J. van der Bij

1° Higgs is light $m_H \ll 1$ TeV

in that case $s \gg m_H^2$ $\quad a_0 \sim \frac{m_H^2}{8\pi v^2}$ small

Here we really have high energy, however little of interest is here within the Standard Model

2° Higgs is heavy $m_H \sim 1$ TeV

then $s \gg m_H^2$ out of reach of LHC,
but strong interactions would be present
Here high energy physics is essentially Higgs line-shape

3° Higgs is superheavy $m_H \gg 1$ TeV

Here high energy means
$s \gg 4 m_W^2$, but still $s \ll m_H^2$

Effective Lagrangian physics

gauged non-linear σ-model

χ-perturbation theory

unitarization

[redacted]

High Energy W-boson scattering.

what does high energy mean? $\left\{ \begin{array}{l} \text{Higgs} \\ \text{LHC} \end{array} \right.$

Look at $W_L^+ W_L^- \to W_L^+ W_L^-$ (Lee, Quigg, Thacker)

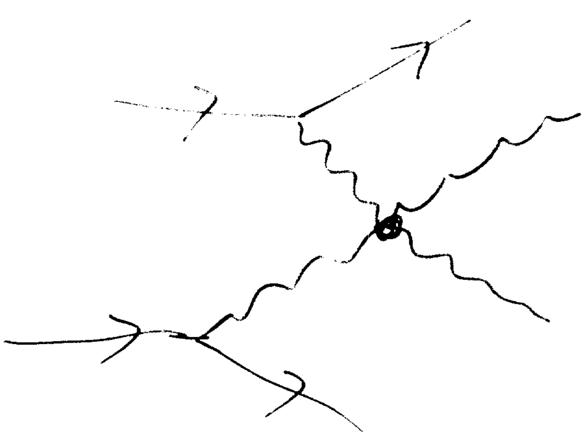
$J=0$ amplitude

$$a_0 = \frac{-1}{16\pi v^2} m_H^2 \left(2 + \frac{m_H^2}{s - m_H^2} - \frac{m_H^2}{s} \log\left(1 + \frac{s}{m_H^2}\right)\right)$$

$s \gg m_H^2$ $\qquad a_0 = \dfrac{m_H^2}{8\pi v^2}$

$s \ll m_H^2$ $\qquad \dfrac{1}{32\pi} \dfrac{s}{v^2}$

At the LHC we do not directly have WW-scattering but only after radiating W-bosons off quarklines



So we are limited to $\sqrt{s_{\text{effective}}} \lesssim 1\,\text{TeV}$

Table 1: Differential $d\sigma/d\cos(\theta)$ and total Born cross sections and relative corrections for unpolarized, purely longitudinal and purely transverse vector bosons at the center-of-mass energy $\sqrt{s} = 500$ GeV and $m_H = 1000$ GeV.

$\gamma\gamma \to W^+W^-$	σ^{unpol}, pb	$\delta^{unpol}, \%$	σ^L, pb	$\delta^L, \%$	σ^T, pb	$\delta^T, \%$
30°	61.97	$-7.83\cdot10^{-3}$	—	—	60.94	$-7.21\cdot10^{-3}$
60°	8.598	$-8.49\cdot10^{-3}$	—	—	7.995	$-6.52\cdot10^{-3}$
90°	4.551	$-8.76\cdot10^{-3}$	—	—	4.044	$-5.99\cdot10^{-3}$
$0° \leqslant \theta \leqslant 180°$	77.48	$-7.77\cdot10^{-3}$	—	—	76.10	$-7.21\cdot10^{-3}$
$\gamma Z \to W^+W^-$	σ^{unpol}, pb	$\delta^{unpol}, \%$	σ^L, pb	$\delta^L, \%$	σ^T, pb	$\delta^T, \%$
30°	171.0	$-2.34\cdot10^{-2}$	—	—	219.4	$-2.35\cdot10^{-2}$
60°	22.66	$-2.30\cdot10^{-2}$	—	—	28.76	$-2.32\cdot10^{-2}$
90°	11.48	$-2.28\cdot10^{-2}$	—	—	14.54	$-2.31\cdot10^{-2}$
$0° < \theta < 180°$	213.1	$-2.34\cdot10^{-2}$	—	—	274.0	$-2.36\cdot10^{-2}$
$W^+W^- \to W^+W^-$	σ^{unpol}, pb	$\delta^{unpol}, \%$	σ^L, pb	$\delta^L, \%$	σ^T, pb	$\delta^T, \%$
30°	816.0	−1.01	1070.	−6.62	1163.	$-5.56\cdot10^{-2}$
60°	100.8	−4.83	375.5	−11.7	94.48	−0.109
90°	36.43	−10.9	192.0	−19.4	21.71	−0.162
120°	19.24	−19.0	101.9	−33.6	11.82	−0.194
150°	12.64	−27.8	60.59	−52.6	10.55	−0.220
$10° < \theta < 170°$	558.8	−1.71	820.4	−10.5	730.8	$-4.71\cdot10^{-2}$
$W^+W^+ \to W^+W^+$	σ^{unpol}, pb	$\delta^{unpol}, \%$	σ^L, pb	$\delta^L, \%$	σ^T, pb	$\delta^T, \%$
30°	436.9	0.612	340.0	7.10	696.0	$-7.05\cdot10^{-3}$
60°	61.71	1.83	136.6	7.51	86.15	$+7.43\cdot10^{-3}$
90°	35.93	2.20	120.2	6.04	43.16	$+4.08\cdot10^{-3}$
$10° < \theta < 170°$	575.6	0.564	542.1	5.46	845.3	$-7.89\cdot10^{-3}$
$W^+W^- \to ZZ$	σ^{unpol}, pb	$\delta^{unpol}, \%$	σ^L, pb	$\delta^L, \%$	σ^T, pb	$\delta^T, \%$
30°	266.3	−1.28	369.2	−7.94	390.6	$-5.56\cdot10^{-2}$
60°	53.95	−4.88	228.3	−10.1	51.43	$-9.03\cdot10^{-2}$
90°	37.01	−6.78	208.2	−10.6	25.81	−0.118
$0° < \theta < 180°$	338.6	−1.72	568.5	−8.88	477.8	$-5.59\cdot10^{-2}$
$W^+Z \to W^+Z$	σ^{unpol}, pb	$\delta^{unpol}, \%$	σ^L, pb	$\delta^L, \%$	σ^T, pb	$\delta^T, \%$
30°	4.429	0.338	$1.79\cdot10^{-2}$	−29.4	6.269	0.251
60°	7.588	1.49	10.32	1.75	7.057	0.134
90°	17.12	3.47	53.24	6.18	13.05	$+2.02\cdot10^{-2}$
120°	54.93	3.28	143.5	9.61	56.90	$-1.32\cdot10^{-2}$
150°	447.3	0.944	406.8	9.20	657.2	$-2.67\cdot10^{-2}$
$0° < \theta < 180°$	282.4	0.887	249.7	8.09	414.7	$-2.68\cdot10^{-2}$
$ZZ \to ZZ$	σ^{unpol}, pb	$\delta^{unpol}, \%$	σ^L, pb	$\delta^L, \%$	σ^T, pb	$\delta^T, \%$
30°	2.763	−48.3	24.42	−48.3	$8.71\cdot10^{-4}$	−49.1
60°	2.225	−46.2	19.49	−46.1	$6.53\cdot10^{-4}$	−47.8
90°	1.969	−44.9	17.24	−44.8	$5.69\cdot10^{-4}$	−47.1
$0° < \theta < 180°$	4.636	−46.7	40.75	−46.6	$1.39\cdot10^{-3}$	−48.1

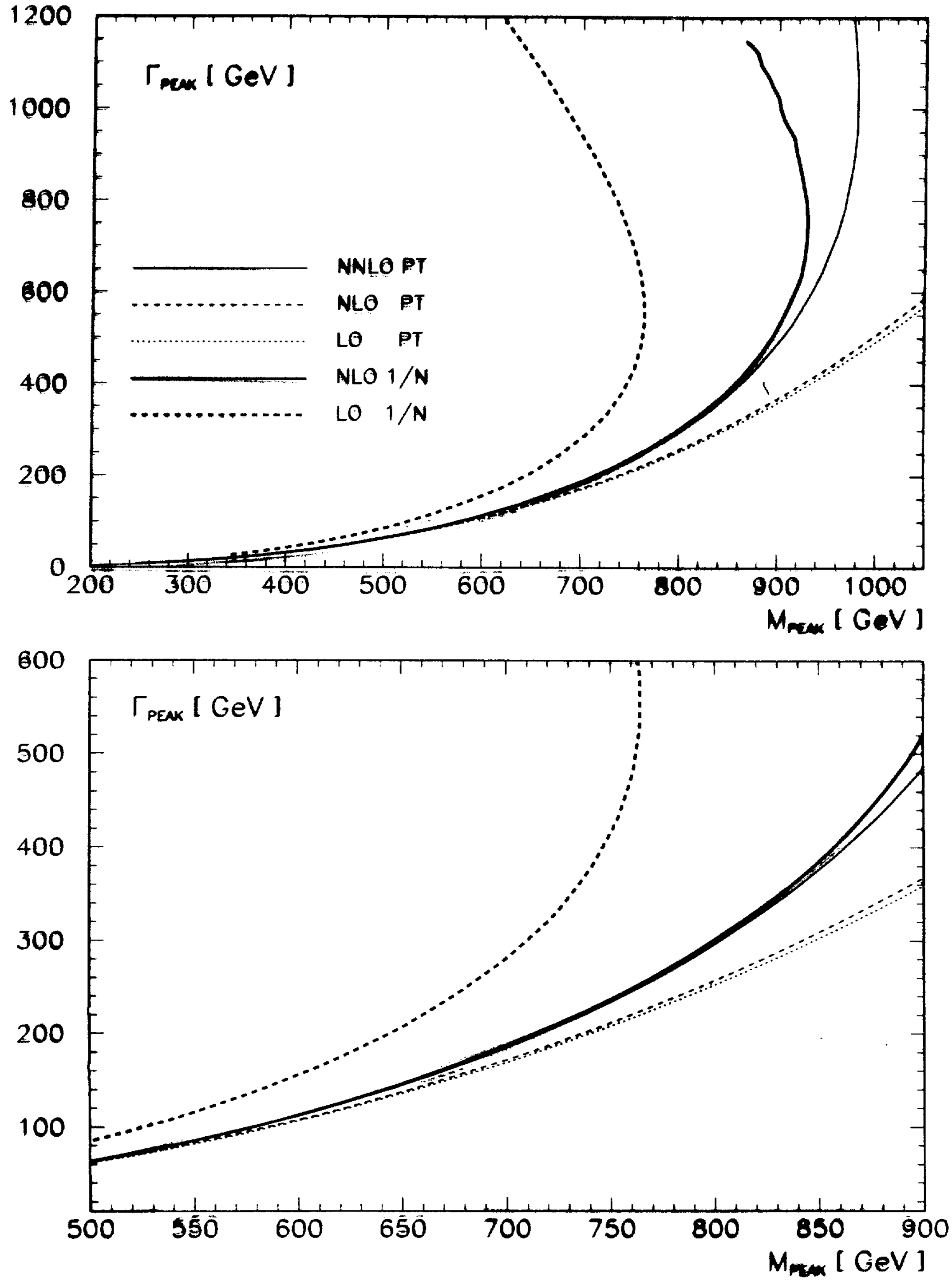


Figure 6: *The relation between the peak variables M_{PEAK} and Γ_{PEAK} in perturbation theory and in the $1/N$ expansion.*

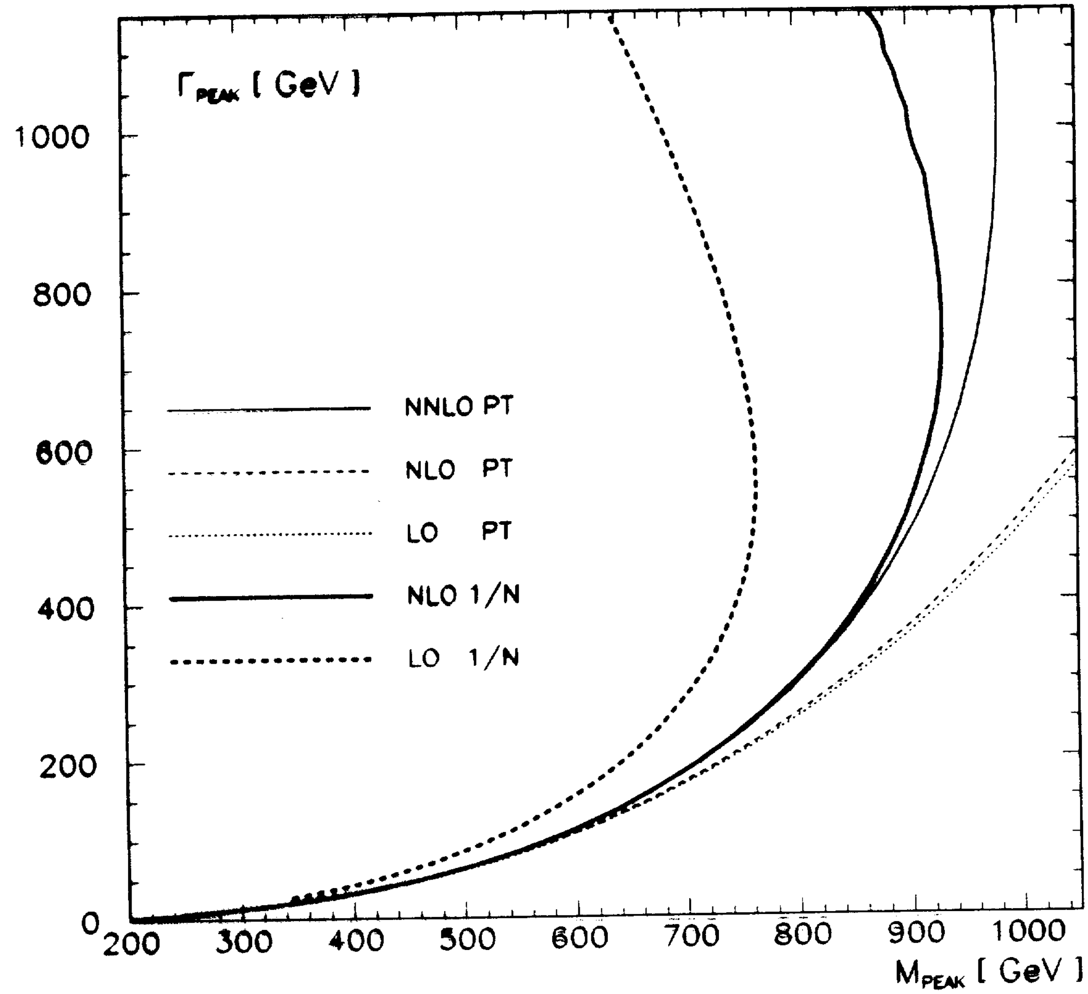


Figure 1: *Width versus mass of the Higgs-boson in perturbation theory and in the 1/N expansion.*

With these propagators defined it is now straightforward to write diagrams for the next-to-leading order contribution O(1/N) to the Higgs-propagator. The vertices can be directly read from the Lagrangian of eq.(2). The propagators are the expressions given above, where one should still take care to subtract the pole at the location of the tachyon. Because of the complicated propagators the evaluation of the graphs is highly involved and can only be performed numerically. The graphs also involve overall divergences and subdivergences, wich were handled by making subtractions at intermediate renormalization scales. In order to do the actual calculation new techniques were necessary, extending the methods of ref.[16]. Details of the calculation, including renormalization and tachyon subtraction, will be given in a subsequent publication.

We note that we need to evaluate the two-point functions for $\sigma\sigma, \chi\chi, \chi\sigma$. After this we have to invert the matrix in order to project out the physical Higgs propagator. This final Higgs propagator is then a physical quantity, which can in principle be measured in the process $\mu\bar{\mu} \rightarrow t\bar{t}$, after taking into account the Yukawa coupling renormalization. The resulting lineshapes can be compared with the known perturbative result [17]. The two-loop and the NLO 1/N lineshapes are so close together that it is not very enlightening to plot examples.

Instead, to study the results in detail, we plotted in fig.(1) an effective Higgs width against the

Strong WW - Rescattering

(with B. Kastening)

method - chiral perturbation theory

Standard model without Higgs

$$\mathcal{L}_{gauge} = -\frac{1}{2} \mathrm{Tr}(W_{\mu\nu} W_{\mu\nu}) + m_W^2 \mathrm{Tr}(V_\mu V_\mu)$$

(SU(2) limit no hypercharge)

$$W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu + ig[W_\mu, W_\nu]$$

$$W_\mu = \frac{1}{2} T^a W_\mu^a \qquad V_\mu = -\frac{i}{g}(D_\mu U)U^+ \quad D_\mu U = \partial_\mu U + ig W_\mu U$$

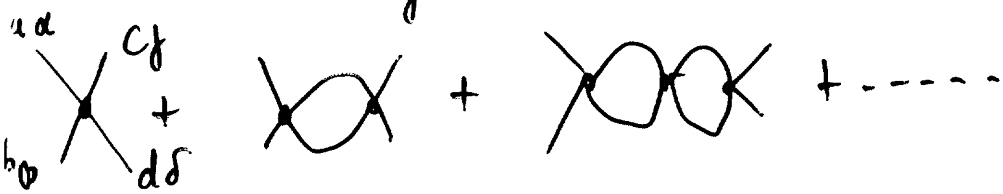
anomalous couplings

$$\mathcal{L}_{ano} = g_4 [\mathrm{Tr}(V_\mu V_\nu)]^2 + g_5 [\mathrm{Tr}(V_\mu V_\mu)]^2$$

physical cut-off

$$\mathcal{L} = \frac{1}{2\Lambda_W^2} \mathrm{Tr}[(D_\alpha W_{\mu\nu})(D_\alpha W_{\mu\nu})] - \frac{m_W^2}{\Lambda_V^2} \mathrm{Tr}[(D_\alpha V_\mu)(D_\alpha V_\mu)]$$

rescattering Bubble-sum



many channels
most interesting

$I=1$, $J=1$

$\sim \left(\delta_{ac}\delta_{bd} - \delta_{ad}\delta_{bc}\right)\left(g_{\alpha\gamma}k_\beta k_\delta + g_{\beta\delta}k_\alpha k_\gamma - g_{\alpha\delta}k_\beta k_\gamma - g_{\beta\gamma}k_\alpha k_\delta\right)$

gives
$$\frac{g_4 - 2g_5}{1-(g_4-2g_5)\frac{\Lambda_V^2}{128\pi^2 M_W^2}\left(k^2 - 4m_W^2\frac{\log(\Lambda_W^2/\Lambda_V^2)}{1-\Lambda_V^2/\Lambda_W^2} + i\pi\frac{(k^2+4m_W^2)(k^2-4m_W^2)^{3/2}}{3\sqrt{k^2}\,\Lambda_V^2}\right)}$$

$g_4 - 2g_5 \to \infty$

resonance
$$m_r = 2m_W\left(\frac{\log \Lambda_W^2/\Lambda_V^2}{1-\Lambda_V^2/\Lambda_W^2}\right)^{1/2}$$

$$\Gamma_r = \pi\frac{(m_r^2+4m_W^2)(m_r^2-4m_W^2)^{3/2}}{3\,m_r^2\,\Lambda_V^2}$$

coupling to W bosons

$$\frac{8\pi m_W^2}{\dots}\quad \varepsilon_{abc}\left(k_\alpha g_{\beta\gamma} - k_\beta g_{\alpha\gamma}\right)$$

phenomenological expectations

$\Lambda_W > \Lambda_V$

$\Lambda_V \sim g\,\Lambda_W$?

LEP_100 experiment $\Lambda_V > 490$ GeV

So: $m_r \gtrsim 200$ GeV

$\Gamma_r < 12$ GeV

LEP_200 deviations at $s = 189$ GeV

Comparison with π - physics

$$g_4 = g^4 \varepsilon_4 \quad g_5 = g^4 \varepsilon_5 \quad g_\rho = 4(\varepsilon_4 - 2\varepsilon_5)$$

$g \to 0$ g_ρ fixed

$$a_{11}(s) \sim \frac{s}{96\pi f_\pi^2}\left[1 + \frac{g_\rho s}{f_\pi^2} + \frac{g_\rho^2 \Lambda_v^2}{32\pi^2 f_\pi^2}\frac{s^2}{f_\pi^4} + \frac{i s}{96\pi f_\pi^2}\left(1 + \frac{g_\rho^2 s^2}{f_\pi^4}\right)\right]$$

Correction to KSRF-relation

$$\Gamma_\rho = \frac{m_\rho^3}{96\pi f_\pi^2}\left(1 - \frac{\Lambda_v^2}{32\pi^2 f_\pi^2}\right)$$

difference with π-physics, we have g_ρ dominant

In chiral limit this is never possible

One needs: $|g_\rho|\, s^2/v^2 \gg s$ for $s > 4 m_W^2$

$$4\,|g_4 - 2g_5| \gg g^2$$