Arianna Borrelli - Wuppertal University

A philosophical experiment: an empirical study of knowledge production at the LHC

"Epistemology of the LHC"

a DFG project cluster based at the University of Wuppertal (Germany)

Three projects:

- **The epistemic dynamics of model development at the LHC *[today!]***
- **LHC-experiments between theory-ladenness and exploration**
- **An epistemological and ontological study of the Higgs mechanism**

Wuppertal: Arianna Borrelli ▪ Simon Friederich▪ Robert Harlander ▪ Koray Karaca
Dennis Lehmkuhl ▪ Peter Mättig ▪ Gregor Schiemann ▪ Erhard Scholz ▪ Christian Zeitnitz

External: Michael Krämer (Aachen) Holger Lyre (Magdeburg) Friedrich Steinle (Berlin)
Michael Stöltzner (S. Carolina)

"Epistemic dynamics of model development at the LHC": how will new knowledge emerge from the interplay of theory and experiment at LHC?

(A.B. ▪ Robert Harlander ▪ Peter Mättig ▪ Friedrich Steinle ▪ Michael Stöltzner)

Novel methodology: a "real time" investigation of a philosophical question

- possibility of keeping track of changing opinions beyond written sources through interviews and surveys
- possibility - at least in principle! - of following in real time new research literature produced through arXiv.org (impossible until a few decades ago)

Methodology like sociologists or historians, but a philosophical research question:

Starting hypothesis (a traditional philosophical view): physicsts compare models and prefer a model over others according to various criteria (simplicity, elegance/beauty, numerical agreement with experiment, explanatory potential...)

Research question: what models of BSM physics do physicists "prefer" and why? how do these preferences change in time, especially due to LHC results?

Tools for the "experimental" investigation:

- preprint classification and analysis (not *all* preprints on BSM-physics!)
- two rounds of interviews (Spring 2011, Autumn 2012)
- two rounds of online-surveys (September 2011, September 2012)

Some questions to be aware of:

- How can we *experimentally* investigate "preferences"?

  two operational definitions of "preferences" were used:

  (a) explicit stated preferences ("which models do you prefer?")

  (b) work choices ("on which model are you working?")

  the two definitions should be equivalent...

- How are the "same" models of new physics perceived by physicists with different background?

  Knowledge about specific models varies a lot in the HEP-community

Some results from the preprint study:

- there are practically no general comparisons of models in the literature
- the same arguments support different models (naturalness, dark matter...)
- physicists may often work on different models at the same time
- many models come and go - only general approaches remain
- increasing role of "model-independent" searches
- no decisive change in the distribution of preprints among classes of BSM-models
  until now, only broad oscillations similar to those of the last decases

----> no clear indications on "preferences" and relevant criteria

Interviews

Experimental physicists:

Jamie Boyd (ATLAS, CERN)
Lutz Feld (CMS, RTWH Aachen)
Fabiola Gianotti (ATLAS, CERN)
Andrei Golutvin (LHCb, IC London, ITEP, CERN)
Cigdem Issever (ATLAS, Oxford)
Vivek Sharma (CMS, UC San Diego)
Guido Tonelli (CMS, Pisa University)

Theoretical physicists:

Luca Di Luzio (KIT Karlsruhe)
John Ellis (CERN, King's College London)
Christophe Grojean (CERN, CEA Saclay)
Michael Krämer (RTWH Aachen)
Michelangelo Mangano (CERN)
Chris Quigg (Fermilab)

Many thanks!

Experimenters - *Q: Is there a model which you prefer above the others?*

VS: I am very agnostic. I have no favourite theory, no favourite models. [...] I want to hear everything but the only way that I really use it is that I look at the bottom line of whatever the theory is and what they predict [...] and whether we will be able to see it…

JB: No, not so much, I probably I have a slight order in my head but not really... I am not a believer in just one things and this is it [...] SUSY is a very popular model and it has some nice features, but it also has some less nice features. [...] Theoretically super-symmetry is very nice, but the problem is that we know that it is a broken symmetry, and this is where the complication come in and where it becomes theoretically less appealing. But personally as an experimentalist I prefer a way of looking at things sort of signature-based rather than model-based

FG: The approach to the search of new physics is twofold: on the one hand we have an approach which is as inclusive as possible without looking for something specific. On the other hand, there are some specific models like supersymmetry, which allow us to optimize the search, to be more effective.

GT: *[when stating a preference for SUSY]* So this is just personal taste, it has nothing to do with science. [...] We are experimental physicists: we take all the inputs coming from our friend theorists - and they produce tens, if not hundreds of models - and we consider them from the ground, although some of them are more popular or more known. We try to produce measurements that will be able to validate or to disprove some of these models, and also we try to produce measurements that will be model-independent.

AG: Look, I am really biased to tell you the truth, because I know what are the most clean observables [of LHCb], and of course I like the theories which predict these clean observables. [...] There are tens of models of new physics which have certain predictions for these observables. Somehow to me personally, the place is so rich [in models] that I think the next step to be done is just for experiment to find some evidence for new physics and then we'll immediately narrow the choice of the right model and start to check it.

- experimenters prefer to have no abstract preferences - i.e. be "unbiassed"
- "work choices"? unclear, how models to be tested are chosen
- for experimenters, a "model" is primarily what they (would) see in the detector
- (too) many models! ----> importance of model-independent searches

Theorists

JE: So I have for many years, almost 30 years now, been interested in supersymmetry because I regard it as the most promising extension of the standard model and the most promising framework for model-building. [...] I would say that probably since about the mid 1990's my interest has been not so much in constructing new models [of supersymmetry], but in seeing what experiment has to tell us about the models that we have, and maybe starting to arrange different models to see whether one could draw conclusions that are model independent.

CQ: I find a lot of intellectual attraction in the dynamical symmetry breaking models because their heritage comes from the BCS theory of superconductivity, which is a nice legacy. [...] Supersymmetry is a beautiful idea. It is totally irrational but I agree completely that it is impossible to believe that nature did not take advantage of it in some place. It could in connection with gravity (and that could happen at arbitrarily high energy), or it could be the solution to our hierarchy problem at a TeV. We just don't know, it is just an experimental question. *[But he is not working on any BSM-model]*

MM: I come from a particular interest in new physics: when I was a student, I worked on supersymmetry.... and then I worked on superstrings, on the phenomenology of superstrings, so I like searching for something new and understanding what is beyond. But then I focussed on the Standard Model, during the past 20 years, if not more, of my work. I am trying to consolidate our understanding of how it works. [...] *[Q: Is there a model you regard as more appealing, beautiful, unifying...?]* In that respect supersymmetry is by far the best, because it is the ultimate possible symmetry of space-time, and many other solutions are simply postponements of a problem to a higher scale. I think supersymmetry will play a role one way or the other.

AB: *[On why he works on SUSY]* Maybe because supersymmetry, when I started five years ago, was really a main topic done by a lot of people and everywhere at conferences. [...] I was also influenced by the experimentalists because there were some experimentalists who were working on supersymmetry and so when you hear about this new physics and the experimentalists that are looking for this new physics, it's a good motivation to have a nearer look. And probably it's also because of this propaganda. You read books and read articles and you see how beautiful supersymmetry is.

CG: I work a lot on models with extra dimensions [...] Recently I also got interested in models where electroweak symmetry is broken dynamically, by some strong interactions [...] When I started my PhD I was already thinking about physics beyond the standard model, but at that time I was thinking more about supersymmetry, even some string-inspired models and then a few years after my PhD there were all these new models using extra-dimensions, so I got interested in them and keep working.

CG: *[Preferences?]* That is very difficult to answer. It is true that many models have very good aspects. If you look at supersymmetry on paper it is really fantastic, because it achieves a lot of things and it's a very aesthetic solution.. but the real question is, is it enough to be sure that this is the way nature works?

CG: *[Commitment to one model or the other?]* No. I also... I try to see which is a field I can contribute with something new.

- theorists often have abstract preferences - but not always work accordingly!
- skills, social environment play an important role in work choices
- individuals models seem to be rather exploratory tools than serious candidates to theories of new physics

Survey 2011 & 2012

The survey questions were focussed on physicists' abstract preferences and their expectations for LHC.

The questions of the two runs were kept as far as possible equal (despite many good suggestions from the respondents!) to allow for a comparison

Sample size:

1st run: 1435 respondents - 745 theorists; 700 experimentalists
- 1296 males; 131 females

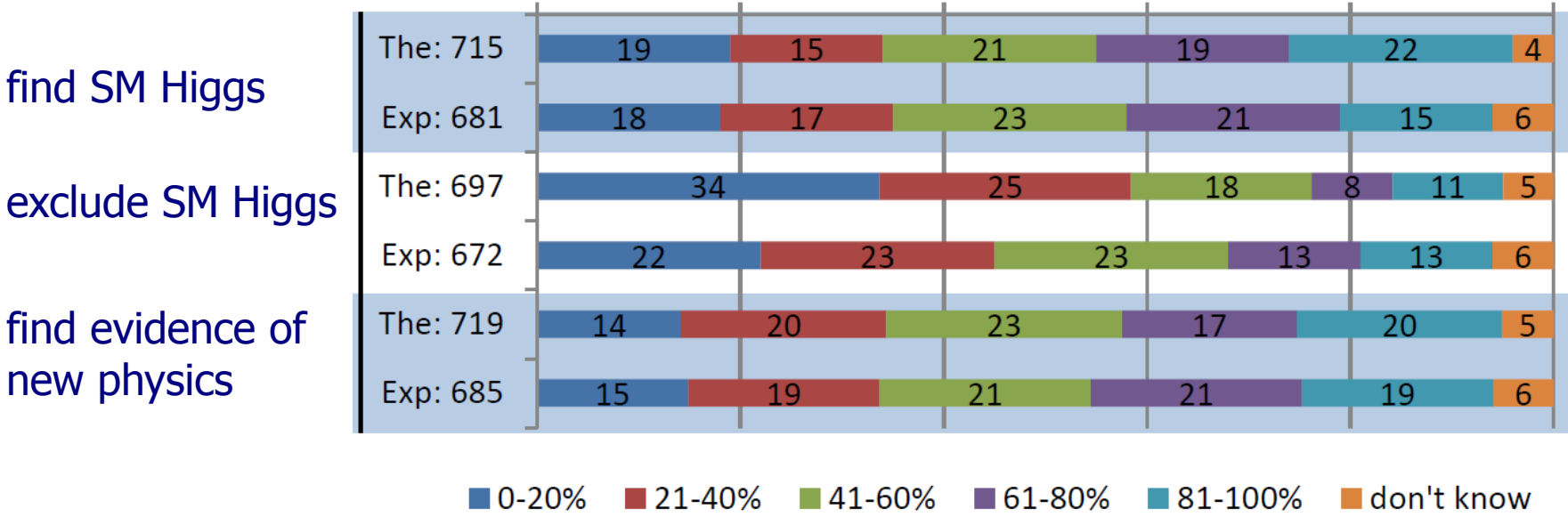
2nd run: 903 respondents - 464 theorists; 439 experimentalists
- 826 males; 77 females

Many thanks to all those who participated!

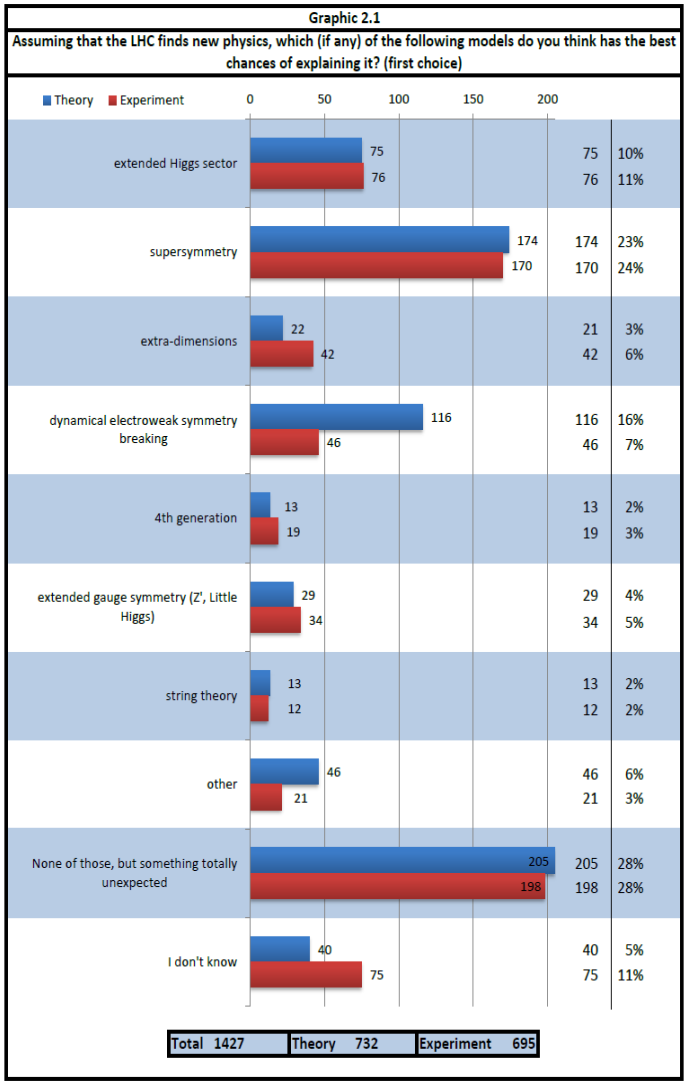
N.B. the survey is not quantitatively representative, but is expected to give a qualitative picture of opinions. Despite the different number of respondents, there is a high general stability of results between the first and second round, as well as specific, significant differences

Survey September 2011

"What is your personal estimate of the probability of the following scenarios? The LHC will...."



(Sept. 2011) - If LHC finds new physics, which model do you think will explain it ?



additional Higgs bosons (10% / 11%)

supersymmetry (23% / 24%)

extra dimensions (3% / 6%)

dynamical EWSB (15% / 7%)

4th fermion generation (2% / 3%)

Z', Little Higgs (4% / 5%)

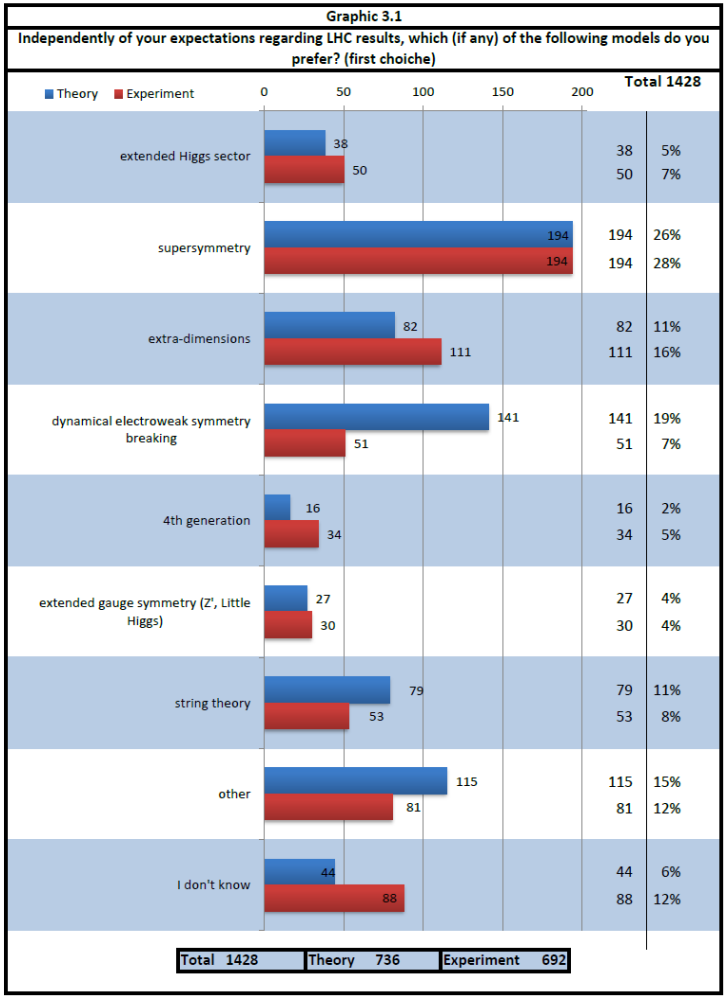
string theory (2% / 2%)

other (6% / 3%)

none of those, but something totally unexpected (28% / 28%)

I don't know (5% / 11%)

(Sept. 2011) - Independently of your expectations regarding LHC results, which (if any) of the following models do you prefer? (TH/EXP)



additional Higgs bosons (5% / 7%)

supersymmetry (26% / 28%)

extra dimensions (11% / 16%)

dynamical EWSB (19% / 7%)

4th fermion generation (2% / 3%)

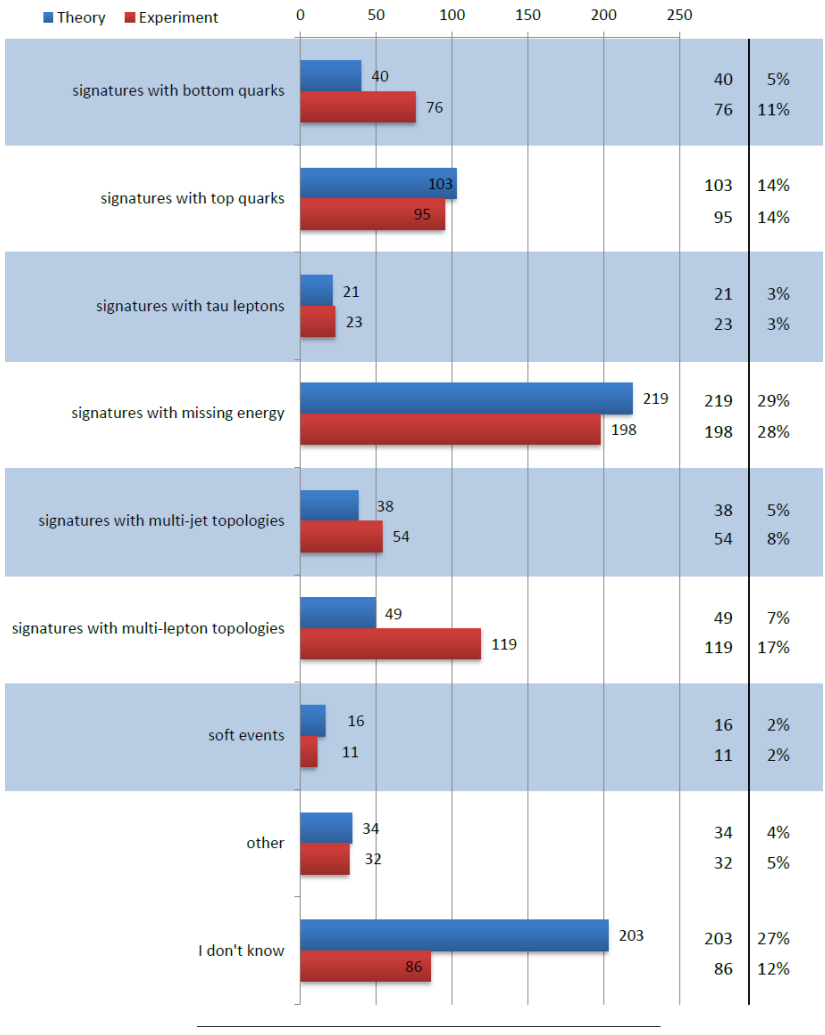
Z', Little Higgs (2% / 5%)

string theory (11% / 8%)

other (15% / 12%)

I don't know (6% / 12%)

(Sept. 2011) - In which signature do you think the LHC is more likely to find new physics ?



sig. with b-quarks (5%/11%)

sig. with t-quarks (14% / 14%)

sig. with taus (3% /3%)

missing energy (29% /28%)

multi-jet topologies (5% /8%)

multi-lepton topol. (7% / 17%)

soft events (2% / 2%)

other (4% / 5%)

I don't know (27% / 12%)

(Sept 2011) How much do you agree with the following statements: LHC results will be very important to understand..

strong interactions

flavour physics

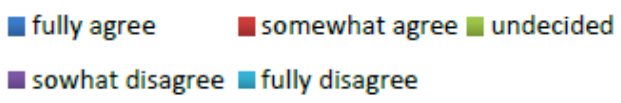
the origin of mass

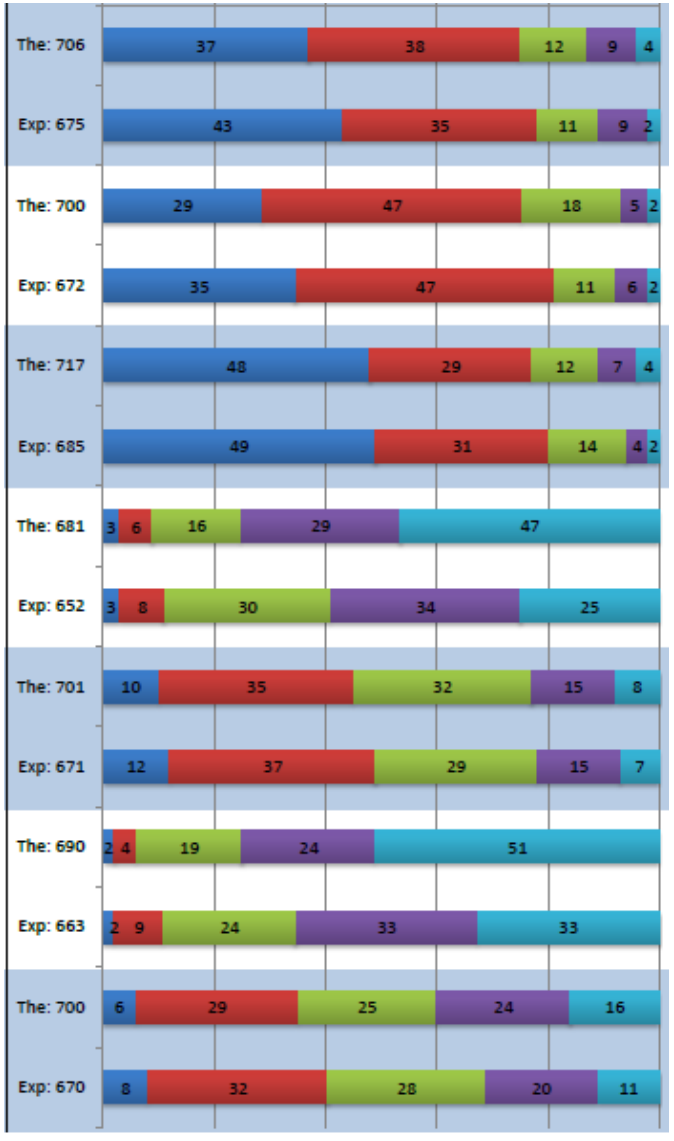
quantum-gravitational effects

dark matter

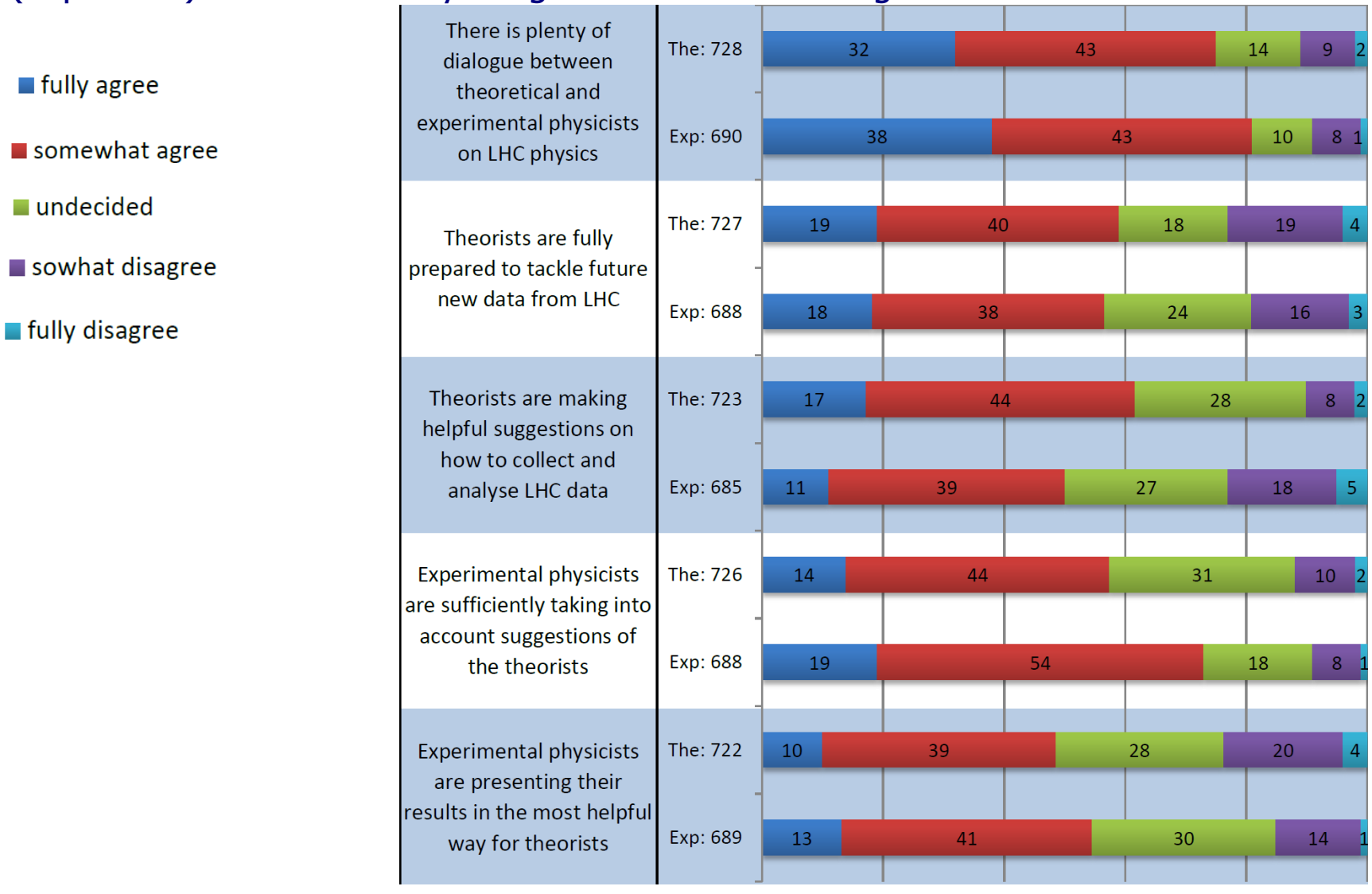
dark energy

cosmology of the early universe





(Sept 2011) How much do you agree with the following statements:



Survey September 2012

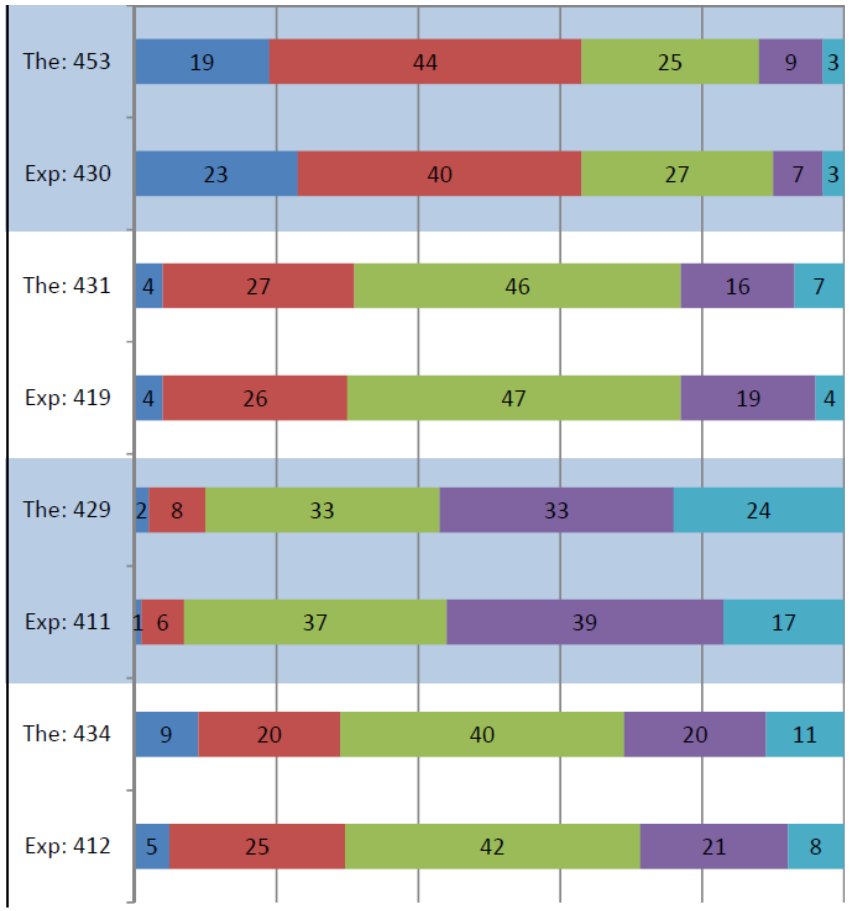
How much do you agree with the following statements?
After the discovery of the new particle at 125 GeV, the LHC will....

confirm the minimal Higgs sector

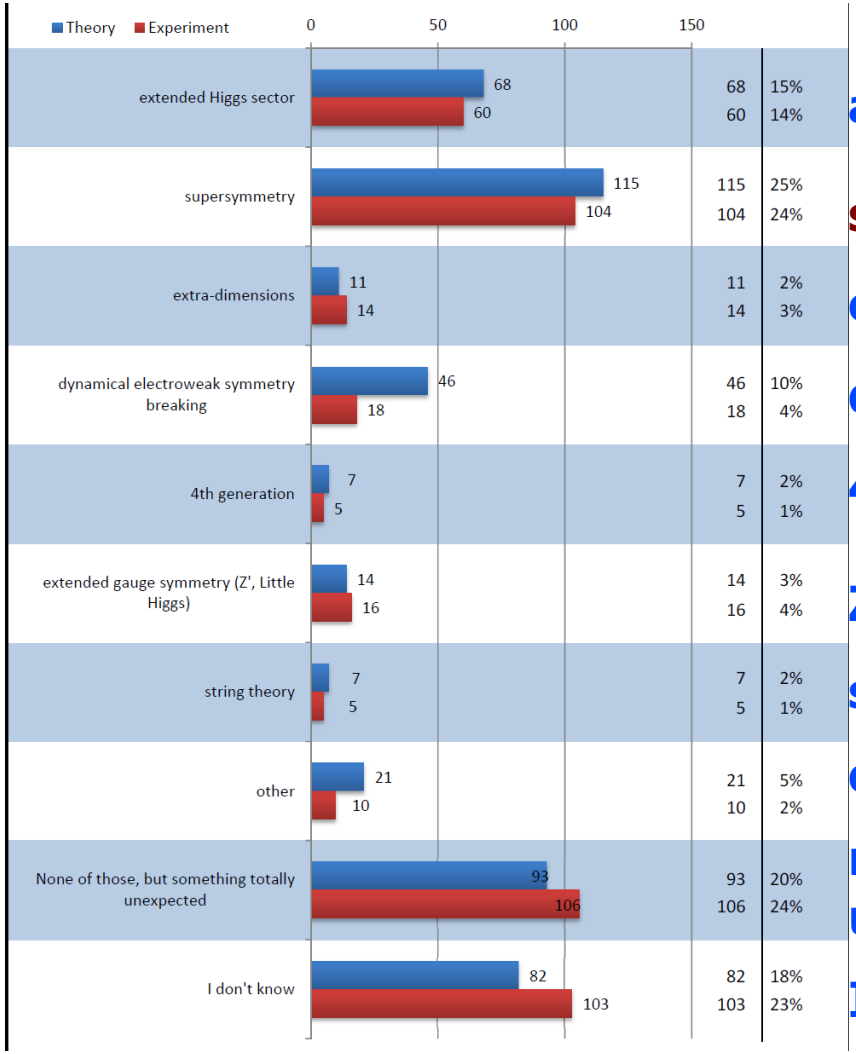
find a more complicated Higgs sector

find an alternative mechanism of EWSB

find indisputable evidence of new physics



(Sept. 2012) - If LHC finds new physics, which model do you think will explain it ?



additional Higgs bosons (15% / 14%)

supersymmetry (25% / 24%)

extra dimensions (2% / 3%)

dynamical EWSB (10% / 4%)

4th fermion generation (2% / 1%)

Z', Little Higgs (3% / 4%)

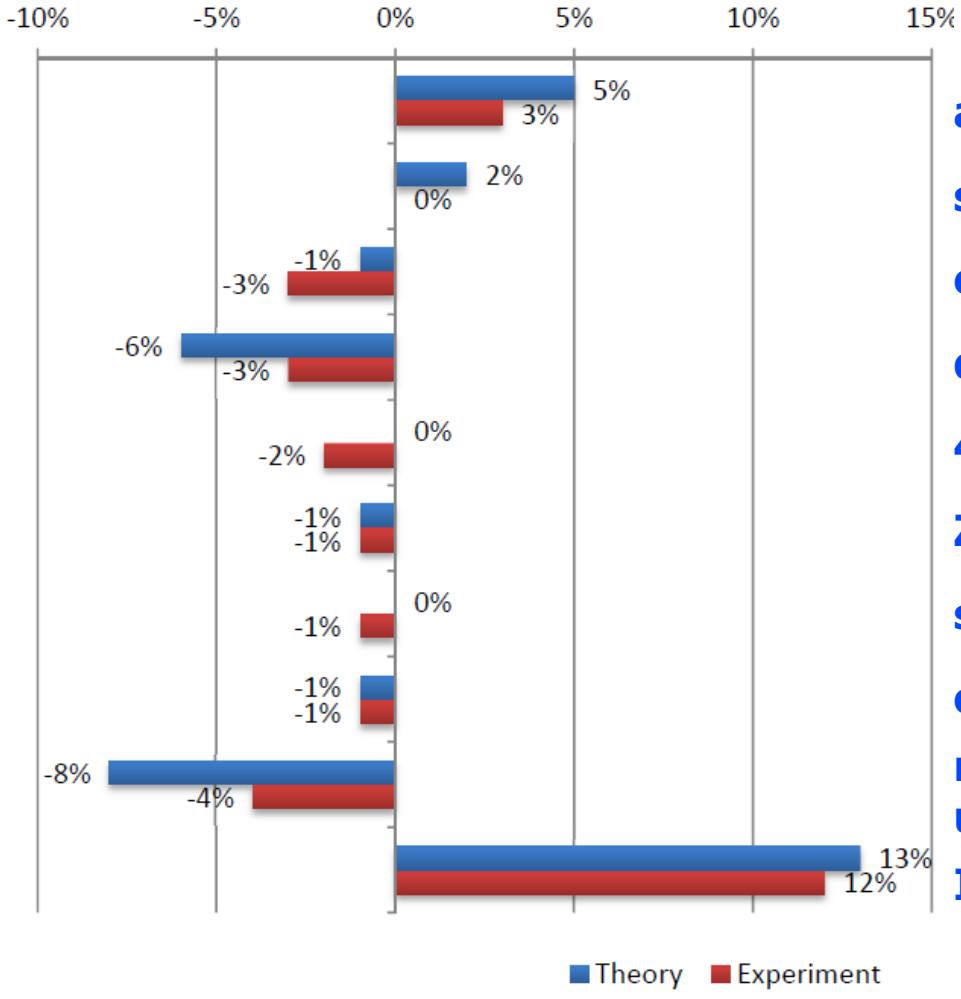
string theory (2% / 1%)

other (5% / 2%)

none of those, but something totally unexpected (20% / 24%)

I don't know (18% / 23%)

(Sept. 2011 vs. Sept. 2012) - If LHC finds new physics, which model do you think will explain it ?



additional Higgs bosons (+5%/3%)

supersymmetry (+2% / 0%)

extra dimensions (-1% /- 3%)

dynamical EWSB (-6% /-3%)

4th fermion generation (0% /-2%)

Z', Little Higgs (-1% / -1%)

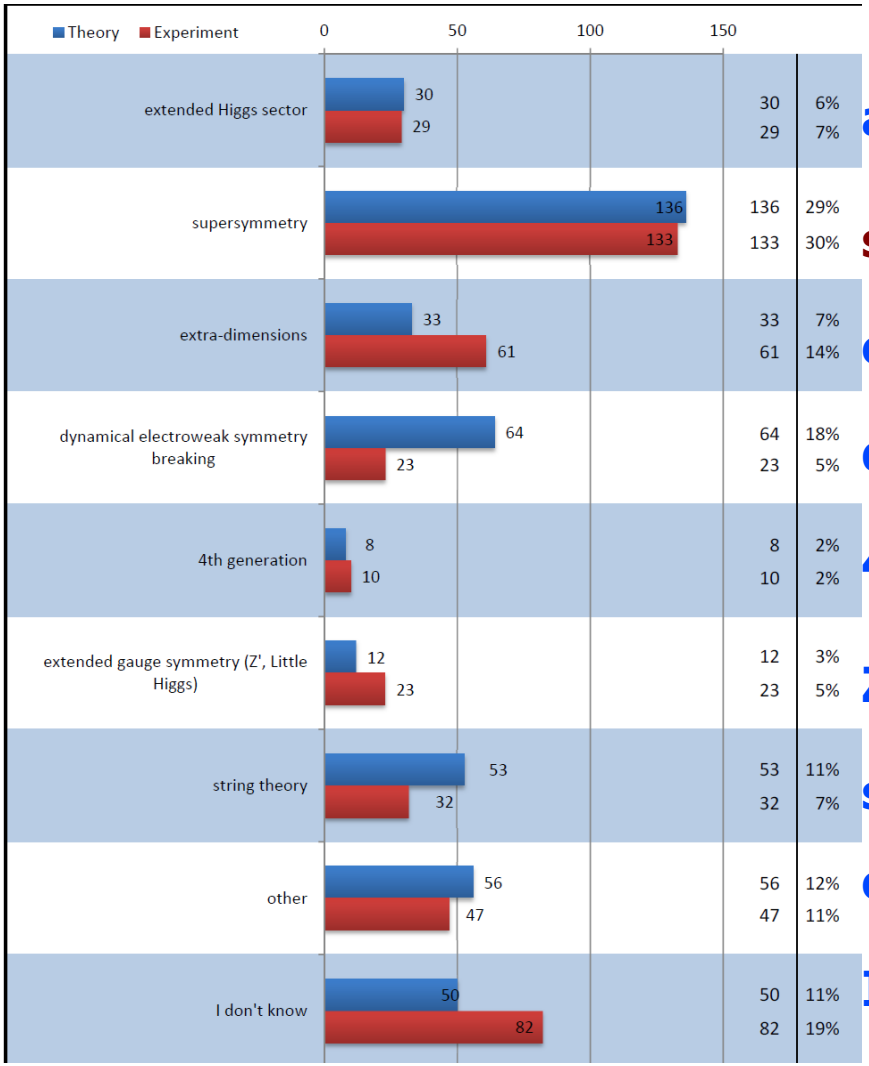
string theory (0% / -1%)

other (-1% / -1%)

none of those, but something totally unexpected (-8% / -4%)

I don't know (+13% / +12%)

(Sept. 2012) - Independently of your expectations regarding LHC results, which (if any) of the following models do you prefer? (TH/EXP)



30 6%
29 7%

additional Higgs bosons (6% / 7%)

136 29%
133 30%

supersymmetry (29% / 30%)

33 7%
61 14%

extra dimensions (7% / 14%)

64 18%
23 5%

dynamical EWSB (18% / 5%)

8 2%
10 2%

4th fermion generation (2% / 2%)

12 3%
23 5%

Z', Little Higgs (3% / 5%)

53 11%
32 7%

string theory (11% / 7%)

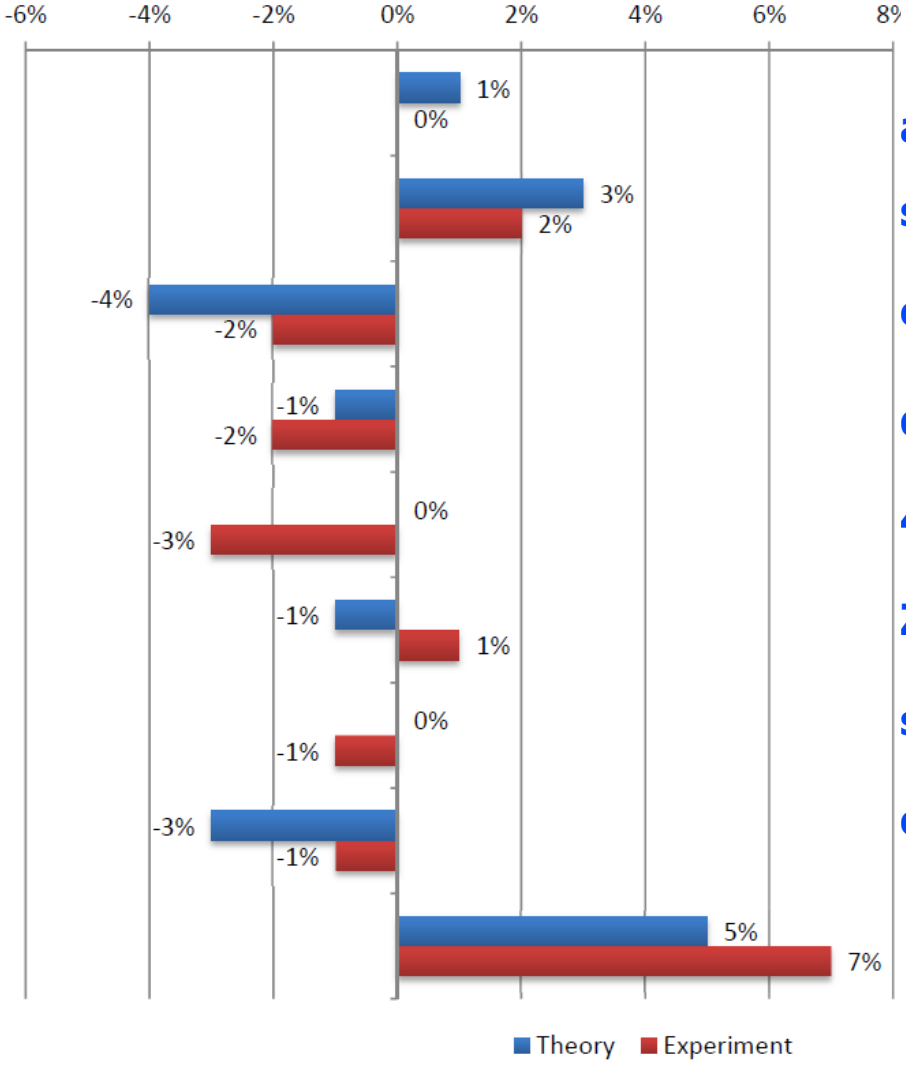
56 12%
47 11%

other (12% / 11%)

50 11%
82 19%

I don't know (11% / 19%)

(Sept. 2011 vs. Sept. 2012) - Independently of LHC results, which model do you prefer?



additional Higgs bosons (+1%/0%)

supersymmetry (+3% / 2%)

extra dimensions (-4% /- 2%)

dynamical EWSB (-1% /-2%)

4th fermion generation (0% /-3%)

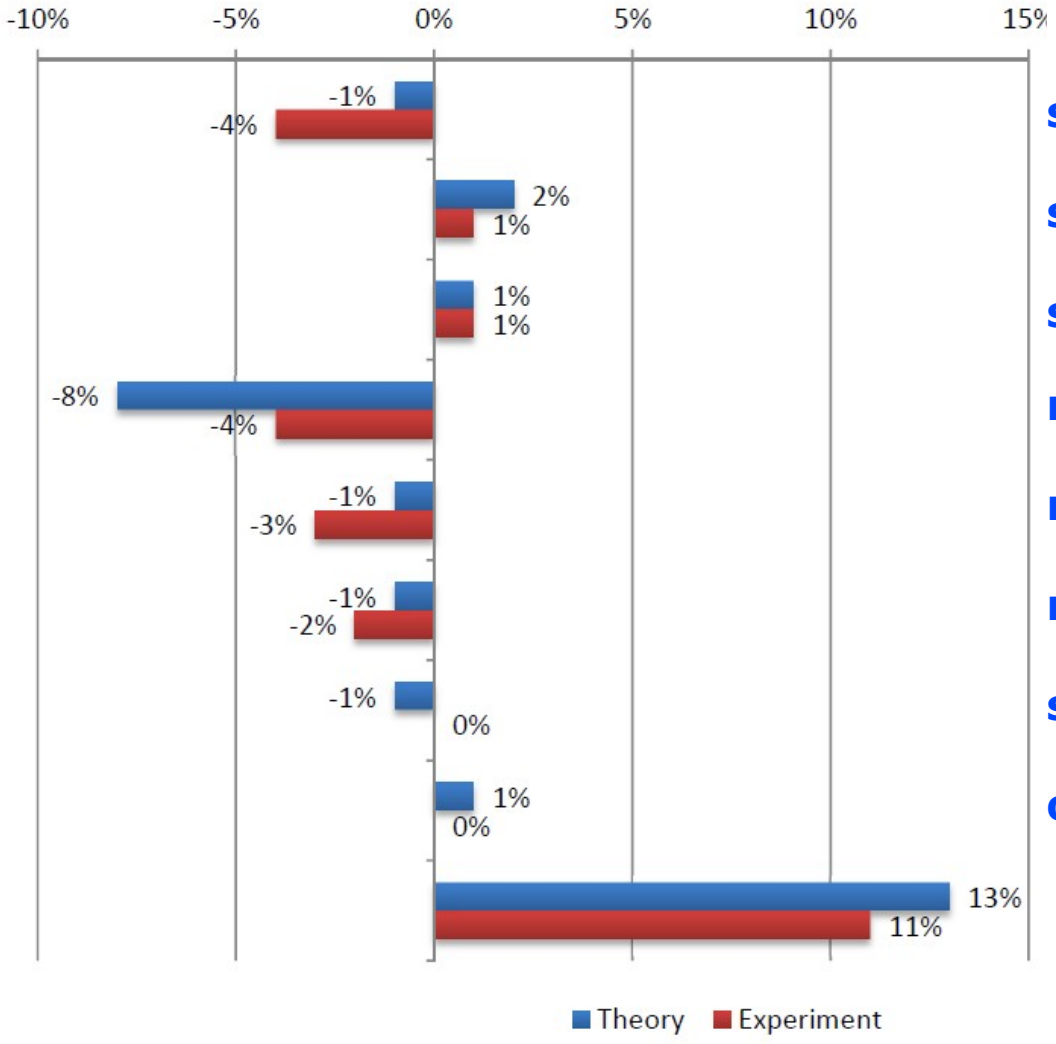
Z', Little Higgs (-1% / 1%)

string theory (0% / -1%)

other (-3% / -1%)

I don't know (+5% / +7%)

(Sept. 2011 vs. Sept. 2012) - In which signature do you think the LHC is more likely to find new physics ?



sig. with b-quarks (-1%/-4%)

sig. with t-quarks (+2% / +1%)

sig. with taus (+1% /1%)

missing energy (-8% /-4%)

multi-jet topologies (-1% /-3%)

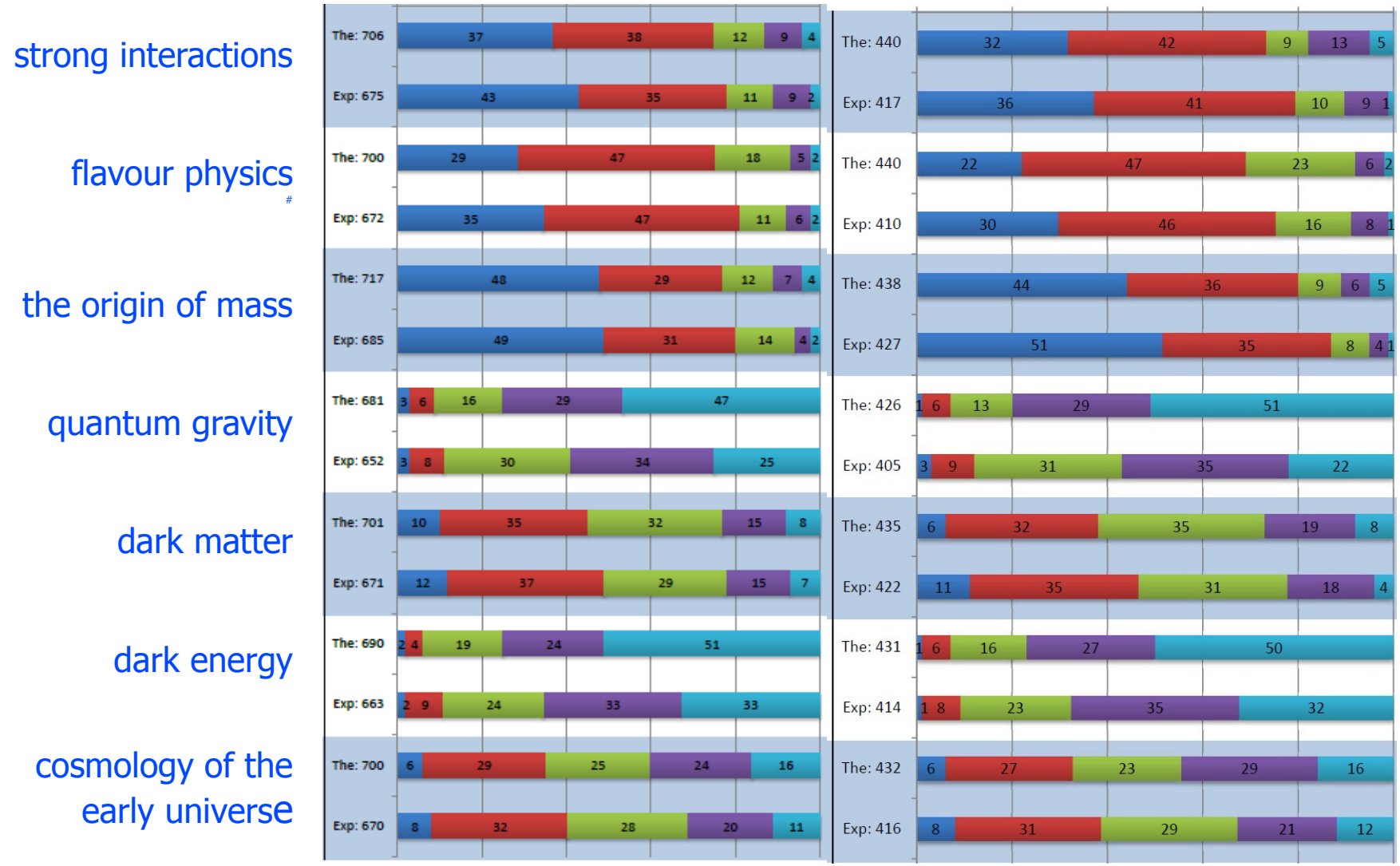
multi-lepton topol. (-1% / -2%)

soft events (-1% / 0%)

other (+1% / 0%)

I don't know (+13% / +11%)

(Sept 2011) How much do you agree with the following statements: LHC results will be very important to understand...



How much do you agree with the following statements:

Interviews (Autumn 2012) - Focus TH: SUSY and the new LHC results

AB: My subjects [of work] changed, not much but they changed. I still have projects going on about SUSY, but I also have other projects more in direction testing... precision tests of the standard model. [...] The point is not simply testing the SM, but also somehow find possible situations where the SM ceases to be valid and new physics comes up

LD: LHC has definitely changed something, because now we know that there is a Higgs boson, at least a minimal realisation of the Higgs mechanism, so when we do models we have to take that into account, and this changes the situation.

MK: I continue with the same type of work as before. [...] If the Higgs' mass had been 140-150 GeV that would have changed a lot, because then all my SUSY models would be dead. [...] Now some of the models are disfavoured, but the principlal idea of this type of research is the same as before. I's now of course more constrained and more interesting.

BC: I have been working on the NMSSM [...] So far the LHC has not changed my work much. It brought in some constraints, that are becoming more relevant everyday but are still loose enough, and subject to interpretation, for a model as rich as the NMSSM. I have not studied them specifically yet. Personally, I am indeed specializing now on other kinds of observables which intervene at much lower energy.

Some tentative conclusions:

- these results do not support the traditional pictures of physicists comparing and preferring models/theories according to some criteria
- models are rather regarded as exploratory tools for research than as serious candidates to a theory of new physics. Yet the general approaches (SUSY, extra dimensions...) are taken seriously ("theoretical cores" Borrelli 2012)
- LHC results did not change much the pattern of (rather feeble) abstract preferences, but seem to have further eroded the belief in individual models - yet interestingly SUSY is somehow slightly, relatively better off (Sept. 2012!)

Outlook: alternative theoretical schemes

- there is little claim of strong motivations to prefer specific BSM-models, but HE-physicists are strongly motivated to invest resources in the search for new physics in general ---> Pickering's "opportunism in context": success in the search would have a high pay off in terms of new research possibilities
- experimeters reject preferences as a bias, and it is unclear how choices on models in large collaborations are made ----> Karin Knorr-Cetina: choices in HEP-experimental collaborations are results of long processes of consensus-formation rather than of point-like decisions by "leaders" or "commitees"