A Method of Top Quark Reconstruction at a Future Linear Collider

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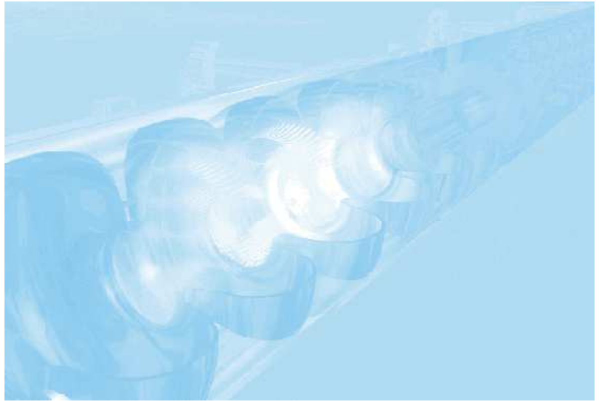


ECFA–DESY Workshop, Prague, 15–18 November 2002.

Introduction – Pure Kinematics

We cannot dictate to the Nature to follow our wishes. We can only justify our theories by an experiment.

The process: $e^+e^- \rightarrow 6\, jets$ can be reconstructed without the SM assumptions.

But one should make some minimal assumptions:

- $e^+e^- \Rightarrow V_a + \overline{V_a}$ go to two parton anti–parton pair ($t\bar{t}$ as one of the possible examples);
- the cascade decay of each intermediate partons is assumed.

$$V_a \Rightarrow \; V_1 + V_c$$

$$\Downarrow$$

$$V_c \rightarrow V_2 + V_3,$$

$\Rightarrow$ 6 quarks or particles in the final state.

Aim: To develop a new method for the measurement of the initial parton mass and QCD dynamics which:

- does not involve knowledge on intermediate parton mass and width;
- effectively suppresses contributions from QCD multi–jet production;
- does not involve kinematic fitting;
- simple.

This method can be applied to the high precision top mass reconstruction without assumption about W–mass and width.

Introduction – Corrections

Major phenomena affecting the reconstruction of top–quarks:

Luminosity curve

Initial state QED radiations $\surd$

Parton level

QCD first order correction (gluons from top) $\surd$

Multiple gluon radiations $\surd$

Fragmentation

Color reconnection effect $\surd$

Particle composition $\surd$

Bose-Einstein correlations $\surd$

Detector effects $\surd$

Introduction

Standard model process: $e^+e^- \Rightarrow t\bar{t} \Rightarrow b\bar{b}\, W^+W^- \Rightarrow b\bar{b} + q_1\overline{q}_2 q_3\overline{q}_4 \Rightarrow 6\, jets$

This decay channel accounts for 45% of all $t\bar{t}$ decays.

For high precision measurements, it is essential to reduce the QCD background from multi-jet events.

This can be achieved by identification of b-initialized jets (the so-called $b-$tagging),

and the calculation of the 4-momenta of W candidates after combining jets not associated with the $b-$quark jets.

Disadvantages

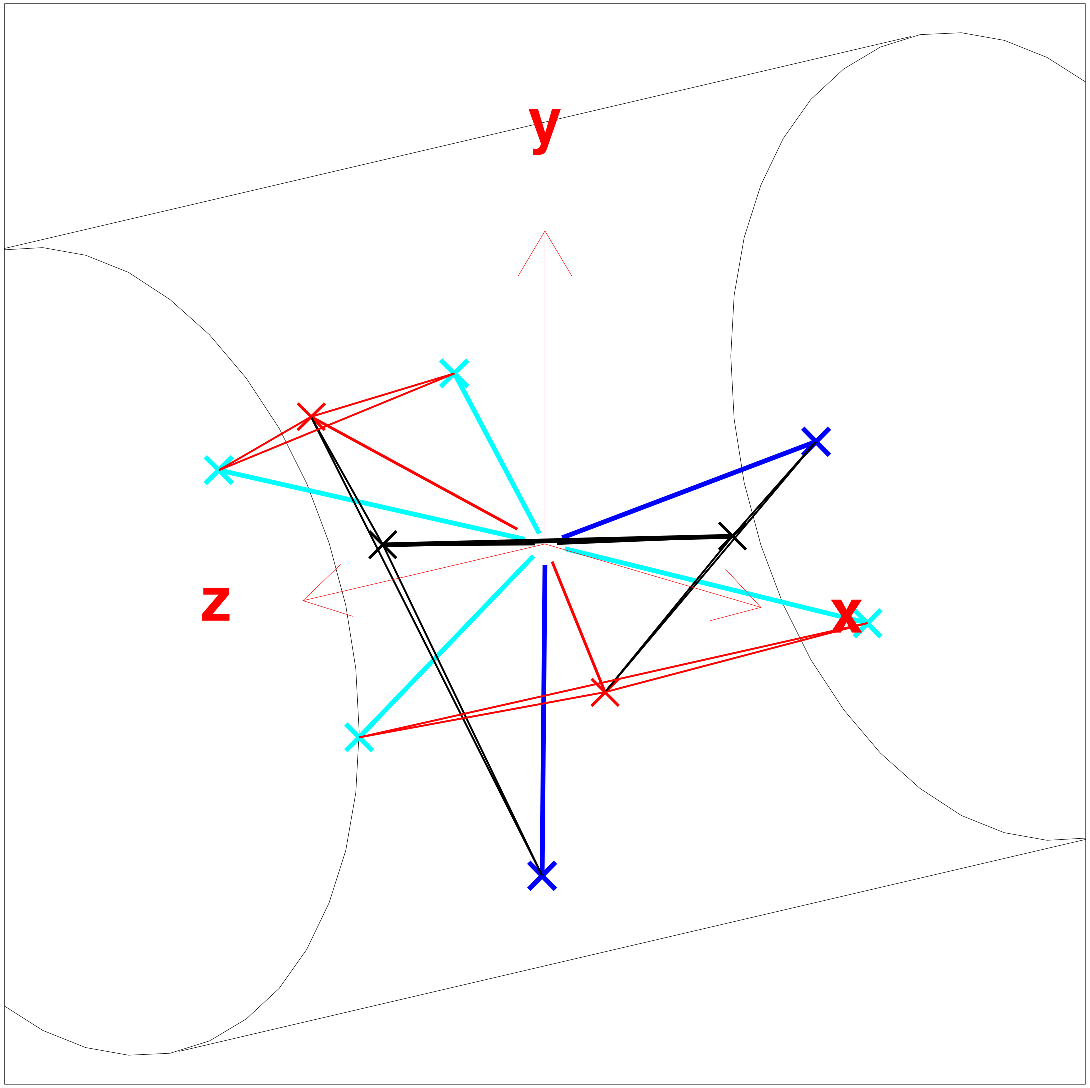
This method is known to be affected by the many systematical uncertainties related to incomplete knowledge of the hadronic final state.

The large Breit-Wigner tails of W-bosons and their treatment directly affect the reconstructed top mass.

Another example - the Bose-Einstein and color reconnection effects which can significantly contribute to the shifts in the W-boson mass, and this again has a direct impact on the reconstruction of the top quarks if the W-bosons are first reconstructed.

Event topology

$$E_{CM} = 500\ GeV, \qquad e^+e^- \to t\bar{t} \to b\bar{b}\ W^+W^- \to b\bar{b} + q_1\bar{q}_2q_3\bar{q}_4 \to 6\,jets$$



Color explanation:

BLACK - top-quark

RED - W-boson

BLUE - b-quark

GREEN - c,s-quarks

AQUAMARINE - u,d-quarks

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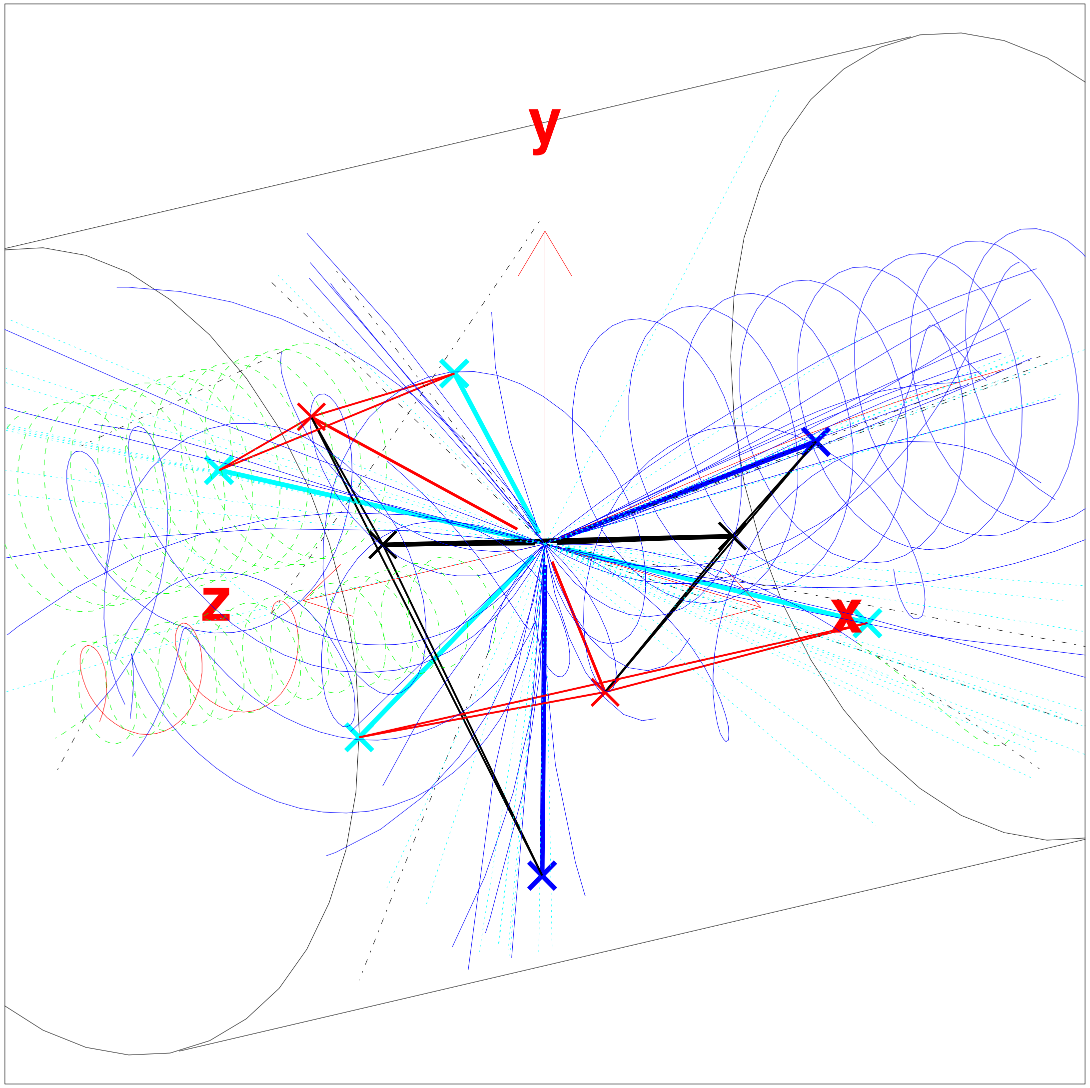

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Monte–Carlo samples

PYTHIA 6.2

e^+e^- events at $E_{CM} = 500\ GeV$

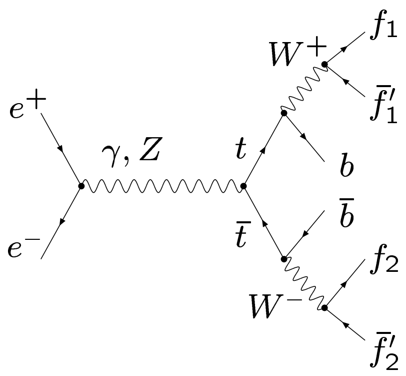
- **290k PYTHIA inclusive** $e^+e^- \to (\gamma, Z) \to$ everything **events (without top quarks) after E-Flow smearing.**
- **9.6k** $e^+e^- \to t\bar{t} \to$ everything events **with the full detector simulation and reconstruction by BRAHMS .**

Statistics corresponds to $\sim$ 20 days of TESLA accelerator running.

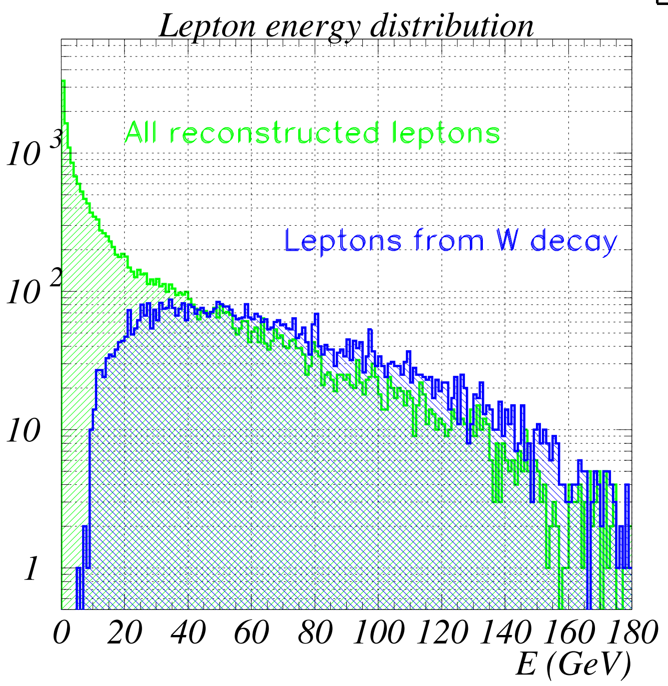
- ISR and first level QCD corrections are included.
- Parameters of E-Flow smearing for continuum events:

$$\sigma_{ch.hadr.} \approx 10^{-4} E^2_{ch.hadr.} \ ; \ \sigma_\gamma \approx 0.12\sqrt{E_\gamma} \ ; \ \sigma_{neut.hadr.} \approx 0.4\sqrt{E_{neut.hadr.}}$$

$e^+e^- \longrightarrow t\bar{t} \longrightarrow b\bar{b}\ W^+W^-$ in PYTHIA



Type	b-jet	W-jet/lepton	W-jet/lepton	N jets	N ν	Prob.
1	2b	2q	2q	6	0	45.60 %
2	2b	2q	τ	5	1	14.625 %
3	2b	2q	e	4	1	14.625 %
4	2b	2q	μ	4	1	14.625 %
5	multi lepton events					10.56 %



Semileptonic decay of W–boson is rejected if one or more lepton with $E_{lept.} \geq 20$ GeV exists.

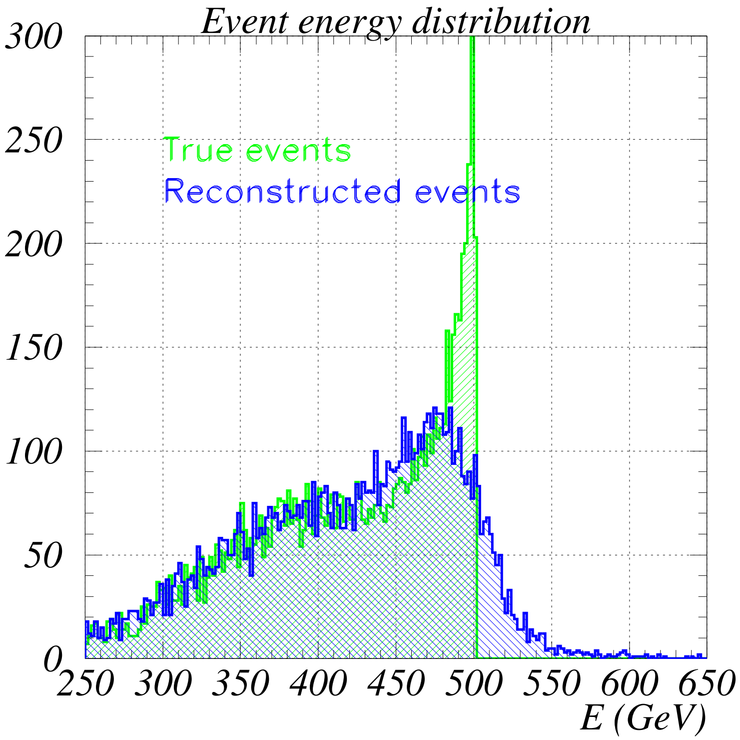
Preselection

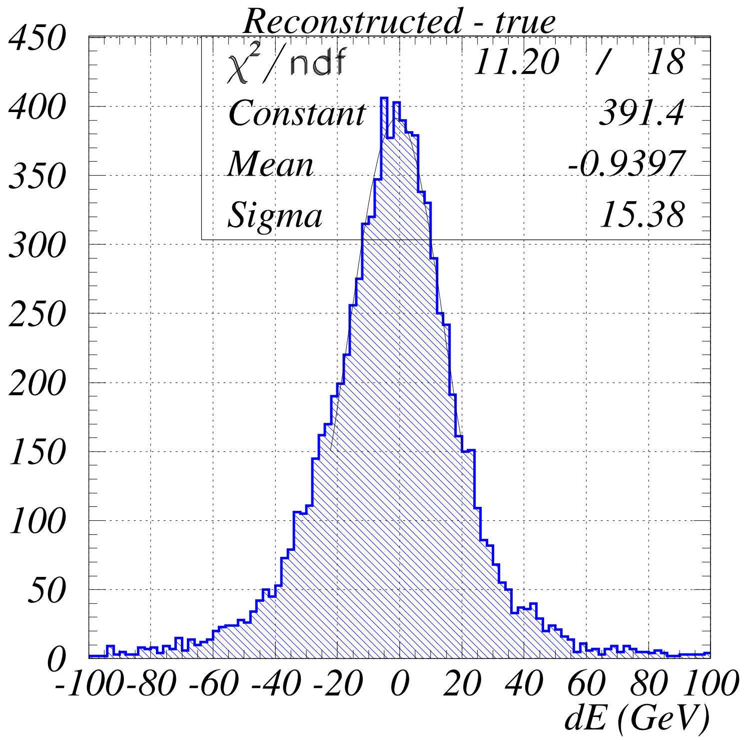
The energy-momentum conservation constraints to reject events with a significant fraction of neutrinos:

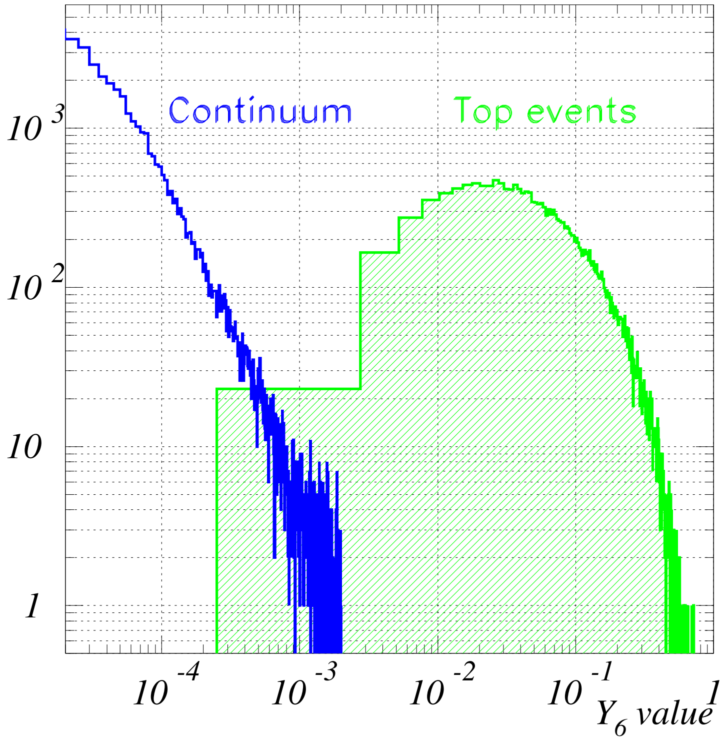
$$\left|\frac{E_{vis}}{\sqrt{s}} - 1\right| < 0.07; \quad \frac{|\sum p_{||i}|}{\sum |\vec{p_i}|} < 0.04; \quad \frac{\sum p_{Ti}}{\sum |\vec{p_i}|} < 0.04$$

where: E_{vis} is the visible energy, $p_{||i}$ and p_{Ti} are the longitudinal and the transverse momentum of a final state particle.

These cuts reject $\sim 50\%$ of the generated top events.







Y_6 cut

As a first step, 6 jets in an event has to be reconstructed. We use the Durham jet finder algorithm, requiring exactly 6 jets in event, without any specific cuts on the transverse momenta and rapidities of the jets.

Y_6 is value of YCUT for which event flips from 7 to 6 jet configuration.

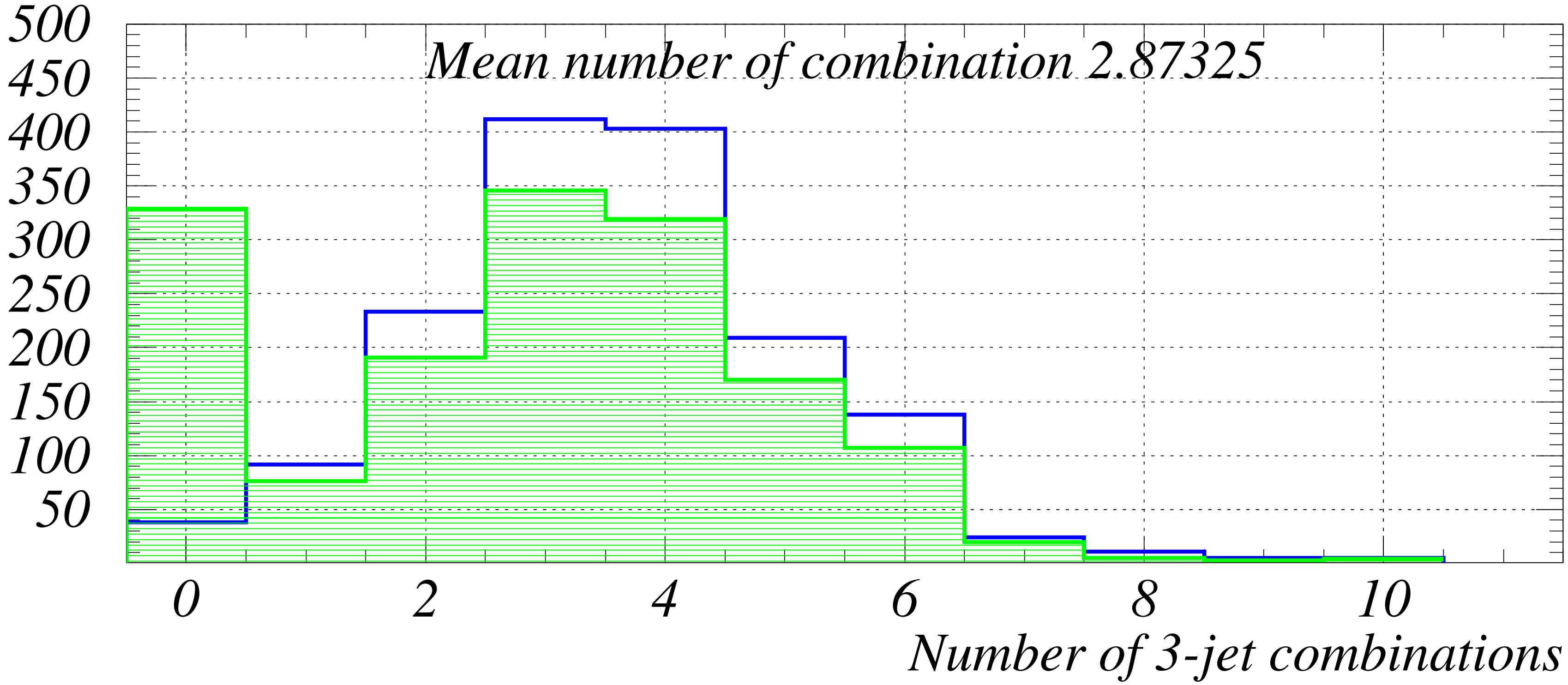
Cut: $Y_6 < 2 \times 10^{-4}$

Top reconstruction

We merge these jets momenta p_I in clusters with 3 jets in each to obtain a list of clusters, $\{P_I(1),\ P_I(2)\}$, where $P_I(1) \equiv P_{i,j,m} = p_i + p_j + p_m$, and $P_I(2)$ was obtained analogously using the rest of the jets in the same event. In total, there are 20 3-jet clusters, which can be grouped into 10 **3-jet combinations with non-identical momenta**, $I = 1, \ldots 10$.

We accept only 3-jet clusters with $|M_I(1) - M_I(2)| < 40$ GeV, where M_I is the invariant mass of the 3-jet cluster with the momentum P_I and with back-to-back momentum imbalance less than 20 GeV.

Distribution of number of 3–jet combinations

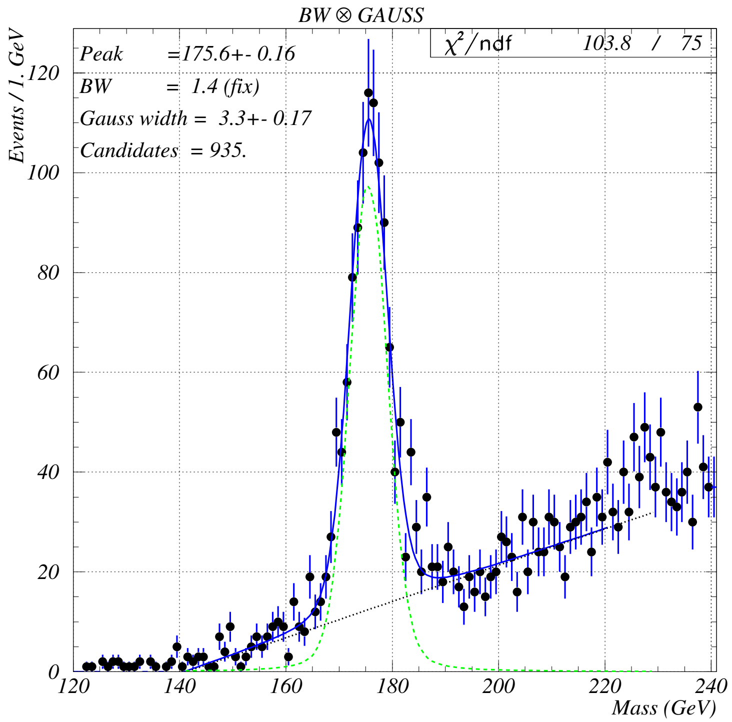


Pair of 3–jet mass difference cut – blue.

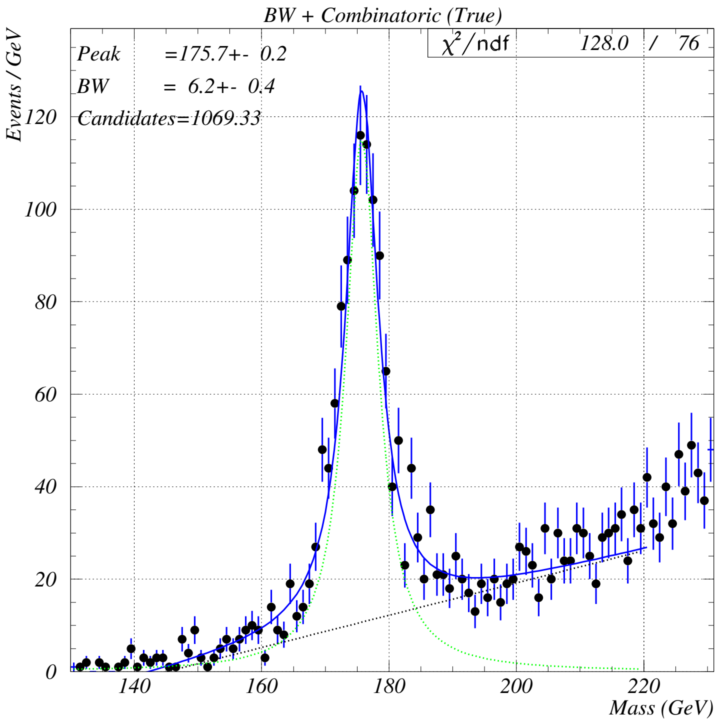
Back-to-back 3–jet momentum imbalance cut – green.

Signal shape for $e^+e^- \longrightarrow t\bar{t}$ (Generator level)

- events with hadronic W decays only;
- particles with $c\tau > 3cm$ are removed;
- missing true energy < 10 GeV;
- ISR is included;
- no neutrinos;
- particles with $\Theta < 0.1$ rad are removed.



Fit with convolution of the initial top quark Breit–Wigner with a Gaussian **($\sigma = 3.3$ GeV)** describing fragmentation and hadronization.

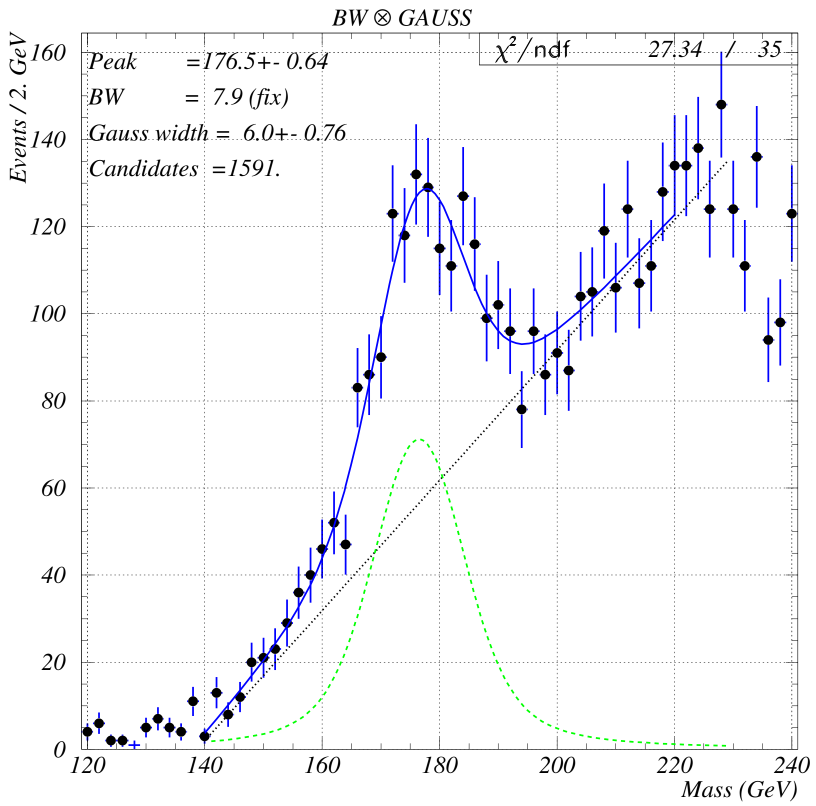


Only Breit–Wigner fit **(width 6.2 GeV)** used in studies of top mass reconstruction.

Detector performance

for special top event selection at the generator level.

Breit–Wigner width from the true events for particular cuts was fixed, and reconstructed events were fitted with Breit–Wigner $\bigotimes$ Gaussian convolution function.



- Tesla detector with Si-W ECAL and Sc-Tile HCAL
- BRAHMS v305 was used for full simulation and reconstruction,
- The last version of tracker reconstruction program,
- SNARK v03 reconstruction program for the calorimeters using the combined energy-flow algorithm.

The resolution of reconstructed 3–jets mass is about 6 GeV.

Top reconstruction in inclusive e^+e^- events

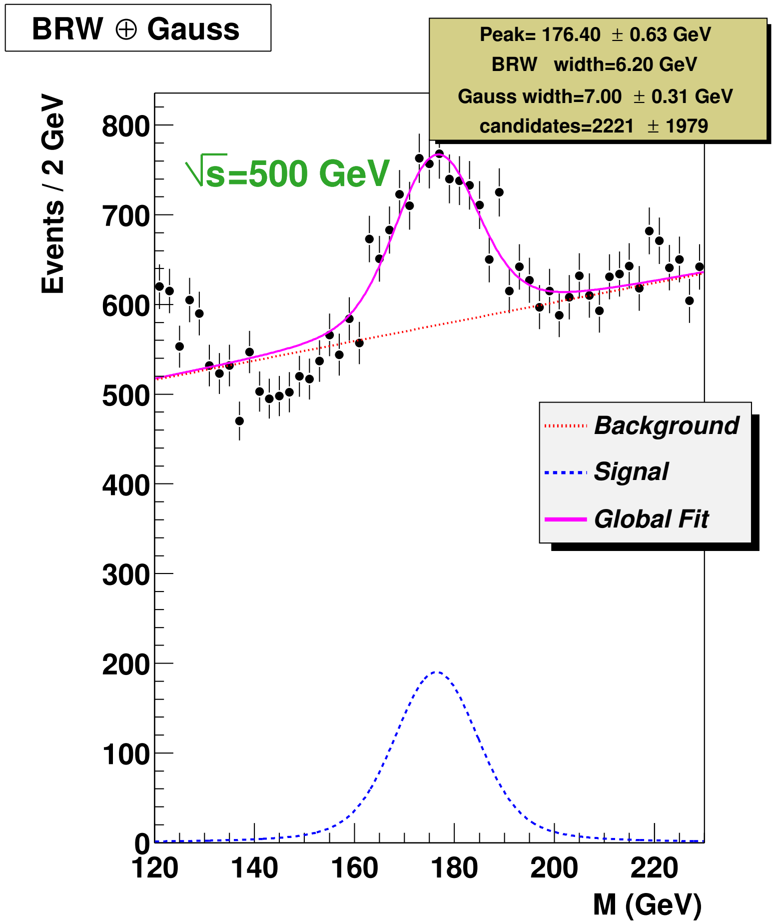
Preselection

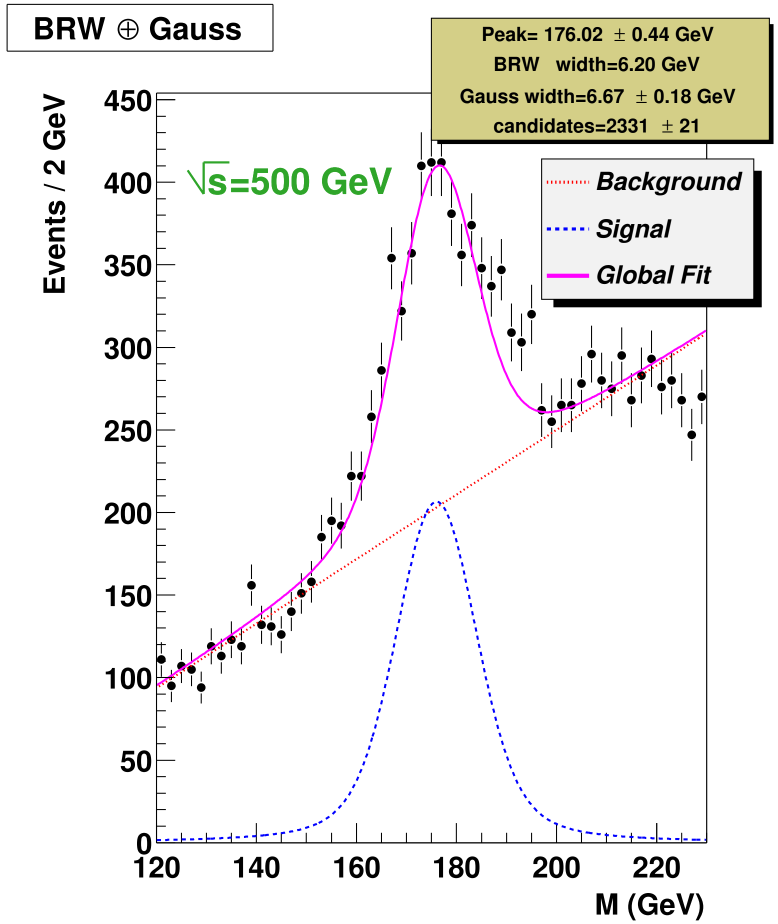
- Energy imbalance is less than 7 % — to remove neutrinos
- Transversal momentum imbalance is less than 4 % — to remove neutrinos
- Semileptonic events cut — to remove semileptonic W decay

Main cuts

- $Y_6 \leq 2 \times 10^{-4}$ — to remove continuum
- Invariant masses of two 3–jets differ by more than 40 GeV — to remove jet combinatoric
- 3–jets back–to–back momentum – $||P_1(I) - P_I(2)|/(P_1(I) + P_I(2))| > 0.1,$ — to remove jet combinatoric
- No b-tagging is used
- No W-mass cut is used
- No any kinematic fit is used

Full detector simulation and reconstruction





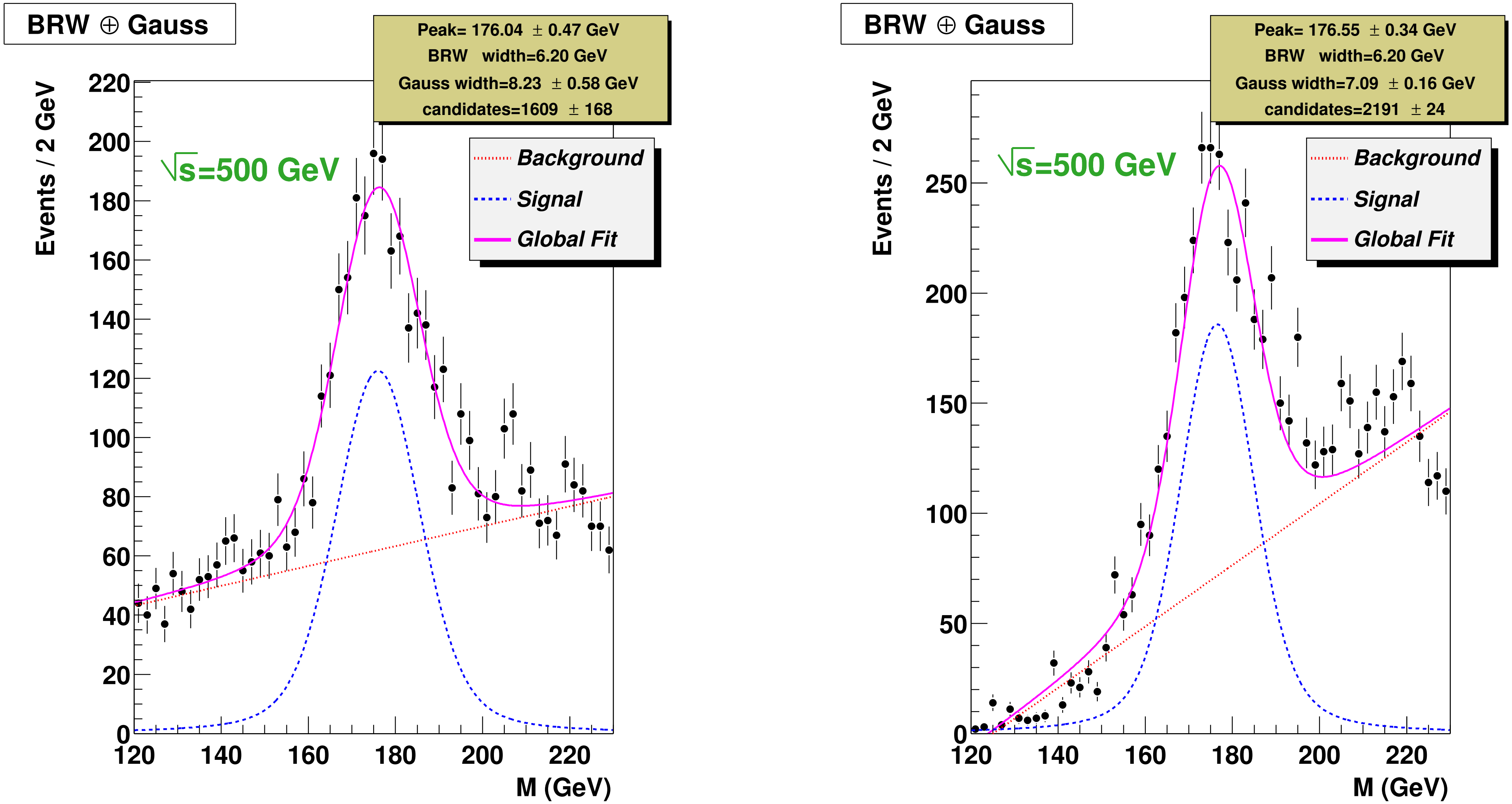
Difference between invariant masses and back–to–back momentum cuts only.

Y_6 cut is added.

$\longrightarrow$ significant reduction of the background.

Peak = 176.0 $\pm$ 0.44 GeV $\Rightarrow$ $\Delta M_{stat.} \approx 100$ MeV for $\mathcal{L} = 300 fb^{-1}$.

Full detector simulation and reconstruction



$65 < M_W < 95\ GeV$ added,

$\longrightarrow$ no significant impact on the top–mass spectra.

No any cuts but Neural Network is used based on 10 variables ($Y_2 - Y_7, T, M_J, M_n, etc$), trained on smeared events.

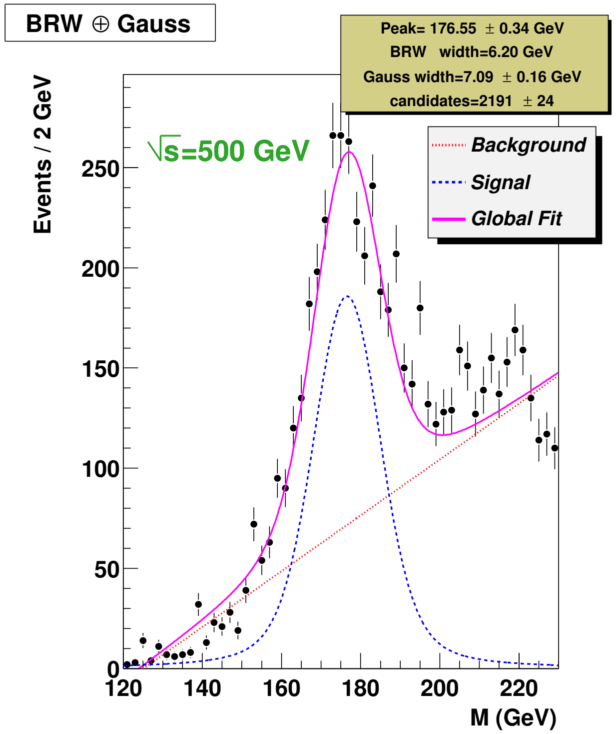
Conclusion

A simple approach to reconstruct the top masses at the next linear colliders was proposed:

- Well suited for the center-of-mass energies far from the top-production threshold.
- Effectively suppresses the QCD multi-jet background
- Does not require a priory knowledge about W mass and width
- Has a reduced experimental and theoretical sensitivity to effects associated with the reconstruction of the W–boson
- Has a good efficiency ($\simeq$ 25 %) for QCD studies of top reconstruction

- PYTHIA gives $\sim$3.3 GeV Gaussian spread of the natural top–quark width due to parton fragmentation and hadronization.
- Statistical error $\sim$ 300–400 MeV for 20 days of data taking

- Full detector simulation (BRAHMS with E-Flow) gives $\sim$6 GeV Gaussian spread of the top–quark mass resolution.



We shell see this in ten years in TESLA control room.