Lepton (non)-universality in W decays in ATLAS

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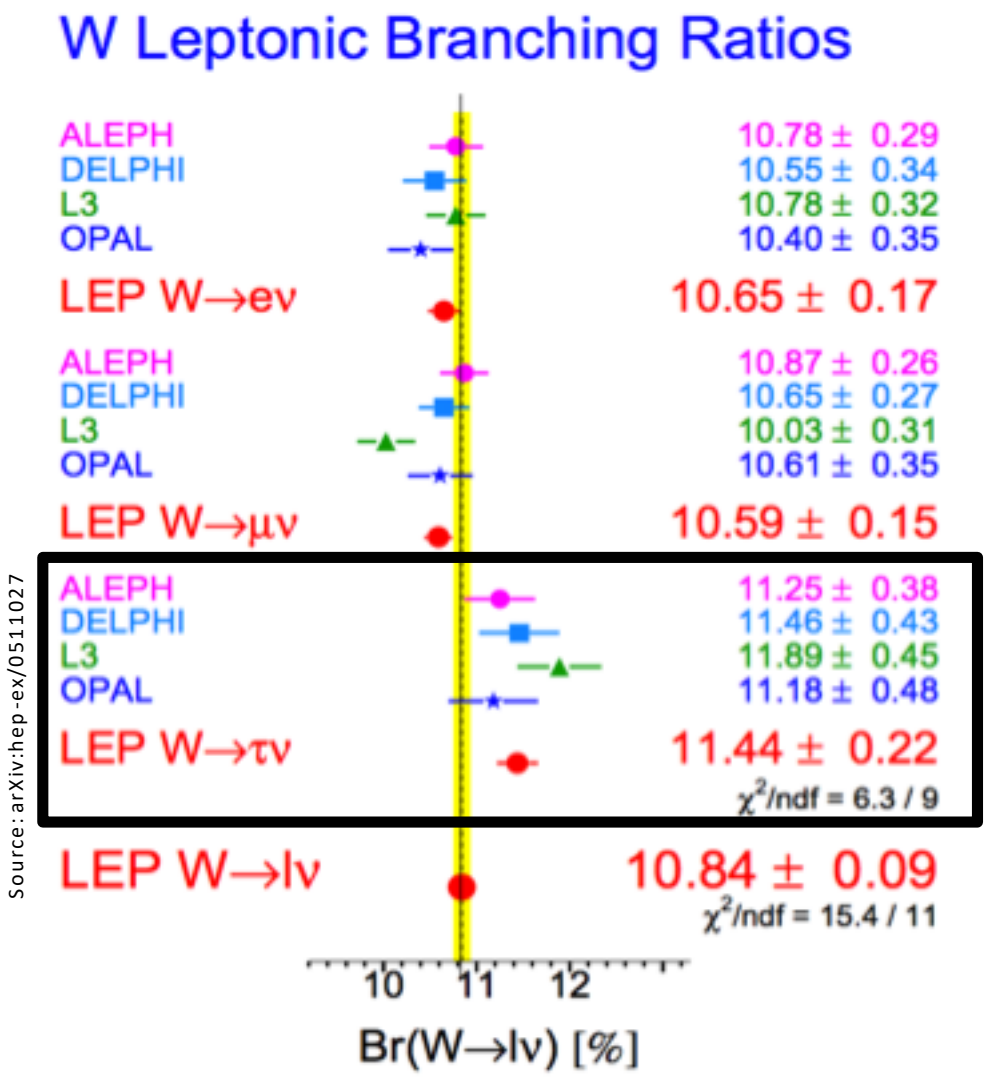
Supervisor: Nicolo de Groot

02-Nov-2018 NNV Annual meeting

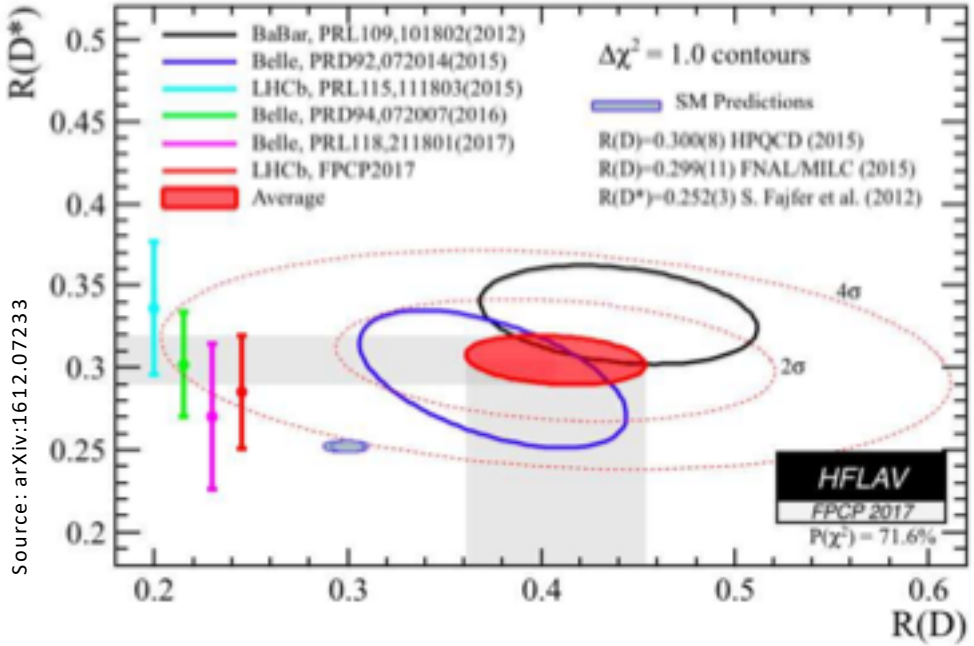
Motivation



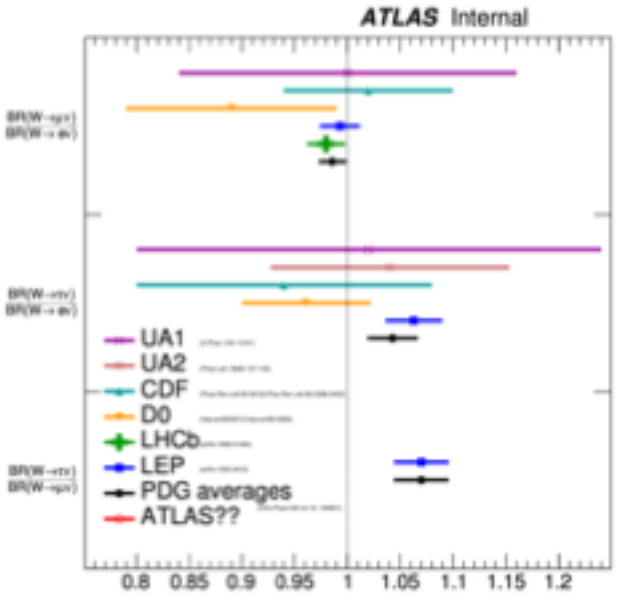
Source: arXiv:hep-ex/0511027

- LEP results shows an excess of the branching ratio $W \rightarrow \tau\nu$ with respect to the other leptons
  - Branching ration have been measured at LEP in the WW final state.
  - More then 2 sigma discrepancy.
  - The branching fractions of W into electrons and into muons perfectly agree.
  - Indicator for BSM physics.

Motivation



Source: arXiv:1612.07233



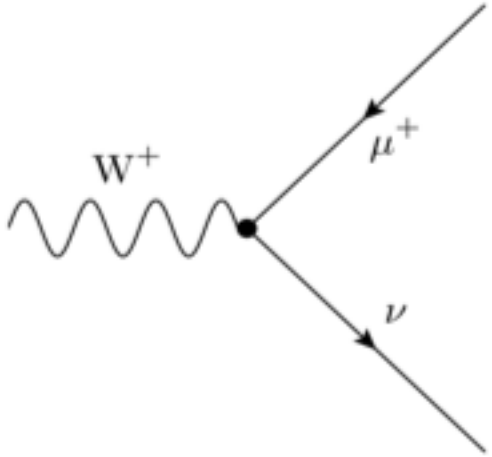
- The goal is to measure the W branching ratio in pp and search for lepton non-universality in ATLAS
  - We have very large statistics for W decay at ATLAS
  - Excellent possibility to test SM and lepton universality
  - The aim of the measurement is to achieve $\mathcal{O}(1.5\%)$ error

Overview and current status

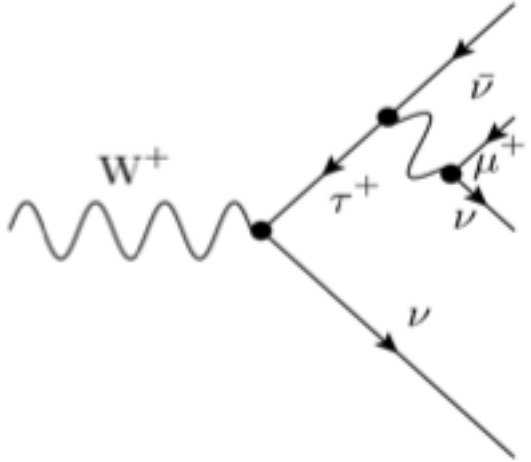
- Final states analysed: $W \rightarrow \tau_{lep}\nu \rightarrow \ell\nu\nu$ and $W \rightarrow \ell\nu$
  - Major signal features:
    - Displacement of the τ decay helps to distinguish leptons from τ decays from prompt leptons.
    - Recoil energy and/or jets to get events with boosted W bosons.
  - Major backgrounds:
    $\mathrm{QCD\ fakes}, Z \rightarrow \tau\tau$

- Analysis strategies
  - Object identification/object quality cuts + Boosted Decision Trees (BDT) classifiers
  - 2D fit on d_0 and BDT output
  - Data-driven background estimation
    - Fake Factor method for MJ background

- Current status
  - Machinery is almost in place.
  - Analysing 2015 year using R21.
  - Kicked off the full-Run2 analysis

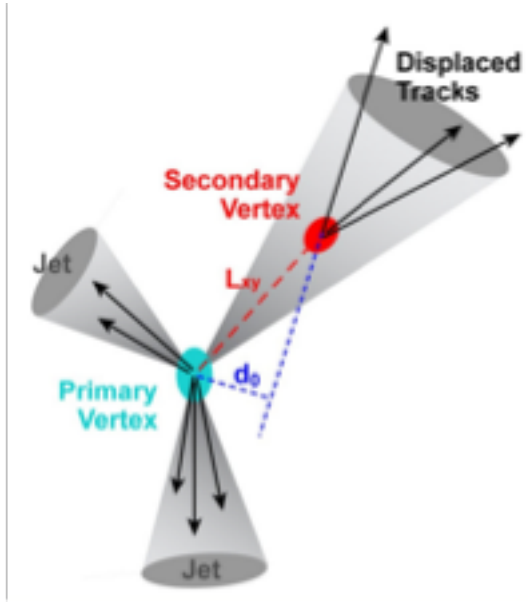


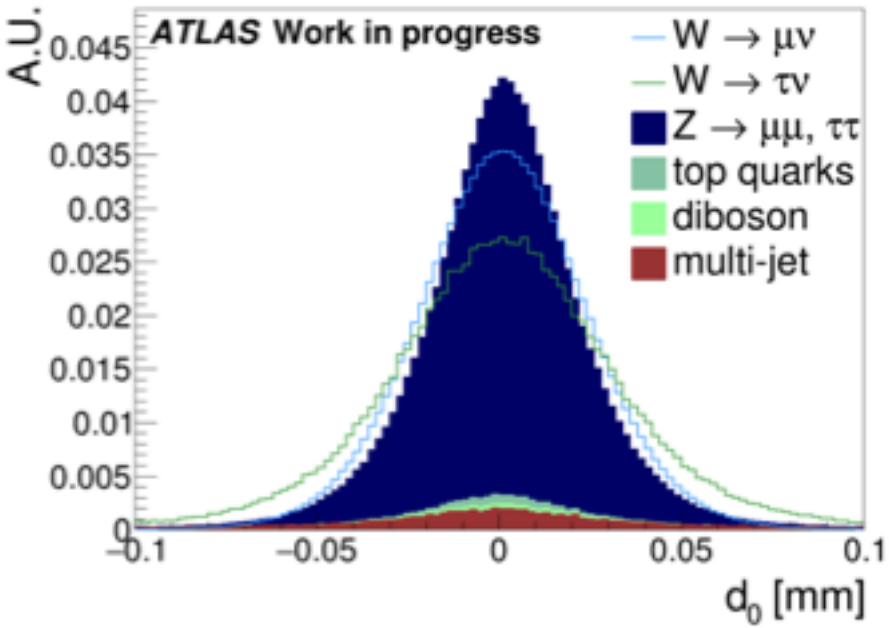
~11%



~11% x 17.4%

Vertexing

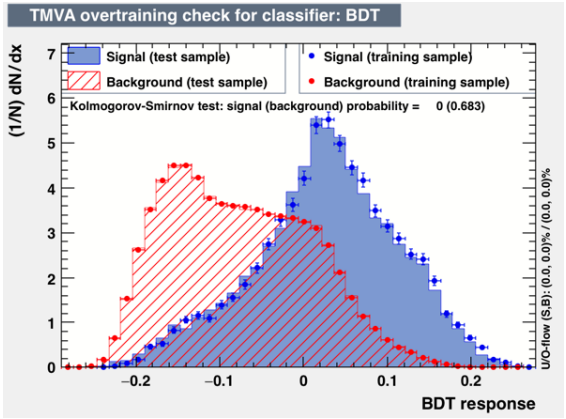


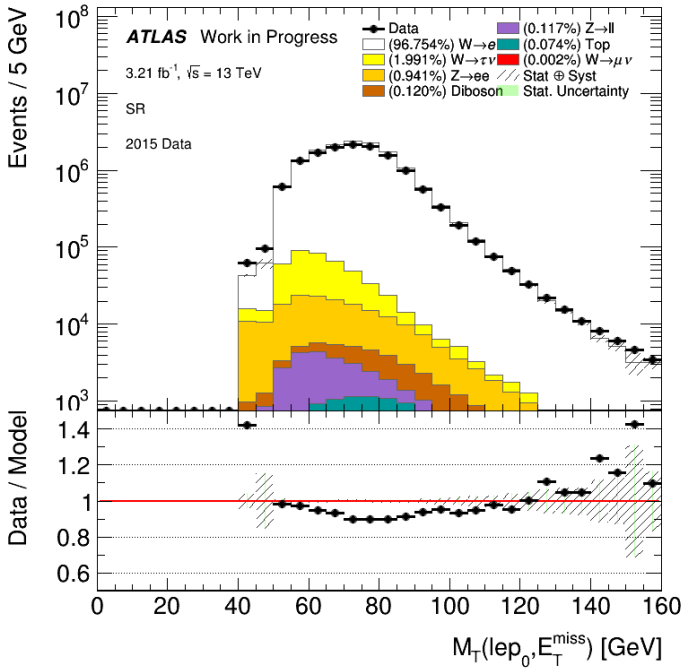


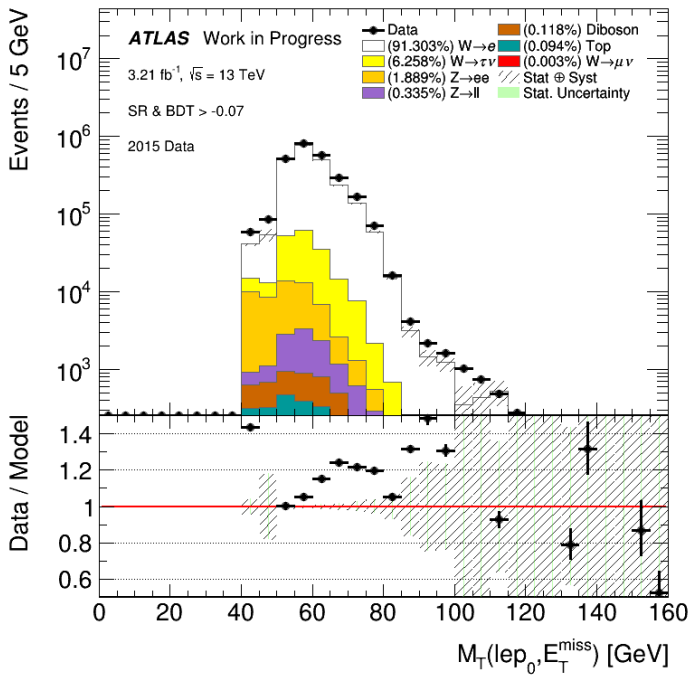
- Impact parameter d_0:
  - Tau lepton has lifetime that causes difference in d_0 shape
    - Mean life $2.906(10)\times10^{-13}$ s
  - Independent from kinematic quantities
  - Can play with recoil energy to get more boosted $W \rightarrow \tau_{lep}\nu$ decays

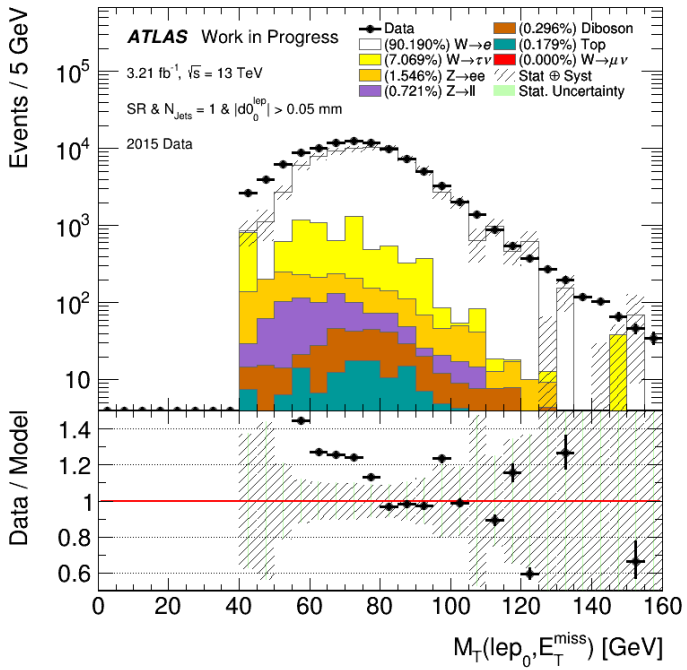
Gaining signal with TMVA

- Simple BDT model works pretty well
  - 11 variables. Most valuable:
    - $p_T^{lep}, d\phi(\ell - E_T^{miss}), d_0, E_T^{miss}, M_T$
  - d_0 is not correlated with BDT – will use it as control variable
  - AUC: 0.794
  - With BDT cut we have up to 6.285% $W \to \tau_{lep}\nu$ decay fraction and still have enough statistics to play with additional cuts.

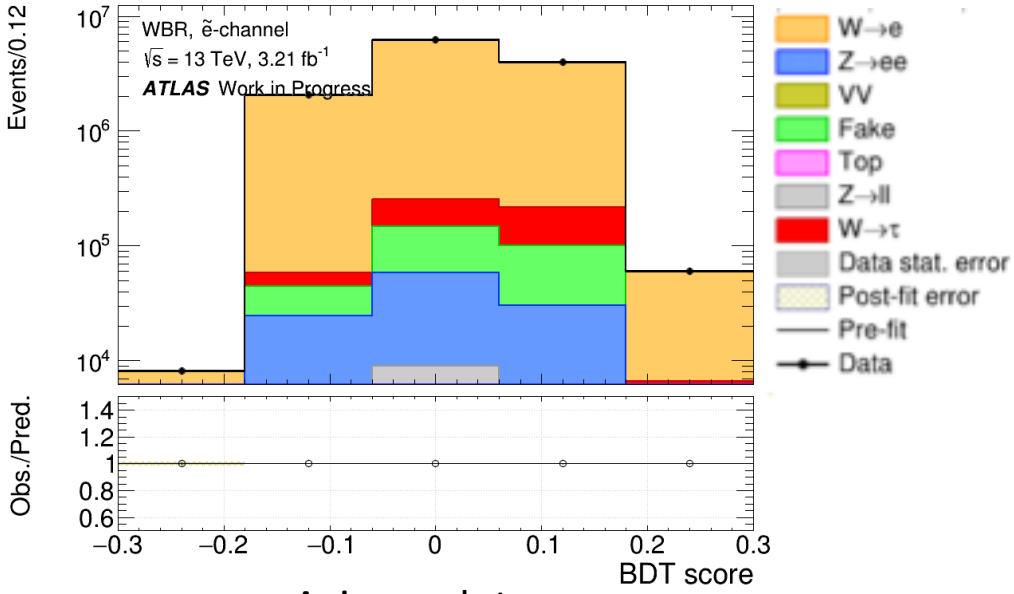






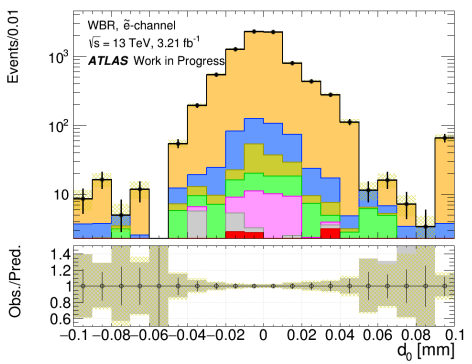


Signal region

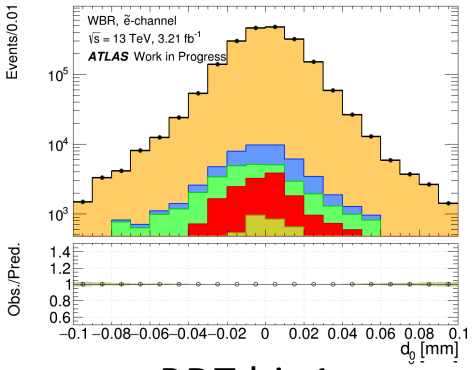


Asimov data

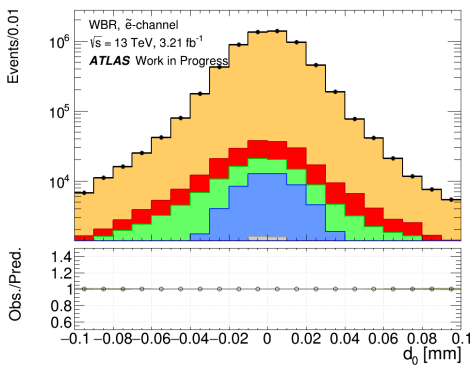
- d_0 has no correlation with other BDT input variables:
  - Use d0 as control variable
- Two dimensional fit performed via 1D hack:
  - Split BDT distribution to the 5 bins.
  - Certainly sufficient approach for any histogram-based model with no 2D continuous function in the fit.



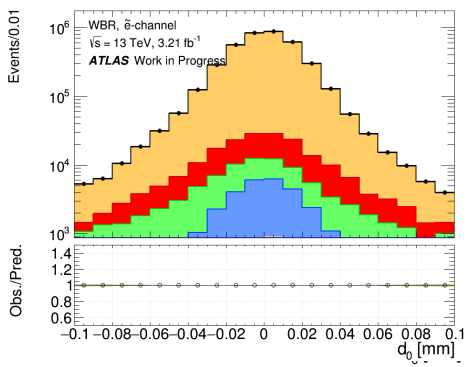
BDT bin0



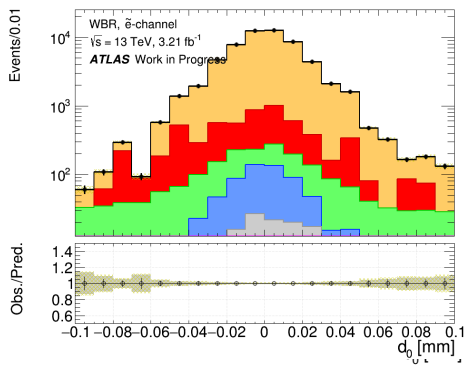
BDT bin1



BDT bin2

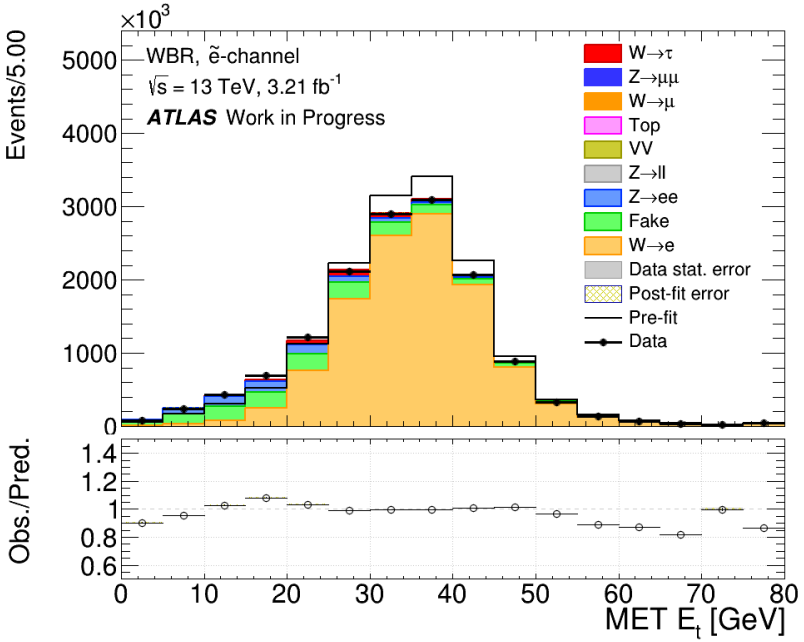


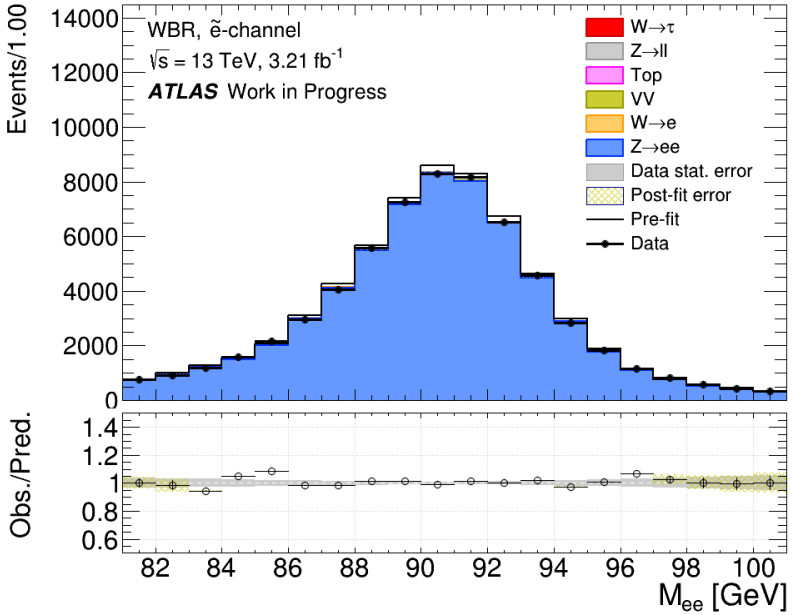
BDT bin3



BDT bin5

Control regions

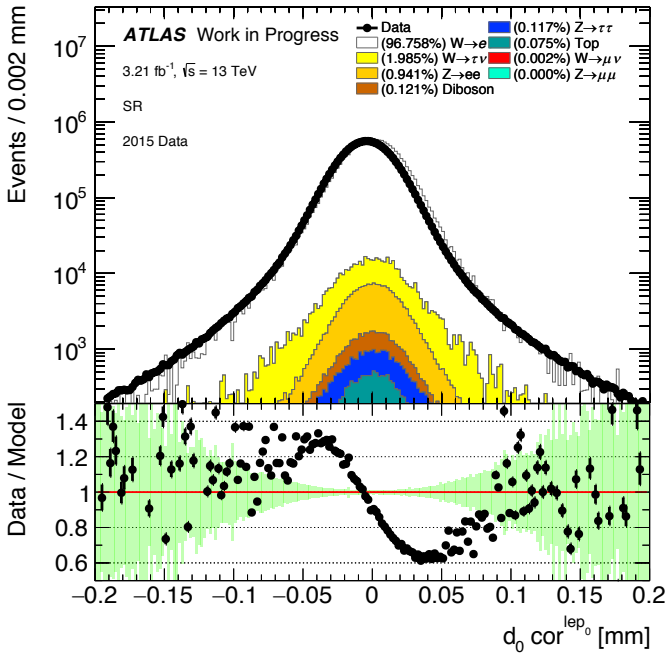


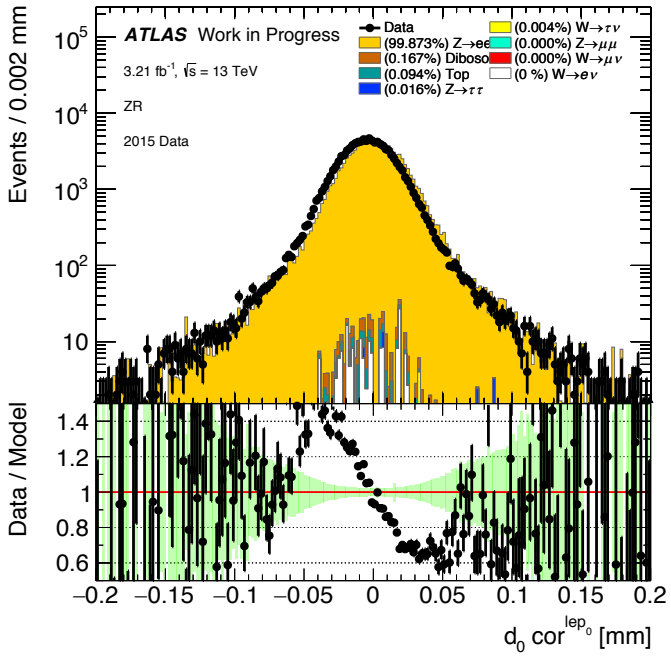


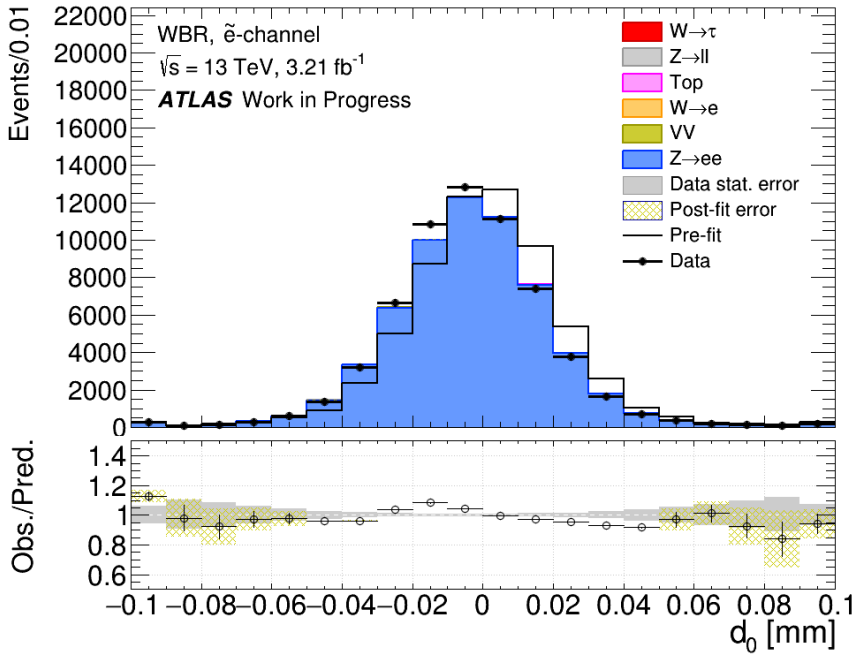
- Fake region
  - To get QCD background scale factor
  - Template fit method:
    - Relaxed cuts om E_T^{MISS} and P_T
    - Inverted lepton Isolation and lepton quality cuts

- Z channel
  - To get EW MC background scale factor
  - $Z \rightarrow ll$ selection:
    - Exactly 2 leptons with opposite charge
    - Mass region 81<|M_{Zll}|<101 [GeV]

d_0 bias for 2015 and 2016







- We have shift for impact parameter d0 for the both years
  - Caused be IBL alignment problem
  - Breaks blinded fit

- Solution:
  - One more region with d0 distribution in $Z \rightarrow ll$
  - introduce nuisance parameter *TRK_d0_bias* in the fit, which is common for all d_0 distributions.
    - Up and down variations as ± 1 bin shift from the nominal histogram.

Fit results: Asimov Data

Nuisance parameter	Value	Uncertainty
TRK_d0_bias	-1.4285e-09	7.33e-03
norm_W	1.	4.35e-04
norm_Z	1.	5.41e-04
norm_QCD	1.	5.43e-03

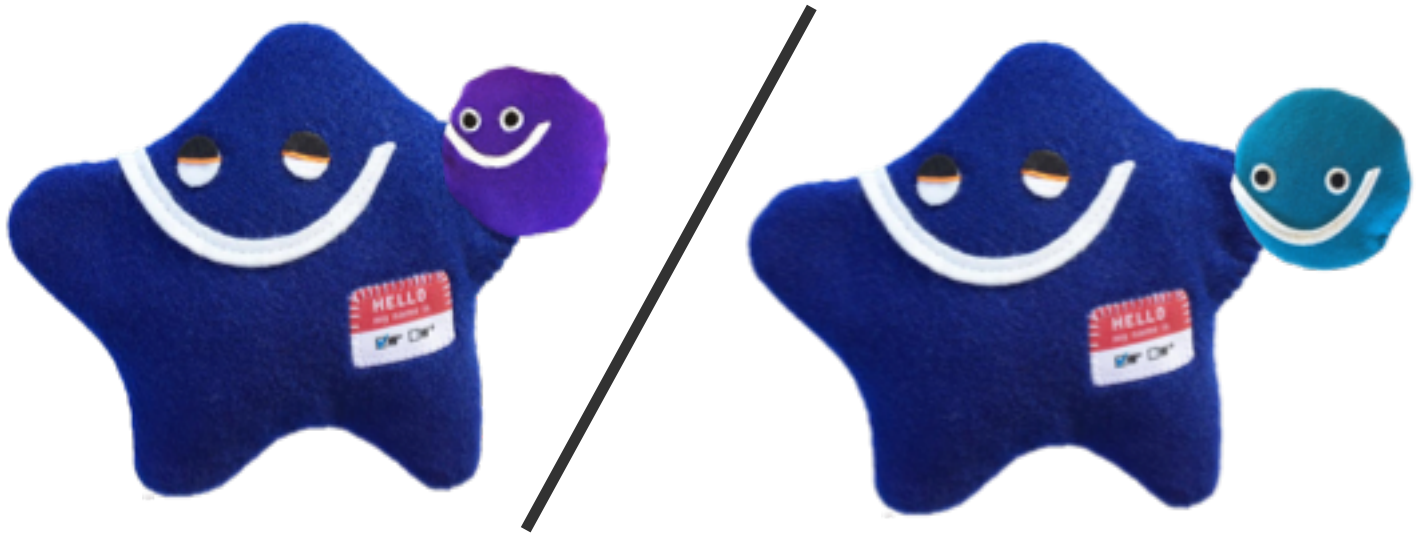
POI	Error
MCSTAT	3.73e-03
NORM	1.83e-02
STAT	8.82e-03
SYST	1.43e-05
Total	2.07e-02

- Fit uncertainty breakdown:
  - SYST includes d0 bias only
  - STAT is the remaining error after all nuisance parameters are held constant
- QCD background is under good control (0.5%)
- POI has 2% uncertainty
  - For 2015 year only. Could be less then 1.2% for all Run-II statistics.

Conclusions

- A lot of things to be done. But…
- …most of the analysis software is ready
  - Package for QCD background estimation
  - TMVA helps to distinguish $W \rightarrow \tau_{lep}\nu$ from the background processes
  - 2D fit
- First fit results:
  - Promising statistical power to perform this analysis
    - Fakes are under good control
    - Signal uncertainty is about 2%.
    - Naive estimation for full Run-II statistic: less then 1.2%
- Plans and timeline:
  - December 2018:
    - Closer look at the Data 2017 and include systematics
  - March 2019:
    - Combine all Run-II data

Backup



Measuring $W \to \tau \to \ell / W \to \ell$

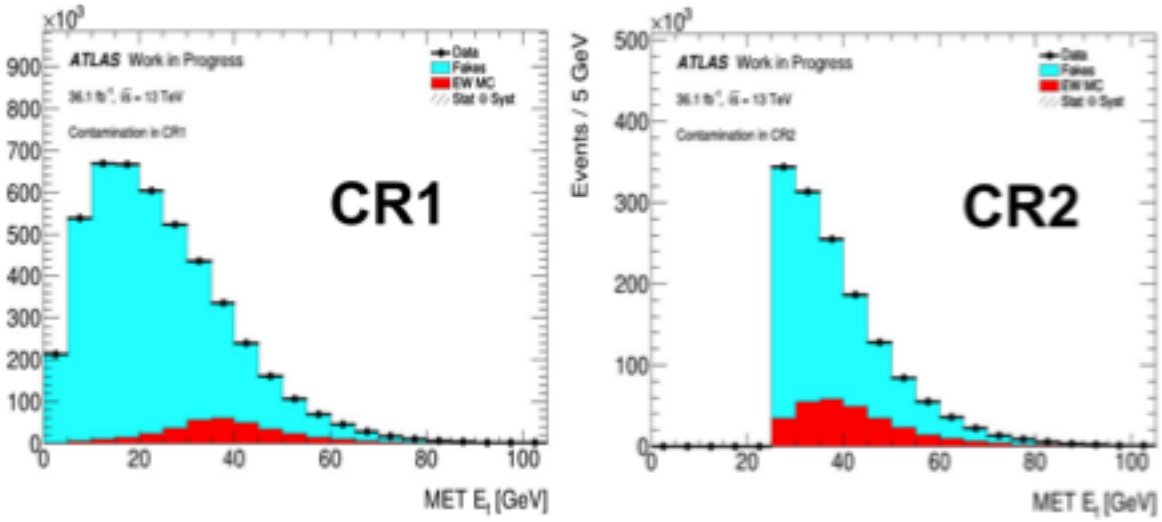
Daniil Ponomarenko, Nicolo de Groot

Links related to $W \to \tau \to \ell / W \to \ell$ analysis

- JIRA:
  - https://its.cern.ch/jira/browse/ATLASSMWBR-1
- GIT:
  - https://gitlab.cern.ch/Wlep_BR
- TWiki:
  - https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/Vtaus13TeV

jet → τ fakes background estimation

- Fakes background is one of the dominant backgrounds
- Need a reliable estimation method with acceptable uncertainties
- Fake Factor (FF) method
  - Basically a transfer factor method



Validation in same-sign $\ell\tau$ regions

- **1.** Obtain FF = pass/fail ratio in Fakes-enriched Region
- **2.** Apply FF in Signal Region

	Signal Region (SR)	Fakes-enriched Region (FR)
Passed *e* ID and Isolation	*Estimation*	Data
Failed *e* ID and Isolation	Data	Data

ToDo list

- Implement recoil energy
  - Current approach is focused on 0 and 1 jet events selection
- Have a look at muon channel
  - Now output contains only electrons
- Correct MC d_0 distribution in 2015/2016
  - Data/MC is shifted - known IBL alignment problem
  - For both muons and electrons
- Tune MJ background estimation
  - Do slicing on $ptcone$
  - Have a look what ML can do for us.
- Improve TMVA separation power
  - Tune BDT model
  - Try out other classification algorithms
- Include CP systematics
- Investigate fit stability with a toy models