With low <mu> data

The d0 for lepton (non)-universality in W decays in ATLAS

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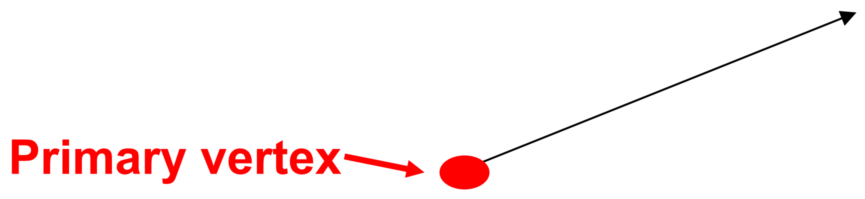
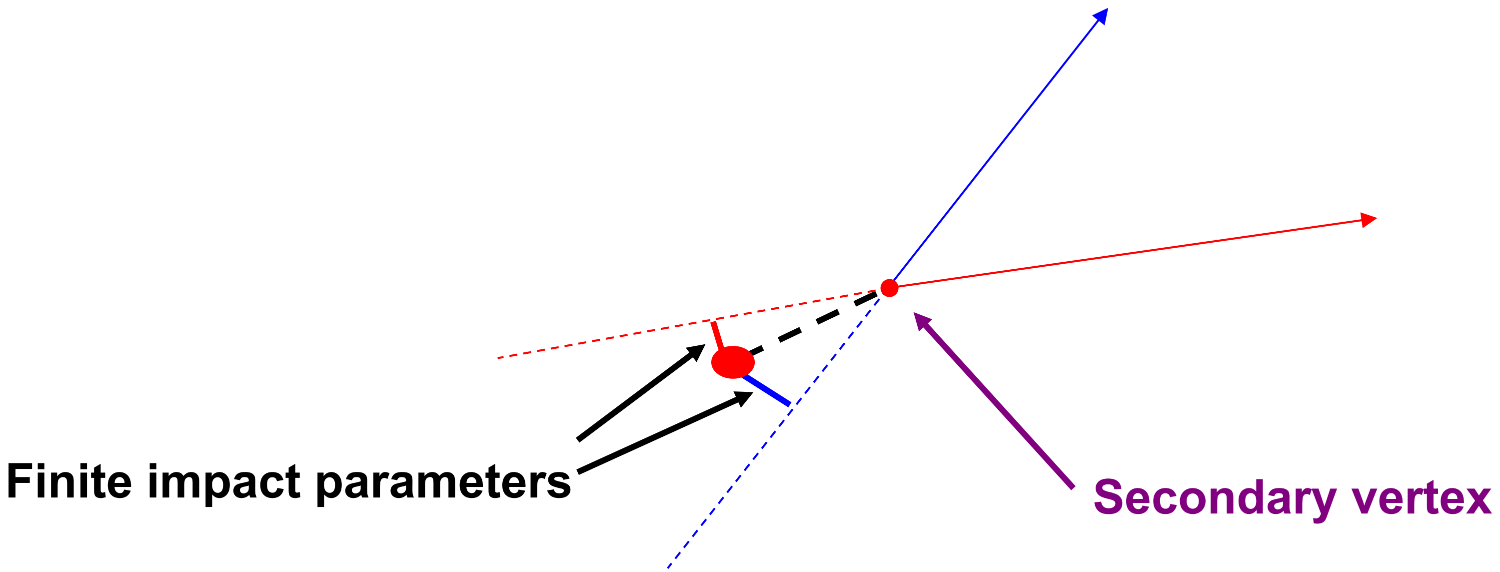
Impact Parameter Measurement: d0

- Stable particles: zero impact parameter:

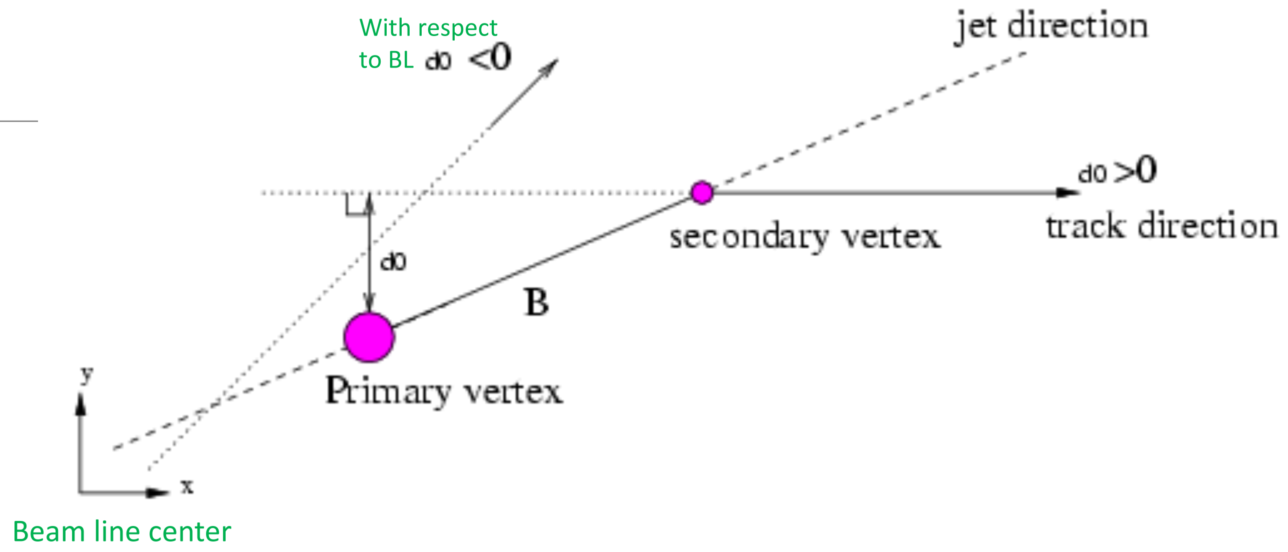


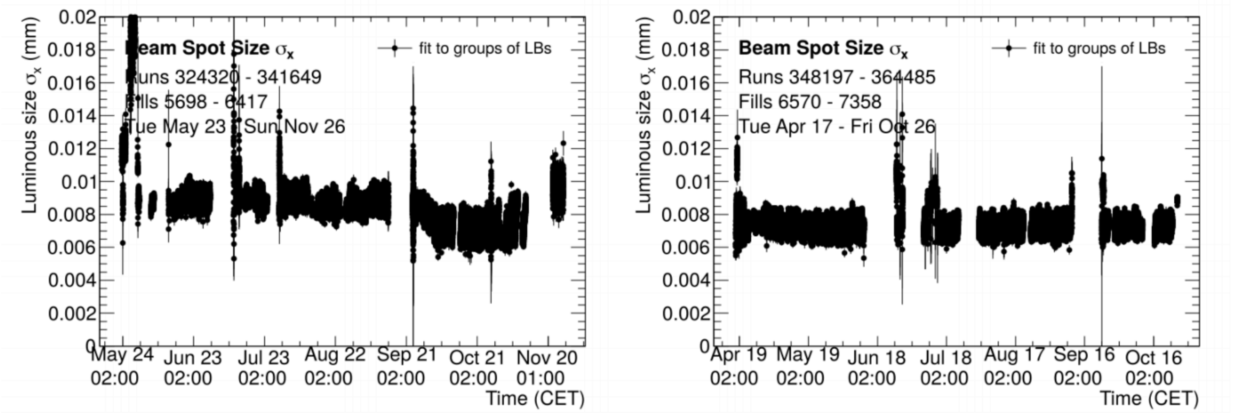
- Short-lived particles: Decay products have non zero impact parameter:



The d0: Beam line

- The d0 with respect to what?
- ATLAS global geometrical frame
  - Could be different from LHC Beam Line
- Beam spot position:
  - Beam spot position is very well known
  - Default in the ATLAS software
  - Gives global reference frame for which it can be defined for any vertex, and for events without any primary vertex



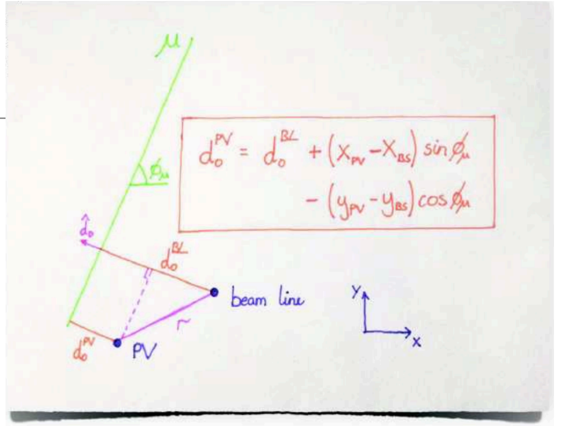


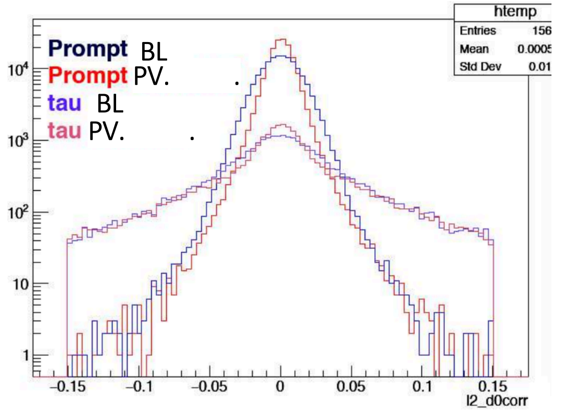
(c) Data 2017 Provided by LHC (d) Data 2018

Figure 14: The width of the beamspot in the x-direction across time for the different years. Note that most of the data comes from the latter years and the latter part of 2016.

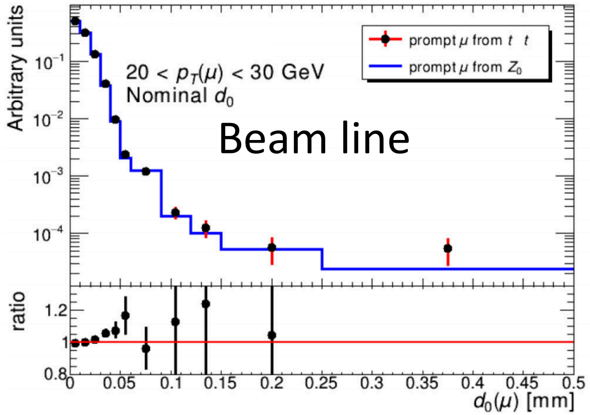
The d0: Primary vertex

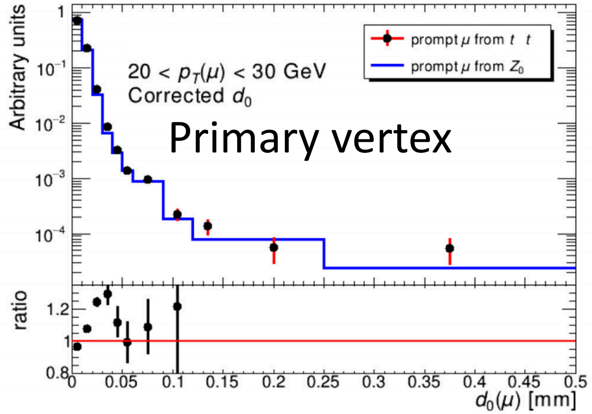
- The width of the beam in the x, y plane is not negligible and therefore it could be advantageous to correct the d0 value for the position of the primary vertex.
- Significant improvement in the resolution of prompt probe muons:
  - d0 resolution depends on the PV resolution of the event – as it is then a convolution of the muon track resolution and the PV resolution;
  - the PV position is biased by the muon track itself as the PV position is a weighted fit of all the tracks (and the beam-spot position).
- There can be a bias between the Z events used to calibrate d0 and the signal events due to the difference in the PV resolution and the difference in bias of the PV position due to the probe muon track.
- There is always another high pT muon in ZR while in the tt sample there are b-tagged jets and another high pT lepton - vertex resolution will be different.
  - The fractional contribution, and hence directional pull, of the probe track will also be different
- These cause an issue as the calibration of d0 relies on closure between Z and tt





- **Larger smearing effect from the beam spot size in the Monte Carlo then in the data:**
  - In the data σx ~ σy ~ 7 μm
  - MC16a/d/e σx = σy = 10 μm and σz = 42 mm





Primary vertex algorithms: Run1 and 2

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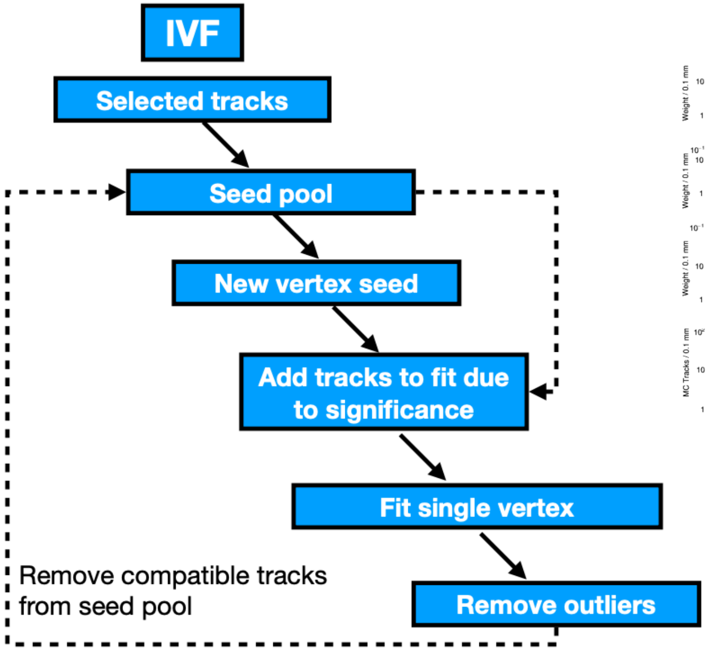
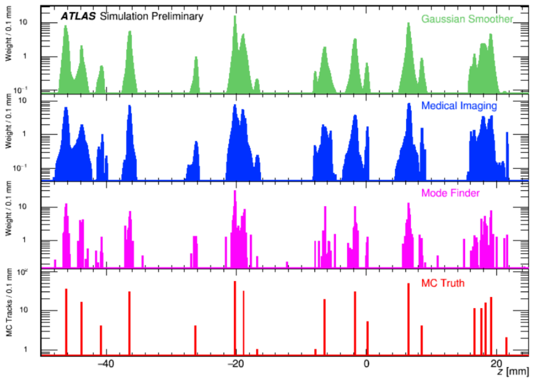
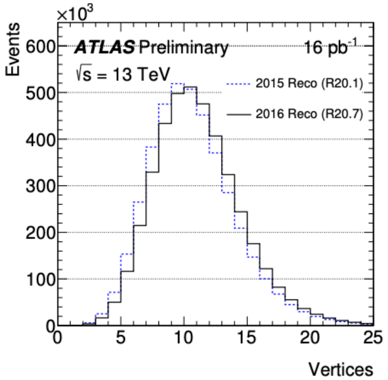
arxiv.org/1611.10235

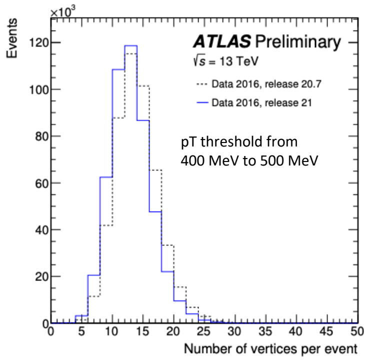
Iterative Vertex Reconstruction(IVF)







Fix for of low-multiplicity pile-up vertices



- Input:
  - Beam spot location and size
  - subset of reconstructed tracks passing a quality selection designed to remove poorly-measured and fake tracks
  - Uses signed radial and longitudinal impact parameters of reconstructed tracks, d0 and z0 respectively, measured from the center of the beam spot
- Seed-finding:
  - Based on “Fraction of Sample Mode with Weights”
  - recursively scans a weighted histogram of z0 to estimate the point of maximum track density along the beam axis
- Track to seed assignment:
  - After a seed is found, the set of nearby tracks to fit is chosen based on impact parameter significance

$$12\sqrt{\sigma^2(d_0)+\sigma^2(z_0)}$$

- Fitting
  - fit using an adaptive Kalman filter
  - Outliers are progressively de-weighted using a deterministic annealing schedule and the weight function
- Acceptance/rejection
  - The new vertex candidate is accepted if the number of degrees of freedom (accounting for final track weights) is greater than three and at least two tracks used in the fit have weights greater than 0.01

Primary vertex algorithms: Run3

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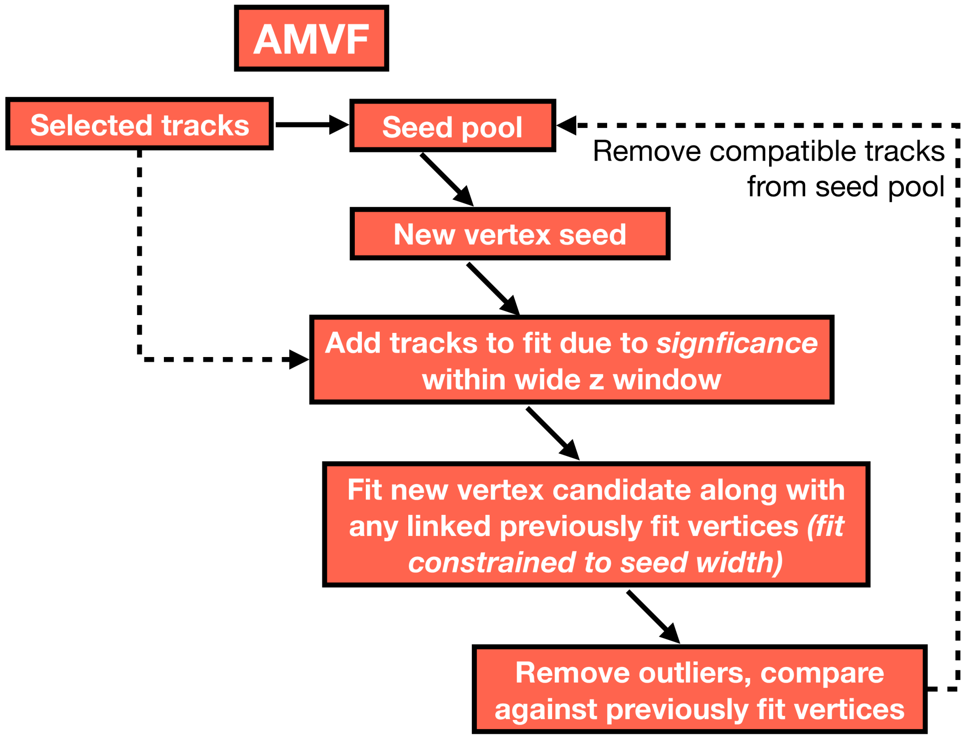
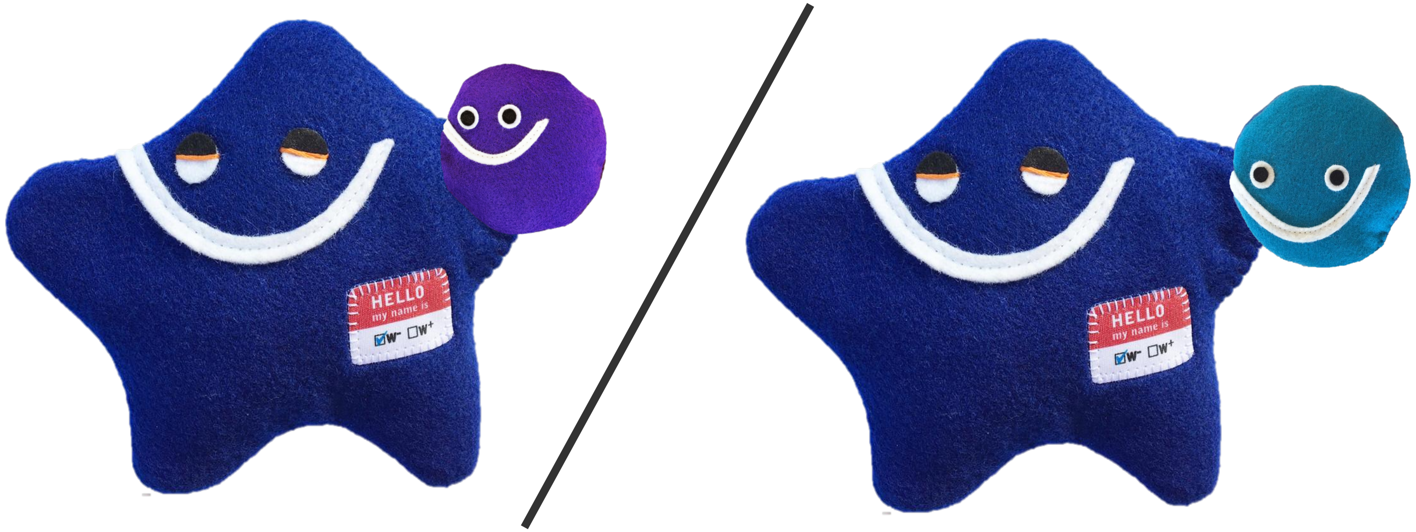
Adaptive Multi-Vertex Fitter (AMVF)



- The idea: extend deterministic annealing to allow tracks to have weights with multiple vertices simultaneously
- As each new seed vertex is added, refit all previously found vertices that are linked to it (directly or indirectly) by shared tracks
- Very loose track/vertex assignment cuts
  - ± 5 mm (!) in original (Run-1) version
  - The fitter is supposed to decide which tracks belong with which vertices
  - For stability of weights, tracks given notional 3 σ compatibility with “unassigned”.



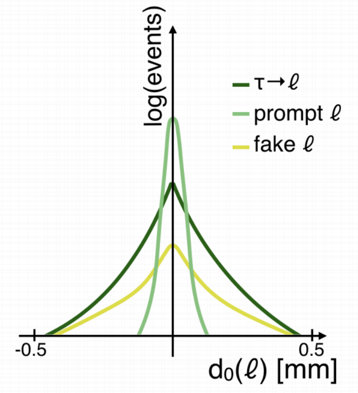
Thanks for attention!

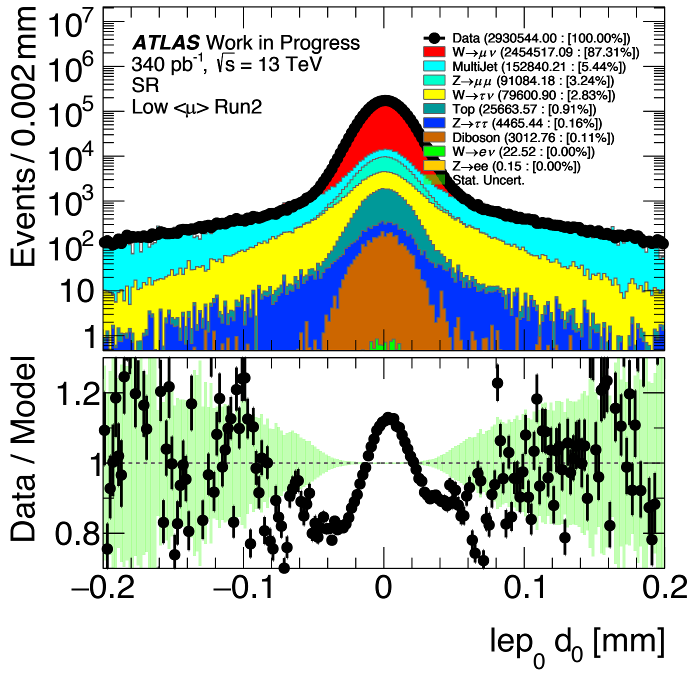
BackUp

- Life time: τ = 0.1 - 2 ps.
- Popper range: $C\tau$ = 30 - 600 µm.
- Range in laboratory:
  - $\gamma C\tau$ = 0.3 mm - 6 mm (for a 80 GeV W meson).
- Decay occurs in the beam pipe (a diameter of few cm).

The d0: Introduction

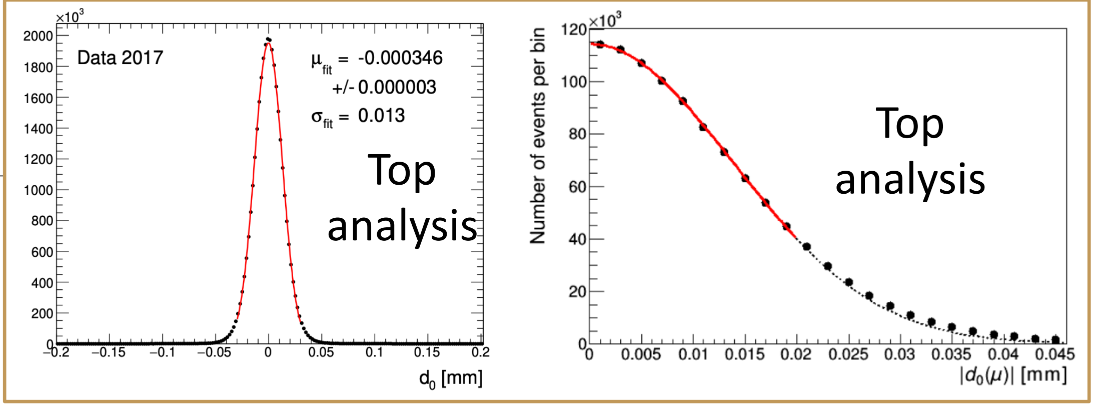
- We define 3 types of tau decays
  - **prompt** (W) leptons are leptons produced in $W \to l\nu$ decays
  - **tau** are leptons produced in the leptonic decay chain $W \to \tau\nu \to l\nu$
  - **prompt** (non W) are leptons from Z^0 or other EWK process where these leptons do not originate from W decays: for example di-boson, single top or $t\bar{t}$ process.
  - **fake** are reconstructed leptons from all other sources, including wrongly identified leptons.
- Use d0 definition with respect to Beam Line
- Bias and mismatching Data/MC for d0 resolution:
  - Needs to be fixed, and validated (next slides)
- No d0 and/or z_0 cuts been applied
  - For now we have tot of bad reconstructed vertexes and cosmic background
  - Will investigate $|z_0 \sin(\text{Theta})|$ cuts
- For now we derive and apply d0 corrections for prompt and tau decays separately
  - Needs to take life-time into account
- Performed as a function of pT and eta bins:
  - 27 kinematic bins in total for prompt → use ZR as control region
  - 8 kinematic bins in total for tau → use ZttR as control region
- Assume that core d0 distribution is a Gaussian
  - The d0 tails has non-Gaussian nature!

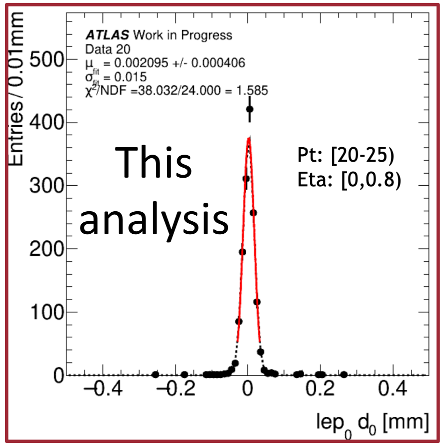




The d0: corrections

- Strategy
  - Take clean ZR region for prompt leptons
    - Slice to 27 kinematic bins in total
    - Derive bias corrections →
      - apply directly to the Data SR
    - Derive Data/MC resolution corrections →
      - apply to the SR *prompt* MC samples
  - Use ZttR for leptons originated from tau decays
    - Slice to 8 kinematic bins in total
    - Derive Data/MC resolution corrections →
      - apply to the SR *tau* MC samples
  - Resolution corrections on per-event basis:





$$n_k = n_{p_T} + 9 * n_\eta$$

- 9 p_T^μ bins
  - [20-25), [25-30), [30-35), [35-40), [40,45), [45, 50), [50,65), [65-80), [80- 250)
- 3 η^μ bins
  - [0, 0.8), [0.8, 1.5), [1.5, 2.5)

Chi2/NDF Data	[20-25)	[25-30)	[30-35)	[35-40)	[40,45)	[45, 50)	[50,65)	[65-80)	[80- 250)
[0, 0.8)	1.585	2.482	2.260	3.047	3.190	2.651	2.854	1.021	1.600
[0.8, 1.5)	1.319	2.080	1.843	2.640	3.394	3.026	2.412	1.377	1.603
[1.5, 2.5)	2.420	2.699	1.850	2.207	1.859	2.636	2.970	1.406	1.512

Chi2/NDF MC	[20-25)	[25-30)	[30-35)	[35-40)	[40,45)	[45, 50)	[50,65)	[65-80)	[80- 250)
[0, 0.8)	3.320	5.577	6.957	10.322	8.716	11.193	9.556	2.995	2.667
[0.8, 1.5)	5.281	7.746	6.346	7.552	10.084	12.127	8.823	2.653	2.136
[1.5, 2.5)	7.784	8.228	8.436	10.711	12.133	13.732	12.812	3.167	1.644

$$n_k = n_{p_T} + 4 * n_\eta$$

- 4 p_T^μ bins
  - [20, 25), [25, 35), [35,45), [45, 250)
- 2 η^μ bins
  - [0, 1.0), [1.0, 2.5)
- Correction from Ztt derived from lep_0 (muon) only, and apply to lep_0 only. (lep_1 is electron)

$$F^\ell(d_0) = \sum_{i=0}^{9}\sum_{j=0}^{2}\left(\bar{d}_{0ij}(MC) + (d_0 - \bar{d}_{0ij}(MC)) * \frac{\sigma_{ij}(RD)}{\sigma_{ij}(MC)}\right)$$

where $\bar{d}_{0ij}(MC)$ stands for mean value of d_0 distribution in Monte Carlo

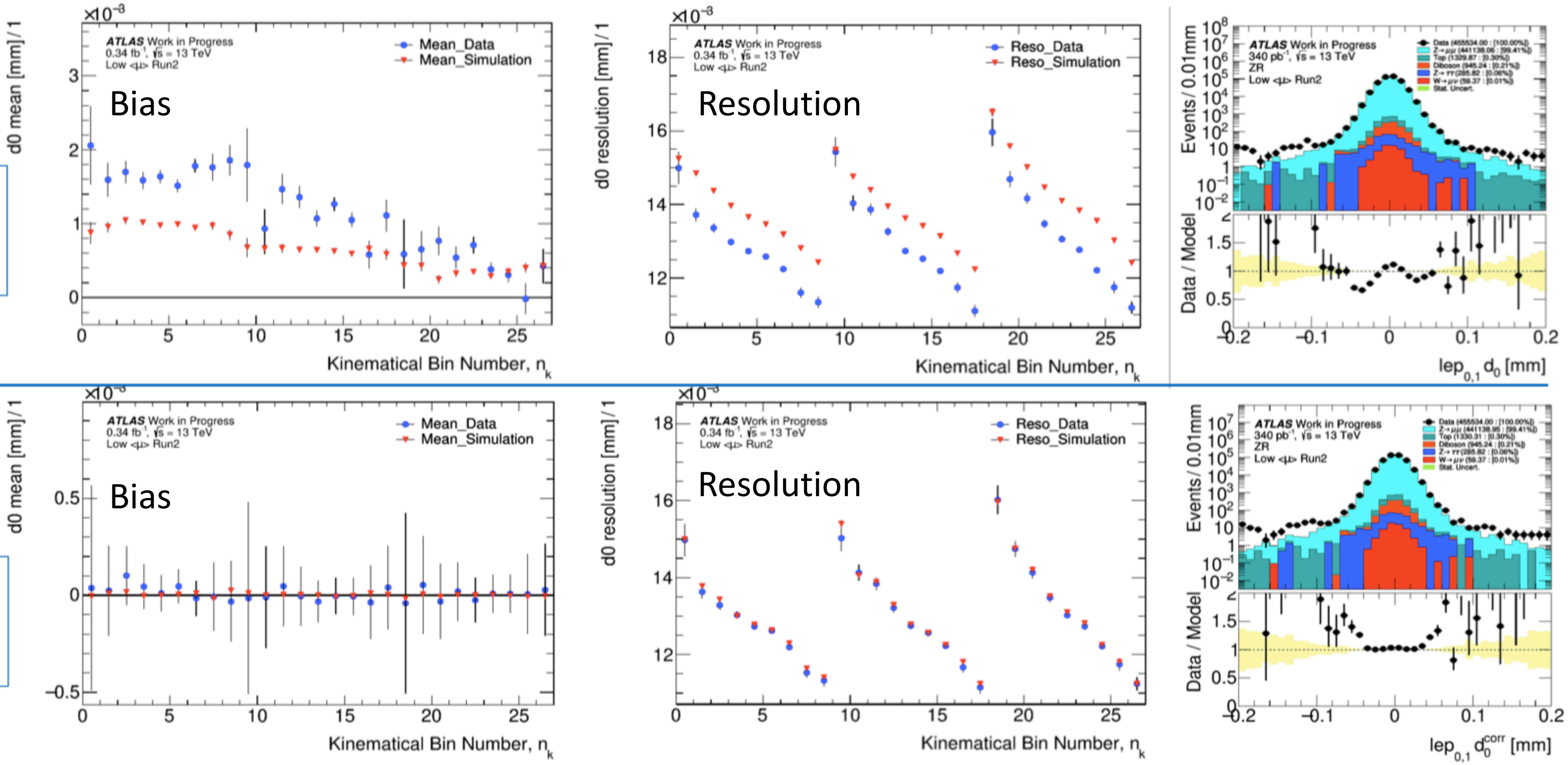
The d0 studies in ZR

$n_k = n_{p_T} + 9 * n_\eta$

- 9 p_T^μ bins
  - [20-25), [25-30), [30-35), [35-40), [40,45), [45, 50), [50,65), [65-80), [80- 250)
- 3 η^μ bins
  - [0, 0.8), [0.8, 1.5), [1.5, 2.5)

before

after



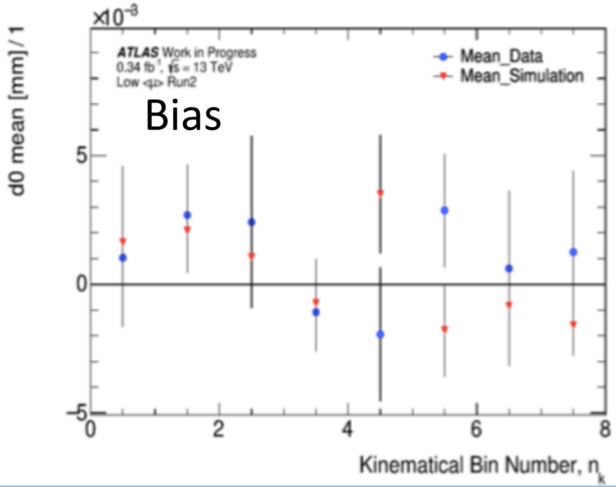
- No d0 and/or z_0 cuts
  - Lot of bad reconstructed vertexes and cosmic background on the tails

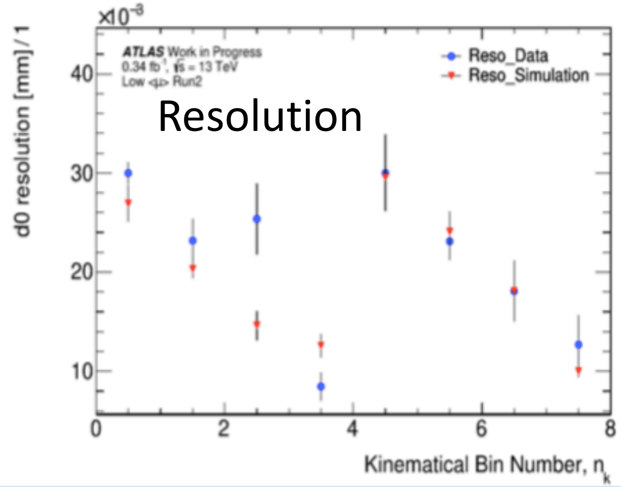
The d0 studies in ZttR

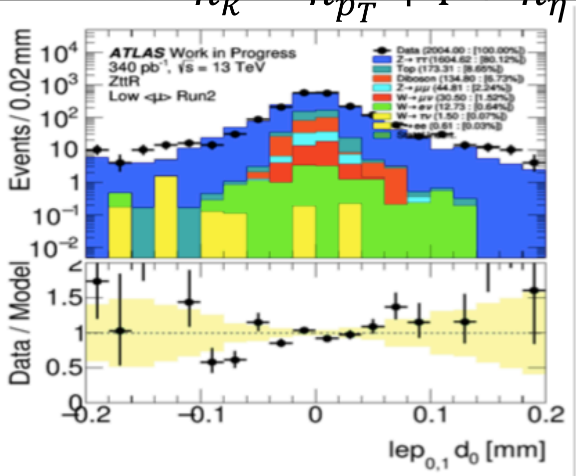
- 4 p_T^{μ} bins
  - [20, 25), [25, 35), [35,45), [45, 250)
- 2 η^{μ} bins
  - [0, 1.0), [1.0, 2.5)
- Correction from Ztt derived from lep_0 (muon) only, and apply to lep_0 only. (lep_1 is electron)

$$n_k = n_{p_T} + 4 * n_{\eta}$$

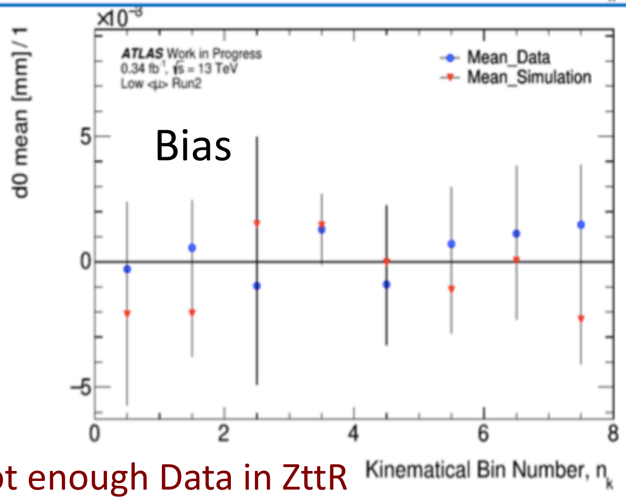
before

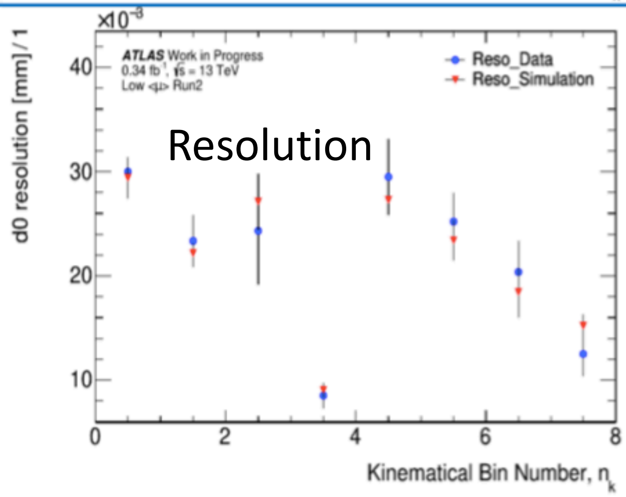


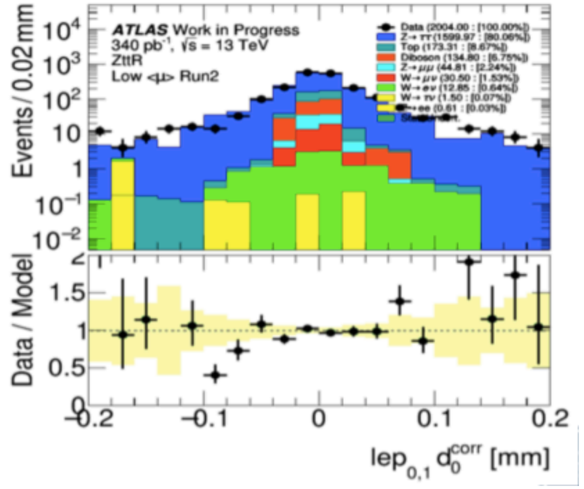




After (Ztt to Ztt)





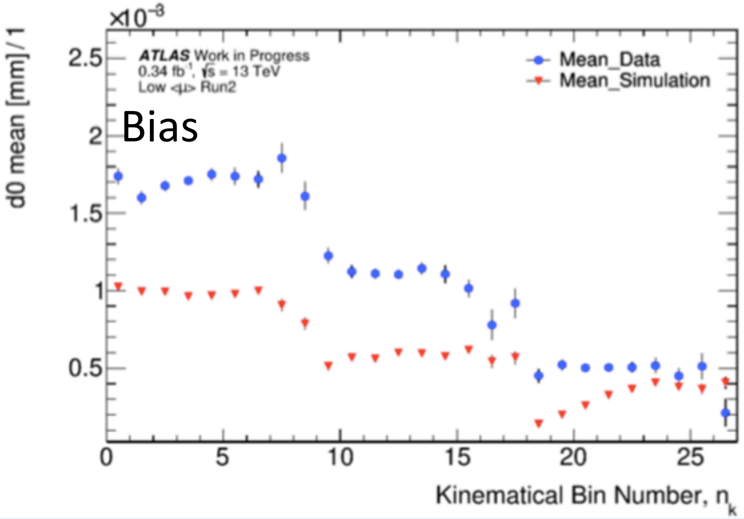


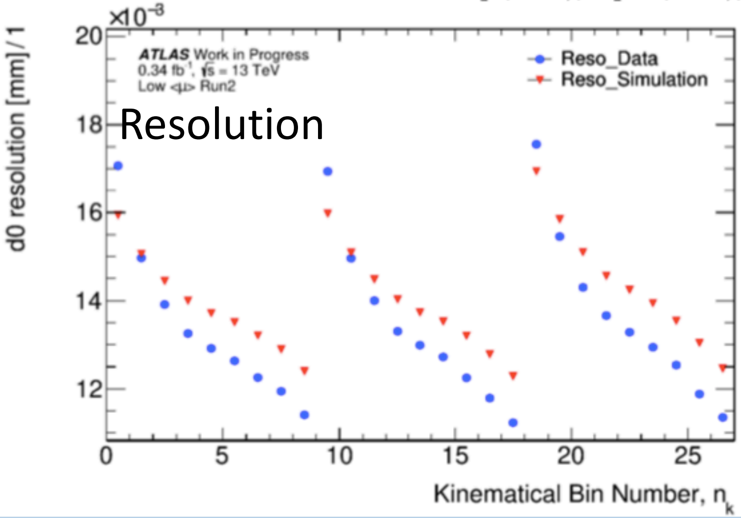
- Not enough Data in ZttR
  - 2k events vs. ~270k in Top analysis for Run2 data
- No d0 and/or z_0 cuts
  - Lot of bad reconstructed vertexes and cosmic background on the tails

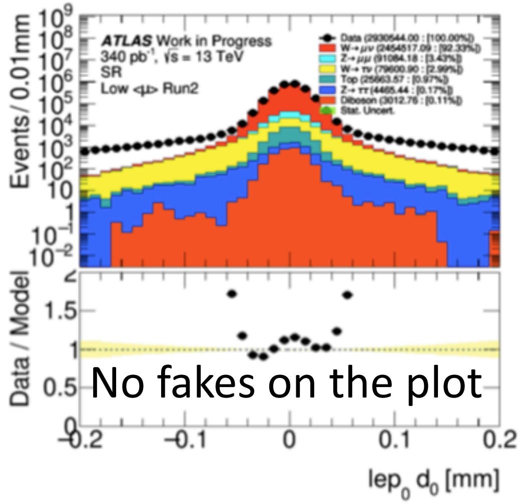
Appling d0 corrections to SR

- 9 p_T^{μ} bins
  - [20-25), [25-30), [30-35), [35-40), [40,45), [45, 50), [50,65), [65-80), [80- 250)
- 3 η^{μ} bins
  - [0, 0.8), [0.8, 1.5), [1.5, 2.5)

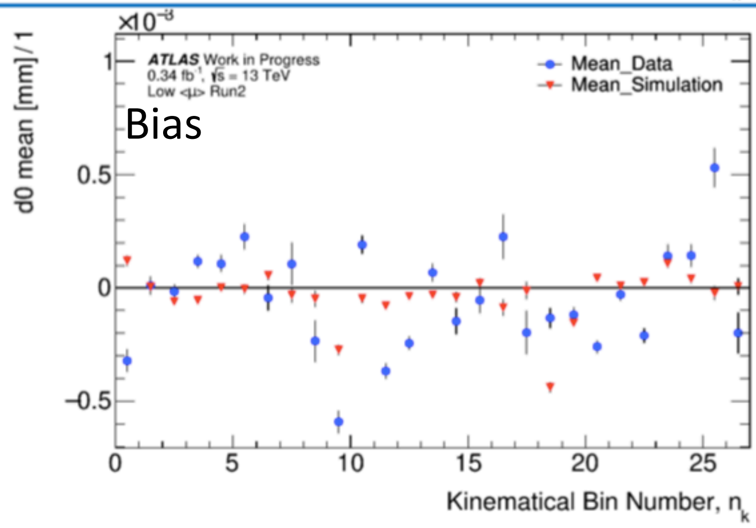
before

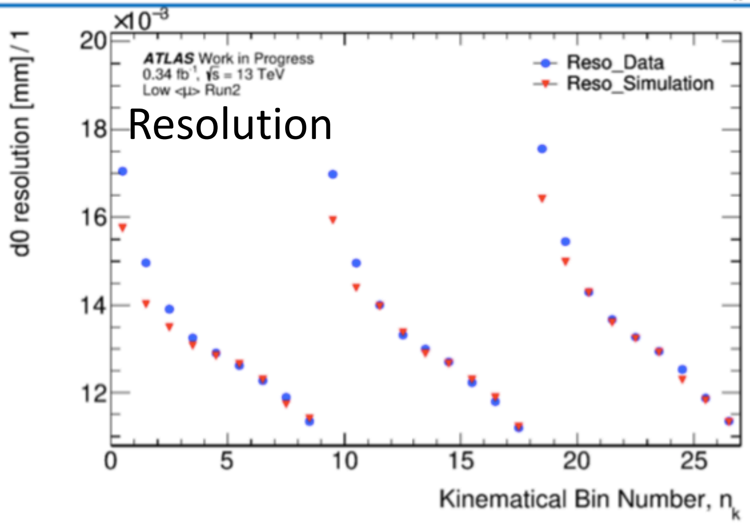


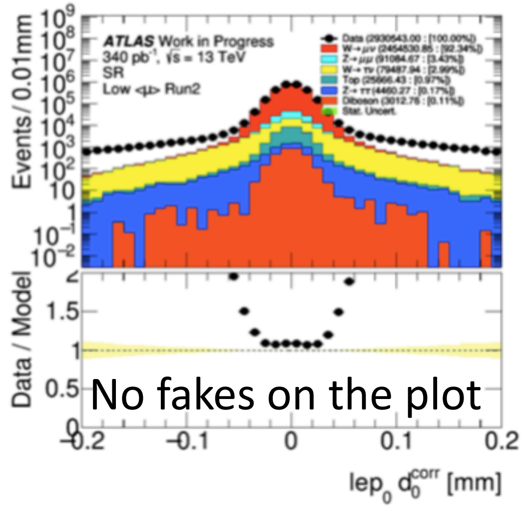




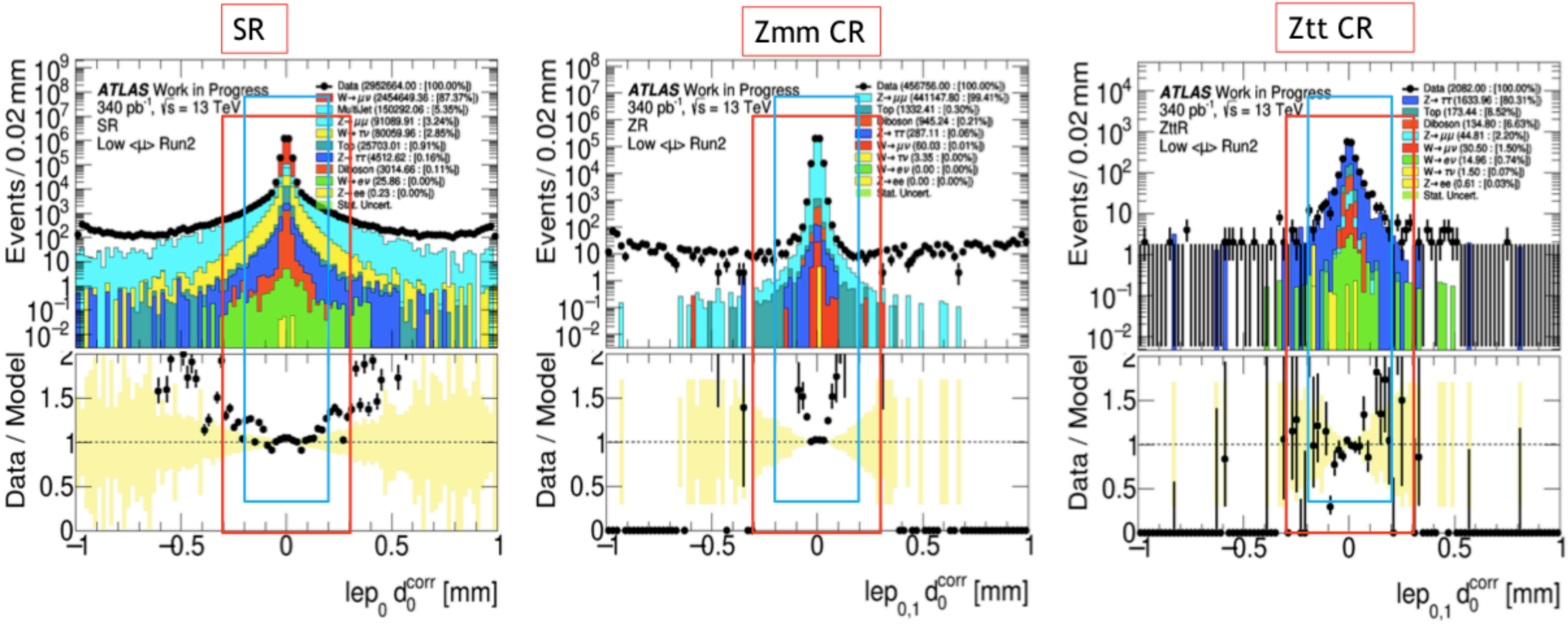
From both Zmm and Ztt







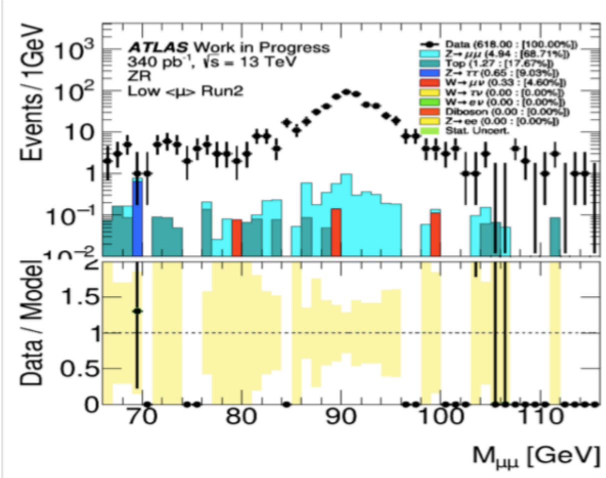
The d0 studies: extended range



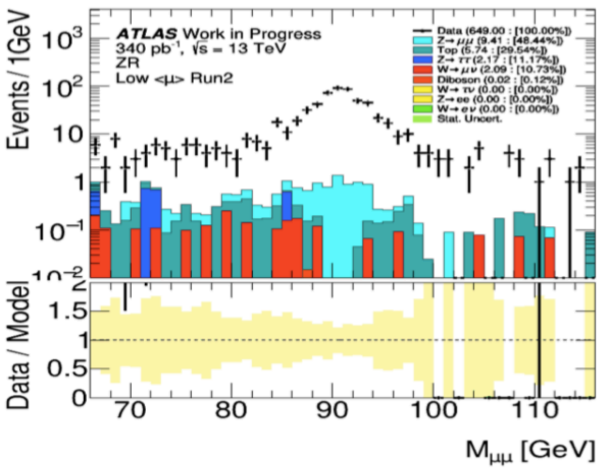
- Correction derived from an approximation of a Gaussian. Only the core where most of the events are, were corrected.
- Not enough MC in region beyond the red box in both Zmm CR and Ztt CR.

The d0 tails in extended range

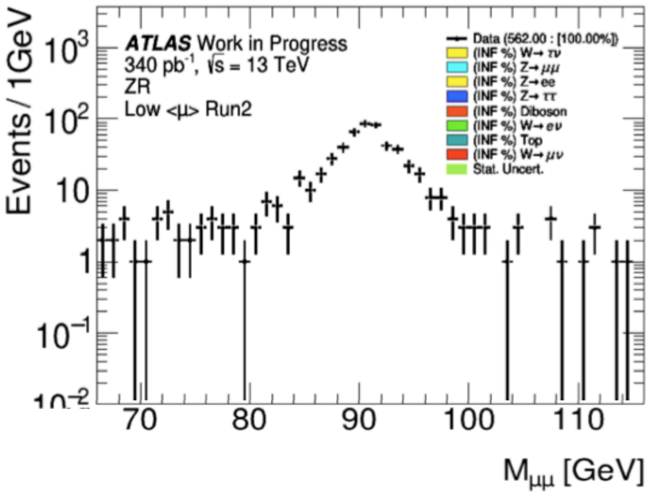
|d0_lep0|>0.2 [mm]



|d0_lep1|>0.2 [mm]

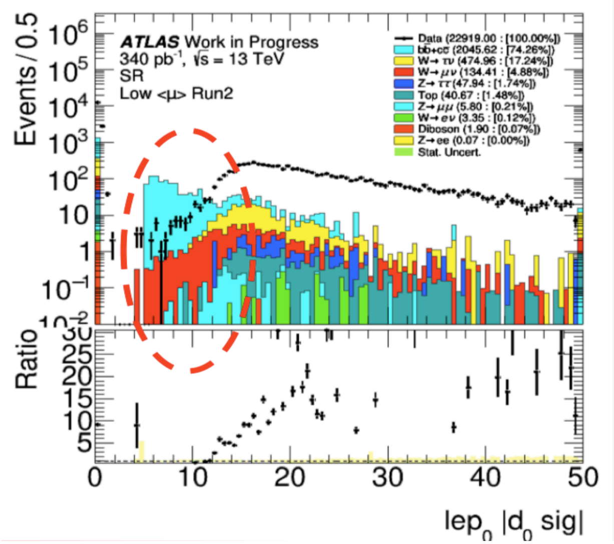


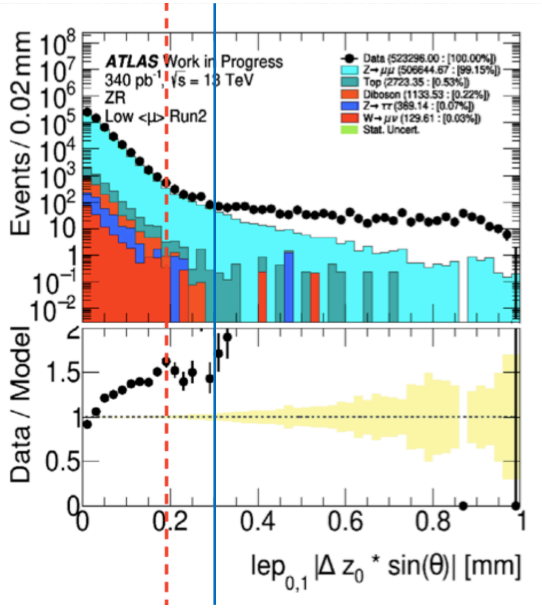
|d0_lep0|>0.2 [mm] && |d0_lep1|>0.2 [mm]



|d0_lep0|>0.2 [mm]

QCD_MC
(DSID's 361250, 361251)



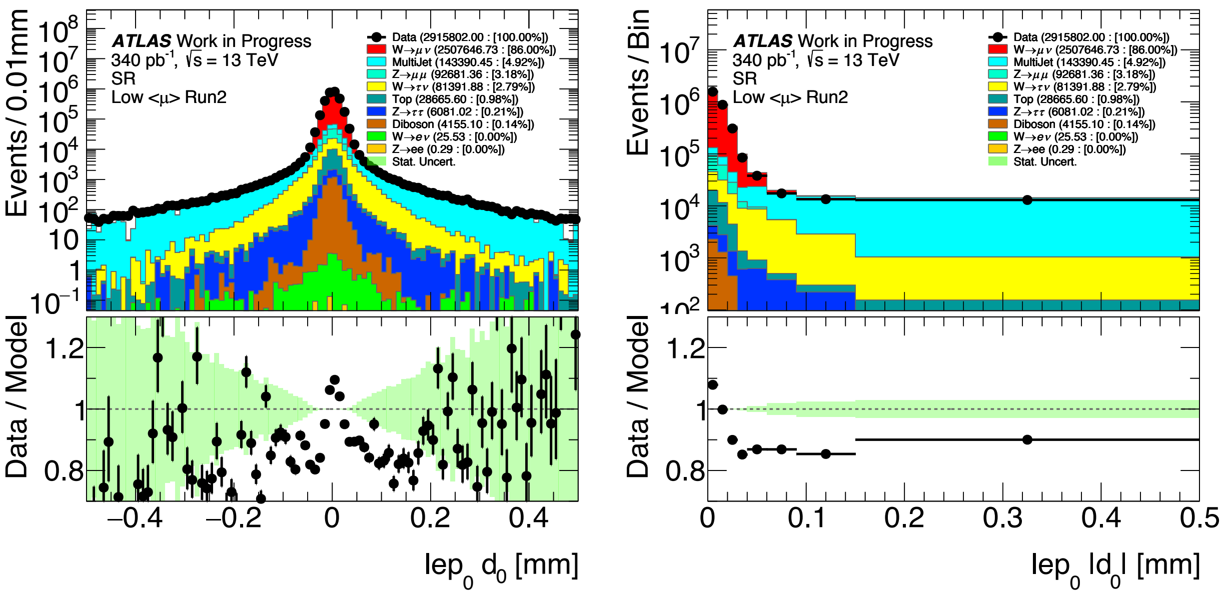


- We see perfect Z peak in the d0 tails in ZR
- For SR we verified that difference comes not from MJ background
- Next steps:
  - investigate cuts |z0sin(theta)| < 0.3 and $|d_0|$<0.5
  - look at the track/vertex fit related variables to see if there is any handle we can use

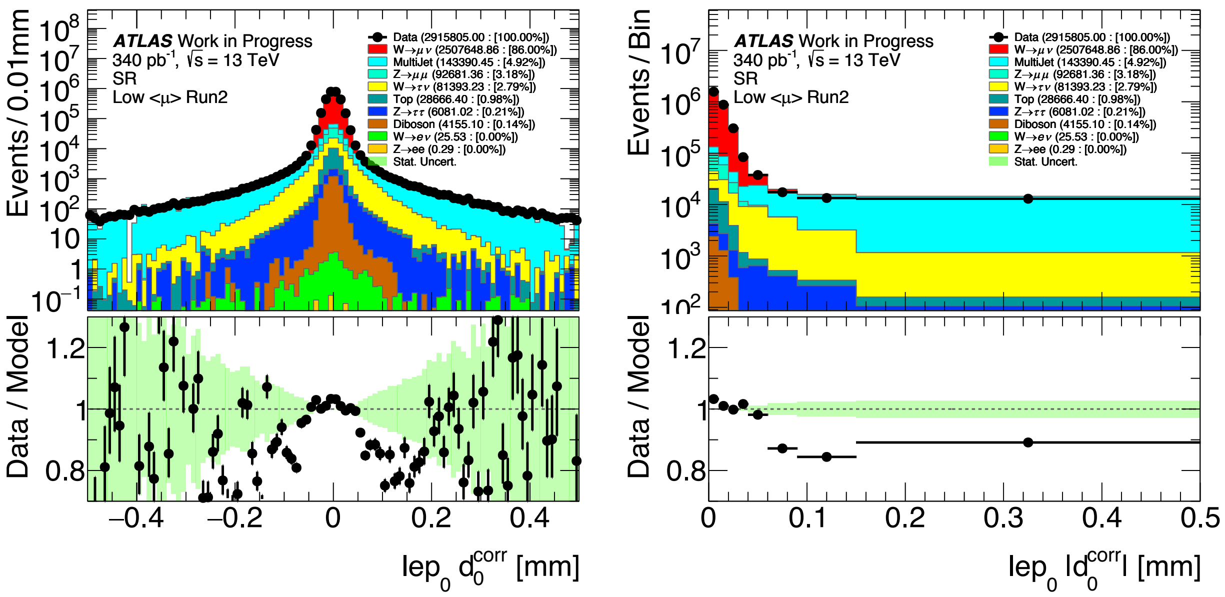
The d0 correction

|lep_0_deltaZ0sinTheta|<0.5 && |lep_0_corrd0|<0.5

Uncorrected



After correction



- Needs to apply d0 resolution corrections from ZR to Wtau and Ztt MC samples
  - For now we use ZttR corrections

Another approach?

- The Top group analysis used template method
- For prompt leptons:
  - Determine shape of |d0| in 27 kinematical bins from data using $Z \to \mu\mu$ selection
    - subtract remaining backgrounds estimated in MC
    - use shapes as prompt muon templates in signal region
    - residual resolution correction from data
  - Systematic uncertainty due to application of |d0| shape from Z boson decays to $t\bar{t}$ signal region
    - estimated by ratio of |d0| between $t\bar{t}$ and $Z \to \mu\mu$
- For leptons produced in tau-lepton decays
  - Use templates from the “tau” MC sources in the SR
  - Apply resolution correction only
  - Check of Impact parameter of τ-decays leptons with $Z \to \tau\tau$ region
- We have small ZttR statistics:
  - 2k events vs. ~270k in Top analysis for Run2 data
  - It would be hard to make validation with ZttR

p_T bin number (n_{p_T})	p_T range (GeV)	p_T bin number (n_{p_T})	p_T range (GeV)
0	5 – 10	6	40 – 50
1	10 – 15	7	50 – 65
2	15 – 20	8	65 – 100
3	20 – 25	9	100 – 250
4	25 – 30	10	> 250
5	30 – 40		

$\|\eta\|$ bin number (n_η)	$\|\eta\|$ range
0	0 – 0.8
1	0.8 – 1.5
2	1.5 – 2.5

$$F^{pr}(d_0) = \sum_{i=0}^{11}\sum_{j=0}^{2} r_{ij}^{pr} F_{ij}^{pr}(d_0)$$

$$\sigma_{ij}^{sm} = \sqrt{\left|\sigma_{ij}^2(RD) - \sigma_{ij}^2(MC)\right|}$$

After random smearing:

$$\delta_{ij}(d_0) = f_{ij}^{sm}(d_0) - f_{ij}^{ns}(d_0).$$

$$\text{If } \sigma_i(RD) > \sigma_i(MC), \quad F_{ij}^{\tau}(d_0) = f_{ij}^{ns}(d_0) + \delta_{ij}(d_0) = f_{ij}^{sm}(d_0).$$

$$\text{If } \sigma_{ij}(RD) < \sigma_{ij}(MC), \quad F_{ij}^{\tau}(d_0) = f_{ij}^{ns}(d_0) - \delta_{ij}(d_0)$$

$$F^{\tau}(d_0) = \sum_{i=0}^{11}\sum_{j=0}^{2} r_{ij}^{\tau} F_{ij}^{\tau}(d_0).$$