Why is Parity *RESTORED* ?

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Why is parity restored ? …

a somewhat provocative title, since for so many years we have wondered « Why is parity violated? »
In this talk, I plan to show that

- Parity violation is the **default expectation** in gauge theories
- Parity violation has **nothing to do** with the presence/absence of **right-handed neutrinos**

and ask the question:

- Since ***we were fooled for centuries*** to think parity was a good symmetry, **why is it indeed restored at the large distances then accessible**?

- And then…**is a *fairly long distance* P violation realized?**

Parity violation

For centuries, getting to the root of physical law has let us to assume that Parity was a law of nature,
with **exceptions linked to biological life (seen as boundary conditions).**

This abstraction proved right for **gravitation, for mechanics**.

It also proved correct **for electromagnetism*** and later for **nuclear forces**.

** Remark : Electromagnetism is a bit tricky, since we seem to introducea «right-hand rule » to define B, but this is only an intermediate construction, the convention applies twice and cancels thus in any physical process …*


Parity is Broken

The discovery of P violation was a real shock

It was first met with disbelief, in **a purely hadronic context**

2 particles, then called Theta T and Tau (nothing to do with the lepton) were observed with similar masses….close to 500 MeV

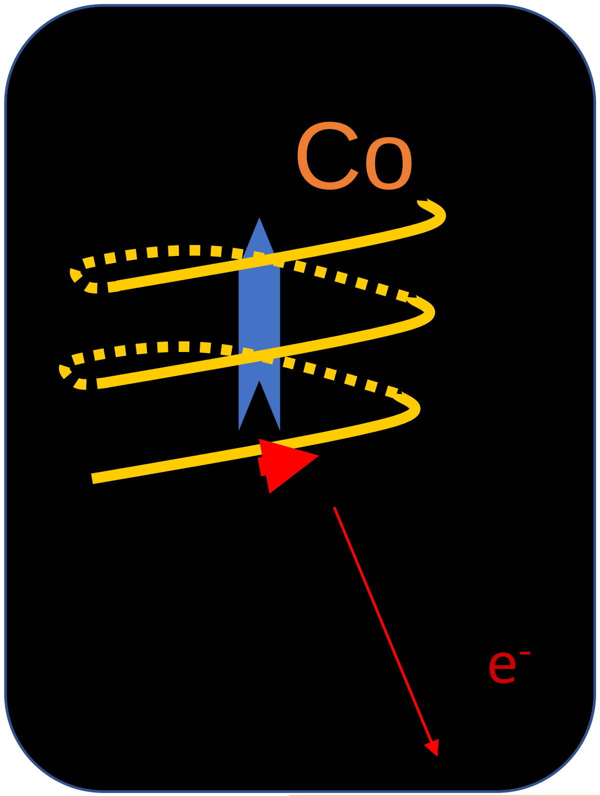
With decays T → 3 π and the Θ → 2 π ,

Since the decays were in S wave and the p parity was known to be (-) there were 2 possibilities

- **Θ and** T were 2 distinct particles, with identical mass (as shown by the experimental progress) and production
→ (parity doubling solution)

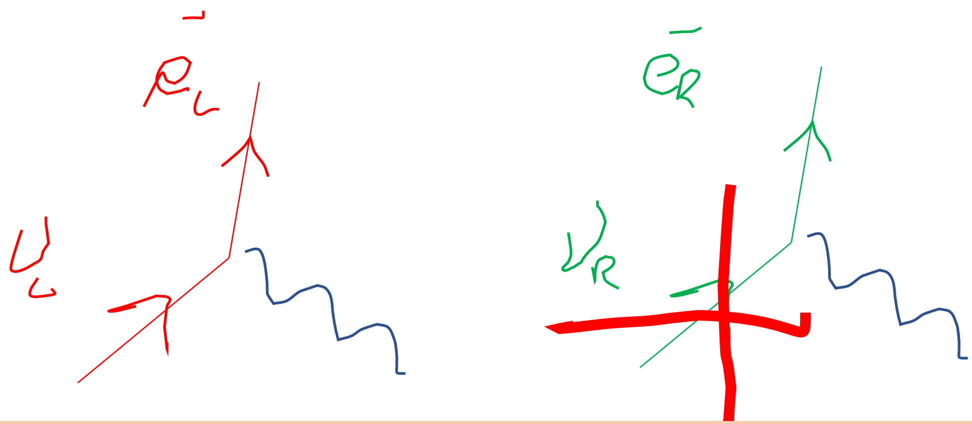
- OR they were the same particle (now K^+) **with broken parity explaining the decays ?**

It was so hard to accept the breaking of Parity (Lee and Yang) ,
that a “demonstration” experiment was conceived , the famous Wu experiment.



P violation was clearly demonstrated
in the Wu experiment ..

It is easy to explain if only left-handed electrons are produced in a charged vector current.



Killing the right-handed neutrino allows for parity violation in charged currents, even if the coupling is (were) pure vector

The WU experiment was convinced …
………………..but led to a wrong track!

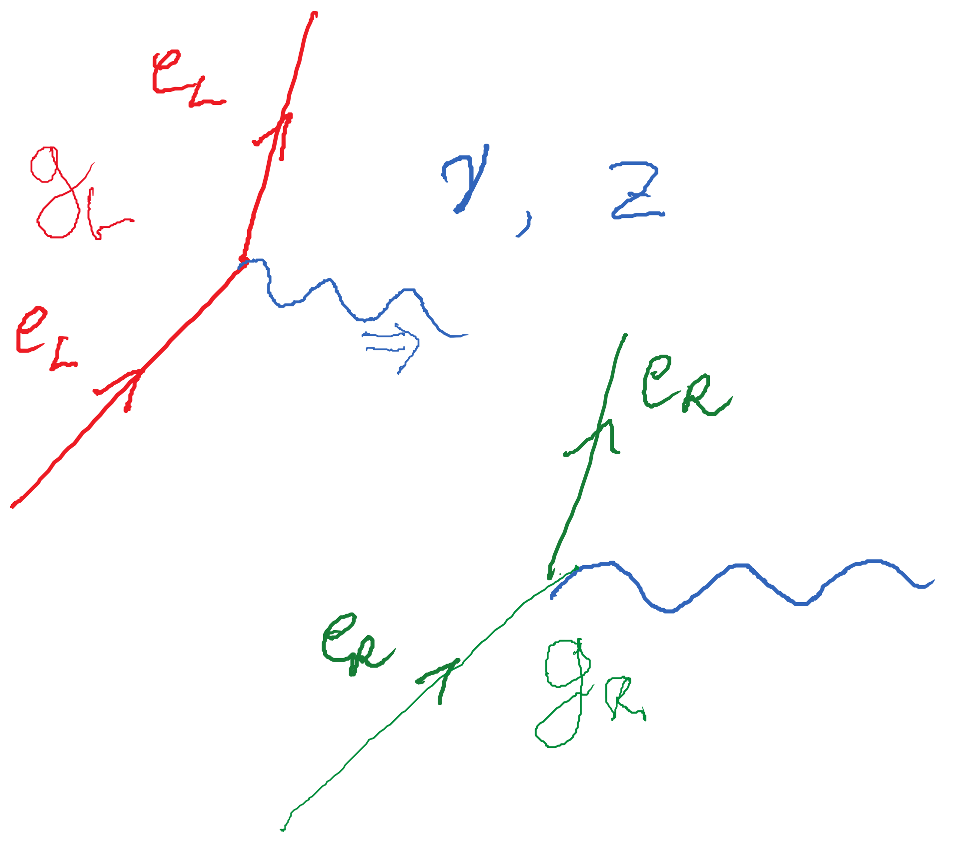
By focusing on neutrinos, and thus on leptons,
it probably led to the often-encountered ***folklore***
that "Parity violation is due to the absence of the right-handed neutrino",

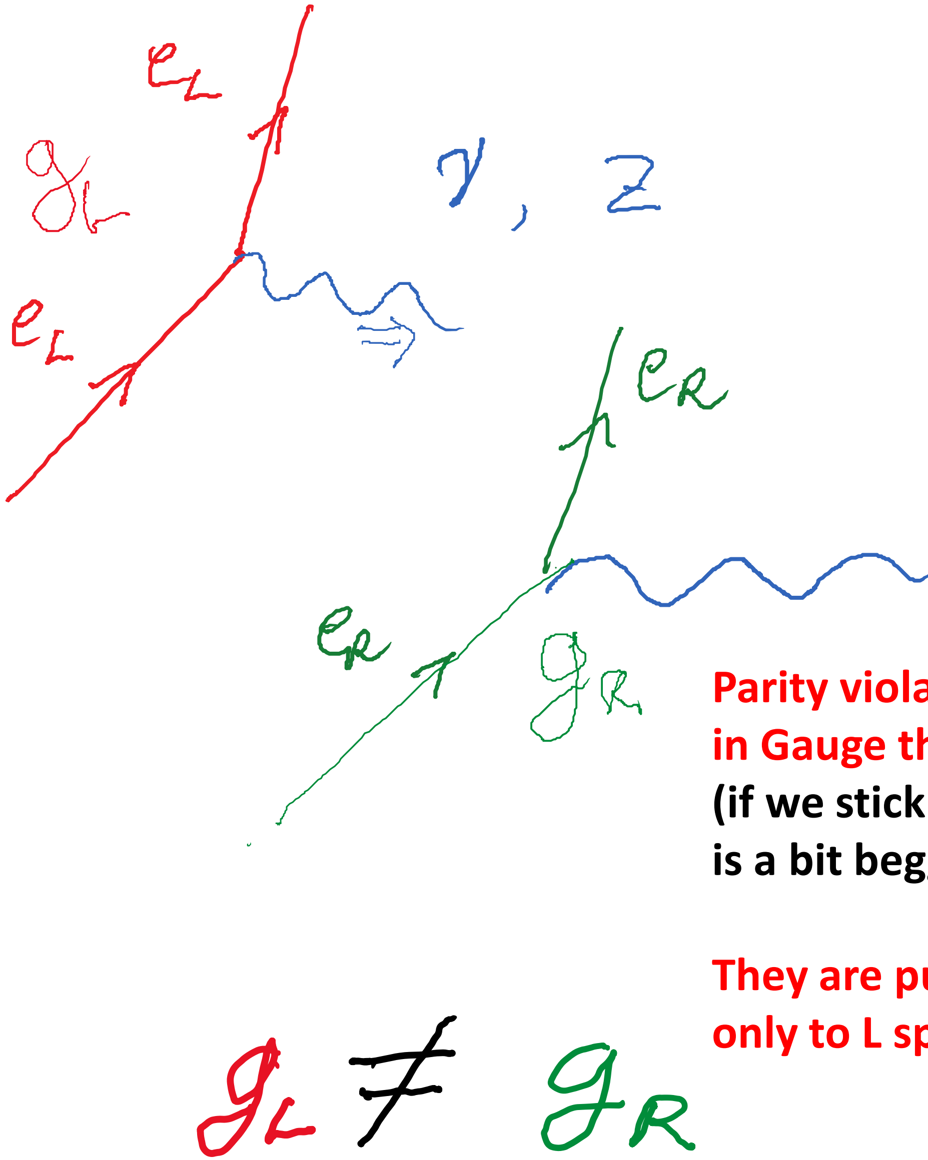
and indirectly to the **artificial exclusion of the ν_R** from the Standard Model.

Of course, this was in contradiction to the initial observation of the K → 2 pi vs K → 3 pi Parity violation, in pure hadronic processes!

Soon, *(on the historical scale!)* the experiments establishing the Standard Model proved

- The existence of neutral currents (they could have been included in the Fermi Lagrangian, but were still *strangely* considered the proof of the gauged SM)
- The violation of parity in neutral current interactions (atomic parity violation) in an easily understandable process without any neutrinos.





Parity violation is indeed the EXPECTED SITUATION in Gauge theories ! **(In 3+1 dimensions)**
(if we stick to representations of $SL(2,C)_+^\uparrow$ which is a bit begging the question)

They are purely chiral, with L spinors speaking only to L spinors and R to R


At long distances
Parity seems restored ...

In fact, the mystery would rather be ....
Why is Parity respected around us?

Take for example the SU(5) unification ... (or any SuSy approach)

All fermions are re-written in terms of the Left-Handed spinors

e.g; $((u_R)^c)_L$ .... In 10 and $\tilde{5}$ of SU(5)

Is it an accident that after breaking, the « long-distance » gauge interactions (in which I would include not only U(1)em but also the unbroken SU(3)color which reaches the proton size) are parity invariant ???

...with the result that we have been fooled for many centuries in believing in Parity as an exact symmetry?

I have no (complete, satisfactory) answer ! …

The mathematical coherence of the theory may give some hints.

- Anomaly conservation
- Gauge invariance of mass term for long-distance interactions
- Singularities in massless gauge bosons coupling with massless fermions may prevent the existence of the latter.

- Anomaly conservation

The discussion must involve the U(1) em and the SU(3) long distance forces (unbroken symmetries)

Let us assume that we start from a grand-unified theory,
say SU(5) (not parity-conserving) or SO (10)

For all the gauged currents, the quantum anomalies must cancel,
and the same must remain true after symmetry breaking.

In a small group, like SU(3) IF we accept only relatively small representations,
this matching can
only be done for SU(3) by compensating 3 by $\bar{3}$ …(excluding the 6)
…which would lead to Parity restauration .

- Only massive fermions are known to have long-distance interactions
  (one neutrino could be massless, but we are not aware of anylong-distance interactions)

Hence a mass term in the Lagrangian must invariant under the corresponding gauge transformation (rotation by φ)

$$m \bar{\psi}_L \psi_R + h.c$$

$$e^{-i\alpha_L \varphi} \qquad e^{i\alpha_R \varphi}$$

$$\alpha_R = \alpha_L$$

(here, m is assumed to be a “number”, after symmetry breaking)

This brings us to an old question :
The problem of parity restauration is solved if only massive fermions can have charges under long-distance interactions (massless gauge bosons)

Indeed, there are singularities,

For instance consider the longitudinal emission, either from a fermion with m → 0 or a massless fermion : the limit might be different

The L R transition is only possible with a small mass term …

In the massless case, the initial L electron is degenerate with a R electron + soft photon, which should be included (kind of PDF treatment) for consistency.

BUT …some Parity violation at “large” distances could show up!

Could we still have some « residual » *fairly long-distance* P violation?

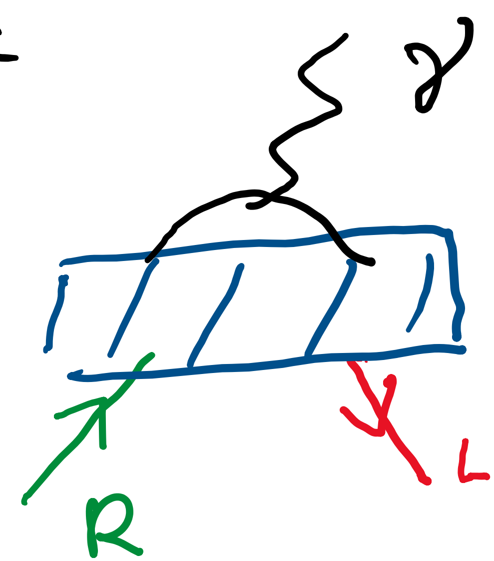
Magnetic Moments

$$\mu \, \vec{S} \cdot \vec{B}$$

$$i\mu \, \bar{f}_L \sigma^{\mu\nu} f_R \, F_{\mu\nu} + h.c$$

Transition Magnetic Moments

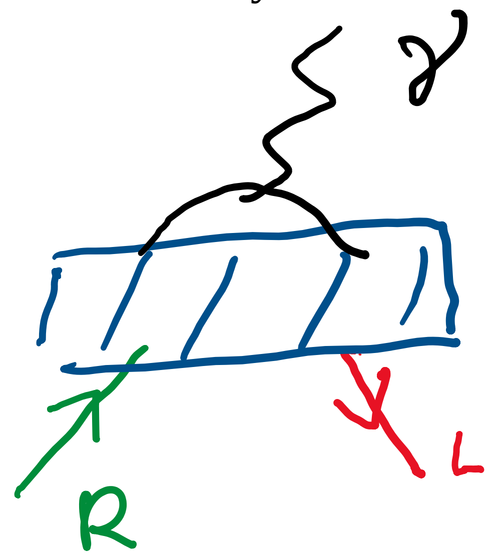
$$i\mu \, \bar{d}_L \sigma^{\mu\nu} s_R \, F_{\mu\nu} + h.c$$



Electric Dipole Moments

EDMs are intrinsically P violating for an *elementary particle*,
as they must align with the spin* but can be induced by local forces.

$$\vec{S} \cdot \vec{E}$$

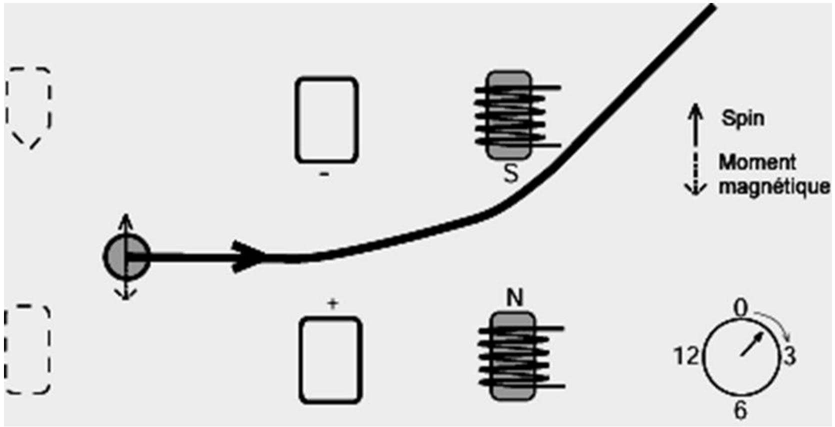


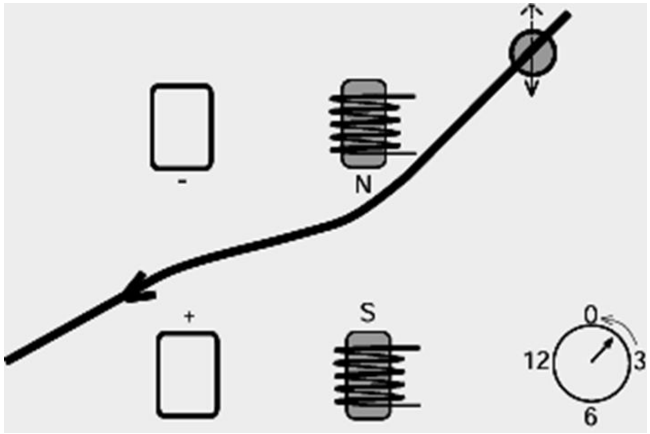
They violate P, CP and T .

They are expected to be tiny in SM, but are predicted (and currently bound by experiment) in most extensions (SuSy, LR, …)

**except maybe in some non-commutative geometries*.

T-violating effect of hypothetical electric dipole moment (gedanken experiment):
We would have a similar effect for P ...I let you figure it out ...*the rule is to apply the flips to the apparatus (and the particle when needed) !*





Parity restoration due to fermion masses ?

Some “long-distance” P violation could persist through dipole moments.

DO we find symmetries where they don’t exist?