# $ZH \rightarrow q\bar{q}c\bar{c}$ study with neural network

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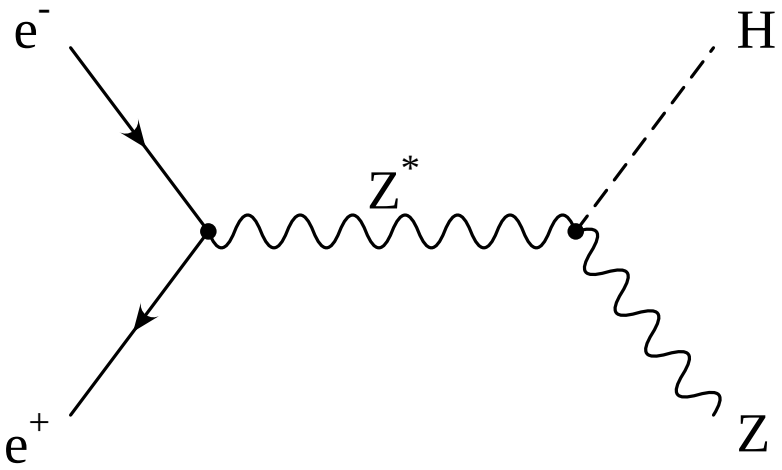
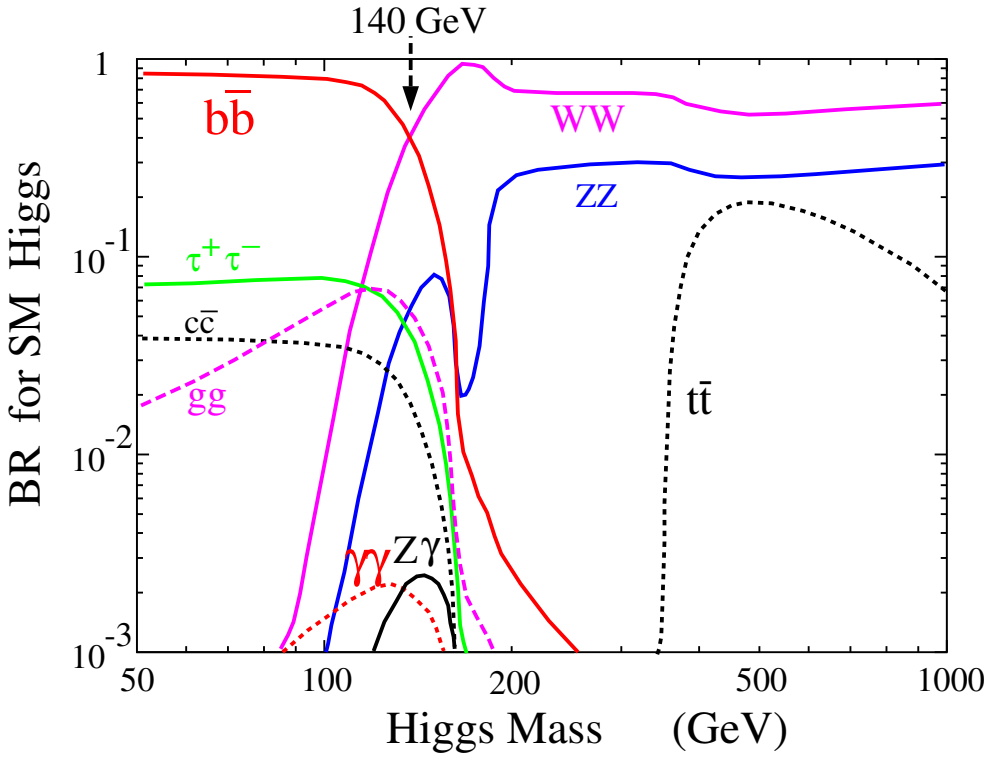



- **introduction**
- **jet resolution**
- **c-tag**
- **neural network @ ZH**
- $Br(H \rightarrow c\bar{c})$

# Higgs decay




- **Higgs branching ratio Br($h \to c\bar{c}$) @ $M_h = 120$ GeV**
- **extract $\frac{\Delta\sigma(ZH\to q\bar{q}c\bar{c})}{\sigma(ZH\to q\bar{q}c\bar{c})}$ and $\frac{\Delta Br(H\to c\bar{c})}{Br(H\to c\bar{c})}$**

# MC data samples @ 250 GeV

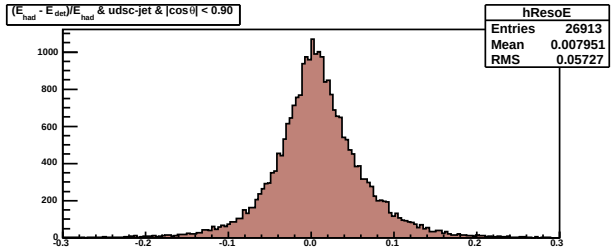
- **signal events $q\bar{q}H \longrightarrow q\bar{q}c\bar{c}$ and background events $q\bar{q}$ and $q\bar{q}q\bar{q}$**
  - **DESY DST files: $(e^+, e^-)$ polarization; (1.0, -1.0) and (-1.0, 1.0)**
  - **combine it for polarization (0.3, -0.8)**
- **detector model ILD00 and event reconstruction ilcinstall v01-06**
- **kinematic fitting MarlinKinfit @ analysis $\longrightarrow$ jet resolution**
  - **$q\bar{q}$ at 20/40/80/91.2/120/160/200/240/300 GeV**
  - **$q = u, d, s, c$: 20K; $q = b$: 10K**
- **event selection with neural network**
  - **100K $q\bar{q}c\bar{c}$ events**

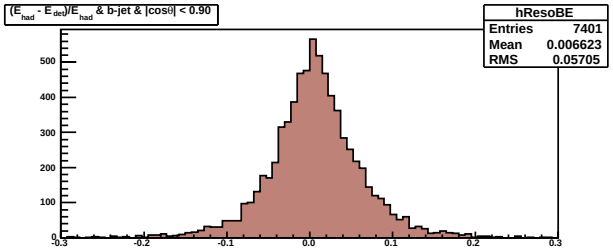
# Jet resolution

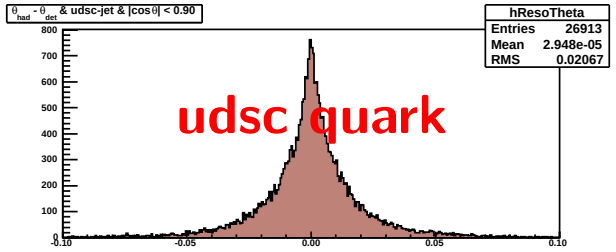
$E$

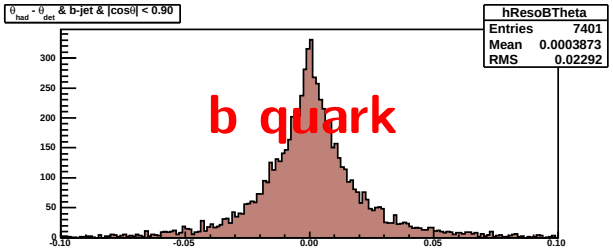
$\theta$

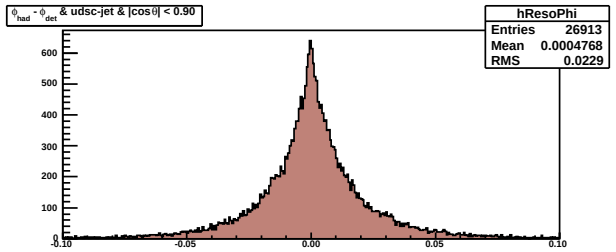
$\phi$

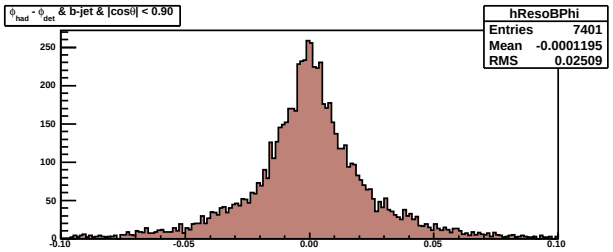


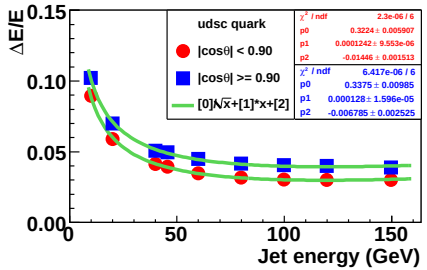



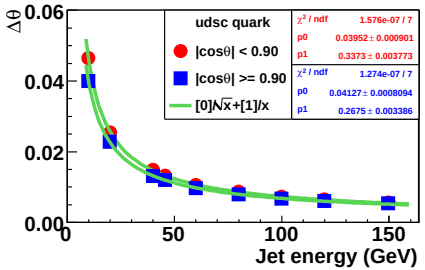



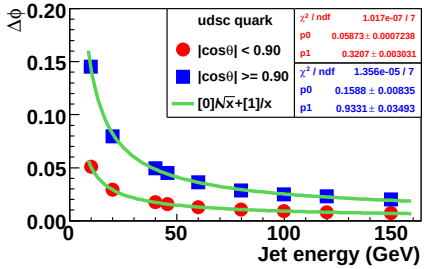



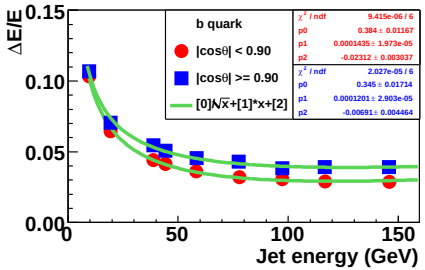

- **jets finding at hadron level: MC stable particles without neutrinos**
- **jets finding at detector level**
- **jet's energy: mean value $\sim 0.8\%$**
- **jet's angle: mean value $\sim 0.0$**

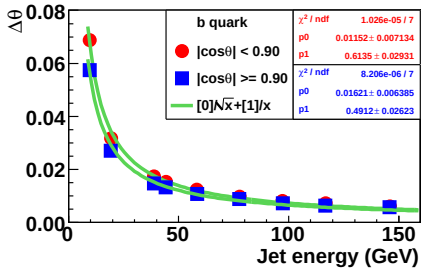
# Jet resolution

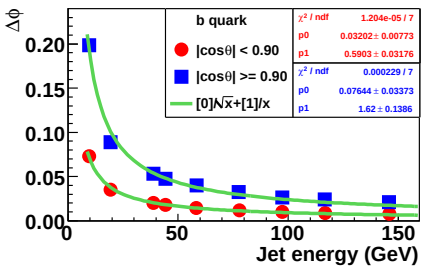


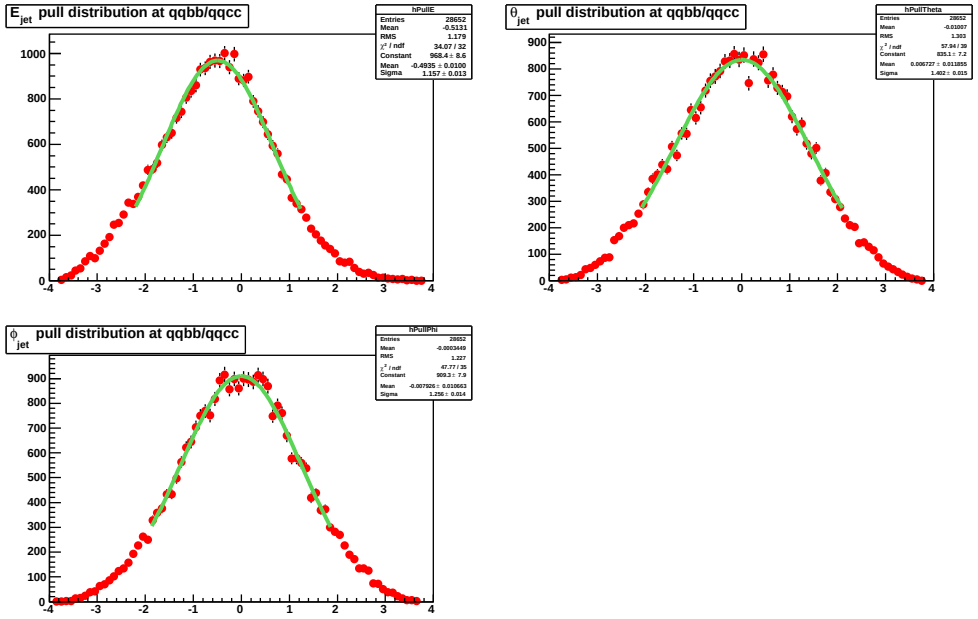




- $e^+e^- \longrightarrow q\bar{q}$ **events without ISR**
- **jets finding at hadron level: MC stable particles without neutrinos**
- **jets finding at detector level**

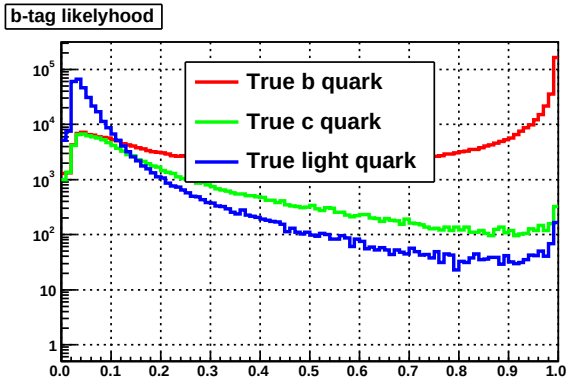
# jet resolution @ $c\bar{c}h$ events

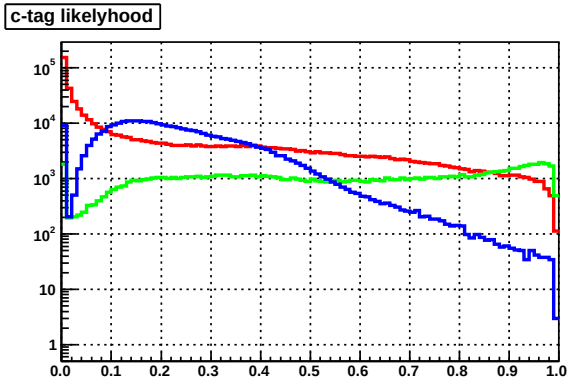
- **kinematic fitting**
  - **energy-momentum conservation and two jets from $Z^0$: $M_{j1j2} = M_Z$**
- **check jet resolution by pull variables**
  - $PULL(x) = (x_{meas} - x_{fit})/(\sqrt{\sigma^2_{meas} - \sigma^2_{fit}})$

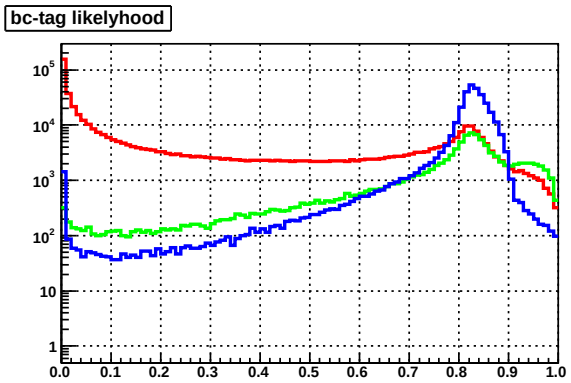


# b-tag/c-tag at ZH 250GeV

- **b-tag, c-tag and bc-tag from LCFIvertex package**
- **$ZH \rightarrow q\bar{q}H$ events with $(e^+, e^-)$ polarization (1.0, -1.0)**



# neural network: 17 used variables

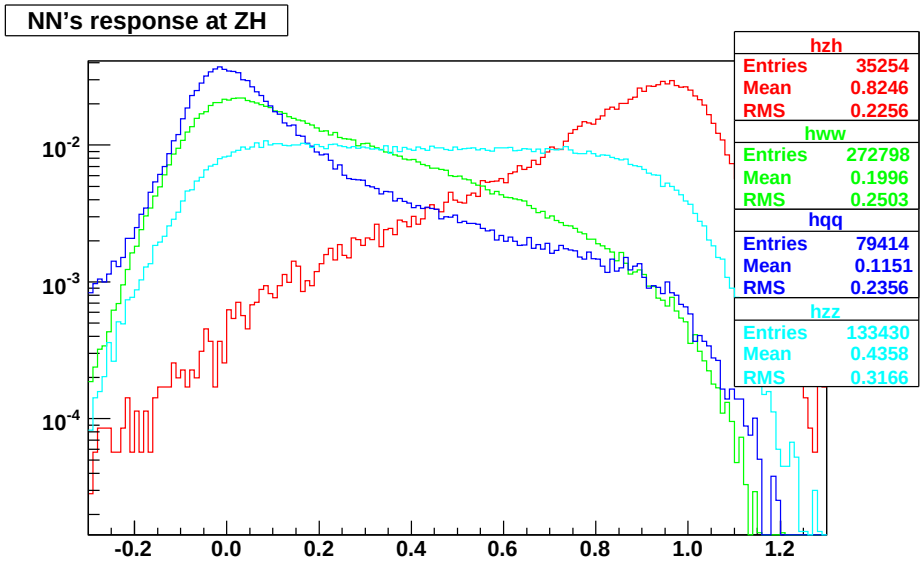
- **total visible energy; PFA number; $y_{34}$;**
- **thrust; theta of thrust axis; sphericity; aplanarity; Fox-Wolfram moments $h_{30}$ and $h_{40}$**
- **$\chi^2$ probability and fitted Higgs mass of 4C $\otimes M_{j_1 j_2} = 91.20$ GeV fitting; $\chi^2$ probability of 4C $\otimes M_{j_1 j_2} = M_{j_3 j_4}$ fitting**
- **$j_{mom}$ and $j_{ang}$ @ OPAL CERN-EP/98-167**
  - **sort jets by jet energy $E_{j1} \geq E_{j2} \geq E_{j3} \geq E_{j4}$**
  - **$j_{mom} = \frac{|\vec{p_1}|+|\vec{p_2}|-|\vec{p_3}|-|\vec{p_4}|}{\sqrt{s}}$**
  - **$j_{ang} = \frac{E_4}{\sqrt{s}}(1 - \cos\theta_{12}\cos\theta_{13}\cos\theta_{23})$**
- **$Z^0$ mass $M_{Z^0}$**
- **c-likeness/bc-likeness of two jets from Higgs**
  **c-likeness= $\frac{c_1 c_2}{c_1 c_2 + (1.0 - c_1) * (1.0 - c_2)}$**

# Neural network architecture

- **TMVA package v3.8.13: Artificial Neural Networks MLP**
- **neural network architecture 17:40:1**
  - **input layers: 17 variables**
  - **one hidden layer: 40 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 @ LDCPrime_02Sc

- **results @ ILD00: ongoing**
- **shown results @ LDCPrime_02Sc**
- **the signal peaks around 1.0; the backgrounds peak around 0.0**
- **plots are normalizes to one; plot hzh: $q\bar{q}H \longrightarrow q\bar{q}X$**



# $\sigma(ZH \rightarrow q\bar{q}c\bar{c})$ @ LDCPrime_02Sc

- $q\bar{q}c\bar{c}$ event selection (LDCPrime_02Sc )
  - neural network's output $> 0.869$
  - $\chi^2$ probability of 4C $\otimes M_{j_1 j_2} = 91.20$ GeV: $> 0.01$
  - fitted Higgs mass 110GeV $< M_H^{fit} <$ 130GeV
  - two jets from Higgs: each jet with c-tag $> 0.50$, c-likeness $> 0.80$

| | $N_{event}$ @ 250 $fb^{-1}$ |
|---|---|
| $ZH \rightarrow q\bar{q}c\bar{c}$ | 107 |
| $WW \rightarrow q_1 q_2 q_3 q_4$ | 291.8 |
| $ZZ \rightarrow q_1 \bar{q}_1 q_2 \bar{q}_2$ | 112 |
| $e^+e^- \rightarrow q\bar{q}$ | 262.2 |
| non-qqcc @ $q\bar{q}H$ | 46 |

- $\Delta\sigma(ZH \rightarrow q\bar{q}c\bar{c})/\sigma(ZH \rightarrow q\bar{q}c\bar{c}) = \sqrt{s+b}/s = 26.8\%$

# $Br(H \to c\bar{c})$ @ LDCPrime_02Sc

- **Higgs branching ratio $Br(H \to c\bar{c})$**

$$Br(H \to c\bar{c}) = \frac{\sigma(e^+e^- \to ZH \to q\bar{q}c\bar{c})}{\sigma(e^+e^- \to ZH)}$$

- **$\sigma(e^+e^- \to ZH)$ from ZH recoil-mass by Kazutoshi Ito**
  - **4.7% for electron channel**
  - **3.8% for muon channel**

- **$\Delta Br(H \to c\bar{c})$ (LDCPrime_02Sc )**

$$\frac{\Delta Br(H \to c\bar{c})}{Br(H \to c\bar{c})} = \sqrt{\left(\frac{\Delta\sigma(e^+e^- \to ZH \to q\bar{q}c\bar{c})}{\sigma(e^+e^- \to ZH \to q\bar{q}c\bar{c})}\right)^2 + \left(\frac{\Delta\sigma(e^+e^- \to ZH)}{\sigma(e^+e^- \to ZH)}\right)^2}$$

$$= 27.2\%$$

# Status and Plan

- **we have**
  - **analysis code for ILD00 on whizard data**
  - **code to find a good neural network architecture**
  - **method to calculate uncertainty for Br($H \longrightarrow c\bar{c}$)**
  - **100K $q\bar{q}c\bar{c}$ traing sample @ -80% electron 30% positron**
- **missing part @ ILD00**
  - **run neural net work for '-80% electron 30% positron'**
  - **calculate uncertainty for Br($H \longrightarrow c\bar{c}$)**