Physics benchmarking study using top-quark pair production at E_{cm} = 500 GeV for the ILD

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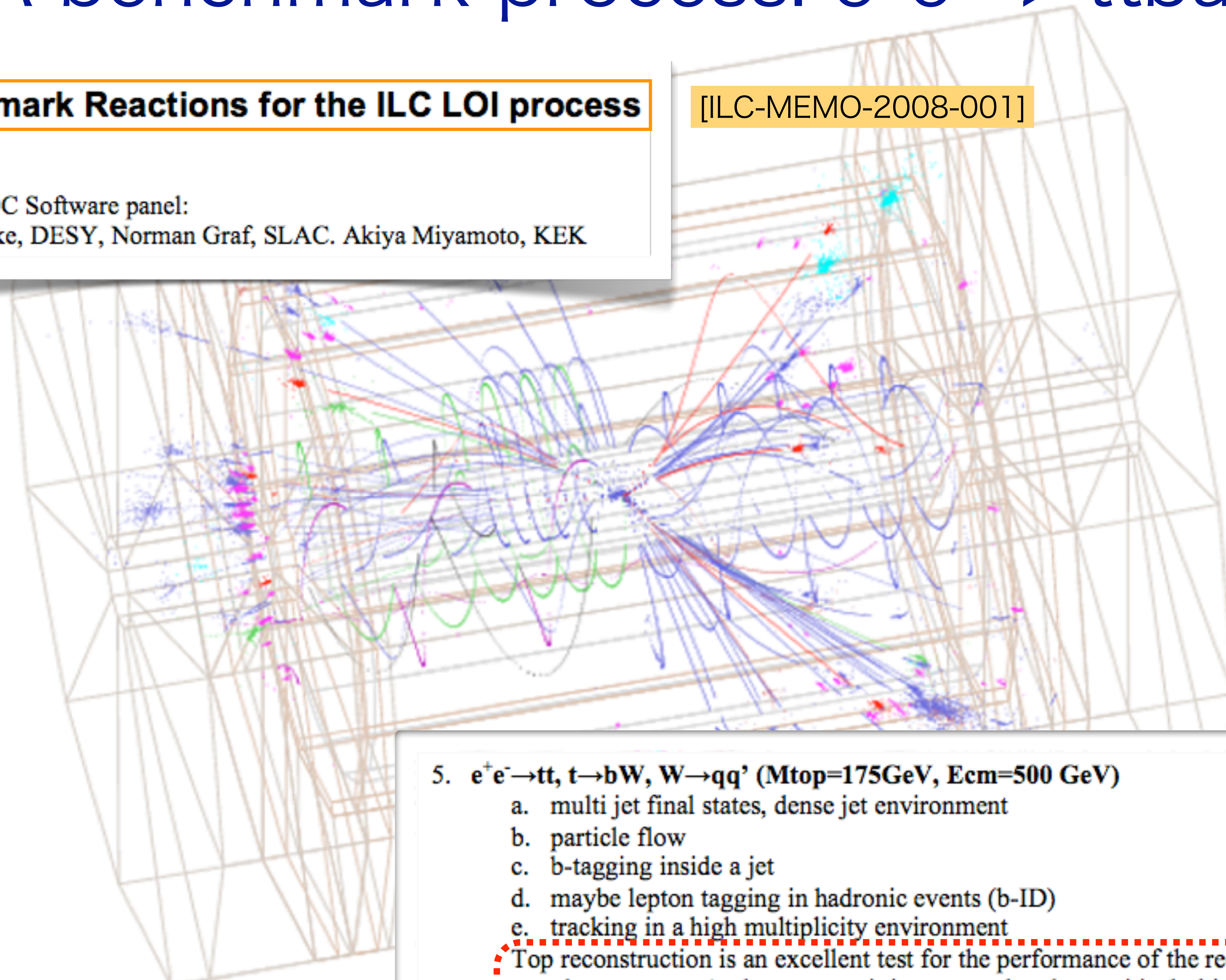
A benchmark process: e^+e^- -> ttbar



Benchmark Reactions for the ILC LOI process

[ILC-MEMO-2008-001]

The WWOC Software panel:
Ties Behnke, DESY, Norman Graf, SLAC. Akiya Miyamoto, KEK

5. **$e^+e^-\rightarrow tt$, $t\rightarrow bW$, $W\rightarrow qq'$ (Mtop=175GeV, Ecm=500 GeV)**
   a. multi jet final states, dense jet environment
   b. particle flow
   c. b-tagging inside a jet
   d. maybe lepton tagging in hadronic events (b-ID)
   e. tracking in a high multiplicity environment

   Top reconstruction is an excellent test for the performance of the reconstruction in very busy events. At the moment it is not yet clear how critical ultimate particle flow performance is for this reaction.

   Physical observables are σ, A_{fb}, and m_{top}

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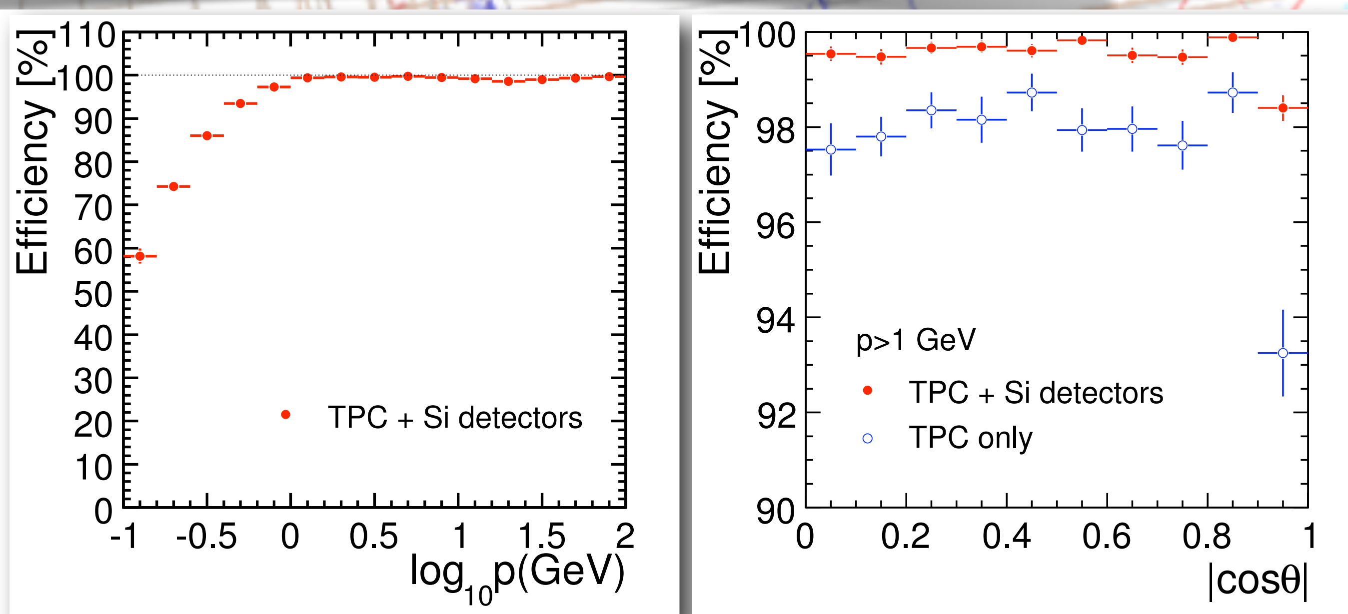

FIGURE 3.2-4. Tracking Efficiency as a function for $t\bar{t} \rightarrow$ 6 jets at 500GeV plotted against a) momentum and b) $\cos\theta$. Efficiencies are plotted with respect to MC tracks which leave at least 4 hits in the tracking detectors including decays and V^0s.

Vertex/Tracking session
Steve Aplin's talk
(ref. ILD-LOI p.29)

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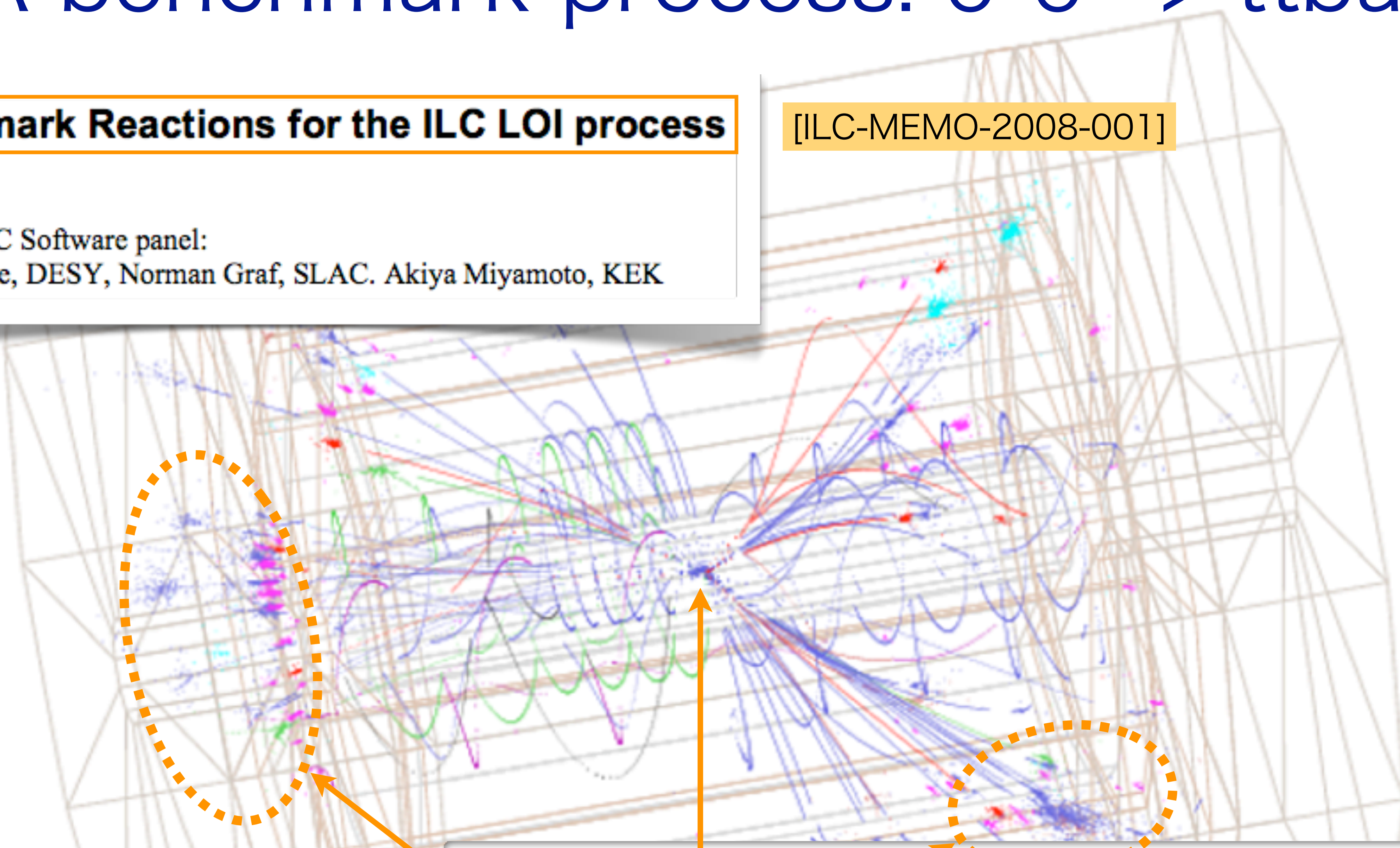

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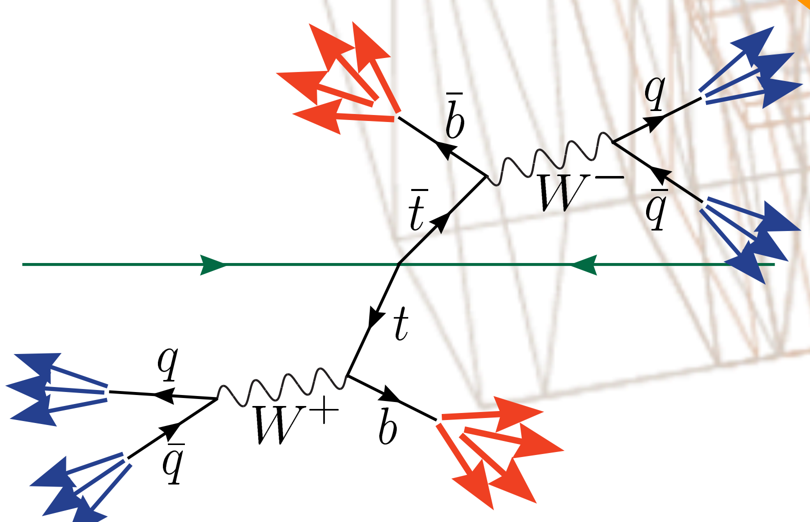
This talk



Analysis framework

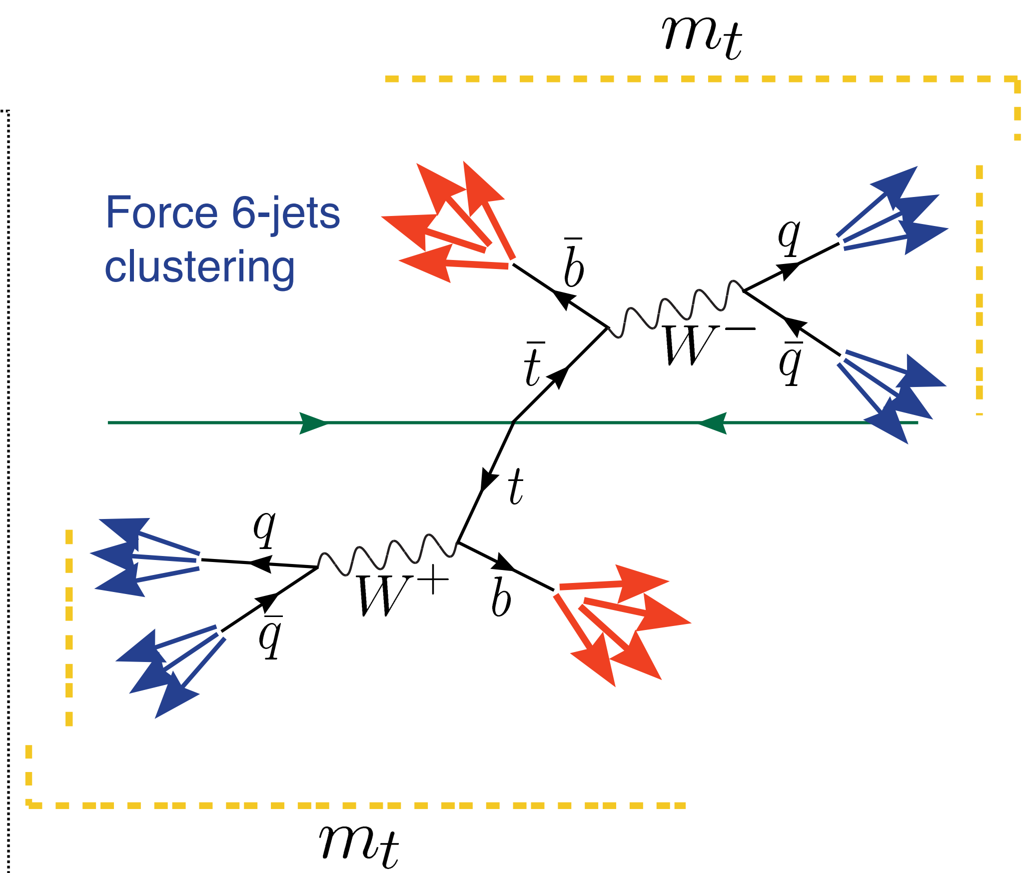
- All standard model MC samples (included signal processes): produced as common inputs (StdHep format) by SLAC team (WHIZARD + PYTHIA)
- Detector exact-hits: Geant4-based detector simulator (Mokka) => Smeared tracker hits and calorimeter hits (MarlinReco)
- Pattern recognition of track segments in the TPC and silicon detector separately / link the found track segments together / track-fit using a Kalman filter (MarlinReco)
- Reconstructed individual particles (Particle flow objects): Sophisticated particle flow algorithm (PandoraPFA)
- 6-jets clustering for signal & all BG events (Durham force 6-jets clustering)
- Heavy flavour tagging: Search for secondary vertices inside jets and determine mass, momentum and decay length of the vertex. In addition, the impact parameter joint probability and the two highest impact parameter significances are used as an input into NN with jets having 0, 1 and more than 1 secondary vertices / Each reconstructed jet is assigned with the NN outputs, referred to as b- and c-tags (LCFIVertex)

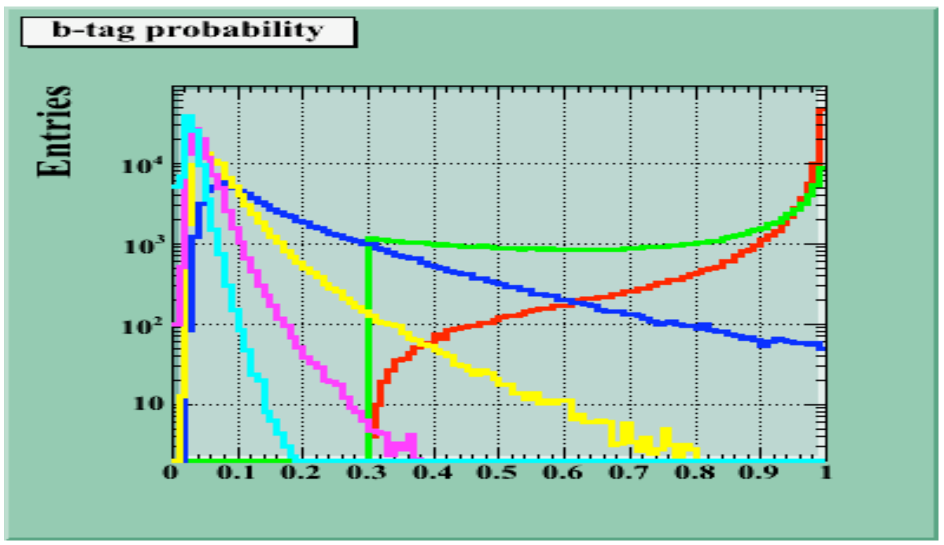
ttbar -> 6-jets reconstruction

- 2 different top-antitop combinatorics schemes and BG rejection (multi-variate or cut-bases) methods: 2 independent analyses (MPI-Munich and KEK)

★6-jets combinatorics scheme (1)

1. Using flavour tagging information, the jets with the 2 highest b-tag values are taken. => They are regarded as b-jets, resulting directly from the top quark decays.
2. The 4 remaining jets are considered as decay products of the 2 W bosons. => There are 3 possible ways to combine 4-jets into 2 di-jets. For each possible combination the quantity $\Delta m_W = |m_{ij} - m_W| + |m_{kl} - m_W|$ is calculated. (with m_{ij} and m_{kl} di-jet masses for a given jet pairing) => The combination yielding the smallest value of Δm_W is chosen to form the 2 W bosons.
3. The 2 top candidates having the same mass is expected. Choose the 2 “di-jet / b-jet pairs” which yields minimal tri-jet mass difference.





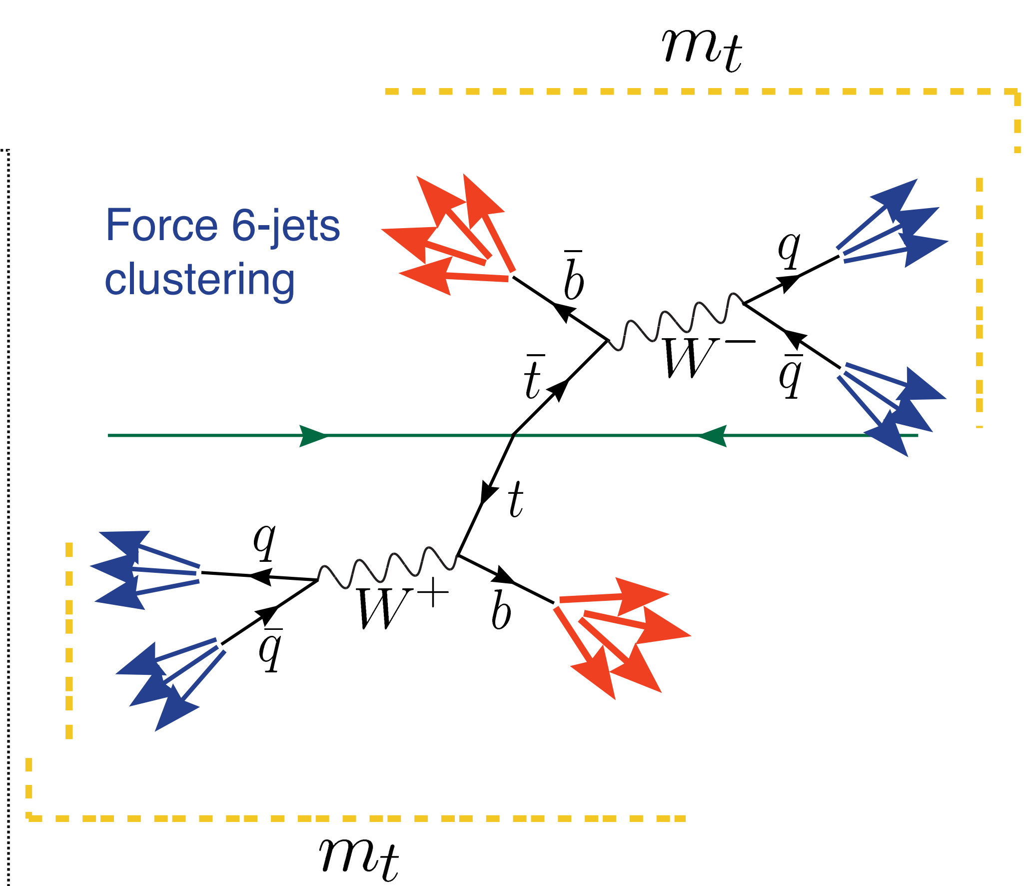
ttbar -> 6-jets reconstruction

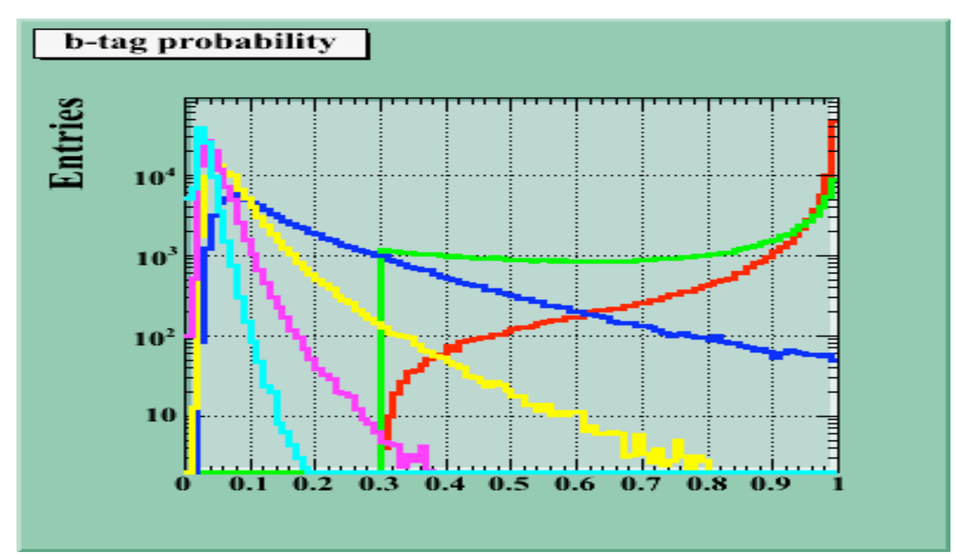
- 2 different top-antitop combinatorics schemes and BG rejection (multi-variate or cut-bases) methods: 2 independent analyses (MPI-Munich and KEK)

★ 6-jets combinatorics scheme (2)

1. Choose all the 15-possible pairs out of 6-jets => W_1 candidate
2. Choose all the 6-possible paris out of remaining 4-jets => W_2 candidate
3. When the remaining 2-jets are b-jets, there are 2 possibilities to attach a b-jet to the W_1 and the W_2 candidates => 2 b-W (t_1 and t_2) candidates
4. Store all solutions w/ $\chi^2 = (m_{W1} - m_W)^2/\sigma^2_{2j} + (m_{W2} - m_W)^2/\sigma^2_{2j} + (m_{t1} - m_t)^2/\sigma^2_{3j} + (m_{t2} - m_t)^2/\sigma^2_{3j}$

I) Sort solutions according to χ^2 => choose the best solution

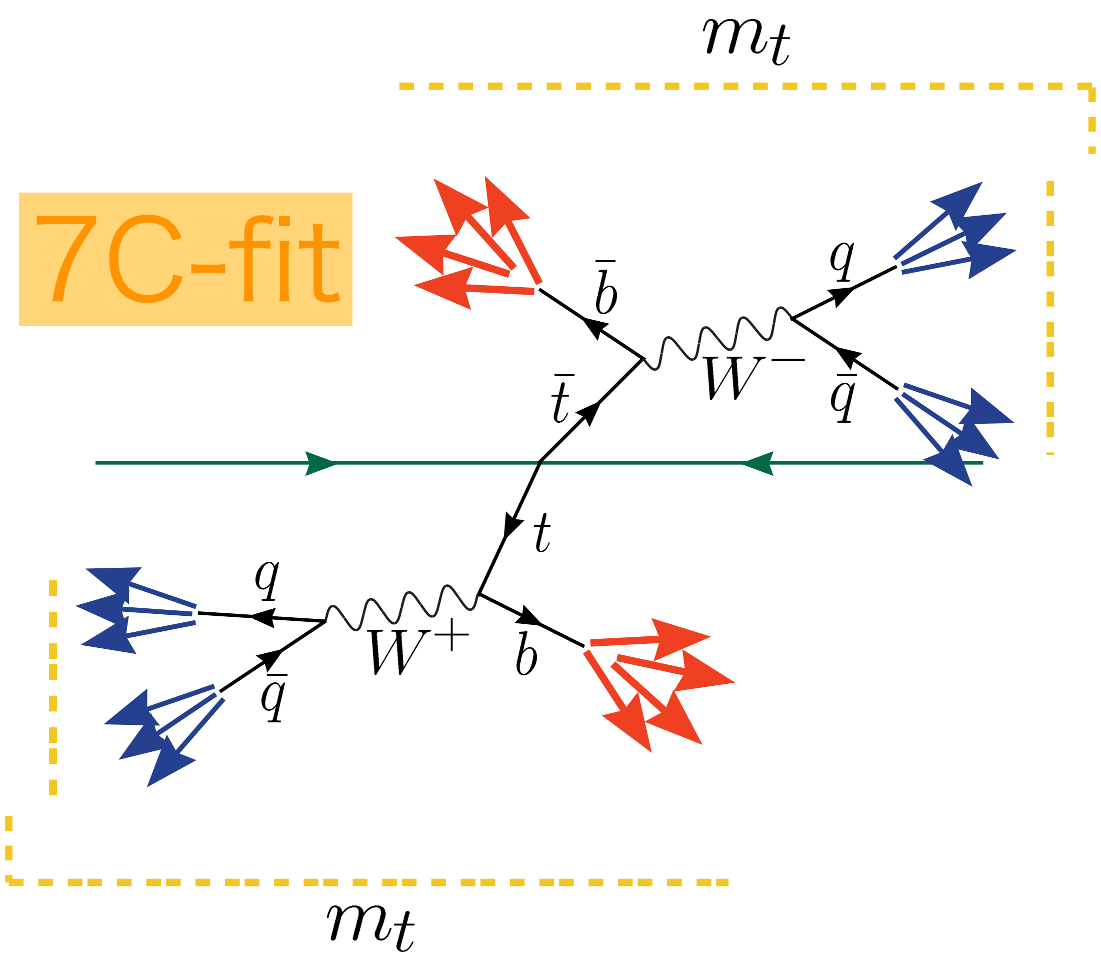


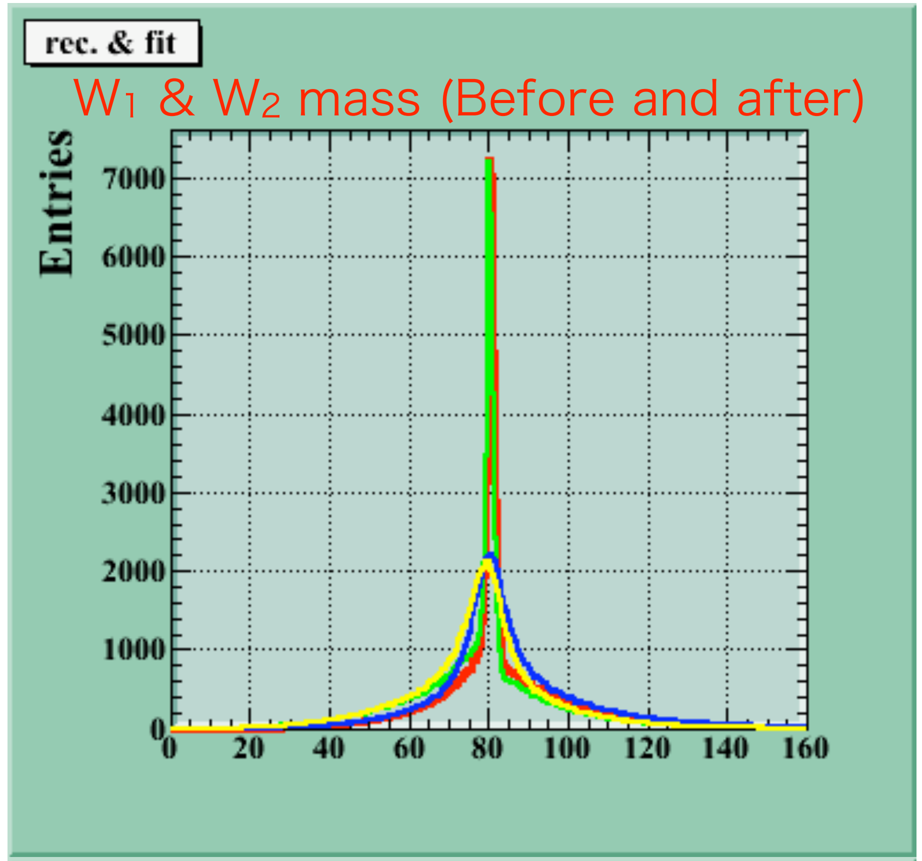


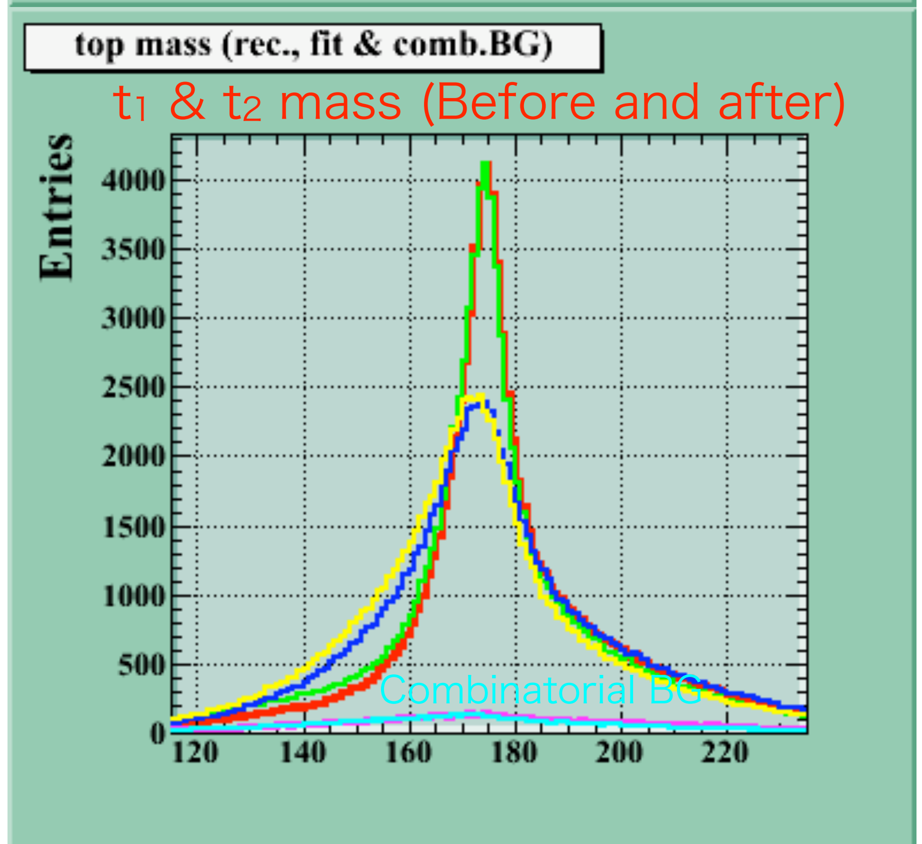
- Consistency check => ILD-LOI result

Kinematic fitting for ttbar -> 6-jets

7C-fit







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

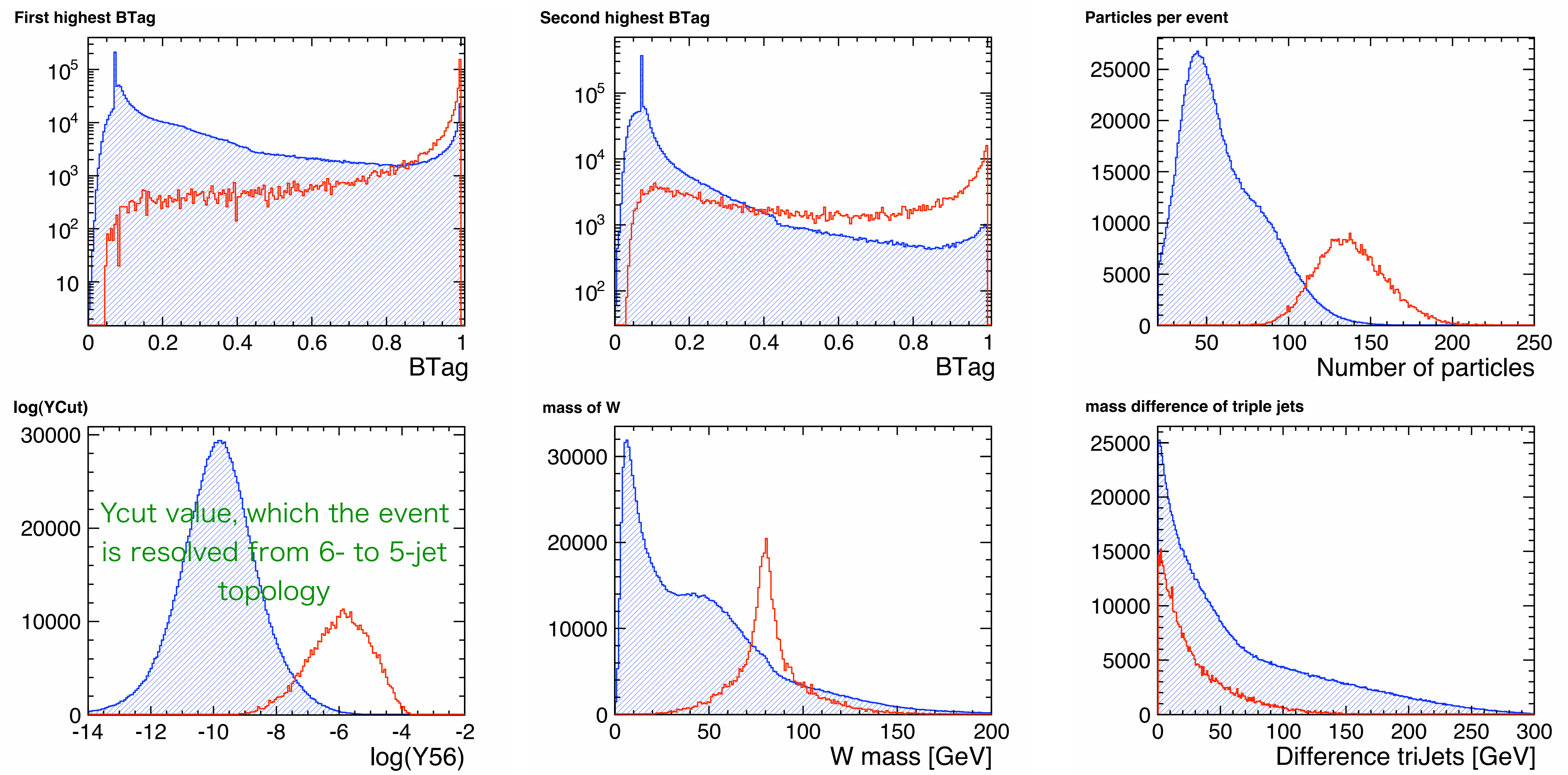
$$\sum_{i=1}^{6} E_i = \sqrt{s}$$ *energy conservation*

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

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

BG rejection - discriminating variables

- Discriminating variables are combined into 1-discriminant (using binned likelihood technique) to reject BGs efficiently

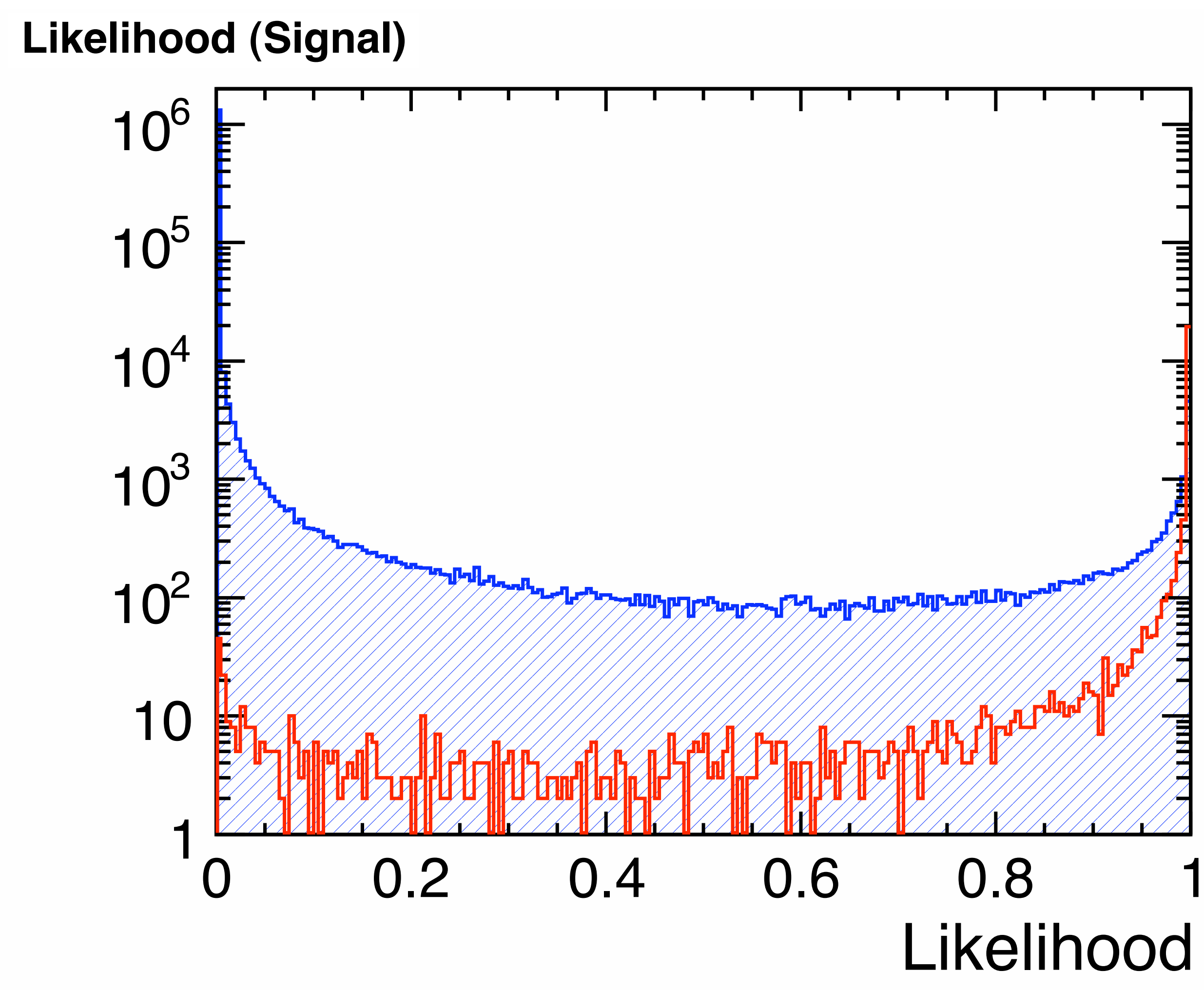


red: signal / blue: BG

Signal distributions are multiplied by a factor 20

BG rejection - likelihood / BG classes

- BG rejection: signal likelihood > 0.9 => S/B = 21210/10530
- Kinematic fitting χ^2 cut: improve S/B (also combinatorial BGs)

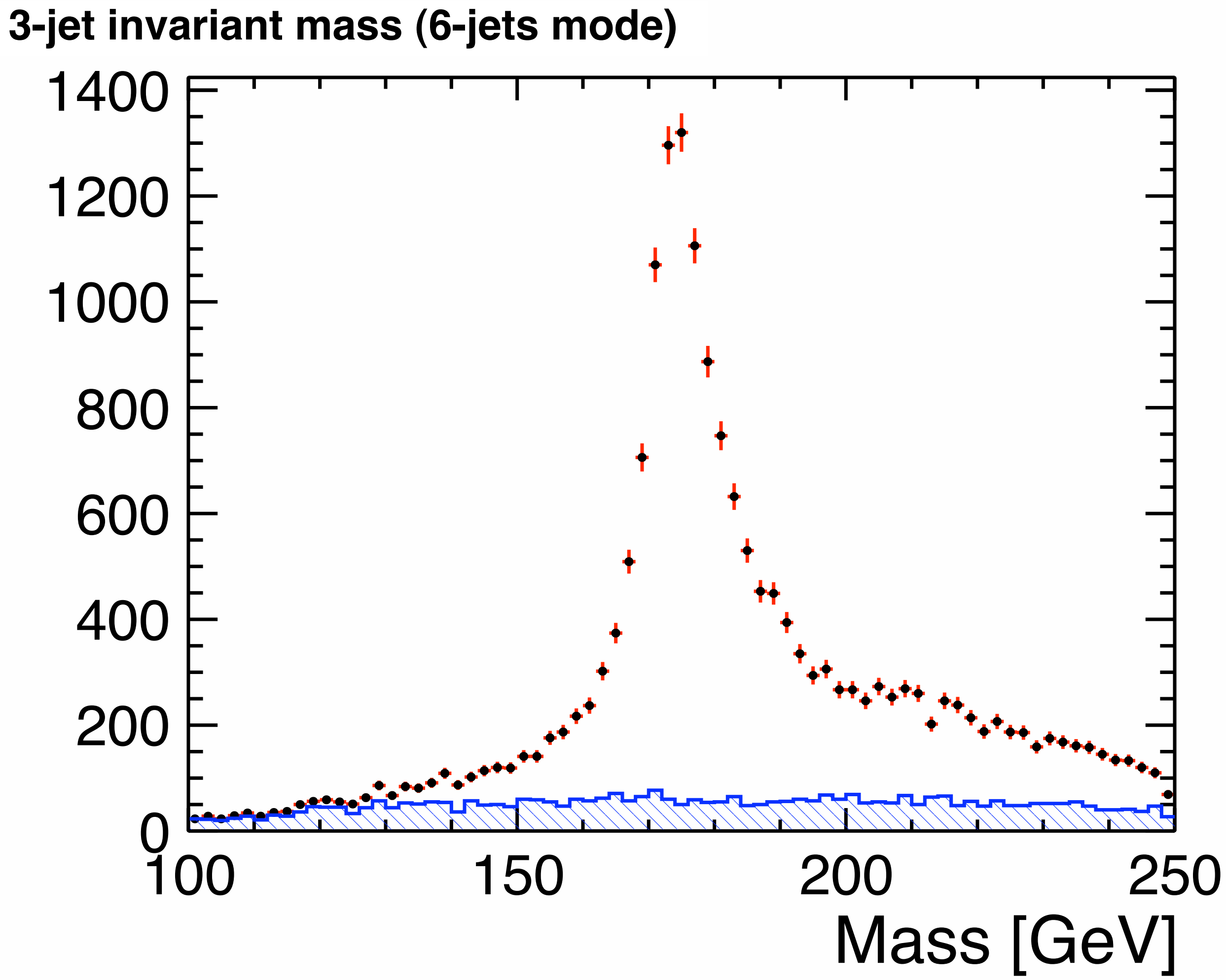


red: signal / blue: BG

BG event classes	Distinction	Contribution to BGs
ttbar semi-leptonic decay	Isolated lepton veto (2806/15946 ~ 17.6%) => kinematic fitting χ^2 cut	Negligible
6-fermion (incl. 2b)	Small cross section	Small contribution
6-fermion (the others)	Double b-tagging	Negligible
4-fermion (4q mainly from W^+W^-)	Large cross section	Main BG source
4-fermion (2q + 2l)	Double b-tagging $Ycut_{56}$	Negligible
2-fermion (bb)	Huge cross section	Main BG source
2-fermion (cc)	Huge cross section Double b-tagging	Small contribution
2-fermion (qq)	Double b-tagging	Negligible

3-jets mass dist. w/ signal + BGs

- Overall selection efficiency: 72%
- Final S/B ~ 4.1 (= 15744/3811 @100fb^{-1})
- σ (e^+e^- -> ttbar) = 0.4 % @500fb^{-1}



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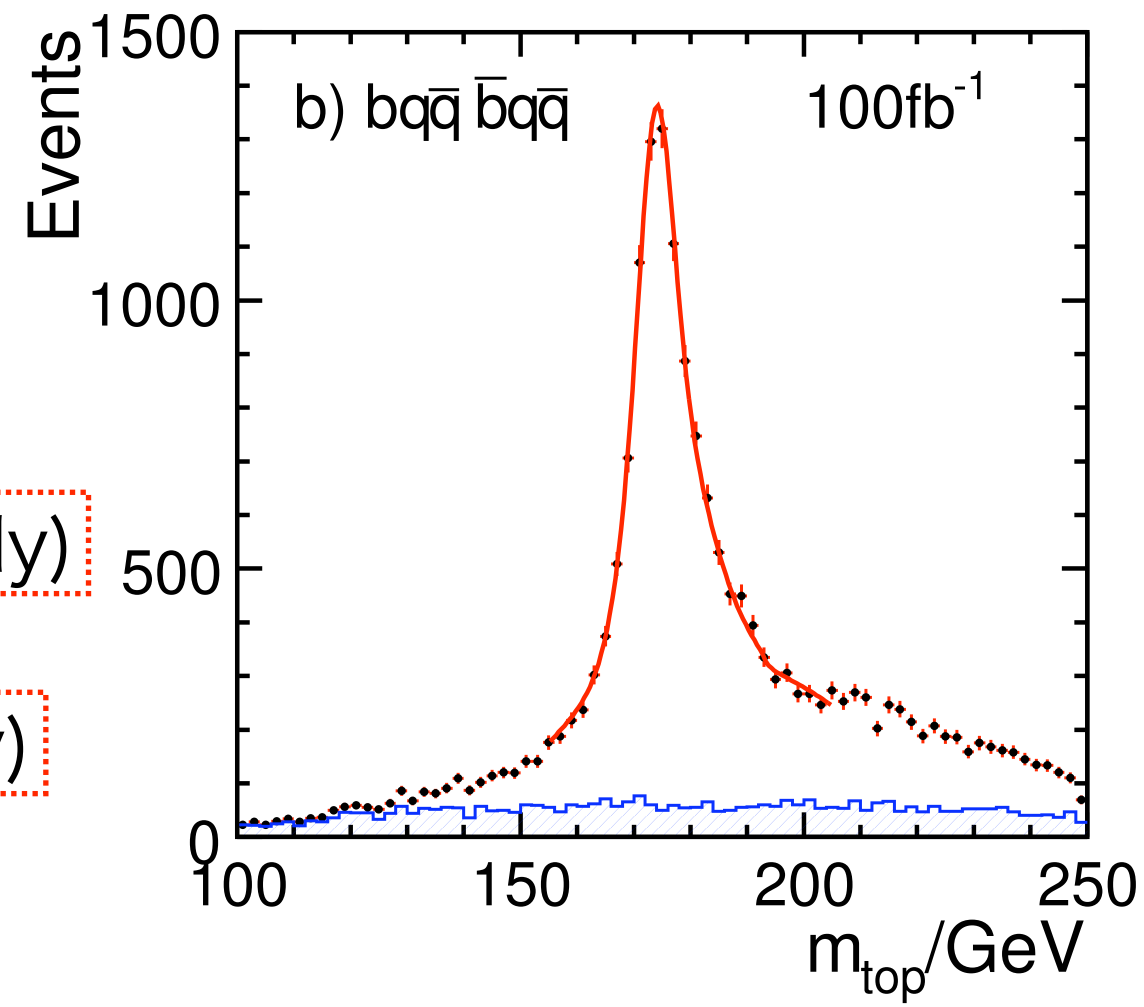
Define line-shape, then fit M_{3j}

- Line-shape function: convoluted Breit-Wigner w/ detector resolution function + 2nd order polynomial
  - Assume detector resolution function as asymmetric double Gaussian (double Gaussian w/ a mean shift and a weight = 4 parameters)
  - Decide resolution functions using hight statistics samples w/ fixed top mass (174 GeV) and top width (1.34 GeV) which were obtained from input SLAC StdHep gen-info.
- M_{3j} fit w/ the line-shape
  - Free 3 parameters (m_t, Γ_t, N_{event})
  - Un-polarized beams

$m_t = 174.0 \pm 0.09$ (stat. only)

$\Gamma_t = 1.44 \pm 0.06$ (stat. only)



Summary

- Precise methods to reconstruct top-quark pair production events using fully-hadronic decay mode are worked out with the ILD detector model and sophisticated software chains.
- For an integrated luminosity of 500 fb^{-1}, $\sigma(e^+e^- \to t\bar{t})$ can be determined with a statistical uncertainty of 0.4 % using the fully-hadronic decays only.
- The invariant mass spectra are fitted with the convolution of a Breit-Wigner function and an asymmetric double Gaussian, the latter representing the detector resolution. The combinatoric background and the background from other process is described by a 2nd order polynomial.
- The fully-hadronic analysis branch results in statistical uncertainties of 90 MeV and 60 MeV for m_t and Γ_t respectively. Scaling the combined results to an integrated luminosity of 500 fb^{-1} leads to uncertainties of 40 MeV on m_t and 27 MeV on Γ_t.

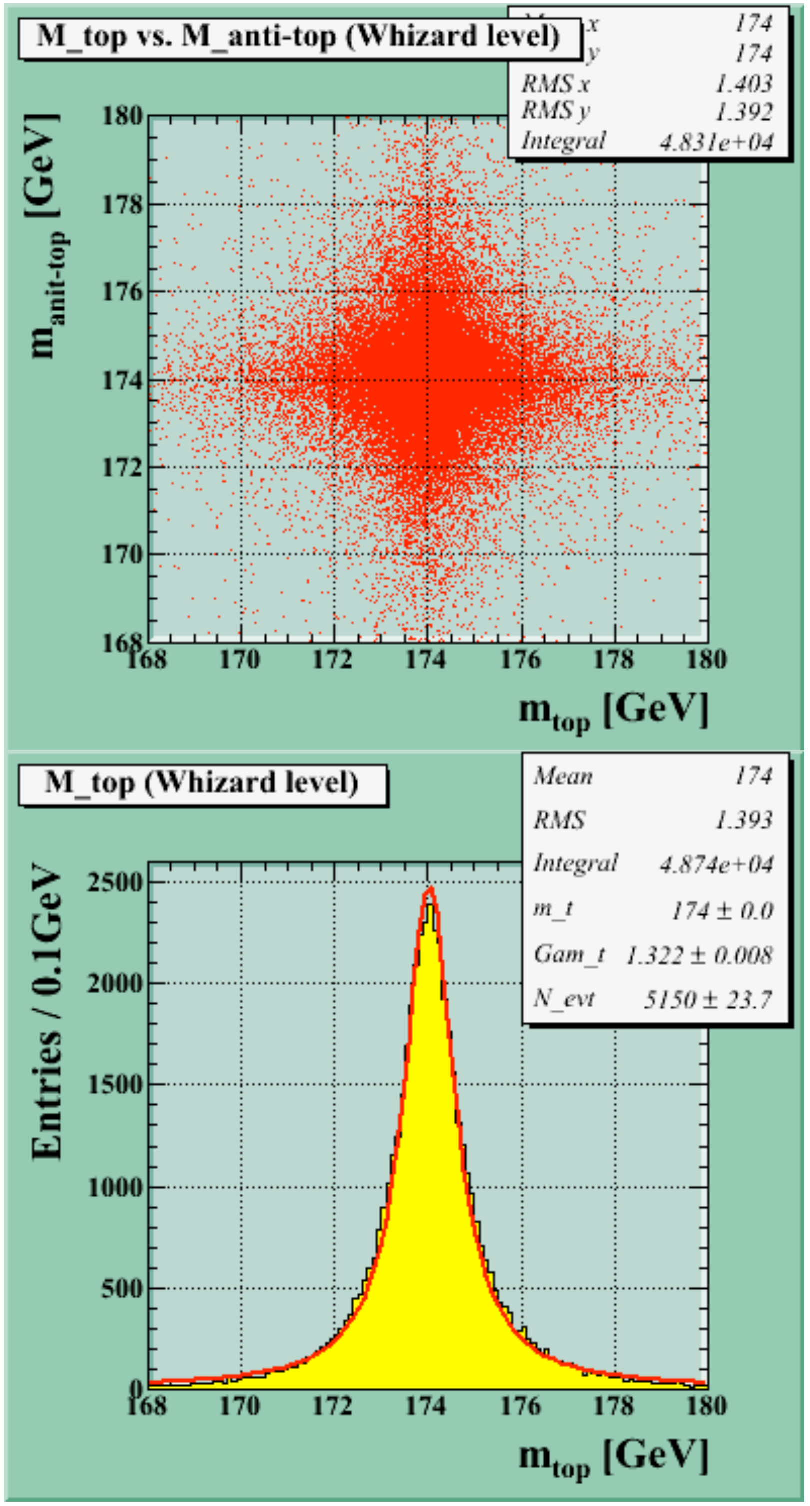
Backup slides

Signal sample

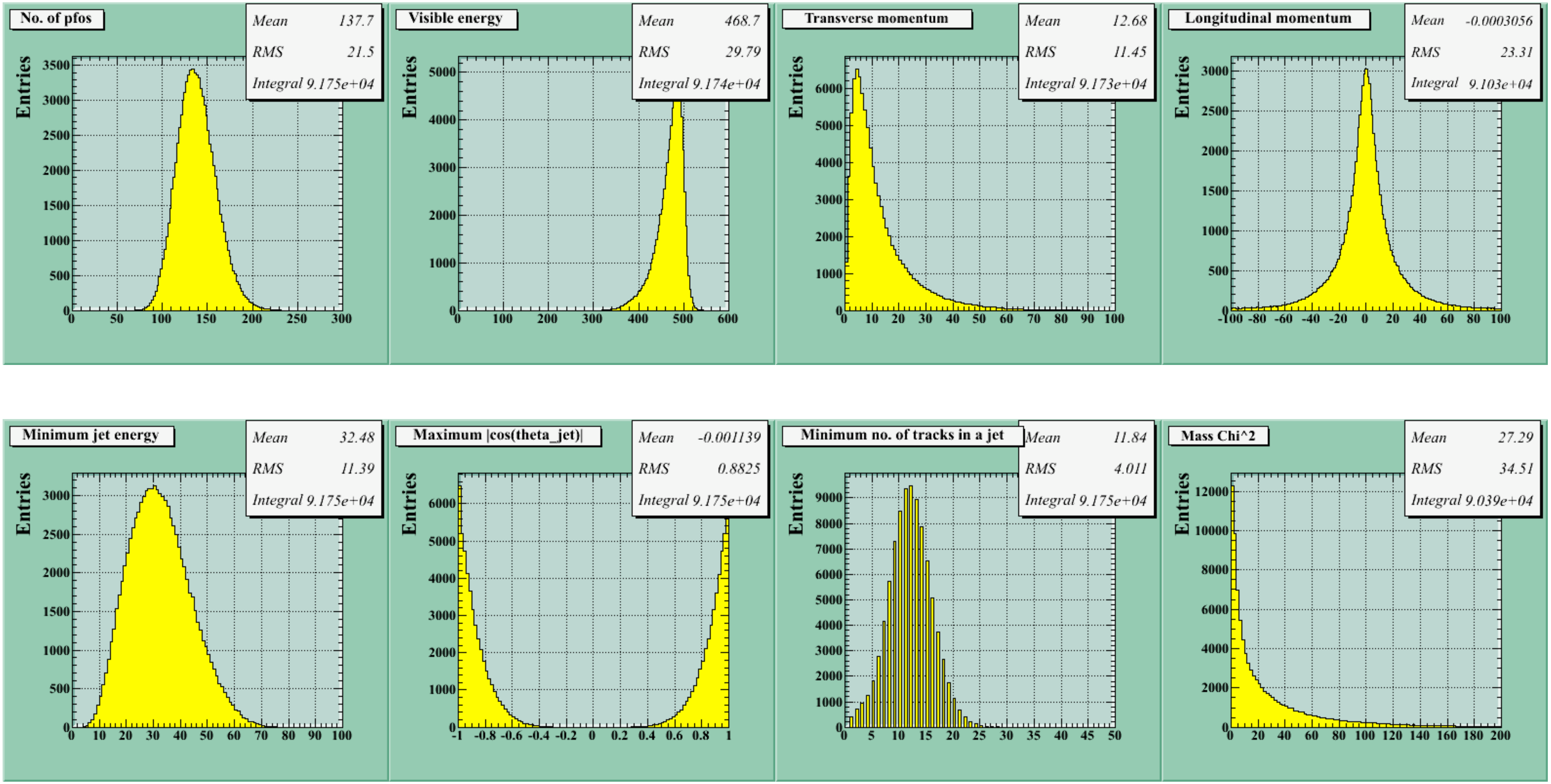
- Common input: SLAC SM StdHep
  - All analyses used in the context of the detector optimization and LoI process need an inclusive sample of the SM Background => SLAC team
- ttbar -> 6-jets samples are included in bbqqqq of 6-fermion SM samples
- bbqqqq samaples also contain no ttbar mediated events: (e^+e^- -> bb with γ ->WW) and (e^+e^- -> WW with Z -> bb) etc.

IDRUPLH	Process	Pol(e^-)	Pol(e^+)	Xsec (fb)
w17765	bbuddu	-1.0	1.0	166.3
w17766	bbuddu	1.0	-1.0	66.0
w17769	bbudsc	-1.0	1.0	164.7
w17770	bbudsc	1.0	-1.0	65.7
w17785	bbcsdu	-1.0	1.0	164.7
w17786	bbcsdu	1.0	-1.0	66.0
w17789	bbcssc	-1.0	1.0	165.1
w17790	bbcssc	1.0	-1.0	66.0

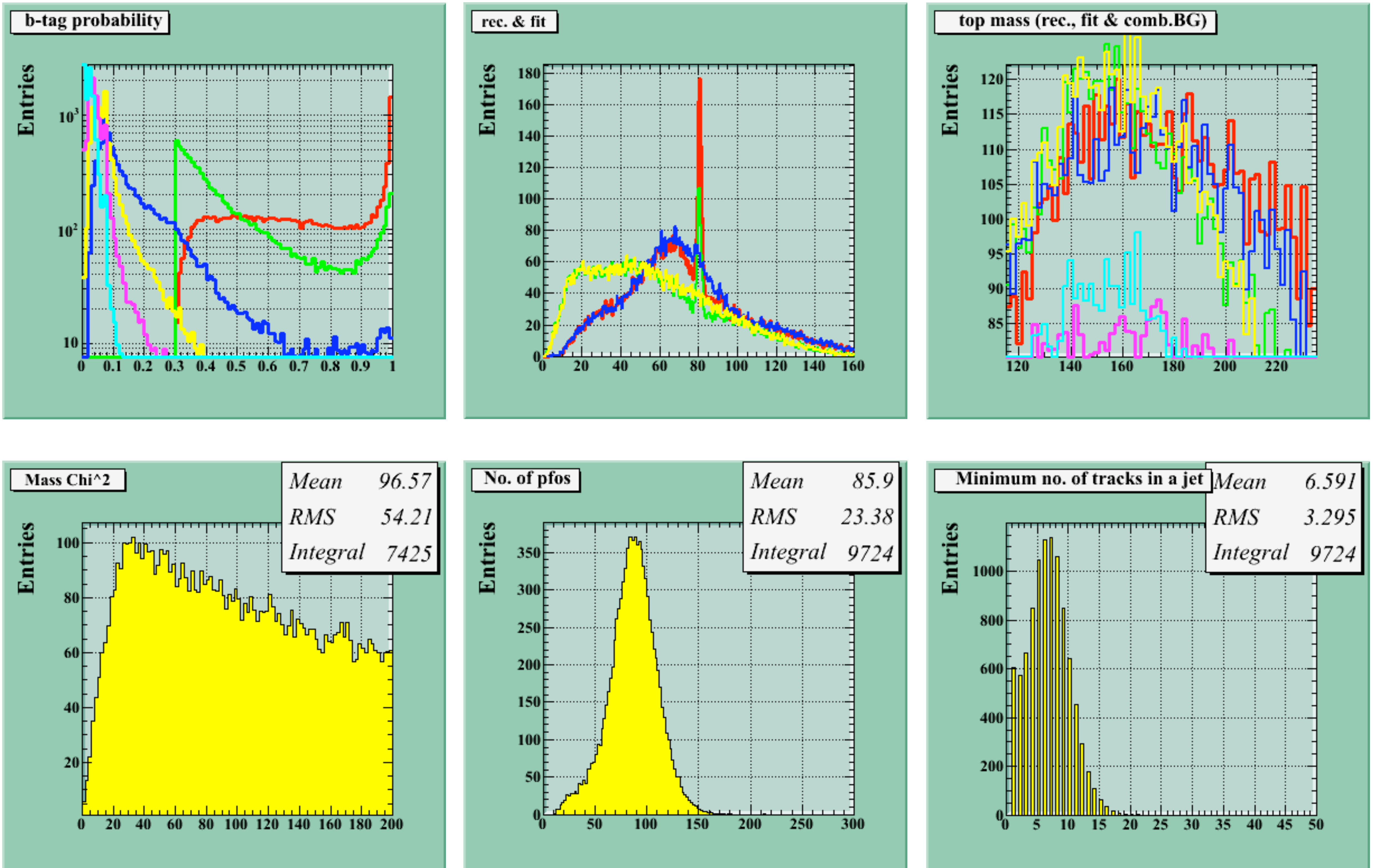
Extract generator info:
on-shell tops from
bbqqqq(w17765 StdHep)



bbqqqq event profile



4F-6F (w/o ffffbb) distribution



M_{3j} fitting line-shape

convolution of Breit-Wigner and resolution fucnctions

```
Double_t convfun(Double_t *xp, Double_t *parm)
{
   Double_t x       = *xp;
   Double_t mt      = parm[0];
   Double_t gamt    = parm[1];
   Double_t m3j     = parm[2];
   Double_t sigmt1  = parm[3];
   Double_t sigmt2  = parm[4];
   Double_t weight1 = parm[5];
   Double_t delm1   = parm[6];

   return TMath::BreitWigner(x, mt, gamt)
          *(weight1 * TMath::Gaus(m3j, x + delm1, sigmt1, kTRUE)
            + (1 - weight1) * TMath::Gaus(m3j, x, sigmt2, kTRUE));
}
```

Detector resolution:

Asymmetric double Gaussian

```
Double_t lineshape(Double_t *m3jp, Double_t *x)
{
   Double_t m3j     = *m3jp;
   Double_t mt      = x[0];
   Double_t gamt    = x[1];
   Double_t norm    = x[2];
   Double_t sigmt1  = x[3];
   Double_t sigmt2  = x[4];
   Double_t weight1 = x[5];
   Double_t delm1   = x[6];

   TF1 func("convfun", convfun, mmin, mmax, 7);
   fun.SetParameters(mt, gamt, m3j, sigmt1, sigmt2, weight1, delm1);
   Double_t val = fun.Integral(mmin, mmax);
   return norm*val;
}
```