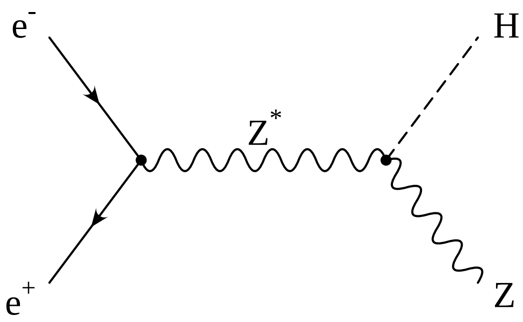
$ZH \longrightarrow q\bar{q}b\bar{b}$ study with neural network

David Ward and Wenbiao Yan

UNIVERSITY OF CAMBRIDGE

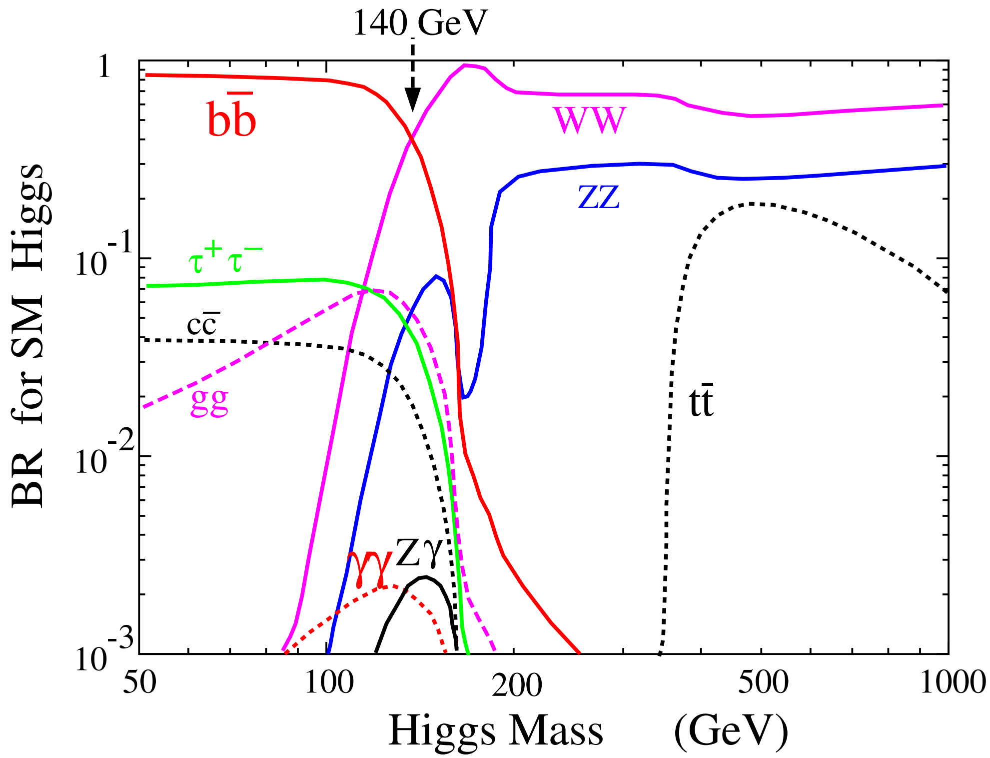
- $ZH \longrightarrow q\bar{q}b\bar{b}$



- $Z \longrightarrow q\bar{q}$; $H \longrightarrow b\bar{b}$

- **introduction**
- **jet energy correction**
- **jet resolution**
- **neural network @ ZH**

Higgs decay



- **Br$(h \to b\bar{b}) \sim$ 70% @ $M_h = 120$ GeV**
- **Higgs mass reconstruction via $M_{b\bar{b}}$**

MC data samples @ 250 GeV

- **Pythia without Beamstralung** $\Longrightarrow$ move to mass production samples when they are available

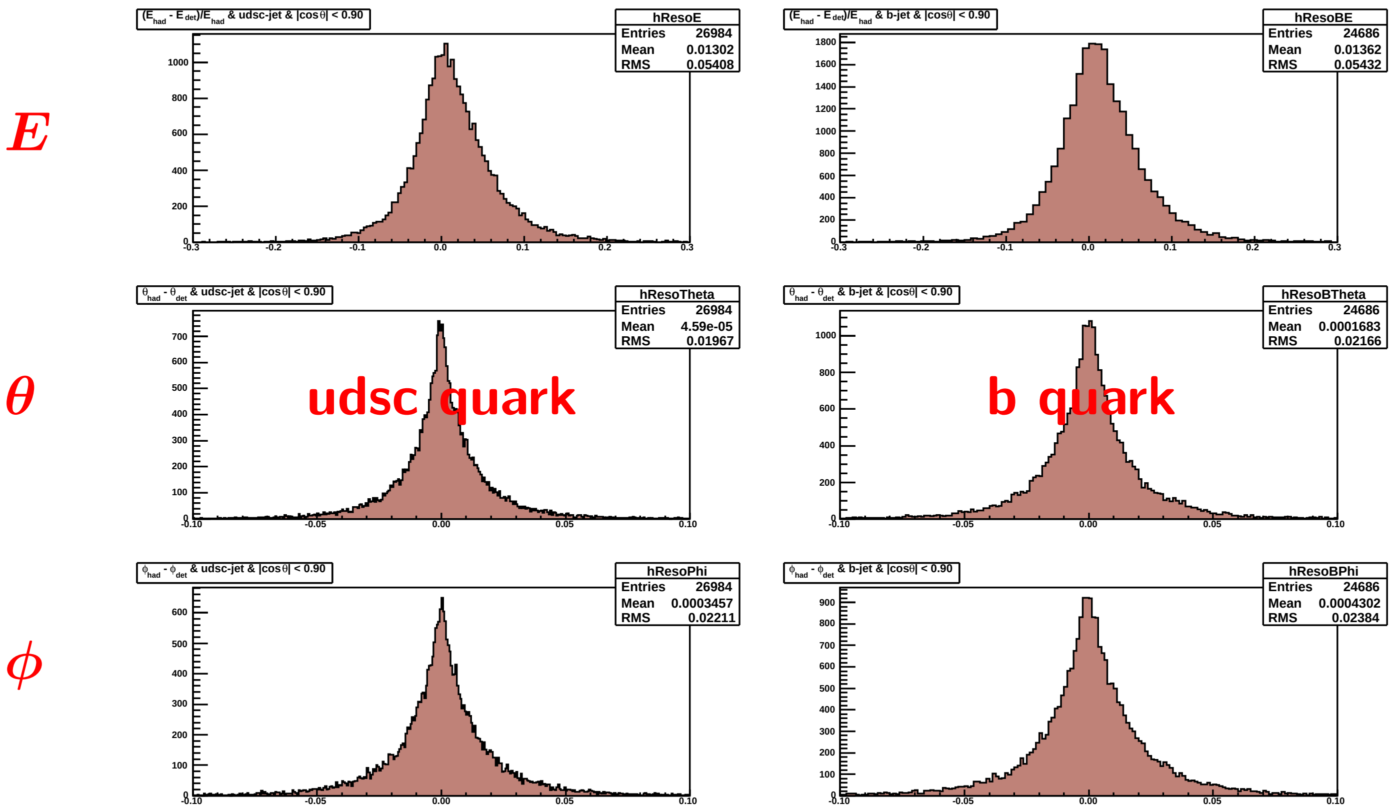
	σ^{my} (fb)	event number	σ^{Akiya} (fb)
$ZH \rightarrow q\bar{q}H$	159.5	40K	157.5
$WW \rightarrow q_1q_2q_3q_4$	7146.84	1786.7K	7109.84
$ZZ \rightarrow q_1\bar{q}_1q_2\bar{q}_2$	588.1	147.3K	586.0
$e^+e^- \rightarrow q\bar{q}$	47682.6	11920K	

- $ZH \rightarrow q\bar{q}H$: Pythia $\sim 40K$ (signal)
  $ZH \rightarrow q\bar{q}b\bar{b}$: Pythia $\sim 80K$ (training & test @ Neural network)

- $WW \rightarrow q_1q_2q_3q_4$: Pythia $\sim 300K$
  $ZZ \rightarrow q_1\bar{q}_1q_2\bar{q}_2$: Pythia $\sim 148K$
  QQ: Pythia $\sim 500K$
  QQ: 20/40/80/91.2/120/160/200/240/300 GeV (jet resolution) $\sim 9*30K$

- LDCPrime_02Sc @ Mokka06-06-p03: (SAME binary package for DESY mass production)
  event reconstruction ilcinstall v01-04

Jet resolution



- **Jets finding at hadron level: MC stable particles without neutrinos**
- **Jets finding at detector level**
- **Jet's energy: mean value $\sim 1.3\%$ $\longrightarrow$ jet energy correction**
- **Jet's angle: mean value ~ 0.0**

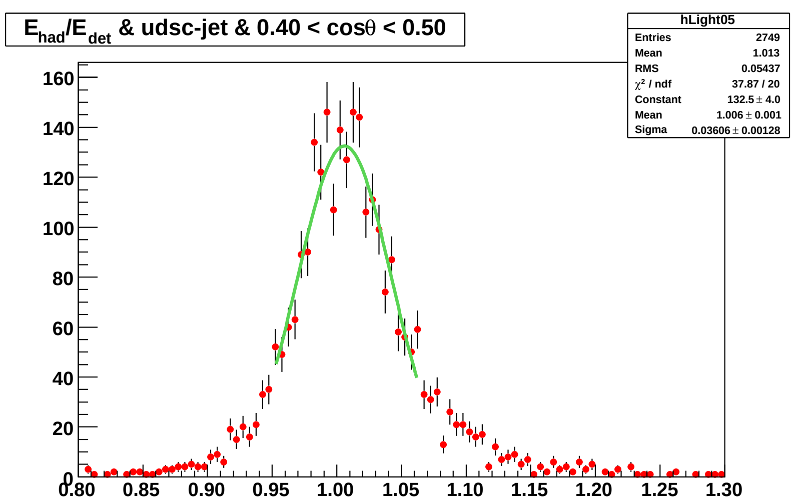
Jet energy correction

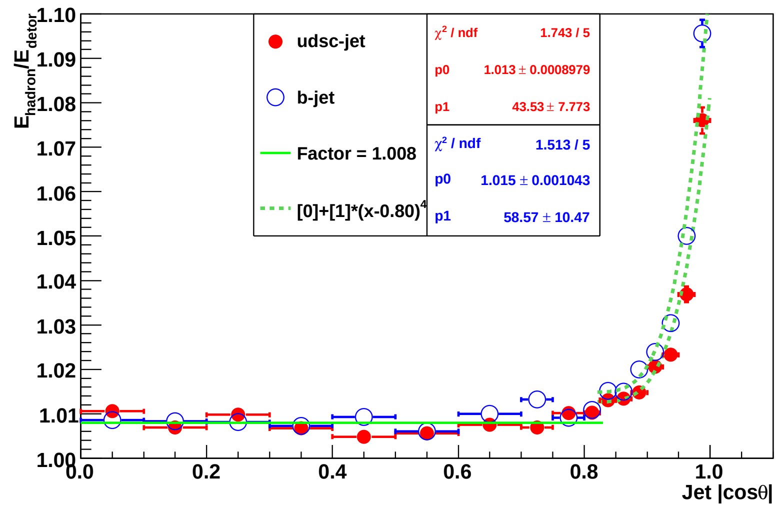
Assuming the direction vector of reconstructed jets correctly measured with that of quarks, the correction factors are scale factor on the jet.

- **Step I: Correct for calibration constants and detector effects**
  - **Jets at hadron level: MC stable particles without neutrinos**
  - **Jets at detector level**
- **Step II: Correct for neutrinos for udsc-jets**
  - **use $Z^0 \rightarrow q\bar{q}$ (q =u, d, s, c) events, let $M_{Z^0} = 91.2$ at detector level**
- **Step III: Correct for neutrinos for b-jets**
  - **use identified leptons inside jets**

Jet energy correction: Step I

- **Correct for calibration constants and detector effects**
  - **Jets at hadron level: MC stable particles without neutrinos**
  - **Jets at detector level**
- $E_{hadron}/E_{detector}$ **for udsc-jet & b-jet**

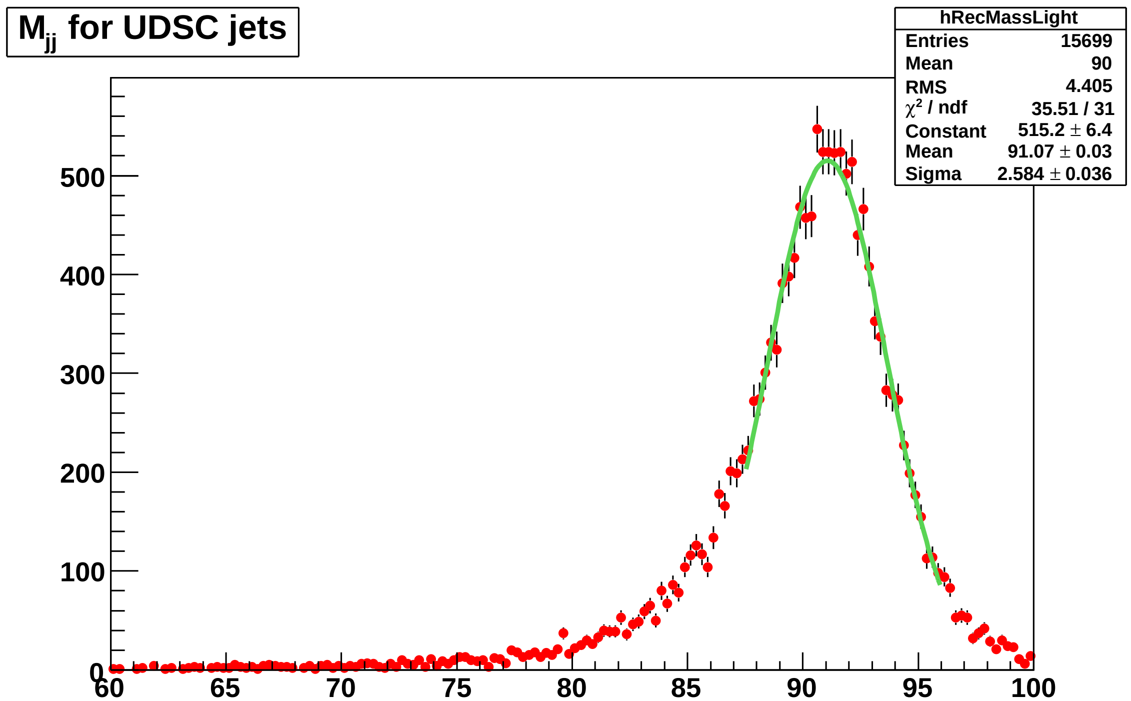




Jet energy correction: Step II

- **neutrinos contribution to udsc-jets: using udsc-jets from Z^0**

- **udsc-jets: 91.2/91.07 = 1.0014; global factor**



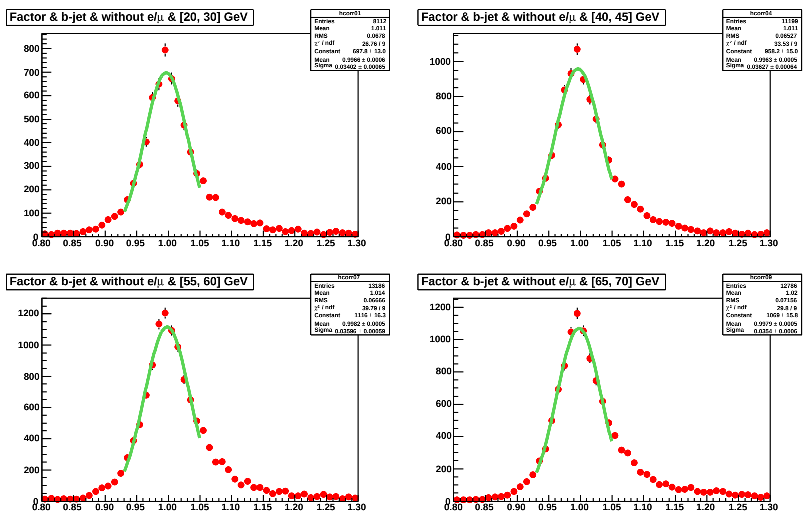
Jet energy correction: Step III

- identified leptons (e/μ) inside jets to correct for neutrinos
- direct decays $b \to l + X$ and cascade decays $b \to c \to l + X$
  - particles at detector level with LCRelation RecoMCTruthLink $\to$ particles at hadron level $\to$ identified leptons with PDG code
  - identified leptons from B-hadron or D-hadron
  - identified leptons $>= 2$: sum of several identified leptons
  - lepton energy: $E_{lepton} > 4.0$GeV
  - $0.95 < E^{rec}_{lepton}/E^{MC}_{lepton} < 1.05$
- selecte b-jets with identified leptons for energy correction
  - lepton energy: $E_{lepton} > 4.0$GeV
  - $0.95 < E^{rec}_{lepton}/E^{MC}_{lepton} < 1.05$
  - $|\cos\theta_{jet}| < 0.80$

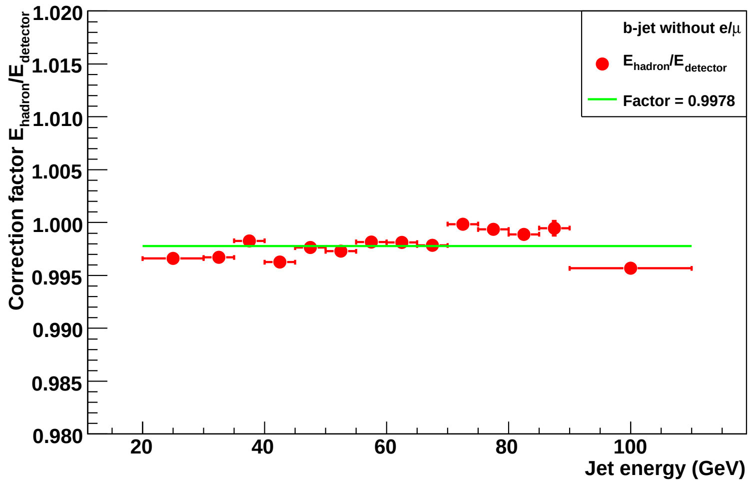
Jet energy correction: b-jet without e/μ

- correction factor $E^{jet}_{hadron}/E^{jet}_{detector}$
  - Jets at hadron level: MC stable particles (with neutrinos)
  - Jets at detector level

- Gaussian fitting: (not bad)
- long tail from τ neutrinos



- mean value from Gaussian fitting
- b-jet correction: average 0.9978

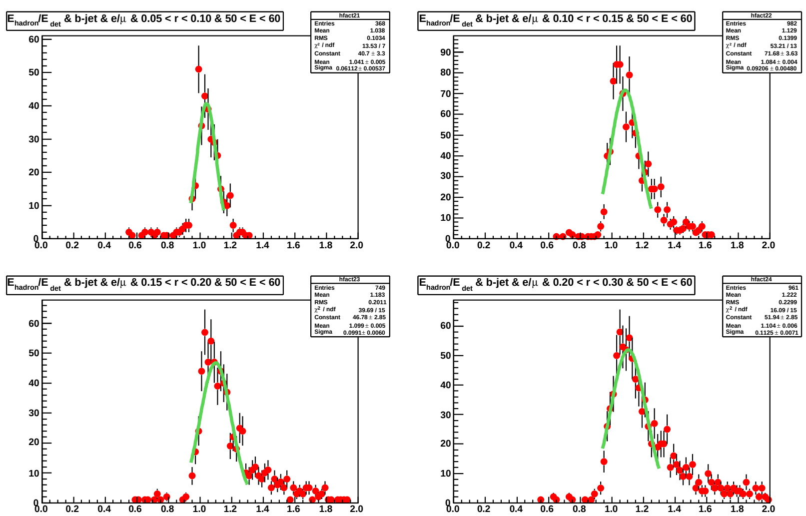


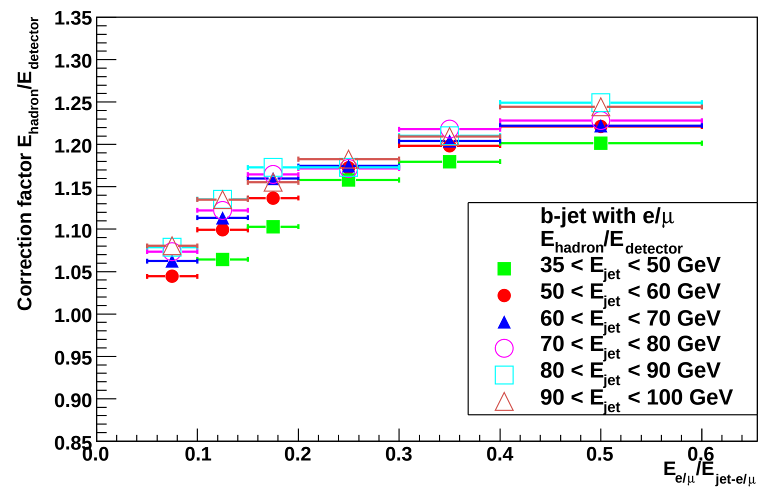
Jet energy correction: b-jet with e/μ

- correction factor $E^{jet}_{hadron}/E^{jet}_{detector}$
  - Jets at hadron level: MC stable particles (with neutrinos)
  - Jets at detector level

- Gaussian fitting: (not good)
- mean value from 90% program

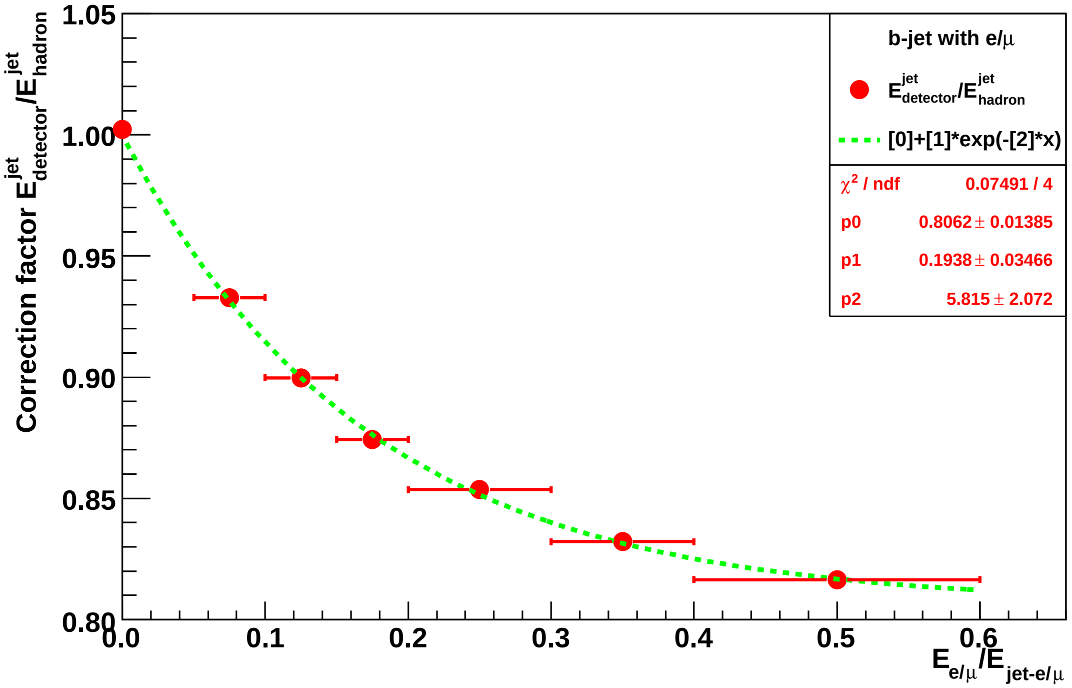
- $E_{e/\mu}$: lepton energy
- $E_{jet-e/\mu}$: $E_{jet} - E_{e/\mu}$



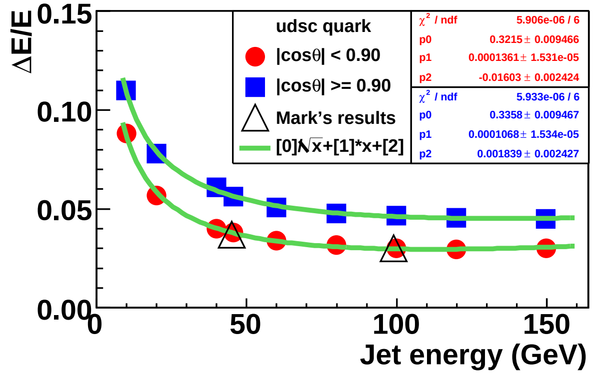


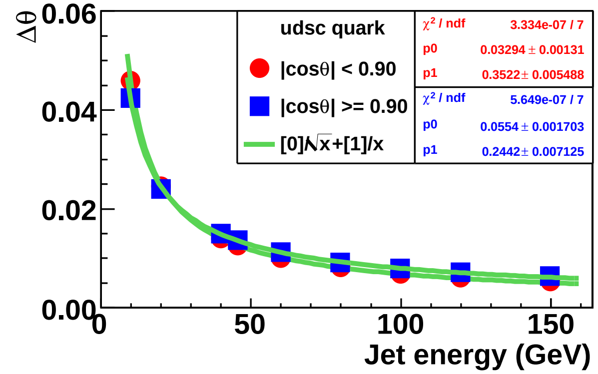
Jet energy correction: b-jet with e/μ

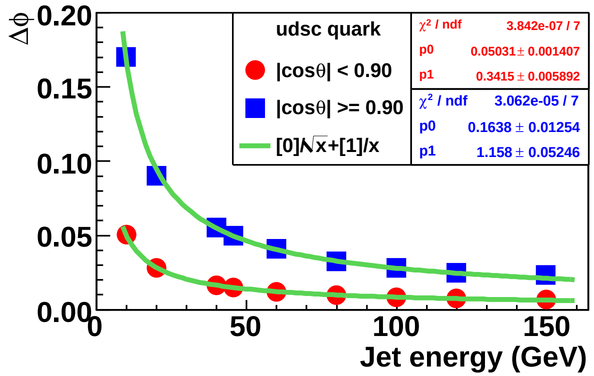
- **correction factor $E^{jet}_{detector}/E^{jet}_{hadron}$ as function of $E_{e/\mu}/E_{jet-e/\mu}$**
- **point (0.0, 1.0/0.9978): b-jet without e/μ**



Jet resolution: udsc-jet

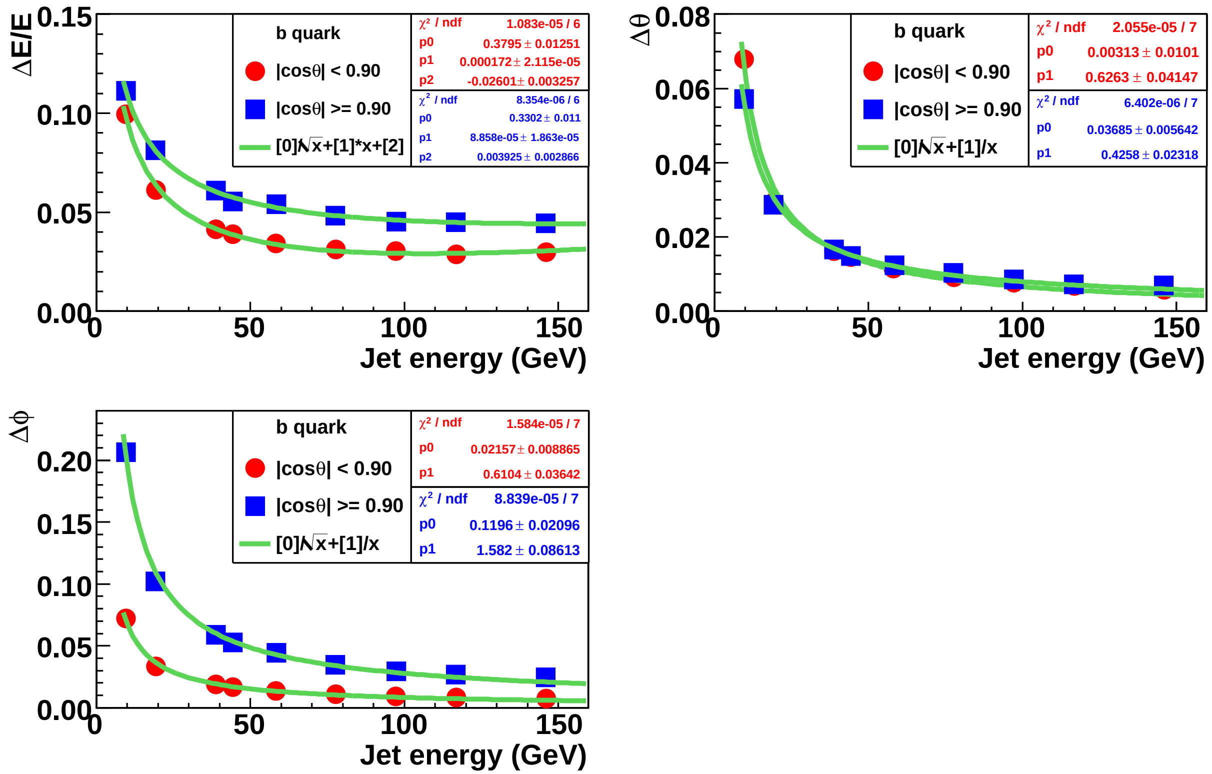






- **$e^+e^- \rightarrow q\bar{q}$ (q = u, d, s, c) without ISR**
- **Jets finding at hadron level: MC stable particles without neutrinos**

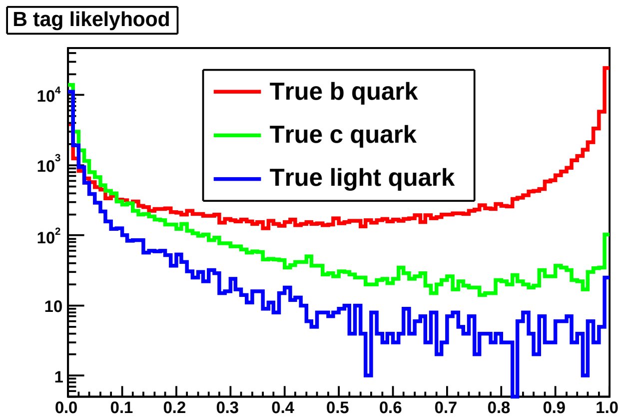
Jet resolution: b-jet

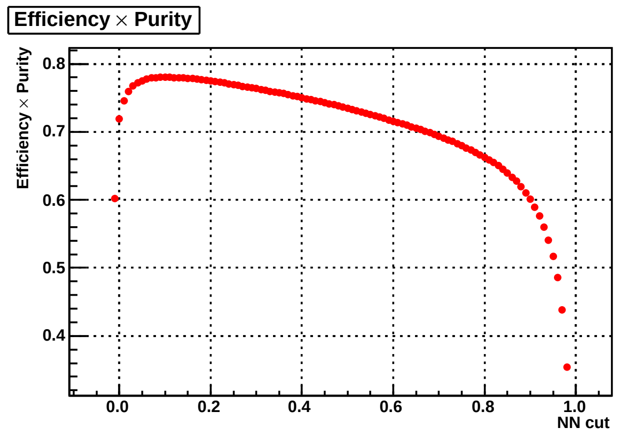


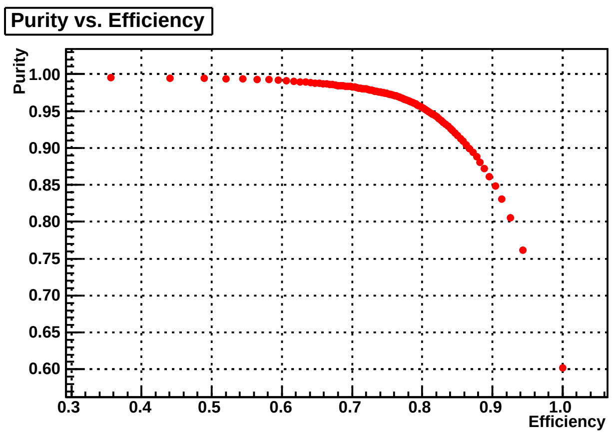
- $e^+e^- \rightarrow q\bar{q}$ **(q = b) without ISR**
- **Jets finding at hadron level: MC stable particles without neutrinos**

B-tag at ZH 250GeV

- **B-tag for $ZH \rightarrow q\bar{q}b\bar{b}$ at 250GeV**







neural network: used variables

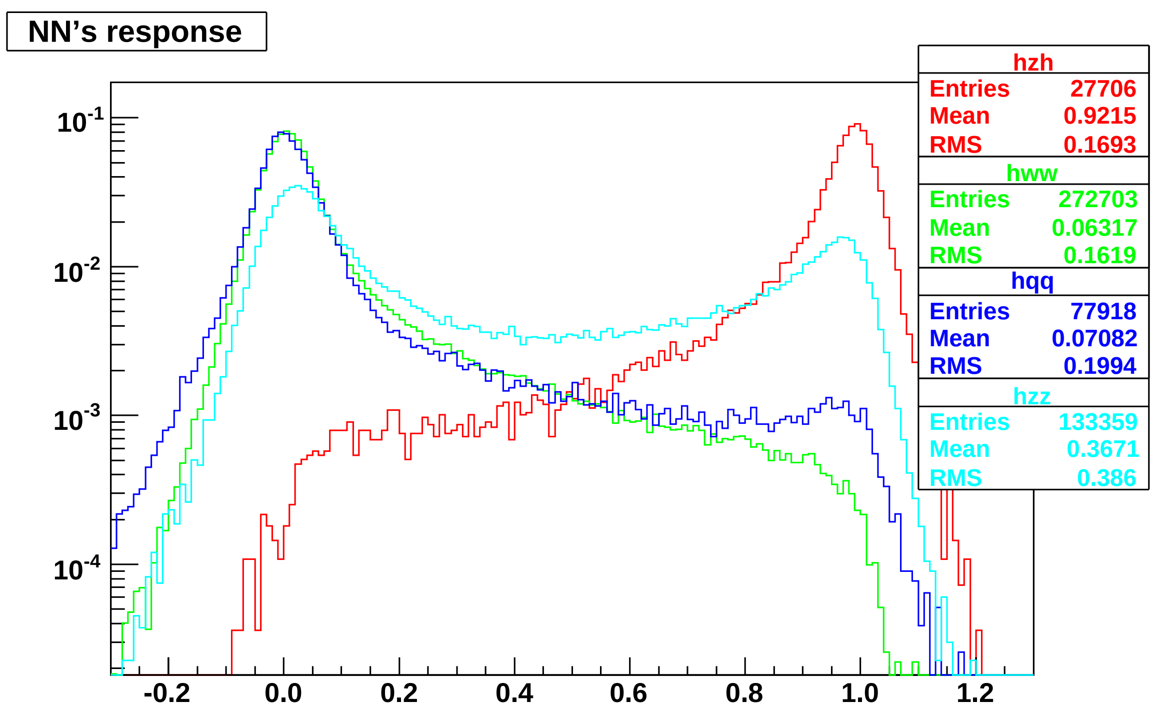
- **total visible energy; PFA number; y_{34}; minimum jet-jet angle**
- **thrust; theta of thrust axis; sphericity; aplanarity; Fox-Wolfram moments h_{30} and h_{40}**
- **χ^2, χ^2 probability and M_{Z^0} of 4C $\otimes M_{j_1 j_2} = 91.20$ GeV fitting;**
  χ^2 of 4C $\otimes M_{j_1 j_2} = M_{j_3 j_4}$ fitting
- **j_{mom}, j_{ang}, modified Nachtmann-Reiter angle @ OPAL CERN-EP/98-167**
  - **sort jets by jet energy $E_{j1} \geq E_{j2} \geq E_{j3} \geq E_{j4}$**
  - $j_{mom} = \frac{|\vec{p_1}|+|\vec{p_2}|-|\vec{p_3}|-|\vec{p_4}|}{\sqrt{s}}$
  - $j_{ang} = \frac{E_4}{\sqrt{s}}(1 - \cos\theta_{12}\cos\theta_{13}\cos\theta_{23})$
  - $|\cos\theta_{N-R}| = \frac{(\vec{p_1}-\vec{p_2})\cdot(\vec{p_3}-\vec{p_4})}{|\vec{p_1}-\vec{p_2}|\cdot|\vec{p_3}-\vec{p_4}|}$
- **maximum b-tag; b-likeness of two jets for Higgs;**
  number of b-jet (b-tag > 0.10)

Neural network architecture

- **TMVA package v3.8.13: Artificial Neural Networks MLP**
- **neural network architecture 20:38:1**
  - **input layers: 20 variables**
  - **one hidden layer: 38 nodes**
  - **output layers: one**
- **learning parameters**
  - **number of training cycles: 800**
  - **learning rate: 0.02 (default)**
  - **decay rate: 0.01 (default)**
- **neuron activation function: sigmoid (default)**
  synapsis function: sum (default)
  learning mode: sequential (default)

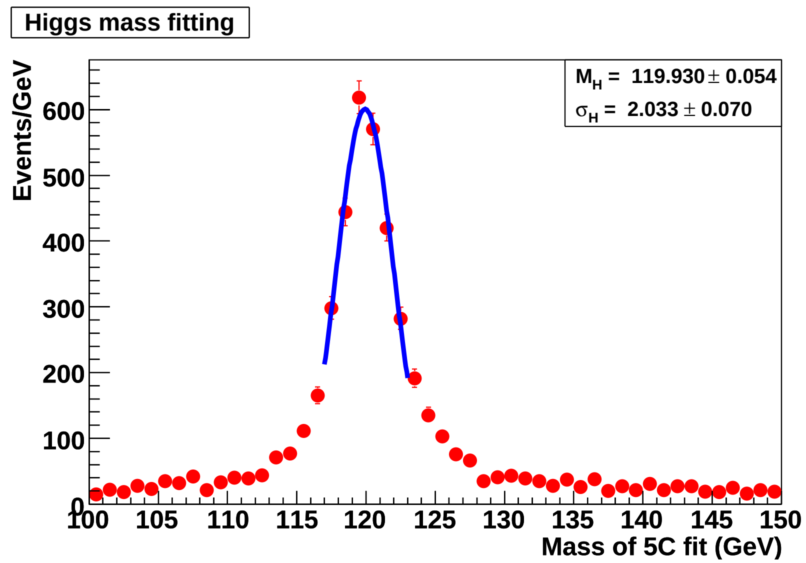
Neural network's response

- **the signal peaks around 1.0; the backgrounds peak around 0.0**
- **plots are normalizes to one**

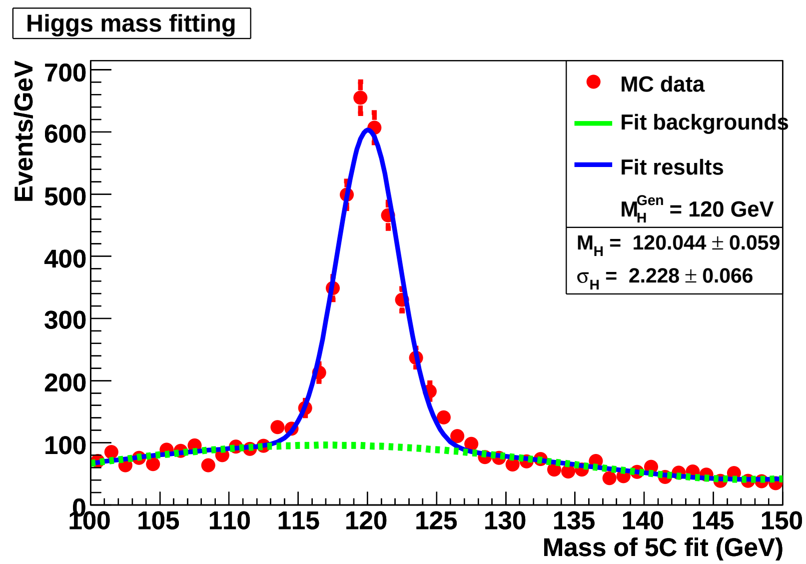


Higgs mass fitting

- only $ZH \rightarrow q\bar{q}b\bar{b}$



- only ZZ background



- 194 WW events @ 300K events $\rightarrow$ 1155 WW @ 250 fb^{-1}
- 179 QQ events @ 500K events $\rightarrow$ 4267 QQ @ 250 fb^{-1}
- need more WW & QQ events for background study

Summary

- $ZH \rightarrow q\bar{q}b\bar{b}$ @ 250GeV for LDCPrime_02Sc
  - about 1340K events
- jet energy correction for udsc-jet and b-jet
- $ZH \rightarrow q\bar{q}b\bar{b}$ selection with neural network
- large WW & QQ samples future
  - pre-selection at generator level
  - detector simulation and event reconstruction

Neural network architecture

- **neural network architectures**
  - **how many variables at input layer ?**
  - **how many hidden layers ?**
    - **one hidden layer is sufficient in principle**
  - **how many nodes at hidden layers ?**
  - **one output node**

- **compare different neural network architectures**
  - $S/\sqrt{S+B}$ **with "0.5-criterion"**
    - **Signal (NN's response > 0.5);**
    - **Background (NN's response < 0.5)**
  - **background-to-Signal ratio B/S with "0.5-criterion"**
  - **gaussian significance $S/\sqrt{B}$ with "0.5-criterion"**

- **TMVA package v3.8.13: Artificial Neural Networks MLP**

Number of variables at input layer

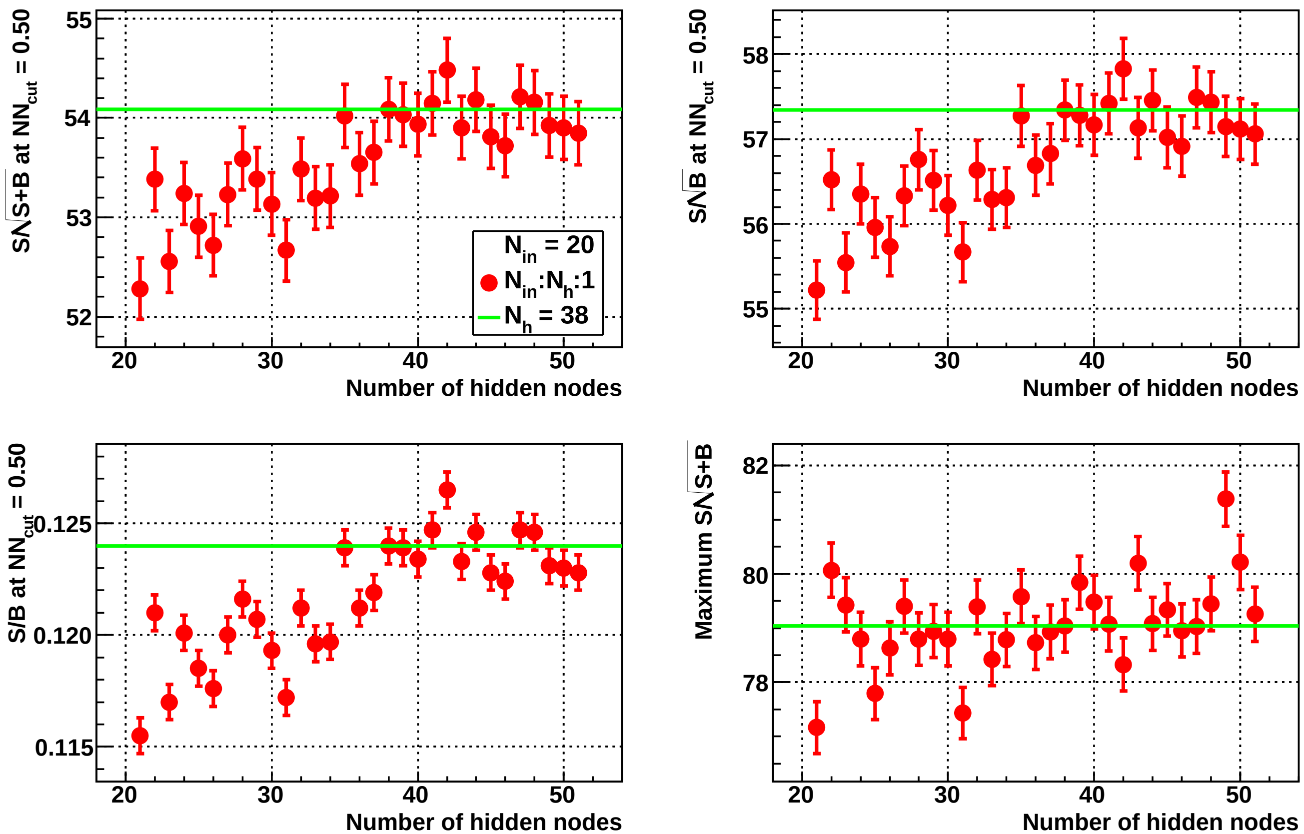
- **From 20 variables, remove variable with smallest** *Importance* **at each step**

  Importance: **sum of the weights-squared of the connections that leave input variable**

```
--- MLP          : Ranking result (top variable is best ranked)
--- MLP          : ----------------------------------------------------------------
--- MLP          : Rank : Variable     : Importance
--- MLP          : ----------------------------------------------------------------
--- MLP          :    1 : aplanarity   : 1.235e+02
--- MLP          :    2 : visible      : 9.100e+01
--- MLP          :    3 : probchi      : 2.375e+01
--- MLP          :    4 : h30          : 2.367e+01
--- MLP          :    5 : jang         : 2.302e+01
--- MLP          :    6 : thrust       : 2.175e+01
--- MLP          :    7 : h40          : 1.890e+01
--- MLP          :    8 : thrusttheta  : 9.918e+00
--- MLP          :    9 : chi2mass     : 6.840e+00
--- MLP          :   10 : ycut         : 6.076e+00
--- MLP          :   11 : sphere       : 3.957e+00
--- MLP          :   12 : blike        : 3.122e+00
--- MLP          :   13 : chi2         : 2.980e+00
--- MLP          :   14 : pfano        : 1.545e+00
--- MLP          :   15 : maxibs       : 1.298e+00
--- MLP          :   16 : jmom         : 9.103e-01
--- MLP          :   17 : bsno         : 1.441e-01
--- MLP          :   18 : massz0       : 1.231e-01
--- MLP          :   19 : nrang        : 5.080e-02
--- MLP          :   20 : smallangle   : 1.654e-02
--- MLP          : ----------------------------------------------------------------
```

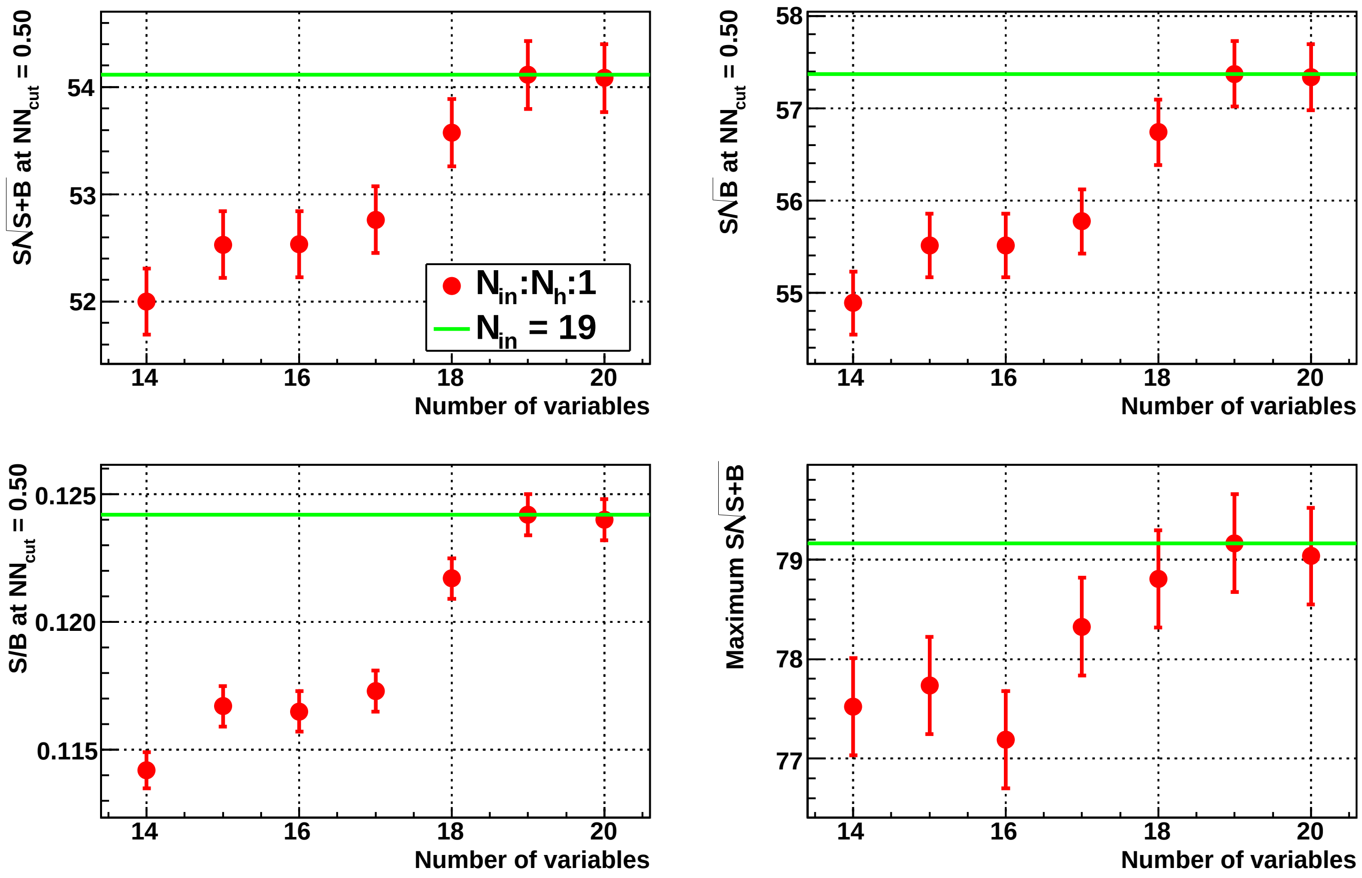
One hidden layer: N:N_h:1

- **for 20 variables: 20:38:1** $\surd$



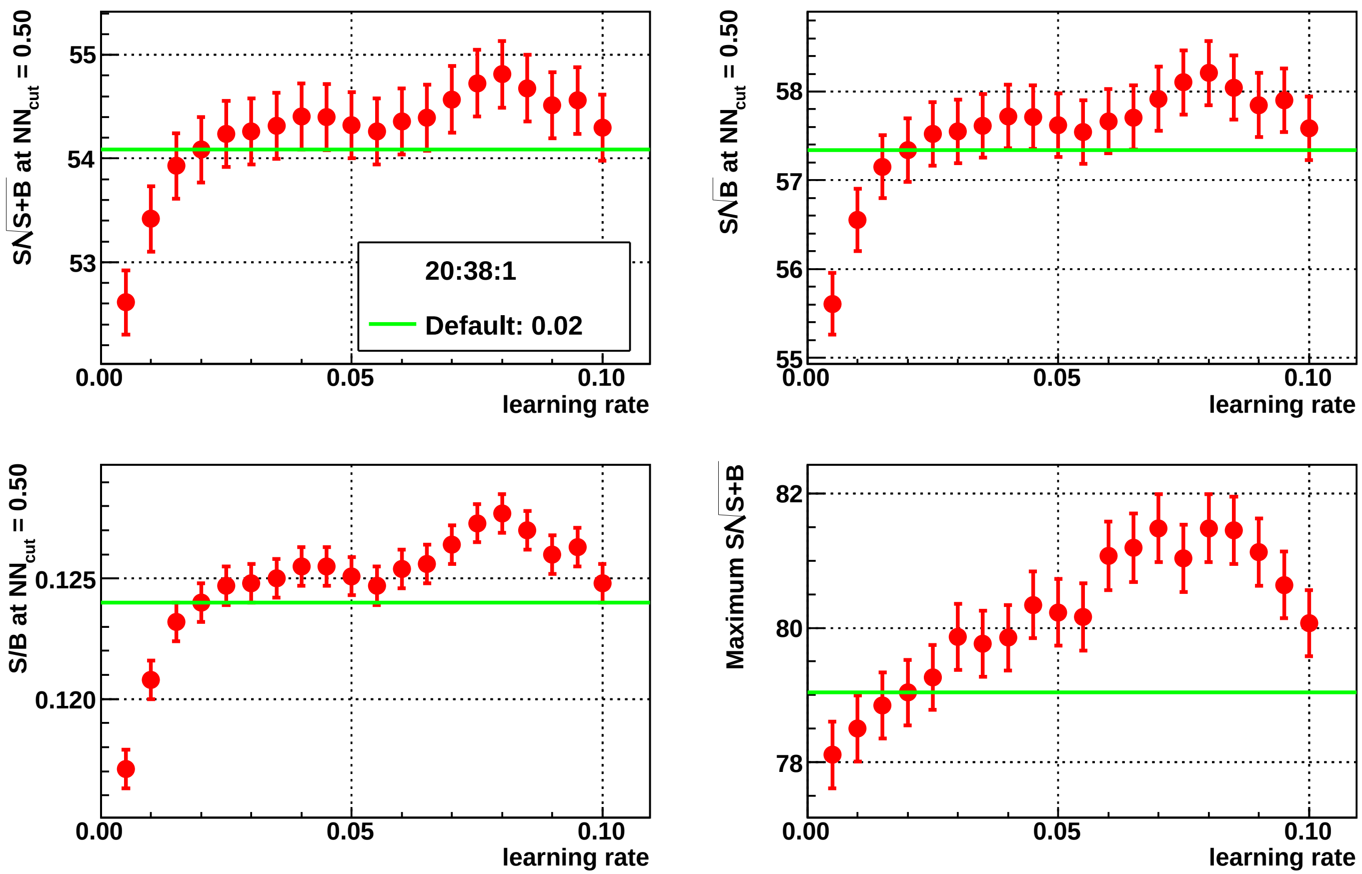
Number of variables at input layer

- **good architectures 19:42:1 and 20:38:1** $\surd$ **due to samller number of weights**
  19:42:1 has 883 weights; 20:38:1 has 837 weights.



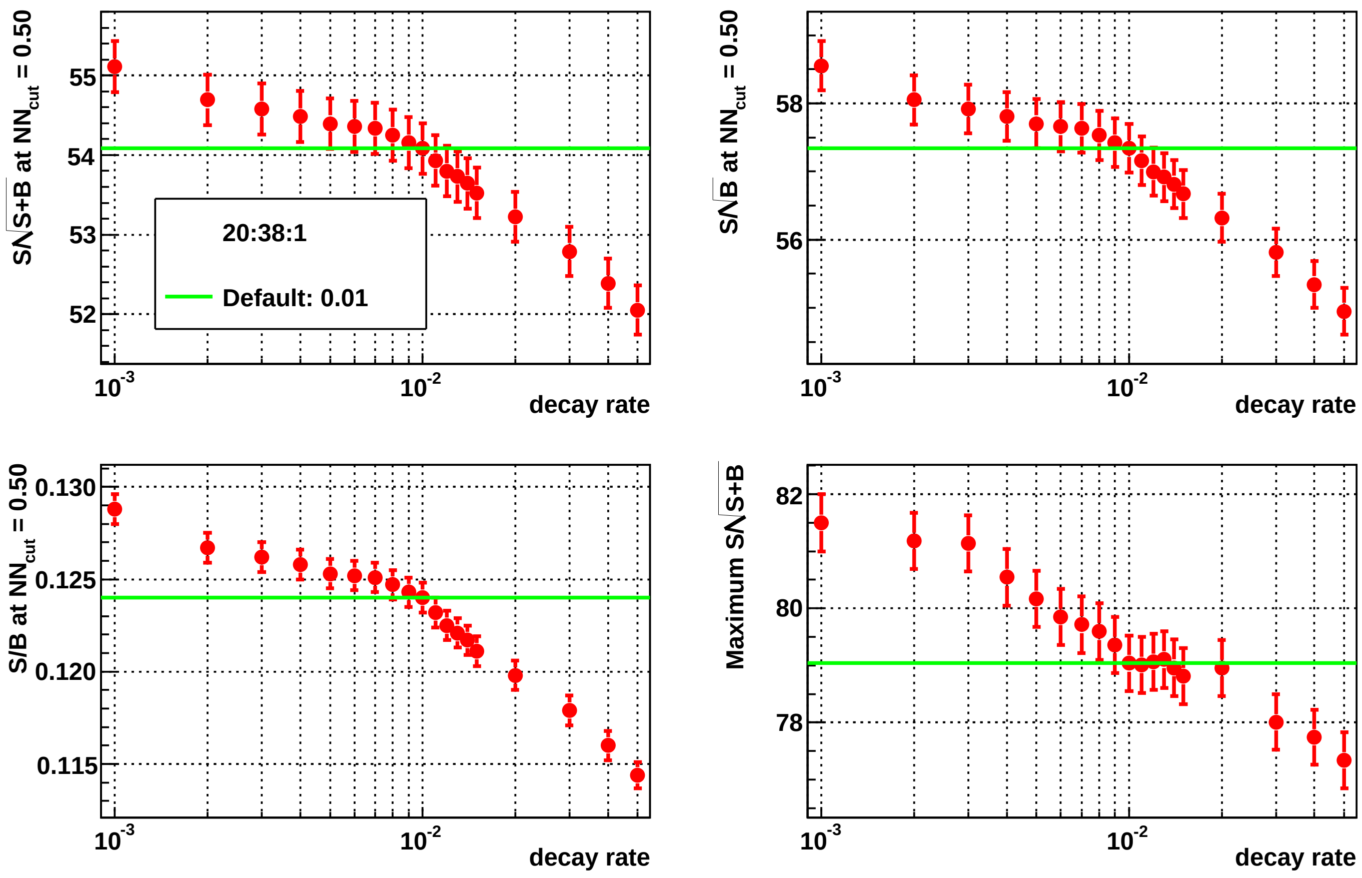
Neural network parameters: learning rate η

- **the positive learning rate η is a factor in updating weights**



Neural network parameters: decay rate

- **the decay rate is a factor for learning parameter; smaller decay rate, larger number of training cycles**



Neural network: training sample size

- **training sample size: factor $\times$ number of weights**