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IMAPP

Rubbia's fail: The False Discovery of the Top Quark

False Discoveries in Particle Physics

Riana Shaba

Supervisor: Dr. Maik Becker

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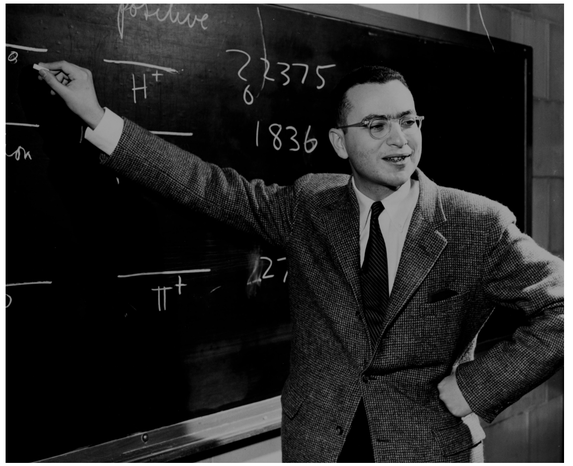
Content

- The Quark Model
- The Discovery of $W^{\pm}, Z$ bosons
- The UA1 and UA2 detectors
- Physics Results of UA1 on Top Quark Search and Where it Went Wrong
- Further Searches
- The True Discovery of the Top Quark
- Personal Thoughts

The Quark Model

- The Eightfold Way (1961 - 1964), Murray Gell-Mann
- The Quark Model (1964), Gell-Mann and George Zweig:
  - Hadrons are composed of **quarks**



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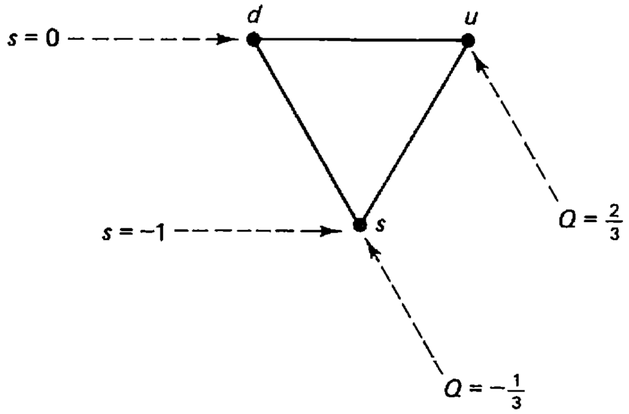
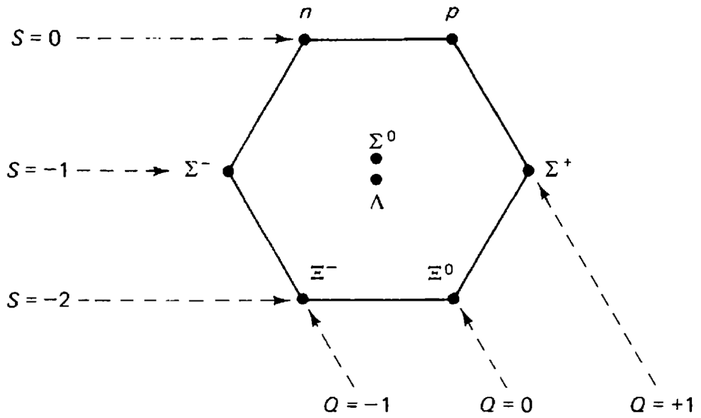


Source: Griffiths, D. (2008). *Introduction to Elementary Particles* (2nd rev. ed., p. 39)



Source: Griffiths, D. (2008). *Introduction to Elementary Particles* (2nd rev. ed., p. 35)

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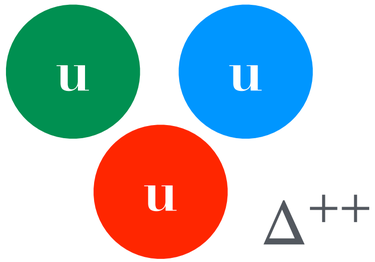
The Quark Model

and skepticism in the late 1960s - 1970s

- Failure of producing isolated quarks and identifying them
- Deep Inelastic Scatterings at SLAC experiment (1968) supported the quark model:
  - proton's constituents are **partons**
- Violation of Pauli Exclusion Principle:
  - O. W. Greenberg (1964), *colour hypothesis*



Δ^{++}

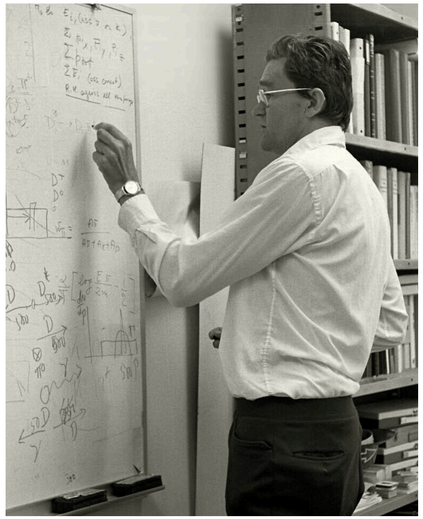
URL: https://academictree.org/physics/peopleinfo.php?pid=167089

$$e, \mu, \nu_e, \nu_\mu$$

$$u, d, s, ?$$

The Quark Model

- First prediction by Bjorken and Glashow (1964)



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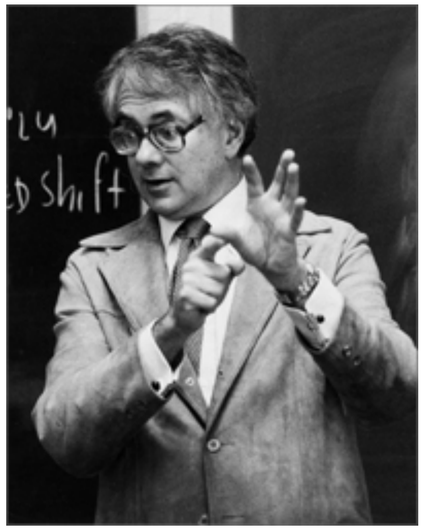

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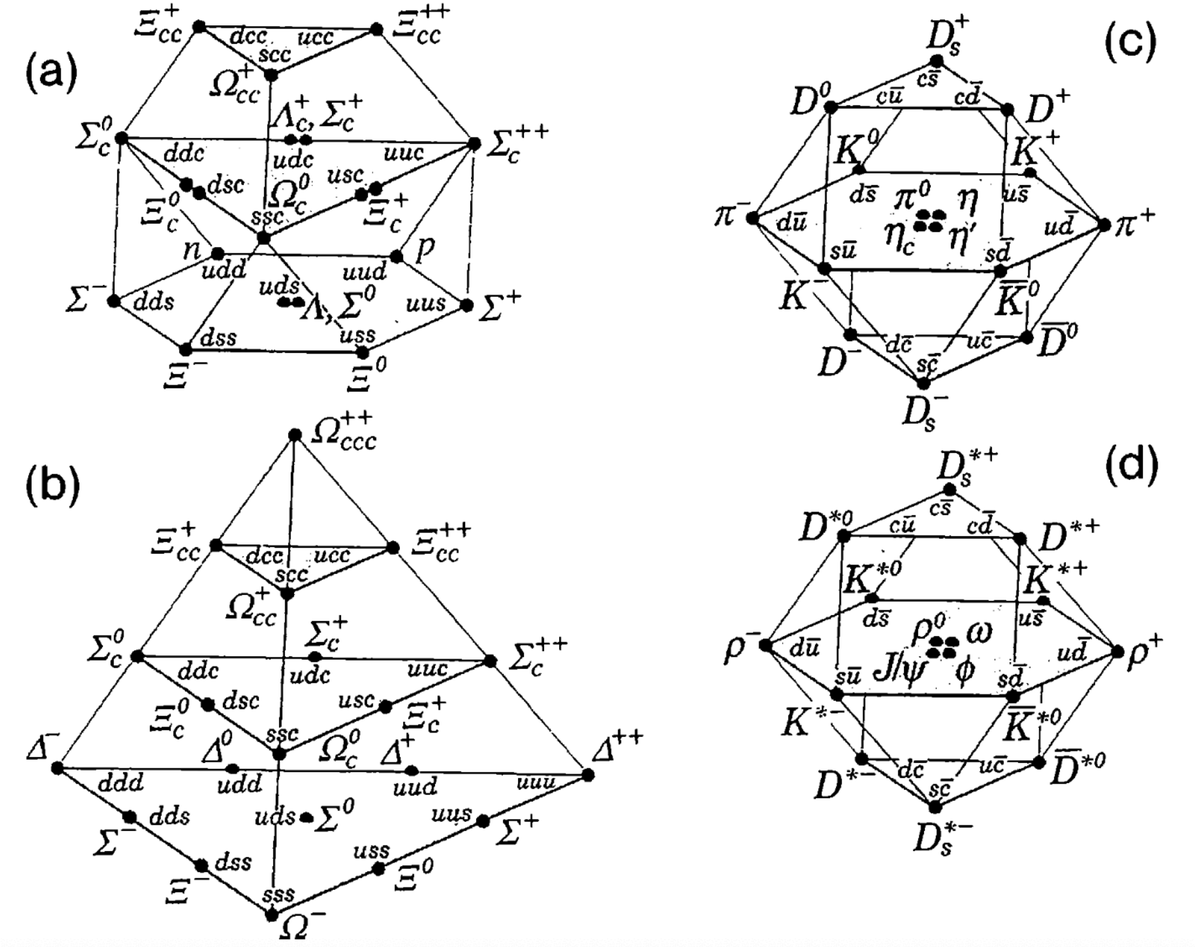
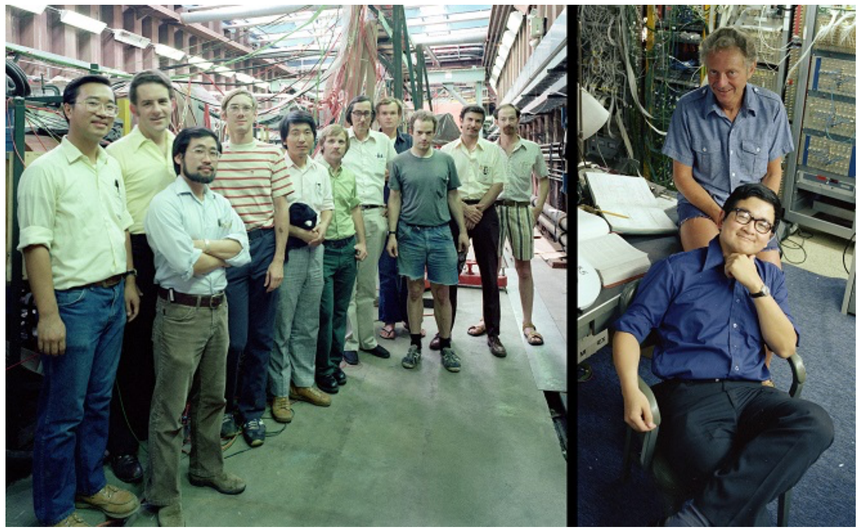


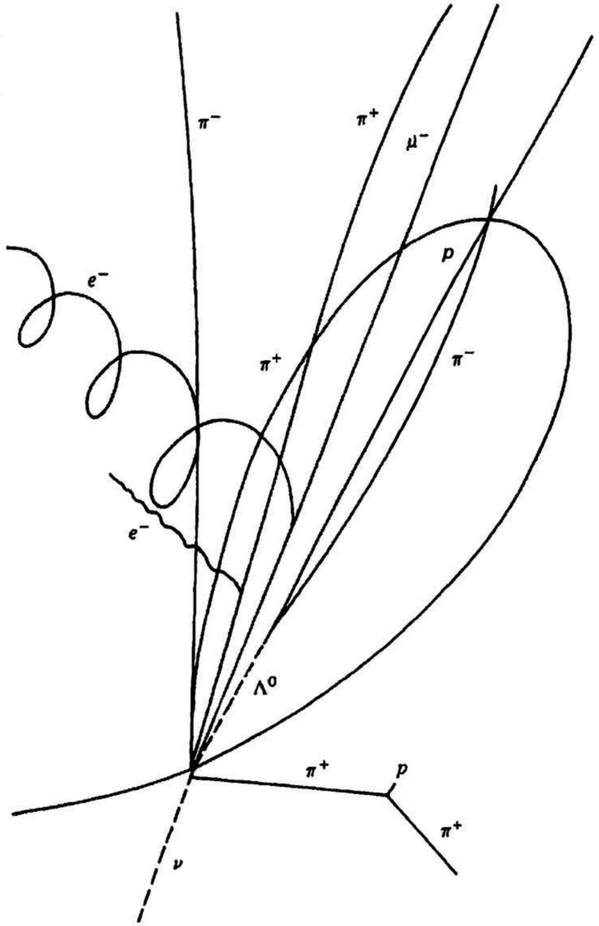
Source: Griffiths, D. (2008). *Introduction to Elementary Particles* (2nd rev. ed., p. 45)

The Quark Model

- First observation at Brookhaven Laboratory (1974):
  - $\psi = (c\bar{c})$ — **charm** quark, c
- (1975), $\Lambda_c^+ = udc$, $\Sigma_c^{++} = uuc$
- (1976), $D^0 = c\bar{u}$, $D^+ = c\bar{d}$
- E288 experiment at Fermilab (1977):
  - $\Upsilon = (b\bar{b})$ — **beauty** quark, b
- Sixth Quark Search begins



URL: https://history.fnal.gov/this_day_1977_07_01.html



Source: Griffiths, D. (2008). *Introduction to Elementary Particles* (2nd rev. ed., p. 46)

But who is Carlo Rubbia?

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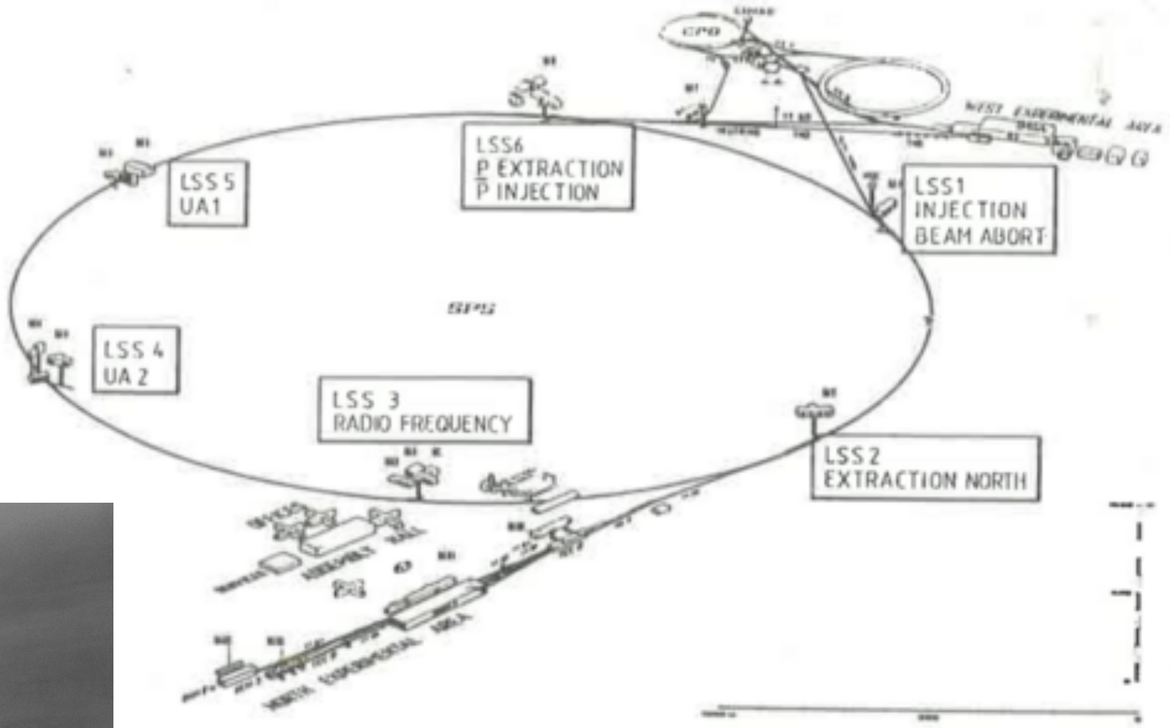
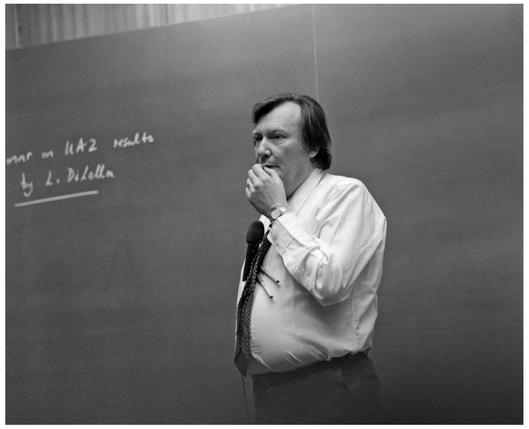
The Discovery of the W and Z bosons

- Weak neutral currents discovery by Gargamelle Collaboration (CERN, 1973)
- **SPS** operation (1976, $\sqrt{s} \sim 30$ GeV)
- **SpS̄** operation (1981, $\sqrt{s} \sim 540$ GeV)
- Provided data for UA1 and UA2



URL: https://en.wikipedia.org/wiki/Super_Proton–Antiproton_Synchrotron

URL: https://cerncourier.com/a/simon-van-der-meer-a-quiet-giant-of-engineering-and-physics/



URL: https://home.cern/fr/node/3117

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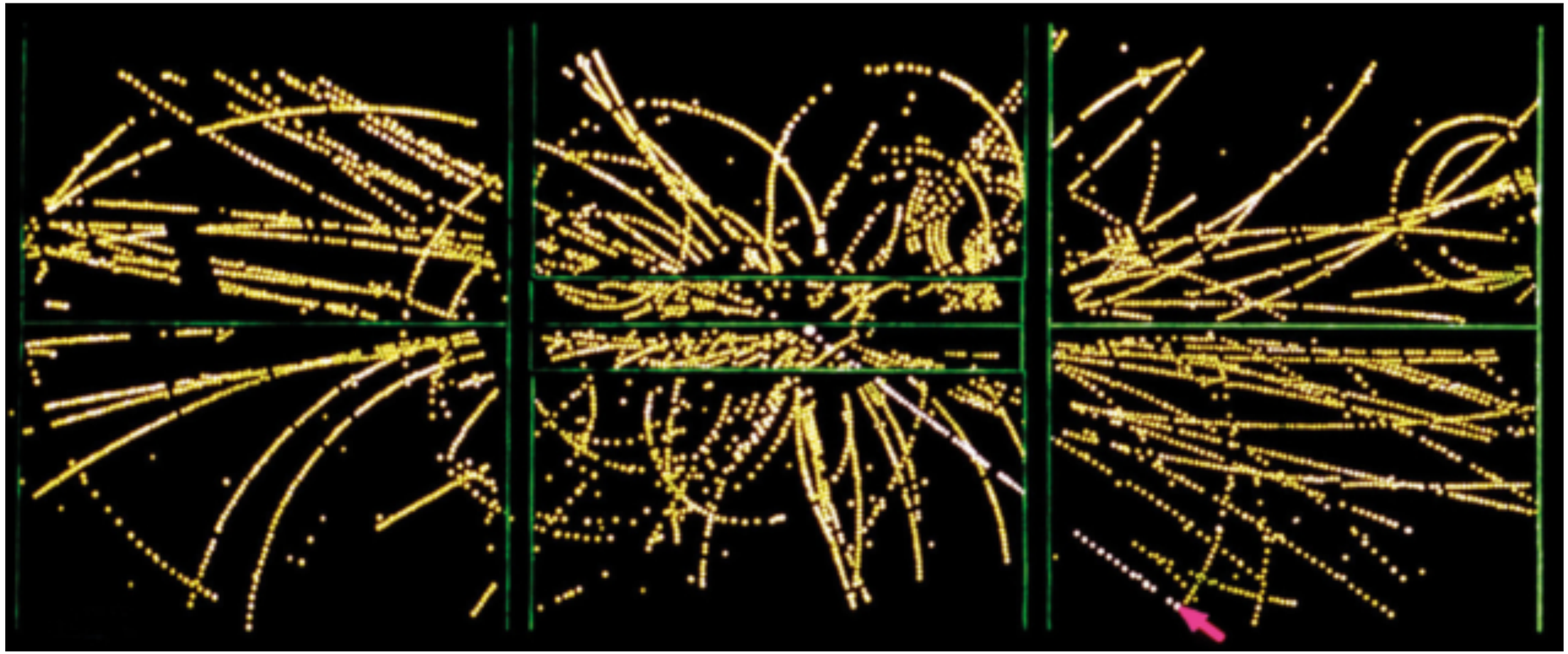
The Discovery of the W and Z bosons

Event Displays

- **Nobel Prize** to Carlo Rubbia and Simon van der Meer (1984)

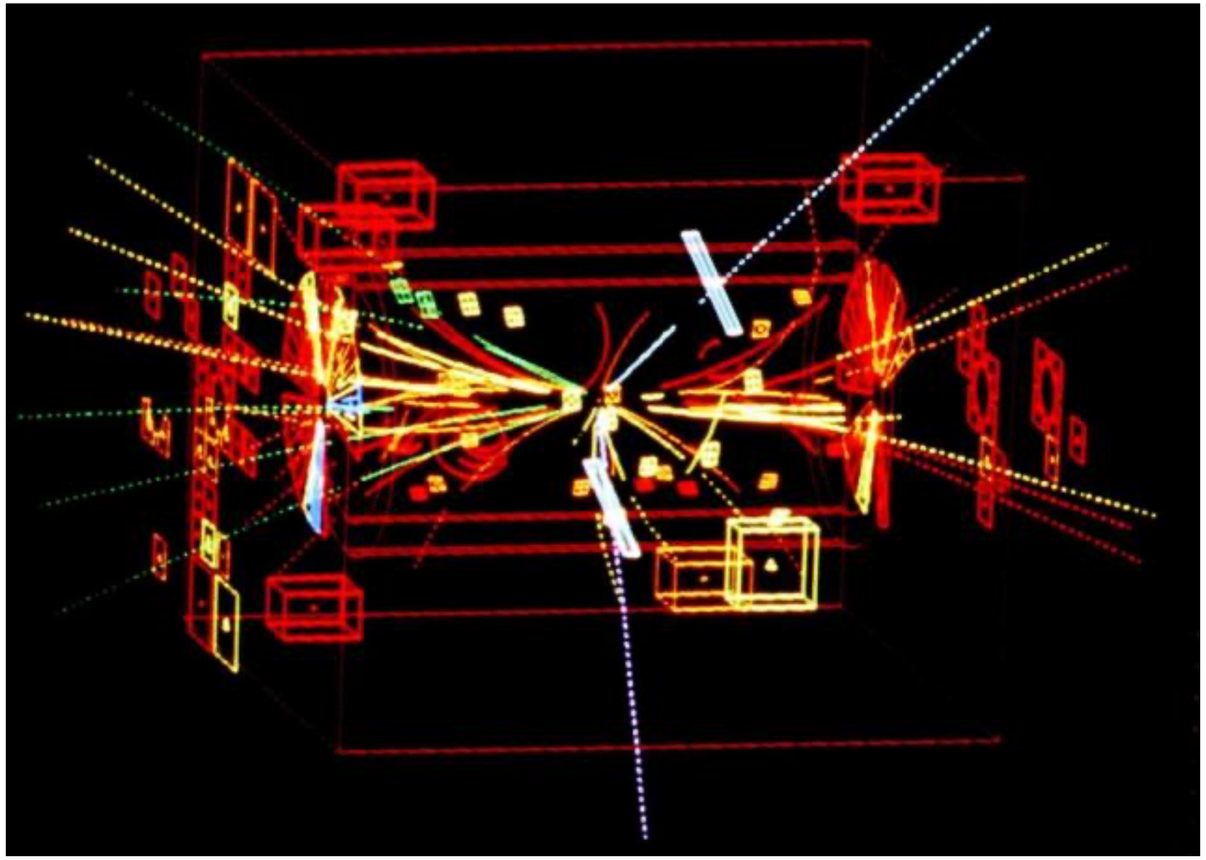


URL: https://cerncourier.com/a/remembering-the-w-discovery/

The Discovery of the W and Z bosons

Event Displays

- **Nobel Prize** to Carlo Rubbia and Simon van der Meer (1984)



URL: https://timeline.web.cern.ch/w-and-z-particles-discovered

UA1 Detector

Aluminium coil

EM detectors

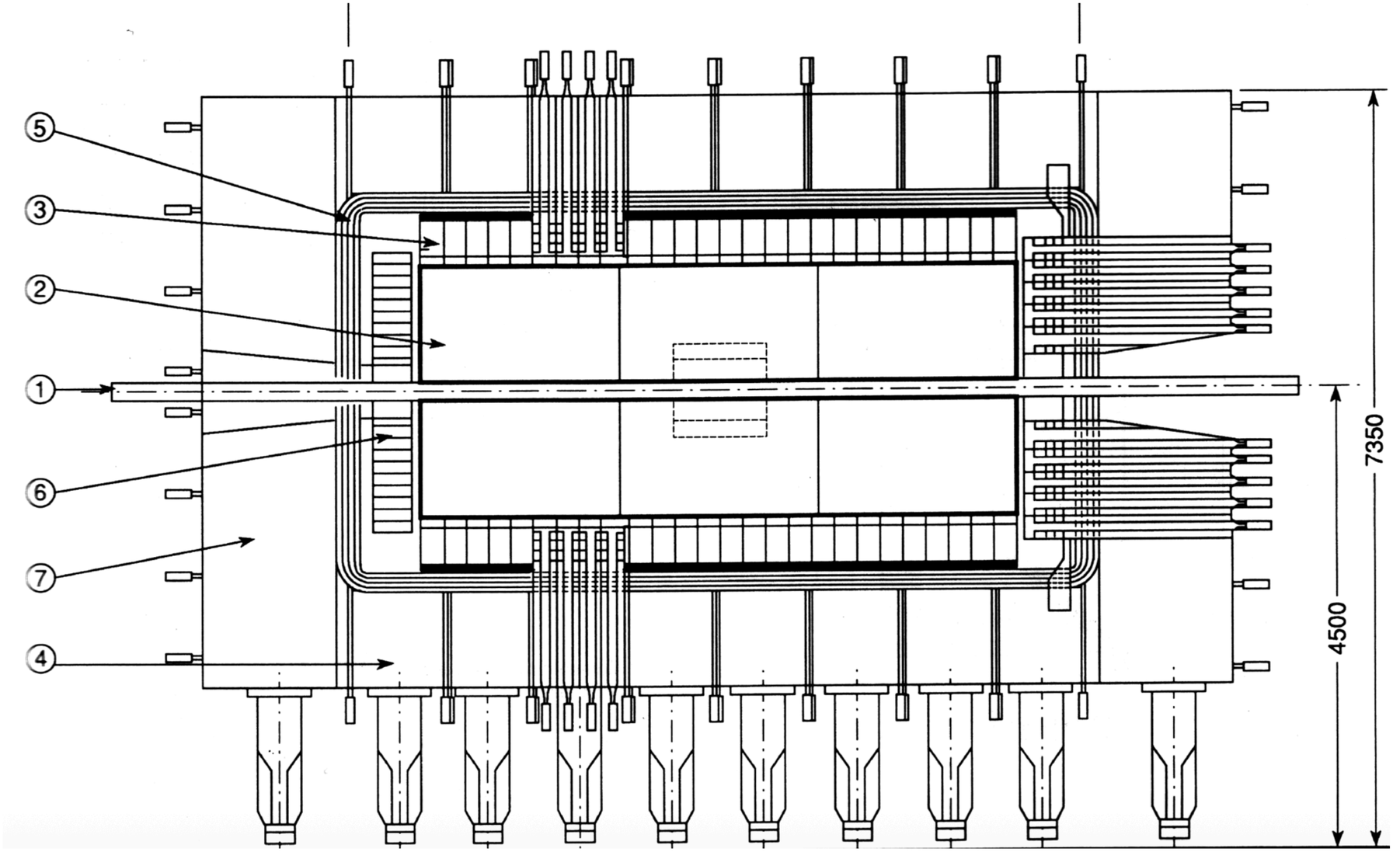
Vertex Chambers

Vacuum Chamber

Forward EM detectors

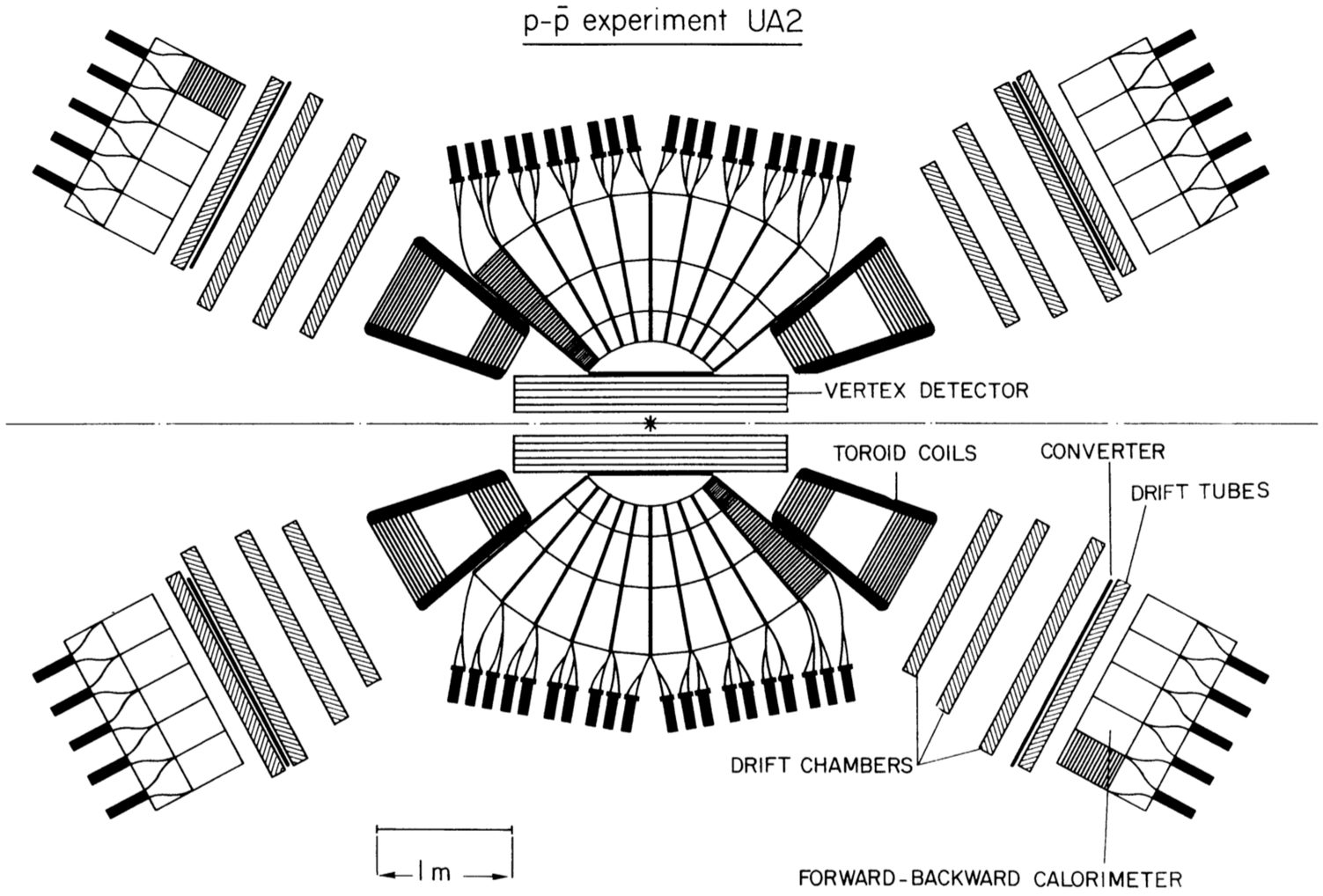
End-caps

Hadron calorimeters
and return yoke



URL: https://web.physik.rwth-aachen.de/user/hebbeker/lectures/pp34/ua1.pdf

UA2 Detector



URL: https://cds.cern.ch/record/878103/files/p46.pdf

Video: https://home.cern/news/news/physics/carrying-weak-force-thirty-years-w-boson

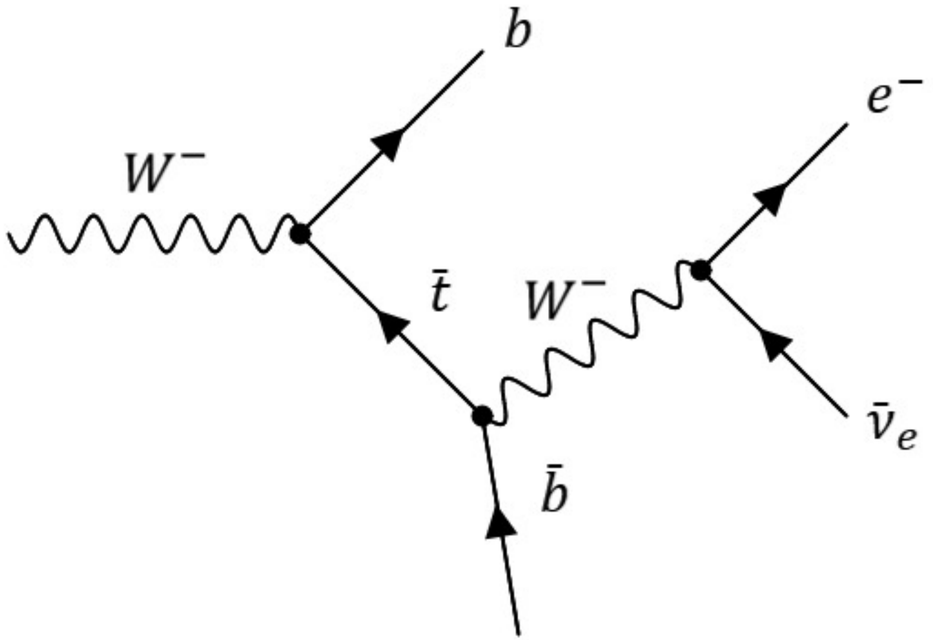
URL: https://home.cern/news/news/physics/carrying-weak-force-thirty-years-w-boson

URL: cds.cern.ch/record/615822

Physics Results of UA1 on Top Quark Search (1984)

Claims and Interpretations

- Event signatures:
  - an isolated, high-transverse-momentum lepton (e or μ)
  - two centrally produced jets
  - missing transverse energy attributed to neutrino
- Interpreted as possible evidence for a novel decay:
  - $W^- \to \bar{t}b$ ($\bar{t} \to \ell^- \nu \bar{b}$)
- Inferred top quark mass: $m_t \simeq (40 \pm 10)\ \mathrm{GeV/c^2}$

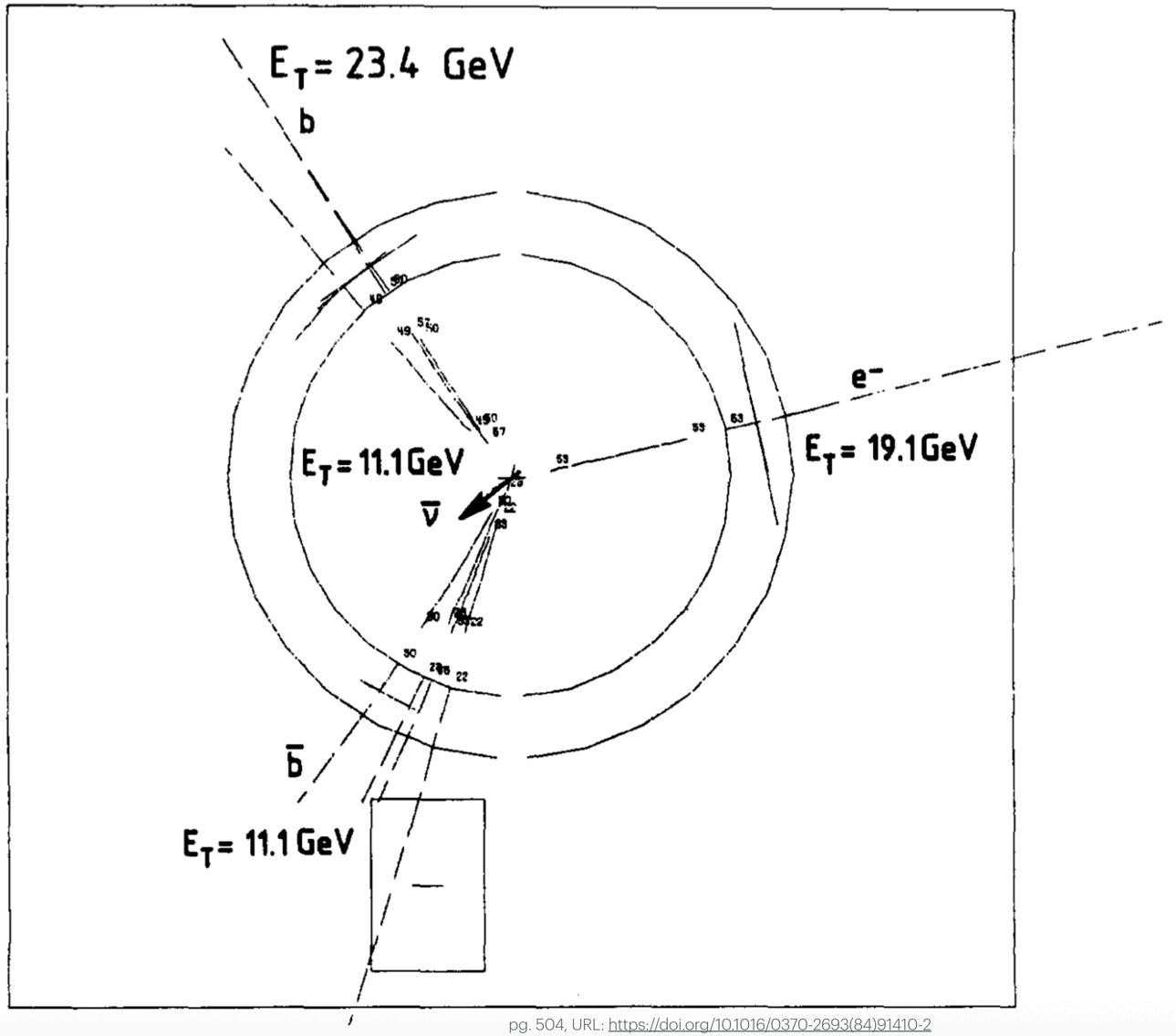


Claims and Interpretations

- **12 events** from each electron and muon sample
- **3.5 events** estimated as background
- 3σ effect
- Hint of a signal
- 6 final candidate events with 2 jets

"We observe a clear signal in the channel of an isolated large-transverse-energy lepton plus two or three associated jets."

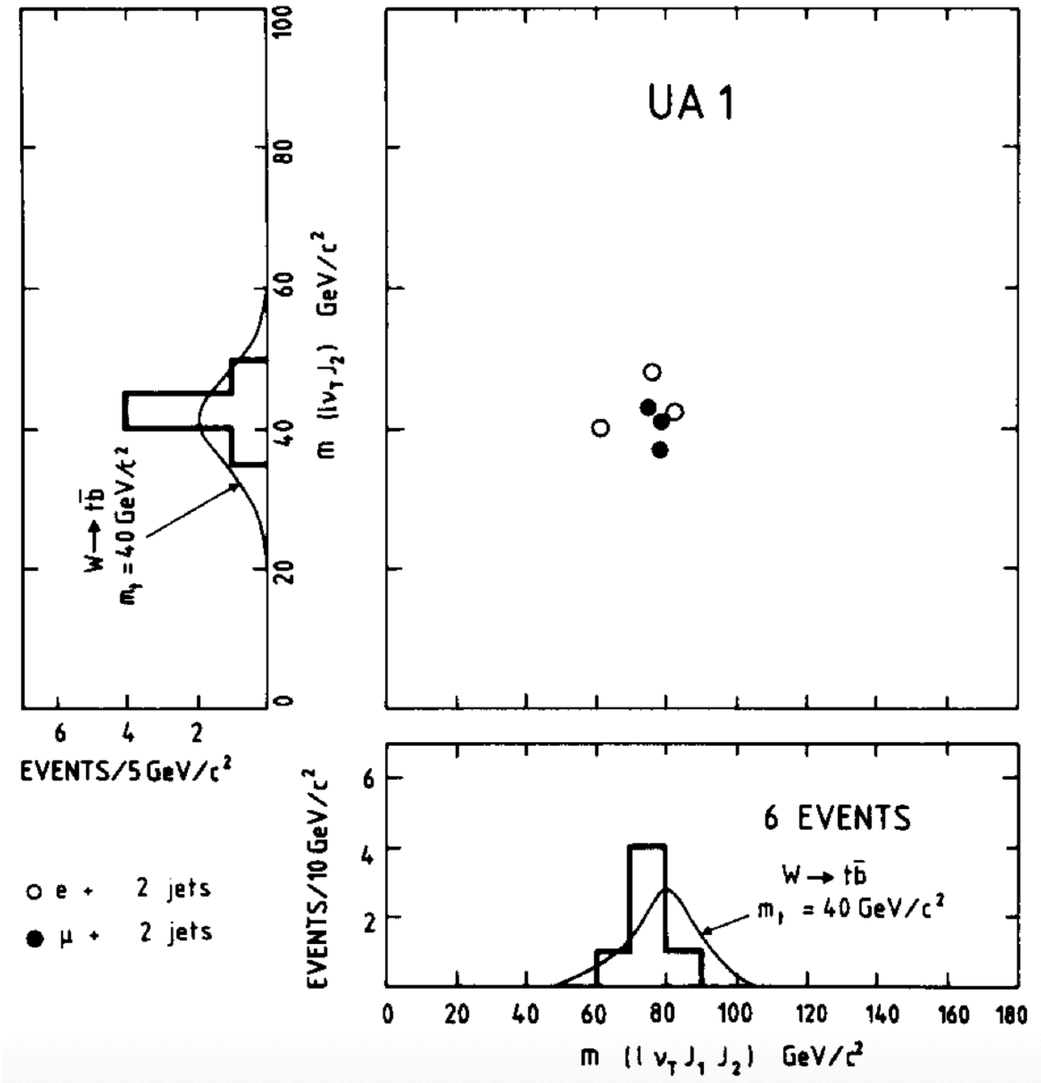
Event Display



pg. 504, URL: https://doi.org/10.1016/0370-2693(84)91410-2

- Six $W \to t\bar{b}$ candidates
- Systematic errors of $\pm 10\,\mathrm{GeV/c^2}$
- Inferred top quark mass: $m_t \simeq (40 \pm 10)\,\mathrm{GeV/c^2}$
- $30\,\mathrm{GeV/c^2} < m_t < 50\,\mathrm{GeV/c^2}$

"We stress that the uncertainty in the ($\ell \nu_T j_2$) is due to the determination of the jet energies, and that more statistics are needed to confirm these conclusions and the true nature of the effect observed."



pg. 505, URL: https://doi.org/10.1016/0370-2693(84)91410-2

- Invited Talk at the International Conference on Neutrino Physics and Astrophysics

PHYSICS RESULTS OF THE UA1 COLLABORATION AT THE CERN PROTON–ANTIPROTON COLLIDER

UA1 Collaboration, CERN, Geneva, Switzerland

Aachen – Annecy (LAPP) – Birmingham – CERN – Harvard – Helsinki – Kiel –
Queen Mary College, London – NIKHEF, Amsterdam – Paris (Coll. de France) –
Riverside – Rome – Rutherford Appleton Lab. – Saclay (CEN) –
Vienna – Wisconsin Collaboration

(Presented by C. Rubbia)

1. INTRODUCTION

In this presentation I will summarize new physics results of the last year from the UA1 experiment at CERN. These data are from proton–antiproton collisions at a total centre-of-mass energy of 540 GeV, corresponding to an integrated luminosity of 136 nb^{-1}. The data were recorded mostly in the spring of 1983.

This paper is divided into two main sections. The first part deals with the observation of events with large missing transverse energy containing either a) a single electromagnetic cluster or b) a single jet. The second section is concerned with the search for the top quark.

URL: https://cds.cern.ch/record/155129/files/198411025.pdf

~ Evidence “looks really good”

The New York Times

PHYSICISTS MAY HAVE TRACKED LAST QUARK TO LAIR

Share full article

By Walter Sullivan

June 25, 1984

The New York Times Archives

URL: https://www.nytimes.com/1984/06/25/us/physicists-may-have-tracked-last-quark-to-lair.html

Was the *truth* discovered?

~~Spoiler Alert!~~

No.

Where it Went Wrong...

- Systematic underestimation of background:
    - Mainly $W \to \ell\nu_\ell + \text{jets}$
- Missing background, $\ell = \tau, \quad \tau \to e/\mu + \nu\nu$ (Terry **Wyatt**)
- Poor Monte Carlo modelling
- UA2 could not confirm the claim

URL: https://royalsociety.org/people/terry-wyatt-12571/

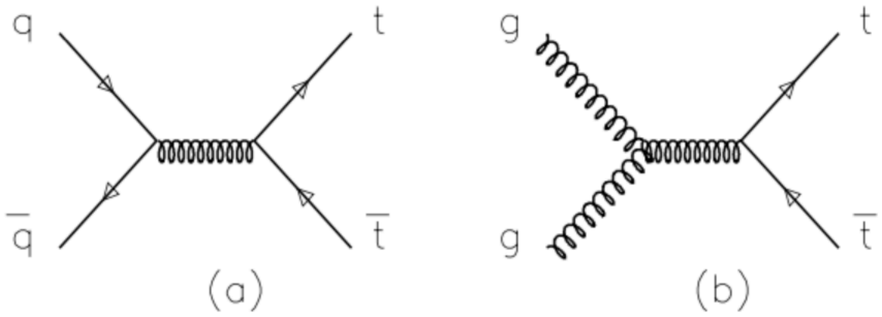
Highlights

- Underestimation of background
- Missing background (tau decays)
- Misinterpretation from poor modelling
- Consistent but misleading kinematics
- Over-interpretation of small statistics
- Lack of independent confirmation (UA2)

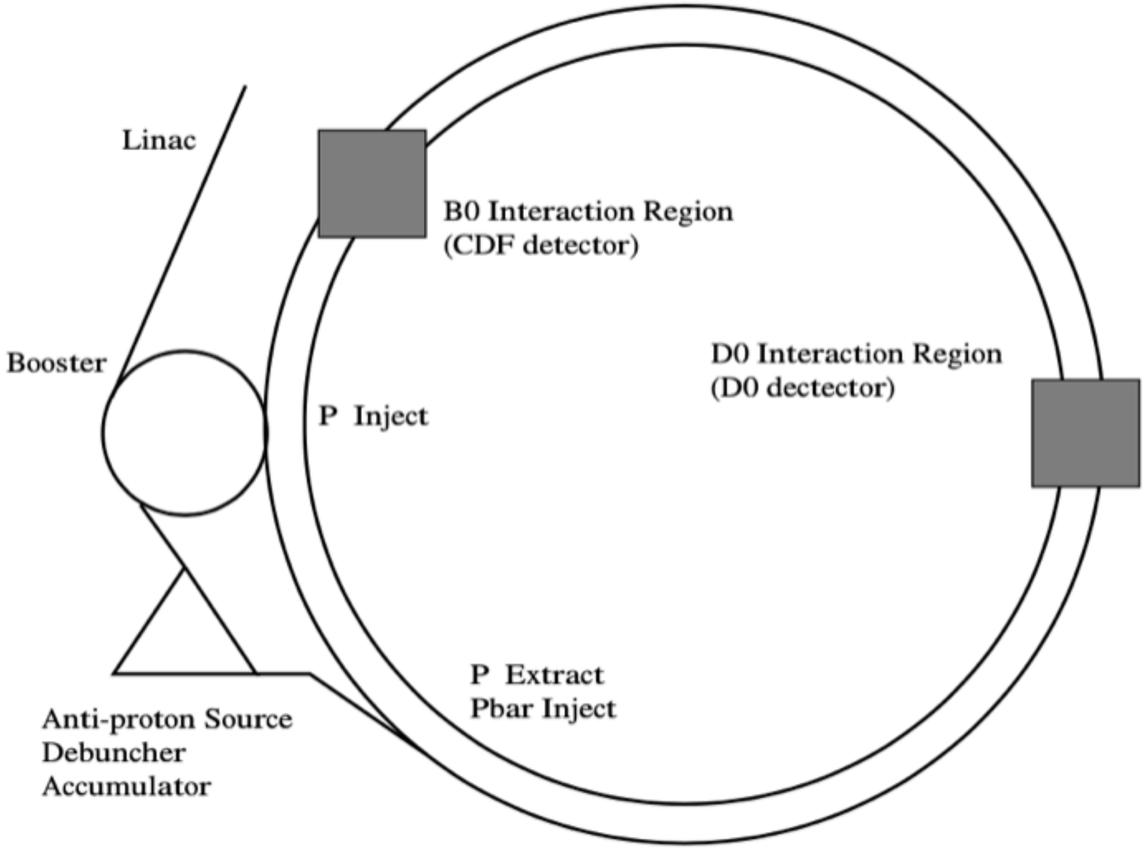
Fast Forward...

Further Searches

- UA2 (1990): $m_t > 69\ \mathrm{GeV}/c^2$
- CDF (1990): $m_t > 77\ \mathrm{GeV}/c^2$
- CDF (1992): $m_t > 91\ \mathrm{GeV}/c^2$
- Top quark Pair-production



URL: http://www.scholarpedia.org/article/File:Top-Figure3.png

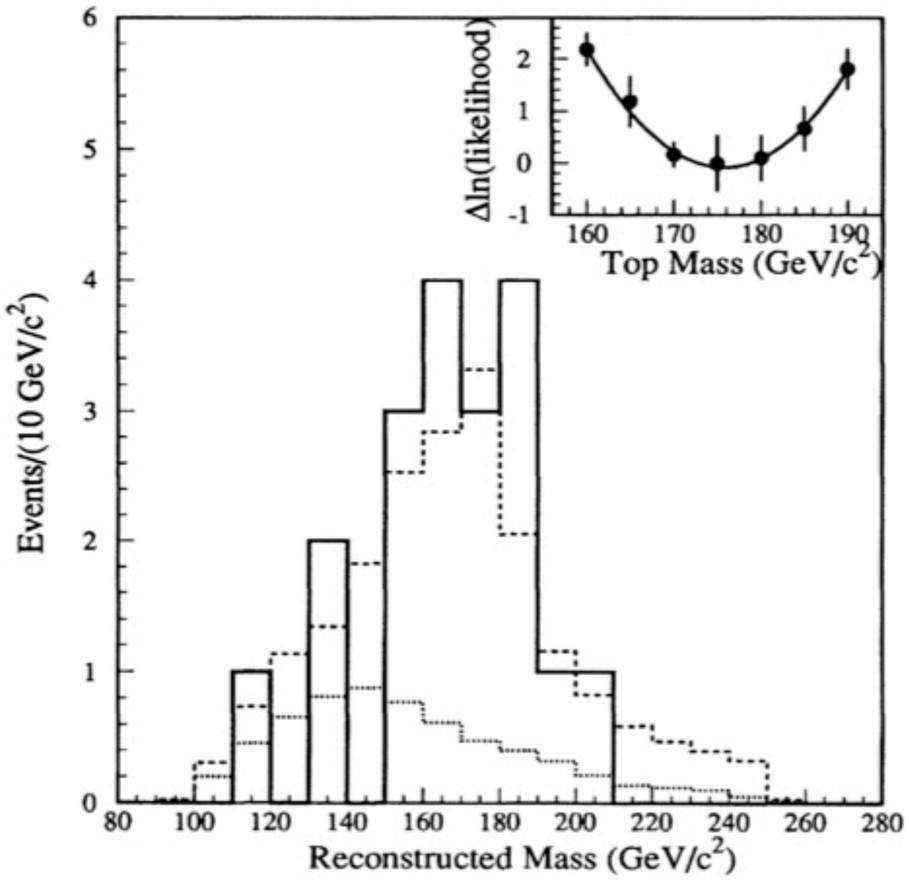


URL: http://www.scholarpedia.org/article/File:Top-Figure1.png

The True Discovery of the Top Quark

Tevatron ($\sqrt{s} \sim 1.8\,\mathrm{TeV}$), Fermilab

- CDF Collaboration (1995):
  - $m_t = 176 \pm 8\,(\mathrm{stat}) \pm 10\,(\mathrm{syst})\ \mathrm{GeV}/c^2$
  - 67 candidate events observed
- DØ Collaboration (1995):
  - $m_t = 199 \pm 20\,(\mathrm{stat}) \pm 22\,(\mathrm{syst})\ \mathrm{GeV}/c^2$
  - 17 candidate events observed



URL: http://www.scholarpedia.org/article/File:Top-Figure5.jpg

Personal Thoughts

- **Retain Objectivity:** reputation and expectations for a new discovery can cloud judgement
- **Encourage Skepticism:** question, doubt and review rigorously the results
- **Scientific Discipline:** strength of science as it evolves, refines and corrects with better understanding
- **Cross-checks with competitor experiments:** important to have other experiments reproducing the same effect and confirming the results
- **Complexity of experimental techniques:** underestimation or missing of key information leads to misinterpreted conclusions
- **Understand the physics:** better understanding will produce better tools for exploring them

“The effect of a concept-driven revolution is to explain old things in new ways. The effect of a tool-driven revolution is to discover new things that have to be explained.”

~ Freeman Dyson, “Imagined Worlds”

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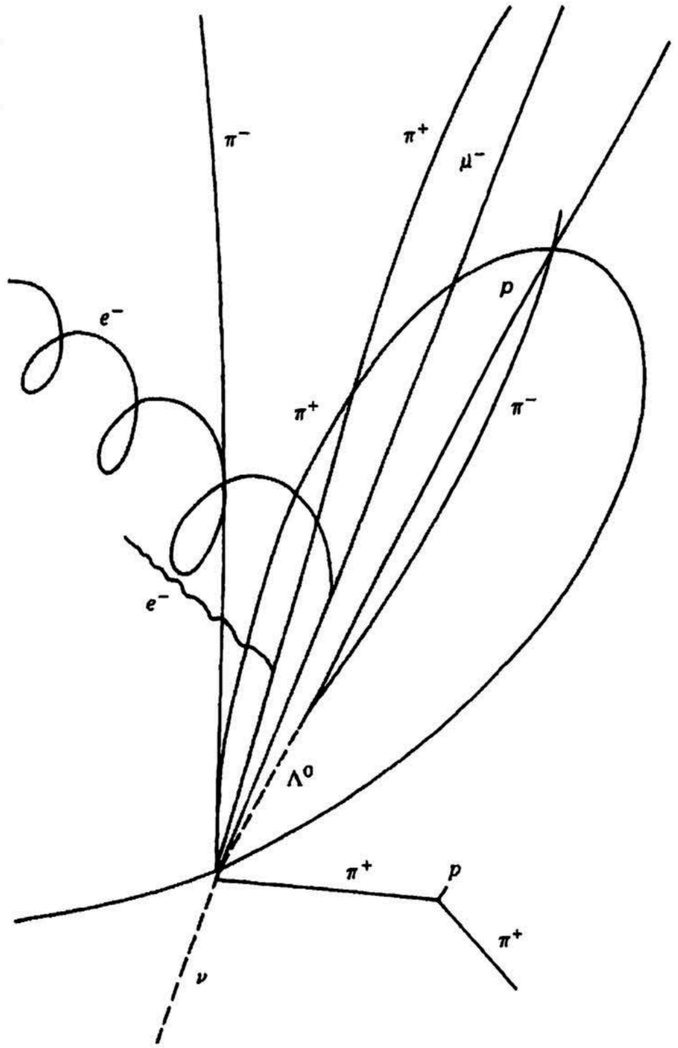
Backup Slides

The Charm Observation

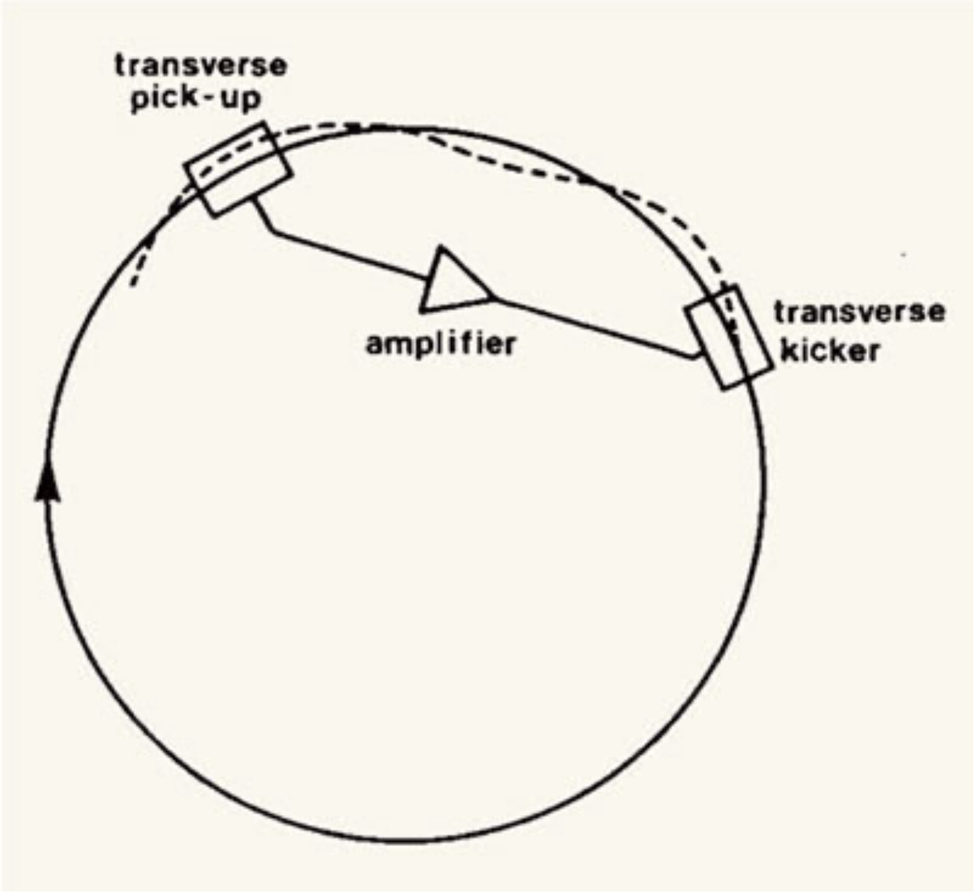
- $\nu_\mu + p \rightarrow \Lambda_c^+ + \mu^- + \pi^+ + \pi^-$
- Decays too soon to leave a track: $\Lambda_c^+(\mathrm{udc}) \rightarrow \Lambda^0 + \pi^+$
- Subsequent decay is visible: $\Lambda^0\,(\mathrm{uds}) \rightarrow p + \pi^-$



Source: Griffiths, D. (2008). *Introduction to Elementary Particles* (2nd rev. ed., p. 46)

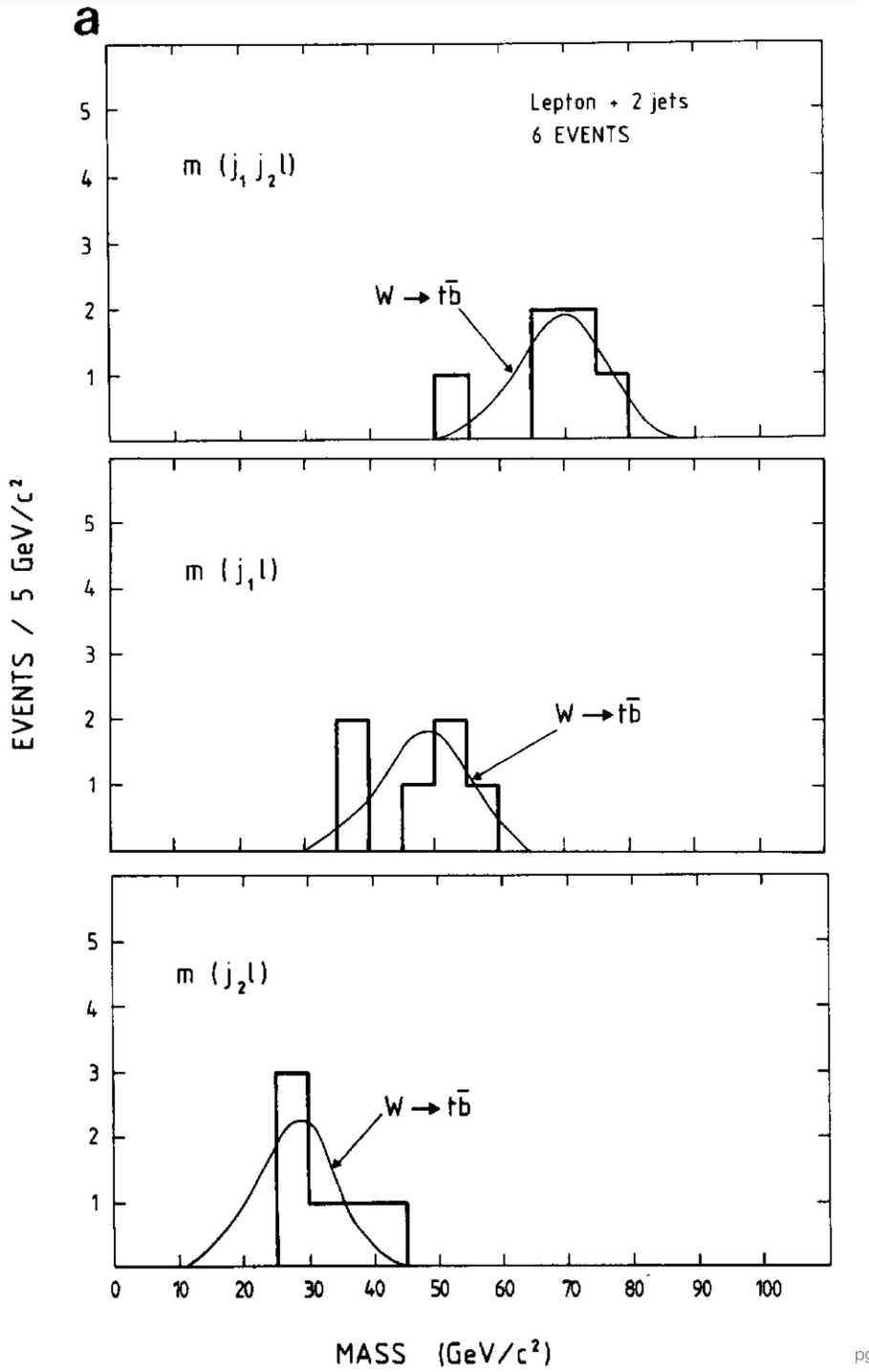
Stochastic Cooling

- Reduce energy spread and angular divergence of the beams of particles
    - Reduce the amplitudes in the motion of particles in a beam in order to contain them in a restricted space and maintain their energies close to a mean value
    - Particles are better organised and the beam is cooled
- Improve beam quality
- Feedback system with 2 components:
    - pick-up: measures the deviation of the centre of gravity of a sample of particles in the beam
    - kicker: applies an electric field to the sample to correct the deviation



Claims and Interpretations

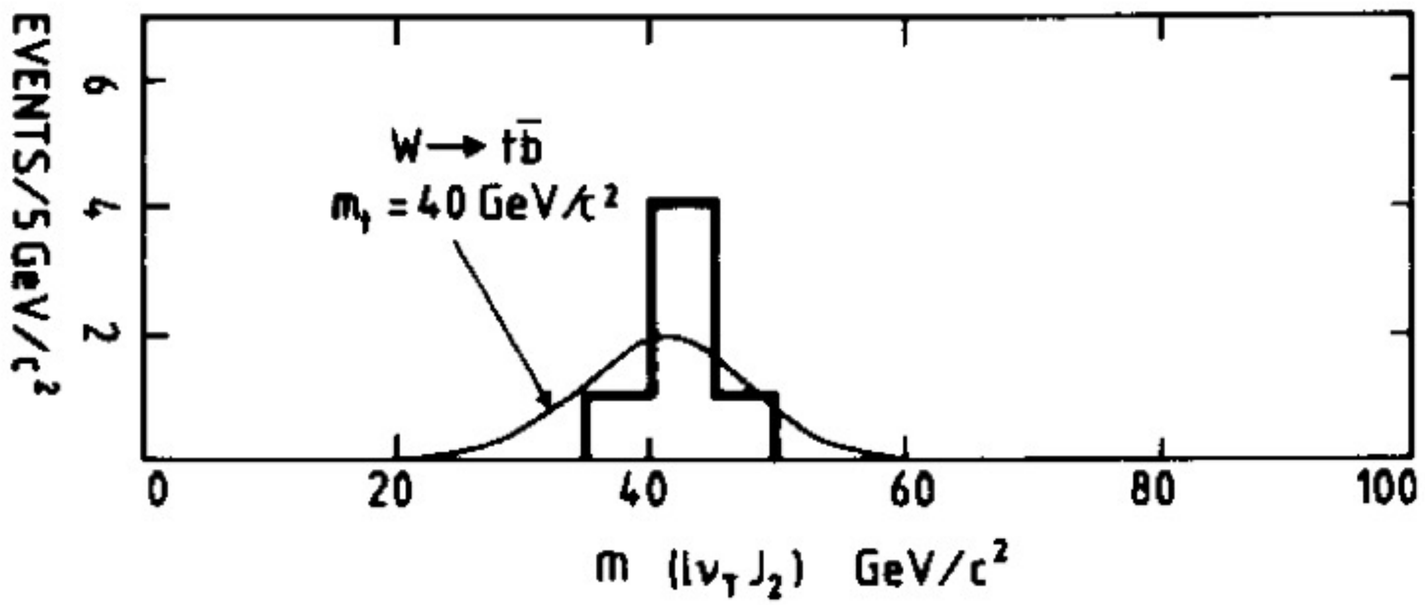
- 12 events (e/μ) final selection:
  - 7 events $e + 1$ jet
  - 5 events $e + \geq 2$ jets
  - 7 events $\mu + 1$ jet
  - 4 events $\mu + 2$ jets
  - 1 events $\mu + 3$ jets



pg. 506, URL: https://doi.org/10.1016/0370-2693(84)91410-2

Claims and Interpretations

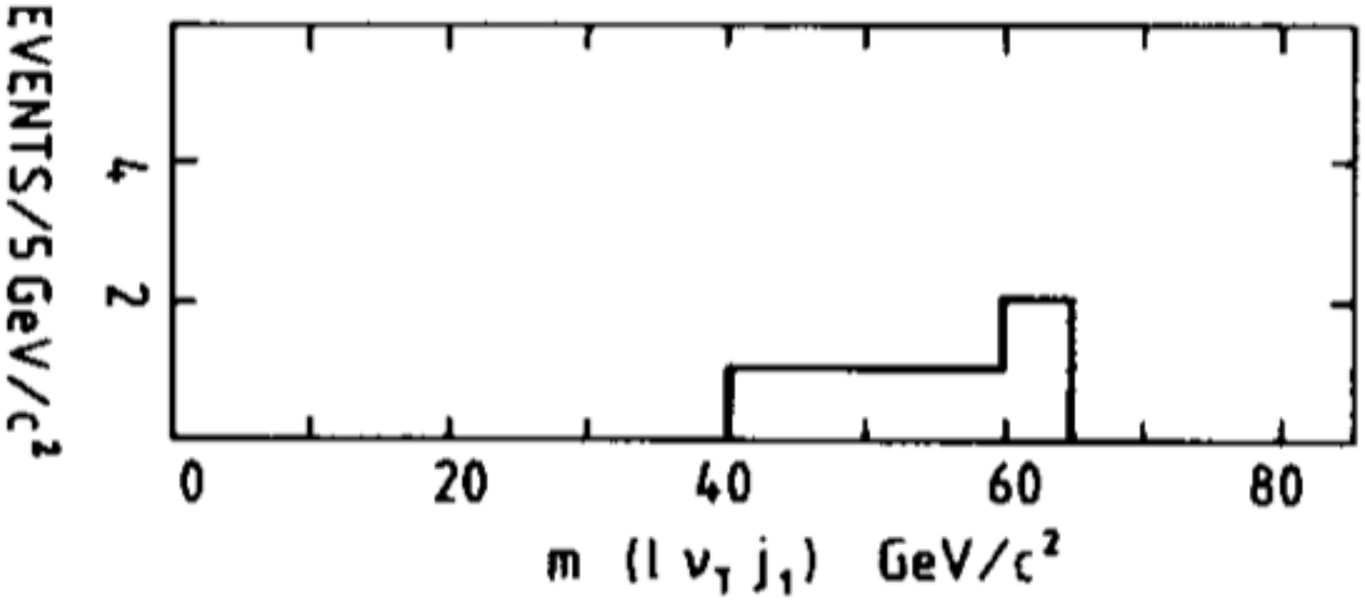
- Top quark mass reconstruction
- $t \to \ell \nu b$
- Three-body mass clusters around $m_t \simeq 40\,\mathrm{GeV}/c^2$
- Systematic errors of $\pm 10\,\mathrm{GeV}/c^2$



pg. 505, URL: https://doi.org/10.1016/0370-2693(84)91410-2

Claims and Interpretations

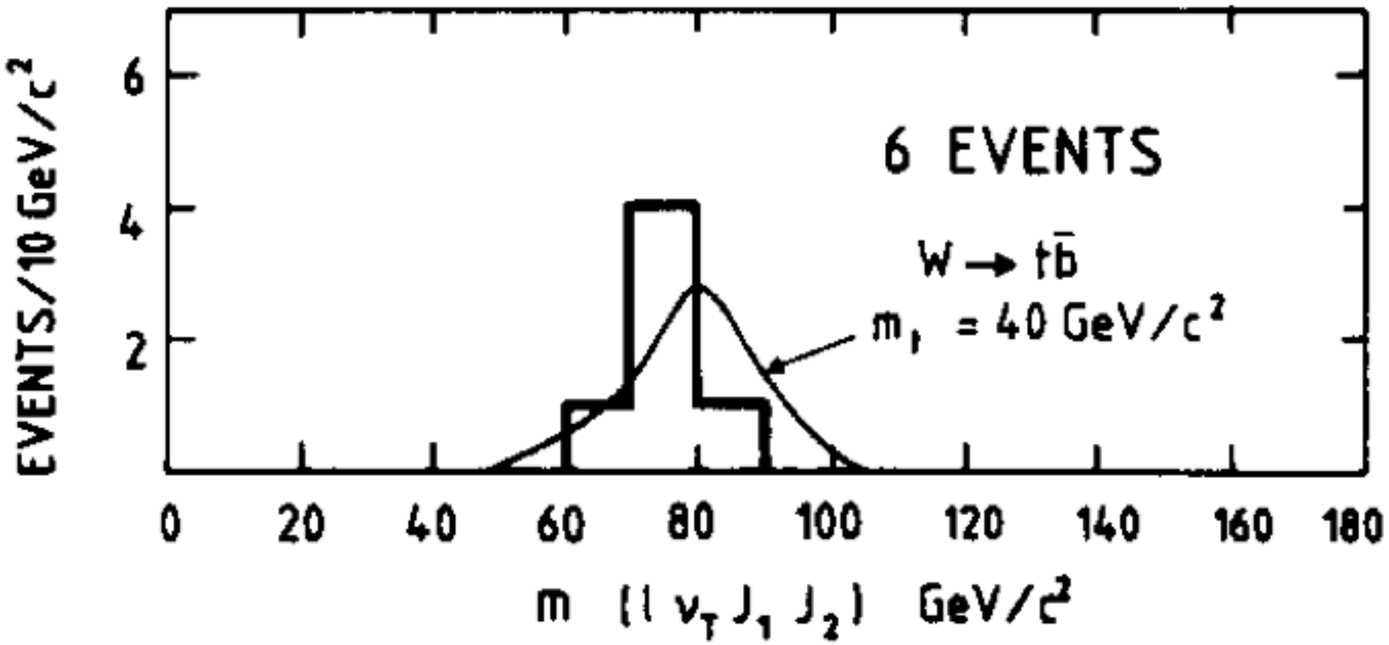
- Higher-E_T jet
- Broader distribution
- Higher masses
- Not chosen for top quark mass reconstruction



pg. 505, URL: https://doi.org/10.1016/0370-2693(84)91410-2

Claims and Interpretations

- W boson mass reconstruction
- $W \to t\bar{b}$
- Four-body mass peaks at $m_W \simeq 80\,\mathrm{GeV/c^2}$
- Systematic errors of $\pm 10\,\mathrm{GeV/c^2}$



pg. 505, URL: https://doi.org/10.1016/0370-2693(84)91410-2