Search for doubly charged Higgs bosons in 4μ channel

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Introduction I

- The Higgs mechanism gives mass to W, Z, quarks and leptons.

- Particles gain their mass by coupling to the Higgs field.
  The coupling connects left handed and right handed fermion fields.

- Neutrinos do not couple to the Higgs field and therefore gain no mass.
  But neutrinos have a nonzero mass by recent neutrino oscillation experiments.

- The Standard Model needs to be extended to explain neutrino masses.
  → Higgs triplet models could explain the non-zero neutrino mass

reference : CMS_NOTE2006_081

Introduction II

- In models with expanded Higgs sector, one can have Higgs triplets.
  → Doubly charged Higgs

- Pair production : through Drell-Yan process

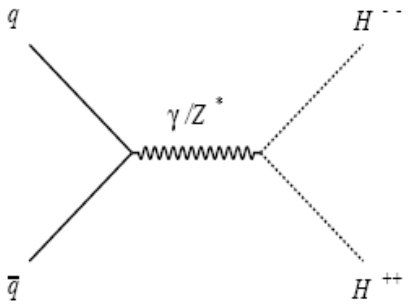
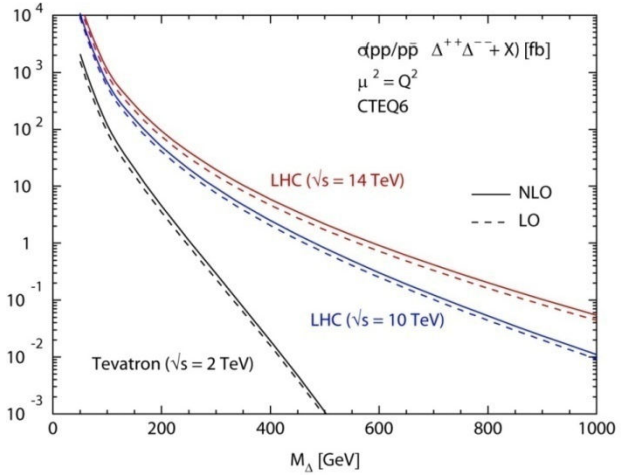


Figure 2: Drell-Yan pair production of doubly charged Higgs Bosons

in CMS_NOTE2006_081



cross section
(hep-ph/9610237)

- Decays : $\mathrm{H}^{\pm\pm} \to l^{\pm} l^{\pm},\ \mathrm{W}^{\pm}\mathrm{W}^{\pm}$
- In this analysis, we only consider di-muon decays
  ($Br(H^{++}H^{--} \text{ to } 4\mu)=1$ is assumed)

Samples

- Used CMSSW version : 2_2_6

- signal data generation & reconstruction ($\sqrt{s}$=10TeV)
  : 10k events of full simulation data (generated by Hyunkwan Seo)
  → M($H^{\pm\pm}$) = 130, 150, 170, 200, 300, 600GeV

- background (generated by Higgs to ZZ group)
  ZZ to 4l
  Zbb_bar to 4l
  tt_bar to 4l

Samples

- $H^{++}H^{--}$ to 4mu : FullSim, STARTUP_V9, 10k events

- ZZ to 4l : FullSim, IDEAL, 782k events, skim sample(glb mu)
  → 202k events(# of MC gen muons≥4)
- Zbb to 4l : FullSim, IDEAL, 683k events, skim sample(glb mu)
  → 105k events(# of MC gen muons≥4)
- tt to 4l : FullSim, IDEAL, 728k events, skim sample(glb mu)
  → 61k events(# of MC gen muons≥4)

samples	M(H^{++})=130 (GeV)	M(H^{++})=150	M(H^{++})=170	M(H^{++})=200	M(H^{++})=300	M(H^{++})=600	ZZ to 4μ	Zbb_bar to 4μ	tt_bar to 4μ
σ(fb)	380	145	101	52.0	9.67	0.314	18.8	63.9	267

$$\text{final cross section} = \text{LO cross section} \times \text{K - factor} \times \text{Pythia filter efficiency}(4(e,\text{mu})\ \text{requirement}) \times \text{skim efficiency} \times \text{acceptance}(4\mu_{\text{gen}})$$

references : https://twiki.cern.ch/twiki/bin/view/CMS/HiggsZZMCsamples,
Margarete Mühlleitner and Michael Spira calculated the cross section of $pp \rightarrow \Delta^{++}\Delta^{--}+X$

Event selection & strategy

- Mass independent selection

  p_T>10GeV, |η|<2.4, 4μ candidates(from global muons)

  track isolation : isolPt<10 GeV, cone size 0.3

  jet isolation : ΔR(jet,μ)>0.5, $p_{T,jet}$>15 GeV, n90(jet)>3, $p_{T,jet}/p_{T,\mu}$>1

- Mass dependent selection

  Z mass cut : Max(|M_Z-M_{Z1}|, |M_Z-M_{Z2}|)>30 GeV

  (M_Z=91.1876 GeV)

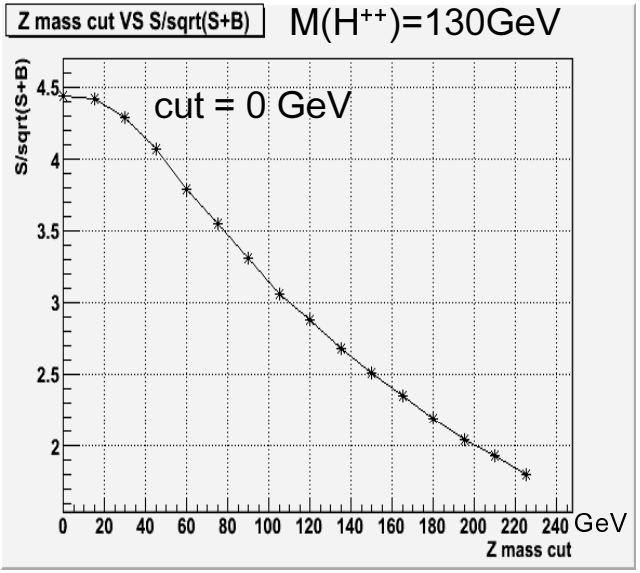
  di-muon pt cut : Max($p_T(H^{++})$,$p_T(H^{--})$,$p_T(Z_1)$,$p_T(Z_2)$)>90 GeV

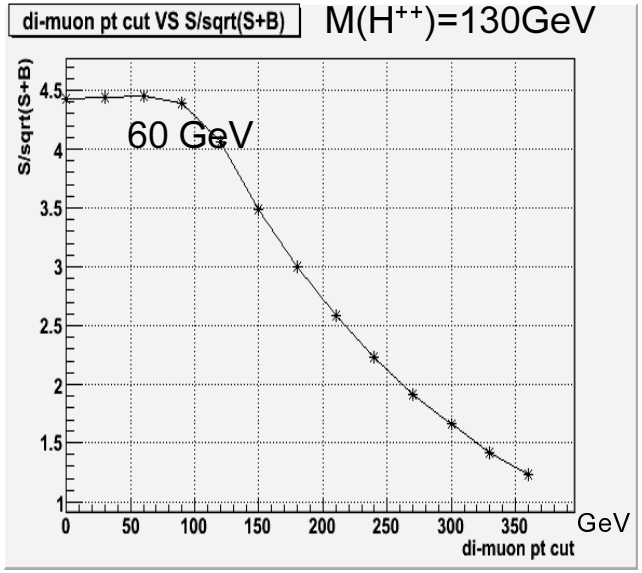
  quad-muon mass cut : $M_{4\mu}$>300 GeV

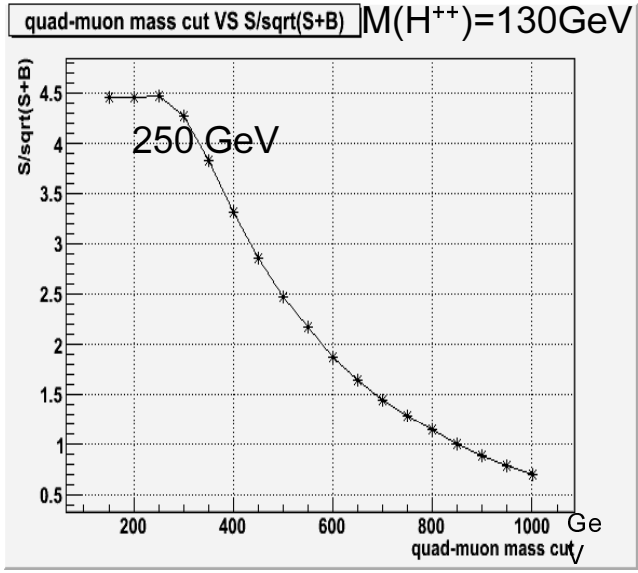
  } for $M(H^{++})$=200GeV

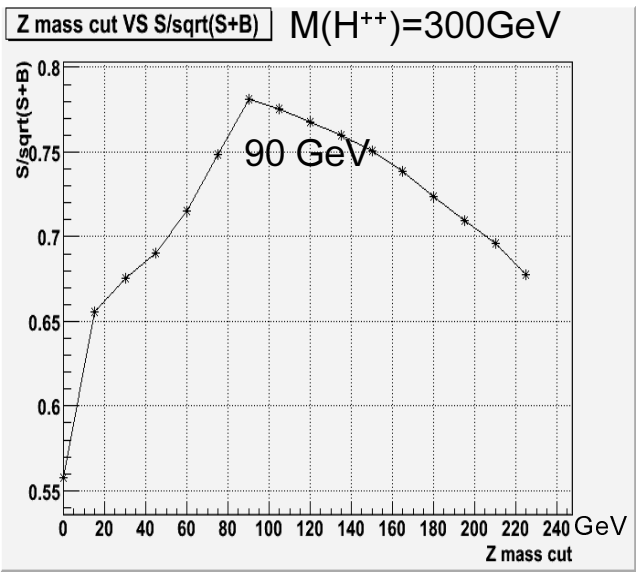
Cut optimization

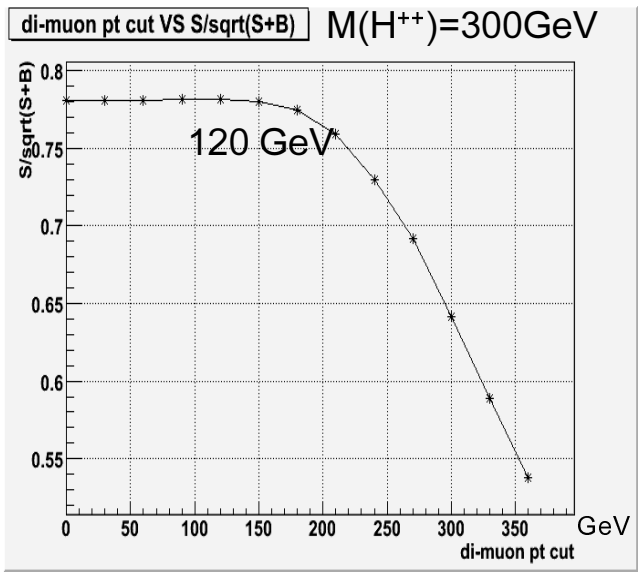
S = expected # of signal events, B = expected # of all background events at $10pb^{-1}$

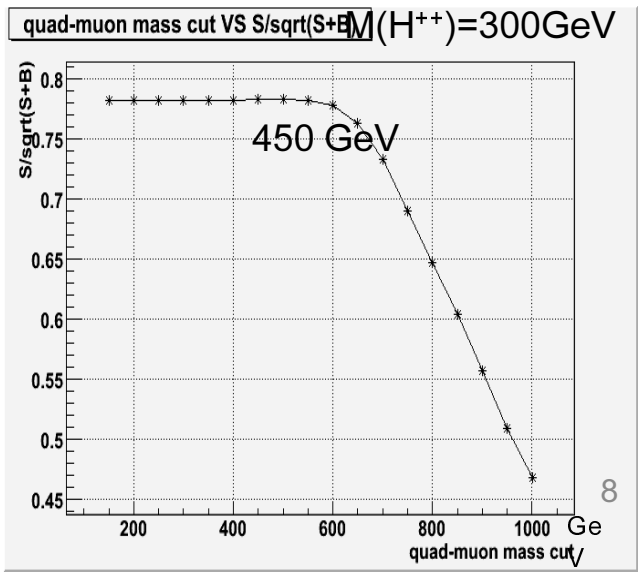












Signal & background efficiency VS cut level

$$signal(bkg.)\ efficiency = \frac{\#\ of\ H^{++}\ candidates\ applied\ cuts}{\#\ of\ generated\ events (\#\ of\ \mu_{gen} \geq 4)}$$

Signal & bkg. efficiency

	all events				in 3σ (H^{++}&H^{--} mass window)			
Cuts	$H^{++}H^{--}$ to 4μ (200GeV,10k)	ZZ to 4μ (202k)	Zbb to 4μ (105k)	tt to 4μ (61k)	$H^{++}H^{--}$ to 4μ (200GeV,10k)	ZZ to 4μ (202k)	Zbb to 4μ (105k)	tt to 4μ (61k)
pt>10GeV, |η|<2.4, 4μ	66.4%	36.3%	7.88%	10.5%	62.9%	1.11%	0.0634%	0.0561%
isolPt<10GeV, cone=0.3	62.7%	35.7%	2.06%	1.07%	59.7%	1.08%	0.0057%	0%
pt(jet)>15, ΔR(jet,μ)>0.5 n90(jet)>3, pt(jet)/pt(μ)>1	61.8%	33.8%	0.320%	0.122%	59.0%	1.06%	0%	0%
Max($\|M_Z-M_{Z1}\|$, $\|M_Z-M_{Z2}\|$) > 30GeV	60.6%	11.4%	0.284%	0.0989%	57.9%	0.223%	0%	0%
Max($p_T(H^{++})$,$p_T(H^{--})$, $p_T(Z_1)$,$p_T(Z_2)$) > 90GeV	60.4%	1.77%	0.0430%	0.0198%	57.7%	0.185%	0%	0%
$M_{4\mu}$>300GeV	60.4%	0.970%	0.0086%	0.0017%	57.7%	0.180%	0%	0%

Signal & background efficiency VS M(H^{++})

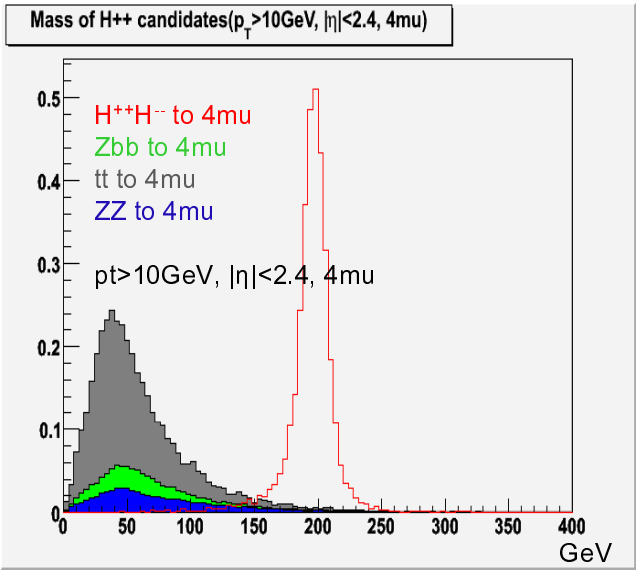
$$signal(bkg.)\ efficiency = \frac{\#\ of\ H^{++}\ candidates\ applied\ all\ cuts}{\#\ of\ generated\ events (\#\ of\ \mu_{gen} \geq 4)}, \quad \delta\varepsilon = \sqrt{\frac{\varepsilon(1-\varepsilon)}{N_{gen}}}$$

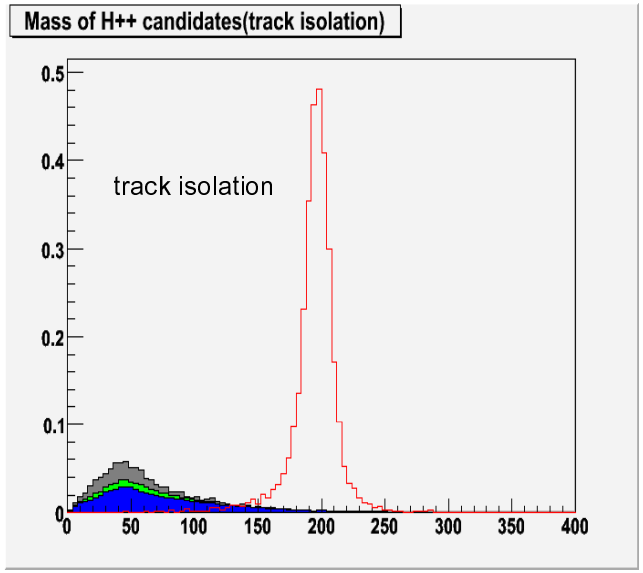
Signal & bkg. efficiency

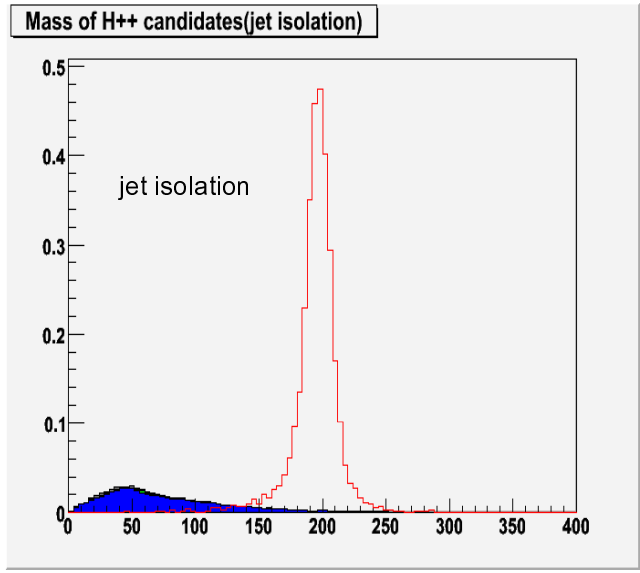
	all events				in 3σ (H^{++}&H^{--} mass window)			
M(H^{++})	$H^{++}H^{--}$ to 4μ (10k)	ZZ to 4μ (202k)	Zbb to 4μ (105k)	tt to 4μ (61k)	$H^{++}H^{--}$ to 4μ (10k)	ZZ to 4μ (202k)	Zbb to 4μ (105k)	tt to 4μ (61k)
130 GeV	52.9% ±0.5%	10.2% ±0.1%	0.0134% ±0.0036%	0.013% ±0.005%	50.8% ±0.5%	1.51% ±0.03%	0%	0.0033% ±0.0023%
150 GeV	56.5% ±0.5%	2.52% ±0.03%	0.0134% ±0.0036%	0.013% ±0.005%	53.8% ±0.5%	0.392% ±0.014%	0%	0.0016% ±0.0016%
170 GeV	57.8% ±0.5%	1.37% ±0.03%	0.0086% ±0.0029%	0.0033% ±0.0023%	55.4% ±0.5%	0.249% ±0.011%	0%	0%
200 GeV	60.4% ±0.5%	0.970% ±0.022%	0.0086% ±0.0029%	0.0017% ±0.0017%	57.7% ±0.5%	0.180% ±0.009%	0%	0%
300 GeV	63.6% ±0.5%	0.148% ±0.009%	0%	0%	60.5% ±0.5%	0.0287% ±0.0038%	0%	0%
600 GeV	66.7% ±0.5%	0.0144% ±0.0027%	0%	0%	62.7% ±0.5%	0.0030% ±0.0012%	0%	0%

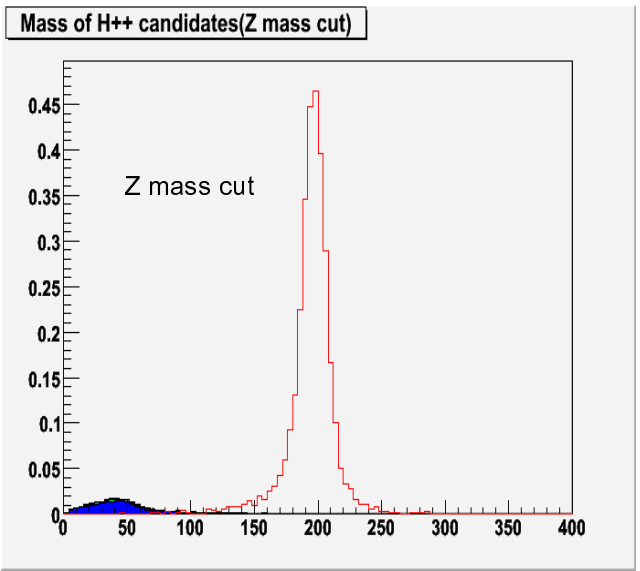
Mass of $\mu^+\mu^+$

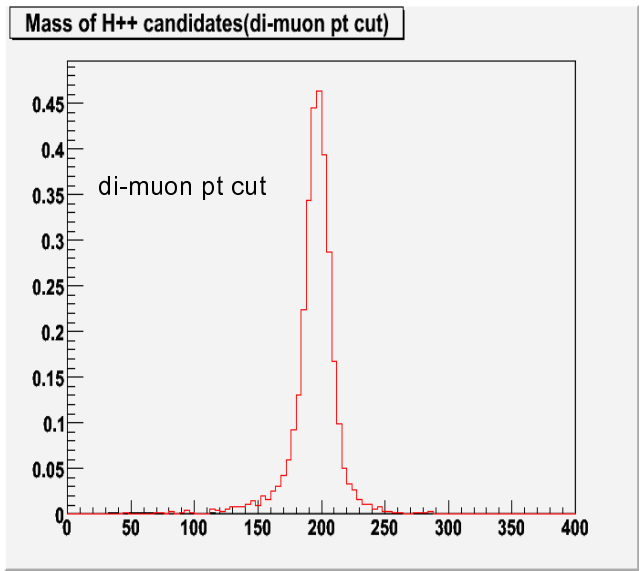
(M(H^{++})=200GeV, normalized to 100pb^{-1}, accumulated histograms except signal)

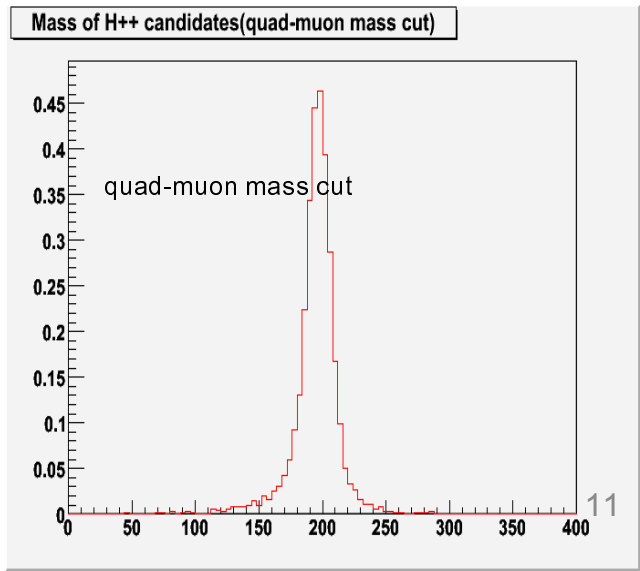






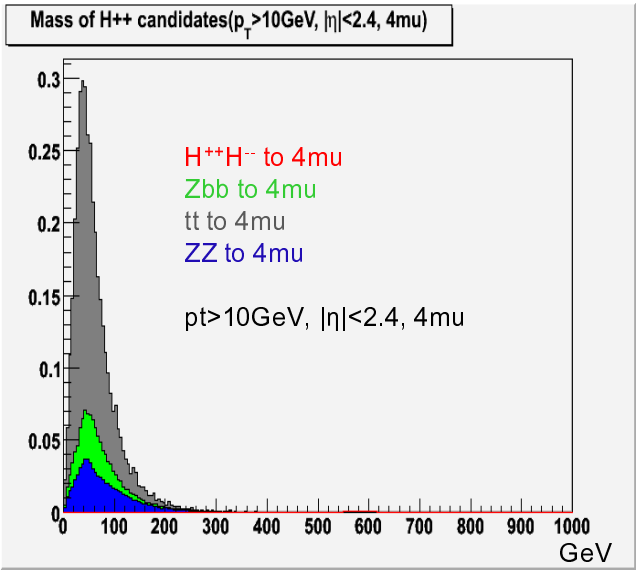


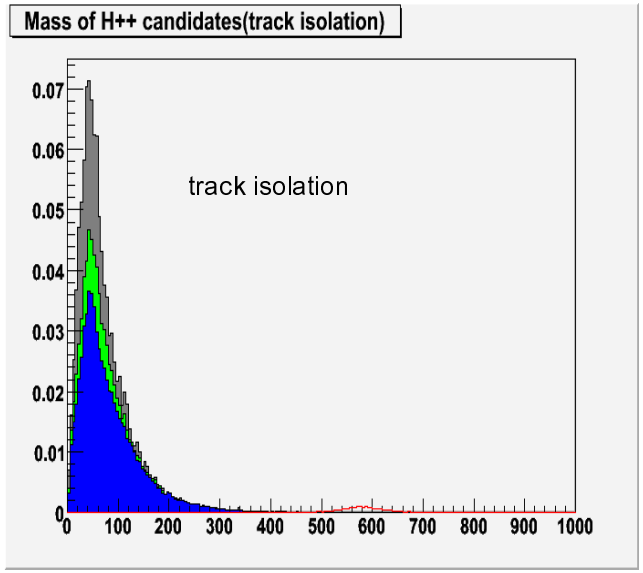


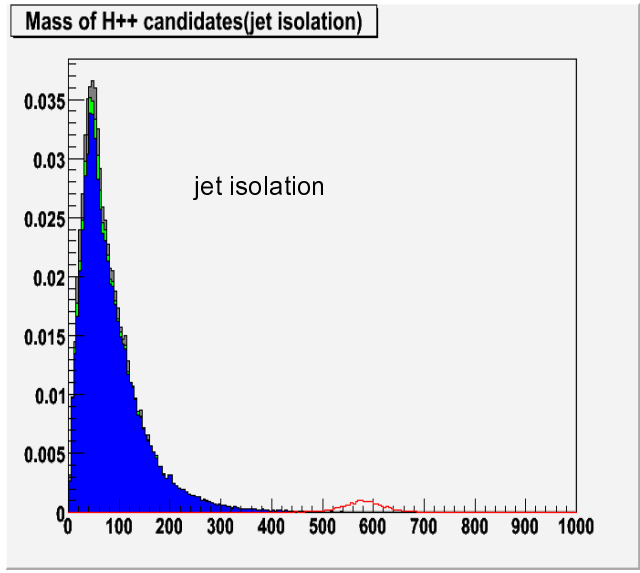


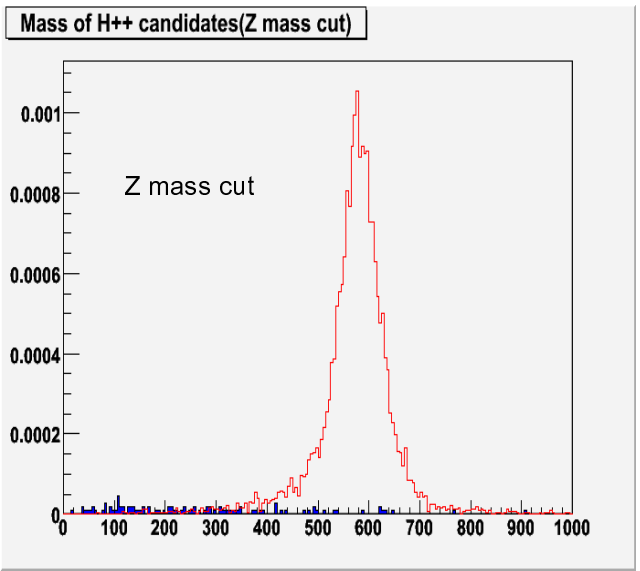
Mass of $\mu^+\mu^+$

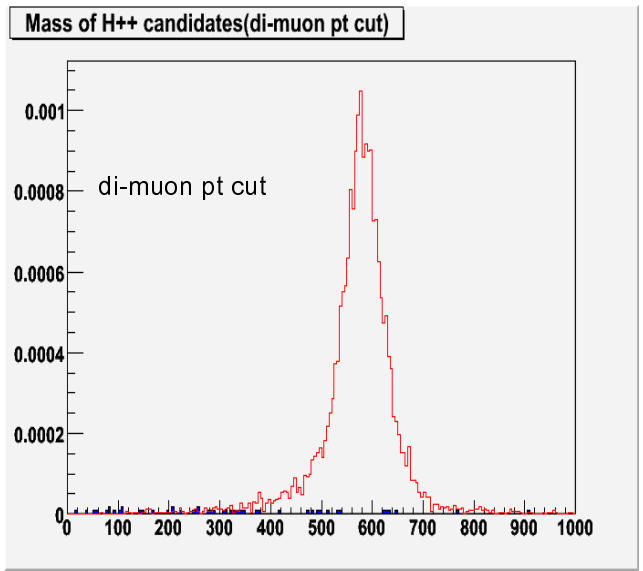
(M(H^{++})=600GeV, normalized to 100pb^{-1}, accumulated histograms except signal)

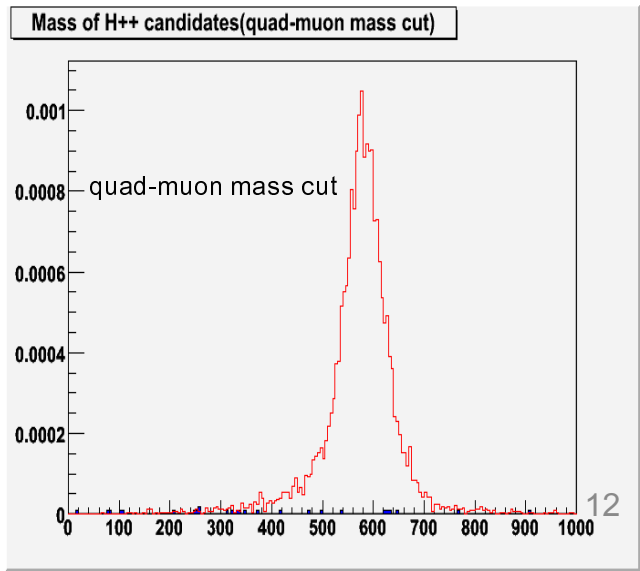






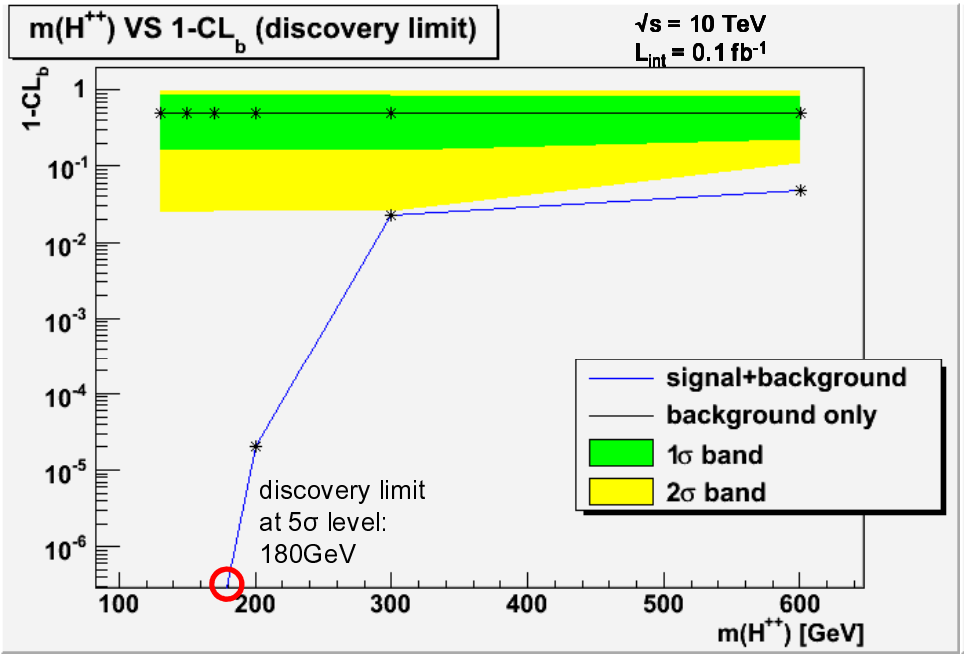


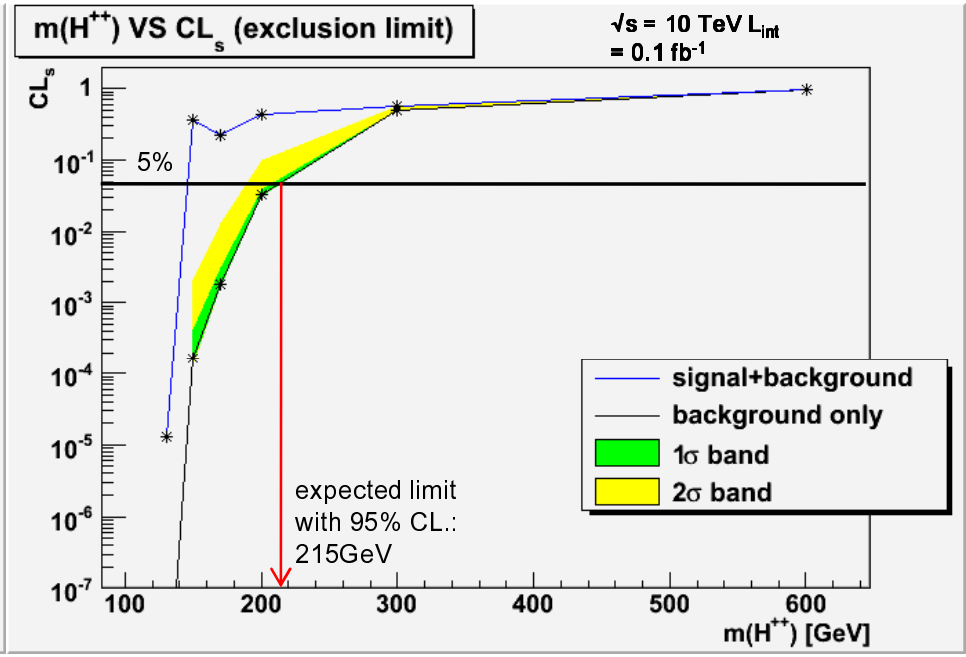




Discovery limit & Exclusion limit

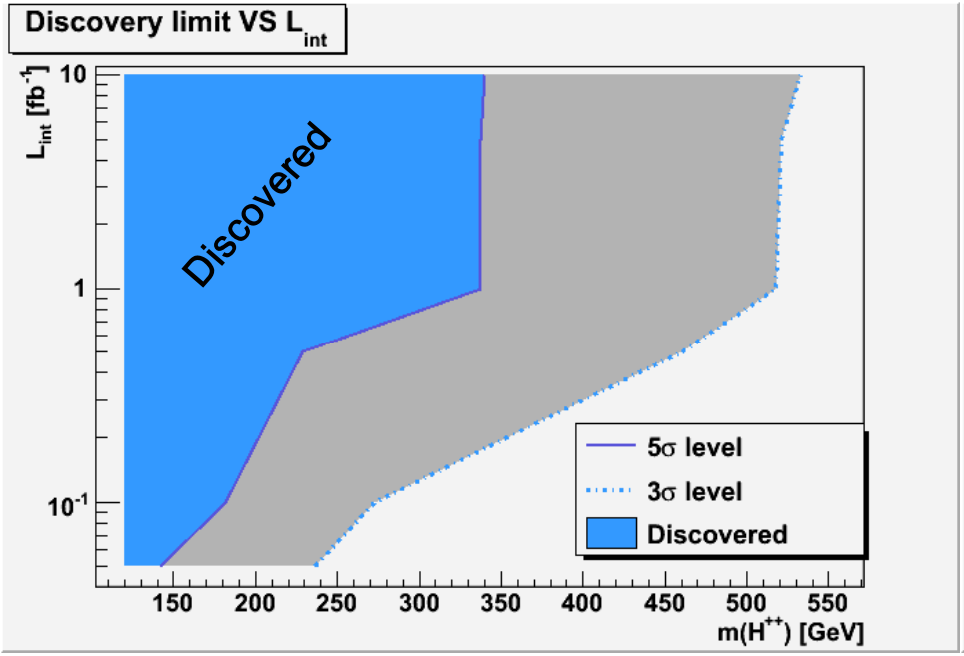
(pt>10GeV, |η|<2.4, 4mu)

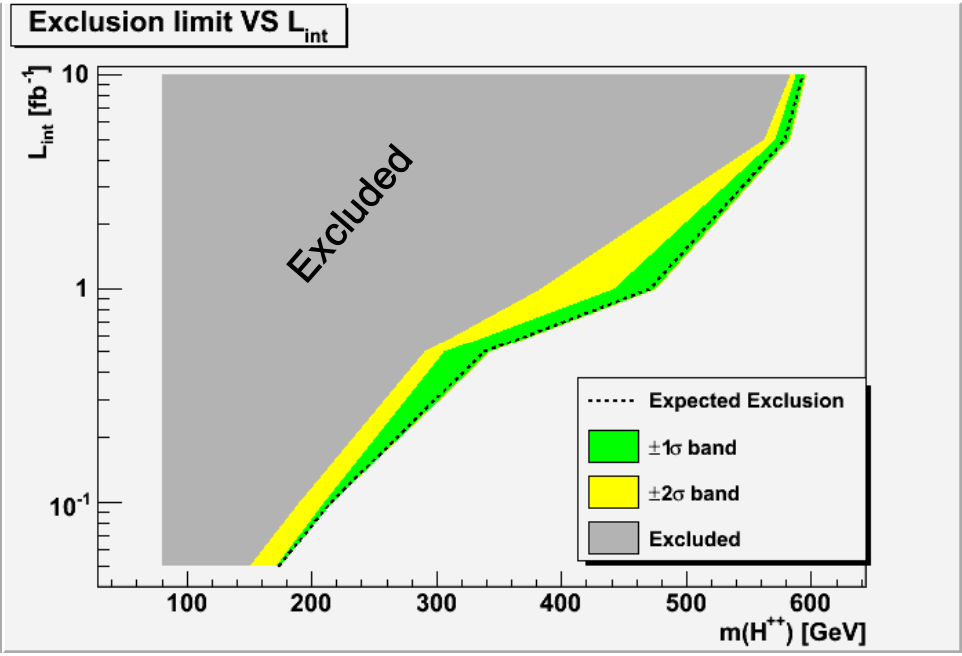




Limit VS L_{int}

(pt>10GeV, |η|<2.4, 4mu)





Conclusion

pt>10 GeV, |η|<2.4, 4mu, track isolation, jet isolation, Z mass cut, di-muon pt cut, quad-muon mass cut

Expected # of events at √s=10TeV & 100pb^{-1}								
	all events				in 3σ (H^{++}&H^{--} mass window)			
M(H^{++})	$H^{++}H^{-}$ to 4μ	ZZ to 4μ	Zbb to 4μ	tt to 4μ	$H^{++}H^{--}$ to 4μ	ZZ to 4μ	Zbb to 4μ	tt to 4μ
130 GeV	20.1 ±0.2	0.192 ±0.002	0.000856 ±0.000229	0.0035 ±0.0013	19.3 ±0.2	0.0283 ±0.0005	0	0.00088 ±0.00062
150 GeV	8.19 ±0.07	0.0474 ±0.0007	0.000856 ±0.000229	0.0035 ±0.0013	7.80 ±0.07	0.00737 ±0.00026	0	0.00044 ±0.00044
170 GeV discovery limit : 180GeV	5.84 ±0.05	0.0257 ±0.0005	0.00055 ±0.00018	0.00088 ±0.00062	5.59 ±0..05	0.00467 ±0.00021	0	0
200 GeV exclusion limit : 215GeV	3.14 ±0.03	0.0182 ±0.0004	0.00055 ±0.00018	0.00044 ±0.00044	3.00 ±0.03	0.00339 ±0.00018	0	0
300 GeV	0.615 ±0.005	0.00277 ±0.00016	0	0	0.585 ±0.005	0.00054 ±0.00007	0	0
600 GeV	0.0209 ±0.0001	0.000279 ±0.000051	0	0	0.0197 ±0.0002	5.6e-05 ±2.3e-05	0	0

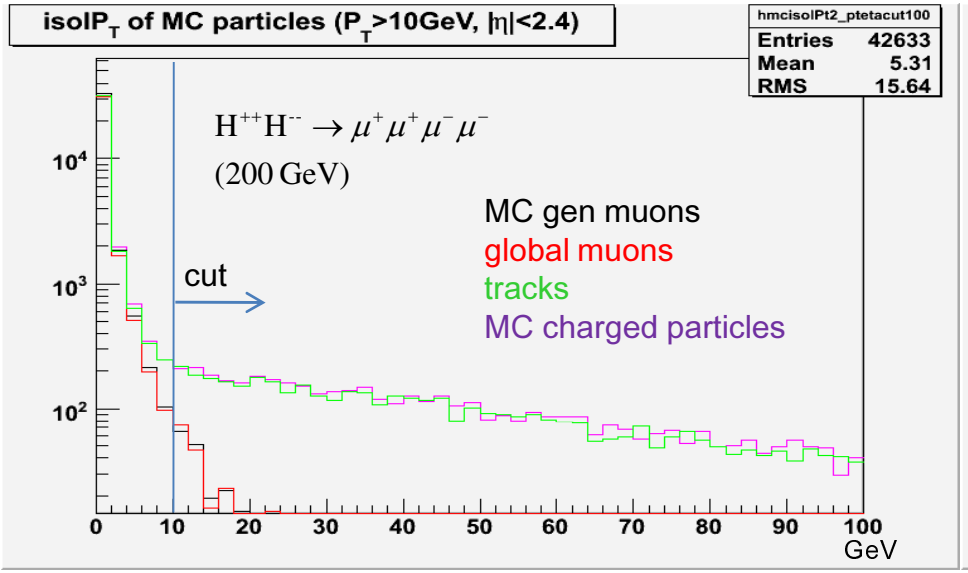
$$\text{Expected \# of events} = \text{final cross section} \times \text{sig.(bkg.) efficiency} \times L_{\text{int}}$$

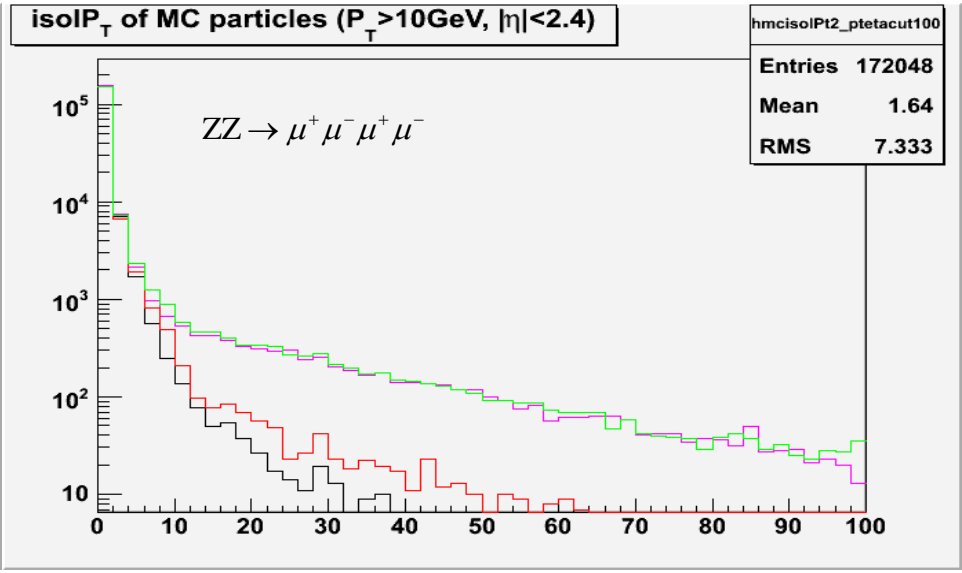
backup

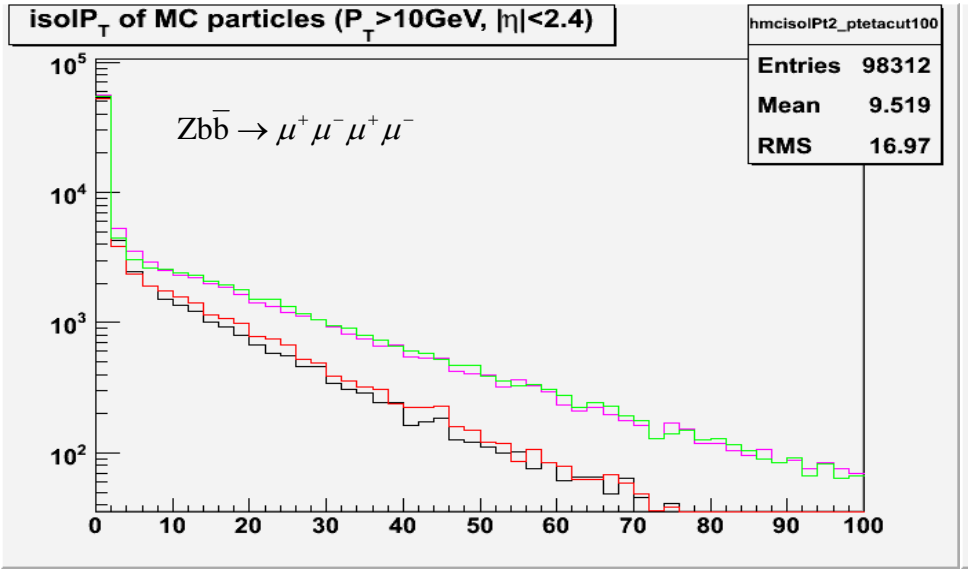
- Track isolation
- Jet isolation
- Z mass cut
- Di-muon pt cut
- Quad-muon mass cut
- 3D impact parameter
- Missing E_T
- Fitting

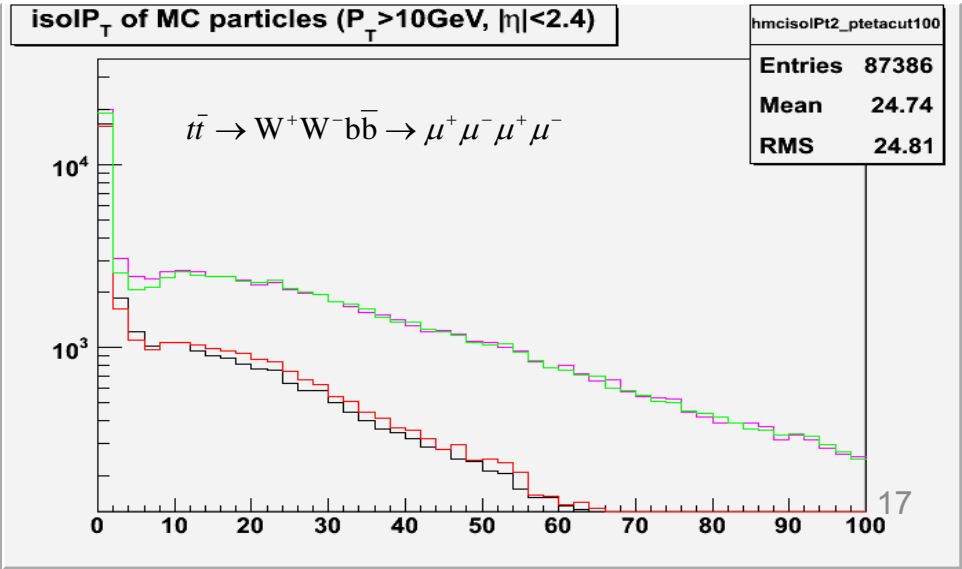
Track isolation

$isolPt = \sum P_T^i$, where the sum runs over charged particle inside a cone of radius $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.3$ except muons



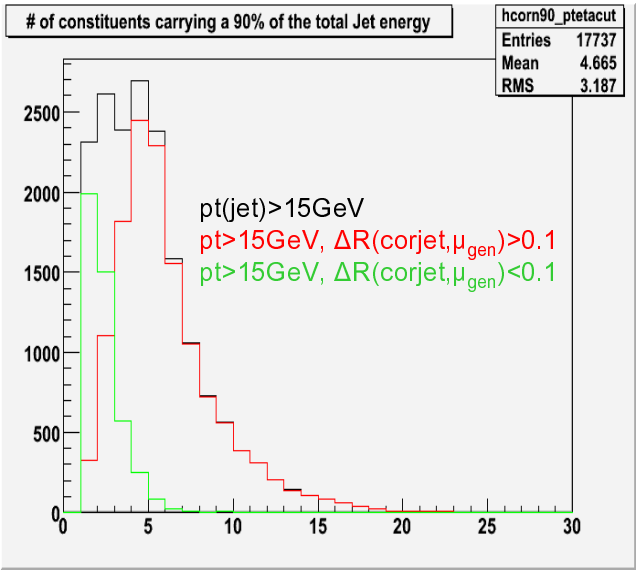


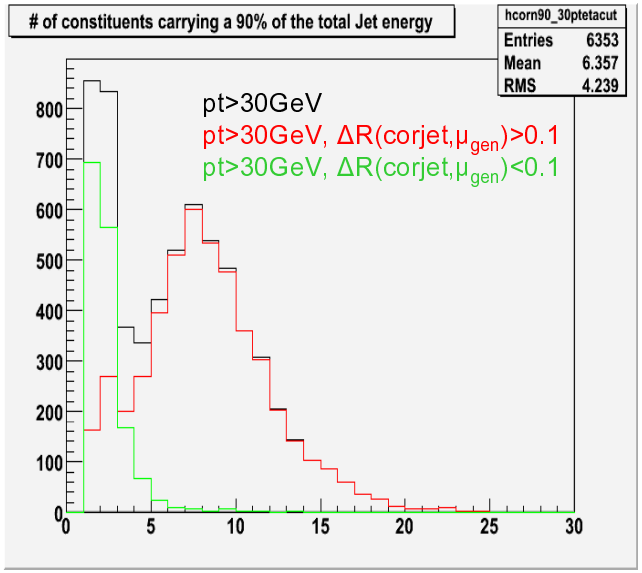


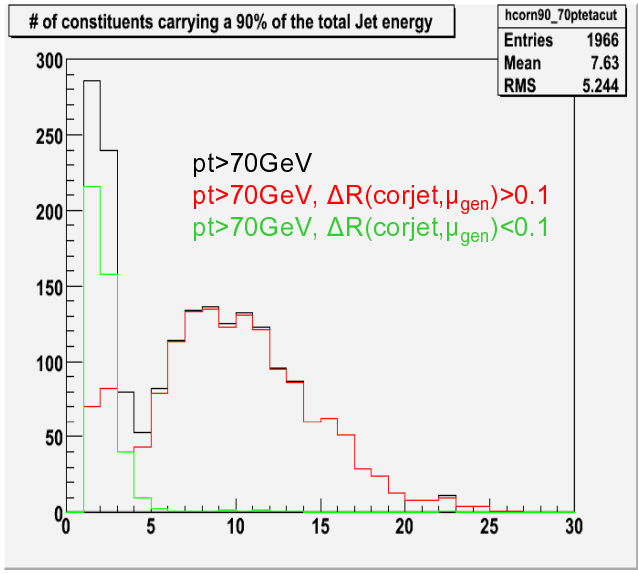


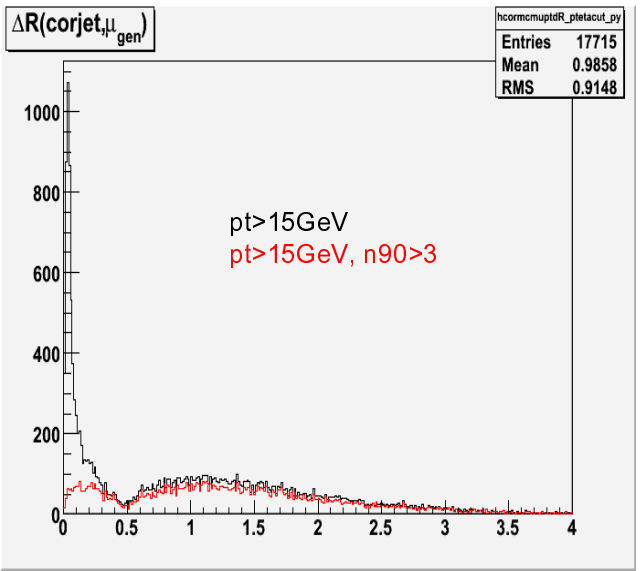
n90(corjet) and ΔR(corjet, μ_{gen})

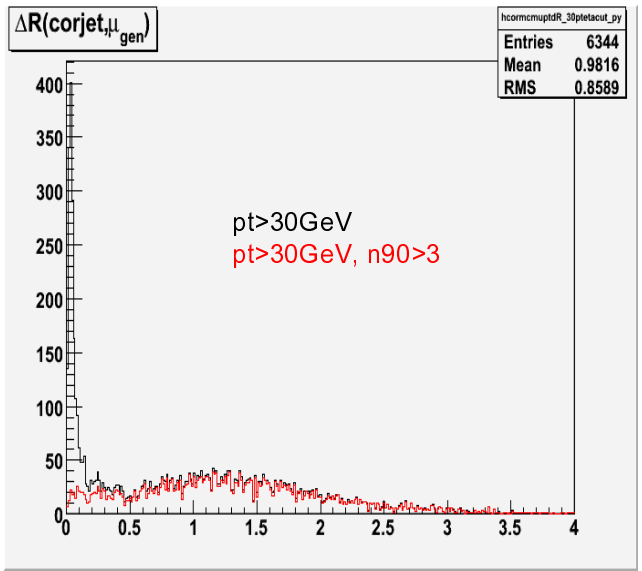
(m(H^{++})=130GeV)

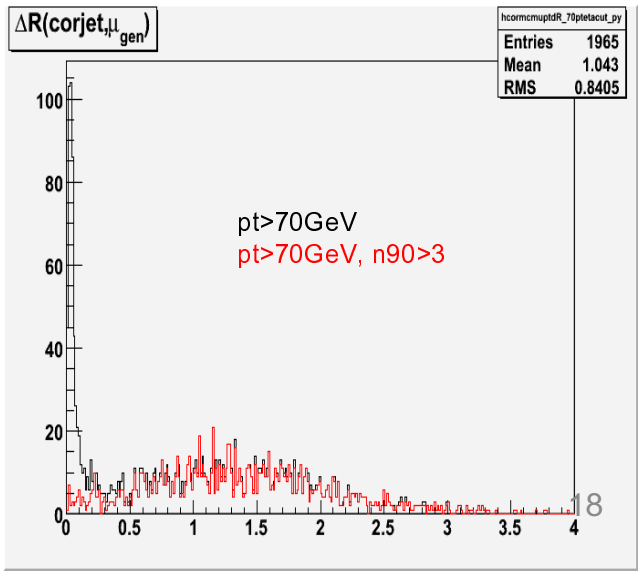






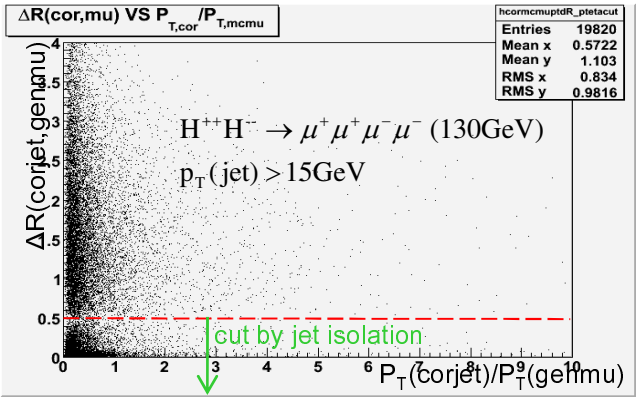


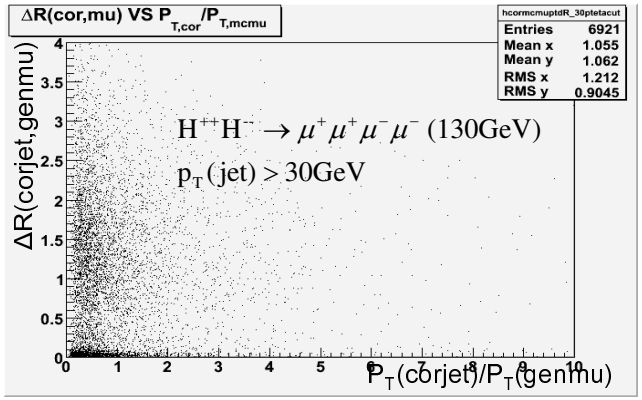


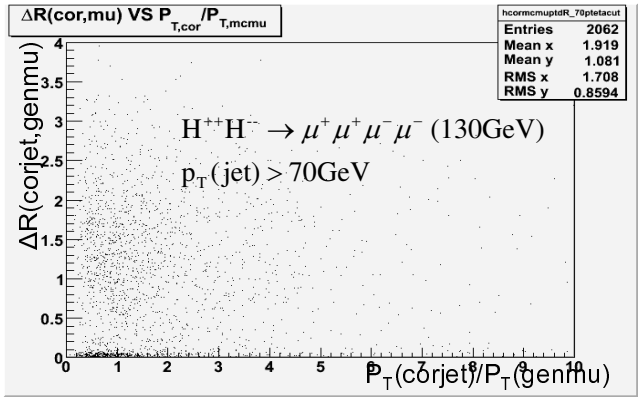


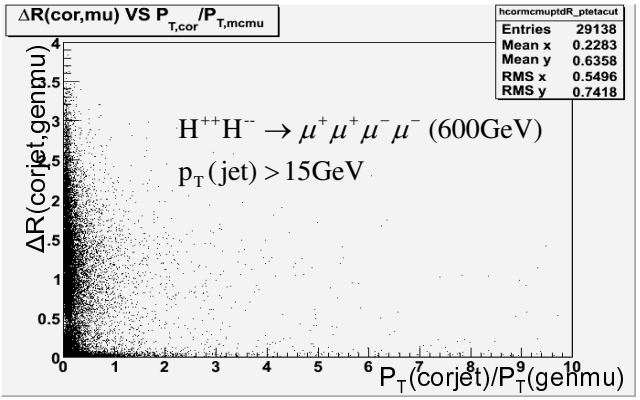
$P_T(jet)/P_T(\mu_{gen})$ VS $\Delta R(jet, \mu_{gen})$

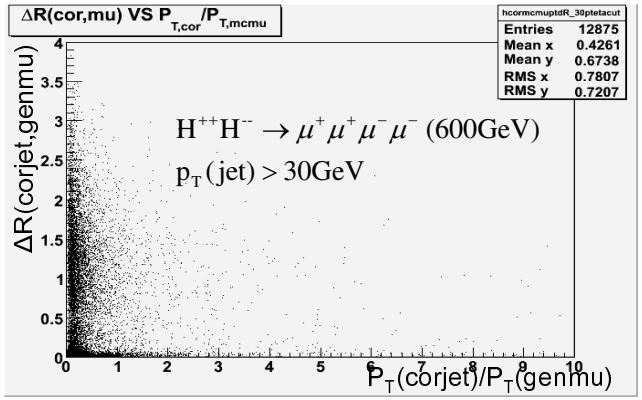
(pt>10GeV, |η|<2.4 for MC gen muons)

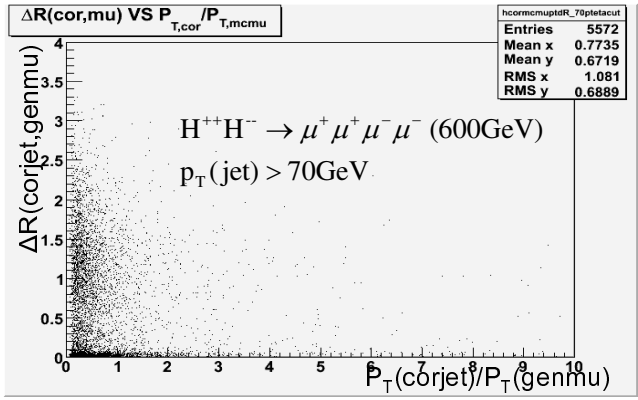


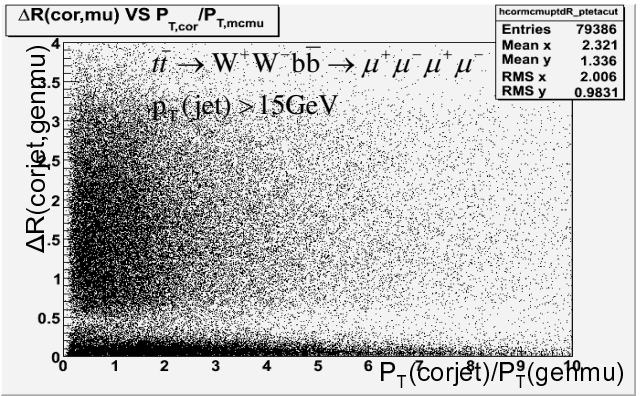


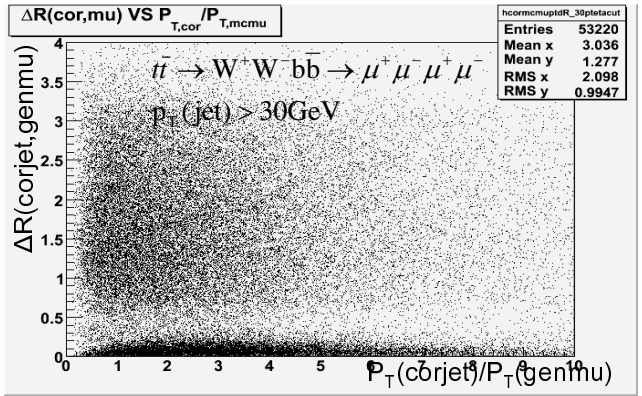


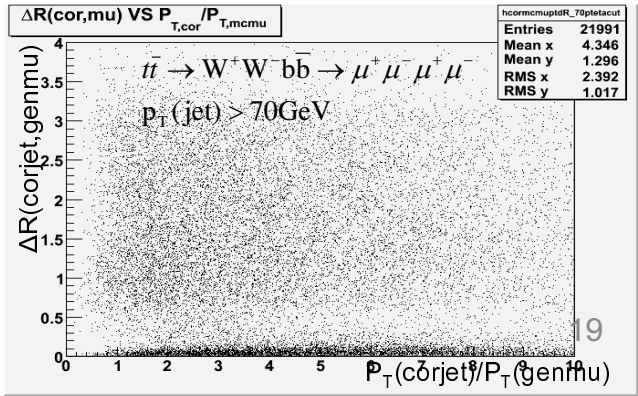






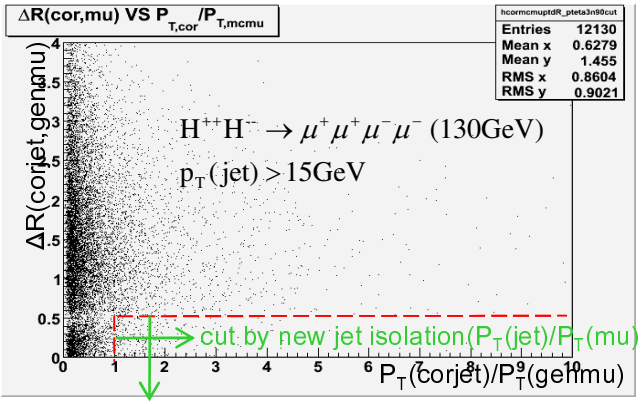


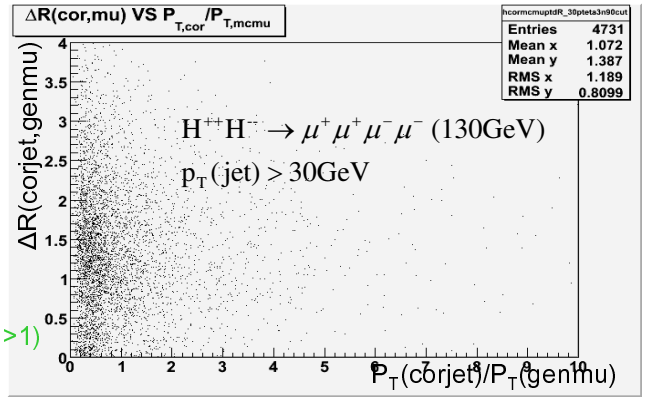


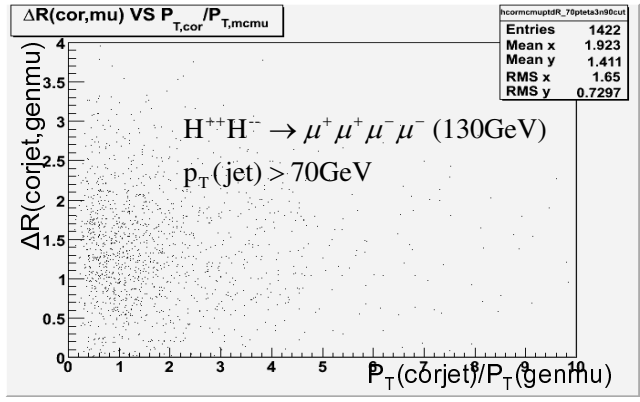


$P_T(jet)/P_T(\mu_{gen})$ VS $\Delta R(jet, \mu_{gen})$

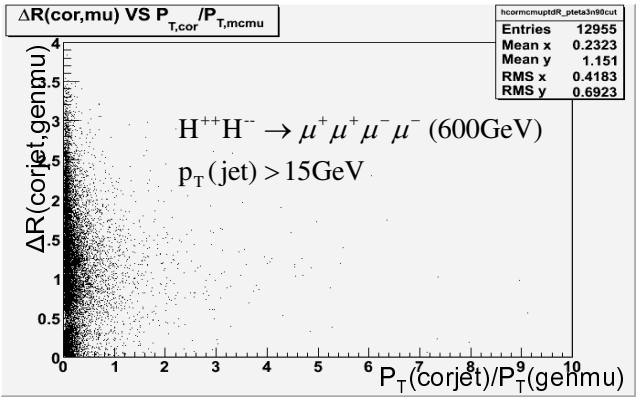
(n90>3 for jets, pt>10GeV, |η|<2.4 for MC gen muons)

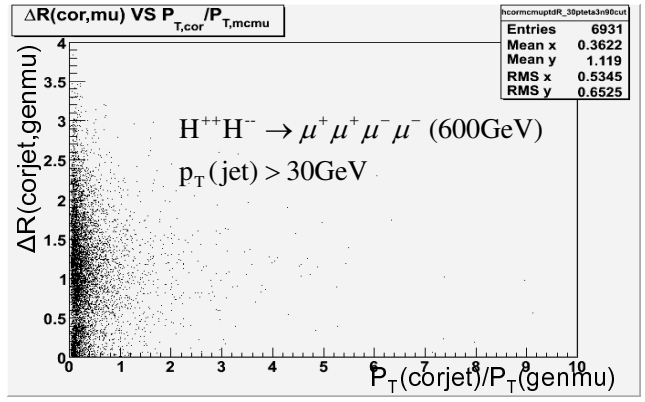


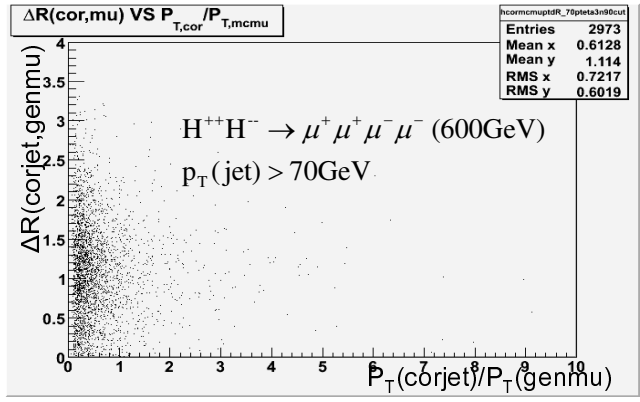


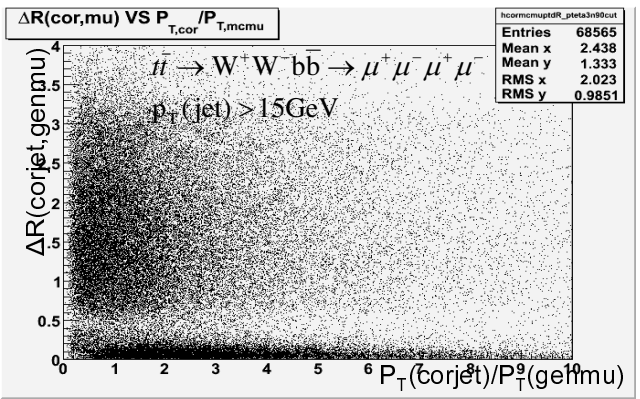


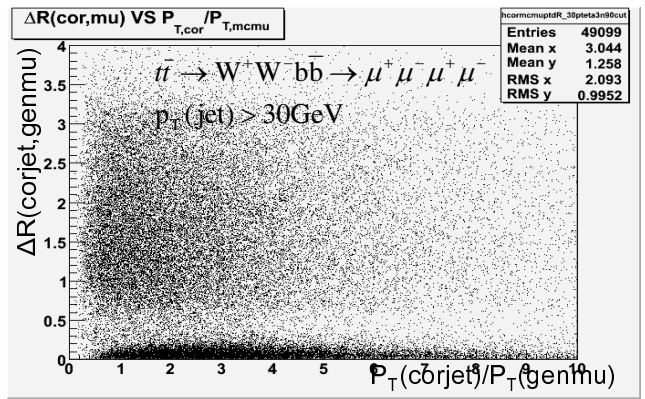
cut by new jet isolation(P_T(jet)/P_T(mu)>1)

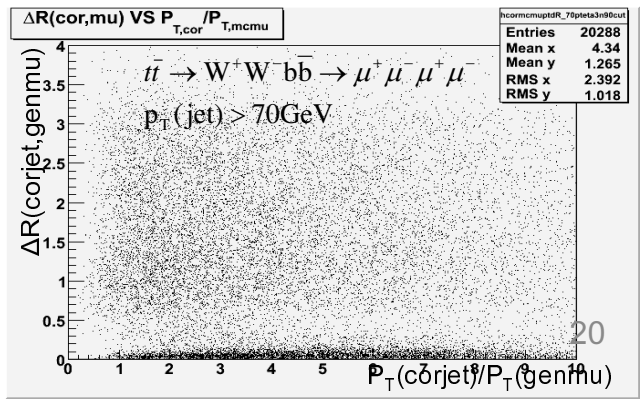






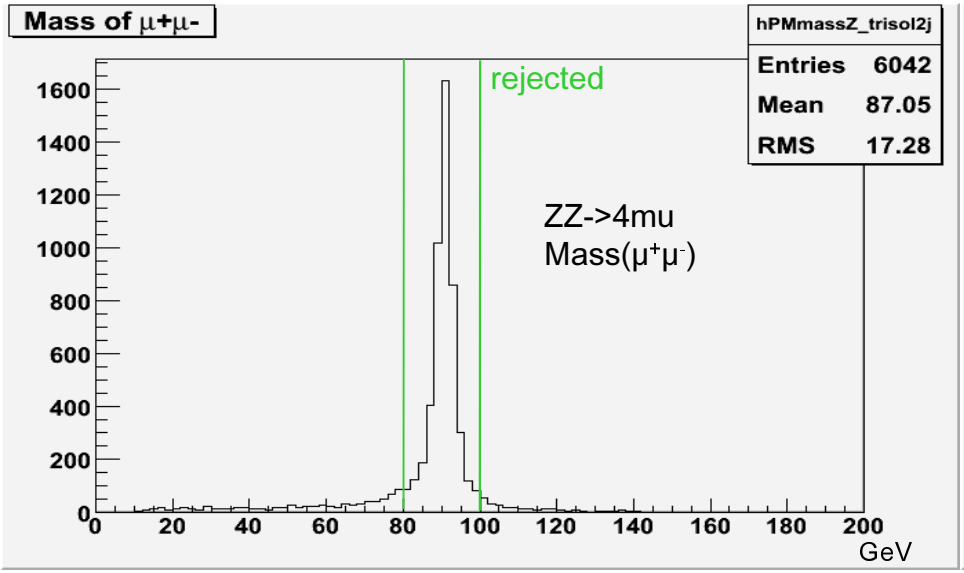


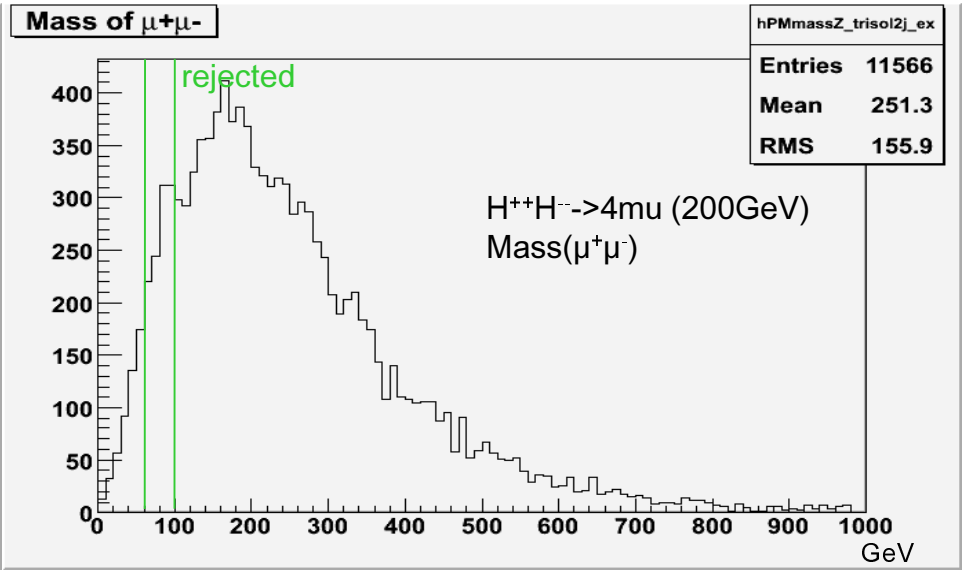


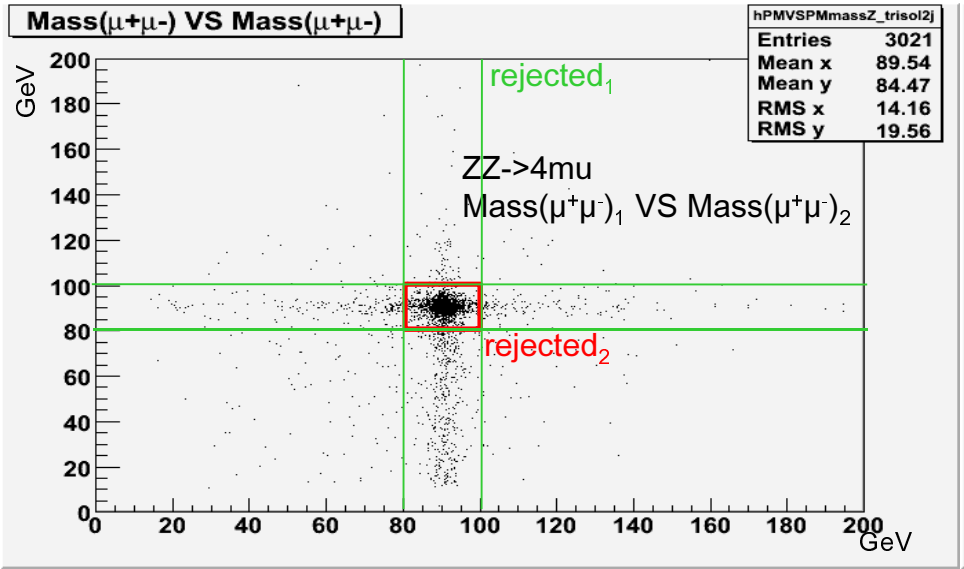


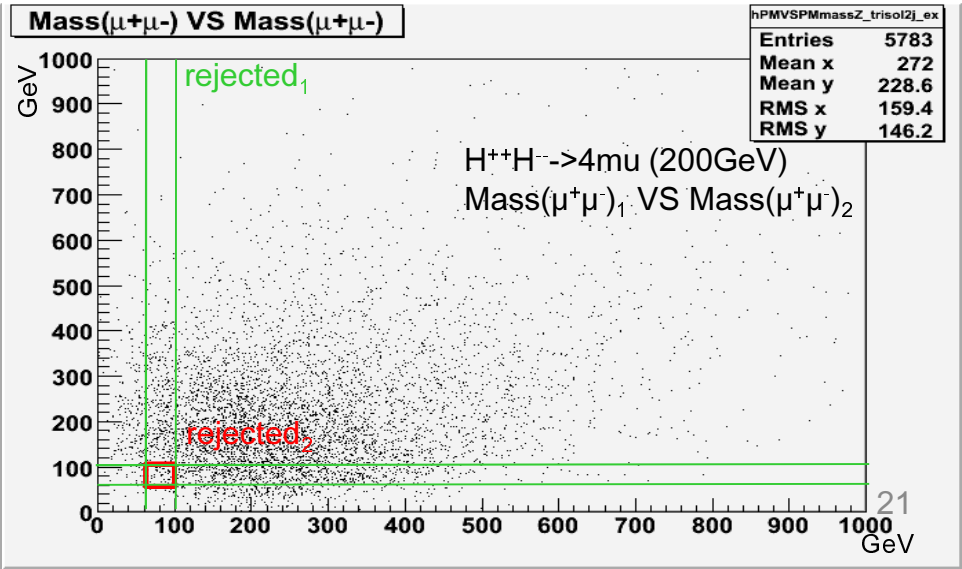
Mass of $\mu^+\mu^-$

(muon candidates)





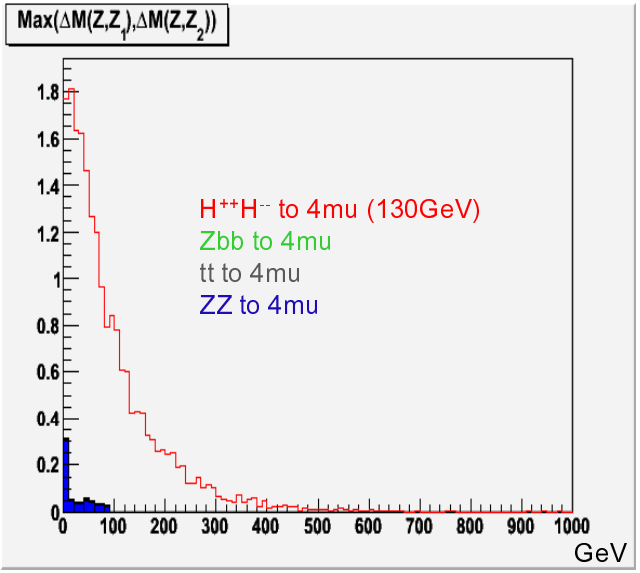


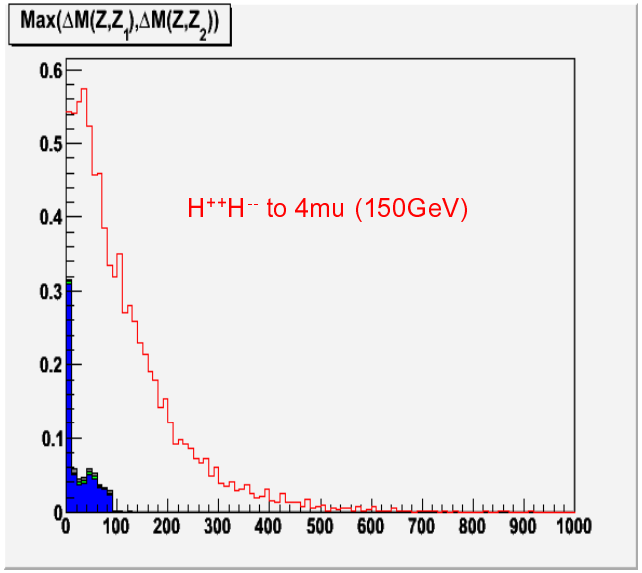


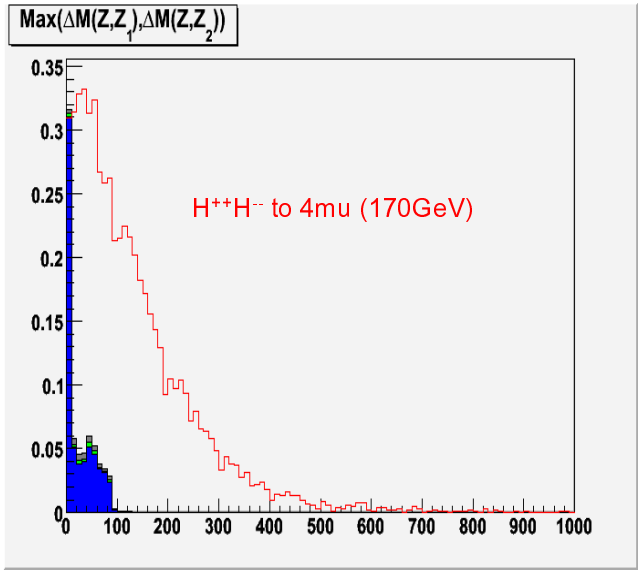
$\Delta M(Z)_{max}$ for Z mass cut

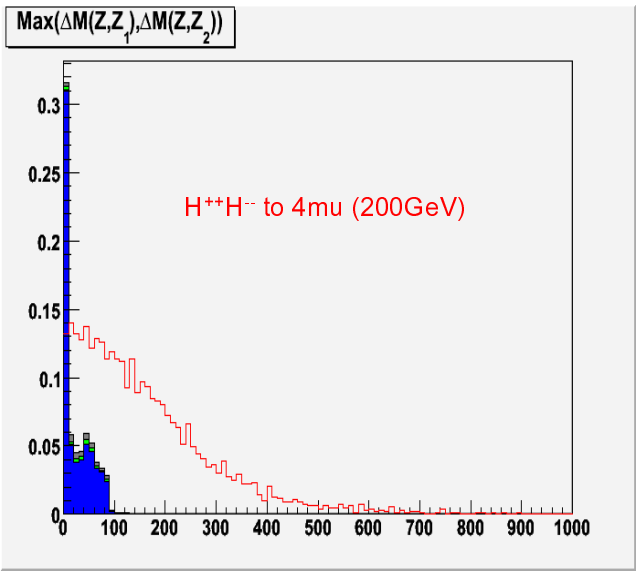
(normalized to 100pb^{-1}, accumulated histograms except signal)

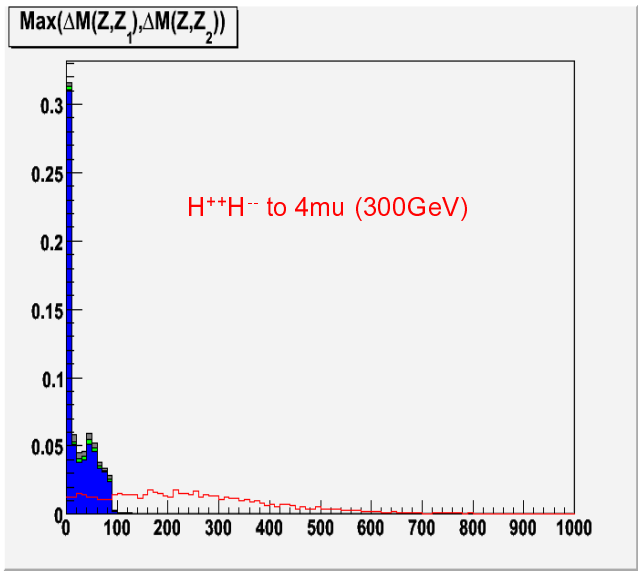
pt>10GeV, |η|<2.4, 4mu, track isolation, jet isolation

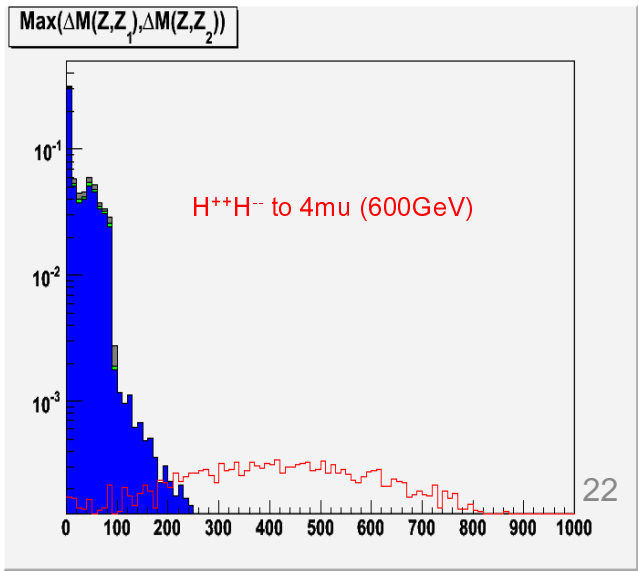






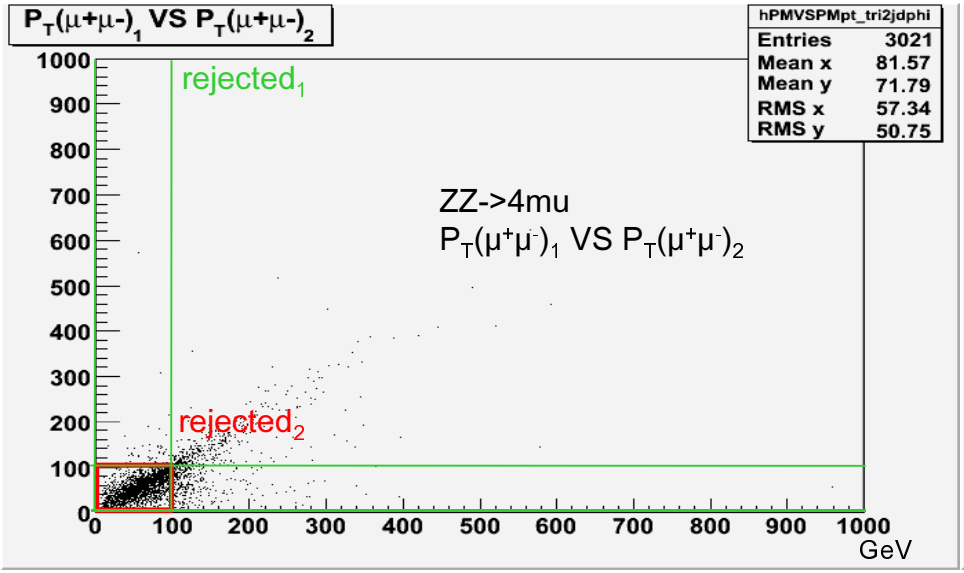


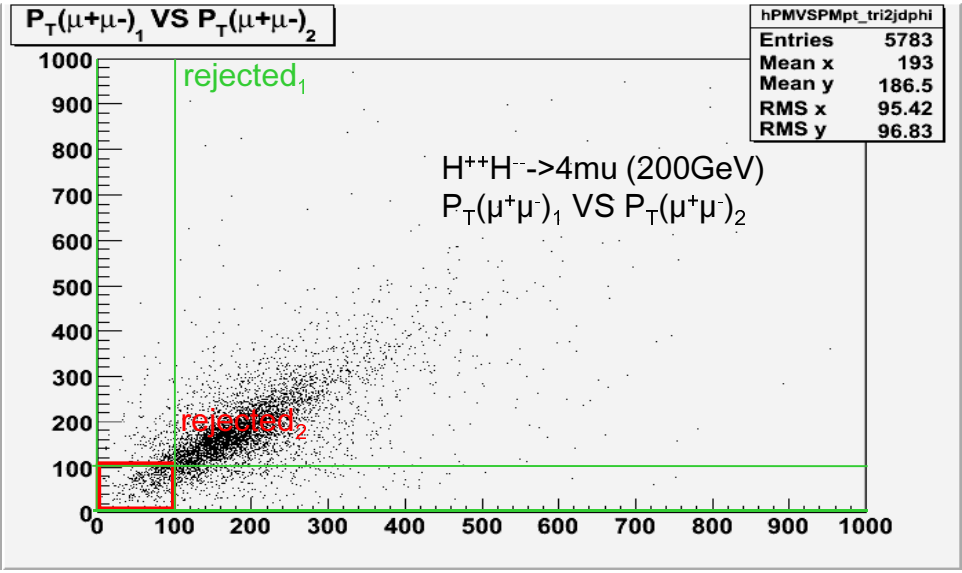


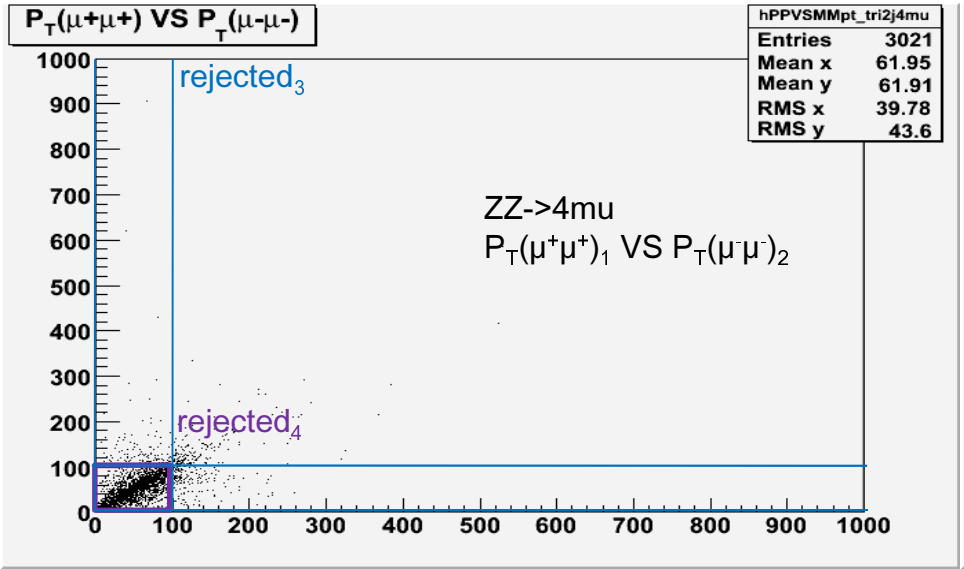


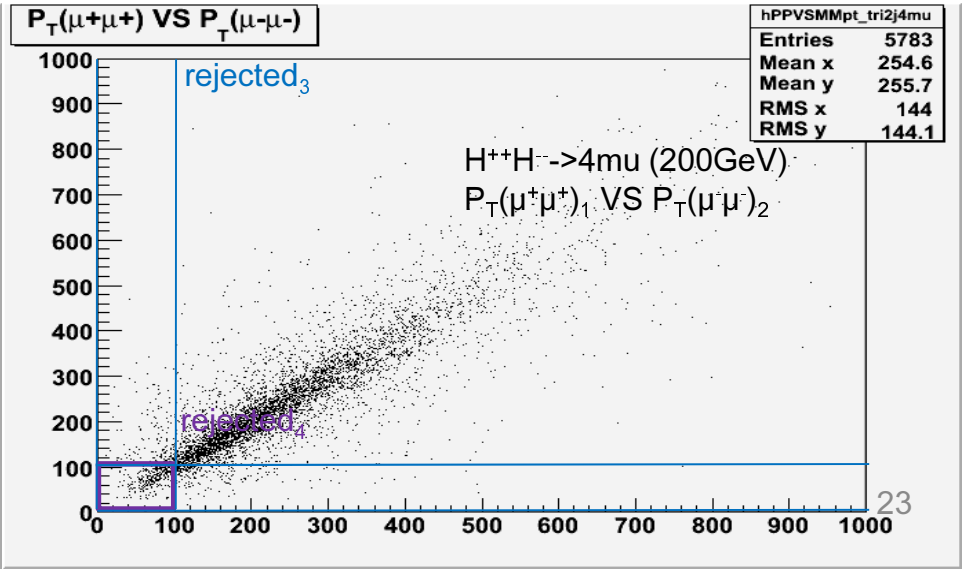
$P_T(\mu^+\mu^-)_1$ VS $P_T(\mu^+\mu^-)_2$ and $P_T(\mu^+\mu^+)$ VS $P_T(\mu^-\mu^-)$

(muon candidates)





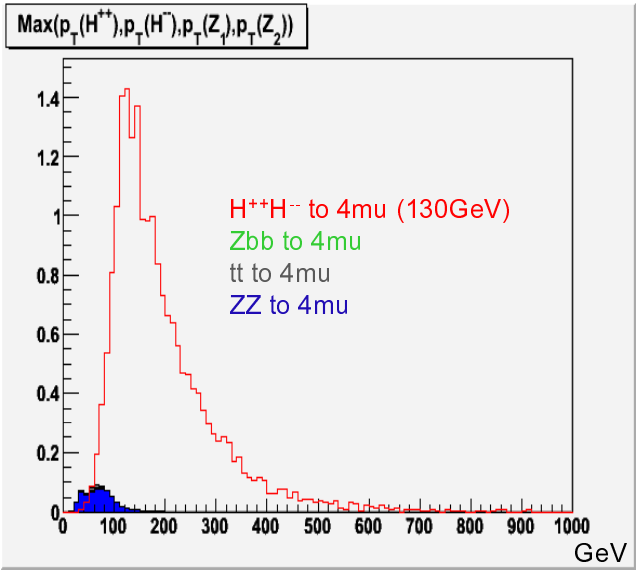


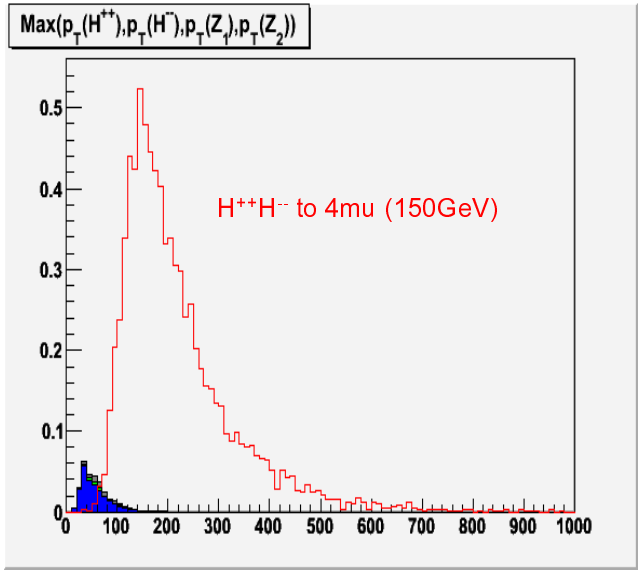


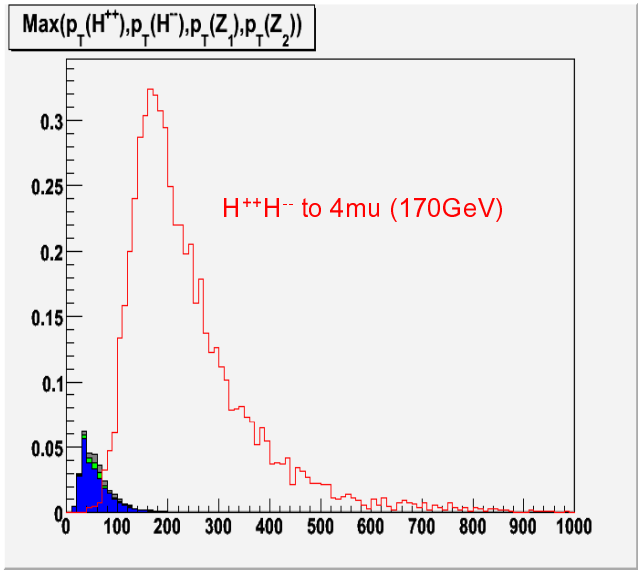
$p_T(\mu\mu)_{max}$ for di-muon pt cut

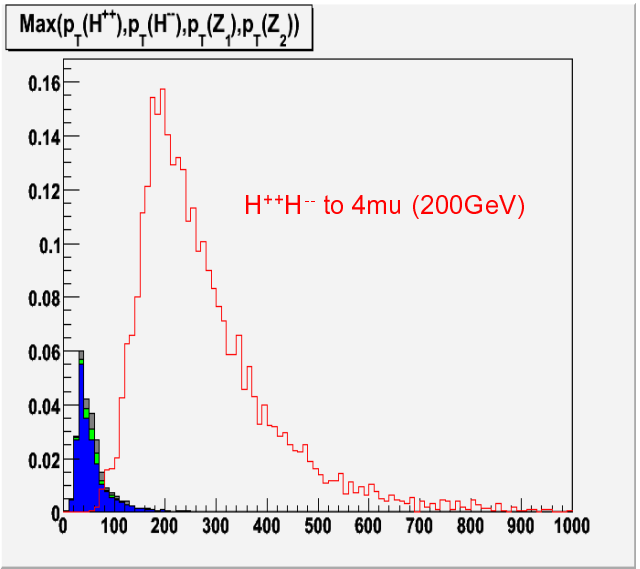
(normalized to 100pb^{-1}, accumulated histograms except signal)

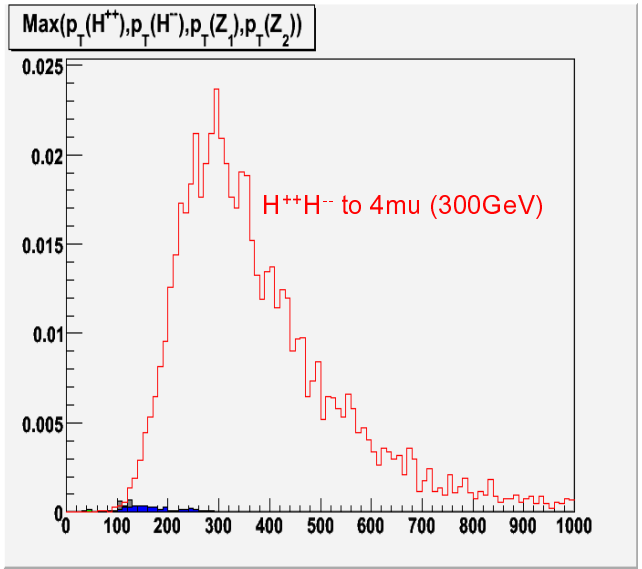
pt>10GeV, |η|<2.4, 4mu, track isolation, jet isolation, Z mass cut

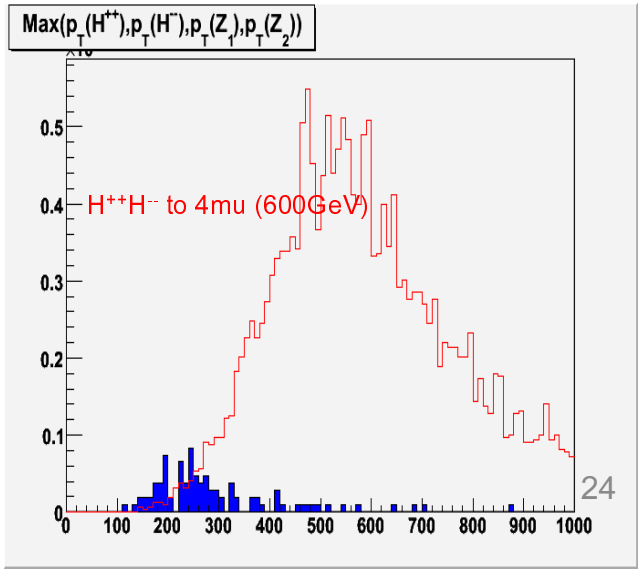








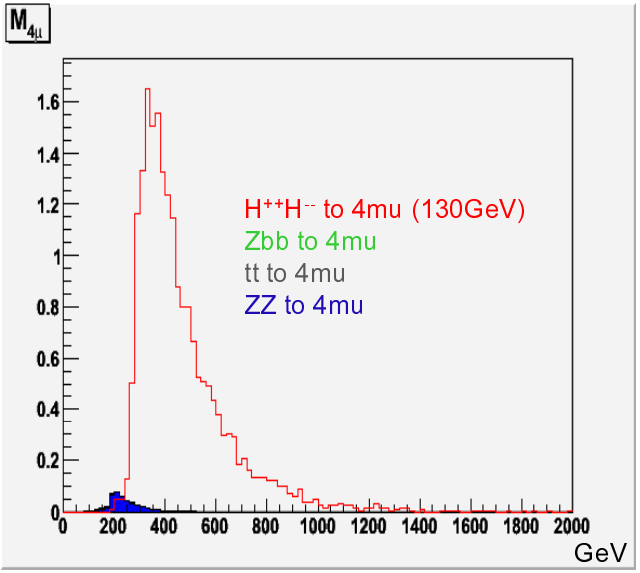


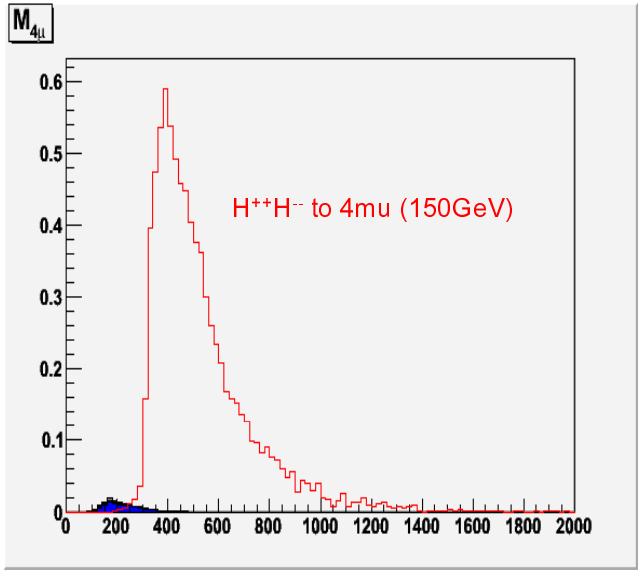


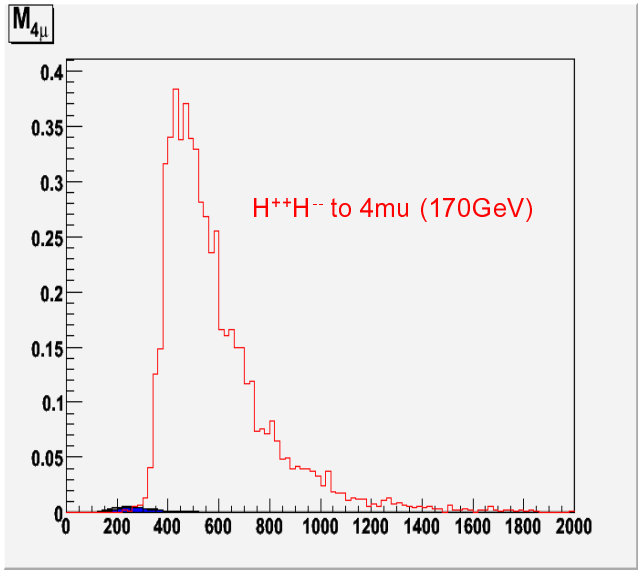
$M_{4\mu}$ for quad-muon mass cut

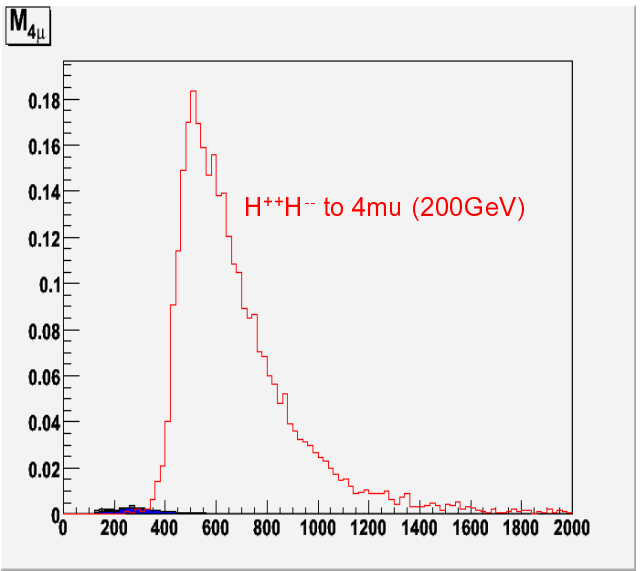
(normalized to 100pb^{-1}, accumulated histograms except signal)

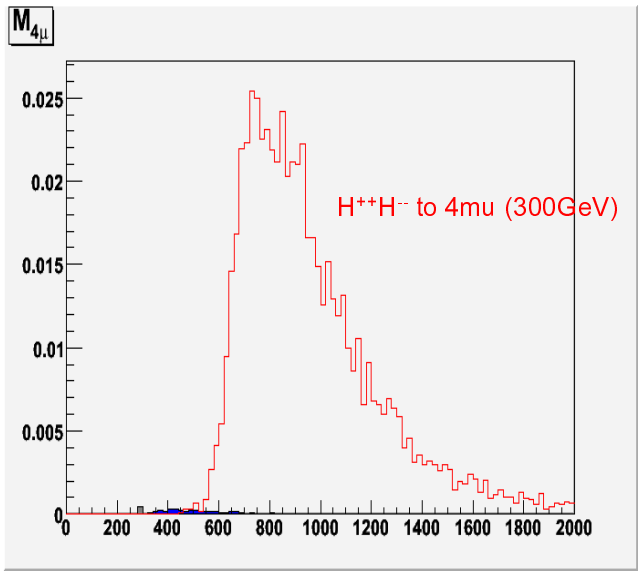
pt>10GeV, |η|<2.4, 4mu, track isolation, jet isolation, Z mass cut, di-muon pt cut

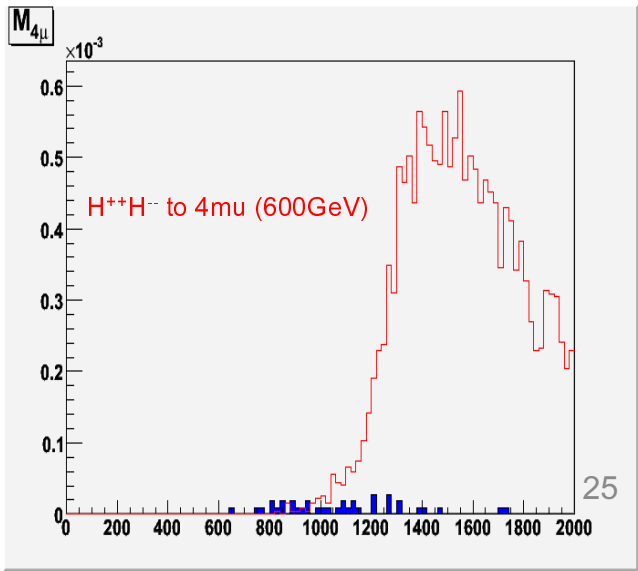






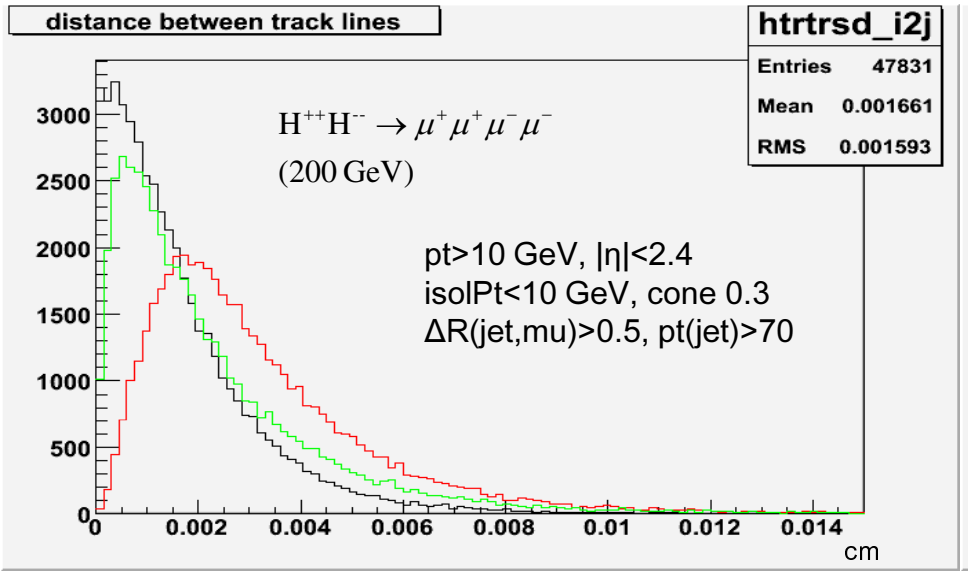


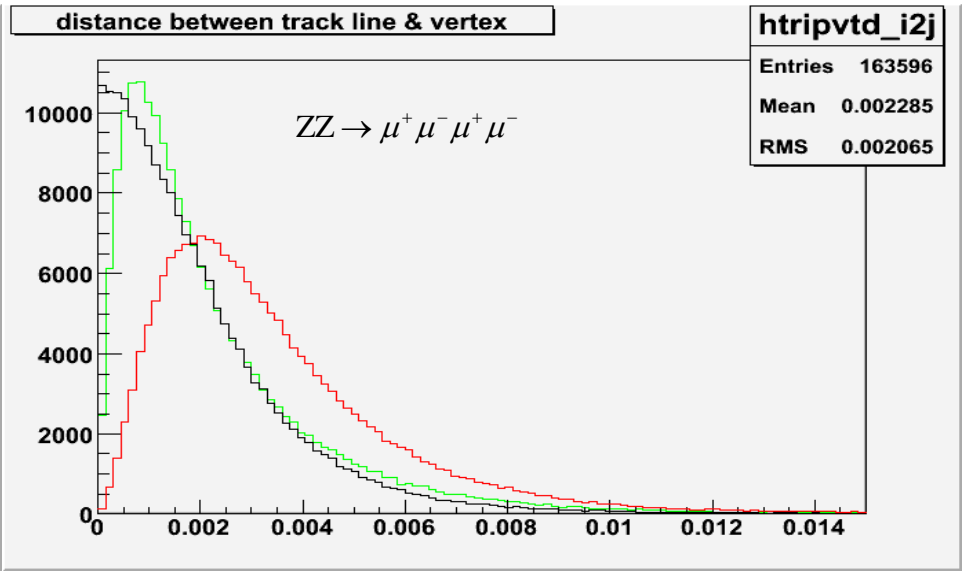


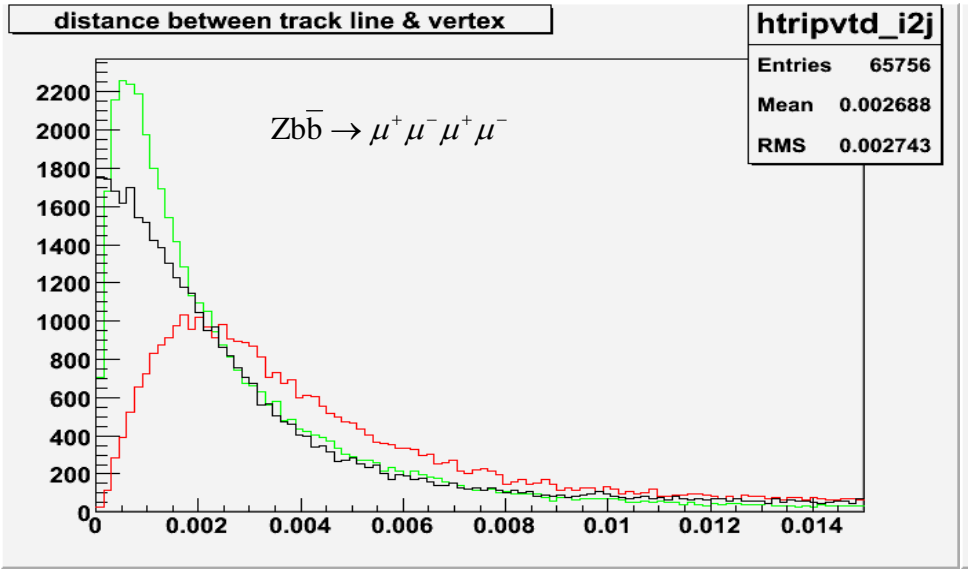


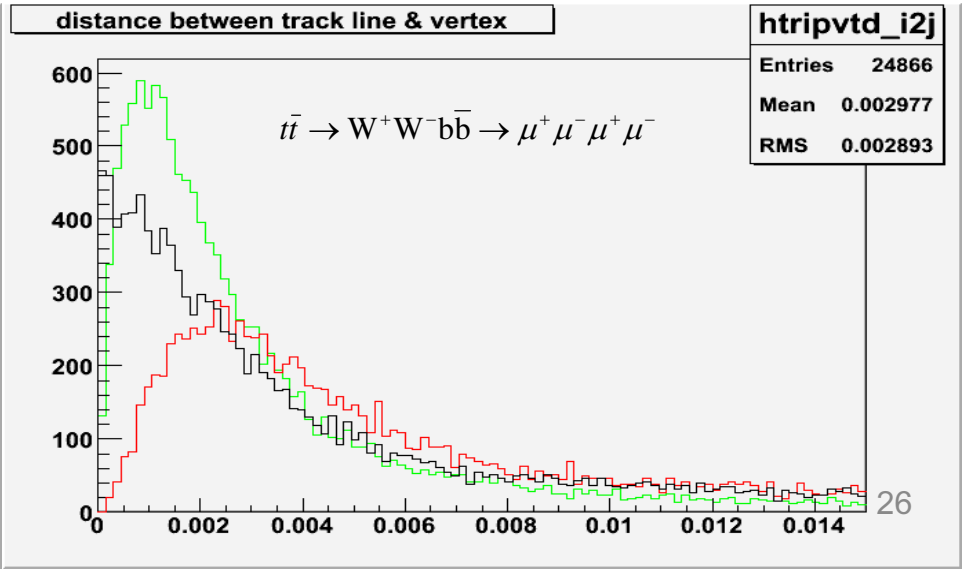
Distance between point & point of μ candidates

(impact point VS vertex, impact points, closest point of tracks : normalized, IDEAL samples)

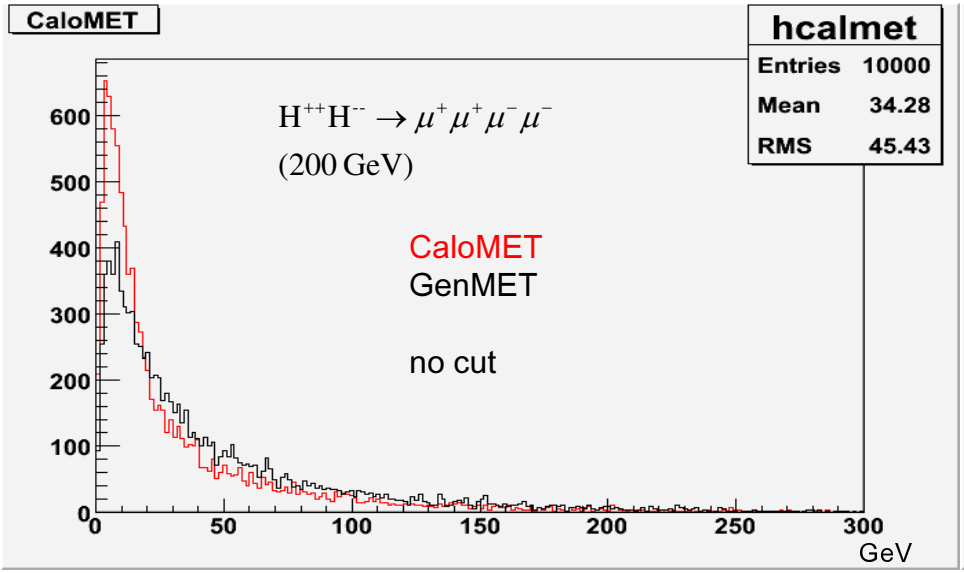


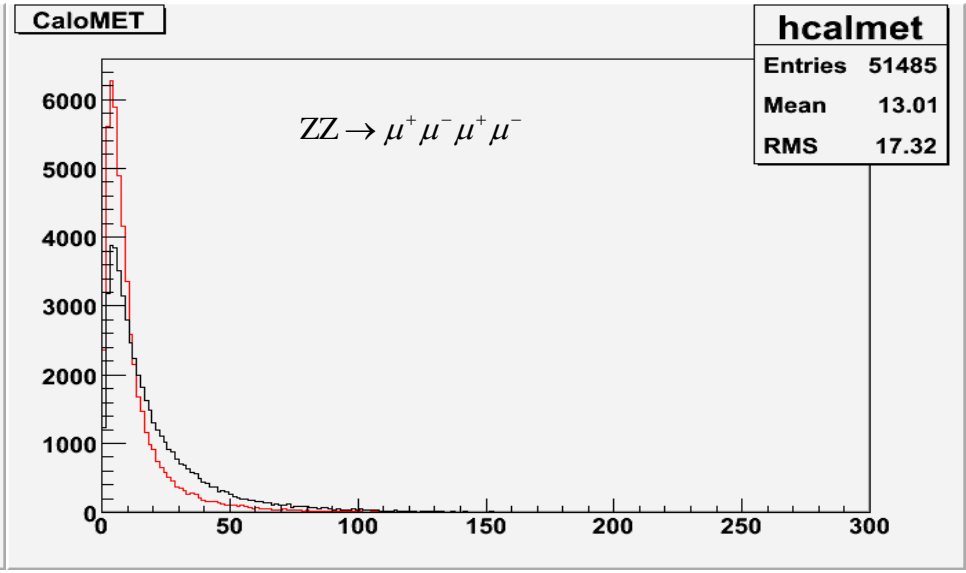


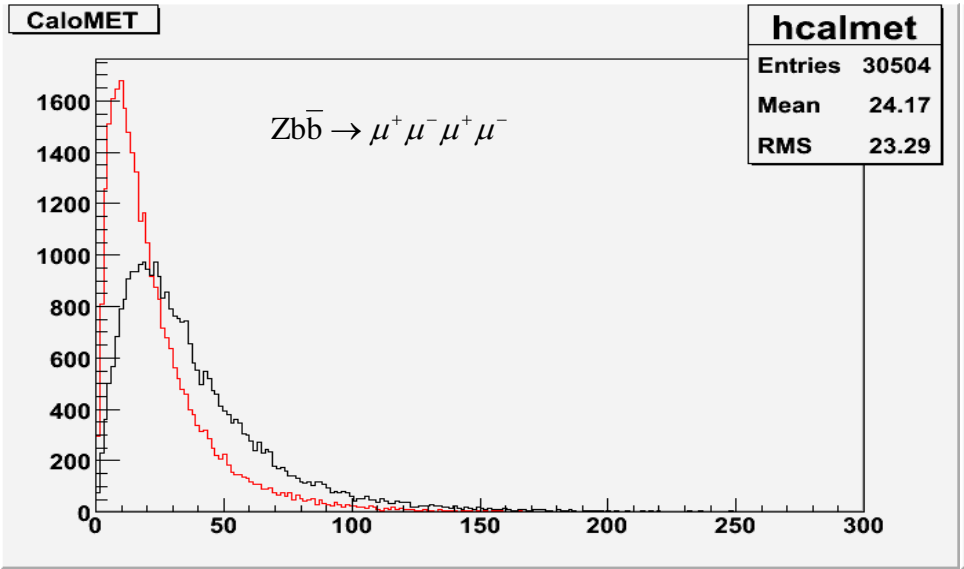


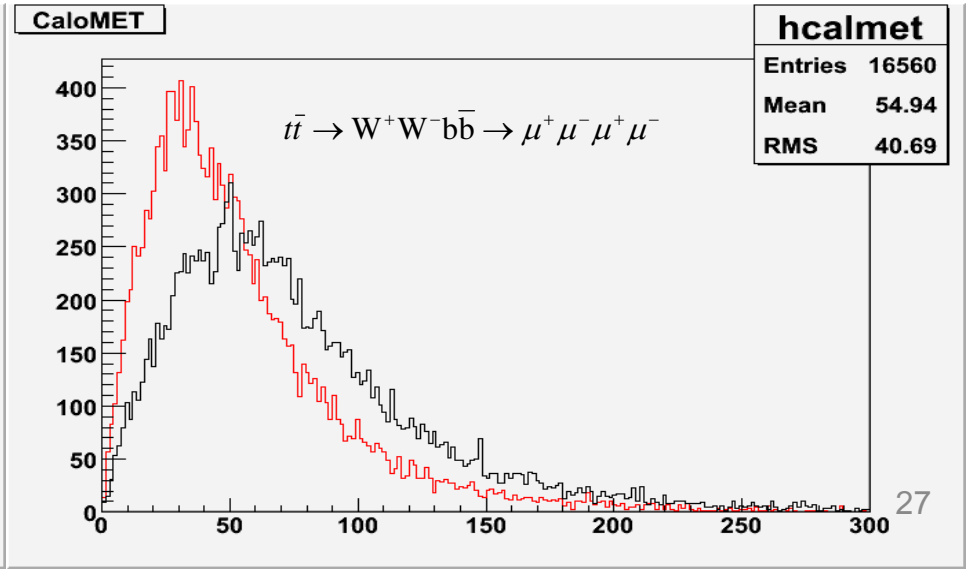


Missing transverse energy(MET)









Voigtian fit for signal

pt>10GeV, |η|<2.4, 4mu, track isolation, jet isolation, Z mass cut, di-muon pt cut, quad-muon mass cut