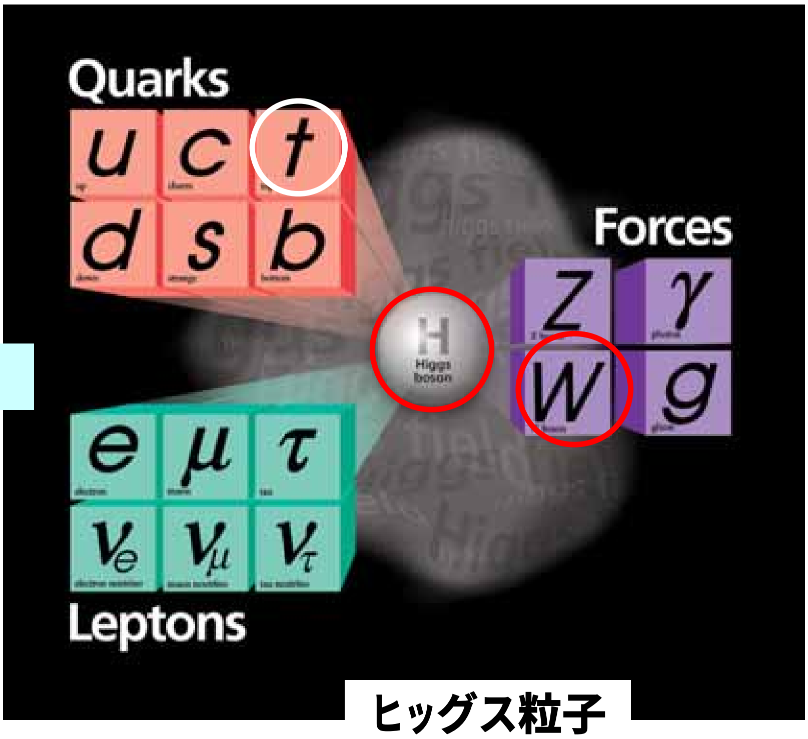
CDF実験の歴史と初期の物理結果

CDF = Collider Detector at Fermilab

TCHoU セミナー
2022年 5月 27日 13:45～
受川 史彦

標準理論における素粒子一覧



クォーク

物質粒子

レプトン

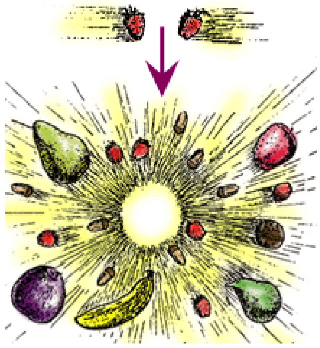
ゲージ粒子

相互作用を媒介

ヒッグス粒子

質量の起源

加速器実験：重心系エネルギー $\sqrt{s}$



$$s \equiv (p_1^\mu + p_2^\mu)^2$$

Collider **とは？**

ビーム・ビーム衝突型加速器

電子・陽電子
陽子・反陽子
陽子・陽子

$(E, \vec{p})$ $\quad\quad$ $(E, -\vec{p})$

$p \longrightarrow \quad \longleftarrow \bar{p}$

$$\sqrt{s} = 2E$$

固定標的実験

$$\sqrt{s} = \sqrt{2mE}$$

ハドロン・ハドロン衝突実験

電子・陽電子衝突型加速器と比べて高いエネルギーを得やすい.

強い相互作用による生成：反応断面積が大きい.

Where	Name	beams	When	$\sqrt{s}$ (GeV)
CERN	ISR	pp	1970's	50
CERN	S$\bar{\text{P}}$PS	$p\bar{p}$	1980's	540 - 630
FNAL	Tevatron	$p\bar{p}$	1985 -	1800 - 2000
CERN	LHC	pp	2009 -	7000 - 14000

歴史を振り返ると重要な役割を果たしてきたことがわかる.
CERN ISR : rising pp cross section
CERN SPS : $W^\pm$ & Z^0 bosonsの発見
Tevatron : top quarkの発見
LHC: Higgsの発見

今後も重要: (HL-)LHC : new physics?

新粒子発見だけではない. 精密測定も可.

Fermi National Accelerator Laboratory

アメリカ合衆国
イリノイ州　Batavia
シカゴの西　約 50 km

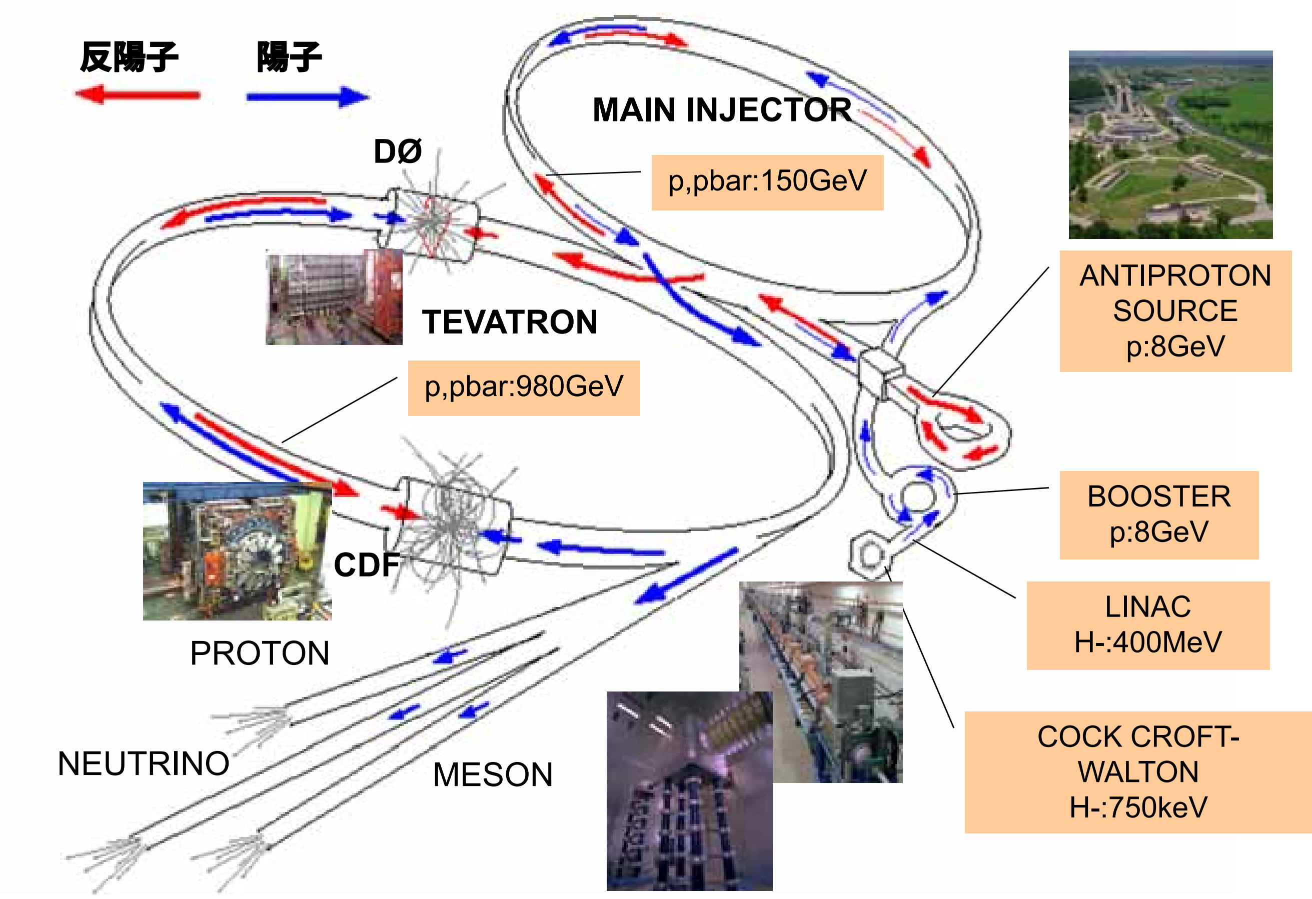
Tevatron 加速器

- **米国フェルミ国立加速器研究所　(Fermilab)**
  イリノイ州シカゴ郊外
- **陽子 (・反陽子衝突型) 加速器**
- **ビームエネルギー 900 → 980 GeV**
- **重心系エネルギー 1800 → 1960 GeV = 1.96 TeV**
- **Tevatron collider は 1985年より稼動**
- **実験 Run-II は 2001年に開始　(2011年9月に終了)**

歴史：
1970's　400 GeV Main Ring 常伝導
1980's　800 GeV Tevatron 超伝導
1985　collider at $\sqrt{s} = 1.6$ TeV
1987　collider at $\sqrt{s} = 1.8$ TeV
1999　150 GeV Main Injector
2000　collider at $\sqrt{s} = 1.96$ TeV

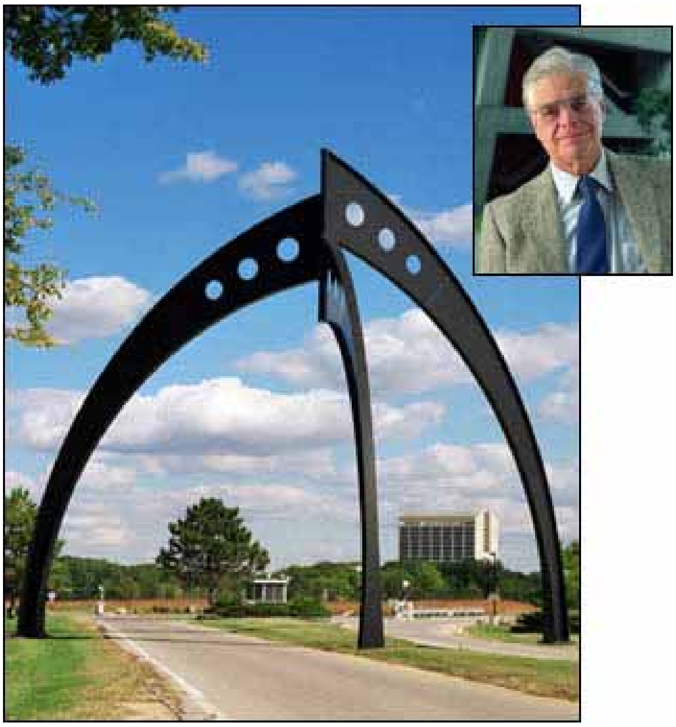
Inside the Tevatron tunnel

加速器チェーン



Wilson Hall 付近　(1999年)

CDF 付近　(1999年)



西側の入り口

Robert R. Wilson (1914 - 2000)
初代所長

Wilson Hall

Buffaloes

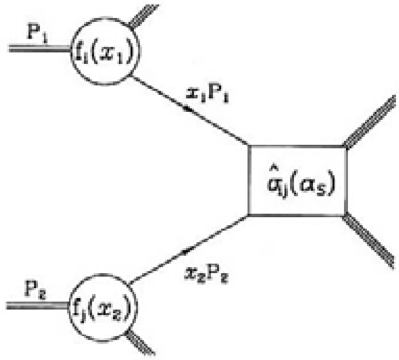
Canadian Geese

ハドロン・ハドロン衝突反応の描像・記述

ハドロン：内部構造を持つ．つまり「素粒子」同士の散乱ではない．
しかし：ハドロンの構成要素は点である ⇔ parton (quarks and gluons)
充分高いエネルギーでの衝突では，partonsは自由粒子としてふるまう
Hard scattering ＝ parton同士の弾性散乱．他のpartonは関与しない．

Factorization：

$$\sigma(P_1,P_2) \;=\; \sum_{i,j}\int dx_1 dx_2\, f_i(x_1,\mu^2)\, f_j(x_2,\mu^2) \times \hat{\sigma}_{ij}(p_1,p_2,\alpha_S(\mu^2),Q^2/\mu^2)$$

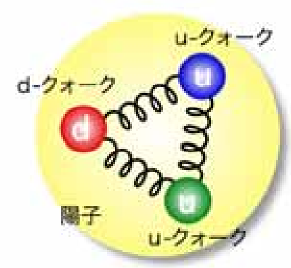


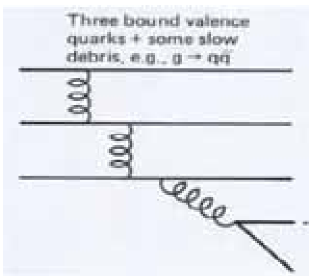
partonの運動量：　$p_1 = x_1P_1,\ p_2 = x_2P_2.$
partonの散乱断面積：　$\hat{\sigma}_{ij}$　($i + j \to$ 何か)
parton分布関数：　$f_i(x,\mu^2)$
parton散乱のエネルギーscale：　Q^2
強い相互作用の結合定数：　$\alpha_S(\mu^2)$

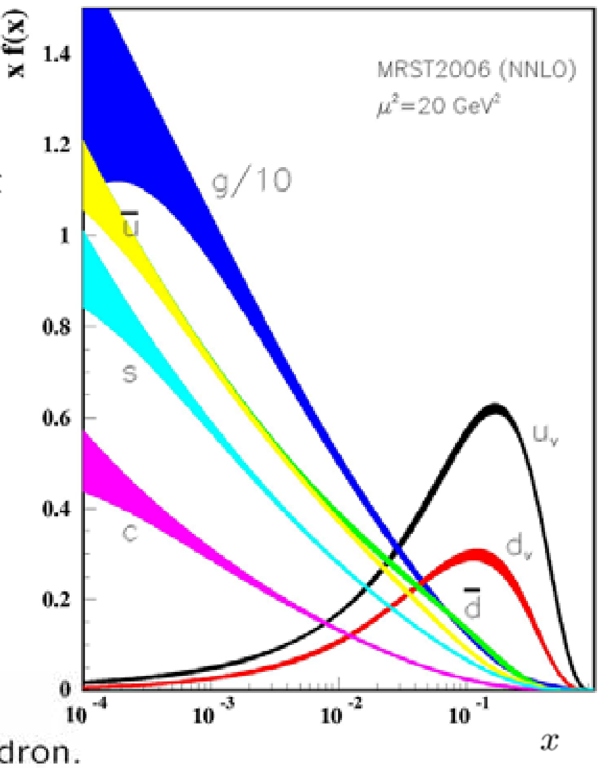
陽子内の parton 分布

x：　partonの持つ運動量 / 陽子の運動量
$f(x)$：　運動量xPを持つpartonの数の分布

$$\sum_i \int_0^1 x\, f_i(x)\, dx = 1$$







valence quarks：$p = uud$による．

gluons:binds valence quarks to form a hadron.

sea quarks：$g \to q\bar{q}$

$f(x) \to f(x,\mu^2)$

small xではgluonがdominant.

陽子･反陽子衝突における種々の反応

beam energy = 900 GeV, $\sqrt{s} = 1.8$ TeV

Process	およそのσ	rate at 10^{32}	$N_{\mathrm{ev}}/10^7$ s
inel. coll.	50 mb	5 MHz	$+\infty$
jets	1 mb	100 kHz	たくさん
b quarks	10 μb	1 kHz	10^{10}
$W^+ \to \ell^+\nu$	1 nb	0.1 Hz	10^6
top quarks	5 pb	10^{-2} Hz	20 k

瞬間luminosity $\mathcal{L} = 1 \times 10^{32}$ cm^{-2} s^{-1}とした.

luminosity $\mathcal{L}$の定義：

$$\frac{dN}{dt} = \mathcal{L}\,\sigma$$

σ：反応断面積

素粒子反応： 断面積 cross sections

素粒子反応の断面積の単位：

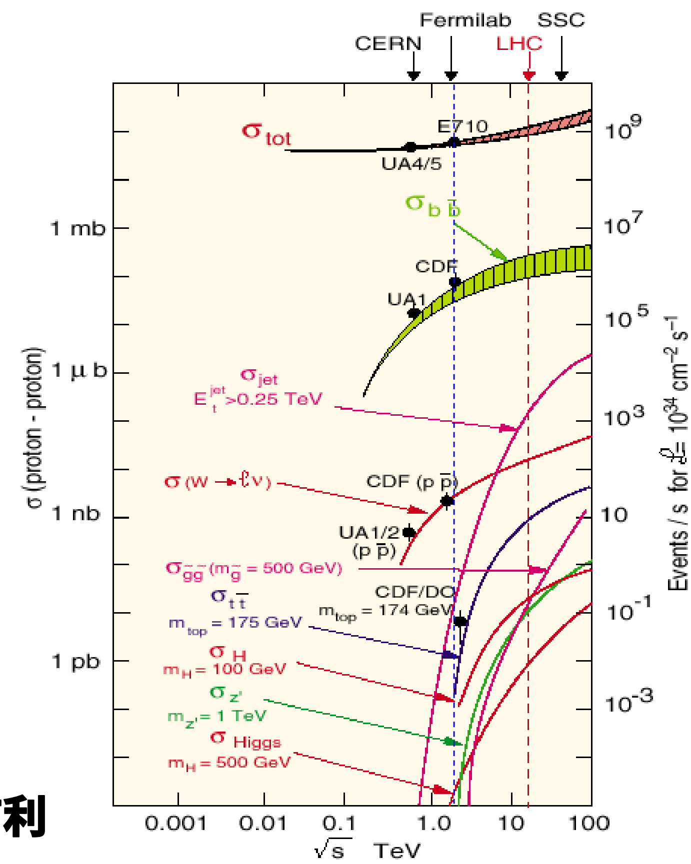
barn (b) $\equiv 10^{-24}$ cm^2

を用いるのが普通

さらに冪乗の補助単位

nano (n) $= 10^{-9}$,

pico (p) $= 10^{-12}$ など



√s とともに増加

特に重い粒子の生成

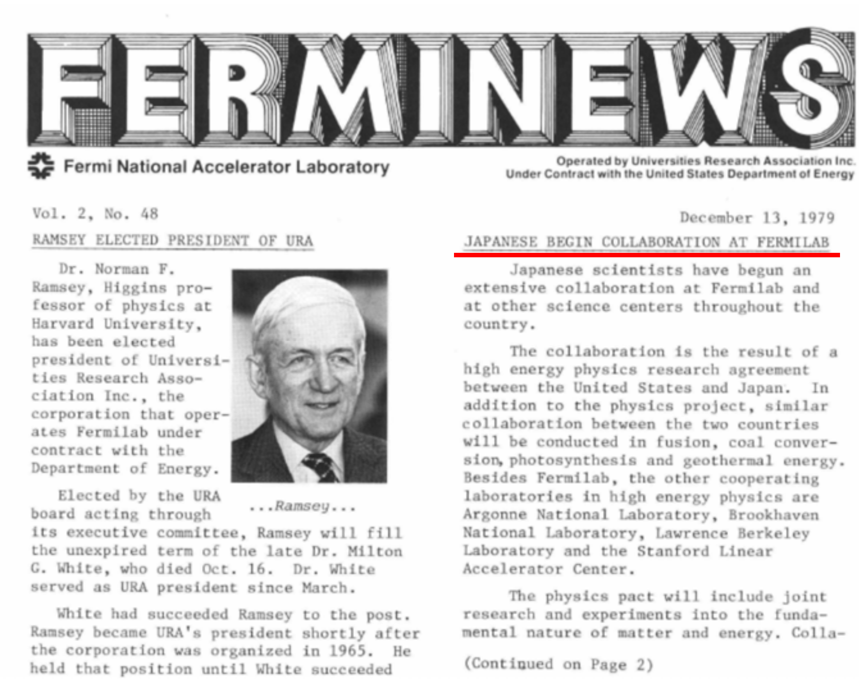
エネルギーが高いほうが有利

Collider Detector at Fermilab : CDF実験と検出器

1979	Collaboration formed
1981	Design Report
1982	CDF建設開始
1985	Central Calorimeters, Vertex TPC
	First collisions, $\sim$ 20 events recorded.
1986	CDF検出器完成.
1987	First run. 25 nb^{-1} (some physics results)
1988 - 89	Physics run. 4.5 pb^{-1}.
1992 - 93	Run Ia. 20 pb^{-1}.
1994 - 96	Run Ib. 90 pb^{-1}.
1996 - 00	Upgrade to CDF Run-II detector.
2001 - 11	Run II. 12 fb^{-1} delivered,
	10 fb^{-1} recorded.

日米科学技術協力事業

- 1970年代 日米貿易摩擦, オイル·ショック
  エネルギー分野での日米連携の開始
  高エネルギー物理学は, エネルギーを産み出すと思われた
  (通訳の誤解？)



FERMINEWS

Fermi National Accelerator Laboratory

Operated by Universities Research Association Inc.
Under Contract with the United States Department of Energy

Vol. 2, No. 48

December 13, 1979

RAMSEY ELECTED PRESIDENT OF URA

Dr. Norman F. Ramsey, Higgins professor of physics at Harvard University, has been elected president of Universities Research Association Inc., the corporation that operates Fermilab under contract with the Department of Energy.

...Ramsey...

Elected by the URA board acting through its executive committee, Ramsey will fill the unexpired term of the late Dr. Milton G. White, who died Oct. 16. Dr. White served as URA president since March.

White had succeeded Ramsey to the post. Ramsey became URA's president shortly after the corporation was organized in 1965. He held that position until White succeeded

JAPANESE BEGIN COLLABORATION AT FERMILAB

Japanese scientists have begun an extensive collaboration at Fermilab and at other science centers throughout the country.

The collaboration is the result of a high energy physics research agreement between the United States and Japan. In addition to the physics project, similar collaboration between the two countries will be conducted in fusion, coal conversion, photosynthesis and geothermal energy. Besides Fermilab, the other cooperating laboratories in high energy physics are Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley Laboratory and the Stanford Linear Accelerator Center.

The physics pact will include joint research and experiments into the fundamental nature of matter and energy. Colla-

(Continued on Page 2)

近藤都登先生

...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...

DESIGN REPORT

FOR THE

FERMILAB COLLIDER DETECTOR FACILITY

(CDF)

AUGUST, 1981

August, 1981

DESIGN REPORT

For the Fermilab Collider Detector Facility (CDF)

Argonne National Laboratory - D. Ayres, R. Diebold, E. May, B. Musgrave, L. Nodulman, J. Sauer, R. Wagner, A.B. Wicklund

University of Chicago - H. Frisch, C. Grosso-Pilcher, M. Shochet

Fermi National Accelerator Laboratory - M. Atac, F. Bedeschi, A. Brenner, T. Collins, T. Droege, J. Elias, J. Freeman, I. Gaines, J. Grimson, D. Gross, D. Hanssen, H. Jensen, R. Kadel, H. Kautzky, R. Kephart, M. Ono, R. Thatcher, D. Theriot, A. Tollestrup, R. Yamada, J. Yoh

Laboratori Nazionali dell' INFN - Frascati - S. Bertolucci, M. Cordelli, P. Giromini, P. Sermoneta

Harvard University - G. Brandenburg, R. Schwitters

University of Illinois - G. Ascoli, B. Eisenstein, L. Holloway, U. Kruse

KEK - S. Inaba, M. Mishina, K. Ogawa, F. Takasaki, Y. Watase

Lawrence Berkeley Laboratory - W. Carithers, W. Chinowsky, R. Kelly, K. Shinsky

University of Pisa - G. Bellettini, R. Bertani, L. Bosisio, C. Bradaschia, R. DelFabbro, E. Focardi, M.A. Giorgi, A. Menzione, L. Ristori, A. Scribano, G. Tonelli

Purdue University - V. Barnes, R.S. Christian, C. Davis, A.F. Garfinkel, A. Laasanen

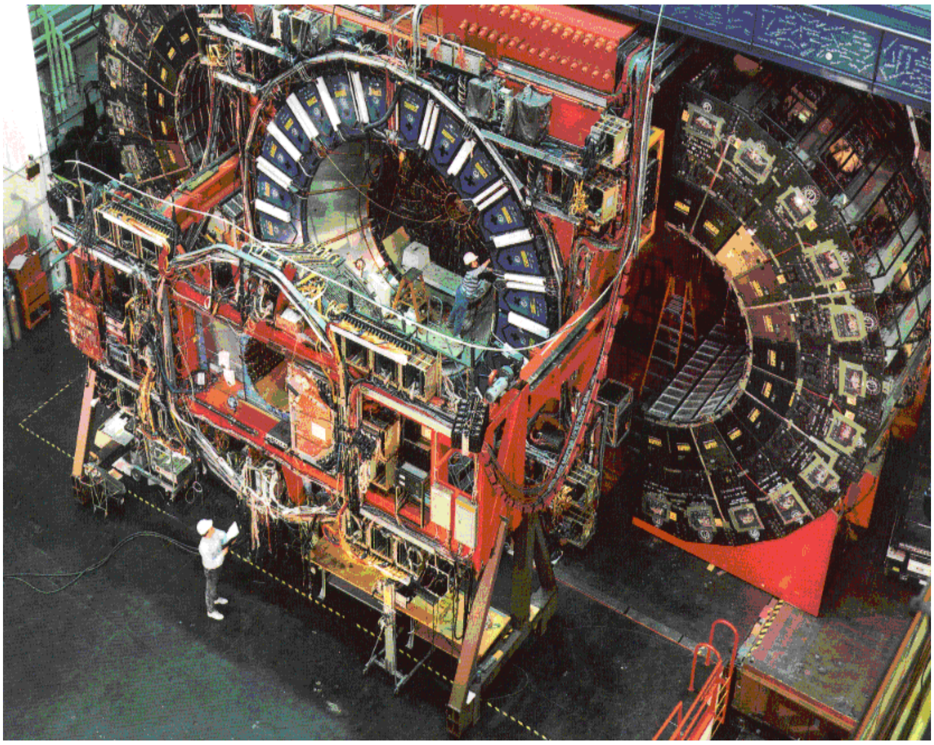
Texas A & M - P. McIntyre, T. Meyer, R. Webb

Tsukuba University - Y. Asano, S. Kim, K. Kondo, S. Miyashita, H. Miyata, S. Mori, I. Nakano, Y. Takaiwa, K. Takikawa, Y. Yasu

University of Wisconsin - D. Cline, R. Loveless, R. Morse, L. Pondrom, D. Reeder, J. Rhoades, M. Sheaff

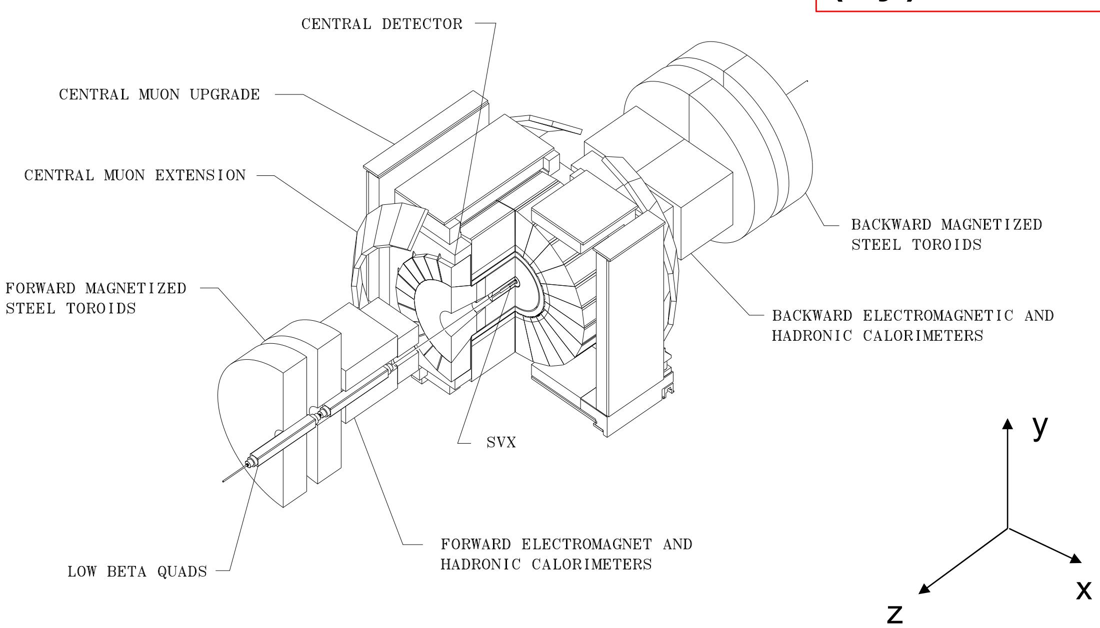
日　　米　　伊

CDF 中央部検出器 (Run-I まで)



CDF Detector (Run-I まで)

座標系：
円筒座標系
ビーム軸： *z* (陽子)
動径 *r*, 角度 θ, ϕ
(*x*,*y*) 平面： "横方向"

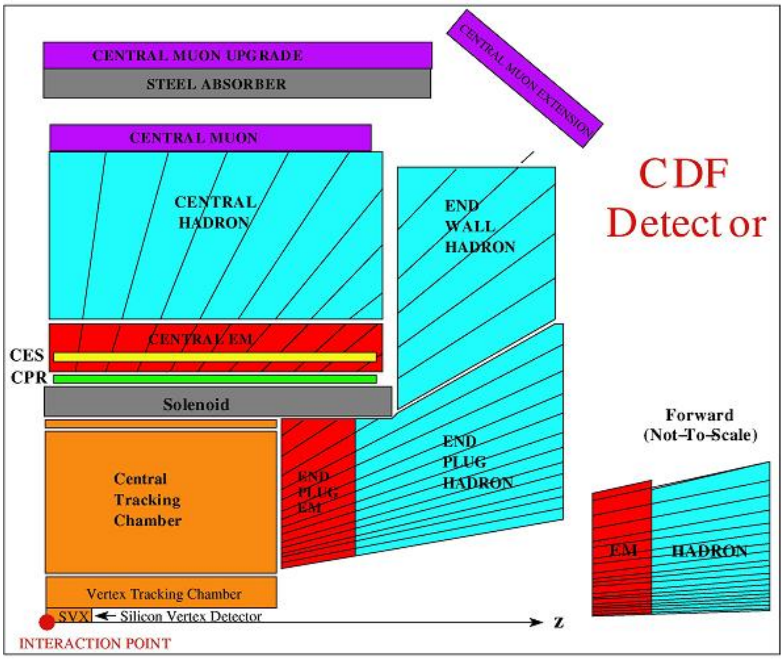


ビーム軸を含む平面 (r,z) での断面図　¼ 部分（第一象限）

- Muon chambers
- Hadron calorimeters
- Electromagnetic calorimeters shower max detector and preshower detector
- Solenoid

日本グループの貢献
（初代検出器）

- 肉薄超伝導ソレノイド
- プラグ部電磁カロリメータ
- シンチレータ, 波長変換板 PMT
- VTPC 読み出しエレキ



- CTC: central tracking chamber
  VTX: vertex tracking chamber (TPC)
  SVX: silicon vertex detector

1981

1982

1982

1982

Sequence of pictures showing progress in the construction of the collider.
1. Before construction.
2. Collision Hall CDF.
3. Central hadron Cal Shell.
4. Wedge, CEM,CHA cal.

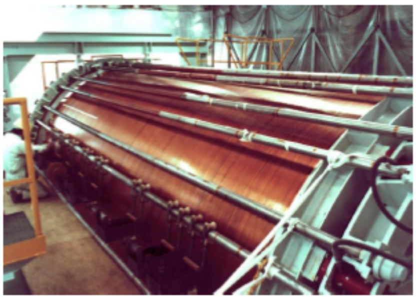
1980年代前半　　現地での日本グループ研究者

金先生　　近藤先生

1.5-Tesla 肉薄 大径 超伝導ソレノイド　　3 m × 5 m

筑波大学 (物理工学系・森茂樹先生), 日立製作所

CDF Solenoid Hitachi 1983



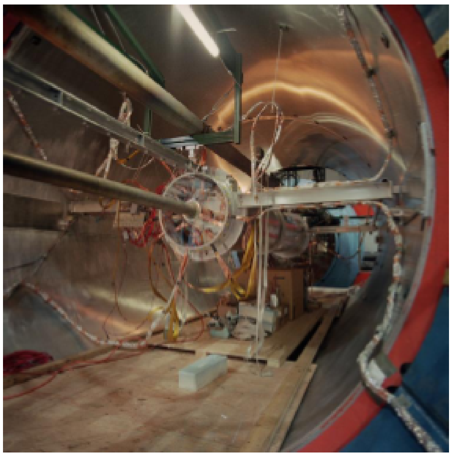
チャーター機で空輸,　CDF 検出器の構造体に設置

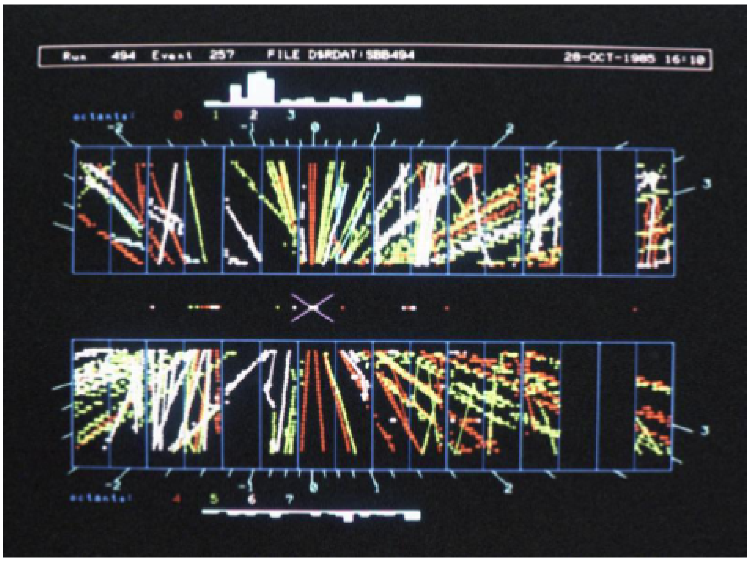
Arrived in 1984!

Coil installed 1984

Yoke and coil 1984

First Collisions: October 13, 1985





“First Collisions” ~20 events!
1987: 29 nb^{-1} . First physics!
88-89: 4 pb^{-1}. W & Z mass, $\sin^2 q_w$
Evidence for top, Start on B physics

Central Tracking Chamber CTC

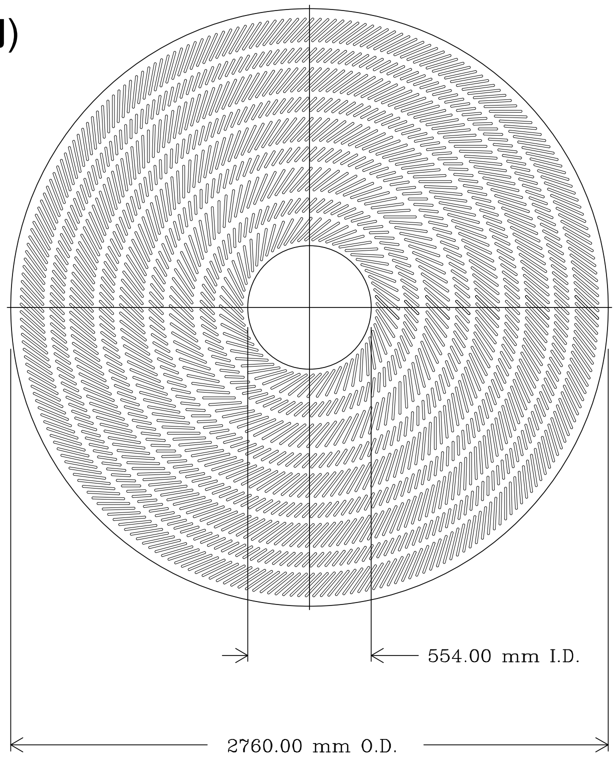
荷電粒子の運動量測定

x-y 平面で円運動　(磁場は z 方向)

- Drift chamber inside 1.4-T solenoid.
- 1.4 m in radius, 3 m in length.
- 84 measurement layers, grouped into 9 "superlayers". Resolution ~ 200 μm.
- 12 × 5 axial layers, 6 × 4 stereo (3°) layers.
- Measures $p_T \equiv p \sin\theta$, with resolution

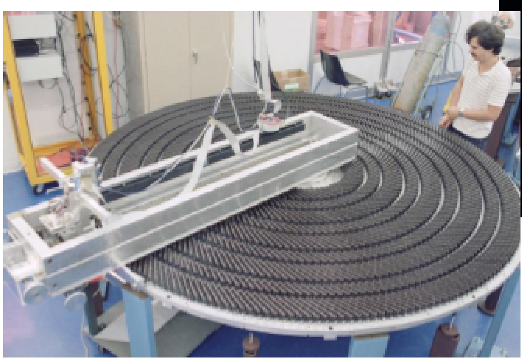
$$\sigma_{p_T}/p_T \simeq 0.001\, p_T$$

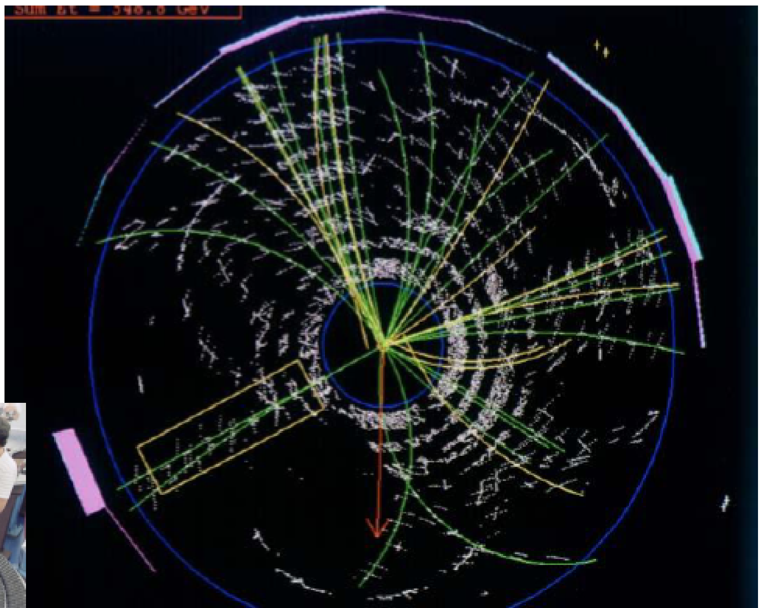
with p_T in units of GeV/c.



CDF Central Tracker

1985





1985

1987

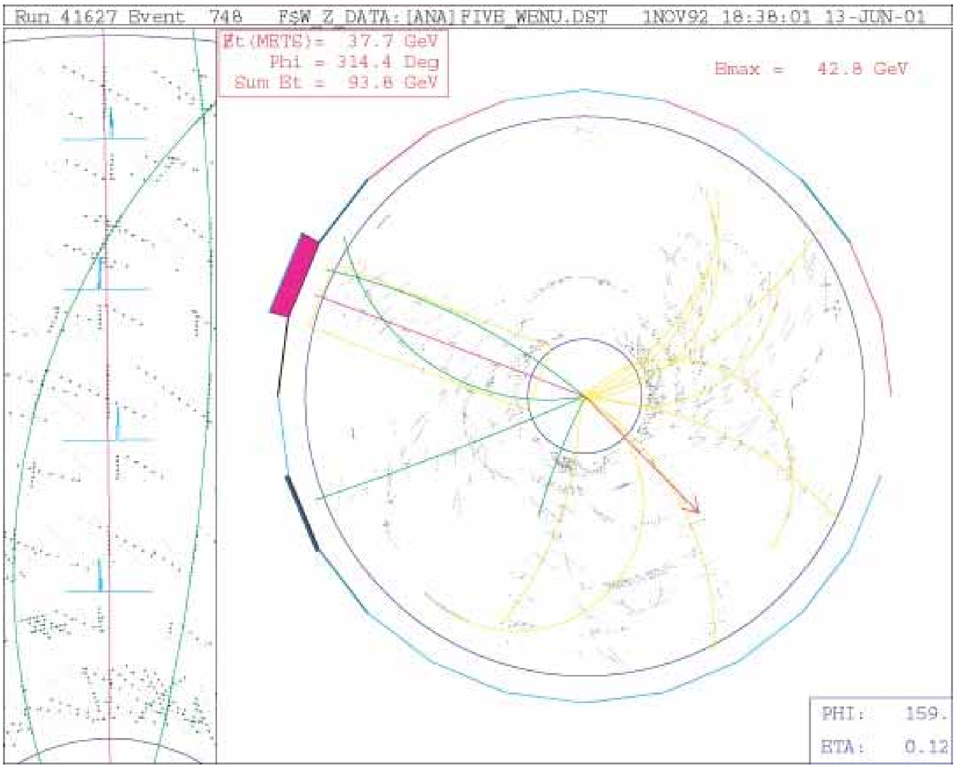
Example of tracking

B = 1.5 T, r < 1.4 m

82 points along the path

Each point ~200 μm

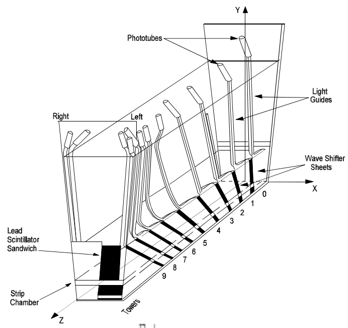
Typical momentum resolution : 0.1%

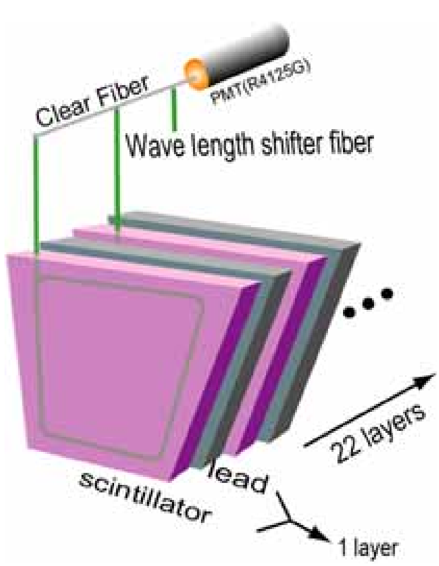


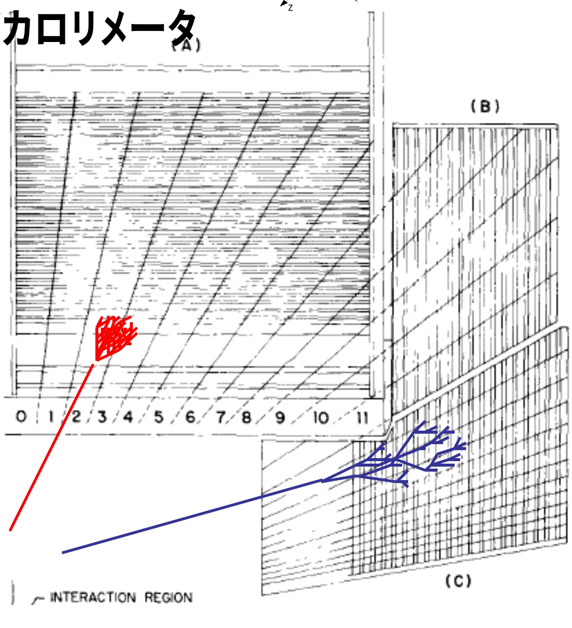
Beams are perpendicular to the picture, collide at the center of the circles

カロリメータ

- **電磁カロリメータ**
  - **鉛/シンチレータのサンプリングカロリメータ**
- **ハドロンカロリメータ**
  - **鉄/シンチレータのサンプリングカロリメータ**



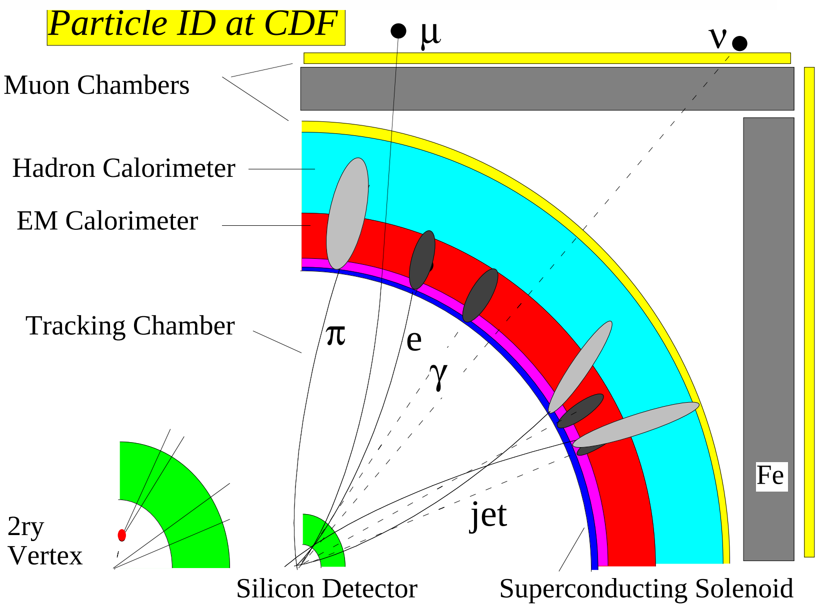




測定するもの

- Charged particle momenta with CTC.
- Electromagnetic and hadronic energies with calorimeters. ($e^{\pm}$, γ, hadrons)
- Detect/identify muons with muon chambers.
- Decay vertices of long-lived particles (e.g. B's) with silicon microstrip detector (SVX).
- Missing transverse energy.

種々の粒子の見え方

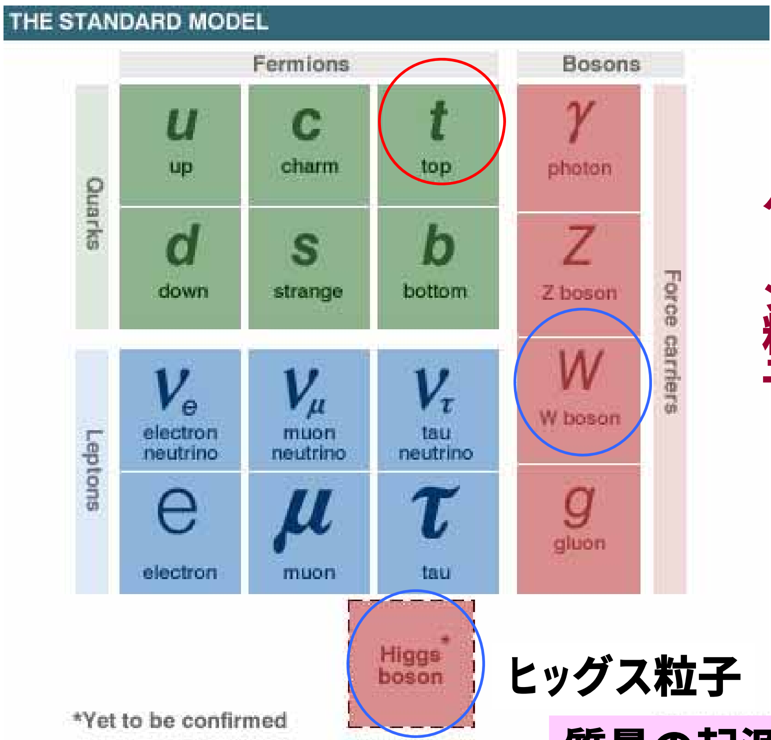


標準理論における素粒子一覧

クォーク

物質粒子

レプトン



ゲージ粒子

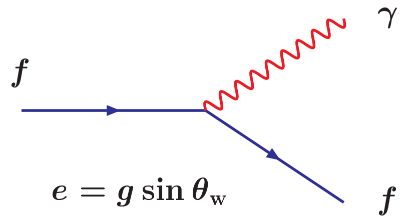
相互作用を媒介

ヒッグス粒子

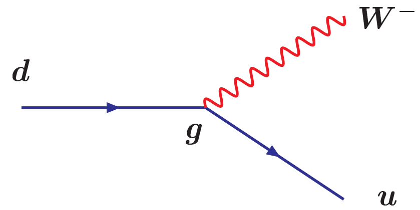
質量の起源

γ, $W^{\pm}$, Z^0 と fermion の結合

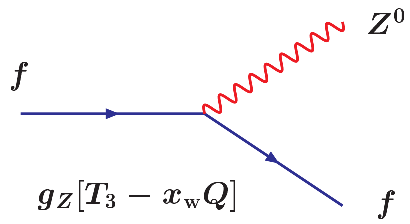
$\mathcal{L}_{\rm em} \sim e\, J^{\mu}_{\rm em}\, A_{\mu}$, $J^{\mu}_{\rm em} = \bar{\psi}\, \gamma^{\mu}\, Q\, \psi$:
Q はcharge operator, 電子の場 ψ に対し $Q\psi = -\psi$.



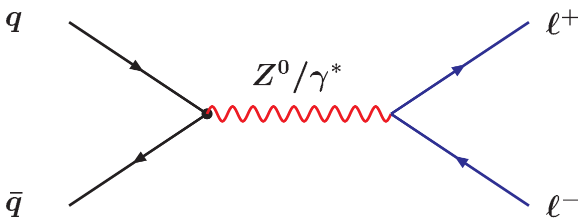
$\mathcal{L}_W \sim g\, W^{\pm}_{\mu}\, \bar{\psi}_{\rm L}\, \gamma^{\mu}\, T^{\pm}\, \psi_{\rm L}$:



$\mathcal{L}_Z \sim g_Z\, Z^0_{\mu}\, \bar{\psi}\, \gamma^{\mu}\, [\, T_3 - x_{\rm W} Q\,]\, \psi$:



Z⁰ の生成, 崩壊 at CDF



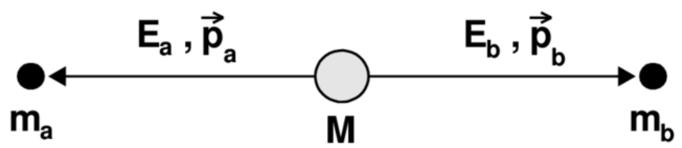
- **クォーク·反クォーク　対消滅**
- **Z^0 の生成**
- **崩壊, 例えば 荷電レプトン対 へ**

再構成

- **終状態のレプトンを2つ捕まえる**
- **運動量/エネルギーの測定**
- **レプトン対の質量を計算**
- **質量分布**

$$M = \sqrt{E^2 - |\vec{P}\,|^2} = \sqrt{\left(\sum_{i=1}^{n} E_i\right)^2 - \left(\sum_{i=1}^{n} \vec{p}_i\right)^2}$$

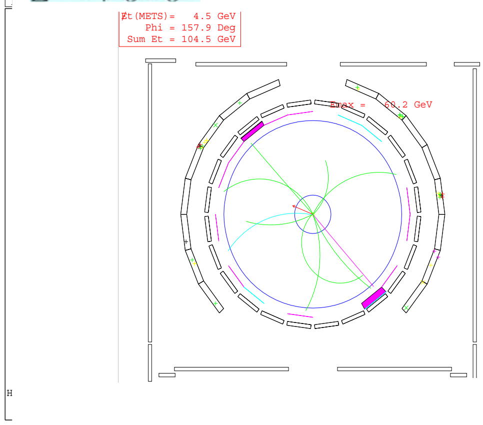
2体崩壊であるので,
親粒子の静止系で考えると:

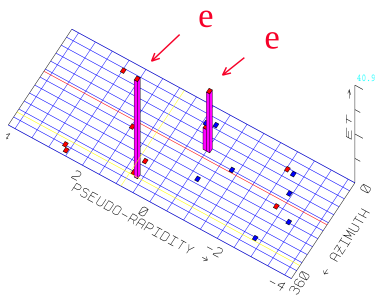


$0 = \vec{p}_a + \vec{p}_b$　　$M = E_a + E_b$

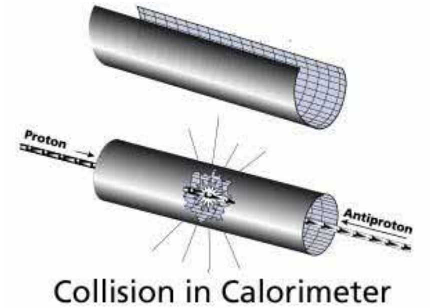
Z→ ee and Z→ μμ Events

$Z^0 \to e^+e^-$

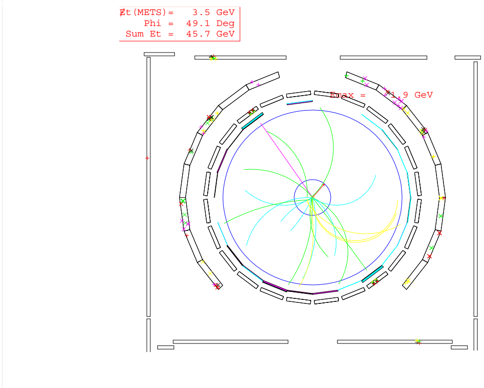


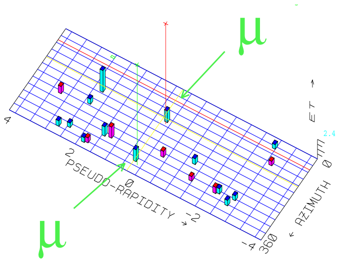


$E_T \cong 44$ and 36 GeV



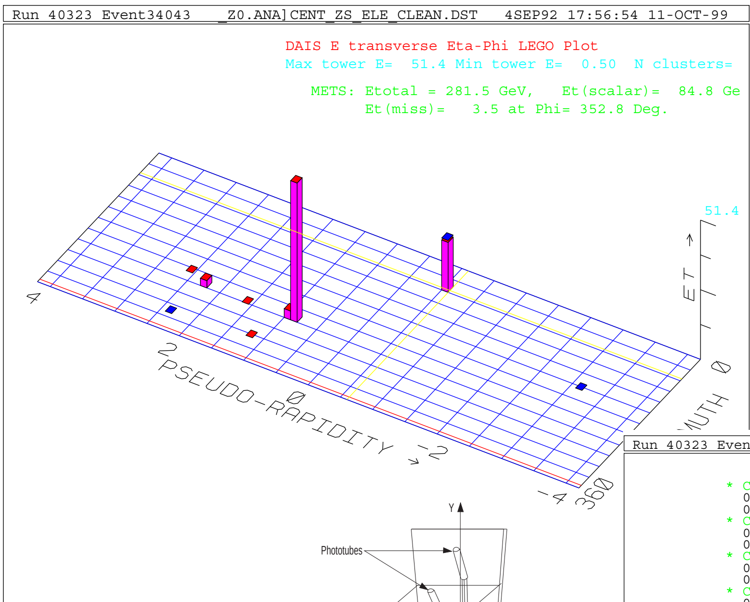
$Z^0 \to \mu^+\mu^-$

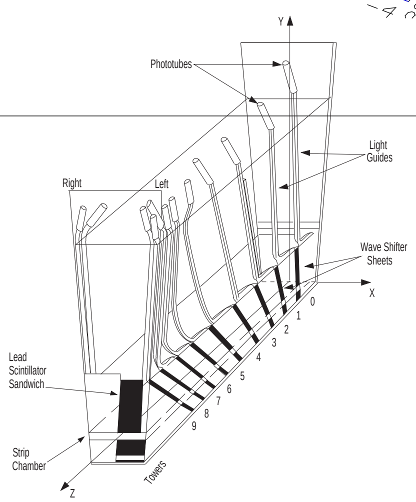


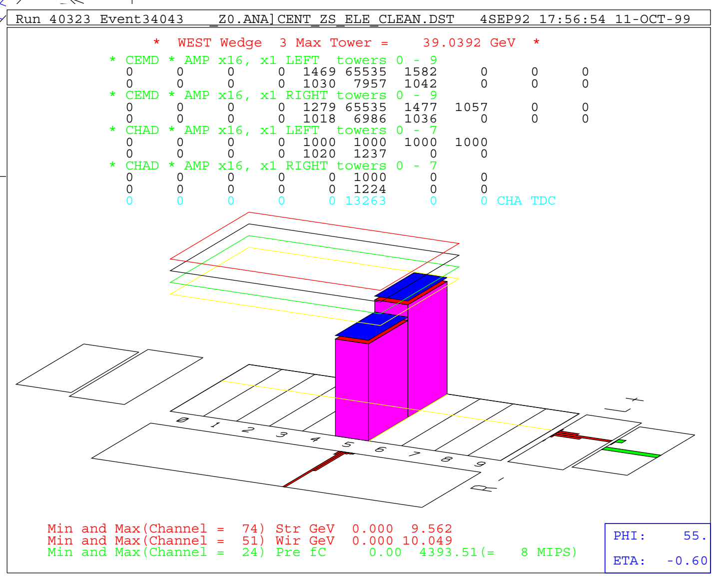


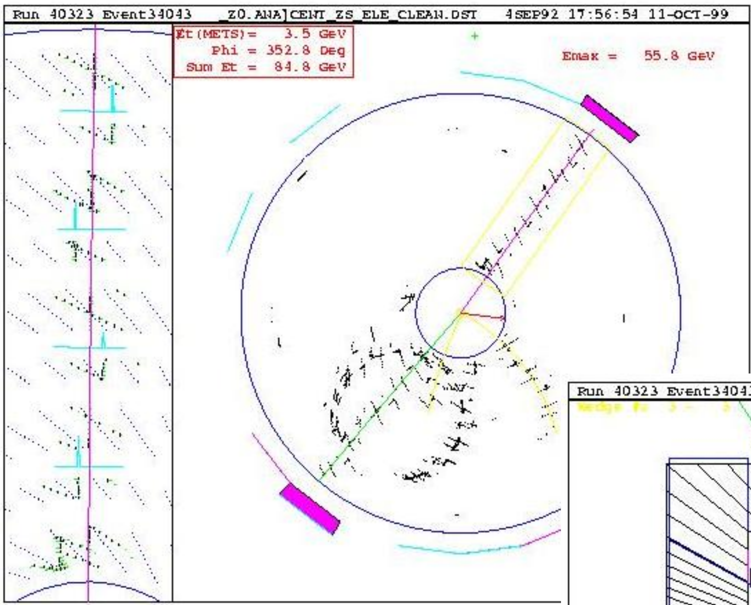
$P_T \cong 50$ and 32 GeV

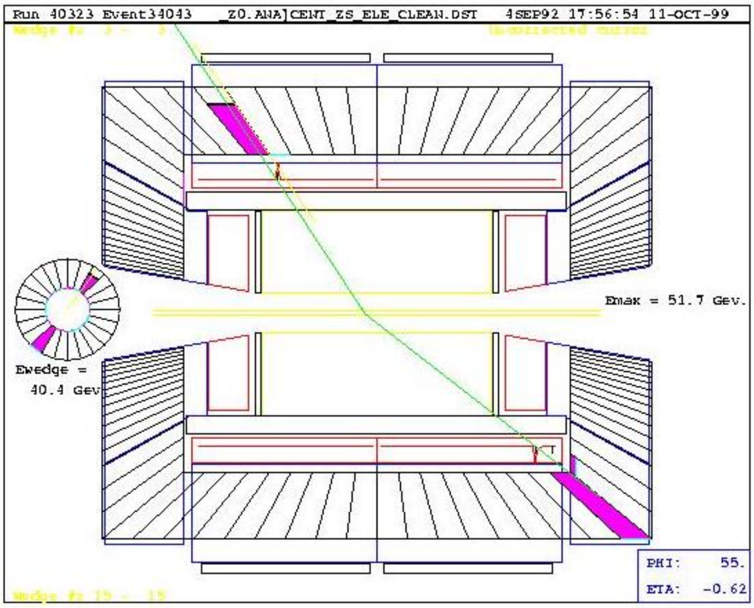
別の $Z^0 \to e^+e^-$ 事象





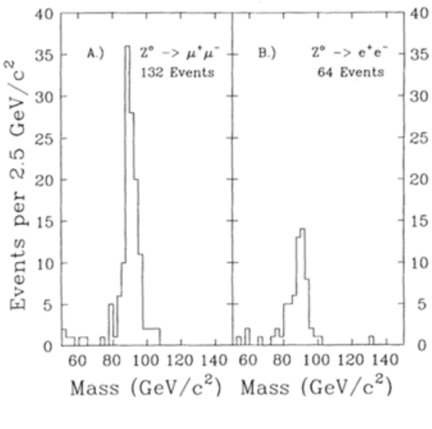




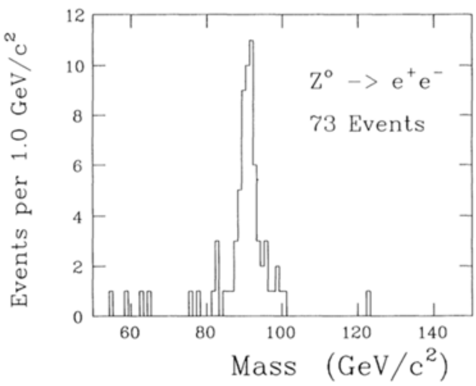


Z^0 の再構成, 質量の測定

$Z^0 \to \mu^+\mu^-$ 運動量測定から



$Z^0 \to e^+e^-$ エネルギー測定から



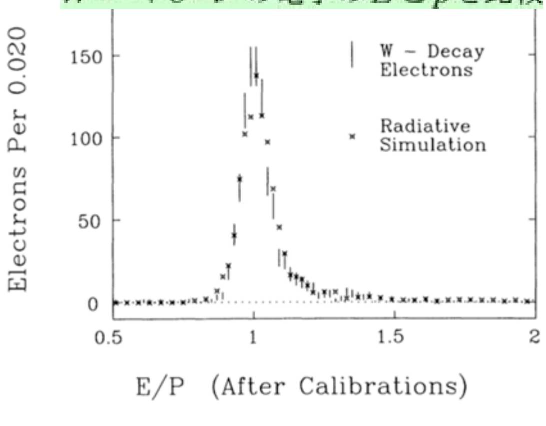
検出器の較正が重要
実データを利用する
calibration *in situ*

既知の粒子を用いて, 運動量を較正

$K^0_S \to \pi^+\pi^-$ $J/\psi \to \mu^+\mu^-$ $\Upsilon \to \mu^+\mu^-$

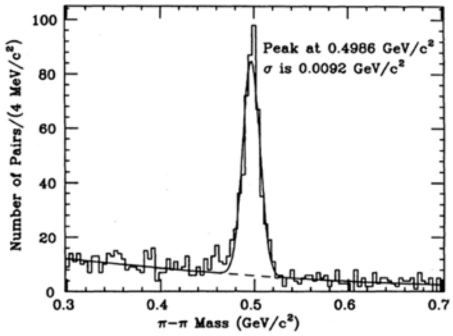
電子の運動量と比較し, エネルギーを較正

$W^\pm \to e^\pm \nu$ の電子の E と p を比較

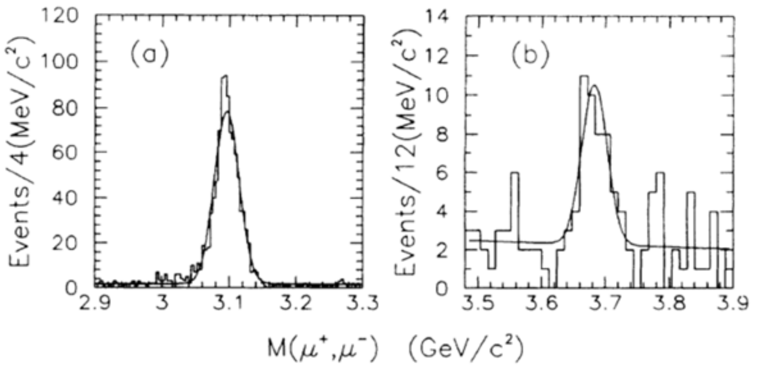


既知の粒子の信号

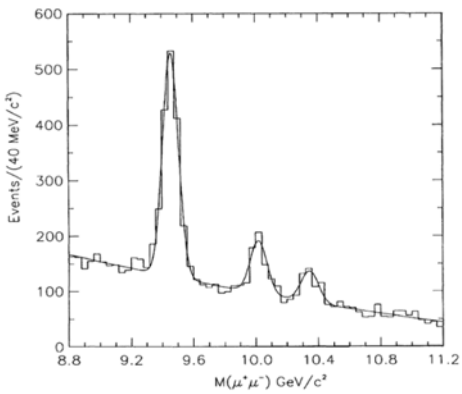
$K_S^0 \to \pi^+\pi^-$



$J/\psi \to \mu^+\mu^-$ $\psi(2S) \to \mu^+\mu^-$



$\Upsilon(1S, 2S, 3S) \to \mu^+\mu^-$



Z^0 の再構成, 質量の測定

1989 年当時の精密測定

$$m_{Z^0} = 90.9 \pm 0.3 \text{ (stat + syst)} \pm 0.2 \text{ (scale)} \quad \text{GeV}/c^2$$

それ以前の精度: 1.5 GeV 程度

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

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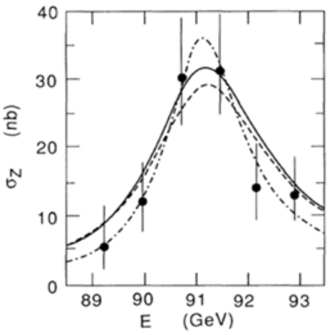
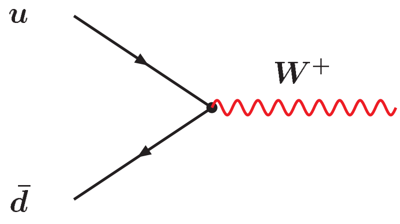
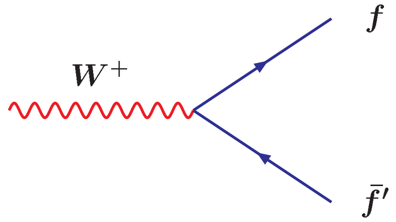
その時の競争相手:
SLAC SLC の Mark II 実験



$W^{\pm}$ bosonの生成・崩壊





崩壊様式：$e^+\nu$, $\mu^+\nu$, $\tau^+\nu$, $u\bar{d}$, $c\bar{s}$.

割合(およそ)： 1　1　1　3　3

$W^{\pm} \to e^{\pm}\nu$,　$W^{\pm} \to \mu^{\pm}\nu$ を用いる

ニュートリノ ν は検出できない

$\Rightarrow$ 運動量保存から推測する

- $\ell^+\nu$ final states clean. $\mathcal{B} \simeq 1/9$.
- How do you detect the neutrino? You don't.
  $\to$ missing transverse energy.
  $$\vec{p}_T^{\,\nu} \equiv \vec{\not{E}}_T \equiv -\sum_i \vec{E}_T^{\,i}$$
  The sum is over all calorimeter towers i.
- In LO, $\vec{p}_T^{\,W} \simeq 0$. Then $\vec{p}_T^{\,\ell} \simeq -\vec{p}_T^{\,\nu}$.

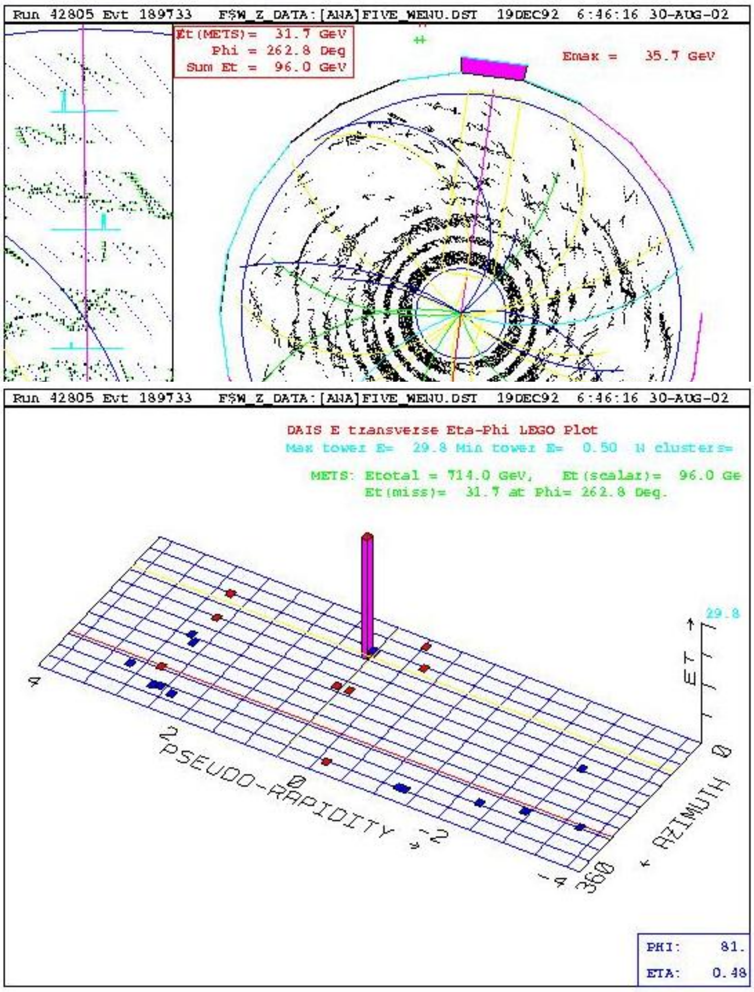
ビーム軸：z とする
Transverse: x-y 平面
始状態：　$p_x = p_y = 0$
終状態：　$p_x = p_y = 0$ のはず

$W \to e\nu$ 候補事象

$\phi \simeq 90°$ に電子（あるいは陽電子）
$E_T = 35.7$ GeV
他に顕著なenergy depositはない

赤い矢印がmissing E_T の方向
ほぼ $\phi \simeq 270°$
大きさ 31.7 GeV

つまり $\vec{p}_T^{\,\ell} \simeq -\vec{p}_T^{\,\nu}$



CDF での $W \to \ell\nu$ の初観測　**1987 : 25 nb^{-1}**

p_x^ν, p_y^ν は測定可能

ふつうは

- high p_T lepton (> 25 GeV/c)
- large missing E_T (> 25 GeV/c)

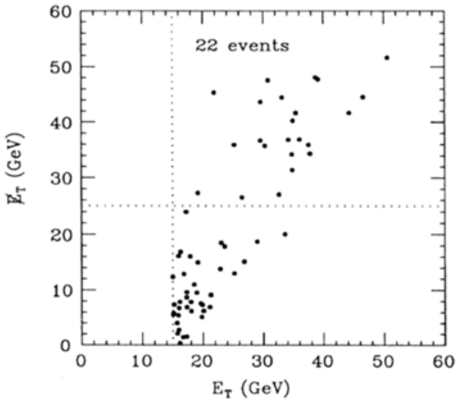
を要求すると，BGは充分小さくなる

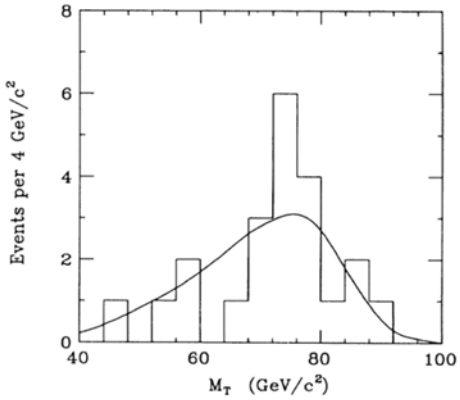
p_z^ν は不可能　$\Rightarrow$ $\ell\nu$ 系の質量は再構成できない

Transverse mass（x-y 平面での質量）を用いる

$$M_T^2 \equiv 2\, p_T^\ell\, p_T^\nu\, (1 - \cos\Delta\phi)$$

dN/dp_T^ℓ, dN/dp_T^ν および dN/dM_T の分布：
$\sim M_W/2$ と $\sim M_W$ に peak を持つ
Jacobian peak と呼ぶ（変数変換による）

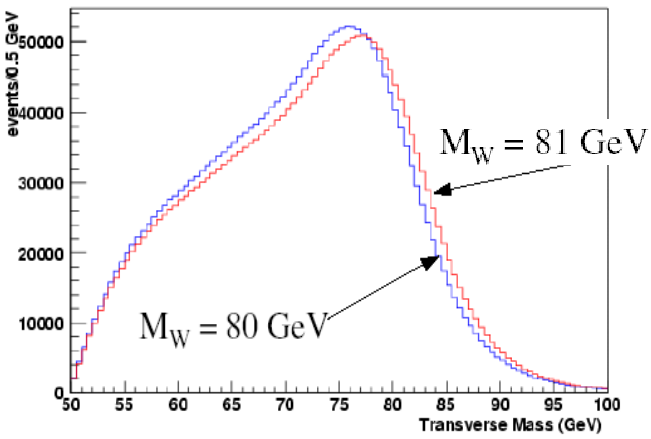




$m_W = 80.0 \pm 3.3 \pm 2.4$ GeV/c^2

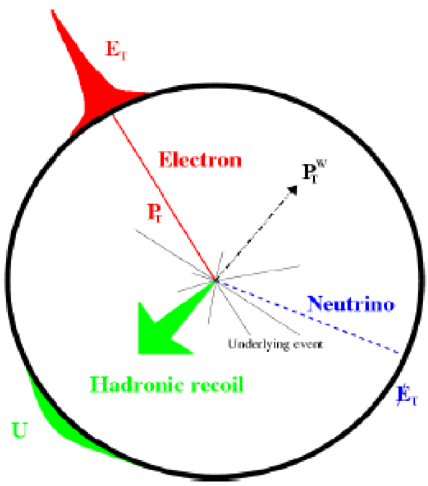
Measuring the *W* mass

Transverse mass : $m_T \equiv \sqrt{2\, p_T^\ell\, p_T^\nu\, (1 - \cos\Delta\phi^{\ell\nu})}$



Jacobian peak at $\sim m_W$
Lorentz invariant under boost in z

$p_T^\nu =$ missing E_T



Lepton energy and hadronic recoil contribute to missing energy resolution.

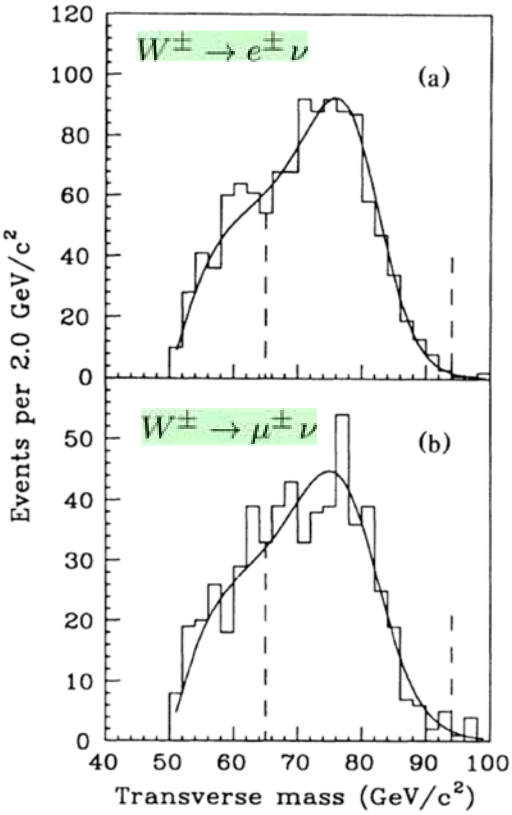
W ボソン質量の本格測定

1988-89 : ～ 4 pb^{-1}

Transverse mass (x-y 平面での質量) を用いる

$$M_T^2 \equiv 2\, p_T^{\ell}\, p_T^{\nu}\, (1 - \cos \Delta\phi)$$

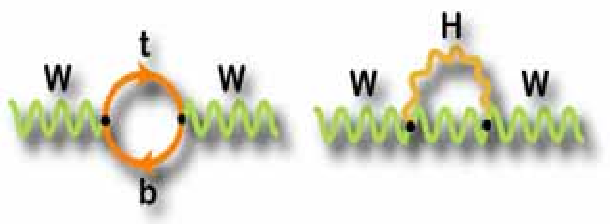
dN/dp_T^{ℓ}, dN/dp_T^{ν} および dN/dM_T の分布 :
$\sim M_W/2$ と $\sim M_W$ に peak を持つ
Jacobian peak と呼ぶ (変数変換による)



$m_W = 79.91 \pm 0.39$ GeV/c^2

W ボソンの質量を測定する意義

- **標準理論の粒子の質量はパラメータ: 実験的に決定する必要あり**
- **標準理論では, W ボソンの質量はヒッグス場による**
- **量子効果により, 粒子間の質量が制限される**



Marciano and Sirlin, 1980
Barger, Hewett, Rizzo, 1990

mixing angle $\sin^2\theta_W$ ($\equiv x_W$) is defined via

$$x_W = 1 - M_W^2/M_Z^2 \tag{2.1}$$

and the radiatively corrected Z mass can be expressed as

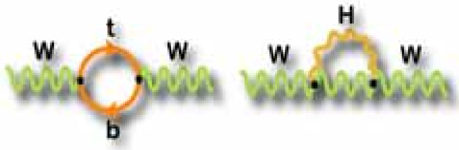
$$M_Z^2 = \frac{A}{x_W(1-x_W)(1-\Delta r)}\ , \tag{2.2}$$

where $A \equiv \pi\alpha(m_e)/\sqrt{2}G_F \simeq (37.280\,22 \quad \text{GeV})^2$ for $\alpha^{-1}(m_e) = 137.035\,989\,5$ and $G_F = 1.166\,389 \times 10^{-5}$ GeV^{-2}. The effects of the radiative corrections are contained in Δr which depends on M_Z and the masses of the top quark (m_t) and Higgs boson (m_H). For given values

$\Delta r \propto m_t^2$

$\Delta r \propto \ln(m_h/m_Z)$

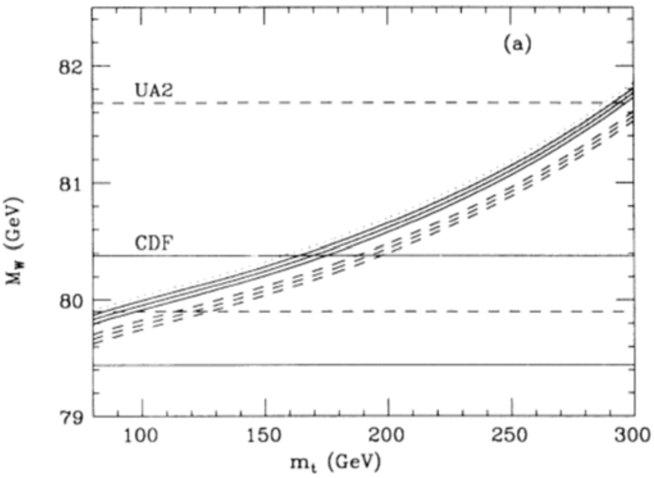
1990年ころの状況



- Z ボソンの精密測定 (LEP)
- Top quark は未発見
  - 直接探索： W ボソンより重い
  - 間接測定： 矛盾しない, きわめて重い

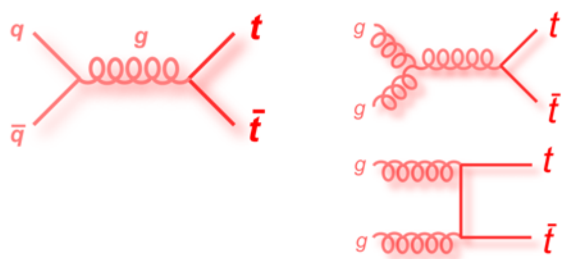
B^0-$\overline{B}^0$ 混合からも

横軸： Top quark 質量
縦軸： W ボソン 質量

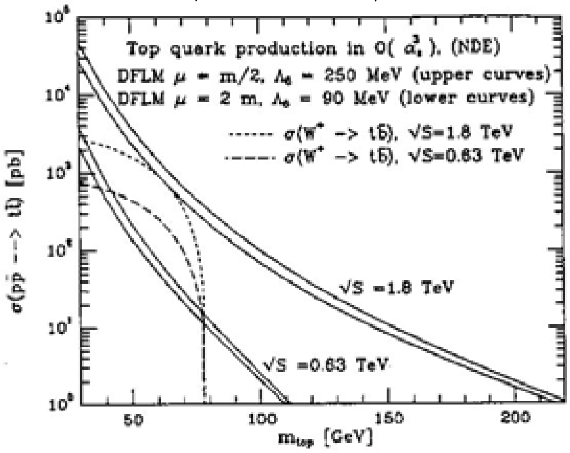


Barger, Hewett, Rizzo, 1990

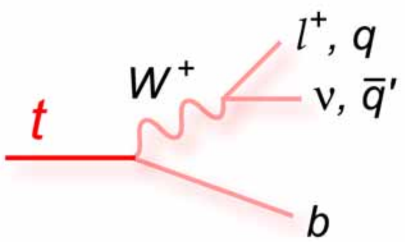
Top quark の生成



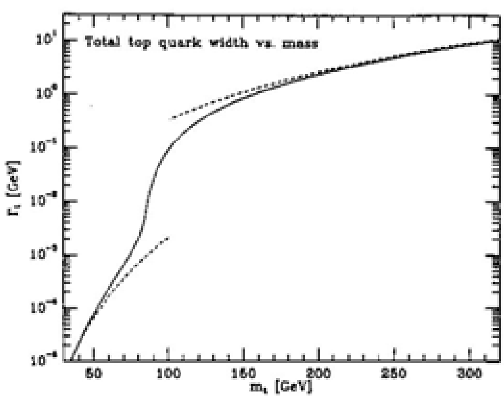
Nason, Dawson, Ellis



Top quark の崩壊

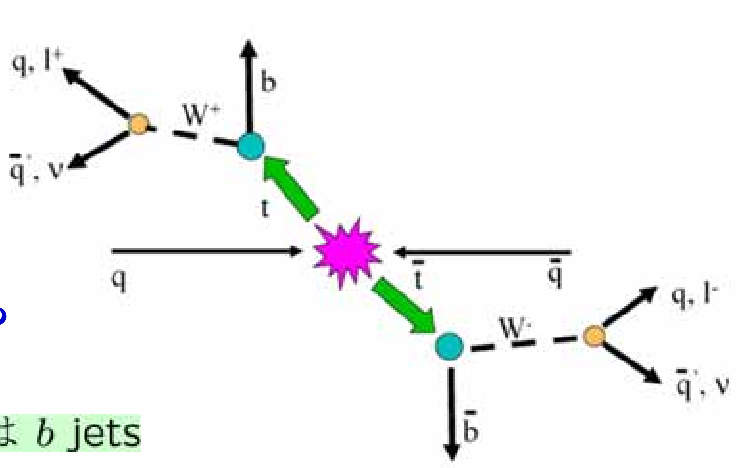


Decay width $\Gamma_t = \mathcal{O}(1\ \text{GeV})$



CDF Run-I : 1992 - 1996 　　110 pb^{-1}

$$\bar{p} + p \to t + \bar{t} + X$$
$$t \to b + W^{+}$$
$$\bar{t} \to \bar{b} + W^{-}$$



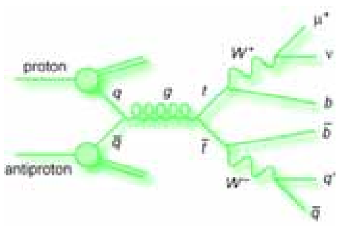
例えば $W^{+} \to \ell^{+} + \nu$
$W^{-} \to d + \bar{u}$ **なら**

$W + 4$ jets
うち 2 つは b jets

例えば $W^{+} \to \ell^{+}\nu$
$W^{-} \to \ell'^{-}\bar{\nu}$ **なら**

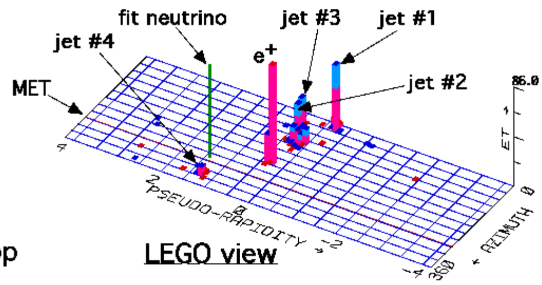
Di-lepton +2 jets
2 つとも b jets

Top quark 対 候補事象 　Lepton + jets channel

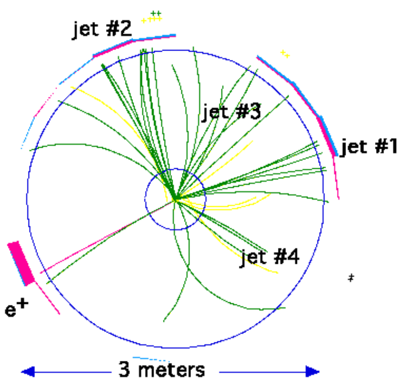


e + 4 jet event
40758_44414
24-September, 1992

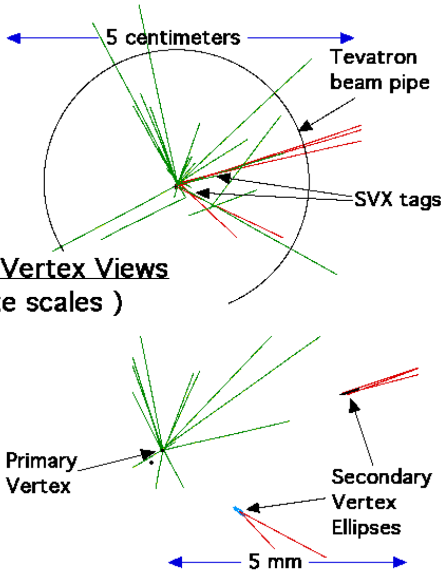
TWO jets tagged by SVX
fit top mass is 170 +- 10 GeV
e^{+}, Missing E_t, jet #4 from top
jets 1,2,3 from top (2&3 from W)



LEGO view



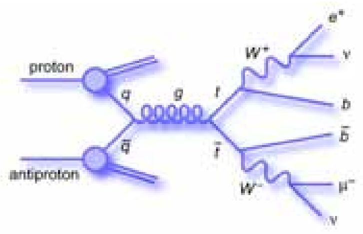
Tracking View

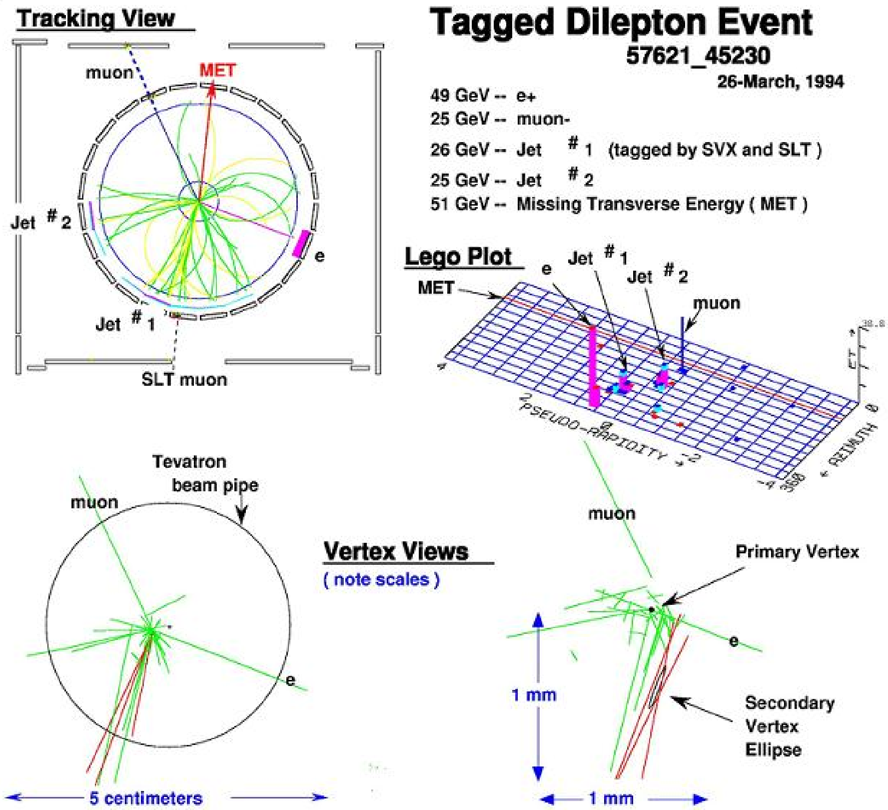


Two Vertex Views
(note scales)

Top quark 対 候補事象 その2

Di-lepton channel





Top quark 生成の証拠 1994

1994年(平成6年)4月23日 土曜日

朝日新聞

トップクオーク確認

日米伊のグループ

素粒子理論の「宿題」解決へ

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Milestone

Evidence for top quark production in $\bar{p}p$ collisions at $\sqrt{s}$ =1.8 TeV

F. Abe *et al.*

Phys. Rev. Lett. **73**, 225 – Published 11 July 1994

An article within the collection: Letters from the Past - A PRL Retrospective

Article References Citing Articles (337) PDF Export Citation

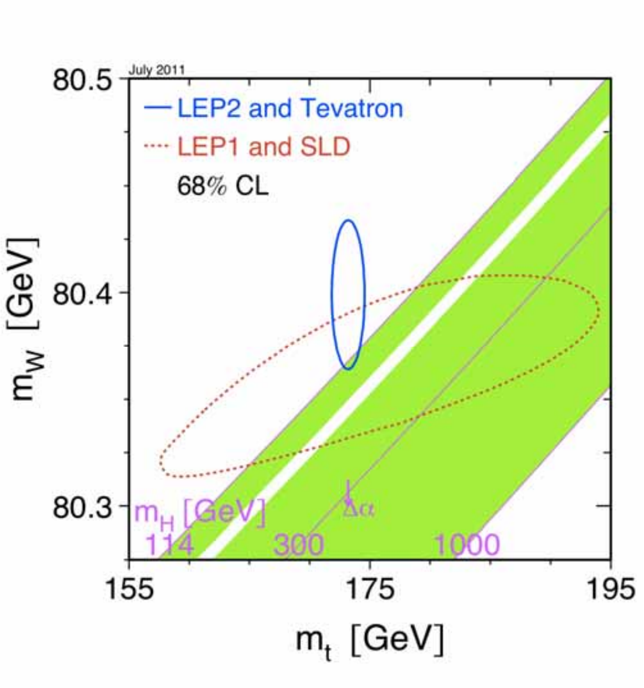
ABSTRACT

We summarize a search for the top quark with the Collider Detector at Fermilab (CDF) in a sample of $\bar{p}p$ collisions at $\sqrt{s}$ =1.8 TeV with an integrated luminosity of 19.3 pb^{-1}. We find 12 events consistent with either two *W* bosons, or a *W* boson and at least one *b* jet. The probability that the measured yield is consistent with the background is 0.26%. Though the statistics are too limited to establish firmly the existence of the top quark, a natural interpretation of the excess is that it is due to $t\bar{t}$ production. Under this assumption, constrained fits to individual events yield a top quark mass of $174\pm10^{+13}_{-12}$ GeV/c^2. The $t\bar{t}$ production cross section is measured to be $13.9^{+6.1}_{-4.8}$ pb.

Top quark 発見後
しばらくして

W mass + top mass
$\Rightarrow$ Higgs mass

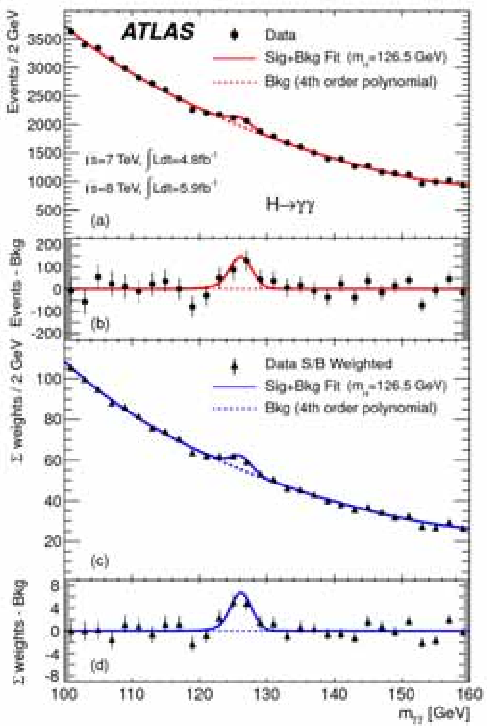
$m_{\text{top}} = 173.2 \pm 0.6 \pm 0.8$ GeV$/c^2$
July 2011



ヒッグスは軽いようだ

$m_H = 92^{+34}_{-26}$ GeV$/c^2$

Higgs 粒子の発見
2012

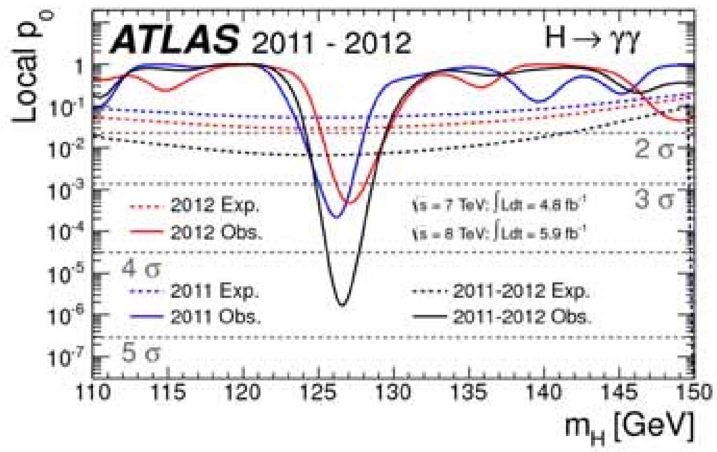


Physics Letters B
Volume 716, Issue 1, 17 September 2012, Pages 1-29

ELSEVIER

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

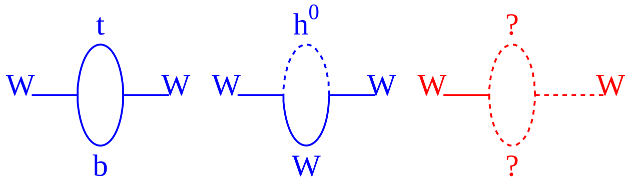
…ollisions …ed …ollected …al …sly …in the 7 …4ℓ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys)GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.



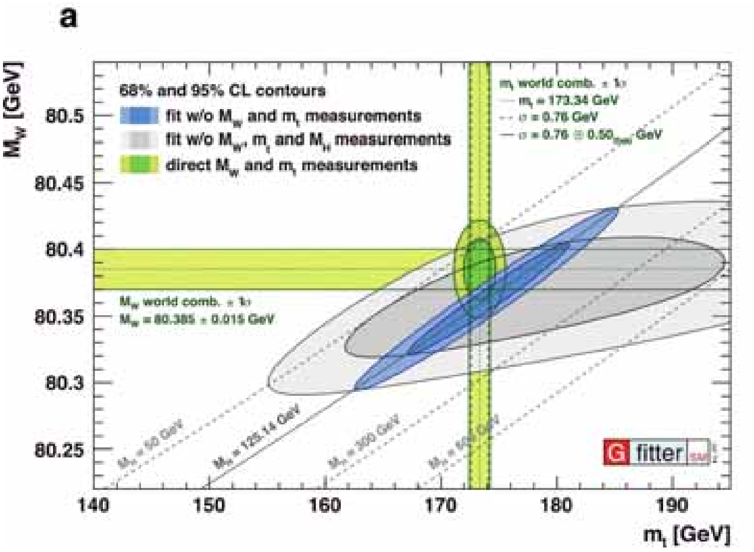
Higgs 粒子の発見後

m_{top}, m_W, m_{higgs} すべて測定

標準理論と整合？　矛盾？



$\Delta M_W \ \alpha \ M_T^2$　$\Delta M_W \ \alpha \ \ln M_H$　New Physics

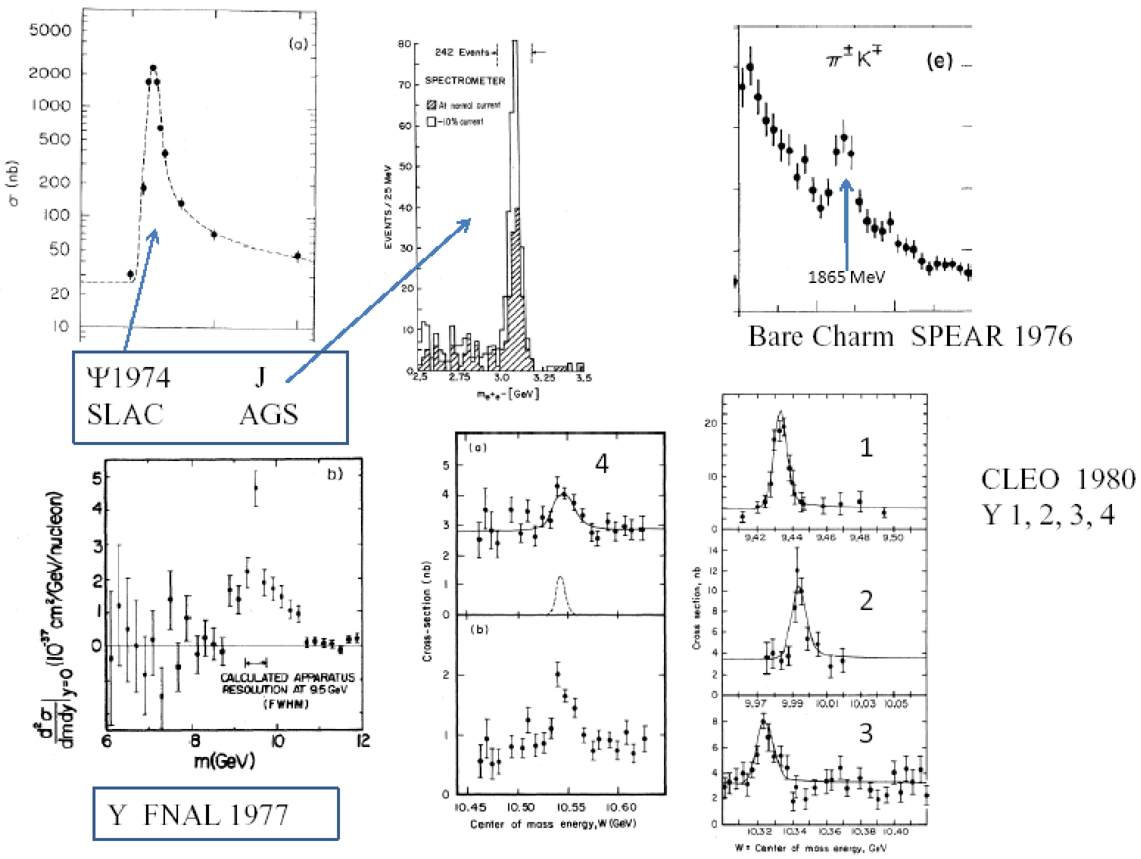


2014

おしまい

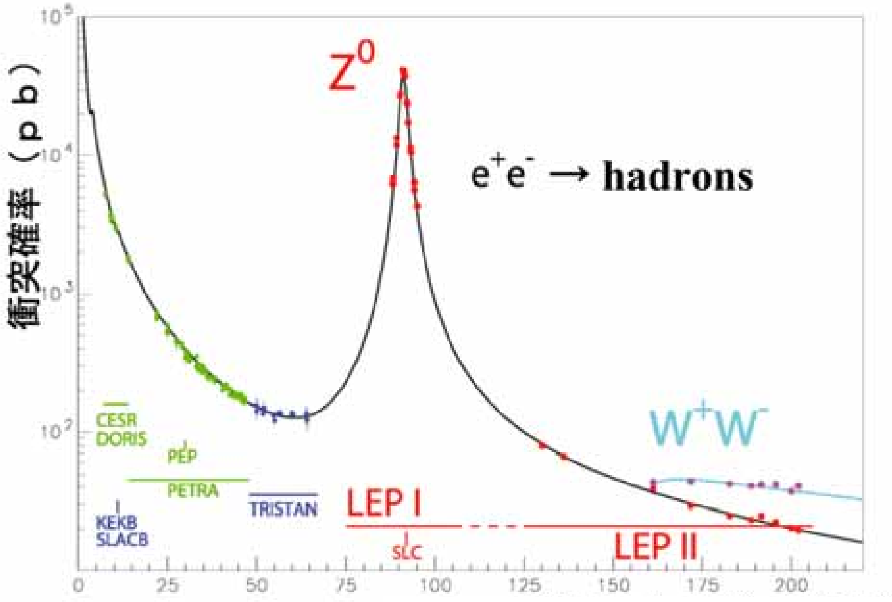
Machines and Events --- Truncated View of 1960-1996

1960-1970	ADA VEP1 ee VEP2	AGS-BNL PS-CERN	Start of collider rings Strong Focusing	
1971-1975	CEA ADONE SPEAR DORIS	MR-FNAL ISR CERN	First evidence stochastic Cooling at ISR	Neutral currents J/Psi
1976-1980	VEP4 CESR PETRA	SPS-CERN ICE CERN	Electron cooling Stochastic cooling	Charm, tau, gluon Upsilon
1981-1985	PEP	TEVATRON PBAR-P CERN	PBARP CERN CDF Start	b **W, Z**
1986-1990	BEPC Tristan LEP SLC	PBAR-P TEVATRON	FIRST COLL. CDF	B_s mixing UA1
1991-1996			D0 DET TEV	t quark, b-physics starts at CDF/DO



電子・陽電子衝突：反応断面積

点電荷同士の衝突：エネルギーとともに減少

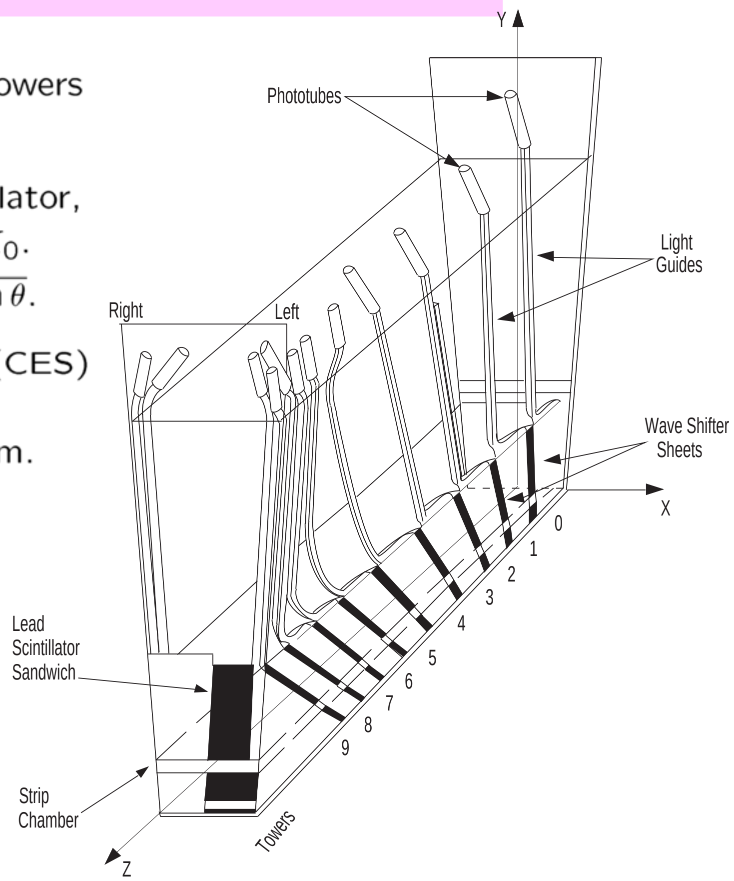


重心系エネルギー √s

LEP I 1989
LEP II 1995

Central Electromagnetic Calorimeter CEM

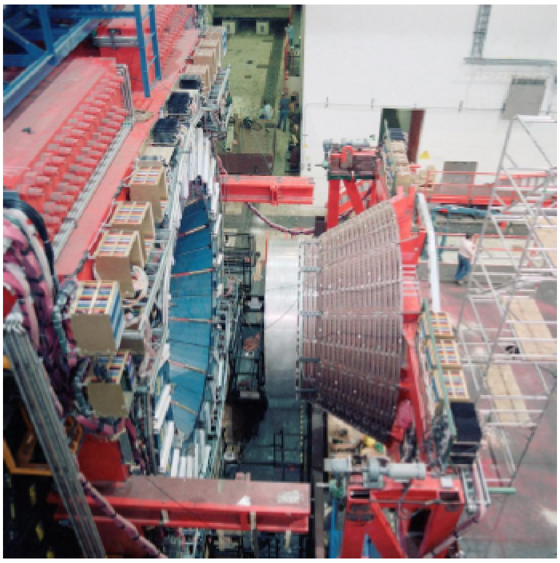
- Covers $\Delta\phi = 15°$, $|\eta| < 1.1$. 10 towers per wedge.
- 3-mm lead, 5-mm plastic scintillator, 31 layers. Total thickness $\simeq 18\,X_0$. Resolution $\sigma_E/E = 13.5\%/\sqrt{E\sin\theta}$.
- A layer of proportional chambers (CES) near shower maximum ($5.9\,X_0$). $\Delta(r\varphi) = 1.5$ cm, $\Delta z = 1.7, 2.0$ cm.



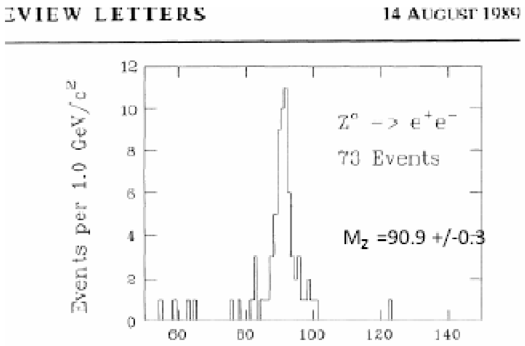
シンチレータ, WLS
PMT
日本で製造

1988-89 Run: Fully functional detector. 4 pb^{-1}

Detector complete as described in 1981 Design Report.



W & Z mass, $\sin^2 q_w$
Limits for top mass
Start on B physics
QCD physics
Defined path for upgrade



We discovered the accuracy of the CTC

素粒子の標準理論

- **物質粒子** 6 quarks and 6 leptons
- **相互作用** 4 **種類** (**ゲージ粒子**)

  強い相互作用, 電磁相互作用, 弱い相互作用, 重力

  → **基本粒子と相互作用の研究**

- **ゲージ相互作用である:**

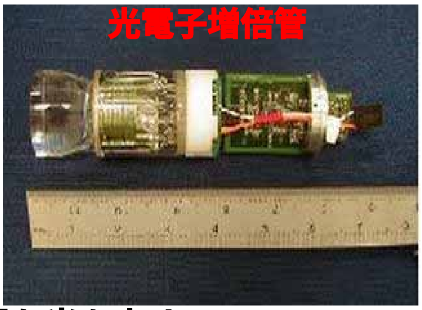
  gluon g, photon γ, $W^{\pm} / Z^0$, graviton (?)

- SU(3) x SU(2) x U(1)

  color weak isospin weak hypercharge

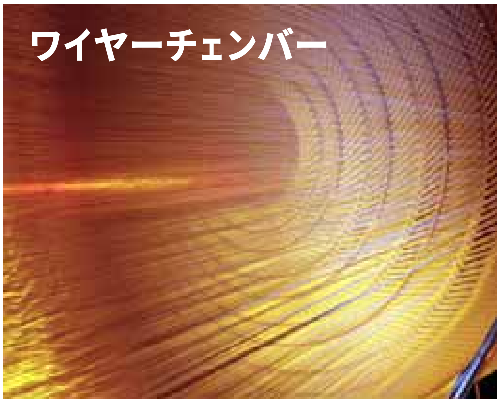
  QCD weak + electromagnetic

粒子検出に用いられる技術（例）



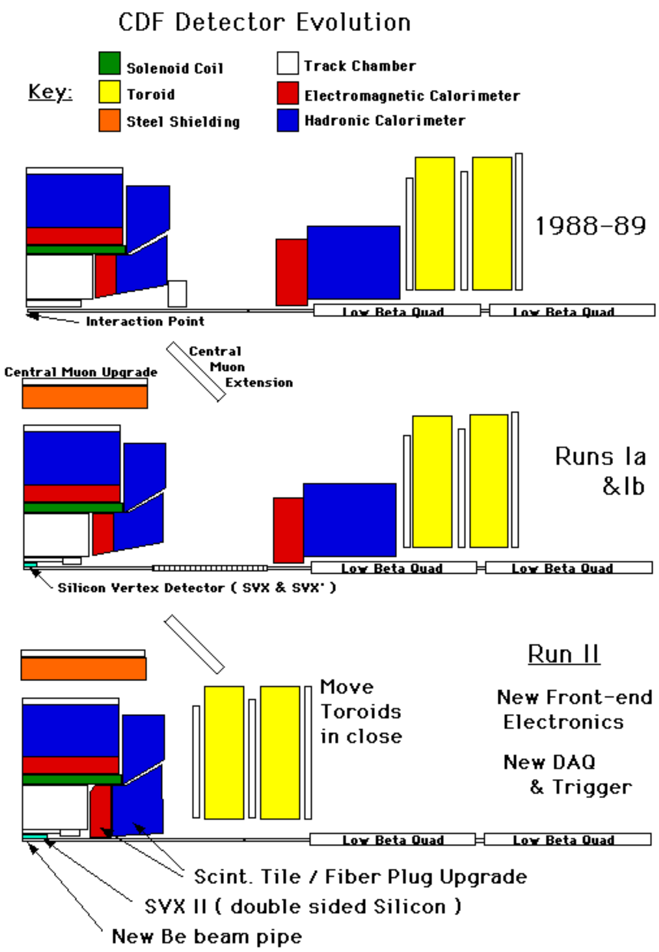
微弱な光を電気信号に変換する。
左のシンチレータと組み合わせて荷電粒子をとらえる。

荷電粒子の通過に伴い微弱な光を出す

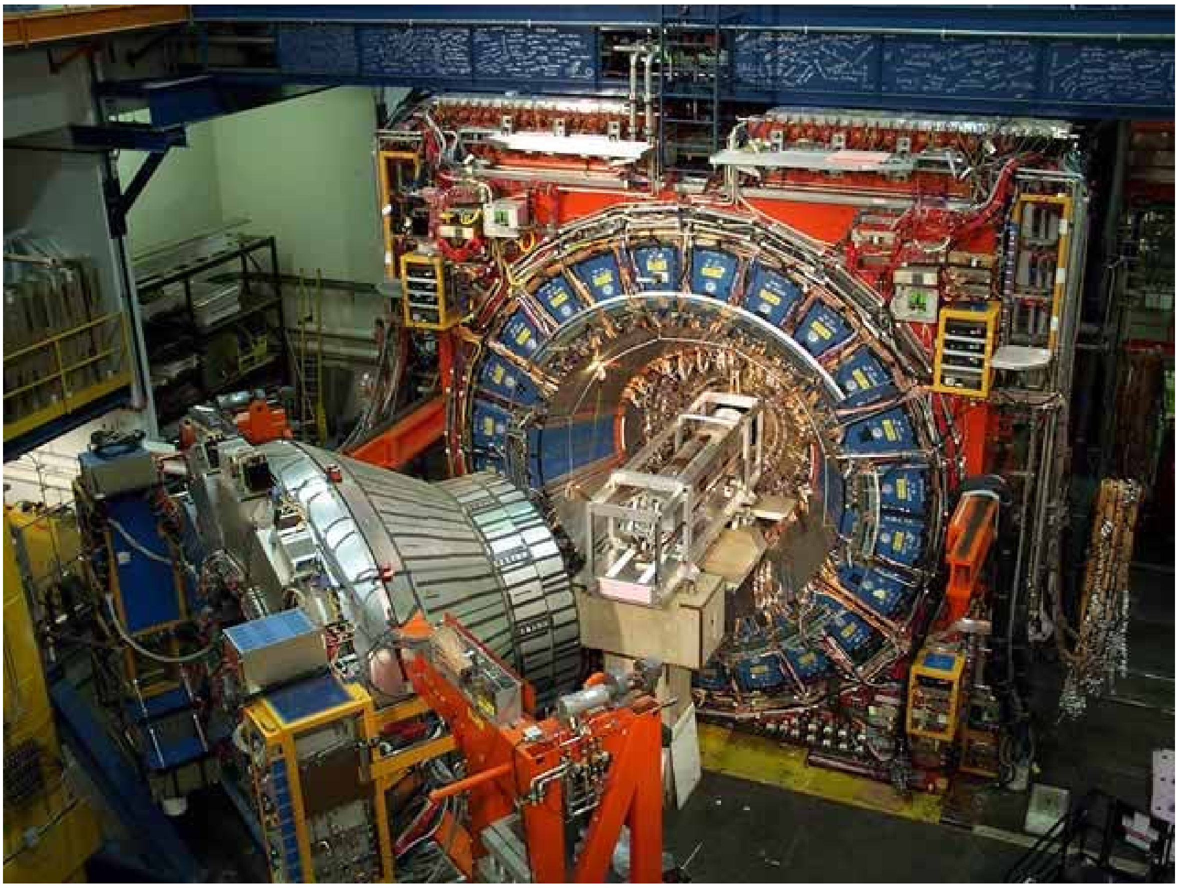


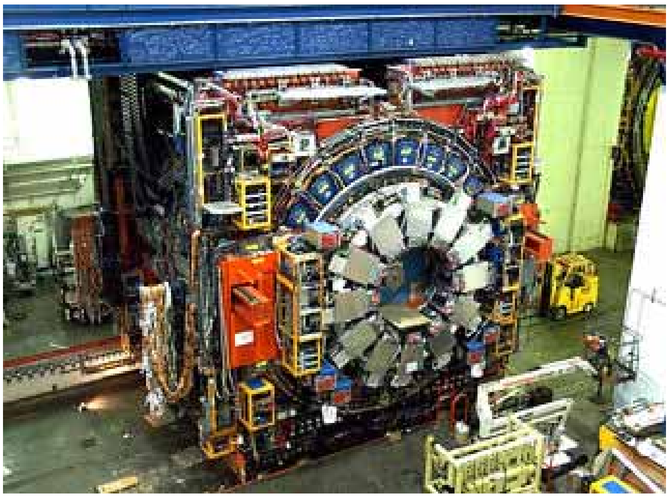
荷電粒子の通過した位置を数十ミクロン間隔で埋め込まれた電極により測定

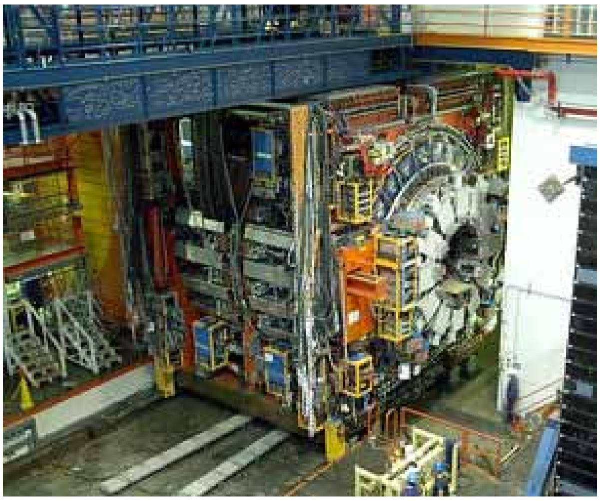
荷電粒子が通ると充満されているガスが電離してワイヤーに信号を残す

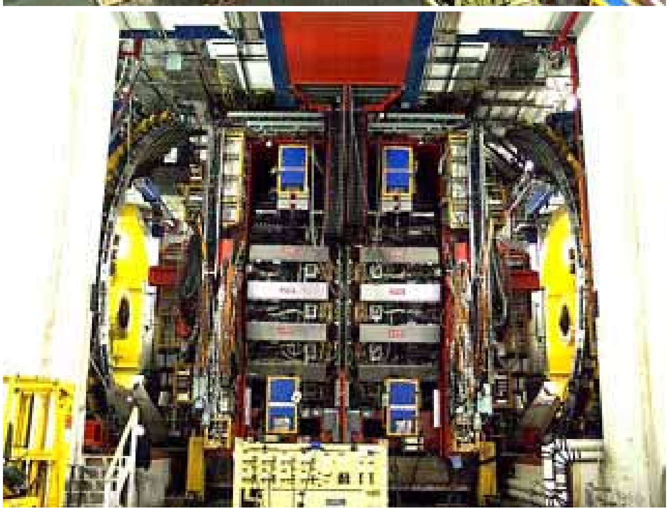


Another component is being installed









The 1200-ton detector is moving to the accelerator collision point