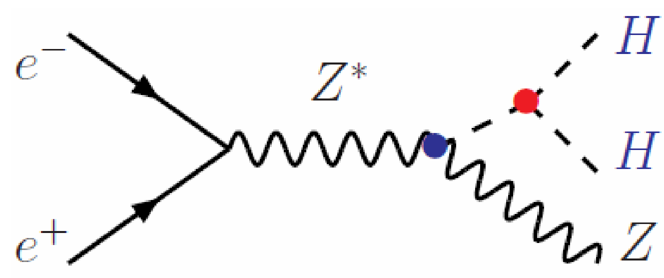
Update on Higgs Self-Coupling Error -- Improved MC Statistics and Final State QCD Rad.

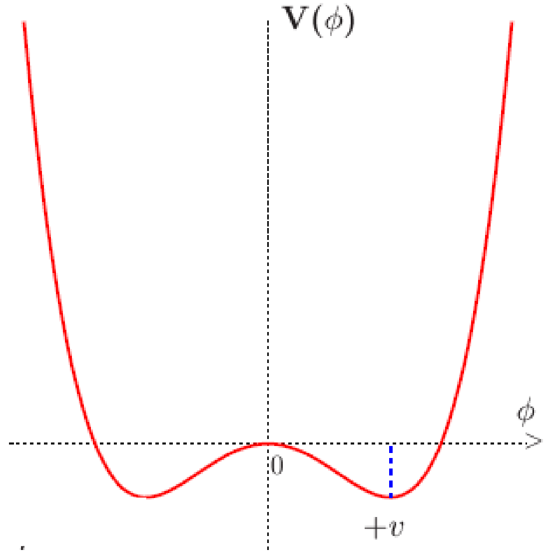
Tim Barklow

SLAC

Mar 13, 2007



$g_{HHH} = -6\mu^2 / \mathrm{v}$



$$V(\phi) = \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$$

Standard Model:

$$M_H^2 = 2\lambda \mathrm{v}^2 = -2\mu^2$$

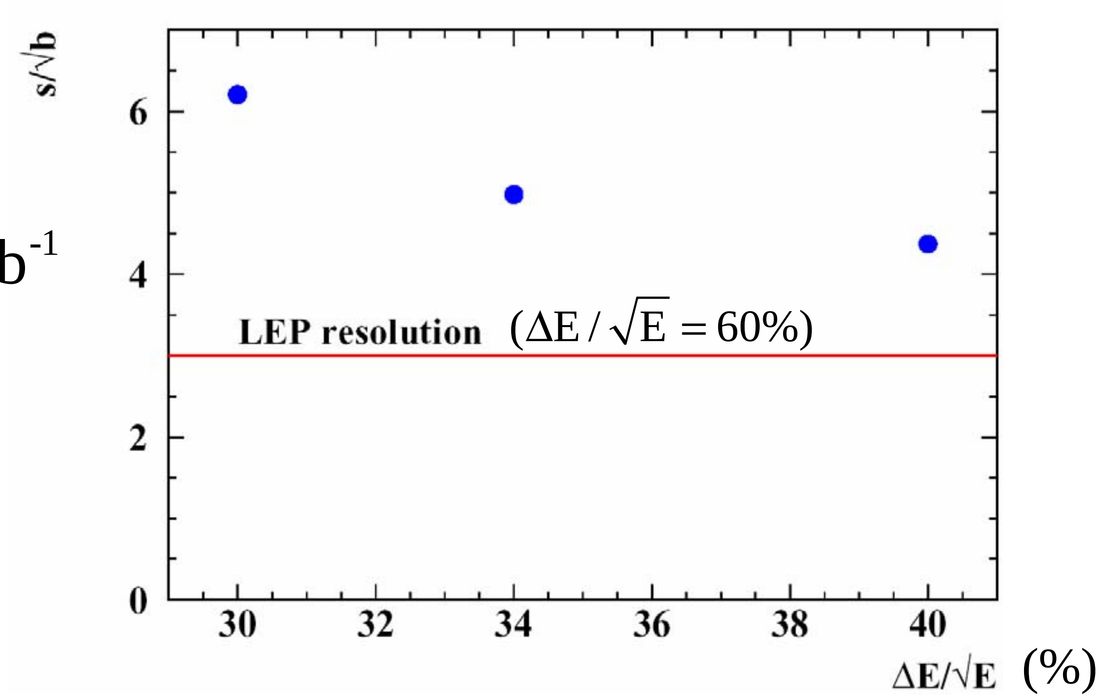
$e^+e^- \to ZHH \to q\bar{q}b\bar{b}b\bar{b}$

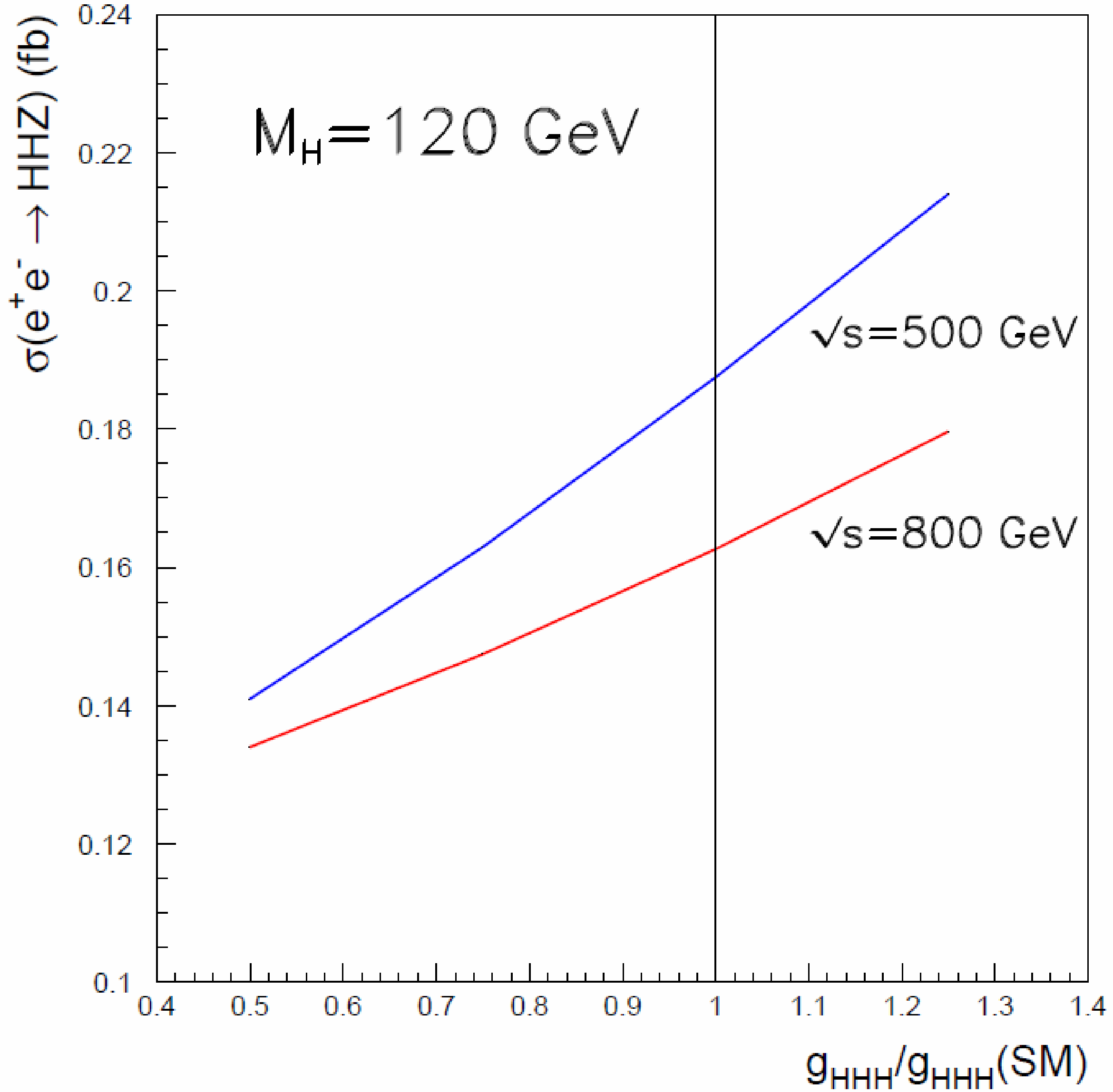
$\sqrt{s}$ = 500 GeV, L=1000 fb^{-1}

$\Delta E/\sqrt{E} = 60\% \to 30\%$

equiv to $4\times$ Lumi

C. Castanier et al. hep-ex/0101028





M_H=120 GeV
√s=500 GeV
√s=800 GeV
$\sigma(e^+e^- \to HHZ)$ (fb)
$g_{HHH}/g_{HHH}(SM)$
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4

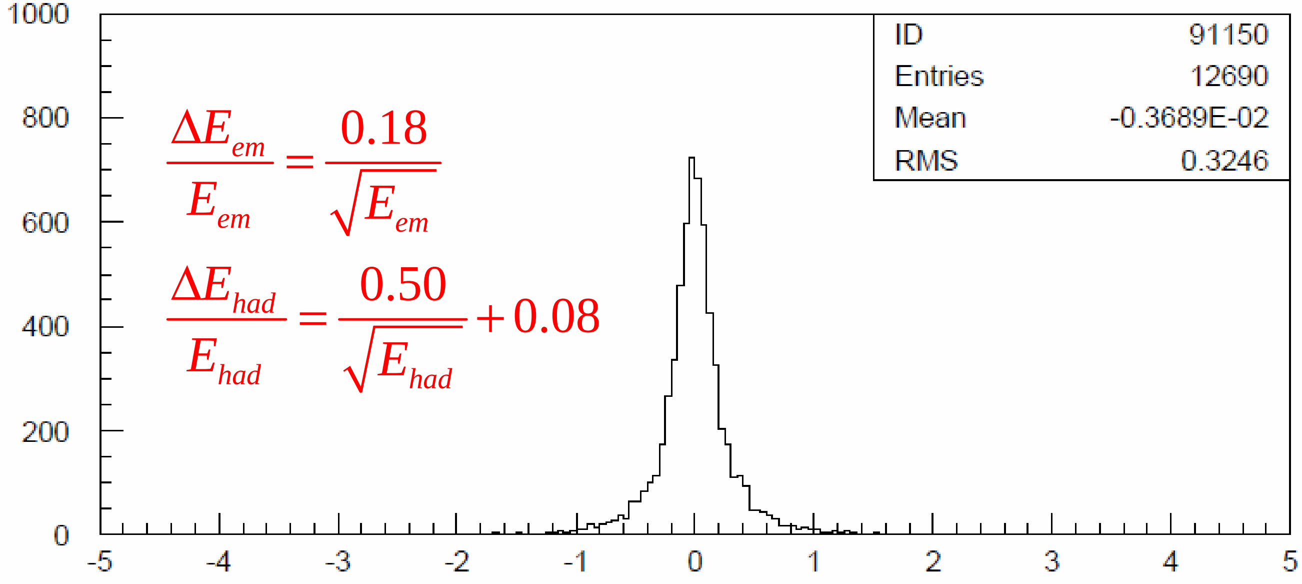
Plan for Analyis

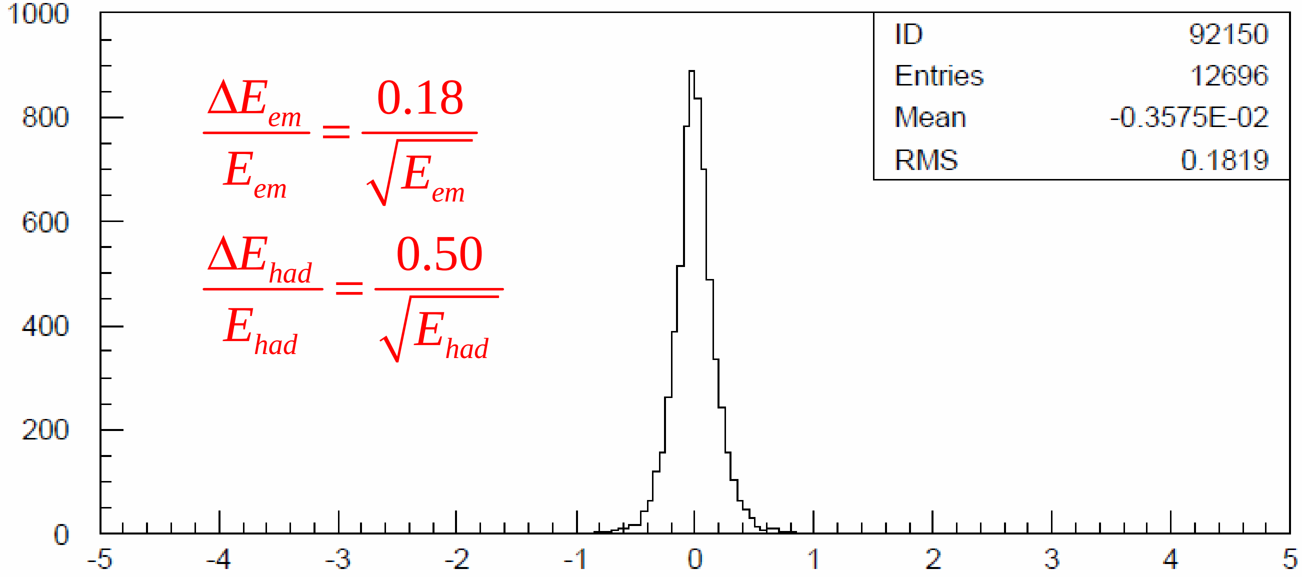
- Perform analysis on qqbbbb channel only at E_{cm}=500 GeV assuming 0% electron polarization. Use org.lcsim Fast MC simulation of baseline SiD. This MC includes a reasonable algorithm for smearing charged track angles, curvature and impact parameters. Calorimeter simulation consists of simple single neutral particle smearing with EM resolution for photons and HAD res for n,$K0_{L}$.
- Scale single particle calorimeter resolutions to get a particular ΔE_{jet} .
- Use org.lcsim ZVTOP for b-tagging
- Turn off final state gluon radiation for signal and bgnd

$\sqrt{s} = 500$ GeV

$e^+e^- \rightarrow u\bar{u}$

E_{true} is adjusted for neutrinos and particles outside detector acceptance





$$\Delta E_{jet} = (E_{rec} - E_{true}) / \sqrt{E_{true}}$$

Drop constant term in single particle resolution for now. Assume negligible contribution from charged particles to jet energy resolution and write

$$\sigma^2 = (1+\lambda(1-r))A_\gamma^2 w_\gamma E_{jet} + (1+\lambda r)A_h^2 w_h E_{jet} = c^2 E_{jet}$$

where $c = 0.3, 0.4, 0.5, 0.6$

$r =$ hadronic resolution degradation fraction

($r = 1$ to only degrade hadronic resolution

$r = 0$ to only degrade em resolution)

$A_\gamma = 0.18 \quad A_h = 0.50 \quad w_\gamma = 0.28 \quad w_h = 0.10$

Given a desired jet energy resolution c the parameter λ is given by

$$\lambda = \frac{c^2 - A_\gamma^2 w_\gamma - A_h^2 w_h}{(1-r)A_\gamma^2 w_\gamma + rA_h^2 w_h}$$

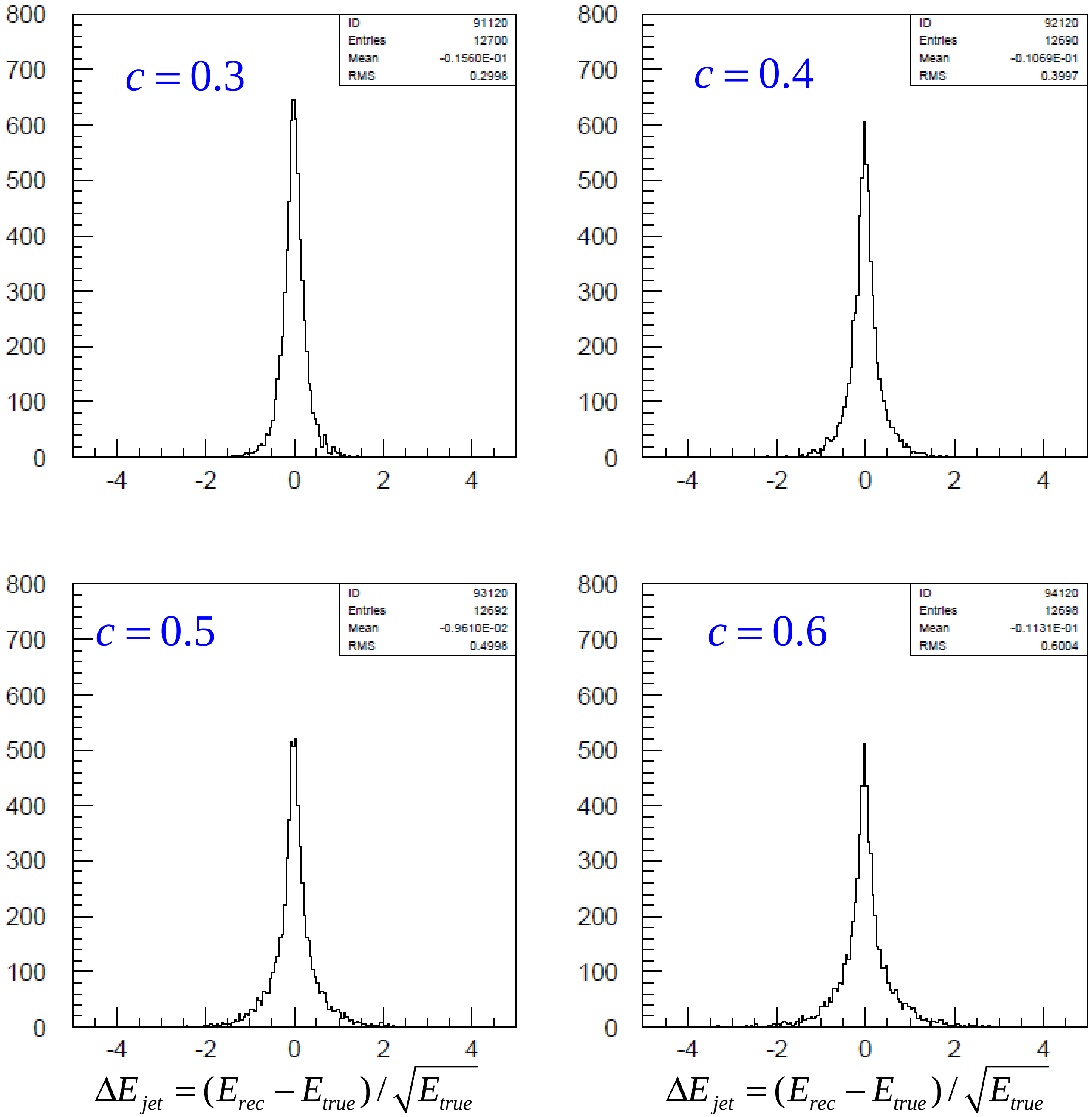
$$e^+e^- \to u\bar{u}$$

$\sqrt{s} =$ 500 GeV

$r = 1.0$

(only degrade had resolution)

call this the "non-Gaussian parameterization"



$\sqrt{s} = 500$ GeV

$$e^+e^- \rightarrow u\bar{u}$$

$r = 1.0$

but use calor E

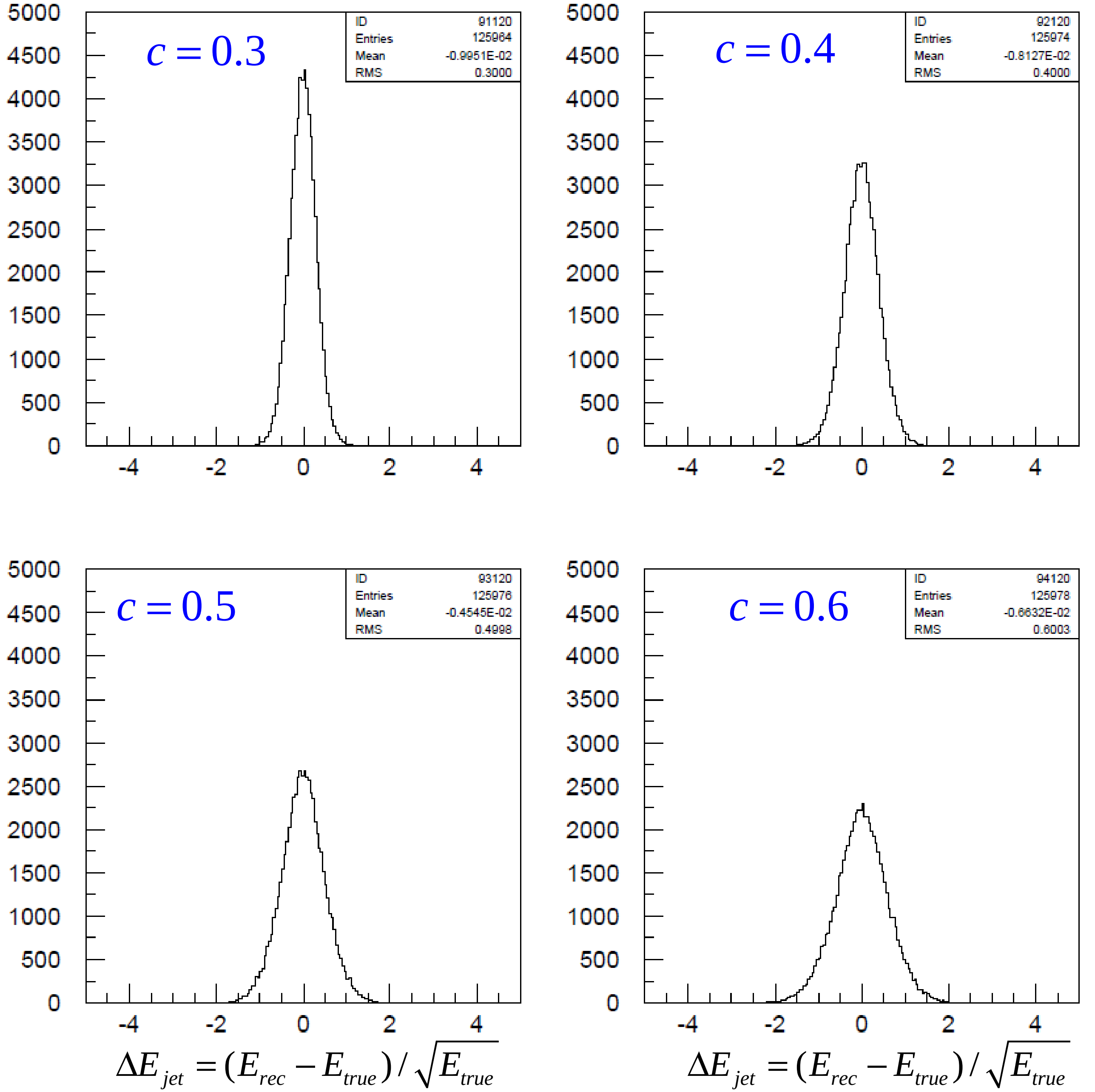
for all chg had

=> $w_h = 0.71$

call this the

"Gaussian

parameterization"



ZHH Preselection

Require:

$$|\cos\theta_{thrust}| < 0.95$$

$$thrust < 0.85$$

$$P_{tot}(z) < 50 \text{ GeV}$$

$$M_{thrust\_hemisphere} > 110 \text{ GeV for at least 1 thrust hemisphere}$$

$$N_{isolated\ leptons} = 0$$

$$6 \leq N_{jets} \leq 8$$

$$N_{chrg\ tracks} \geq 35$$

$$E_{jet}(photons) / E_{jet}(total) < 0.8 \text{ for all 6 jets}$$

NN_{btag}

- Use udscb jets in ZHH events to train NN_{btag}
- Perform jet analysis on charged and neutral objects allowing number of jets to vary; for each jet perform ZVTOP analysis as implemented in org.lcsim
- Use the following variables in the btag neural net:

E_{jet}

E_{vtx}

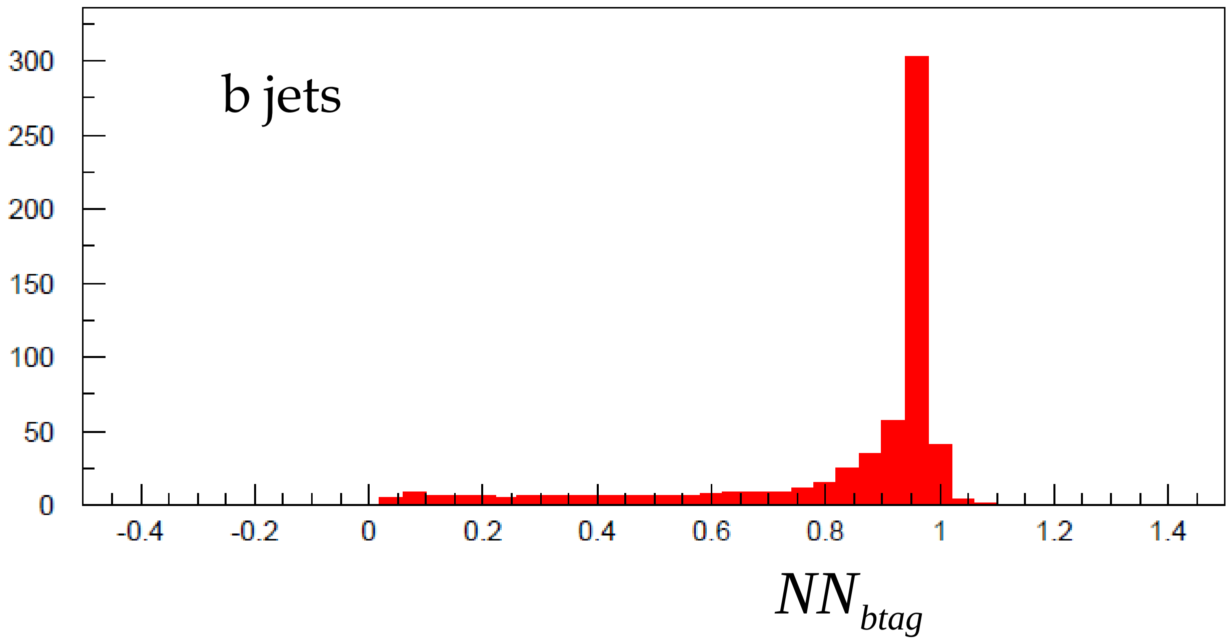
M_{vtx}

Pt-Corrected M_{vtx}

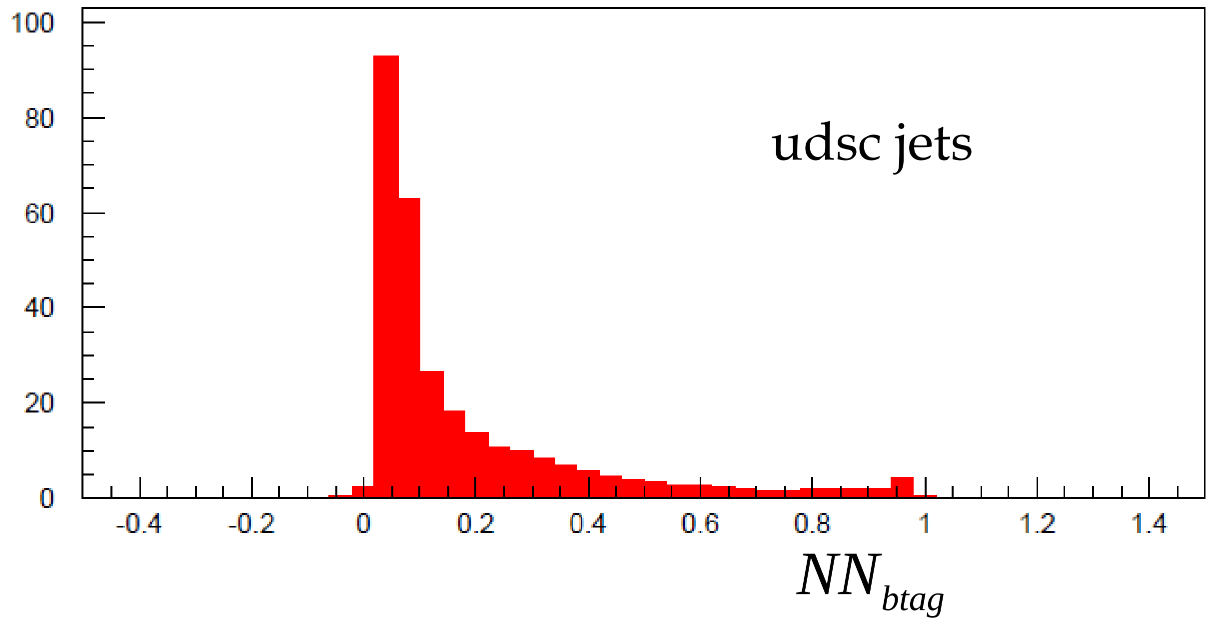
Secondary Vertices

Unassociated Large Impact Parameter Tracks

ZHH events



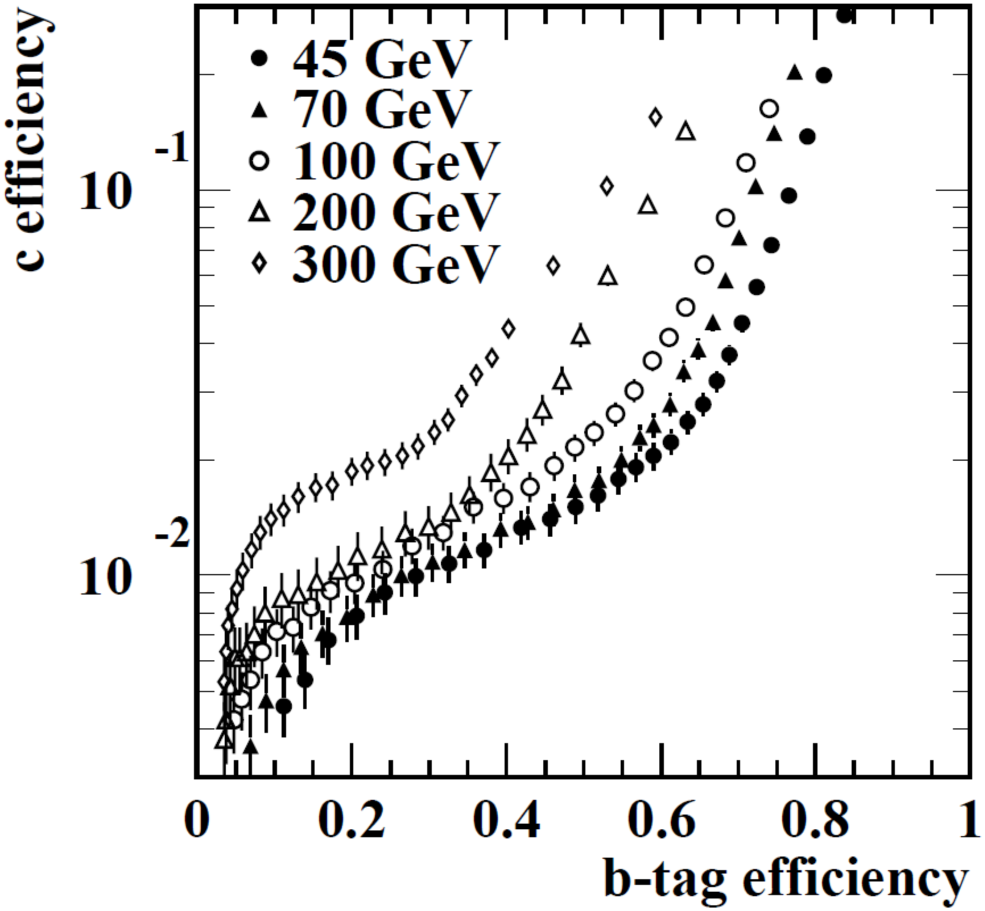
b jets
300
250
200
150
100
50
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
NN_{btag}



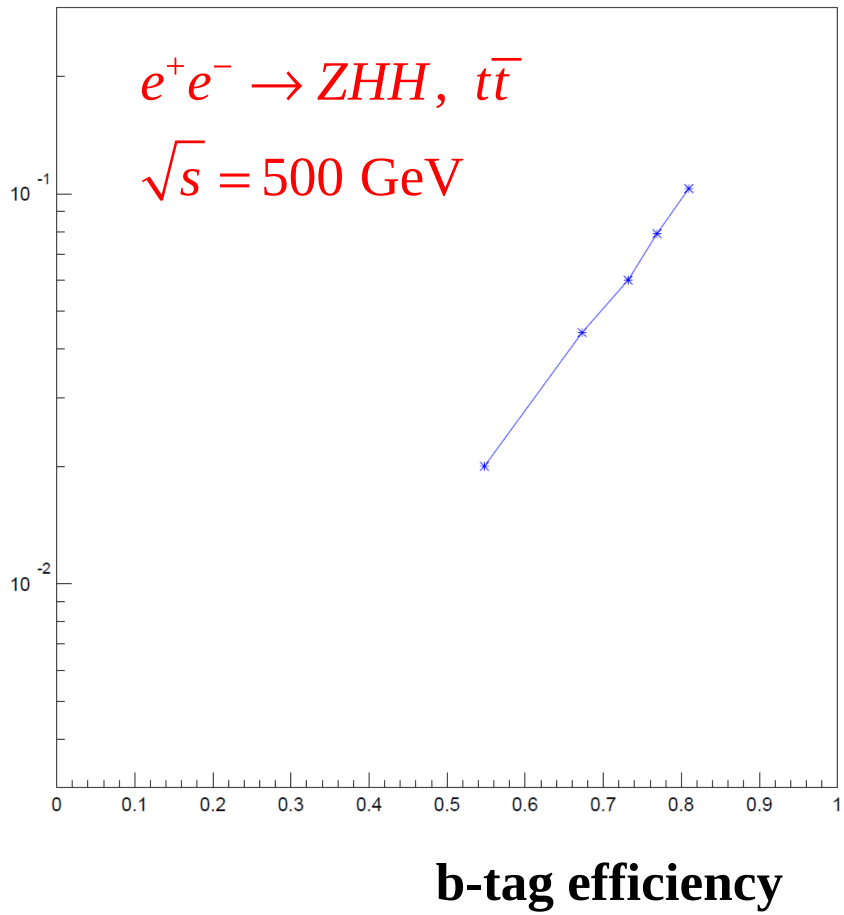
udsc jets
100
80
60
40
20
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
NN_{btag}

charm mis-id efficiency versus b-tag efficiency

R. Hawkings, LC-PHSM-2000-021



SiD ZHH Analysis

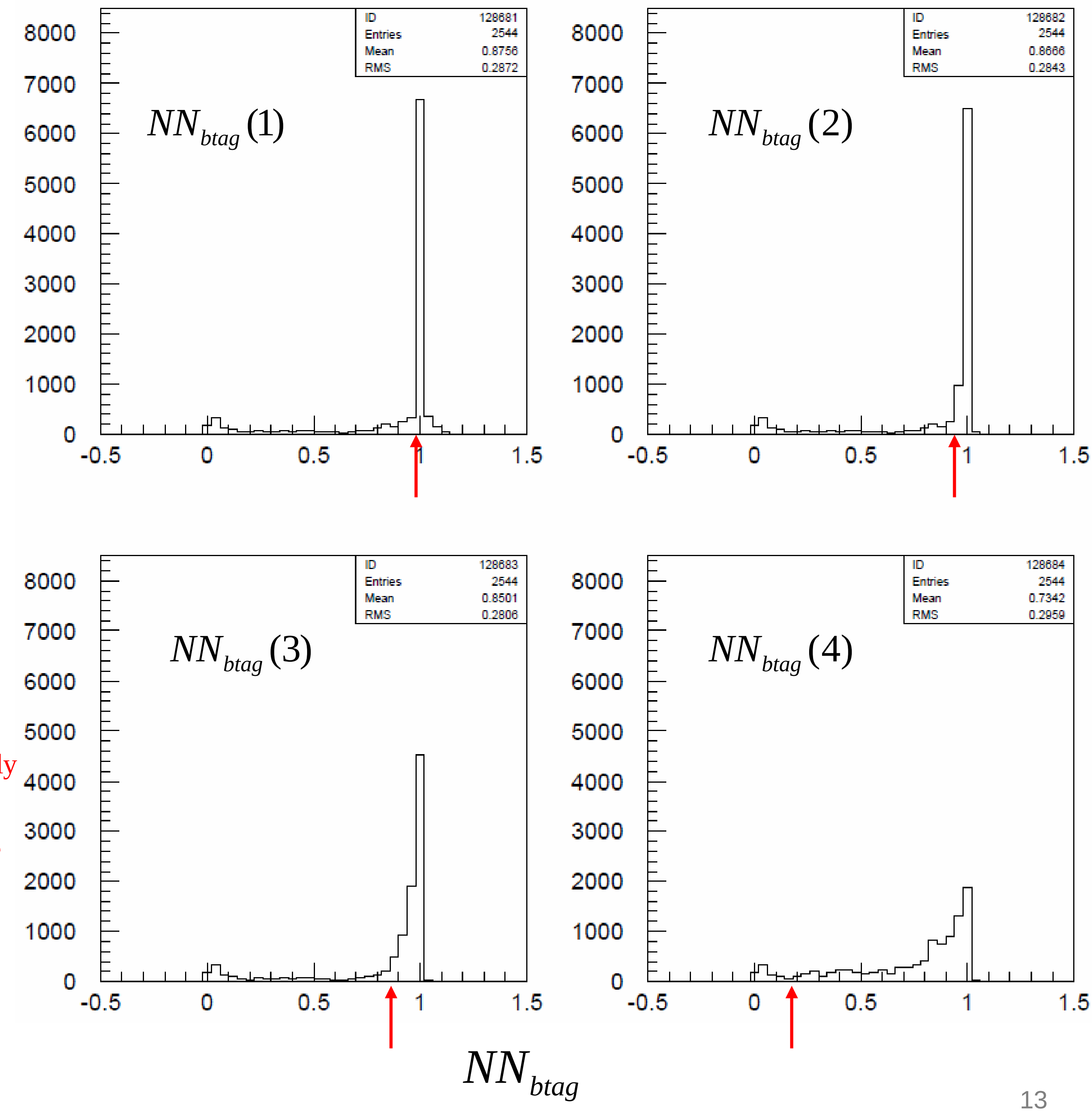


ZHH→qqbbbb

Force reconstrcted particles into 6jets.

Order NN_{btag} for candidate 4jets from HH . Reject 4jet comb if any jet fails min NN_{btag} cut (red arrows)

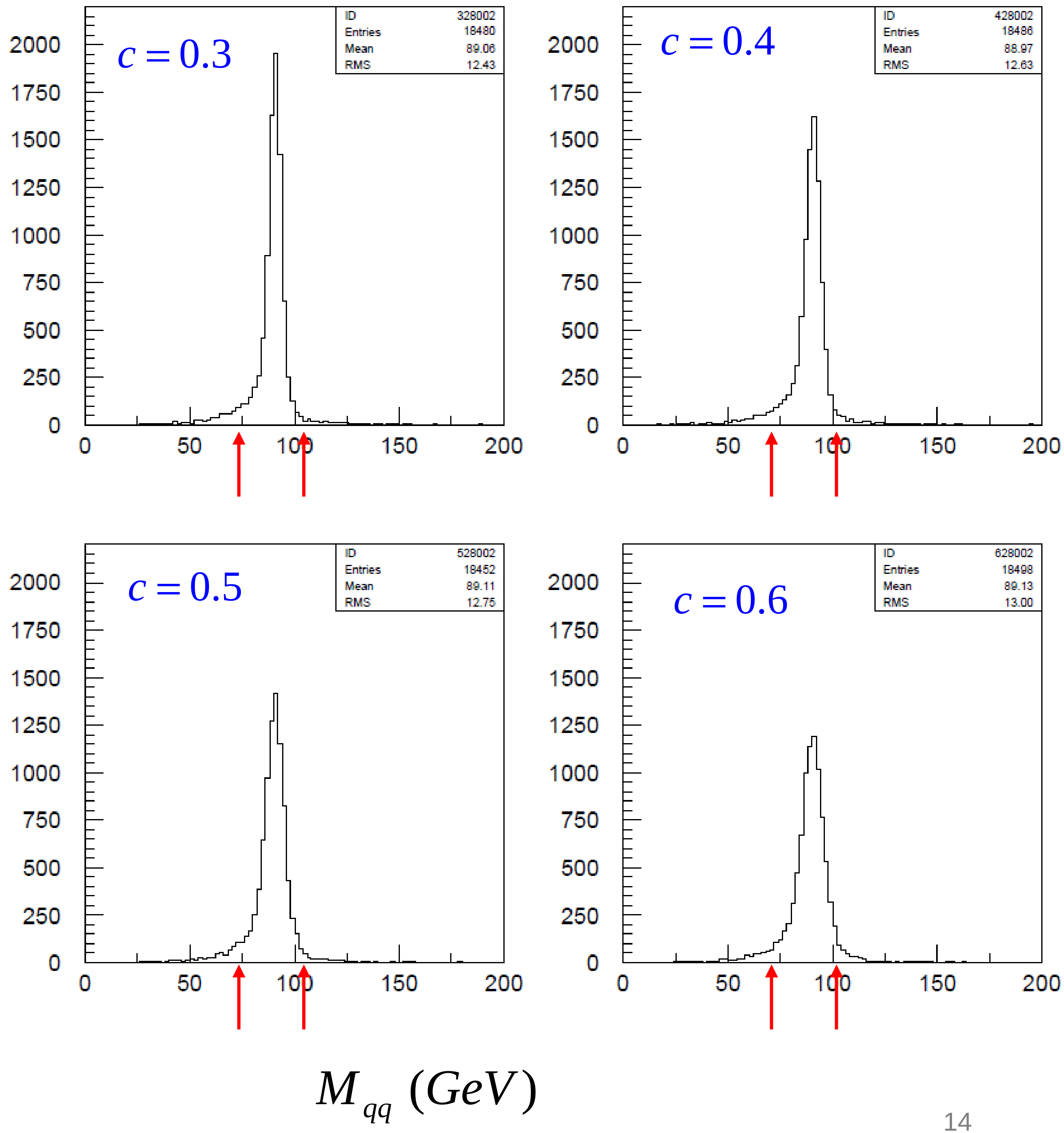
Note that we are effectively requiring that 3 of the 4 jets recoiling against the Z be tagged as b-jets



ZHH→qqbbbb

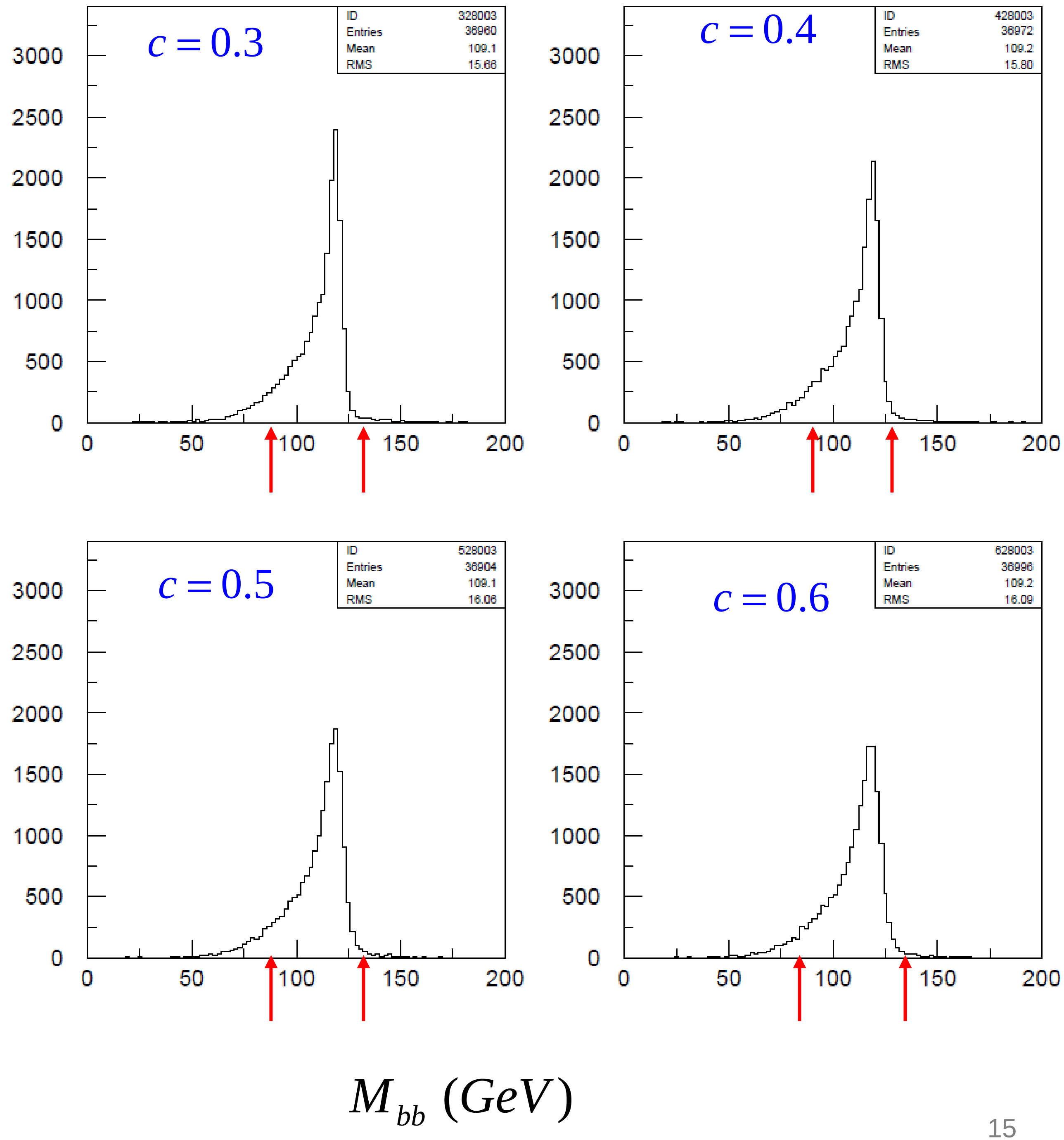
Z mass

Reject Z → 2jet comb if mass outside range $74 < M_{qq} < 104\,\mathrm{GeV}$ (red arrows)

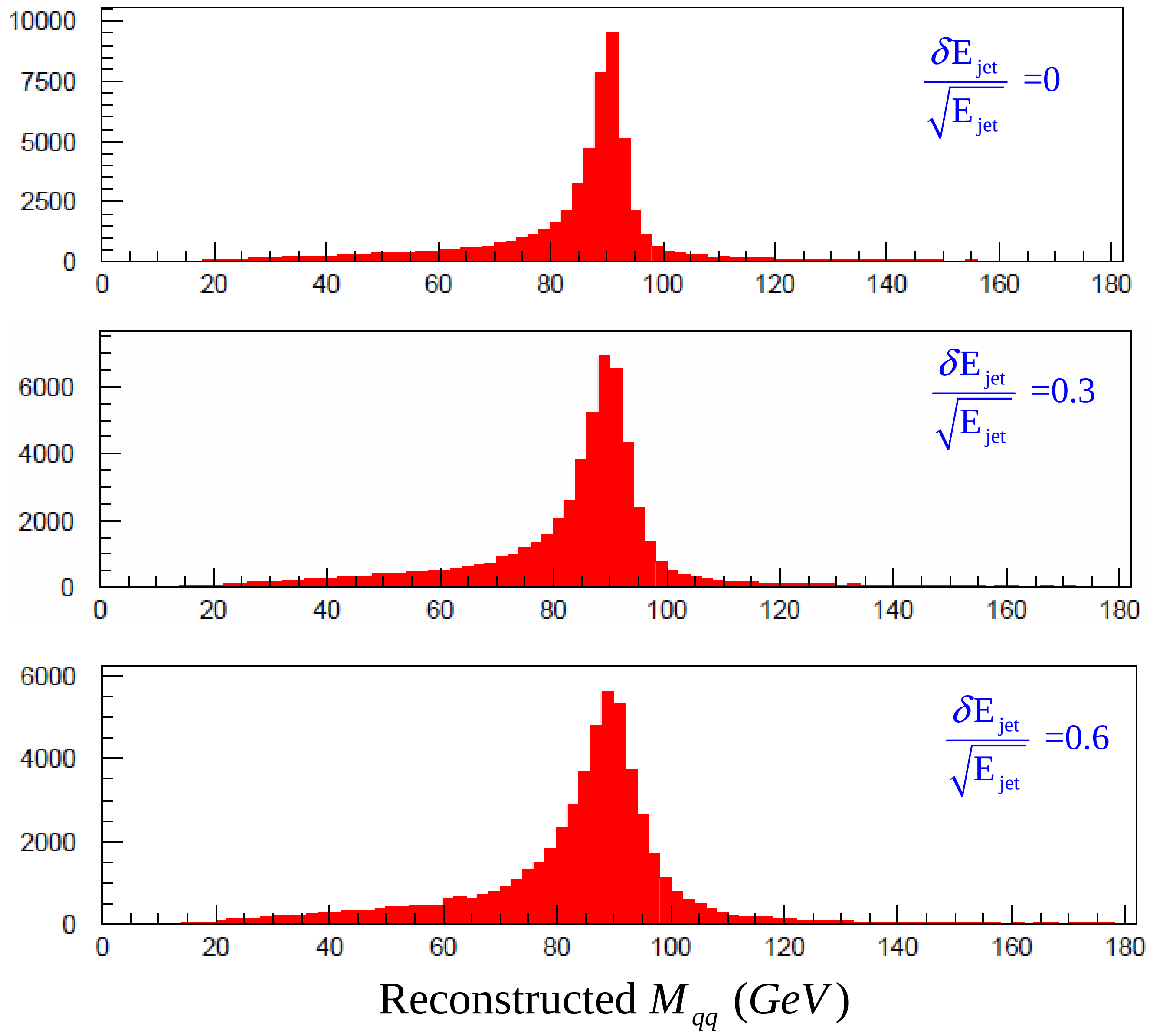


ZHH→qqbbbb
H mass

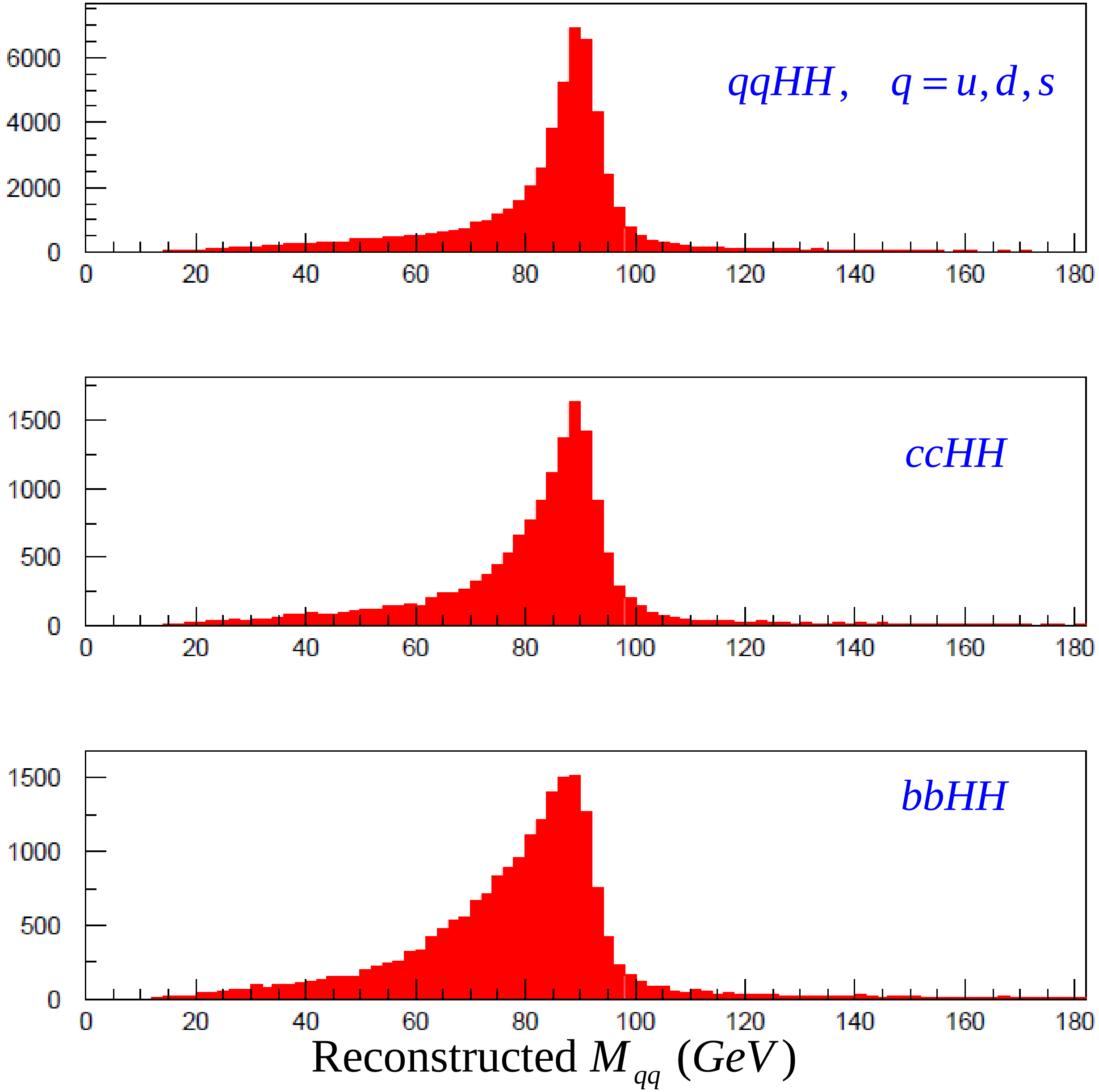
Reject H $\to$ 2jet comb if mass outside range $86 < M_{bb} < 133\,\mathrm{GeV}$ (red arrows)



$e^+e^- \to qqHH, \quad q = u, d, s$ non-Gaussian Parameterization



$$e^+e^- \rightarrow qqHH, \quad \frac{\delta \mathrm{E}_{\mathrm{jet}}}{\sqrt{\mathrm{E}_{\mathrm{jet}}}} = 0.3, \quad \text{non-Gaussian Parameterization}$$



NN_{ZHH}

- Use signal and background events that pass preselection to train NN_{ZHH}
- Use the following variables in the ZHH neural net:

χ^2_{ZHH} $\chi^2_{ZHH\_HHmass}$ $\chi^2_{ZHH\_ZHHmass}$

χ^2_{TT} $\chi^2_{TT\_WWmass}$ $\chi^2_{TT\_TTmass}$

χ^2_{ZZZ} $\chi^2_{ZZH\_ZZHmass}$

χ^2_{ZZ} $\chi^2_{ZH\_ZHmass}$

$NNbtag_j\ ,\ j = 1, 2, 3, 4, 5, 6$

$\min(M_{jet}(k)\ ,\ k = 1, 2, 3, 4, 5, 6)$

$|\cos\theta_{thrust}|$

$\#$ jets

χ^2_{ZHH}

- Force charged and neutral objects into 6 jets
- Loop over 45 jet-pair combinations & minimize χ^2_{ZHH}

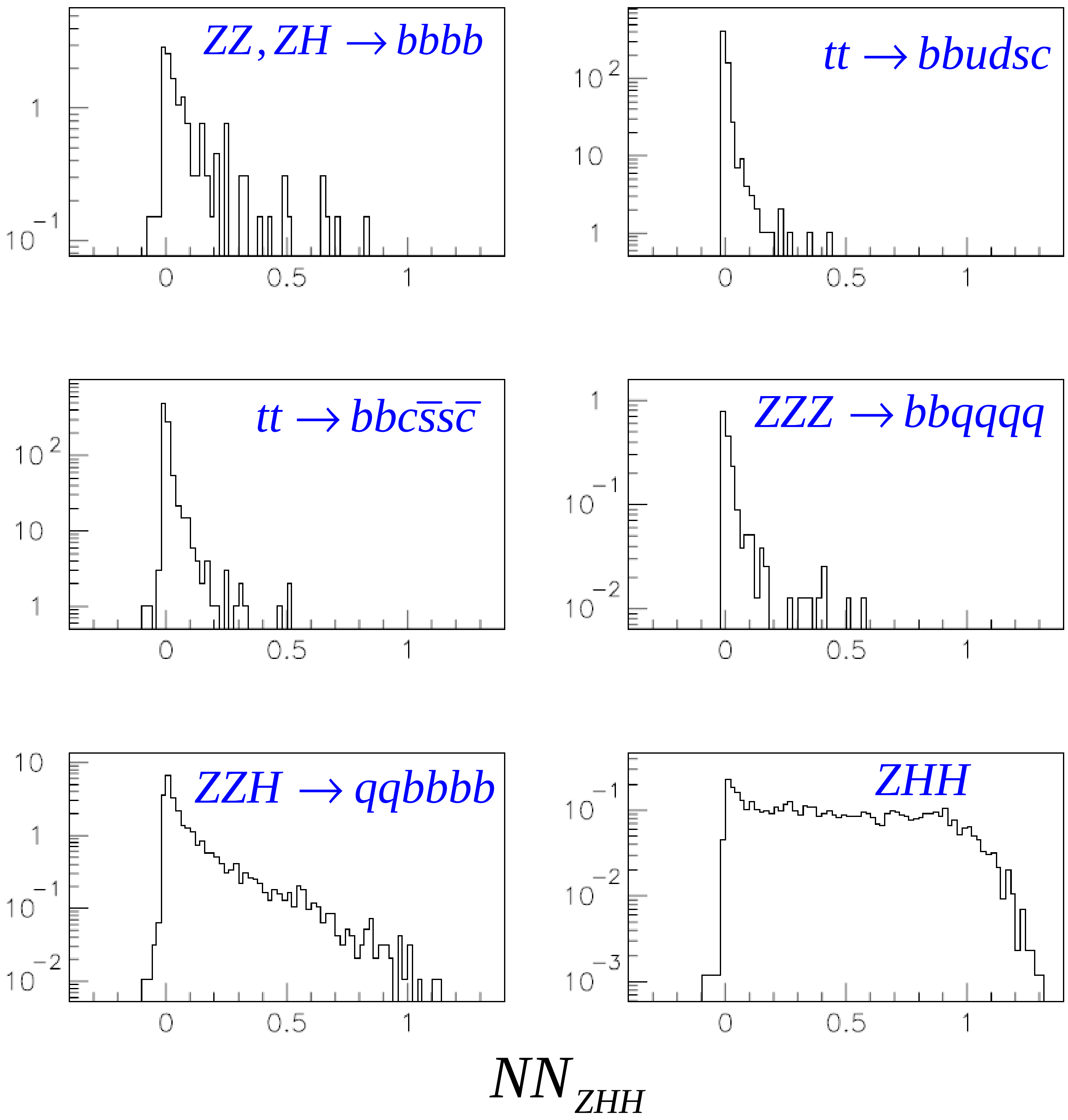
$$\chi^2_{ZHH} = \chi^2_{ZHH\_ZHHmass} + \sum_{j=3}^{6} \frac{(NNbtag_j - 1)^2}{\sigma^2_{NNbtag}}$$

$$\chi^2_{ZHH\_ZHHmass} = \chi^2_{ZHH\_HHmass} + \frac{(M_{12} - M_Z)^2}{\sigma^2_{M_Z}}$$

$$\chi^2_{ZHH\_HHmass} = \frac{(M_{34} - M_H)^2}{\sigma^2_{M_H}} + \frac{(M_{56} - M_H)^2}{\sigma^2_{M_H}}$$

$M_{ij} =$ Mass for jet-pair combination *ij*

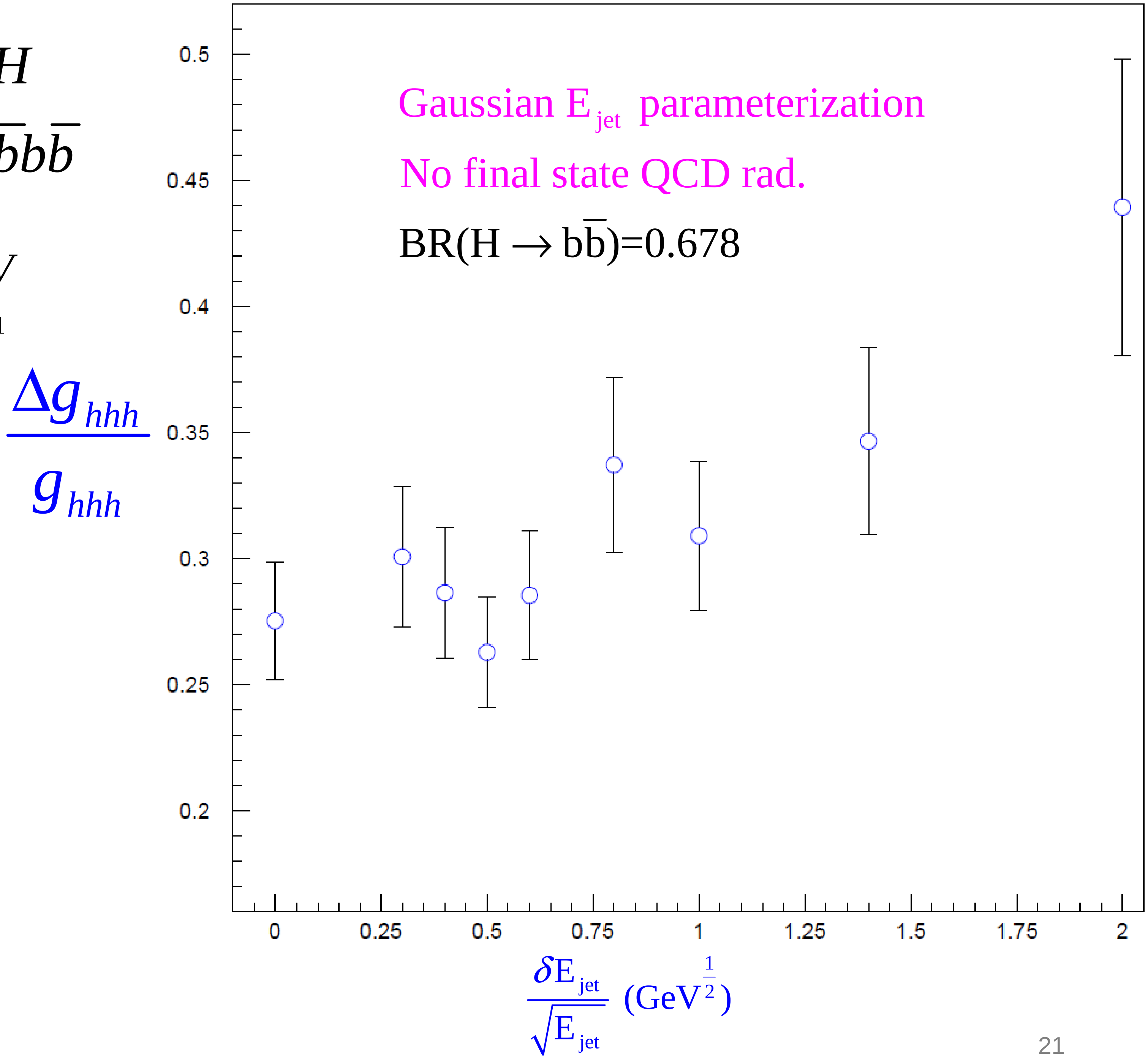
$NNbtag_j =$ btag neural net variable for jet j


ZZ, ZH → bbbb
tt → bbudsc
tt → bbcs̄sc̄
ZZZ → bbqqqq
ZZH → qqbbbb
ZHH
0
0.5
1
NN_ZHH

$$e^+e^- \to ZHH$$
$$\to qqb\bar{b}b\bar{b}$$

$\sqrt{s} = 500\ GeV$

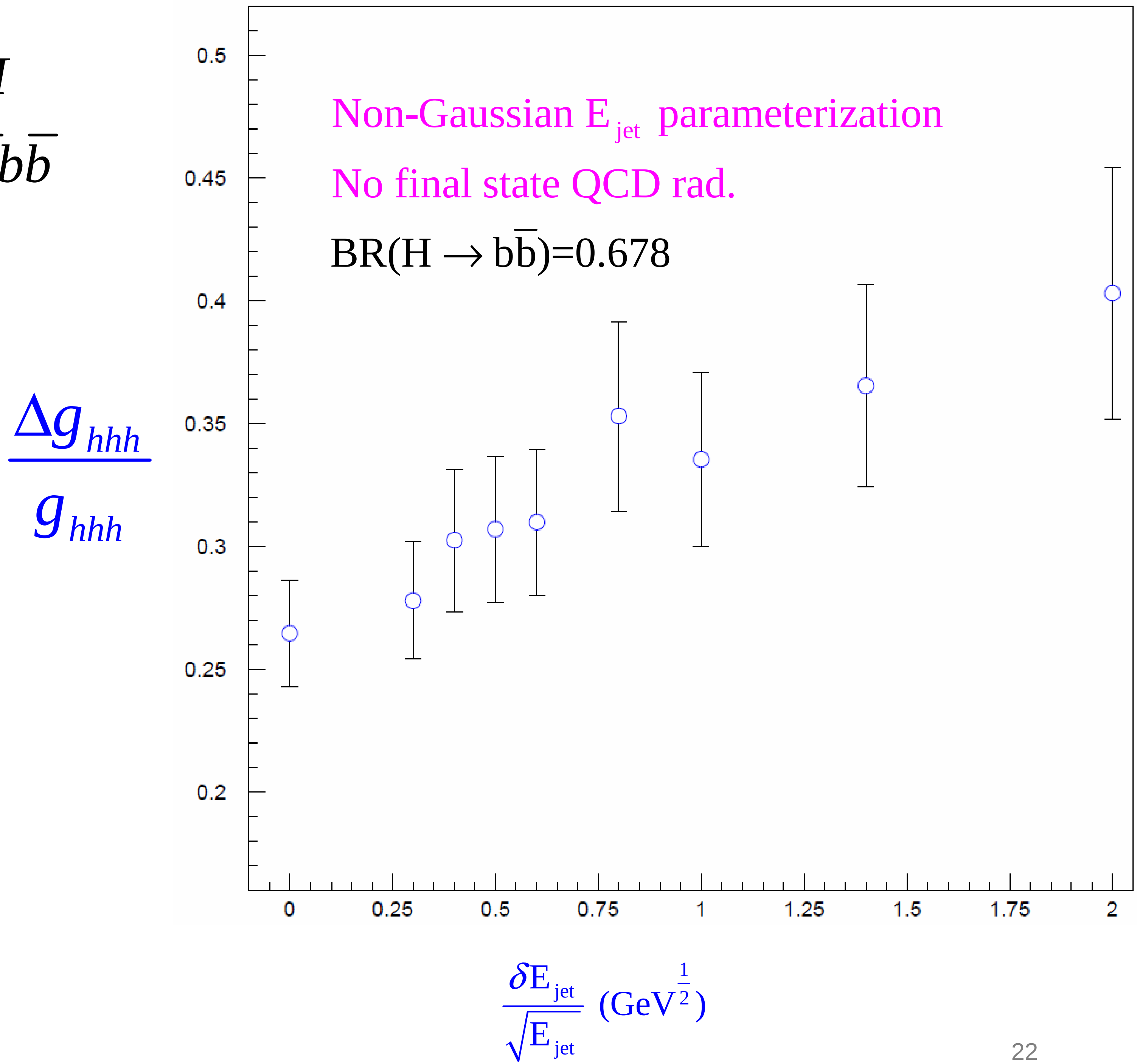
$L = 2000\ fb^{-1}$



$$e^+e^- \to ZHH$$
$$\to qqb\bar{b}b\bar{b}$$

$\sqrt{s} = 500\ GeV$

$L = 2000\ fb^{-1}$



$BR(H \to b\bar{b})=0.68$

$e^+e^- \to ZHH$

$\sqrt{s} = 500\ GeV$

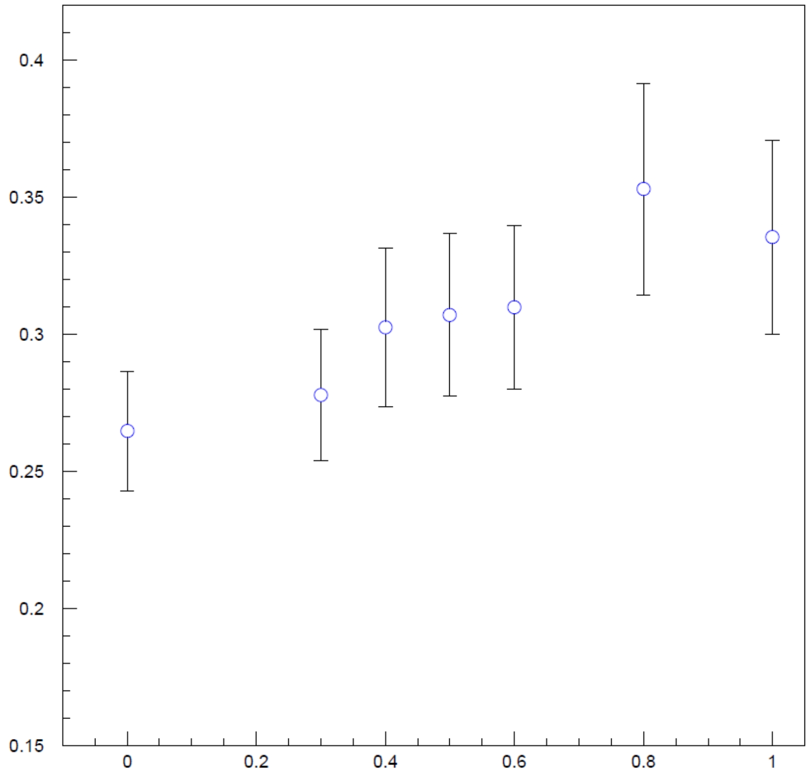
$L = 2000\ fb^{-1}$

Non-Gaussian E_{jet} parameterization

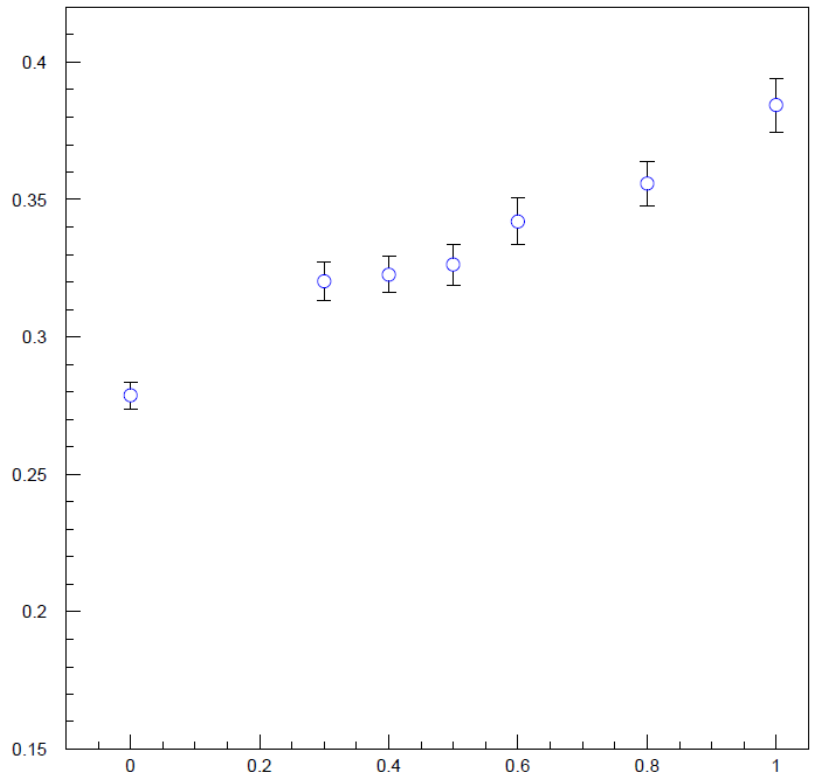
No final state QCD rad.

$qqb\bar{b}b\bar{b}$ only

Old MC statistics



New MC statistics

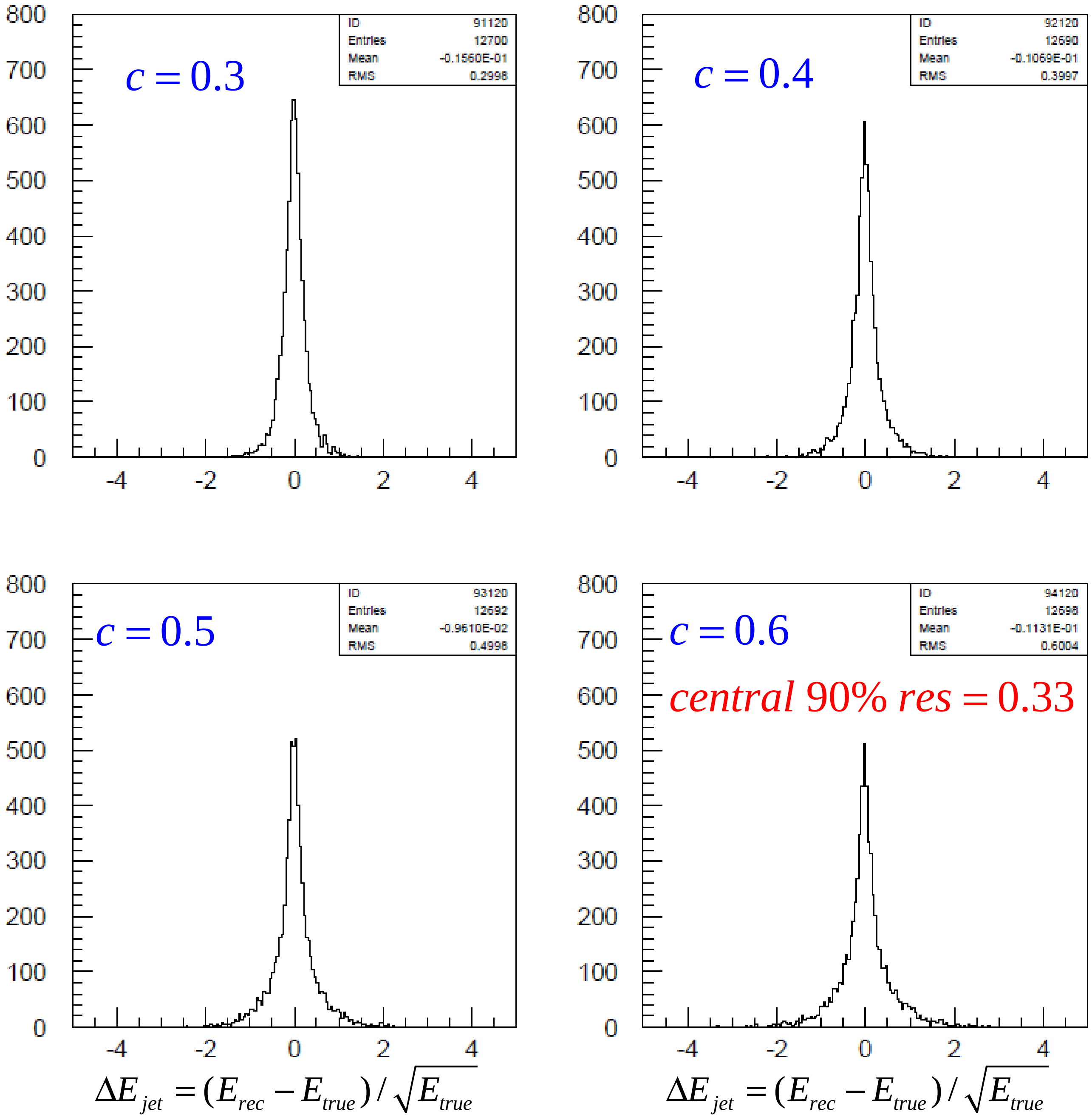


$\frac{\Delta g_{hhh}}{g_{hhh}}$

$\frac{\delta E_{jet}}{\sqrt{E_{jet}}}\ (GeV^{\frac{1}{2}})$

$$e^+e^- \rightarrow u\bar{u}$$

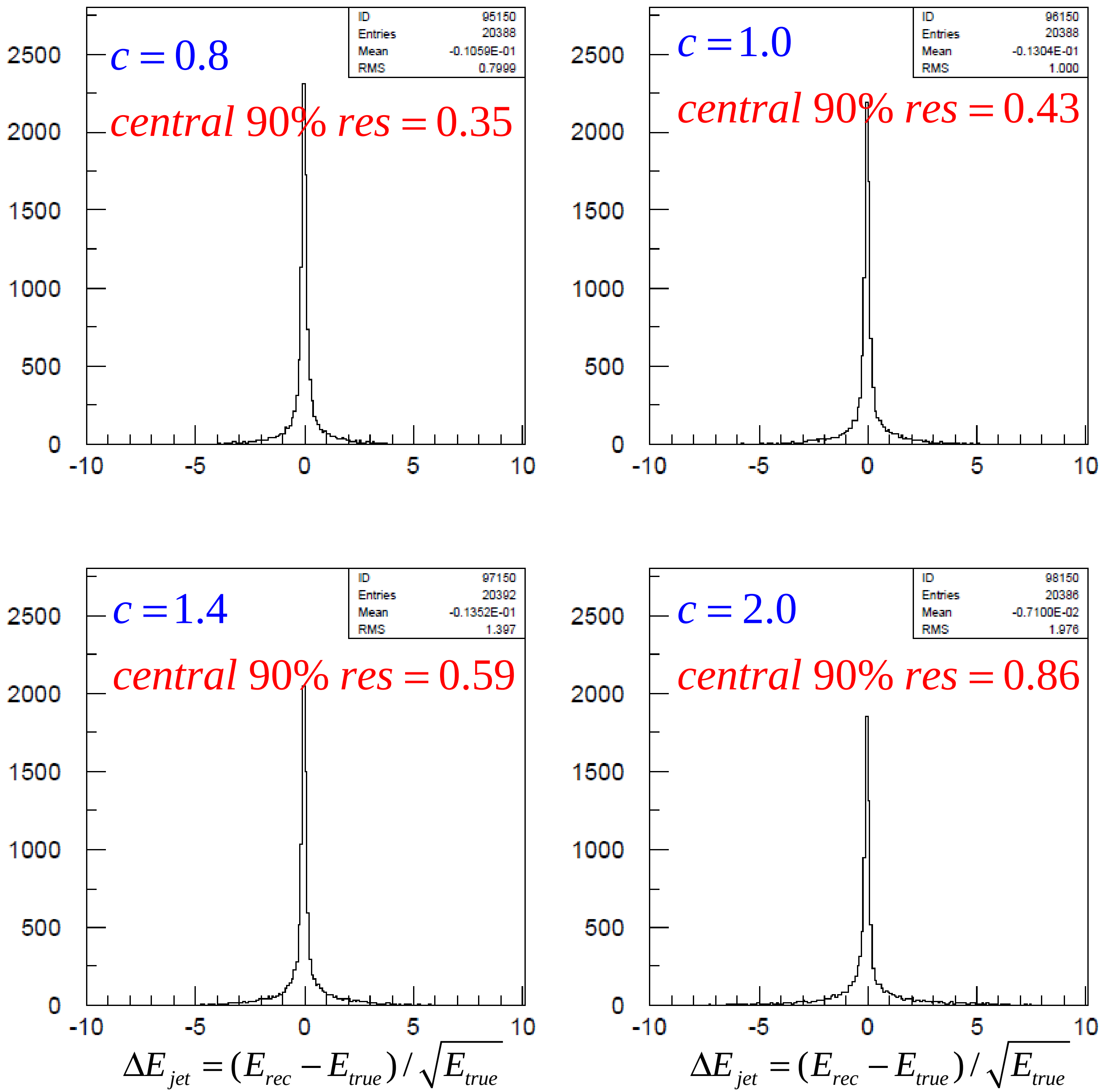
$\sqrt{s} =$ 500 GeV



org.lcsim Fast MC

$$e^+e^- \rightarrow u\bar{u}$$

$\sqrt{s} =$ 500 GeV



org.lcsim Fast MC

$BR(H \to b\bar{b})=0.68$

$$e^+e^- \to ZHH \qquad \sqrt{s}=500\ GeV \qquad L=2000\ fb^{-1}$$

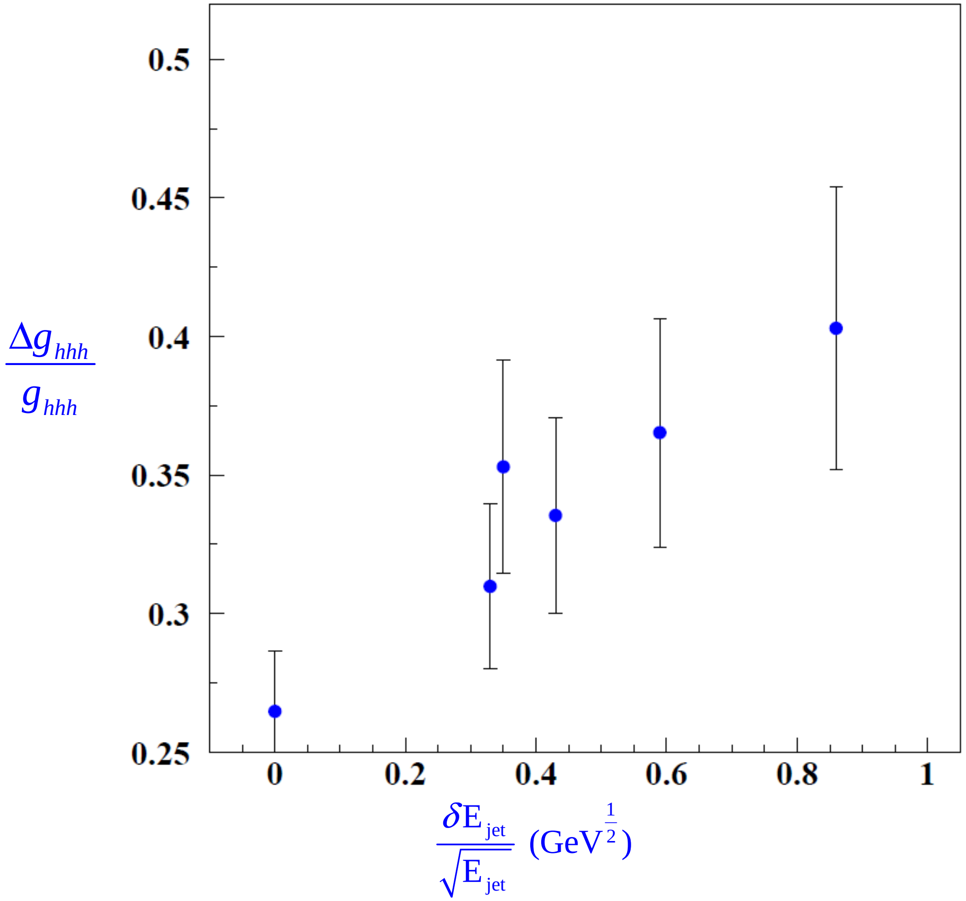
Non-Gaussian E_{jet} parameterization

No final state QCD rad.

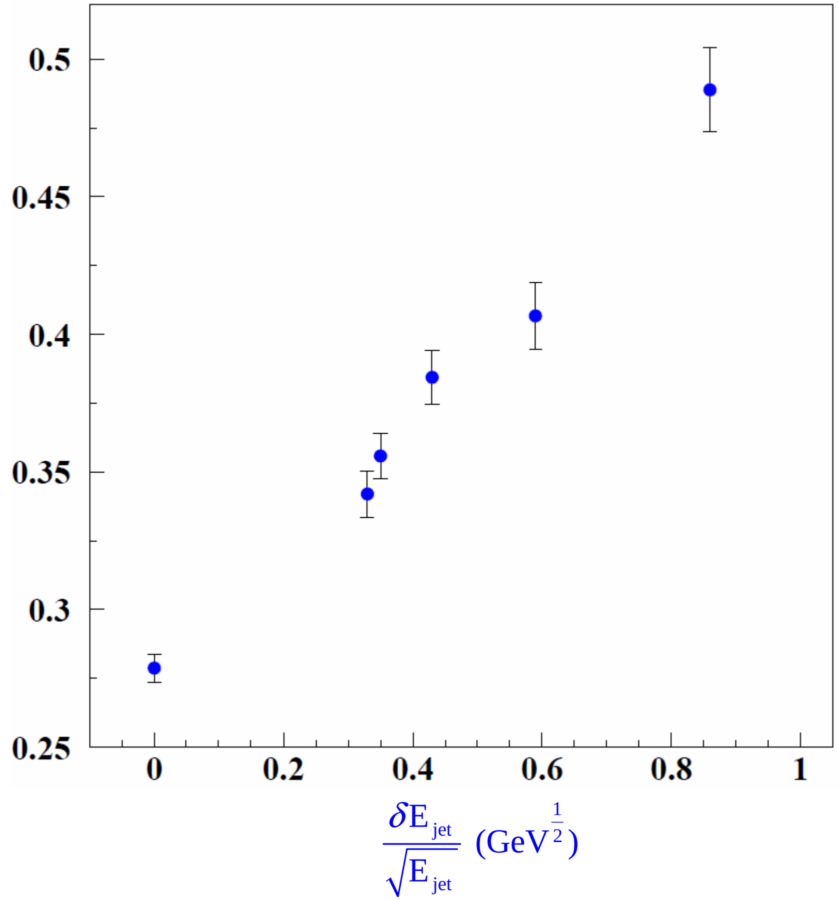
$qqb\bar{b}b\bar{b}$ only

Use rms of central 90% core to define $\frac{\delta E_{jet}}{\sqrt{E_{jet}}}$

Old MC statistics



New MC statistics



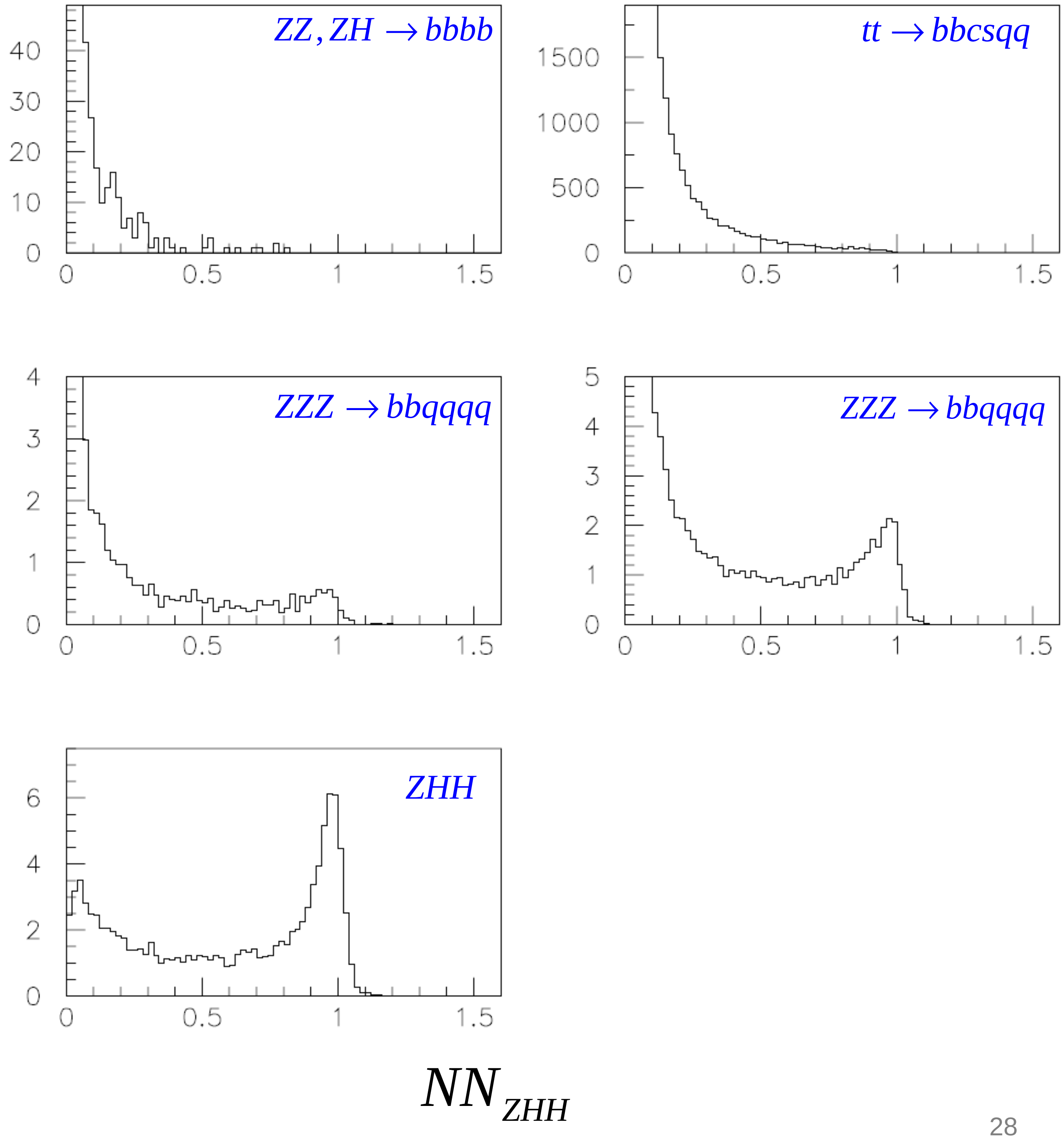
$\frac{\Delta g_{hhh}}{g_{hhh}}$ vs. $\frac{\delta E_{jet}}{\sqrt{E_{jet}}}\ (GeV^{\frac{1}{2}})$

When final state QCD rad. is turned on $\frac{\Delta g_{hhh}}{g_{hhh}}$ jumps

from 0.32 to 0.57 for $\frac{\delta \mathrm{E}_{\mathrm{jet}}}{\sqrt{\mathrm{E}_{\mathrm{jet}}}} = 0.3$

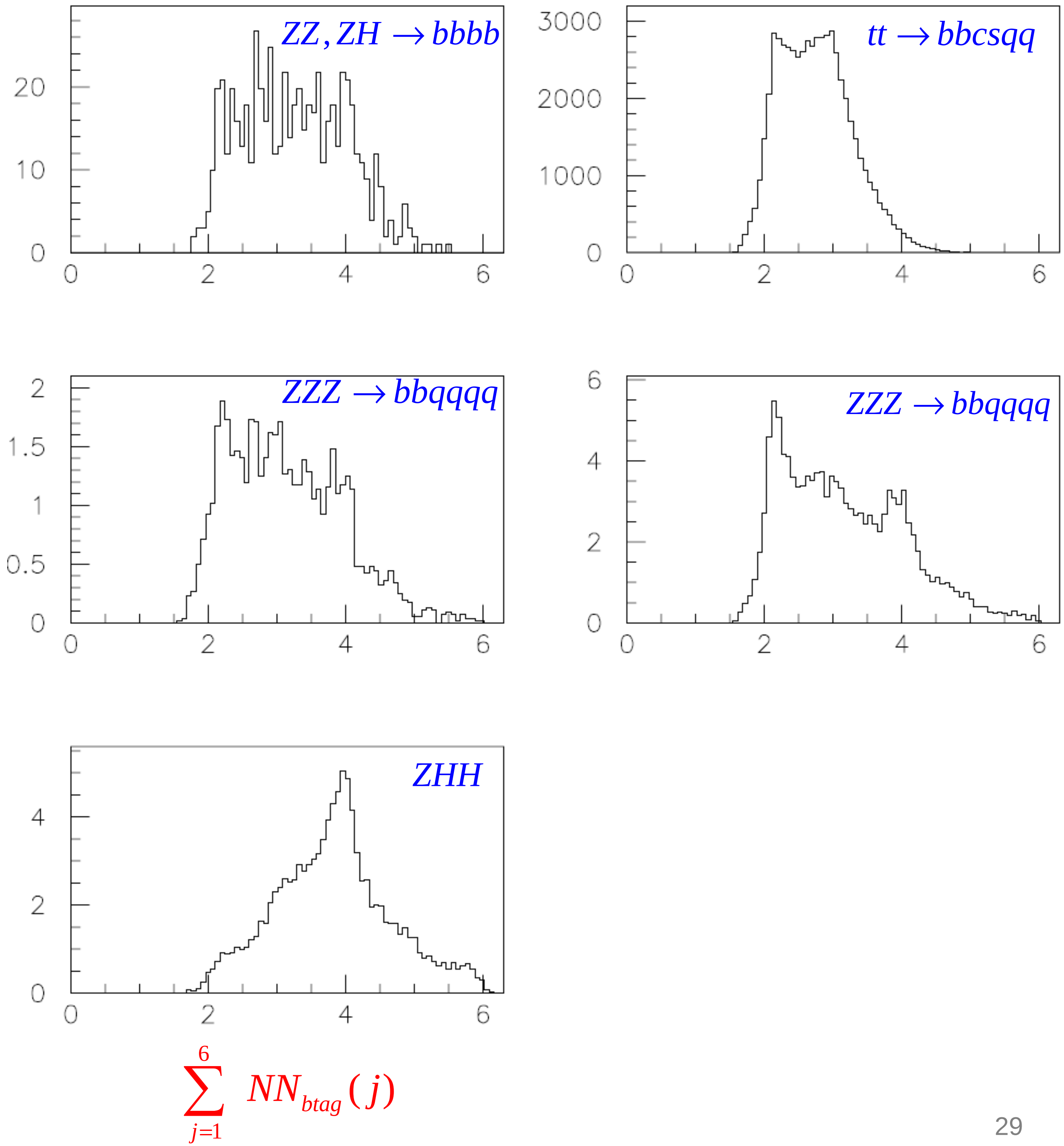
The signal to background is too small after QCD rad. is turned on.

QCD rad turned on



Distributions in $\sum_{j=1}^{6} NN_{btag}(j)$ following preselection cuts and loose cut on χ^2_{ZHH}

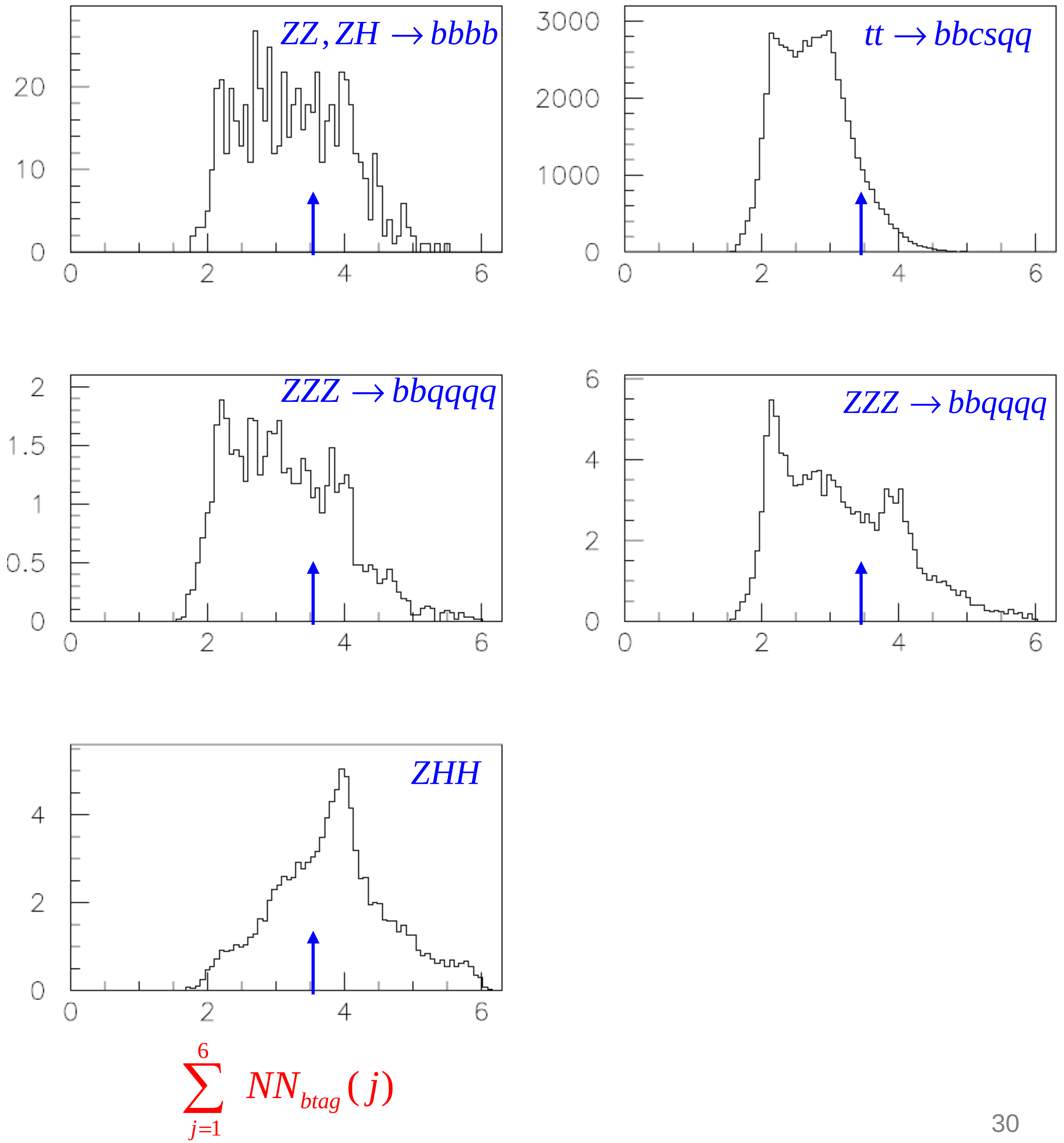
QCD rad turned on



Try new approach.
Instead of variables such as χ^2_{ZHH} , which contain kinematic info for 1 of 45 combinations, feed neural net all jet pair masses where jets are ordered according to jet btag neural net value (jet 1 is the most b-like, jet 2 is 2nd most b-like, etc.)

Require

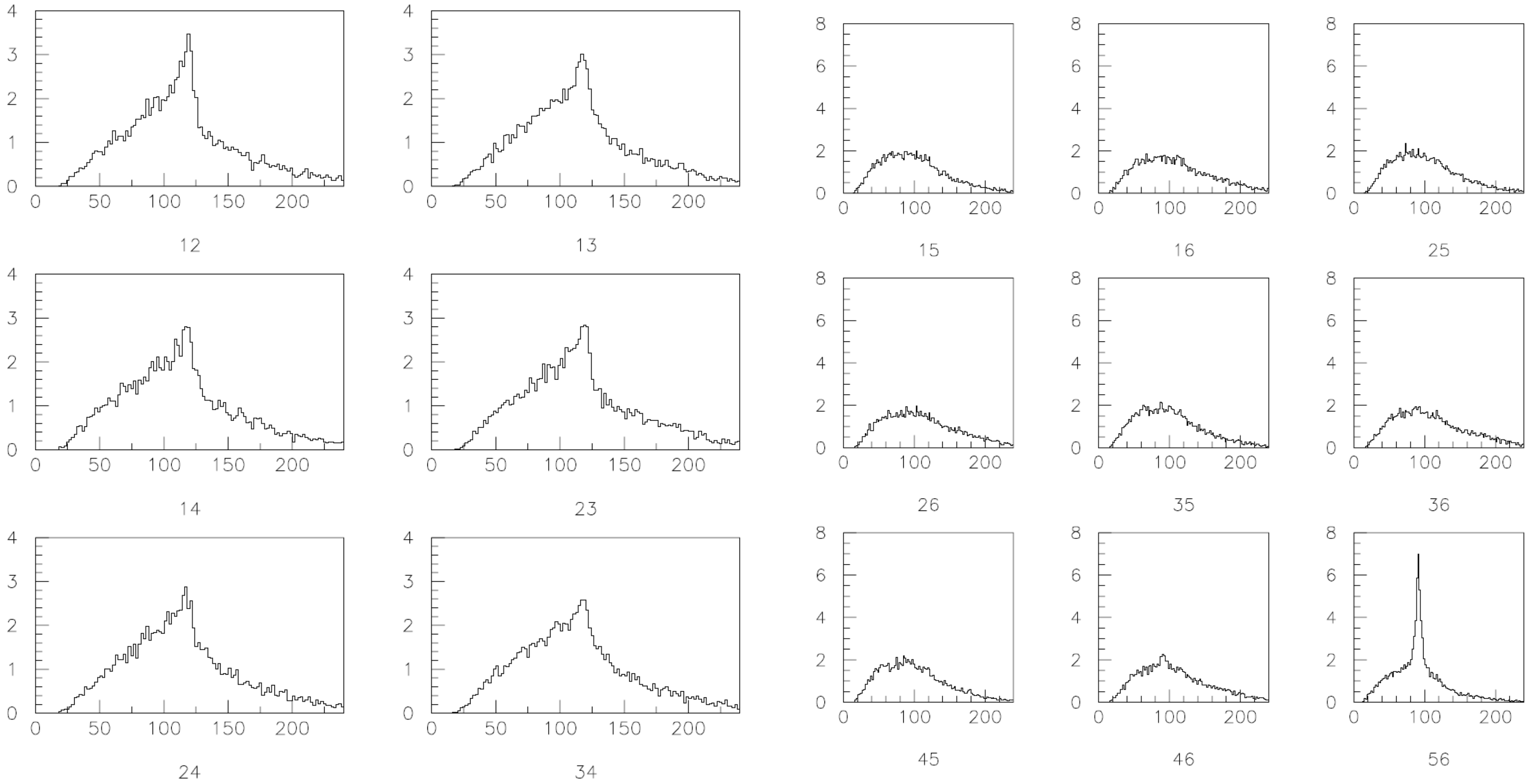
$$\sum_{j=1}^{6} NN_{btag}(j) > 3.5$$



Jet pair masses where jets are ordered according to jet btag neural net value

(jet 1 is the most b-like, jet 2 is 2nd most b-like,etc.) Require $\sum_{j=1}^{6} NN_{btag}(j) > 3.5$

ZHH

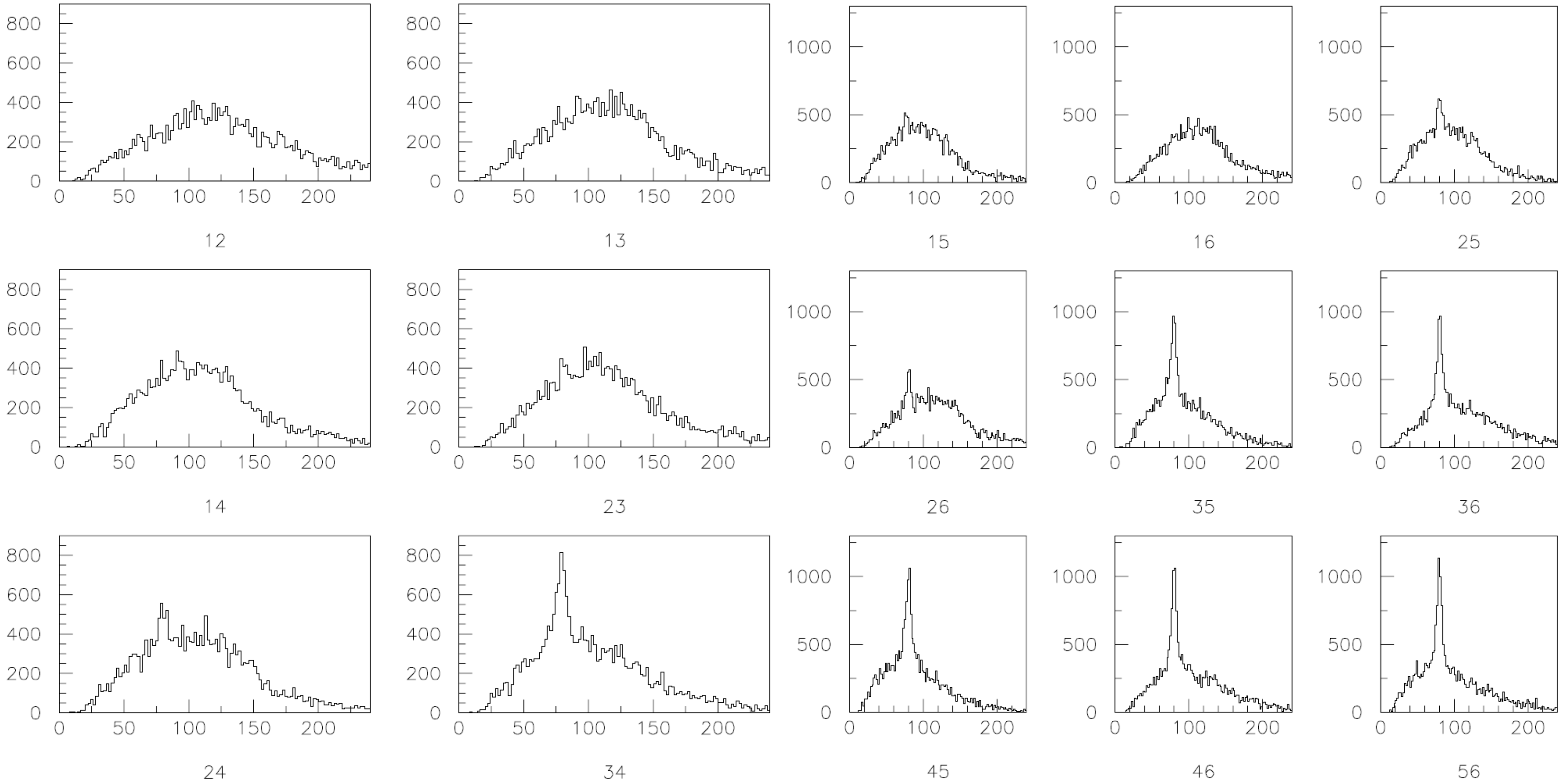


$M_{jk}\ (GeV)$

Jet pair masses where jets are ordered according to jet btag neural net value

(jet 1 is the most b-like, jet 2 is 2nd most b-like,etc.) Require $\sum_{j=1}^{6} NN_{btag}(j) > 3.5$

$t\bar{t}$

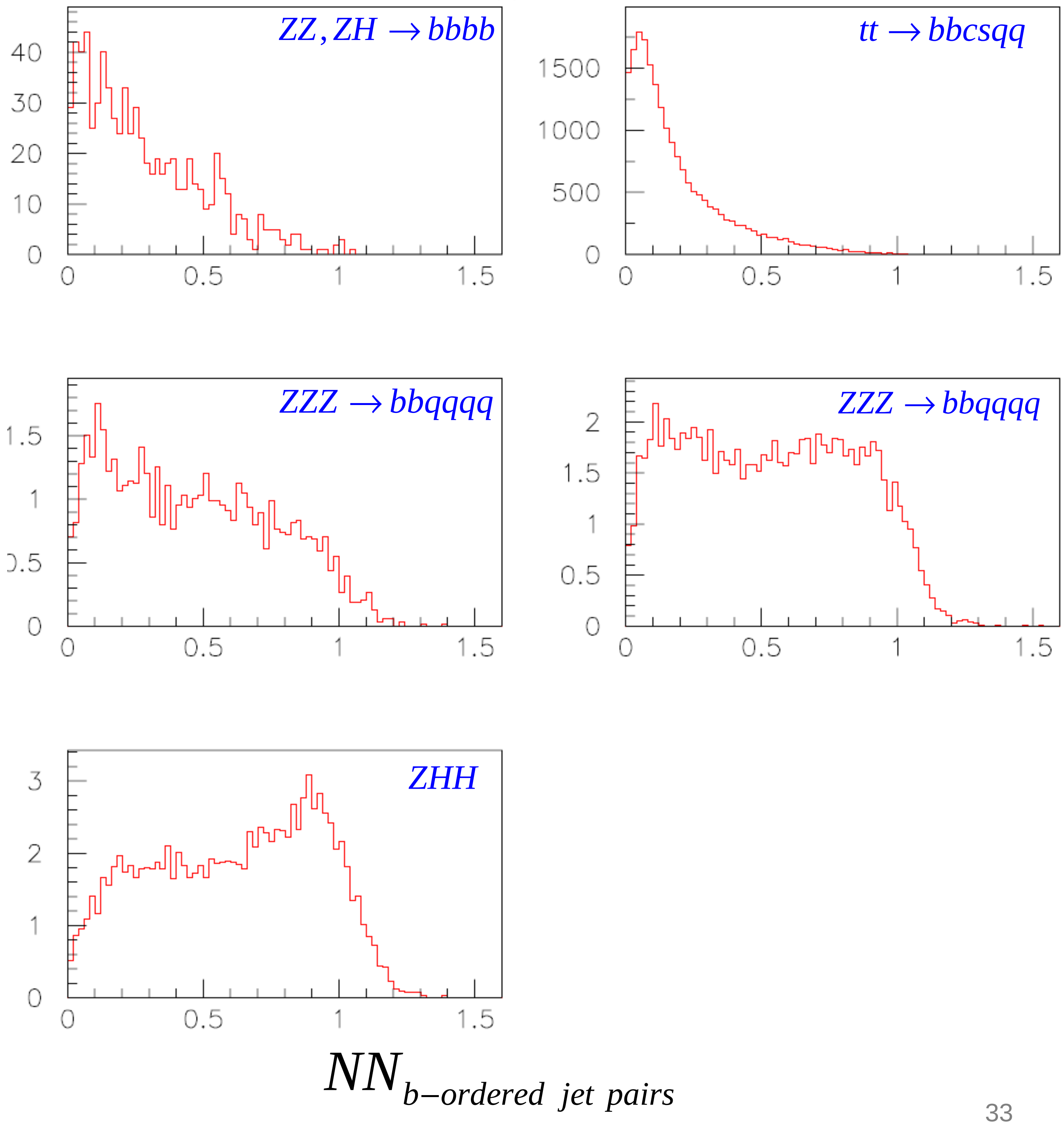


$M_{jk}\ (GeV)$

Neural net based on b-tag ordered jet pair masses instead of χ^2_{xxx}

QCD rad turned on

Alas, no improvement over old approach. Tail from tt still too large.



Use this figure for the DCR

Assume that final state QCD problem will be solved with a more sophisticated jet algorithm and better b/c tagging. Note that we currently force recon particles into 6 jets, which may not be best approach in presence of hard gluon radiation. Better b/c tagging, including flavor tagging, can reduce combinatorics and provide b/c weighted jet energy corrections.

$e^+e^- \to ZHH$

$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\ GeV$

$L = 2000\ fb^{-1}$

$\Delta E/\sqrt{E} = 60\% \to 30\%$

equiv to 1.4× Lumi