Precision Top Quark Threshold Measurements at the ILC

(or another motivation for precision energy spectrometry)

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Talk Outline

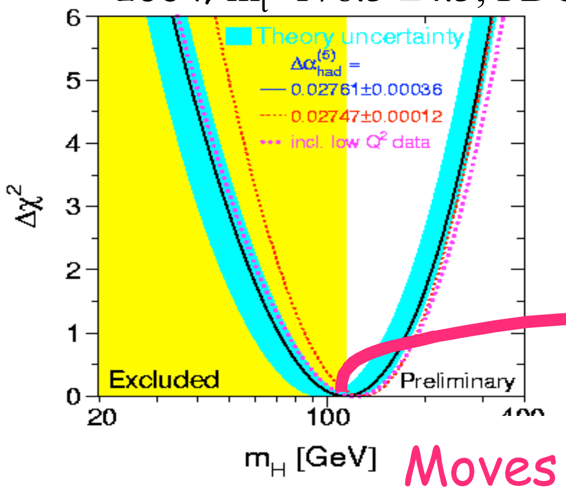
- Introduction
  - Why so precise top measurements?
  - ttbar threshold @ ILC
  - luminosity spectrum
- Threshold Simulations
  - what we have
    - ttbar threshold total cross-section simulations
    - Luminosity spectrum extraction
  - what we need
    - Full MC based ttbar threshold analysis
    - Complete understanding of luminosity spectrum impact and extraction related systematics
    - Precise absolute energy measurements
- Summary and outlook..

Why top quark precision ?

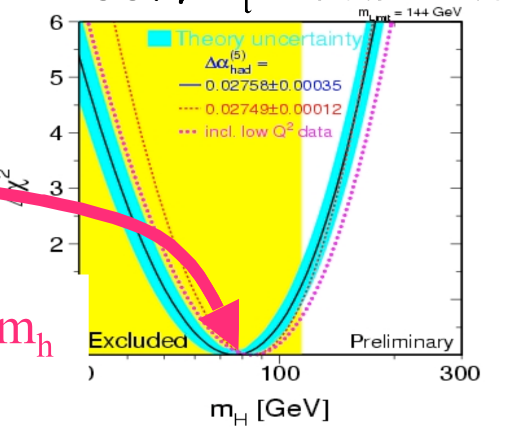
- Why want Mt presicion of 50-100 MeV or less ?

Strong dependence on SM parameters and beyond..

2004; m_t=178.3 ±4.3; PDG



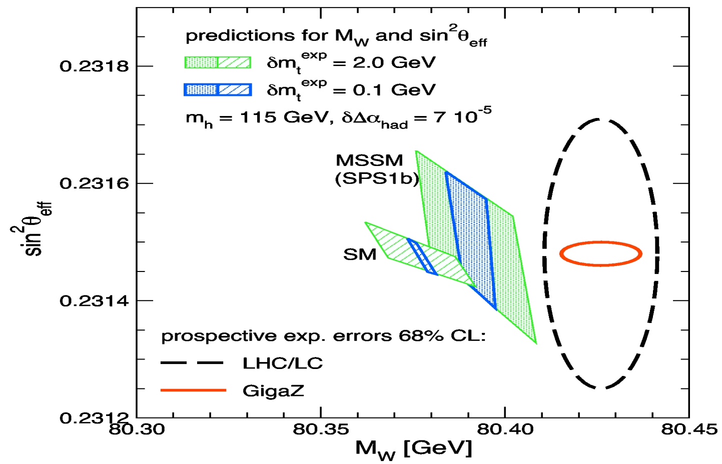
2007; m_t=170.9 ±1.8



Moves best fit m_h by > 30 GeV.
Very sensitive.

Updated from DJ Miller EuroTeV talk

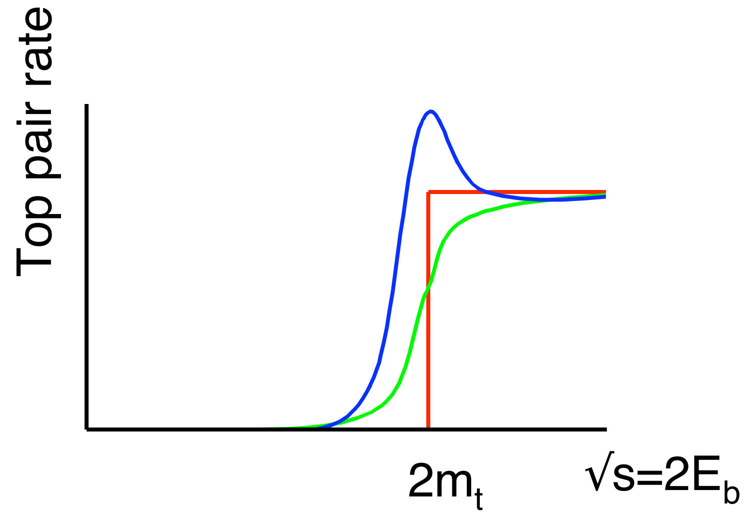
Achievable precision (?): $$\frac{50\,MeV}{175\,Gev} \approx 3.10^{-4}$$



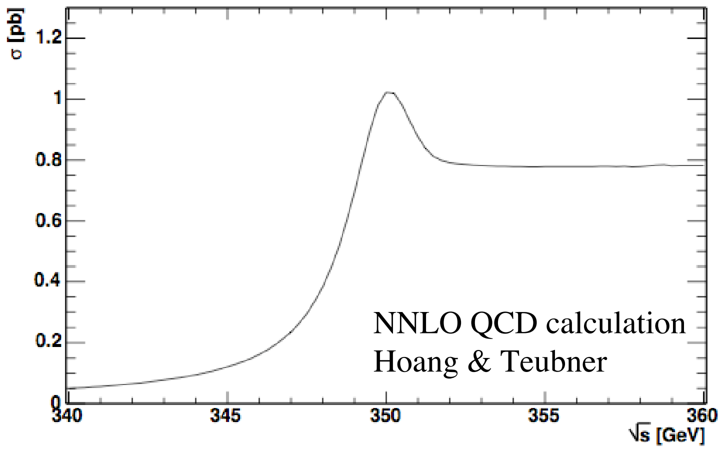
Sven Heinemeyer et al

ttbar threshold @ the ILC

- One of the important ILC physics targets.
- At the ILC top quarks offer a unique QCD system :
  - Perturbative (non relativistic) QCD applicable since $\Gamma_t > \Lambda_{QCD}$ -> no hadronization.
  - Classically cannot be produced when total energy $< 2m_t$
  - Quantum effects smear sharp threshold
  - Binding between top and anti-top
  - Also clean experimental environment, well understood backgrounds



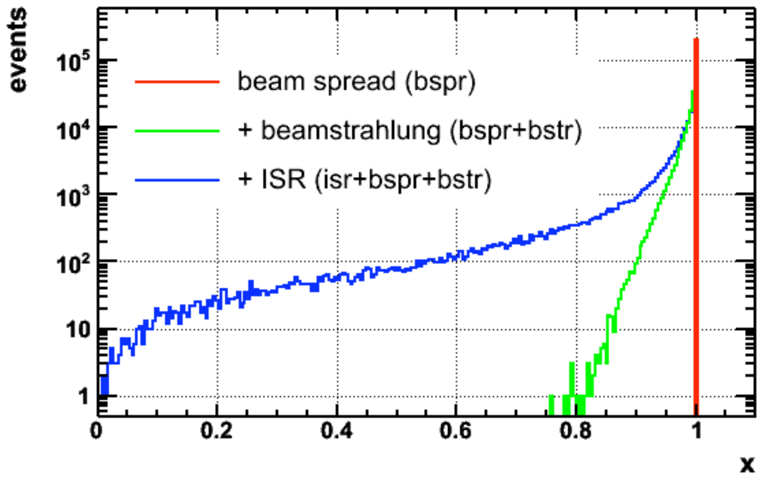
- Best direct measurement of top mass will be at the ttbar threshold.
  - Vary the beam energy (Precisely measure the beam energy)
  - Count the number of top-antitop events
  - Precision on beam energy goes directly into the measurement
- Total cross-section sensitive to M_t, Γ_t, α_s .
  - Can extract information about α_s and top-Yukawa coupling
- Complications arise due to the luminosity spectrum

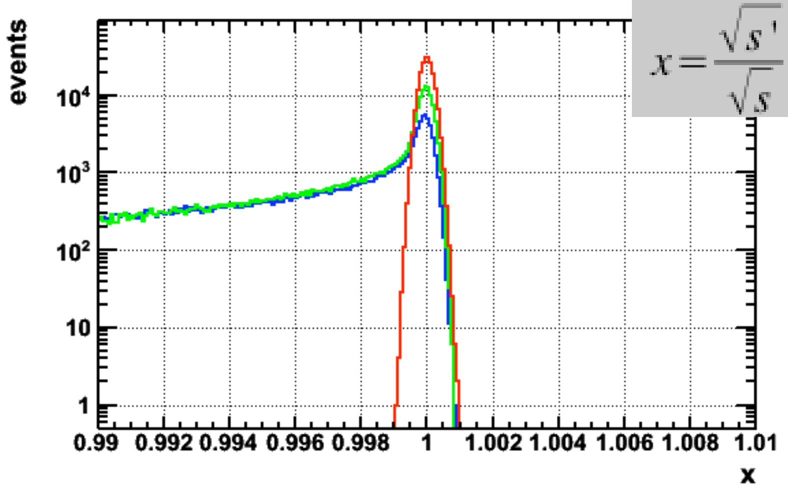


Luminosity Spectrum

- At the ILC the beam energy at the IP gets smeared by various energy loss mechanisms
- Centre of mass energy variation, three main sources:
  - Initial State Radiation (ISR)
    - Calculable to high precision in QED
  - Accelerator Beam Spread
    - Intrinsic machine energy spread, typically (Gaussian !?) ~0.1 %
  - Beamstrahlung
    - Beam-beam effect due to strong bunch magnetic fields, causing electrons to radiate.
    - ~ 1 %
    - Cannot be analytically calculated, need to trust complicated plasma physics based simulations (GuineaPig, CAIN etc)

- Can only simulate through GuineaPig/CAIN or parametrize with beamstrahlung function (circe etc) based on simulated data





$$x = \frac{\sqrt{s'}}{\sqrt{s}}$$

Luminosity Spectrum Extraction : Bhabha Acolinearity

- Bhabha scattering to monitor lumi spectrum
  - e^+e^- -> $e^+e^-(n)\gamma$
  - High enough rate compared to top threshold
  - Only monitors x distribution, for absolute energy scale need energy spectrometers

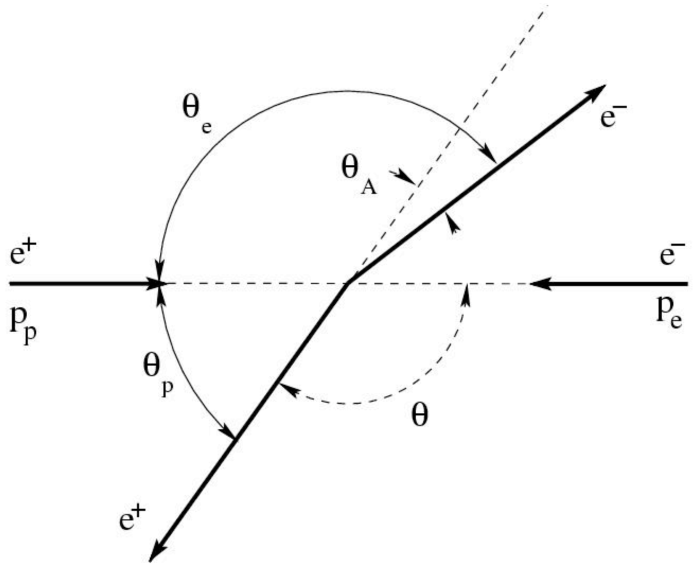
- Two approximate reconstruction methods:
  - Only uses angles of scattered electron and positron
  - Based on assumption of single photon radiation

  - Frary-Miller

$$x = 1 - \frac{\theta_A}{2 \sin \bar{\theta}}$$

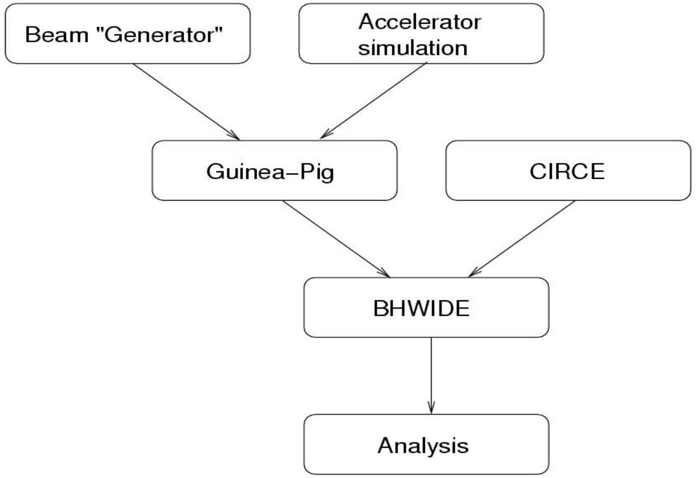
  - K. Mönig

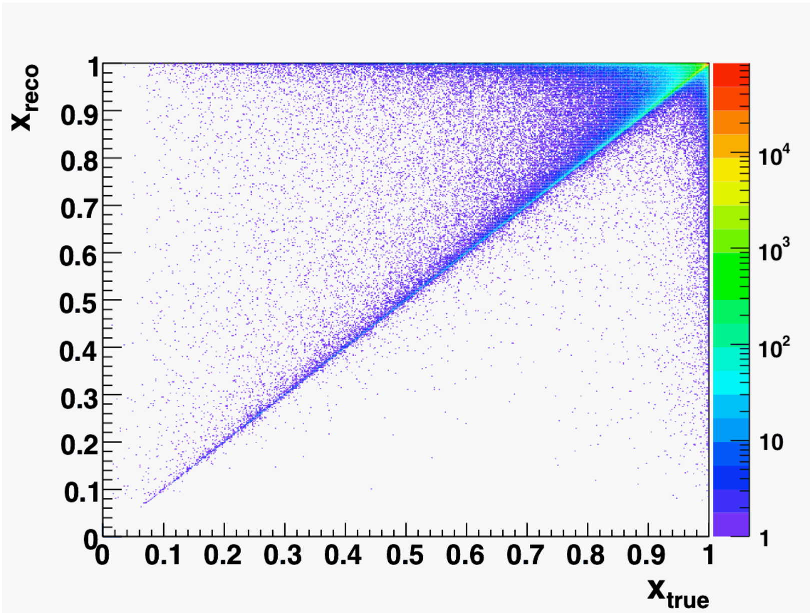
$$x = \sqrt{\cot \frac{\theta_p}{2} \cot \frac{\theta_e}{2}}$$



Simulation (for spectrum extraction)

- Simulation :
  - Define accelerator beam (linac simulation?)
  - Simulate beam-beam effects
    - Get beamstrahlung from GuineaPig and/or parametrize (CIRCE)
  - Generate bhabha scattering with BHWIDE (BHabha WIDE angle monte carlo)
  - Apply beam-beam effects to bhabhas
  - Analyze / Extract spectrum

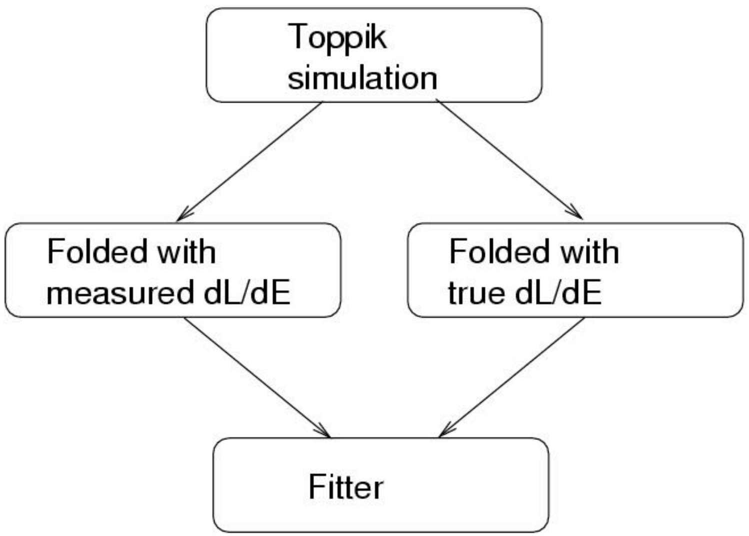


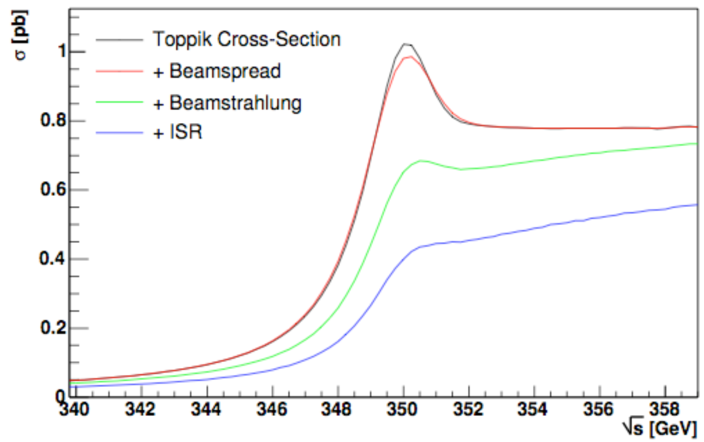


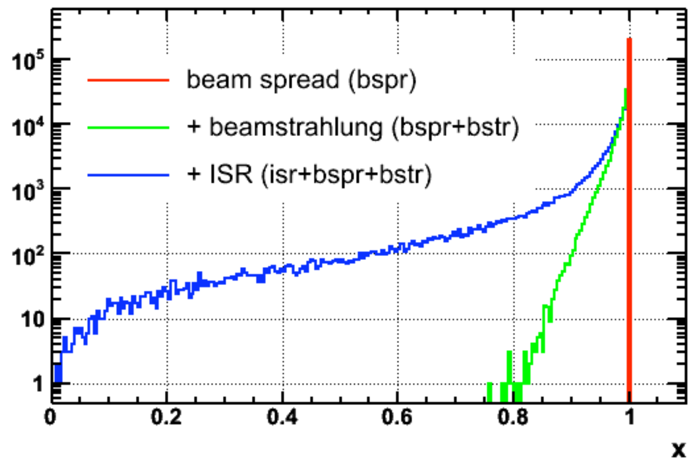
ttbar threshold simulations

- The luminosity spectrum effectively smears the ttbar threshold cross-section.

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



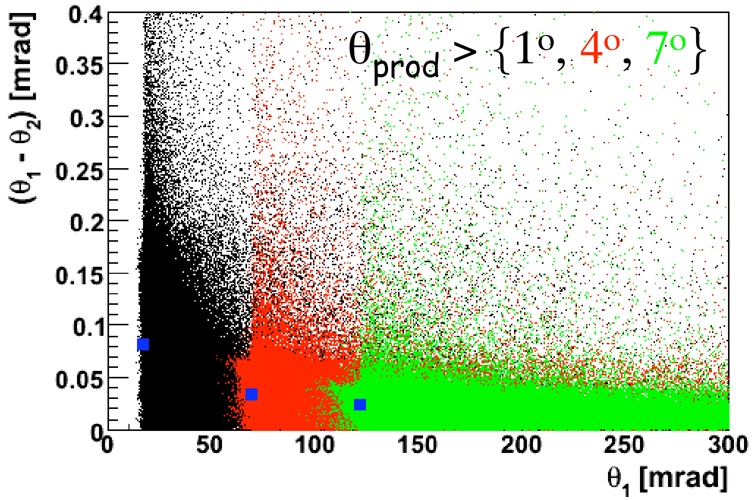




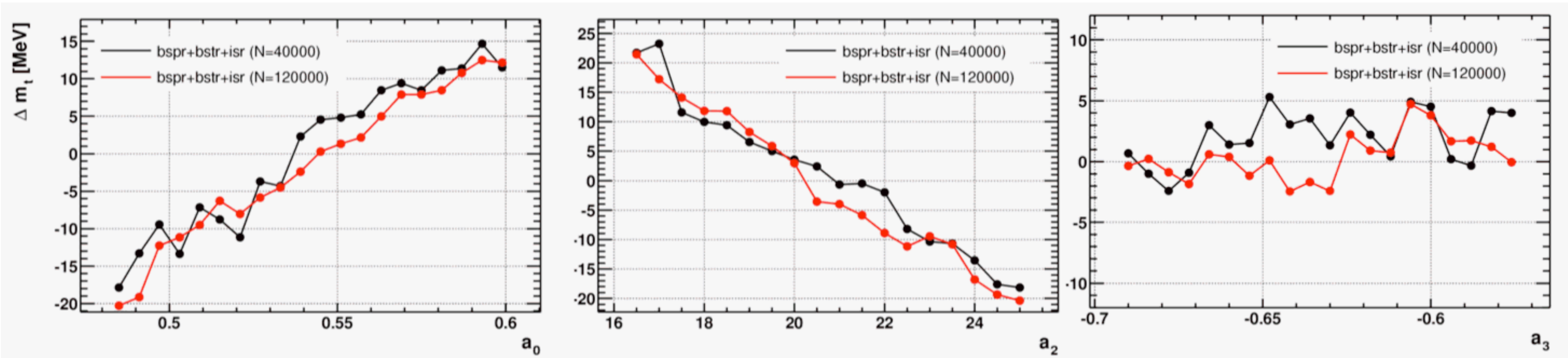
- For extracting precise physics measurements using a threshold scan, precise knowledge of the luminosity spectrum is needed.

Extraction Systematics Impact

- Recent study showed that luminosity spectrum extraction techique is not influenced by potential systemetic effects including: (see talk by FG at LAL-MDI meeting 29/3/07)
  - EM deflections of Bhabhas due to bunch field
  - Migration of events into/out of detector acceptance
  - Computational parameters in simulation (GuineaPig) etc..



- Older study by S.Boogert (LCWS '05 - Paris) shows that small variations in beamstrahlung spectrum don't have a large effect on M_t measurements



Updates in ttbar threshold simulations

- Up to now only 'brute force' $\sigma_{tot} \times \mathcal{L}$ folding and fitting simulations exist (S.Boogert - FG, Martinez - Miquel etc)

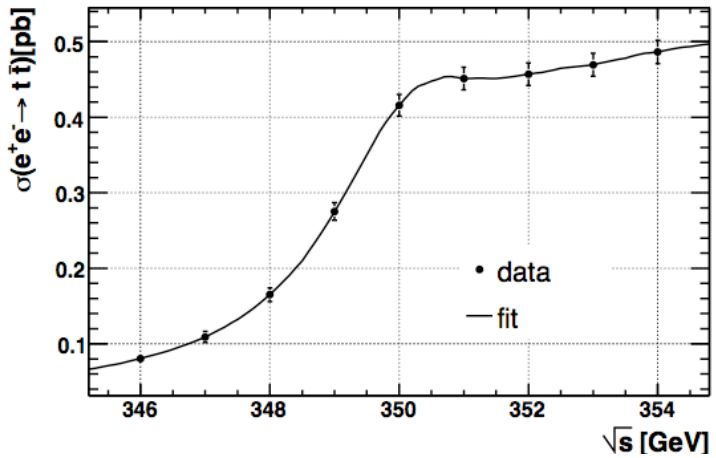
- For precise understanding of the top threshold we need to go to fully differential simulations, event generation etc.

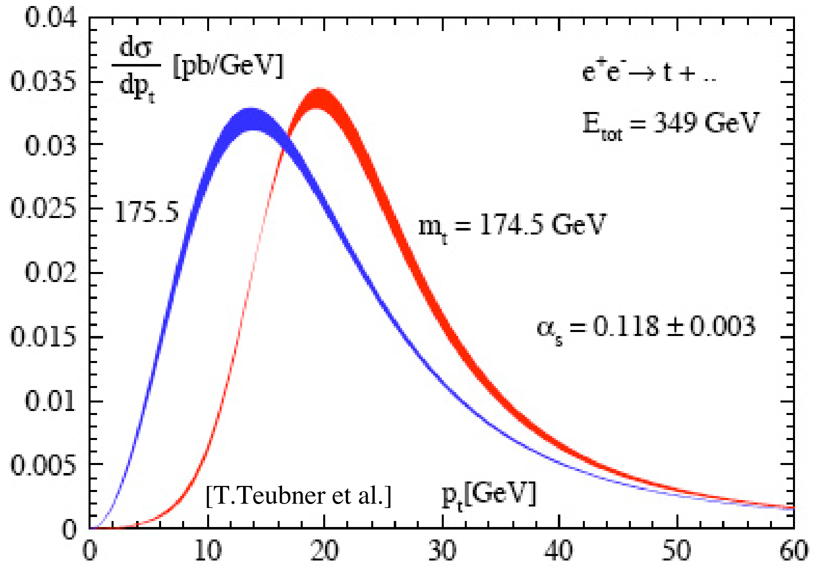
- Can see the effects of the luminosity spectrum in detail.

- Top momentum distribution sensitive to M_t and α_s
  - Gives info independent of Γ_t measurement.
  - Different correlations than in σ_{tot}
  - Need to use both σ_{tot} and $\frac{d\sigma}{dp_t}$ to mea M_t and α_s
  - A_{FB} independent of M_t, sensitive to α_s and Γ_t.

- Sensitivity to Z, W, γ couplings :
  - Affect angular distributions and top polarization
  - Anomalous couplings -> EW/QCD effects (new physics ?)

See top/QCD session at LCWS '07 for ttbar threshold MC [FG,S.Boogert]





Summary and Outlook

- From current status of top threshold studies it seems that the systematic effects from luminosity spectrum extraction are under control (as always devil is in the detail..)
- Largest contribution to the measurement will come from determination of the absolute beam energy.
- The luminosity spectrum extraction only provides the x distribution but not what x is !!
- The precision of the beam energy measurements will dictate the precision that the top threshold measurements can reach…
- A 50MeV measurement of M_t translates into:

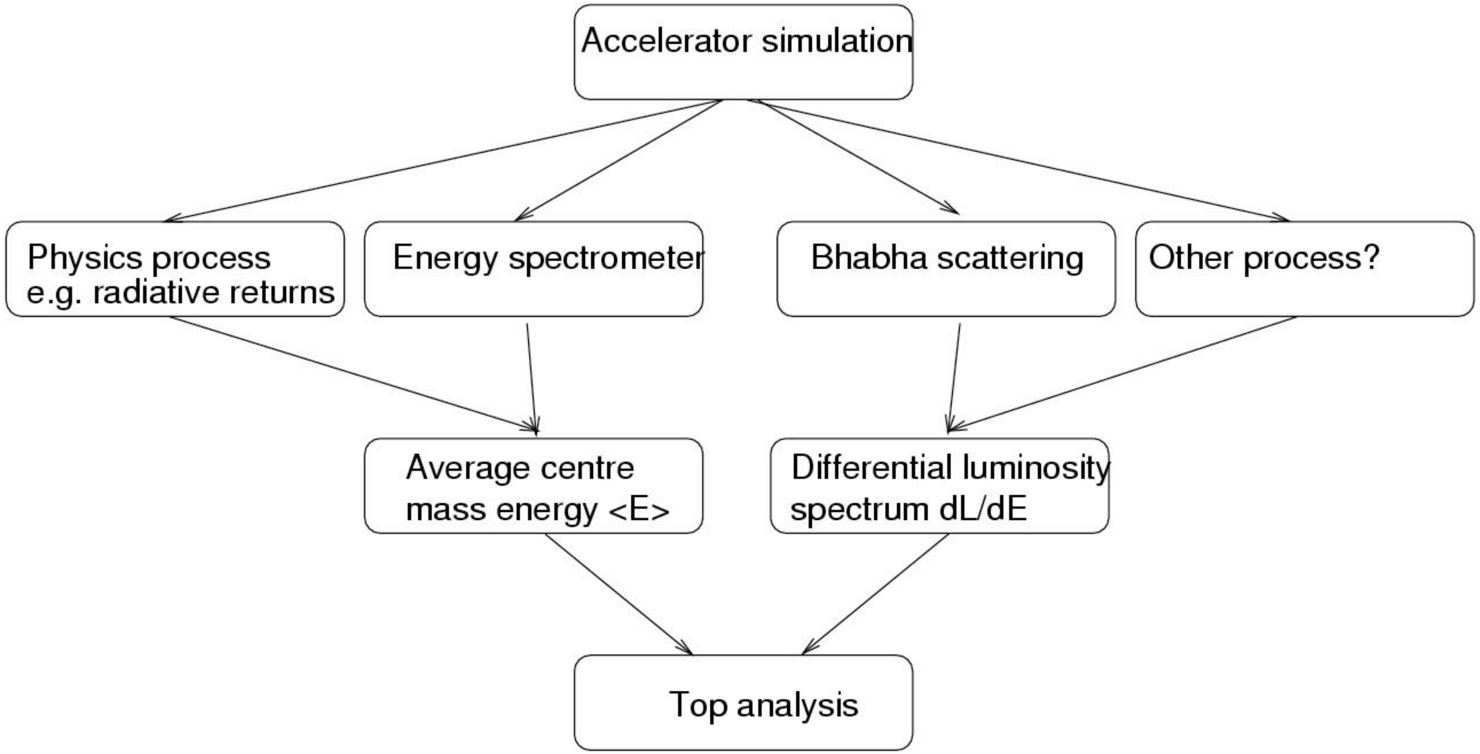
$$\frac{50\,MeV}{175\,Gev} \approx 3.10^{-4}$$

which means energy measurement precision should be greater or equal..

- Investigation under way to define :
  - Effect of luminosity spectrum in a fully differential analysis
  - Finalize luminosity spectrum extraction study by performing the full simulation (including detector effects) of the bhabha samples
  - Precision the measurement can reach that will need to be matched by the spectrometers

- Most arguments above about precision energy measurements required for the top threshold apply for most other threshold scan measurements (W+W-, SUSY etc) @ the ILC…

SPARE



Accelerator simulation
Physics process
e.g. radiative returns
Energy spectrometer
Bhabha scattering
Other process?
Average centre
mass energy <E>
Differential luminosity
spectrum dL/dE
Top analysis