Fake Lepton Backgrounds

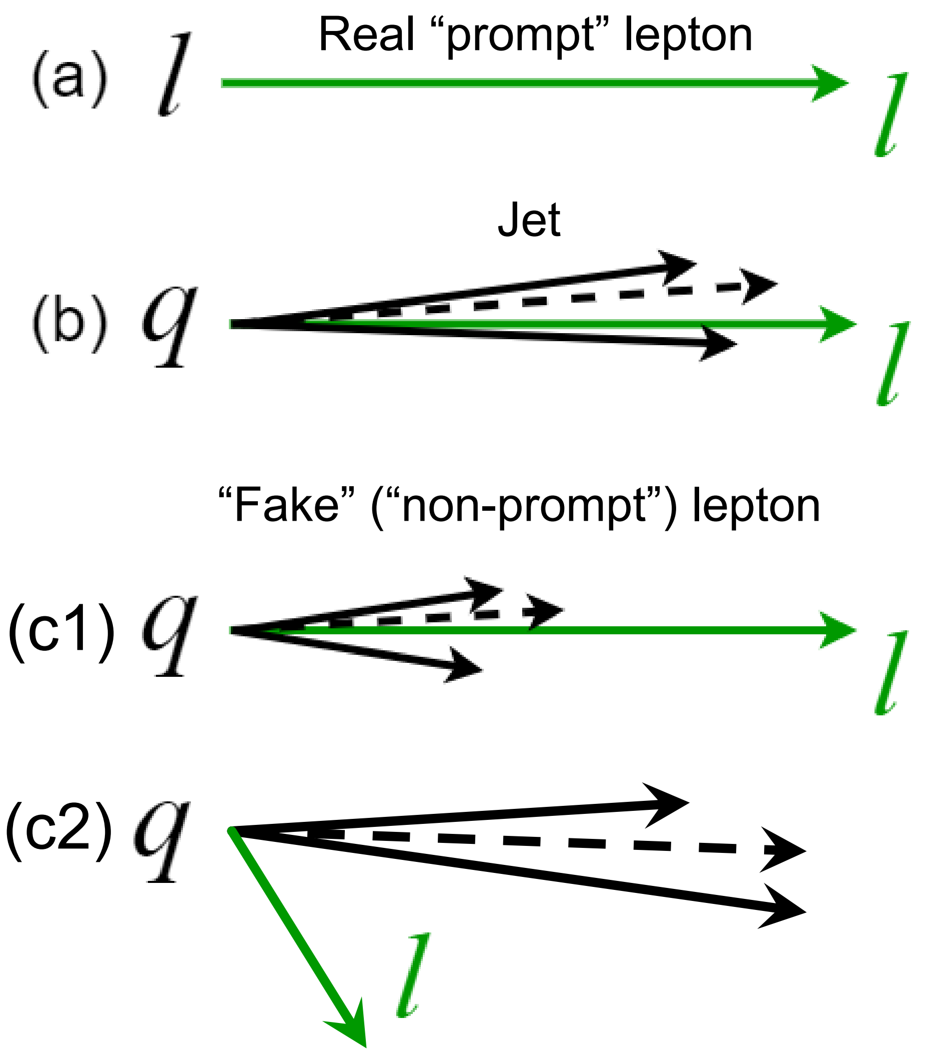
Marijus Ambrozas

marijus.ambrozas@cern.ch

2025-11-05

What are “fake” leptons?

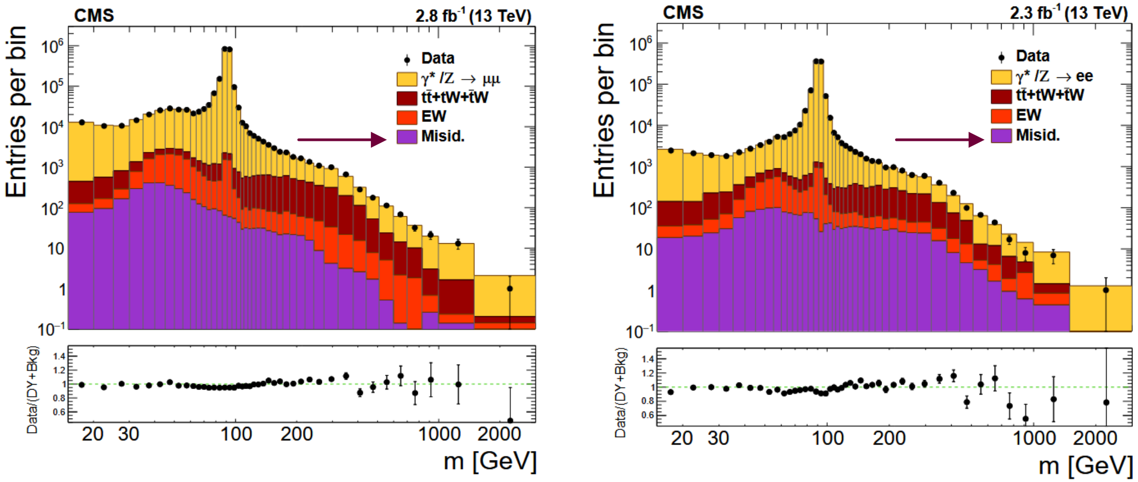
- In Drell-Yan analysis, we are interested in signal leptons coming from the primary vertex
  - These are often called “prompt” leptons
- In some rare cases, RECO leptons that do not originate from the primary vertex still manage to pass the lepton cuts
- There are a few types of such leptons:
  1. “Non-prompt leptons” (dominant contribution):
     - Real leptons can be produced in heavy-flavor decay chains inside jets
     - When the lepton has dominant momentum inside the jet, it can pass the isolation cuts
     - Alternatively (but rarely), photon conversions can produce electrons and in-flight π/K decays can produce muons
  2. “Instrumental fakes” (nearly-negligible contribution):
     - Muon channel: jet hadronic punch-through may create signals in muon detectors and be reconstructed as a muon
     - Electron channel: π^0-rich jets may have high electromagnetic content and be misreconstructed as electrons
- When we say “fake lepton backgrounds”, we usually mean all of the above
  - Though, “fake leptons” is a slang and should not be used in official documents
  - “Non-prompt” or “misidentified” are the most common terms in publications



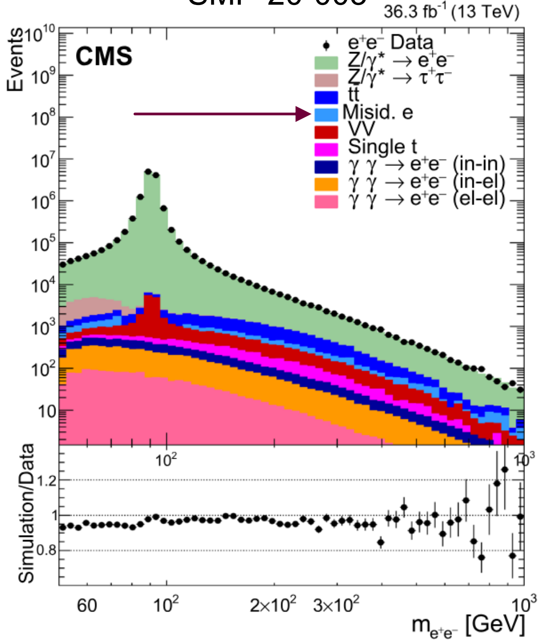
Fake lepton backgrounds

- Drell-Yan final state has 2 leptons, so the fake lepton background consists of 2 main types
  1. 1 prompt lepton, 1 fake lepton
  2. 2 fake leptons
- In principle, any process could contribute to the fake lepton background
  - ➢ Even DY itself, if there are ISR jets
- However, there are two (three) most dominant ones:
  1. W+jets (1 fake lepton)
  2. QCD multijet (2 fake leptons)
  3. γ+jets (2 fake leptons, only in the electron channel, almost negligible)
- Fake lepton background is the most prominent in the low mass and low lepton p_T region
- It is negligible in the Z peak region but should be estimated (at least) outside it to achieve high precision

SMP-17-001



SMP-20-003

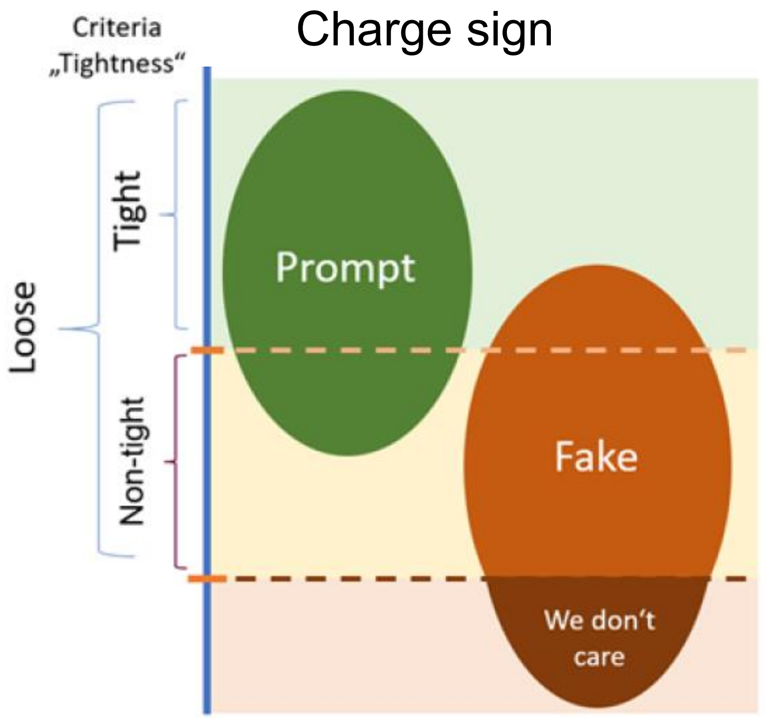


Fake lepton background estimation techniques

- Fake lepton background cannot be estimated from MC
  - Very large cross section and very low fake lepton production probability
  - Extremely large MC datasets should be produced to collect sufficient statistics after event selection
  - Also, the simulation accuracy is not great
- Therefore, we rely on data-driven methods
- There are many data-driven methods available:

Fake lepton background estimation techniques

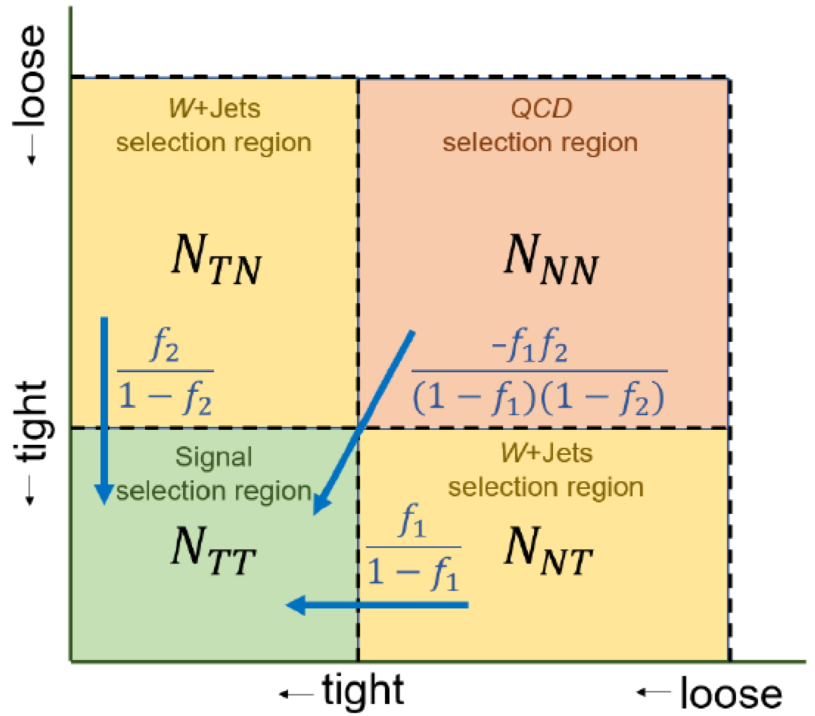
- Fake lepton background cannot be estimated from MC
  - Very large cross section and very low fake lepton production probability
  - Extremely large MC datasets should be produced to collect sufficient statistics after event selection
  - Also, the simulation accuracy is not great
- Therefore, we rely on data-driven methods
- There are many data-driven methods available:
  1. Matrix method
     - In theory, the most sophisticated, the least reliant on MC
     - In practice, the most difficult to properly implement (the matrix is ill-conditioned)



$$\begin{pmatrix} N_{PP} \\ N_{PF} \\ N_{FP} \\ N_{FF} \end{pmatrix} = \frac{1}{(f_1 - p_1)(f_2 - p_2)} \begin{pmatrix} \tilde{f}_1\tilde{f}_2 & -\tilde{f}_1 f_2 & -f_1\tilde{f}_2 & f_1 f_2 \\ -\tilde{f}_1\tilde{p}_2 & \tilde{f}_1 p_2 & f_1\tilde{p}_2 & -f_1 p_2 \\ -\tilde{p}_1\tilde{f}_2 & \tilde{p}_1 f_2 & p_1\tilde{f}_2 & -p_1 f_2 \\ \tilde{p}_1\tilde{p}_2 & -\tilde{p}_1 p_2 & -p_1\tilde{p}_2 & p_1 p_2 \end{pmatrix} \begin{pmatrix} N_{TT} \\ N_{TN} \\ N_{NT} \\ N_{NN} \end{pmatrix}$$

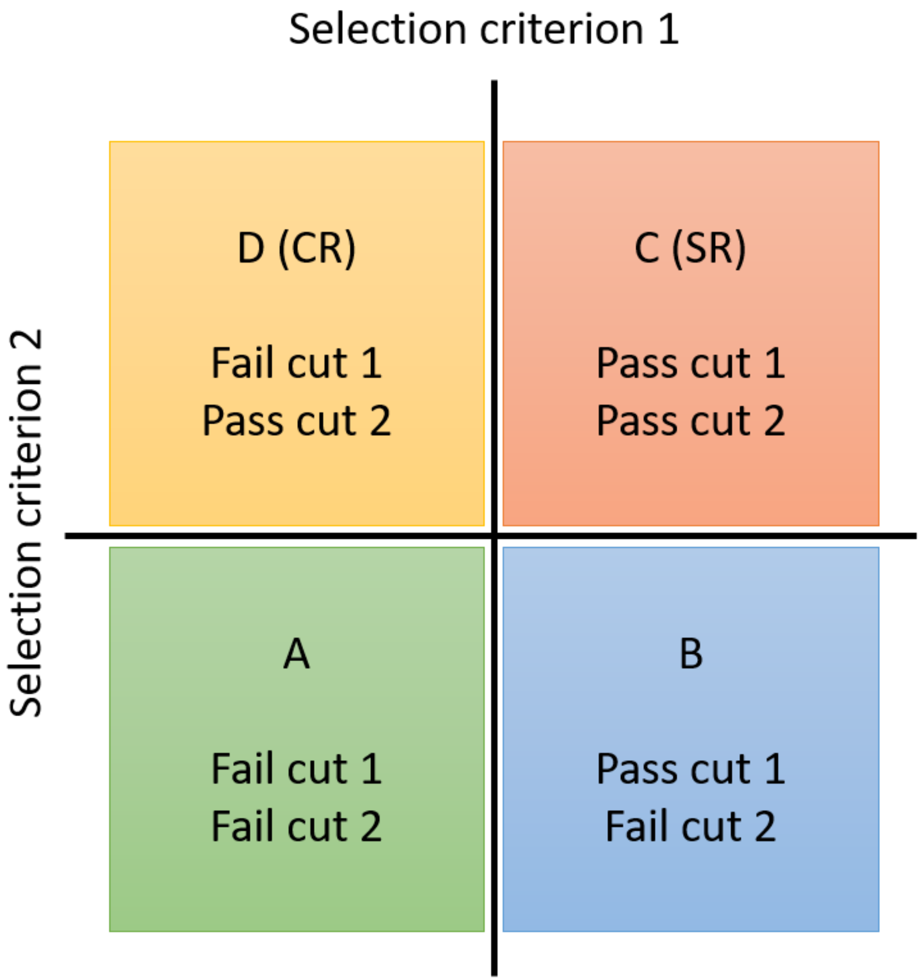
Fake lepton background estimation techniques

- Fake lepton background cannot be estimated from MC
  - Very large cross section and very low fake lepton production probability
  - Extremely large MC datasets should be produced to collect sufficient statistics after event selection
  - Also, the simulation accuracy is not great
- Therefore, we rely on data-driven methods
- There are many data-driven methods available:
  1. Matrix method
     - In theory, the most sophisticated, the least reliant on MC
     - In practice, the most difficult to properly implement (the matrix is ill-conditioned)
  2. Fake rate method
     - A simplification of the matrix method
     - Does not need the “prompt rate” but more reliant on MC
     - Still not easy to implement, needs different datasets and prescaled triggers



Fake lepton background estimation techniques

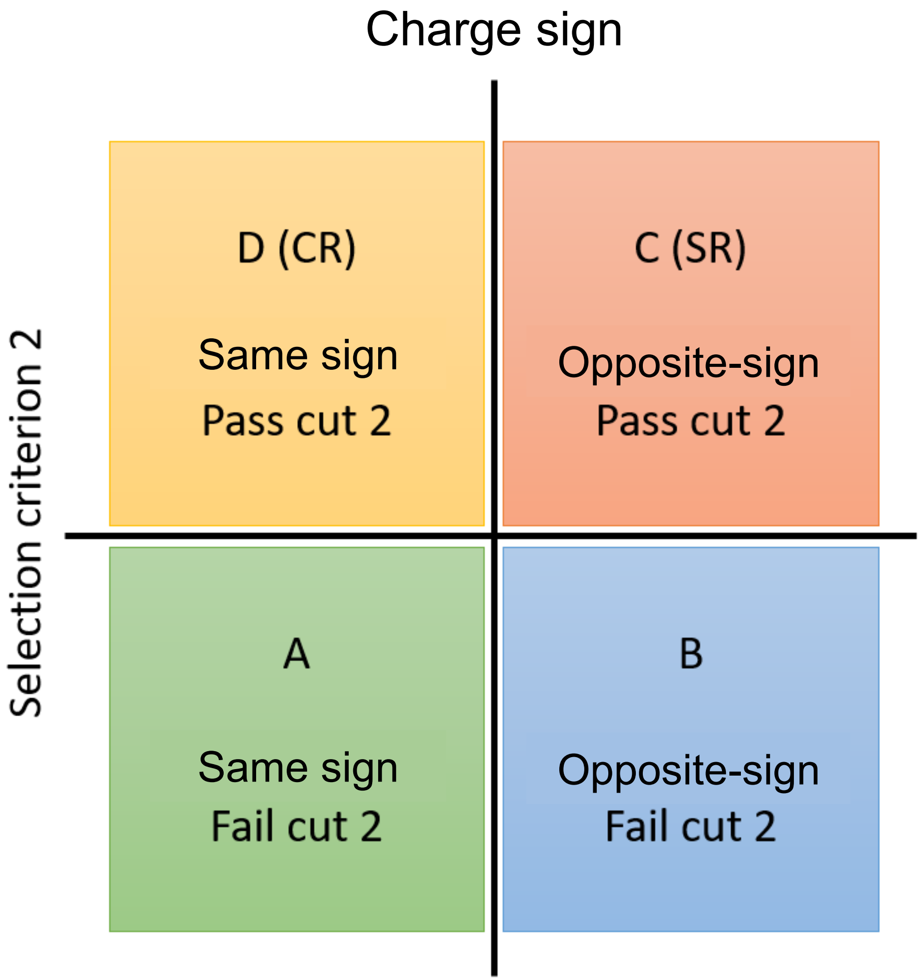
- Fake lepton background cannot be estimated from MC
  - Very large cross section and very low fake lepton production probability
  - Extremely large MC datasets should be produced to collect sufficient statistics after event selection
  - Also, the simulation accuracy is not great
- Therefore, we rely on data-driven methods
- There are many data-driven methods available:
  1. Matrix method
     - In theory, the most sophisticated, the least reliant on MC
     - In practice, the most difficult to properly implement (the matrix is ill-conditioned)
  2. Fake rate method
     - A simplification of the matrix method
     - Does not need the “prompt rate” but more reliant on MC
     - Still not easy to implement, needs different datasets and prescaled triggers
  3. ABCD method
     - Relatively easy to implement
     - Performance depends on the chosen control regions



Fake lepton background estimation techniques

- Fake lepton background cannot be estimated from MC
  - Very large cross section and very low fake lepton production probability
  - Extremely large MC datasets should be produced to collect sufficient statistics after event selection
  - Also, the simulation accuracy is not great
- Therefore, we rely on data-driven methods
- There are many data-driven methods available:

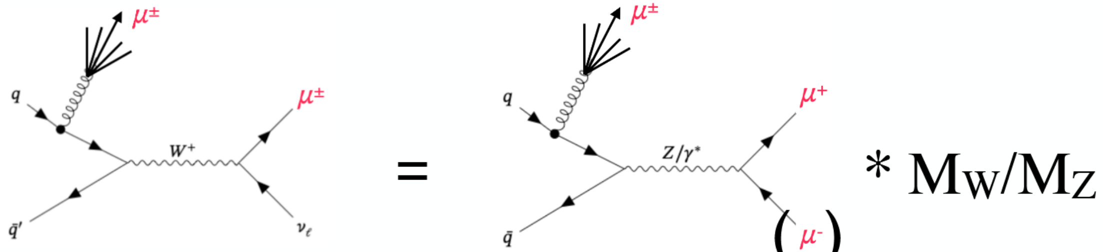
1. Matrix method
   - In theory, the most sophisticated, the least reliant on MC
   - In practice, the most difficult to properly implement (the matrix is ill-conditioned)
2. Fake rate method
   - A simplification of the matrix method
   - Does not need the “prompt rate” but more reliant on MC
   - Still not easy to implement, needs different datasets and prescaled triggers
3. ABCD method
   - Relatively easy to implement
   - Performance depends on the chosen control regions
4. **Same-sign method**
   - **A subset of ABCD method**



Fake lepton background estimation techniques

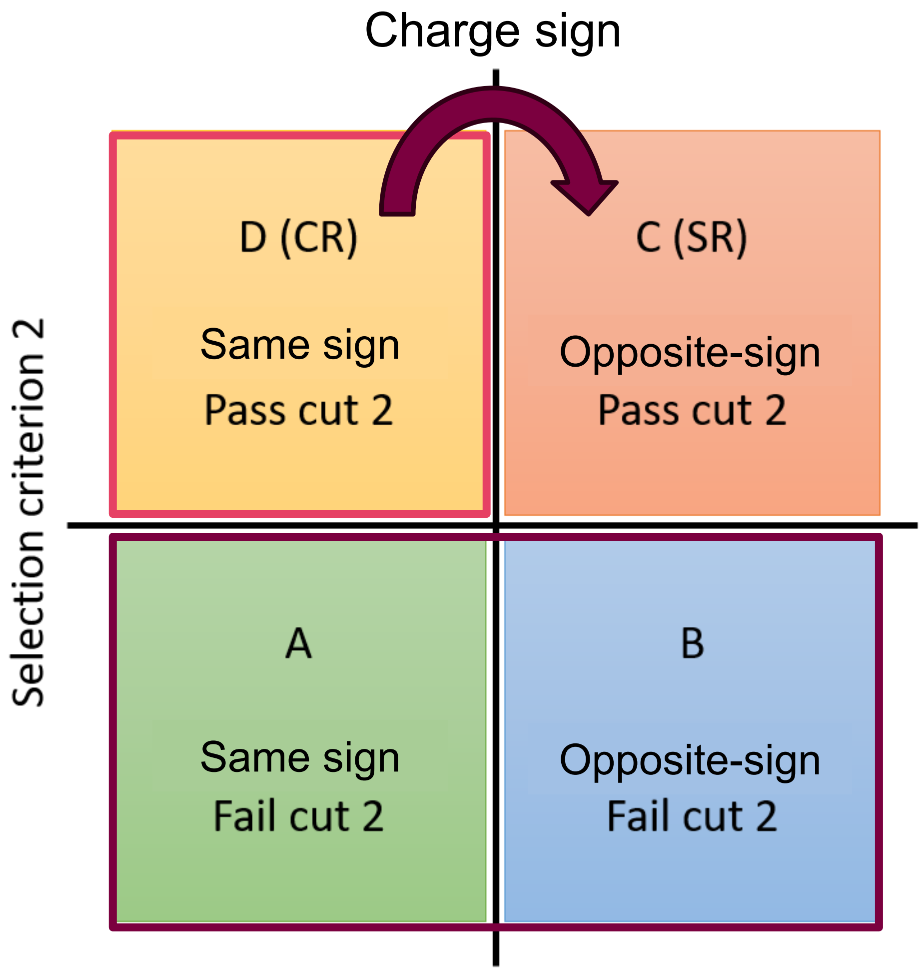
- Fake lepton background cannot be estimated from MC
  - Very large cross section and very low fake lepton production probability
  - Extremely large MC datasets should be produced to collect sufficient statistics after event selection
  - Also, the simulation accuracy is not great
- Therefore, we rely on data-driven methods
- There are many data-driven methods available:

1. Matrix method
   - In theory, the most sophisticated, the least reliant on MC
   - In practice, the most difficult to properly implement (the matrix is ill-conditioned)
2. Fake rate method
   - A simplification of the matrix method
   - Does not need the “prompt rate” but more reliant on MC
   - Still not easy to implement, needs different datasets and prescaled triggers
3. ABCD method
   - Relatively easy to implement
   - Performance depends on the chosen control regions
4. **Same-sign method**
   - **A subset of ABCD method**
5. Other methods
   - Z→W ?



Same-sign method – the basic idea

- In our DY analysis, we used the fake rate method initially but abandoned the idea
  - Some information important for the fake rate measurement was missing in nanoAOD
- Currently, we are using the same-sign method
  - Mainly because of its simplicity
- The method works as follows:
  1. Perform the usual event selection but require the leptons to have the same charge
  2. Obtained sample should be (almost) signal-free and enriched with fake lepton backgrounds
  3. Estimate the fake lepton background by MC subtraction in the same-sign sample
  4. Extrapolate the result to the opposite-sign region by using the transfer ratio $R_{OS/SS}$(~1) taken from the sideband region
- Considering only QCD, we could expect the ratio to be ≈1 in the electron channel and ≈1.75 in the muon channel (CMS-AN-13-180)



$$C = D \times \frac{B}{A} \qquad R_{OS/SS} = \frac{B}{A}$$

Same-sign method – the nuances

- Implementing the same-sign method in a real (precision) analysis has a few more challenges:

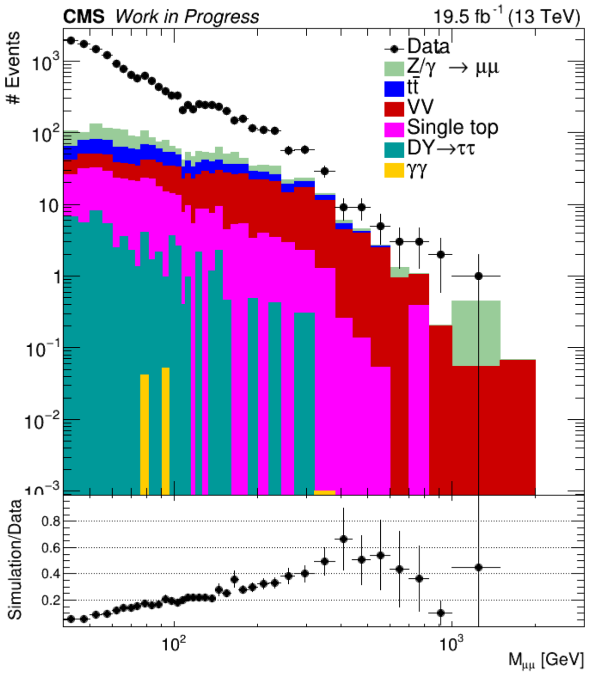
1. Same-sign method does not differentiate between single-fake and double-fake events
   - Estimates both QCD and W+Jets at the same time
   - If the $R_{OS/SS}$ is different between QCD and W+Jets, one needs to evaluate the average $R_{OS/SS}$ that takes into account relative QCD and W+Jets fractions
   - **Solution:** very carefully choose the sideband (A and B) regions to have the relative QCD/W+Jets fraction well represented
2. $R_{OS/SS}$ might be a function of some variables
   - **Solution:** find the event variables $R_{OS/SS}$ is the most sensitive to and measure $R_{OS/SS}$ as a function of those variables
   - Then, apply the $R_{OS/SS}$ event-by-event on the D region
   - Validity of this method must be checked with a closure test
3. Non-negligible electron charge misidentification probability (only in electron channel)
   - Same-sign electron sample "contaminated" by signal
   - Need to reweight the signal MC to account for charge misidentification differences between data and MC
   - Still the background estimation error around the Z peak is very high, making the result unreliable
   - **Solution:** discard the result around the Z peak and interpolate from outside it into the Z peak region instead

- We now proceed with the actual implementation of these methods

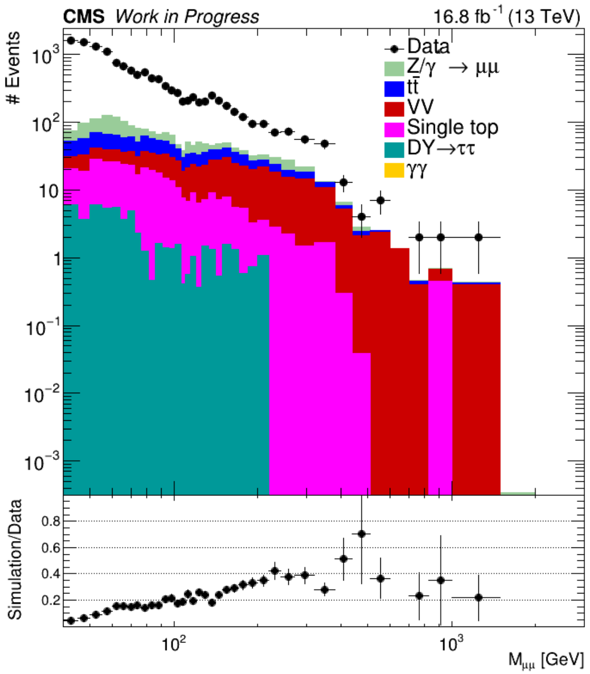
Same-sign sample: muon channel

- The big difference between data and MC is attributed to the fake muon background
- We can clearly see that the fake muon background is the most dominant

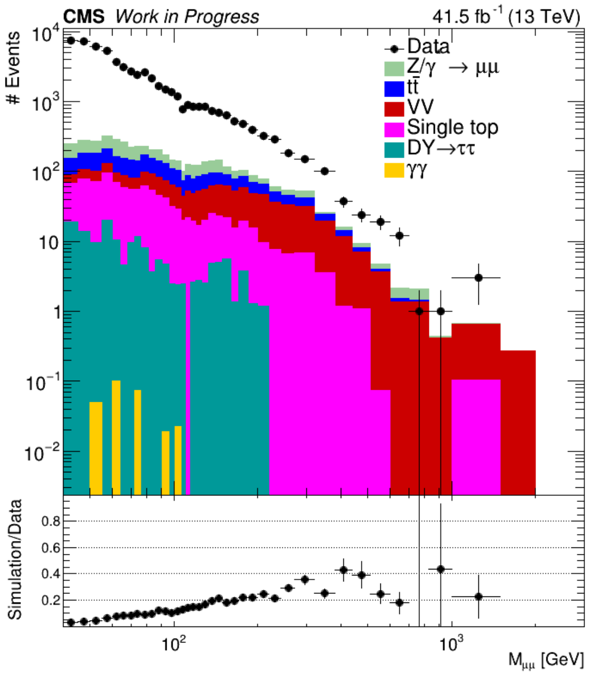
2016preAPV



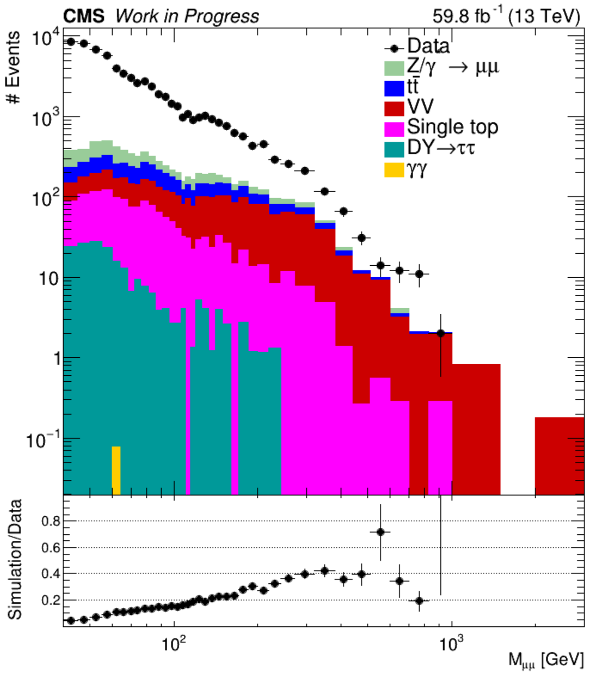
2016postAPV



2017



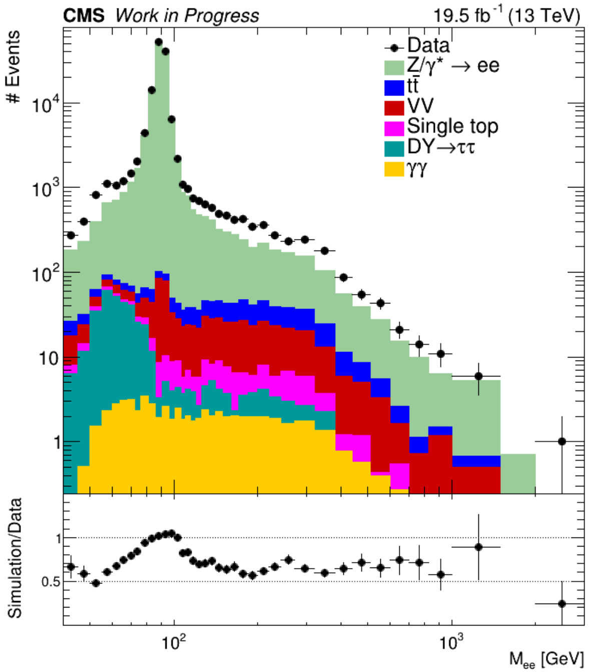
2018



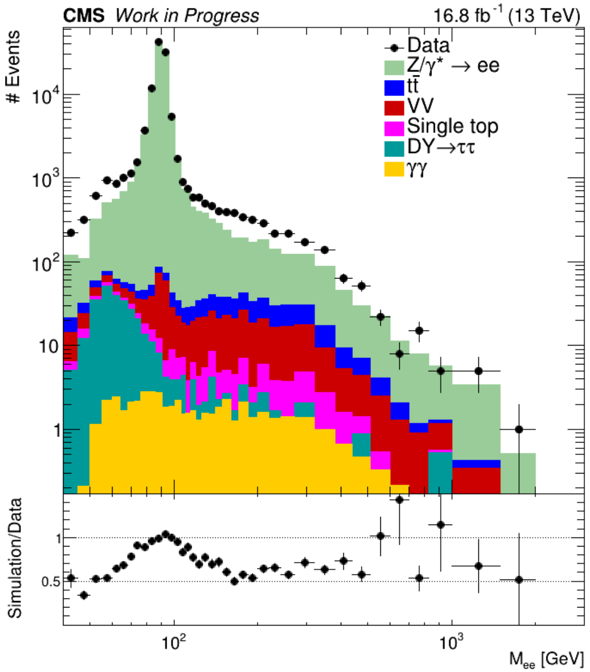
Same-sign sample: electron channel

- The big difference between data and MC is attributed to the fake electron background
- We can clearly see that the largest contribution comes from DY because of the electron charge misidentification
- Charge misidentification is very different between data and MC in 2017 and 2018 → need to correct MC (next slide)

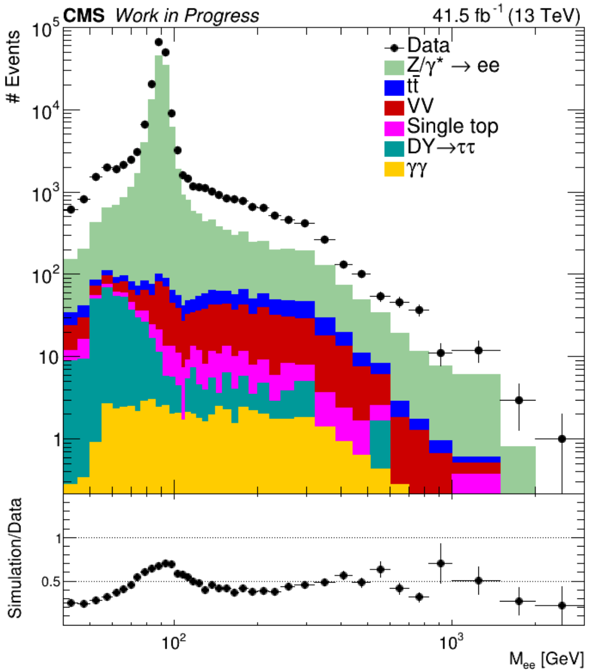
2016preAPV



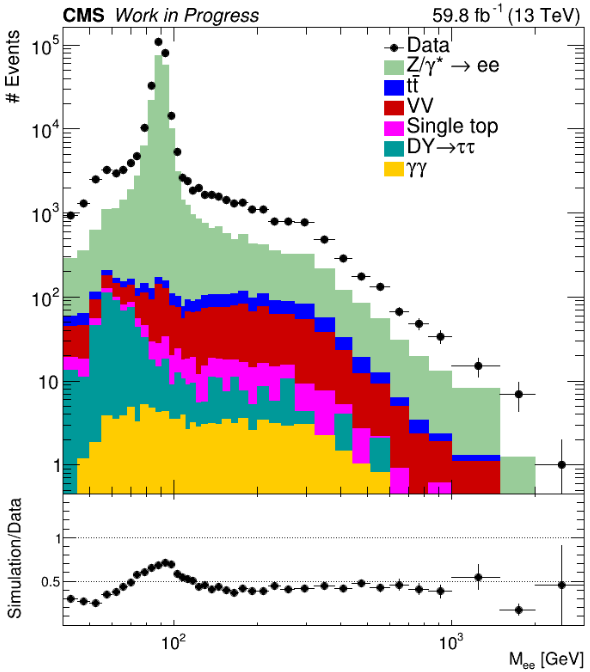
2016postAPV



2017

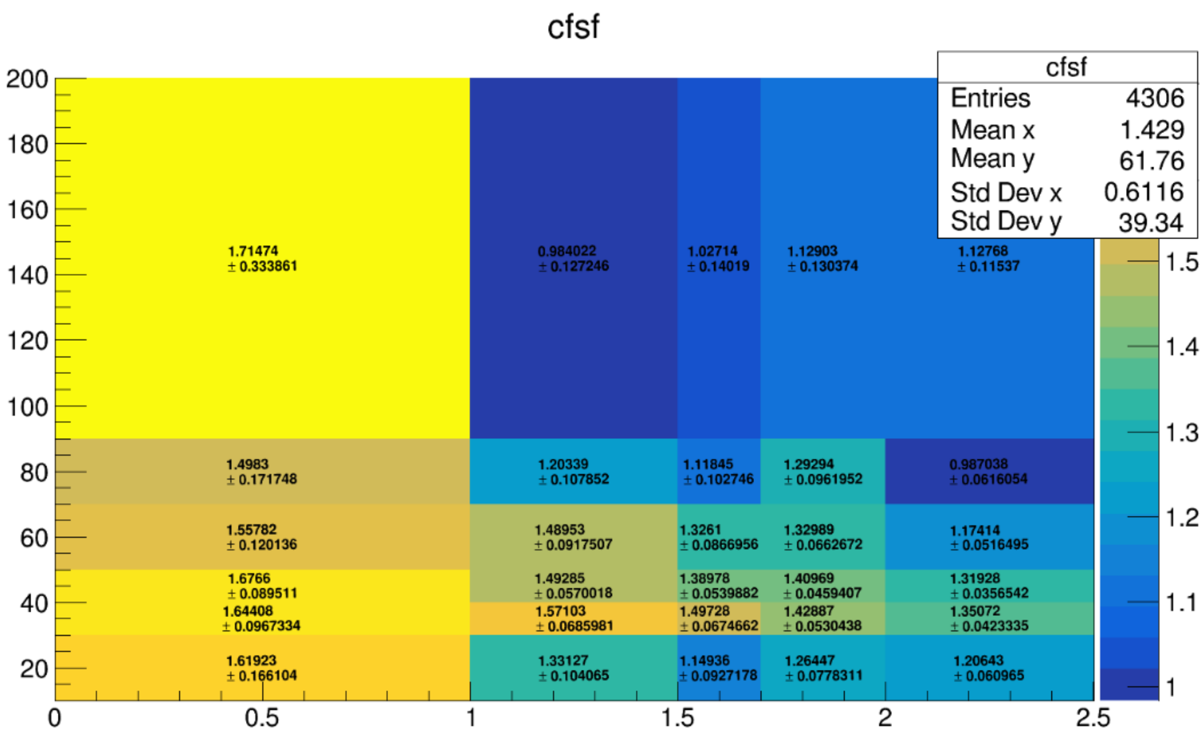


2018



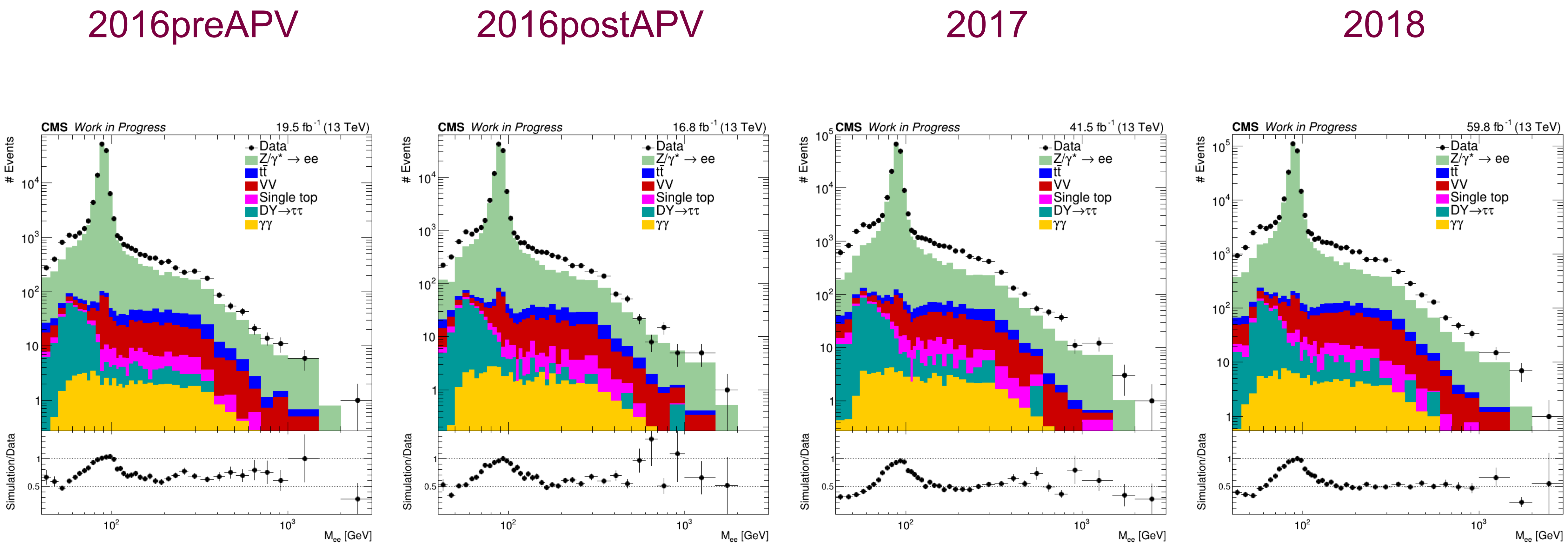
Electron charge misidentification

- Charge misidentification SFs were used to reweight MC so its charge misidentification probability better matches that of real experiment
- We are using charge misID SFs provided by DY AFB group
- The SFs are applied event-by-event as follows:
  1. Match the electrons with their GEN counterparts
  2. Check which electrons have their RECO charge ≠ GEN charge
  3. For those electrons, pick the corresponding SF value, depending on its p_T and $|\eta|$
  4. Multiply the SF value with the total weight of the event
- Corrected result in next slide



Same-sign sample: electron channel (corrected)

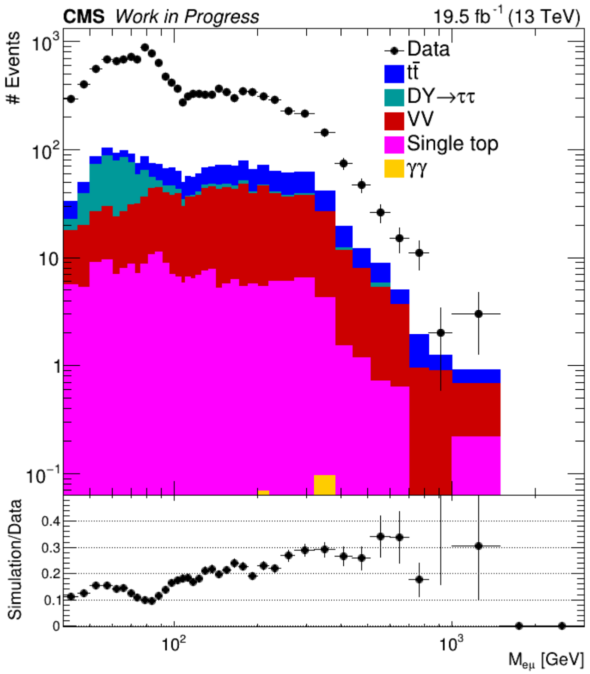
- We can notice the MC/Data agreement at the Z peak becoming a lot better than before (especially for 2017 and 2018)



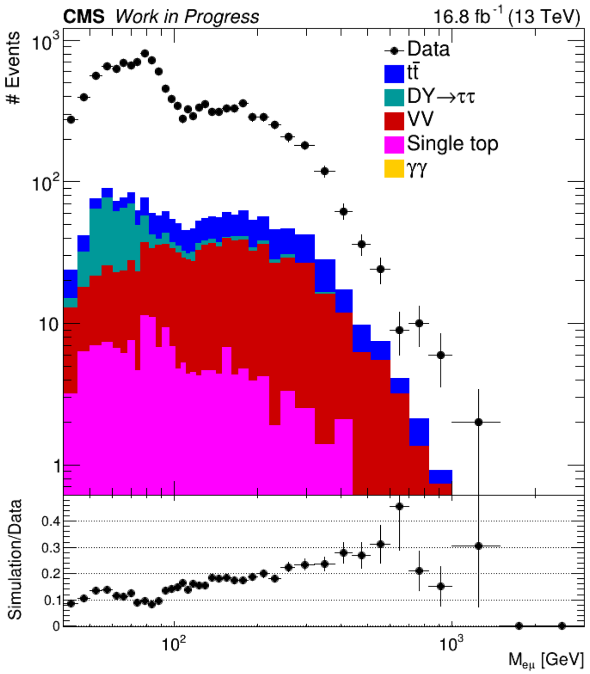
Same-sign sample: eμ channel

- Fake lepton backgrounds are also important for the eμ method (used to improve the top quark background estimation)
- Therefore, we perform the same procedure on eμ events
- The charge misidentification correction was also applied on the electron here

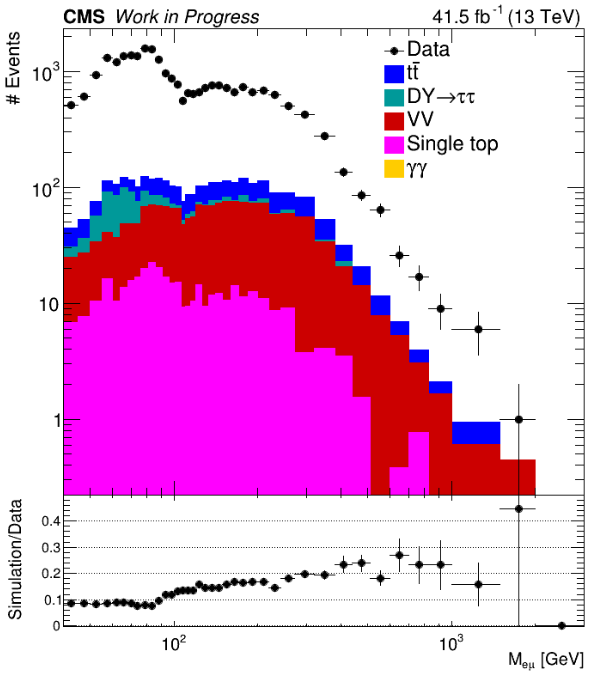
2016preAPV



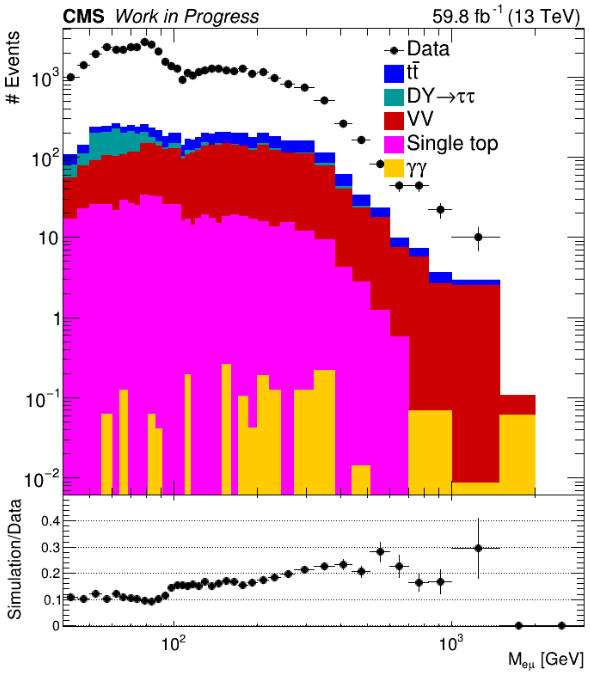
2016postAPV



2017

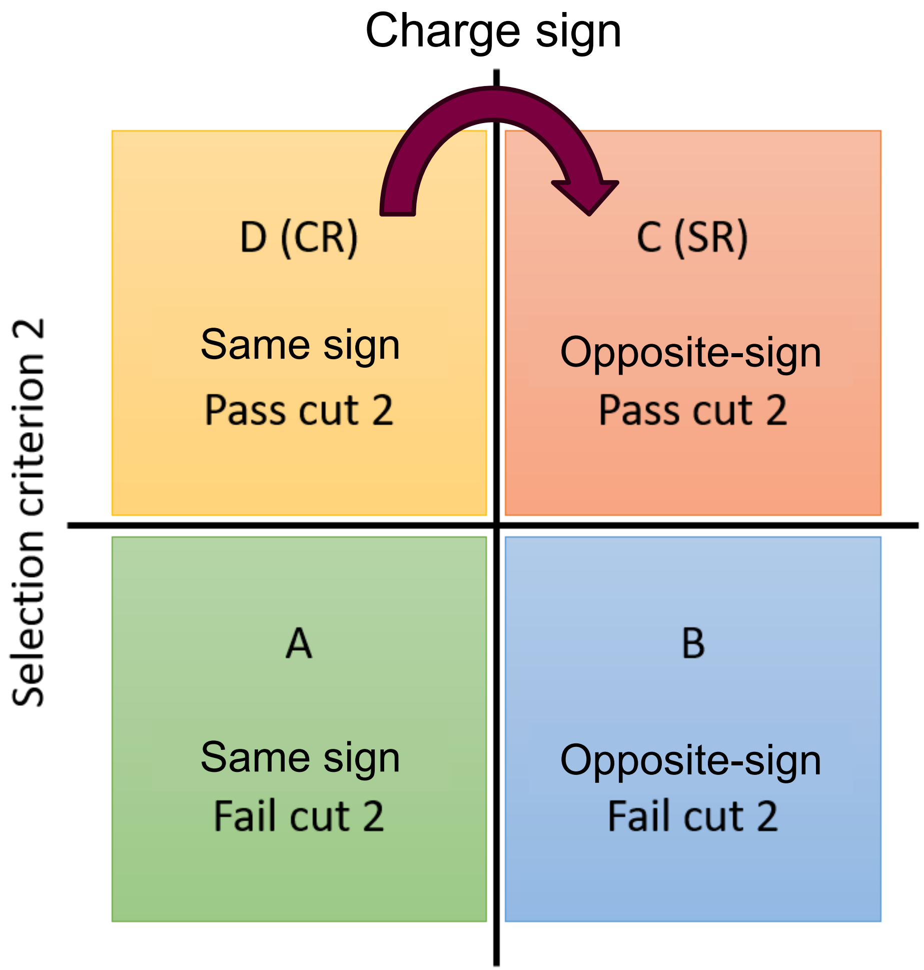


2018



OS/SS ratio estimation

- We need to estimate the OS/SS ratio to extrapolate the fake lepton background from SS to OS region
- W+Jets and QCD have different $R_{OS/SS}$ values (backup)
- Since we are estimating both W+Jets and QCD at the same time, we want to get the average $R_{OS/SS}$ right
- We need a sideband that has the relative amount of W+Jets vs. QCD as close as possible to the signal region
- Two main sidebands were considered:
  1. Regular event selection but **one** muon (electron) fails Tight PF ISO (Medium ID)
  2. Regular event selection but **both** muons (electrons) fail Tight PF ISO (Medium ID)
- For the eμ channel, we have two types of sideband 1 (one with failing muon, another with failing electron)

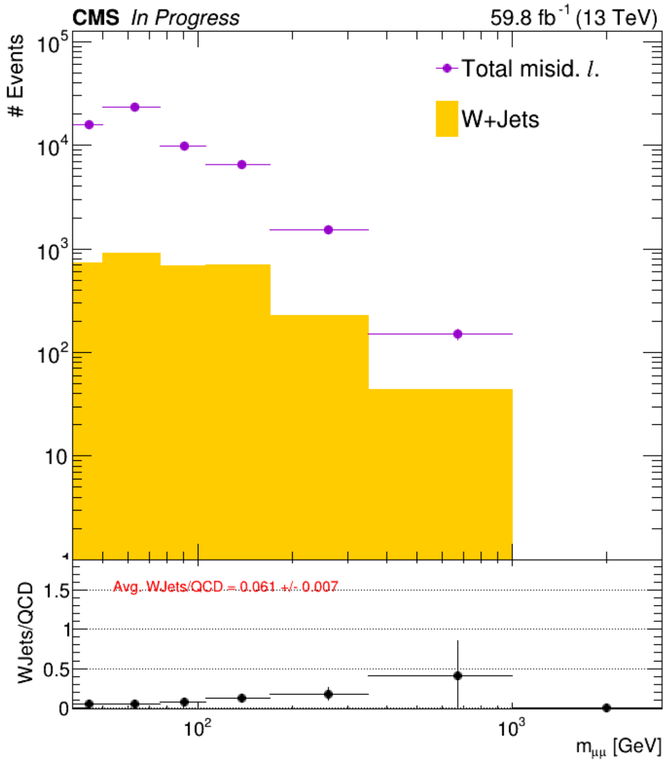


$$C = D \times \frac{B}{A} \qquad R_{OS/SS} = \frac{B}{A}$$

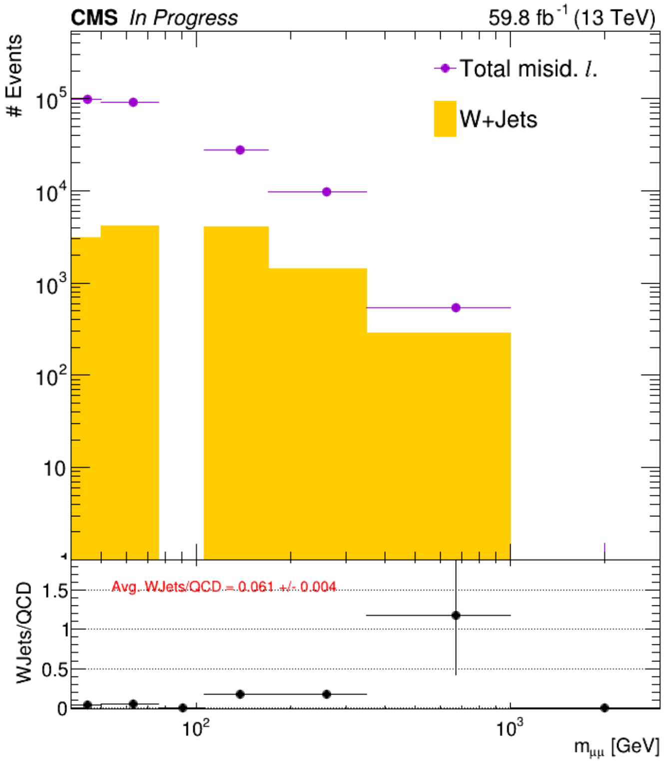
Choosing the best sideband: muon channel

- Only 2018 shown, other eras similar
- Sideband 1 has very similar W+Jets/QCD ratio to the signal region
- **Thus, we use sideband 1 to evaluate $R_{OS/SS}$ in the muon channel**

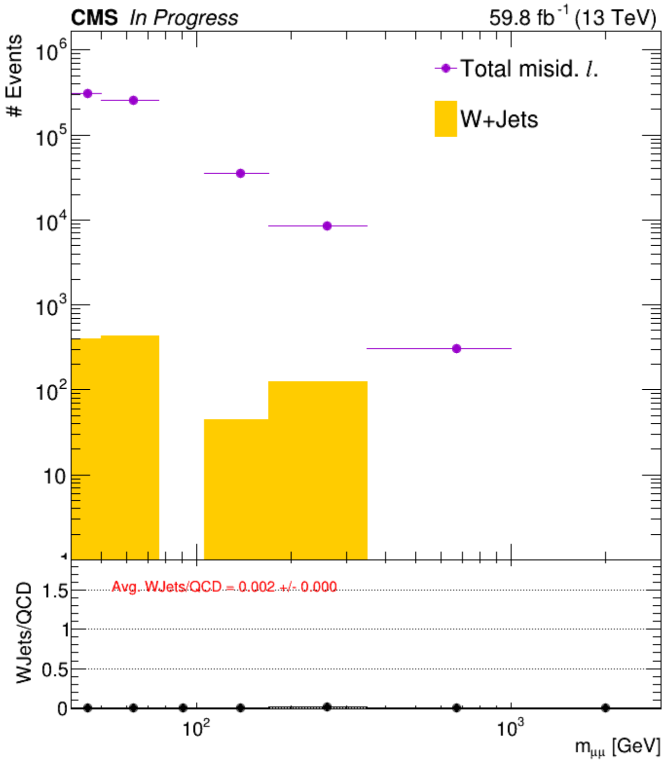
Signal region



Sideband 1



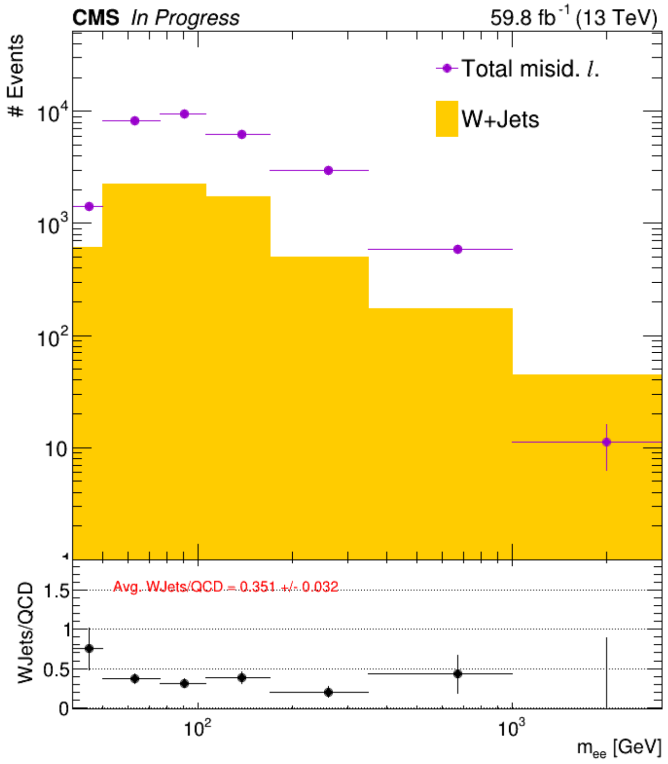
Sideband 2



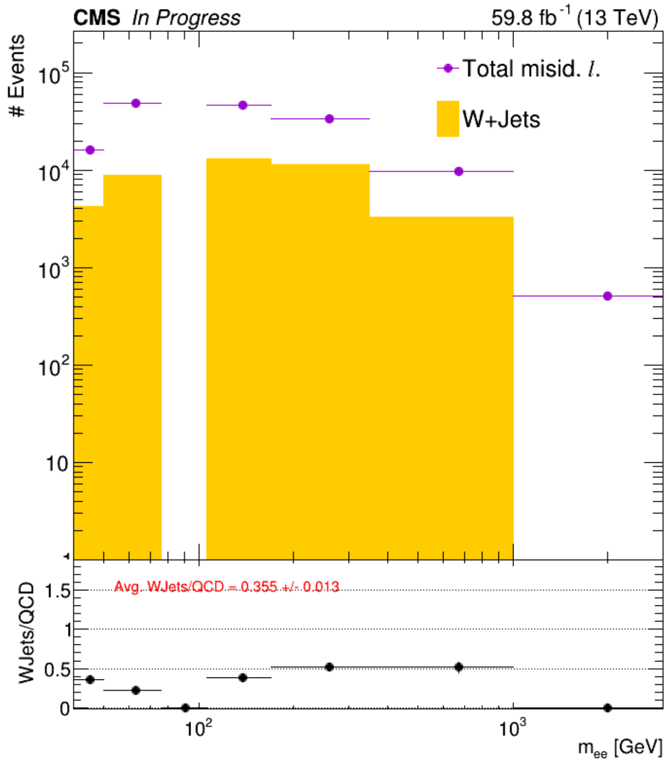
Choosing the best sideband: electron channel

- Only 2018 shown, other eras similar
- Sideband 1 has very similar W+Jets/QCD ratio to the signal region
- **Thus, we use sideband 1 to evaluate $R_{OS/SS}$ in the electron channel**

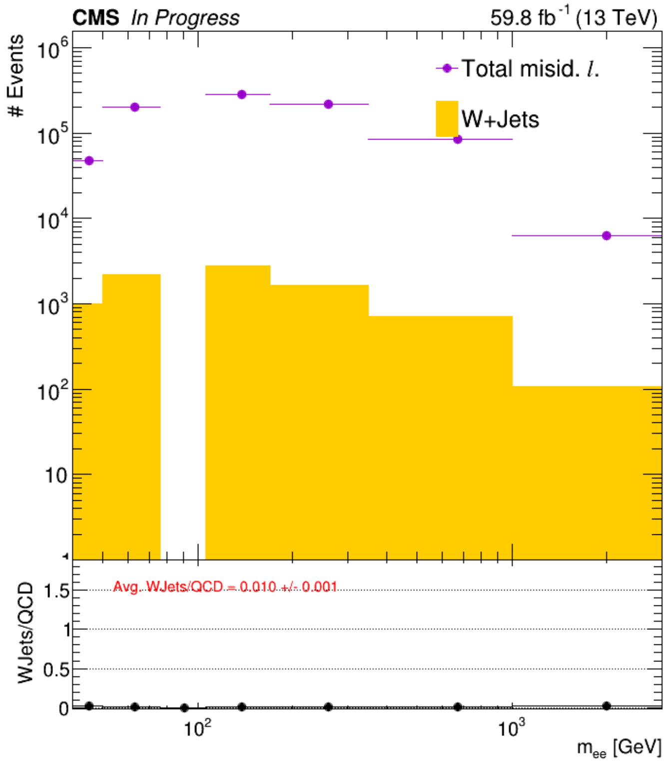
Signal region



Sideband 1



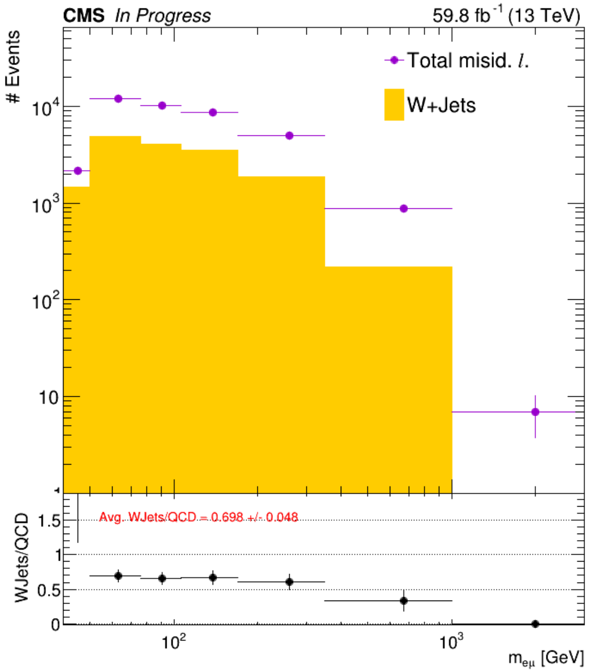
Sideband 2



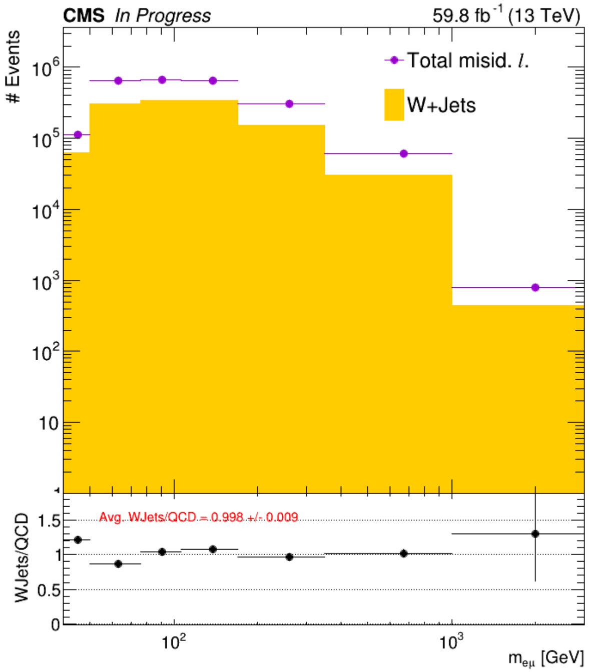
Choosing the best sideband: eμ channel

- Only 2018 shown, other eras similar
- Sideband 1a – invert the electron cut, 1b – invert the muon cut
- **We choose sideband 1a to evaluate $R_{OS/SS}$ in the eμ channel** as it most closely resembles the signal region

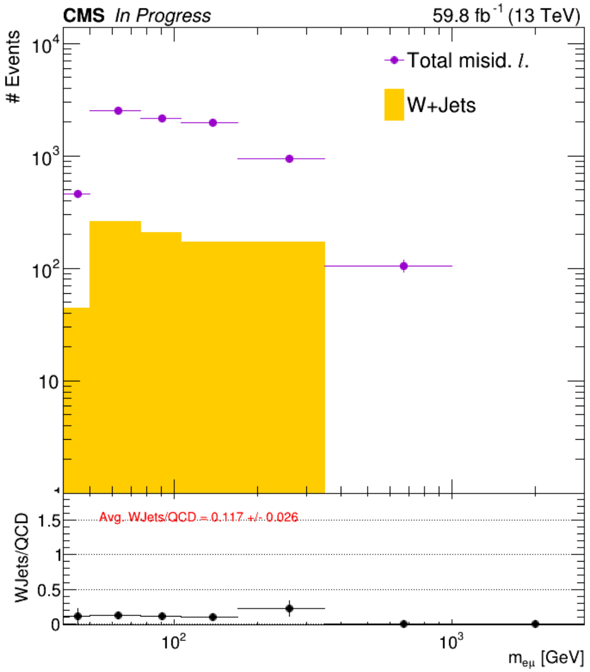
Signal region



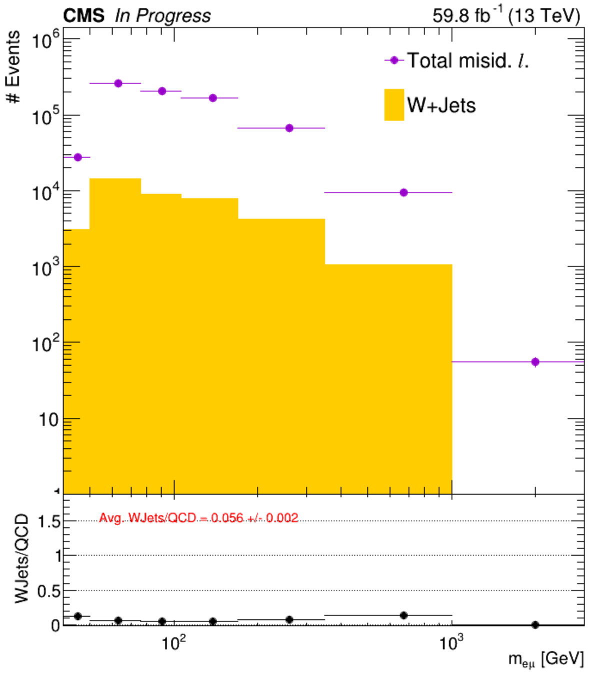
Sideband 1a



Sideband 1b



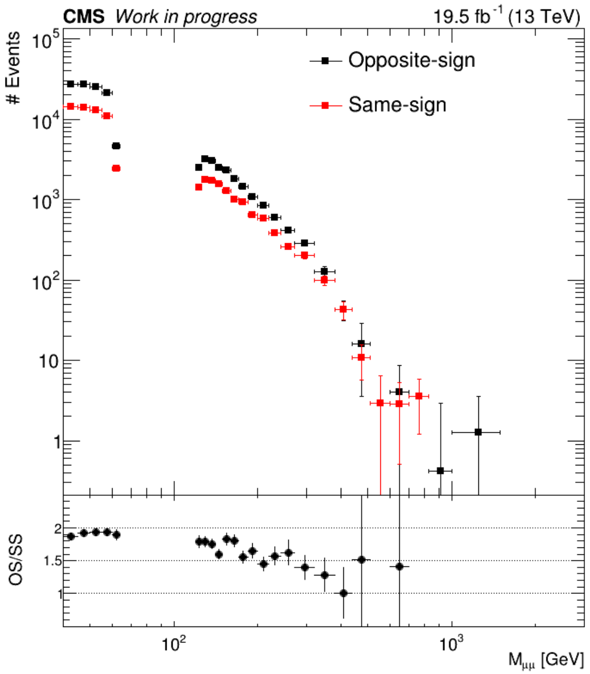
Sideband2



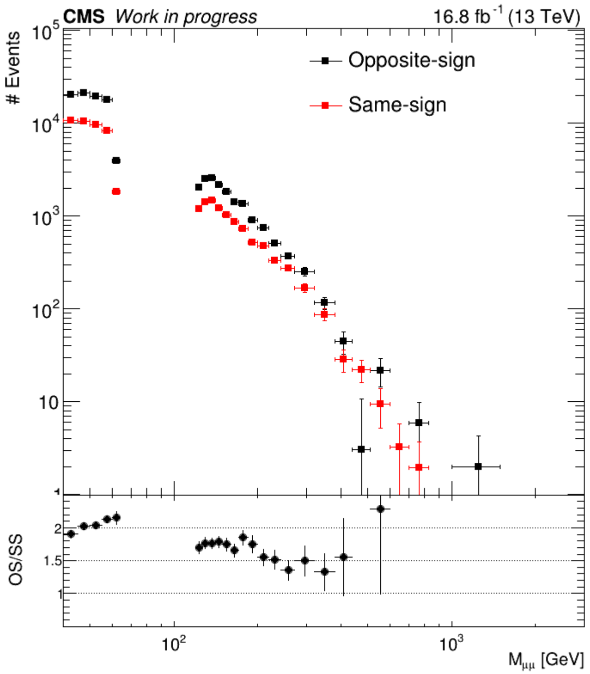
OS/SS ratio: muon channel

- Comparing OS and SS distributions in the muon channel sideband 1
- $R_{OS/SS}$ changes as a function of dilepton mass
- Check if there are strong dependencies on other variables (next slide)

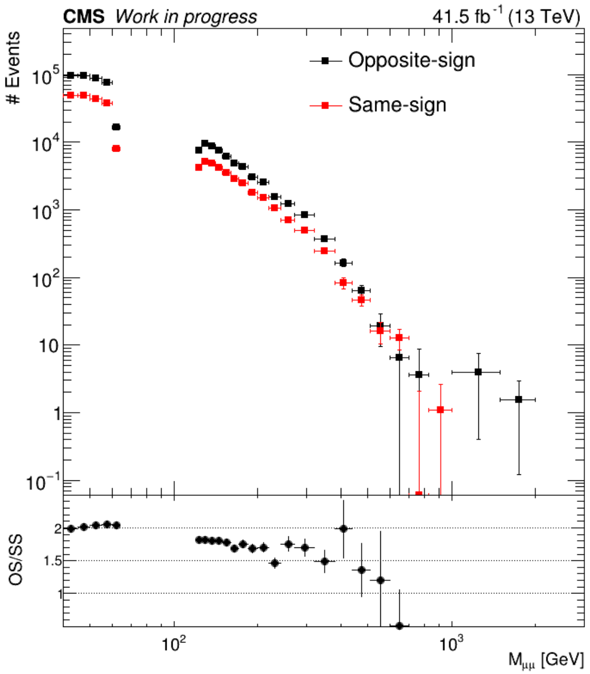
2016preAPV



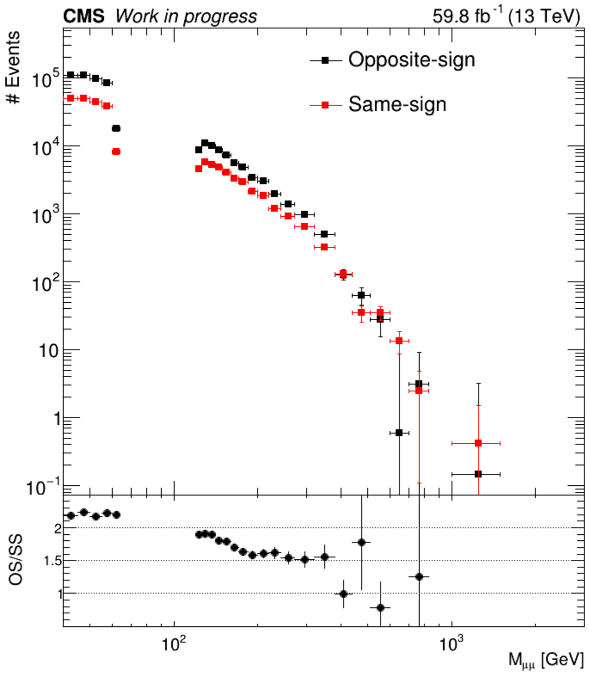
2016postAPV



2017



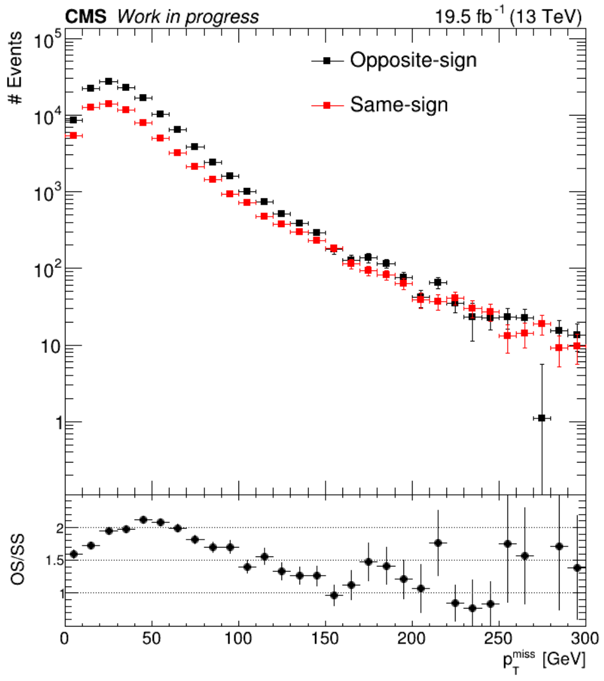
2018



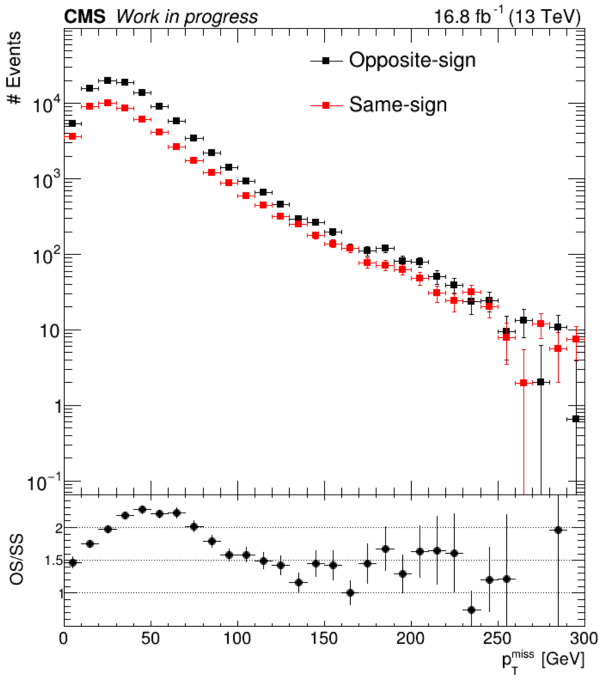
OS/SS ratio: muon channel (II)

- $R_{OS/SS}$ also has strong dependence on missing p_T (possibly due to separation between W+Jets and QCD w.r.t. this variable)
- **Therefore, we measure $R_{OS/SS}$ in the muon channel as a 2D function of mass and missing p_T**
- The 2D ratio is fitted with an analytical 2D function (next slide)

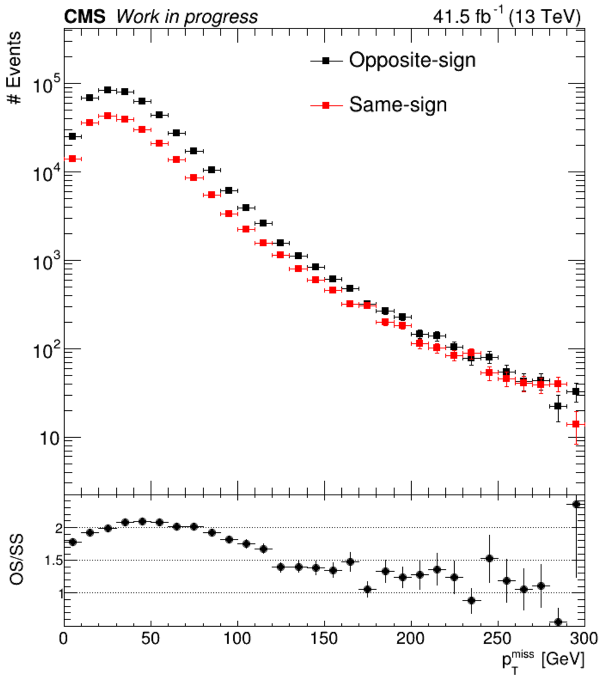
2016preAPV



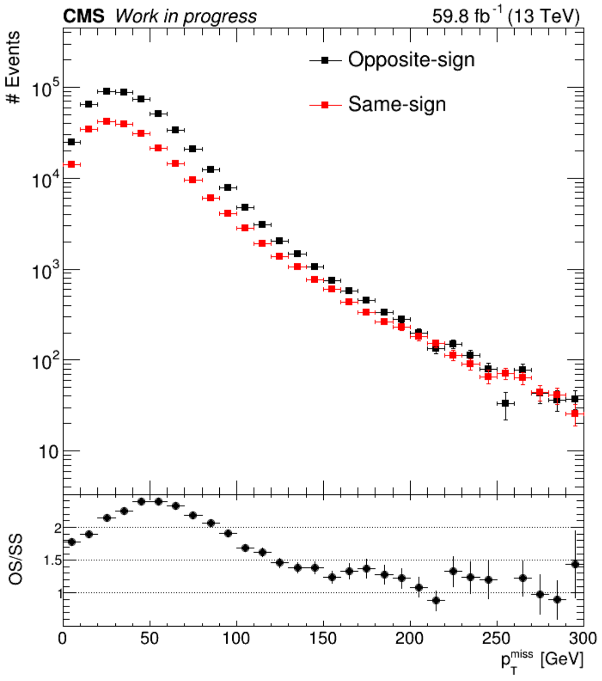
2016postAPV



2017



2018

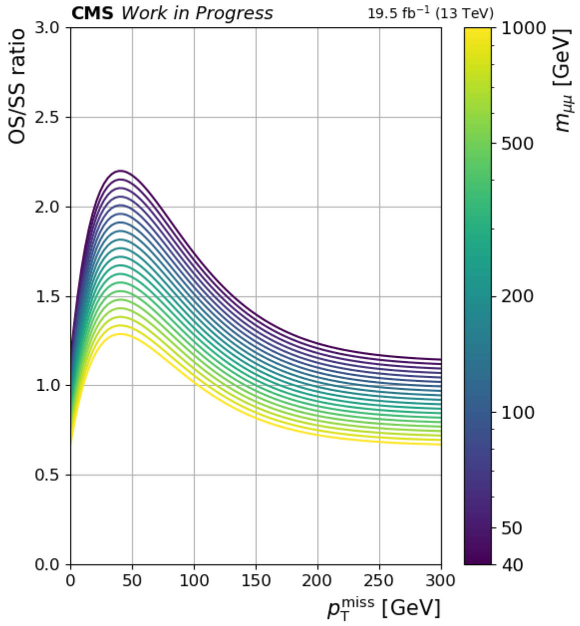


2D OS/SS ratio: muon channel

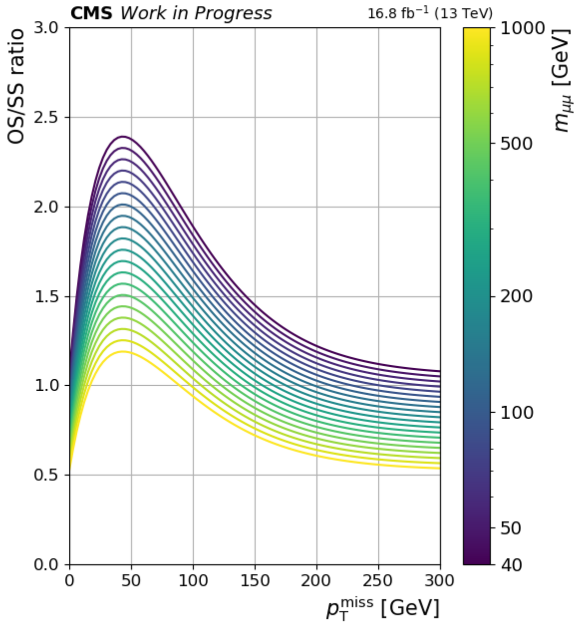
- Different colors show different dilepton mass values
  - But the function is not binned in mass, it is a smooth distribution

$$R_{\mathrm{OS/SS}}(m_{\mu\mu}, E_{\mathrm{T}}^{\mathrm{miss}}) = \left[a_0 + a_1 \log_{10}(m_{\mu\mu})\right] \left[a_2 - a_3 E_{\mathrm{T}}^{\mathrm{miss}} \exp\left(-a_4 E_{\mathrm{T}}^{\mathrm{miss}}\right)\right]$$

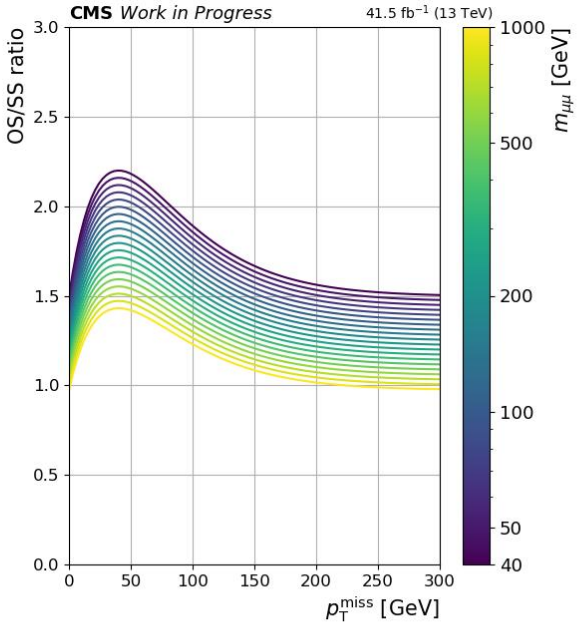
2016preAPV



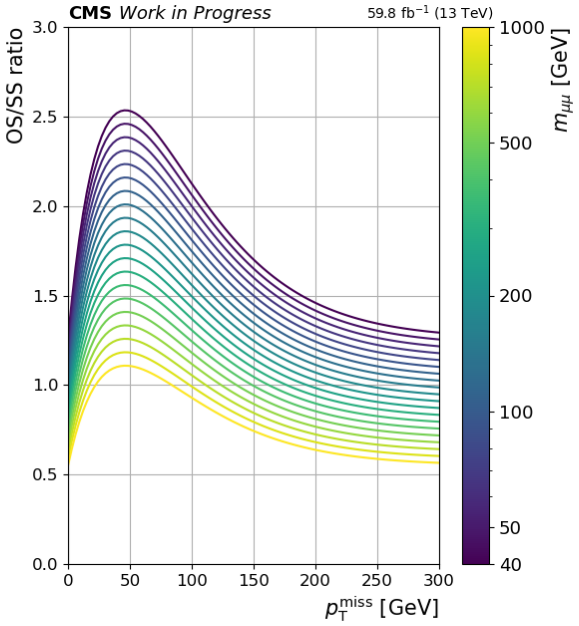
2016postAPV



2017



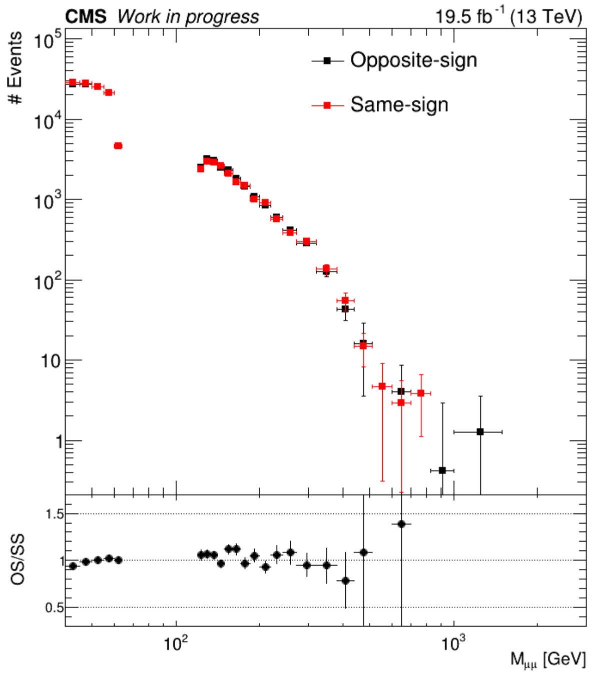
2018



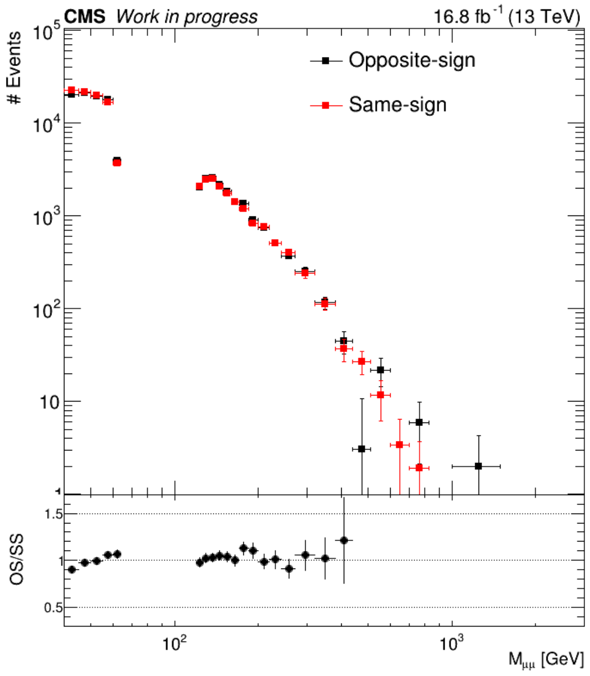
OS/SS ratio validation: muon channel

- We validate the obtained ratios by performing a closure test
  - Reweigh the SS events in the sideband itself and see if it matches the OS distribution there
- We can see that the closure is nearly perfect

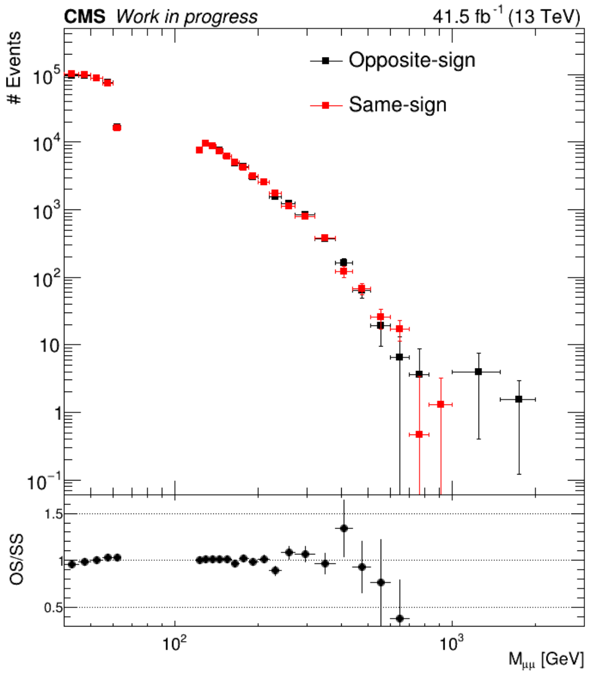
2016preAPV



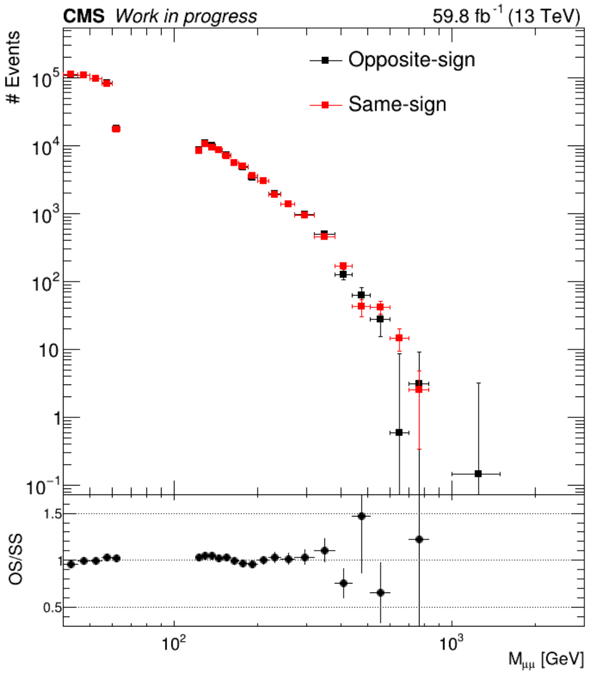
2016postAPV



2017



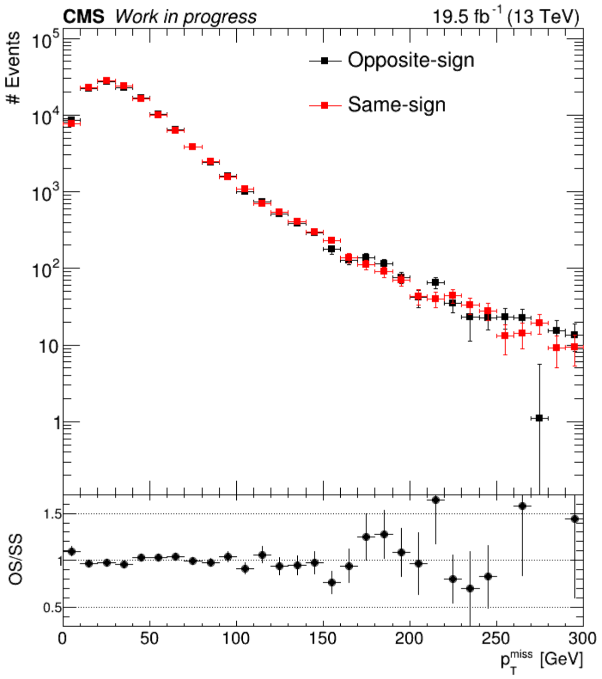
2018



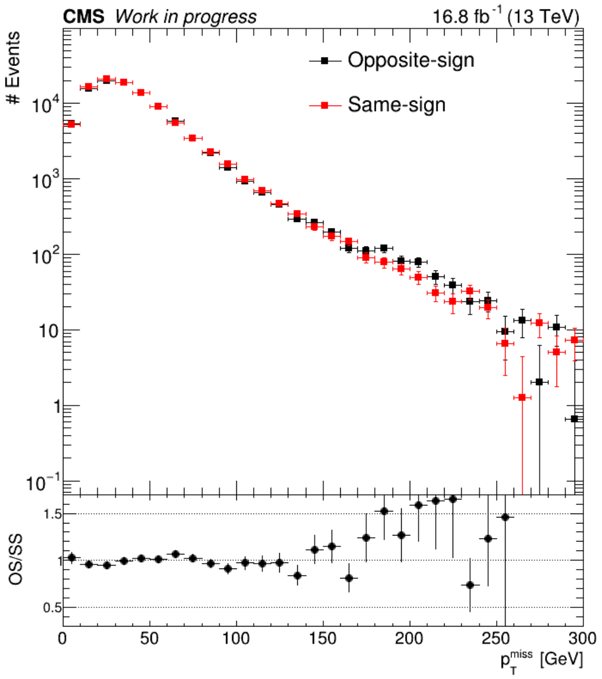
OS/SS ratio validation: muon channel (II)

- We validate the obtained ratios by performing a closure test
  - Reweigh the SS events in the sideband itself and see if it matches the OS distribution there
- We can see that the closure is nearly perfect

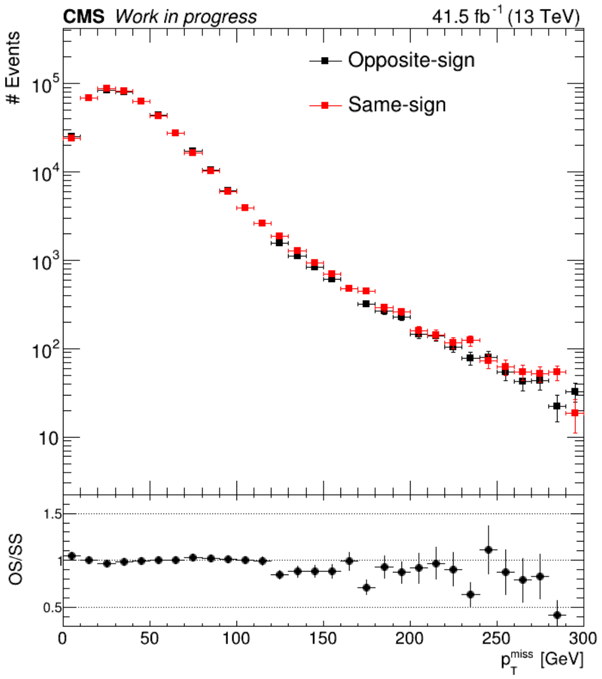
2016preAPV



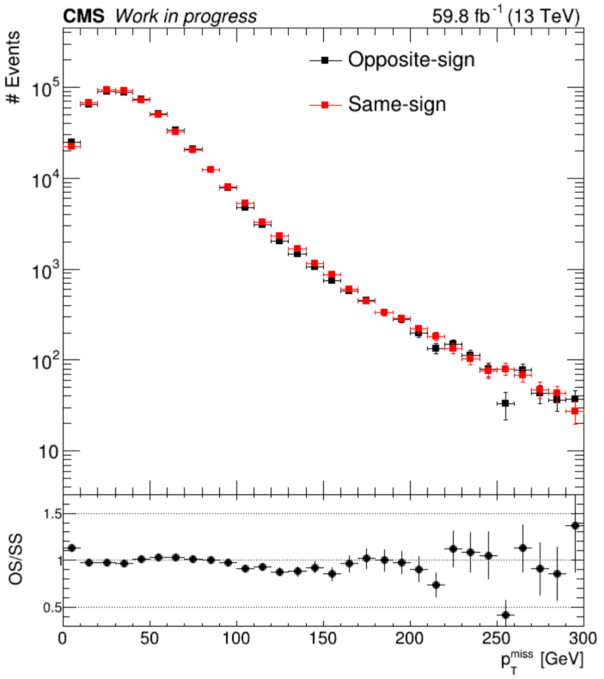
2016postAPV



2017



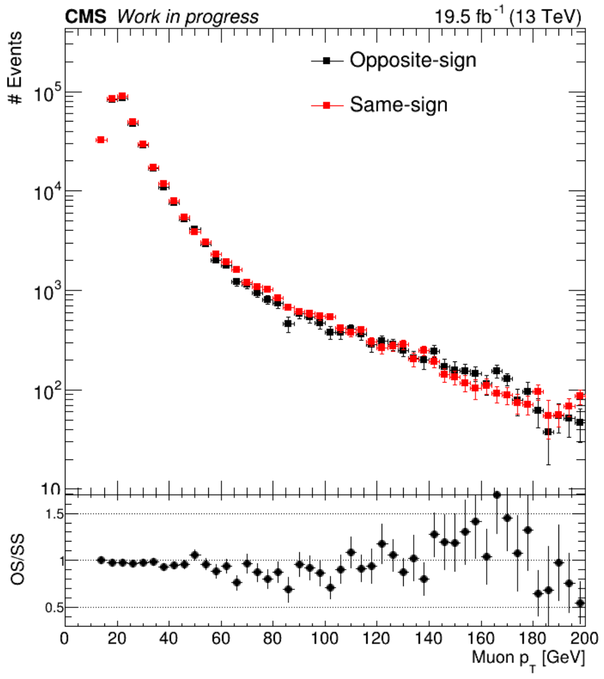
2018



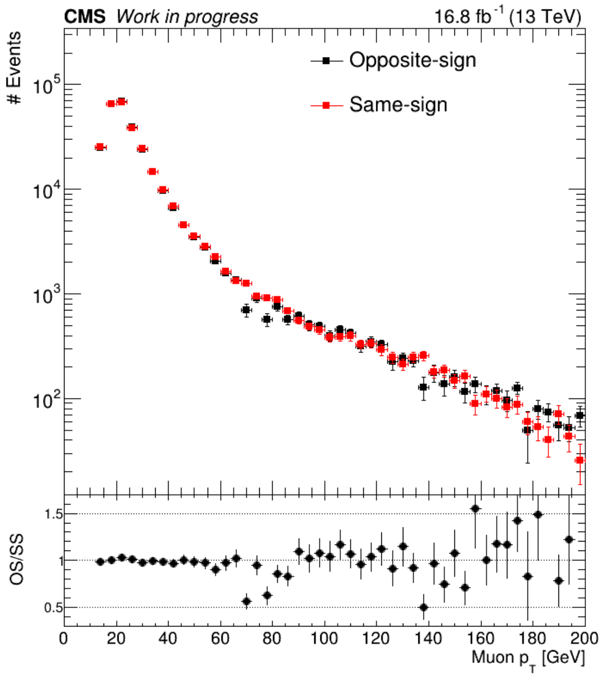
OS/SS ratio validation: muon channel (III)

- We validate the obtained ratios by performing a closure test
  - Reweigh the SS events in the sideband itself and see if it matches the OS distribution there
- We can see that the closure is nearly perfect

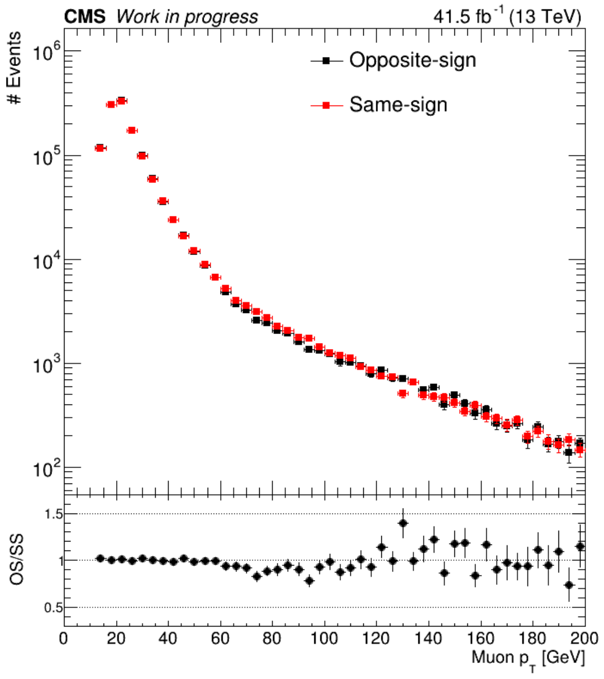
2016preAPV



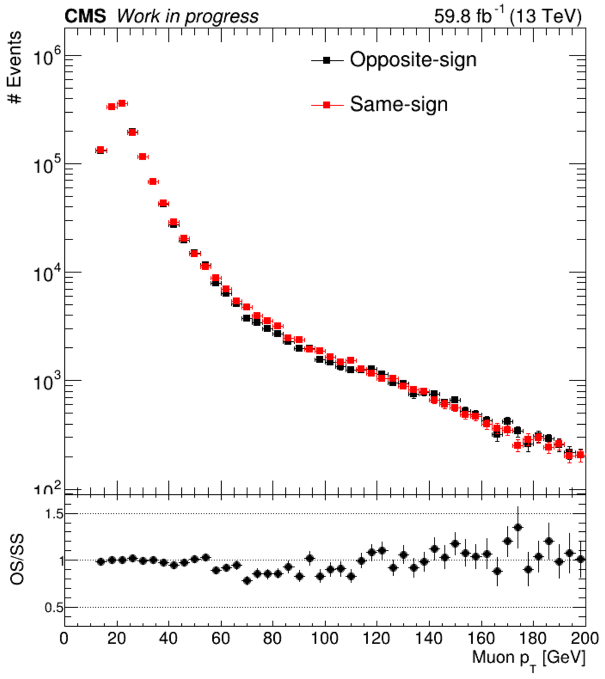
2016postAPV



2017



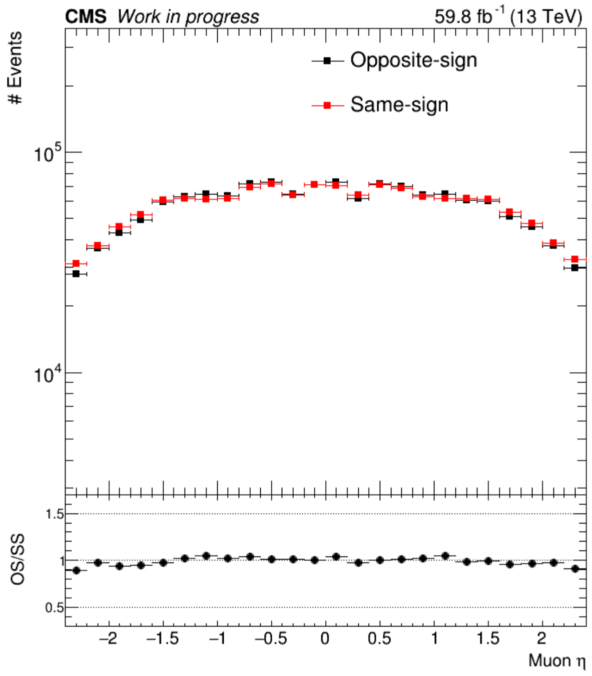
2018



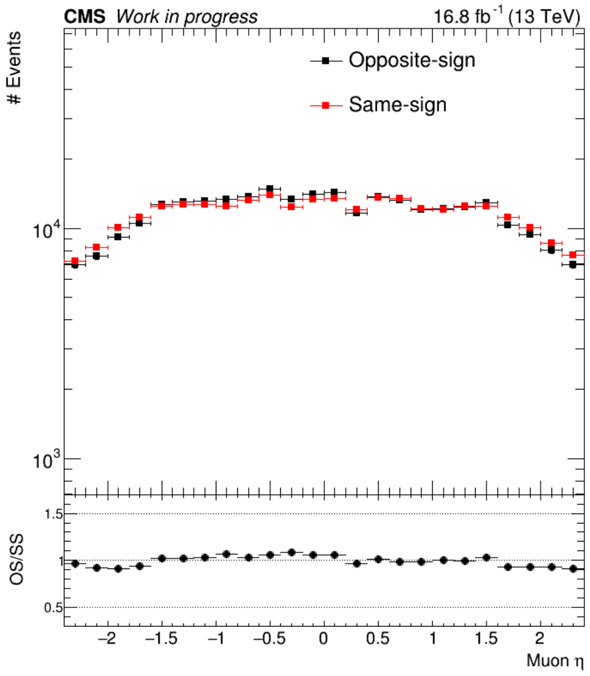
OS/SS ratio validation: muon channel (IV)

- We validate the obtained ratios by performing a closure test
  - Reweigh the SS events in the sideband itself and see if it matches the OS distribution there
- We can see that the closure is nearly perfect

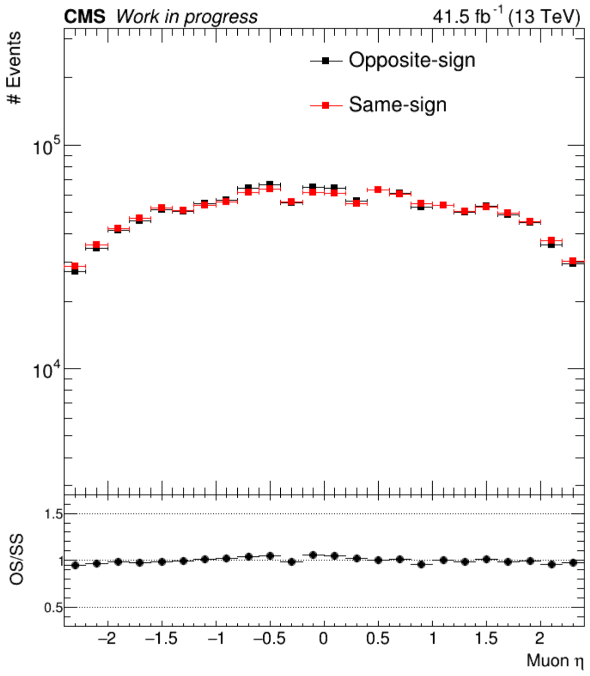
2016preAPV



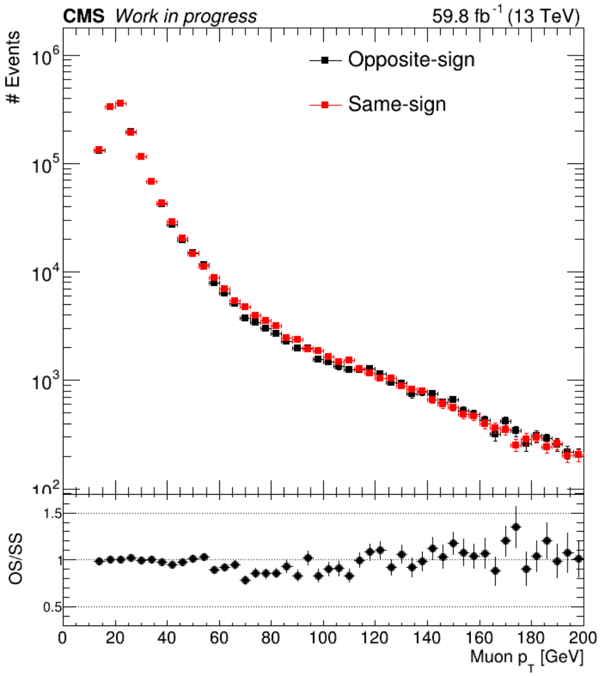
2016postAPV



2017



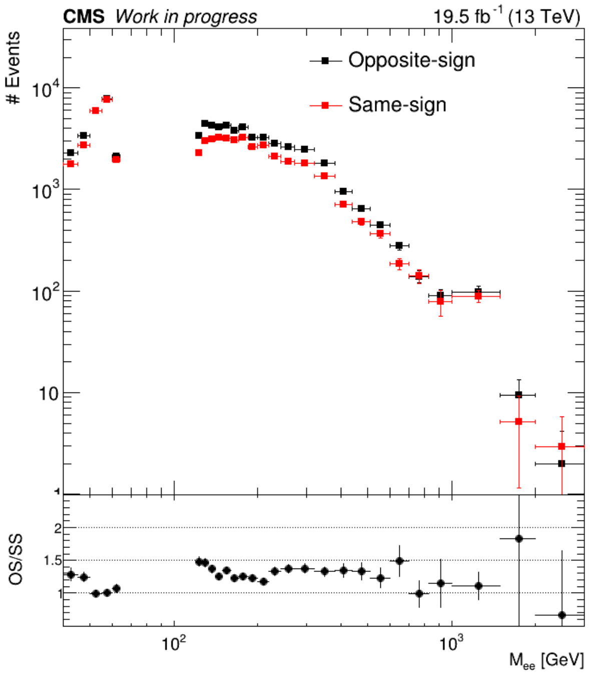
2018



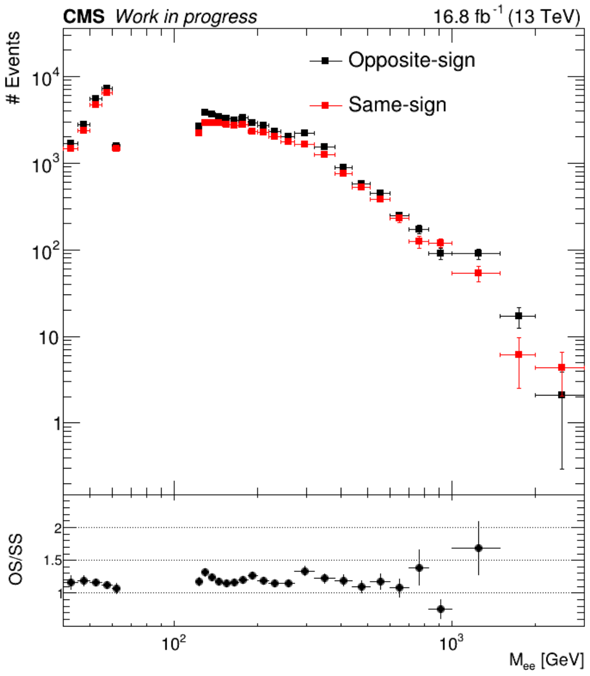
OS/SS ratio: electron channel

- Comparing OS and SS distributions in the electron channel sideband 1
- $R_{OS/SS}$ almost flat w.r.t. dilepton mass
- Check if there are strong dependencies on other variables (next slide)

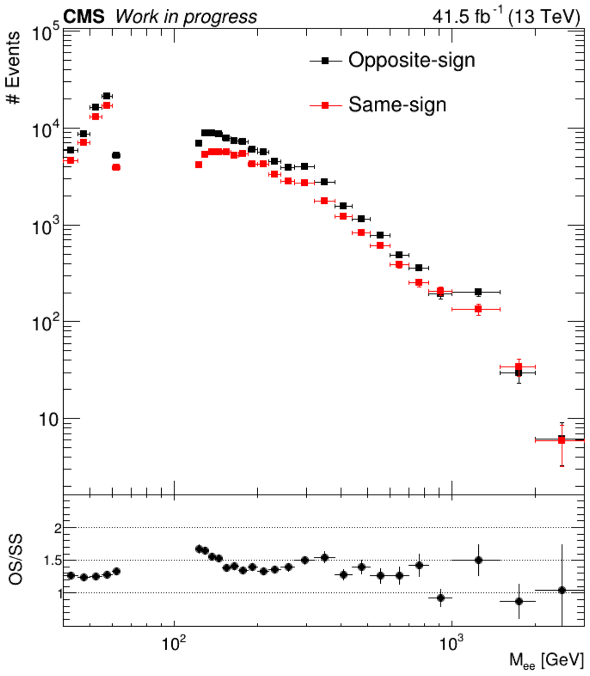
2016preAPV



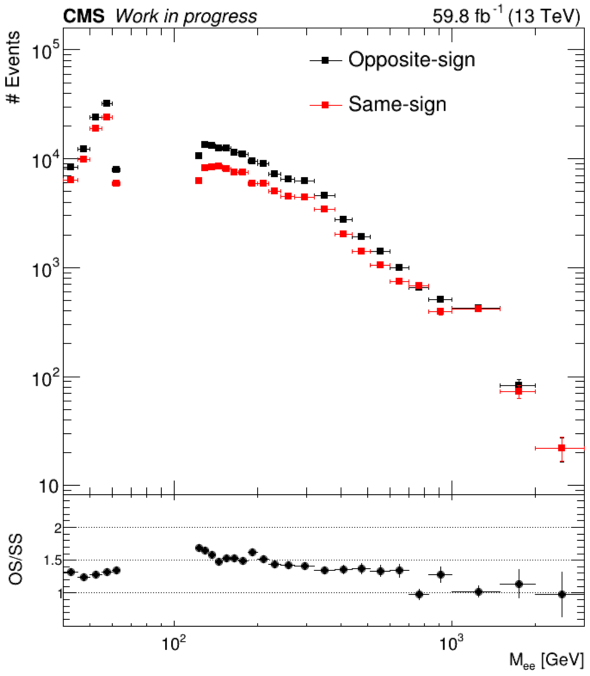
2016postAPV



2017



2018

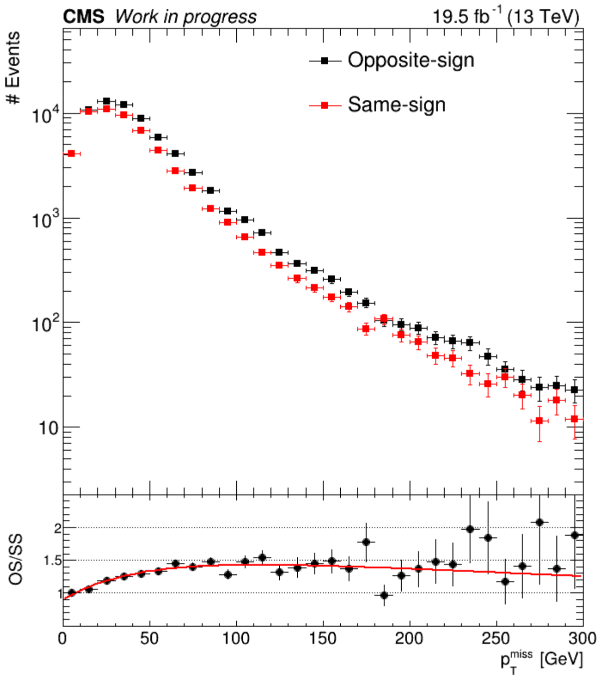


OS/SS ratio: electron channel (II)

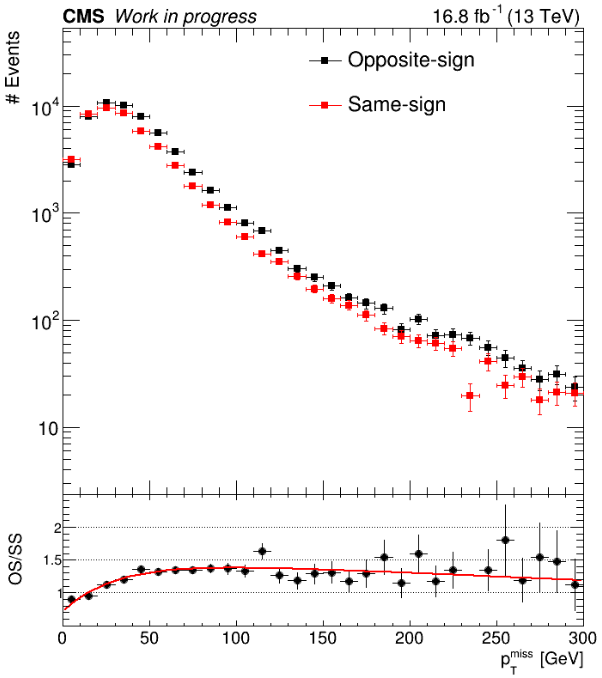
- $R_{OS/SS}$ also has strong dependence on missing p_T (possibly due to separation between W+Jets and QCD w.r.t. this variable)
- **Therefore, we measure $R_{OS/SS}$ in the electron channel as a 1D function of missing p_T**
- The ratio is fitted with an analytical 1D function (it is already shown in the ratio plot)

$$R_{OS/SS}(E_T^{miss}) = a_0 - a_1 E_T^{miss} - \exp\left(a_2 - a_3 E_T^{miss}\right)$$

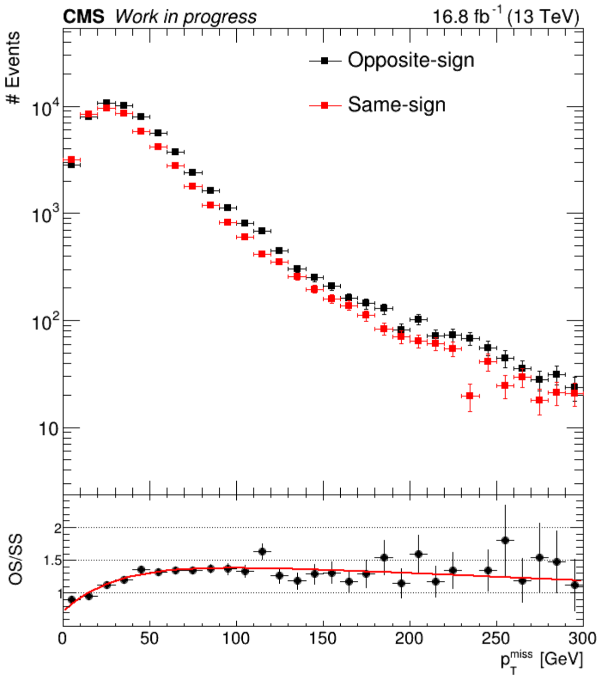
2016preAPV



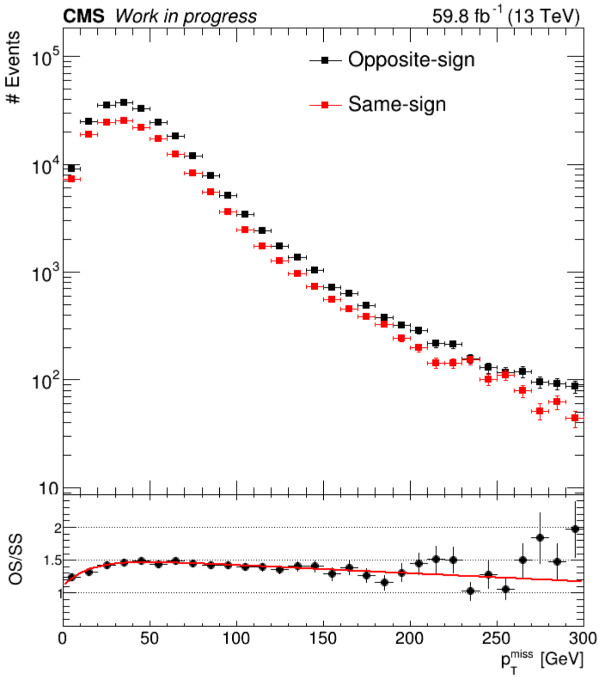
2016postAPV



2017



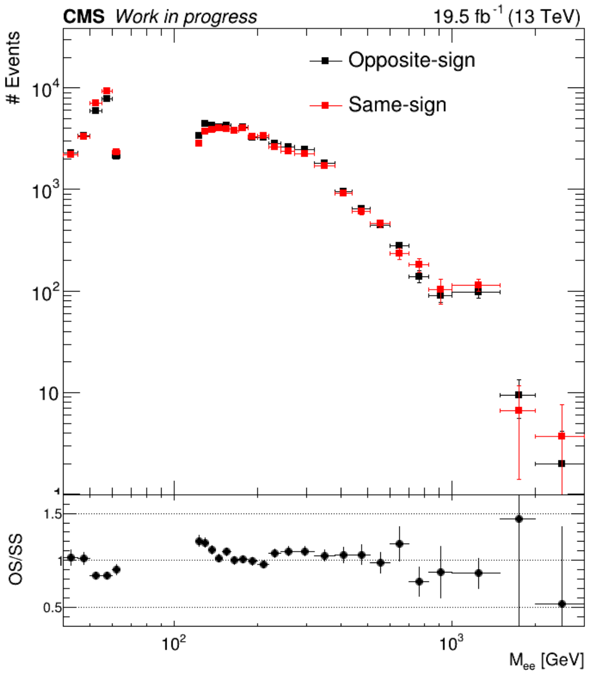
2018



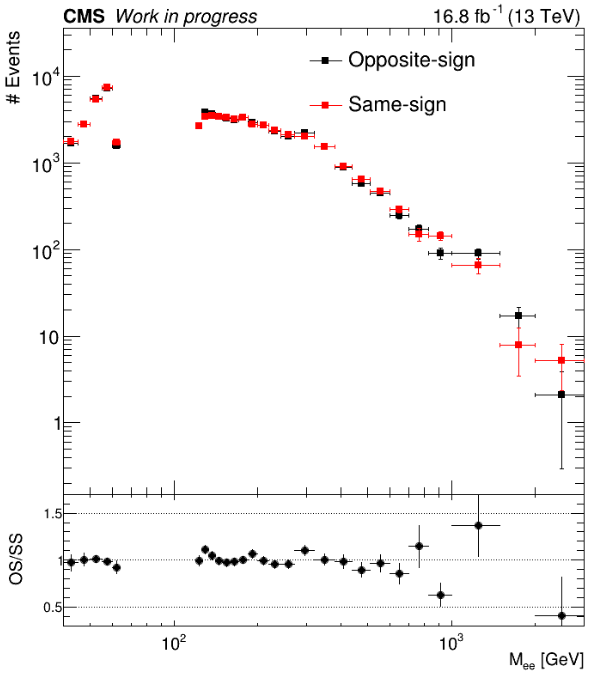
OS/SS ratio validation: electron channel

- We validate the obtained ratios by performing a closure test
  - Reweigh the SS events in the sideband itself and see if it matches the OS distribution there
- We can see that the closure is nearly perfect

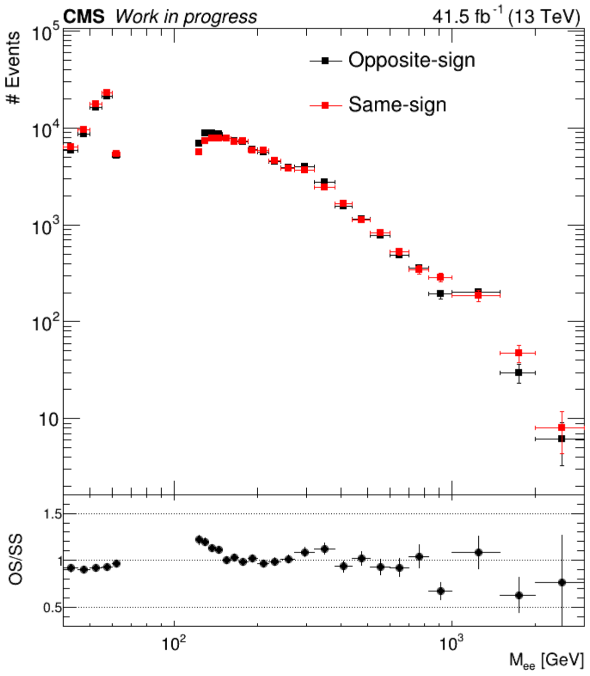
2016preAPV



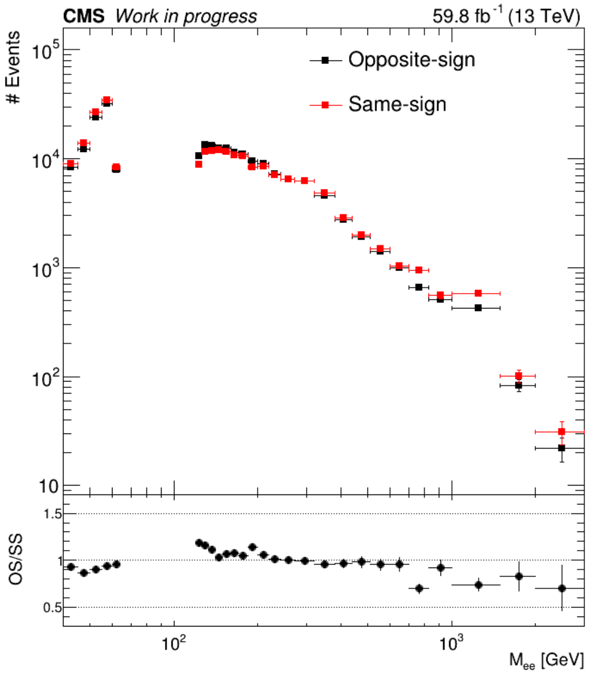
2016postAPV



2017



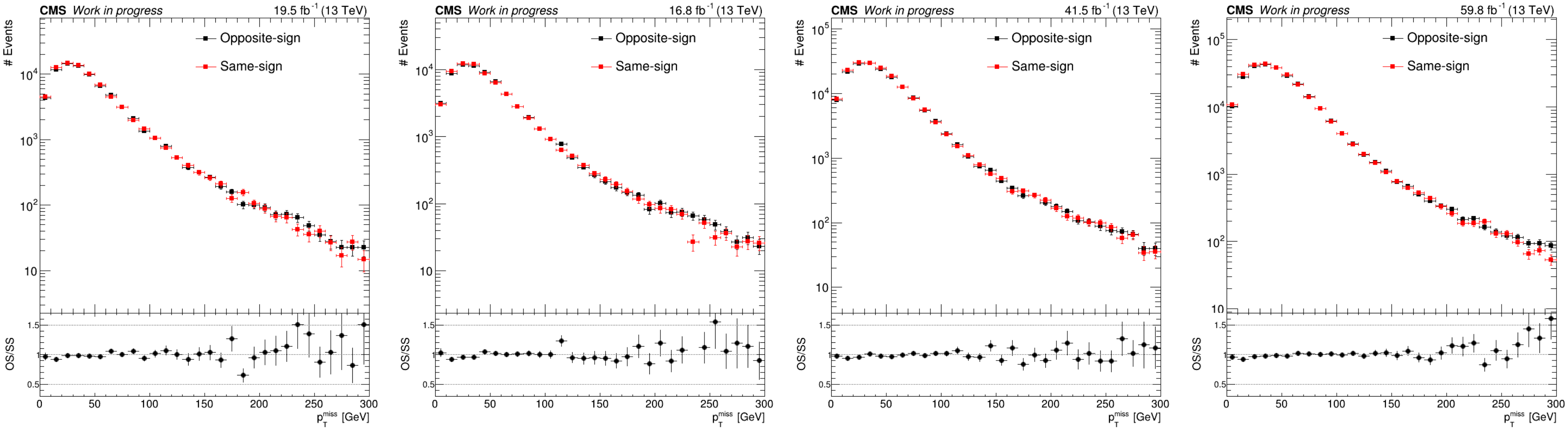
2018



OS/SS ratio validation: electron channel (II)

- We validate the obtained ratios by performing a closure test
  - Reweigh the SS events in the sideband itself and see if it matches the OS distribution there
- We can see that the closure is nearly perfect

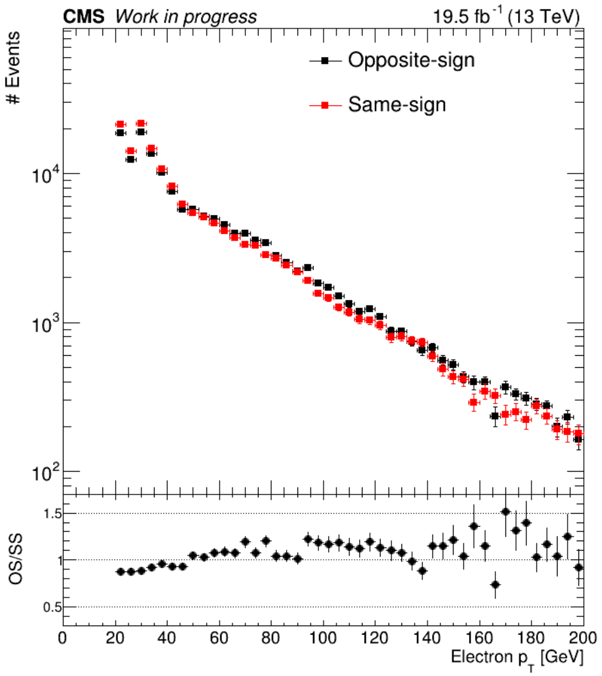
2016preAPV | 2016postAPV | 2017 | 2018



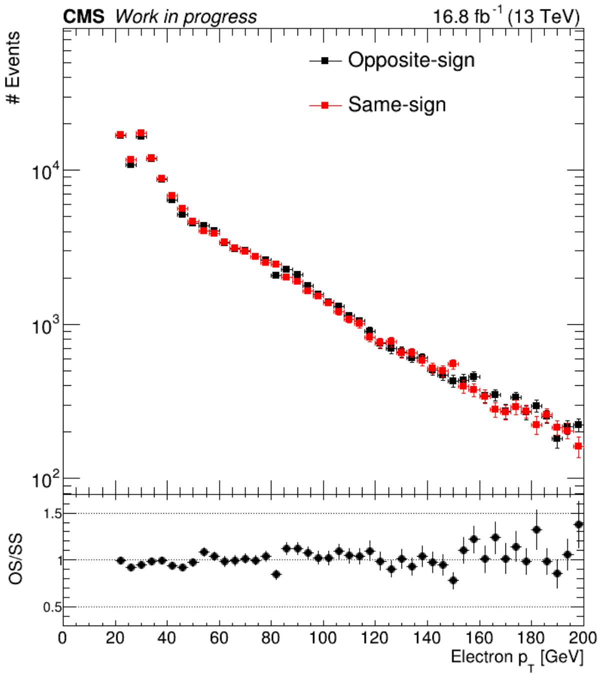
OS/SS ratio validation: electron channel (III)

- We validate the obtained ratios by performing a closure test
  - Reweigh the SS events in the sideband itself and see if it matches the OS distribution there
- There is some bias w.r.t electron p_T
  - **Acceptable for the current study, should be improved for the 2D measurement**

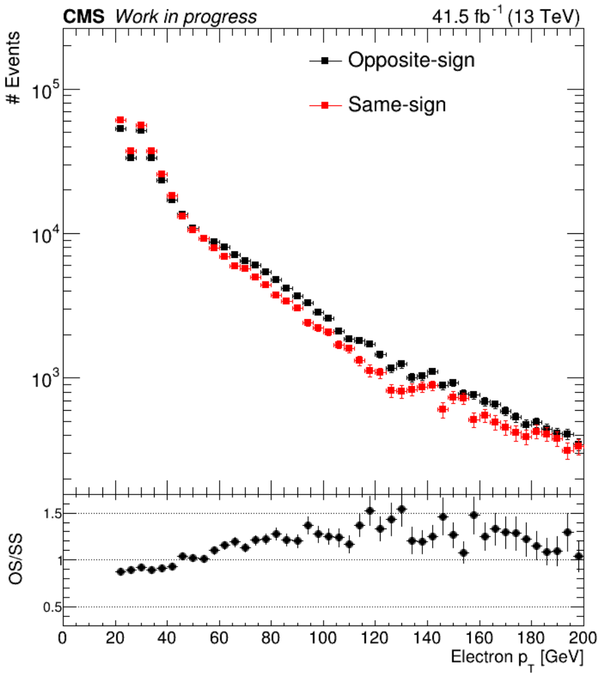
2016preAPV



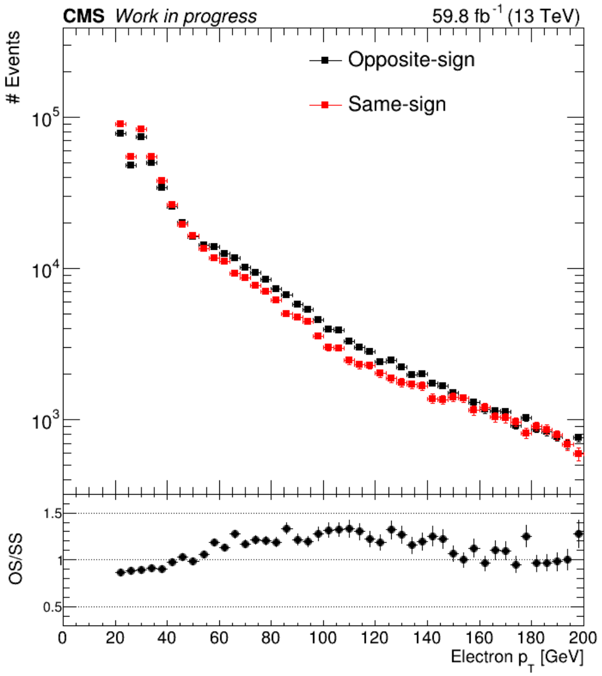
2016postAPV



2017



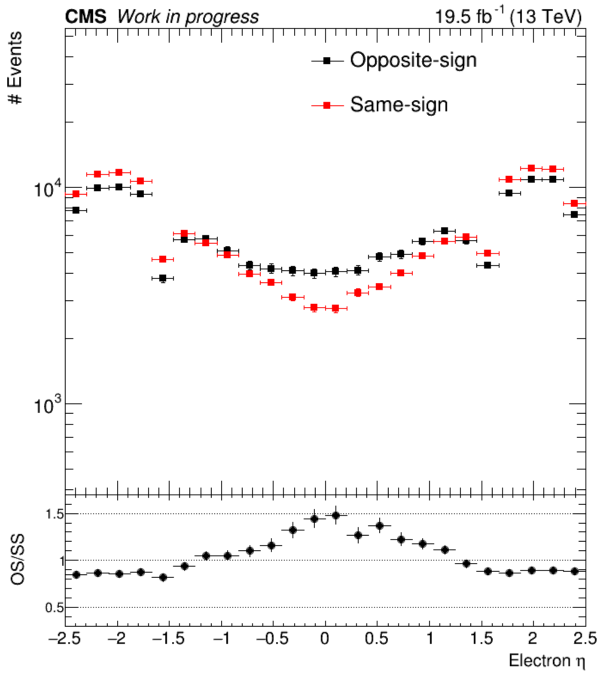
2018



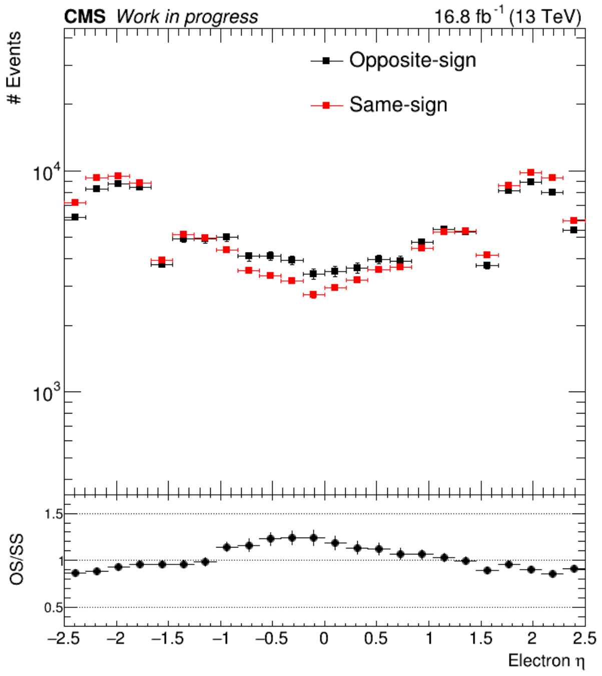
OS/SS ratio validation: electron channel (IV)

- We validate the obtained ratios by performing a closure test
  - Reweigh the SS events in the sideband itself and see if it matches the OS distribution there
- There is some relatively strong bias w.r.t electron η
  - **Acceptable for the current study, must be improved for the 2D measurement**

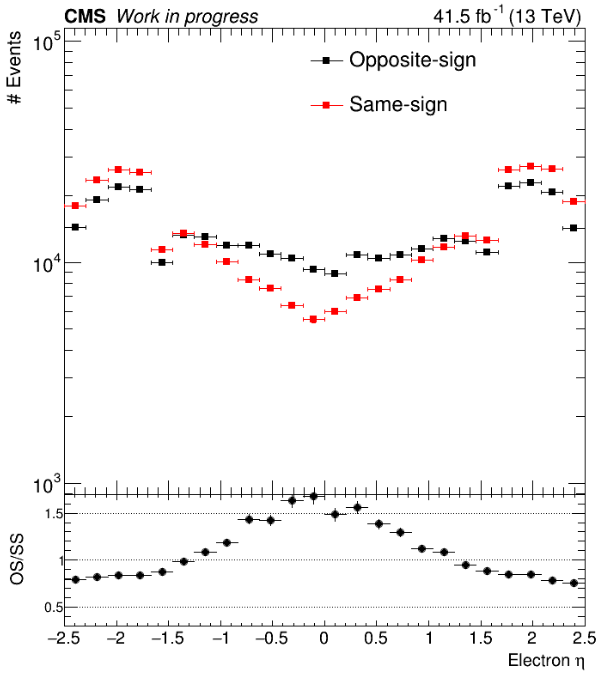
2016preAPV



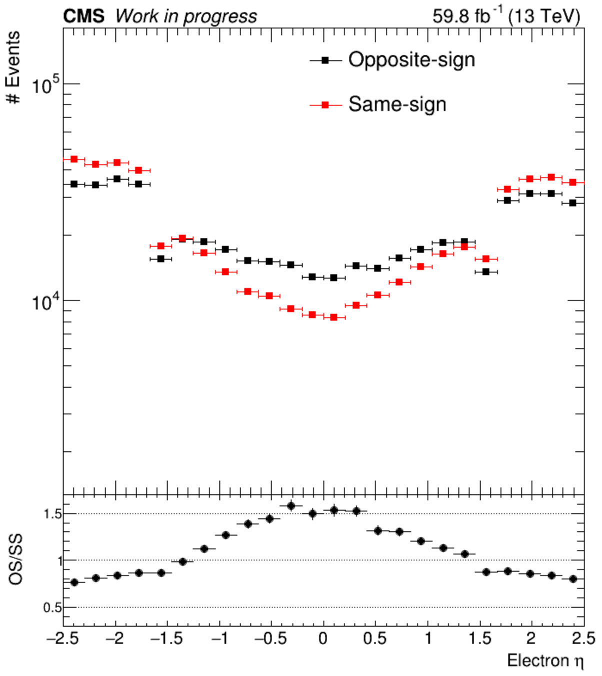
2016postAPV



2017



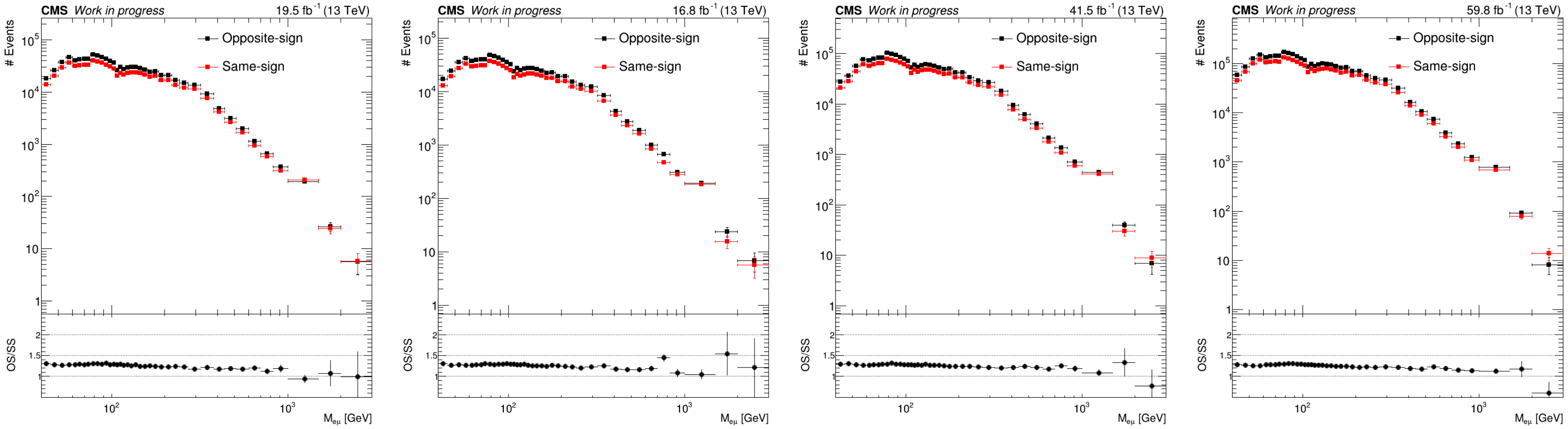
2018



OS/SS ratio: eμ channel

- The ratio is almost perfectly flat w.r.t dilepton mass
  - Similar with other distributions
- Therefore, we use a constant value $R_{OS/SS}$=1.27 for all eras
- No closure test is needed for a constant ratio (it is just rescaling the whole histogram)

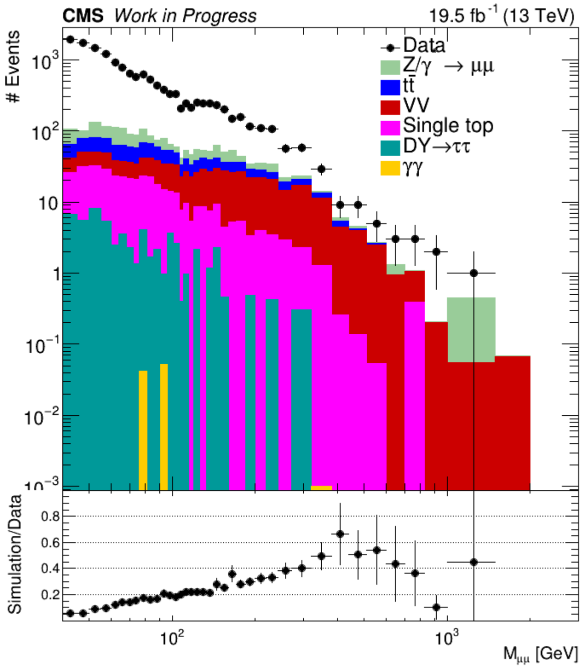
2016preAPV 2016postAPV 2017 2018



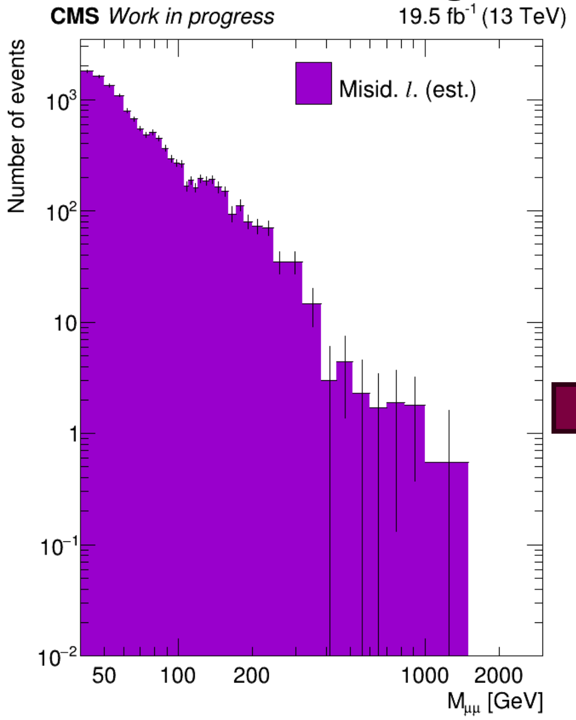
Fake lepton background estimation

Data-MC

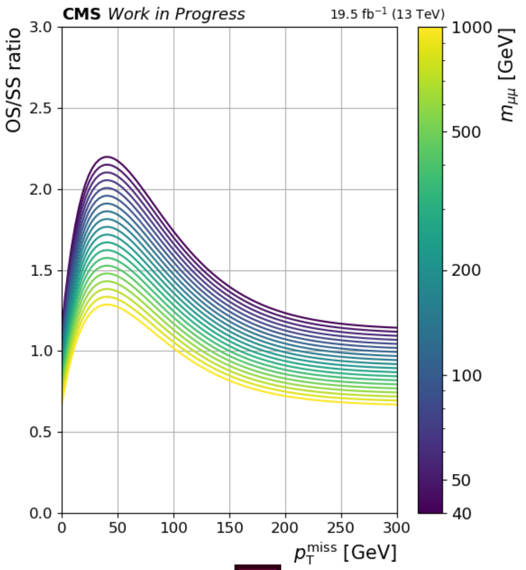
Same-sign



Fakes, same-sign



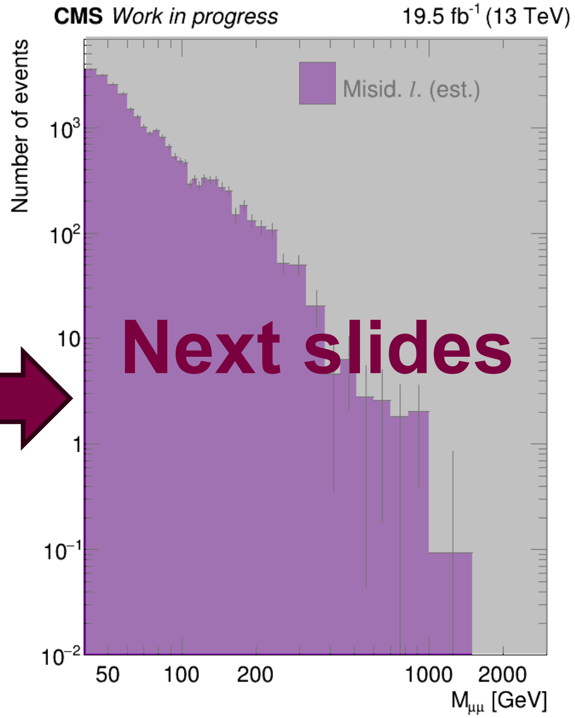
$R_{OS/SS}$, sideband



Use these weights

Reweight

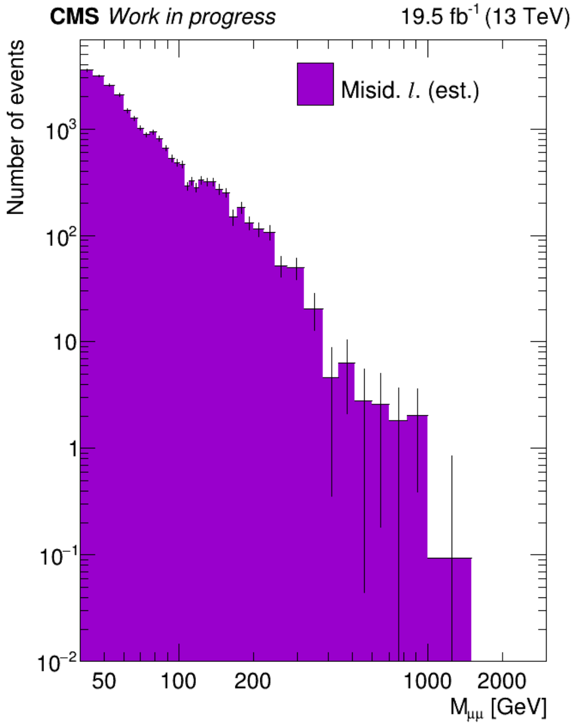
Fakes, opposite sign (signal region)



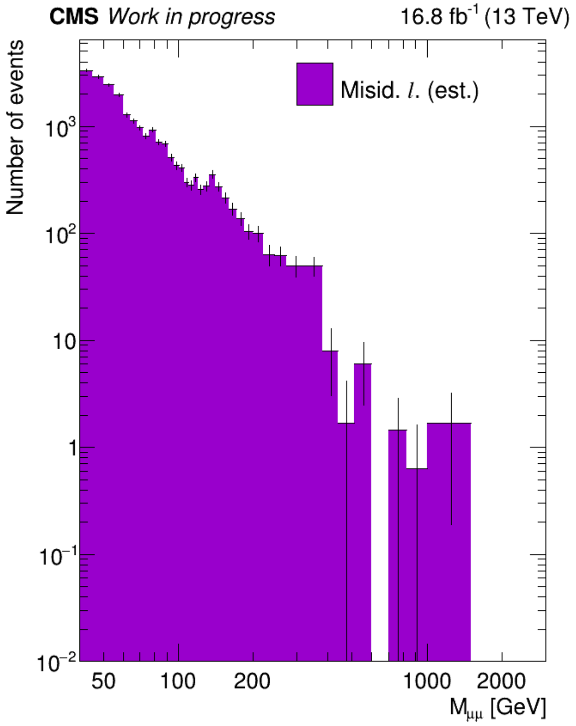
Next slides

Final fake lepton background (opposite-sign): muon channel

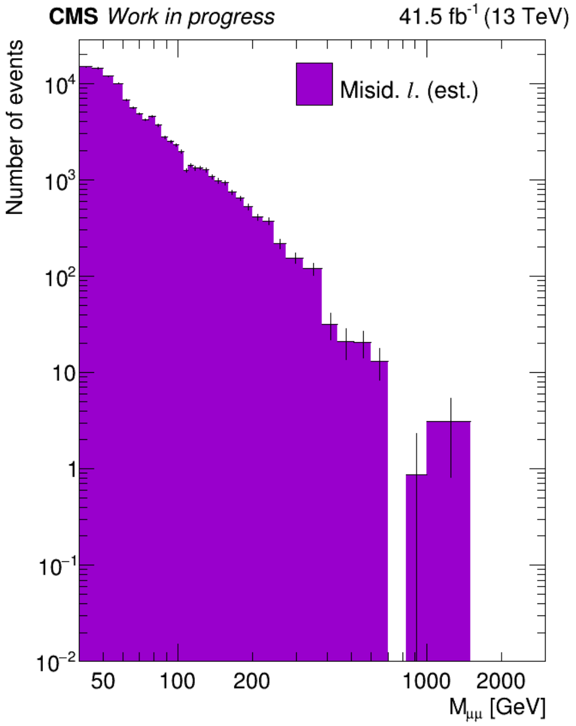
2016preAPV



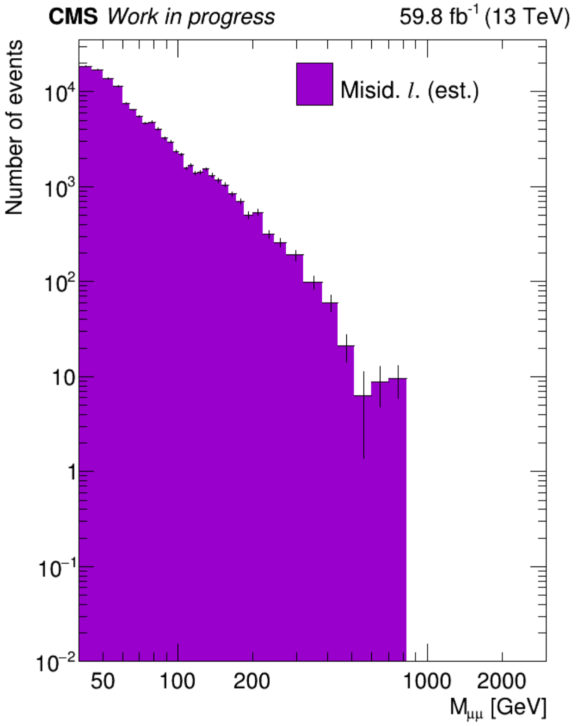
2016postAPV



2017



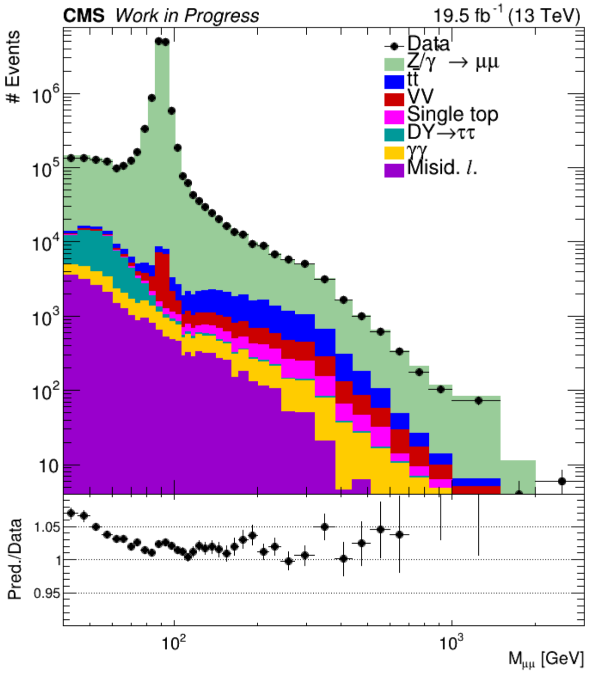
2018



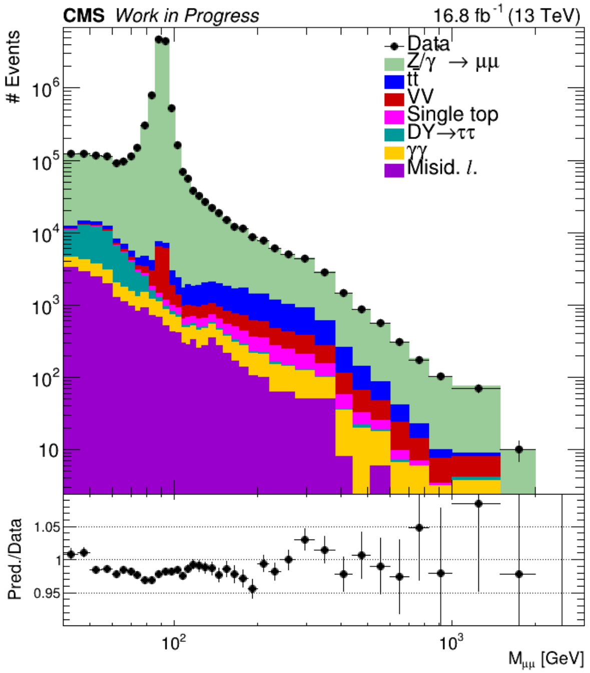
Final fake lepton background (opposite-sign): muon channel (II)

- View of the whole signal region
- Discrepancy at low mass was already apparent before adding fake lepton backgrounds

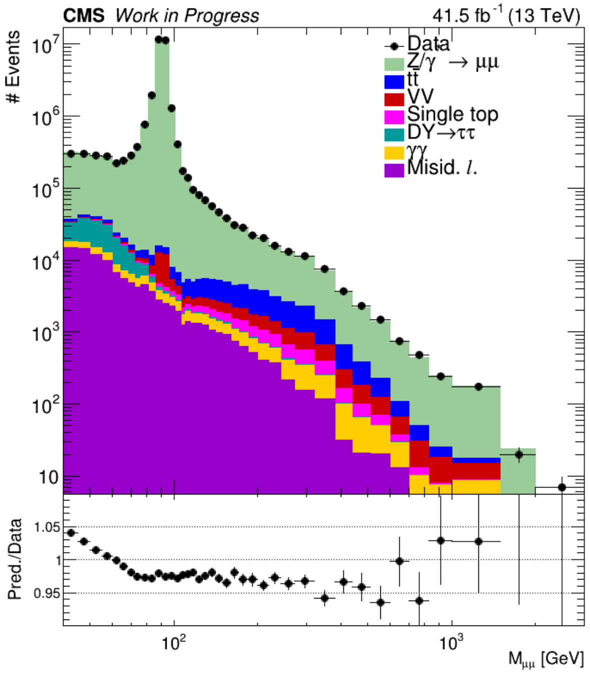
2016preAPV



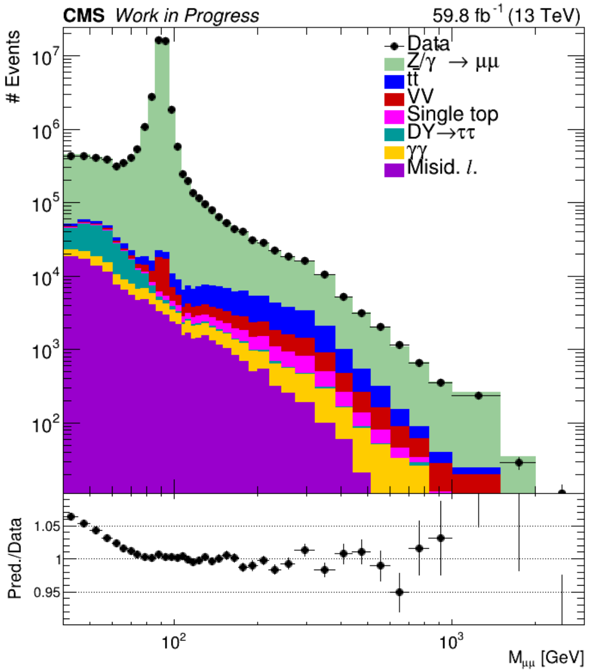
2016postAPV



2017



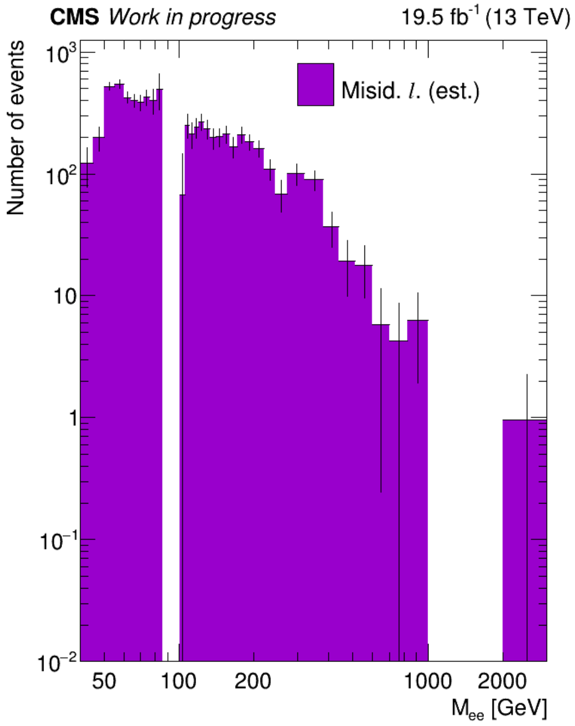
2018



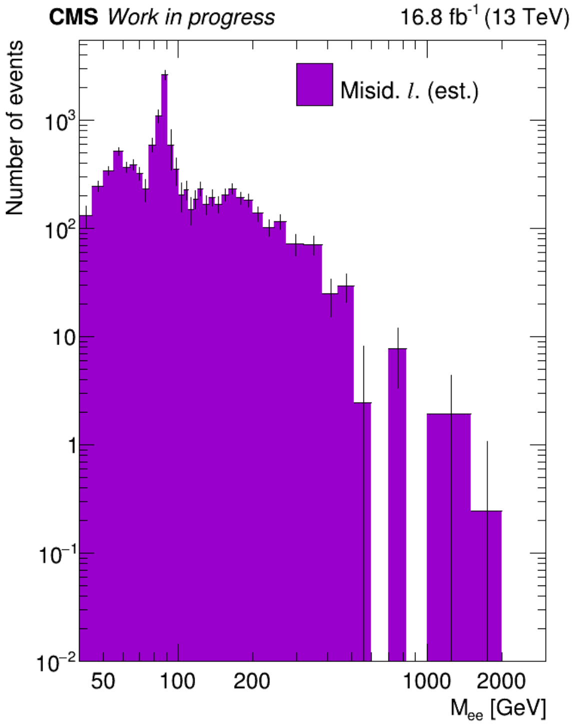
Fake lepton background (opposite-sign): electron channel

- Result unreliable in the Z peak region
- Fakes are negligible compared to DY in that region
- Nevertheless, we improve the result by linearly interpolating from outside into the Z peak region

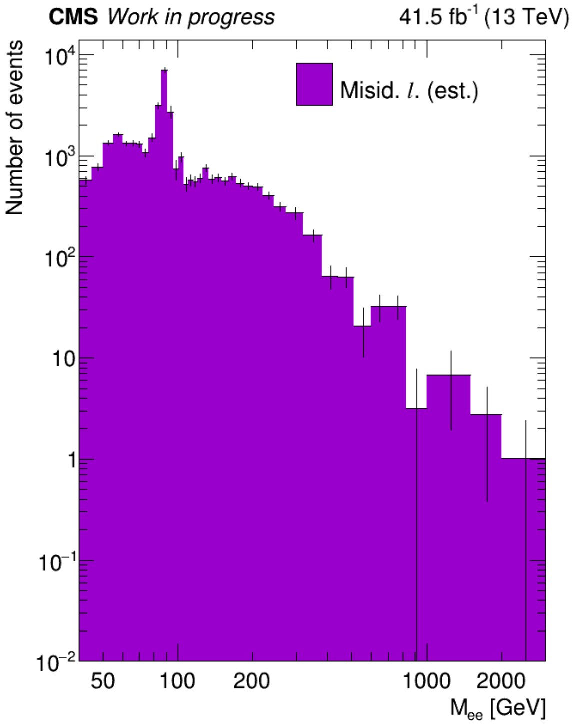
2016preAPV



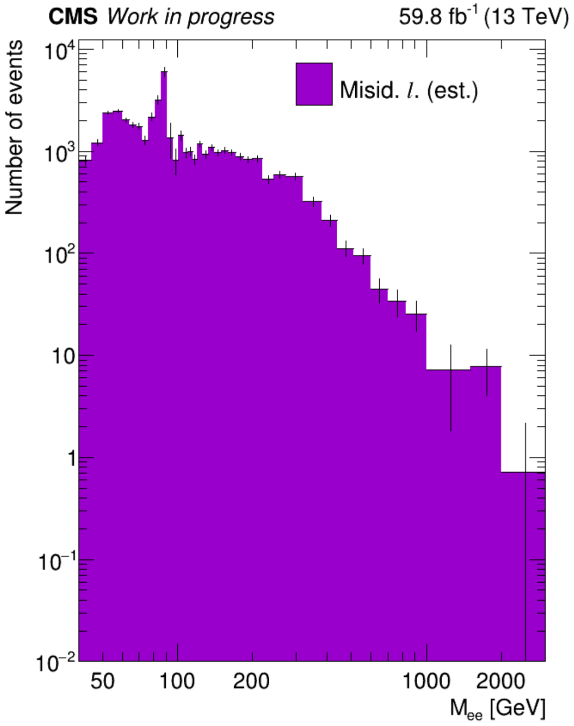
2016postAPV



2017



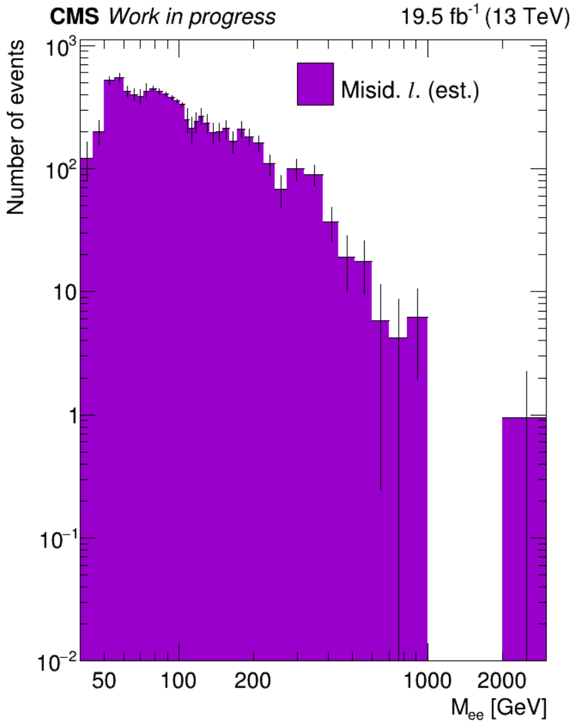
2018



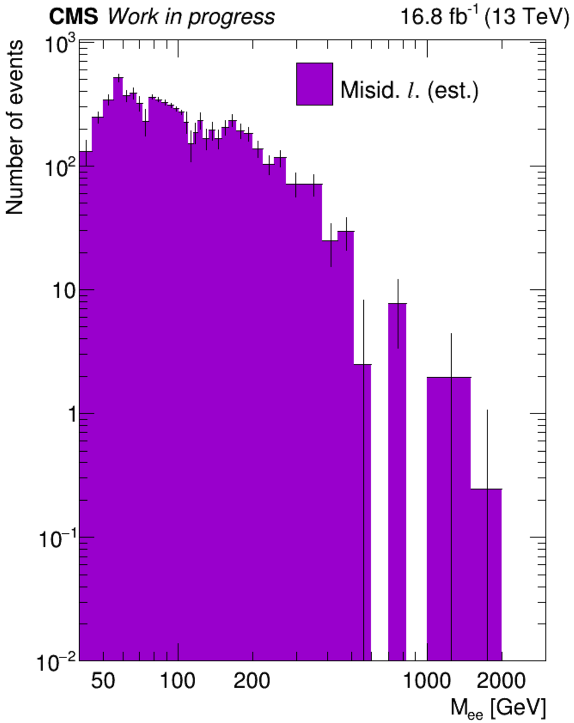
Final fake lepton background (opposite-sign): electron channel

- The apparent "jump" where the interpolated result starts is mainly due to binning
  - I am interpolating the density plot and then reverting it back into a simple histogram

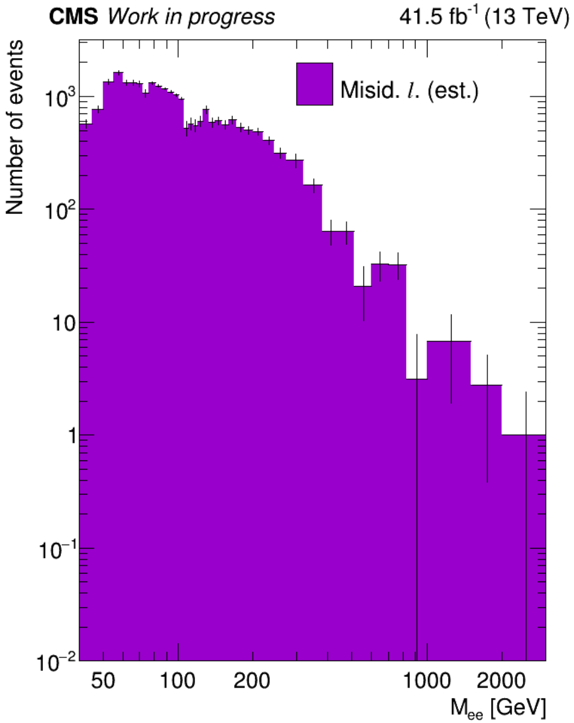
2016preAPV



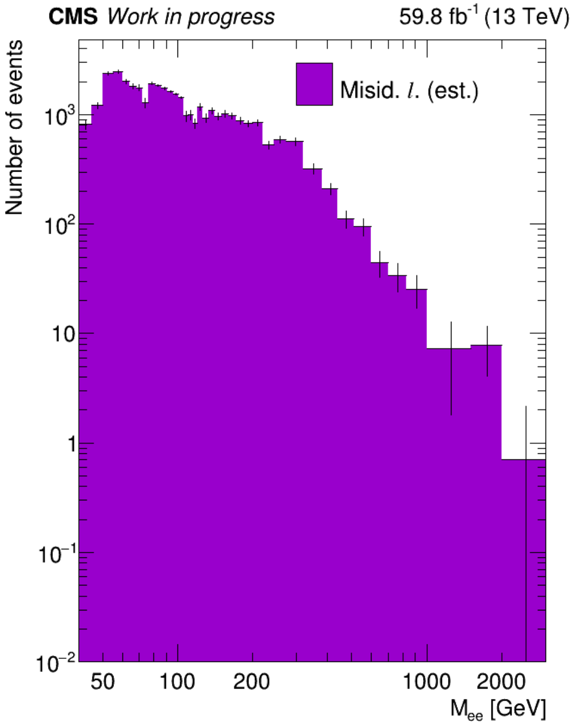
2016postAPV



2017



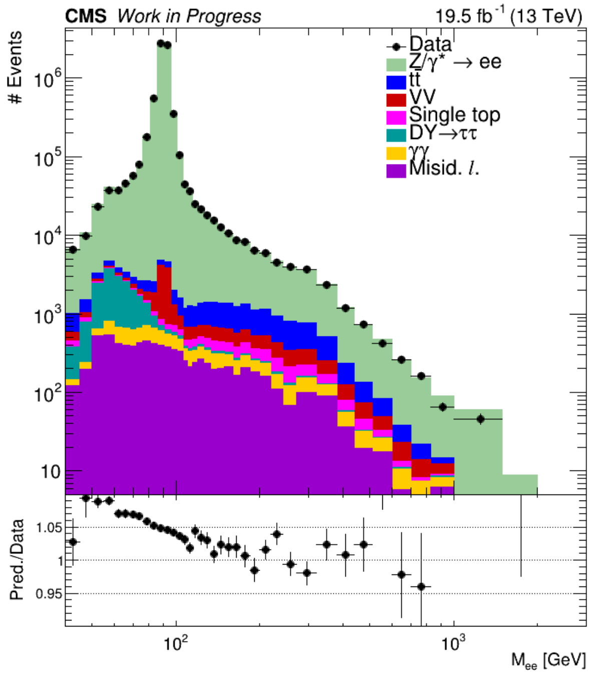
2018



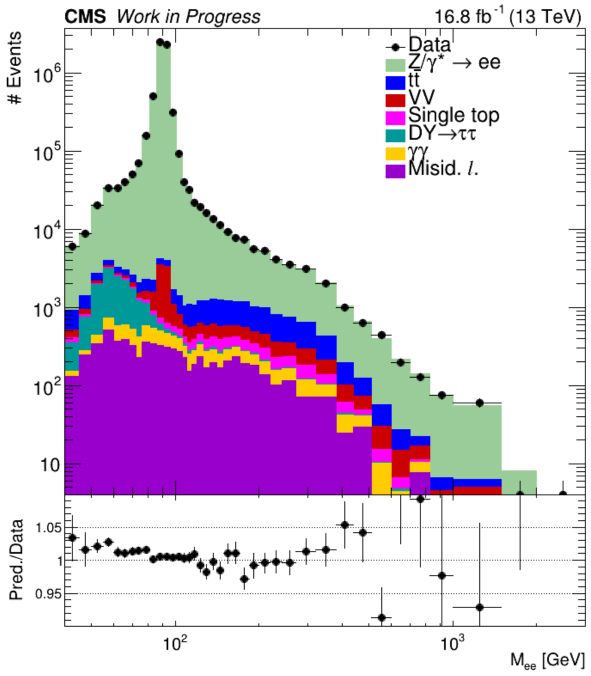
Final fake lepton background (opposite-sign): electron channel (II)

- View of the whole signal region

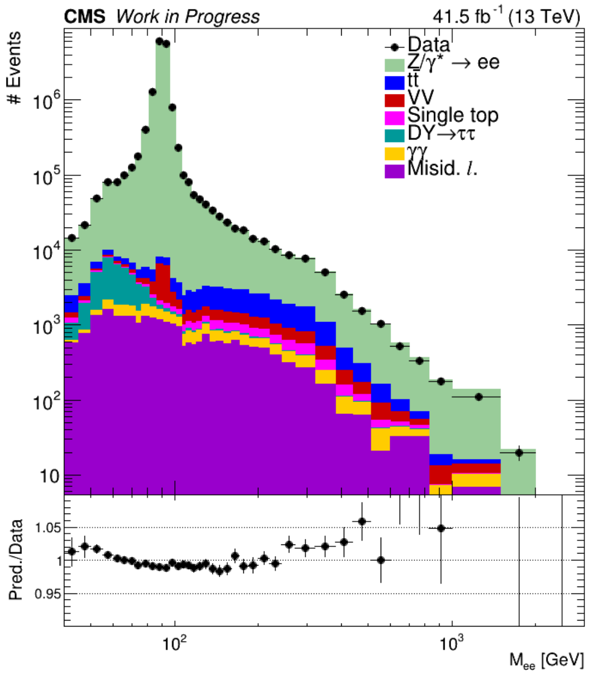
2016preAPV



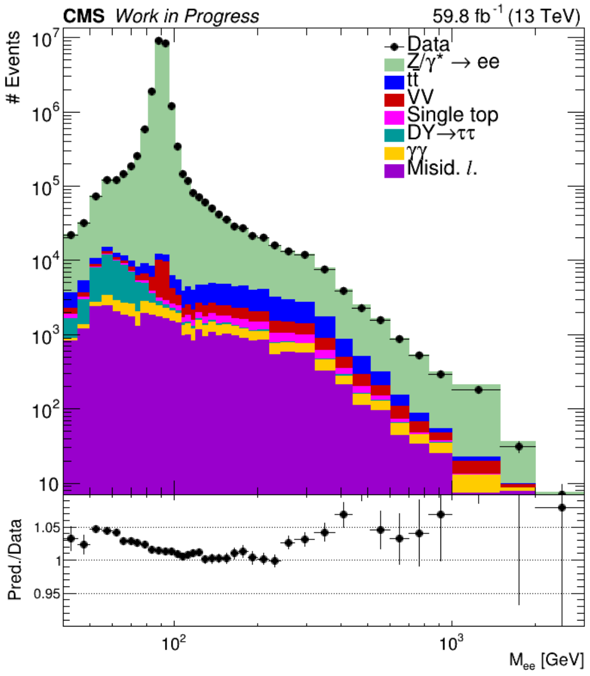
2016postAPV



2017



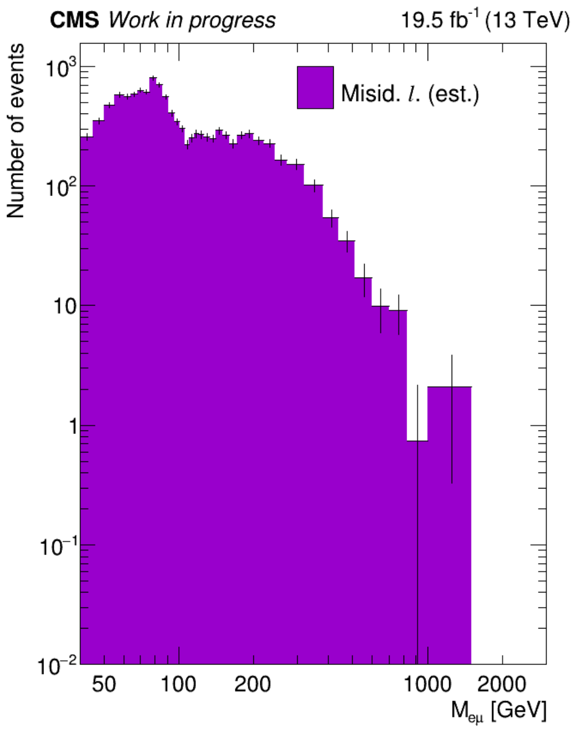
2018



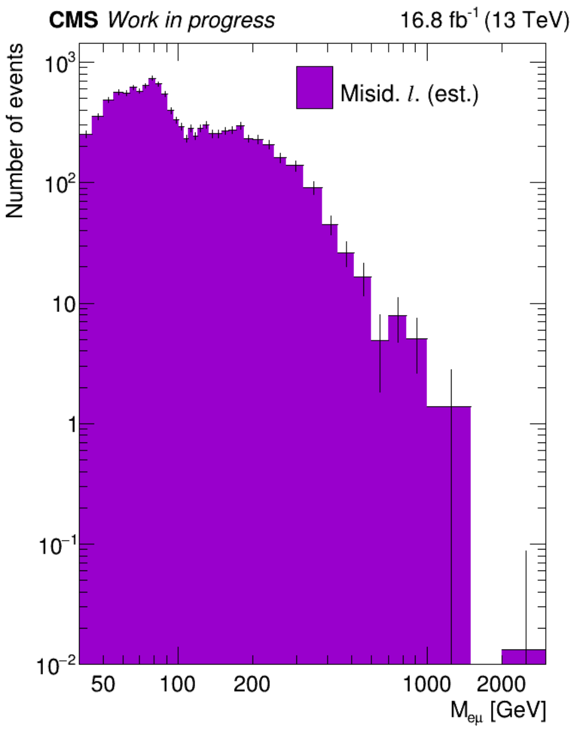
Final fake lepton background (opposite-sign): eμ channel

- The shape is reminiscent of the electron channel fakes
- Maybe could be used as a template in electron channel?

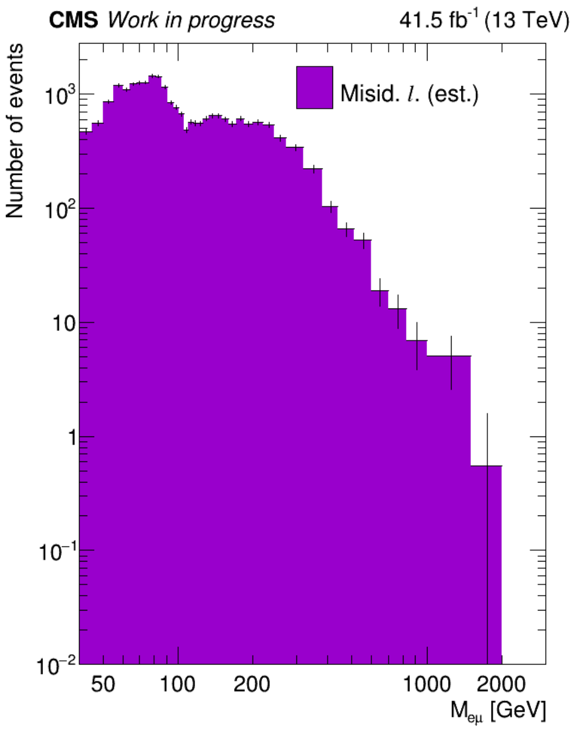
2016preAPV



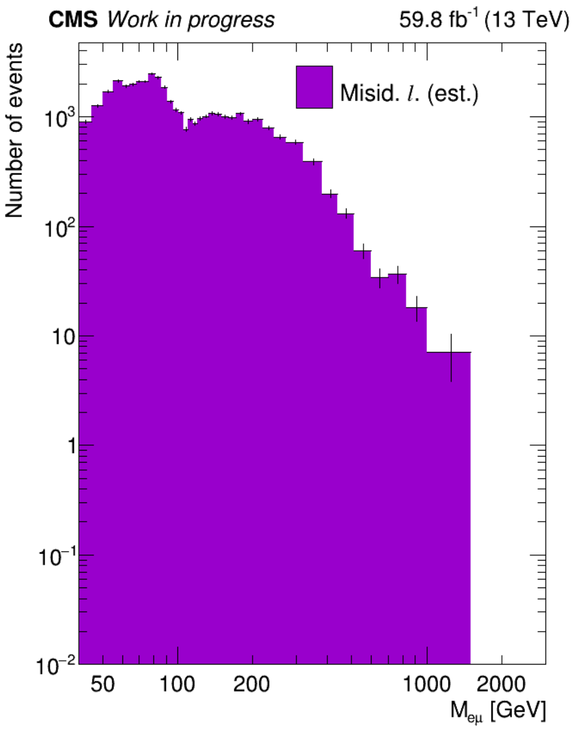
2016postAPV



2017



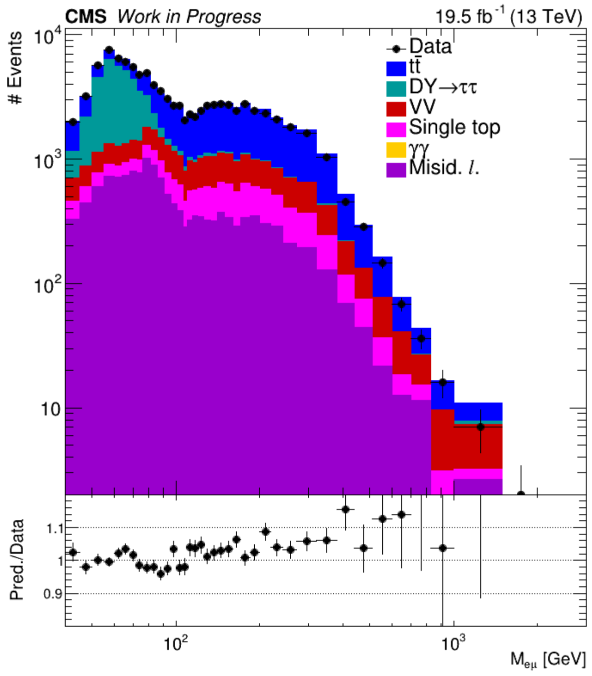
2018



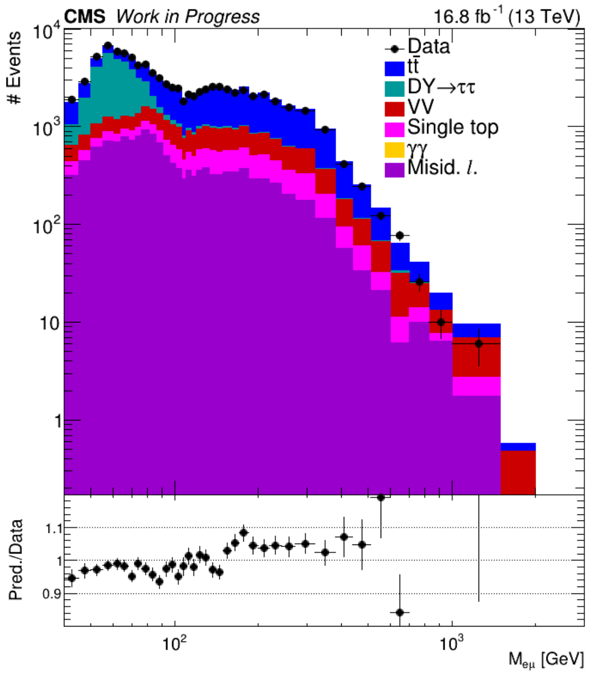
Final fake lepton background (opposite-sign): eμ channel (II)

- View of the whole “signal” region

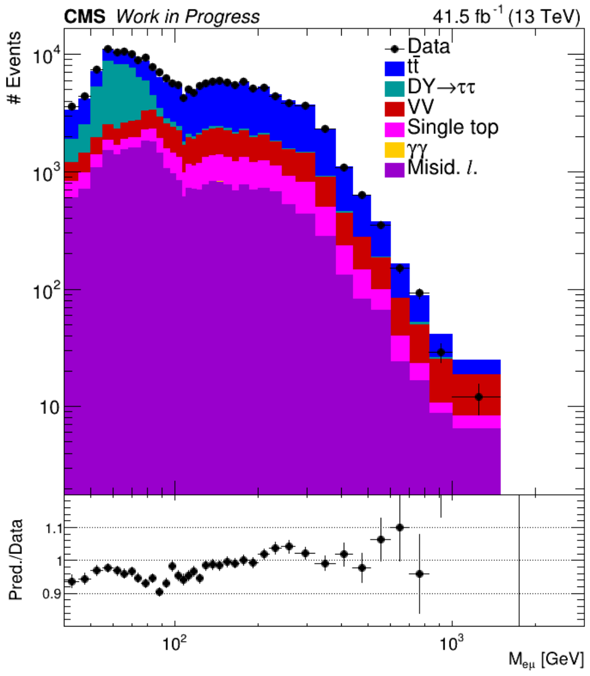
2016preAPV



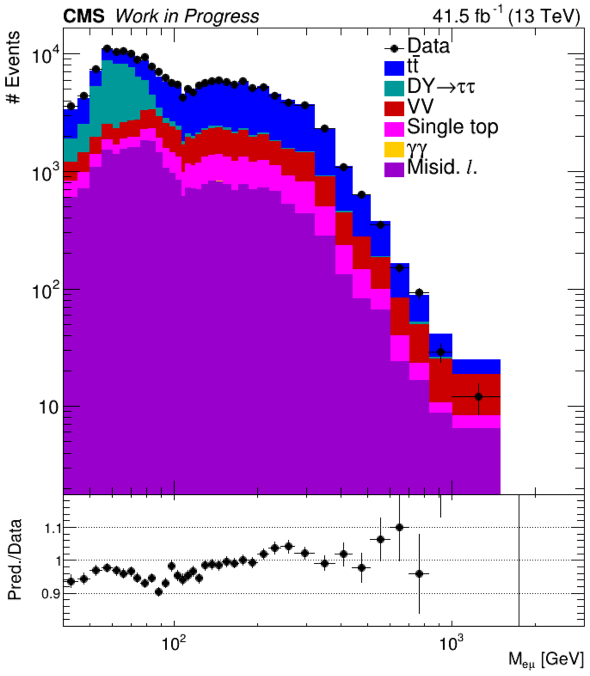
2016postAPV



2017



2018



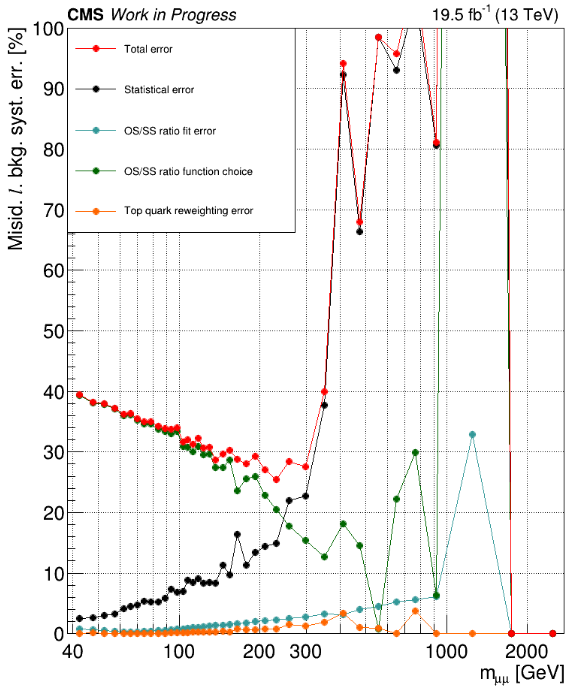
Systematic uncertainty

- The following systematic uncertainty sources were considered for the fake background estimation (grey – only for electron channel):
  1. $R_{OS/SS}$ fit parameter uncertainties
     - Estimated using fit parameter variations by the error values given from the fit
  2. $R_{OS/SS}$ fit function choice
     - Estimated using an alternative $R_{OS/SS}$ value which is just a constant average $R_{OS/SS}$
  3. Same-sign top quark background reweighting using the eμ method
     - Estimated as the difference between the nominal result and the one where MC top background is not reweighted
  4. Electron charge misidentification scale factor uncertainty
     - Estimated from up/down variation of charge misID SFs within their provided errors
  5. Z peak interpolation choice
     - Estimated using an alternative cubic interpolation
- For the eμ channel, considering that no fitting, interpolation, or top quark background reweighting was done to evaluate the fake lepton backgrounds, a constant systematic uncertainty of 10% was assigned

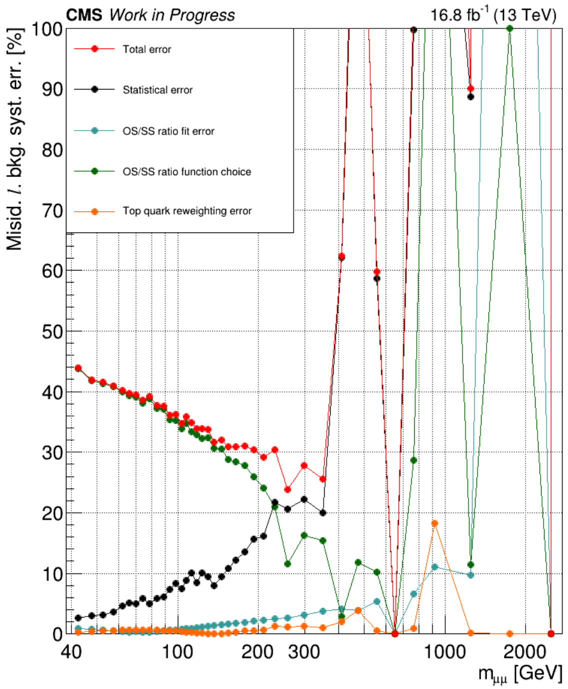
Systematic uncertainty: muon channel

- The total error does not exceed 50% for masses below 400 GeV
- $R_{OS/SS}$ function choice error dominant at low mass
- Statistical error dominant at high mass

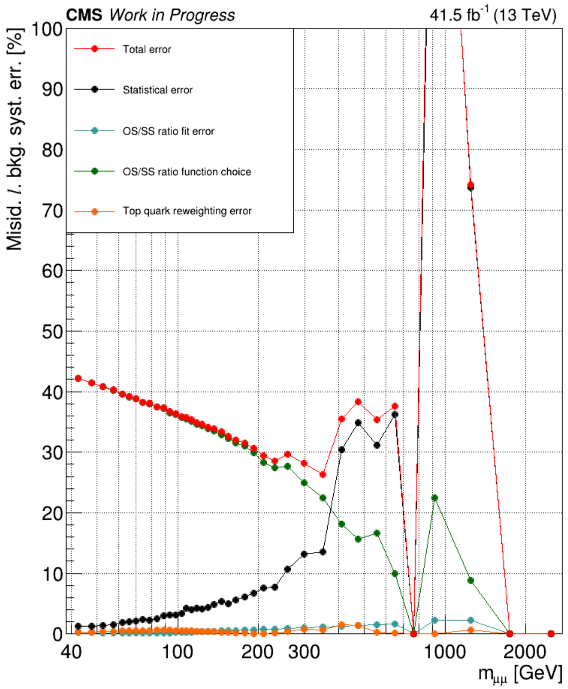
2016preAPV



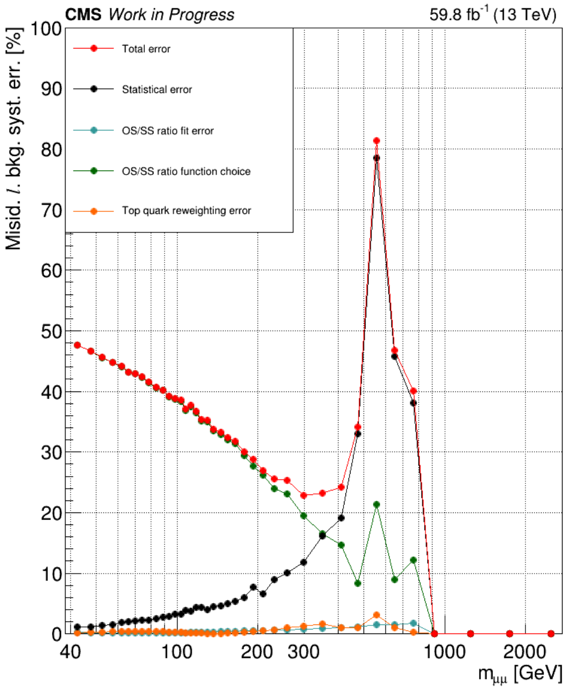
2016postAPV



2017



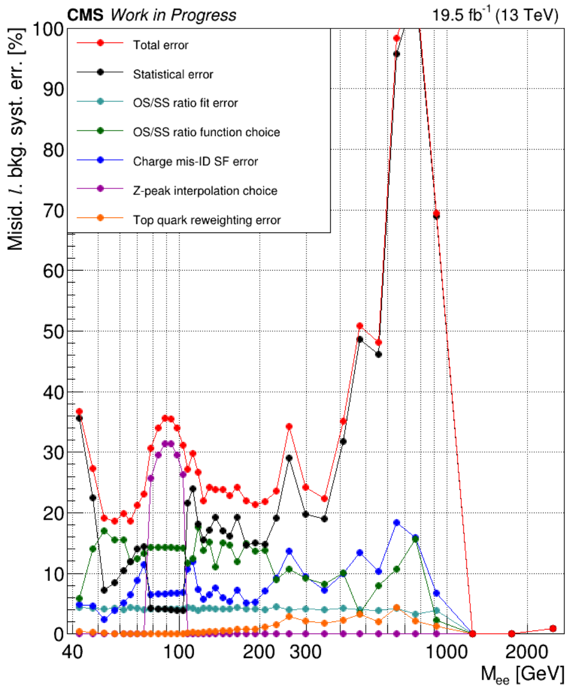
2018



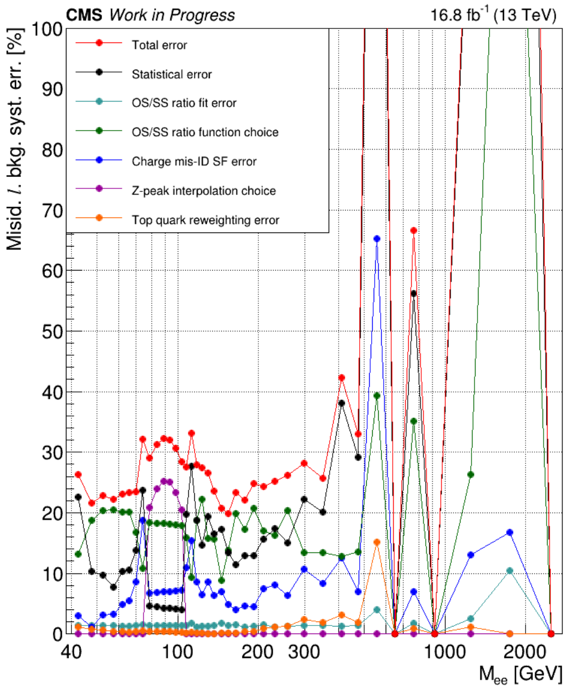
Systematic uncertainty: electron channel

- The total error does not exceed 40% for masses below 400 GeV
- $R_{OS/SS}$ function choice error dominant at low mass
- Interpolation error dominant in the Z peak region
- Statistical error dominant at high mass

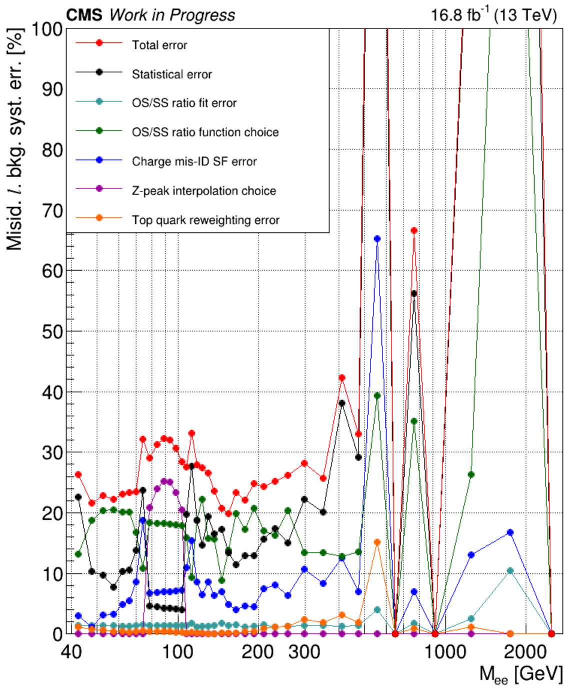
2016preAPV



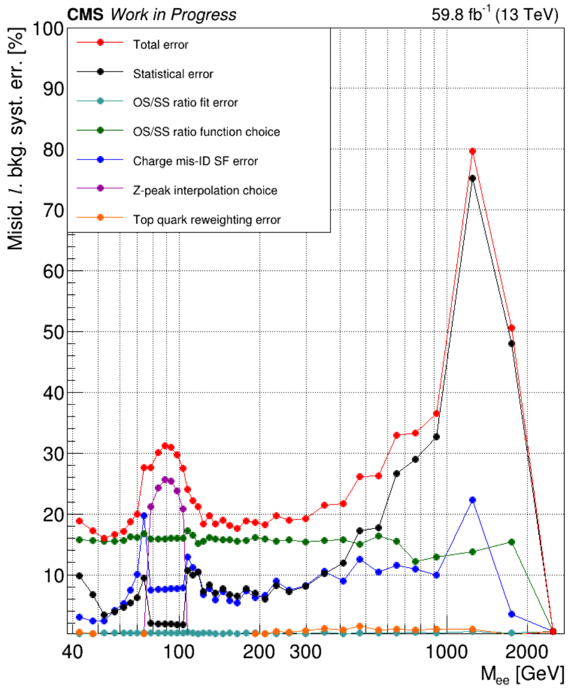
2016postAPV



2017



2018



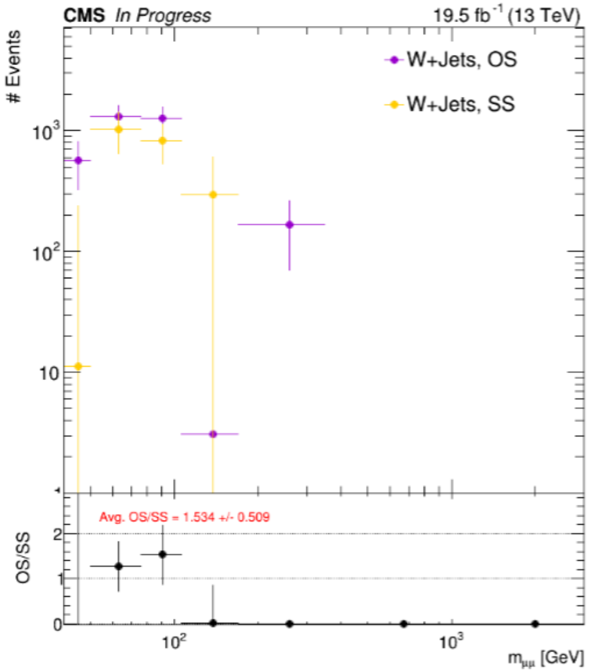
Wrap-up and discussion

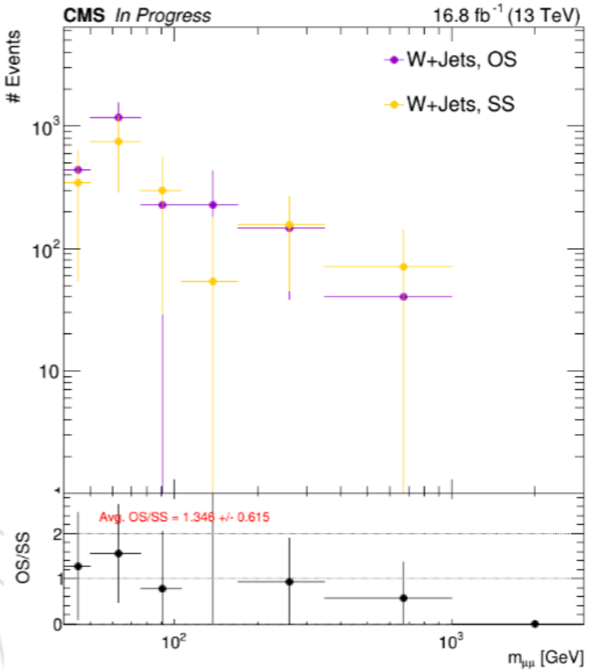
- “Fake” lepton backgrounds – mainly from non-prompt decays inside jets
- Dominant fake lepton backgrounds in DY analysis: W+Jets, QCD multijet, (γ+jets almost negligible)
- Data-driven methods needed, many different are available
- Same-sign method is the choice for our analysis, mainly due to simplicity

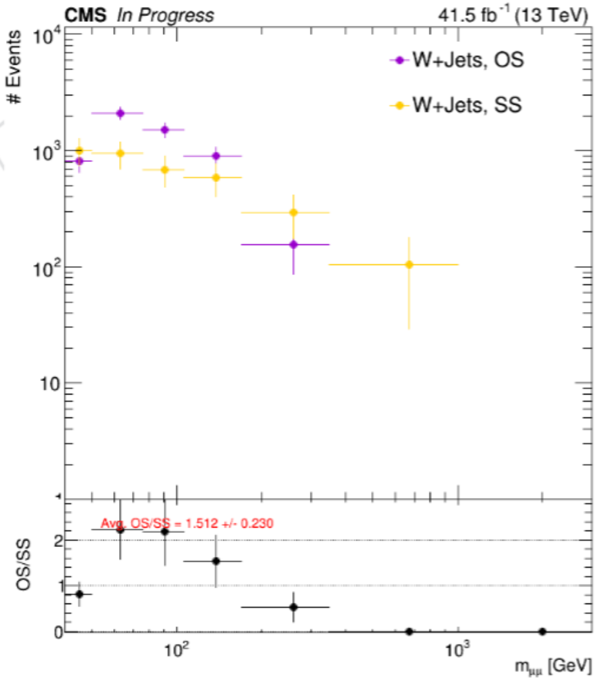
- Same-sign method: estimate the background in the same-sign region, reweight using the transfer ratio estimated from the sideband
- The best sideband – where one muon (electron) fails the ISO (Medium ID) cut
- OS/SS transfer ratio estimated as a function of event variables
- Closure test shows that the method is robust but should be improved in the electron channel for the 2D analysis
- Electron channel uses electron charge misidentification correction and histogram interpolation to the Z peak region to obtain a more reliable result
- The final result has errors <50% in the low mass region (where the background is the most relevant)

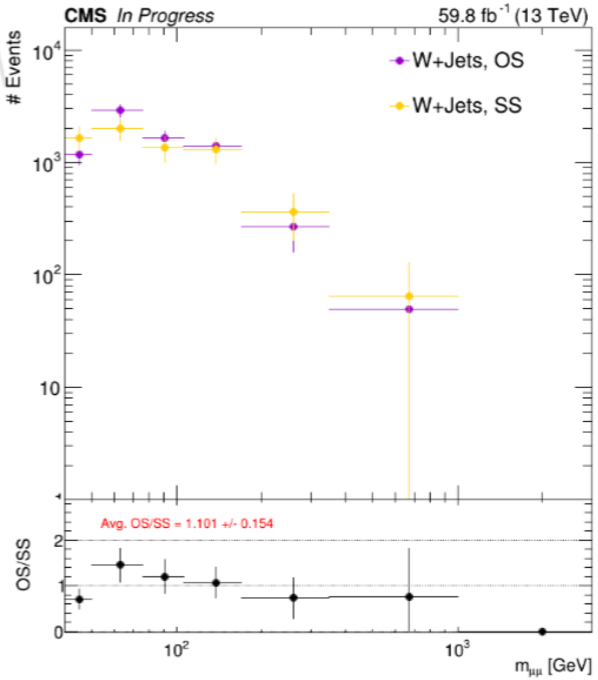
Backup

OS/SS ratio for W+Jets → μμ

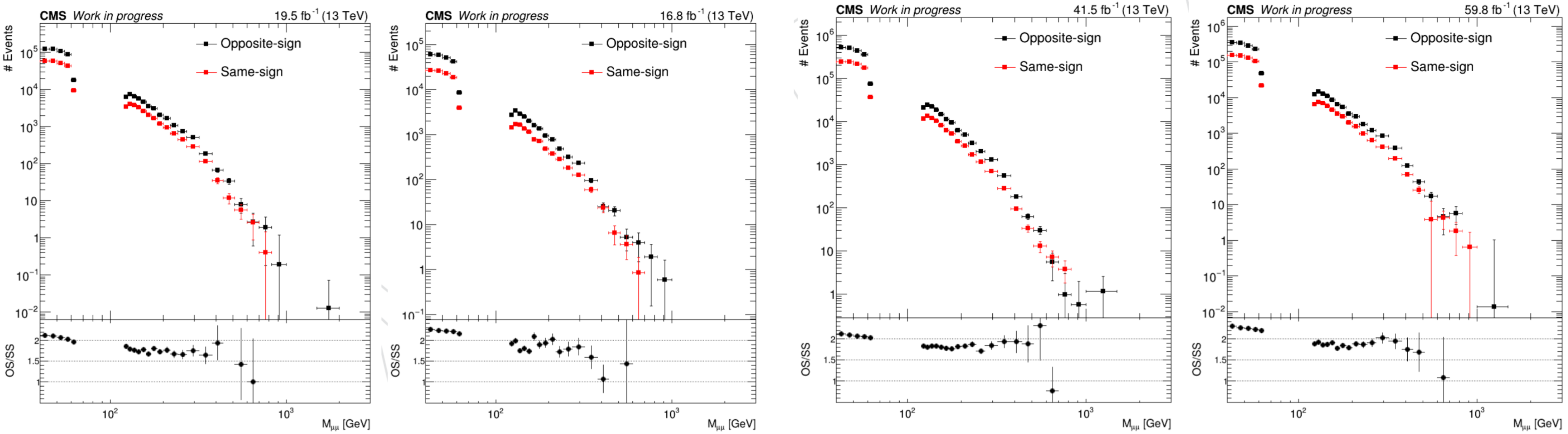




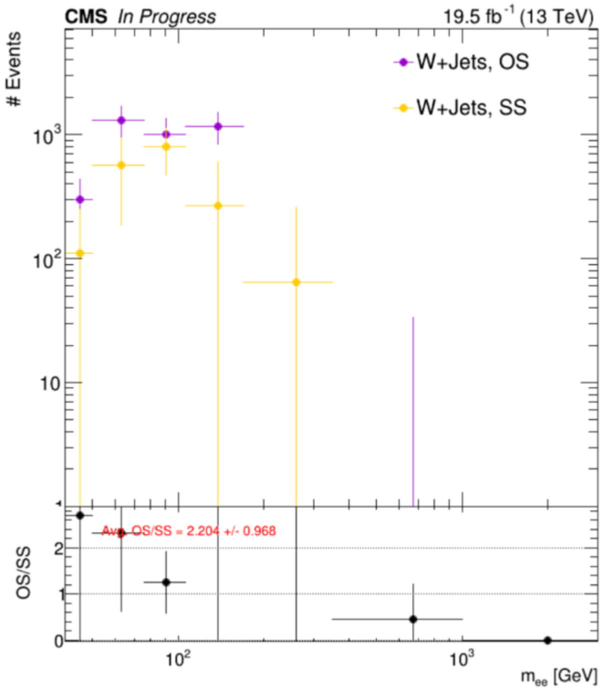


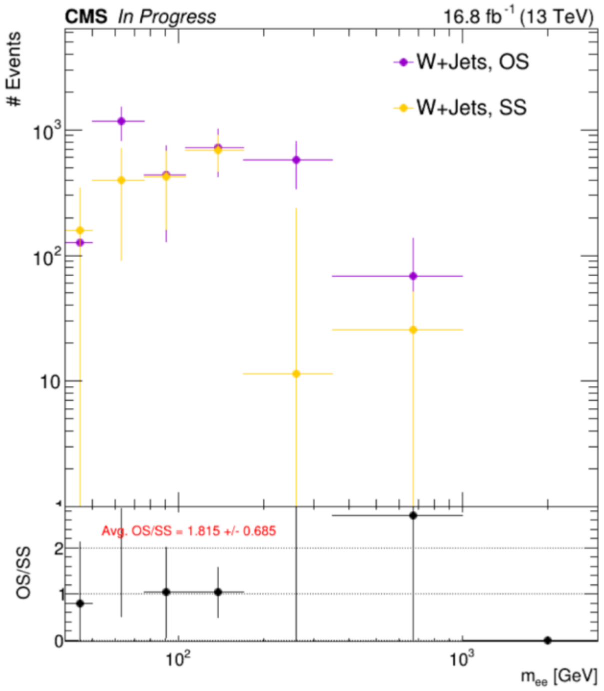


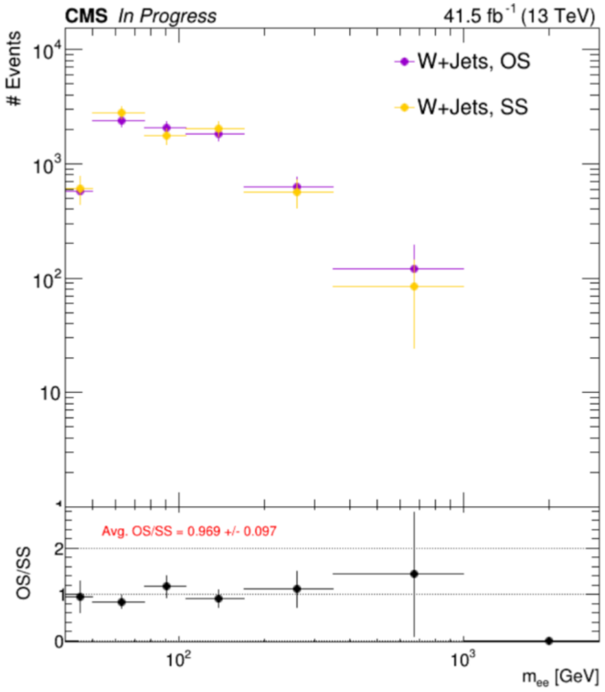
OS/SS ratio for QCD → μμ

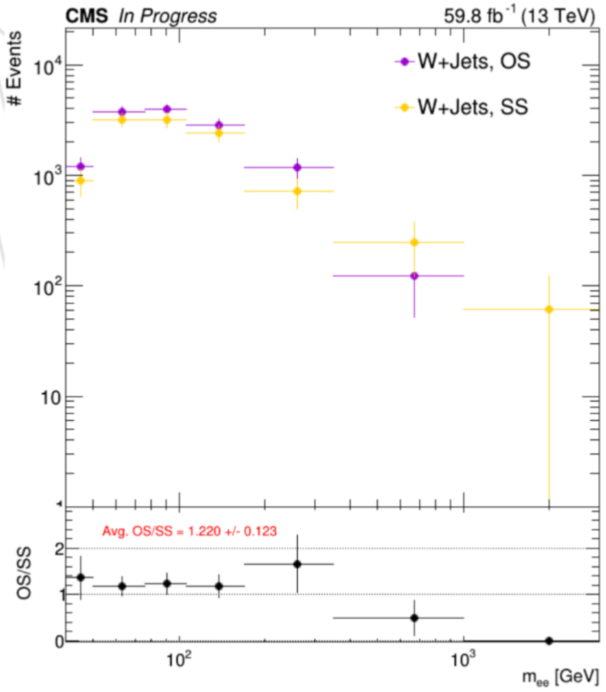


OS/SS ratio for W+Jets → ee









OS/SS ratio for QCD → ee