Physics at the energy frontier

Proseminar in Theoretical Physics, HS2015

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1 Introduction

This proseminar cycle explores particle physics as it appears at the highest energy scale achieved to-date in laboratory conditions: the TeV scale at the Large Hadron Collider (LHC). Topics include the Standard Model of particle physics, the Higgs boson field (its discovery and the measurements of its interactions), as well as models for new physics whose signatures are currently searched for at the LHC.

The goal of the proseminar cycle is to bring you in contact with cutting edge research in particle physics phenomenology, and to approach the key theory ideas, the current status and the future perspectives of the physics tested in the LHC. At the same time you will be exposed to the process of grasping new knowledge in a relatively short period of time, recognising the important concepts and presenting them to an audience of your peers in a coherent way.

2 What this proseminar is NOT

The proseminar is not a course in Quantum Field Theory or in calculation techniques necessary for particle physics. The material here spans, in a cavalier way, the length of many courses within the particle physics Master program. If you have already mastered QFT 1, and Phenomenology of Particle Physics 1 and 2, or are planning to take some of these courses in parallel to the proseminar, your understanding will be enhanced. They are not, however, pre-requisites, nor is the proseminar a substitute for any of them. We will, therefore, have to repeatedly sacrifice mathematical rigour for fast access to key ideas, in order to reach our intellectual destination. You will probably end up with many, potentially deep, unanswered questions about the inner structure of field theories and the precise way it all works. If this happens, the main goal will have been reached: not to stuff you with more knowledge, but to light some fires.

3 Organization

3.1 Criteria for passing the module

- Give a pedagogical presentation of the material assigned to your topic, demonstrating solid understanding of the underlying theory. The presentation should be given using a computer and the beamer provided in the classroom.

- Complete and hand in the presentation file one week before your scheduled talk.

- Hand in a written report of your presentation, in English, in pdf format, produced in LaTeX, not later than two weeks after your talk. The report should not be too short (2 pages) or too extensive (50 pages). Its precise length depends on you, and on the topic you present.

- Be present (and preferably active!) at least 80% of the time.

3.2 Operational structure

- After a period of six weeks, we will start with two presentations per week.

- Each presentation should be 50-60 mins long. There will be 2 presentations per class session, followed by a short discussion. Questions will be allowed during the presentation.

- The presentations will take place on Monday morning, 8:45-10:45.

- You will be assigned a research assistant from the institute as tutor. You should contact your tutor at least 6 weeks before your talk and set up a meeting to discuss logistics. Your tutor can help you with specific questions and general guidance, but will not have the time to introduce you to TeX or Powerpoint/Keynote/LaTeX Beamer etc. Maintaining contact with your tutor is very important during the six weeks before your talk.

- Similarly to what happens in many conferences, at the very last lecture I will give a summary talk that will include few slides - the most impressive ones - from each talk.

3.3 General guidelines

- For each of the topics below there is a list of key concepts that you have to cover along with some indicative literature. You don't have to confine yourself to the suggested literature. In fact you are strongly encourage to expand it as you see fit.

- Try to co-ordinate with the talks before and after yours, so that there is no large overlap of key concepts, and the flow of the course remains smooth. When planning your talk, remember that the better understanding of the background of your audience you have, the more effective your talk will be. You shouldn't consider me or your tutor as your target audience: the talks are intended to communicate the material to your fellow students. Also, please bare in mind that the level of the group varies since there are master and bachelor students among you.
- Do not overload your slides with material: as a general guideline, each point you want to make corresponds to one slide. Hence you should try to avoid bullet lists. On the other hand, you should include figures and plots or other graphic elements that help getting your point across.
- Most of the topics revolve around one or more experimental plots that convey a large amount of information in a very condensed way. You should try to explain to your colleagues how to see this information. But remember that this is a theory proseminar, so we are mostly interested in key theory ideas and theory predictions, not the experimental details.
- Please bring your own laptop and test it before the session begins (before 8:45).

4 Topics

4.1 Quantum Field Theory, Feynman diagrams, cross-sections and all that.

Speaker: Martin Renner. **Tutor**: Yang Zhang (email) **date**: 16.11

A very short introduction to Quantum Field Theory: what is a field and what is a particle, what is the Lagrangian density of a model, how does it correspond to Feynman diagrams, what are the rules for computing Feynman diagrams, how do we compute cross-sections.

Bibliography: Any book on QFT. In particular, see [PS95] §1-5, [Gri08] §2,3,6,7, [Sch14] §7

4.2 The Standard Model

Speaker: Lena Bartha . **Tutor**: Cheng Peng (email) **date**: 16.11

The particle content of the Standard Model, its Lagrangian, its Feynman rules, and basic properties of the Standard Model interactions. What kinds of charges are there? how are the particles organized in multiplets under the different gauge groups?

Bibliography: [DGH] §1-2, [Pok00]§12, [HM84]§1, 15, [Tho13]§7

4.3 Electroweak symmetry breaking

Speaker: Lukas Zobernig. **Tutor**: Yang Zhang (email) **date**: 23.11

Short description of spontaneous symmetry breaking. The Higgs sector. Which symmetry is broken? What happens to the Goldstone bosons? What is the origin of quark masses according to the SM?

Bibliography: [Geo84]§2.4-2.7 (online updated version), [Pok00]§10-11, [PS95] §20, [Djo08], [Sch14]§28

4.4 Higgsology 1: discovery

How is the Higgs boson produced at the LHC, and how does it decay? What are the main observable channels? In which channels was it discovered, in which channels has it been observed by now? Why? See fig. 1.

Speaker: Viola Vogler. **Tutor**: Achilleas Lazopoulos (email) **date**: 23.11

Biblography: [Djo08], [Oli+14] §11.I - 11.III (direct link to §11), [Tho13]§17

4.5 Higgsology 2: properties

Student: Achilleas Lazopoulos. **Tutor**: N/A **date**: 30.11

Is what is measured the Standard Model Higgs boson? How do we measure the couplings of the Higgs boson to other particles? How do we measure other properties? What is the current measurement and what are the perspectives for the future? See fig. 2.

Bibliography: [Djo08], [Oli+14] §11.IV (direct link to §11)

4.6 Standard Model: electroweak measurements

Speaker: Chris Marentini. **Tutor**: Alexander Huss (email) **date**: 30.11

What are the main measurements within the Standard Model that do not include new particles or the Higgs boson? Are there any deviations from the SM predictions, see fig 3? Do they always have to signify new physics? The measurement of the mass of the W boson with high precision: why is it important?

Bibliography: [Gri08]§10, [Oli+14] W-mass review (direct link to the W mass review), [Tho13]§15-16-17, [Sch14] §31.

4.7 Standard Model: Top quark, Heavy flavors and the CKM matrix

Speaker: Justin Zimmerman. **Tutor**: Alexander Huss (email) **date**: 7.12

The top quark cross section, the top pair production in association with a Higgs boson, the measurement of the top mass with high precision: why are these related and why are they important for new physics? What is the CKM matrix and why is it important? How can we constrain the free parameters of the CKM matrix? Do the leptons mix? See fig. 4

Bibliography: [Oli+14] top quark review (direct link to the top quark review), [Oli+14] CKM matrix review (direct link to the CKM matrix review), [ESW96]§10.2, 10.5

4.8 Supersymmetry

Speaker: Martin Lickteig. **Tutor**: Cheng Peng (email) **date**: 7.12

A very short introduction to supersymmetry, its key attractive ideas, and the main experimental signatures. Is supersymmetry excluded at the LHC? See fig.5.

Bibliography: [MPT12], [BT06], [Wei13]

4.9 Strong dynamics

Speaker: Sokratis Trifinopoulos. **Tutor**: Ben Hoare (email) **date**: 14.12

What are the main ideas behind models with strong dynamics in the TeV energy range? What are the most promising experimental signatures? Are models with strong dynamics already excluded at the LHC? What is the significance of not finding any resonance related to such models until now? See fig. 6

Bibliography: [Oli+14] §11.V.6-11.V.7 (direct link to §11), [Con11], [MPT12]

4.10 Dark matter searches

Speaker: Julian Riebartsch. **Tutor**: Ben Hoare (email) **date**: 14.12

What is dark matter and how do we know it exists? Under which conditions is dark matter even possible to be detected at the LHC? What are the main signatures that are promising at the LHC? What has been found up to now? See fig.7

Bibliography: [Abe+15]

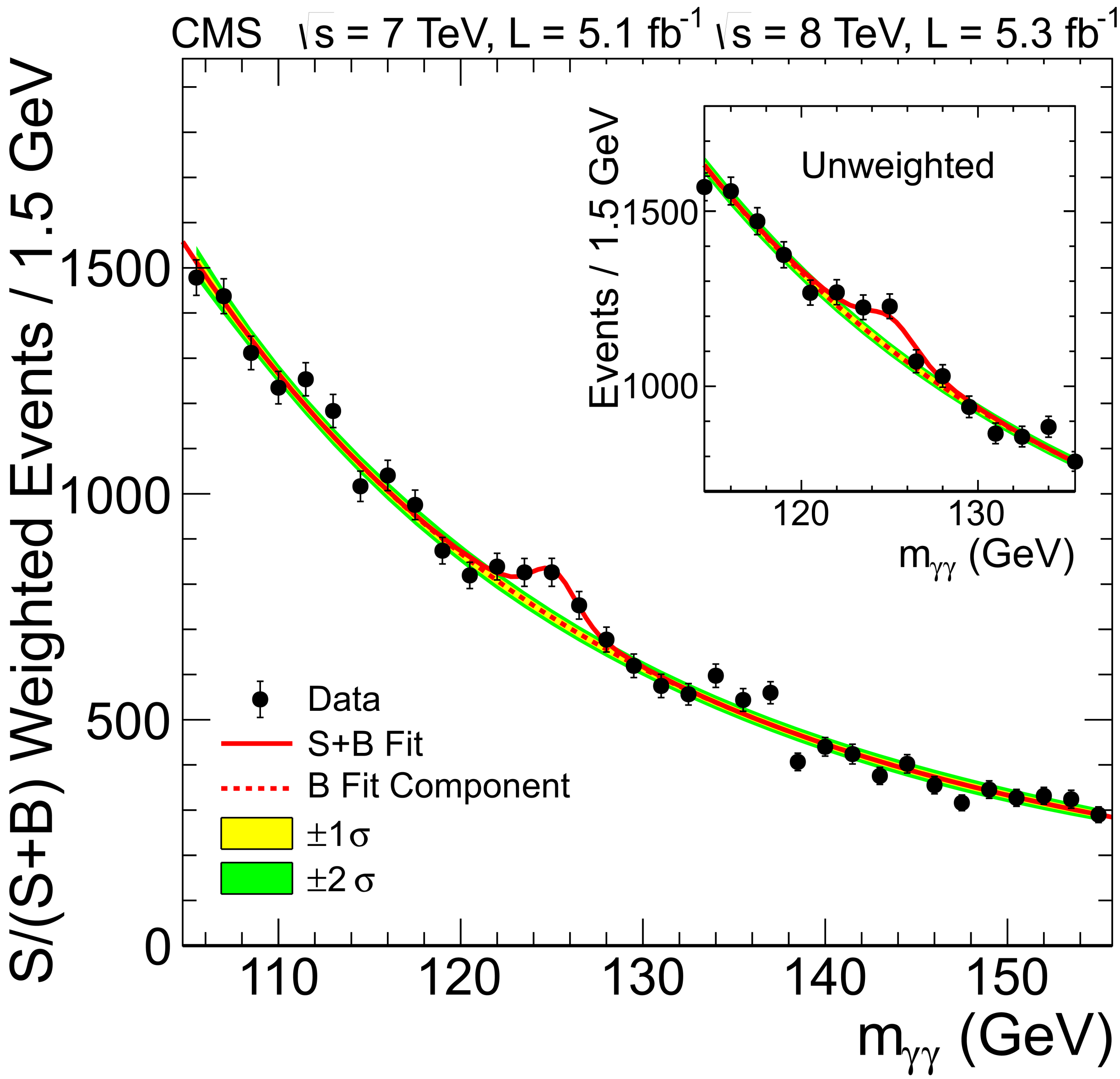

Figure 1: Higgs discovery in diphoton channel CMS, Higgs

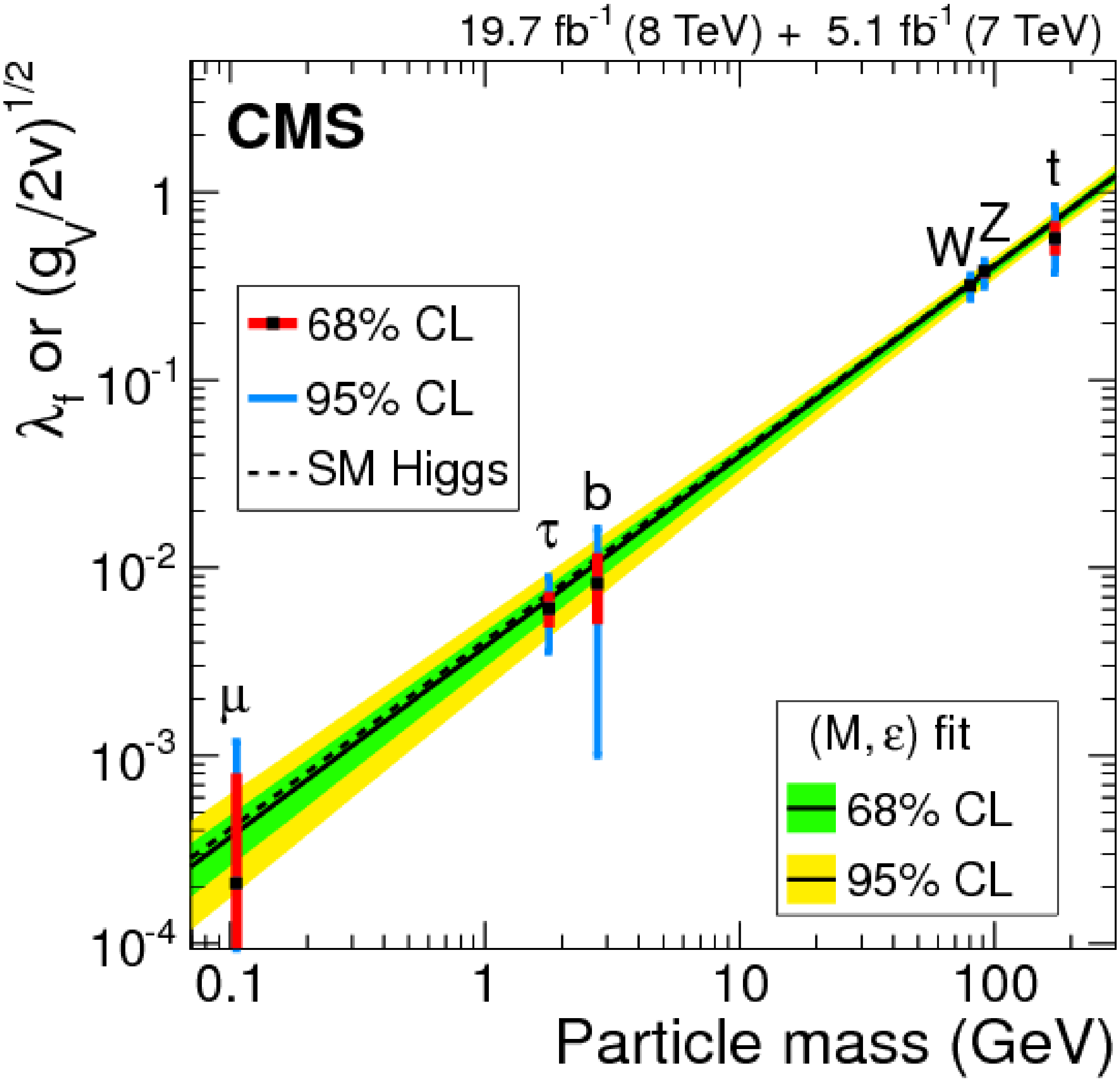

Figure 2: Higgs couplings CMS, Higgs couplings

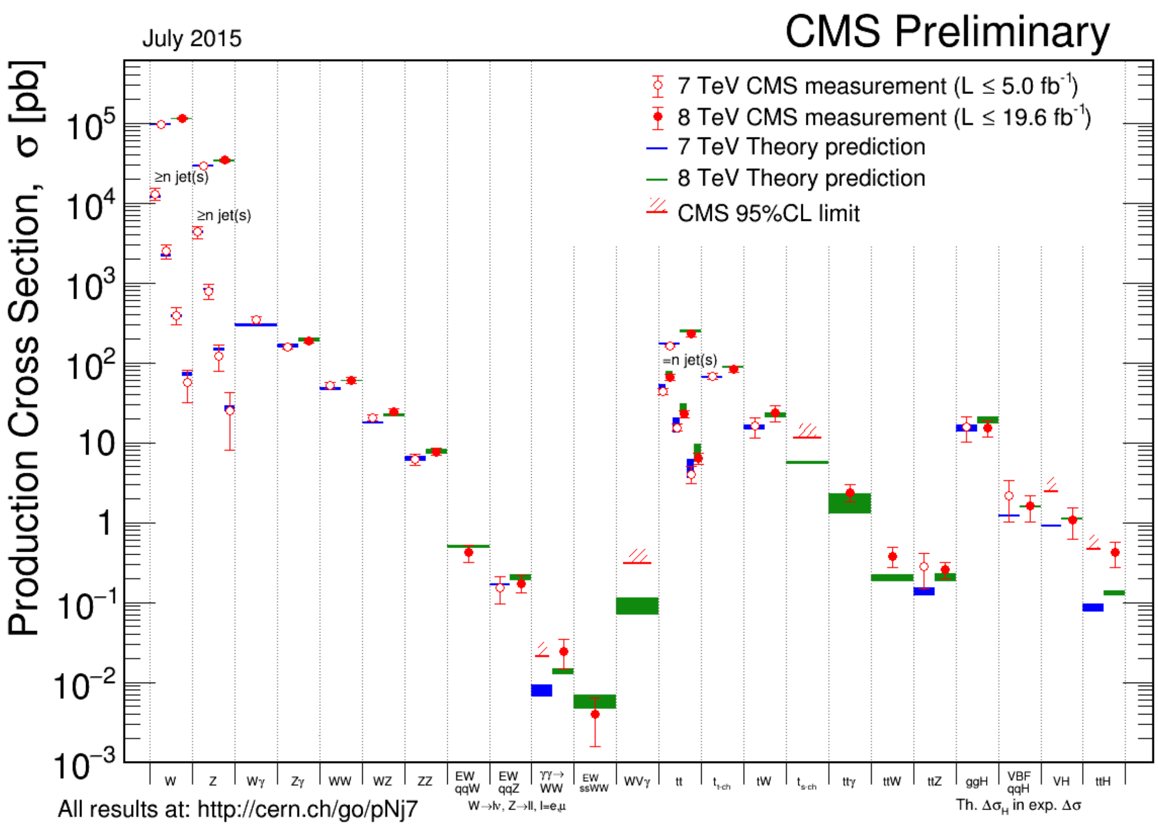

Figure 3: SM cross-sections (also known as the 'Stairway to Heaven plot') CMS, SM combined

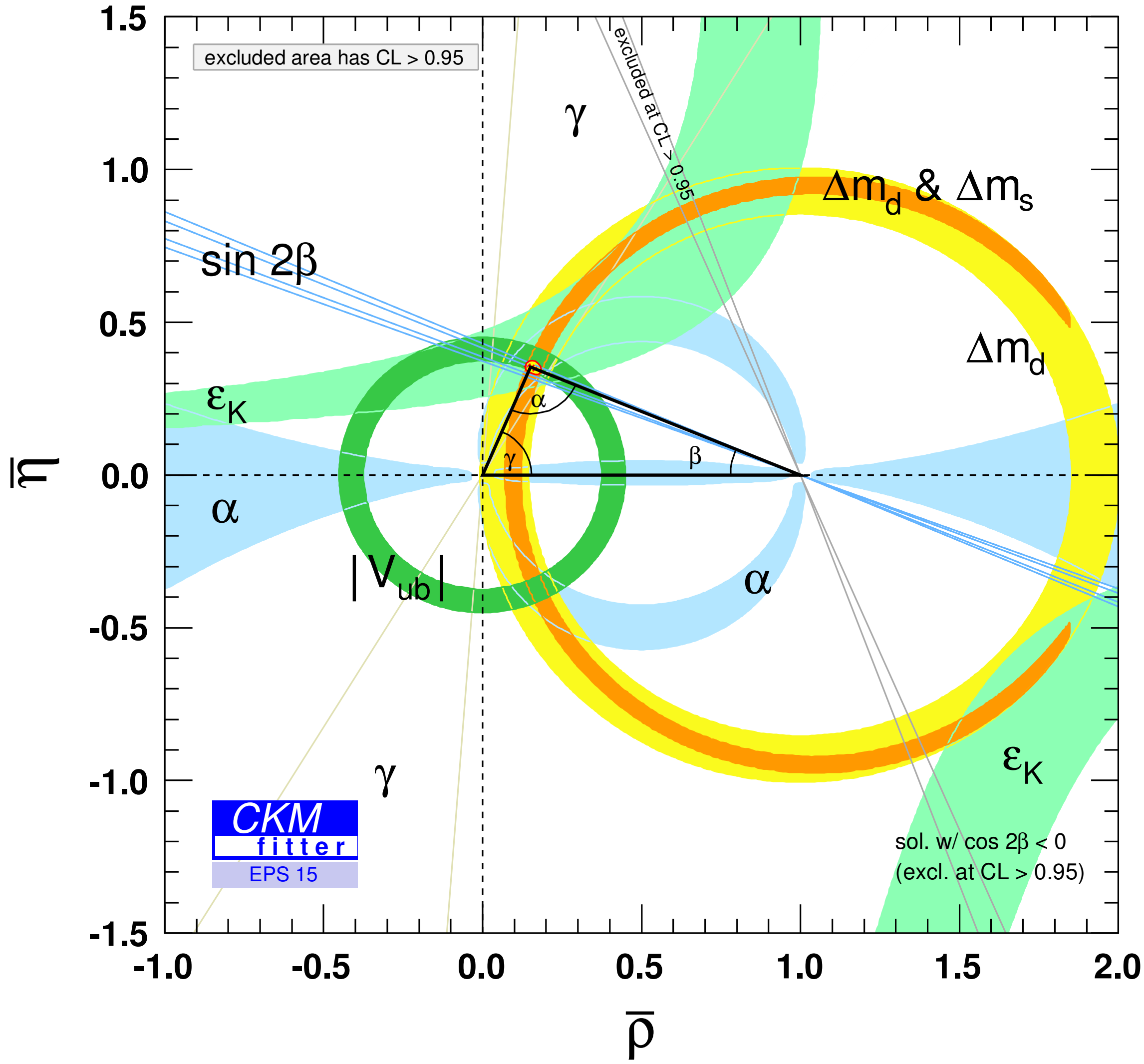

Figure 4: Rho-theta plot CKM fitter

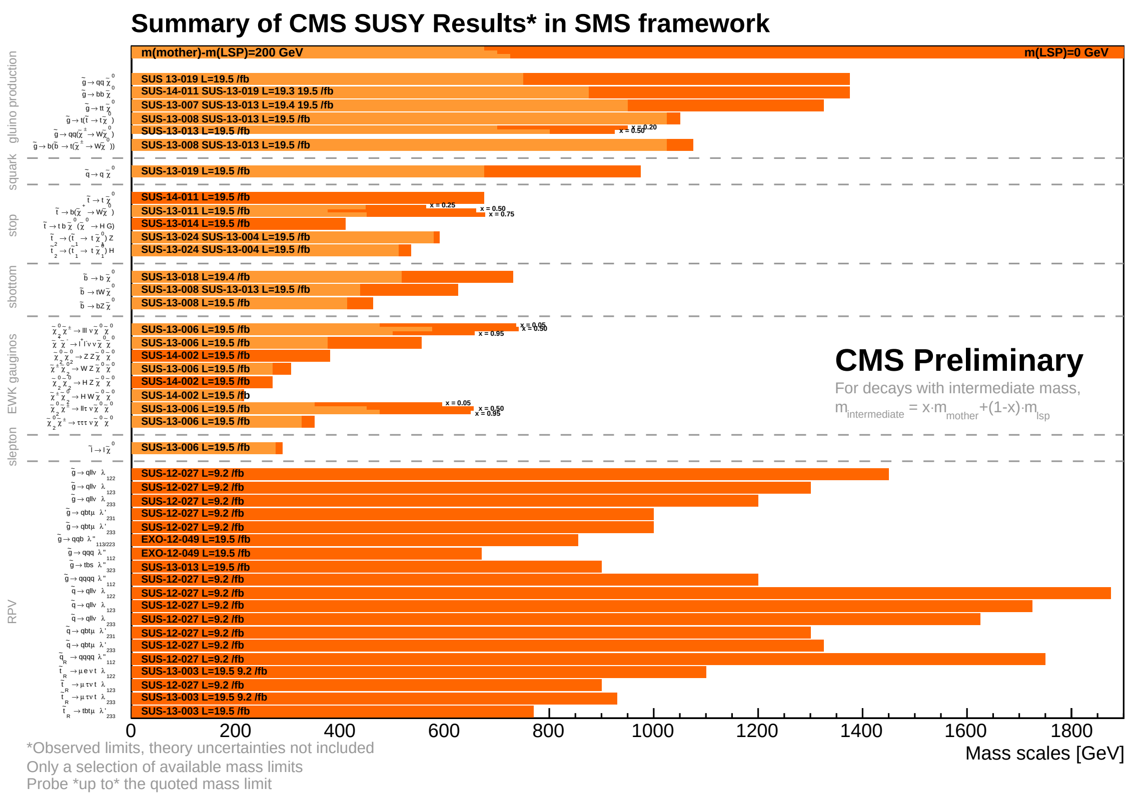

Figure 5: Supersymmetry exclusion plot, CMS, susy searches

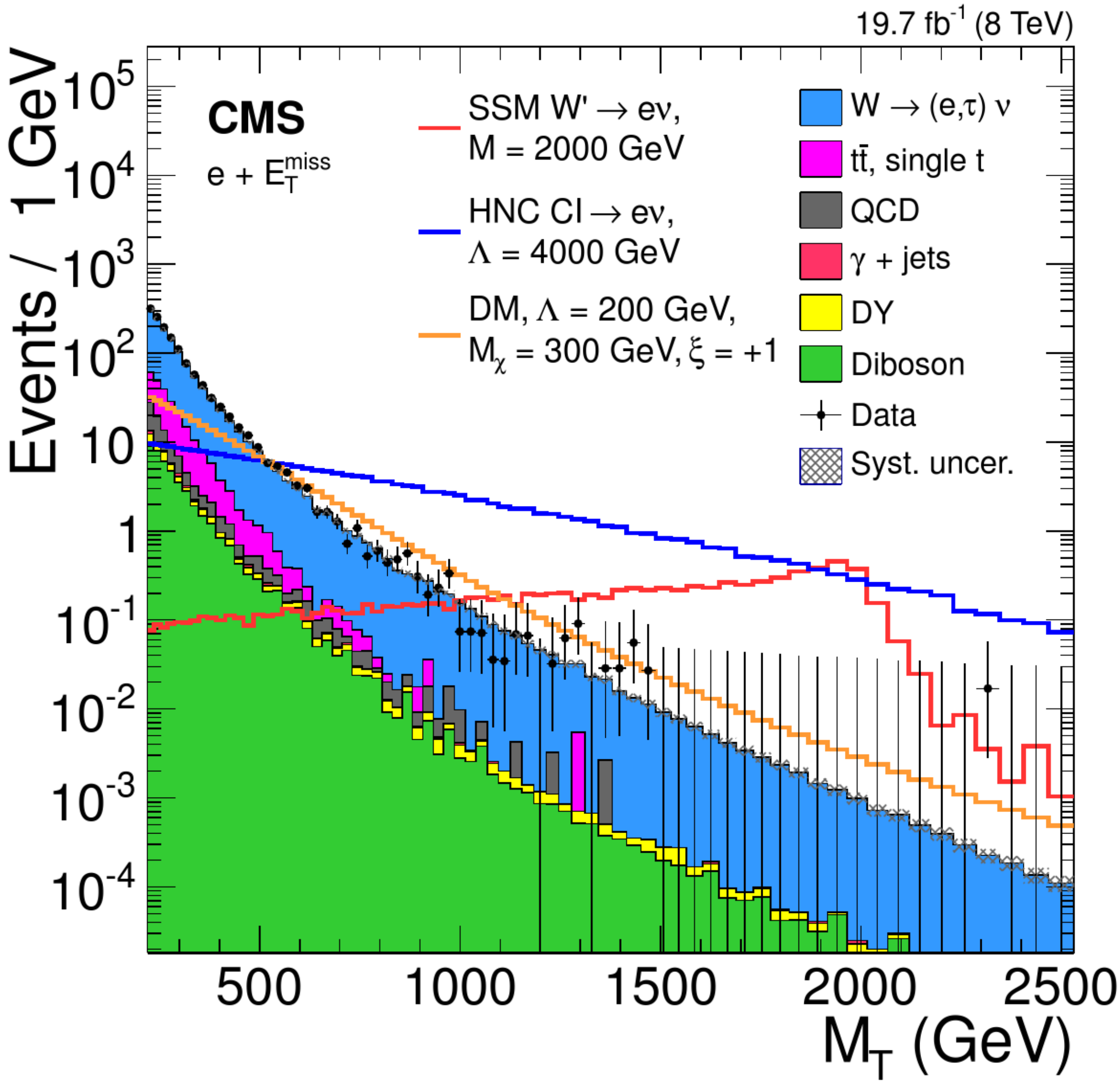

Figure 6: Searches for W', CMS, exotica

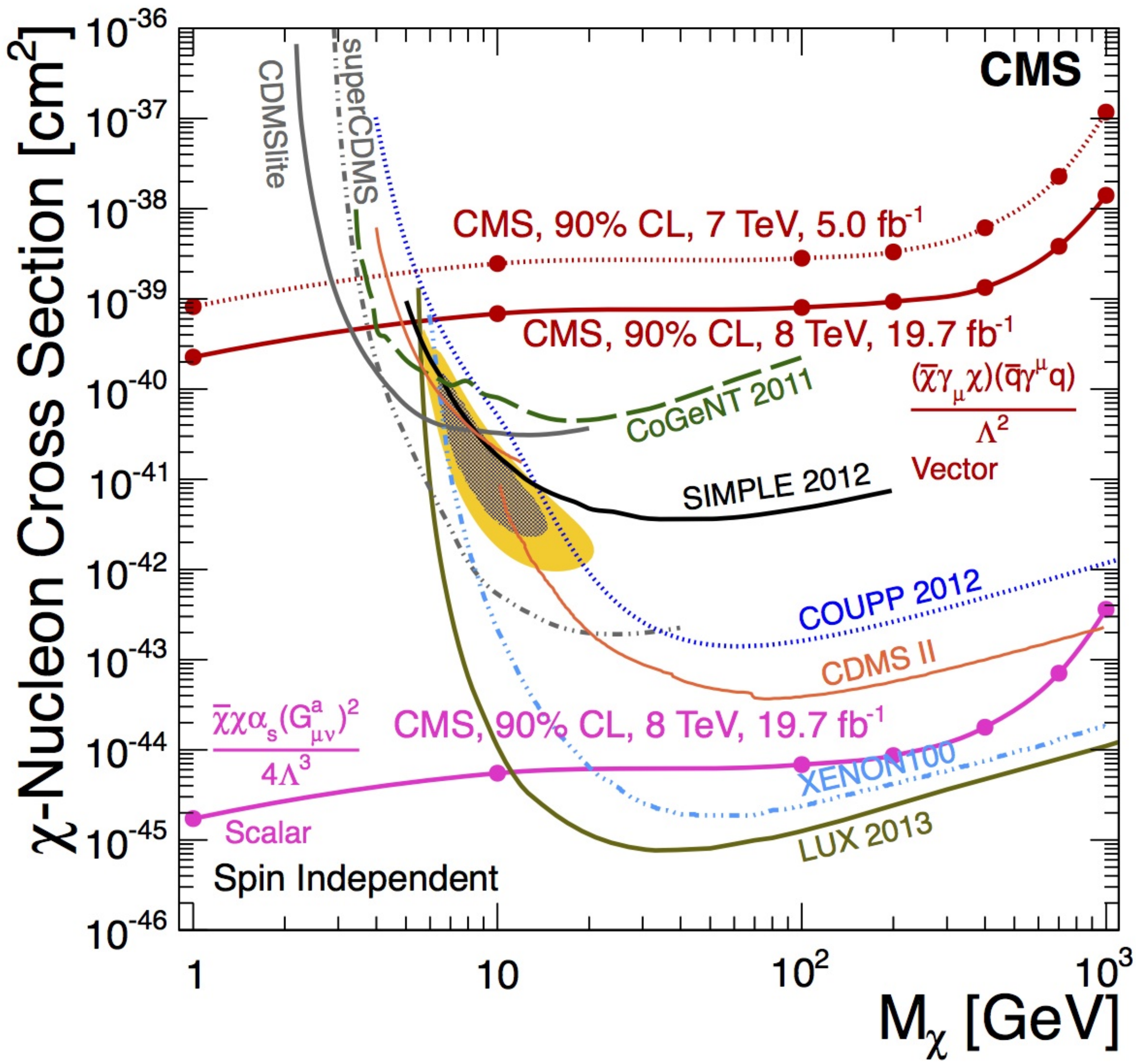

Figure 7: Monojet searches for Dark MatterCMS, exotica, monojets

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