Breaking questions

- Given the intrinsic parity of particles and that the parity of the orbital wavefunction is given by $(-1)^l$, where 'l' is the orbital angular momentum, are these decays allowed or forbidden

    - $\rho^0(1^-) \rightarrow \pi^+(0^-) + \pi^-(0^-)$

    - $\eta(0^-) \rightarrow \pi^+(0^-) + \pi^-(0^-)$

- The values in brackets are J^P

Wu-Experiment

1956: Lee and Yang:

No evidence for parity conservation
in weak IA, thus proposed set of measurements
on of them was the Wu-Experiment

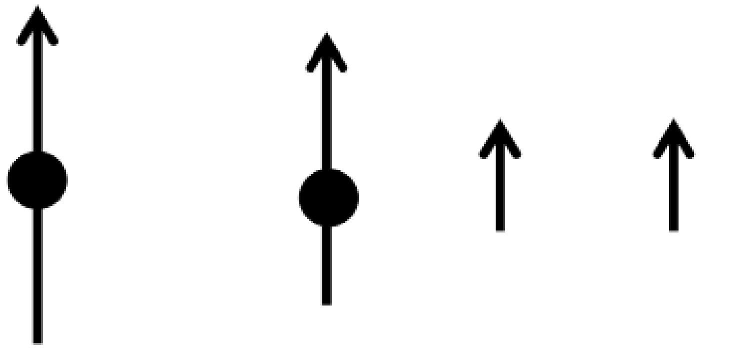
Wu-Experiment:

(performed by M^me Wu and collaborators)

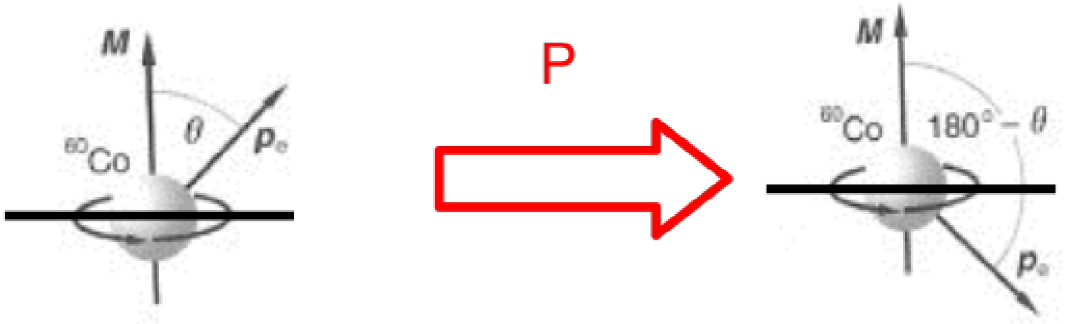
Partiy conservation: physics stays invariant under parity conservation

Idea: Check that number of electrons emitted in direction of spin ($\vec{J}$) of ^{60}Co and in opposite direction (-$\vec{J}$) are the same.

$$^{60}Co \rightarrow ^{60} Ni^* + e^- + \overline{\nu_e}$$



J=5 J=4



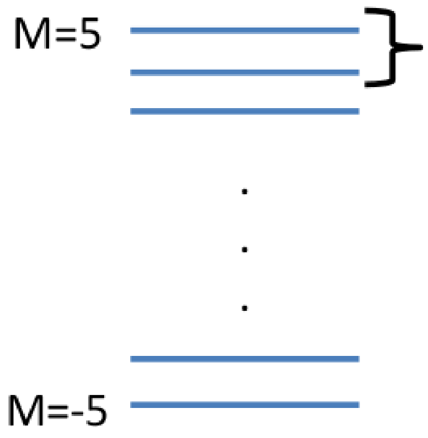
Experiment: Invert polarization of ^{60}Co and compare electron rate in same angle Θ

$$Ni^* \rightarrow Ni + \gamma$$

photons are preferentially emitted in direction of spin. Use photon distribution to test polarization of ^{60}Co. (elm IA conserves parity)

MAIN CHALLENGE: Polarization of ^{60}C0

Spin of ^{60}Co: J=5 → M = -5,-4, …., 4, 5



$\Delta E = g\ \mu_K\ B$

$\mu_K \sim 5.05 \times 10^{-27}$ J/T

Population of energy levels follows Boltzmann distribution:

$$e^{-\frac{E}{k_B T}}$$

for $\Delta E >> k_B T$ only lowest energy level is populated, however for given B field in experiment (2.3 T) very low temperatures needed

g factor depends on gitter structure

Example: g= 7.5 (^{60}Co), B = 2.3 T, T = 0.003 K

$$\frac{P(m=-4)}{P(m=-5)} = e^{-\frac{\Delta E}{k_B T}} = 0.074$$ → 92% polarized ^{60}Co

Solution Part-I: embedding ^{60}C0 in a paramagnetic material (B ~ μ_r ; μ_r ~ 3-4)
still temepratures of T=0.01K needed

Adiabatic Colling

1926 von Debye proposed method to create low temperature

Fundamental relation of thermodynamics: $dU = T\,dS - p\,dV$

1. Step: isotherm magnetisation
   - paramagnetic material in helium gas is put into magnetic field
   - energy levels are split up, only lower once are populated
   - entropy gets smaller: $dS < 0 \rightarrow dU < 0$, helium gas absorbes heat

2. Step: helium gas removed → thermal isolation of nitrit

3. Step: adiabatic cooling
   - magnetic field is slowly switched off
   - split off of energy levels get smaller
   - system likes to polpulate higher states, however $dU = const$ due to isolation
   - dS gets larger thus T gets smaller

Caveat: need magnetic field to get polarized ^{60}Co

How to combine Cooling and Polarization?

Two competing effects needed in the nitrit-crystal to get high degree of ploarization

1) Need high B field and low temperature to get polarization
2) Switch off B field to lower temperature via adiabatical cooling
   B field on → warm up, B field off → cool down

How does this work?

Solution: Some paramagnetic material have large anisotropic distribution of g-factors
(artefact of crystal structure, different binding mechanisms)

B field for adiabatic cooling in direction with high g-factor
Thus large split up of energy levels, thus large cooling effect

B field for polarization in direction of low g-factor, thus only little warm up

Wu-Experiment

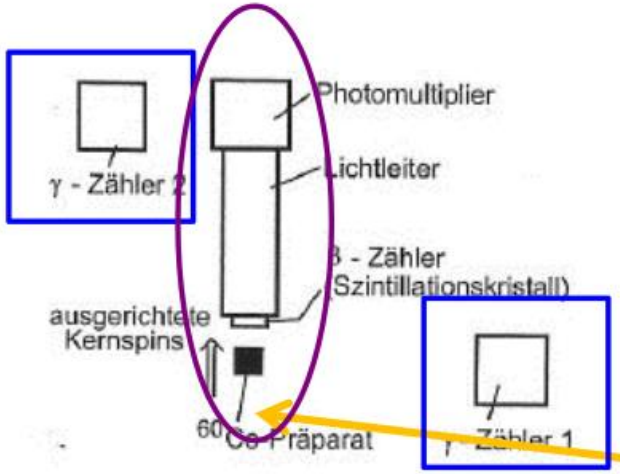
Requirements:

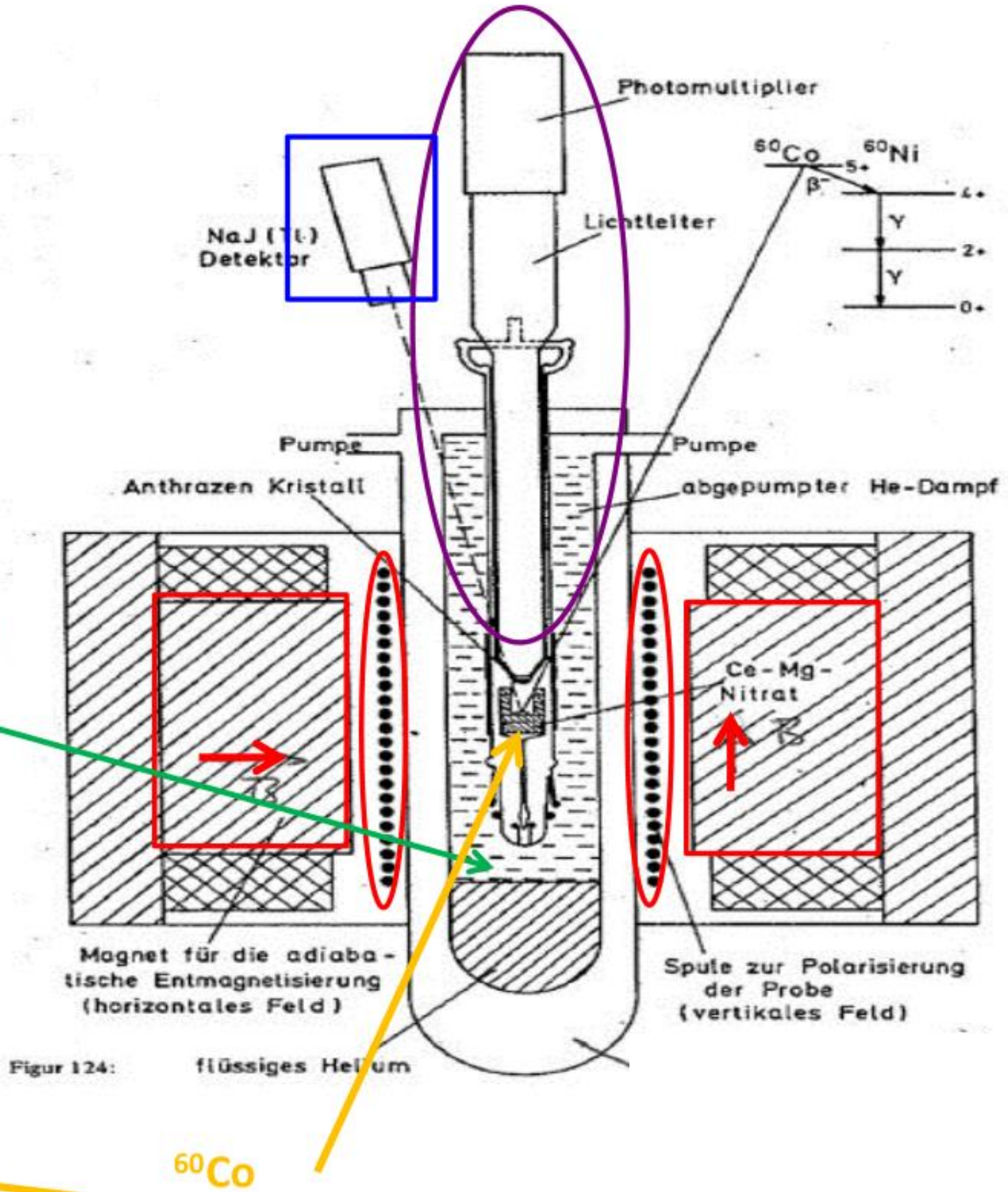
- 2 B fields in orthogonal directions

- detection of emitted electron
  (cover a small opening angle Θ)

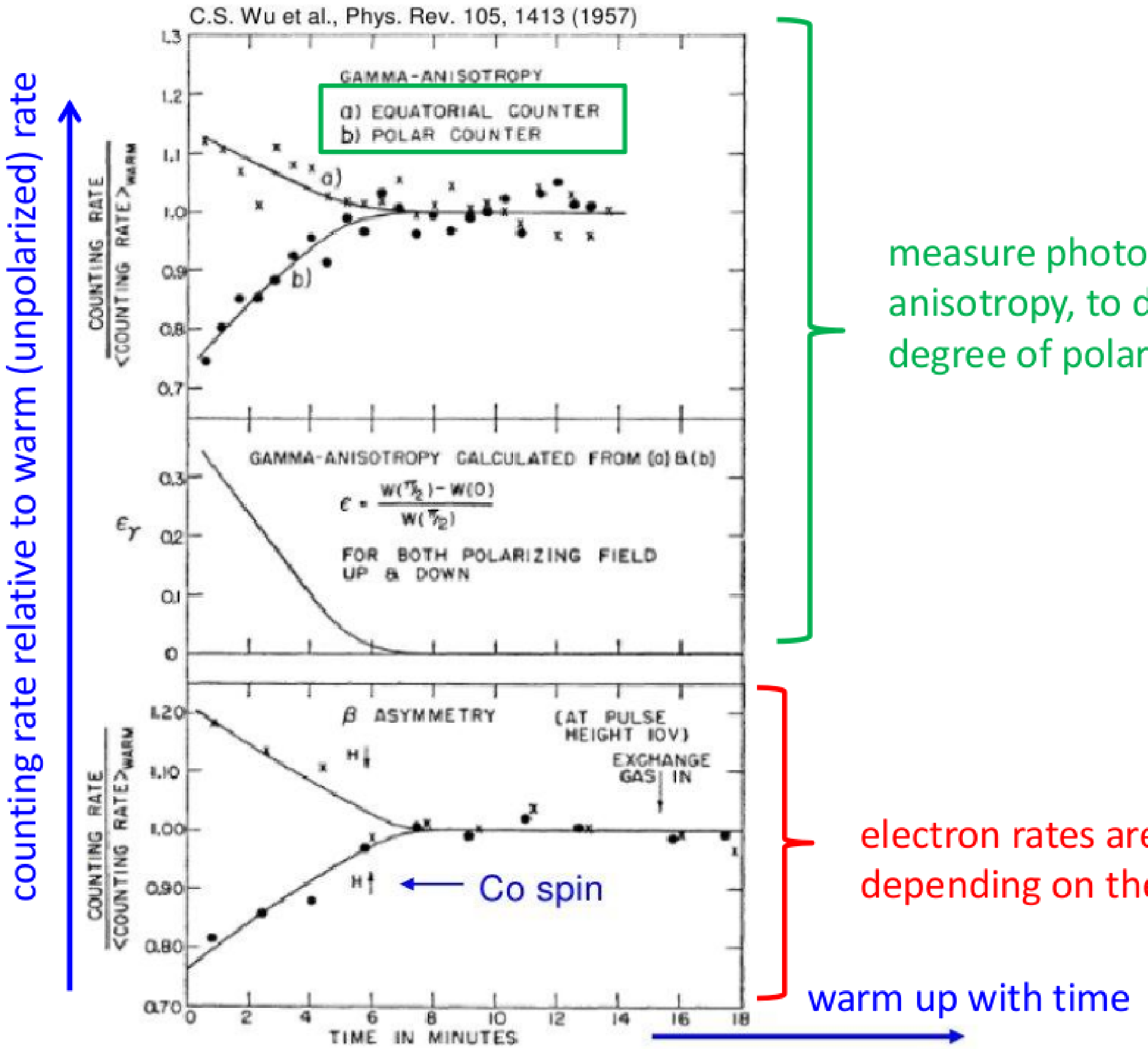
- detection of emitted gamma
  (to test polarization of ^{60}Co)

- crystal needs to be located
  in helium bath first than in vacuum





Wu-Experiment: Results

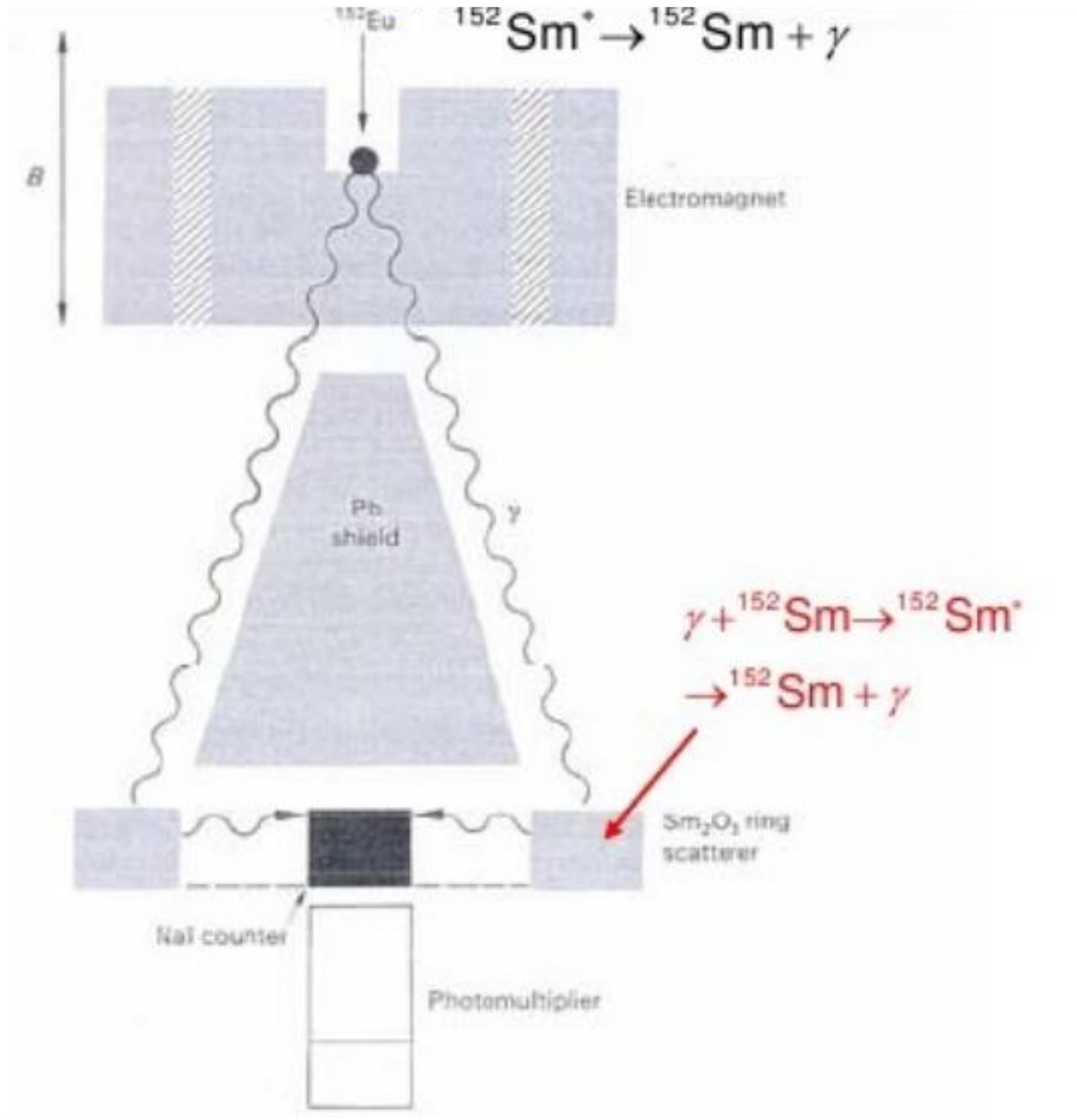


measure photon anisotropy, to determine degree of polarization

electron rates are different depending on the polarization!

→ **Parity violation**

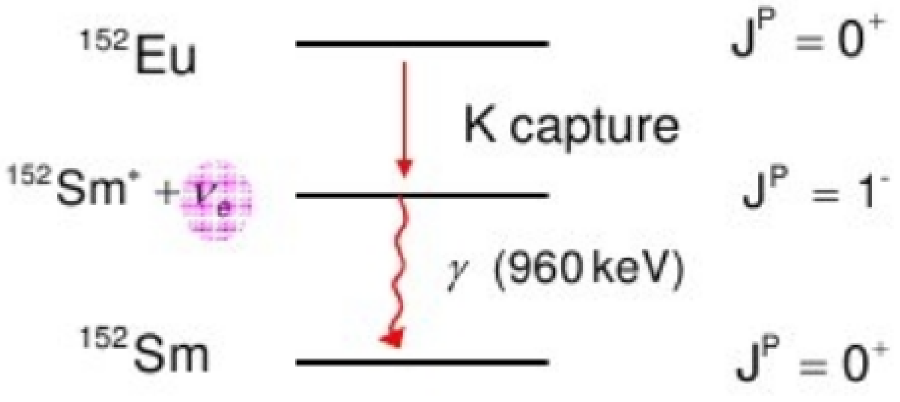
Goldhaber Experiment: What is the helicity of Neutrinos?

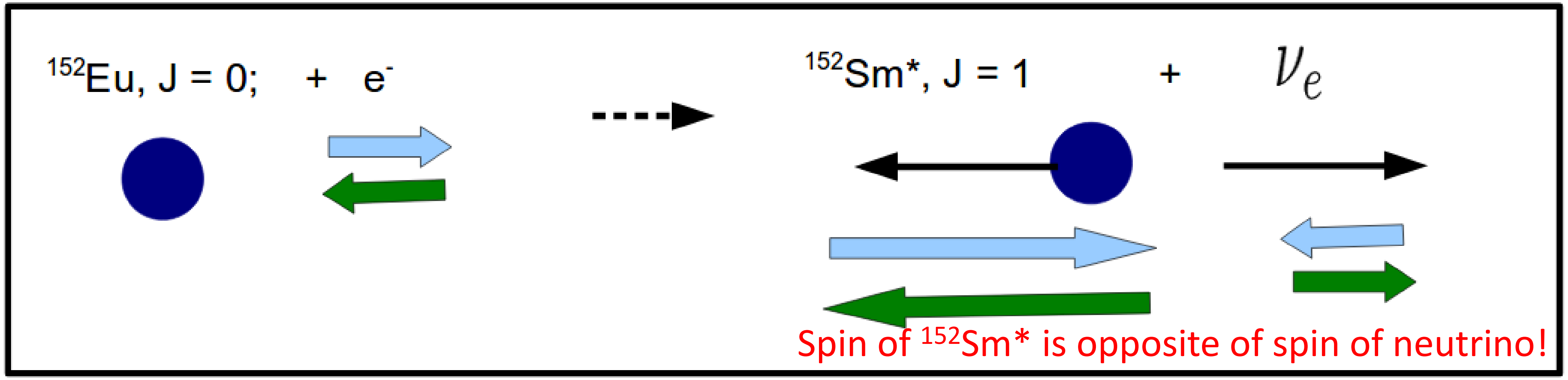


Goldhaber Experiment: What is the helicity of Neutrinos?

Indirect measurement of the neutrino helicity in an electron capture experiment

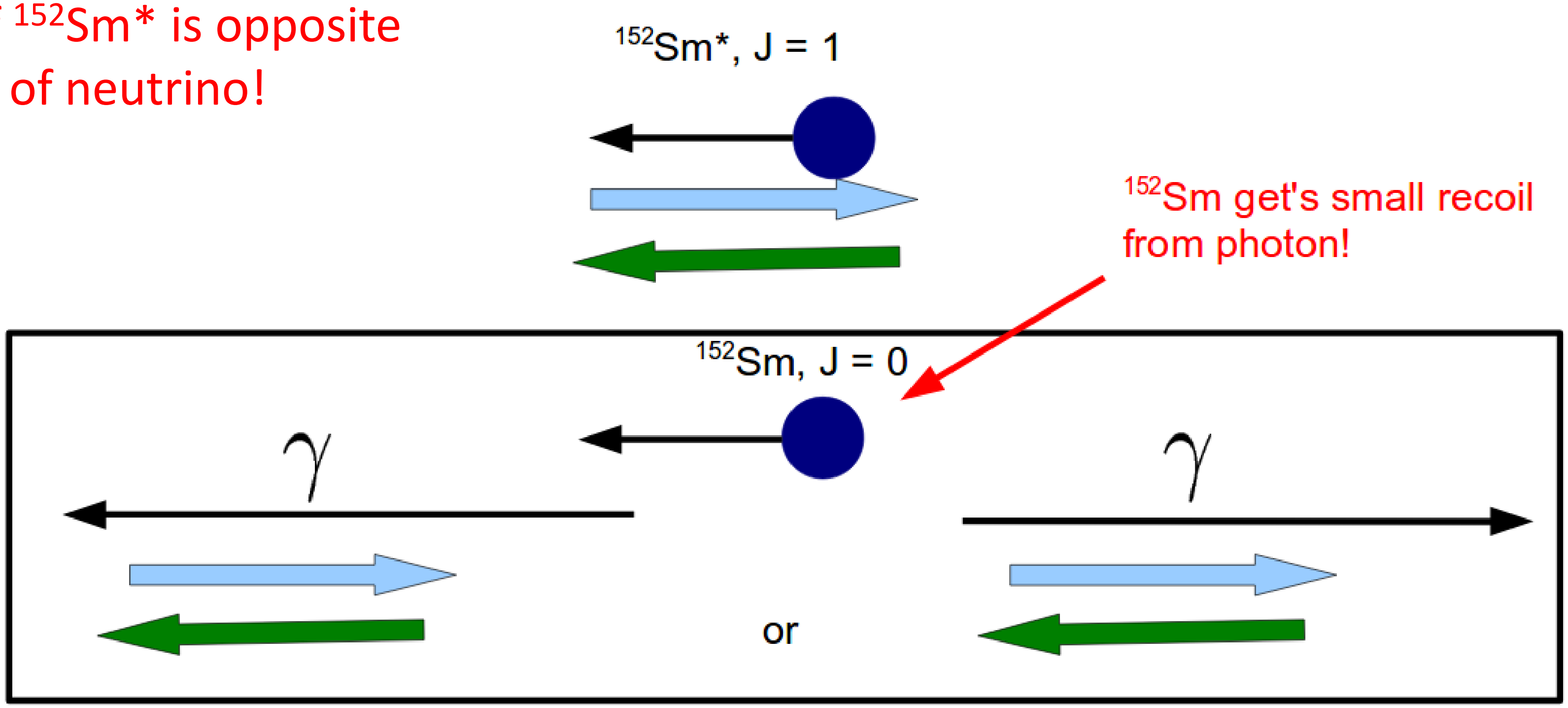
$$^{152m}Eu + e^- \rightarrow ^{152}Sm^* \rightarrow ^{152}Sm + \gamma$$





Goldhaber Experiment: What is the helicity of Neutrinos?

Spin of $^{152}Sm^*$ is opposite of spin of neutrino!



direction of spin of photon is opposite of neutrino

emitted in direction of Sm*	emitted in opposite direction of Sm*
$h(\gamma) = h(\nu_e)$	$h(\gamma) = -h(\nu_e)$

Two open question: 1) What is the direction of emission of the photon?

2) What is the polarization of the photon?

Goldhaber Experiment: What is the helicity of Neutrinos?

1) Resonant scattering

Scattered Photons carry helicity of neutrinos!

Resonant scattering:

To compensate the nuclear recoil, the photon energy must be slightly larger than 960 keV.

This is the case for photons which have been emitted in the direction of the Eu→Sm recoil (Doppler-effect).

Resonant scattering only possible for "forward" emitted photons, which carry the polarization of the Sm^* and thus the polarization of the neutrinos.

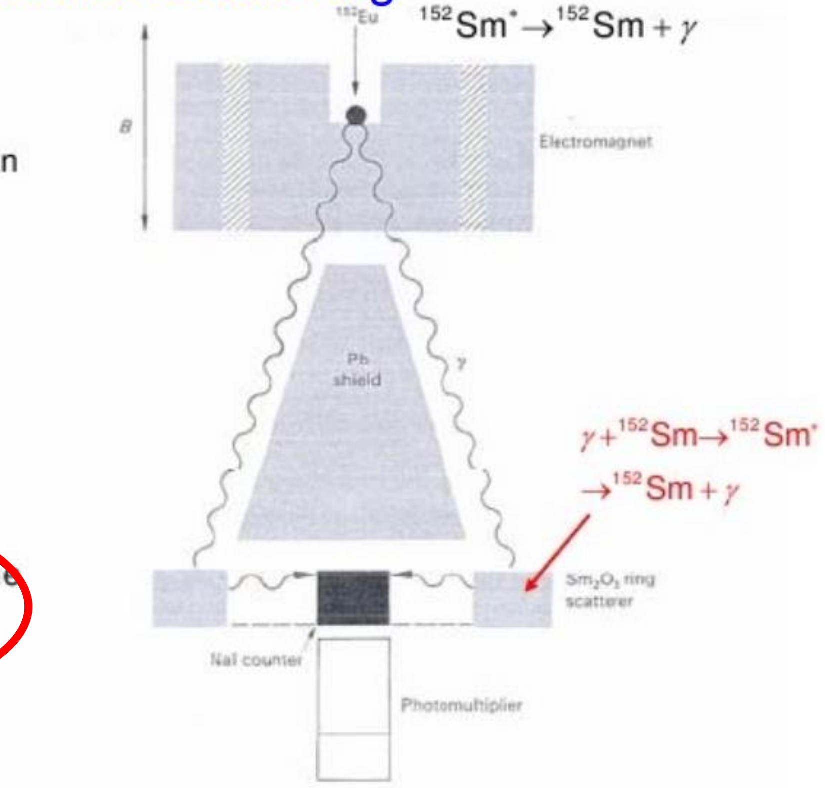


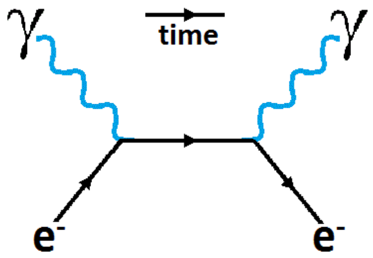
Fig. 7.8. Schematic diagram of the apparatus used by Goldhaber *et al.*, in which γ-rays from the decay of $^{152}Sm^*$, produced following K-capture in ^{152}Eu, undergo resonance scattering in Sm_2O_3 and are recorded by a sodium iodide scintillator and photomultiplier. The transmission of photons through the iron surrounding the source depends on their helicity and the direction of the magnetic field **B**.

Foto of experiment

Goldhaber Experiment: What is the helicity of Neutrinos?

2) Measurement of polarization of photon

Exploit that the transmission index through magnetized iron is polarization dependent: Compton scattering in magnetized iron



γ LH	γ RH
$\vec{B}$	$\vec{B}$
Polarization of electrons in iron	Polarization of electrons in iron
(to minimize pot. energy)	Absorption leads to spin flip
LH photons cannot be absorbed: Good transmission	RH photons undergo Compton scattering: Bad transmission

Photons w/ polarization anti-parallel to magnetization undergo less absorption

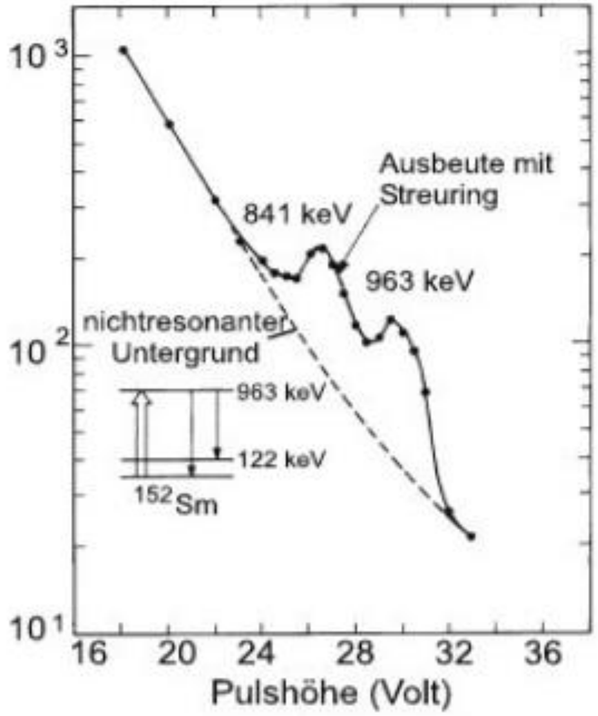
Goldhaber Experiment: What is the helicity of Neutrinos?

- Due to geometry of experiment, only resonant scattered photons are detected
  Helicity of detected photons identical to helicity of neutrino.

- Detect photons which pass trough magnetized iron.
  B field points in flight direction of photons → measure fraction of LH photons
  B field points in opposit direction → measure fraction of RH photons

$$P(\gamma) = -0.66 \pm 0.14$$

→ Determine polarization of photon: $H(\nu) = -1$



From a calculation with 100% photon polarization one expects a measureable Value of $P(\gamma) \sim 0.75$

Neutrinos are left handed and anti-neutrinos are right handed particles!