Six-jet production in $e^+e^- \to t\bar{t}$ at the NLC

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- Introduction
- Parton-level reconstruction of top and W masses
- Mass resolutions from hadron-level
- Effects from ECAL/HCAL smearing
- Energy-flow algorithm (EFA)
- Conclusions

Introduction

e^+e^- collider operating at the $t\bar{t}$ threshold allows to study the properties of top quarks under clean experimental conditions

$\mathcal{L} \sim 300$ fb^{-1} $\rightarrow \sim 300000$ $t\bar{t}$ pairs

Production of top quarks in the process:

$$e^+e^- \rightarrow b\bar{b}W^+W^- \rightarrow b\bar{b}q_1\bar{q}_2q_3\bar{q}_4 \rightarrow 6 \text{ jets}$$

has the following features:

- dominant decay channel (accounts for 44% of all $t\bar{t}$ decays)
- no missing energy (no neutrinos in the final state)
- background from QCD multijet production
- complementarity with the top production at LHC

High-precision measurements of:

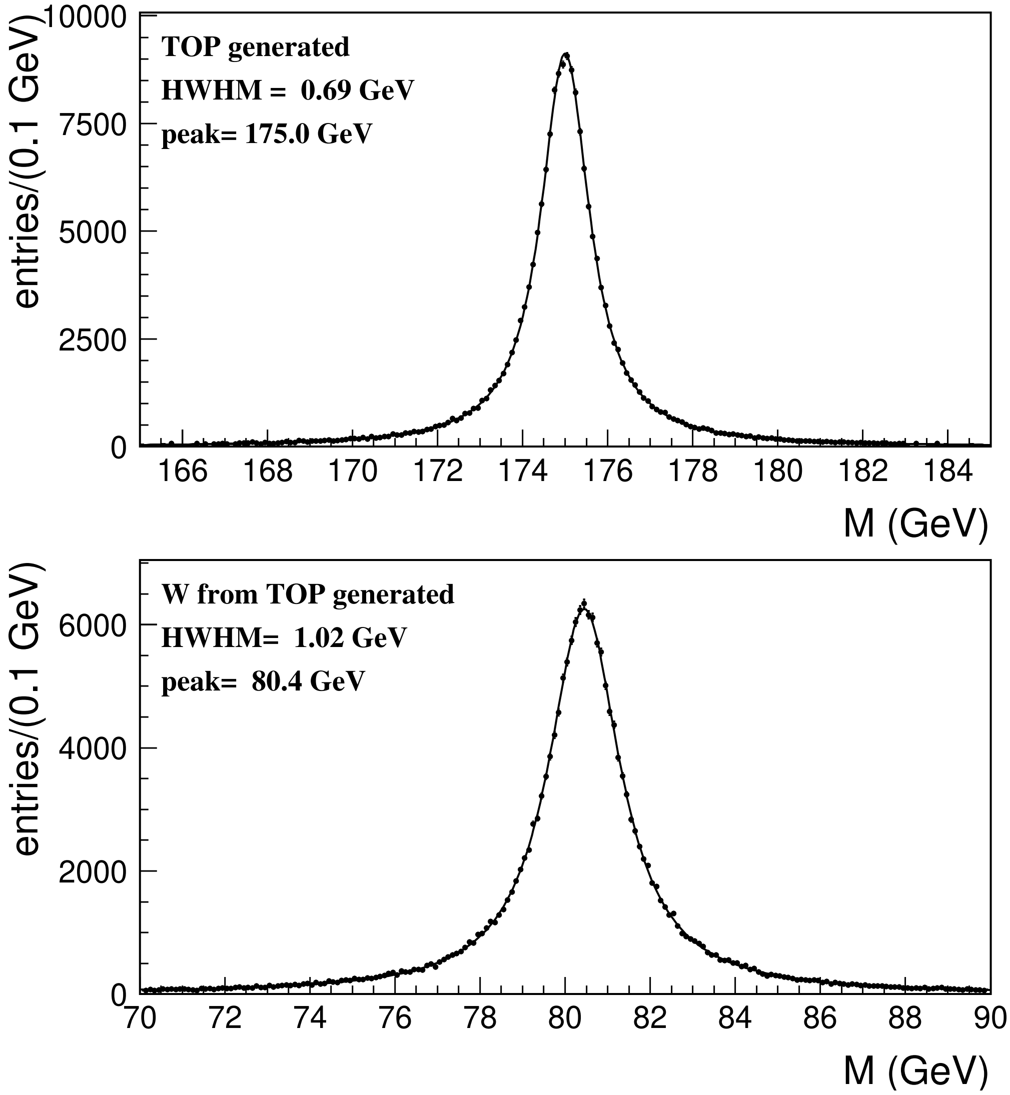
- Top-quark mass and width;
- Top-quark differential cross sections;
- Top-quark quantum numbers, form factors, polarization etc.

require:

- Excellent energy resolution
- Excellent angular resolution to resolve 6 jets
- b-tagging to reduce QCD background

Breit-Wigner mass distributions

- PYTHIA 6.2 is used for e^+e^- at $\sqrt{s} = 500$ GeV
- 100000 $e^+e^- \rightarrow b\bar{b}W^+W^- \rightarrow b\bar{b}q_1\bar{q}_2q_3\bar{q}_4$ events
- t and W masses are distributed according to the Breit-Wigner with the PYTHIA default widths (1.402 and 2.060 GeV)
- No initial-state radiation, color reconnection and BE effects



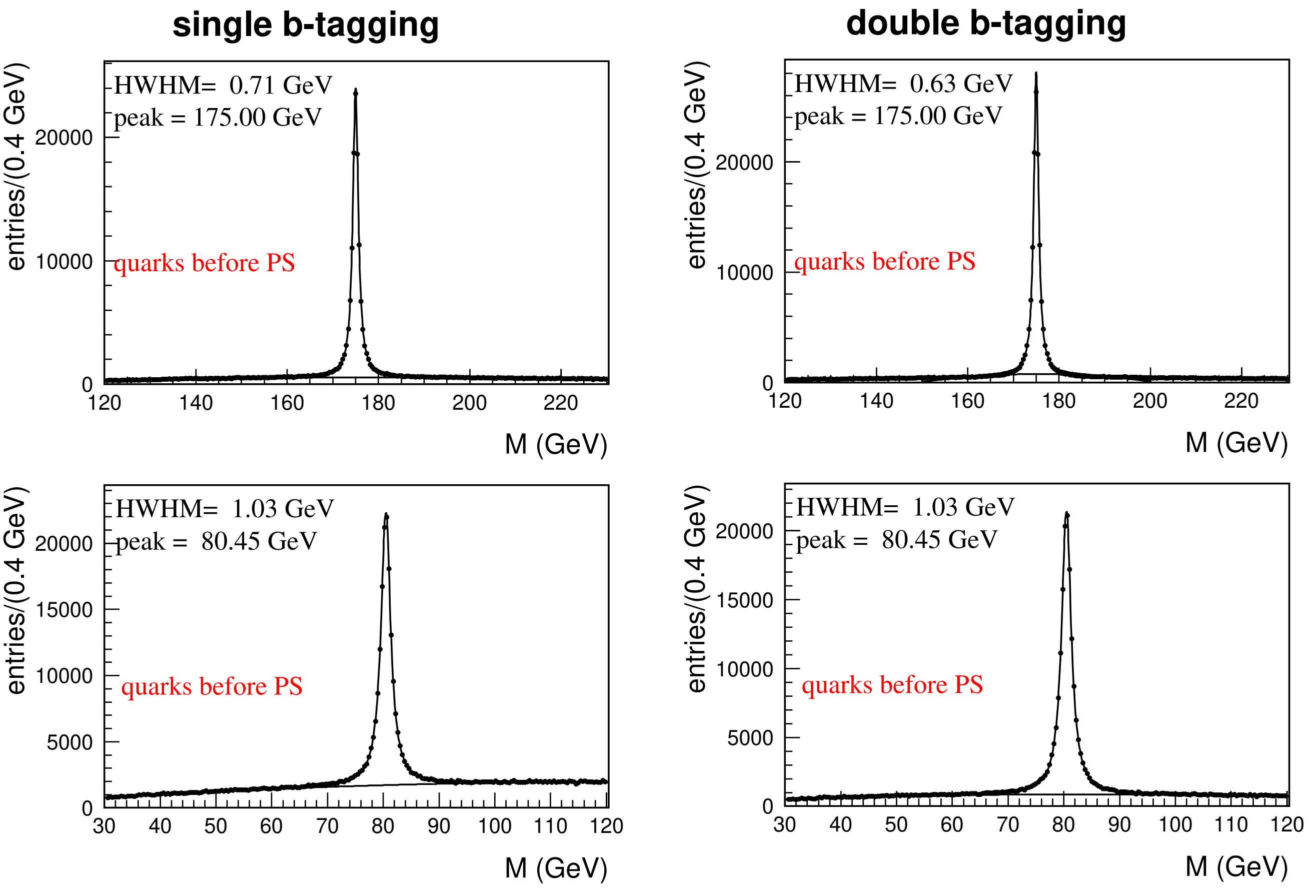
Half-width at half maximum (HWHM) is used for resolutions

Invariant masses from 6-quark state

- 6 final-state quarks generated using $e^+e^- \to b\bar{b}W^+W^- \to b\bar{b}q_1\bar{q}_2q_3\bar{q}_4$

(no gluon radiation and hadronization)

- Select quarks with $E_T > 10$ GeV and $\mid \eta \mid < 5$



5 quarks are used for W spectrum; W's are combined with one b-quark and quarks not used in the W reconstruction

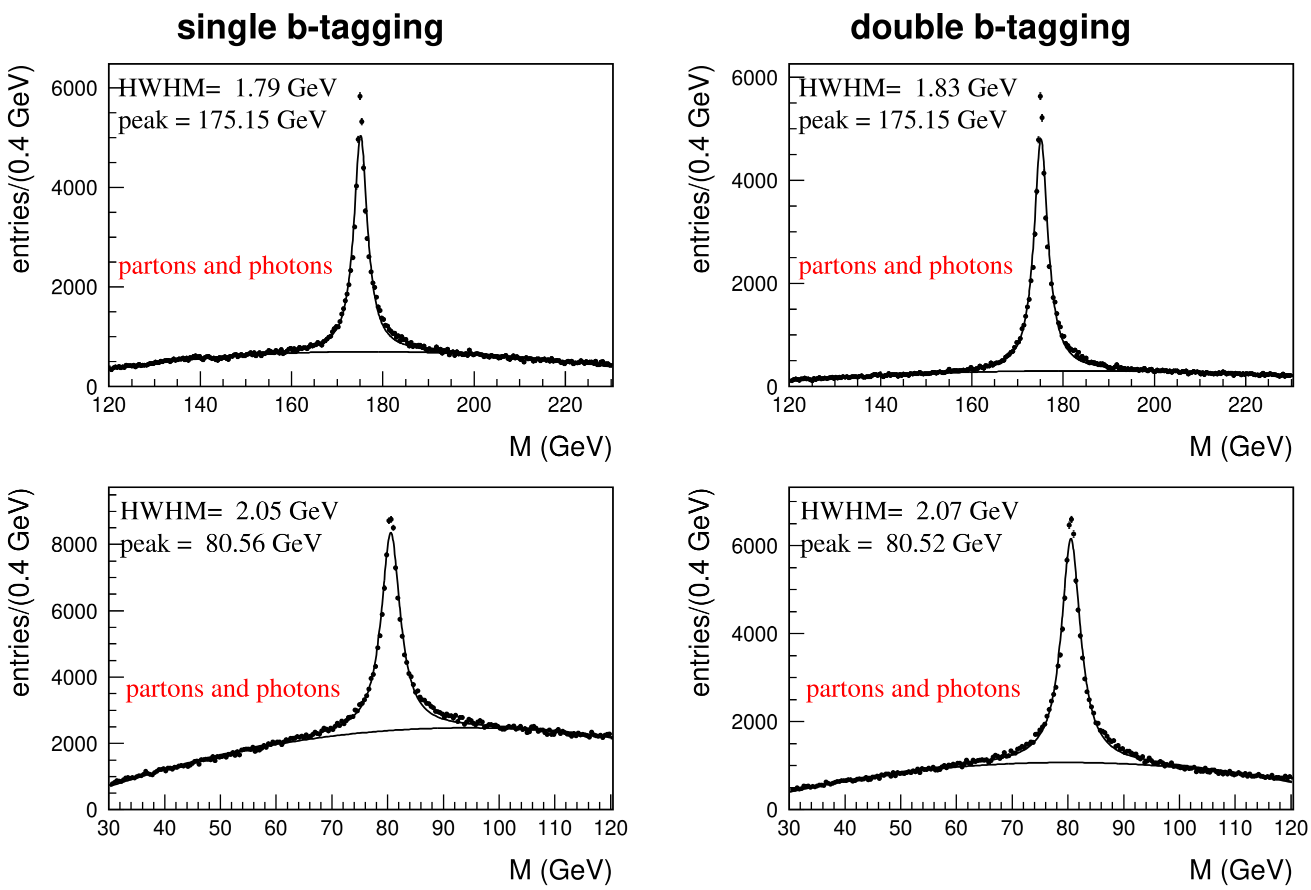
W spectrum from 4 quarks
W's combined with 2 b-quarks

Breit-Wigner σ is close to the natural widths

Parton-level studies

Final state: 6 quarks + parton shower (PS)

- The k_T algorithm is used to reconstruct 6 jets
- Selected jets with $E_T > 10$ GeV and $|\eta| < 5$
- Used a cone algorithm in $\eta - \phi$ to match true b-quark momenta to momenta of reconstructed jets ('b-tagging')
- $a + bx + cx^3$ to describe the background



HWHM increases by a factor ~ 2 with respect to 6-quark state

Double b-tagging mainly affects the background level

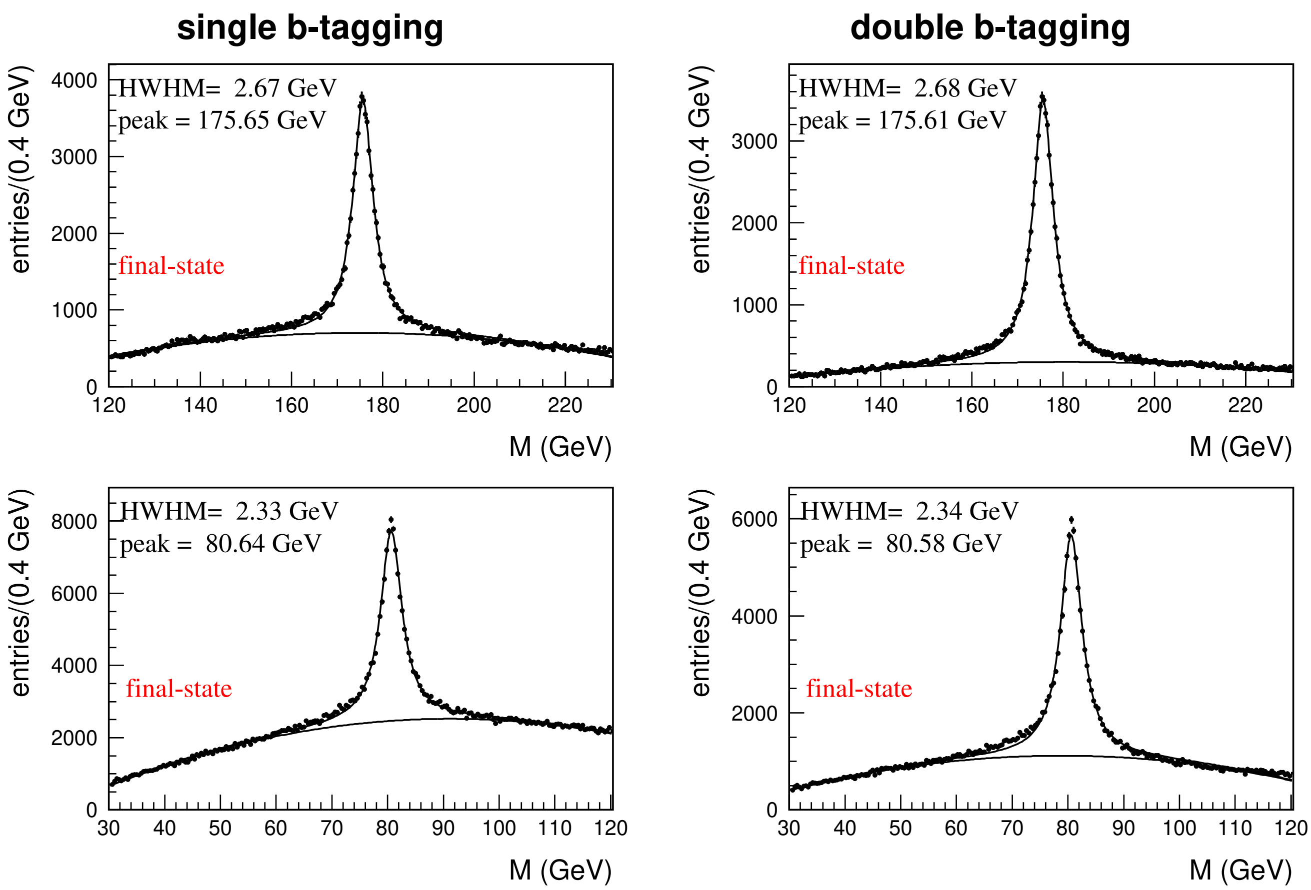
Invariant masses from the final state

Final state: hadrons, photons, leptons

- stable particles with $c\tau > 15$ cm
- the k_T algorithm to reconstruct 6 jets
- $E_T > 10$ GeV and $\mid \eta \mid < 5$
- energy-momentum conservation constraints:

$$0.8 < \frac{E_{vis}}{\sqrt{s}} < 1.2 \qquad \frac{\mid \sum_i p_{||i} \mid}{\sum_i \mid \vec{p}_i \mid} < 0.2 \qquad \frac{\mid \sum_i p_{Ti} \mid}{\sum_i \mid \vec{p}_i \mid} < 0.2$$

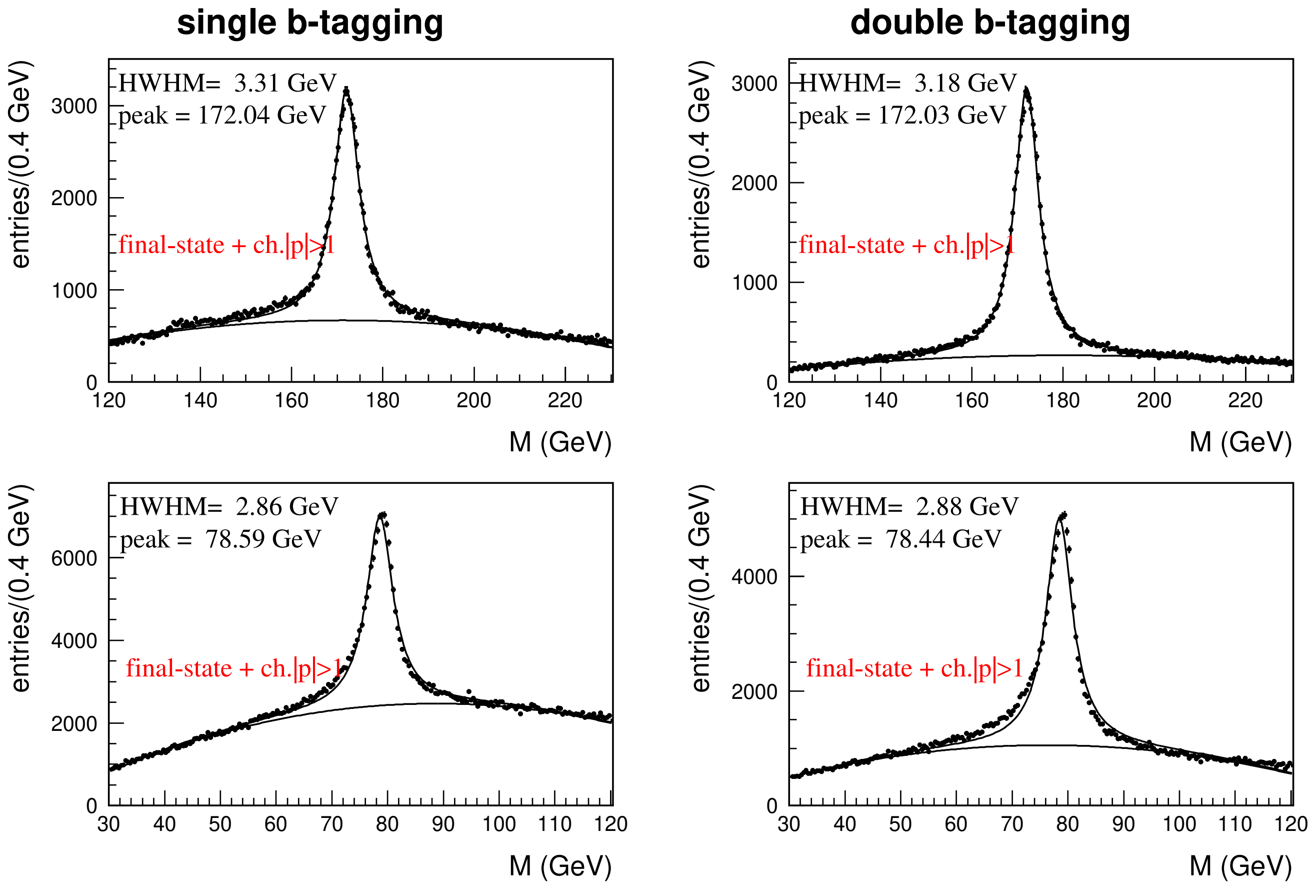
- A cone algorithm with the radius 0.2 for "b-tagging" ($\sim$ 95% efficiency)



HWHM increases by $\sim$ 50% with respect to parton level

Invariant masses from the final state

Charged particles with $|\, p \,| < 1$ GeV are ignored



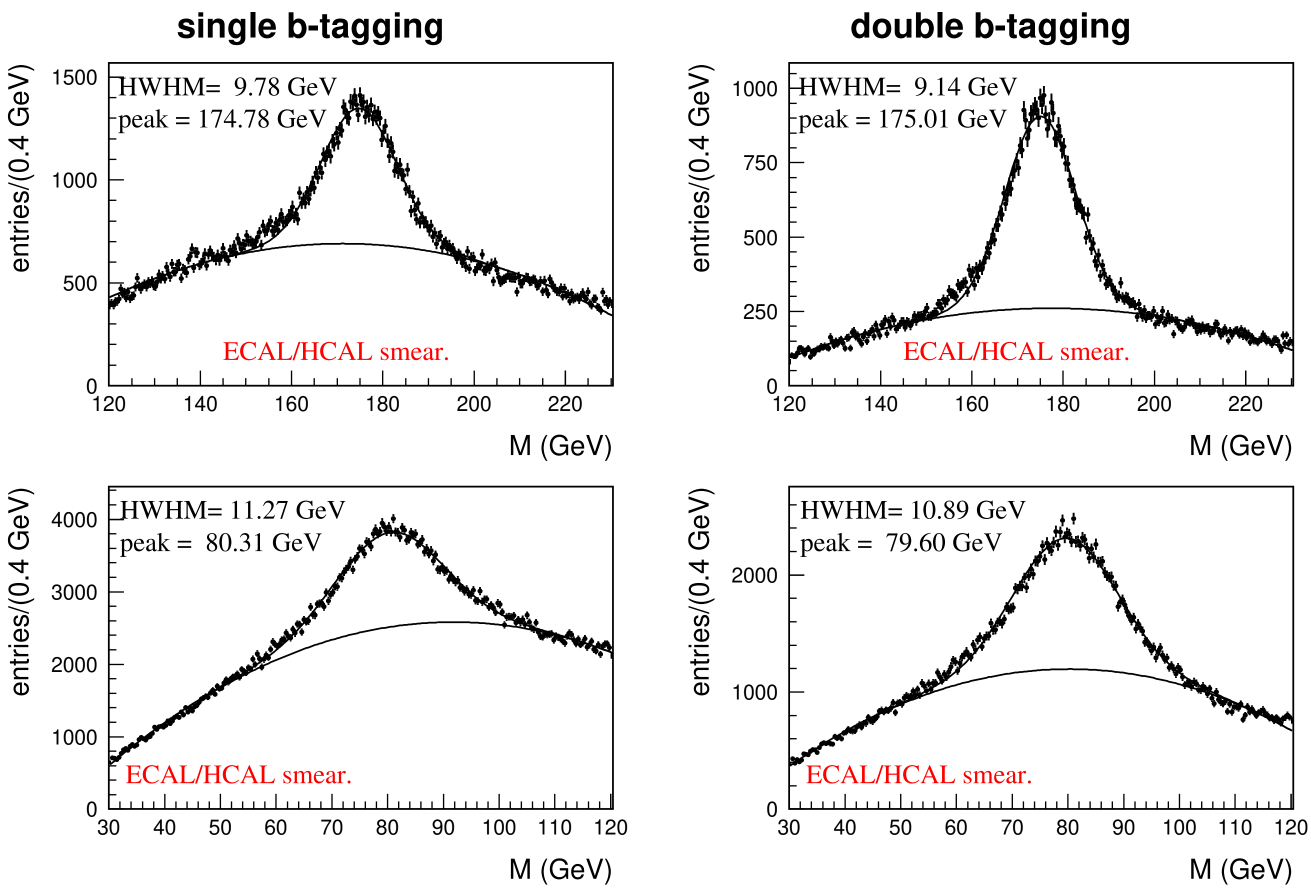
HWHM increases by $\sim 20\%$ with respect to complete final state

Calorimeter only resolution

smear energies of all final-state particles according to:

$$\text{ECAL}: \quad \frac{\sigma}{E} = \frac{13\%}{\sqrt{E}} + 0.7\% \qquad \text{HCAL}: \quad \frac{\sigma}{E} = \frac{32\%}{\sqrt{E}} + 4\%$$

ECAL: photons and leptons **HCAL:** all other particles



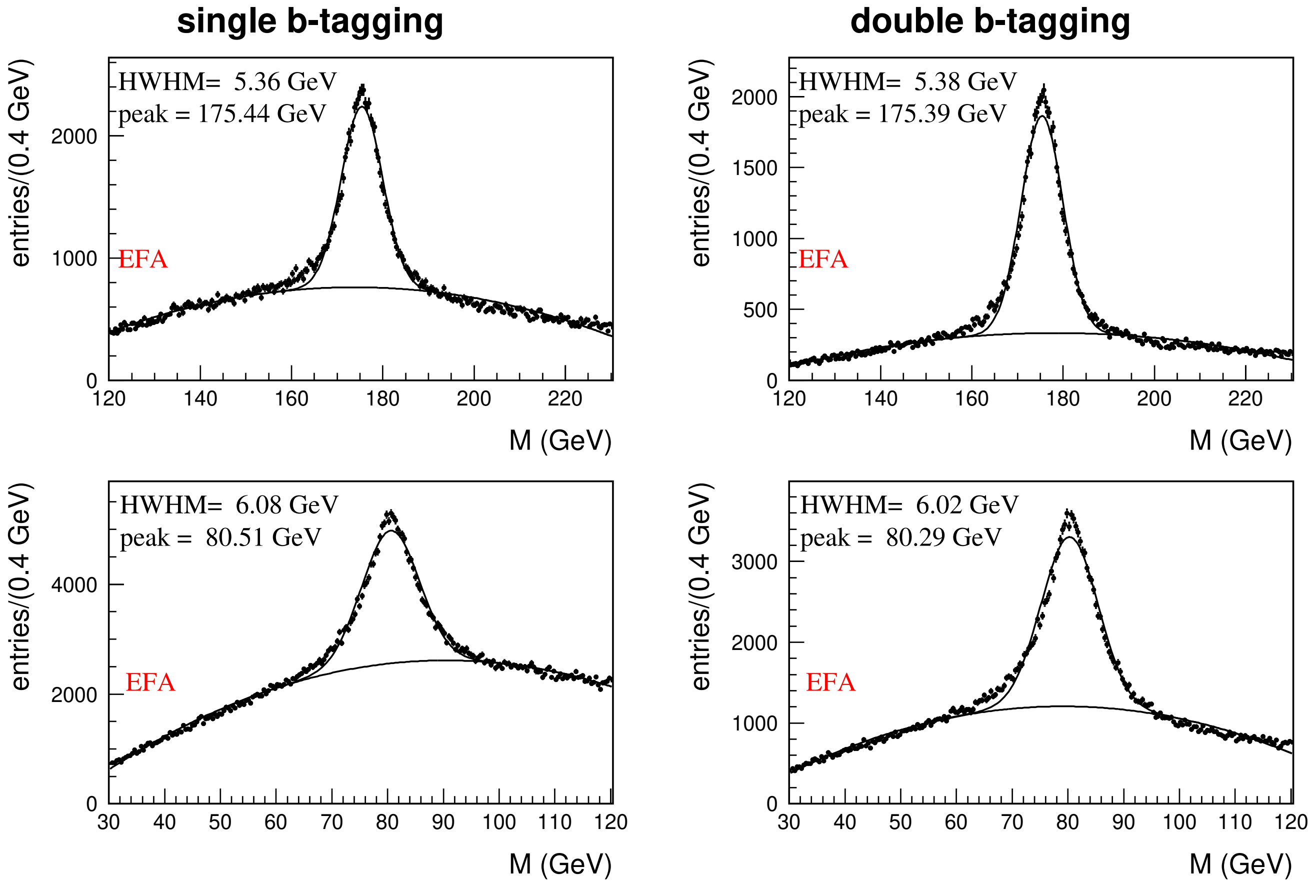
Breit-Wigner fit does not work: need a Gaussian fit

HWHM is 3 – 4 times worse than for the final state

10-12 times worse than the natural widths !

Energy-flow algorithm (EFA)

- use true momenta for charged particles ($e^{\pm}, \mu^{\pm}, \pi^{\pm}, p$ etc.)
- apply ECAL/HCAL smearing for neutrals (γ, K_0^L, n etc.)

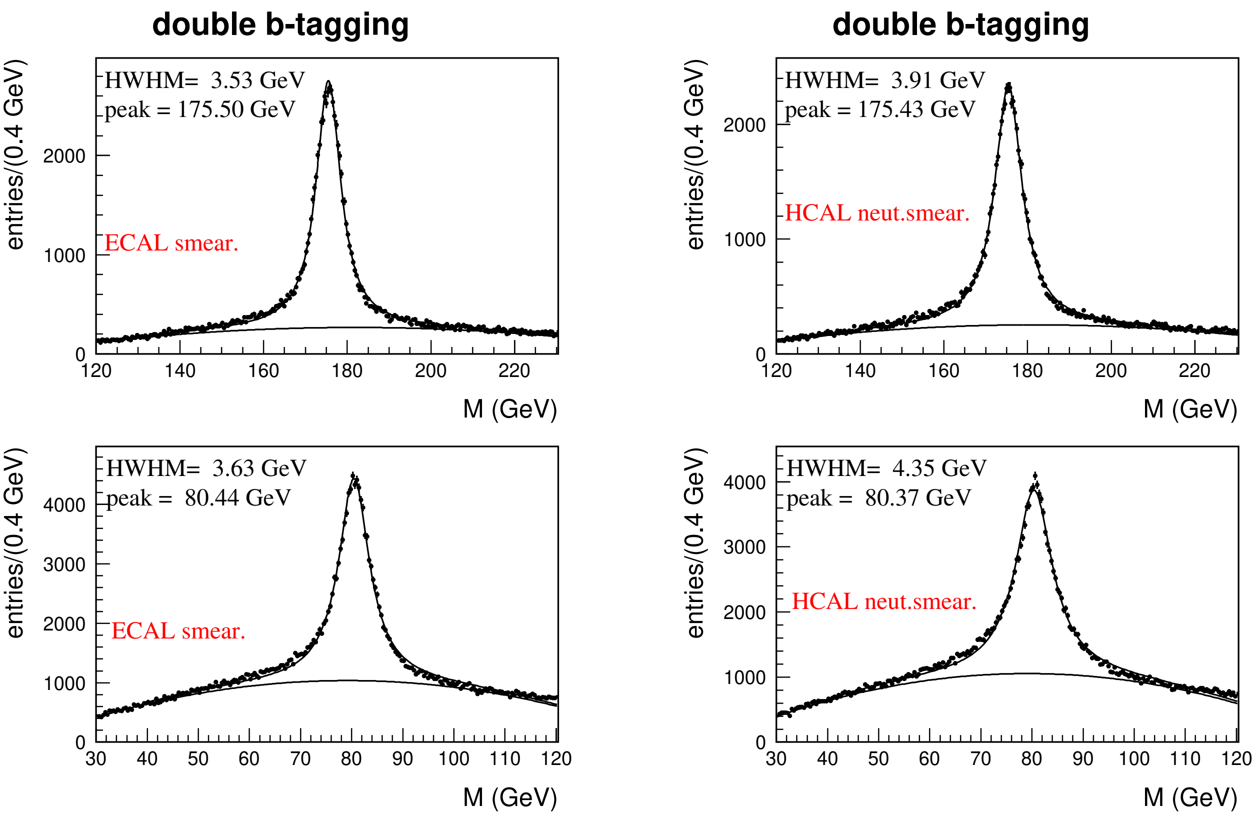


HWHM by a factor 2 smaller than for pure calorimeter reconstruction

Effects from ECAL and HCAL separately

Fractions of energy in jets (in %)

	ECAL	HCAL	Neutrals	ECAL neutrals	HCAL neutrals
Fraction	31.4	68.6	38.7	28.6	10.1



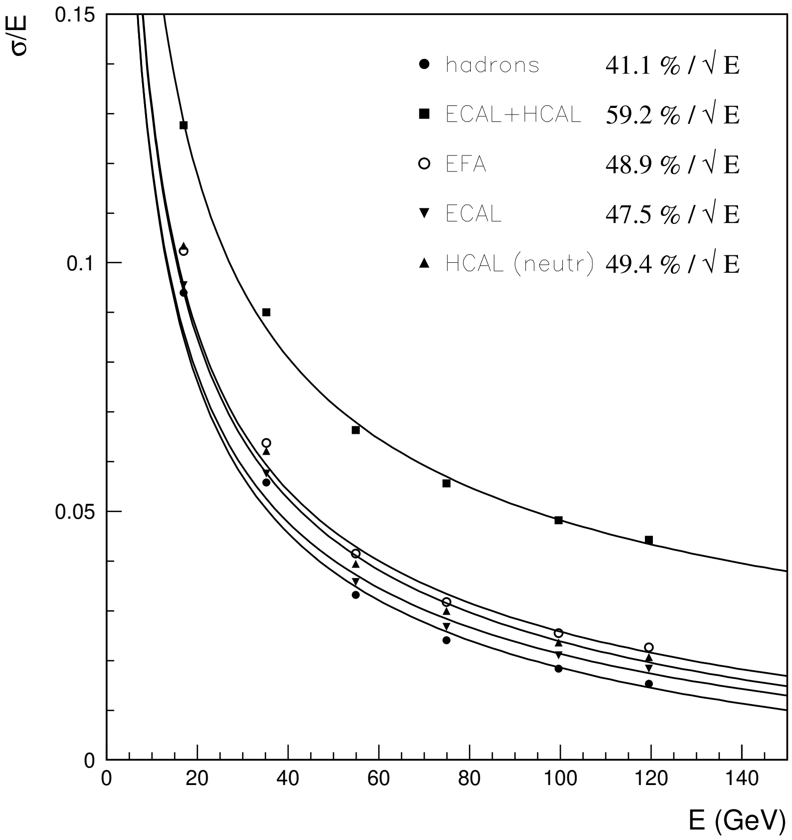
HWHM for ECAL (only) $\sim$ HCAL (neutrals only)

Large contribution of heavy particles in jets (K_0^L, n etc.)?

Jet resolution study

1) Calculate $(E_{jet}^{meas} - E_{jet}^{partons})/E_{jet}^{partons}$ for each jet

2) Define σ's using Gaussian fits



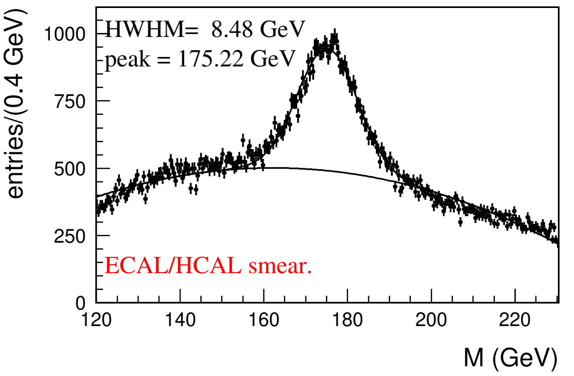
$+ \sim 2 - 3\%$ constant terms

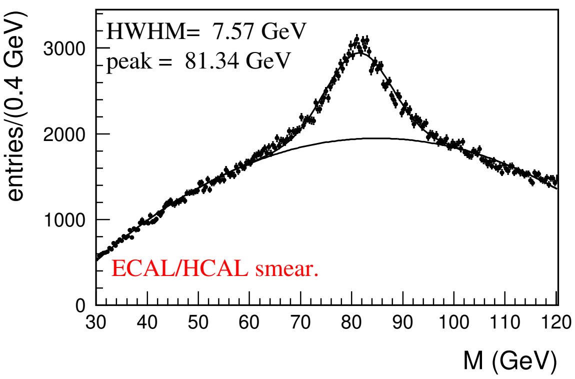
Significant contribution from hadronization

Jet resolution from EFA $\simeq$ hadron level

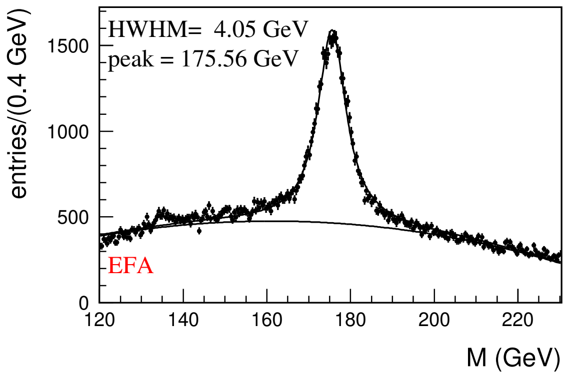
Mass resolutions from all processes in e^+e^- annihilation

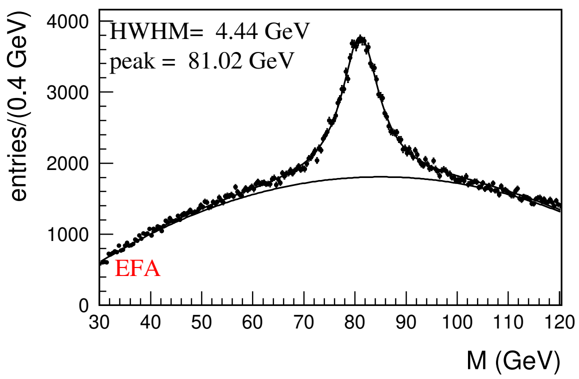
single b-tagging



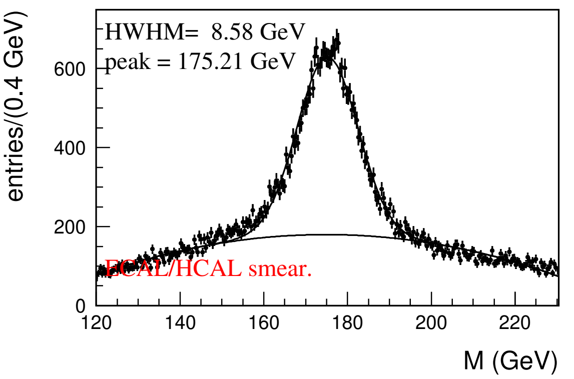


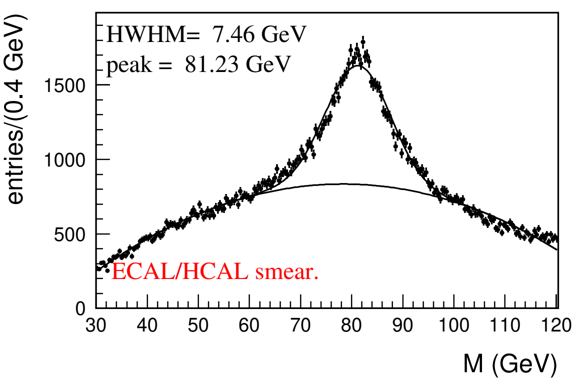
single b-tagging



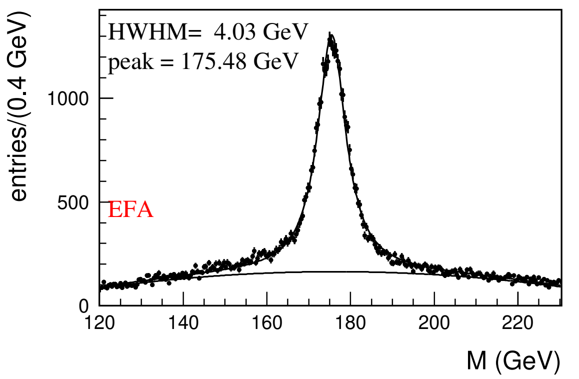


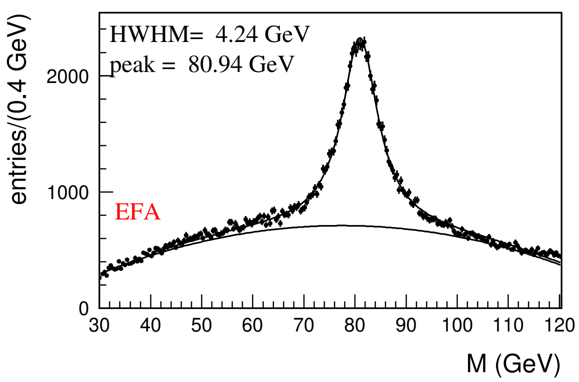
double b-tagging





double b-tagging





Summary

HWHM (in GeV)

	true	quarks only	quarks +PS	final-state	ECAL only	HCAL neutr	ECAL/ HCAL	EFA
t	0.69	0.63	1.83	2.68	3.53	3.91	9.14	5.38
W	1.02	1.03	2.07	2.34	3.63	4.35	10.89	6.02

- HWHM of M_t and M_W using the parton level and the k_T algorithm to reconstruct jets is by a factor ~ 2 larger than the natural widths
- Large increase in HWHM when ECAL/HCAL smearing is used
- EFA significantly improves the HWHM (by a factor 2)
- Double b-tagging is essential to reduce the background
- Kinematic fits are under investigation
- Realistic GEANT simulation is essential for final conclusions