An attempt to measure the WW cross section in the fully hadronic decay channel with ATLAS

Young scientists workshop – Castle Ringberg

24th of July 2013

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

ATLAS

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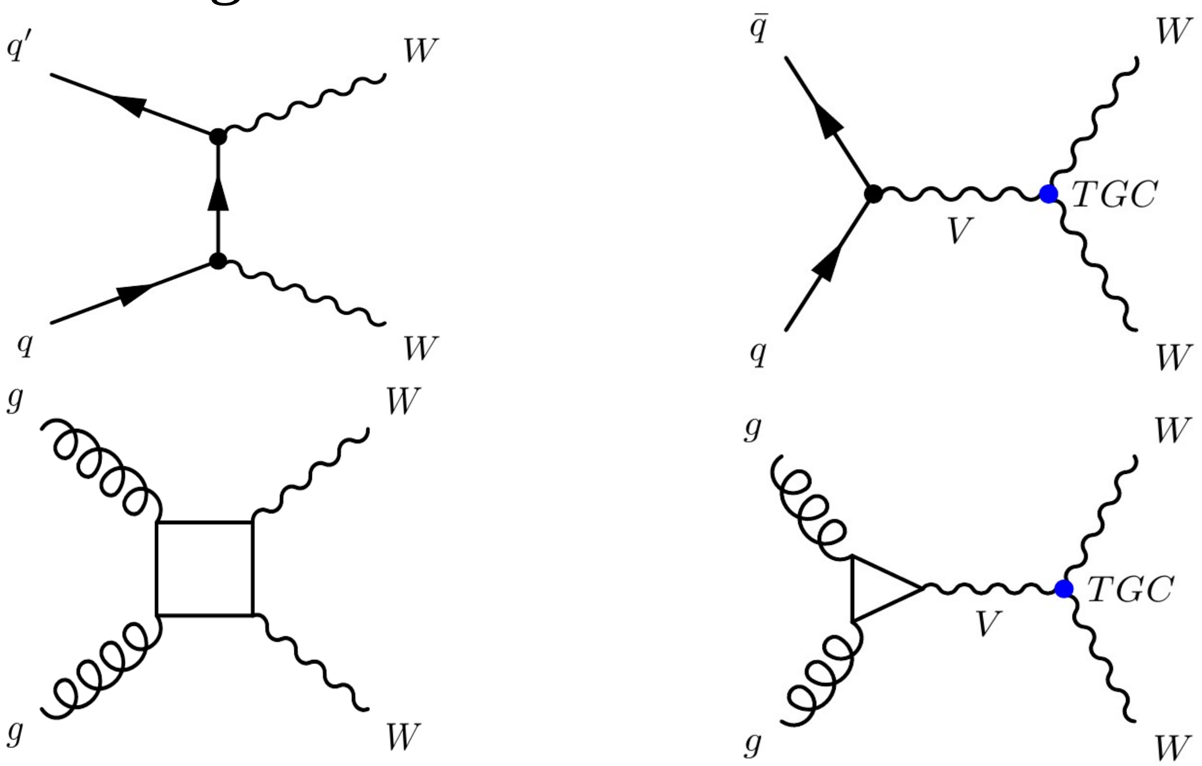
Outline

1. **Motivation**
2. **First „naive“ attempt**
3. **Refined method**
4. **Conclusion**

Motivation

- WW production sensitive to anomalous triple gauge boson couplings
- $W_L W_L$ - cross section gets unitarized by Higgs presence
  - ➔ Important test for SM
- Dominant background for $H \rightarrow W W^*$

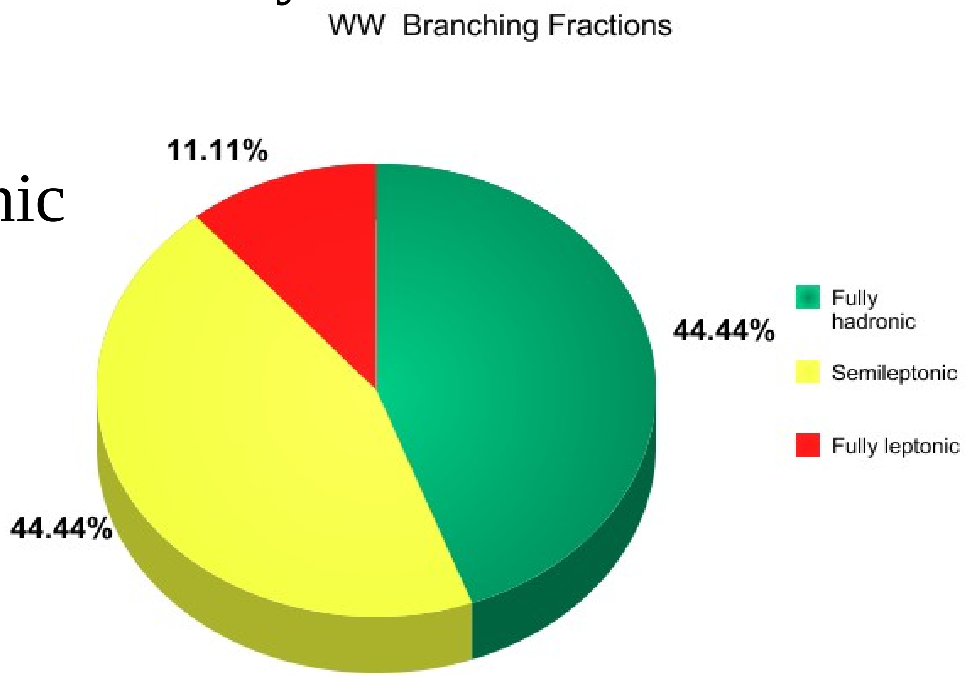


Motivation

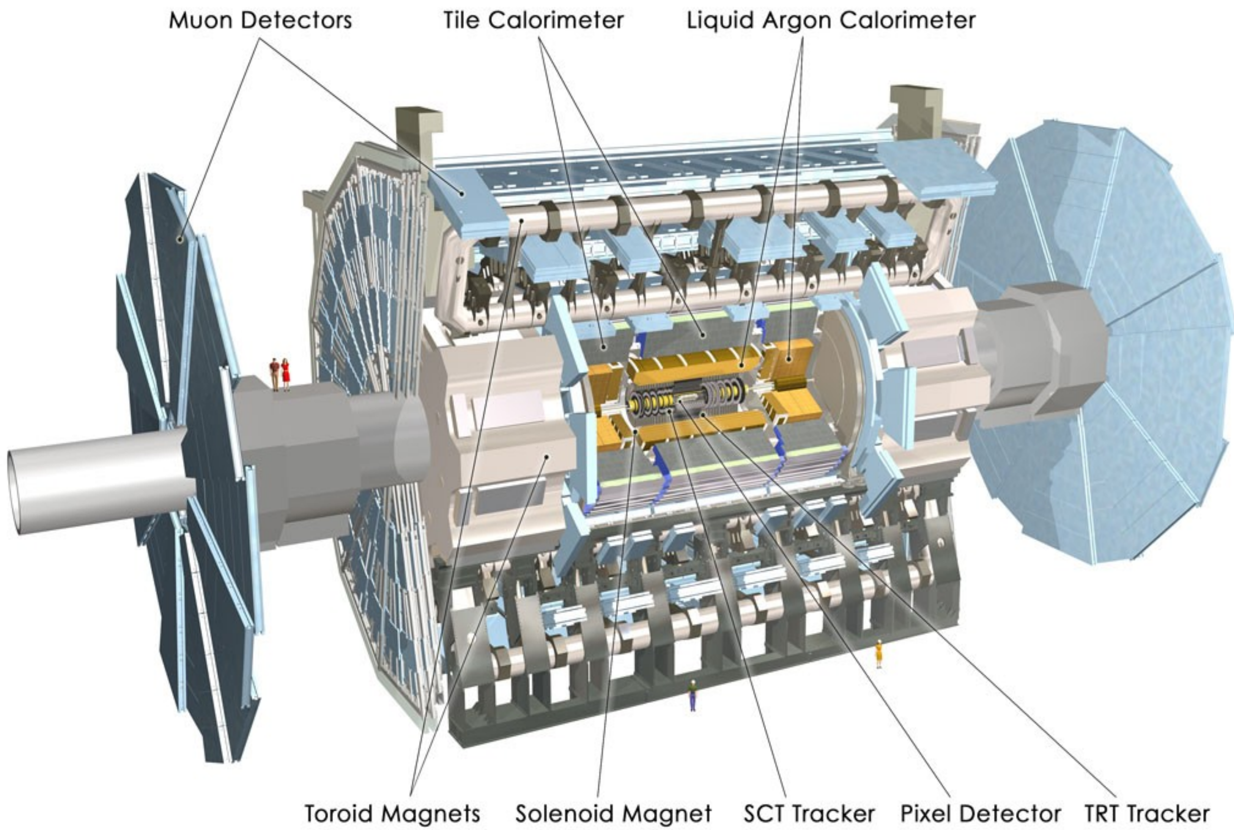
- Fully leptonic analysis from ATLAS already existing in 1fb^{-1}

Phys. Lett. B712 (2012) 289-308

- $BR(WW \rightarrow l\nu l\nu) \approx 5\%, \quad (l = e, \mu)$
- Whereas $BR(WW \rightarrow q\bar{q}q\bar{q}) \approx 45\% \rightarrow$ gain in statistics
- FH channel permits full control over WW system
  - Sensitive to new physics
- Group already working on hadronic top quark decays
  - Large overlap



ATLAS @ LHC

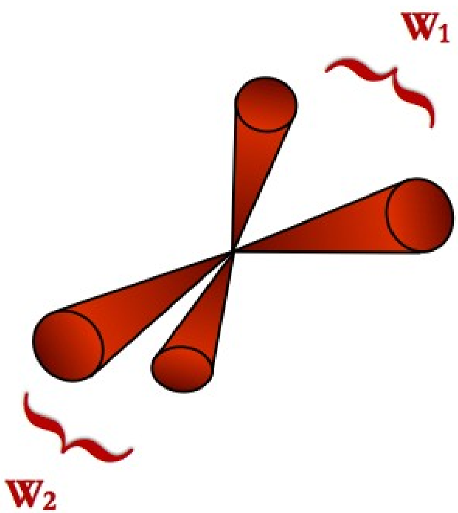


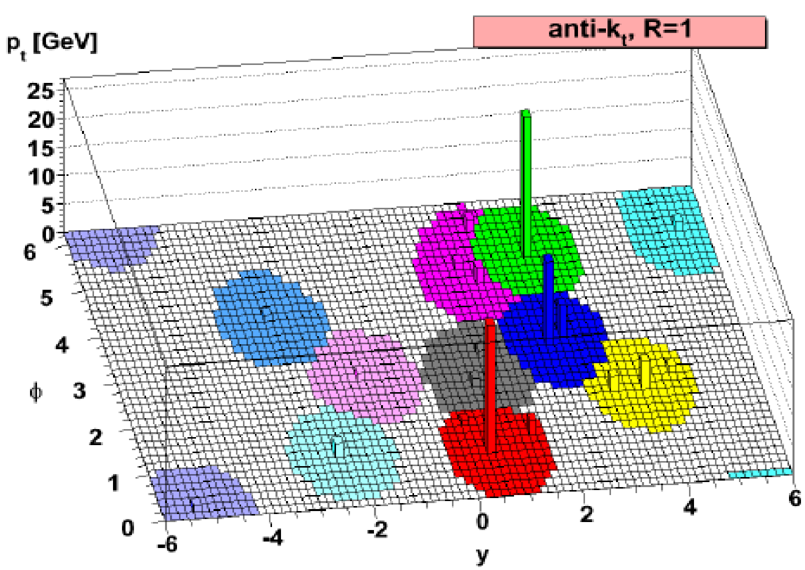
ATLAS Detector at CERN

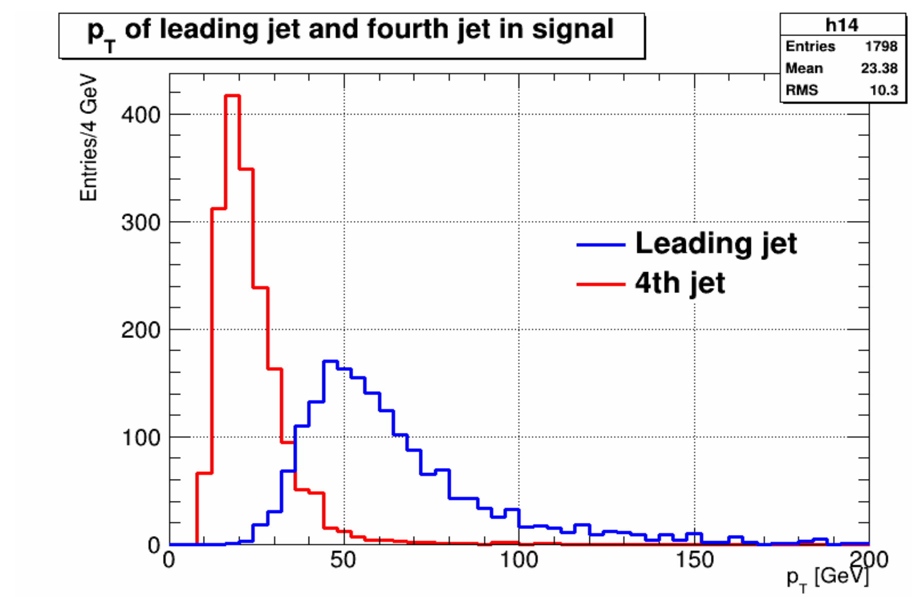
- Start with 2011 data → $\int \mathcal{L}\, dt = 4.7\,\text{fb}^{-1}$ → $85\,000$ events
- 2nd approach, 2012 data → $\int \mathcal{L}\, dt = 21\,\text{fb}^{-1}$ → $360\,000$ events

WW - full hadronic channel

- Expect final states with 4 hadronic jets
- No lepton/neutrino → No significant E_T^{miss}
- Use local hadron calibrated jets, reconstructed with the Anti- K_T -4 -algorithm
- Choose p_T threshold of 30 GeV







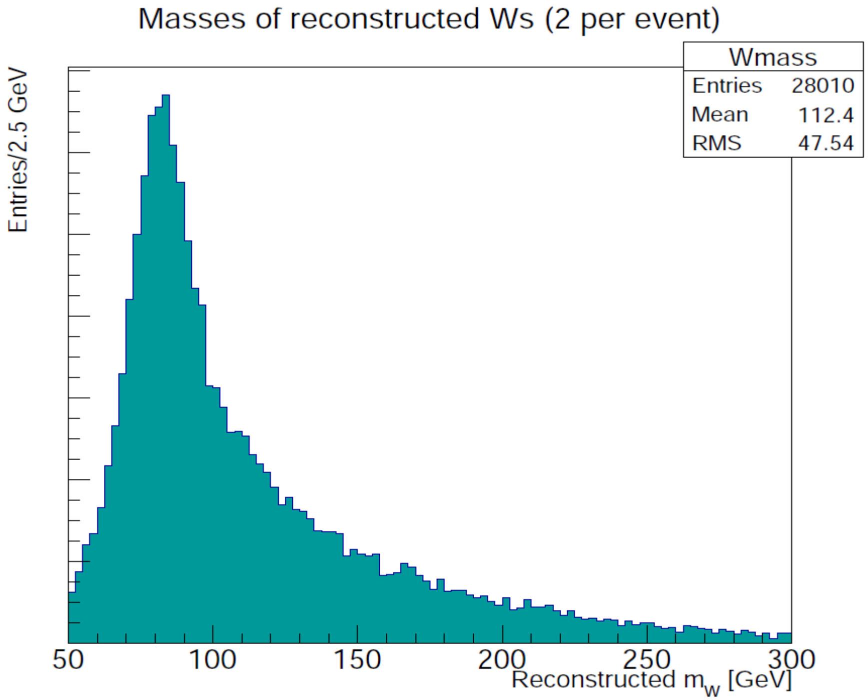
JHEP 0804:063,2008

WW - reconstruction

- If signal can be separated from background
- 3 possible jet pair combinations
- After topological cuts:
- Selecting method: $\Delta m_{W_1 W_2} = \text{minimal}$

$$W_1 = \binom{1}{2} \Leftrightarrow \binom{1}{3} \Leftrightarrow \binom{1}{4}$$

$$W_2 = \binom{3}{4} \Leftrightarrow \binom{2}{4} \Leftrightarrow \binom{3}{2}$$



- Simple solution suffers from combinatorial background

Trigger

- General problem: p_T of jets relatively low (20-30 GeV)
  - Single jet triggers highly prescaled (1 Jet 20 GeV, $P_{2011} \approx 18 \cdot 10^3$)

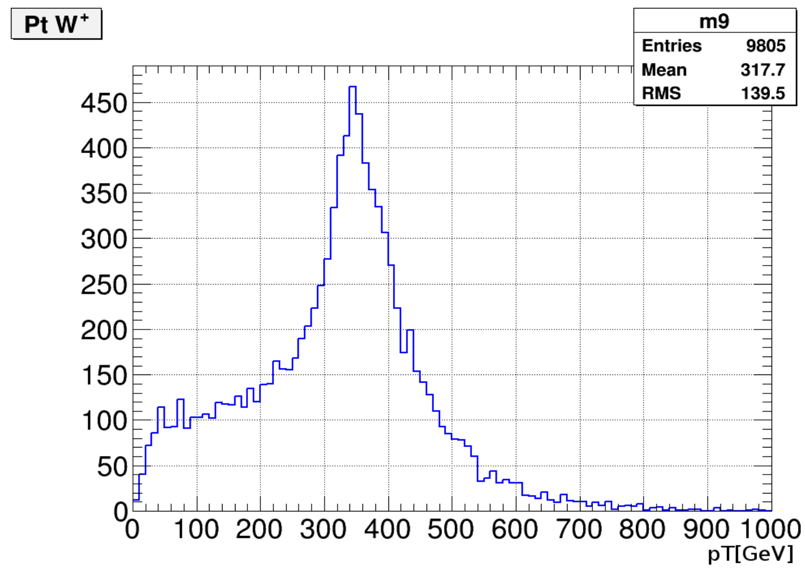
    (**Prescale:**
    Factor of suppression of event recording, in order to save computing power etc.)
- Use **multijet trigger** to get a higher frequency

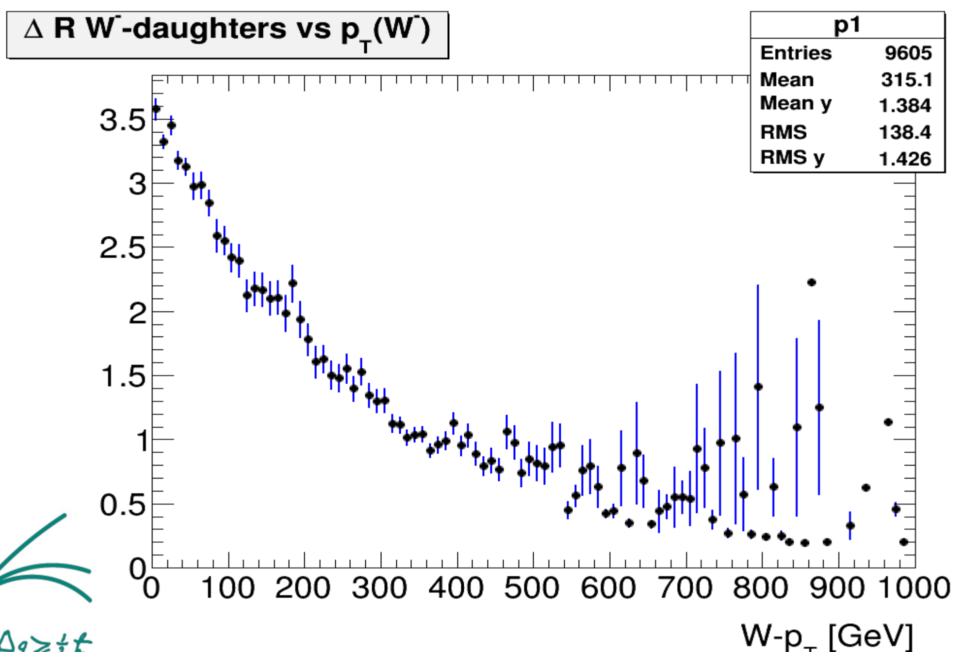
- Only suitable trigger: 4 Jet 30 GeV , P=20...200
- Trigger uses **uncalibrated jets** → low efficiency at 30 GeV
- Finally only around **10** expected events were left in event selection
  - Move on to different topology

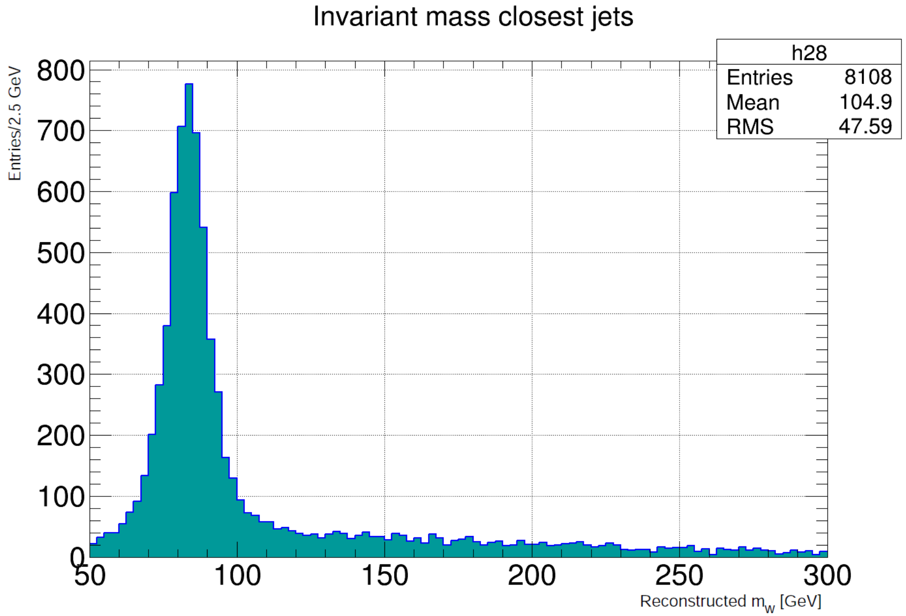
Boosted topology

- Idea is to use events where at least one W has very high p_T (~350 GeV)
- Found unprescaled trigger:

  $1\,\mathrm{Jet}(p_T = 145\,\mathrm{GeV}), H_T = 700\,\mathrm{GeV}$
- ~800 Events in 2012 (gain factor of 80)
- Further advantage:
  - ➔ Decay products of W are collimated
- Combinatorics „for free“

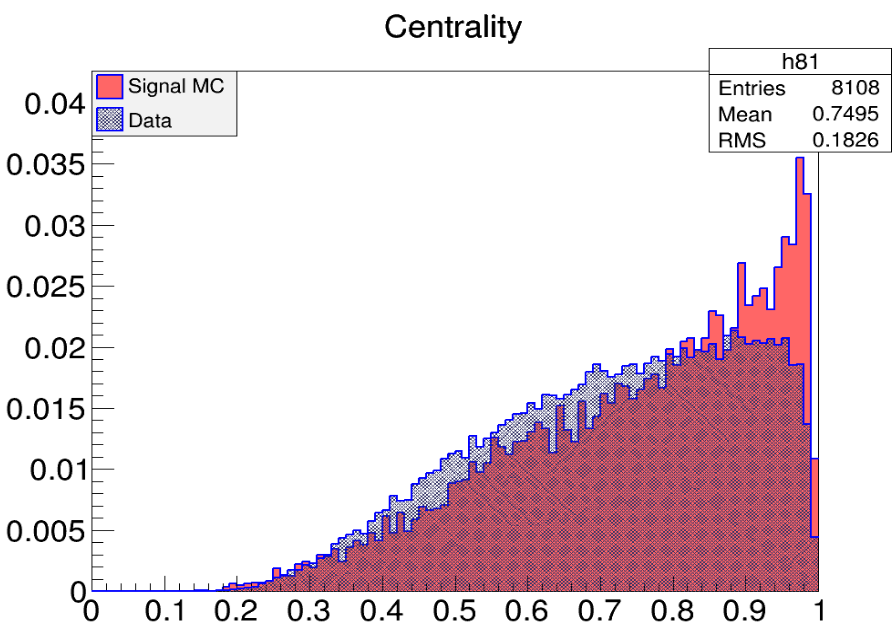


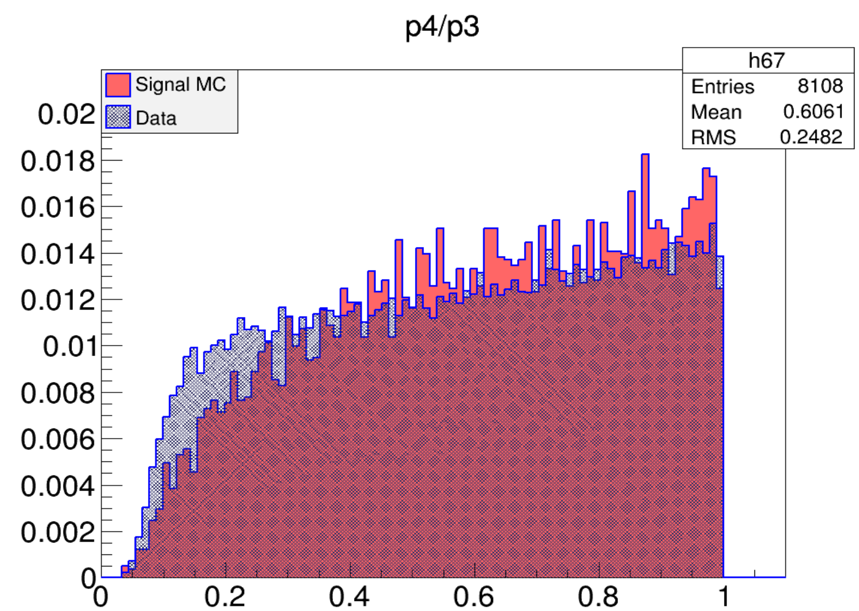




Separating signal and background

- Very hard to distinguish from QCD, bg cross section some 10^5 times higher
- No strong discriminator like high - p_T lepton for example
- But many variables with moderate separating power
- Cutting throws away too many signal events



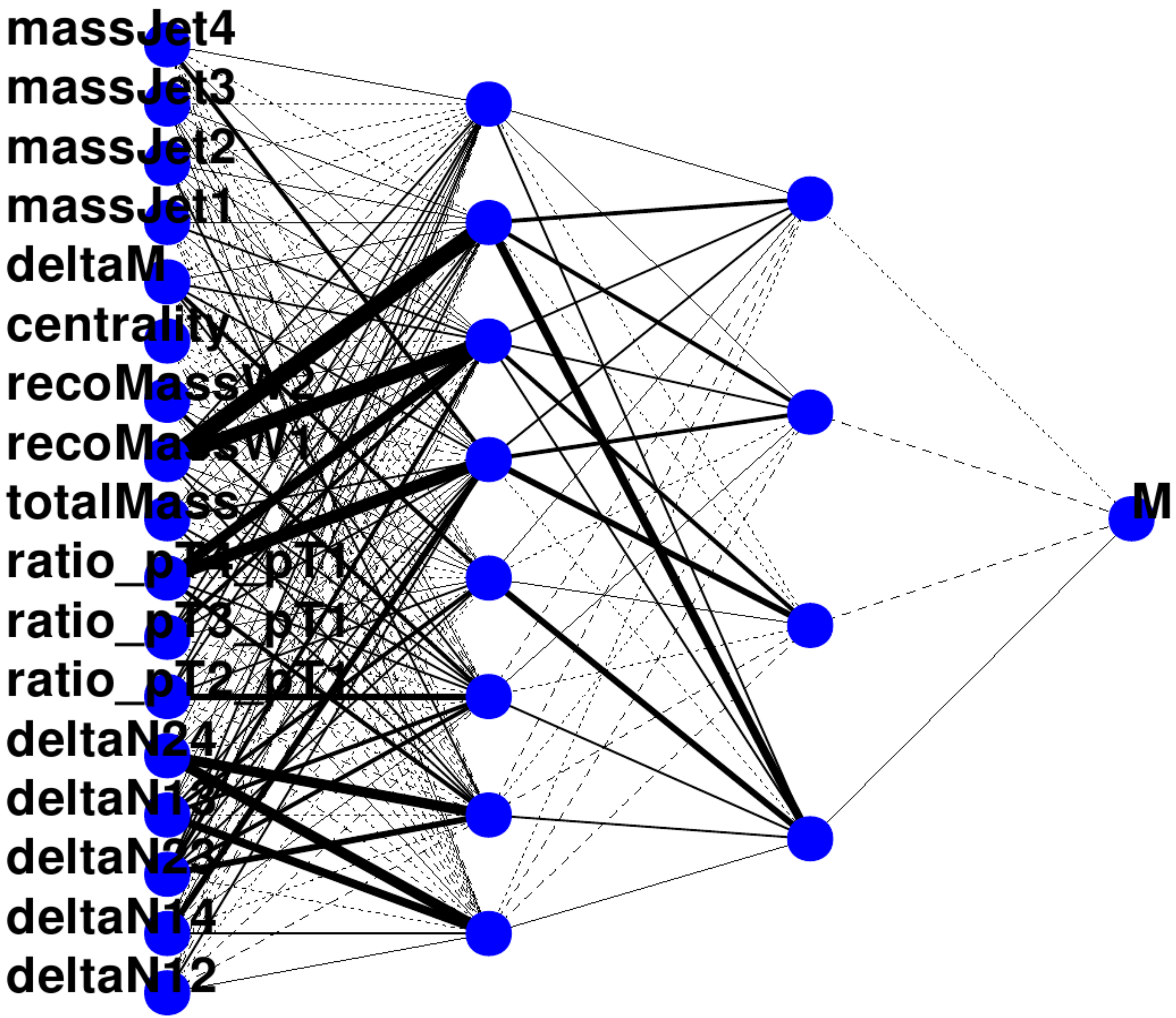


Separating signal and background

- Idea is to combine separating power of many little separating variables
- Solution: **Multivariate method** → Artificial Neural Network (ANN)
- Very powerful at recognizing patterns → Classification
- Has to be trained with many signal and background events (~50k each)

How does it work?

Separating signal and background



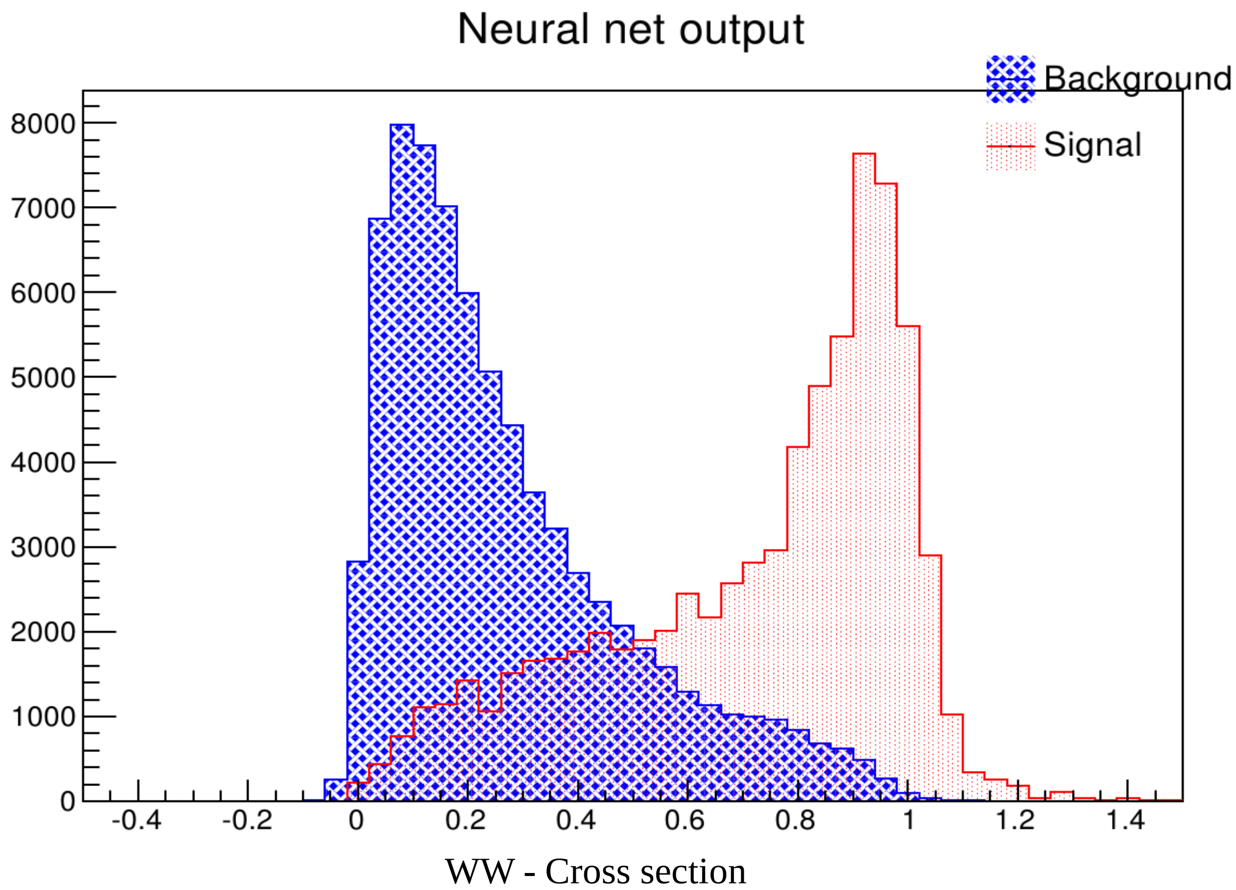
Separating signal and background

How does it work?

- Not programmed, but *trained*
- Supervised learning
- Feed the NN with all signal and bkg. events, where each is flagged as such
- After that (1 epoch) adjust weights of every synapse and node
- In signal case, answer at output layer shall be 1, other wise 0
- Train with some thousand epochs
- Apply trained network on data

Separating signal and background

- For training, use data instead of MC as background
- Assumption data is bkg only very well justified: $\frac{S}{B} \approx 2 \cdot 10^{-5}$

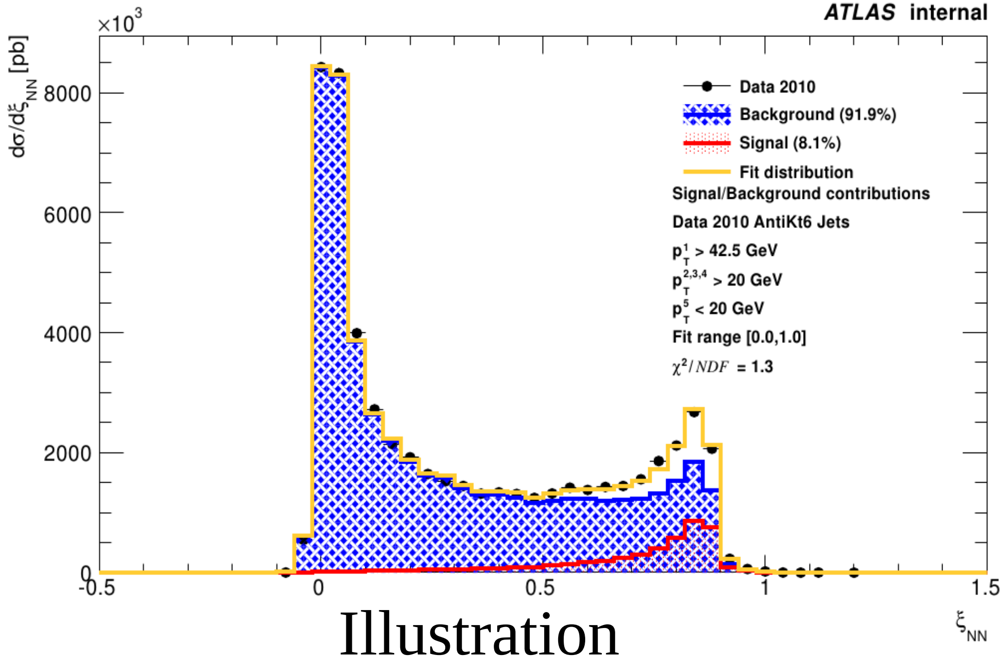


Separating signal and background

- Absolute amount of signal events still very small
- Cutting on the NN output would further reduce signal rate
- Better possibility:

  Run NN on data and then perform a fit of sig. and bg. output distributions to determine fraction of signal in data
- Access to the cross section

$$F(out) = f_{Sig} \cdot NN_{Sig} + (1 - f_{Sig}) \cdot NN_{Bkg}$$



Illustration

Orel Gueta,
Tel Aviv University

Conclusion

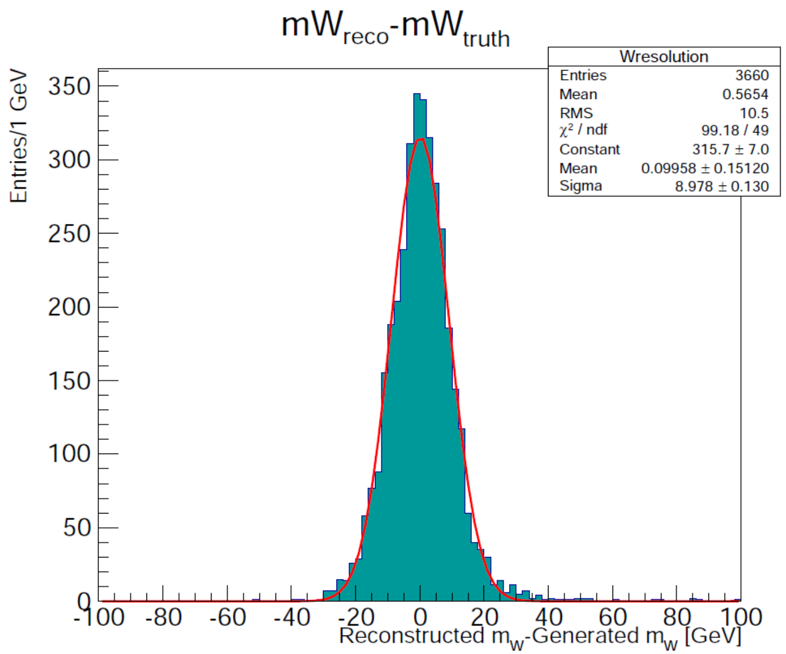
- We tried as hard as we could
  - But one day one has to admit the facts
  - Analysis in the fh channel is definitely not possible!
- Either the trigger or the event selection reduces S/B ratio enormously
- Still very interesting, will try to use the gained experience and knowledge for W+jets analysis in the fully hadronic channel as well
- Could aim to measure a differential cross section $\frac{d\sigma}{dE}$
- To be continued...

Thank you for your attention!

Backup

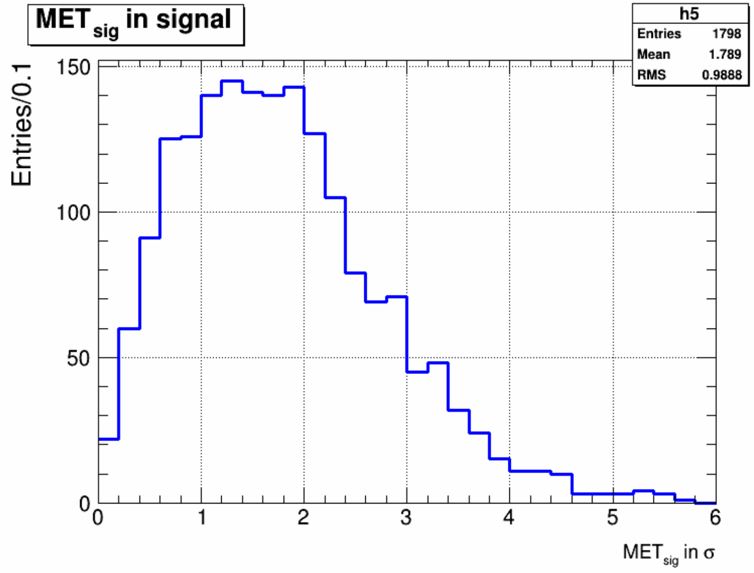
Resolution

Detector mass resolution:

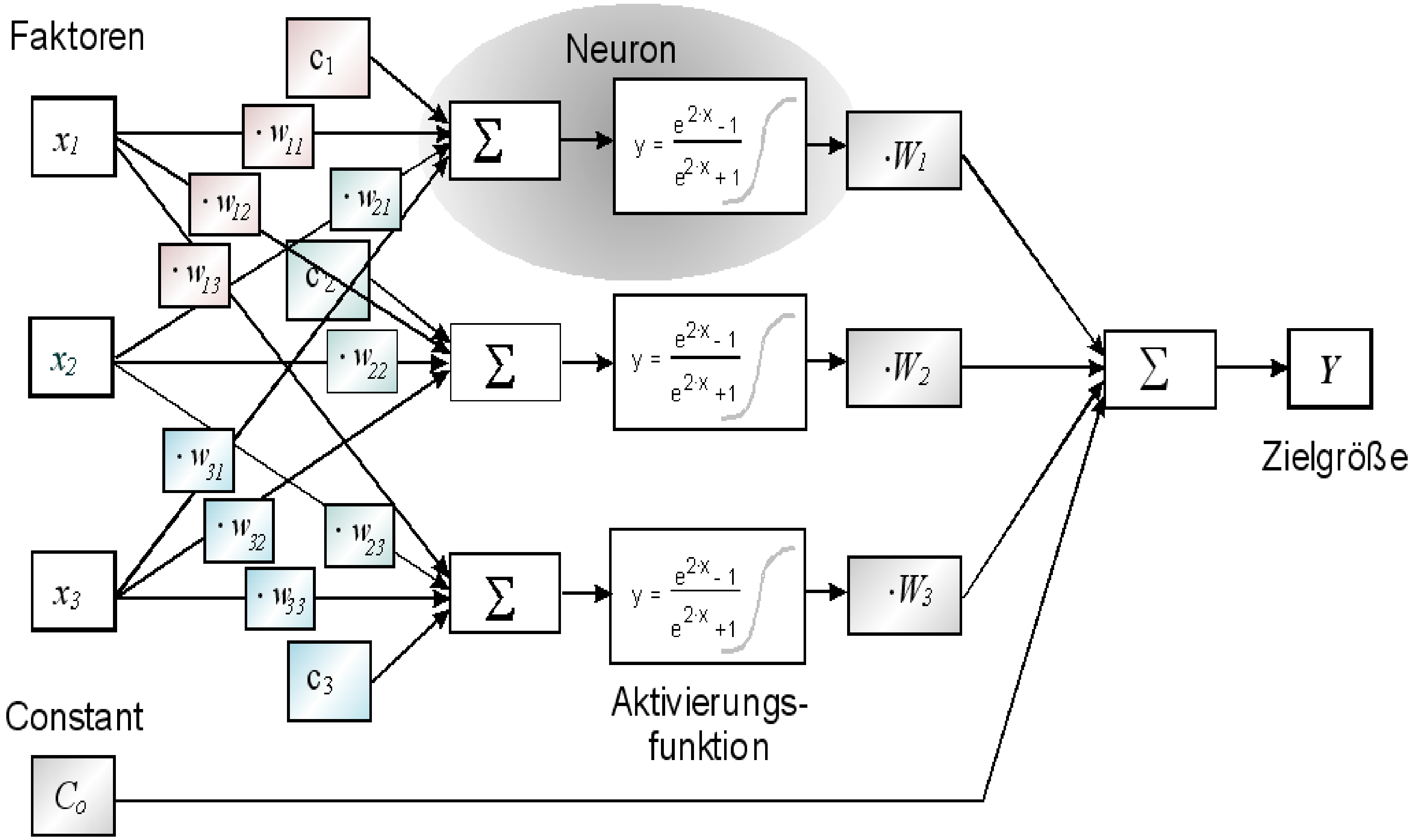


Separating signal from background

- Signal cross section at NLO: $\sigma_{SM} \cdot BR(WW_{FH}) = (21 \pm 2)$ pb JHEP 1107:018,2011
- QCD-background cross section: $\sigma_{QCD|4\text{Jets}, p_T > 30\ \text{GeV}} \approx 700$ nb $\rightarrow \frac{S}{B} \approx \frac{1}{33 \cdot 10^3}$
- Cut based event selection:
  1. No isolated electron
  2. No isolated muon
  3. E_T^{miss} significance of $METsig < 3.5\,\sigma$ $\quad METsig = \frac{E_T^{miss}}{0.5\sqrt{(sumE_T)}}$
  4. Exactly 4 Jets with $p_T \geq 30\,\text{GeV}$
- Cut based event selection has too little separating power and rejects too many signal events



Neural Net


Faktoren
Neuron
x_1
x_2
x_3
c_1
c_2
c_3
$\cdot w_{11}$
$\cdot w_{12}$
$\cdot w_{13}$
$\cdot w_{21}$
$\cdot w_{22}$
$\cdot w_{23}$
$\cdot w_{31}$
$\cdot w_{32}$
$\cdot w_{33}$
Σ
$y = \frac{e^{2 \cdot x} - 1}{e^{2 \cdot x} + 1}$
$\cdot W_1$
$\cdot W_2$
$\cdot W_3$
Y
Zielgröße
Aktivierungs-
funktion
Constant
C_0

Separating signal and background

- For training, use data instead of MC as background
- Assumption data is bkg only very well justified: $\frac{S}{B} \approx 2 \cdot 10^{-5}$
- Cutting on NN output at 0.95, one obtains:

Separating signal and background

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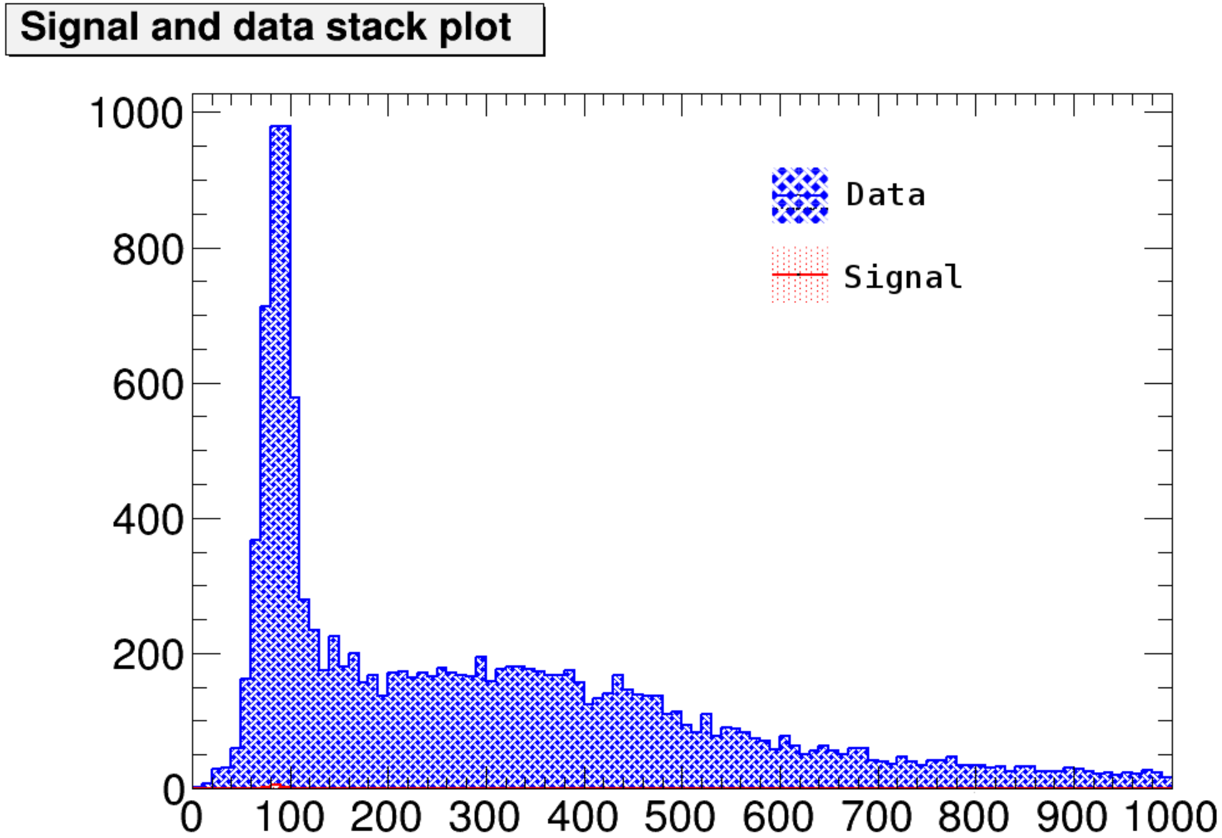
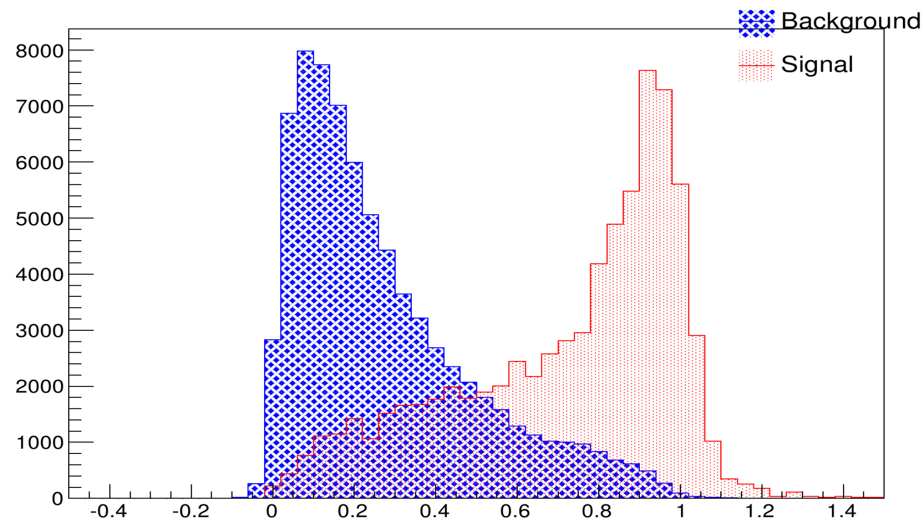
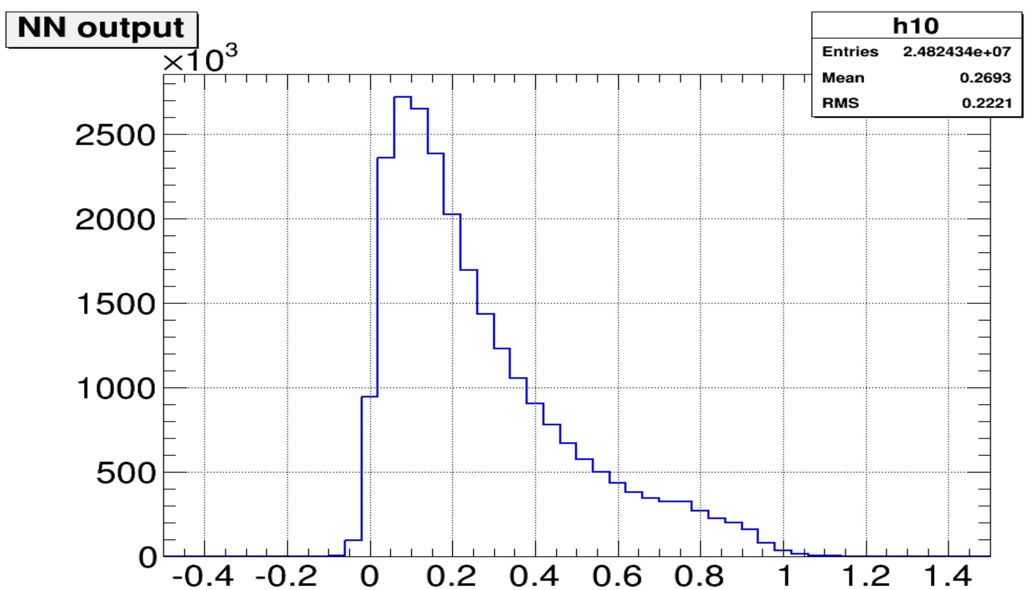


Separating signal and background

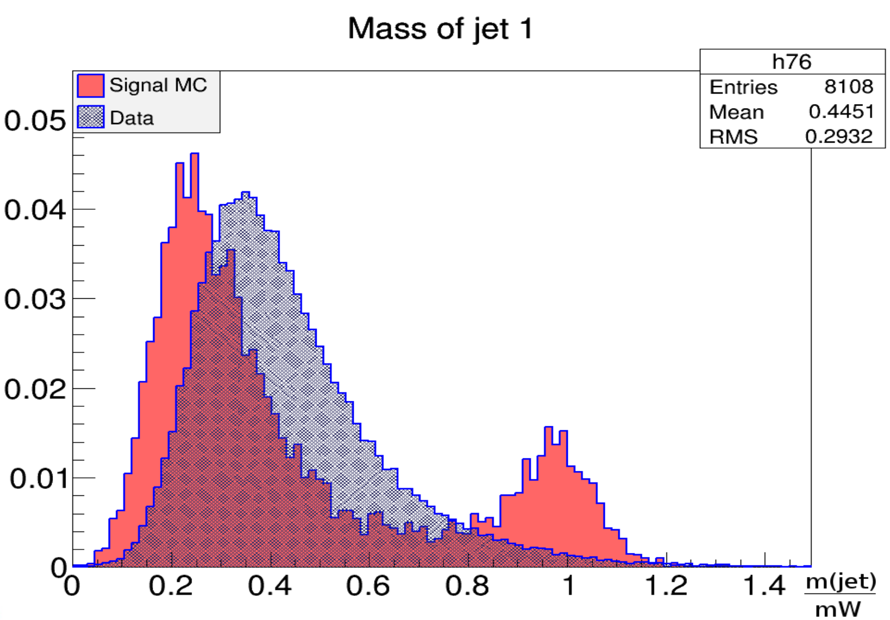
- Running over entire 2012 data:

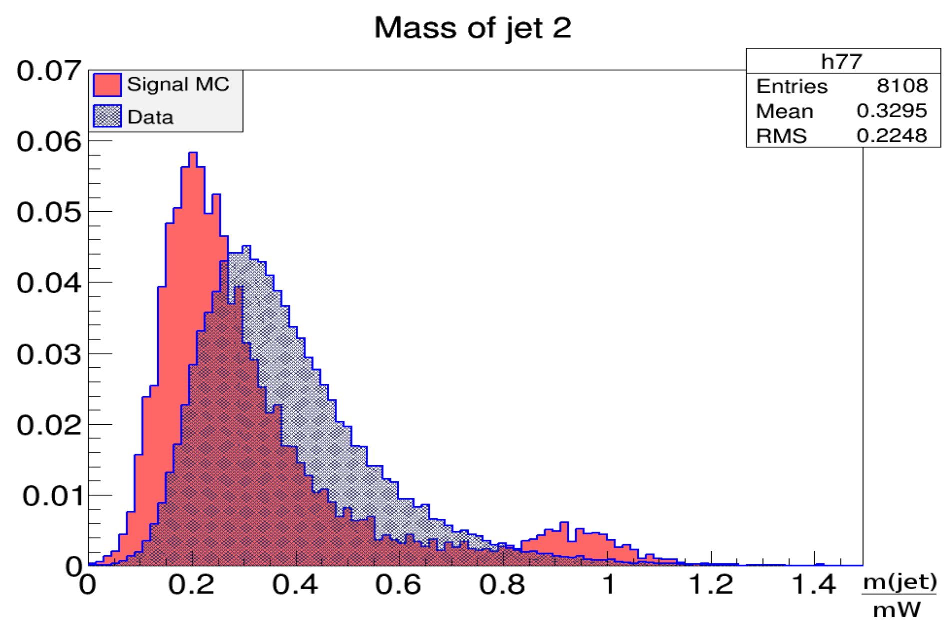




Reconstruction - Jet Masses

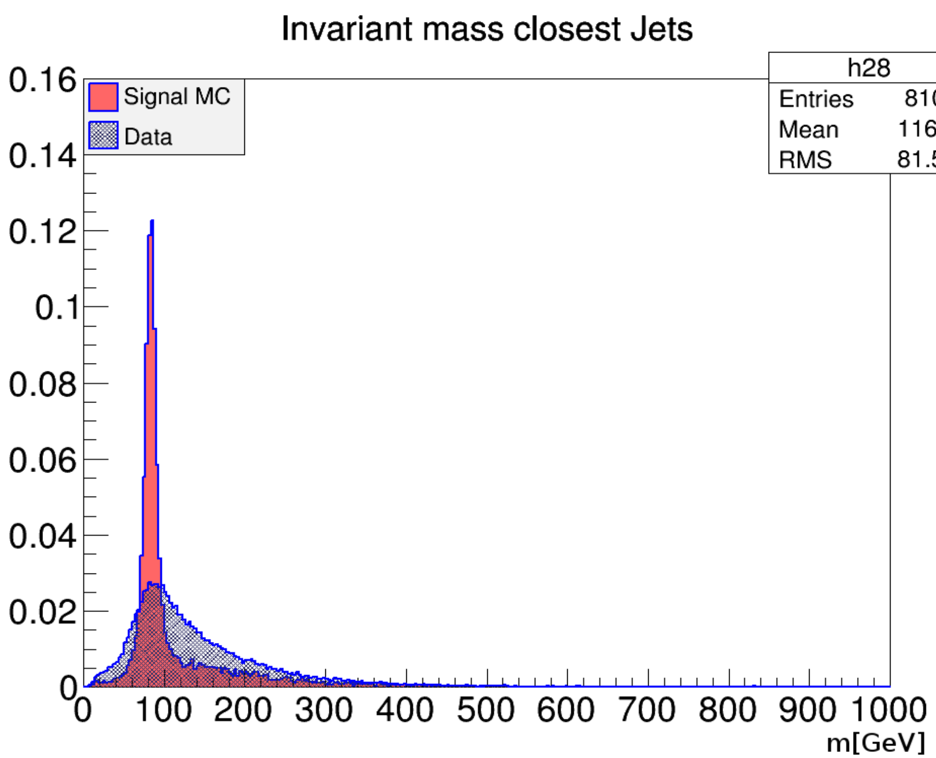
- Two classes of events
  1. „Normal“ case, jet masses relatively small
  2. One jet already contains one entire W (strongly boosted)
  3. Gluon jets have higher mass
- Distinguish classes for more efficient reconstruction
- Good for sig/bg separation as well

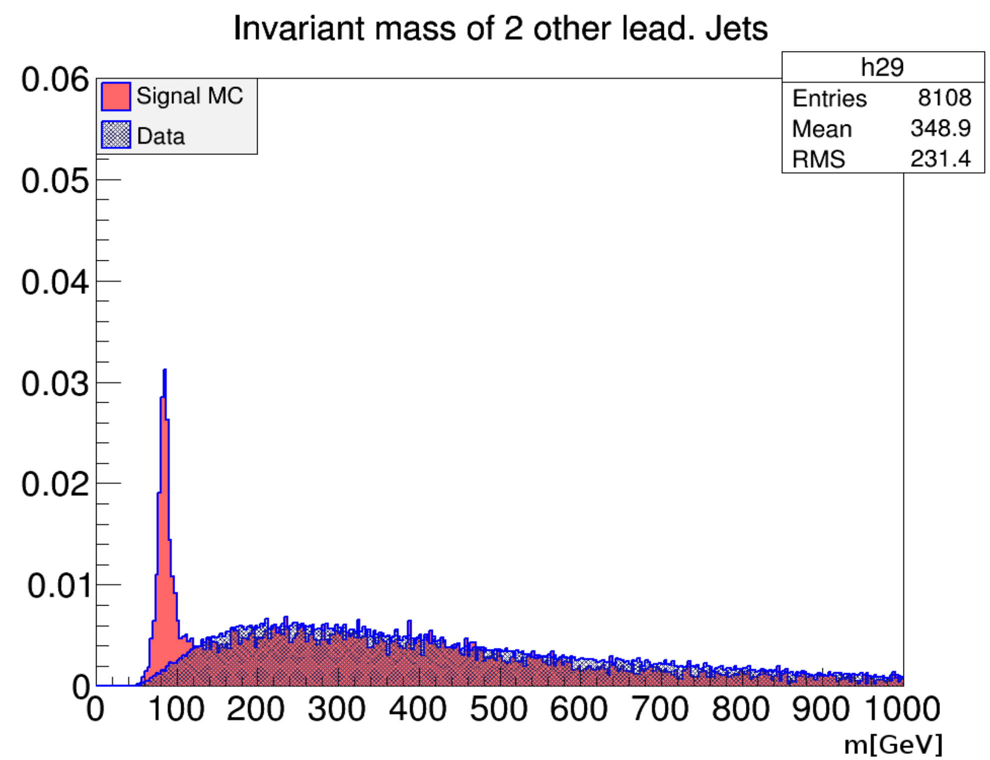




Reconstruction

- Normal reconstruction method
  1. Combine closest pair in ΔR
  2. Combine remaining two, of the four leading jets





Reconstruction

- Refined reconstruction method
  1. If no W-jet exists, use old method
  2. Else, use W-jet as first W and combine remaining two of the first three leading jets