Searching for new physics in dilepton final states with the ATLAS detector

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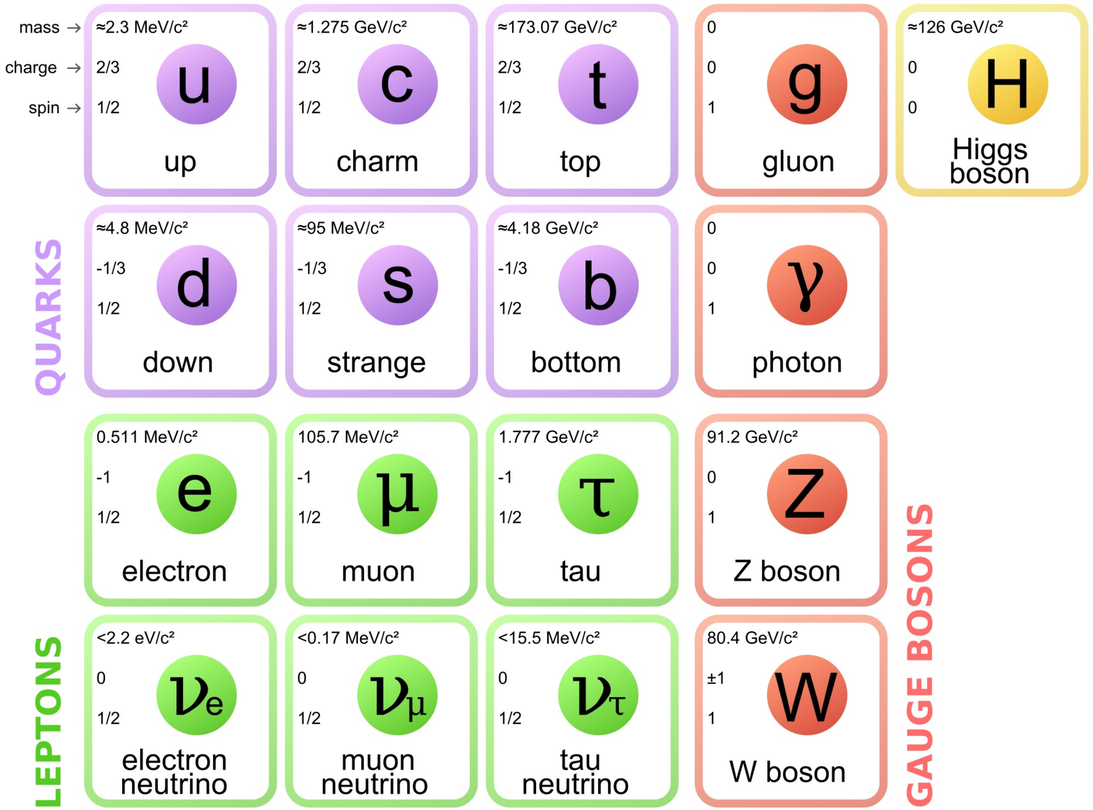
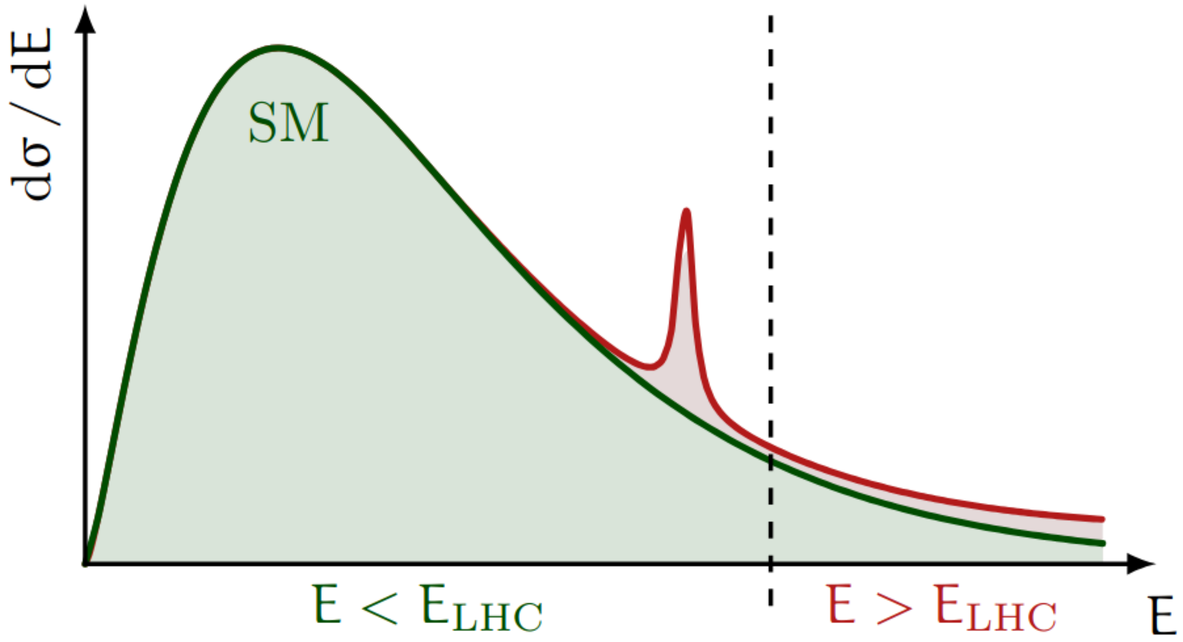
The Standard Model

- A powerful but incomplete description of our universe
  - No dark matter candidate
  - No description of gravity
  - No matter/antimatter asymmetry explanations
  - …
- At collider experiments we can **measure** SM processes and parameters or **search** directly for new physics



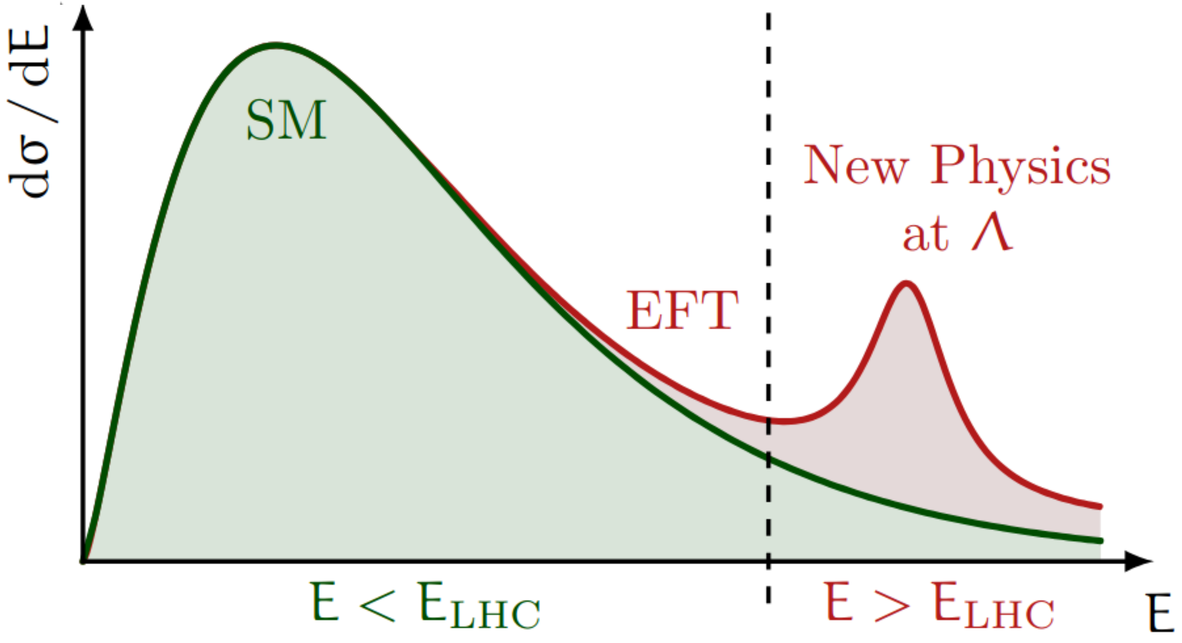
How to find new physics?

Searches



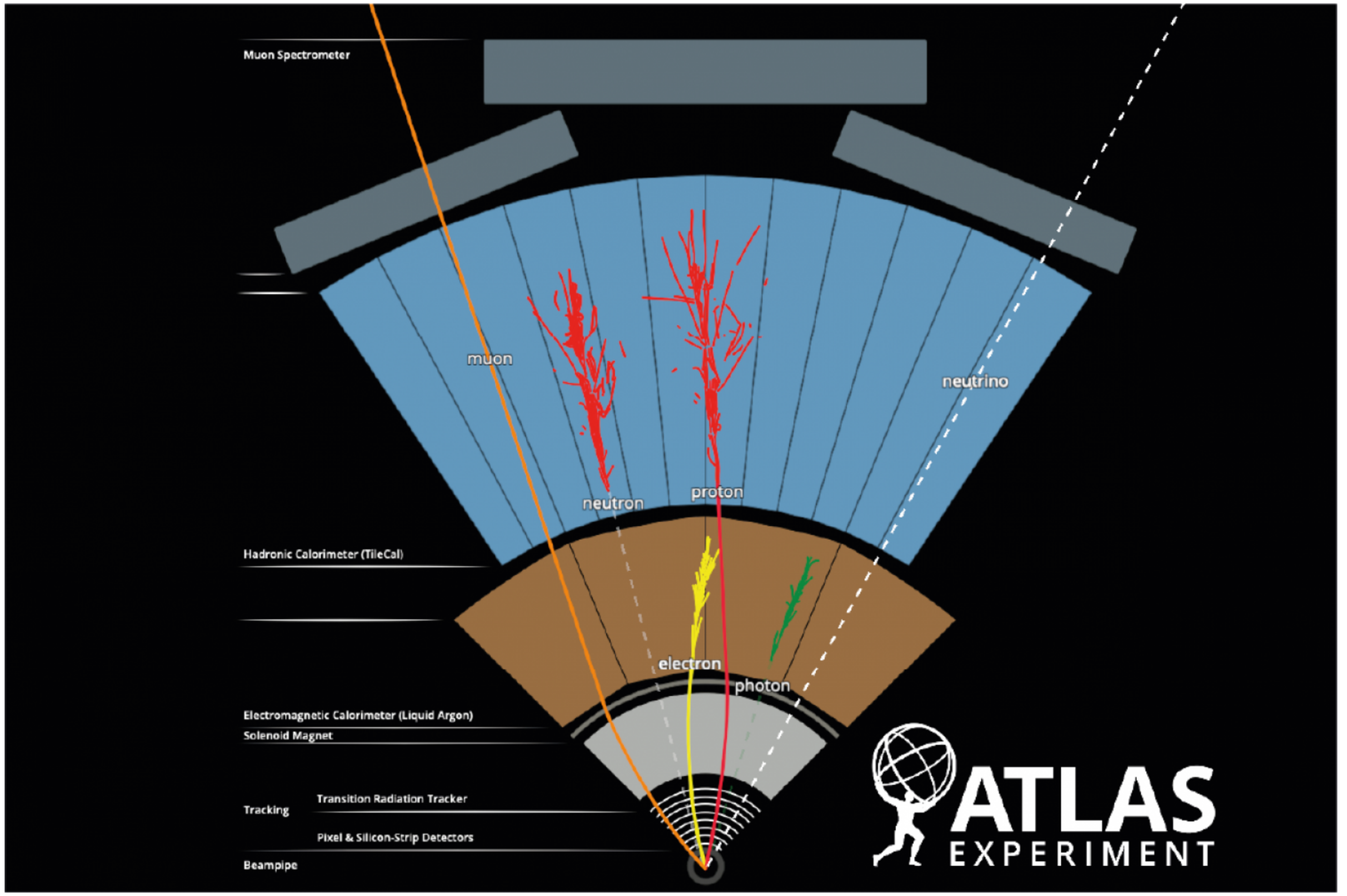
- Model dependent
- Assumes new physics is accessible at LHC energies

Measurements

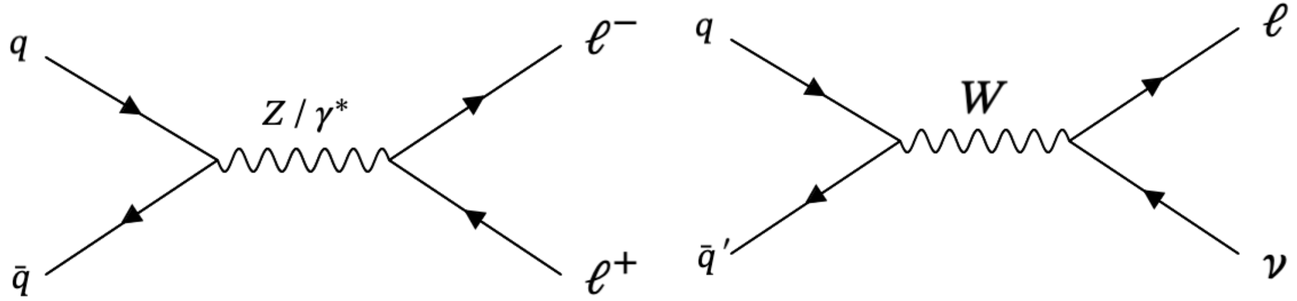


- Model independent Effective Field Theory (EFT)
- Requires precision measurements to probe deviations from SM in high-energy tails

The ATLAS detector



Dilepton production



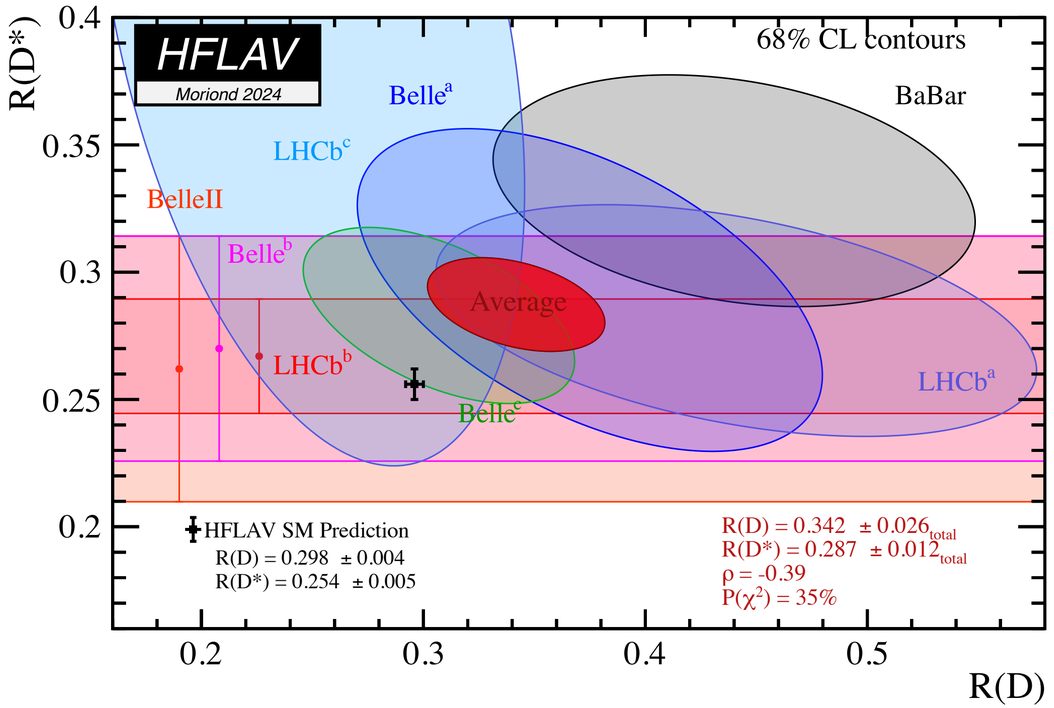
- Study of neutral current ($Z/\gamma*$) and charged current ($W^{\pm}$) Drell-Yan processes in proton-proton collisions
- Large production cross-section → high statistical precision
- Clean experimental signatures for e and μ
- τ channels more challenging but potentially preferential coupling to new physics
- High-mass region more sensitive to new physics
- Exploration of lepton flavour universality (LFU) possible through ratios of different channels

	Neutral current	**Charged current**
Light leptons	$\ell\ell$	$\ell\nu$
Tau leptons	$\tau\tau$	$\tau\nu$

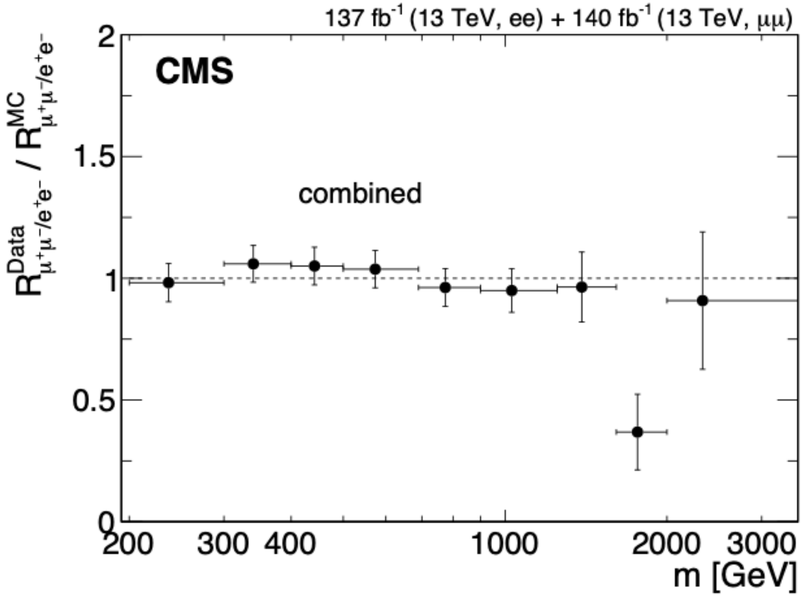
$\ell = e, \mu$

Flavour anomalies

- Tensions with the SM have been observed in vertices involving quarks and leptons ($q \to q'\ell\ell'$)
- Measurements of Drell-Yan probe the same vertices ($qq' \to \ell\ell'$)
  - CMS even sees a small tension in these measurements
- Performing measurements in association with b-hadron-tagged jets can further probe specifically the “B-anomalies” (i.e. $bs\ell\ell/bc\tau\nu$ vertices)



HFLAV



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Searches in Run-2

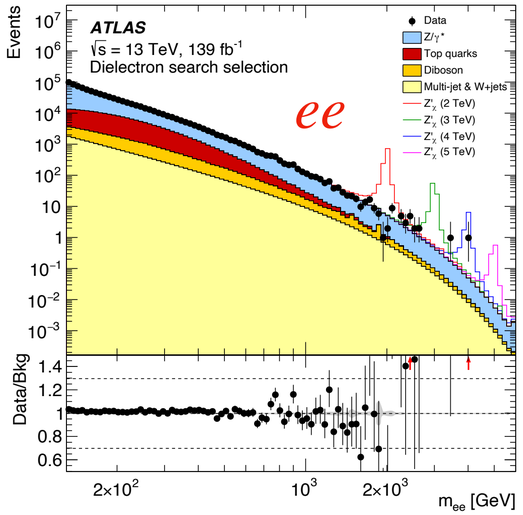
$\ell\ell$ - Phys. Lett. B 796 (2019) 68

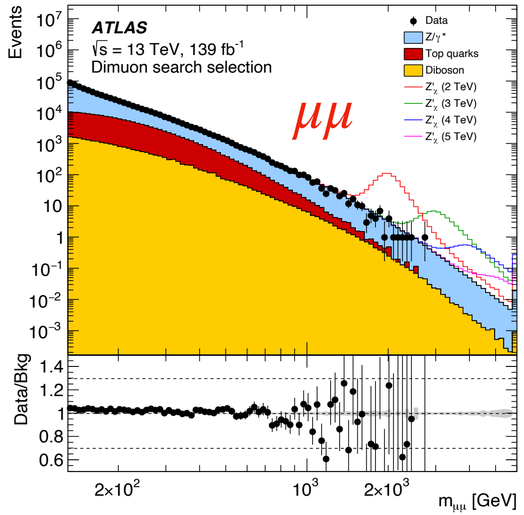
$\ell\nu$ - Phys. Rev. D 100 (2019) 052013

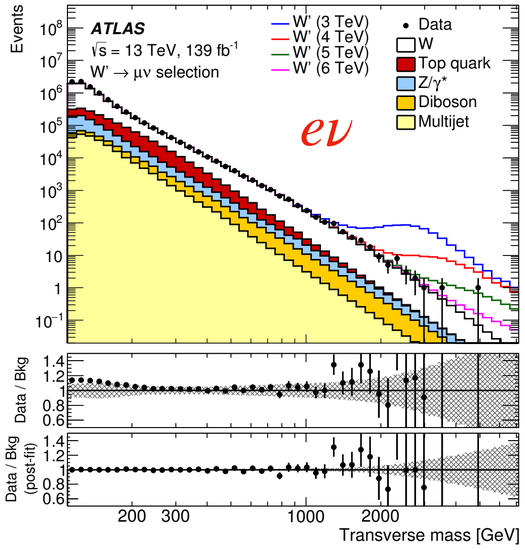
$\tau\tau$ - JHEP 01 (2018) 055

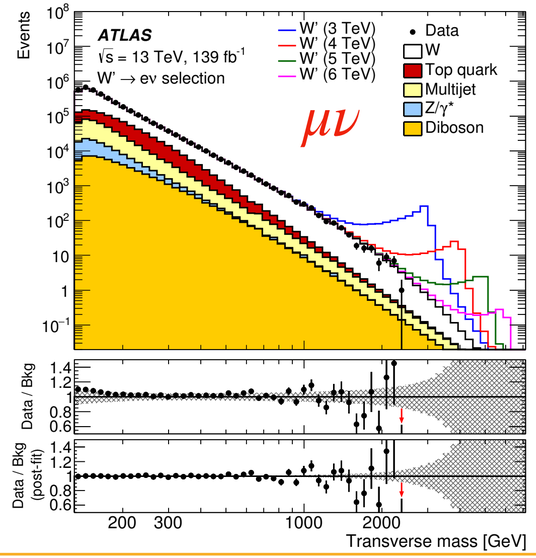
$\tau\nu$ - Phys. Rev. D 109 (2024) 112008

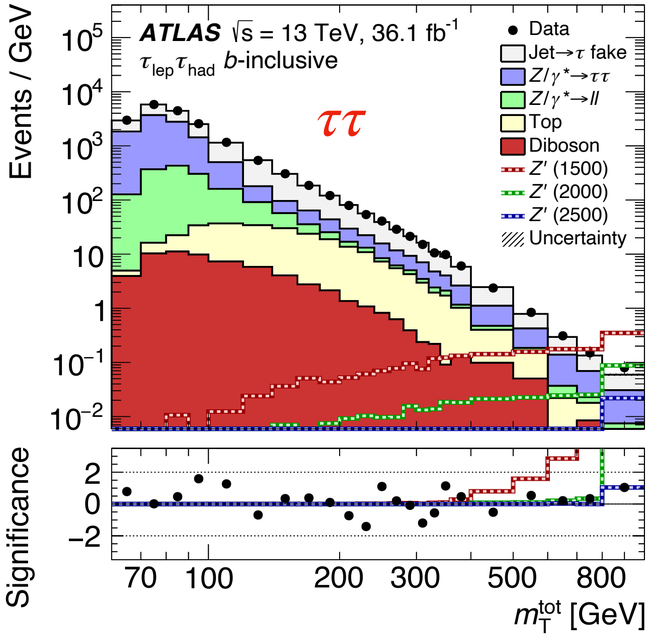
- Searches for new phenomena using 140 fb^{-1} data collected between 2015-2018
- All channels already published
- Contributions from Enigmass funding

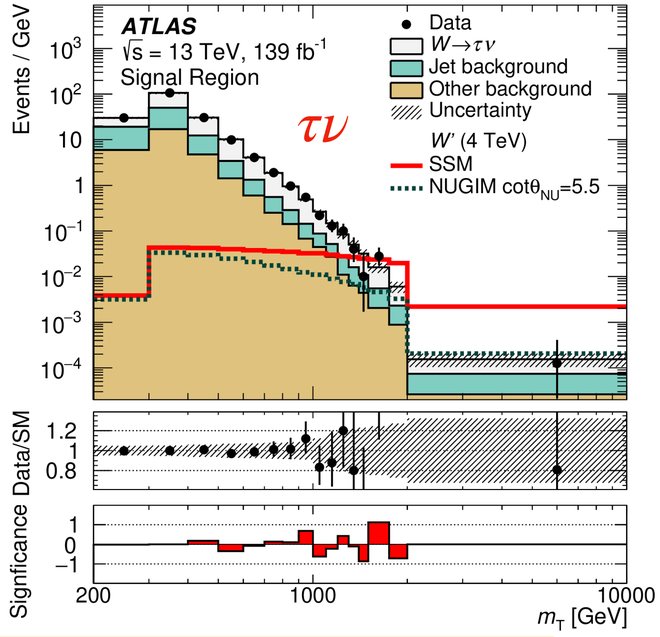








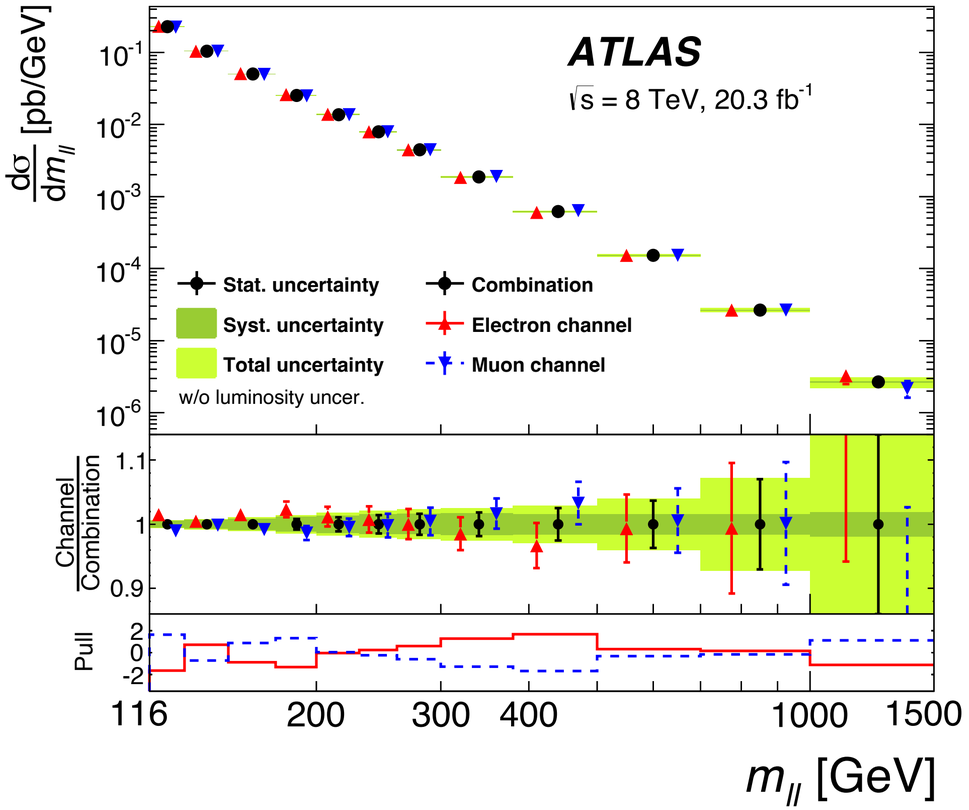




Measurements in Run-2

- Further exploit the data in order to measure precision cross-sections of processes
  - Powerful SM tests in their own right
- Requires very good control of **systematic uncertainties** and understanding of **backgrounds**, e.g. for $\ell\ell$:
  - $t\bar{t} \to bW^+\bar{b}W^- \to b\ell^+\nu_\ell\bar{b}\ell^-\bar{\nu}_\ell$ (~20%)
  - Diboson, mostly $WW \to \ell\nu\ell\nu$ (~2%)
  - Misidentified leptons (~2% electrons, ~0.3% muons)
- Run-2 measurements ongoing - expected improvement of precision up to factor 2.5

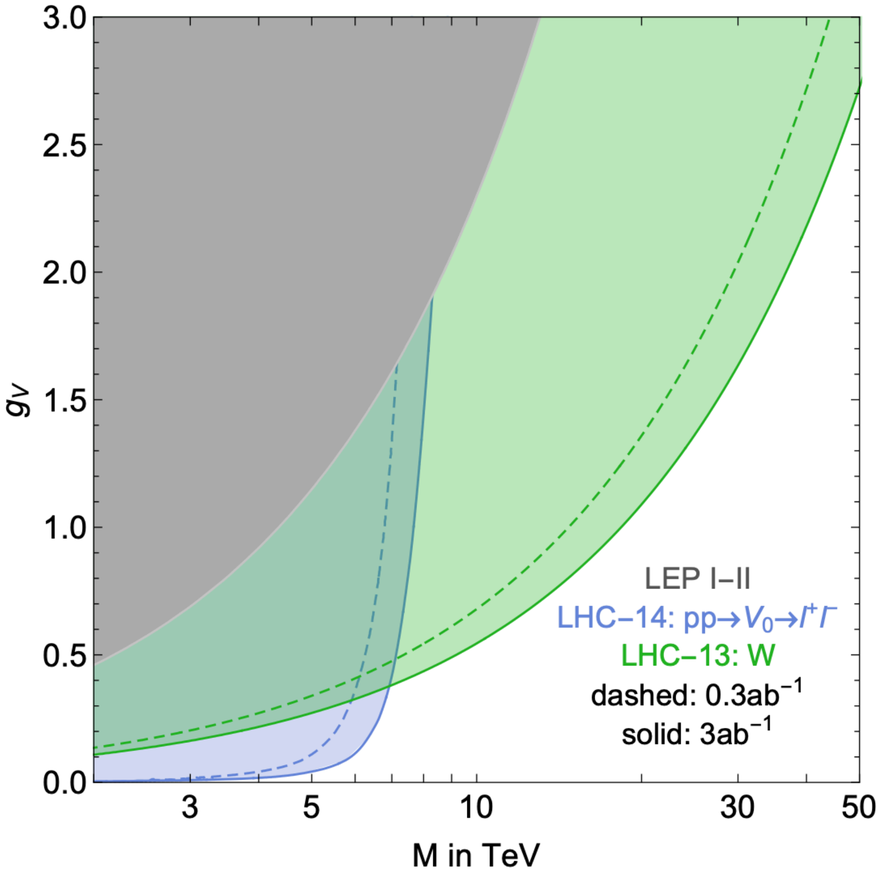
Example from Run-1!



JHEP 08 (2016) 009

Why measurements?

- Measurements are “unfolded” to truth level based on simulation particles
  - Correct for detector inefficiency, resolution and geometry
  - Easier comparison to theory predictions and other experiments
- Choice of binning for unfolding is also an important consideration for EFT sensitivity
- Measurements are used as inputs to EFT interpretations which can be used to extend reach beyond direct searches

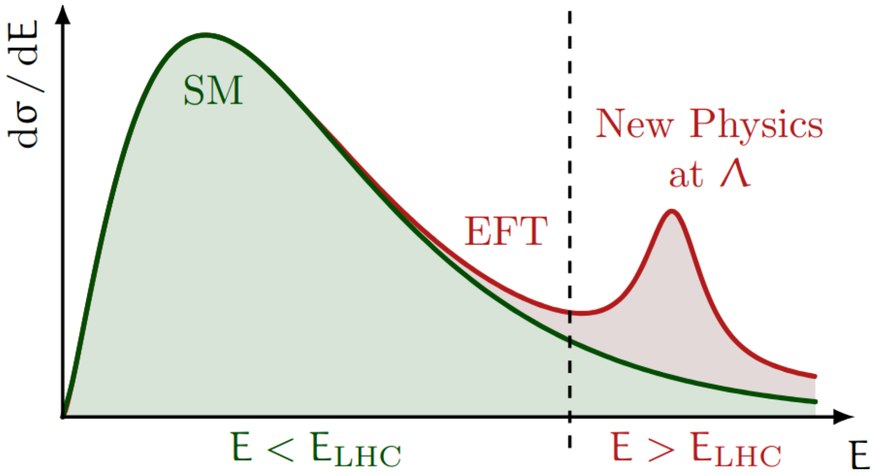


arXiv [hep-ph] 1609.08157

Effective field theories

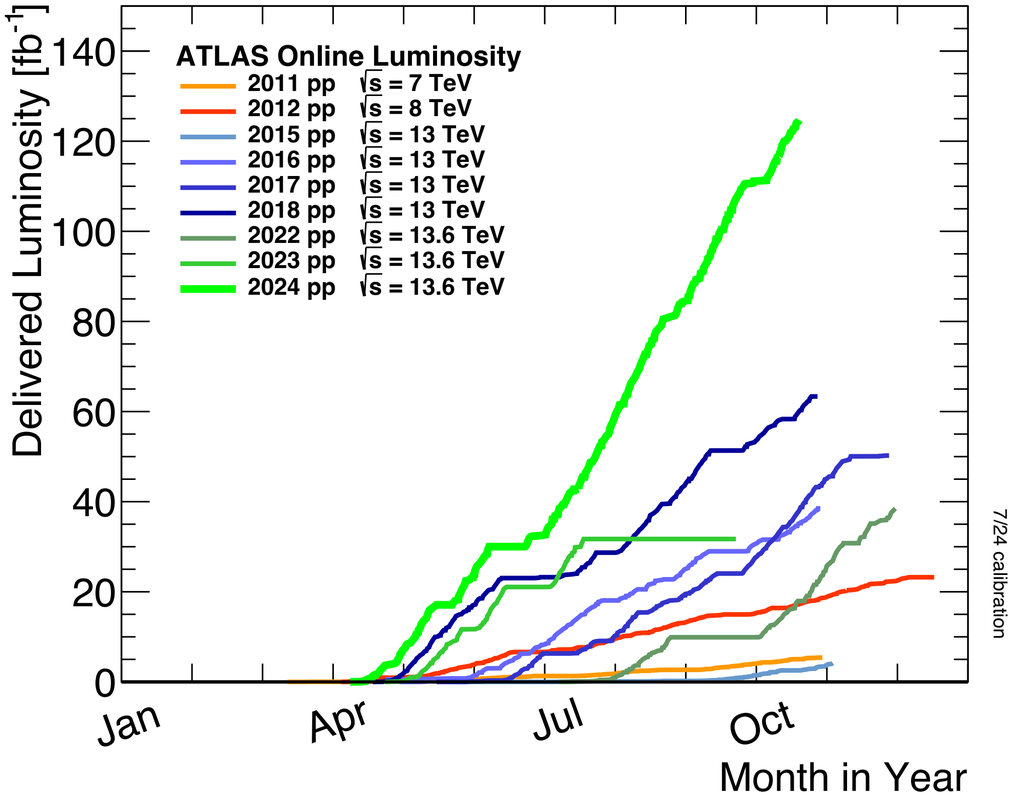
- Operators ($\mathcal{O}_i$) describing dimension-6 interactions arising at an energy scale Λ with corresponding couplings c_i
- High-mass Drell-Yan measurements provide strong constraints as precision is good (<20%) in the very high-mass (>500 GeV) regions, i.e. the most sensitive regions
  - Particularly for operators describing 4-fermion interactions
  - Enhanced sensitivity when also including b-jets
- Many measurements can also be combined to perform a **global fit** to provide the best limits on EFT operators
  - Also a contribution from LAPP here thanks to Enigmass funding

$$L_{SMEFT} = L_{SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)}$$



LHC Run-3

- Run-3 ongoing until ~mid 2026
- Centre-of-mass energy 13 → 13.6 TeV
- Factor ~2-3 luminosity increase, particularly important for statistically dominated bins at high mass - improving sensitivity to new physics
- Expected improvements in object reconstruction/ calibration
  - Applying state-of-the-art neural network techniques
  - Can be dominant source of uncertainty in some regions
- Proceed with a more harmonised effort between the different channels, common framework for LFU/EFT interpretations



Run 2 integrated luminosity: 140 fb^{-1}
Run 3 expected integrated luminosity: 300-400 fb^{-1}

Outlook

- Dilepton channels provide powerful ways to probe SM and search for new physics
- Many search papers published looking at these final states - new physics signs remain elusive!
- We are currently completing the Run-2 programme in these channels by measuring these channels and providing EFT interpretations
- Planning has already begun for Run-3 measurements

Thanks for your attention!

DITTO - GA 101089007