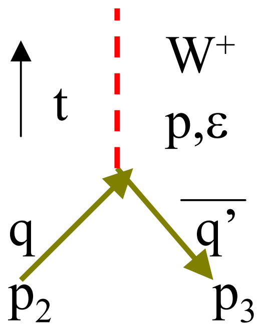
Produzione adronica di W e Z

Sezione d-urto elementare

$$q\bar{q}' \to W^+, q\bar{q} \to Z$$



$$M^W = -\frac{ig_W}{\sqrt{2}} V_{qq'} \varepsilon_\mu(\lambda) \bar{v}(p_3)\gamma^\mu(1-\gamma_5)u(p_2)$$

$$M^Z = -\frac{ig_Z}{\sqrt{2}} \varepsilon_\mu(\lambda) \bar{v}(p_3)\gamma^\mu \frac{(C_V - C_A\gamma_5)}{2} u(p_2)$$

$$\sum_s \left|M^W\right|^2 = \left|V_{qq'}\right|^2 \frac{g_W^2}{4} M_W^2 = \left|V_{qq'}\right|^2 \frac{2G}{\sqrt{2}} M_W^4$$

$$d\sigma = \left|M^W\right|^2 \frac{1}{4\sqrt{(p_2 \cdot p_3)^2}} \frac{d^3p}{(2\pi)^3 2E}(2\pi)^4 \delta^4(p - p_2 - p_3) \quad ma,\ 2p_2 \cdot p_3 = \hat{s},\ \text{integrando su } \delta^3:$$

$$\hat{\sigma}_W = 2\pi \left|V_{qq'}\right|^2 \frac{G}{\sqrt{2}} M_W^2 \delta(\hat{s} - M_W^2)$$

$$\hat{\sigma}_Z = 8\pi \frac{G}{\sqrt{2}} \left[C_A^2 + C_V^2\right] M_Z^2 \delta(\hat{s} - M_Z^2)$$

La sezione d'urto totale si ottiene pesando le $\hat{\sigma}$ con le densita' dei quark

$$\sigma(A + B \to W^+ + X) = \frac{1}{3}\int_0^1 dx_a \int_0^1 dx_b \sum_{a,b} q(x_a)\bar{q}'(x_b)\hat{\sigma}^W$$

colore

Cambiamo variabili:

$$dx_a dx_b = \frac{d\hat{s}dy}{s}\ (\hat{\mathrm{s}} = \text{energia nel cm } q\bar{q}' = x_a x_b s, \text{ e y la rapidita' del W}: y = \frac{1}{2}\ln\frac{E_W + P_{LW}}{E_W - P_{LW}}$$

$$con: \frac{2P_{LW}}{\sqrt{s}} = x_a - x_b, \frac{2E_W}{\sqrt{s}} = x_a + x_b$$

E integriamo sulla $\delta(\hat{s} - M_W^2)$

$$\frac{d\sigma}{dy}(W) = \frac{2\pi G}{3\sqrt{2}}\sum_{q,\bar{q}'}\left|V_{qq'}\right|^2 x_a x_b q(x_a)\bar{q}'(x_b) \text{ con } x_{a,b} = \frac{M_W}{\sqrt{s}}e^{\pm y}$$

$$Nel \text{ caso A} = \mathrm{p}, \mathrm{B} = \bar{\mathrm{p}} \text{ con}: \bar{\bar{\mathrm{d}}}(\bar{\mathrm{p}}) = \mathrm{d}(\mathrm{p}) \equiv \mathrm{d}; \bar{\mathrm{u}}(\bar{\mathrm{p}}) = \mathrm{u}(\mathrm{p}) \equiv \mathrm{u}$$

$$\frac{d\sigma}{dy}(W) = \frac{2\pi G}{3\sqrt{2}} x_a x_b \{\cos_C^2[u(x_a)d(x_b) + \bar{d}(x_a)\bar{u}(x_b)] + \sin_C^2[u(x_a)s(x_b) + \bar{s}(x_a)\bar{u}(x_b)]\}$$

Approssimando ai soli quark di valenza e con $\cos^2\theta_C=1$:

$$\frac{d\sigma}{dy}(p\bar{p} \to W^+ + X) = \frac{2\pi G}{3\sqrt{2}} x_a x_b u(x_a) d(x_b)$$

Integrando in y con: $-\ln\frac{\sqrt{s}}{M_W}(x_b = 1) \le y \le \ln\frac{\sqrt{s}}{M_W}(x_a = 1)$

Otteniamo la sezione d'urto totale (conoscendo $u(x_a)$ e $d(x_b)$)

$$p\bar{p}, \sqrt{s} = 630\ \mathrm{GeV}, \sigma(\mathrm{W}^\pm) \approx 3\ \mathrm{nb}\ \ (\mathrm{ud})$$

$$p\bar{p}, \sqrt{s} = 2\ \mathrm{TeV}, \sigma(\mathrm{W}^\pm) \approx 20\ \mathrm{nb}\ \ (\mathrm{ud})$$

$$pp, \sqrt{s} = 14\ TeV, \sigma(W^\pm) \approx 100\ nb\ \ (u\bar{d} + \bar{d}u)$$

La sezione d'urto aumenta con l'energia sia a causa degli estremi di integrazione in y sia per il peso delle densita' di quark a

$$x_a x_b = M_W^2 / s$$

Per lo Z:

$$\frac{d\sigma}{dy}(Z)=\frac{1}{3}\frac{2\pi G}{\sqrt{2}}\sum_q\left[C_A^2+C_V^2\right]x_a x_b q(x_a)\bar{q}(x_b)$$

Chiamando $x_W=\sin^2\theta_W$ $\quad C_V^u=\frac{1}{2}-\frac{4}{3}x_W, C_A^u=\frac{1}{2};\quad C_V^{d.s}=-\frac{1}{2}+\frac{2}{3}x_W, C_A^{d,s}=-\frac{1}{2}$

In $p\bar{p}$ con i soli quark di valenza $(u\bar{u}),(d\bar{d})$

$$\frac{d\sigma}{dy}(Z)=\frac{2\pi G}{3\sqrt{2}}x_a x_b\left[1+\frac{8}{3}x_W+\frac{32}{9}x_W^2\right]\mathrm{u}(\mathrm{x}_a)u(x_b)+\left[1+\frac{4}{3}x_W+\frac{8}{9}x_W^2\right]d(x_a)d(x_b)$$

$p\bar{p},\sqrt{s}=630\,\mathrm{GeV}, \sigma(\mathrm{Z})\approx 1.8\,\mathrm{nb}\ \ (\mathrm{uu}+\mathrm{dd})$

$p\bar{p},\sqrt{s}=2\,\mathrm{TeV}, \sigma(\mathrm{Z})\approx 6.4\,\mathrm{nb}$ "

$pp,\sqrt{s}=14\ TeV,\ \sigma(Z)\approx 30\ nb\ \ (u\bar{u}+d\bar{d})$

+ correzioni di QCD

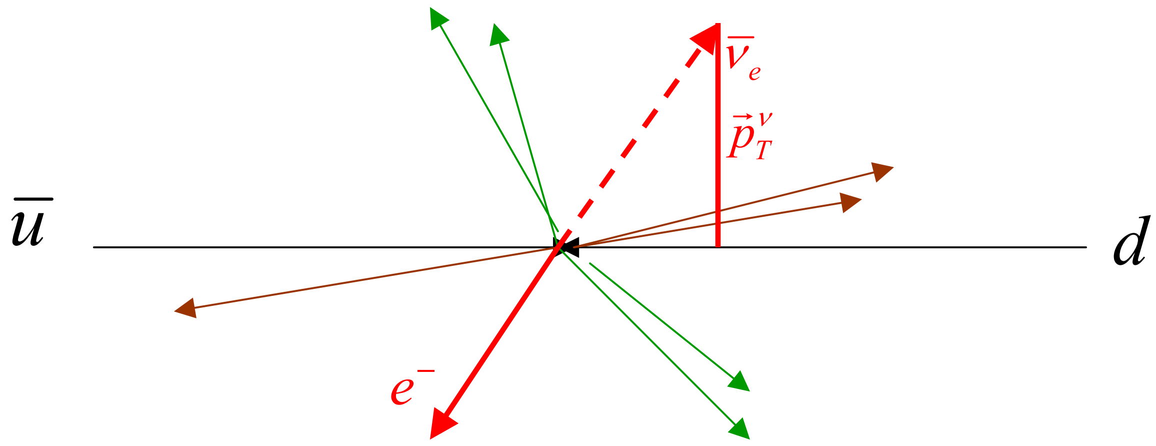
Come si misurano W e Z ?

Per lo Z e' "facile": canali leptonici $Z \to e^+e^-, \mu^+\mu^-, \tau^+\tau^-$ (B.R. ~ 3.3%)

$\Longrightarrow$ Entrambe le particelle del decadimento sono rivelabili: massa invariante

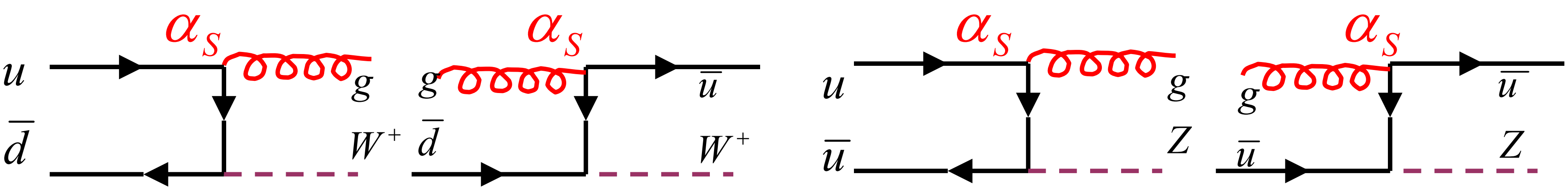
Per il W i canali leptonici (B.R. 11%) $W^- \to e^-\overline{\nu}_e, \mu^-\overline{\nu}_\mu, \tau^-\overline{\nu}_\tau$

Solo il leptone carico e' direttamente misurabile, per il neutrino si misura la componente trasversa dell'impulso e solo come **impulso mancante.**



Importante la copertura ermetica del rivelatore

Correzioni QCD a σ(W), σ(Z)



Processi del tipo W+jet(s), Z+jet(s), utili anche per estrarre α_S

Contributo alla sezione d'urto ~ 10% (α_S~ 0.1)

Calcolo O(α_S^2) a √s=1.8 TeV $\sigma_W = \sigma_W^{LO}(1+0.16(O(\alpha_S))+0.02(O(\alpha_S^2)))$

Ricorda :

$$B(W \to e\nu) = \frac{\Gamma(W \to e\nu)}{\Gamma_{tot}} = 0.108;$$

$$B(Z \to e^+e^-) = \frac{\Gamma(Z \to e^+e^-)}{\Gamma_{tot}} = 0.034;$$

9.4 W and Z boson production 315

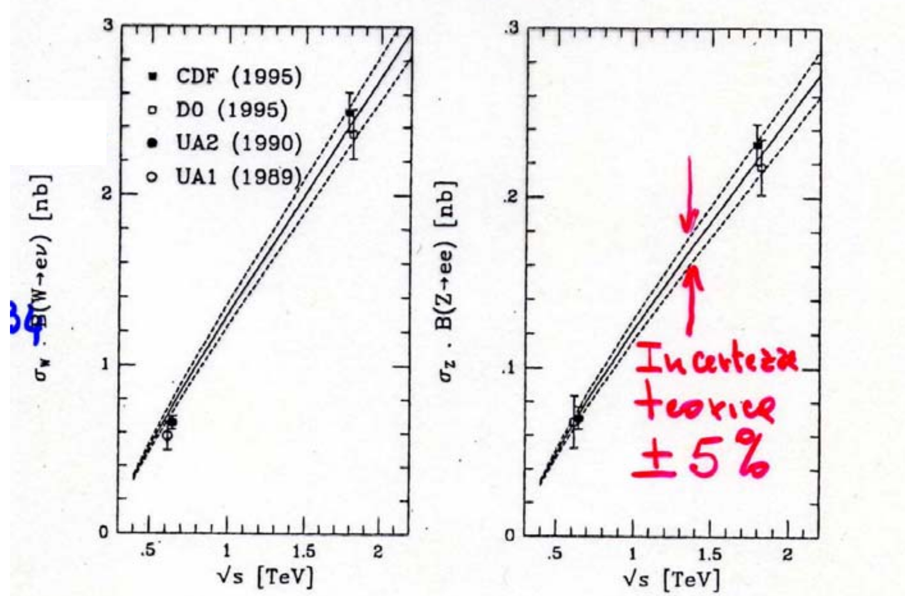
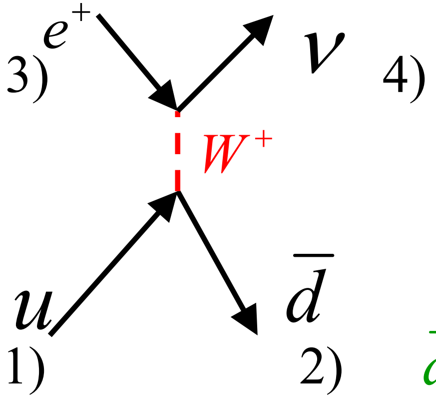


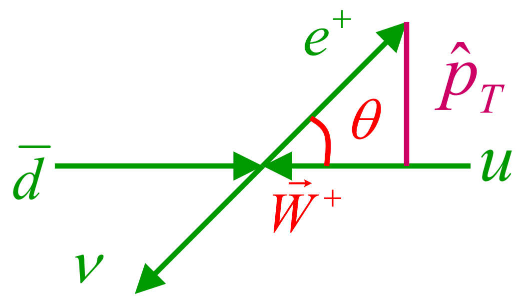
Fig. 9.6. Comparison of *W* and *Z* cross section measurements in $p\bar{p}$ collisions with theoretical predictions. The systematic and statistical errors on the measurements have been combined in quadrature.

Il processo di annichilazione

$u\bar{d} \to W^+ \to e^+\nu$ e' un'interazione di tipo antifermione-fermione $(\bar{\nu}_e e^- \to \bar{\nu}_\mu \mu^-)$



$$Con: |M|^2 \propto (p_1 p_4)(p_3 p_2) = \hat{u}^2 \xrightarrow{c.m.} \frac{\hat{s}^2}{4}(1+\cos\hat{\theta})^2$$



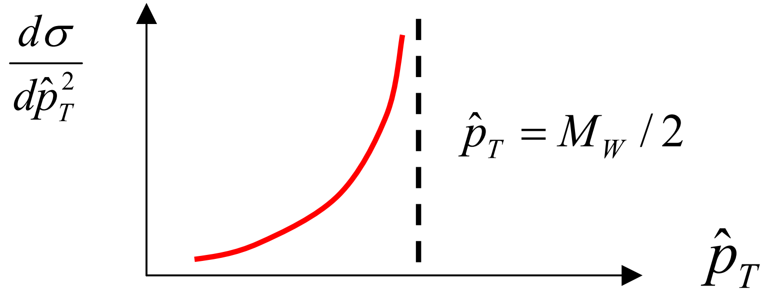
$$con: \hat{p}^2{}_T = \frac{\hat{s}\cdot\sin^2\hat{\theta}}{4}$$

$$Quindi: \frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\cos\theta} = K(1+\cos\hat{\theta})^2 (si \text{ annulla a } \theta = \pi, elicita')$$

$$\cos\hat{\theta} = \left(1 - \frac{4p_T^2}{\hat{s}}\right)^{1/2} \Rightarrow \frac{d\cos\hat{\theta}}{d\hat{p}_T^2} = -\frac{2}{\hat{s}}\left[1 - \frac{4\hat{p}_T^2}{\hat{s}}\right]^{-1/2} = \frac{-2}{\hat{s}\cos\hat{\theta}} \qquad \Rightarrow \frac{d\sigma}{d\hat{p}_T^2} = K\frac{(1+\cos^2\hat{\theta})}{\cos\hat{\theta}}$$

Il termine lineare nel coseno sparisce perche' a $\hat{\theta}$ e $\pi - \hat{\theta}$ contribuisce allo stesso $\hat{p}_T^2$ ma con segno opposto.

$$\frac{d\sigma}{d\hat{p}_T^2} = K \frac{(1-2\hat{p}_T^2/\hat{s})}{(1-4\hat{p}_T^2/\hat{s})^{1/2}}$$

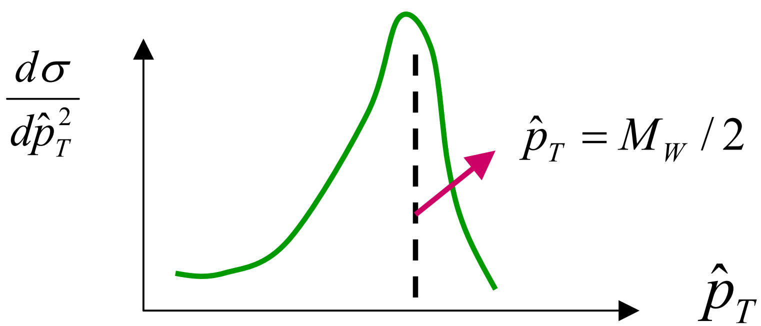


$diverge$ a $\hat{\theta} = \frac{\pi}{2}$, o $\hat{p}_T = \frac{\sqrt{\hat{s}}}{2} \sim M_W/2$

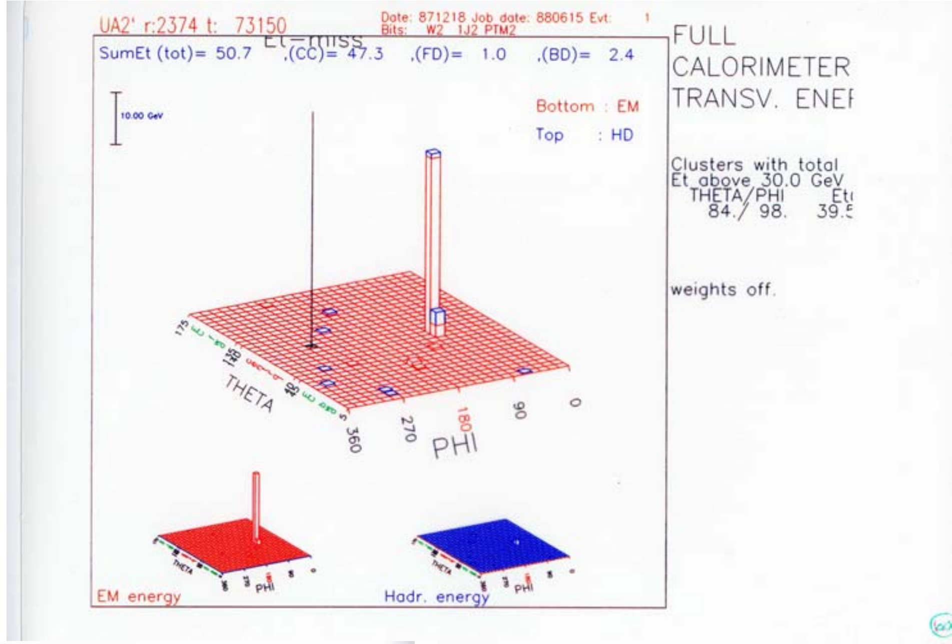
Picco Iacobiano

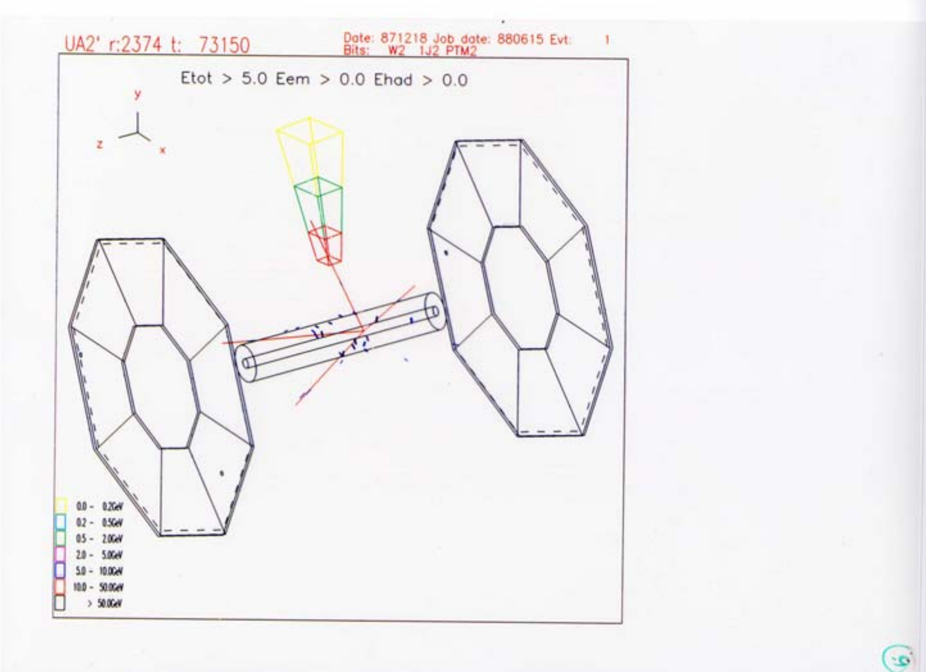
N.B. $\hat{p}_T = p_T^{lab}$

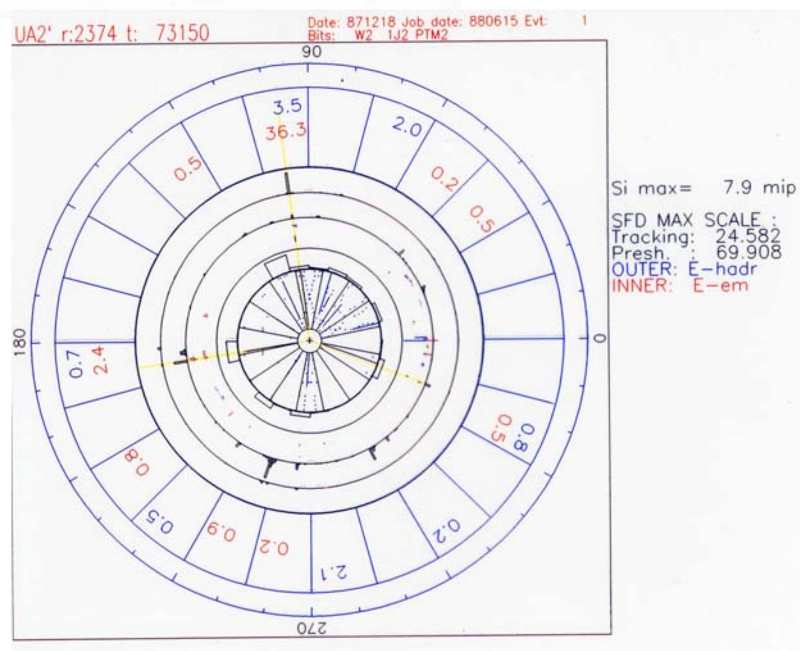
Nel laboratorio la divergenza e' "diluita" dal fatto che $\frac{d\sigma}{d\hat{p}_T^2}$ deve essere convoluta con una Breit/Wigner che dipende da $\hat{s}$ (funzioni di distribuzione dei quark $x_1 x_2$), inoltre p_T^W non e' nullo + effetti sperimentali (risoluzione).



Picco Iacobiano


UA2' r:2374 t: 73150
Date: 871218 Job date: 880615 Evt: 1
Bits: W2 1J2 PTM2
Et-miss
SumEt (tot)= 50.7 ,(CC)= 47.3 ,(FD)= 1.0 ,(BD)= 2.4
FULL
CALORIMETER
TRANSV. ENEF
10.00 GeV
Bottom : EM
Top : HD
Clusters with total
Et above 30.0 GeV
THETA/PHI Et
84./ 98. 39.5
weights off.
THETA
PHI
360 270 180 90 0
EM energy
Hadr. energy


UA2' r:2374 t: 73150
Date: 871218 Job date: 880615 Evt: 1
Bits: W2 1J2 PTM2
Etot > 5.0 Eem > 0.0 Ehad > 0.0
y
z
x
0.0 - 0.2GeV
0.2 - 0.5GeV
0.5 - 2.0GeV
2.0 - 5.0GeV
5.0 - 10.0GeV
10.0 - 50.0GeV
> 50.0GeV


UA2' r:2374 t: 73150
Date: 871218 Job date: 880615 Evt: 1
Bits: W2 1J2 PTM2
90
180
0
270
3.5
36.3
2.0
0.2
0.5
0.7
2.4
Si max= 7.9 mip
SFD MAX SCALE :
Tracking: 24.582
Presh. : 69.908
OUTER: E-hadr
INNER: E-em

Misura della massa del W

1)Dalla posizione del picco Iacobiano in p_T^e o p_T^ν (tanto meglio definito tanto migliore e' la risoluzione).($\vec{p}_T^{\,\nu} = \vec{p}_T^{\,miss} = -\vec{p}_T^{\,e} - \sum_i \vec{p}_T^{\,i}$)

2)Dalla massa trasversa m_T $m_T^2(e,\nu) = \left[\left|\vec{p}_T^{\,e}\right| + \left|\vec{p}_T^{\,\nu}\right|\right]^2 - (\vec{p}_T^{\,e} + \vec{p}_T^{\,\nu})^2 = 2\left|\vec{p}_T^{\,e}\right|\left|\vec{p}_T^{\,\nu}\right|(1-\cos\phi_{e\nu})$

$$0 \le m_T \le M_W;\ \text{se}\ p_T^W = 0,\ \vec{p}_T^{\,e} = -\vec{p}_T^{\,\nu} \Rightarrow m_T = 2\left|\vec{p}_T^{\,e}\right| = 2\left|\vec{p}_T^{\,\nu}\right|$$

La distribuzione in m_T e' poco sensibile al moto trasverso dei W (correzioni in β_{TW}^2 e non β_{TW}). Infatti per le trasformazioni di Galileo:

$$p_T^e = p_T^* + \tfrac{1}{2} p_T^W,\ p_T^\nu = p_T^* - \tfrac{1}{2} p_T^W,\ quindi\ p_T^\nu \cdot p_T^e\ \text{varia come}\ p_{TW}^2$$

Se p_T^W=0 e a fisso $\hat{s}$ (trasformando $\cos\hat{\theta} \to m_T^2$ e $m_T = 2p_T$)

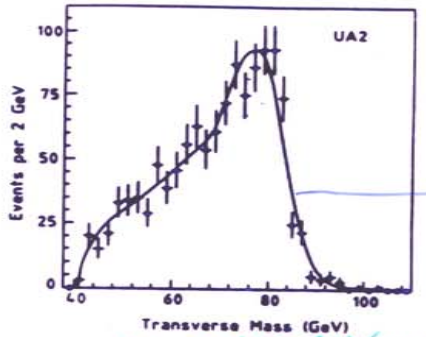
$$\frac{d\sigma}{dm_T^2} = \frac{\left|V_{qq'}\right|^2}{4\pi}\left[\frac{GM_W^2}{\sqrt{2}}\right]^2 \frac{1}{(\hat{s}-M_W^2)+(\Gamma_W M_W)^2} \frac{2-m_T^2/\hat{s}}{(1-m_T^2/\hat{s})^{1/2}}$$

Picco a $\hat{s} = M_W^2 \sim m_T^2$

allargato dall'integrazione sulla larghezza del W, dall'impulso trasverso non nullo del W e dalla risoluzione sperimentale

UA2 data 1988 - 1989

Fit con 1 (M_W) o 2 (M_W, Γ_W) parametri liberi



$m_T^2 = 2 p_T(e) p_T(\nu)(1 - \cos\phi_{e\nu})$

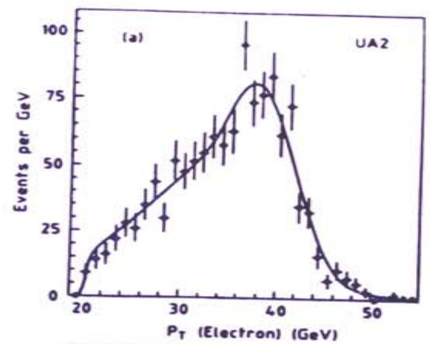
	1	2
m_W	80.75 ± 0.31	80.78 ± 0.31
Γ_W	2.1	$1.89^{+0.47}_{-0.40}$
C.L	84%	89%

la pendenza dipende da Γ_W.

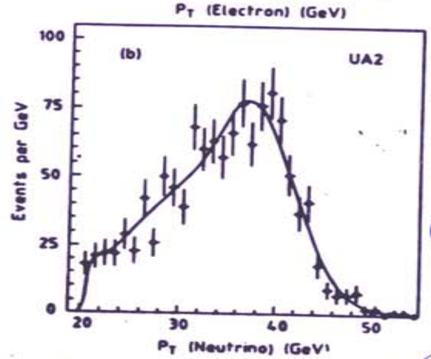
$p_T^\nu > 20$ GeV

$p_T^e > 20$ "

$M_T > 40$ "



	1	2
m_W	80.79 ± 0.38	80.83 ± 0.31
Γ_W	2.1	$1.60^{+0.78}_{-0.68}$
C.L	95%	97%



	1	2
m_W	80.32 ± 0.41	80.33 ± 0.42
Γ_W	2.1	$2.03^{+0.82}_{-0.72}$
C.L	83%	88%

Strutture conoscenza p_T^W
p_T^ν (energy scale)
Procedure per costruire likelihood
radiative decay

Fit. masse trasverse:

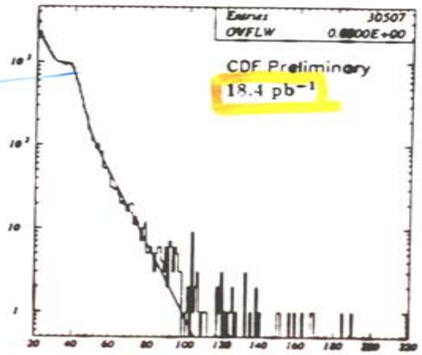
UA2: $m_W = 80.79 \pm 0.31\,(\text{stat.}) \pm 0.21\,(\text{sys}) \pm 0.81\,(\text{scala})$ GeV

CDF(μ+e) $m_W = 80.410 \pm .180$ GeV (1995)

CDF

$\left.\frac{dN}{dE_T}\right|_e$

Picco jacobiano dovuto a W e Z.



E_T^e

Fig. 1. The E_T spectrum of inclusive electrons. Note the Jacobian peak of the W and Z.

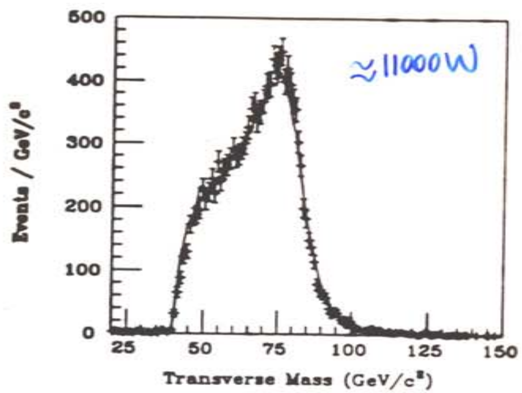


Fig. 2. The W transverse mass spectrum.

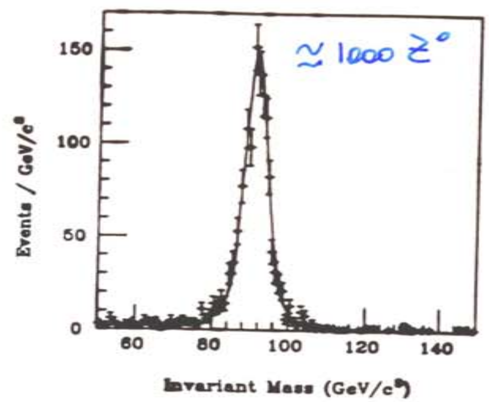


Fig.3. The Z invariant mass spectrum.

Table 1: Comparison of measurements of the W width

Who	Mode	Reference	W width
CDF	e	PRL 64.152 (1990)	$\Gamma(W) = 2.20 \pm 0.16$ GeV
CDF	μ	PRL 69.128 (1991)	$\Gamma(W) = 2.21 \pm 0.27$ GeV
UA1	μ	Phys. Lett. B253 503 (1991)	$\Gamma(W) = 2.19 \pm 0.30$ GeV
UA2	e	Phys. Lett. B276.365 (1991)	$\Gamma(W) = 2.10 \pm 0.16$ GeV
CDF	e	Preliminary 1993	$\Gamma(W) = 2.033 \pm 0.09$ GeV
St. Mod.	e,μ	Ref. [8]	$\Gamma(W) = 2.067 \pm 0.021$ GeV

Migliore determinazione di Γ_W

$$consideriamo: R = \frac{N(W \to l\nu)}{N(Z \to l^+l^-)} = \frac{\sigma_W}{\sigma_Z}\frac{BR(W \to l\nu)}{(Z \to l^+l^-)} = R^\sigma \cdot R^{BR}$$

$$dove: R^{BR} \equiv \frac{BR(W \to l\nu)}{BR(Z \to l^+l^-)} = \frac{\Gamma(W \to l\nu)}{\Gamma_W}\frac{\Gamma_Z}{\Gamma(Z \to l^+l^-)}$$

R^σ e' calcolabile teoricamente: le incertezze dalle funzioni di struttura e dalle correzioni a ordine superiore si elidono.

$$\frac{\Gamma_Z}{\Gamma(Z \to l^+l^-)} \text{ e' misurato accuratamente a LEP}: \Gamma_Z = 2490 \pm 7\ MeV, \Gamma(Z \to l^+l^-) = 83.83 \pm 0.27 \text{ MeV}$$

$\Gamma(W \to l\nu)$ puo' essere calcolato con precisione

R puo' essere misurato con precisione: gli effetti sistematici come luminosita'efficienza si elidono nel rapporto

$$R = 10.9 \pm 0.49 \text{ (D0)}; \text{R} = 10.9 \pm 0.32\text{(stat)} \pm 0.29\text{(sis)}$$

$$\boxed{\begin{aligned} \Gamma_W &= 2.044 \pm 0.092 \text{ GeV (D0)} \\ &= 2.064 \pm 0.085 \text{ GeV (CDF)} \\ \overline{\Gamma}_W &= 2.06 \pm 0.06 \text{ GeV} \end{aligned}}$$

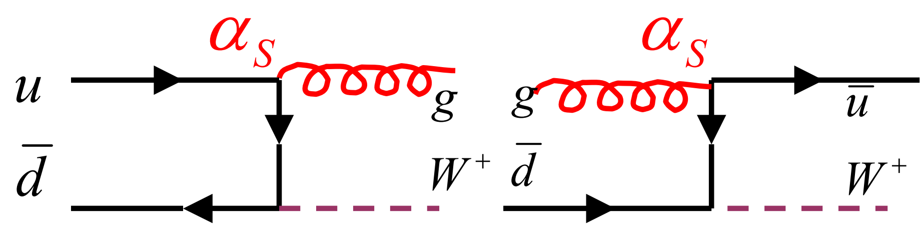
$$\boxed{LEP + Collider: \Gamma_W = 2.118 \pm 0.042 \text{ GeV}}$$

$$\boxed{Teorico: \Gamma_W = 2.085 \pm 0.012 \text{ GeV}}$$

W+jets

Test di QCD, misurati fino a 4 jet

Diagrammi W+1 jet



Annichilazione Compton

In entrambi i diagrammi il propagatore ha spin=1/2 $\boxed{\Rightarrow \frac{d\sigma}{d\cos\theta^*} \sim \frac{1}{1-|\cos\theta^*|}}$

Invece in qq⟶qq (QCD) il propagatore (gluone) ha spin 1 $\Rightarrow \frac{d\sigma}{d\cos\theta^*} \sim \frac{1}{(1-|\cos\theta^*|)^2}$

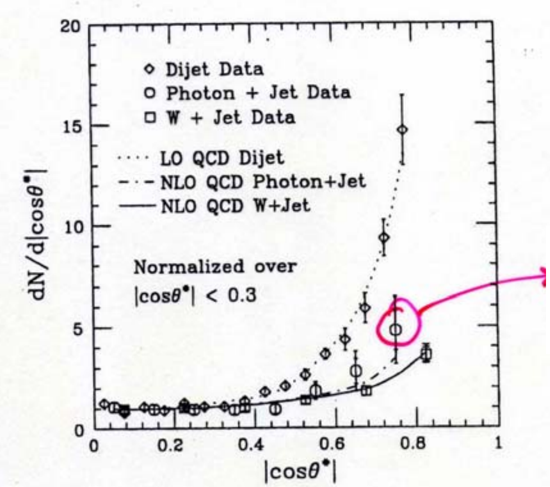
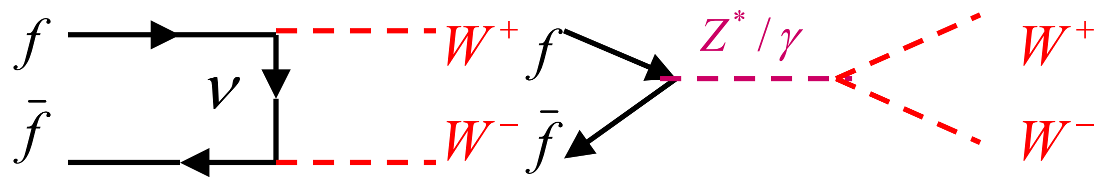


Fig. 9.14. Distribution in the polar angle θ^* for W + jet, jet + jet and photon + jet production measured by the CDF collaboration compared with theoretical predictions. Figure from ref. [42].

Contaminato da π^0(jet)?

Produzione di WW

Due diagrammi all'ordine piu' basso:



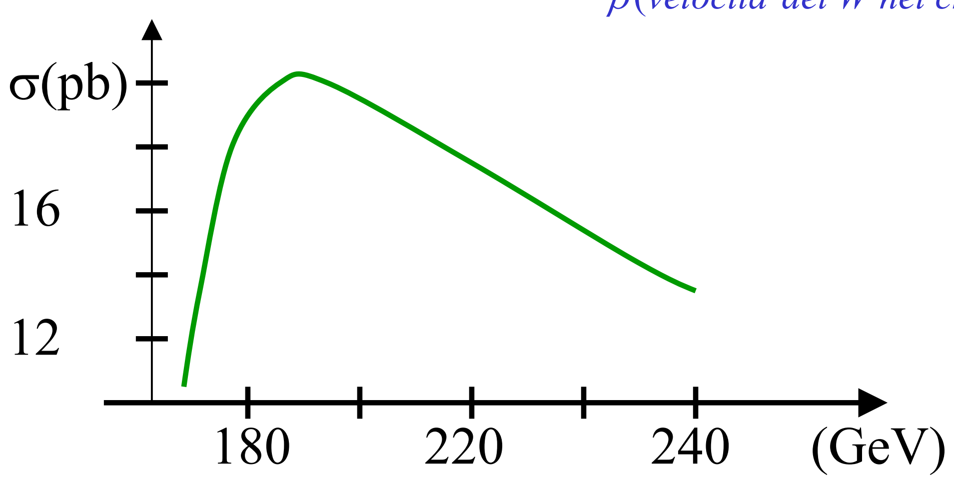
N.B. Singolarmente i diagrammi divergono come s

La sezione d'urto, all'ordine piu' basso e a β_W<<1 (contributo solo del canale t)

$$\sigma_{Born}(f\bar{f} \to W^+W^-) \cong \frac{\pi\alpha^2}{s}\frac{4\beta}{4s_W^4} + O(\beta^3)$$

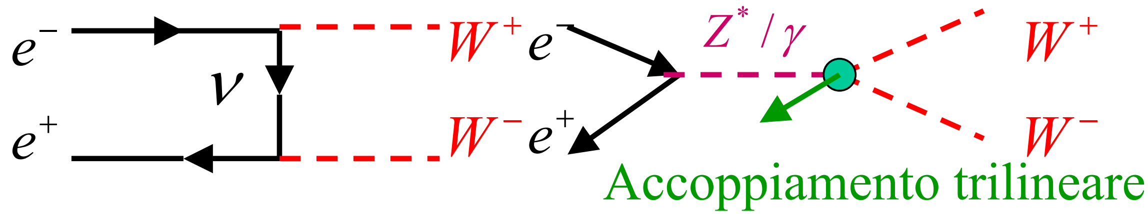
$$s_W = (angolo\ \text{di Weinberg}) = \sqrt{1 - (\frac{\mathrm{M_W}}{\mathrm{M_Z}})^2};$$

$$\beta(velocita'\ del\ W\ nel\ cm\ f\bar{f}) = \sqrt{1 - \frac{M_W^2}{E^2}} = \sqrt{1 - \frac{1}{\gamma_W^2}}$$

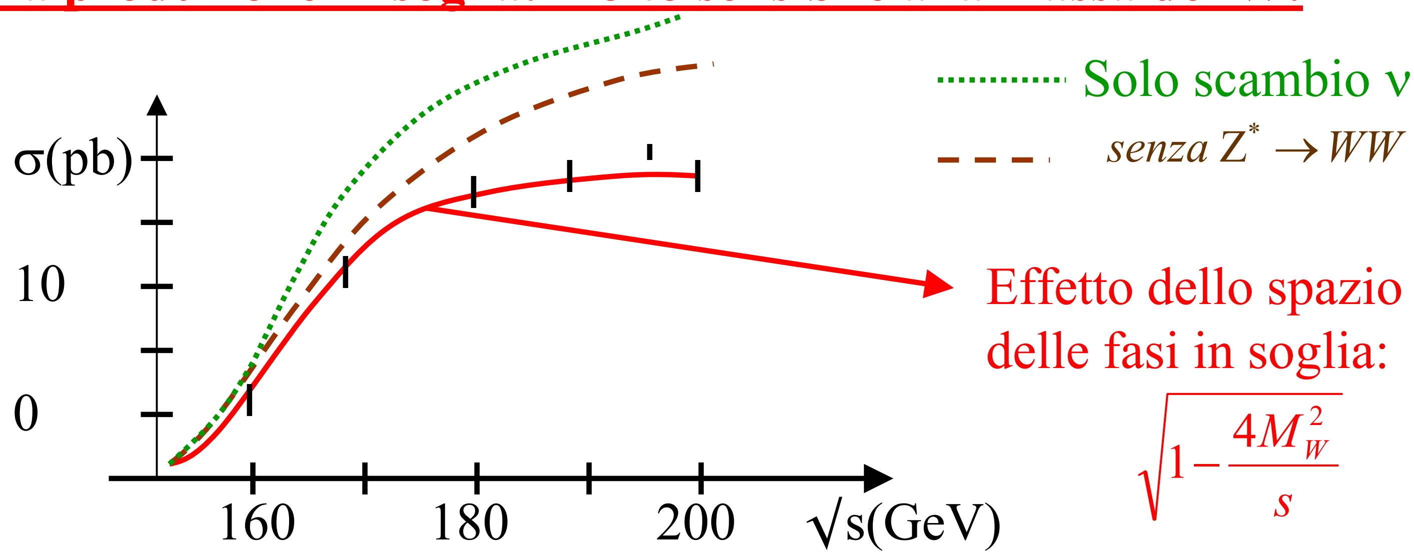


Misura di $e^+e^- \longrightarrow W^+W^-$

Processi:



E' una produzione in soglia: molto sensibile alla massa del W!



$$Dati\ p\,\overline{p} + e^+e^-:\quad M_W = 80.42 \pm 0.04\ \ GeV$$

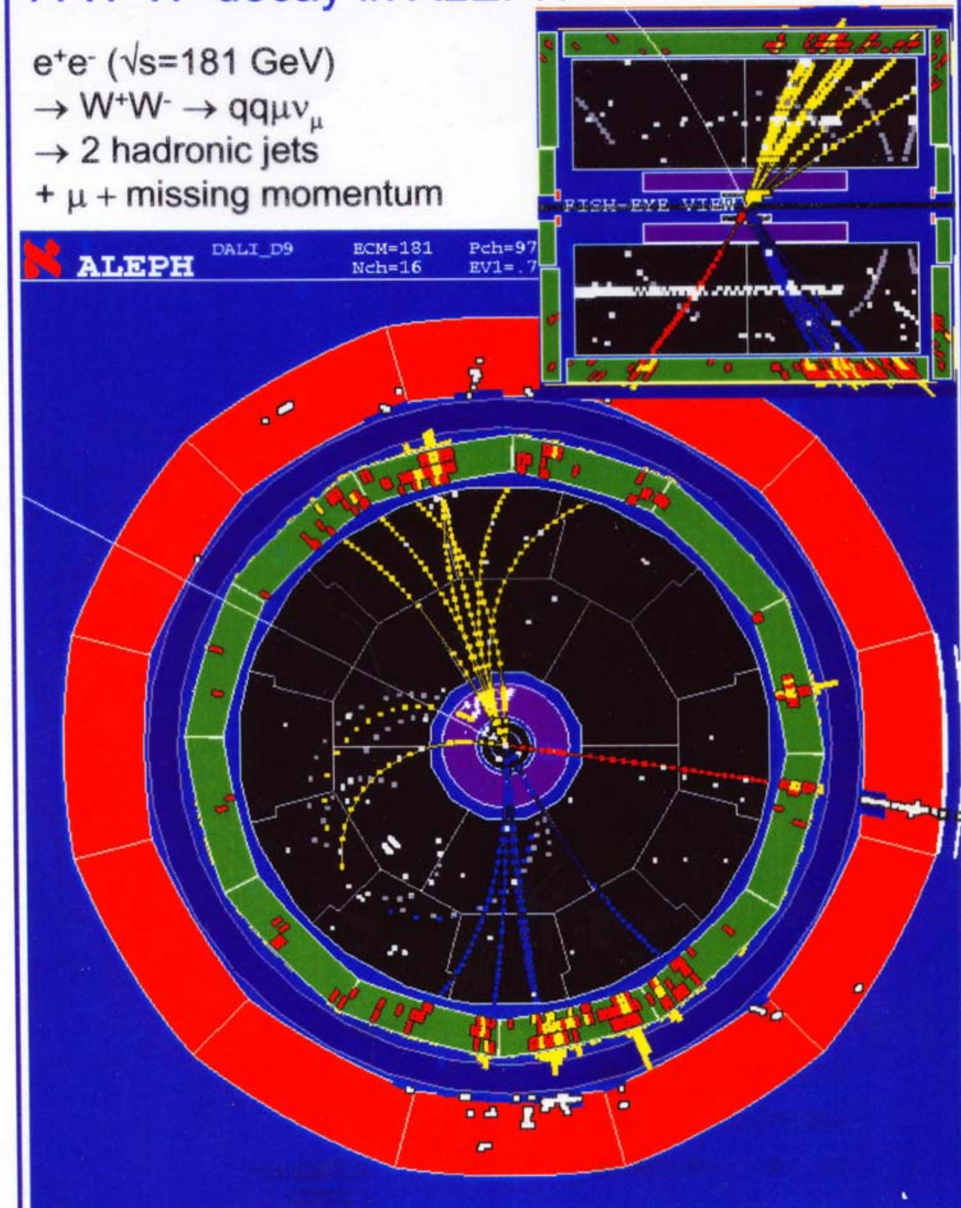
$$\Gamma_W = 2.12 \pm 0.042\ \ GeV$$

$$Dati\ e^+e^- \qquad M_Z = 91.188 \pm 0.002\ \ GeV$$

$$\Gamma_Z = 2.495 \pm 0.0025\ \ GeV$$

A W^+W^- decay in ALEPH

e^+e^- ($\sqrt{s}$=181 GeV)
$\rightarrow W^+W^- \rightarrow qq\mu\nu_\mu$
$\rightarrow$ 2 hadronic jets
$+ \mu +$ missing momentum



Sezione d'urto WW,ZZ per ogni β

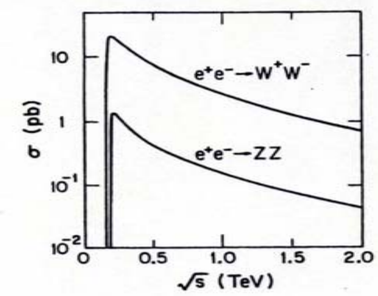


Fig. 8.19. Total cross sections for $e^+e^- \to W^+W^-$ and ZZ versus the total c.m. energy $\sqrt{s}$.

$$\sigma(WW, scambio\ \nu) \sim \frac{\pi\alpha^2 s}{96 \sin^2\theta_W M_W^4}$$

$$\sigma(WW, totale) \sim \frac{\pi\alpha^2}{\sin^2\theta_W s} \ln\left(\frac{s}{M_W^2}\right)$$

Distribuzioni angolari

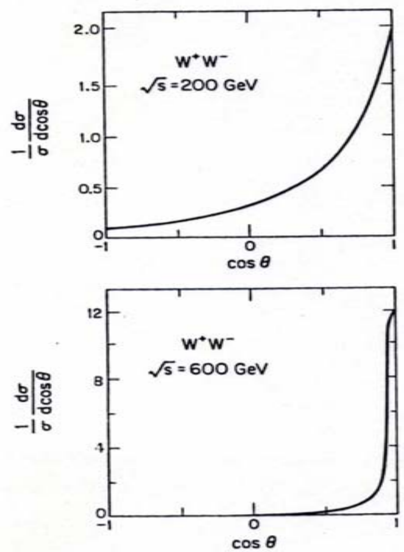
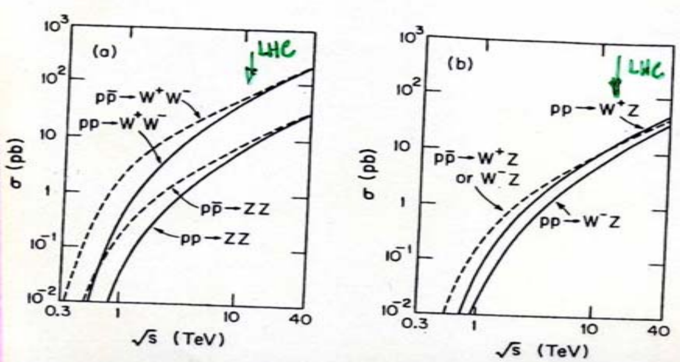


Fig. 8.20. Angular distribution of $e^+e^- \to W^+W^-$. θ is the angle between W^+ and e^+.

La distribuzione angolare molto piccata in avanti e' separabile da segnali ex H⟶WW che sono piu' centrali

Sezioni d'urto in interazioni protone-protone protone-antiprotone



Diagrammi per $p\bar{p}, pp \to WZ$?

Incertezze sulla scala di massa

Necessita' di calibrazione assoluta del calorimetro (pC=GeV) a un test beam con fasci noti di elettroni, muoni, pioni.

Ma sia la risposta della parte attiva del calorimetro, ad es. lo scintillatore, che dell'elettronica, ad es. i fotomoltiplicatori, possono cambiare con il tempo.

Necessaria una calibrazione durante tutto il periodo di presa dati con:
-light flashers;
-sorgenti radioattive;
-ricalibrazioniu di alcuni moduli

Incertezze di calibrazione: "cell to cell" (risoluzione), scala assoluta di energia:

$$\pm 3.2\,\%\ \mathrm{UA1}, \pm 1.6\,\%\ \mathrm{UA2},\ \leq 0.1\,\%\ \mathrm{CDF}\ (\text{calibrazione con l'impulso})$$

N.B. del 1.6 % di UA2 ~ 0.7 viene dalla cattiva conoscenza dell' energia del fascio al test beam

N.B. in $e^+e^- \longrightarrow e^+e$, e $e^+e^- \longrightarrow jj$ le energie dei fasci danno una calibrazione "in situ"
Molto piu' difficile in interazione adroniche dove non ho un fascio di partoni iniziali "monocromatici", ma posso tuttavia utilizzare risonanze note:

J/Ψ (m=3.1 GeV), Υ(m=9.5 GeV), Z(m=91 GeV)

Esempio di calibrazione per il calorimetro adronico di ATLAS

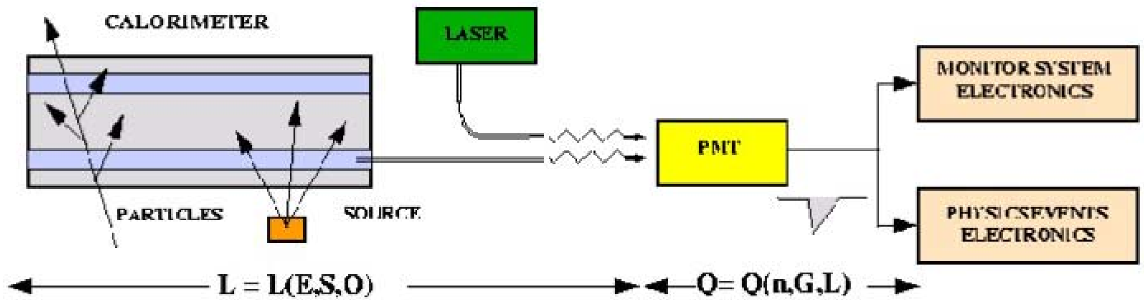


Figure 7-1 Conceptual diagram of signal path for the Tile Calorimeter and calibration entry points (see text for definitions of the functions L and Q).

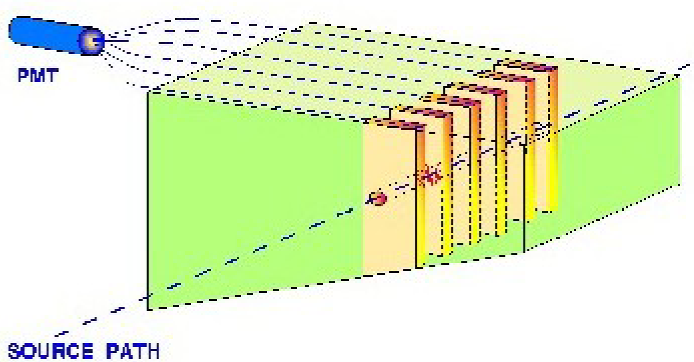


Figure 7-5 Mechanical concept of the source calibration system.

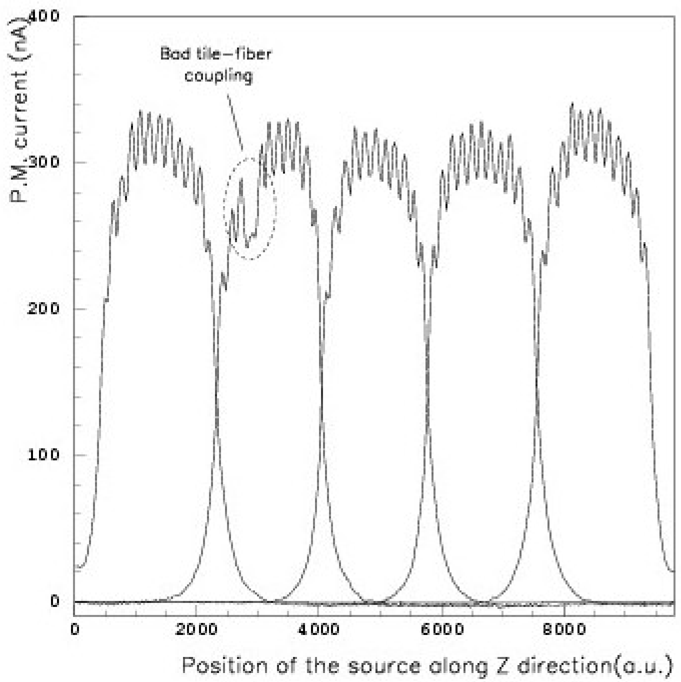


Figure 7-6 Current measured in the PMTs as a function of the source position along the rod (z axis).

J/ψ (media mon.)
: 3096.88 ± 0.04 KeV
Γ_T = 88 ± 5 KeV

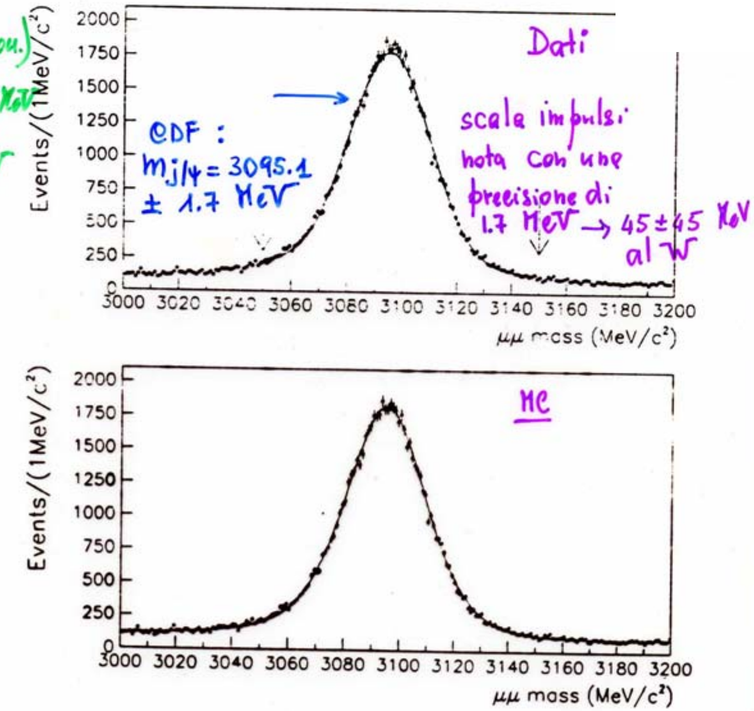


Figure 3.5: The dimuon mass spectrum from the data, points, near the J/ψ mass in a 200 MeV/c² window. Upper: The curve is a Gaussian fit with a linear background in a 100 MeV/c² window. The arrows indicate the fit region. Lower: The curve is a Monte Carlo simulation including radiative effects.

Correzioni estrapolate alla Υ per verifica

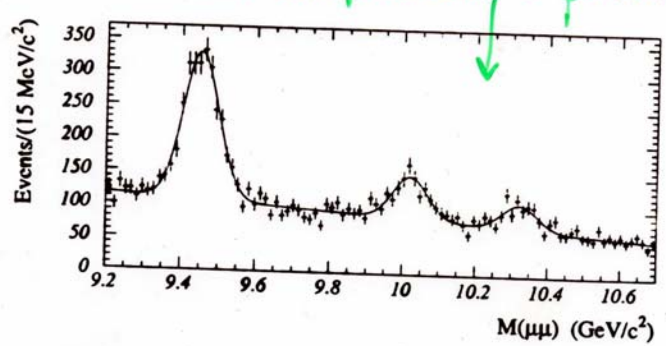


Figure 3.6: The dimuon mass spectrum near the Υ mass. The fits are Gaussian with a quadratic background.

CDF

Perche' e' importante misurare con precisione M_W

Nello Standard Model le relazioni tra le costanti fondamentali sono:

$$g_W^2 = \frac{e^2}{\sin^2\theta_W}; g_W^2/4\pi = \frac{\alpha}{\sin^2\theta_W};$$

$$\frac{G}{\sqrt{2}} = \frac{g_W^2}{M_W^2}; M_W = \sqrt{\frac{\pi\alpha}{G\sin^2\theta_W}}$$

$$g_z^2 = \frac{e^2}{\sin^2\theta_W\cos^2\theta_W}; g_Z^2/4\pi = \frac{\alpha}{\sin^2\theta_W\cos^2\theta_W};$$

$$M_W = M_Z\cos\theta_W$$

Solo 3 parametri sono indipendenti ex:

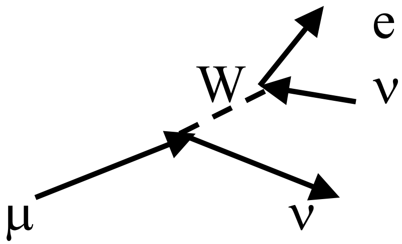
$$\alpha, \left[\frac{\Delta\alpha}{\alpha}\right] = 0.004\cdot 10^{-6} \text{ (a } \mathrm{Q}^2 = 0\text{) dai livelli atomici;}$$

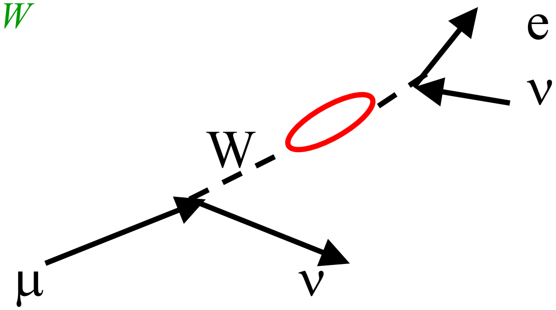
$$\mathrm{G}, \left[\frac{\Delta \mathrm{G}}{\mathrm{G}}\right] = 9\cdot 10^{-6} \text{ (dal decadimento } \mu \to \mathrm{e}\nu\nu\text{);}$$

$$\mathrm{M_W}, \left[\frac{\Delta M_W}{M_W}\right] = 500\cdot 10^{-6}; \sin^2\theta_W, \left[\frac{\Delta\sin^2\theta_W}{\sin^2\theta_W}\right] = 70\cdot 10^{-6}$$

Le relazioni a livello albero sono modificate da correzioni radiative. Ex:

$$\frac{G}{\sqrt{2}} = \frac{g_W^2}{8M_W^2} \rightarrow \frac{G}{\sqrt{2}} = \frac{g_W^2}{8M_W^2}(1-\Delta r)$$

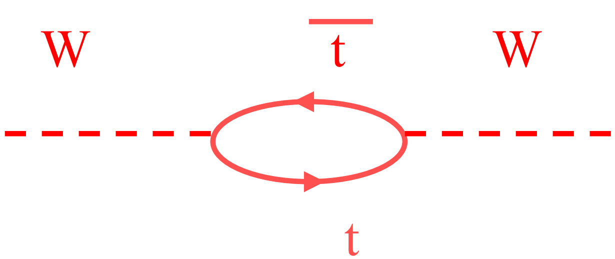


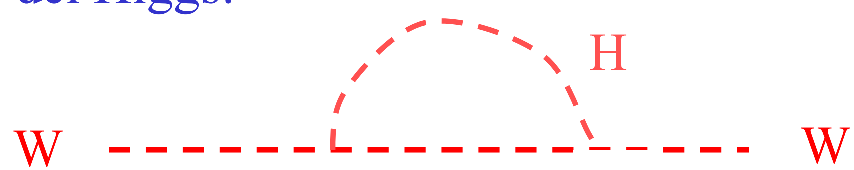


$$da: M_W^2 = \frac{\pi\alpha}{G\sin^2\theta_W\sqrt{2}} \rightarrow \sin^2\theta_W\cos^2\theta_W = \left(1-\frac{M_W^2}{M_Z^2}\right)\frac{M_W^2}{M_Z^2} = \frac{\pi\alpha(M_Z)}{\sqrt{2}GM_Z^2(1-\Delta r)}$$

$$\Delta r \sim \Delta\alpha + \frac{G}{8\sqrt{2}\pi^2}\left(-3\cot^2\theta_W m_t^2 + \frac{11}{3}M_W^2\ln\frac{M_H^2}{M_W^2}\right)+\dots \qquad \Delta\alpha \cong 1-\frac{\alpha}{\alpha(M_Z^2)} \approx 0.06$$

Le correzioni alla M_W vengono da loop con t e H e quindi sono sensibili alla massa del top e del Higgs:

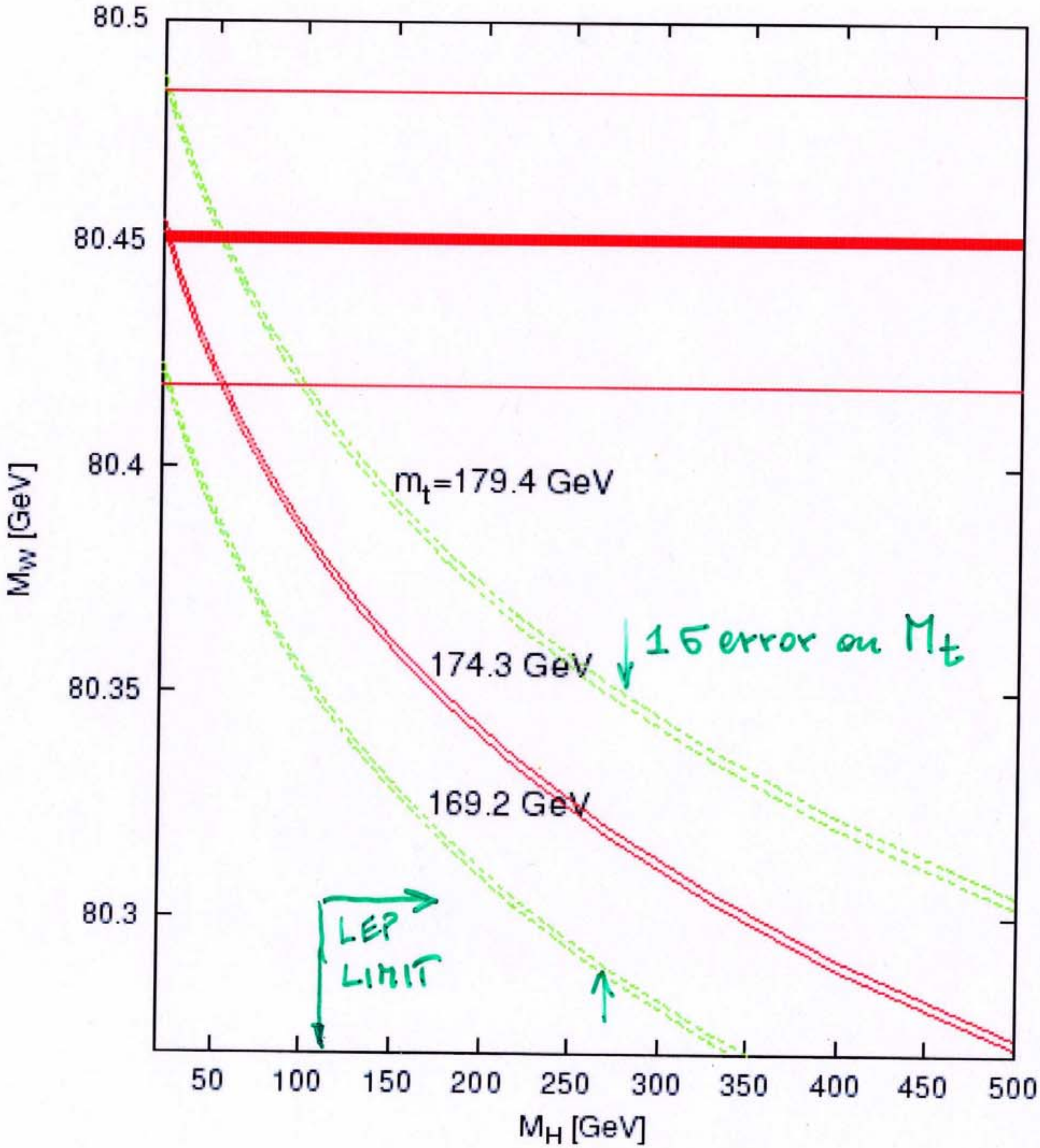




Plot m_W vs m_H

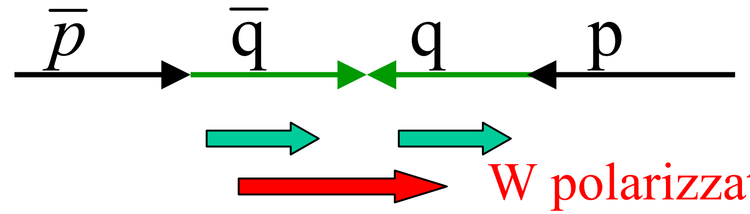
m_W points to a light Higgs

Like $[\sin^2\theta_{eff}]_l$



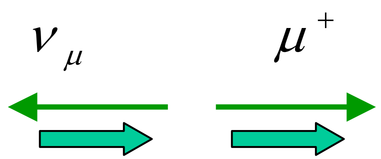
Asimmetria di carica nei decadimenti di $W^{\pm}$

Dominio dei quark di valenza:

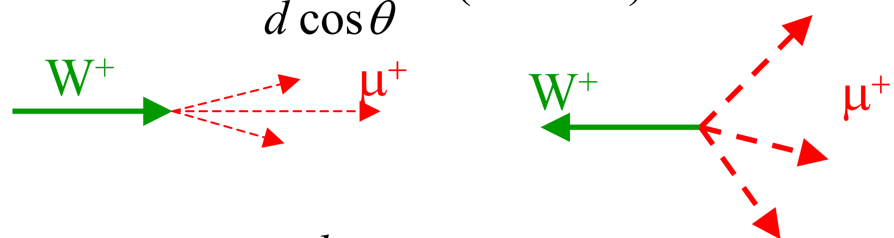


W polarizzato con elicita' h=+1 o h=-1

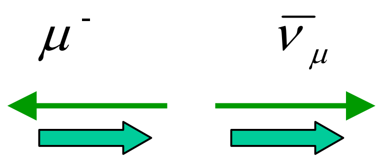
W^{+}, θ=angolo tra $\bar{q}$ ($\bar{p}$) e il μ^{+}: nel cm $\frac{d\sigma}{d\cos\theta} \propto (1+\cos\theta)^2$



Nel lab:



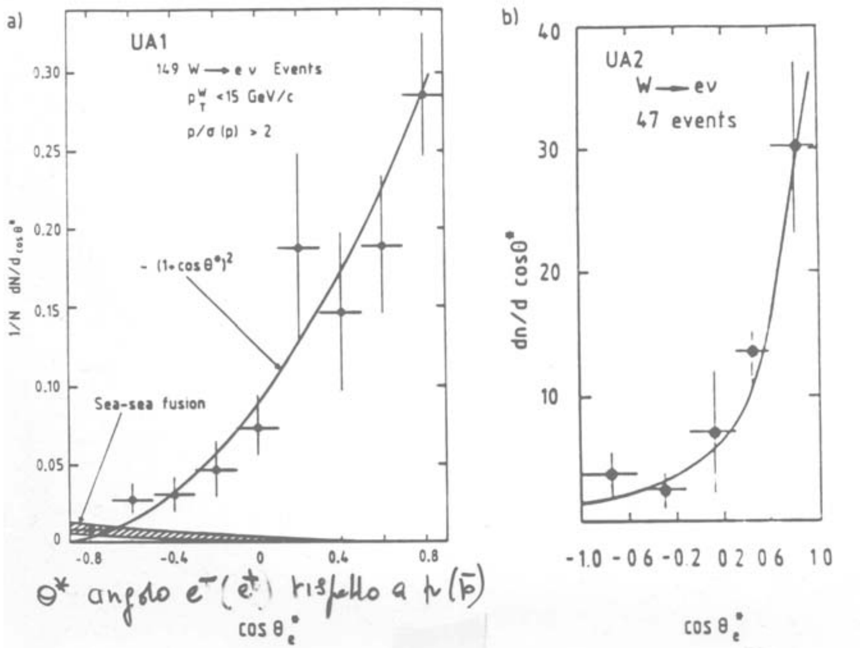
W^{-}, θ=angolo tra q (p) e il μ^{-}: nel cm $\frac{d\sigma}{d\cos\theta} \propto (1+\cos\theta)^2$



Nel lab:

Nel decadimento i leptoni (μ^{-} e ν_{μ}) sono emessi preferenzialmente opposti alla polarizzazione del W e viceversa per gli antileptoni (μ^{+} e $\bar{\nu}_{\mu}$)

Per verificare la $(1+\cos\theta)^2$ bisogna andare nel cm del W, cioe' bisogna conoscere p^{μ} e p^{ν}. Tuttavia del neutrino si conosce solo l'impulso trasverso (impulso mancante). Si puo' trovare p_L^{ν} imponendo che $2(|\vec{p}_{\mu}|\left|\sqrt{p_{T\mu}^2 + p_{L\mu}^2}\right|)(1 - \vec{p}_{T\mu}\cdot\vec{p}_{T\nu} - p_{L\mu}p_{L\nu}) = M_W^2$



N.B. $(1+\cos\theta)^2$ non distingue tra V-A e V+A: tutte le elicita' cambiano segno e la distribuzione resta la stessa. Bisogna misurare l'elicita' del leptone. Ad es. nel decadimento:

$$W^- \rightarrow \tau^- \overline{\nu}_\tau, \tau^- \rightarrow \mu^- \overline{\nu}_\mu \nu_\tau$$

il μ^- e' emesso preferenzialmente all'indietro rispetto alla direzione di volo del τ^- (V-A).

Spin del W (M.Jacob N.Cimento 9,826 (1058)): data una particella di spin J≠0 generata da una coppia con elicita' globale μ (il sistema $u\overline{d}$) e che decade in una coppia di particelle con elicita' λ (il sistema $e^+\nu$) vale:

$$\left\langle \cos\theta^* \right\rangle = \frac{\langle\lambda\rangle \cdot \langle\mu\rangle}{J(J+1)}$$

$$per\,(\mathrm{V\text{-}A})\langle\mu\rangle = -1, \langle\lambda\rangle = -1 \Rightarrow \left\langle \cos\theta^* \right\rangle = 0.5\,\mathrm{se\,J} = 1;$$

$$\leq 1/6\,\mathrm{se\,J} \geq 2.$$

$$\mathrm{Sperimentalmente}\left\langle \cos\theta^* \right\rangle = 0.43 \pm 0.07\,(\mathrm{UA1})$$

La larghezza adronica del W dipende dalla massa del top e sarebbe possibile se :

$\mathbf{m_t < M_W - m_b}$

CDF

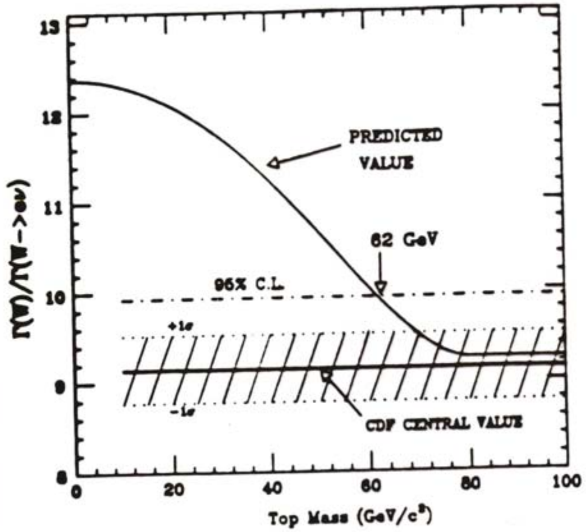


Fig.4. The predicted dependence of the inverse of the branching ratio, $\Gamma(W)/\Gamma(W \to e\nu)$, as a function of top mass. The preliminary results from CDF are shown, with both the 68% and 95% confidence limits.

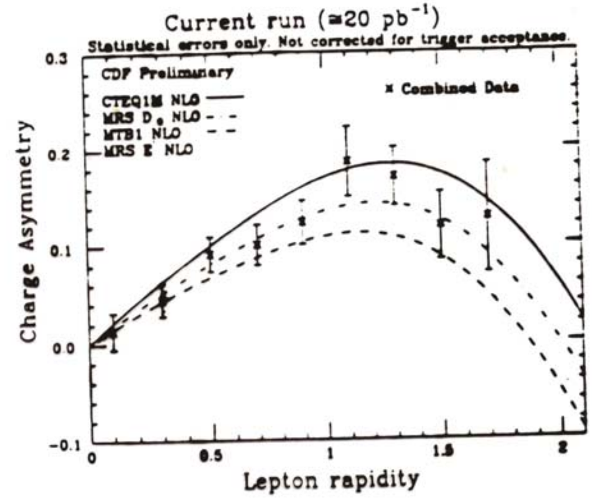
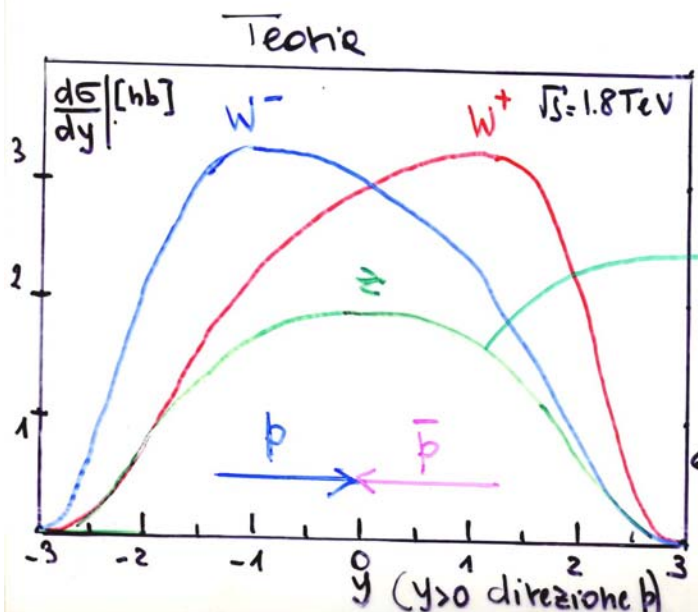


Fig. 5. Preliminary results on the forward-backward charge asymmetry versus lepton rapidity.

a fissa rapidità (θ) si calcola $\dfrac{N(e^-) - N(e^+)}{N(e^-) + N(e^+)}$



Simmetrica per CP

Ancora evidenza di violazione P e C.

N.B. l'asimmetria nelle $\frac{d\sigma}{dy}$ dipende dall'asimmetria u, d : u è mediamente più veloce di d.

$x_p = \frac{M_W}{\sqrt{s}} e^{y}$; $x_{\bar p} = \frac{M_W}{\sqrt{s}} e^{-y}$

Asimmetria $\frac{d\sigma}{dy}(W^+)$: $\frac{d\sigma}{dy}^{W^+} = \frac{k\,2\pi G}{3\sqrt{2}}\, x_p u(x_p)\, x_{\bar p} d(x_{\bar p})$

ex con $x u(x) = 1.8\sqrt{x}(1-x)^3$; $x d(x) = 0.7\sqrt{x}(1-x)^4$

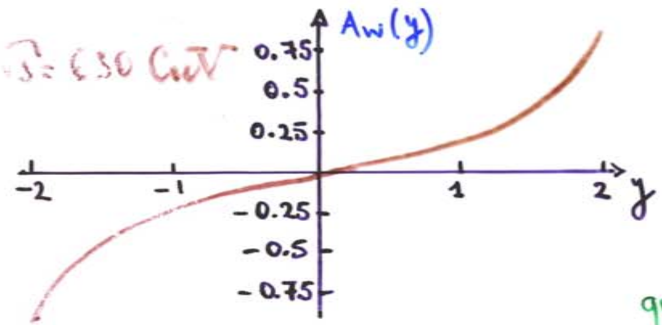
con W^- : $\left.\frac{d\sigma}{dy}\right|^{W^-} = \frac{k\,2\pi G}{3\sqrt{2}}\, x_p d(x_p)\, x_{\bar p} u(x_{\bar p})$

definendo : $A_W(y) = \dfrac{u(x_p)d(x_{\bar p}) - d(x_p)\cdot u(x_{\bar p})}{+} =$

$= \left(\left.\frac{d\sigma}{dy}\right|^{W^+} - \left.\frac{d\sigma}{dy}\right|^{W^-}\right) \Big/ \left(\left.\frac{d\sigma}{dy}\right|^{W^+} + \left.\frac{d\sigma}{dy}\right|^{W^-}\right)$

se $R(x) = d(x)/u(x)$ $\Rightarrow$ divid. per $u(x_p)\cdot u(x_{\bar p})$

$A_W = \dfrac{R(x_{\bar p}) - R(x_p)}{R(x_{\bar p}) + R(x_p)}$

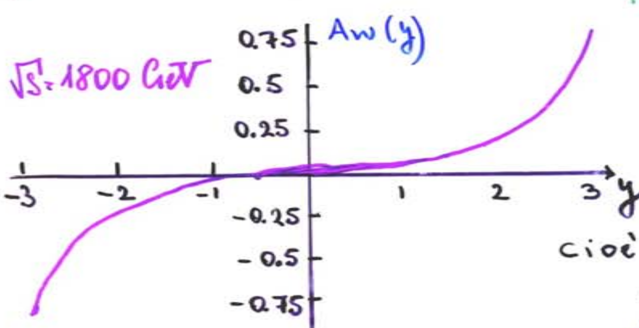


per $y \sim 0$: $x_p \sim \frac{M_W}{\sqrt{s}} + y\frac{M_W}{\sqrt{s}}$

$x_{\bar p} = \frac{M_W}{\sqrt{s}} - y\frac{M_W}{\sqrt{s}}$

quindi: $R(x_p) = R\left(\frac{M_W}{\sqrt{s}}\right) + y\frac{M_W}{\sqrt{s}} R'\left(\frac{M_W}{\sqrt{s}}\right)$

$R(x_{\bar p}) = \quad -$



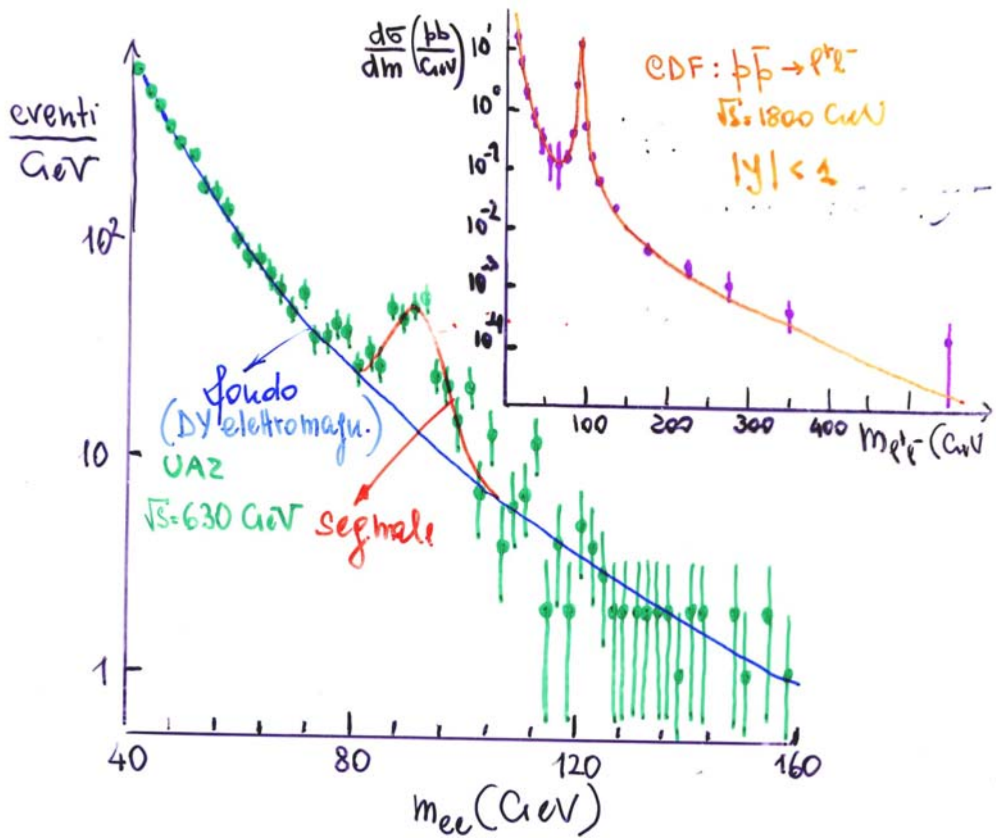
$\Rightarrow A_W \sim -y\frac{M_W}{\sqrt{s}} \cdot \dfrac{R'\left(\frac{M_W}{\sqrt{s}}\right)}{R\left(\frac{M_W}{\sqrt{s}}\right)}$

cioè : A_W è lineare a $y \sim 0$; e la pendenza è $\propto$ alla derivata di $\frac{d(x)}{u(x)}$ a $x = \frac{M_W}{\sqrt{s}}$

N.B nel nostro esempio: $\frac{d(x)}{u(x)} = (1-x)$!!

Misura dello Z

Piu' facile da misurare del W: $Z \longrightarrow e^+e^-$. In UA1, UA2 l'efficienza per $e^\pm \sim 75$ % e quindi per la coppia sarebbe ~ 50%. Si applica una selezione severa solo su uno dei due rami.

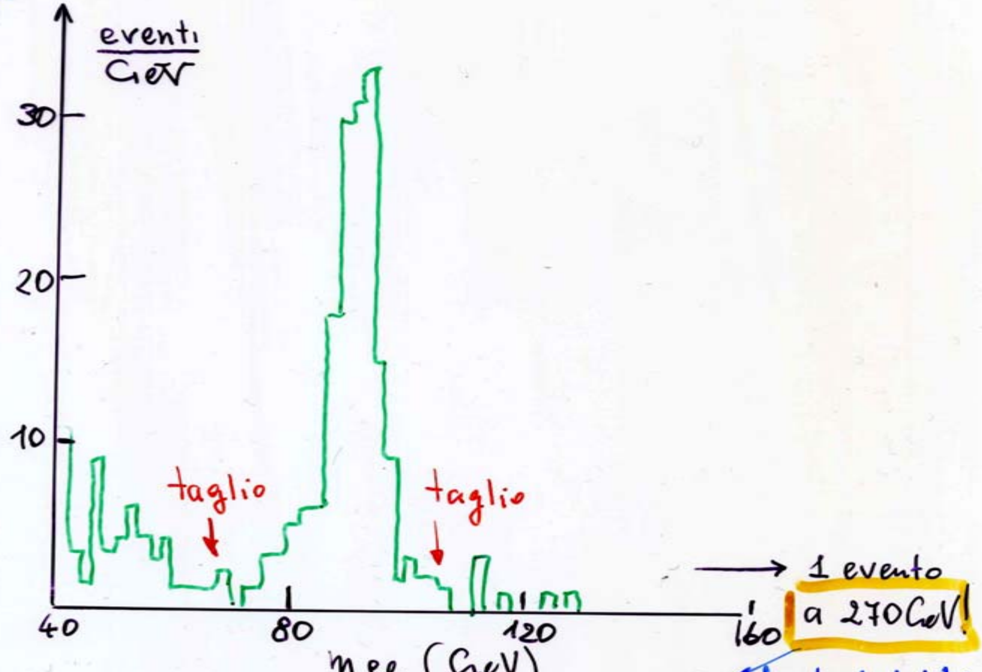


Le distribuzioni di massa invariante ottenute solo con la richiesta calorimetrica, senza richiedere la presenza di una traccia carica che punta al jet calorimetrico.

Analisi Z in UA2 :

richiesta elettrone "standard solo su 1 ramo
secondo ramo tagli meno severi ⟹

- 169 eventi $76 < m_{ee} < 110$ GeV
- Fondo 2.4 ± 0.4 eventi ($\pi^0\, \pi^0$)
- c'e' qualche evento $Z \to ee\gamma$ [3 cluster e.l.m.] in questo caso masse invariante e 3 corpi



quale la probabilità

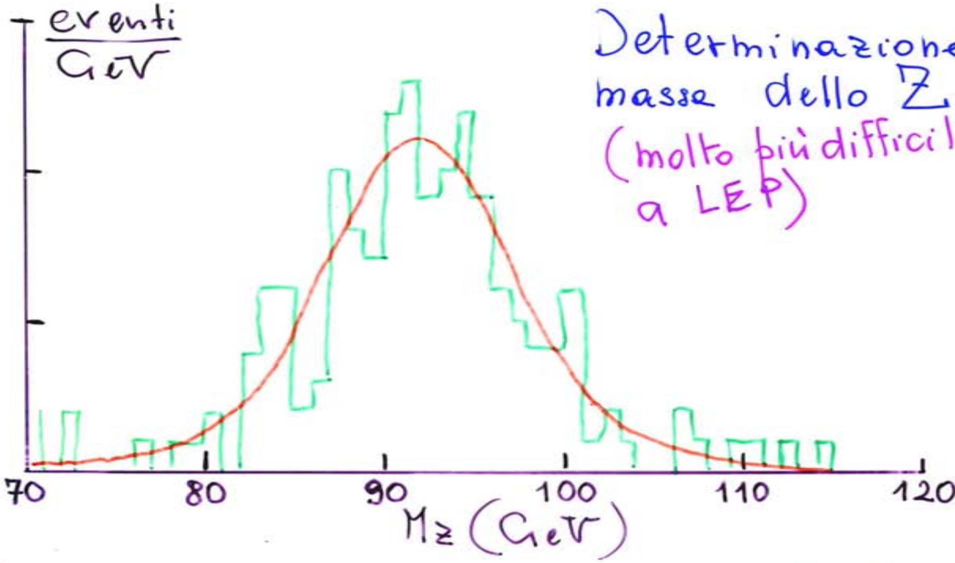
Sezione d'urto:

ε_{eff} = Accettanza * efficienza tagli

$\sigma_Z = N_Z / \mathcal{L} \cdot \varepsilon_{eff.}$ ⟹

$\sigma_{Z \atop Z\to e^+e^-}(p\bar{p}, \sqrt{s} = 630\text{ GeV}) = 70.4 \pm 5.5 \pm 4.0$ pb

Determinazione massa dello Z (molto più difficile che a LEP)



N.B. La B/W realtivistica:

$$\frac{s}{(s\text{-}M_Z)^2 + \frac{s^2}{M_Z^2}\Gamma_Z^2} \quad \textit{rispetto a}$$

quella normale: $\dfrac{s}{(s\text{-}M_Z)^2 + M_Z^2\Gamma_Z^2}$

e' deformata leggermente a favore dei valori $s < M_Z^2$ *per tener conto di possibili effetti radiativi iniziali.*

funzione di probabilità per il fit (max likelihood)

espressione analitica (a ciascun mee misurato): $\mathcal{L} = \prod f_i$; $\begin{cases} \frac{\partial \ln \mathcal{L}}{\partial m_Z} = 0 \\ \frac{\partial \ln \mathcal{L}}{\partial \Gamma_Z} = 0 \end{cases}$

distorsione dovuta alle luminosità partoniche crescenti

$$f(\underbrace{m_{ee}, \sigma}_{\text{input}}, \underbrace{m_Z, \Gamma_Z}_{\text{output}}) \propto \int dm' \underbrace{\frac{m'^2 \exp(-\beta m')}{(m'^2 - m_Z^2)^2 + m'^4 \Gamma_Z^2 / m_Z^2}}_{\text{Breit/Wigner (relativistica) + densità partonica}} \times \underbrace{\exp\left[-(m_{ee} - m')^2 / 2\sigma^2\right]}_{\text{Risoluzione sperimentale } (\sigma \sim 3 \text{ GeV})}$$

Γ_Z fisso (2.5 GeV) o parametro libero

$M_Z = 91.74 \pm 0.28(\text{stat}) \pm 0.12(\text{sist.}) \pm \boxed{0.92(\text{scala})}$

(LEP: 91.187±0.007 ...).

Parametro libero Γ_Z: $M_Z = 91.7$

$\Gamma_Z = 2.96^{+0.98}_{-0.78}$ (Non si possono escludere ulteriori famiglie...)

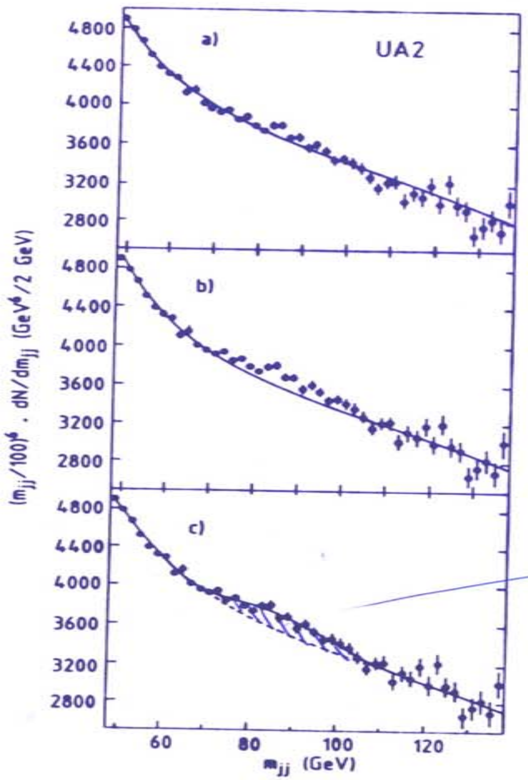
W e Z possono decadere in coppie quark (jet)

$$\frac{\Gamma(W \to \bar{q}q')}{\Gamma(W \to e\nu)} = 6.25 \qquad \frac{\Gamma(Z \to q\bar{q})}{\Gamma(Z \to e^+e^-)} = 21.1$$

Problema: identificazione e misure impulso jet

: Fondo da interazioni forti, $\sim 50/1$.

Fit: $G = B(\alpha, \beta, \gamma) + S(m_W, \sigma_m, N)$



$$B = m^{-\alpha} \cdot e^{-\beta m} \cdot e^{-\gamma m^2}$$

$$S = N \cdot \frac{1}{\sqrt{2\pi}} \cdot \Big\{$$

$$\Big\{ \frac{1}{\sigma_m} \exp\left[-\frac{(m_{jj} - m_W)^2}{\sigma^2_m}\right] +$$

$$+ \frac{1}{3\sigma_m} \exp\left[-\frac{(m_{jj} - m_Z)^2}{\sigma_m^2}\right] \Big\}$$

rapporto σ_Z / σ_W

$m_Z = 1.14\ m_W$

Parametri: $\alpha, \beta, \gamma, \sigma_m, m_W, N$

Segnale:

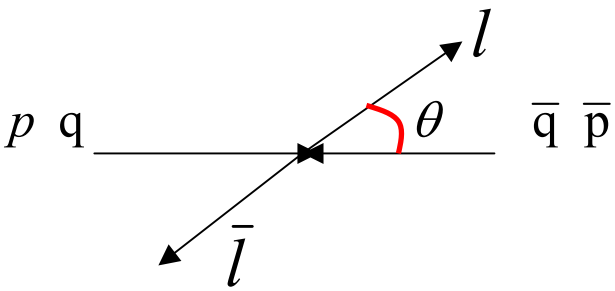
$N = 5618 \pm 1334$

aspettati dal modello Standard: $N \sim 4000$.

Fig. 4a–c. The two-jet mass spectrum in the region around the expected W, Z signal ($48 < m_{jj} < 138$ GeV). The vertical axis presents the number of observed events in a 2 GeV wide mass bin weighted by factors $(m/100)^6$. Three different fits have been overlayed on the data: **a** Background fit performed over the full mass range. **b** Background fit excluding the mass range $70 < m_{jj} < 100$ GeV. **c** Combined fit to QCD background and the W, Z signal described by 3 free parameters as explained in the text. The dashed line represents the background contribution only

Distribuzione angolare nel decadimento dello Z

Andiamo nel c.m. dello Z:



La distribuzione angolare e' analoga a quanto gia' visto nel caso:

$$e^+e^- \to Z \to f\bar{f}$$

$$g_Z = \frac{g_W}{\cos\theta_W}, \frac{g_W^2}{8\pi M_W^2} = \frac{G_F}{\sqrt{2}}$$

$$\frac{d\sigma}{d\Omega} = \left[\frac{g_Z^2 E}{16\pi\left\{\left[(2E)^2 - M_Z^2\right] + \left[M_Z\Gamma_Z\right]^2\right\}}\right]^2 \cdot$$

$$\left\{\left[(C_V^l)^2 + (C_A^l)^2\right]\cdot\left[(C_V^q)^2 + (C_A^q)^2\right]\cdot(1+\cos^2\theta) + 8C_V^l C_A^l C_V^q C_A^q \cos\theta\right\}$$

Osservazioni:

a)C'e' un termine di asimmetria in θ: ci sono piu' leptoni emessi nella direzione del quark incidente (protone) che nella direzione opposta:

la probabilita' di emissione e' maggiore a θ che a π–θ.

b)Il termine di asimmetria e' proporzionale a $C_V^l C_A^l C_V^q C_A^q$

che e' **una quantita' sensibile a $\sin^2\theta_W$**

$$C_V^l = -\frac{1}{2} + 2\sin^2\theta_W, C_A^l = -\frac{1}{2};$$

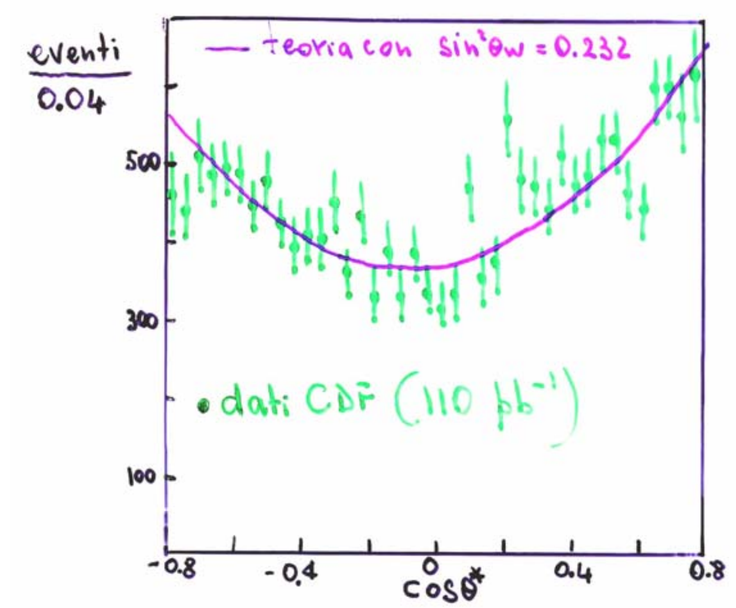
$$C_V^u = -\frac{1}{2} - \frac{4}{3}\sin^2\theta_W, C_A^l = \frac{1}{2};$$

$$C_V^d = -\frac{1}{2} + \frac{2}{3}\sin^2\theta_W, C_A^l = -\frac{1}{2}$$

La combinazione:

$$u\bar{u} + d\bar{d} \Rightarrow \text{termine di asimmetria} \propto (1 - 4\sin^2\theta_W)$$

ma $\sin^2\theta_W \sim 0.23$ ...



Bibliografia

-Barger/Phillips: “Collider physics”, Addison Wesley, 1997;

-R.K. Ellis et al.: “QCD and Collider physics”, Cambridge University Press ,1996.