A short history of ISAJET

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Frank was a unique high energy physicist with a deep understanding of HEP theory coupled with an eagerness to connect theoretical predictions with actual measurements.

Many who worked on hadron collider physics at BNL, Fermilab or CERN, relied on him for advice on data analysis, what signatures to look for and how to suppress backgrounds.

The need to see how theoretical models matched experimental data motivated Frank to create the Monte Carlo (MC) program ISAJET and to continuously add features to simulate such models.

Frank was averse to publishing ISAJET in a scientific journal.
He rather spend his time constantly adding new models and refining it as new experimental data became available.
Consequently all citations of ISAJET in HEP publications are to various BNL reports or conference proceedings.
Together there are $>$ 1000 ISAJET citations.

Origins

In 1974 HEPAP recommended that a pp collider, ISABELLE, be built at BNL. This was to be the next step after the ISR at CERN.

Main Goal: find the W and Z bosons.
200+200 GeV beam energies chosen to be high enough.

Construction started in 1978 and the proposed energy raised to 400+400 GeV.
Urgent need: MC program simulating processes expected at ISABELLE.

Frank had written a FORTRAN program to calculate W,Z production cross sections and was developing code to calculate QCD cross sections.

Someone suggested (Nick Samios, Bob Palmer?) that we get together to create the needed MC program with his code as a starting point.

After months of intense discussions ISAJET 1.0 was born (1979). Frank supplied all the code for physics calculations and kinematics. My contributions were mainly technical: defining common blocks, a user interface, i/o and decay tables.

In those days FORTRAN was the main computer language for HEP computations and programs were kept in boxes filled with punched cards. The original ISAJET program required ≈ 1000 cards. Eventually it was stored on disk and punched cards used only to supply user instructions or modifications.

The most powerful computer available in 1979 was the CDC 7600, with considerably less CPU power and memory than the cheapest iPAD today. Much of our effort went into speeding up algorithms and minimizing memory useage.

Many days were spent figuring out a way to keep track of all the particles produced and how to label the multitude of hadronic particles and resonances.
Eventually, we came up with a scheme of particle IDs that much later (1990's) became with some variations the PDG (Particle Data Group) ID now in general use.

ISAJET 1.0 included only three processes: DRELLYAN for W, Z production, TWOJET for QCD jet production and MINBIAS for minimum bias events.

Frank foresaw that the program had to constantly evolve. Thus the ISAJET FORTRAN code was embedded into the CERN code management system PATCHY to keep track of changes.
It was soon expanded to include WW, technicolor and gluino production.

Early uses

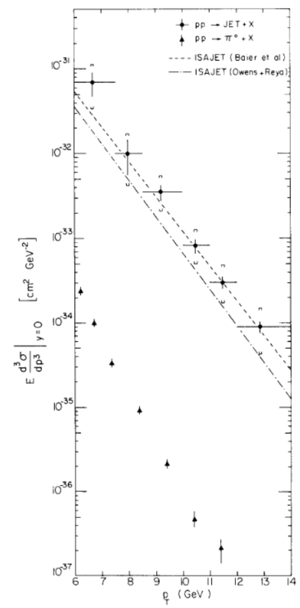
First use was to help design experiments for ISABELLE.
In addition to W and Z bosons we realized ISABELLE would be a copious source of hadrons with b quarks. A detector to observe such hadrons was designed relying heavily on ISAJET.

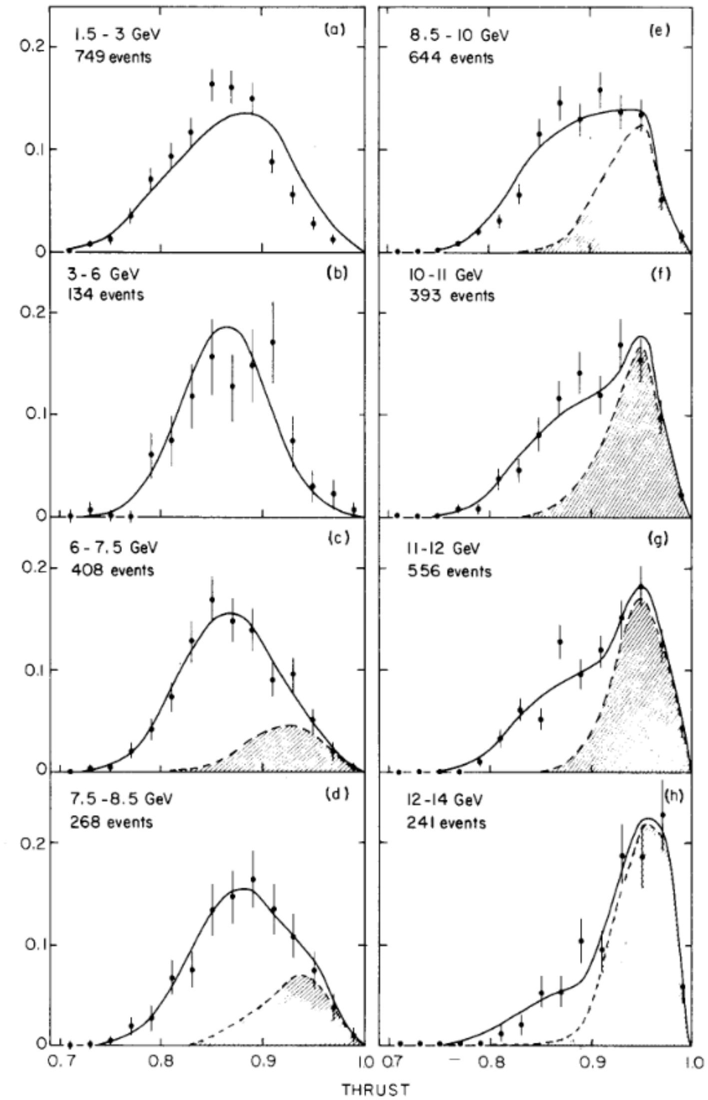
ISAJET came into general use to understand the needs of hadron collider detectors at the Snowmass 1982 workshop on future HEP facilities. Frank was an ubiquitous presence there.

The first analysis of experimental data using ISAJET was to show that hadronic jets are produced in ISR pp collisions (observed in e^+e^- collisions).
The ISR Axial Field Spectrometer (AFS) and UA2 detector at the S$p\bar{p}$S were the first proving hadronic jets were produced in hadron colliders (1982). In $p\bar{p}$ collisions at $\sqrt{s} = 540$ GeV high p_T jets are abundant, easily observed in a detector with large ϕ coverage (UA2). No MC simulation needed to prove it.

At the CERN ISR the highest E pp collisions were at $\sqrt{s} = 63$ GeV low p_T jets and AFS calorimeter with only partial ϕ coverage
$\Rightarrow$ jets not easily observed.
Measurements relied on a quantity, Thrust (T), and ISAJET to predict the T dependence on transverse E deposited in the calorimeter.

Phys.Lett. 118B, 185 (1982)





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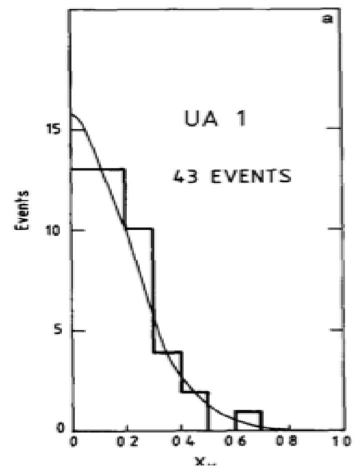
W and Z bosons at S$p\bar{p}$S

Unfortunately, ISABELLE superconducting magnet construction run into technical problems. As a result of the delay the W and Z bosons were found with the UA1 and UA2 detectors at the CERN S$p\bar{p}$S collider instead (1983).

Both UA1 and UA2 relied on ISAJET to estimate detector acceptance and efficiency

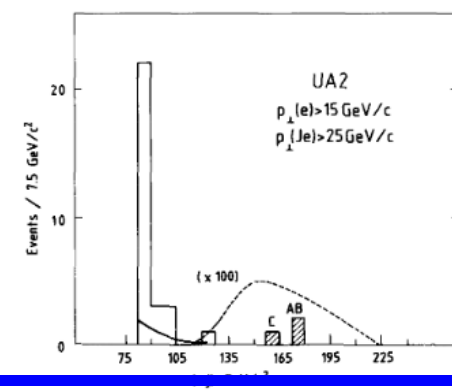
Distribution of W events (UA1)
as function of fraction of beam energy
x_W carried by W
Curve is from ISAJET

Phys. Lett. 129B, 103 (1983)



M(Wj) distribution (UA2)
agrees with ISAJET below 105 GeV
curve is expected background

Phys. Lett. 139B, 105 (1984)



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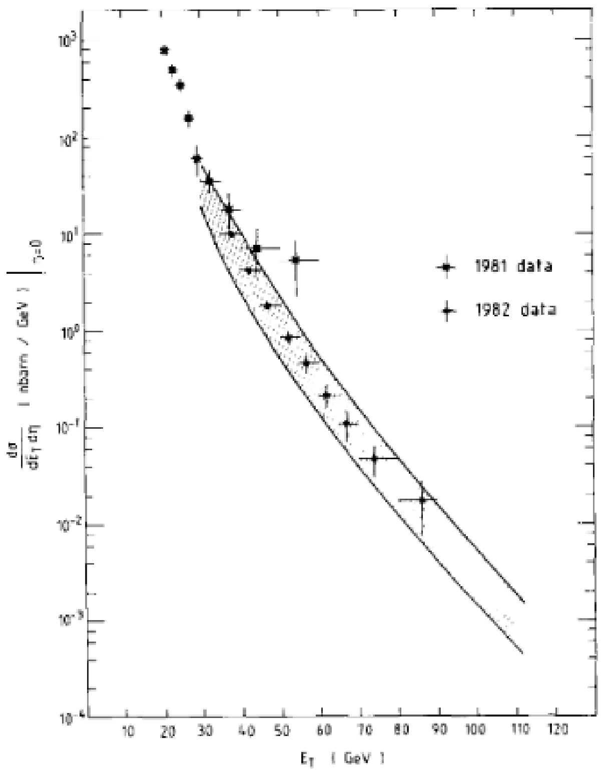
Inclusive Jets at S$p\bar{p}$S

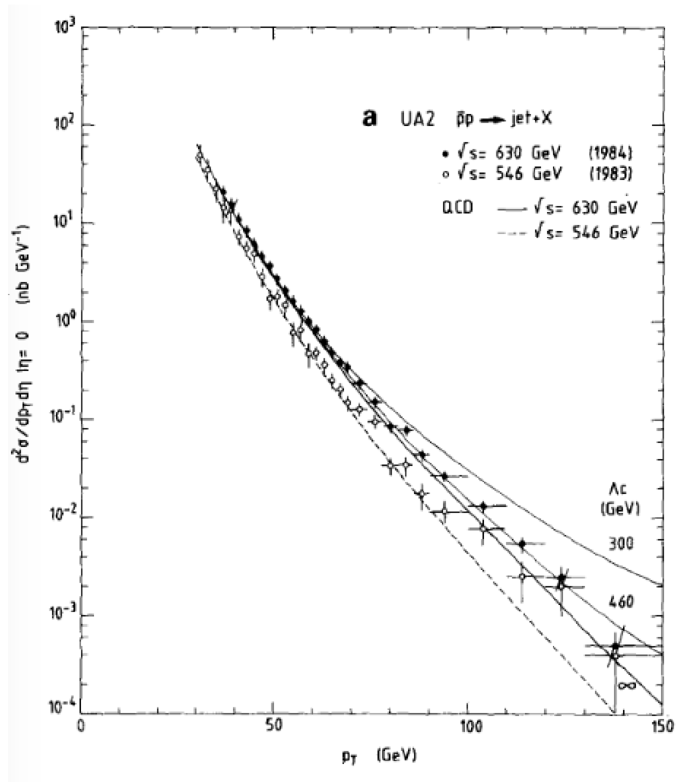
Curves are QCD predictions, acceptance corrections using ISAJET.

UA1



Phys. Lett. 132B, 214 (1983)

UA2



Phys. Lett. 160B, 349 (1985)

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The 1980's I

In the decade 1980-1990 ISAJET was used heavily to understand the acceptances of hadron collider detectors for anticipated and observed processes.

- **Snowmass workshop 1982: focused on the ISR, the upcoming Sp$\bar{p}$S, proposed ISABELLE *pp* and Tevatron *p$\bar{p}$* colliders.**

  ISR closed in 1984, ISABELLE cancelled in 1983

- **Snowmass workshop 1984:**
  main focus shifted to the SSC
  More processes added to ISAJET:
  WW, SUSY, Higgs, WHiggs, Technicolor

- **Snowmass workshop 1986:**
  more on SSC physics and detectors
  ISAJET improved jet fragmentation model
  use EHLQ PDF

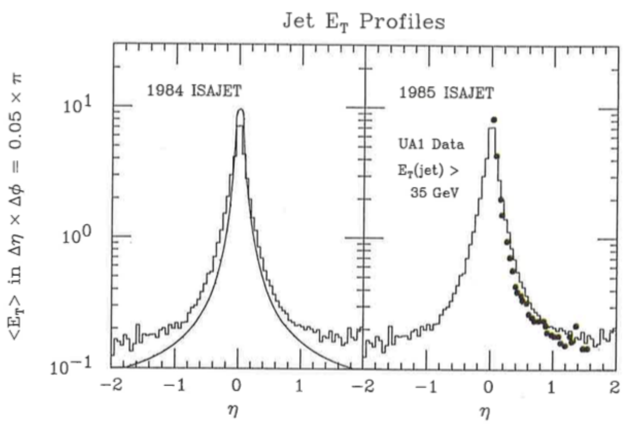


Fig. 4. Jet profiles according to old and new ISAJET.

The 1980's II

S$p\bar{p}$S ran until 1991. UA1 and UA2 relied on ISAJET to correct for detector acceptance and compare distributions of W,Z and QCD jet events to theory. Half of their publications cite ISAJET.

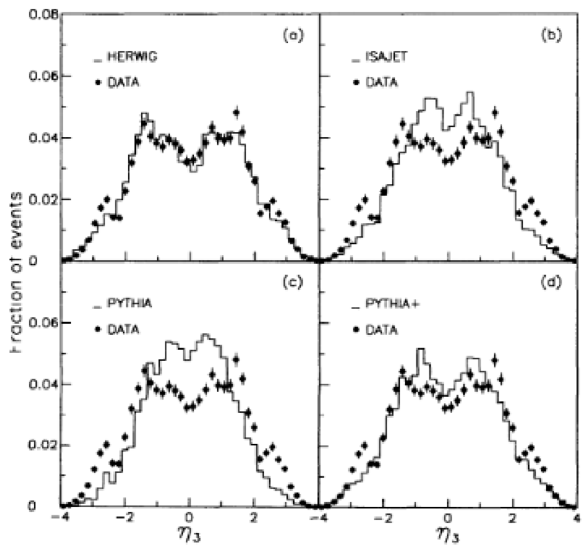
The first Tevatron $p\bar{p}$ collision was at the end of 1986.
Only CDF detector operational in the 1980's
all publications from data collected between 1988 and 1989.
Over half cite ISAJET: for W,Z and QCD jet distributions, limits on toq quark mass, searches for SUSY and leptoquarks.

By 1988 two other hadron collider MC programs became available for general use: PYTHIA and HERWIG. Same underlying physics as ISAJET but added features to model effects of QCD color (ignored by ISAJET). PYTHIA used the Lund string model, HERWIG introduced angle ordering to mimic color coherence.

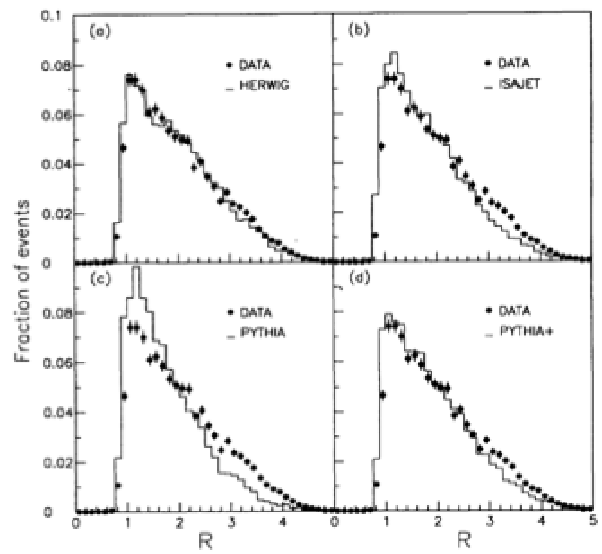
Comparison of CDF 3 jet data and MC programs

1990 versions of ISAJET, HERWIG and PYTHIA give same p_T distributions for all 3 jets ($p_T^{jet1} > 100$ GEV) but differ on the angular distribution of 3rd jet. HERWIG describes that better. ISAJET and PYTHIA underestimate the number of 3rd jets at large η_3 and at a large separation from 2nd jet.

η_3



$\Delta R(j_2, j_3)$



PRD 50, 5562 (1994)

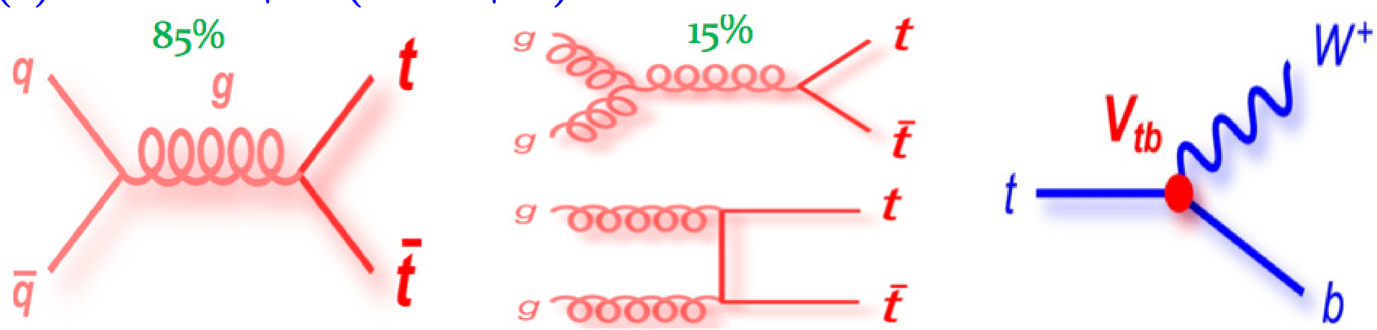
The top quark I

Run I of the Tevatron $p\bar{p}$ collider started in 1992

2 detectors: CDF and DØ .

Main goal: find the top quark.

Previous mass limits $\Rightarrow$ main production process $q\bar{q} \to t\bar{t}$ with $t(\bar{t}) \to W^+ + \bar{b}$ $(W^- + b)$.



Suppress QCD background by requiring one (or both) W decay to a lepton + neutrino.

CDF had big advantages over DØ : Two years of data taking, a vertex detector to identify b-quark jets (critical for suppressing W+jets background) and 30% more luminosity.

DØ only advantage was a superior hermetic calorimeter.

The top quark II

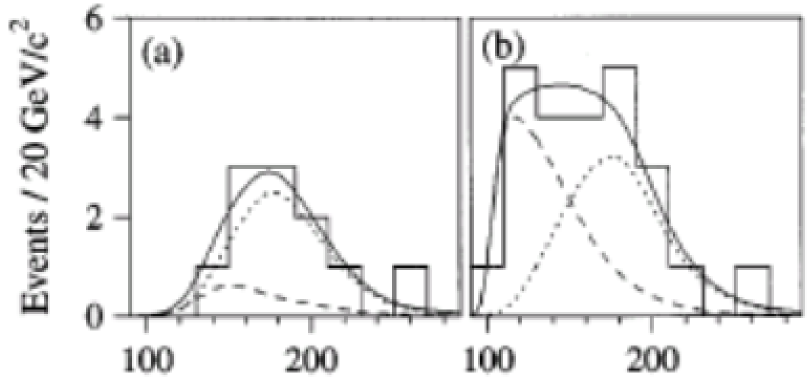
The CDF strategy was to look for events with

1. **two high p_T leptons and > 1 jets**
2. **a single high p_T lepton, > 2 jets and count the number of b-quark jets**

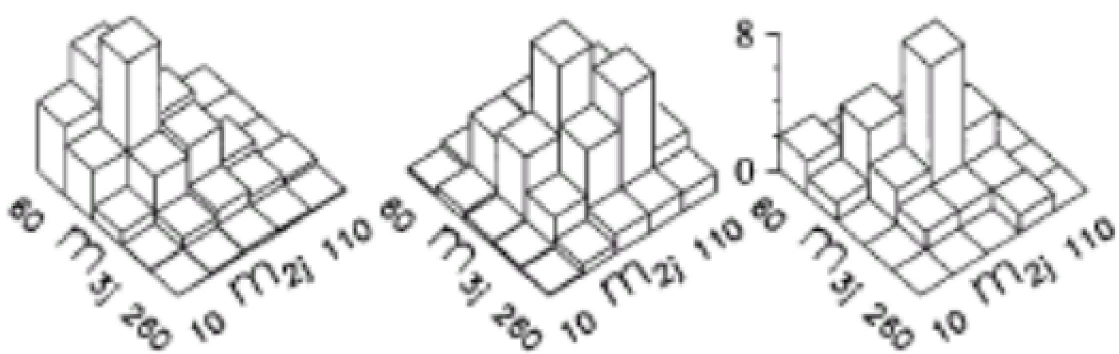
Option 2 yields more $t\bar{t}$ events but was not available to DØ .
Instead, it had to exploit the different multi-jet topology of background and signal events.
Main sources of background to 2: QCD multi-jet, with a jet misidentified as a lepton, and W+3 or more jets.
QCD was estimated from data
W+jets had to rely on MC simulation.
None of the available simulation programs could give an adequate distribution of jets for $W+ \geq 3$ jets.

A program (W. Giele's VECBOS) could rigorously calculate the distributions of up to 4 partons produced in association with a W but did not do subsequent parton evolution into jets nor the W decay.

With Frank's help:
interfaced VECBOS to ISAJET
Solved technical problems
such as jet double counting
handling VECBOS weights.



Phys. Rev. Letters 74, 2632 (1995)



Beyond the Standard Model

After 1990 HERWIG and PYTHIA came into wide use to simulate hadron collisions. HERWIG in particular gave a better description of QCD multi-jet processes.

Yet ISAJET remained the most cited hadron collider MC program by DØ and CDF throughout the 1990's.
The main reason is that Frank continuously added more models to simulate.

The most important addition occured when Howie Baer and Frank (1993) incorporated into ISAJET the SUSYSM program Howie and Xerxes Tata wrote based on MSSM (Minimal Supersymmetry Model) to calculate SUSY particles mass spectra and branching ratios for any set of MSSM parameters.

Given Baer and Tata's program connection to ISAJET, their program was renamed ISASUSY and became part of ISAJET 7.0.

ISAJET/ISASUSY was not only used in searches for SUSY particles at the Tevatron.
Under Frank's direction used prominently to develop strategies for future SUSY searches and to find ways to measure SUSY masses (if signals were found) at the LHC.
Published results of those studies were cited $>$ 100 times in ATLAS and CMS papers, and SUSY Conference Proceedings.

Bachacou, Hinchcliffe and Paige, PRD 62,015009 (2000)

Before the LHC turned on (2010), it was widely believed the LHC would be the collider that would find evidence for SUSY.
Unfortunately, so far Nature did not cooperate.
Frank's advice on future searches will be sorely missed.