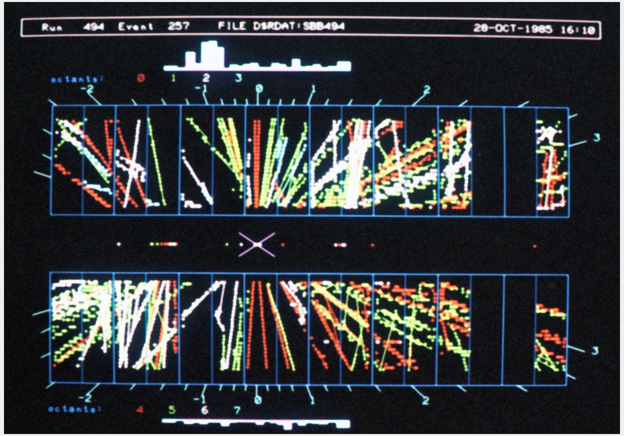
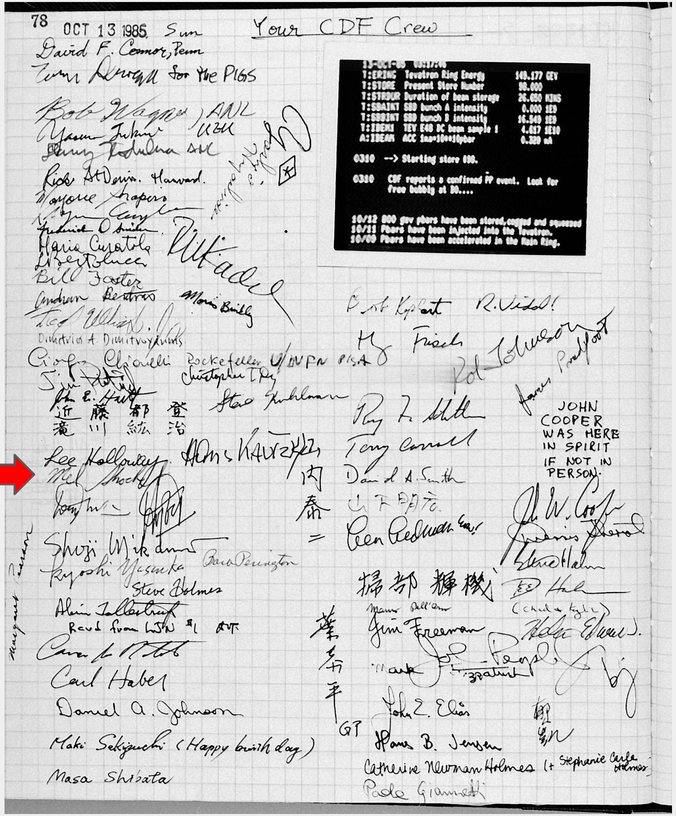
CDF: Electroweak Precision Measurements

Sarah Eno
University of Maryland
(Chicago postdoc, 1989-1993,
CDF EWK convener 1993)





Some CDF EWK thesis students

David Saltzberg

Oliver Stelzer-Chilton

Ed Kearns

Sacha Kopp

Phil Schlabach

Bill Ashmanskas

Mark Krasberg

Paul Derwent

Federico Sforza

Stefano Camarda

Randy Keup

graduate student Sourav Sen (Duke) who worked on the 2022 W mass publication

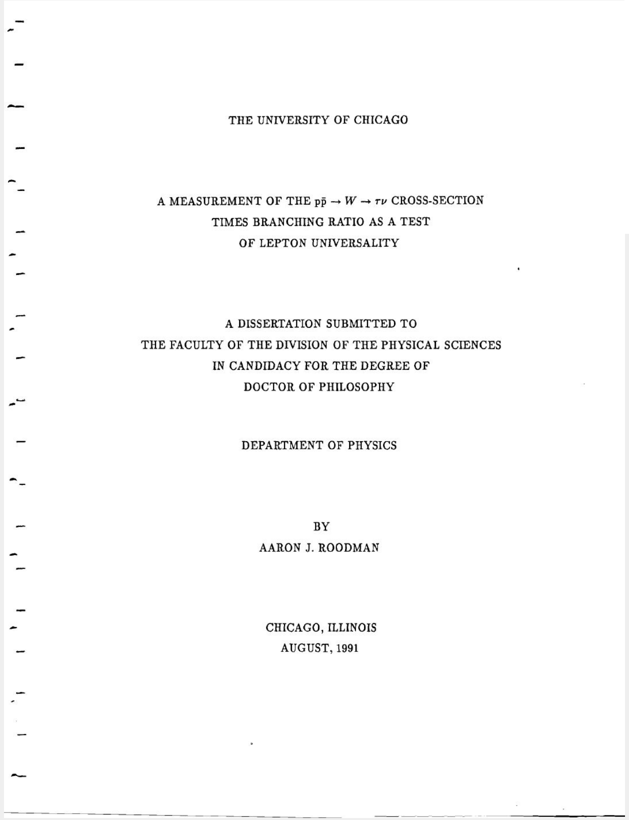
Vic Scarpine Karen Byrum

Group photo at Duke University garden of the 2007 W mass publication team: graduate students are Ian Vollrath (far left) and Oliver Stelzer-Chilton (far right). Trischuk is in the orange shirt.

Collage assembled for Fermilab result of the week, 2012 W mass publication: graduate students are Tom Riddick (UCL), Dan Beecher (UCL), Sarah Malik (UCL), Ravi Shekhar (Duke), Yu Zeng (Duke) and one undergraduate student Siyuan Sun (Duke)

W to tau

Mel made all these results possible due to his leading role in CMS, without which none of this would be possible, he has a more intimate connection to one result.



THE UNIVERSITY OF CHICAGO

A MEASUREMENT OF THE $p\bar{p} \to W \to \tau\nu$ CROSS-SECTION
TIMES BRANCHING RATIO AS A TEST
OF LEPTON UNIVERSALITY

A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICS

BY
AARON J. ROODMAN

CHICAGO, ILLINOIS
AUGUST, 1991

Finally, much gratitude is due to my thesis advisor, Mel Shochet, whose calm and reasoned advice was so necessary during the analysis which lead to this thesis. Mel's method of approaching a problem, completely logical and straightforward, is one which I have tried much to emulate.

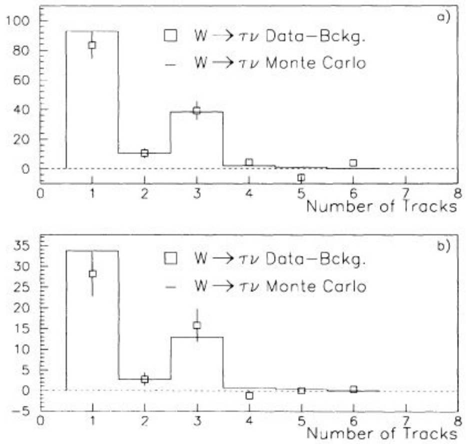


FIG. 2. N_{track} for tau clusters with $N_{isolation}=0$, for the $W \to \tau\nu$ data sample with background subtracted (squares) and the Monte Carlo prediction (histogram): (a) Missing-E_T trigger sample; (b) tau trigger sample.

What a journey!

Theses:

- W,Z cross section 23
- WW, WZ 11
- W,Z gamma 10
- W mass 9
- Jet production with W/Z 8
- W asymmetry 7
- Z transverse momentum, rapidity 3
- Z forward-backward 3
- Taus in W or Z decays 3
- W width 3
- W transverse momentum 2
- Z mass 1
- Hadronic WZ decays 1
- Diffractive W production 1

Run 1 papers

- W,Z cross section 10
- W mass 8
- W or Z + jets 6
- Rare W decays 4
- W,Z pT 3
- Z forward-backward 3
- W asymmetry 3
- W,Z gamma 2
- W width 2
- Di or Tri boson 2
- Diffraction W 1
- Taus in W,Z decay 1

Run 2 papers

- Di or tri boson 16
- Z asymmetry 6
- W mass 6
- W or Z + jets 6
- W or Z gamma 4
- W, Z cross section 3
- W asymmetry 3
- W or Z pT and/or rapidity 2
- Diffractive W or Z 2
- W or Z to tau 1
- W width 1
- Hadronic W or Z decays 1
- Rare W decays 1

This is an impressive canon of contributions to our knowledge of the W and Z boson.

- Most popular: W and Z cross section
- Strong interest in di-bosons in Run 2.

I cannot cover all these important topics in my 20 minutes. My apologies

Don't take these counts too seriously., I got interrupted several times while trying to do them.

CDF’s competitive spirit

Z mass

Aug. 1989.Tension between UA1 CERN (direct), UA2 (direct) and TRISTAN (indirect) Z mass measurements.

https://www.sciencedirect.com/science/article/pii/0370269387903248

https://cds.cern.ch/record/192294?ln=en

https://www.sciencedirect.com/science/article/pii/037026938991455X?via%3Dihub

MEASUREMENT OF THE STANDARD MODEL PARAMETERS FROM A STUDY OF W AND Z BOSONS

The UA2 Collaboration

Bern–CERN–Copenhagen (NBI)–Heidelberg–Orsay (LAL)–Pavia–Perugia–Pisa–Saclay (CEN)

R. ANSARI [a], P. BAGNAIA [b], M. BANNER [c], R. BATTISTON [d], K. BERNLÖHR [e], C.N. BOOTH [b], K. BORER [f], M. BORGHINI [b], G. CARBONI [g], V. CAVASINNI [g], P. CENCI [b,1], J.-C. CHOLLET [a], A.G. CLARK [b], C. CONTA [h], F. COSTANTINI [g], P. DARRIULAT [b], B. DE LOTTO [a], T. DEL PRETE [g], L. DI LELLA [b], J. DINES-HANSEN [i], K. EINSWEILER [b], L. FAYARD [a], R. FERRARI [h], M. FRATERNALI [h], D. FROIDEVAUX [a], J.-M. GAILLARD [a], O. GILDEMEISTER [b], V.G. GOGGI [h], C. GÖSSLING [b], B. HAHN [f], H. HÄNNI [b], J.R. HANSEN [b], P. HANSEN [i], K. HARA [f], N. HARNEW [b], E. HUGENTOBLER [f], E. IACOPINI [g,2], L. ICONOMIDOU-FAYARD [a], K. JAKOBS [e], P. JENNI [b], E.E. KLUGE [e], O. KOFOED-HANSEN [i], E. LANÇON [c], P. LARICCIA [g,3], B. LISOWSKI [b,4], M. LIVAN [h], S. LOUCATOS [c], B. MADSEN [i], B. MANSOULIÉ [c], G.C. MANTOVANI [d], L. MAPELLI [b,5] K. MEIER [b], B. MERKEL [a], R. MÖLLERUD [i], M. MONIEZ [a], R. MONING [f], M. MORGANTI [g], C. ONIONS [b], T. PAL [b], M.A. PARKER [b], G. PARROUR [a], F. PASTORE [h], M. PEPE [d], Ch. PETRIDOU [b], H. PLOTHOW-BESCH [e], M. POLVEREL [c], L. RASMUSSEN [b], J.-P. REPELLIN [a], A. ROUSSARIE [c], V. RUHLMANN [c], G. SAUVAGE [a], J. SCHACHER [f], F. STOCKER [f,6], M. SWARTZ [b], J. TEIGER [c], S.N. TOVEY [b,7], W.Y. TSANG [8], M. VALDATA-NAPPI [g], V. VERCESI [h], A.R. WEIDBERG [b], M. WUNSCH [e], H. ZACCONE [c] and J.A. ZAKRZEWSKI [b,i]

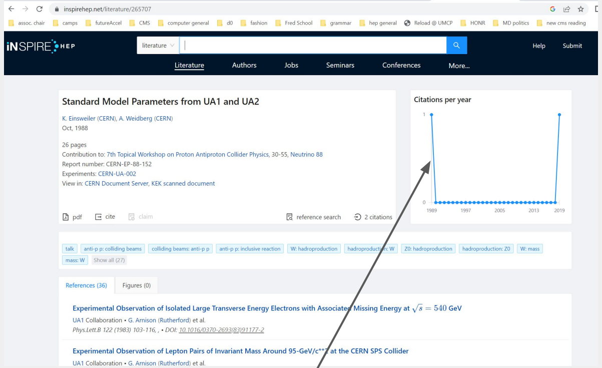
[a] *Laboratoire de l'Accélérateur Linéaire, Université de Paris-Sud, F-91405 Orsay Cedex, France*
[b] *CERN, CH-1211 Geneva 23, Switzerland*
[c] *Centre d'Etudes Nucléaires de Saclay, F-91191 Gif sur Yvette Cedex, France*
[d] *Gruppo INFN del Dipartimento di Fisica dell'Università di Perugia and INFN, I-06100 Perugia, Italy*
[e] *Institut für Hochenergiephysik der Universität Heidelberg, Schröderstrasse 90, D-6900 Heidelberg, Fed. Rep. Germany*
[f] *Laboratorium für Hochenergiephysik, Universität Bern, Sidlerstrasse 5, CH-3012 Bern Switzerland*
[g] *Dipartimento di Fisica dell'Università di Pisa and INFN, Sezione di Pisa, Via Livornese, S. Piero a Grado, I-56010 Pisa, Italy*
[h] *Dipartimento di Fisica Nucleare e Teorica, Università di Pavia and INFN, Sezione di Pavia, Via Bassi 6, I-27100 Pavia, Italy*
[i] *Niels Bohr Institute, Blegdamsvej 17, Dk-2100 Copenhagen, Denmark*

Received 8 January 1987

A study has been made of the decays $W \to e\nu$ and $Z \to e^+e^-$, using the UA2 detector at the CERN $\bar{p}p$ Collider. The data correspond to an integrated luminosity of 142 nb^{-1} at a centre-of-mass collision energy $\sqrt{s}=546$ GeV, and 768 nb^{-1} at $\sqrt{s}=630$ GeV. Measurements of the standard model parameters from samples of 251 W decay and 39 Z decay candidates are compared with expectations of the standard electroweak model.

Phys. Lett. B186, 440

$$m_Z = 91.5 \pm 1.2 \text{ (stat)} \pm 1.7 \text{ (syst) GeV},$$



You can see the CDF cite

$$m_Z = 93.1 \pm 1.0 \text{ (stat.)} \pm 3.1 \text{ (syst.) GeV}/c^2 \quad \text{(UA1)}, \qquad (8a)$$

$$= 91.5 \pm 1.2 \text{ (stat.)} \pm 1.7 \text{ (syst.) GeV}/c^2 \quad \text{(UA2)}. \qquad (8b)$$

ELSEVIER

Physics Letters B

Volume 218, Issue 4, 2 March 1989, Pages 499-507

Measurements of the e^+e^- total hadronic cross section and a determination of M_Z and $\Lambda_{\overline{MS}}$

AMY Collaboration, T. Mori [a], T. Nozaki [b], D. Blanis [a], A. Bodek [a], H. Budd [a], R. Coombes [a], S. Eno [a], C.A. Fry [a], H. Harada [a], Y.H. Ho [a], Y.K. Kim [a], T. Kumita [a], S.L. Olsen [a c], P. Perez [a], A. Sill [a], N.M. Shaw [a], E.H. Thorndike [a], K. Ueno [a], H.W. Zheng [a]...K. Ohta [t]

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https://doi.org/10.1016/0370-2693(89)91455-X

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Abstract

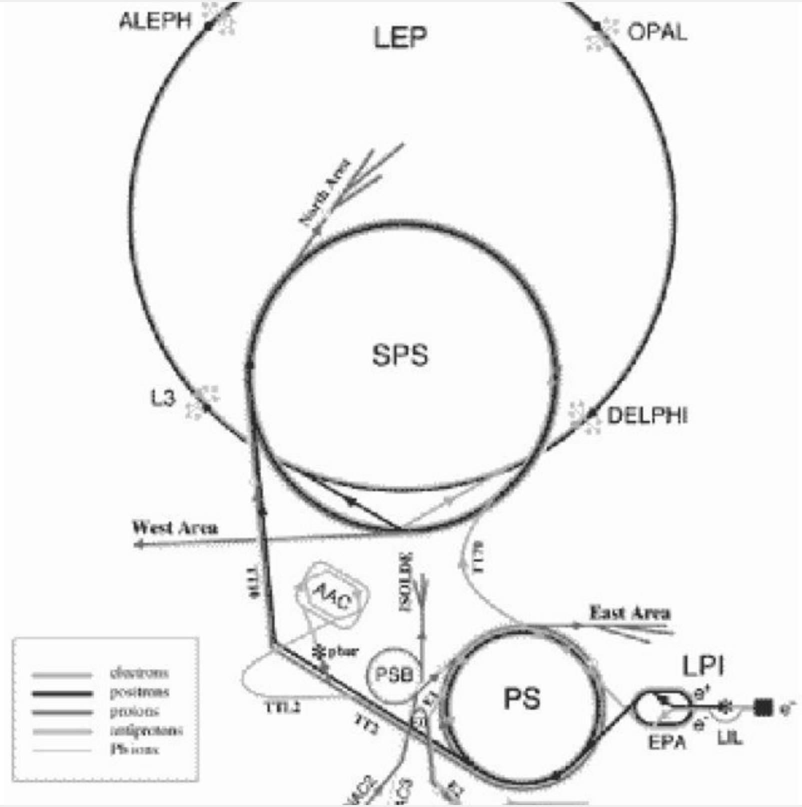
The total cross section for e^+e^- annihilation into hadrons has been measured for CM energies ranging from 50 to 57 GeV. We fit the predictions of the standard model to these measurements and those at lower energies. The mass of the Z^0 boson, M_Z, and the QCD scale parameter, $\Lambda_{\overline{MS}}$, are derived from the fit. The results are $M_Z=88.6_{-1.8}^{+2.0}$ GeV/c^2, and $\Lambda_{\overline{MS}}=0.15_{-0.11}^{+0.16}$ GeV.

$$M_Z = 88.6^{+2.0}_{-1.8}\ GeV$$

13 Aug 1989

A look back at events leading up to first collisions in LEP, 20 years ago.

The packed control room at the start-up of LEP on 14 July 1989. Carlo Rubbia, director-general of CERN at the time, is in the centre (with tie) and to his right Herwig Schopper, former director-general. Steve Myers is at the desk to the right.



Z mass: Phys. Rev. Lett **14 Aug 1989**

Measurement of the Mass and Width of the Z^0 Boson at the Fermilab Tevatron

Accepted without review at the request of John Peoples under policy announced 26 April 1976

An analysis of $Z^0 \to e^+e^-$ and $Z^0 \to \mu^+\mu^-$ data from the Collider Detector at Fermilab in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV yields a mass of the Z^0 boson of $M_Z = 90.9 \pm 0.3$ (stat + syst) ± 0.2 (scale) GeV/c^2 and a width of $\Gamma_Z = 3.8 \pm 0.8 \pm 1.0$ GeV.

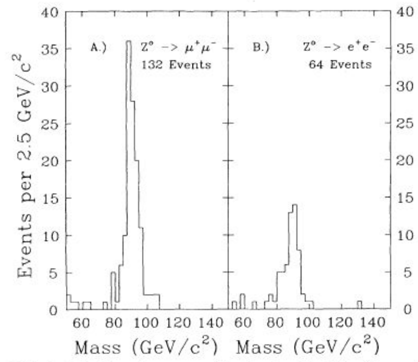


FIG. 1. The invariant-mass distribution for (a) $Z^0 \to \mu^+\mu^-$ candidates and (b) $Z^0 \to e^+e^-$ candidates using the track information.

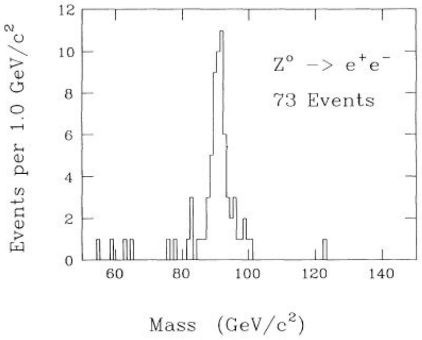


FIG. 3. The invariant-mass distribution for $Z^0 \to e^+e^-$ candidates using the information from the calorimeter.

In conclusion, we have determined the Z^0 boson mass to be 90.9 ± 0.3 (stat+syst) ± 0.2 (scale) GeV/c^2 and the width of the Z^0 boson to be $3.8 \pm 0.8 \pm 1.0$ GeV. Our measured value for the Z^0 mass is consistent with previous measurements by UA1 of $93.1 \pm 1.0 \pm 3.1$ GeV/c^2 and UA2 of $91.5 \pm 1.2 \pm 1.7$ GeV/c^2.[6] The Z^0 width is consistent with standard-model expectations.

$$M_Z = 90.9 \pm 0.3 \pm 0.2\ GeV$$

$$\Gamma_Z = 3.8 \pm 0.8 \pm 1.0\ GeV$$

Higgs

Another expedited review request

Dear [redacted]

We would appreciate your review of this manuscript, which has been submitted to Physical Review Letters.

Thanks for agreeing to review it today! Please email me (garisto@aps.org) when you report.

Yours sincerely,

/Robert/

Robert Garisto
Editor

PHYSICAL REVIEW LETTERS

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Evidence for a Particle Produced in Association with Weak Bosons and Decaying to a Bottom-Antibottom Quark Pair in Higgs Boson Searches at the Tevatron

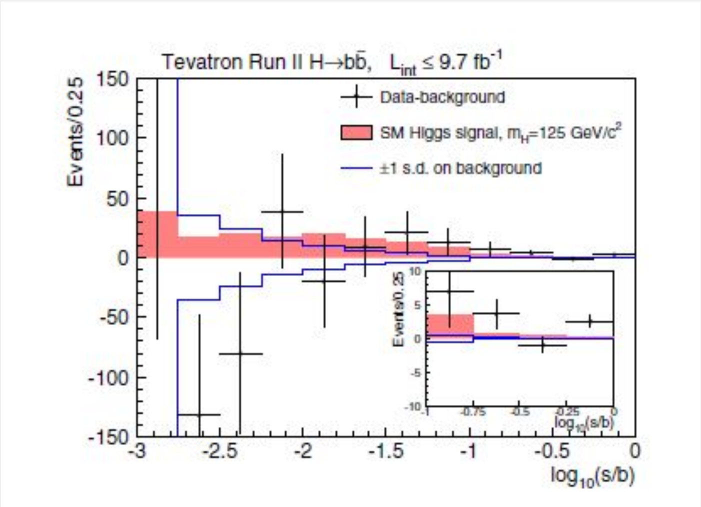
T. Aaltonen *et al.* (CDF Collaboration, D0 Collaboration)
Phys. Rev. Lett. **109**, 071804 – Published 14 August 2012

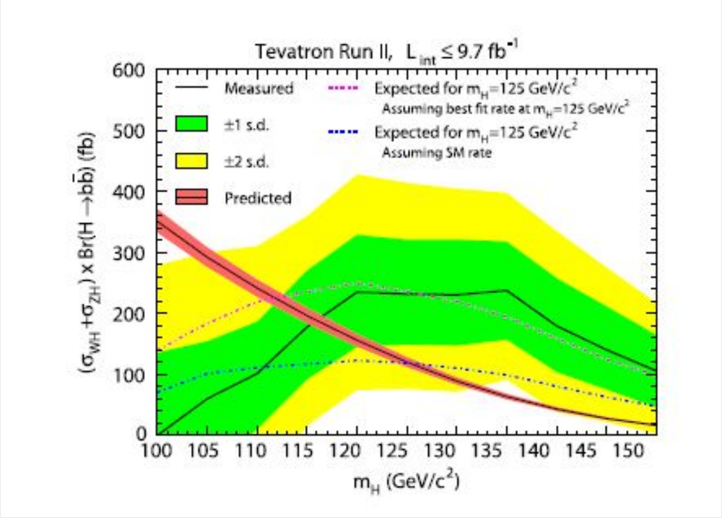
Physics See Viewpoint: A Fuller Picture of the Higgs Boson

Article | References | Citing Articles (176) | PDF | HTML | Export Citation

ABSTRACT

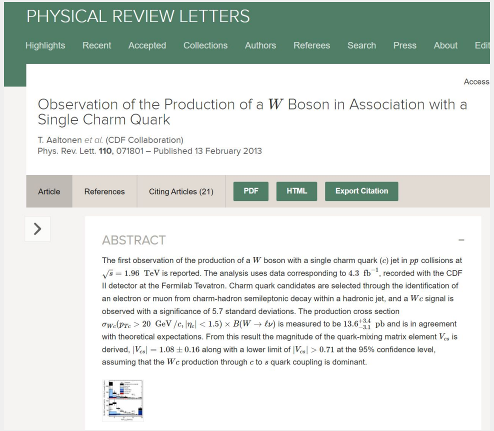
We combine searches by the CDF and D0 Collaborations for the associated production of a Higgs boson with a W or Z boson and subsequent decay of the Higgs boson to a bottom-antibottom quark pair. The data, originating from Fermilab Tevatron $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, correspond to integrated luminosities of up to 9.7 fb^{-1}. The searches are conducted for a Higgs boson with mass in the range 100–150 GeV/c^2. We observe an excess of events in the data compared with the background predictions, which is most significant in the mass range between 120 and 135 GeV/c^2. The largest local significance is 3.3 standard deviations, corresponding to a global significance of 3.1 standard deviations. We interpret this as evidence for the presence of a new particle consistent with the standard model Higgs boson, which is produced in association with a weak vector boson and decays to a bottom-antibottom quark pair.





CDF’s spirit of discovery

Observations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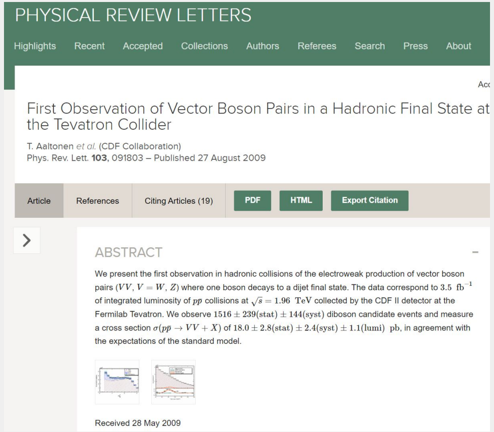
Observation of the Production of a W Boson in Association with a Single Charm Quark

T. Aaltonen *et al.* (CDF Collaboration)
Phys. Rev. Lett. **110**, 071801 – Published 13 February 2013

Article | References | Citing Articles (21) | PDF | HTML | Export Citation

ABSTRACT

The first observation of the production of a W boson with a single charm quark (c) jet in pp collisions at $\sqrt{s} = 1.96$ TeV is reported. The analysis uses data corresponding to 4.3 fb^{-1}, recorded with the CDF II detector at the Fermilab Tevatron. Charm quark candidates are selected through the identification of an electron or muon from charm-hadron semileptonic decay within a hadronic jet, and a Wc signal is observed with a significance of 5.7 standard deviations. The production cross section $\sigma_{Wc}(p_{Tc} > 20\ \mathrm{GeV}/c, |\eta_c| < 1.5) \times B(W \to \ell\nu)$ is measured to be $13.6^{+3.4}_{-3.1}$ pb and is in agreement with theoretical expectations. From this result the magnitude of the quark-mixing matrix element V_{cs} is derived, $|V_{cs}| = 1.08 \pm 0.16$ along with a lower limit of $|V_{cs}| > 0.71$ at the 95% confidence level, assuming that the Wc production through c to s quark coupling is dominant.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First Observation of Vector Boson Pairs in a Hadronic Final State at the Tevatron Collider

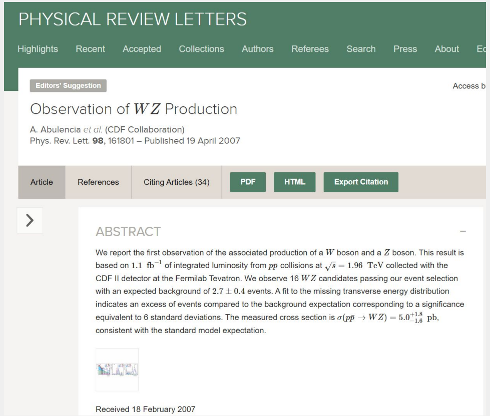
T. Aaltonen *et al.* (CDF Collaboration)
Phys. Rev. Lett. **103**, 091803 – Published 27 August 2009

Article | References | Citing Articles (19) | PDF | HTML | Export Citation

ABSTRACT

We present the first observation in hadronic collisions of the electroweak production of vector boson pairs (VV, $V = W, Z$) where one boson decays to a dijet final state. The data correspond to 3.5 fb^{-1} of integrated luminosity of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV collected by the CDF II detector at the Fermilab Tevatron. We observe $1516 \pm 239(\mathrm{stat}) \pm 144(\mathrm{syst})$ diboson candidate events and measure a cross section $\sigma(p\bar{p} \to VV + X)$ of $18.0 \pm 2.8(\mathrm{stat}) \pm 2.4(\mathrm{syst}) \pm 1.1(\mathrm{lumi})$ pb, in agreement with the expectations of the standard model.

Received 28 May 2009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Observation of WZ Production

A. Abulencia *et al.* (CDF Collaboration)
Phys. Rev. Lett. **98**, 161801 – Published 19 April 2007

Article | References | Citing Articles (34) | PDF | HTML | Export Citation

ABSTRACT

We report the first observation of the associated production of a W boson and a Z boson. This result is based on 1.1 fb^{-1} of integrated luminosity from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV collected with the CDF II detector at the Fermilab Tevatron. We observe 16 WZ candidates passing our event selection with an expected background of 2.7 ± 0.4 events. A fit to the missing transverse energy distribution indicates an excess of events compared to the background expectation corresponding to a significance equivalent to 6 standard deviations. The measured cross section is $\sigma(p\bar{p} \to WZ) = 5.0^{+1.8}_{-1.6}$ pb, consistent with the standard model expectation.

Received 18 February 2007


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Observation of Diffractive W-Boson Production at the Fermilab Tevatron

F. Abe *et al.* (CDF Collaboration)
Phys. Rev. Lett. **78**, 2698 – Published 7 April 1997

Article | References | Citing Articles (79) | PDF | Export Citation

ABSTRACT

We report the first observation of diffractively produced W bosons. In a sample of $W \to e\nu$ events produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$, we find an excess of events with a forward rapidity gap, which is attributed to diffraction. The probability that this excess is consistent with nondiffractive production is 1.1×10^{-4} (3.8σ). The relatively low fraction of $W + \mathrm{jet}$ events observed within this excess implies that mainly quarks from the Pomeron, which mediates diffraction, participate in W production. The diffractive to nondiffractive W production ratio is found to be $R_W = (1.15 \pm 0.55)\%$.

Received 14 January 1997

DOI: https://doi.org/10.1103/PhysRevLett.78.2698

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Evidence for W^+W^- Production in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$

F. Abe *et al.* (CDF Collaboration)
Phys. Rev. Lett. **78**, 4536 – Published 16 June 1997

Article | References | Citing Articles (37) | PDF | Export Citation

ABSTRACT

We present results of a search for W^+W^- production through the leptonic decay channel $W^+W^- \to l^+l^-\nu\bar{\nu}$ in $\bar{p}p$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$. In a $108\mathrm{pb}^{-1}$ data sample recorded with the Collider Detector at Fermilab, five W^+W^- candidates are found with an expected standard model background of 1.2 ± 0.3 events. The W^+W^- production cross section is measured to be $\sigma(\bar{p}p \to W^+W^-) = 10.2^{+6.3}_{-5.1}(\mathrm{stat}) \pm 1.6(\mathrm{syst})$ pb, in agreement with the standard model prediction. Limits on $WW\gamma$ and WWZ anomalous couplings are presented.

Received 13 September 1996

DOI: https://doi.org/10.1103/PhysRevLett.78.4536

- WW
- WZ
- WZ/WW/ZZ hadronic
- W+charm
- Diffractive W

$$gq \to Wc$$

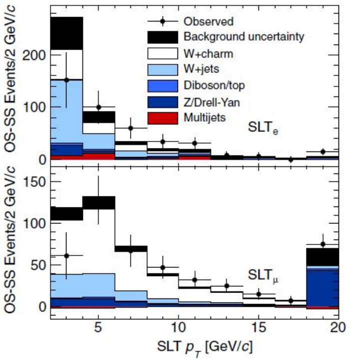
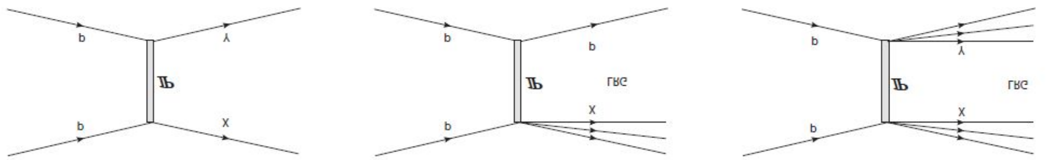


FIG. 1 (color online). The soft muon and soft electron p_T distributions. The Wc contribution is normalized to the measured cross section.

this kinematic region of 1.6 ± 0.5. Since the majority of Wc production proceeds through c to s quark coupling, we can relate the measured value of the cross section with the theoretical prediction and derive $|V_{cs}|$. Using $\sigma_{Wc}^{\text{theory}} = 9.8(\pm 1.1)|V_{cs}|^2 + 2.1(\pm 0.2)$ pb [27] we obtain $|V_{cs}| = 1.08 \pm 0.16$, where the uncertainties in the cross section measurement and in the theoretical prediction have been added in quadrature. Restricting the range of $|V_{cs}|$ to the interval [0,1], a lower limit of $|V_{cs}| > 0.71$ at the 95% confidence level is extracted.



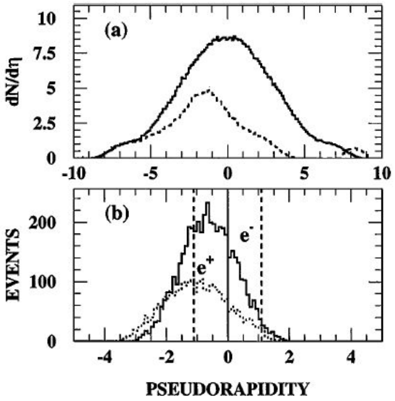


FIG. 1. Monte Carlo generated η distributions: (a) Particle densities for nondiffractive (solid) and for diffractive (dashed) W events for Pomerons of beam momentum fraction $\xi = 0.03$ emitted by protons (at positive η); the small bump at $\eta \approx 8.5$ is due to the leading protons. (b) Electrons and positrons from diffractive $W^{\pm} (\to e^{\pm}\nu)$ events for all Pomerons of $\xi < 0.1$ emitted by protons (the vertical dashed lines define the boundaries of the region of this measurement).

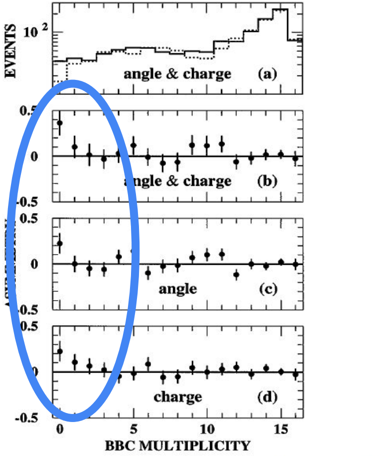


FIG. 2. (a) Electron angle and charge doubly correlated (solid) and anticorrelated (dashed) distributions (see text) versus BBC multiplicity and (b) the corresponding asymmetry, defined as the bin-by-bin difference over sum of the two distributions in (a). The diffractive signal is seen in the first bin as an excess of events in the correlated distribution in (a), and as a positive asymmetry in (b). An asymmetry is also seen in the first bin of the individual angle (c) and charge (d) distributions.

CDF and precision

precision

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	299 792 458 m s^{-1}	exact
Planck constant	h	6.626 070 15×10^{-34} J s (or J/Hz) §	exact
Planck constant, reduced	$\hbar \equiv h/2\pi$	1.054 571 817... $\times 10^{-34}$ J s	exact*
		= 6.582 119 569... $\times 10^{-22}$ MeV s	exact*
electron charge magnitude	e	1.602 176 634×10^{-19} C	exact
conversion constant	$\hbar c$	197.326 980 4... MeV fm	exact*
conversion constant	$(\hbar c)^2$	0.389 379 372 1... GeV^2 mbarn	exact*
electron mass	m_e	0.510 998 950 00(15) MeV/c^2 = 9.109 383 $7015(28)\times10^{-31}$ kg	0.30
proton mass	m_p	938.272 088 16(29) MeV/c^2 = 1.672 621 923 $69(51)\times10^{-27}$ kg	0.31
		= 1.007 276 466 621(53) u = 1836.152 673 43(11) m_e	0.053, 0.060
neutron mass	m_n	939.565 420 52(54) MeV/c^2 = 1.008 664 915 95(49) u	0.57, 0.48
deuteron mass	m_d	1875.612 942 57(57) MeV/c^2	0.30
unified atomic mass unit**	u = (mass ^{12}C atom)/12	931.494 102 42(28) MeV/c^2 = 1.660 539 066 $60(50)\times10^{-27}$ kg	0.30
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	8.854 187 8128(13) $\times10^{-12}$ F m^{-1}	0.15
permeability of free space	$\mu_0/(4\pi \times 10^{-7})$	1.000 000 000 55(15) N A^{-2}	0.15
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	7.297 352 $5693(11)\times10^{-3}$ = 1/137.035 999 084(21)† ‡‡	0.15
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 $3262(13)\times10^{-15}$ m	0.45
(e^- Compton wavelength)/2π	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	3.861 592 $6796(12)\times10^{-13}$ m	0.30
Bohr radius ($m_{\text{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	0.529 177 210 $903(80)\times10^{-10}$ m	0.15
wavelength of 1 eV/c particle	$hc/(1\text{ eV})$	1.239 841 984... $\times 10^{-6}$ m	exact*
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	13.605 693 122 994(26) eV	1.9×10^{-3}
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0.665 245 873 21(60) barn	0.91
Bohr magneton	$\mu_B = e\hbar/2m_e$	5.788 381 $8060(17)\times10^{-11}$ MeV T^{-1}	0.30
nuclear magneton	$\mu_N = e\hbar/2m_p$	3.152 451 258 $44(96)\times10^{-14}$ MeV T^{-1}	0.31
electron cyclotron freq./field	$\omega^e_{\text{cycl}}/B = e/m_e$	1.758 820 010 $76(53)\times10^{11}$ rad s^{-1} T^{-1}	0.30
proton cyclotron freq./field	$\omega^p_{\text{cycl}}/B = e/m_p$	9.578 833 $1560(29)\times10^{7}$ rad s^{-1} T^{-1}	0.31
gravitational constant‡	G_N	6.674 $30(15)\times10^{-11}$ m^3 kg^{-1} s^{-2}	2.2×10^4
		= 6.708 $83(15)\times10^{-39}$ $\hbar c$ $(GeV/c^2)^{-2}$	2.2×10^4
standard gravitational accel.	g_N	9.806 65 m s^{-2}	exact
Avogadro constant	N_A	6.022 140 76×10^{23} mol^{-1}	exact
Boltzmann constant	k	1.380 649×10^{-23} J K^{-1}	exact
		= 8.617 333 262... $\times 10^{-5}$ eV K^{-1}	exact*
molar volume, ideal gas at STP	$N_A k$ (273.15 K)/(101 325 Pa)	22.413 969 54... $\times 10^{-3}$ m^3 mol^{-1}	exact*
Wien displacement law constant	$b = \lambda_{\max} T$	2.897 771 955... $\times 10^{-3}$ m K	exact*
Stefan-Boltzmann constant	$\sigma = \pi^2 k^4/60\hbar^3 c^2$	5.670 374 419... $\times 10^{-8}$ W m^{-2} K^{-4}	exact*
Fermi coupling constant‡‡	$G_F/(\hbar c)^3$	1.166 378 $8(6)\times10^{-5}$ GeV^{-2}	510
weak-mixing angle	$\sin^2\widehat{\theta}(M_Z)$ ($\overline{\text{MS}}$)	0.231 21(4)††	1.7×10^5
$W^\pm$ boson mass	m_W	80.377(12) GeV/c^2¶	1.5×10^5
Z^0 boson mass	m_Z	91.1876(21) GeV/c^2	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	0.1179(9)	7.6×10^6

While the parameters of QED are known with sub-ppb precision, the parameters of the gravity, weak, and strong force are less constrained

W mass 0.015%

Z mass 0.002%

θ_W 0.002%

α_S 8%

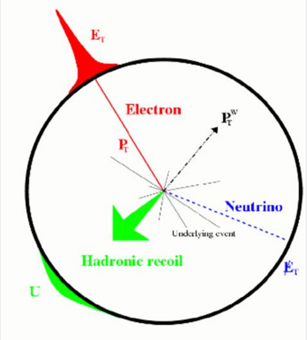
G_N 0.002%

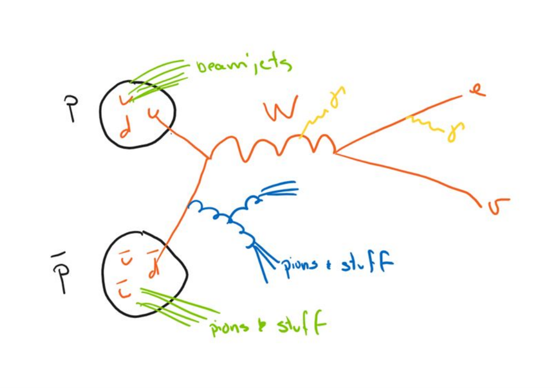
G_F 0.001%

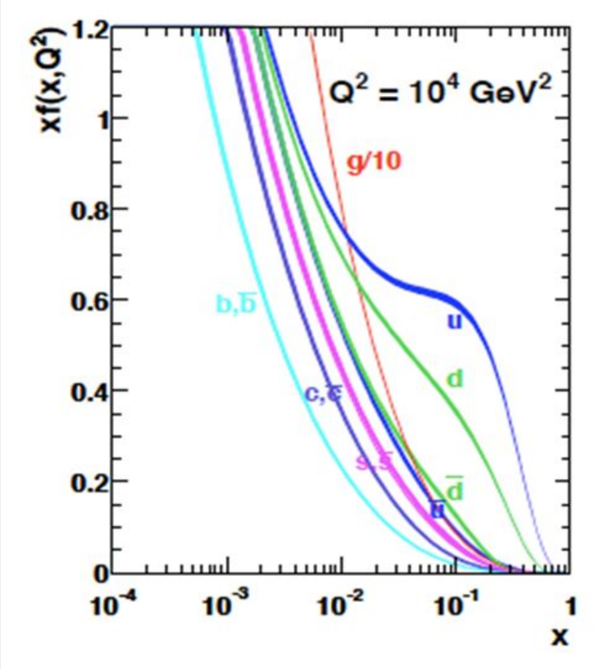
Will talk about CDF's measurements of two weak-force quantities, W mass and θ_W , in the challenging hadron collider environment.

precision

It's hard at a hadron collider

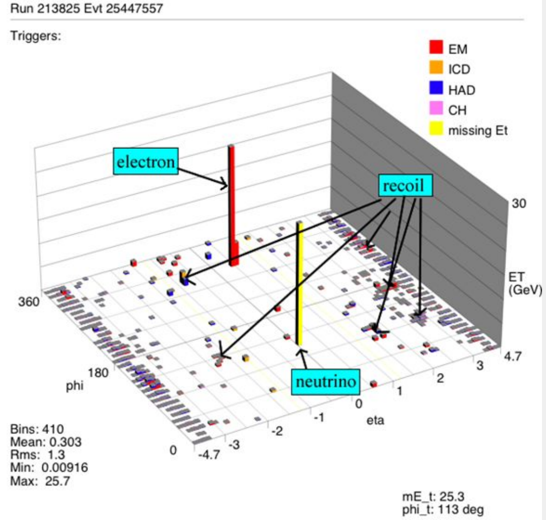




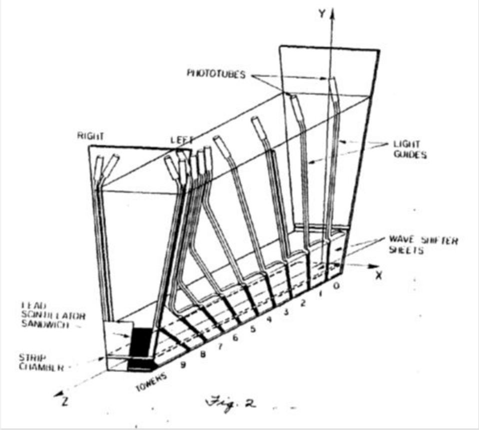


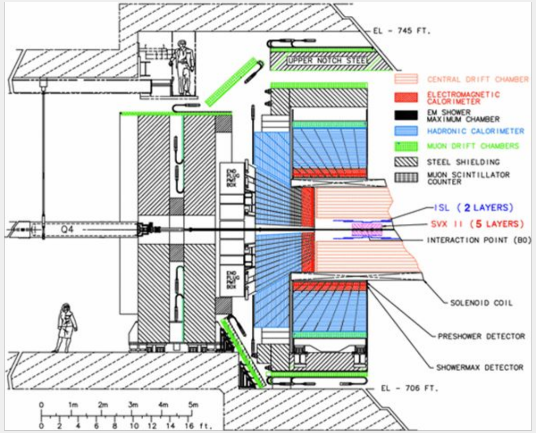
Neutrino measurements challenging for W mass

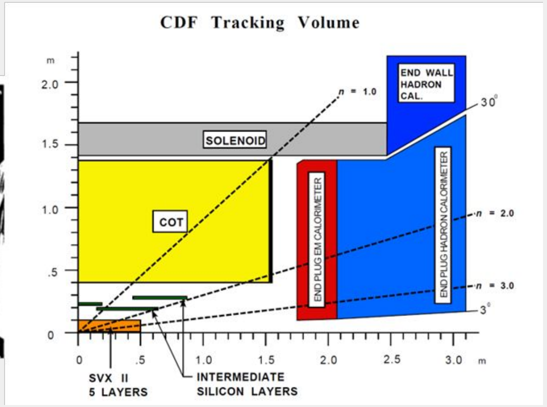
Plays a role in both the Z-based measurement of θ_W and the W mass.



Harder still with a “classic” detector







Central EM calorimeter has had a 28 year run.

Z asymmetry and Θ_W

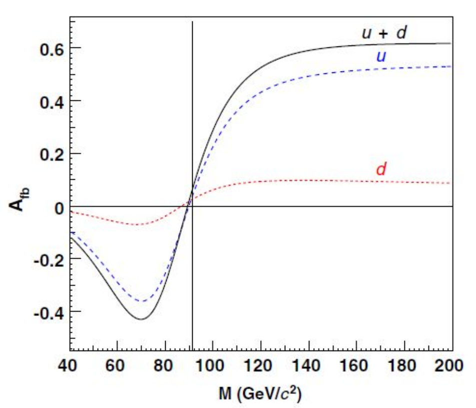
$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$

$$g_V^f = T_3^f - 2Q_f \sin^2\theta_W, \quad g_A^f = T_3^f$$

At zero transverse boost, in Z rest frame

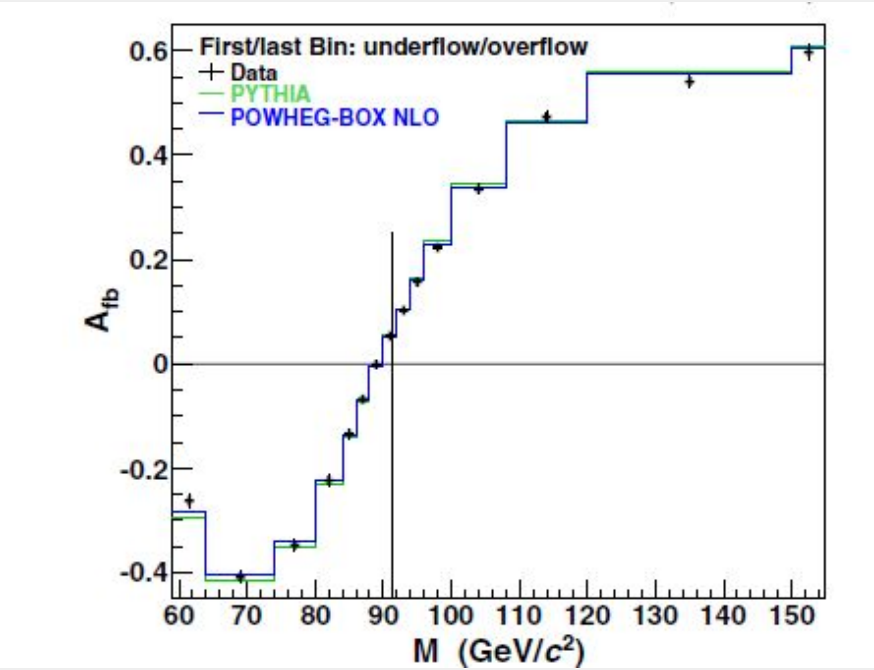
$$\frac{dN}{d\Omega} = 1 + \cos^2\theta + A_4 \cos\theta$$

$$A_{fb}(M) = \frac{\sigma^+(M) - \sigma^-(M)}{\sigma^+(M) + \sigma^-(M)} = \frac{3}{8}A_4(M)$$

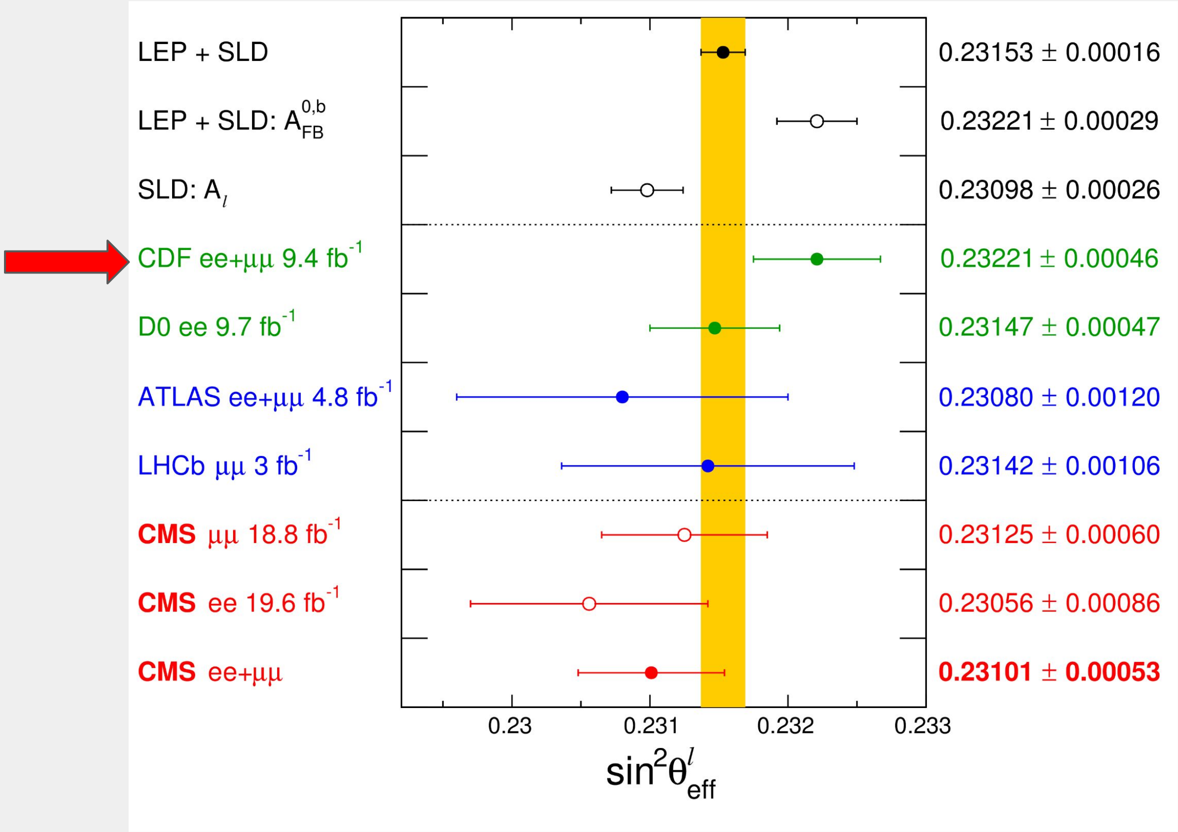


At the Z sensitive to Θ_W, away mostly sensitive to the u,d flux, size set by

$$(M^2 - M_Z^2)/M^2$$



Some old CDF folks have continued at CMS



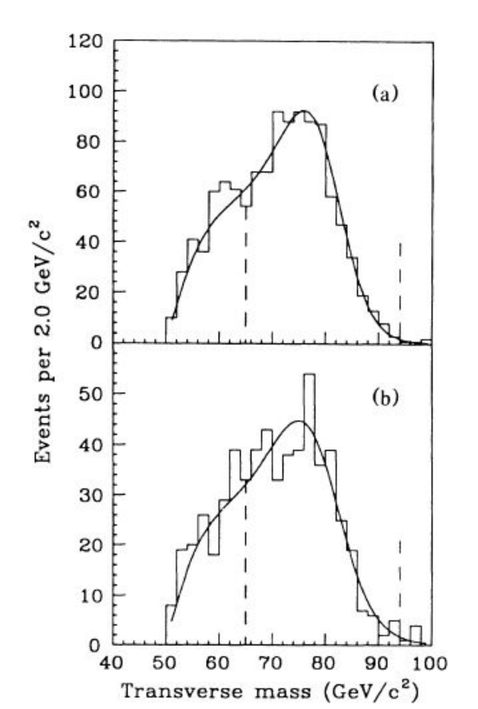
Still the best from a hadron collider

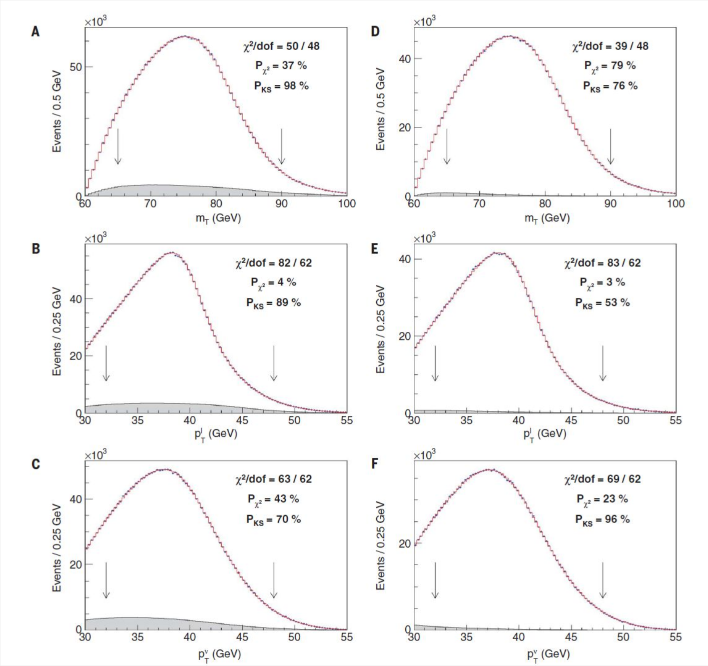
From Oliver Stelzer-Chilton

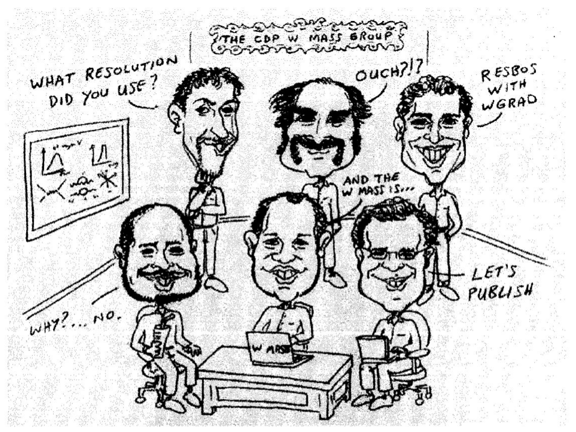
W mass

Phys. Rev. Lett. 65, 2243 (1990)

Science, 376, 170 (2022)







front: Ashutosh, myself and William; back: Chris, Larry and Ian.

This remarkable increase in precision over 32 years is not only due to the excellent performance of the Tevatron and the CDF collaboration, it builds on the suite of W,Z studies documented in the large number of CDF papers.

$$M_W = 79.91 \pm 0.39\ GeV$$

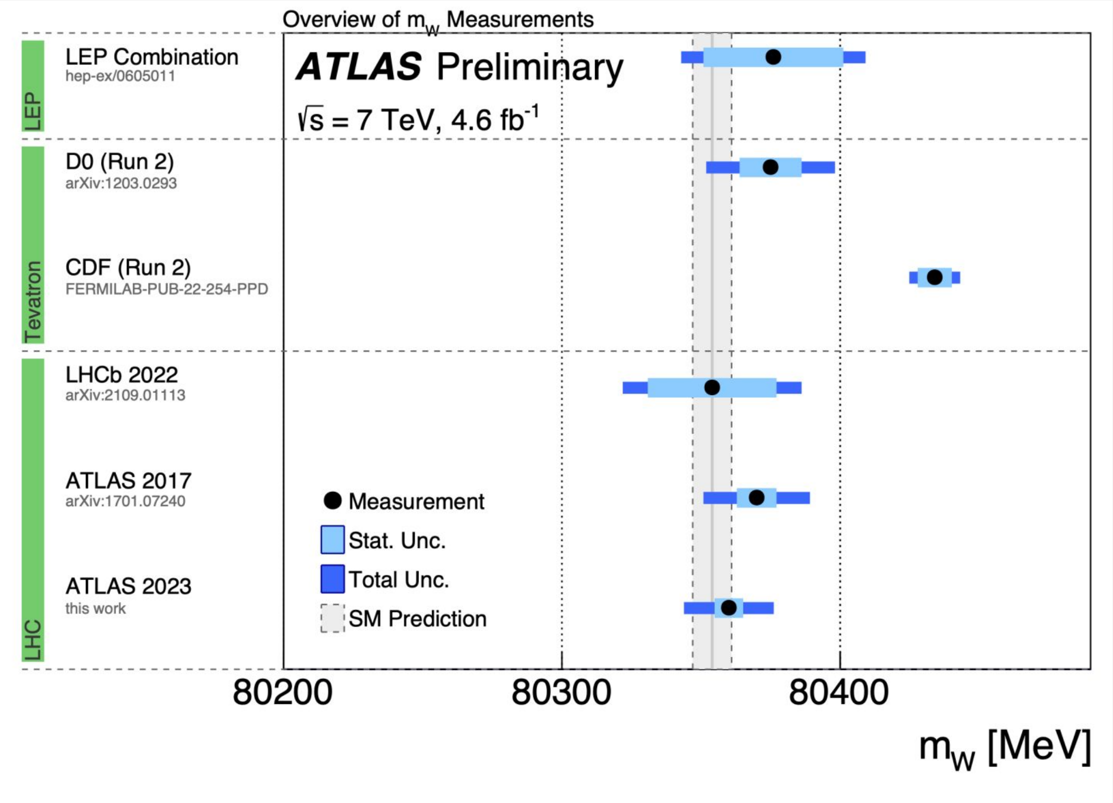
$$M_W = 80.4335 \pm 0.0094\ GeV$$

0.5%

0.01%

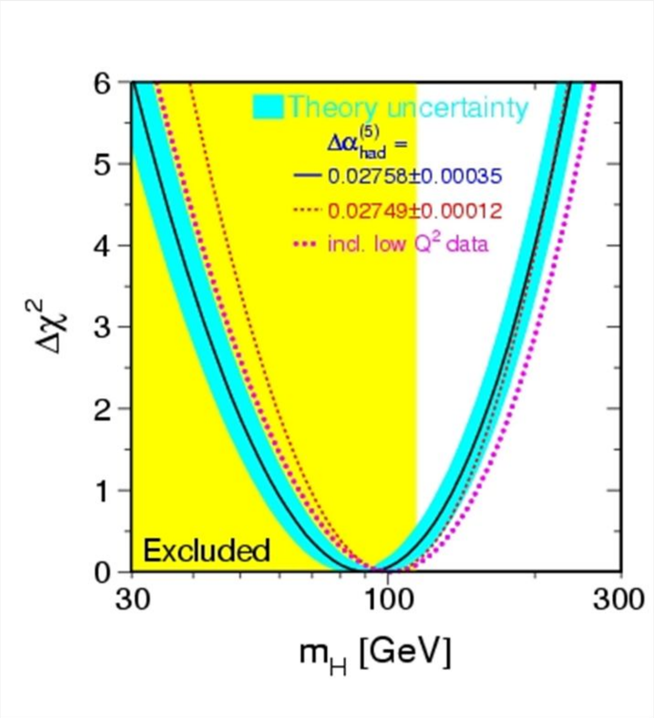
Factor 50 improvement

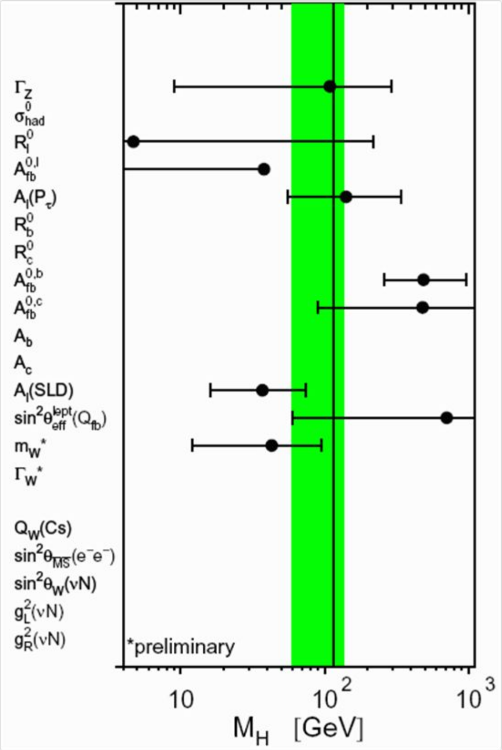
World W mass summary



W mass impact

2009
CDF W and top mass meausurements were key to knowing that the Higgs was within reach of the LHC.





W mass impact

2023
Is the new W mass measurement a window into new physics?

Showing 1–50 of 139 results

Search v0.5.6 released

Query: order: -announced_date_first; size: 50; date_range: from 2022-04-08 ; include_cross_list: True; terms: AND all=cdf w mass

Refine query | New search

50 results per page. Sort results by Announcement date (newest first) Go

1 2 3 Next

1. arXiv:2305.04681 [pdf, other] hep-ph

   Minimal model inspired by family number and dark matter

   Authors: Duong Van Loi, Cao H. Nam, Phung Van Dong

   Abstract: …charge assignments are inspired by the number of fermion families and the stability of dark matter, as observed, respectively. We examine the **mass** spectra of fermions, scalars, and gauge bosons, as well as their interactions, in presence of a kinetic mixing term between $U(1)_{X,N}$ gauge fields. We discuss in detail the phenomenology of the new gauge boson… ▽ More

   Submitted 8 May, 2023; **originally announced** May 2023.

   Comments: 30 pages, 4 figures, 5 tables

2. arXiv:2304.11439 [pdf, other] hep-ph

   Scalar extensions of the SM and recent experimental anomalies

   Authors: Thomas Biekötter

   Abstract: The Brout-Englert-Higgs mechanism describes the generation of **masses** of fundamental particles in the Standard Model (SM). It predicts the existence of one scalar particle with precisely predicted couplings to fermions and gauge bosons. Deviations from these predictions, such as the observation of additional scalar particles, would indicate non-minimal Higgs… ▽ More

   Submitted 22 April, 2023; **originally announced** April 2023.

   Comments: contribution to the 2023 Electroweak session of the 57th Rencontres de Moriond

   Report number: KA-TP-05-2023

3. arXiv:2304.10560 [pdf, other] hep-ph

Already 361 citations

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Date of paper: 2015 – 2023

Number of authors: Single author 87; 10 authors or less 347

Exclude RPP: Exclude Review of Particle Physics 361

Document Type: article 304; published 184; thesis 30; conference paper 25; note 2

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#1 Low Seesaw Scale Solution for M_W and $(g-2)_\mu$
A. de Giorgi (Madrid, IFT), L. Merlo (Madrid, IFT), S. Pokorski (Apr 17, 2023)
Contribution to: Moriond EW 2023 • e-Print: 2304.08438 [hep-ph]
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#2 Constraint for a light charged Higgs boson and its neutral fellows from top quark pairs at the LHC
ChunHao Fu, Jun Gao (Apr 16, 2023)
e-Print: 2304.07782 [hep-ph]
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#3 Grand unification, small vs large representations, hadron colliders and all that
Goran Senjanović, Michael Zantedeschi (Apr 16, 2023)
Contribution to: CORFU2022 • e-Print: 2304.07932 [hep-ph]
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#4 Dimension-8 SMEFT Analysis of Minimal Scalar Field Extensions of the Standard Model
John Ellis (King's Coll. London and CERN), Ken Mimasu (King's Coll. London), Francesca Zampedri (King's Coll. London) (Apr 13, 2023)
e-Print: 2304.06663 [hep-ph]
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#5 Explicit parametrization of more than one vector-like quark of Nelson-Barr type
G.H.S. Alves (ABC Federal U.), A.L. Cherchiglia (Campinas State U. and Granada U., Theor. Phys. Astrophys.), C.C. Nishi (ABC Federal U.) (Apr 12, 2023)

Other highly cited EWK papers

Measurements of inclusive W and Z cross sections in p anti-p collisions at s(1/2) = 1.96-TeV** #56

CDF Collaboration • A. Abulencia (Illinois U., Urbana) et al. (Aug, 2005)

Published in: *J.Phys.G* 34 (2007) 2457-2544 • e-Print: hep-ex/0508029 [hep-ex]

pdf links DOI cite claim reference search 343 citations

A Measurement of the W boson mass #20

CDF Collaboration • F. Abe et al. (Aug, 1990)

Published in: *Phys.Rev.Lett.* 65 (1990) 2243-2246

pdf links DOI cite datasets claim reference search 333 citations

A Measurement of the W boson mass in 1.8 TeV $\bar{p}p$ collisions #21

CDF Collaboration • F. Abe (KEK, Tsukuba) et al. (Aug, 1990)

Published in: *Phys.Rev.D* 43 (1991) 2070-2093

pdf links DOI cite claim reference search 321 citations

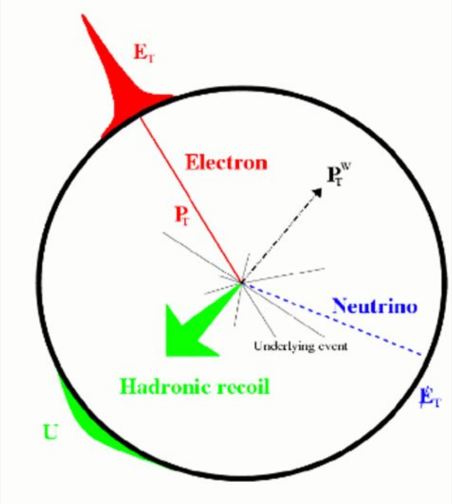
Measurement of the W boson mass #91

CDF Collaboration • F. Abe et al. (Mar, 1995)

Published in: *Phys.Rev.D* 52 (1995) 4784-4827

pdf links DOI cite claim reference search 310 citations

The W mass analysis builds on an encyclopedia



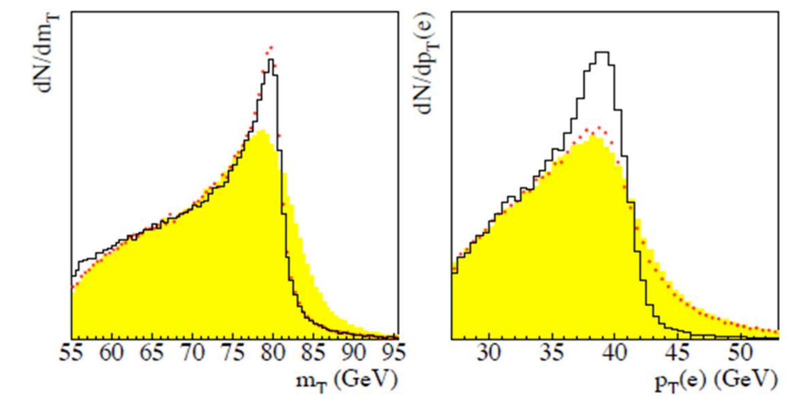
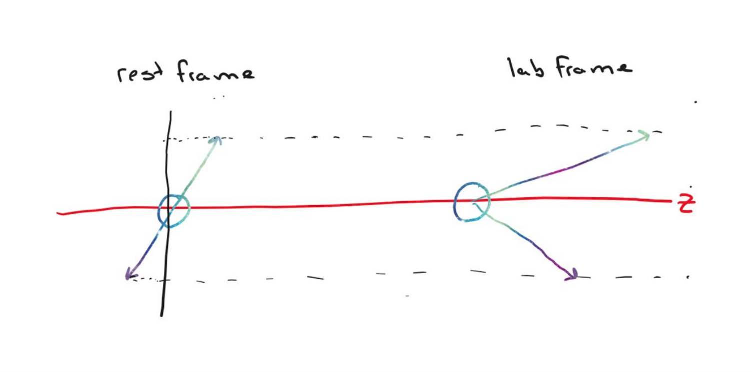


Figure 3.2: M_T (left) and $p_T(e)$ (right) spectra for W bosons with $p_T^W = 0$ (solid line), with the correct p_T^W spectrum (points), and with detector resolutions (shaded area).



A simple system, but need each part precisely

Understanding the W in a hadron collider

Table 2. Uncertainties on the combined M_W result.

Source	Uncertainty (MeV)
Lepton energy scale	3.0
Lepton energy resolution	1.2
Recoil energy scale	1.2
Recoil energy resolution	1.8
Lepton efficiency	0.4
Lepton removal	1.2
Backgrounds	3.3
p_T^Z model	1.8
p_T^W/p_T^Z model	1.3
Parton distributions	3.9
QED radiation	2.7
W boson statistics	6.4
Total	9.4

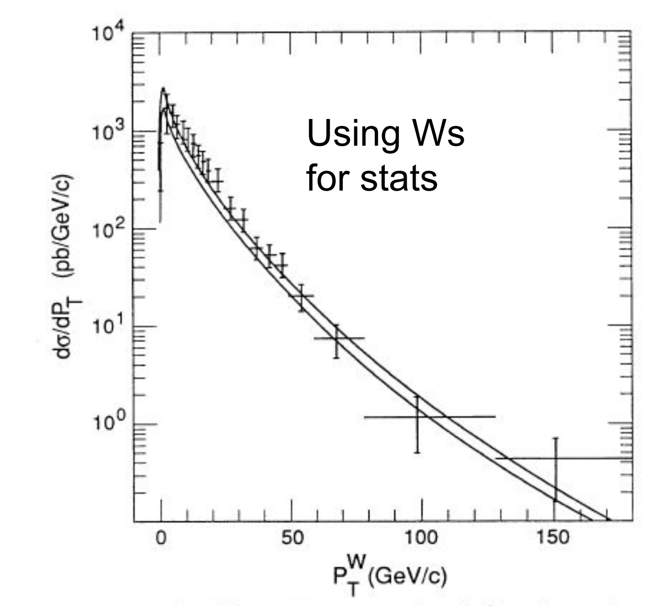
Detector performance

W and Z pT

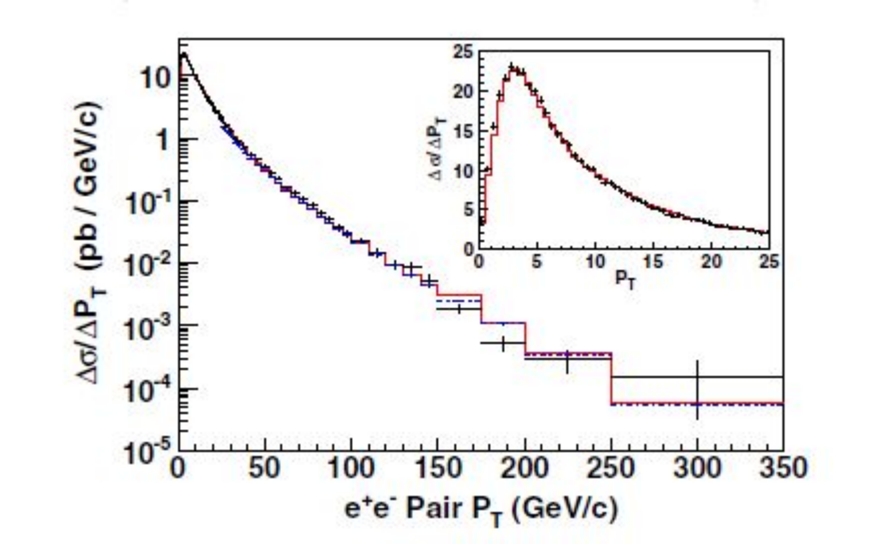
$$\frac{d^2\sigma_V}{dp_T dy} \sim \frac{\alpha_W \alpha_S}{p_T^2} ln(\frac{Q^2}{p_T^2})[\nu_1 + \nu_2 \alpha_S ln^2(\frac{Q^2}{p_T^2}) + \nu_3 \alpha_S^2 ln^4(\frac{Q^2}{p_T^2}) + ...]$$

$$W(b,Q) \sim e^{-S(b,Q)}$$

$$S_{NP}(b,Q) = g_1 b^2 + g_1 b^2 ln(\frac{Q^2}{Q_0^2}) + g_1 g_3 b \ ln(100 x_i x_j)$$

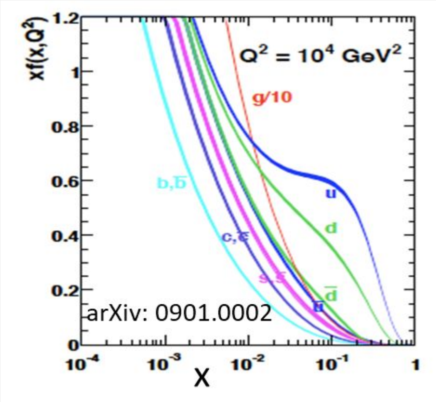


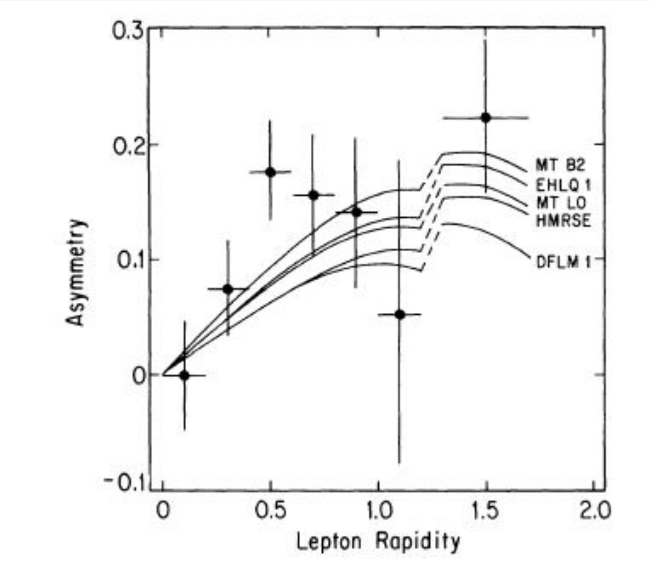
PHYS. Rev. Lett. 66, 2951 (1991)

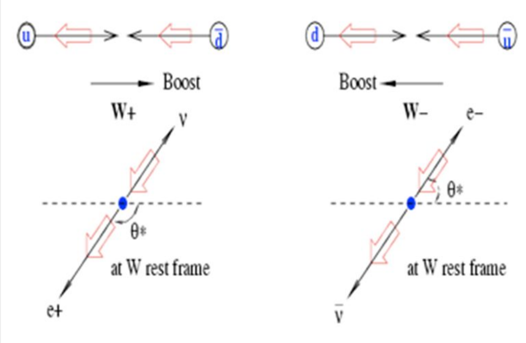


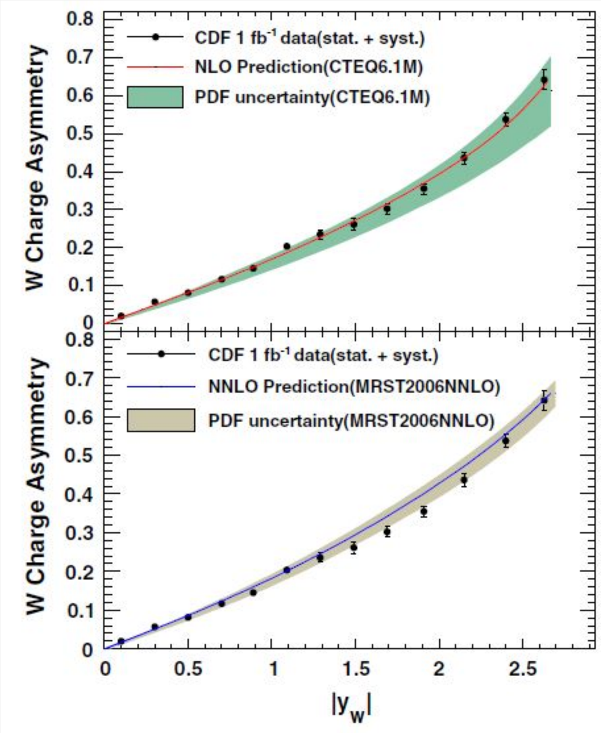
Phys. Rev. D 052010 (2012)

W asymmetry









Phys. Rev. Lett 68, 1461 (1992)

Phys. Rev. Lett 102, 181801 (2009)

impact

CDF’s legacy of precision EWK physics at hadron colliders is being continued at the LHC

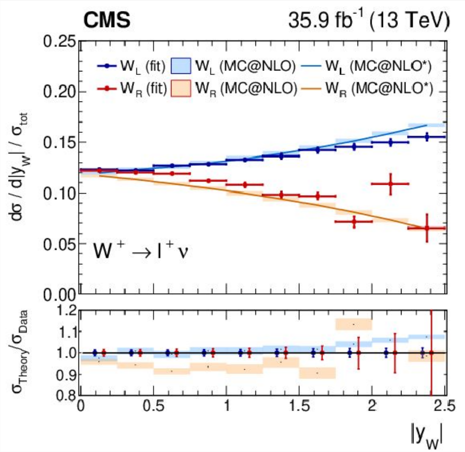
Open Access

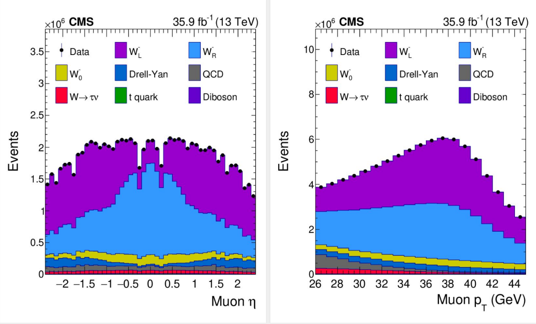
Access by University

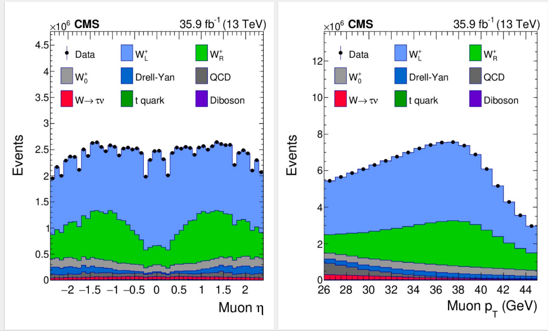
Measurements of the W boson rapidity, helicity, double-differential cross sections, and charge asymmetry in pp collisions at $\sqrt{s} = 13$ TeV

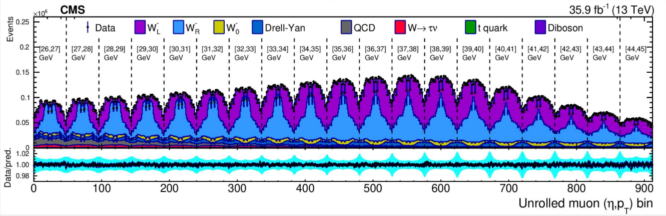
A. M. Sirunyan *et al.* (CMS Collaboration CERN)

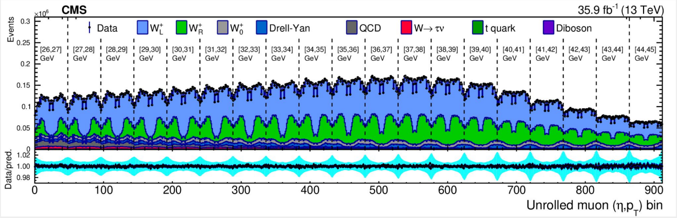
Phys. Rev. D **102**, 092012 – Published 30 November 2020











future

0.015%→0.0005%

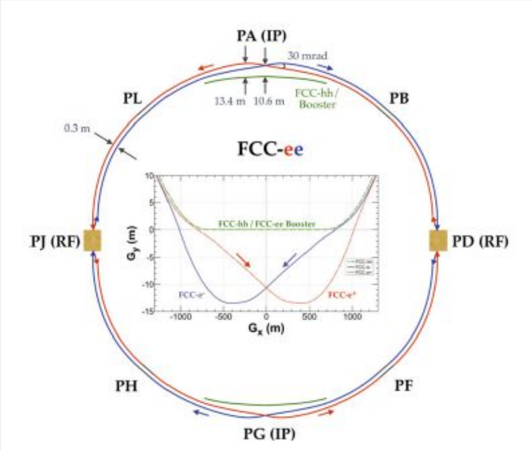
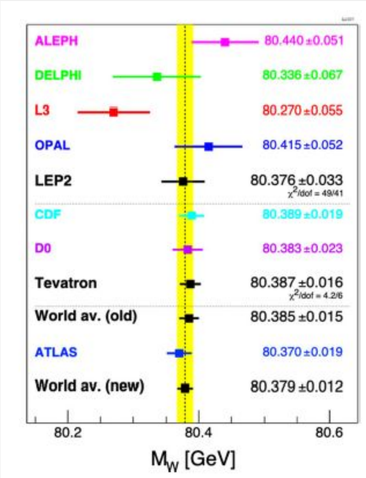
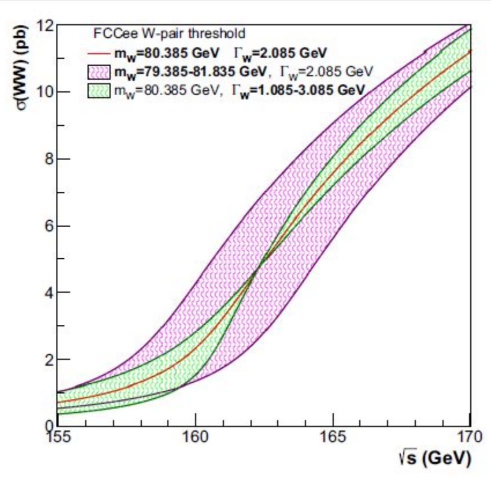


Table 3 Measurement of selected precision measurements at FCC-ee, compared with present precision. Statistical errors are indicated in boed phase. The systematic uncertainties are initial estimates, aim is to improve down to statistical errors. This set of measurements, together with those of the Higgs properties, achieves indirect sensitivity to new physics up to a scale Λ of 70 TeV in a description with dim 6 operators, and possibly much higher in specific new physics (non-decoupling) models

Observable	Present value ± error	FCC-ee stat.	FCC-ee syst.	Comment and leading exp. error
m_Z (keV)	91186700 ± 2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	**4**	25	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{eff}(\times 10^6)$	231480 ± 160	**2**	2.4	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)(\times 10^3)$	128952 ± 14	**3**	Small	From $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
R_ℓ^Z $(\times 10^3)$	20767 ± 25	**0.06**	0.2–1	Ratio of hadrons to leptons Acceptance for leptons
$\alpha_s(m_Z^2)$ $(\times 10^4)$	1196 ± 30	**0.1**	0.4–1.6	From R_ℓ^Z above
σ_{had}^0 $(\times 10^3)$ (nb)	41541 ± 37	**0.1**	4	Peak hadronic cross section Luminosity measurement
$N_\nu(\times 10^3)$	2996 ± 7	**0.005**	1	Z peak cross sections Luminosity measurement
R_b $(\times 10^6)$	216290 ± 660	**0.3**	< 60	Ratio of $b\bar{b}$ to hadrons Stat. extrapol. from SLD
A_{FB}^b, 0 $(\times 10^4)$	992 ± 16	**0.02**	1–3	b-quark asymmetry at Z pole From jet charge
$A_{FB}^{pol,\tau}$ $(\times 10^4)$	1498 ± 49	**0.15**	<2	τ polarization asymmetry τ decay physics
τ lifetime (fs)	290.3 ± 0.5	**0.001**	0.04	Radial alignment
τ mass (MeV)	1776.86 ±0.12	**0.004**	0.04	Momentum scale
τ leptonic $(\mu\nu_\mu\nu_\tau)$ B.R. (%)	17.38 ±0.04	**0.0001**	0.003	e/μ/hadron separation
m_W (MeV)	80350 ± 15	**0.25**	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085 ± 42	**1.2**	0.3	From WW threshold scan Beam energy calibration
$\alpha_s(m_W^2)(\times 10^4)$	1170 ± 420	**3**	Small	from R_ℓ^W
$N_\nu(\times 10^3)$	2920 ± 50	**0.8**	Small	Ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV/c^2)	172740 ± 500	**17**	Small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV/c^2)	1410 ± 190	**45**	Small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	**0.10**	Small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	**0.5–1.5%**	Small	From $\sqrt{s} = 365$ GeV run





Email me to join US-FCC! We are havings lots of fun!

A great thank you!