Top Quark Physics, Luminosity Spectrum and the Beam Energy Spectrometer at the ILC

1st Year Talk

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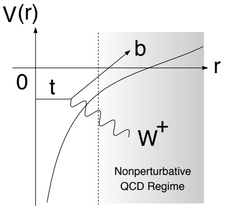
Top Threshold at the ILC

The top quark at the ILC offers a unique QCD system to study :



- Large top quark mass allows precise perturbative QCD calculations of its properties.
- Large top width Γ_t acts as infrared cutoff preventing hadronization effects.
- With main decay to $b\bar{b}W^+W^-$ top quark spin information are preserved in its decay products

- Can measure α_s to high precision, together with measurements of the top-Yukawa coupling
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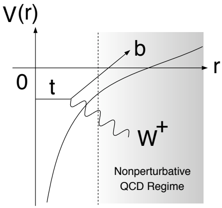

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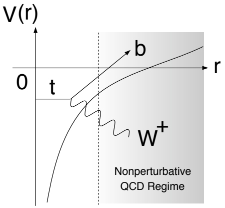

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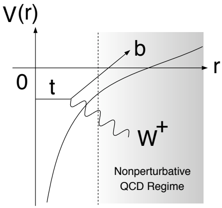

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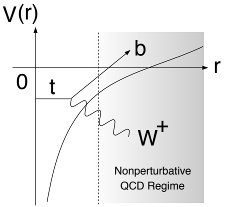

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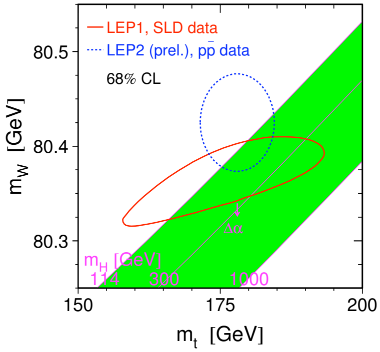
Need for Top Quark Precision



- Top Mass provides constraints on Higgs mass
- Also is important parameter for selecting between the different flavours of SUSY
- Current best measurement at 172.5 ± 2.3 GeV
- The LHC can achieve ± 1 GeV

The ILC claims it can achieve $\pm 50 - 100$ MeV.
The aim of my PhD is to determine if the claimed precision can be achieved

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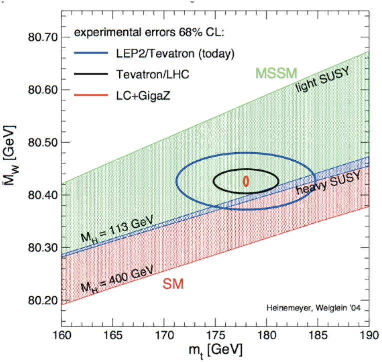

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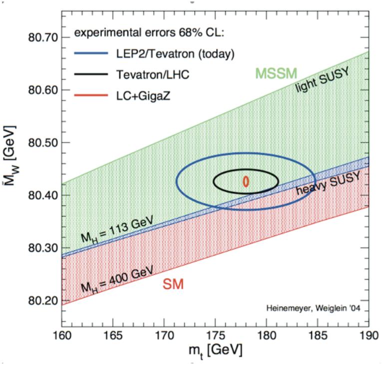

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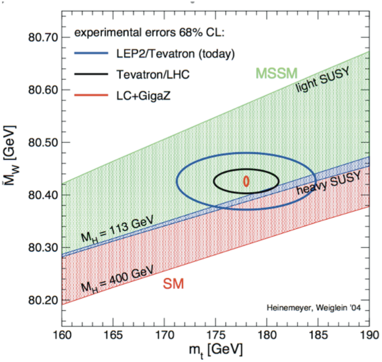

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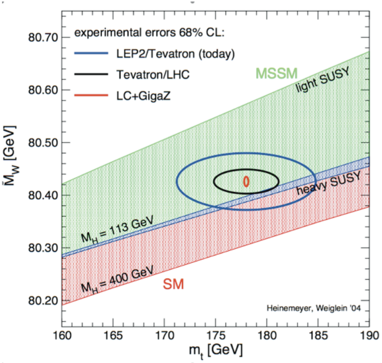

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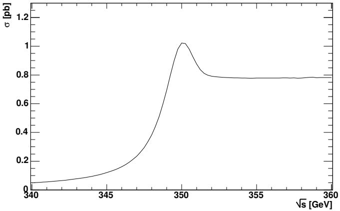
Top Threshold and the Luminosity Spectrum



- The top will be measured at the ILC by a threshold scan at $\sqrt{s} \approx 2M_t$
- One of the main uncertainties in this measurement will come from knowledge of the machine's luminosity spectrum
- Various energy loss mechanisms give a complicated luminosity spectrum at the ILC

- Hence the top threshold observables will be smeared by the luminosity spectrum effects

$$\frac{d\sigma_{obs}^{e^+e^-}}{d\Omega}(\sqrt{s}) = \int_0^1 dx_1 dx_2 D_{e^+e^-}(x_1, x2, \sqrt{s}) \frac{d\sigma^{e^+e^-}}{d\Omega'}(x_1, x_2, \sqrt{s})$$

- For precise threshold physics, a good knowledge of the luminosity spectrum and its inclusion in event generation is fundamental

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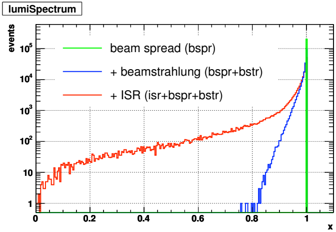

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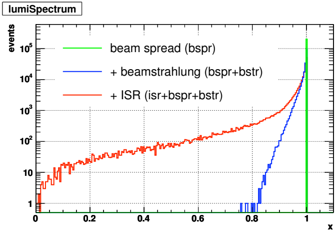

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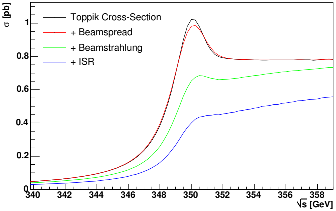

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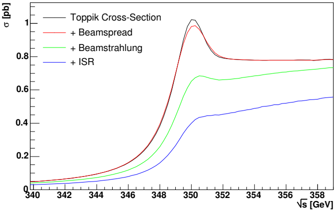

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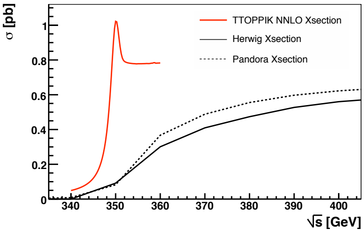

- Precision measurement depends on precise knowledge of threshold lineshape
- Current theoretical tools fail to describe the top threshold
- Over the last 10-15 years, theoretical physicists have performed a wealth of precision calculations for top pair production at threshold.
- However, no event generator exists (yet) that uses these calculations so that precise physics studies can be performed
- The luminosity spectrum is an important factor in describing the top threshold, and thus a precise description must be incoperated in event generation

This is what we are trying to do !!
(in collaboration with T.Teubner and S.Boogert)

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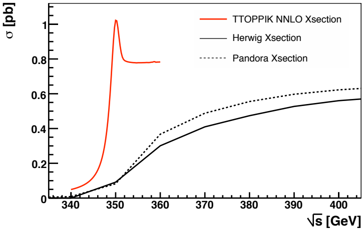

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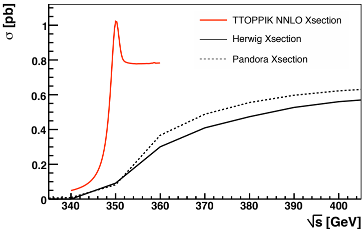

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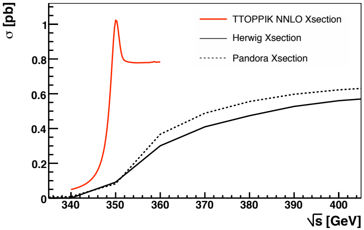

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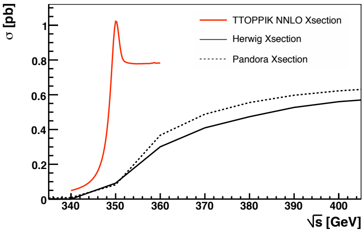

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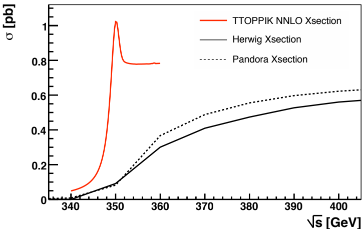

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Precision Calculations - Nomenclature

- Top quarks at threshold are non relativistic $\nu \ll c$
- Also due to Coulomb singularities, usual perturbative expansion in α_s not possible
- Hence top threshold requires different than usual theoretical treatment
- Use of Non Relativistic QCD (NRQCD) and employment of Effective Field Theories (EFTs) to describe threshold
- Solving the Lippmann-Schwinger eq. exactly in momentum space with the Green function technique

$$\Downarrow$$

NNLO calculations from TOPPIK (A.Hoang & T.Teubner)

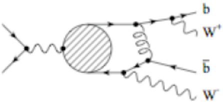
topMC in a Nutshell

NLO rescattering corrections

Modify Green's functions

NNLL renormalization group improved total Cross section (only)

Scale total Cross section reduces theoretical uncertainty



NNLO Cross section + differential quantities $d\sigma/dp$, A_{FB} etc

Include Beam Effects !!

Top quark pair 4-momenta → Decay top quarks

Give decay products to Pythia / Herwig for further decays and hadronization

Event Generator

Fast Generator

- Main problem with TOPPIK is that it is very slow !!
  ($>$ 1.5sec per calculation)
- Forbids direct use in event generation
- Solution is fast access to the Green functions
- This is done by fast 5-dimensional interpolation on Green functions in $(M_t, \Gamma_t, \alpha_s, \sqrt{s})$ parameter space
- The rest of the calculation can be performed on the interpolated Green functions

Fast Multidimensional Interpolation

- Calculate with TOPPIK once and store interpolation grid in $(M_t, \Gamma_t, \alpha_s, \sqrt{s})$
- Transform Re\Im Green functions in 'simpler' Magnitude\Phase distributions
- Perform fast piecewise linear interpolations in required parameters
- All parameter interpolation is $\times 5$ faster than TOPPIK
- Interpolations only in $\sqrt{s}$ are $\times 10^6$ faster !!

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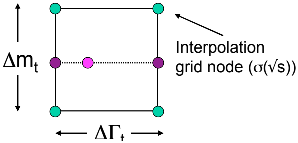

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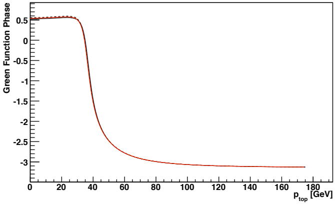

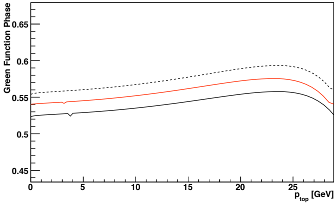

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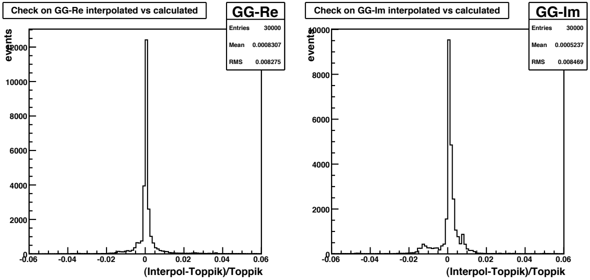

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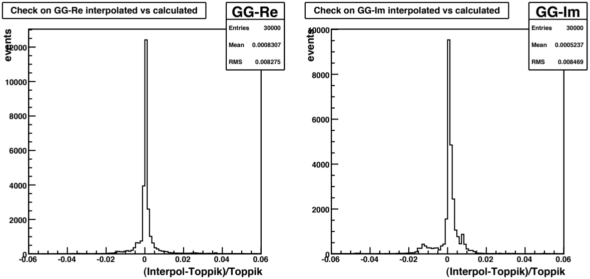

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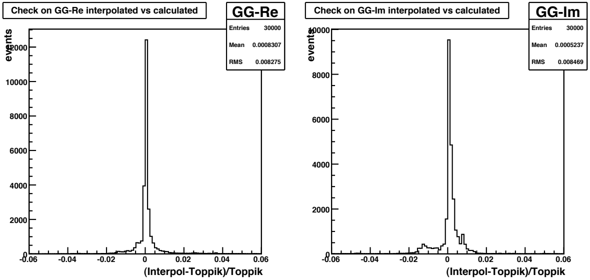

Reproducing Calculations

- Implement full calculations in OO framework
- Reproduce Gauss-Legenrde integration grid

$$\int f(x)dx \approx \sum_{i=1}^{n} w_i f(x_i)$$

- S-wave differential momentum distribution
- Total cross sections

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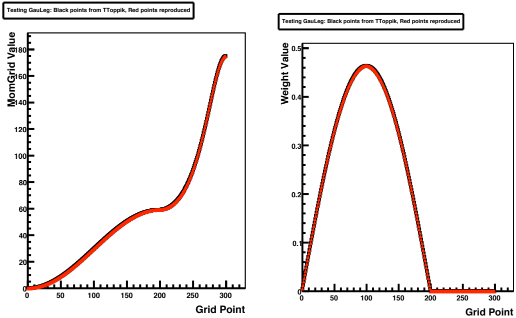

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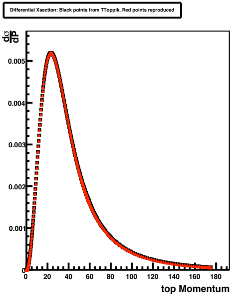

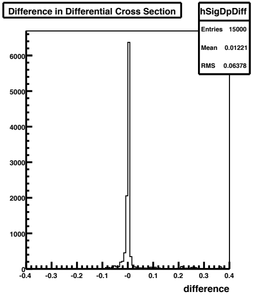

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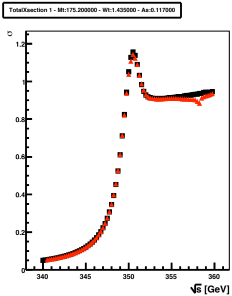
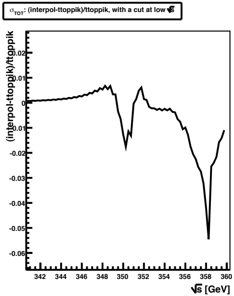


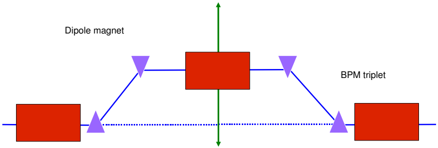


We are (almost) there !!

- Major problem solved: Demonstrated that interpolation works !
- Can reproduce all 'observable' quantities implemented in TOPPIK
- Next step is to feed these quantities in a MC Integrator (Foam,Vegas) and start generating simple events
- Then decay the top quarks and interface to multipurpose generator for further decays and hadronization
- Start thinking about implementation of beam effects

The Beam Energy Spectrometer

- By precise measurements of the deflection of the beam by a known magnetic field, the absolute beam energy can be measured



- For top measurements precision better than 30 ppm is required
- To reach required performance, precision Beam Position Monitors (BPM) and magnetic field measurements are required
- The UCL group is developing a spectrometer specific BPM design
- Also, careful understanding and monitoring of systematic effects influencing stability of the measurement (temperature variations, ground motion, beam conditions etc)
- An intensive programme of test beam experiments is taking place at SLAC's ESA to test performance and stability of this concept

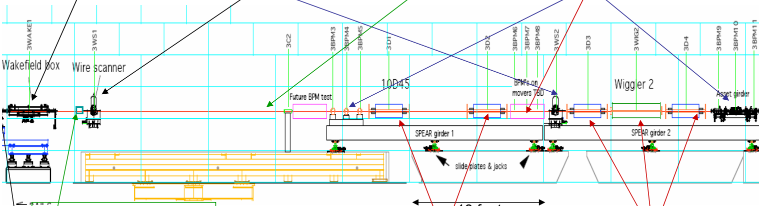
End Station A : Experimental Setup

Wakefield box

Wire Scanners

FONT-ESA

rf BPMs



Ceramic gap BLMs

+ ceramic gap (downstream of 3BPM11, not shown) for EMI studies

Dipoles + Wiggler

Upstream

4 rf BPMs for incoming trajectory
1st Ceramic gap w/ 4 diodes (16GHz, 23GHz, 2 @ 100GHz), 2 EMI antennas

blue=April '06
green=July '06
red=FY07

+ T-487 for longitudinal bunch profile (location tbd)
using pyroelectric detectors for Smith-Purcell radiation

BPM Analysis in 1 slide

- As a bunch of particles traverses through a BPM, it excites electromagnetic waves in the cavity
- Amount of EM power stored in dipole eigenmode of cavity is linearly proportional to beam position inside the cavity
- Careful extraction and processing of signal required
- BPM calibrations needed to extract useful information from cavities (mover or corrector magnet scans)
- Resolution is width of distribution of residuals between expected and measured beam position in BPM

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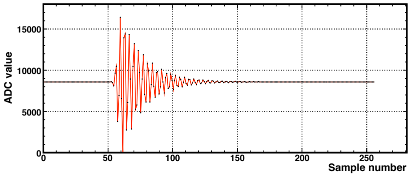

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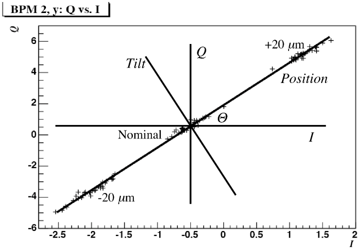

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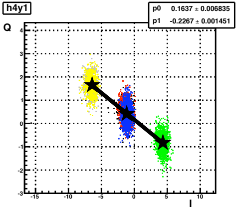

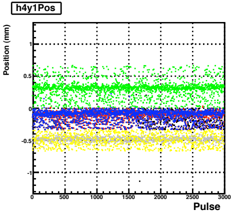

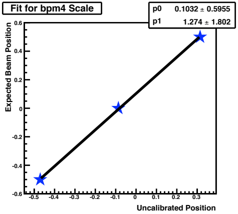

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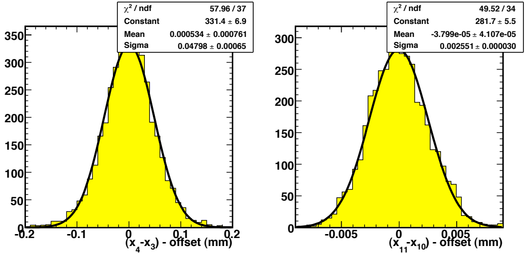

The Future

- Completion of top threshold MC event generator
- Studies of luminosity spectrum and extraction of the different components
- Study effects of luminosity spectrum in a realistic top threshold (i.e. differential quantities)
- Continued participation in running and analysis of Energy Spectrometer test beam experiments at SLAC
- Possibly (time permitting) studies of detector effects in top threshold measurements
- Any other interesting thing that might come up . . .

UCL team at SLAC