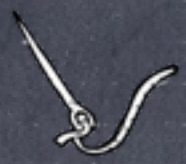
Precision BSM Searches and the 100 TeV collider



Francesco Riva (EPFL - Lausanne)

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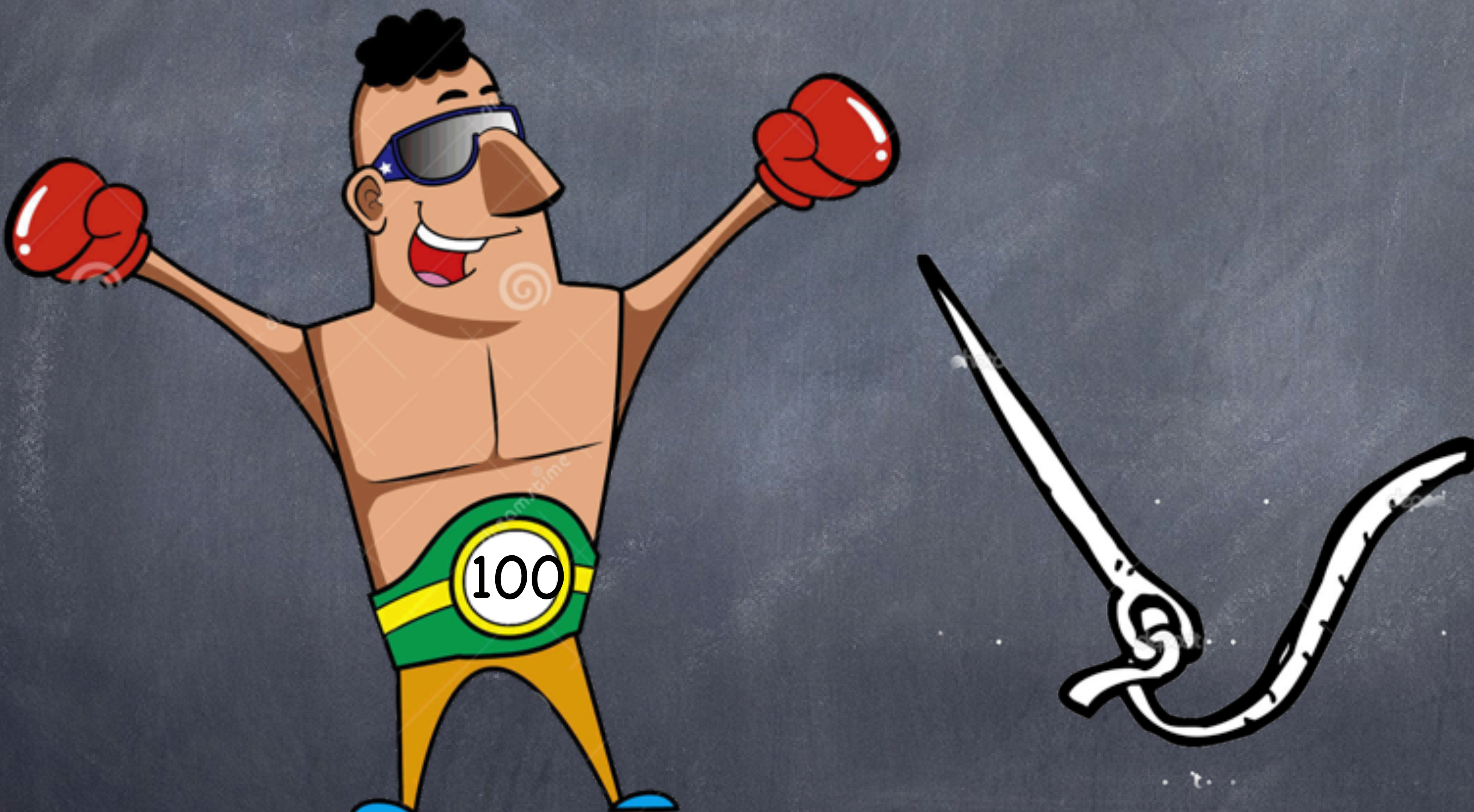

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Foreword

Precision SM searches ⟷ Effective Field Theory (EFT) parametrization

SM well established:
no need to be tested per-se

EFT is BSM inspired:
interpretable as search
self-consistent

comparable with
other (direct) searches

(See later and A.Thamm talk)

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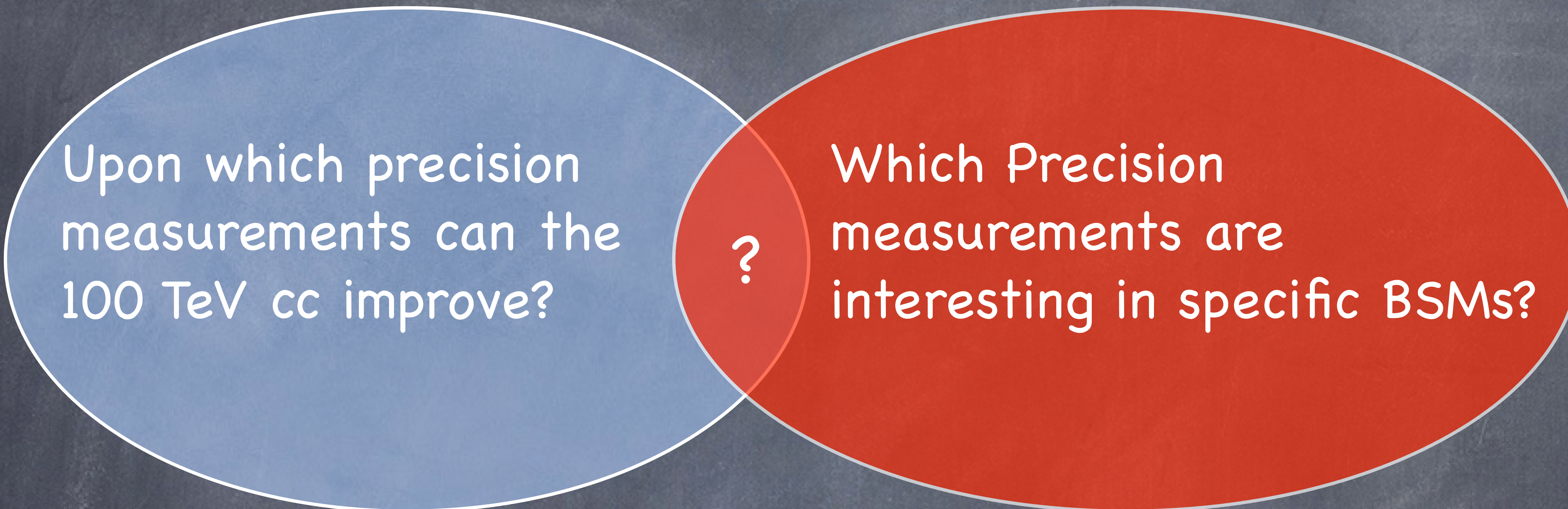
Motivation and Outline



Thought in progress...

EFT Parametrization

Power-Counting:

BSM coupling and scale $M > \sqrt{s_{part}}$

H/fermions coupling to BSM

BSM gauge symmetric

$$\mathcal{L}_{\rm eff} = \frac{M^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{M}, \frac{g_* H}{M}, \frac{g_*\Psi_{L,R}}{M^{3/2}}, \frac{gF_{\mu\nu}}{M^2}\right) \simeq \mathcal{L}_4 + \mathcal{L}_6 + \cdots \qquad \mathcal{L}_6 = \sum_i \frac{\mathcal{O}_i}{\Lambda_i^2}$$

SM

$$\frac{1}{\Lambda_i^2} = \frac{g_*^2}{M^2}$$

$$\mathcal{O}_{y_\Psi} = |H|^2 \bar{\Psi}_L H \Psi_R$$

$\dots$

$$\frac{1}{\Lambda_i^2} = \frac{1}{M^2}$$

$$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a D^\mu H\right) D^\nu W^a_{\mu\nu}$$

$\dots$

1

More BSM-based assumptions

Giudice,Grojean,Pomarol,Rattazzi'07; Gupta,Montull,FR'12
Contino,Ghezzi,Muhlleitner,Grojean,Spira'13;...

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①

$$\mathcal{O}_{y_\Psi} = |H|^2 \bar{\Psi}_L H \Psi_R \quad \cdots \qquad\qquad \mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a D^\mu H\right) D^\nu W^a_{\mu\nu} \quad \cdots$$

$$\times \tan\beta \qquad \times \cot\beta \qquad\qquad \times \frac{g^2}{16\pi^2}$$

②

Selection-Rules/ Matching:

Associated with theory at M (PNGB Higgs,R-symmetry,...)

$$\mathcal{O}_{y_d} = |H|^2 \bar{Q}_L H d_R \qquad \mathcal{O}_{y_u} = |H|^2 \bar{Q}_L H u_R$$

$M = m_H$ Specific Expectations (based e.g. on Naturalness)

More BSM-based assumptions

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Generic EFT

All Parameters are equally interesting
(but some can be enhanced by generic coupling)

- Take experiment's point of view: What can be measured well at 100 TeV?

EFT

Modification of SM-like vertices
(Ex: δg_{Ze_R} at LEP1 on Z-pole)

New EFT Structures
(Ex: $\bar{L}\gamma_\mu L \bar{L}\gamma^\mu L$ interactions at LEP2)

Largest effect in
SM resonant processes:

$$\sigma \sim \sigma_{SM}\left(1 + \frac{m_h^2}{M^2} + \cdots\right)$$

$\ll 1$

- E-insensitive

- Improves with Luminosity
  (limited by systematics)

- Ideal for TLEP (syst. small)

- At 100TeV will only add luminosity to LHC
  (or systematics smaller?)
  Interesting mostly for interactions invisible
  at TLEP

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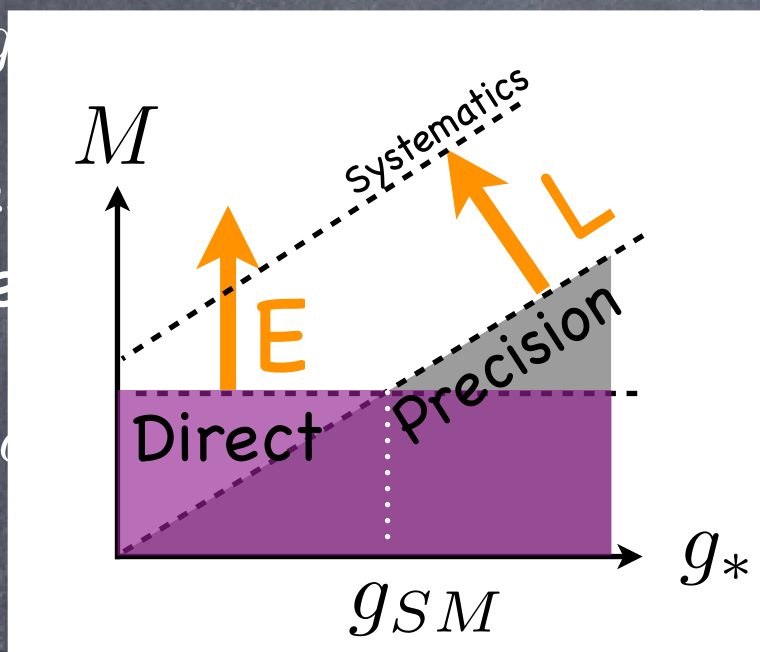

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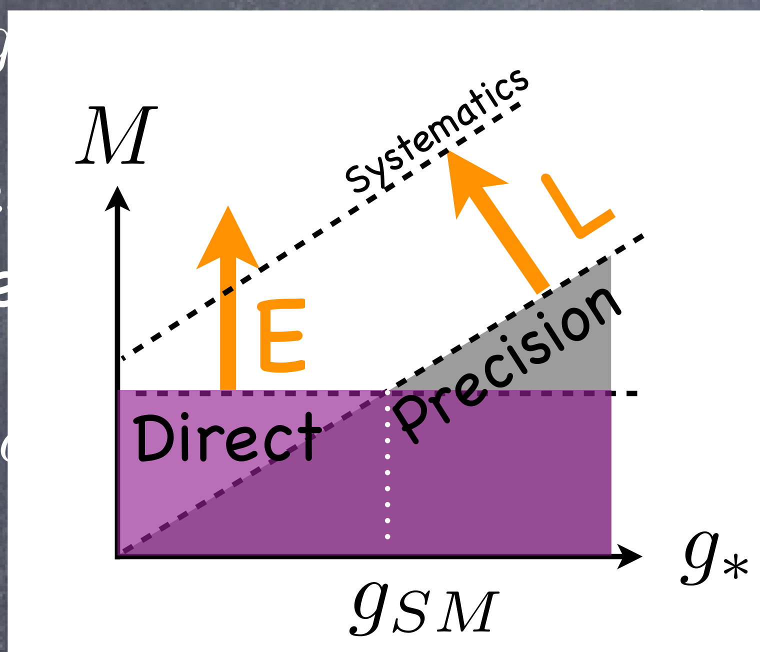

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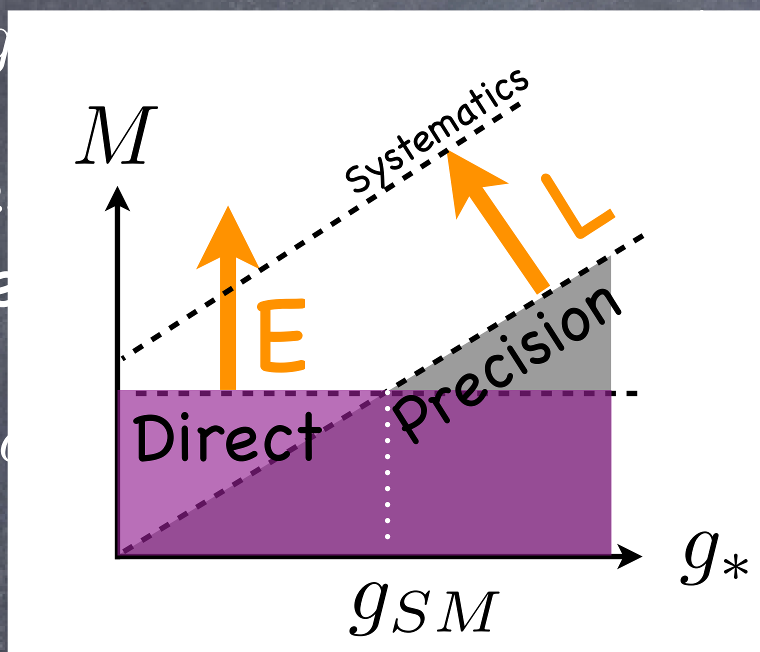

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$$\sigma \sim \sigma_{SM}\left(1 + \frac{g_*^2}{g_{SM}^2}\frac{E^2}{M^2} + \cdots\right)$$

$\ll 1$

$\gtrsim 1$ ➜ E-enhanced

➜ Benefits from High-E
and High-Luminosity

➜ Ideal for High-E (100 TeV) collider
(or useful only for $g_* \approx 4\pi$?)

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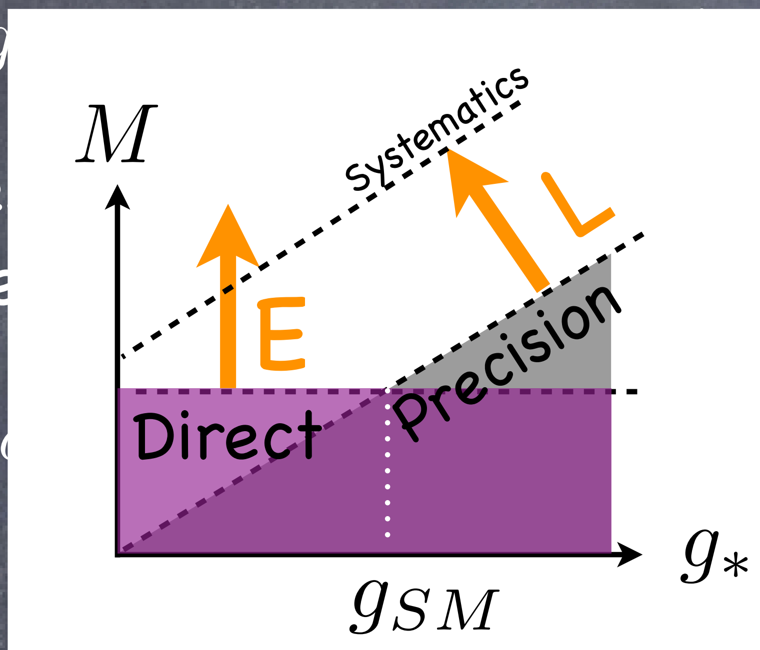

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(Ex: interactions at LEP2)

$\ll 1$

ses:

$+ \cdots$

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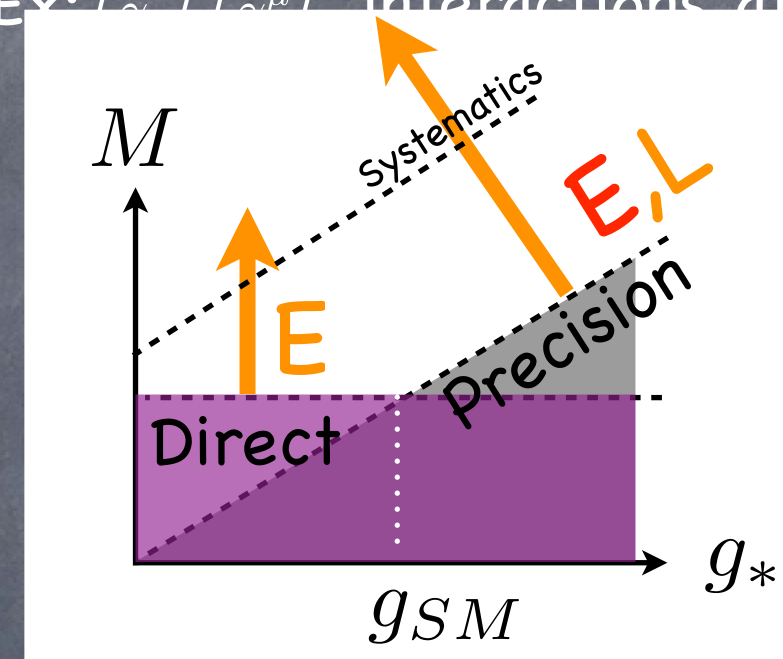

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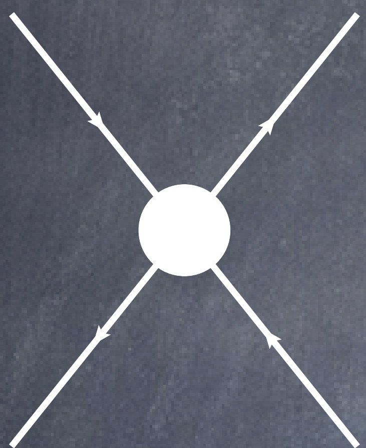
2 -> 2 scatterings

Where BSM induces High-Energy enhancement of SM processes

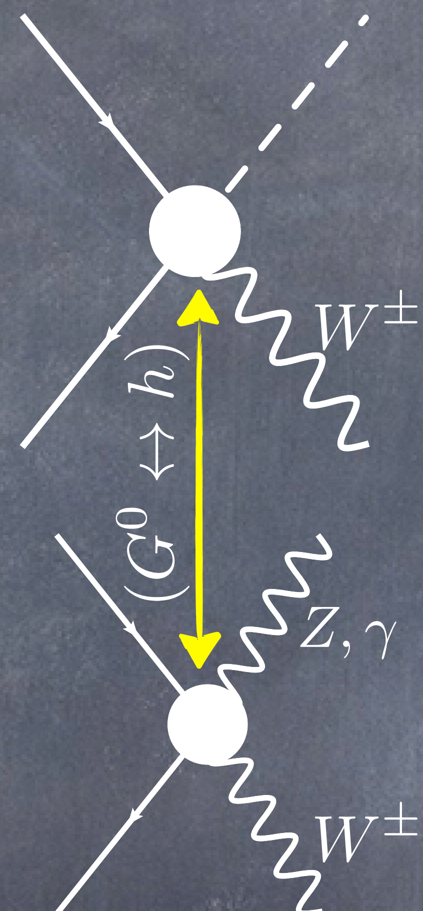
Dijets



Enormous reach on quark compositeness!

$\bar{Q}_L \gamma^\mu Q_L \bar{Q}_L \gamma_\mu Q_L$

VH/diboson



$g \epsilon_{abc} W^{a\,\nu}_{\mu} W^{b}_{\nu\rho} W^{c\,\rho\mu}$

h*->ZZ

double-h

...

Biekotter,Knochel,Kramer,Liu,FR'14; Domenech,Pomarol,Serra'12; Englert,Spannowsky'14;Liu,Pomarol,Rattazzi,FR'15xxx;...

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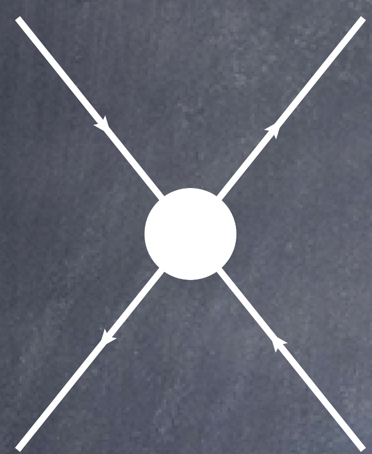

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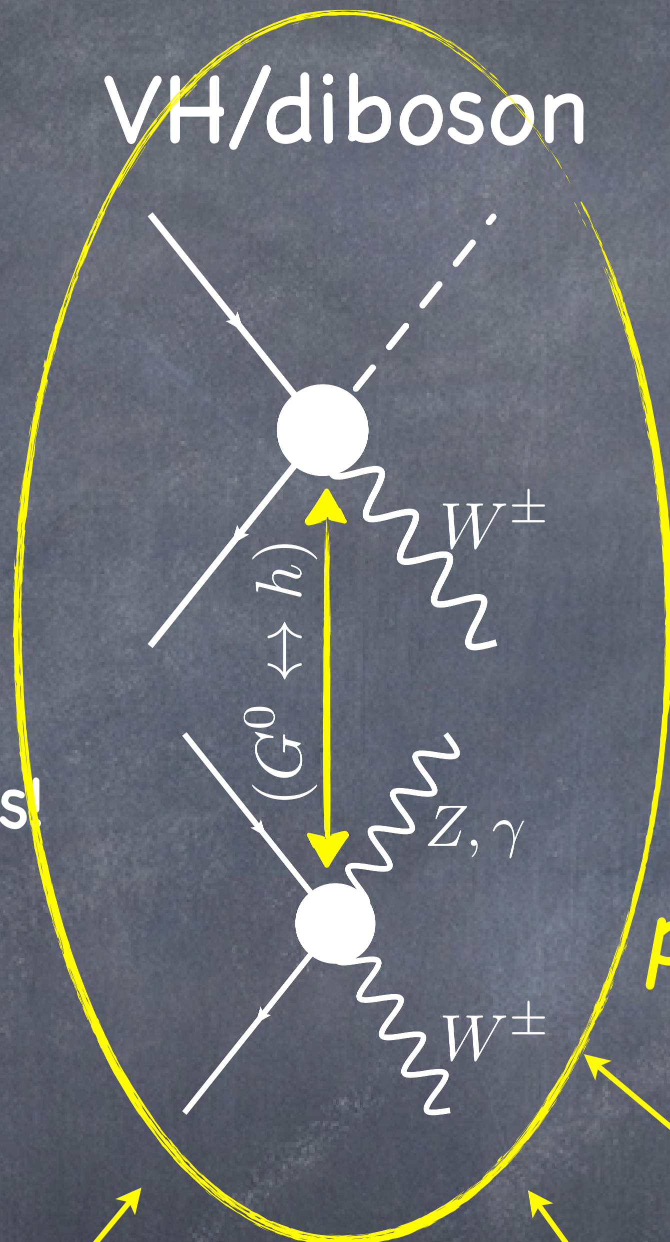

h*->ZZ

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$\bar{Q}_L \gamma^\mu Q_L \bar{Q}_L \gamma_\mu Q_L$

Precision Higgs physics at 100 TeV

$H^\dagger D_\mu \sigma^a H \bar{D}_\nu W^a_{\mu\nu}$ Related to S in most models, but...

$H^\dagger D_\mu H \bar{Q}_L \gamma^\mu Q_L$

Measured at LEP1, but...

$g\epsilon_{abc} W^{a\,\nu}_{\mu} W^{b}_{\nu\rho} W^{c\,\rho\mu}$ Very small in most models, but...

Biekotter,Knochel,Kramer,Liu,FR'14; Domenech,Pomarol,Serra'12; Englert,Spannowsky'14;Liu,Pomarol,Rattazzi,FR`15xxx;...

MSSM

$g_* \simeq g_{SM}$

Selection Rules/ Matching

R-Parity: no tree-level contributions from sparticles (only H_2)

Weakly coupled: loop effects small unless sparticles very light

$\mathcal{O}_H = \frac{1}{2}(\partial^\mu |H|^2)^2$

$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$

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$\mathcal{O}_{y_u} = y_u \|H\|^2 \bar{Q}_L \widetilde{H} u_R + \text{h.c.}$	$\mathcal{O}_{y_d} = y_d \|H\|^2 \bar{Q}_L H d_R + \text{h.c.}$	$\mathcal{O}_{y_e} = y_e \|H\|^2 \bar{L}_L H e_R + \text{h.c.}$
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Gupta,Montull,FR'12

Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

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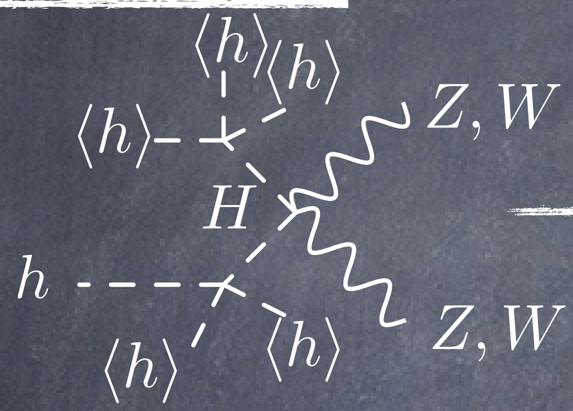
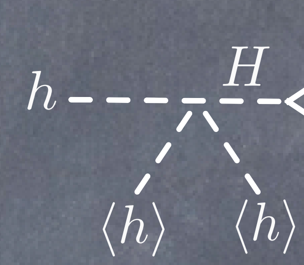


$$c_H \sim \frac{m_Z^4}{m_H^4}$$



$$c_{y_t} \sim \frac{m_Z^2}{m_H^2} \cot \beta$$

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Largest effects in hbb, related to m_{H2}

Gupta,Montull,FR'12
Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

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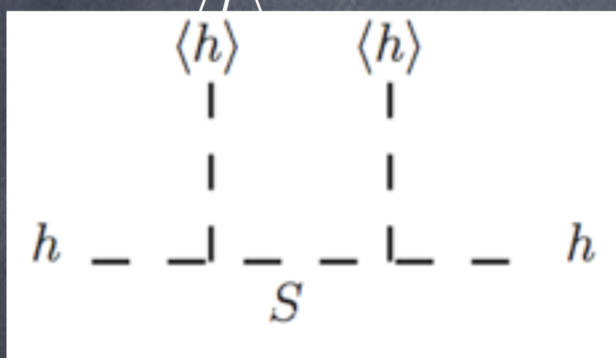

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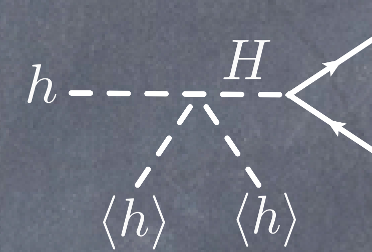

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Largest effects in hbb/hVV, related to m_{H2} and m_S

Gupta,Montull,FR'12
Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

Composite Higgs (PNGB)

Selection Rules/ Matching

Shift Symmetry: terms that violate it are suppressed

Custodial Symmetry: terms that violate it are suppressed

Minimal coupling: non-covariant-D couplings to vectors suppressed

Universal: fermions weakly coupled to BSM

No strong coupling enhancement

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Largest effects in hff/hVV/hhh

measure of naturalness!

Gupta,Montull,FR'12
Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

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Universal: fermions weakly coupled to BSM

No strong coupling enhancement

$\mathcal{O}_H = \frac{1}{2}(\partial^\mu \lvert H\rvert^2)^2$
$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$
$\mathcal{O}_6 = \lambda \lvert H\rvert^6$
$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D^\mu} H\right) D^\nu W^a_{\mu\nu}$
$\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right) \partial^\nu B_{\mu\nu}$

$\mathcal{O}_{BB} = g'^2 \lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$
$\mathcal{O}_{GG} = g_s^2 \lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$
$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$
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$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon_{abc} W^{a\,\nu}_\mu W^b_{\nu\rho} W^{c\,\rho\mu}$

$\mathcal{O}_{y_u} = y_u \lvert H\rvert^2 \bar{Q}_L \widetilde{H} u_R + \text{h.c.}$	$\mathcal{O}_{y_d} = y_d \lvert H\rvert^2 \bar{Q}_L H d_R + \text{h.c.}$	$\mathcal{O}_{y_e} = y_e \lvert H\rvert^2 \bar{L}_L H e_R + \text{h.c.}$
$\mathcal{O}^u_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R \gamma^\mu u_R)$ $\mathcal{O}^q_L = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L \gamma^\mu Q_L)$ $\mathcal{O}^{(3)\,q}_L = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L \sigma^a \gamma^\mu Q_L)$	$\mathcal{O}^d_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}^e_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$
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Largest effects in hff/hVV/hhh

measure of naturalness!

Gupta,Montull,FR'12
Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

Composite Higgs (PNGB) - Part.Comp.

Selection Rules/ Matching

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and interactions with fermions

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Conclusions

- Theoretical bias: effects in EFT parametrization are associated with new physics scale and naturally "just around the corner"

  CH: Mainly modifications of SM-like Higgs couplings

  MSSM: Mainly modifications of SM-like hbb

- Experimental bias: systematics must decrease and statistics increase for 100 TeV to beat HL-LHC on SM-like couplings

  a 100TeV cc can probe very well non-SM-like couplings that contribute to (non-resonant) processes in an E-growing way

Great reach on Fermion/Gauge-boson (&Higgs) compositeness

Perhaps new theoretical paradigms useful for 100TeV...

(e.g. Composite gauge bosons)

Liu,Pomarol,Rattazzi,FR`15xxx;...

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