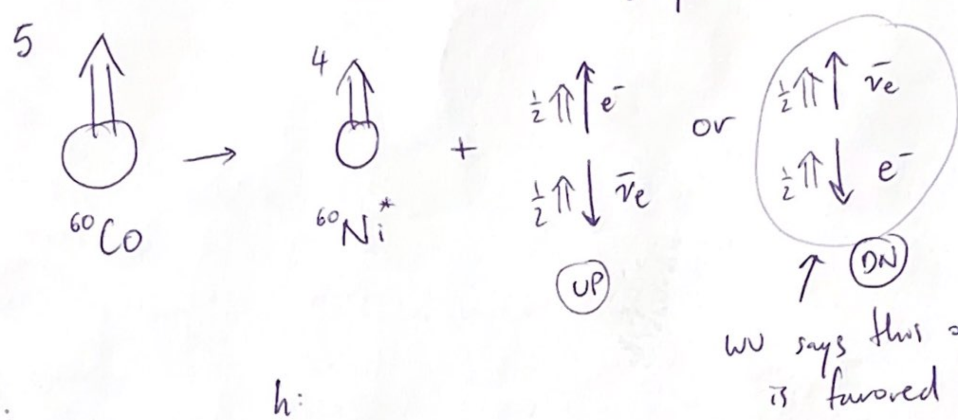
HELICITY OF THE NEUTRINO

WU → PARITY IS VIOLATED IN WEAK INT.

→ CROSS SECTIONS CAN DEPEND ON

$$\vec{\sigma}\cdot\vec{p}$$



in (UP):

		h:
e^-:	$\vec{\sigma}\ \Rightarrow$, $\vec{p}\ \longrightarrow$	$+1$
$\bar{\nu}_e$:	$\vec{\sigma}\ \Leftarrow$, $\vec{p}\ \longrightarrow$	-1

let's define helicity:

$$h = \frac{\vec{\sigma}\cdot\vec{p}}{|\vec{\sigma}\cdot\vec{p}|}$$

in (DN):

		h:
e^-:	$\vec{\sigma}\ \Leftarrow$, $\vec{p}\ \longrightarrow$	-1
$\bar{\nu}_e$:	$\vec{\sigma}\ \Rightarrow$, $\longrightarrow$	$+1$

IN GENERAL h is NOT an invariant → depends on frame

⟺ $\exists$ boost β, γ that flips $\vec{p}$ so

$$\overset{\vec{\sigma}\ \Rightarrow}{\underset{p}{\longrightarrow}}\ h=+1 \quad \xrightarrow{\text{boost}} \quad \overset{\vec{\sigma}\ \Rightarrow}{\underset{\vec{p}}{\longleftarrow}}\ h=-1$$

HOWEVER in SM $m_\nu = 0$ $\Rightarrow$ $v = c$

$\Rightarrow$ $\nexists$ boost that flips its $\vec{p}$

$\Rightarrow$ h of neutrinos is invariant

I.E. if a neutrino is produced with $h = -1$ it will have $h = -1$ forever

NOW, weak int. can distinguish between the two

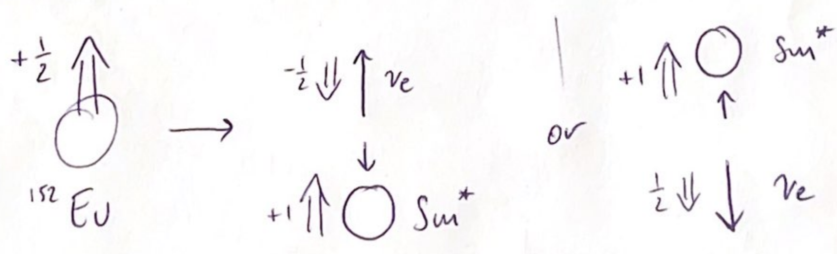
if parity is maximally violated the weak force will interact with only one $h = \pm 1$

$\Rightarrow$ <u>GOLDHABER EXPERIMENT</u> (1957)

To measure the helicity of the neutrino

electron capture

Based on $^{152}Eu \ (+e^-) \longrightarrow \nu_e + {}^{152}Sm^*$



Here: $h(\nu) = -1$ | $h(\nu) = +1$

$h(Sm^*) = -1$ | $h(Sm^*) = +1$

$h(\nu) = h(Sm^*)$!

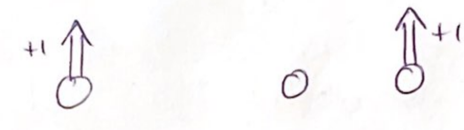
Then: EM decay of Sm^*

$$\tau(Sm^*) \sim 10^{-14}\,s$$

$$^{152}Sm^* \rightarrow {}^{152}Sm + \gamma$$

SPIN: $+1$ $\quad 0 \quad +1$

$\Rightarrow$ eg.



So if γ emitted in direction of flight

$$h=+1 \qquad \xrightarrow[Sm^*]{\Rightarrow} \qquad \underset{Sm}{\bullet} \qquad \xrightarrow[\gamma]{\Rightarrow} \qquad h(\gamma) = h(Sm^*) \ (= h(\nu))$$

$$h=-1 \qquad \xrightarrow[Sm^*]{\Leftarrow} \qquad \underset{Sm}{\bullet} \qquad \xrightarrow[\gamma]{\Leftarrow} \qquad h(\gamma) = h(Sm^*)$$

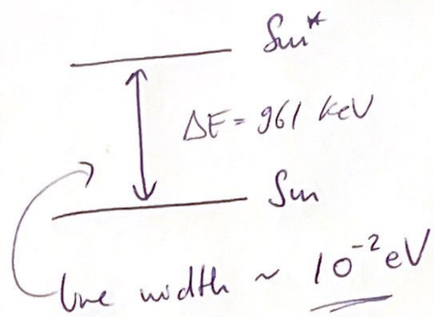
TRANSFERRING THE HELICITY

from ν to Sm^* to γ

NOW

$Sm^* \rightarrow \gamma + Sm$

$E(\gamma) = 961$ keV



if this photon encounters another Sm it will not be reabsorbed by

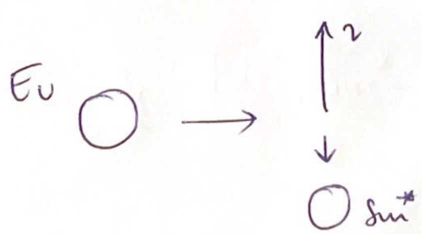
$\gamma + Sm \rightarrow Sm^*$

why? Because part of the energy (~ 3.2 eV) is lost to give it to the recoiling Sm

LAB FRAME

$\Rightarrow$ in LAB frame $E(\gamma) < 961$ keV $= \Delta E(Sm^*, Sm)$

HOWEVER



← Sm* produced with boost in −z direction

<u>LAB</u> ↓ ○ Sm^*

<u>CdM</u> • Sm^* ↓ γ

so if γ emitted in $-z$ (in CdM)

⇒ it will get a boost in $-z$

⇒ E increases thanks to boost

⇒ goes back to resonant 961 keV

THIS ONLY HAPPENS WHEN γ emitted in direction of flight of Sm^*

RECAP: Selecting γ that decay in direction of Sm^*

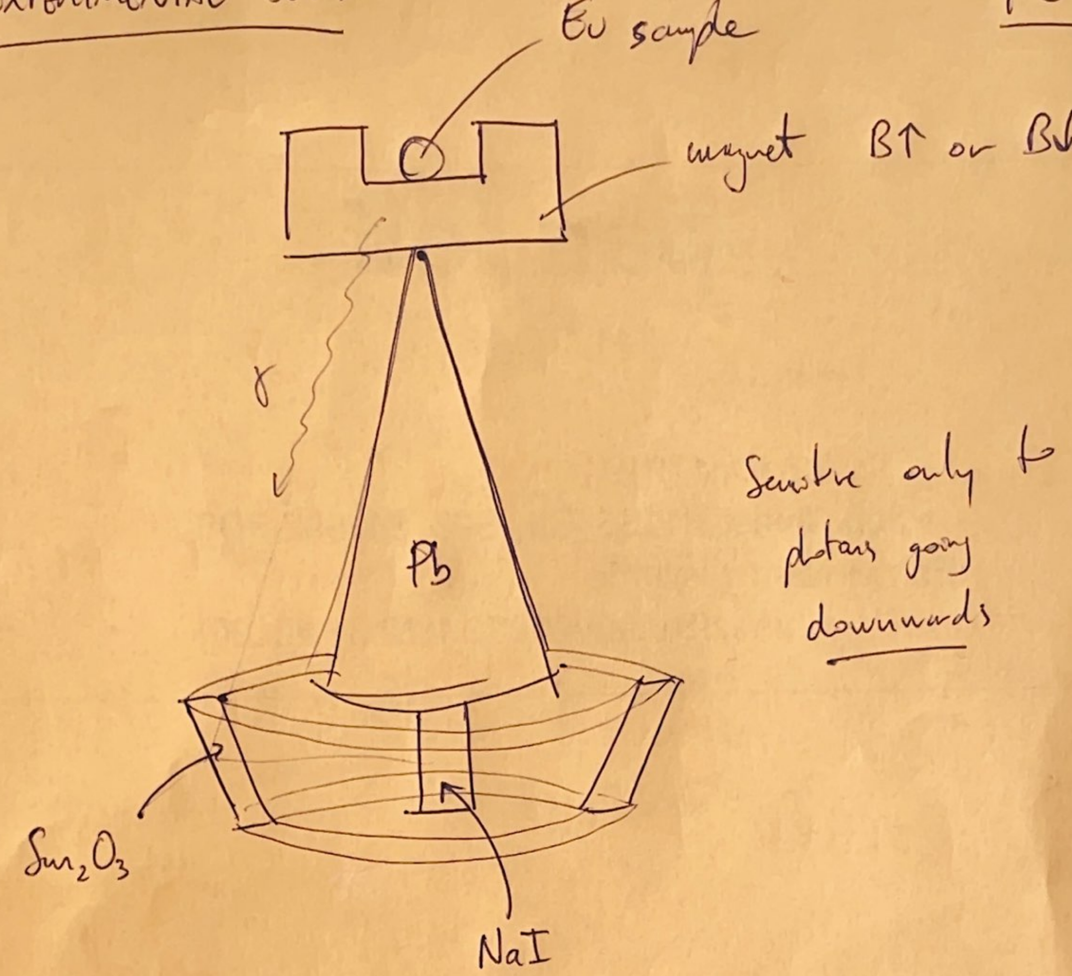
⇒ (1) they have same h as neutrino

(2) they have $E = \Delta E(Sm^*, Sm)$

↑ resonance

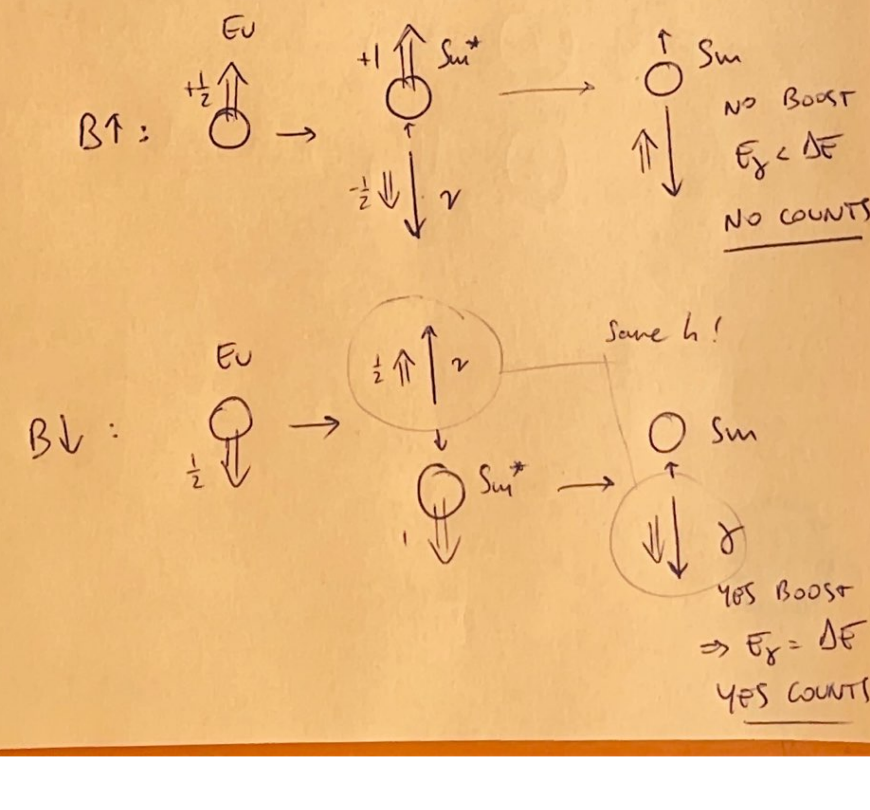
⇒ can be reabsorbed by Sm

EXPERIMENTAL SETUP



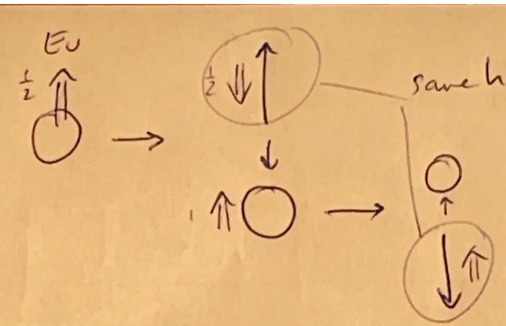
CASES

if $h(\nu) = +1$



if $h(\nu) = -1$

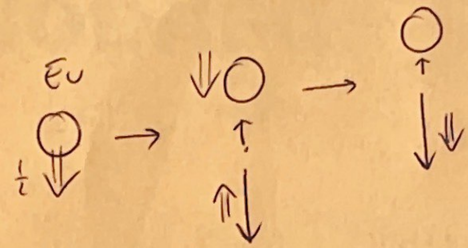
$B\uparrow$:



YES BOOST $\Rightarrow E = \Delta E$

<u>YES COUNTS</u>

$B\downarrow$:



NO BOOST

<u>NO COUNTS</u>

so

	$h_\nu = +1$	$h_\nu = -1$
$B\uparrow$	NO COUNTS	YES COUNTS
$B\downarrow$	YES COUNTS	NO COUNTS

DATA compatible with ONLY $h_\nu = -1$

$\Rightarrow$ ~~NEUTRINOS only exist with $h = -1$~~

~~ANTINEUTRINOS only exist with $h = +1$~~

$\Rightarrow$ WEAK INTERACTIONS only see NEUTRINOS with $h = -1$ (and antineutrinos with $h = +1$)

what about neutrinos with $h=+1$?

$q=0 \Rightarrow$ no EM interaction

color $=0 \rightarrow$ no strong

$m=0 \Rightarrow$ no gravity (and no Higgs)

$h=+1 \Rightarrow$ no weak

$\Rightarrow$ neutrinos with $h=+1$ DO NOT EXIST

(may have been produced at big bang
but then unable to interact with anything else)

BUT AS SAID HELICITY IS NOT AN INVARIANT

so if WEAK really "saw" only $h=-1$ would mean that WEAK int. are not invariant

$\rightarrow$ not a good physical theory

WHAT MATTERS IS CHIRALITY

P_R $\qquad$ P_L projection operators

$$\psi(x) = \frac{1}{2}(1+\gamma^5)\psi + \frac{1}{2}(1-\gamma^5)\psi$$

$$\equiv \underset{\text{"RIGHT"}}{\psi_R(x)} + \underset{\text{"LEFT"}}{\psi_L(x)}$$

INVARIANT

$\rightarrow$ WEAK INTERACTIONS ONLY COUPLE TO LEFT FIELDS

FOR MASSLESS PARTICLES

HELICITY = CHIRALITY

$\Rightarrow \quad h=-1 \Leftrightarrow$ LEFT

$h=+1 \Leftrightarrow$ RIGHT

FOR MASSIVE PARTICLES HELICITY $\neq$ CHIRALITY

depends on frame

on β of particle in given frame

~~[illegible]~~ let's take an electron with β

if $h(e)=-1$ helicity $=1$

$\Rightarrow$ this state has both e_L and e_R components

$\Rightarrow \quad h=-1 \neq e_L$

there is $e_R \neq 0$ but suppressed by $(1-\beta)$

this is why $\pi^{\pm} \to \mu^{\mp} \nu_\mu$

$\pi^- \to \mu^- \bar{\nu}_\mu$

$\pi^- \to e^- \bar{\nu}_e$

$m(\pi^-) \sim 140$ MeV

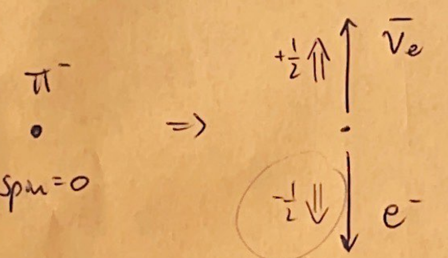
$m(\mu^-) \sim 106$ MeV

$m(e^-) \sim 0.5$ MeV

$\Rightarrow$ $\pi^- \to e^- \bar{\nu}_e$ is favored by phase space

BUT IN π^- rest frame

massless $\Rightarrow$ can only $\exists$ with $h = +1$



$\Rightarrow$ to conserve spin $\Rightarrow$ $h(e^-) = +1$

~~this is suppressed by (1-β)~~

only the LEFT part of this is involved in WEAK int for particles:

$h = -1$

$\Leftarrow$

$\longrightarrow$ has $\psi_L \sim \frac{1}{2}(1+\beta)$

$\psi_R \sim \frac{1}{2}(1-\beta)$

$h = +1$

$\Rightarrow$

$\longrightarrow$ has $\psi_L \sim \frac{1}{2}(1-\beta)$

$\psi_R \sim \frac{1}{2}(1+\beta)$

(OPPOSITE FOR ANTIPARTICLES)

in $\pi^- \to e^- \bar{\nu}_e$

$$\beta_e = 0.99997 \quad (ex)$$

$\Rightarrow$ heavily suppressed

for $\pi^- \to \mu^- \bar{\nu}_\mu$

$$\beta_\mu = 0.27$$

THIS IS WHY $R_\pi \equiv \dfrac{\pi \to e\nu}{\pi \to \mu\nu} \sim 10^{-4}$