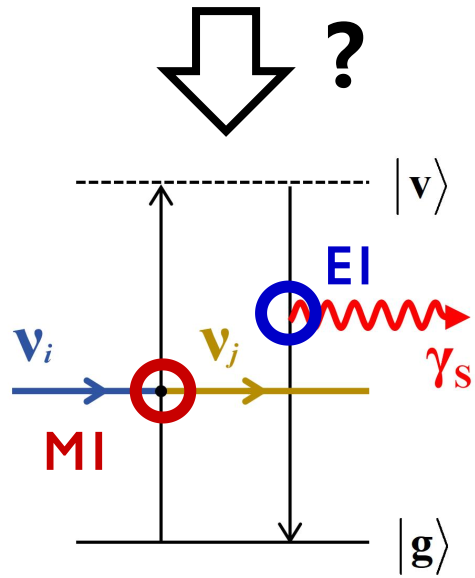
For E1 transition



For M1 transition

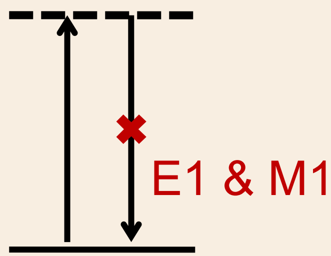


?



Further enhancement

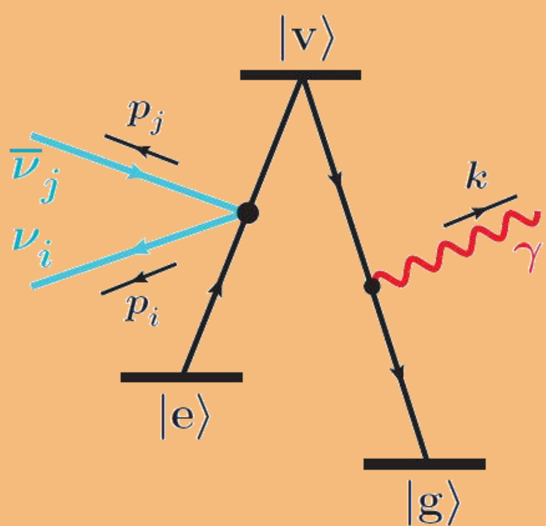
Parity mixing

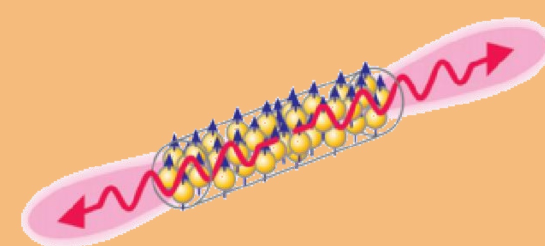


We know that this is not allowed from our atomic physics textbook: parity violation as well as selection rules

In modern AMO, we can use techniques such as the Stark effect to make it happen.

Superradiance





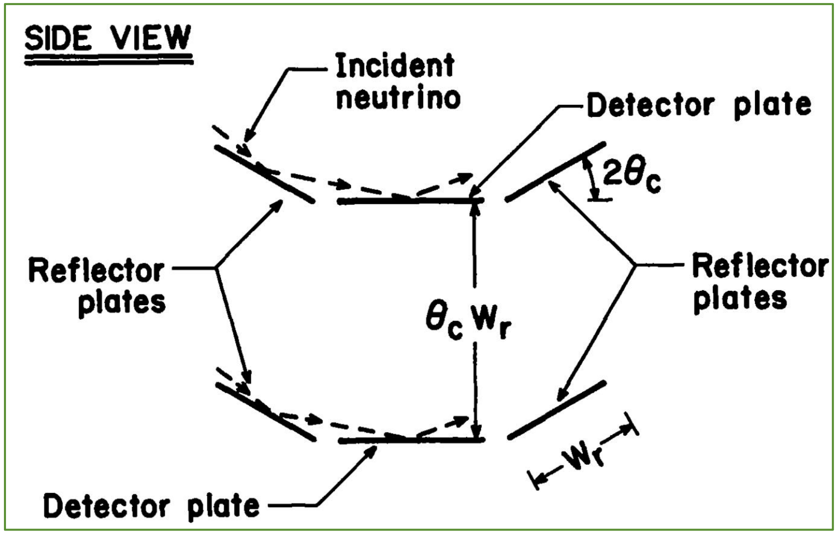
The time cycle for maintaining the coherence is of nano second scale, but we need year long collection time.

The system is not in ground state.
Overwhelming QED background.

Recoil Force

Opher's proposal: Total reflection

Opher, Astron. Astrophys. 37 (1974) , 135-137



Matter potential

$$U = \frac{G_F}{2\sqrt{2}} \rho_{\text{matter}} \times \begin{cases} (-)(3Z - A) & \text{for } \nu_e \ (\bar{\nu}_e) \\ (-)(Z - A) & \text{for } \nu_{\mu,\tau} \ (\bar{\nu}_{\mu,\tau}) \end{cases}$$

Refractive index

$$n_\nu - 1 \equiv \delta_\nu = -\langle \frac{m_\nu U}{k_\nu^2} \rangle \quad \sim 10^{-8}$$

Critical angle

$$\boldsymbol{\theta_C} = \sqrt{-2\delta_\nu} \ \propto \boldsymbol{G_F^{1/2}} \quad \sim 10^{-4}$$

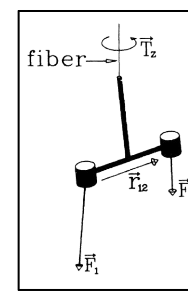
$\sim 0.01^\circ$

The recoil force here will be of order G_F

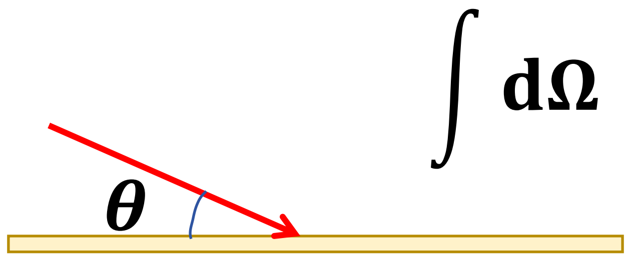
2. Lewis's idea of refraction

- Mechanical recoil
- Torque

Lewis, Phys. Rev. D 21 (1980) 663.



Recoil Force



N. Cabibbo and L. Maiani, Phys. Lett. B 114 (1982) 115–117

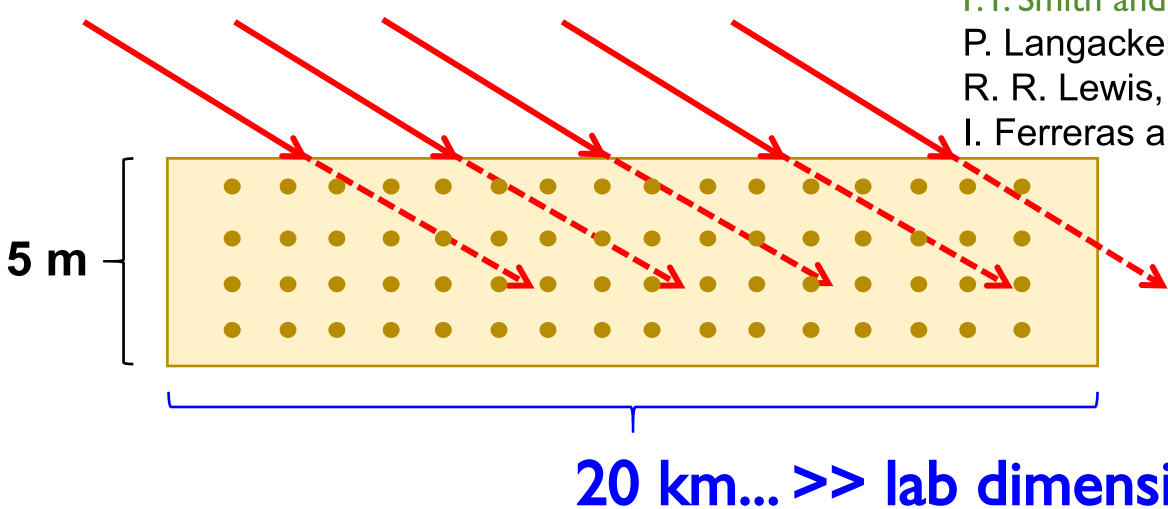
How many G_F's for the force?

- reflection recoil ($\theta_c \propto G_F^{1/2}$)
- isotropic flux (θ_c)
- inclined surface (θ_c)

By integrating over both sides, Cabibbo and Maiani find only G_F^2 force remains and claim G_F force holds only for collimated neutrino flux

However, this is not true even for collimated neutrinos...

P. F. Smith and J. D. Lewin, PLB 127 (1983) 185
P. Langacker et al., PRD 27 (1983) 1228.
R. R. Lewis, PRD 35 (1987) 2134.
I. Ferreras and I. Wasserman, PRD 52 (1995) 5459

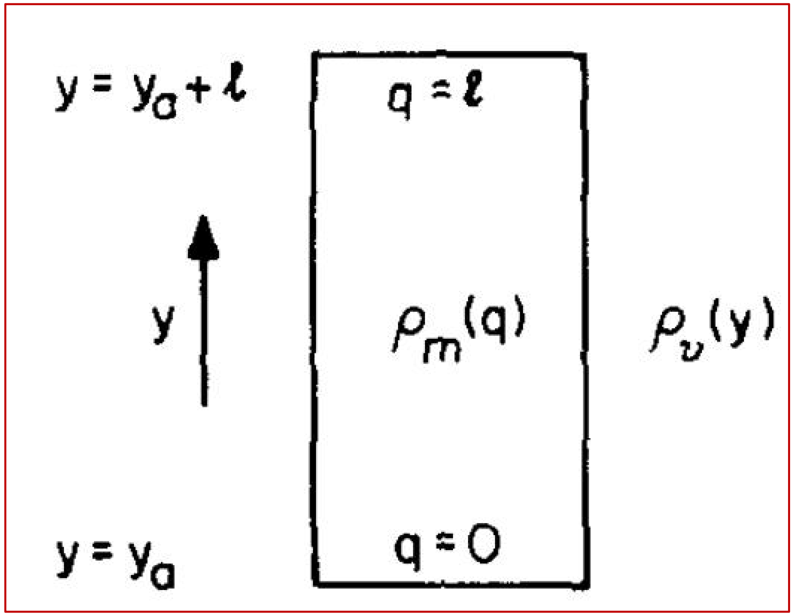


Total reflection is not a sudden reaction at the surface

Gradient effect

Matter potential, but role reversed

$$\mathcal{H}_{\text{eff}}(x) = \frac{G_{\text{F}}}{\sqrt{2}} \boxed{\overline{\nu}_e(x)\gamma^\mu(1-\gamma_5)\nu_e}(x)\boxed{\overline{e}(x)\gamma_\mu\left(g^e_{\text{V}} - g^e_{\text{A}}\gamma_5\right)e(x)}$$



$$U(\mathbf{x}_d, t) = \frac{G_F}{\mu}\int_{\mathcal{V}} d^3x\,\rho(\mathbf{x})[n_\nu(\mathbf{x}_d+\mathbf{x}, t) - n_{\bar{\nu}}(\mathbf{x}_d+\mathbf{x}, t)] \ ,$$

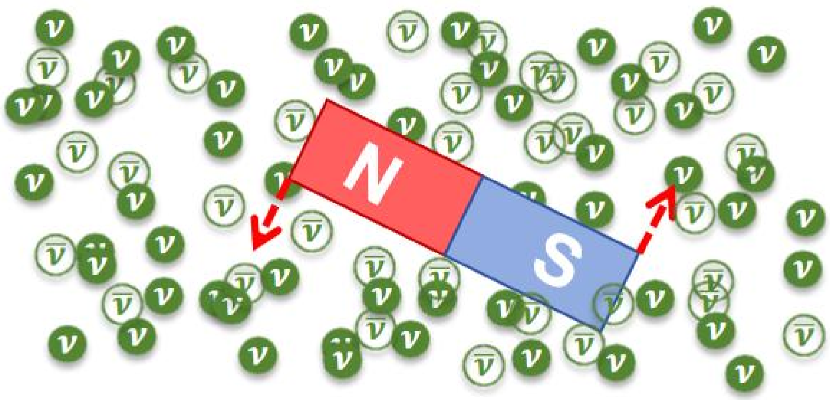
$$E = S\int_0^l U_1\,\rho_{\text{m}}(q)\,\rho_\nu(y_a+q)\,\mathrm{d}q$$

$$F_y = -\frac{V}{l}\int_0^l U_1\,\rho_{\text{m}}(q)\,\frac{\partial}{\partial y_a}\rho_\nu(y_a+q)\,\mathrm{d}q$$

"There is no known way to generate artificial density gradients large enough to result in easily measurable steady forces O(G_F)"

Ferreras & Wasserman, 1995

Stodolsky effect



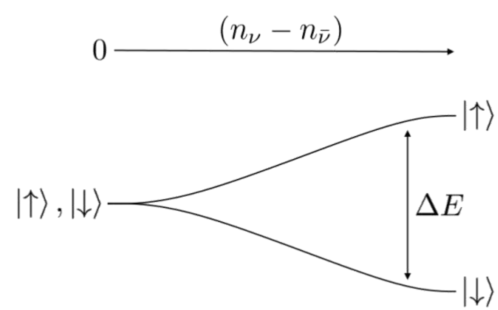
Stodolsky has discussed two effects in his original paper:

- Electron spin rotation in vacuum
- Torque of ferromagnet

Stodolsky, Phys. Rev. Lett. 34 (1975) 110

Energy spliting between two spin/helicity states (relativistic nu)

$$E \approx -2\sqrt{2} G_F g_A \vec{s}_e \bullet \vec{\beta}_{earth} (n_\nu - n_{\bar{\nu}})$$



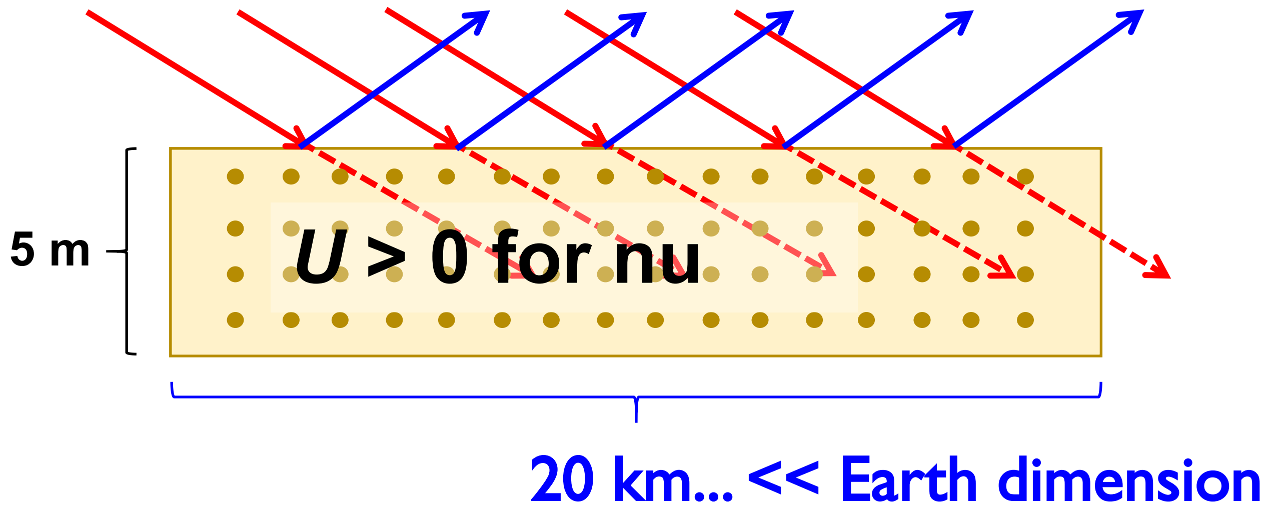
©Jack D. Shergold

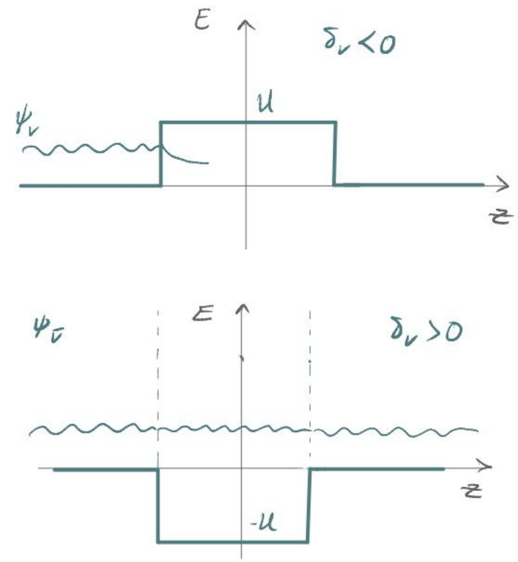
Torque acceleration for a magnet

$$a^R_{G_F} \approx 4 \cdot 10^{-29} \frac{n_{\bar{\nu}_\mu} - n_{\nu_\mu}}{2\,\bar{n}_\nu} \mathrm{cm/s}^2$$

Unfortunately, the suppresion of neutrino-antineutrino asymmetry will worsen the situation

Total reflection by the Earth

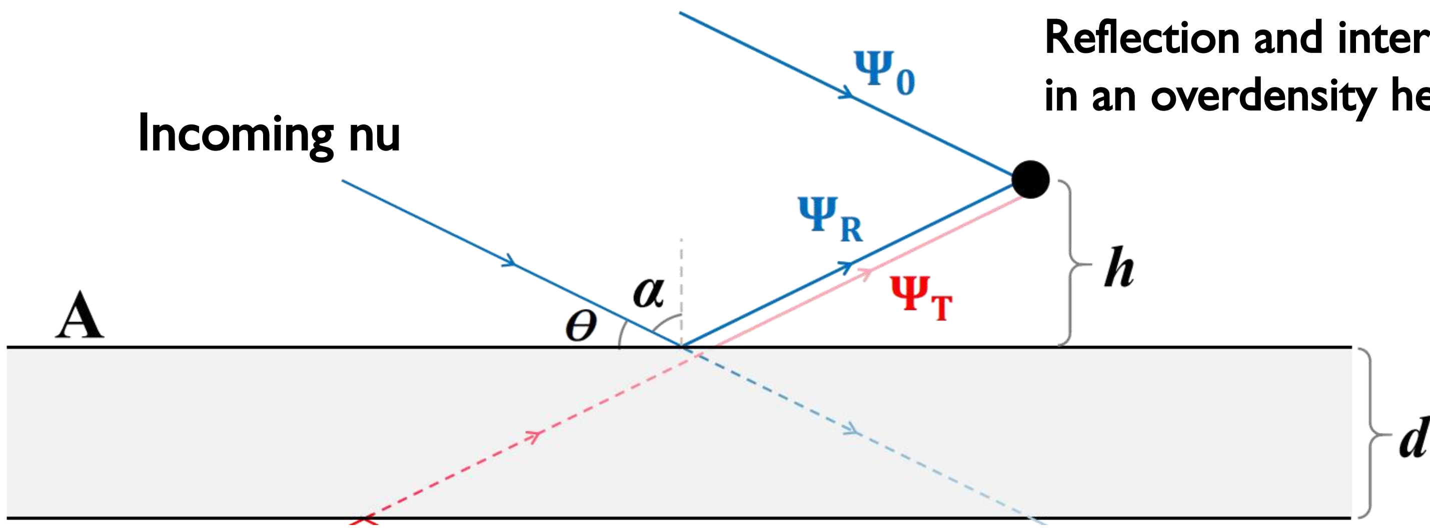




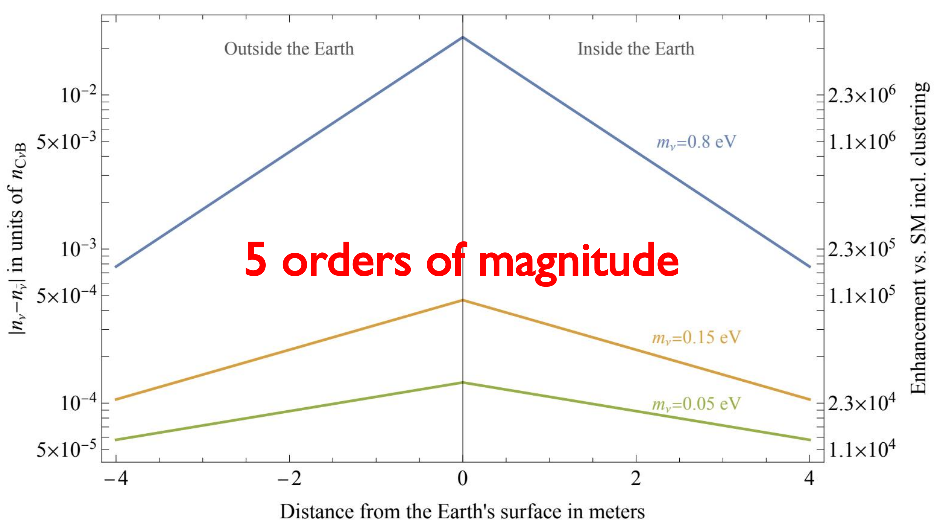
A. Arvanitaki and S. Dimopoulos, Phys. Rev. D 108 (2023) 043517

“total reflection of cosmic neutrinos from the surface of the Earth results in a local ν−νbar asymmetry”

Enhanced asymmetry and gradient



Reflection and interference results in an overdensity here



An asymmetry peaked at the surface and decreasing away the surface

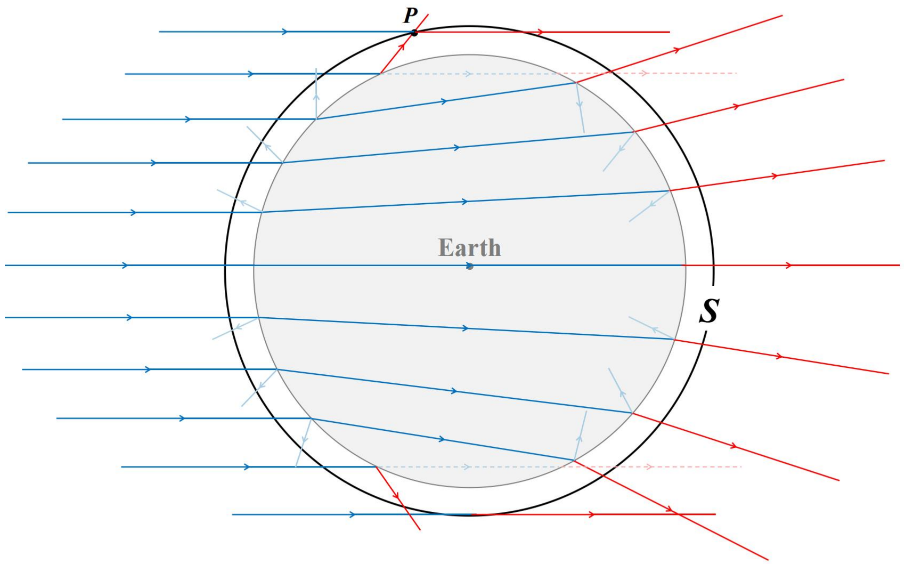
$$\frac{n_\nu - \bar{n}_\nu}{n_\nu}(z) = \frac{2}{15}\sqrt{2|\delta_\nu|}\left(3 + 5e^{-\frac{|z|}{\lambda_{\rm cr}}}\right)$$

Asymmetry ✓

Gradient ✓

an acceleration of order 10^{-30} cm/s^2

Semiclassical treatment



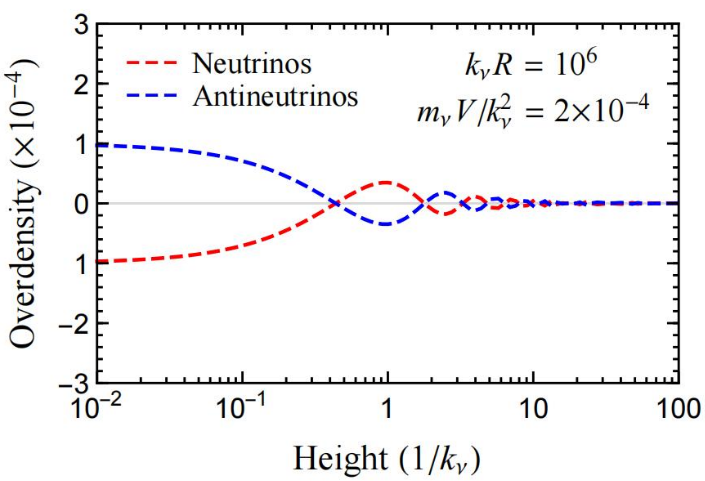
In the semiclassical limit (ignoring interference)

Three conservation laws

- Particle number
- Kinetical energy
- Angular momentum

$$n_\nu(r) = n_0$$

GYH, JHEP 11 (2024) 153



$$-\delta n_\nu \approx \delta n_{\overline{\nu}} \approx 1.25 \times 10^{-8}$$

$$\frac{\delta_\nu}{2}$$

However, even with order one asymmetry, the acceleration is unreachable

$$a^R_{G_F} \approx 4 \cdot 10^{-29} \frac{n_{\bar{\nu}_\mu} - n_{\nu_\mu}}{2\,\bar{n}_\nu} \,\mathrm{cm/s^2}$$