# tt~ Production at ATLAS
# and
# tt~ Monte Carlo Generators

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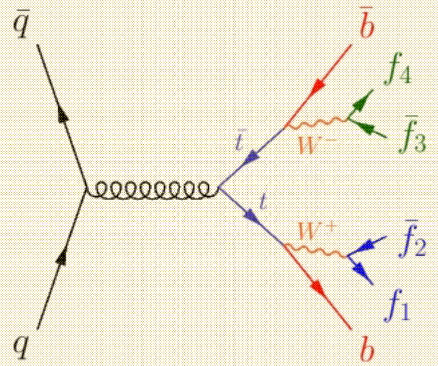
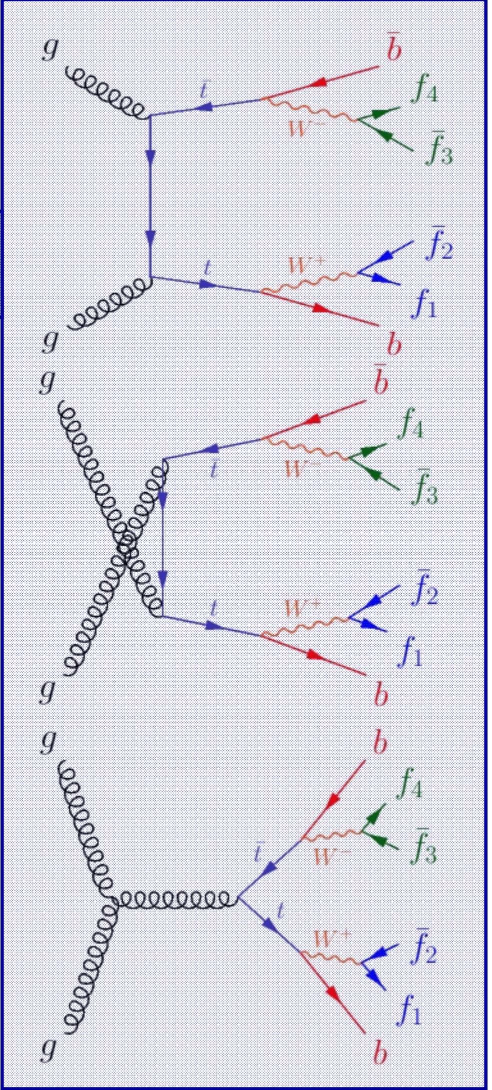
# What is tt~ production at LHC?

- NLO Cross-section for tt~ production at LHC is $\sigma$(tt)~830 ± 100 $pb^{-1}$(LO about ½ of this at the same scale)
  - → About 90% contribution from gg colissions
  - → the remaining 10% from qq~ collisions

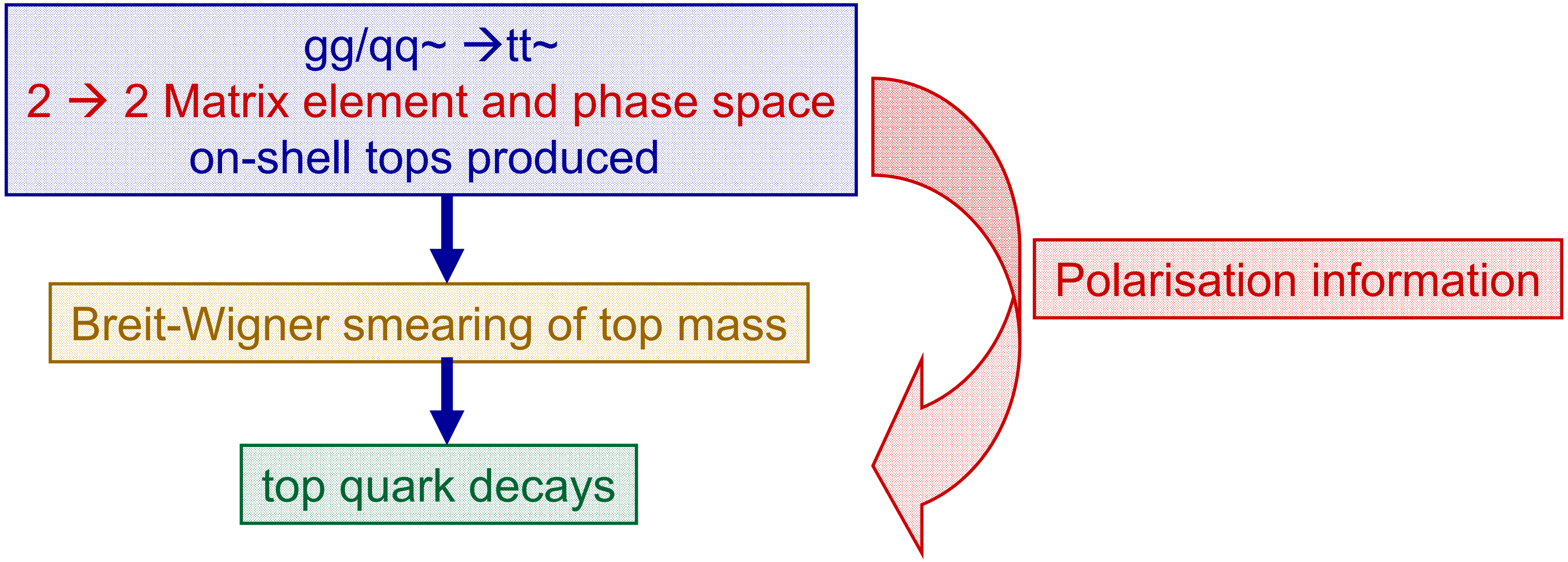


  - → Main sources of uncertainties are the scale choice and the PDF uncertainties
- Two sequential resonant (Breit-Wigner type) decays of tops and W-s
- Angular (spin) correlations between the decay products.



# Simplifications

- Monte Carlo generation of the full 2 → 6 process (gg/qq~ → bb~$f_1f_2f_3f_4$) turns out to be difficult.
- To simplify the generation procedure approximations are often used:



gg/qq~ →tt~

2 → 2 Matrix element and phase space

on-shell tops produced

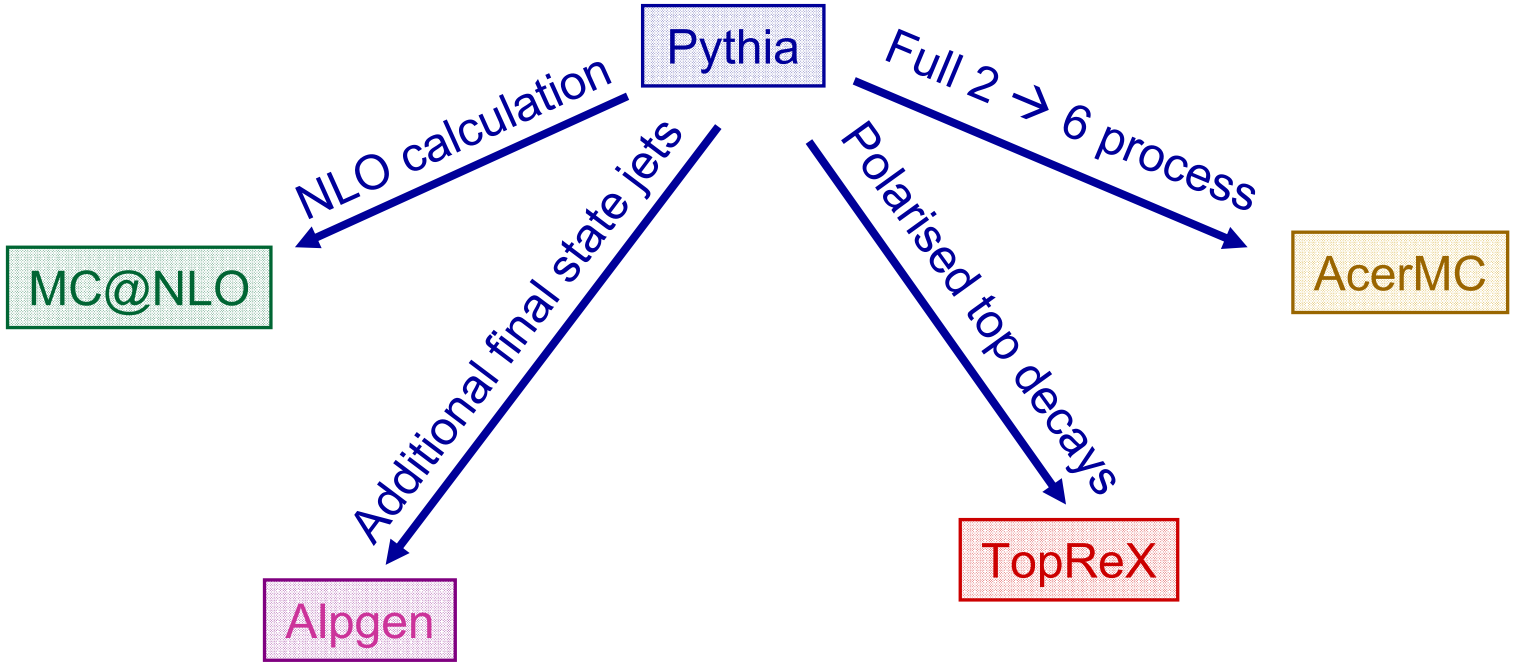
Breit-Wigner smearing of top mass

top quark decays

Polarisation information

# Progress in tt~ Monte Carlos

- To schematically illustrate the development of tt~ Monte Carlo generators (ATLAS uses all of them):



Pythia

NLO calculation

MC@NLO

Additional final state jets

Alpgen

Polarised top decays

TopReX

Full 2 → 6 process

AcerMC

# Comparison between tt~ generators

- Pythia has: 2→2 LO ME, BW top smearing, unpolarised top decays
- TopRex has: 2→2 LO ME, BW top smearing, polarised top decays
- Alpgen has: 2→2 LO ME, no BW top and W smearing, polarised top decays, up to four additional jets (quarks and gluons)
- MC@NLO has: 2→2 NLO ME, BW top smearing, unpolarised top decays
- AcerMC has: full 2→6 LO ME and phase space (polarisations implicit).

What we want at ATLAS is clearly
all of it!
:-)

# Full 2 →6 process: Why is it so difficult?

- One thing is the matrix element itself; today automatic tools like Madgraph/HELAS exist that do it for you.
  - → There are however still some issues!
- First and foremost however, the efficient Phase Space sampling is difficult to achieve!
  - → Experimentalists want unweighted events to pass through the complex detector simulation/digitization/reconstruction!
    - The complexity of the problem increases with the number of Feynman diagrams for a certain process.
    - Difficulty level also increases with the number of particles in the final state.
    - Also hard to efficiently describe are the invariant mass. distributions at the threshold of heavy particle production.

# AcerMC 2.x Monte Carlo Generator

- The Monte Carlo generator for a select list of processes at ATLAS/LHC.
- Current version is AcerMC 2.4
- Code and documentation available from the web: http://cern.ch/borut

**Currently implemented processes**

1. $gg \to t\bar{t}b\bar{b}$
2. $q\bar{q} \to t\bar{t}b\bar{b}$
3. $q\bar{q} \to W(\to f\nu)b\bar{b}$
4. $q\bar{q} \to W(\to f\nu)t\bar{t}$
5. $gg \to Z/\gamma^*(\to f\bar{f})b\bar{b}$
6. $q\bar{q} \to Z/\gamma^*(\to f\bar{f})b\bar{b}$
7. $gg \to Z/\gamma^*(\to f\bar{f})t\bar{t}$
8. $q\bar{q} \to Z/\gamma^*(\to f\bar{f})t\bar{t}$
9. $gg \to (Z/W/\gamma^* \to)t\bar{t}b\bar{b}$
10. $q\bar{q} \to (Z/W/\gamma^* \to)t\bar{t}b\bar{b}$
11. $gg \to t\bar{t} \to b\bar{b}f\bar{f}f\bar{f}$
12. $q\bar{q} \to t\bar{t} \to b\bar{b}f\bar{f}f\bar{f}$
13. $gg \to b\bar{b}f\bar{f}f\bar{f}$
14. $q\bar{q} \to b\bar{b}f\bar{f}f\bar{f}$
15. $gg \to t\bar{t}t\bar{t}$
16. $q\bar{q} \to t\bar{t}t\bar{t}$

**Top quark production**

# AcerMC 2.x Monte Carlo Generator

- LO Matrix elements obtained from modified MADGRAPH/HELAS3 code:
  T. Stelzer and W. F. Long, Comput. Phys. Commun. **81** (1994) 357.
- Parton density functions from LHAPDF or PDFLIB804.
- Phase space sampling done by native AcerMC routines based on:
  - Adaptive multi-channel approach,
    R. Kleiss, and R. Pittau, Comput. Phys. Commun. **83** (1994) 141.
  - Revised Kajantie-Byckling phase space factorisation,
    E. Byckling and K. Kajantie, Nucl. Phys **B9** (1969) 568.
    B. Kersevan and E. Richter-Was, Eur. Phys. J. **C39** (2005) 439.
  - AcerMC native 'massive' importance sampling functions of particle four-momenta.
    B. Kersevan and E. Richter-Was, hep-ph/0405247.
  - Additional Ac-VEGAS adaptive grids/algorithms:
    G. P. Lepage, J. Comput. Phys. **27** (1978) 192.

**The final unweighting efficiency is between 10-40%, depending on the process!**

# AcerMC tt~ 2 → 6 process

- Generation (unweighing) efficiency ~ 15% achieved.
- The inclusive cross-section matches other LO predictions.
- The spin correlations are certainly there as shown by the helicity angle distribution:

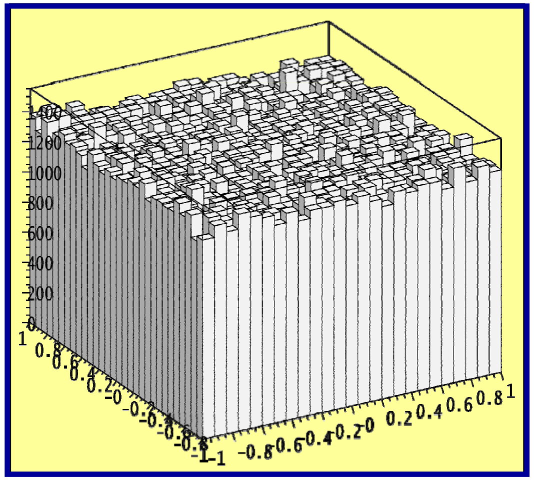
$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1 + C\kappa\cos\theta_+\cos\theta_-}{4}$$

$C = -0.34$ (degree of spin correlation in helicity base)

$\kappa$ (spin analyser quality : 1 for leptons)

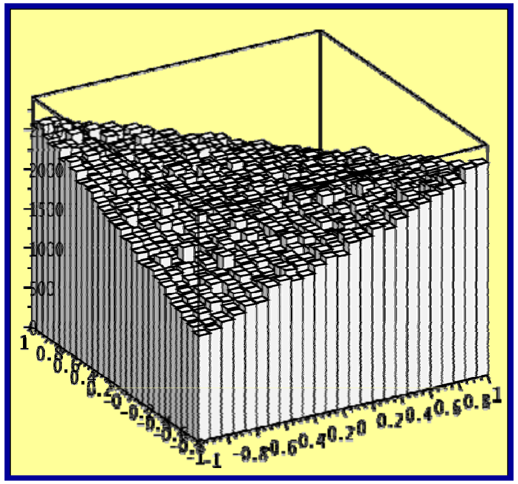
No helicity correlation

<CosΘ+ · CosΘ->



Helicity correlation

<CosΘ+ · CosΘ->



AcerMC Helicity correlation

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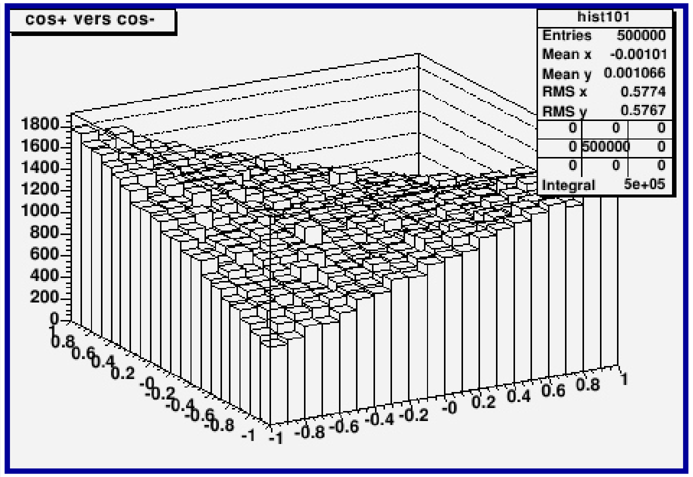
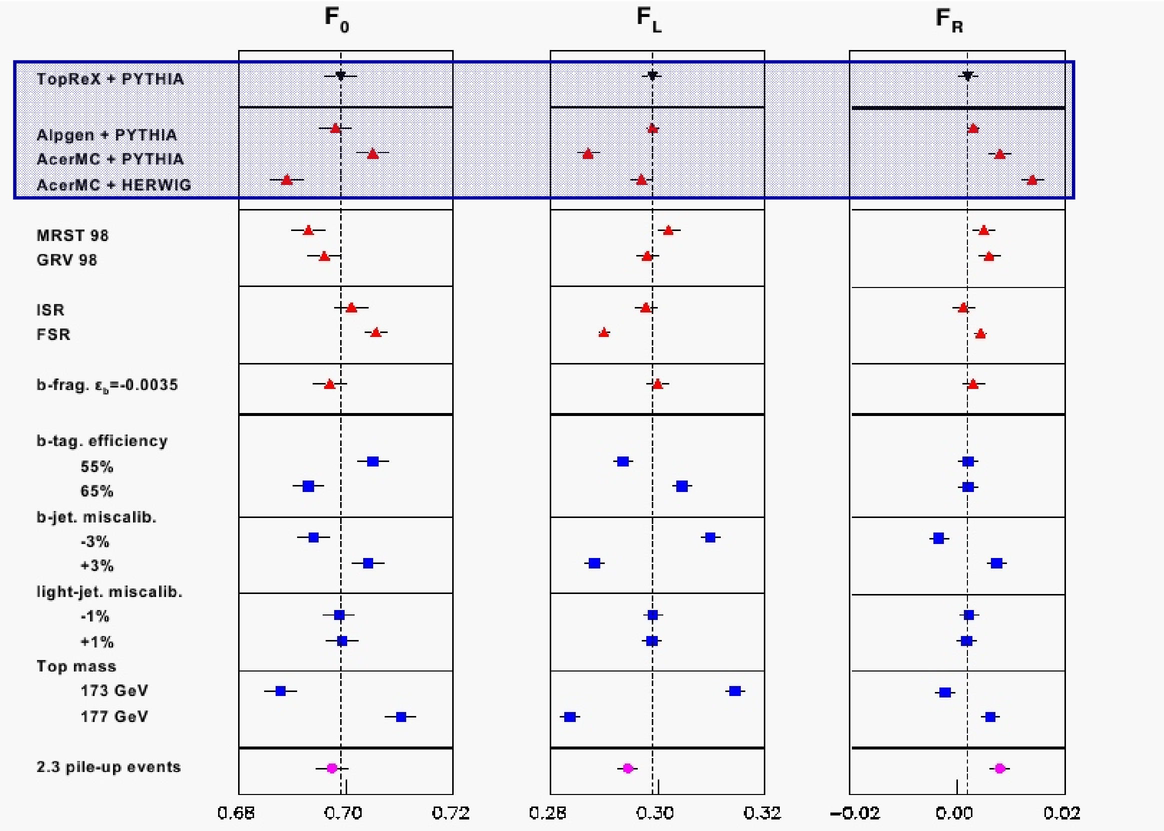


# AcerMC tt~ 2 →6 process

- The question is of course, whether there are any observable differences?
  → Results from F. Hubaut et al doing W polarisation studies in tt~ events

Toprex is taken as input,
agrees reasonably well with
Alpgen
which uses similar strategy

AcerMC shows
a small disagreement
(hard process scales not matched)

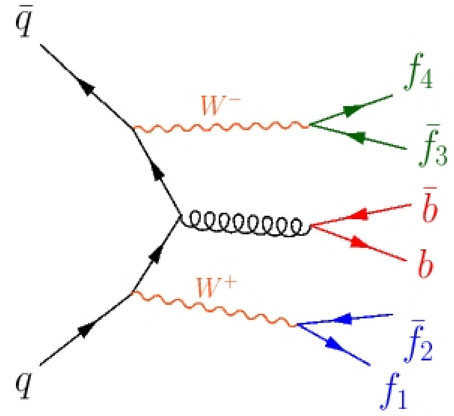


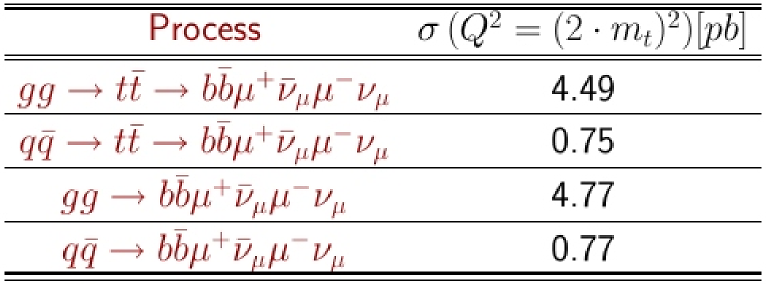
ATLAS scientific note SN-ATLAS-2005-052

# We can go one step further: Adding non-resonant contributions

- AcerMC handles well 6 particle final states:
  - → We expand the tt~ matrix element to include all WWbb intermediate states: 45 Feynman diagrams
  - → The contributions to the total cross-section quite small, however turn out to be vital to the Higgs searches at LHC: Studies show an up to a factor 2 increase in backgrounds!
    - N. Kauer Phys.Rev.D67:054013,2003
  - → Further studies needed!

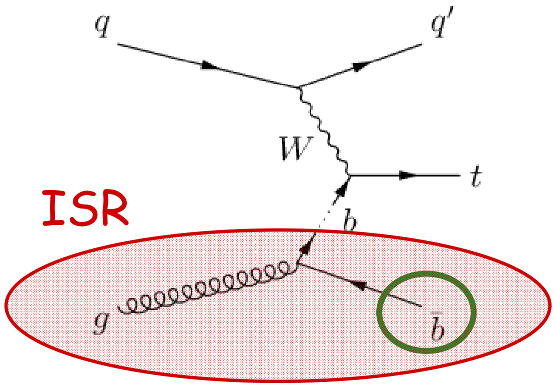
A representative 'non-resonant' diagram





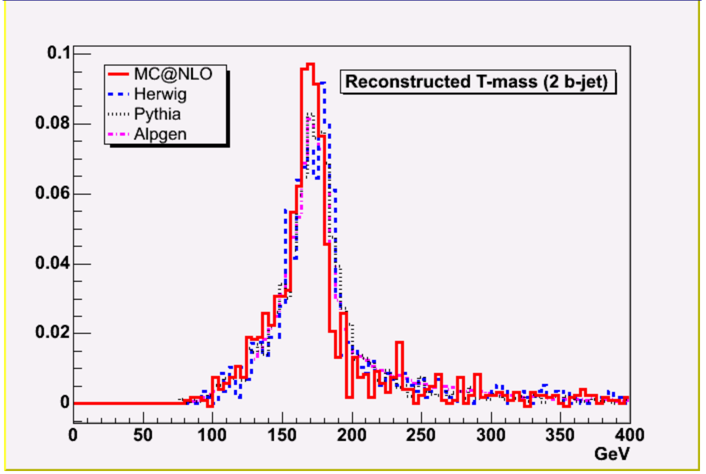
| Process | $\sigma\,(Q^2 = (2\cdot m_t)^2)[pb]$ |
|---|---|
| $gg \to t\bar{t} \to b\bar{b}\mu^+\bar{\nu}_\mu\mu^-\nu_\mu$ | 4.49 |
| $q\bar{q} \to t\bar{t} \to b\bar{b}\mu^+\bar{\nu}_\mu\mu^-\nu_\mu$ | 0.75 |
| $gg \to b\bar{b}\mu^+\bar{\nu}_\mu\mu^-\nu_\mu$ | 4.77 |
| $q\bar{q} \to b\bar{b}\mu^+\bar{\nu}_\mu\mu^-\nu_\mu$ | 0.77 |

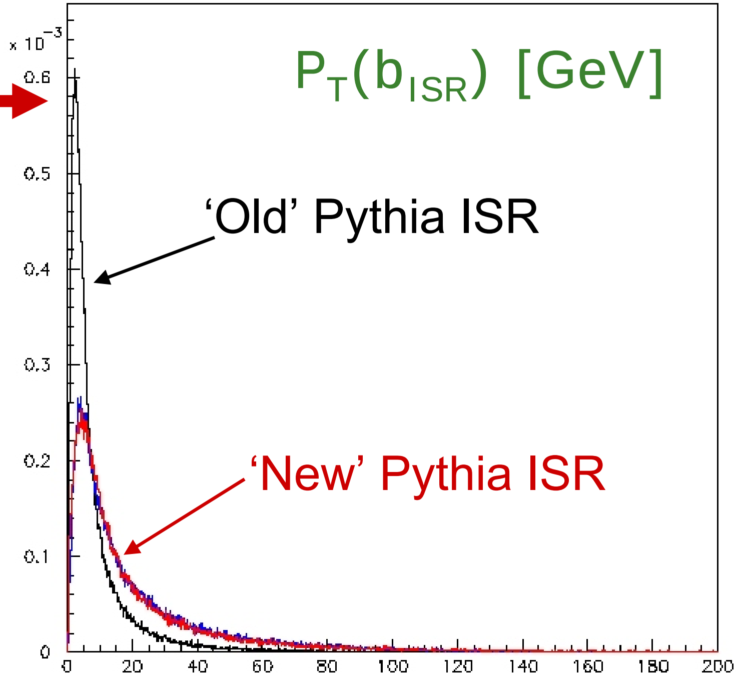
# Interface to showering/fragmentation Generators



- ATLAS uses Herwig 6.507.2 with 'native' (ATLAS) fixes - a must for MC@NLO; in addition Jimmy 4.2 is used for UE simulation.
- ATLAS also uses Pythia 6.324 with the new showering and underlying event modeling: some changes ahead!

Studies done by the ATLAS NIKHEF group





# ATLAS UE/MB tunings

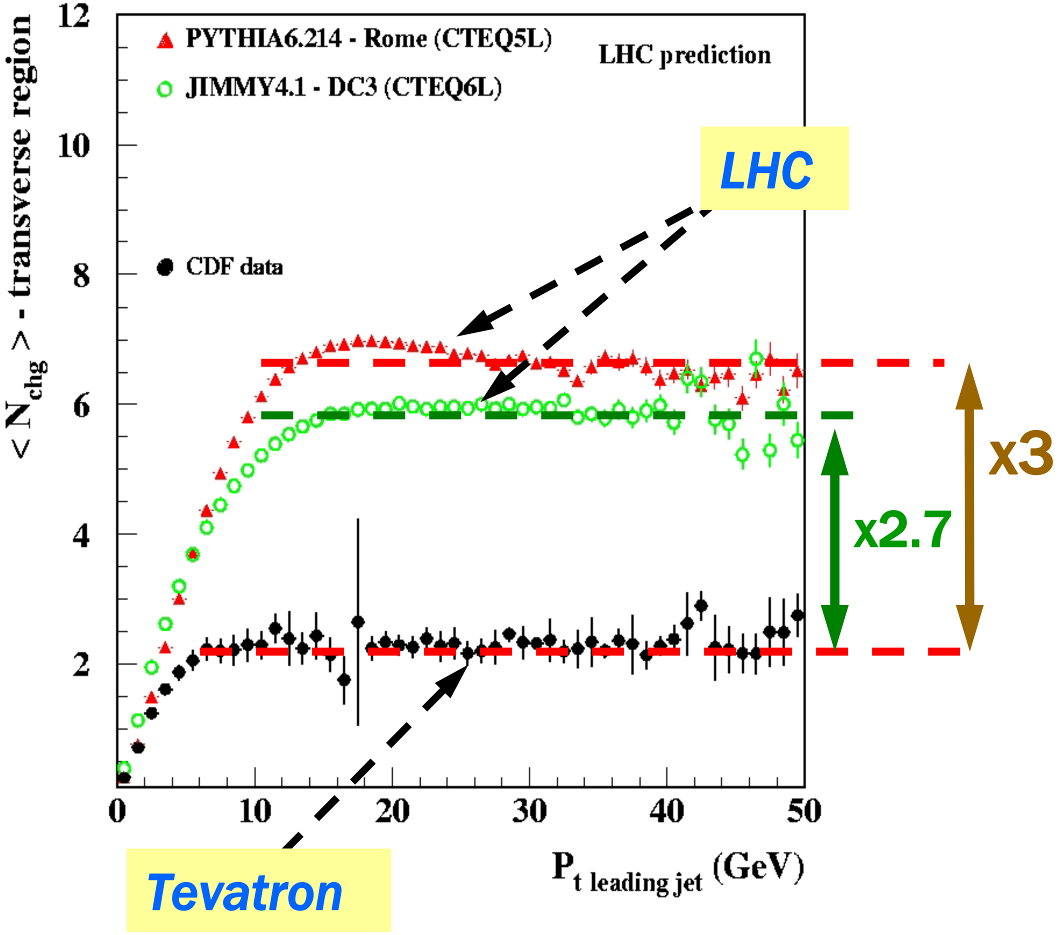
- Using new energy dependent tunings of Jimmy 4.1

  → (*A. Moraes et. al.*)

**PTJIM=4.9**

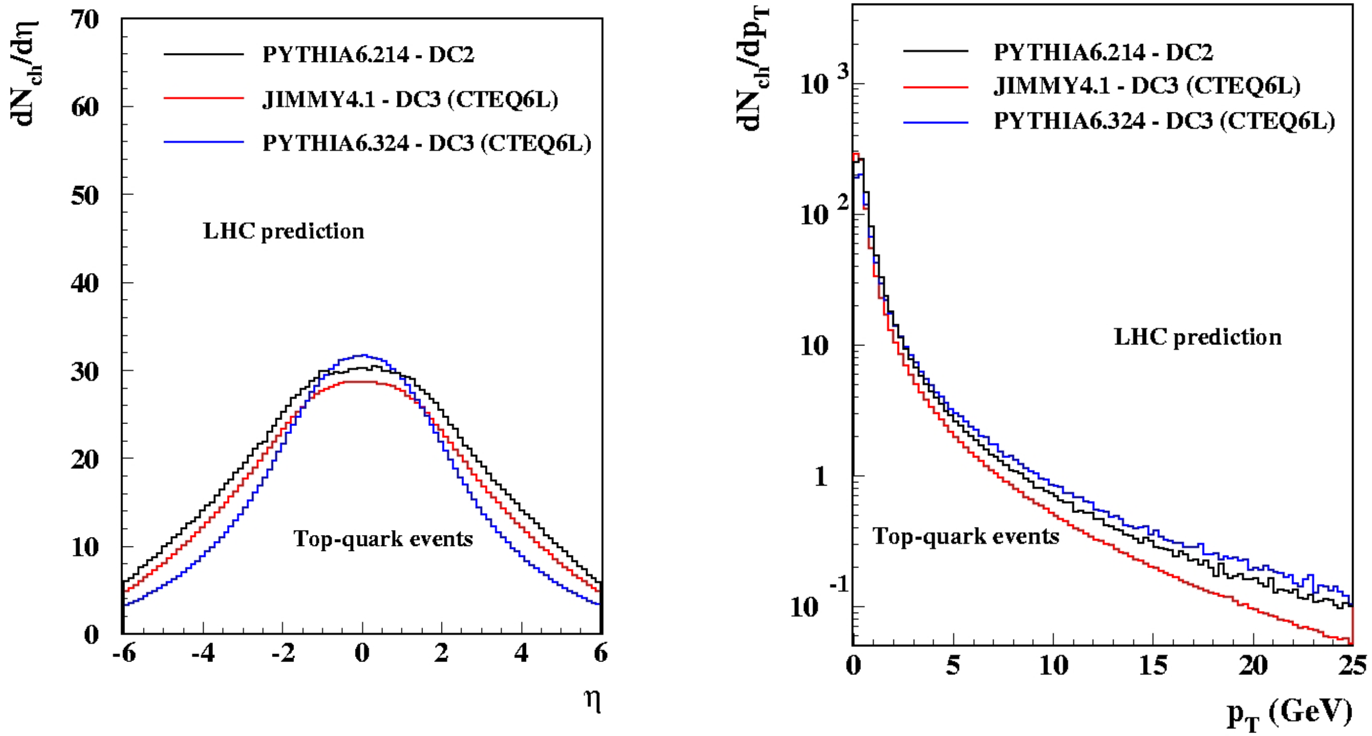
**$= 2.8 \times (14 / 1.8)^{0.27}$**

**Energy dependent PTJIM generates UE predictions similar to the ones generated by PYTHIA6.2 – ATLAS.**



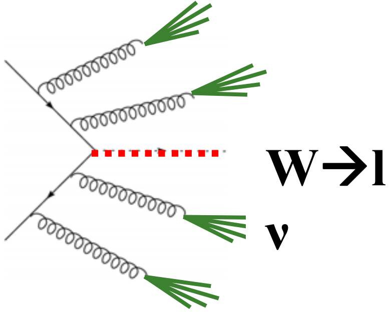
# ATLAS UE/MB tuning:
# tt~ events

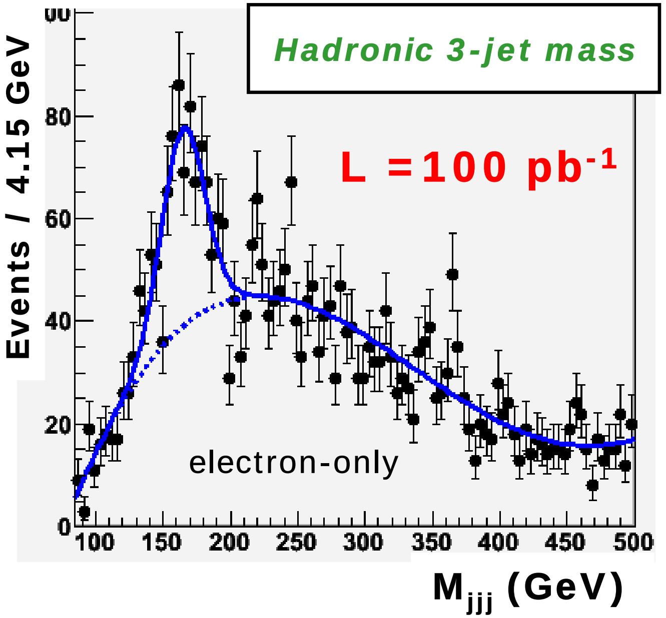
- 'Data Challenge 3` tuning: tuning based on comparisons to UE data leads to a natural agreement to PYTHIA's prediction for particle density in tt~ events at LHC.



# Just a note on backgrounds: Commissioning studies

- An interesting ATLAS commissioning study (assuming no b-tag, no jet calibration but good lepton ID) done by the ATLAS NIKHEF group uses the ALPGEN W+jets - where the strength of ALPGEN becomes obvious (exact ME for W+4 jets, MLM matching of W+n jets).





**Semi-leptonic event selection:**

- Isolated lepton with $P_T$>20 GeV
  - Exactly 4 jets with $P_T$>40 GeV and $\eta$<2.5
  - Missing $E_T$>20 GeV
  - Reconstruct top from 3 jets with maximal resulting $P_T$
  - Fit the distribution with basic shapes
  - Estimated $\varepsilon$ ~ 1%

$\Delta\sigma_{stat}$(t-tbar) ~ 2% (1 week) !!!

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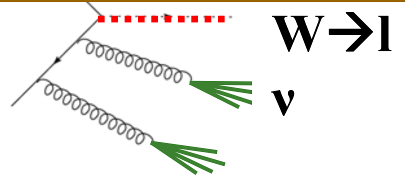
The next step is then of course to tune and test our tt~ Monte-Carlo on these distributions (as well as to include b-tag, jet calibration etc..)



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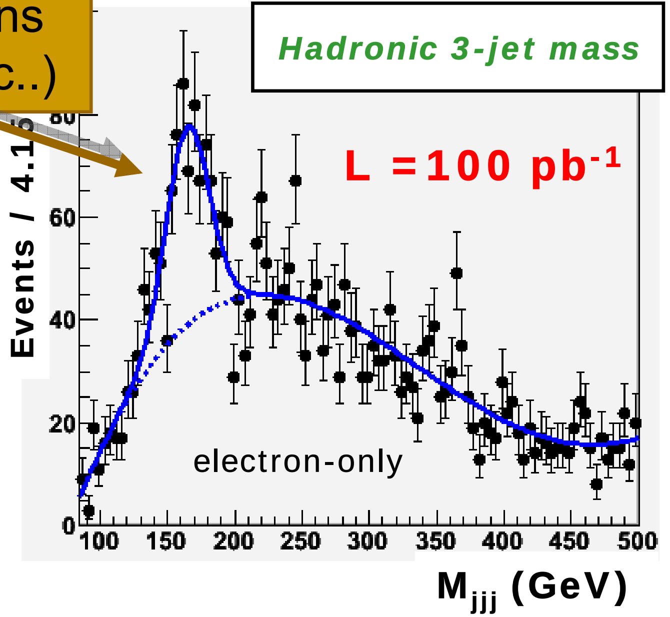

$\Delta\sigma_{stat}$(t-tbar) ~ 2% (1 week) !!!

# Conclusions

- At ATLAS we use a wide variety of Monte Carlo generators for tt~ production.
  - → Each generator has its strong points.
  - → For systematics studies and comparisons it is advantageous to use all of them.
  - → We believe to have a certain edge with the AcerMC Monte Carlo generator of full 2 → 6 tt~ production processes with resonant and non-resonant contributions.
  - → We also use different showering and fragmentation as well as UE/MB models with promising tuning procedures being implemented.
  - → Advanced studies of different Monte Carlo tools for generation of background processes are also of the essence.
- *A lot of work still to be done but we strongly believe we will be well prepared for the first top events next year!*