Bounds on new light particles from very small momentum transfer np elastic scattering data

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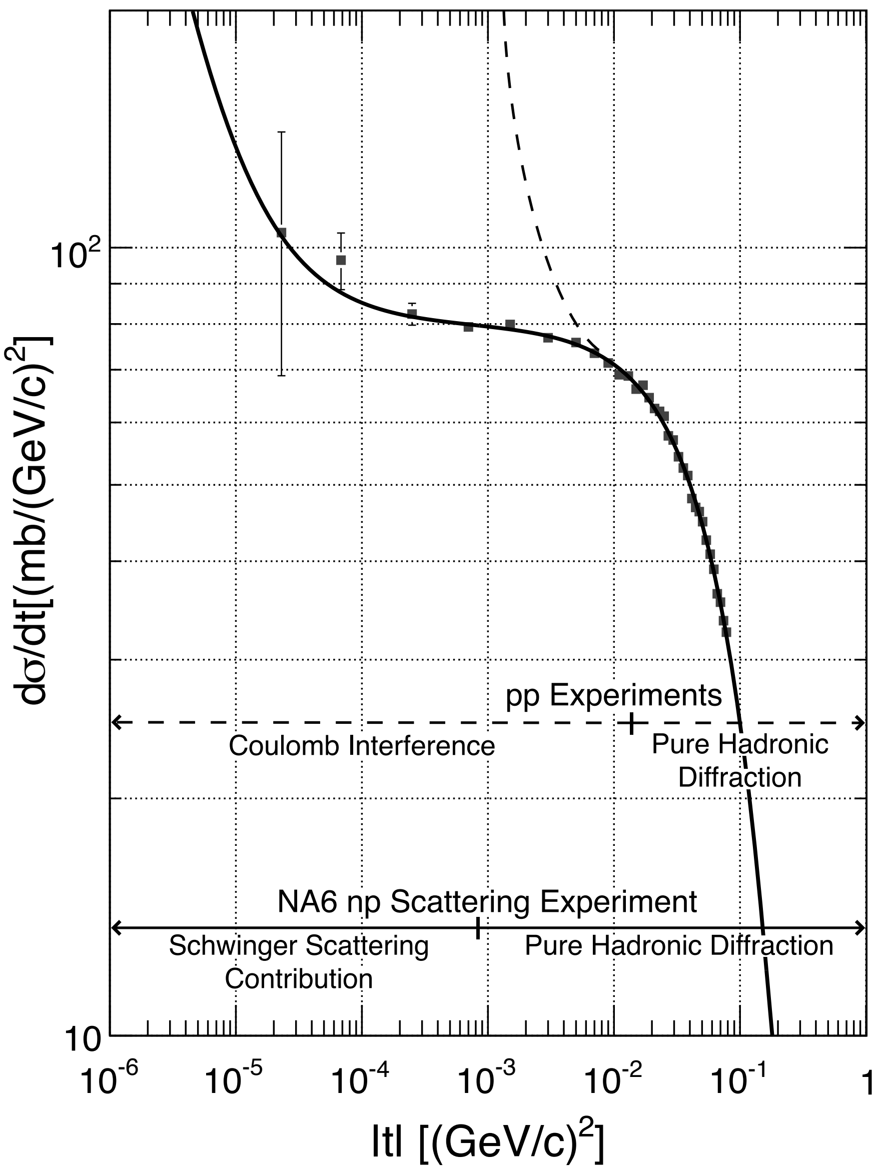
NA-6 experiment, CERN SPS,

Results published in 1984

$E_n = 100 - 400$ GeV, gaseous hydrogen target

very small |t|



$d\sigma/dt[(mb/(GeV/c)^2]$
10^2
10
10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1
$|t|\ [(GeV/c)^2]$
pp Experiments
Coulomb Interference
Pure Hadronic Diffraction
NA6 np Scattering Experiment
Schwinger Scattering Contribution
Pure Hadronic Diffraction

$$\frac{d\sigma}{dt} = A \exp[bt] - 2\left(\frac{\alpha k_n}{m_n}\right)^2 \frac{\pi}{t} \quad , \tag{1}$$

where $A = (79.78 \pm 0.26) mb/\mathrm{GeV}^2$ and $b = (11.63 \pm 0.08)$ GeV^{-2} were determined from the fit to the data;
$k_n = -1.91$ is the neutron magnetic moment in nuclear magnetons;
factor "2" in the Schwinger term accounts for noncoherent sum of the scattering of neutron magnetic moment on proton and electron electric charges

NP

$$\frac{d\sigma_i}{dt}(g,\mu)|_{\rm new} = \frac{|A_i|^2}{16\pi s(s-4m^2)} \quad , \tag{2}$$

where $s = (p_n + p_p)^2$ is the invariant energy square and m is the nucleon mass.

$$|A_S|^2 = \frac{g_S^4}{(t-\mu^2)^2}(4m^2 - t)^2 \quad , \tag{3}$$

$$|A_P|^2 = \frac{g_P^4 t^2}{(t-\mu^2)^2} \quad , \tag{4}$$

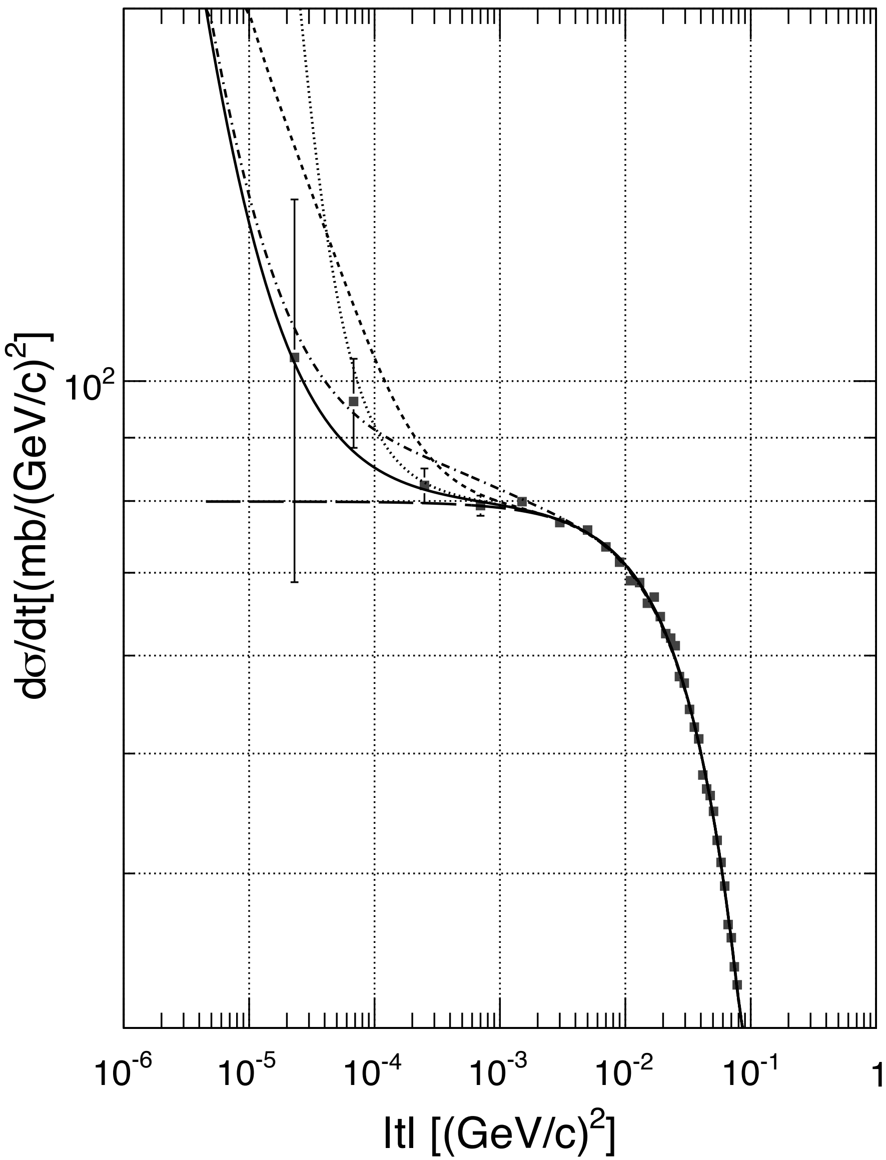
$$|A_V|^2 = \frac{4g_V^4}{(t-\mu^2)^2}[s^2 - 4m^2 s + 4m^4 + st + \frac{1}{2}t^2] \quad , \tag{5}$$

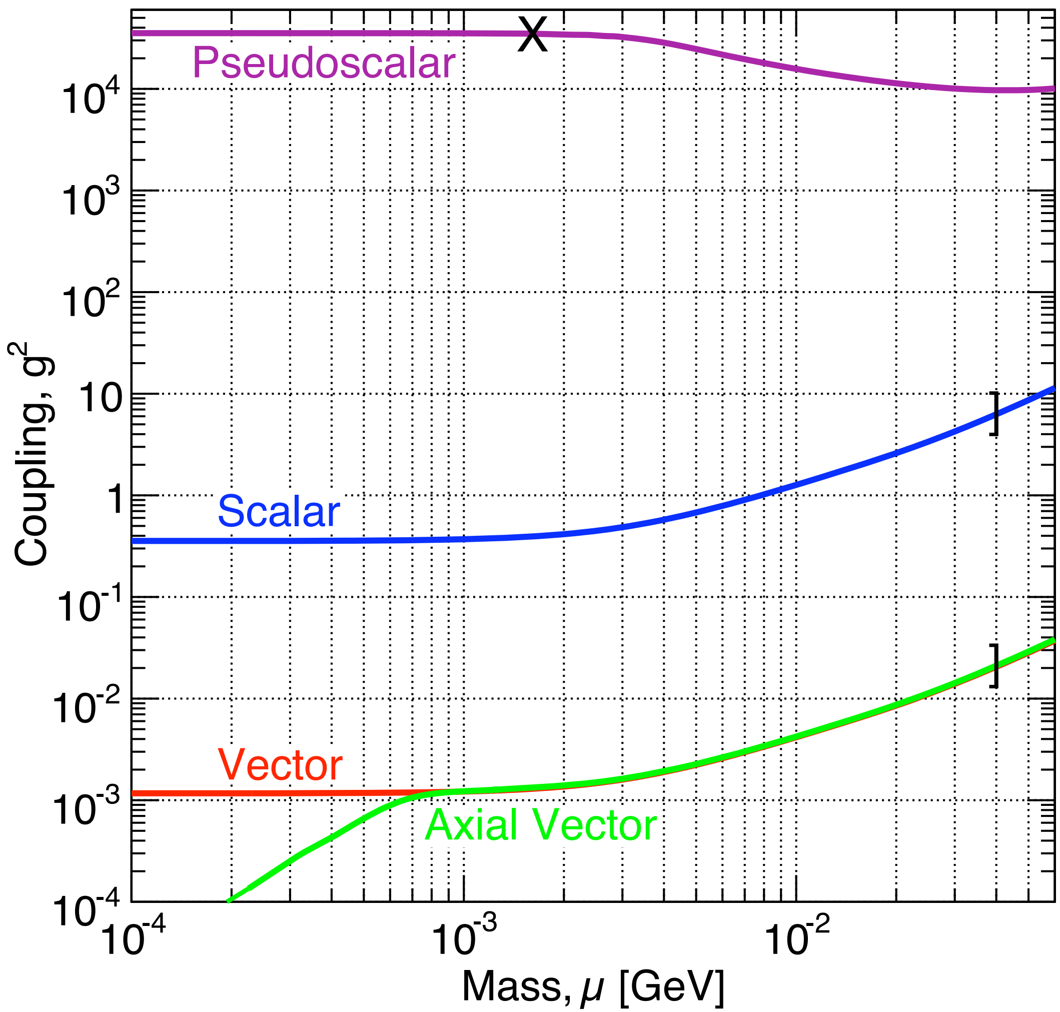
$$|A_A|^2 = \frac{4g_A^4}{(t-\mu^2)^2}[s^2 + 4m^2 s + 4m^4 + st + \frac{1}{2}t^2 + \frac{4m^4 t^2}{\mu^4} + \frac{8m^4 t}{\mu^2}] \quad , \tag{6}$$

where coupling constants $g_i^2 \equiv g_p^i g_n^i$.

$A \sim s^\alpha; A_P \sim t$

Lack of fundamental theory for SI np scattering amplitude does not prevent us from excluding light new particles as far as there are NO SI particles lighter than pion, $m_\pi = 140MeV$


10^2
$d\sigma/dt[(mb/(GeV/c)^2]$
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
$|t|$ [$(GeV/c)^2$]


Pseudoscalar
X
Scalar
Vector
Axial Vector
Coupling, g^2
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-4}
10^{-3}
10^{-2}
Mass, μ [GeV]

90% C.L. bounds

Our bounds on the parameters g_V^2 and g_A^2 are rather strong; say for $\mu = 10$ MeV, $g_{V,A}^2 < 5 \cdot 10^{-3}$ at 90% C.L., which corresponds to

$$g_N^{V,A} < 0.071 \quad , \tag{7}$$

four times smaller than the QED coupling constant $\sqrt{4\pi\alpha} \simeq 0.3$. For scalar exchange, taking $\mu = 10$ MeV, we get a much weaker bound, $g_S^2 < 1.4$.

It is quite natural to suppose that couplings of a new light particle with nucleons originate from its couplings with quarks. In this case A_V and A_A are modified. For vector exchange the induced magnetic moment interaction term should be added to the scattering amplitude. Since its numerator contains momentum transfer divided by m_N which in considered kinematics gives a factor much smaller than 1, we can safely neglect it.

The case of axial exchange is more delicate:

$$
\begin{aligned}
\tilde{A}_A &= g_A^2 \bar{n}\gamma_\beta\gamma_5 n \left(g_{\alpha\beta} - \frac{k_\alpha k_\beta}{k^2 - m_\pi^2}\right) \frac{(g_{\alpha\mu} - \frac{k_\alpha k_\mu}{\mu^2})}{k^2 - \mu^2} * \\
&* \left(g_{\mu\nu} - \frac{k_\mu k_\nu}{k^2 - m_\pi^2}\right) \bar{p}\gamma_\nu\gamma_5 p = \\
&= \frac{g_A^2}{k^2 - \mu^2} \left[g_{\alpha\beta} - \frac{k_\alpha k_\beta}{\mu^2} \frac{(m_\pi^4 - 2\mu^2 m_\pi^2 + k^2\mu^2)}{(k^2 - m_\pi^2)^2}\right] * \\
&* \bar{n}\gamma_\alpha\gamma_5 n \bar{p}\gamma_\beta\gamma_5 p
\end{aligned} \tag{8}
$$

for massless pion the axial current is conserved, while term $k_\alpha k_\beta / k^2 \longrightarrow m_N^2/k^2$ in the amplitude leads to regular diff. crossection at $t \longrightarrow 0$.

literature 1

$$V(r) = -G_N \frac{m_1 m_2}{r}[1 + \alpha_G \exp(-r/\lambda)] \ , \tag{9}$$

$$\alpha_G = \frac{g^2_{V,S}}{4\pi G_N m_p m_n} = 1.35 \cdot 10^{37} g^2_{V,S} \ , \quad \lg \alpha = \lg g^2_{V,S} + 37.13 \tag{10}$$

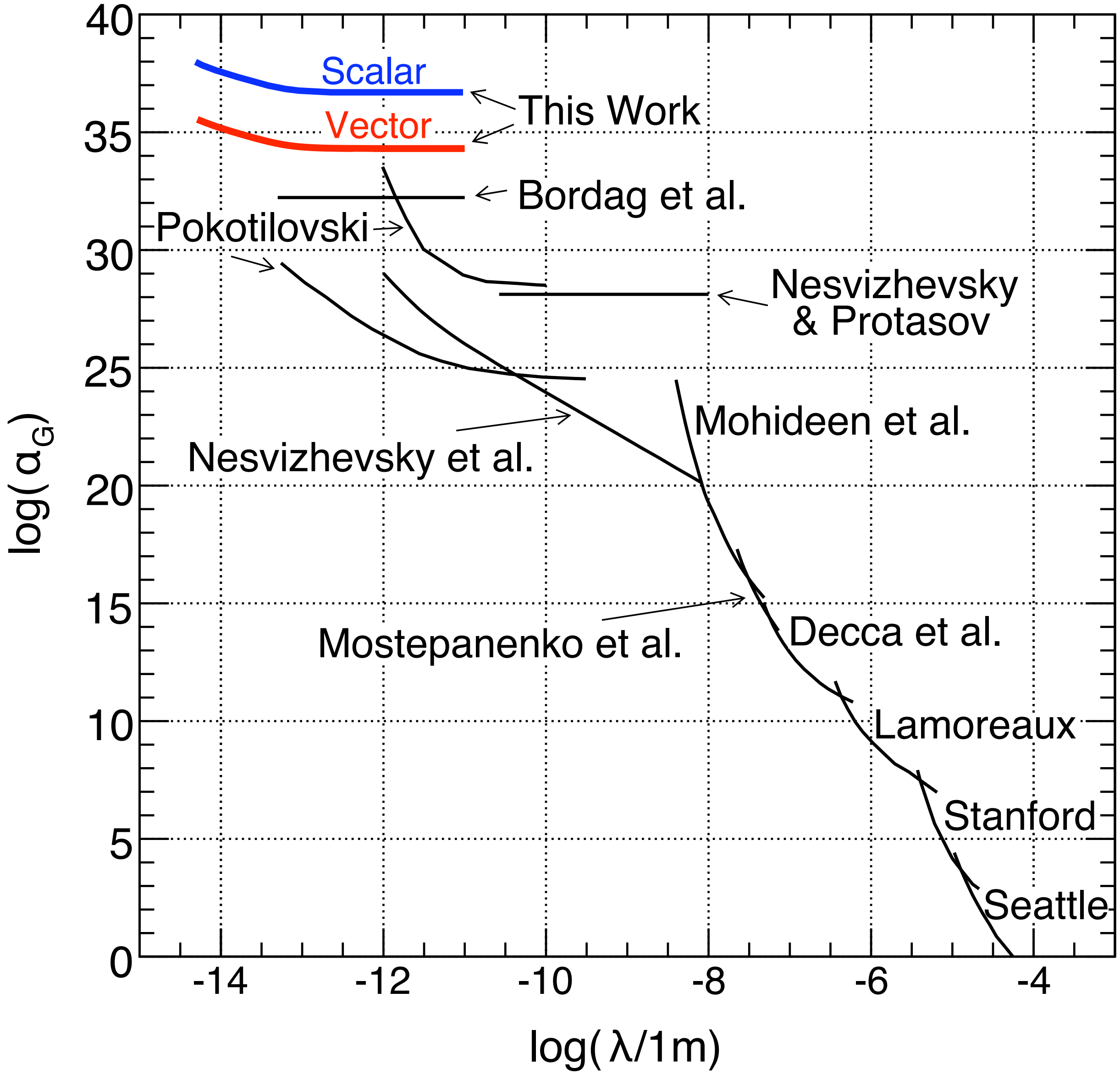
literature 2

low energy (KeV) $n - {}^{208}\mathrm{Pb}$ scattering

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_0}{4\pi}[1 + \omega E \cos\theta] \quad , \tag{11}$$

$$|\Delta\omega| = \frac{16 m_n^2}{\sqrt{\sigma_0/4\pi}} \frac{g_n^2}{4\pi} \frac{A}{\mu^4} \quad . \tag{12}$$

$g_{V,S}^2 < 4 \cdot 10^{-6}$ for 10MeV boson


40
35
30
25
20
15
10
5
0
-14
-12
-10
-8
-6
-4
log(α_G)
log(λ/1m)
Scalar
Vector
This Work
Bordag et al.
Pokotilovski
Nesvizhevsky
& Protasov
Mohideen et al.
Nesvizhevsky et al.
Mostepanenko et al.
Decca et al.
Lamoreaux
Stanford
Seattle

literature 3

Couplings of new light bosons with quarks are bounded by pion and kaon decays:

$$Br(\pi^0 \to \nu\nu) < 2.7 \cdot 10^{-7}$$

$$Br(\pi^0 \to \gamma\nu\nu) < 6 \cdot 10^{-4}$$

$$Br(K^+ \to \pi^+ + \nu\nu) < 2 \cdot 10^{-10}$$

Bounds on axial and scalar couplings are considerably stronger while the bound on vector coupling is comparable with those from np scattering

literature 4

NP contribution to nuclear matter EOS; neutron stars
Krivoruchenko, Simkovic, Faessler, 2009

the fact that the bounds are similar to ours is not surprising: $\delta V \sim g^2/\mu^2$, so precision data on np - scattering compete with information from observations of neutron stars.

Conclusions

- Electric neutrality of neutron allows to look for large distance NP effects in small angle neutron scattering data
- High energy scattering gives access to small values of vector and axial coupling constants
- Our bound on g_V is comparable with bounds from neutral pion and kaon decays