Top pair production I

Andreas Moll
Alexei Raspereza

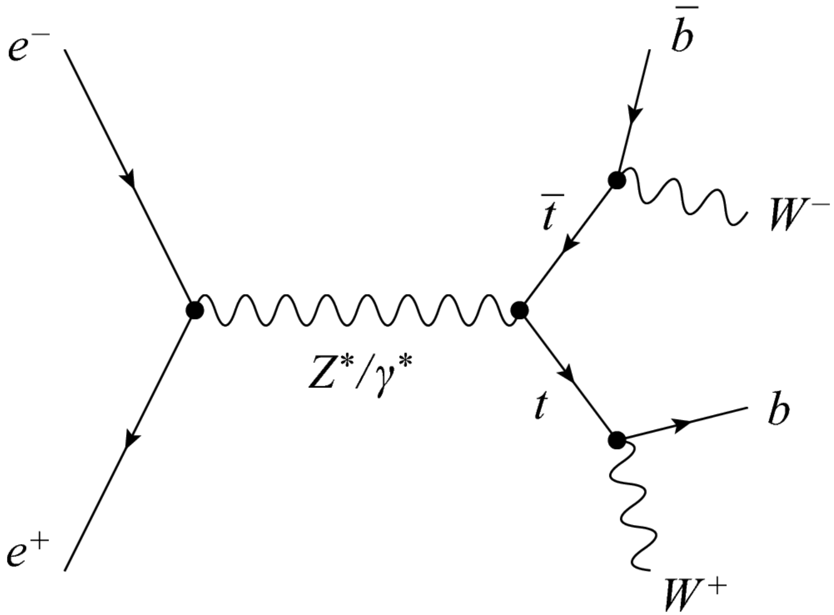
ILD Workshop Seoul

16 - 18 February 2009

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

- **Introduction**
- **The analysis chain**
  - LeptonVeto
  - Combinatorics
  - Kinematic fitting
- **The analysis**
  - Events used
  - Background rejection
- **Fitting the final distributions**

Analysis goal: estimate statistical error on m_t and width from direct reconstruction of top quark decays.



Combination of measurements at DØ and CDF

$$m_t = 172.4 \pm 0.7\, GeV\, (stat.)$$

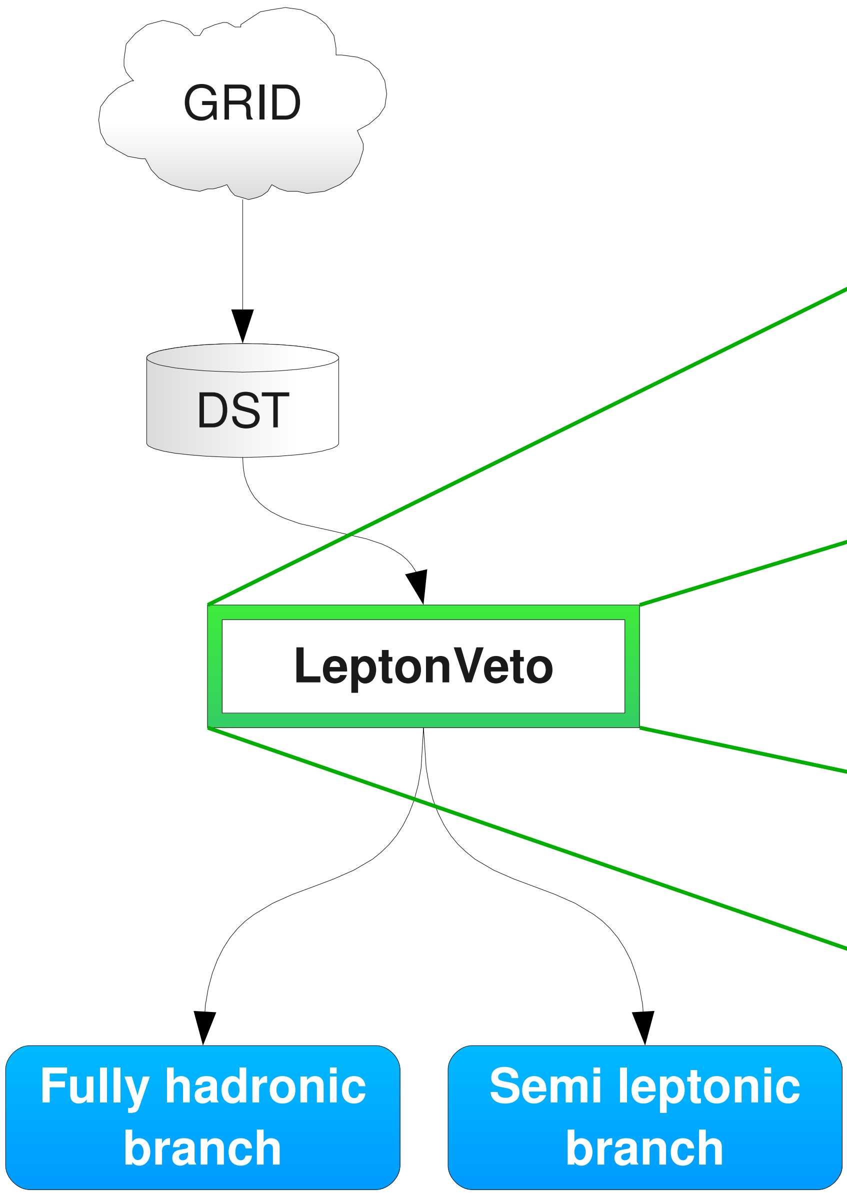
The top quark almost exclusively decays into a W boson and a b quark.

$$t\bar{t} \rightarrow (W^+ b)(W^- \bar{b})$$

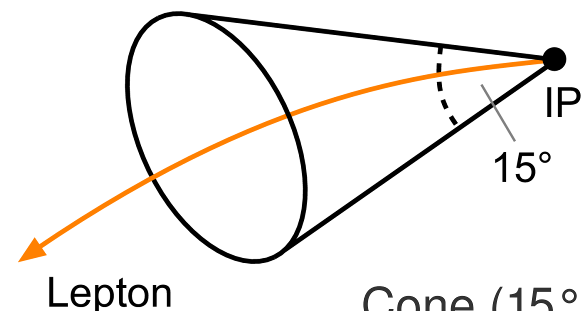
The W can either decay **hadronically** into a $q\bar{q}$ pair or **leptonically** into $l\nu$.

In this analysis:

$t\bar{t} \rightarrow (bq\bar{q})(\bar{b}q\bar{q})$	*Fully hadronic, FH*
$t\bar{t} \rightarrow (bq\bar{q})(\bar{b}l\nu)$	*Semi leptonic, SL*
Analysis done for:	$100\, fb^{-1}$ unpolarized beams



Particle ID information is used to identify high energy electrons and muons.

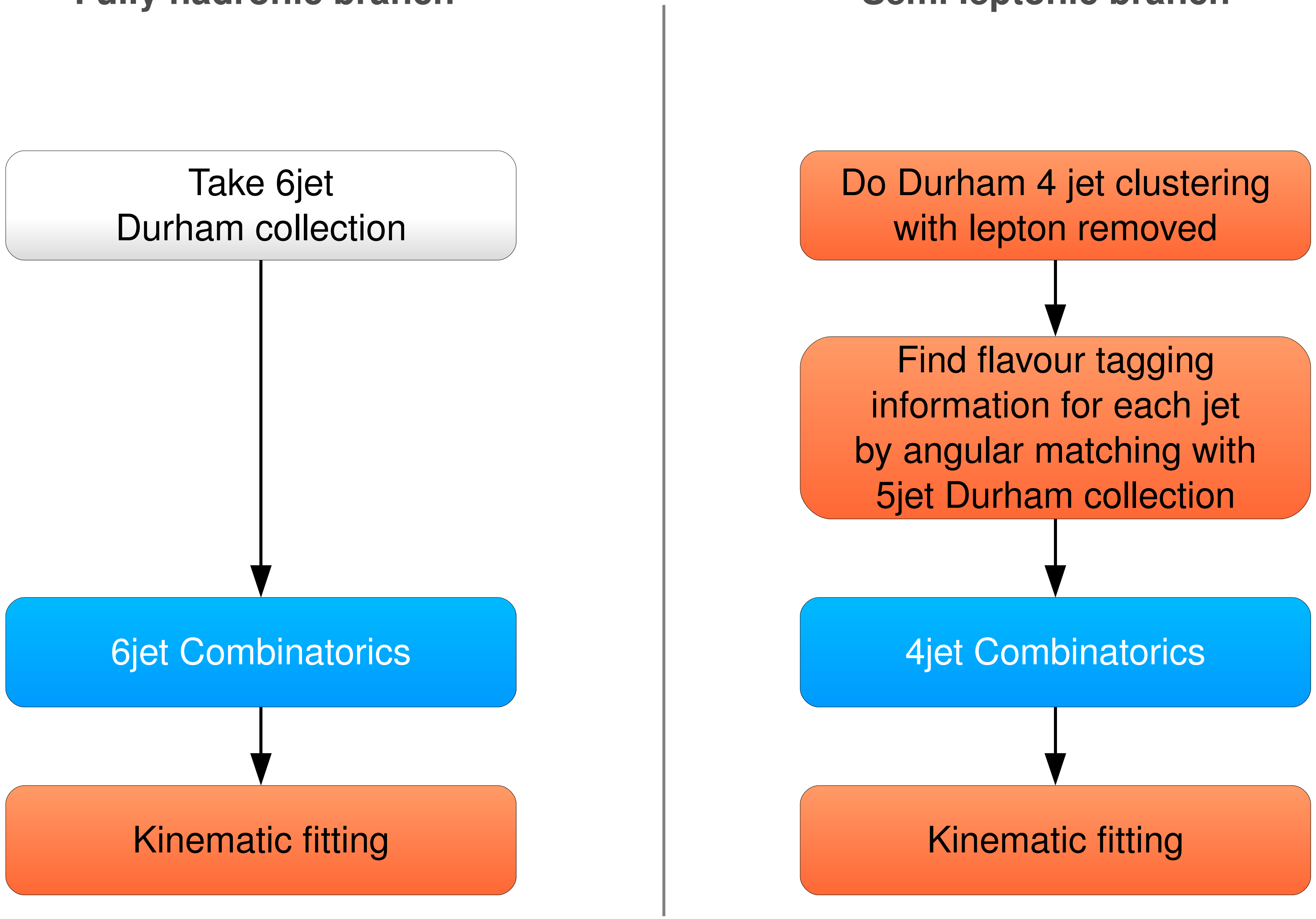


Cone (15°)
charged tracks < 2

Lepton energy > 10 GeV

Lepton found ⇒ Semi leptonic branch

Fully hadronic branch | **Semi leptonic branch**



1. Using **flavour tagging** information, the jets with the two highest b-tag values are taken.
   ⇨ They are regarded as **b-jets**, resulting directly from the top quark decays.

2. The four remaining jets are considered as decay products of the two **W bosons**.
   ⇨ There are **three** possible ways to combine four jets into two di-jets.
   For each possible combination the quantity Δ_W is calculated:

$$\Delta_W = |m_{ij} - m_W| + |m_{kl} - m_W|$$

with m_{ij} and m_{kl} di-jet masses for a given jet pairing

The combination yielding the **smallest value** of Δ_W is chosen to form the two W bosons.

3. The production of two heavy states (top quarks) having the **same mass** is expected.
   ⇨ Choose the two di-jet / b-jet pairs which yields **minimal three-jet mass difference**.

1. Using **flavour tagging** information, the jets with the two highest b-tag values are taken.
   ⇒ They are regarded as **b-jets**, resulting directly from the top quark decays.

2. The two remaining jets are considered as decay products of the **hadronically decaying W boson**.

3. The three-momentum of the neutrino is defined as the **missing momentum** vector of the event. The energy is defined as the **magnitude** of the momentum vector.

4. Identified lepton (from LeptonVeto) and neutrino are considered as decay products of the **leptonically decaying W boson**.

5. Choose the combination of the hadronically and leptonically decaying W bosons with the two b-jets which gives the minimal Δ_t:

$$\Delta_t = |m_{t1} - m_{t2}|$$

with m_{t1} and m_{t2} invariant masses of reconstructed top quarks.

Kinematic fitting is performed using **MarlinKinFit** package.

Fully hadronic branch

7 constraints

$\sum_{i=1}^{6} \vec{p}_i = 0$ *momentum conservation*

$\sum_{i=1}^{6} E_i = \sqrt{s}$ *energy conservation*

$|m_{ij} - m_W| = 0$
$|m_{kl} - m_W| = 0$ *mass difference W di-jet and nominal W mass*

$\Delta m_3 = 0$ *same mass t and $\bar{t}$*

Semi leptonic branch

4 constraints

$\sum_{i=1}^{6} E_i = \sqrt{s}$ *energy conservation*

$|m_{ij} - m_W| = 0$
$|m_{kl} - m_W| = 0$ *mass difference W di-jet and nominal W mass*

$\Delta m_3 = 0$ *same mass t and $\bar{t}$*

Signal Fully hadronic

bbuddu, bbudsc, bbcsdu, bbcssc

Signal Semi leptonic

bbn1e1du, bbn1e1sc, bbude1n1, bbcse1n1
bbn2e2du, bbn2e2sc, bbude2n2, bbcse2n2

2-fermion background

uu, dd, ss, cc, bb

4-fermion background

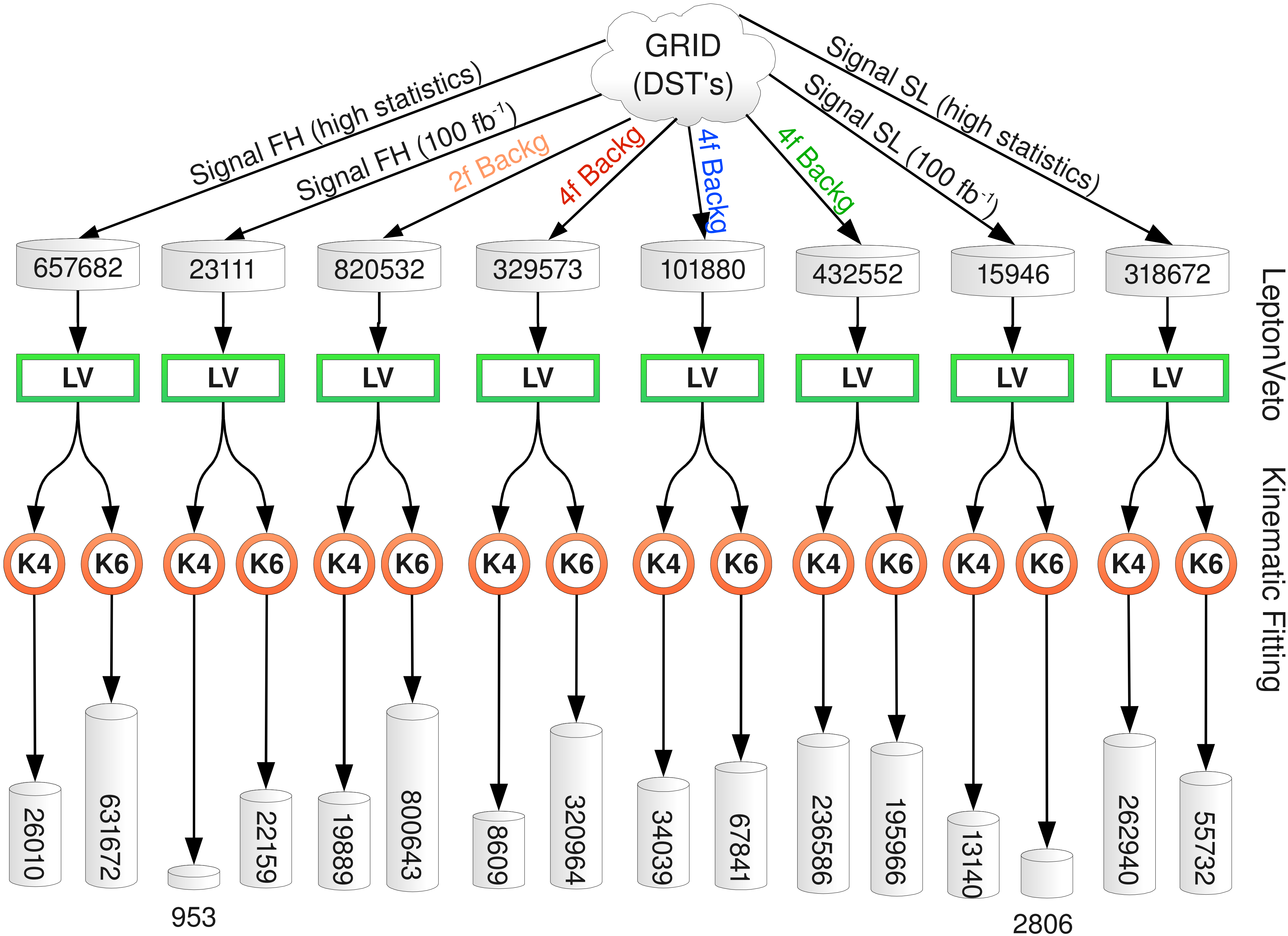
uddu, udsc, csdu, cssc, uuuu, uuss
uucc, uubb, dddd, ddss, ddcc, ddbb
ssss, ssbb, cccc, ccbb, bbbb

4-fermion background

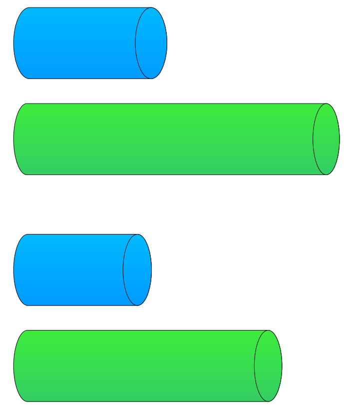
n1e1du, ude1n1, n1e1sc, cse1n1
n2e2du, ude2n2, n2e2sc, cse2n2
n3e3du, ude3n3, n3e3sc, cse3n3

4-fermion background

uue1e1, e1e1dd, e1e1ss, cce1e1, e1e1bb
uue2e2, e2e2dd, e2e2ss, cce2e2, e2e2bb
uue3e3, e3e3dd, e3e3ss, cce3e3, e3e3bb



GRID
(DST's)
Signal FH (high statistics)
Signal FH (100 fb-1)
2f Backg
4f Backg
4f Backg
4f Backg
Signal SL (100 fb-1)
Signal SL (high statistics)
657682
23111
820532
329573
101880
432552
15946
318672
LV
LeptonVeto
K4
K6
Kinematic Fitting
26010
631672
953
22159
19889
800643
8609
320964
34039
67841
236586
195966
13140
2806
262940
55732

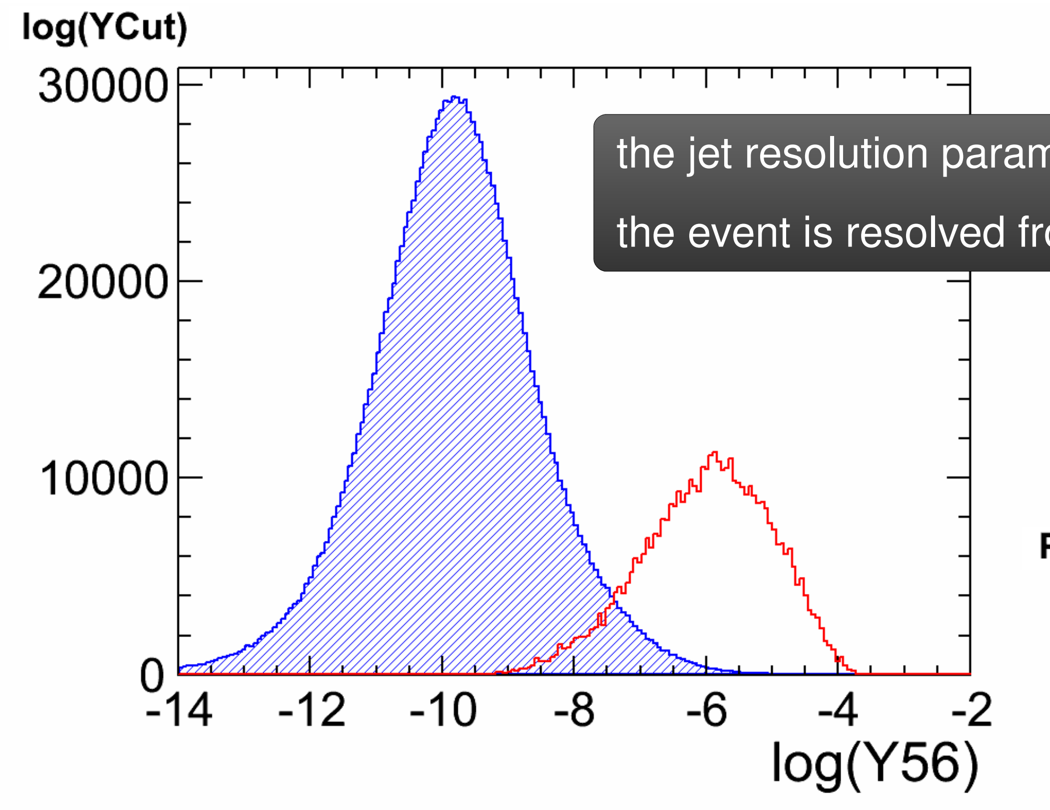


Fully hadronic branch	Signal	$24 \cdot 10^3$
	Background	$1385 \cdot 10^3$
Semi leptonic branch	Signal	$14 \cdot 10^3$
	Background	$299 \cdot 10^3$

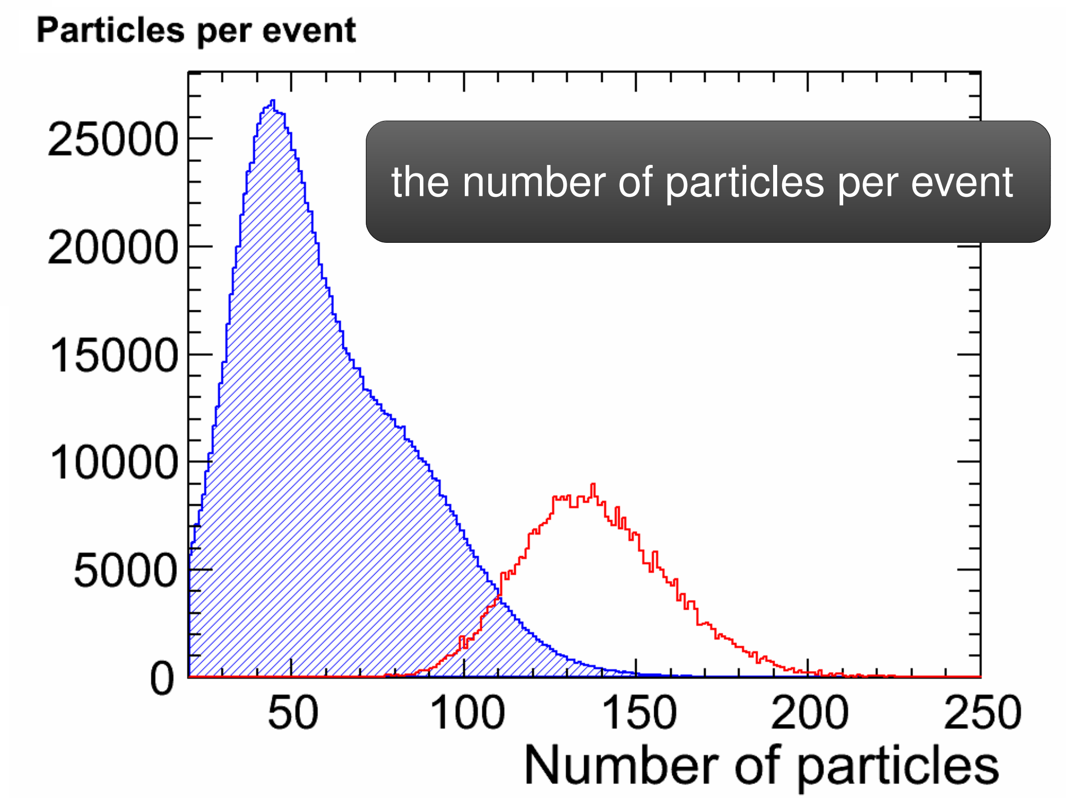
Background rejection is performed using the **binned likelihood technique**.

⇨ Therefore, the most discriminating variables are chosen

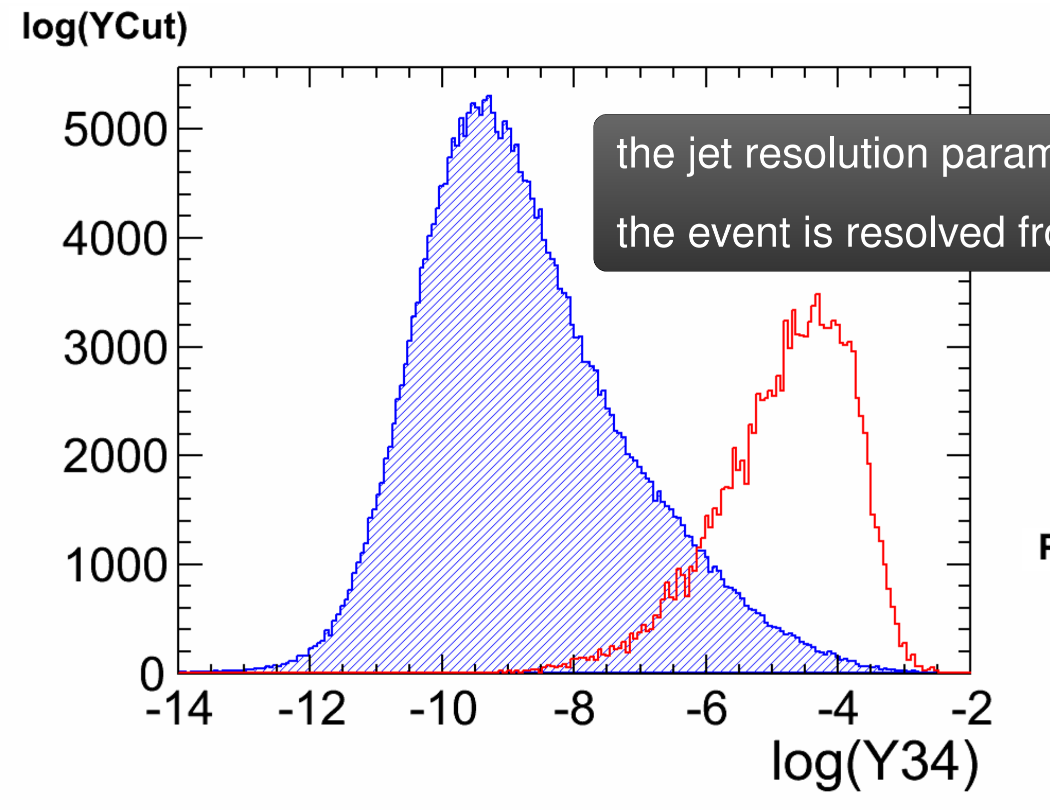
Fully hadronic	Semi leptonic	
$btag_1$	$btag_1$	the highest b-tag value among six jets
$btag_2$	$btag_2$	the second highest b-tag value
y_{56}	y_{34}	the jet resolution parameter for which the event is resolved from 6/4 to 5/3 topology.
m_W	m_W	the masses of the reconstructed W bosons
Δm_{3j}	Δm_{3j}	the mass difference of the reconstructed top quarks
$N_{Particles}$	$N_{Particles}$	the number of particles per event



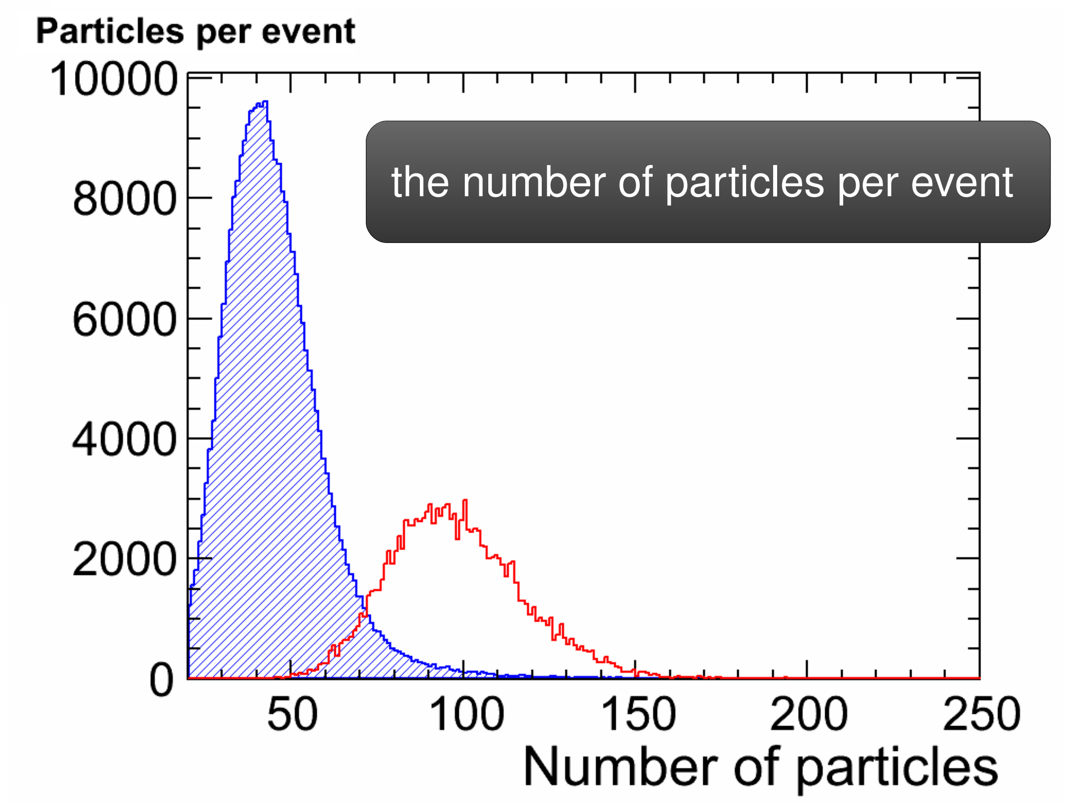
the jet resolution parameter for which the event is resolved from 6 to 5 topology.



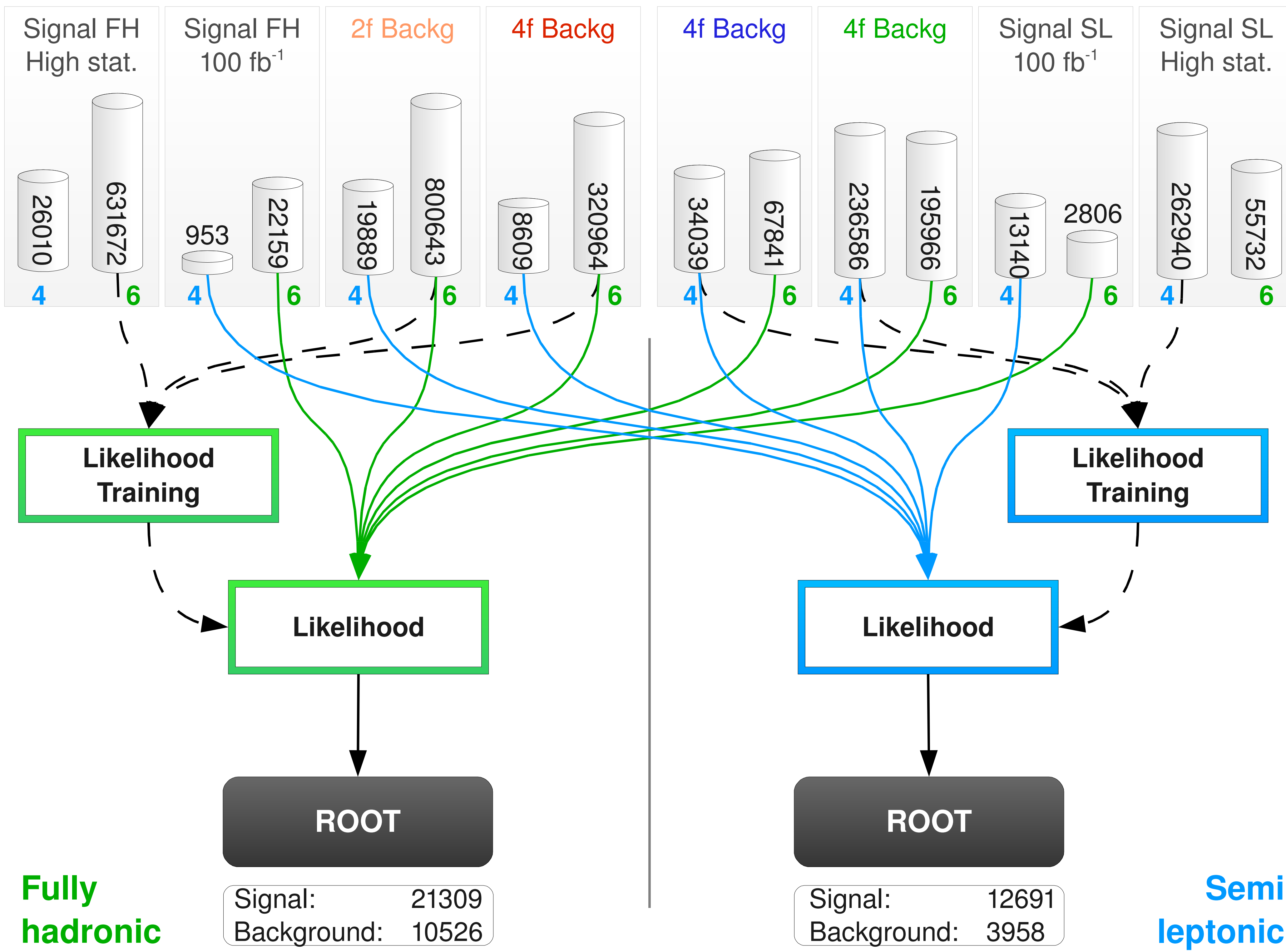
the number of particles per event



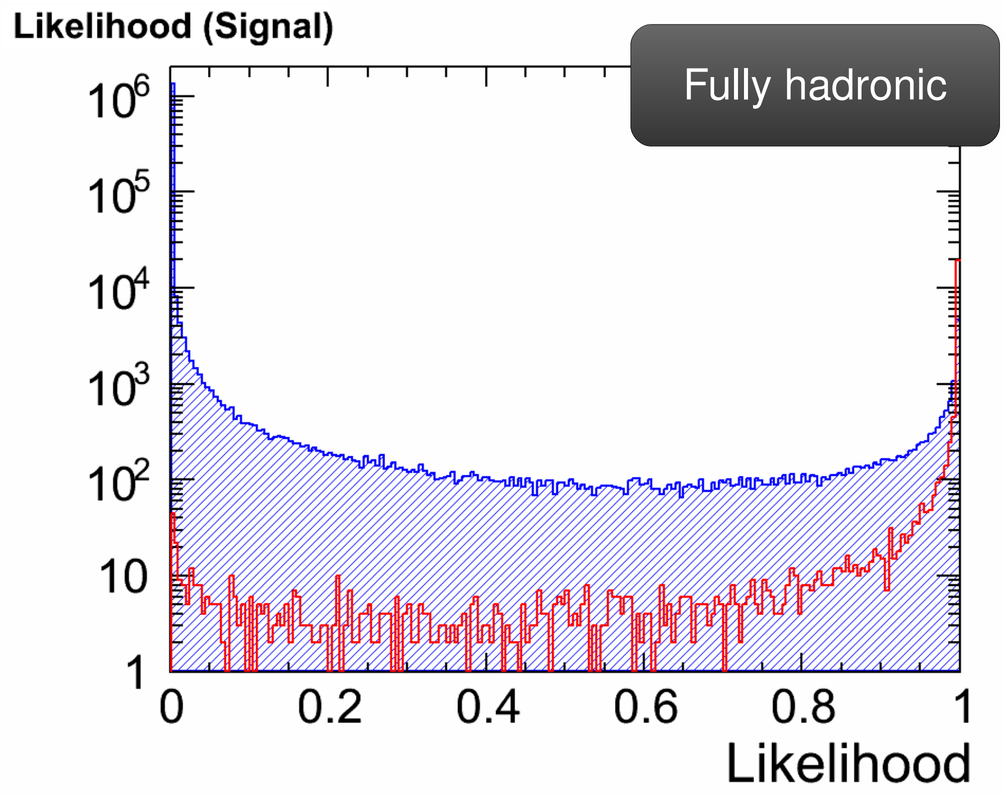
the jet resolution parameter for which the event is resolved from 4 to 3 topology.



the number of particles per event

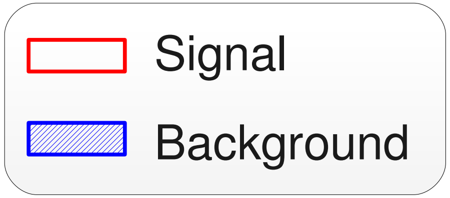


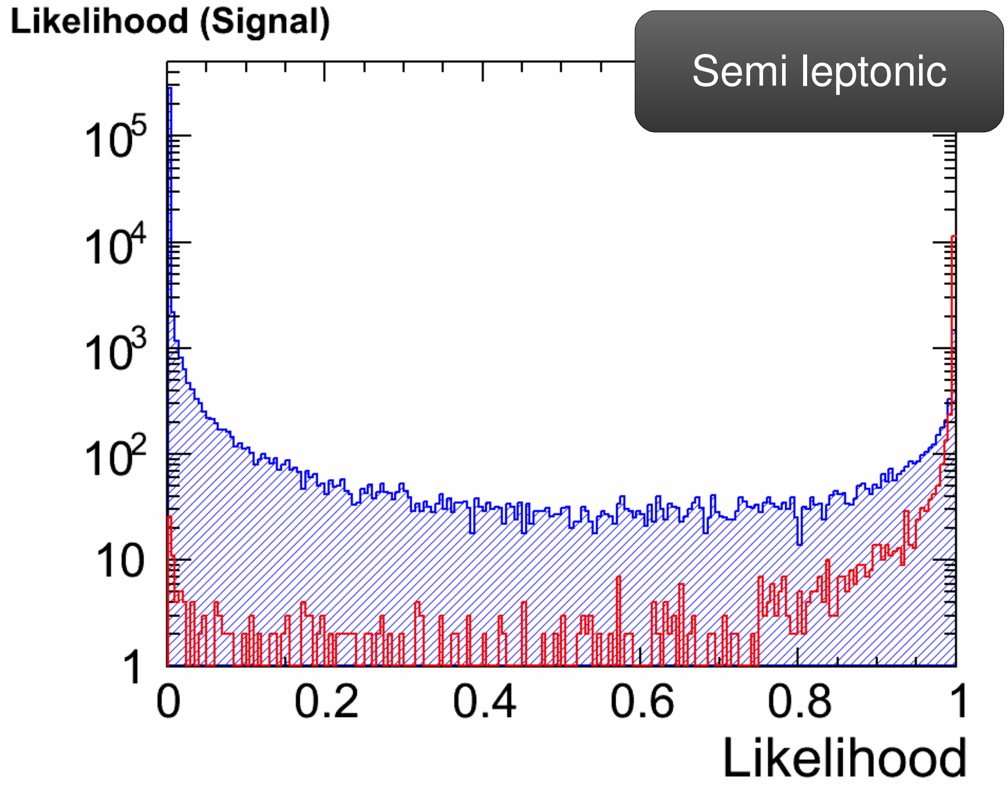
Signal FH
High stat.
26010
631672
Signal FH
100 fb-1
953
22159
2f Backg
19889
800643
4f Backg
8609
320964
4f Backg
34039
67841
4f Backg
236586
195966
Signal SL
100 fb-1
13140
2806
Signal SL
High stat.
262940
55732
4
6
Likelihood
Training
Likelihood
ROOT
Signal: 21309
Background: 10526
Likelihood
Training
Likelihood
ROOT
Signal: 12691
Background: 3958
Fully
hadronic
Semi
leptonic

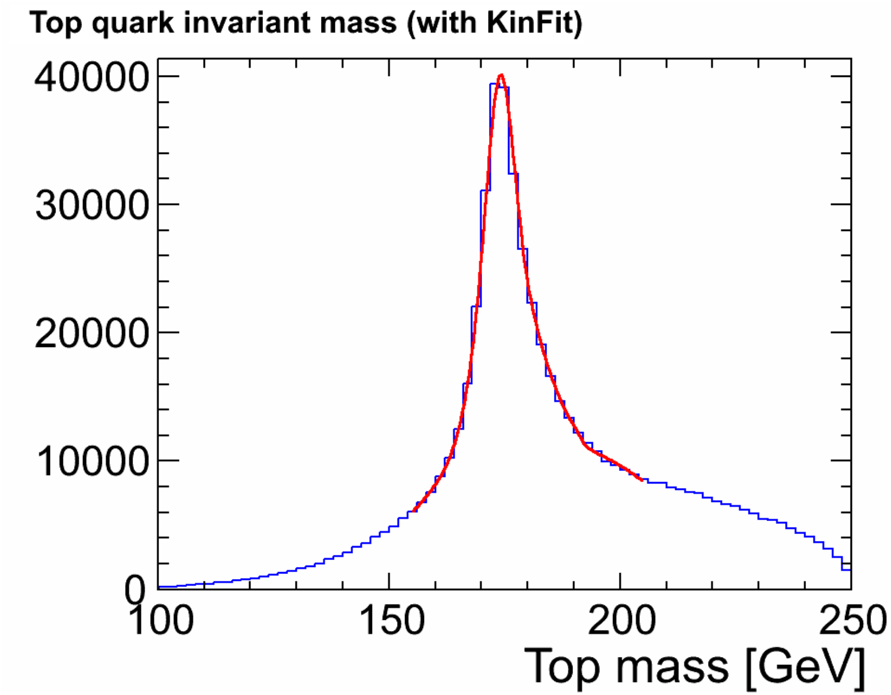


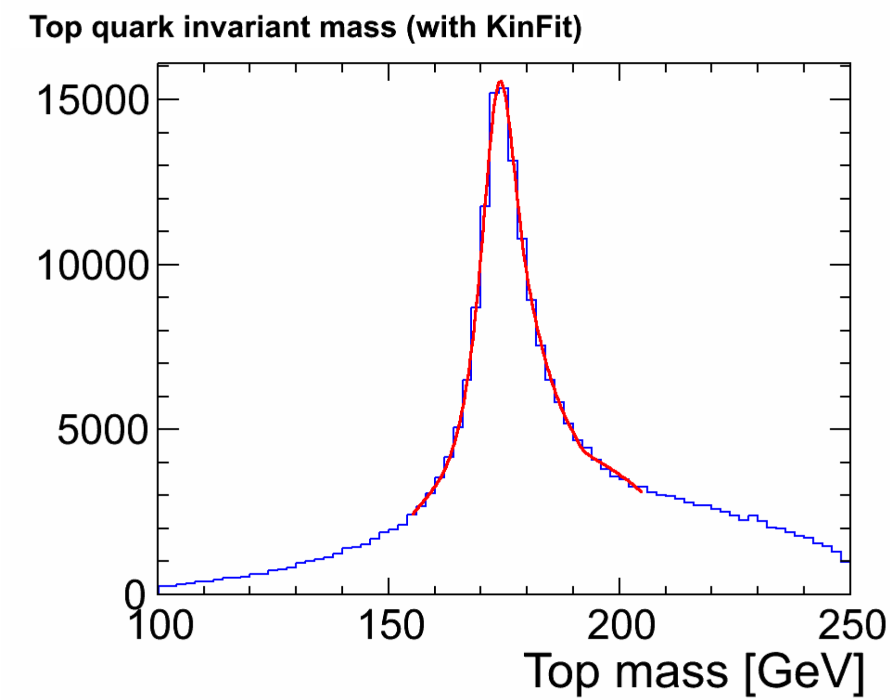
Likelihood cut value: **0.9**

optimized by minimizing the statistical error on the top quark mass









Extract the parameters defining the detector **resolution function**.

Top quark mass and width is fixed.

Fit Signal with convolution of

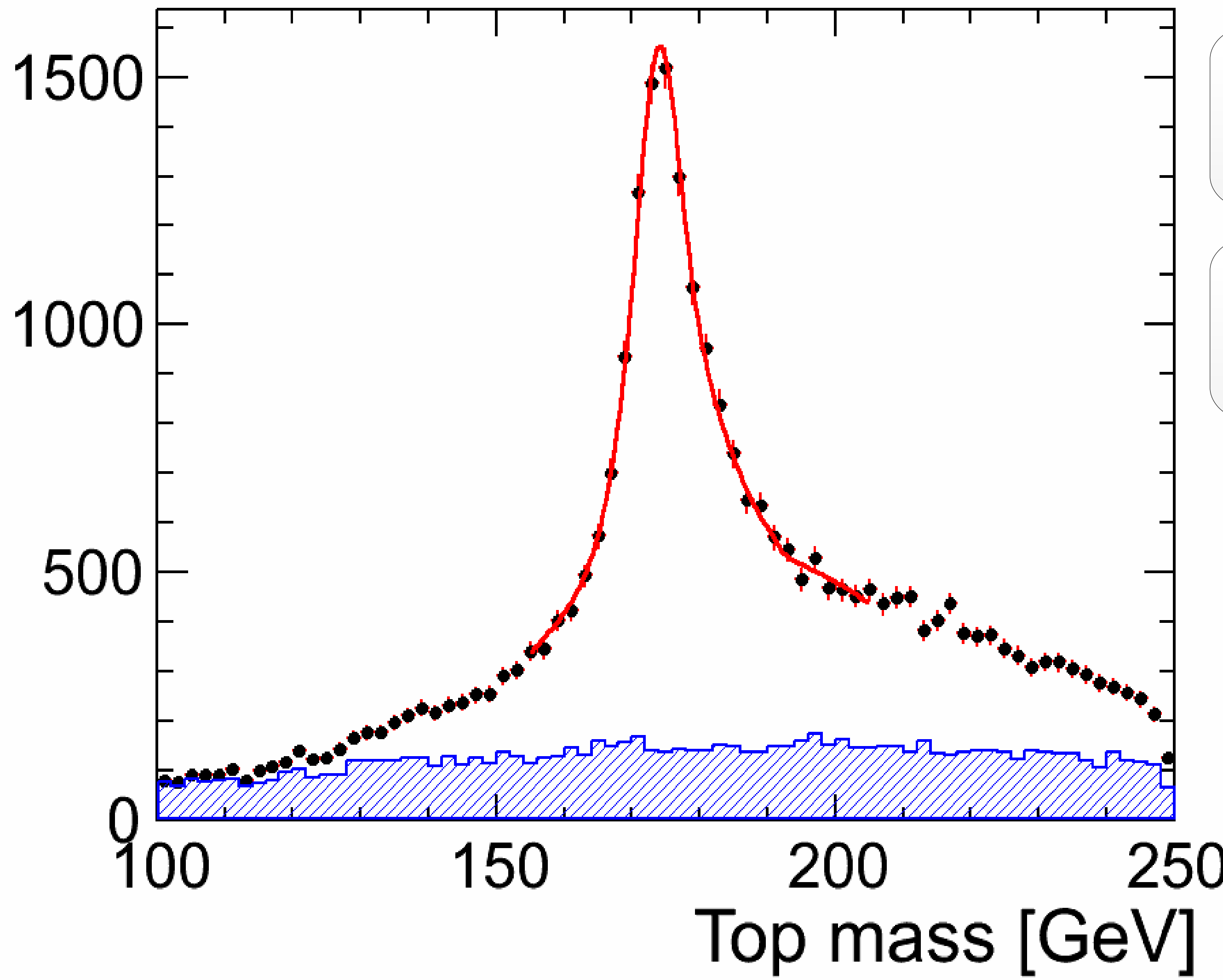
Breit-Wigner

+ asymmetric double Gaussian

Fit combinatorial background with

polynomial of second order

Top quark invariant mass (with KinFit)



$m_{top} = 173.96 \pm 0.11\,(stat.)\,GeV$

$\Gamma_{top} = 1.57 \pm 0.07\ \ GeV$

Signal

Physical background

Selection efficiency: **91.7 %**

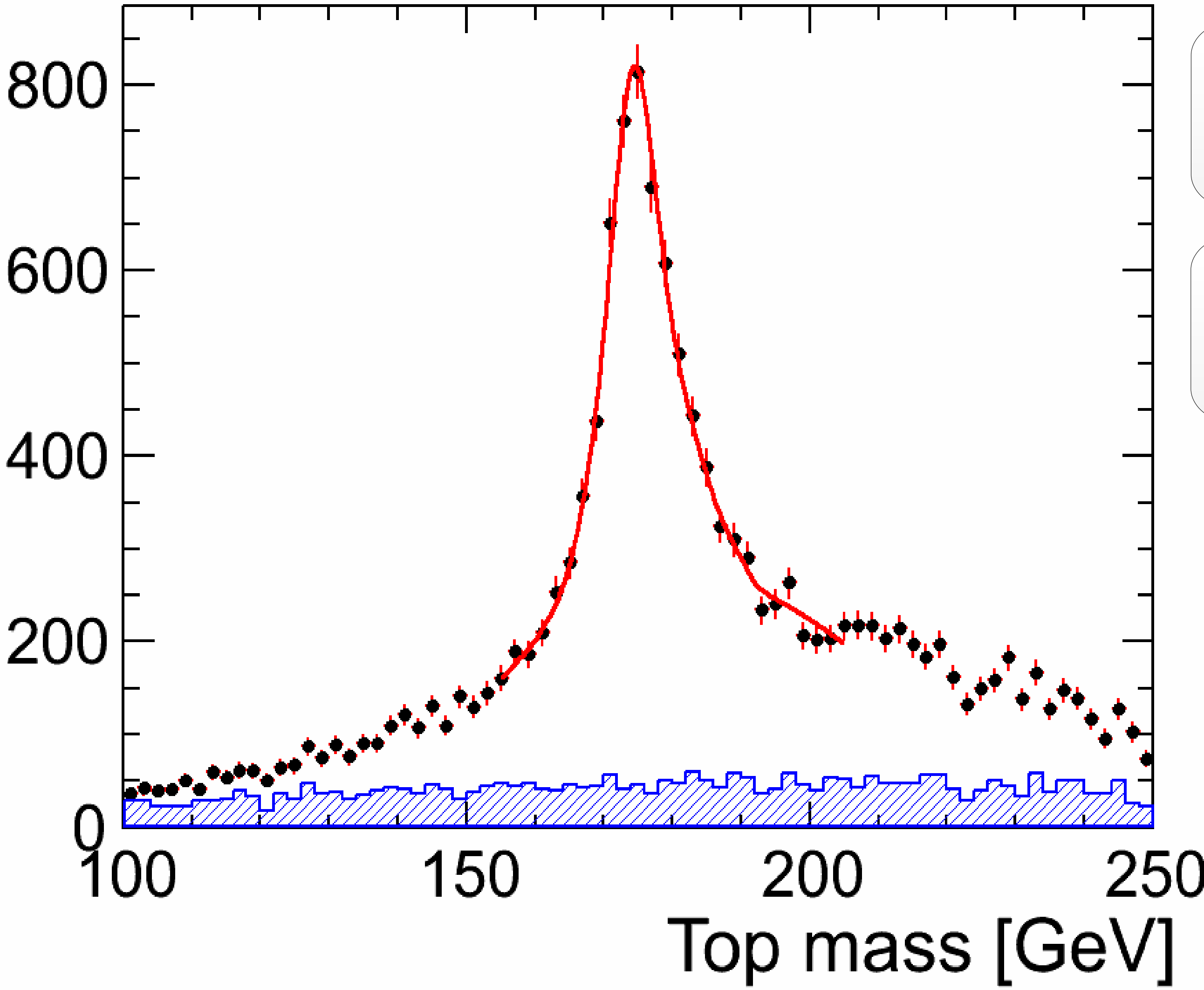
Background rejection eff.: **99.4 %**

- Physical background fitted with **polynomial function of second order**.
- Mass spectrum fitted using

  Parameters from **resolution function fit**

  free parameters: top mass, top width, overall normalization

Top quark invariant mass (with KinFit)



$m_{top} = 174.33 \pm 0.14\,(stat.)\,GeV$

$\Gamma_{top} = 1.56 \pm 0.08\ \ GeV$

Signal

Physical background

Selection efficiency: **87.5 %**

Background rejection eff.: **99.8 %**

- Physical background fitted with **polynomial function of second order**.
- Mass spectrum fitted using

  Parameters from **resolution function fit**

  free parameters: top mass, top width, overall normalization

Analysis of the top pair production at the ILC

- Developed a **method** to measure top quark mass and width
- Used fully **hadronic** and semi **leptonic** decays of top pairs
- Added appropriate **background**

Luminosity:	100 fb^{-1}
Beams:	*unpolarized*
Input values:	$m_{top}=174\ GeV$
	$\Gamma_{top}=1.5\ GeV$
Center-of-mass energy:	$500\ GeV$
Detector model:	*ILD_00*

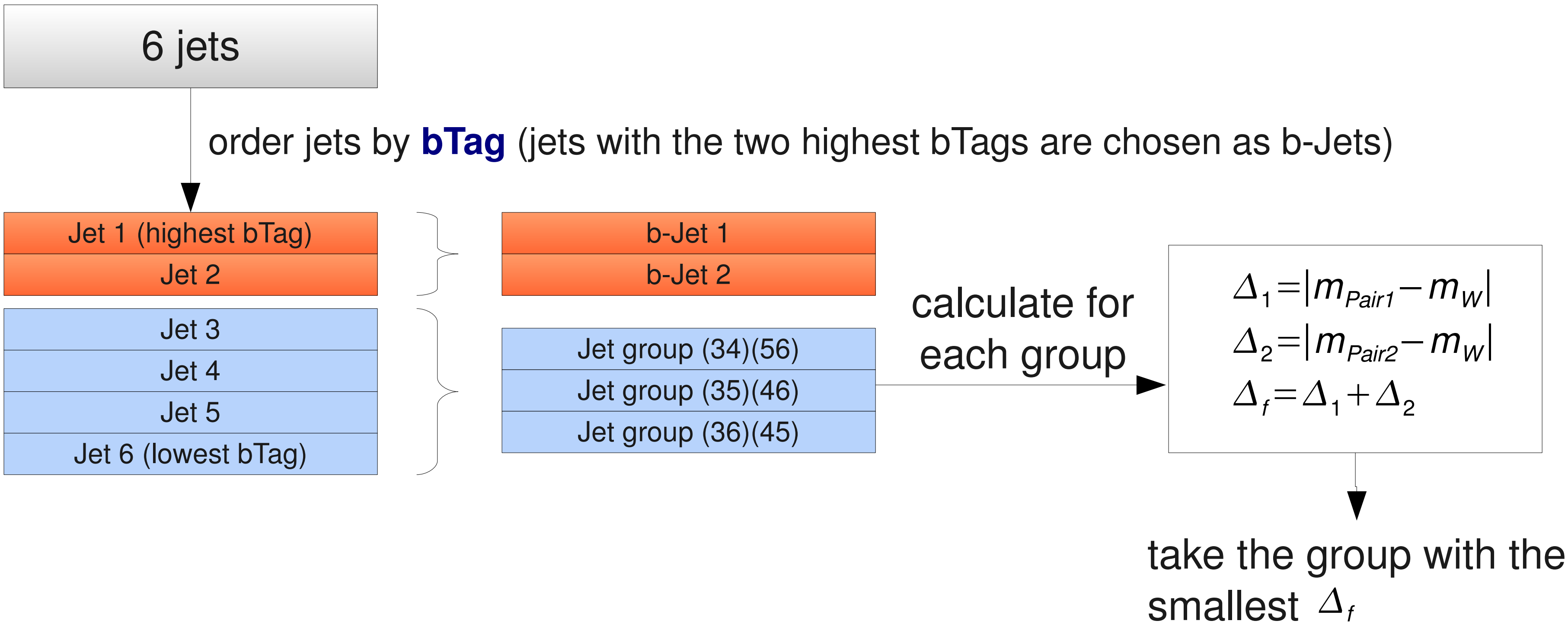
Result:

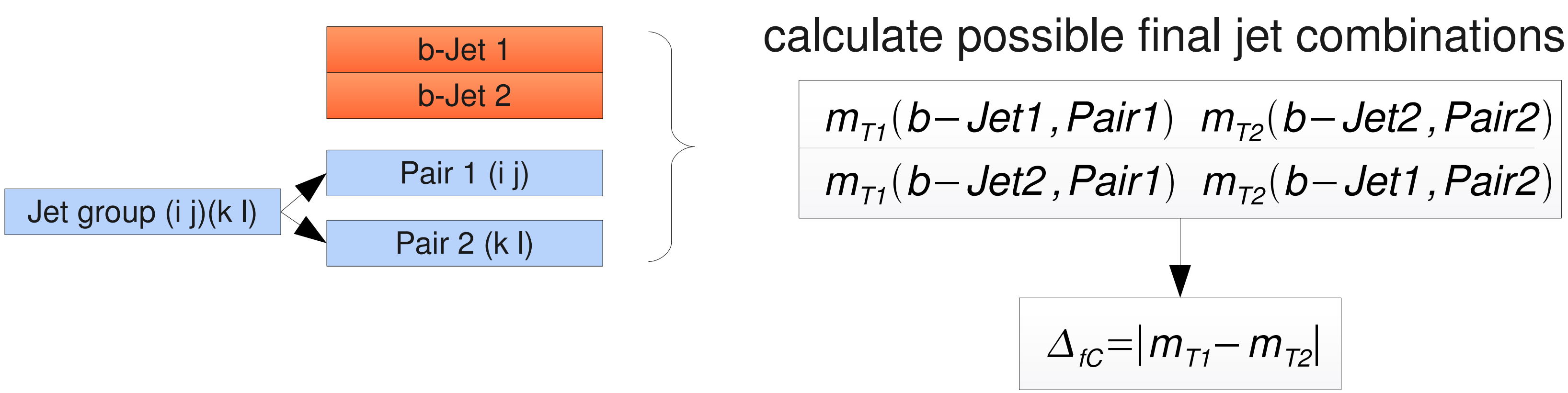
Fully hadronic: $m_{top}=173.96\pm0.11(stat.)GeV$ $\Gamma_{top}=1.57\pm0.07\ GeV$

Semi leptonic: $m_{top}=174.33\pm0.14(stat.)GeV$ $\Gamma_{top}=1.56\pm0.08\ GeV$

Combined: $m_{top}=174.09\pm0.08(stat.)GeV$ $\Gamma_{top}=1.57\pm0.05\ GeV$

Backup Slides





⇨ Take the Tri-Jet (b-Jet/Pair) combination with smallest Δ_{fC} as **final jet** state.

Finding the final jet combination – 4 jet

4 jets + lepton

order jets by **bTag** (jets with the two highest bTags are chosen as b-Jets)

Jet 1 (highest bTag)
Jet 2
→ b-Jet 1, b-Jet 2

Jet 3
Jet 4 (lowest bTag)
→ W (hadronic decay)

Lepton

Neutrino

calculate missing neutrino momentum from momentum conservation

$$\vec{p}_{Neutrino} = -\vec{p}_{b\text{-}Jet1} - \vec{p}_{b\text{-}Jet2} - \vec{p}_{W} - \vec{p}_{Lepton}$$

b-Jet 1
b-Jet 2

Jet 3
Jet 4
→ W (hadronic decay)

Lepton
Neutrino
→ W (leptonic decay)

$$m_{T1}(b-Jet1, W_{Hadronic}) \quad m_{T2}(b-Jet2, W_{Leptonic})$$

$$m_{T1}(b-Jet2, W_{Hadronic}) \quad m_{T2}(b-Jet1, W_{Leptonic})$$

$$\Delta_{fC} = |m_{T1} - m_{T2}|$$

⇨ Take the combination with smallest Δ_{fC} as **final jet** state.