High mass Drell-Yan measurement at the ATLAS experiment

and its phenomenological interpretation

Ricardo González López
Supervised by: Prof. Uta Klein

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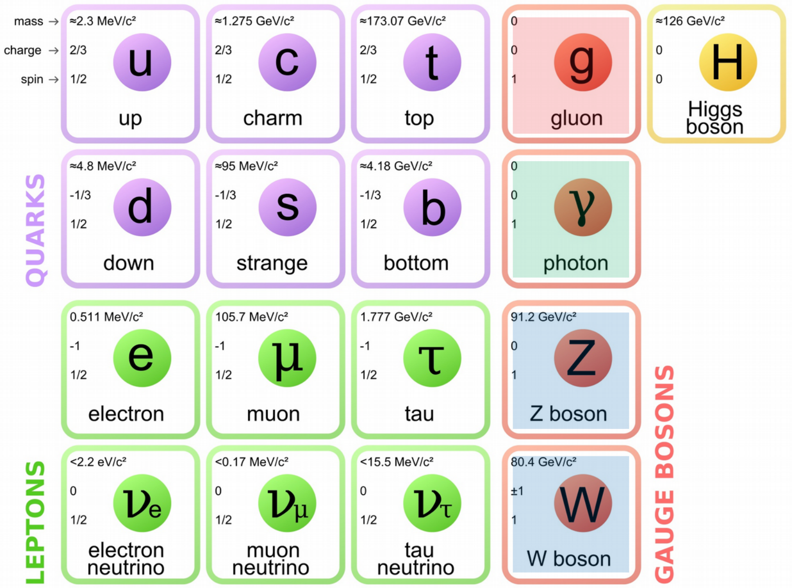
The Standard Model

- The "LEGO set" particle physicists use to explain a wide variety of phenomena in the universe

Building blocks



mass → charge → spin →	≈2.3 MeV/c^2 2/3 1/2 u up	≈1.275 GeV/c^2 2/3 1/2 c charm	≈173.07 GeV/c^2 2/3 1/2 t top	0 0 1 g gluon	≈126 GeV/c^2 0 0 H Higgs boson
QUARKS	≈4.8 MeV/c^2 -1/3 1/2 d down	≈95 MeV/c^2 -1/3 1/2 s strange	≈4.18 GeV/c^2 -1/3 1/2 b bottom	0 0 1 γ photon	
	0.511 MeV/c^2 -1 1/2 e electron	105.7 MeV/c^2 -1 1/2 μ muon	1.777 GeV/c^2 -1 1/2 τ tau	91.2 GeV/c^2 0 1 Z Z boson	GAUGE BOSONS
LEPTONS	<2.2 eV/c^2 0 1/2 ν_e electron neutrino	<0.17 MeV/c^2 0 1/2 ν_μ muon neutrino	<15.5 MeV/c^2 0 1/2 ν_τ tau neutrino	80.4 GeV/c^2 ±1 1 W W boson	

Instructions' book

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

Fundamental forces:

Strong

Electromagnetic

Weak

The Standard Model

- The "LEGO set" particle physicists use to explain a wide variety of phenomena in the universe

Building blocks

Instructions' book

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

Fundamental forces:

Strong

Electromagnetic

Weak

We know there are things SM fails to explain:

Dark matter/energy

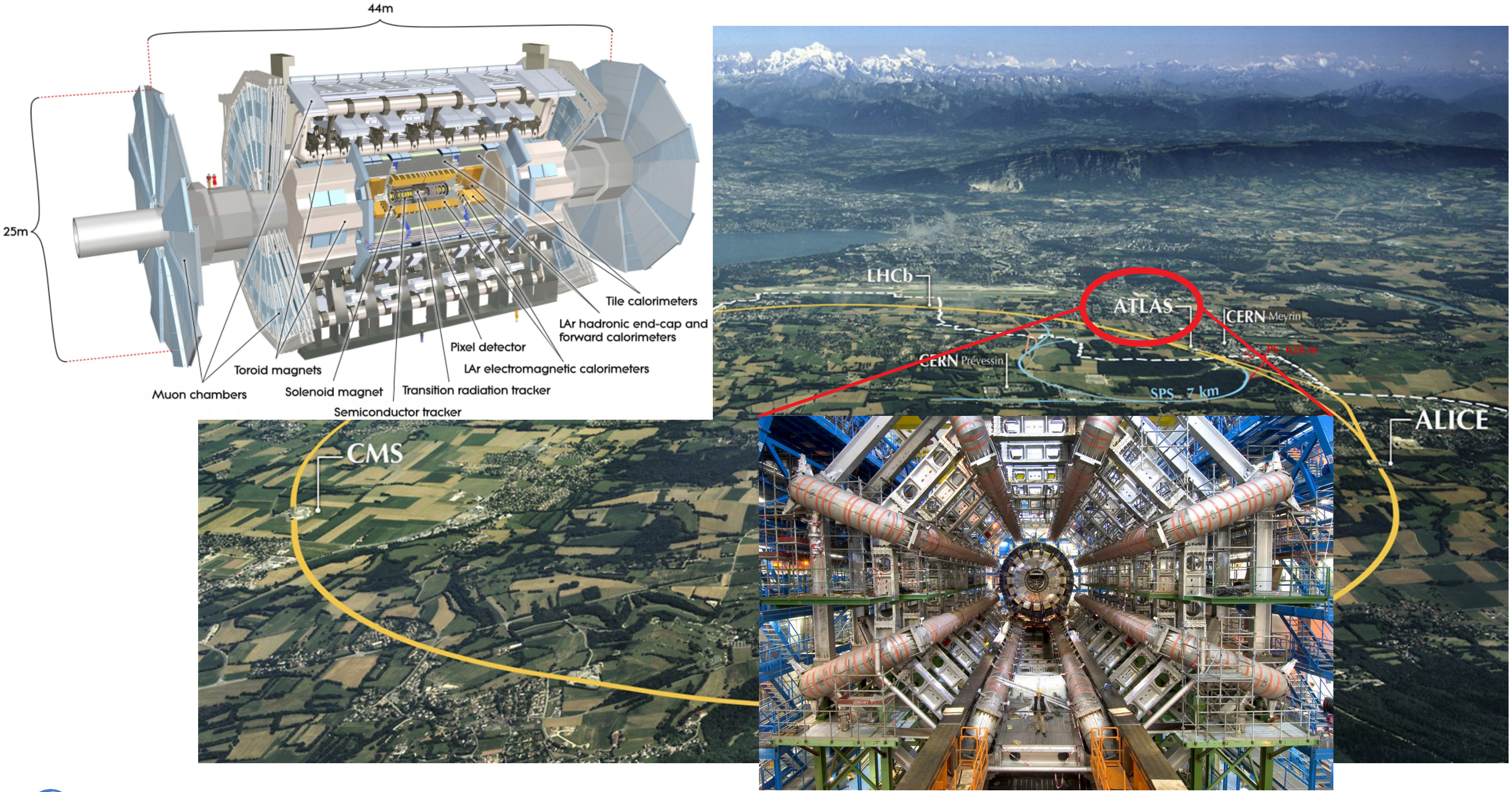
Neutrino oscillations

Gravitational interactions

...

Either one of the blocks rolled down the couch or we're missing pages in the instructions book, need to find them!

LHC and the ATLAS experiment



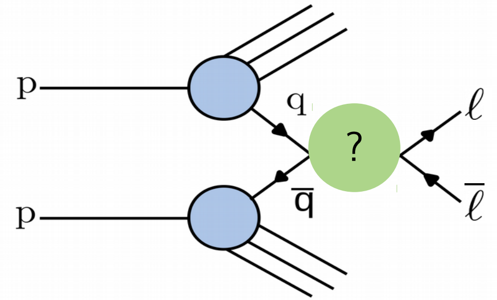
BSM searches in the dilepton final state

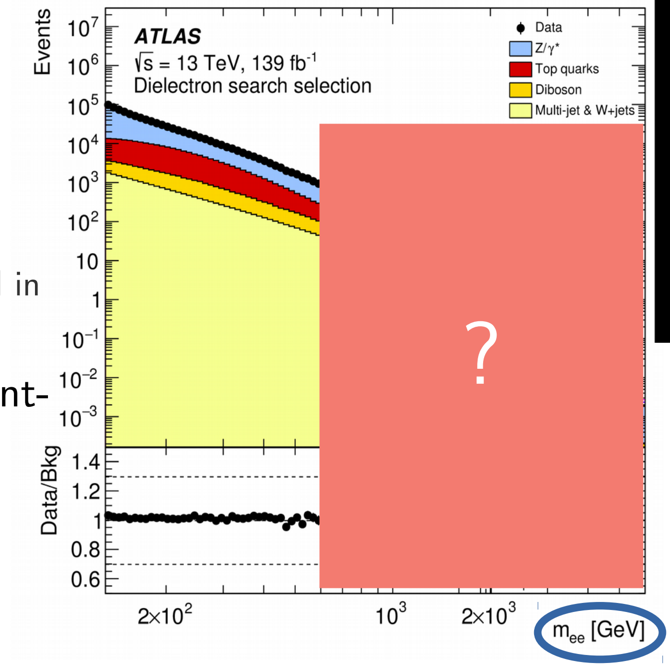
- LHC allows us to probe energies that hadn't been looked at before, ATLAS collected 139 fb^{-1} of proton-proton collision data at $\sqrt{s}=13$ TeV in Run 2.
- This presentation will focus at dilepton final states.
- Here new physics may arise in different ways:
  - If we add new symmetries to the $SU(3)\otimes SU(2)\otimes U(1)$ group that forms the Standard Model new gauge bosons appear.

    → Resonances

    By searching for resonances many particles were found in the 20th century.
  - If we assume quarks and leptons are not point-like, new interactions may arise.

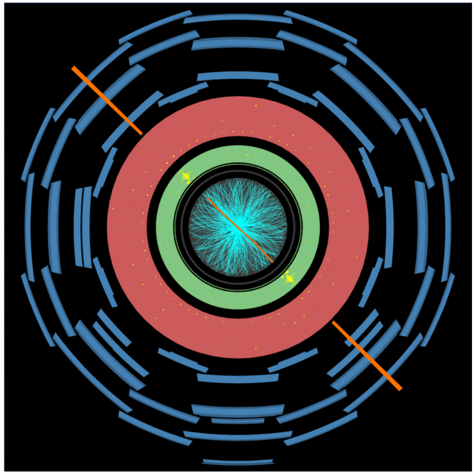
    → Contact interactions, non-resonant phenomena





Bottom: dielectron event as seen by ATLAS

Phys. Lett. B 796 (2019) 68



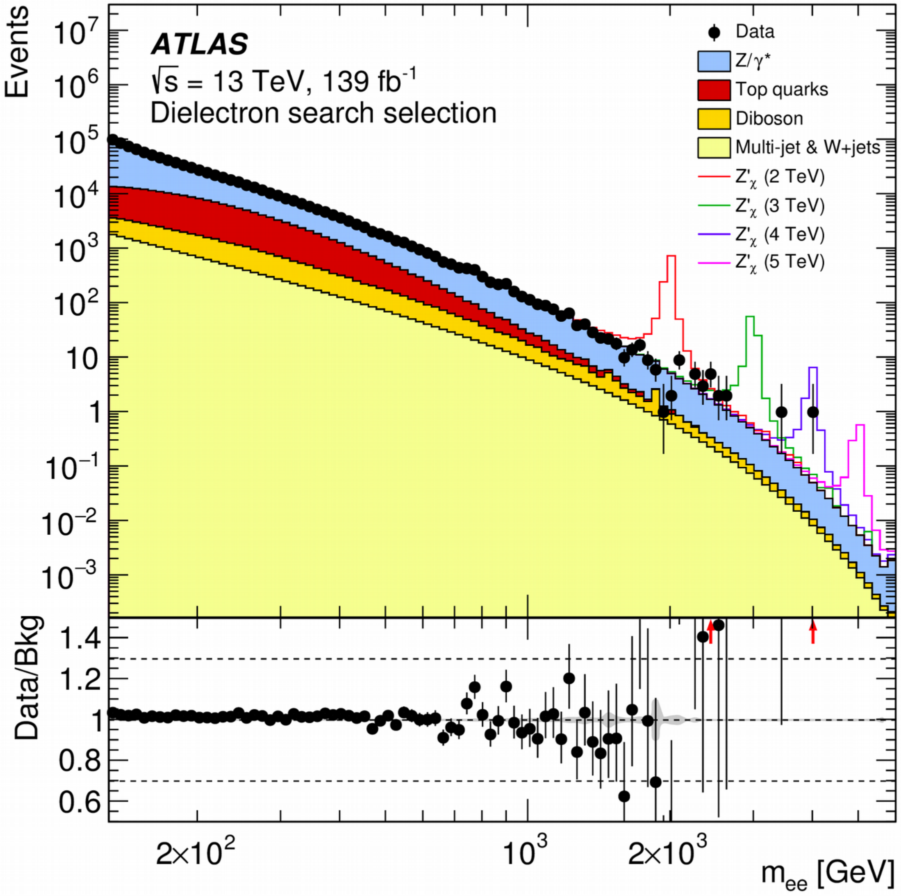
Discriminant variable used is the dilepton mass, sum of the 4-momentum of the dilepton pair in an event. Gives a handle on the "energy" of the pair.

BSM searches in the dilepton final state: resonances

- Assuming the existence of new Z' bosons, their decays could make resonant peaks appear at high mass.

- The mass of the considered Z' candidate determines the position of the resonance in the m_{ee} spectrum, just as the decay of the SM Z boson creates a resonance at m_{ee}~90 GeV.

- No significant deviation is observed, but we can set a limit on the lowest $m_{Z'}$ value compatible with data: $m_{Z'}>4.50$ TeV
  - Limits are set on σ·Br, which depends on the Z' model we consider. Results shown for Z'_{ψ}.

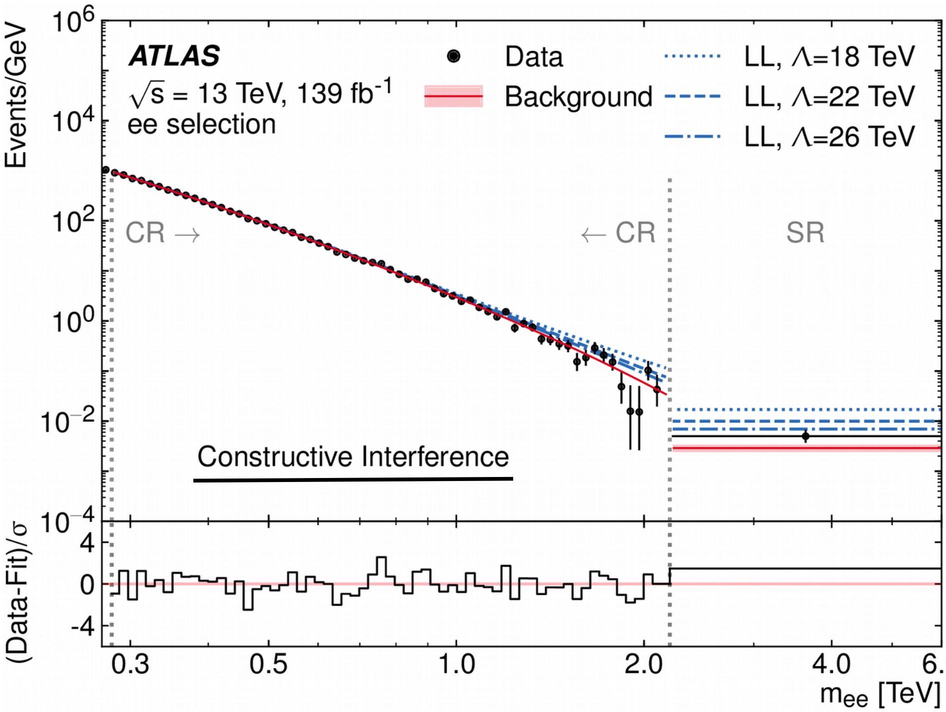


From Phys. Lett. B 796 (2019) 68

BSM searches in the dilepton final state: contact interaction

- Signature is a quark-lepton contact interaction, implying quarks and leptons are composite.
- This interaction would manifest as an effective contact interaction below the compositeness scale, Λ.
    - The same idea behind Fermi's theory of beta decay. Contact interaction at low energies, W mediates at high energies.
- The interaction would <u>enhance</u> the dilepton event rate at the TeV mass scale.
- No significant deviation is observed, but we can set observed (expected) limits on the lowest Λ value compatible with data: $\Lambda > 35.8(37.6)$ TeV.

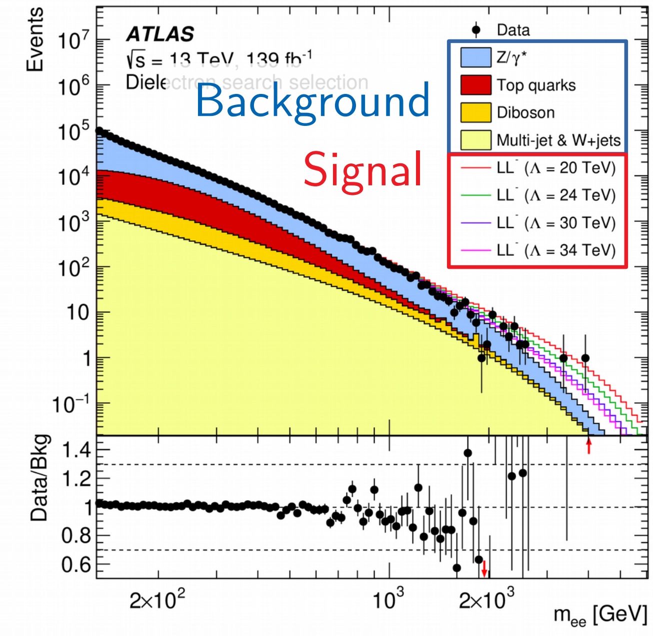
$$\mathcal{L} = \frac{g^2}{\Lambda^2}\{\ \eta_{LL}(\bar{q}_L\gamma_\mu q_L)(\bar{\ell}_L\gamma_\mu\ell_L) + \eta_{RR}(\bar{q}_R\gamma_\mu q_R)(\bar{\ell}_R\gamma_\mu\ell_R) + \eta_{LR}(\bar{q}_L\gamma_\mu q_L)(\bar{\ell}_R\gamma_\mu\ell_R) + \eta_{RL}(\bar{q}_R\gamma_\mu q_R)(\bar{\ell}_L\gamma_\mu\ell_L)\}$$

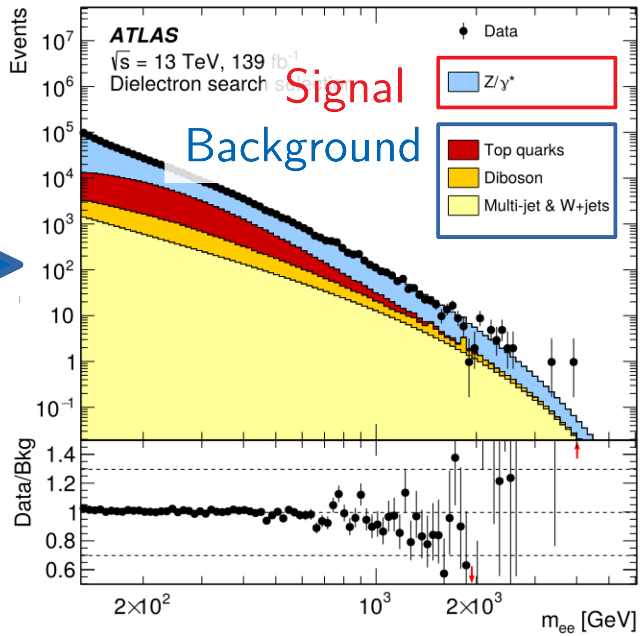


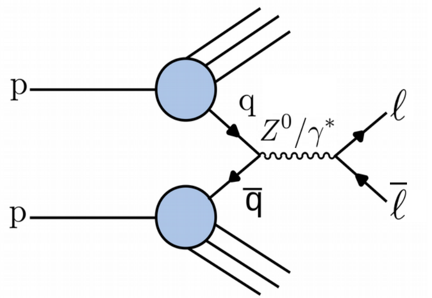
From JHEP 11 (2020) 005

From BSM searches to SM precision measurements

- No sign of new physics was found, but we can change our approach on how we interpret our data.
- Rather than searching for new physics, we can provide precision measurements of the cross section of the dilepton production.





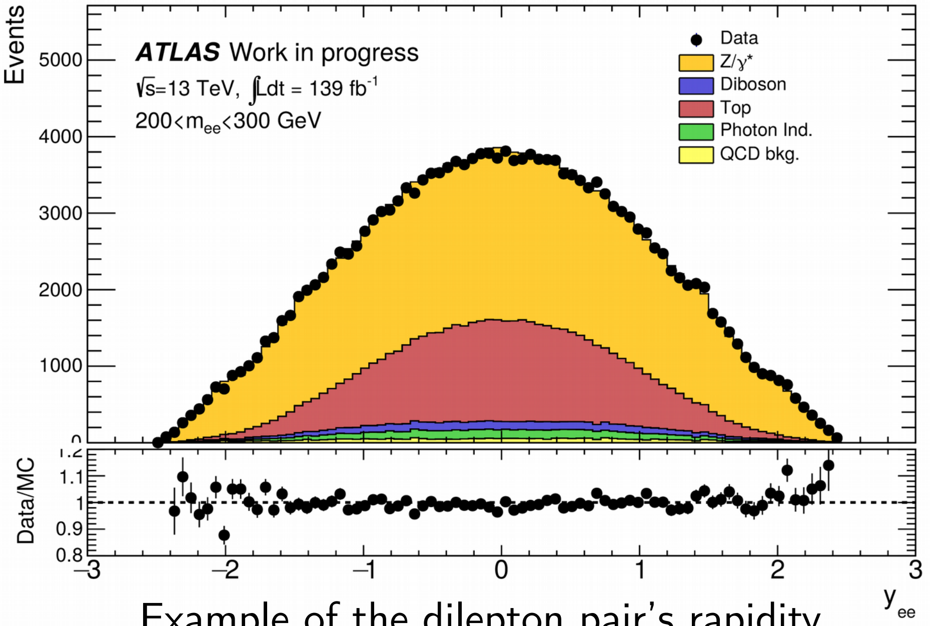


Can be used to:

- Set PDF constraints in wide *X*-range.
- Understand QCD modelling of boson's p_T from ~0 GeV to large values.
- EFT interpretations.

High-mass Drell Yan

- The analysis aims to measure single ($d\sigma/dm_{ll}$) and double ($d^2\sigma/dm_{ll}d|y_{ll}|$) production cross sections of neutral-current DY at $116<m_{ll}<5000$ GeV.
- High energy probed by this analysis provides a significant input to EFT fits (see following slides).
  - Future plans also include PDF fits.
- The results are corrected for detector efficiencies and unfolded to particle level.
- Measurement performed in the electron and muon channels, testing the compatibility of both lepton decays and providing the combination of their cross sections.



Example of the dilepton pair's rapidity measurement in the mass slice $200<m_{ee}<300$ GeV.

The cross section can be extracted by measuring the number of data events recorded and subtracting the other SM backgrounds that decay into a dilepton pair.

High-mass Drell Yan: EFT interpretation

- SM precision measurements still leave room for potential BSM physics interpretations.
- An Effective Field Theory (EFT) approach can be used to set model-independent constraints on BSM physics:

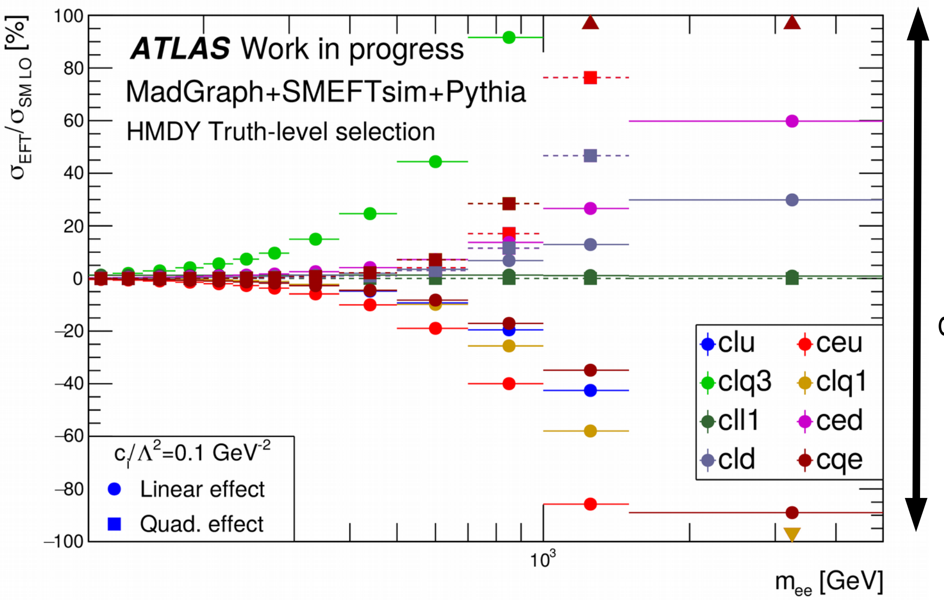
$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{d>4} \mathcal{L}^{(d)} = \underbrace{\boxed{\mathcal{L}_{\mathrm{SM}}}}_{\text{SM}} + \boxed{\sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}}\ \text{New physics}$$

- SM is interpreted as the low-energy regime of a more general theory, where new physics is introduced by higher-dimensional operators (O_i) suppressed by the energy scale of the new physics (Λ).
- Each operator is associated to a coefficient c_i, which measures the impact of said operator.
- The impact of each operator on the SM amplitude splits in the interference with SM (linear), the pure EFT contribution (quadratic).

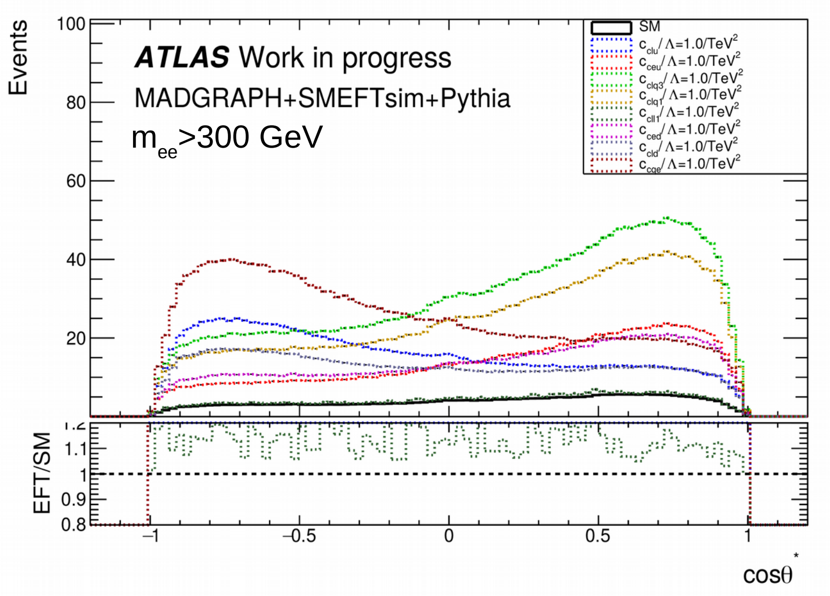
$$|\mathcal{A}_{\mathrm{SM}} + \sum_i c_i \mathcal{A}_i|^2 = |\mathcal{A}_{\mathrm{SM}}|^2 + \sum_i \underbrace{c_i 2\mathrm{Re}(\mathcal{A}_{\mathrm{SM}}^* \mathcal{A}_i)}_{\text{Linear}} + \sum_i \underbrace{c_i^2 |\mathcal{A}_i|^2}_{\text{Quadratic}}$$

High-mass Drell Yan: EFT interpretation

- EFT contributions are modelled using SMEFTsim: JHEP 12 (2017) 070
- New operators alter the cross section, increasing (decreasing) the total cross section when positively (negatively) interfering with the SM processes.



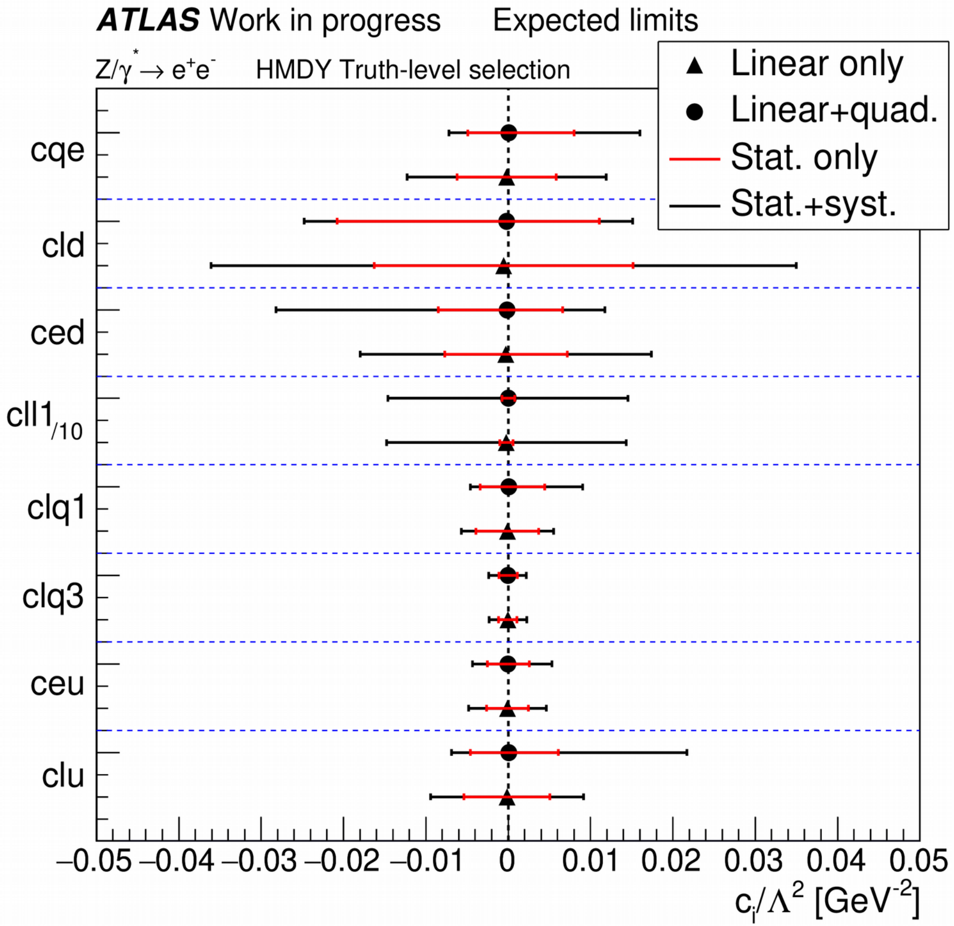
EFT contribution with respect to the SM cross section in each given bin.



- Angular variables offer a lot of potential for EFT fits in neutral-current Drell-Yan.
- Left: each operator not only increases the SM cross section, but shifts the distribution in different directions.

Drell Yan analyses: HMDY EFT interpretation

- Dimension 6 operators are considered. SM flavour assumptions are also taken to reduce the number of operators ($>2500 \rightarrow 93$ parameters)
- Limits are set on the c_i/Λ^2, both give a handle on the operator's impact and we cannot disentangle them.
- Limits currently set using 1D ($d\sigma/dm_{ll}$) pseudo-data using the expected statistical and systematic uncertainties → Expected limits
- The combination of electron and muon decay channels allows for improved limits.
- Neutral-current DY offers the potential for leading constraints on 4-fermion operators.



Conclusion

- The Run 2 ATLAS dataset contains wealth of data taken at energies never reached before, a good place to look for BSM phenomena.
- The searches in high-mass dilepton final states didn't find any significant deviation from Standard Model, although leading constraints were set on the mass of potential new bosons and contact interaction energy scales.
- Precision Standard Model measurements are now on-going, aiming to provide crucial inputs for a wide variety of studies.
- This still leaves room for BSM interpretations, such as Effective Field Theories. We aim to set leading constraints to this thriving framework.

Thanks for your attention!