Precision Measurements in SM with ATLAS Experiment

Workshop RENAFAE
April 26th 2022

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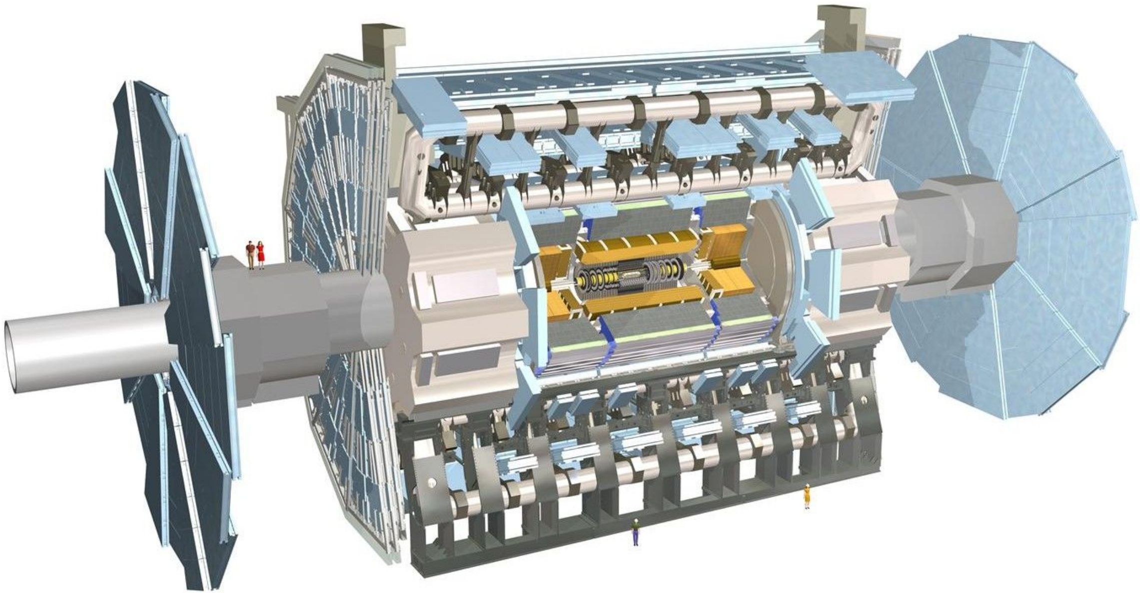
THE ATLAS EXPERIMENT



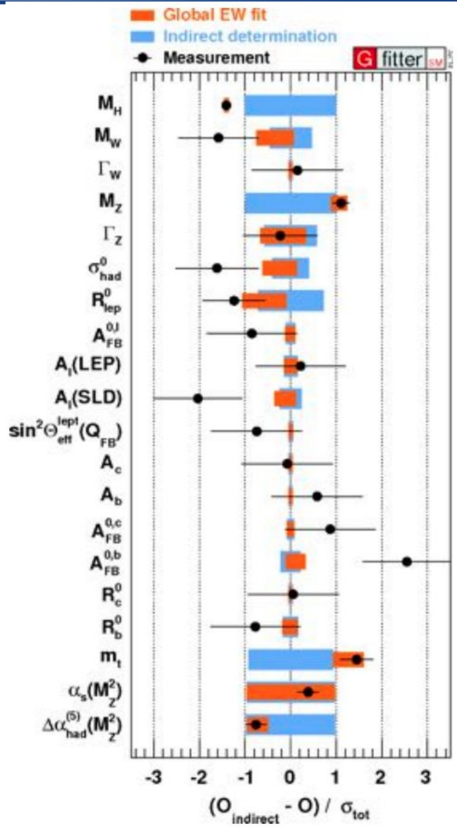
- **Multi-purpose experiment @ LHC**
- **Large acceptance and full azimuthal coverage**
- More than 3000 collaborators
- More than 1000 students developing their thesis topics in ATLAS
- 139fb^{-1} at $\sqrt{s}$=13 TeV available (pp)
- Expecting more ~300 fb^{-1} at $\sqrt{s}$=13.6 TeV (pp) during Run-III

PRECISION MEASUREMENTS IN SM WITH ATLAS

- So far, no signs of new physics (SM works pretty well…)
- New physics may be out of the LHC reach by **direct searches** (too heavy, too broad...)
- We need to keep going as the LHC will be the highest energy collider for (quite) long
- Disclaimer: following the focus of this session, *this will not be* a review of ATLAS precision measurements, but focus on what our group is doing …

What can we do (ATLAS) ?

1) “Conventional” precision measurements of SM fundamental parameters
    - M_W, M_{top}, M_{Higgs},$\sin^2\theta_{eff}$ etc.
    - input for EWK global fit
    - Still some tensions, but good so far …
    - More precision measurements to come (are coming…)
    - Not easy (e.g. m_W)
    - We need higher precision (model and experiment)
        - then hope it breaks somewhere …
    - If it breaks, someone needs to come with a fix to the model used in the global fit (new physics)



[Gfitter Collaboration]

https://arxiv.org/pdf/1902.05142.pdf

2. **Standard Model Effective Field Theory** Framework→ accounts for BSM effects at a mass scale Λ that is large in comparison to the EWK scale.
   - The theory provides predictions for experimental observables in terms of an expansion in E/Λ, where E is the typical energy exchanged in the process.
   - Measurements of observables sensitive to the effect of SMEFT operators allow to constrain $c^{(d)}_i/\Lambda^{d-4}$, where $c^{(d)}_i$ are the Wilson coefficients associated to the dimension-d operator O (d)

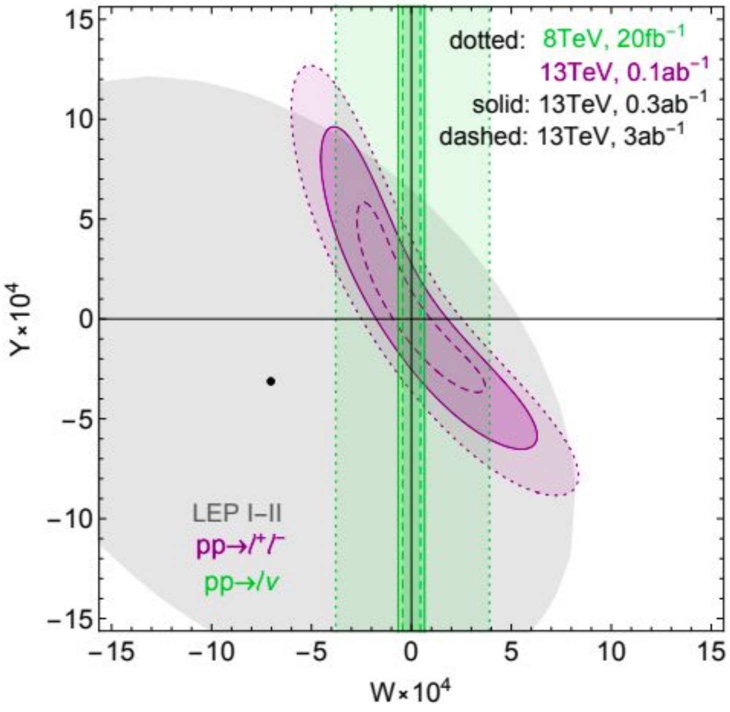
$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(5)}}{\Lambda} O_i^{(5)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \dots$$

   - Ignoring odd-dimensional operators (responsible for lepton and baryon number violation) and stopping at dimension-6 :

$$\mathcal{L}_{\mathrm{SMEFT}} \approx \mathcal{L}_{\mathrm{SM}}^{(4)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)}$$

DRELL-YAN PROCESSES AS PROBE FOR NEW PHYSICS

- SMEFT interpretation turns a **hadron collider** in a competitive tool for EWK precision measurements
- New physics on DY modifies EWK boson propagators
  - Represented by oblique parameters S,T,Y,W
  - W,Y are generated by dim-6 EFT operators and **effects grow with energy**
  - **Look at the tails in the observables rates**
  - in **CC DY, LHC may surpass LEP by far in sensitivity**
- Needs tight control of reconstruction →**precision**
- Explore extreme of phase space (will need luminosity…)

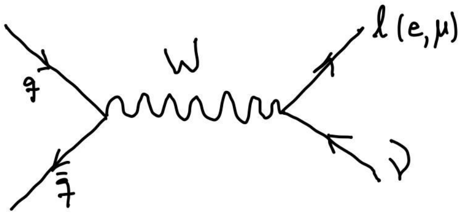


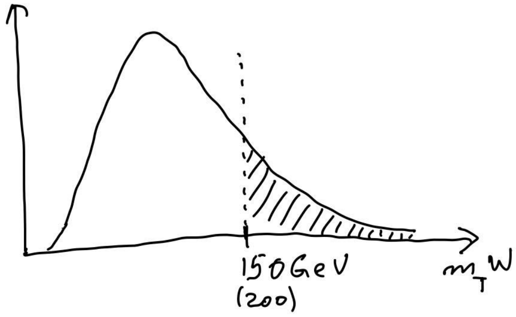
https://arxiv.org/abs/1609.08157

HIGH TRANSVERSE MASS CC DY ANALYSIS

- ATLAS CC DY High Mass Analysis (ANA-STDM-208-041)
  - Signal : PowHeg BoxV1 + Pythia8 + PHOTOS (NLO)
  - CT10 NLO PDF (can be reweighted to a more recent one, like CT18NNLO)
  - Corrected to NNLO (QCD+EWK) **k(m_V)** factors
  - Bulk sample (on-shell) …
  - … stitched to 18 High mass slices (>120 GeV) generated to increase data with m_W up to beam energy
  - e and μ channels, charge separated
  - main kinematic selection mT > 200 (150) GeV
  - Sherpa 2.2.11 as additional signal MC (theory syst.)

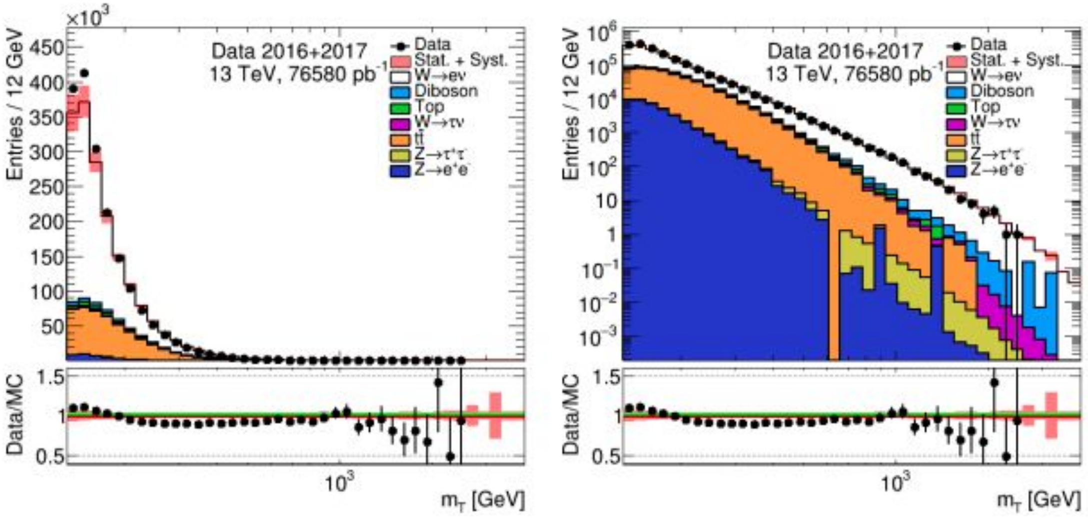
- These considerations also applies to NC High Mass DY analysis in ATLAS (ATL-COM-PHYS-2022-052, final phase) adding
  - contribution from photon induced process
  - cos(θ)* observable



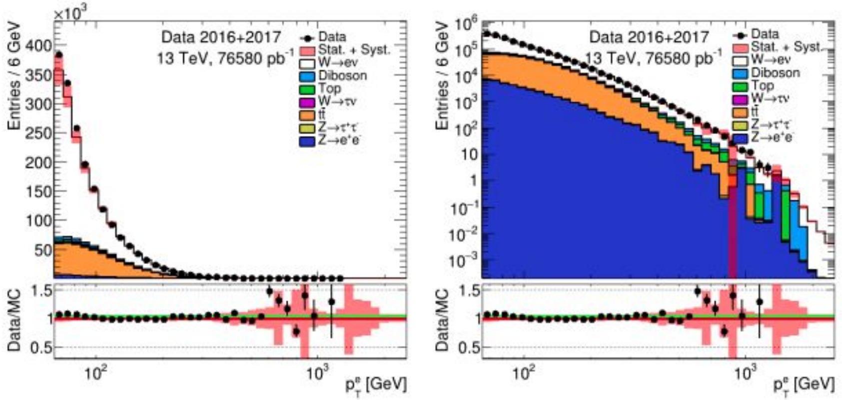


HIGH TRANSVERSE MASS CC DY ANALYSIS

- 139 fb^{-1} (Run-II) data
- Selection criteria :
  - mT > 200 GeV (150 GeV)
  - 1 *tight* lepton (pT > 65 GeV)
  - E_TMiss > 85 GeV
  - $|\eta| < 2.4$
- Main backgrounds
  - ttbar
  - single top
  - $Z \rightarrow ll$, $W \rightarrow \tau\nu$
  - Di-boson
  - Multijet (data driven)
- measure $m_T W$, $p_T l$, $|\eta| l$
- measure $mT \otimes |\eta|_l$
- Unfold to particle level
  - 1-dim
  - 2-dim



Particle Level Unfolded Data



HIGH TRANSVERSE MASS CC DY ANALYSIS

- Now back to the SMEFT …
- Scan for the Wilson coefficients sensitive to the phase-space
- Generate the SM sample, add EFT effects, shower it
- Use unfolded observables cross section
- Perform a likelihood fit with the unfolded data (may be combined charge or flavor separated)
- **Any significant pull in one coefficient needs further investigation** …

- Unfolded particle level observables we use in DY analysis :
  - $m_T W$
  - $p_T l$
  - $|\eta| l$
  - $m_T W \otimes |\eta|_l$
  - others ? maybe, what is the impact on systematics ?

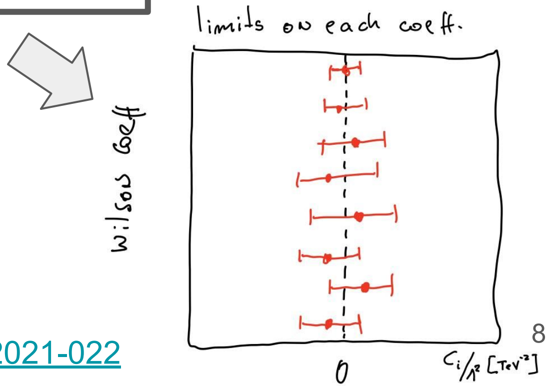
MADGRAPH5 (SM EVGEN)

SMEFT (using the select terms)

Shower (Pythia)

Profile Likelyhood Fit with unfolded data

Particle level Unfolded Data

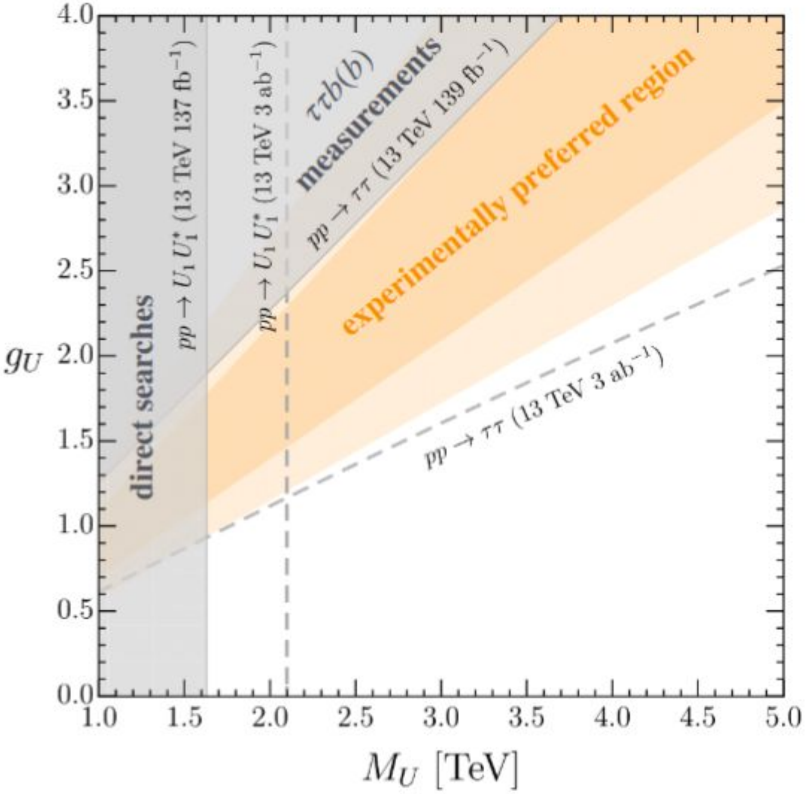


- We can also do a fit of more than one operator at a time
- Use a principal component analysis to construct a new base (linear combination of all operators in the Warsaw basis).
- Then do a simultaneous measurement of all relevant Wilson coefficients.

ATL-PHYS-PUB-2021-022

CC and NC DY IN THE τ DECAY CHANNEL

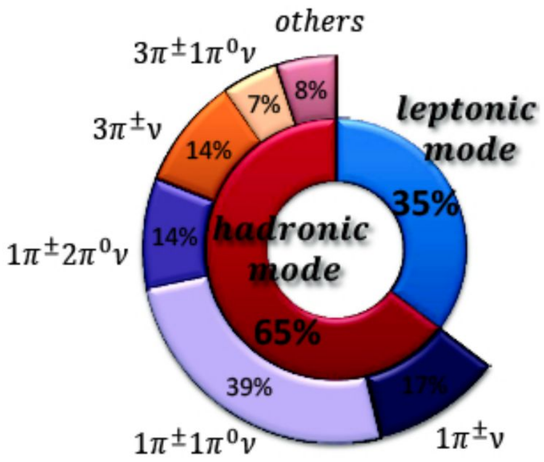
- We are now looking at τ channel (mid 2021→)
  - both NC (1st) and CC
  - Z→$\tau\tau$ (fully hadronic, semi-leptonic)
  - W→$\tau\nu$ (hadronic, leptonic)
  - include associated *b* jet production
- **Few LHC analysis on 3rd lepton generation, many BSM scenarios** sensitive to 3rd generation
- **High priority for understanding the *b* →*l* anomalies**
  - **Search for DY processes mediated by a leptoquark**
- Other interpretations are also on the table …

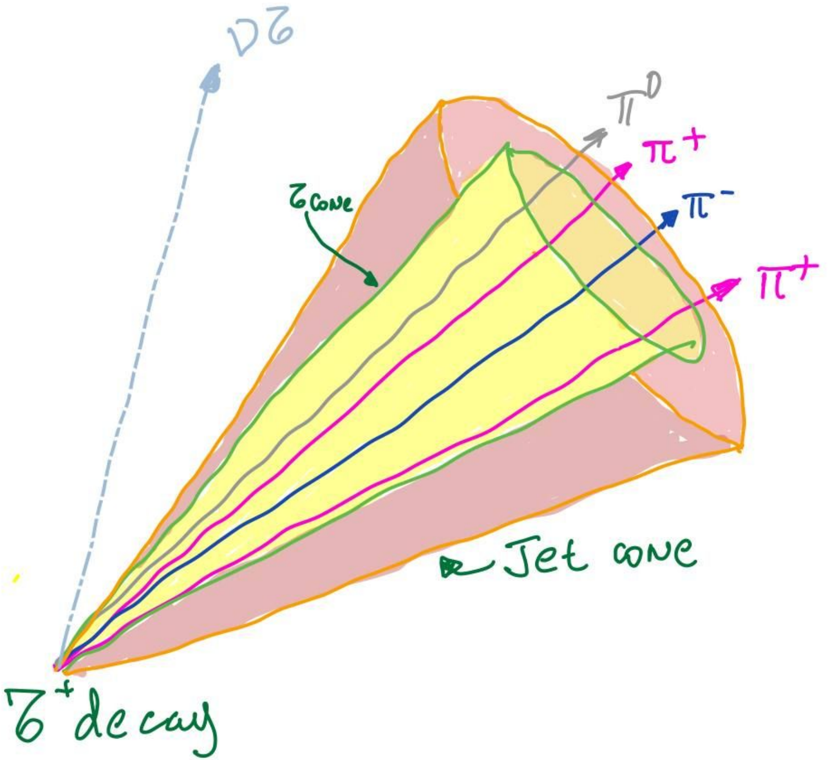


https://arxiv.org/abs/2103.16558v2

CC and NC DY IN THE τ DECAY CHANNEL

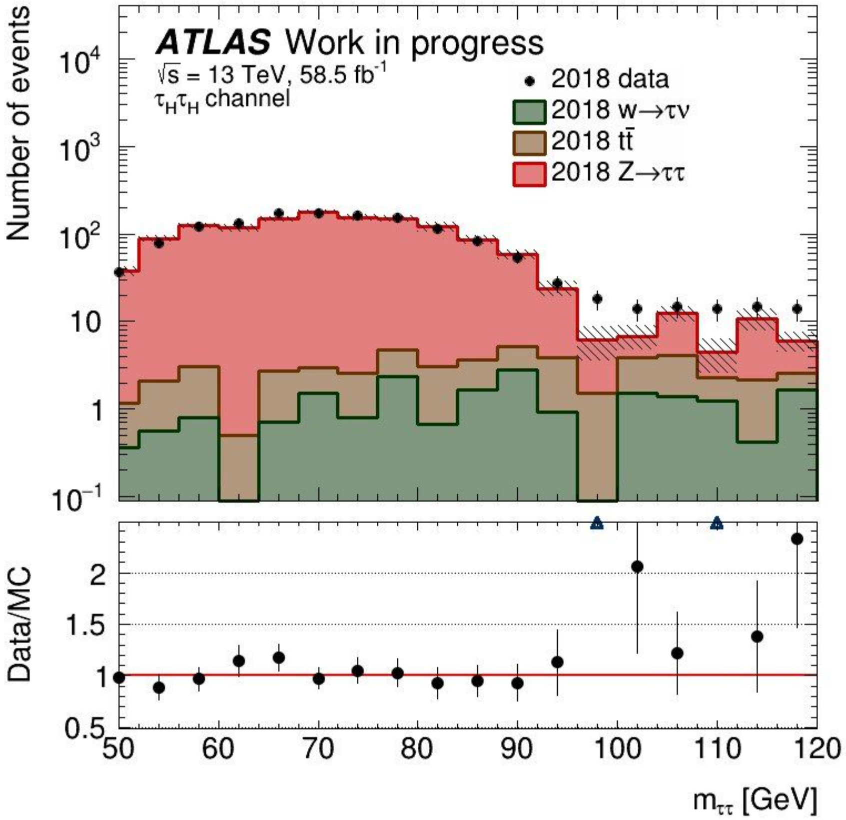
- More experimentally challenging
- $Z \rightarrow \tau\tau$ (fully hadronic, semi-leptonic)
- $W \rightarrow \tau\nu$ (hadronic, leptonic)





CC and NC DY IN THE τ DECAY CHANNEL

- Full Run-II data, 139 fb^{-1}(ANA-STDM-2021-10)
- Analysis on the pole and high mll mass region (>120GeV)
- Model generator baseline will be Sherpa 2.2.11
- Because of ν^{τ} the dilepton invariant mass reconstruction is challenging
  - missing mass calculator (ATLAS)
  - SVFit (CMS)
  - needs validation in the extended phase space
- Unfolded particle level observables we (may) use in DY τ-channel analysis :
  - m_{ll} (NC), mT (CC)
  - $\cos(\theta)^*$ (NC)
  - y_l (NC,CC), y_{ll} (NC)
  - $m_{ll}\otimes\cos(\theta)^*$, $m_{ll}\otimes\cos(\theta)^* y_{ll}$ (NC)
  - $mT\otimes|\eta|_l$(CC)
  - … plus associated ***b*** production
- On-going work on modeling to include BSM effects



FINAL REMARKS

- Results to be published soon (CC and NC DY light leptons decay channels)
- These measurements (CC) lay the groundwork for ΓW measurement
- We need stringent control of performance reconstruction
- We need to unfold to particle level, and convergence/bin migration is always a delicate experimental issue, and have impact in the limits
- Run-II has already enough data to look at tails up to 2 TeV. Run-III may not help that much (unless we really start to see something)
- Extreme region of phase space needs analytical enhancement techniques at event generator
- New analysis looking at third generation lepton decays of CC and NC DY open very interesting possibilities given the observed B meson decay anomalies