Towards a MC event generator for ttbar production at threshold

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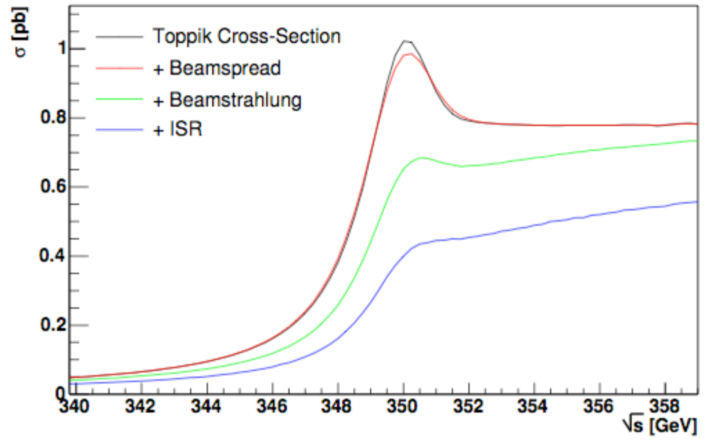
Talk Outline

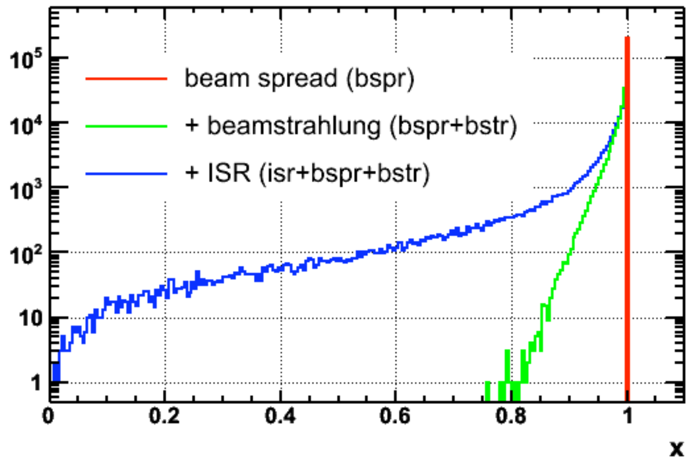
- Introduction
  - ttbar threshold @ ILC
  - luminosity spectrum (details in next talk by S.Boogert)
- Threshold Simulations
  - what we have
  - what we need
  - new generator for ttbar threshold
- Conclusions and Future Plans

ttbar threshold @ the ILC

- One of the important ILC physics targets.
- Best direct measurement of top mass will be at the ttbar threshold (CME~$2M_t$) .
  - Perturbative (non relativistic) QCD applicable since $\Gamma_t > \Lambda_{QCD}$ -> no hadronization.
  - Clean experimental environment, well understood backgrounds
- Total cross-section sensitive to M_t, Γ_t, α_s .
  - Simple color singlet counting experiment
  - Can extract information about α_s and top-Yukawa coupling
- Complications arise due to the luminosity spectrum
  - At the ILC the beam energy at the IP gets smeared by various energy loss mechanisms :
    - Initial State Radiation (ISR)
    - Beamspread
    - Beamstrahlung
  - See next talk in this session by S.Boogert
- Threshold observables will be smeared by the luminosity spectrum :

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

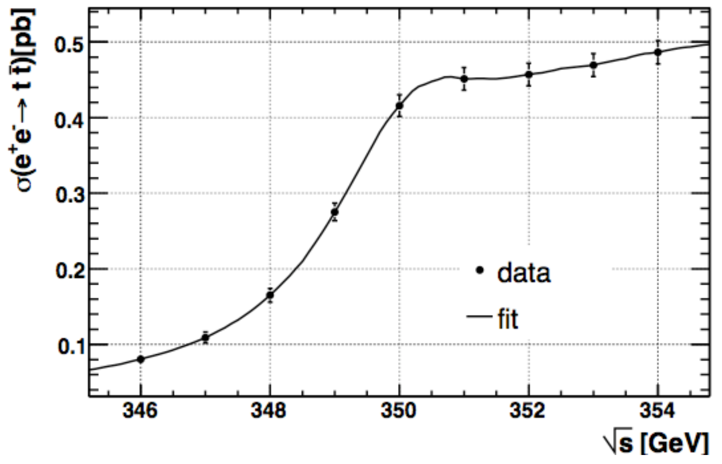


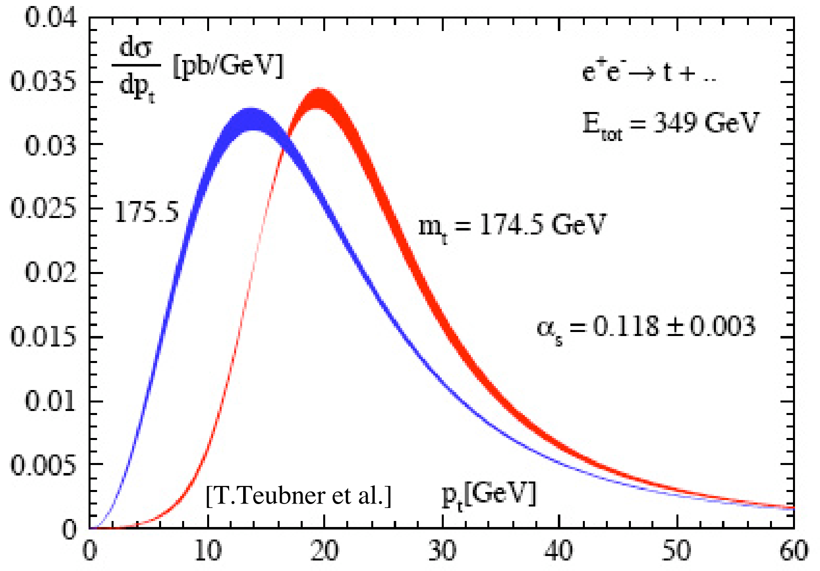


For precision threshold physics a good knowledge of the luminosity spectrum and its inclusion in event generation is fundamental

Threshold Simulations

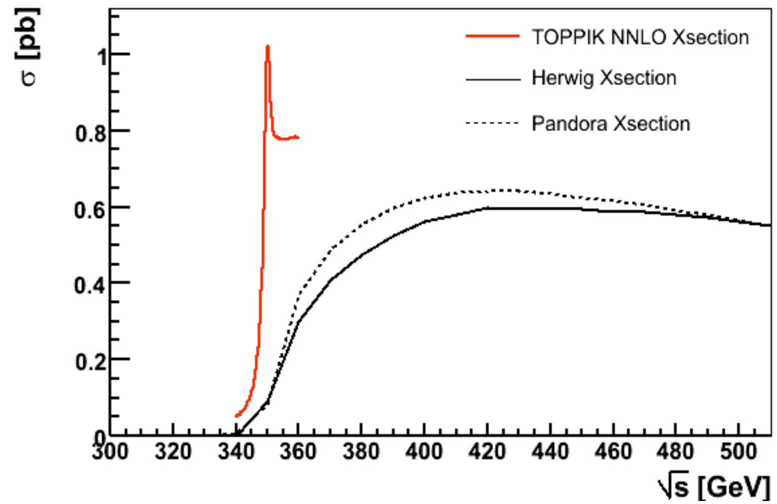
- Up to now only 'brute force' $\sigma_{tot} \times \mathcal{L}$ folding and fitting simulations exist (S.Boogert - FG, Martinez - Miquel etc)
- For precise understanding of the top threshold we need to go to fully differential simulations, event generation etc.
- Can see the effects of the luminosity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





theoretical tools and problems

- MCs on the market not precise enough for ttbar threshold (need to include all QCD effects etc.)
- High order calculations exist for many years now, but never implemented into a (usable) generator.
- TOPPIK (Hoang & Teubner) is best available theoretical description :
  - NNLO QCD including differential quantities
  - NNLL total cross-section & NLO rescattering corrections



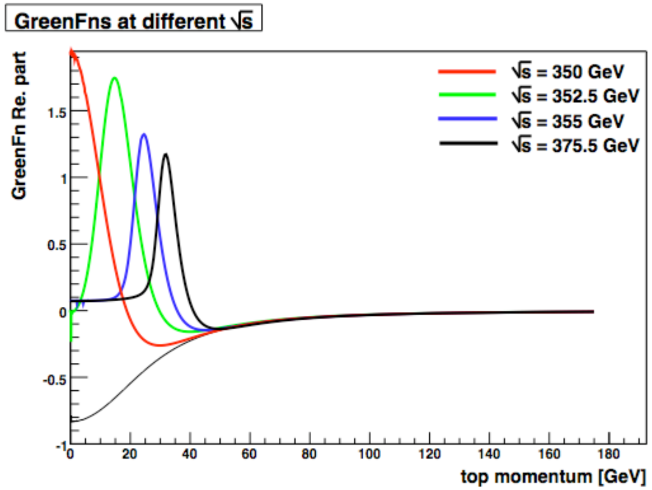
MC based on TOPPIK

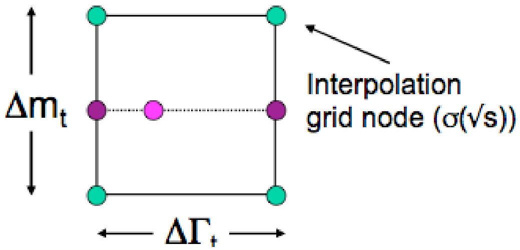
Technical challenge to make TOPPIK into a MC

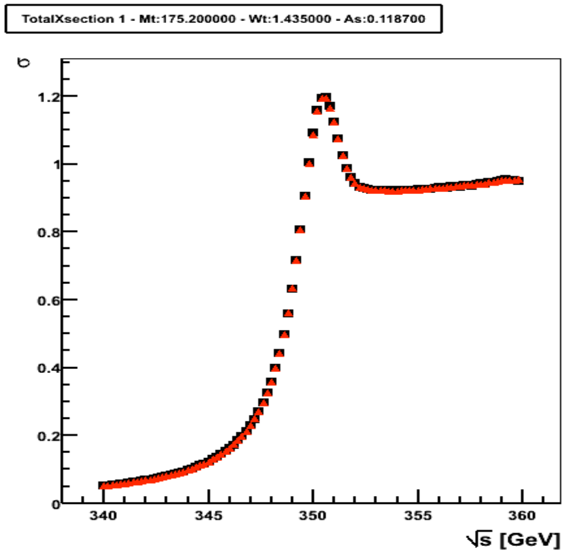
- Speed the main issue with >1.5sec per calculation
- Impractical to 'dynamically' calculate theory and generate events

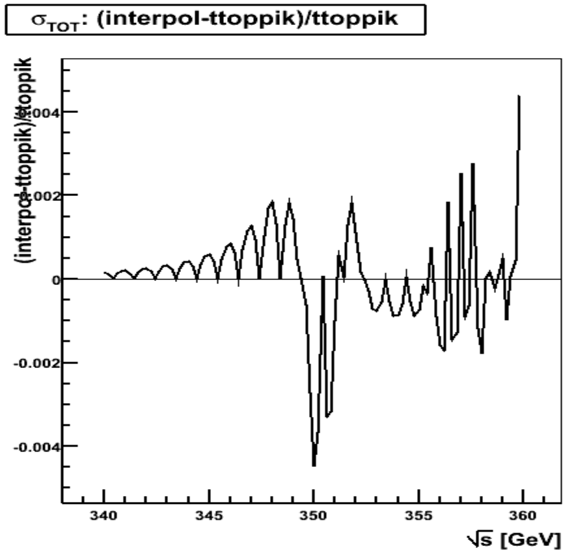
the solution: fast interpolation

- NNLO calculation by solving the Lippmann-Schwinger eq. in momentum space.
- Effectively calculating a set of Green functions for every set of $(M_t, \Gamma_t, \alpha_s, \sqrt{s})$
- By calculating once and storing the distributions can apply multidimensional interpolation techniques to access any point of the parameter space within the stored grid.
- Interpolation in all parameters gives a x5 speed up
- Interpolation only in CME gives a $x10^6$ speed up !!!
- Can calculate all observables from the Green functions









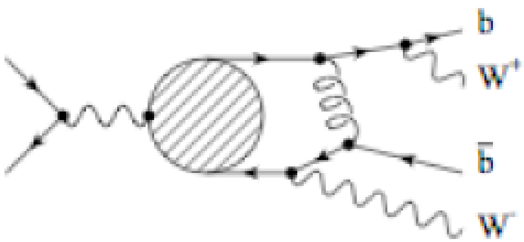
ttbar threshold event generator (schematic)

With guidance of Thomas Teubner

NLO rescattering corrections

Modify Green's functions

NNLL renormalization group improved total Cross section (only)



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

Scale total Cross section reduces theoretical uncertainty

Apply beam effects !!

Top quark four momenta

Give to Pythia / Herwig to decay top quarks

Event Generator

Lots of interfacing and technical issues involved.

ttbar threshold event generator (technical)

- At the technical level the threshold generator keeps the basic layout/structure of Pandora.
  - OO C++ code
  - Process class defining physics process and giving cross-section etc calculations (wrapped around the interpolator)
  - Beam classes for defining ILC-like beams (all inherit from generic beam class so user can add-on its own methods)
  - Interface class to MC Integrator - currently using FOAM (S.Jadach), Pandora uses Vegas.

- MC Integrator does the phase space integration and returns events weighted by :

$$\sigma_{tot}^{exp} = \int_0^1 D(x_1, x_2)\sigma_{tot}^{th}(x_1 x_2 E_1 E_2) dx_1 dx_2$$

- Event class format keeps Pandora layout and thus planning to use the pandora_pythia interface for hadronization.

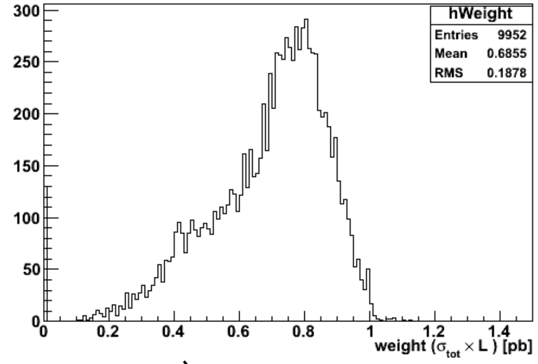
- Full ROOT integration with object persistency etc.
  - Nice feature of FOAM is that it is integrated in ROOT, thus inheriting all the ROOT I/O.
  - This means that at any point you can write the generator status to disk, stop the process, and next time you restart it starts exactly at the state it was before -> Useful for mass production of events.

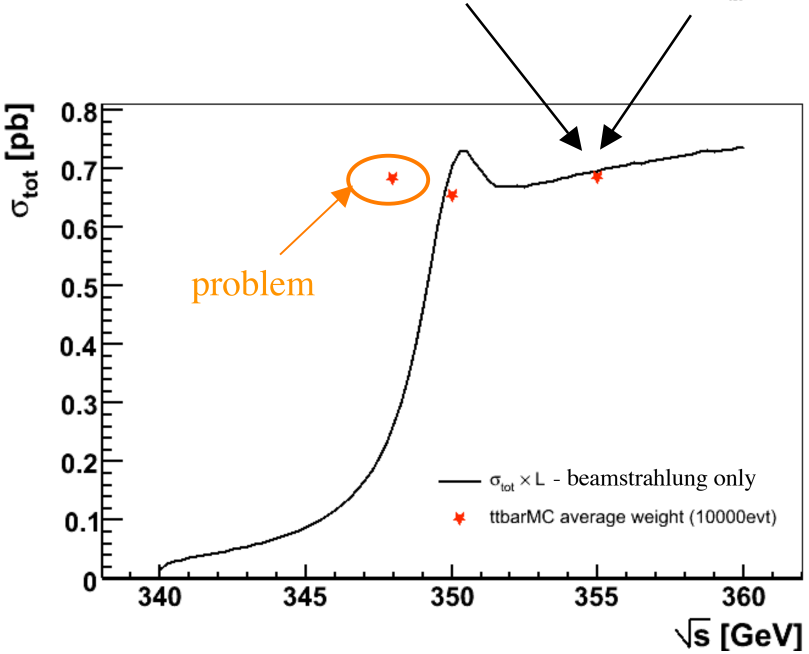
weighting the event generation

- MC integration surface defines the probability by which you choose events in generation
- Weight should be the luminosity spectrum folded cross-section
- Effectively computing the luminosity spectrum folded cross-section integral (of previous slide) to build up the integration surface.
- Generate events according to $\sigma_{tot} \times \mathcal{L}$

- Need to optimize integrator for our purpose (out of the box Foam is not optimal)
  - takes too long to build integration surface
  - gives some fraction of events with unrealistic weights (even when correct weights go into integration surface)

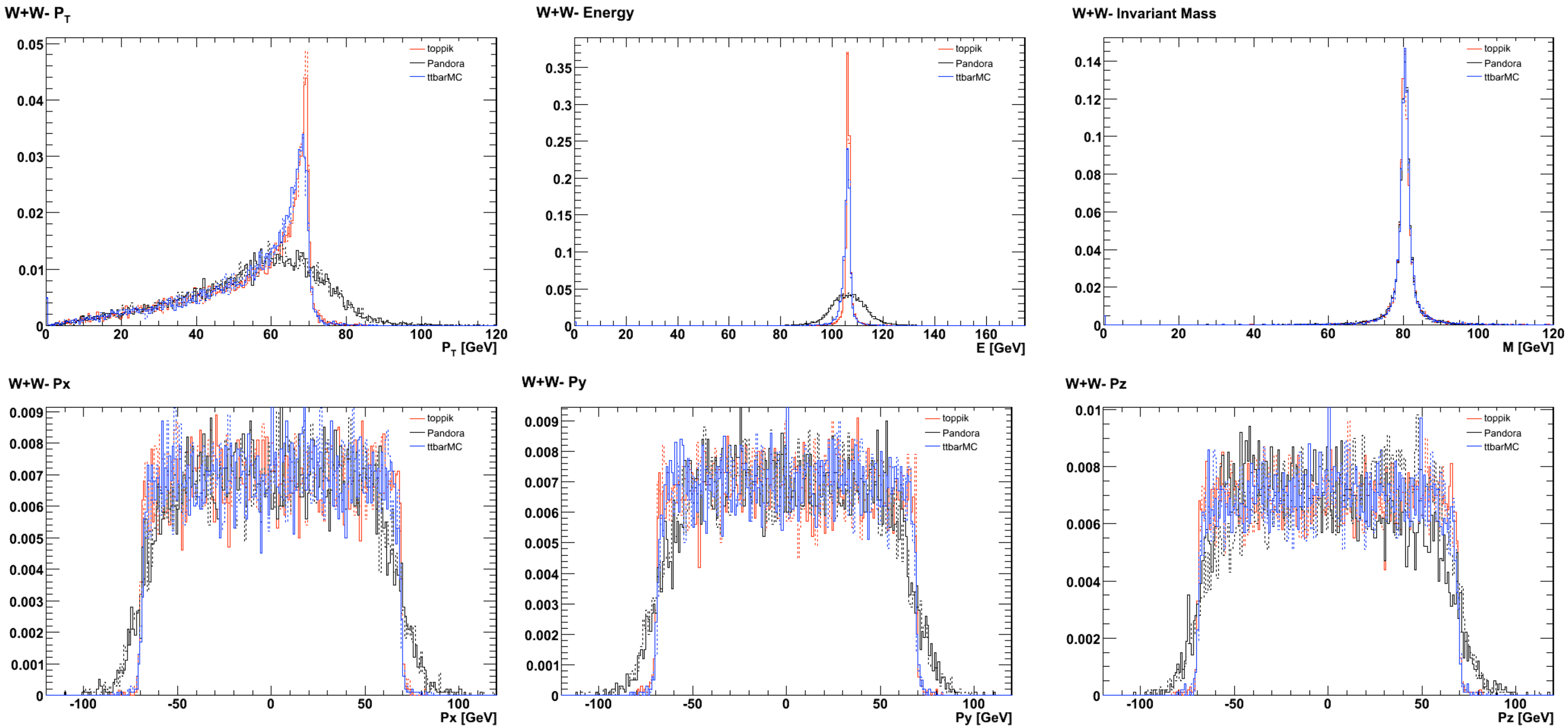
- Pandora uses Vegas (which seems fast and robust)
- Can easily interface our code with Vegas
- Talk with Pandora / Foam people about this..
- This has been done before and should be relatively easy to fix…





Preliminary distributions (using MC integrator)

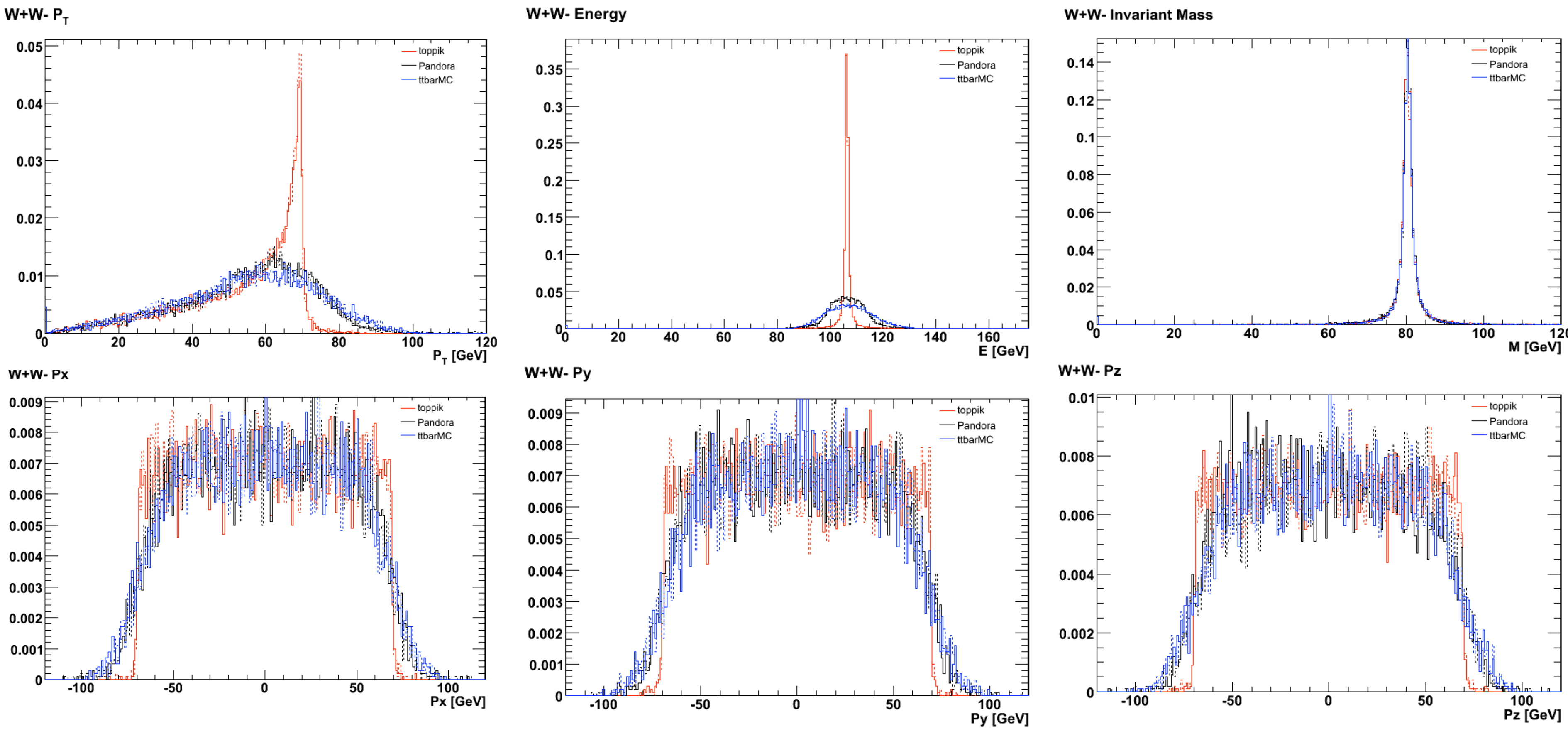
- Preliminary distributions (using FOAM for MC integration) at CME = 352 GeV
  - Pandora and ttbarMC both include a luminosity spectrum, toppik uses 'perfect' beams.



toppik in these plots corresponds to an old attempt by T.Teubner & M.Jezabek to an event generator (using NLO calculations) that ended up being too slow.

Preliminary distributions (no integrator)

- Not using integrator, just simple random number throwing (and kinematic checks).
  - Using same settings (CME = 352GeV) but no lumi spectrum now.
- Distributions now match Pandora in shape!
- Something very wrong in the way we generate? Bug? … work in progress…



Conclusions and the future…

UCL

- The long-awaited prototype version of a 'realistic' ttbar threshold event generator is (almost) here.

- Main problem until now (speed) is fixed.
- Framework is ready and awaiting few last issues to be resolved
- Still lots of things to be included:
  - Fix problem with Foam and choose between it and Vegas…
  - Implementation of :
    - NNLL corrections - will change weight of total cross-section
    - NLO rescattering corrections to be included in the pre-computed Green functions
    - Include polarization
    - Interface general purpose 'hadronizer' (Jetset / Pythia)
  - Test test test…

- Eventually have a distribution version (soon !!) and write-up
- Perform a 'realistic' ttbar threshold analysis, determine effect of luminosity spectrum and define luminosity spectrum dependent requirements related to threshold scans.
  - Absolute energy measurements (energy spectrometers) - required precision? [See Saturday MDI session]
  - Luminosity spectrum reconstruction - required precision? [See Tomorrow's MDI session]
  - Threshold scan strategy (luminosity per point/where to put the scan points etc)