Bounds on New Physics from APV in cesium

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Experiment 1999

$$Q_W\left({}^{133}_{55}\mathrm{Cs}\right) = -72.06 \pm (0.28)_{exp} \pm (0.34)_{theor}$$

$$= -72.06 \pm 0.44 \quad (0.6\ \%)$$

Standard Model

$$Q_W\left({}^{133}_{55}\mathrm{Cs}\right) = -73.24 \pm 0.13 \quad \text{(light Higgs)}$$

↑ (hadronic loops)

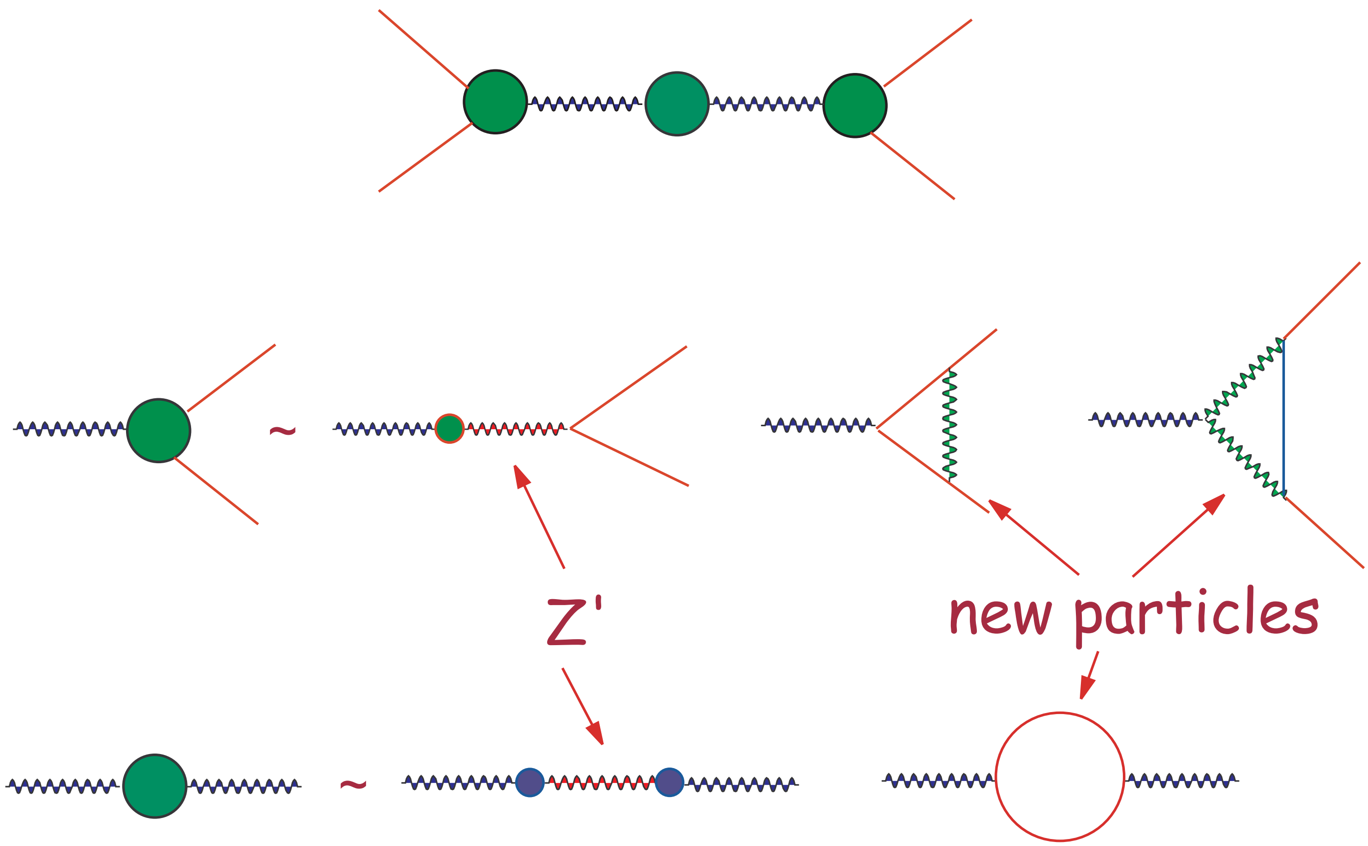
Deviation

$$Q_W^{exp} - Q_W^{theor} = 1.18 \pm 0.46$$

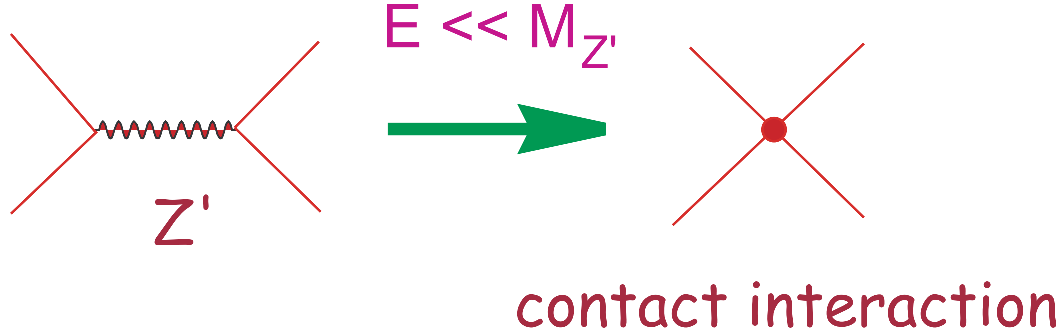
2.57 SD

disfavored at 99% C.L.

LEP physics puts heavy constraints on new physics. But which kind of new physics is detectable at LEP?



New physics invisible at LEP may come from new 4-fermi interactions



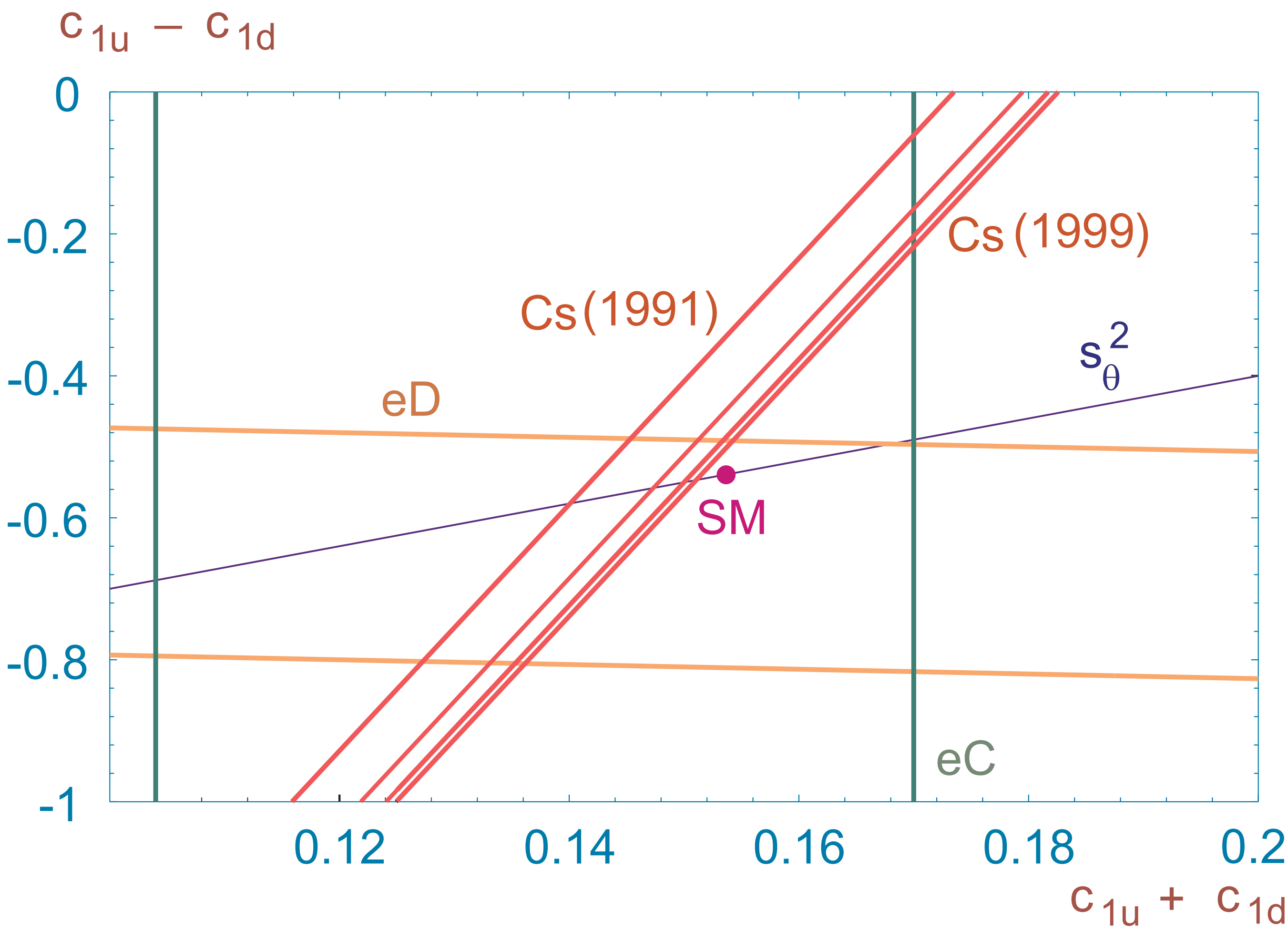
Main physical effects of contact interactions is to change the effective couplings of the gauge bosons to the fermions. Although LEP puts heavy constraints on the couplings it is not really capable of measuring the couplings to the light quarks. A good possibility are experiments in

Atomic Parity Violation

Measure the combinations $v_e a_q$, $a_e v_q$. In particular from the atomic cesium one gets

$$c_{1u,1d} = -8\, a_e\, v_{1u,1d}$$

(see fig.)



$c_{1u} - c_{1d}$
0
-0.2
-0.4
-0.6
-0.8
-1
0.12
0.14
0.16
0.18
0.2
$c_{1u} + c_{1d}$
Cs (1999)
Cs (1991)
s_θ^2
eD
SM
eC

Summary

- Discussion of the experiment on atomic cesium
- Implications of APV for new physics
  - New Vector Bosons
  - Extra-dimensions
  - Composite Models
  - Lepto-quarks
- Conclusions

Atomic Parity Violation

Within the SM the relevant 4-fermi PV interaction between charged leptons and quarks is given by

$$\mathcal{L}_{\text{eff}}^{PV} = \frac{G_F}{\sqrt{2}} \Big[(\bar{\ell}\gamma_\mu \gamma_5 \ell) \sum_{q=u,d} c_{1q} \bar{q}\gamma^\mu q +$$

$$+ (\bar{\ell}\gamma_\mu \ell) \sum_{q=u,d} c_{2q} \bar{q}\gamma^\mu \gamma_5 q \Big]$$

where

$$c_{1q} = -8 a_\ell v_q = -(T_3^q - 2 s_\theta^2 Q^q)$$

$$c_{2q} = -8 v_\ell a_q = -T_3^q (1 - 4 s_\theta^2)$$

$$a_f = -\frac{1}{2} T_{3L}^f, \qquad v_f = \frac{1}{2} \left(T_{3L}^f - 2 s_\theta^2 Q^f \right)$$

In terms of nucleons

$$\mathcal{L}_{\text{eff}}^{PV} = -\frac{G_F}{\sqrt{2}}\Big[(\bar{\ell}\gamma_\mu\gamma_5\ell)\sum_{N=p,n} c_{1N}\bar{N}\gamma^\mu N +$$

$$+(\bar{\ell}\gamma_\mu\ell)\sum_{N=p,n} c_{2N}\bar{N}\gamma^\mu\gamma_5 N\Big]$$

where

$$c_{1p} = -2c_{1u} - c_{1d}, \qquad c_{1n} = -c_{1u} - 2c_{1d}$$

In the non-relativistic limit one gets, for a single nucleon,

$$H_{PV} = \frac{G_F}{2\sqrt{2}m_\ell}\Big[c_{1N}\vec{\sigma}_\ell\cdot[\vec{p},\delta^3(\vec{r})]_+ +$$

$$+c_{2N}\vec{\sigma}_N\cdot[\vec{p},\delta^3(\vec{r})]_+ - ic_{2N}(\vec{\sigma}_\ell\wedge\vec{\sigma}_N)\cdot[\vec{p},\delta^3(\vec{r})]_+\Big]$$

Finally, for a point-like nucleus

$$H_{PV} = \frac{G_F}{4\sqrt{2}m_\ell}\Big[Q_W(Z,A)\vec{\sigma}_\ell\cdot[\vec{p},\delta^3(\vec{r})]_+ +$$

$$+2(c_{2p}\vec{S}_p + c_{2N}\vec{S}_n)\cdot[\vec{p},\delta^3(\vec{r})]_+$$

$$-2i\vec{\sigma}_\ell\wedge(c_{2p}\vec{S}_p + c_{2n}\vec{S}_n)\cdot[\vec{p},\delta^3(\vec{r})]_+\Big]$$

The weak charge of the nucleus is defined as

$$Q_W(Z, A) = 2\left[c_{1p}Z + c_{1n}N\right]$$

For large values of Z, the term in Q_W is dominant. There is a coherence effect (Bouchiat and Bouchiat 1974-75)

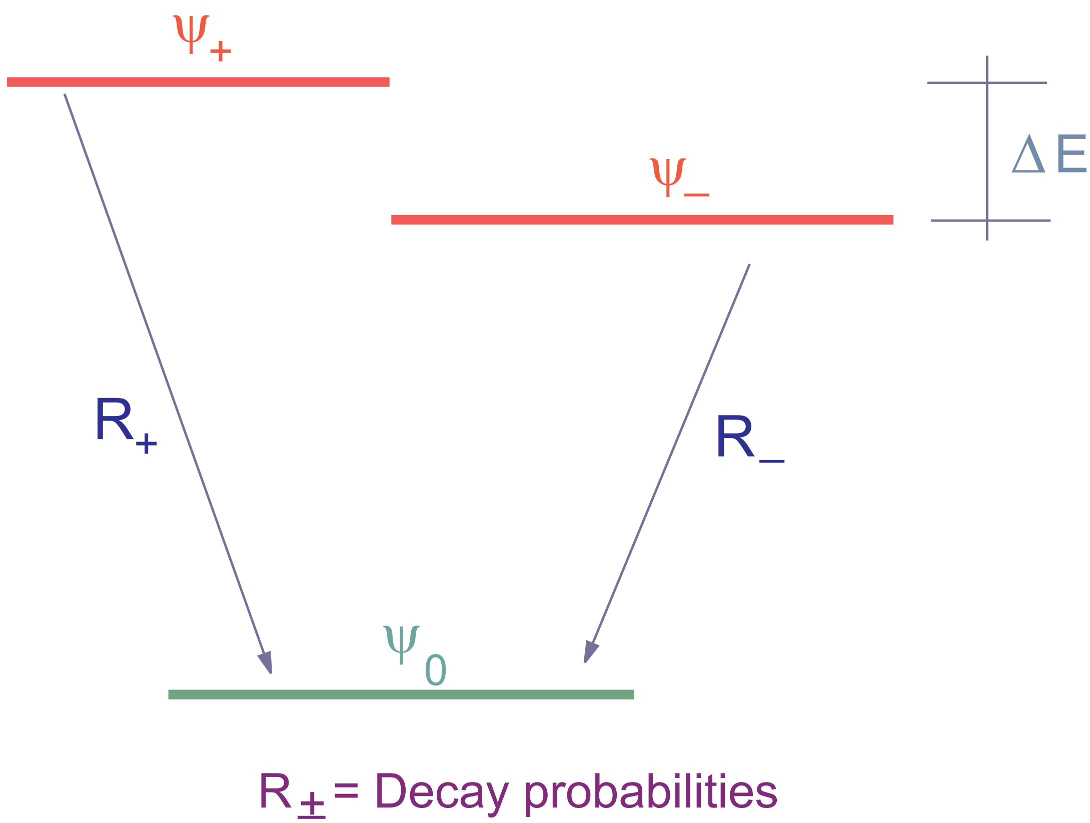
$$\langle H_{PV}\rangle \propto Z^2 Q_W(Z, A) \propto Z^3$$

In fact, since

$$H_{PV} \propto Q_W \vec{\sigma}_\ell \cdot [\vec{p}, \delta^3(\vec{r})]_+$$

one gets one Z from $\vec{p}$ and one Z from the wave function at the origin. Whereas, for large Z, spin terms tend to cancel.

The general idea is to consider two parity eigenstates $\psi_\pm$ mixed by H_{PV}, with ψ_+ of the same nominal parity as ψ_0.



$$|\psi_+\rangle \to |\psi_+\rangle + \eta|\psi_-\rangle$$

with

$$\eta = \frac{\langle\psi_+|H_{PV}|\psi_-\rangle}{\Delta E}$$

and construct the quantity

$$A = \frac{|\langle\psi_0 + \gamma|\psi\rangle|^2 - |\langle\psi_0 + \gamma|\psi\rangle_P|^2}{|\langle\psi_0 + \gamma|\psi\rangle|^2 + |\langle\psi_0 + \gamma|\psi\rangle_P|^2} \approx 2\eta\left(\frac{R_-}{R_+}\right)^{1/2}$$

$$\eta = \frac{\langle\psi_+|H_{PV}|\psi_-\rangle}{\Delta E}$$

To get big A requires

- $\langle\psi_+|H_{PV}|\psi_-\rangle$ large:
  - coherence
  - large overlap of $\psi_\pm$ with the nucleus
- ΔE small
- R_-/R_+ large, R_+ suppressed transition

Large overlap

It could be realized in nuclei

$$\langle \psi_+ | H_{PV} | \psi_- \rangle \approx \frac{1}{V}$$

Since

$$\eta = \frac{\langle \psi_+ | H_{PV} | \psi_- \rangle}{\Delta E}$$

we get

$$\frac{\eta_{\text{atoms}}}{\eta_{\text{nuclei}}} \approx Z^3 \left[\frac{1}{r^3 \Delta E}\right]_{\text{atoms}} \Big/ \left[\frac{1}{r^3 \Delta E}\right]_{\text{nuclei}} \approx$$

$$\approx Z^3 \left(\frac{r_{\text{nuclei}}}{r_{\text{atoms}}}\right)^3 \frac{\Delta E_{\text{nuclei}}}{\Delta E_{\text{atoms}}} \approx Z^3 (10^{-4})^3 10^6 \approx$$

$$\approx Z^3\, 10^{-6}$$

For an atom like cesium, $Z = 55$ ($Z^3 \approx 2 \cdot 10^5$) we get

$$\frac{\eta_{\text{nuclei}}}{\eta_{\text{atoms}}} \approx 1$$

In presence of parity violation there are two physical effects related to the light propagation, due to the dependence of the refraction index on the circular polarization of photons traveling in a medium of atomic vapor density D

$$n_{\pm} = 1 - \frac{2\pi D}{\hbar}\left[R_{+} \pm 2Im(\eta)\sqrt{R_{+}R_{-}}\right] f(\omega, \omega_0)$$

For a photon of frequency ω, close to a resonant frequency ω_0, $f(\omega, \omega_0)$ describes the lineshape of the resonance.

- Optical rotation: The difference of the real parts of $n_{\pm}$ gives rise to a rotation of the polarization plane of a linearly polarized laser beam tuned to ω_0

$$\phi \approx Im(\eta)\sqrt{R_{+}R_{-}}$$

- Circular dichroism: The resonant absorption of circularly polarized photons depends on the polarization

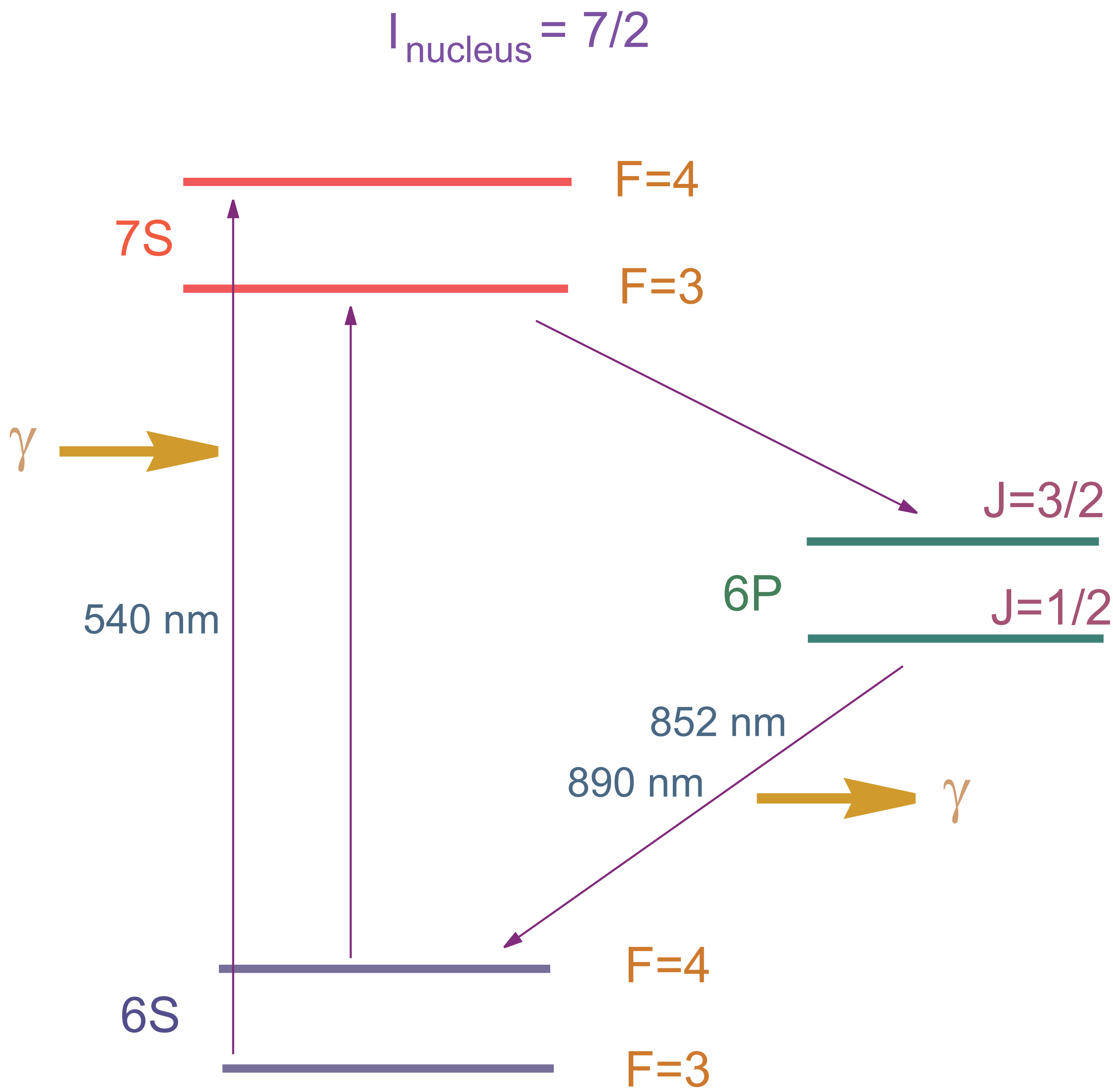
$$\delta = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx 2Im(\eta)\sqrt{\frac{R_-}{R_+}}$$

The amounts of fluorescence light depends on the handedness of the radiation

Last technique has been used in conjunction with a forbidden transition R_+, in atomic cesium, giving rise to $\delta \approx 10^{-4} \div 10^{-3}$, in Paris (1982, 1984) and in Boulder (1985, 1988, 1997). To overcome the background the interference with a large electro-induced (Stark) transition has been used.

Experiment $\longrightarrow \langle H_{PV} \rangle \approx Q_W \, \kappa_{PV}$.

The atomic form-factor κ_{PV} must be evaluated theoretically.



I nucleus = 7/2
F=4
7S
F=3
γ
J=3/2
6P
J=1/2
540 nm
852 nm
890 nm
γ
F=4
6S
F=3

Status of the theoretical evaluation of κ_{PV}

Although the cesium is a relatively simple atom since it is well described by a single valence electron outside a spherically symmetric core, the evaluation is not from first principles

- Many-body perturbative theory with Hartree-Fock potential
  - Exp. values of PC observables agree within a given error
  - Stability within a given error against variation of the parameters
  - Different approximation scheme gives the same result within the given error

- Taken into account
  - Nuclear distribution
  - Nuclear spin-dependent effects
  - Z-exchange among the electrons ($< 0.03\%$)

Many auxiliary variables have been computed

- Allowed $E1$ transitions rates and excited states lifetimes (test ψ at large r)

- Energies and fine structure splittings

- Hyperfine structure splittings (test ψ near $r = 0$), very important for APV

- Stark-induced $E1$ amplitudes

Theoretical error in 1992 $\approx 1\%$

In 1999 down to 0.4%**!!!!**

The main reason is that after new measurements of relevant quantities in cesium the agreement with the theoretical calculation is much better. Furthermore a problem of the previous calculations, when applied to sodium and lithium, leading to 1% discrepancy in the lifetimes, it has now disappeared after new experiments.

Quantity measured	Calculation tested	Difference ($\times 10^3$) Dzuba, *et al.*	Blundell *et al.*	σ_{Expt}
$\rightarrow$7S dc Stark shift	$\langle 7P \parallel D \parallel 7S \rangle$	−3.4[19]	−0.7[22]	1.0[4]
$6P_{1/2}$ lifetime	$\langle 6S \parallel D \parallel 6P_{1/2} \rangle$	−4.2[−8]	4.3[1]	1.0[43]
$6P_{3/2}$ lifetime	$\langle 6S \parallel D \parallel 6P_{3/2} \rangle$	−2.6[−41]	7.9[−31]	2.3[22]
α	$\langle 7S \parallel D \parallel 6P_{1/2} \rangle$, and $\langle 7S \parallel D \parallel 6P_{3/2} \rangle$	–	−1.4	3.2
β	same as α	–	−0.8	3.0
6S HFS	$\psi_{6S}(r=0)$	1.8	−3.1	–
7S HFS	$\psi_{7S}(r=0)$	−6.0	−3.4	0.2
$6P_{1/2}$ HFS	$\langle 1/r^3 \rangle_{6P}$	−6.1	2.6	0.2
$7P_{1/2}$ HFS	$\langle 1/r^3 \rangle_{7P}$	−7.1	−1.5	0.5

Many Body Perturbation Theory

Decompose the hamiltonian as

$$H = H_C + H_{Br} = H_{free} + V_{nucl.} + \sum \frac{\alpha}{|\vec{r}_i - \vec{r}_j|}$$

$$H_{Br} = \text{ spin part}$$

then introducing one-body potential $\sum U(\vec{r}_i)$

$$H_C = H_0 + V_C$$

$$H_0 = H_{free} + V_{nucl.} + \sum U(\vec{r}_i)$$

$$V_C = \sum \frac{\alpha}{|\vec{r}_i - \vec{r}_j|} - \sum U(\vec{r}_i)$$

since H_0 is separable one has to solve one-body problem, and then use this wave functions to construct the Fock space. The Coulomb part is defined in the Fock space as

$$V_C = \frac{1}{2} \sum g_{ijkl} a_i^\dagger a_j^\dagger a_l a_k - \sum_{ij} U_{ij} a_i^\dagger a_j$$

$$g_{ijkl} = \alpha \int \frac{1}{|\vec{r} - \vec{r}'|} \psi_i^\dagger(\vec{r}) \psi_k(\vec{r}) \psi_j^\dagger(\vec{r}') \psi_l(\vec{r}')$$

The fundamental state of the cesium is taken as

$$|v\rangle = a_v^\dagger |0_C\rangle$$

that is a valence electron creation operator acting upon the ground-state configuration of the xenon. The one-body potential is taken as the frozen-core V^{N-1}. One solves HF for Cs^+ in the configuration of the ground-state of the xenon. Then keeping these orbitals fixed one solves for the valence orbitals. A further improvement is obtained by expanding the ground state wave function as

$$|\Psi\rangle \approx \left(1 + \sum \rho_{ijkl} a_i^\dagger a_j^\dagger a_k a_l + \text{tripleterms}\right) |0_C\rangle$$

and solving in the self-consistent HF potential for the coefficients in the expansion.

An alternative calculation is to start in a parity mixed basis by putting H_{PV} in the one-body hamiltonian. Agreement within a few per mill.

The data on APV

In 1988 (Boulder) gets Q_W at a level of 2.5%

$Q_W\left({}^{133}_{55}Cs\right) = -71.04 \pm (1.58)_{\text{exp}} \pm (0.88)_{\text{theor}}$

to be compared with the SM result

$Q_W^{\text{SM}}\left({}^{133}_{55}Cs\right) = -73.24 \pm 0.13, \quad m_H \approx 100\ GeV$

leading to

$$Q_W^{\text{exp}} - Q_W^{\text{theor}} = 2.2 \pm 1.81, \quad (1.21\ SD)$$

In 1999 the same group, with uncertainty 0.6%

$$Q_W\left({}^{133}_{55}Cs\right) = -72.06 \pm (0.28)_{\text{exp}} \pm (0.34)_{\text{theor}}$$

$$Q_W^{\text{exp}} - Q_W^{\text{theor}} = 1.18 \pm 0.46, \quad (2.57\ SD)$$

SM disfavored at 99 % CL

For increasing m_H, Q_W decreases and the discrepancy increases

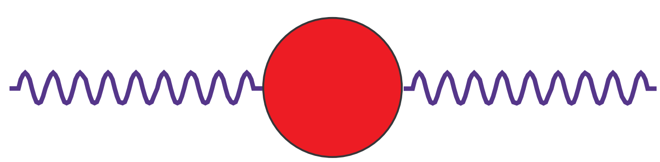
Let us parameterize

$$Q_W = -72.72 \pm 0.13 - 102\epsilon_3^{\rm rad} + \delta_N Q_W$$

$\epsilon_3^{\rm rad}$ comes from radiative corrections in the SM and depends on m_H and m_t. For $m_t = 175\ GeV$

$$m_H = 100\ GeV \quad \epsilon_3^{\rm rad} = 5.110 \times 10^{-3}$$
$$m_H = 300\ GeV \quad \epsilon_3^{\rm rad} = 6.115 \times 10^{-3}$$
$$m_H = 1000\ GeV \quad \epsilon_3^{\rm rad} = 6.65 \times 10^{-3}$$

LEP and SLC physics constrains strongly deviations from the SM (see the pulls). For instance, considers new physics contributing to the Z self-energy (oblique corrections)

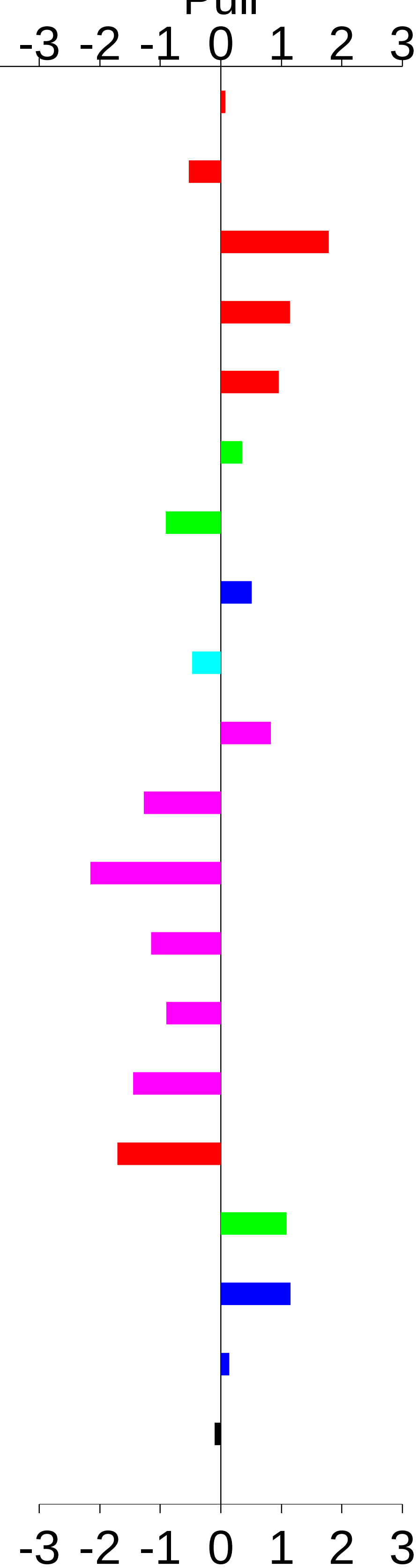


contributes to Q_W as $\epsilon_3^{\rm rad}$

$$\delta_N Q_W(\text{oblique}) = -102\,\epsilon_{3N}$$

Tampere 1999

	Measurement	Pull
m_Z [GeV]	91.1871 ± 0.0021	.07
Γ_Z [GeV]	2.4944 ± 0.0024	-.53
σ^0_{hadr} [nb]	41.544 ± 0.037	1.78
R_e	20.768 ± 0.024	1.15
$A^{0,e}_{fb}$	0.01701 ± 0.00095	.96
A_e	0.1483 ± 0.0051	.35
A_τ	0.1425 ± 0.0044	-.91
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010	.51
m_W [GeV]	80.350 ± 0.056	-.48
R_b	0.21642 ± 0.00073	.83
R_c	0.1674 ± 0.0038	-1.27
$A^{0,b}_{fb}$	0.0984 ± 0.0020	-2.15
$A^{0,c}_{fb}$	0.0691 ± 0.0037	-1.15
A_b	0.912 ± 0.025	-.90
A_c	0.630 ± 0.026	-1.45
$\sin^2\theta^{lept}_{eff}$	0.23109 ± 0.00029	-1.71
$\sin^2\theta_W$	0.2255 ± 0.0021	1.09
m_W [GeV]	80.448 ± 0.062	1.15
m_t [GeV]	174.3 ± 5.1	.13
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065	-.10



To compensate the discrepancy one would need

$$\epsilon_{3N} = (-11.6 \pm 4.5) \times 10^{-3}$$

whereas

$$\epsilon_3^{\text{exp}} = \epsilon_3^{\text{rad}} + \epsilon_{3N} = (4.19 \pm 1) \times 10^{-3}$$

and for a light Higgs

$$\epsilon_{3N} = (-0.92 \pm 1) \times 10^{-3}$$

almost an order of magnitude too small.

We need new physics not constrained by LEP.

Bounds on $\delta_N Q_W$

$$\Delta Q_W = Q_W^{\text{exp}} - Q_W^{\text{theor}}(m_H)$$

$$\Delta Q_W = 0.66 + 102\epsilon_3(m_H) - \delta_N Q_W \pm 0.46$$

At a given CL we have the bound

$$b_- \le \delta_N Q_W \le b_+$$

$$b_\pm = 0.66 + 102\epsilon_3(m_H) \pm 0.46\, c$$

where c depends on the CL. For a light Higgs

$$95\%\text{CL}, \quad 0.28 \le \delta_N Q_W \le 2.08$$

$$99\%\text{CL}, \quad 0 \le \delta_N Q_W \le 2.37$$

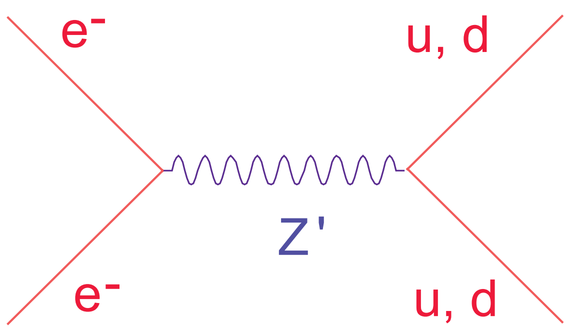
The positive lower bound implies strong restrictions on new physics. For increasing m_H both bounds increase.

Models of New Physics

Extra-U(1) Models

Models with a further massive neutral vector boson, Z' coupled to ordinary fermions with a current

$$J^f_{Z'\mu} = \bar{\psi}_f \left[\gamma_\mu v'_f + \gamma_\mu \gamma_5 a'_f\right] \psi_f$$



The couplings depend on the angle θ_2

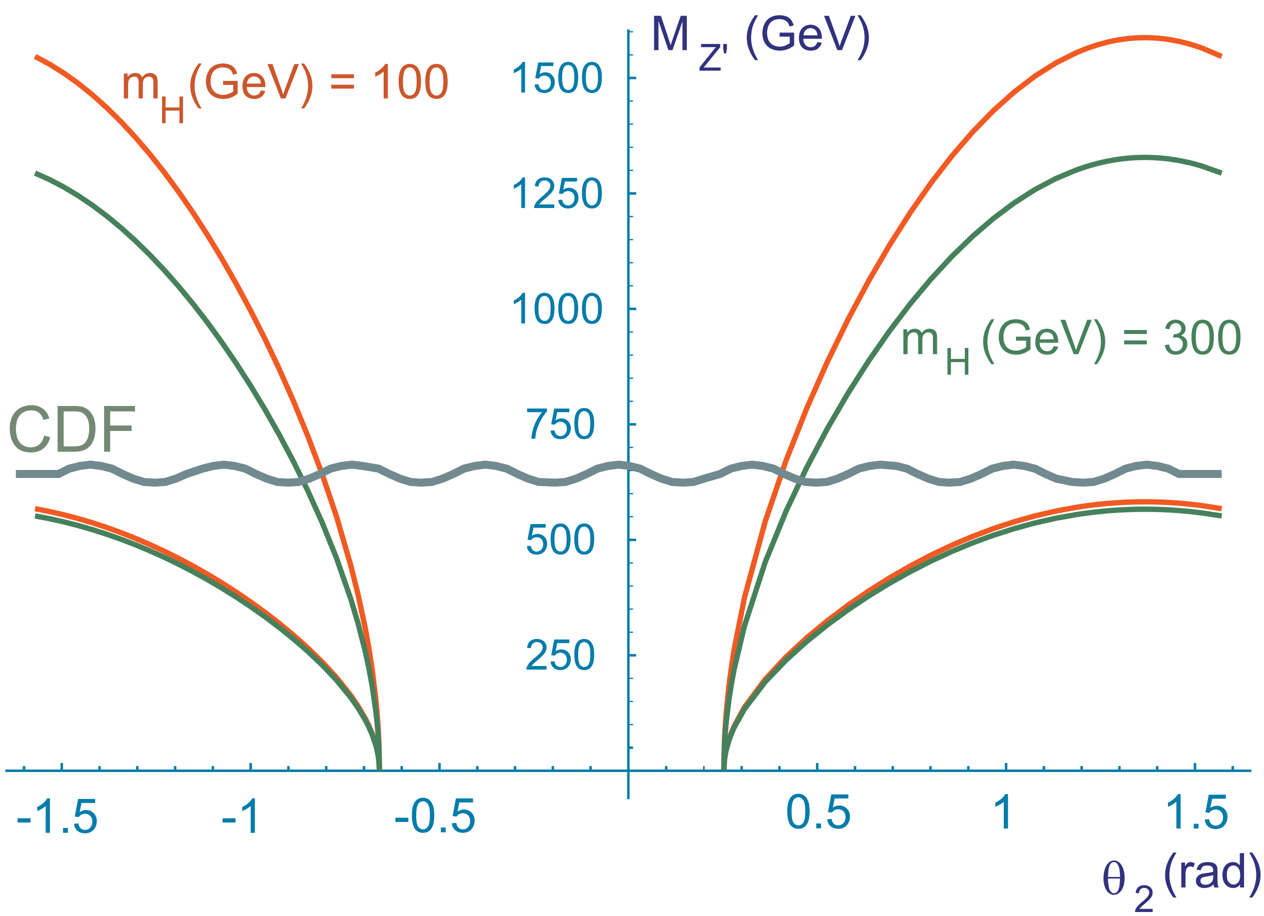
$$a'_e = \frac{1}{4} s_\theta \left[-\frac{1}{3} c_2 + \sqrt{\frac{5}{3}} s_2\right] \qquad c_2 = \cos\theta_2$$

$$v'_d = \frac{1}{4} s_\theta \left[c_2 + \sqrt{\frac{5}{3}} s_2\right] \qquad v'_u = 0$$

The corrections at Q_W, for Z' non mixed to Z, is

$$\delta_N Q_W = 16 a'_e \left[(2Z+N)v'_u + (Z+2N)v'_d\right] \frac{M_Z^2}{M_{Z'}^2},$$

Bounds on $\delta_N Q_W \rightarrow$ 95 % CL bounds on $M_{Z'}$



Lower positive bound on $\delta_N Q_W \longrightarrow$ upper bound on $M_{Z'}$. Excluded region $\longrightarrow \delta_N Q_W \leq 0$.

Direct search at Tevatron $\longrightarrow$ gives approximately $M_{Z'}(GeV) \geq 600$.

LR models

LR symmetric models with fermionic couplings

$$a'_e v'_{u,d} = -a_e^{SM} v_{u,d}^{SM}$$

giving

$$\delta_N Q_W = -\frac{M_Z^2}{M_{Z'}^2} Q_W^{SM} > 0$$

The bound is (for light Higgs)

$$540 \le M_{Z'}(GeV) \le 1470$$

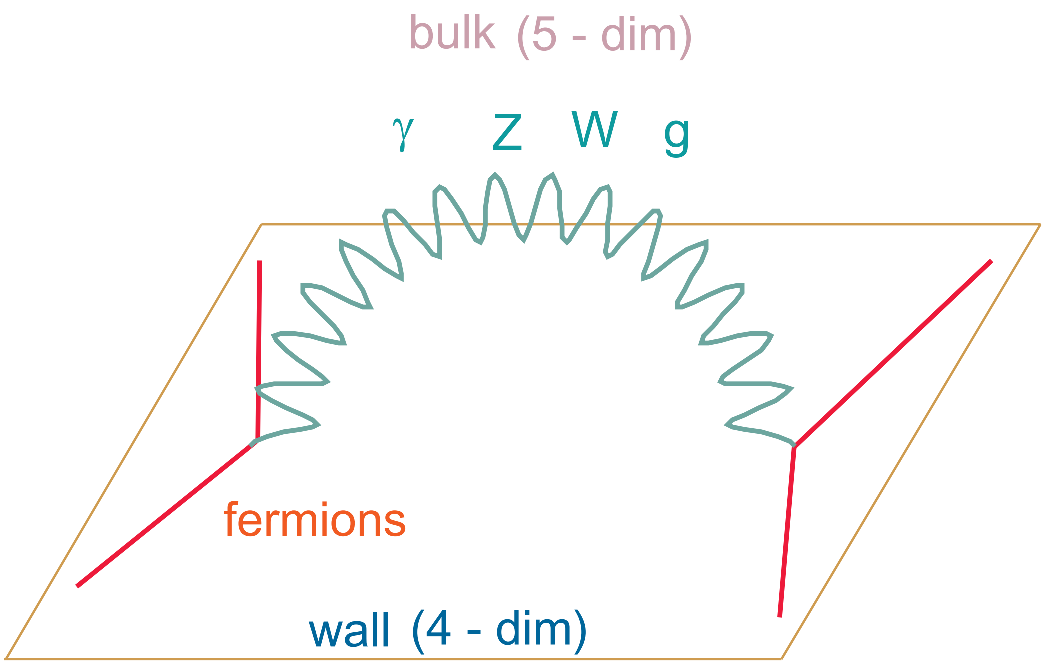
The limit from Tevatron is $M_{Z'} \ge 630\ GeV$

Notice that a simple scaled Z' model would give the opposite sign

$$\delta_N Q_W = \frac{M_Z^2}{M_{Z'}^2} Q_W^{SM} < 0$$

Excluded at more than 99% CL

Extra-dimension Models



= infinite tower of KK-resonances in 4 dim

The extra-dimensions are supposed to be compactified with a compactification radius R ($>$ than a few TeV). The KK excitations of the SM gauge bosons have a mass

$$M_{KK}^2 = \frac{n^2}{R^2}$$

The couplings of the KK modes to fermions are

$$\text{KK couplings} = \sqrt{2}\ \text{SM couplings}$$

If there were only Z-like KK modes, the correction to Q_W would be

$$\delta_N Q_W = (\sqrt{2})^2 \sum_{n=1}^{\infty} M_Z^2 \frac{R^2}{n^2} Q_W$$

However the W-like KK modes give a correction to G_F implying ($M_Z^2 > M_W^2$)

$$\delta_N Q_W \to (\sqrt{2})^2 \sum_{n=1}^{\infty} (M_Z^2 - M_W^2) \frac{R^2}{n^2} Q_W < 0$$

The change of s_θ also gives $\delta_N Q_W < 0$.

Extra-dimension models are disfavored at more than 99% CL for any compactification radius.

The result does not change in presence of mixing terms as long as $\sin\beta < 0.707$ ($\delta_N Q_W < 0$).

Z **Physics** ($E \approx m_Z << M$)

$$\mathcal{L}_{eff}^{charged} = -\tilde{g}(1 - s_\beta^2 \tilde{c}_\theta^2 X) \sum_{i=1}^{2} J_\mu^i W^{i\mu}$$

$$-\frac{\tilde{g}^2}{2m_Z^2} X \sum_{i=1}^{2} J_\mu^i J^{i\mu}$$

$$\mathcal{L}_{eff}^{neutral} = -\frac{e}{\tilde{s}_\theta \tilde{c}_\theta} J_\mu^Z Z^\mu (1 - s_\beta^2 X) - e J_\mu^{em} A^\mu$$

$$-\frac{e^2}{2\tilde{s}_\theta^2 \tilde{c}_\theta^2 m_Z^2} X J_\mu^Z J^{Z\mu} - \frac{e^2}{2m_Z^2} X J_\mu^{em} J^{em\mu}$$

$$X = \frac{\pi^2}{3} \frac{m_Z^2}{M^2} \qquad \tilde{s}_\theta^2 = s_\theta^2 \left(1 + \frac{\tilde{c}_\theta^2}{c_{2\theta}} \Delta\right) \qquad \tilde{e} = e$$

$$\Delta = \left(\tilde{c}_\theta^2 (1 - s_\beta^2)^2 - s_\beta^4\right) X \qquad \frac{G_F}{\sqrt{2}} = \frac{e^2}{8 s_\theta^2 c_\theta^2 m_Z^2}$$

$$\frac{m_W^2}{m_Z^2} = c_\theta^2 \left(1 - \frac{s_\theta^2}{c_{2\theta}} \Delta r_W\right)$$

$$\Delta r_W = \tilde{c}_\theta^2 \left(1 - 2s_\beta^2 - s_\beta^4\right) X$$

Low-energy Physics ($E << m_Z$)

$$\mathcal{L}_{eff}^{\text{low-en}} = -4\frac{G_F}{\sqrt{2}}\Big[\sum_{i=1}^{2} J_\mu^i J^{\mu i}$$

$$+ (1 + s_\theta^2(1 - s_\beta^2)^2 X) J_\mu^Z J^{\mu Z}\Big]$$

Deviations from the SM

Z-pole

$$\epsilon_{1N} = -c_\theta^2 X[1 + s_\beta^2 \frac{s_\theta^2}{c_\theta^2}(1 + c_\beta^2)]$$

$$\epsilon_{2N} = -c_\theta^2 X \qquad \epsilon_{3N} = -2c_\theta^2 s_\beta^2 X$$

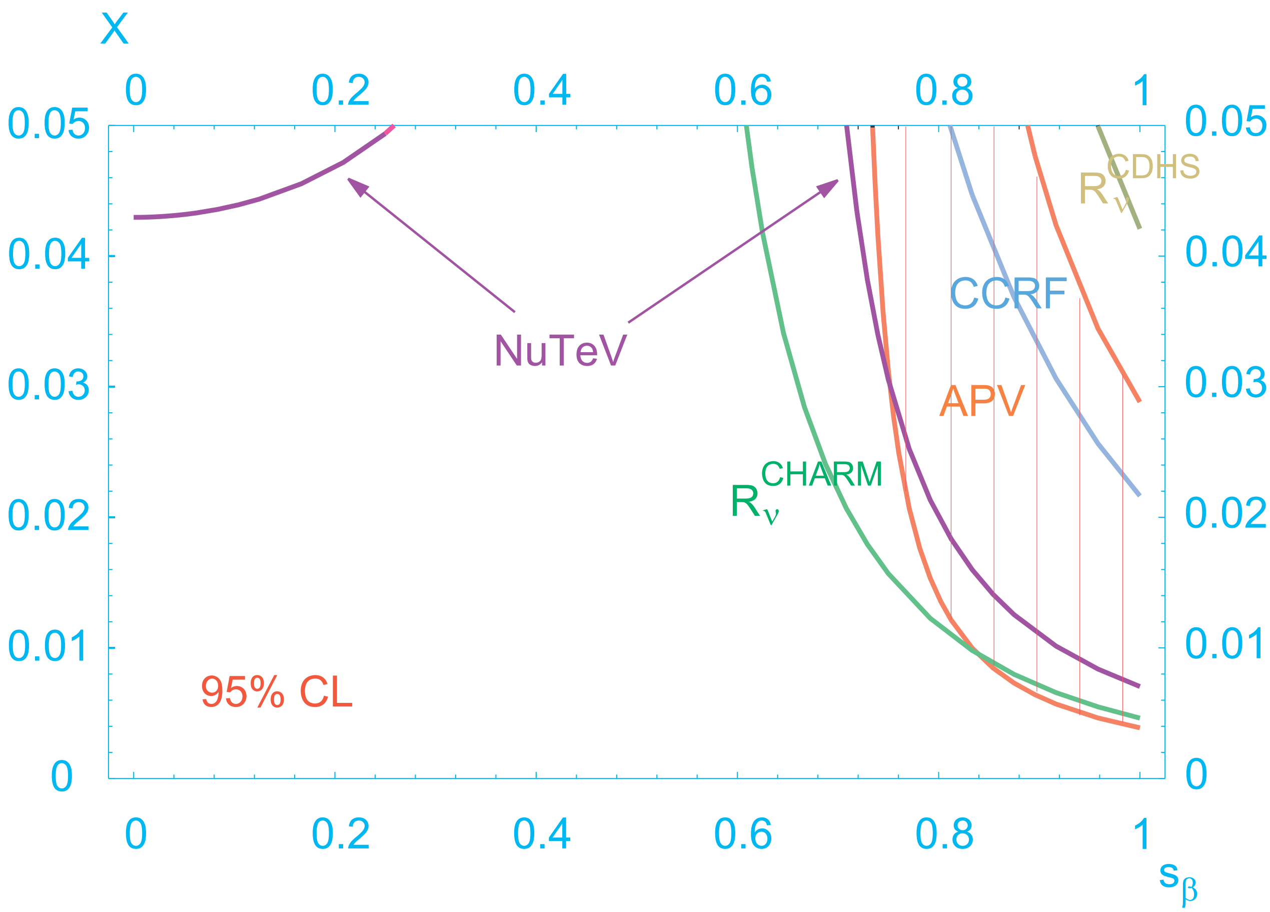
Low-energy

$$Q_W = \bar{Q}_W[1 + s_\theta^2 X(s_\beta^2 - 1)^2] - 4\frac{s_\theta^2 c_\theta^2}{c_{2\theta}} Z\Delta$$

$$\Delta = \left(\tilde{c}_\theta^2(1 - s_\beta^2)^2 - s_\beta^4\right) X$$

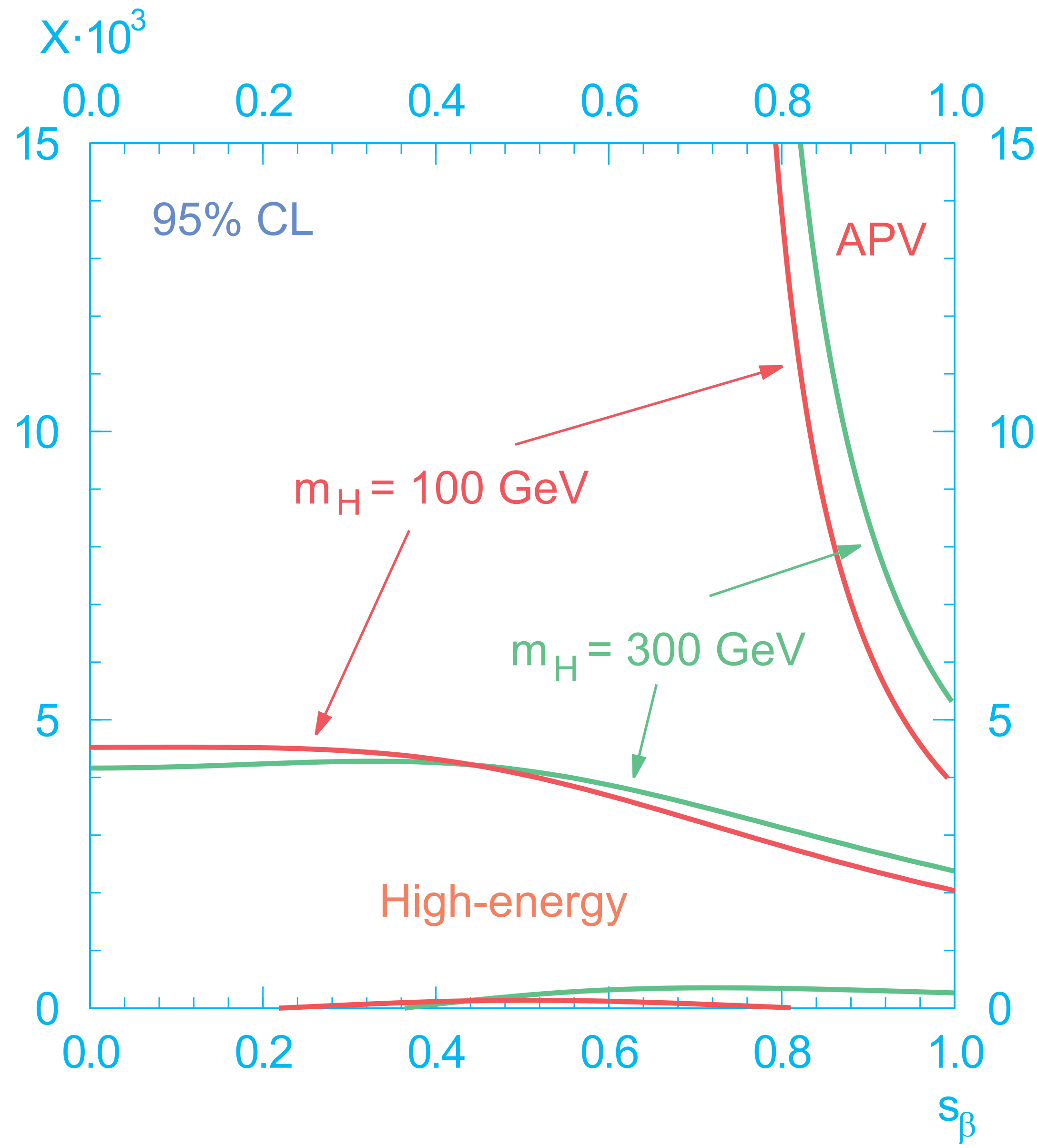
95% CL Bounds on Extra Dimension Models from low-energy data

$$X = 2\frac{m_Z^2}{M^2}\sum_{\vec{n}}\frac{f(\vec{n}^2)}{\vec{n}^2} \rightarrow \frac{\pi^2}{3}\frac{m_Z^2}{M^2} \quad \text{(for 1 ED)}$$

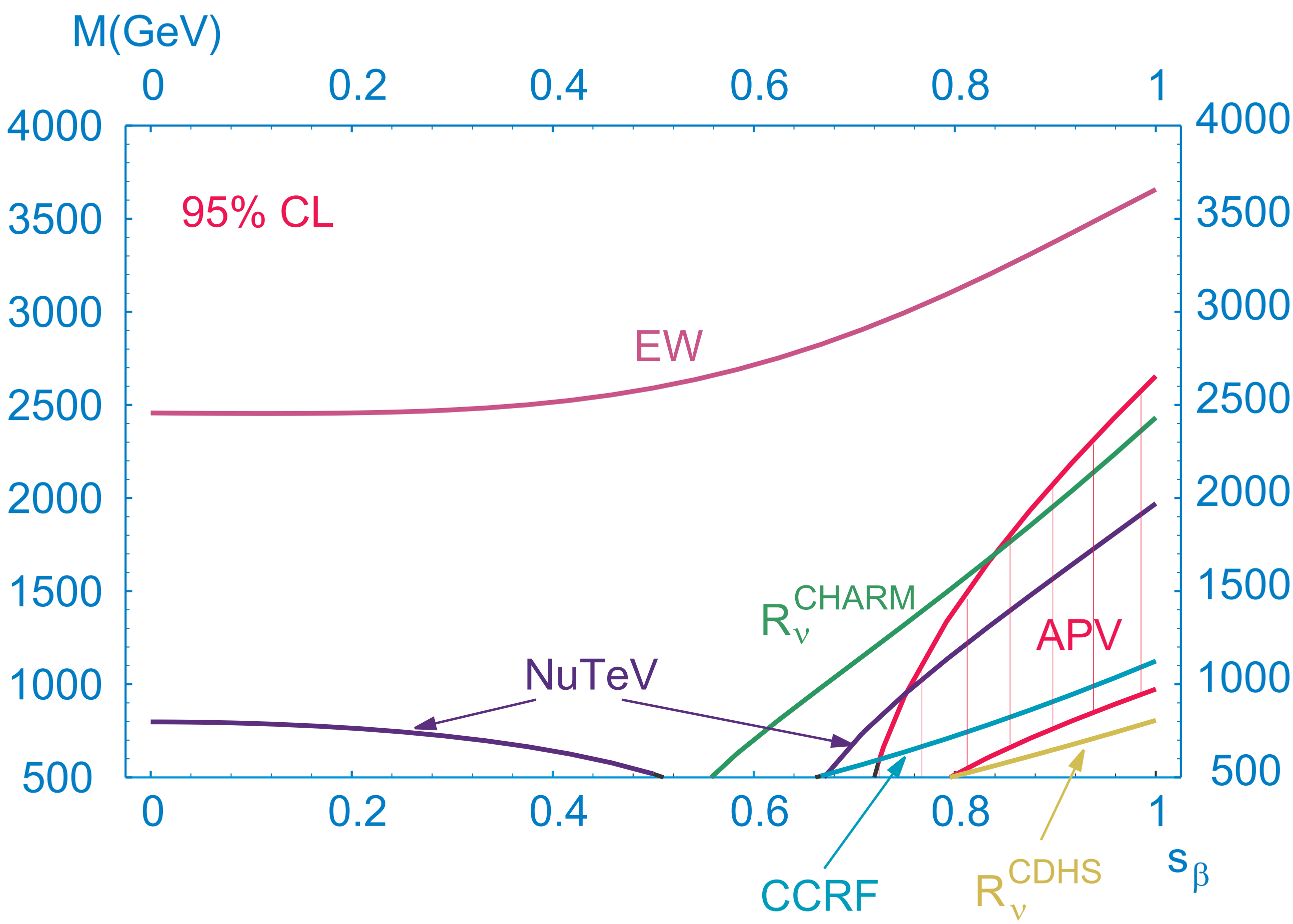


95% CL Bounds on Extra Dimension Models from APV and high-energy data

$$X = 2\frac{m_Z^2}{M^2}\sum_{\vec{n}}\frac{f(\vec{n}^2)}{\vec{n}^2} \rightarrow \frac{\pi^2}{3}\frac{m_Z^2}{M^2} \quad \text{(for 1 ED)}$$



95% CL Bounds on Extra Dimension Models



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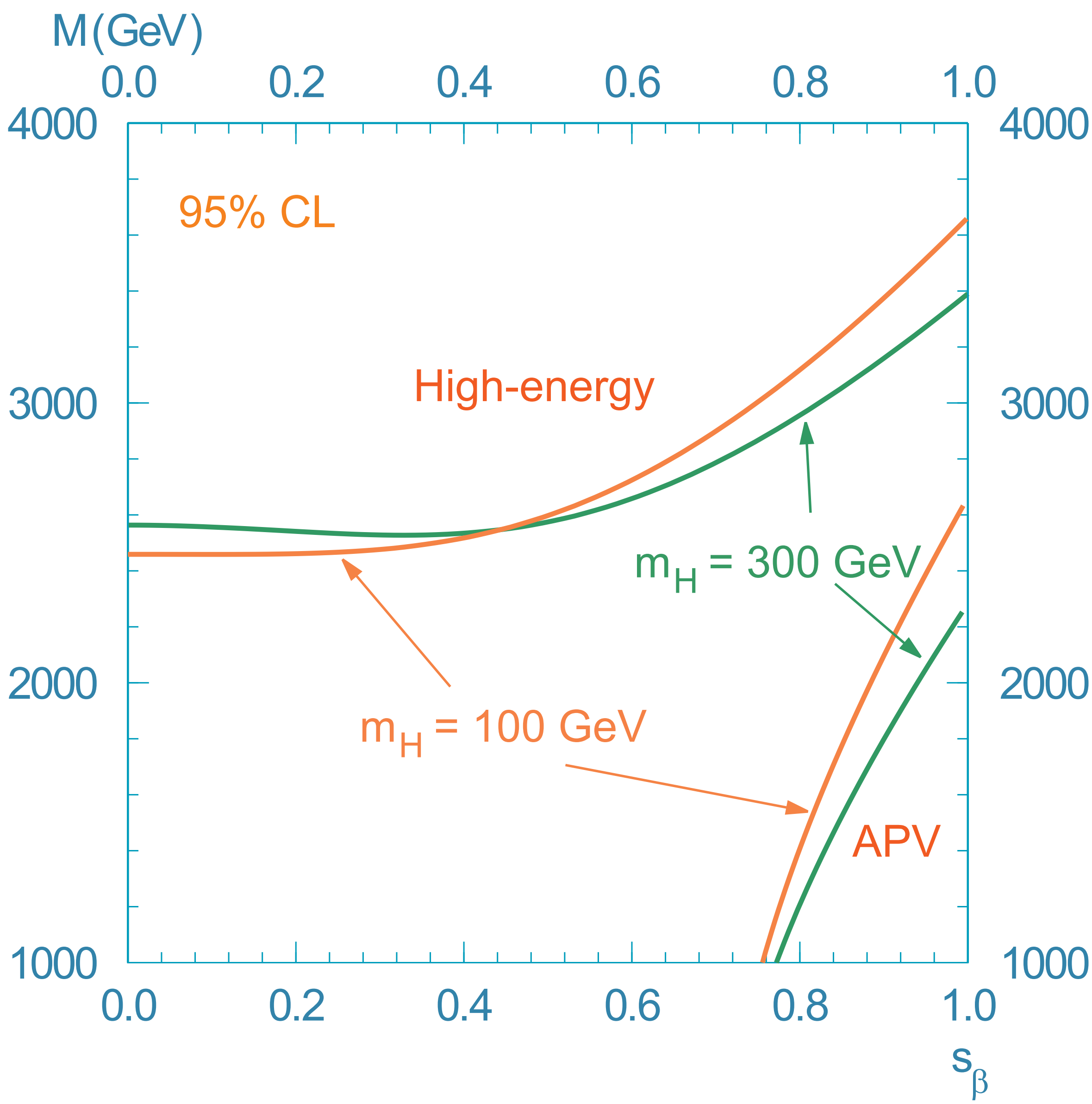


Other Contact Interactions

Using

$$Q_W = 2\left[c_{1p}Z + c_{1n}N\right]$$

and

$$c_{1p} = -2c_{1u} - c_{1d}, \quad c_{1n} = -c_{1u} - 2c_{1d}$$

we find

$$Q_W = -2\left[(2Z+N)c_{1u} + (Z+2N)c_{1d}\right]$$

The contact interactions modify the coefficients $c_{1u,1d}$

$$c_{1u,1d} \to c_{1u,1d} + \Delta C_{1u,1d}$$

$$\Delta C \geq 0 \longrightarrow \delta_N Q_W \leq 0$$

leads to exclusion at more than 99 %CL

Composite Models

$$\mathcal{L} = \pm \frac{g^2}{\Lambda^2} \bar{e}\, \Gamma_\mu\, e\, \bar{q}\, \Gamma^\mu\, q$$

with $\Gamma_\mu = \gamma_\mu \frac{1-\gamma_5}{2}$.

$$c_{1u,1d} \to c_{1u,1d} + \Delta C$$

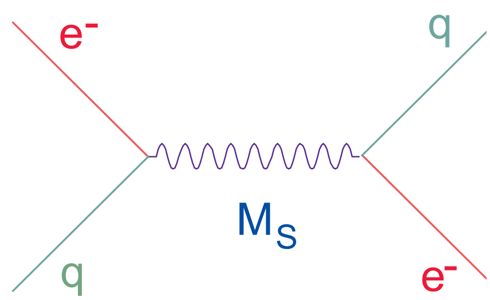
In these models the contact interaction is generated by a strong interaction, then we expect $g^2 \approx 4\pi$

$$\Delta C = \mp \frac{\sqrt{2}\pi}{G_F \Lambda^2}$$

The negative sign in $\mathcal{L}$ is excluded, whereas for the positive sign we have the 95 % CL bound

$$12.1 \leq \Lambda(TeV) \leq 32.9$$

Lepto-quarks



$$\mathcal{L} = \frac{\eta_L^2}{2M_S^2}\bar{e}_L \Gamma_\mu e_L \bar{u}_L \Gamma^\mu u_L + \frac{\eta_R^2}{2M_S^2}\bar{e}_R \Gamma_\mu e_R \bar{u}_R \Gamma^\mu u_R$$

with $e_L = \frac{1-\gamma_5}{2}e$.

$$c_{1u} \to c_{1u} + \Delta C, \quad \Delta C = \mp\frac{\sqrt{2}\eta_{L,R}^2}{8G_F M_S 2}$$

From $\pi^0 \to \ell^+\ell^- \to \eta_L \approx 0$ or $\eta_R \approx 0$.

If $\eta_R \neq 0$, $\Delta C > 0 \longrightarrow \delta_N Q_W < 0$ (excluded).

If $\eta_R = 0$ $(\eta_L \neq 0)$ the 95 % CL bound is

$$1.7 \leq \frac{M_S(TeV)}{\eta_L} \leq 4.5$$

or, assuming a weak interaction, $\eta_L^2 \approx 4\pi\alpha_{\rm em}$

$$0.5 \leq M_S(TeV) \leq 1.4$$

Conclusions

The new determination of Q_W could be affected by several errors

- Statistical fluctuations
- Bigger errors on $\langle H_{PV} \rangle \longrightarrow$ peculiar modifications of ψ, in view of the agreement with PC quantities, testing all possible distances
- Overlooked SM corrections to the atomic quantities

Otherwise:

clear indication of new physics

Then our main conclusions are

- The SM is disfavored at 99 % CL
- Only new physics with no measurable effects at LEP is possible
- Q_W puts lower and upper bound on new scales
- In particular models
  - Extra-$U(1)$, the region $-0.66 \leq \theta_2 \leq 0.25$ is excluded, upper bounds on $M_{Z'} \approx 1 \div 1.5\ TeV$ (similar for LR)
  - Extra-dimension disfavored at more than 99% CL ($\sin\beta < 0.707$)
  - Composite models, $12 \leq \Lambda(TeV) \leq 33$
  - Lepto-quarks, $0.5 \leq M_S(TeV) \leq 1.4$

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