with low <mu> data

W-Ai measurements

Daniil Ponomarenko

MEPhI@ATLAS group meeting, 19-Janurary-2022

ATLAS EXPERIMENT

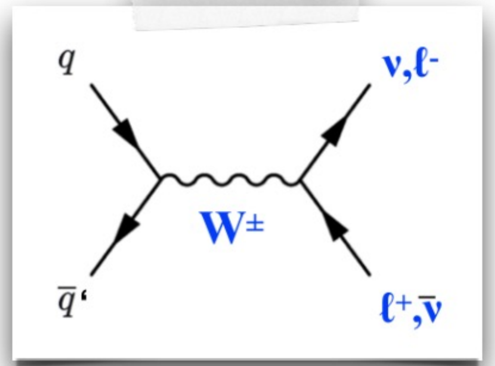
IN·DEI·NOMINE·FELICITER Radboud Universiteit Nijmegen

NATIONAL RESEARCH NUCLEAR UNIVERSITY NRNU MEPhI MEPhI

Motivation

from Ruth Jacobs @ status report

What are angular coefficients?



$$\frac{d\sigma}{dpdq} = \frac{d^3\sigma^{U+L}}{dp_T dy dm}\left(1 + \cos^2\theta + \sum_{i=0}^{7} A_i(y, p_T, m) P_i(\cos\theta, \phi)\right)$$

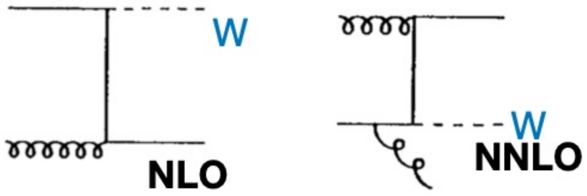
$$\begin{aligned}
P_0(\cos\theta,\phi) &= \frac{1}{2}(1-3\cos^2\theta)\\
P_1(\cos\theta,\phi) &= \sin 2\theta \cos\phi\\
P_2(\cos\theta,\phi) &= \frac{1}{2}\sin^2\theta\cos 2\phi\\
P_3(\cos\theta,\phi) &= \sin\theta\cos\phi\\
P_4(\cos\theta,\phi) &= \cos\theta\\
P_5(\cos\theta,\phi) &= \sin^2\theta\sin 2\phi\\
P_6(\cos\theta,\phi) &= \sin 2\theta\sin\phi\\
P_7(\cos\theta,\phi) &= \sin\theta\sin\phi
\end{aligned}$$

Angular distributions:

- enable precise measurements of DY production dynamics
- spin-correlations between initial partons and final state leptons (born-level)
- DY cross section: decompose into:
  9 harmonic polynomials $P_i(\cos\theta,\phi)$
  \+ angular coefficients $A_i(p_T,y,m)$
  \+ unpolarized cross-section $\sigma^{U+L}(p_T,y,m)$

Angular coefficients A_i:

- for 2→2 (LO): angular dependence fully analytical!
- higher orders: A_i encode hadronic dynamics from production mechanism



Analysis Goal: Determine A_i from cosθ and ϕ distributions of leptons from charged DY production!

The Drell-Yan differential cross-section can be split into 8 helicity dependent cross-sections.

The ratios of these helicity dependent cross-sections over the unpolarized cross-section are denoted by **Ai** and are known as the **Drell-Yan Angular Coefficients**.

Coefficients are coupled to polynomials **Pi** , which are related to spherical harmonics.

Motivation

from Ruth Jacobs @ status report

Why measure A_i in W events?

First (and foremost): The A_i have never been measured before for the W!

- also an important input to W mass measurement:

m_W (ATLAS @7TeV) = 80370 ±6.8 (stat) ±10.6 (exp. sys)±13.6 (mod. sys) MeV

- total uncertainty on ATLAS W mass measurement ~19MeV still larger than 8MeV from electroweak fit
- Bottleneck: Physics modelling uncertainties

W-A_i analysis (+ x-section):

→ A_i: Stringent test of QCD & physics modelling!

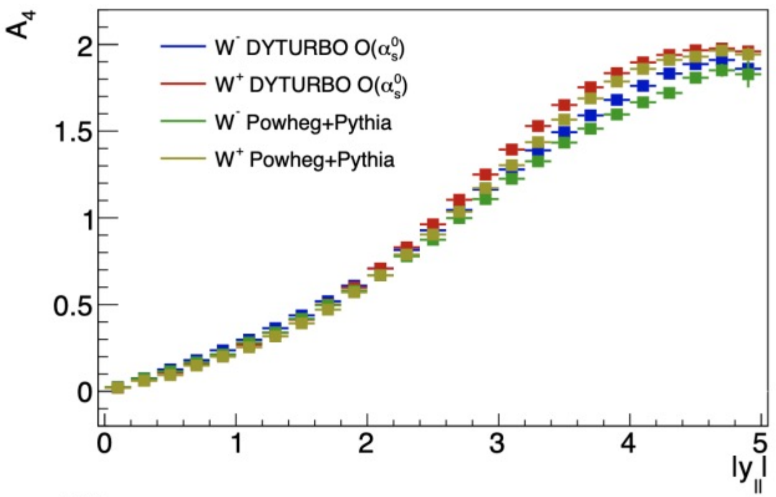
→ Charge asymmetry measurement: Input for PDF fits

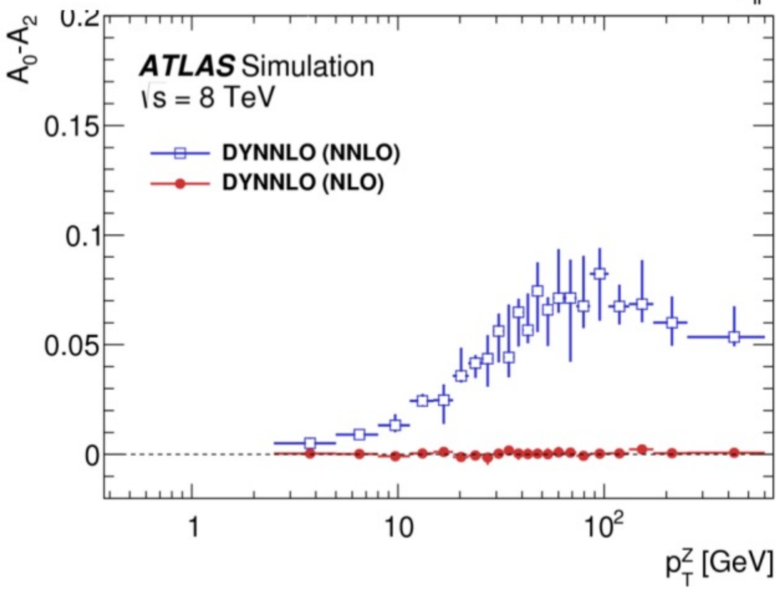
physics modelling

Data sample	7 TeV, $\mu \sim 9$	
Luminosity	4.5 fb^{-1}	Improuved
Nb. of candidates	$\sim 15 \times 10^6$	
Most sensitive dist.	p_T^ℓ	
Physics Modelling Unc.		
EW	5 → latest MC gen.	2
QCD (p_T^W)	6 → WpT meas.	< 3
QCD (A_i)	6 → data input	< 3
PDFs	9 → PDF profiling	6

Analysis goals

from Ruth Jacobs @ status report



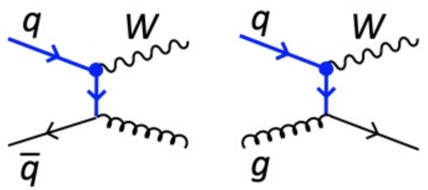


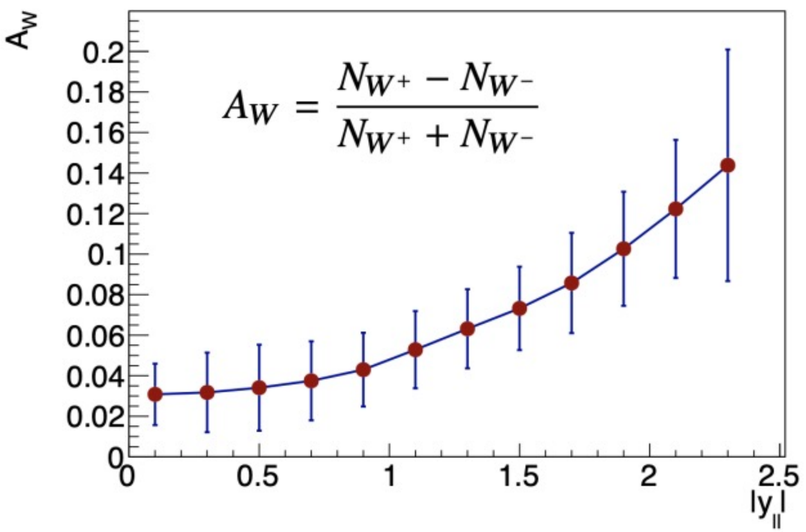
i) A_4

- A_4: forward-backward asymmetry for W
- direct measurement of W longitudinal polarization
- polarization: important source of uncertainty for the W-mass extraction from lepton p_T -spectrum

ii) Lam-Tung relation (A_0-A_2)

- prediction Lam-Tung: A_0-A_2=0 (because of gluon spin-1
- holds at $O(\alpha_s)$, can be violated at $O(\alpha_s^2)$
- Z-boson-events: observe violation of Lam-Tung at $O(\alpha_s^2)$ (factor ~2 larger than predicted)
  → also observed in W events?





iii) Charge Asymmetry

- measure as function of boson rapidity: add more information than in measurement as function of lepton p_T
- A_i Framework: extract cross-section in full phase-space

All of these are new measurements, never been done before in W events!

Measurement Strategy

from Ruth Jacobs @ status report

Same as for Z A_i

1.) Theoretical predictions (Reference A_i)

- A_i enter MC prediction implicitly
- orthogonality of polynomials $P_i(\cos\theta,\phi)$
  → average of P_i relates to A_i

2.) Templates of angular distributions

- after selections on final state leptons, angular distributions are sculpted
- can no longer describe by 9 polynomials!
- "fold" P_i to reco space using MC to model acceptance, efficiency

3.) Template fit to angular distributions in data:

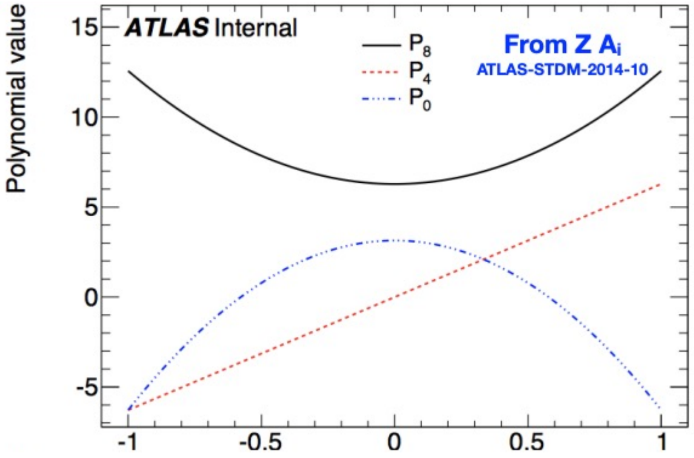
- fit folded P_i templates to data, extract A_i in full phase space
- include background templates

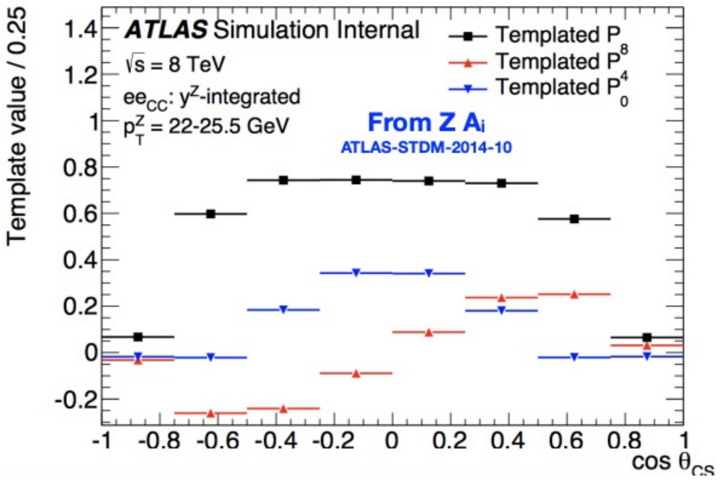
$$\langle\frac{1}{2}(1-3\cos^2\theta)\rangle = \frac{3}{20}(A_0-\frac{2}{3});\quad \langle\sin 2\theta\cos\phi\rangle = \frac{1}{5}A_1;\quad \langle\sin^2\theta\cos 2\phi\rangle = \frac{1}{10}A_2;$$

$$\langle\sin\theta\cos\phi\rangle = \frac{1}{4}A_3;\quad \langle\cos\theta\rangle = \frac{1}{4}A_4;\quad \langle\sin^2\theta\sin 2\phi\rangle = \frac{1}{5}A_5;$$

$$\langle\sin 2\theta\sin\phi\rangle = \frac{1}{5}A_6;\quad \langle\sin\theta\sin\phi\rangle = \frac{1}{4}A_7.$$

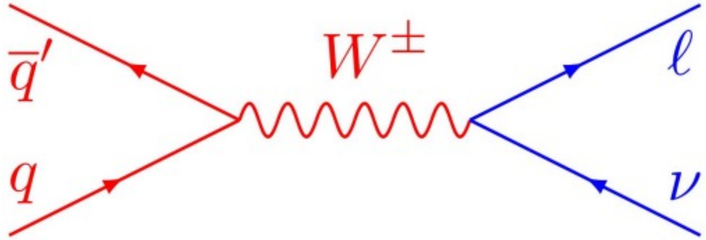
$$\langle P(\cos\theta,\phi)\rangle = \frac{\int P(\cos\theta,\phi)d\sigma(\cos\theta,\phi)d\cos\theta d\phi}{\int d\sigma(\cos\theta,\phi)d\cos\theta d\phi}.$$





Measurement Strategy

from Alexander Bachiu @ WAI report



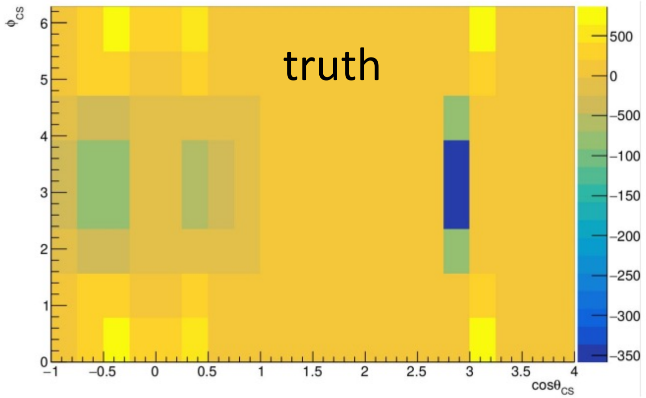
$$\frac{d\sigma}{dp_T^W dy^W dm^W d\cos\theta d\varphi} = \frac{3}{16\pi} \frac{d\sigma^{U+L}}{dp_T^W dy^W dm^W} \left\{ (1+\cos^2\theta) + \sum_{i=0}^{7} A_i(p_T^W, y^W, m^W) P_i(\cos\theta, \varphi) \right\}$$

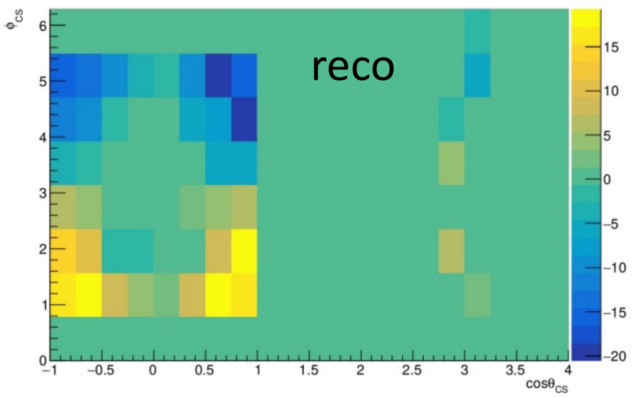
Reference coefficients are created by taking the moment using truth MC.

$$\langle P_i(\theta,\varphi)\rangle = \frac{\int d\sigma(p_T, y, \theta, \varphi) P_i(\theta,\varphi) d\cos\theta d\varphi}{\int d\sigma(p_T, y, \theta, \varphi) d\cos\theta d\varphi} \qquad \langle \sin\theta\cos\varphi\rangle = \frac{1}{4}A_3$$

Templates of the polynomial distributions are created in the truth and reco phase.

$$T_{ij} = \sum_{event\in\Delta_j} \frac{P_i\left(\cos\theta_{CS}^{Reco}, \varphi_{CS}^{Reco}\right) w_{event}(r,t)}{\sigma_j \left\{ P_8\left(\cos\theta_{CS}^{Truth}, \varphi_{CS}^{Truth}\right) + \sum_{i=0}^{7} A_{ij}^{ref} P_i\left(\cos\theta_{CS}^{Truth}, \varphi_{CS}^{Truth}\right)\right\}}$$

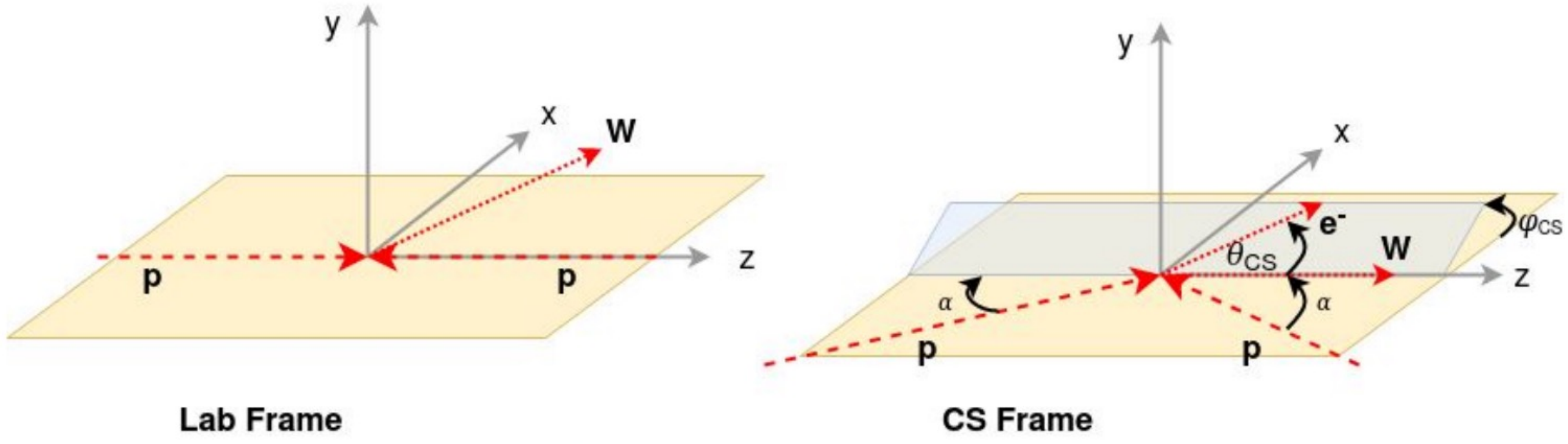




Truth phase space templates are folded into the reco phase space in likelihood fit.

$$\mathcal{L}(A_{ij}, \mu_j | N) = \prod_{events}^{N} \left\{ \sum_{j=1}^{N_{p_T}^{bins}} \mu_j \left[T_{8,j} + \sum_{i=0}^{7} A_{ij} \times T_{ij} \right] + \sum_{B}^{bkgds} T_B + T_{Fakes} \right\}$$

The Colins-Soper Rest Frame



Angular variables θ and ϕ defined in Colins-Soper (CS) rest frame:

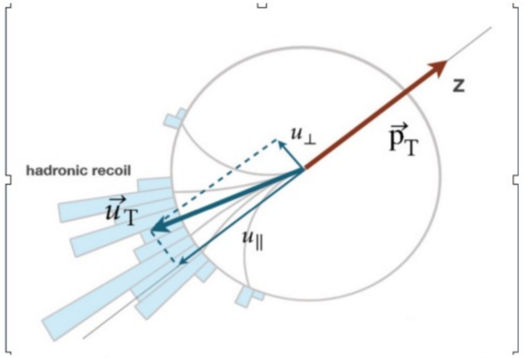
- boost into the W-boson rest frame
- rotation into special CS frame
- CS frame: incoming partons lie in plane spanned by x- and z-axis
- angles θ and ϕ defined as angles between negative lepton (or neutrino) and xz plane
- choice of rest frame is arbitrary, CS has been conventional choice

Neutrino Pz reconstruction

from Ruth Jacobs @ status report

Neutrino reconstruction: Hadronic recoil

- vectorial sum of all transverse momenta of ISR objects
- ATLAS: use PFlow objects (neutral & charged (+ complications e.g. to make insensitive to e,μ channel)



$$E_T^{\vec{\text{miss}}} = \vec{p_T}^{\nu} = -\left(\vec{u_T} + \vec{p_T}^{\ell}\right)$$

Solving for the Neutrino Pz:

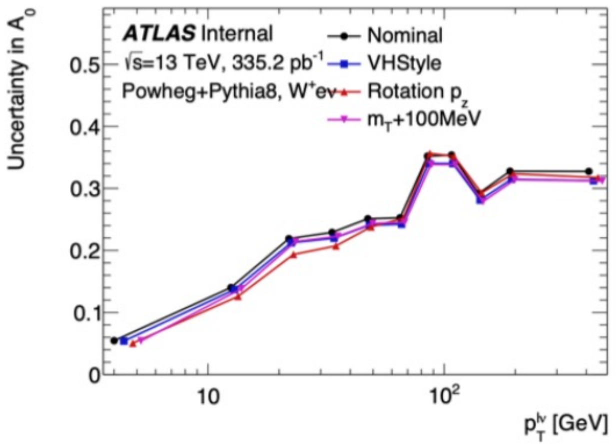
- W mass constraint: quadratic equation

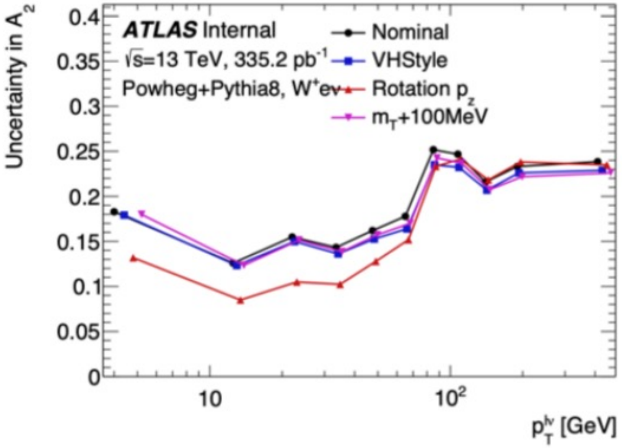
$$(p^\mu + q^\mu)^2 = m_W^2 \quad \Rightarrow \quad q_z(1,2) = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

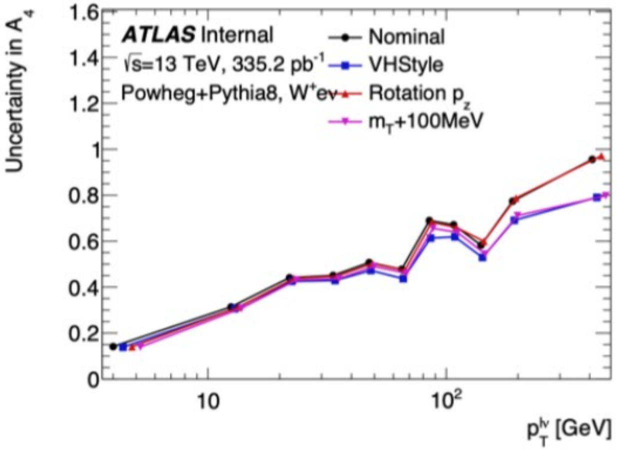
- two real solutions ($m_T \leq m_W$): ambiguity in cosθ
  solve statistically → pick one at random!
- complex solution → set to default cosθ → **We optimized procedure when there is no solution!**
  (can still exploit ϕ information!)

Which solution style gives us the best statistical gain?

- Nominal: Only real solutions chosen randomly, when no solution given default $\cos\theta_{CS}$ value and ϕ_{CS} calculated
- VHStyle: When Δ < 0, take the real part, pz = -b/2a
- Rotation pz : When Δ < 0, rotate the MET by the minimum amount needed for a solution* M_T
- +100MeV: When $M_T > M_{W\,PDG}$, replace $M_W \to M_T$ +100MeV



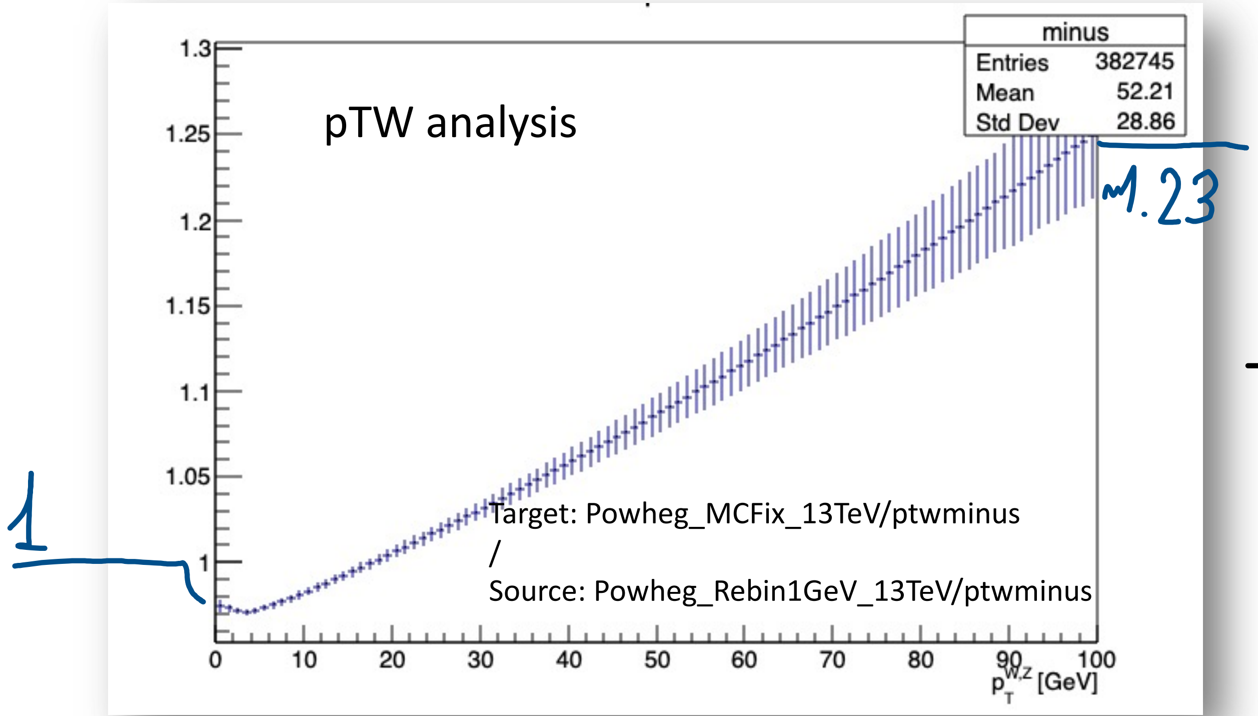


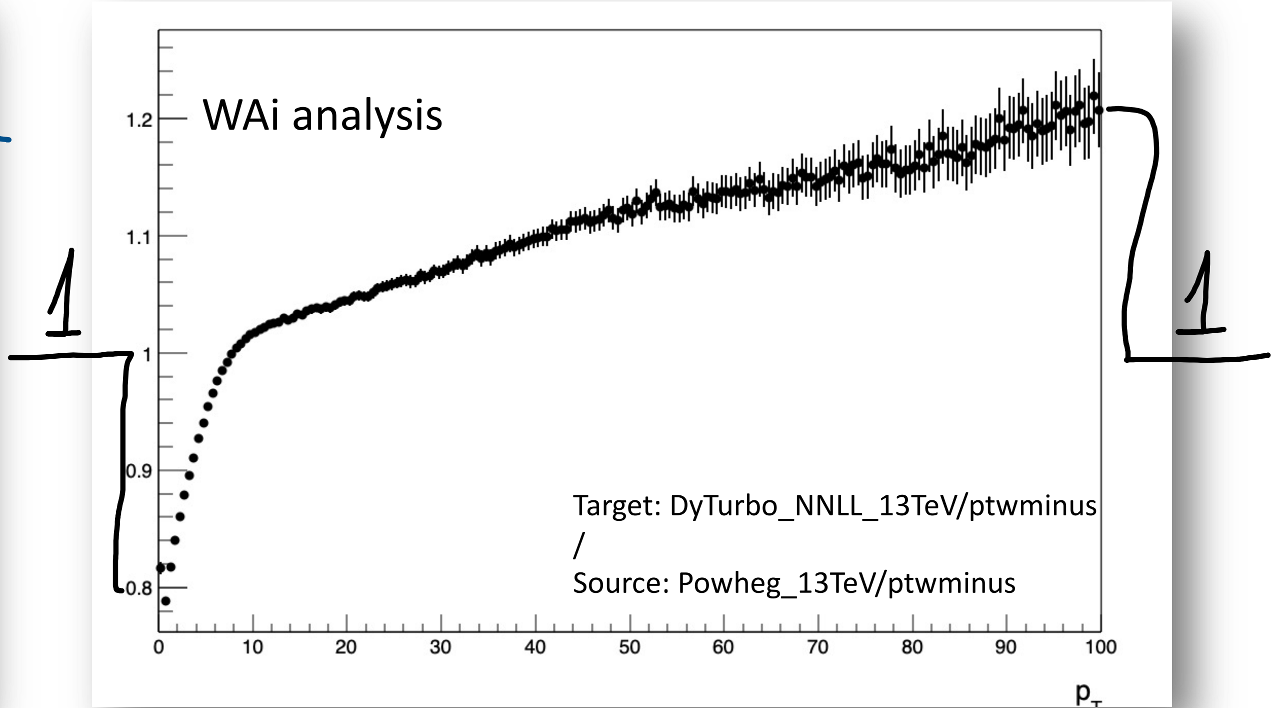


Final solution choice: Rotation Pz

PtYMReweightingTool corrections

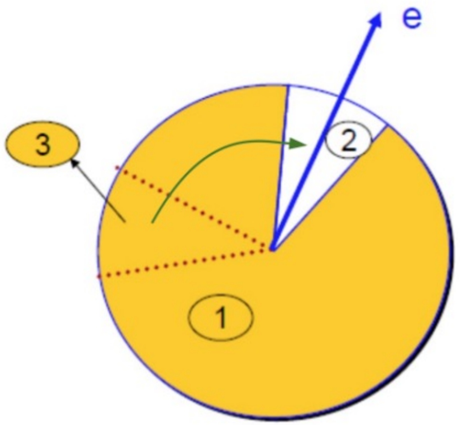
- Aim to use well-known DYTURBO prediction
- pTW corrections range is from 0 to 100 GeV
  - Overflow/Underflow pTW entry defines *weight_truth = 1*
  - pTW tail's bins would be renormalized during final fit
- pTW analisys uses a bit different approach:
  - use 1D reweighting, that best fit to reco-level data, this is designed to measure the pT spectrum with a small unfolding bias.
  - Eventually, e.g for mW, best model will be a tune to pT measurement, and once have it group can 2D (or 1D, y-sliced) reweight to that tune.





Recoil correction

from Ruth Jacobs @ MJ studies



Improved recoil calculation:

- recoil calculated from all Pflow objects in event
- cone of ΔR=0.2 around lepton excluded to prevent double-counting
- replace by random ΔR=0.2 cone in the event away from leptons or jets
- this is ok for isolated leptons…

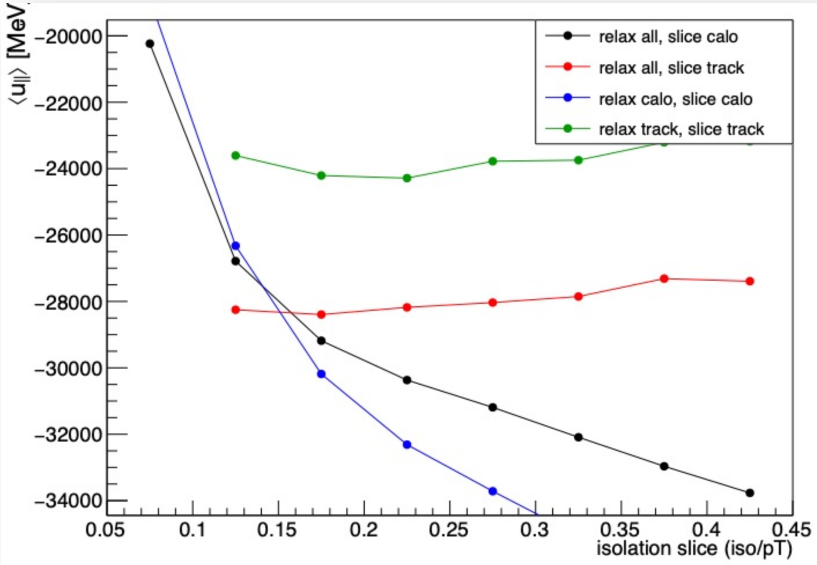
…BUT…

- in MJ events leptons are mostly close to jets
- above method fails

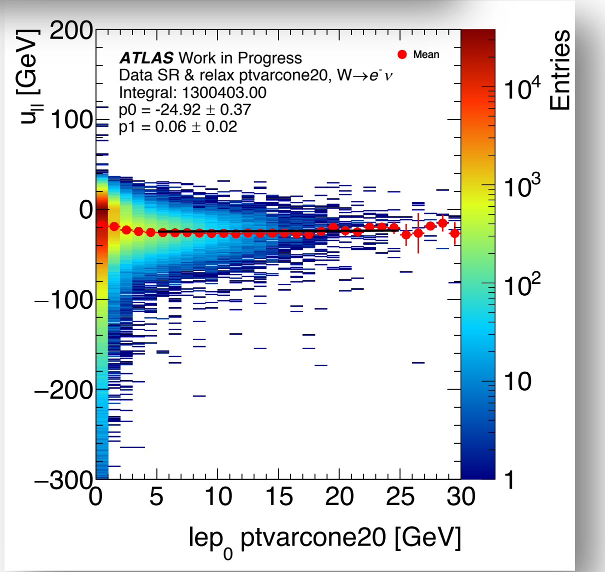
Solution:

- instead of underlying-event-type cone, use isolation:

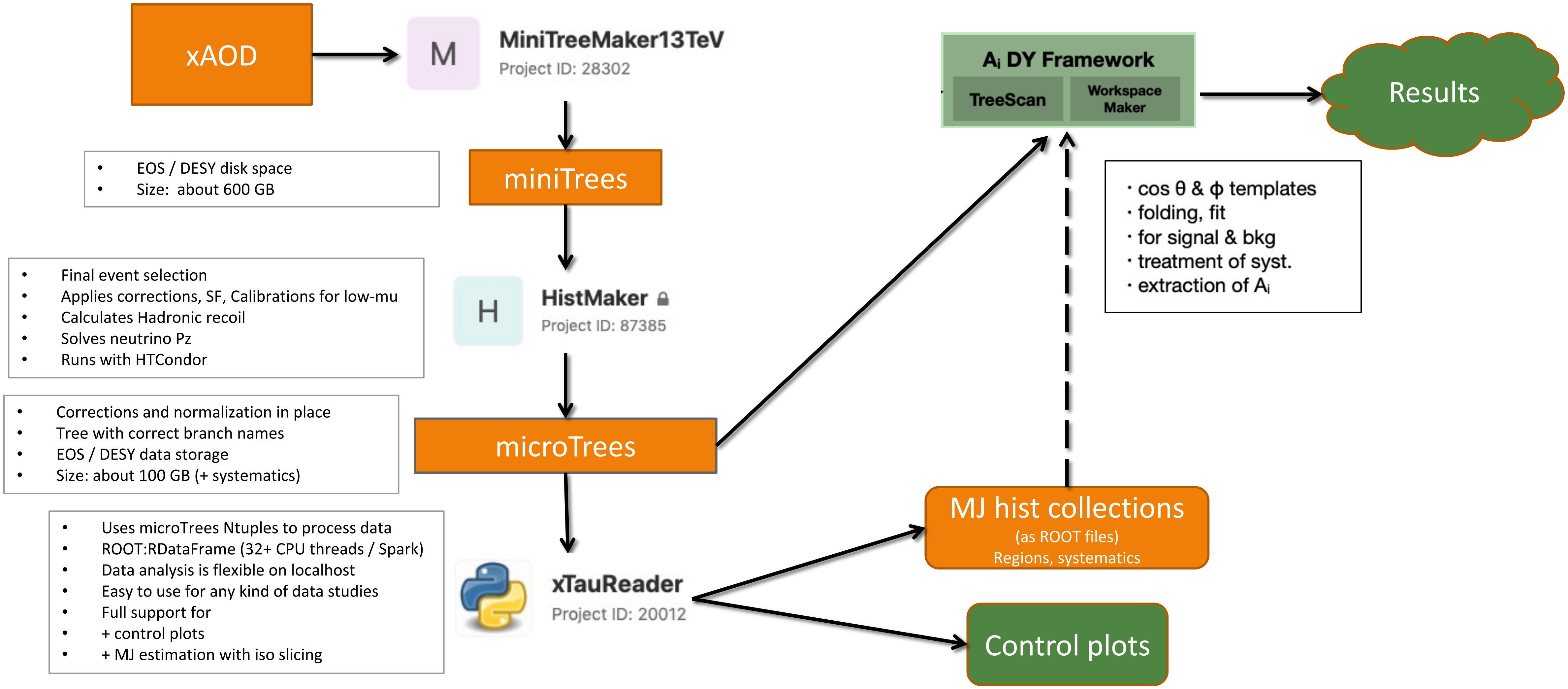
$$\vec{u}^{\rm corr} = \vec{u}^{\rm baseline} + \vec{u}^{\rm iso}, \text{ where}$$
$$\vec{u}^{\rm iso} \equiv \texttt{ptcone20} \cdot \vec{n}_\ell$$



- Cross-check:
  - define $u_{||}$: projection of recoil on lepton axis
  - if the recoil isolation correction works, average of $u_{||}$ is independent of iso slice



Software organization



Event Selection

Reco: Loose preselection

Electrons	Muons
Loose LH	Medium muons
pT > 20 GeV	pT > 18 GeV
|eta|<2.47, w/o crack from 1.37-1.52	|eta| < 2.4
No isolation	No isolation
|d0significance| < 5	|d0significance| < 3
DeltaZ*sinTheta < 0.5	DeltaZ*sinTheta < 0.5

Reco: Final Selection Signal Region

Electrons	Muons
Tight LH	Medium muons
pT > 25 GeV	pT > 25 GeV
ptvarcone20/pt<0.1 topoetcone20/pt < 0.05	ptvarcone20/pt < 0.1 topoetcone20/pt < 0.05

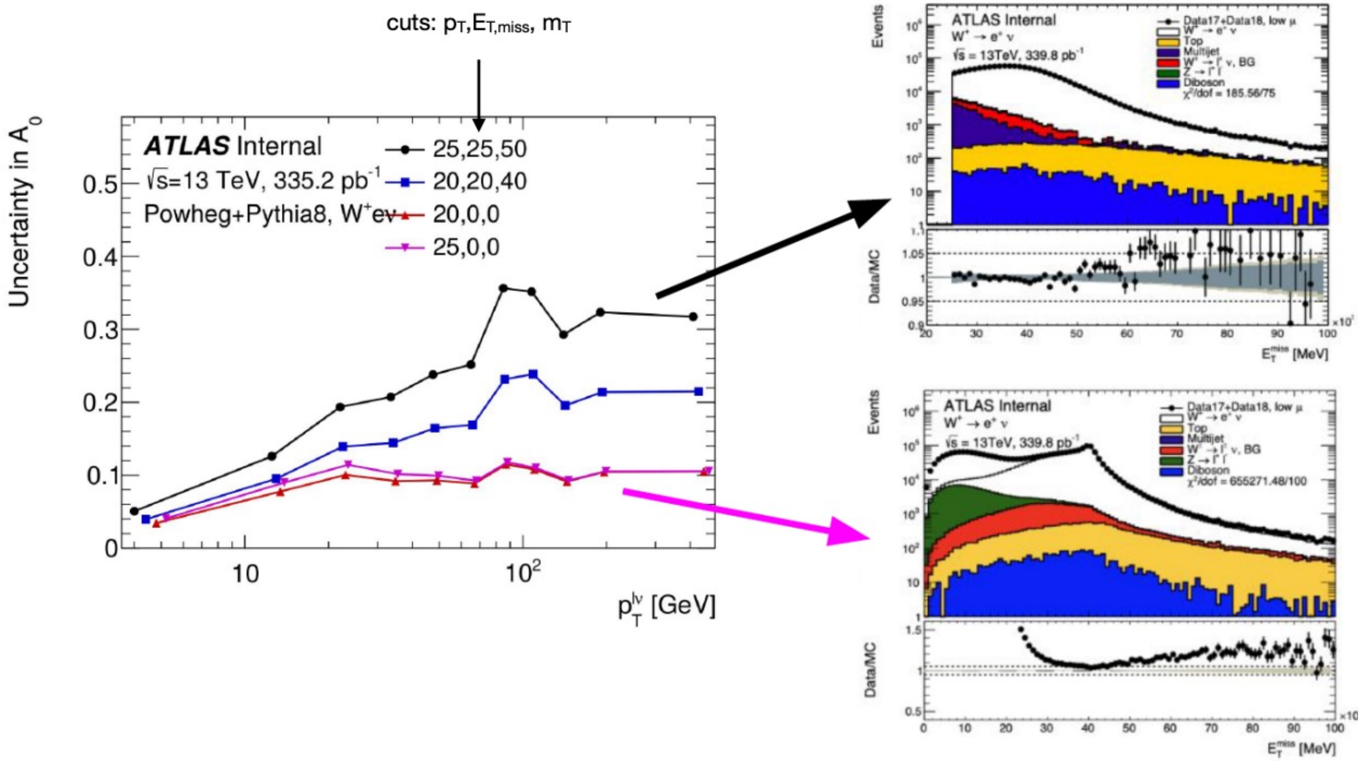
No cuts on MET and mT !

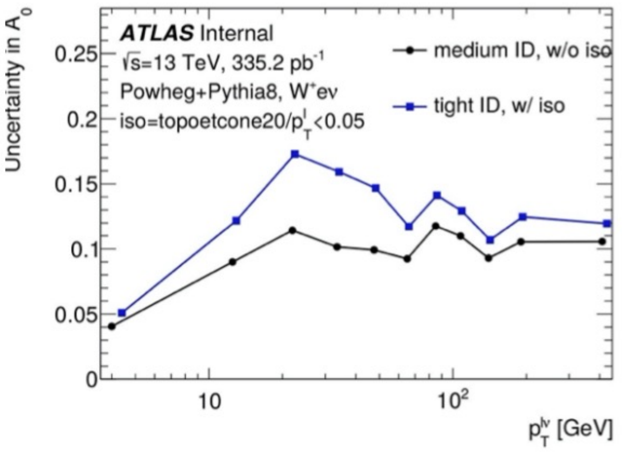
TRUTH: Fiducial Region

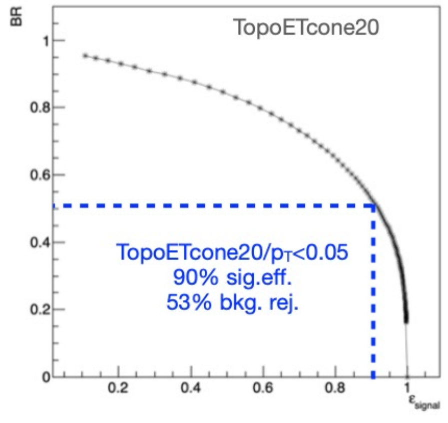
- no cuts applied*, keep all truth events
- folding of templates before fit takes migrations into account
- aim: measure A_i in full phase space

Sensitivity Studies: Event Selection

link on slides







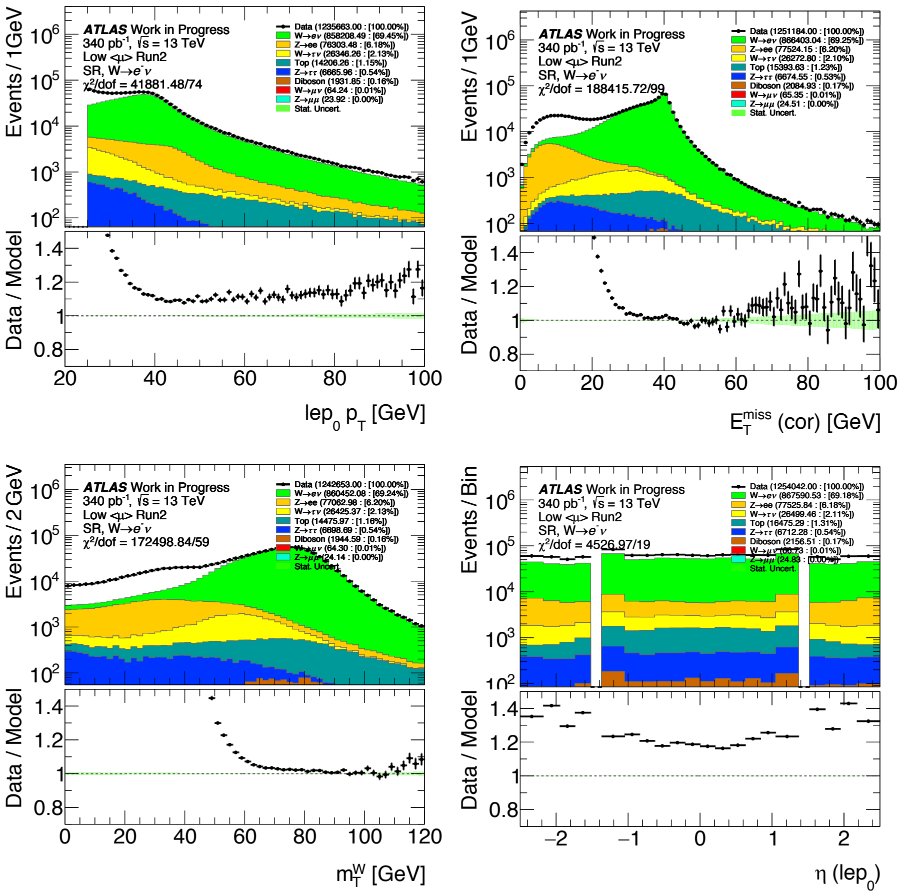
- statistical uncertainty only (expected to be dominant)
- gained a lot of A_i sensitivity by relaxing cuts on MET and $m_{T,W}$ in our signal region
- but also a lot of background…

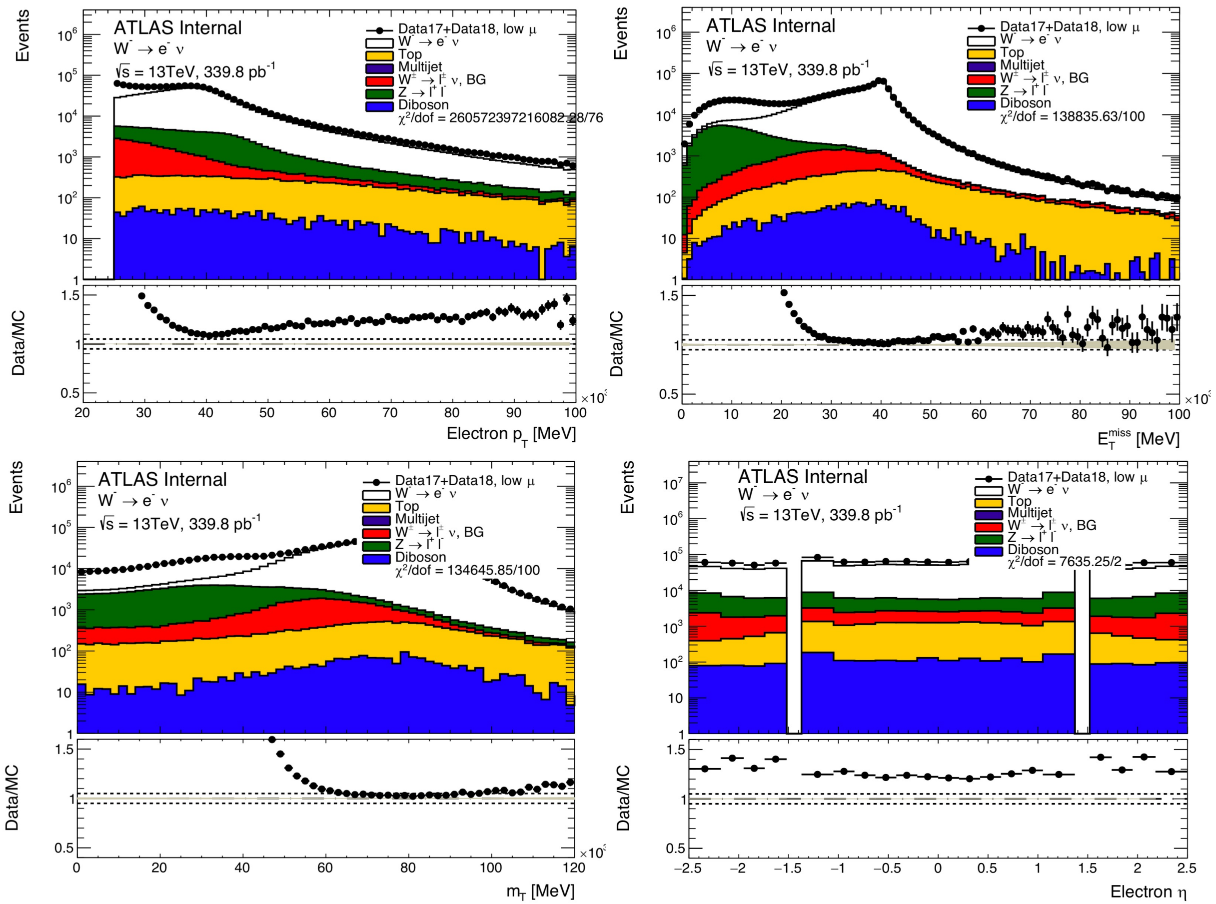
$W^+ \to e^+ + \nu_e$					
Cut	No. of Data Events	No. of Signal Events	No. of EW Bkg Events	No. of MJ Events	Signal/Data
lepPt > 25 GeV	2452868	1314812	170669	967387	0.54
lepPt > 25 GeV Electron Tight iD	1965857 (0.8)	1214360 (0.92)	155216 (0.91)	596281 (0.62)	0.62 (+15%)
lepPt > 25 GeV Electron Tight iD topoetcone20/lepPt < 0.05	1525477 (0.62)	1099013 (0.84)	140191 (0.82)	286273 (0.3)	0.72 (+33%)

We now cut on two isolation variables (track- & calo-based) and use tight Electron ID → reject 70% (65%) of MJ background in e (μ) channel !

New selection had required new SF: slides

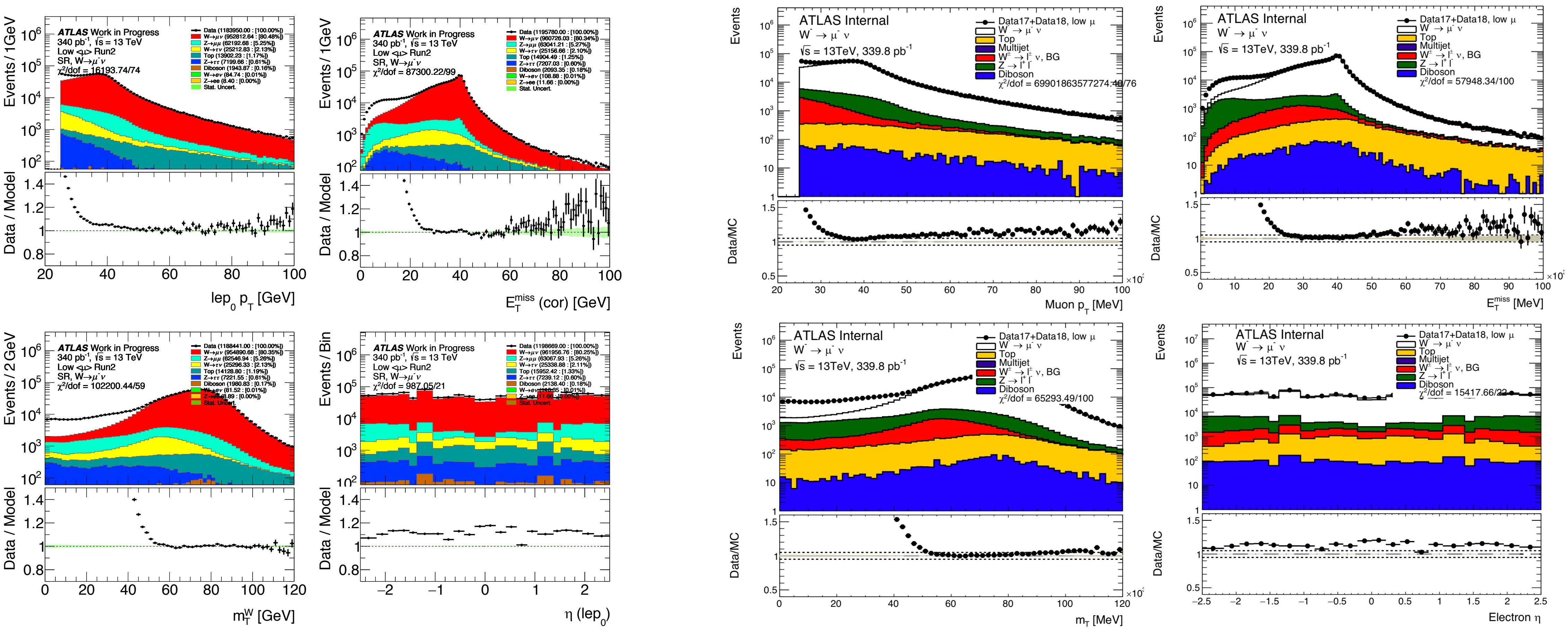
Validation using Craig’s plots ($W \to e^{-}\nu$)





- Able to reproduce Craig’s plots using xTR.
- No pt reweighting applied

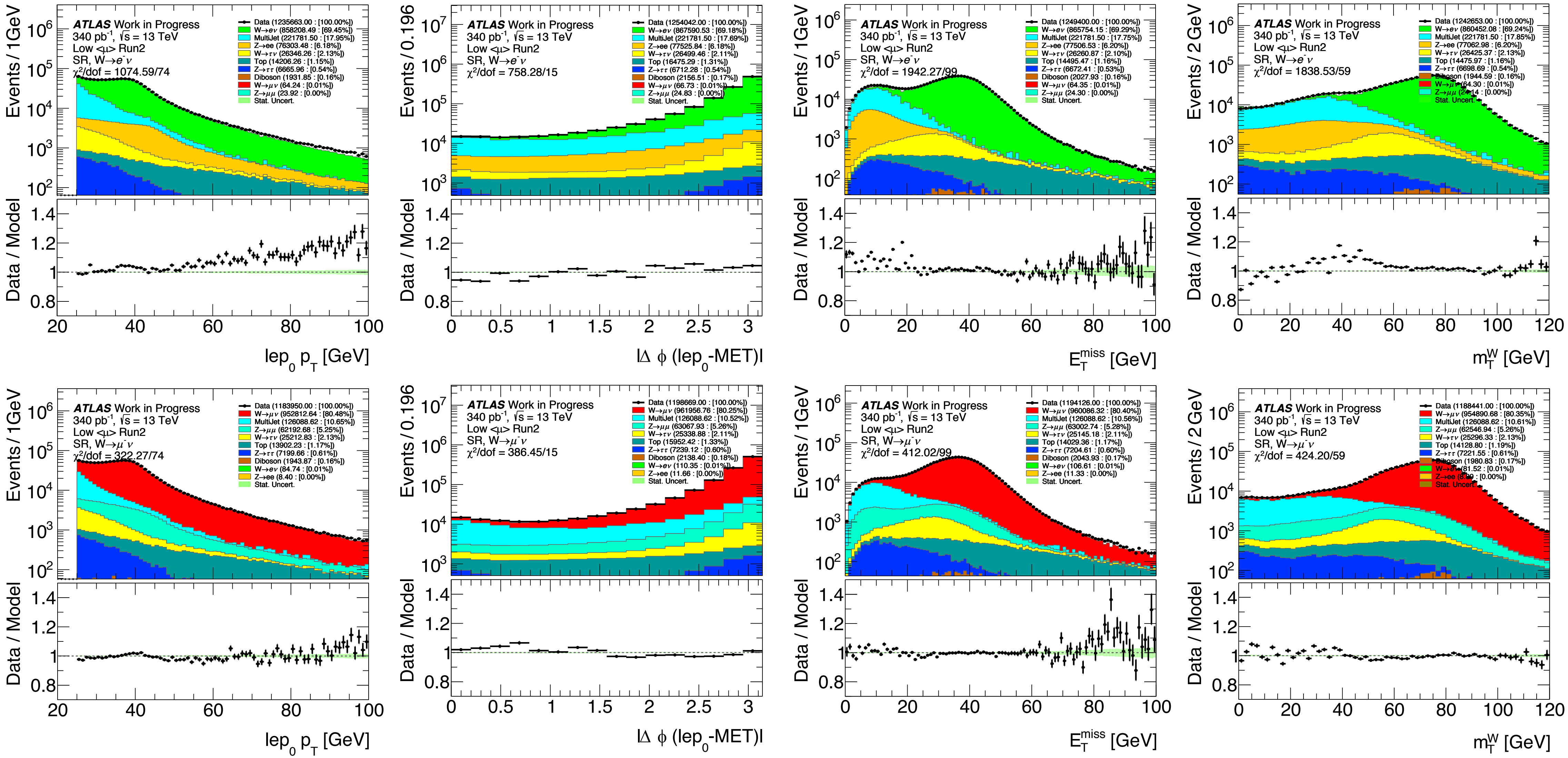
Validation using Craig's plots ($W \to \mu^{-}\nu$)



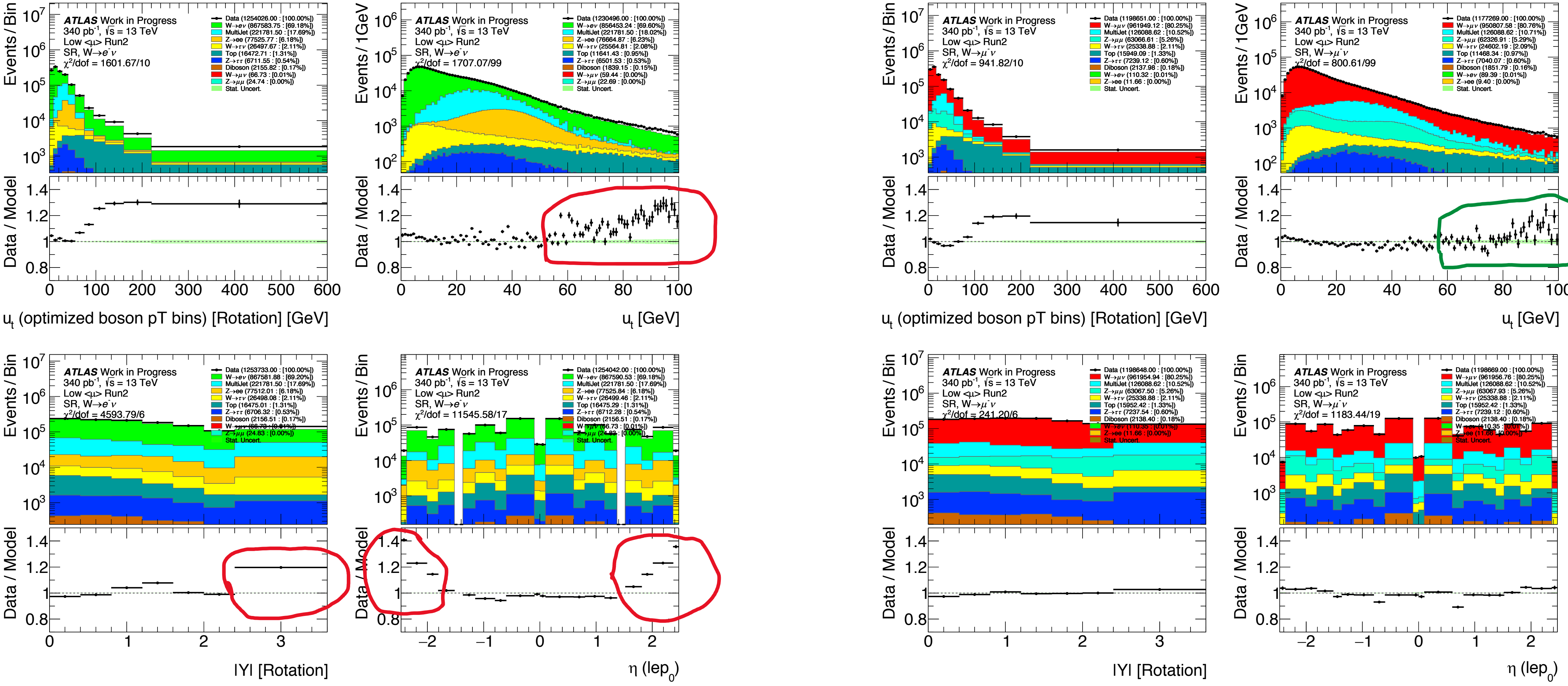
- Able to reproduce Craig's plots using xTR.
- No pt reweighting applied

Control plots with PTRW

1st/3 tasks from Daniel



Current issues

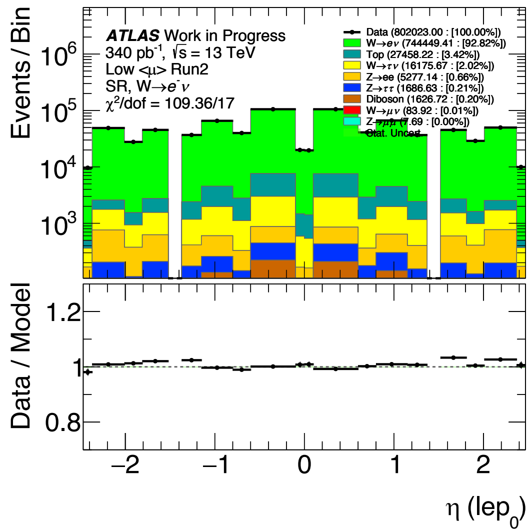


- See uT problems in electrons and not muons:
  - ruled out the possibility that the problem is caused by the signal modeling. Is it coming from MJ?

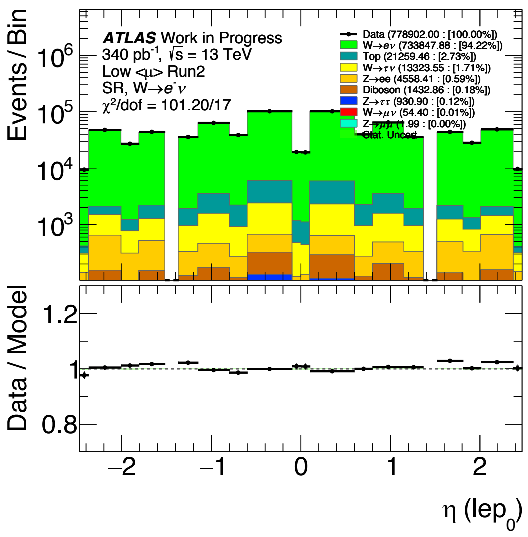
Studies on MET and mT cuts

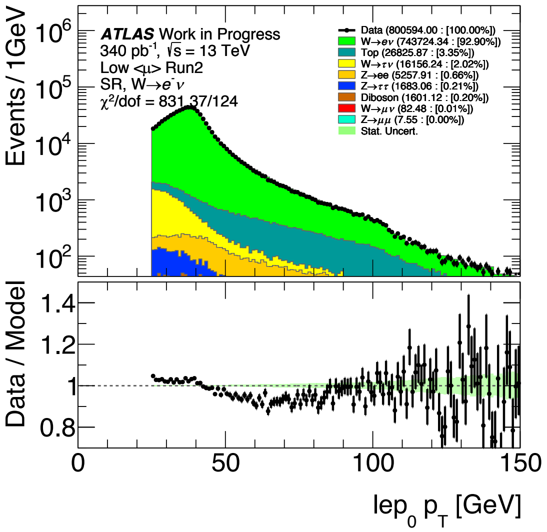
v20210713ptrw_ruth
+ SF corrections from Alex

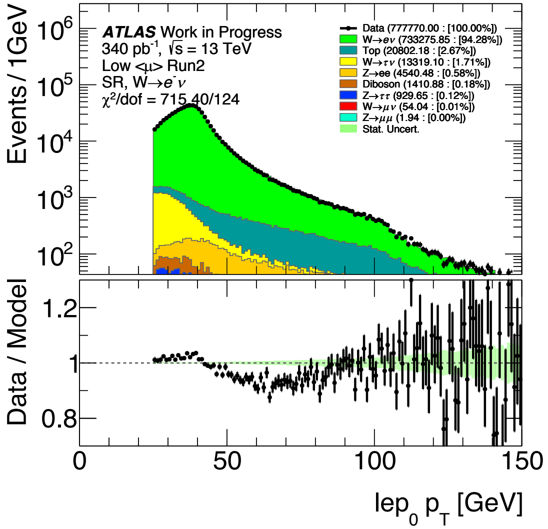
Wai SR & MET > 25 GeV



SR & MET > 25 GeV & mT > 50 GeV

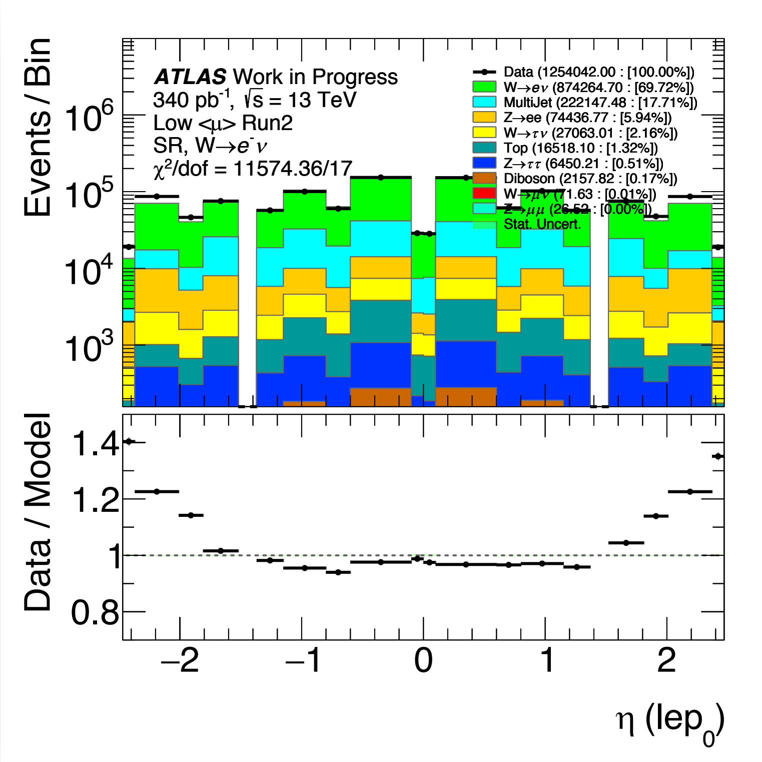


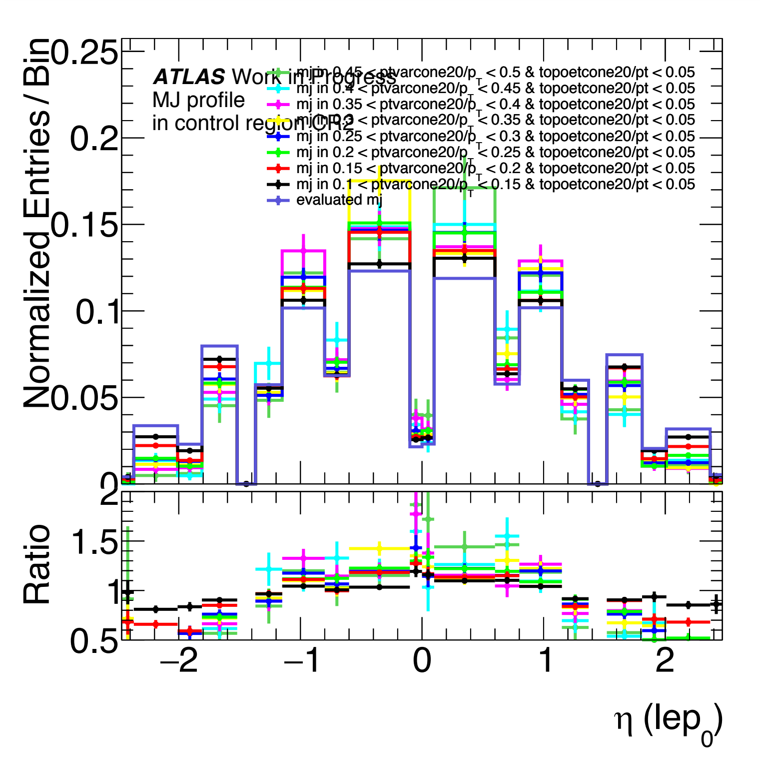


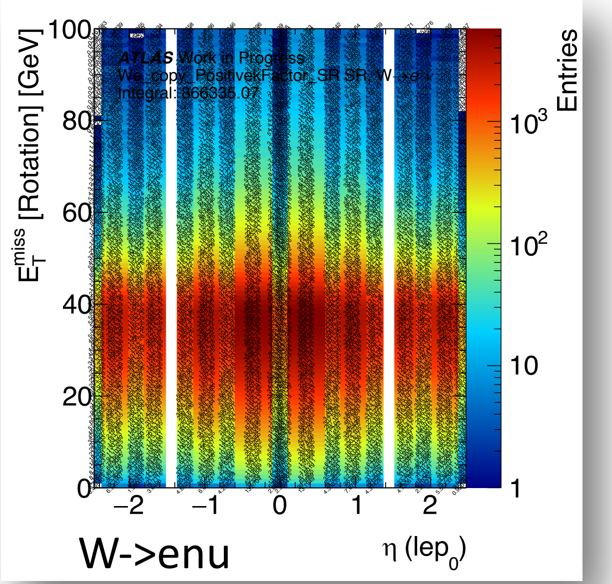


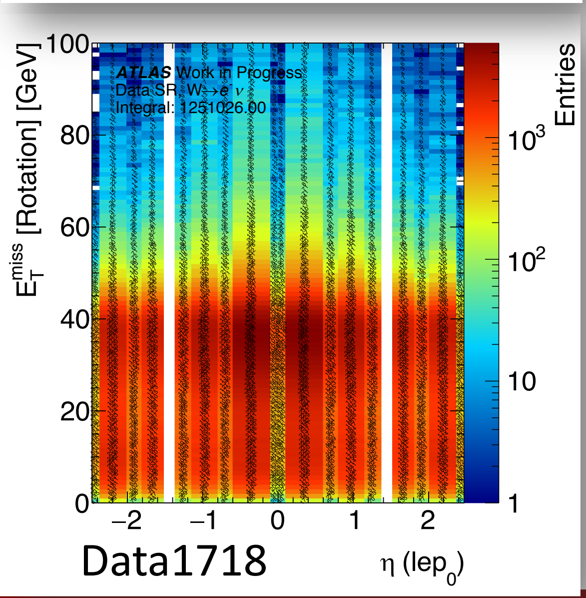
- Moving to the pTWanalysis kinematics we see great Data/MC agreement
  - MJ contribution is around 0.5%
  - MJ yield is different from pTW analysis because we have tighter ID and iso selection
- Do we have some SF implemented in the HistMaker that are working incorrectly for our relaxed signal region?

Leading lepton eta distribution



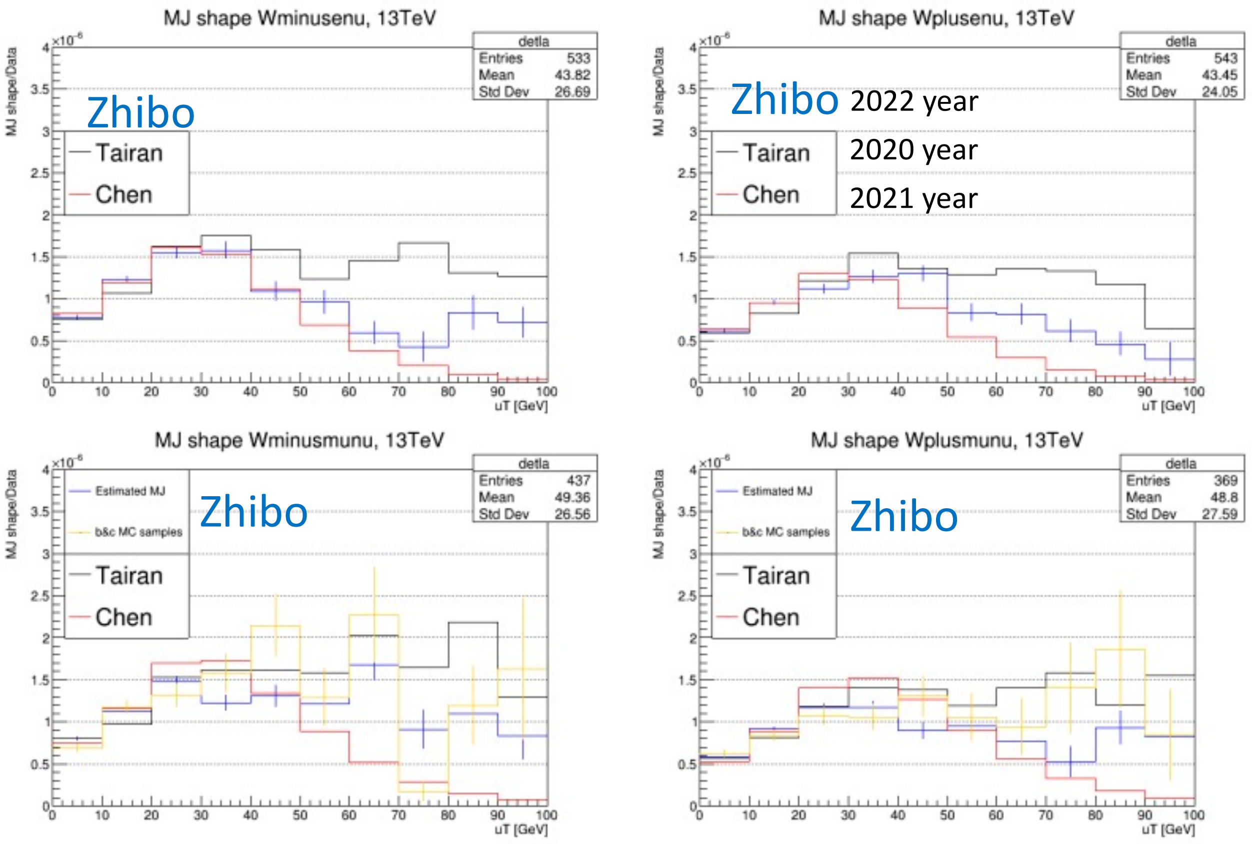






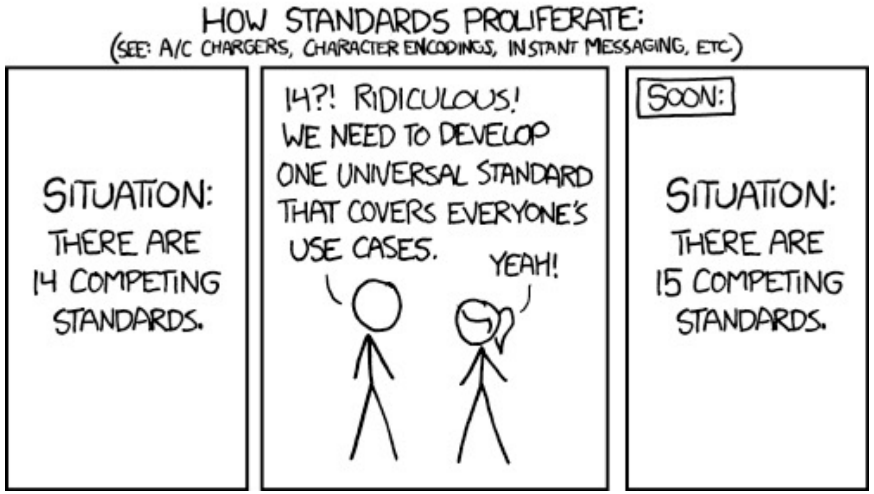
Where eta lepton discrepancy comes from?

pTW analysis faces the same uT problem



From Zhibo Wo talk

- Main goals:
  - Validate MJ estimation algorithm Wai analysis uses
  - Resolve u_T tail issue which is common for both analysis
- Rerunning analysis using latest HistMaker version for pTW analysis selection
  - expect to reproduce Zhibo's results
  - Rolling back to older HistMaker versions might help to find where impact comes from
- Hope we will match with Zhibo, otherwise…



pTW analysis selection

Electrons preselection:

- $p_T > 15$ GeV (supporting note says 18 GeV)
- Vertexing cut: $|\Delta z_0| < 0.5$ && $|d_0^{sig}| < 5$.
- Crack cut: $|\eta| <= 1.37$ or $|\eta| >= 1.52$
- Eta cut: $|\eta| <= 2.47$
- Medium ID: $el\_isMedium == 1$

HistMaker's selection for NTuples:

- Charge: $elcut\_charge[0] < 0$
- One electron: $elcut\_n == 1$
- Electron trig matched: $elcut\_triggerMatched[0] == 1$
- $p_T^e > 25$ GeV: $elcut\_tlv[0].Pt() > 25000$

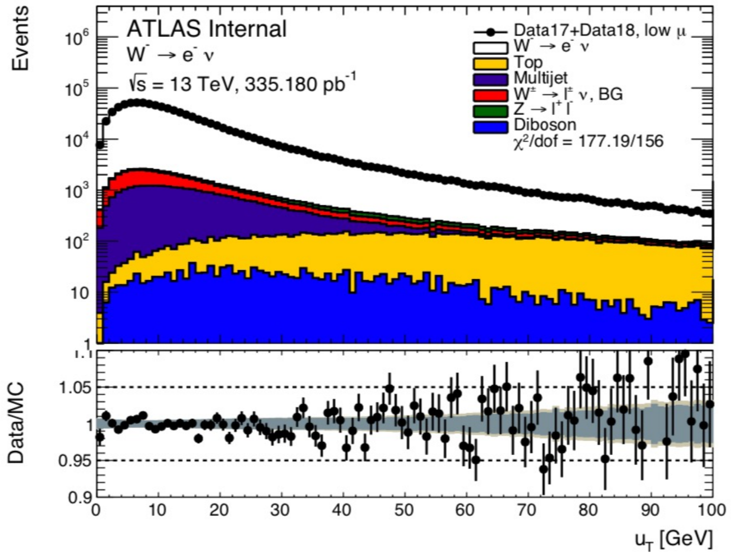
xTauReader's selection on NTuples:

SR:

- $E_T^{miss} > 25$ GeV ($m\_treeOut \to met\_tlv$)
- $m_T^{W,reco} > 50$ GeV ($m\_treeOut \to recoW\_mT$)
- $ptvarcone20/pt < 0.1$

CR2:

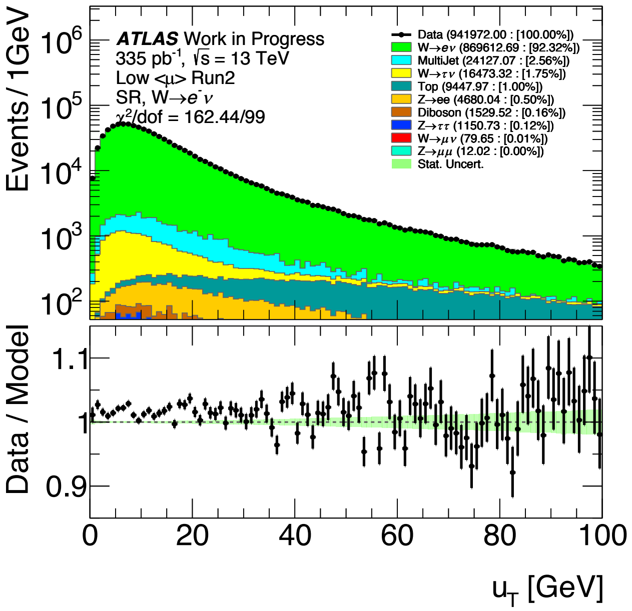
- $E_T^{miss} > 25$ GeV ($m\_treeOut \to met\_tlv$)
- $m_T^{W,reco} > 50$ GeV ($m\_treeOut \to recoW\_mT$)
- $ptvarcone20/pt > 0.1$



Cut	Data	Signal	$W^\pm \to \ell^\pm \nu$ BG	$Z \to \ell\ell$	Top	Diboson	Multijet
One electron	7471742	1323710 ± 330	78230 ± 230	140980 ± 140	61951 ± 86	3059 ± 58	-
Electron trig matched	7402574	1267710 ± 330	72240 ± 230	133580 ± 140	59950 ± 85	2968 ± 57	-
Isolation	4949352	1260540 ± 330	71550 ± 230	132740 ± 140	58689 ± 84	2937 ± 57	-
$p_T^e > 25$GeV	2113364	1053510 ± 300	39660 ± 160	101350 ± 110	52923 ± 79	2544 ± 53	-
$E_T^{miss} > 25$GeV	1008915	900640 ± 280	25900 ± 130	7954 ± 45	45065 ± 73	1962 ± 48	-
$m_T > 50$GeV	949362	887810 ± 270	22400 ± 120	6052 ± 35	34177 ± 64	1695 ± 44	27400 ± 2000

Table 6: Analysis cut flow for $W^- \to e^- \nu$ 13 TeV signal selection. The minimum lepton p_T required before the final p_T cut is 18 GeV.

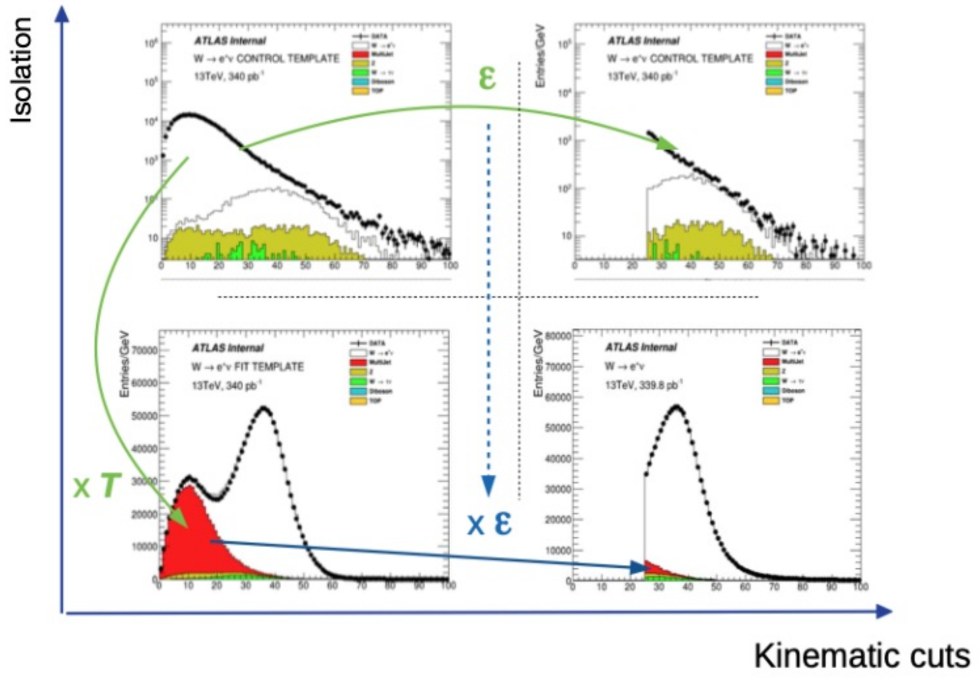
https://cds.cern.ch/record/2632159?

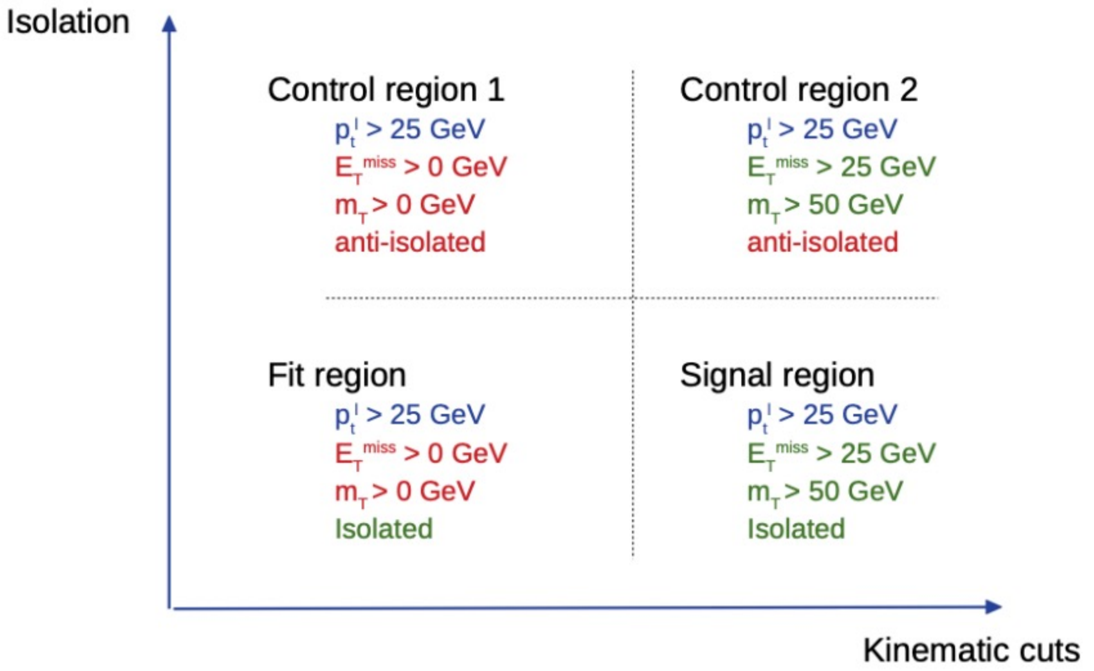


MJ

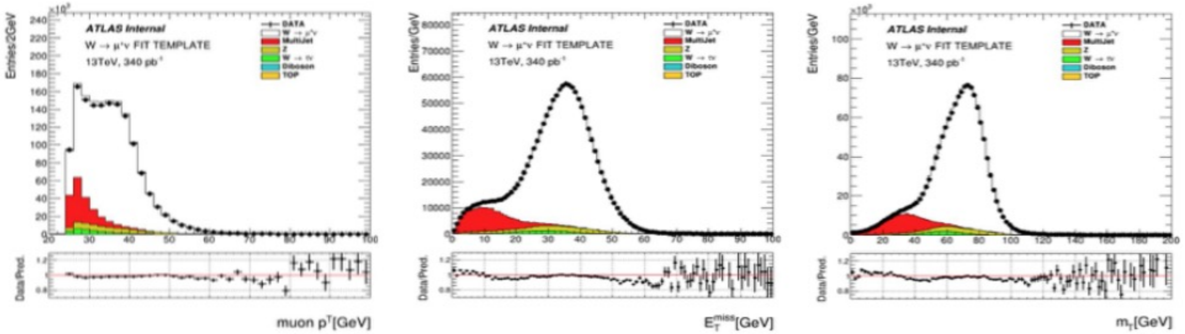
MJ estimate in low-mu WpT analysis

ATL-COM-PHYS-2019-076





p_t^l, E_t^{miss}, m_T all carry discriminating power

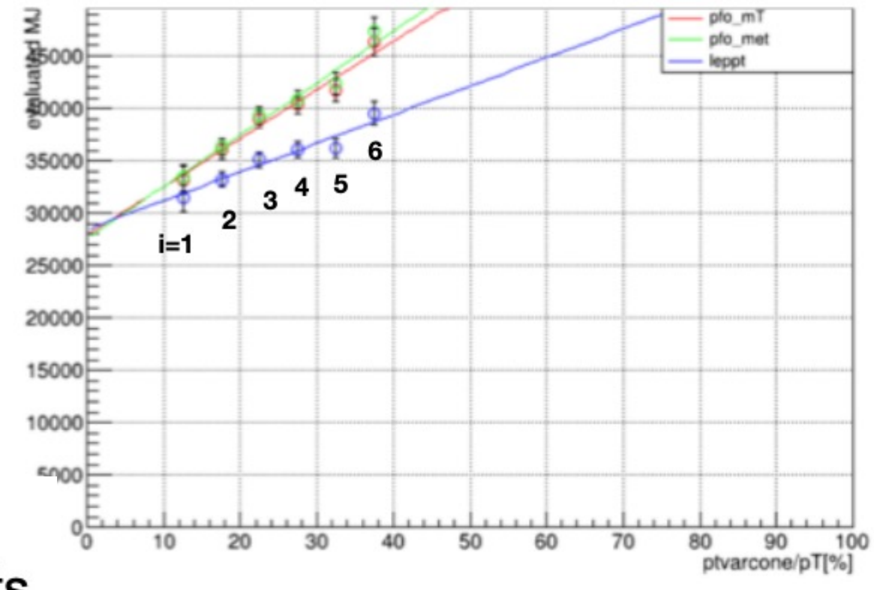


MJ estimate in low-mu WpT analysis

ATL-COM-PHYS-2019-076

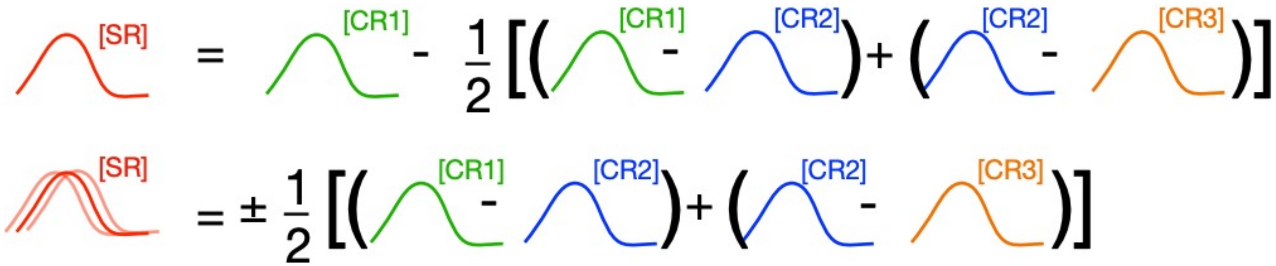
MJ Normalization:

- repeat MJ estimation for different anti-isolation slices (CR_i)
- fit linear function
- extrapolate back to the SR



MJ Template Shape:

- MJ distributions in CR_i don't match their SR counterparts
- bin-by bin linear shape extrapolation
- assign 100% uncertainty

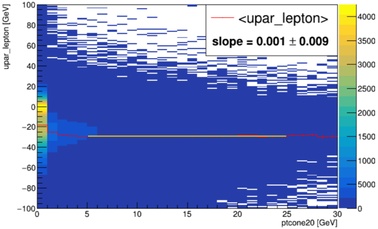


The *ptcone*20 recoil correction for $W \to e^{-}\nu$

Applying *ptcone* correction :

$k = 1.179$

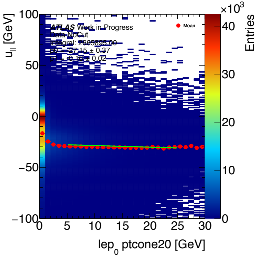
By Zhibo ($SR + CR_{tight}$):



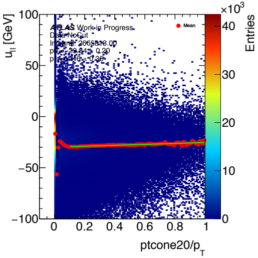
- What selection is behind $SR + CR_{tight}$?

HistMaker's selection:

slope = -0.16



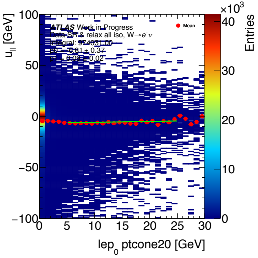
slope = 4.46



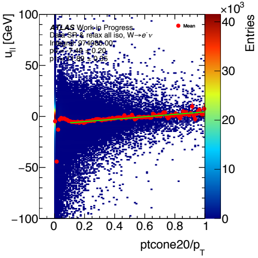
SR + CR2

(no isolation cut):

slope = 0.09



slope = 11.89



Calculate MJ template shape: $W \to e^{-}\nu$ channel

In assumption, extrapolation is linear:

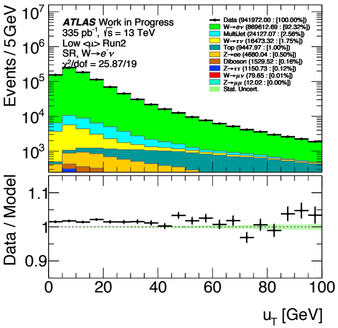
$$H_{MJ}^{[0.A,0.B]}[X] = H_{Data}^{[0.A,0.B]}[X] - H_{MC}^{[0.A,0.B]}[X]$$

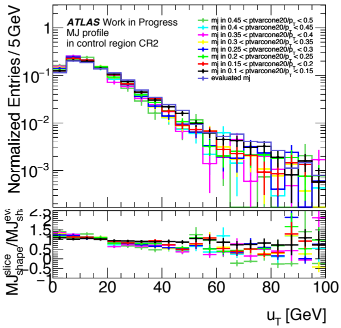
$$\Delta H[X] = \frac{1}{4}\{(H_{MJ}^{0.1,0.15} - H_{MJ}^{0.15,0.2}) + (H_{MJ}^{0.2,0.25} - H_{MJ}^{0.25,0.3}) + (H_{MJ}^{0.3,0.35} - H_{MJ}^{0.35,0.4}) + (H_{MJ}^{0.4,0.45} - H_{MJ}^{0.45,0.5})\}$$

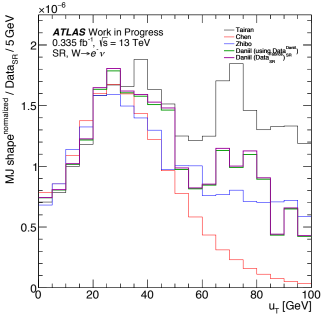
$$H_{MJ}^{sig}[X] = H_{MJ}^{0.1,0.15}[X] + 2 \cdot \Delta H[X]$$

However, some $\bar{iso}$-bins shows non-linear behaviour.

- Compared my MJ shape with both Data shapes from SR:
  - My Data shape in SR
  - Data shape provided by Fabrice: ../v20210602_fballi_prod_pTWanalysis/pTWanalysis_wminusenu_DATA_13TeV/Nominal/data1718_WZ_lowMu_repro_13TeV.root







Calculate MJ template shape in 3 slices: $W \rightarrow e^{-}\nu$ channel

Limit $a\bar{n}ti$-isolation slices scan to 3 bins: $Binning(3, 0.1, 0.4)$

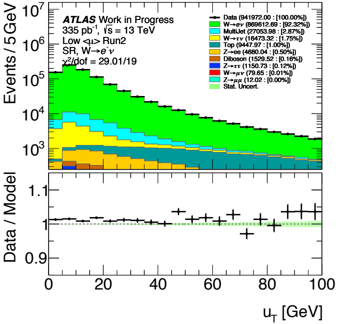
$$H_{MJ}^{[0.A,0.B]}[X] = H_{Data}^{[0.A,0.B]}[X] - H_{MC}^{[0.A,0.B]}[X]$$

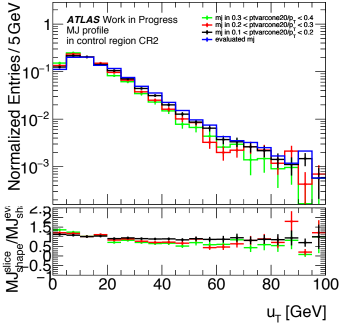
$$\Delta H[X] = \frac{1}{2}\{(H_{MJ}^{0.1,0.2} - H_{MJ}^{0.2,0.3}) + (H_{MJ}^{0.2,0.3} - H_{MJ}^{0.3,0.4})\}$$

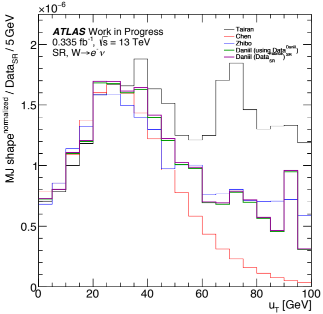
$$H_{MJ}^{sig}[X] = H_{MJ}^{0.1,0.2}[X] + \Delta H[X]$$

However, some $i\bar{s}o$-bins shows non-linear behaviour.

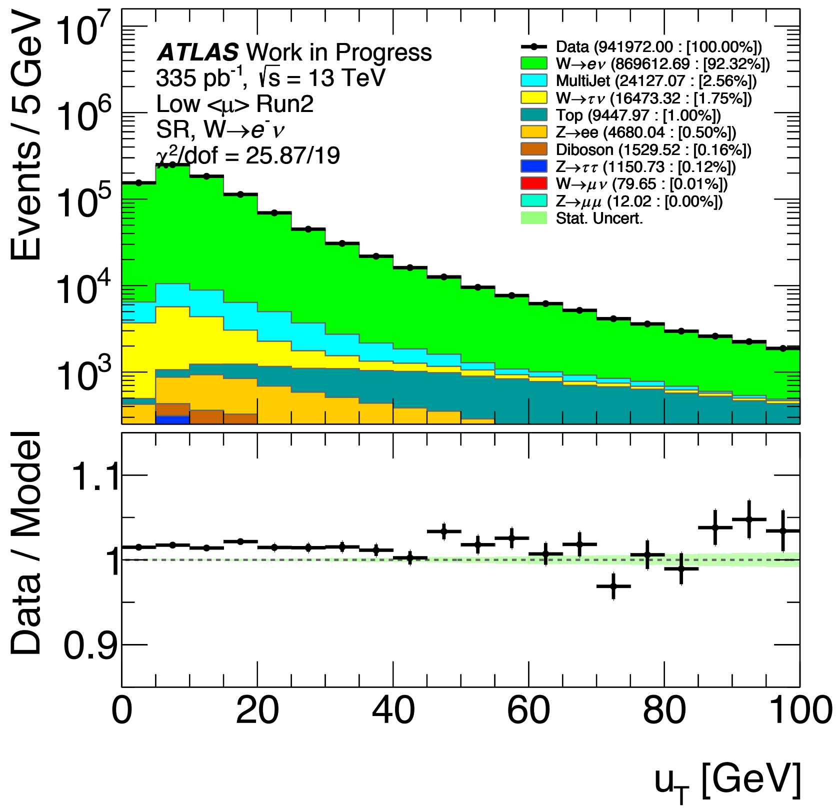
- Compared my MJ shape with both Data shapes from SR:
  - My Data shape in SR
  - Data shape provided by Fabrice: ../v20210602_fballi_prod_pTWanalysis/ pTWanalysis_wminusenu_DATA_13TeV/ Nominal/data1718_WZ_lowMu_repro_13TeV.root

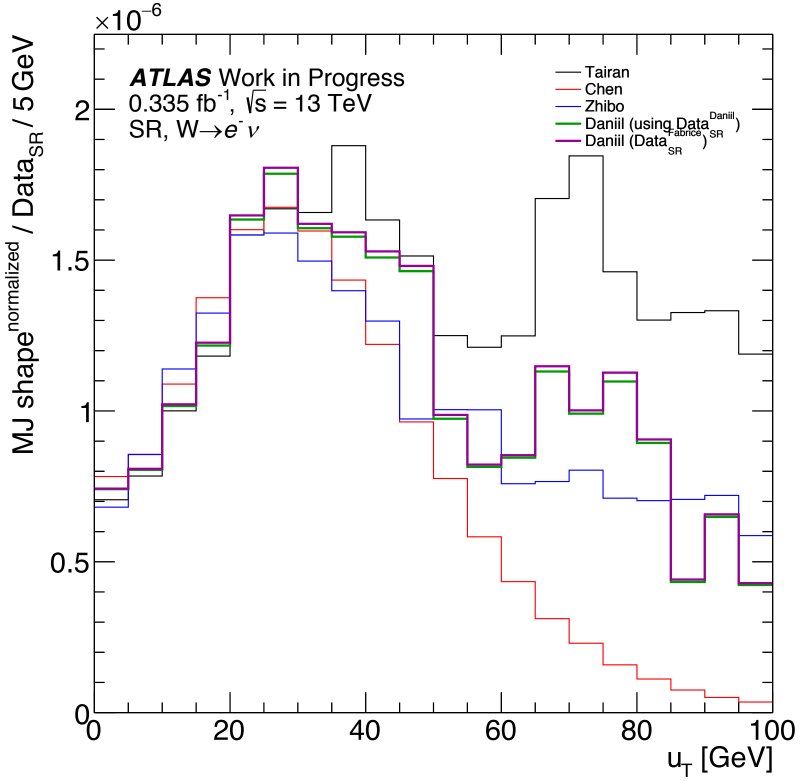






Reproducing pTWanalysis





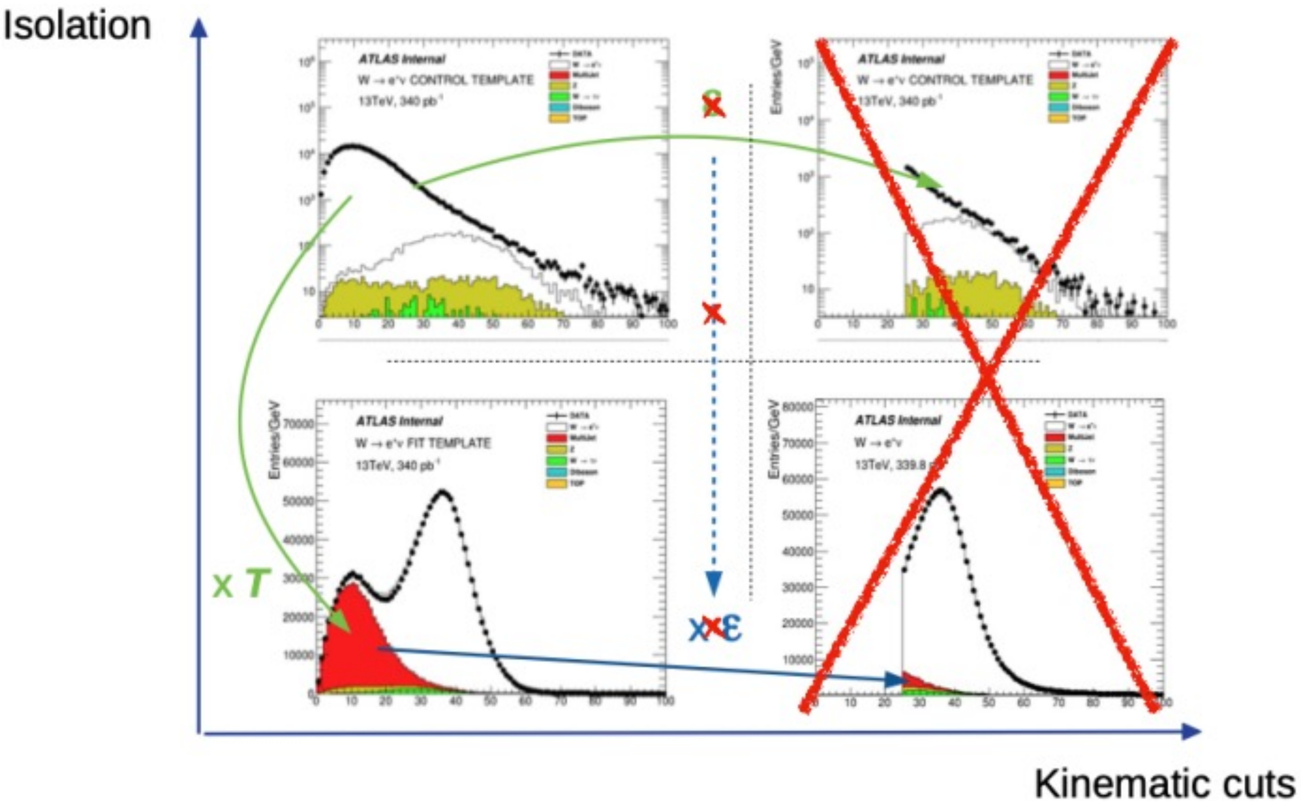
- Have to check data samples on DESY
  - Might be some Data files are missing
- My results are close to Zhibo's
  - Doesn't mean results are correct.
  - Just a smoking gun that issue somewhere on MiniTreeMaker or HistMaker side
- …

MJ estimate in WAi

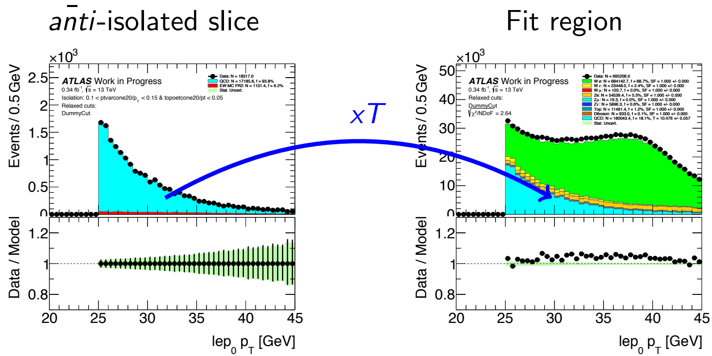
1) Selection

- relaxed cuts on MET or $m_{T,W}$ in our signal region
- cut on track-based isolation (ptvarcone20/pt<0.1) & calo-based isolation (TopoETcone20/p_T<0.05)

- cannot use our signal region directly to derive templates (dominated by signal modelling)
- define CR to extract MJ shape:
    - relax only track isolation
- define anti-isolation slices based on track isolation



MJ background in W-Ai analysis



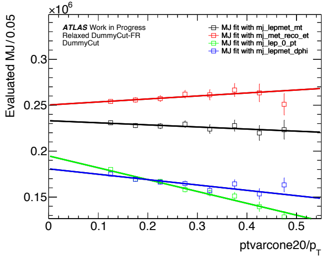
Note for $W^- \to e^- \nu$

- The EWK comtamination in the 1^{st} isolation slice is 6.2%
- 5.2% comes from the signal
- for muons we have almost the same

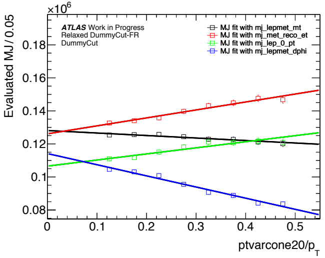
- Two steps to get MJ background:
  - Calculate MJ normalization:
    - ★ repeat MJ estimation for different anti-isolation slices
    - ★ fit linear function
    - ★ extrapolate back to SR
  - Calculate MJ template shape:
    - ★ MJ distributions in $\bar{iso}$-slices don't match SR shape
    - ★ apply bin-by-bin linear shape extrapolation
    - ★ assign 100% uncertainty
- Use 4 discriminative variables:
  - p_T, m_T, E_T^{miss} and $|\Delta\phi(\ell - MET)|$
- Use 8 slicing bins in $ptvarcone20/pt$:
  - Binning(8, 0.1, 0.5)
- In the fit use fixed EWK background normalization.
- Isolation $ptvarcone20/pt$ slices for $W^- \to e^- \nu$ for all 4 variables are on Slides 21, 22, 23 and 24.

Calculate MJ normalization in the signal region

$W^- \to e^- \nu$



$W^- \to \mu^- \nu$



$W^- \to e^- \nu$	Signal region
Total Number of MJ bkg	**213593**
Luminosity and cross section	774 (0.36%)
Intersection point	37474 (17.54%)
Extrapolation target	1109 (0.52%)
Choice of hists	12492 (5.82%)
Isolation correction	*NaN*
Correlated Uncertainty	**39542 (18.5%)**

$W^- \to \mu^- \nu$	Signal region
Total Number of MJ bkg	**118754**
Luminosity and cross section	405 (0.34%)
Intersection point	11269 (9.49%)
Extrapolation target	15 (0.01%)
Choice of hists	3756 (3.16%)
Isolation correction	*NaN*
Correlated Uncertainty	**11275 (9.49%)**

- The error bars are multiplied by $\sqrt{\chi^2/NDoF}$
- Take final MJ yield as mean at $ptvarcone20/pt = 0.025$
- Less MJ background contribution for muon channel (as expected)
- Dominant MJ yield uncertainty comes from intersection point
- For now we don't use u_T slicing as pTW analysis does:
  - To improve yields precision might also consider to use set of u_T cuts to take control over jets activity: *[15, 20, 25, 30, 35, 40,* **None***]*

Calculate MJ template shape

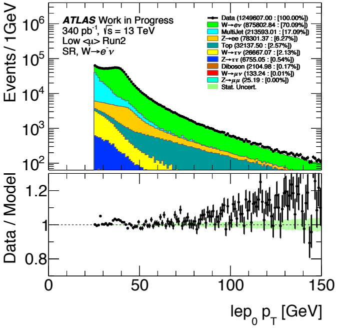
- Calculate shape correction using isolation slices for final MJ templates
- Given the large statistical uncertainty and the linear approximation used, the shift $\Delta H[X]$ applied is assigned a 100% relative uncertainty

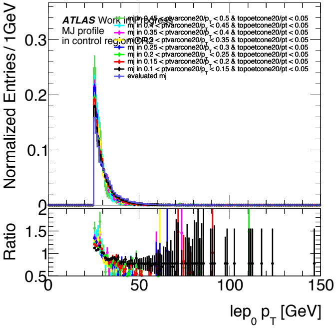
In assumption, extrapolation is linear:

$$H_{MJ}^{[0.A,0.B]}[X] = H_{Data}^{[0.A,0.B]}[X] - H_{MC}^{[0.A,0.B]}[X]$$

$$\Delta H[X] = \frac{1}{4}\{(H_{MJ}^{0.1,0.15} - H_{MJ}^{0.15,0.2}) + (H_{MJ}^{0.2,0.25} - H_{MJ}^{0.25,0.3}) + (H_{MJ}^{0.3,0.35} - H_{MJ}^{0.35,0.4}) + (H_{MJ}^{0.4,0.45} - H_{MJ}^{0.45,0.5})\}$$

$$H_{MJ}^{sig}[X] = H_{MJ}^{0.1,0.15}[X] + 2 \cdot \Delta H[X]$$



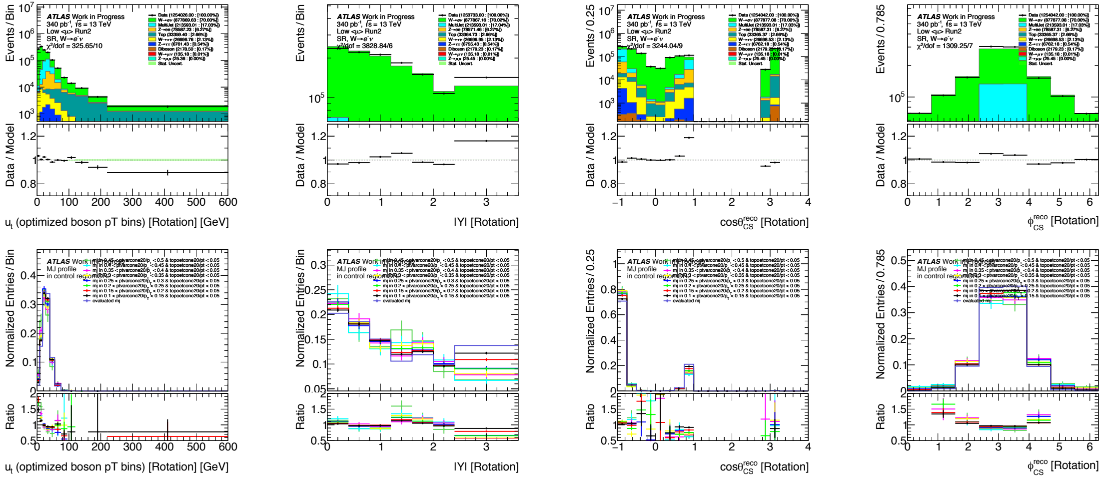


$W^- \rightarrow e^-\nu$	Signal region
Total Number of MJ bkg	**213593**
Data Stat.	1546 (0.72%)
MC Stat.	2120 (1%)
Shape Correction	3236 (1.52%)
Uncorrelated Uncertainty	**4166 (1.95%)**

$W^- \rightarrow \mu^-\nu$	Signal region
Total Number of MJ bkg	**118754**
Data Stat.	775 (0.63%)
MC Stat.	924 (0.78%)
Shape Correction	1014 (0.85%)
Uncorrelated Uncertainty	**1561 (1.31%)**

However, some bins shows non-linear behaviour.

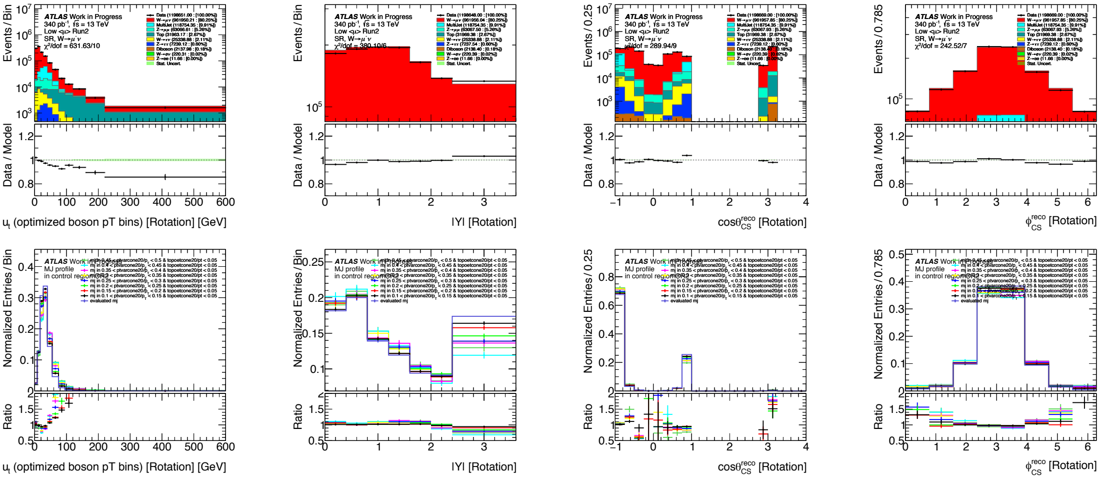
MJ background: control plots in the Signal Region for $W^- \to e^-\nu$



Not good Data/Bkg agreement for u_T and $|Y|$ distributions. Problems with $\cos\theta_{CS}$ in SR.

- tail of u_T seems has wrong correction or bad Top modelling? This also observed for muons (see slide 8).
- high $|Y|$ region: non linear $\bar{iso}$-extrapolation effects in MJ?

MJ background: control plots in the Signal Region for $W^- \to \mu^- \nu$



Bearable Data/Bkg agreement except u_T distribution:

- Might be wrong u_T correction for W decay or bad Top modelling.
- Comparing to electrons: high rapidity region works better. No huge discrepancies for $\cos\theta_{CS}$ and ϕ_{CS}.

Towards MJ in 2D

2D MJ estimation: general idea

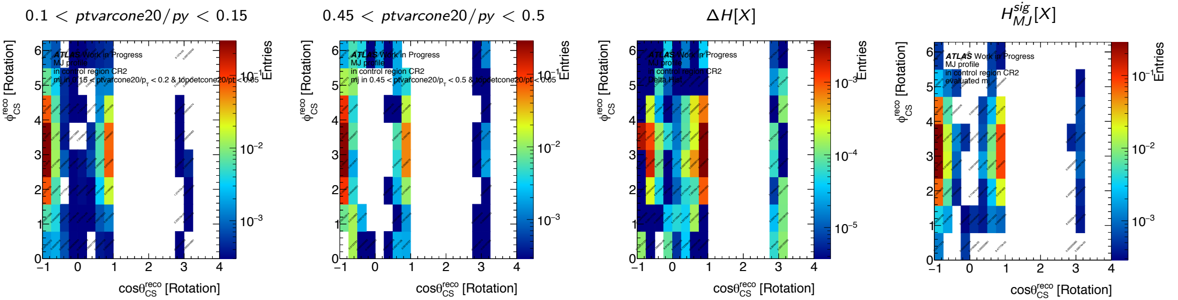
- Same approach as for 1D (bin-by-bin extrapolation), but working with 2D histograms:
  1. Calculate 2D shape via isolation extrapolation method in SR
  2. Scale derived MJ template by MJ yield from SR (see Slide 5)
- If possible, use one MJ template from SR along all $|Y|$ and u_T bins.

Example of 2D MJ shape calculations for $\cos\theta_{CS}^{reco}$ vs. ϕ_{CS}^{reco}:

Note

Some bins for derived 2D templates are negative.

- Set them to 0.
- More on Slide 25

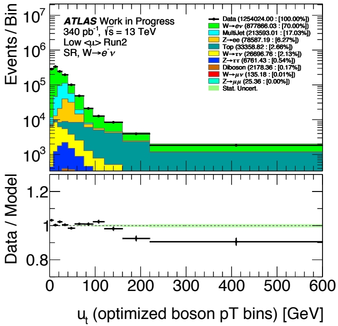


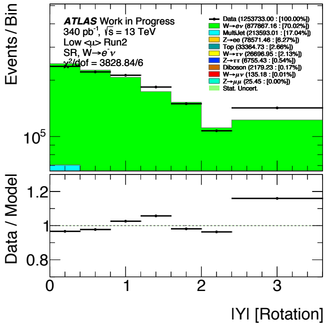
W-Ai analysis binning and MJ shape

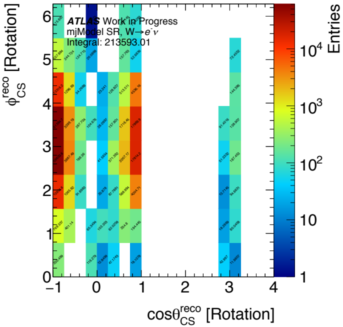
Signal region binning

- u_T: [0., 8., 17., 27., 40., 55., 75., 95., 120., 160., 220., 600]
- $|Y|$: [0, 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 3.6]
- Have to provide MJ estimation for **18 bins in total**

- Use MJ yield normalization from given bin in 1D distribution
- Use 2D MJ template ($\cos\theta_{CS}^{reco}$ vs. ϕ_{CS}^{reco}) derived from SR for all u_T and $|Y|$ bins:
  - as a temporary solution to see if MJ shape from SR would work for all bins.
  - in short - it doesn't work for electrons (slides 12 and 15).

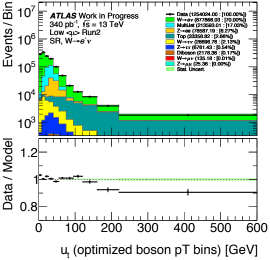




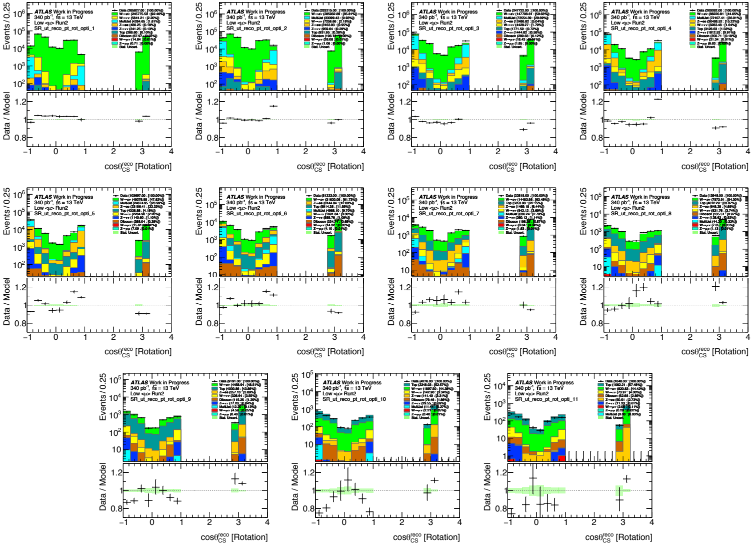


MJ agreement: $\cos\theta^{reco}_{CS}$ as function of u_T bins

Binning variable:

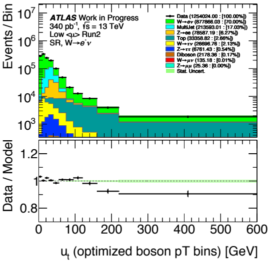


- Use $\cos\theta^{reco}_{CS}$ MJ template from SR for all u_T bins
- MJ yield normalization is provided by MJ yield in given u_T bin
- In the MJ populated u_T bins (2,3 and 4) Data/Bkg prediction discrepancy $\sim 20\%$ at the $\cos\theta^{reco}_{CS}$ tails

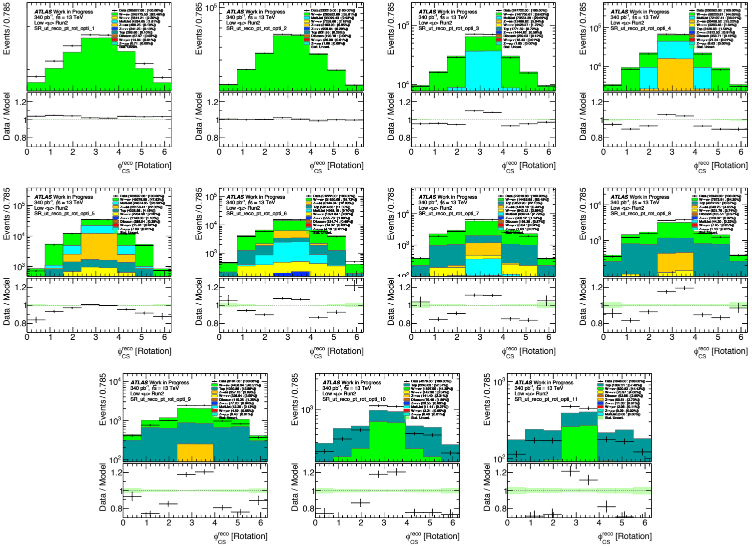


MJ agreement: ϕ_{CS}^{reco} as function of u_T bins

Binning variable:

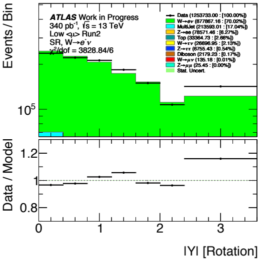


- Use ϕ_{CS}^{reco} MJ template from SR for all u_T bins
- MJ yield normalization is provided by MJ yield in given u_T bin
- In the MJ populated u_T bins (3 and 4) Data/Bkg prediction discrepancy $\sim 15\%$

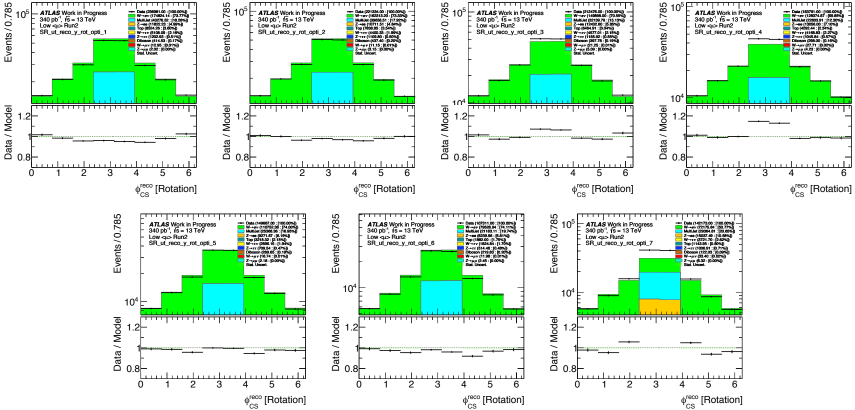


MJ agreement: ϕ_{CS}^{reco} as function of $|Y|$ bins

Binning variable:



- Use ϕ_{CS}^{reco} MJ template from SR for all $|Y|$ bins
- MJ yield normalization is provided by MJ yield in given $|Y|$ bin

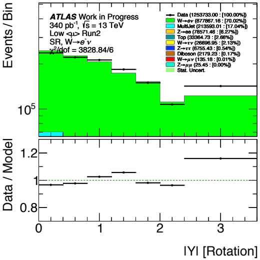


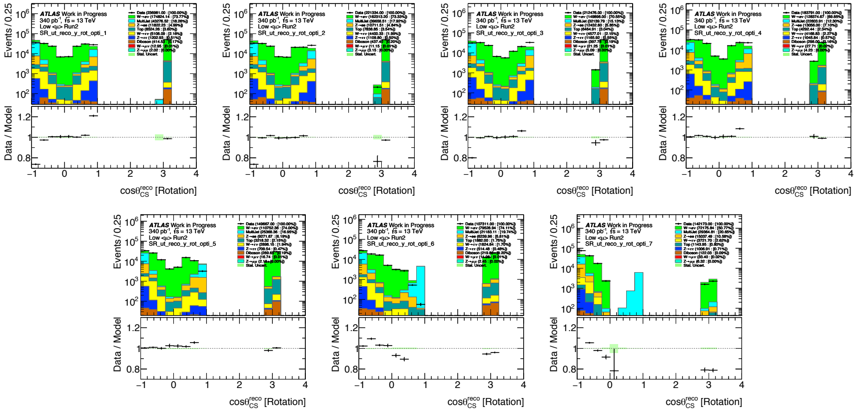
Note

- ϕ_{CS}^{reco} shows some MJ normalization problems

MJ agreement: $\cos\theta_{CS}^{reco}$ as function of $|Y|$ bins

Binning variable:



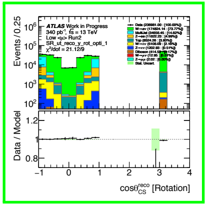


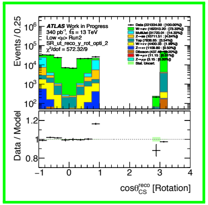
- Use $\cos\theta_{CS}^{reco}$ MJ template from SR for all $|Y|$ bins
- MJ yield normalization is provided by MJ yield in given $|Y|$ bin

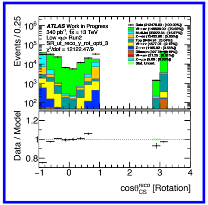
Note

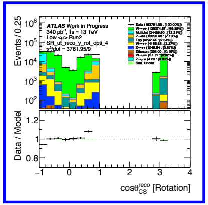
- $\cos\theta_{CS}^{reco}$ MJ shape should be treated as function of $|Y|$
- We have enough statistics to split $|Y|$ in 3 regions and derive MJ templates for each region individually

MJ from 3 independent $|Y|$ bins: $\cos\theta_{CS}^{reco}$ as function of $|Y|$ bins



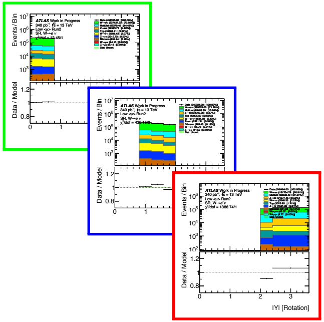


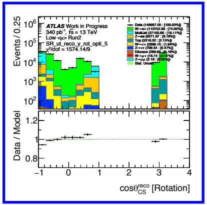


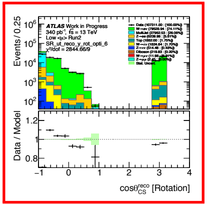


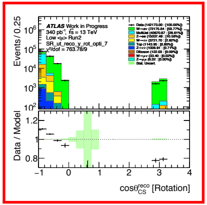
Split SR in 3 regions:

- $|Y| < 0.8$
- $0.8 < |Y| < 2.0$
- $|Y| > 2.0$



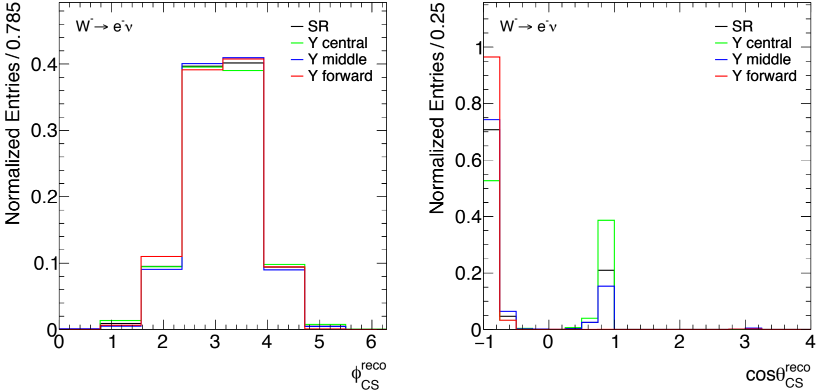






- Calculate MJ yield and shape individually for each $|Y|$ region
- Splitting in 3 $|Y|$ bins shows positive effect, but not able to cope with $\cos\theta_{CS}^{reco}$ vs $|Y|$ dependency effectively

MJ from 3 independent $|Y|$ bins: $\cos\theta_{CS}^{reco}$ and ϕ_{CS}^{reco} as function of $|Y|$ bins



Note

- $\cos\theta_{CS}^{reco}$ MJ template shape depends on $|Y|$
- Same behaviour in the muon channel

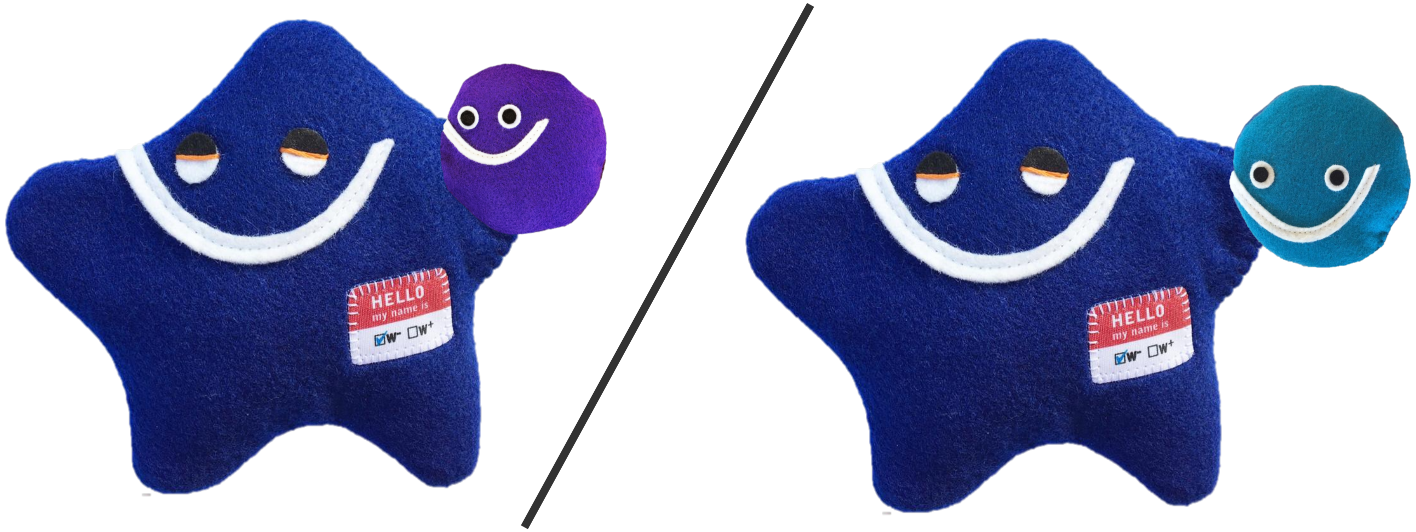
Impact of $|Y|$ binning on sys. uncertainty for $W^- \to e^- \nu$

$W^- \to e^- \nu$	Signal region	Central $\|Y\| < 0.8$	Middle $0.8 < \|Y\| < 2.0$	Forward $\|Y\| > 2.0$
Total Number of MJ bkg	**213593**	66379	85483	68633
Luminosity and cross section	774 (0.36%)	234 (0.35%)	332 (0.39%)	172 (0.25%)
Intersection point	37474 (17.54%)	13077 (19.7%)	19137 (22.39%)	14634 (21.32%)
Extrapolation target	1109 (0.52%)	457 (0.69%)	798 (0.93%)	1260 (1.84%)
Choice of hists	12492 (5.85%)	4359 (6.57%)	6379 (7.46%)	4878 (7.11%)
Isolation correction	N/A	N/A	N/A	N/A
Correlated Uncertainty	39542 **(18.5%)**	13079 (19.7%)	20191 (23.6%)	15478 (22.5%)
Data Stat.	1546 (0.72%)	770 (1.16%)	984 (1.15%)	1071 (1.56%)
MC Stat.	2120 (1%)	1039 (1.57%)	1257 (1.47%)	1779 (2.59%)
Shape Correction	3236 (1.52%)	1017 (1.53%)	1785 (2.09%)	1031 (1.5%)
Uncorrelated Uncertainty	4166 **(1.95%)**	1645 (2.48%)	2394 (2.8%)	2318 (3.38%)

- Preliminary MJ uncertainty estimation
  - have to sync MJ unc. calculation with W precision analyses
  - *TODO:* no sys. unc. for isolation correction included.

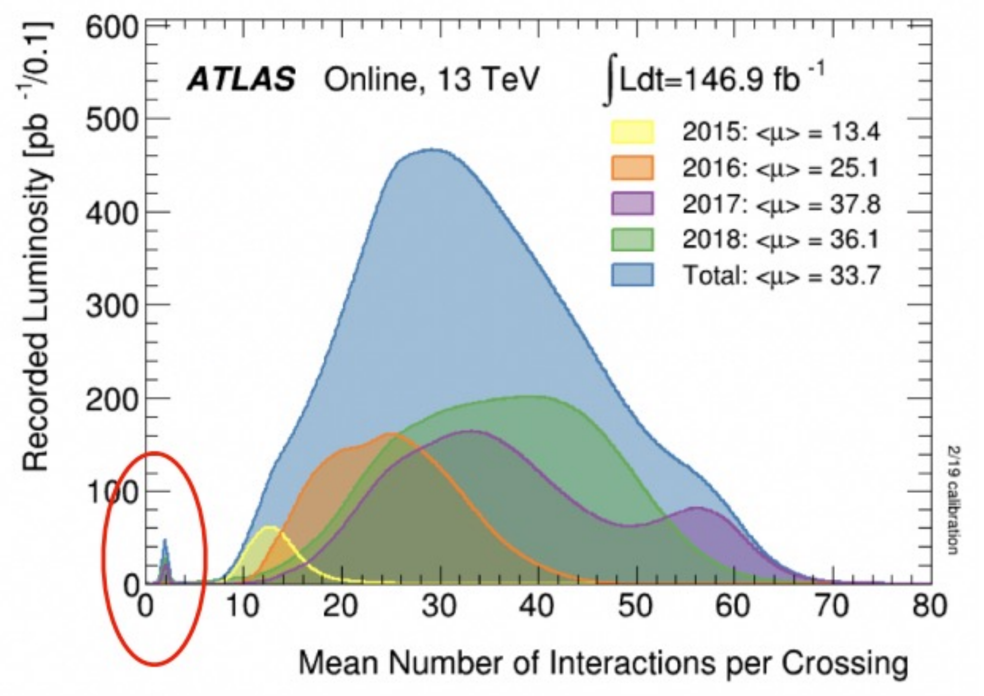
Conclusions

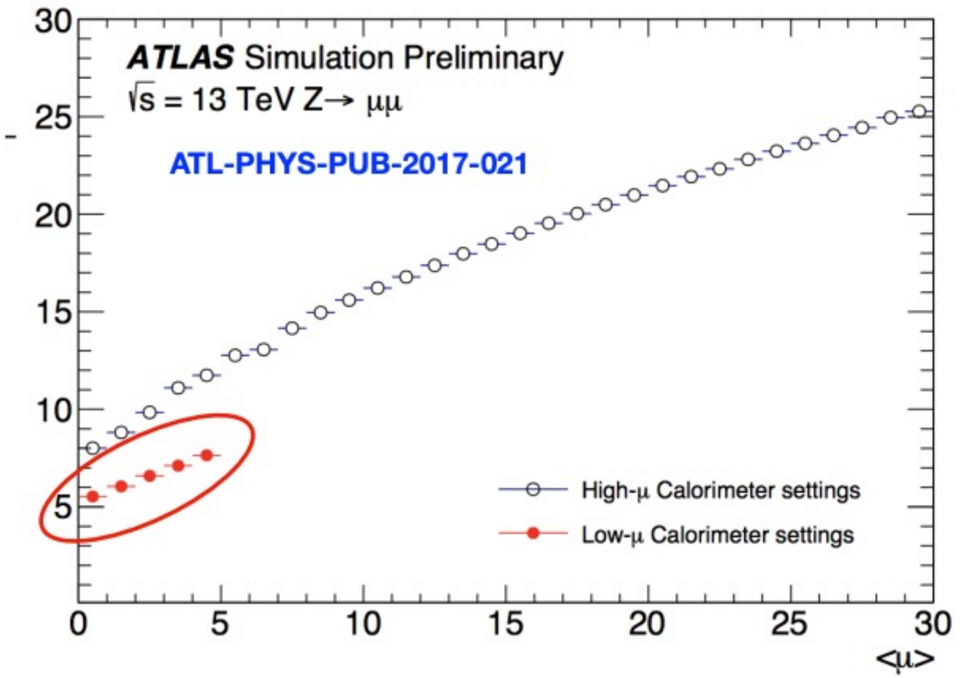
- Control 1D plots (u_T and $|Y|$) shows Data/Bkg disagreement:
  - For high u_T due to problems with u_T reweighing in electrons and muons
  - For high $|Y|$ bins underestimate MJ background yield in electrons channel only
- For 2D MJ template some bins are negative. This happens for regions where MJ close to 0.
  - set all negative bins to 0
- MJ templates for $\cos\theta_{CS}^{reco}$ depends on Y and u_T:
  - Same behaviour for electron and muon channels
  - Calculating MJ $\cos\theta_{CS}^{reco}$ individually for 3 $|Y|$ bins doesn't solve an issue for electrons, but might be an option for muons
    - Could be this is effect of Data/MC disagreement for electrons for ϕ_{CS} and $\cos\theta_{CS}$ in SR
  - Might consider building acceptance functions to calculate MJ templates for each u_T and $|Y|$ bin using MJ 2D template from signal regions
- Preliminary 2D templates are available on */eos* for electron and muons channels (3 Y bins):
  - Electrons */eos/home-d/dponomar/Storage/Science/Wai/results/v20210713ptrw_ruth/WS*
  - Muons */eos/home-d/dponomar/Storage/Science/Wai/results/v20210906ptrw_ruth/WS*
  - Summary for muon channel is in the backup slides
- $W^- \to e^-\nu$ in the SR: 213593 $\pm$ 18.5% (corr) $\pm$ 1.95% (uncorr)
- $W^- \to \mu^-\nu$ in the SR: 118754 $\pm$ 9.49% (corr) $\pm$ 1.31% (uncorr)



Thanks for attention!

Why low-μ data?



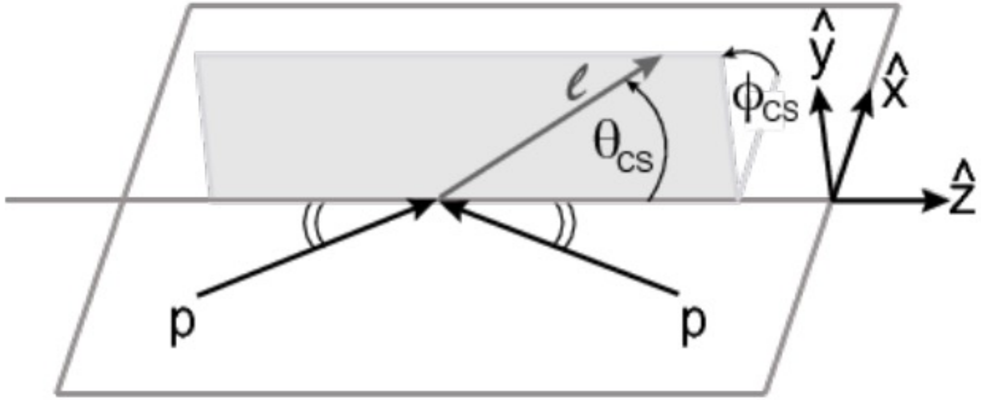


- Aim: measure W-A_i in 340pb^{-1} of 13TeV data
- less statistics in low-μ dataset, **BUT:**
- resolution of hadronic recoil factor O(5) lower in low-μ data than in full high-μ dataset

Data and MC samples for low <mu> analysis

Channel	Samples
Wmu	mc16_13TeV.361101.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Wplusmunu mc16_13TeV.361104.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Wminusmunu
We	mc16_13TeV.361100.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Wplusenu mc16_13TeV.361103.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Wminusenu
Wtau	mc16_13TeV.361102.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Wplustaunu mc16_13TeV.361105.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Wminustaunu
Zee	mc16_13TeV.361106.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Zee
Zmm	mc16_13TeV.361107.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Zmumu
Ztt	mc16_13TeV.361108.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Ztautau
DiBoson	mc16_13TeV.363356.Sherpa_221_NNPDF30NNLO_ZqqZll mc16_13TeV.363358.Sherpa_221_NNPDF30NNLO_WqqZll mc16_13TeV.363359.Sherpa_221_NNPDF30NNLO_WpqqWmlv mc16_13TeV.363360.Sherpa_221_NNPDF30NNLO_WplvWmqq mc16_13TeV.363489.Sherpa_221_NNPDF30NNLO_WlvZqq mc16_13TeV.364250.Sherpa_222_NNPDF30NNLO_llll mc16_13TeV.364253.Sherpa_222_NNPDF30NNLO_lllv mc16_13TeV.364254.Sherpa_222_NNPDF30NNLO_llvv mc16_13TeV.364255.Sherpa_222_NNPDF30NNLO_lvvv
Top	mc16_13TeV.410013.PowhegPythiaEvtGen_P2012_Wt_inclusive_top mc16_13TeV.410014.PowhegPythiaEvtGen_P2012_Wt_inclusive_antitop mc16_13TeV.410642.PhPy8EG_A14_tchan_lept_top mc16_13TeV.410643.PhPy8EG_A14_tchan_lept_antitop mc16_13TeV.410644.PowhegPythia8EvtGen_A14_singletop_schan_lept_top mc16_13TeV.410645.PowhegPythia8EvtGen_A14_singletop_schan_lept_antitop mc16_13TeV.410470.PhPy8EG_A14_ttbar_hdamp258p75_nonallhad

The Colins-Soper Rest Frame



Angular variables θ and ϕ defined in Colins-Soper (CS) rest frame:

- boost into the W-boson rest frame
- rotation into special CS frame
- CS frame: incoming partons lie in plane spanned by x- and z-axis
- angles θ and ϕ defined as angles between negative lepton (or neutrino) and xz plane
- choice of rest frame is arbitrary, CS has been conventional choice

Improving our sensitivity

from Ruth Jacobs @ status report

Analysis goal: Measure W angular coefficients in 340pb-1 of 13TeV ATLAS low-μ data!

Measurement in pT and Y bins (1D)

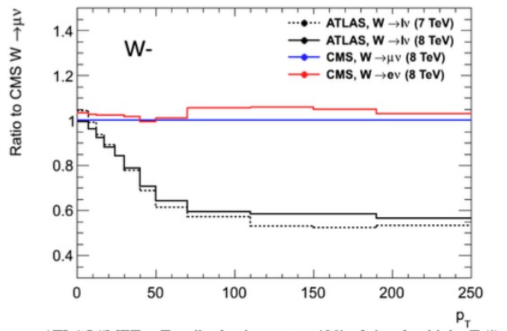
Low-μ data: Low *statistics*, but better recoil resolution, less bkg.

Gain in statistics

- looser kinematic selection (drop E_{Tmiss}, m_T cuts)
- background rejection: tighter lepton ID and isolation cuts

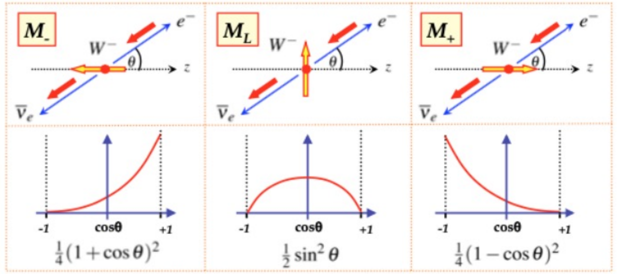
Improve neutrino pz reconstruction

- get P_z from W mass constraint
- impose additional kinematic constraints or from physics
- use P_z reconstruction similar to: https://arxiv.org/pdf/1005.3196.pdf



ATLAS "MET, mT cut" selection costs ~40% of signal at high pT (!)

★ The angular distributions can be understood in terms of the spin of the particles



5

Analysis goal: Measure W angular coefficients in 340pb-1 of 13TeV ATLAS low-μ data!

Full 2D measurement in pT and Y bins

- Low-μ data: Low *statistics*, but better recoil resolution, less bkg.

C

From here

Gain in statistic: **Event selection**

- Lower lepton pT threshold from 25 to 20 GeV
- Lower ETmiss cut (https://indico.cern.ch/event/367442/contributions/868167/attachments/730549/1002372/Mw_topical_230215.pdf)
- New Isolation better rejection

A

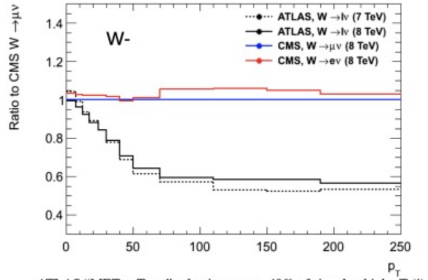
improve sensitivity on **recovering neutrino pT z**

- alternative NN or MVA analysis to pick the right solution (Alex talk)
- imposing additional kinematic or physics symmetries (eg +y = -y)
- https://arxiv.org/pdf/1005.3196.pdf

B

improve **recoil resolution**?

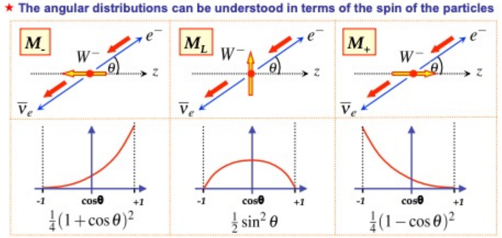
MVA calibration of the recoil using p-flow constituents,



ATLAS "MET, mT cut" selection costs ~40% of signal at high pT (!)

The sign of the (1 ± cos θ) distribution depends on the helicity of the lepton and the helicity of the incoming parton with highest-x, (anti-)quarks

★ The angular distributions can be understood in terms of the spin of the particles



$$|M_-|^2 = g_W^2 m_W^2 \tfrac{1}{4}(1+\cos\theta)^2$$
$$|M_L|^2 = g_W^2 m_W^2 \tfrac{1}{2}\sin^2\theta$$
$$|M_+|^2 = g_W^2 m_W^2 \tfrac{1}{4}(1-\cos\theta)^2$$

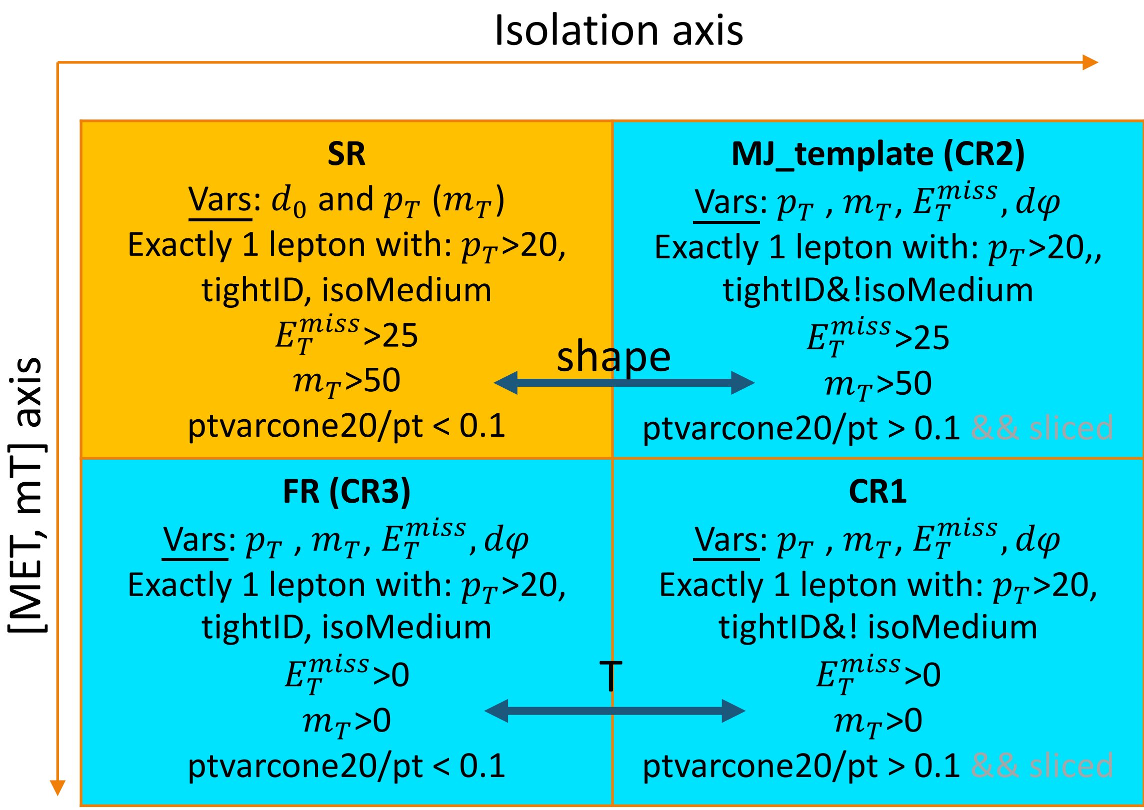
MJ Introduction

- Algorithm is same as in ATL-COM-PHYS-2019-076
- MJ Background Estimation consists of 2 parts:
  - The shape of MJ background
  - The total number of MJ background
- A data-driven method
  - Reverse two independent cuts and 3 control region (CR)

$$\frac{N_{CR3}}{N_{CR1}} = \frac{N_{SR}^{BKG}}{N_{CR2}}$$

  - Here we can do the calculation bin-by-bin and get both the shape and the total number of MJ background
  - We can take other BKG into the consideration, so we have

$$T = \frac{N_{CR3}^{Data} - N_{CR3}^{EW\,BKG}}{N_{CR1}^{Data} - N_{CR1}^{EW\,BKG}} = \frac{N_{SR}^{MJ\,BKG}}{N_{CR2}^{Data} - N_{CR2}^{EW\,BKG}}$$



MJ: low <mu> analysis strategy

$$T = \frac{N_{CR3}^{Data} - N_{CR3}^{EW\ BKG}}{N_{CR1}^{Data} - N_{CR1}^{EW\ BKG}} = \frac{N_{SR}^{MJ\ BKG}}{N_{CR2}^{Data} - N_{CR2}^{EW\ BKG}}$$

- Strategy
  - For FR and CR1, both M_T and E_T^{miss} cuts are removed
    - Great point from Daniel, why not orthogonal?!
  - Additional u_T cut for CR1 and FR to suppress jet activity
    - u_T < [15,20,30,10000]
  - Choose 8 different slices of CR, with different isolation region
    - [0.1,0.15,0.2,0.25, 0.3,0.35,0.5]
  - A scaling parameter is used instead of the direct calculation to get the parameter T
    - $N_{FR}^{Data} = \alpha N_{FR}^{EW\ BKG} + T\,(N_{CR1}^{Data} - N_{CR1}^{EW\ BKG})$
  - α is also a parameter in the fitting, but it should be close to 1 within the uncertainty
  - Extrapolate $N_{SR}^{MJ\ BKG} = T\,(N_{CR2}^{Data} - N_{CR2}^{EW\ BKG})$ by a linear relationship to 0

Isolation axis

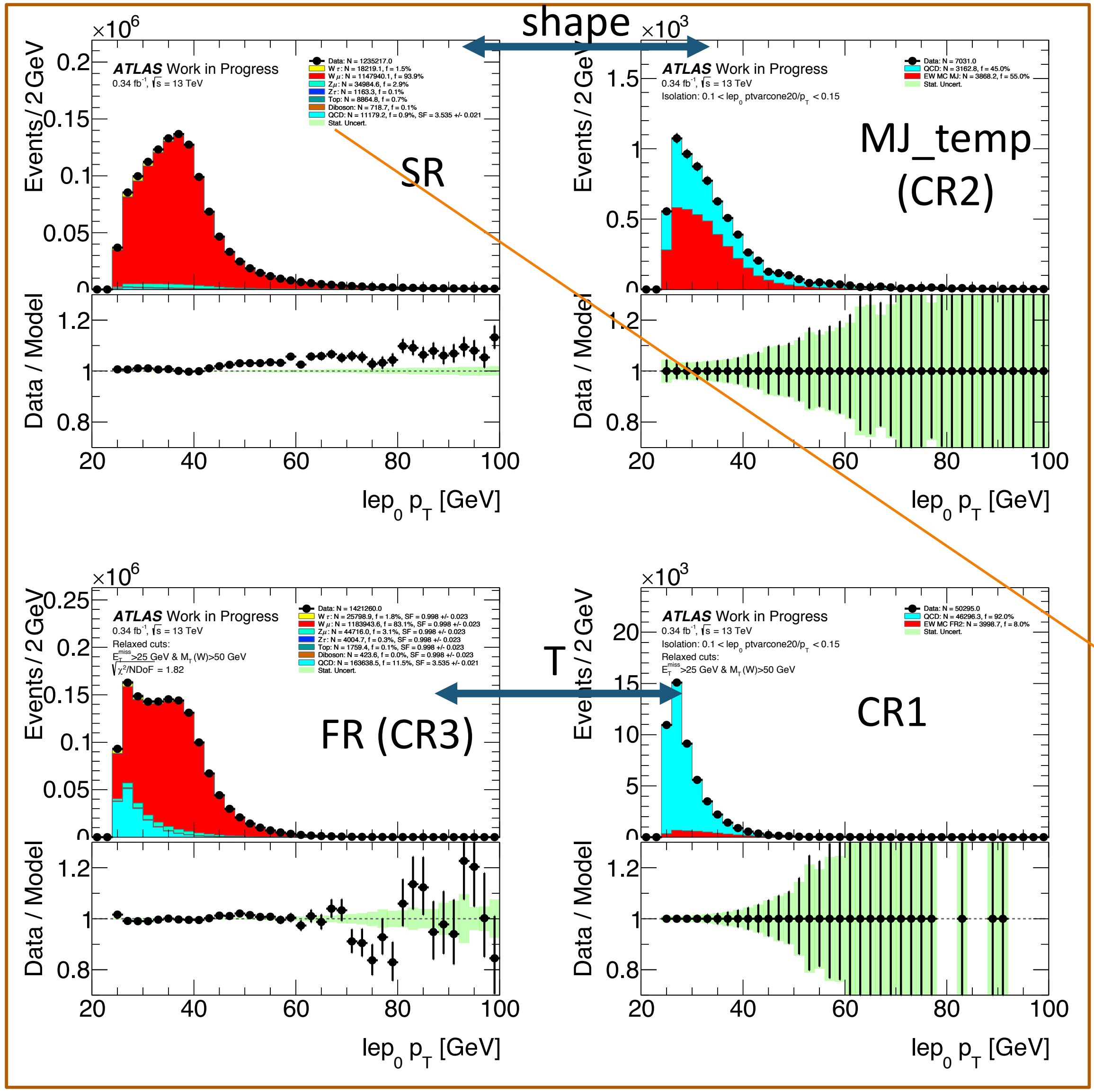
[MET, mT] axis

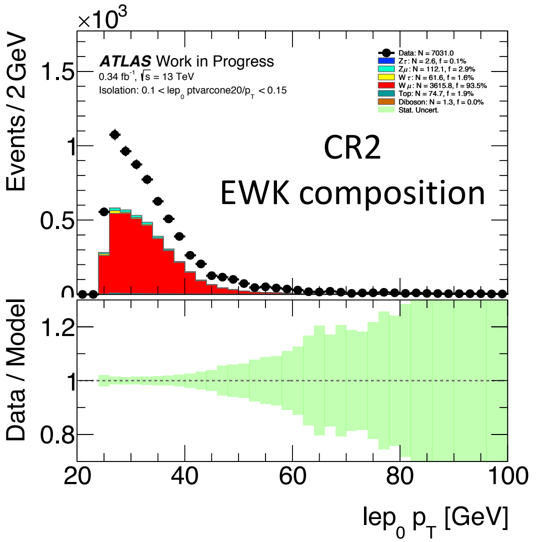
SR Vars: d_0 and p_T (m_T) Exactly 1 lepton with: p_T>20, tightID, isoMedium E_T^{miss}>25 m_T>50 ptvarcone20/pt < 0.1	**MJ_template (CR2)** Vars: p_T, m_T, E_T^{miss}, $d\varphi$ Exactly 1 lepton with: p_T>20,, tightID&!isoMedium E_T^{miss}>25 m_T>50 ptvarcone20/pt > 0.1 && sliced
FR (CR3) Vars: p_T, m_T, E_T^{miss}, $d\varphi$ Exactly 1 lepton with: p_T>20, tightID, isoMedium E_T^{miss}>0 m_T>0 ptvarcone20/pt < 0.1	**CR1** Vars: p_T, m_T, E_T^{miss}, $d\varphi$ Exactly 1 lepton with: p_T>20, tightID&! isoMedium E_T^{miss}>0 m_T>0 ptvarcone20/pt > 0.1 && sliced

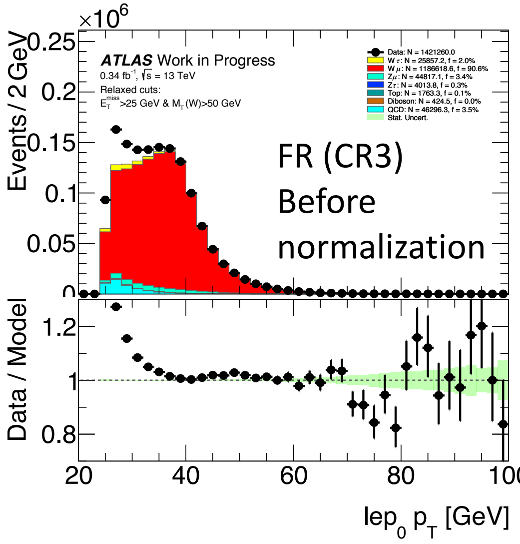
T

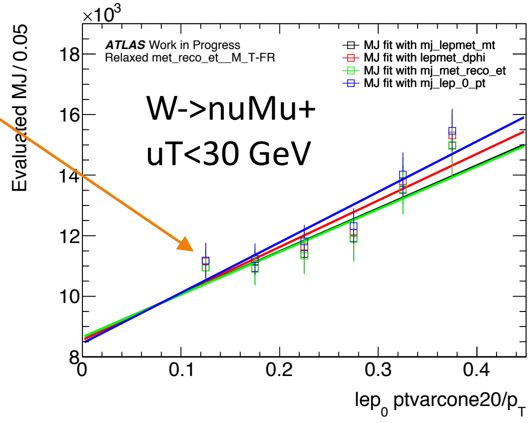
MJ strategy: example

- Choose 6 different slices of CR, with different isolation region
  - [0.1,0.15,0.2,0.25, 0.3,0.35,0.4]
- Make 32 iso slice scans:
  - 4 MJ discriminant variables:
    - pT , mT, MET, $d\varphi$
  - Additional u_T cut for CR1 and FR to suppress jet activity
    - u_T < [15,20,30,10000]

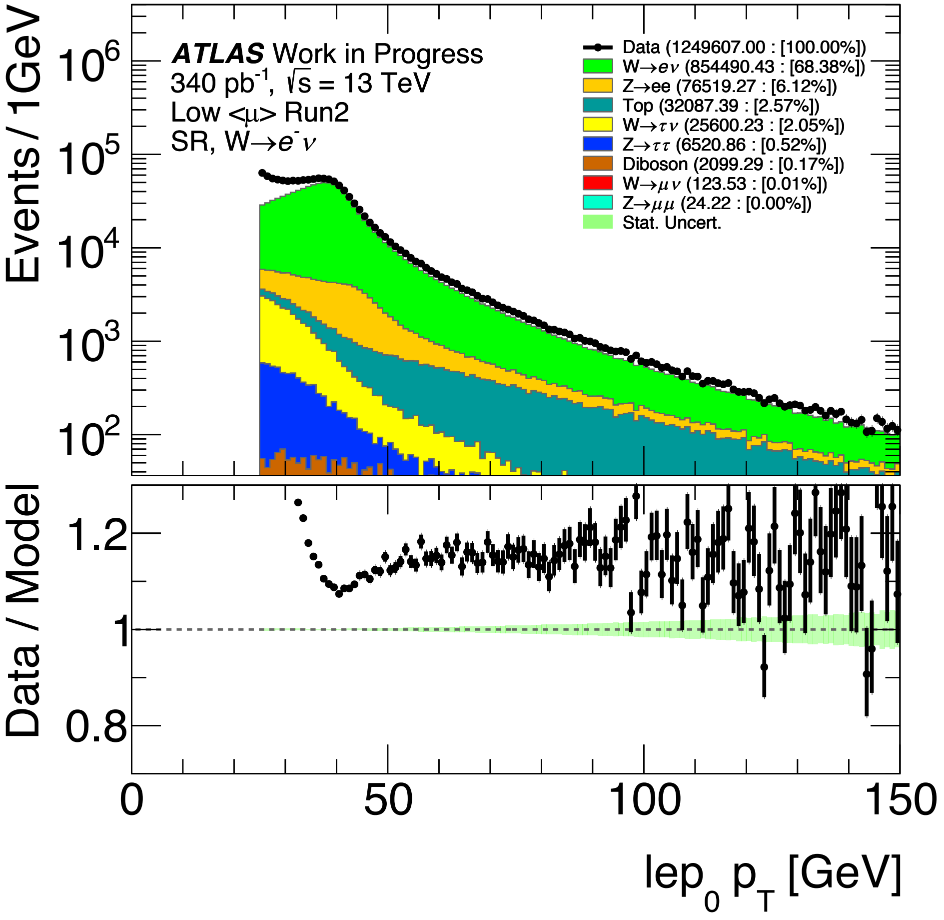


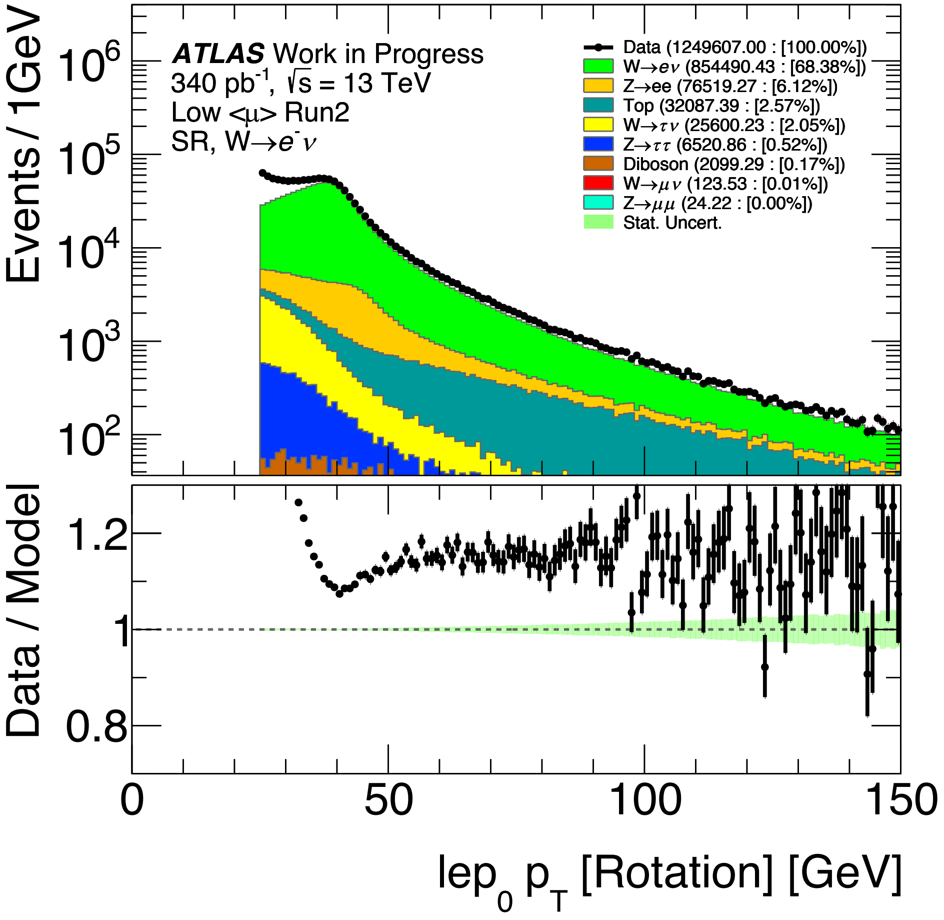






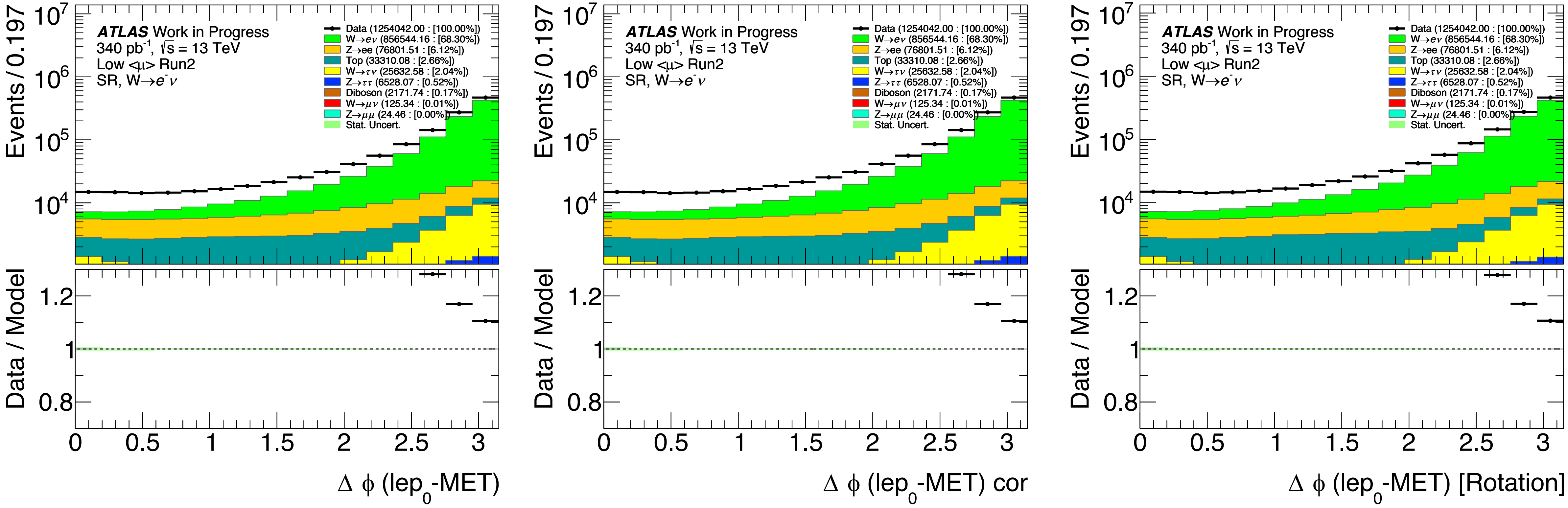
Constrained p_T variables [SR]





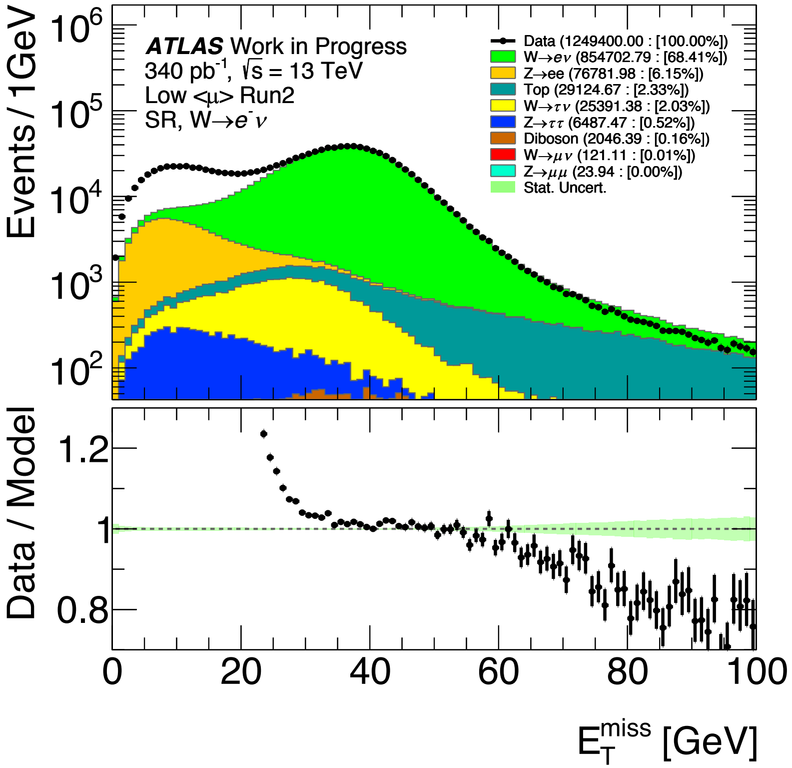
- No difference
- Same for muons: see backup

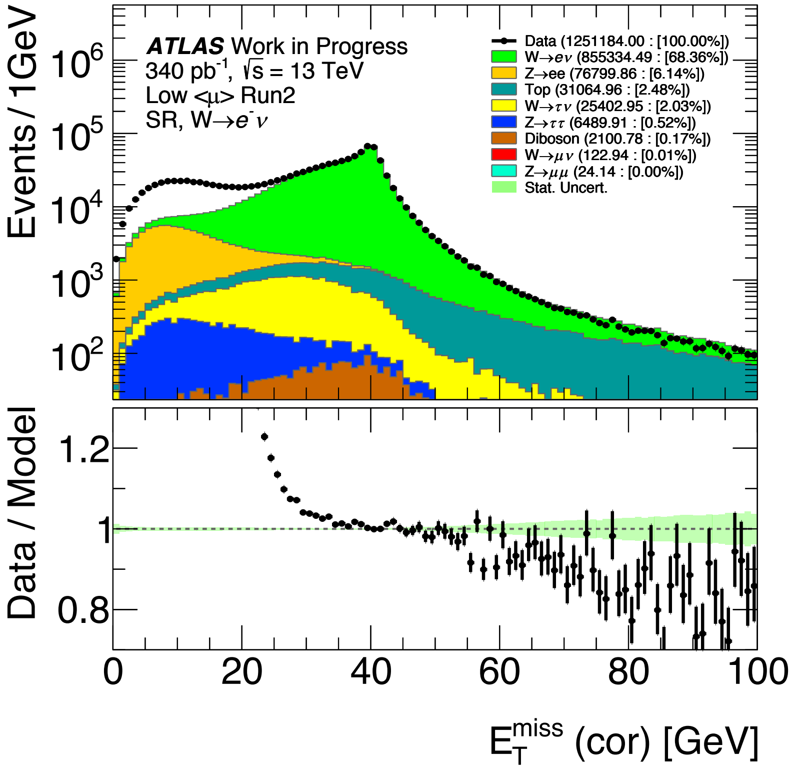
Constrained $\Delta\varphi$ variables [SR]

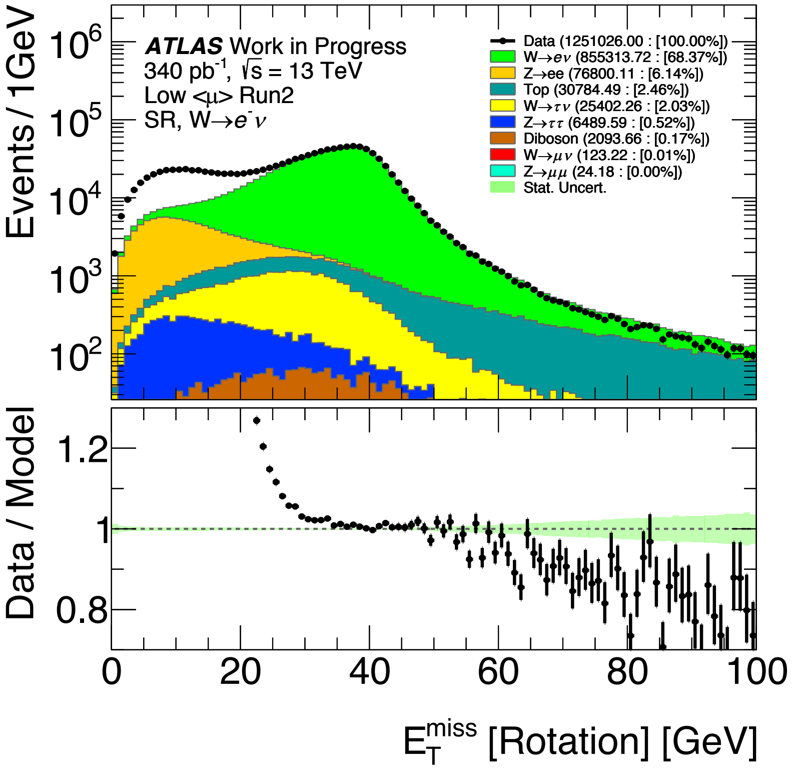


- Almost no difference

Constrained E_T^{miss} variables [SR]

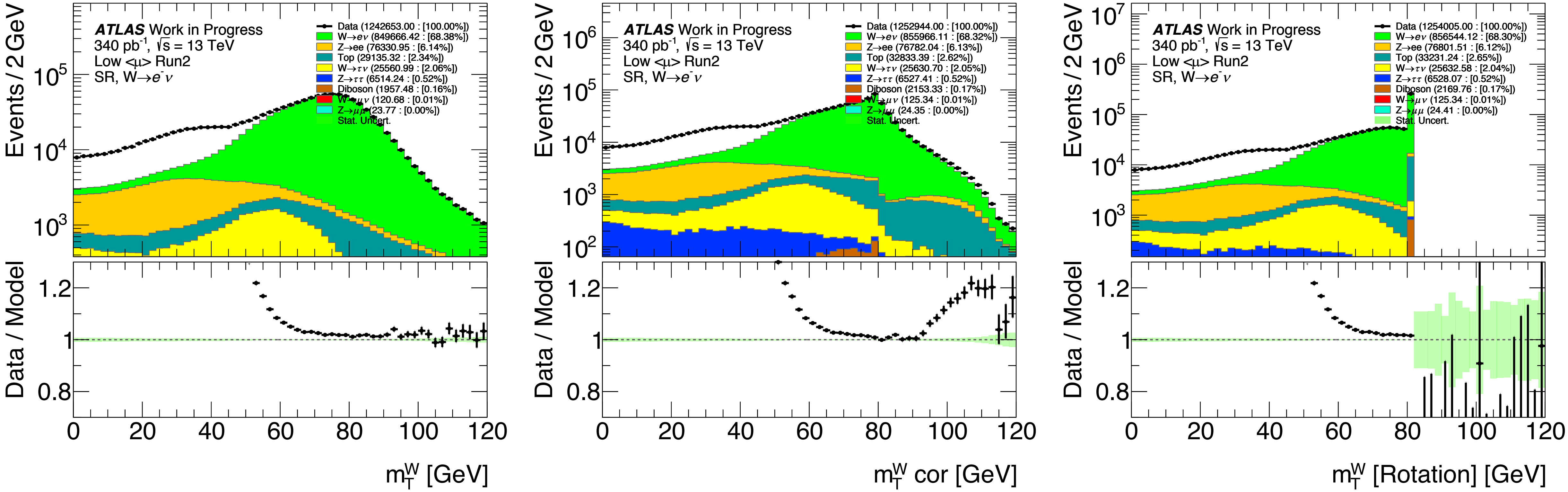






- Seems to be legit

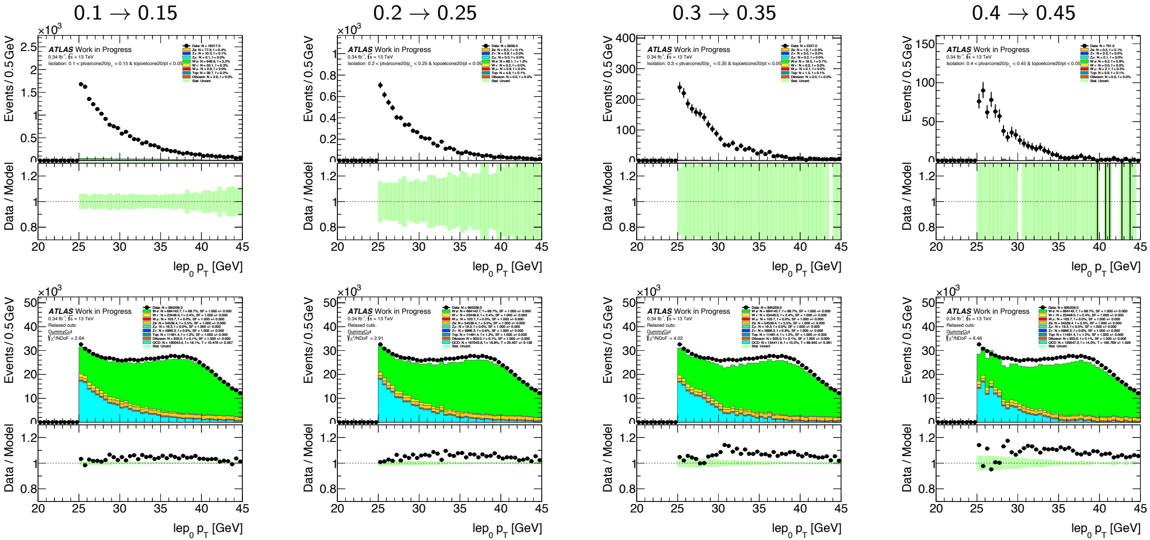
Constrained m_T variables [SR]



- Is it expected?
- Should we limit MJ fit region to [0, 82]?
  - For this presentation keep [0, 120]

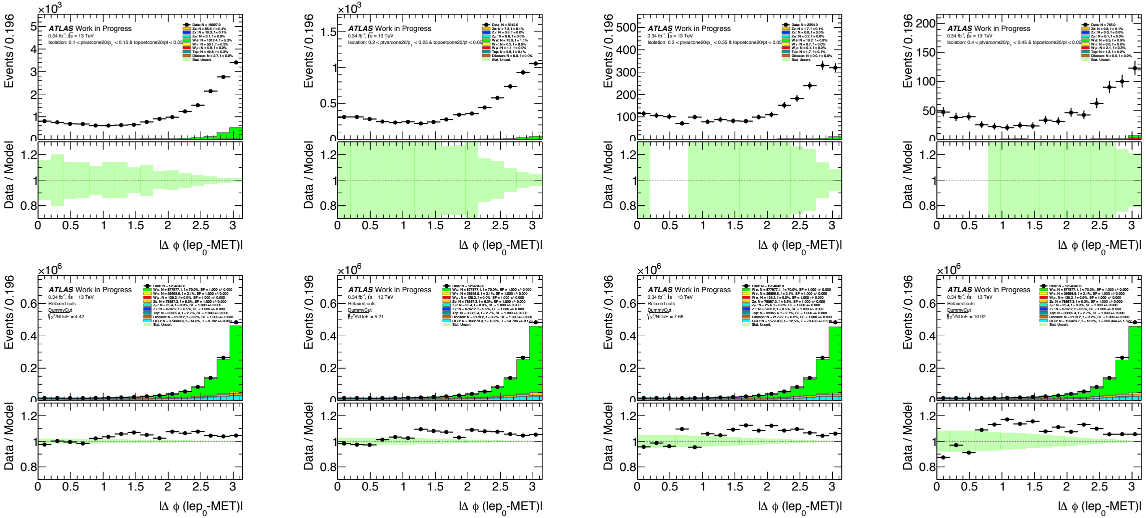
Backup

Isolation $ptvarcone20/pt$ slices for $W^- \to e^-\nu$: leading lepton p_T



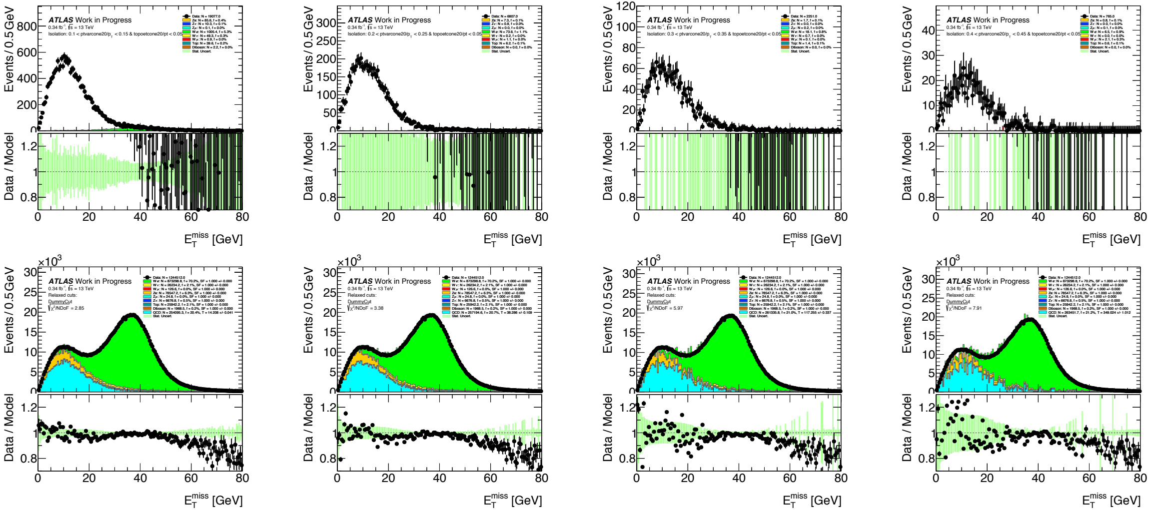
Isolation $ptvarcone20/pt$ slices for $W^{-} \rightarrow e^{-}\nu$: $|\Delta\phi(\ell - MET)|$

$0.1 \rightarrow 0.15$ | $0.2 \rightarrow 0.25$ | $0.3 \rightarrow 0.35$ | $0.4 \rightarrow 0.45$



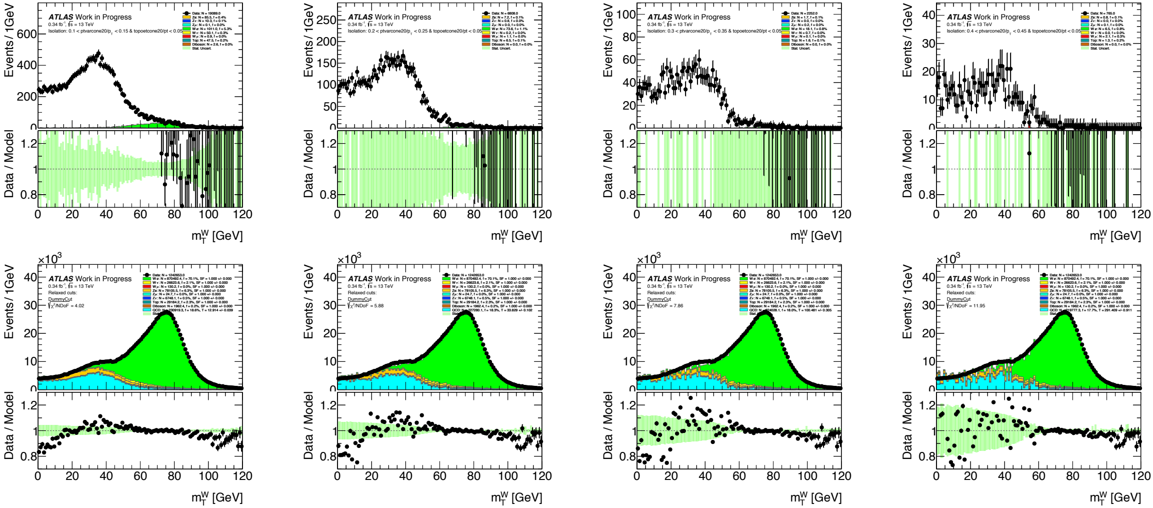
Isolation $ptvarcone20/pt$ slices for $W^- \to e^-\nu$: E_T^{miss}

0.1 → 0.15 | 0.2 → 0.25 | 0.3 → 0.35 | 0.4 → 0.45

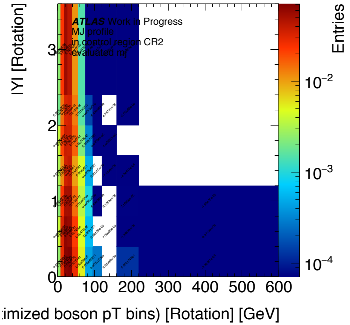


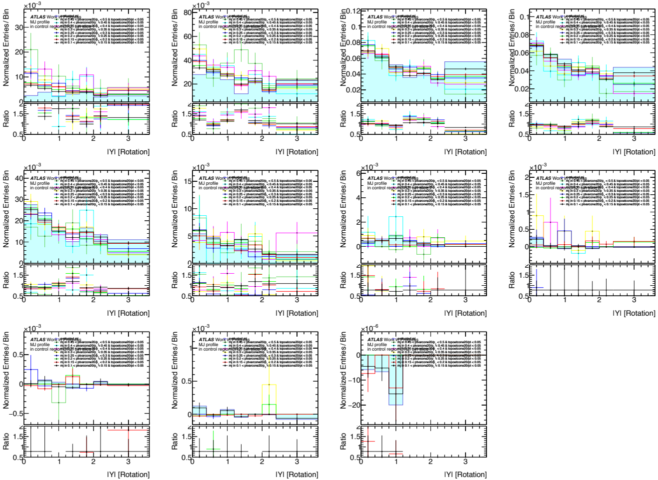
Isolation $ptvarcone20/pt$ slices for $W^- \to e^-\nu$: m_T^W

0.1 → 0.15 | 0.2 → 0.25 | 0.3 → 0.35 | 0.4 → 0.45



2D MJ estimation: extrapolation and projections on Y axis





- Some of the bins are negative.
- Set them to 0 with assumption it should not affect overall normalization too much.

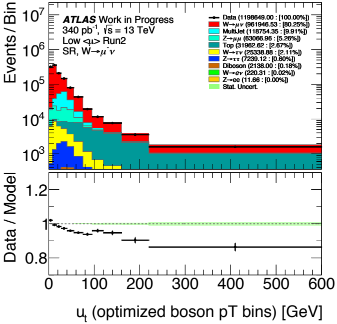
Muons

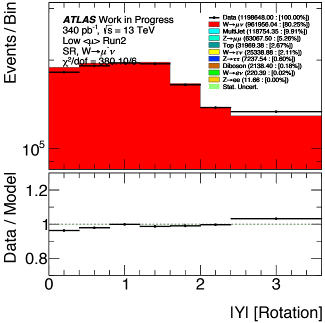
W-Ai analysis binning and MJ shape

Signal region binning

- u_T: [0., 8., 17., 27., 40., 55., 75., 95., 120., 160., 220., 600]
- $|Y|$: [0, 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 3.6]
- Have to provide MJ estimation for **18 bins in total**

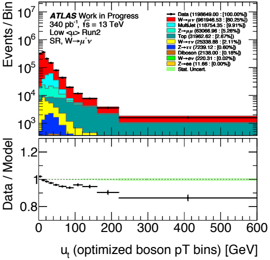
- Use MJ yield normalization from given bin in 1D distribution
- Use 2D MJ template ($\cos\theta_{CS}^{reco}$ vs. ϕ_{CS}^{reco}) derived from SR for all u_T and $|Y|$ bins:
  - as a temporary solution to see if MJ shape from SR would work for all bins.
  - could work for muons(Slide 28).



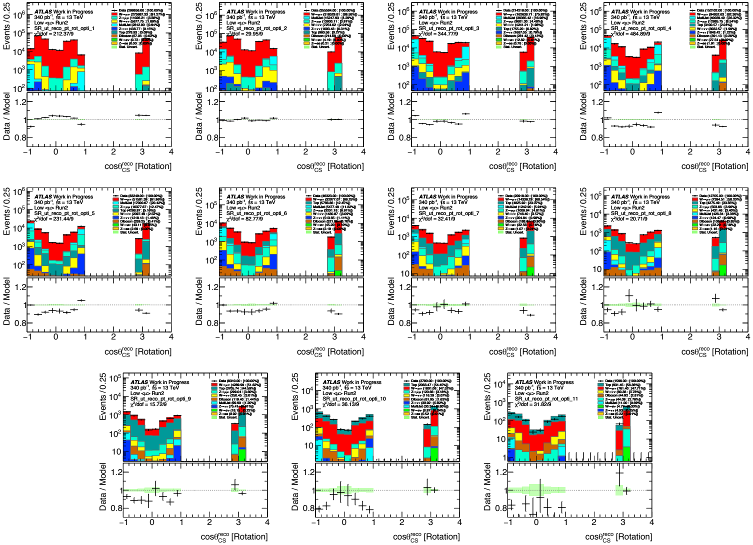


MJ agreement: $\cos\theta_{CS}^{reco}$ as function of u_T bins

Binning variable:

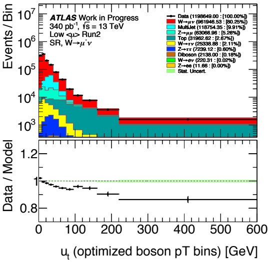


- Use $\cos\theta_{CS}^{reco}$ MJ template from SR for all u_T bins
- MJ yield normalization is provided by MJ yield in given u_T bin
- In the MJ populated u_T bins (3, 4 and 5) Data/Bkg prediction discrepancy $\sim$ 12%.

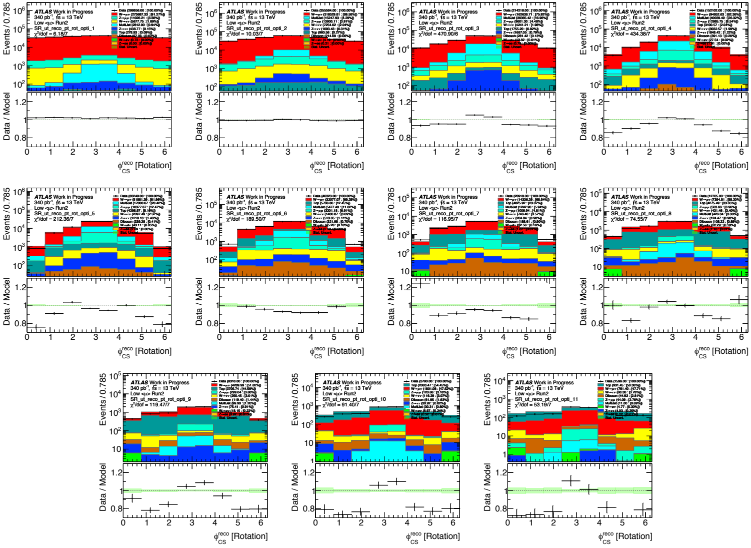


MJ agreement: ϕ_{CS}^{reco} as function of u_T bins

Binning variable:

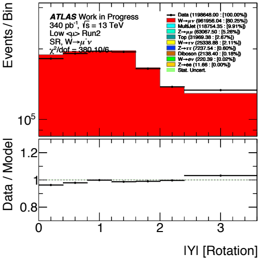


- Use ϕ_{CS}^{reco} MJ template from SR for all u_T bins
- MJ yield normalization is provided by MJ yield in given u_T bin
- In the MJ populated u_T bins (3 and 4) Data/Bkg prediction discrepancy $\sim$ 15%

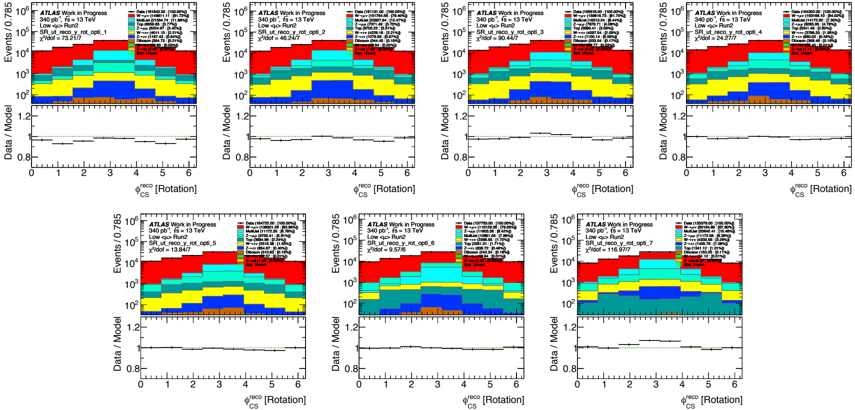


MJ agreement: ϕ_{CS}^{reco} as function of $|Y|$ bins

Binning variable:



- Use ϕ_{CS}^{reco} MJ template from SR for all $|Y|$ bins
- MJ yield normalization is provided by MJ yield in given $|Y|$ bin

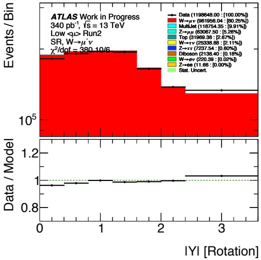


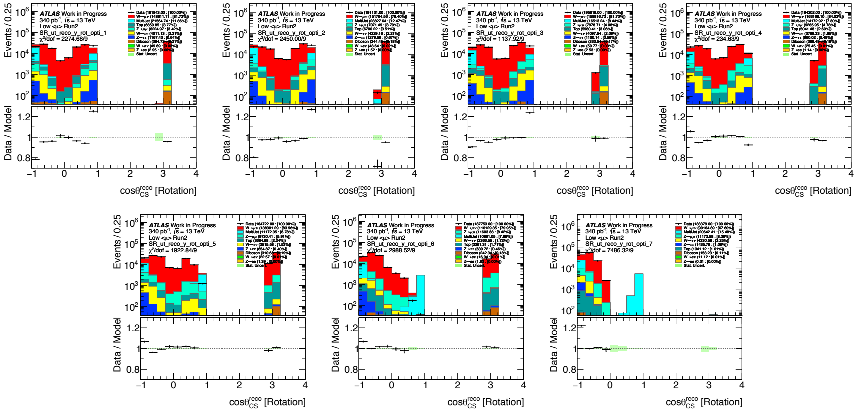
Note

- For muons ϕ_{CS}^{reco} overall good agreement

MJ agreement: $\cos\theta_{CS}^{reco}$ as function of $|Y|$ bins

Binning variable:





- Use $\cos\theta_{CS}^{reco}$ MJ template from SR for all $|Y|$ bins
- MJ yield normalization is provided by MJ yield in given $|Y|$ bin

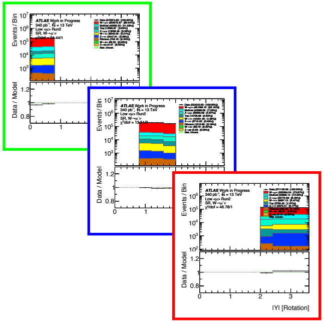
Note

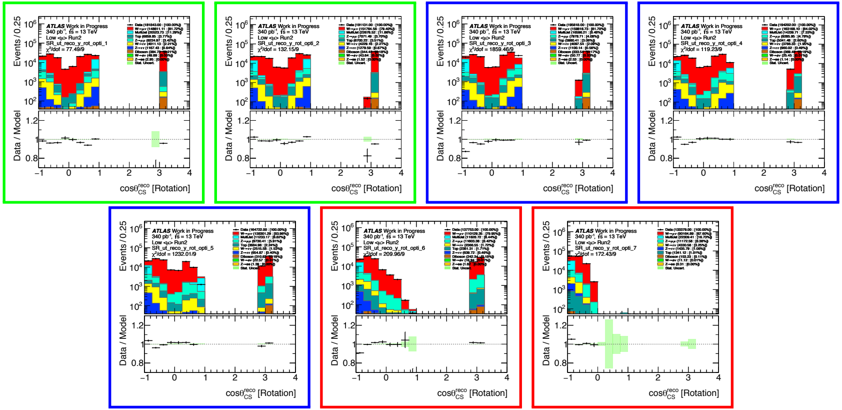
- $\cos\theta_{CS}^{reco}$ MJ shape should be treated as function of $|Y|$
- We can split $|Y|$ in 3 regions and derive MJ templates for each of them individually

MJ from 3 independent $|Y|$ bins: $\cos\theta_{CS}^{reco}$ as function of $|Y|$ bins

Split SR in 3 regions:

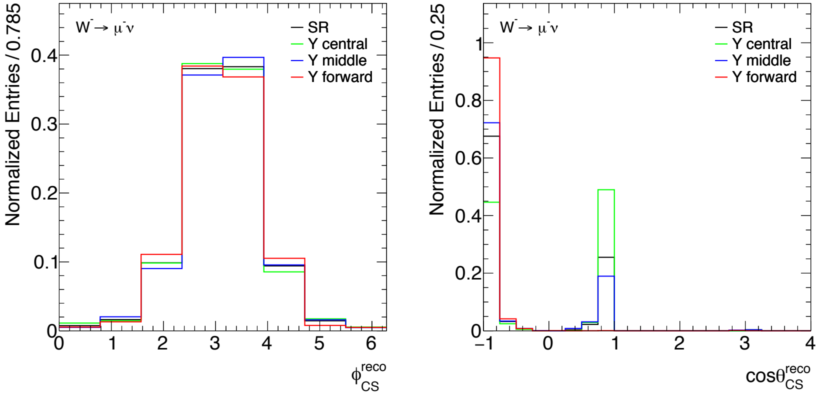
- $|Y| < 0.8$
- $0.8 < |Y| < 2.0$
- $|Y| > 2.0$





- Calculate MJ normalization and shape individually for aech $|Y|$ region
- Splitting in 3 $|Y|$ bins shows positive effect, but not able to cope with $\cos\theta_{CS}^{reco}$ vs $|Y|$ dependency effectively

MJ from 3 independent $|Y|$ bins: $\cos\theta_{CS}^{reco}$ and ϕ_{CS}^{reco} as function of $|Y|$ bins



Note

- $\cos\theta_{CS}^{reco}$ MJ template shape depands on $|Y|$
- Same observation in the electron channel

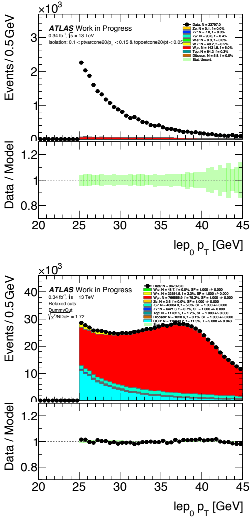
Impact of $|Y|$ binning on sys. uncertainty for $W^- \to \mu^- \nu$

$W^- \to \mu^- \nu$	Signal region	Central $\lvert Y\rvert < 0.8$	Middle $0.8 < \lvert Y\rvert < 2.0$	Forward $\lvert Y\rvert > 2.0$
Total Number of MJ bkg	**118754**	43200	42069	33938
Luminosity and cross section	406 (0.34%)	126 (0.29%)	175 (0.42%)	103 (0.3%)
Intersection point	11269 (9.49%)	3581 (8.29%)	6078 (14.45%)	1744 (5.14%)
Extrapolation target	15 (0.01%)	66 (0.15%)	82 (0.2%)	42 (0.12%)
Choice of hists	3756 (3.16%)	1194 (2.76%)	2026 (4.82%)	582 (1.71%)
Isolation correction	N/A	N/A	N/A	N/A
Correlated Uncertainty	11275 **(9.49%)**	3777 (8.74%)	6081 (14.46%)	1748 (5.15%)
Data Stat.	775 (0.63%)	438 (1.01%)	436 (1.04%)	424 (1.25%)
MC Stat.	924 (0.78%)	599 (1.39%)	479 (1.14%)	563 (1.66%)
Shape Correction	1014 (0.85%)	759 (1.76%)	419 (1.0%)	67 (0.2%)
Uncorrelated Uncertainty	1561 **(1.31%)**	1061 (2.46%)	771 (1.83%)	708 (2.09%)

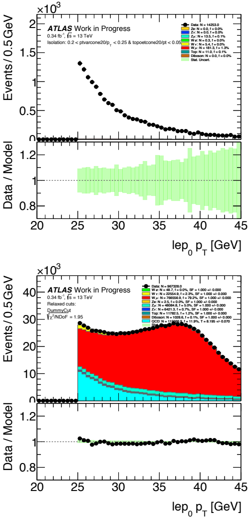
- Preliminary MJ uncertainty estimation
  - have to sync MJ unc. calculation with W precision analyses
  - *TODO:* no sys. unc. for isolation correction included.

Isolation *ptvarcone20/pt* slices for $W^- \to \mu^- \nu$: leading lepton p_T

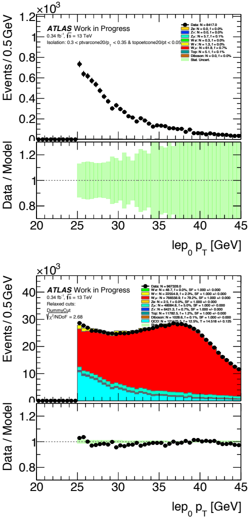
$0.1 \to 0.15$



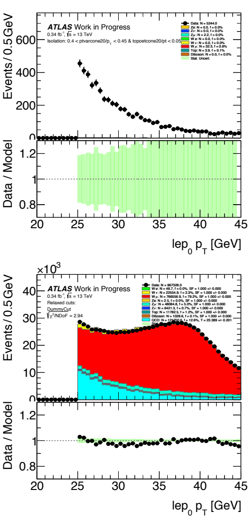
$0.2 \to 0.25$



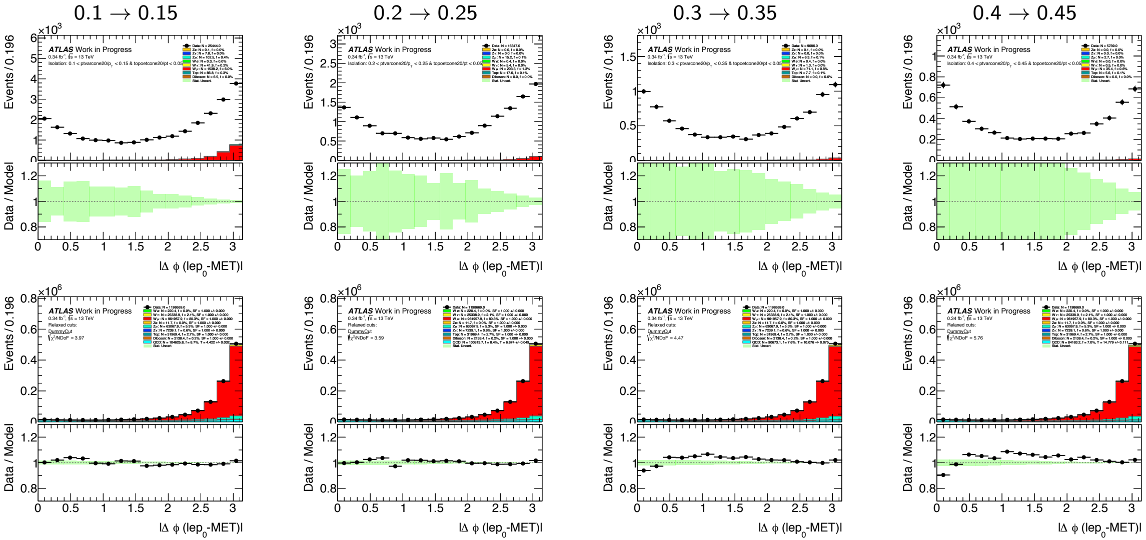
$0.3 \to 0.35$



$0.4 \to 0.45$

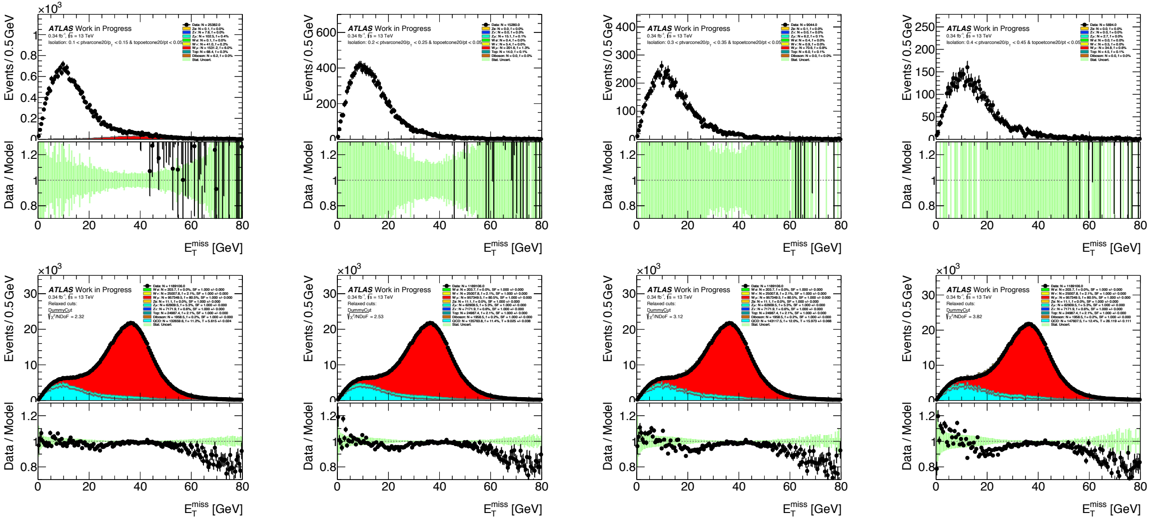


Isolation $ptvarcone20/pt$ slices for $W^- \to \mu^- \nu$: $|\Delta\phi(\ell - MET)|$



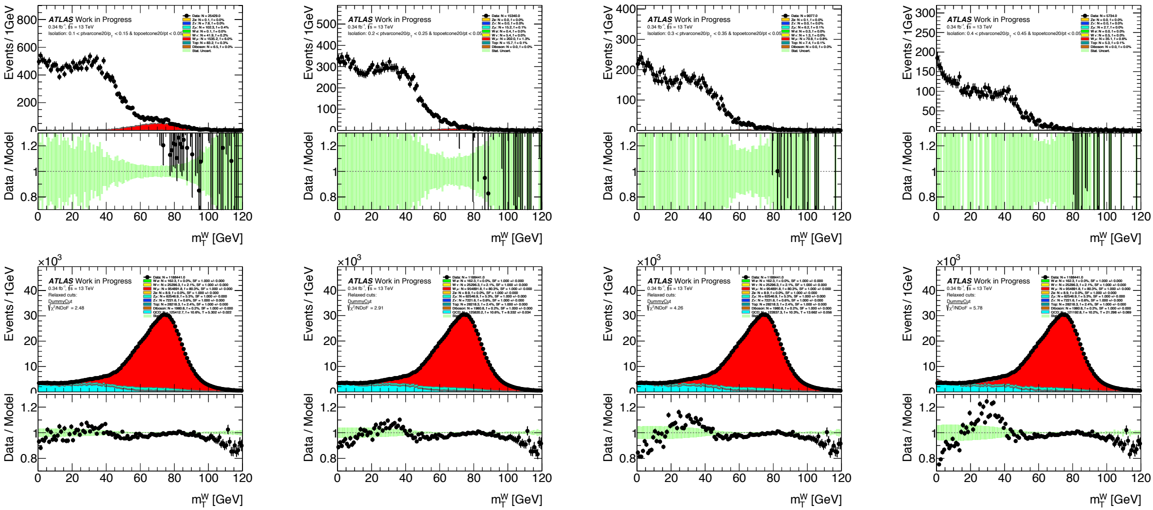
Isolation $ptvarcone20/pt$ slices for $W^- \to \mu^- \nu$: E_T^{miss}

$0.1 \to 0.15$ | $0.2 \to 0.25$ | $0.3 \to 0.35$ | $0.4 \to 0.45$

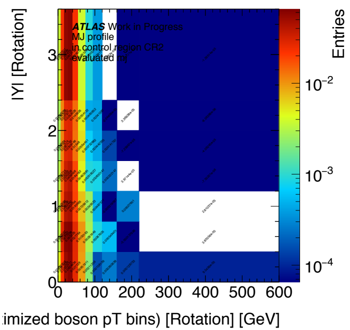


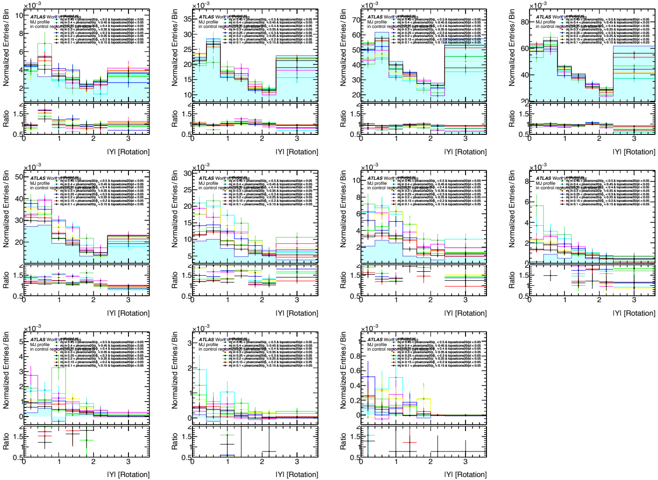
Isolation *ptvarcone20/pt* slices for $W^- \to \mu^- \nu$: m_T^W

$0.1 \to 0.15$	$0.2 \to 0.25$	$0.3 \to 0.35$	$0.4 \to 0.45$



2D MJ estimation: extrapolation and projections on Y axis for $W^- \to \mu^- \nu$





- Some of the bins are negative.
- Set them to 0 with assumption it should not affect overall normalization too much.

MJ summary table

u_T Cut	Slice No.	Iso_{min}	Iso_{max}	N_{FR}^{Data}	N_{FR}^{EW}	N_{CR1}^{Data}	N_{CR1}^{EW}	N_{CR1}^{MJ}	T	α	χ^2	NDoF	$\sqrt{\chi^2/NDoF}$	N_{CR2}^{Data}	N_{CR2}^{EW}	N_{CR2}^{MJ}	N_{SR}^{MJ}
–	0	0.1	0.2	2113364 ± 1454	1202160 ± 364	265157 ± 515	3774 ± 21	261383 ± 515	3.391 ± 0.006	1.021 ± 0.018	2734.47	20	11.69	12408 ± 111	2961 ± 18	9447 ± 113	32034 ± 4522
–	1	0.2	0.3	2113364 ± 1454	1202160 ± 364	150818 ± 388	636 ± 9	150182 ± 388	6.036 ± 0.011	1.004 ± 0.026	2300.96	20	10.73	6506 ± 81	507 ± 8	5999 ± 81	36210 ± 5291
–	2	0.3	0.4	2113364 ± 1454	1202160 ± 364	80303 ± 283	233 ± 5	80070 ± 283	11.757 ± 0.021	0.975 ± 0.015	2400.67	20	10.96	3871 ± 62	185 ± 5	3686 ± 62	43340 ± 8079

Table: Numbers for the electron u_T fits on 13 TeV for 3 $\bar{a}nti$-isolation slices. Numbers in FR are not affected by Slice No. The uncertainty of the numbers of events are statistical only except N_{SR}^{MJ} which is multiplied by $\sqrt{\chi^2/NDoF}$ and the uncertainty of the parameters are from the statistical uncertainty of the fitting.

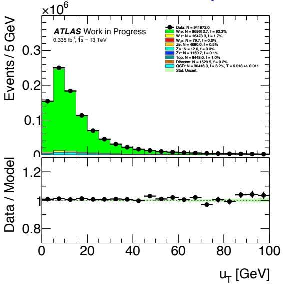
u_T Cut	Slice No.	Iso_{min}	Iso_{max}	N_{FR}^{Data}	N_{FR}^{EW}	N_{CR1}^{Data}	N_{CR1}^{EW}	N_{CR1}^{MJ}	T	α	χ^2	NDoF	$\sqrt{\chi^2/NDoF}$	N_{CR2}^{Data}	N_{CR2}^{EW}	N_{CR2}^{MJ}	N_{SR}^{MJ}
–	0	0.1	0.15	2082663 ± 1443	1177864 ± 358	149341 ± 386	2830 ± 18	146511 ± 387	6.013 ± 0.011	1.023 ± 0.017	142576.13	20	84.43	7278 ± 85	2220 ± 15	5058 ± 87	30416 ± 44240
–	1	0.15	0.2	2082663 ± 1443	1177864 ± 358	115214 ± 339	893 ± 10	114321 ± 340	7.772 ± 0.014	1.018 ± 0.019	134165.04	20	81.90	5074 ± 71	714 ± 9	4360 ± 72	33887 ± 45948
–	2	0.2	0.25	2082663 ± 1443	1177864 ± 358	86638 ± 294	398 ± 7	86240 ± 294	10.424 ± 0.019	1.009 ± 0.025	134660.18	20	82.05	3608 ± 60	323 ± 6	3285 ± 60	34245 ± 51886
–	3	0.25	0.3	2082663 ± 1443	1177864 ± 358	63872 ± 253	222 ± 5	63650 ± 253	14.335 ± 0.026	0.998 ± 0.019	130496.30	20	80.78	2872 ± 54	177 ± 5	2695 ± 54	38635 ± 62523
–	4	0.3	0.35	2082663 ± 1443	1177864 ± 358	46548 ± 216	133 ± 4	46415 ± 216	19.968 ± 0.035	0.985 ± 0.015	130182.41	20	80.68	2138 ± 46	107 ± 3	2031 ± 46	40560 ± 74903
–	5	0.35	0.4	2082663 ± 1443	1177864 ± 358	33553 ± 183	93 ± 4	33460 ± 183	28.564 ± 0.050	0.961 ± 0.016	132431.96	20	81.37	1717 ± 41	74 ± 3	1643 ± 42	46923 ± 96810
–	6	0.4	0.45	2082663 ± 1443	1177864 ± 358	24168 ± 155	58 ± 2	24110 ± 155	39.982 ± 0.070	0.952 ± 0.016	135352.85	20	82.27	1289 ± 36	48 ± 2	1241 ± 36	49602 ± 118539
–	7	0.45	0.5	2082663 ± 1443	1177864 ± 358	17306 ± 132	45 ± 3	17261 ± 132	56.772 ± 0.099	0.940 ± 0.016	129257.61	20	80.39	944 ± 31	36 ± 2	908 ± 31	51573 ± 140835

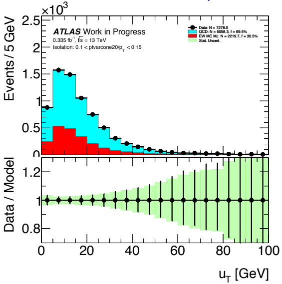
Table: Numbers for the electron u_T fits on 13 TeV for 8 $\bar{a}nti$-isolation slices. Numbers in FR are not affected by Slice No. The uncertainty of the numbers of events are statistical only except N_{SR}^{MJ} which is multiplied by $\sqrt{\chi^2/NDoF}$ and the uncertainty of the parameters are from the statistical uncertainty of the fitting.

Details on MJ: u_T $\bar{iso}$-slice #0 ($0.1 < ptvarcone20/p_T < 0.15$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50GeV$
- $E_T^{miss,reco} > 25GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



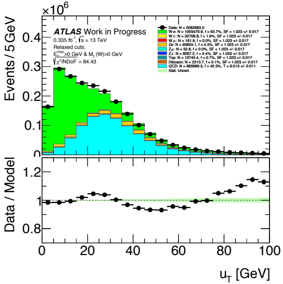


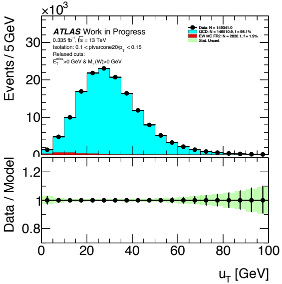
CR2

- $m_T^{reco} > 50GeV$
- $E_T^{miss,reco} > 25GeV$
- $0.1 < ptvarcone20/p_T < 0.15$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0GeV$
- $E_T^{miss,reco} > 0GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





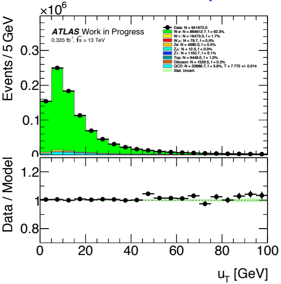
CR1

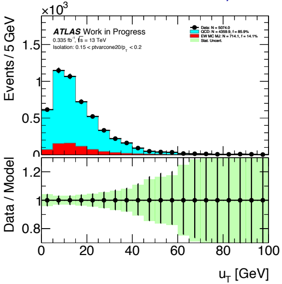
- $m_T^{reco} > 0GeV$
- $E_T^{miss,reco} > 0GeV$
- $0.1 < ptvarcone20/p_T < 0.15$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #1 ($0.15 < ptvarcone20/p_T < 0.2$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



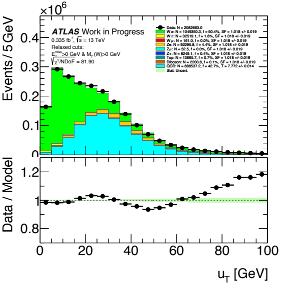


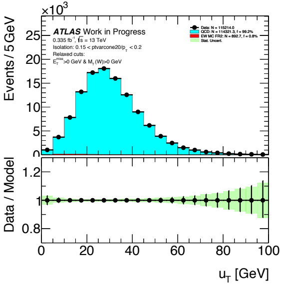
CR2

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $0.15 < ptvarcone20/p_T < 0.2$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





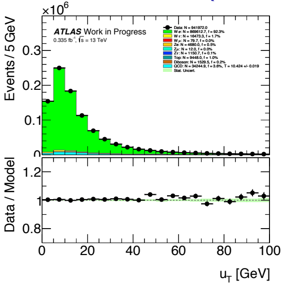
CR1

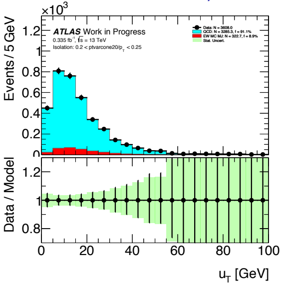
- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $0.15 < ptvarcone20/p_T < 0.2$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #2 ($0.2 < ptvarcone20/p_T < 0.25$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



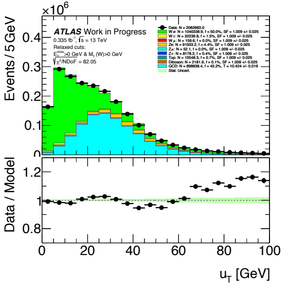


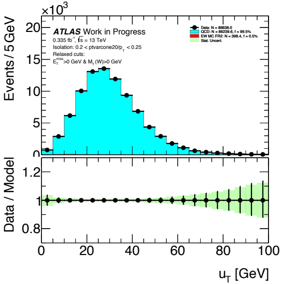
CR2

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $0.2 < ptvarcone20/p_T < 0.25$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





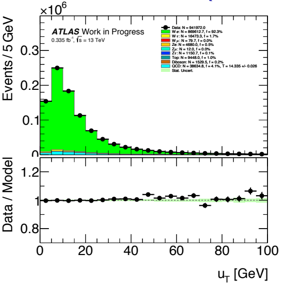
CR1

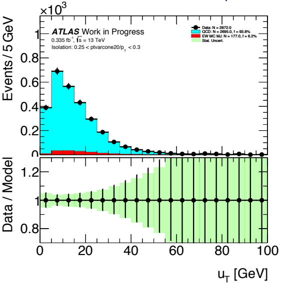
- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $0.2 < ptvarcone20/p_T < 0.25$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #3 ($0.25 < ptvarcone20/p_T < 0.3$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



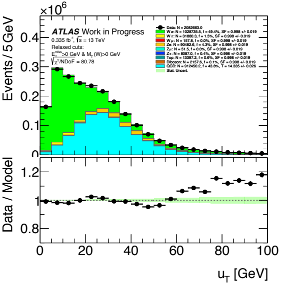


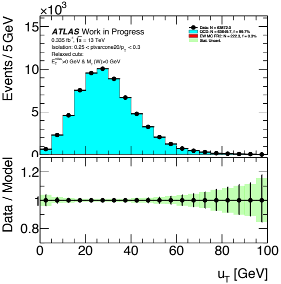
CR2

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $0.25 < ptvarcone20/p_T < 0.3$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





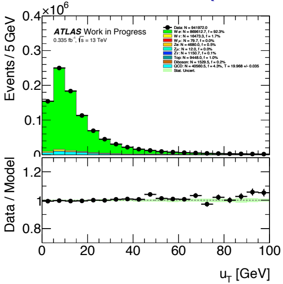
CR1

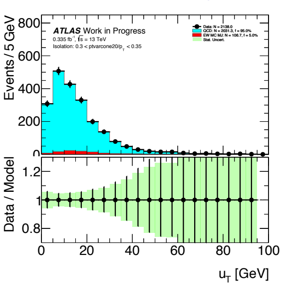
- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $0.25 < ptvarcone20/p_T < 0.3$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #4 ($0.3 < ptvarcone20/p_T < 0.35$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50GeV$
- $E_T^{miss,reco} > 25GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



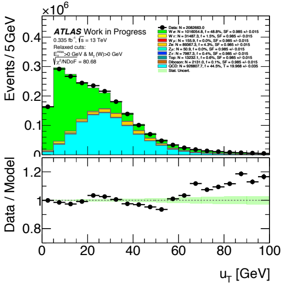


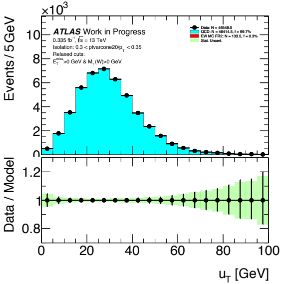
CR2

- $m_T^{reco} > 50GeV$
- $E_T^{miss,reco} > 25GeV$
- $0.3 < ptvarcone20/p_T < 0.35$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0GeV$
- $E_T^{miss,reco} > 0GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





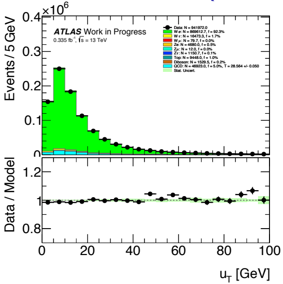
CR1

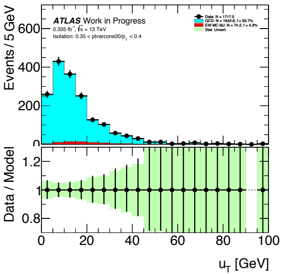
- $m_T^{reco} > 0GeV$
- $E_T^{miss,reco} > 0GeV$
- $0.3 < ptvarcone20/p_T < 0.35$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #5 ($0.35 < ptvarcone20/p_T < 0.4$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50GeV$
- $E_T^{miss,reco} > 25GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



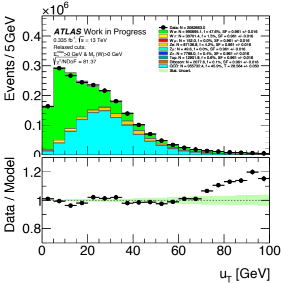


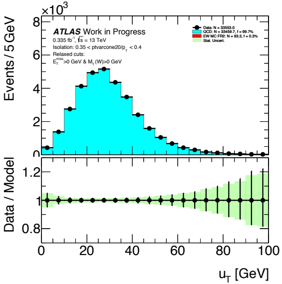
CR2

- $m_T^{reco} > 50GeV$
- $E_T^{miss,reco} > 25GeV$
- $0.35 < ptvarcone20/p_T < 0.4$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0GeV$
- $E_T^{miss,reco} > 0GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





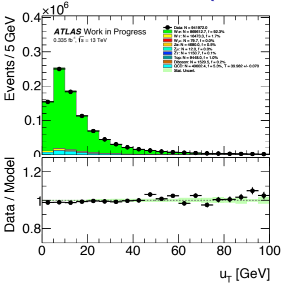
CR1

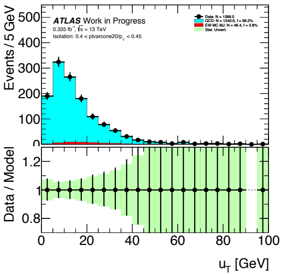
- $m_T^{reco} > 0GeV$
- $E_T^{miss,reco} > 0GeV$
- $0.35 < ptvarcone20/p_T < 0.4$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #6 ($0.4 < ptvarcone20/p_T < 0.45$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



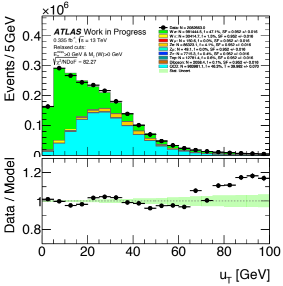


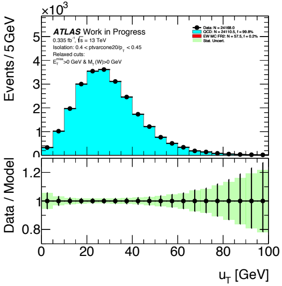
CR2

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $0.4 < ptvarcone20/p_T < 0.45$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





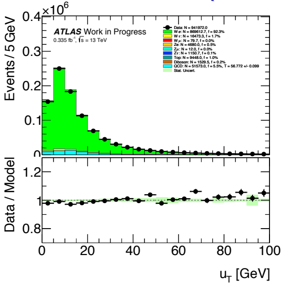
CR1

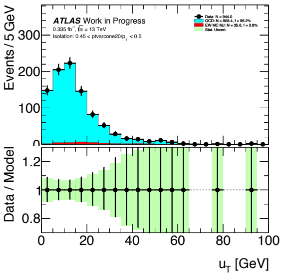
- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $0.4 < ptvarcone20/p_T < 0.45$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #7 ($0.45 < ptvarcone20/p_T < 0.5$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



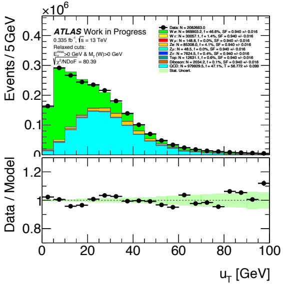


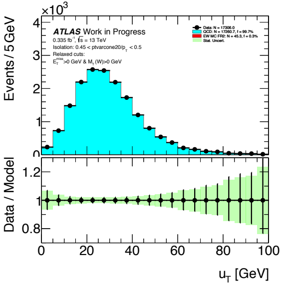
CR2

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $0.45 < ptvarcone20/p_T < 0.5$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





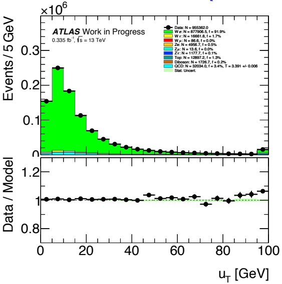
CR1

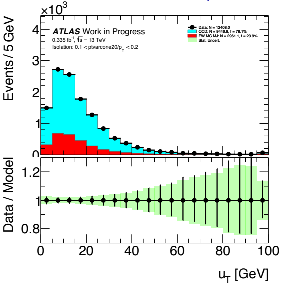
- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $0.45 < ptvarcone20/p_T < 0.5$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #0 ($0.1 < ptvarcone20/p_T < 0.2$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



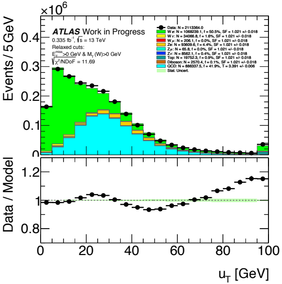


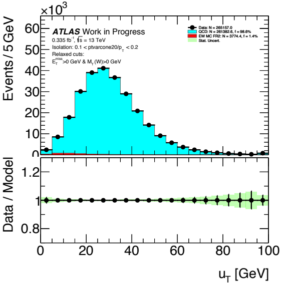
CR2

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $0.1 < ptvarcone20/p_T < 0.2$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





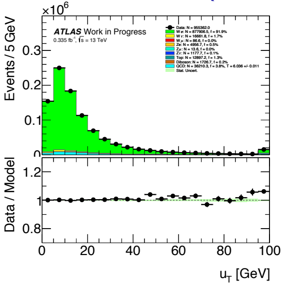
CR1

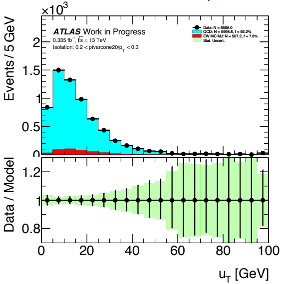
- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $0.1 < ptvarcone20/p_T < 0.2$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\overline{iso}$-slice #1 $(0.2 < ptvarcone20/p_T < 0.3)$

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



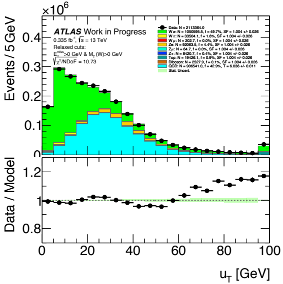


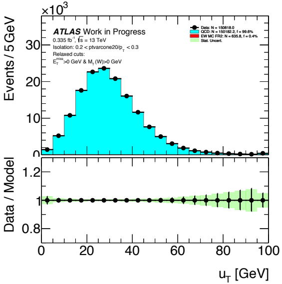
CR2

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $0.2 < ptvarcone20/p_T < 0.3$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





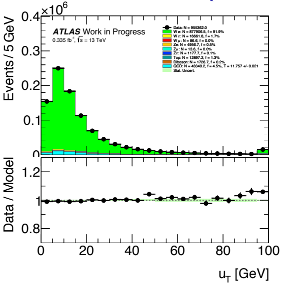
CR1

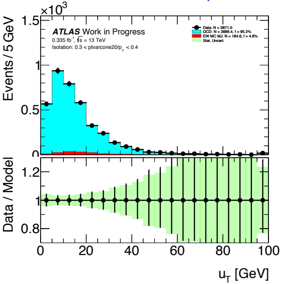
- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $0.2 < ptvarcone20/p_T < 0.3$
- No cut $topoetcone/p_T$

Details on MJ: u_T $\bar{iso}$-slice #2 ($0.3 < ptvarcone20/p_T < 0.4$)

SR with MJ^{CR2}_{shape}

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$



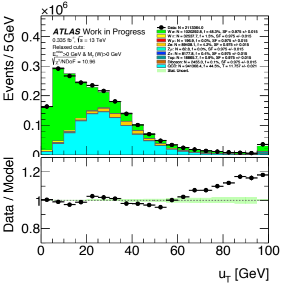


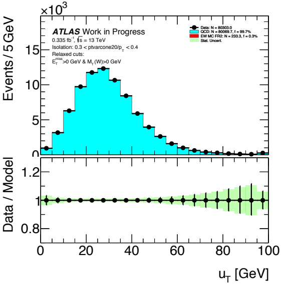
CR2

- $m_T^{reco} > 50 GeV$
- $E_T^{miss,reco} > 25 GeV$
- $0.3 < ptvarcone20/p_T < 0.4$
- No cut $topoetcone/p_T$

FR with MJ^{CR1}_{shape}

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $ptvarcone20/p_T < 0.1$
- No cut $topoetcone/p_T$





CR1

- $m_T^{reco} > 0 GeV$
- $E_T^{miss,reco} > 0 GeV$
- $0.3 < ptvarcone20/p_T < 0.4$
- No cut $topoetcone/p_T$