Top mass determination from the J/Ψ+lepton invariant mass in top decay at the LHC and ILC

Alexander Mitov
University of Hawaii

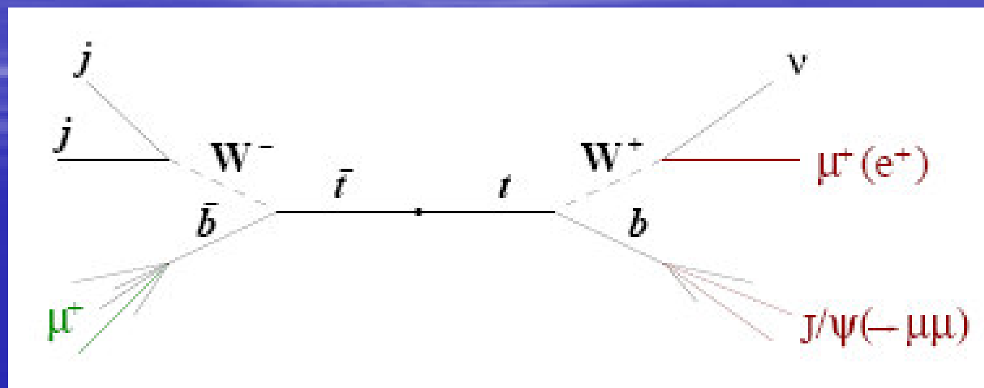
Outline

- Top mass measurement at the LHC
- Method and numbers
- Theoretical predictions
- The ILC case and LHC/ILC synergy
- Comparison to other extraction methods
- Prospects and conclusions

Top mass measurement at the LHC

Jet measurements are hard at the LHC; check out the lepton signal

A. Kharchilava, hep-ph/9912320:

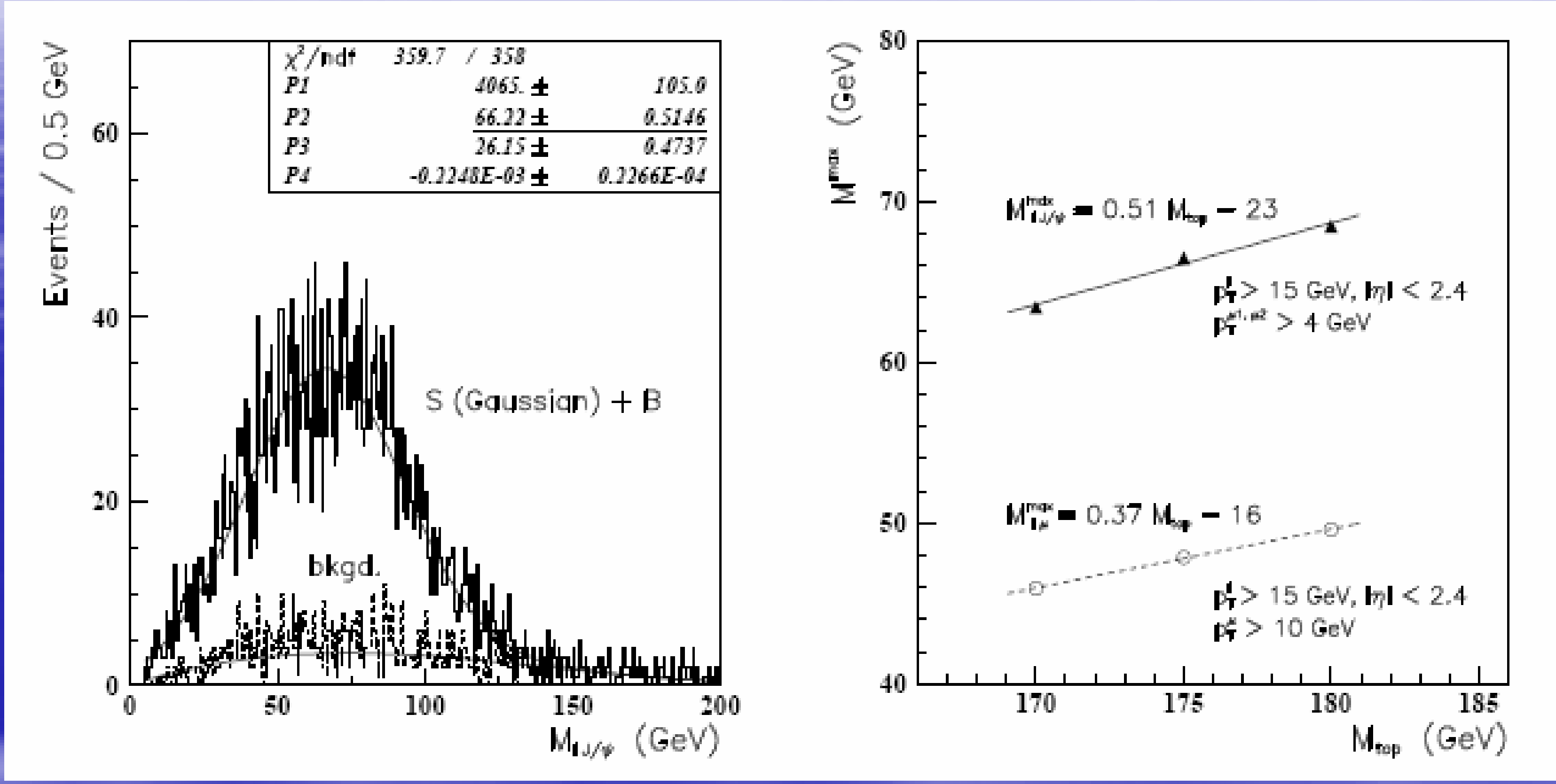


Method: study the invariant mass distribution of $M_{J/\psi-\ell}$ in top decay

- Experimentally very clean signal
- Low branching ratio ~ 10^{-5} , but
- Compensated by large top production rates
- Expected 1000 events/year at LHC
- Accuracy ≤ 1 GeV for 4 years of running.

Top mass determination method

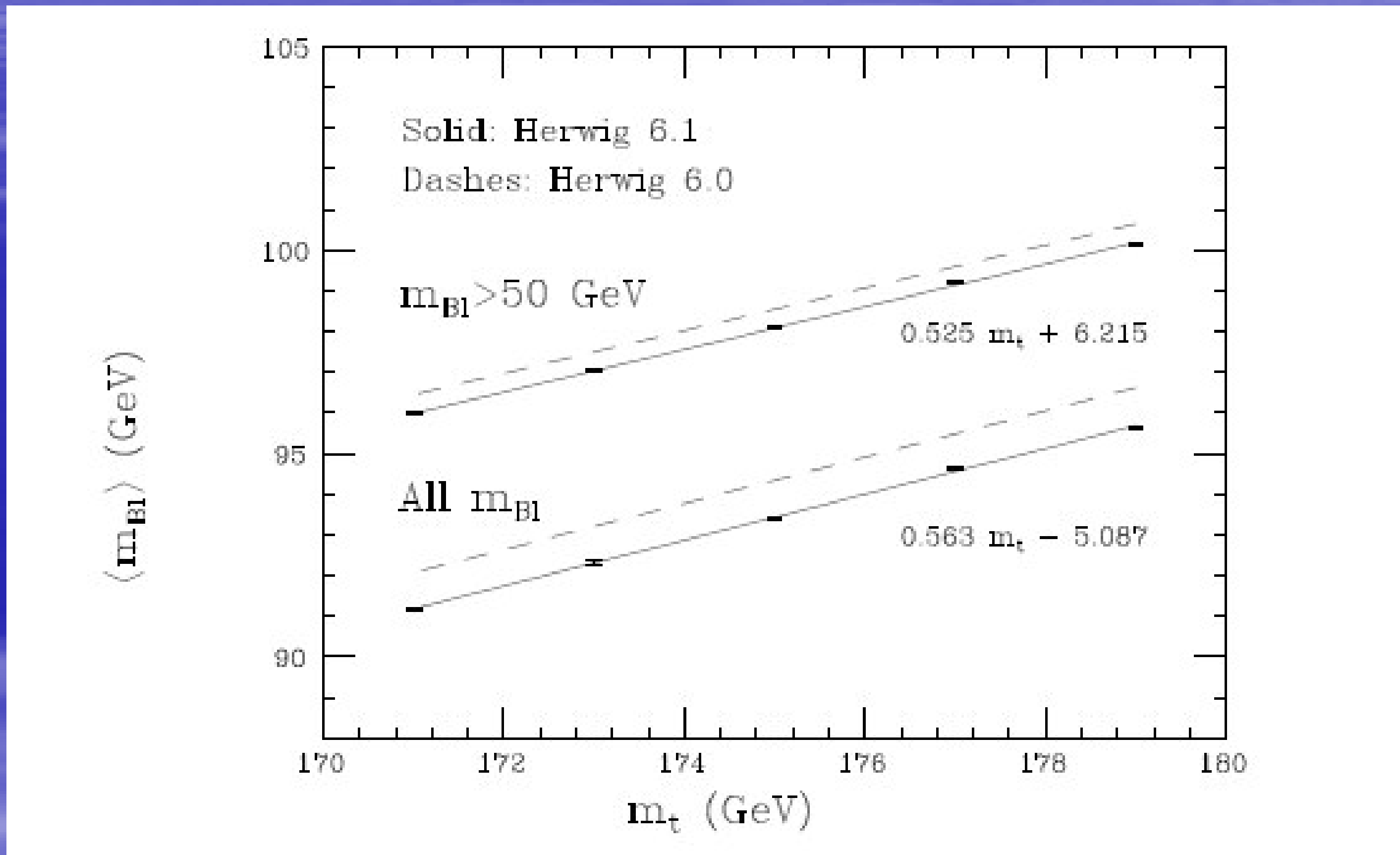
A. Kharchilava, hep-ph/9912320



- The top mass is correlated with the position of the peak of $M_{J/\Psi-\ell}$
- Above studies obtained from PYTHIA 5.7 or HERWIG 5.9

- Further studies with MC's:

  Corcella, Mangano and Seymour: hep-ph/0004179
- Based on HERWIG 6.0 and 6.1
- Only the B production was studied there; not the B-> J/Ψ transition



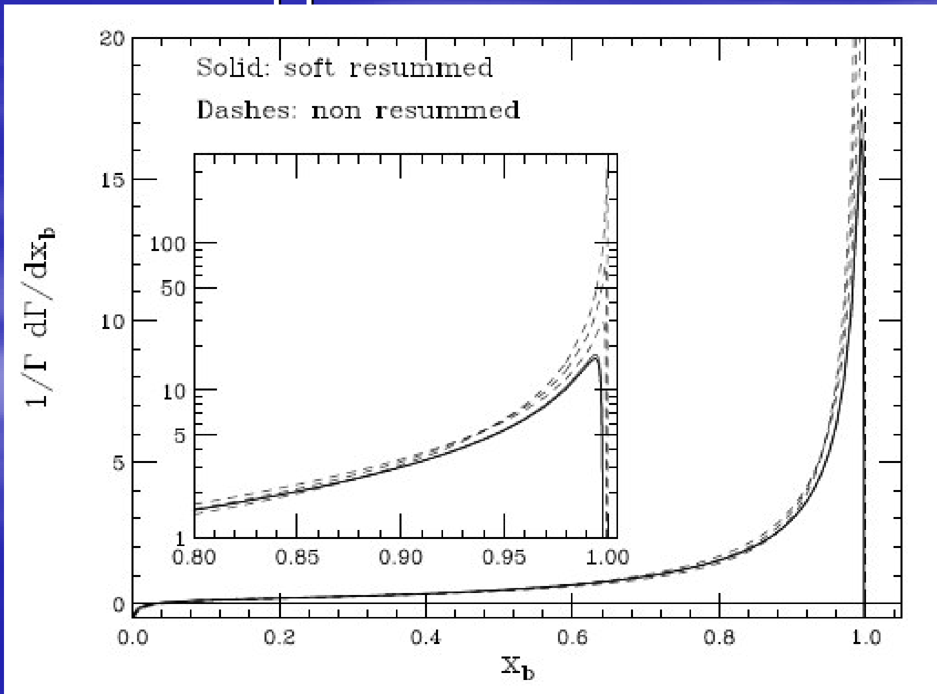
- Large difference (1.0~1.5 GeV) in M_top between the two versions.
- A significant fraction (~0.5 GeV) of that difference comes from the hadronization.

Clearly, because of the intrinsic uncertainties in these studies, they must be supported by a dedicated calculation.

What are the prospects for such a calculation and what are its expected uncertainties?

- An NLO + NLL calculation is easy to do (in progress). It is available for a related observable: b-energy spectrum in top decay.
- One can perform resummation of large logs with much better control and accuracy compared to any other approach.
- An NNLO level result is also feasible. It can be supplemented with a NNLL resummation (already possible).

Uncertainties at perturbative level are well under control!



How about the non-perturbative effects?

From the b -> B transition:

- This is presently extracted from LEP data. Extractions of both the whole non-perturbative function and of some of its moments is possible!

DELPHI Collaboration

	$\langle x \rangle$	$\langle x^2 \rangle$	$\langle x^3 \rangle$	$\langle x^4 \rangle$
e^+e^- data σ_N^B	0.7153±0.0052	0.5401±0.0064	0.4236±0.0065	0.3406±0.0064

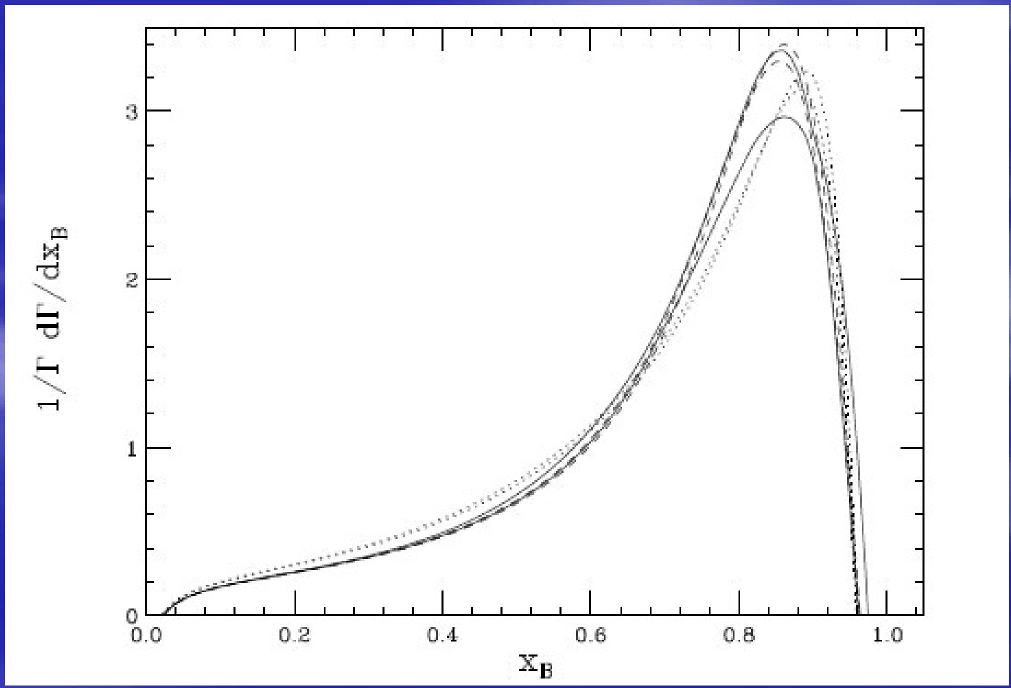
Cacciari, Corcella and A.M. **hep-ph/0209204**

t-decay Γ_N^B [A]	0.7231	0.5555	0.4440	0.3637
t-decay Γ_N^B [B]	0.7228	0.5553	0.4435	0.3633

Uncertainties are at:

± 0.5%~1% for n=1

± 7% for n=10



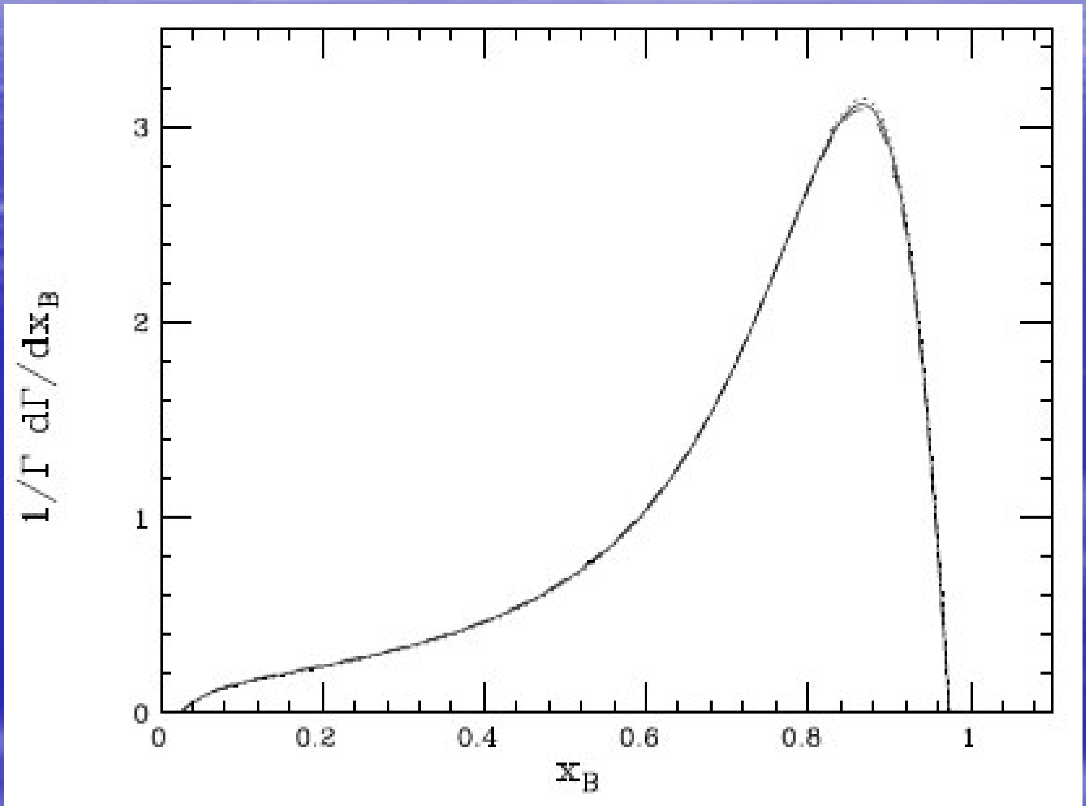
How about the non-perturbative effects?

From the B -> J/Ψ transition:

- Can be modeled from data on B-decays from B-factories.
- Has been applied for the study of the transverse momentum distribution of B-mesons at the Tevatron (Cacciari et al. hep-ph/0312132).
- Their prediction was compared with the result from MC@NLO.
- The conclusion was that improvement in the modeling of the B->J/Ψ transition in the MC is needed.

A related observable: B-energy in top decay.

- This observable is also sensitive to the value of the top quark.



- The normalized energy distribution for three values of M_top:
- M_top = 170,175,180 GeV
- The correlation <E_B> ≈ const. M_top is similar to the J/Ψ+lepton case.
- The experimental prospects on that variable have not been detailed.

The ILC case

One can also perform the measurement of $M_{J/\Psi-\ell}$ at ILC!

- Ignoring top production and decay correlations (excellent approx.):

$$\frac{1}{\sigma}\frac{d\sigma}{dM_{J/\Psi\ell}} = \frac{1}{\Gamma}\frac{d\Gamma}{dM_{J/\Psi\ell}}$$

- The accuracy for the same measurement is expected to be comparable at the one for LHC.
- However, an extraction permitting much better accuracy was claimed by: M. Nekrasov, hep-ph/0412219.

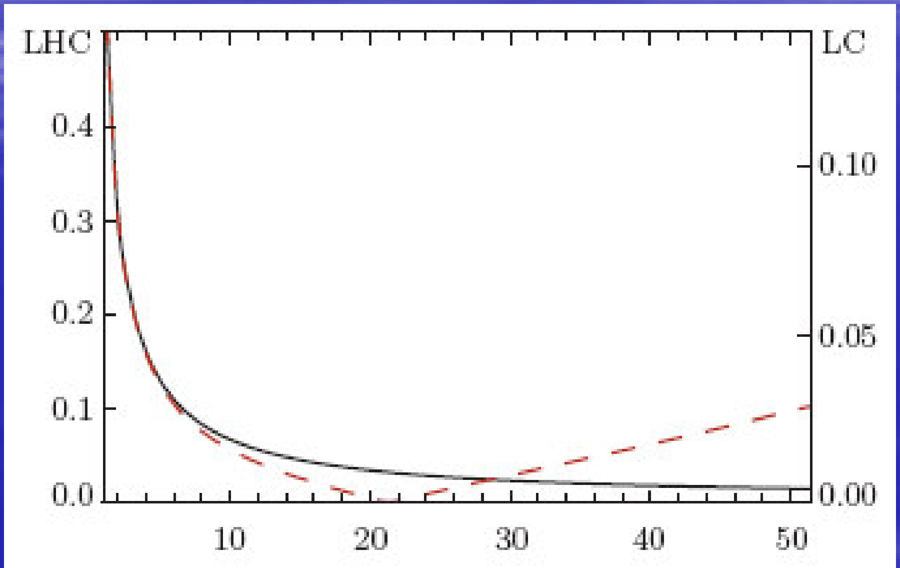
- His method relies on extraction of M_top from higher moments ($n \approx 15$) of the invariant mass distribution.

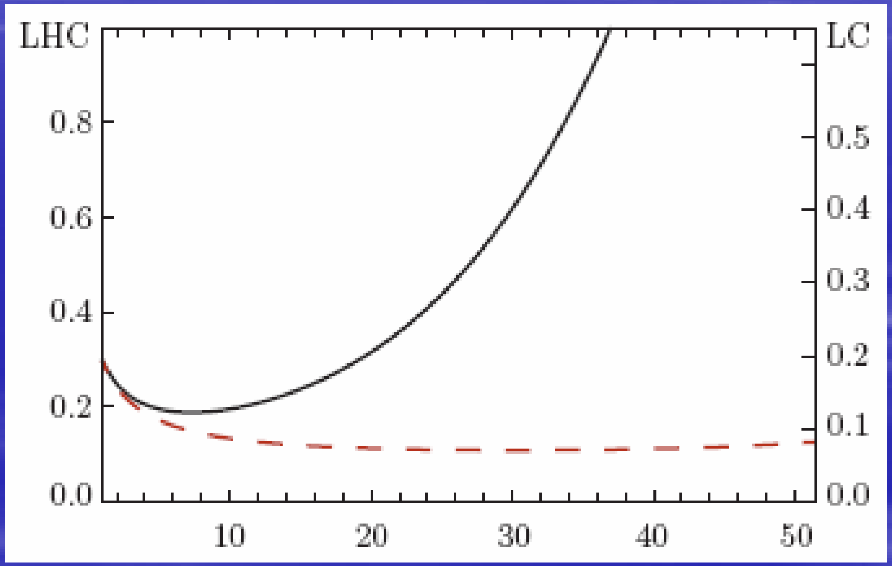
- There (at the level of b-quark production) the following uncertainties were found: $\delta M\_top \leq 500$ MeV (LHC) and $\delta M\_top \leq 200$ MeV (LC).

Note that in the above error analysis, the results from the previous LHC analysis are used (i.e. the same uncertainty from b-fragmentation).

- Systematic errors (in GeV) for LHC and LC as a function of the moments at the level of b-quark production.

Nekrasov, hep-ph/0412219.





- However: recall the increasing uncertainty of the non-perturbative transition with increasing moments that was shown previously.

- Note that improved extraction of the non-perturbative fragmentation function with NNLO + NNLL accuracy may decrease the errors at higher moments.

The LHC/ILC synergy

- Concurrent running of both machines will permit simultaneous analysis of the two measurements.
- That may lead to improving of the experimental techniques used in these experiments or of the method itself.
- However, if ILC gets its GigaZ regime, then the improvement can be very different:
- From GigaZ 2-3 times improvement in the b-measurements is expected.
- If that is translated into similar precision in the extraction of the b->B non-perturbative fragmentation function, then the method described here can produce results with $\delta M\_top \leq 300$ MeV without the use of higher moments!
- Clearly, a concurrent running will permit the LHC data to be reanalyzed while LHC is still running.

Comparison to other methods for extraction of the top mass

Case A) LHC alone:

- Then this is the the best method for determination of M_top with error of δM_top ≤1 GeV . Note that the systematics (for the LHC study) are (+600-800) MeV. However ~ 2/3 of that is from the b-fragmentation!

Case B) LHC + ILC + GigaZ:

- This method can produce (theory) δM_top ≤300 MeV or even less.
- Exactly the same if not better than the results from a direct reconstruction of the top-decay products: Chekanov, hep-ph/0206264.

$$e^+e^- \to t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}q_1\bar{q}_2q_3\bar{q}_4 \to 6 \text{ jets},$$
$$e^+e^- \to t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}l\nu q_1\bar{q}_2 \to \text{lepton} + 4 \text{ jets}.$$

- With results of δM_top ≤(340-425) MeV or δM_top ≤250 MeV resp.

- Top threshold scan is expected to give δM_top ≤100 MeV .

Conclusions

- I have reviewed a method for obtaining M_top, that is based on a study of the invariant mass of the decay products (all leptons) of the top quark.
- This method has the best precision for LHC with $\delta M\_top \leq 1$ GeV .
- The largest (~2/3) systematic error comes from b-fragmentation.
- A concurrent running of LHC/ILC can lead to non-trivial “interference”.
- A GigaZ regime can reduce the b-fragmentation uncertainty 2-3 times.
- Then: the expected uncertainty is around $\delta M\_top \leq 300$ MeV.

  This method will be competitive (or better) than the methods based on the reconstruction of the final state of the decaying top pair, and close to the top-threshold scanning method.
- This is a method with potential that has to be explored in detail!