# Search for

# $H^+ \rightarrow WA$

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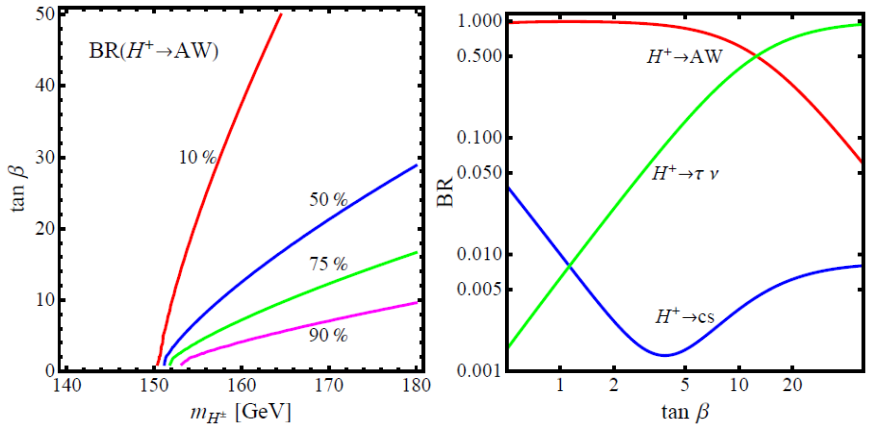
# Introduction

- 125GeV Higgs boson was discovered at LHC.
- But there are also theoretical expectations that more Higgs bosons could exist.

  e.g. 5 Higgs bosons in 2HDM($H^{\pm}$, A, h, H)
- Depending on models and their parameters, $\mathbf{H^+ \rightarrow AW}$ can be one of the most dominant decay mode.(Ex. F.Kling et al., JHEP 11 (2015) 051)
- Dark photon can also be produced in decays of $H^+$ (Dark Z model: K.Kong et al., Phys. Rev. D 89, 074007 (2014))



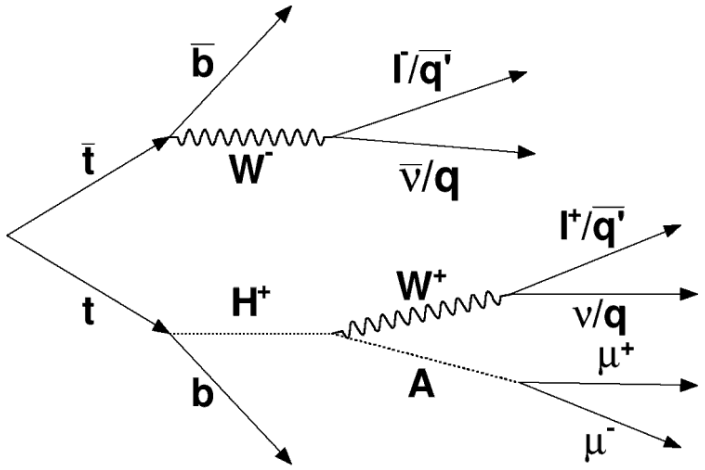

Plots from [JHEP11 (2015) 051, arXiv:1504.06624v1]

# Introduction

- Search for $H^+ \to AW,\ A \to \mu^+\mu^-$ in $t\bar{t}$ events
- Search Region : 3l+≥3jet(≥1b) (1e+2μ, 3μ)

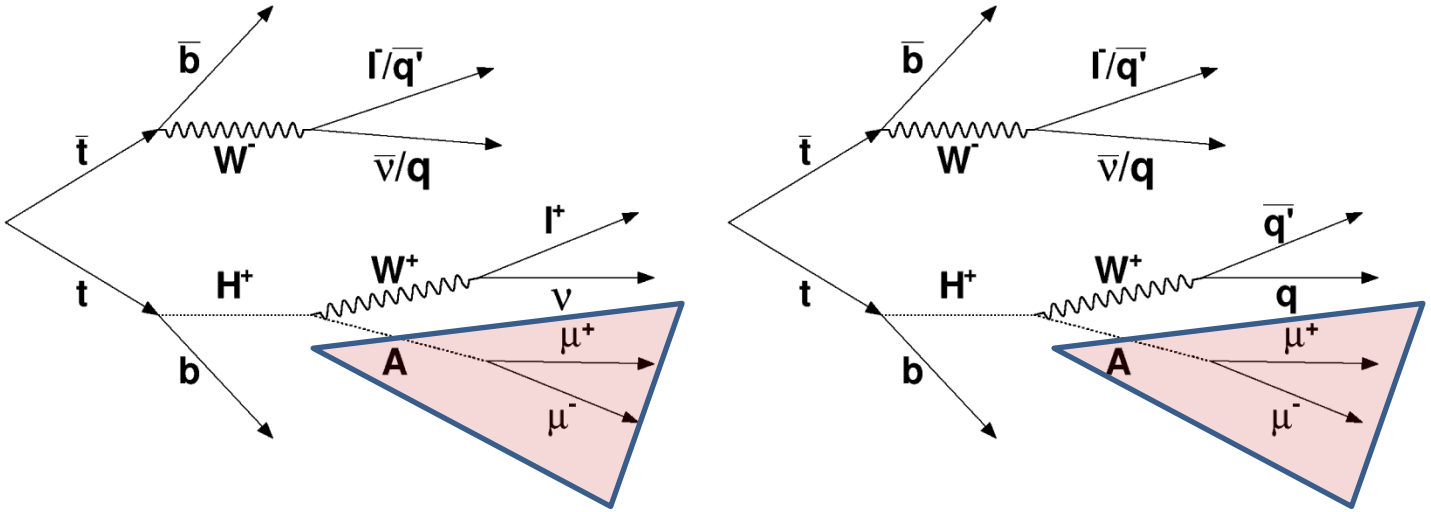
  (All signal decays except both W decaying hadronically can enter the signal region)
- Benchmark model for signal MC: 2HDM

  (But the search is model independent)
- Mass range in search : $H^+$: 90-160 GeV, A: 12-35GeV



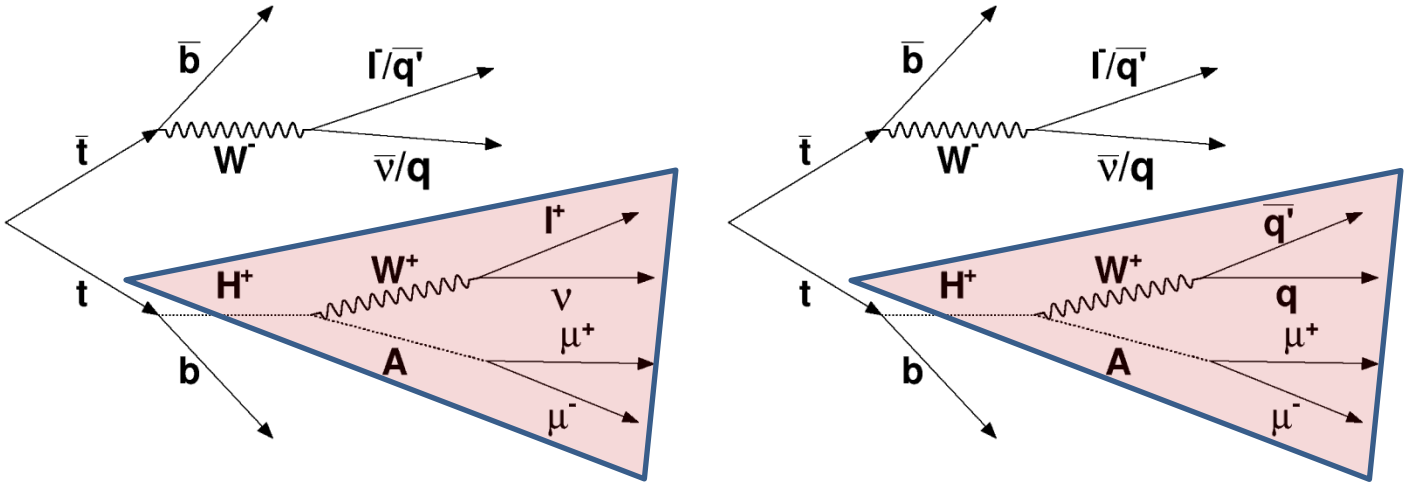
# Signatures of Signal

- Signature variable : M(μμ), M(μμlν), M(μμjj)
- A produces a bump in dimuon mass distribution



# Signatures of Signal

- Signature variable : M(μμ), M(μμlν), M(μμjj)
- $H^+$ will produce a bump in M(μμlν), M(μμjj) distribution



# Dataset & Event Selection

- Dataset & Trigger

Event selected with following triggers(DoubleMuon, MuonEG PD) (35.9 $fb^{-1}$)

3μ : HLT_Mu17_TrkIsoVVL_(Tk)Mu8_TrkIsoVVL_DZ_v*

1e2μ : HLT_Mu8(12)_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_(DZ)_v*

- Object Selection

| | | | |
|---|---|---|---|
| Electron | Cut based POG Tight / $P_T$>10GeV / \|η\|<2.5 / d0<0.05cm/ dz<0.1cm/ σ(d0)<3 | Loose | PFRelIso<0.5 |
| | | Tight | PFRelIso<0.05 |
| Muon | POG Tight / $P_T$>10GeV / \|η\|<2.4 / d0<0.05cm / σ(d0)<3 | Loose | PFRelIso<0.4 |
| | | Tight | PFRelIso<0.1 |
| Jet | AK4PFCHS, PFLoose, $P_T$>25GeV / \|η\|<2.4 / R(l,j)>0.4 | B tag | CSVv2 > 0.8484 |
| MET | Type 1 PFMET | | |

- Event Selection

1e2μ : 1e2μ + ≥3j(≥1b) with PT(e)>25, PT(μ)>15,10

3μ : 3μ + ≥3j(≥1b) with PT(μ)>20,10,10

# Background Estimation

- Prompt Processes
  - Processes that involves at least 3 prompt leptons
  - Estimated from MC simulation
  - Processes : $t\bar{t}$+X(X=W,Z,H), VV(WZ, ZZ), Rare(VVV, H)

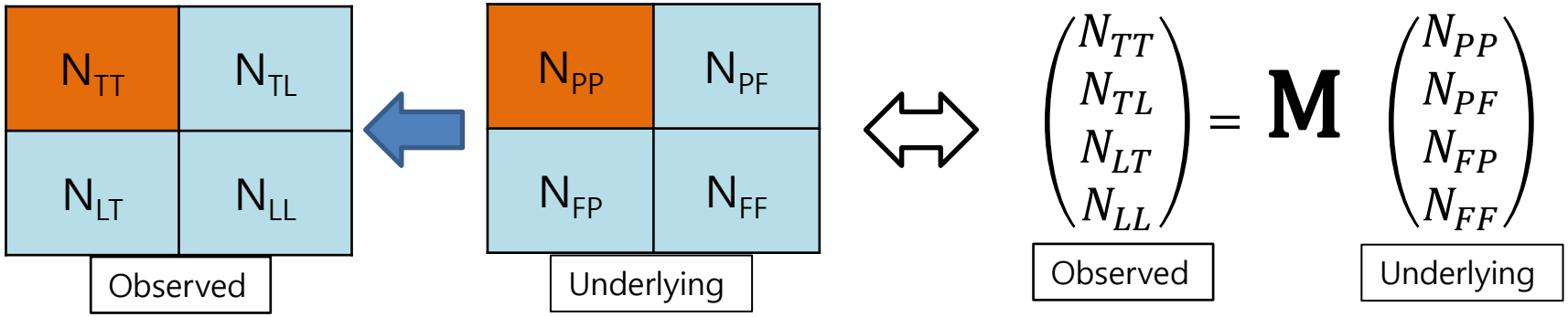
- Non-prompt Processes

  1) Non-prompt lepton from jet activity
     - Estimated from data-driven method (Matrix method)
     - Major sources : DY+fakes, $t\bar{t}$+fakes

  2) Soft pair production or fakes from conversion
     - Estimated from MC

# Non-prompt Estimation

- Matrix Method




T(Tight) - Tight ID used for signal region , P(Prompt) - Leptons from EWK boson or higgs,
L(Loose) - ID criteria looser than tight , F(Fake) - Leptons from jet activity or misidentified.

Idea : Prompt and fakes have different ID variable distributions; $\varepsilon(P) \equiv \frac{N_T(P)}{N_L(P)} \neq \varepsilon(F) \equiv \frac{N_T(F)}{N_L(F)}$

⇒ Possible to estimate fake contribution in signal region from observed ID composition and tight to loose ratio(:fake rate) measured in other CR.

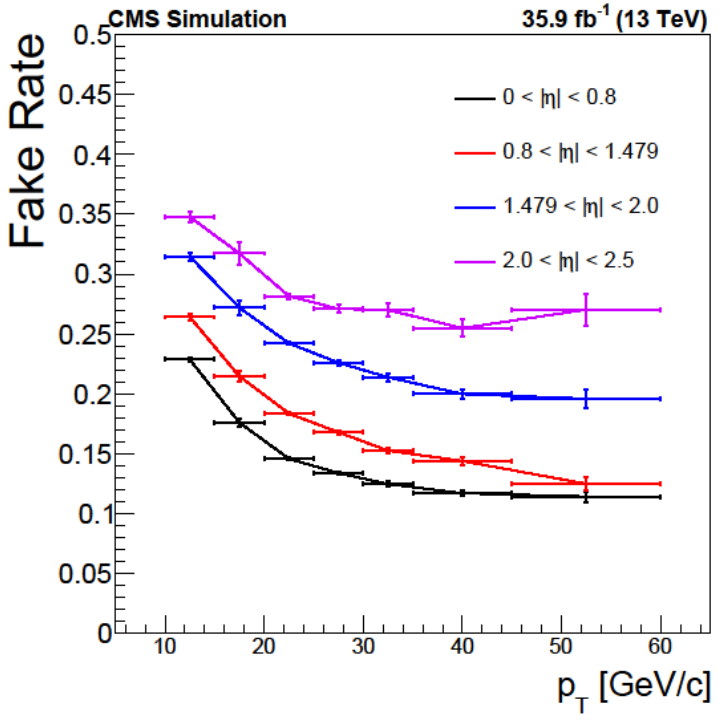
$$N(ID_1, ID_2, ID_3) = \sum_{f_1, f_2, f_3} M(ID_1, ID_2, ID_3, f_1, f_2, f_3)\, N(f_1, f_2, f_3)$$

(3l events)

$$M(ID_1, ID_2, ID_3, f_1, f_2, f_3) = \prod_{i\ on\ Tight\ ID} \varepsilon_i(f_i) \prod_{j\ on\ Loose\ ID} (1 - \varepsilon_j(f_j))$$

# Non-prompt Estimation

- Fake Rate




- Definition : Tight ID efficiency of fake objects relative to loose ID

- What actually constitutes matrix M.

- Measured in fake enriched events and projected to loose ID used in application region by factorized relation,

$$\varepsilon(T|L)(f, low\ d0) = \underbrace{\varepsilon(T|L)(f, high\ d0)(Data)}_{\text{Measured in data}} \times \underbrace{\frac{\varepsilon(T|L)(f, low\ d0)}{\varepsilon(T|L)(f, high\ d0)}(MC)}_{\text{Measured in QCD MC}}$$

# Notes

- Muon Labeling in 3μ Channel

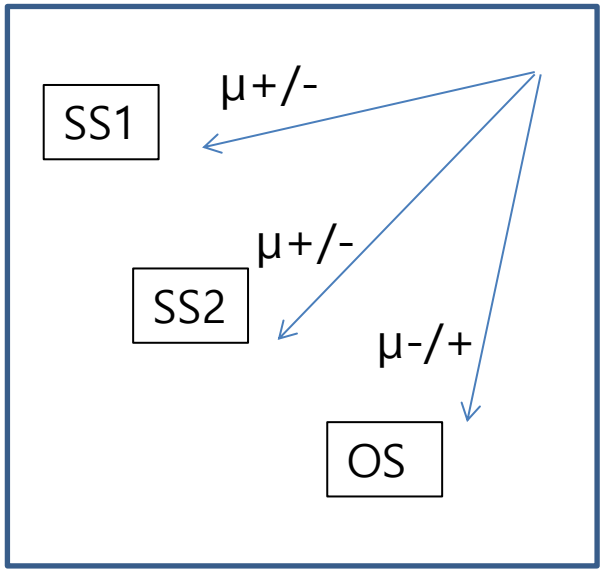
SS1: Of the 2 muons having the same-sign in 3μ events, one having larger PT

SS2: Of the 2 muons having the same-sign in 3μ events, one having smaller PT

OS : One having other sign than the others in 3μ events

- Error bars only include statistical uncertainties.

  Systematic uncertainty is not yet included.



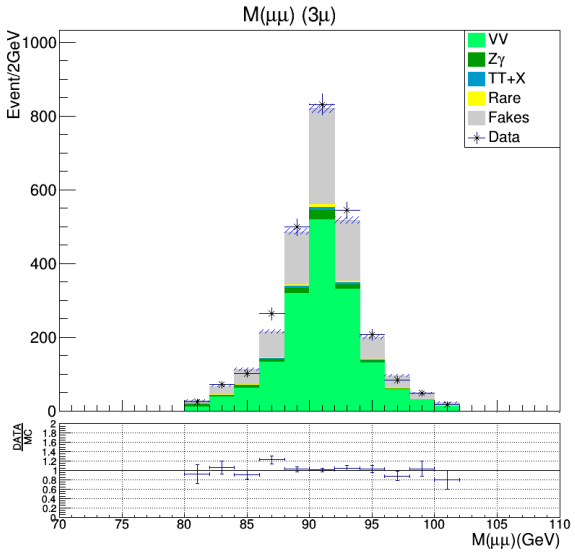
# Control Region 1

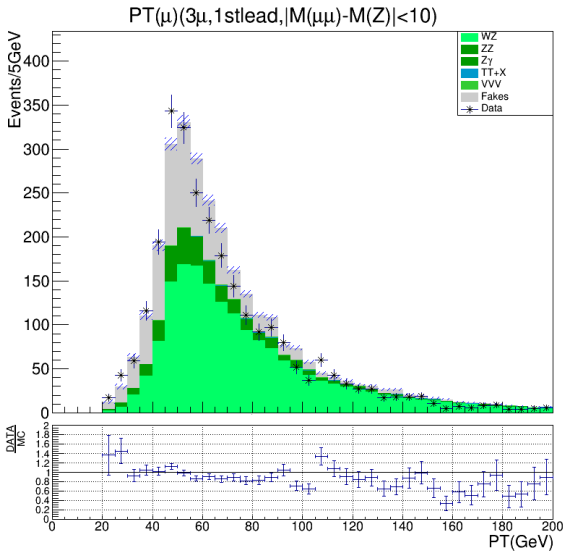
- Purpose

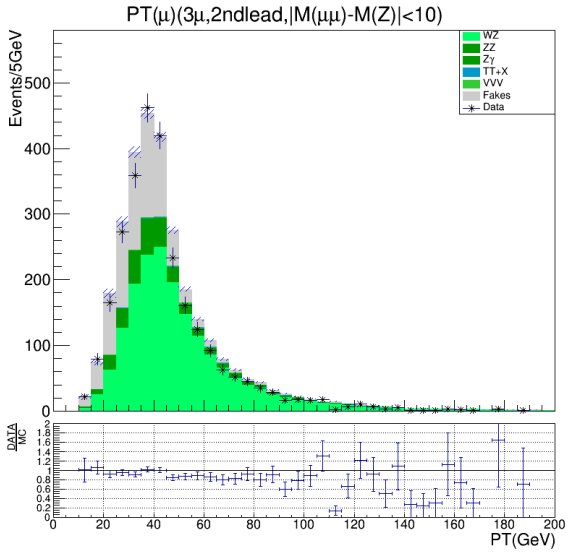
  Validation of fake rate and application method

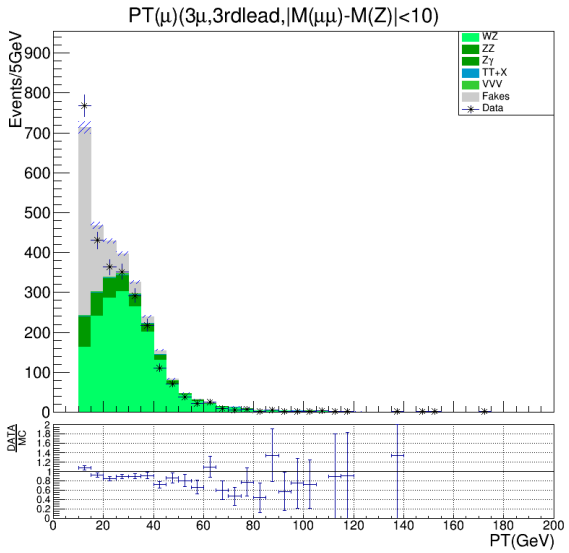
- Event Selection

  - 3 tight μ with OS pair
  - |M(μμ)-91.2|<10
  - No B-tagged jets
  - No additional loose leptons.



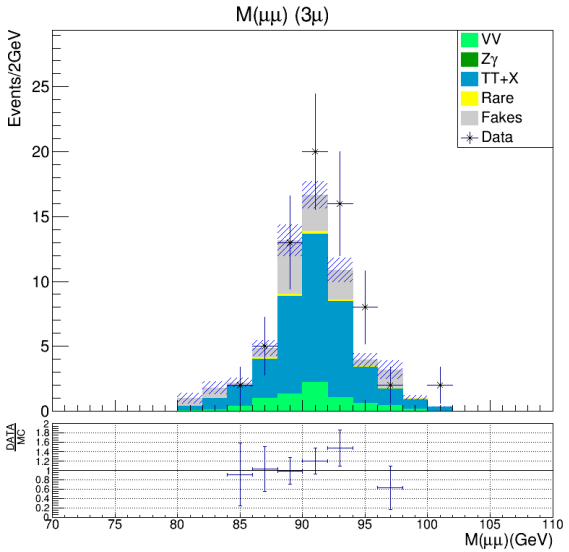
# Control Region 2

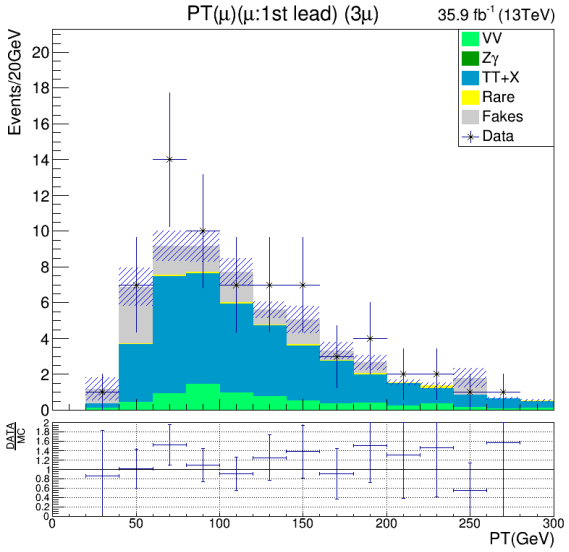
- Purpose

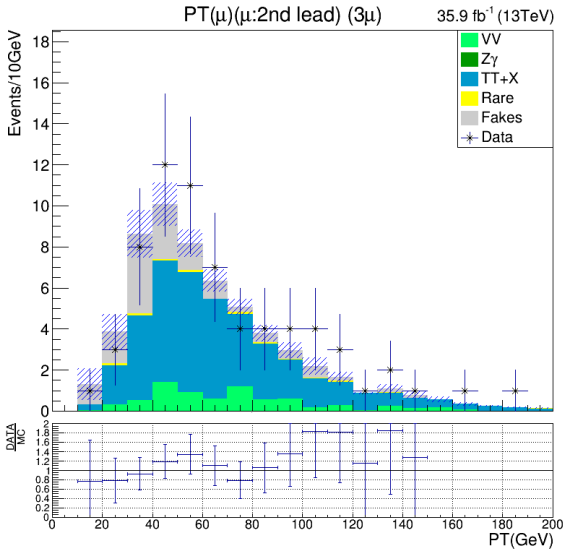
  Validation of ttZ prediction, which is largest background in signal region.

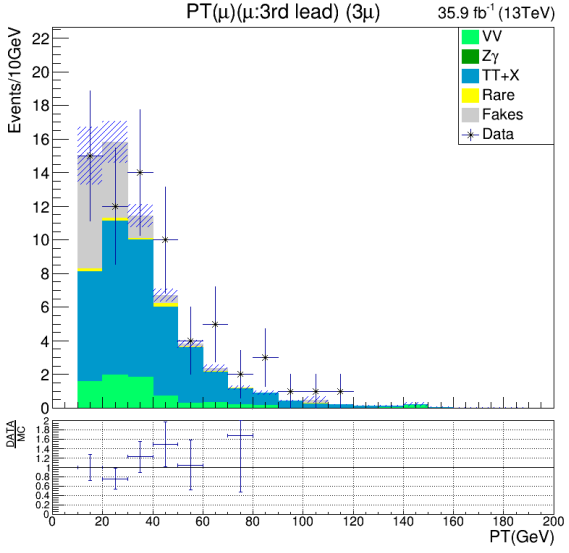
- Event Selection

  - 3 tight μ with OS pair
  - |M(μμ)-91.2|<10
  - ≥3j (≥1b)
  - M(μμ)>40 for any OS pair
  - No additional loose lepton



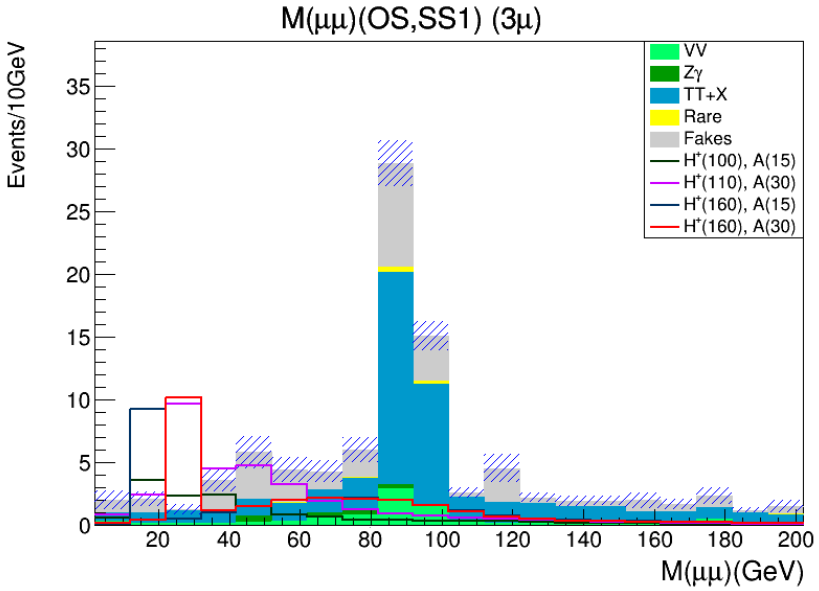



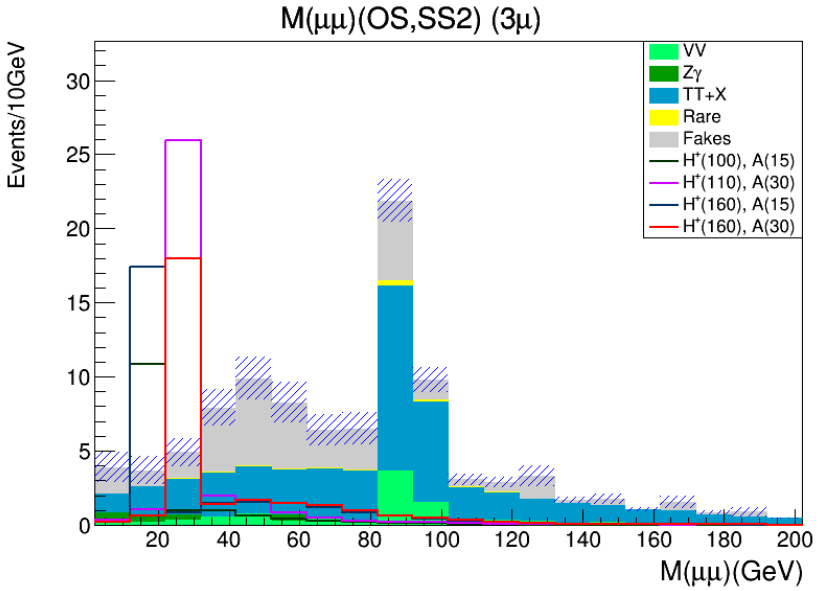
# Signal Region Expectation(MC)

- Event Selection : 3μ with OS pair, ≥3j (≥1b)
- All signal MC's are drawn with assumption of 100fb cross section.

  ( i.e. $\sigma(t\bar{t}) * \{2 * Br(t \to bH^+) * Br(H^+ \to AW^+) * Br(A \to \mu\mu)\} = 100fb$ )
- Expected background composition : ttX(52.7%), Fakes(34.6%), VV(10%),

  Conversion(1.7%), Rare(1%)
- Signature distribution of A decays



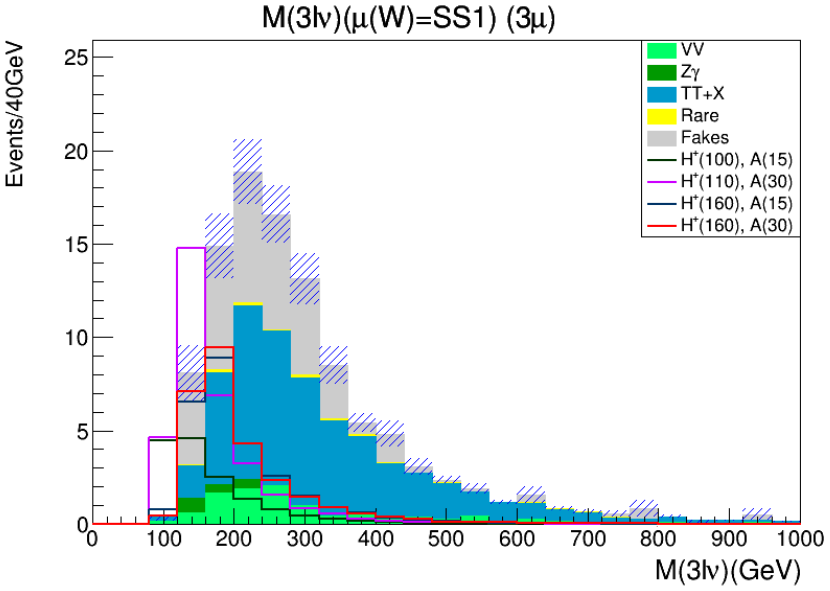
# Signal Region Expectation(MC)

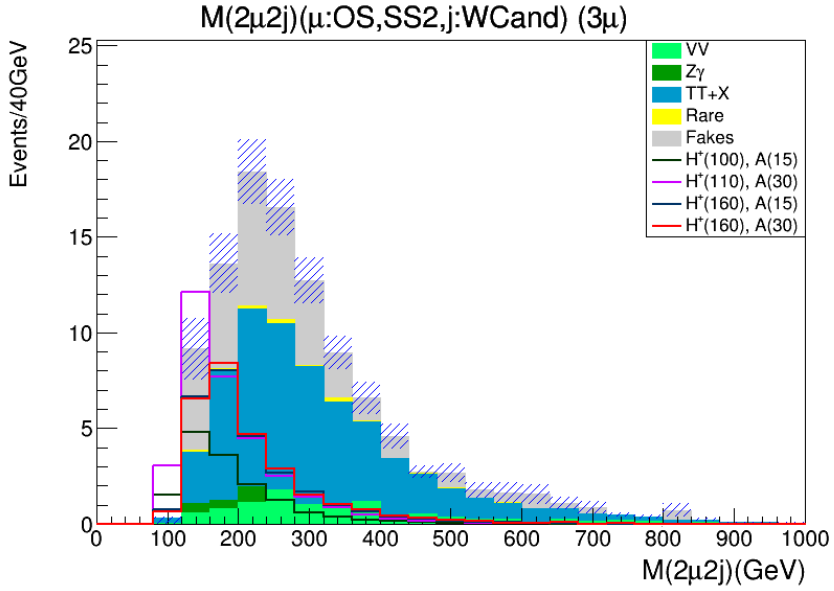
- Signature distributions of $H^+$ decays

  - For M(3lv), Pz(v) is calculated from $\vec{p}(\mu(SS1))$, MET, W mass constraint

    (Solution with smaller absolute value is chosen)

  - For M(2l2j), 2 jets with dijet mass closest to W mass, OS, SS2 muons are used.



# Summary

- We search for $H^+ \rightarrow AW$ from top pair in 3 lepton +≥3j (≥1b) events. (1e2μ, 3μ channel)
- 3μ channel background contribution is understood, and we checked fair agreement in control regions.
- We expect good sensitivity of the process ($\sigma(t\bar{t}) * Br \sim O(10 \sim 100)$ fb) from this search.
- 1e2μ channel analysis and further studies including systematic uncertainty are in progress.

# Backup