EFT vs Top Down Approaches

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Searching for new physics: two main strategies
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**direct searches**

produce new particles at a collider → leads to actual *discoveries*

we *need to know* beforehand what the new particle looks like

only works if new particles are *within the energy reach* of the collider

requires *high energy*
Searching for new physics: two main strategies

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**indirect searches**

- look for the **effect** of new particles without necessarily producing them

- we don’t need to specify in detail what we are looking for

- gives valuable information even if the new particles are **out of the energy reach**

- requires **precise measurements**
Searching for new physics: two main strategies

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Provocative Statement:

“Direct Search” → Top Down Approach

“Indirect Search” → Effective Field Theories (EFT)
Top Down Approach

ATLAS Exotics Searches* - 95\% CL Upper Exclusion Limits

Status: May 2019

<table>
<thead>
<tr>
<th>Model</th>
<th>E_{\text{miss}}</th>
<th>\ell, \gamma</th>
<th>Jets</th>
<th>\text{Limit}</th>
<th>\text{Reference}</th>
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</thead>
<tbody>
<tr>
<td>ADO $G_{\chi} + g/\gamma$</td>
<td>$0 &lt; \mu &lt; 1$</td>
<td>$1 &lt; \gamma$</td>
<td>Yes</td>
<td>$3.8 \text{ TeV}$</td>
<td>$\ell = 2$</td>
</tr>
<tr>
<td>ADO non-resonant $g/\gamma$</td>
<td>$2 &lt; \gamma$</td>
<td>$1 &lt; \gamma$</td>
<td>Yes</td>
<td>$4.2 \text{ TeV}$</td>
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<tr>
<td>Extra dimensions</td>
<td>$2 &lt; \gamma$</td>
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<td>LHC experiments cover many different final states with dedicated searches for specific models.</td>
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**Key Idea:** If new physics is directly observable at the LHC, should be seen as a resonance or broad excess/deficit.

**LHC experiments cover many different final states with dedicated searches for specific models.**
Top Down Approach

- Are efforts in both ATLAS and CMS to bring these separate searches together into a more general framework.
Top Down Approach

• Are efforts in both ATLAS and CMS to bring these separate searches together into a more general framework.

• Rather than simply setting limits on xsec and mass, also make statement about SM coupling.

• Still not truly agnostic (Spin-0/2, non-resonant, complex structure)

• Searches != Precision Measurements
Figure 1-26. Upper cross-section limits for the process $q\bar{q} \to Z' \to e^+e^-$, set at 95% CL using a Bayesian statistical interpretation given 3000 $fb^{-1}$ of data collected at $\sqrt{s} = 14$ TeV. Various signal scenarios are overlayed, with mass exclusion limits extracted at the intersection of the theory-expected lines.
Figure 1-26. Upper cross-section limits for the process $q\bar{q} \rightarrow Z' \rightarrow e^+e^-$, set at 95% CL using a Bayesian statistical interpretation given 3000 fb$^{-1}$ of data collected at $\sqrt{s} = 14$ TeV. Various signal scenarios are overlayed, with mass exclusion limits extracted at the intersection of the theory-expected lines.
• Possibility that new states exist (just) beyond the energy reach of the LHC
• We may still observe indirect effects of such particles in the kinematic tails, e.g., LEP limits on ~ TeV Z'
• Intrinsically small effects that require precise theoretical control on signal and background predictions

Framework: SM effective field theory (SMEFT)

Theoretically consistent, 'model independent' approach to deviations of interactions between SM fields

Limitations

**Figure 1-26.** Upper cross-section limits for the process $q\bar{q} \rightarrow Z' \rightarrow e^+e^-$, set at 95% CL using a Bayesian statistical interpretation given 3000 fb$^{-1}$ of data collected at $\sqrt{s} = 14$ TeV. Various signal scenarios are overlayed, with mass exclusion limits extracted at the intersection of the theory-expected lines.
EFT Approach

• **Key Idea:** If new physics is characterized by a very large energy scale $\Lambda$ (particle mass / compositeness scale / ...), it’s impact at the LHC can be described by an EFT.

• **Pros of EFT Approach:**
  - Model independent, within assumptions.
  - Do not need knowledge of UV model to make predictions.
  - Better than just anomalous couplings, as it’s a full QFT.
  - Gives a systematic classification of all possible BSM effects.
  - Gives access to physics beyond LHC reach.
An EFT for BSM searches: The SMEFT

fundamental assumptions:

- new physics nearly decoupled: $\Lambda \gg (\nu, E)$
- at the accessible scale: SM fields + symmetries
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Taylor expansion in canonical dimensions (\( \delta = \nu/\Lambda \) or \( E/\Lambda \)):

\[
\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda} \mathcal{L}_5 + \frac{1}{\Lambda^2} \mathcal{L}_6 + \frac{1}{\Lambda^3} \mathcal{L}_7 + \frac{1}{\Lambda^4} \mathcal{L}_8 + \ldots
\]

\[
\mathcal{L}_n = \sum_i C_i \mathcal{O}_i^{d=n}
\]

- \( C_i \) free parameters (Wilson coefficients)
- \( \mathcal{O}_i \) invariant operators that form a complete, non-redundant basis
What precision is needed?

A back-of-the-envelope estimate:

\[
\text{on poles} \quad \text{NP impact} \sim \frac{v^2 g}{M^2} = \frac{v^2}{\Lambda^2} \quad \text{EFT cutoff}
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\[g \approx 1 \quad M \gtrsim 2 - 3 \text{ TeV} \rightarrow 1\% \quad \text{at least!}
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- A parameter space reduction
- B experimental precision required

### Pole observables

- A remarkable
- B need 1 %

### Tails of dist.

- A difficult \((\psi^4)\)
- B ok with tens of %

Pole and tails are complementary!
Current Measurements & HL-LHC Projections

ATLAS

H → ZZ* → 4l
\(\sqrt{s} = 13\) TeV, 139 fb\(^{-1}\)
Production Mode - |\(y_H| < 2.5$

- Observed: Stat+Sys
- Observed: Stat-Only
- SM Prediction
- p-value = 91%
Current Measurements & HL-LHC Projections
Status in Global Fits
Status in Global Fits

95% Limits, Marginalized
Some Starter Questions for Discussion…

1. How does the EFT reach, in terms of new physics scale, compare to that of direct searches?

2. What is the precision needed for EFT to do better than Top Down?
   - Which measurements can realistically expect this?

3. Is there any regime where the two approaches overlap?
   - If so, how can this complementarity be best exploited?
   - Otherwise, is there a blind spot?

4. How can we better control the large theory uncertainties which limit both approaches? Is one approach more resilient?

5. Can searches performed with the Top Down approach in mind be easily cast into EFT?
   - Could be useful for where precision measurements do not exist.