Search for neutral MSSM Higgs bosons in the decay channel $A/H \rightarrow \tau^+\tau^-$ with the ATLAS detector

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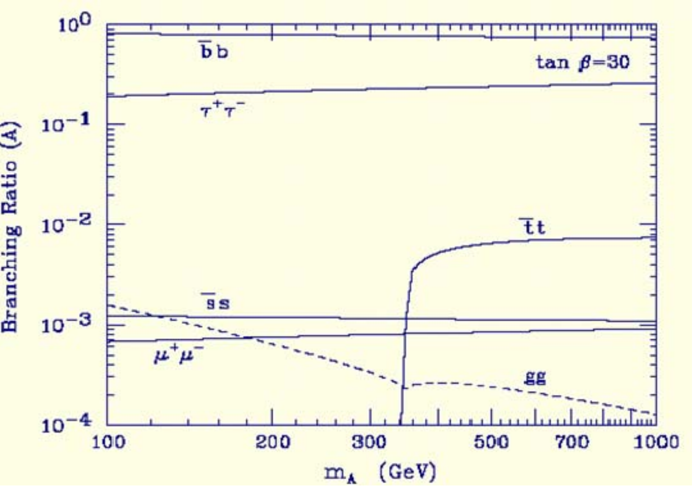
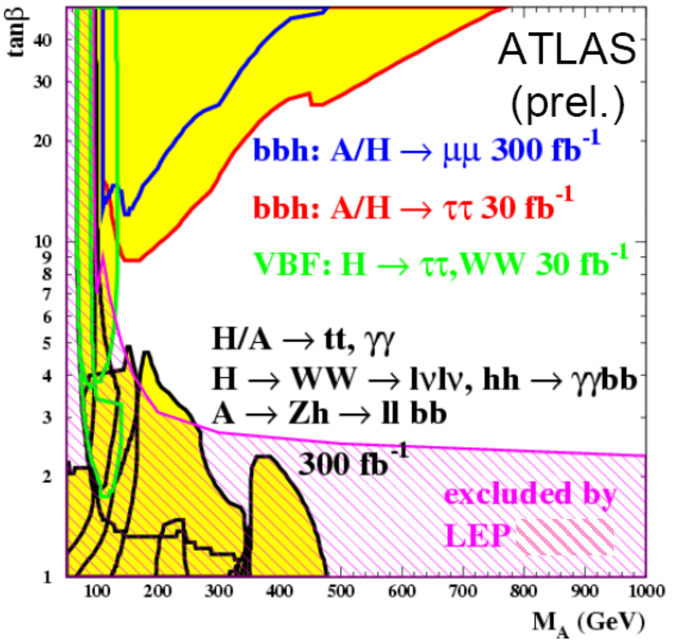
Motivation

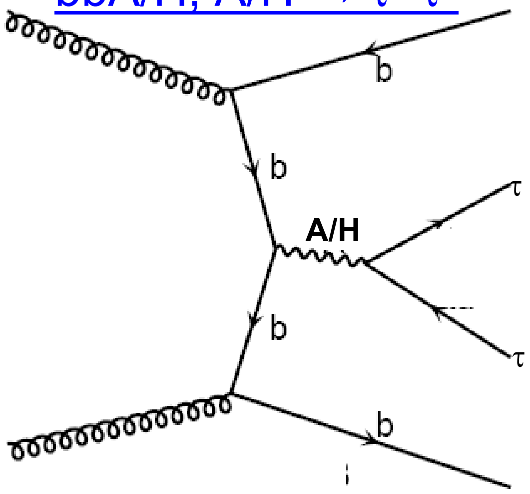




- In the Minimal Supersymmetric extension of the Standard Model (MSSM), two Higgs doublets are required, resulting in 5 physical states H^+, H^-, h (neutral light scalar), H (neutral heavy scalar), A (neutral pseudoscalar)
- At the tree level 2 free parameters m_A and $\tan\beta$
- MSSM H/A can be enhanced wrt SM
- MSSM Higgs Branching Ratio to $\tau^+\tau^-$ is the major leptonic one
- Covers a large parameter space for neutral Higgs discovery

Channel Description I

bbA/H, A/H → $\tau^+ \tau^-$



Tau hadronic decay mode
1 prong: $\tau \to \nu_\tau + \pi^\pm + N\pi^o$ $\tau \to \nu_\tau + K^\pm + N\pi^o$ 3 prong: $\tau \to \nu_\tau + 3\pi^\pm + N\pi^o$

- Two production mechanisms:
  direct production: gg→A/H

  associated production : qq,gg→bb A/H
  dominant for large tanβ(>10)
- Enhanced wrt SM:

$$\sigma_{MSSM}(H) = \frac{\cos^2(\alpha)}{\cos^2(\beta)} \times \sigma_{SM}$$

, cos(a): mixing angle between h and H

$$\sigma_{MSSM}(A) = \tan^2(\beta) \times \sigma_{SM}$$

- For large tanβ A and H are degenerate in mass so their signals can be added
- A/H→ $\tau^+\tau^-$ can give lepton – lepton , lepton – hadron , hadron – hadron final states
- Better sensitivity in the leptonic – hadronic $(\ell \nu_\ell \nu_\tau - h \nu_\tau)$ decay channel ($BR_{\tau\tau \to lh}$ = 46%)
- Hadronic tau signature in the detector:
  Well collimated Calorimeter cluster with 1 or 3 associated charged tracks
  Large fraction of energy deposition in the Hadronic Calorimeter , Charge ±1

Channel Description II

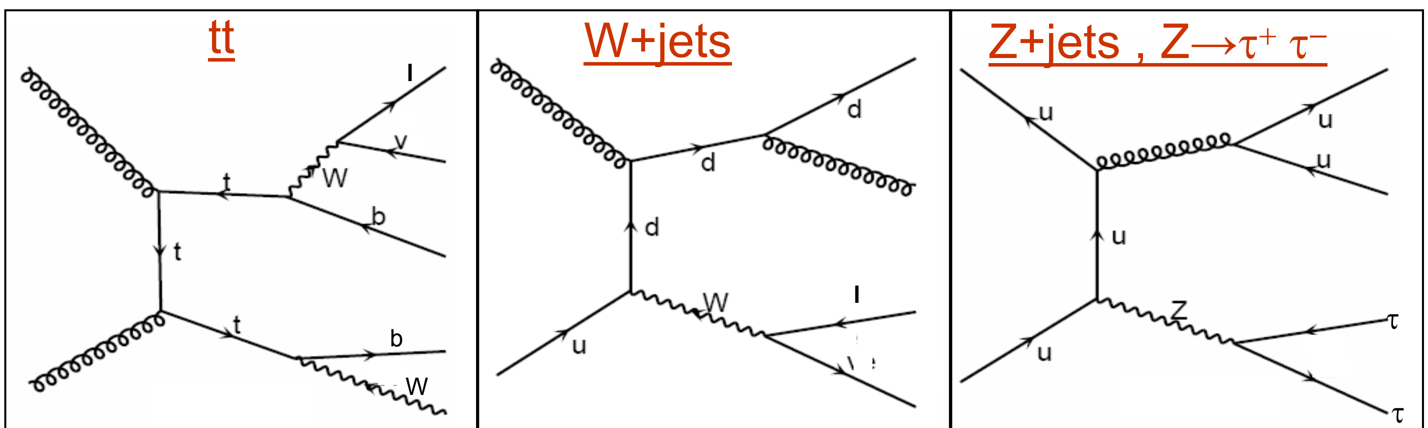
- Main background processes:

$tt \to W^{\pm}W^{\mp}$, $W^{\pm} \to l^{\pm}\,\nu$ and $W^{\mp} \to$ to everything

$W^{\pm}$+2jets, $W^{\pm} \to \mu^{\pm}\,\nu$

$W^{\pm}$+2jets, $W^{\pm} \to \tau^{\pm}\,\nu$

Z+2jets, $Z \to \tau^{+}\,\tau^{-}$



Data Samples

- Simulated data samples, $\tan\beta$=10 / 30

Process	Generator	σ x BR x filter	ATLFAST	Full	Luminosity	
bbA/H, A/H $\rightarrow \tau^+\tau^-$, 300GeV	Pythia	0.26 pb / 2.4 pb	60k	30k	230 fb^{-1} / 26 fb^{-1}	115 fb^{-1} / 13 fb^{-1}
tt $\rightarrow W^{\pm}W^{\mp}$ $W^{\pm} \rightarrow l^{\pm}\nu$ $W^{\mp} \rightarrow$ to everything	MC@NLO	461 pb	8M	380k	18 fb^{-1}	0.8 fb^{-1}
$W^{\pm}$+2jets, $W^{\pm} \rightarrow \mu^{\pm}\nu$	Pythia	253 pb	6M	-	24 fb^{-1}	
$W^{\pm}$+2jets, $W^{\pm} \rightarrow \tau^{\pm}\nu$	Pythia	141 pb	4M	-	30 fb^{-1}	
Z+2jets, $Z \rightarrow \tau^+\tau^-$	Alpgen	6.1 pb	90k	-	15 fb^{-1}	

- Two strategies for producing the needed data for the analysis:

  ATLFAST: A fast simulation program with parametrised detector response

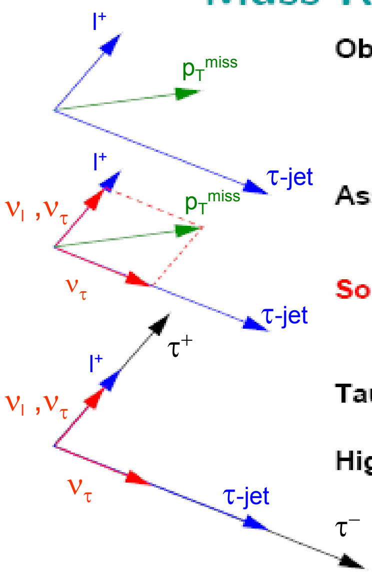
  (Less realistic – Less CPU time consuming)

  Full Simulation: A detailed description of the detector response based on GEANT4 simulation, following every particle in each active module and dead material area of the detector

  (More accurate – More CPU time consuming)

Discrimination variables I

Mass Reconstruction:



Observe
missing transverse momentum
and visible Tau–decay products

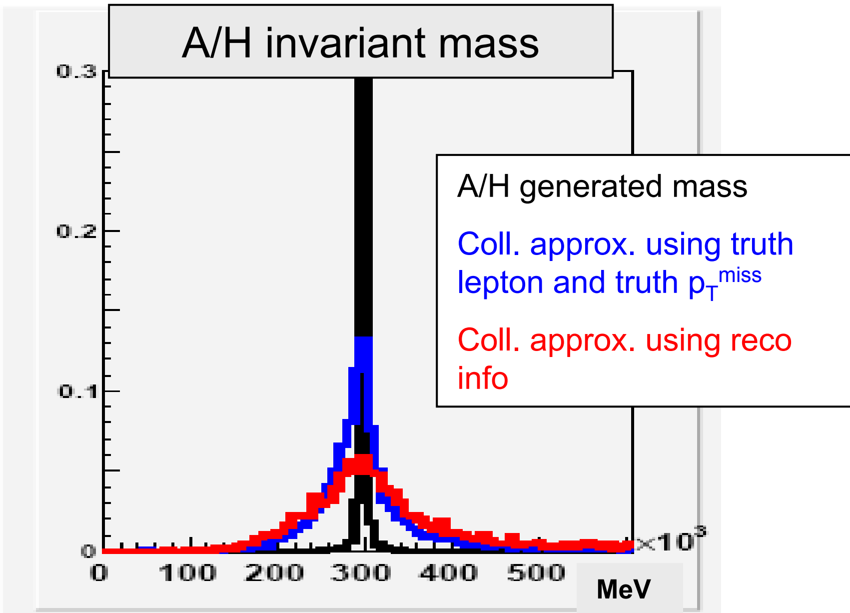
Assume Tau decay products
collinear with original Tau

Solve 2 linear equations
for the neutrinos

Taus can be reconstructed

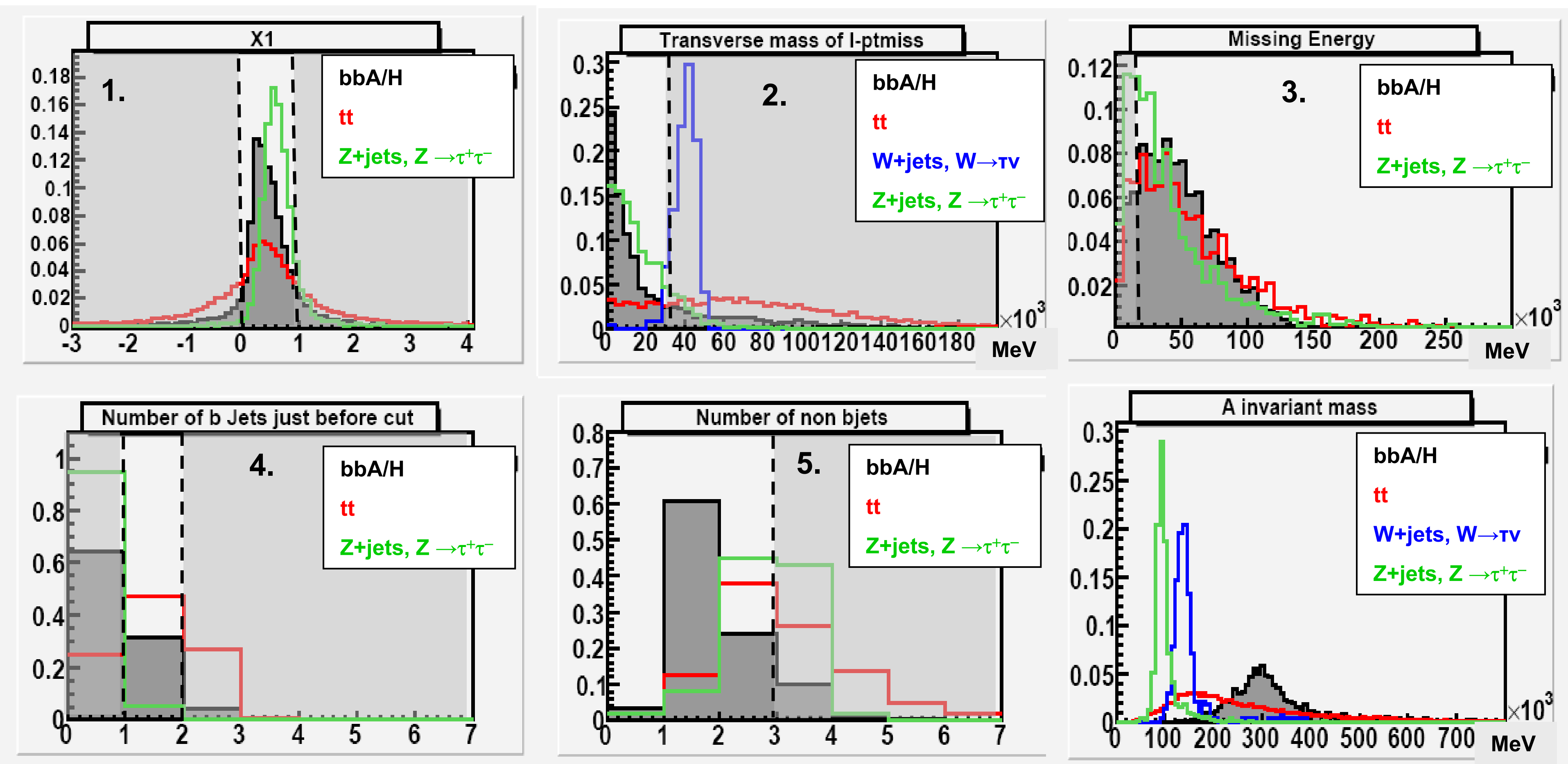
Higgs can be reconstructed

$$x_1 = \frac{p_T^{l^+}}{p_T^{\tau^+}} \qquad x_2 = \frac{p_T^{\tau-jet}}{p_T^{\tau^-}}$$



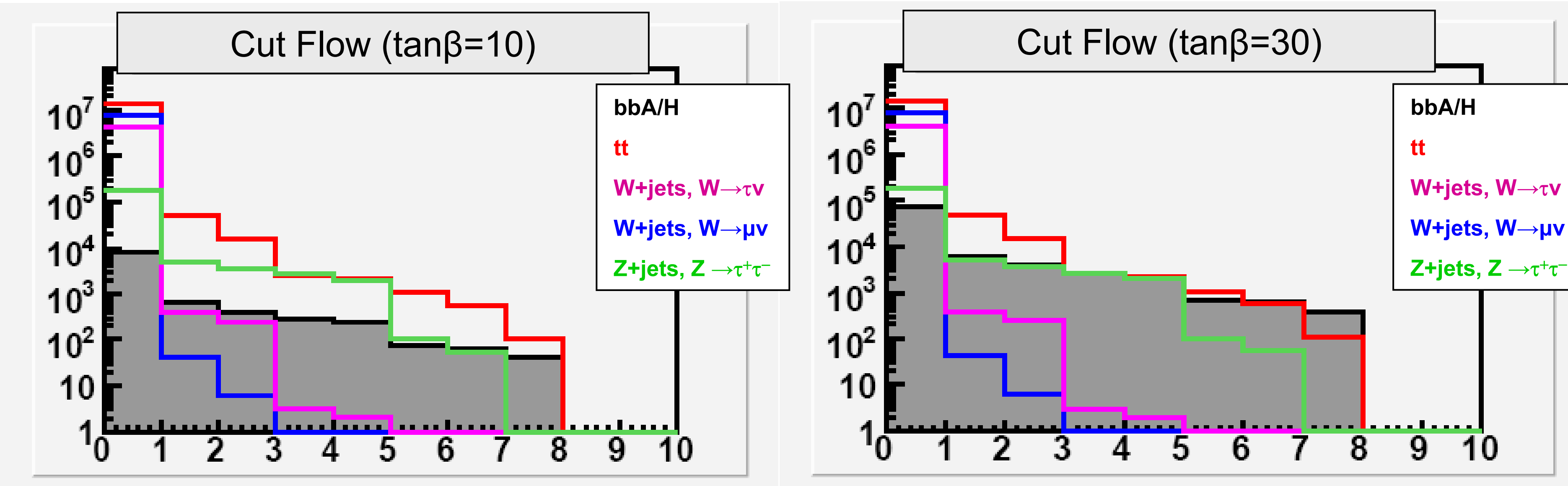
- Require exactly 1 b-jet: Optimized for associated production, rejecting tt events where both b-jets are often reconstructed.
- Require missing energy: Due to neutrino presence in the final state.
- Use events with low $M_T = \sqrt{2 \cdot P_T^l \cdot P_T^{miss} \cdot (1 - \cos \Delta\phi)}$: Reject much of W background which peaks at high (close to W mass) M_T values
- Count events within a mass window around M_A: ΔM=1.5σ (55 GeV)

Discriminating variables II



Analysis

- Expected number of events at 30fb^{-1} and tanβ=10 / 30 , M_A=300GeV



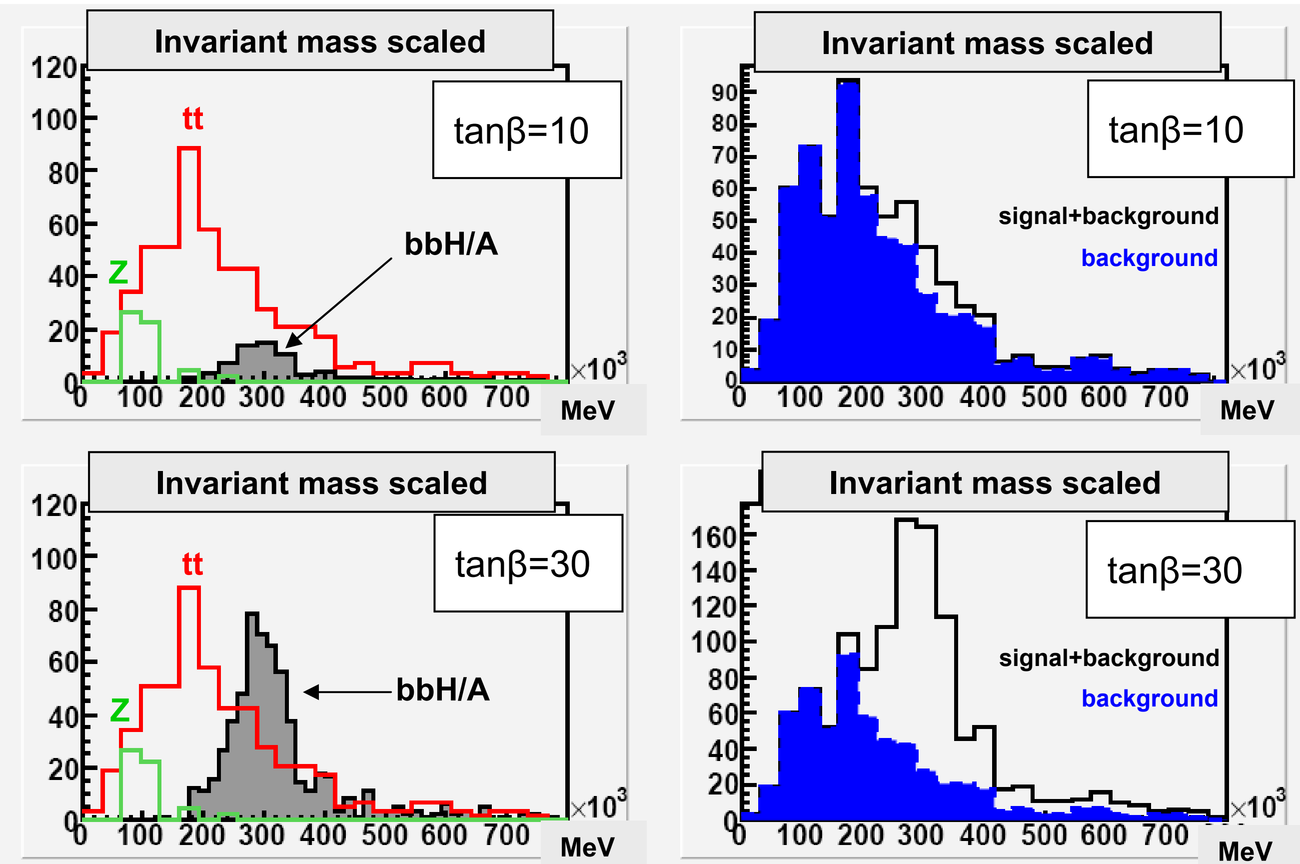
Cuts Applied:

0. All events	**3. M_T**	**6. non b-jet number**
1. lepton-hadron	**4. E_T^{miss}**	**7. $M_A \pm \Delta M$**
2. Coll. Approximation	**5. b-jet number**	

	bbA/H, A/H→τ+τ−	tt → WW W → l ν W → to everything	W± +2jets, W± → μ±ν	W± +2jets, W± → τ±ν	Z+2jets, Z → τ+τ-
$M_A \pm \Delta M$, ΔM = 55 GeV	42±2/385±21	104±13	< 4 (95% CL)	< 3 (95% CL)	< 6 (95% CL)

Analysis results

- For $M_{A/H}$ = 300 GeV at 30 fb^{-1} and tanβ=10 , tanβ=30



	S /√B
tanβ=10	4.1 ± 0.3 (stat)
tanβ=30	38 ± 3 (stat)

- Counting events in a mass window of M_A ± 55 GeV
- For tanβ=10 / 30

signal events 42 / 385

background events 104

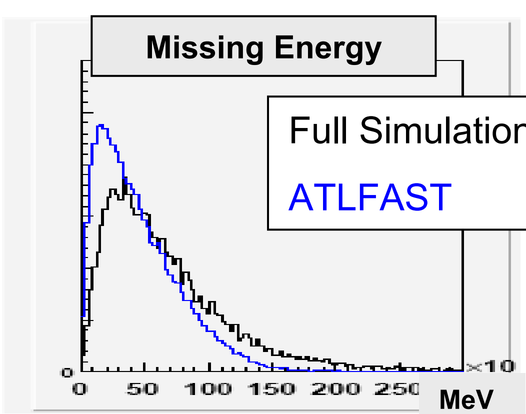
- Signal scaled with a factor 0.13 (tanβ=10) , 1.2 (tanβ=30)
- Background scaled up with a factor 1.7

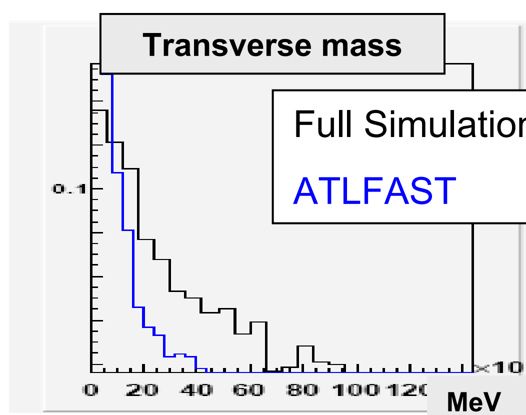
Full Simulation – ATLFAST

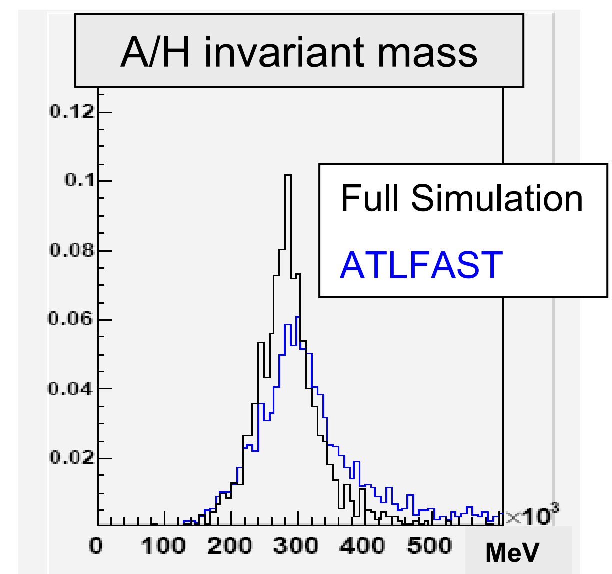
	ATLFAST efficiency	FullSim efficiency	Not matched to truth ATLFAST	Not matched to truth FullSim
μ	93%	90%	0.5%	1%
e	93%	83%	3%	6%
b-jet	52%	45%	8%	6%
τ-jet	40%	38%	1%	5%

- Similar performance
- But overestimated electron reconstruction efficiency in ATLFAST

- Differences that affect event selection







Summary

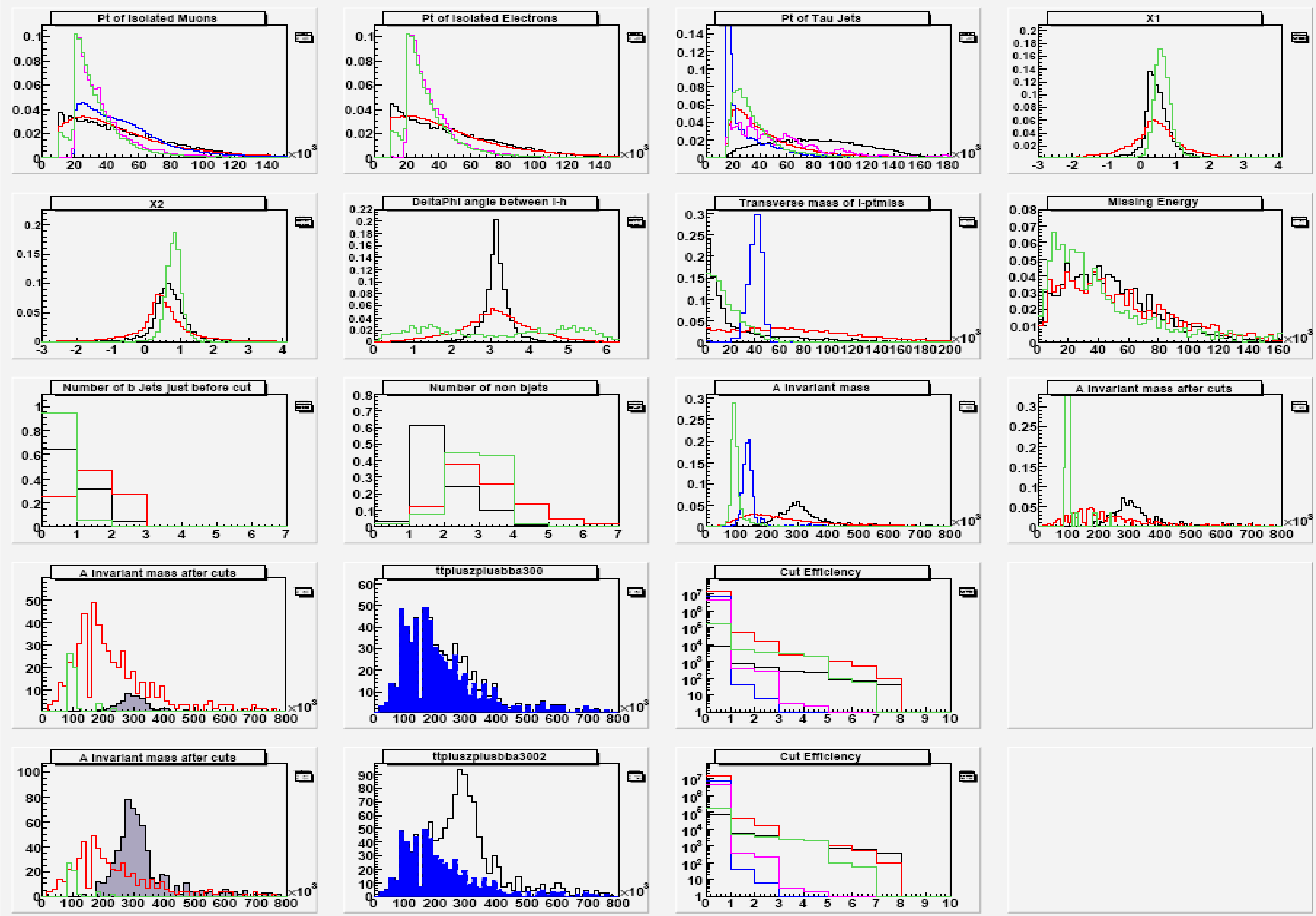
- Analysis in the channel bbA/H, A/H$\rightarrow\tau^+\tau^-\rightarrow$lepton-hadron performed with ATLFAST data using TDR cuts
- For Higgs mass of 300GeV, signal can be observed for tan$\beta\geq$10
- Additional statistics for background are required (smoother shapes for dominant tt, better estimation for Z+jets and W+jets)
- Fast and Full simulation seem to have similar performance with some exceptions to be investigated and understood

<u>To be done:</u>

- ATLFAST Analysis optimization
- Detailed comparison between ATLFAST and Full Simulation

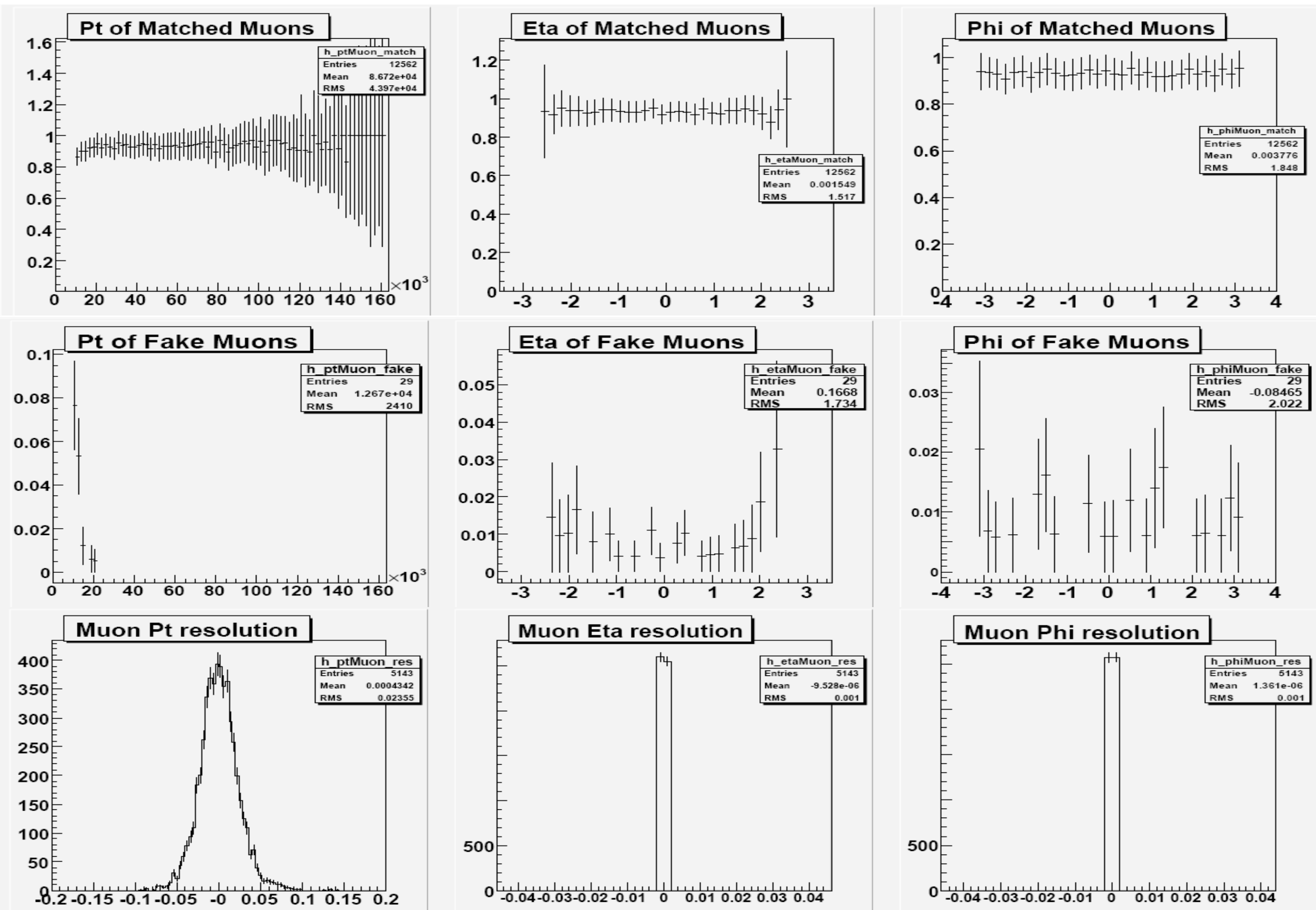
Backup

Discriminating variables – mass



Cut	bbA/H, $A/H \to \tau^+\tau^-$	$tt \to WW$ **$W \to l\nu$** **$W \to$ to everything**	$W^\pm$+2jets, $W^\pm \to \mu^\pm\nu$	$W^\pm$+2jets, $W^\pm \to \tau^\pm\nu$	Z+2jets, $Z \to \tau^+\tau^-$
All Events	7800 / 72000	13.8M	7.6M	4.2M	180k
At least 1 l P_t^l > 24 GeV , $\|n_l\|$<2.5 and 1 τ-jet P_t^h > 40 GeV , $\|n_{\tau jet}\|$<2.5	638 / 5887	44050	42	385	4530
X1, X2	395 / 3643	14022	6	248	3303
M_t < 25 GeV (*)	267 / 2465	2368	0	3	2499
P_t^{miss} > 18 GeV	227 / 2095	2006	0	2	1795
Number of bjets = 1	71 / 655	933	0	1	90
Number of non bjets < 3	67 / 614	546	0	0	56
$M_A \pm \Delta M$, ΔM = 55 GeV	42±2/385±21	104±13	< 4 (95% CL)	< 3 (95% CL)	< 6 (95% CL)

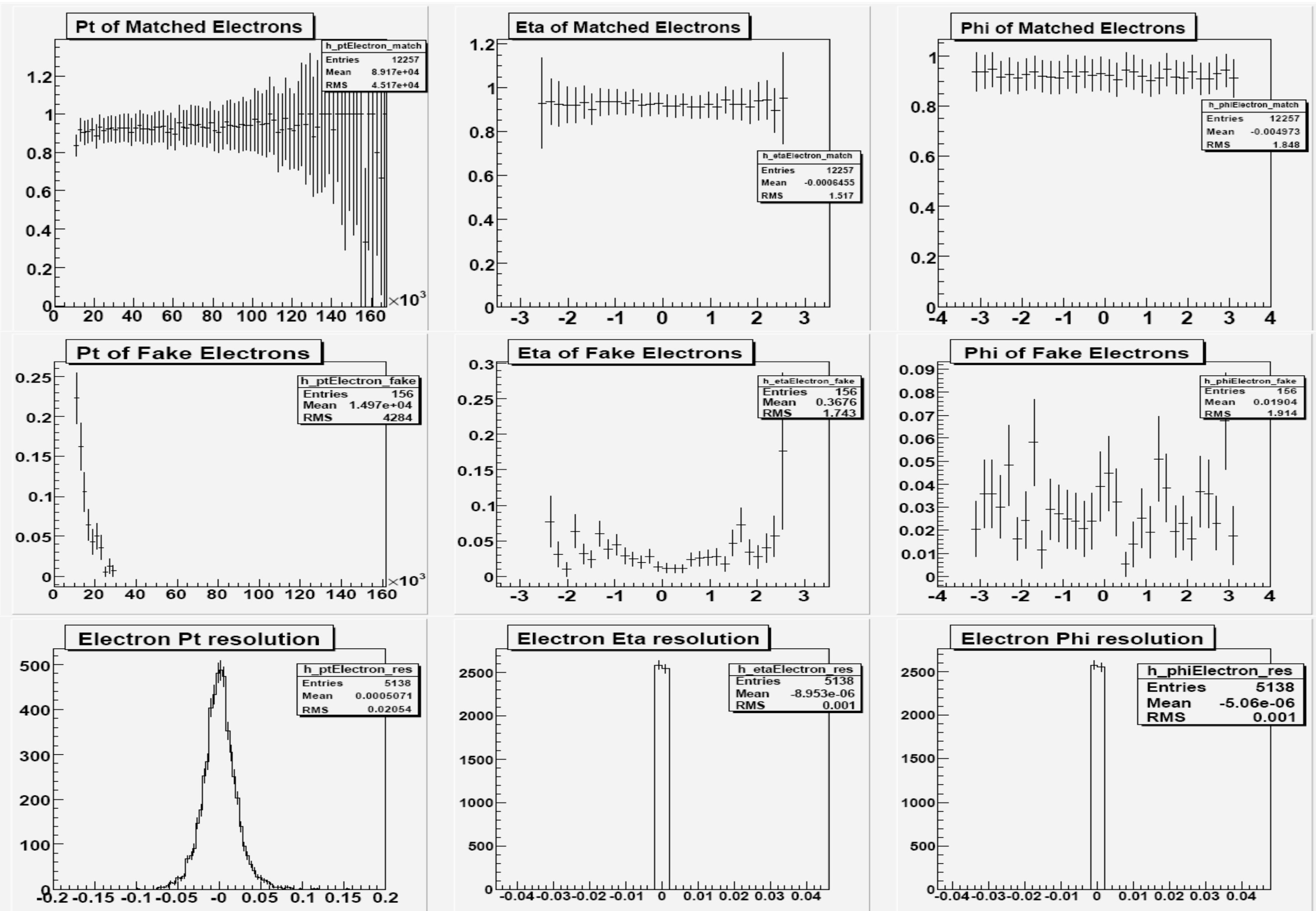
Muon efficiency/fake/resolution



ATLFAST

bbA

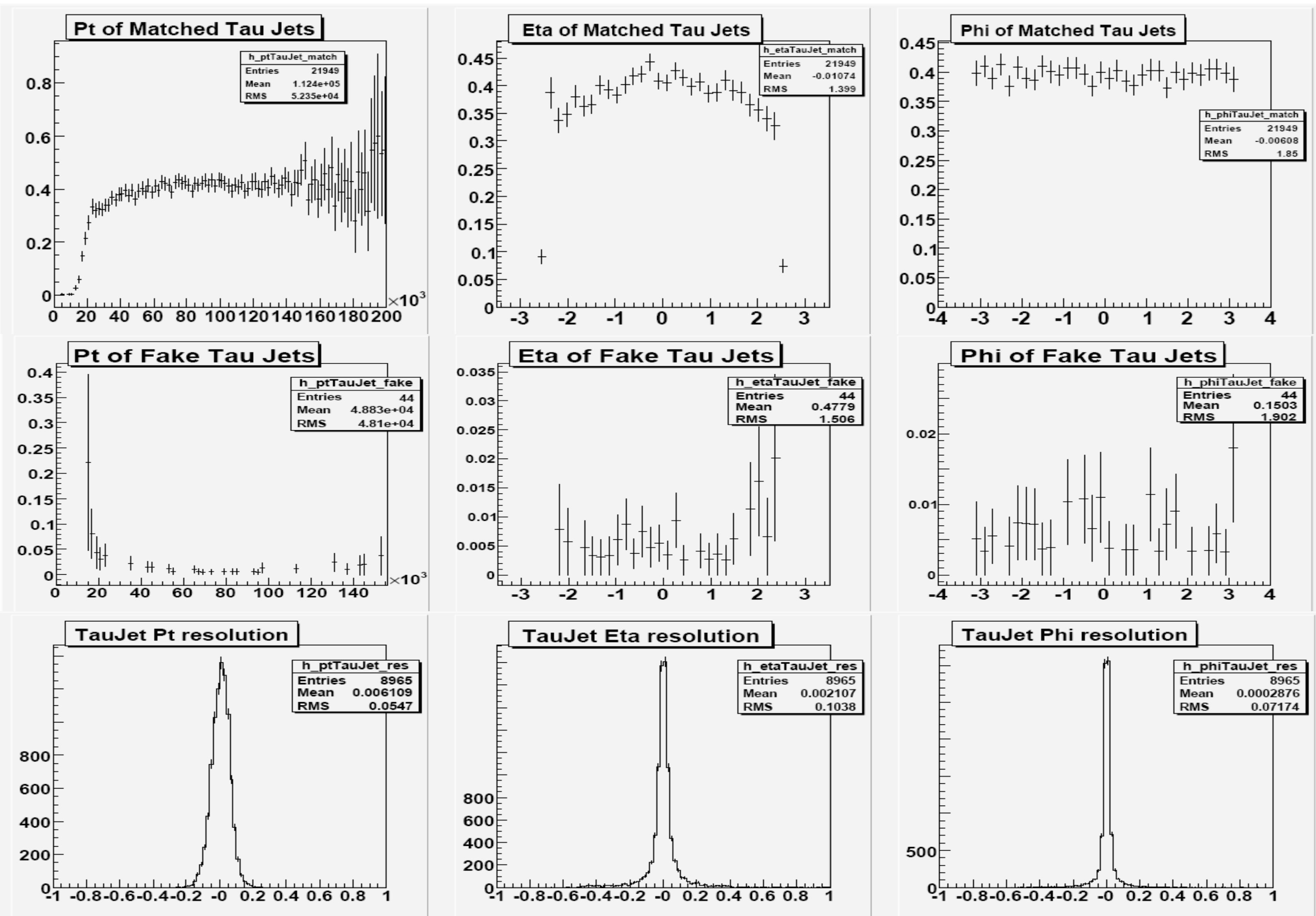
Electron efficiency/fake/resolution



ATLFAST

bbA

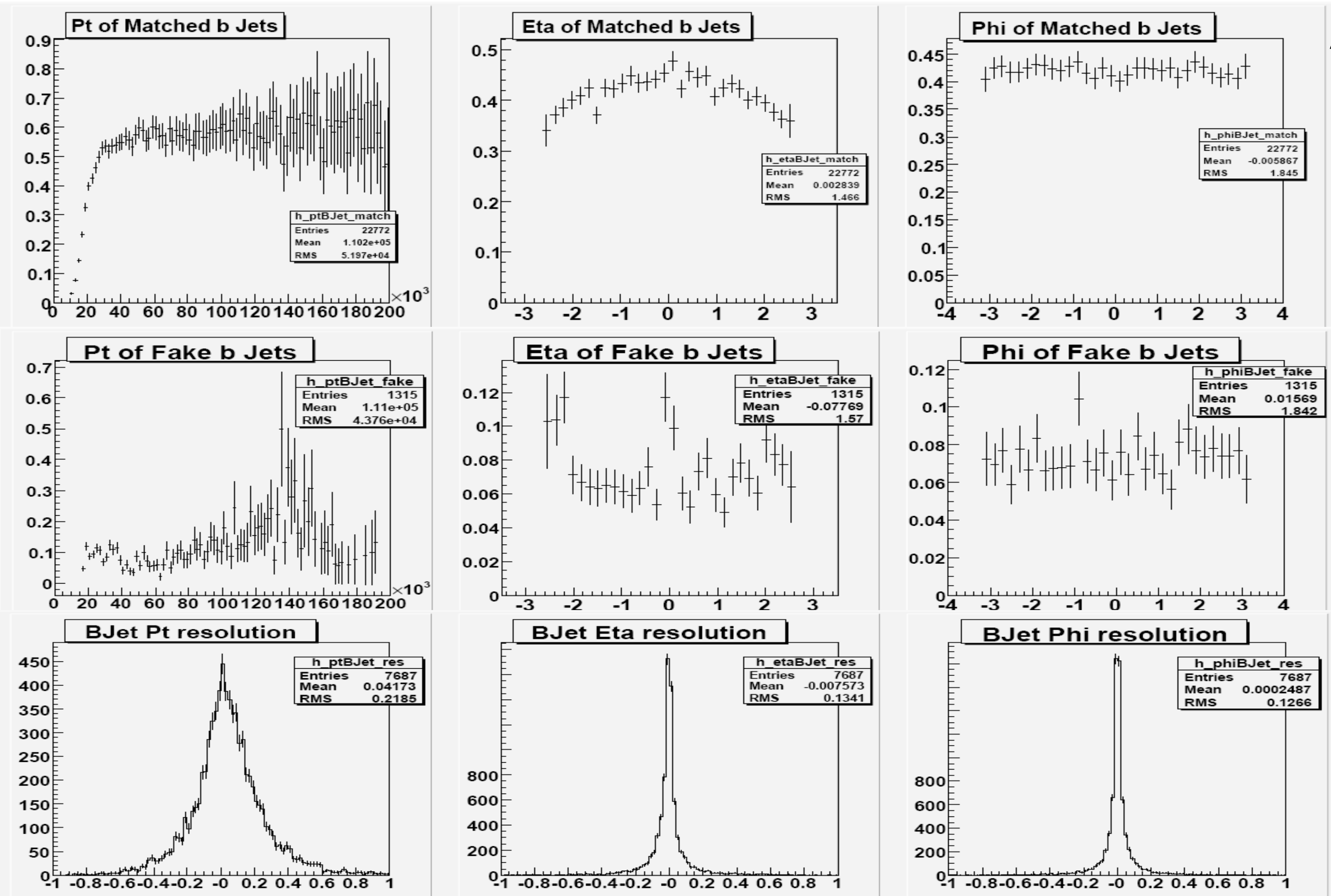
T-jet efficiency/fake/resolution



ATLFAST

bbA

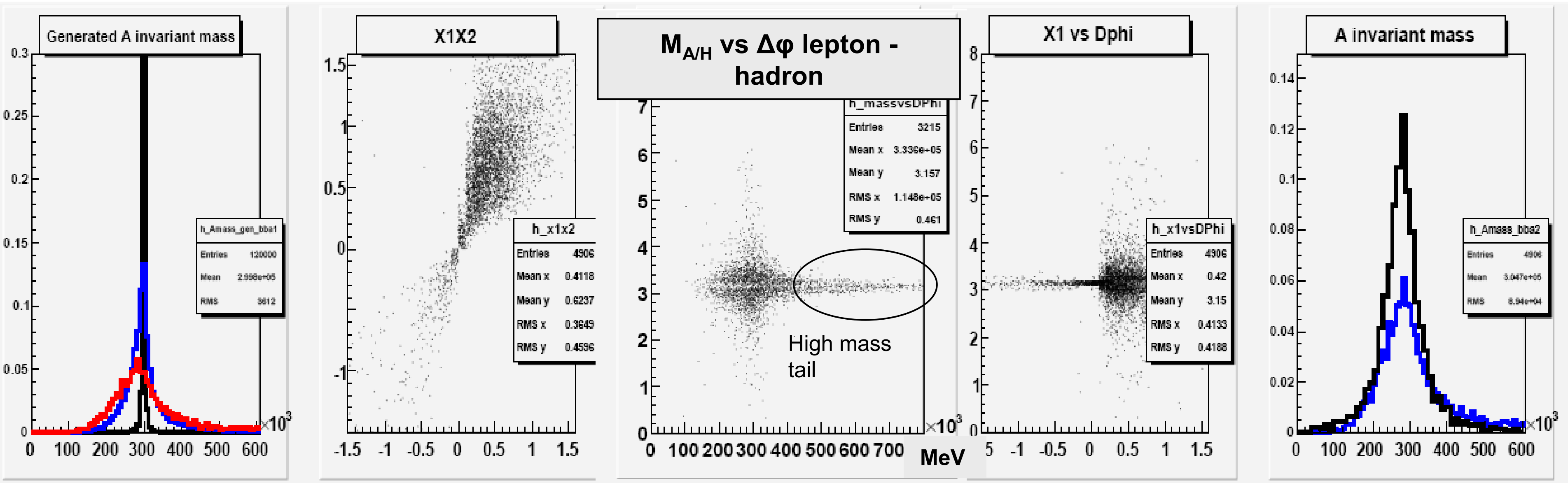
b-jet efficiency/fake/resolution



ATLFAST

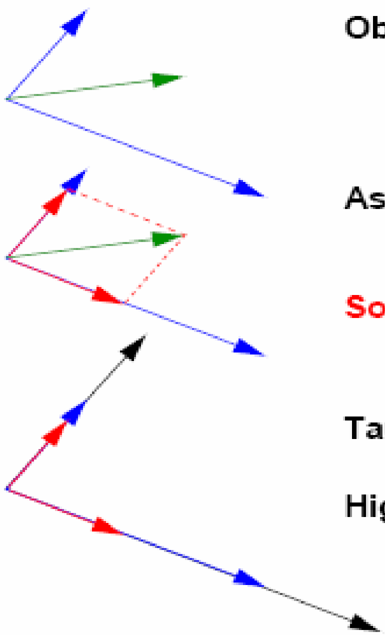
bbA

Mass reconstruction



Mass reconstruction

Mass Reconstruction:



Observe

missing transverse momentum

and visible Tau−decay products

Assume Tau decay products

collinear with original Tau

Solve 2 linear equations

for the neutrinos

Taus can be reconstructed

Higgs can be reconstructed

$$x_{\tau h} = \frac{h_x l_y - h_y l_x}{h_x l_y + \not{p}_x l_y - h_y l_x - \not{p}_y l_x}$$

$$x_{\tau l} = \frac{h_x l_y - h_y l_x}{h_x l_y - \not{p}_x h_y - h_y l_x + \not{p}_y h_x}$$

$$M_{\tau\tau} = \sqrt{2(E_h + E_{\nu h})(E_l + E_{\nu l})(1 - \cos\theta_{\tau\tau})}$$

is equivalent to $M_{\tau\tau} = \frac{M_{ll}}{\sqrt{x_{\tau l} x_{\tau h}}}$

only when $0 < x_\tau < 1$