THE ALTARELLI COCKTAIL AND OTHER MEMORIES

Luigi Di Lella
Physics Dept., University of Pisa

- When and where I first met Guido
- Guido and the experiments at the CERN proton – antiproton ($Sp\bar{p}S$) collider

Guido Altarelli Memorial Symposium
CERN, 10th June 2016

When and where I first met Guido:

at the beginning of 1970 on the occasion of a meeting
at the Nevis Laboratories of Columbia University to discuss
new results from an experiment performed by Leon Lederman
(the Lab Director) and his group at the the Brookhaven 30 GeV
proton synchrotron (AGS) to search for muon pairs produced
in proton – nucleus collisions.

The experiment had rather poor dimuon mass resolution
(muon momentum measured using counters and residual range in Iron)
but very high "luminosity"
(it used the full AGS proton beam and a thick Uranium target)

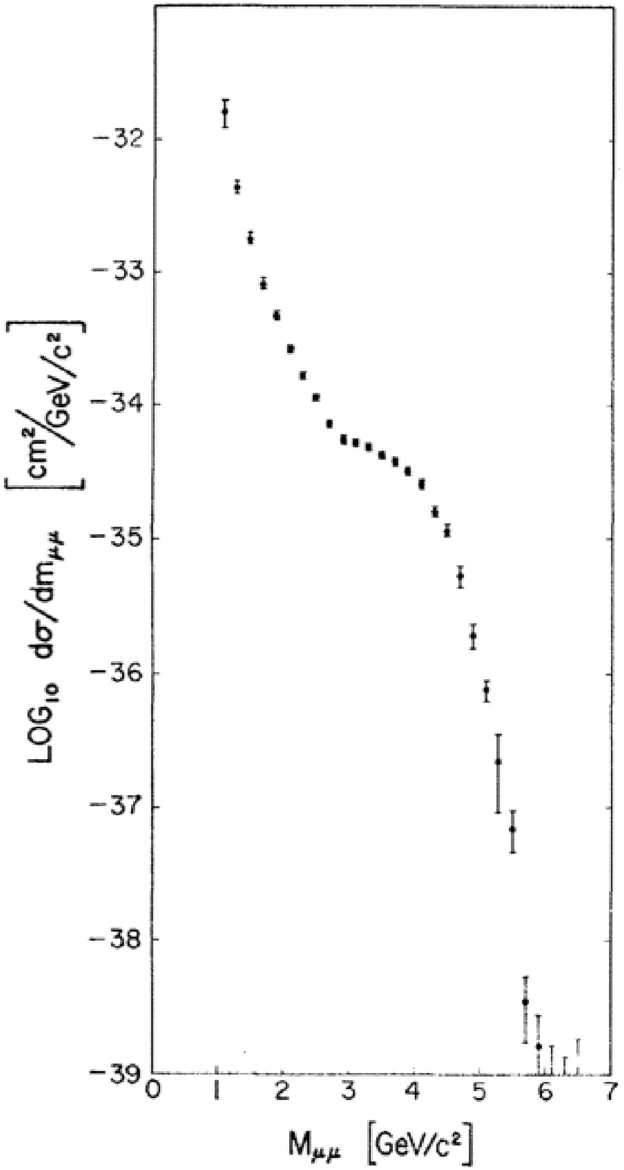
The results were interesting and puzzling

The measured dimuon invariant mass distribution

J.R. Christenson et al., PRL 25 (1970) 1523

The "shoulder" above 3 GeV
is most likely the J/Ψ distorted by
the poor mass resolution 4 years
before its official discovery in 1974.
It was not taken seriously by the authors.

The continuum distribution had no obvious explanation at that time



In 1968 experiments at SLAC on deep-inelastic electron – nucleon scattering had given evidence for electrically charged, point-like constituents (named "partons" by Feynman)

Lederman had the "feeling" that the dimuon continuum had something to do with partons.

A discussion of the dimuon results with theorists was needed but there are no theorists at the Nevis Labs

(the Nevis Labs are the working place of Columbia experimental particle physics groups and are located at ~30 km distance from the Columbia Physics Department in Manhattan).

Lederman looked for theorists with knowledge of parton physics in the New York area and found three at the Rockefeller University:

- **Guido Altarelli**
- **Richard Brandt**
- **Giuliano Preparata**

They came to the Nevis Labs on a Saturday and presented their ideas on possible mechanisms capable of producing muon pairs in hadron collisions.

They discussed an operator representation for the behaviour of the product of two electromagnetic currents near the light cone, taking into account constraints from the SLAC deep-inelastic scattering experiments and Regge theory.

I was not familiar with most of these concepts, nevertheless I understood from Guido's presentation that, in the framework of the parton model they were talking about parton – antiparton annihilation.

However, nobody knew at that time what these partons and antipartons were:

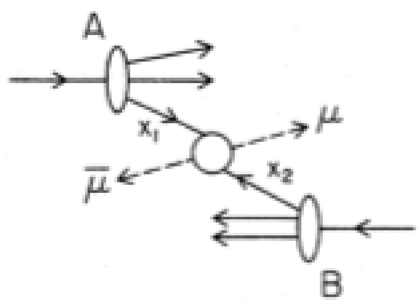
- **Partons had not yet been identified as quarks;**
- **Gell-Mann himself had often declared that, in his opinion, quarks were not physical particles but only useful mathematical concepts to describe the known SU(3) hadron multiplets.**

Today the production of lepton pairs in hadron collisions is known as the Drell – Yan process from the authors of the first theoretical paper describing the reaction in terms of parton – antiparton annihilation:

S.D. Drell and T.M. Yan, Phys. Rev. Lett. **25** (1970) 316

MASSIVE LEPTON-PAIR PRODUCTION IN HADRON-HADRON COLLISIONS AT HIGH ENERGIES*

Sidney D. Drell and Tung-Mow Yan
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 25 May 1970)



$Q^2 = x_1 x_2 s$

Note added in proof.—We have just received a preprint of a related study by Altarelli, Brandt, and Preparata at Rockefeller University, who have made an analysis based on a direct study of the light cone behavior of (4).

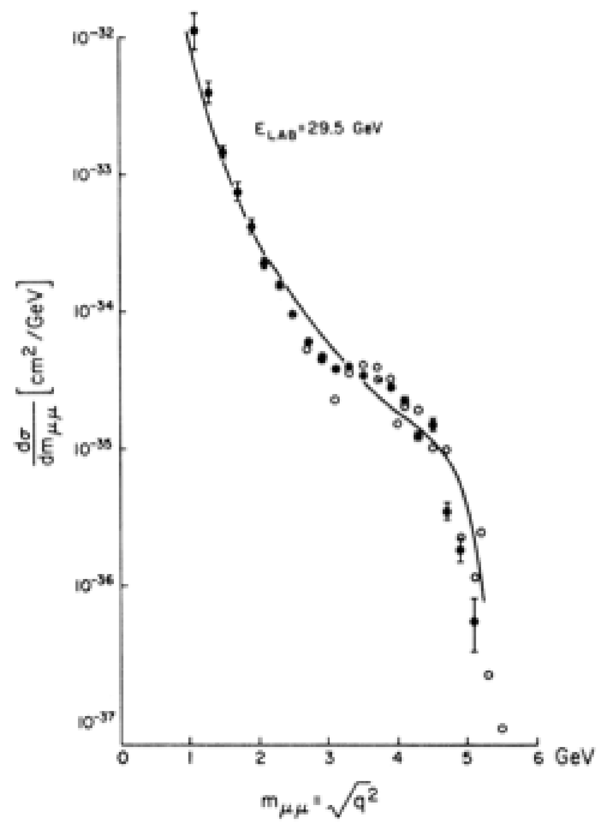
The paper by Altarelli, Brandt and Preparata was published soon after:

VOLUME 26, NUMBER 1 PHYSICAL REVIEW LETTERS 4 JANUARY 1971

Light-Cone Analysis of Massive μ-Pair Production*

Guido Altarelli,† Richard A. Brandt,‡ and Giuliano Preparata†
Rockefeller University, New York, New York 10021
(Received 9 September 1970)

This paper presents a fit to the dimuon mass distribution measured by the Lederman group



The Altarelli cocktail
Guido and the experiments at the proton – antiproton collider

Following the discovery of the W and Z bosons at the CERN $\bar{p}p$ Collider ($S\bar{p}pS$) in 1983, further analysis of those data had found a few peculiar unexpected events which, at first sight, seemed to be inconsistent with Standard Model backgrounds.

These events were presented at the 4th Topical Workshop on Proton – Antiproton Collider Physics in Bern, Switzerland, 5 – 8 March 1984, and published soon after.

They produced much excitement and lots of theoretical papers were written to explain them, all based on new physics beyond the Standard Model.

Most of these events (but not all) had hadronic jets in the final state and large missing transverse momentum.

Volume 139B, number 1,2 PHYSICS LETTERS 3 May 1984

EXPERIMENTAL OBSERVATION OF EVENTS WITH LARGE MISSING TRANSVERSE ENERGY ACCOMPANIED BY A JET OR A PHOTON (S) IN $p\bar{p}$ COLLISIONS AT $\sqrt{s}$ = 540 GeV

UA1 Collaboration, CERN, Geneva, Switzerland

Received 30 March 1984

We report the observation of five events in which a missing transverse energy larger than 40 GeV is associated with a narrow hadronic jet and of two similar events with a neutral electromagnetic cluster (either one or more closely spaced photons). We cannot find an explanation for such events in terms of backgrounds or within the expectations of the Standard Model.

In its first phase (1981 – 85) UA2 had only partial calorimetric coverage
→ Large missing transverse momentum could result from undetected, high-p_T particles or hadronic jets.

However, UA2 also presented “peculiar” events:

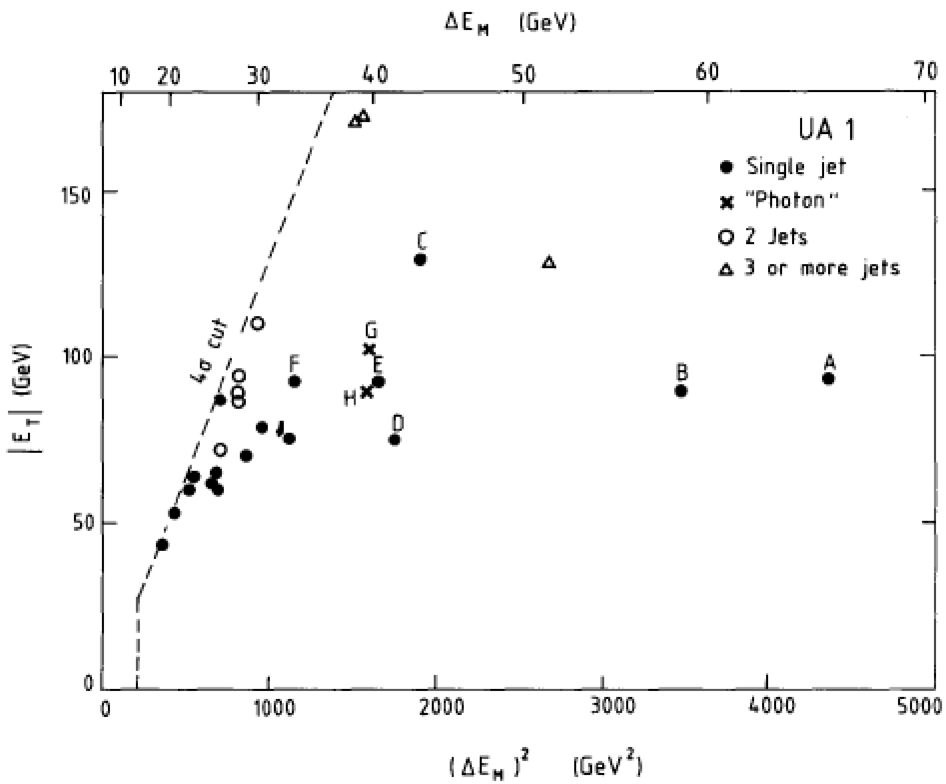
- **An $e^+e^-\gamma$ event consistent with the Z mass, with all three particles quite energetic and at large angles from each other;**
- **Three events containing a W → e ν decay and associated high-p_T jet(s) consistent with a unique value of the W + jet(s) invariant mass.**

In the UA1 detector events with no genuine missing transverse momentum (ΔE_M) may have $\Delta E_M > 0$ because of measurement errors:

$$\sigma(\Delta EM) \approx 0.7\sqrt{|ET|}$$

where $|E_T|$ is the scalar sum of all transverse energies in the event in GeV.

➡ **The cut $\Delta E_M > 4\sigma(\Delta EM)$ selects events with genuine ΔE_M**



Events with W leptonic decays are excluded

Events A, B, C, D were named "monojets"

It was initially suggested that monojet events might provide evidence for SuperSymmetry (in this case the large missing P_T in the event would be associated with the Lightest SUSY particle escaping detection).

Example of a paper showing the excitement of those times:

ELSEVIER

Physics Letters B

Volume 153, Issues 4–5, 4 April 1985, Pages 265-273

Supersymmetry at bay?

H. Baer [1], John Ellis [1], D.V. Nanopoulos [1], Xerxes Tata [1]

CERN, CH 1211 Geneva, Switzerland

Received 10 December 1984, Available online 18 October 2002

and also the title of a lecture course presented at the Yukon Advanced Study Institute on Quarks and Leptons, Whitehouse, Yukon, August 1984:

SUPERSYMMETRY --SPECTROSCOPY OF THE FUTURE?

OR OF THE PRESENT?

(CERN-TH 4017/84)

Meanwhile Guido and his collaborators were working on a precise evaluation of the W and Z boson transverse momentum from QCD effects:

Nuclear Physics B246 (1984) 12–44

VECTOR BOSON PRODUCTION AT COLLIDERS: A THEORETICAL REAPPRAISAL

G. ALTARELLI

CERN, Geneva, Switzerland and Dipartimento di Fisica, Università "La Sapienza", Roma, Italy
INFN, Sezioue di Roma, Italy

R.K. ELLIS*

INFN, Sezione di Roma, Italy

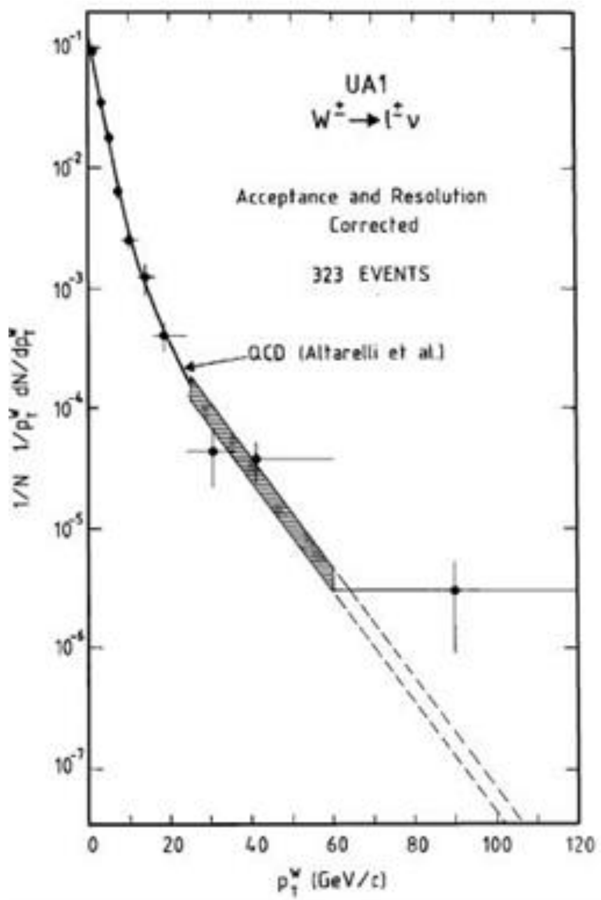
M. GRECO and G. MARTINELLI

INFN, Laboratori Nazionali di Frascati, Italy

Received 2 May 1984
(Revised 13 June 1984)

We study the production of vector bosons in hadron-hadron collisions via the Drell-Yan mechanism in QCD. Our treatment of the transverse momentum and rapidity distributions of the produced bosons takes all available theoretical principles and results into account in a systematic way. The resulting q_T distribution reduces to the perturbative limit for large q_T, includes the summation of soft gluons and reproduces the known results for the total cross section. A full numerical analysis of W and Z cross sections at collider and tevatron energies is made.

Their predictions describe well the W p_T distribution as measured by UA1 from all data taken before 1986



At high W p_T the W is seen to recoil against a high p_T hadronic jet

Another run took place at the CERN S$\bar{p}$pS collider in 1984.

The centre-of-mass energy was increased from 540 to 630 GeV and the total integrated luminosity in UA1 and UA2 went from ~130 to ~400 nb^{-1}.

Preliminary results were presented at the 5th Topical Workshop on Proton – Antiproton Collider Physics, Saint Vincent, Aosta Valley (Italy), 25th February – 1st March 1985

From the Introduction by the Workshop Chairperson (Mario Greco):

….. But the highlights of the 1984 Berne Meeting were the presentations of a few unexpected events, in particular those with high missing transverse energy, which could hardly be accounted for in the Standard Model. These events have generated much excitement and great expectations in the high-energy physics community …. The new data taken from September 1984 to the end of the year at higher center-of-mass energy will certainly shed some light on the possibility that new physics is starting in the O(100 GeV) energy region.

Carlo Rubbia reported on "UA1 UPDATE"

(only the copy of his slides is available in the Workshop Proceedings)

240

ANOMALIES – SCORE

EFFECT	4TH WORKSHOP (BERNE) UA1	4TH WORKSHOP (BERNE) UA2	5TH WORKSHOP (S. VINCENT) (~400 + 400 nb^{-1})
* J-J RESONANCE AT 148 GeV	NOT SEEN	✓	NOT CONFIRMED
* W + JET ACTIVITY (W – W)	NOT SEEN	✓	NOT CONFIRMED
* "HOT" Z^0	? ✓	NOT SEEN	NOT CONFIRMED
* RADIATIVE Z^0 DECAYS	✓	✓	NOT CONFIRMED
* MISSING ENERGY JETS	✓	—	CONFIRMED
* EQUAL SIGN, QUIET DIMUONS	✓	—	CONFIRMED

(there were no new anomalous events in UA2

Guido’s contribution in the discussion following Rubbia’s presentation:

- We agree that it is not possible to explain all UA1 monojet events in terms of a single Standard Model process, such as Z + gluon $\rightarrow \nu\bar{\nu}$ (invisible) + jet ;
- However, one should try a “wisely composed cocktail” of known processes, such as:
  - two or three W $\rightarrow \tau\nu$ followed by τ hadronic decay;
  - a couple of Z + gluon $\rightarrow \nu\bar{\nu}$ (invisible) + jet;
  - one or two W + gluon $\rightarrow e(\mu)\nu$ + jet with the charged lepton escaping detection;
  - and also (perhaps) a genuine two-jet event with one jet mismeasured.

An estimate of the background to the monojet events from Altarelli’s cocktail was attempted and presented at the Workshop on the day following Guido’s suggestion.

THE STANDARD MODEL AND MISSING E_T

OR

THE MANY ROADS TO PARADISE

Stephen D. Ellis[‡]

CERN - Geneva

ABSTRACT

The processes $p+\bar{p} \to W^{\pm}, Z^{\circ} + 0,1,2$ jets are studied in the context of the observation of events with large missing E_T at the CERN $p\bar{p}$ collider. The conclusion is that vector bosons which decay into undetected or unidentified leptons can constitute a non-negligible source of such events. By correlating these unidentified decays with those in which the leptons are identified we can, in principle, eliminate the theoretical uncertainties in such perturbative QCD calculations.

......We are thus able to sum the contributions of MANY SMALL sources which were absent in previous studies and which can, in the sum, yield a sizeable result. These are the "many roads" of the title. [This concern, that many small numbers can yield a large sum, was colourfully voiced at the meeting by G. Altarelli who described his vision of a mixture of small effects -- the Altarelli cocktail -- leading to the observed signal.]

From the Summary Talk "Where we are and where we are going" by S.L. Glashow

(only the copy of his slides are available in the Workshop Proceedings)

WHAT ARE THE SURVIVING EXPLANATIONS FOR THE SURVIVING ANOMALIES ?

I SUPERSYMMETRY: Double the FLAVOR, DOUBLE THE FUN.

(here S.L. Glashow compares SuperSymmetry to a disease and gives a short list of people affected by the disease)

AND, SS CAN MIMIC ALMOST ANY DATA: EITHER THE 1983 "MONOJETS" OR THE 1984 "MULTIJETS" OR THE 1985 WHATEVER. IT IS A THEORY THAT PREDICTS NOTHING YET EXPLAINS ANYTHING. IT CANNOT BE PROVEN WRONG, BUT ONLY REPLACED BY SOMETHING BETTER, LIKE...

II THE STANDARD MODEL, WITH HALF AS MANY PARAMETERS AND PARTICLES AS S.S. IT IS OBTAINED FROM S.S. BY SIMPLE DELETION OF UNOBSERVED PARTICLES, AND YET, IT OFFERS JUST AS GOOD AN EXPLANATION OF OBSERVED PHENOMENA AS SS.

CAN THE CERN MONOJETS BE COMPLETELY CONVENTIONAL? ARE THEY EXPLAINED IN TERMS OF THE "ALTARELLI COCKTAIL" OF QCD CORRECTIONS TO W+Z PRODUCTION, PLUS A FEW STRUCTURAL FLAWS OF THE UA(1) ?? THIS IS QUESTION NUMERO UNO!

From the Workshop "Experimental Summary" by R.F. Schwitters:

For now, the Altarelli cocktail is as good an explanation of the reported data as any.

…….

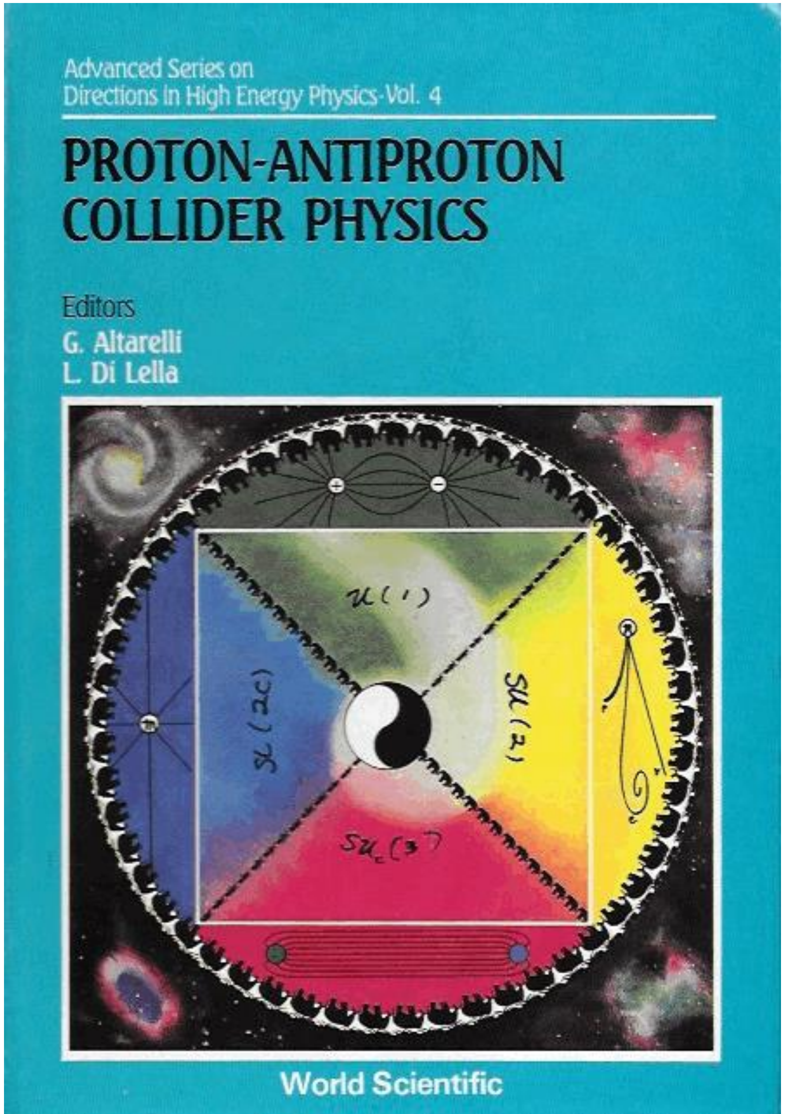
The overwhelming conclusion of this Workshop is that the Standard Model is alive and well.

Guido's comment at the 1985 Workshop marked the beginning of the end of SUSY speculations to explain the UA1 monojet events.

With his suggestion to try a "wisely composed cocktail" he called on the particle physics community (theorists and experimentalists) to stop wishful thinking about new physics and to start a serious, quantitative background evaluation.

Subsequent work along these guidelines concluded that indeed all anomalous results from the S$\bar{p}$pS collider could just be explained by the Standard Model.

1986 – 88: Working with Guido as Editors of a book



(published in February 1989)

CONTENTS

* also published as CERN-TH- 5258-88

1987 – 90: the last years of the CERN proton – antiproton collider
Luminosity increased ~10 times

Physics goals:

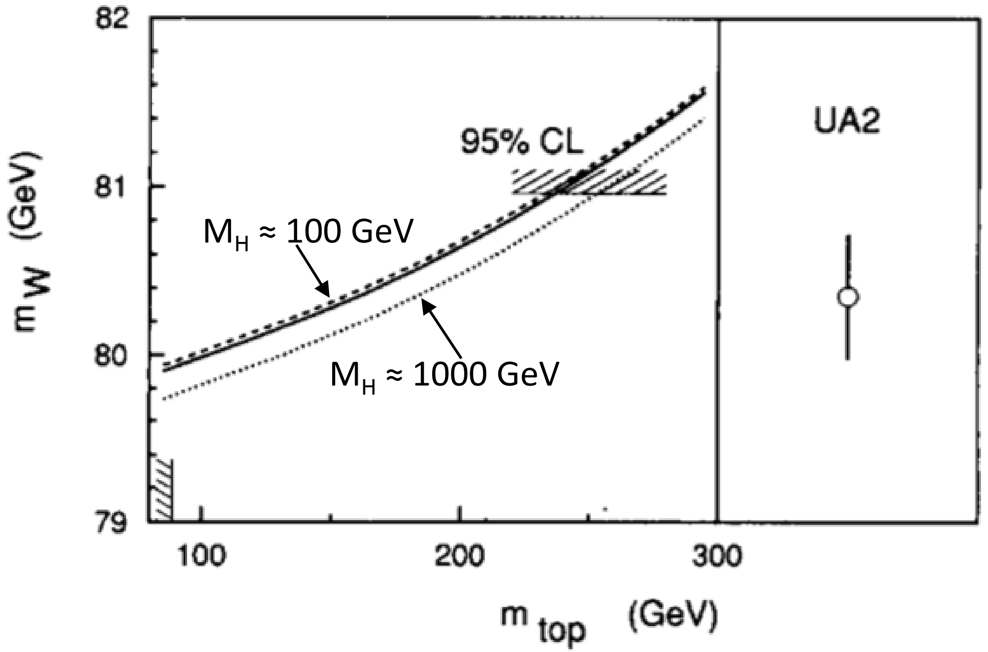
- **Search for the top quark**
  (observable at the $S\bar{p}pS$ only if $W \rightarrow t\bar{b}$ decay is kinematically allowed)
- **Searches for new physics**

Final results:

- **No top quark seen**
- **No evidence for new physics**
- **2065 $W \rightarrow e\nu$, 251 $Z \rightarrow e^+e^-$ collected by UA2 allowing a precise measurement of the mass ratio M_W / M_Z**
  (experiments measuring the electron energy with scintillation calorimetry suffer from a systematic uncertainty of ~1% on the energy scale which largely cancels in the mass ratio)

At the beginning of 1989 Guido suggested that the measured ratio M_W / M_Z could be used together with the first precise measurement of the Z mass at LEP (expected by the end of 1989) to obtain a precise determination of M_W
(an important measurement because M_W depends strongly on the top quark mass through radiative corrections involving a $t\bar{b}$ loop).
Guido also provided help in estimating the final systematic uncertainty on M_W
(measuring the W mass is harder than measuring the Z mass at hadron colliders because the neutrino longitudinal momentum cannot be measured)

We measured $M_W / M_Z = 0.8813 \pm 0.0036 \pm 0.0019$
Using the first LEP result, $M_Z = 91.175 \pm 0.021$ GeV,
we obtained $M_W = 80.35 \pm 0.33 \pm 0.17$ GeV



From this result we obtained $m_{top} = 160^{+50}_{-60}$ GeV

(4 years before the top quark discovery at Fermilab)

A NICE EXAMPLE OF FRUITFUL INTERACTION BETWEEN GUIDO AND AN EXPERIMENTAL GROUP

ADDITIONAL PERSONAL COMMENTS

Over the last 30 years I have often consulted Guido on various physics subjects for which I needed some explanation or clarification.

I always found him willing to help, kind, patient and very clear in explaining even very difficult theoretical details. He often tried a different explanation if I failed to understand the first one he had offered, until he was convinced that I had fully understood the problem.

The last time I consulted Guido was at the beginning of May 2015, when I asked him a question about the differences of the neutrino mixing matrix for Dirac and Maiorana neutrinos. As usual, when I left him I knew more physics than before.

As for most of my experimental colleagues, I will miss his physics insight, his wisdom and his human qualities.