2nd year of PhD: Probing new phenomena in the final state with two leptons in the ATLAS detector at the LHC

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Timoty Duong 05/06/2026

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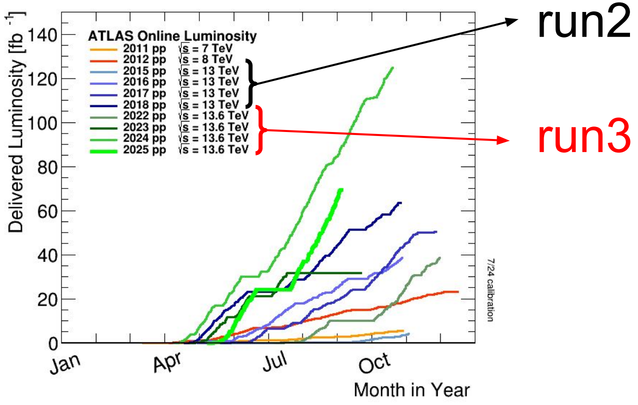
DITTO - GA 101089007

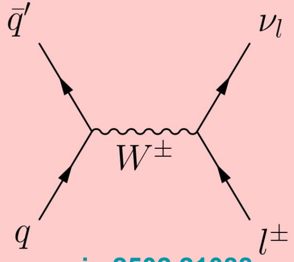
ATLAS Drell-Yan analyses overview

$l =$ light flavour leptons $\quad e/\mu$



CC Drell-Yan

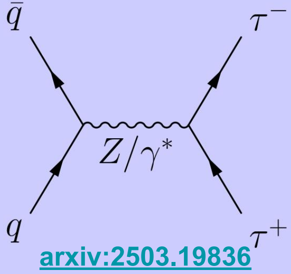
$W^{+-} \rightarrow l^{+-}\nu_l$



arxiv:2502.21088

NC Drell-Yan($\tau\tau$)

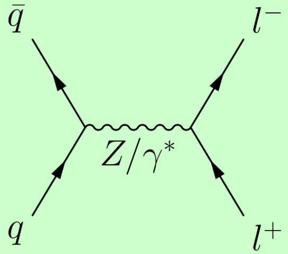
$Z/\gamma^* \rightarrow \tau^+\tau^-$ (+b)



arxiv:2503.19836

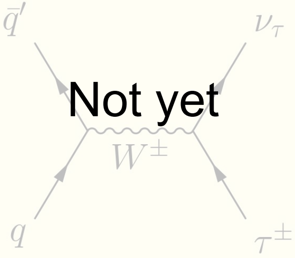
NC Drell-Yan(ll)

$Z/\gamma^* \rightarrow l^-l^+$ (+b)



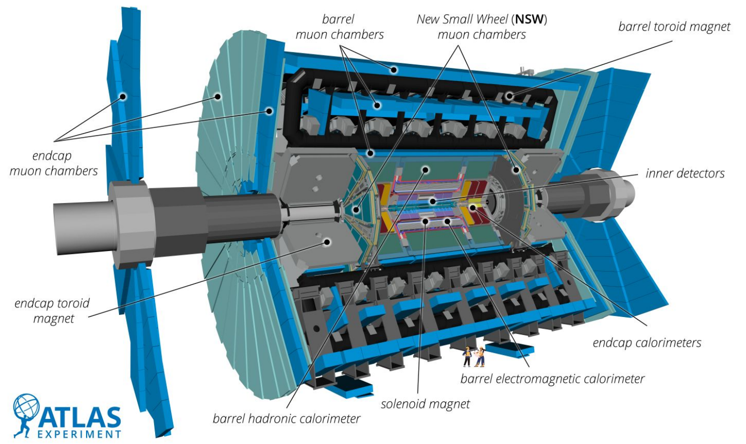
($\tau\nu$) Drell-Yan

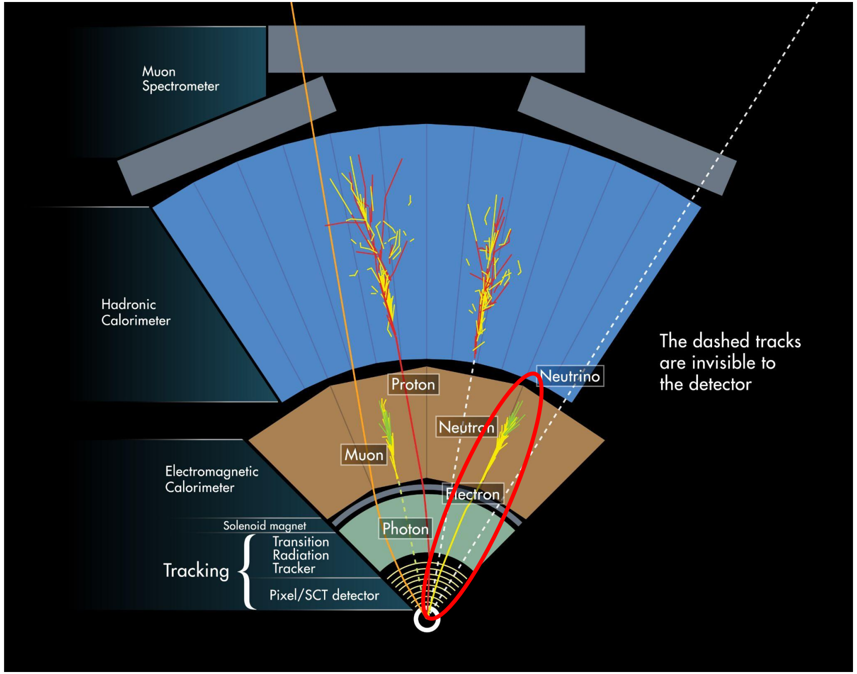
$W^{+-} \rightarrow \tau^{+-}\nu_\tau$



At LAPP

Object reconstruction in ATLAS





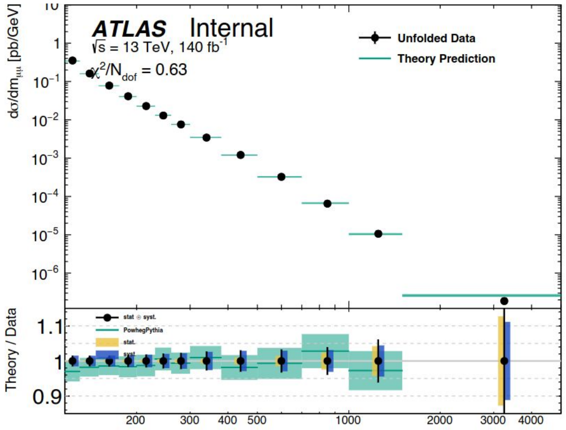
- We don't detect particles but their interaction with our detector !

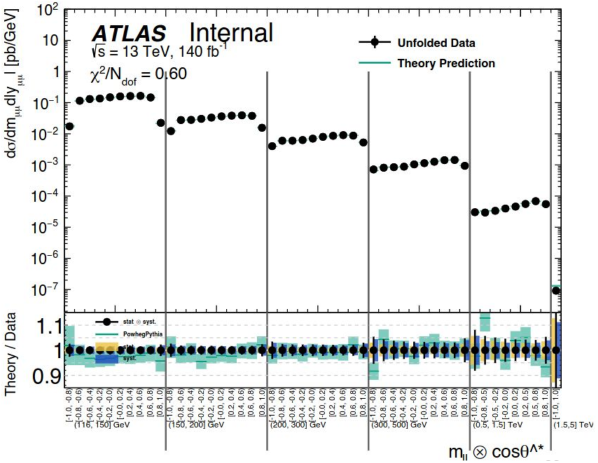
Neutral current Drell-Yan measurements

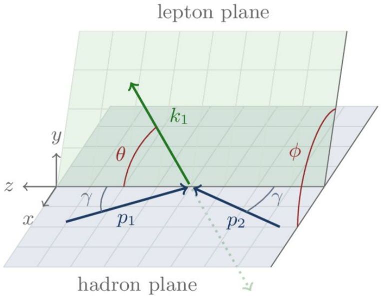
- **2 measurements:**

Differential unfolded cross-section as a function of the di-lepton invariant mass **(1D)**

Double differential unfolded cross-section as a function of the invariant mass and cos(θ*) **(2D)**







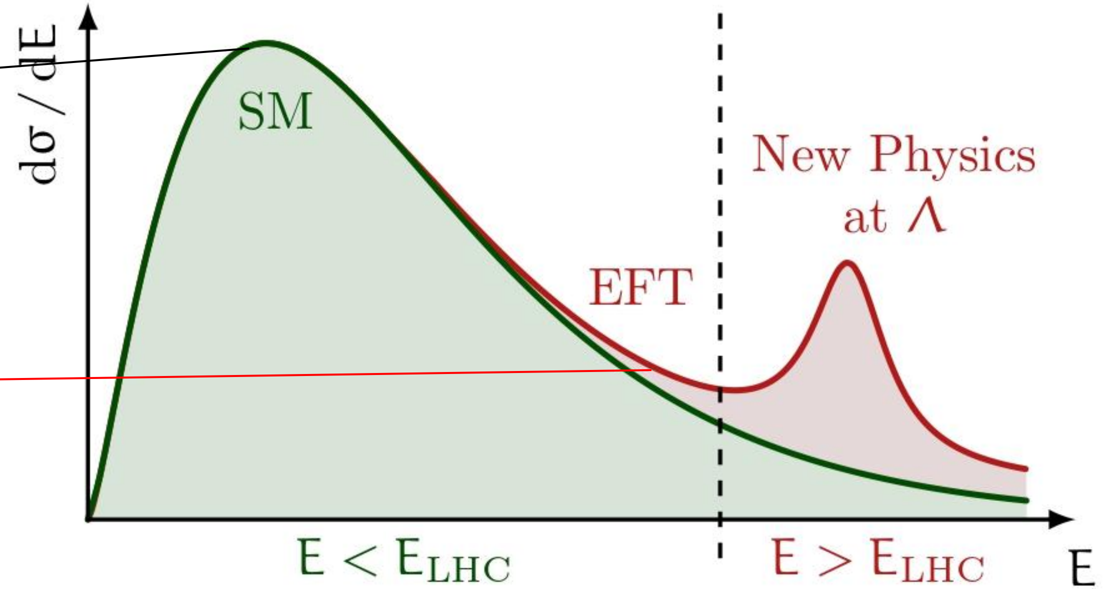
Mass spectrum up to 5 TeV

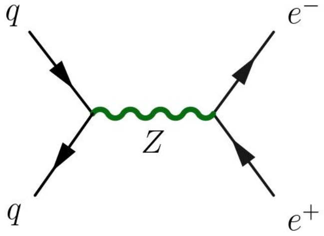
Mass spectrum + angular information : cos(θ*)

New Physics with Effective Field Theory (EFT)

Known Standard Model

Precision measurements sensitive to small deviations from known Standard Model





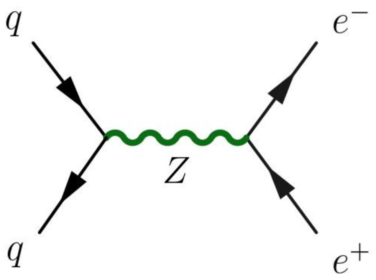
$$L_{SMEFT} = L_{SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)}$$

EFT operators for Neutral Current HMDY

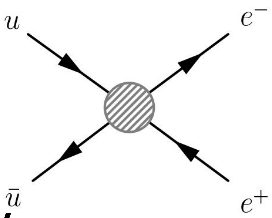
- In total **45 operators** affecting the measurements, 24 out of 45 correspond to 4-fermion operators

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

Each process is sensitive to specific interactions !
For the Drell-Yan process :



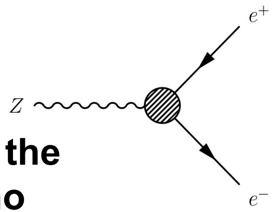
$$(\mathcal{O}_{lu})_{11} = ((\bar{l}_p \gamma_\mu l_r)(\bar{u}\gamma^\mu u))_{11}$$



$$(c_{lu})_{11}$$

4-fermions operators with a strong kinematic dependence on the energy

$$(\mathcal{O}_{Hl}^{(1)})_{11} = (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)_{11}$$



$$(c_{Hl}^{(1)})_{11}$$

Normalisation operators changing the couplings to the the bosons with no strong kinematic dependence

Neutral current Drell-Yan measurements with SMEFT

- Each new operator changes the cross-section of the process from the Standard Model one.

- I used MadGraph+Pythia to generate the SMEFT cross-section for different terms of expansion:

$$|M^2| = |M_{SM} + \sum_i \frac{c_i}{\Lambda^2} M_i|^2 = |M_{SM}|^2 + 2\sum_i \frac{c_i}{\Lambda^2} Re(M_{SM}^* M_i) + \sum_i \frac{c_i^2}{\Lambda^4} |M_i|^2$$

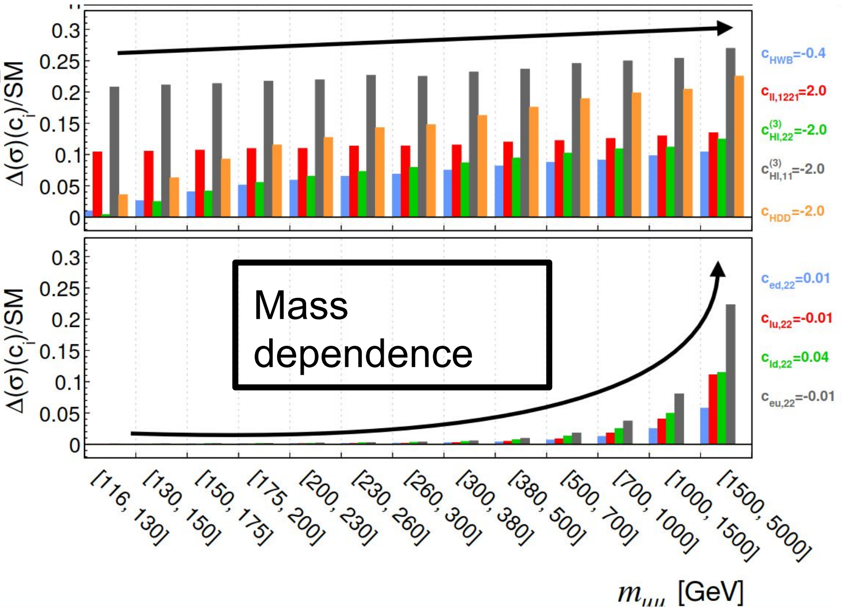
	Standard Model	Linear terms	Quadratic terms
Number of samples :	1	45	~400

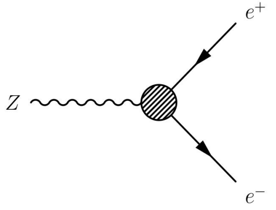
- Samples generated with c = 1 and Λ=1 TeV

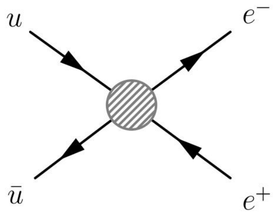
Parameterisation of the SMEFT effects

Normalisation operators

4 fermions operators with growing mass dependence



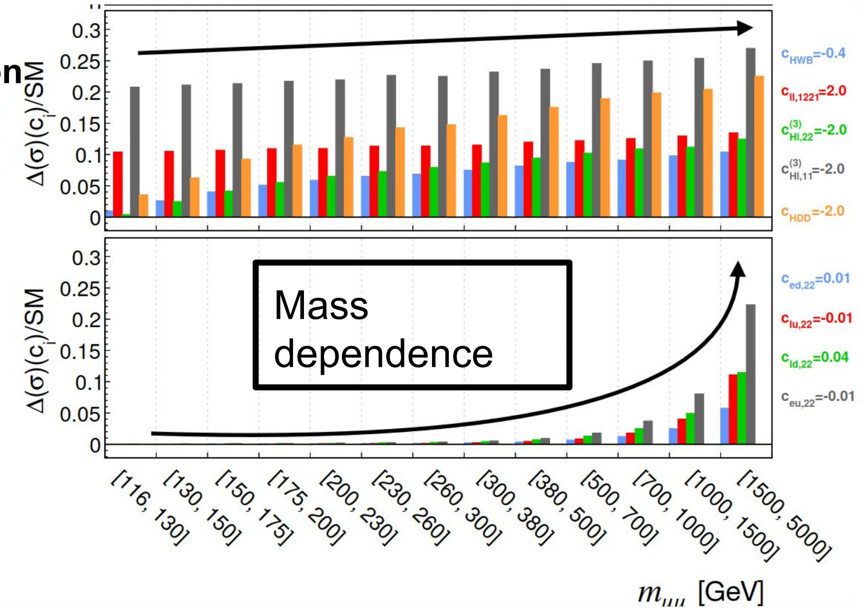




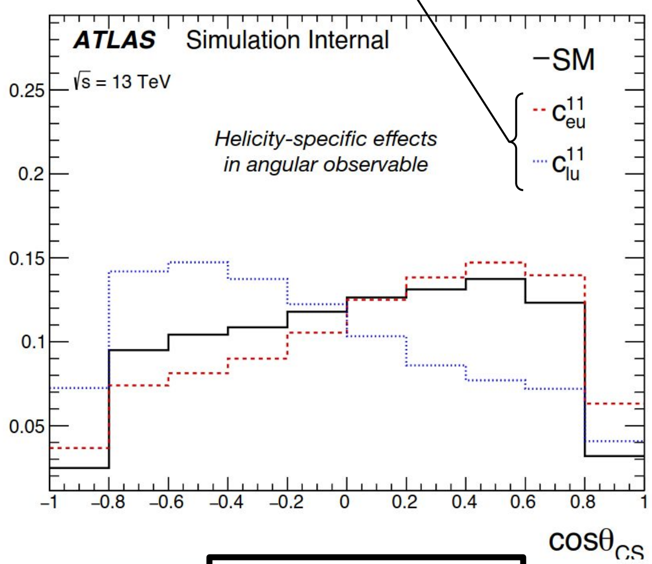
Parameterisation of the SMEFT effects

Normalisation operators

4 fermions operators with growing mass dependence



Opposite helicities



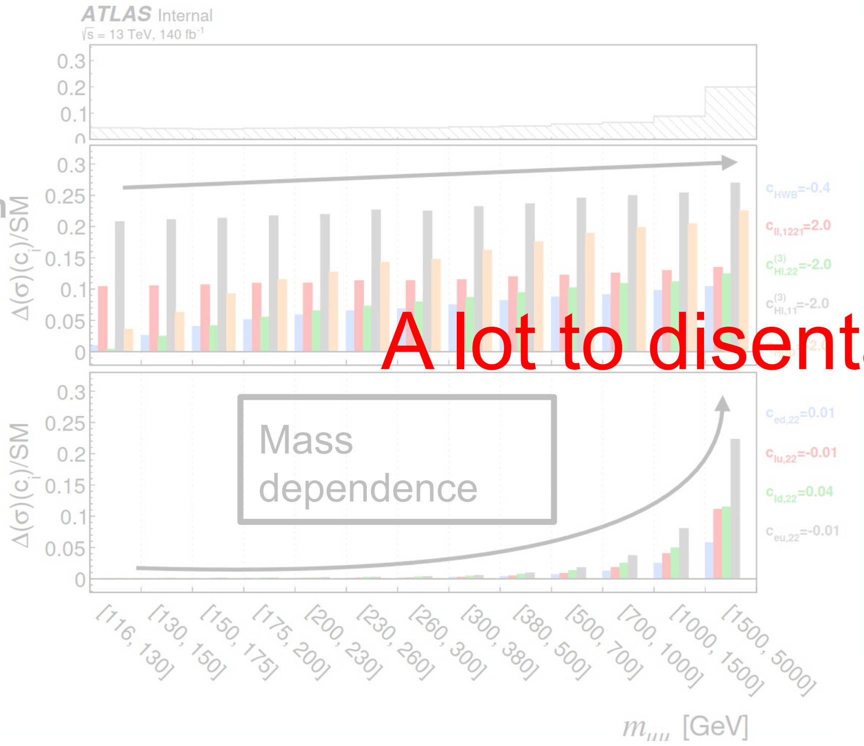
Angular dependence

Parameterisation of the SMEFT effects

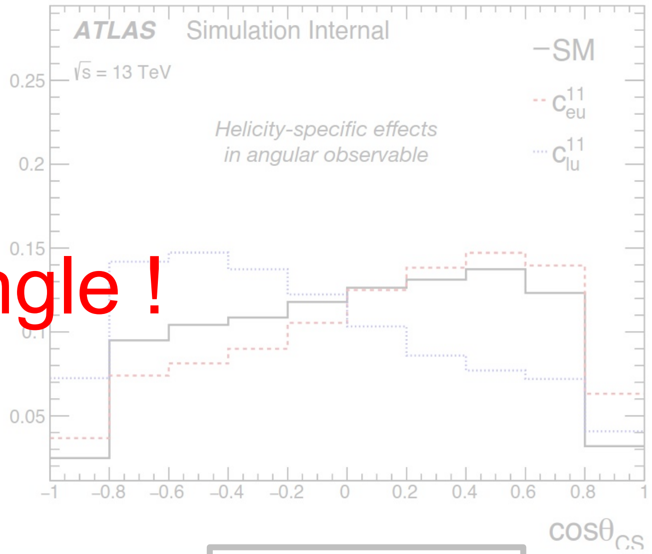
measurement uncertainty

Normalisation operators

4 fermions operators with growing mass dependence



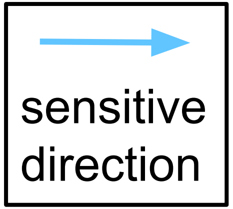
A lot to disentangle !

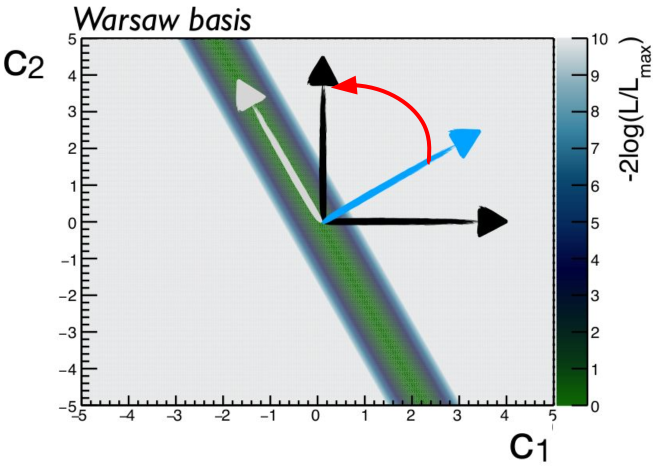


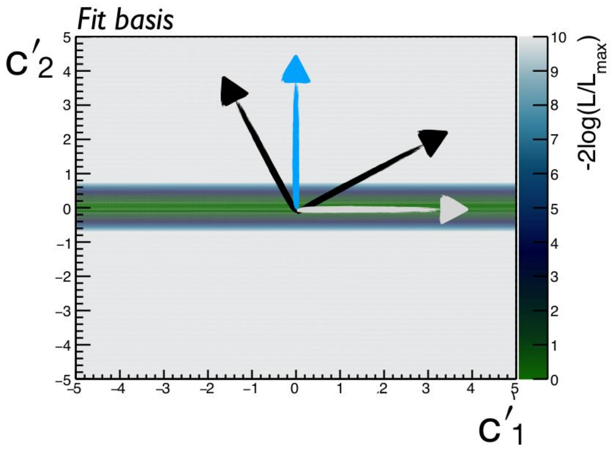
Angular dependence

Finding sensitive directions

- Principal Component Analysis (PCA) : reparametrize (fit basis) the coupling space (Warsaw basis) by doing a rotation to eliminate direction we can not constrain
- The fitbasis can be more practical when confronting to measurements than the Warsaw basis (built on theory considerations)
- This allows us to constrain multiple parameters at the same time !







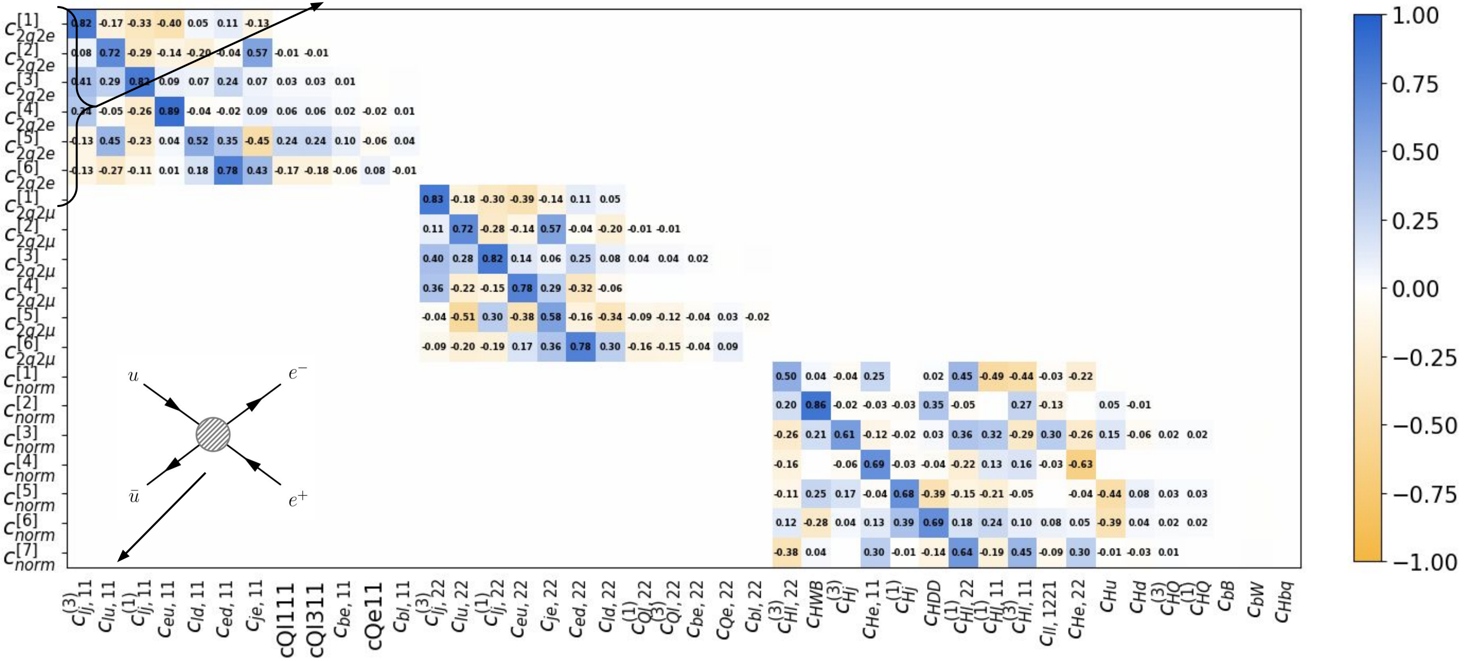
So c1’ and c2’ are linear combinations of c1 and c2

Fit basis definition for cos(θ*) vs invariant mass results

- Fit basis based on groups of operators with physical meaning
  For example 2q2e are 4-fermion operators for electrons

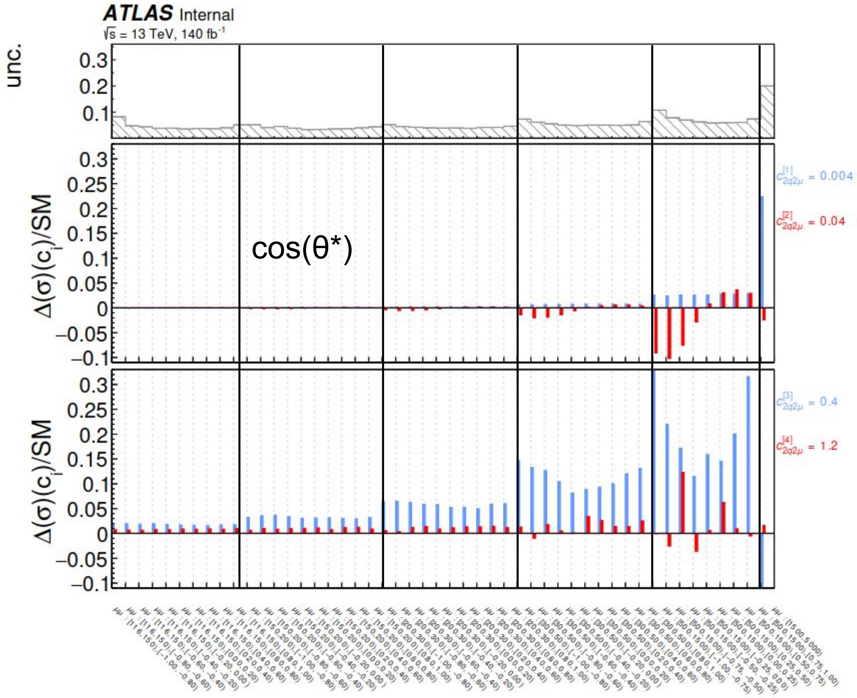
New parameters to be measured

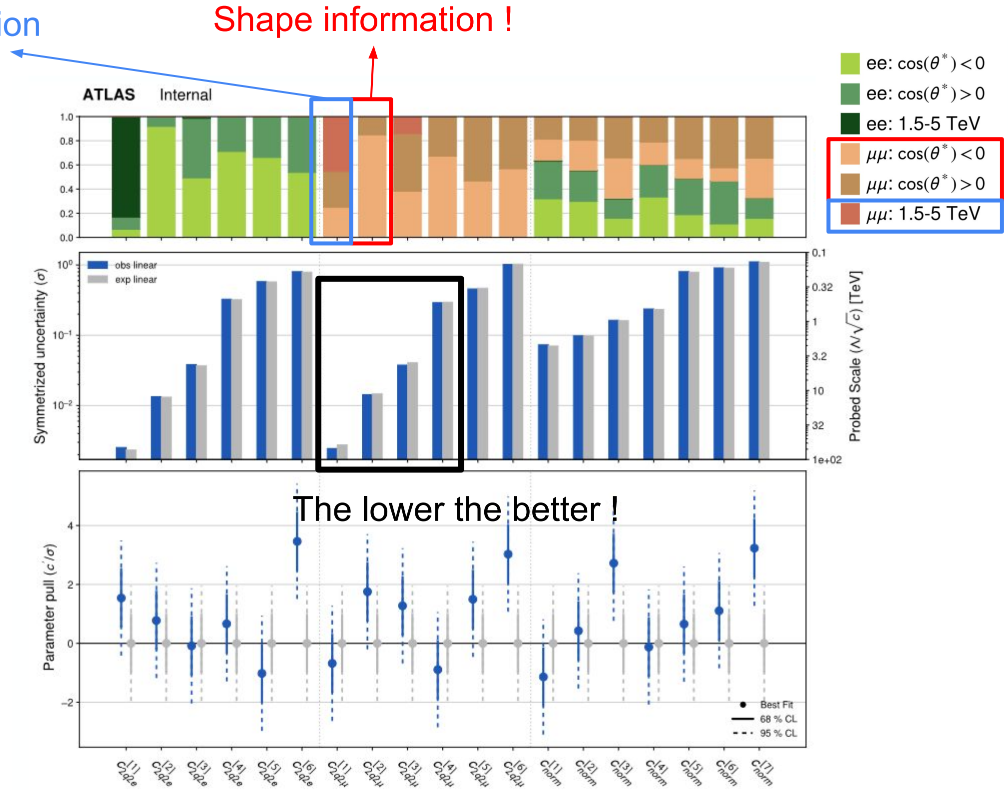
19 fit basis directions with unc <1



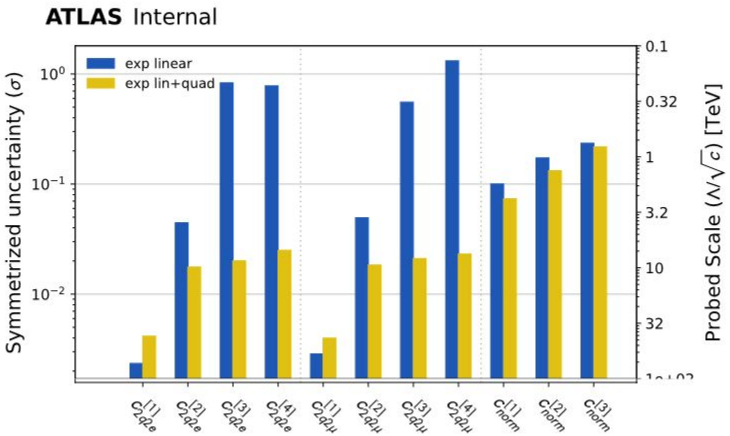
Warsaw basis (theory)

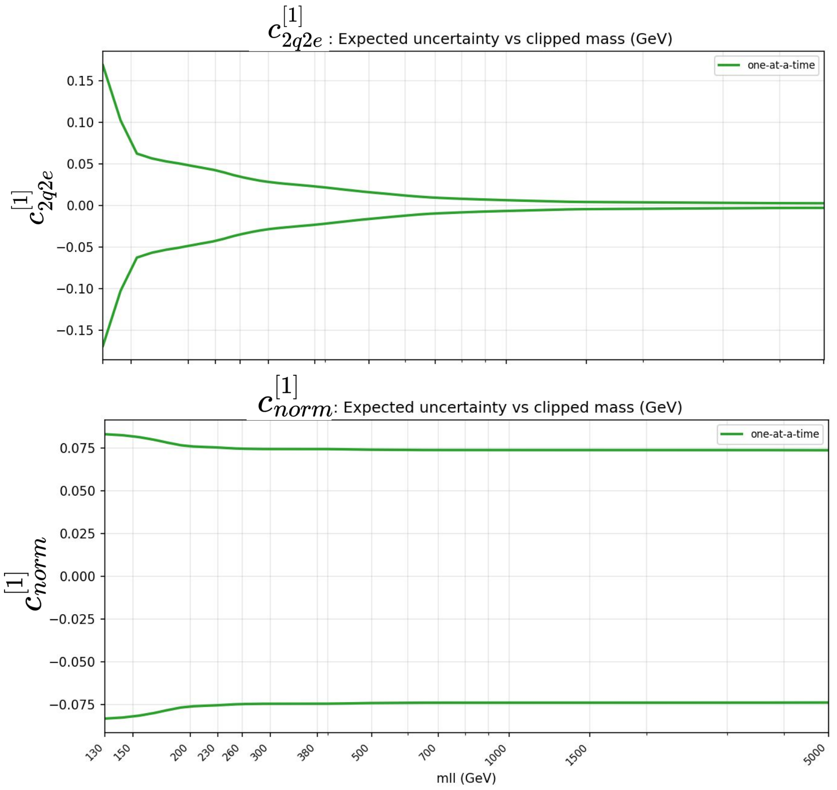
2D cos(θ*) vs invariant mass measurements results





Quadratic terms impact and validity





EFT expansion is valid if constraints remain stable when including quadratic terms.

However, 4f-operator groups are highly sensitive the the inclusion of the quadratic terms

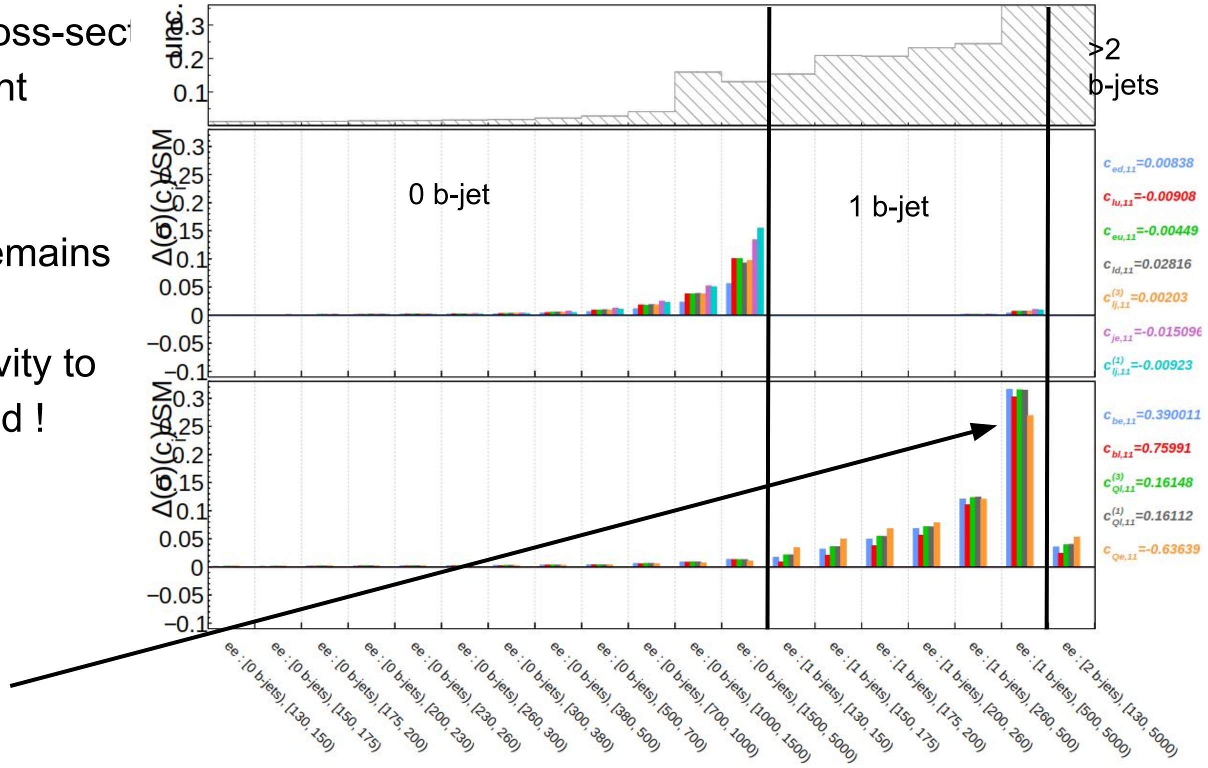
Clipping studies to probe the sensitivity of the constraints to high-mass bins

Number of b-jets vs invariant mass sensitivity studies

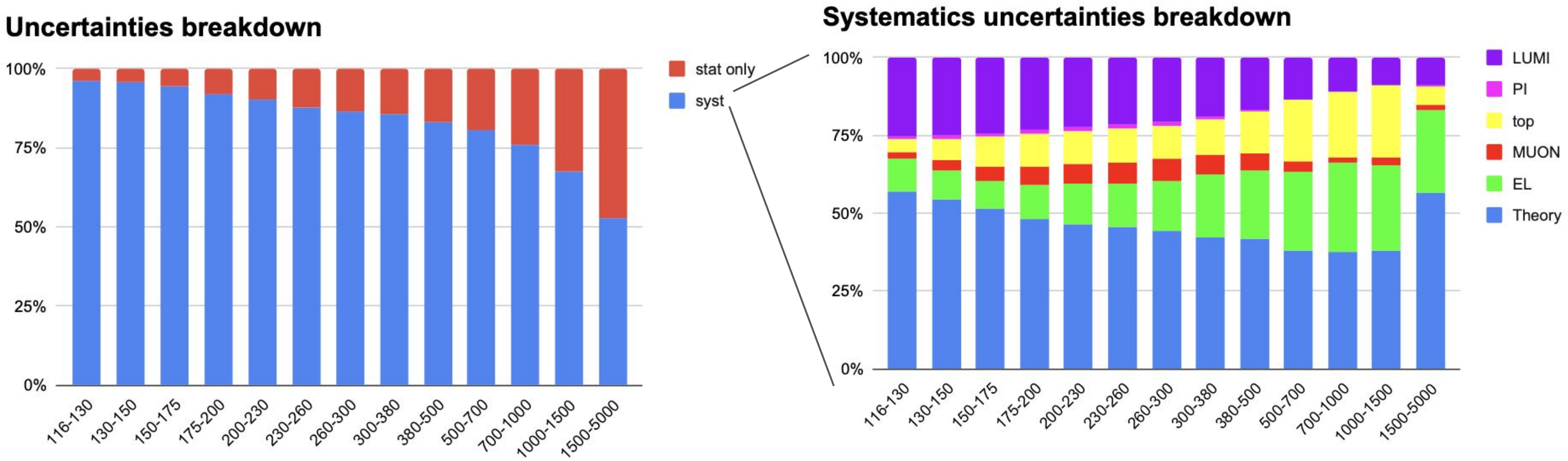
- Double differential unfolded cross-sect as a function of the di-lepton invariant mass and the number of b-jets

- The list of SMEFT operators remains unchanged from the inclusive measurements, but the sensitivity to b-related operators is enhanced !

- I expect to have competitive constraints for these operators



Uncertainties breakdown for HMDY analysis



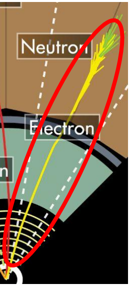
- Uncertainty on the signal strength of the distribution mainly limited by systematic unc. arising primarily from theory unc.

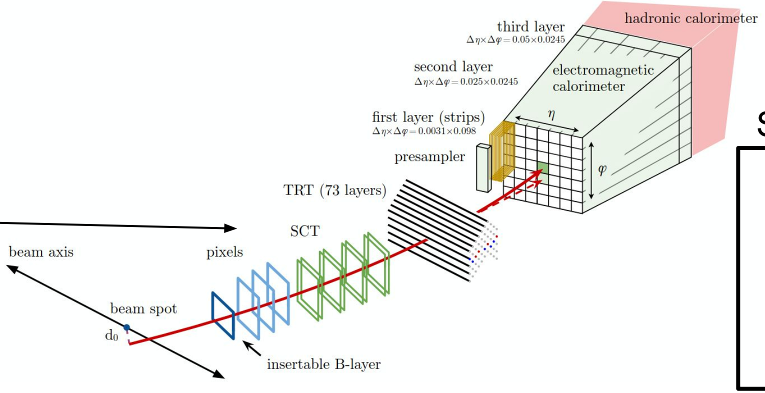
- Leading experimental unc. source include,
  i. ee channel : El_scale at high mass , **El_ID** at very high mass
  ii. μμ channel : Muon_trig at high mass , Muon_bkg at very high mass

Can be reduced with better electron identification performances

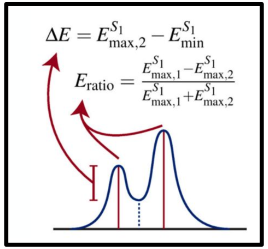
Electron performance : Towards a data-driven Deep Neural Network based electron identification

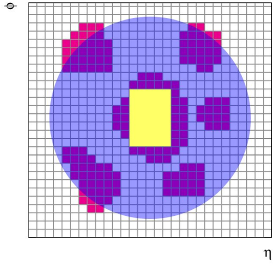
Electrons reconstruction in ATLAS





Shower Shape !





Reconstruction:
Energy deposit in the calorimeter (**Cluster**) + **Tracks** (trajectory in the inner detector)

Identification:
More specific calorimeter informations like **Shower shapes**

(Isolation)

"Offline" objects **used in analyses**

Electron identification (Likelihood / DNN)

- Likelihood :

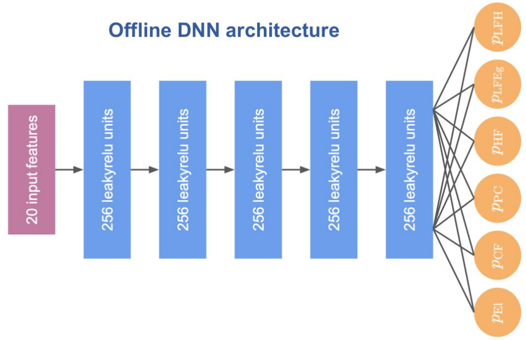
  Using probability density function (**PDFs**) of discriminating variables (such as **Shower shapes**) from Monte Carlo simulations

$$L_{s(b)} = \prod_{i=1}^{n} P_{s(b),i}(x_i)$$

$$d_L = \frac{L_s}{L_s + L_b}$$

- DNN :

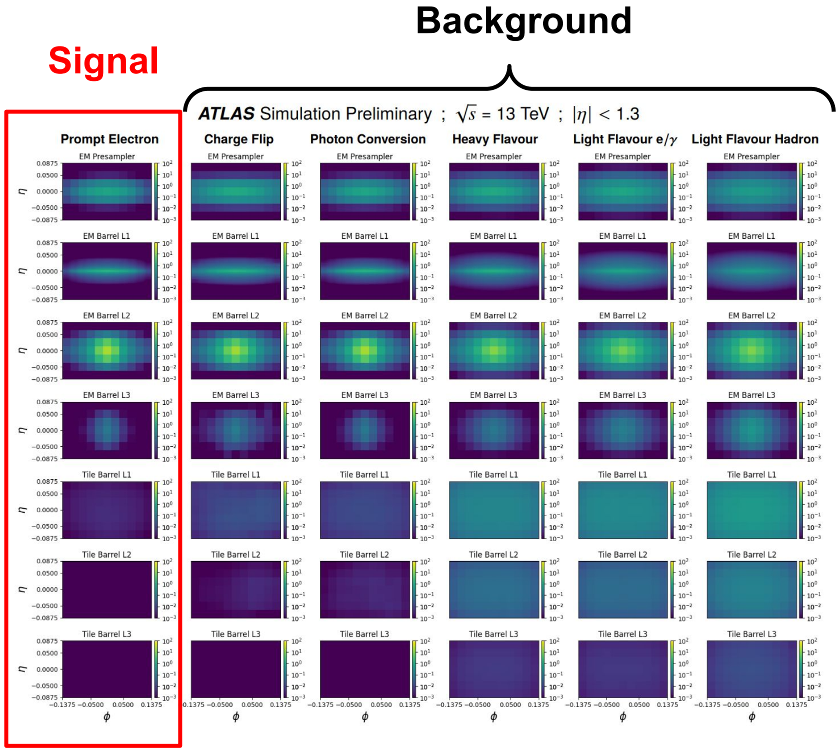
  Trained on Monte Carlo (including **Shower Shapes variables**) with 6 output classes
  1 for signal and 5 for each type of background



Electron identification with DNN

- The current DNN model is trained on simulation, but investigating a DNN with **data-driven** input variables !

- Need inputs for the **background**:
    - Following the procedure done in Run 2 (2017)
    - Need work on the software side !
    - Will show results for :

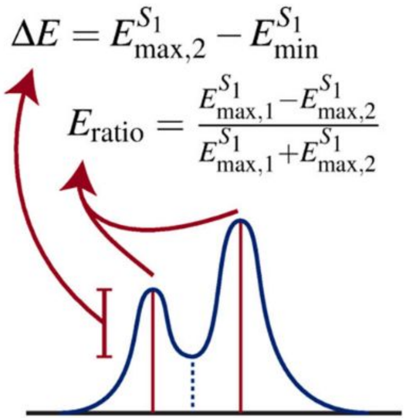


- data : **Run 2** previous results
- data : **Run 3**, 2024 (my results)
- MC : di-jets simulations (JF17)

Selections and variables used

Focus on E_{ratio}

Ratio of the energy difference between the maximum energy deposit and the energy deposit in the secondary maximum in the cluster to the sum of these energies

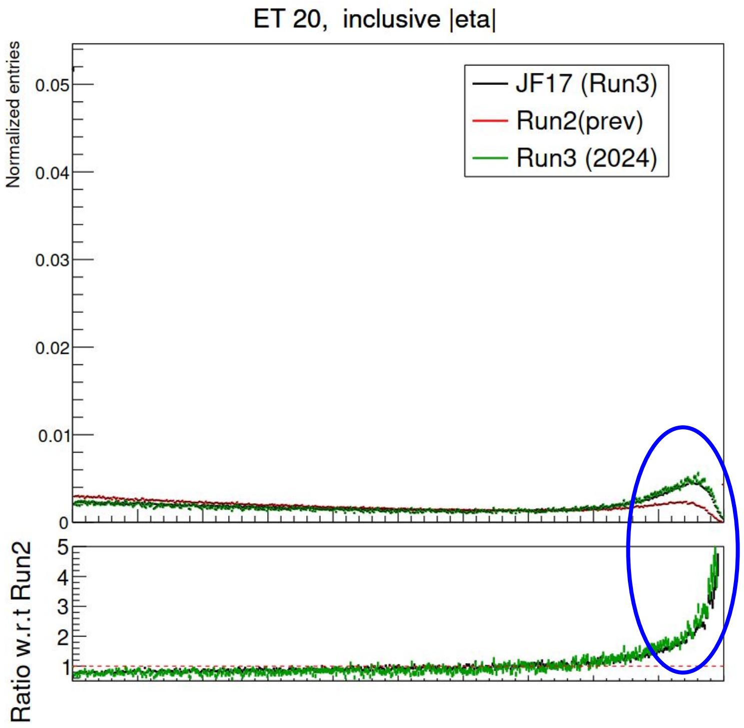


Background selections

Selection for data-driven background electron candidates
Prescaled single electron supporting trigger fired; see Table 11
Electron candidate with $p_T > 4$ GeV
Electron candidate $\|\eta\| < 2.47$
Electron candiate has good track-quality ($n_{\text{Pixel}} \geq 1$, $n_{\text{Silicon}} \geq 7$)
ΔR(reco electron candidate, trigger electron) < 0.10
Electron candidate passes LAr object quality requirement
$E_T^{\text{miss}} < 25$ GeV
$m_T < 40$ GeV
(70 GeV $< m_{ee} \,\|\|\, m_{ee} >$ 110 GeV) for events containing an additional *Medium* electron

pT "matching" for electron candidates (making sure their pT match the trigger used)

Comparison for eratio with JF17 MC and Run3 2024

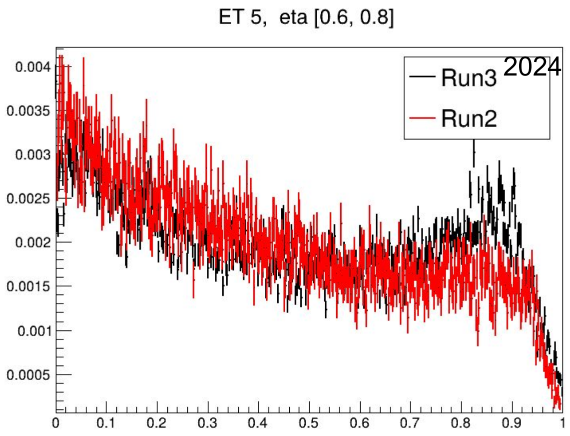


Black: Monte Carlo simulations
Red: Previous Run 2 results
Green: Run3 2024

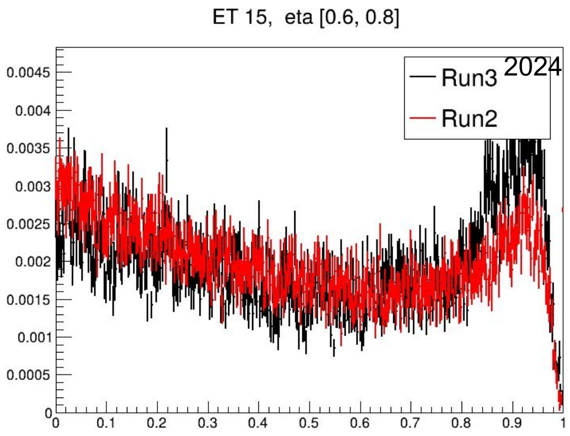
MC and 2024 have very similar behaviours !

-> Can use the Monte Carlo to investigate source of the signal like behaviour

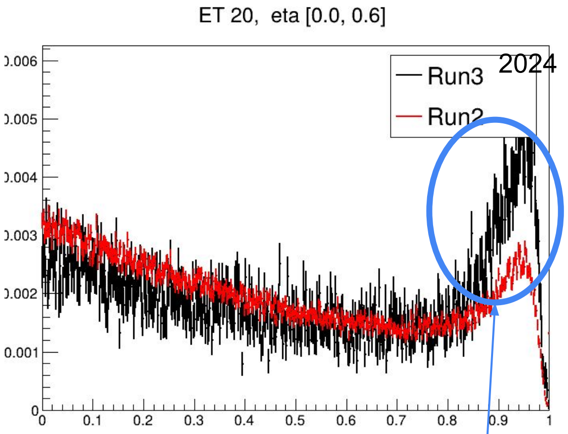
Comparison with Run2 and Run3 for eratio



HLT_e5_etcut_L1eEM5



HLT_e15_etcut_L1eEM9

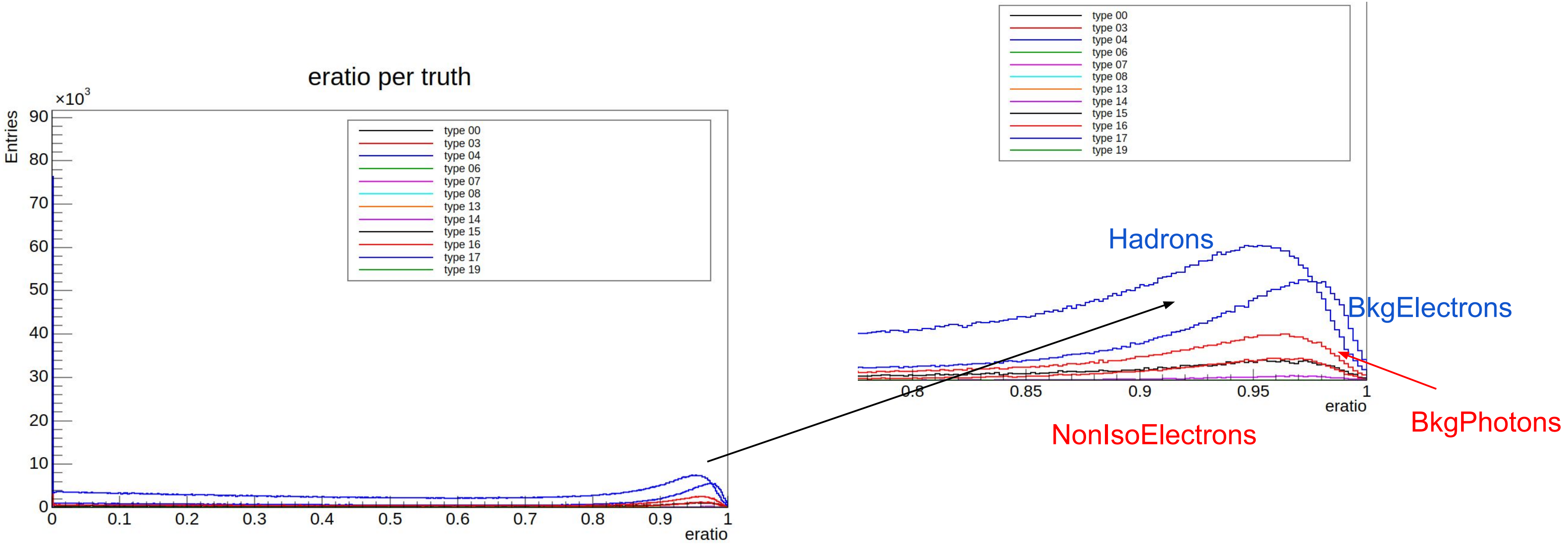


HLT_e20_etcut_L1eEM18M

for Run2 (e5 : e4+e7)

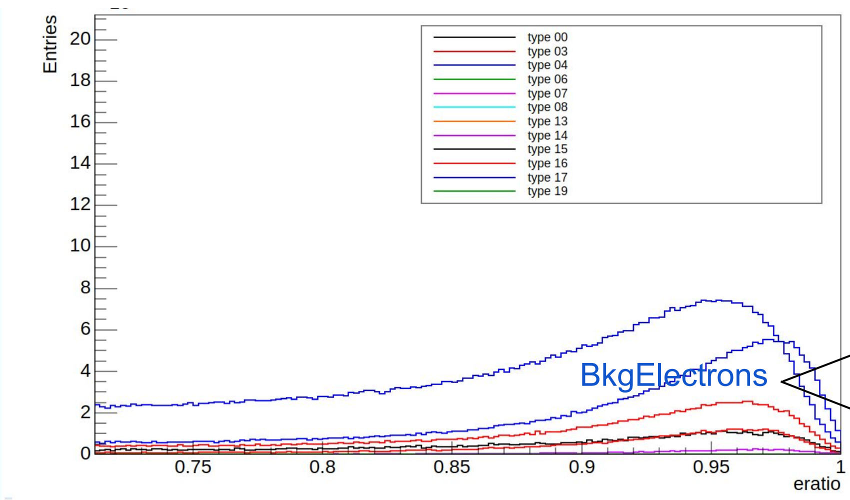
Signal like behaviour in Run3 !

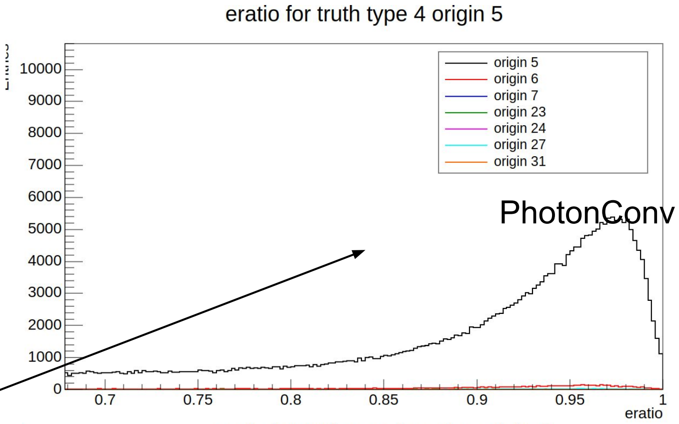
Monte Carlo studies eratio / particle type

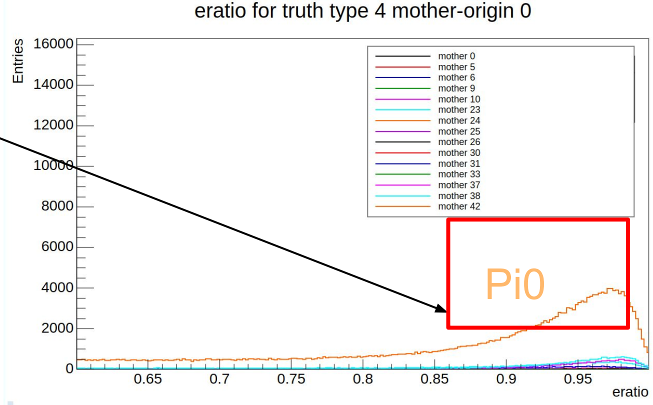


- I Investigated the source of the signal peak by looking at the type of particles in the simulations -> BkgElectron need to be vetoed !

Monte Carlo studies eratio / for BkgElectrons







- Currently optimising a selection to reject π^0 as much as possible
- Once this is done i can provide the background inputs to train the DNN on data !

Conclusion

- Physics Analysis :
  - I am responsible for the final EFT interpretation for the two ATLAS HMDY measurement papers currently in progress
  - Expect results to become public early next year with 2 papers :
    - High Mass Drell-Yan at 13 TeV (Neutral Current Drell-Yan high mass measurements)
    - Differential HMDY+b (Neutral Current Drell-Yan high mass measurements + b-jets)
  - I plan to take part of the Run 3 iteration of the measurements

- Electron performance :
  - A Monte Carlo based DNN will be available for analyses in Run 3
  - The data-driven DNN studies aim for Run 4
  - A DNN paper is expected !
  - My previous single electron trigger performance results are now public Link and a paper on electron trigger performance is on the way
  - I presented my work in
    - JRJC2025 Slides with proceedings incoming
    - DIS2026 Slides with proceedings incoming

Adum formations

- Formations/conferences :

- Summer school PhysTeV Les Houches SM Session
- Teaching at Polytech Annecy (last 3 semester)
- Teaching at IUT Annecy (last semester)
- ATLAS Egamma workshop at CERN
- ATLAS Egamma workshop in Edinburgh (incoming)
- ATLAS Electron trigger expert shifts
- 2026 CERN summer school in Poland (incoming)
- EFT@LHC 2025 - 2026
- JRJC2025 (+proceedings incoming)
- DIS2026 (+proceedings incoming)

- 107/120 hours done
  (40 in formation disciplinaire, in formation transversale and in insertion professionnel)
  missing 13 hours should be covered by teachings (already done)

Backup

SMEFT at dimension 6

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

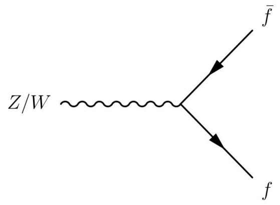
Different analyses allow to probe different groups of operators:

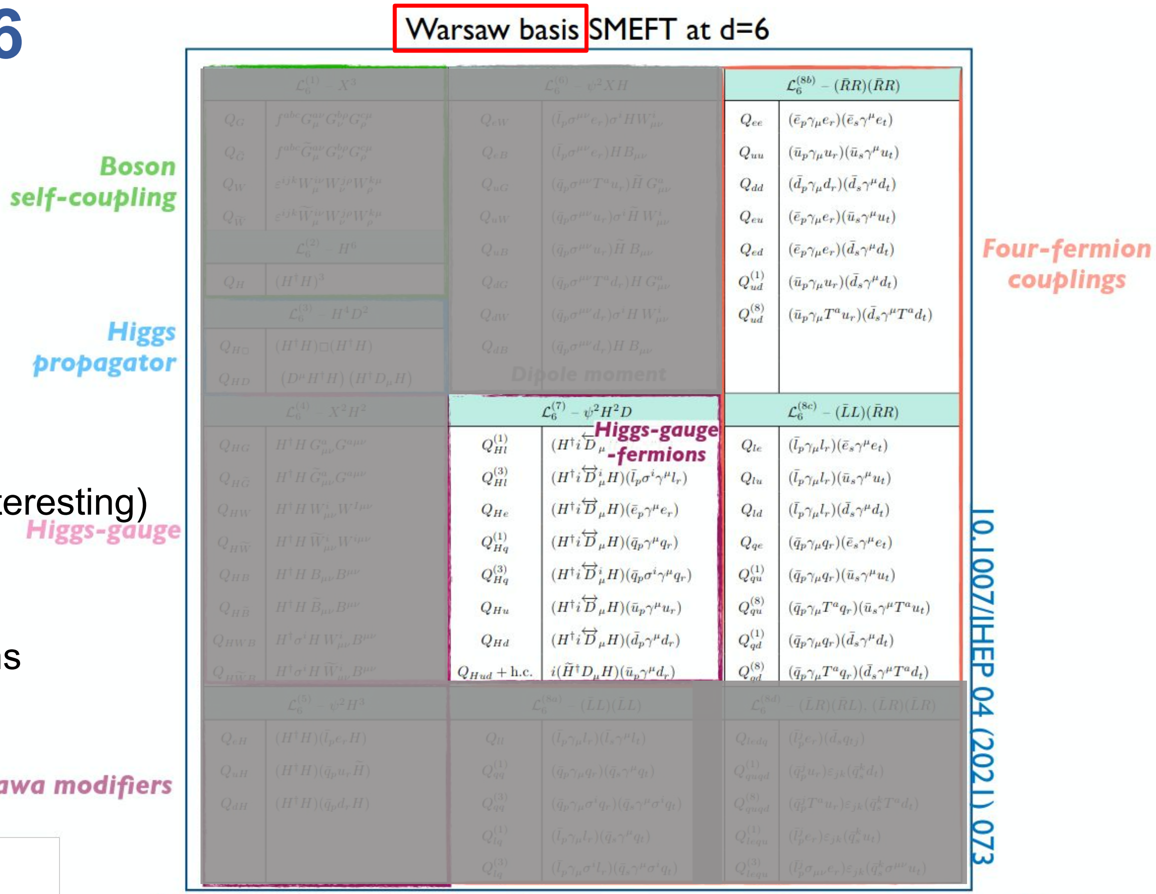
High Mass Drell-Yan processes :

- Four-fermion operators with growing energy dependence (angular observables interesting)

$$O_{2q2l}$$

- Higgs-gauge and Higgs-gauge-fermions affecting Vff coupling

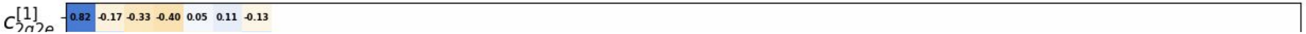




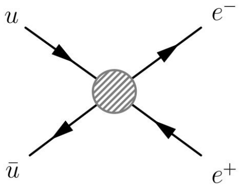
$U(3)^5$ flavour symmetry : all generations affected by the same effect

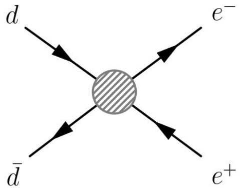
Fit basis definition for cos(θ*) vs invariant mass results

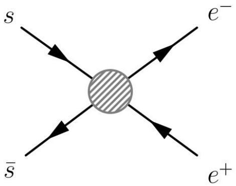
- Fit basis based on groups of operators with physical meaning
  For example 2q2e are 4-fermion operators for electrons

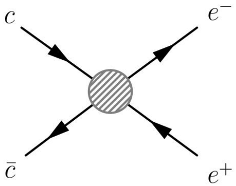


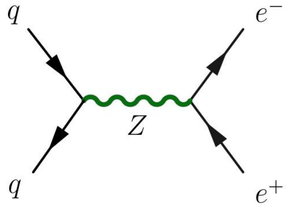
$$c^{[1]}_{2q2e} = 0.83c^{(3)}_{lj,11} - 0.40c_{eu,11} - 0.33c^{(1)}_{lj,11} - 0.17c_{lu,11} - 0.13c_{je,11} + 0.11c_{ed,11} + 0.04c_{ld,11}$$











Distribution binning

Λ is taken at 1 TeV

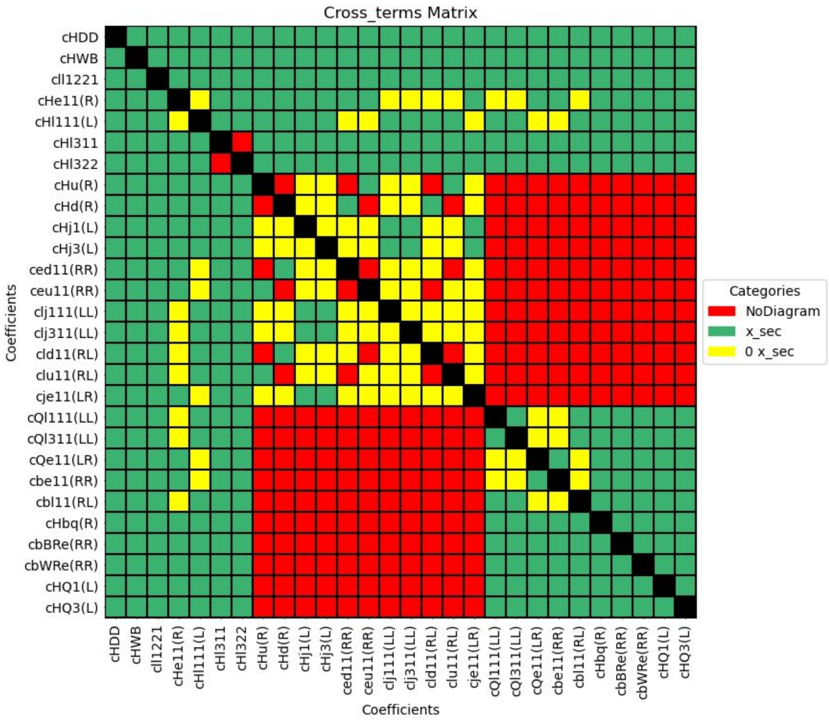
Generator slices	1D	2D	
	mll	mll	cosθ*
	116-130	116-150	[-1,-0.8,-0.6,-0.4,-0.2,0,0.2,0.4,0.6,0.8,1]
	130-150		
	150-175	150-200	[-1,-0.8,-0.6,-0.4,-0.2,0,0.2,0.4,0.6,0.8,1]
	175-200		
	200-230	200-300	[-1,-0.8,-0.6,-0.4,-0.2,0,0.2,0.4,0.6,0.8,1]
	230-260		
	260-300		
	300-380	300-500	[-1,-0.8,-0.6,-0.4,-0.2,0,0.2,0.4,0.6,0.8,1]
	380-500		
	500-700	500-1500	[-1,-0.75,-0.5,-0.25,0,0.25,0.5,0.75,1]
	700-1000		
	1000-1500		
	1500-5000	1500-5000	x
Total	13		49

EFT samples generation

- **SMEFTsim_v3_0_2** using **MadGraph5_aMC@NLO** version 2.9.9 and **Pythia** version 8.307

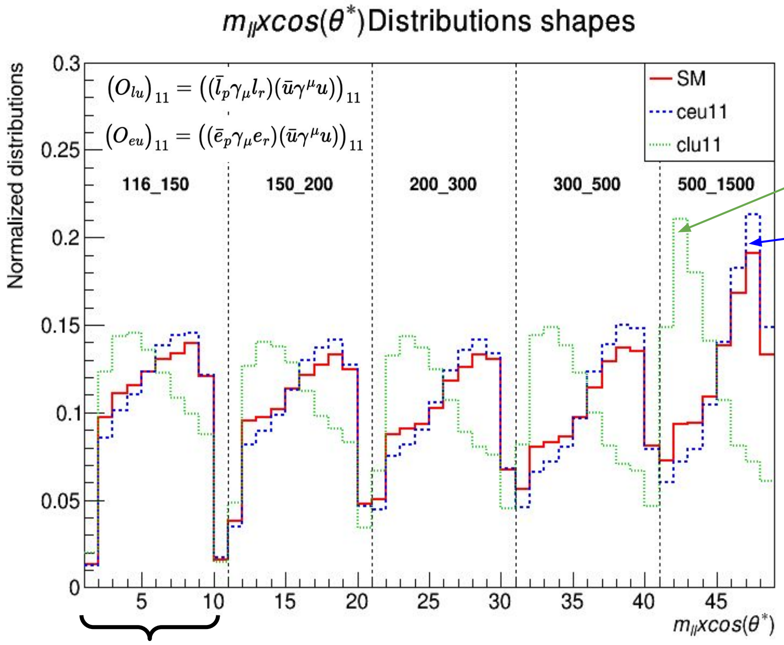
- Samples generated for **6 different slices** in m_{ll}:
116-150 / 150-200 / 200-300 /
300-500 / 500-1500 / 1500 - 5000 GeV

- **378** cross terms, directly generated using NP^2==2 NPc1^2==1 NPc2^2==1 syntax supported by SMEFTsim
203 contribute
120 NoDiagram exception
55 zero cross-section



- Different final state helicity (-)
- Different initial state helicity(-)
- Mismatch of flavour (-)

2D mll x cos(θ*) shape distribution



each mll slice : cos(θ*) normalized

$$c_{lu} \longrightarrow (\bar{l}\gamma_\mu l)(\bar{u}\gamma^\mu u) : (\overline{L}L)(\overline{R}R)$$

$$c_{eu} \longrightarrow (\bar{e}\gamma_\mu e)(\bar{u}\gamma^\mu u) : (\overline{R}R)(\overline{R}R)$$

Sensitivity to leptons helicities

- cos(θ*) information allows to distinguish four-fermion operator with different helicities, (LLRR) operators have flipped shape wrt SM

Alternative prediction for the exclusive (with b-jets) results (Ongoing)

- Motivation :
  - Study the impact of the flavour scheme choice on the measurements
  - Having another prediction (current is Sherpa) to evaluate systematic uncertainty due to the choice of Monte Carlo generator

4-Flavour Scheme	5-Flavour Scheme
• (b)-quark treated as massive	• (b)-quark included in proton PDFs
• No initial-state (b)-partons	• Initial-state (b)-partons allowed

- Using MadGraph@NLO and generating very computationally expensive processes, with a bias reweighting method to increase statistics at high mass !

DNN : Types of background definition

Class	Description	Label	Sample
Prompt Electrons	Prompt isolated electrons, e.g. electrons from $Z \to ee$, $W \to e\nu$, $J/\psi \to ee$ decays with the J/ψ being produced in the hard scatter. Electrons from a final state radiation photon or bremsstrahlung are also considered here if the origin is a prompt electron. Furthermore, the reconstructed charge is the same as the true charge.	El	$Z \to ee$, $J/\psi \to ee$
Charge Flip	Same as prompt electrons, but the reconstructed charge is the opposite of the true charge. In case of an electron originating from bremsstrahlung, the charge of the original prompt electron is considered the true charge.	CF	$Z \to ee$, $J/\psi \to ee$
Photon Conversion	Electrons from prompt photons which convert into an e^+e^- pair. Prompt photons which are reconstructed as an electron are also considered for this class.	PC	JF17, $t\bar{t}$, $Z\gamma$
Heavy-Flavour	Electrons coming from a decay of a $b-$ or $c-$ hadron. Prompt quarkonium decays such as $J/\psi \to ee$ where the J/ψ is produced in the hard scatter event are not included here but rather as prompt electrons.	HF	JF17, $t\bar{t}$
Light-Flavour e/γ	Electrons and photons from a decay of a $u-$, $d-$, or $s-$ hadron. This also includes for instance electrons from intermediate photon conversions: $\pi^0 \to \gamma\gamma$ with $\gamma \to ee$.	LFEg	JF17
Light-Flavour Hadrons	Undecayed hadrons	LFH	JF17

DNN ROC curve : background rejection vs signal efficiency