Interplay (and collaboration) between theory and experiment

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Particle Physics Day, Helsinki 24.11.2022

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Introduction and summary

A large part of particle physics is summarized in

$$N = \frac{1}{2s}\int \frac{\mathrm{d}x_1}{x_1}\frac{\mathrm{d}x_2}{x_2} f_a(x_1,\mu_F) f_b(x_2,\mu_F) |\mathcal{M}(ab \to ijk\ldots,\mu_R)|^2$$

$$\times D_i^{h_i}(z,\mu_F) D_j^{h_j}(z,\mu_F)\ldots \times \Pi_f \epsilon_f(p_T^f,\Delta\Omega) \times \Delta\Omega \times \int \mathcal{L}\mathrm{d}t$$

To properly understand this, a lot of interplay between experiment and theory is needed:

- PDFs: fitting fixed-order calculations to experimental data (Eskola, Paukkunen et al./JYU: nuclear PDFs)
- Hard matrix element: Fixed-order calculations, model building, understanding what final states can be detected (almost all)
- Fragmentation functions: phenomenological modelling to experimental data
- Efficiencies: Triggering, particle ID, detector acceptance (Lehti/τ, Voutilainen/jets, HY)
- And obviously you need a detector in the right place (CMS detector group) and the beams running

The Standard Model needs to be extended

Numerous LHC analyses have given results that are compatible with the SM, but...

- neutrinos are massive
- there is no cold dark matter candidate
- there is no first order phase transition
- gravity is not a part of the SM

No lack of theoretical ideas: gauge extensions, Higgs extensions, seesaw models, supersymmetry, extra dimensions, composite models ...

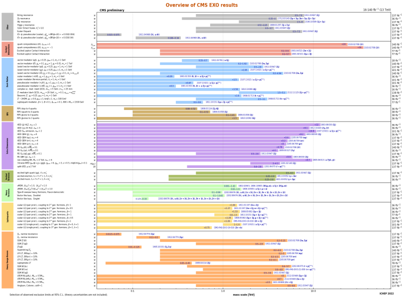
Nor of experimental signatures: resonances (dijet, dilepton, diboson), mono-X signatures, multileptons (with or without MET), lepton flavor violation, lepton number violation, displaced signatures, disappearing tracks, ...

One can look for deviations in SM particle properties...

- Even rather basic measurements of m_W, m_t or α_s are important as they reduce the errors of the SM predictions
- The Higgs looks SM-like, few interesting channels to discover at LHC: $b\bar{b}h$ productioid, hh production, $h \to Z\gamma$ decay
- Muon anomalous magnetic moment has a tension between experiment and SM prediction, though also tension between results from lattice and dispersion relations
- Several flavor anomalies deviating from the SM at 3σ level, remaining for several years, but central values moving towards SM
- Searches for rare/forbidden processes ($B_{s,d} \to \mu^+\mu^-$, $0\nu\beta\beta$, $\mu \to e\gamma$, ...), so far no surprises, but constrain a number of models

Theorists can try optimal fits or try to fit their favorite model, best fits obviously change with new data, error bars still so large that a large number of models can explain data
Theory tries to compute perturbative corrections so that the error matches experimental precision

. . . or directly for the new particles



- Impressive list of exclusion limits, no clear indication of a signal since the 750 GeV diphoton excess
- Searches quite comprehensive in the sense that it's very difficult to hide a EW scale particle that could be seen, but would not have given a hint of itself yet
- An excess in direct searches would be a lot easier to interpret, though still several models would survive
- Theorists can now play with open data or recasting tools

Collaboration needs a bit of practice from both sides

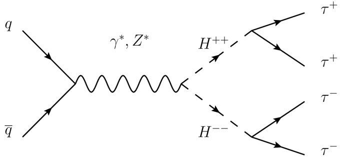
Experimentalist

- Wants to be model-independent, interested in the signature
- Wants the analysis to target as many models as possible
- Lot of work to estimate the background, prefers validated data-driven backgrounds
- Fighting against systematic uncertainties
- Not too aware of models that give the signature or cross correlations between signatures

Theorist

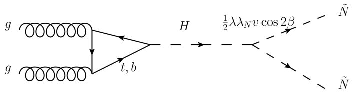
- Has to define a model (=Lagrangian), so that calculations can be done
- Wants to optimise the analysis for their favorite model
- Usually trusts on Monte Carlo backgrounds (what else is available?)
- Usually does not know what a systematic uncertainty is
- Can easily generate benchmark scenarios and aware of cross correlations between signatures

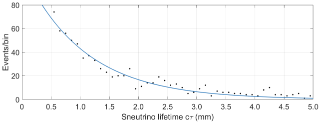
Hide and seek with left-right supersymmetry



- We did a study (2003.08443), where we tried to make discovering left-right supersymmetry as difficult as possible
- The first indication would likely be a doubly charged Higgs boson and the most difficult channel is the ditau channel
- Our experimentalists had experience with $H^{\pm} \to \tau^{\pm}\nu$, so they took the challenge of $H^{\pm\pm} \to \tau^{\pm}\tau^{\pm}$, too
- I've been the theory expert for S. Lehti and R. Öhrnberg as they are estimating the sensitivity of their analysis
- Obviously the actual analysis will target also other models than left-right supersymmetry, which will give some complications

Neutrino physics from sneutrinos





- In 2012.14034 we did a phenomenological paper showing how neutrino dynamics could be measured from sneutrino decays
- Signature was two displaced same-sign leptons from the decays of right-handed sneutrinos — a signature not actually studied! (opposite-sign displaced dileptons studied recently)
- From lepton displacements one could deduce tiny neutrino Yukawa couplings (smaller than electron Yukawa)
- Collaboration with experimentalists helped in understanding what the detector can do, how does the b-tagging work and also what we should not try to do

Actual summary

- Some interplay of experiment and theory present in almost all particle physics
- The number of available models is huge, only experiments can guide us to choose between them
- Collaboration between experimentalists and theorists can give interesting results