Sensitivity to the Higgs self-coupling using full simulation

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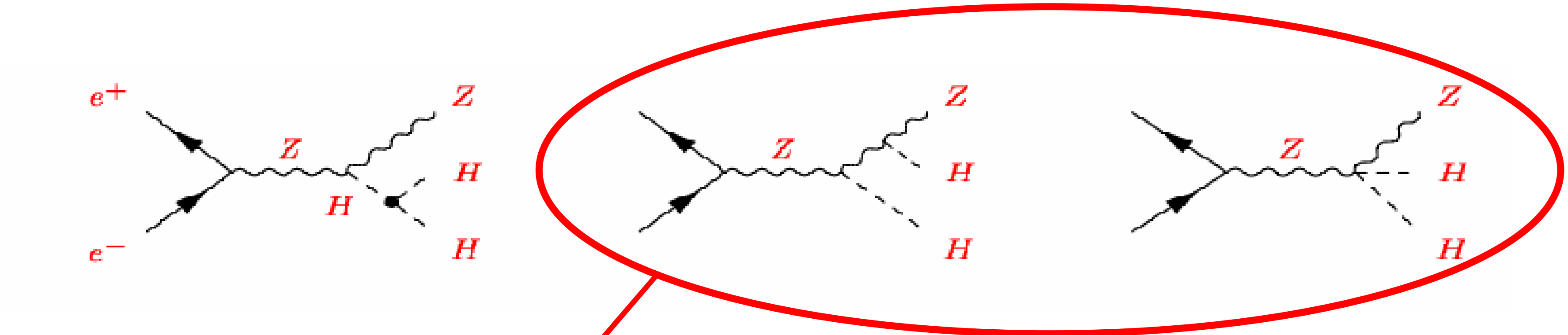
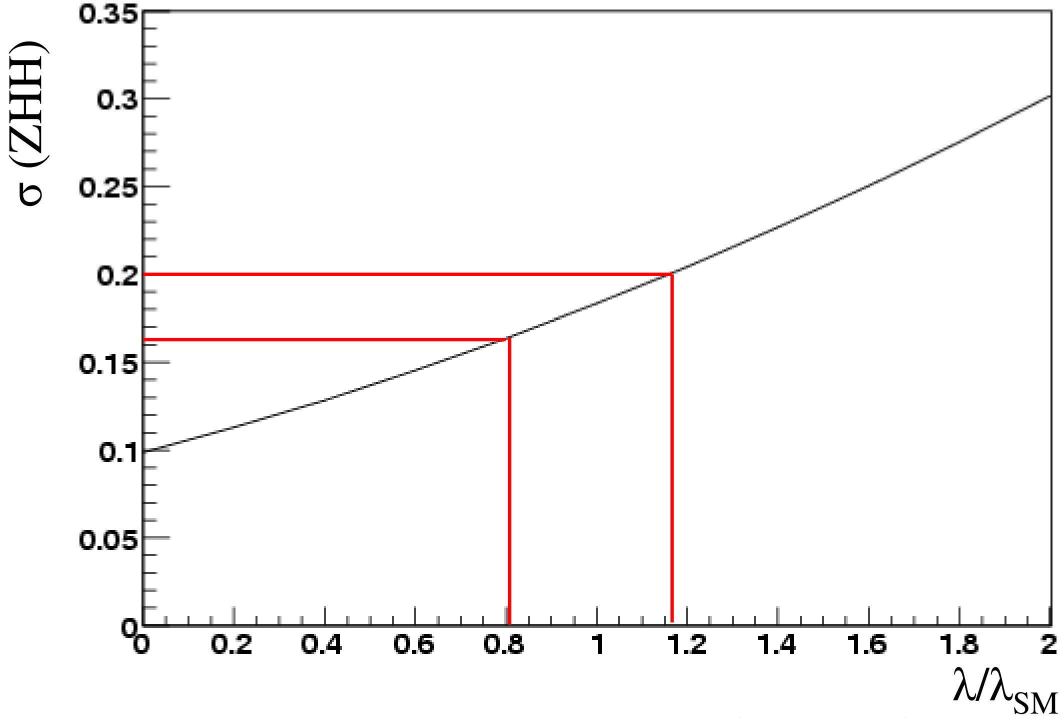
Overview

- Introduction:
  - from ZHH cross section to Higgs self-coupling
- Event simulation and reconstruction
- Cut-based analysis
- Boson selection
  - Realistic and Perfect PFA
- Neural network analysis
- B tagging performance
- Conclusion

Theory



The sensitivity on the cross section and the self coupling are not linear.



10% resolution on σ (ZHH)

↓

18% resolution on λ

Physics parameters

- CM energy 500 GeV and M_H = 120 GeV
  - Maximizes the cross section
- Main channel is ZHH → qqbbbb
  - BR = 40%
- The signal cross section is 0.18 fb
  - less than 100 signal events for 500 fb^{-1}
  - Only 34 qqbbbb events
- Several backgrounds with 6-jet final state:
  - tt is the main one with σ = 710 fb
    - 160,000 hadronic events

Samples generated at RHUL

- 500 fb^{-1} simulated and reconstructed
  - Generator: Pandora Pythia and Whizard
  - Beam line: NLC500
  - Beam Polarization: 80% (e^-), 0% (e^+)
- Detector simulation: Mokka v06-04
  - Detector model: LDC00Sc
  - Physics list: LCPhys
- Reconstruction similar to mass production:
  - Pandora and Perfect Pandora particle flow
  - Vertex reconstruction
    - Including vertex charge

Analysis

- PFA creates the clusters and reconstructed particles
- Force 6 jets reconstruction (Durham)
- B and c tagging from vertex reconstruction
  - Using LCFI package
- Apply preliminary cuts to select ZHH events
- Z → qq + H → bb candidates selected minimizing χ^2 variable
  - Min(χ^2) distribution used to separate signal from backgrounds

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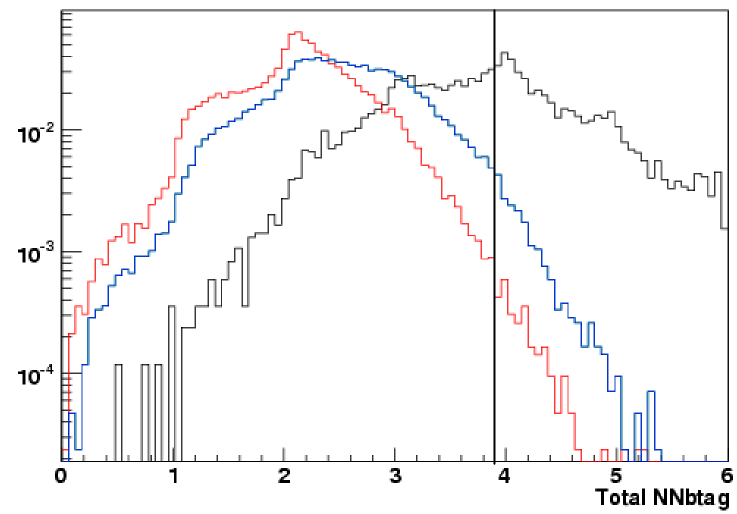
Cut base selection

- b tagging > 3.9 NNBtag
  - Main variable
- Missing energy:
  - Total reconstructed energy
- Topological cuts:
  - Cos(θ_{thrust}), Thrust, Fox-Wolfram moments



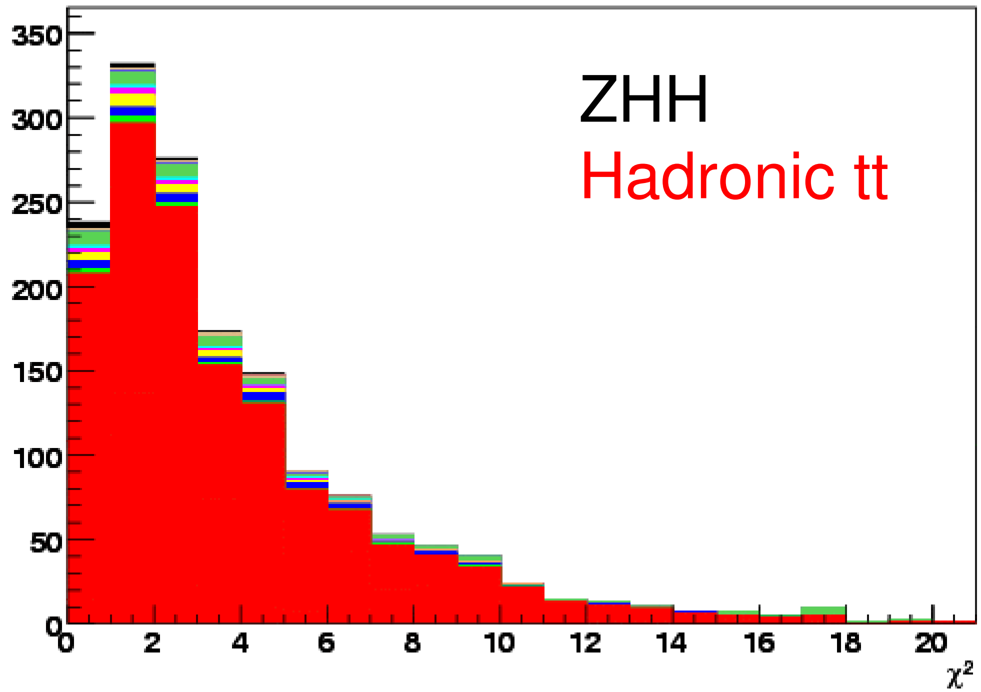
- 2- and 4-jets events can be rejected using:
  - Jets EnergyEM/Energy, Jet number of particles, Y_6, Number of charged tracks
- Multi-variables optimization performed to maximize $S/\sqrt{(S+B)}$
- After cuts $S/\sqrt{(S+B)} = 0.36 \pm 0.01$

Jet pairing

- The jets are combined in all 45 possible permutations
- For each permutation a χ^2 is evaluated

$$\chi^2 = \frac{(M_{12} - M_Z)^2}{\sigma_Z^2} + \frac{(M_{34} - M_H)^2}{\sigma_H^2} + \frac{(M_{56} - M_H)^2}{\sigma_H^2}$$

- The combination that give the minimum χ^2 is chosen



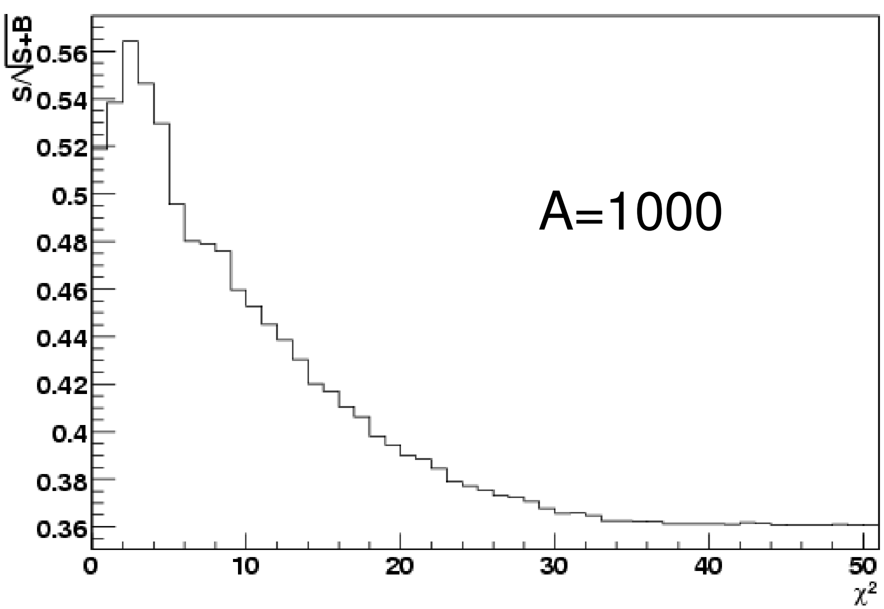
No separation

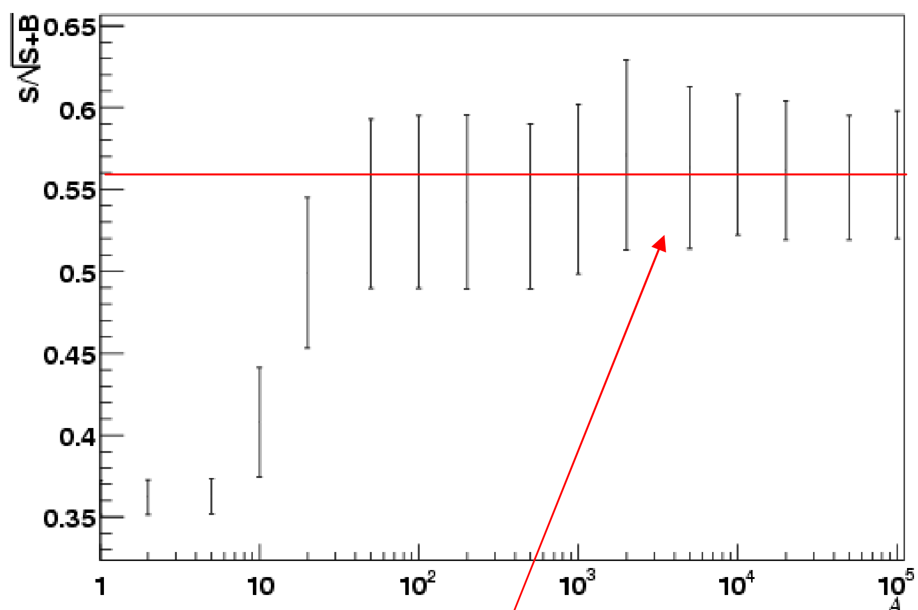
Combining b tagging

- A second χ^2 has been used combining the masses (PFA dependent) and b tagging

$$\chi^2 = \frac{(M_{12}-M_Z)^2}{\sigma_Z^2} + \frac{(M_{34}-M_H)^2}{\sigma_H^2} + \frac{(M_{56}-M_H)^2}{\sigma_H^2} + \sum_{i=3,4,5,6} A(NNbtag(i)-1)^2$$

Optimized maximizing S/√(S+B)





Flat for high *A* → B tag dominates

Kinematic fitting

- Kinematic fitting is performed varying the jet energy E^{fit}

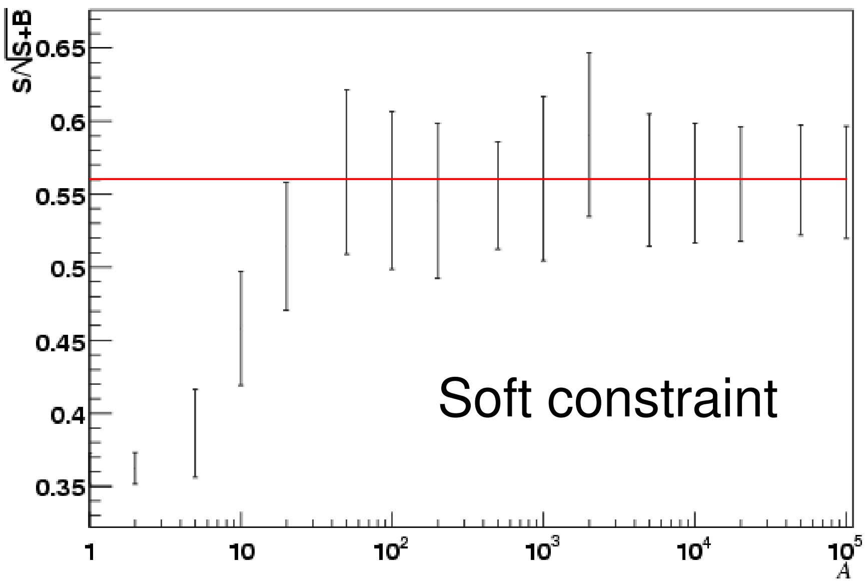
$$\chi^2 = \frac{\left(M_{12}^{fit} - M_Z\right)^2}{\sigma_Z^2} + \frac{\left(M_{34}^{fit} - M_H\right)^2}{\sigma_H^2} + \frac{\left(M_{56}^{fit} - M_H\right)^2}{\sigma_H^2} +$$

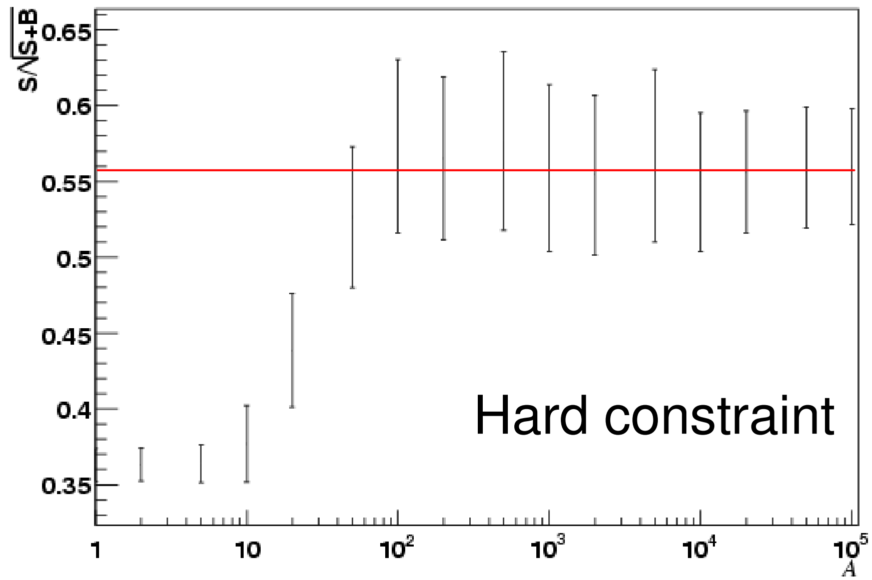
$$\sum_{i=3,4,5,6} A\left(NNbtag\ (i) - 1\right)^2 + \sum_{i=1}^{6} \frac{\left(E^{fit} - E^{reco}\right)^2}{\sigma_{ene}^2}$$

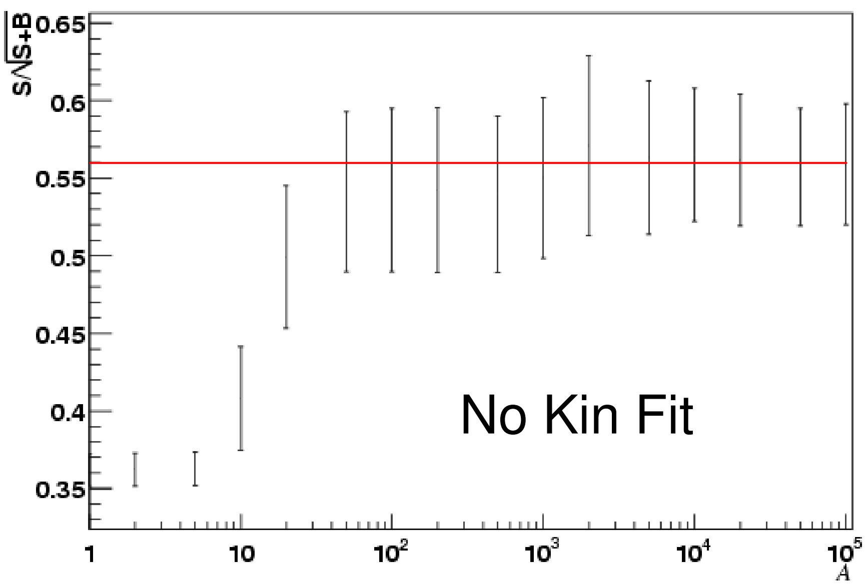
σ

- Two possibilities to constrain the Higgs:
  - Hard constraint → σ_H = 30 MeV
  - Soft constraint → σ_H = 7.2 GeV
- A optimized as before

S/√(S+B) Realistic PFA



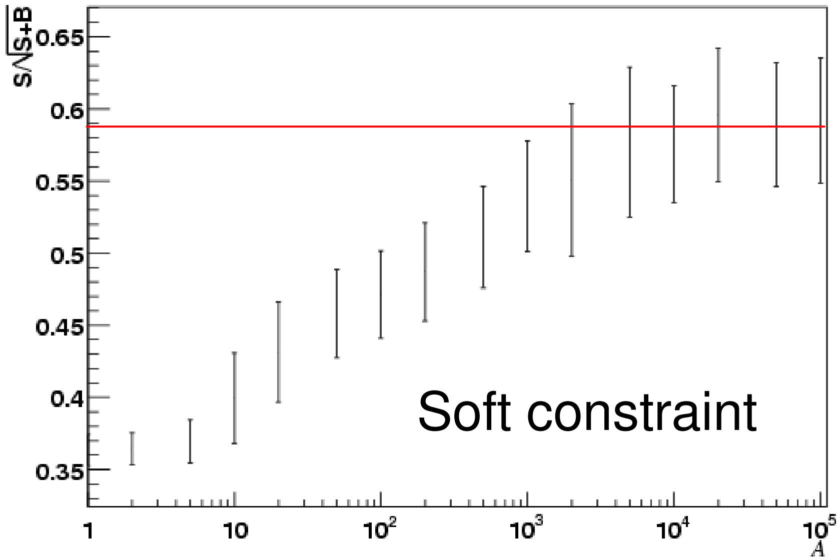


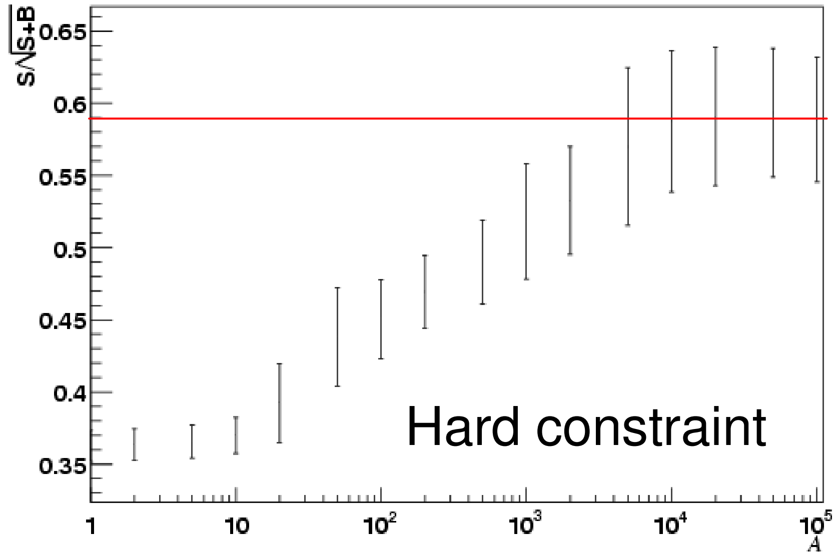


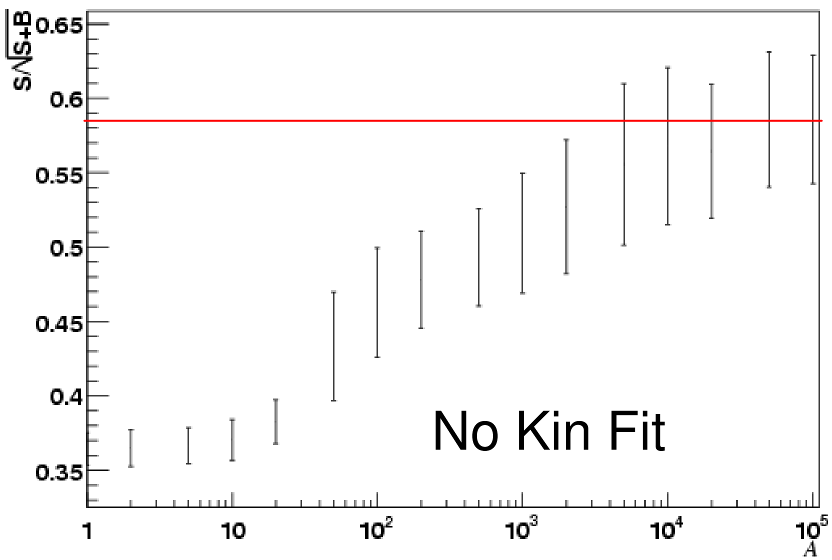
Similar result with and without kin fit

Best S/√(S+B) is 0.56±0.06

S/√(S+B) Perfect PFA







Realistic PFA

Best S/√(S+B): 0.56 ±0.06

Perfect PFA

Best S/√(S+B): 0.59 ±0.06

Neural network analysis

- Different samples are used to train the networks:
  - 30000 ZHH → qqbbbb
  - 125 fb^{-1} for the backgrounds.
- Events that pass the selection cuts, are used to train the neural network.
  - Only 300 background events passes the cuts, too few to include many variables in the network.
- ANN in TMVA is used for implementing the neural network.

Neural network analysis

- Three variables are considered:
  - $\chi_{ZHH}^{2} = \frac{\left(M_{12}^{fit} - M_Z\right)^2}{\Gamma_Z^2} + \frac{\left(M_{34}^{fit} - M_H\right)^2}{\Gamma_H^2} + \frac{\left(M_{56}^{fit} - M_H\right)^2}{\Gamma_H^2}$
  - $\chi_{tt}^{2} = \frac{\left(M_{12}^{fit} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(M_{45}^{fit} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(M_{123}^{fit} - M_T\right)^2}{\Gamma_T^2} + \frac{\left(M_{456}^{fit} - M_T\right)^2}{\Gamma_T^2}$
  - B tagging of 4 most b-like jets
- Two networks trained:
  - First and last variables only
  - All three variables
- Optimization performed using max(S/√(S+B)), calculated as a function of the NN output

NN result

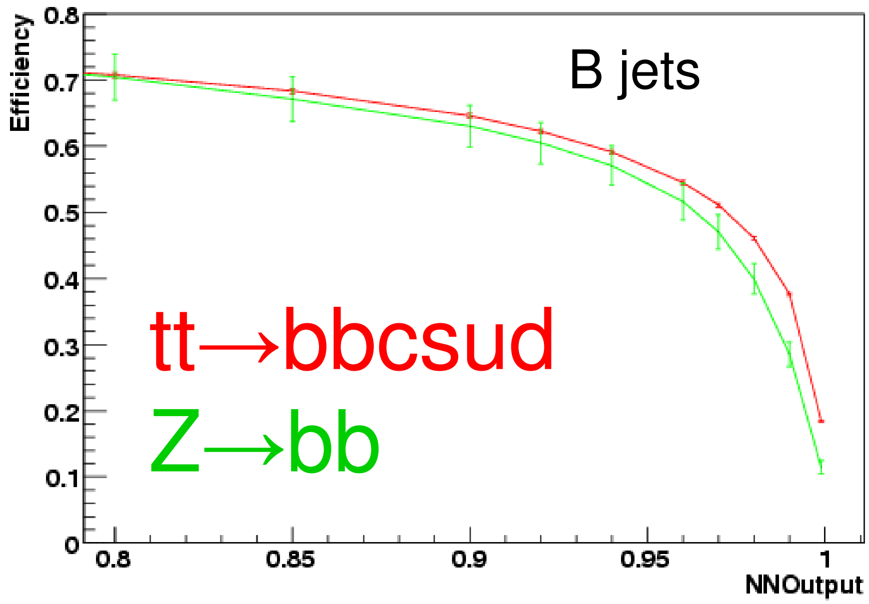
- The two networks give similar results:
  - 2 Var. : $S/\sqrt{(S+B)} = 0.57 \pm 0.06$
  - 3 Var. : $S/\sqrt{(S+B)} = 0.54 \pm 0.06$

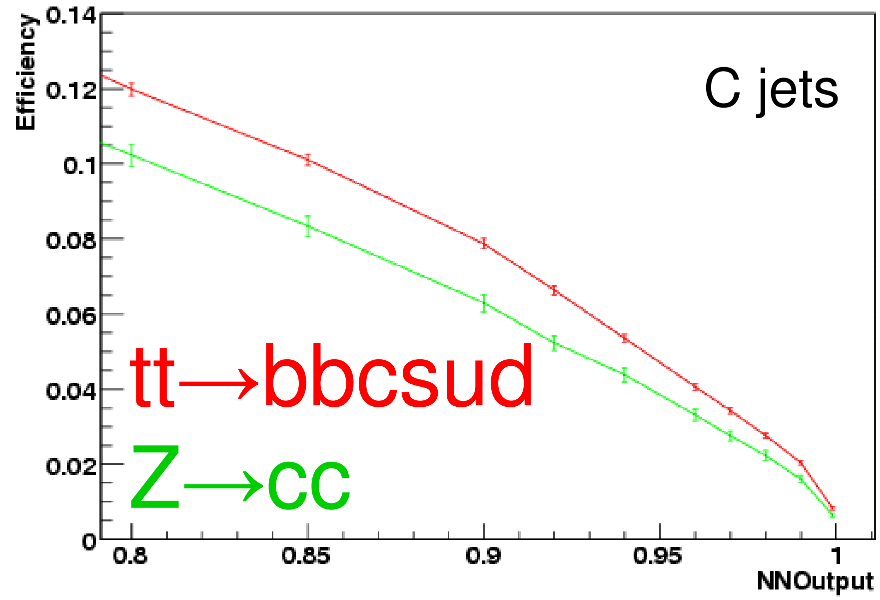
B-tagging crucial for the analysis

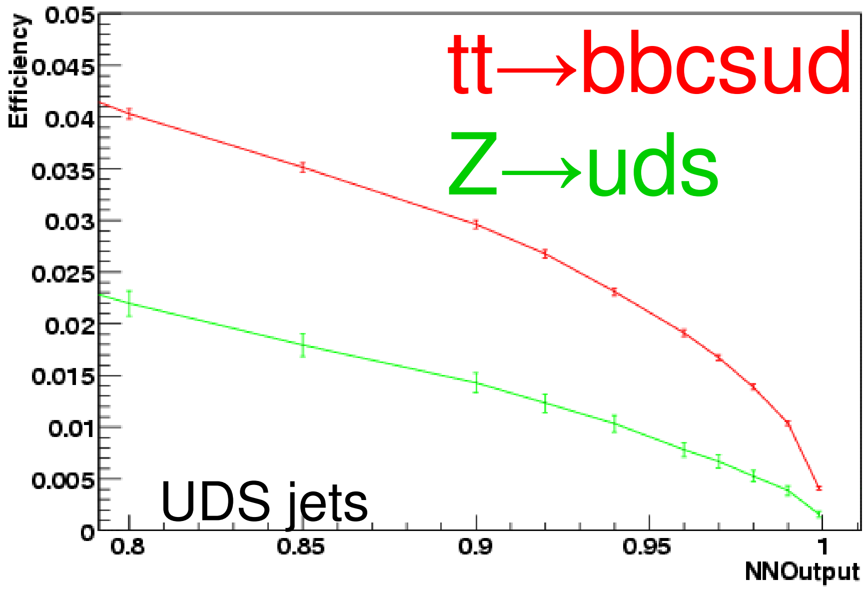
Analysis	$S/\sqrt{(S+B)}$	S	B
Simple $\chi 2$	0.36 ± 0.01	13.5	1364.5
$\chi 2$ with b tag term	0.55 ± 0.06	4	47
$\chi 2$ with b tag term and kin. fit.	0.56 ± 0.06	6.4	124.4
NN two variables	0.57 ± 0.06	5.8	99.2
NN three variables	0.54 ± 0.06	7.5	186

- The resolution ($\frac{\sqrt{S+B}}{S}$) to such process is 180%

B tagging





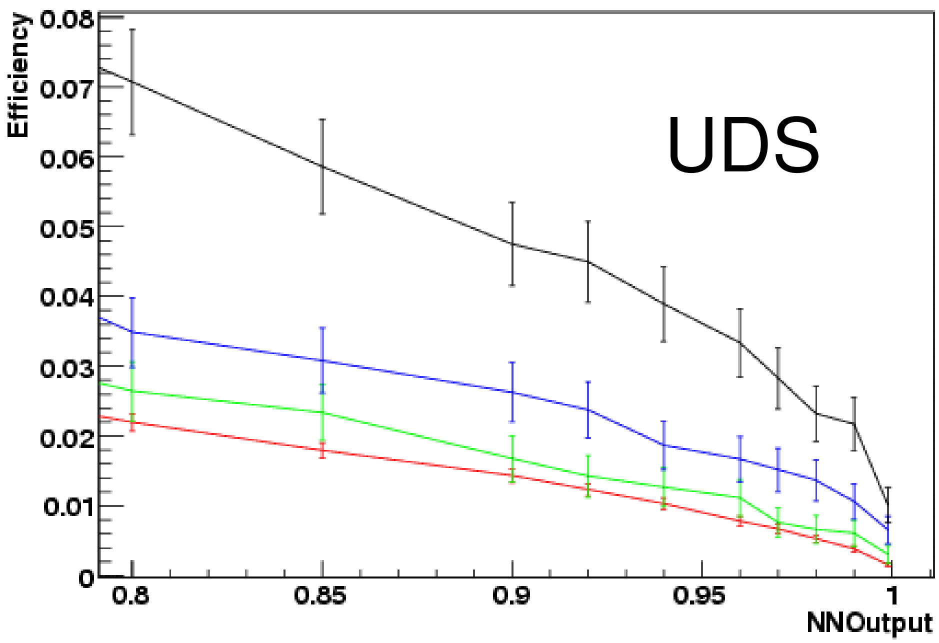


Better b tagging efficiency for b jets
Fake rate for c jets is ~25% higher
Fake rate is almost double for light jets

Difference is only due to environment, can it be corrected?

tt always higher than Z, can it be energy dependent?

B tagging



It is energy dependent!

Z→qq at 500 GeV
Z→qq at 360 GeV
Z→qq at 200 GeV
Z→qq at 90 GeV

Studies and improvements needed on b-tagging algorithms as a function of:

- number of jets
- jet energy

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Conclusions

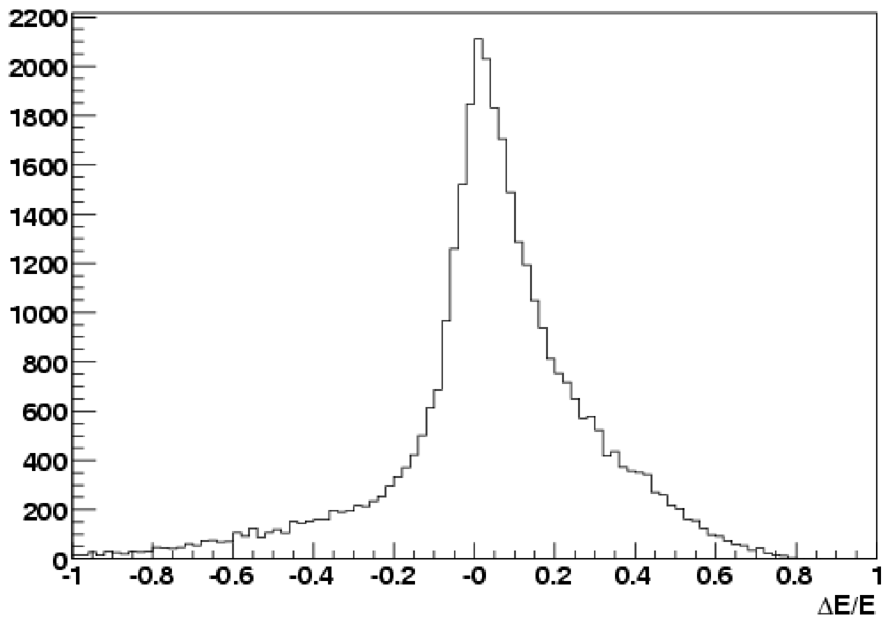
- An LC note will soon be released
- The resolution ($\frac{\sqrt{S+B}}{S}$) to such process is 180%
- Using b-tagging performances similar to the Z→qq in 6-jets environment, the obtained resolution is 95%
  - This value is close the resolution obtained from fast simulation studies (scaling to same integrated luminosity)

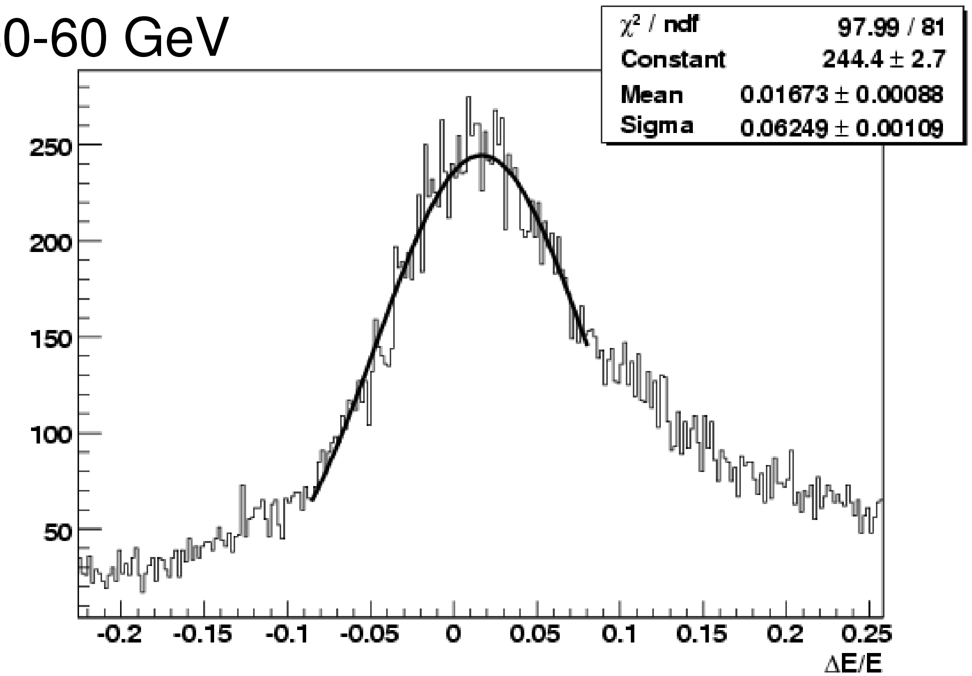
Backup Slides

Jet energy resolution

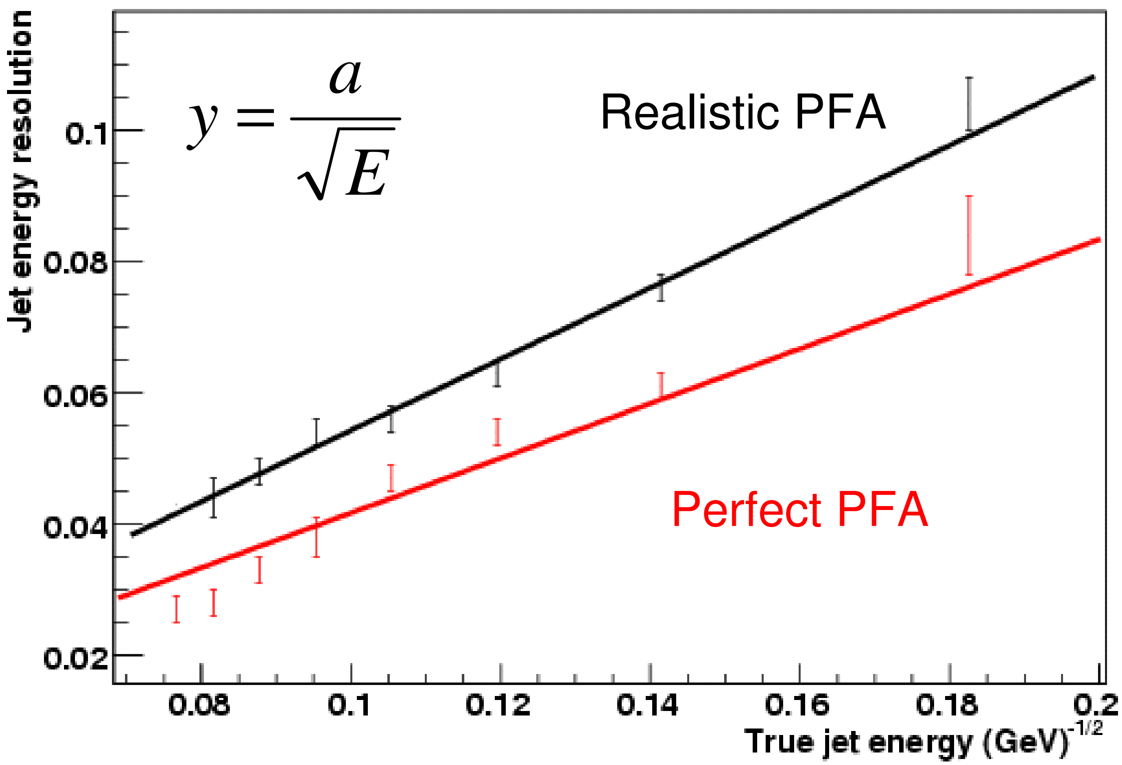
- The reconstructed jets are paired to the Monte Carlo quarks using the combination that maximizes the sum of the six scalar products
- All jets are divided in bins of energy, for each bin the resolution is evaluated

Jets of 40-60 GeV





Jet energy resolution

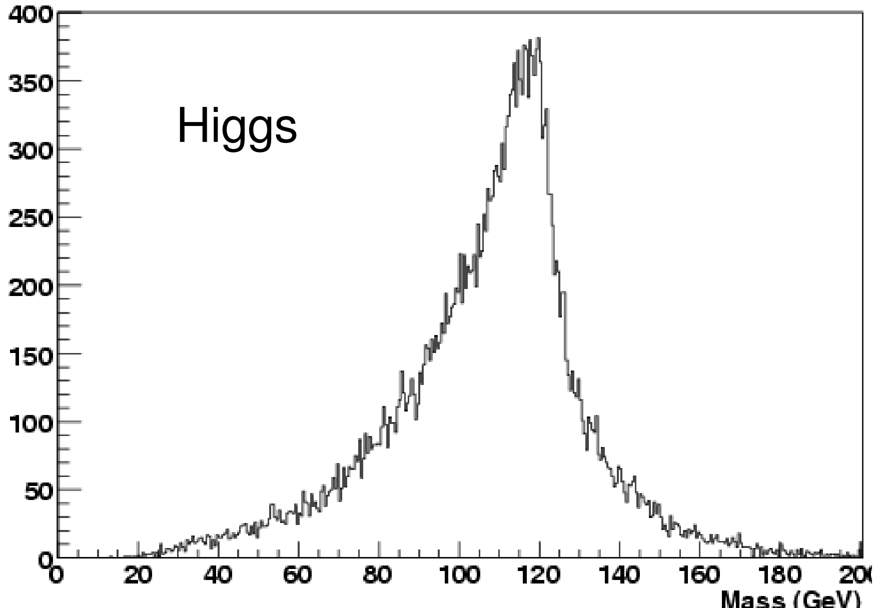


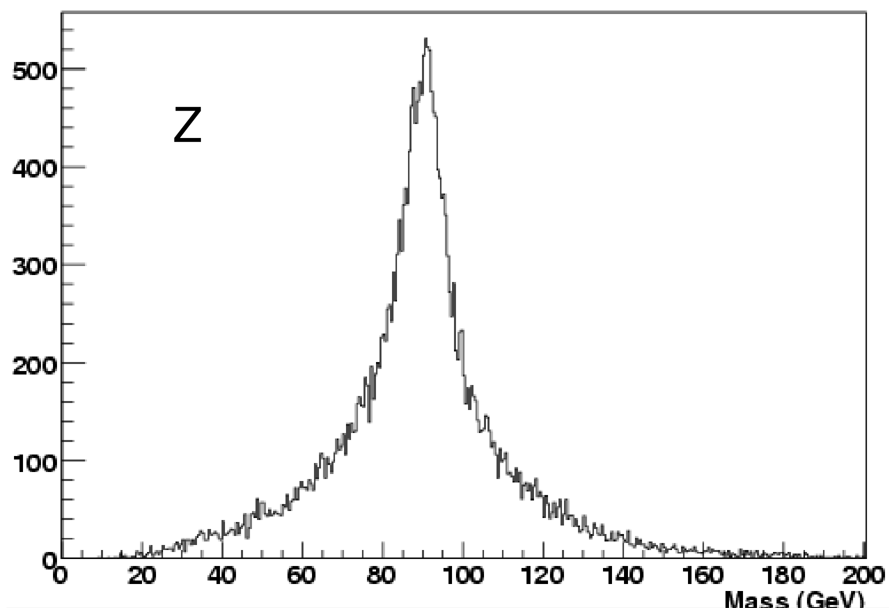
	Jet energy resolution
Realistic PFA	$(54 \pm 1)\%/\sqrt{E}$
Perfect PFA	$(42 \pm 1)\%/\sqrt{E}$

NB: reconstruction tested on Z→uu events and RMS agrees with M. Thomson results.

Boson mass resolution

- Using the same pairing, it is possible to reconstruct the bosons using the correct jets

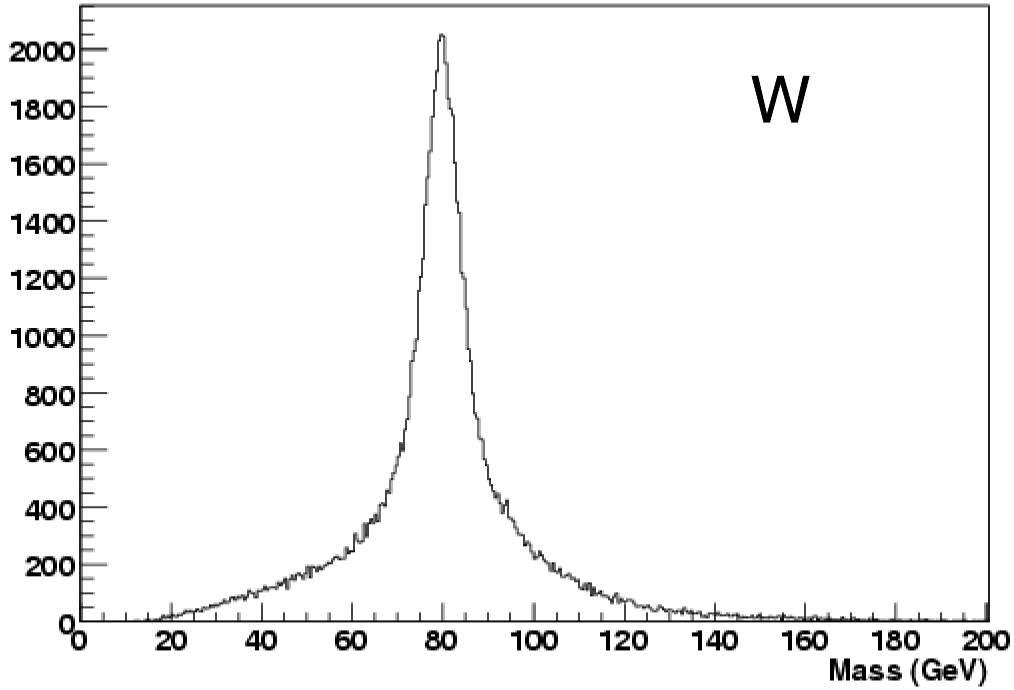


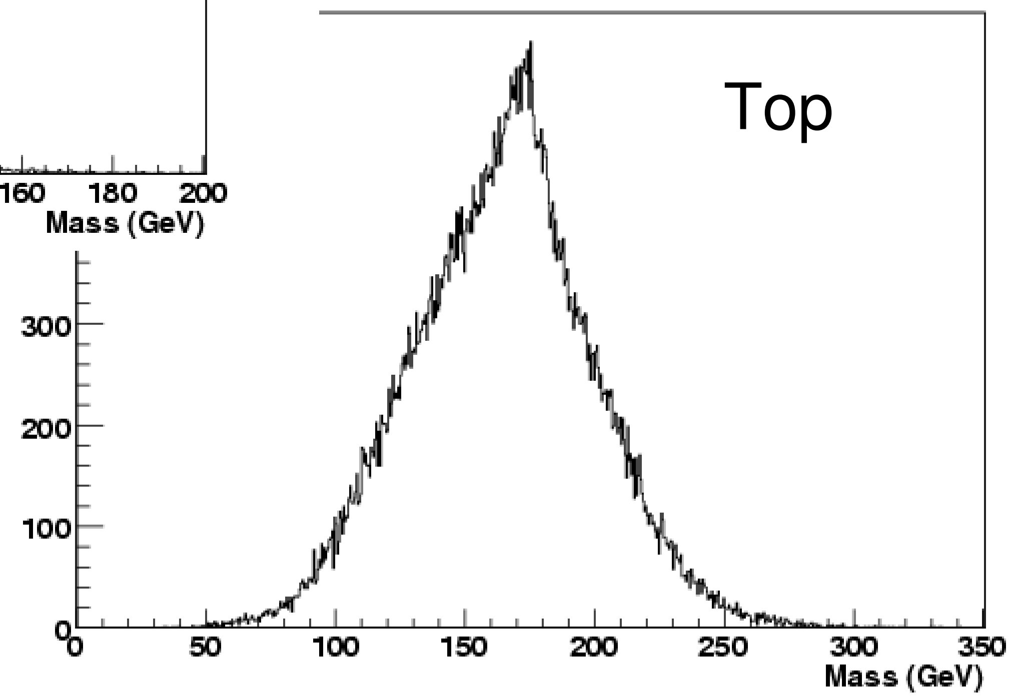


Realistic PFA	Mass (GeV)	Width (GeV)
Higgs	116.6 ± 0.3	7.2 ± 0.4
Top	172.8 ± 0.4	20 ± 2
Z	90.3 ± 0.1	6.0 ± 0.1
W	79.9 ± 0.1	4.8 ± 0.1

Perfect PFA	Mass (GeV)	Width (GeV)
Higgs	115.6 ± 0.2	5.8 ± 0.4
Top	169.1 ± 0.3	15 ± 2
Z	88.7 ± 0.1	5.1 ± 0.2
W	78.6 ± 0.1	3.8 ± 0.1

Mass W and Top





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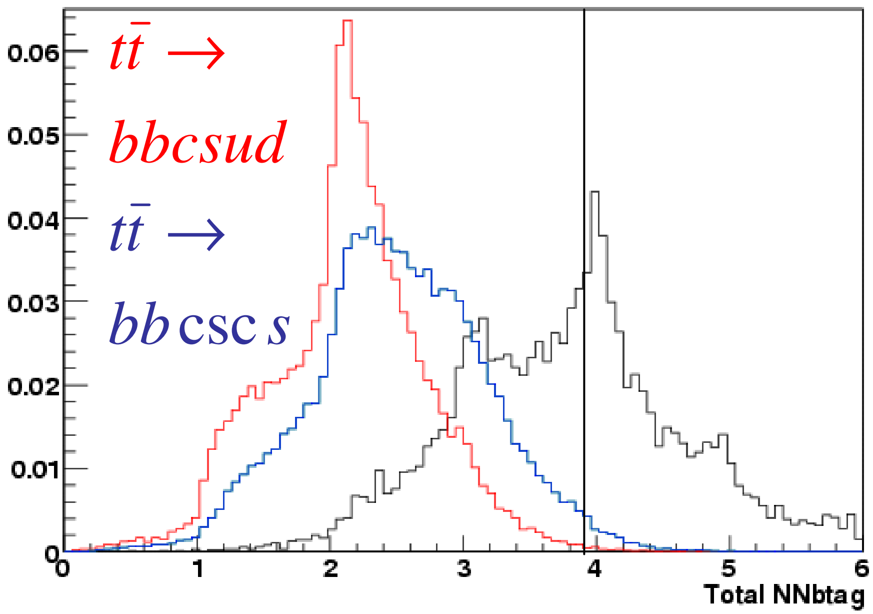
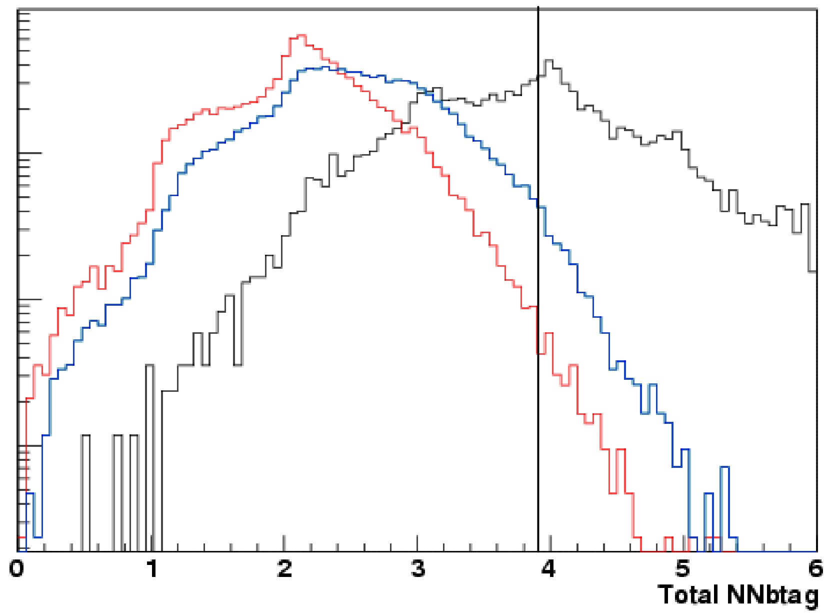
B tagging cut

- b tagging plays a central role in reducing the background: requiring 3.9 NNBtag





- After the cut $S/\sqrt{(S+B)} = 0.24$

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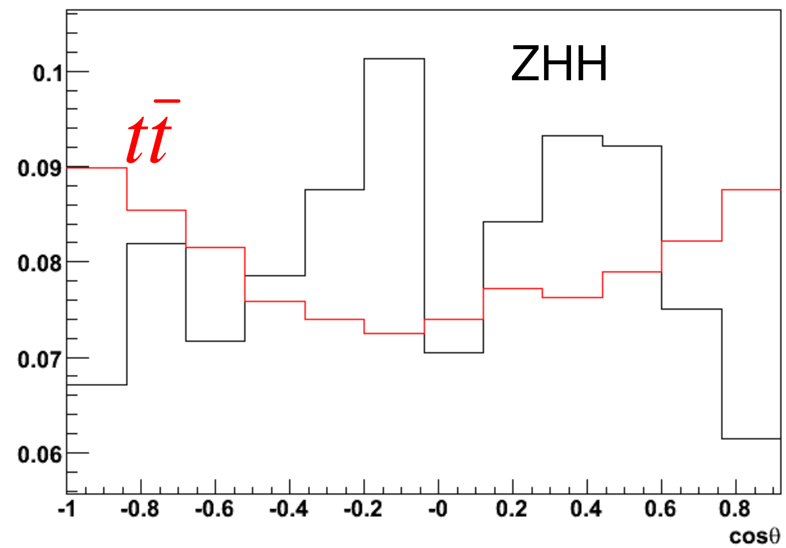
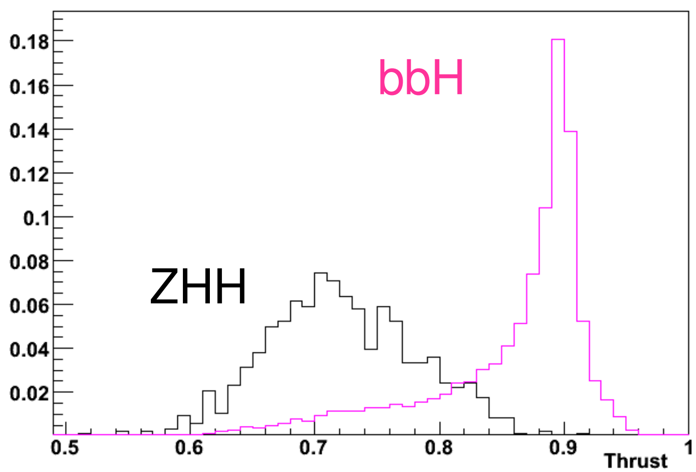
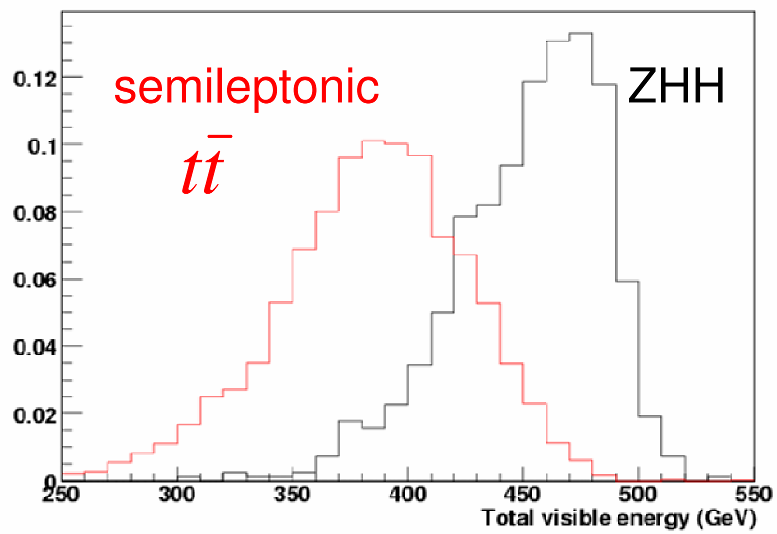
Used cuts

- Topological cuts:
  - Cos(θ_{thrust})
  - Thrust
  - Fox-Wolfram moments
- Missing energy:
  - Total reconstructed energy







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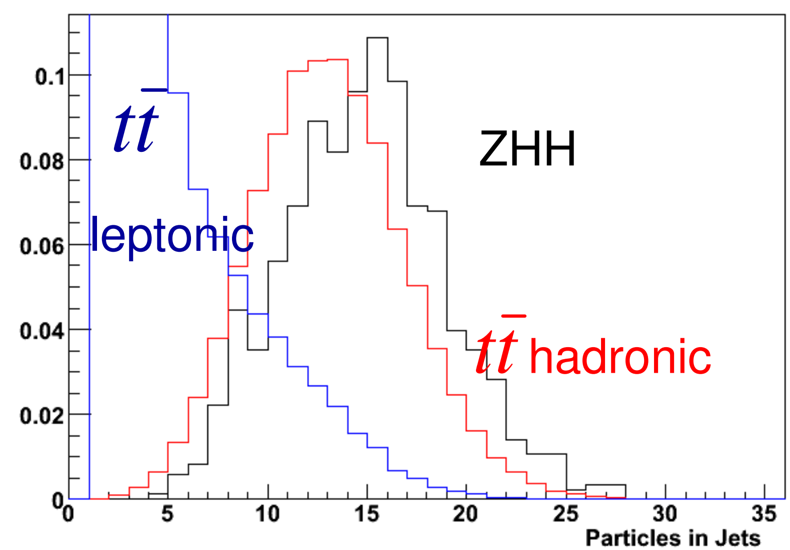
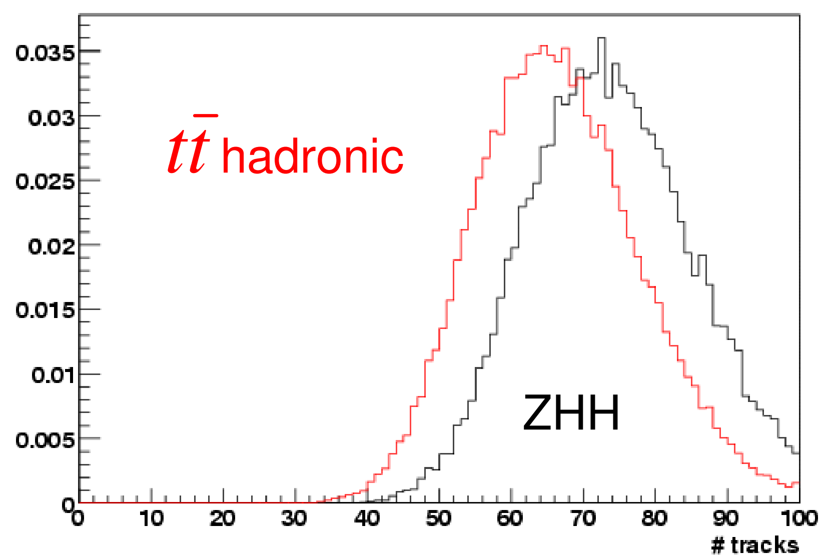
Used cuts

- 2 and 4 jets events can be rejected using:
  - Jets EnergyEM/Energy
  - Jet number of particles
  - Y_6
  - Number of charged tracks



- Multi variables optimization performed to maximize $S/\sqrt{(S+B)}$

- After cuts $S/\sqrt{(S+B)} = 0.36$



Cross sections

Event type	σ (fb)	Events/500fb^{-1}	Generated events (PP)	Simulated events (Mokka)	% of available events/500fb^{-1}
Zhh (tot)	0.16	80			
Zhh→qqbbbb	0.0593	34	1000	1000	3375
ttbar (lept)	73	36500	100000	30000	82
ttbat (mixed)	310	155000	100000	45000	29
ttbar (cqcq)	82	41000	200000	41000	100
ttbar (uquq)	82	41000	200000	15000	37
ttbar (cquq)	164	82000	300000	41000	50
bbh	10.6	5300	30000	16000	302
ZZh	0.174	87	1000	1000	1150
ZZZ	1.05	525	0	0	0
WWZ	35.3	17650	0	0	0
tth	0.15	75	0	0	0
ttZ	0.7	350	0	0	0
tbW	16.8	8400	0	0	0

Fast MC results

- Two studies performed by P. Gay and T. Barklow.
- P. Gay group achieves a resolution on the cross section of ~10% using all Z decay channels
- T. Barklow reaches ~ 20% using only hadronic one.
- Both use 2000 fb^{-1} instead of 500 fb^{-1} and jet energy resolution of $30\%/\sqrt{E}$
- However these analyses do not have gluon emission
  - Barklow made a study pointing out a factor 2 worse resolution when using gluon emission
- Considering both the luminosity and the gluon emission factors, a resolution of about 80% should be achieved