Why aren't there any quirks results from ATLAS or CMS yet?

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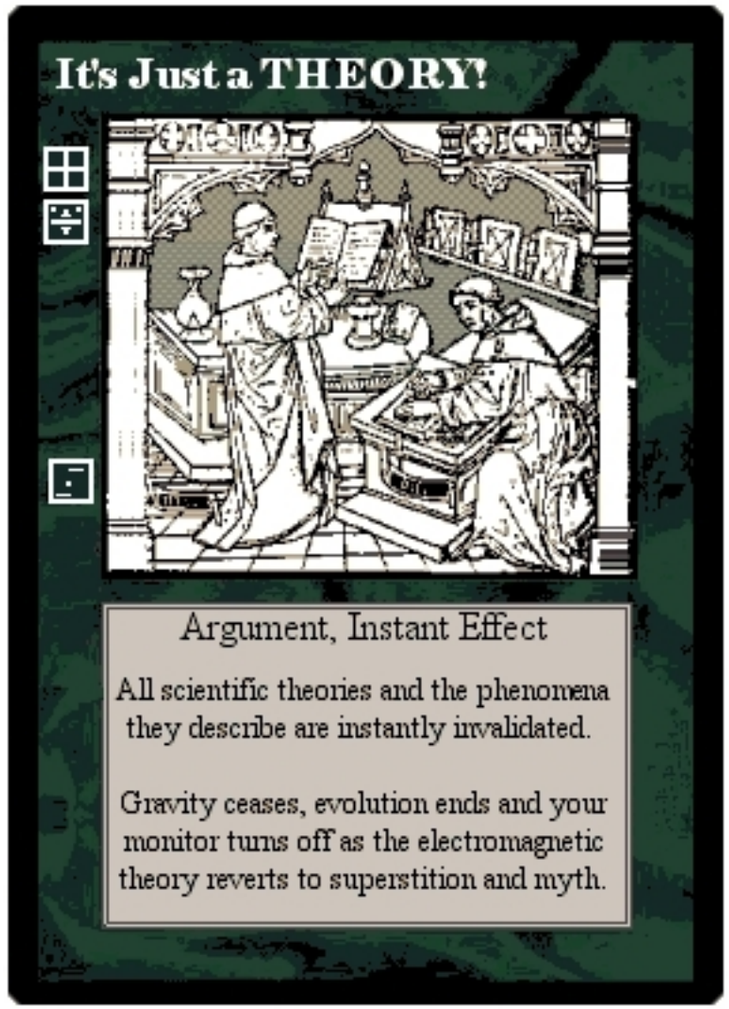
Spoiler: there are lots!

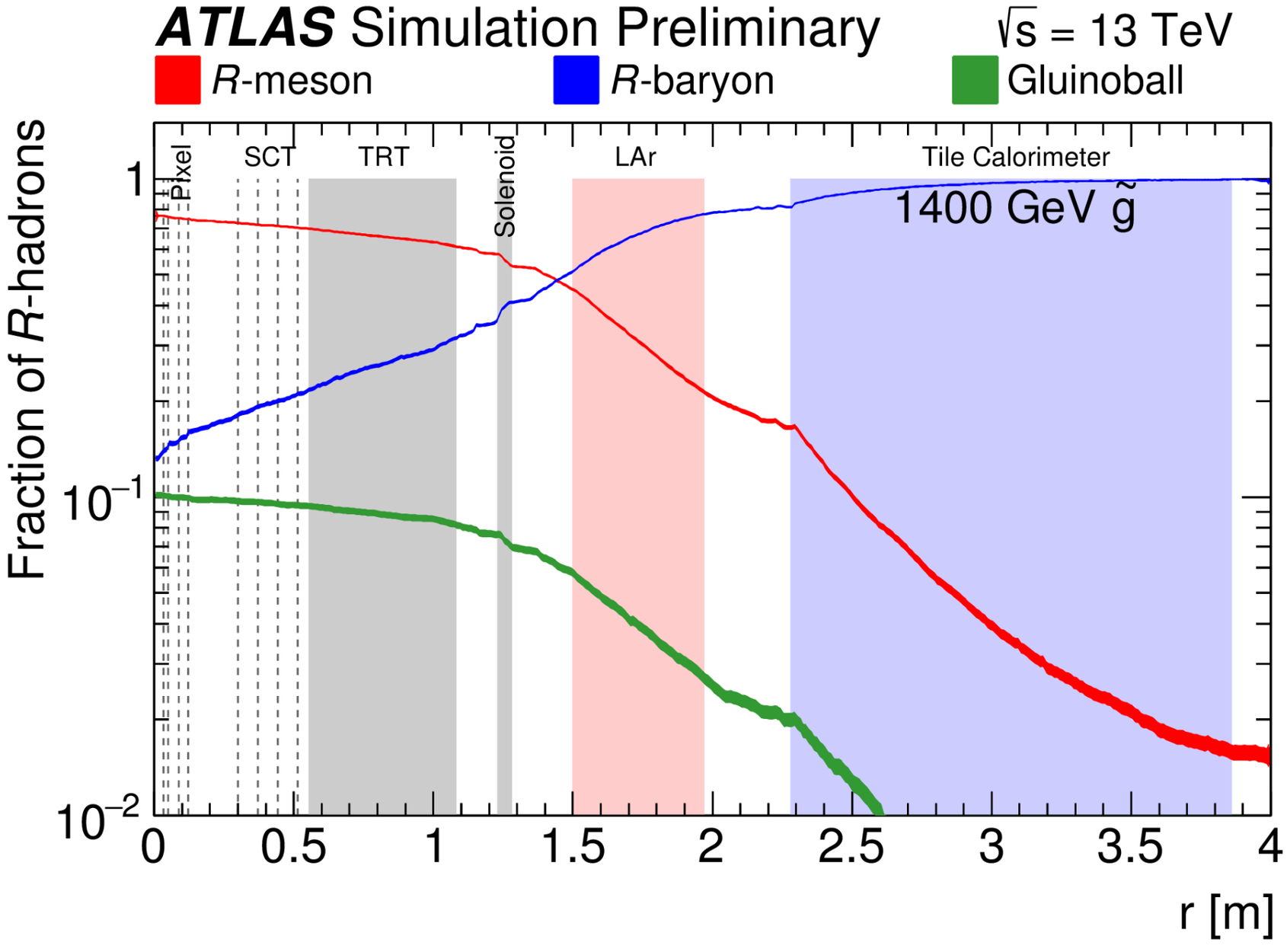
Detector Simulation

- Historically, there was an assumption that BSM particles are too application-specific to be included in Geant4
  - This means ATLAS and CMS might not use the same setups for BSM particles (this is a problem that several people have proposed to solve recently)
  - We adapted the same underlying hadronic interaction code for R-hadrons, and we've done some cross-checks
- This has left us to each solve the Quirk problem on our own
- There are a few hard parts to Quirk simulation
  - There are a few ways to solve them, and I'm aware of a few attempts in CMS and ATLAS
  - I don't think anyone loves their solution yet



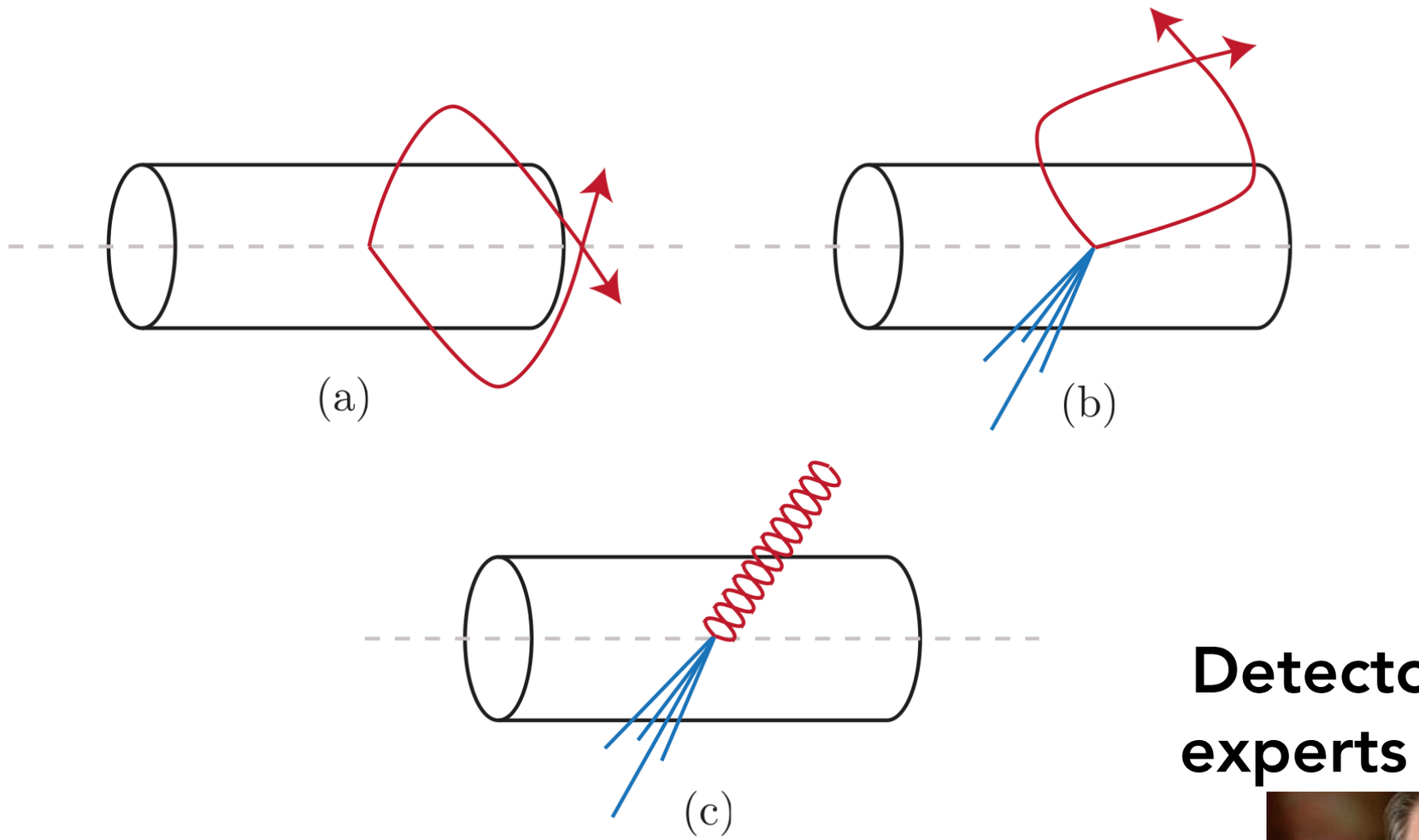
Models Can Get Tricky

- Take R-hadrons for example. They re-hadronize as they move through the detector, and properties can evolve…



Reminder of quirk setups

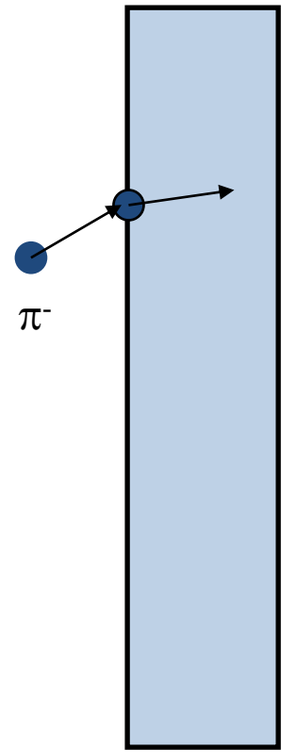
- "Quirks" would form *macroscopic bound states*



Detector simulation experts everywhere:

What's Hard about Quirks

- Geant4 assumes *all particles are* ***independent***
- When Geant4 propagates a particle, it knows:
  - where in the geometry that particle is
  - what the possible interactions are
  - what the next expected interaction is (including geometric boundary crossings)
- It picks a process or boundary to propagate to, and does one "step" to update the particle state
- Several assumptions break with quirks
  - The two quirks are not independent
  - "Where in the geometry" is not unique, and where the next boundary is has different answers for each particle. Issues like "out of the detector" are *extremely* complicated to get right.
  - We propagate through two materials at once, and have two particles with possible "next interactions"
  - For color charged quirks, the interactions may be different for each



Comments on quirk trajectories

- We have a bunch of different setups to distinguish, some of which are identical to searches that are already done.

Binding energy	**Quirks with SM Electric Charge**	**Quirks with SM Color Charge**
High energy (small distance)	Quirks propagate like a neutral particle, deposit energy like a doubly-charged particle. Search for (charged) SMP or HIP.	Quirks propagate like an even worse R-hadron. Search for a singly-produced SMP or R-hadron.
Medium energy	Actually strange trajectories like those on the last slide. Needs custom Geant4 setup.	Completely bananas trajectories. Needs combination of custom quirk transportation and R-hadron-like hadronic interactions.
Low energy (loose binding)	Quirks look independent. Search for a charged SMP.	Quirk looks independent. Search for pair-produced R-hadron-like things.

Quirk searches

- As has been pointed out, quirks can also stop in the detector, so our stopped particle searches are also sensitive to them
  - This was one motivation for some of the signal regions in the recent ATLAS stopped particles search
- Of course, if the quirks decay, we have many searches that could be sensitive (depending on the decay mode and lifetime involved)
- A number of ATLAS and CMS searches are sensitive *in principle* to certain quirk setups, but we've generally not done the explicit interpretation
  - When we do these things, we want to do them completely correctly
  - Getting this right is *hard*, and intimidating for a graduate student who might do a search like this
  - Joining forces on solving the modeling issues and providing a single central solution in Geant4 would be nice (a la R-hadrons!)
  - Alternatively, doing the 'simple' setups where we can approximate away the fundamental simulation issues would be fairly straightforward

Little Summary

- We've done lots of searches in ATLAS and CMS that are sensitive to a variety of quirk models, but I'm not aware of (m)any explicit interpretations in quirk models
- One of the big hurdles up to now has been getting the simulation right
  - Doing this correctly in Geant4 is hard
  - It'd be very nice if ATLAS, CMS, and others could work together on this!
- We could certainly do some interpretations "quickly" in more extreme (binding energy) models without too much difficulty, and this might even be doable via reinterpretation