HELMHOLTZ ASSOCIATION

Exotic production of new vector-like quarks

Mikael Chala (DESY)

in collaboration with **J. Santiago.** Based on *1305.1940*

[and recently brought to the real world by ATLAS in *1602.06034*]

BSM faces LHC run-2 realities, September 16$^{\text{th}}$ 2016

From theory to experiment

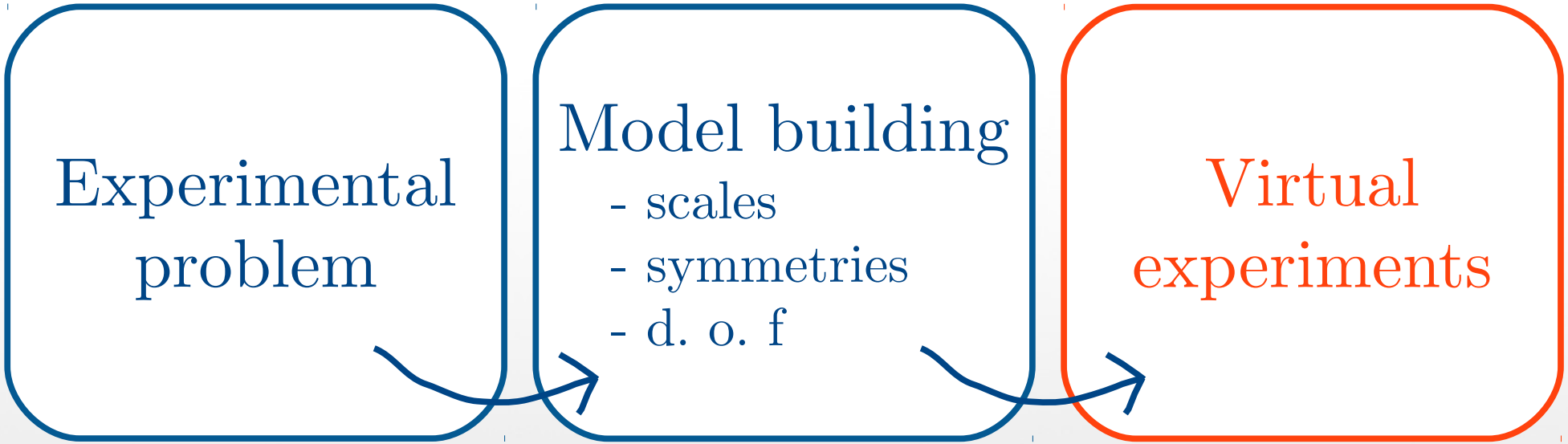
Experimental problem

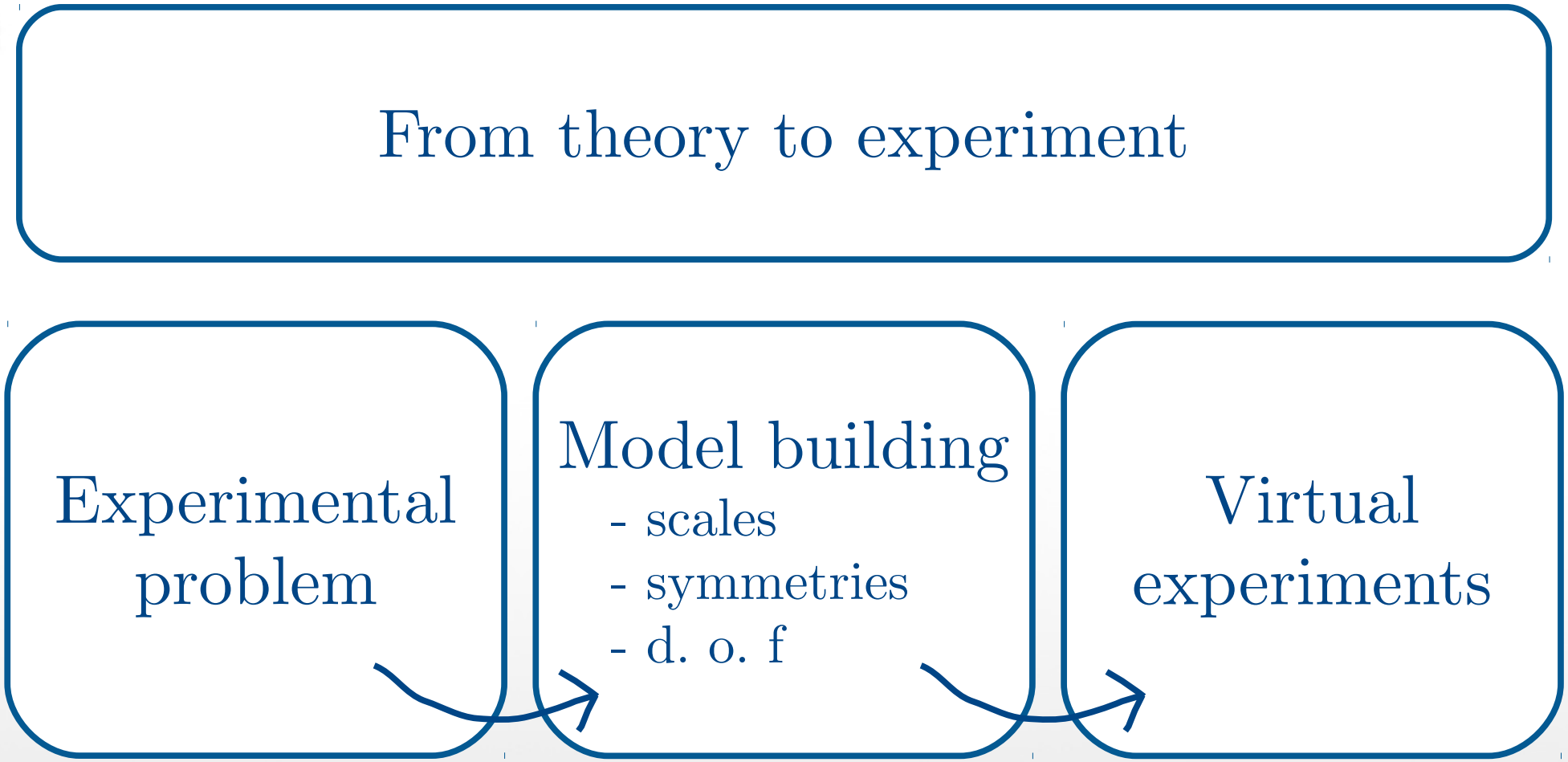
From theory to experiment

Experimental problem

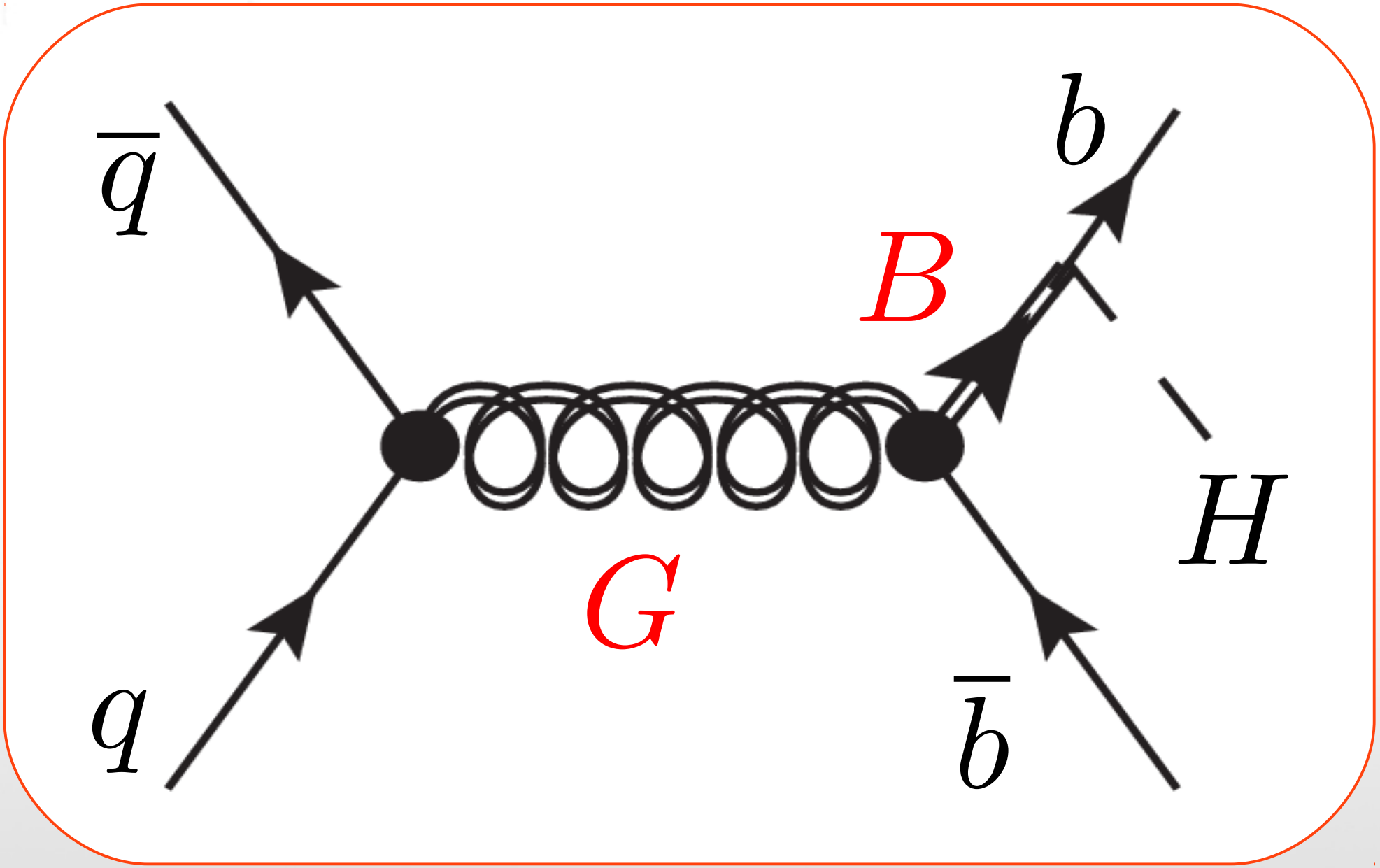
Model building
- scales
- symmetries
- d. o. f

From theory to experiment





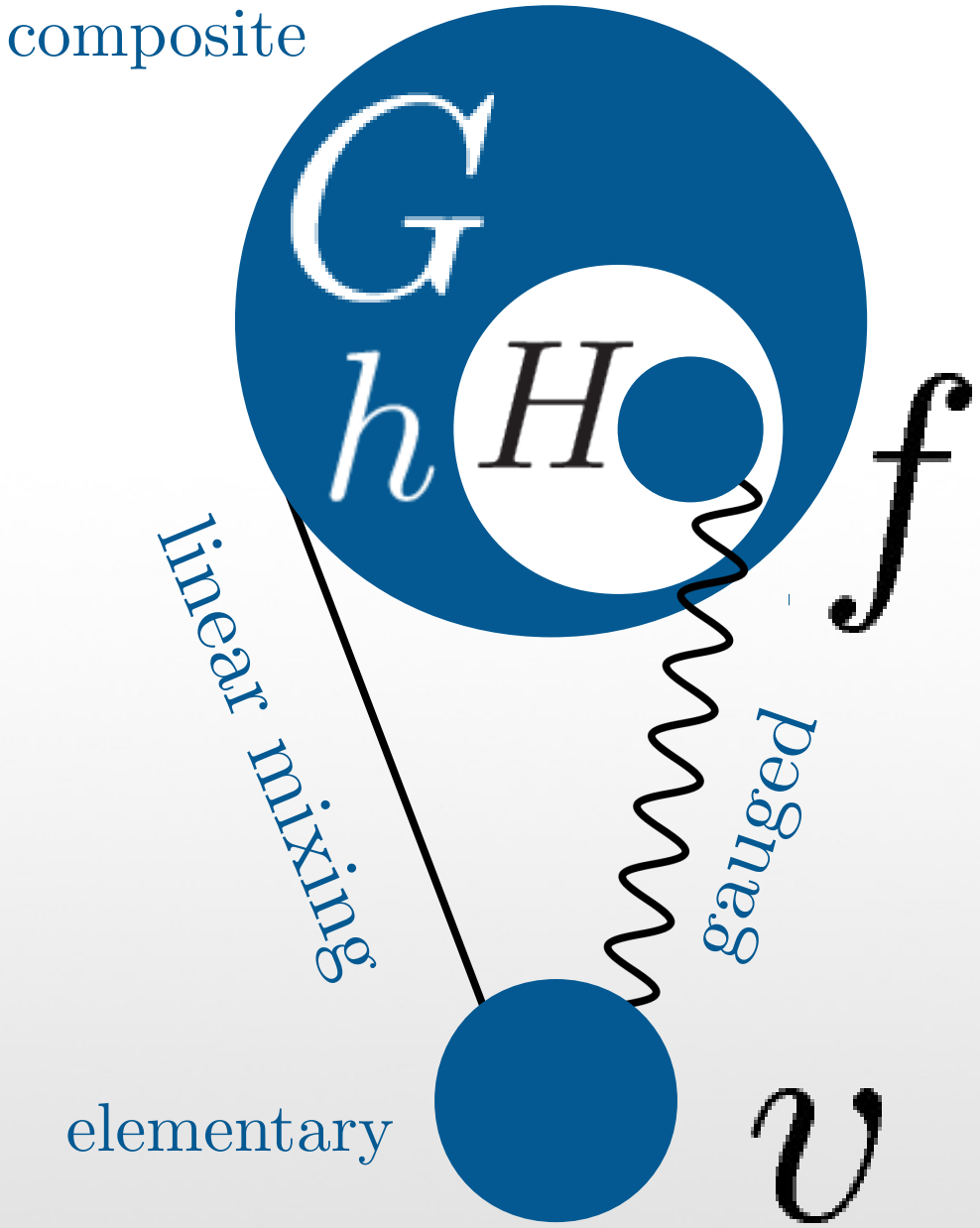
Test your hipothesis in the real world!


$\overline{q}$
b
B
H
G
q
$\overline{b}$

The Higgs boson, h, is a **bound state** of a new strongly interacting sector

The Higgs boson mass is protected by its finite size

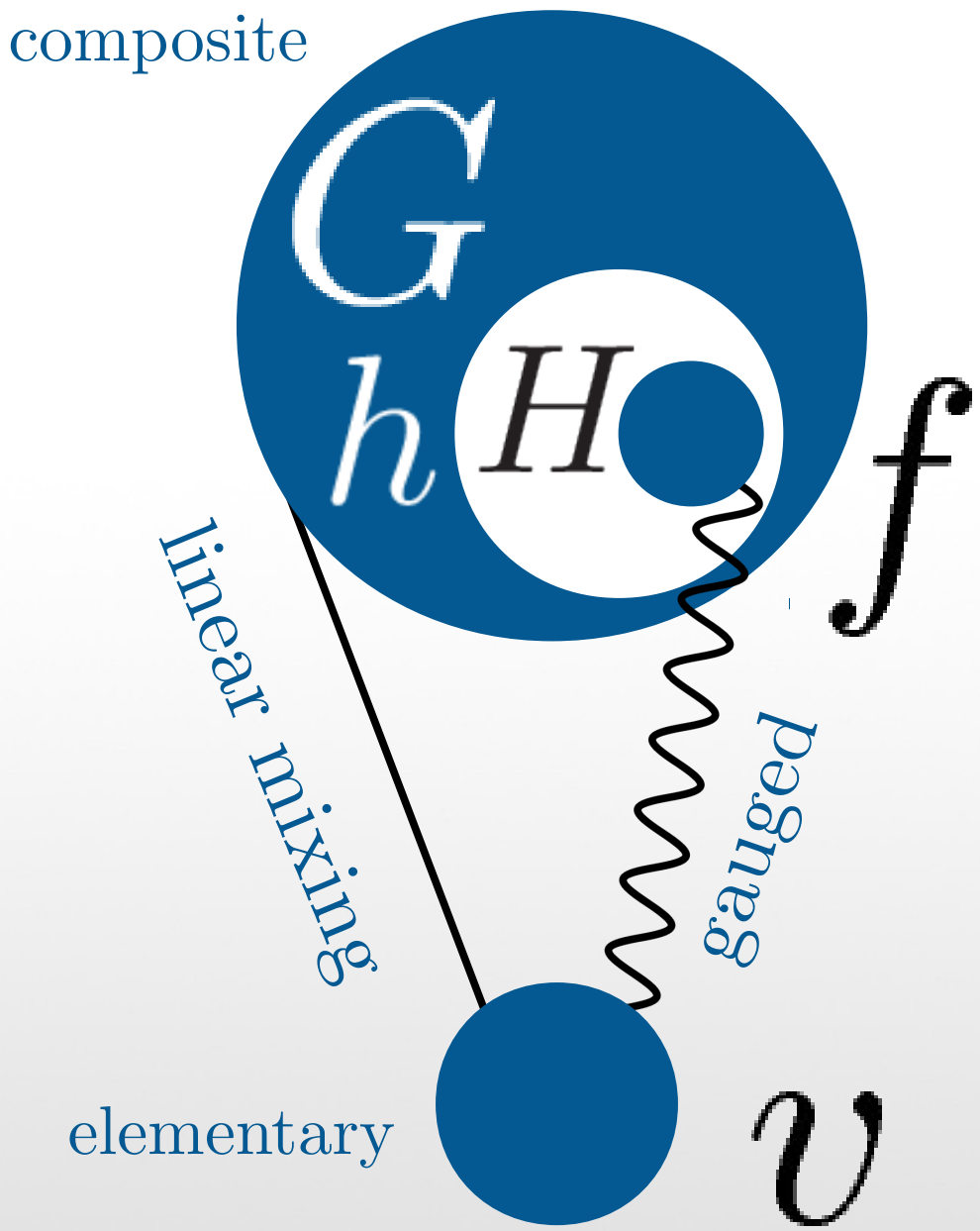
$$SM \subset H \subset G$$



The Higgs boson, h, is a **pNG boson** of a new strongly interacting sector

The Higgs boson mass is protected by its finite size

It is naturally light



Generation of the quark mass hierarchy

(the top quark interacts stronger with the new sector)

UV scale

RGE...

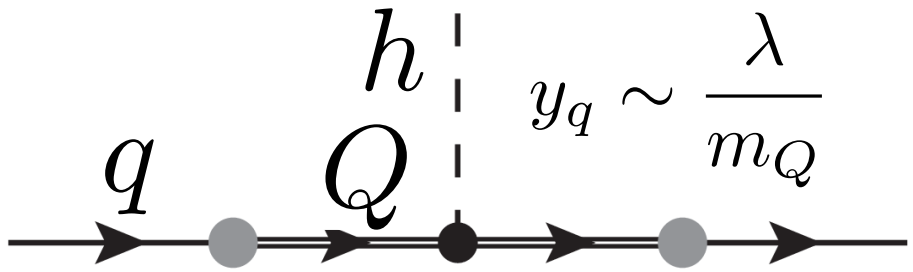
Confinement scale
~ TeV

Electroweak scale

$$\mathcal{L} \sim \lambda[\Lambda_{UV}]\overline{q_i}\mathcal{O}_F^{d_i} + \text{h.c.}$$

$$\mathcal{L} \sim \lambda[\text{TeV}]\overline{q_i}Q^i + \text{h.c.}$$

elementary-composite mixing



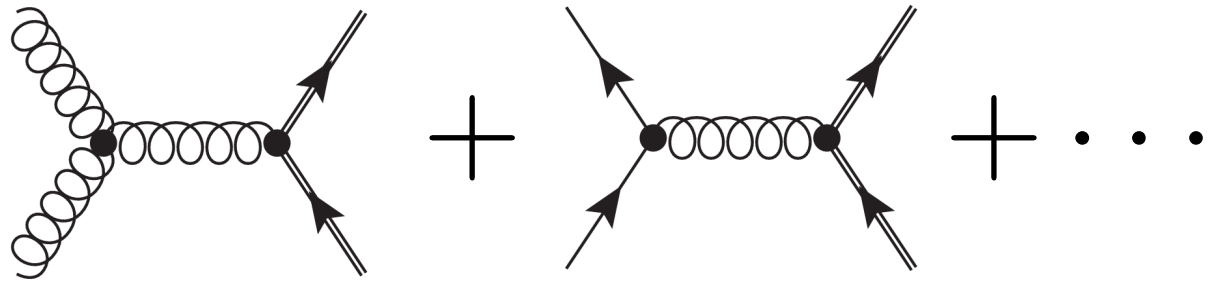
Phenomenological implications

- Low-energy physics: S and T parameters, corrections to the Zbb vertex, etc.
  (can be controlled by symmetries)
- Higgs phenomenology: modified couplings.
- Unavoidable **new fermionic resonances.**

$$\mathcal{L} \sim \mathcal{L}_{SM} + \sum_{i,j} \left\{ \overline{Q_i} \not{D} Q_i + \left[\Delta_{ij} \overline{Q_i} q_j + \text{h.c.} \right] \right\}$$

General properties of top/bottom partners

- **Rather light** (TeV scale), large fine tuning otherwise.
- Charged under SU(3), and hence copiously produced.
- Top (bottom) partners decay **only** into tZ, th, Wb (bZ, bh, Wt). BRs dictated by the linear mixings.

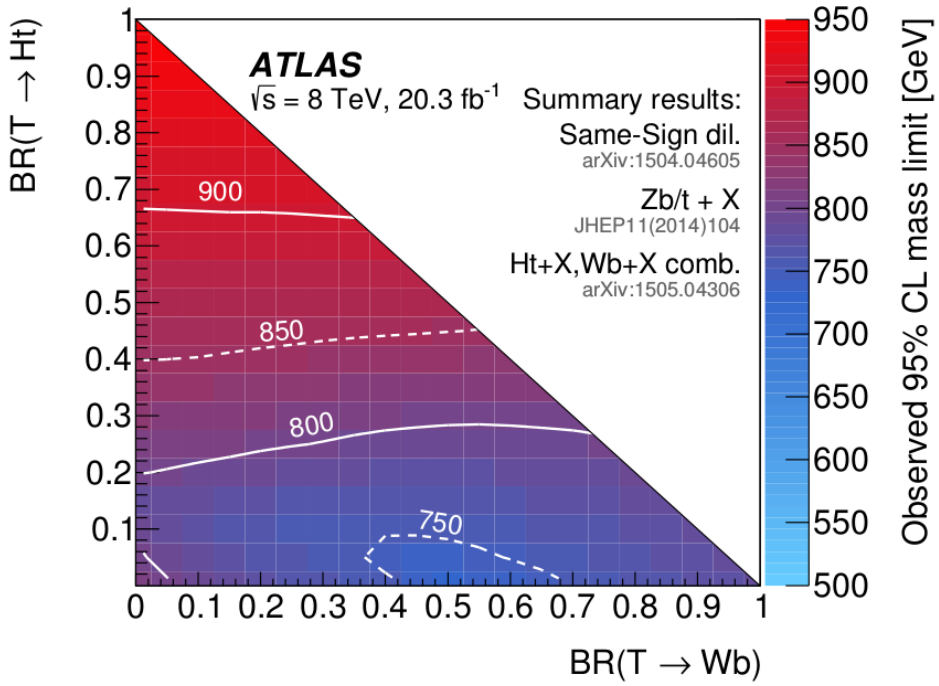


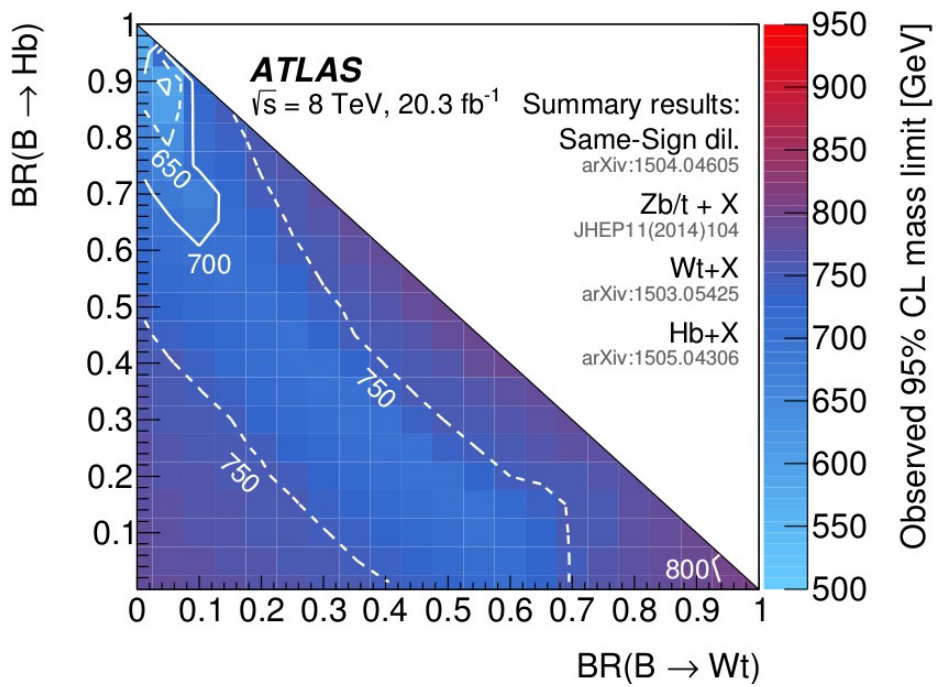
Dictated by QCD:

model-independent

Current searches

arXiv:1505.04306



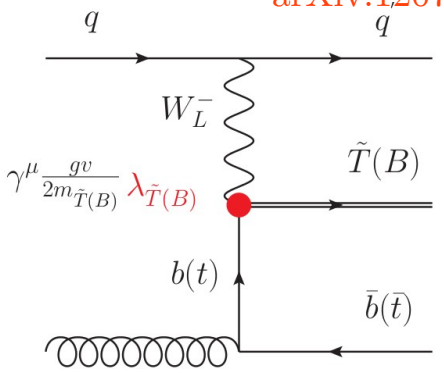


Model-independent limits on **mT** $<$ **750 GeV** and **mB** $<$ **600 GeV**.

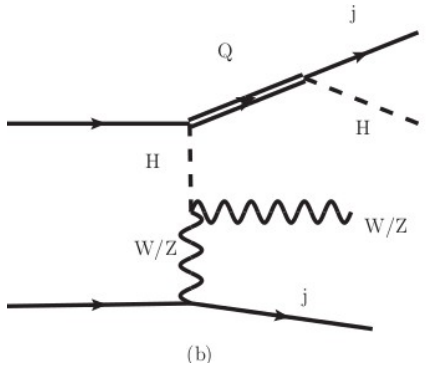
Other searches for heavy quarks

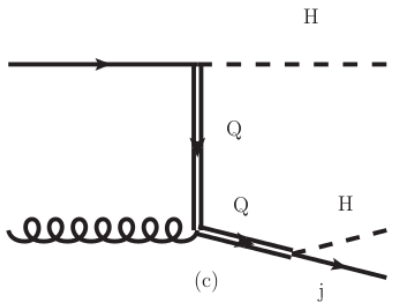
- Searches in single production can shed light over the mixing structure.
- Searches for resonances of the light quarks can give rise to very interesting topologies: double Higgs production, ...

arXiv:1207.0830



arXiv:1302.0270





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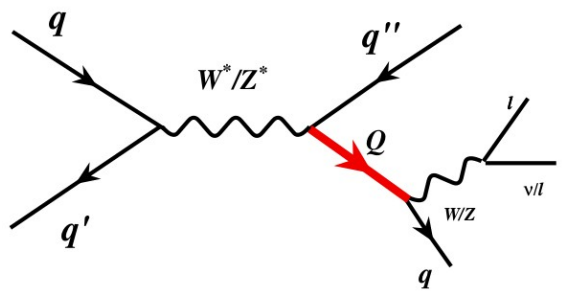
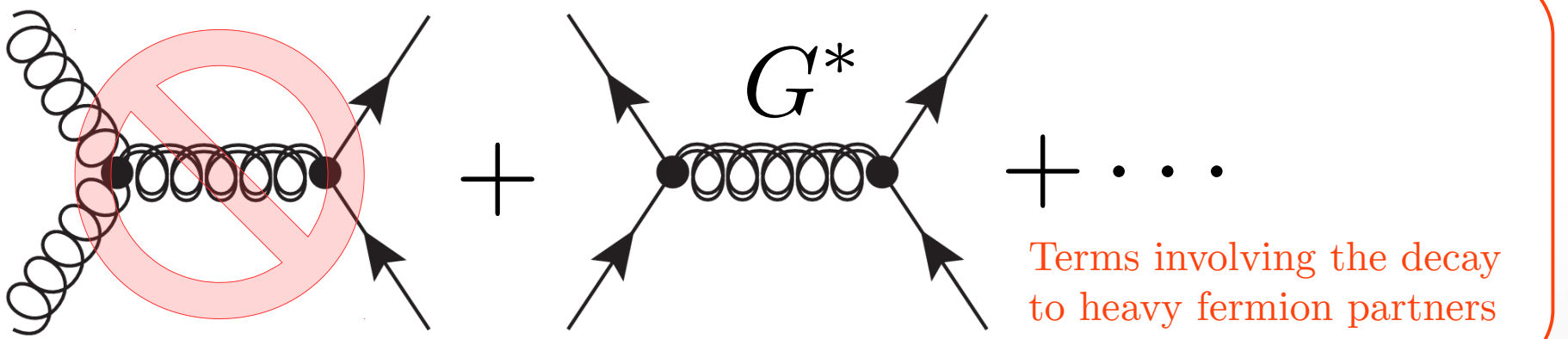
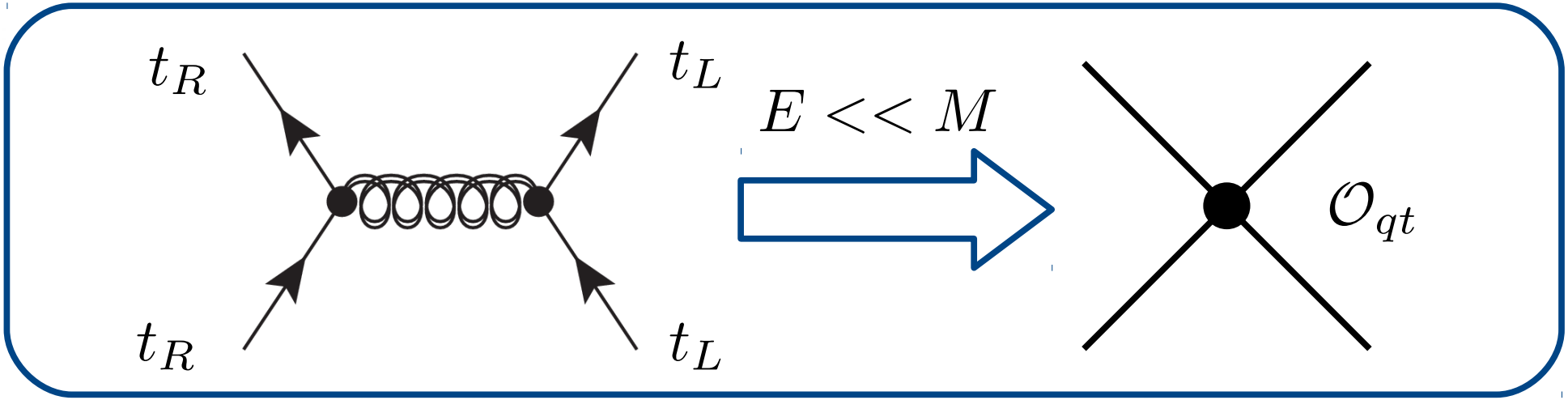


Vector resonances can be also present



- Dramatic implications if G^* decays also into heavy fermion partners: much **heavier width**, **different final states**.

- Current constraints together with naturalness arguments suggest that this is actually the case.



Running from the new physics scale **down to the electroweak scale**

$$c_{\phi q}^{(1),(3)} \sim \frac{N_c y_t^2}{16\pi^2} c_{qt}^{(1)} \log \frac{\Lambda}{v}$$

Blas, **MC**, Santiago

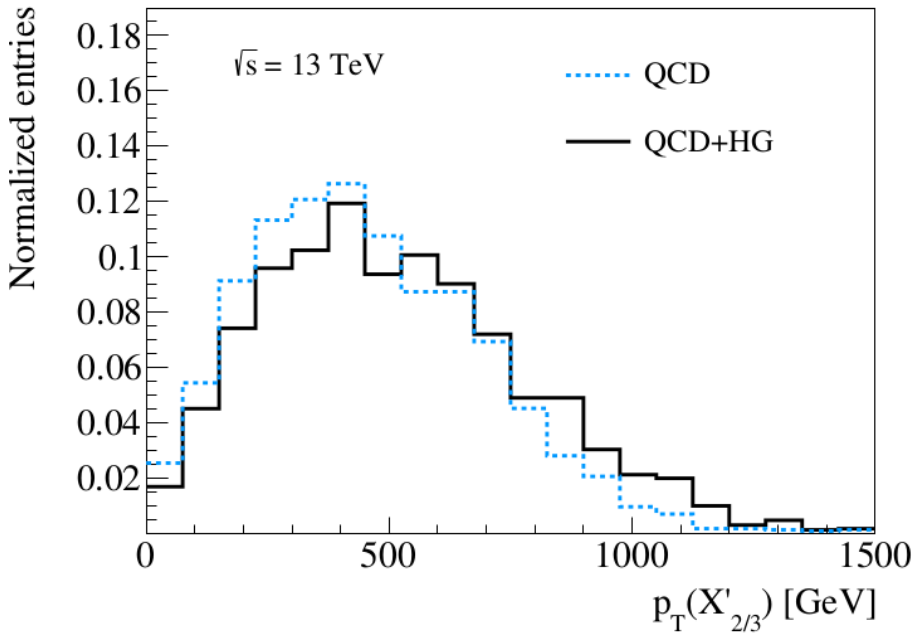
1507.00757

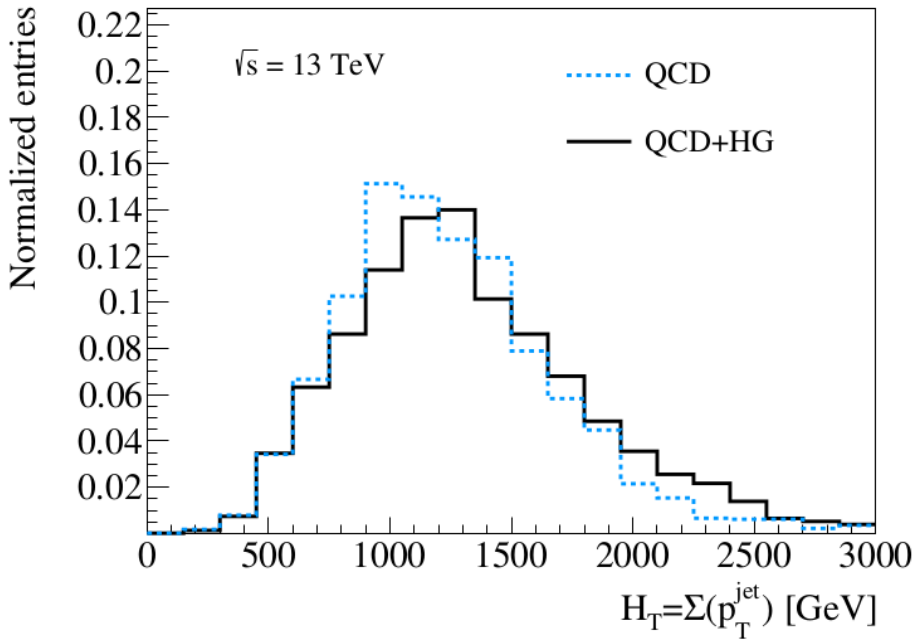
It translates into **constraints** on the new scale **of order TeV** for couplings of order 1

Probably, the decay into two heavy fermions is also open

Implications on searches for pair-produced heavy quarks:

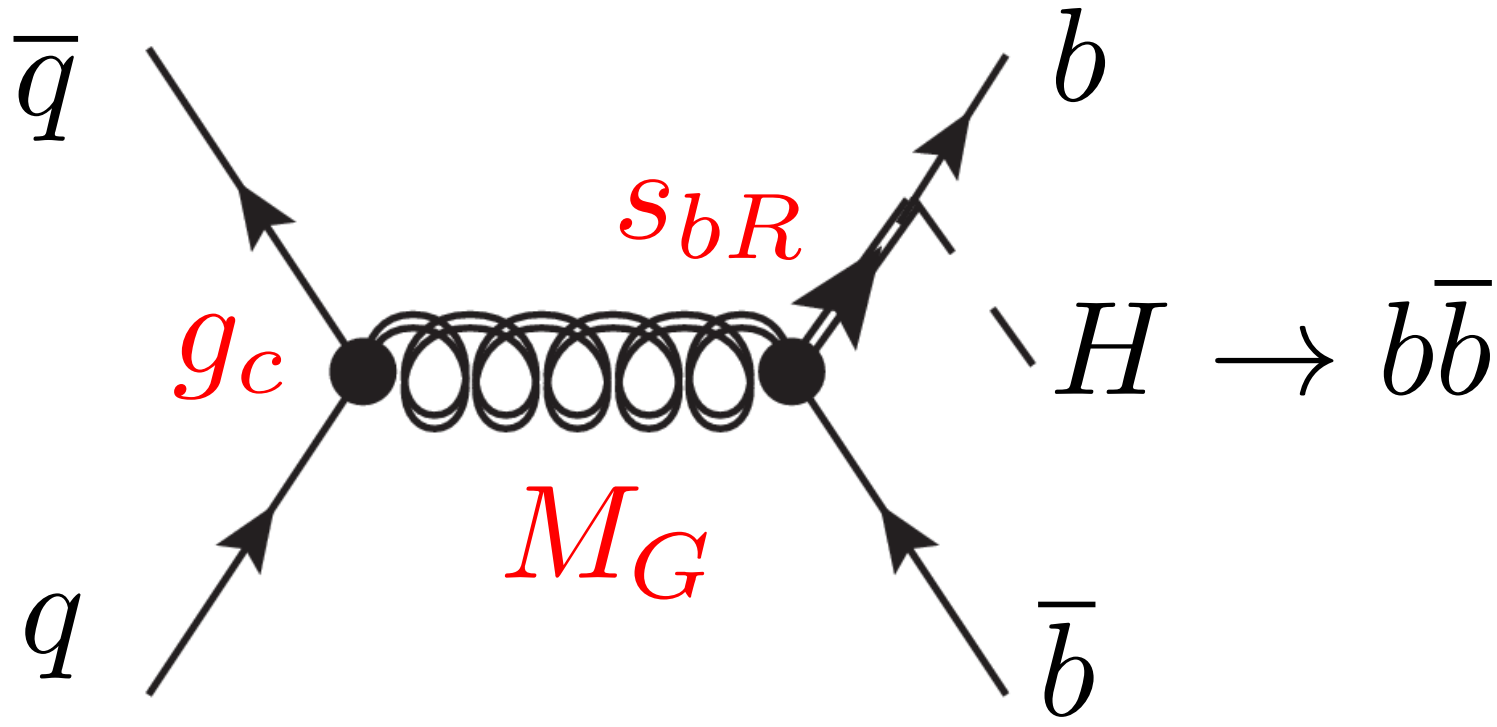
arXiv:1507.06628 (similar conclusions in 1505.01506)





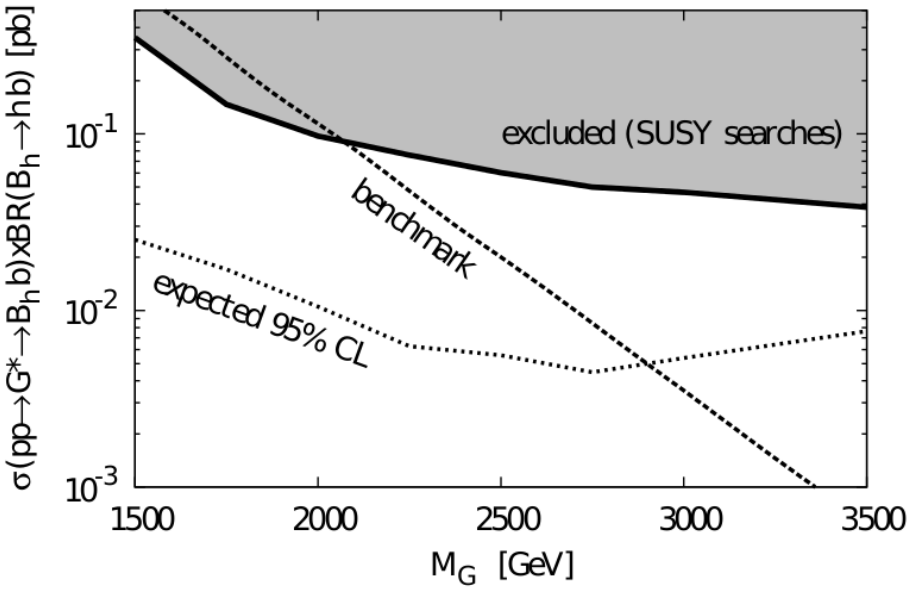
Let us consider an intermediate regime

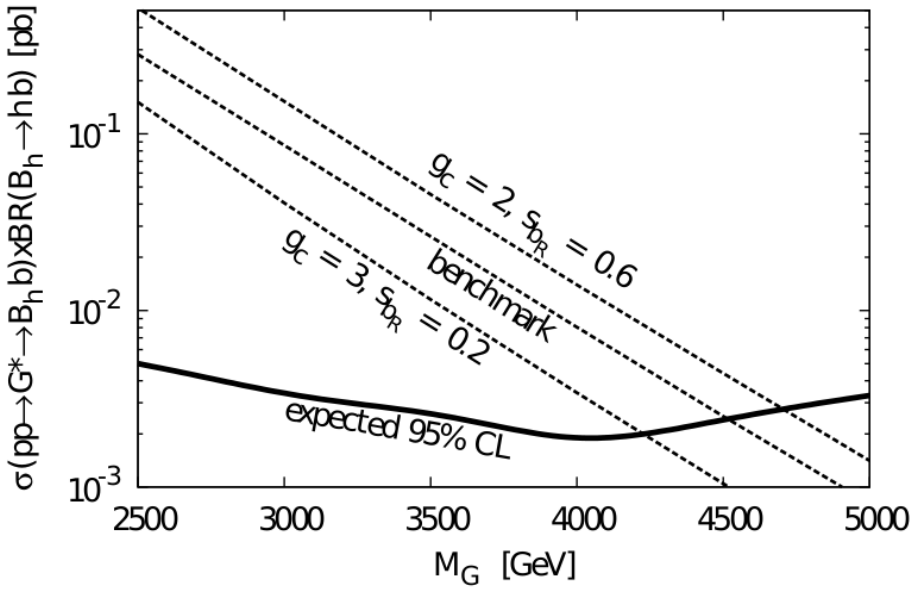
Model details: SO(5)/SO(4), fermions in the 5, numerical mass matrix diagonalization, **heavy quark decays 100% into *Hb***



Cross sections and constraints

Dijet searches, ttbar searches, searches for Hbb in SUSY, and searches for multi-b with missing energy in SUSY.





Our suggested strategy

- Require no leptons,
- require **four b-tagged** jets,
- require large momenta,
- cut on the heavy mass.
- pair two b-tagged jets,
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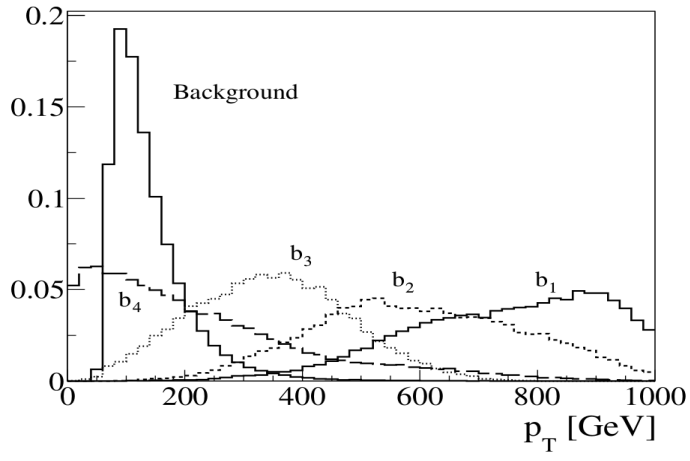

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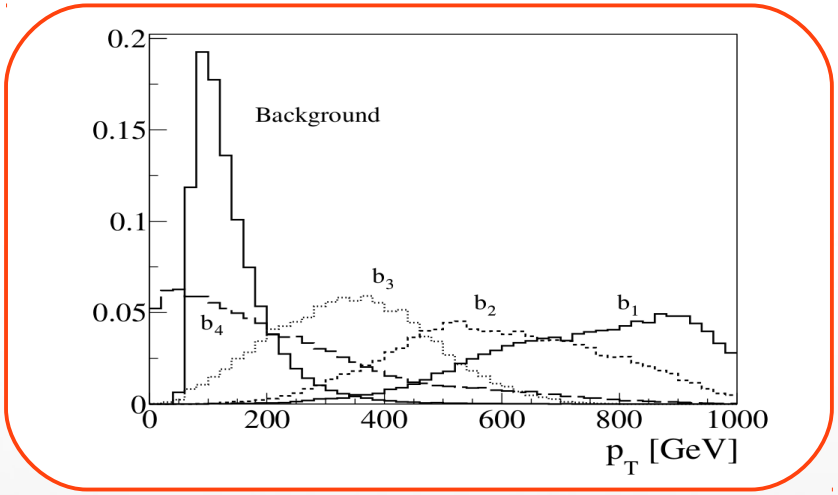

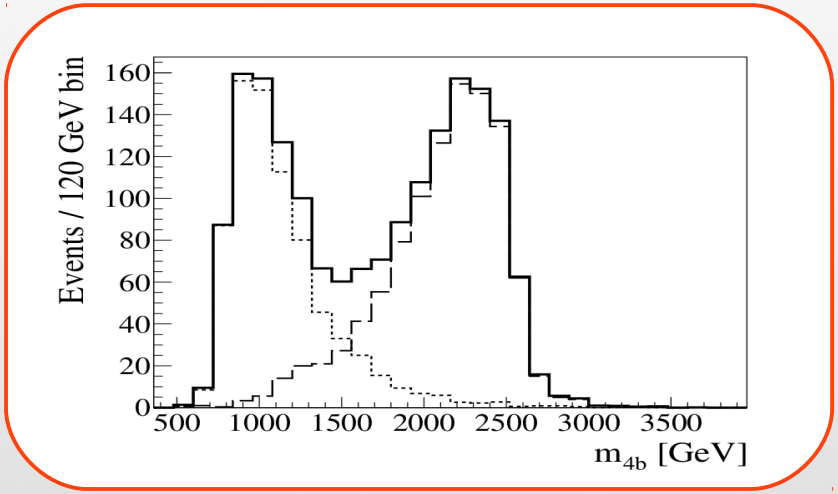

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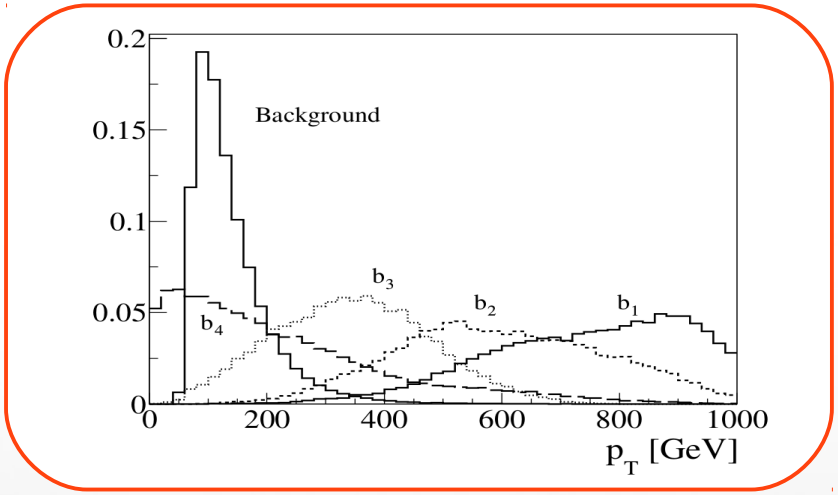

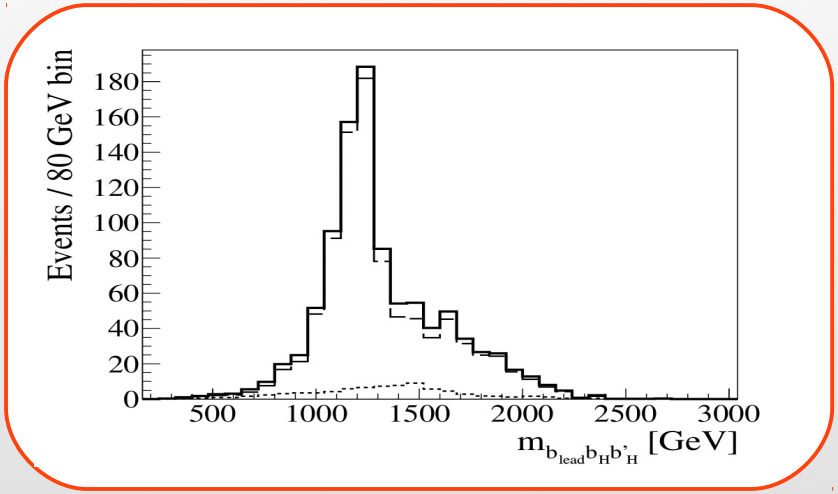

The Standard Model background

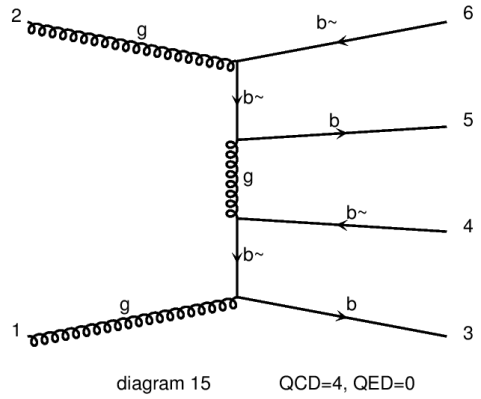

diagram 15 QCD=4, QED=0

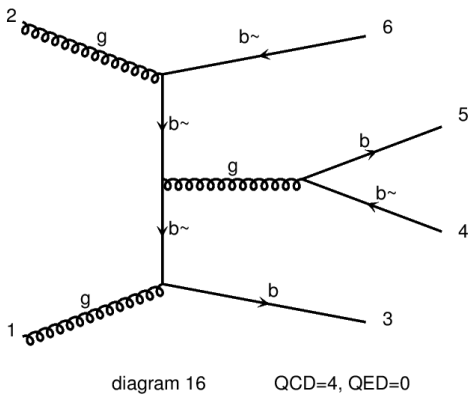

diagram 16 QCD=4, QED=0

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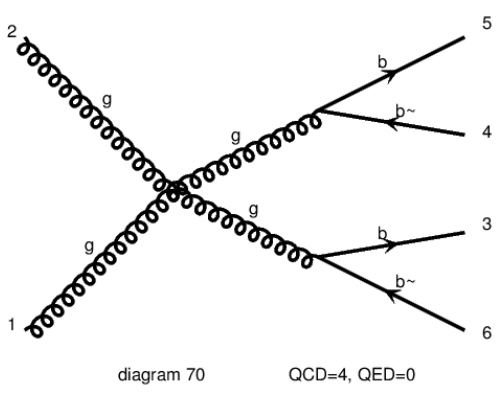

diagram 70 QCD=4, QED=0

- easily computed with MG (or ALPGEN),
- disregard light QCD,
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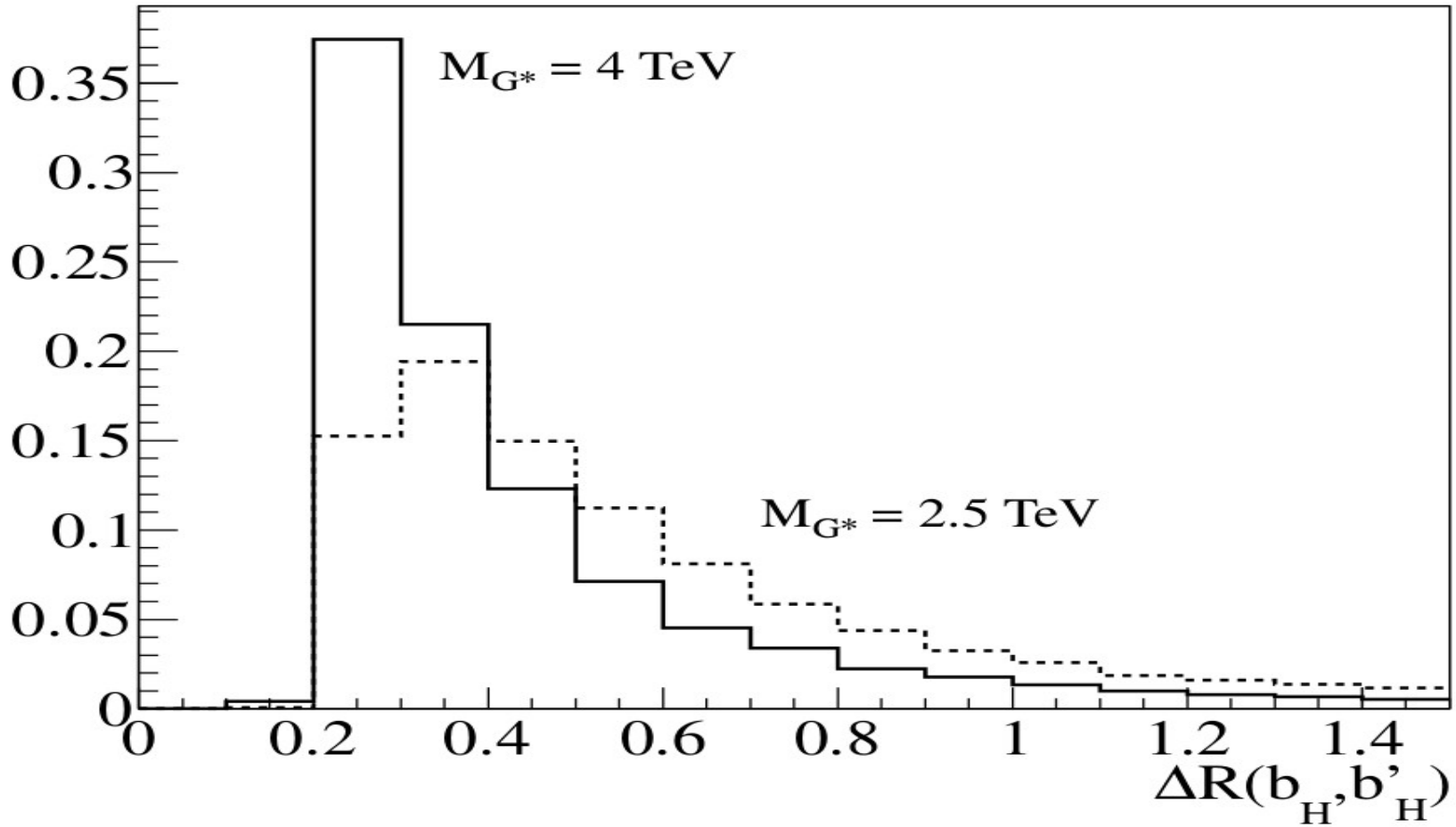
We can not estimate the three-b final state in the Standard Model

The boosted regime at 8 TeV



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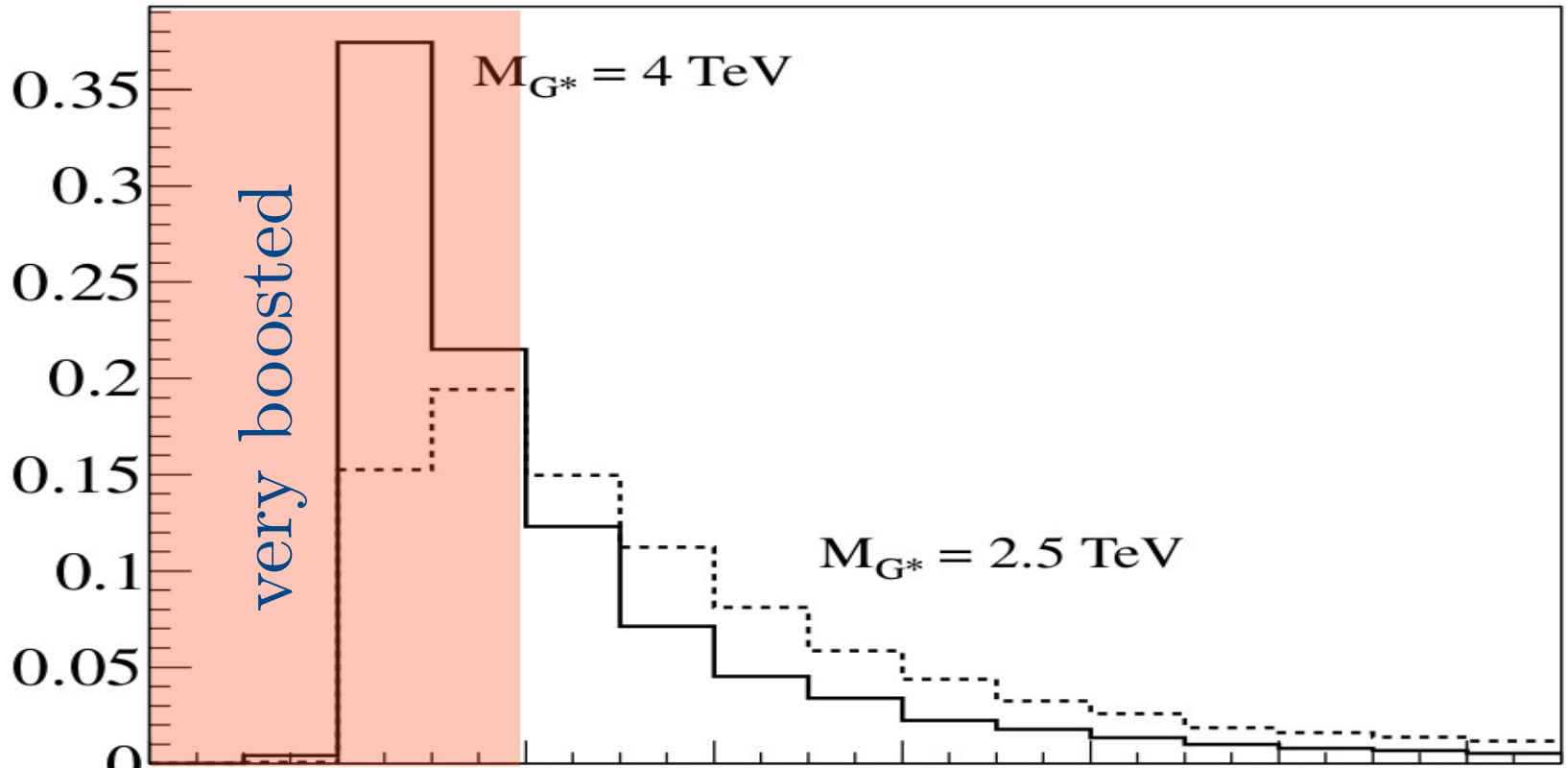

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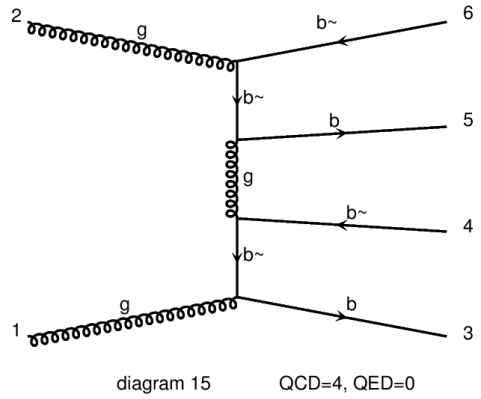

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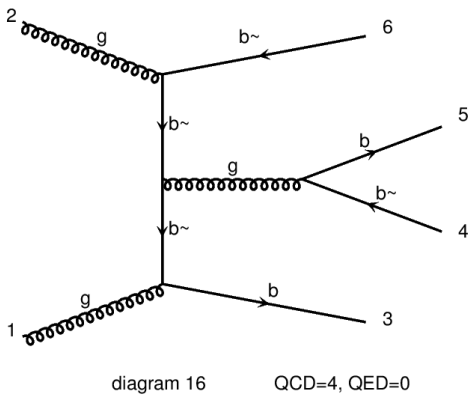

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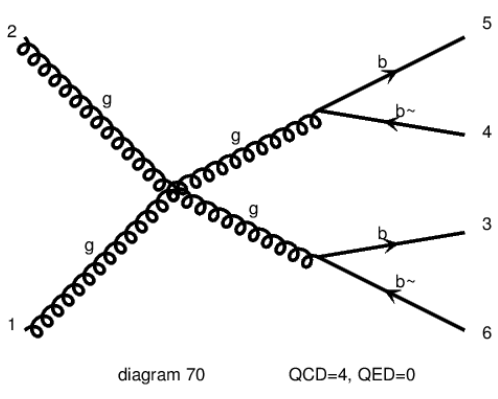

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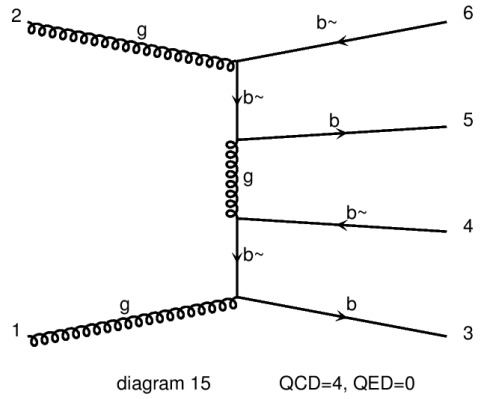

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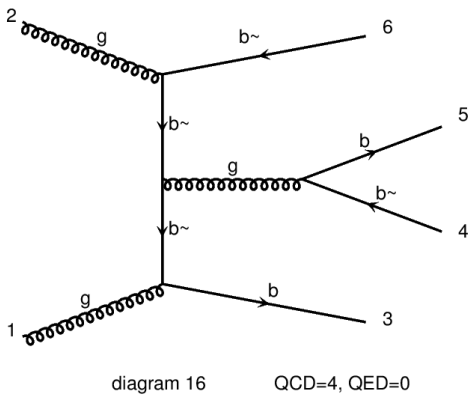

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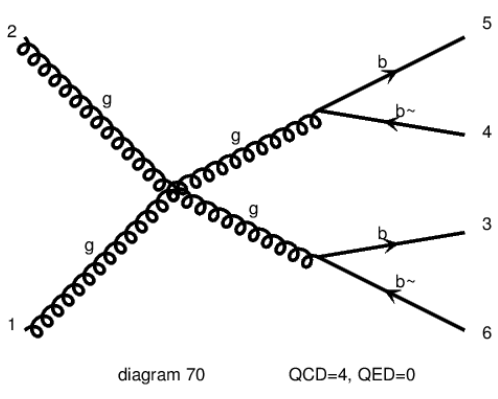

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Data driven for dummies ($ABCD$ method)

$$N_A/N_B = N_C/N_D \Longrightarrow N_A = N_B/N_D \times N_C$$

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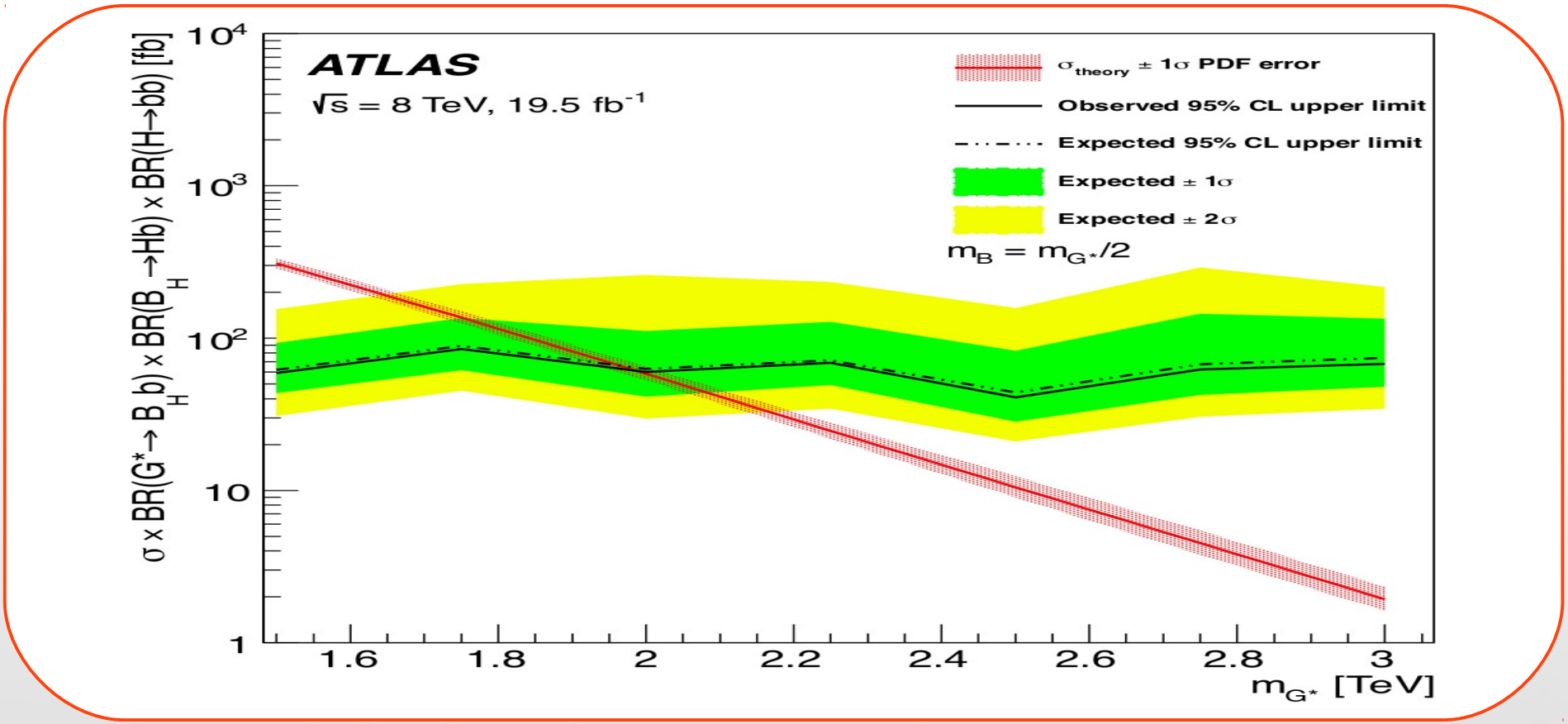
Analysis focused on three-b final states (smaller sensitivity, but ready for 13 TeV)



- Composite Higgs models are an appealing solution to the hierarchy problem (including the quark mass puzzle).
- Vector-like quarks and heavy bosons arise naturally in this framework.
- New signatures when the heavy gluons can not decay into pairs of heavy fermions.
- Do as much as possible to **test hypotheses experimentally** (apparently it is important for science).