The measurement of W-charge asymmetry at 13 TeV with the CMS detector.

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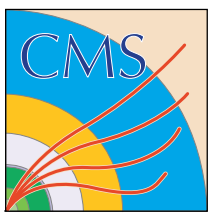
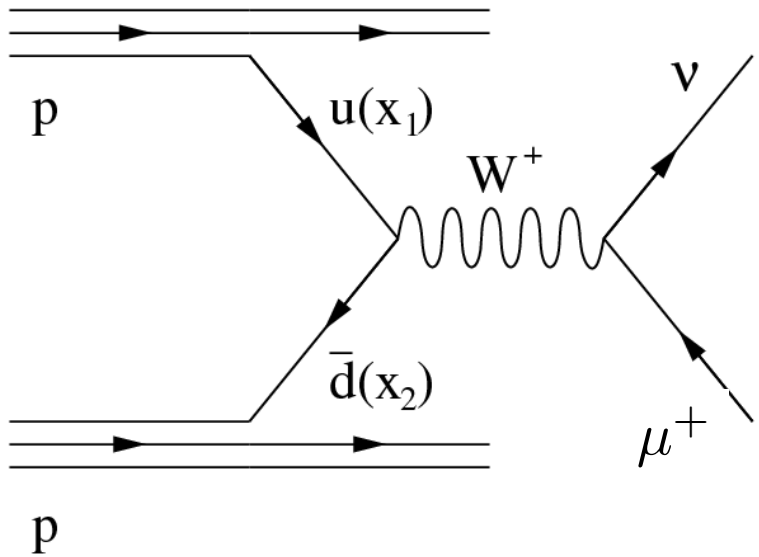


W charge asymmetry

- $W^{\pm}$ bosons primarily produced in pp collisions through $u\bar{d} \to W^{+}$ and $\bar{u}d \to W^{-}$
- W asymmetry is an effect of asymmetric production of W^{+} bosons over W^{-}

$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^{+} \to \mu^{+}\nu) - \frac{d\sigma}{d\eta}(W^{-} \to \mu^{-}\bar{\nu})}{\frac{d\sigma}{d\eta}(W^{+} \to \mu^{+}\nu) + \frac{d\sigma}{d\eta}(W^{-} \to \mu^{-}\bar{\nu})}$$



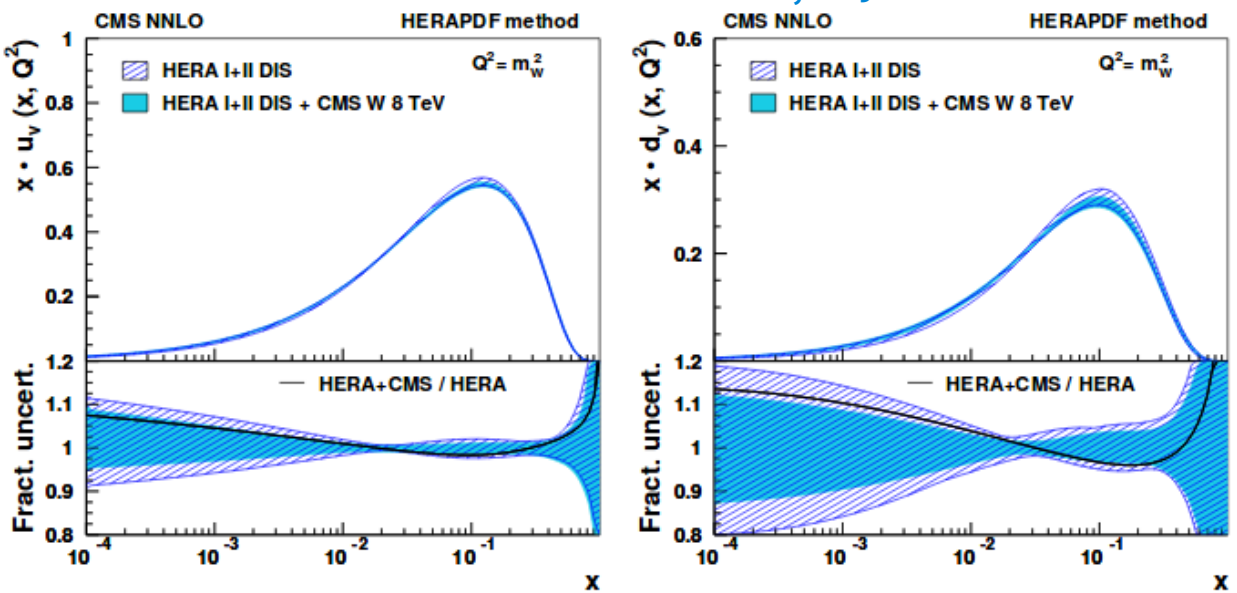
Previous studies

W asymmetry was studied by ATLAS, CMS and LHCb.
Main topics of interest:

- Studies of additional constraints on the d/u ratio and on the sea antiquark densities in the proton.
- improvement of the the PDF uncertainties for d and u quark flavors.

Previous CMS studies:

- 7 TeV: arXiv:1312.6283, Phys. Rev. D 90 (2014) 032004
- 8 TeV: arXiv:1603.01803, Eur. Phys. J. C 76 (2016) 469



Significant improvement for $10^{-3} < x < 10^{-1}$

$W^{\pm}$ production cross section analysis

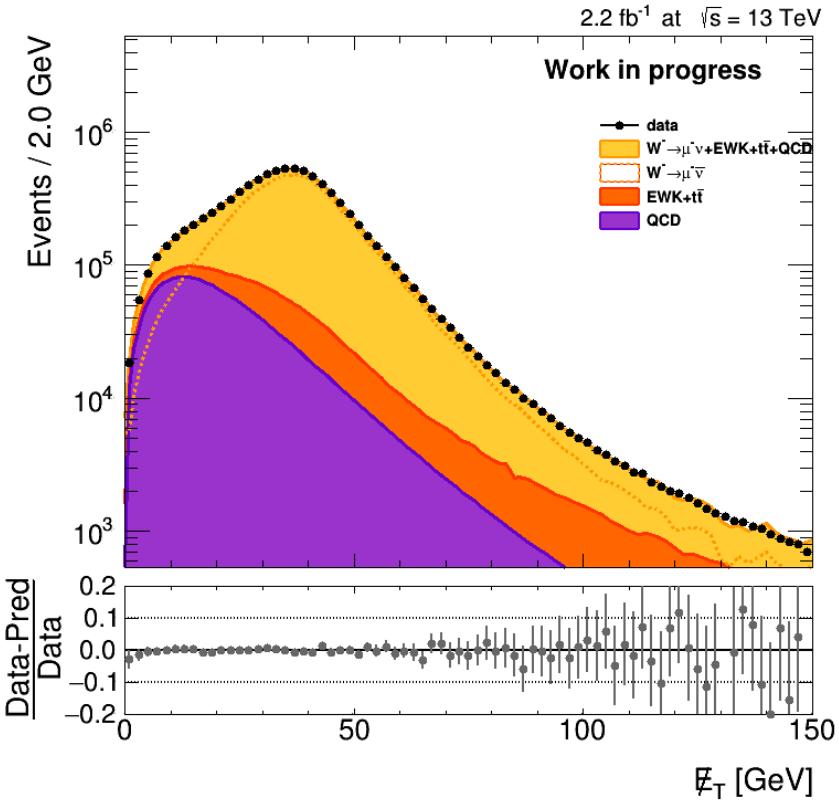
Data sample:

- 2015 at 13 TeV
- Integrated luminocity $2.2\ fb^{-1}$

Events selection:

- at least one muon, $p_T > 25$ GeV, $|\eta| < 2.4$

MET ($\not{E}_T$) estimation is used to extract the $W^{\pm}$ boson signal from the background.

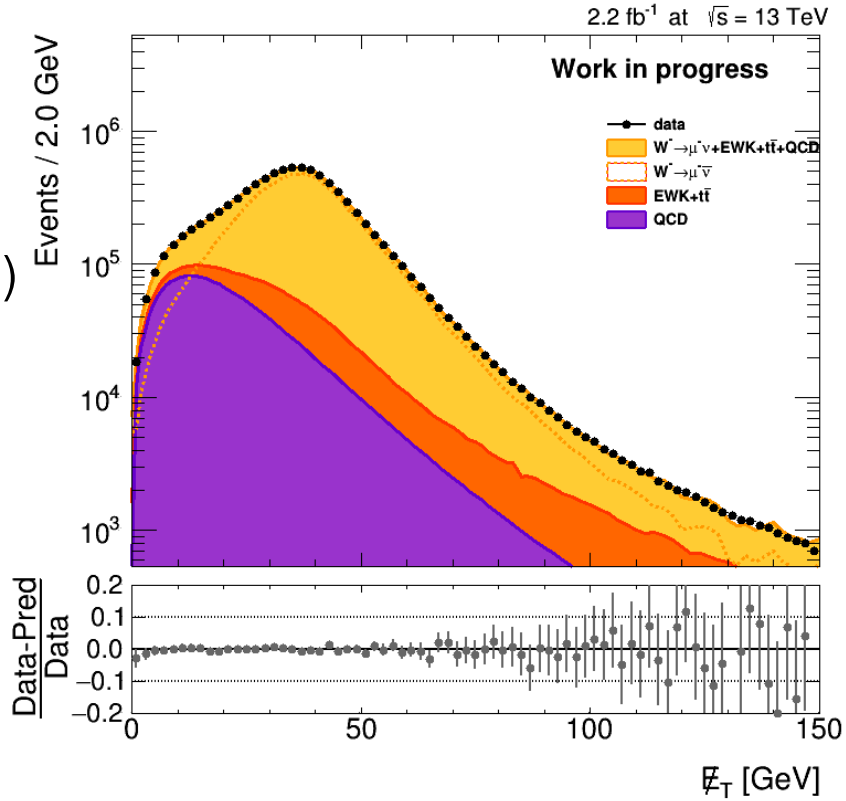


$\not{E}_T$ and signal extraction

The E^T_{miss} model is fitted to the observed distribution as the sum of three contributions:

- Signal: $W^{\pm}$
- Background:
  - EWK + $t\bar{t}$ (modeled with simulation-based fitting functions.)
  - QCD (modeled by an $analytic\ function$)

The W boson $signal$ and $background\ yields$ are obtained from the $\not{E}_T$ distributions using an unbinned $maximum\text{-}likelihood\ fit$.

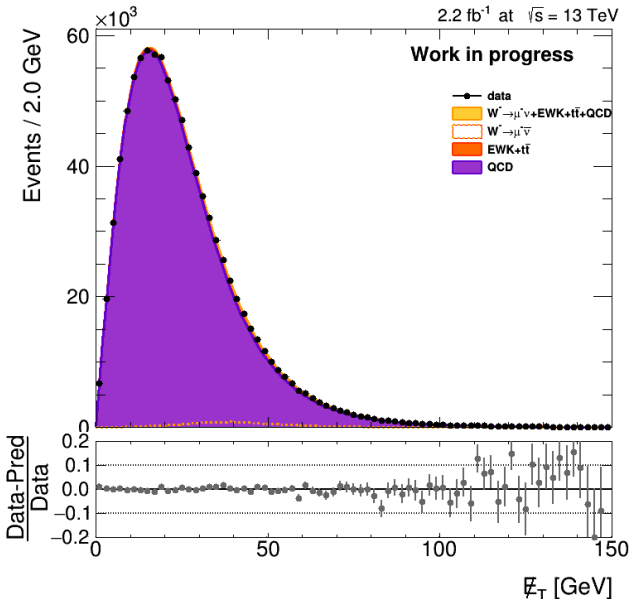


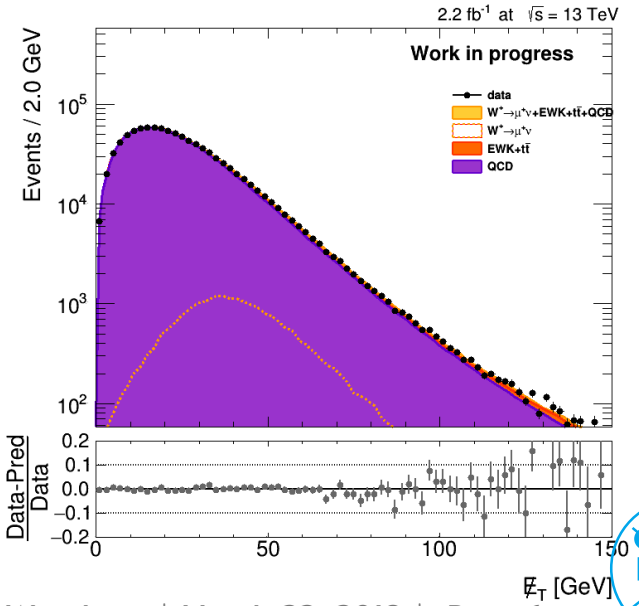
QCD background

QCD estimation is performed using $fake\ factor\ method$:

- Control region:
  - prescaled non-isolated muon trigger
  - inverted isolation requirements
- The shape of the $\not{E}_T$ control sample distribution is modeled by modified Rayleigh distribution:

$$f(x) = x * e^{\frac{x^2}{ax^2+bx+c}} * (ax^2 + bx + c) > 0$$
$$a = 4.0 \in [-10.0, 10.0]$$
$$b = 6.0 \in [0.0, 20.0]$$
$$c = 2.9 \in [0.3, 6.0]$$
$$x \in [0.0, 2.0, 150.0]$$

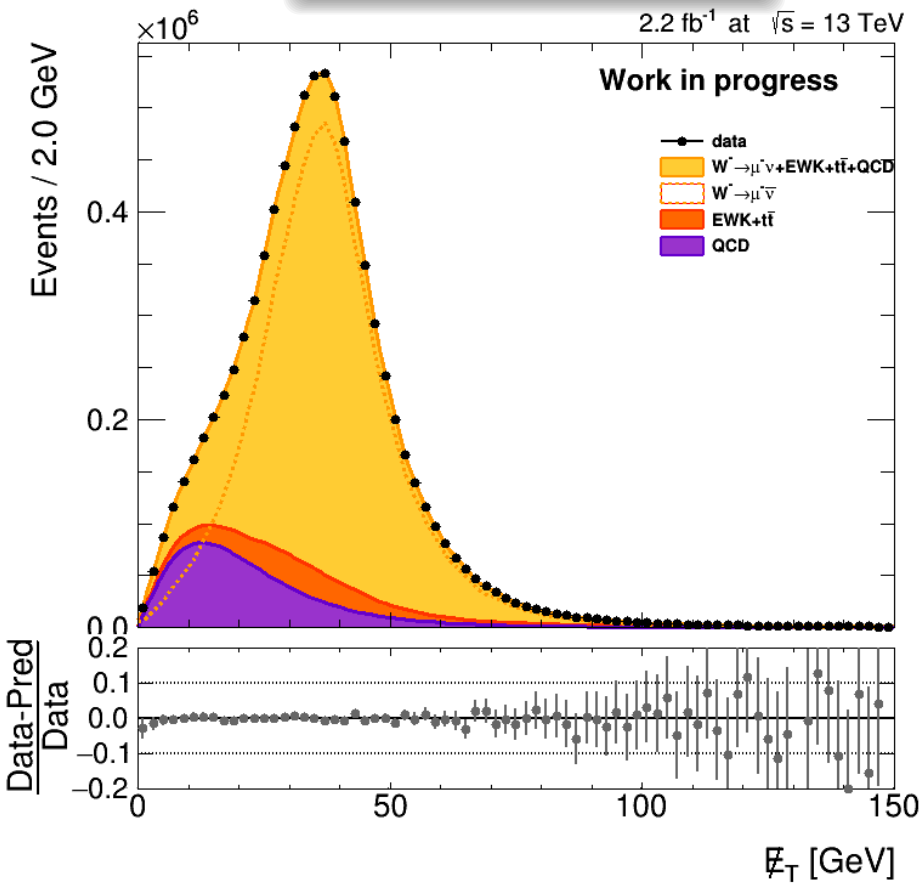




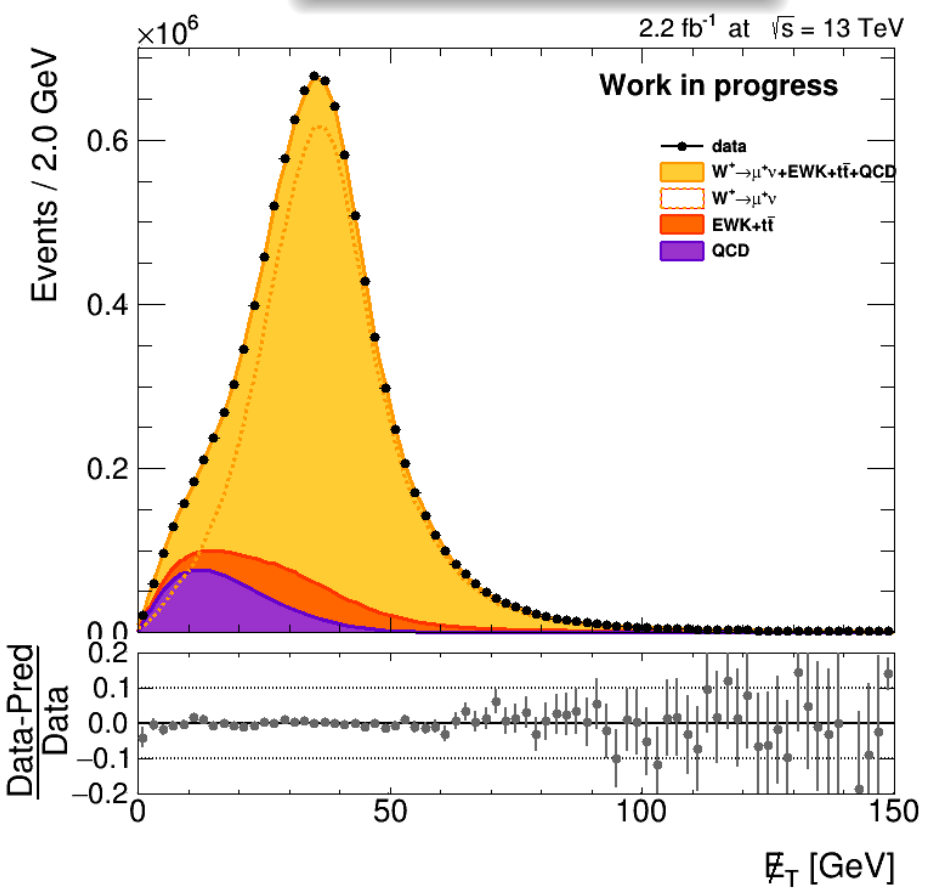
Missing E^T for the whole eta region for W^+ & W^-

Results represent signal extraction.

$W^- \to \mu^- \bar{\nu}$



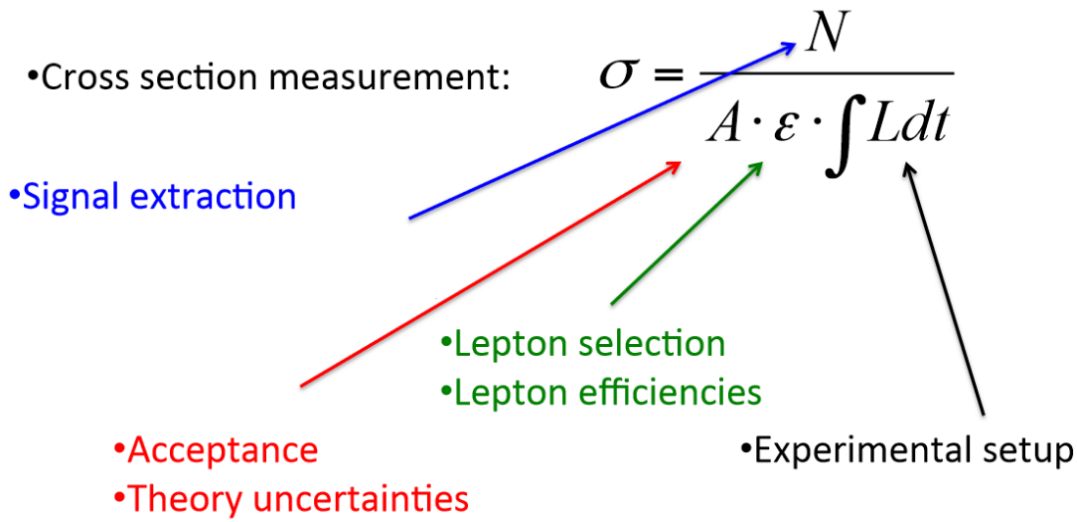
$W^+ \to \mu^+ \nu$



Pseudorapidity binning and cross section

For the future W asymmetry studies, $\not{E}_T$ has to be represented in a bins of η:

Region	η_{min}	η_{max}
1	0.0	0.2
2	0.2	0.4
3	0.4	0.6
4	0.6	0.8
5	0.8	1.0
6	1.0	1.2
7	1.2	1.4
8	1.4	1.6
9	1.6	1.85
10	1.85	2.1
11	2.1	2.4



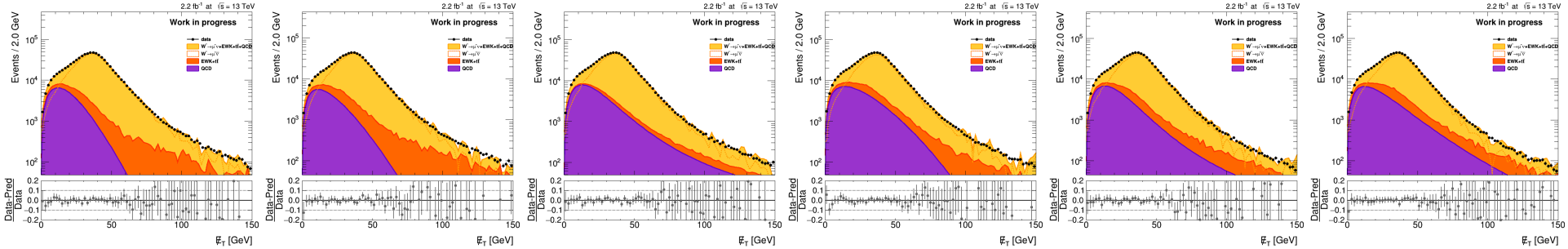
Cross section per eta region allows to obtain the asymmetry values

$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+ \nu) - \frac{d\sigma}{d\eta}(W^- \to \mu^- \bar{\nu})}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+ \nu) + \frac{d\sigma}{d\eta}(W^- \to \mu^- \bar{\nu})}$$

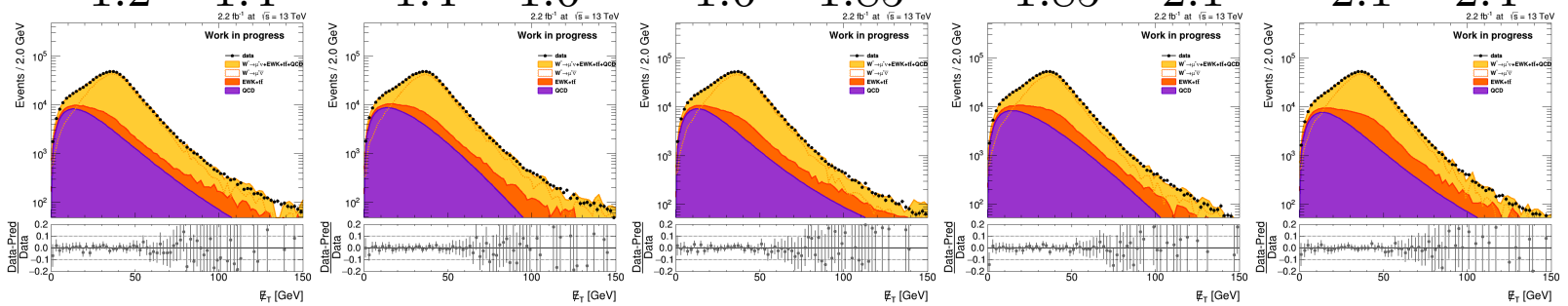
Eta binned results in a log scale for $W^- \to \mu^- \bar{\nu}$

Converged fits provide signal yields
for the cross-section calculations:

$0.0 - 0.2$ $0.2 - 0.4$ $0.4 - 0.6$ $0.6 - 0.8$ $0.8 - 1.0$ $1.0 - 1.2$



$1.2 - 1.4$ $1.4 - 1.6$ $1.6 - 1.85$ $1.85 - 2.1$ $2.1 - 2.4$

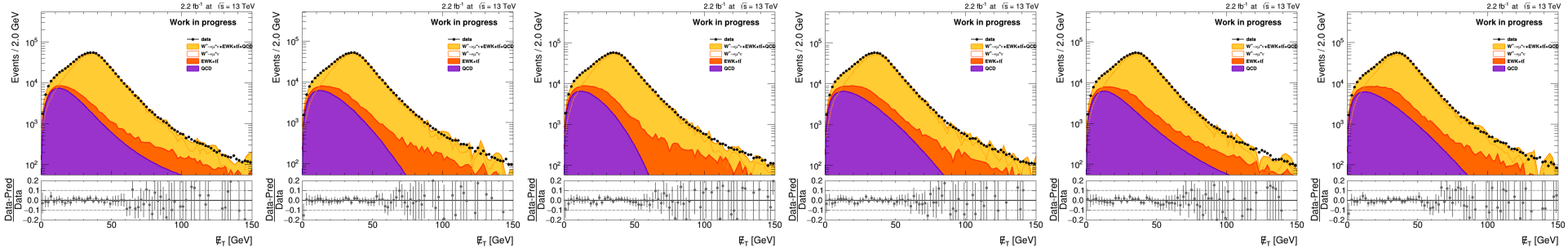


All eta regions shows a good agreement of MC with the Data

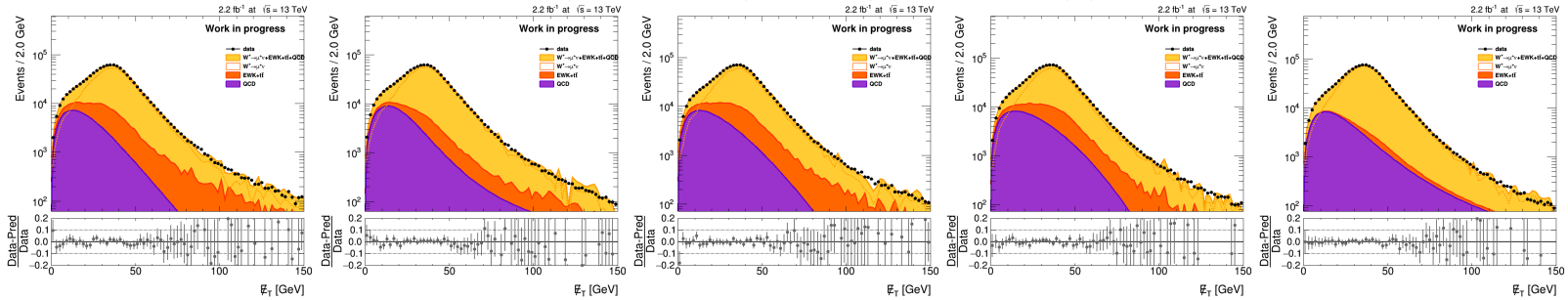
Eta binned results in a log scale for $W^+ \to \mu^+\nu$

Converged fits provide signal yields
for the cross-section calculations:

$0.0 - 0.2$ $0.2 - 0.4$ $0.4 - 0.6$ $0.6 - 0.8$ $0.8 - 1.0$ $1.0 - 1.2$



$1.2 - 1.4$ $1.4 - 1.6$ $1.6 - 1.85$ $1.85 - 2.1$ $2.1 - 2.4$



All eta regions shows a good agreement of MC with the Data

Summary and outlook

Summary:

- Well converged fit allowed η-binning implementation.
- Extracted signal yields for different pseudorapidity regions allow to calculate the cross-section values.

Outlook:

- Cross sections calculated for each pseudorapidity region will allow us to obtain the asymmetry values.
- The muon charge asymmetry can be used in the global QCD analysis at NNLO together with the combined measurements of neutral- and charged-current cross sections of DIS at HERA:

  → *xFitter tool will be used for the fitting*

BACK-UP

Muon selection requirements

Muons are identified using the following requirements:

Observable	Value or Range
p_T	$> 25\ GeV$
$\|\eta\|$	< 2.4
Id	Global Muon
Id	PFMuon
χ^2/ndof	< 10
# Valid Muon Hits	> 0
# Matched Stations	> 1
# Tracker Layers	> 5
# Valid Pixel Hits	> 0
$\|d_{0,pv}\|$	< 0.2
$\|d_{z,pv}\|$	< 0.5
PFIso/p_T	< 0.12

Additional Muon Veto selection requirements

Events with additional muons are vetoed.
This veto-muon passes a looser selection:

Observable	Value or Range
p_T	$> 10\ GeV$
$\|\eta\|$	< 2.4
Id	Global Muon || TrackerMuon
Id	PFMuon
PFIso/p_T	< 0.2

Lepton efficiencies

The muon efficiencies are estimated in data and simulation using tag-n-probe technique:

$$e_{total} = e_{tracking+ID+ISO} \times e_{STA} \times e_{trigger}$$

- $e_{tracking+ID+ISO}$ – *efficiency for a track in the muon detector to be matched to a global muon that passes the identification and isolation criteria.*
- e_{STA} – *efficiency for an isolated tracker track from a muon to be matched to a global muon.*
- $e_{trigger}$ – *efficiency for a fully identified and isolated muon to pass the trigger (HLT and Level-1) requirements.*

Fit quality $W^+ \to \mu^+\nu$

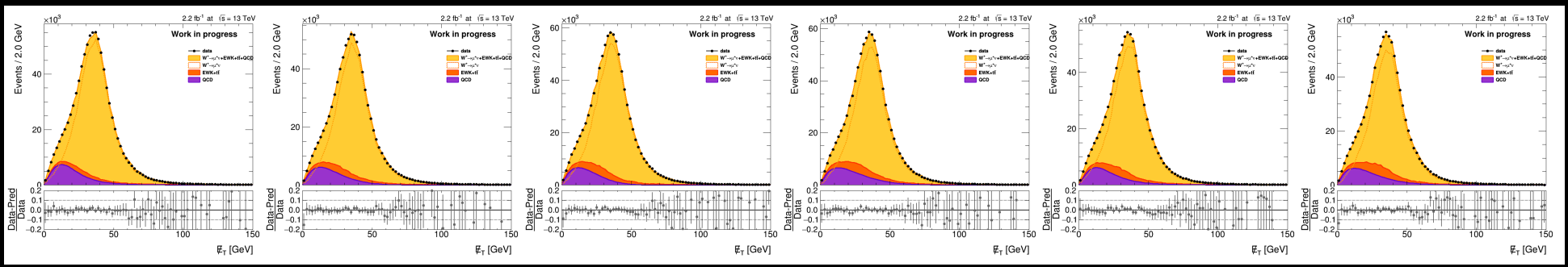
```
 *** Yields ***
Selected: 11007396
  Signal: 9171279.624 +/- 8594.765364
     QCD: 947603.7237 +/- 2854.891504
   Other: 888508.0627 +/- 9905.635918
AntiSelected: 973747
  AntiSignal: 22270.53557 +/- 2235.639688
     AntiQCD: 944095.664 +/- 3131.211926
   AntiOther: 7368.341286 +/- 739.6749019


  RooFitResult: minimized FCN value: -122103698.9, estimated distance to minimum: 6.212239145e-08
                covariance matrix quality: Full, accurate covariance matrix
                Status : MIGRAD=4 HESSE=0 MINOS=6

    Constant Parameter    Value
  --------------------  ------------
                dewkp    3.3086e-01

    Floating Parameter  InitialValue    FinalValue (+HiError,-LoError)    GblCorr.
  --------------------  ------------  ----------------------------------  --------
              a1_aqcdp    4.0000e+00    4.2476e+00         +/-  7.98e-02  <none>
               a1_qcdp    4.0000e+00   -7.7499e+00         +/-  4.06e-10  <none>
              a2_aqcdp    6.0000e+00    6.0991e+00 (+0.00e+00,-1.07e-01)  <none>
               a2_qcdp    6.0000e+00    1.0953e+01         +/-  6.89e-10  <none>
              a3_aqcdp    2.9000e+00    3.0379e+00 (+0.00e+00,-3.13e-02)  <none>
               a3_qcdp    2.9000e+00    1.0076e+00         +/-  1.18e-09  <none>
                 cewkp    9.1957e-02    9.6879e-02         +/-  1.16e-03  <none>
             nAntiQCDp    8.7637e+05    9.4410e+05 (+0.00e+00,-3.18e+03)  <none>
             nAntiSigp    1.8132e+04    2.2271e+04 (+0.00e+00,-2.27e+03)  <none>
                 nQCDp    3.3022e+06    9.4760e+05         +/-  2.85e+03  <none>
                 nSigp    8.8464e+06    9.1713e+06         +/-  8.59e+03  <none>


 Correlation Matrix
--------------------
  1.0000  -0.0000  -0.9529   0.0000   0.8551   0.0000  -0.0013  -0.2692   0.2825   0.0018   0.0008
 -0.0000   1.0000   0.0000  -0.0000  -0.0000   0.0000   0.0000  -0.0000   0.0000   0.0000  -0.0000
 -0.9529   0.0000   1.0000  -0.0000  -0.8919  -0.0000   0.0010   0.4385  -0.4604  -0.0013  -0.0006
  0.0000  -0.0000  -0.0000   1.0000   0.0000  -0.0000   0.0000   0.0000   0.0000   0.0000  -0.0000
  0.8551  -0.0000  -0.8919   0.0000   1.0000   0.0000  -0.0015  -0.1110   0.1165   0.0020   0.0009
  0.0000   0.0000  -0.0000  -0.0000   0.0000   1.0000  -0.0000   0.0000  -0.0000   0.0000  -0.0000
 -0.0013   0.0000   0.0010   0.0000  -0.0015  -0.0000   1.0000  -0.0014   0.0014  -0.6904  -0.9217
 -0.2692  -0.0000   0.4385   0.0000  -0.1110   0.0000  -0.0014   1.0000  -0.9491   0.0018   0.0008
  0.2825   0.0000  -0.4604   0.0000   0.1165  -0.0000   0.0014  -0.9491   1.0000  -0.0019  -0.0008
  0.0018   0.0000  -0.0013   0.0000   0.0020   0.0000  -0.6904   0.0018  -0.0019   1.0000   0.5131
  0.0008  -0.0000  -0.0006  -0.0000   0.0009  -0.0000  -0.9217   0.0008  -0.0008   0.5131   1.0000

 Chi2 Test
-----------
      prob = 0.9984
  chi2/ndf = 0.584

 KS Test
---------
  prob = 0.9646
  prob = 0.859 with 1000 pseudo-experiments
```

Fit quality $W^- \to \mu^- \bar{\nu}$

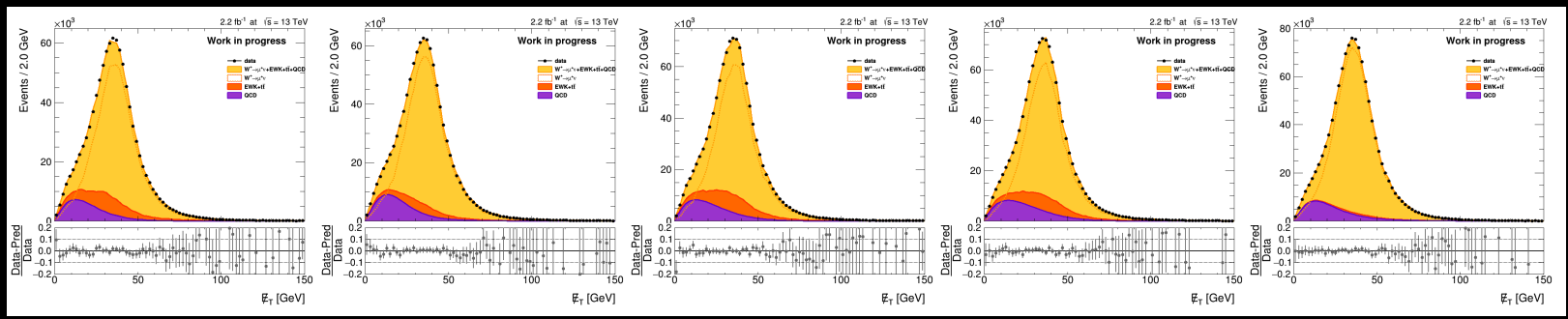
```
 *** Yields ***
Selected: 8835493
  Signal: 7046466.383 +/- 11483.67287
     QCD: 1180845.792 +/- 15895.04083
   Other: 608190.3923 +/- 22129.60178
AntiSelected: 963128
  Signal: 15609.54649 +/- 1734.483761
     QCD: 940758.7991 +/- 2672.340669
   Other: 6767.430474 +/- 751.9756113


  RooFitResult: minimized FCN value: -97437178.98, estimated distance to minimum: 0.5290934814
                covariance matrix quality: Full, accurate covariance matrix
                Status : MIGRAD=4 HESSE=0 MINOS=6

    Constant Parameter    Value
  --------------------  ------------
                 dewkm    4.3354e-01

    Floating Parameter  InitialValue    FinalValue (+HiError,-LoError)    GblCorr.
  --------------------  ------------  ---------------------------------  --------
              a1_aqcdm    4.0000e+00    4.2187e+00 (+8.12e-02,--0.00e+00)  <none>
               a1_qcdm    4.0000e+00    4.4075e+00 (+0.00e+00,-1.28e-01)  <none>
              a2_aqcdm    6.0000e+00    6.1310e+00 (+9.82e-02,--0.00e+00)  <none>
               a2_qcdm    6.0000e+00    6.5184e+00 (+1.14e-01,-2.19e-01)  <none>
              a3_aqcdm    2.9000e+00    3.0465e+00 (+3.21e-02,--0.00e+00)  <none>
               a3_qcdm    2.9000e+00    1.6982e+00 (+0.00e+00,-1.03e-02)  <none>
                 cewkm    1.0695e-01    8.6311e-02         +/-  3.24e-03  <none>
             nAntiQCDm    8.6682e+05    9.4076e+05 (+2.63e+03,-2.71e+03)  <none>
             nAntiSigm    1.3471e+04    1.5610e+04 (+1.75e+03,-1.72e+03)  <none>
                 nQCDm    2.6506e+06    1.1808e+06 (+1.60e+04,-1.48e+04)  <none>
                 nSigm    6.8191e+06    7.0465e+06         +/-  1.15e+04  <none>


 Correlation Matrix
--------------------
  1.0000  -0.0007  -0.9516  -0.0002   0.8601   0.0004   0.0010  -0.1947   0.2086  -0.0008  -0.0008
 -0.0007   1.0000   0.0010  -0.4405  -0.0006  -0.4077  -0.6559   0.0011  -0.0012   0.3317   0.7786
 -0.9516   0.0010   1.0000   0.0003  -0.9130  -0.0006  -0.0013   0.3622  -0.3880   0.0011   0.0010
 -0.0002  -0.4405   0.0003   1.0000  -0.0001   0.0397  -0.2942   0.0006  -0.0006   0.6729  -0.3184
  0.8601  -0.0006  -0.9130  -0.0001   1.0000   0.0004   0.0008  -0.1028   0.1101  -0.0007  -0.0007
  0.0004  -0.4077  -0.0006   0.0397   0.0004   1.0000   0.4007  -0.0007   0.0007  -0.1673  -0.5208
  0.0010  -0.6559  -0.0013  -0.2942   0.0008   0.4007   1.0000  -0.0018   0.0019  -0.8612  -0.7343
 -0.1947   0.0011   0.3622   0.0006  -0.1028  -0.0007  -0.0018   1.0000  -0.9301   0.0016   0.0012
  0.2086  -0.0012  -0.3880  -0.0006   0.1101   0.0007   0.0019  -0.9301   1.0000  -0.0017  -0.0013
 -0.0008   0.3317   0.0011   0.6729  -0.0007  -0.1673  -0.8612   0.0016  -0.0017   1.0000   0.3092
 -0.0008   0.7786   0.0010  -0.3184  -0.0007  -0.5208  -0.7343   0.0012  -0.0013   0.3092   1.0000

 Chi2 Test
-----------
      prob = 1
  chi2/ndf = 0.4089

 KS Test
---------
  prob = 1
  prob = 0.997 with 1000 pseudo-experiments
```

Eta binned results in a linear scale for $W^+ \to \mu^+\nu$

$0.0 - 0.2$ $0.2 - 0.4$ $0.4 - 0.6$ $0.6 - 0.8$ $0.8 - 1.0$ $1.0 - 1.2$

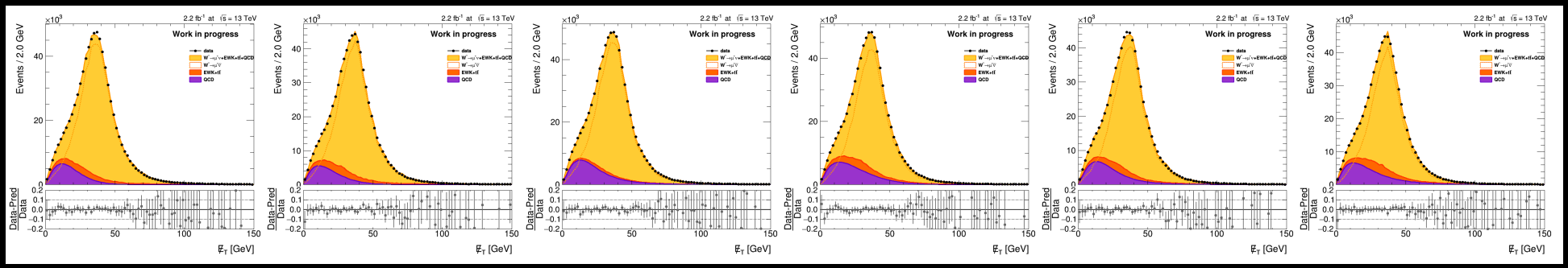


$1.2 - 1.4$ $1.4 - 1.6$ $1.6 - 1.85$ $1.85 - 2.1$ $2.1 - 2.4$

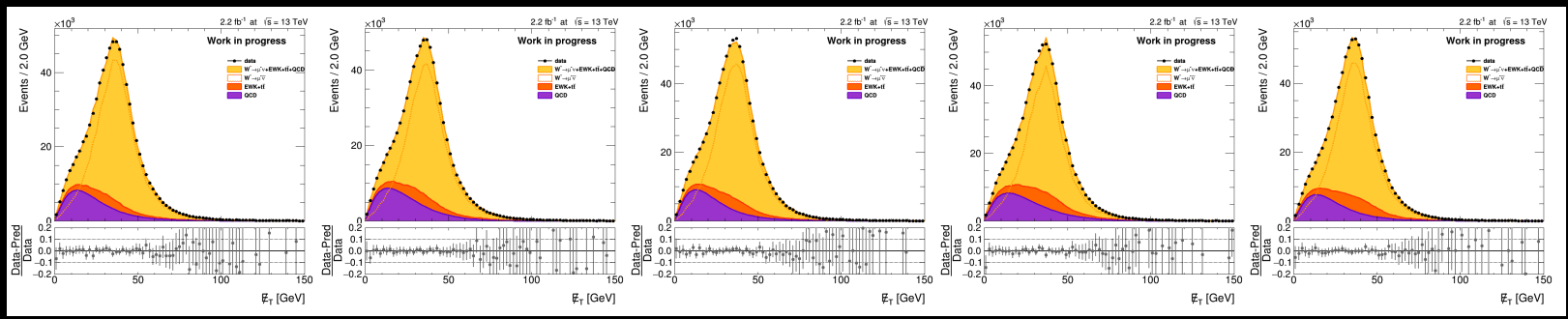


Eta binned results in a linear scale for $W^- \to \mu^- \bar{\nu}$

$0.0 - 0.2$ $0.2 - 0.4$ $0.4 - 0.6$ $0.6 - 0.8$ $0.8 - 1.0$ $1.0 - 1.2$

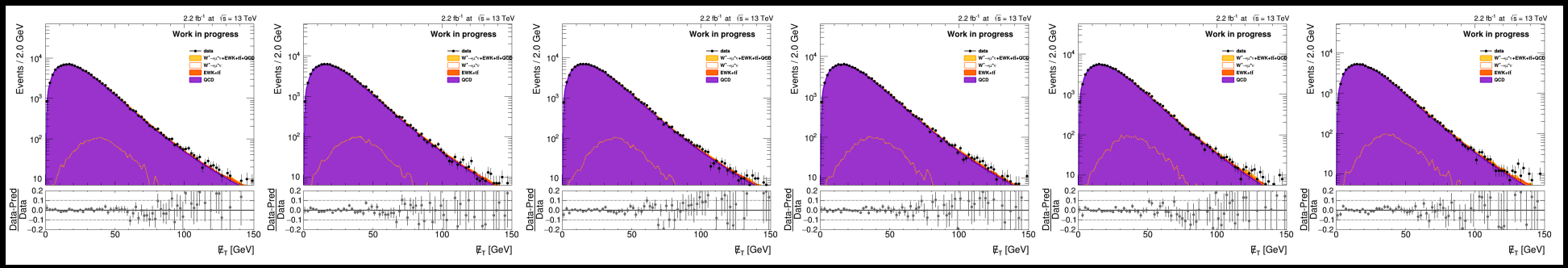


$1.2 - 1.4$ $1.4 - 1.6$ $1.6 - 1.85$ $1.85 - 2.1$ $2.1 - 2.4$

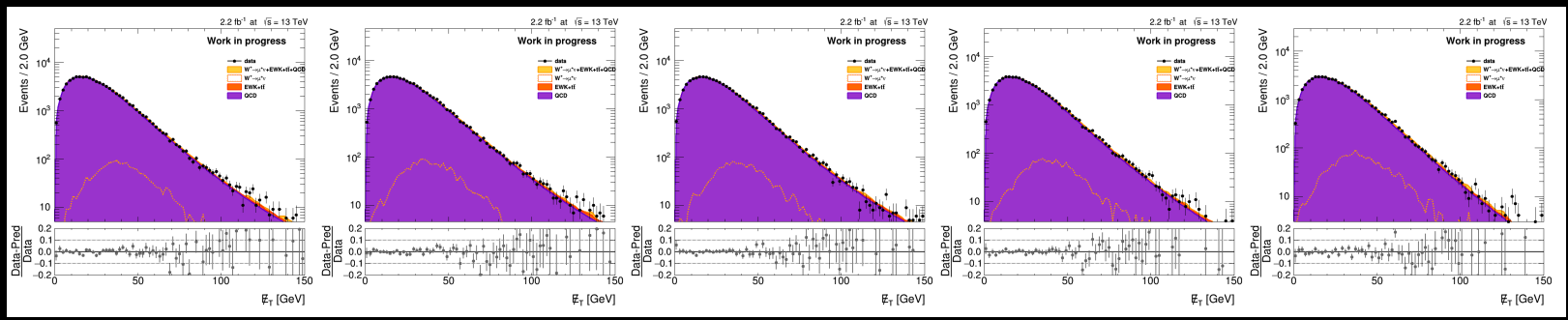


Eta binned results in a log scale for $W^+ \to \mu^+\nu$

$0.0 - 0.2$ $0.2 - 0.4$ $0.4 - 0.6$ $0.6 - 0.8$ $0.8 - 1.0$ $1.0 - 1.2$

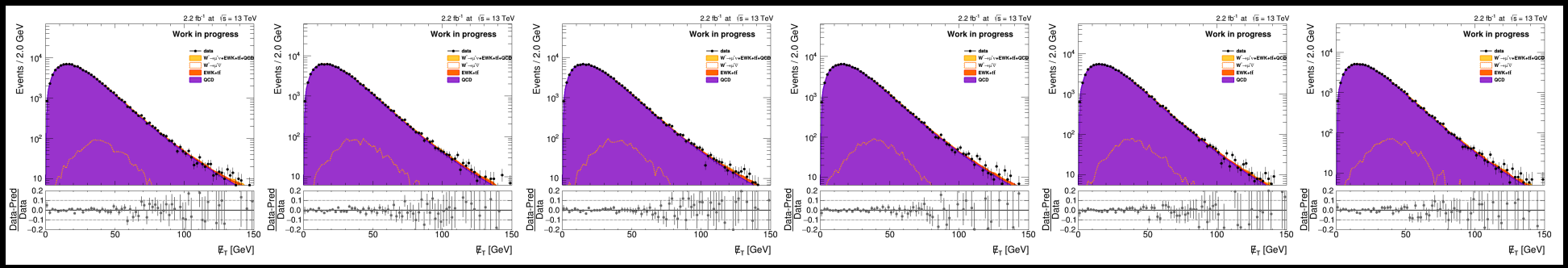


$1.2 - 1.4$ $1.4 - 1.6$ $1.6 - 1.85$ $1.85 - 2.1$ $2.1 - 2.4$



Control region eta binned results in a log scale for $W^- \to \mu^- \bar{\nu}$

$0.0 - 0.2$ $0.2 - 0.4$ $0.4 - 0.6$ $0.6 - 0.8$ $0.8 - 1.0$ $1.0 - 1.2$



$1.2 - 1.4$ $1.4 - 1.6$ $1.6 - 1.85$ $1.85 - 2.1$ $2.1 - 2.4$