From the precision frontier to physics beyond the Standard Model

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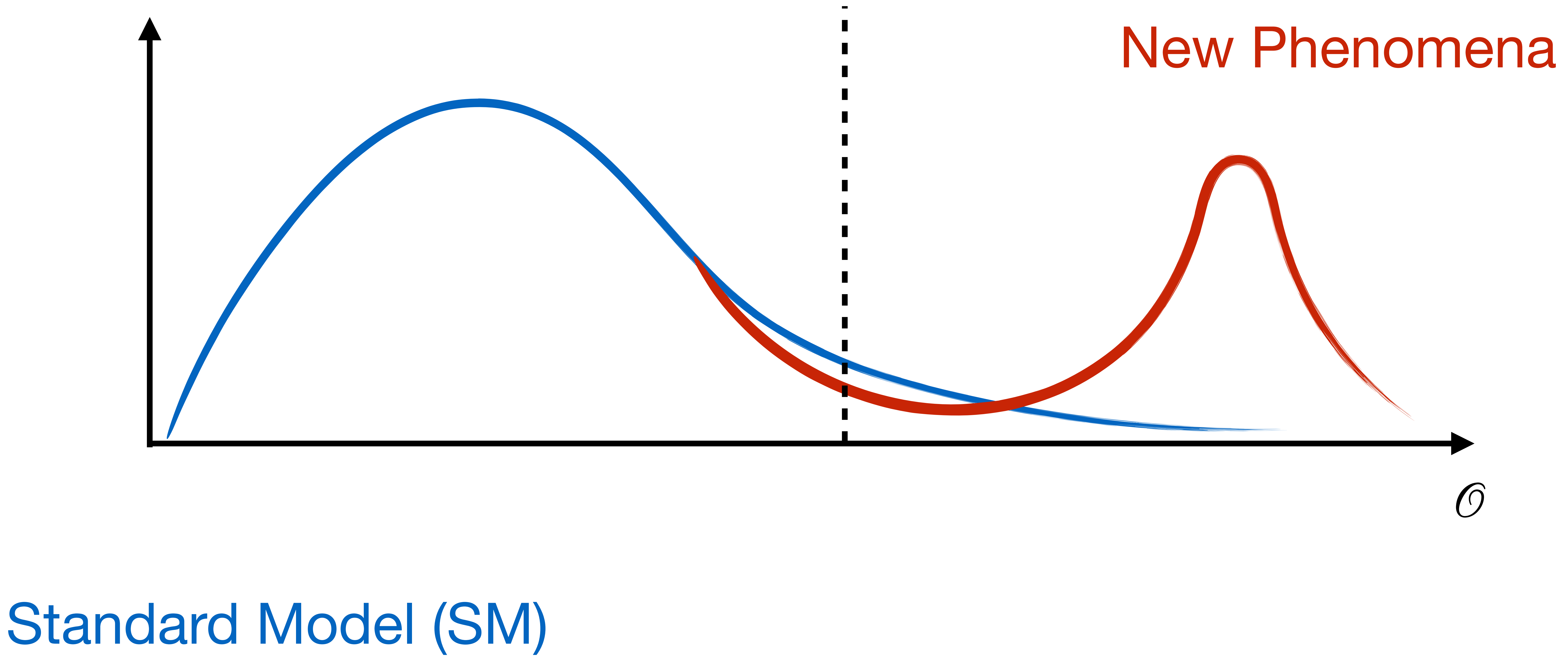
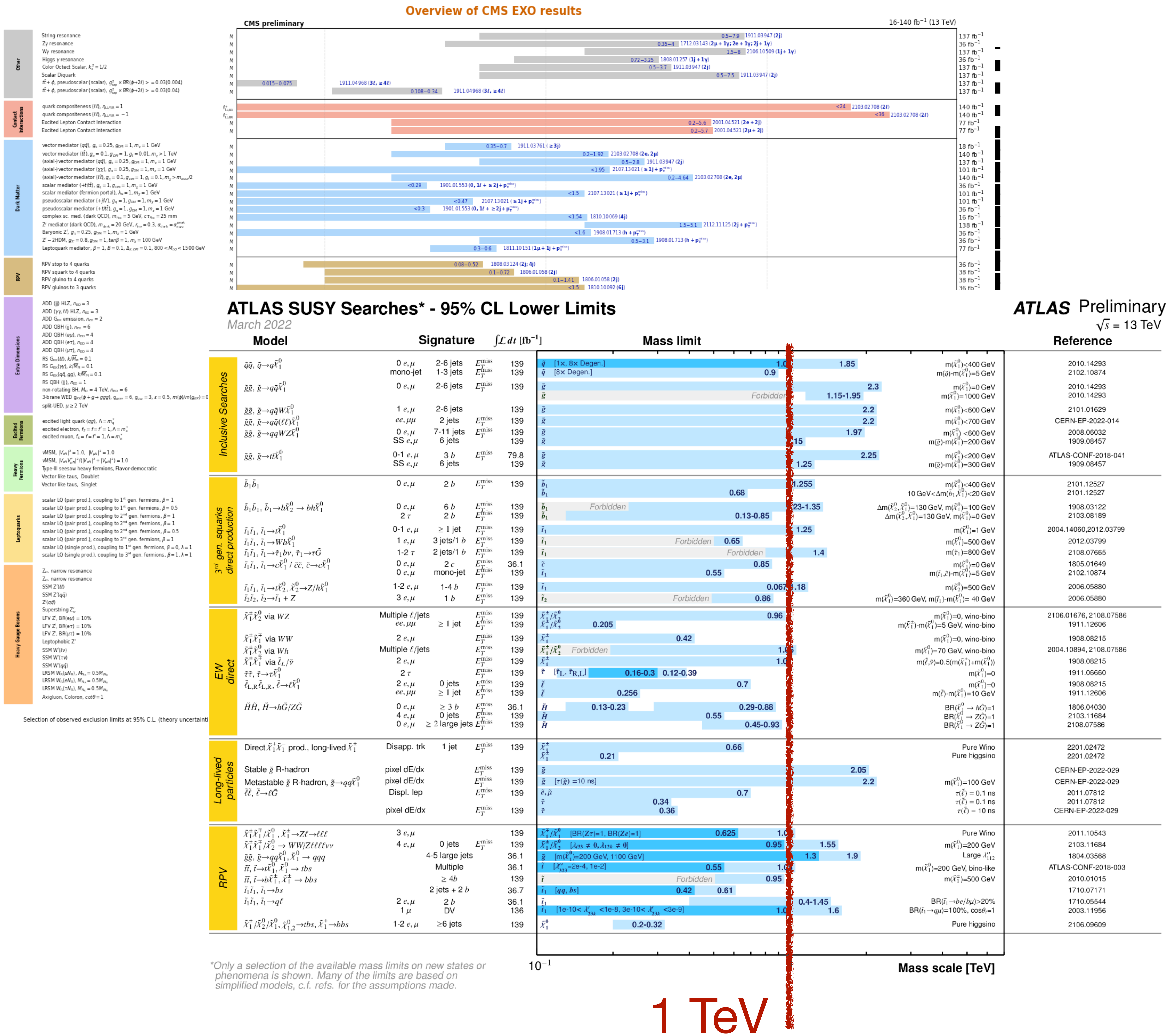
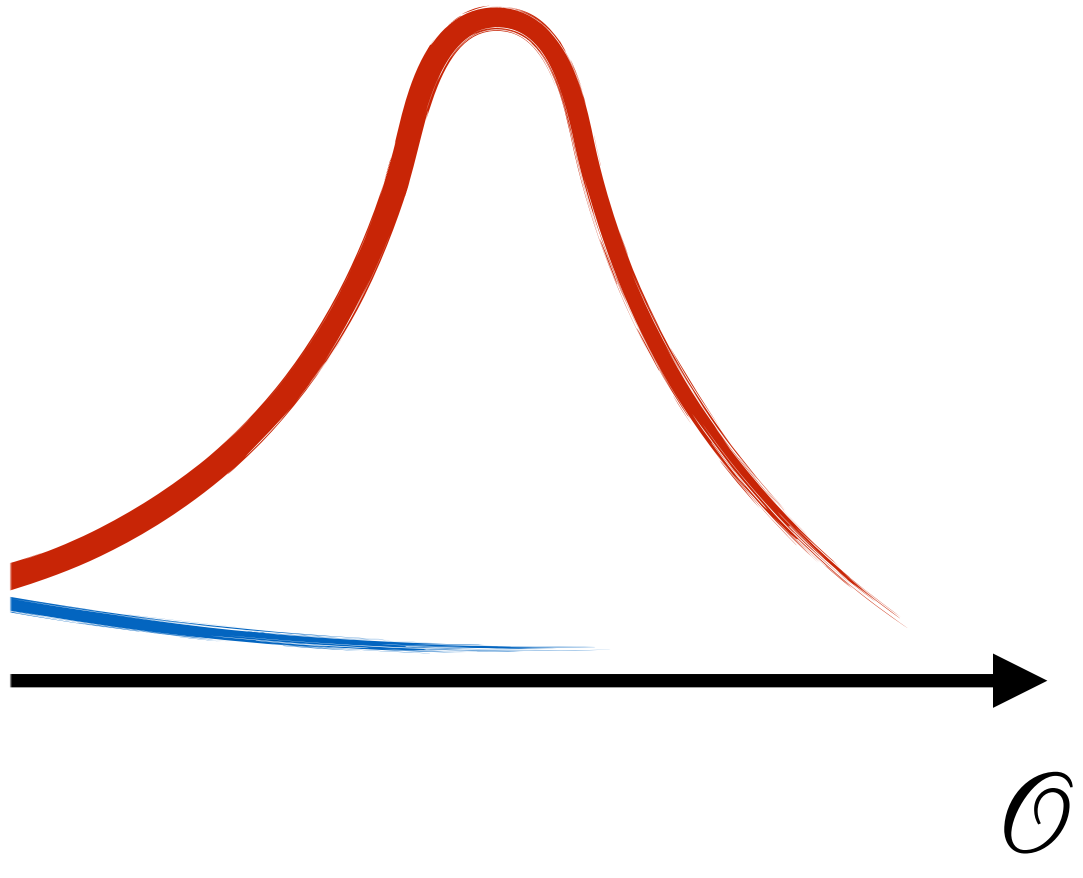
Physics at the Large Hadron Collider



A DEDICATED SEARCH PROGRAM

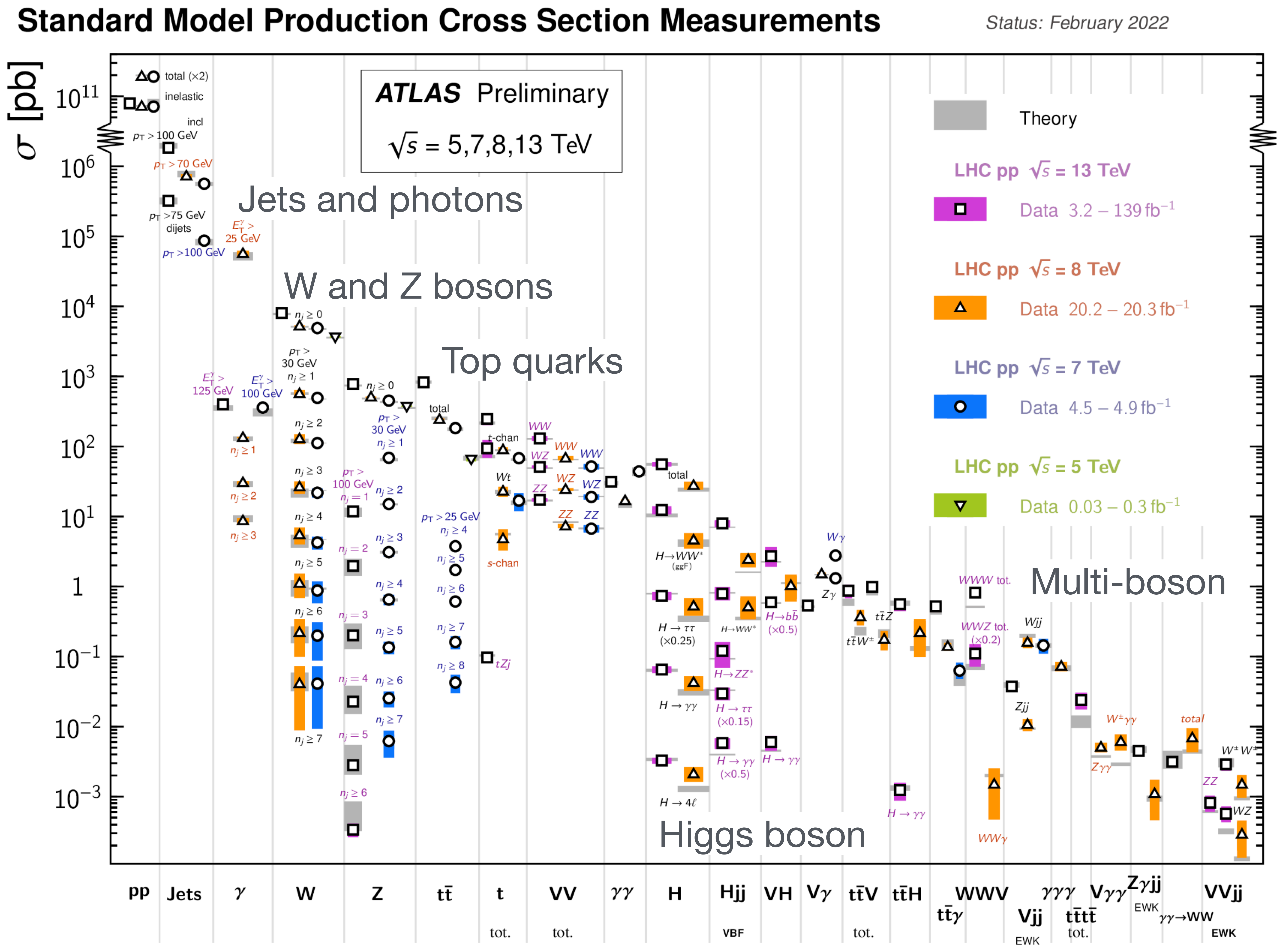


New Phenomena

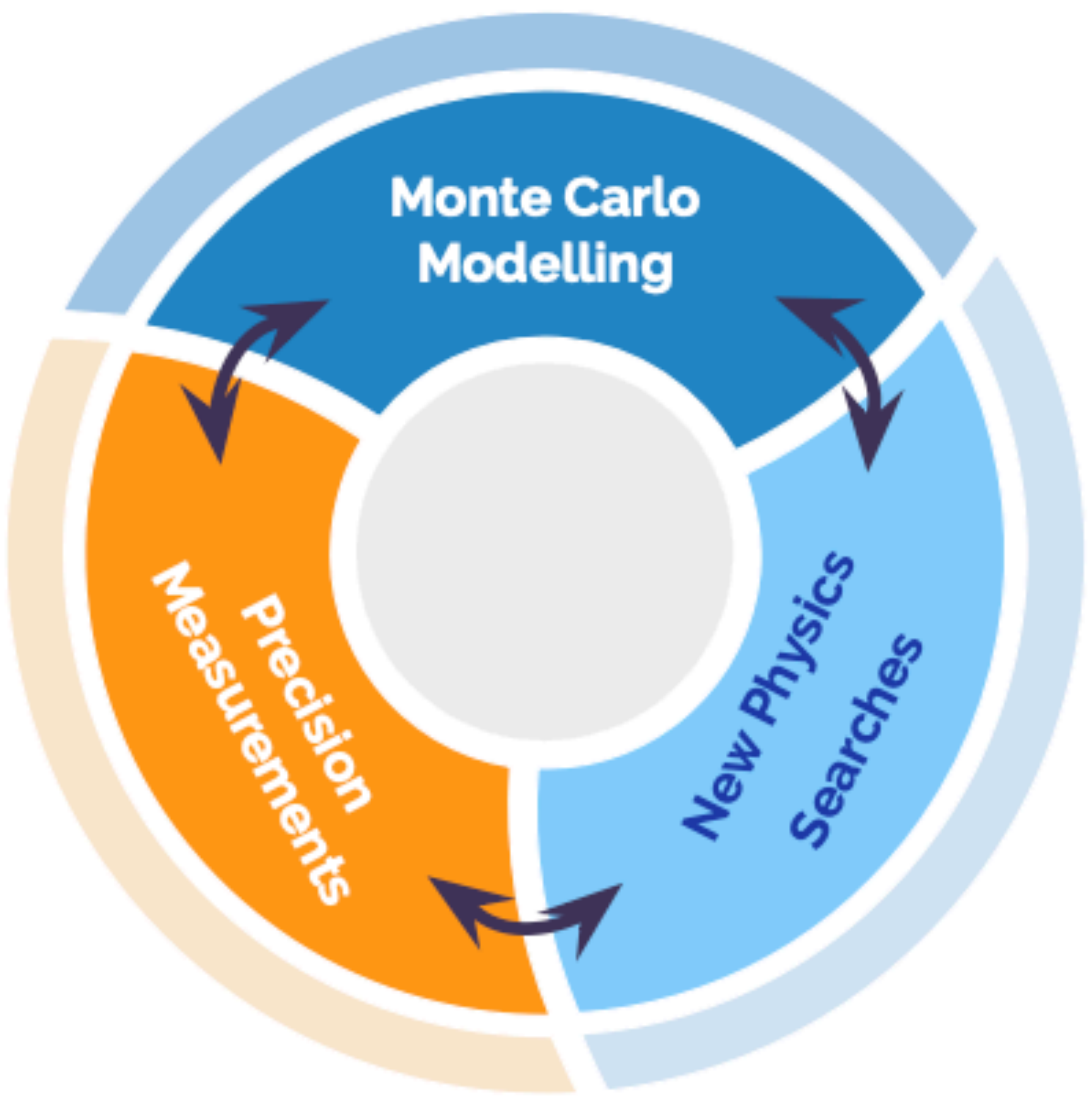


- Extensive (~1000 results)
- Signature/model driven
- Fast ➜ detector level

Standard Model measurements

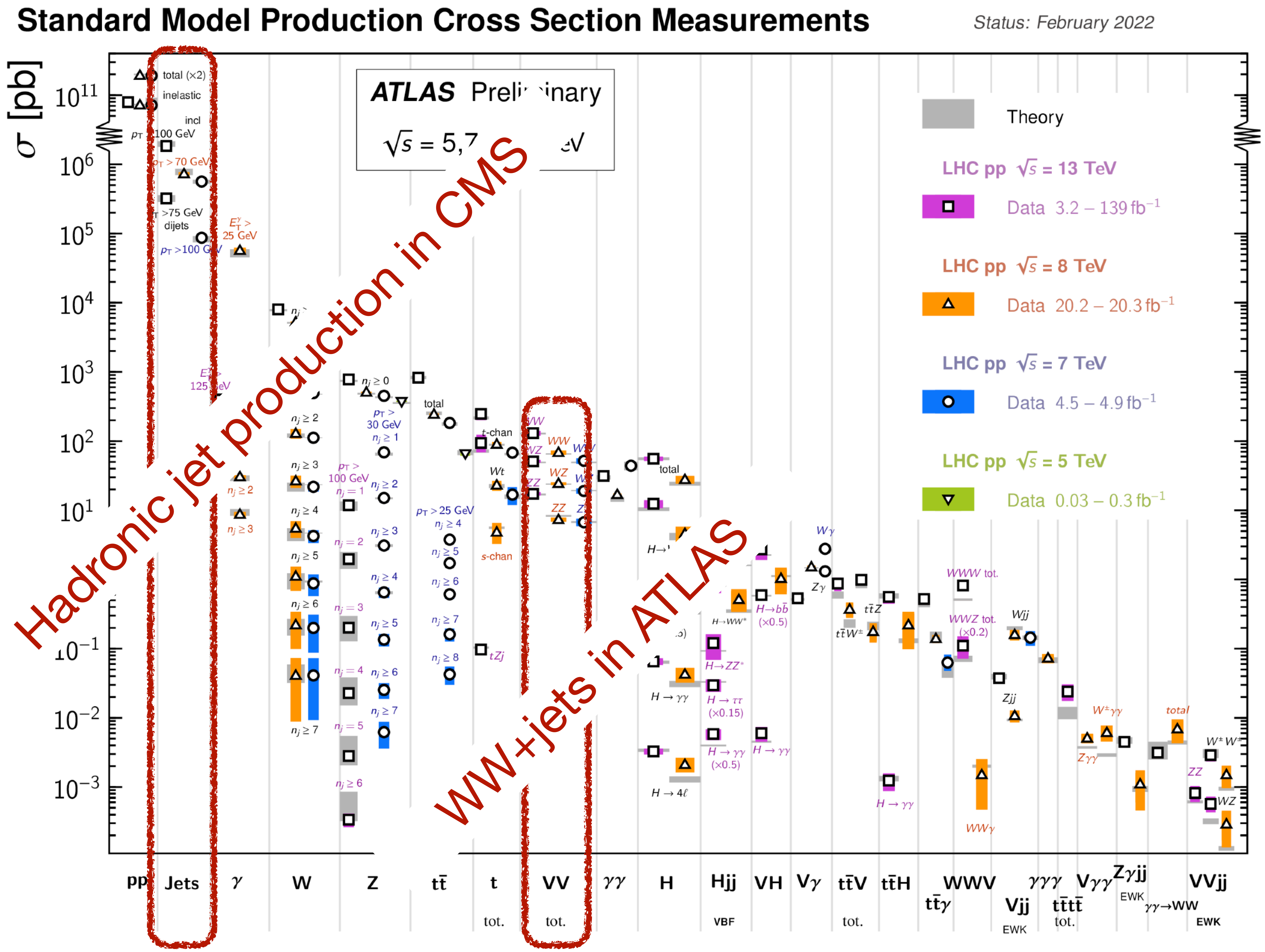


- SM process driven
- Detector-corrected
- Focus on precision/longevity



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2022-009/

Standard Model measurements



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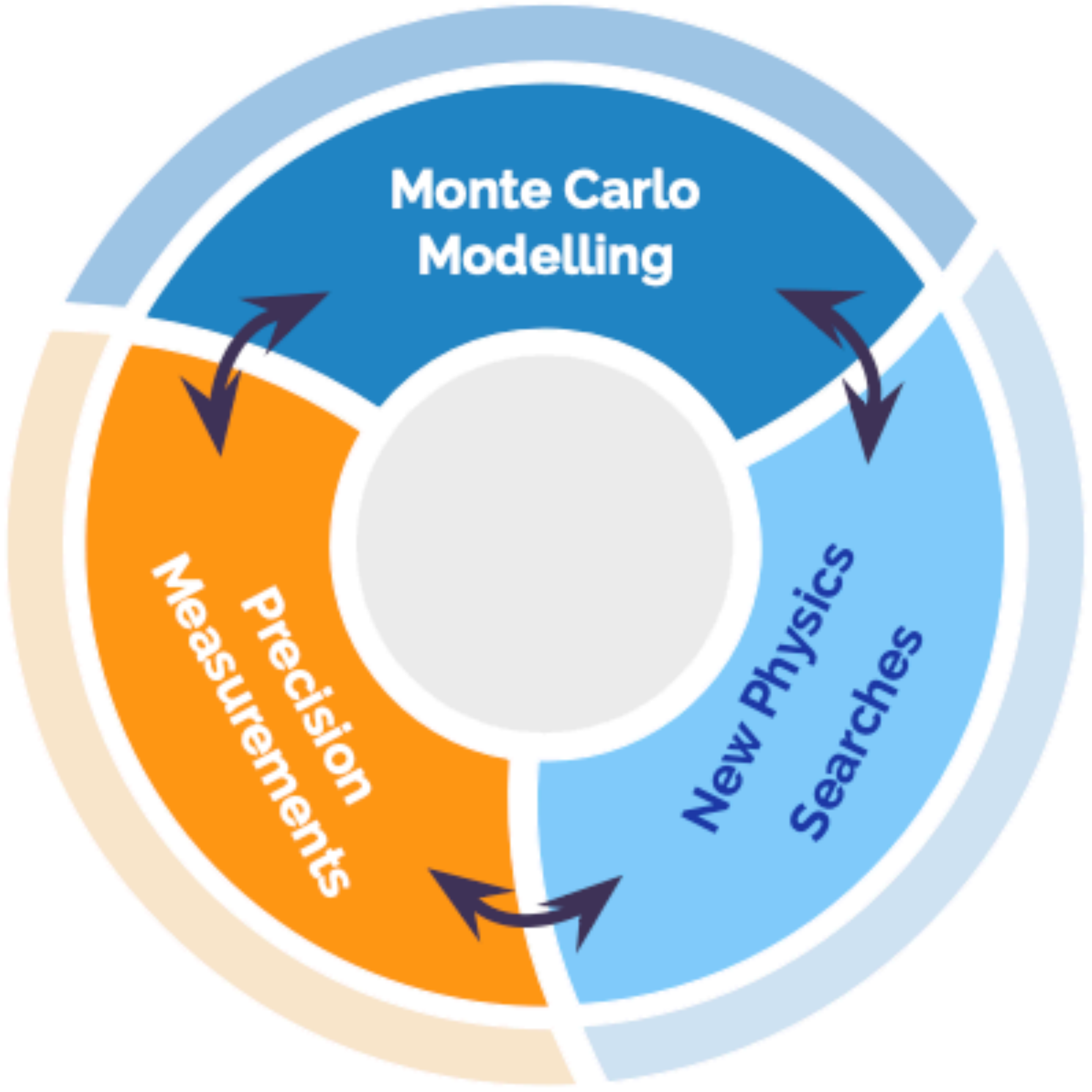
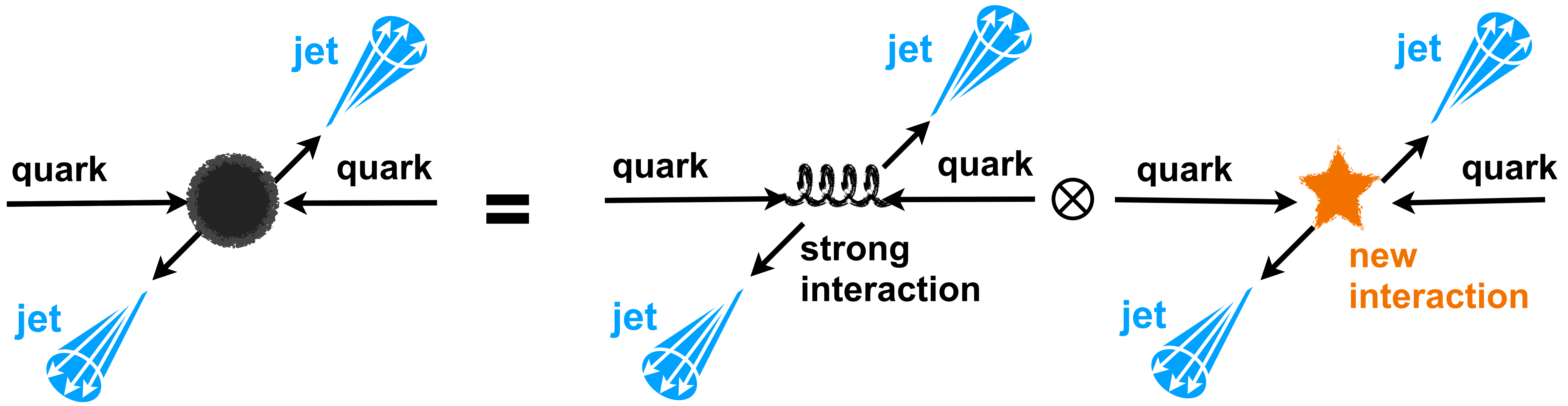
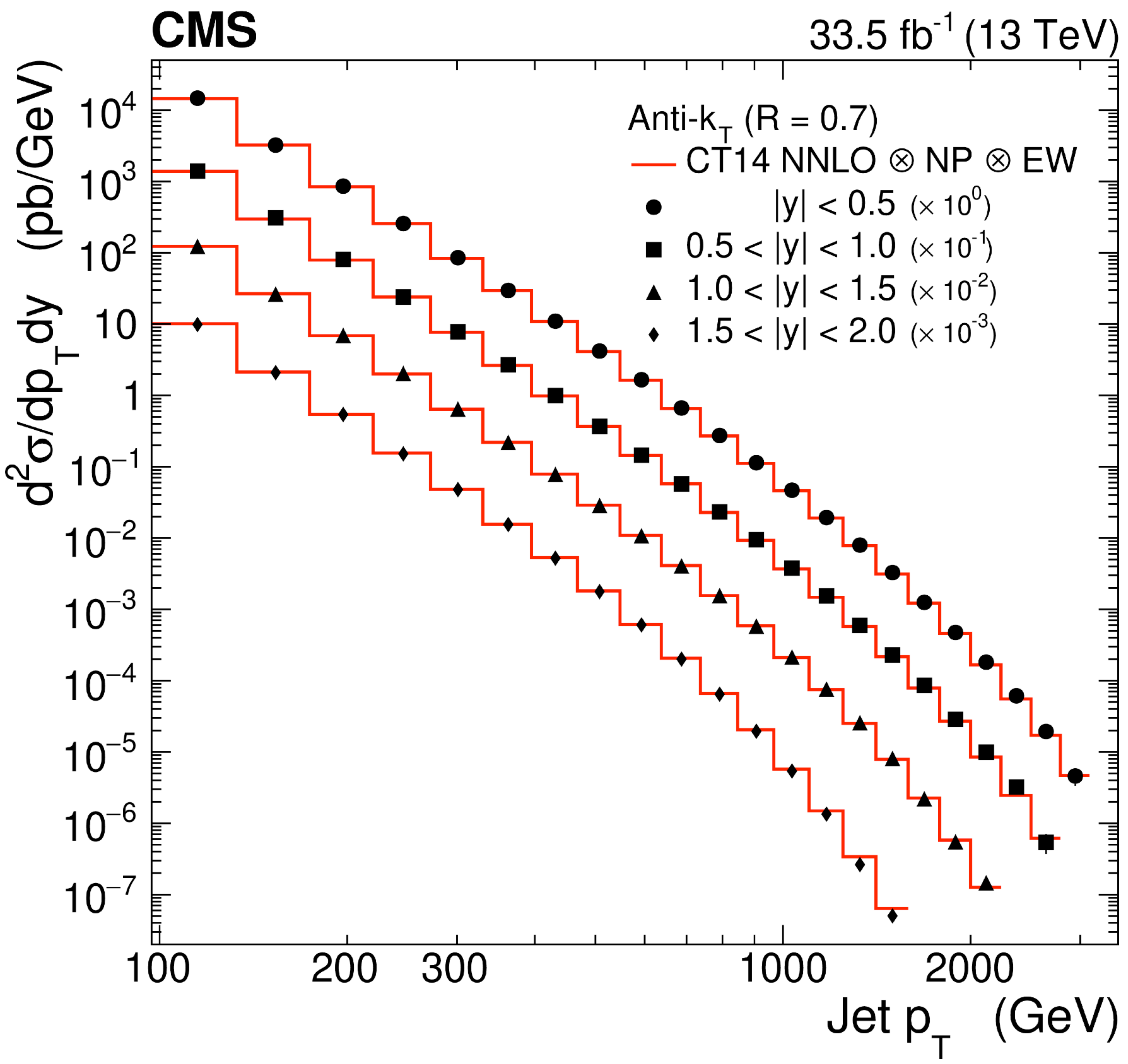


Hadronic jets as probe of the strong force



- Sensitive to the **proton structure** (PDFs)
- Extract **strong coupling** $\alpha_S(m_Z)$, least well known fundamental constant: $\alpha_S(m_Z) = 0.1170 \pm 0.0017$

  Most precise $\alpha_S(m_Z)$ from a hadron collider experiment
- Probe **physics beyond the SM**
  - Parametrised with effective couplings c_i valid up to new physics scale Λ (EFT)
  - For vector-like couplings new physics scale $\Lambda > 32$ TeV



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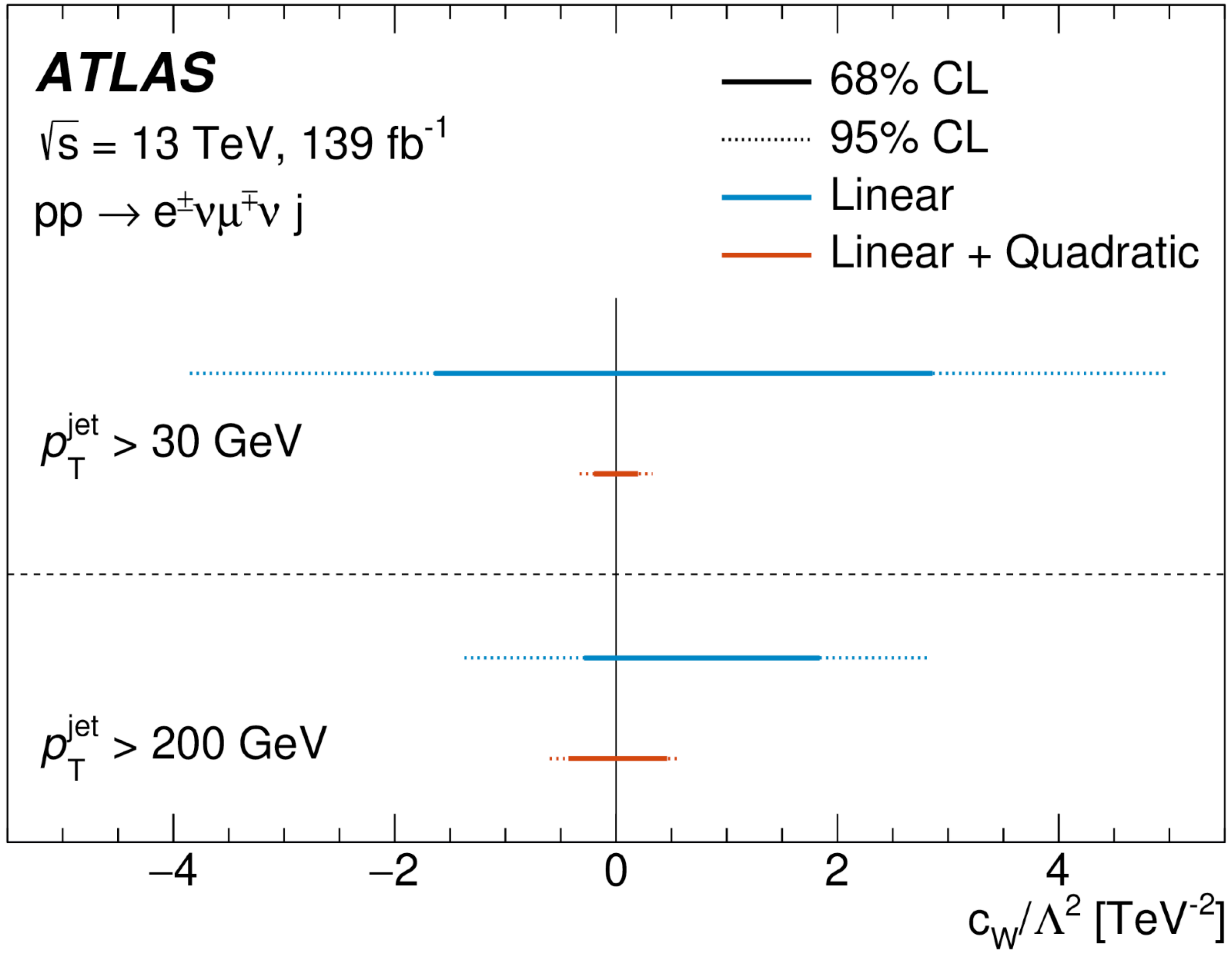
Electroweak interactions in WW+jets

- ATLAS precise measurement of $pp \to e^{\pm}\nu\mu^{\pm}\nu j$
  - Sensitive to electroweak boson self-interactions and higher orders in the strong coupling



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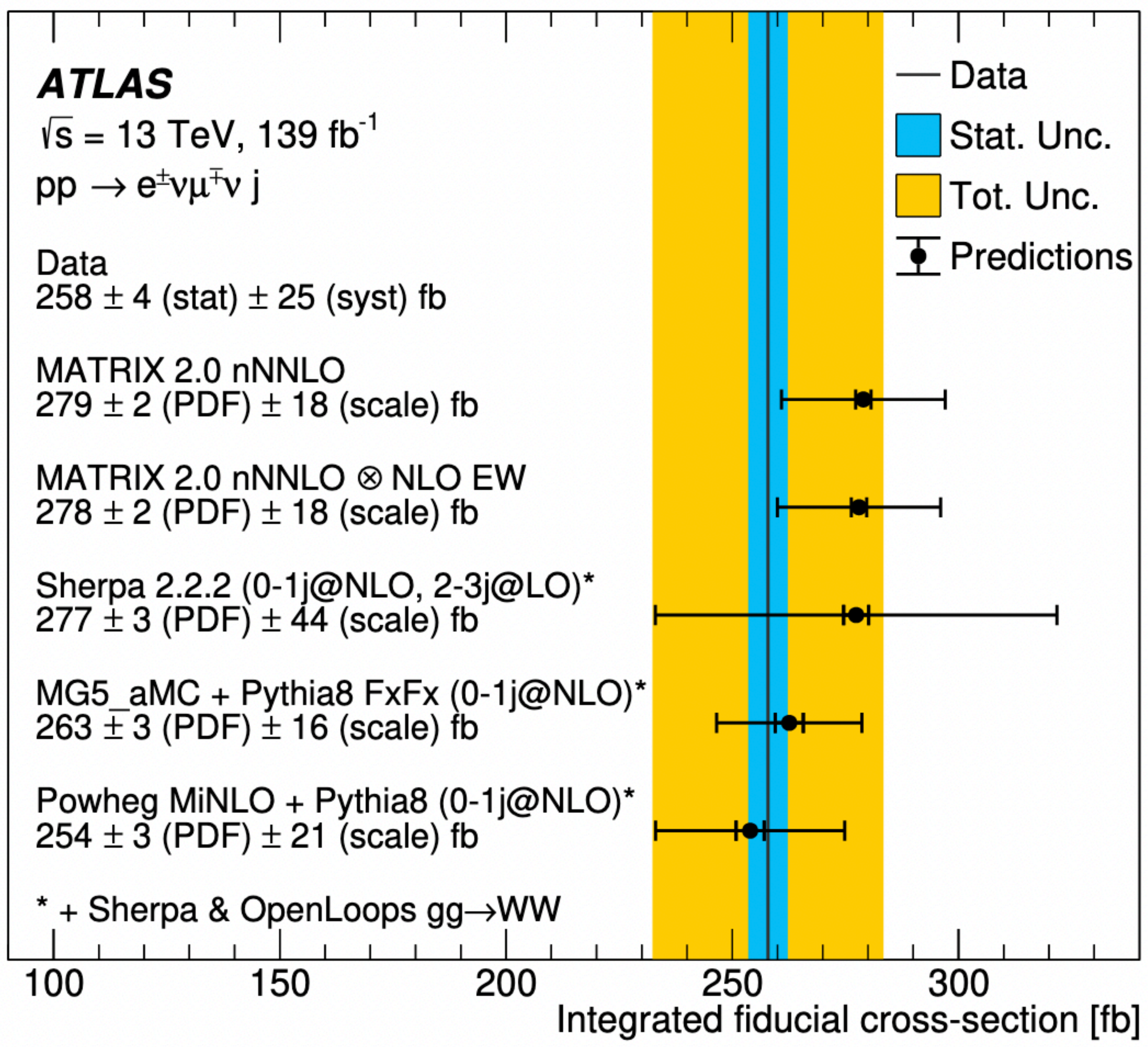
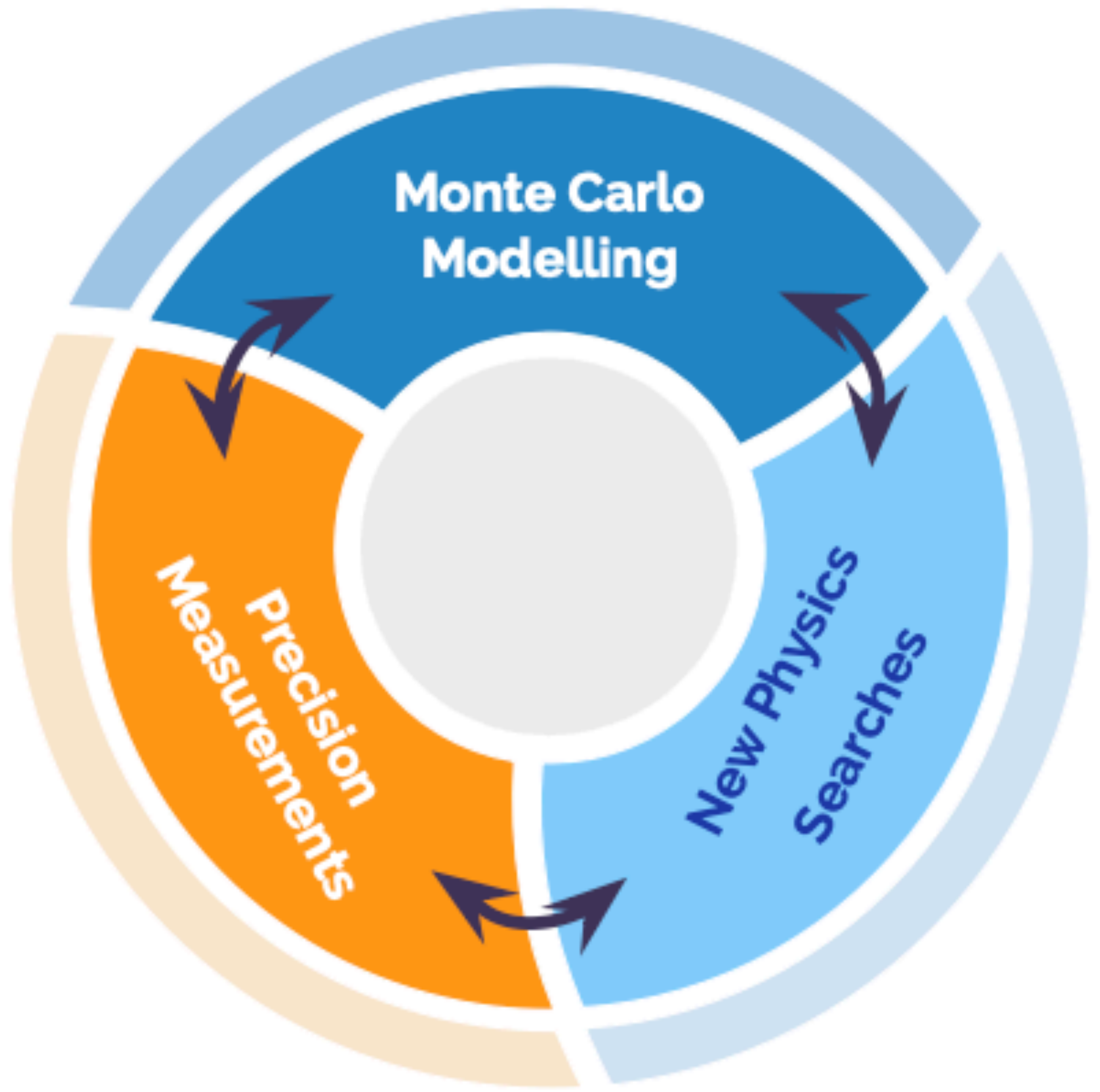


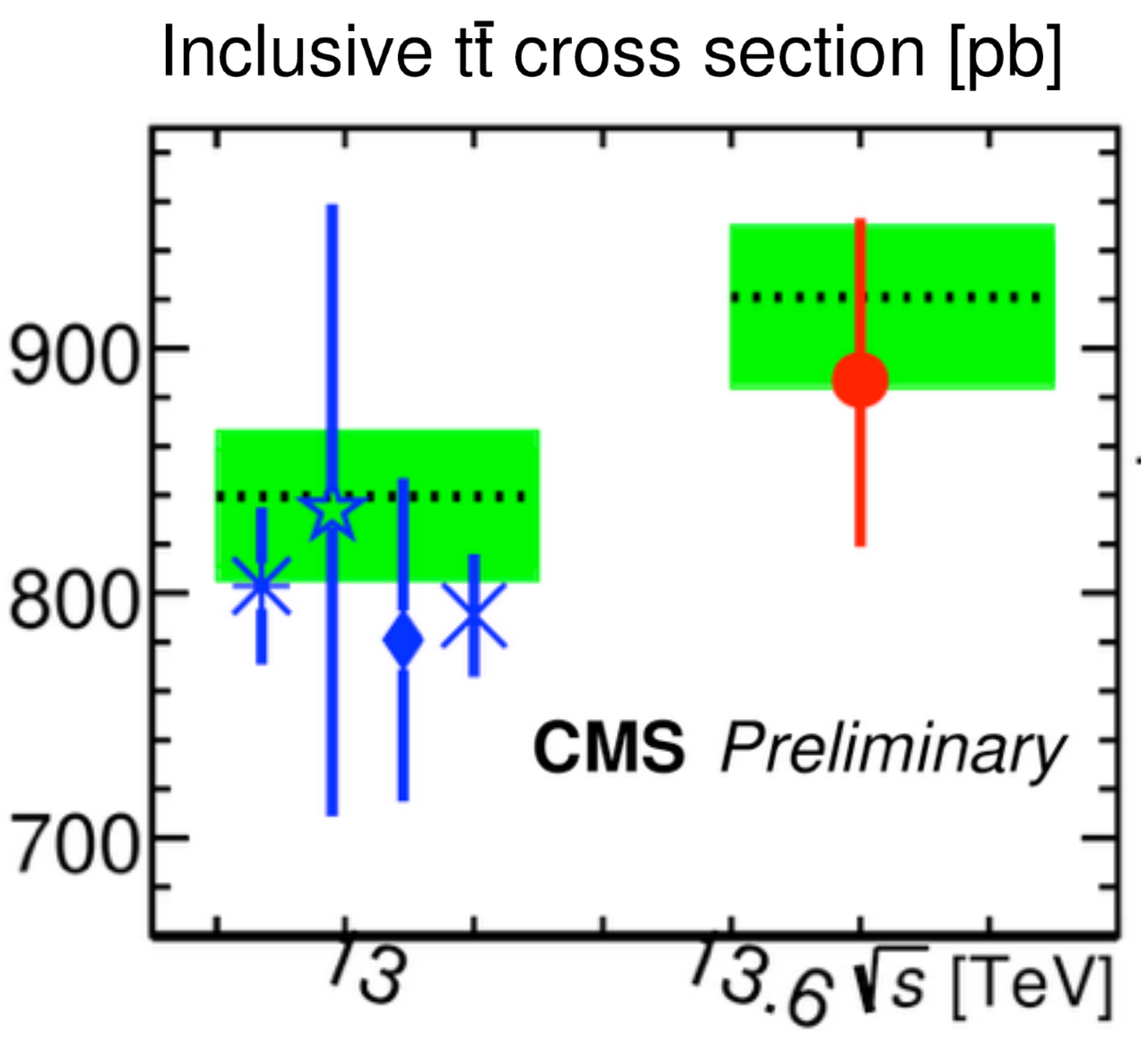
- Compared to state-of-the-art theoretical predictions
- Differential distributions constrain **effective couplings**

Summary

* We have only scraped the surface of the potential of the LHC data



* SM measurements constraint BSM physics beyond the LHC direct reach



CMS-TOP-22-012

* Only touched upon two 13 TeV results, but Run3 data is already with us

Backup

Display of a two jet event in CMS

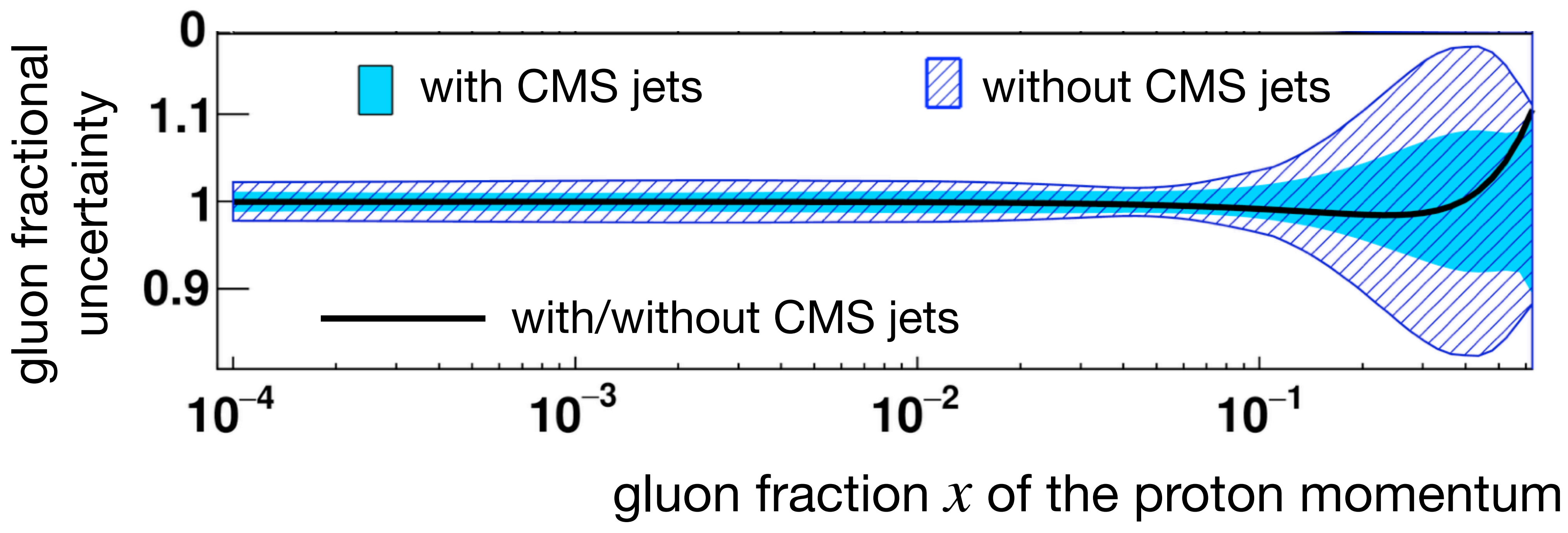
Inclusive jets and $\alpha_S(m_Z)$

- QCD analysis at NNLO QCD
  - Joint determination of the proton PDFs and $\alpha_S(m_Z)$ using the CMS jet and HERA2 DIS data
  - Avoid circularity: jets -> gluon PDF, jets -> $\alpha_S(m_Z)$

Data statistics — Parametric uncertainties

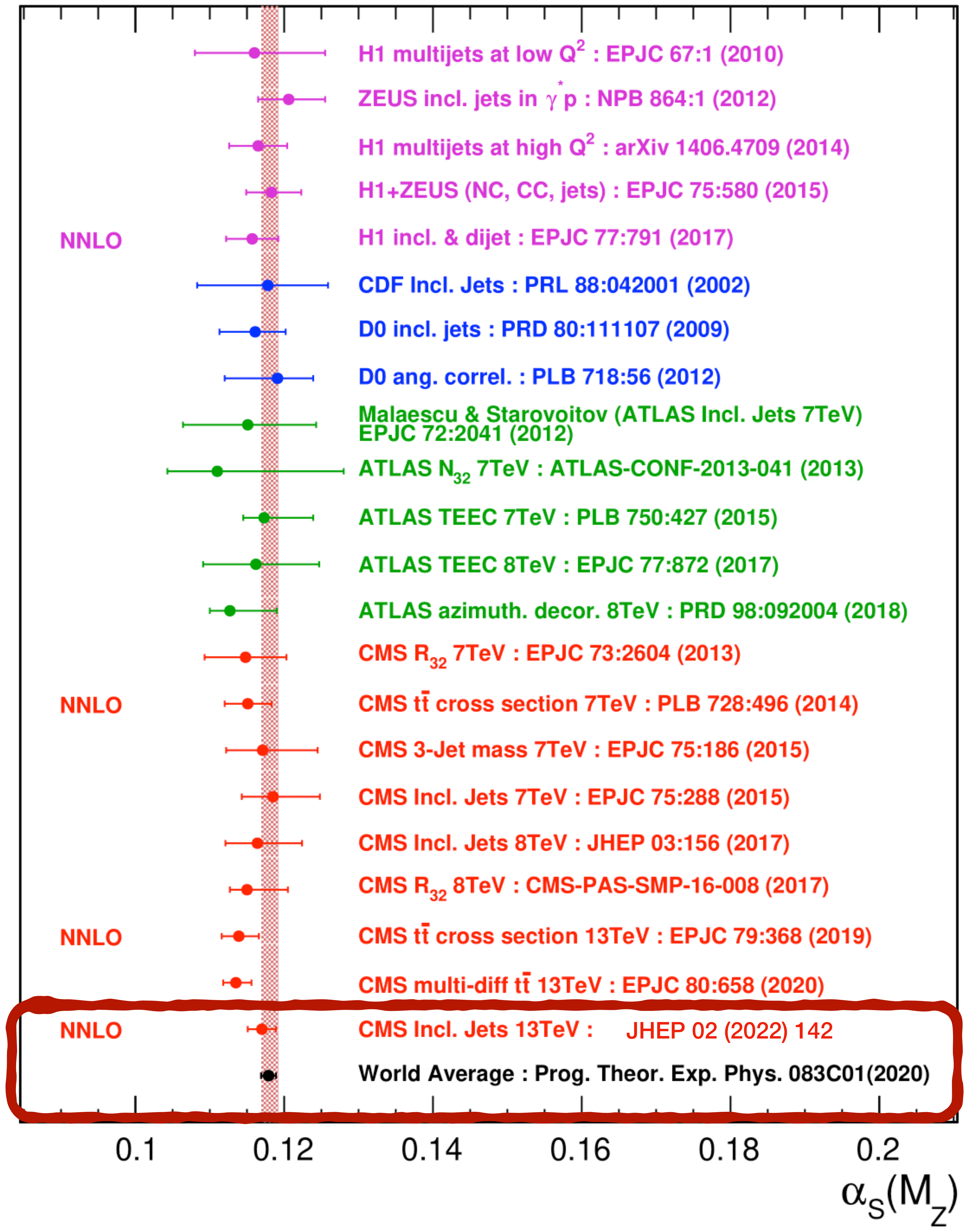
$$\alpha_S(m_Z) = 0.1170 \pm 0.0014(\text{fit}) \pm 0.0007(\text{model}) \pm 0.0008(\text{scale}) \pm 0.0001(\text{parametrisation})$$

QCD scale variations — PDF functional form



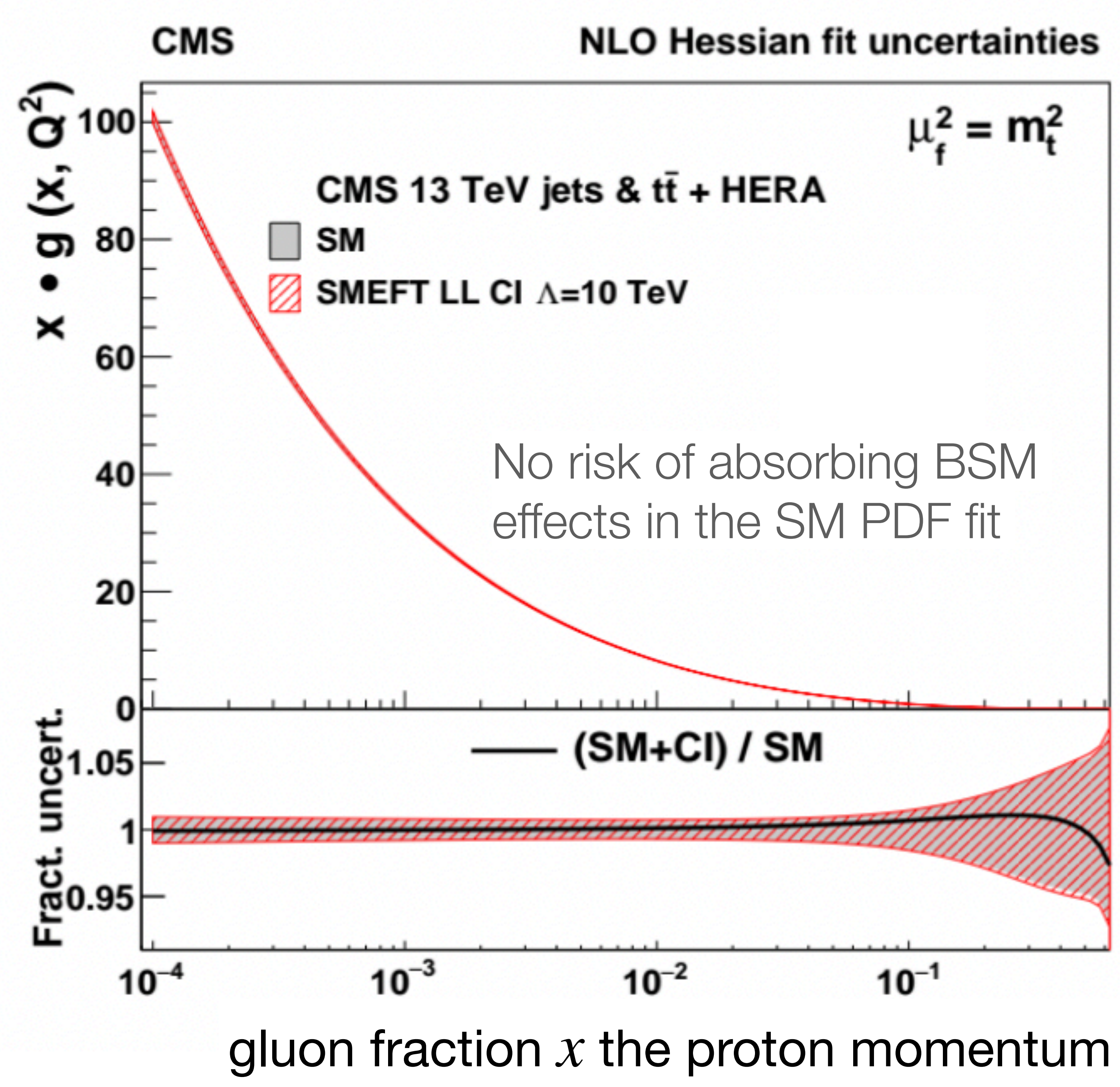
- Most precise $\alpha_S(m_Z)$ from single experiment, in agreement with world average

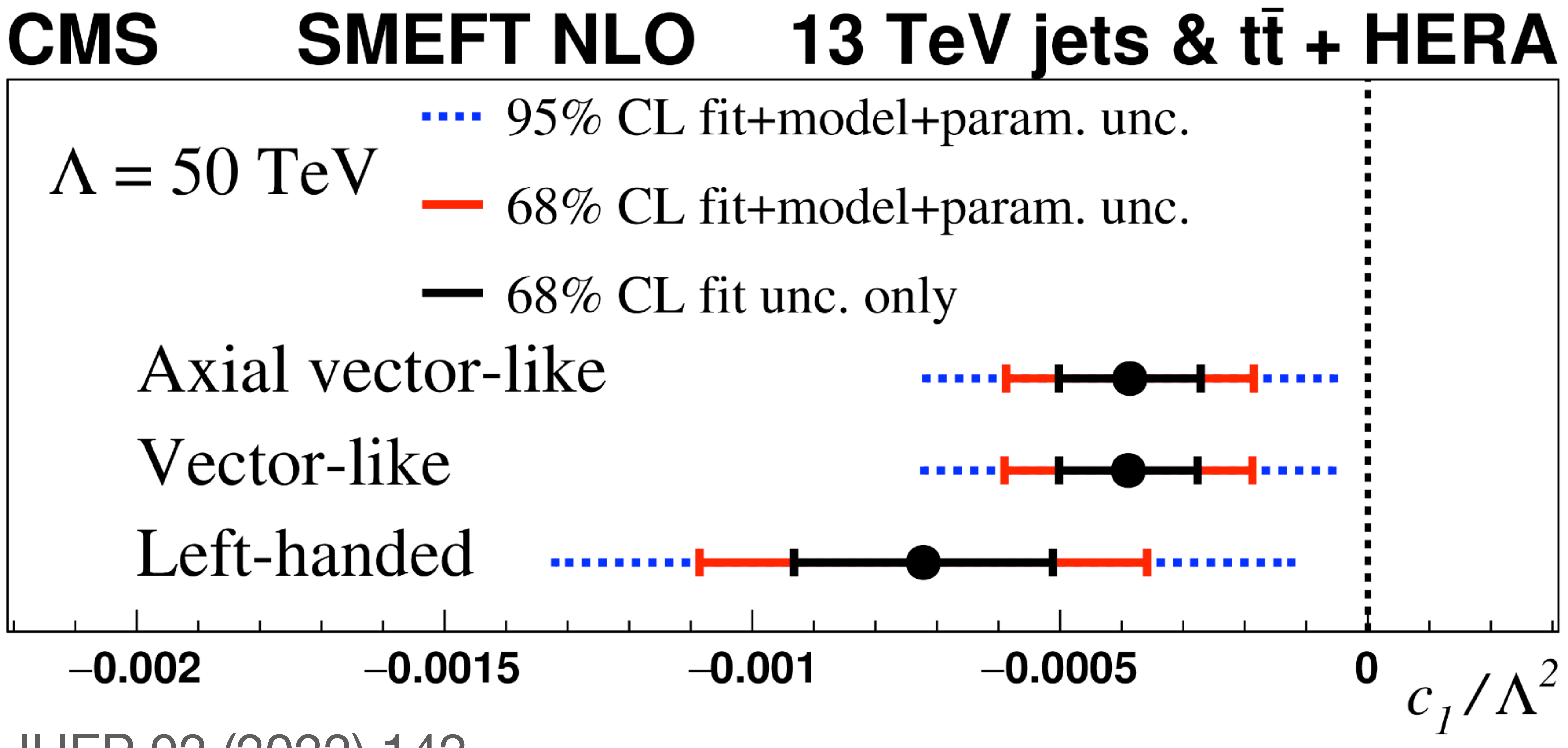
$\alpha_S(m_Z)$ at hadron collider from jets data



Jets & new physics

- Unbiased search for Contact Interactions in high-p_T jets
  - Issue: SM prediction based on PDFs including LHC jet data
  - Solution: BSM effects are not absorbed into the PDFs by determining them in a simultaneous fit





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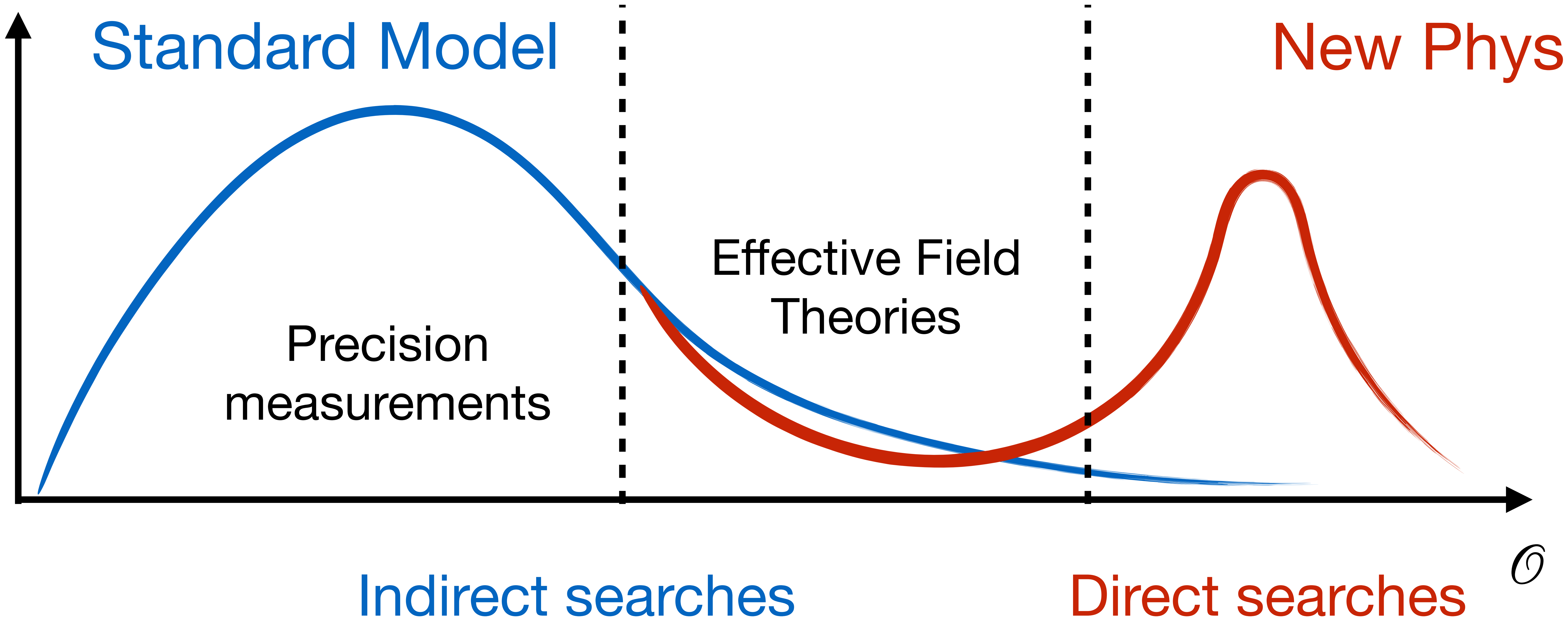
- Results consistent with the SM
- Constrain new physics scale Λ assuming $c_1 = -1$
  - $\Lambda > 32$ TeV for vector-like coupling

Physics at the LHC

- Physics Beyond the Standard Model more elusive than expected
- Time to *rethink our approaches*



- **Effective Field Theory:** parametrise high scale physics at low energies
- Access energy scales much higher than those directly accessible

Effective Field Theories

- If BSM physics is heavy we can *"integrate it out"*, leaving higher dimensional operators in the Lagrangian - an **EFT**

c_i Wilson coefficient

$O_i^{(d)}$ operator of dimension *d*

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} \mathcal{O}^{(6)} + \dots$$

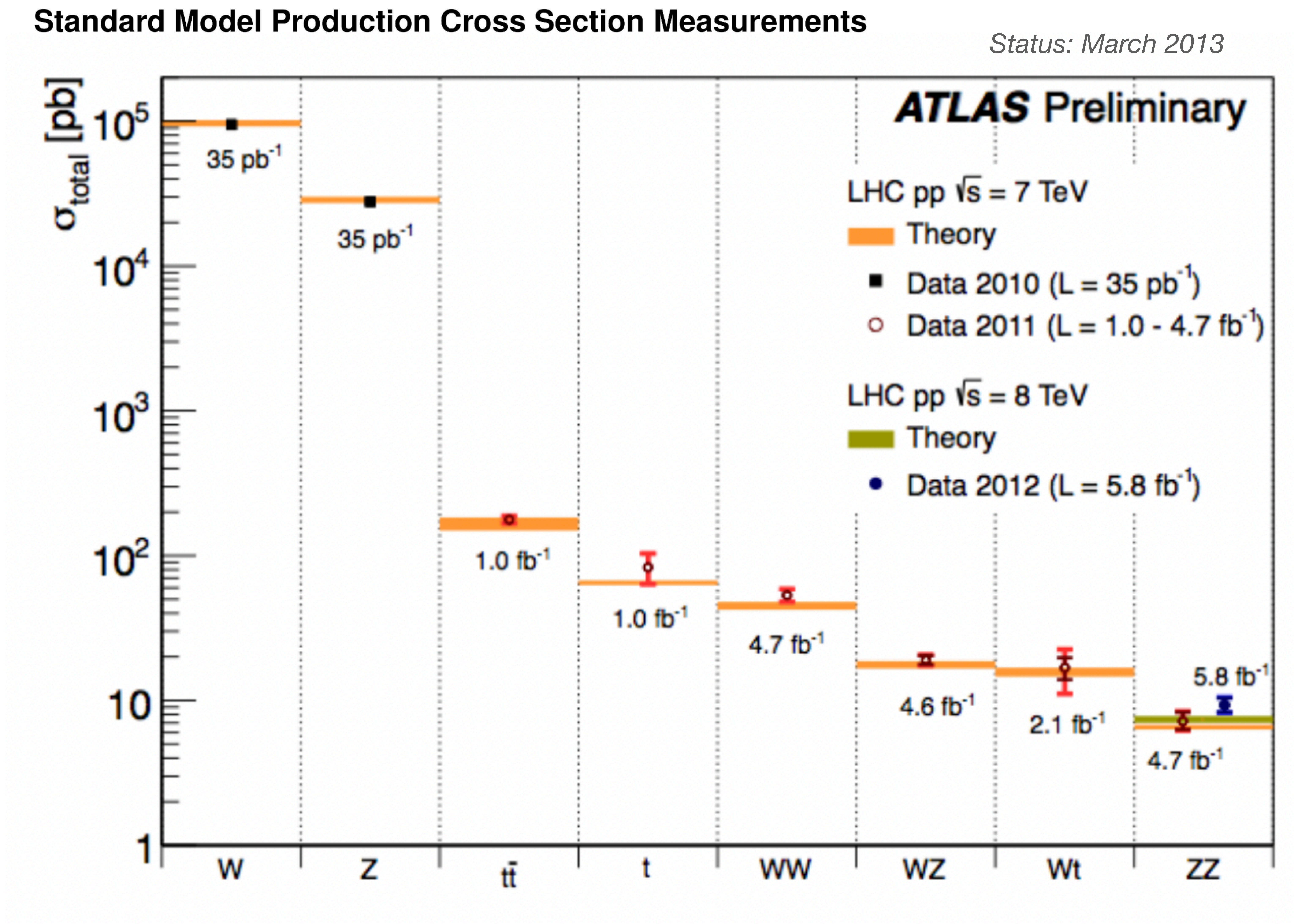
Fitted to experimental measurements

Λ scale of new physics

New physics to show up as $c_i \neq 0$

- Contribution of certain operators grows with partonic center-of-mass energy
  - Increased **sensitivity in TeV region**
- Dim-6: **1000s of operators**, complex phase space to explore
- Complementarity between different measurements and processes

Standard Model at the LHC: the beginnings



- Discovery of the Higgs
- Precision measurements of QCD and EW processes
- Exploration of BSM physics via direct and indirect searches

Global EFT fit to diboson data

- ATLAS combined interpretation of WW, WZ, ZZ, and VBF Z measurements
  - Allows to constrain more flat directions in the EFT space

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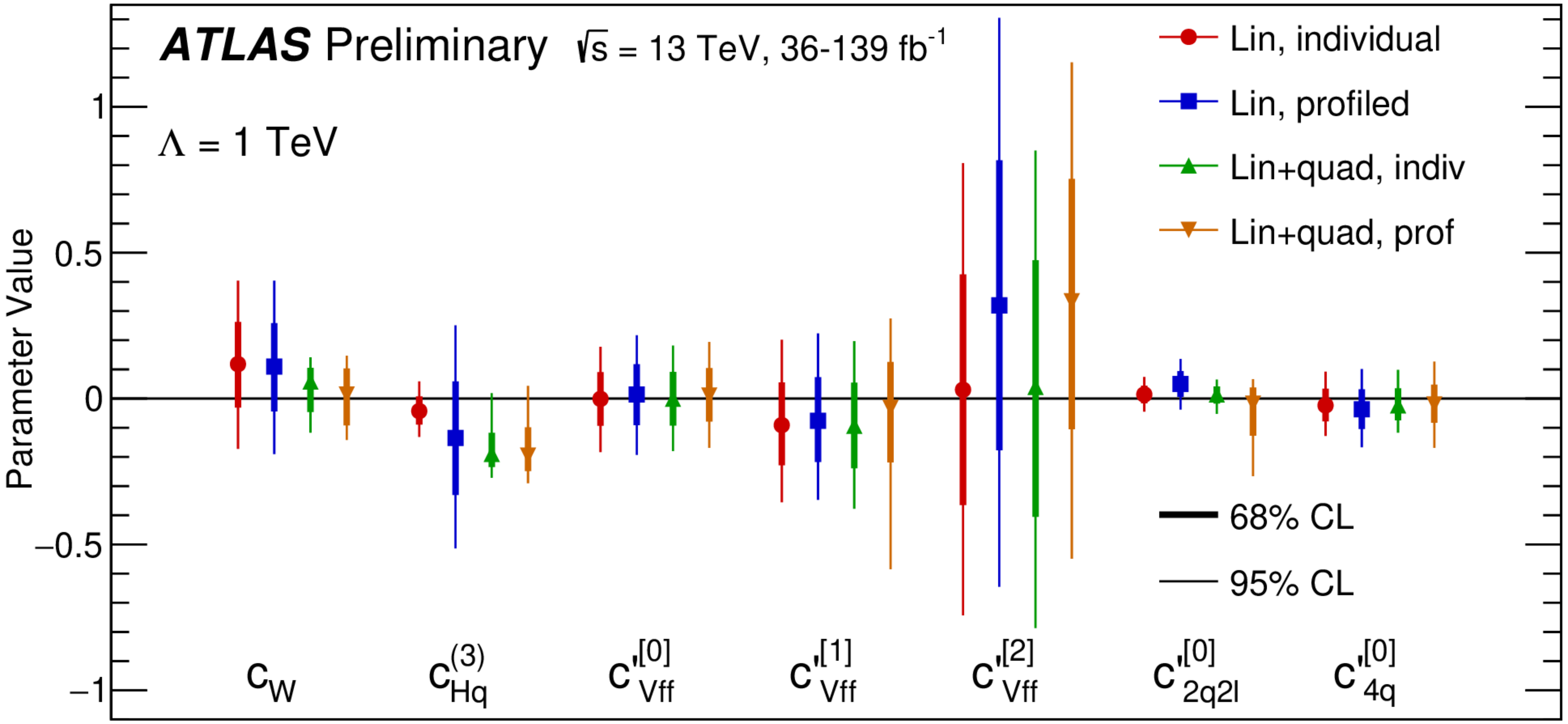

Results in agreement with SM prediction ($c_i = 0$)

- First step towards global EFT interpretations of multiple processes