Fourth Family Neutrinos and Higgs Boson

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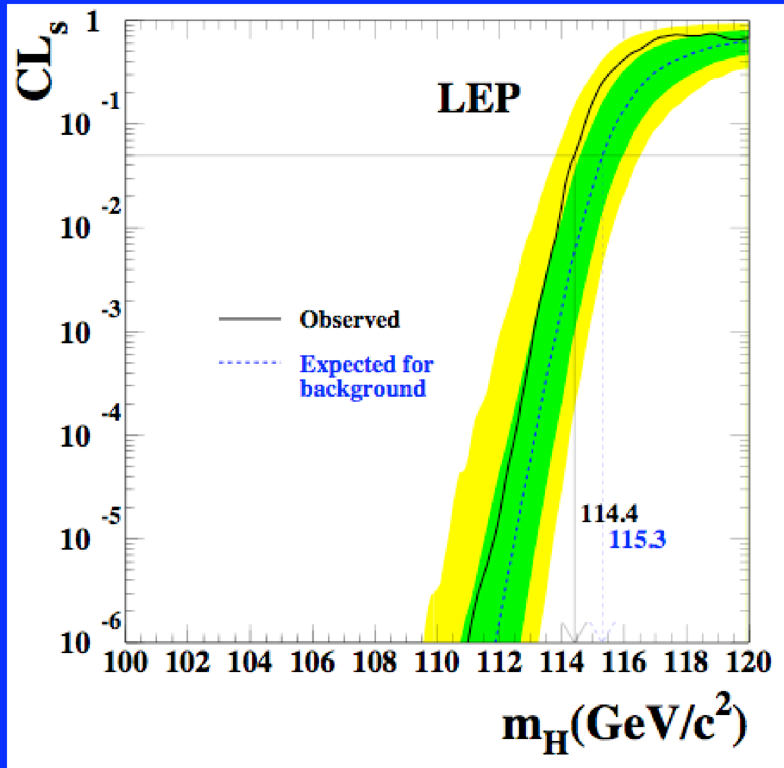
Outline

- Introduction
- Cross section, branching fraction of h and ν_4
- Signal and Background Events
- Generators & Production chain
- Event selection efficiency
- Results - Reconstructed ν_4, h and significances
- Conclusion



- The lower limit on Higgs mass by LEP experiments (ALEPH, DELPHI, L3, OPAL)
  $m_H > 114.4$ GeV at 95% CL

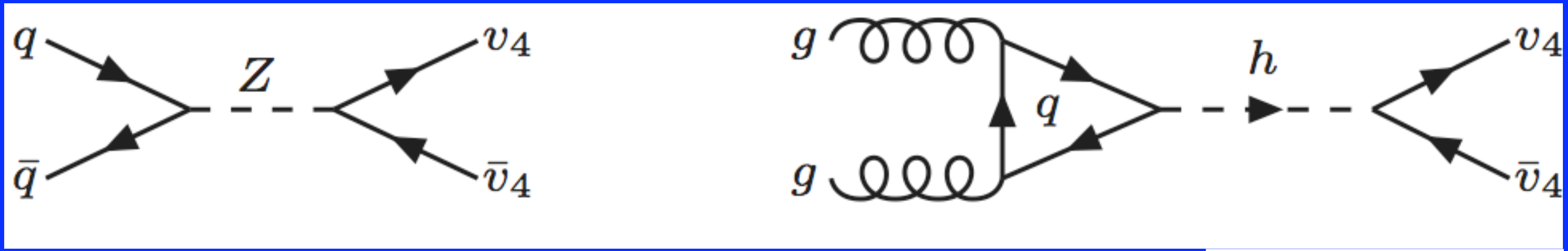
Introduction

- Can the 4th family members be observed in LHC/ATLAS ?
- We have investigated the existence of ν_4 and the impact on the SM Higgs boson through ("silver mode") :

$$pp \to h \to \nu_4 \bar{\nu}_4$$ (suggested by S. Sultansoy & G. Unel, Tr.J.Phys. 31 2007)

- ν_4 can still be produced via (in case Higgs does not exist)

$$pp \to Z \to \nu_4 \bar{\nu}_4$$



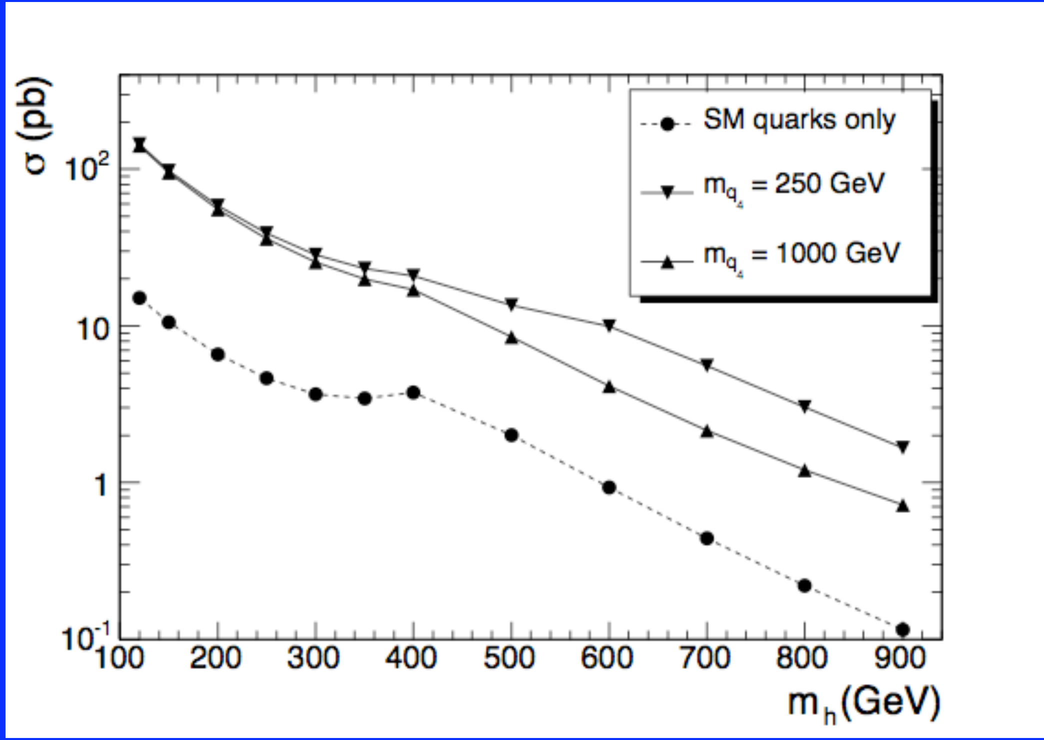
q = t, b, u_4, d_4

- Majorana or Dirac nature of ν_4 is studied
  - Particle =? Anti-Particle

- Preliminary results available in ArXiv:0806.4003v3 [hep-ph], Submitted to JHEP.

Higgs Production Cross Section

- The dominating Higgs production mechanism at the LHC ➔ Gluon Fusion process
- Higgs cross section due to fourth family quarks computed with HIGLU
- Cross section depends on the fourth quark mass (m_{q4})
- For the analysis, cross section with
  $m_{q4} = m_{u4} = m_{d4} = 500$ GeV
  (same mass favored by DMM approach)



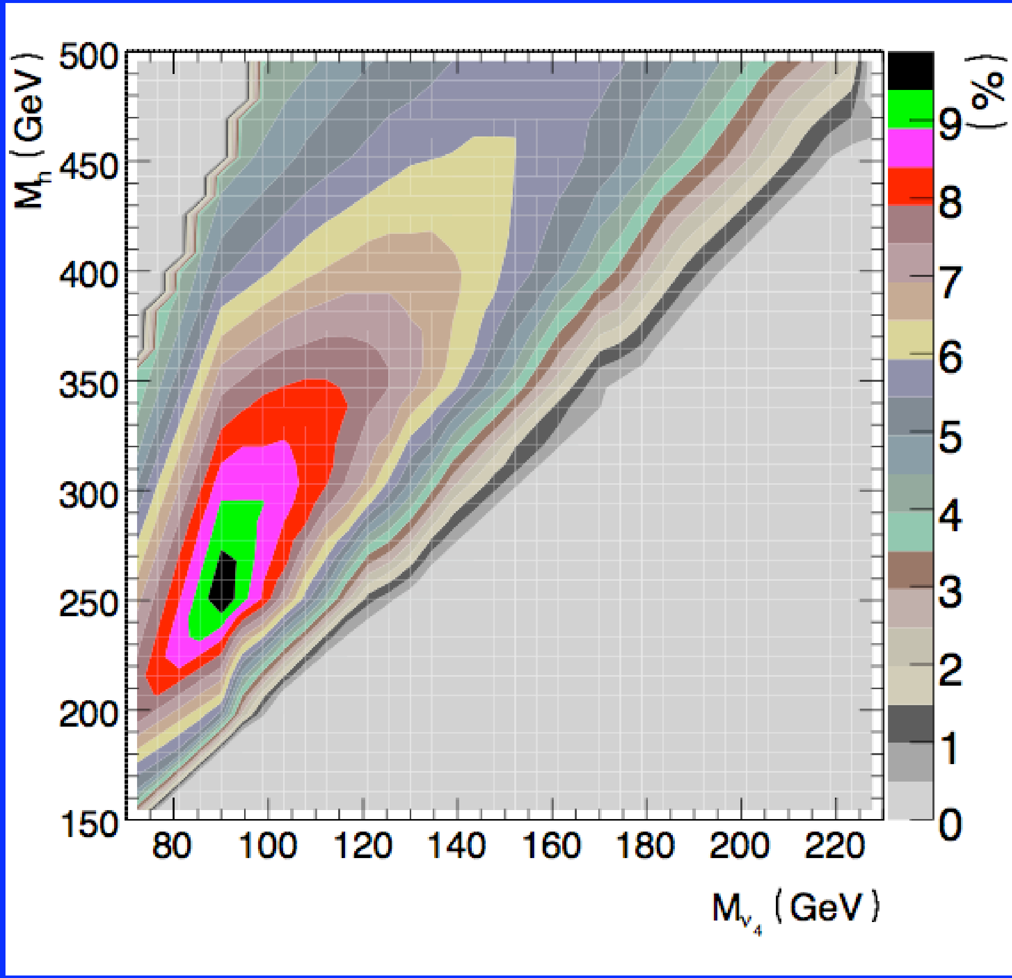
Cross section as a function of higgs mass for m_{q4} = 250, 1000 GeV compared to SM

Higgs Decay Branching Fraction

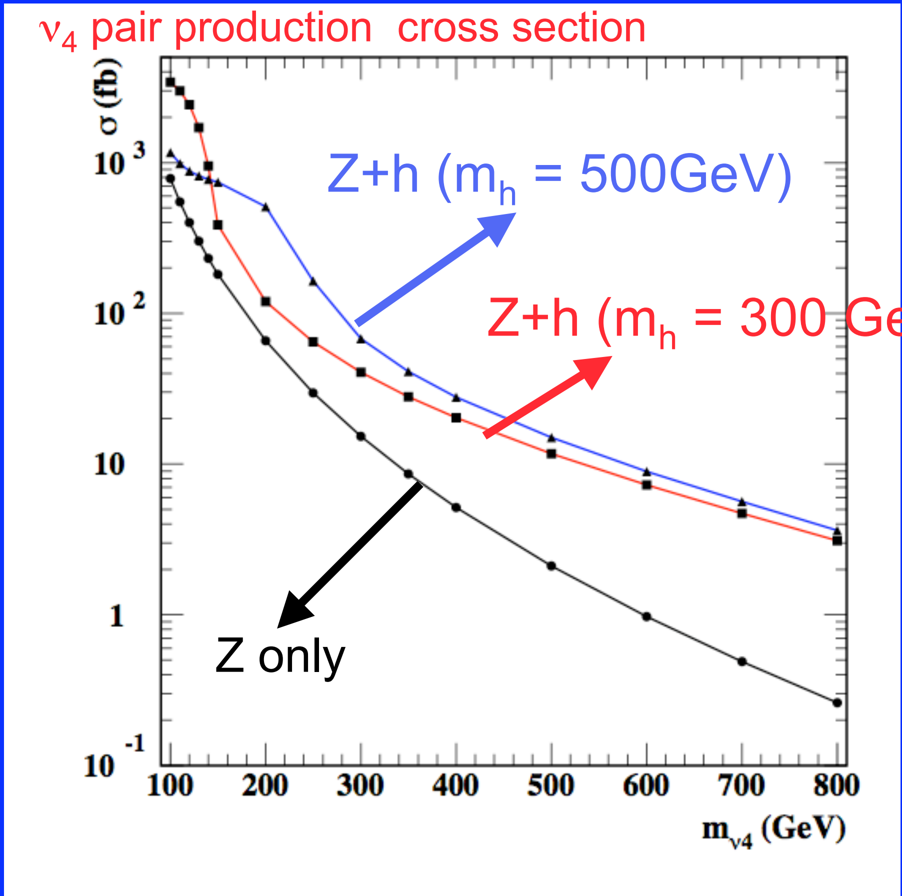
- Branching fraction of Higgs decaying into heavy neutrino pairs computed via CompHEP

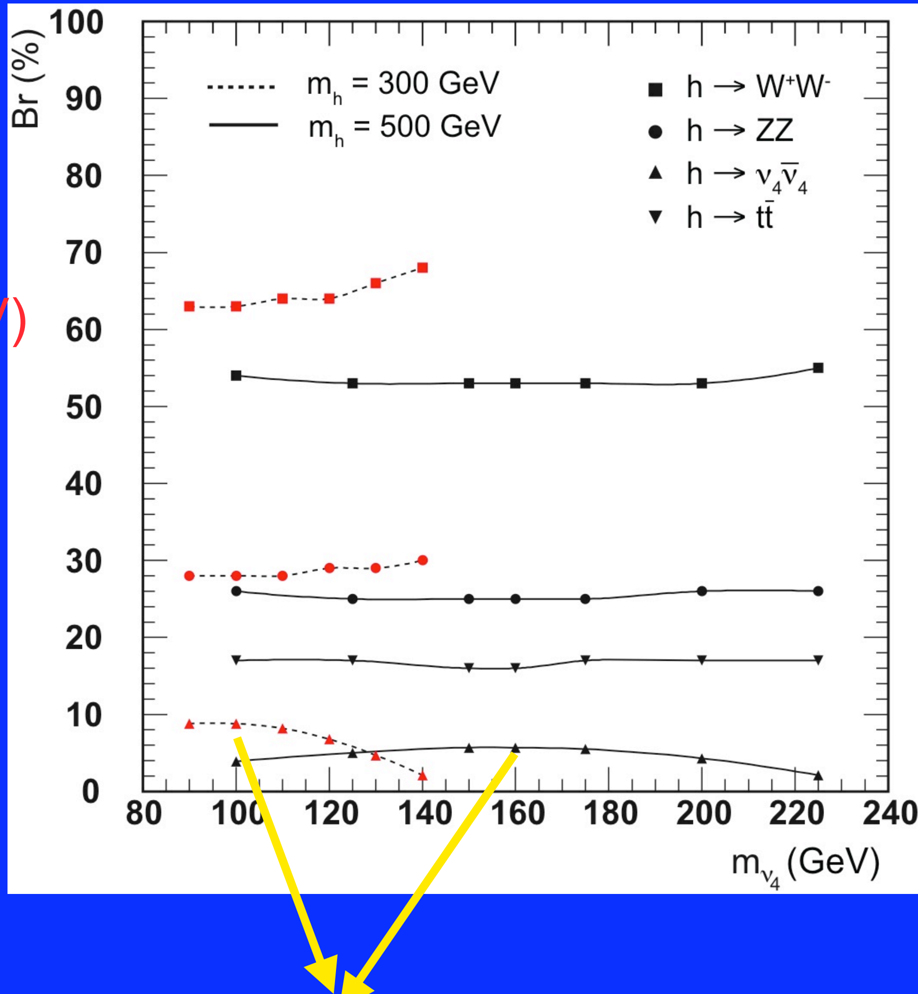
- Highest branching fraction
  BR($h \to \nu_4 \bar{\nu}_4$) ~10 % at
  $m_{\nu 4}$ = 90 GeV & m_h = 250 GeV

- Two points chosen for the test
  m_h = 300, Γ = 9 GeV
  m_h = 500, Γ =67 GeV



ν_4 Cross Section & Branching fraction





Two ν_4 mass values chosen as benchmark points

Signal Events

- pp $\rightarrow$ h/Z $\rightarrow$ $\nu_4 \bar{\nu}_4$

  $\hookrightarrow$ l W (l = μ)

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  - BR ($\nu_4 \rightarrow \mu W$) ~ 68% (PRD **72 (2005) 053006**)

  - Considering only the hadronic decay of W

    Final State : 2μ + 4j

Summary of Benchmark points:

	$\sigma_{pp\to Z\to\nu_4\bar{\nu}_4}$ (fb)	m_h (GeV)	$\sigma_{gg\to h}$ (pb)	m_{ν_4} (GeV)	BR($h \to \nu_4\bar{\nu}_4$)	$\sigma_{pp\to\nu_4\bar{\nu}_4\to WW\mu\mu}$ (fb)
S1	782	N/A	N/A	100	N/A	362
S2	782	300	30	100	0.088	1583
S3	144	500	10	160	0.055	321

Background events

- Di-boson + di-muon
  - 2V+2μ , V = W / Z produced with MadGraph
  - Total cross section is negligible
    - less than 5 fb

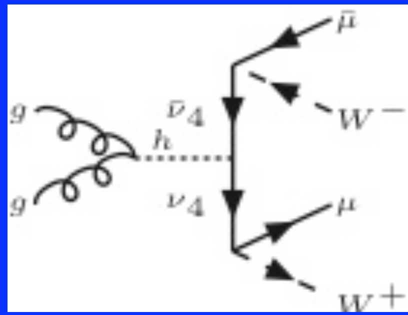
Process	cross section (fb)
$W^+W^-\mu^+\mu^-$	2.56 ± 0.02
$ZZ\mu^+\mu^-$	0.70 ± 0.06
$W^+Z\mu^+\mu^-$	0.97 ± 0.01
$W^-Z\mu^+\mu^-$	0.48 ± 0.06
Direct Total	4.71 ± 0.09

  - Muon $p_T > 15$ GeV; $|n_\mu| < 2.5$ and $m_{QCD} = m_Z$
- Di-muon + 4j (Z/γ + 4j)
  - Produced with MadGraph (compared with AlpGen)
  - Not negligible contribution, 57 pb
  - Muon and jet $p_T > 15$ GeV; $|n_\mu| < 2.5$, $|n_j| < 5$; $\delta R_{jj} > 0.4$ and $m_{QCD} = m_Z$
- $t\bar{t}$ background
  - Not negligible 755 pb

Generators & Production chain

CTEQ6L1

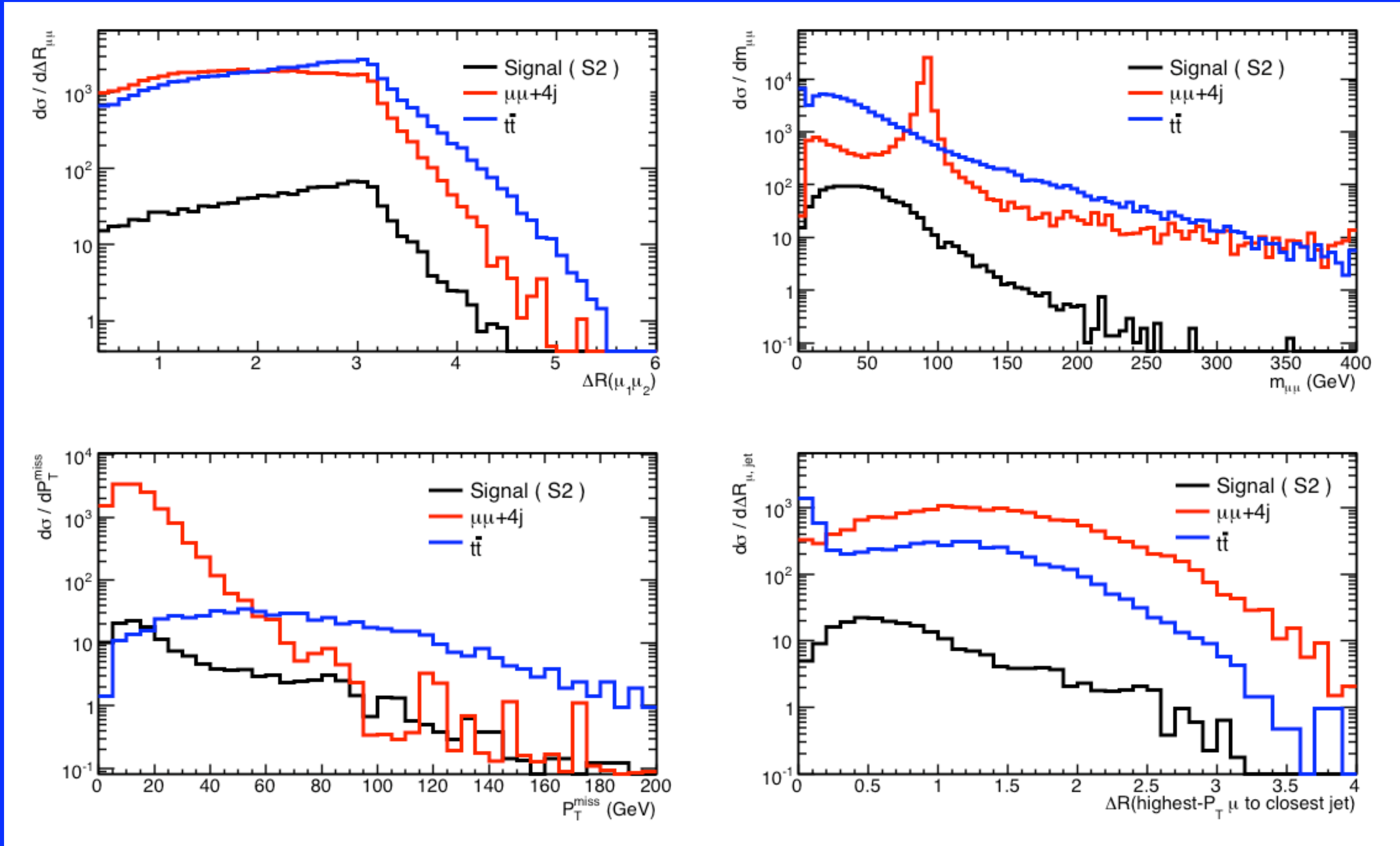
- Event Generation
  - CompHEP + MadGraph
    - Small sample with AlpGen for comparison purpose
- Pythia
    - Parton Showering, Hadronization, multiple interactions etc.
- PGS
    - For detector Simulation
      - ATLAS parameterization
    - Muon mischarge rate is parameterized as a function of $(p_T)_\mu$ and added manually to PGS
- ROOT based analysis



"ggh"effective coupling implemented In CompHEP

Kinematic Distributions

For S2 Benchmark point



$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

Event Selection Efficiencies

The cuts applied to select $2\mu+4j$ final states :

Selection criterion	S1	S2	S3	$2\mu4j$	$t\bar{t}$
At least 2μ	63.6	77.9	84.1	93.3	8.1
$p_T(\mu)$ > 15 GeV	50.7	55.1	95.1	88.8	29.5
At least 4j	73.6	82.3	82.6	86.0	88.7
$p_T(j)$ > 15 GeV	53.3	65.6	72.2	70.4	76.0
$\|M_{jj} - M_W\| < 20$ GeV	63.1	60.5	60.3	45.9	52.8
$\Delta R_{\mu j} > 0.4$	64.5	65.9	77.4	83.0	17.4
No j_b	93.6	92.0	91.5	93.6	53.4
Missing E_T < 30 GeV	74.4	64.9	68.7	79.4	15.4
Common ε_{reco}	3.7	5.7	13.4	24.2	1.2×10^{-2}

- Choose two high p_T muons and four jets with enough p_T
- Make best two W's out of 4 jets
- Reject muons coming from b via isolation cut

ν_4 : Dirac or Majorana ?

- Further selection criterion applied to selected 2μ4j events to study the nature of ν_4
- Dirac type $\nu_4 \bar{\nu}_4$ decay to: 100% opposite-sign leptons and bosons

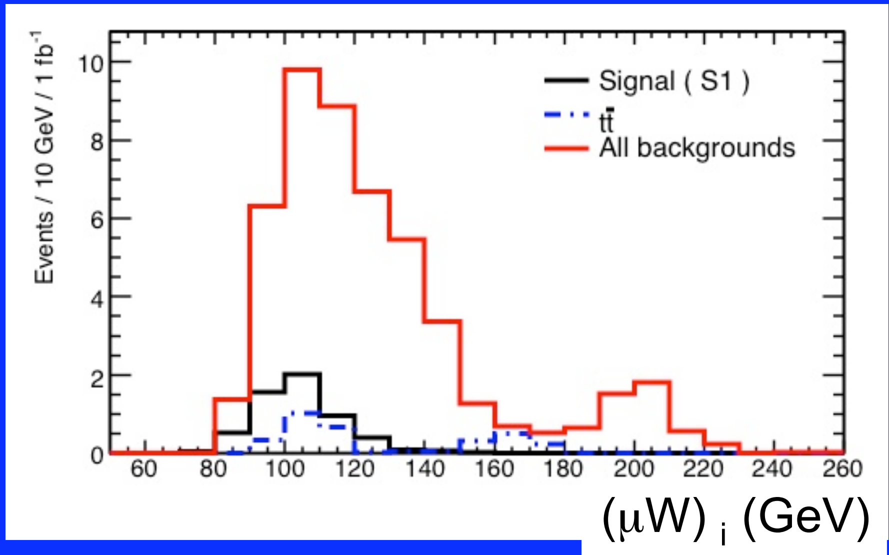
Selection criterion	S1	S2	2μ4j	$t\bar{t}$	S3	2μ4j	$t\bar{t}$
$Sign(\mu_1)xSign(\mu_2) = -1$	97.3	96.5	99.9	84.5	99.2	99.9	84.5
$\lvert m_{\mu+\mu-} - m_Z \rvert > 25$ GeV	79.1	74.1	10.0	67.7	77.6	10.0	67.7
$\Delta R_{\mu\mu} > 2.0$	72.9	65.6	34.3	59.5	74.7	34.3	59.5
$\lvert \Delta m_{\nu4}$ (reco) - $\Delta m_{\nu4}$(true) $\rvert < 20$ GeV	67.9	60.4	5.5	6.1	39.6	6.06	13.6
Dirac ε_{total}	1.4	1.6	4.5×10^{-2}	2.5×10^{-4}	3.1	5.0×10^{-2}	5.7×10^{-4}

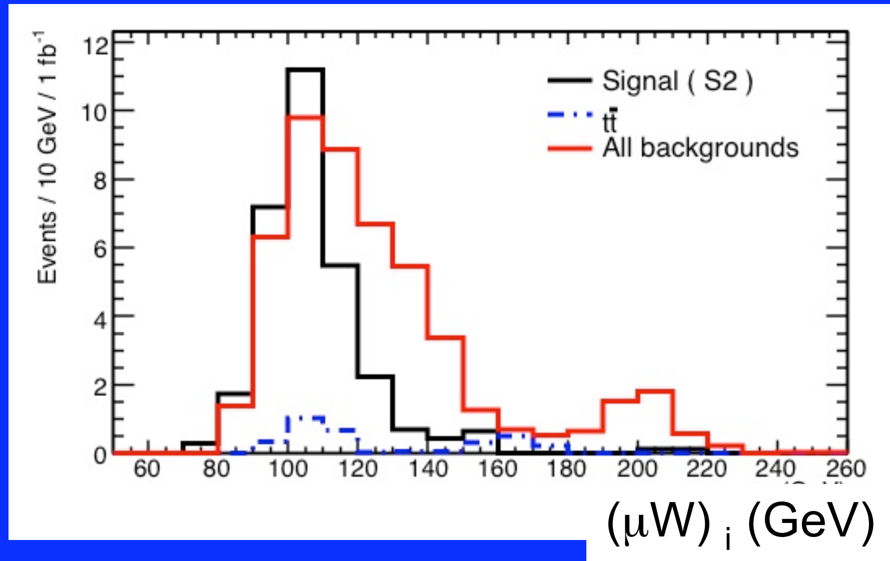
- Majorana type $\nu_4 \bar{\nu}_4$ decay to : 50% same-sign leptons and bosons ; 50% opposite sign leptons and bosons

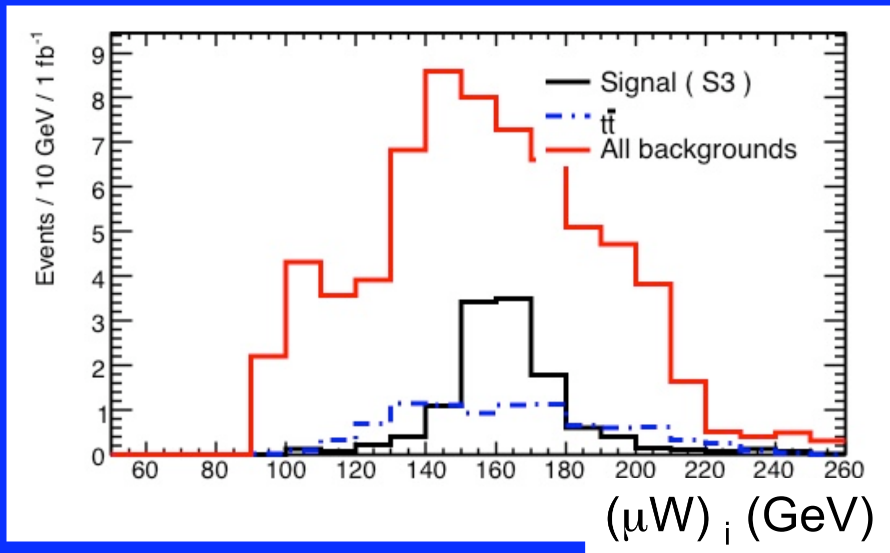
Selection criterion	S1	S2	S3	2μ4j	$t\bar{t}$
$Sign(\mu_1)xSign(\mu_2) = 1$	46.6	45.5	51.2	6.8×10^{-2}	15.5
$\Delta m_{\nu4} / \overline{\Delta m_{\nu4}} < 0.25$	88.2	85.2	74.3	52.0	58.8
Majorana ε_{total}	1.5	2.1	5.3	8.6×10^{-3}	1.1×10^{-3}

backgrounds

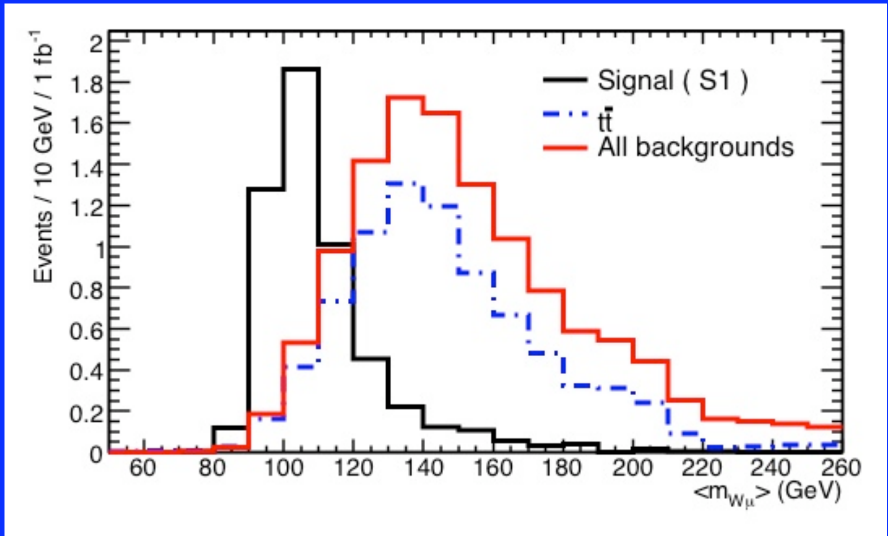
Results of Dirac ν_4

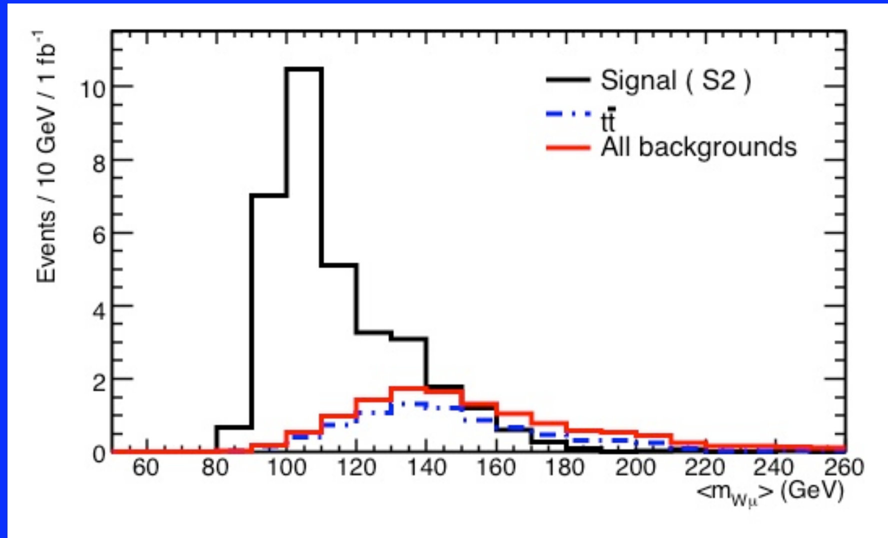


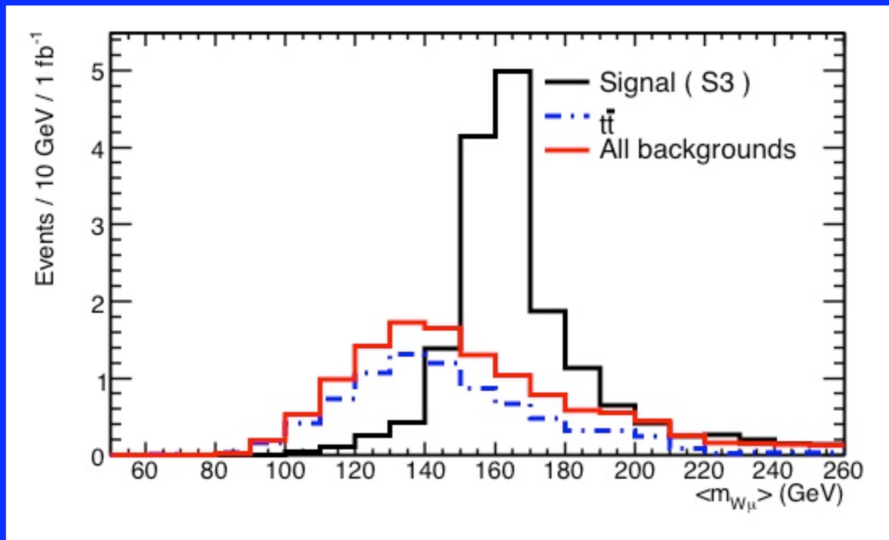




Results of Majorana ν_4

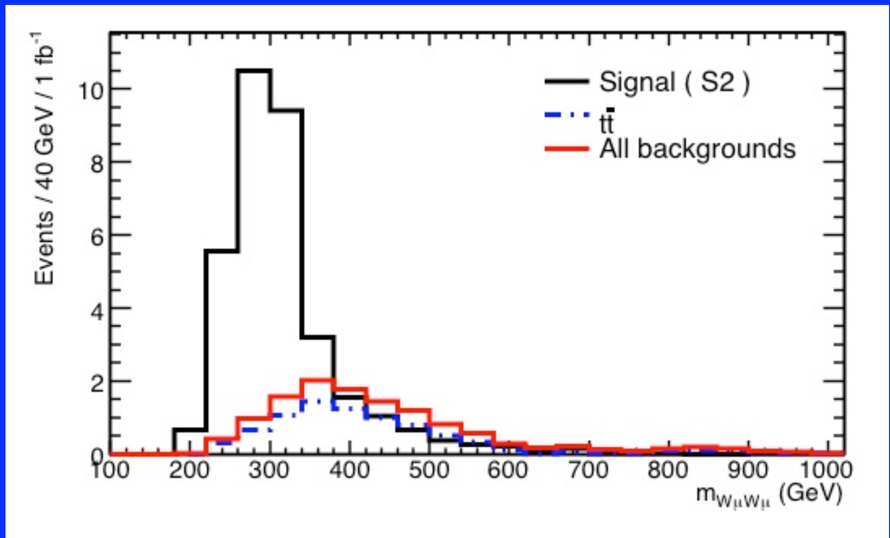


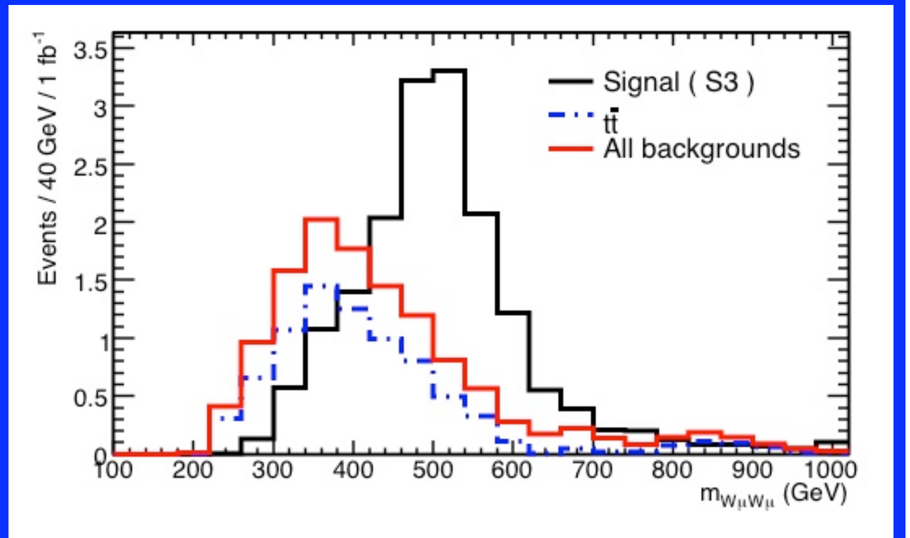




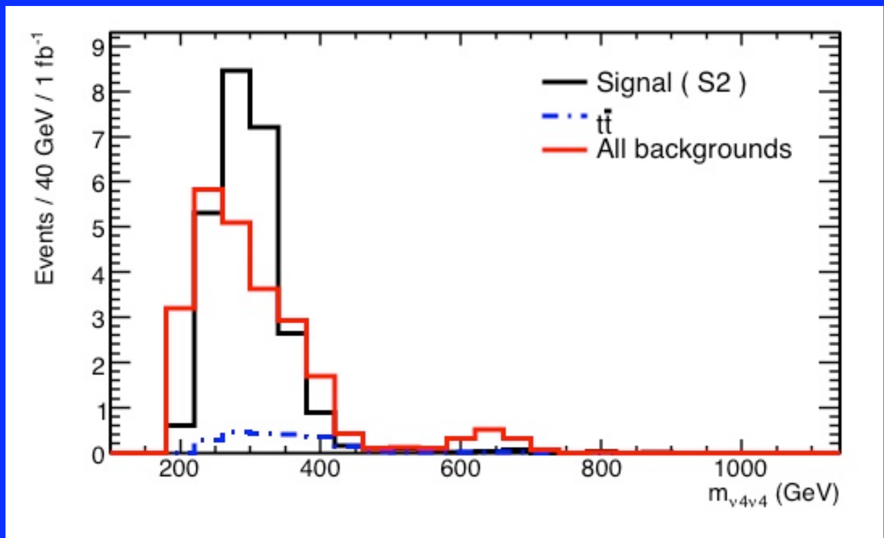
Reconstructed Higgs Mass

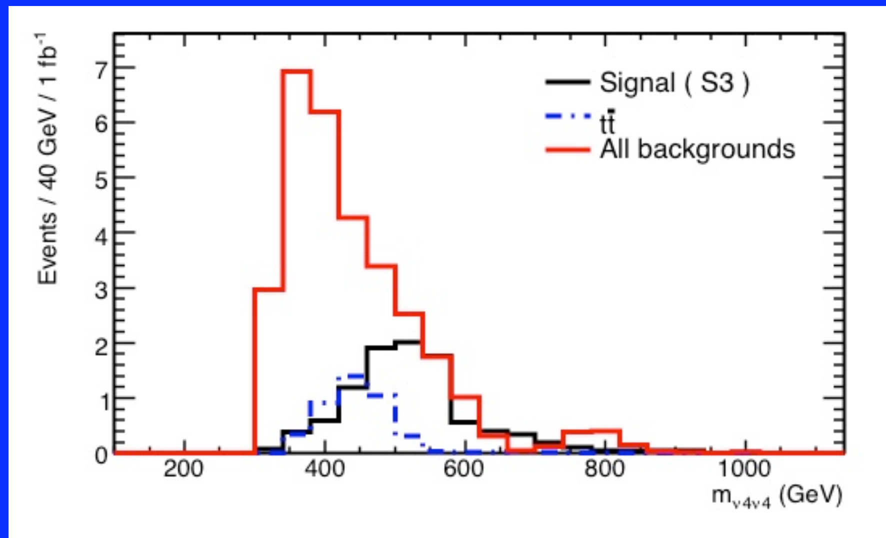
Majorana case





Dirac case

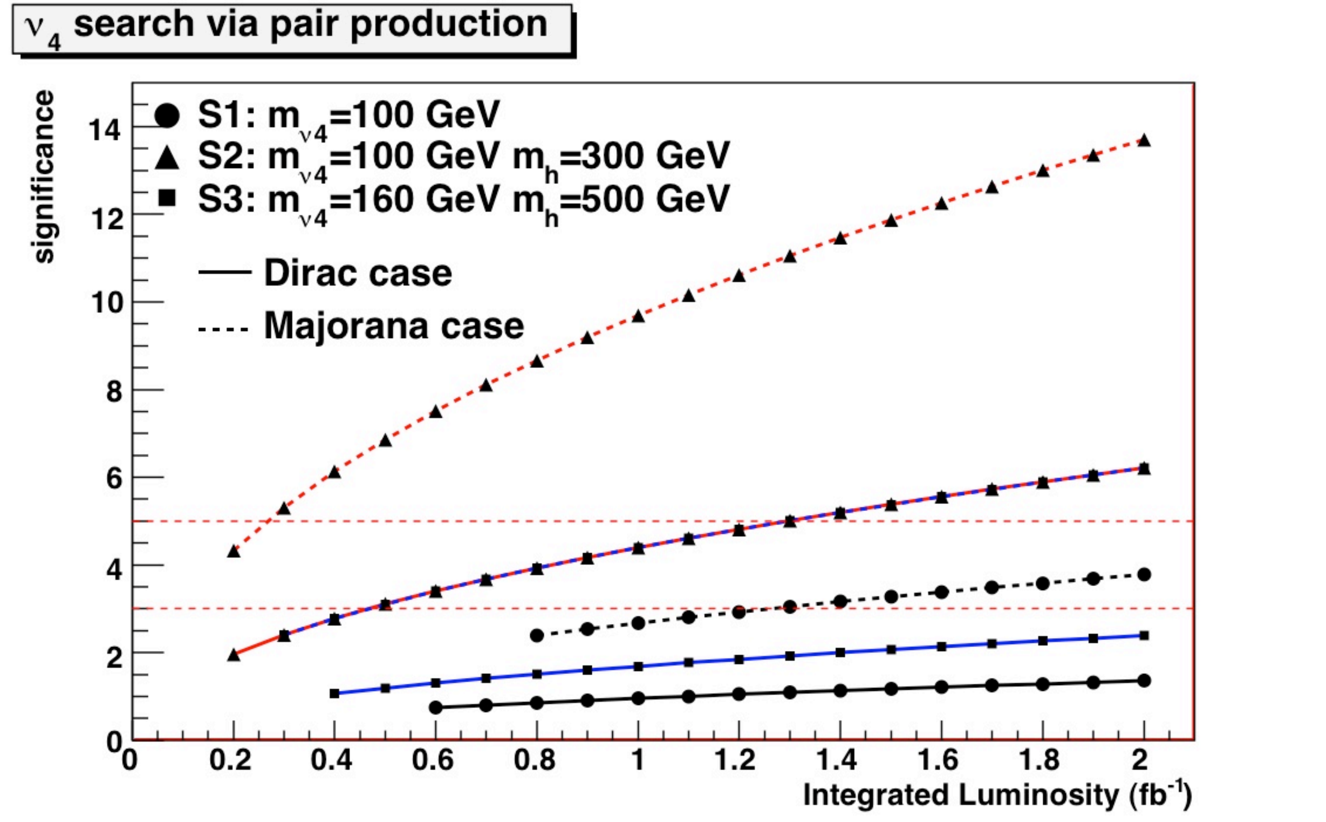




Significance

$$\sqrt{2 \times \left[(s+b)\ln\left(1+\frac{s}{b}\right) - s \right]}$$

- For each scenarios, significance computed from the 4 bins around signal peak
- Majorana ν_4 will be accessible for three benchmark points (i.e. with or without Higgs boson) around 1-2 fb^{-1}
- Dirac ν_4 can only be seen with Higgs

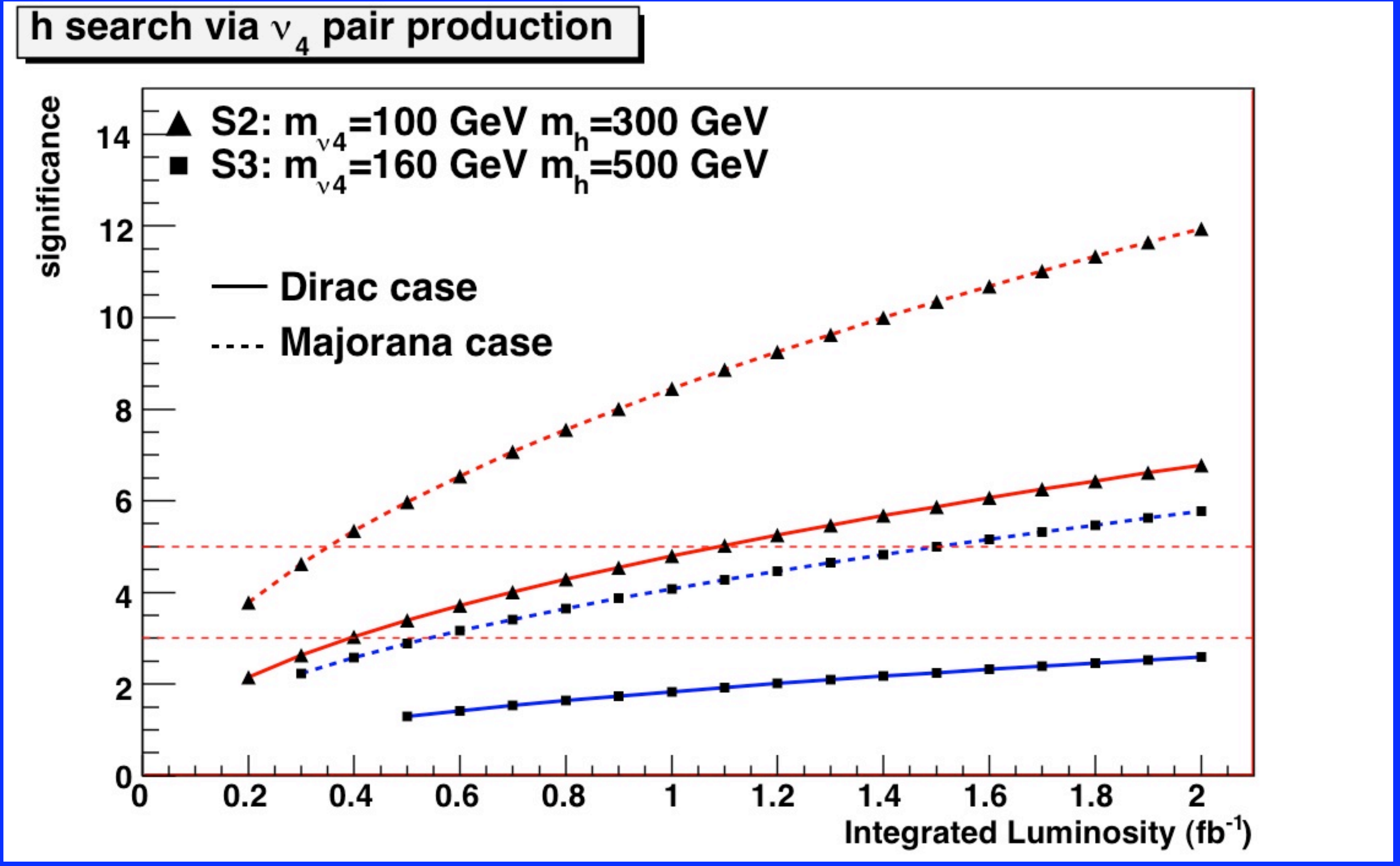


Significance (cont'd)

Majorana case: m_h = 300 GeV, 5σ with 0.3 fb^{-1} can be achieved

m_h = 500 GeV, 3σ with 1.5 fb^{-1} can be achieved

Dirac case: requires ~2x more luminosity to achieve the same significance



Summary and Outlook

- We have made a feasibility study to determine whether

  SM higgs boson can be detected through its decay into ν_4-pair in ATLAS

  and/or

  ν_4 can be discovered

- Two masses of higgs boson are considered

- With 1-2 fb^{-1}, both ν_4 and Higgs boson can be discovered at the same time
  - Majorana case is promising

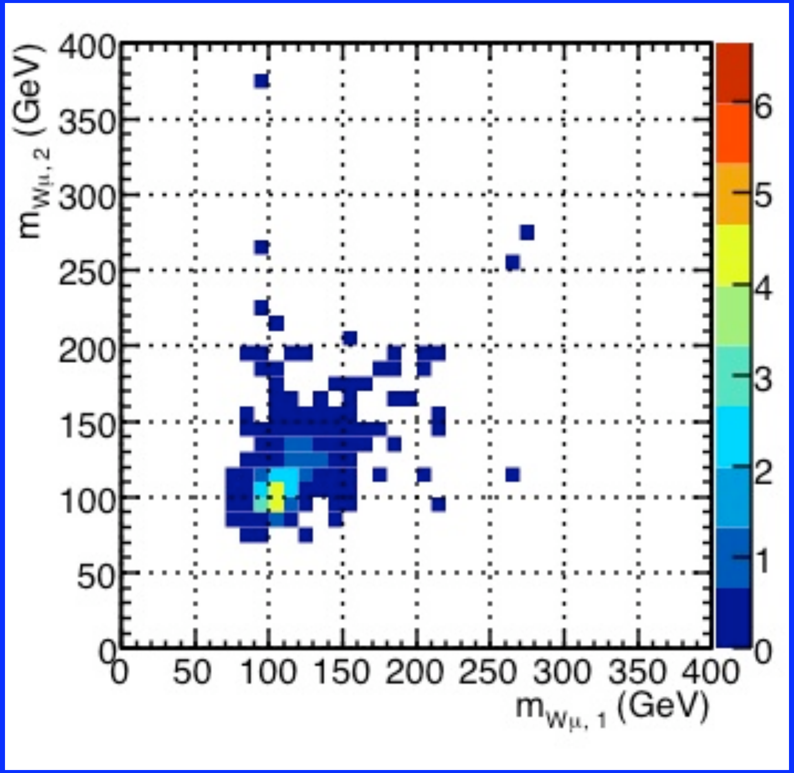
The analysis can be improved by :

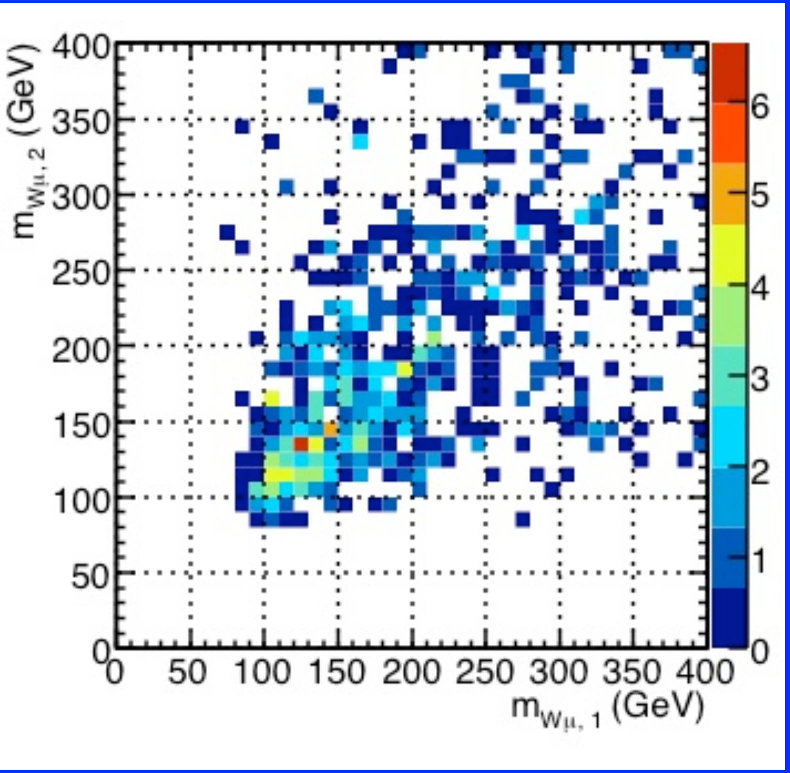
- Cut optimization
  - Analysis based on the cut and count analysis
  - More statistics of background sample needed

Backup Slides

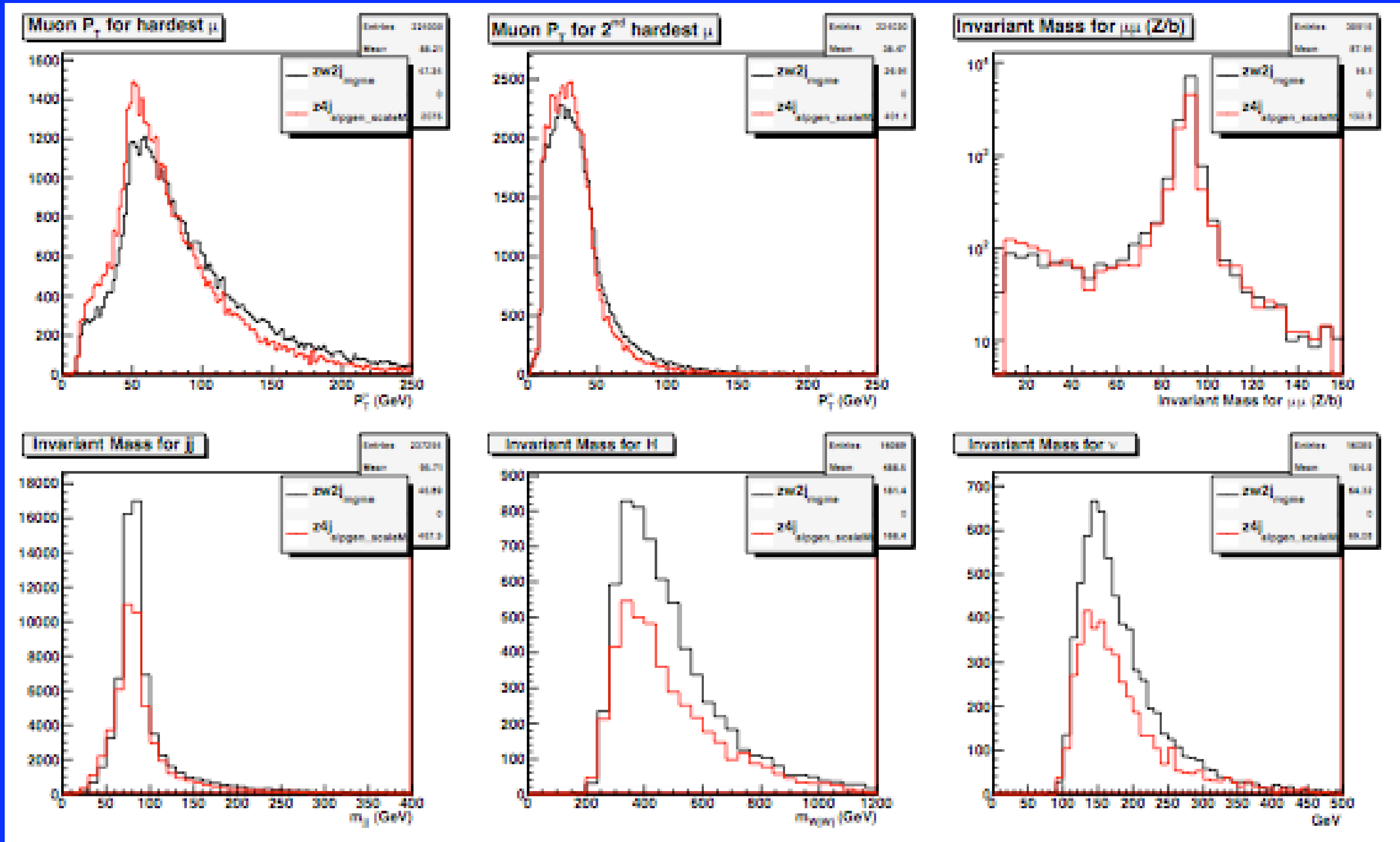
Dirac case: Background rejection

- For S2 and Dirac case :
  - Applied 2D selection : masses of each ν_4





Comparison of Generators



(Red line) : AlpGen : Z/γ + 4j
(Black line) : MadGraph: Z/γ + W+2j (W→jj) (scaled to AlpGen)

Motivation

Th. Models

- In Standard Model, 3rd generation is completed with the discovery of top quark at FNAL
- Is there any other generation (4th, 5th etc) ?
- Recent EW data does not exclude the existence of the 4th generation

  V.A. Novikov, L.B. Okun, A. N, Rozanov, M.I. Vysotsky, PLB 529 (2002)

  G.D. Kribs, T.Plehn, M.Spannowsky, T.M.P. Tait, PRD 76 (2007)
- charge - spin unification

  G. Bregar, M. Breskvar, D. Lukman, N.S. Mankoc Borstnik arXiv:0708.2846 (hep-ph)
- DMM (Democratic Mass Matrix) approach

  Review: S. Sultansoy hep-ph/0610279