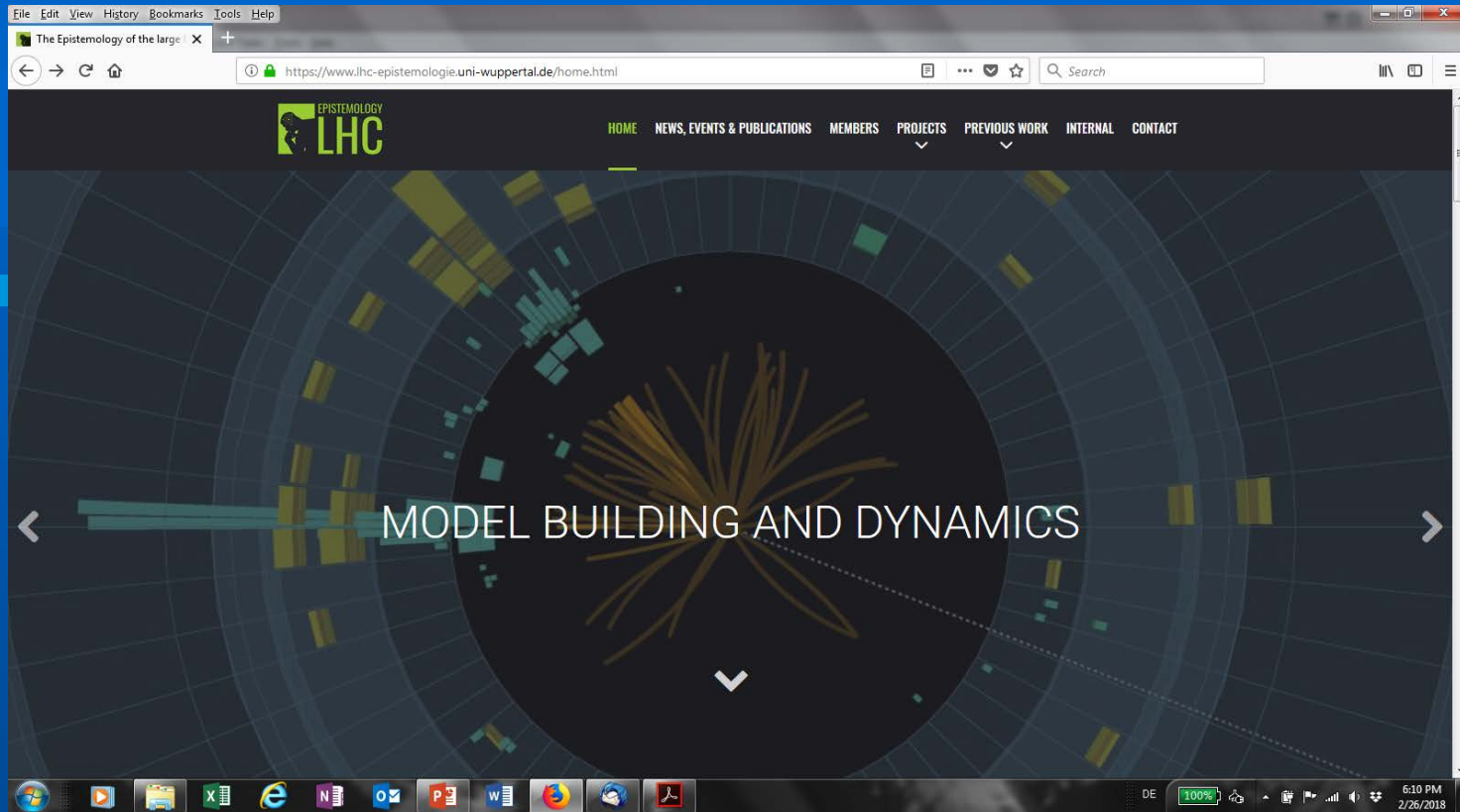# Naturalness as a Value of Model Preference

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- Several results together with Peter Mättig and with Cristin Chall, Martin King, and Peter Mättig.

Main Themes

Criteria of theory/model choice understood as epistemic and pragmatic values that have to be weighed in in factual practice.

- Model preference is not primarily expressed in linguistic-logical terms but epistemic strategies.

Naturalness is a complex value that is nevertheless consistently applied across HEP community.

- Notwithstanding such a "consistency in practice" its aspects may be separated in philosophical analysis.

Main Themes - 2

Values of model preference may be embedded into broader narratives.

- Such narratives typically involve explanatory ideals that are connected to a model but may refer to the discipline as a whole.

- Larger background of naturalness as a consideration about scales.

Empirical epistemology

- Analysis of activity in different categories of models (with Arianna Borrelli, PM, RH)
- Questionnaires sent to 15,000 physicists on the Spires databases in summer of 2011 and fall of 2012. Return rate around 10% (6%).
- Combined with expert interviews at respective times (conducted by AB).
- New run and keyword statistics of model dynamics in 2018, together with Cristin Chall and Martin King.

1

THE STANDARD MODEL AND ITS CORROBORATION
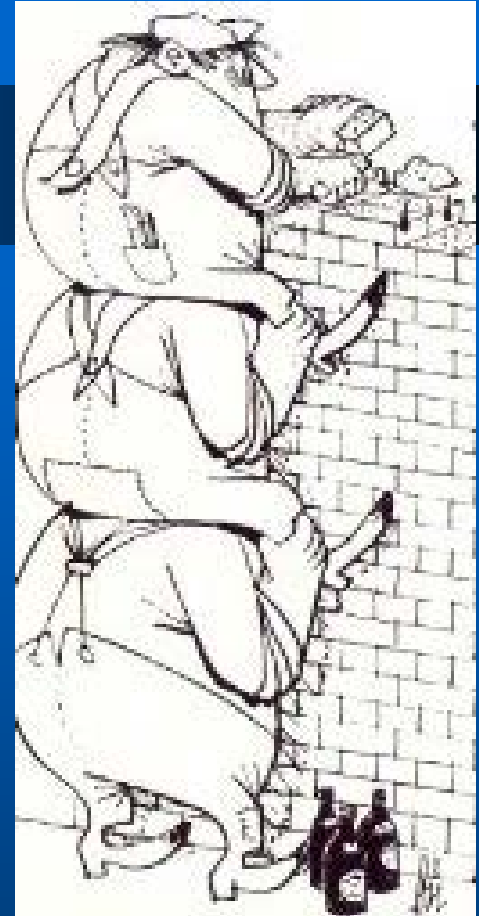
A model among many

- Glashow-Weinberg-Salam model was one among many proposals and geared to explore the general ideas presented in it.

- SSB and Higgs mechanism: import of ideas from solid state physics, but with subtle differences.

- Renormalizability put GWS center-stage.

SM is explanans and explanandum

- Many believe that SM cannot be the ultimate theory
  - Internal deficiencies (many parameters, unnaturalness)
  - Phenomena beyond its reach (dark matter).
- Many BSM models were developed.
- This does not necessarily preclude realist commitments because particle physicists have learned to live with successive and well-separated layers of physical reality, initially often taking an instrumentalist attitude towards a deeper level at higher energies.

Timeline of a discovery

- July 2012: *Observation* (5σ) of a Higgs boson.
  - Is it SM Higgs or are there additional Higgs modes?
  - The 5σ criterion (against fluctuations of known physics) has emerged as convention in particle experiments. But it alone does not suffice.
- From "likely Higgs boson", "The Boson", "likely SM Higgs boson". Stepwise corroboration of its properties (spin, parity, couplings) and exclusion of a more complicated signature.
  - Fundamental scalar renders naturalness a real problem
- All searches for physics BSM have been unsuccessful,
  - which might speak against explicitly defined models,
  - reduces the parameter space for possible candidates,
  - influences the naturalness problem.

2

FROM THE QUESTIONNAIRES

Expectations 3 months before publication of "evidence"

The LHC will find the Standard Model Higgs boson

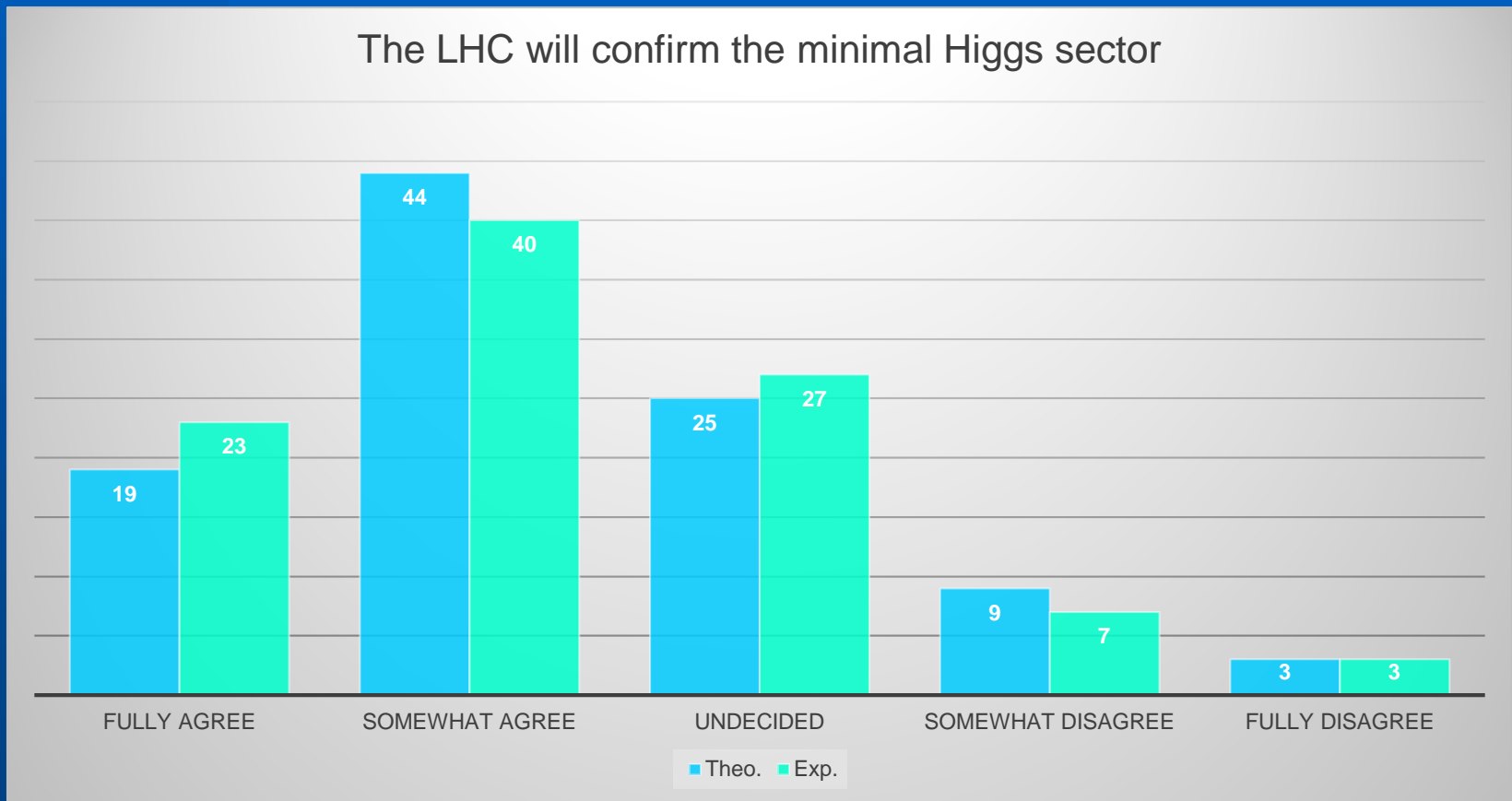|	0-20%	21-40%	41-60%	61-80	81-100%	DON'T KNOW
Theo.	19	15	21	19	22	4
Exp.	18	17	23	21	15	6

Percentages denote subjective probabilities (degrees of belief)

Physicists were pretty skeptical

- To many, the Higgs mechanism appeared as ad hoc explanation of mass generation.
  - Higgs has basically only this function.
- Its renormalization produces the naturalness problem, which would be resolved by certain types of physics BSM.
  - A more complicated Higgs sector alone does not necessarily solve the naturalness problem
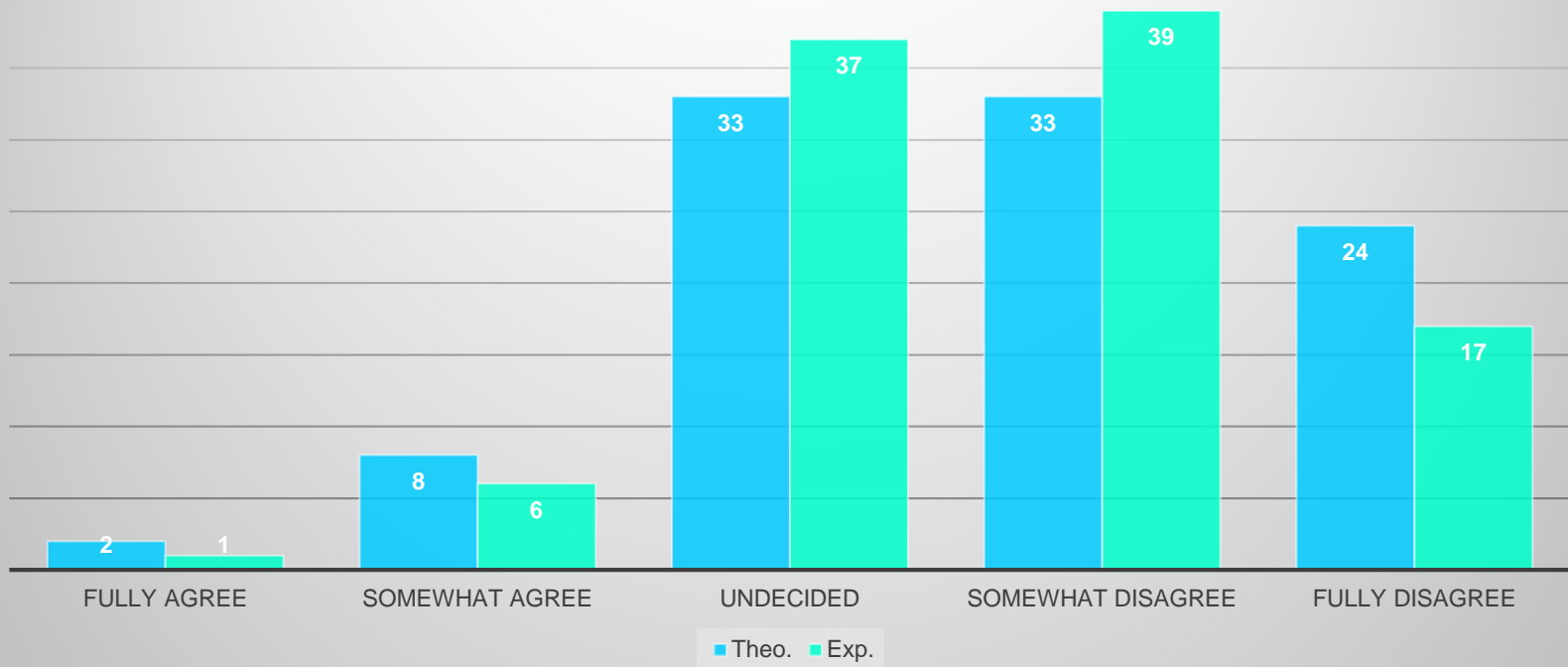
September 2012: A majority now believes in minimal (SM) Higgs

The LHC will confirm the minimal Higgs sector

|	FULLY AGREE	SOMEWHAT AGREE	UNDECIDED	SOMEWHAT DISAGREE	FULLY DISAGREE
Theo.	19	44	25	9	3
Exp.	23	40	27	7	3

Compare "fully agree" to 80-100% probability

and is skeptical about alternative mechanisms, e.g., dynamical EWSB

The LHC will find alternative mechanism of EWSB

	FULLY AGREE	SOMEWHAT AGREE	UNDECIDED	SOMEWHAT DISAGREE	FULLY DISAGREE
Theo.	2	8	33	33	24
Exp.	1	6	37	39	17

SM Higgs and BSM at LHC

- Separation of SM from "conservative" extensions (extended Higgs sector) took time.

- Hence confirming SM was not a simple yes/no alternative and embedded into a broader experimental program in which SM testing and BSM searches coexisted.

- Theoretically attractive BSM models persist despite lack of positive evidence, as long as there is parameter space left.

- Difference between confirmation and acceptance.
  - Acceptance is a place where pragmatic criteria and values such as naturalness may come into play.
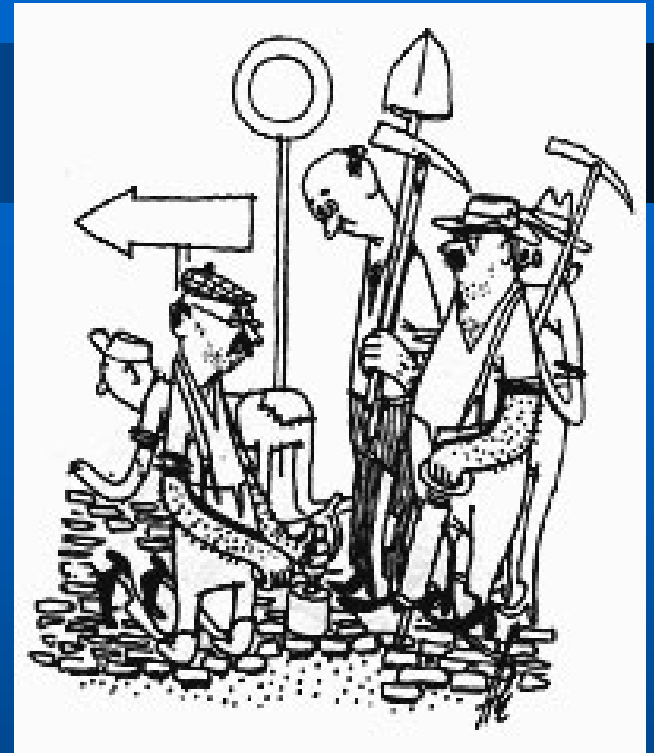
3

PREFERENCES IN THE MODEL LANDSCAPE

Models and model landscapes

- Following Morgan and Morrison, we take models as partly autonomous entities containing some representative commitments and adaptable parameters.

- Model Landscape of EPP is divided into several groups, some of which can be subdivided further.
  - No exhaustive partition because there are models that combine features from different model groups.

- Many address the naturalness problem in some form or other.
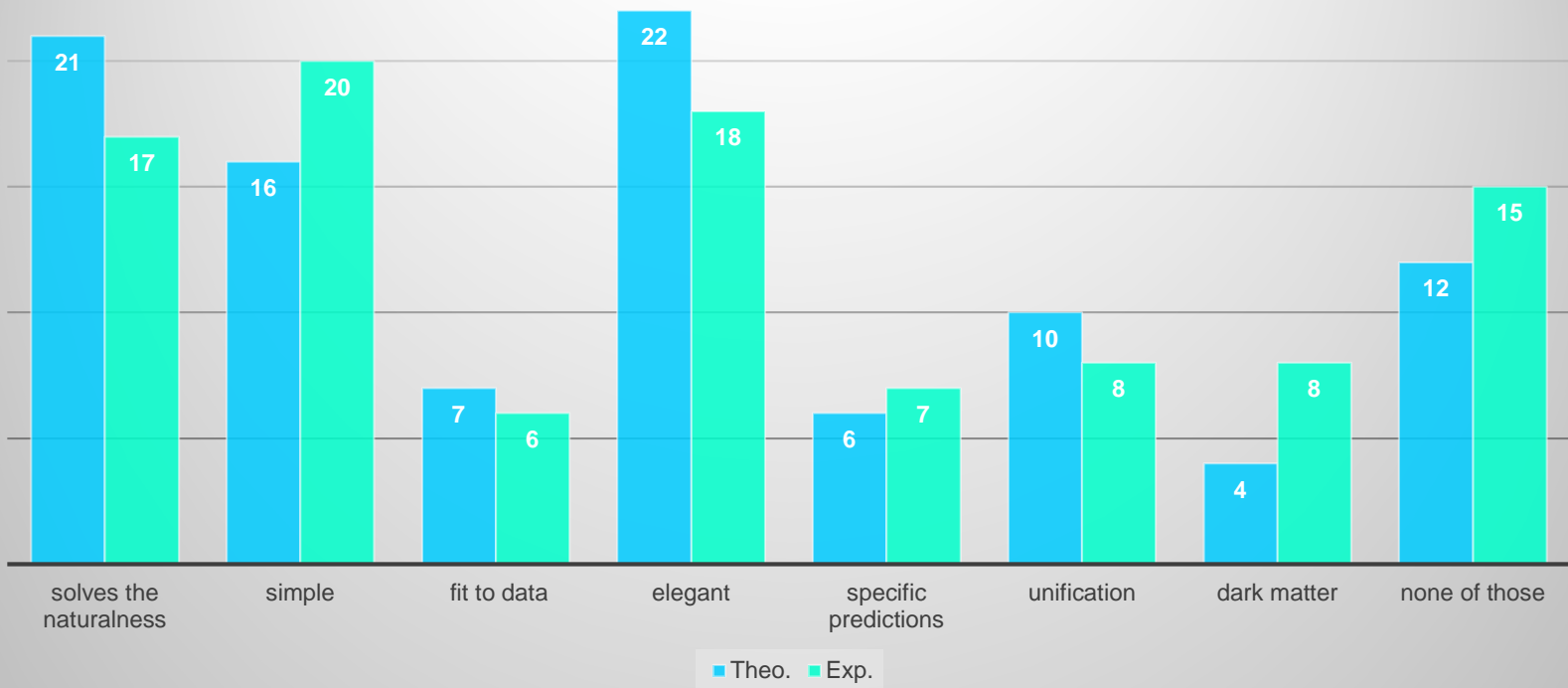
Alternative models independently of LHC

a) extended Higgs sector
b) supersymmetry
c) extra-dimensions
d) dynamical electroweak symmetry breaking
e) 4th generation
f) extended gauge symmetry (Z', Little Higgs)
g) string theory
h) other.

18

Preferences

- In 2011/2 we asked – and will ask again – about preference w.r.t. an assumed discovery at LHC and preference in general (not assuming a discovery).

- As regards the first, quite a few people voted for "something totally unexpected" which underscores their trust in LHC and that there were quite some uncertainties about the models.

- Following the second question, we asked about criteria for the preference expressed.
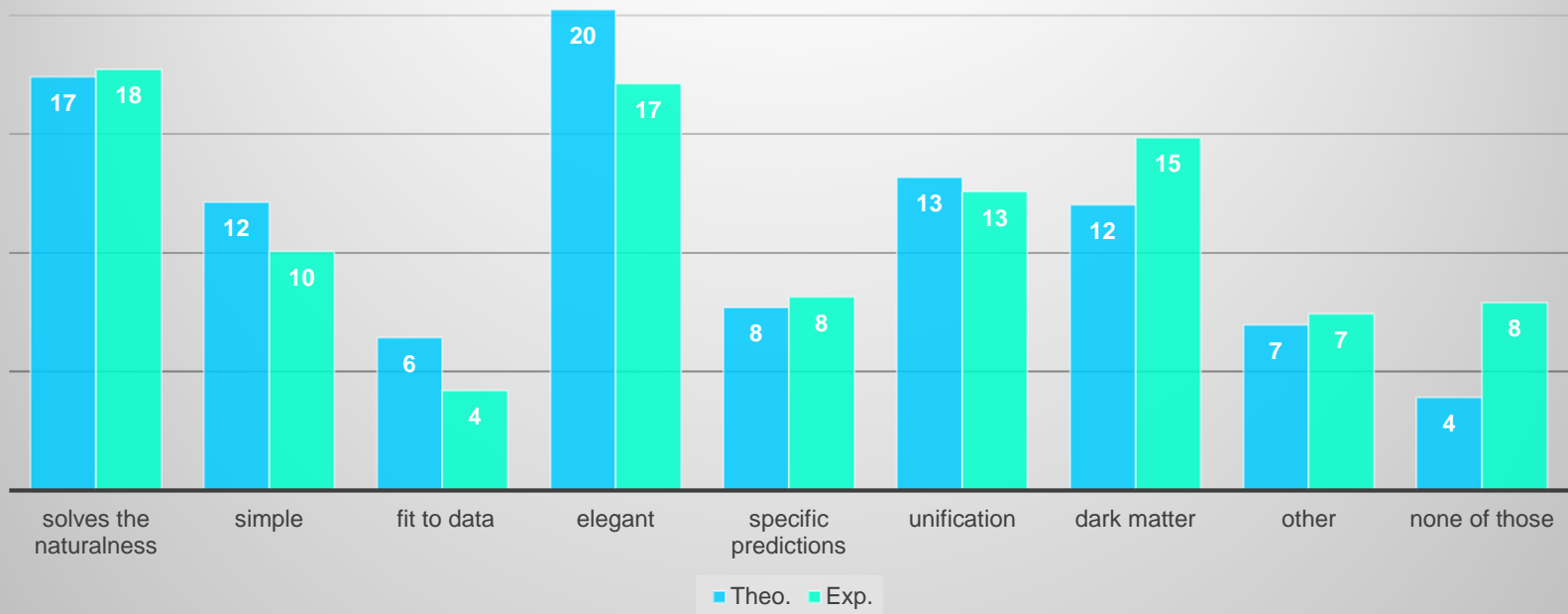
Criteria of preference in 2011

Which (if any) of the following criteria have guided you in answering the previous question?

Theo. / Exp. values by criteria:
- solves the naturalness: 21 / 17
- simple: 16 / 20
- fit to data: 7 / 6
- elegant: 22 / 18
- specific predictions: 6 / 7
- unification: 10 / 8
- dark matter: 4 / 8
- none of those: 12 / 15

■ Theo. ■ Exp.

Criteria in 2012

Epistemic and pragmatic criteria

- Fit the data or specific predictions are clearly epistemic criteria (empirical adequacy).
  - Low value for "fit the data" and "specific predictions" suggests that this was taken for granted for most models.
- Elegance and simplicity are pragmatic criteria.
- Naturalness scores on a par with both of them.
- Fruitfulness, ability to explain dark matter, score lower because no concrete avenue inside particle phenomenology.
- Naturalness gives clearer hints to model builders.

We also asked for the most critical flaws of the SM

- Dark matter and no gravity now ahead of many parameters and naturalness problem, followed by more specific issues.

- But naturalness still scores on a par with the most classical complaint about the SM that was effective in motivating model builders, to wit, the many parameters.

«Siehgst, da wo jetzt da Fahrradständer steht, war früher 's Gipfelkreuz . . .»
(Zeichnung: Ernst Hürlimann)

4

VALUES OF PREFERENCE A CLOSER LOOK

Criteria of theory/model choice

- Traditionally epistemic criteria (e.g. empirical adequacy, theoretical consistency) and pragmatic criteria (simplicity, fertility, parsimony) were rigidly separated.

- Kuhn advocated a broader list of characteristics of a good scientific theory, including "empirical "accuracy, consistency [internally and with respect to other theories], scope, simplicity, and fruitfulness."

Values of preference

- Not mutually independent, often context-dependent, may point in opposite directions, and shaped by history of a research field (including its major experiments) – but not a matter of taste.

- Preference is historically factual, not rationally enforced.

Douglas attempt at restoring the separation

I.   minimal criteria applied to the theory per se, e.g. internal consistency;

II.   minimal criteria applied to the relation of theory and evidence, among them empirical adequacy;

III.   desiderata applied to theories per se, among them scope, simplicity, and potential explanatory power.

IV.   desiderata applied to the relation of theory and evidence, among them being supported by a broad range of empirical evidence and not being contrived to match a small domain of facts in an ad hoc fashion.

Douglas - 2

- While categories (i) and (ii) are epistemic, category (iii) contains "strategic or pragmatic values" that facilitate scientific activity.
- Group (iv) "provides assurance that our scientific claims are more likely to be reliable."
- But the threshold of reliability can only be agreed upon by social convention (5σ or accepted toxicity level)
- Main goal of this reparation is to reduce conflicts.
  - "While simplicity, scope, and explanatory power are often thought to pull against each other when considering theories alone (group 3), they pull together when considering a theory in relation to evidence (group 4)."
  - So the criteria plus social conventions should be rationally compelling in a broader sense, not just factual.

Limits of this conception

- Douglas admits that one can suspend (i) temporarily to explore what is in a theory (iii).

- The tenacity of models that are poorly supported by empirical evidence but maintained because of their pragmatic promise however endangers Douglas' separation agenda.

- Naturalness will pose another problem.

5

NATURALNESS

Problems in renormalization

- $m_H^2 = m_B^2 + \frac{y_t^2}{16\pi^2}\Lambda^2 + o(m_{weak}^2)$
- m_H is the measured Higgs mass
- m_B is the unobservable bare mass
- Λ is renormalization cut-off in top-loop.

A fourfold way to naturalness (Williams & Wells)

1. quadratic divergences in renormalisation;
2. t'Hooft's suggestion that setting a small parameter to zero must increase the symmetry of the system;
3. a specific version of the problem of fine-tuning of fundamental constants;
4. an aesthetic criterion.

Is naturalness at all coherent?

- Grinbaum and Borrelli think that, in virtue of its complexity and vagueness, naturalness is basically an aesthetic criterion respectively a community narrative.

- In interviews we found that physicists used the mentioned concepts interchangeably but without feeling any inconsistency.

- Thus a consistent actors category.

Some quotes from interviews

- 'the progress of science is always driven by an aesthetic judgement …. that goes beyond mechanical relations between formulas, equations. …

- when you see some "accident", it is natural for a scientist to consider the possibility that … there is something beyond and then this accident becomes natural. Now, this is not always correct, … but for the issue of naturalness, all of it, … the picture is quite compelling.'

➢ Quest for explanation by means of new physics that fulfills a certain ideal of explanation.

Some quotes from interviews -2

There are also skeptics:

- "I cannot see any reason,. …. we put this fine-tuning by hand, … it cannot happen in nature.'

There is also a pragmatic case to be made:

- "We need the guidelines. Because, it's not just the experiment, it's not just mathematics. … One guideline could be this naturalness, … which is a theoretical guideline. Or, 'minimality', that is, for a model to have the minimal number of free parameters.

Quotes from 2012

- 'I would say that now that it is certain that there is a Higgs state at this mass, [the naturalness problem] is more alive than ever'.

- 'is this problem a real problem or just a fantasy of theoretical physicists? …. I've been trained to look at it as a serious problem'.

- I'm not so sure anymore whether this is actually something that leads us into the right direction.' 'People have just accepted the fact that there is more and more fine-tuning now, because of the limits that become larger and larger. And it's not so clear to me whether it's still a good idea to consider that'.

- This is the main argument which … I think, drove … the theoretical community for the last twenty or thirty years. But it's not a solid argument'.

The effect of the Higgs discovery

- Naturalness turned from a potential problem to a real problem aggravated by the non-observation of particles in the TeV range.

- Recently, critical statements also in print, e.g.:
  - Dawn of the post-naturalness era (Guidice)

A complex value of preference

- Renormalizability ensures finiteness, i.e., theoretical consistency – clearly an epistemic value. Unnaturalness corresponds to departure from this value.

- Triggers a pragmatic consideration how much unnaturalness we accept, that is, a fine-tuning argument.

➢ Thus epistemic criterion prompts a pragmatic one.

➢ Not a confrontation or equilibration of separate criteria in the Kuhnian sense and a mixing of Douglasian criteria.

What are these values for, if applied to models?

- They would only be required to yield a compelling rational choice if we think of them within the context of a logical version of Duhem's underdetermination problem, i.e., as the need to decide between two models as theoretical entities in the face of relevant evidence.

- But this is not the role that models play in particle physics at the intersection between experiment and theorizing.

- Models are to a large extent an autonomous element of scientific practice. They combine representative and narrative features, which play a role in their justification and application.

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THE NARRATIVE DIMENSION
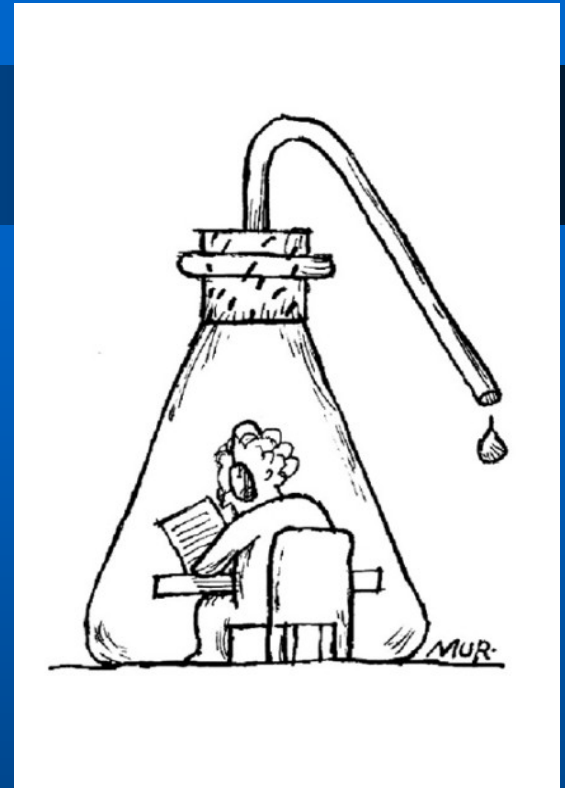
Stories and narratives

- "A story is a narrative told *around* the formalism of the model. … It … takes advantage of the vocabulary of the theory (such as 'gluon') and refers to some of its features (such as its complicated vacuum structure). Using more general terms, the story fits the model in a larger framework (a world picture) in a non-deductive way […]; it complements the formalism." (Hartmann 1999)
- Distinction formalism-narrative is blurry.
- Complementing does not mean separation.

The narrative dimension

- Narratives invoke explanatory ideals (even if they do not fully correspond to them).

- Values of preference are a major motivation to embark on BSM despite success of SM. They can be part of narratives justifying models.

- My main point is that there is not simply a dichotomy formalism – narrative, rational choice – rationality-free aesthetic preference.

Naturalness as a narrative

- Naturalness combines an epistemic and a pragmatic value into a coherent narrative that targets an explanatory deficit of the SM and advocates an explanatory ideal.

- There are debates whether the values or the narrative are convincing, especially after the Higgs discovery and the lack of BSM evidence.

Naturalness and the scales

- Naturalness problem is resolved by new physics of a certain kind at some scale. It puts theoretical constraints on the nature of this physics, but only pragmatic concerns about the scale.

- William's conception of naturalness: expression of the central dogma of effective field theories according to which widely separated scales should eventually decouple.

- Naturalness seems to endanger the level separation that was so essential for physicists combination of instrumentalism and realism.

- This aspect of the narrative goes beyond values of preference and is closer to a theoretical principle.

CONCLUSION
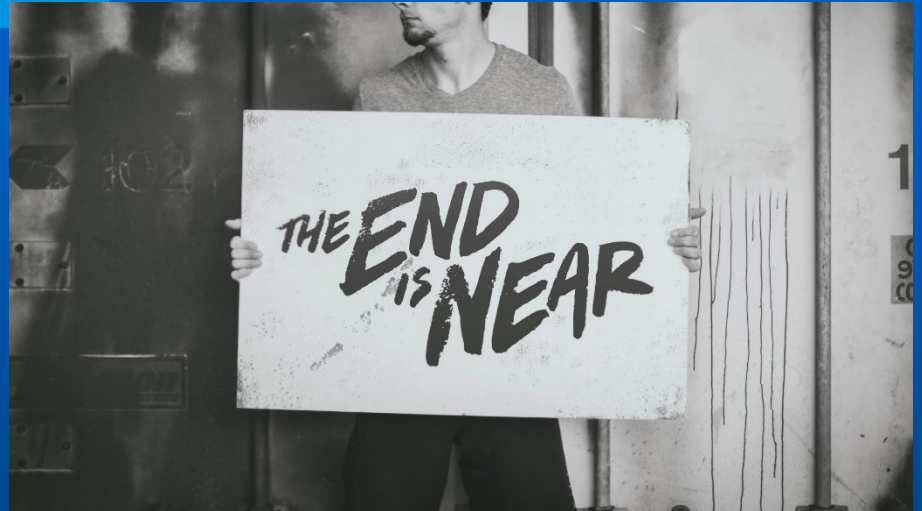
Conclusion

- Epistemic and pragmatic values have to be weighed in in factual practice.

- Naturalness is a complex value that is nevertheless consistently applied across HEP community.

- Values of model preference may be embedded into broader narratives.

- Such narratives involve explanatory ideals that are connected to a model but may refer to the discipline as a whole.