The top quark threshold @ the ILC*

* or any other future e^-e^+ collider

Filimon Gournaris
University College London

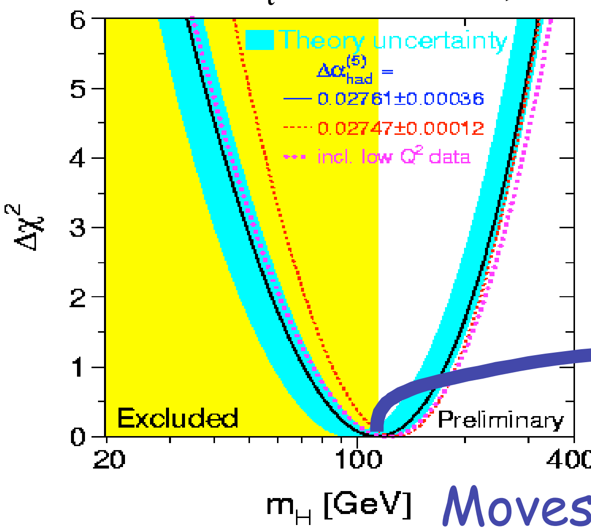
01.04.2008

IoP HEPP Annual Meeting

Lancaster University

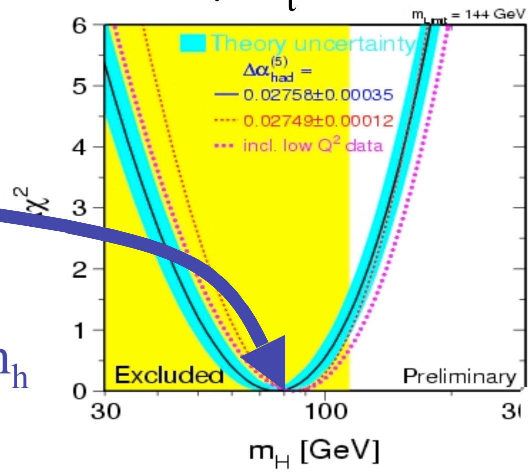
Why top quark precision ?

2004; m_t=178.3 ±4.3; PDG



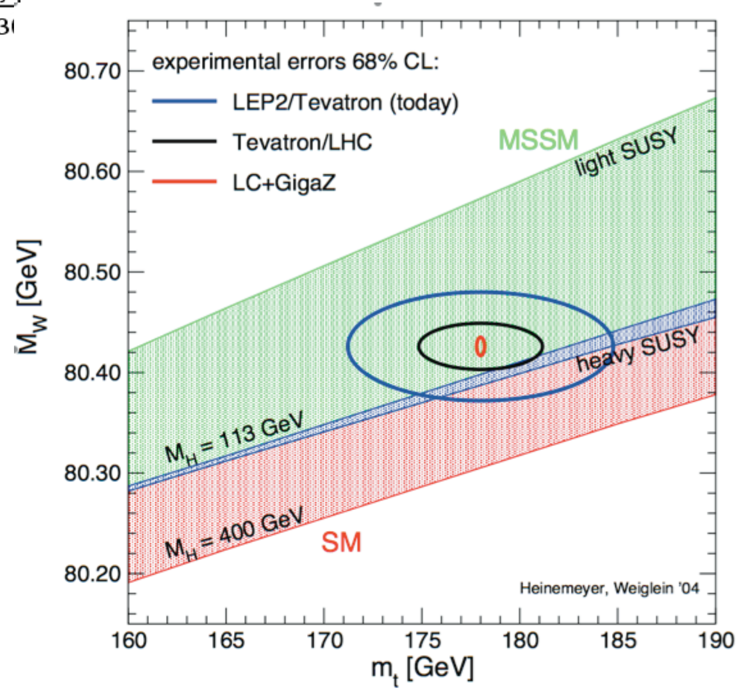
Strong dependence on SM parameters and beyond..

2007; m_t=170.9 ±1.8



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

Updated from DJ Miller EuroTeV talk



Sven Heinemeyer et al

Achievable precision (?):

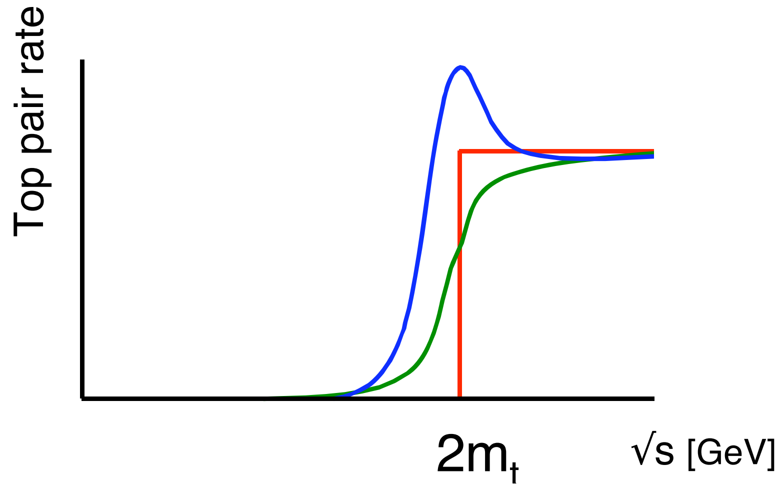
$$\frac{50\,MeV}{175\,Gev} \approx 3.10^{-4}$$

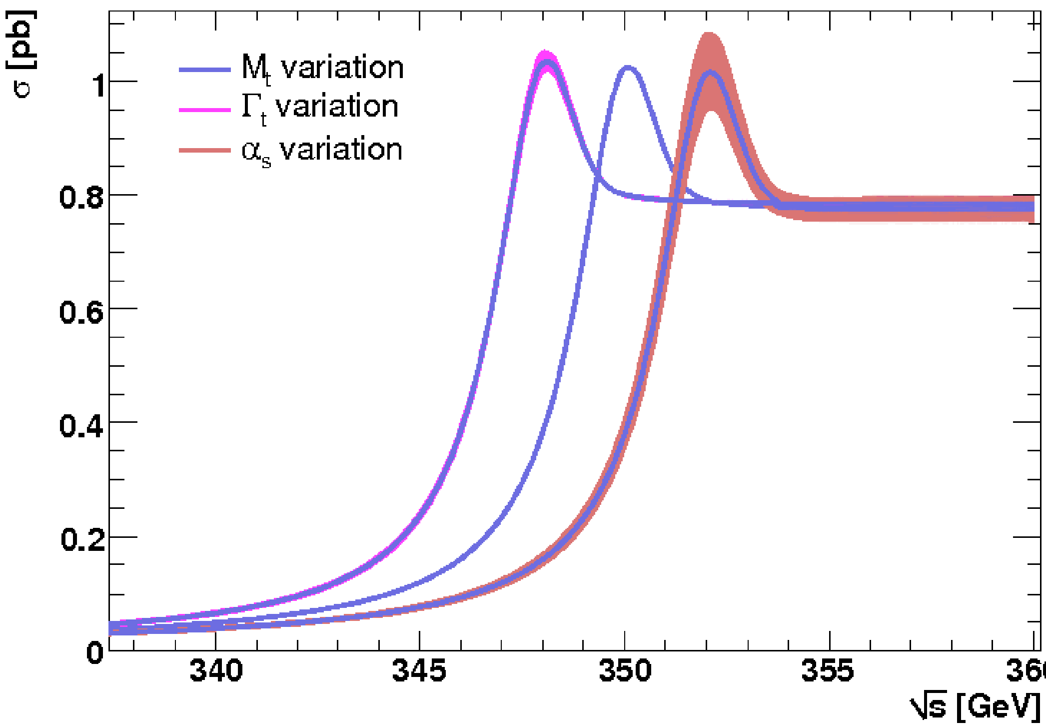
Dictated by :

- Luminosity Spectrum?
- Energy Spectrometers?
- Detector?
- Theory?

ttbar threshold @ the ILC

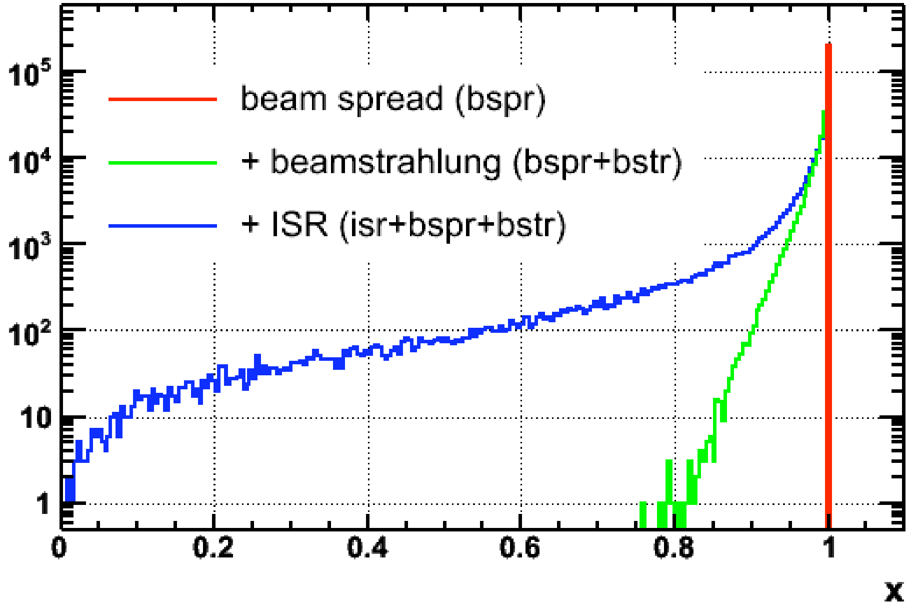
- One of the important ILC physics targets.
- At the ILC top quarks offer a unique QCD system :
  - Perturbative (non relativistic) QCD applicable since $\Gamma_t > \Lambda_{QCD}$ -> no hadronization.
  - Classically cannot be produced when total energy < $2m_t$
  - Quantum effects smear sharp threshold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

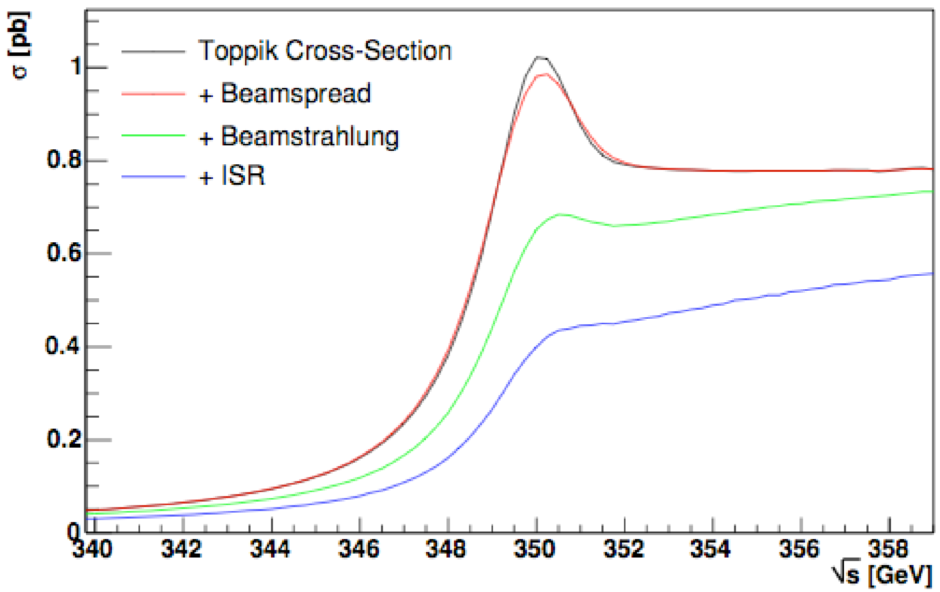




Luminosity Spectrum

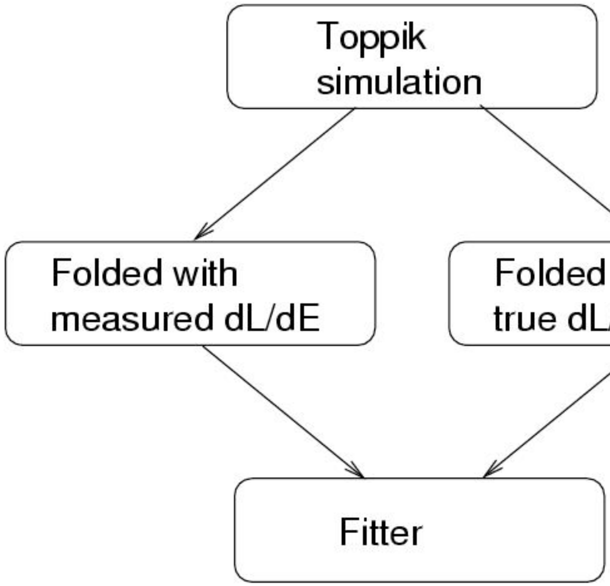
- At the ILC the beam energy at the IP gets smeared by various energy loss mechanisms
- Centre of mass energy variation, three main sources:
  - Initial State Radiation (ISR)
    - Calculable to high precision in QED
  - Accelerator Beam Spread
    - Intrinsic machine energy spread, typically (Gaussian !?) ~0.1 %
  - Beamstrahlung
    - Beam-beam effect due to strong bunch magnetic fields, causing electrons to radiate.
    - ~ 1 %
- The luminosity spectrum (measurement) only provides the x distribution but not what x is !! (need upstream/downstream energy spectrometer)

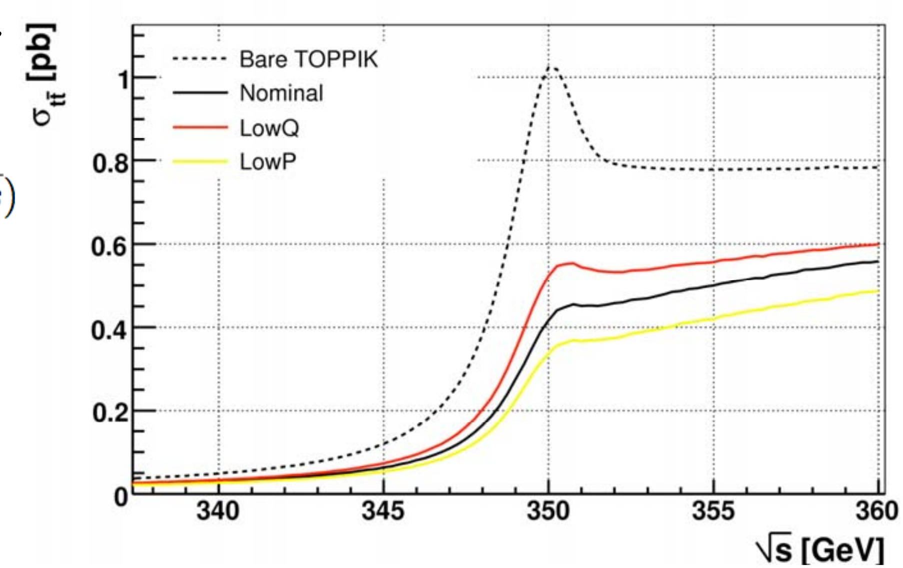


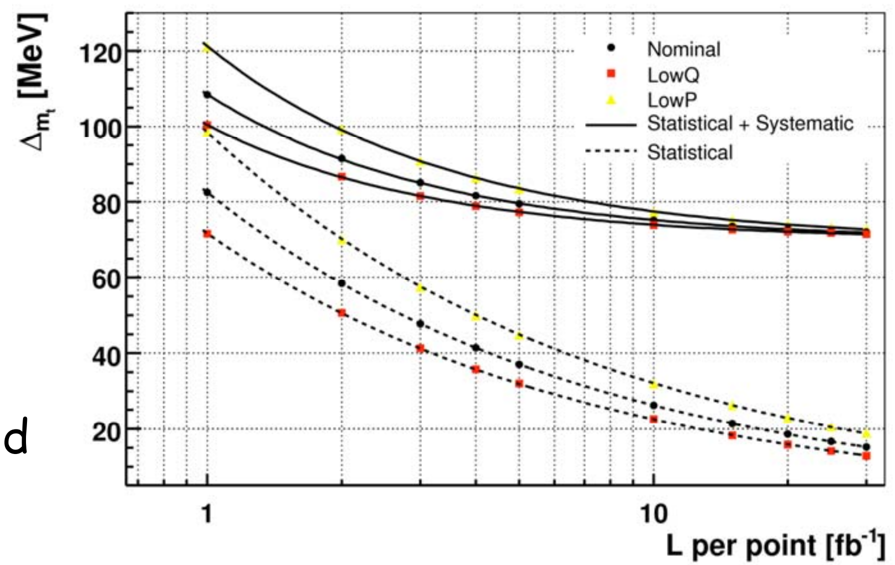


- The luminosity spectrum effectively smears the ttbar threshold cross-section.

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







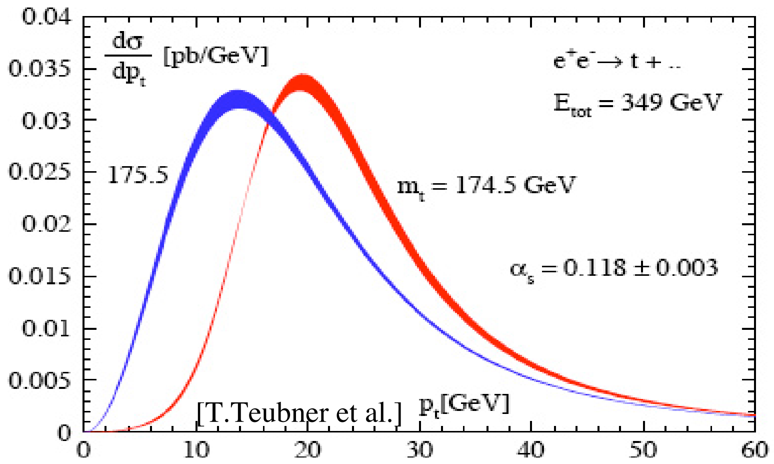
- For extracting precision physics out of threshold scans at the ILC, a good knowledge of the luminosity spectrum and the absolute energy scale are needed.

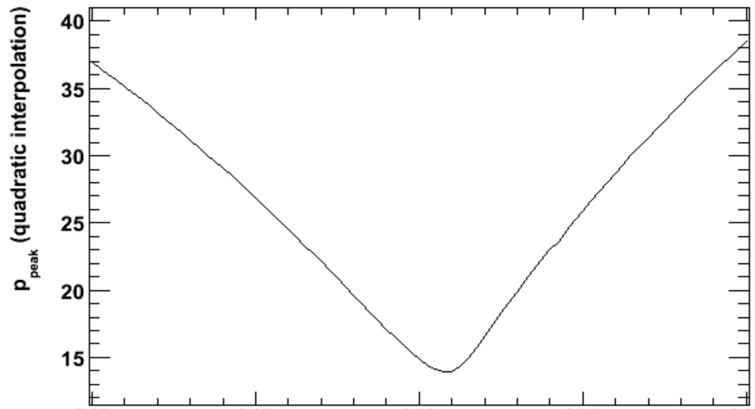
But we can do better…

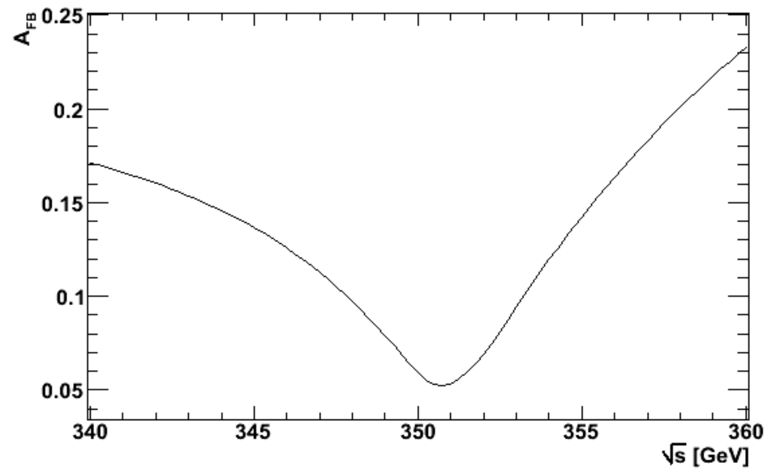
- Up to now only 'brute force' $\sigma_{tot} \times \mathcal{L}$ folding and fitting simulations exist (Boogert - FG, Martinez - Miquel etc)
- For precise understanding of the top threshold we need to go to fully differential simulations, event generation etc.
- Can see the effects of the luminosity spectrum in detail.

- Also… 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 measure 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 ?)

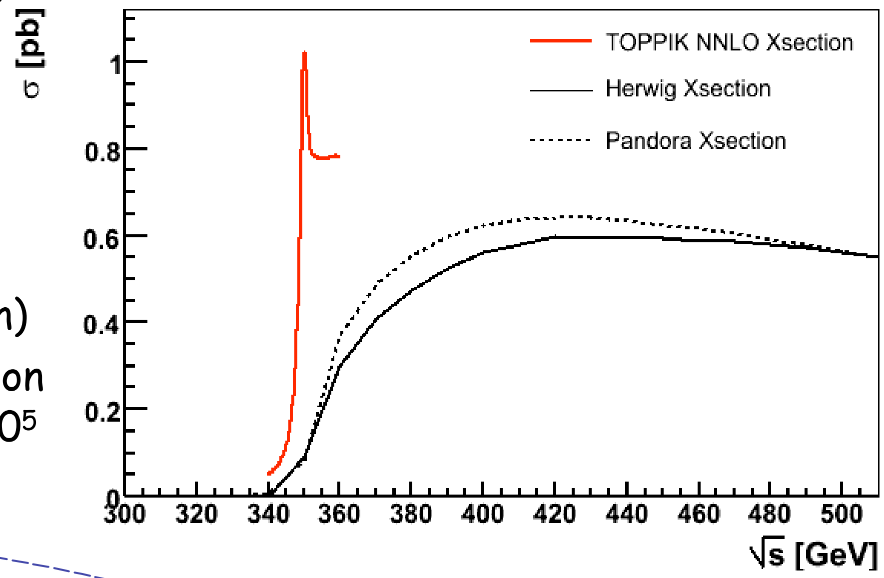






ttbar threshold event generator

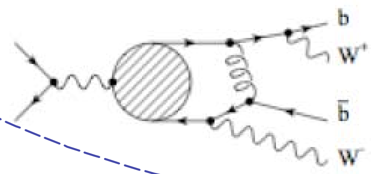
- MCs on the market not precise enough for ttbar threshold (need to include all QCD effects etc.)
- TOPPIK (Hoang & Teubner) is best available theoretical description :
  - NNLO NR-QCD including differential quantities
  - NNLL total cross-section & NLO rescattering corrections
- Main problem with TOPPIK is speed (>1.5sec per calculation)
- New generator works with multidimensional interpolations on a TOPPIK produced look-up table which gives a factor of 10^5 speedup (details in [FG and Boogert, LCWS '07 talk and proceedings])



Based on fast multidimensional interpolation

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 $d\sigma/dp$, P_{peak}, A_{FB} etc

Apply beam effects using realistic Luminosity Spectrum

Perform monte carlo integration using FOAM/VEGAS

Decay top quarks into W+W-bbar

Kinematic checks

Give to Pythia for hadronization…

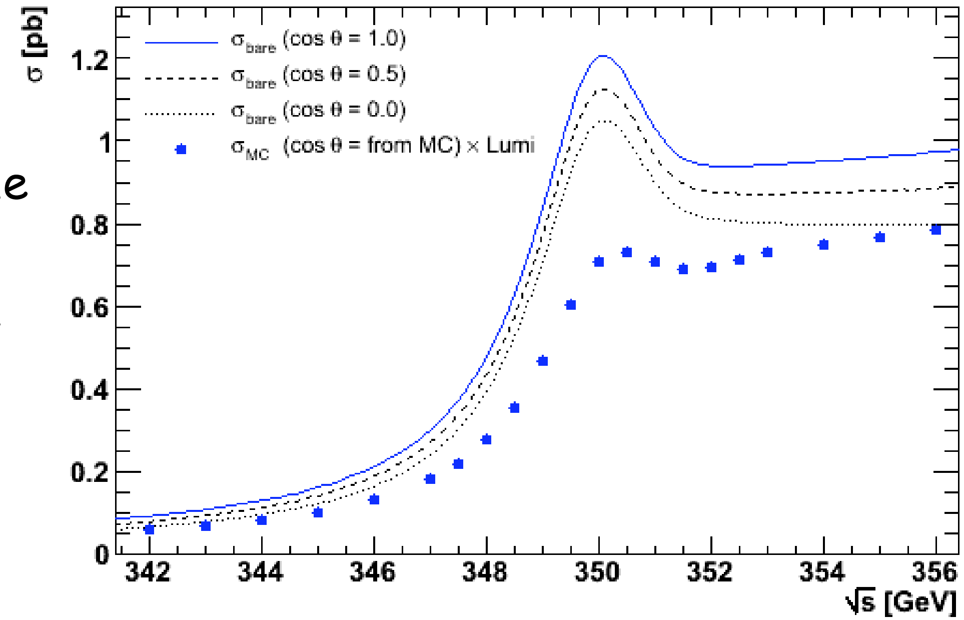
Event Generator

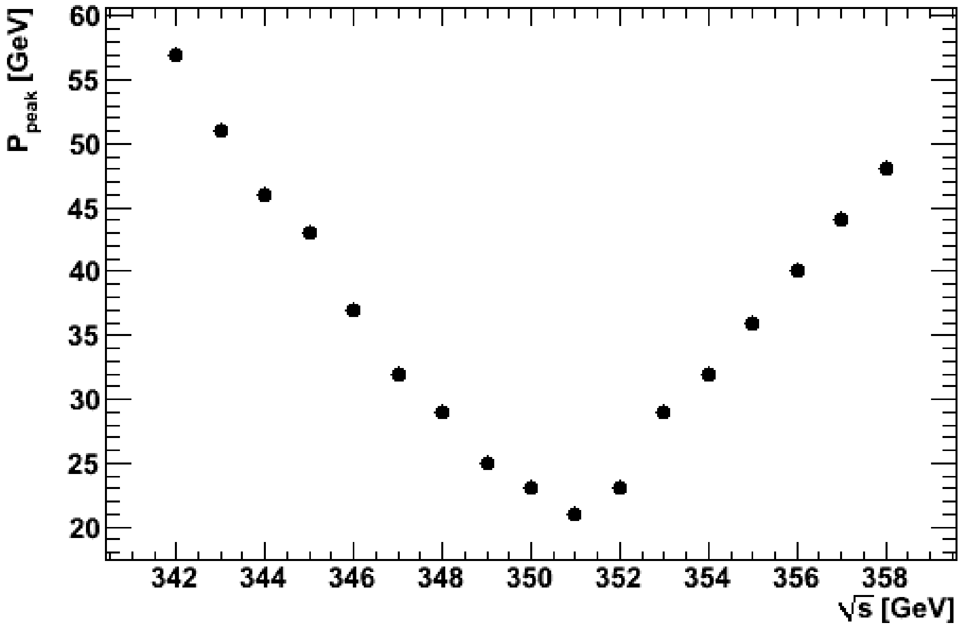
With guidance from Thomas Teubner (Liverpool Theory)

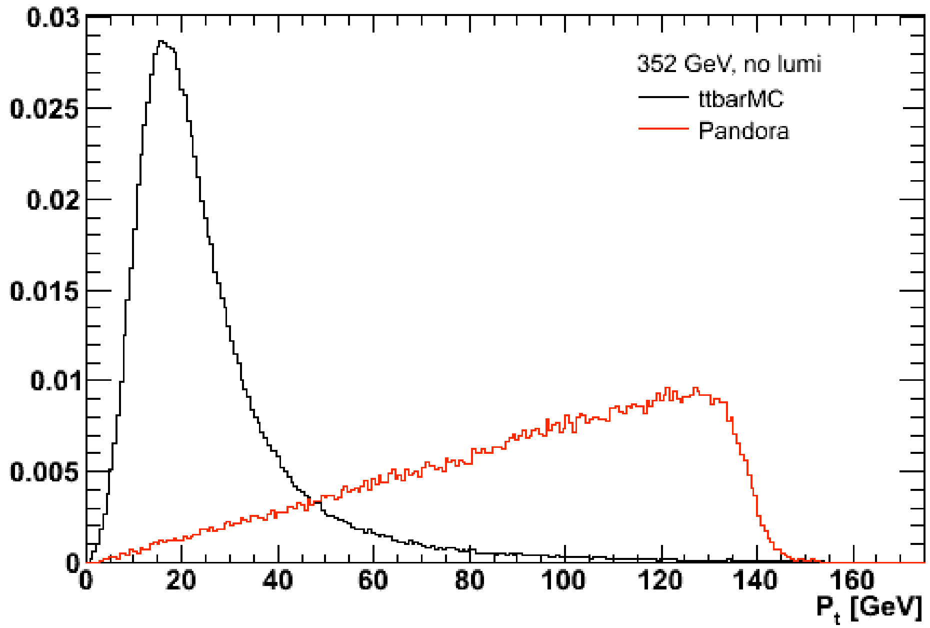
ttbarMC distributions

UCL

- All generator distributions are as expected..
- The hadronization part is also complete and follows the recipe of pandora_pythia hence the important checks are only at the parton level
- Next step (already underway) is to repeat the previous luminosity spectrum impact studies using the full generator (parton level) and do the mass/width/a_s fits on the full distributions..





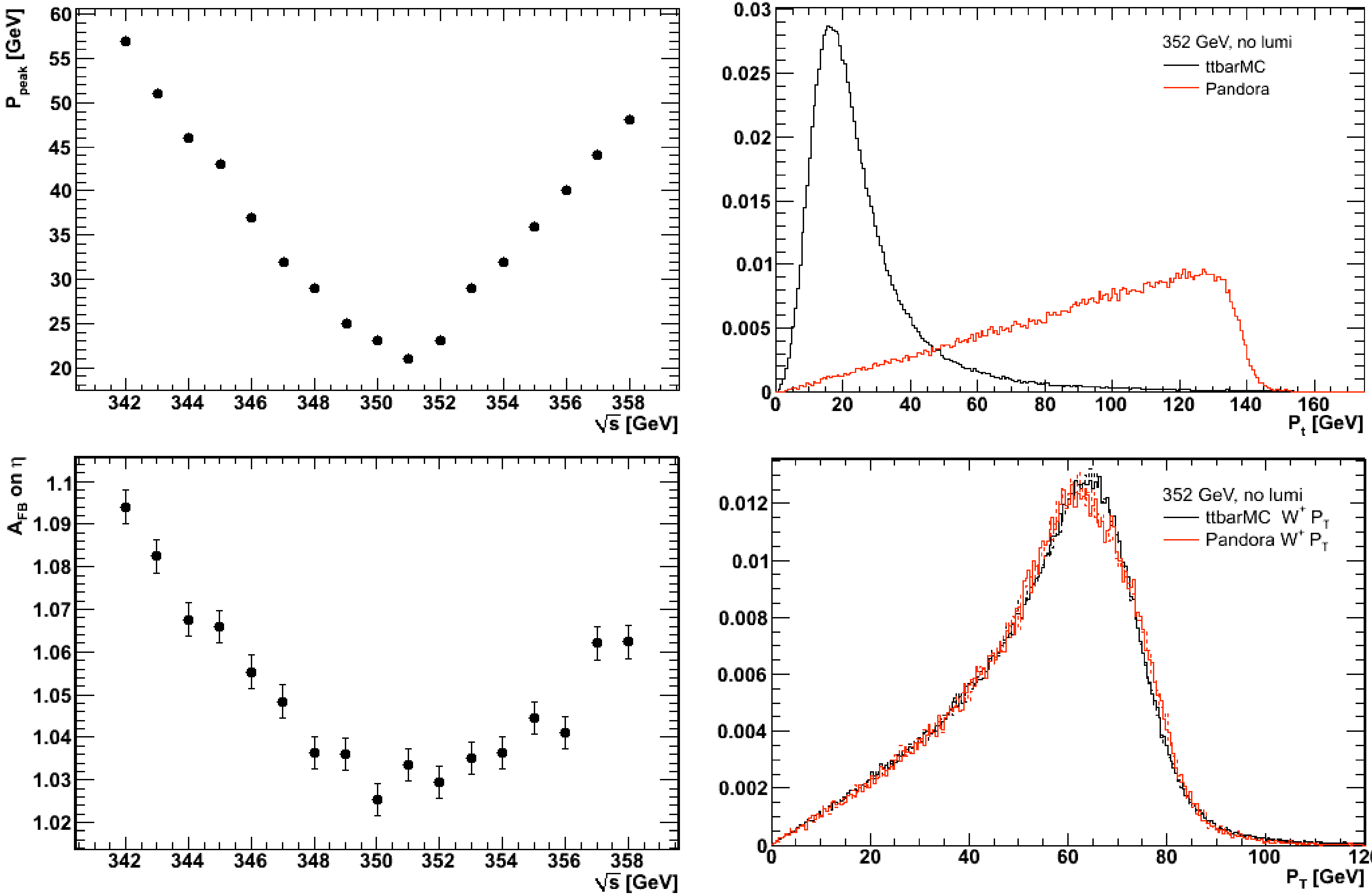


Summary and Outlook

- This is a benchmark measurement for any future e^-e^+ collider. Also methodology and luminosity spectrum issues the same for most other threshold scan measurements (W+W-, SUSY etc)
- The method and tools for a detailed and conclusive study are finally here.
- Now what remains is to 'turn the crank' for determining the luminosity spectrum impact on the top threshold
- There is progress also in luminosity spectrum extraction and related systematics studies but not reported in this talk (12min never enough)..
- Final part of this study will be quick (i.e. SIMDET) ILD study of ttbar reconstruction performance and (time permitting) luminosity spectrum detector reconstruction study.
- We are trying to define :
  - Effect of luminosity spectrum (solo and extracted) on full differential threshold measurements
  - Luminosity spectrum extraction precision needed and method validation
  - Precision needed to be matched by the absolute beam energy measurements (upstream/downstream energy spectrometers)
  - In some way these studies also constraint the acceptable accelerator parameter plane.. (at least at the ttbar threshold)…
- For results look out at the next big ILC conference (and for publication in autumn ?)

BACK UP

example ttbarMC distributions



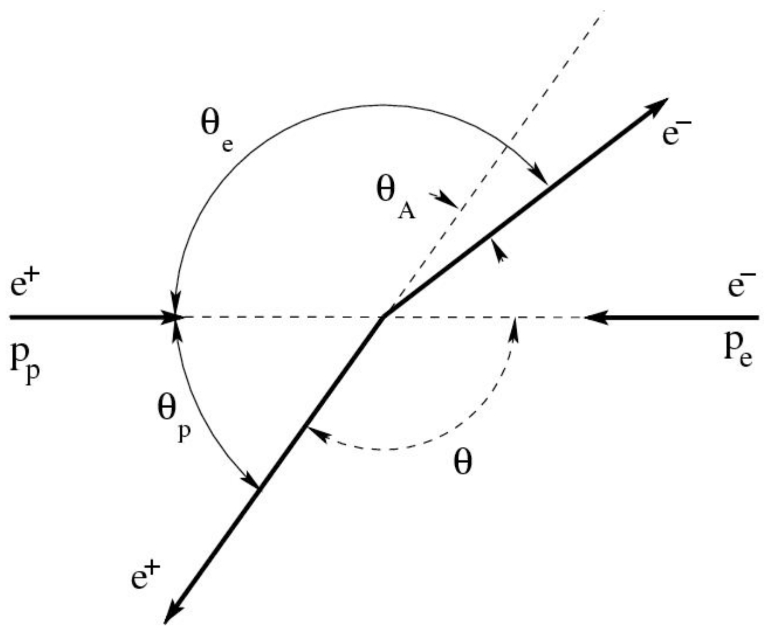
Bhabha Acolinearity

- Bhabha scattering to monitor lumi spectrum
  - $e^+e^- \to e^+e^-(n)\gamma$
  - High enough rate (statistics)
- Two approximate reconstruction methods:
  - Only uses angles of scattered electron and positron
  - Based on assumption of single photon radiation
  - Frary-Miller

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

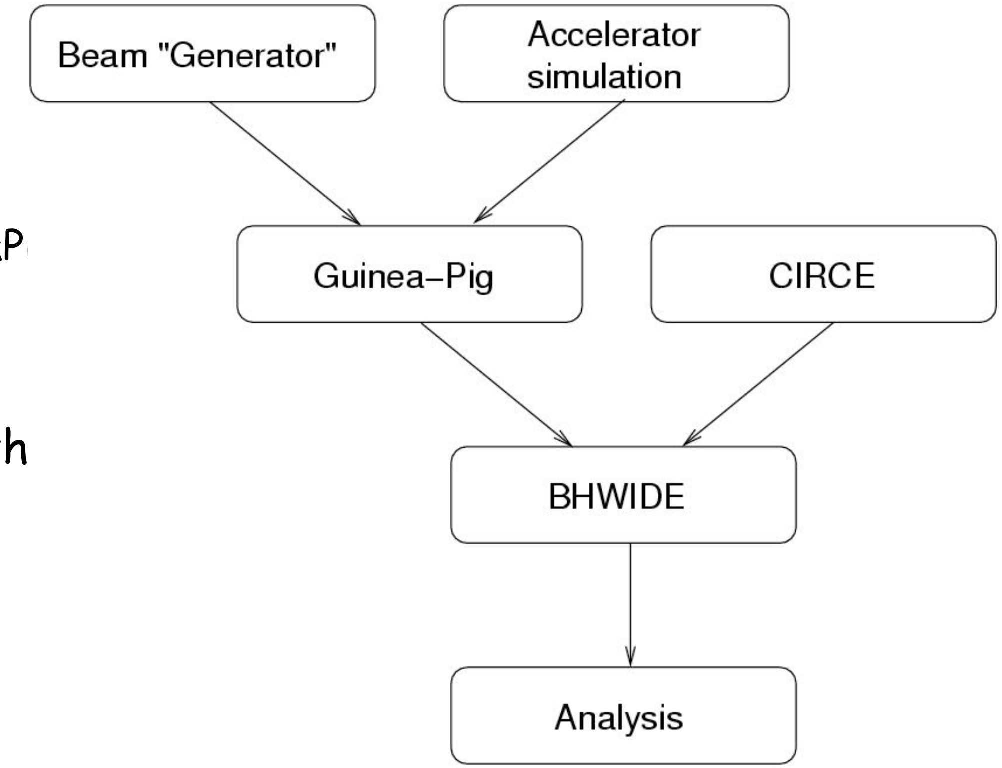
  - K. Mönig

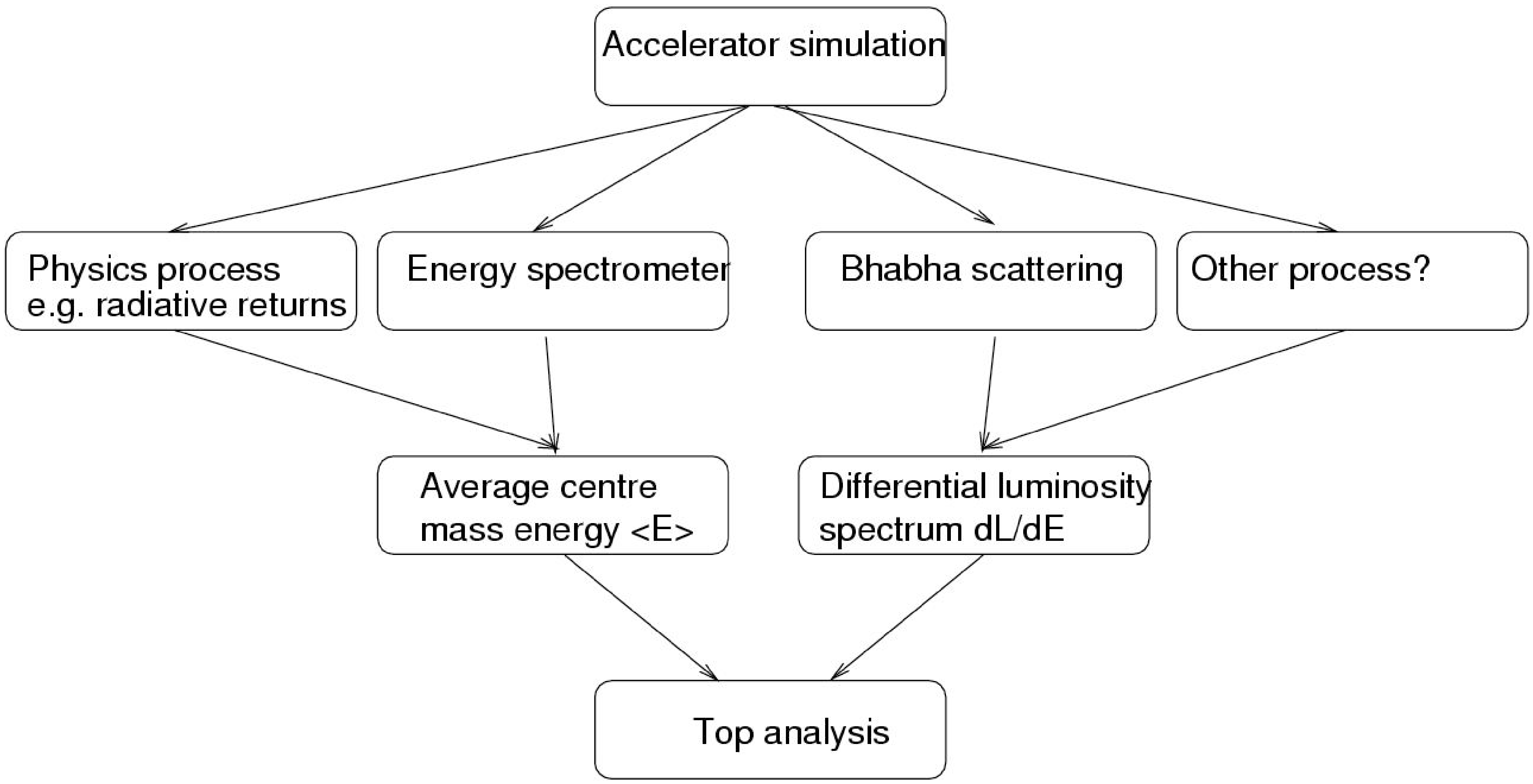
$$x = \sqrt{\cot\frac{\theta_p}{2}\cot\frac{\theta_e}{2}}$$



Simulation (for spectrum extraction)

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




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