Status Update $H^{++}H^{--} \rightarrow$ Lep Search

UNIVERSITÉ
LIBRE
DE BRUXELLES

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About us

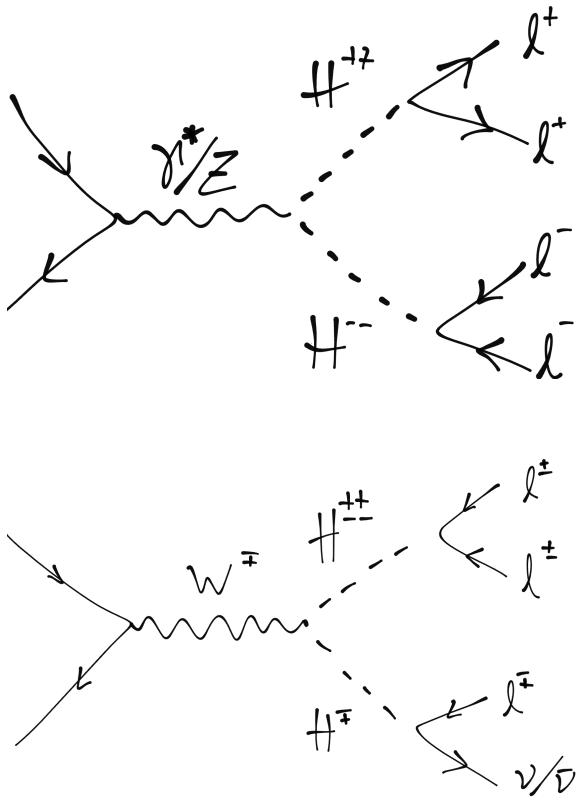
Laurent Thomas
Postdoc

Santiago Paredes Sáenz
Postdoc

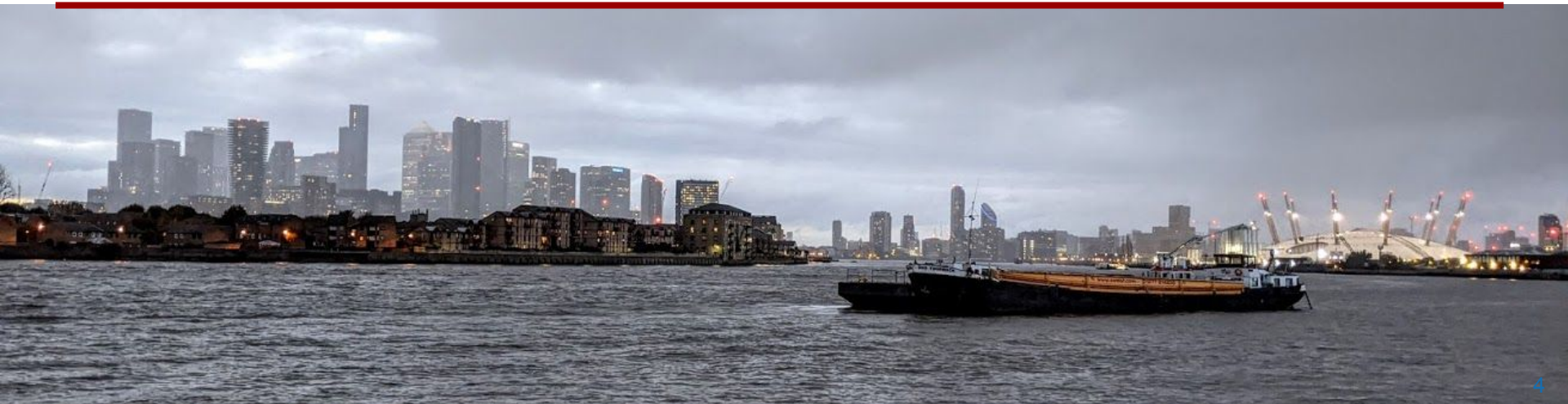
Barbara Clerbaux
Professor

Current Results

- CMS-PAS-HIG-16-036 (12.9 fb^{-1})
  - ➢ **Draft** of update: CMS-AN-17-100 (35.9 fb^{-1})
    - ↳ **Archived** since 2018
  - ➢ By **Devin N. Taylor** (UC Davis)
- ATLAS Paper (36.1 fb^{-1})
  - ➢ CERN-EP-2017-198; arXiv:1710.09748
    - → *Only targets pair-production

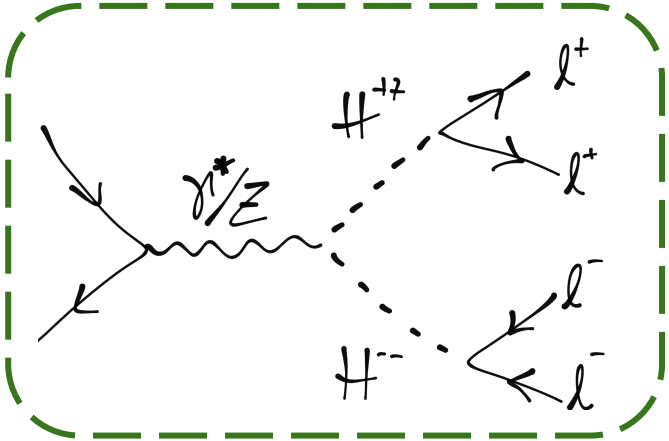


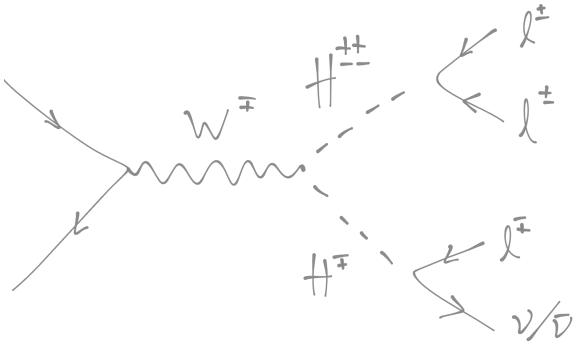
Status



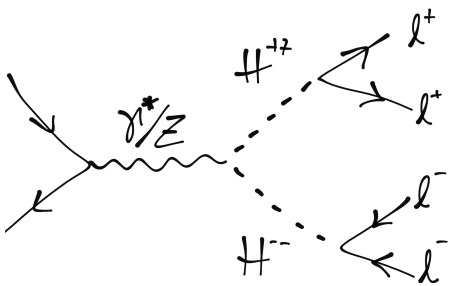
Status

- **Strategy:**
  - ↳ **Combining** ideas from **CMS** and **ATLAS** analyses
- Focus on **4 lepton** channel in **UL2017** at first
  - ↳ **e/μ** only
- Currently studying:
  - ↳ **Data** VS **MC** in control regions
  - ↳ Processing **other bkg MC**





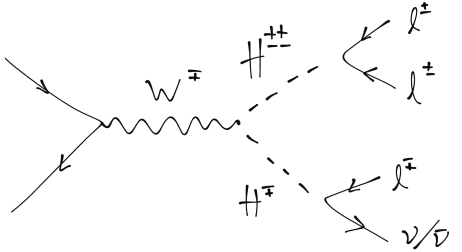
Status - channels



$H^{\pm\pm}$ \ $H^{\pm\pm}$	ee	eμ	μμ	ττ	τe	τμ
ee						
eμ						
μμ						
ττ						
τe						
τμ						

$H^{\pm\pm}$ (missing lep)

$H^{\pm\pm}$ \ $H^{\pm\pm}$	e	μ	τ
ee			
eμ			
μμ			
ττ			
τe			
τμ			

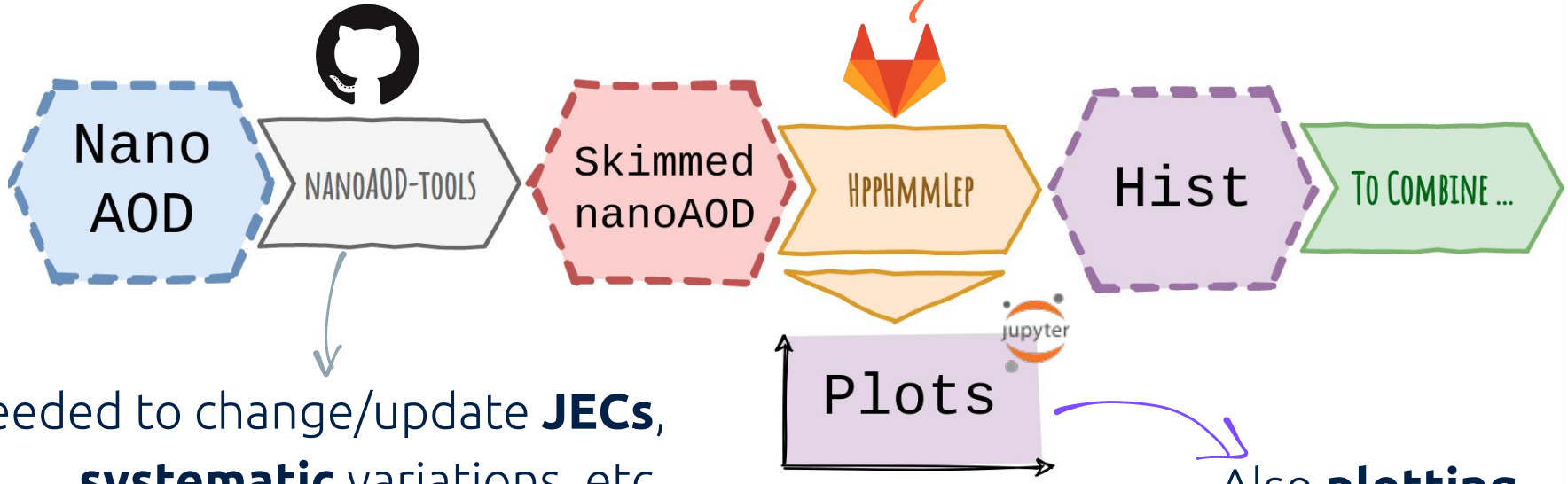


$H^{\pm\pm}$ \ $H^{\pm}$	eν	μν	τν
ee			
eμ			
μμ			
ττ			
τe			
τμ			

currently working on →
potential addition →
no plan to add →

Status - software

- **Software framework**



Object & Event **Selection**, weighting, etc.

Needed to change/update **JECs**, **systematic** variations, etc. + some **initial cuts**

Also **plotting**

Status - selections

- **Work in progress:** Selections

Electrons

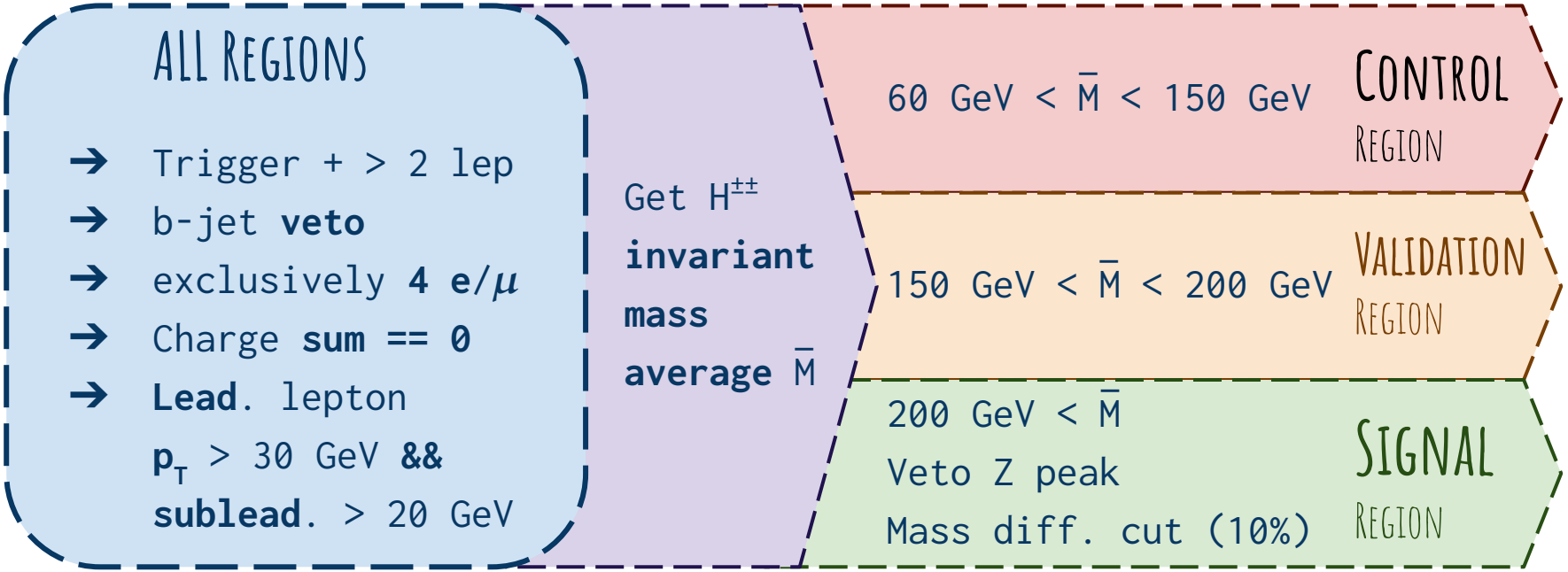
- p_T > 20 GeV
- $|\eta|$ < 2.5
- **Iso**: cutBasedHEEP
- d**xy** < 0.05
- d**z** < 0.1

Muons

- p_T > 20 GeV
- $|\eta|$ < 2.4
- **ID**: mediumID
- d**xy** < 0.2
- d**z** < 0.5
- tkRelIso/p_T < 0.4

Status - selections

- **Work in progress:** Cuts



Status - selections

- **Efficiency**

	signal	ttbar	ZZ	signal (%)	ttbar (%)	ZZ (%)
Initial Events	198000	21412700	14284590	-	-	-
Trigger + preprocessing	145650	8648554	647153	73.56%	40.39%	4.53%
b-jet veto	142692	2440269	639693	72.07%	11.40%	4.48%
exactly 4 e/mu	39288	611	7825	19.84%	>0.01%	0.05%
lep. charge sum == 0	37927	449	7733	19.16%	>0.01%	0.05%
Control	6	315	5123	>0.01%	>0.01%	0.04%
Validation	13	28	872	0.01%	>0.01%	0.01%
Signal	21322	2	56	10.77%	>0.01%	>0.01%
Overall efficiency (SR)	10.77%	>0.01%	>0.01%	10.77%	>0.01%	>0.01%

Full lists of data and MC datasets in backup

- **MC (UL2017)**

NanoAODs

/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1/NANOAODSIM

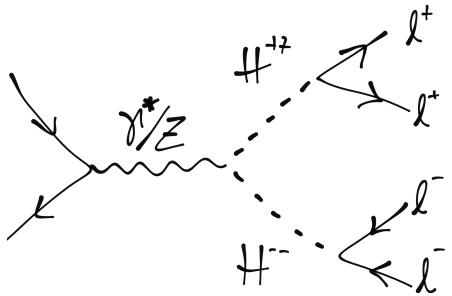
'Homebrew' NanoAOD made from
/ZZTo4L_M-1toInf_TuneCP5_13TeV_powheg_pythia8/RunIISummer20UL17MiniAOD-106X_mc2017_realistic_v6-v1/MINIAODSIM

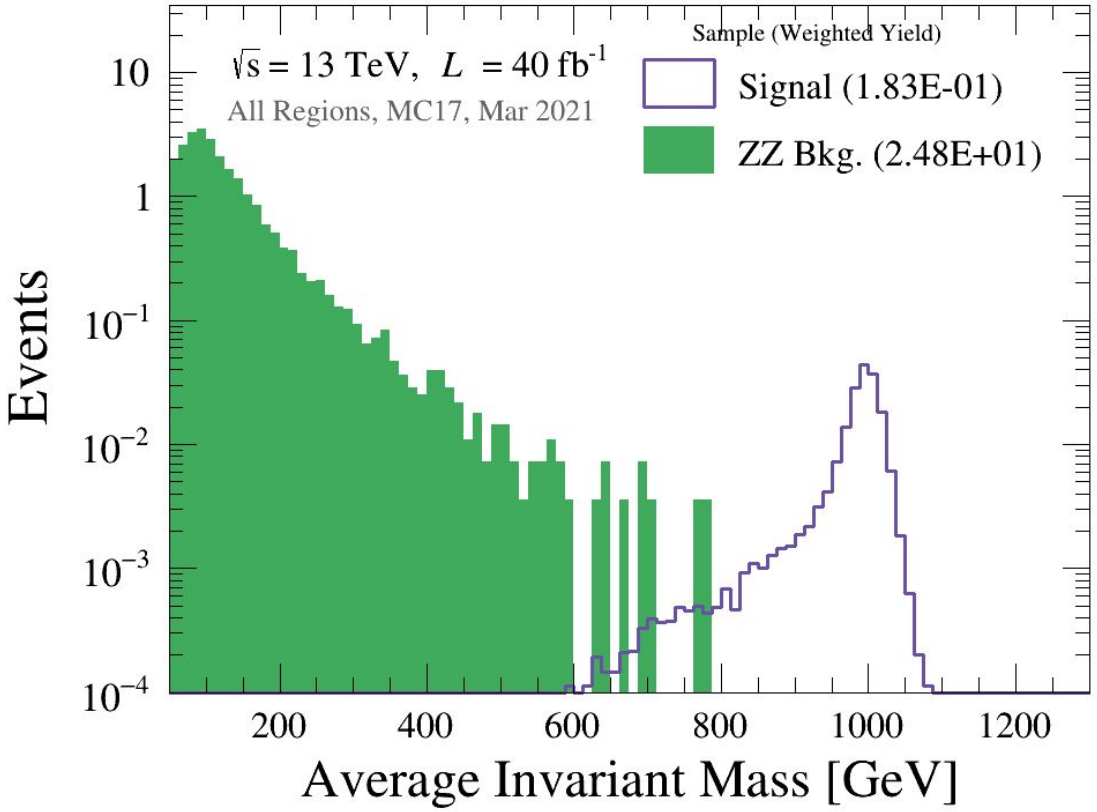
Custom NanoAODs

/HPlusPlusHMinusMinusHTo4L_M-1000_TuneCP5_13TeV_pythia8/NANOAODStep_UL17 → Privately generated

Status - signal

- Signal MC
  - ↳ Same as CMS-AN-17-100
  - ↳ 'LeftRightSymmmetry' in **PYTHIA** 8, **1 TeV** , vev ~0
  - ↳ Equal coupling to **e/μ/τ**
    → Selecting **e/μ** only!





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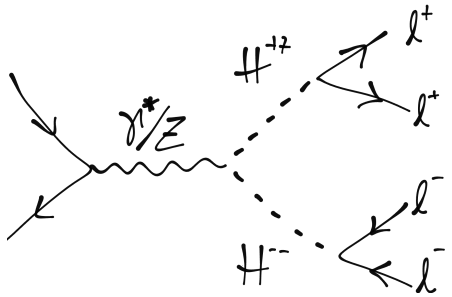
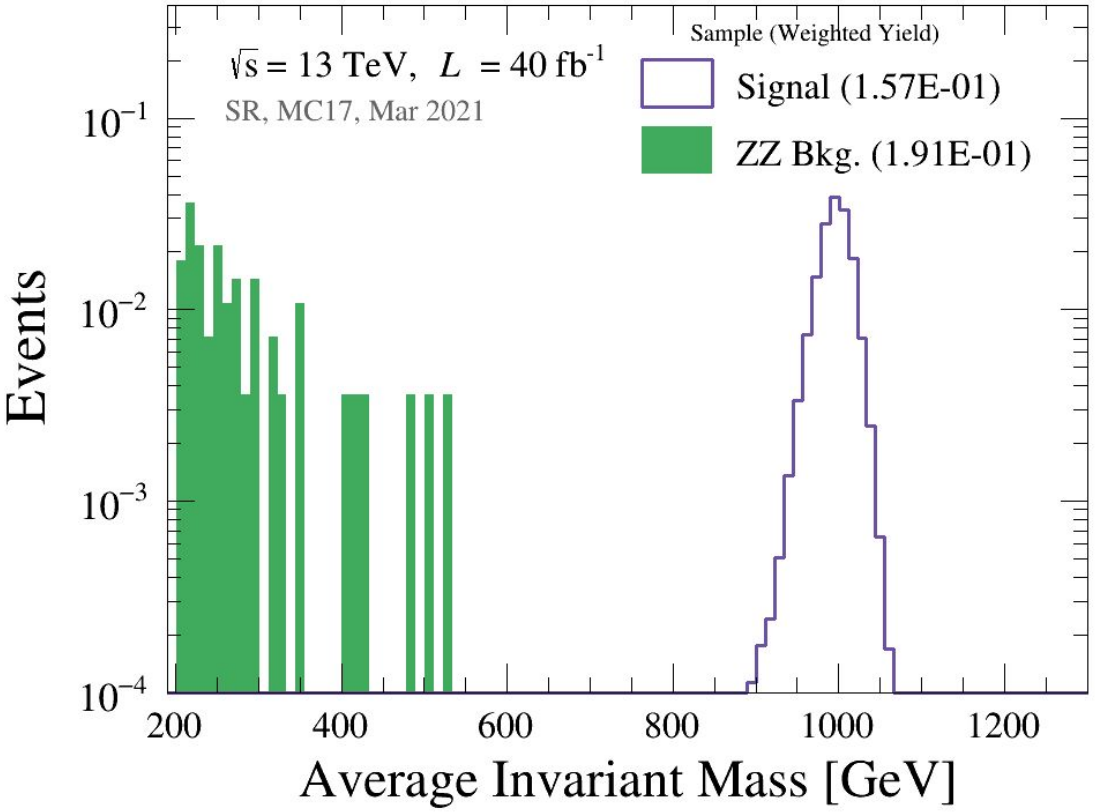
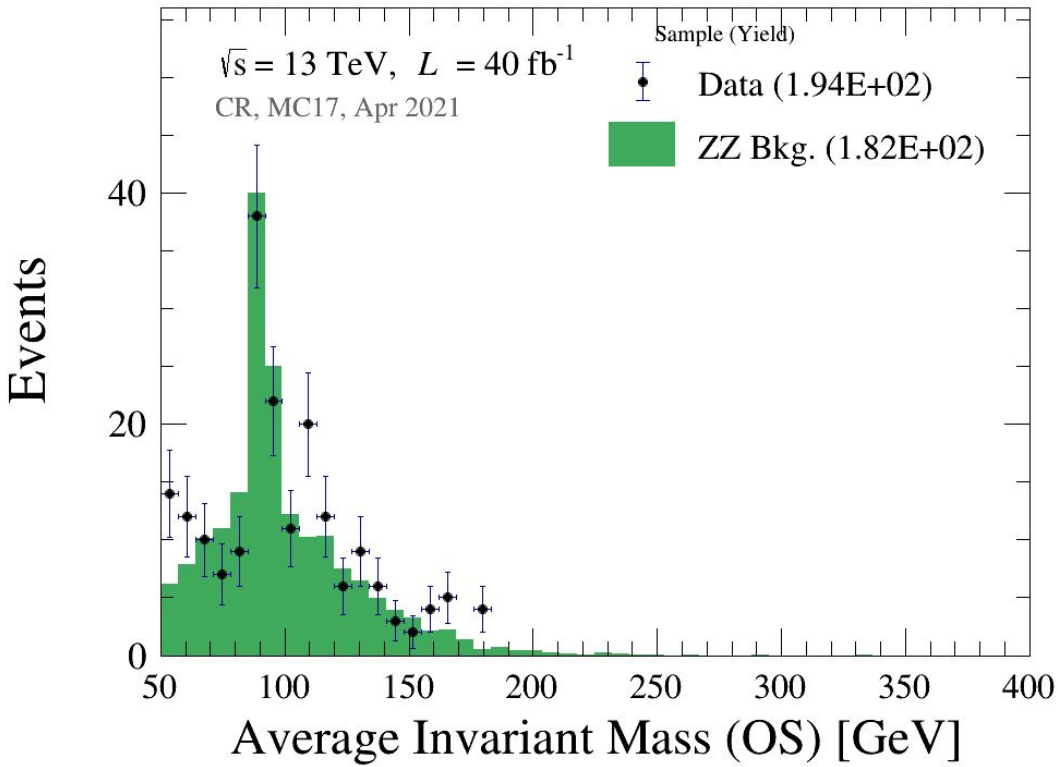




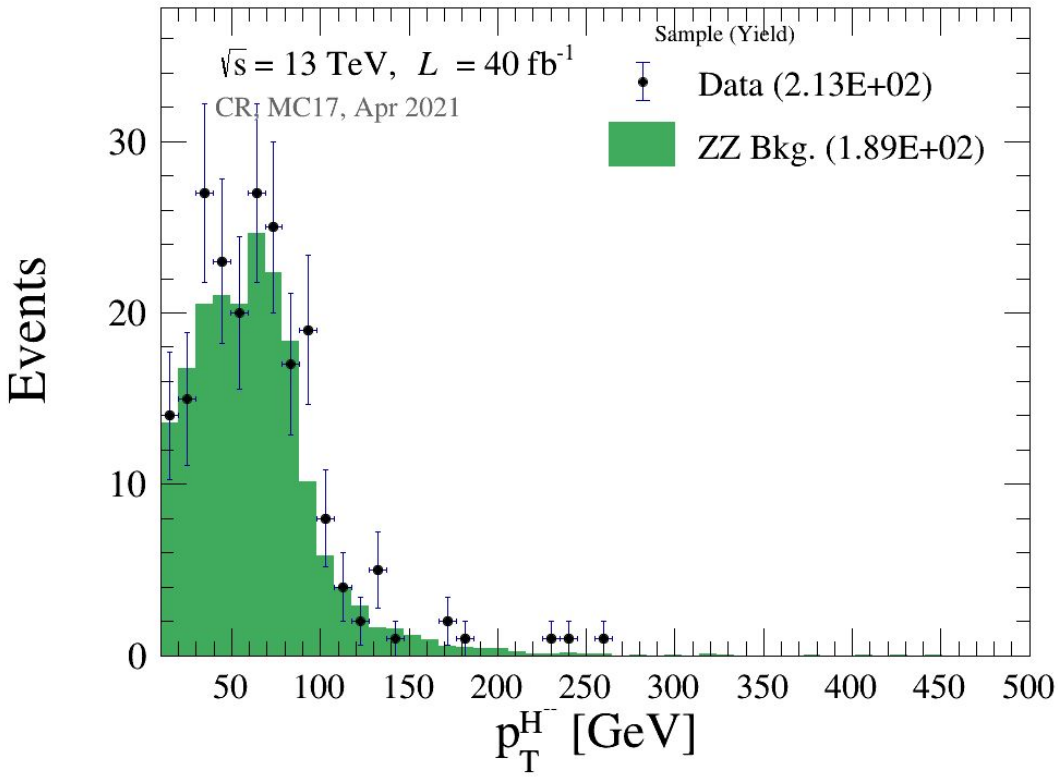
Status - data VS MC

- **Control** region
- **Opposite-sign** lepton pairs
- **Only ZZ** background
  - ↳ Mostly **OK**
  - ↳ Some discrepancy



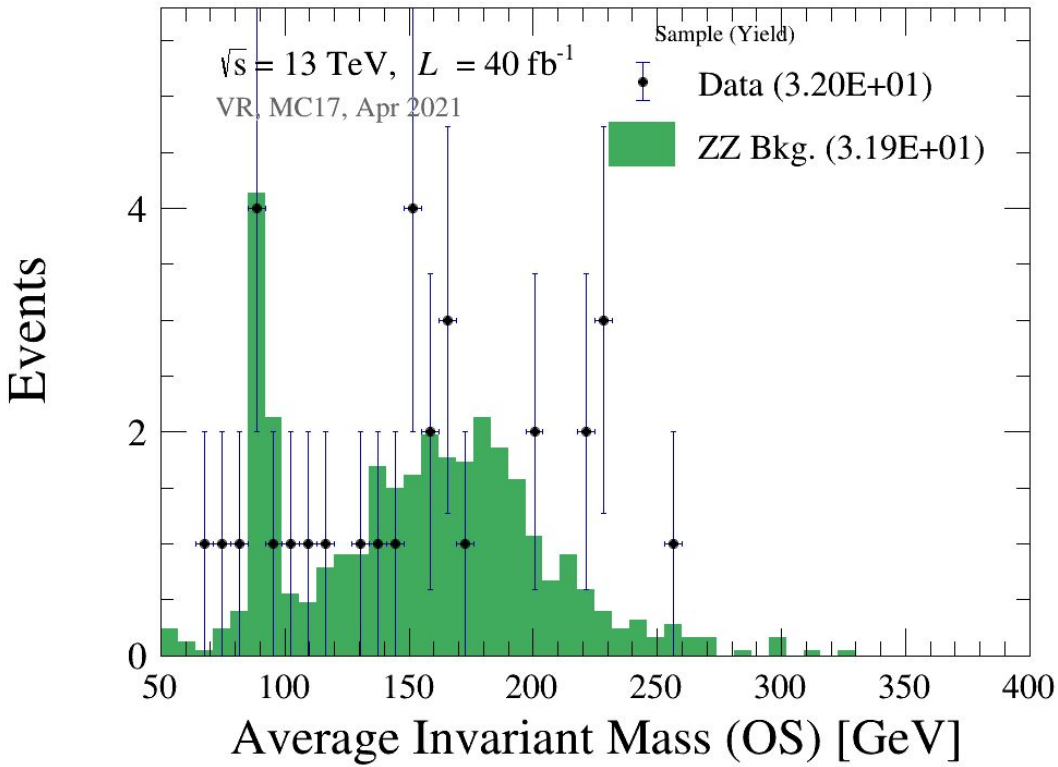
Status - data VS MC

- **Control** region
- **H^{--}** candidate p_T
- **Only ZZ** background



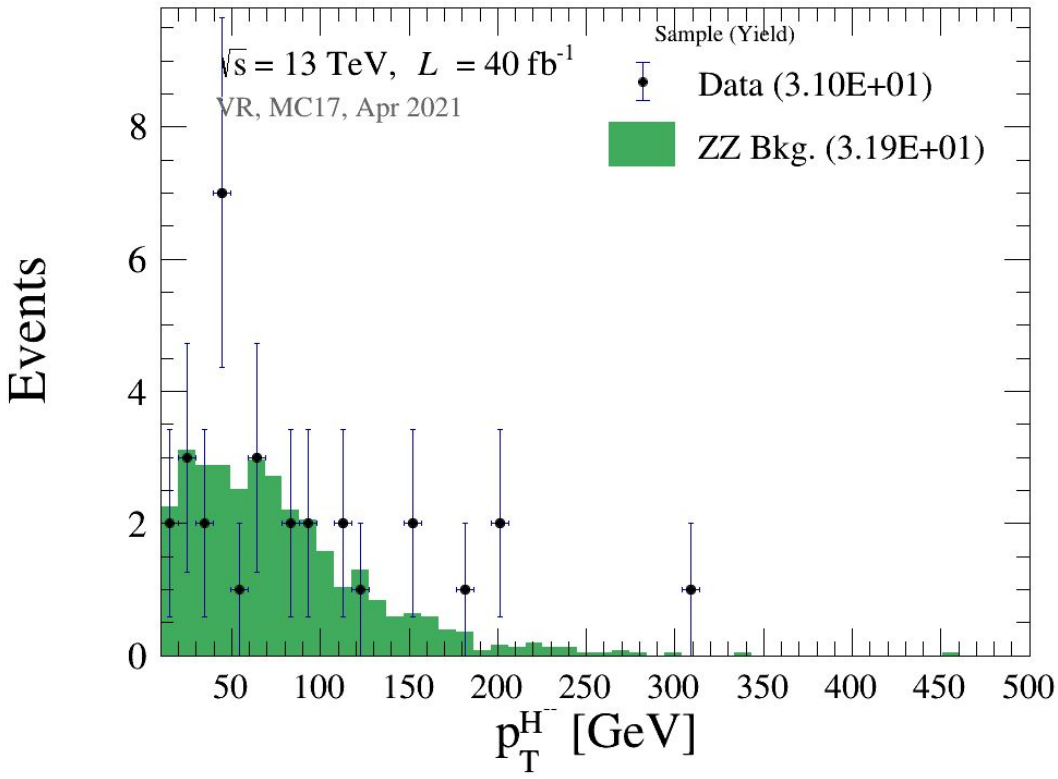
Status - data VS MC

- **Validation** region
- **Opposite-sign** lepton pairs
- **Only ZZ** background
- Very low stats



Status - data VS MC

- **Validation** region
- H^{--} candidate p_T
- **Only ZZ** background
- Very low stats



Next Steps

Next Steps

- **Next** steps:
  - ↳ Run on more **MC background** samples
  - ↳ **Produce** more **signal** mass points
  - ↳ Finalize **MC background** estimate (UL2017)
  - ↳ **Data driven backgrounds** - charge misID, etc.
  - ↳ **First pass of** statistical setup in **Combine**
  - ↳ **Explore** new **variables**, **cuts** on MC
    - → **+** optimize

Next Steps

- **Next** steps:
  - ↳ Finalize **trigger** strategy + check **efficiency** ☐
  - ↳ Finalize **selection** and **optimization** ☐
  - ↳ Apply all **scale factors** ☐
  - ↳ **Final background** estimation **CR+VR** and plots ☐
  - ↳ **Unblind** 10% or 20% of **SR** ☐
  - ↳ **Run** analysis on **2016** and **2018** ☐
  - ↳ **Finalize statistical** analysis + **Combine** setup ☐

Thanks!

Useful stuff:

12.9 fb-1 PAS

35.9 fb-1 CADI

ATLAS (36.1 fb-1) Paper

HppHmmLep GitLab repository

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April 2021

Backup

Barbara Clerbaux, **Santiago Paredes Saenz**, Laurent Thomas
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Triggers

- **Work in progress:** Trigger list

OR OF:

- 'HLT_Ele27_WPTight_Gsf',
- 'HLT_IsoMu24',
- 'HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ',
- 'HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ',
- ‘HLT_Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ',
- 'HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ'

Data Samples List

- **2016** NANOAOD **not** yet **ready**

2017 & 2018:

```
/DoubleMuon/Run2017*-UL2017_MiniAODv1_NanoAODv2-v1/NANOAOD
/DoubleMuon/Run2018*-UL2018_MiniAODv1_NanoAODv2-v2/NANOAOD

/DoubleEG/Run2017*-UL2017_MiniAODv1_NanoAODv2-v1/NANOAOD
/EGamma/Run2018*-UL2018_MiniAODv1_NanoAODv2-v1/NANOAOD

/MuonEG/Run2017*-UL2017_MiniAODv1_NanoAODv2-v1/NANOAOD
/MuonEG/Run2018*-UL2018_MiniAODv1_NanoAODv2-v1/NANOAOD
```

MC Samples List

NANOAODSIM's:
/WZTo3LNu_mllmin01_NNPDF31_TuneCP5_13TeV_powheg_pythia8/RunIISummer20UL17NanoAODv2-106X_mc2017_realistic_v8-v1
/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1
/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1
/WWTo2L2Nu_TuneCP5_DoubleScattering_13TeV-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1
/TTWJetsToLNu_TuneCP5_13TeV-amcatnloFXFX-madspin-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1
/TT_Mtt-1000toInf_TuneCP5_13TeV-powheg-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1
/TT_Mtt-700to1000_TuneCP5_13TeV-powheg-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1
/ST_tW_antitop_5f_NoFullyHadronicDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1
/ST_tW_top_5f_NoFullyHadronicDecays_TuneCP5_13TeV-powheg-pythia8/RunIISummer19UL17NanoAODv2-106X_mc2017_realistic_v8-v1

Homebrew NANOAOD's:
/pnfs/iihe/cms/store/user/lathomas/ZZTo4L_M-1toInf_TuneCP5_13TeV_powheg_pythia8/NANOAODStep_UL17/210212_190310

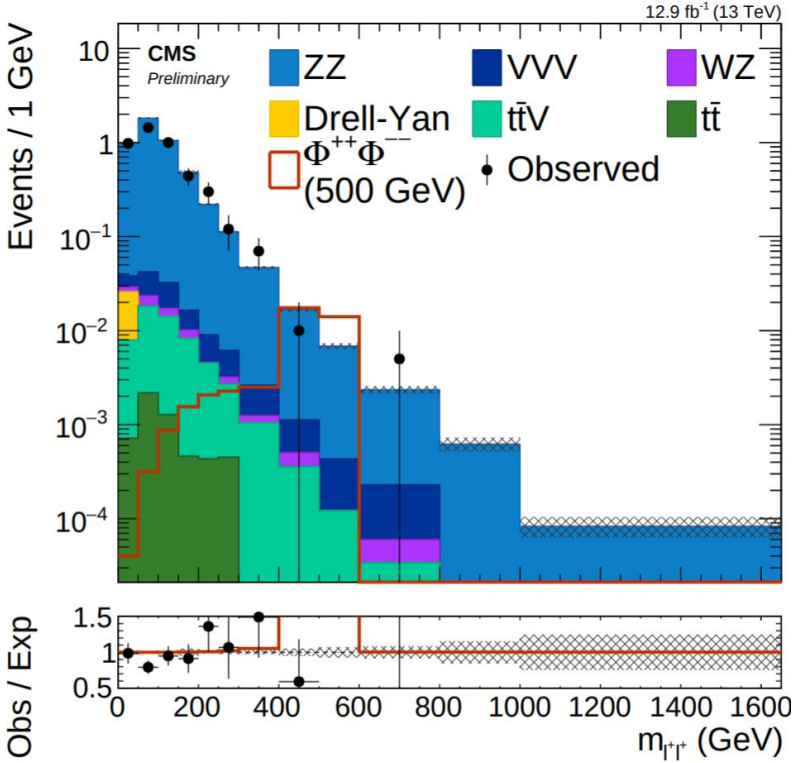
HppHmmLep Package

- eventSelection.py
  - ↳ **Main** analysis **script** written in **python**
  - ↳ `ROOT::RDataFrame` and `ROOT::VecOps::RVec` for event and object selection
    - → Efficient, readable code
    - → Multi-thread friendly(`ROOT.EnableImplicitMT(1)`)
  - ↳ Easy **configuration** and **pipeline integration**

Analysis Strategy

Analysis Strategy: CMS

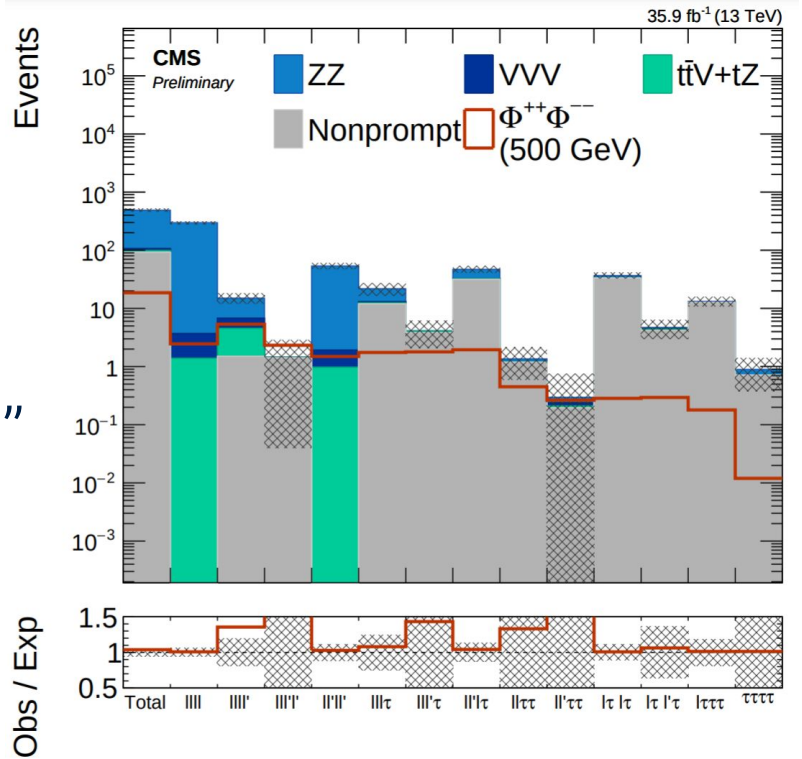
- Search for **3** or **4 leptons** in the final state
  - ↳ **Pair** - Production: + + - -
  - ↳ **Asso** - Production: ± ± ∓
- **Pre**selection: p_T, η, ΔR_{ll}, m_{ll}, b-veto
- Selection
  - ↳ 3 lep: **Σp_T**(lep), **MET**, **m_H**
  - ↳ 4 lep: **Σp_T**(lep), **m_H**



(a) $\ell^+\ell^+\ell^-\ell^-$

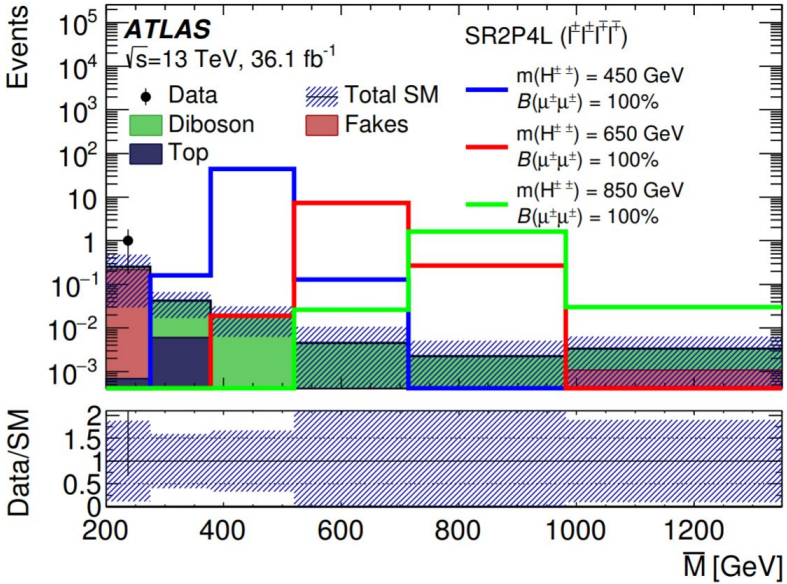
Analysis Strategy: CMS

- Background estimation
  - ↳ **Prompt** bkg → **MC** Simulation
    - Various **control/validation** regions
  - ↳ **Nonprompt** → "**tight-to-loose**" method (data+MC)
  - ↳ Use **sideband** regions in m_{ll}
    - **2D** for **4 lep**, **1D** for **3 lep**



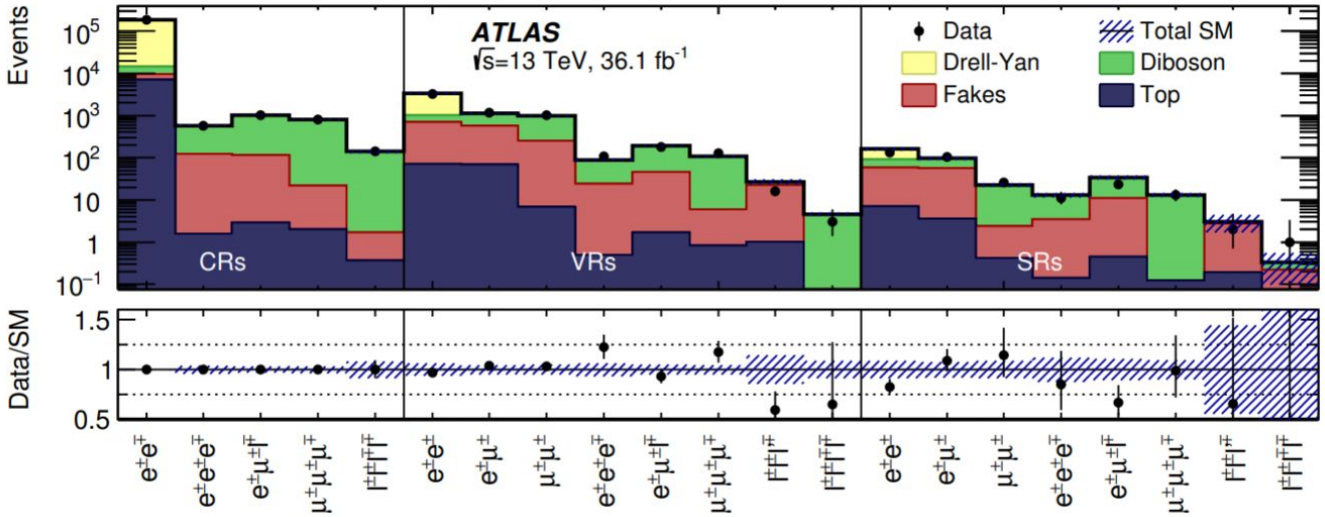
Analysis Strategy: ATLAS

- Search for **2**, **3** or **4 leptons** in the final state
  - ↳ **All** target **pair-production**
- **Pre**selection: p_T, η, b-veto
- Selection
  - ↳ 2, 3 lep: ΔR_{ll}, $p_T(H)$, $\mathbf{\Sigma p_T}$(lep), $\mathbf{m_H}$
  - ↳ 4 lep: **average $\mathbf{m_H}$**, **separation** of $\mathbf{m_{H++}}$ and $\mathbf{m_{H--}}$, Z veto



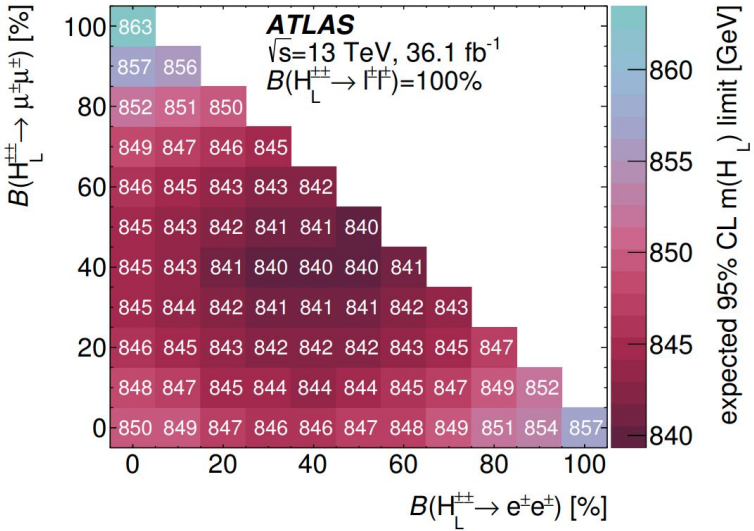
Analysis Strategy: ATLAS

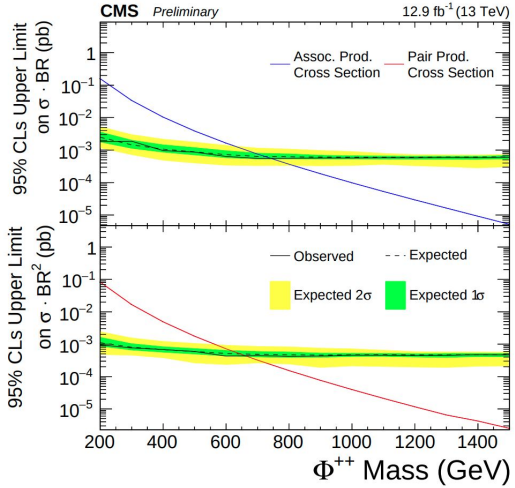
- Define various **m_h regions**
  - ↳ Control/validation/signal
- Estimate **background** via MC simulation
  - ↳ **Fake** bkg in data



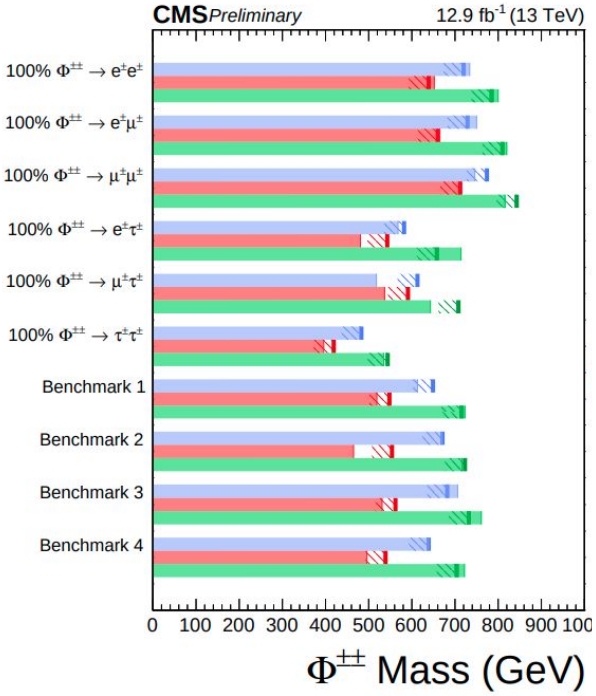
Analysis Strategy

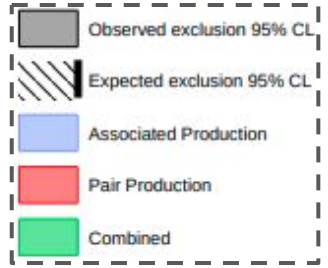
- **Various** statistical **approaches**
  - ↳ Possible **expansions** to other **models**, **generic** same-sign lepton search, etc.





(a) 100% ee





Analysis Strategy

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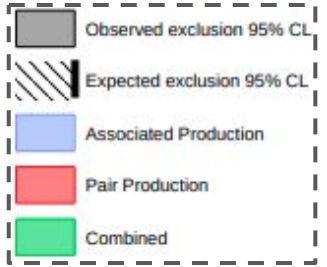
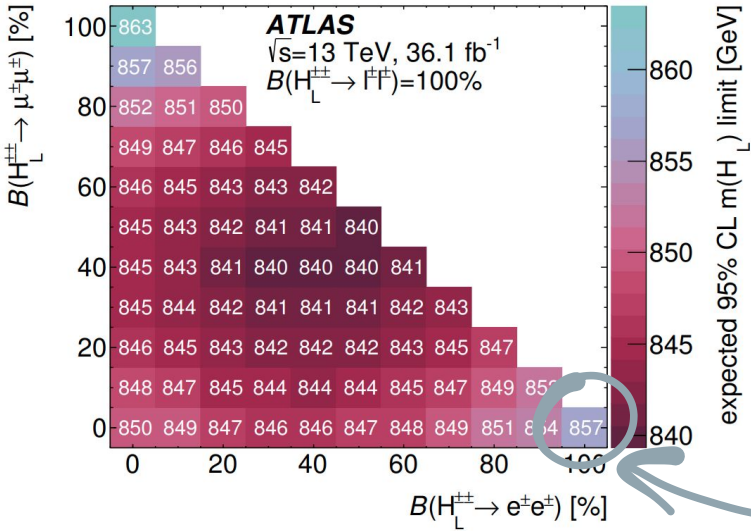
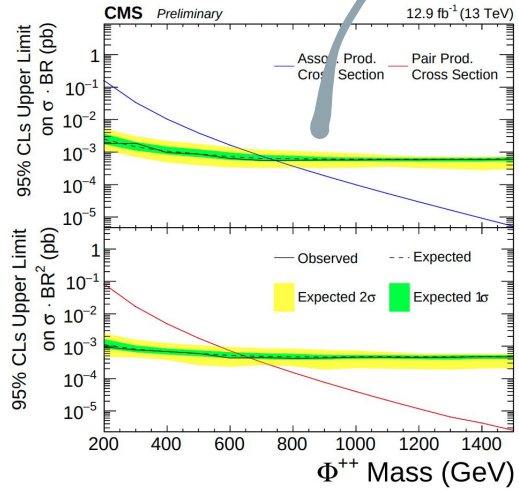
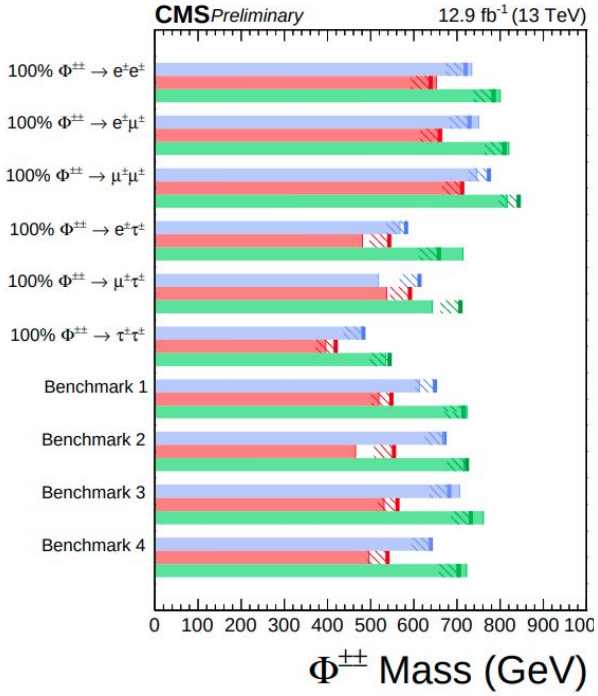
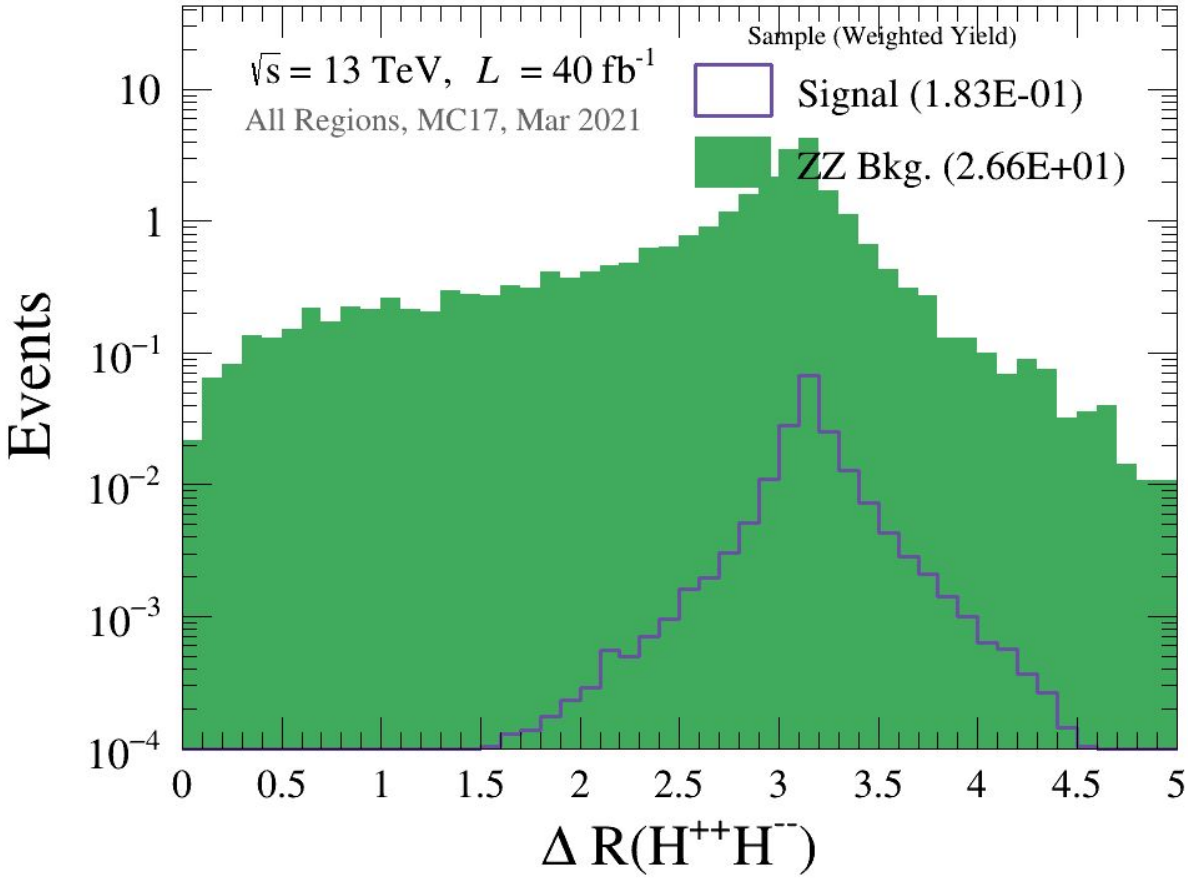


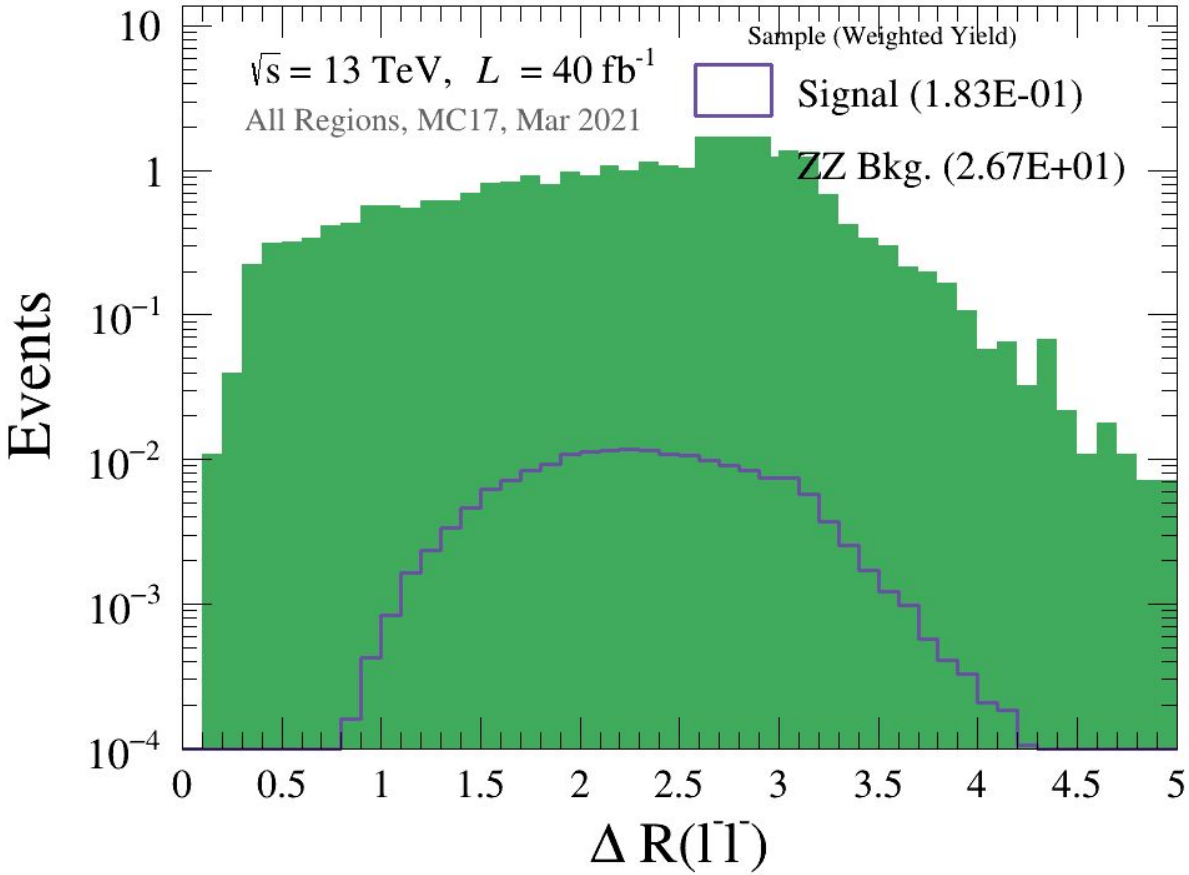


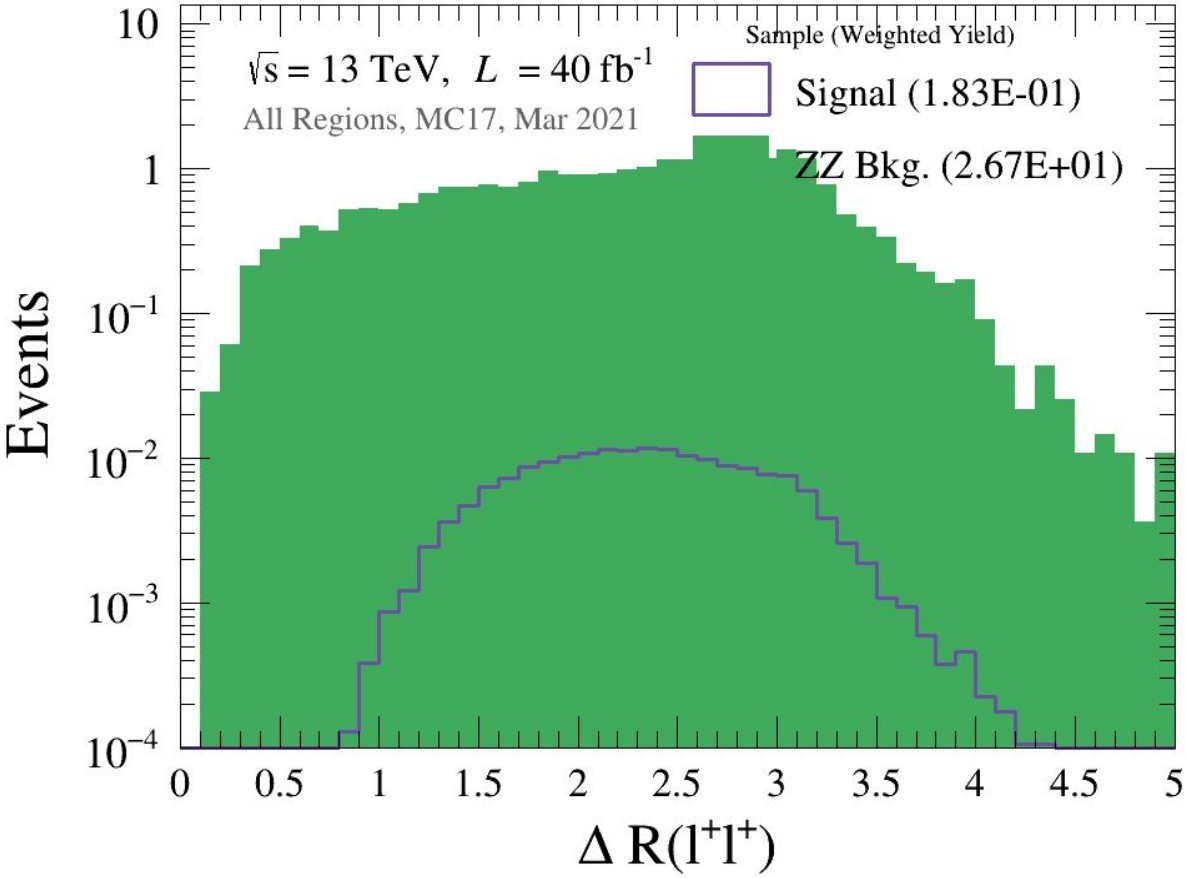


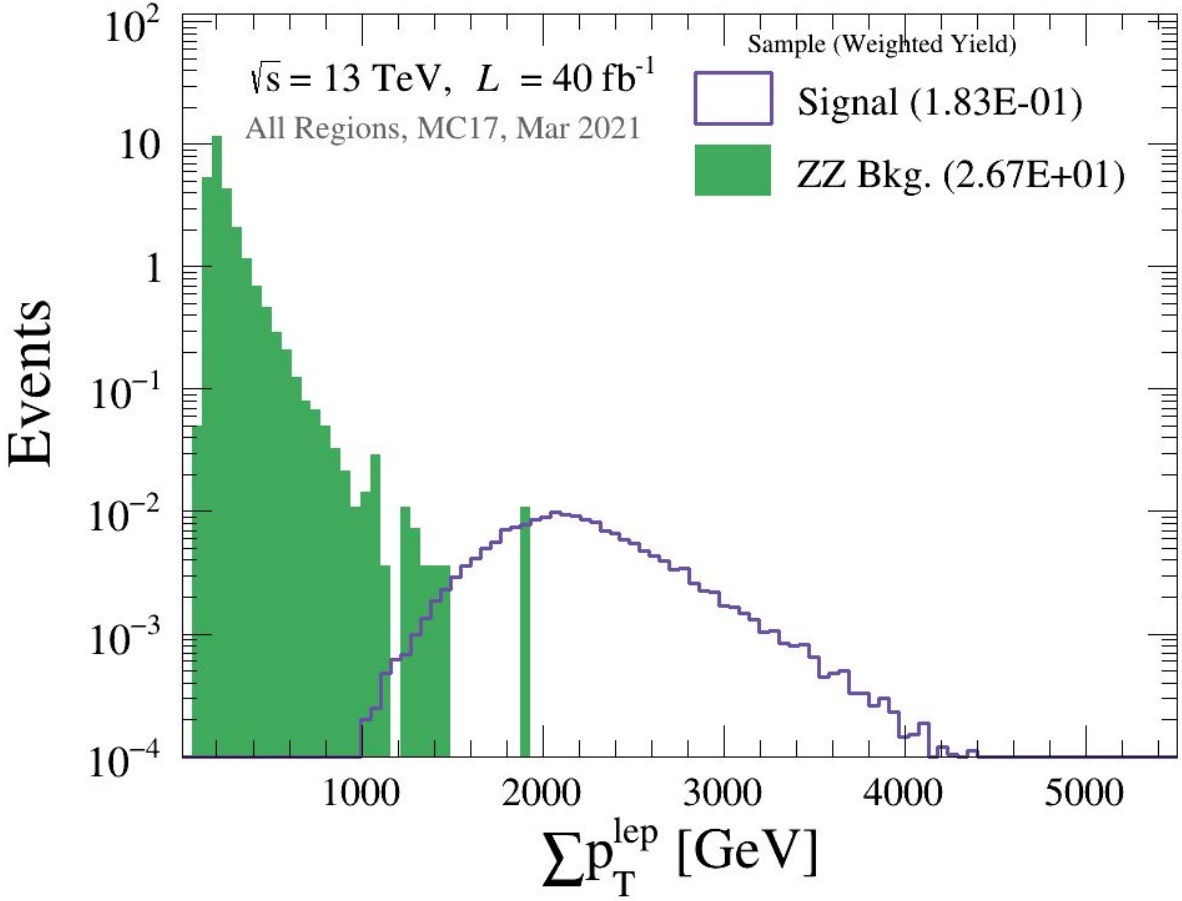
(a) 100% ee

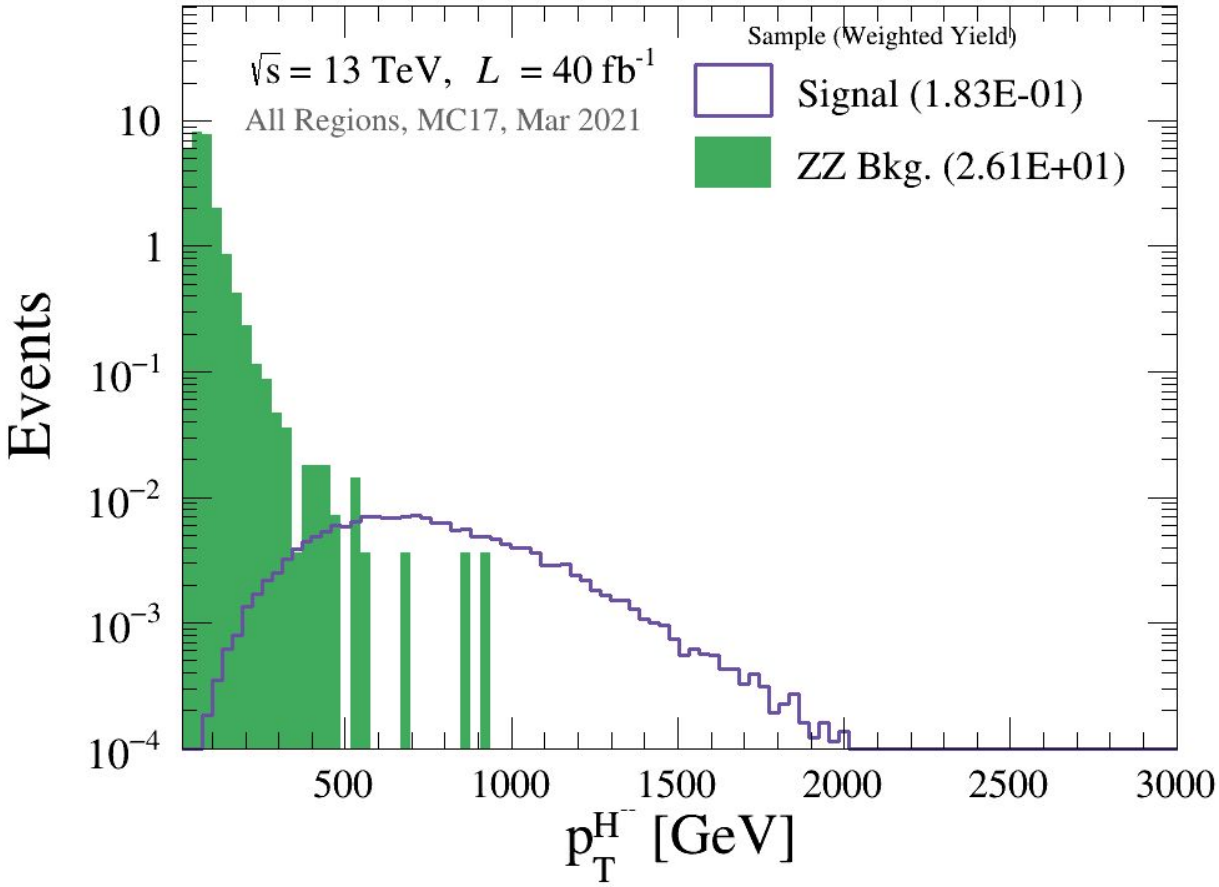


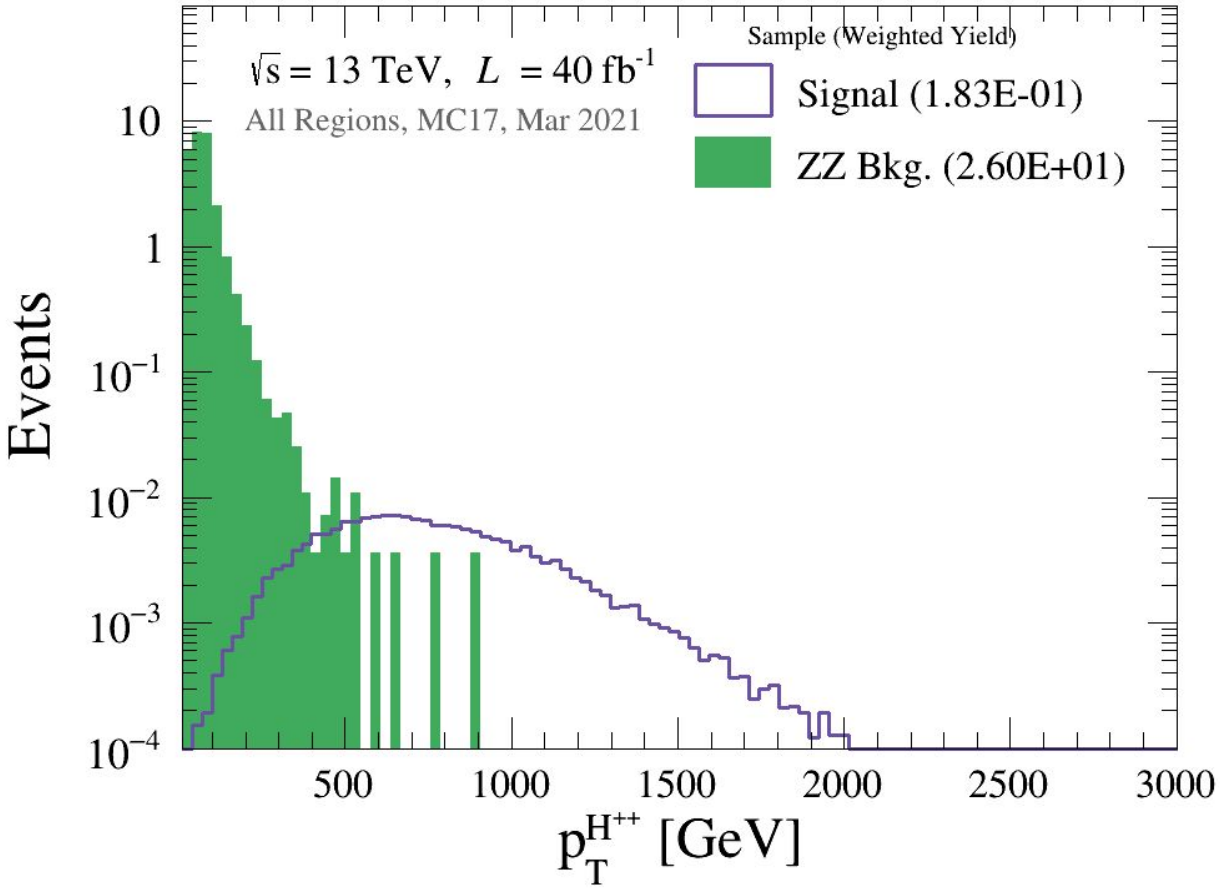

Sample (Weighted Yield)
$\sqrt{s}$ = 13 TeV, L = 40 fb^{-1}
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.66E+01)
Events
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$\Delta R(H^{++}H^{--})$

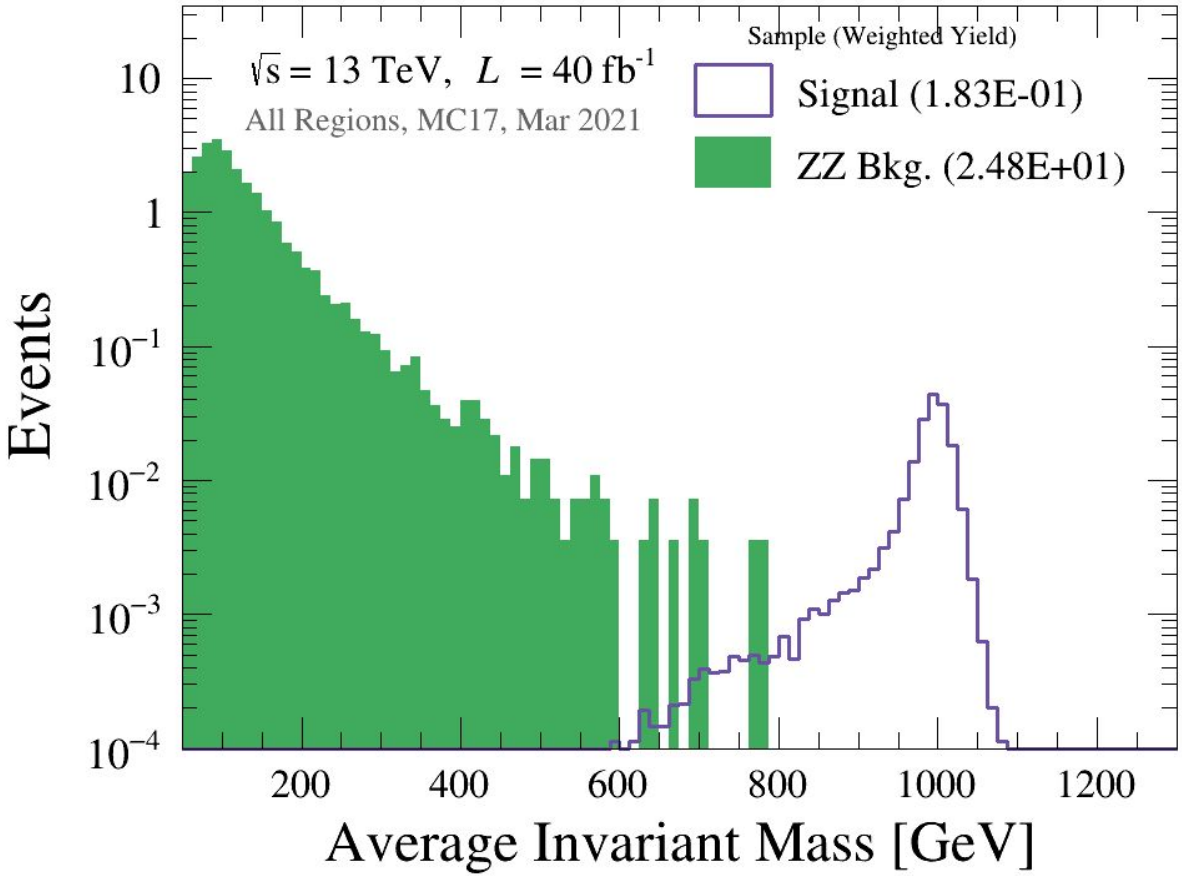

Sample (Weighted Yield)
$\sqrt{s}$ = 13 TeV, L = 40 fb^{-1}
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.67E+01)
Events
Δ R(l$\bar{l}$)
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

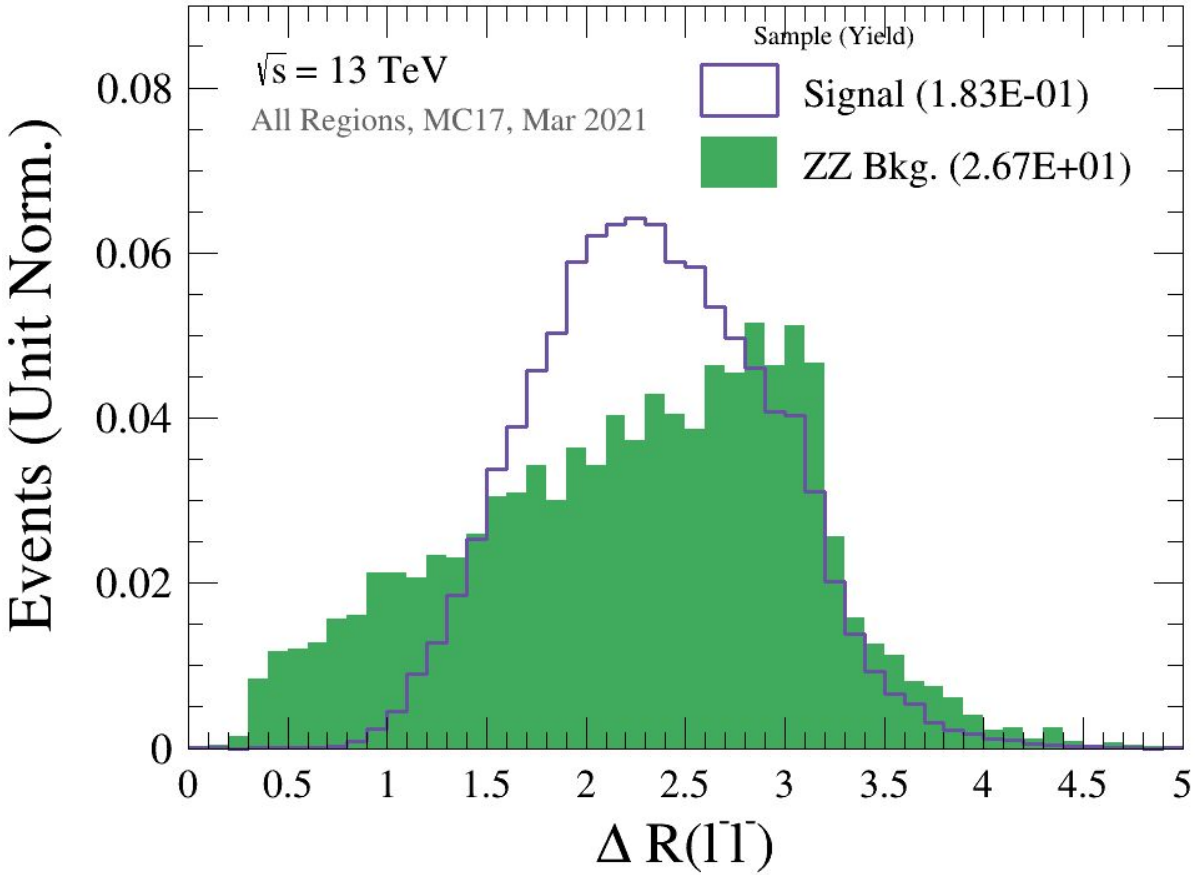

Sample (Weighted Yield)
$\sqrt{s}$ = 13 TeV, L = 40 fb^{-1}
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.67E+01)
Events
Δ R(l$^+$l$^+$)
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

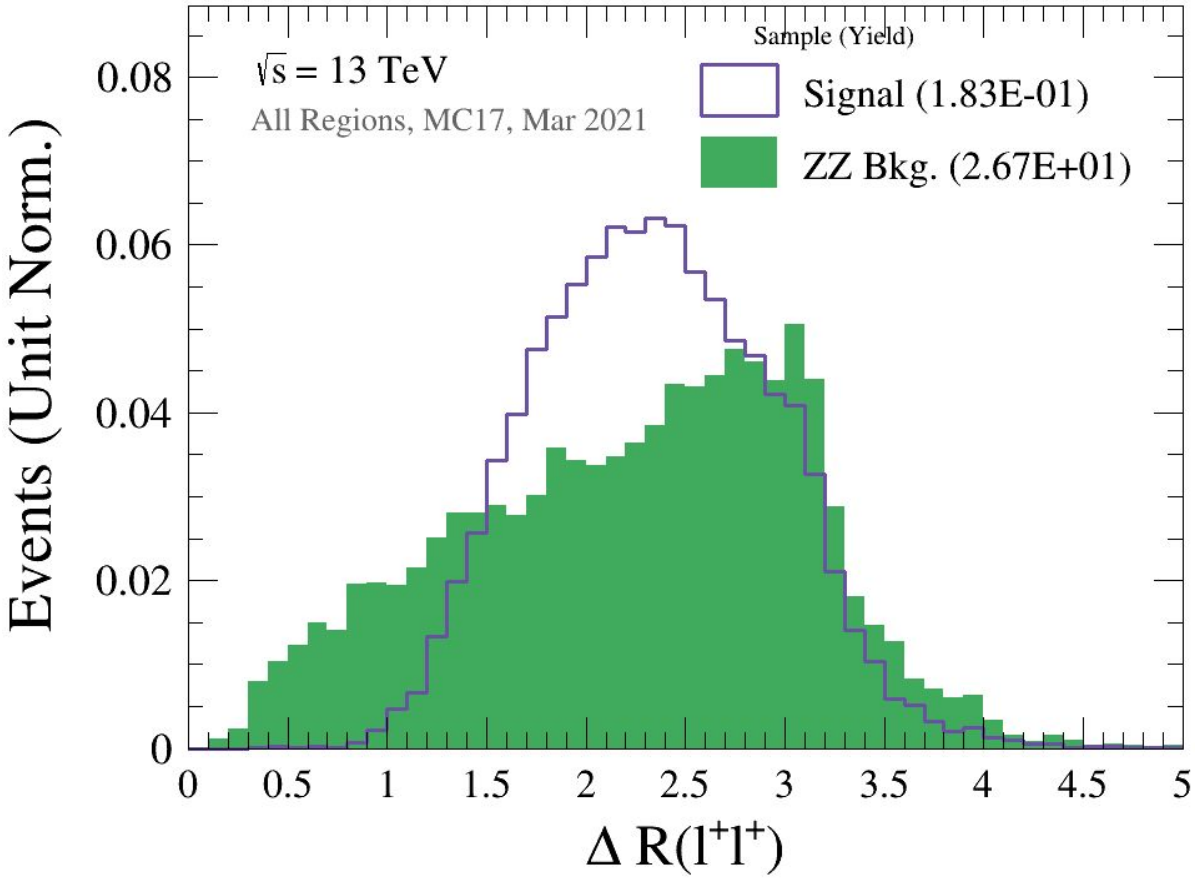

Sample (Weighted Yield)
$\sqrt{s}$ = 13 TeV, L = 40 fb^{-1}
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.67E+01)
Events
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1000
2000
3000
4000
5000
$\sum p_T^{lep}$ [GeV]

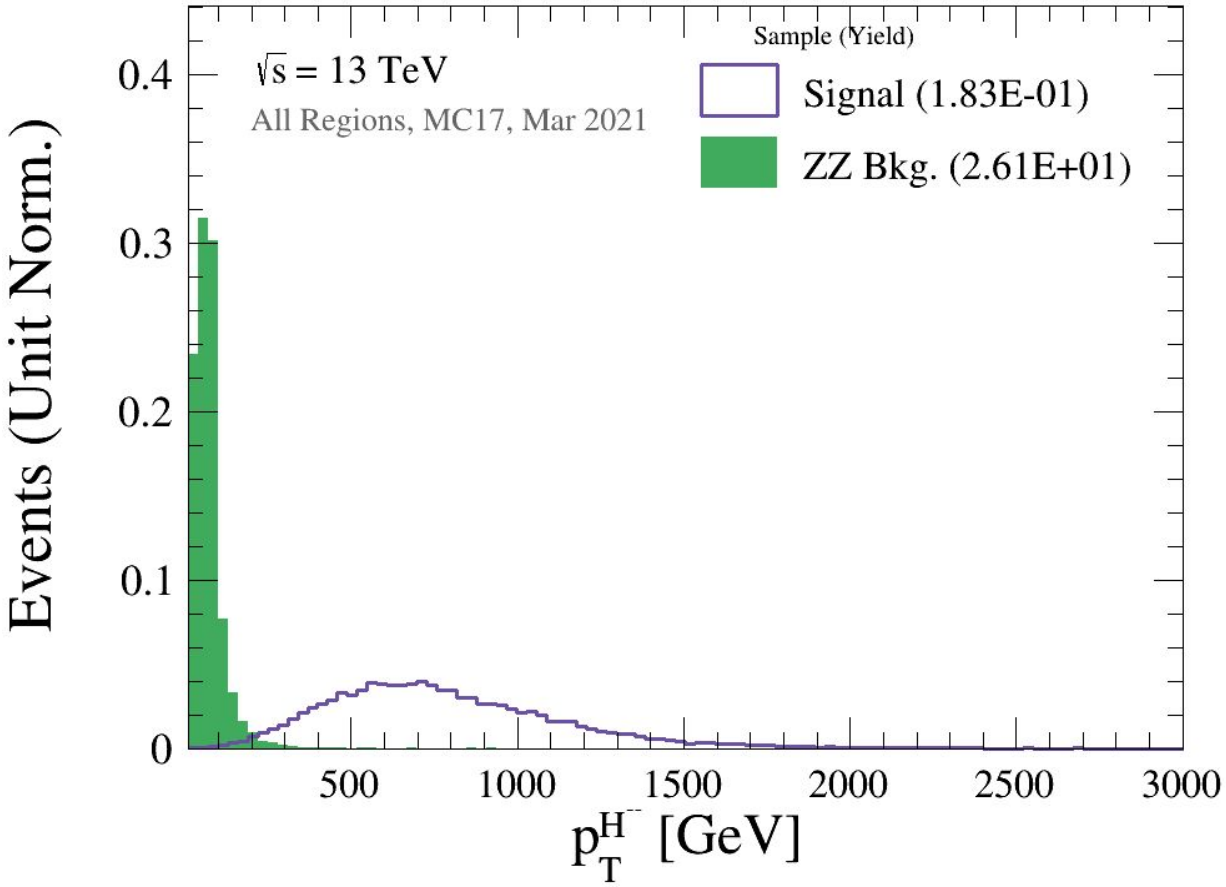

Sample (Weighted Yield)
$\sqrt{s}$ = 13 TeV, L = 40 fb^{-1}
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.61E+01)
Events
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
500
1000
1500
2000
2500
3000
$p_T^{H^{--}}$ [GeV]

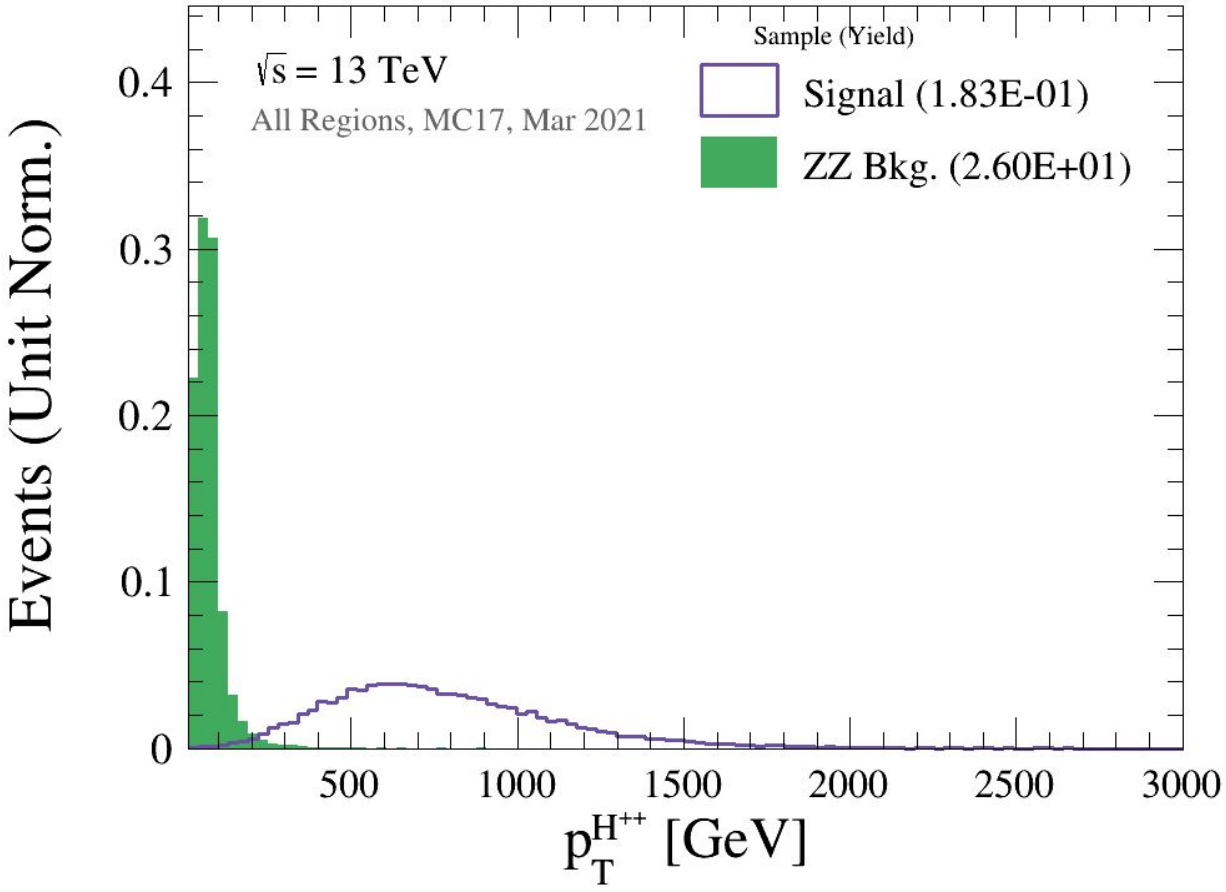

Sample (Weighted Yield)
$\sqrt{s}$ = 13 TeV, L = 40 fb^{-1}
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.60E+01)
Events
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
500
1000
1500
2000
2500
3000
$p_T^{H^{++}}$ [GeV]

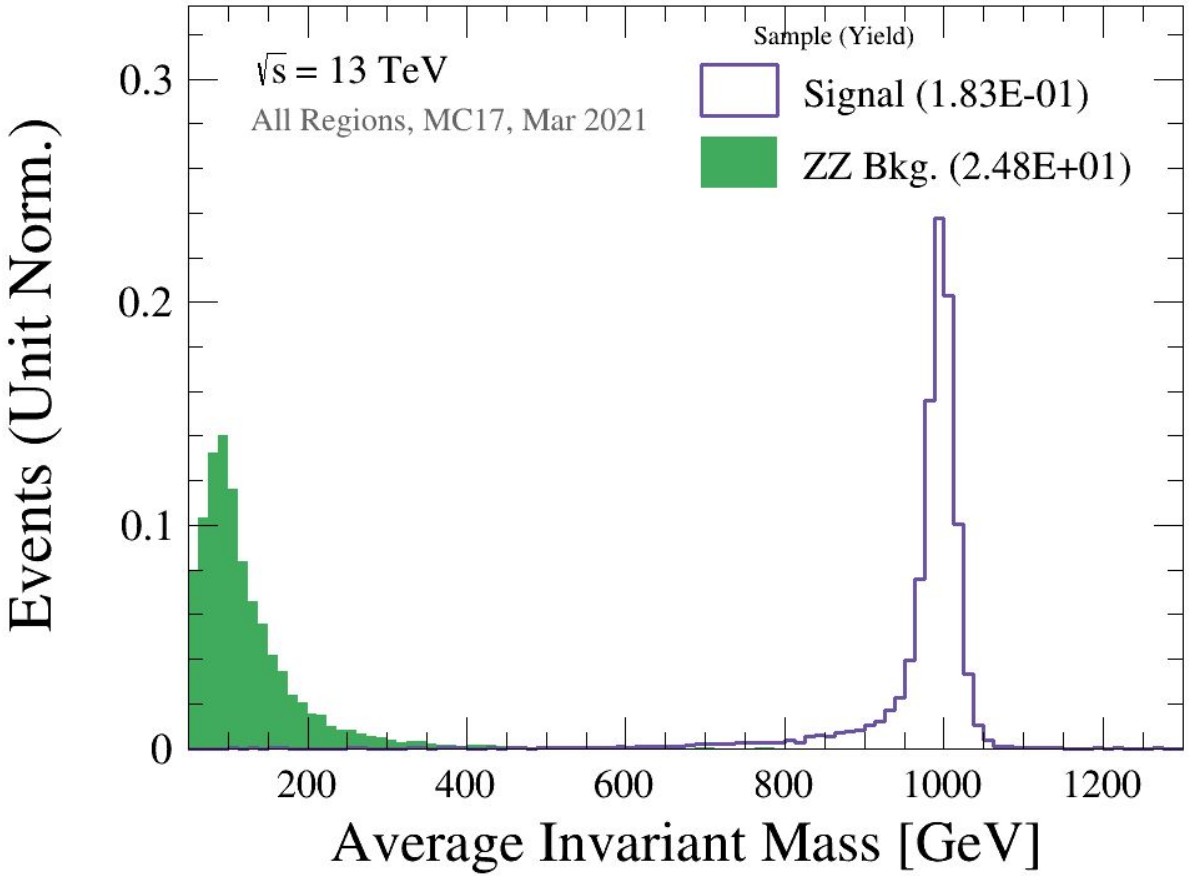

Sample (Weighted Yield)
$\sqrt{s}$ = 13 TeV, L = 40 fb^{-1}
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.48E+01)
Events
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
200
400
600
800
1000
1200
Average Invariant Mass [GeV]

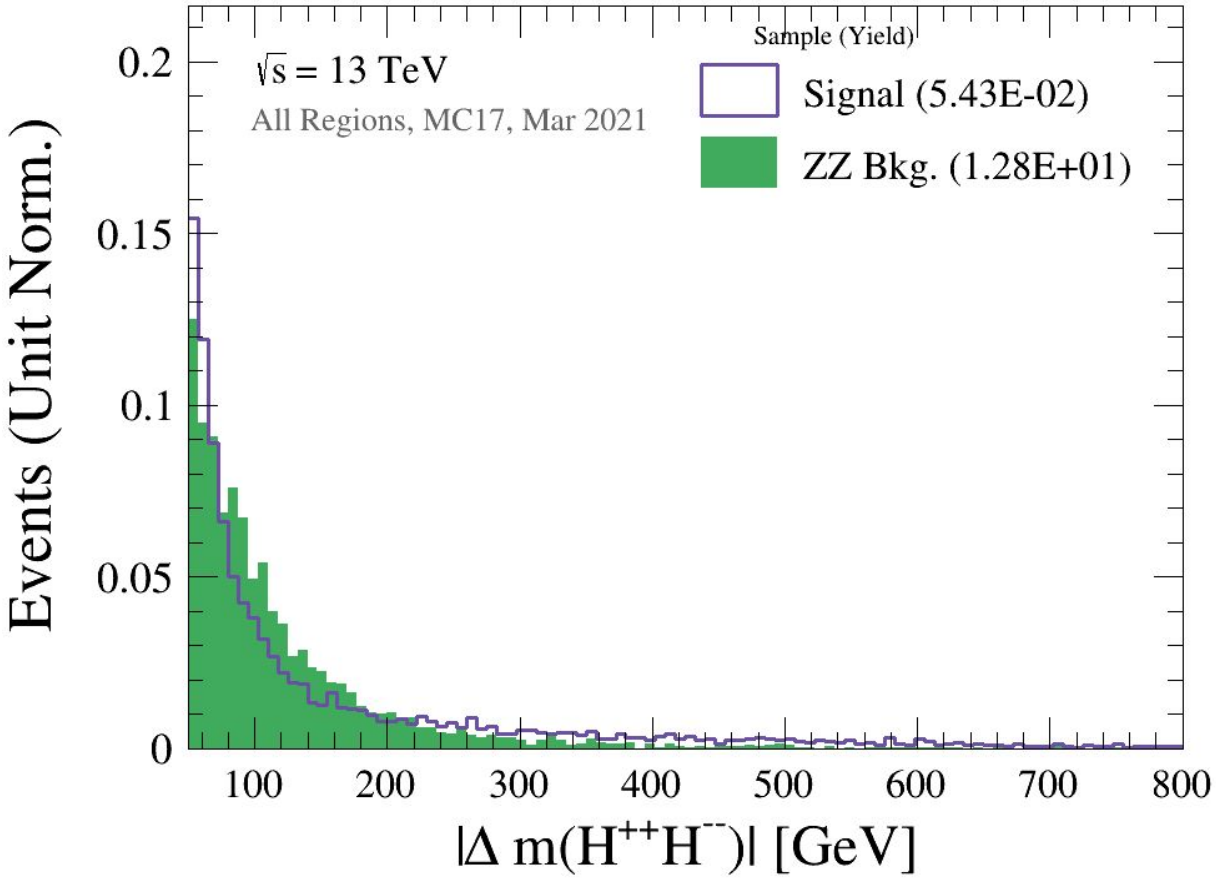

Sample (Yield)
√s = 13 TeV
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.67E+01)
Events (Unit Norm.)
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Δ R(l̄l̄)

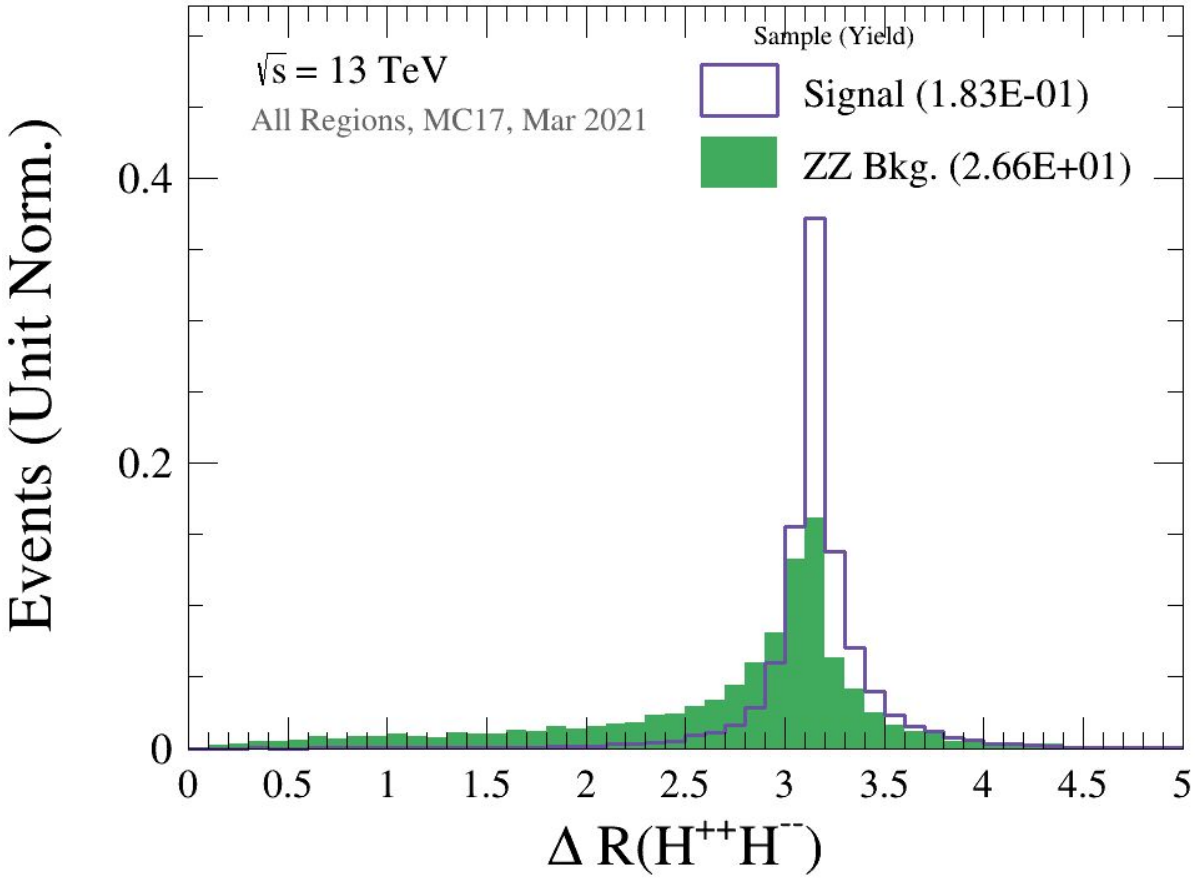

Sample (Yield)
√s = 13 TeV
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.67E+01)
Events (Unit Norm.)
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Δ R(l⁺l⁺)


Sample (Yield)
√s = 13 TeV
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.61E+01)
Events (Unit Norm.)
0.4
0.3
0.2
0.1
0
500
1000
1500
2000
2500
3000
$p_T^{H^{--}}$ [GeV]


Sample (Yield)
√s = 13 TeV
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.60E+01)
Events (Unit Norm.)
0.4
0.3
0.2
0.1
0
500
1000
1500
2000
2500
3000
$p_T^{H^{++}}$ [GeV]

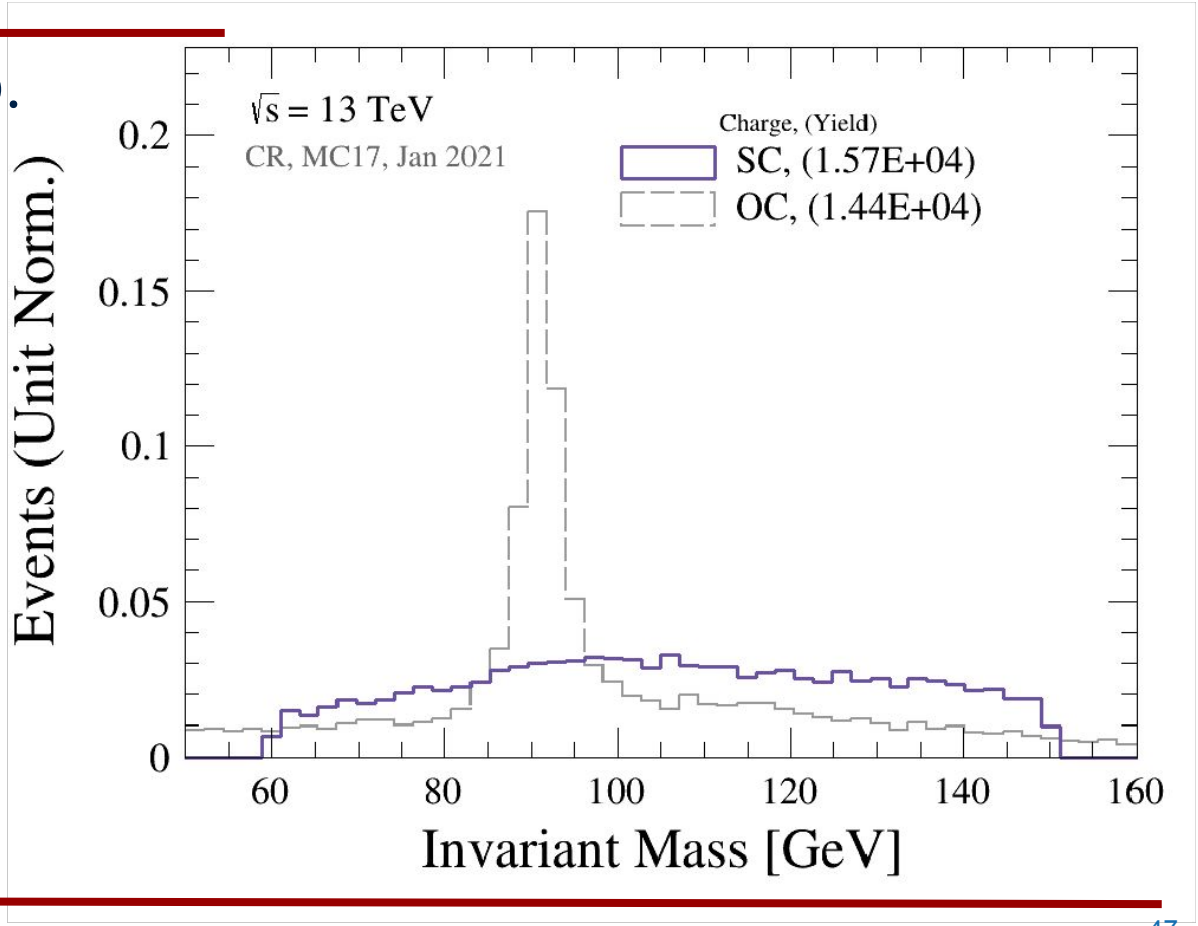

Sample (Yield)
√s = 13 TeV
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.48E+01)
Events (Unit Norm.)
0.3
0.2
0.1
0
200
400
600
800
1000
1200
Average Invariant Mass [GeV]


Sample (Yield)
√s = 13 TeV
All Regions, MC17, Mar 2021
Signal (5.43E-02)
ZZ Bkg. (1.28E+01)
Events (Unit Norm.)
0.2
0.15
0.1
0.05
0
100
200
300
400
500
600
700
800
|Δ m(H++H--)| [GeV]

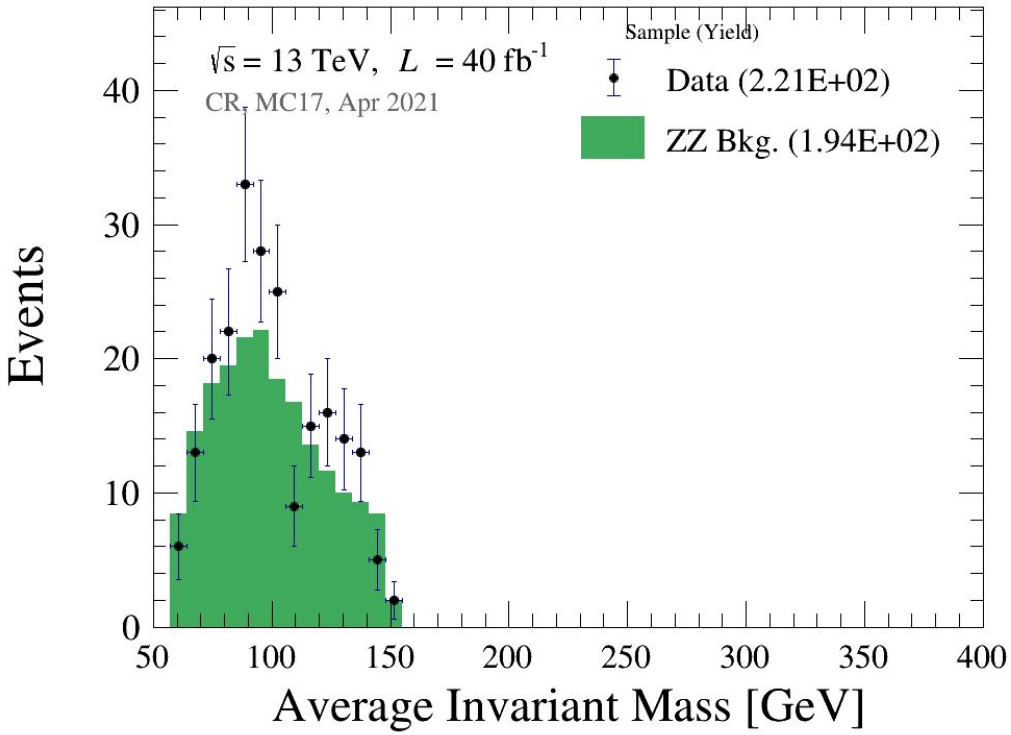

Sample (Yield)
√s = 13 TeV
All Regions, MC17, Mar 2021
Signal (1.83E-01)
ZZ Bkg. (2.66E+01)
Events (Unit Norm.)
0
0.2
0.4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Δ R(H++H--)

Status

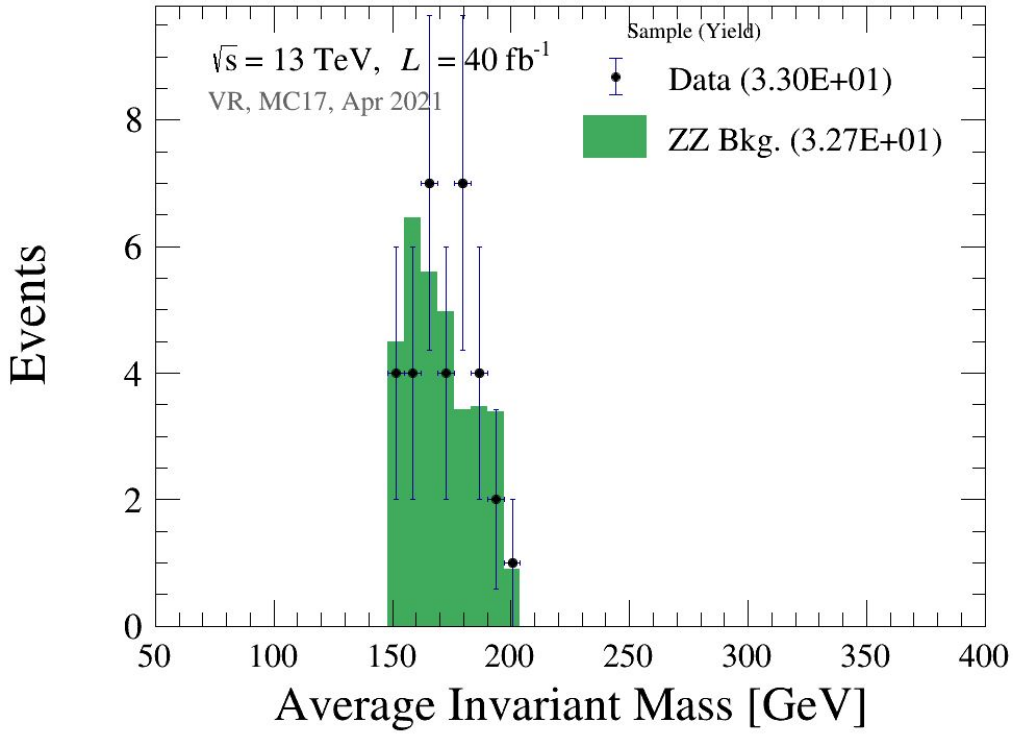
ZZ → 4ℓ MC Nano.



Status


Sample (Yield)
√s = 13 TeV, L = 40 fb-1
CR, MC17, Apr 2021
Data (2.21E+02)
ZZ Bkg. (1.94E+02)
Events
Average Invariant Mass [GeV]
0
10
20
30
40
50
100
150
200
250
300
350
400

Status


√s = 13 TeV, L = 40 fb-1
VR, MC17, Apr 2021
Sample (Yield)
Data (3.30E+01)
ZZ Bkg. (3.27E+01)
Events
0
2
4
6
8
50
100
150
200
250
300
350
400
Average Invariant Mass [GeV]