UV clues from IR fingerprints

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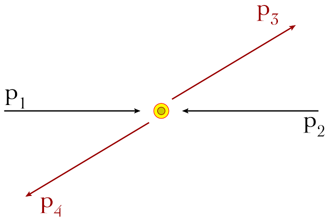
CERN - March, 29 2012

WHAT IF THE HIGGS COUPLINGS TO W & Z BOSONS ARE LARGER THAN IN THE STANDARD MODEL?

Jointly with: Adam Falkowski
Slava Rychkov

Generalities



$$s = (p_1 + p_2)^2 = 4E^2$$

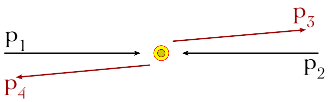
$$t = (p_1 - p_3)^2 = -2(E^2 - m^2)(1 - \cos\theta)$$

$$u = (p_1 - p_4)^2 = -2(E^2 - m^2)(1 + \cos\theta)$$

$$s + t + u = 4m^2$$

$$A(s, t, u)$$

Generalities



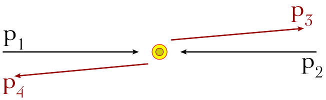
$$s = (p_1 + p_2)^2 = 4E^2$$

$$t = 0$$

$$u = -s + 4m^2$$

$$A(s, 0, -s + 4m^2)$$

Generalities



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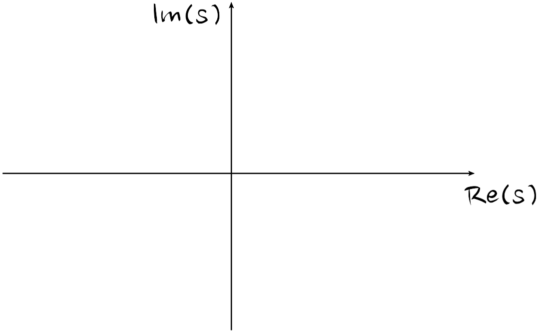
$$A(s)$$

Analytic Proprieties



A(s)

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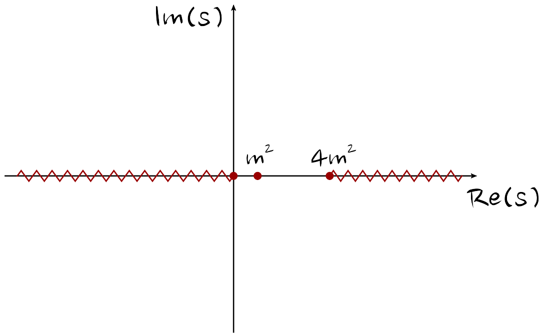

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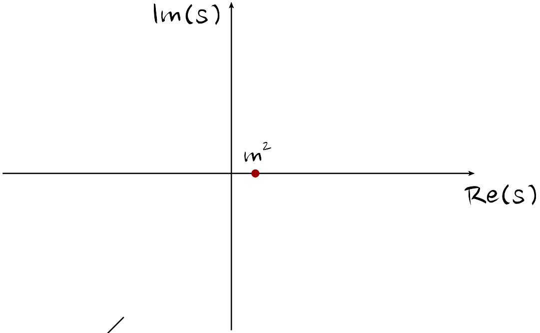
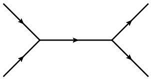
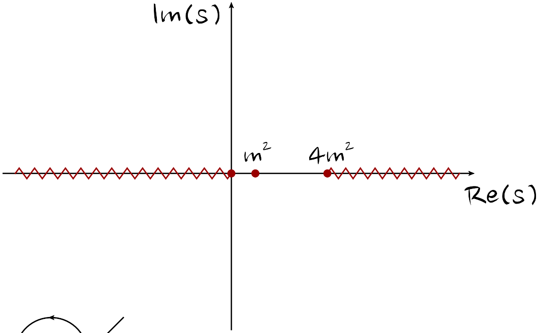
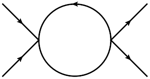




$$A(s) \sim \frac{1}{s - m^2}$$

Analytic Proprieties





$$A(s) \sim \ln\left(-\frac{s}{4m^2}+1\right)$$

An inspiring example

Adams, Arkani-Hamed, Dubovsky,
Nicolis, Rattazzi JHEP 0610, 014 (2006)

An inspiring example

$$\mathcal{L} = \partial_\mu \pi \partial^\mu \pi + \frac{c_3}{\Lambda^4} (\partial_\mu \pi \partial^\mu \pi)^2 + \ldots$$

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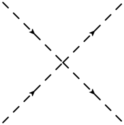
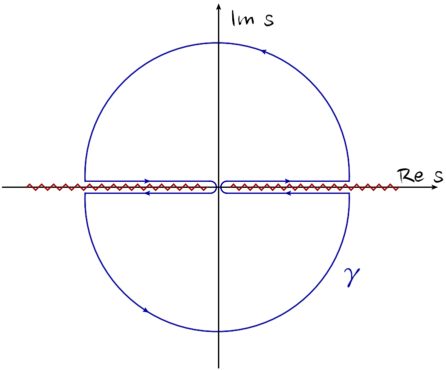


$$A(s) = \frac{c_3}{\Lambda^4} s^2$$

An inspiring example

$$1 = \oint_{\gamma} \frac{ds}{2\pi i} \frac{A(s)}{s^3}$$

An inspiring example



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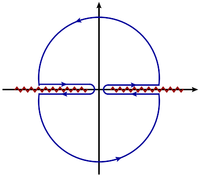

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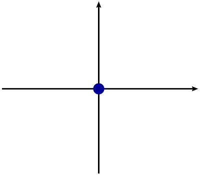

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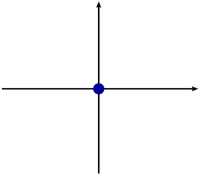

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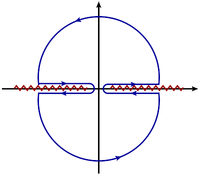

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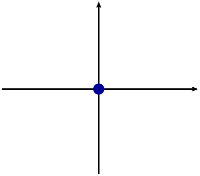

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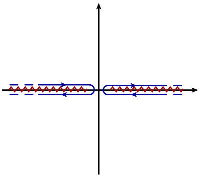


$$1 = \frac{2}{\pi}\int_0^\infty ds\, \frac{\sigma(s)}{s^2}$$

An inspiring example

$c_3 > 0$!!!

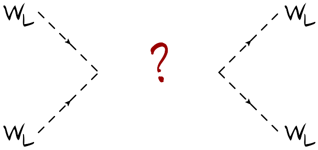
$$1 = \oint_{\gamma} \frac{ds}{2\pi i} \frac{A(s)}{s^3}$$

WW Scattering

What about Longitudinal W scattering?

WW Scattering

What about the UV completion of the SM?



SM Higgs?
A Higgs "impersonator"?
Resonances of a strong sector?

WW Scattering

$$\mathcal{L} = \frac{1}{2}(\partial h)^2 - V(h)$$

$$+ \frac{v^2}{4} \mathrm{Tr}[(DU)^\dagger (DU)] \left(1 + \frac{2ah}{v} + \frac{bh^2}{v^2} + \dots \right)$$

WW Scattering

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$$U = \exp(i\vec{\sigma}\cdot\vec{\pi}/v)$$

$$\pi^\pm \sim W_L^\pm$$

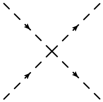
$$\pi^3 \sim Z_L$$

WW Scattering

$$\mathcal{L} =$$

$$+\frac{v^2}{4}\mathrm{Tr}[(DU)^\dagger(DU)]$$

$\pi^+\pi^- \to \pi^3\pi^3$



$$A(s) = \frac{s}{v^2}$$

WW Scattering

$$\mathcal{L} = \frac{1}{2}(\partial h)^2 - V(h) + \frac{v^2}{4}\mathrm{Tr}[(DU)^\dagger(DU)]\left(1 + \frac{2h}{v} + \frac{h^2}{v^2} + \dots\right)$$

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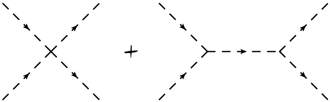

$$A(s) = \frac{(s - s)}{v^2}$$

WW Scattering

$$\mathcal{L} = \frac{1}{2}(\partial h)^2 - V(h) + \frac{v^2}{4}\mathrm{Tr}[(DU)^\dagger(DU)]\left(1 + \frac{2ah}{v} + \frac{bh^2}{v^2} + \dots\right)$$

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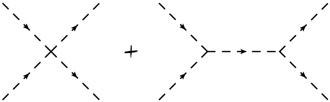

$$A(s) = \frac{s(1-a^2)}{v^2}$$

On the importance of a

$$\mathcal{L} = +\frac{v^2}{4}\mathrm{Tr}[(DU)^\dagger(DU)]\,\frac{2ah}{v}$$

On the importance of a (Unitary gauge)

$$\mathcal{L} = \frac{a h}{v}\left(2 m_W^2 W^+ W^- + m_Z^2 Z^2\right)$$

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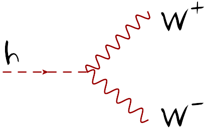
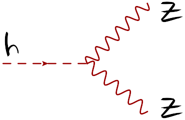
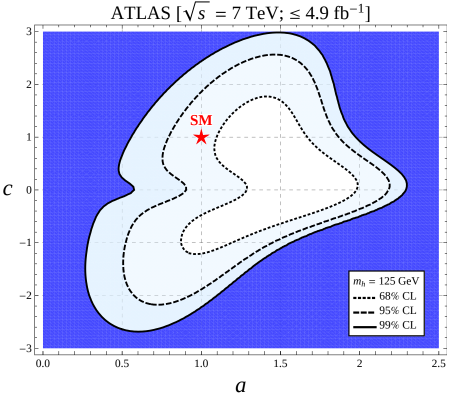
$$\mathcal{L} = \frac{ah}{v}\left(2m_W^2 W^+ W^- + m_Z^2 Z^2\right)$$





$$\frac{\Gamma(h\to WW)}{\Gamma_{SM}(h\to WW)} = \frac{\Gamma(h\to ZZ)}{\Gamma_{SM}(h\to ZZ)} = a^2$$



Azatov, Contino, Galloway - 1202.3415

Sum Rule

$$1 = \oint_{\gamma} \frac{ds}{2\pi i} \frac{A(s)}{s^2}$$

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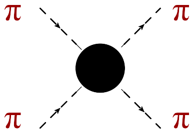

?

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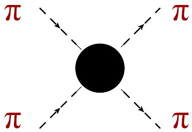


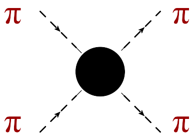
$$|\pi^+\rangle = |1, 1\rangle$$

$$|\pi^3\rangle = |1, 0\rangle$$

$$|\pi^-\rangle = |1, -1\rangle$$

Sum Rule

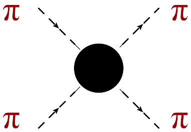
$$1 = \oint_{\gamma} \frac{ds}{2\pi i}\frac{A(s)}{s^2}$$



$$1 \otimes 1 = 2 \oplus 1 \oplus 0$$

Sum Rule

$$1 = \oint_{\gamma} \frac{ds}{2\pi i} \frac{A(s)}{s^2}$$



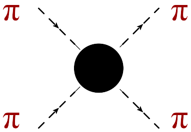
$$A(\pi^+\pi^- \to \pi^3\pi^3) = (T_0 - T_2)/3$$

$$A(\pi^+\pi^- \to \pi^+\pi^-) = T_0/3 + T_1/2 + T_2/6$$

$$A(\pi^+\pi^+ \to \pi^+\pi^+) = T_2$$

Sum Rule

$$1 = \oint_{\gamma} \frac{ds}{2\pi i} \frac{A(s)}{s^2}$$



$$A(s) = \sum_{I} w_I \, T_I(s, t=0)$$

Sum Rule

$$1 = \oint_{\gamma} \frac{ds}{2\pi i} \frac{A(s)}{s^2}$$

$$\frac{c_3}{\Lambda^4} = \frac{2}{\pi} \int_0^\infty ds \frac{\sigma(s)}{s^2}$$

Sum Rule

$$1 = \oint_{\gamma} \frac{ds}{2\pi i} \frac{A(s)}{s^2}$$

$$1 - a^2 = \frac{v^2}{6\pi} \int_0^{\infty} \frac{ds}{s} \left[2\sigma^{tot}_{I=0}(s) + 3\sigma^{tot}_{I=1}(s) - 5\sigma^{tot}_{I=2}(s) \right]$$

Sum Rule

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- The sum rule cannot fix the sign of $(1-a^2)$ but it constraints the sources of negative contributions.
- If $(1-a^2)<0$ there must be a large contribution from the channel with total isospin $I=2$.

$I = 2$ Exercise

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$I = 2$ Exercise

$$Q = (Q^{++}, Q^{+}, Q^{0}, Q^{-}, Q^{--}) \qquad g_Q, \; m_Q$$

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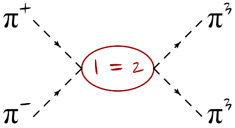

$$A(s,t,u) = \frac{s(1-a^2)}{v^2}$$

$I = 2$ Exercise

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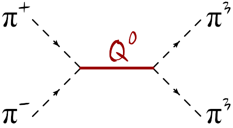
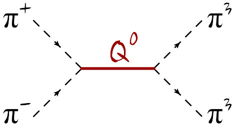
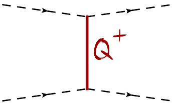


$$A(s,t,u) = \frac{s(1-a^2)}{v^2} + \frac{g_Q^2}{v^2}\left[\frac{s^2}{3(s-m_Q^2)}\qquad\qquad\right]$$

$I = 2$ Exercise

$$Q = (Q^{++}, Q^{+}, Q^{0}, Q^{-}, Q^{--}) \qquad g_Q, \quad m_Q$$





$$A(s,t,u) = \frac{s(1-a^2)}{v^2} + \frac{g_Q^2}{v^2}\left[\frac{s^2}{3(s-m_Q^2)} - \frac{t^2}{2(t-m_Q^2)}\right]$$

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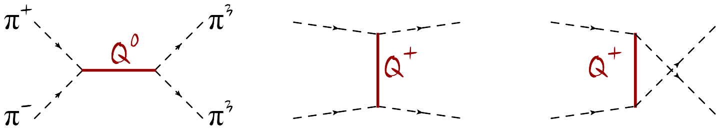

$$A(s,t,u) = \frac{s(1-a^2)}{v^2} + \frac{g_Q^2}{v^2}\left[\frac{s^2}{3(s-m_Q^2)} - \frac{t^2}{2(t-m_Q^2)} - \frac{u^2}{2(u-m_Q^2)}\right]$$

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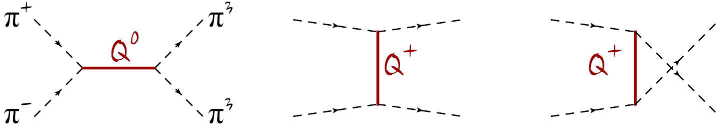

$$A(s, t=0) = \frac{s(1-a^2)}{v^2} + \frac{5 g_Q^2 s}{6 v^2}$$

$I = 2$ Exercise

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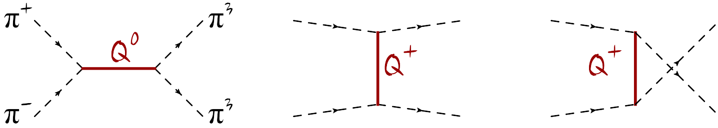

$$A(s, t=0) = 0 \qquad \text{if} \qquad g_Q^2 = \frac{6(a^2-1)}{5}$$

I = 2 Exercise

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$$1 - a^2 = \frac{v^2}{6\pi} \int_0^\infty \frac{ds}{s} \left[2\sigma^{tot}_{I=0}(s) + 3\sigma^{tot}_{I=1}(s) - 5\sigma^{tot}_{I=2}(s) \right]$$

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Imaginary part from the resonant pole

$$g_Q^2 = \frac{6(a^2-1)}{5}$$

CONCLUSIONS

- We applied dispersion relation techniques to the longitudinal scattering of EW gauge bosons;
- we argued that an observation of enhanced coupling of the Higgs boson to the W and Z bosons implies the enhancement of the longitudinal gauge boson scattering cross section in the isospin-2 channel.