DØ Run I Physics

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Jefferson Lab

DØ Collaboration Meeting
June 10, 2014

Outline

The World in 1992

Strong Interactions

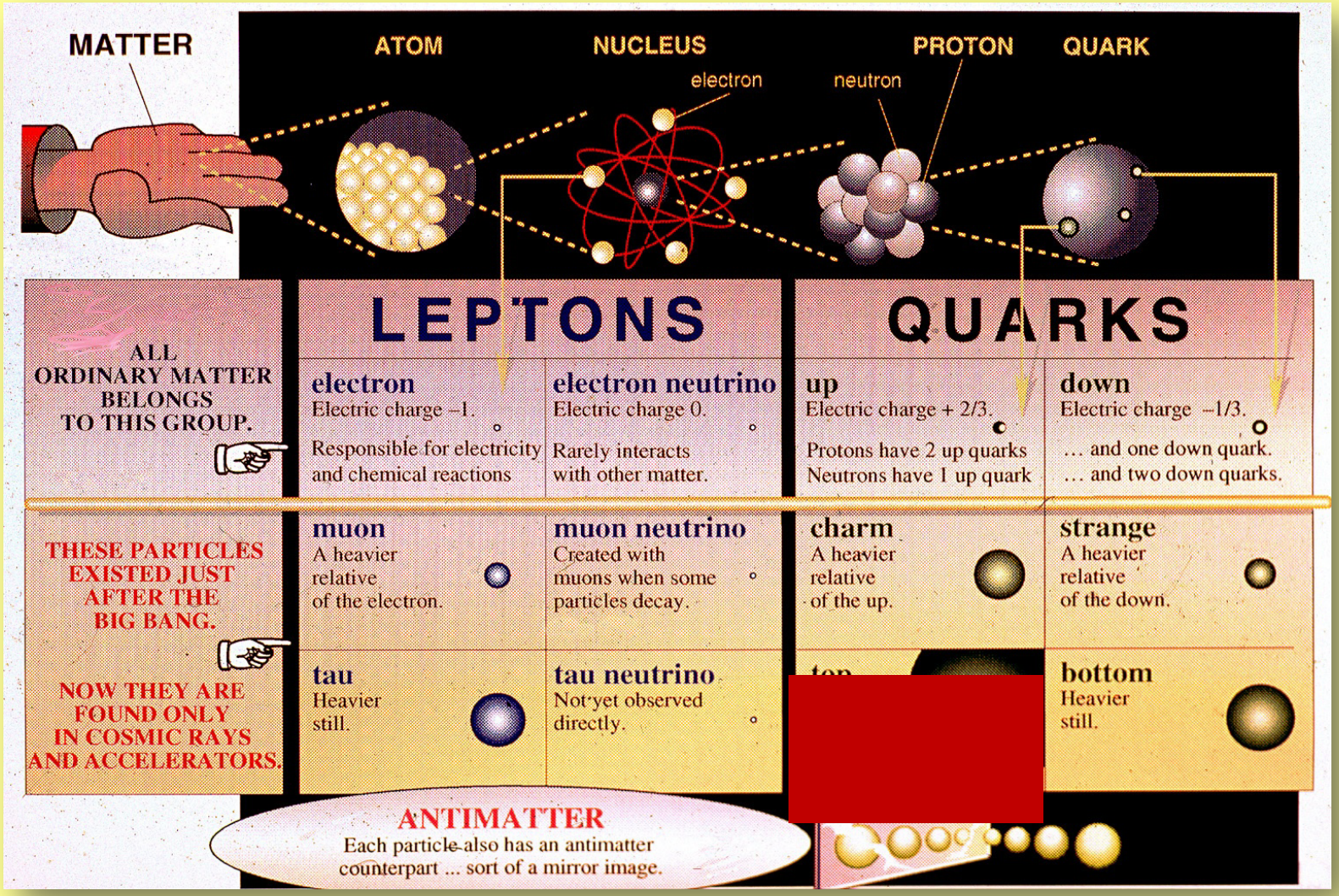
Electroweak Interactions

The Top Quark

New Phenomena

The World in 1996

Particle Physics 1992



The Virtual Life of the Top Quark

~1990: $b \rightarrow s\, e^+e^-$ (CLEO) and B_d mixing (ARGUS) show that b has weak isospin = 1/2, thus has a partner 'top' quark

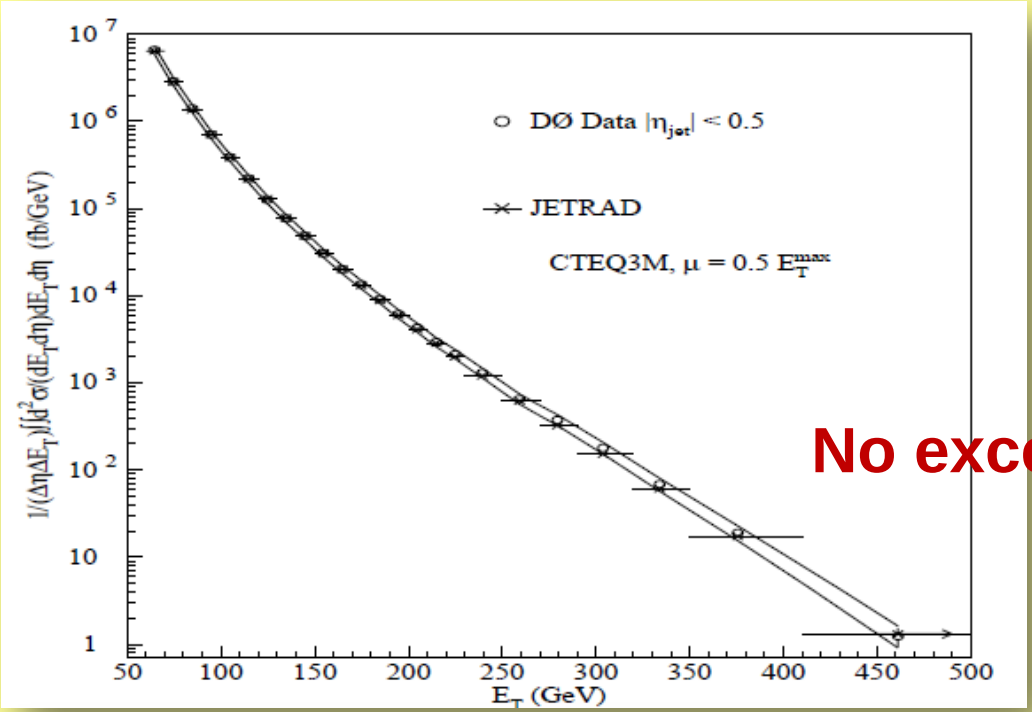
1980 – 1990: Although the 'factor of 3' argument suggested a top quark at ~ 15 GeV, e^+e^- colliders PETRA, TRISTAN, LEP/SLC do not observe top pairs up to $m_t = 45$ GeV

1984 – 1994: Hadron collider searches raise the limit on m_t: 69 GeV (UA2 and UA1), 91 GeV (CDF), 131 GeV (DØ)

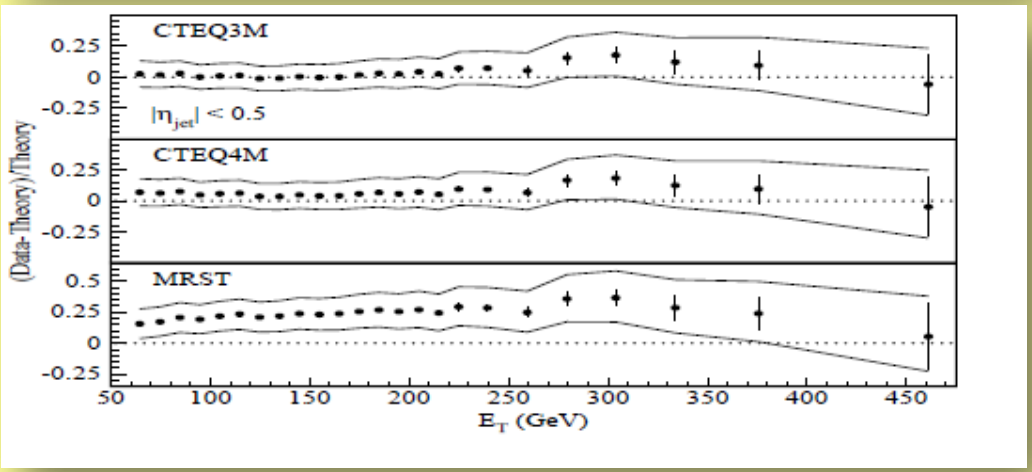
Year	Collider	Particles	References	Limit on m_t
1979-84	PETRA (DESY)	e^+e^-	[45]-[58]	$> 23.3\ \mathrm{GeV}/c^2$
1987-90	TRISTAN (KEK)	e^+e^-	[59]-[63]	$> 30.2\ \mathrm{GeV}/c^2$
1989-90	SLC (SLAC), LEP (CERN)	e^+e^-	[64]-[67]	$> 45.8\ \mathrm{GeV}/c^2$
1984	SppS (CERN)	$p\bar{p}$	[70]	$> 45.0\ \mathrm{GeV}/c^2$
1990	SppS (CERN)	$p\bar{p}$	[71, 72]	$> 69\ \mathrm{GeV}/c^2$
1991	TEVATRON (FNAL)	$p\bar{p}$	[73]-[75]	$> 77\ \mathrm{GeV}/c^2$
1992	TEVATRON (FNAL)	$p\bar{p}$	[76, 77]	$> 91\ \mathrm{GeV}/c^2$
1994	TEVATRON (FNAL)	$p\bar{p}$	[79, 80]	$> 131\ \mathrm{GeV}/c^2$

DØ Valentine's Day 1992

Strong Interactions

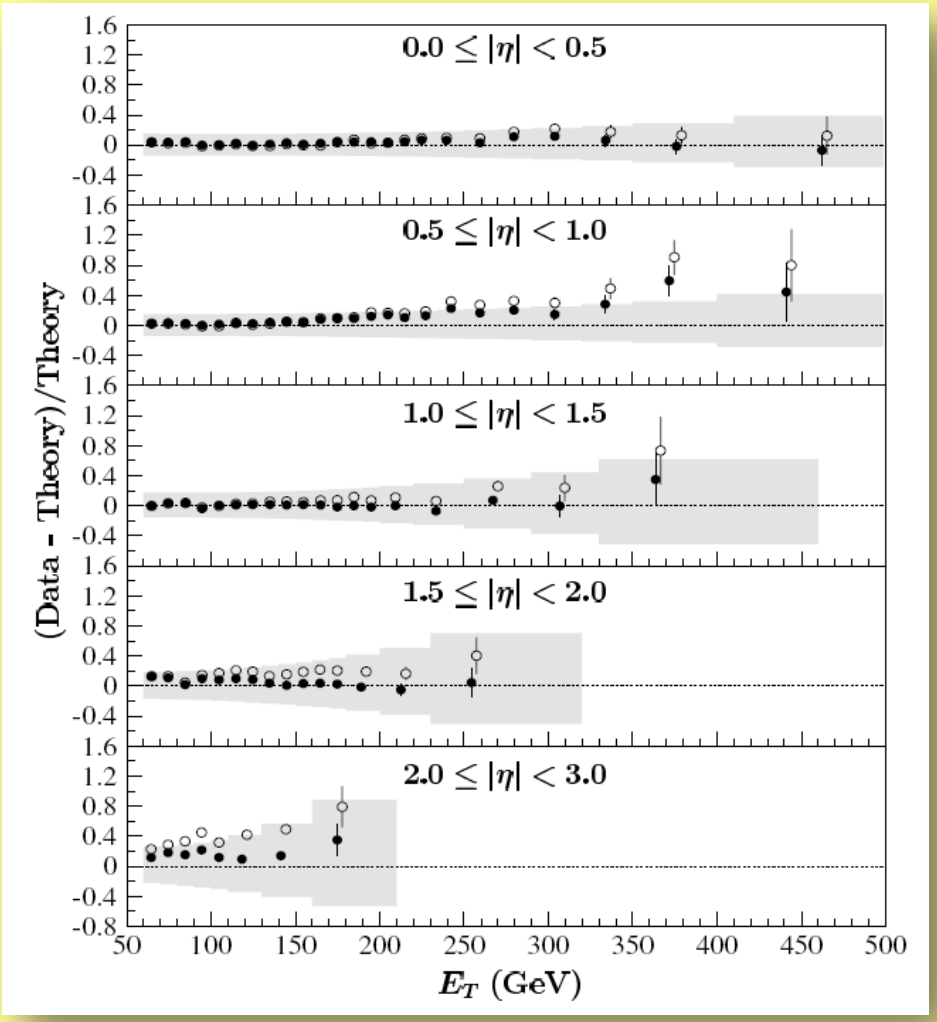


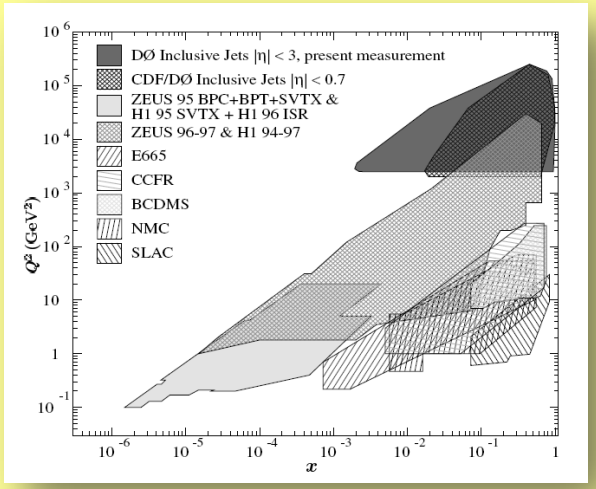
No excess at high E_T.



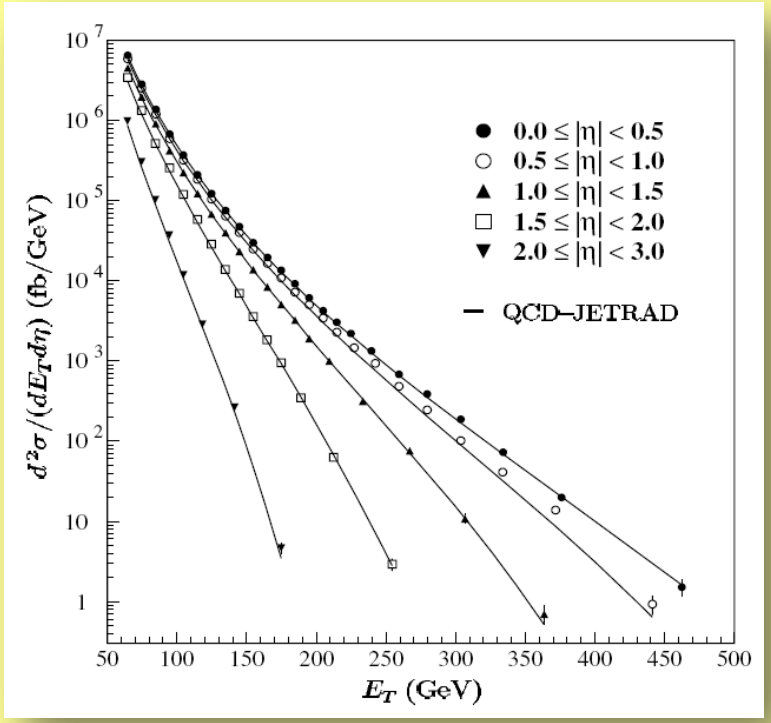
Strong Interactions

DØ reach in Q^2 – x plane: focus on pQCD at high Q^2 (and selected non-pQCD studies at low p_T)



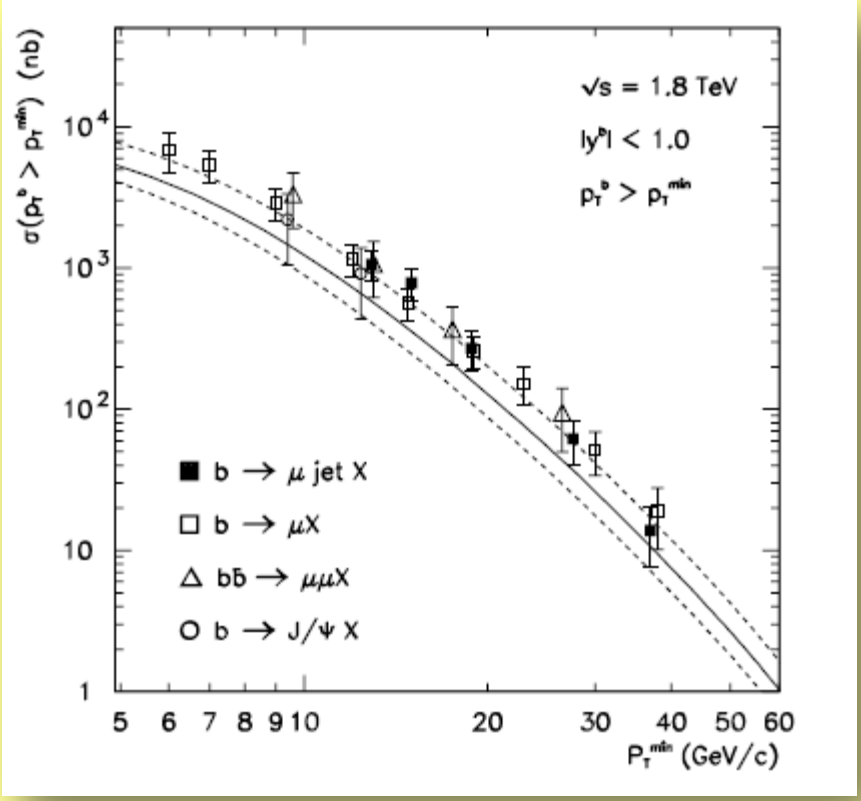


Inclusive jet XS: (Pub 101) Good data-theory agreement with CTEQHJ or MRSTg↑ (enhanced gluon content).



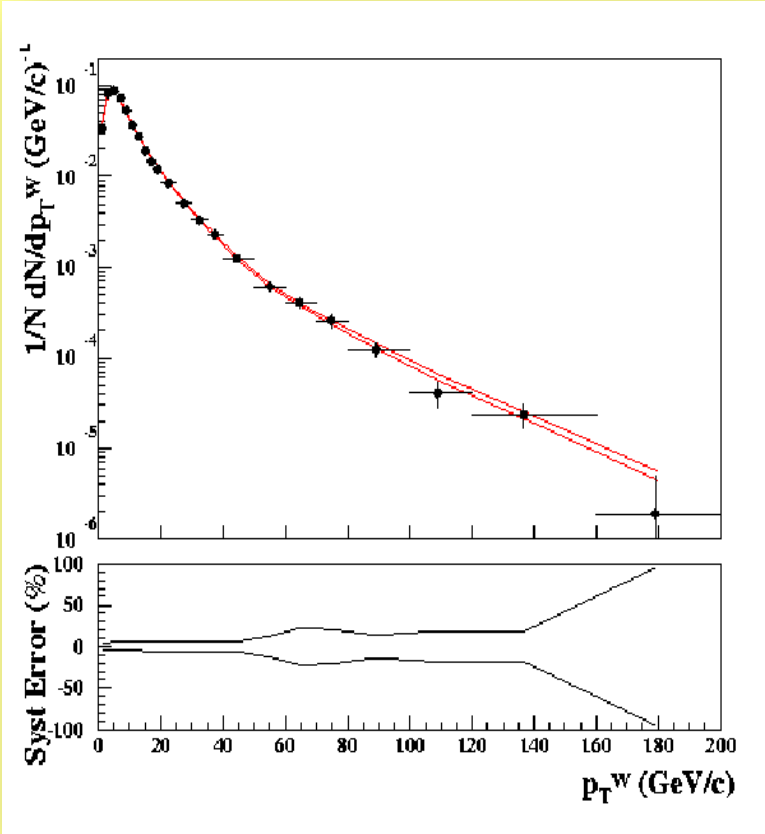
B Physics

- Rather B production cross sections
- Consistently larger than theory predictions

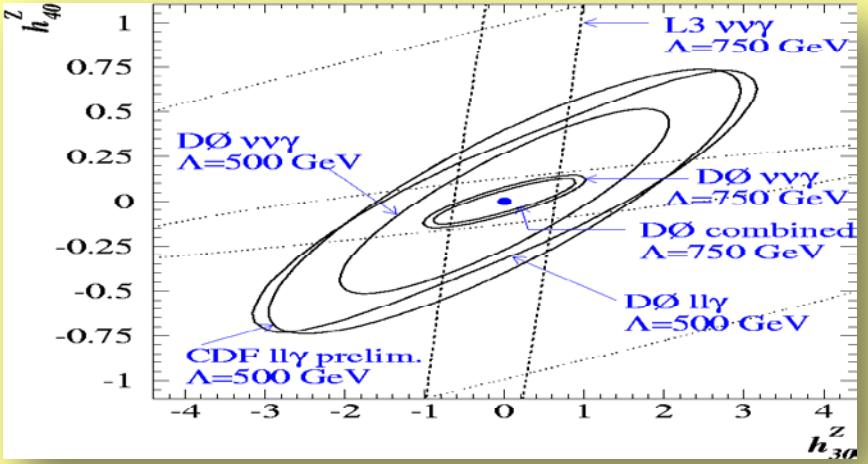


Electroweak Interactions

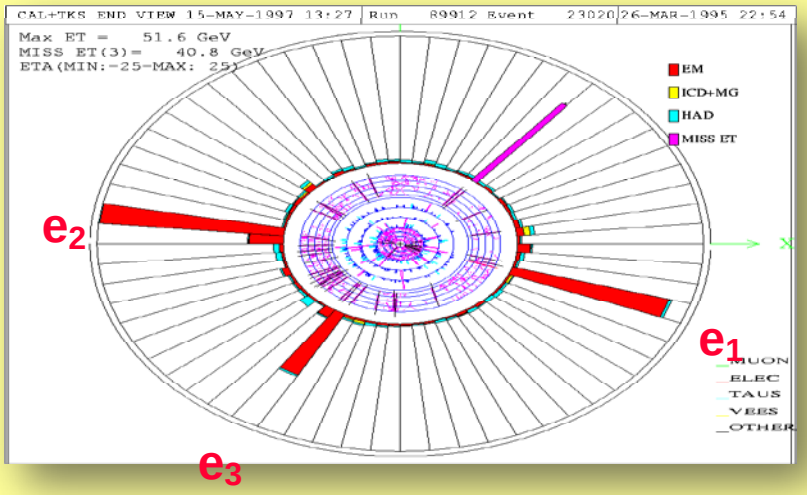
Informing Strong Interactions
Boson transverse momenta



Gauge Boson Interactions

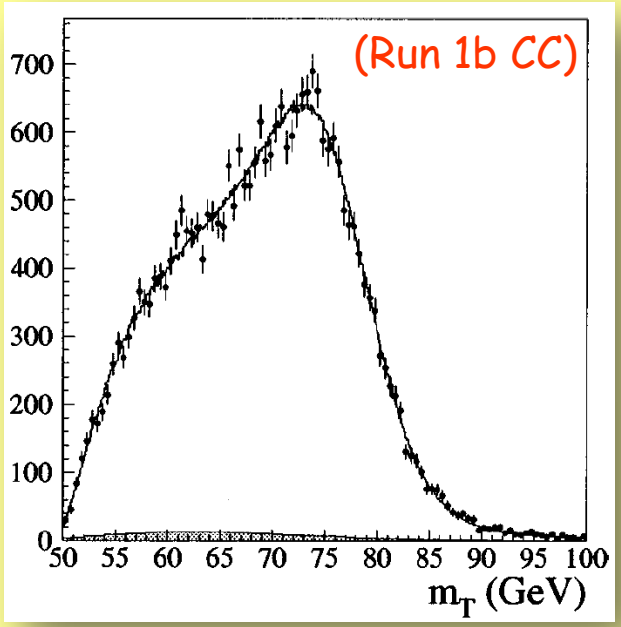


WZ Production



The Mass of the W Boson

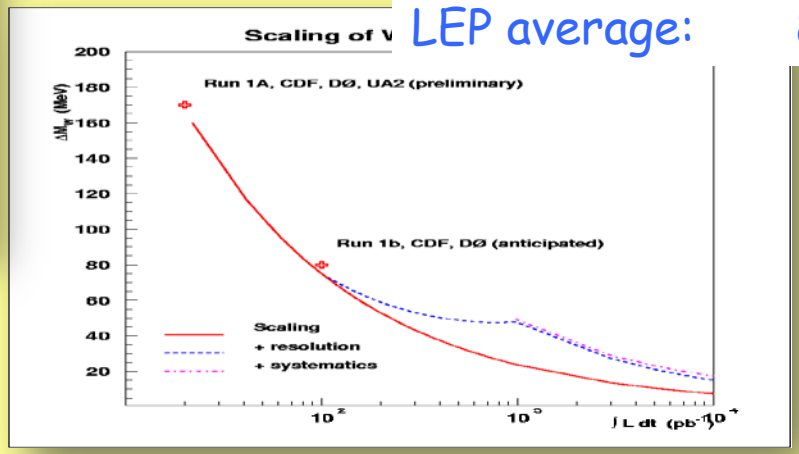
- Discovery 1982 with a few events in each of UA1, UA2
- Serious mass measurement by UA2, 1992
- Run 1 ~ 100k events



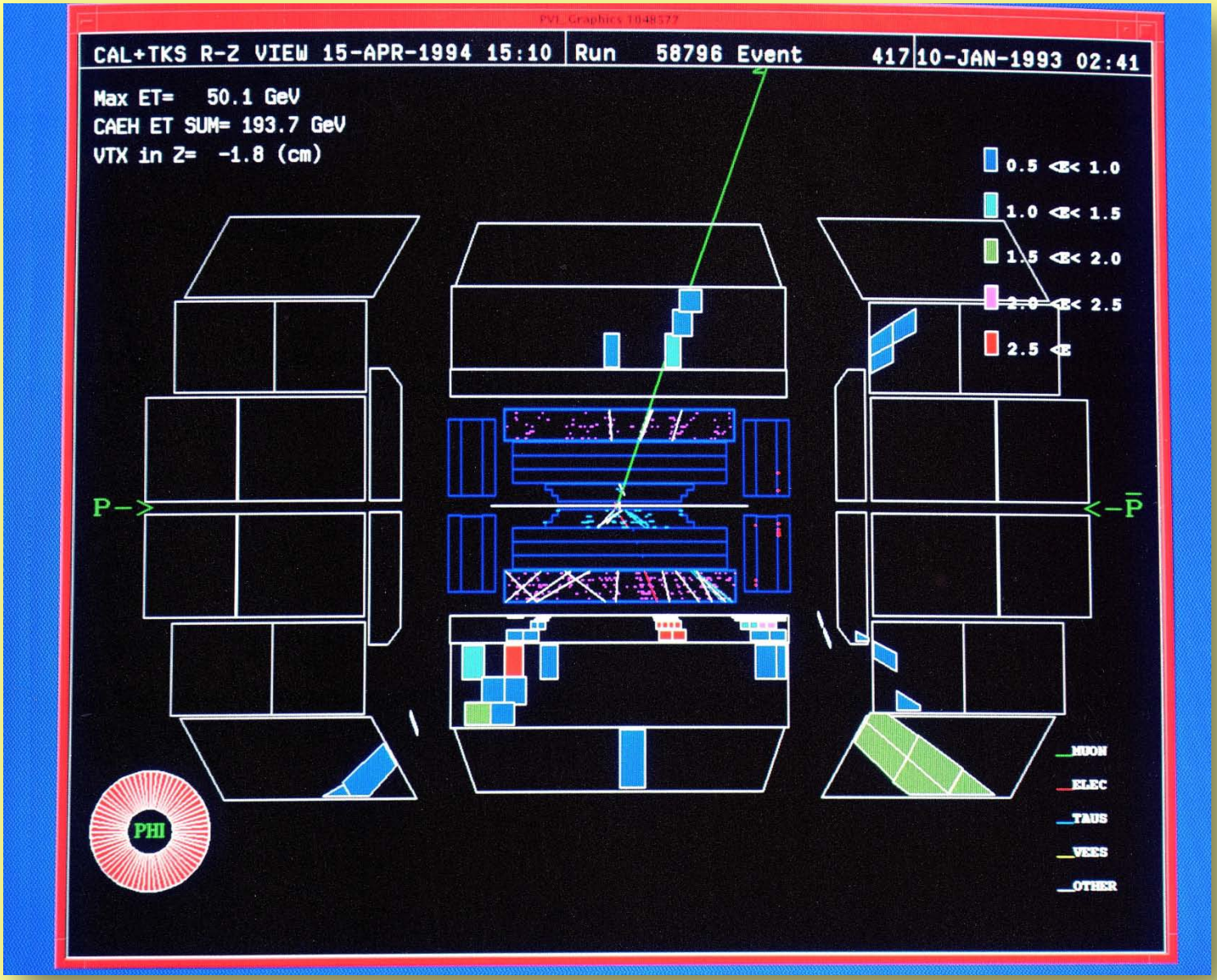
Measurement	m_W	Dm_W	cumulative
Run 1a *CC*	80.35	±0.27	
Run 1b *CC*	80.44	±0.12	80.43±0.11
EC	80.691	±0.227	80.482±0.091
CC module edge	80.574	±0.405	**80.483±0.084**

Run 1 Tevatron: 80.454±0.059

LEP average: 80.450±0.039

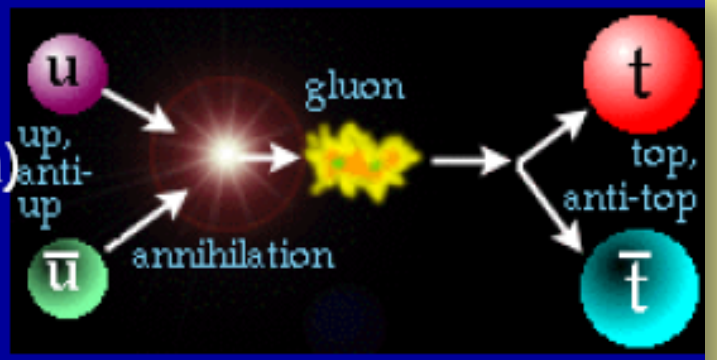


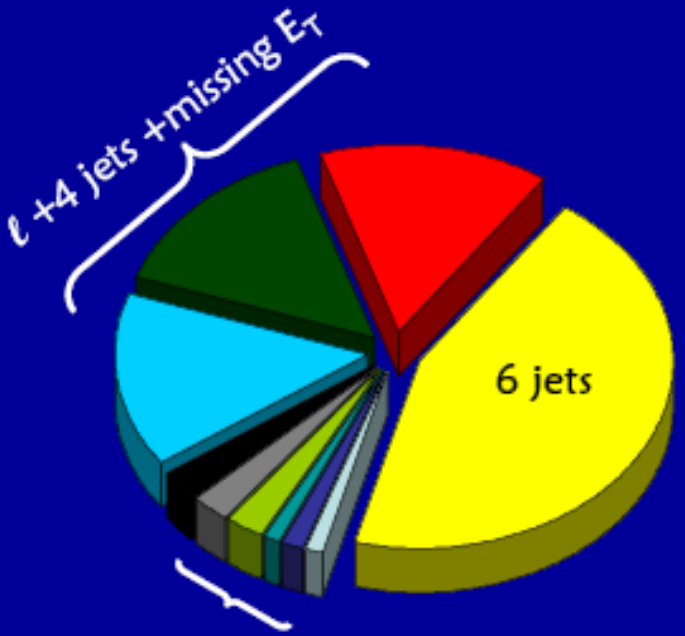
A DØ Top Quark?



Profile of the Top Quark

At Tevatron, 85% of $\bar{t}t$ production is from $\bar{q}q$ annihilation (15% gluon fusion)





e-e	(1/81)
mu-mu	(1/81)
tau-tau	(1/81)
e -mu	(2/81)
e -tau	(2/81)
mu-tau	(2/81)
e+jets	(12/81)
mu+jets	(12/81)
tau+jets	(12/81)
jets	(36/81)

~100% decays $t \rightarrow Wb$ so final states governed solely by the two W branching fractions (~2/3 qq', 1/3 $\ell\nu$ each). Two of the final jets are b-quarks.

Can have extra jets from initial/final state radiation

DØ Top Observation

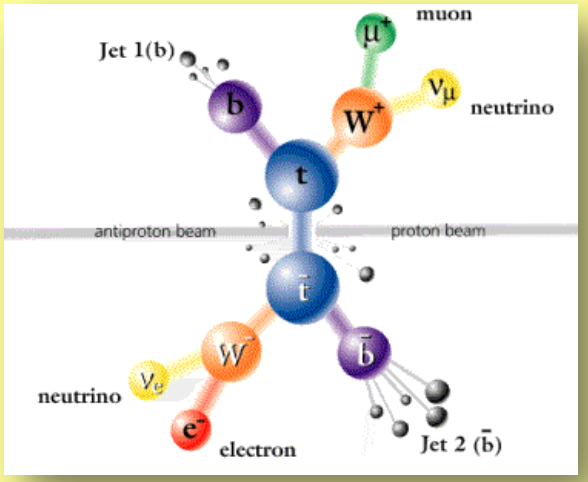
- Dileptons
  - 3 events observed,
  - estimated background 0.65 +-0.14 events
- Lepton + jets (4 jets untagged, 3 jets with tag
  - 14 events observed
  - Estimated background 3.1 +- 0.5 events
- Significance of Observation

Probability of background upward fluctuation 2×10^{-6} (4.6σ).

$\sigma_t = 6.4 \pm 2.2$ pb; $M_t = 199 \pm 30$ GeV

Constraints/Observables

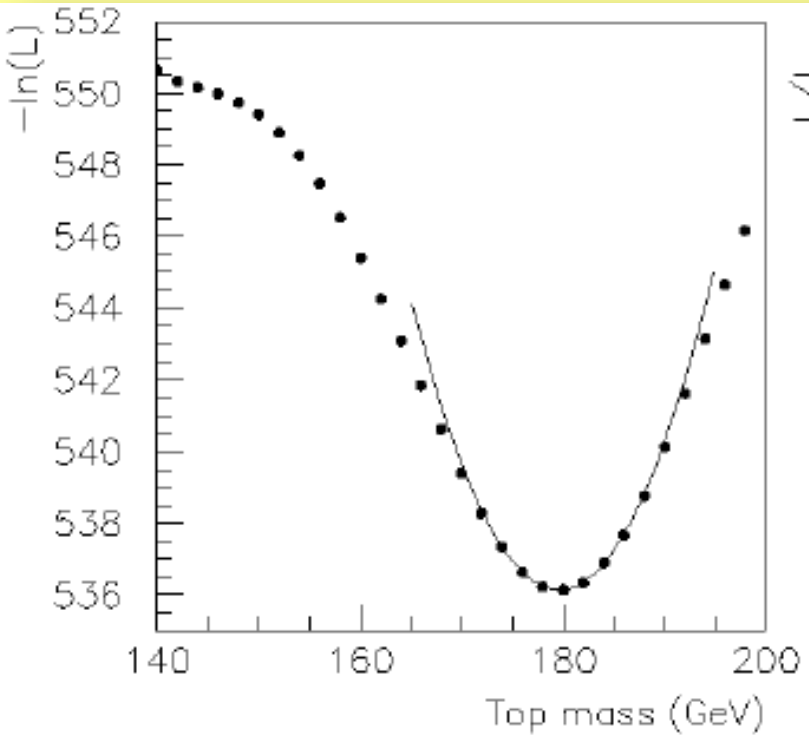
- 18 fermion 3-vector components
- Use constraints
  - W mass (twice) (2)
  - Mass of top = mass of antitop (1)
  - Assume mass for top
  - Fit using measurement errors

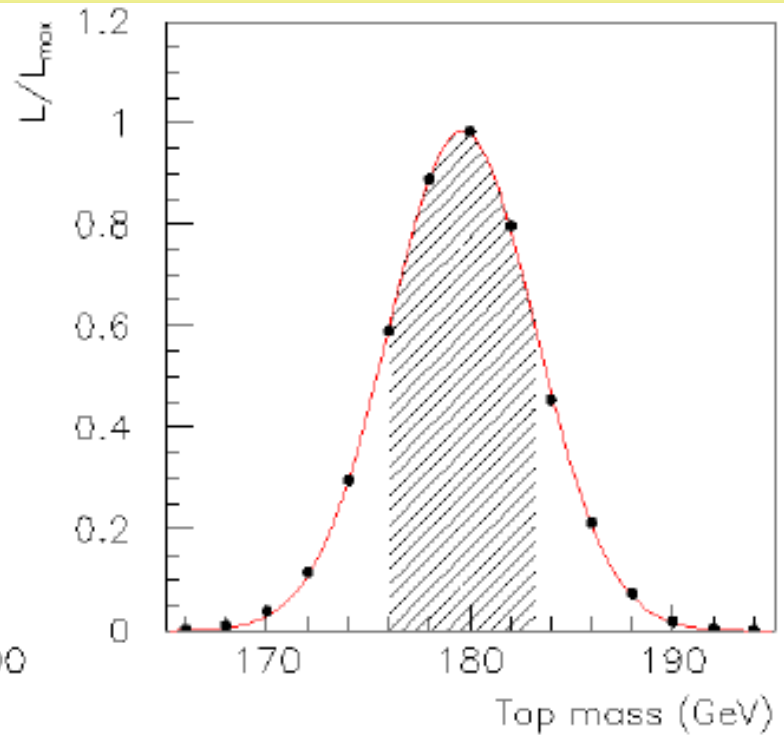


- Measure 1 lepton(3) and 4 jets (12) and Missing Transverse Energy (2)
  - 20 constraints plus measurements (20-18→ 2C)
- Measure 2 leptons(6) and 2 jets (6) and Missing Transverse Energy (2)
  - 17 constraints plus measurements (17-18→ -1C)
- Further constraints
  - The parton distributions (poor man's beam energy)
  - Internal characteristics
  - Full matrix element

DØ Run I – Full Matrix Element

For each event estimate probability for a top mass value using all measured quantities compared to distribution of t-tbar production matrix element.
(Need to integrate over measurement resolutions)





$M_t = 180.1 \pm 3.6$ GeV $\pm$ SYST - preliminary

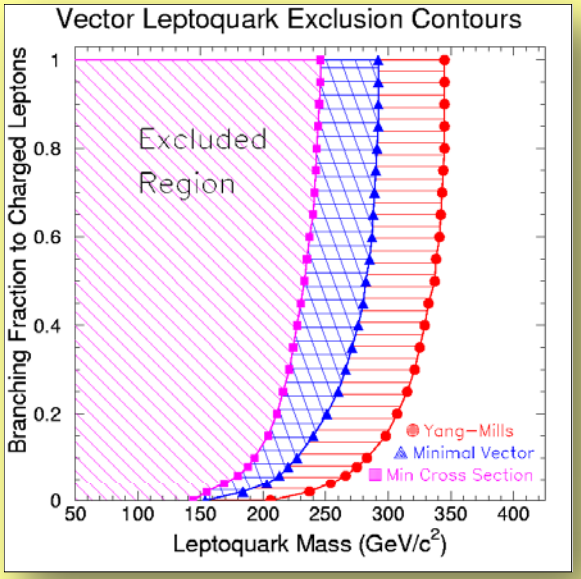
This new technique improves the statistical error on M_t from 5.6 GeV [PRD 58 52001, (1998)] to 3.6 GeV. This is equivalent to a factor of 2.4 in the number of events. 22 events pass our cuts, from fit: (12 s + 10 b)

(0.5 GeV shift has been applied, from MC studies)

Juan Cruz Estrada - Fermilab

New Phenomena

1st Generation

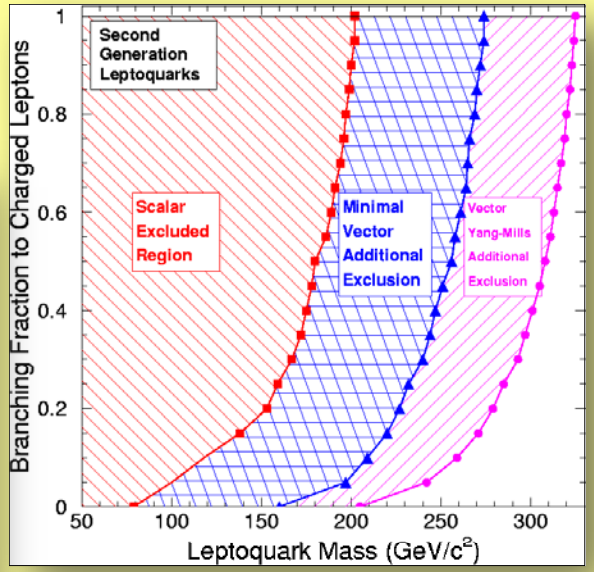


Leptoquarks

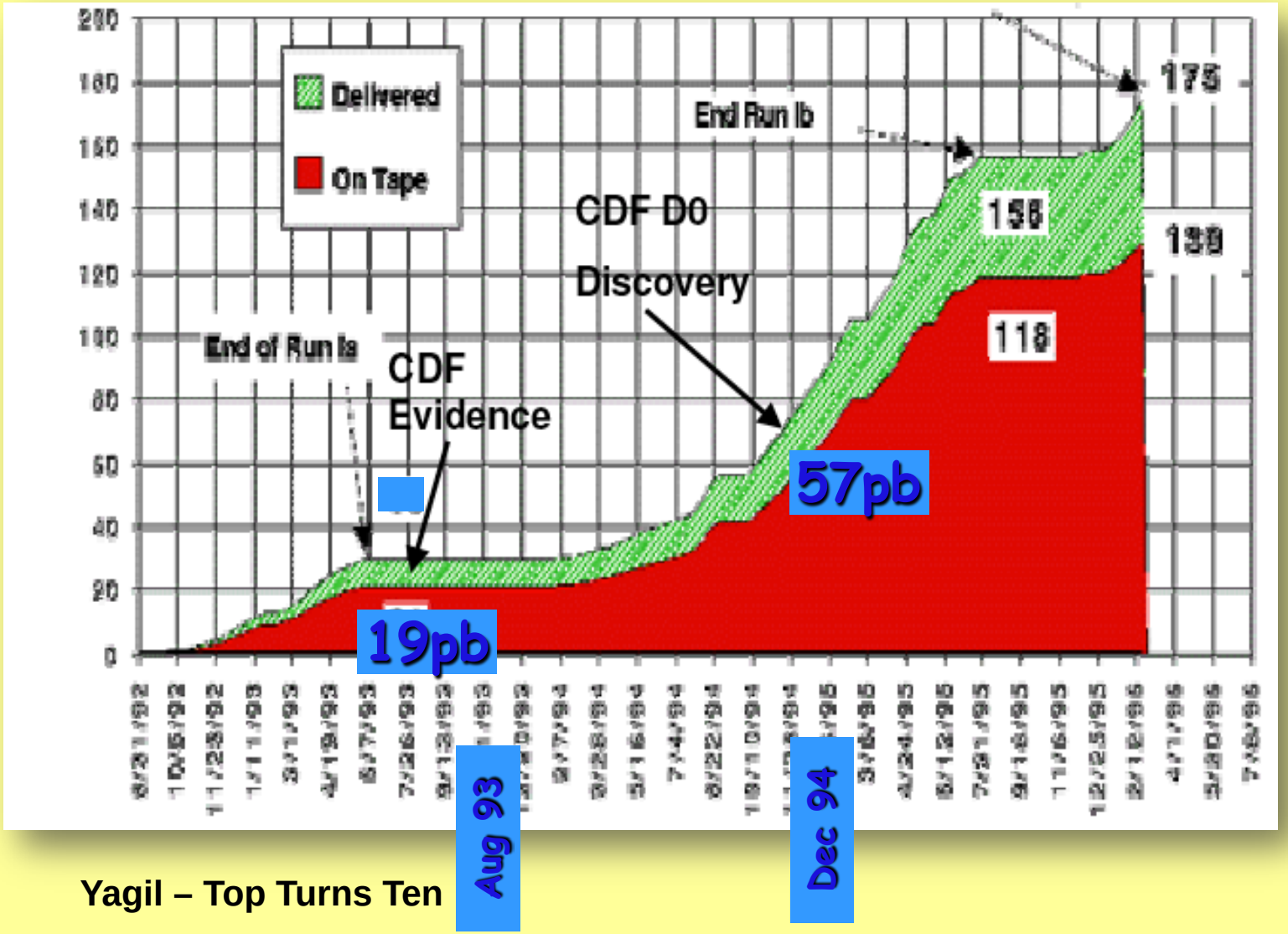
Leptoquark Mass Limits

channel	β	M_{LQ}((GeV/c^2)	($\int \mathcal{L}dt$(pb^{-1}))
first generation scalar			
$eejj$	1	213	CDF (110)
$eejj$	1	225	DØ (123)
$e(e/\nu)jj$	0.5	204	DØ (115)
$\nu\nu jj$	1	79	DØ (7.4)
$eejj$	1	242	CDF/DØ
first generation vector (Yang-Mills couplings)			
$eejj$	1	340	DØ (123)
$e(e/\nu)jj$	0.5	329	DØ (115)
$\nu\nu jj$	0	200	DØ (7.4)
second generation scalar			
$\mu\mu jj$	1	195	CDF (110)
$\mu\mu jj$	0.5	133	CDF (110)
$\mu\mu jj$	1	185	DØ
$\mu\mu jj$	0.5	140	DØ
third generation scalar			
$\tau\tau jj$	1	99	CDF (110)
$\nu\nu b\bar{b}$	0	94	DØ (1a,1b)
third generation vector (Yang-Mills couplings)			
$\tau\tau jj$	1	225	CDF (110)
$\nu\nu b\bar{b}$	0	216	DØ (1a,11b)

2nd Generation



Tevatron Run I and Top



The World in 1996

Major advances in understanding high energy perturbative QCD

A beautiful measurement of the mass of the W Boson

Rigorous examination of the interactions between vector bosons

Observation of the top quark

A first examination of the properties of the top quark

Imaginative but unsuccessful searches for new phenomena

Run 1 Physics

New Phenomena QCD b-physics

Electroweak Top

DØ RUN I (not an engineering run!)

RUN Ia ('92-'93): 15 pb^{-1}

RUN Ib ('94-'95): 88 pb^{-1}

RUN Ic ('96): 13 pb^{-1}

Total (at $\sqrt{s}$ = 1.8 TeV) 116 pb^{-1}

+ 0.46 pb^{-1} at $\sqrt{s}$ = 630 GeV

Efficiency of operation:
Record 86% of delivered luminosity outside of Main Ring in DØ
(71% overall efficiency

Record 150M events to tape

132 Run 1 Physics publications:

38 New Phenomena

32 QCD

7 b physics

31 Electroweak

21 Top

3 Detector

List of Institutions on Dzero at time of discovery

THE DØ COLLABORATION

Universidad de los Andes, Bogota, Colombia
University of Arizona
Brookhaven National Laboratory
Brown University
University of California, Davis
University of California, Irvine
University of California, Riverside
LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
CINVESTAV, Mexico City, Mexico
Columbia University
Delhi University, Delhi, India
Fermi National Accelerator Laboratory
Florida State University
University of Hawaii
University of Illinois, Chicago
Indiana University
Iowa State University
Korea University, Seoul, Korea
Kyungsung University, Pusan, Korea
Institute of Nuclear Physics, Kraków, Poland
Lawrence Berkeley Laboratory
University of Maryland
University of Michigan
Michigan State University
Moscow State University, Russia
University of Nebraska
New York University
Northeastern University
Northern Illinois University
Northwestern University
University of Notre Dame
University of Oklahoma
Panjab University, Chandigarh, India
Institute for High Energy Physics, Protvino, Russia
Purdue University
Rice University
University of Rochester
DAPNIA/SPP-CE Saclay, Gif-sur-Yvette, France
Seoul National University, Seoul, Korea
State University of New York, Stony Brook
Superconducting Supercollider Laboratory
Tata Institute of Fundamental Research, Bombay, India
University of Texas, Arlington
Texas A&M University

44 Institutions

Brazil
Colombia
France
India
Korea
Mexico
Poland
Russia
USA

Dzero Author List

Abachi to Zylberstejn

Thanks to all

S. Abachi,[12] B. Abbott,[33] M. Abolins,[23] B.S. Acharya,[40] I. Adam,[10] D.L. Adams,[34] M. Adams,[15] S. Ahn,[12] H. Aihara,[20] J. Alitti,[36] G. Álvarez,[16] G.A. Alves,[8] E. Amidi,[27] N. Amos,[22] E.W. Anderson,[17] S.H. Aronson,[3] R. Astur,[38] R.E. Avery,[29] A. Baden,[21] V. Balamurali,[30] J. Balderston,[14] B. Baldin,[12] J. Bantly,[4] J.F. Bartlett,[12] K. Basisi,[7] J. Bendich,[20] S.B. Beri,[31] I. Bertram,[34] V.A. Bezzubov,[32] P.C. Bhat,[12] V. Bhatnagar,[31] M. Bhattacharjee,[11] A. Bischoff,[7] N. Biswas,[30] G. Blazey,[12] S. Blessing,[13] A. Boehnlein,[12] N.I. Bojko,[32] F. Borcherding,[12] J. Borders,[35] C. Boswell,[7] A. Brandt,[12] R. Brock,[23] A. Bross,[12] D. Buchholz,[29] V.S. Burtovoi,[32] J.M. Butler,[12] D. Casey,[35] H. Castilla-Valdez,[9] D. Chakraborty,[38] S.-M. Chang,[27] S.V. Chekulaev,[32] L.-P. Chen,[20] W. Chen,[38] L. Chevalier,[36] S. Chopra,[31] B.C. Choudhary,[7] J.H. Christenson,[12] M. Chung,[15] D. Claes,[38] A.R. Clark,[20] W.G. Cobau,[21] J. Cochran,[7] W.E. Cooper,[12] C. Cretsinger,[35] D. Cullen-Vidal,[4] M. Cummings,[14] D. Cutts,[4] O.I. Dahl,[20] K. De,[41] M. Demarteau,[12] R. Demina,[27] K. Denisenko,[12] N. Denisenko,[12] D. Denisov,[12] S.P. Denisov,[32] W. Dharmaratna,[13] H.T. Diehl,[12] M. Diesburg,[12] G. Diloreto,[23] R. Dixon,[12] P. Draper,[41] J. Drinkard,[6] Y. Ducros,[36] S.R. Dugad,[40] S. Durston-Johnson,[33] D. Edmunds,[23] A.O. Efimov,[32] J. Ellison,[7] V.D. Elvira,[12,‡] R. Engelmann,[38] S. Eno,[21] G. Eppley,[34] P. Ermolov,[24] O.V. Eroshin,[32] V.N. Evdokimov,[32] S. Fahey,[23] T. Fahland,[4] M. Fatyga,[3] M.K. Fatyga,[35] J. Featherly,[3] S. Feher,[38] D. Fein,[2] T. Ferbel,[35] G. Finocchiaro,[38] H.E. Fisk,[12] Yu. Fisyak,[24] E. Flattum,[23] G.E. Forden,[2] M. Fortner,[28] K.C. Frame,[23] P. Franzini,[10] S. Fredriksen,[39] S. Fuess,[12] A.N. Galjaev,[32] E. Gallas,[41] C.S. Gao,[12,*] S. Gao,[12,*] T.L. Geld,[23] R.J. Genik II,[23] K. Genser,[12] C.E. Gerber,[12,‡] B. Gibbard,[3] M. Glaubman,[27] V. Glebov,[35] S. Glenn,[5] J.F. Glicenstein,[36] B. Gobbi,[29] M. Goforth,[13] A. Goldschmidt,[20] B. Gomes,[1] P.I. Goncharov,[32] H. Gordon,[3] L.T. Goss,[42] N. Graf,[3] P.D. Grannis,[38] D.R. Green,[12] J. Green,[28] H. Greenlee,[12] G. Griffin,[6] N. Grossman,[12] P. Grudberg,[20] S. Grünendahl,[35] J.A. Guida,[38] J.M. Guida,[3] W. Guryn,[3] S.N. Gurzhiev,[32] Y.E. Gutnikov,[32] N.J. Hadley,[21] H. Haggerty,[12] S. Hagopian,[13] V. Hagopian,[13] K.S. Hahn,[35] R.E. Hall,[6] S. Hansen,[12] R. Hatcher,[23] J.M. Hauptman,[17] D. Hedin,[28] A.P. Heinson,[7] U. Heintz,[12] R. Hernandez-Montoya,[9] T. Heuring,[13] R. Hirosky,[13] J.D. Hobbs,[12] B. Hoeneisen,[1,¶] J.S. Hoftun,[4] F. Hsieh,[22] Ting Hu,[38] Tong Hu,[16] T. Huehn,[7] S. Igarashi,[12] A.S. Ito,[12] E. James,[2] J. Jaques,[30] S.A. Jerger,[23] J.Z.-Y. Jiang,[38] T. Joffe-Minor,[29] H. Johari,[27] K. Johns,[2] M. Johnson,[12] H. Johnstad,[39] A. Jonckheere,[12] H. Jöstlein,[12] S.Y. 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404 Authors

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