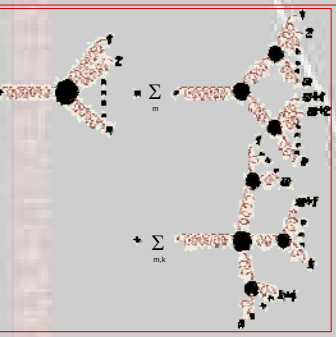
Estimating Top Backgrounds

The long road from conception to application

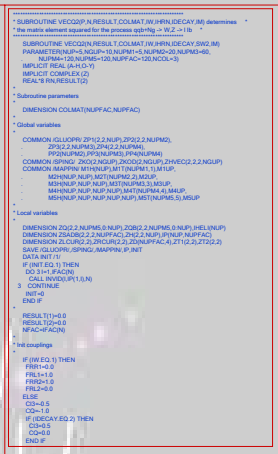


Origins of VECBOS

Development phase 1987-1989
F.A. Berends and W.T. Giele
University of Leiden

In the late 1980's theorists started to think about background estimates for a potential top quark discovery at the upcoming Run I at Fermilab.
The most important background to understand for a discovery of the top quark was the *W+ 4 jets* final state.
At leading order in perturbative QCD this process involves well over 600 Feynman diagrams (see table). The techniques to calculate and evaluate these diagrams were at that time inadequate. Only *W + 2 jets* was completed (with just 13 Feynman diagrams). New techniques were needed to scale up the complexity of the calculation by almost 2 orders of magnitude.
Clearly, any successful new technique was should be more algorithmic based such that calculations could be performed on computers.
The developed method was a recursive scheme in the number of gluons such that calculations with fewer jets were re-used (see picture). With this technique the calculation of the leading order matrix elements became feasible.

Processes	n=0	n=1	n=2	n=3	n=4	n=5
$gg \rightarrow n\,g$	-	1	4	25	220	2485
$qq \rightarrow n\,g$	-	1	3	16	123	1240
$V \rightarrow qq + n\,g$	1	2	8	50	428	4670
$qq \rightarrow q'q' + (n-2)\,g$	-	-	1	5	36	341
$V \rightarrow qq + q'q' + (n-2)\,g$	-	-	4	24	196	2040

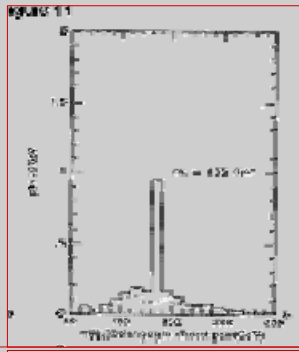


Construction of VECBOS

Coding and testing phase 1990-1992
F.A. Berends, W.T. Giele, H. Kuijf and B. Tausk

Fermilab and University of Leiden

Now that a technique was developed to evaluate all the Feynman diagrams for the *W+ 4 jets* background the next step had to be made.
This involves an explicit computer program, VECBOS, which calculates actual fully differential cross sections for the *W+ jets* final state.
Correctly developing such a code is notoriously difficult and error prone. Not only do the matrix elements need to be implemented, but also the phase space integration has to be performed correctly
At all phases of the development of the program many cross checks were developed (soft/collinear behavior, gauge invariance,…). The final check is actually producing distributions. In the graph is the first comparison ever of the 3 jet mass in lepton+neutrino+4 jets between the VECBOS monte carlo (dashed) and a top quark pair monte carlo at parton level (solid is combined signal). This simple comparison lacked all the sophistication needed for a confrontation with real data, but it gave confidence the top discovery was around the corner.



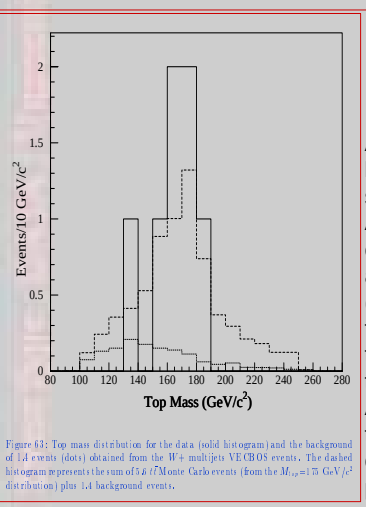


Figure 63: Top mass distribution for the data (solid histogram) and the background of 14 events (dots) obtained from the We multijets VECBOS events. The dashed histogram represents the sum of 52.6 fMonte Carlo events (from the $M_{top}=175$ GeV/c^2 distribution) plus 14 background events.

VECBOS in Action

Running phase 1993-
CDF, D0, theorists

After VECBOS was completed the code had to be implemented within the analysis software of both CDF and D0.
A close collaboration between experimenters and theorists was required at this phase on issues from the mundane (what do the parameters do) to the more fundamental issues (uncertainties in the theory prediction due to the truncation of the perturbative series).
A more difficult issue at the time was how to extend the parton level VECBOS monte carlo to a hadronic particle data prediction.
For this purpose some ad-hoc methods were developed to interface the parton level VECBOS monte carlo with the ISAJET and HERWIG shower monte carlo's which evolved the energetic partons to hadrons. From a theoretical point of view this was at the time less than satisfactory. But from the more practical experimental viewpoint it worked well (for the precisions at the time of the top quark search). The top plot is from the CDF evidence paper and compares the 3-jet mass distribution with the theory (VECBOS+ Top).
The bottom plot is the equivalent graph from the D0 observation paper.

All in all VECBOS gave experimenters confidence they understood the *W + 4 jets* background sufficiently to be sure about the top quark discovery.
This finalized a long 8 year road from trying to calculate a background (at a Leiden university) to its use in a discovery at Fermilab.

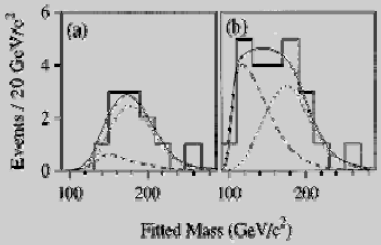


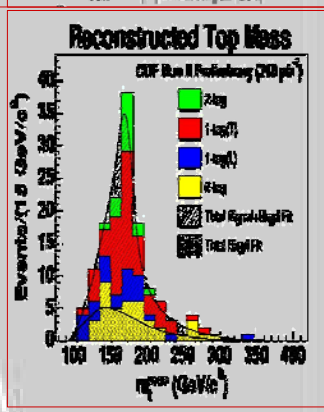
FIG. 5. Fitted mass distribution for candidate events (histogram) with the expected mass distribution for 199 GeV/c^2 top quark events (dotted curve), background (dashed curve), and the sum of top and background (solid curve) for (a) standard and (b) loose event selection.

Lessons for the Future

Many theorists…..

What did theorists learn from the top quark discovery episode?

- We saw that leading order worked pretty well for shapes.
- We saw that interfacing the parton level calculations with the parton shower monte carlo's such as PYTHIA is important.
- We realized the importance of experimenters input in what to calculate and how to implement these calculations.



With the advent of Run II at Fermilab collider phenomenology has made great strides in overcoming the Run 1 issues:

- Advanced leading order generators surpassing VECBOS have been constructed for use at hadron colliders (ALPHGEN, MADGRAF,…).
- Many techniques have been developed to interface leading order and beyond with shower monte carlo's (CKKW, MC@NLO,...).
- New shower monte carlo's are emerging, allowing exact matching between matrix element calculations and shower monte carlo's.

For the LHC era all the advances in collider phenomenology can be merged into unified tools: "Virtual Colliders". At the Fermilab theory group we are working on such a tool, VIRCOL. It incorporates:

- Next-to-leading order for high multiplicity final states (e.g. *W W+ 2 jets*, *TTbar + BBbar*, *W + 3 jets*,…)
- Exact matching to a dipole shower monte carlo which evolves the hard scattering resolution scale down to the hadronization scale.

Such tools will integrate all aspects of the theory.

Presented by Walter Giele