UNIVERSITÄT
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SEIT 1386

EXPLORING THE LIMITS OF NEW PHYSICS AT THE LHC

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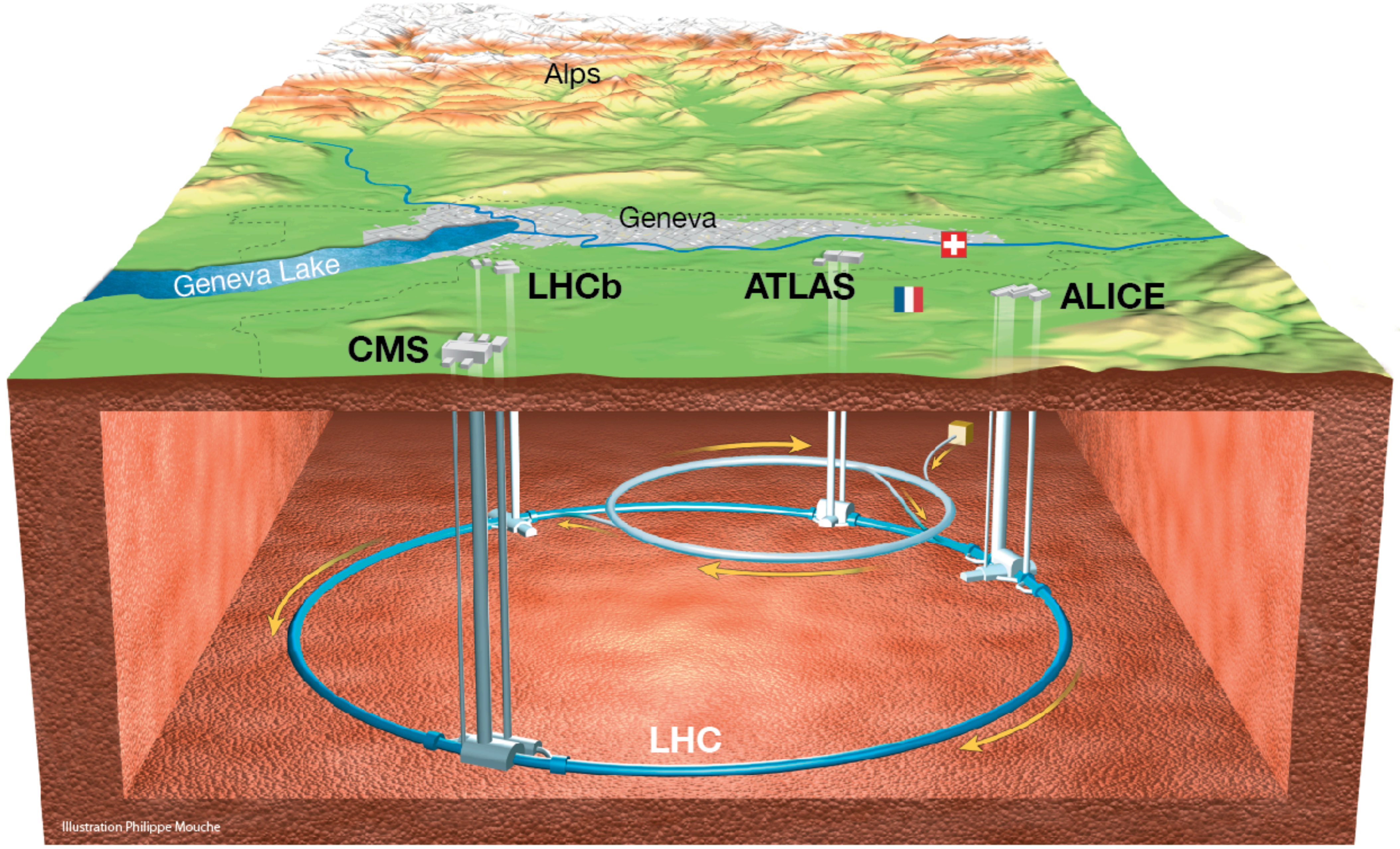
The Large Hadron Collider (LHC)

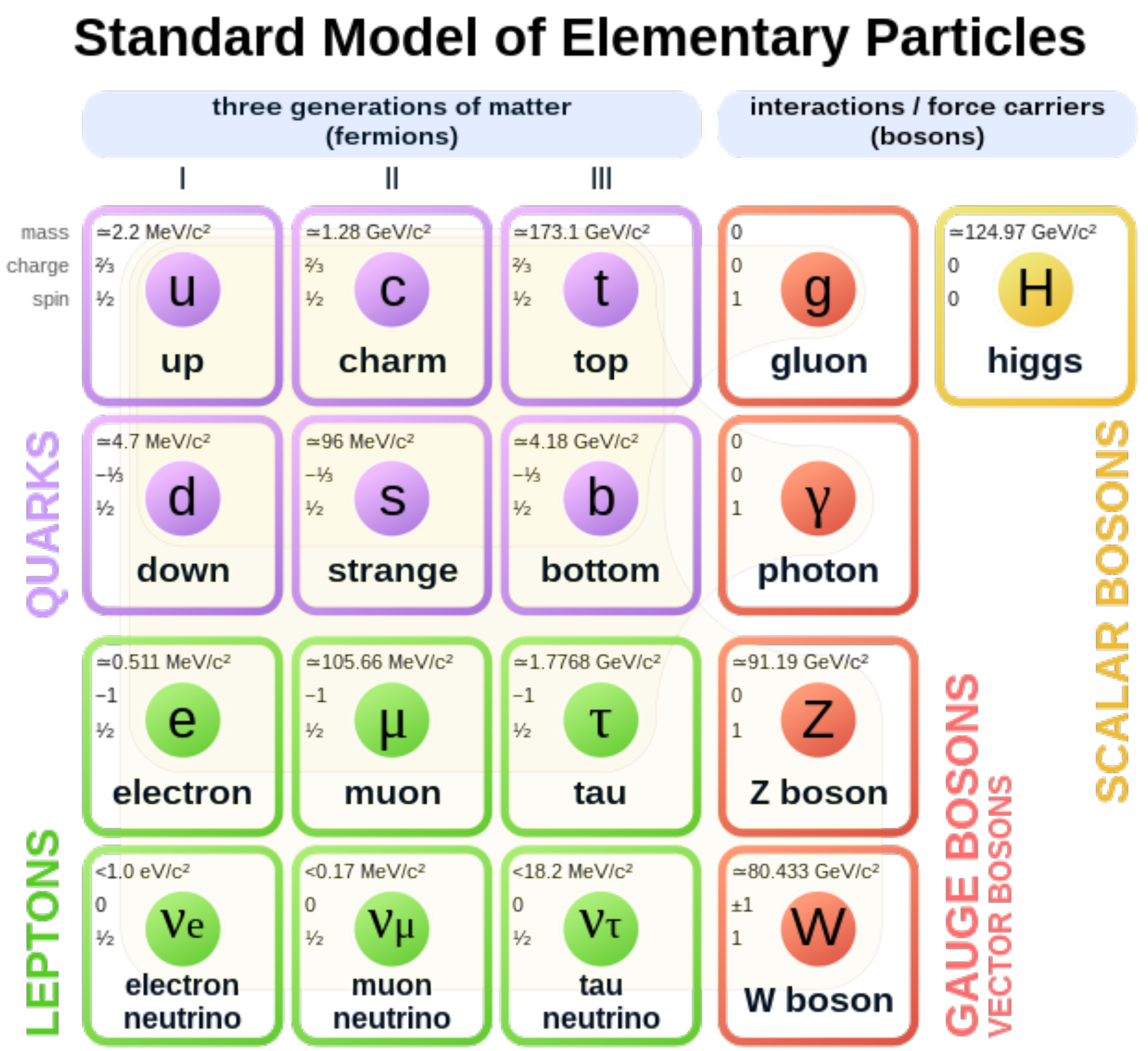
- Particle accelerator with 27km circumference
- Four different interaction points (ATLAS, CMS, LHCb, ALICE)
- Protons with energies of 6.5 TeV collide **every 25 ns** (Run 2)
  - Dataflow of order **PB/s**



Source: https://www.physi.uni-heidelberg.de/Forschung/he/ATLAS/pics-new/lhc_overview.png

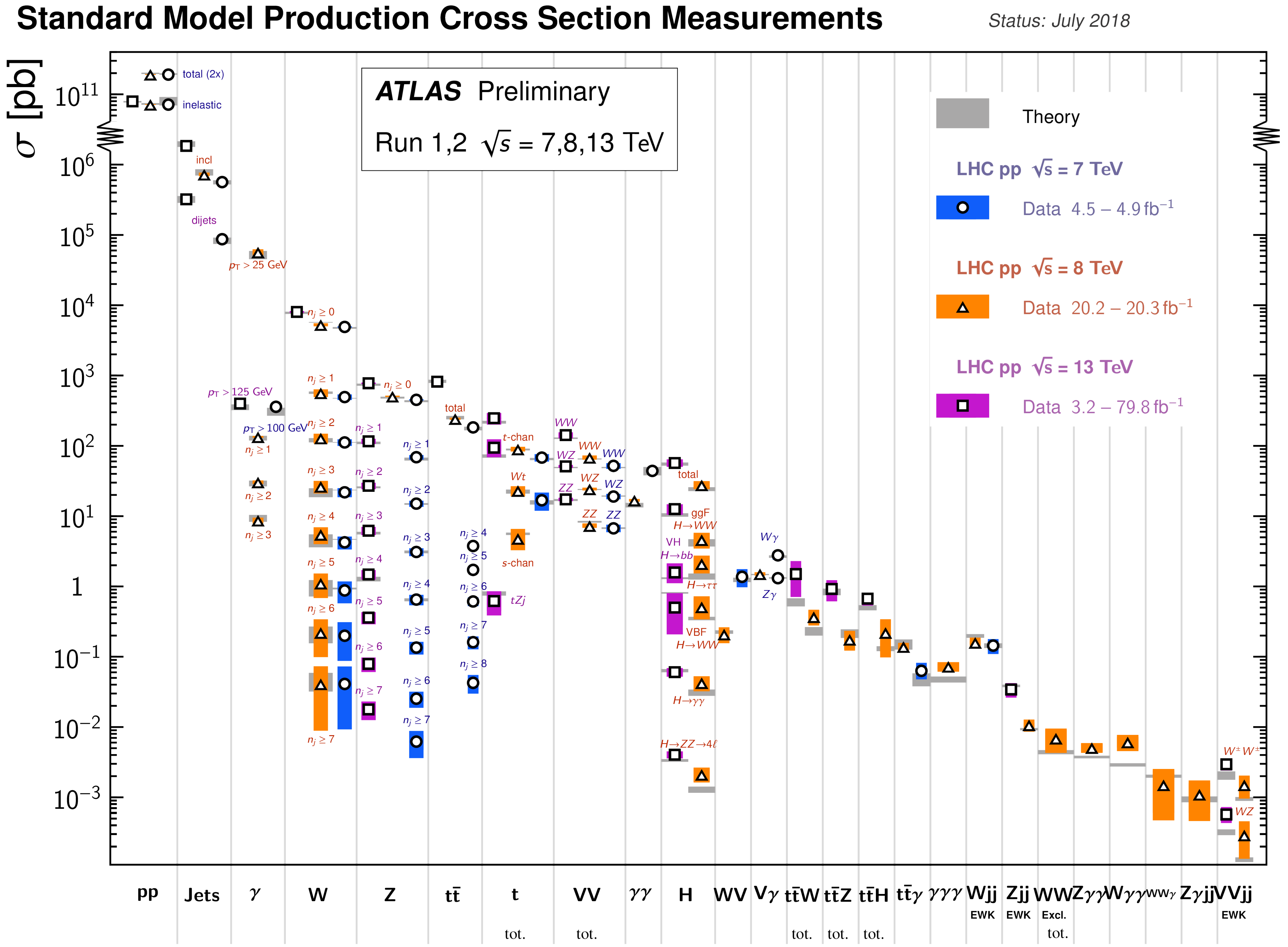
The Standard Model of Particle Physics

- ➤ Theoretical framework describing our current understanding of particle physics
- ➤ Experimental discovery of the Higgs boson at the LHC ‘completed’ the Standard Model
- ➤ Shows **great success** at describing large number of observations



The Standard Model of Particle Physics

➤ **Impressive agreement** for large number of different measurements

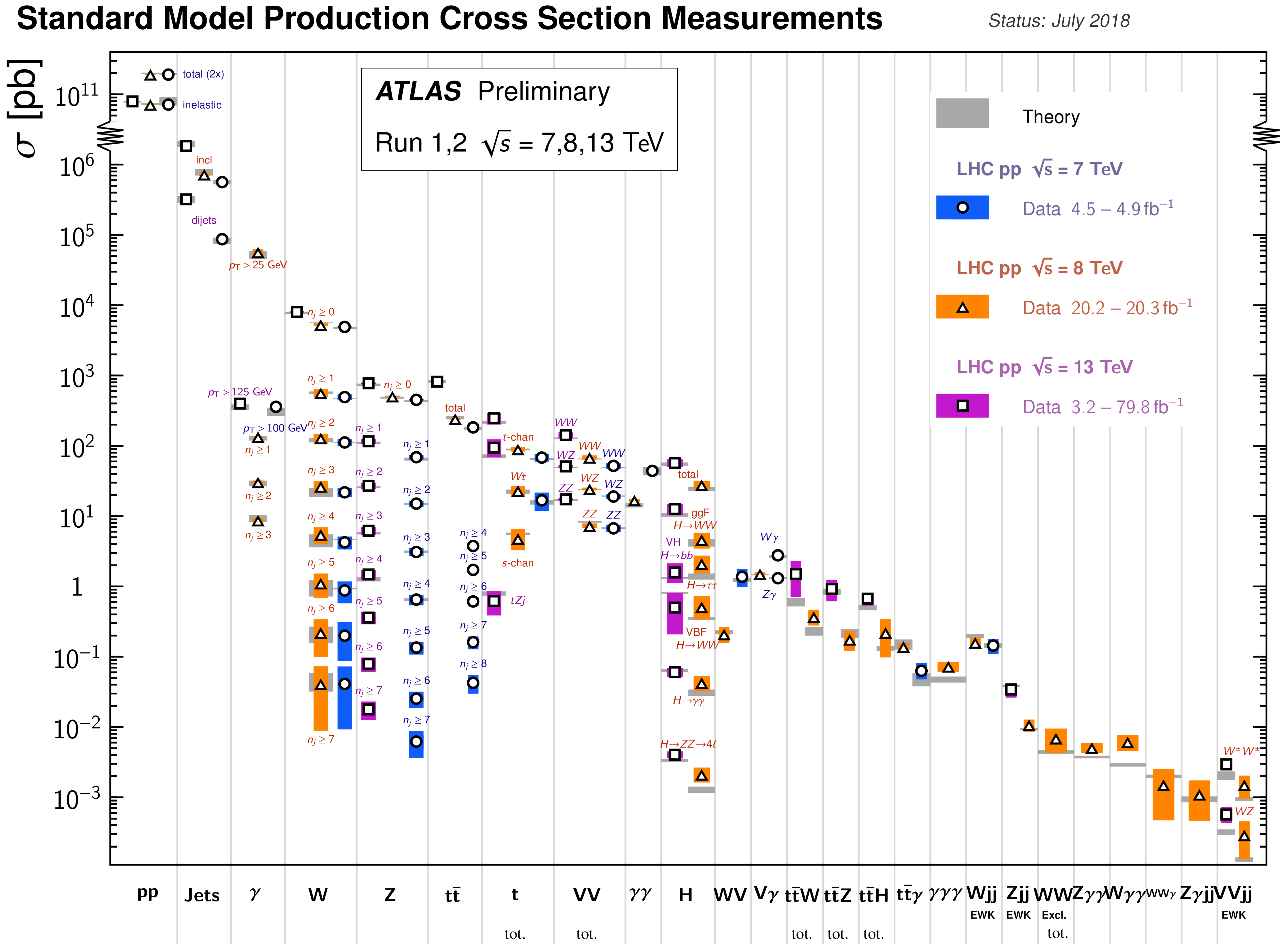


ATL-PHYS PUB-2022-009

The Standard Model of Particle Physics

- ➤ **Impressive agreement** for large number of different measurements

- ➤ **However:** Large number of unanswered questions
  - ➤ Dark matter/energy
  - ➤ Matter/Antimatter asymmetry
  - ➤ Neutrino masses
  - ➤ Strong CP problem



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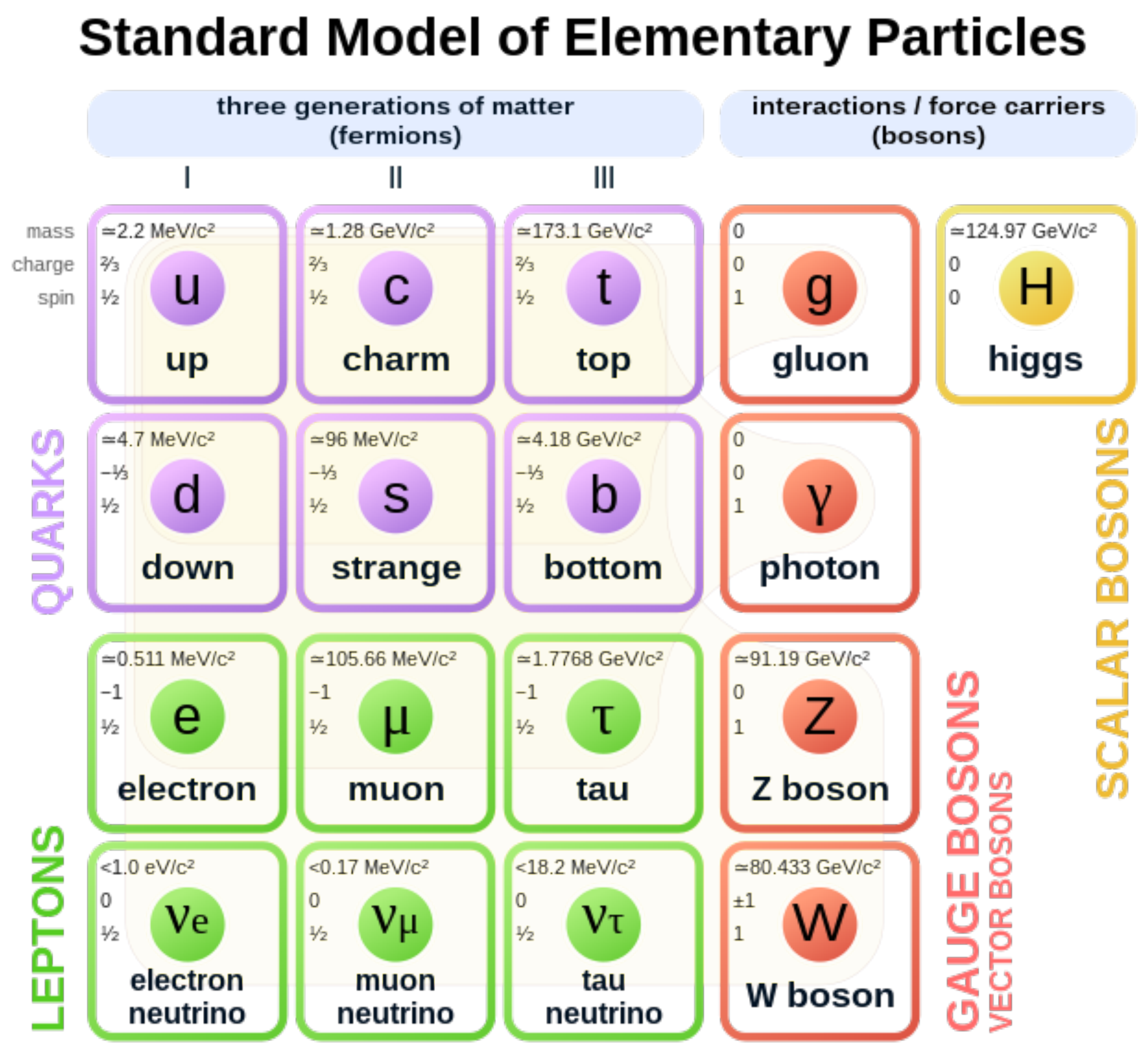
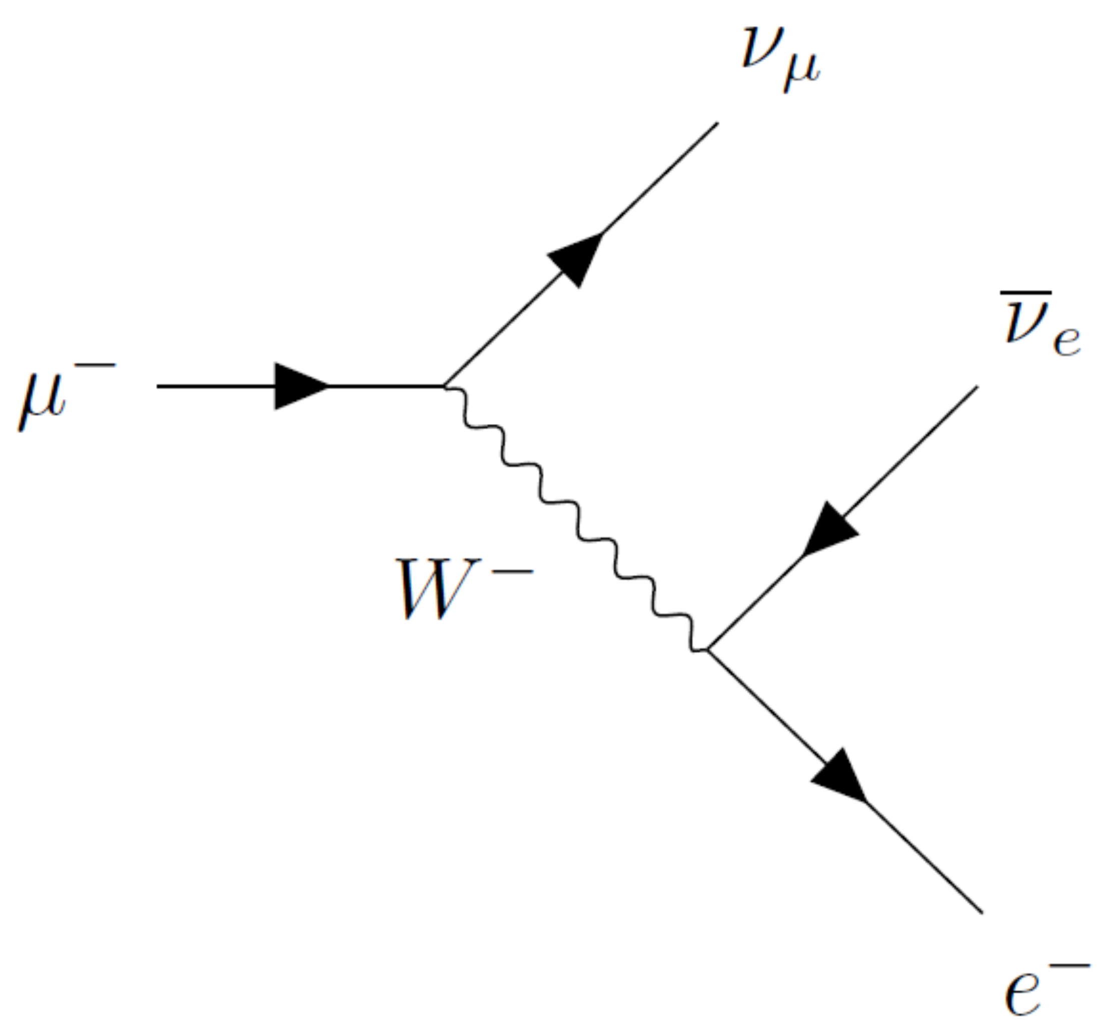
Going beyond the Standard Model

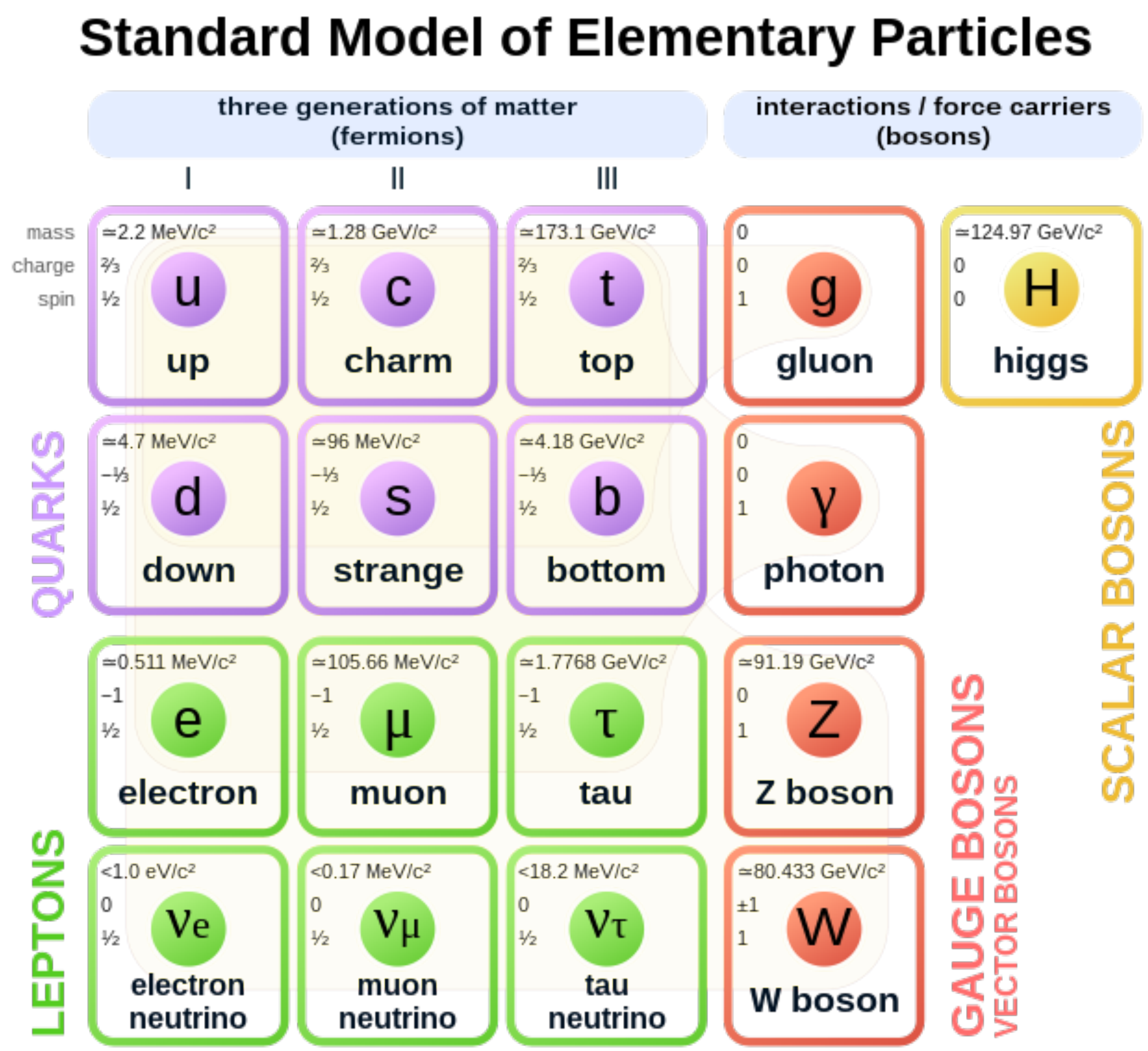
- **Idea:** Introduce additional new particles (axions, sterile neutrinos, supersymmetry)
- **Problem:** Countless number of possible models to test individually
- **Solution:** Use a model agnostic approach to look for new physics



Standard Model Effective Field Theory

- **Solution:** Extend the SM via a so-called Effective Field Theory approach
  - Consider the decay: $\mu^- \longrightarrow e^- \nu_e \nu_\mu$





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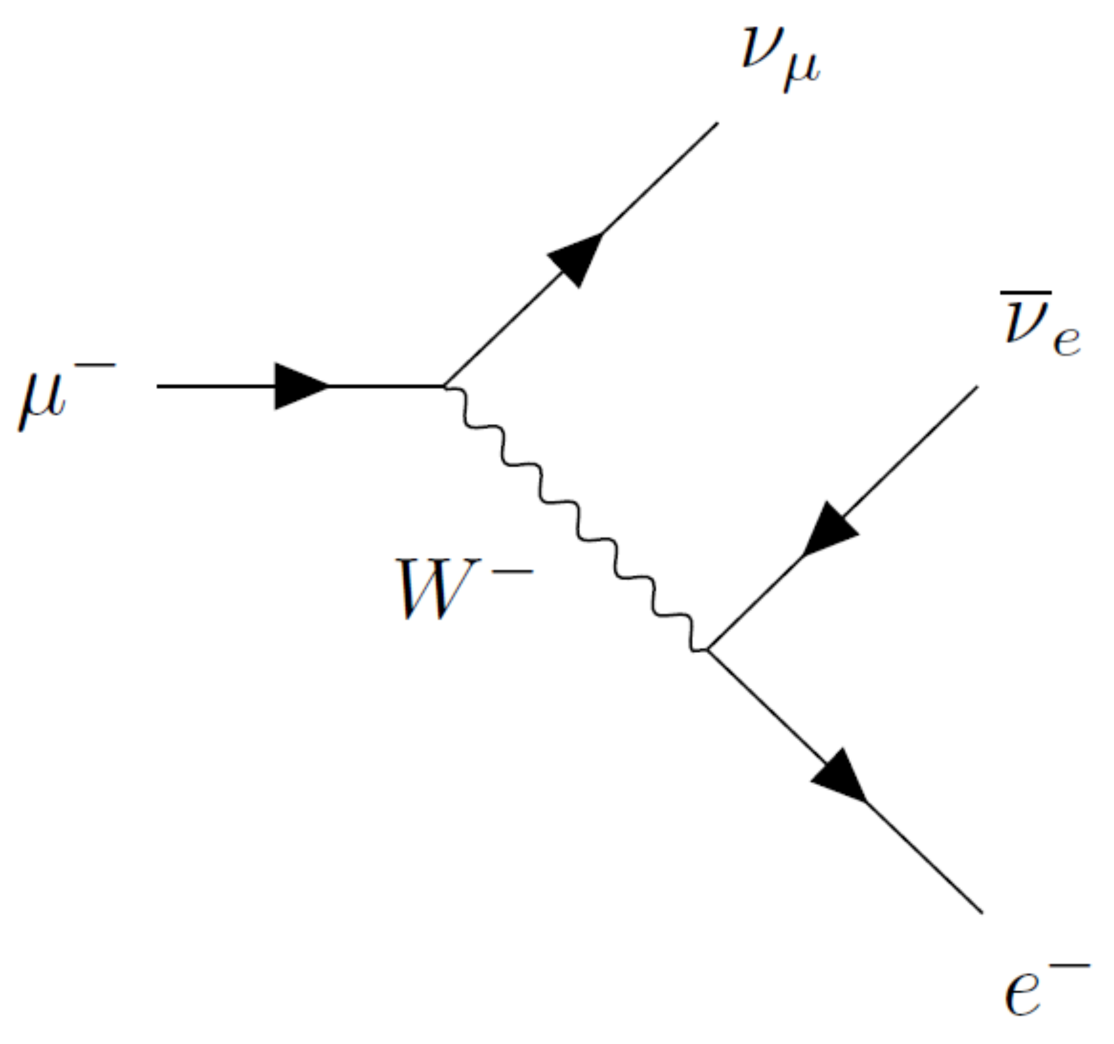

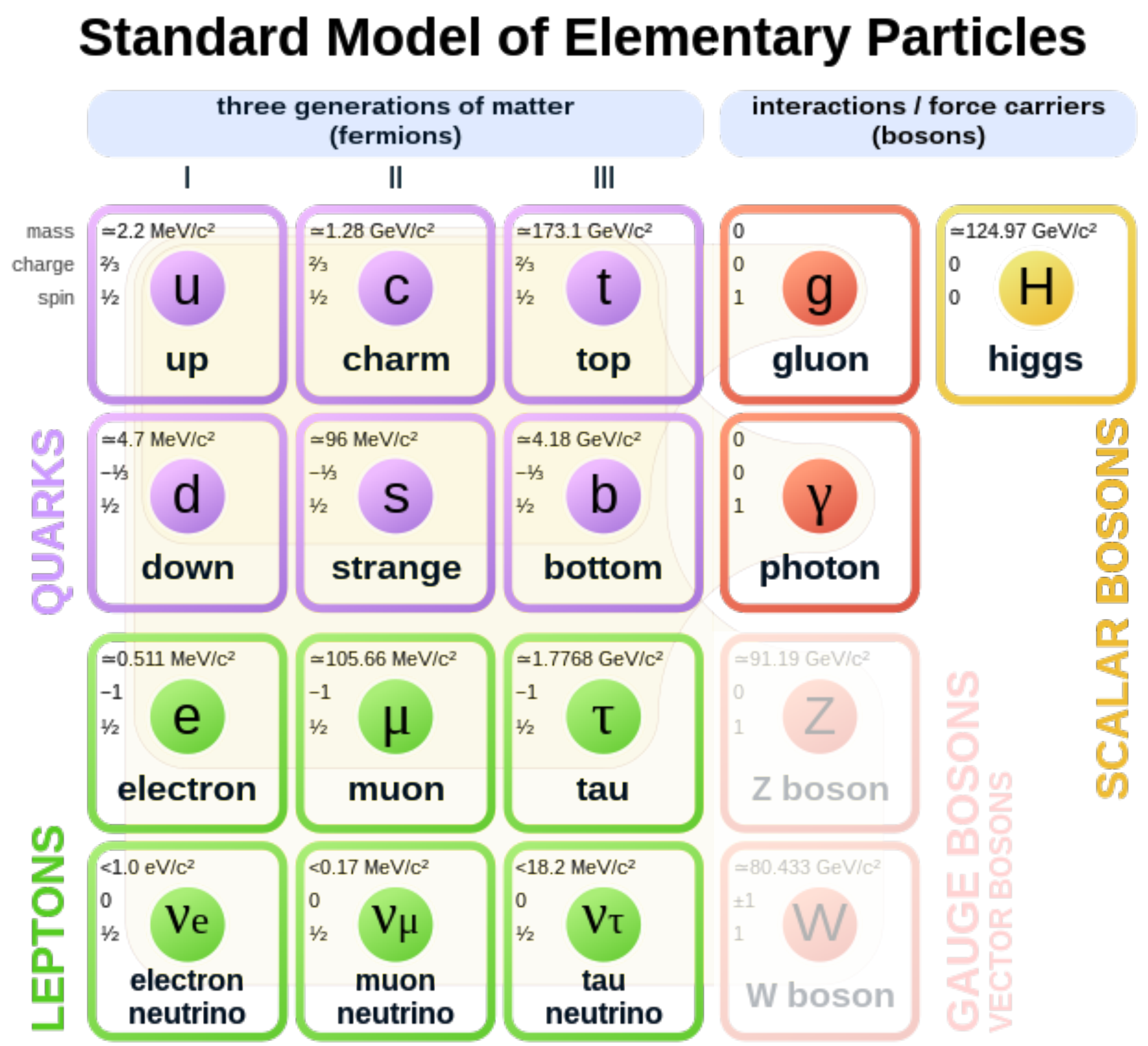

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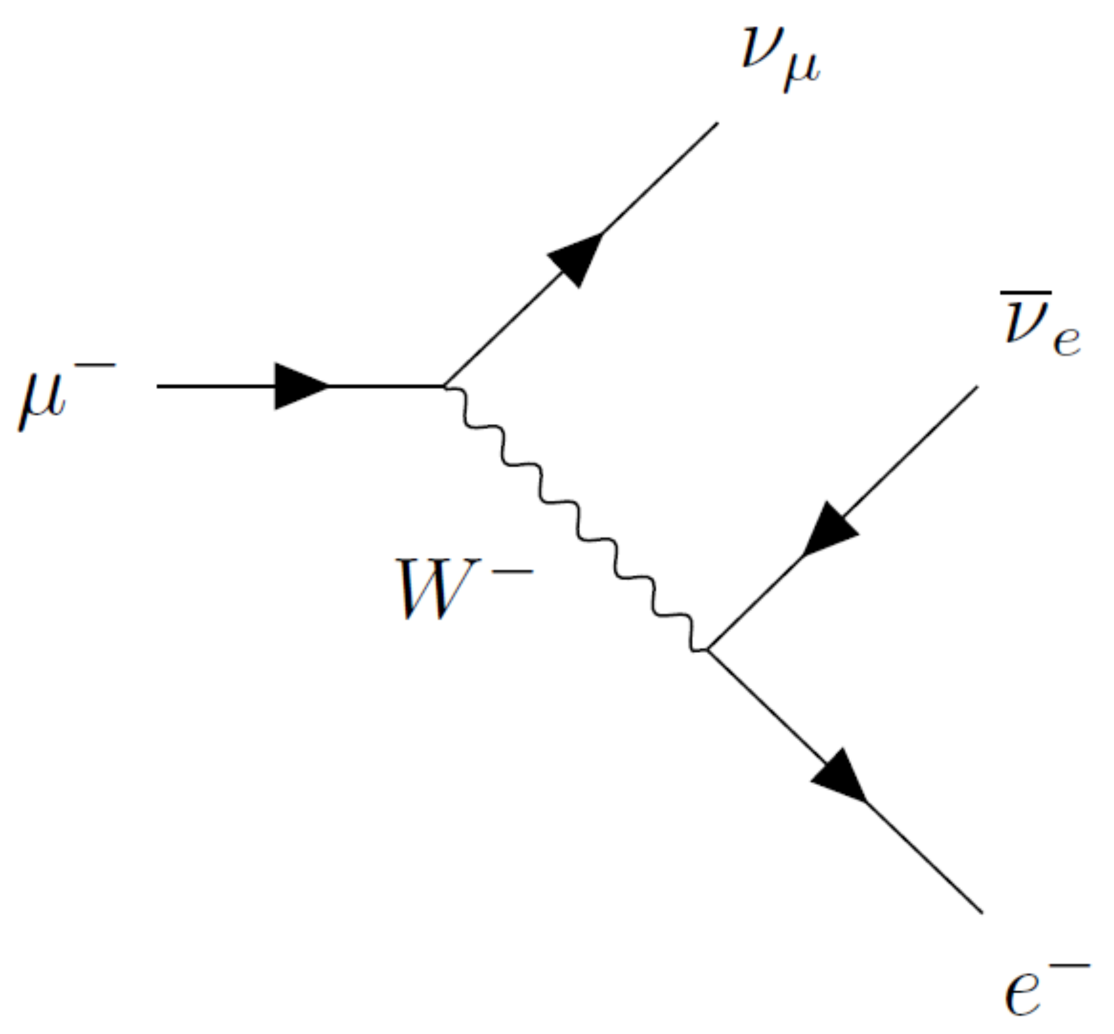
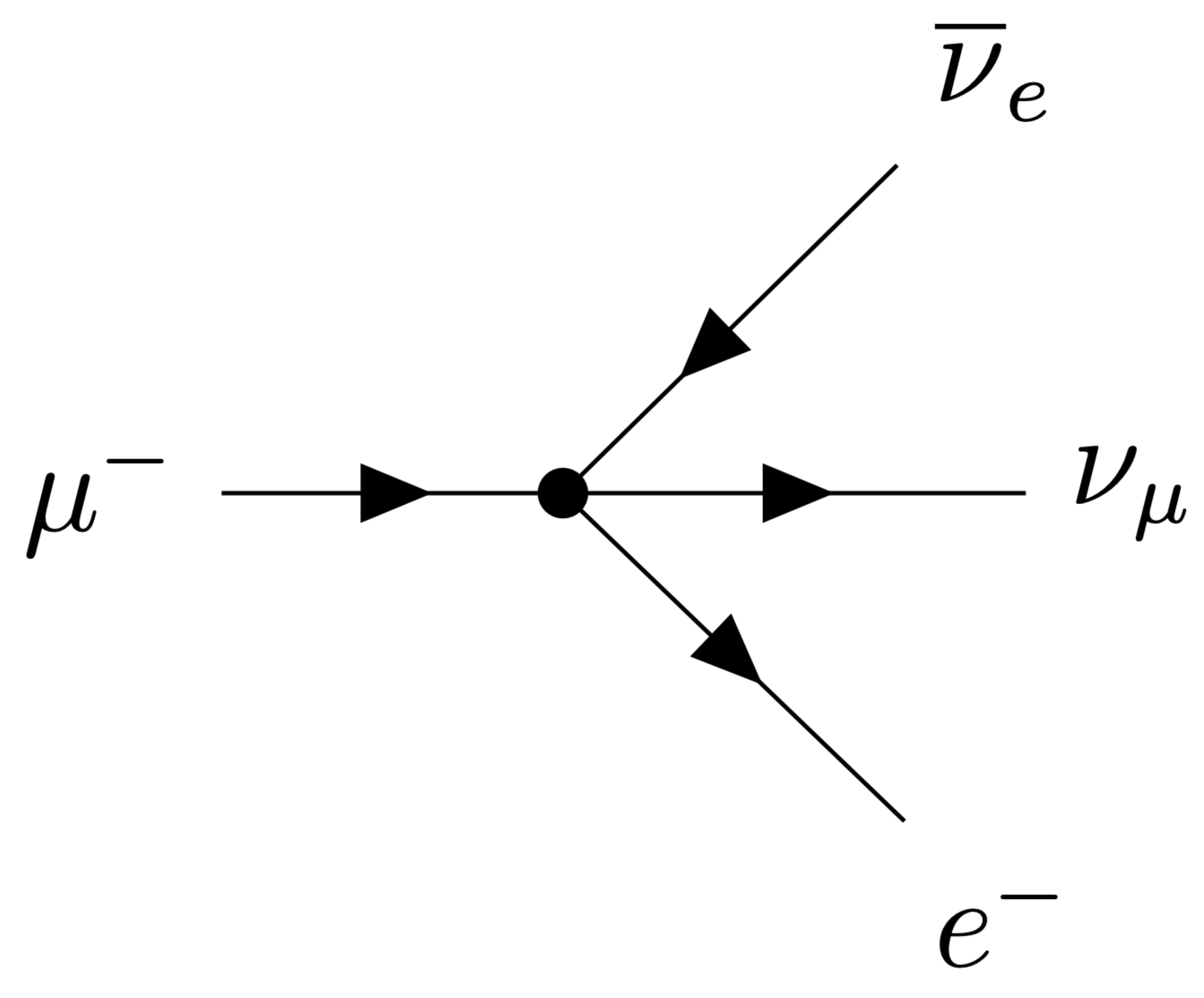
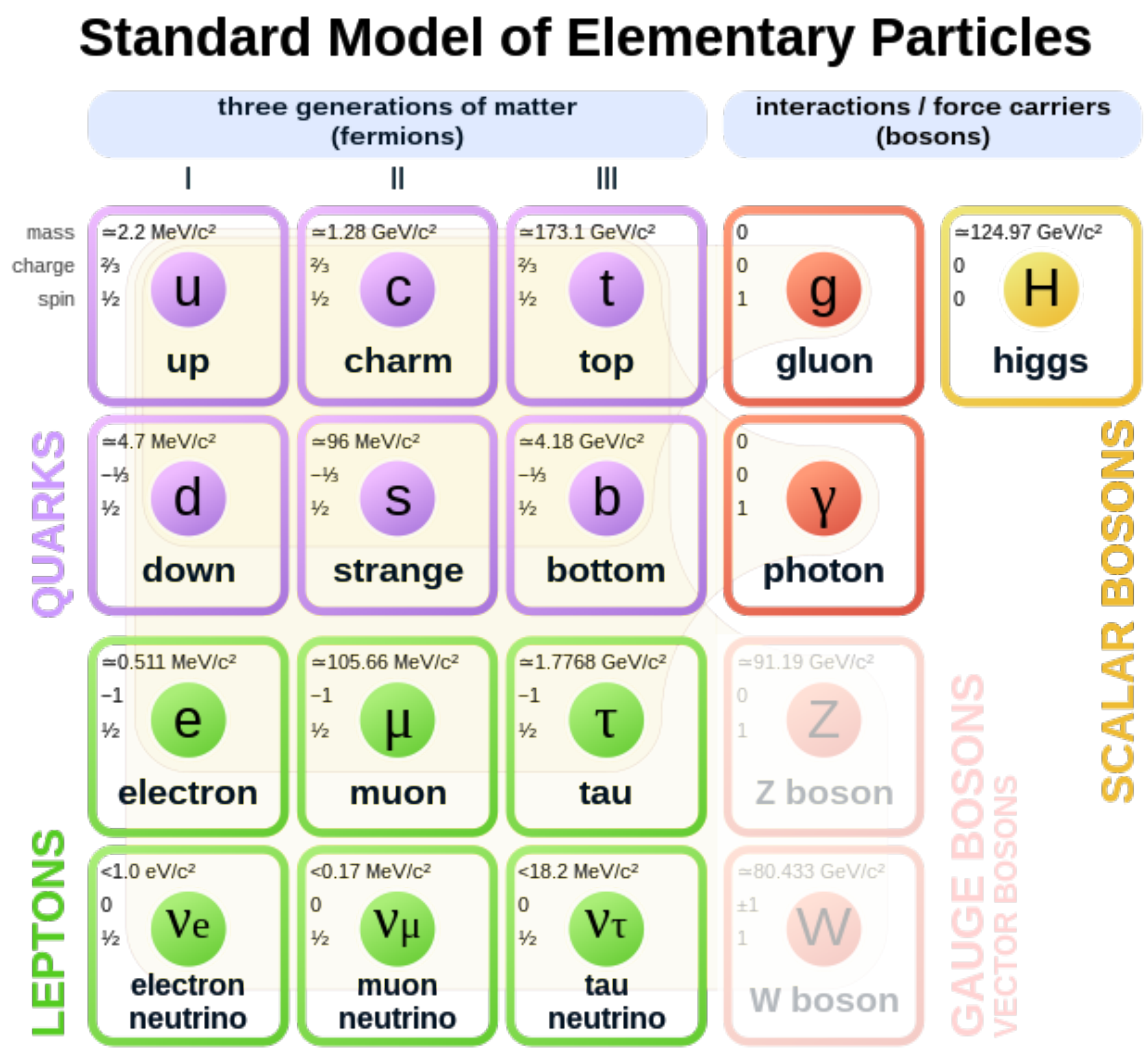
Decreasing energy







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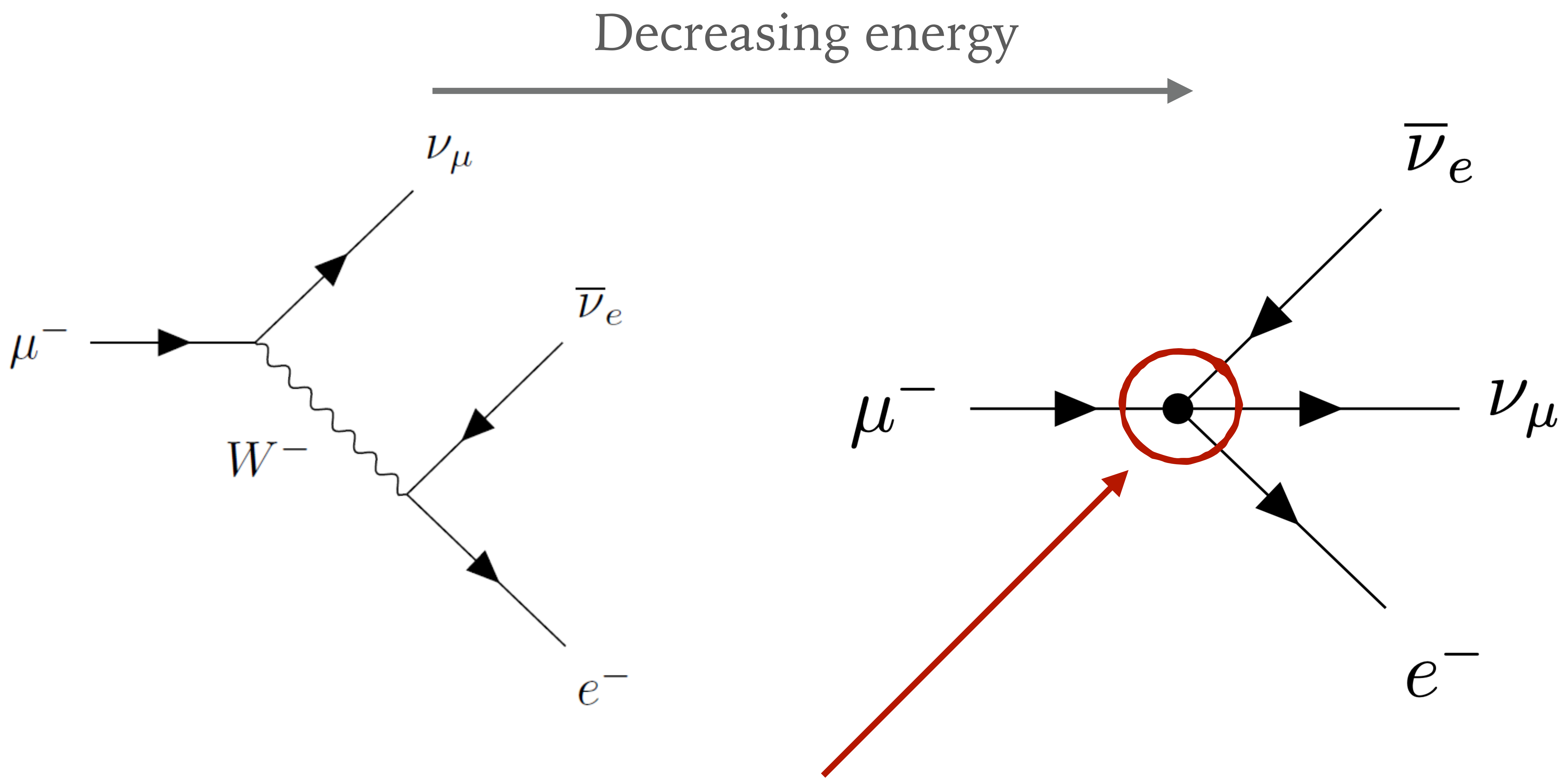
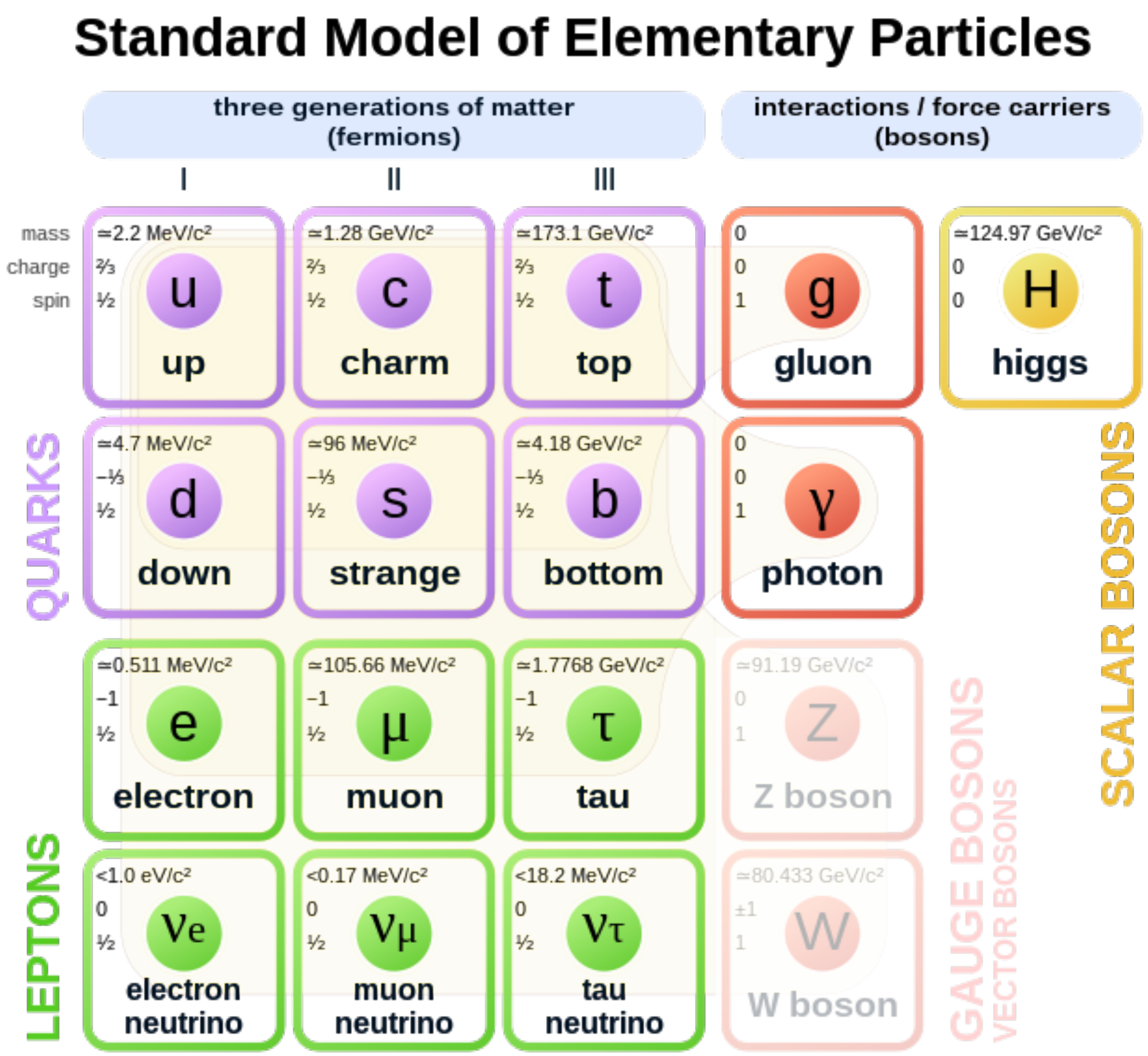


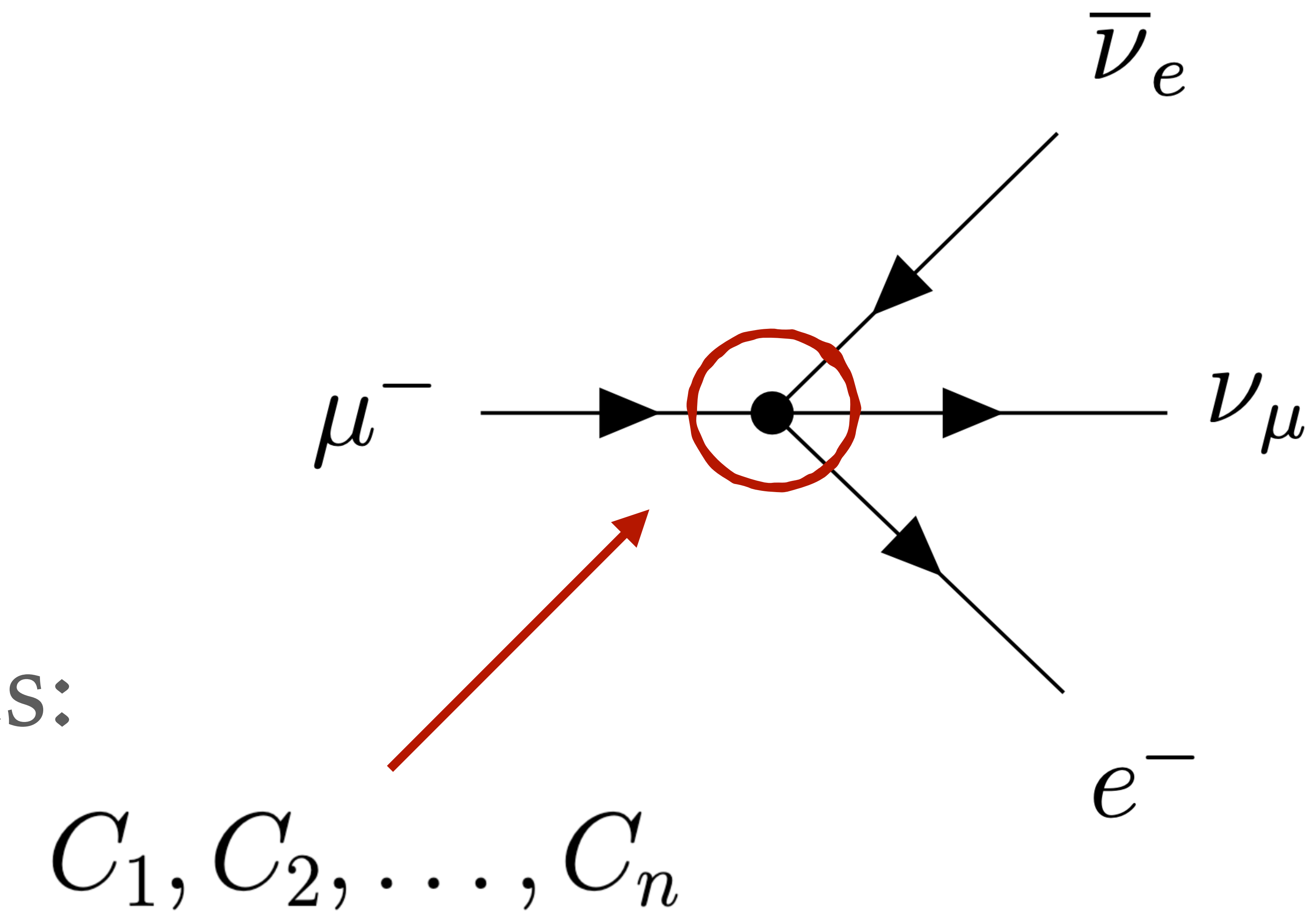


The interesting physics happening here cannot be resolved

Standard Model Effective Field Theory

- SMEFT framework **parametrizes the new physics** in such vertices

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_{d=5}^{n} \frac{C_i^{(d)}}{\Lambda^{d-4}} O_i^{(d)}$$



- We use these parameters to put limits on new physics:
  - **Large number** of possible contributions
  - Contributions depend on **processes considered**

- **Goal:** Put constraints on these contributions

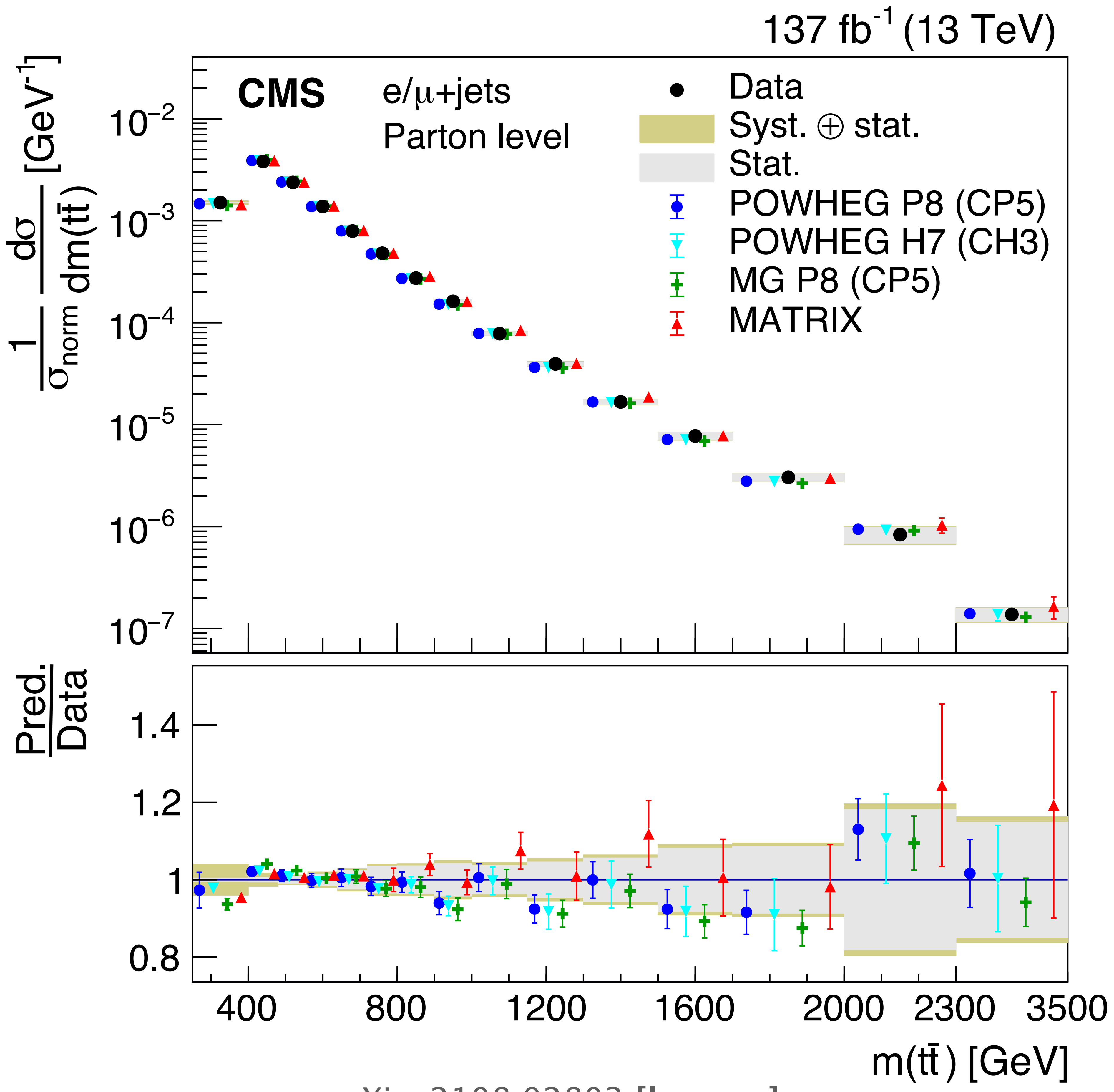
Performing statistical analyses

- Compute the likelihood that given data matches theory

$$\mathcal{L}_{excl} = \text{Pois}(d|p(\alpha_n, \theta_i, b))\text{Pois}(b_{CR}|b\,k)\prod_i \mathcal{C}(\theta_i, \sigma_i)$$

- We use LHC data published by both the ATLAS and CMS experiments
  - For results shown here Higgs, Di-Boson and electroweak data (LEP); $\sim$ 400 datapoints
- Sufficiently **accurate theory predictions** are necessary
  - This is where **NEMO** comes in

Computing theory predictions

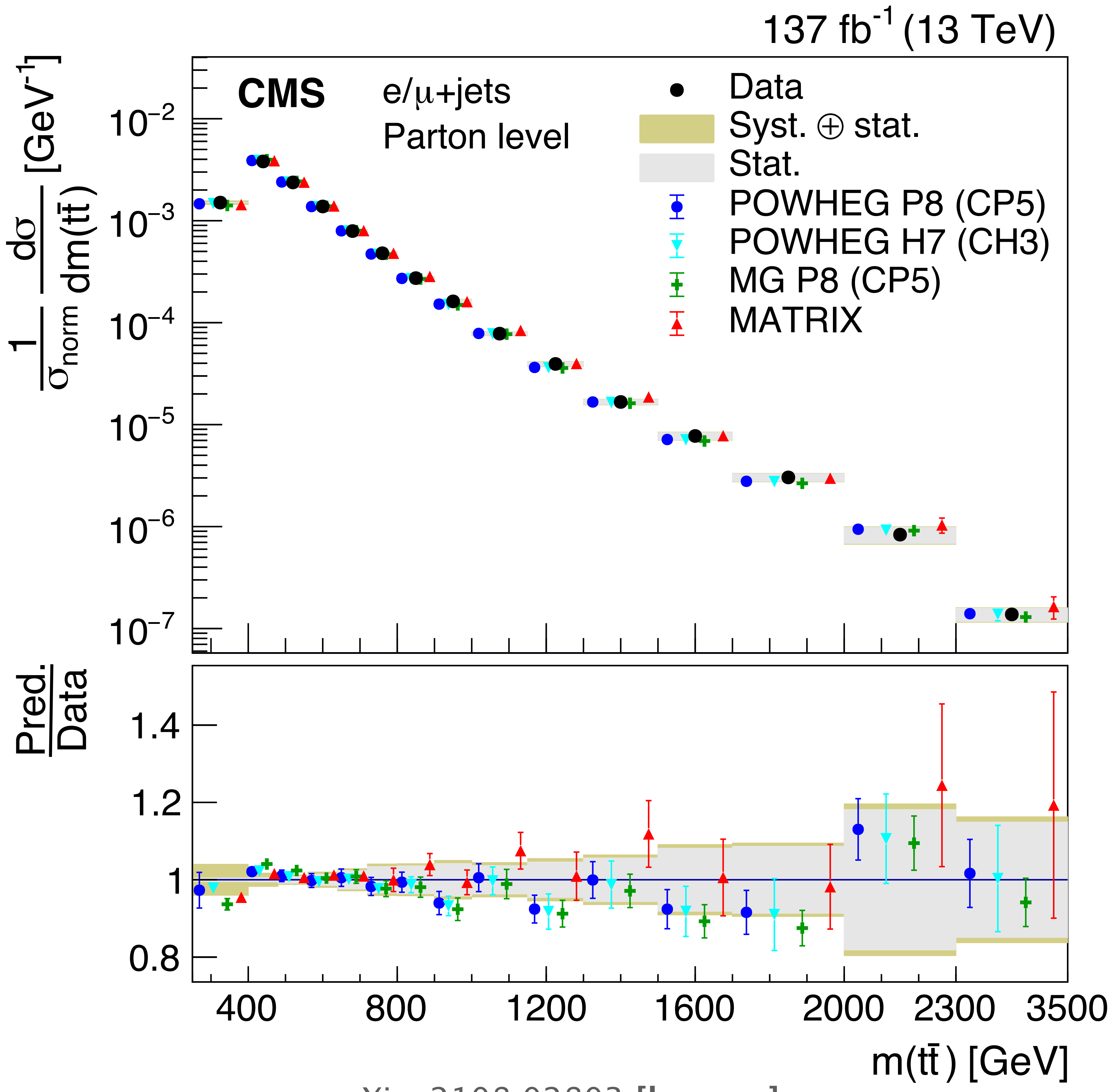


arXiv: 2108.02803 [hep-ex]

Credit: Stefan Hoche

➤ Analyses require computation of **theory predictions**

Computing theory predictions



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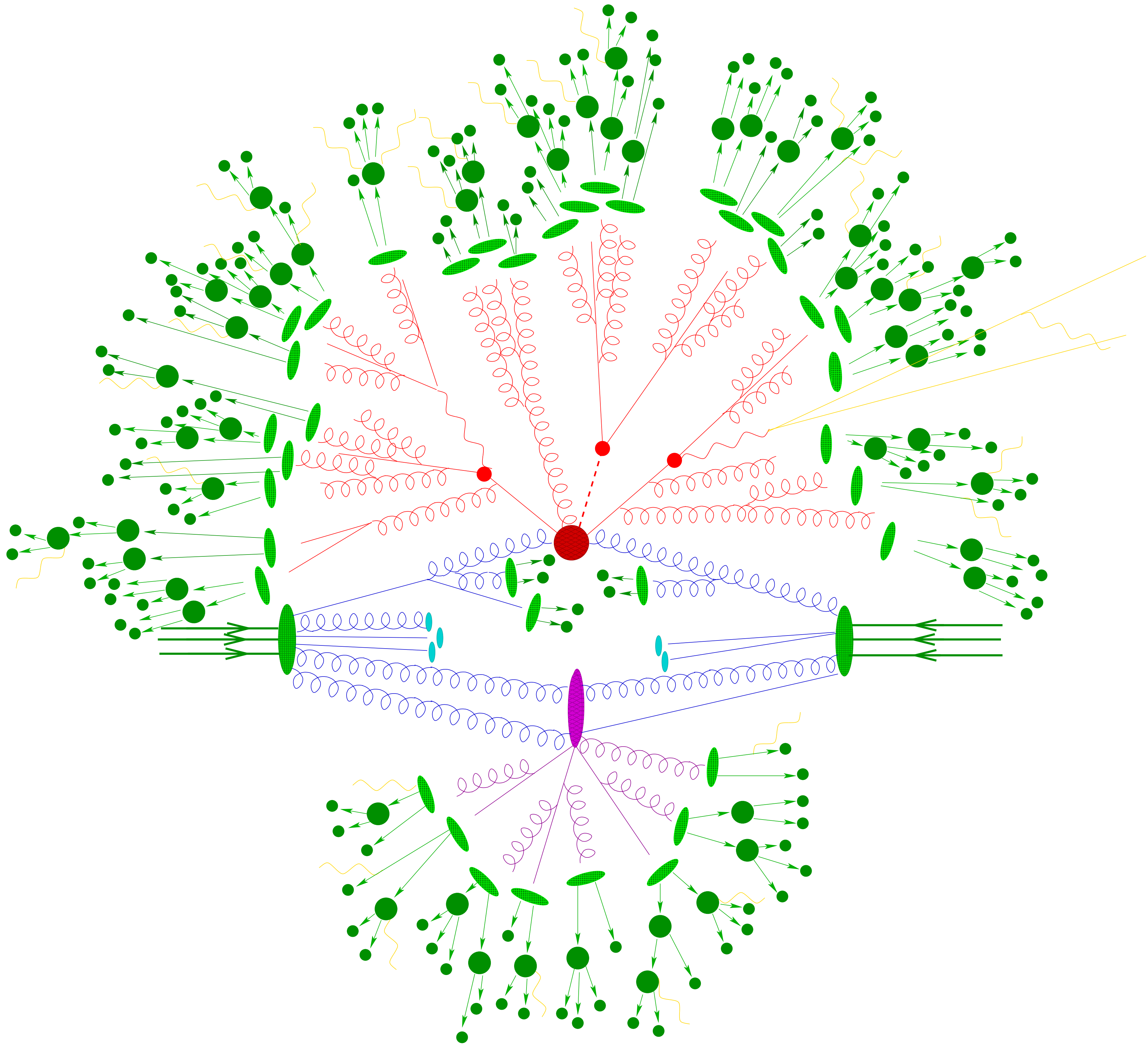

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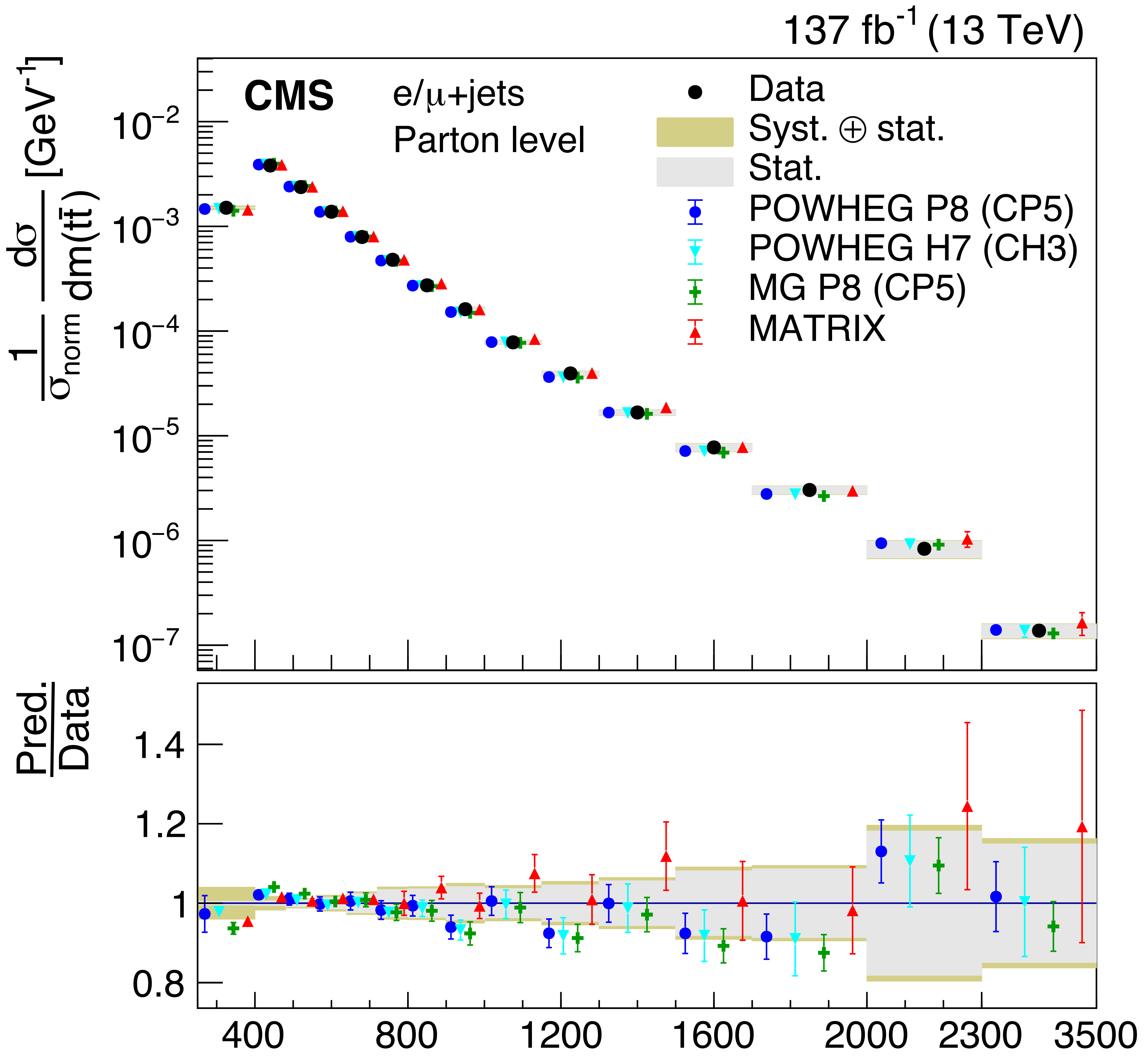
- Analyses require computation of **complex theory predictions**

Computing theory predictions



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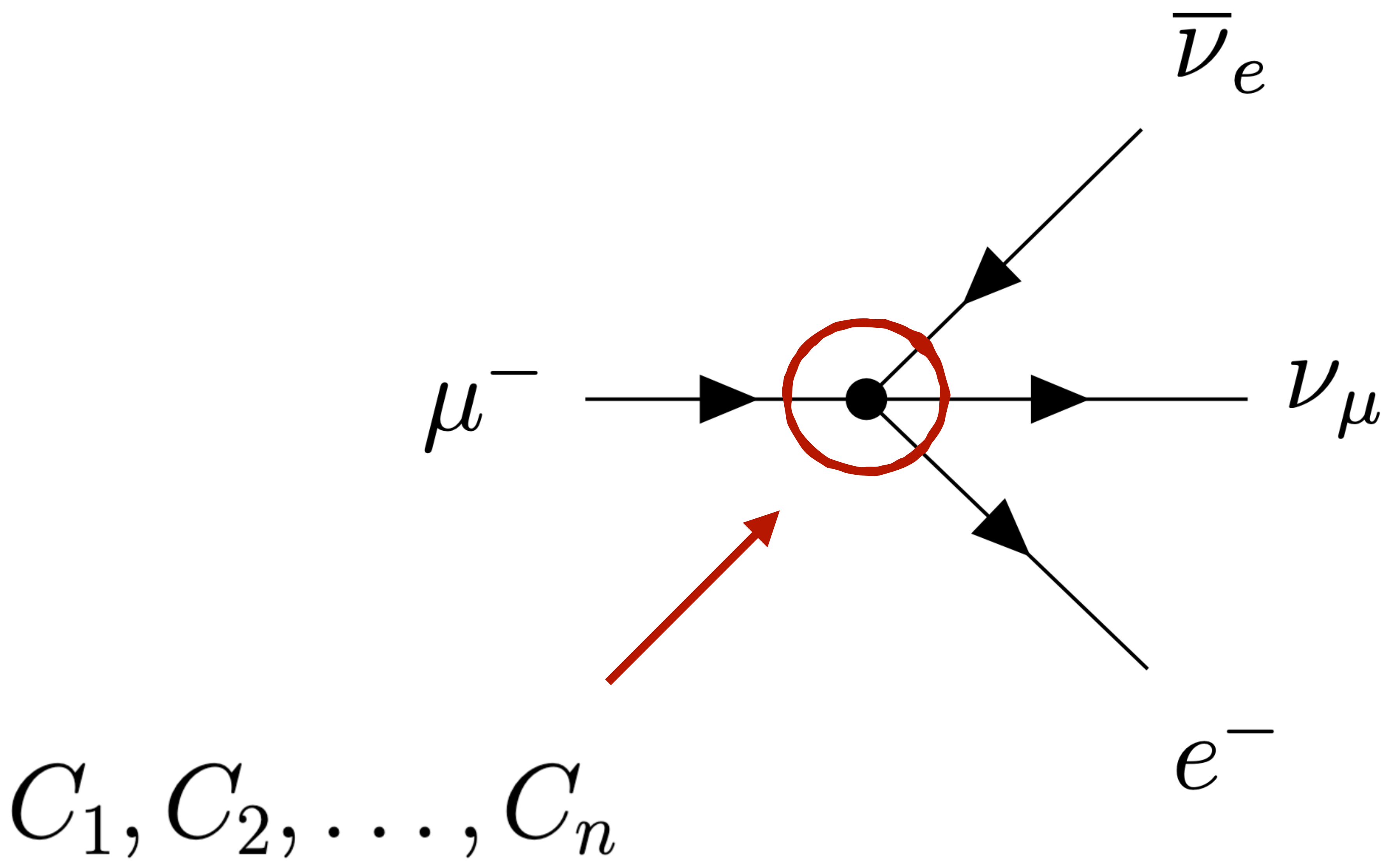
➤ Earlier Example: $\mu^- \longrightarrow e^- \nu_e \nu_\mu$



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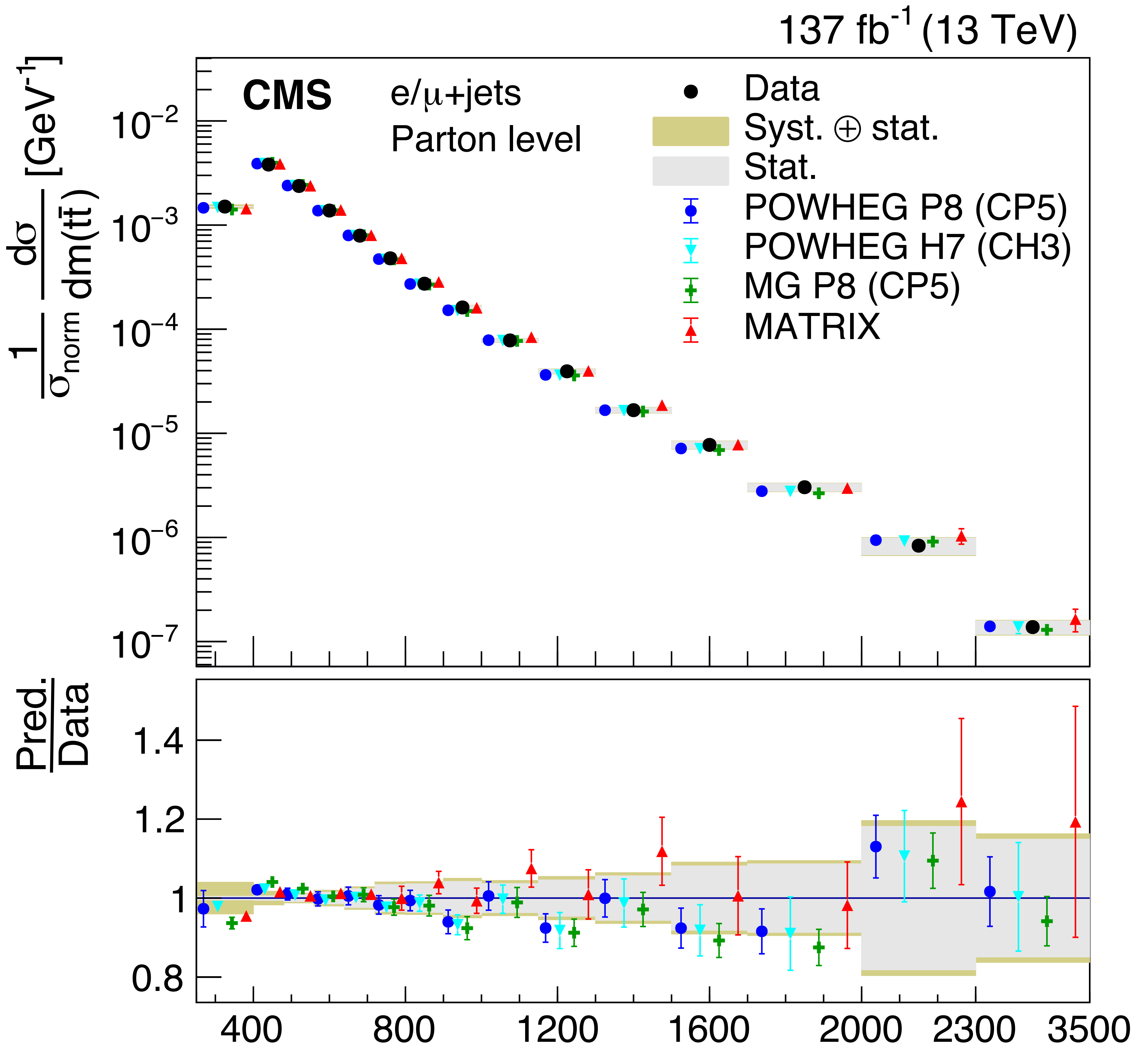

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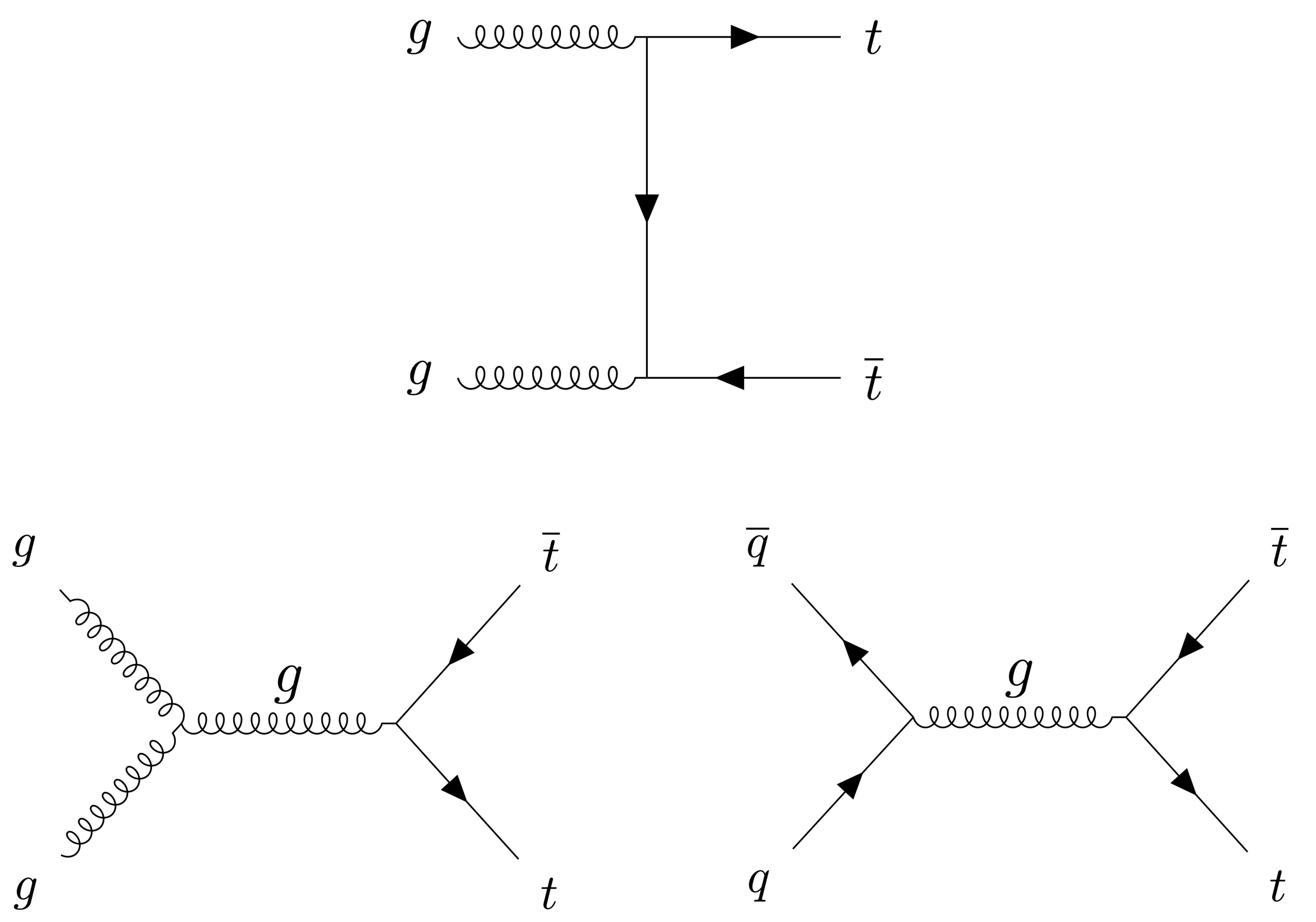
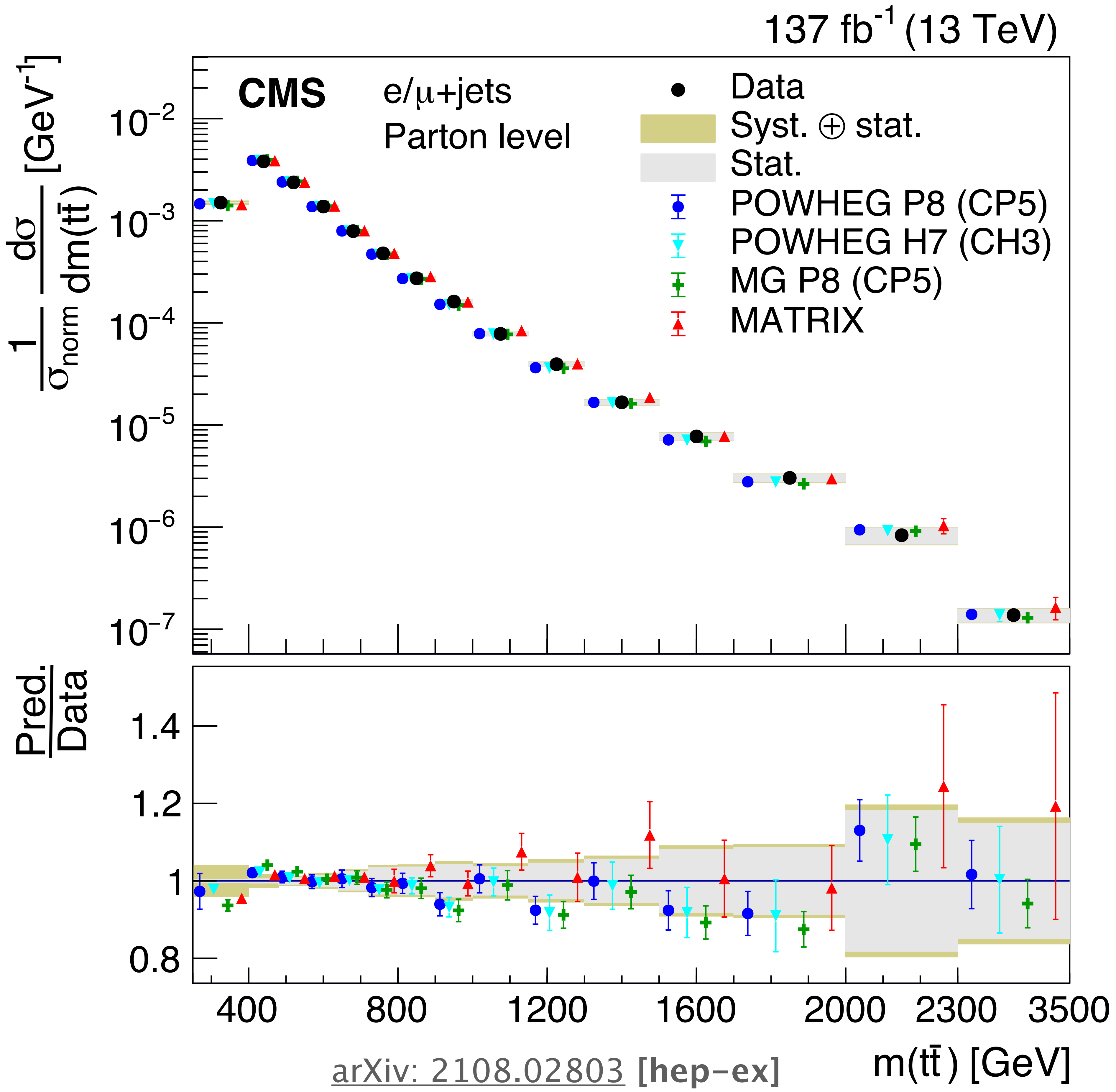
➤ For the measurement shown:



Computing theory predictions



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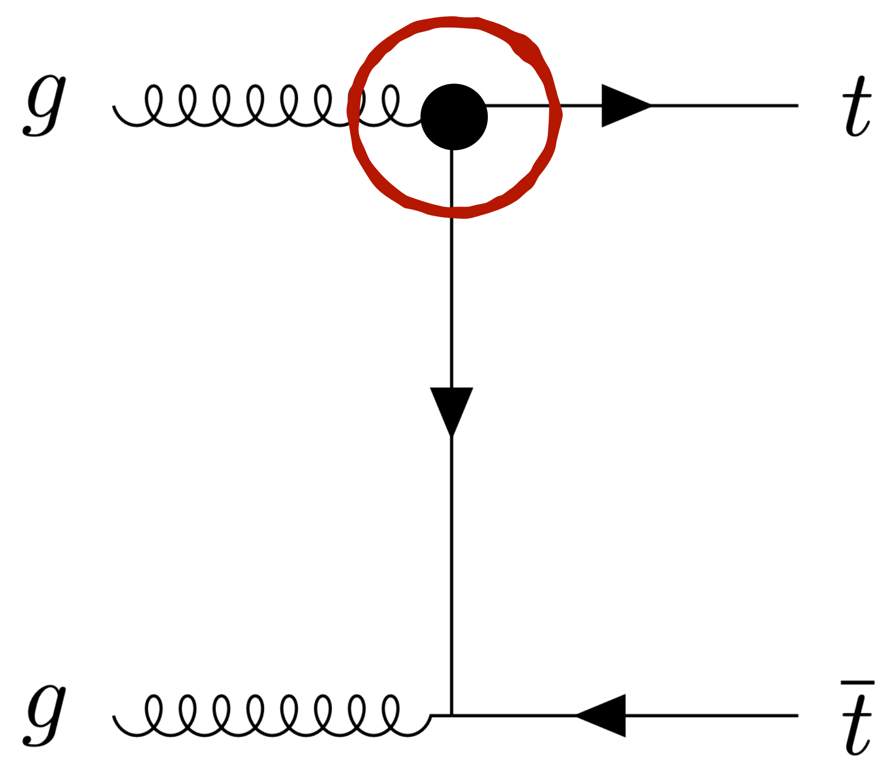
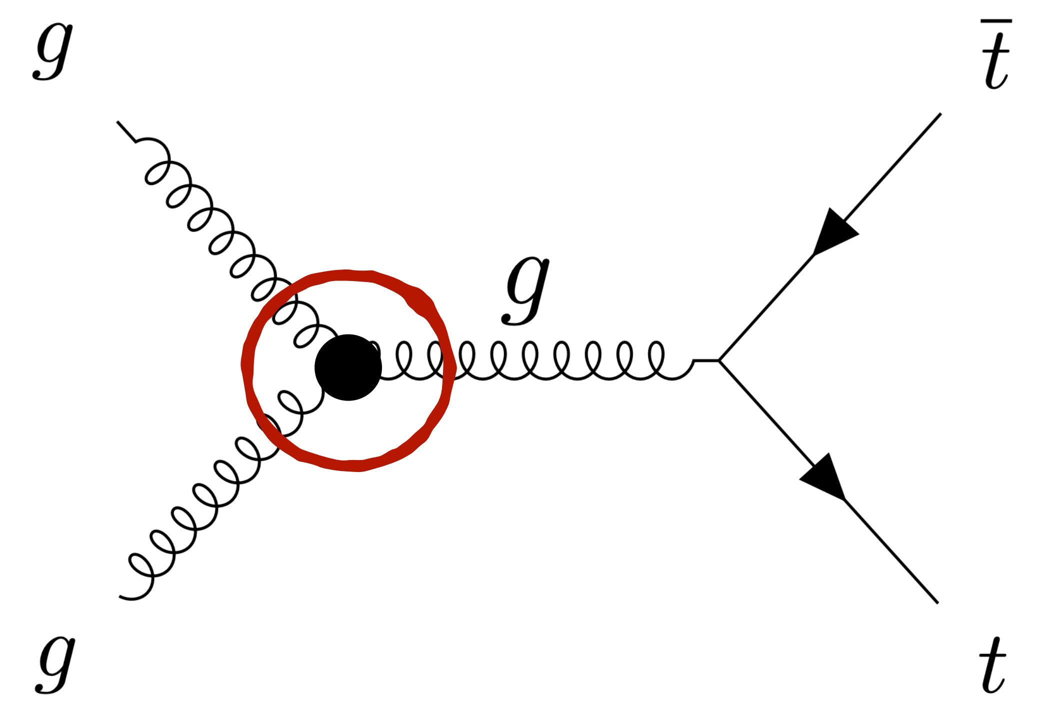
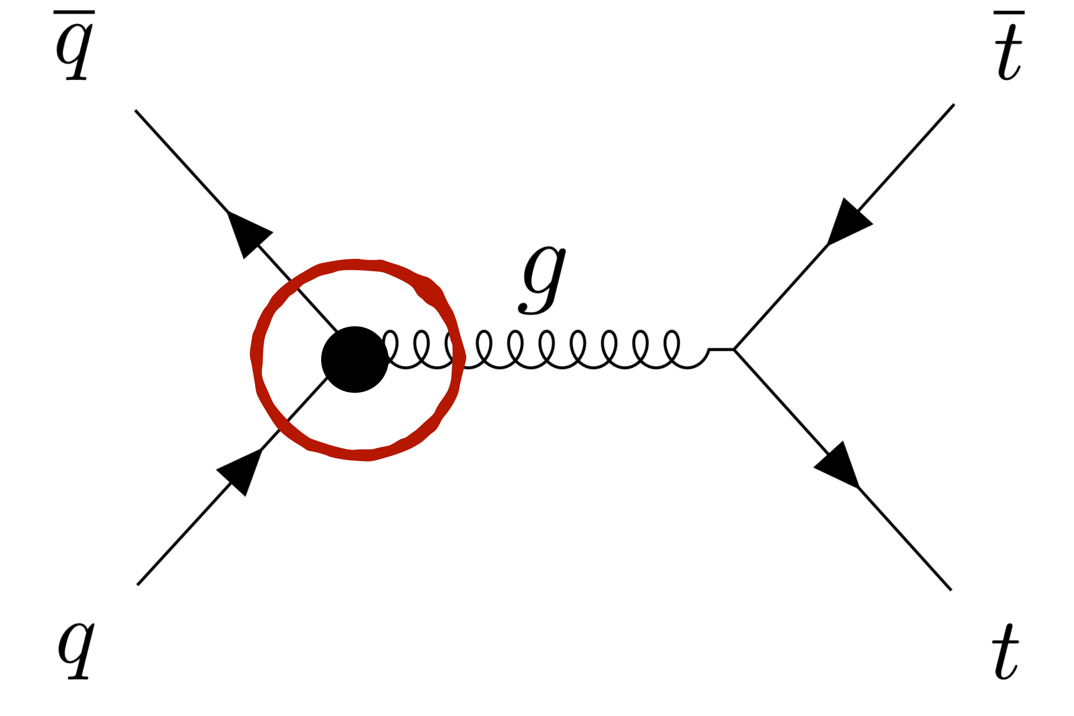


+ more





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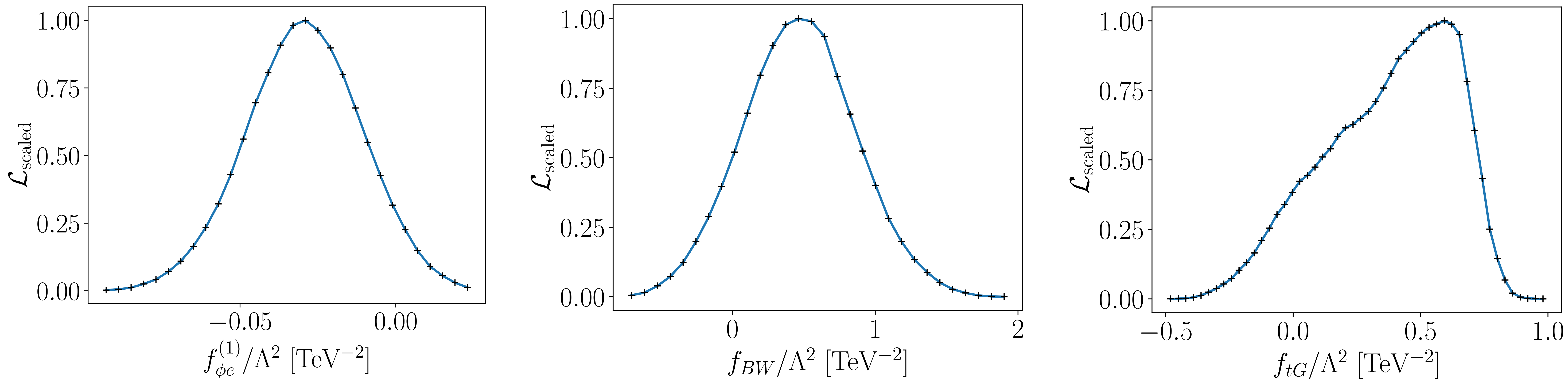
- Theory predictions are computed using **NEMO**
  - Large number of **different processes**
  - Effects from all **21 additional parameters** describing new physics
- **21-dimensional likelihood** now needs to be mapped
  - Use **NEMO** to run multiple Markov chains

Results from a global SMEFT analysis

One-dimensional results

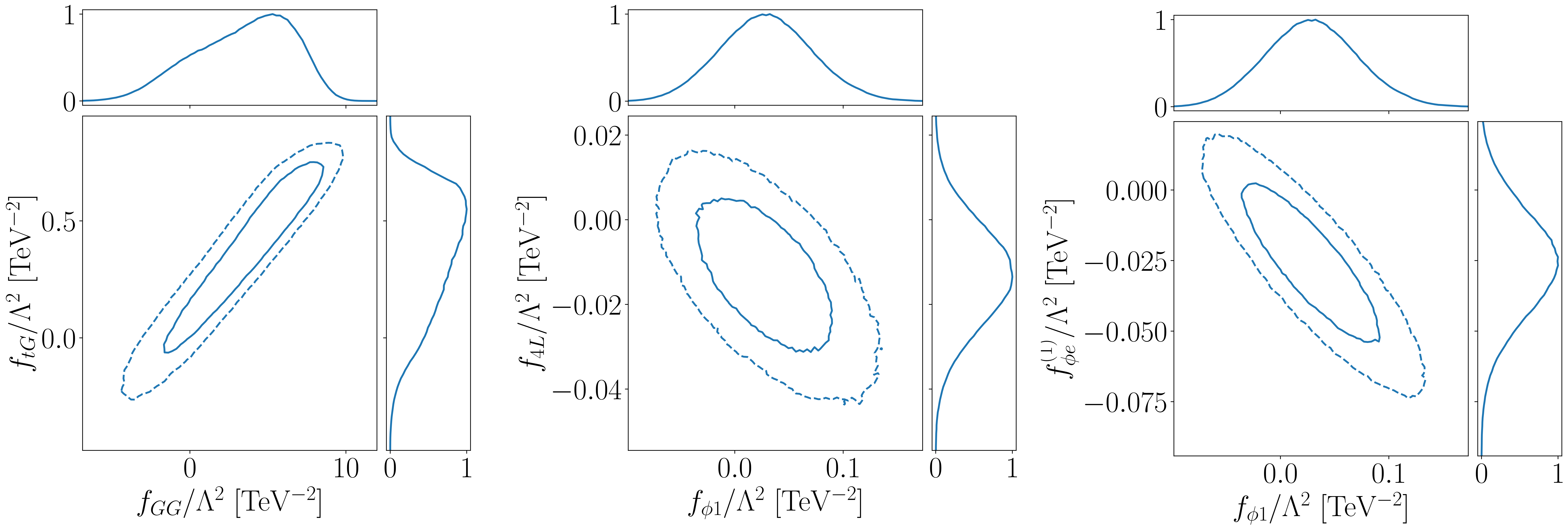
arXiv:2208.08454 [hep-ph]



- Each distribution describes one of the parameters for new physics effects
- Extract **limits for new physics** from these

Results from a global SMEFT analysis

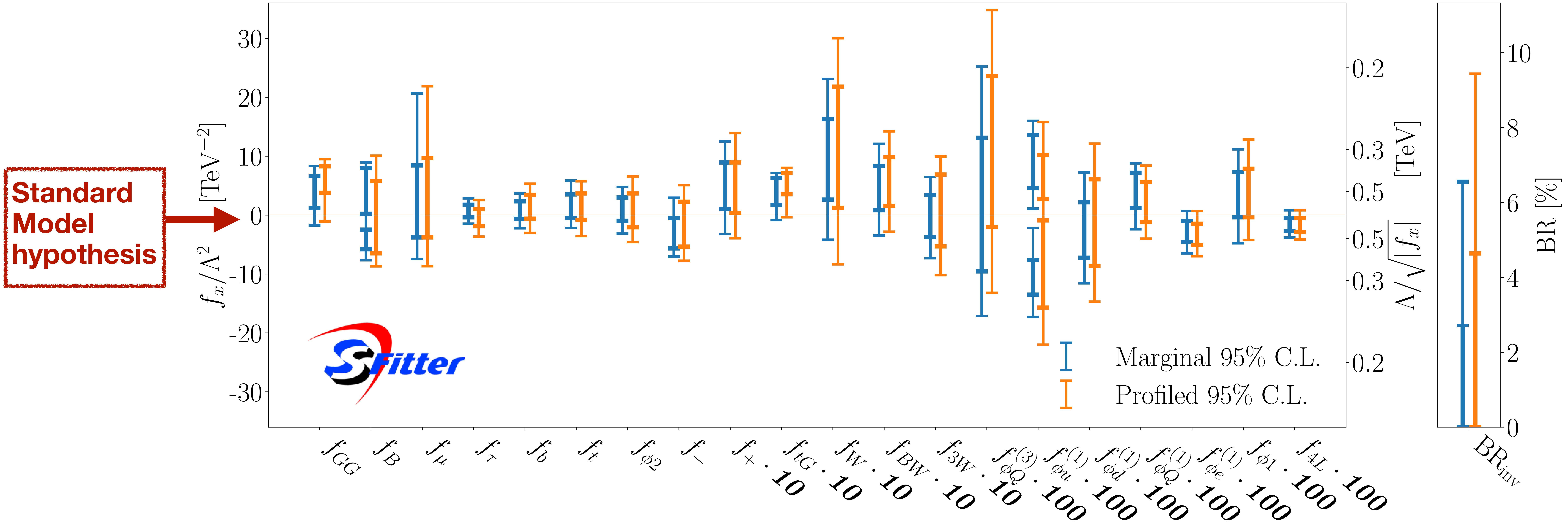
Two-dimensional results



➤ Study **correlations** between different parameters

Results from a global SMEFT analysis

Extracted limits



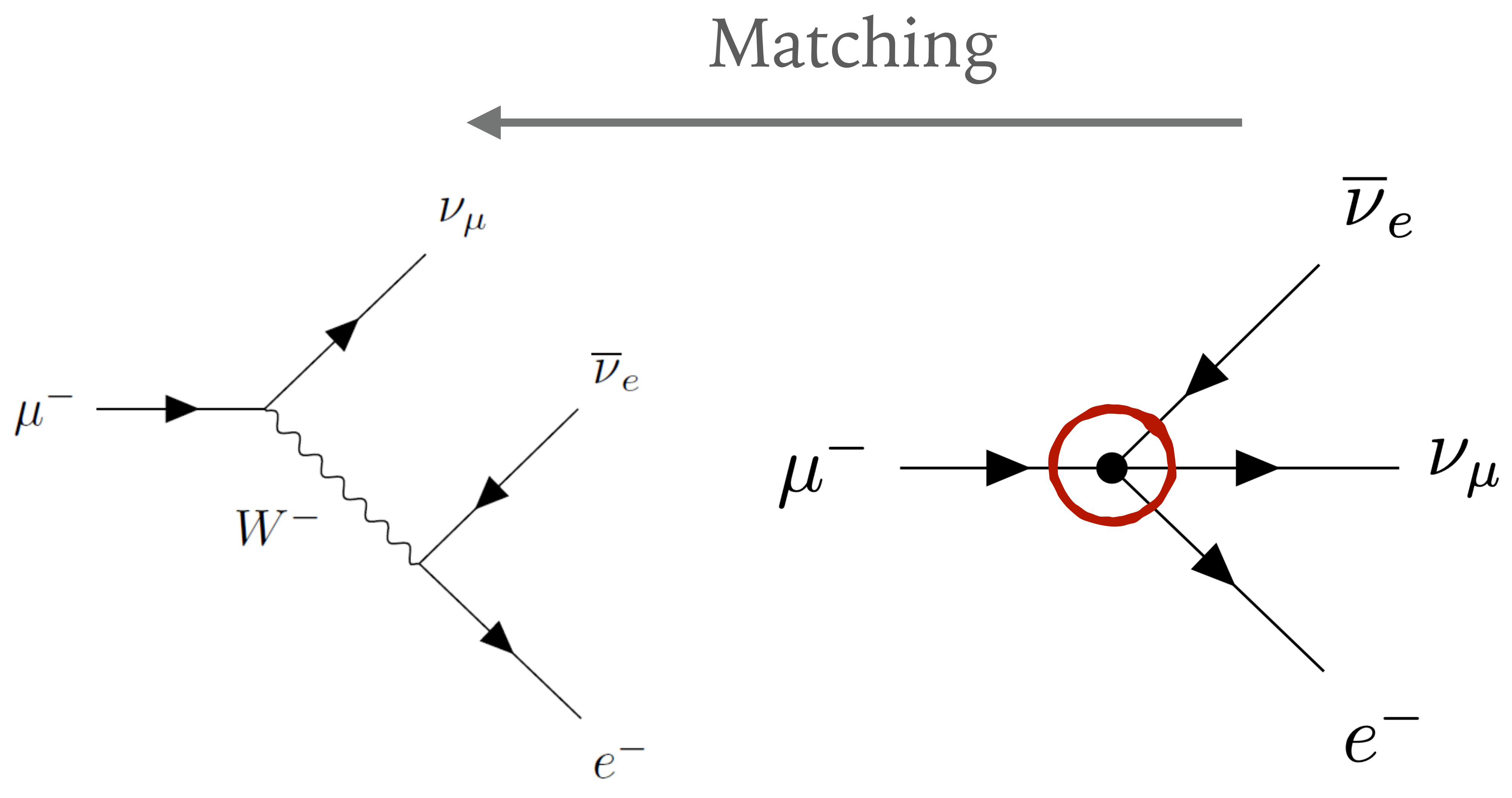
➤ What do these limits tell us?

arXiv:2208.08454 [hep-ph]

Results from a global SMEFT analysis

Matching constraints to models

- Back to our example:



Matching to model with W-Boson

predicts new physics at ≈ 100 GeV

Results from a global SMEFT analysis

Matching constraints to models

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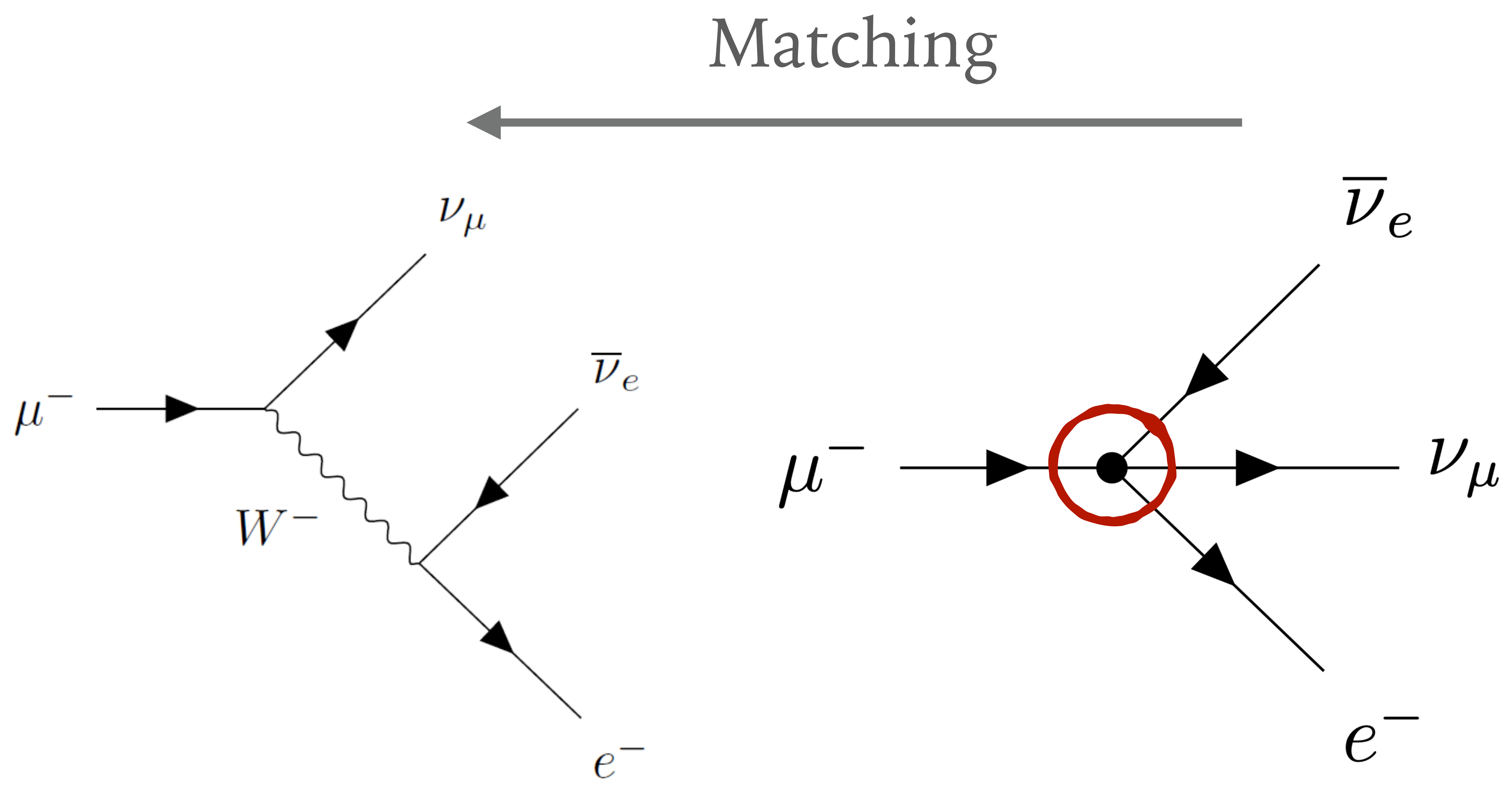

Matching to model with W-Boson **predicts new physics at $\approx$ 100 GeV**

Nowadays we know: $m_W \approx 81$ GeV

- Matching for one of our studies in arXiv:2108.01094 **[hep-ph]**

Outlook and Summary

- **Where do we go from here?**
  - Shown results from an analysis using 21 parameters; ∼400 datapoints
  - Current work extends parameters space up to 39 and extends the dataset

- **Why NEMO is indispensable:**
  - Computation of **numerous complex theory predictions**
  - Mapping of **high-dimensional parameter spaces**

Thank you for your attention!