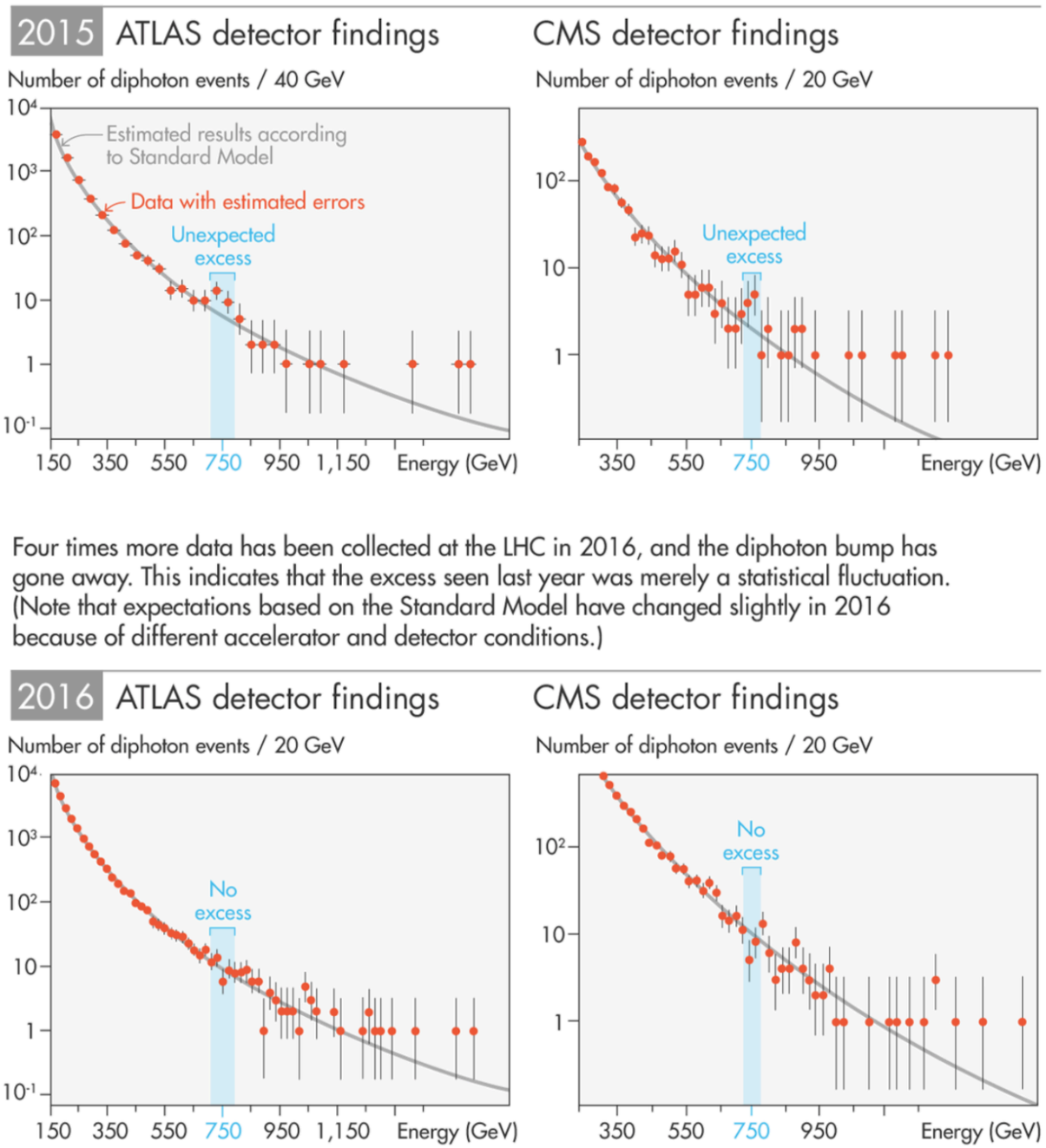
The Nightmare Scenario

What No New Particles Means for Physics

Physicists at LHC have explored properties of nature higher energies than ever before, and have found something profound: **nothing new.**

Infamous **diphoton bump** that arose in data plots has disappeared, indicating was fleeting statistical fluctuation rather than revolutionary new fundamental particle.

The bump that went away



Four times more data has been collected at the LHC in 2016, and the diphoton bump has gone away. This indicates that the excess seen last year was merely a statistical fluctuation. (Note that expectations based on the Standard Model have changed slightly in 2016 because of different accelerator and detector conditions.)

Note: generated 500 theoretical papers!!

In fact, machine's collisions have so far conjured up no particles at all beyond those catalogued in long-reigning **Standard Model** of particle physics. In collision debris, physicists have found no particles that could comprise dark matter, no siblings or cousins of Higgs boson, no sign of extra dimensions, no leptoquarks - and above all, none of desperately sought supersymmetry particles that would round out equations and satisfy **naturalness** - a deep principle about how laws of nature ought to work.

Lack of new physics deepens crisis that started in 2012 during LHC's first run, when became clear that 8-TeV collisions would not generate any new physics beyond Standard Model. Higgs boson, discovered that year, was Standard Model's final puzzle piece, rather than an extension of it.

Main reason physicists felt sure that Standard Model could not be whole story is that its linchpin, Higgs boson, has highly unnatural-seeming mass. In equations of Standard Model, Higgs coupled to many other particles. This coupling endows those particles with mass, allowing them in turn to drive value of Higgs mass to and fro, like competitors in a tug-of-war. Some of competitors are extremely strong - hypothetical particles associated with gravity might contribute (or deduct) as much as 10 million billion TeV to Higgs mass - yet somehow its mass ends up as 0.125 TeV, as if competitors in tug-of-war finish in near-perfect tie. This seems absurd - unless there is some reasonable explanation for why competing teams are so evenly matched.

Supersymmetry(early 1980s) does the trick. Says that for every **fermion** that exists in nature - such as electron or quark, that adds to Higgs mass - there is supersymmetric **boson**, or force-carrying particle, that subtracts from Higgs mass. This way, every participant in tug-of-war game has rival of equal strength, and Higgs is **naturally** stabilized. Theorists devised alternative proposals for how **naturalness** might be achieved, but supersymmetry had additional arguments in its favor: It caused strengths of three quantum forces to exactly converge at high energies, suggesting they were unified at beginning of universe. And it supplied an inert, stable particle of just right mass to be dark matter.

Hence surprise when supersymmetric partners of known particles didn't show up. As colliders searched ever- higher energies, gap has widened between known particles and hypothetical superpartners, which must be much heavier in order to have avoided detection. Ultimately, supersymmetry becomes so "broken" that effects of particles and their superpartners on Higgs mass no longer cancel out, and supersymmetry fails as solution to naturalness problem.

Some will say that enough is enough, but for others there are still loopholes to cling to. Among myriad supersymmetric extensions of Standard Model, there are more complicated versions in which quarks heavier than 1 TeV conspire with additional supersymmetric particles to counterbalance top quark, tuning the Higgs mass. Theory has so many variants that killing it outright almost impossible.

Particles can hide in nooks and crannies. If, for example, the super-top quark and lightest neutralino (supersymmetry's candidate for dark matter) happen to have nearly same mass, might have stayed hidden so far. Reason for this is that, when super-top quark created in collision and decays, producing neutralino, very little energy will be freed up to take form of motion. **When the super-top decays, there's a dark-matter particle just kind of sitting there. You don't see it. So in those regions it's very diffcult to look for.** In that case, a super-top quark with a mass as low as 0.6 TeV could still be hiding in data.

Many particle theorists now acknowledge a long-looming possibility: that mass of Higgs boson is simply unnatural - its small value resulting from an accidental, fine-tuned cancellation in a cosmic game of tug-of-war - and that we observe such a peculiar property because our lives depend on it. In this scenario, there are many, many universes, each shaped by different chance combinations of effects. Out of all these universes, only the ones with accidentally lightweight Higgs bosons will allow atoms to form and thus give rise to living beings. But this **anthropic** argument is widely disliked for being seemingly untestable.

In past two years, some theoretical physicists have started to devise totally new natural explanations for the Higgs mass that avoid fatalism of anthropic reasoning and do not rely on new particles showing up at LHC. Theorists discuss nascent ideas such as the **relaxion hypothesis** - which supposes that Higgs mass, rather than being shaped by symmetry, was sculpted dynamically by the birth of cosmos - and possible ways to test these ideas. Theorist who works on an idea called **neutral naturalness,** said **Now that everyone is past their diphoton hangover, we're going back to these questions that are really aimed at coping with the lack of apparent new physics at the LHC.**

Several theorists recently proposed another new approach called **Nnaturalness.** Many theorists feel that we're in a totally unique time, where questions on table are really huge, structural ones, not details of next particle. Very lucky to get to live in period like this - even if there may not be major, verified progress in our lifetimes."

There's still hope that new physics will show up. But discovering nothing, in many a theorist's view, is a discovery all the same - especially when it heralds the death of cherished ideas. **Experimentalists have no religion**, they say!