Search for the MSSM Higgs bosons in the channel $H/A \rightarrow \tau\tau \rightarrow \mu + \tau_{jet}$ in the CMS detector

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Outline

- Physics motivation
- HLT path for the $A/H \to \tau\tau \to \mu + \tau_{jet}$ channel
- Trigger efficiencies and rates for signal and background
- Offline selection
  - Observables' distributions
  - Preliminary τ impact parameter studies
  - Study on MET reconstruction
- Final results (with limited statistics)

Physics motivation: MSSM Higgses couplings to fermions.

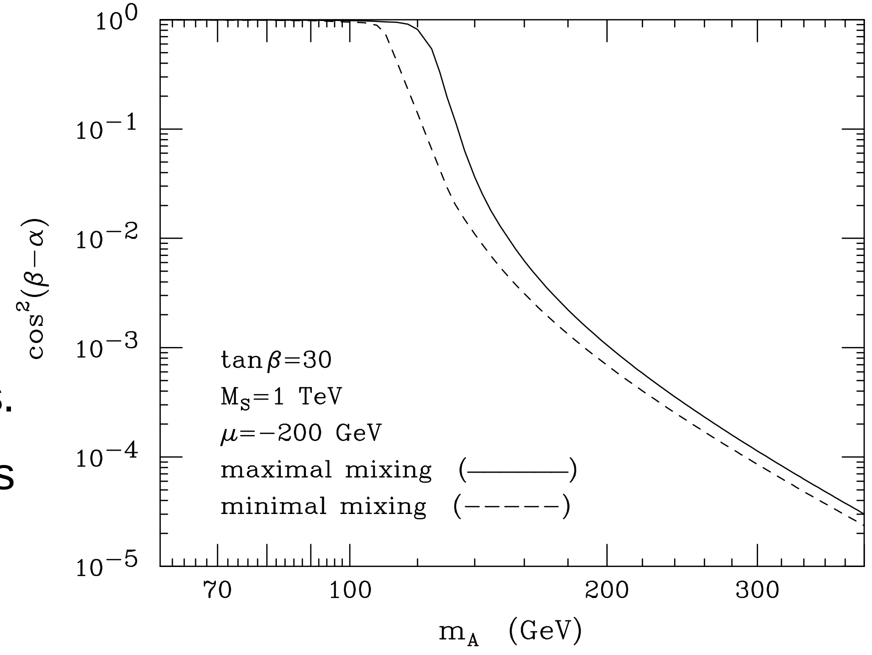
For large $tan\beta$ **A** and **H** couplings to down-type fermions are enchanced relative to the Standard Model values $gm_f/2m_W$:

$$hb\bar{b}\;(or\;h\tau^+\tau^-):\quad -\frac{sin\alpha}{cos\beta} = sin(\beta-\alpha) - tan\beta\cdot cos(\beta-\alpha)$$

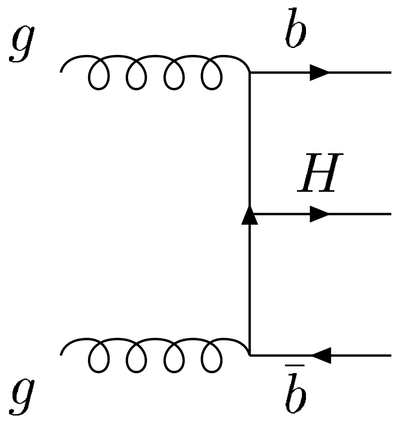
$$Hb\bar{b}\;(or\;H\tau^+\tau^-):\quad \frac{cos\alpha}{cos\beta} = cos(\beta-\alpha) + tan\beta\cdot sin(\beta-\alpha)$$

$$Ab\bar{b}\;(or\;A\tau^+\tau^-):\quad \gamma_5 tan\beta$$

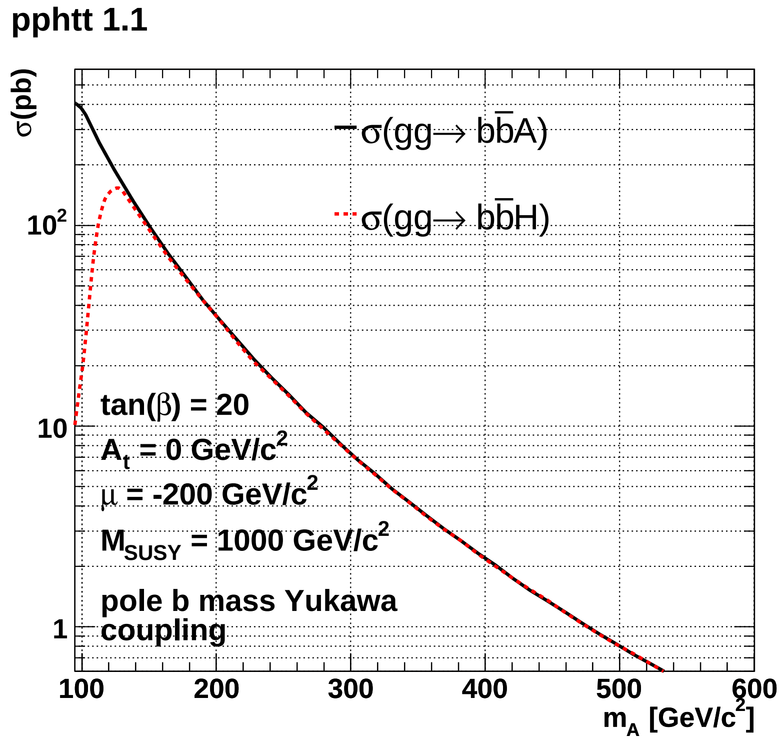
These couplings are modified by radiative corrections. In particular there are some MSSM parameters sets that suppress the $Hb\bar{b}$ coupling.



We are interested in the asociated Higgs production with pair of *b* quarks. Main process here is *gluon* fusion (*Quark* fusion is neglidible.):



Tagging at least one b quark reduces many background processes, including minimum bias QCD.

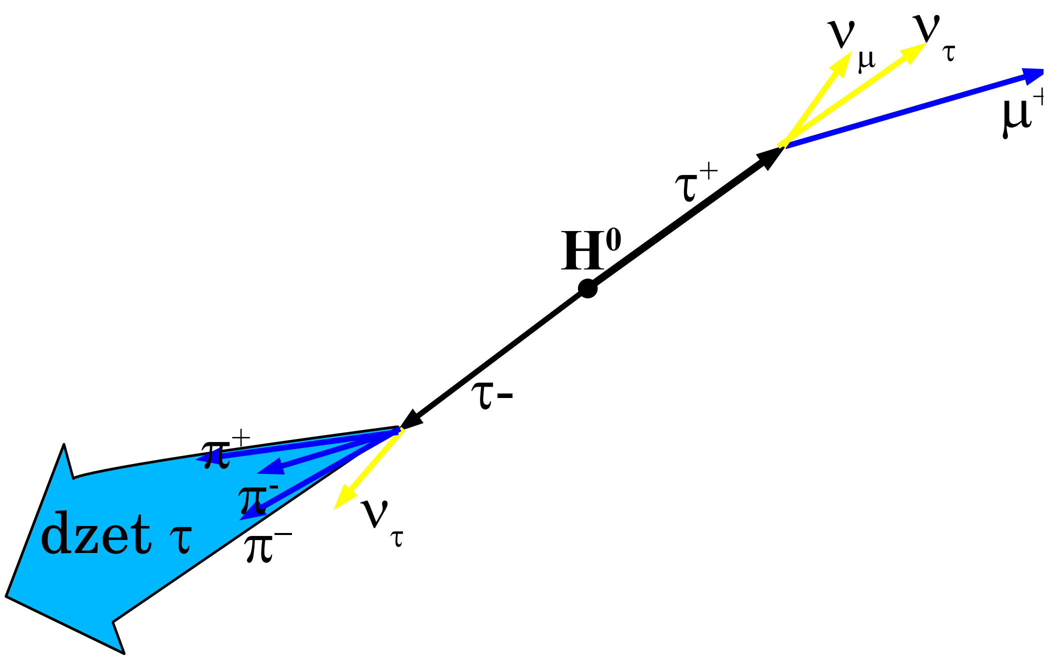


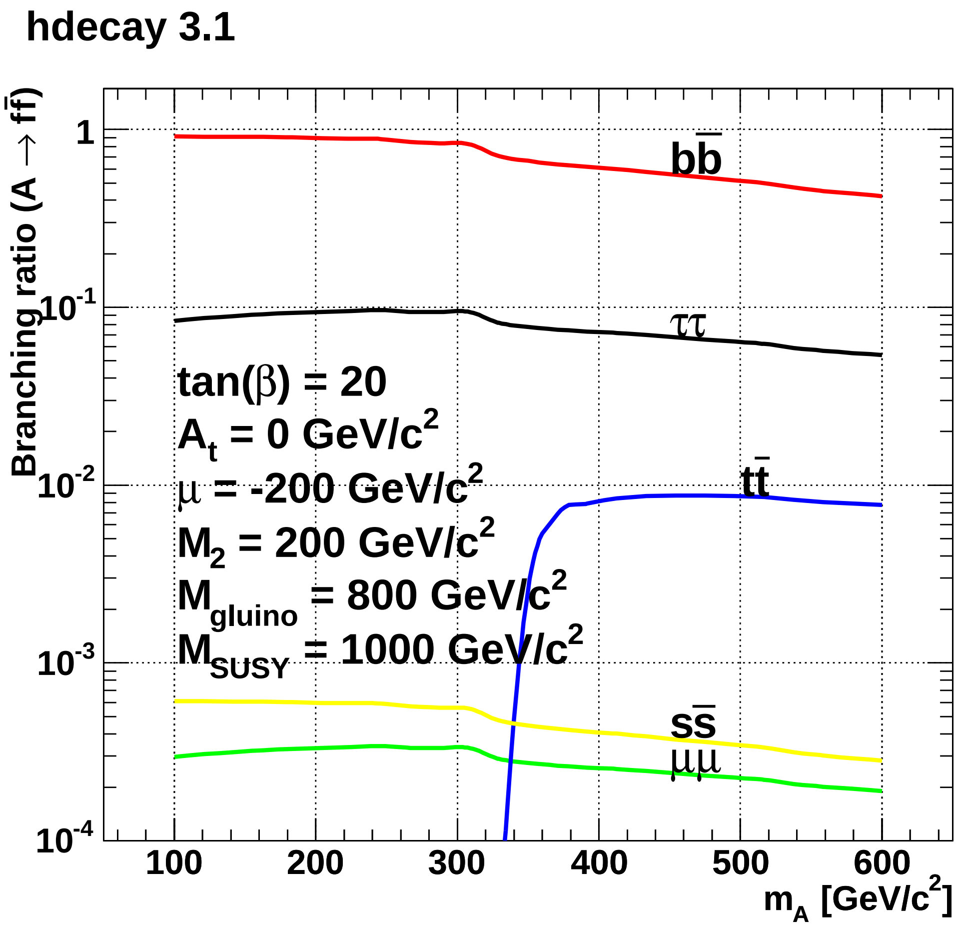
For $m_A > 150\ GeV/c^2$ and large $tan\beta$ CP even **H** and CP odd **A** are almost degenerate in mass and have similar cross sections.

For large $tan(\beta)$: BR($H/A \rightarrow \tau\tau$) $\simeq$ 0.1

with BR($\tau\tau \rightarrow \mu + \tau_{jet} + \nu$) = 0.22

gives BR($H/A \rightarrow \tau\tau \rightarrow \mu + \tau_{jet} + \nu$) $\simeq$ 0.022





We have a clear signature: isolated, high p_T muon on one side, and collimated τ_{jet} of 1 or 3 particles on the other side.

Signal and background cross sections

Process	Pythia 6.233 [pb]	Calculations		
		Source	[pb]	K factor
$gg, qq \rightarrow bbA/H \rightarrow bb\tau\tau$	3.39	PPHTT 1.1, HDECAY 3.1	6.60231	1.95
$b\bar{b}$	$4.78 \cdot 10^8$	cernrep / 2000-004	$5 \cdot 10^8$	1.05
$t\bar{t}$	490	Kidonakis, Vogt, Phys. Rev. D **68**	875	1.79
$gb \rightarrow Wt$	281	Belyaev, Boos, Phys. Rev. D **63**	62	n.a.
$Wjet$	$4.1457 \cdot 10^4$	–	–	
$Z/\gamma^* \rightarrow \tau\tau \rightarrow \mu + \tau_{jet}$	$8.801 \cdot 10^3$	–	–	

With $20\ fb^{-1}$ (one year with low luminosity) one gets **29040** signal events.

Simulation

Samples where generated with **CMKIN 1.2.0**(FORTRAN) and simulated with **cms133**(FORTRAN). To save the CPU time and disk space a preselection selecting events likely to pass the HLT was performed on the generator level. We required:

- one isolated μ with $p_T \geq 15\ GeV/c, |\eta| \leq 2.4$
- one isolated τ_{jet} with $E_T > 30\ GeV, |\eta| \leq 2.4$

The signal samples where simulated using the **TAUOLA**(FORTRAN) package.

There was a bug in the preselecction routine for Z/γ^*. A small (1k) sample was reproduced with fixed software.

Digitization was done for $\mathcal{L} = 2 \cdot 10^{33} \frac{1}{cm^2 s}$ with **ORCA 8.2.0** (C++).

- L1
  - single μ with $p_T \geq$ 12 GeV/c
  - OR single τ_{jet} with $E_T \geq$ 93 GeV
- HLT
  - L2 Calo jet with $E_T \geq 40\, GeV$ and Eisol$\leq 5.3\, GeV$, isolated in pixel detector
  - AND L2 μ with $p_T \geq 15\, GeV/c$ and calorimetry isolation ≤ 0.97
  - AND L3 μ with $p_T \geq 15\, GeV/c$ and tracker isolation ≤ 0.97 (the tracker isolation was not used in this study)

L2 Calo jet: IterativeCone(R=0.6), Et recombination scheme, closest to the hardest L1 tau jet, but not further than 0.8

Eisol: Energy in the ECAL in the ring around the jet direction $0.14 < R < 0.4$

μ **calo isol variable**: Efficiency for the $W \to \mu\nu_\mu$ sample

Trigger efficiencies (wrt preselected events) table

Cut	$bbH(200)$	$b\bar{b}$	$t\bar{t}$	Wt	$Wjet$	Z/γ^*
single L1 Mu(12)	0.89	0.84	0.9	0.88	0.84	0.89
single L1 Tau(93)	0.27	0.004	0.32	0.071	0.058	0.044
L1Mu(12) OR L1Tau(93)	**0.92**	**0.84**	**0.93**	**0.89**	**0.84**	**0.89**
L1 AND single L2 Mu(15)	0.89	0.8	0.9	0.86	0.82	0.86
L1 AND single L2 Tau(40)	0.76	0.2	0.81	0.66	0.4	0.43
L1 AND L2Mu(15) AND L2Tau(40)	**0.73**	**0.19**	**0.78**	**0.64**	**0.38**	**0.42**
L1 AND L2MuPt(15) Isol(0.97) AND L2TauEt(40)	0.71	0.14	0.73	0.61	0.37	0.41
L1 AND L2MuPt(15) AND L2TauEt(40) Isol	0.63	0.094	0.33	0.35	0.21	0.36
L1 AND L2Mu(15) AND L2Tau(40) both with isol	**0.62**	**0.071**	**0.31**	**0.33**	**0.2**	**0.35**
L1 AND L2 AND single L3 Mu(15)	0.61	0.07	0.3	0.33	0.2	0.35
L1 AND L2 AND single L3 Tau (L2 tau with px isol)	0.48	0.037	0.12	0.15	0.055	0.22
L1 AND L2 AND single L3 Mu (15) with isol(1.00)	0.61	0.07	0.3	0.33	0.2	0.35
L1 AND L2 AND L3Mu(15) AND L3Tau(40) with isol	**0.48**	**0.036**	**0.12**	**0.15**	**0.055**	**0.22**

	$bbH(200)$	$b\bar{b}$	$t\bar{t}$	Wt	$Wjet$	Z/γ^*
Cross section * BR [pb]	6.6	3.1e+06	8.8e+02	62	4.1e+04	8.8e+03
Preselection eff	0.095	0.00076	0.09	0.066	0.014	0.0031
HLT eff	0.48	0.036	0.12	0.15	0.055	0.22
(HLT eff)*(preselection eff)	0.046	2.7e-05	0.01	0.0097	0.00079	0.0007
Rate after HLT [Hz]	0.0006	0.0045	0.018	0.0012	0.065	0.012

Total rate: 0.1 [Hz] (DAQ TDR for min. bias only: 0.2 [Hz])

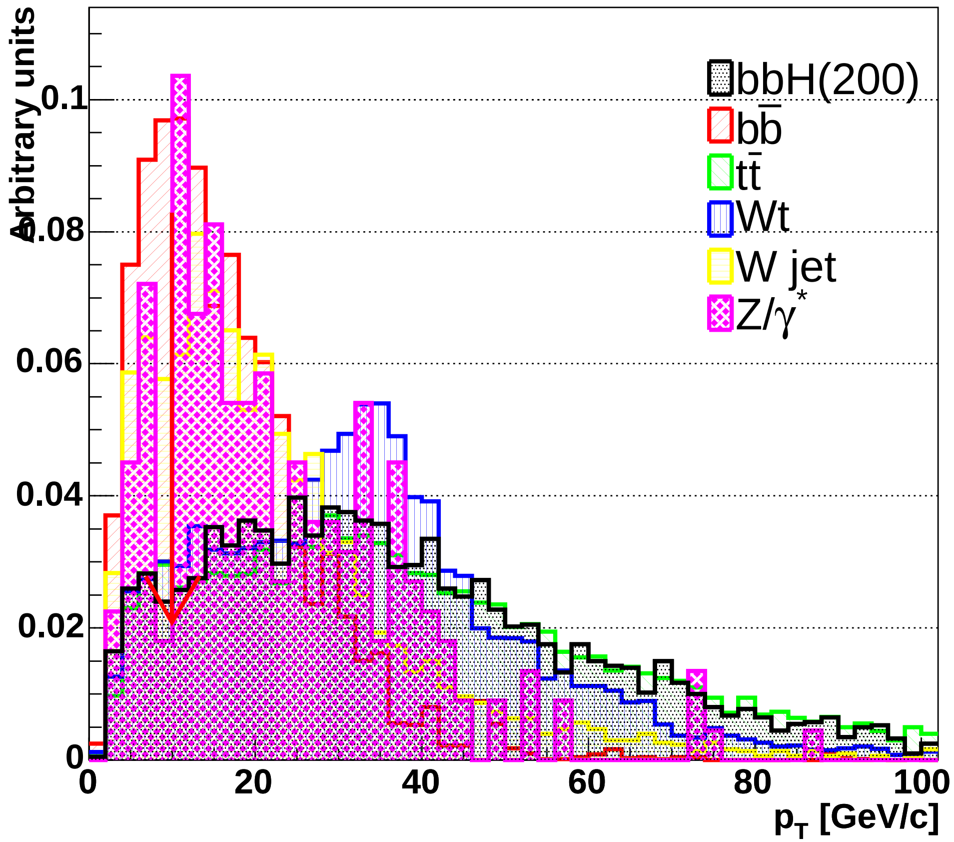
Rate [Hz] = $\mathcal{L}\left[\frac{1}{pb \cdot s}\right] \cdot \sigma[pb] \cdot \epsilon_{pres} \cdot \epsilon_{HLT}$

Numbers quoted for $\mathcal{L} = 2 \cdot 10^{33}[\frac{1}{cm^2 s}]$

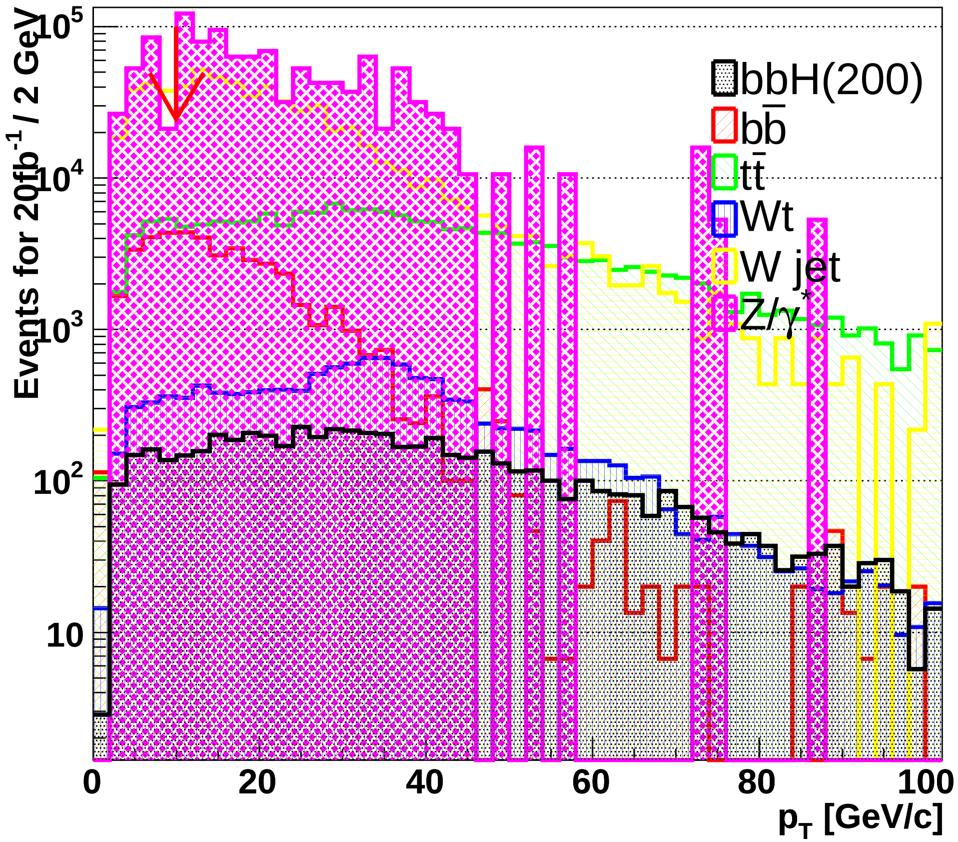
Rate for $b\bar{b}$ includes event's weight $\simeq 0.03$.

Offline cuts

- Full tracker τ isolation
- 1 or 3 tracks in the $\tau's$ signal cone
- Leading τ_{jet} track $p_T > 10\ GeV/c$
- Opposite charge of the μ and signal tracks
- Single b Tagging
- Jet veto (no jet with $Et \geq 20$ and $|\eta| \leq 2.5$)
- $m_T(l, MET) \leq 30\ GeV$
- $-0.997 \leq cos(\Delta\varphi) \leq -0.5$
- Ratio HCAL energy/leading track $E \geq 0.3$
- $E_{\nu 1} \geq 0\ AND\ E_{\nu 2} \geq 0$



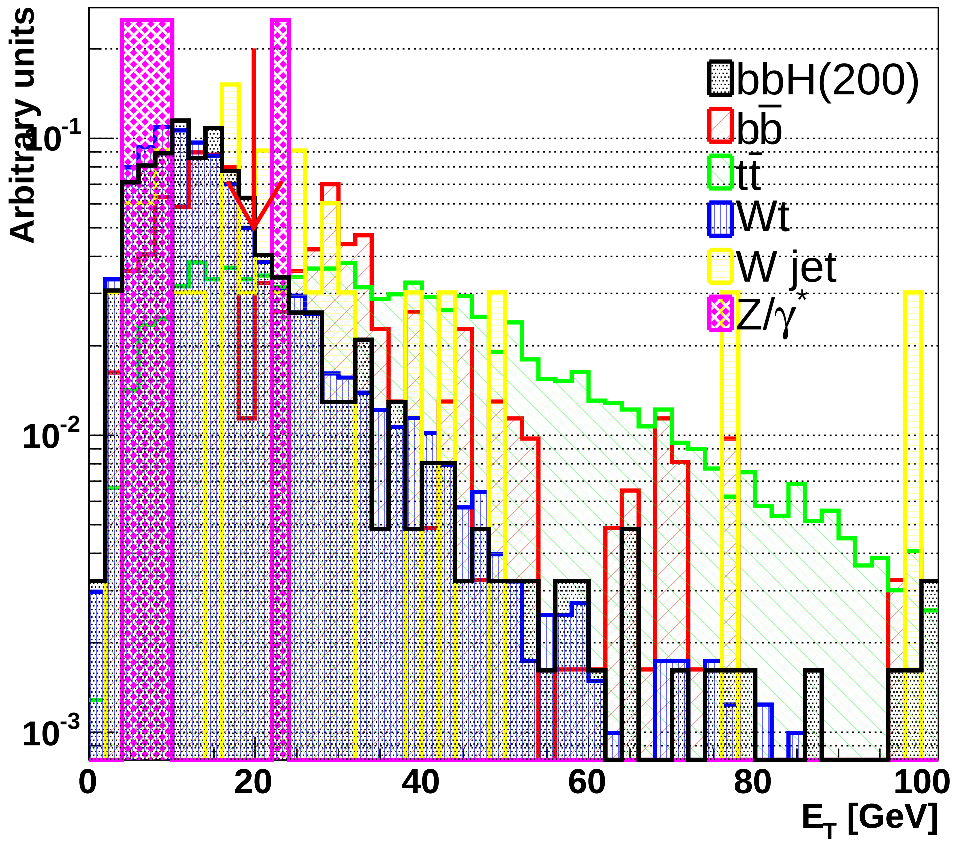
τ_{jet} leading track
Arbitrary units
0
0.02
0.04
0.06
0.08
0.1
0
20
40
60
80
100
p_T [GeV/c]
bbH(200)
$b\bar{b}$
$t\bar{t}$
Wt
W jet
Z/γ^*



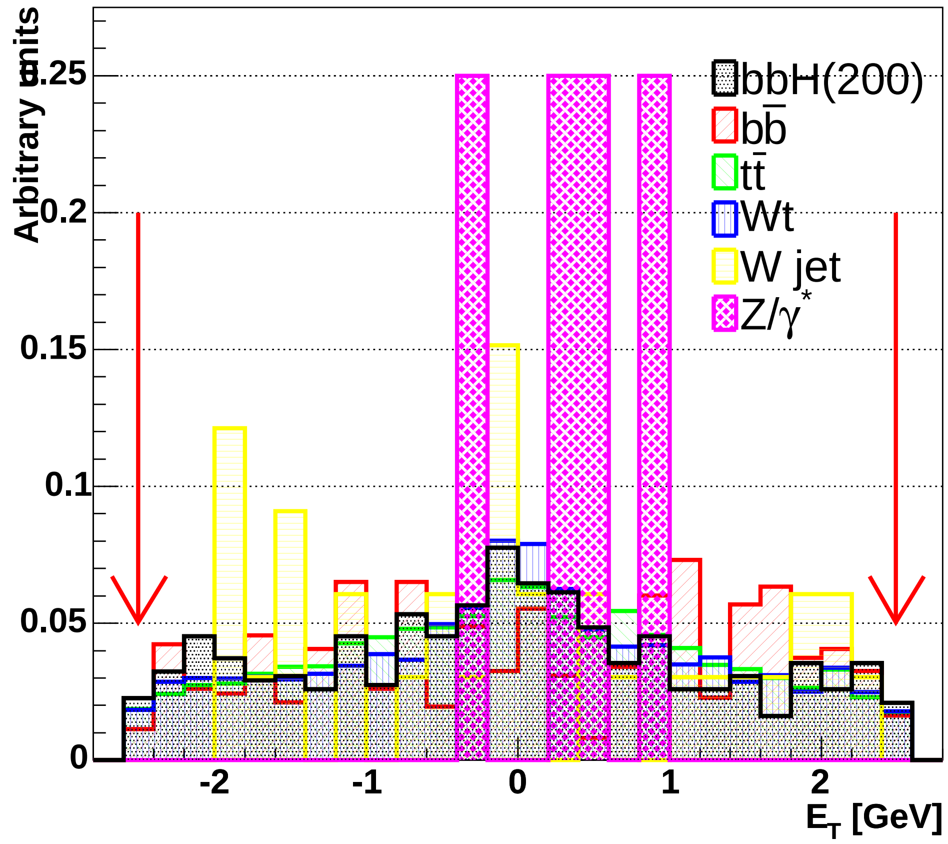
τ_{jet} leading track after HLT
Events for 20fb^{-1} / 2 GeV
10
10^2
10^3
10^4
10^5
0
20
40
60
80
100
p_T [GeV/c]
bbH(200)
$b\bar{b}$
$t\bar{t}$
Wt
W jet
Z/γ^*

Central jet veto

Veto jet E_T

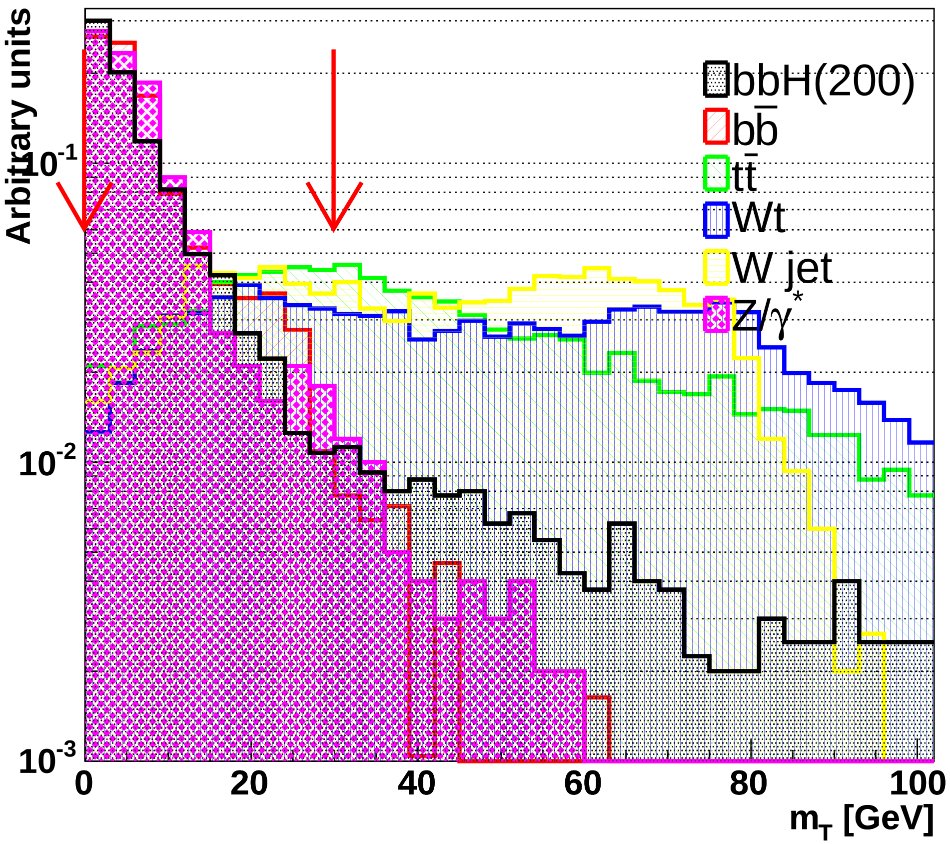


Veto jet η

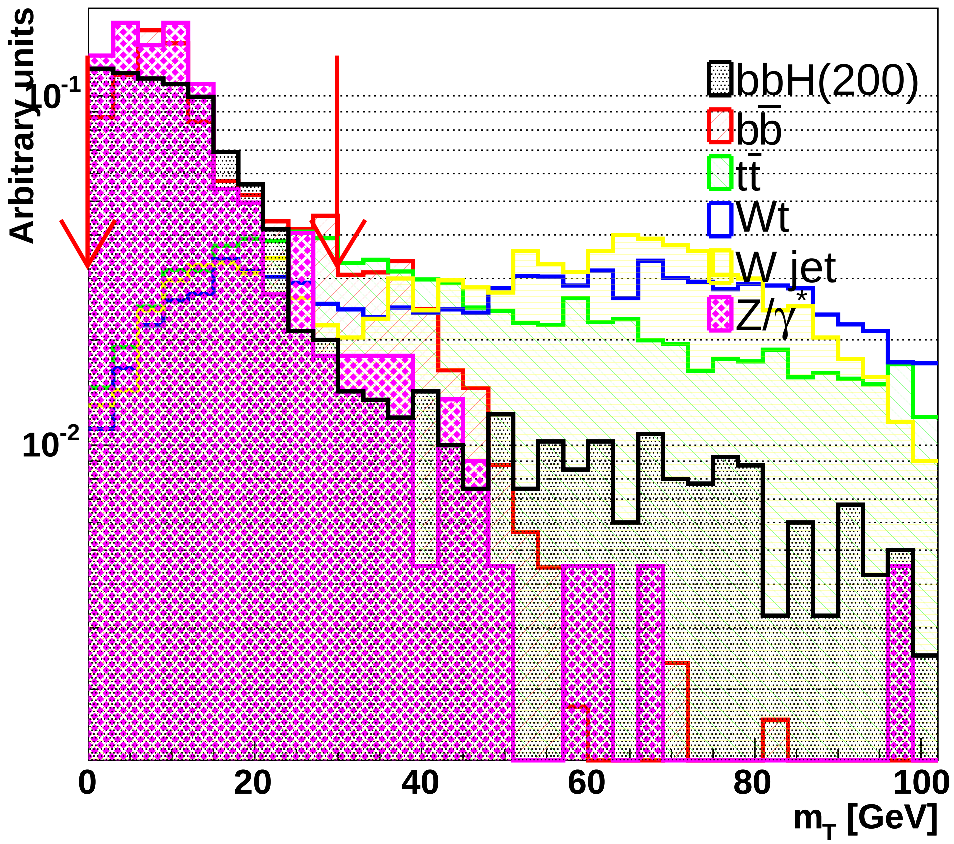


Transverse mass of the μ and missing E_T system

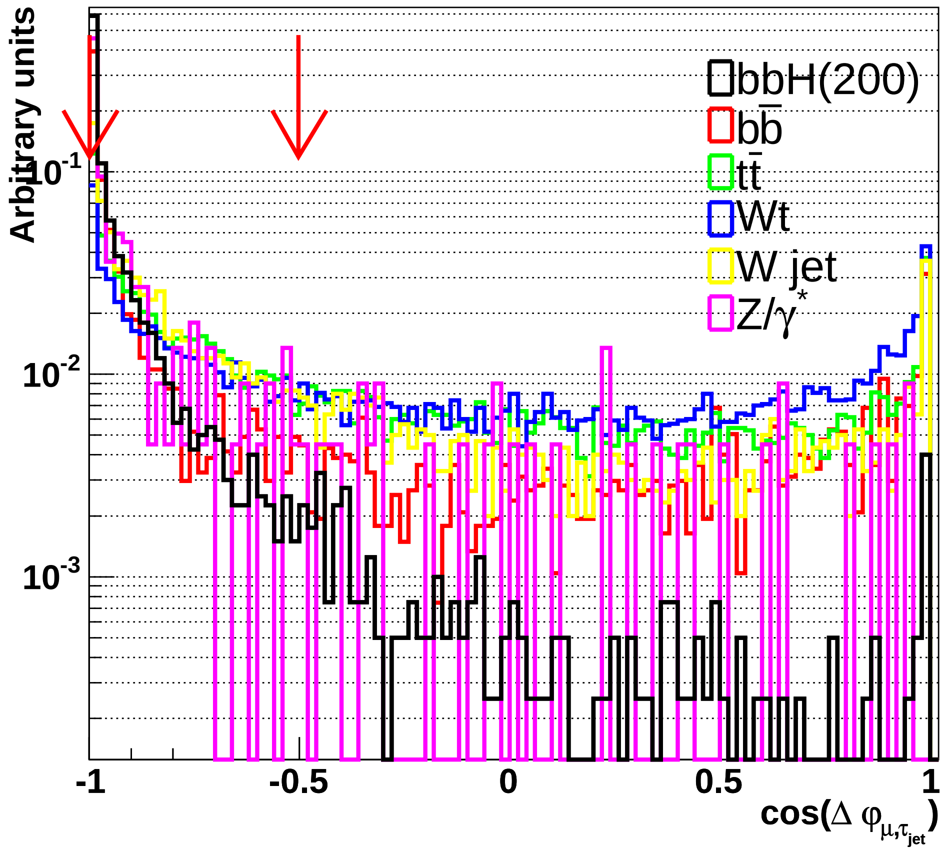
MC transverse mass of (μ,$\not{E}_T$) system



Rec transverse mass of (μ,$\not{E}_T$) system

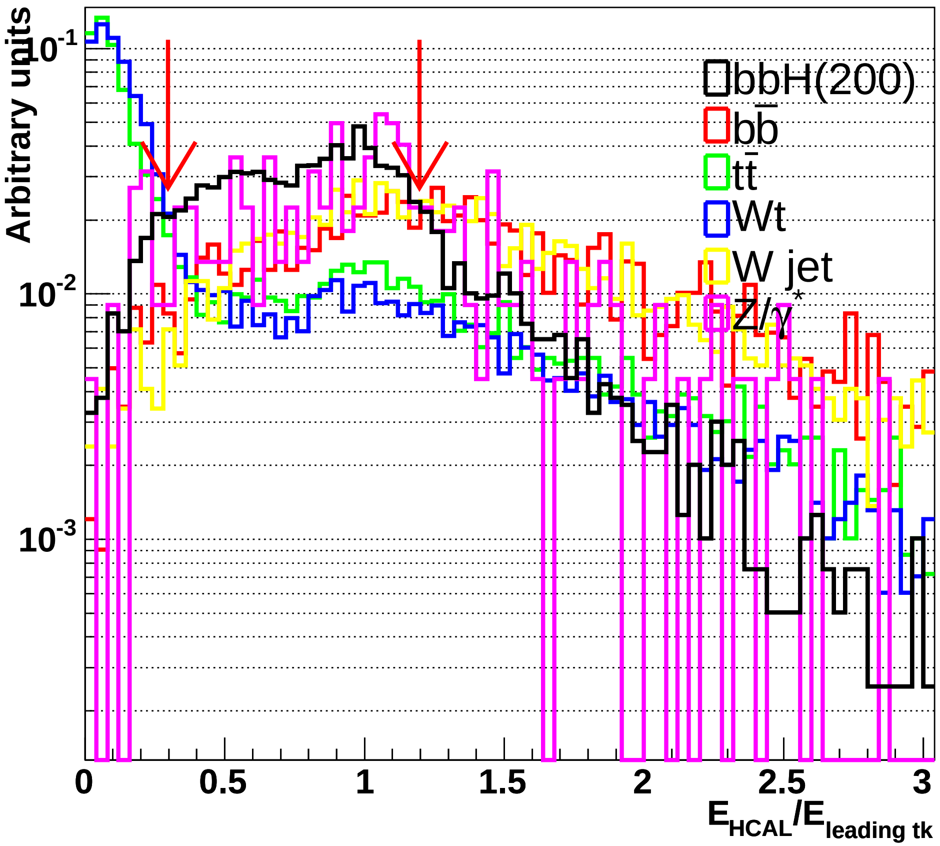


cos(Δ φ) between p_T^{μ} and $E_T^{\tau\ jet}$



$$cos(\Delta\varphi) = \hat{p}_T^{\mu} \cdot \hat{p}_T^{\tau_{jet}}$$

Jet hadronic energy vs leading track energy



Conclusion: τ_{jet} in $t\bar{t}$ and Wtb samples are mainly faked by electrons coming from W decay

If we define:

$$\hat{e}_{Tjet} = \frac{\vec{p}_T^{\,\tau\ jet}}{p_T^{\tau\ jet}} \qquad \hat{e}_{T\mu} = \frac{\vec{p}_T^{\,\mu}}{p_T^{\mu}}$$

$$cos(\varphi_{\mu-jet}) = \hat{e}_{Tjet} \cdot \hat{e}_{T\mu},$$

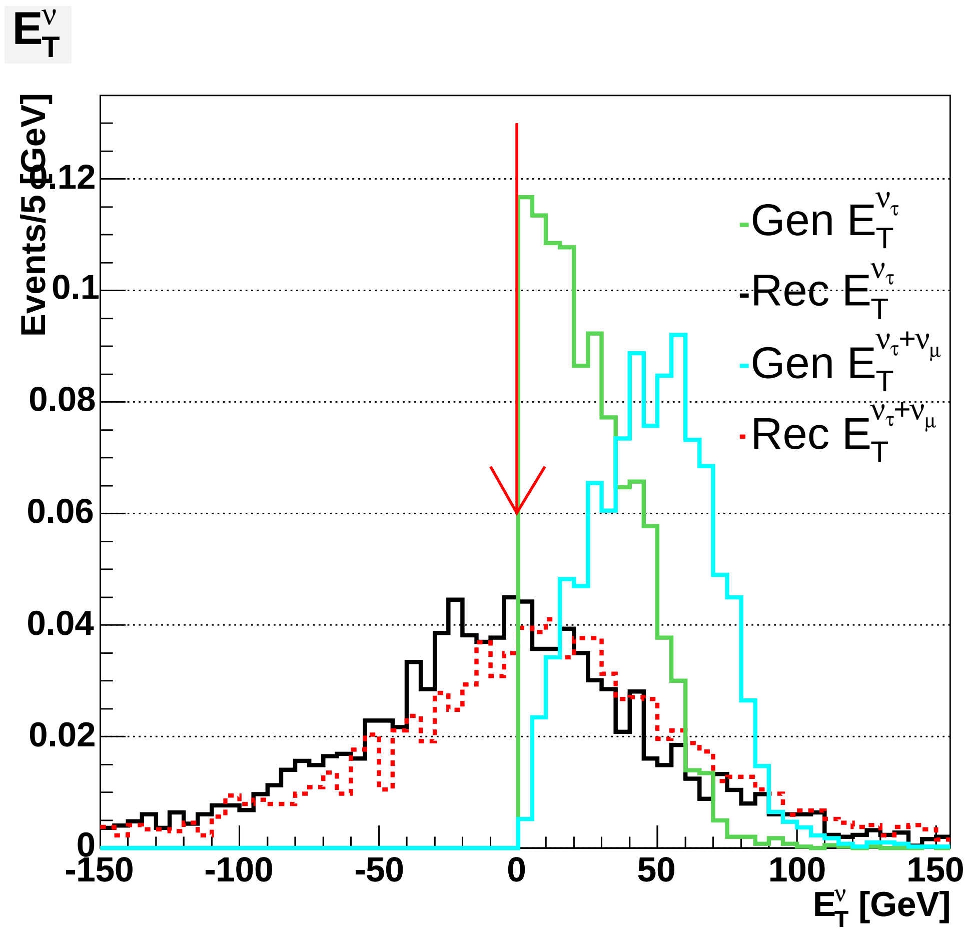
we get:

$$E^{\tau}_{\nu_1} = M\vec{E}T \cdot \frac{(\hat{e}_{Tjet} - \hat{e}_{T\mu} \cdot cos(\varphi_{\mu-jet}))}{sin(\theta_{jet}) \cdot (1 - cos^2(\varphi_{\mu-jet}))}$$

$$E^{\tau}_{\nu_2} = M\vec{E}T \cdot \frac{(\hat{e}_{Tmu} - \hat{e}_{Tjet} \cdot cos(\varphi_{\mu-jet}))}{sin(\theta_{mu}) \cdot (1 - cos^2(\varphi_{\mu-jet}))}$$

Reconstruction is done for

$$-0.997 < cos(\varphi_{\mu-jet}) < -0.5$$



Offline efficiencies (wrt HLT events) table

Sample:	$bbH(200)$	$b\bar{b}$	$t\bar{t}$	Wt	$Wjet$	Z/γ^*
Offline τ_{jet} isolation	0.92	0.72	0.79	0.83	0.54	0.82
1 or 3 tk. in τ_{jet} signal cone	0.84	0.5	0.69	0.74	0.33	0.74
Leading track $p_T > 10\ GeV/c$	0.76	0.34	0.64	0.69	0.24	0.62
$Q_\mu \cdot Q_{jet} = -1$	0.75	0.18	0.61	0.67	0.19	0.59
Single b tag	0.12	0.011	0.41	0.28	0.002	0.014
No jet with $E_T > 20$, $\|\eta\| < 2.5$	0.086	0.0052	0.11	0.22	0	0.009
Tau impact parameter > 2.5	0.086	0.0052	0.11	0.22	0	0.009
$m_T(l, MET) < 30$	0.066	0.0036	0.036	0.058	0	0.009
$-0.997 < cos(\Delta\varphi) < -0.5$	0.055	0.0016	0.02	0.034	0	0
HCAL/leading tk. E: $0.3 < R < 1.3$	0.042	0.0012	0.0028	0.0044	0	0
$E_\nu^1 > 0, E_\nu^2 > 0$	0.02	0.0004	0.0011	0.0016	0	0
Events for $20\ fb^{-1}$	**119**	**6.7**	**197**	**19.3**	**$<$3.98e+03**	**$<$7.45e+03**

Tau tagging by impact parameter

Method:

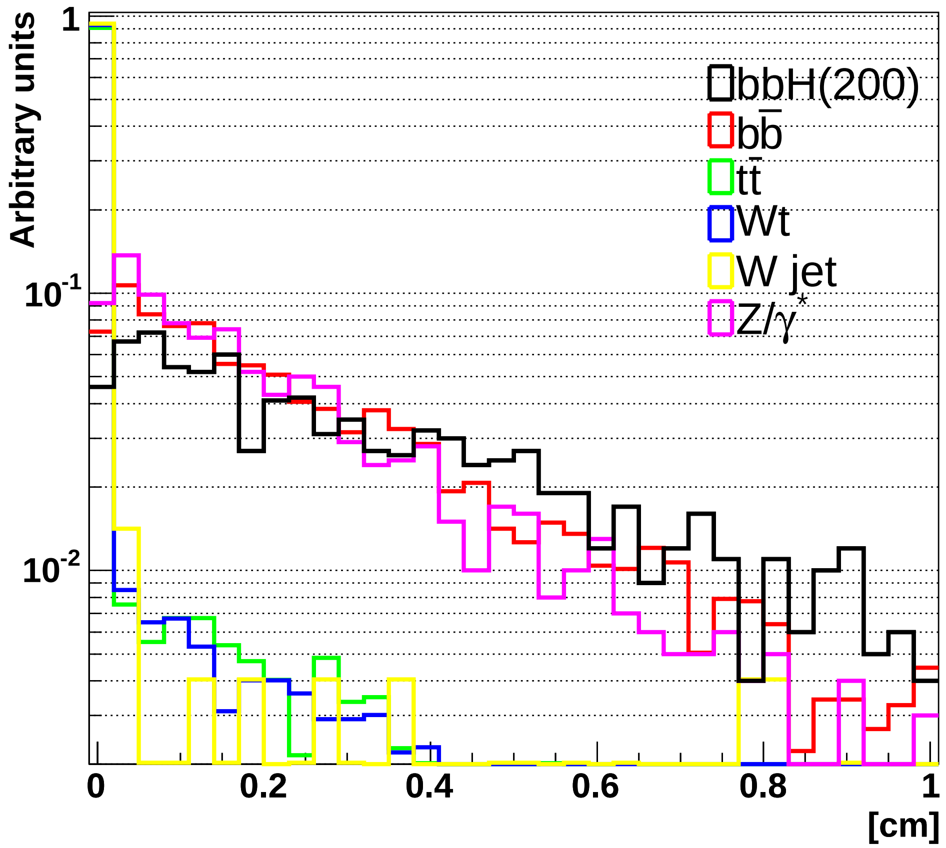
$$S = |\vec{r}^{\,2D}_{trackIP}|/\delta$$

$\vec{r}_{trackIP}$ is obtained by taking the trajectory state at the inner most layer and propagating it to the plane containing the IP, and transverse to the beam line:

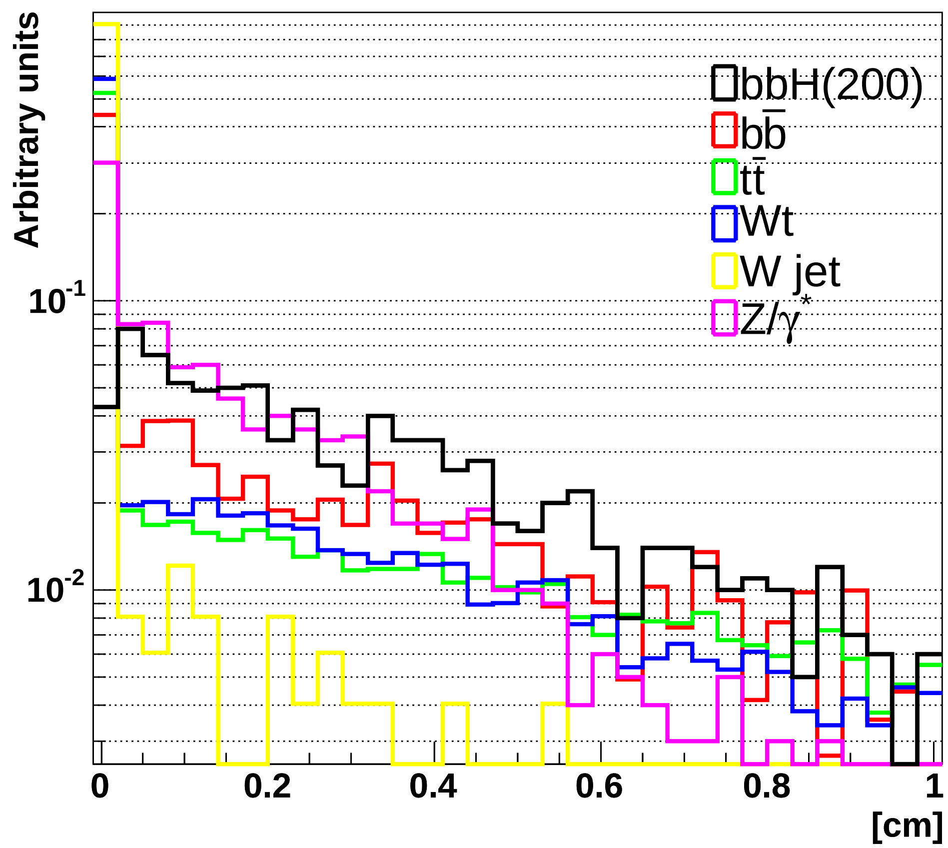
```
FreeTrajectoryState *
FTS(aRecTrack.stateAtFirstPoint().freeTrajectoryState());
GlobalPoint vertex(aRecoVertex.position().x(),
                   aRecoVertex.position().y(),
                   aRecoVertex.position().z());
TransverseImpactPointExtrapolator TIPE;
TrajectoryStateOnSurface TSOS = TIPE.extrapolate(*FTS, vertex);
```

Tau tagging by impact parameter. Generator level.

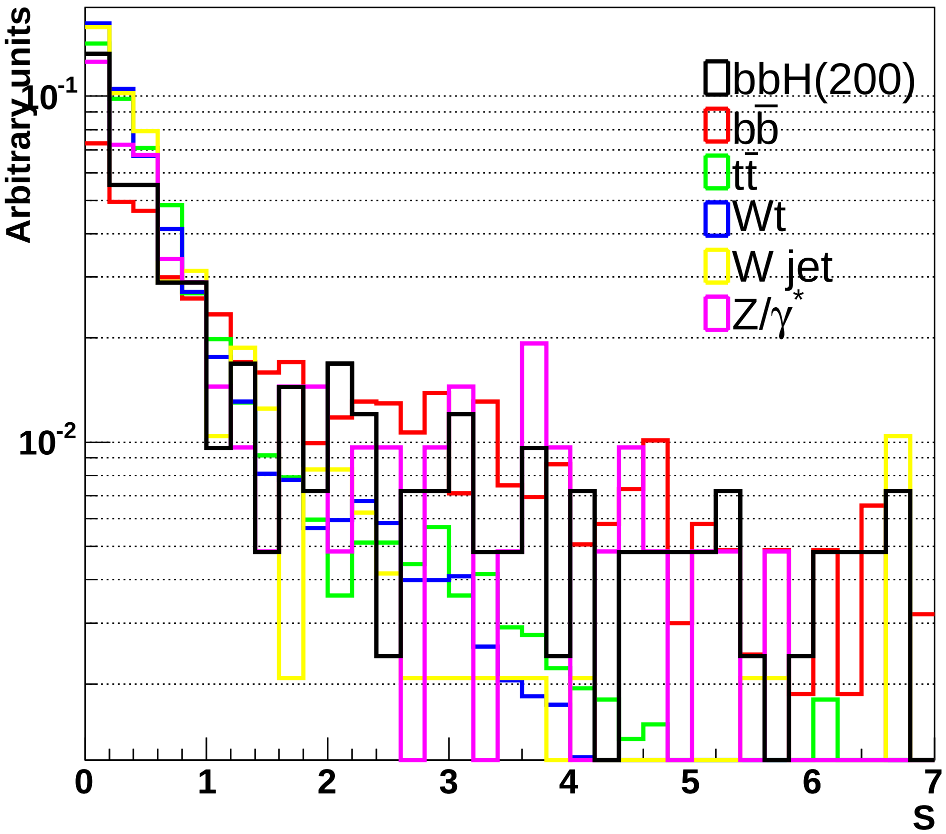
MC transverse distance between PV and muon vertex.



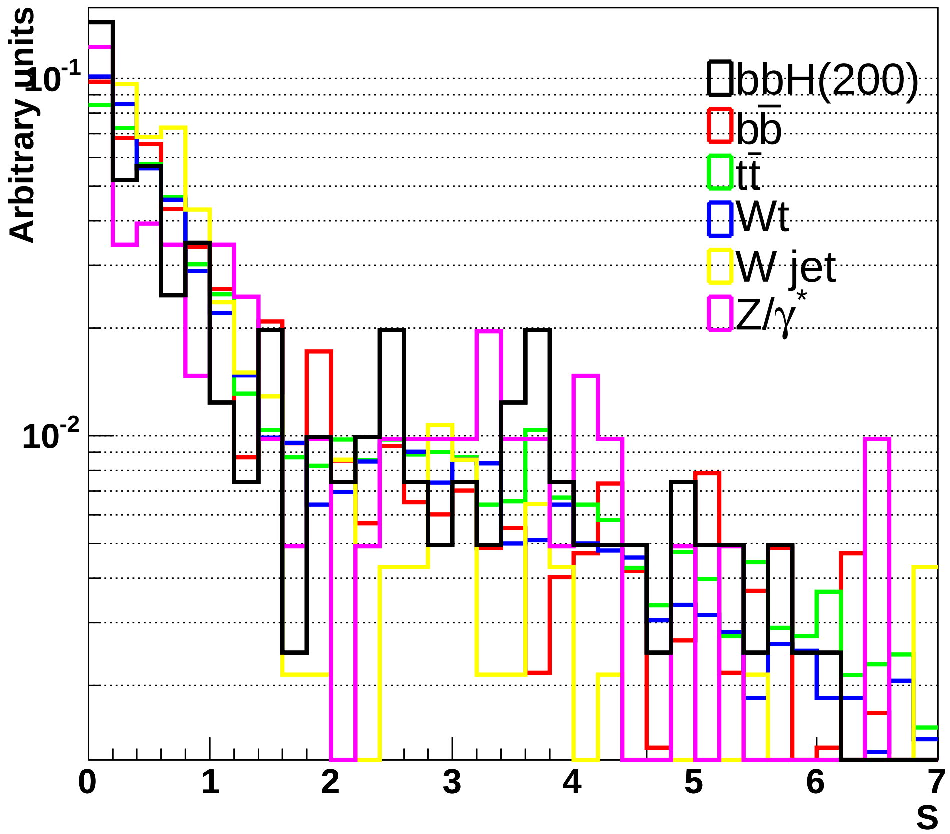
MC transverse distance between PV and leading track vertex.



μ track impact parameter significance

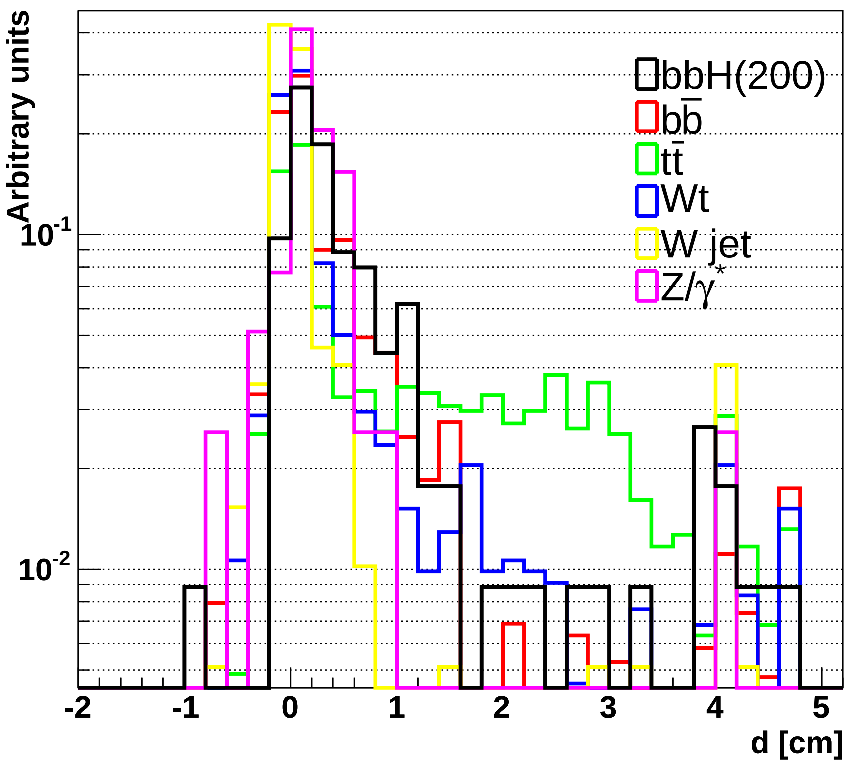


τ_{jet} leading track impact parameter significance



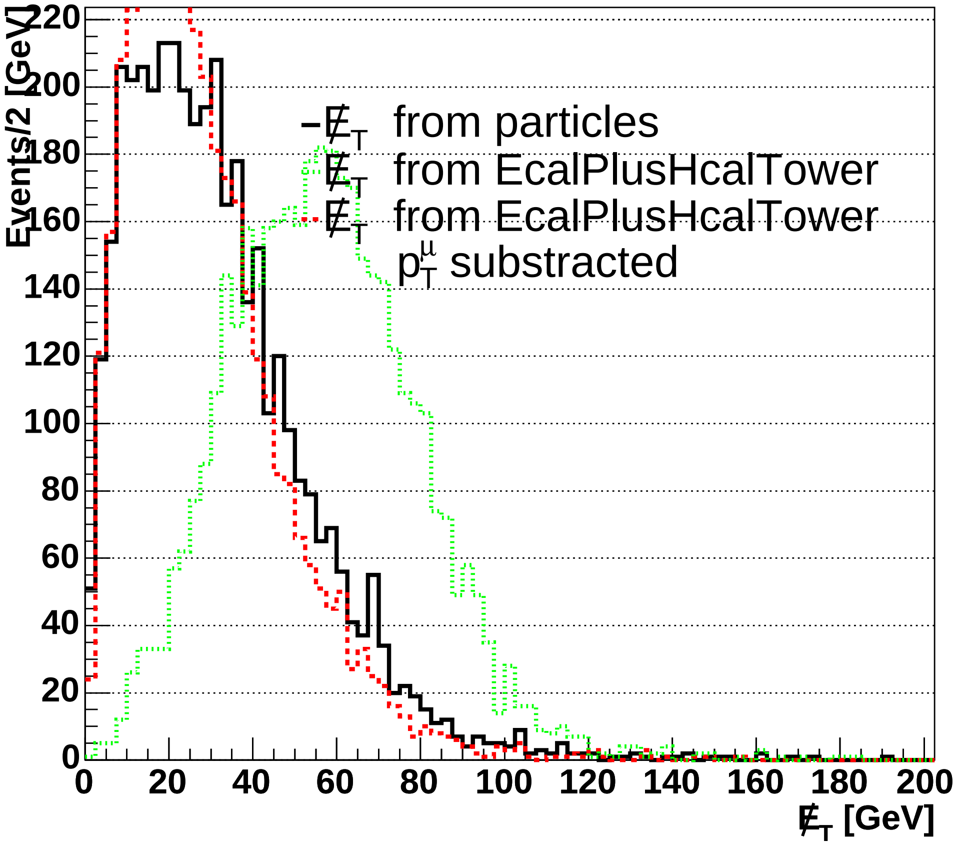
Secondary vertex from signal tracks

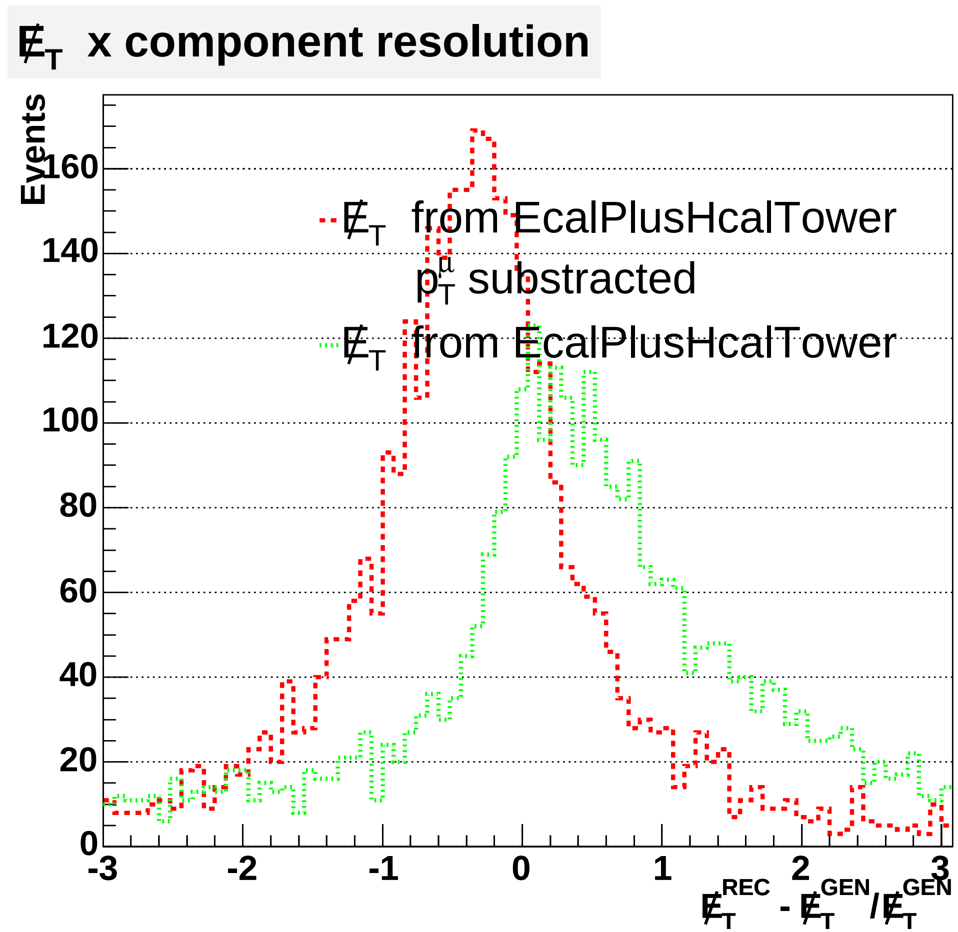
Rec transverse distance between PV and secondary tau jet vertex



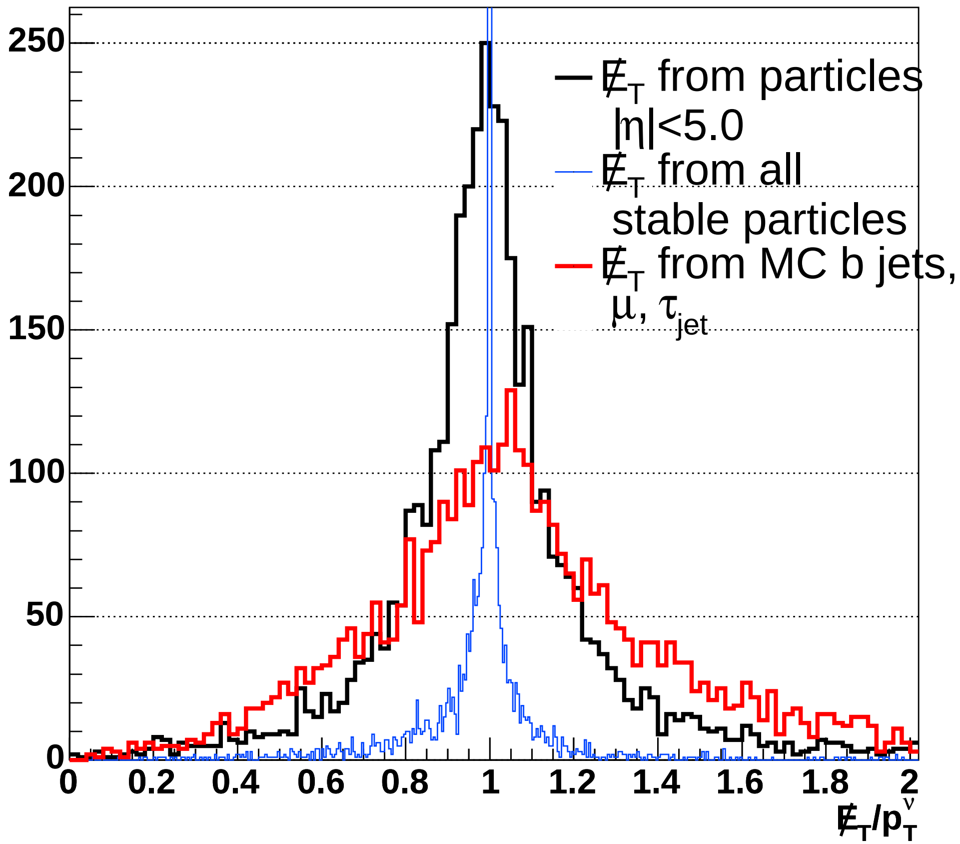

```
if(mySignalTracks.size()>1){
PrincipalVertexReconstructor *myPVR =
new DefaultPrincipalVertexReconstructor();
vector<RecVertex> myPVVertices =
myPVR->vertices(mySignalTracks);
vector<RecVertex>::const_iterator ci =
myPVVertices.begin();
for(;ci!=myPVVertices.end();ci++)
vxPos = (ci)->position();
delete myPVR; }
return vxPos;
```

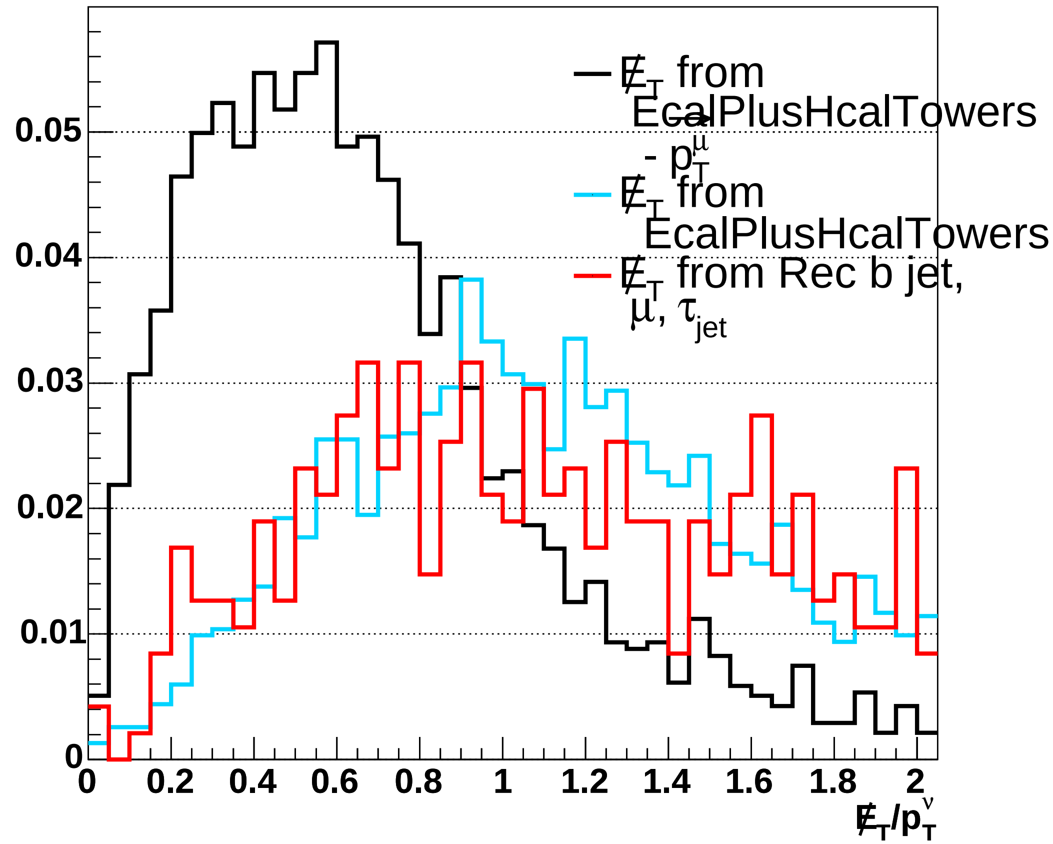
Missing E_T vs. neutrinos' p_T studies.

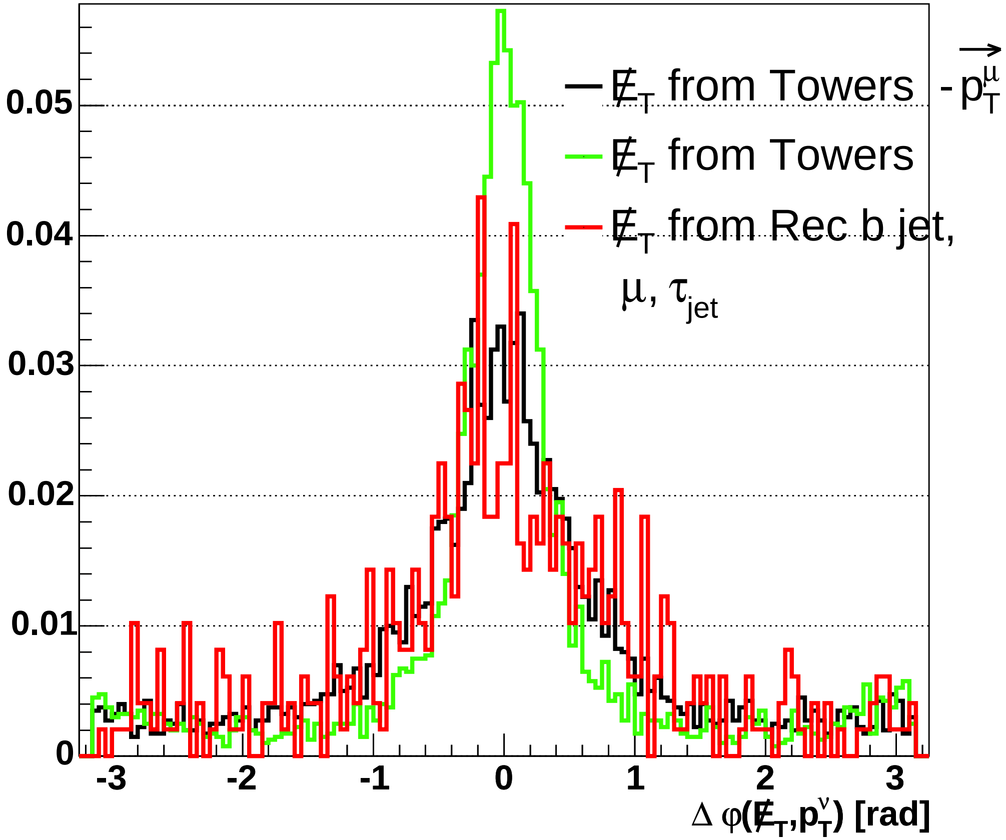




Missing E_T vs. neutrinos' p_T studies.







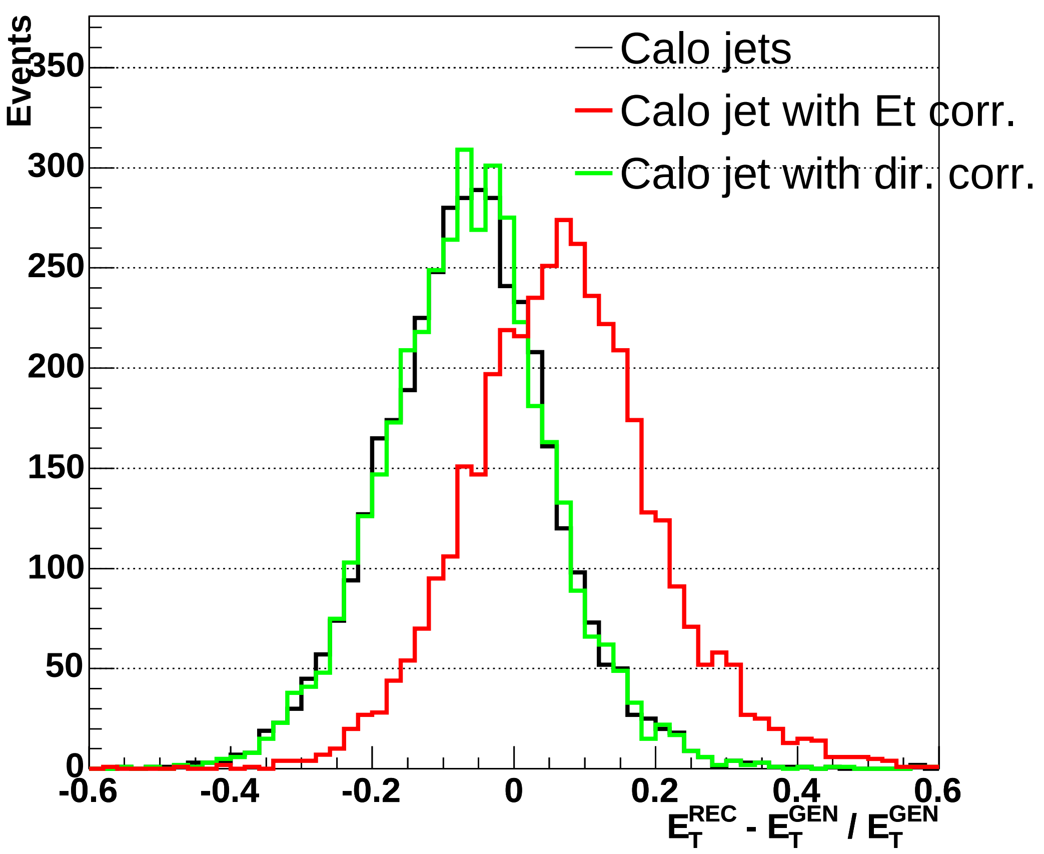
Conclusions: Need better MET corrections.

Basing on results for both possibilities:

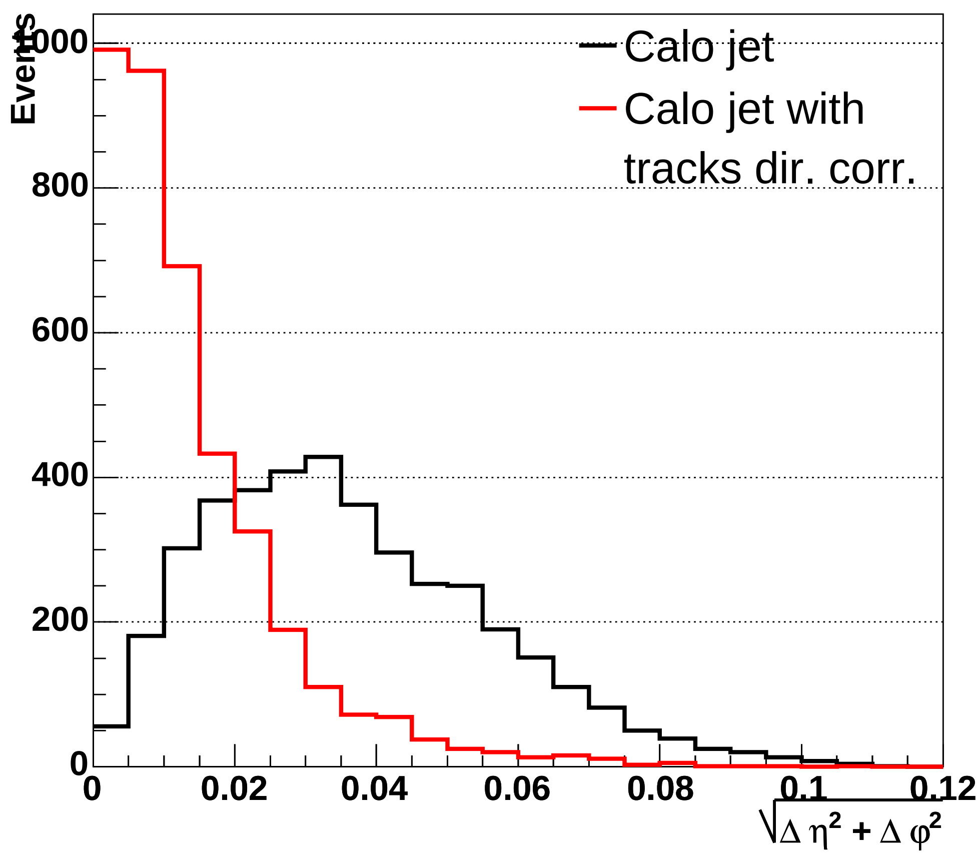
- for $m_T(\mu, \tau_{jet})$ the corrected MET was used.
- for Higgs mass reconstruction the uncorrected MET was used.
- "local" evaluation of MET seems promising, but needs more clever treatment of the b jet (at least an energy correction)

Jet corrections

Rec jets (l3, offline) energy resolution



dR(rec jet, generator level τ_{jet})

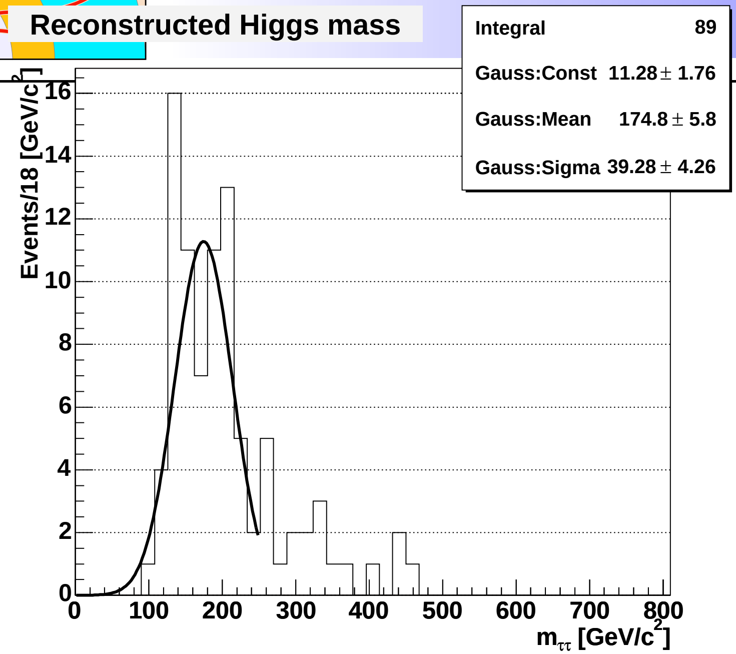


$$E_T^{corr} = 1.02 * E_T + 5.7\ [GeV]$$

Formula taken from the DAQ TDR studies.

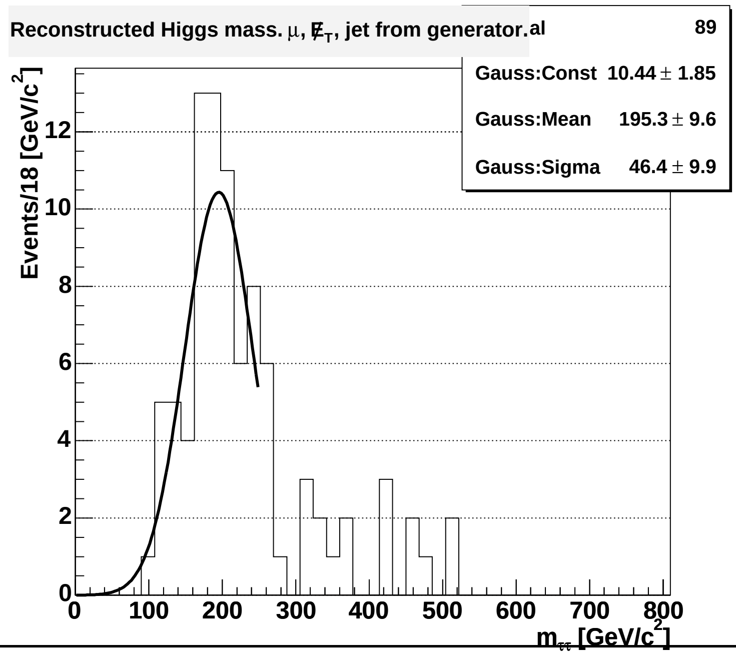
For corrected jet the direction is taken from the signal tracks, and EM clusters.

Invariant mass of $\tau\tau$ system. Signal only



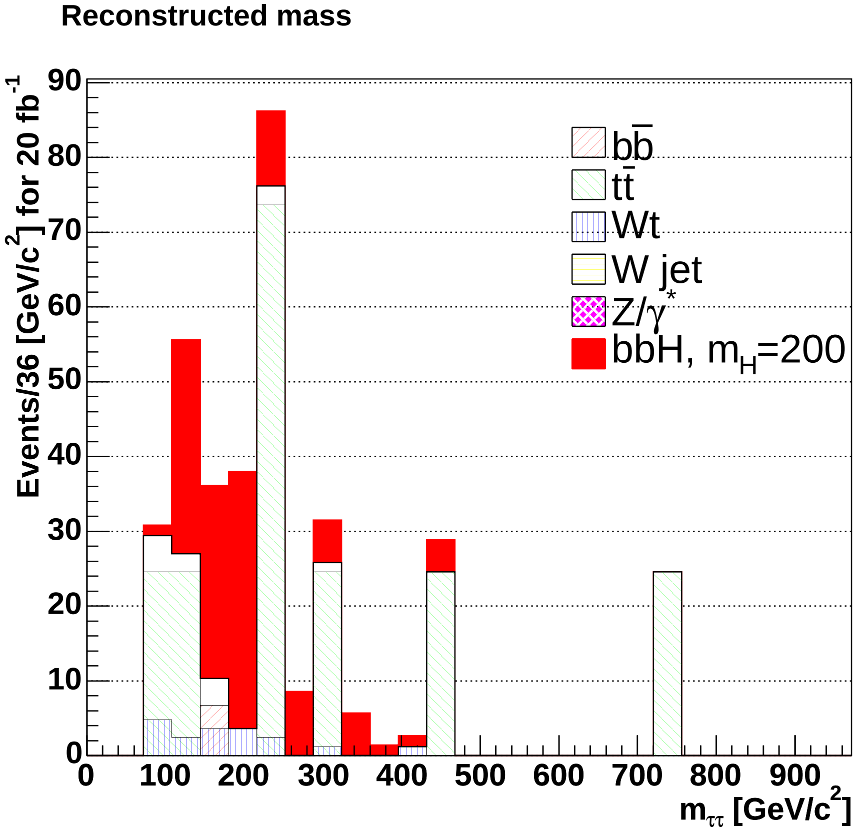
Components used:

- GlobalMuon
- Calo jet **without** E_T correction, **with** direction correction
- **Corrected** MET



Components used:

- GlobalMuon
- Calo jet **with** E_T and direction corrections
- **Uncorrected** MET



Components used:

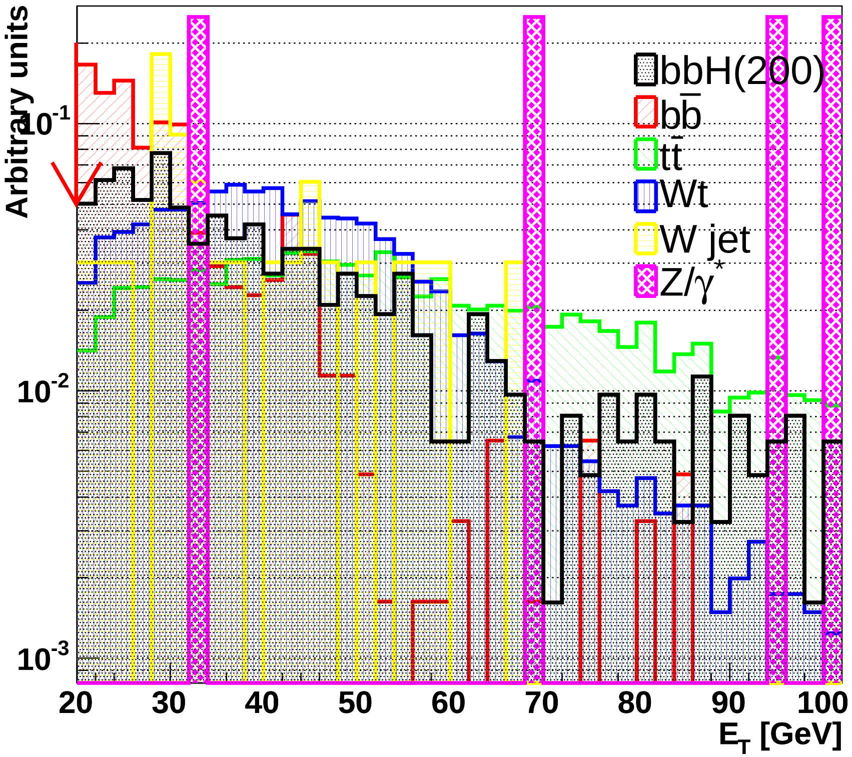
- GlobalMuon
- Calo jet **without** E_T and **with** direction correction
- **Uncorrected** MET

To do

- Evaluate contribution from the $Zb\bar{b}, Zb$ backgrounds
- Optimize the cuts' values
- Make the discovery reach plots on the $< m_A, tan(\beta) >$ plane

Backup slides

First b tagged jet



Track counting method:

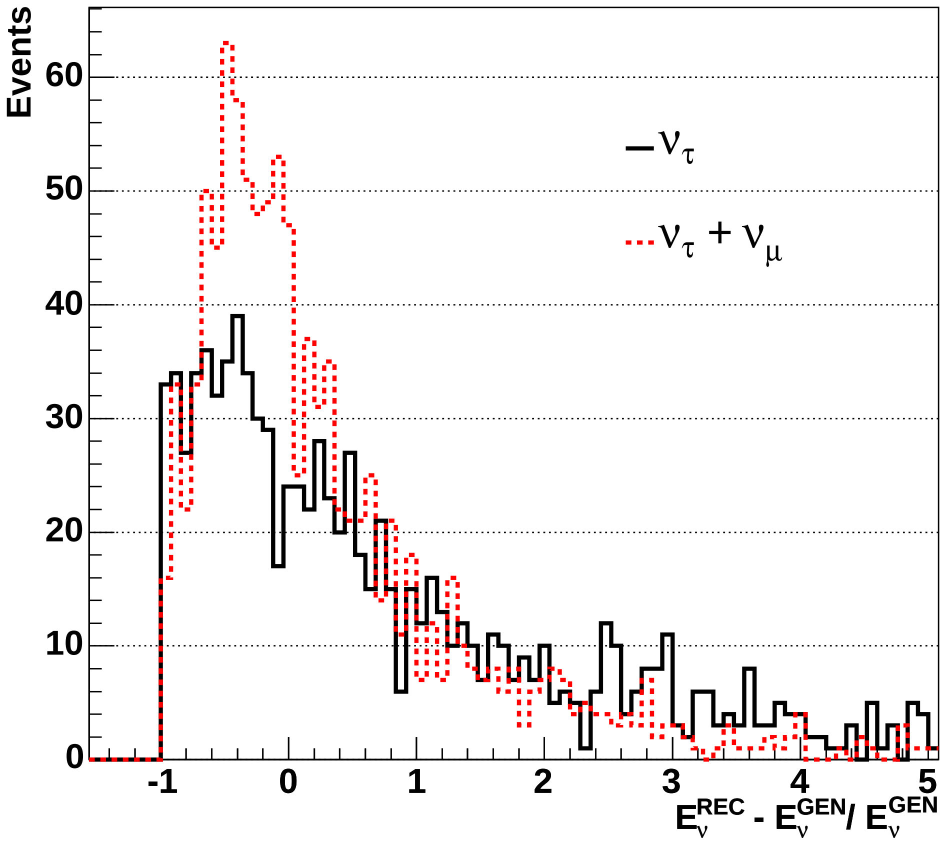
at least **2** tracks with impact parameter significance >**2**

Iterative Cone(R=0.6) jet with $E_T > 20\ GeV, |\eta| < 2.4$

Efficiency is computed wrt. previous offline cut (charge correlation).

Purity - fraction of b tagged jest close to MC b jet.

Process	Efficiency	Purity
$bbA/H(M_A = 200)$	0.16	0.96
$b\bar{b}$	0.058	0.85
$t\bar{t}$	0.68	0.96
$gb \to Wt$	0.42	0.93
$Wjet$	0.01	n.a.
Z/γ^*	0.023	n.a.



Components used:

- GlobalMuon
- Calo jet **without** direction correction
- **Corrected** MET