Higgs compositeness in high-mass dilepton states

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Standard Model

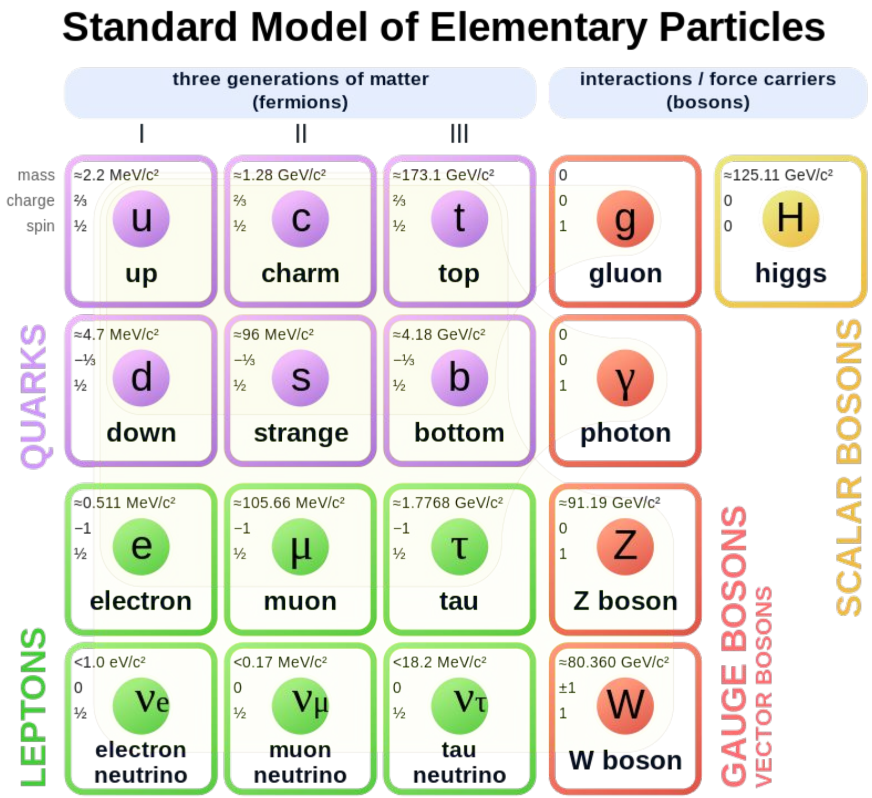
In the Standard Model we have:

- Fermions: the “matter”; quarks and leptons.
- Bosons: the interactions; gauge bosons and scalar bosons.

Each gauge boson mediates one interaction:

- ➔ Photon: electromagnetic.
- ➔ Z and W: weak.
- ➔ Gluons: strong.

Is that all?



Standard Model of Elementary Particles

	three generations of matter (fermions) I	 II	 III	interactions / force carriers (bosons)	
mass charge spin QUARKS	≈2.2 MeV/c^2 ⅔ ½ u up	≈1.28 GeV/c^2 ⅔ ½ c charm	≈173.1 GeV/c^2 ⅔ ½ t top	0 0 1 g gluon	≈125.11 GeV/c^2 0 0 H higgs
QUARKS	≈4.7 MeV/c^2 −⅓ ½ d down	≈96 MeV/c^2 −⅓ ½ s strange	≈4.18 GeV/c^2 −⅓ ½ b bottom	0 0 1 γ photon	SCALAR BOSONS
LEPTONS	≈0.511 MeV/c^2 −1 ½ e electron	≈105.66 MeV/c^2 −1 ½ μ muon	≈1.7768 GeV/c^2 −1 ½ τ tau	≈91.19 GeV/c^2 0 1 Z Z boson	GAUGE BOSONS VECTOR BOSONS
LEPTONS	<1.0 eV/c^2 0 ½ ν_e electron neutrino	<0.17 MeV/c^2 0 ½ ν_μ muon neutrino	<18.2 MeV/c^2 0 ½ ν_τ tau neutrino	≈80.360 GeV/c^2 ±1 1 W W boson	

Higgs Compositeness: Why?

Standard Model does not explain everything ⇒ **"Effective Theory"**:

- New physics at higher energies Λ
    - Plank scales **Λ ~ 10^{19} GeV**? → the gravity could show some quantum effects.

If we compute the radiative corrections to the Higgs mass we get **$\delta m_H \propto \Lambda$**.

Thus:

$$\begin{tikzcd} m_H^2 \arrow[d] & = m_H^{(0)2} + & \delta m_H^2 \arrow[d, "\delta m_H \propto \Lambda!"] \\ (125\text{GeV})^2 & & (\lesssim 10^{19}\text{GeV})^2 \end{tikzcd}$$

Fine tunning between $m_H^{(0)}$ and δm_H! → Naturalness or hierarchy problem

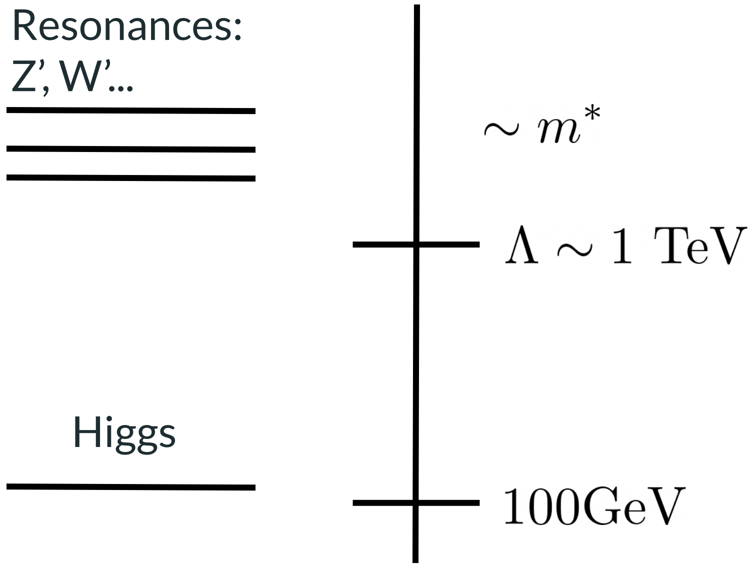
Higgs Compositeness: What is it?

Higgs Compositeness theories: Higgs is a composite particle.

Two regimes:

- **E ~ Λ**: resonances of mass ~ m* interacting “strongly” with coupling g*.
- **E < Λ**: typical Higgs field.

Strongly Interacting Light Higgs



Resonances:
Z’, W’...

$\sim m^*$

$\Lambda \sim 1\ \mathrm{TeV}$

Higgs

$100\mathrm{GeV}$

Small deviations from the SM would appears at **E < Λ**:

➢ Quantified using the electroweak oblique parameters W and Y:

$$W \equiv \frac{g^2 m_W^2}{g*^2\, m*^2} \qquad Y \equiv \frac{g'^2 m_W^2}{g*^2\, m*^2}$$

W=0 and Y=0 in SM

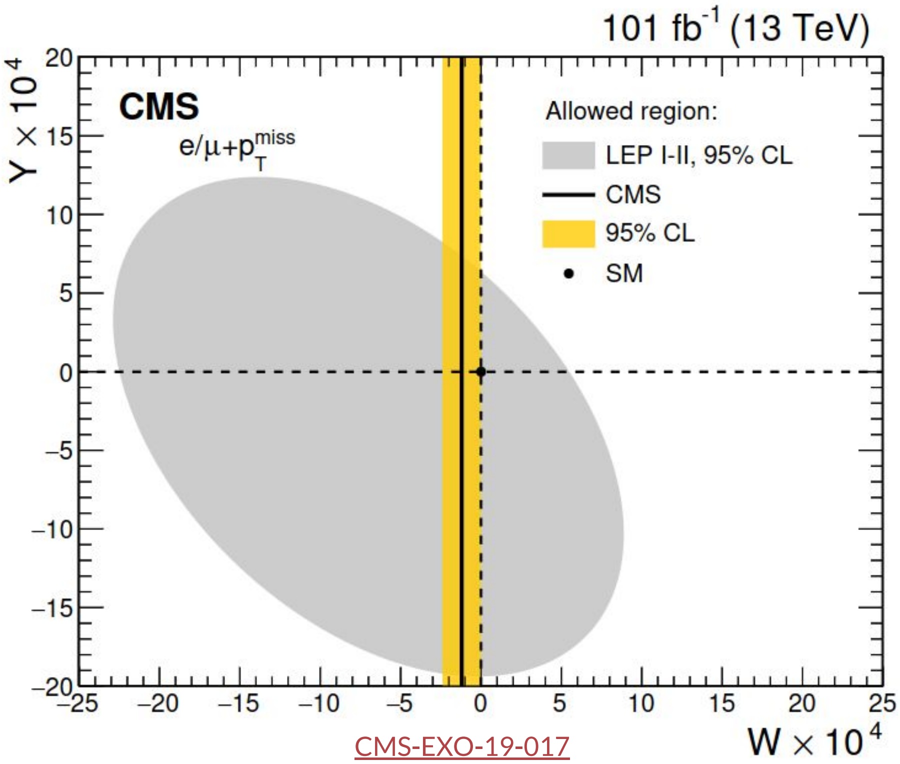
Being g and g’ the coupling constants of the SU(2)L and U(1)Y groups of the SM.

What are we going to do?

Searching for these smooth deviations:

- **Final l^+l^- (ee,μμ) states.**
- **Invariant mass distribution** at high energies.
- Setting limits on W and Y and, therefore, on m* and g*.

By measuring Y ⇒ measurements of the oblique parameter W of Run 2 (CMS-EXO-19-017) complemented.



CMS-EXO-19-017

With increasing luminosity we need a careful treatment of theoretical predictions and experimental systematics.

Analysis strategy

For each set of W and Y values ⇒ different contribution:

- We introduce this effect by reweighting **exactly at NLO** at generator level the Drell-Yan samples (formulas in backup).
- **Fit:** Y and W that maximize the Data-MC agreement by modifying the Drell-Yan distribution with the reweighting.

We will perform this analysis by fixing the total number of expected entries in MC to the number of data entries ➪ **SHAPE analysis**.

This reweighting method is very powerful:

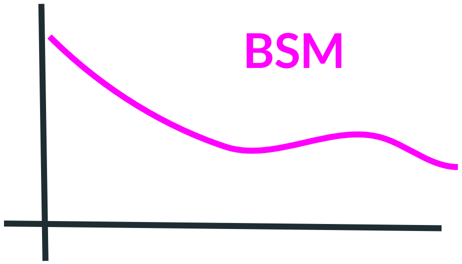
- Exact at NLO.
- It can be applied to any Drell-Yall signal (resonant or non-resonant).

See CIEMAT Technical Report, AN-24-082 and also this presentation.

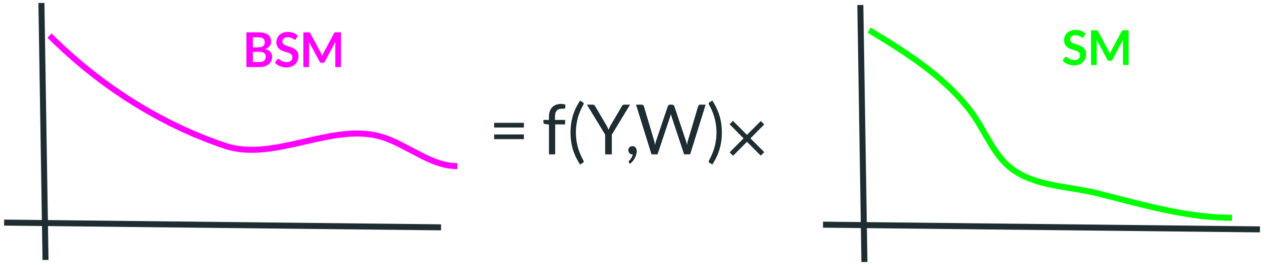
Reweighting?... Naively

I want BSM MC → two options:

1. I produce **MC for a particular BSM** (W and Y fixed).



2. I produce **MC for the SM** and compute for each event the <u>"ratio of probabilities" of producing the event</u> in the BSM (W and Y not) and in the SM: **f(X,Y)**



Analysis strategy: selection criteria

- **Selection cuts** and **dilepton reconstruction** ⇨ those used in dilepton resonance searches for Run 2, see:

JHEP 07 (2021) 208

- We **blind** the data for **mass > 1 TeV** .

You can see also these analysis notes for more information!

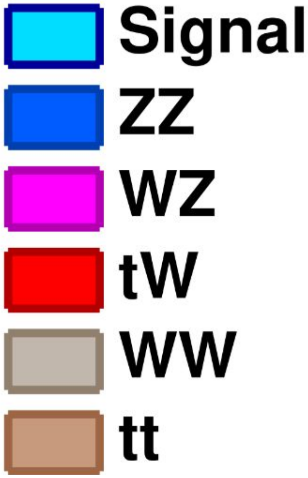
CMS AN-2018/011 (dimuon resonant)

CMS AN-2019/101 (dielectron resonant)

CMS AN-2019/024 (dilepton non-resonant)

What samples do we have?

- Data: Run 2 and Run 3 (2022 + 2023), dielectrons and dimuons
  - Data blinded for mass>1 TeV
  - Run3 electron results not shown for the moment: scale/smearing corrections not finalized yet, HEEP SFs preliminary.
  - ➢ The most energetic events (details in backup):
    - Dimuon in 2023 with $m_{\mu\mu}$=3.9 TeV.
    - Dielectron in 2022 with m_{ee}=5.3 TeV.
- Backgrounds (sources of high energy dileptons):
  - ZZ, WZ, ttbar, tW, WW
- Signal + Drell-Yan background (they interfere):
  - Reweighted Drell-Yan samples ($\to$ ee, $\mu\mu$, $\tau\tau$ samples)



All MC samples are corrected according to Egamma POG (HEEP Id, HLT Zvtx, MC smearing) and Muon POG (reconstruction, isolation, trigger and resolution for high-p_T muons) recommendations. Energy scale corrections are also applied to electron data, and the official pileup and pre-triggering corrections are applied in MC.

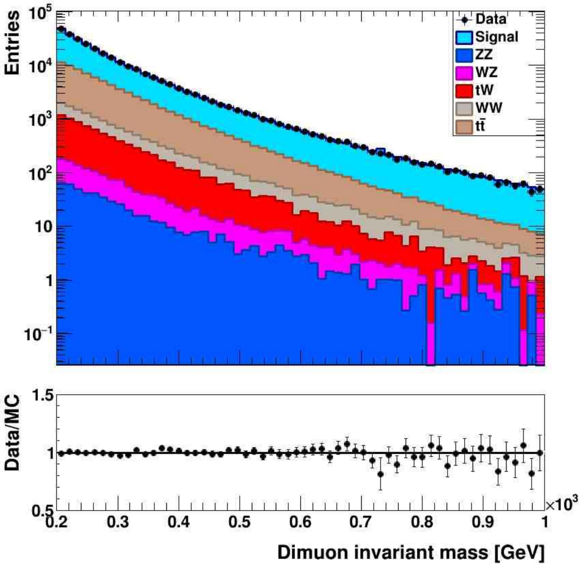
The top background normalization (tt and tW) are determined using control samples (details in AN-24-008 and backup).

Invariant mass distributions.

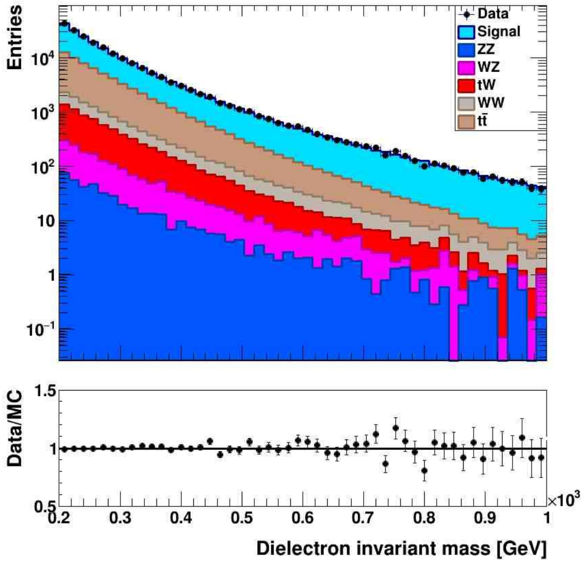
***MC normalized to Data, but Data match the predictions at the 2% level.

Muons

Run2



Electrons

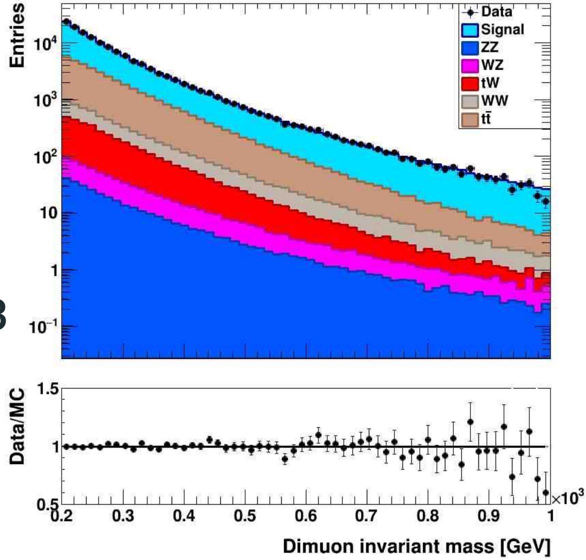


Shapes are in good agreement!

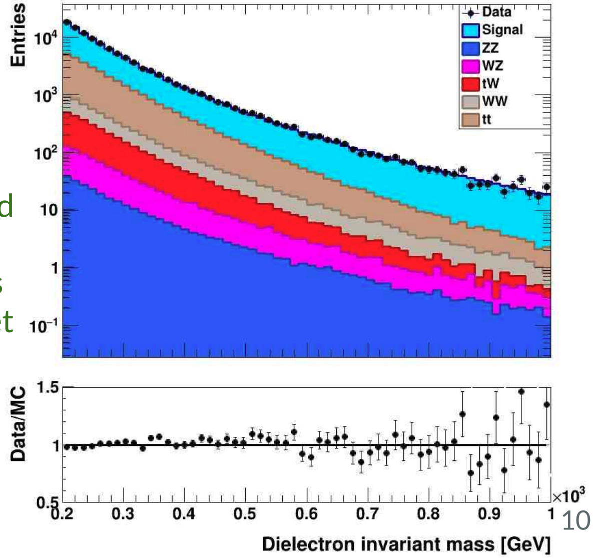
- 🟦 Signal
- 🟦 ZZ
- 🟪 WZ
- 🟥 tW
- ⬜ WW
- 🟫 tt

Run3:

- **2022+2023**



Scale and smearing corrections not yet available!



Fitting procedure

We perform **likelihood binned fits** to the invariant mass distributions

- Assuming Poisson statistics in each bin.
- Starting at 300 GeV.

Fit not sensitive to global normalization factors ⇨ **Shape analysis**:

➢ Only systematics that depend on kinematics will be relevant.

Contributions to systematic uncertainties considered:

- MC statistical uncertainties.
- Pileup uncertainties.
- Top background normalization (≈2-3%).
- WW background (10%).
- Muon momentum scale and resolution uncertainties.
- Electron energy scale uncertainties.
- **PDF set uncertainties** (PDF4LHC21, α_s uncertainty on PDFs).
- Factorization and renormalization scale uncertainties.
- Initial and final state radiation uncertainties.

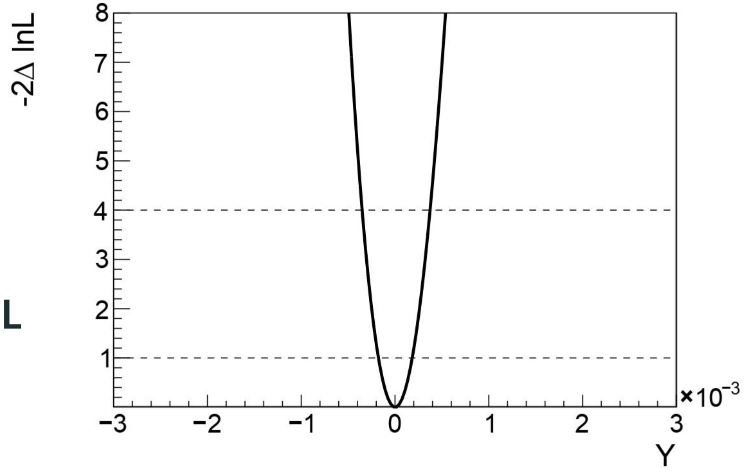
Higher impact on the shape!

Expected fits: Run 2 + Run 3 (ee and $\mu\mu$)

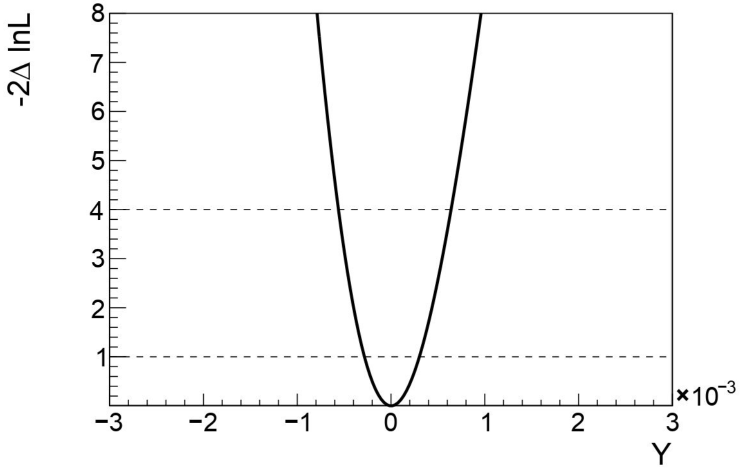
Expected 1-D fits of Y, setting W=0

$|Y| \lesssim 6 \times 10^{-4}$ at 95% CL

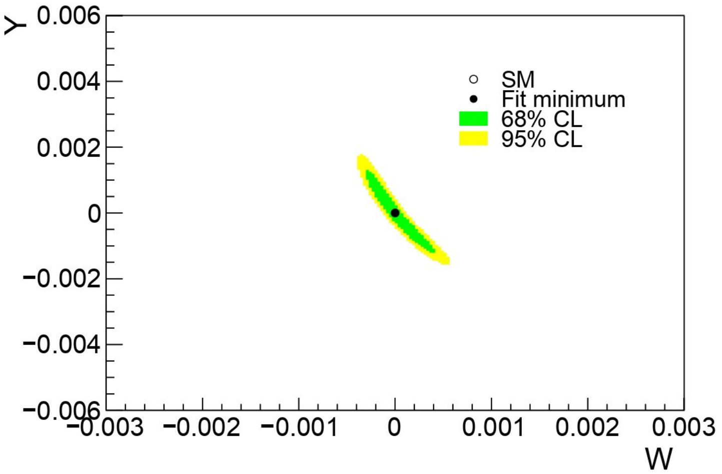
Data is SM: MC with W=Y=0, stats.

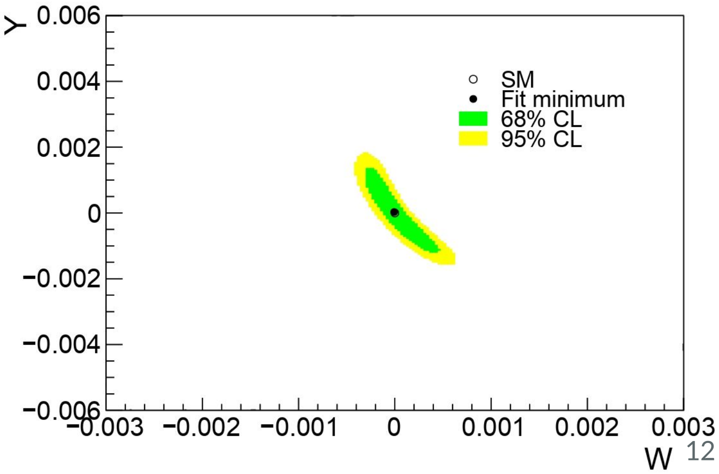


Data is SM: MC with W=Y=0, stats. + syst.



Expected 2-D fits of W and Y



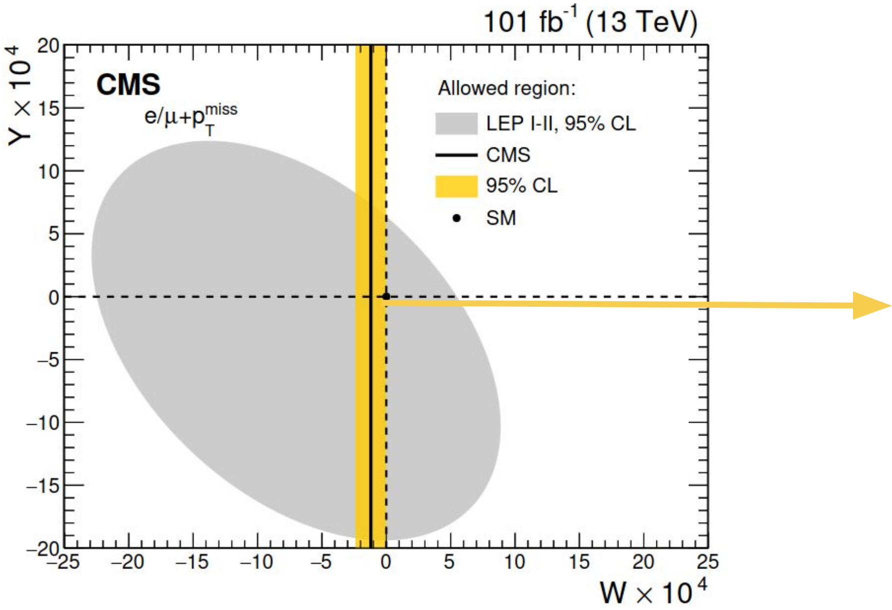


Expected fits: Run 2 + Run 3 (ee and $\mu\mu$)

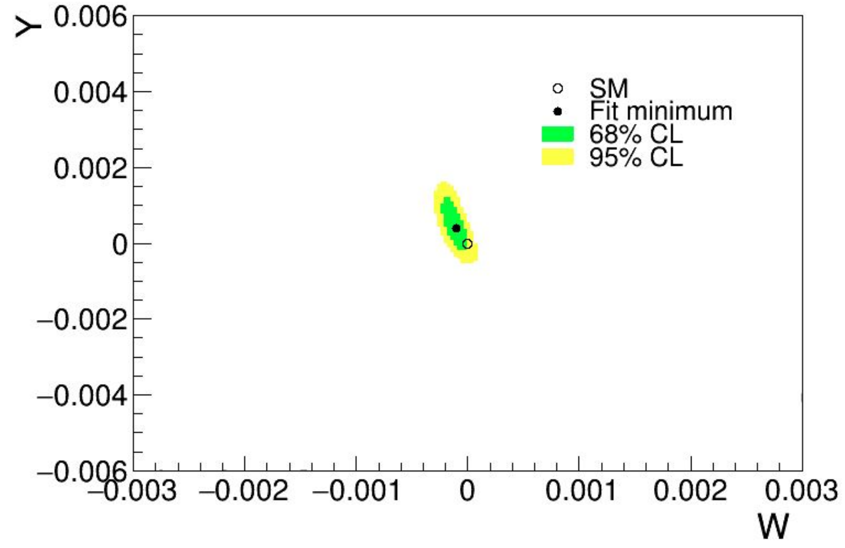
***Preliminary.

Expected 2-D fits of Y and W when using the MC for W=Y=0 as Data including the W Run2 measurement from the lepton+MET analysis (CMS-EXO-19-017, W=-1.2e-4 ± 0.6e-4 at 68% CL)

Data is SM: MC with W=Y=0, stats. + syst.



CMS-EXO-19-017



Status

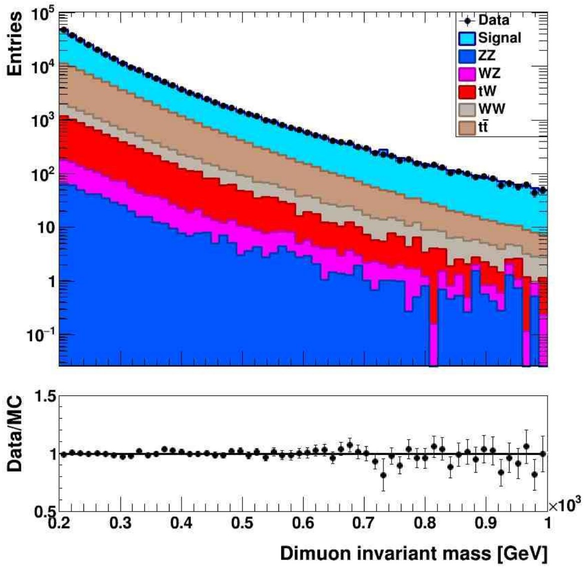
Framework of the analysis is ready!

1. **Selection criteria** and **dilepton reconstruction**.
2. MC samples ready and **corrections applied** (scale/smearing for Run3 electrons).
3. **Fitting procedure** and systematics also ready.

Now ⇨ performing studies to reduce uncertainties (stat+syst) and improve sensitivity:

- Use of the information of **$\cos\theta_{CS}$**
- **Veto top events**.
- Optimizing **mass fit range**.
- **Binning**.

For this studies we are using the Run2 dimuon dataset.



Improving sensitivity: cosθ$_{CS}$

Two sensitive distributions:

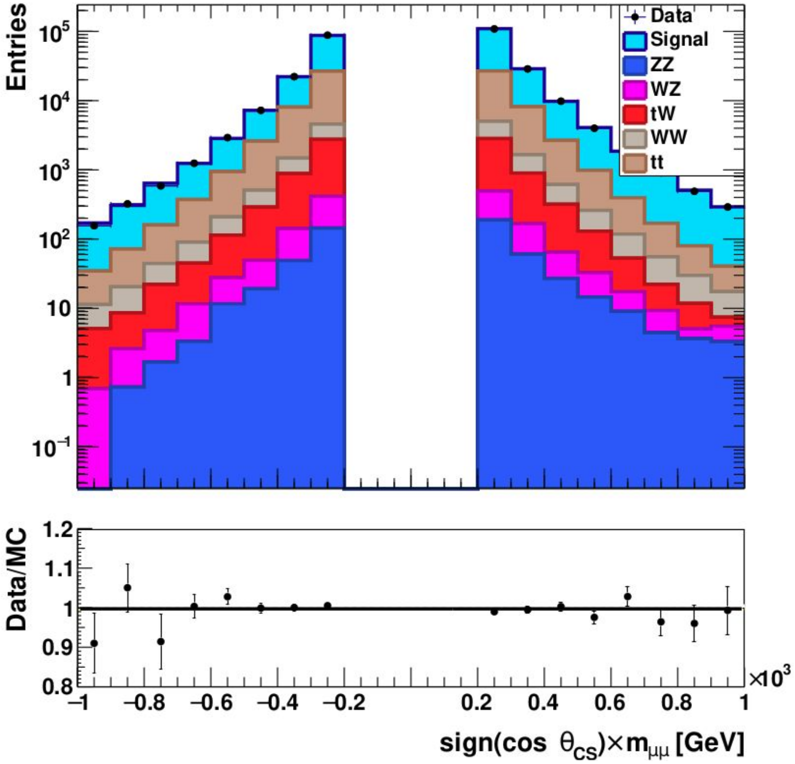
- Dilepton Invariant mass **m$_{ll}$**
- Cosine of the Collins-Soper angle **cosθ$_{CS}$**
  - ➢ Highly affected by the PDF uncertainties

$$\boxed{\cos\theta_{CS} = \frac{2(p_Z^{l_1}E^{l_2} - p_Z^{l_2}E^{l_1})}{m_{ll}\sqrt{{m_{ll}}^2 + {p_T}_{ll}^2}}}$$

where l$_1$ refers to the lepton and l$_2$ to the antilepton.

Using cosθ$_{CS}$ is worth?

⇒ Fit the distribution **sign(cosθ$_{CS}$) ✕ m$_{ll}$** (also done JHEP 07 (2021) 208).



*** No requirement on electron charge (JHEP 07 (2021) 208 criteria) :

- In case of charge coincidence, the one with the lower pT prevails.

Improving sensitivity: $\cos\theta_{CS}$

Computing the interval of **Y at 95% of CL** using as Data the MC for W=Y=0 ($-2\Delta\ln L=4$):

For $\mathbf{m_{ll}}$:

$[-0.000741, 0.000901]$

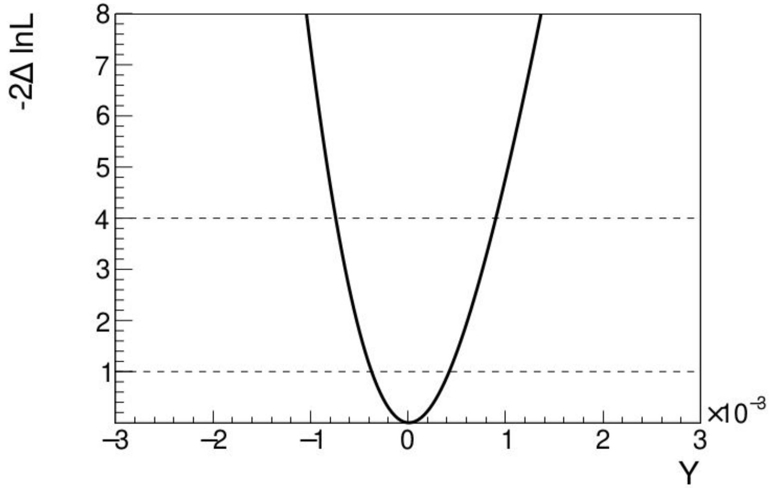
$\mathbf{Y_{max} - Y_{min} = 0.001642}$

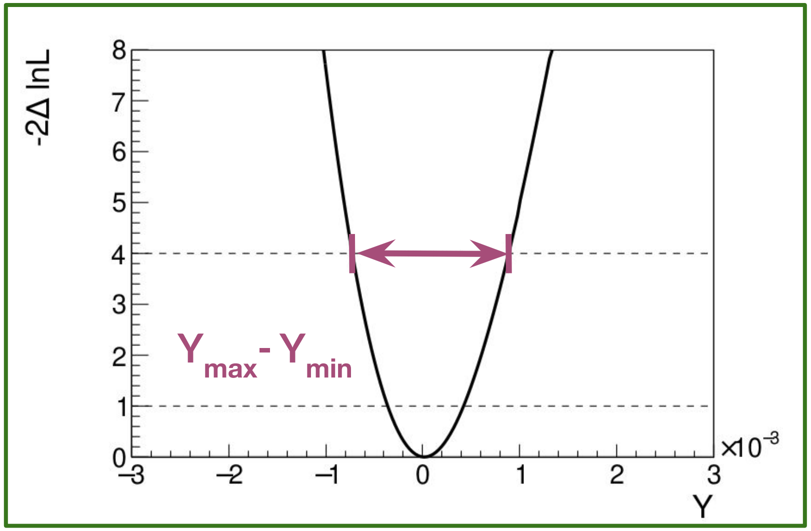
For $\mathbf{sign(\cos\theta_{CS}) \times m_{ll}}$:

$[-0.000725, 0.000885]$

$\mathbf{Y_{max} - Y_{min} = 0.001610}$

2% more sensitive





Barely 2% sensitivity improvement:

- We maintain the analysis 1-dimensional fitting $\mathbf{sign(\cos\theta_{CS}) \times m_{ll}}$

⇒ Making the observations more consistent.

Improving sensitivity: veto top events

We set the **normalization of the tops backgrounds** using control samples:

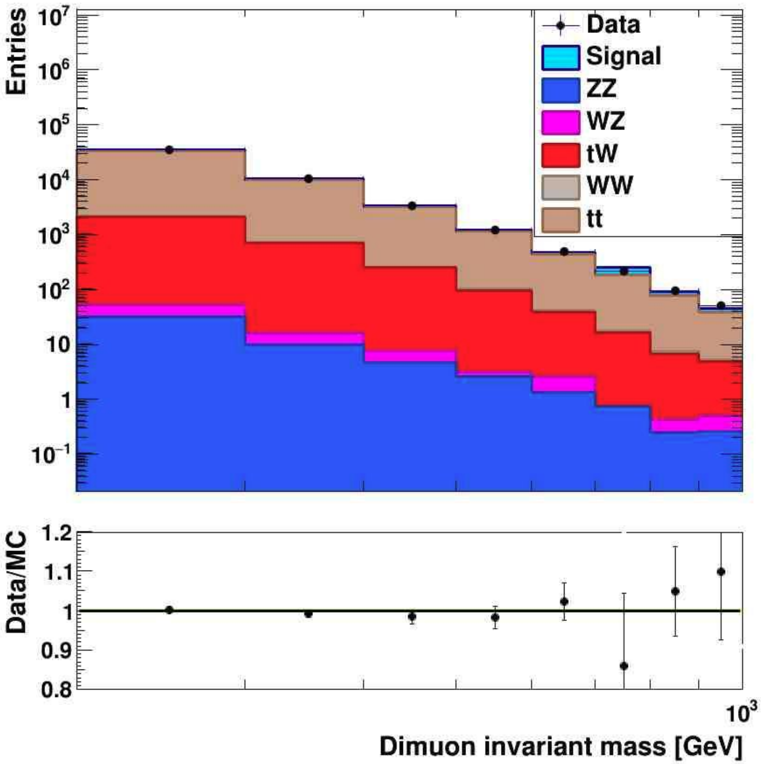
we select events with at **least two jets,** and **one jet b-tagged** that satisfied

- Jet pt>25 GeV
- |Jet η| < 2.5
- ID: tight lepton veto
- b-tag at Medium WP with DeepFlavB (period dependent, typical values around 0.3)

But we can **veto top events** using also this selection criteria:

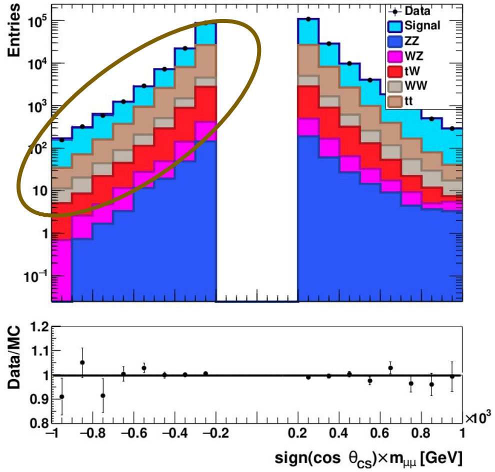
- We reduce ⅔ of the tops background
- More robust measurement at the level of assignment of systematics.

tt and tW: the most important backgrounds

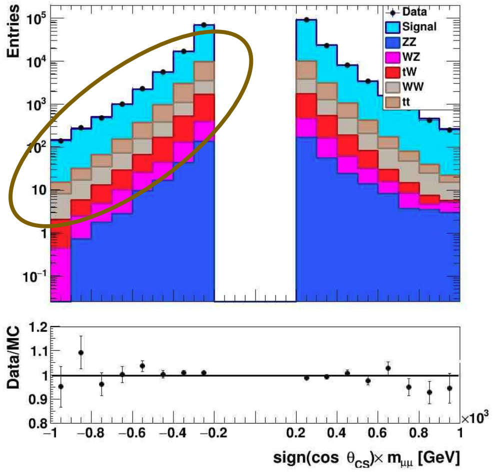


Improving sensitivity: veto top events

Doing this we reduce ⅔ of the tops background, giving us a more robust measurement at the level of assignment of systematics.



tt+tW: 70487.884
Data: 277570



tt+tW: 21762.878
Data: 226386

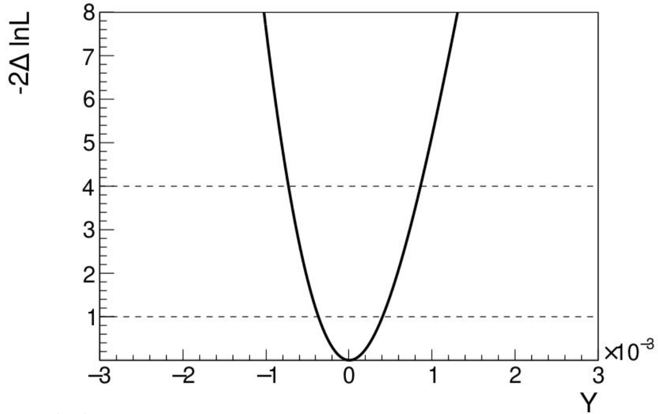
Difference:

- **tt+tW: 48725.006**
- **Data: 51184**

We are mostly removing tops events!

We also **improve the sensitivity** with this veto:

- After applying the veto: [-0.000728,0.000860]; **Y_{max} - Y_{min} = 0.001587**.
- Before applying the veto: [-0.000725, 0.000885]; **Y_{max} - Y_{min} = 0.001610.**



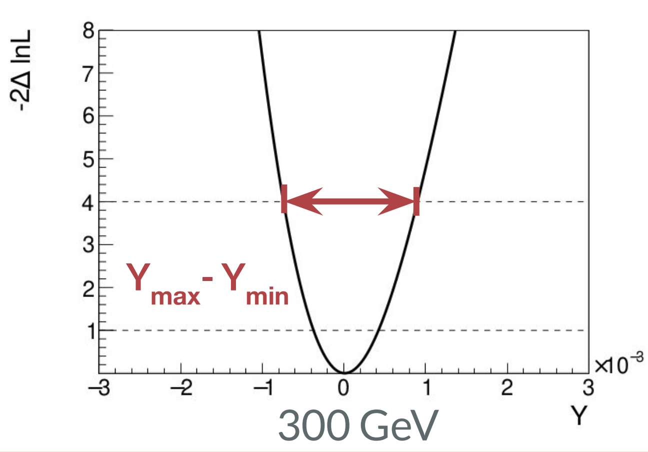
1.5% more sensitive!

Improving sensitivity: mass fit range

Optimize the mass fit range ⇒ reduce uncertainties (stat+syst) and improve sensitivity.

We compute the **interval of Y at 95% of CL** using as Data the MC for W=Y=0 (-2ΔlnL=4):

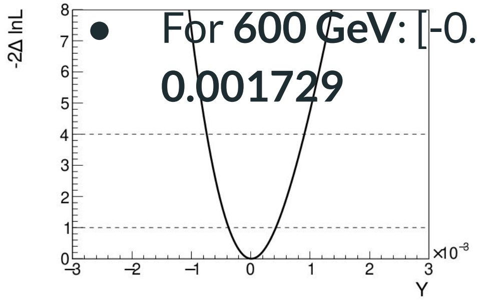
- 200 GeV is affected by edge effect.
- For 300 GeV: [-0.000741, 0.000901]; $Y_{max} - Y_{min} =$ 0.001642
- For **400 GeV**: [-0.000740, 0.000903]; $\mathbf{Y_{max} - Y_{min} =}$ **0.001643**
- For **500 GeV**: [-0.000747, 0.000922]; $\mathbf{Y_{max} - Y_{min} =}$ **0.001670**
- For **600 GeV**: [-0.000764, 0.000966]; $\mathbf{Y_{max} - Y_{min} =}$ **0.001729**



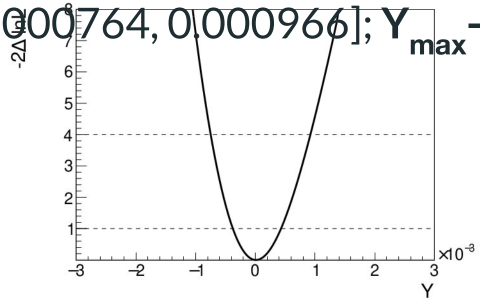
300 GeV

The most sensitive!

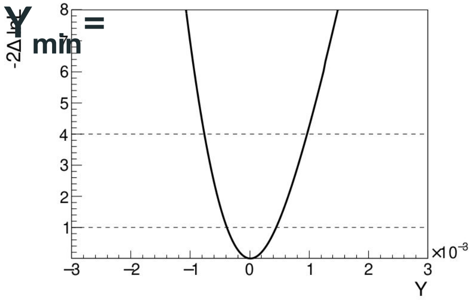
400 GeV



500 GeV



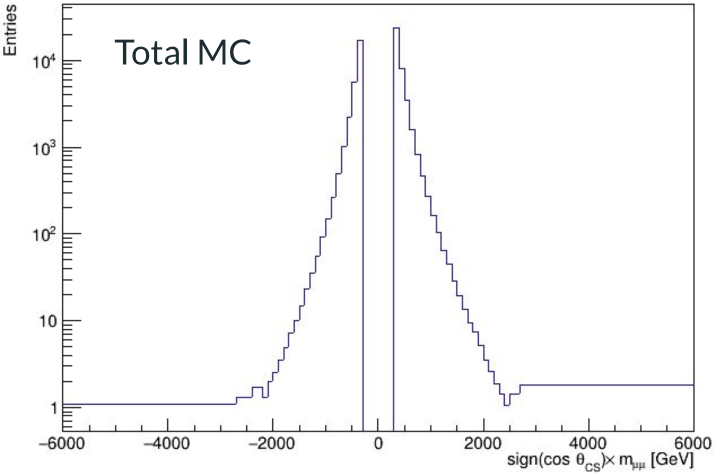
600 GeV

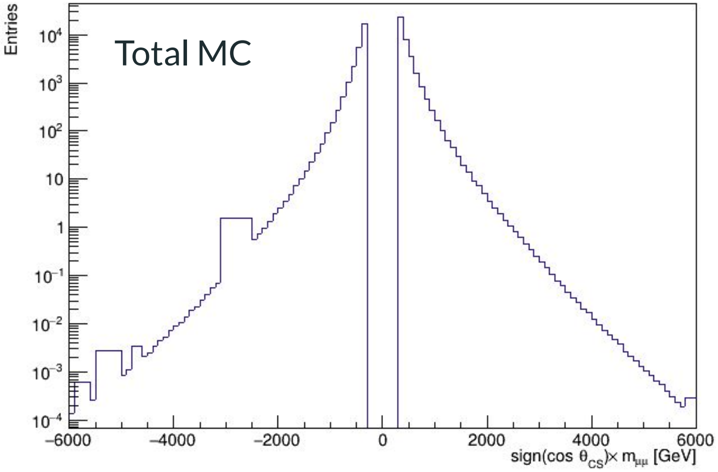


***Without veto tops events and sign($\cos\theta_{CS}$)

Run2 muons

Improving sensitivity: binning.





Optimize the binning ⇒ reduce uncertainties (stat+syst) and improve sensitivity.

After cutting tops events with the current binning: **100 GeV binwidth** [-0.000728,0.000860]; $\mathbf{Y_{max} - Y_{min} = 0.001587}$.

Let's try others criteria:

- Minimum bin total MC entries:
  - ⩾ 1 entries per bin: [-0.000731, 0.000864];

    $\mathbf{Y_{max} - Y_{min} = 0.001595}$.
  - ⩾ 10 entries per bin: [-0.000746, 0.000869]; $\mathbf{Y_{max} - Y_{min} = 0.001615}$.
- Minimum (bin entries)/(bin error) in total MC:
  - (bin entries)/(bin error) ⩾ 10**:**

    [-0.000729, 0.000862]; $\mathbf{Y_{max} - Y_{min} = 0.001590}$.

No improvement.

Next steps

- Pulls of nuisance parameter.
- Studies of the stability of the fit for non-zero W and Y
- Translate the current W and Y exclusions into **g* and m* exclusion plots**.

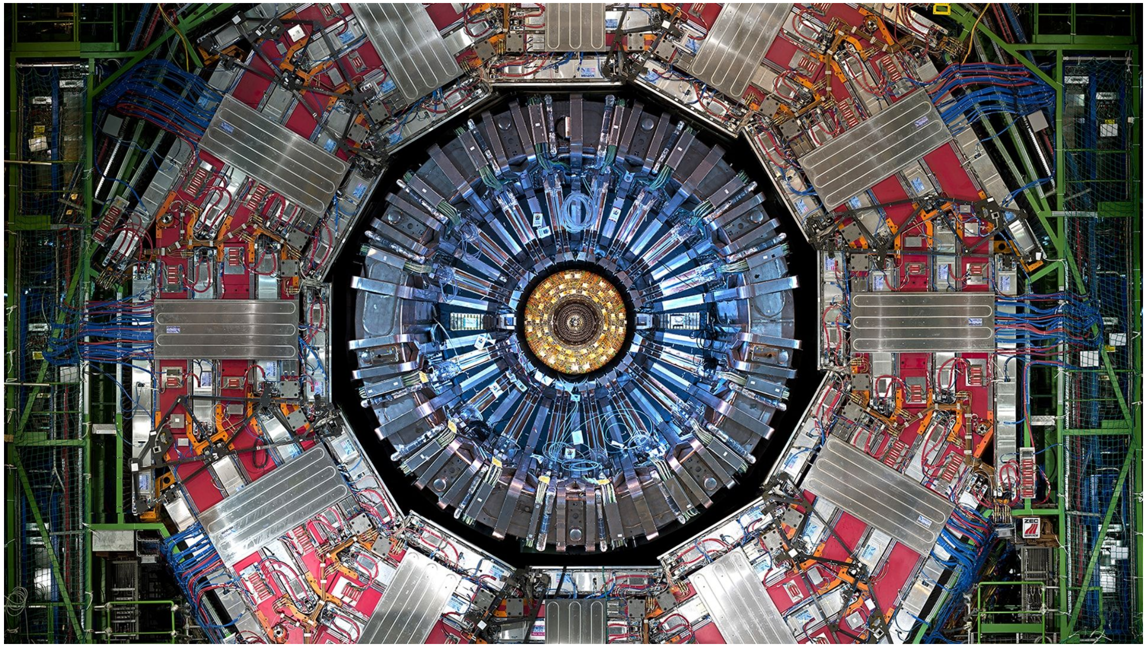
- Apply electron scale/smearing corrections for Run3
  - ➢ study the systematic.
- Electron trigger crosscheck.

Medium/long term:

- Planned extensions of this analysis:
  - ➢ llqq contact interaction term (LL, LR, RL, RR) constraints for Run 2 + Run 3 (via reweighting) exactly at NLO (previously done at LO).
  - ➢ Direct search for medium/wide width resonances, like Y-sequential in a compositeness scenario.

For further details see AN-24-082 and EXO non-hadronic talks on Apr 2024 and March 2023.

Backup

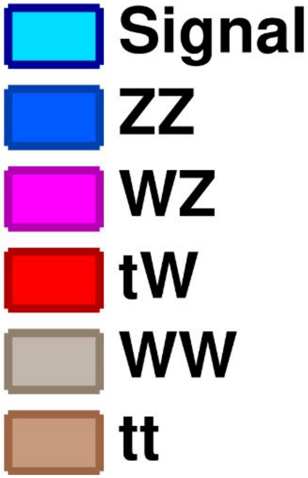


What samples do we have?

- Data: Run 2 and Run 3 (2022 + 2023), dielectrons and dimuons
  - Data blinded for mass>1 TeV
  - Run3 electrons: scale/smearing corrections not available yet.

- Backgrounds (sources of high energy dileptons):
  - ZZ, WZ, ttbar, tW, WW

- Signal + Drell-Yan background (they interfere):
  - Reweighted Drell-Yan samples ($\rightarrow$ ee, $\mu\mu$, $\tau\tau$ samples)



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The top background normalization (tt and tW) are determined using control samples (details in AN-24-008 and backup).

Z/Z’ analysis: Data Samples (Run 2)

Data for Muons :

  - 2016 UL
- /SingleMuon/Run2016B-ver2_HIPM_UL2016_MiniAODv2_NanoAODv9-v2/NANOAOD
- /SingleMuon/Run2016**[C,D,E,F]**-HIPM_UL2016_MiniAODv2_NanoAODv9-v2/NANOAOD
- /SingleMuon/Run2016**[F,G,H]**-UL2016_MiniAODv2_NanoAODv9-v1/NANOAOD
  - 2017 UL
- /SingleMuon/Run2017**[B,C,D,F]**-UL2017_MiniAODv2_NanoAODv9_GT36-v1/NANOAOD
- /SingleMuon/Run2017E-UL2017_MiniAODv2_NanoAODv9_GT36-v2/NANOAOD
  - 2018 UL
- /SingleMuon/Run2018**[A,B,C,D]**-UL2018_MiniAODv2_NanoAODv9_GT36-v1/NANOAOD

Data for Electrons :

  - 2016 UL
- /DoubleEG/Run2016B-ver2_HIPM_UL2016_MiniAODv2_NanoAODv9-v3/NANOAOD
- /DoubleEG/Run2016**[C,D,E,F]**-HIPM_UL2016_MiniAODv2_NanoAODv9-v2/NANOAOD
- /DoubleEG/Run2016**[F,G,H]**-UL2016_MiniAODv2_NanoAODv9-v1/NANOAOD
  - 2017 UL
- /DoubleEG/Run2017**[B,C,D,E,F]**-UL2017_MiniAODv2_NanoAODv9-v1/NANOAOD
  - 2018 UL
- /EGamma/Run2018**[A,B,C]**-UL2018_MiniAODv2_NanoAODv9_GT36-v1/NANOAOD
- /EGamma/Run2018D-UL2018_MiniAODv2_NanoAODv9-v3/NANOAOD

Z/Z’ analysis: MC Samples (UL16)

MC for Muons and Electrons :

Tags (change between samples)

- **preVFP:** /RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM
- **postVFP:** /RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM

- /TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 (pre v11-v1, post v17-v1)
- /TTToLL_MLL_***bins***_TuneCP5_13TeV-powheg-pythia8 (pre v11-v1, post v17-v1)
  bins: 500to800, 800to1200, 1200to1800,1800toInf
  /ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8 (pre v11-v1, post v17-v2)
- /ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8 (pre v11-v1, post v17-v2)
- /WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 (pre v11-v1, post v17-v1)
- /WWTo2L2Nu_MLL_200To600_TuneCP5_13TeV-powheg-pythia8 (pre v11-v1, post v17-v1)
  bins: 200to600, 600to1200, 1200to2500, 1800toInf
- /WZ_TuneCP5_13TeV-pythia8 (pre v11-v1, post v17-v1)
- /ZZ_TuneCP5_13TeV-pythia8 (pre v11-v1, post v17-v1)
- /DYJetsToTauTau_M-50_AtLeastOneEorMuDecay_TuneCP5_13TeV-powhegMiNNLO-pythia8-photos (pre v11-v1, post v17-v1)
- /ZToMuMu_M-***bins***_TuneCP5_13TeV-powheg-pythia8 (pre v11-v1, post v17-v1)
  bins: 50to120, 120to200, 200to400, 400to800, 800to1400, 1400to2300, 2300to3500, 3500to4500, 4500to6000, 6000toInf (for electrons we dont use 50to120)

Z/Z' analysis: MC Samples (UL17)

MC for Muons and Electrons :

Tags (change between samples)
- /RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM

- /TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 v9-v1
- /TTToLL_MLL_***bins***_TuneCP5_13TeV-powheg-pythia8 v9-v1
  bins: 500to800, 800to1200, 1200to1800,1800toInf
- /ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8 v9-v2
- /ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8 v9-v2
- /WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 v9-v1
- /WWTo2L2Nu_MLL_200To600_TuneCP5_13TeV-powheg-pythia8 v9-v1
  bins: 200to600, 600to1200, 1200to2500, 1800toInf
- /WZ_TuneCP5_13TeV-pythia8 v9-v1
- /ZZ_TuneCP5_13TeV-pythia8 v9-v1
- /DYJetsToTauTau_M-50_AtLeastOneEorMuDecay_TuneCP5_13TeV-powhegMiNNLO-pythia8-photos v9-v2
- /ZToMuMu_M-***bins***_TuneCP5_13TeV-powheg-pythia8 v9-v1
  bins: 50to120, 120to200, 200to400, 400to800, 800to1400, 1400to2300, 2300to3500, 3500to4500, 4500to6000, 6000toInf (for electrons we dont use 50to120)

Z/Z' analysis: MC Samples (UL18)

MC for Muons and Electrons :

Tags (change between samples)

- /RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM

- /TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 v1-v1
- /TTToLL_MLL_***bins***_TuneCP5_13TeV-powheg-pythia8 v1-v1
  bins: 500to800, 800to1200, 1200to1800,1800toInf
- /ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8 v1-v2
- /ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8 v1-v2
- /WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 v1-v1
- /WWTo2L2Nu_MLL_200To600_TuneCP5_13TeV-powheg-pythia8 v1-v1
  bins: 200to600, 600to1200, 1200to2500, 1800toInf
- /WZ_TuneCP5_13TeV-pythia8 v1-v1
- /ZZ_TuneCP5_13TeV-pythia8 v1-v1
- /DYJetsToTauTau_M-50_AtLeastOneEorMuDecay_TuneCP5_13TeV-powhegMiNNLO-pythia8-photos v1-v2
- /ZToMuMu_M-***bins***_TuneCP5_13TeV-powheg-pythia8 v1-v1
  bins: 50to120, 120to200, 200to400, 400to800, 800to1400, 1400to2300, 2300to3500, 3500to4500, 4500to6000, 6000toInf (for electrons we dont use 50to120)

Z/Z’ analysis: Data & MC Samples (2022)

Data:

- /**[Muon,EGamma]**/Run2022**[C,D,E]**-ReRecoNanoAODv11-v1/NANOAOD
- /**[Muon,EGamma]**/Run2022**[F,G]**-PromptNanoAODv11_v1-v2/NANOAOD

MC:

Tags (change between samples)

- **preEE:** Run3Summer22NanoAODv11-126X_mcRun3_2022_realistic_v2-v1/NANOAODSIM
- **postEE:** Run3Summer22EENanoAODv11-126X_mcRun3_2022_realistic_postEE_v1-v1/NANOAODSIM

- TTto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v1, post v1-v1)
- WWto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v2, post v1-v2)
- TWminusto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v1, post v1-v1)
- TbarWplusto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v1, post v1-v1)
- WZto3LNu_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v2, post v1-v2)
- ZZto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v2, post v1-v2)
- ZZto2L2Q_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v2, post v1-v2)
- ZZto4L_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v2, post v1-v2)
- DYto2**[Mu,E,Tau]**_MLL-***bins***_TuneCP5_13p6TeV_powheg-pythia8 (pre v2-v2, post v1-v2)
    - ***bins:*** 50to120, 120to200, 200to400, 400to800, 800to1500, 1500to2500, 2500to4000, 4000to6000, 6000

Z/Z' analysis: Data & MC Samples (2023)

Data:

- /**[Muon,EGamma][0,1]**/Run2023**[C,D]**-22Sep2023*/NANOAOD

MC:

Tags (change between samples)

- **2023C:** Run3Summer23NanoAODv12-130X_mcRun3_2023_realistic_v*-v*/NANOAODSIM
- **2023D:** Run3Summer23BPixNanoAODv12-130X_mcRun3_2023_realistic_postBPix_v*-v*/NANOAODSIM

- TTto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (2023C v14-v2, 2023D v2-v3)
- WWto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (2023C v14-v4, 2023D v2-v3)
- TWminusto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (2023C v14-v2, 2023D v2-v3)
- TbarWplusto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (2023C v15-v4, 2023D v6-v2)
- WZto3LNu_TuneCP5_13p6TeV_powheg-pythia8 (2023C v14-v2, 2023D v2-v2)
- ZZto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8 (2023C v14-v3, 2023D v2-v3)
- ZZto2L2Q_TuneCP5_13p6TeV_powheg-pythia8 (2023C v14-v3, 2023D v2-v3)
- ZZto4L_TuneCP5_13p6TeV_powheg-pythia8 (2023C v14-v3, 2023D v2-v3)
- DYto2**[Mu,E,Tau]**_MLL-***bins***_TuneCP5_13p6TeV_powheg-pythia8 (2023C v14-*, 2023D v2-*)
  - ***bins:*** 50to120, 120to200, 200to400, 400to800, 800to1500, 1500to2500, 2500to4000, 4000to6000, 6000

Analysis strategy: reweighting

The even-by-event weight is of the type ***:

$$\rho_{\mathsf{n}}(q^2, \Omega_\ell | W, Y) = \frac{\sum_{\chi_{\mathsf{q}},\chi_\ell} \frac{d\rho^{\chi_{\mathsf{q}}\chi_\ell}}{d\Omega_\ell} \left|(C^0_{\mathsf{SM}}(q^2, \chi_{\mathsf{q}}, \chi_\ell) + C^0_{\mathsf{BSM}}(\chi_{\mathsf{q}}, \chi_\ell | W, Y)\right|^2}{\sum_{\chi_{\mathsf{q}},\chi_\ell} \frac{d\rho^{\chi_{\mathsf{q}}\chi_\ell}}{d\Omega_\ell} \left|C^0_{\mathsf{SM}}(q^2, \chi_{\mathsf{q}}, \chi_\ell)\right|^2}$$

where χ_{i} is the chirality of the quarks and leptons and Ω_{l} is the solid angle of the lepton in the dilepton center-of-mass system.

*** It is a matrix-element reweighting for a given quark/lepton helicity combination that depends only on the dilepton mass q^2. The matrix-elements are averaged over all helicities depending on angular distribution of the lepton ($d\rho^{\chi q \chi l}/d\Omega_{\mathrm{l}}$).

All the dependence on Y and W is contained in the term:

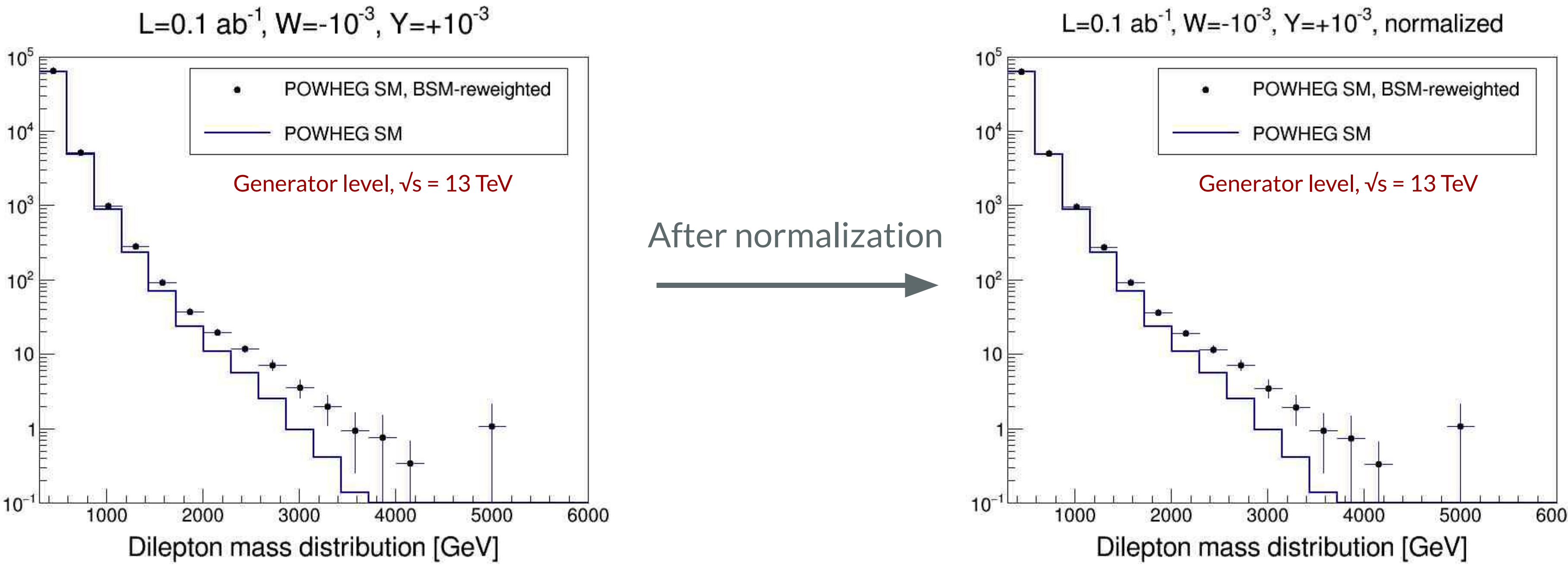
$$C^0_{\mathsf{BSM}}(\chi_{\mathsf{q}}, \chi_\ell | W, Y) = \frac{-g^2 T^3_q T^3_\ell \, W - g'^2 Y_q Y_l \, Y}{m^2_W}$$

Note that for W=Y=0, the values in the SM, this term is 0 so the weight is 1.

(More details in AN-24-082 and also Alcaraz Maestre, J; Bachiller Perea, I; De La Cruz Martínez, B; Fernández Del Val, D.; Carretero, O.M.; *Searches for compositeness at the LHC*, Ciemat Technical Report 1528, ISSN: 2695-8864.)

Analysis strategy: shape analysis

- We will perform this analysis by fixing the total number of expected entries in MC to the number of data entries, i.e. it will be a **SHAPE analysis** .
- In this way, we avoid systematics (>2%) with a larger effect than the loss of sensitivity when using only the shape of the distribution. Also, within the expected sensitivity range of W and Y for the current integrated luminosities, changes in shape have more weight in the fit than changes in normalization:



Luminosities

Muons

Run 2:

- 2016preVFP: 19.50 fb^{-1}
- 2016postVFP : 17.18 fb^{-1}
- 2017: 42.04 fb^{-1}
- 2018: 61.31 fb^{-1}

Run 3:

- 2022-preEE: 9.77 fb^{-1}
- 2022-postEE: 27.84 fb^{-1}
- 2023-preBPix: 18.11 fb^{-1}
- 2023-postBPix: 9.57 fb^{-1}

Electrons

Run 2:

- 2016preVFP : 19.33 fb^{-1}
- 2016postVFP: 16.98 fb^{-1}
- 2017: 41.48 fb^{-1}
- 2018 : 59.83 fb^{-1}

Run 3:

- 2022-preEE : 8.17 fb^{-1}
- 2022-postEE: 27.01 fb^{-1}
- 2023-preBPix: 17.79 fb^{-1}
- 2023-postBPix: 9.45 fb^{-1}

Muons. Summary of cuts.

We ask for events firing the following triggers (depending on the year):

- HLT_Mu50 || HLT_TkMu100 || HLT_OldMu100 || HLT_TkMu50.

We only use “good” muons, i.e. muons that satisfied the following requirements (used in these analyses):

- Some ID requirements: global high pt and Global muon.
- Muon pt > 53 GeV (in the HLT_MU trigger plateau).
- Tracker relative isolation < 0.1

Note that we use the muon pT given by the TuneP algorithm.

Now we take the time to form dimuons of different charge $\mu^+\mu^-$, taking the one with highest invariant mass.

- In order to avoid “fake high-energy dimuons”, where one comes from a Z, we exclude the event when there is one possible dimuon with mass $|m_{\text{inv}} - m_Z| < 20$ GeV .
- In order to reject cosmic muons we exclude the dimuon if the acollinearity of the muons is <0.02

Electrons. Summary of cuts.

We also ask that the event fires one of the following triggers (depending on the year):

- HLT_DoubleEle33_CaloIdL_MW || HLT_DoubleEle33_CaloIdL_GsfTrkIdVL || HLT_DoubleEle25_CaloIdL_MW.

We only use "good" electrons that satisfy (as done here):

- HEEP ID

An with them we form dielectrons ee (no requirements on charge!), taking the one with the highest invariant mass.

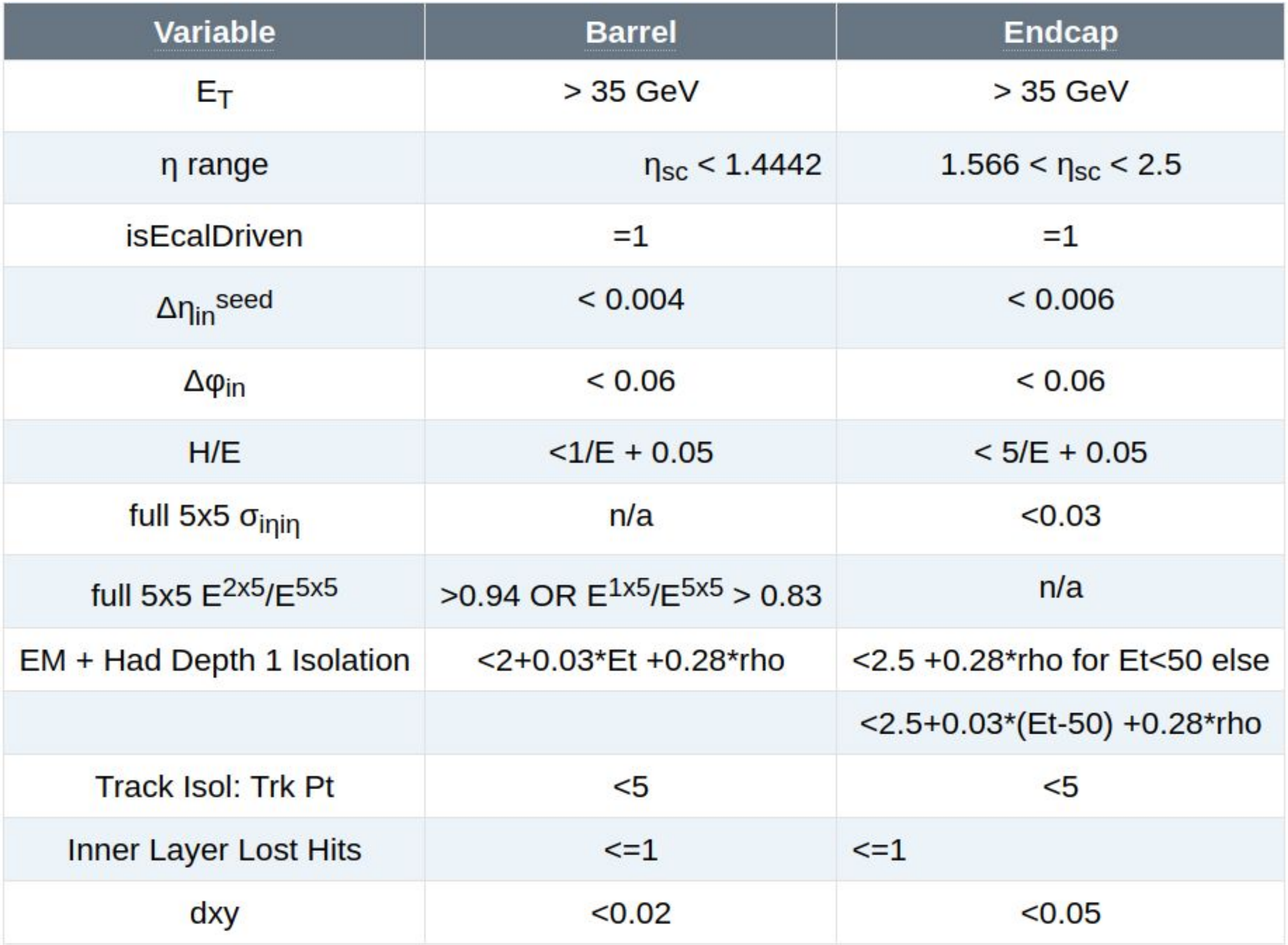
- ❑ As we did for the muons, we exclude the event when there is one possible dielectron with mass $|m_{\text{inv}} - m_Z| < 20$ GeV to avoid "fake high-energy dielectrons", where one comes from a Z.
- ❑ We also ask that one of the electrons be in the barrel.

Global High pT Muon (or High pT Muon)

- Global muon.
- At least one muon-chamber hit included in the global-muon track fit or in the TuneP fit.
- Muon segments in at least two muon stations, or if the muon only has one matched station it must be a tracker muon and must satisfy at least one of these conditions: has one or zero expected matched station based on the extrapolation of the inner track, the single matched station should not be the first muon station, or has at least two matched RPC layers.
- The p_T relative error of the muon best track is less than 30% .
- Its tracker track has transverse impact parameter $d_{xy} < 2$ mm w.r.t. the primary vertex.
- The longitudinal distance of the tracker track wrt. the primary vertex is $d_z < 5$ mm .
- Number of pixel hits > 0 .
- Cut on number of tracker layers with hits >5 .

HEEP ID

***See this page for more information



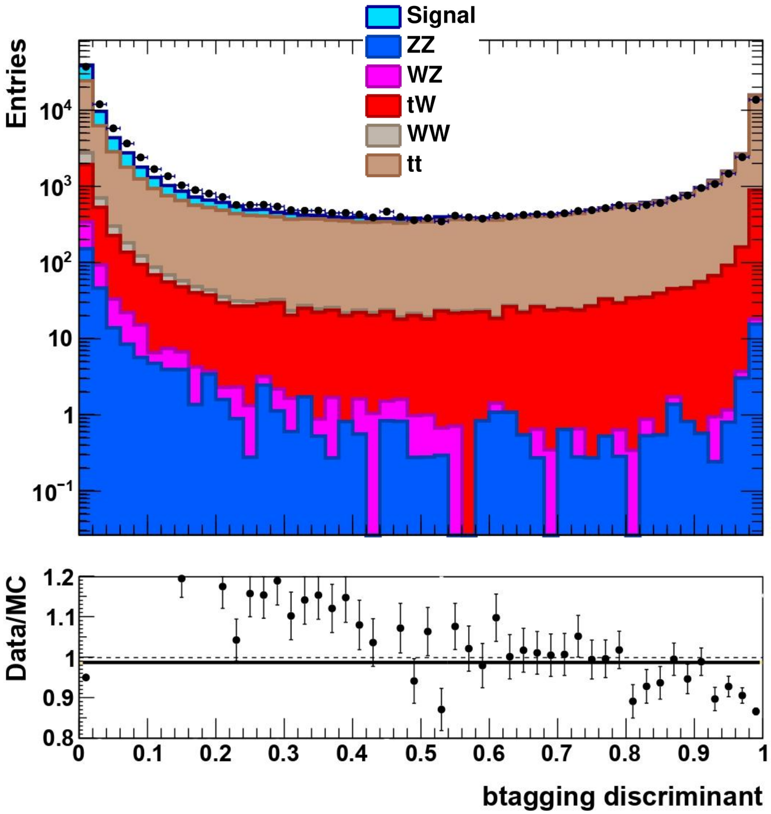
Variable	Barrel	Endcap
E_T	> 35 GeV	> 35 GeV
η range	$\eta_{sc} < 1.4442$	$1.566 < \eta_{sc} < 2.5$
isEcalDriven	=1	=1
$\Delta\eta_{in}^{seed}$	< 0.004	< 0.006
$\Delta\varphi_{in}$	< 0.06	< 0.06
H/E	<1/E + 0.05	< 5/E + 0.05
full 5x5 $\sigma_{i\eta i\eta}$	n/a	<0.03
full 5x5 E^{2x5}/E^{5x5}	>0.94 OR $E^{1x5}/E^{5x5} > 0.83$	n/a
EM + Had Depth 1 Isolation	<2+0.03*Et +0.28*rho	<2.5 +0.28*rho for Et<50 else <2.5+0.03*(Et-50) +0.28*rho
Track Isol: Trk Pt	<5	<5
Inner Layer Lost Hits	<=1	<=1
dxy	<0.02	<0.05

Muons. Studying the tt/tW background.

We select events with at least two jets, and one jet b-tagged that satisfied:

- Jet pt>25 GeV
- |Jet η| < 2.5
- ID: tight lepton veto
- b-tag at Medium WP with DeepFlavB (period dependent, typical values around 0.3)

Before computing the correction factor from the control sample, we normalized all MCs to the Data/MC coefficient and corrected due to the b-tagging, using the SFs from the QCD measurements (mujets) and the efficiencies computed.



2018 cut is 0.2783

***We discard studying the tt/tW background using an emu sample, as the variation between years and between muons and electrons is too large, which could lead to much larger systematics.

Muons. Studying the tt/tW background.

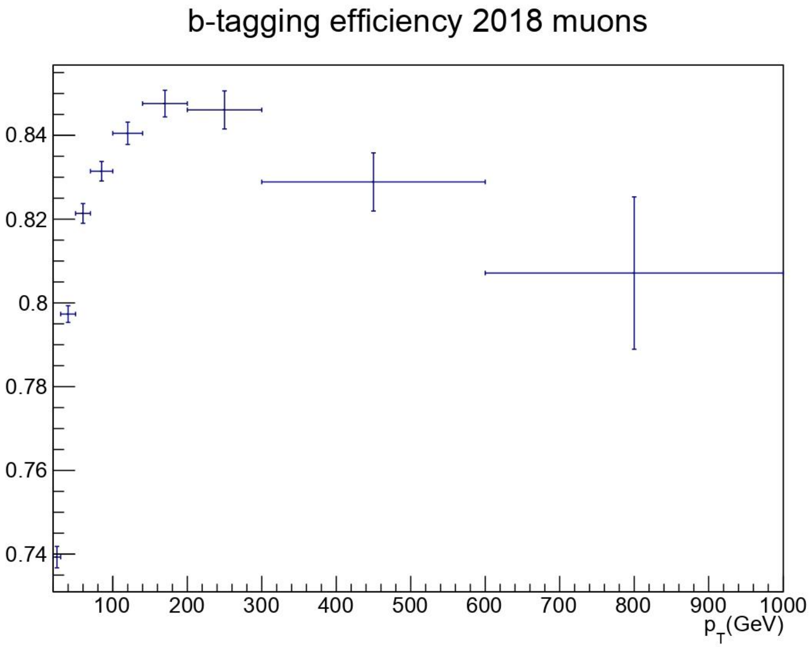
We compute the b-tagging efficiencies in MC with the same pT binning as the SFs for each year as:

$$\varepsilon = \frac{N_{b-jet}^{tagged}}{N_{b-jet}}$$

Where a b-jet satisfy:

- b-jet at generator level
- |Jet η| < 2.5
- ID: tight lepton veto

And tagged if it satisfies the Medium WP with DeepFlavB.



Muons. Studying the tt/tW background.

Once we have the efficiencies we correct the MC due to the b-tagging, applying the weight according to the BTV POG recommendations:

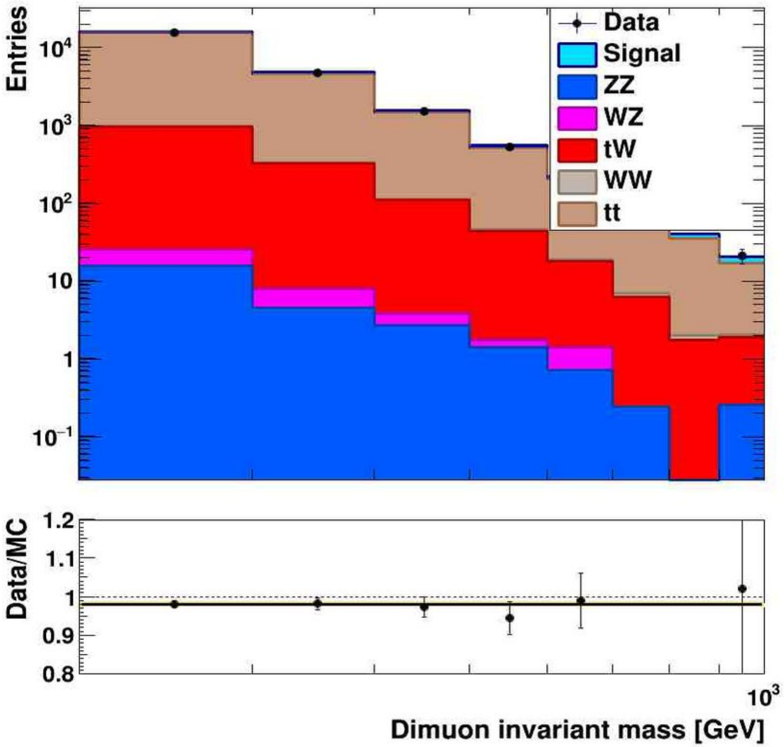
$$w = \frac{\prod_{\mathrm{i=not\ tagged}}(1 - \mathrm{SF_i}\varepsilon_\mathrm{i}) \prod_{\mathrm{j=tagged}} \mathrm{SF_j}\varepsilon_\mathrm{j}}{\prod_{\mathrm{i=not\ tagged}}(1 - \varepsilon_\mathrm{i}) \prod_{\mathrm{j=tagged}} \varepsilon_\mathrm{j}}$$

Where we run over jets that satisfy:

- b-jet at generator level
- Jet pt>25 GeV
- |Jet η| < 2.5
- ID: tight lepton veto

And the b-tag is at Medium WP with DeepFlavB.

2018 plot



Muons. Studying the tt/tW background.

Thus, we can fix the "tt/tW backgrounds" by reweighting them with the Data/MC ratio obtained. We get the following ratios for the different periods:

- 2016preVFP: 1.008 ± 0.019 (stat. + syst.)
- 2016postVFP: 0.998 ± 0.020 (stat. + syst.)
- 2017: 0.991 ± 0.020 (stat. + syst.)
- 2018: 0.981 ± 0.020 (stat. + syst.)
- 2022-preEE: 0.965 ± 0.035 (stat. + syst.)
- 2022-postEE: 0.961 ± 0.031 (stat. + syst.)
- 2023-preBPix: 0.888 ± 0.012 (stat., SF missing)
- 2023-postBPix: 0.894 ± 0.016 (stat., SF missing)

These correction factors are dominated by systematics except in periods of low luminosity (uncertainty from the efficiencies is negligible) .For 2018 we have:

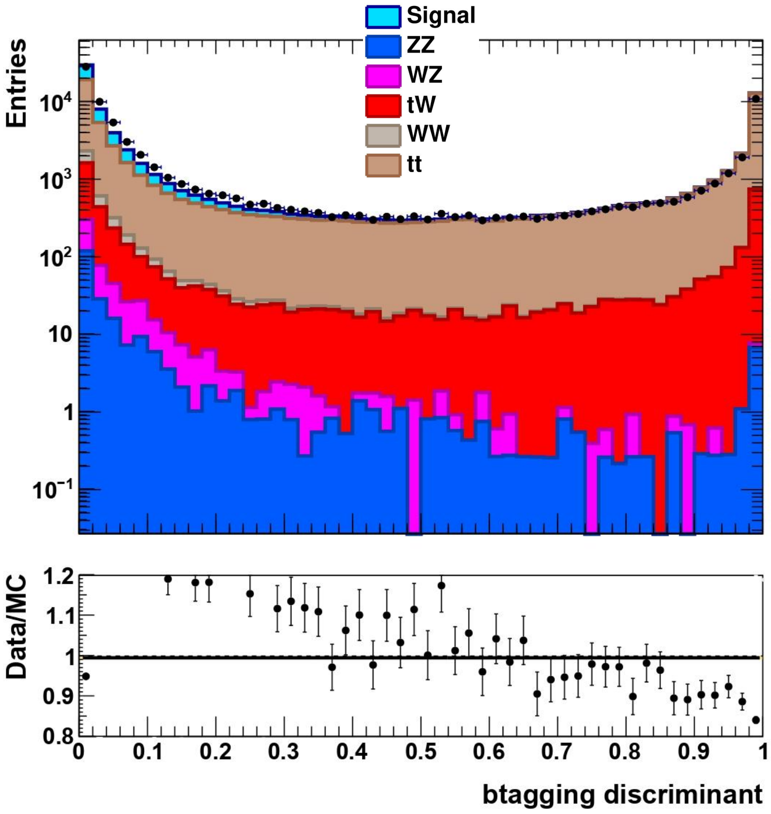
- 2018: $0.9808 \pm 0.0069(stat.)^{+0.0166}_{-0.0186}(syst.corr.)^{+0.0053}_{-0.0055}(syst.uncorr.)^{+0.0008}_{-0.0008}(eff.)$

Electrons. Studying the tt/tW background.

The process is the same as for muons, we select events with at least two jets, and one jet b-tagged that satisfied:

- Jet pt>25 GeV
- |Jet η| < 2.5
- ID: tight lepton veto
- b-tag at Medium WP with DeepFlavB (period dependent, typical values around 0.3)

Before computing the correction factor from the control sample, we normalized all MCs to the Data/MC coefficient and corrected due to the b-tagging, using the SFs from the QCD measurements (mujets) and the efficiencies computed.



2018 cut is 0.2783

Electrons. Studying the tt/tW background.

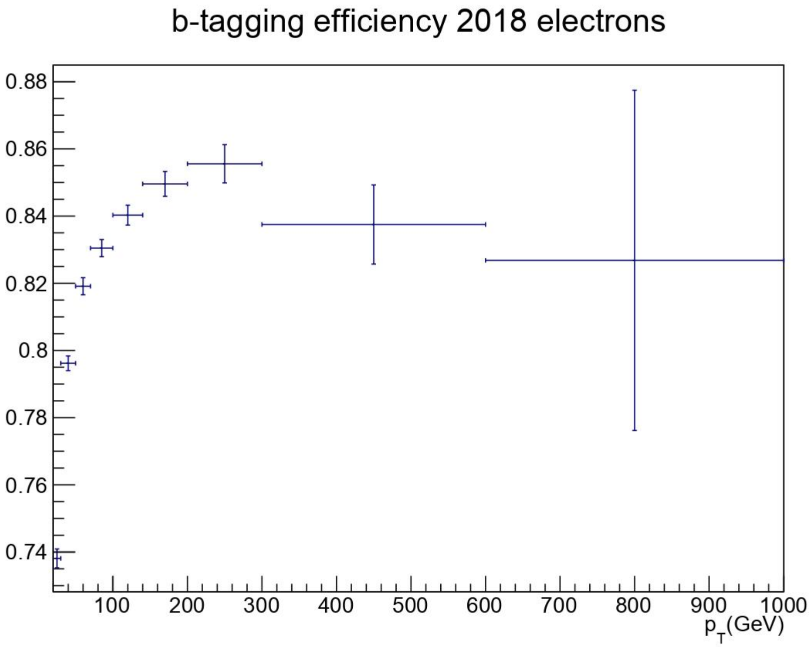
We compute the b-tagging efficiencies in MC with the same pT binning as the SFs for each year as:

$$\varepsilon = \frac{N_{\mathrm{b-jet}}^{\mathrm{tagged}}}{N_{\mathrm{b-jet}}}$$

Where a b-jet satisfy:

- b-jet at generator level
- |Jet η| < 2.5
- ID: tight lepton veto

And tagged if it satisfies the Medium WP with DeepFlavB.



Electrons. Studying the tt/tW background.

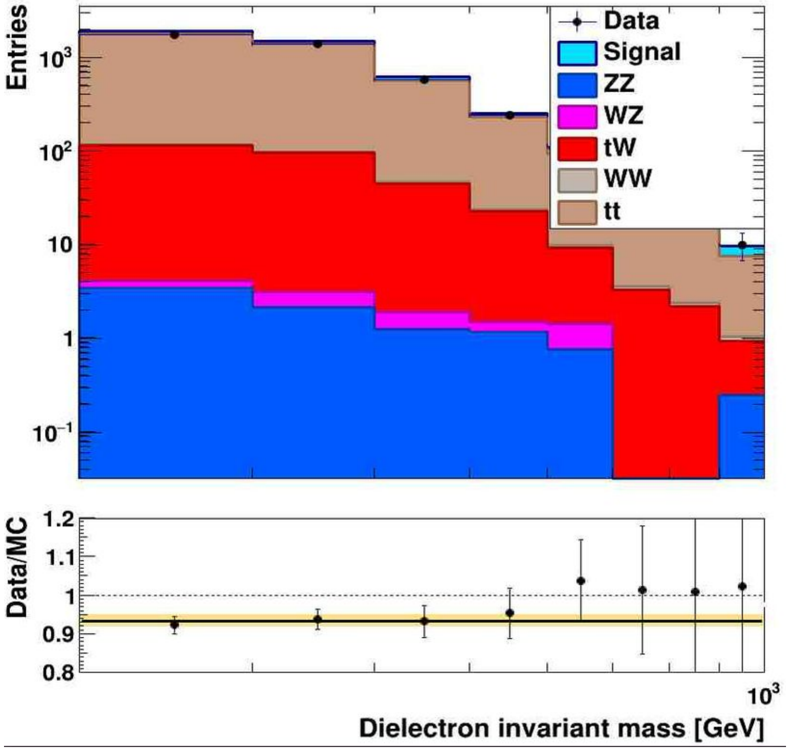
Once we have the efficiencies we correct the MC due to the b-tagging, applying the weight according to the BTV POG recommendations :

$$w = \frac{\prod_{\mathrm{i=not\ tagged}}(1-\mathrm{SF_i}\varepsilon_\mathrm{i})\prod_{\mathrm{j=tagged}}\mathrm{SF_j}\varepsilon_\mathrm{j}}{\prod_{\mathrm{i=not\ tagged}}(1-\varepsilon_\mathrm{i})\prod_{\mathrm{j=tagged}}\varepsilon_\mathrm{j}}$$

Where we run over jets that satisfy:

- b-jet at generator level
- Jet pt>25 GeV
- |Jet η| < 2.5
- ID: tight lepton veto

And the b-tag is at Medium WP with DeepFlavB.



2018 plot

Electrons. Studying the tt/tW background.

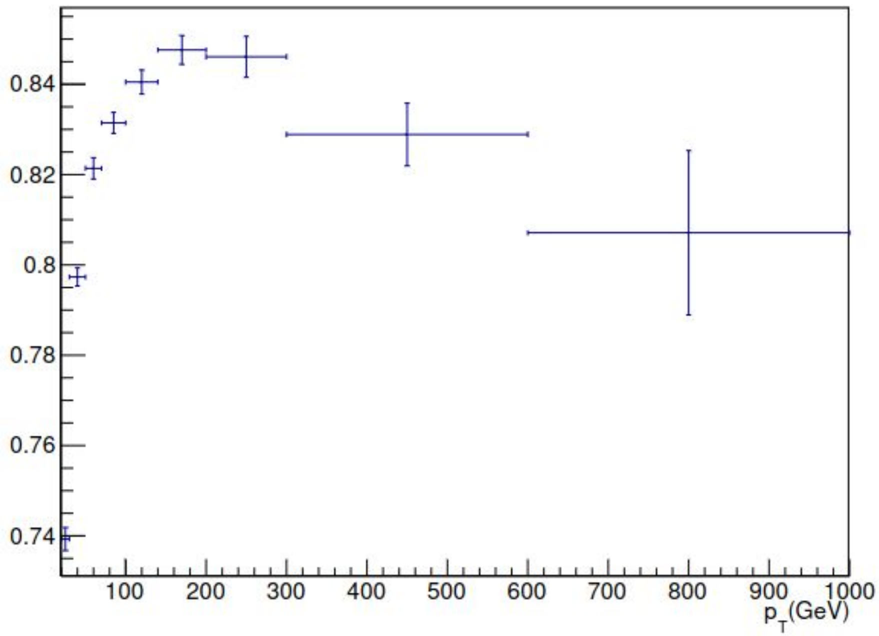
The process is the same as for muons (in the backup you can find the detailed study for electrons). We get the following ratios for the different periods:

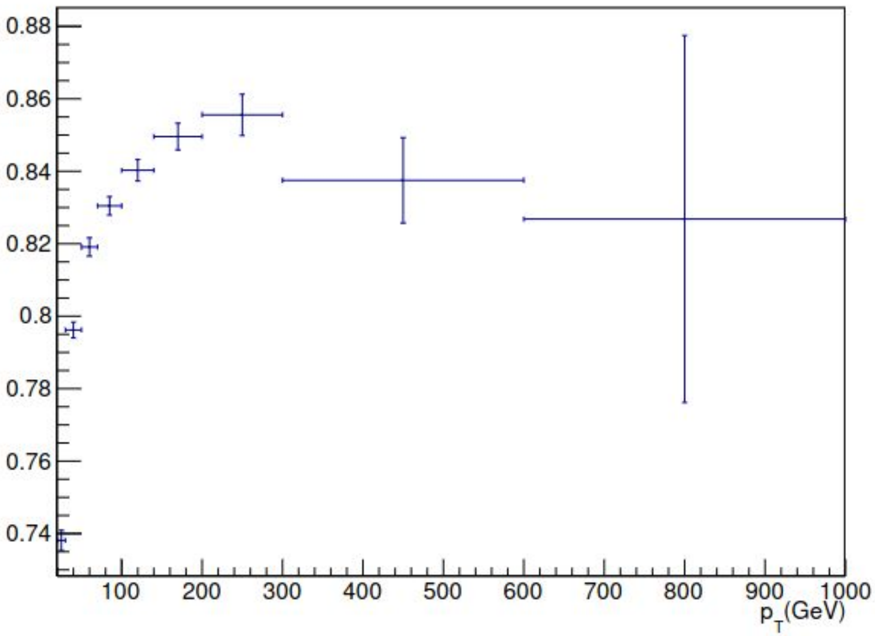
- 2016preVFP: 0.932 ± 0.018 (stat. + syst.)
- 2016postVFP: 0.955 ± 0.020 (stat. + syst.)
- 2017: 0.953 ± 0.019 (stat. + syst.)
- 2018: 0.955 ± 0.019 (stat. + syst.)
- 2022-preEE: 0.928 ± 0.033 (stat. + syst.)
- 2022-postEE: 0.930 ± 0.029 (stat. + syst.)
- 2023-preBPix: 0.853 ± 0.012 (stat., SF missing)
- 2023-postBPix: 0.868 ± 0.017 (stat., SF missing)

Comparing efficiencies: 2018.

Let's compare the average b-tagging efficiency for the Medium WP available in the twiki BTV (different samples) with those we have calculated.

- BTV twiki: 80.7%


b-tagging efficiency 2018 muons

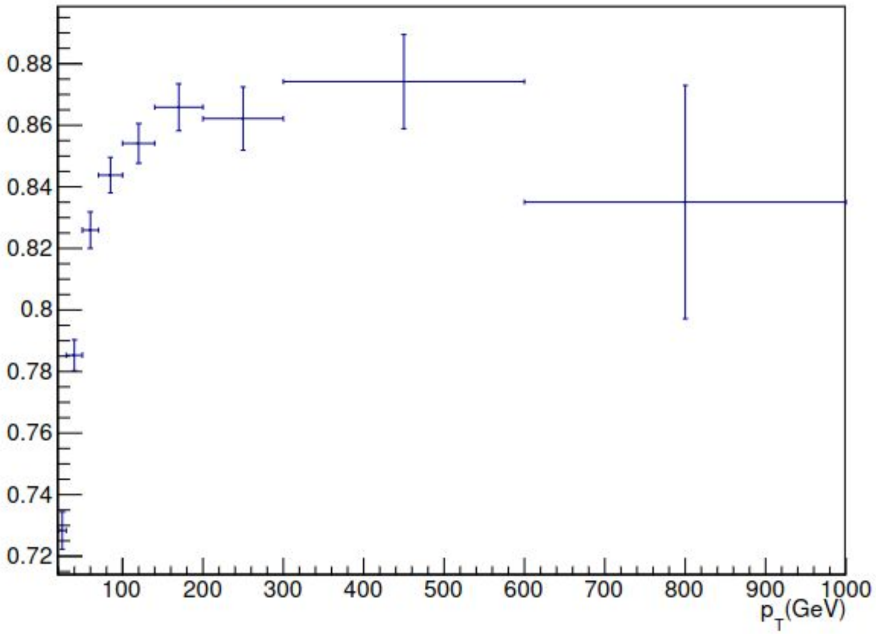

b-tagging efficiency 2018 electrons

Oliver M. Carretero

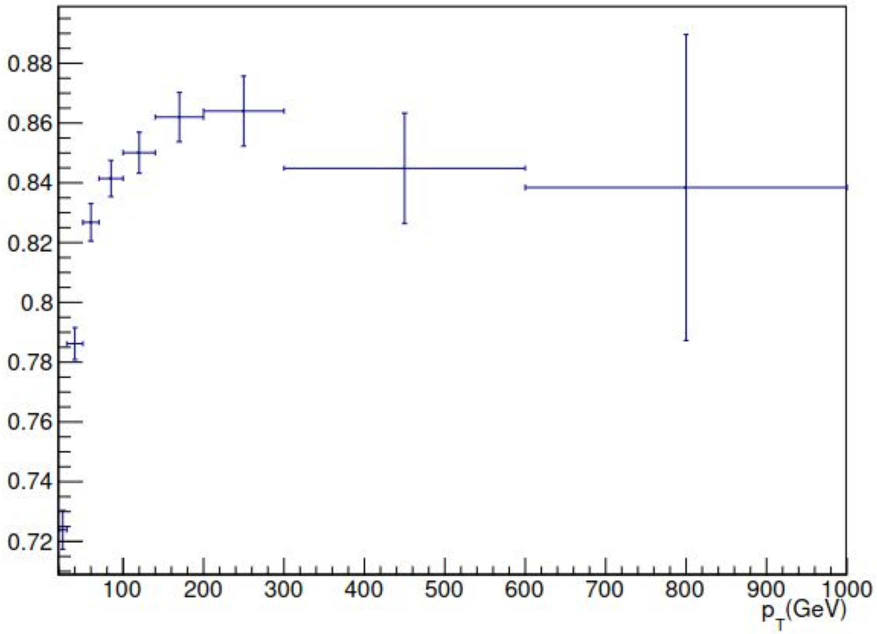
Comparing efficiencies: 2022preEE.

Let's compare the average b-tagging efficiency for the Medium WP available in the twiki BTV (different samples) with those we have calculated.

- BTV twiki: 80.2%



b-tagging efficiency 2022preEE muons



b-tagging efficiency 2022preEE electrons