Parity Violation in N-N scattering

Electromagnetic
Strong
> forces conserve C, P, T

Weak force violates $\cancel{C}$, $\cancel{P}$, $\cancel{CP}$ and $\cancel{T}$

only CPT OK

Violation of P is maximal

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IPN - ORSAY

NP01 WORKSHOP

KEK, 10-12 DEC 2001

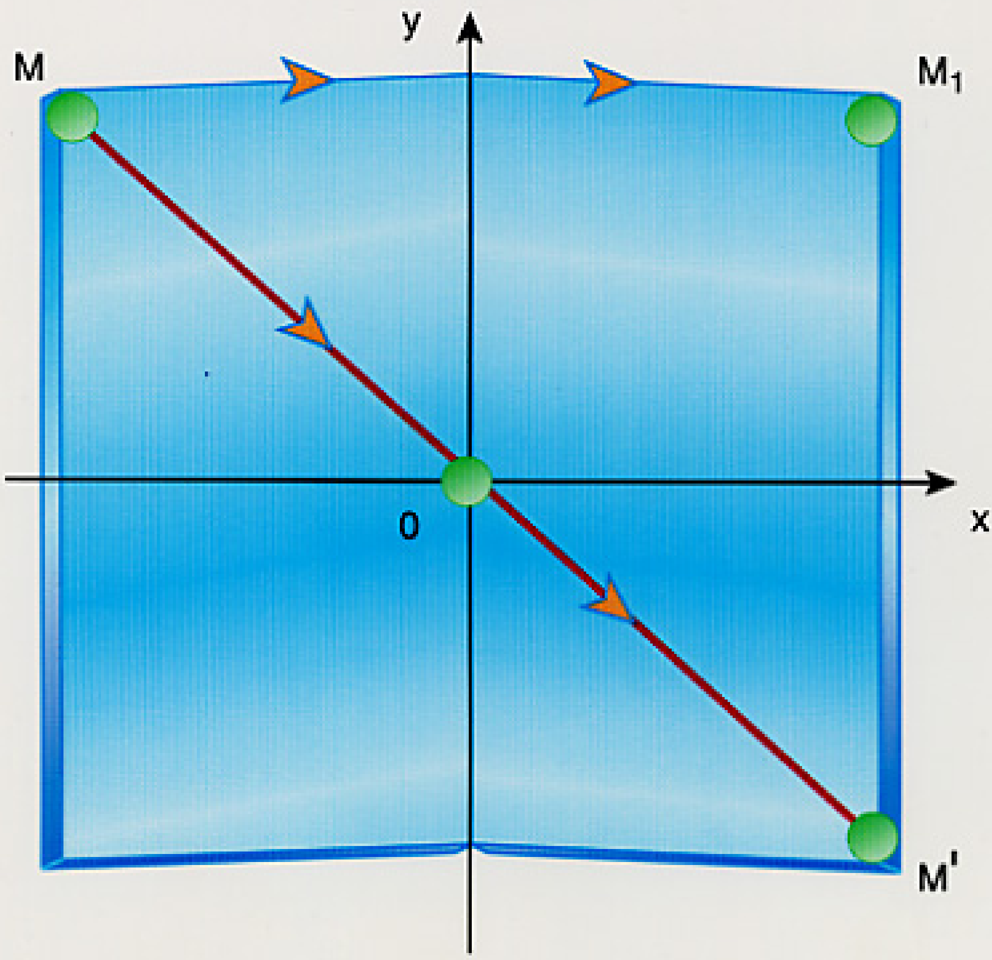
PARITY $x, y, z \rightarrow -x, -y, -z$

$M \rightarrow M_1$ = mirror-symmetry
$M_1 \rightarrow M'$ = 180° rotation around 0x

Rotations in space $M_1 \rightarrow M'$
don't change laws physicals so, if there is parity violation, it's during $M \rightarrow M_1$ that it happens.

Parity ⟷ Mirror-Symmetry

MIRROR



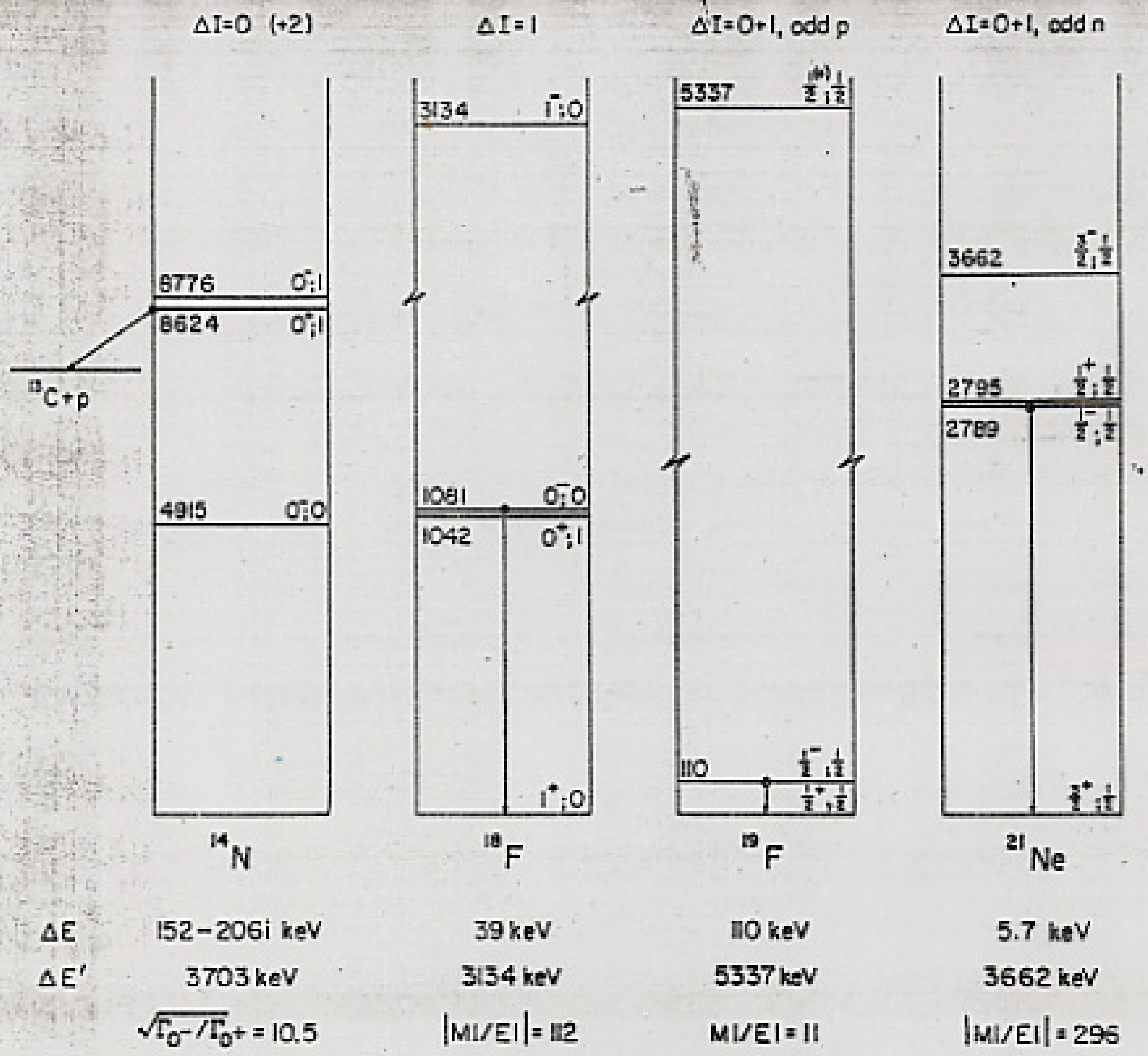


Figure 9 Parity-mixed doublets in light nuclei. The transitions displaying the amplified PNC effect are indicated. The quantities ΔE and $\Delta E'$ are the smallest and next smallest energy denominators governing the parity mixing. The quantities shown in the bottom row are "amplification factors."

$$\epsilon = \frac{\langle \phi_{J-} | H_{wk} | \phi_{J+} \rangle}{E^+ - E^-} \sim \frac{1\,\mathrm{eV}}{E^+ - E^-}$$

If $E^+ - E^- \sim 100\ \mathrm{eV} \Rightarrow \epsilon \sim 10^{-2}$

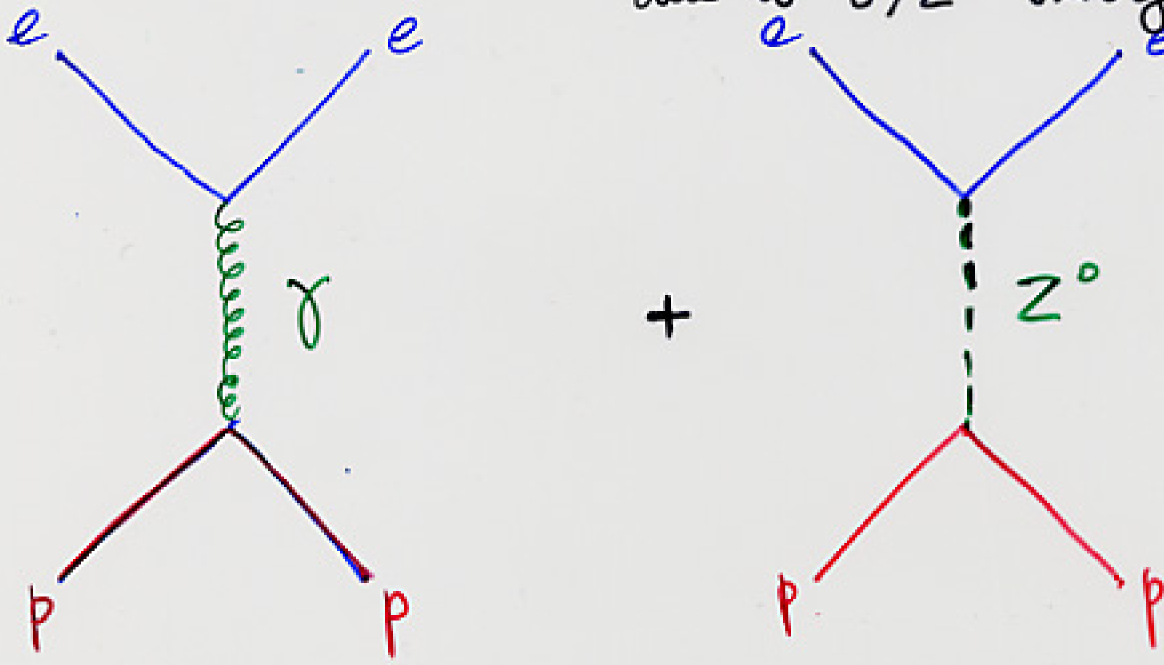
e.g. $^{139}La \Rightarrow A_z = (9.55 \pm 0.35) \times 10^{-2} \sim 10^{-1}$

Parity violation in different systems

Weak disintegrations $\Rightarrow$ 100% effect
ex: Wu's experiment

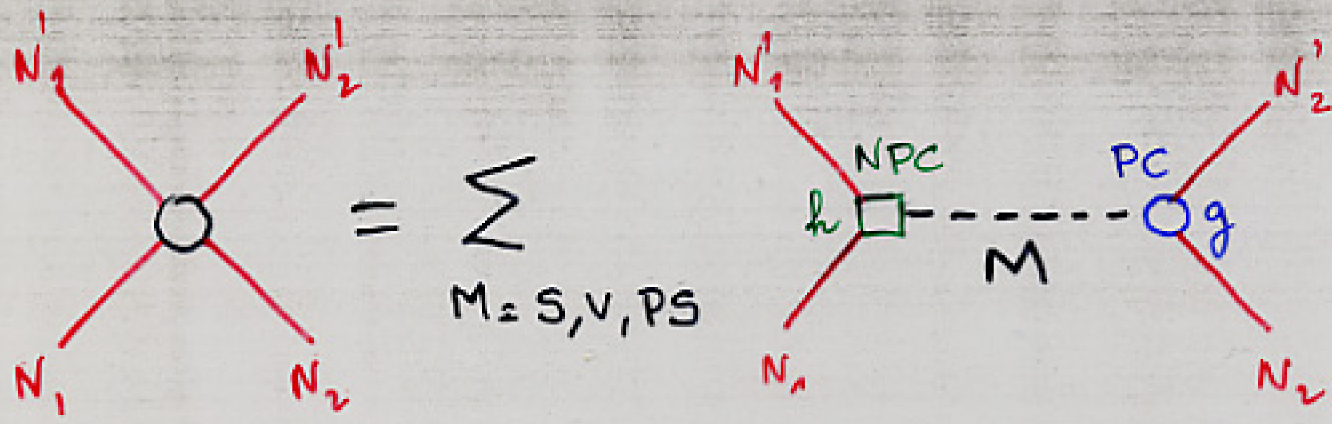
In nuclei $\Rightarrow$ $A \sim 10^{-2} - 10^{-5}$
due to parity-mixing between states with opposite parity
ex: ^{14}N; ^{18}F, ^{19}F, ^{21}Ne

In electron-scattering $\Rightarrow$ $A \sim 10^{-5} \times Q^2$
due to γ / Z^0 interference



ex: HAPPEX, SAMPLE, PV-A4, Gϕ

Parity Violation in NN interactions



$$
\frac{V^{PNC}_{NN\pi}}{V^{PC}_{NN\pi}} \sim \underbrace{G_F}_{\to\, 1.166\times10^{-5}\ \text{gev}^{-2}}\, m_\pi^2 \sim 10^{-5}\,\frac{m_\pi^2}{m_N^2} \sim 10^{-7}
$$

$$
\boxed{H^{PC}} = i g_{\pi NN}\bar{N}\gamma_5\tau\cdot\phi_\pi N + g_\rho\bar{N}\left(\gamma_\mu + i\frac{\mu_v}{2M}\sigma_{\mu\nu}k^\nu\right)\tau\cdot\phi^\mu_\rho N
$$

$$
+ g_\omega\bar{N}\left(\gamma_\mu + i\frac{\mu_s}{2M}\sigma_{\mu\nu}k^\nu\right)\phi^\mu_\omega N;
$$

$$
\boxed{H^{PNC}} = \frac{f_\pi}{2}\bar{N}[\tau\times\phi_\pi)_z N
$$
→ SCALAR

$$
+\bar{N}\left(h^0_\rho\tau\cdot\phi^\mu_\rho + h^1_\rho\phi^\mu_{\rho z} + \frac{h^2_\rho}{2\sqrt{6}}(3\tau_z\phi^\mu_{\rho z} - \tau\cdot\phi^\mu_\rho)\right)\gamma_\mu\gamma_5 N
$$
→ AXIAL-VECTOR

$$
+\bar{N}(h^0_\omega\phi^\mu_\omega + h^1_\omega\tau_z\phi^\mu_\omega)\gamma_\mu\gamma_5 N - h'^1_\rho\bar{N}\cancel{(\tau\times\phi^\mu_\rho)_z\frac{\sigma_{\mu\nu}k^\nu}{2M}}\gamma_5 N.
$$

AXIAL-VECTOR PSEUDO-SCALAR

3 Strong coupling constants are known

$$\frac{g^2_{\pi NN}}{4\pi} \sim 14$$

$$\frac{g^2_\rho}{4\pi} = \frac{1}{9}\,\frac{g^2_\omega}{4\pi} = 0.62$$

6 weak coupling constants to be determined

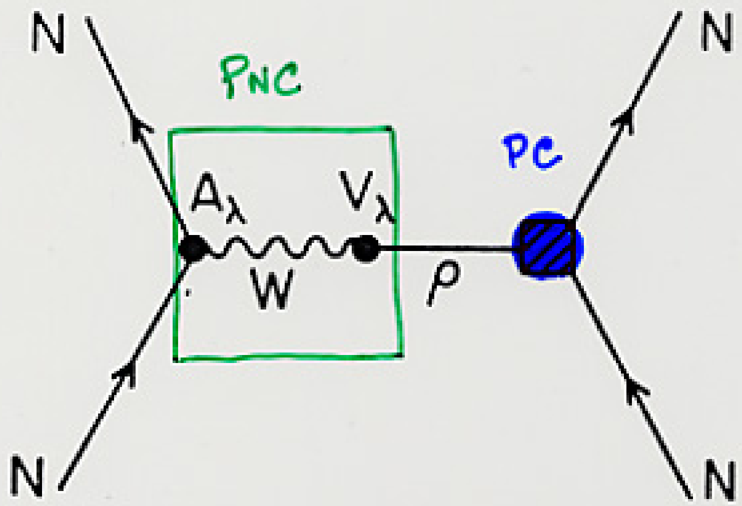
$$f_\pi \,,\quad h_\rho^{0,1,2} \,,\quad h_\omega^{0,1}$$

NB NN scattering not sensitive to f_π since π's are responsible for long range part of NN interaction ~~and~~ whereas PV is very short range (needs a Z° or W exchange).

The experimentally determined $h_\rho^{0,1,2}$ and $h_\omega^{0,1}$ can then be compared to quark models → RESULTS

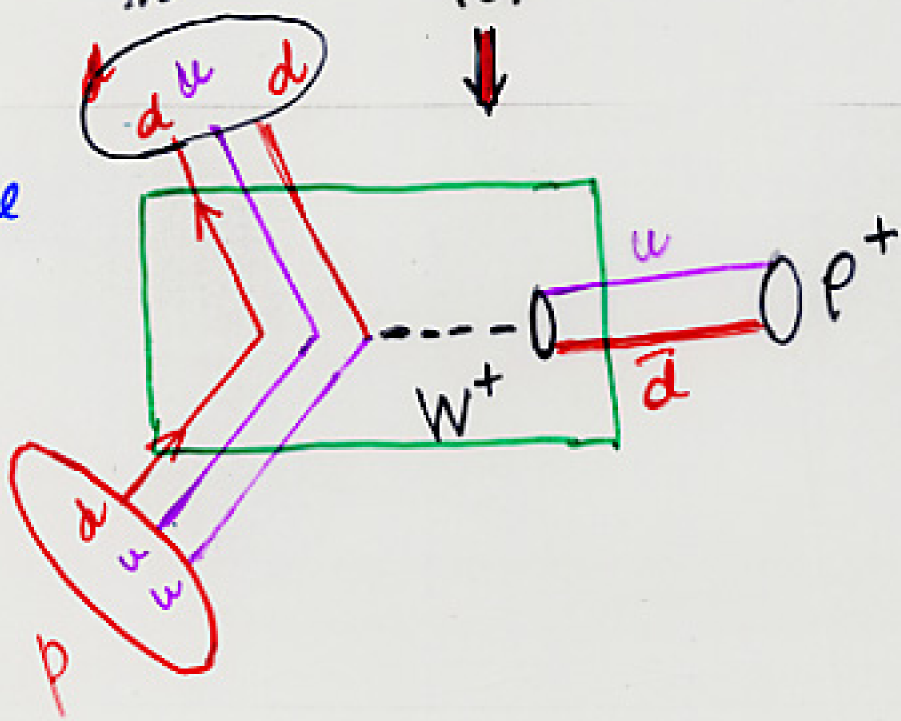
Microscopic models for weak coupling constants

POLE TERM

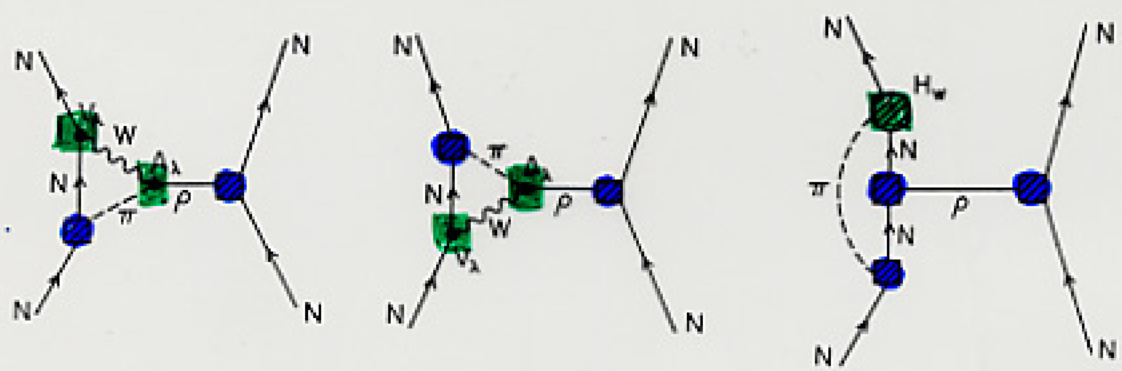


(e)

quark-model description



NON POLE TERMS



(a) (b) (c)

Asymmetries in NN Scattering (< 1 GeV)

pp

longitudinally polarized protons

BONN: $A^{z}_{pp}(13.6\text{ MeV}) = (-0.93 \pm 0.20 \pm 0.05) \times 10^{-7}$

LOS-ALAMOS: $(15.0\text{ MeV}) = (-1.7 \pm 0.8) \times 10^{-7}$

SIN: $(45\text{ MeV}) = (-1.57 \pm 0.23) \times 10^{-7}$

LOS ALAMOS: $(800\text{ MeV}) = (2.4 \pm 1.1) \times 10^{-7}$

pd

LOS ALAMOS: $A^{z}_{pd}(15\text{ MeV}) = (+0.35 \pm 0.85) \cdot 10^{-7}$

SIN $(45\text{ MeV}) = (+0.4 \pm 0.7) \times 10^{-7}$

LOS ALAMOS $(800\text{ MeV}) = (1.7 \pm 0.8 \pm 1.0) \cdot 10^{-7}$

pα

SIN: $A^{z}_{p\alpha}(45\text{ MeV}) = (-3.34 \pm 0.93) \times 10^{-7}$

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p-H_2O (> 1 GeV)

ARGONNE: $A^{z}_{pH_2O}(5.1\text{ GeV}) = (26.5 \pm 6 \pm 3.6) \times 10^{-7}$

Comparison with theory (low energy)

Weak coupling constants (best value + reasonable range) from Desplanques, Donoghue and Holstein (DDH)

Table 1 Weak coupling constants from the "best value" and "reasonable range" results of Desplanques, Donoghue & Holstein (8) for the Glashow-Weinberg-Salam model[a]

Coefficient	Equivalent	"Best value" ($\times 10^{-6}$)	"Reasonable range" ($\times 10^{-6}$)
F_π	$g_{\pi NN} f_\pi/\sqrt{32}$	1.08	0:2.71
F_0	$-g_\rho h_\rho^0/2$	1.59	−1.59:4.29
F_1	$-g_\rho h_\rho^1/2$	0.027	0:0.053
F_2	$-g_\rho h_\rho^2/2$	1.33	−1.06:1.54
G_0	$-g_\omega h_\omega^0/2$	0.80	−2.39:4.29
G_1	$-g_\omega h_\omega^1/2$	0.48	0.32:0.80
H_1	$-g_\rho h_\rho^{\prime 1}/4$	0.0	

[a] We have taken $g_{\pi NN} = 13.45$, $g_\rho = 2.79$, and $g_\omega = 8.37$.

DDH, Annals of Phys. (NY) 124 (1980) 449

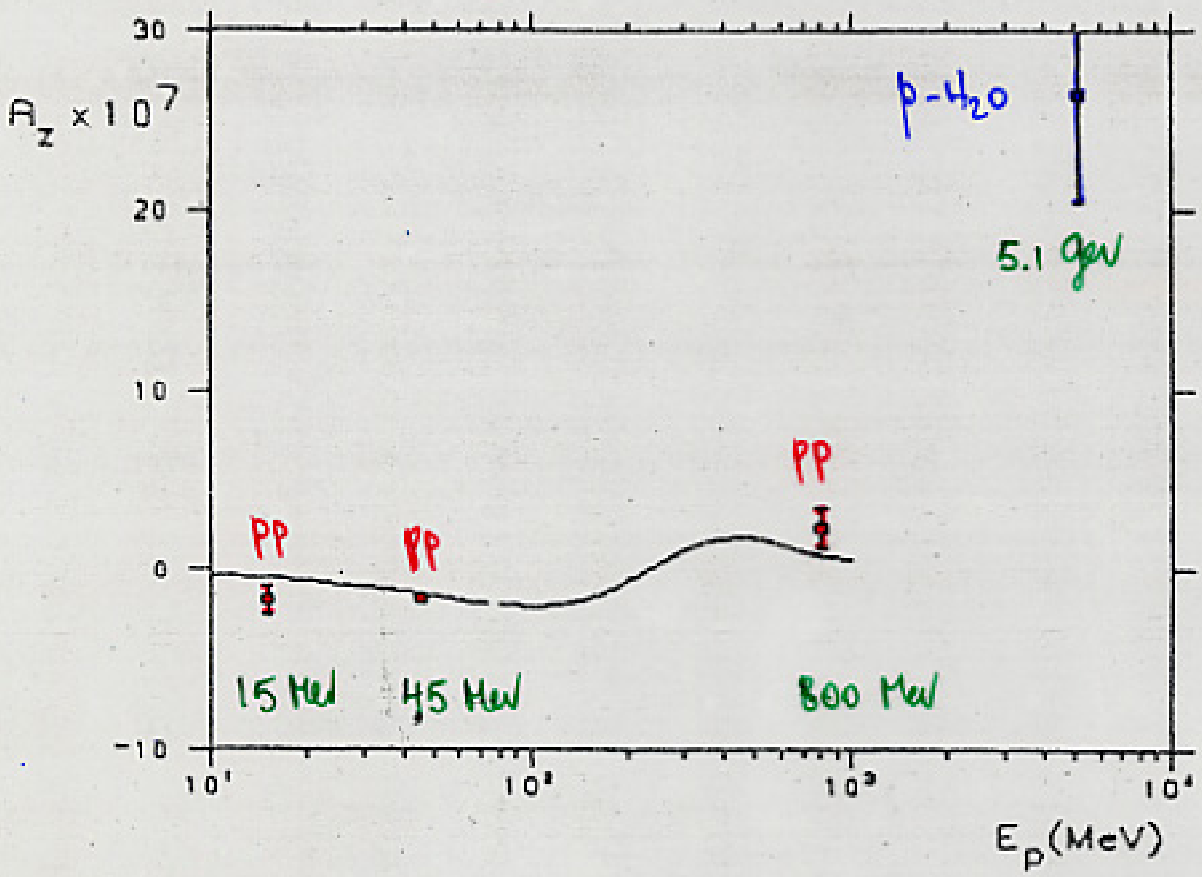


Figure 1. Energy dependence of the longitudinal analyzing powe $\vec{p}$-p scattering. Solid line: theoretical prediction (Ref.10)

Comparison with theory (high energy)

① E.M. Henley [NP A483 (1988) 596]

Relativistic Meson Exchange Model

$$A^L_{p\text{-}H_2O}\ (5.1\ \text{gev}) \sim [0 - 1.4 \times 10^{-7}]$$

② T. Oka [Prog. Th. Phys. 66 (1981) 977]

OBE + QCD Corrections

Note that T. Oka calculates A^L_{pp}, not $A^L_{p\text{-}H_2O}$

With inelastic contributions $\Rightarrow \frac{\sigma_{tot}}{\sigma_{el}} \sim 4 \Rightarrow \frac{A_{tot}}{A_{el}} \sim \left(\frac{\sigma_{tot}}{\sigma_{el}}\right)^2 \sim 16$

$\downarrow$

right order of magnitude but crude argument

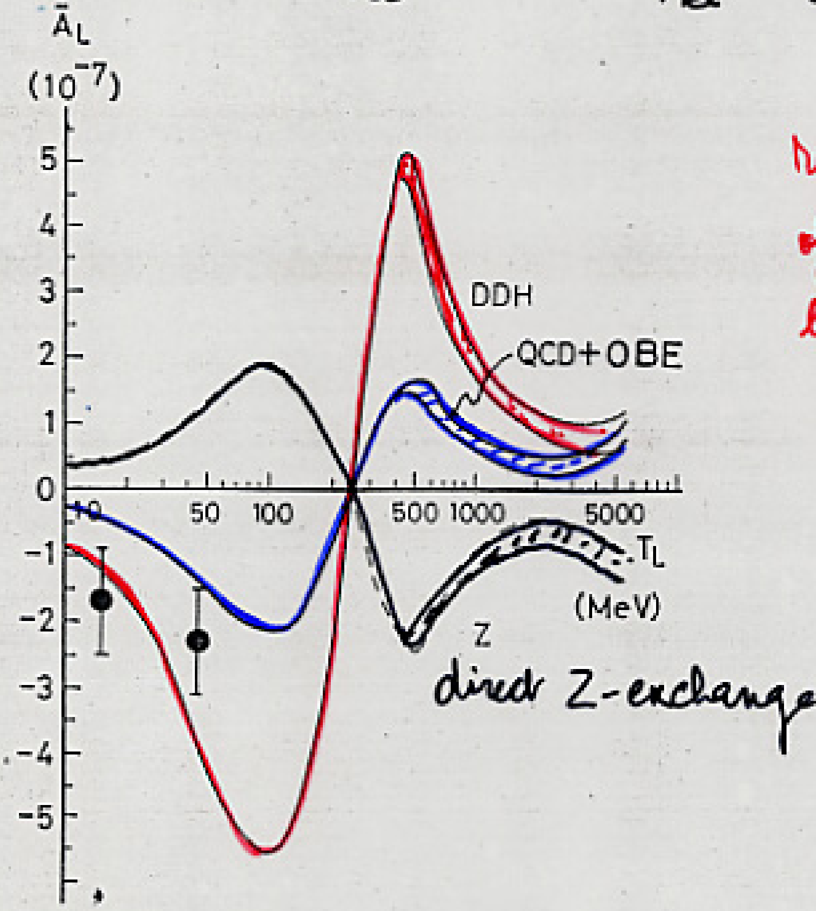
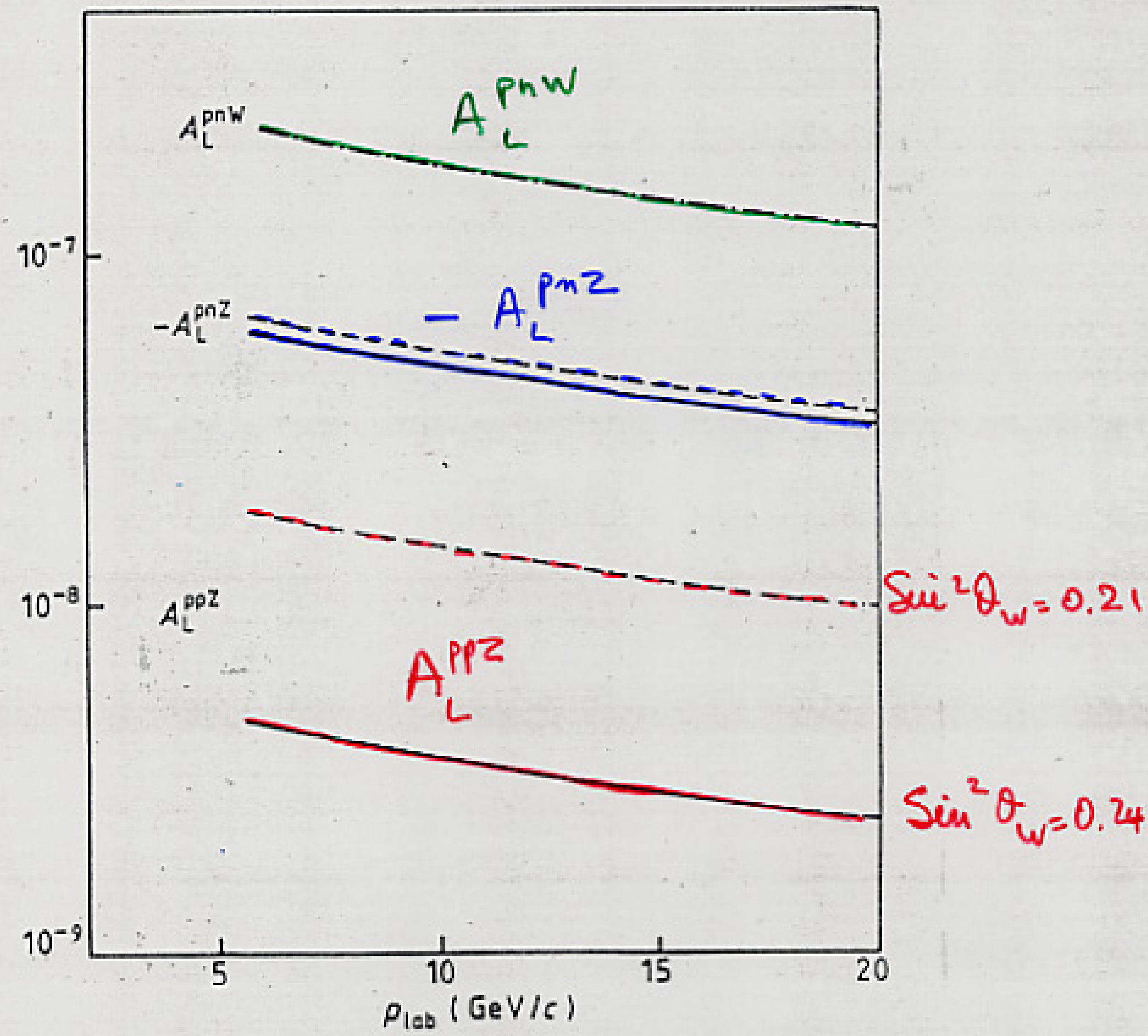


Fig. 3. The asymmetry $\bar{A}_L$ by (i) the parameters from six-quark model with QCD correction and one-boson-exchange model (ii) DDH parameters and vector meson universality (iii) Z-boson exchange.

③ P. Chiapetta, J. Soffer and T.T. Wu
[J. Phys. G : Nucl. Phys. 8 (1982) L93]

Heavy Boson Exchange Model



Note the large compensation between pp and pn for Z-exchange.

(4) A. Barroso and D. Tadič [N.P. A 364 (1981) 194)

Glauber Model

$A_{p\text{-}H_2O}$ (5.1 GeV) = 0.46×10^{-7}

Note the large compensation between pp and np

→ Compare pp and pd

TABLE 4

Contributions to the asymmetry due to different diagrams

p_ℓ (GeV/c)	$a_{pp} \times 10^7$					$a_{pn} \times 10^7$				
	π	ρ	ω	2π	total	π	ρ	ω	2π	total
1.3		−6.00	−1.97	2.16	−5.81	0.04	2.56	1.04	−0.36	3.28
1.5		−5.29	−1.79	−0.86	−7.94	−0.17	2.32	1.47	−0.35	3.27
3.0		0.44	0.18	−0.41	0.21	−0.13	−0.41	0.79	0.08	0.33
5.0		0.81	0.38	−0.32	0.87	−0.08	−0.89	0.79	0.04	−0.14
5.1 GeV 6.0 GeV/c		0.70	0.34	−0.08	0.96	−0.05	−0.80	0.63	0.03	−0.19
7.0		0.74	0.36	−0.05	1.05	−0.05	−0.85	0.63	0.02	−0.25
9.0		0.61	0.31	0.07	0.99	−0.03	−0.71	0.48	0.01	−0.25

Possible explanations (cont'ed)

1. M. Simonius and L. Unger [Phys. Lett. B198 (1987) 547]

quark-diquark model

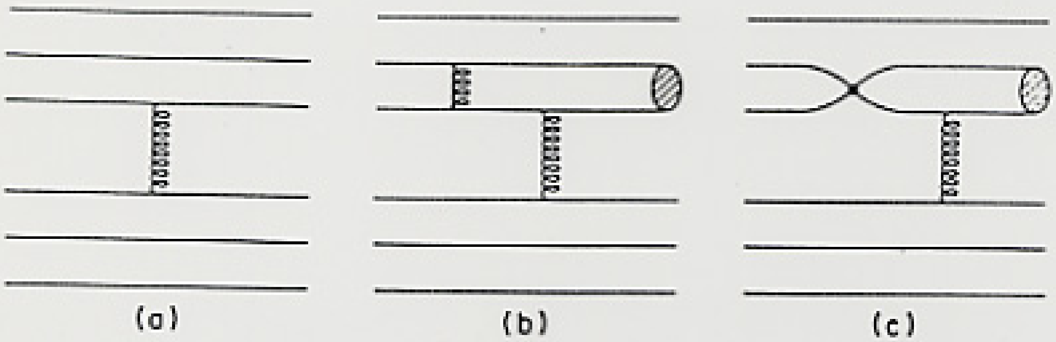
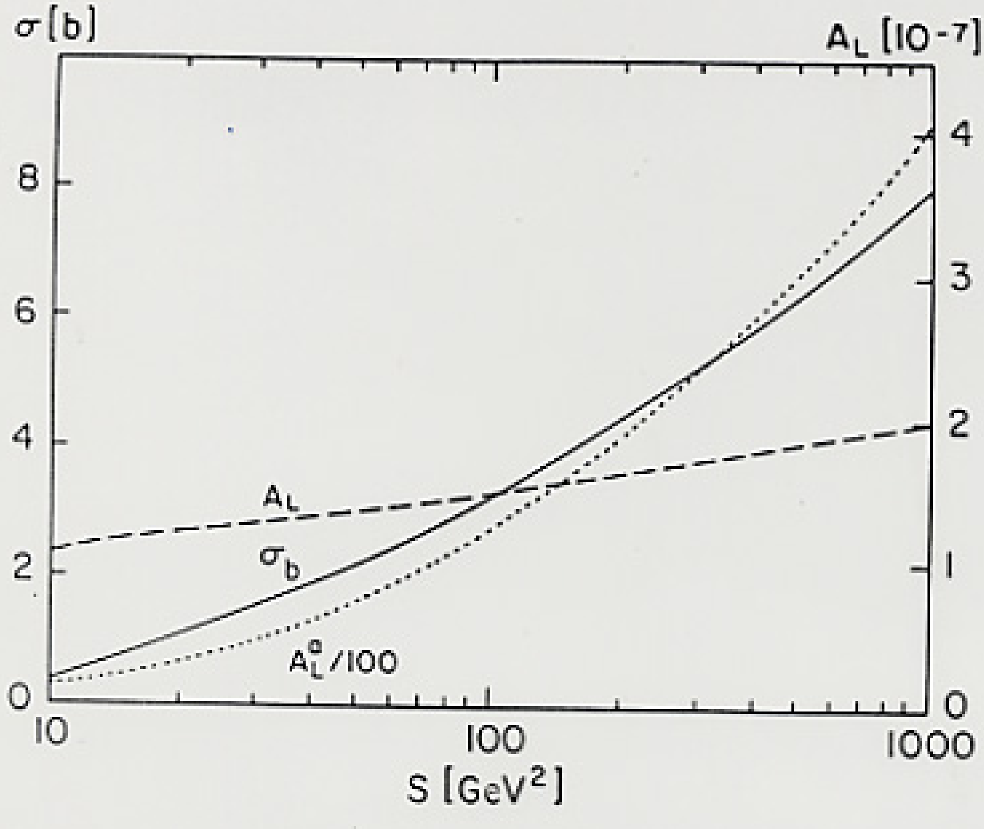


Fig. 1. Quark–quark (a) and quark–diquark (b, c) contributions to nucleon–nucleon scattering amplitudes. Wavy lines represent gluon exchange and the dot an effective parity violating (weak) four-fermion interaction.

$A_L \approx$ few $\times 10^{-7} \Rightarrow$ not a good explanation



Possible explanations (cont'ed)

3. G. Nardulli and G. Preparata [Phys. Lett. 137B (1984) 111]

Wave-function renormalization ⇒ Small negative parity component in nucleon w.f. due to self-interaction with weak bosons

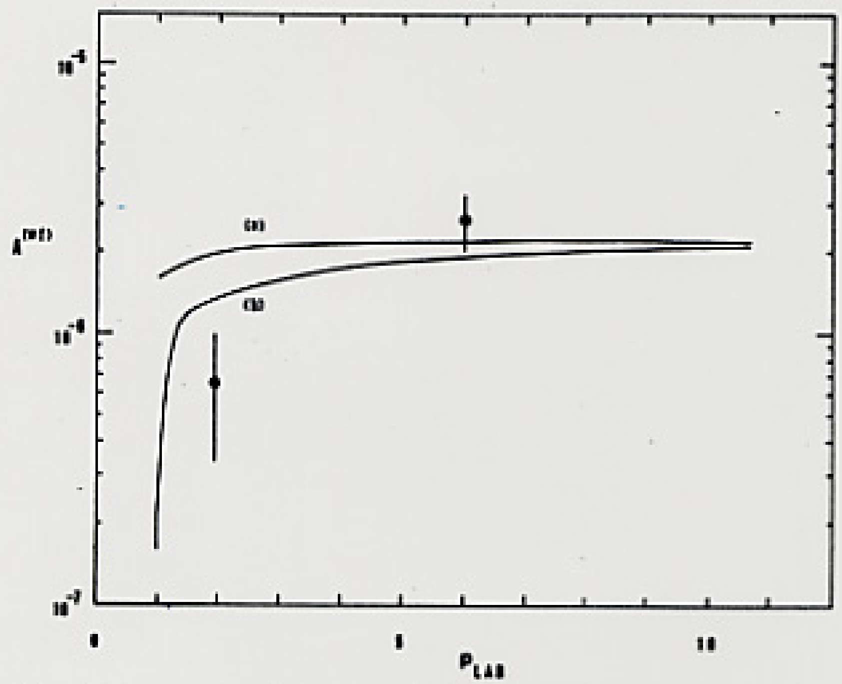


Fig. 1. Asymmetry due to wavefunction weak renormalization for proton–water scattering as a function of p_{lab}. Curve (a) includes only pomeron exchange (A_{∞}^{WF} in the text) while curve (b) includes 2π-exchange too. Experimental points are from refs. [3,20].

Gives the right order of magnitude

Proposal: study as function of energy between 1 and 10 GeV (A_L should be approximately constant)

Possible explanations (cont'ed)

2. L.L. Frankfurt and M.I. Strikman
[Phys. Rev D 33 (1986) 293]

Glauber shadowing $\Rightarrow$ Compressed quark-gluons configurations a.k.a MINI-HADRONS

GLAUBER THEORY $\Rightarrow$
$E = 1-10$ GeV

$$\frac{A_L(pA)}{A_L(pN)} = 0.50\left(\frac{A}{16}\right)^{-1/3} \text{ for } A \geq 16$$

MINI HADRONS $\rightarrow$
$E > 10$ GeV

$$\frac{A_L(pA)}{A_L(pN)} \simeq 0.77\left(\frac{A}{16}\right)^{-0.09}$$

Difference of factor 2 for $A \simeq 50$
2.8 . $A = 200$

Does not explain the Hto data at 5.1 GeV

Proposal. Study A-dependence ($A = 16-200$) in energy range 1-20 GeV to search for mini-hadron signature

CONCLUSIONS

1). Parity violation experiments with polarized protons at GeV energies are of fundamental importance

2) They allow to make connections between atomic physics, low energy nuclear physics, electron scattering and quark physics

3) But these are difficult experiments ($A_L \sim 10^{-7}$) belonging to second generation of polarization experiments

4) In view of the existence of a polarized proton beam with similar energies at AGS / RHIC-Spin, should one make a polarized beam at JHF? The question is open and the answer depends on the existence of an enthusiastic community behind such a big project.