Particle Theory: a strategic outlook

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Strategy PP Meeting 2018, March 13th Uppsala

Fundamental Particle Theory: the past Strategy

Quoting the European Strategy for Particle Physics (update 2013):

Preamble:

"…the field has made impressive progress in the pursuit of its core mission, elucidating the laws of nature at the most fundamental level…"

"…These results raise further questions on the origin of elementary particle masses and on the role of the Higgs boson in the more fundamental theory underlying the Standard Model, which may involve additional particles…"

Other scientific activities essential to the particle physics programme:

"Theory is a strong driver of particle physics and provides essential input to experiments, witness the major role played by theory in the recent discovery of the Higgs boson, from the foundations of the Standard Model to detailed calculations guiding the experimental searches. Europe should support a diverse, vibrant theoretical physics programme, ranging from abstract to applied topics, in close collaboration with experiments and extending to neighbouring fields such as astroparticle physics and cosmology"

How the particle theory community works

Developing the new concept or principle ⇨ **Building a theoretically consistent model** ⇨ **Phenomenological consistency checks** ⇨ **New predictions for experiment**

✓ **QUESTION I: What are the fundamental principles (laws) of nature that could or should be tested in Particle Physics experiments?**

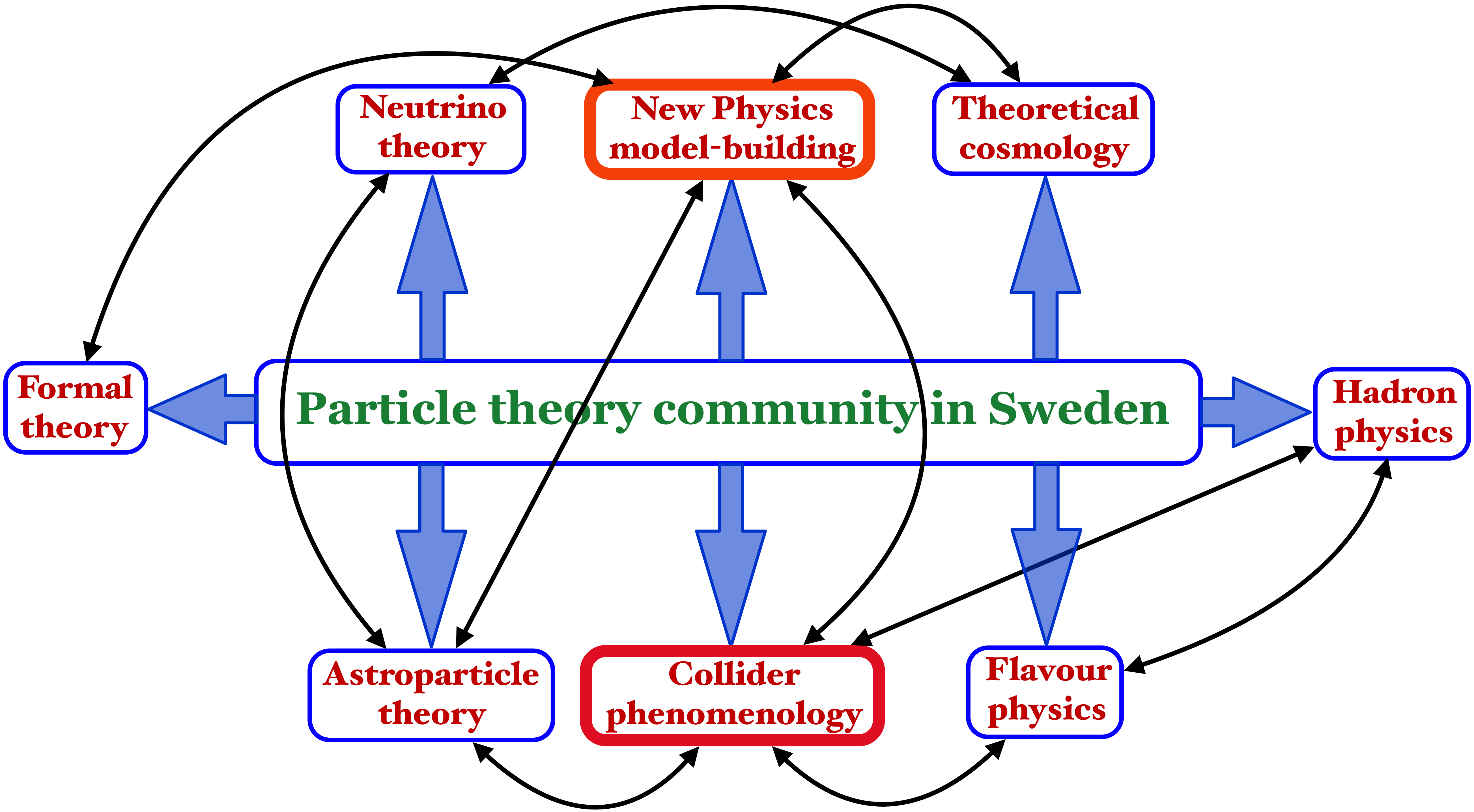
✓ **QUESTION II: How a more fundamental theory (i.e. New Physics) underlying the SM (possibly, encoding new yet undiscovered principles) could or should look like provided:**

(i) the wealth of experimental bounds on new interactions and states;
(ii) the plethora theoretical achievements over past decades ("theory bounds");
(iii) that it solves, at least, one of the fundamental problems raised by the foundations of the SM itself

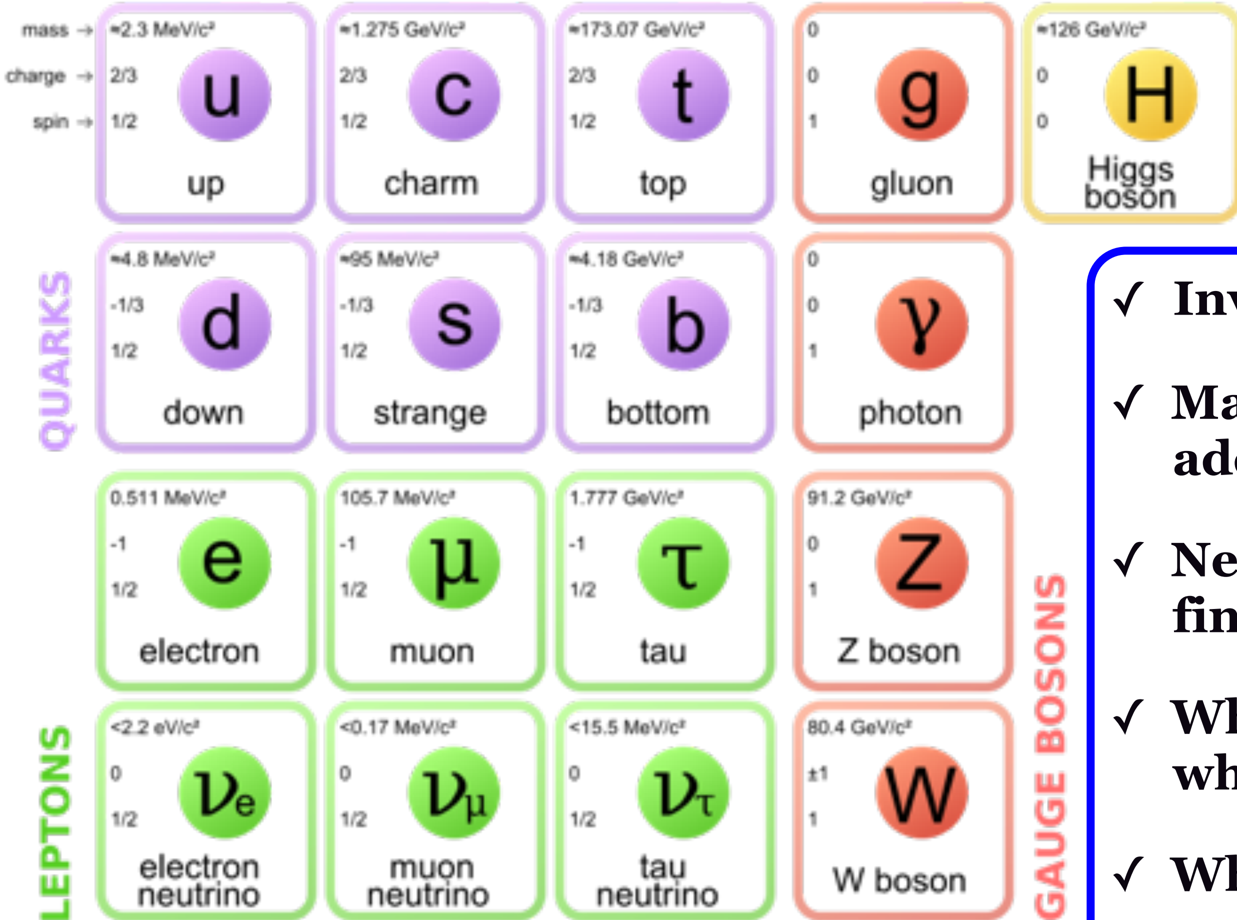
✓ **QUESTION III: In which particular way a given (new or existing?) symmetry or a principle of nature could be found in a given Particle Physics experiment (if at all), or which experiment should be built/realised in order to make such a discovery?**

✓ **QUESTION IV: Which methods/approaches/tools must be developed for the theory to be able to give reliable predictions for experiments as well as to properly understand the experimental measurement?**

Particle Theory: research areas



"Cosmic DNA": the road ahead



Unexpectedly successful in its minimal formulation!

Theorists are not very happy though…

- ✓ Invisible mass of the Universe (~96%) is unexplained
- ✓ Matter-antimatter asymmetry in the Universe requires additional sources of CPV and a much stronger PT
- ✓ Neutrino decoupling requires either an enormous fine-tuning or extra heavy (sterile) states
- ✓ Why both quarks and leptons appear in three generations, while having very different interaction properties?
- ✓ What causes huge hierarchies in the fermion spectrum?
- ✓ Whether the vacuum is stable or not?
- ✓ Why the quantum vacuum yields vanishingly small contribution to the cosmological constant?
- ✓ Why do the gauge interactions if the SM appear so different? (varied strength/RG behaviour, vector-like vs chiral, weakly-coupled vs strongly-coupled)
- ✓ Most of the above points can be resolved in multi-Higgs models, why do we find only one Higgs boson at the LHC?
- ✓ Which dynamics triggers the EW symmetry breaking?
- ✓ If the SM is only an EFT, where does the next energy scale enter the game, and whether/why is it so decoupled from the EW one?

Any suitable Beyond-the-SM theory must provide compelling and adequate answers to these questions

Non-observation of New Physics yet must not prevent us from moving forward looking for alternative precision ways to probe it in yet (many!) unexplored scenarios

Particle Theory: ongoing activities

- ✓ ***Gauge couplings unification/RG evolution*** **provides a clue where fundamental forces come from and development of tools for complicated GUT-scale theories is crucial their phenomenological verification (Nordita; Stockholm U., OKC; Lund)**

- ✓ **The search for, and model-building with, *dynamical EW symmetry breaking* is ongoing that explains the origin of the EW scale, fermion hierarchies and the (composite) Higgs boson due a new strongly-coupled dynamics (Chalmers; Nordita; Lund)**

- ✓ **The *Dark Matter and neutrino properties in various extensions of the SM* need to be properly constrained and simulated, also together with constraints on neutrino masses (Stockholm U., OKC; Uppsala)**

- ✓ **Extensive *exploration of viable corners of the parameter space in low-scale SUSY models* is relevant for making predictions for ongoing and future measurements (Stockholm U., OKC)**

- ✓ ***Baryogenesis and leptogenesis mechanisms in various SM extensions*** **(with R-neutrinos and multi-Higgs extensions) provide relevant connections with cosmological constraints (Stockholm, OKC; Lund)**

Particle Theory: ongoing activities

✓ **Any *suitable extension of the SM*, either emerging from a GUT-scale theory as a low-energy EFT or stand-alone constructions with additional symmetries, that are *capable of baryogenesis, neutrino mass generation, Dark Matter, and generation of a strong splitting in fermions mass/mixing spectra*, contain more than one Higgs doublet and such multi-Higgs models need to be properly studied (Lund; Uppsala; Stockholm U., OKC)**

✓ ***Supersymmetry* may be present *at high-energy scales* e.g. unifying Higgs bosons' sector with leptons into the same multiplet, and exhibits itself in features of particle and interactions at low-energies (Lund)**

✓ **An emergence of the *"fifth force" of nature*, such as gauge family symmetries, at the next energy scale above the EW one (e.g. *Z'* models) is under active exploration (Uppsala; Lund)**

✓ ***Flavor physics constraints on New Physics model space* gains a larger weight after recent findings of flavour anomalies (lepton-flavor violation) at the LHC (Stockholm U., OKC)**

✓ ***Formal theory developments* such as gravity models, extended supersymmetries, dynamical Dark Energy models, formal aspects of quantum field theory, string theory, integrability, cosmological models, physical vacuum, SUSY breaking mechanics (Uppsala; Nordita; Chalmers; Lund)**