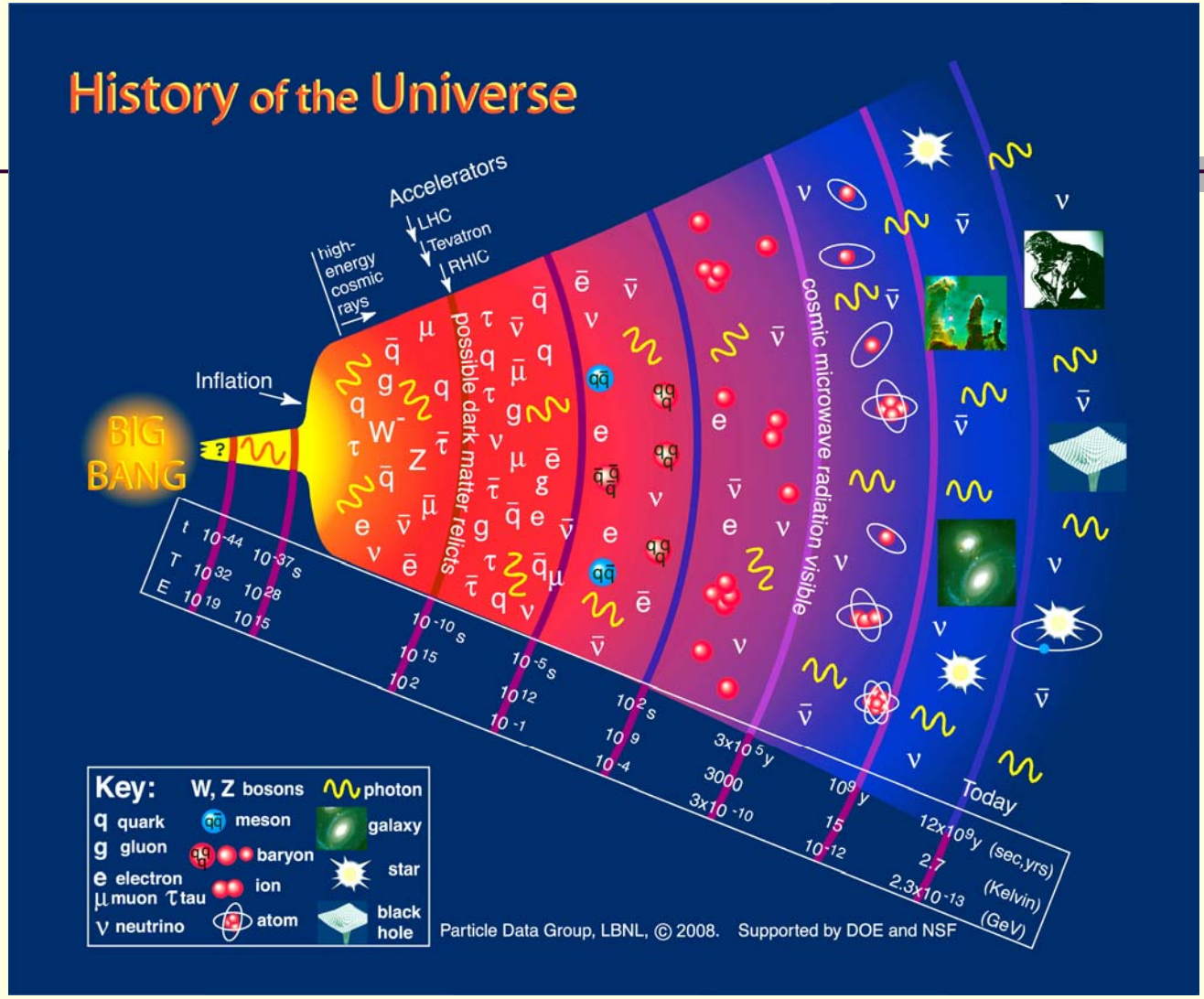
CDF実験の30年

金　信弘
（筑波大学 数理物質系）

日本物理学会　第67回年次大会
於　関西学院大学
2012年3月25日

宇宙史

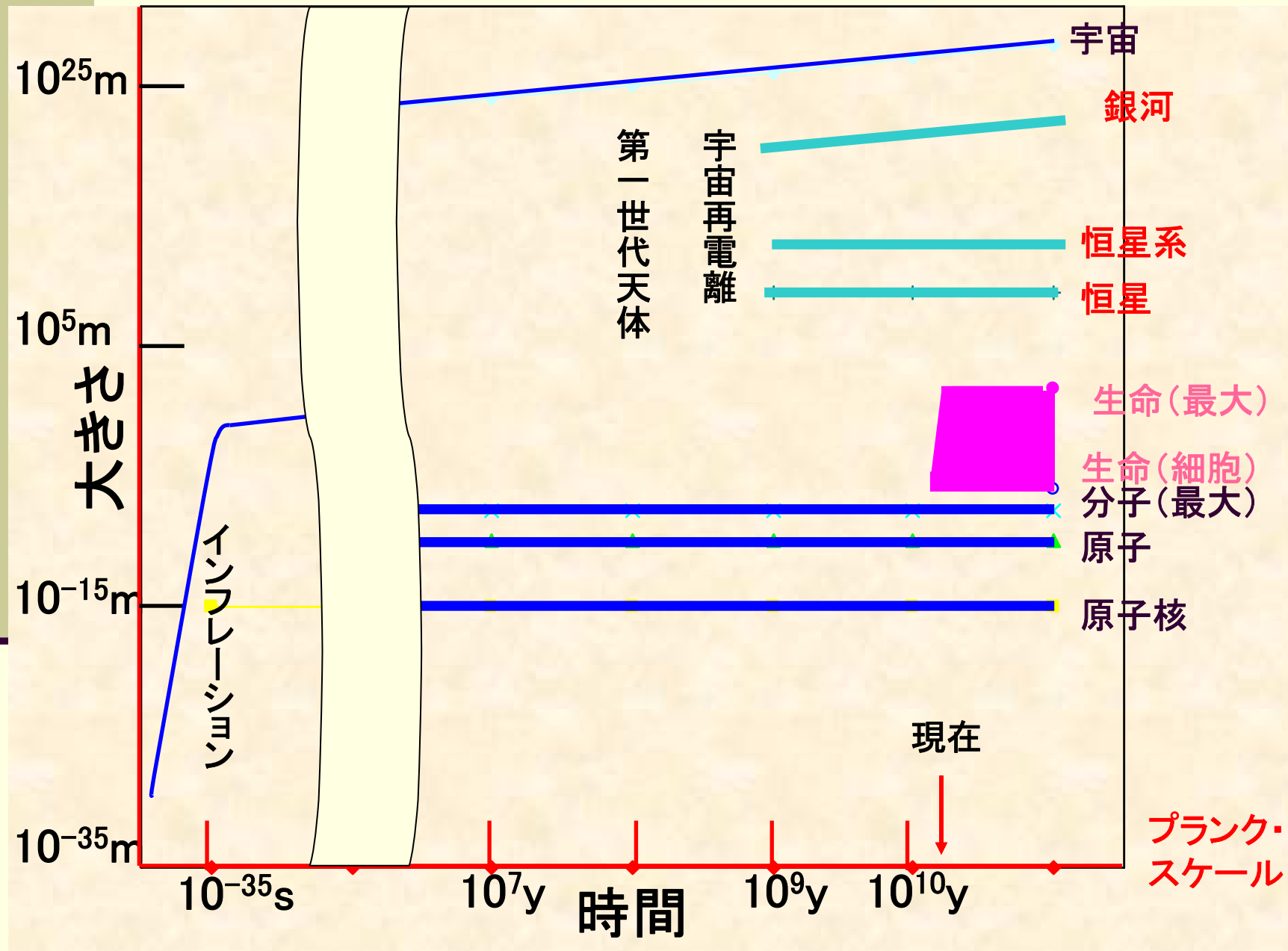


2007年度～　宇宙史一貫教育プログラム

筑波大で素粒子・原子核・宇宙観測を統合的に教育。

CDF,RHIC,LHC,電波望遠鏡観測,宇宙赤外線観測。 2011年度　修士21名　博士15名

宇宙・物質・生命の階層と歴史



Tevatron 運転終了： 2011/9/30

Helen Edwards dumps the TeV beam

Fermilab Today 2011/10/3

http://www.fnal.gov/pub/tevatron/milestones/interactive-timeline.html テバトロン30年史

CDF と日米協力の始まり

TEVATRON AUTHORIZED JULY 1979

1979: Sho Ohnuma and R. Yamada indicated that K. Kondo and several other Japanese we in the U. S. looking for ways to collaborate in HEP. I met them at a Conference at BNL and told them about our plans for a colliding beams experiment at FNAL. They came to visit and met with Lederman. The collaboration with CDF was finalized at the end of the year!

...Prof. Kunitaka Kondo (second from right) visits with (L-R) Hans Jensen, Alvin V. Tollestrup and Ryuji Yamada, all with the Fermilab Colliding Detector Facility. On the table before them is a model of the colliding detector...

Fermi News: Dec 1979

1980: Italians joined CDF

1981: Conceptual Design Document

1982, July 1. CDF Construction Begins!
Start construction of pbar source.

1983, July 3. First Beam in Tevatron!

1985, Oct. 13. First Collisions at CDF

CDF Design Report (1981)

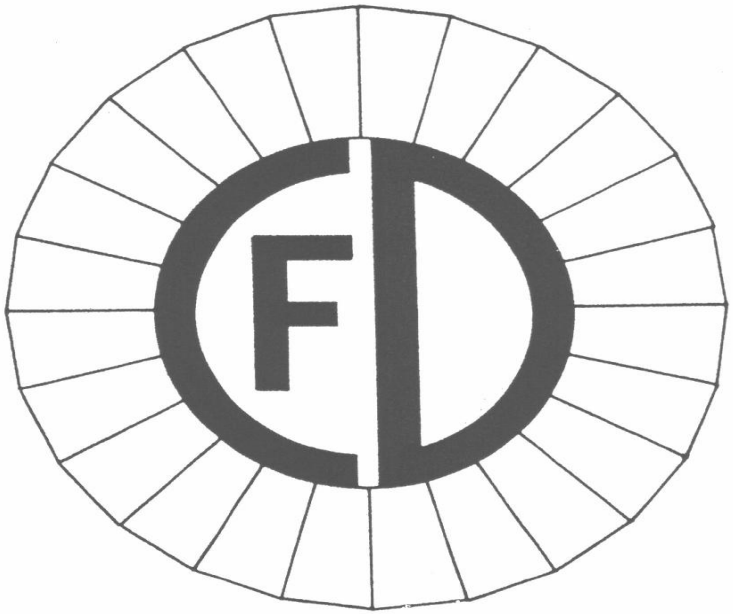
DESIGN REPORT

FOR THE

FERMILAB COLLIDER DETECTOR FACILITY

(CDF)

AUGUST, 1981



Number of Collaborators 87

CDF collaboration

Design Report (1981)

Country : 3	# Members : 87		# Institutions : 13
USA	57	(66%)	9
Italy	15		2
Japan	15	(17%)	2

Run I (1995 Observation of Top Quark Production)

Country : 5	# Members : 436		# Institutions : 35
USA	315	(72%)	25
Italy	57		4
Japan	47	(11%)	4
Canada	8	(2%)	1
Taiwan	9	(2%)	1

Run II (2004)

Country : 11	# Members : 615		# Institutions : 58
USA	376	(61%)	32
Italy	85		7
Japan	40	(7%)	6
Canada	15	(2%)	1
Taiwan	8	(1.3%)	1
Germany	16		1
Switzerland	8		1
Russia	12		2
UK	33		4
Spain	10		1
Korea	12	(2%)	1

5月12日　近藤先生　逝去

Fermilab Today

Monday, July 18, 2011

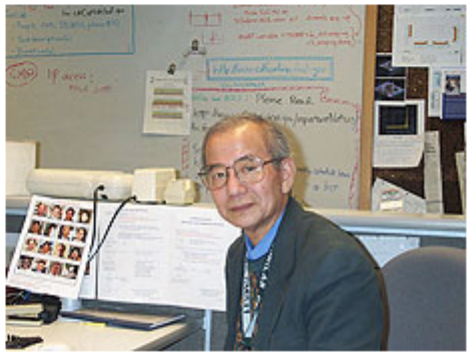
Calendar

Have a safe day!

Monday, July 18
PARTICLE ASTROPHYSICS SEMINARS WILL RESUME IN THE FALL
2 p.m.
LHC Physics Center Topic of the Week Seminar - Sunrise WH11NE
Speaker: Daniel Elvira, Fermilab
Title: SUSY Searches III: CMS Results
2:30 p.m.
Joint Experimental-Theoretical Physics Seminar - One west
Speaker: Mark Hartz, University of Toronto/York University
Title: Results from T2K: Indication of Electron Neutrino Appearance in a Muon Neutrino Beam
3:30 p.m.
DIRECTOR'S COFFEE BREAK - 2nd Flr X-Over
4 p.m.

In Memoriam

In Memoriam: Kuni Kondo



Kuni Kondo

Professor Kuni Kondo, an innovator and leader in particle physics, passed away unexpectedly on May 12 in Tokyo after a brief illness. He was 76.

Professor Kondo began his career as a research associate at the University of Tokyo in 1962 after receiving his Ph.D. in physics. He continued his career at Yale University where he worked with an international particle physics collaboration while using particle beam accelerators. He worked as an assistant and then a full professor at the University of Tokyo and

CDF積分ルミノシティー

- First Collision(1985.10)
- Engineering RUN
  (1987.1 – 1987.5) 27nb^{-1}
- RUN0
  (1988.9 – 1989.4) 4.4pb^{-1}
- RUN1
  (1992.8 – 1996.3) 130pb^{-1}

1994.7 Top Evidence
1995.4 Top Observation

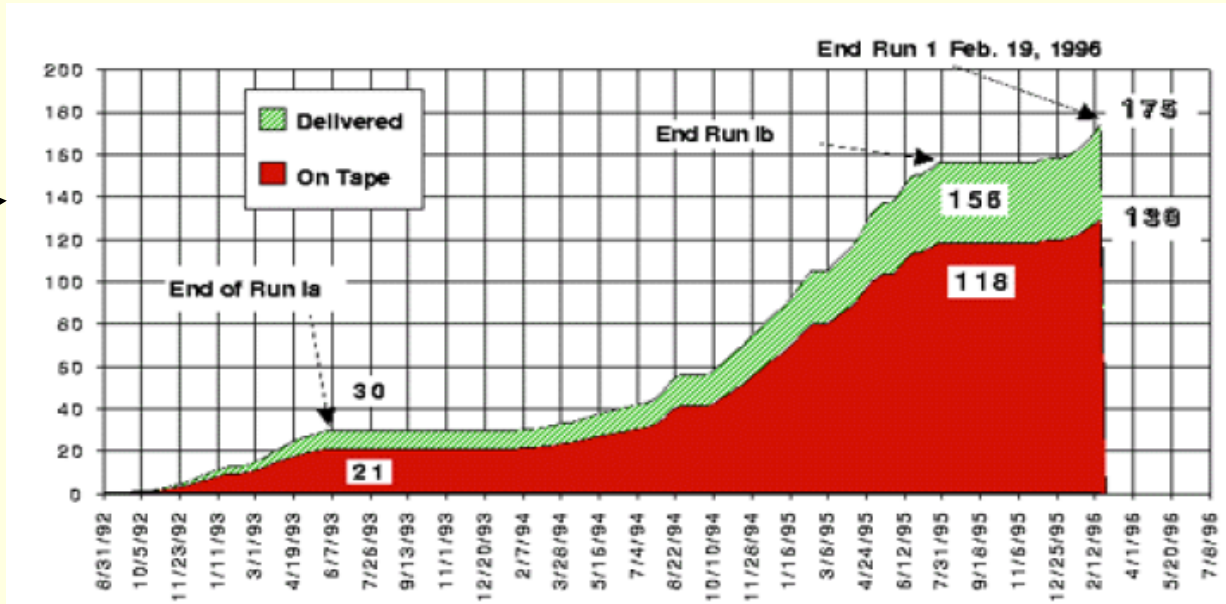
1998.12 B_c Observation

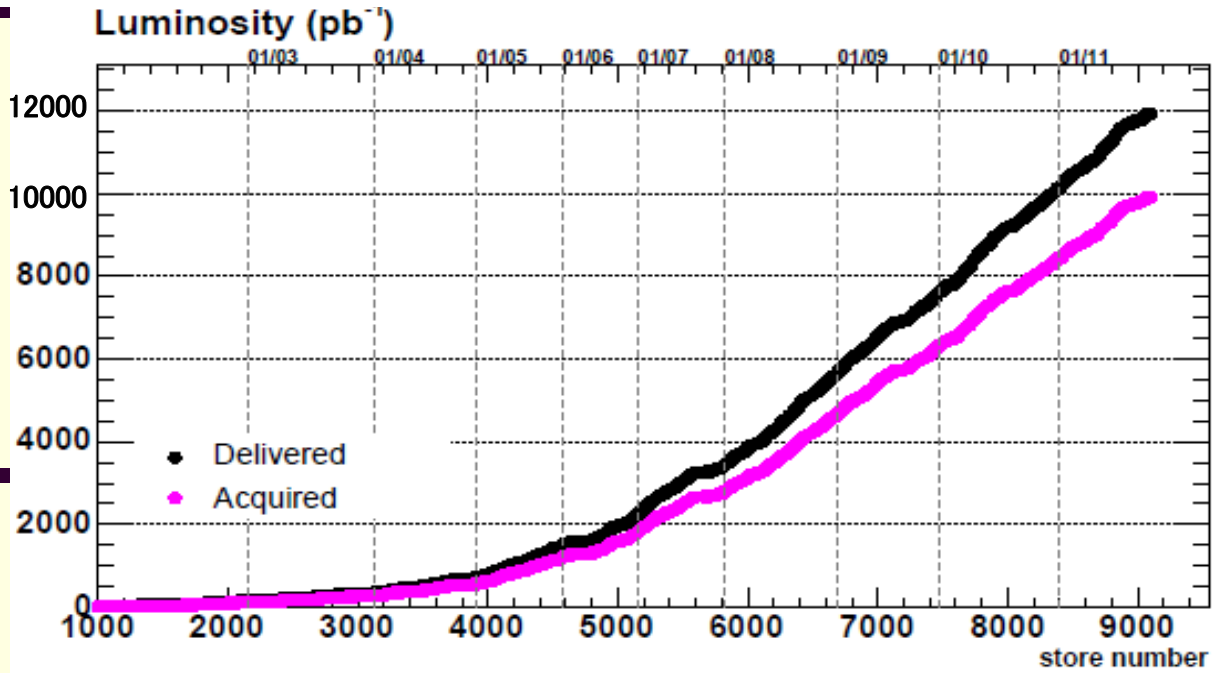
- RUN2
  (2001.6 – 2011.9.30)
  10.0fb^{-1}

2006.3 Precision M_{top}
ΔM_{top}=3GeV→M_H<186GeV

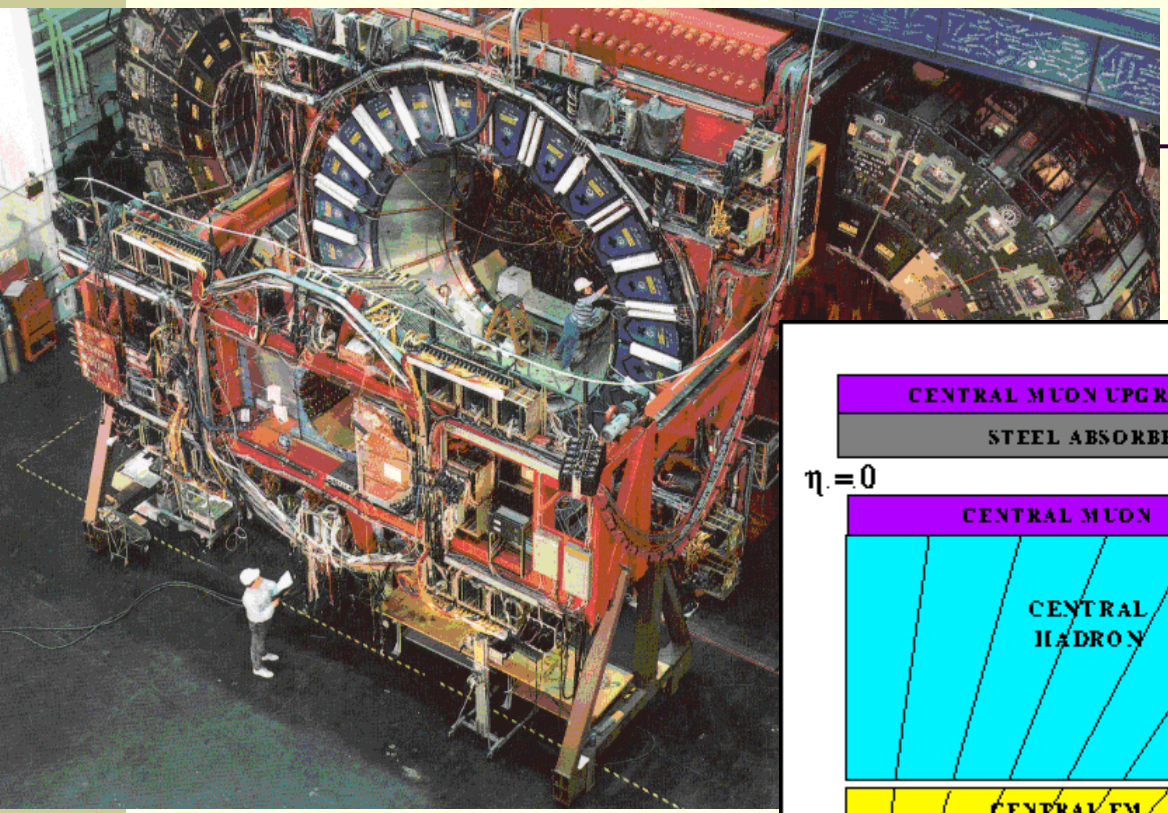
2006.12 Observation of
B_s Oscillation

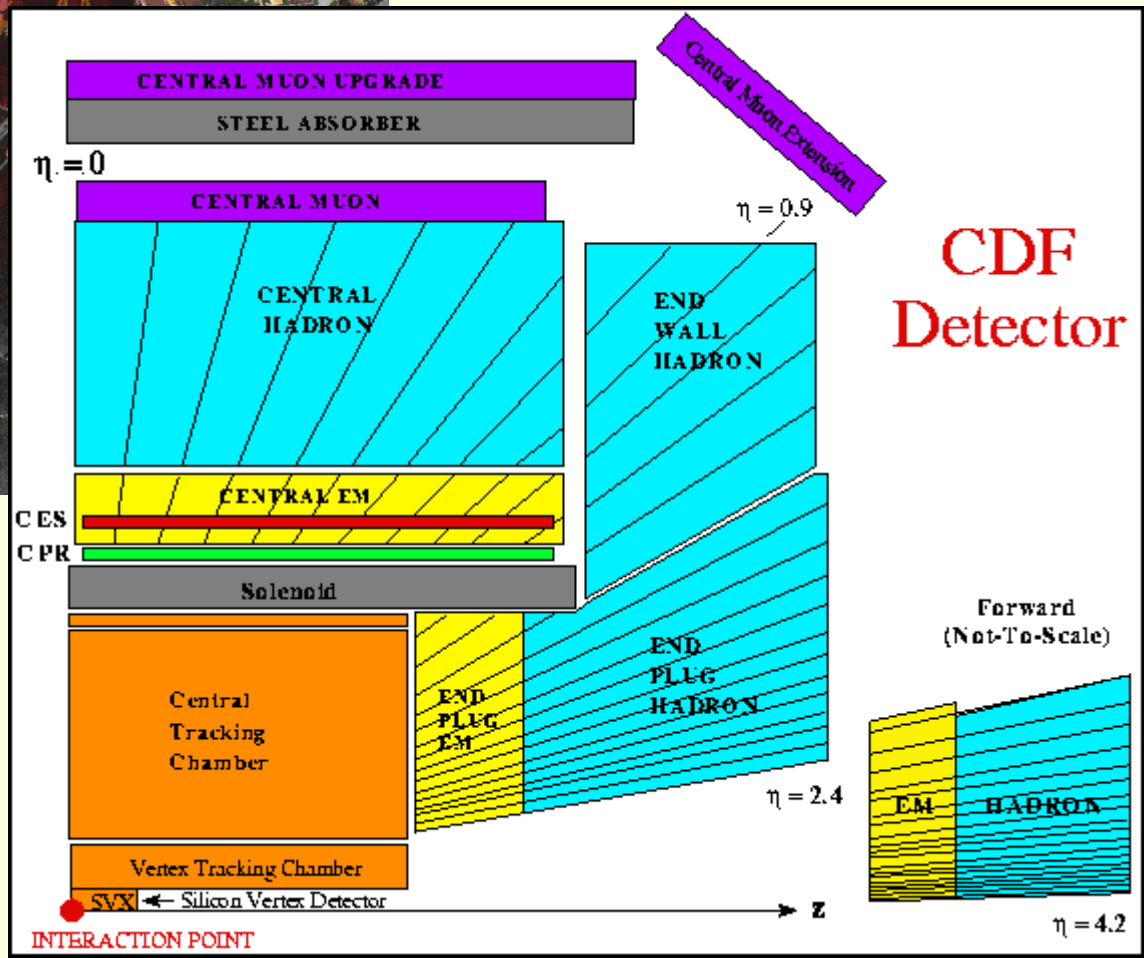
2011.7 Direct Higgs Search
Exclude M_H of
156GeV-177GeV





CDF検出器 （RUN Ⅰとそれ以前 ～1996）





日本グループの測定器製作運転への貢献
RUNI(1992～1996)以前

- **Superconducting Solenoid Coil**
- PEM
  Resistive Plastic Tube Chamber + Pb, whole Structure, Readout
- CEM
  Scintillator, WLS shifter
- VTPC
  Readout
-CMUP
  Readout
-DST Production
- Data logger

測定器製作 Detector Construction

Superconducting Solenoid Coil

Superconducting solenoid coil was made at Hitachi company in a collaboration with University of Tsukuba and Fermilab.

People at University of Tsukuba and KEK in front of the CDF detector with a Superconducting solenoid coil installed in 1984.

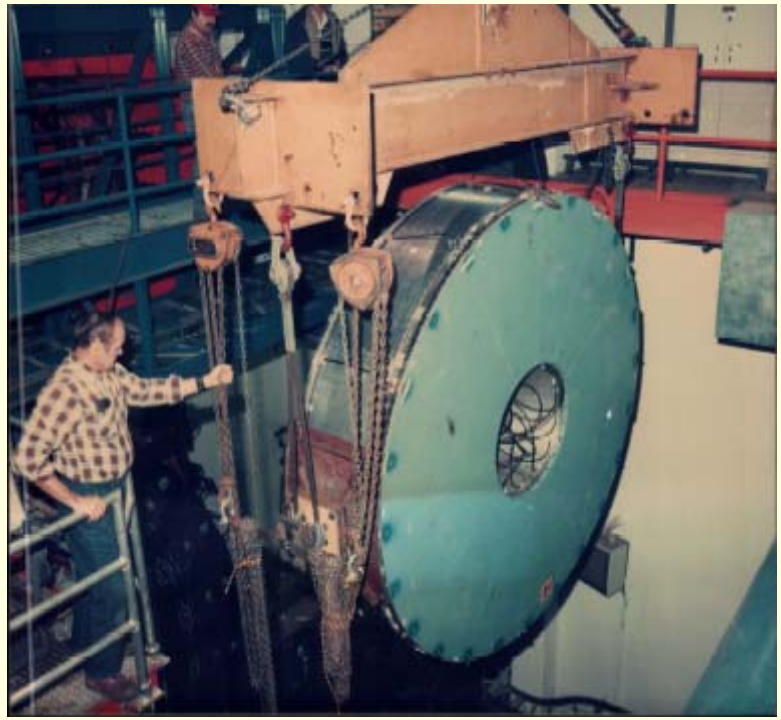
測定器製作 Detector Construction

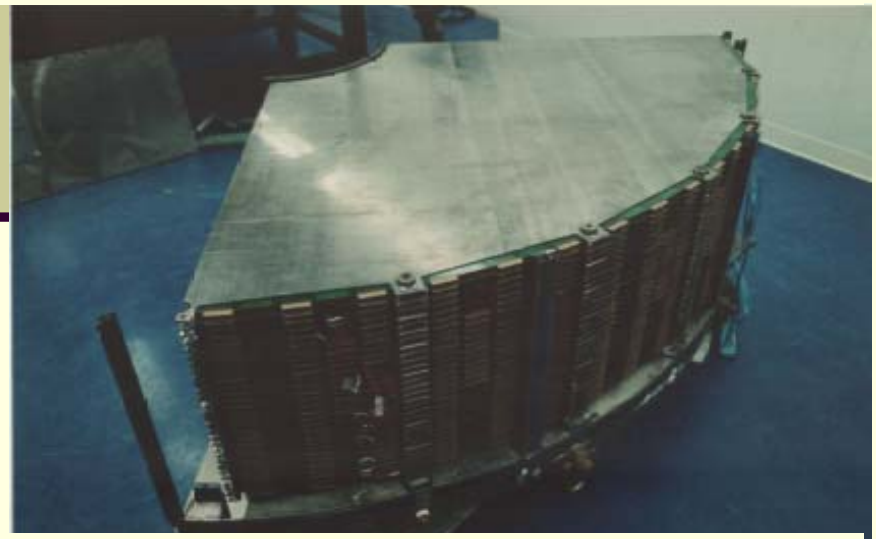
PEM prototype completed in 1983.

Plug ElectroMagnetic Calorimeter (PEM)

The gas proportional chamber with resistive plastic tubes for PEM was developed at Tsukuba.
Testbeam calibration of PEM was done by University of Tsukuba and KEK members.

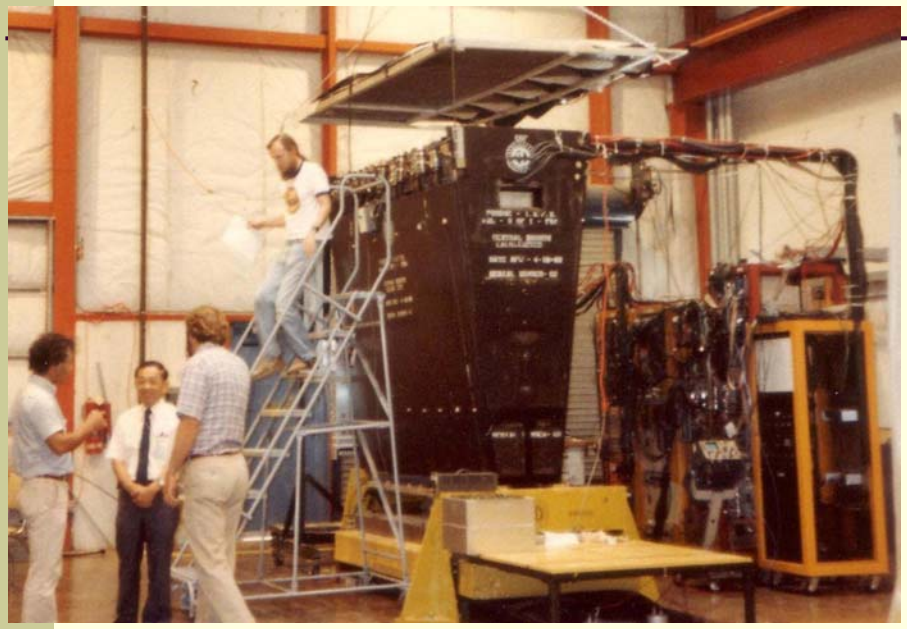
A whole PEM is being installed at B0 assembly hall after the calibration of testbeam in 1986.





A PEM quadrant module.

測定器製作　Detector Construction

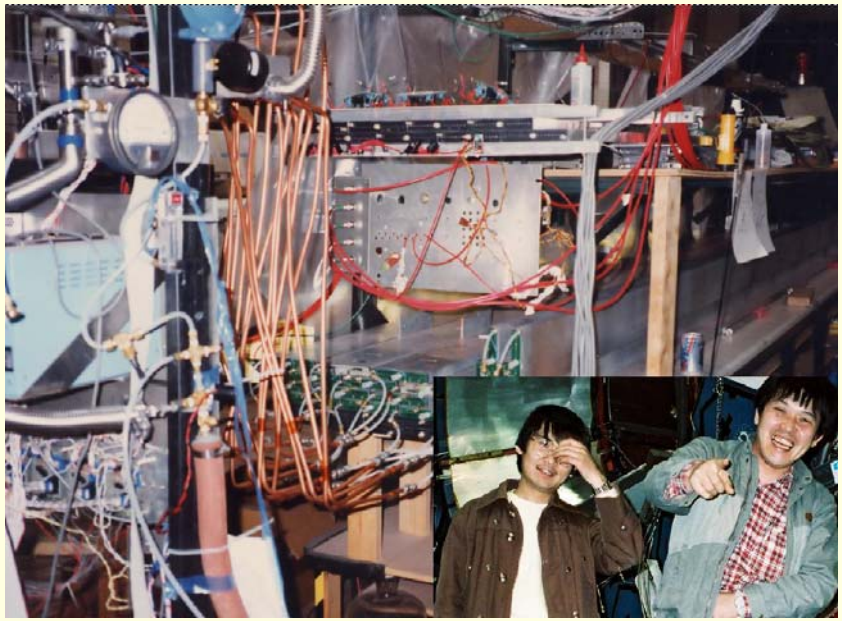


Central ElectroMagnetic Calorimeter (CEM)

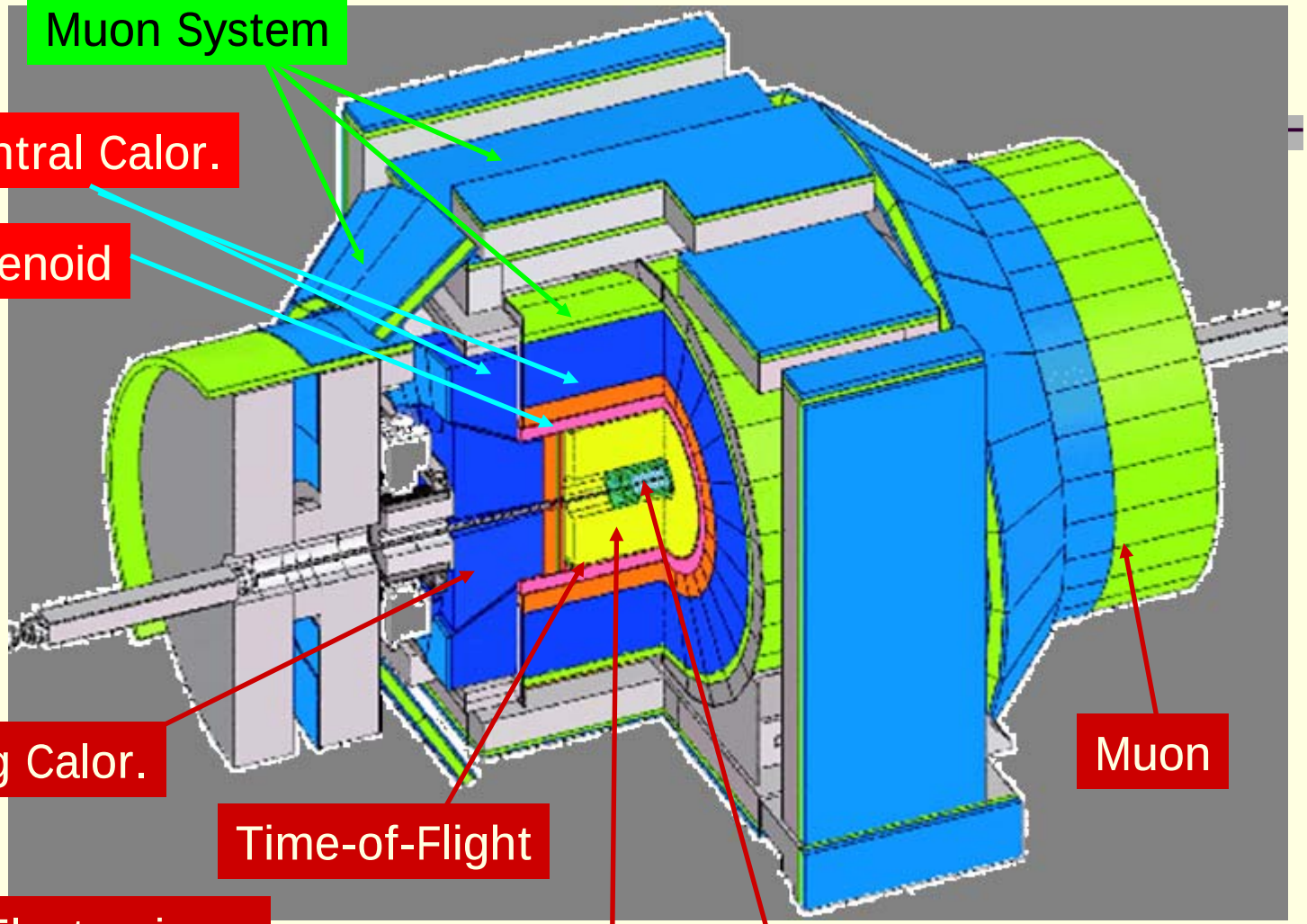
Scintillator and wavelength-shifter were procured and tested in Japan. The assembly of scintillator was done based on the light yield and thickness measured in Japan. University of Tsukuba and KEK worked on the cosmic ray test and testbeam calibration of CEM.

Central Muon chamber Upgrade (CMUP)

Tsukuba group has made the front-end electronics boards for signal readout and HV distribution. The QC system (gas, HV) was designed and brought to U of Illinois.



CDF Ⅱ 測定器　RUN Ⅱ



New

Old

Partially New

Front End Electronics
Triggers / DAQ (pipeline)
Online & Offline Software

日本グループの測定器製作運転への貢献
RUNII（2001～2011)以前

- PEM
  Scintillating Tile/Fiber Unit, Structure
- SVX II
  Silicon sensors
-ISL
  Silicon sensors
- TOF
  Finemesh PMT
- CPR2
  Multianode PMT
- DST Production
- Data logger
- Online monitor

CDF実験の物理成果

CDF実験 高引用数(＞200)論文 (Before Run1)

Run 0

1. Anomalous J/ψ production 570, 223, 301, 346

Measurement of the $J/¥psi$ meson and $b-$hadron production cross sections in $p¥bar{p}$ collisions at $¥sqrt{s} = 1960$ GeV.Phys.Rev.D71:032001,2005. | Cited 570 times RUN2
Production of $J/¥psi$ mesons from $¥chi_c$ meson decays in $p¥bar{p}$ collisions at $¥sqrt{s} = 1.8$ TeV. Phys.Rev.Lett.79:578-583,1997. | Cited 223 times RUN1
$J/¥psi$ and $¥psi(2S)$ production in $p¥bar{p}$ collisions at $¥sqrt{s} = 1.8$ TeV. Phys.Rev.Lett.79:572-577,1997. | Cited 301 times RUN1
Inclusive $J/¥psi$, $¥psi(2S)$ and b quark production in $¥bar{p}p$ collisions at $¥sqrt{s} = 1.8$ TeV. Phys.Rev.Lett.69:3704-3708,1992. | Cited 346 times

2. W boson mass 235, 269, 279

Measurement of the W boson mass. Phys.Rev.D52:4784-4827,1995. | Cited 235 times RUN1
A Measurement of the W boson mass in 1.8 TeV $¥bar{p}p$ collisions. Phys.Rev.D43:2070-2093,1991. | Cited 269 times
A Measurement of the W boson mass.Phys.Rev.Lett.65:2243-2246,1990. | Cited 279 times

3. Three jet events 405

The Topology of three jet events in $¥bar{p}p$ collisions at $¥sqrt{s} = 1.8$ TeV. Phys.Rev.D45:1448-1458,1992. | Cited 405 times

4. Charged particle $dn/d\eta$ 405

Pseudorapidity distributions of charged particles produced in $¥bar{p}p$ interactions at $¥sqrt{s} = 630$ GeV and 1800 GeV. Phys.Rev.D41:2330,1990. | Cited 210 times |

5. Total cross section 287

Measurement of the $¥bar{p}p$ total cross-section at $¥sqrt{s} = 546$ GeV and 1800-GeV. Phys.Rev.D50:5550-5561,1994.| Cited 287 times

6. Top quark search 251

A search for the top quark in the reaction $¥bar{p} p ¥to e + {¥rm jets}$ at $¥sqrt{s} = 1.8$ TeV. Phys. Rev. Lett. 64:142-146,1990. | Cited 251 times

7. Charged particle p_T distribution 210

Transverse momentum distributions of charged particles produced in $¥bar{p}p$ interactions at $¥sqrt{s} = 630$ GeV and 1800 GeV. Phys.Rev.Lett.61:1819,1988. Cited 210 times

CDF実験 高引用数(＞200)論文 (Run1)

Run 1

8. Top Quark Discovery 1902, 660, 810

Observation of top quark production in $¥bar{p}p$ collisions. Phys.Rev.Lett.74:2626-2631,1995. | Cited 1902 times
Evidence for top quark production in $¥bar{p}p$ collisions at $¥sqrt{s} = 1.8$ TeV. Phys.Rev.Lett.73:225-231,1994. | Cited 660 times
Evidence for top quark production in $¥bar{p}p$ collisions at $¥sqrt{s} = 1.8$ TeV. Phys.Rev.D50:2966-3026,1994. | Cited 810 times

9. *Bc* Discovery 215, 203

Observation of the B_c meson in $p¥bar{p}$ collisions at $¥sqrt{s} = 1.8$ TeV. Phys.Rev.Lett.81:2432-2437,1998. | Cited 215 times
Observation of B_c mesons in $p¥bar{p}$ collisions at $¥sqrt{s} = 1.8$ TeV.Phys.Rev.D58:112004,1998. | Cited 203 times

10. Inclusive jet 331

Inclusive jet cross section in ${¥bar p p}$ collisions at $¥sqrt{s}=1.8$ TeV.Phys.Rev.Lett.77:438-443,1996.| Cited 331 times

11. sin 2β 266

A measurement of $¥sin(2¥beta)$ from $B ¥to J/¥psi K^0_S$ with the {CDF} detector. Phys.Rev.D61:072005,2000. | Cited 266 times

CDF実験 高引用数(＞150)論文（ Run2 ）

Run 2

12. *Bs* oscillation 428, 232

Observation of B0(s) - anti-B0(s) Oscillations. Phys.Rev.Lett.97:242003,2006. | Cited 428 times
Measurement of the B^0_{s}-¥bar{B}^0_s Oscillation Frequency. Phys.Rev.Lett.97:062003,2006. | Cited 232 times

13. Top pair production cross section 244

Measurement of the t¥bar{t} production cross section in p¥bar{p} collisions at $¥sqrt{s} = 1.96$ TeV
using lepton + jets events with secondary vertex b-tagging. Phys.Rev.D71:052003,2005. | Cited 244 times

14. X(3872) 391

Observation of the narrow state X(3872) ¥to J/¥psi ¥pi^+ ¥pi^- in ¥bar{p}p collisions at ¥sqrt{s} = 1.96 TeV. Phys.Rev.Lett.93:072001,2004. | Cited 391 times

15. CP violaton in $Bs \to J/\psi\,\phi$ decay 235

First Flavor-Tagged Determination of Bounds on Mixing-Induced CP Violation in B^0_{s} ¥to J/¥psi ¥phi Decays. Phys.Rev.Lett.100:161802,2008. | Cited 235 times

16. Search for $Bs \to \mu\,\mu$ and $Bd \to \mu\,\mu$ and $J/\psi\,\phi$ decay 211

Search for B^0_{s} ¥to ¥mu^{+} ¥mu^{-} and B^0_{d} to mu^{+} ¥mu^{-} decays with 2fb^{-1} of p ¥bar{p} collisions. Phys.Rev.Lett.100:101802,2008. | Cited 211 times

17. ttbar forward-backward asymmetry 185, 154

Evidence for a Mass Dependent Forward-Backward Asymmetry in Top Quark Pair Production. Phys.Rev.D83:112003,2011. | Cited 185 times
Forward-Backward Asymmetry in Top Quark Production in $p¥bar{p}$ Collisions at $sqrt{s}=1.96$ TeV. Phys.Rev.Lett.101:202001,2008. | Cited 154 times

18. Single top production 171

First Observation of Electroweak Single Top Quark Production.Phys.Rev.Lett.103:092002,2009. | Cited 171 times

CDF実験 重要論文（Run2）

Run 2

19. Direct Higgs Search 86, 53

Combination of Tevatron searches for the standard model Higgs boson in the W+W- decay mode.Phys.Rev.Lett.104:061802,2010. | Cited 86 times
Combined CDF and D0 Upper Limits on Standard Model Higgs Boson Production with up to 8.2 fb^{-1} of Data.: arXiv:1103.3233 | Cited 53 times

20. Top Quark Mass 111

Top quark mass measurement using the template method in the lepton + jets channel at CDF II. Phys.Rev.D73:032003,2006.. | Cited 111 times

トップクォークの発見

Preparation for CDF physics analysis in Japan in 1986-1987

Version 1.10

Reviews and Simulations for CDF '86 - '87 Run

59 pages report on simulation study by 15 CDF Japan members for the CDF Engineering Run in 1987.

Contents

Jet reconstruction is crucial for top quark search.

Jet energy scale

CDF/JET/ANAL/CDFR/798

November 11,1988

Inclusive Jet Production Cross Section

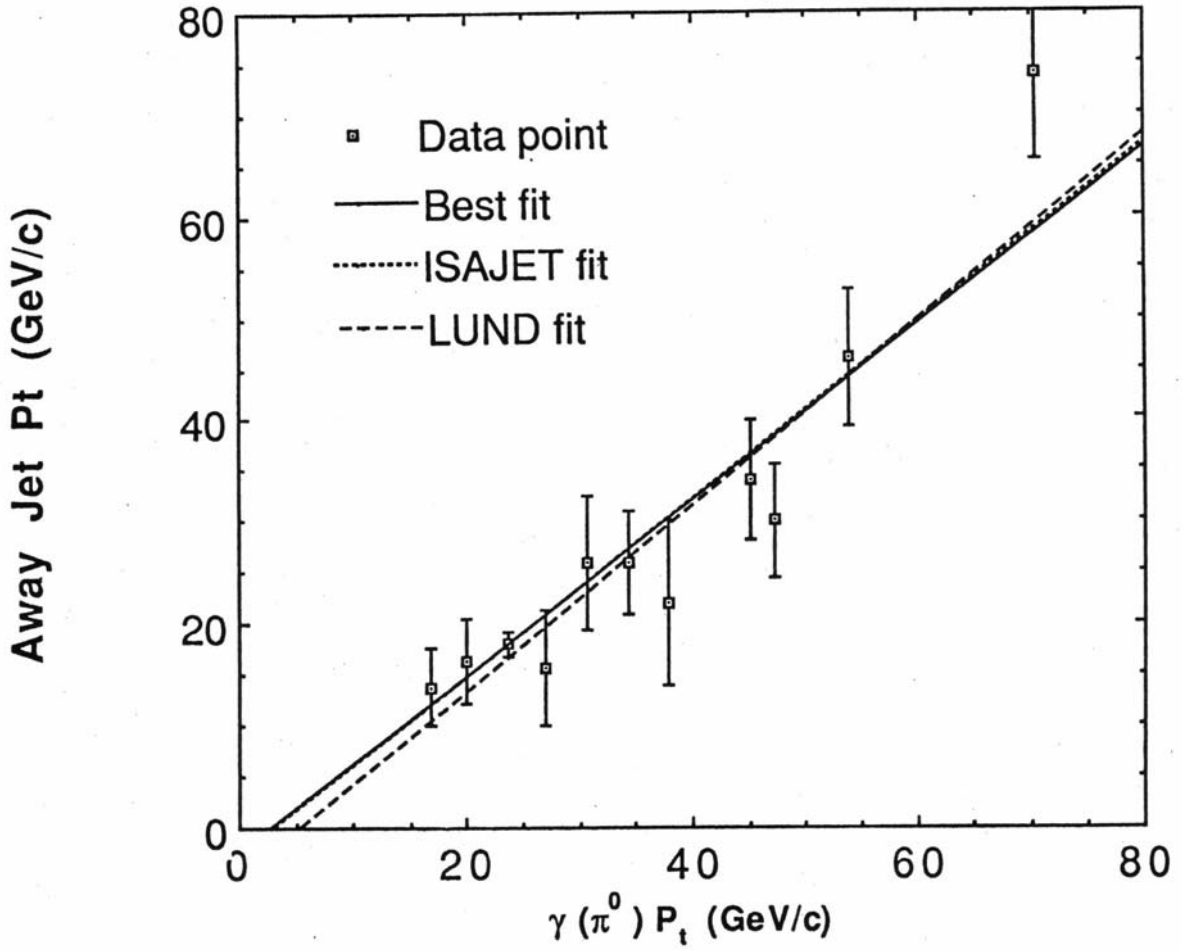
in $\bar{p}p$ collisions at $\sqrt{s}$ = 1.8 TeV

A.Yamashita, S.Kim, K.Kondo, S.Mi

M.Shibata, K.Takikawa and K.Yas

Institute of Physics.
University of Tsukuba
Ibaraki 305, Japan

We showed that we can use γ -jet E_T balancing for the jet energy calibration.



Report on Top Quark Mass Analysis at the CDF Collaboration Meeting

Update on PLR Analyses

(Dilepton and W ($\rightarrow e\nu$ or $\mu\nu$) + $\geq$ 4 jets channels)

July 15, 1993 S. Kim, K.Kondo and R.Oishi

1 DLM Analysis in the dilepton channel

2 KLM Analysis in the W ($\rightarrow e\nu$ or $\mu\nu$) + $\geq$ 4 jets channels

Use Likelihood of only propagator and detector resolution.
Almost the same as the present top mass fitter.

- Parton Level full Reconstruction (PLR)
  - Likelihood Method with the use of Dynamics (DLM)
  - Likelihood Method with Kinematics only (KLM)

4 Summary

- DLM mass distribution of three dilepton top candidates has an average of 155 GeV in Joint Probability.
- We performed KLM analysis on the W ($\longrightarrow \mu$ or e $+\nu$) + $\geq$ 4 jets data in the CDF 92/93 run (integrated luminosity of 20 pb^{-1}). We had an overlapping with two SVX_b_tagging events with a mass around 180 GeV, 10 Cobal-Grassman events with mass from 120 to 180 GeV and 7 Sliwa events with a mass from 120 to 190 GeV.
- KLM mass distribution for W + $\geq$ 4 jets data shows some enhancements around 150 GeV (about 20 events) and 180 GeV (about 7 events). We need more VECBOS W + jets events to estimate the background mass spectra.

SVX b-tag 2 events.
The masses of these two events were consistent with those reported by LBL group in this meeting.

Five months later,

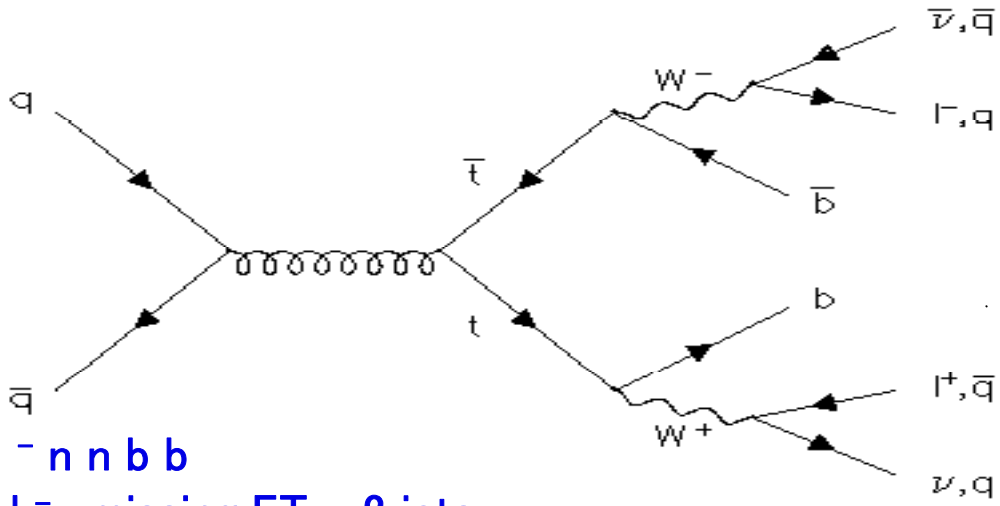
CDF/TOP/PHYS/2401
December 23, 1993
Version 1.0

Comparison of fitting methods on top candidate events

J.Lys, M.Binkley, L.Galtieri, B.Harral, S.Kim, K.Kondo, K.Sliwa, D.Wu

Nine months later, CDF published "Evidence for Top Quark Production".

CDFでのトップクォーク対生成の同定



● Dilepton チャンネル

t t → W⁺ b W⁻ b → l⁺ l⁻ n n b b

事象選別の信号： l⁺, l⁻, missing ET , 2 jets

◎ b tagging は要求しない。

● Lepton + Jets チャンネル

t t → W⁺ b W⁻ b → l± n q' q b b

事象選別の信号： l ±, missing ET , ≧3 jets, b tagging

● Multi-Jets (All Hadronic)チャンネル

t t → W⁺ b W⁻ b → q' q q' q b b

事象選別の信号： ≧5 jets, S ET , b tagging

b tagging:

◎ silicon vertex detector (SVX) で b の崩壊点を検出。

トップクォーク候補事象の一例

e + 4 jet event

40758_44414

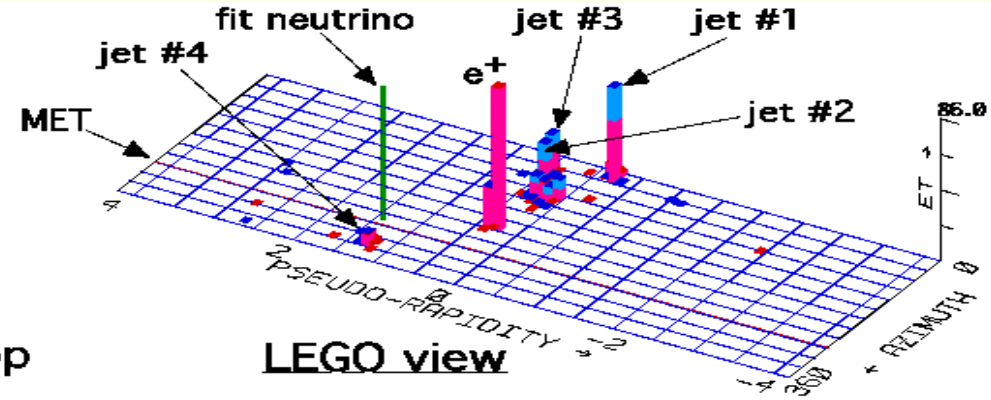
24-September, 1992

TWO jets tagged by SVX

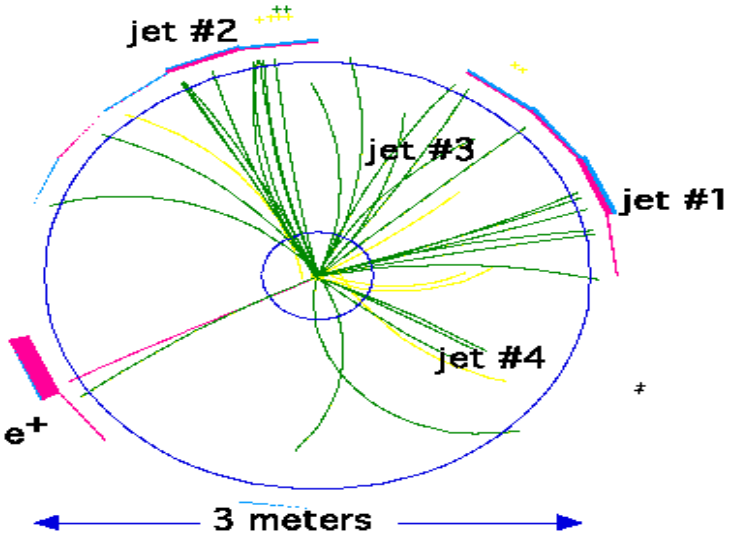
fit top mass is 170 +- 10 GeV

e^+, Missing E_t, jet #4 from top

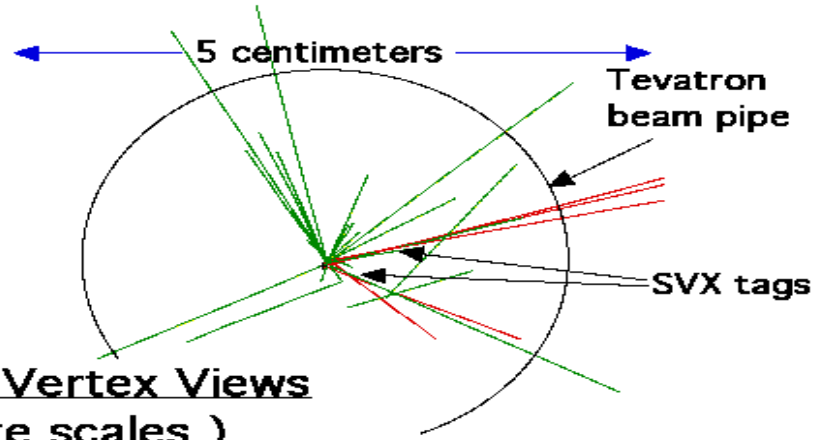
jets 1,2,3 from top (2&3 from W)



LEGO view

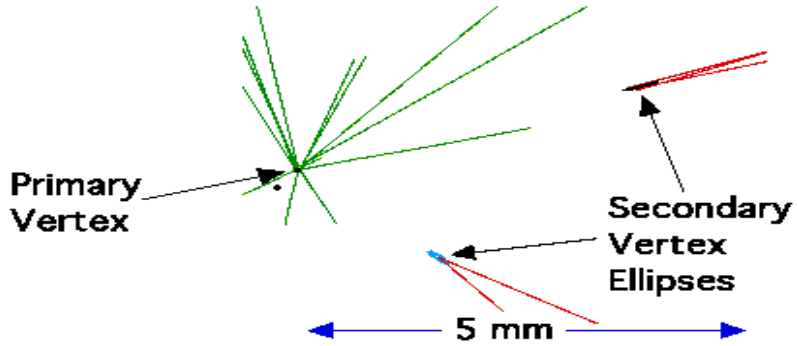


Tracking View

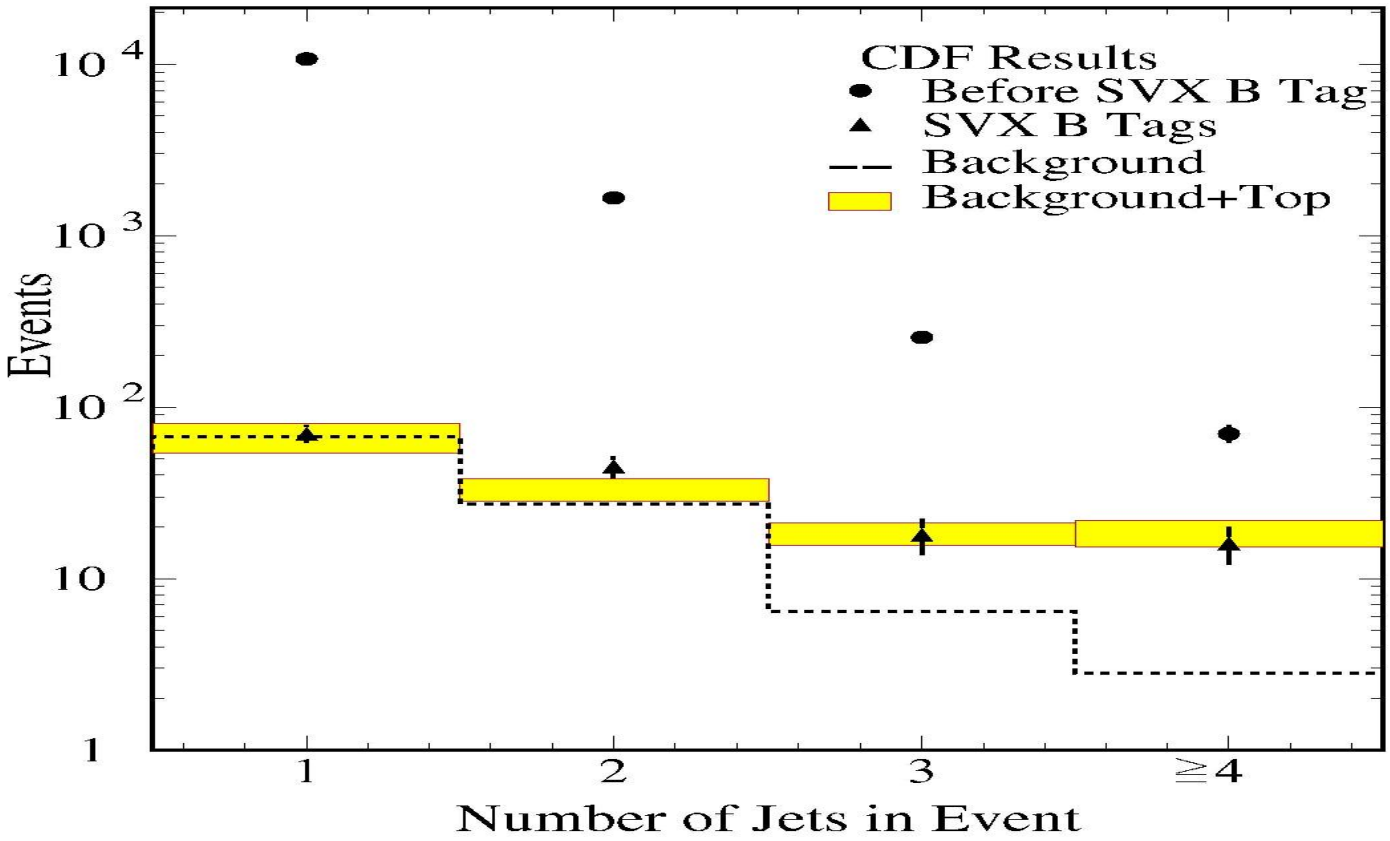


Two Vertex Views

(note scales)



W(→lν)+ジェット事象のジェット数分布



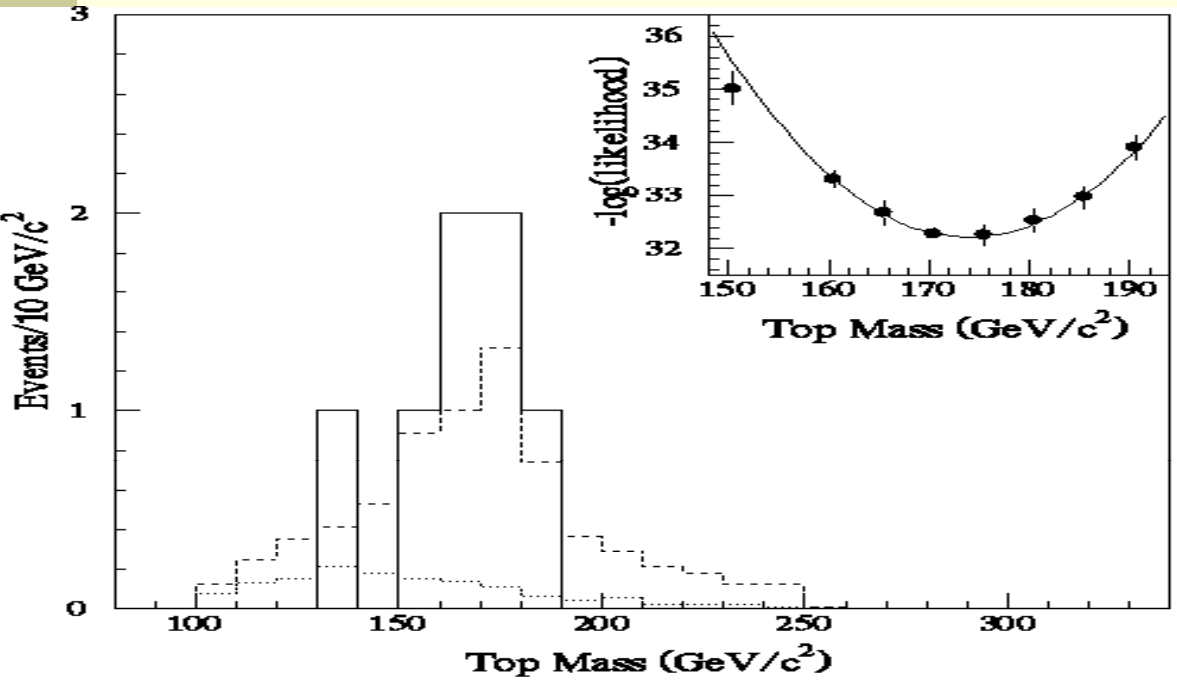
トップクォーク生成の証拠

Run 1A (1992-93, 19 pb-1) の結果　PRL('94); PRD('94)

	観測事象数	bkgd 期待値	統計的有意性
Dilepton	2 events	0.56 +0.25/−0.13	12.0%
SVX	6 tags	2.3 ± 0.3	3.2%
SLT	7 tags	3.1 ± 0.3	4.1%

三つを総合した
統計的有意性:
P = 0.26% (2.8σ)

質量分布(Lepton + 4 jets 事象の再構成)



質量分布から求めた信号の
統計的有意性:
P = 2.0%　(2.3σ)

Countingとmass spectra を
総合した統計的有意性:
P = 0.057%　(3.5σ)

M_{top} = 174 ± 10 (統計) +13/−12(系統) GeV/c²

σ(t t) = 13.9 +6.1/−4.8 pb

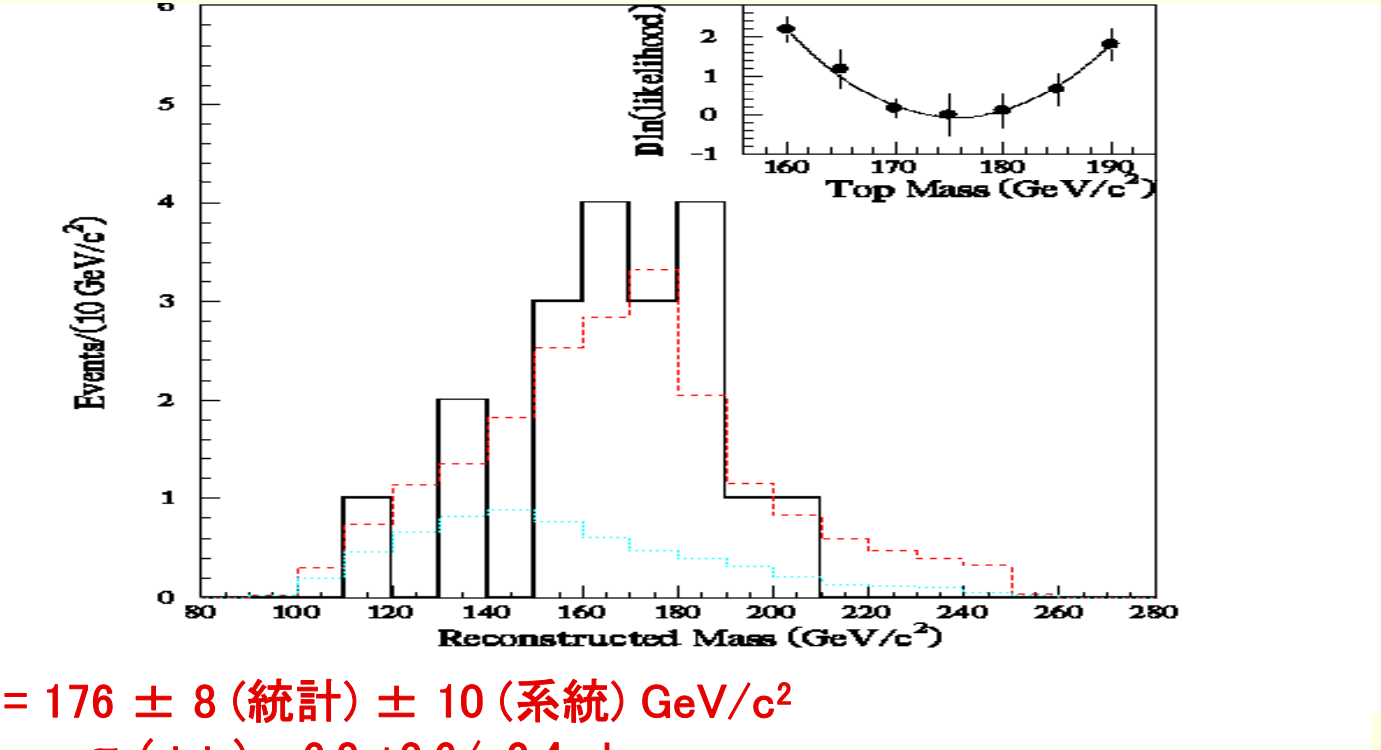
トップクォーク生成の確認

Run 1A +1B ; 67 pb-1 の結果 PRL('95)

	観測事象数	bkgd 期待値	統計的有意性
Dilepton	6 events	1.3 ± 0.3	3×10^{-3} (2.7σ)
SVX	27 tags	6.7 ± 2.1	2×10^{-5} (4.0σ)
SLT	23 tags	15.4 ± 2.0	6×10^{-2} (1.9σ)

三つを総合した統計的有意性：$P = 1\times10^{-6}$(4.8σ)

質量分布(Lepton + 4 jets 事象の再構成)



M_{top} = 176 ± 8 (統計) ± 10 (系統) GeV/c^2

σ(tt) = 6.8 +3.6/−2.4 pb

B_c中間子の発見

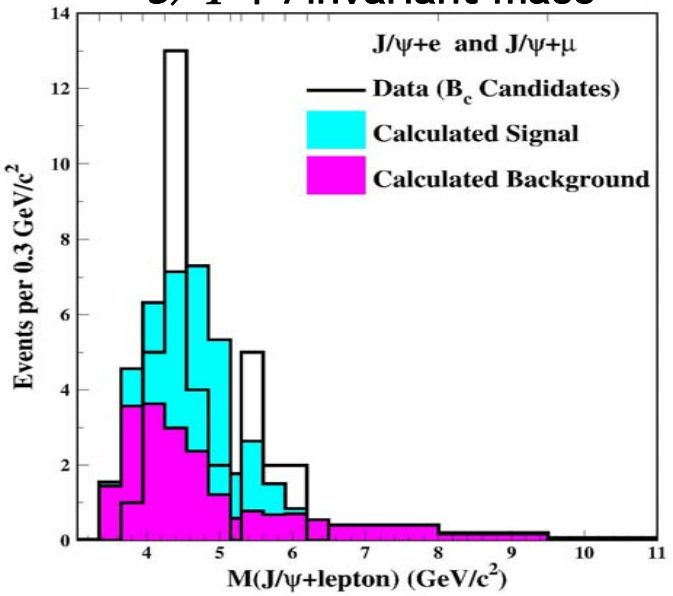
B_s中間子の粒子反粒子振動の初観測

B_c 中間子の発見

CDF RUN I

Observation of B_c meson in $B_c \to J/\Psi l \nu$ decay mode (1998).

J/Ψ+ / invariant mass



$$N(B_c) = 20.4^{+6.2}_{-5.6}$$

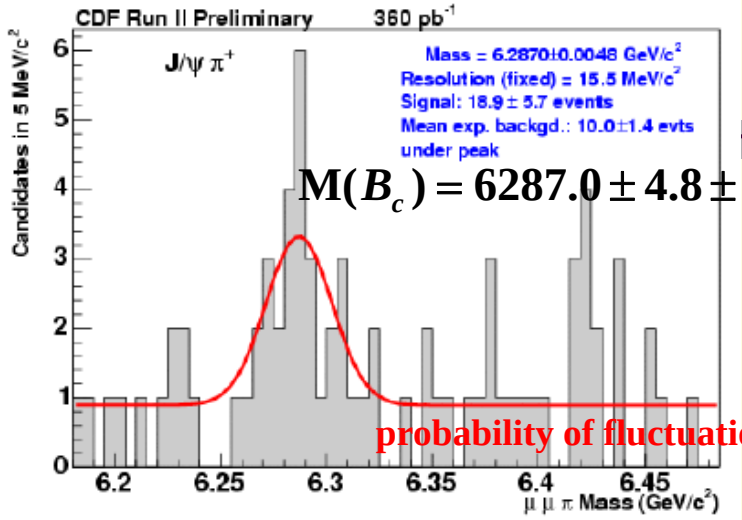
$$\tau(B_c) = 0.46 \pm 0.18\ \text{ps}$$

$$\frac{\sigma(p\bar{p} \to B_c X)BR(B_c \to J/\psi \ell \nu)}{\sigma(p\bar{p} \to B_u X)BR(B_u \to J/\psi K)} = 0.132\ ^{+0.061}_{-0.052}$$

J. Suzuki PhD Thesis (1998)

CDF RUN II

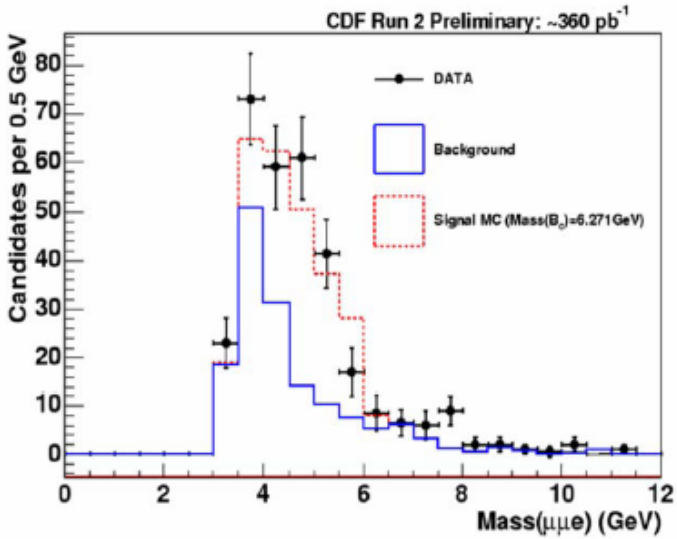
$B_c \to J/\psi \pi$ decay mode



$$M(B_c) = 6287.0 \pm 4.8 \pm 1.1\ \text{MeV/c}^2$$

probability of fluctuation < 0.1%

$B_c \to J/\Psi e \nu$ decay mode



$$\sigma_{ratio}(pT > 4, |y| < 1) = 0.284 \pm 0.040(stat.) \pm 0.043(yield) \pm 0.065(acceptance)$$

M. Aoki, PhD Theses

- This plots assume:

  - flavor tagging:

    add same-side kaon tagging
    $\varepsilon D^2 = 1.6 + 3.0\%$
  - Vertex resolution:

    improved by 20%
  - Trigger bandwidth:

    utilize 50% of CDF data

5 σ observation:

L=2 fb^{-1} : $\Delta m_S < 15\ ps^{-1}$

L=8 fb^{-1} : $\Delta m_S < 22\ ps^{-1}$