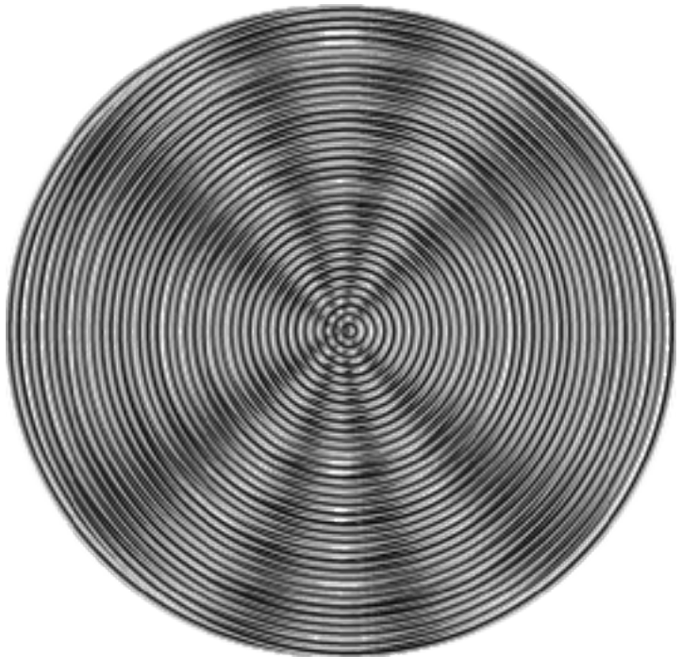
Helicity Selection Rules and Non-Interference for BSM Amplitudes



Francesco Riva
(CERN)

In collaboration with
Azatov, Contino, Machado 1607.05236
Liu, Pomarol, Rattazzi 1603.03064
Contino, Falkowski, Goertz, Grojean,1604.06444

!

The following arguments hold for any parametrization for SM precision tests that involves a Derivative Expansion:

EFT, Non-linear EFT, Higgs-characterization, Pseudo Observables,...

(a consequence of Lorentz invariance and the equivalence theorem)

Interference

When SM and BSM contribute to the same amplitude:

$$Amp = SM + BSM = SM(1 + \delta_{BSM})$$

- $$\sigma \propto |Amp|^2 \simeq SM^2(1 + \delta_{BSM} + \delta_{BSM}^2)$$

For small BSM effects $1 \gg \delta_{BSM}$, interference dominates $\delta_{BSM} \gg \delta_{BSM}^2$

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e.g. EW fits to LEP-1 observables:

Experiment very precise → $1 \gg \delta_{BSM}$

- (EFT) expansion in $\delta_{BSM} = \frac{v^2}{\Lambda^2}$ well defined, often approximated at linear order (interference only)

Non-Interference

Derivative (energy) expansion:

dimension-6

$$\delta_{BSM} = c_i \frac{E^2}{\Lambda^2} + \cdots$$

If SM and BSM contribute to different amplitudes:

interference vanishes

- $$\sigma \propto \sum |Amp|^2 \simeq SM^2(1 + \cancel{c_i \frac{E^2}{\Lambda^2}} + c_i^2 \frac{E^4}{\Lambda^4})$$

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The leading effects BSM are $O\left(\frac{1}{\Lambda^4}\right)$:

the same order as dimension-8 that do interfere

- Question of interference relevant for expansion consistency

LHC

High-energy (2→2,2→3,...)processes important part of LHC search program:

e.g. Drell-Yann, TGC, QGC, VH associated production, VBF, tth, h+j,...

This Talk: Interference in High-energy processes and its implications

Non-Interference for BSM_6 amplitudes

Azatov,Contino,Machado,FR'16

Exploit:

For $E \gg m_W$ states have well defined helicity

Amplitudes for 2→2 with different total h don't interfere

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Theorem:

Any BSM dim-6 operator

A_4	$\lvert h(A_4^{\rm SM})\rvert$	$\lvert h(A_4^{\rm BSM})\rvert$
VVVV	0	4,2
$VV\phi\phi$	0	2
$VV\psi\psi$	0	2
$V\psi\psi\phi$	0	2
$\psi\psi\psi\psi$	2,0	2,0
$\psi\psi\phi\phi$	0	0
$\phi\phi\phi\phi$	0	0

Massless limit + tree level + at least one transverse vector

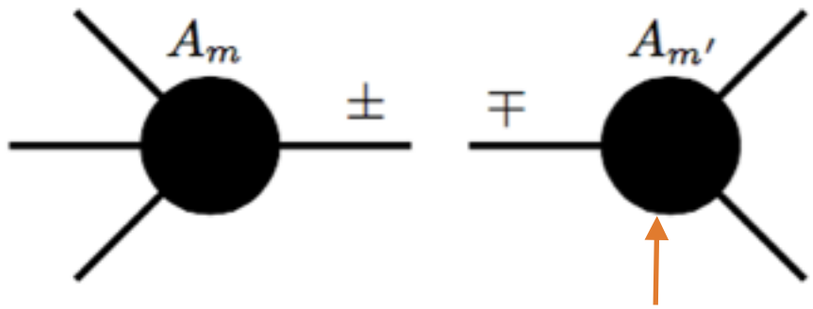
- SM and BSM_6 contribute to different helicity amplitudes
- No interference

Non-Interference for BSM_6 amplitudes

Azatov,Contino,Machado,FR'16

How? i) Helicity sums: $h(A_n) = h(A_m) + h(A_{m'})$

n=m+m'-2 legs



SM or BSM_6 (*)

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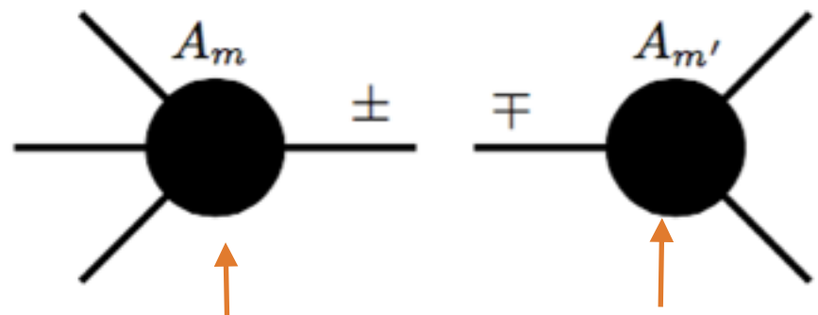

SM or BSM_6 (*)

$p \in \mathbb{C}$ (outgoing)so that on-shell condition $p^2 = 0$ satisfied also for A_3

(*)=In a basis where all effects proportional to the Equations of Motion have been eliminated

Non-Interference for BSM$_6$ amplitudes

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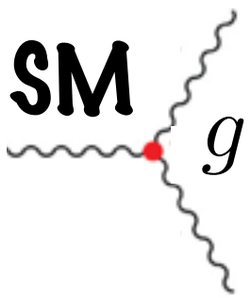
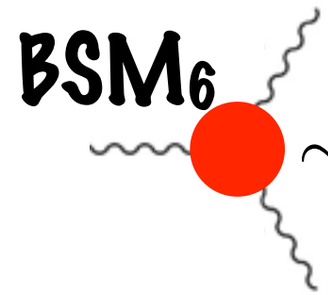
How?

ii) Helicity of 3-point↔coupling dimension:

$$|h(A_3)| = 1 - [g]$$



$$g \Rightarrow |h^{SM}| = 1$$



$$\sim \frac{1}{\Lambda^2} \Rightarrow |h^{BSM}| = 3$$

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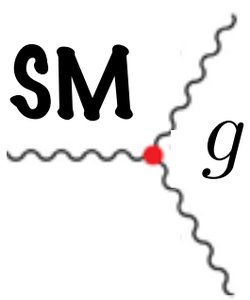
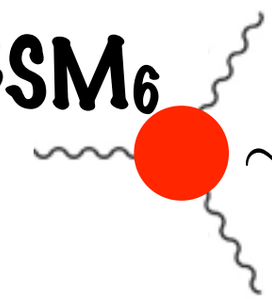
SM  $g \Rightarrow |h^{SM}| = 1$

BSM$_6$  $\sim \frac{1}{\Lambda^2} \Rightarrow |h^{BSM}| = 3$

Spinor Helicity Formalism:

$$v_+(p) = (|p]_a, 0) \quad \epsilon_+^\mu(p;q) = \frac{\langle q|\gamma^\mu|p]}{\sqrt{2}\langle qp\rangle}$$

$$v_-(p) = (0, |p\rangle^{\dot{a}})$$

$$-\not{p} = |p\rangle[p| + |p]\langle p|$$

irreps of $SU(2) \times SU(2) \simeq SO(3,1)$

(familiar in SUSY)

Little Group scaling (Poincarré) $|p_i\rangle \to t_i|p_i\rangle \quad |p_i] \to t_i^{-1}|p_i]$ → p_i^μ invariant → $A \sim t_i^{-2h_i}$

Dimensional Analysis $[|p\rangle] \sim [|p]] \sim \mathrm{GeV}^{1/2}$ $\qquad [A_{3point}] \sim \mathrm{GeV}$

3-point kinematics $\langle p_1 p_2\rangle[p_1 p_2] = 2p_1.p_2 = (p_1+p_2)^2 = (-p_3)^2 = 0$ → $\begin{cases} A_3 \sim \langle p_1 p_2\rangle \cdots \\ \text{or} \\ A_3 \sim [p_1 p_2] \cdots \end{cases}$

- $A_3(1^{h_1}2^{h_2}3^{h_3}) = g\langle 12\rangle^{h_3-h_1-h_2}\langle 13\rangle^{h_2-h_1-h_3}\langle 23\rangle^{h_1-h_2-h_3}$ uniquely fixed

Non-Interference for BSM_6 amplitudes

Azatov,Contino,Machado,FR'16

How? iii) SUSY* Ward Identities: $|h(A_4^{SM})| < 2$ (except $\psi^+\psi^+\psi^+\psi^+$)

$$SM: \; A(V^+V^+V^+V^-) = A(V^+V^+\psi^+\psi^-) = A(V^+V^+\phi\phi) = A(V^+\psi^+\psi^+\phi) = 0$$

BSM : Operators with transverse V not supersymmetrizable

Elias-Miro,Espinosa,Pomarol'14

- no restriction on total helicity for BSM

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*in the limit of either y_u=0 or y_d=y_l=0:

SM upliftable to SUSY+R-parity (with 1 Higgs doublett)

Grisaru,Pendleton,vanNieuwenhuizen'77

→ e.g. $0 = \langle 0|[Q, \Psi^+V^+V^+V^+]|0\rangle = \sum_i \langle 0|\Psi^+...[Q, V^+]...V^+|0\rangle \propto \langle 0|V^+V^+V^+V^+|0\rangle$

$[Q,\psi] \sim V \quad [Q,V] \sim \psi \qquad \psi^+\psi^+\cdots = 0$

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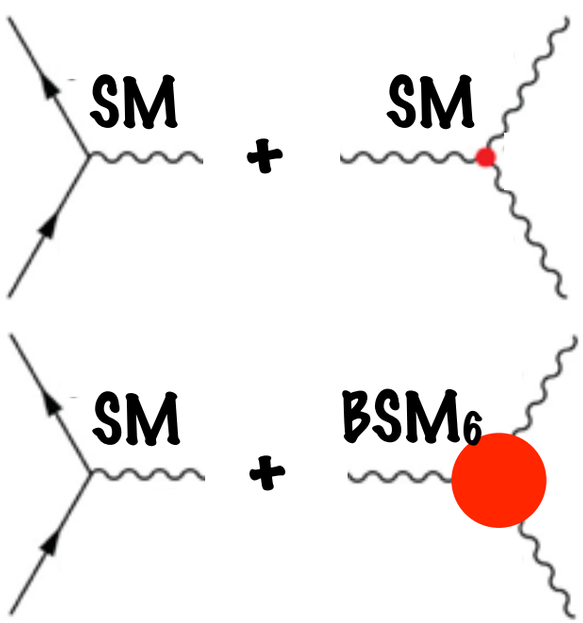

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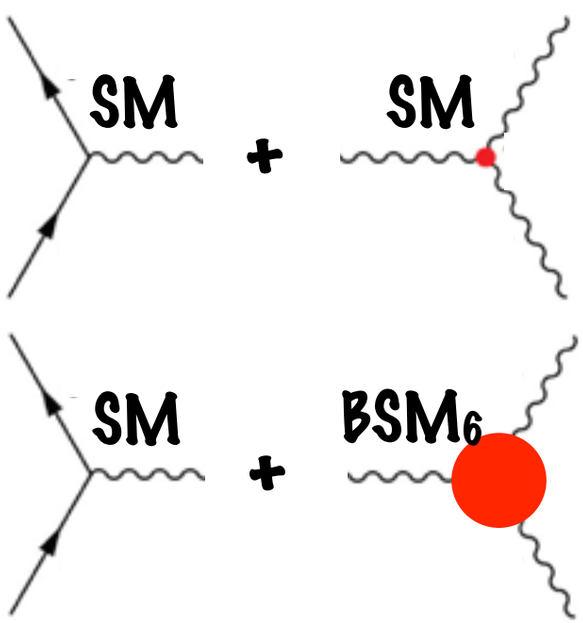

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No Interference
(dim-6, 4-point)

Implications

At $E \gg m_W$ dimension-6 with transverse vectors don't interfere in 2 →2

- Naive derivative expansion truncated at dim-6 inconsistent

Processes Concerned:

- di-boson WW,WZ,Wγ pair production*
- VH, tth associated production
- gg->tt
- VBF
- VV scattering
- ...

see Eleni's Talk

What to do?

(*= Notice that this concerns also LEPII TGC analyses)

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What to do?

1) Ignore analyses that already test these dim-6
2) Fit also dimension-8 that interfere
3) Study 2 →3 processes with extra, e.g., jets that interfere
4) Find BSM context in which these searches actually make sense
5) Forget consistency and take dimension-6 as a complete benchmark

see Dixon,Shadmi'93; Azatov et al' in progre

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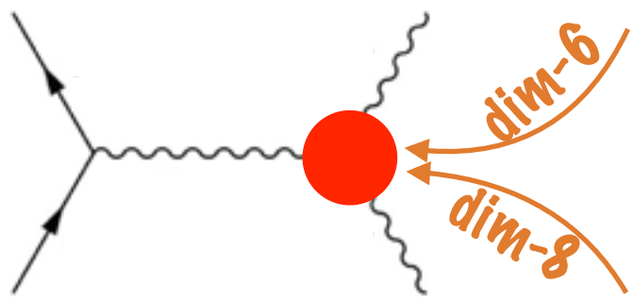
BSM context in which dim-6 searches make sense

Liu,Pomarol,Rattazzi,FR'16

Implications?

$$\bar{q}q \to VV'$$

$V^{(\prime)} = W^{\pm}, Z, \gamma$



$$\frac{g_*}{M^2}\epsilon_{abc}W^{a\,\nu}_{\mu}W^{b}_{\nu\rho}W^{c\,\rho\mu}$$

doesn't interfere for $m_W \to 0$

$$\frac{g_*}{M^4}\epsilon_{abc}\Box W^{a\,\nu}_{\mu}W^{b}_{\nu\rho}W^{c\,\rho\mu}$$

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(3-point vertex has dimension of coupling → weight with g* for illustration)

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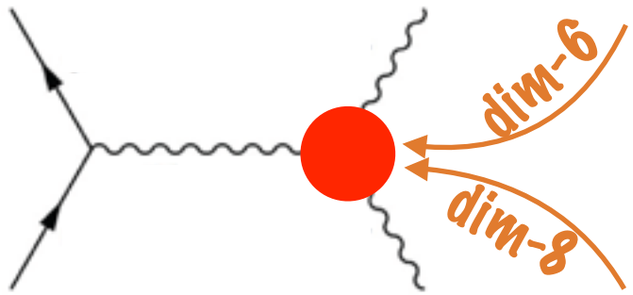

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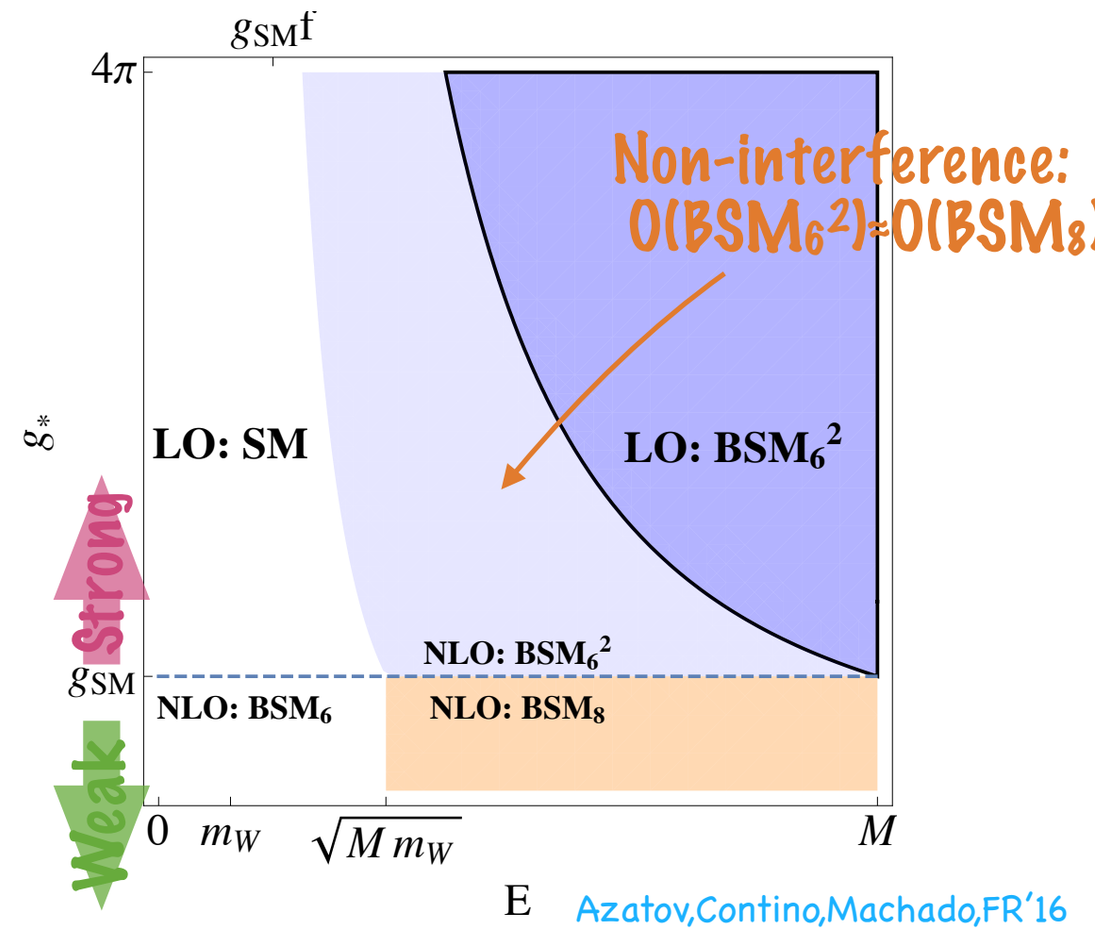
$$\sigma_T \sim \frac{g_{\rm SM}^4}{E^2}\Bigg[1 + \overbrace{\frac{g_*}{g_{\rm SM}}\frac{m_W^2}{\Lambda^2}}^{\rm BSM_6\times SM} + \overbrace{\frac{g_*^2}{g_{\rm SM}^2}\frac{E^4}{\Lambda^4}}^{\rm BSM_6{}^2} + \underbrace{\frac{g_*}{g_{\rm SM}}\frac{E^4}{\Lambda^4}}_{\rm BSM_8\times SM} + \dots\Bigg]$$



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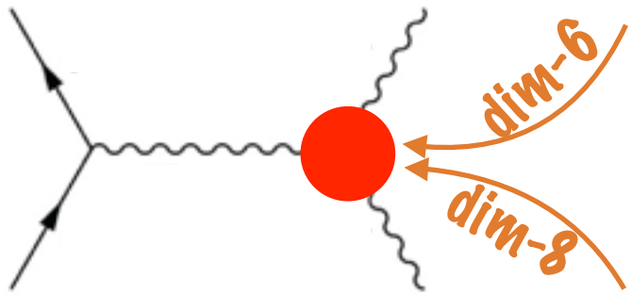

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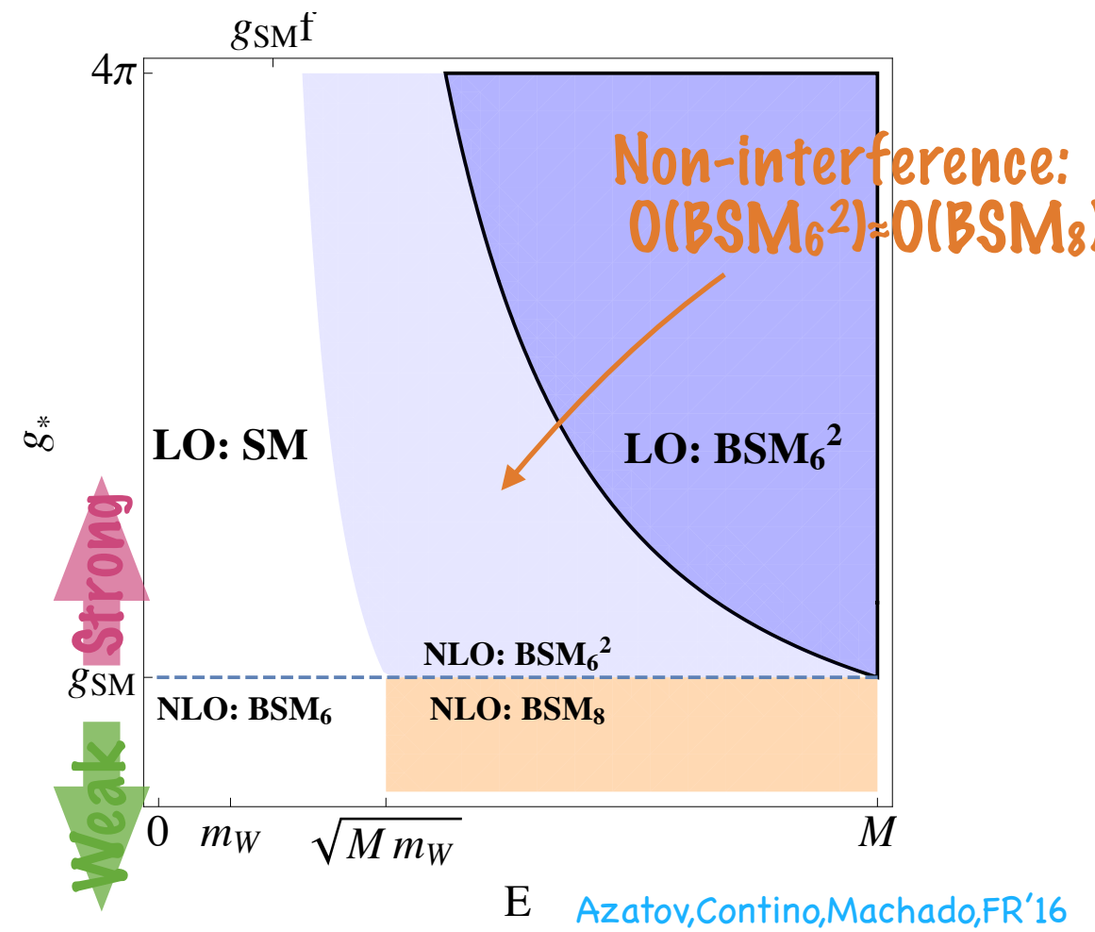

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In Strongly coupled theories dim-6^2 might be bigger than dim-8 and analysis with dim-6 only is consistent

Conclusions

In some high-energy (off-resonance) processes, SM and the "leading" BSM (dimension-6 in derivative expansion) do not interfere.

- (dim-6)^2 same order $O(1/\Lambda^4)$ as dim-8

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- In this context present dim-6 analyses make sense

Liu,Pomarol,Rattazzi,FR'16

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It would be interesting to explore strategies to make these analyses consistent also for weakly coupled physics, e.g:

1) Study 2 →3 processes that interfere see Dixon,Shadmi'93; Azatov et al' in progress
2) Tag polarization to reduce non-interfering piece
3) Improve sensitivity at small energy where mass-effects relevant
4) ...?

...in progress