

Elektroschwache Physik bei HERA und Tevatron und die Suche nach dem Higgs Boson



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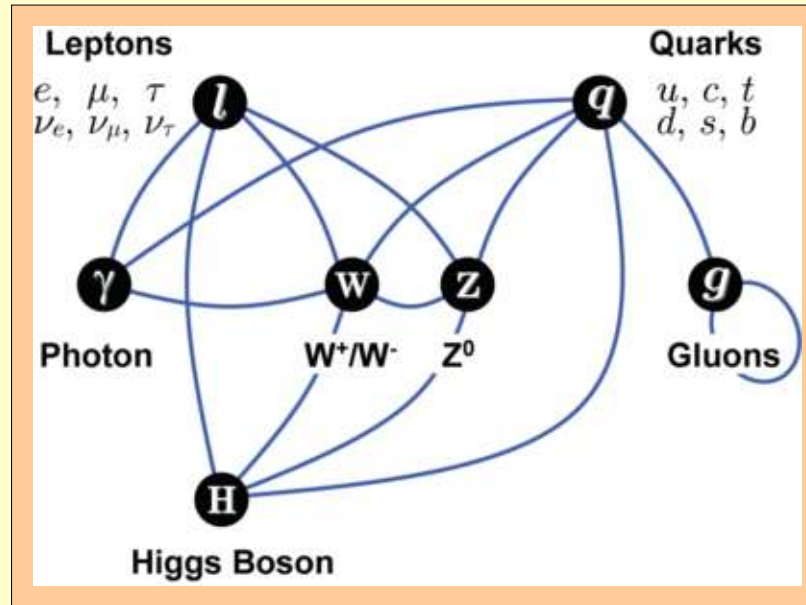


Überblick

- Einleitung
 - Standard Modell + Elektroschwache Physik
- HERA II
 - Neutrale + Geladene Strom, Polarisation
 - Kombinierte Elektroschwache+QCD Fits
- Tevatron Run II
 - W und Top Masse
 - Di-Boson Produktion
 - Higgs Suchen
- Zusammenfassung/Ausblick

Das Standard Modell (SM) der Teilchenphysik

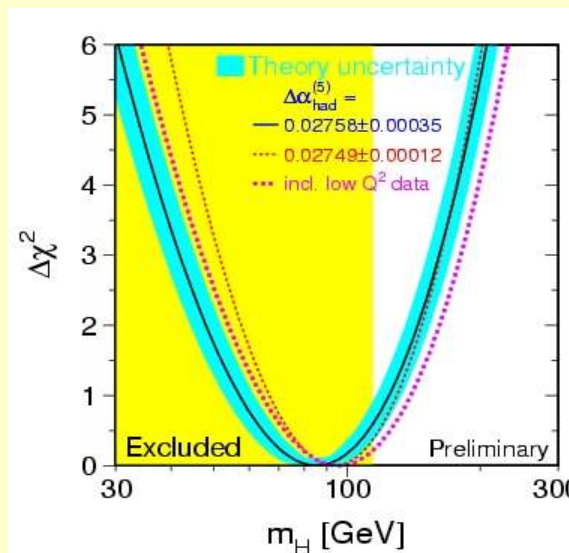
Leptons spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0
e electron	0.000511	-1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	-1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	-1



Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c ²	Electric charge
u up	0.003	2/3
d down	0.006	-1/3
c charm	1.3	2/3
s strange	0.1	-1/3
t top	175	2/3
b bottom	4.3	-1/3

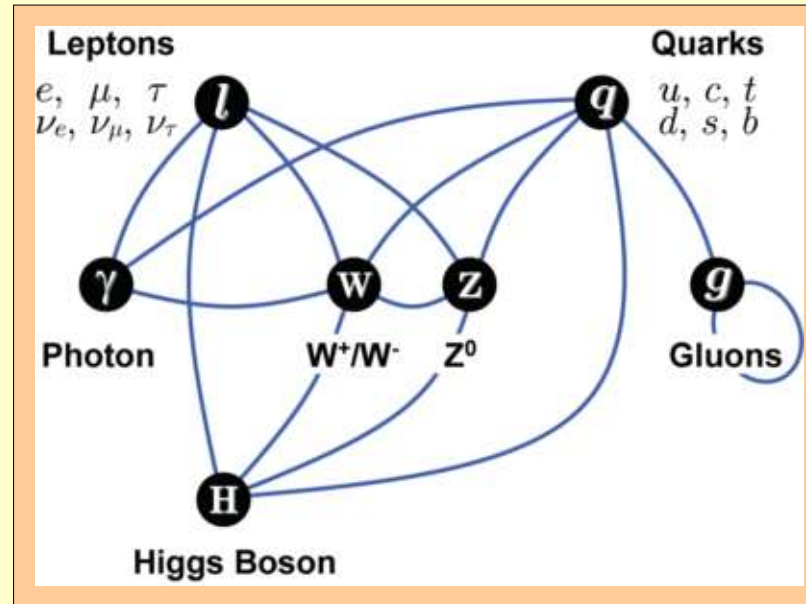
Unified Electroweak spin = 1		
Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W⁻	80.4	-1
W⁺	80.4	+1
Z⁰	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge
g gluon	0	0



Das Standard Modell (SM) der Teilchenphysik

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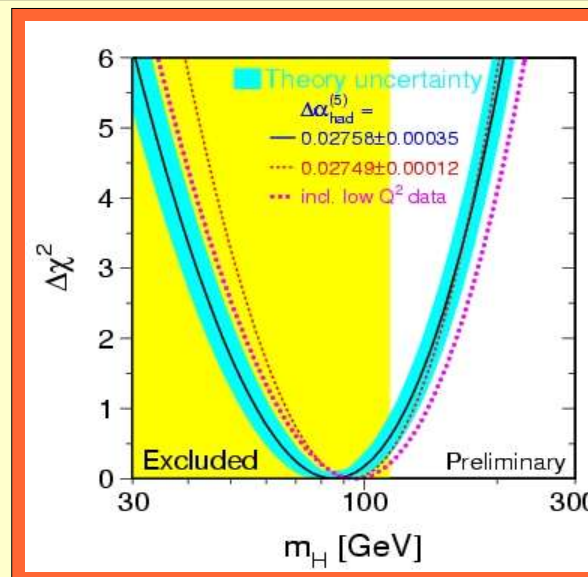
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Strong (color) spin = 1		
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T111.1 "NeutrinoPhysik"
Tobias Lachenmeyer

Unified Electroweak spin = 1		
Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W⁻	80.4	-1
W⁺	80.4	+1
Z⁰	91.187	0

T111.2 "Elektroschwache Physik"



T111.2 "The Quest of solving QCD"
Karl Jansen

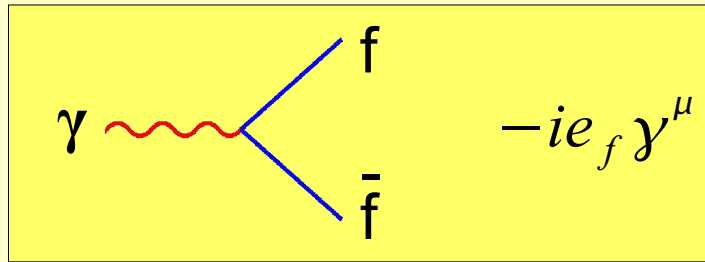
T113.1 "Heavy Flavour Physik"
Stefanie Menzemer

T113.2 "CP-Verletzung+Quark Mischung"
Heiko Lacker

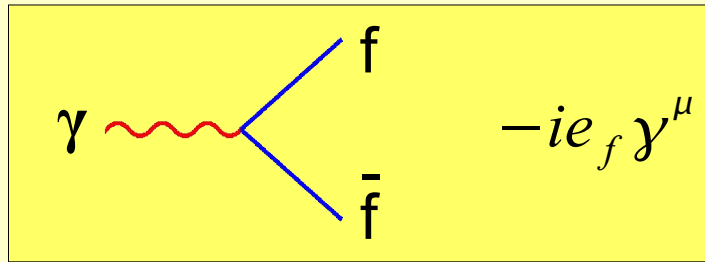
T114.1 "QCD Prazisionsmessungen"
Thomas Gehrmann

T114.1 "Proton Struktur und low x"
Victor Lendermann

Das Elektroschwache Model



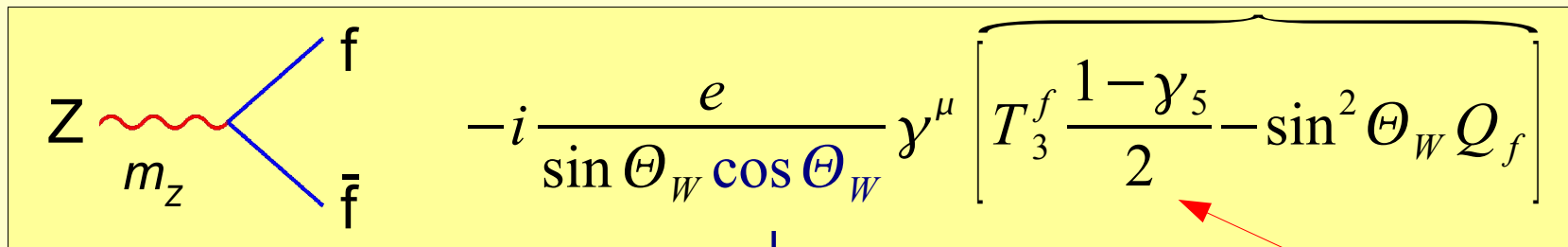
Das Elektroschwache Model



$$g_{A_f} \stackrel{\text{def}}{=} T_3^f \quad (=a_f)$$

$$g_{V_f} \stackrel{\text{def}}{=} T_3^f - 2 \sin^2 \Theta_W e_f \quad (=v_f)$$

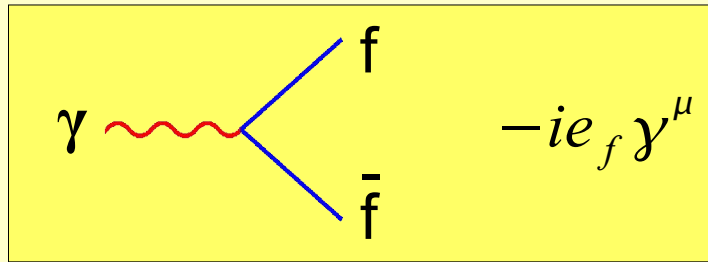
g_{A_f}, g_{V_f}



$\hookrightarrow = m_w / m_Z$

V-A Kopplung

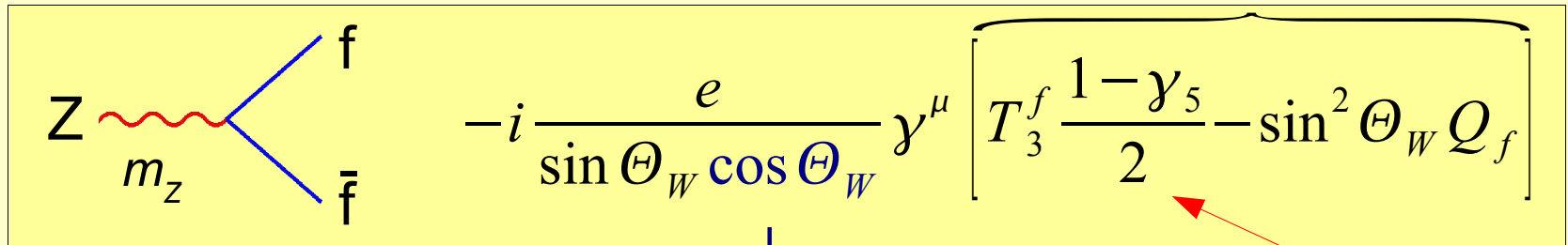
Das Elektroschwache Model



$$g_{A_f} \stackrel{\text{def}}{=} T_3^f \quad (=a_f)$$

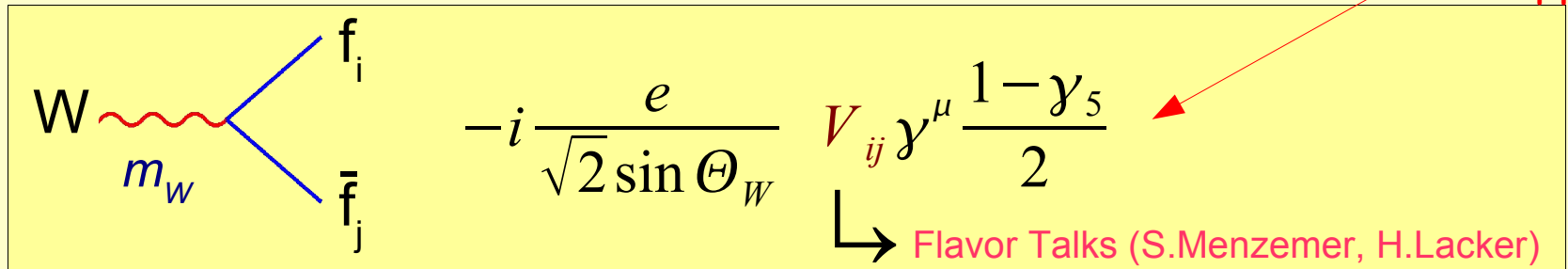
$$g_{V_f} \stackrel{\text{def}}{=} T_3^f - 2 \sin^2 \Theta_W e_f \quad (=v_f)$$

g_{A_f}, g_{V_f}



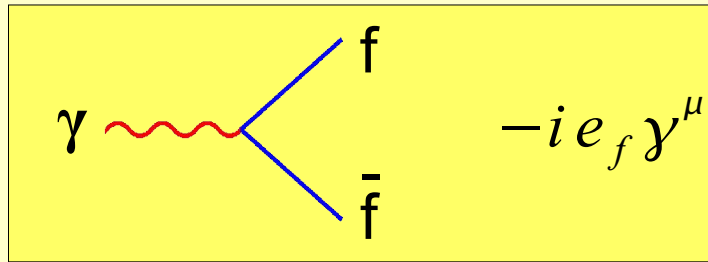
$\hookrightarrow = m_w / m_Z$

V-A Kopplung



\hookrightarrow Flavor Talks (S.Menzemer, H.Lacker)

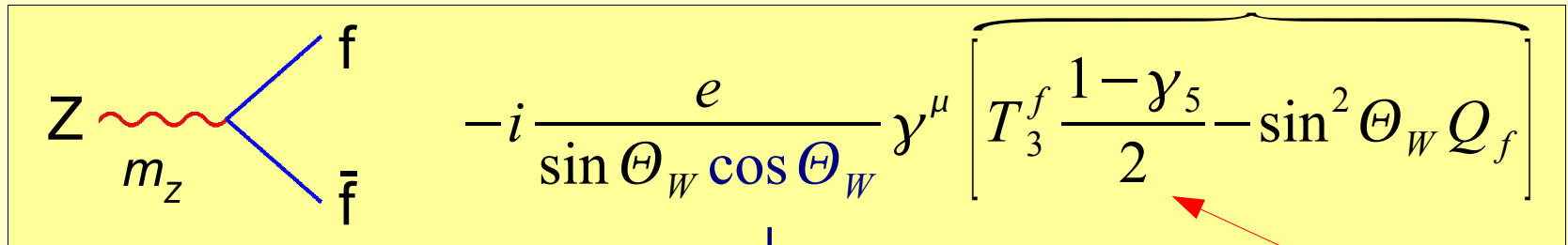
Das Elektroschwache Model



$$g_{A_f} \stackrel{\text{def}}{=} T_3^f \quad (=a_f)$$

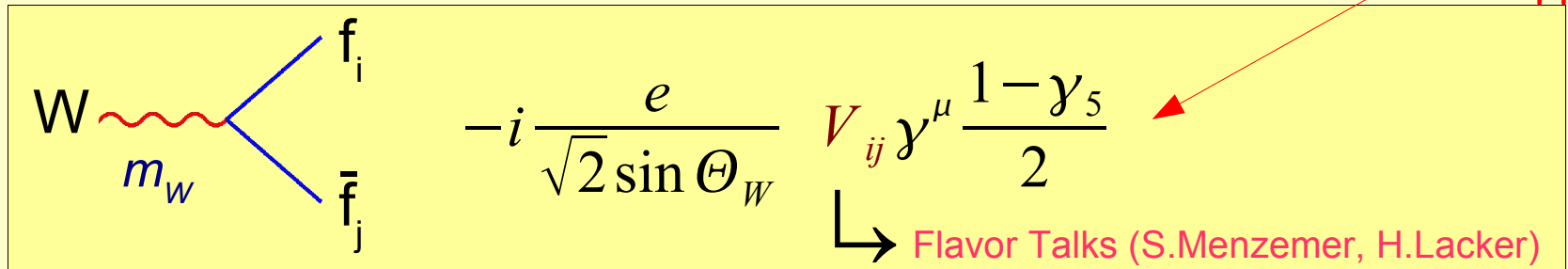
$$g_{V_f} \stackrel{\text{def}}{=} T_3^f - 2 \sin^2 \Theta_W e_f \quad (=v_f)$$

g_{A_f}, g_{V_f}

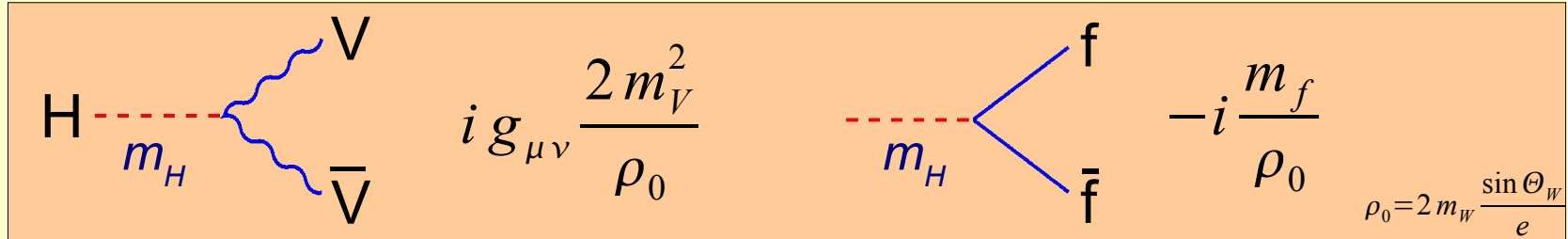


$\hookrightarrow = m_w/m_Z$

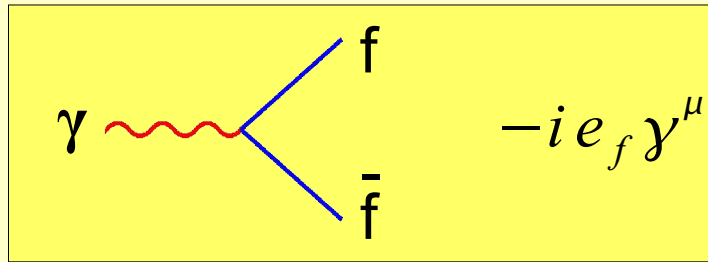
V-A Kopplung



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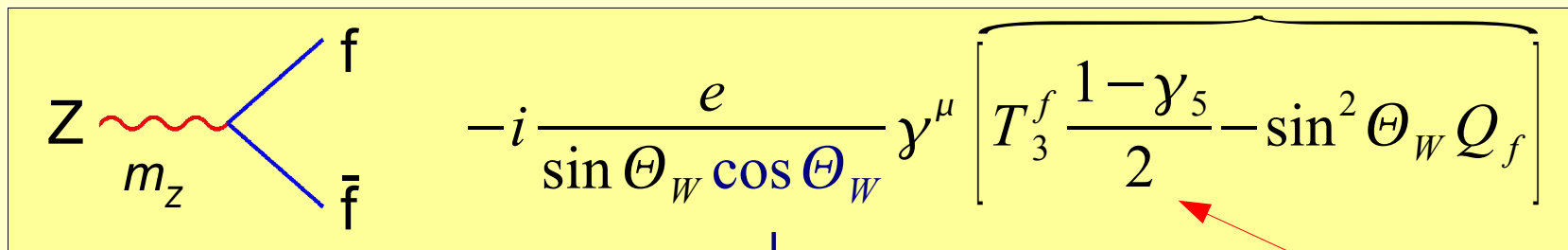
Das Elektroschwache Model



$$g_{A_f} \stackrel{\text{def}}{=} T_3^f \quad (= a_f)$$

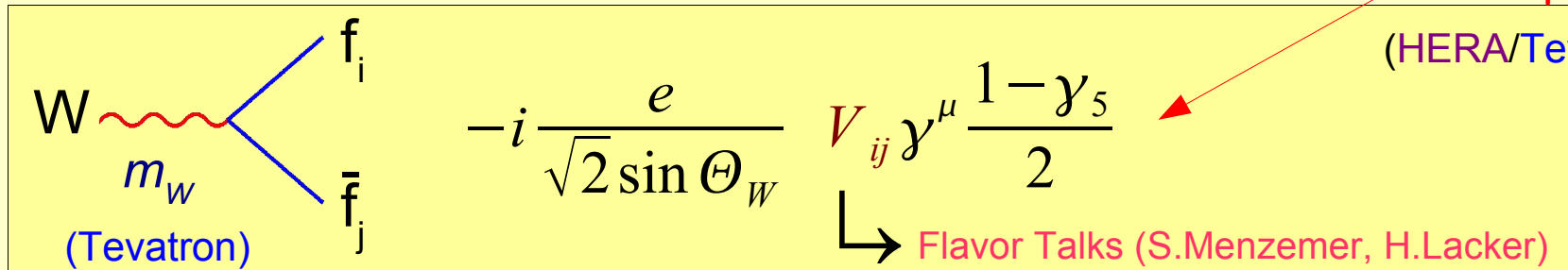
$$g_{V_f} \stackrel{\text{def}}{=} T_3^f - 2 \sin^2 \Theta_W e_f \quad (= v_f)$$

$g_{A_f}, g_{V_f} \leftarrow$ (HERA)

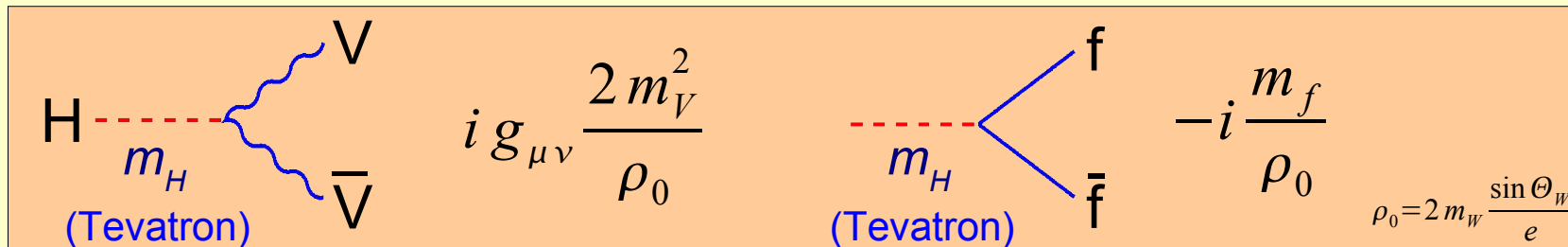


$\hookrightarrow = m_w / m_Z$

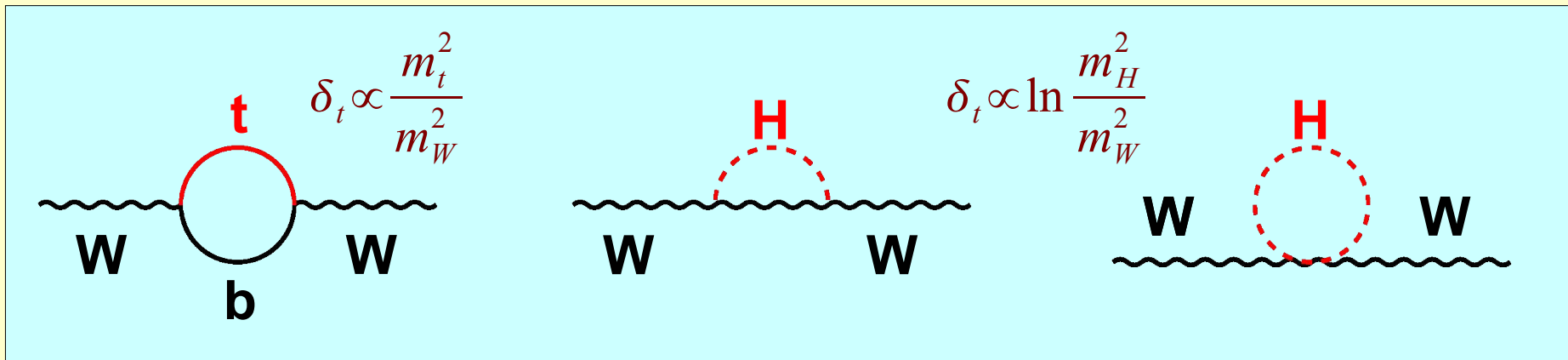
V-A Kopplung
(HERA/Tevatron)



\hookrightarrow Flavor Talks (S.Menzemer, H.Lacker)

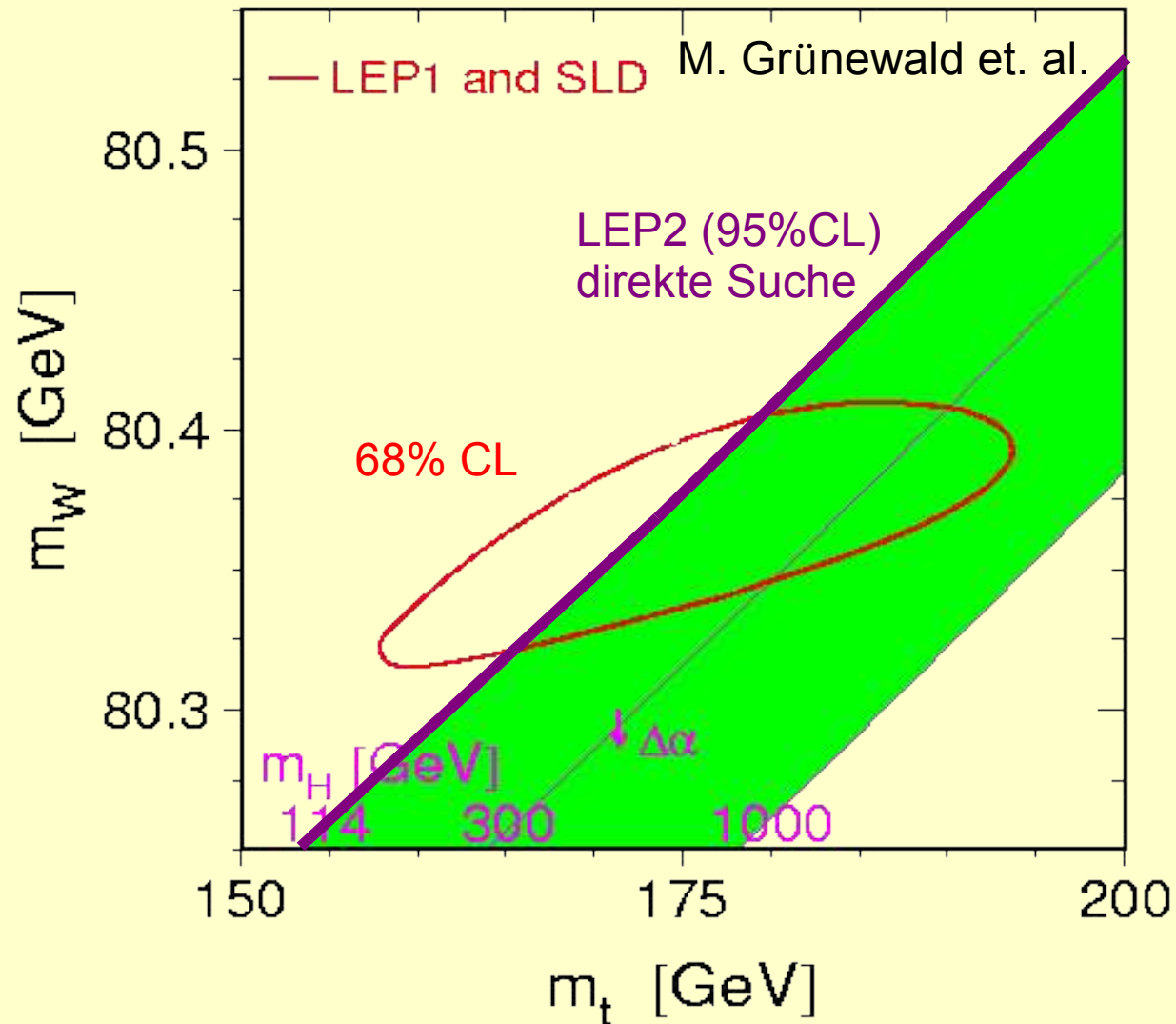


- Higgs und top Masse tragen bei zu W,Z-Selbstenergiekorrekturen
→ **Vorhersagen!**
- EW Kopplungskonstanten sind klein (im Gegensatz zur QCD)
→ **störungstheoretische Rechnungen!**



SM Vorhersagen

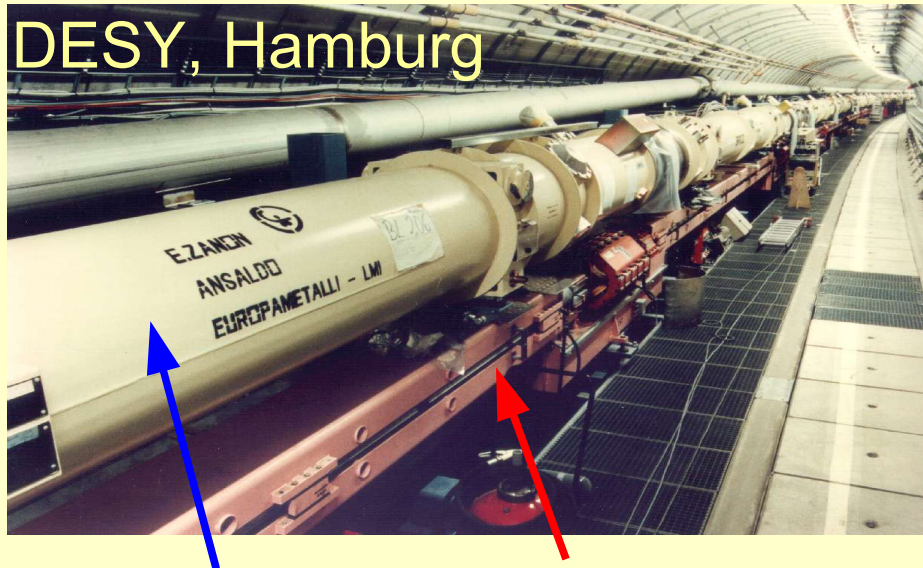
Vorhersage von m_t und m_H durch SM Präzisionsmessungen über virtuelle Loopeffekte



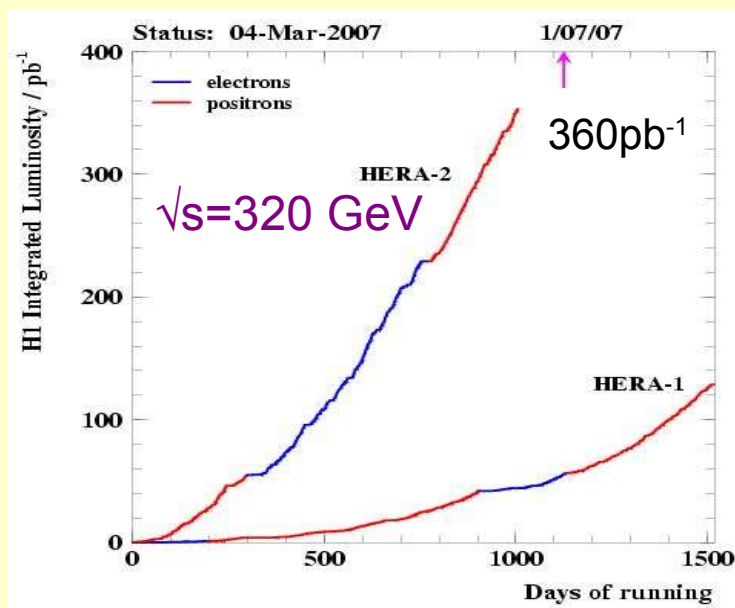
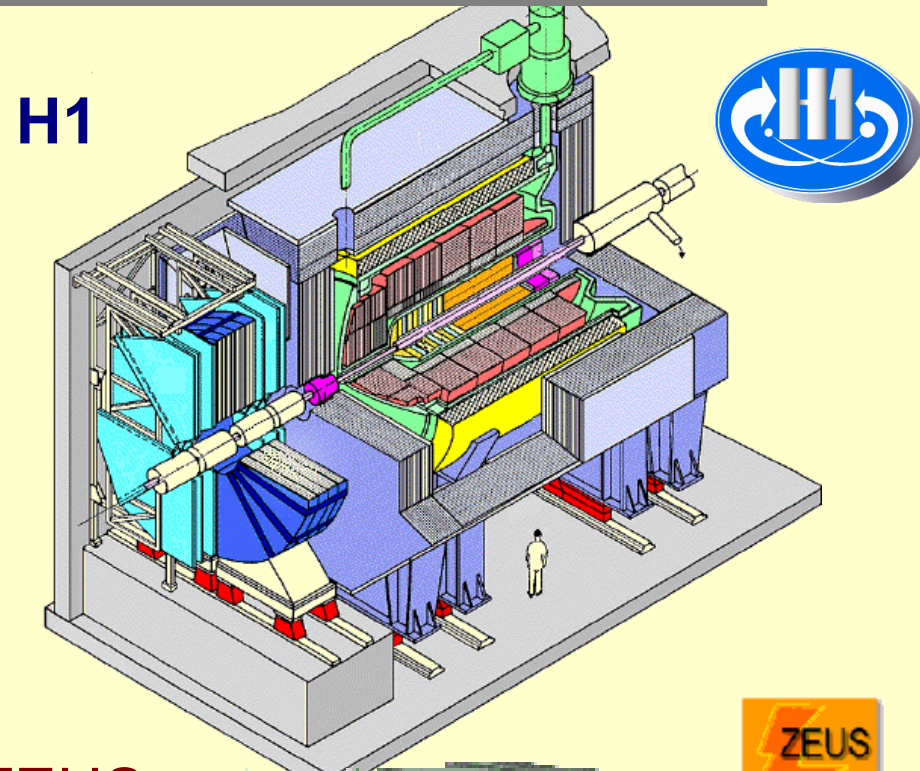
SM erlaubt!

LEP2
+
Tevatron
→ später

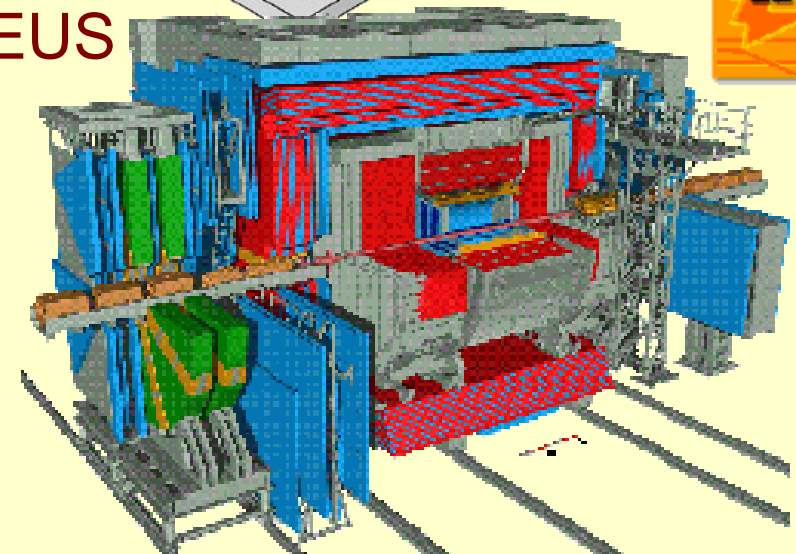
Elektron-Proton Collider HERA



920 GeV Protonen + 27.5 GeV Elektronen

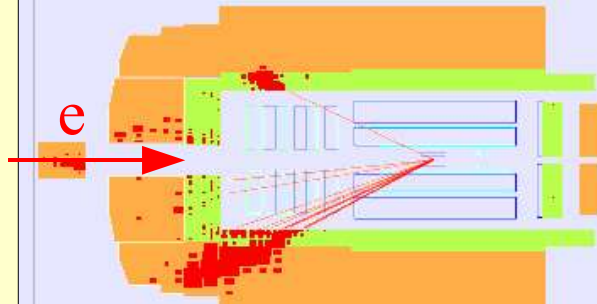
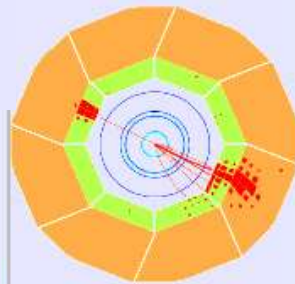
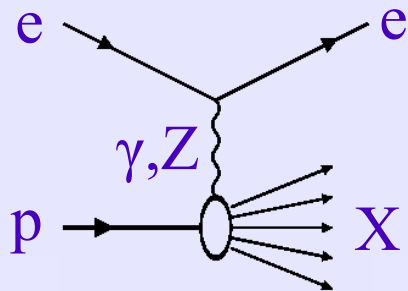


ZEUS

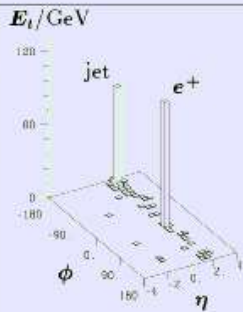


Physik bei HERA

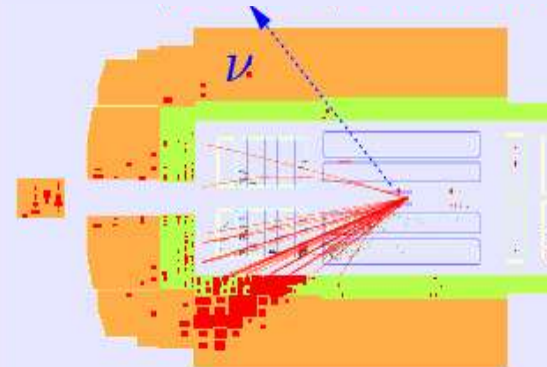
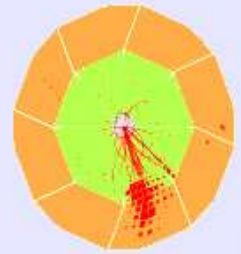
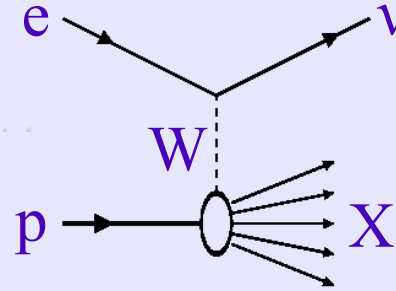
$e p \rightarrow e X$ (Neutraler Strom **NC**)



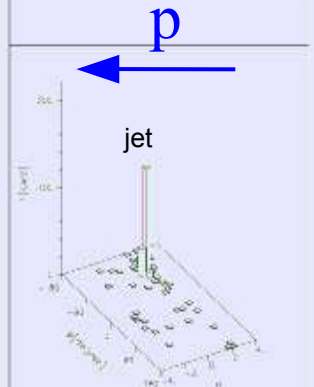
$Q^2 = 25000 \text{ GeV}^2, x=0.45$



$e p \rightarrow \nu X$ (geladener Strom **CC**)



$Q^2 = 21000 \text{ GeV}^2, x=0.42$





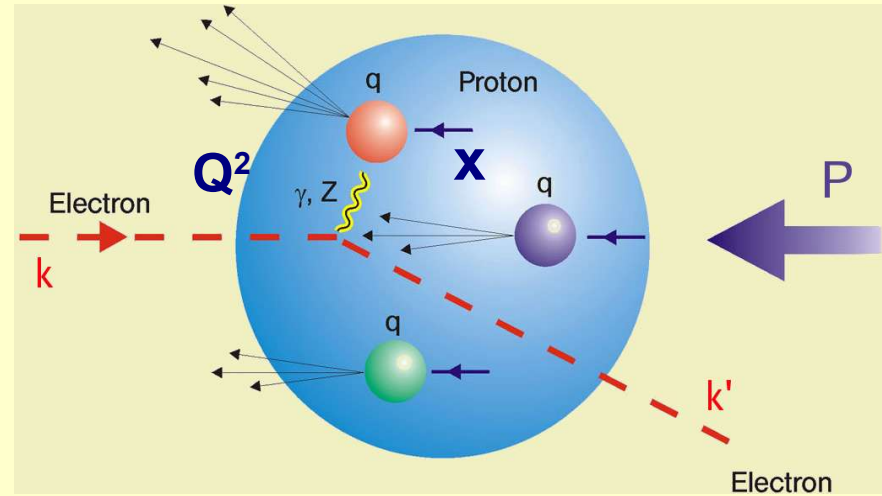
Wirkungsquerschnitt



Tiefinelastische Streuung (**DIS**):

Kinematik: $Q^2 = s \times y$

4-Impulsübertrag: $Q^2 = - (k' - k)^2$
 rel. Partonimpuls: x
 Inelastizität: y



$$\frac{d\sigma^\pm}{dx dQ^2} \propto \sum_{j=\text{quark}} PDF_j(x, Q^2) \left| \sum_{i=\text{boson}} \frac{1}{m_i^2 + Q^2} C_{ij}^\pm(y) \right|^2$$

QCD
(Partondichten)

Eichbosonen **Kopplungen**

NC: γ, Z

e, g_V, g_A

CC: W

V-A (CKM)

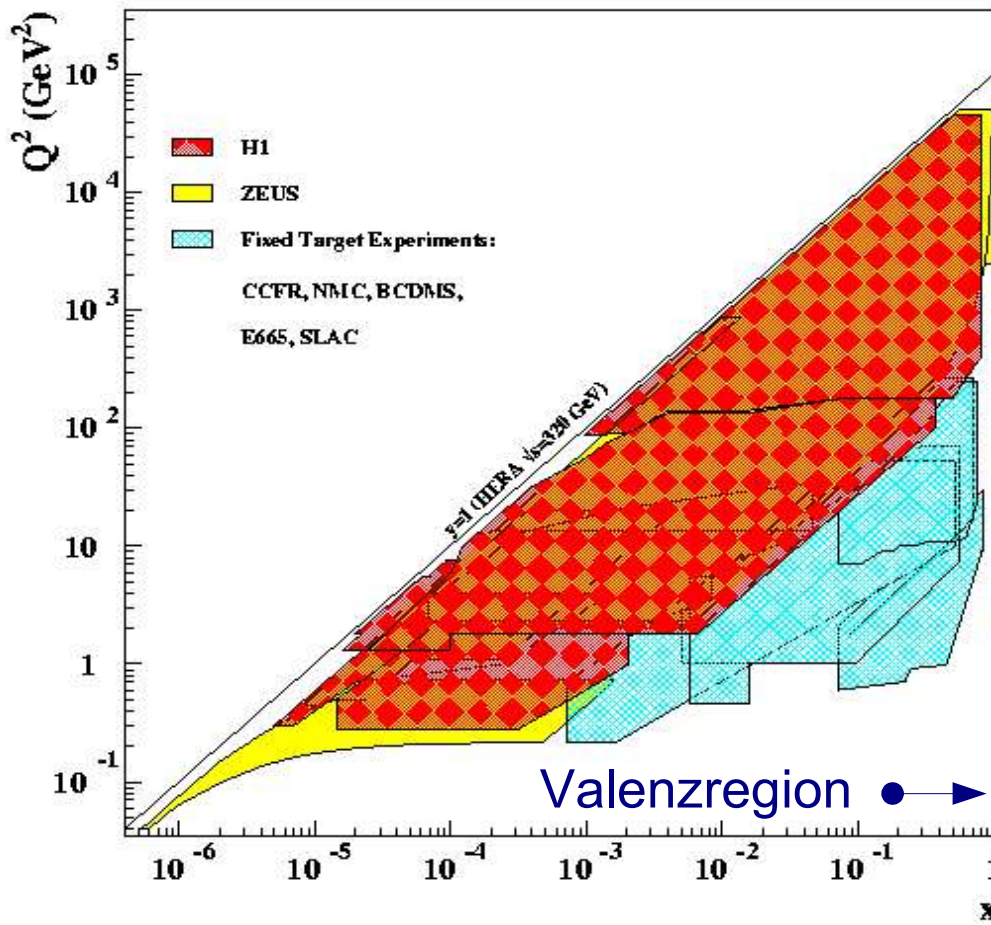
DIS als Werkzeug: **QCD** \leftrightarrow **Elektroschwache Physik**



Kinematischer Bereich



Kinematischer Bereich HERA



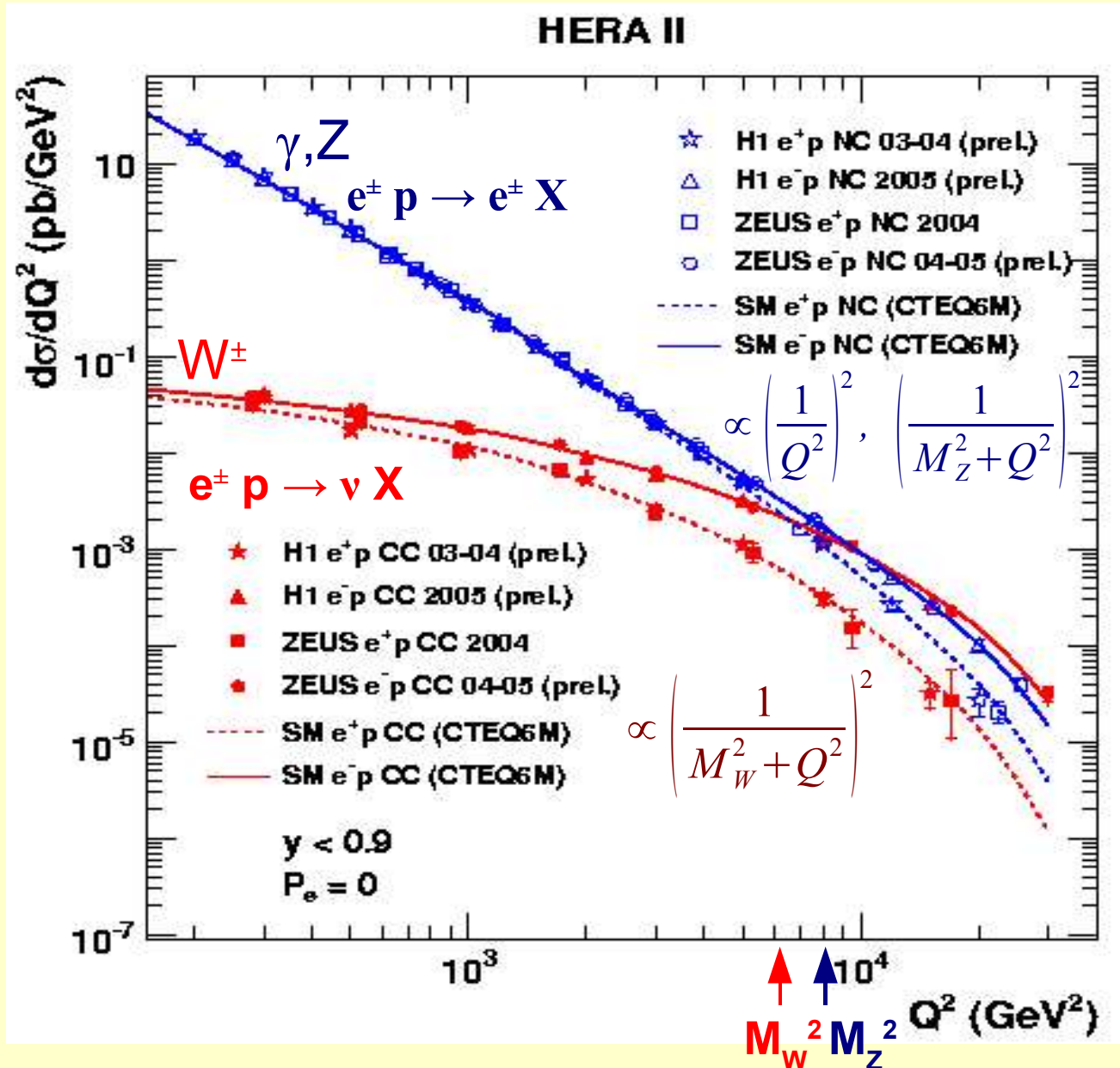
Elektroschwache
Physik
(hohe Energie)

DGLAP
Evolution
(Altarelli-Parisi Gleichungen)

QCD (Partondynamik)



Elektroweak Unificaton





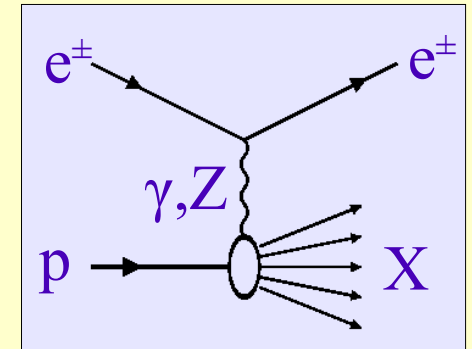
NC Strukturfunktionen



Tiefinelastische Streuung: $e^\pm p \rightarrow e^\pm X$

$$\frac{d\sigma_{NC}^\pm}{dx dQ^2} \approx \frac{e^4}{8\pi x} \left[\frac{1}{Q^2} \right]^2 \left[Y_+ \tilde{F}_2 \left[\begin{smallmatrix} + \\ - \end{smallmatrix} \right] Y_- \left[\begin{smallmatrix} x \tilde{F}_3 \end{smallmatrix} \right] \right]$$

$$Y_\pm = 1 \pm (1-y)^2$$



Strukturfunktionen (generalisiert):

$$\tilde{F}_2 = \sum_{\Sigma} x(q_i + \bar{q}_i) \cdot \left(\underbrace{e_i^2}_{\gamma} - 2 \underbrace{e_i v_i v_e}_{\gamma/Z} \Pi_Z + \underbrace{(v_e^2 + a_e^2)(v_i^2 + a_i^2)}_Z \Pi_Z^2 \right)$$

$$x \tilde{F}_3 = \sum_{\Delta} x(q_i - \bar{q}_i) \cdot \left(-2 e_i a_i a_e \Pi_Z + 4 a_i v_i v_e a_e \Pi_Z^2 \right)$$

$$\Pi_Z = \frac{Q^2}{m_Z^2 + Q^2} \cdot \frac{1}{\sin^2 2\Theta_W}$$

QCD Studien:

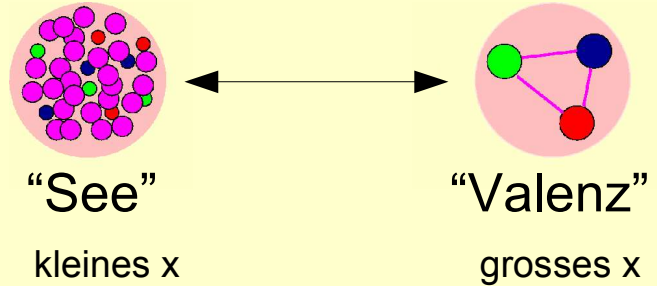
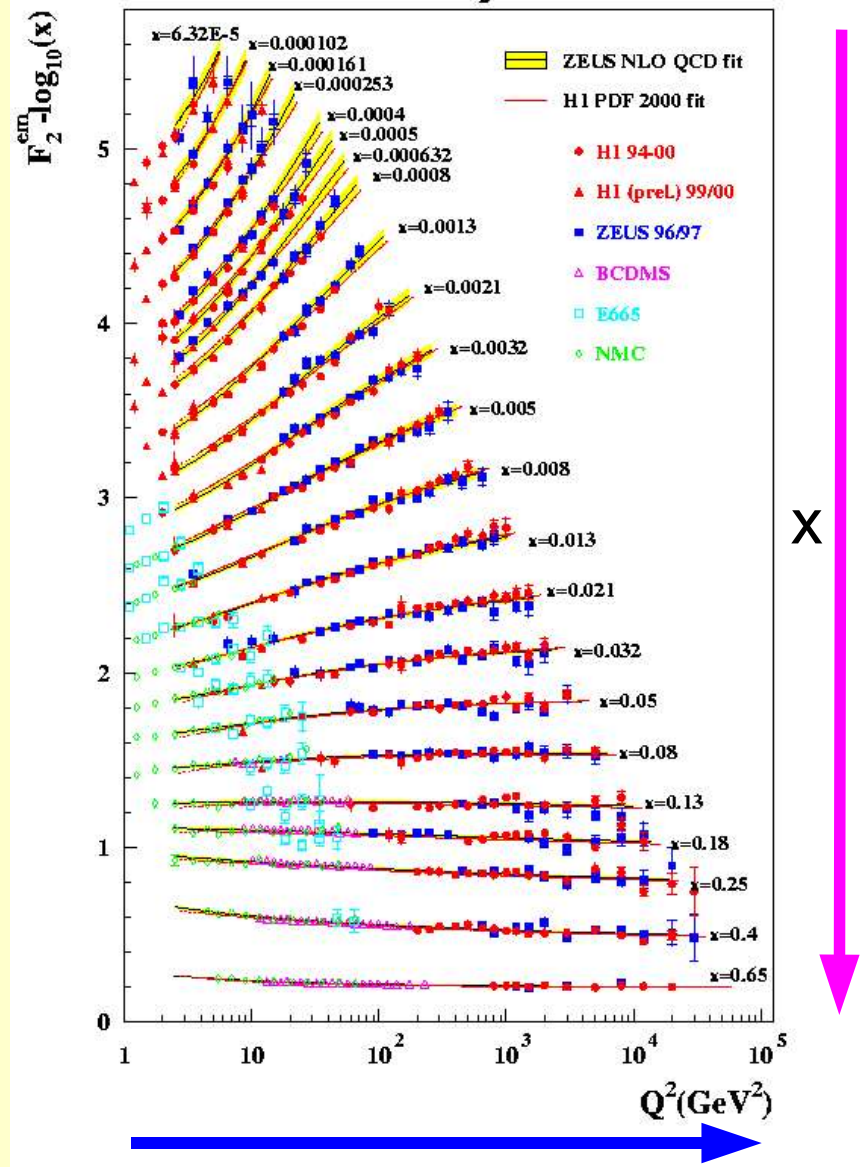
$$\rightarrow F_2^{em} = \sum x(q_i + \bar{q}_i) \cdot e_i^2 \propto x(4U + D)$$



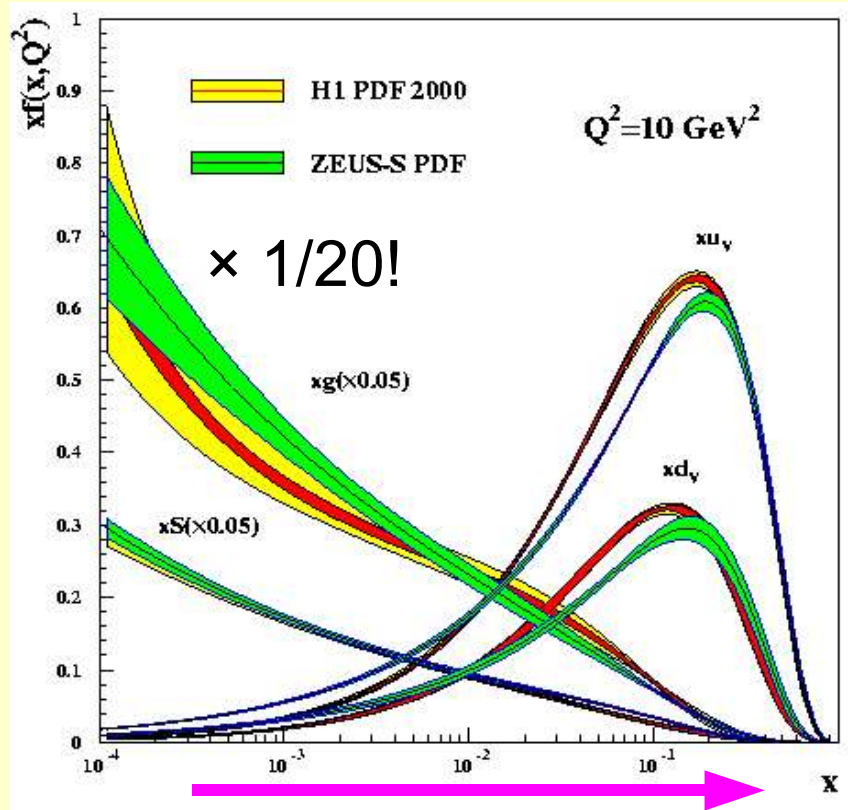
Proton Strukturfunktion F_2



Proton Strukturfunktion F_2 HERA F_2



Parton Dichten des Protons





Die Strukturfunktion $x F_3$



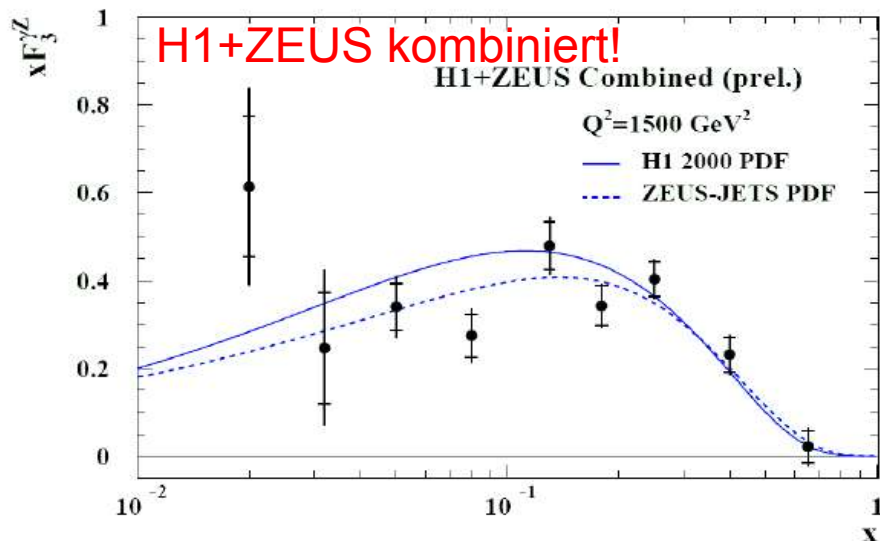
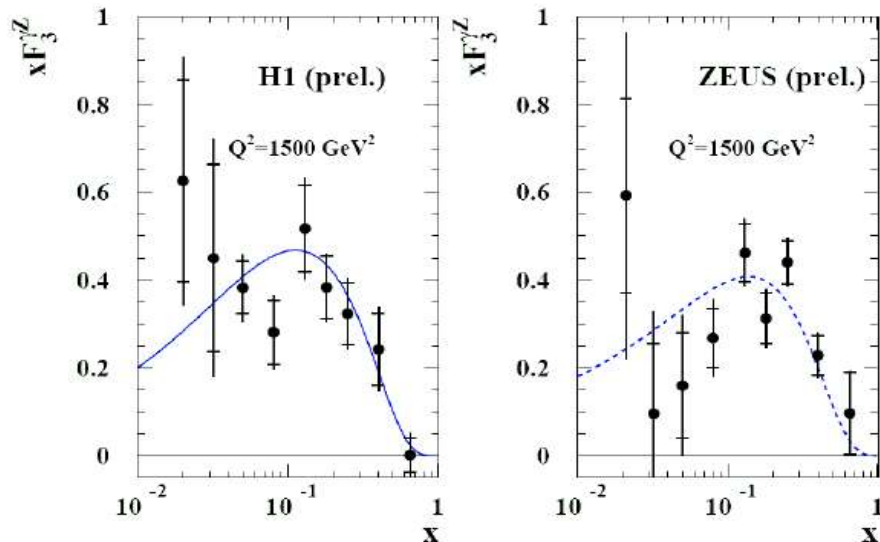
Differenz von e^-p und e^+p Daten:

$$x F_3^{yZ} = -x \tilde{F}_3 \frac{1}{a_e \Pi_Z}$$

Funktion der Valenzquarks:

$$x F_3^{yZ} = 2x \cdot [e_u a_u (U - \bar{U}) + e_d a_d (D - \bar{D})]$$

$$\int_0^1 F_3^{yZ} dx = \frac{1}{3} \int_0^1 (2u_v + d_v) dx = \frac{5}{3}$$



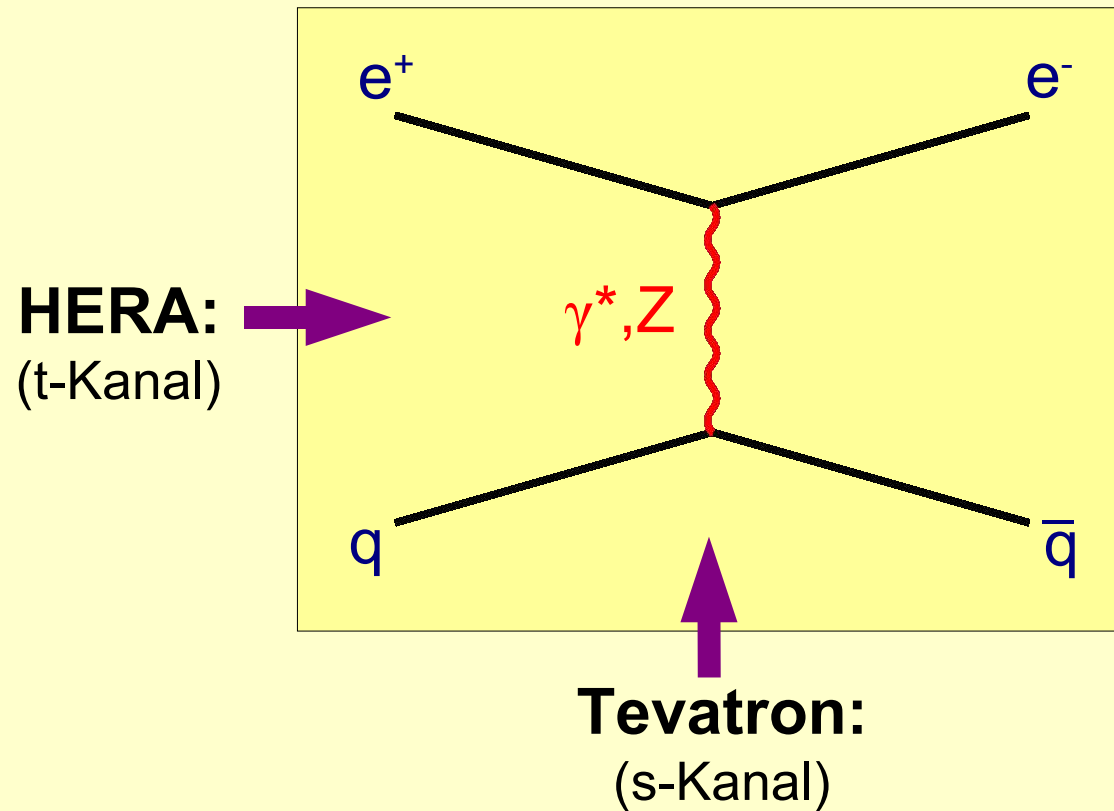
H1+Zeus Messung:

$$\int_{0.02}^{0.65} F_3^{yZ} dx = 1.21 \pm 0.09 (stat) \pm 0.08 (syst)$$

- Evidenz für gamma/Z Interferenz
- Fingerabdruck von Valenz-Quarks

Statistisch limitiert!

Vergleich HERA-Tevatron

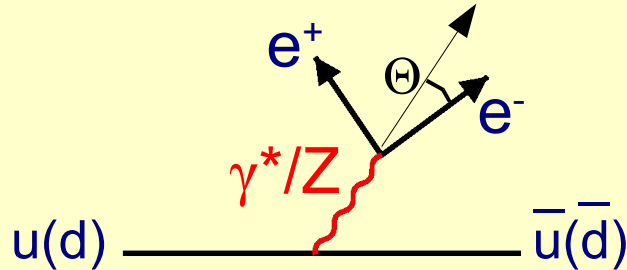


γ^*/Z Interferenz verschwindet für: $m_{ee} = m_Z$

Z Vorwärts-Rückwärts Asymmetrie ($x F_3$) bei Tevatron



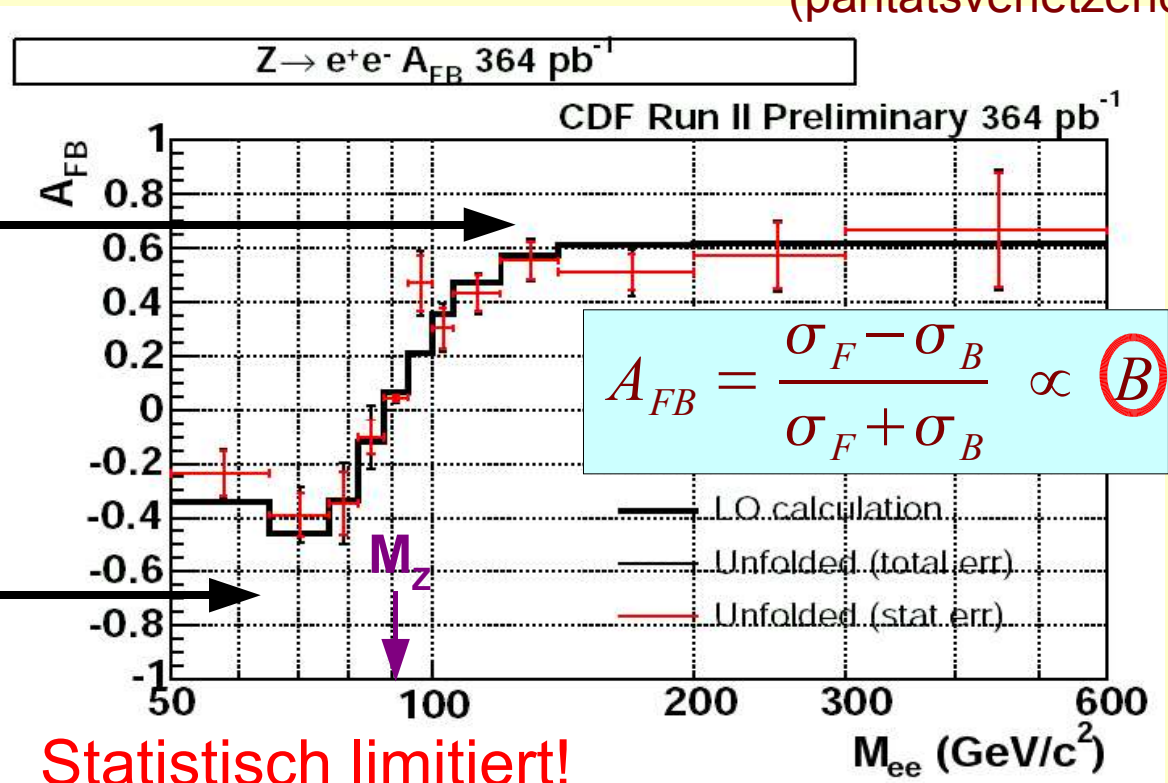
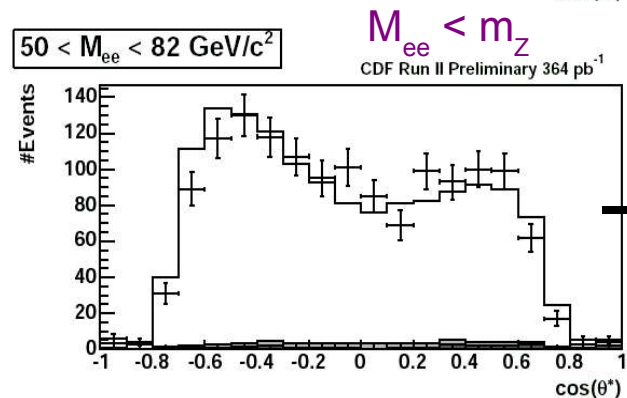
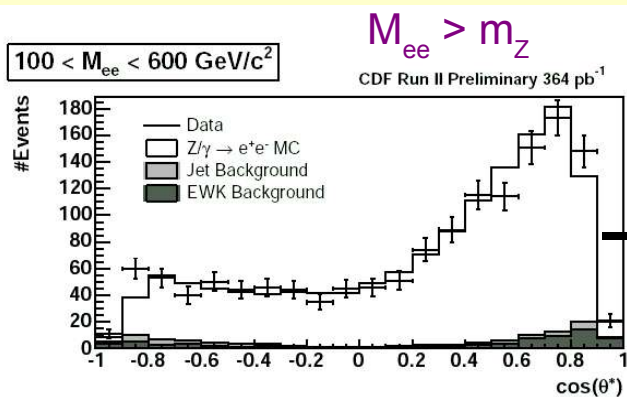
Drell-Yan Prozess: $p\bar{p} \rightarrow \gamma^*/Z + X \rightarrow e^+ e^- + X$



$$\frac{d\sigma}{d\cos\Theta^*} = \frac{4\pi\alpha^2}{3s} \left[A (1 + \cos^2\Theta^*) + B \cos\Theta^* \right]$$

$$A \propto x F_2$$

$$B \propto x F_3 \quad (\text{paritätsverletzend})$$



Statistisch limitiert!

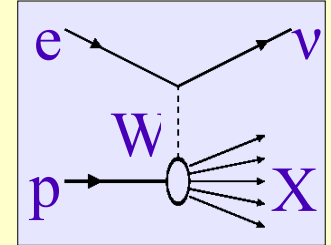


CC Wirkungsquerschnitt



Tiefinelastische Streuung:

$$\frac{d\sigma_{CC}^{\pm}}{dx dQ^2} \approx \frac{g^4}{64 \pi x} \left[\frac{1}{M_W^2 + Q^2} \right]^2 \left[Y_+ \tilde{W}_2^{\pm} \mp Y_- x \tilde{W}_3^{\pm} \right]$$



$$\begin{aligned} \tilde{W}_2^+ &\propto \sum x(D_i + \bar{U}_i) & x \tilde{W}_3^+ &\propto \sum x(D_i - \bar{U}_i) \\ \tilde{W}_2^- &\propto \sum x(U_i + \bar{D}_i) & x \tilde{W}_3^- &\propto \sum x(U_i - \bar{D}_i) \end{aligned}$$

CC e⁺p cross section

Sensitive to d-quark density

$$\frac{d^2 \sigma_{CC}^+}{dx dQ^2} = \frac{G_F^2}{2 \pi} \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2 \cdot \left[\bar{u} + \bar{c} + (1-y)^2 (d + s) \right]$$

CC e⁻p cross section

$\tilde{\sigma}(x, Q^2)/x$ reduzierter CC WQ

$$\frac{d^2 \sigma_{CC}^-}{dx dQ^2} = \frac{G_F^2}{2 \pi} \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2 \cdot \left[u + c + (1-y)^2 (\bar{d} + \bar{s}) \right]$$

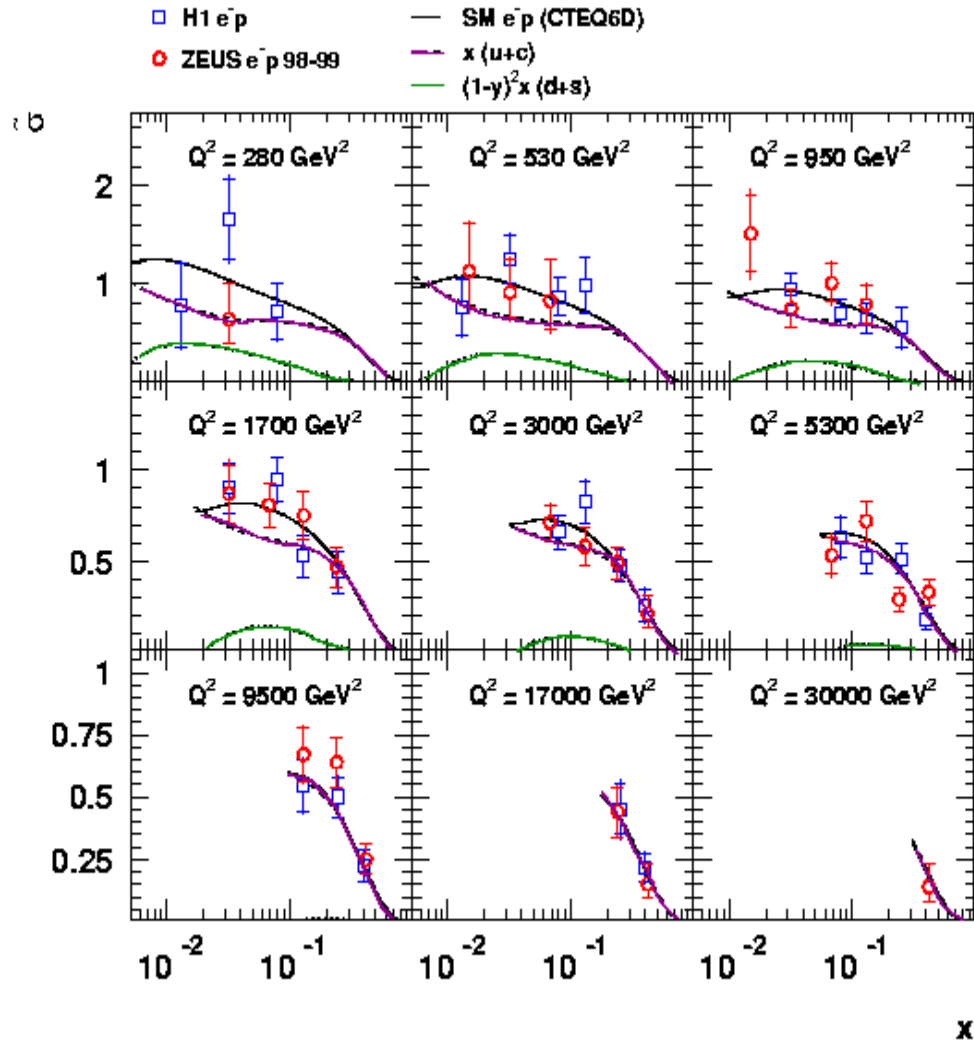
Sensitive to u-quark density



Differentieller CC WQ

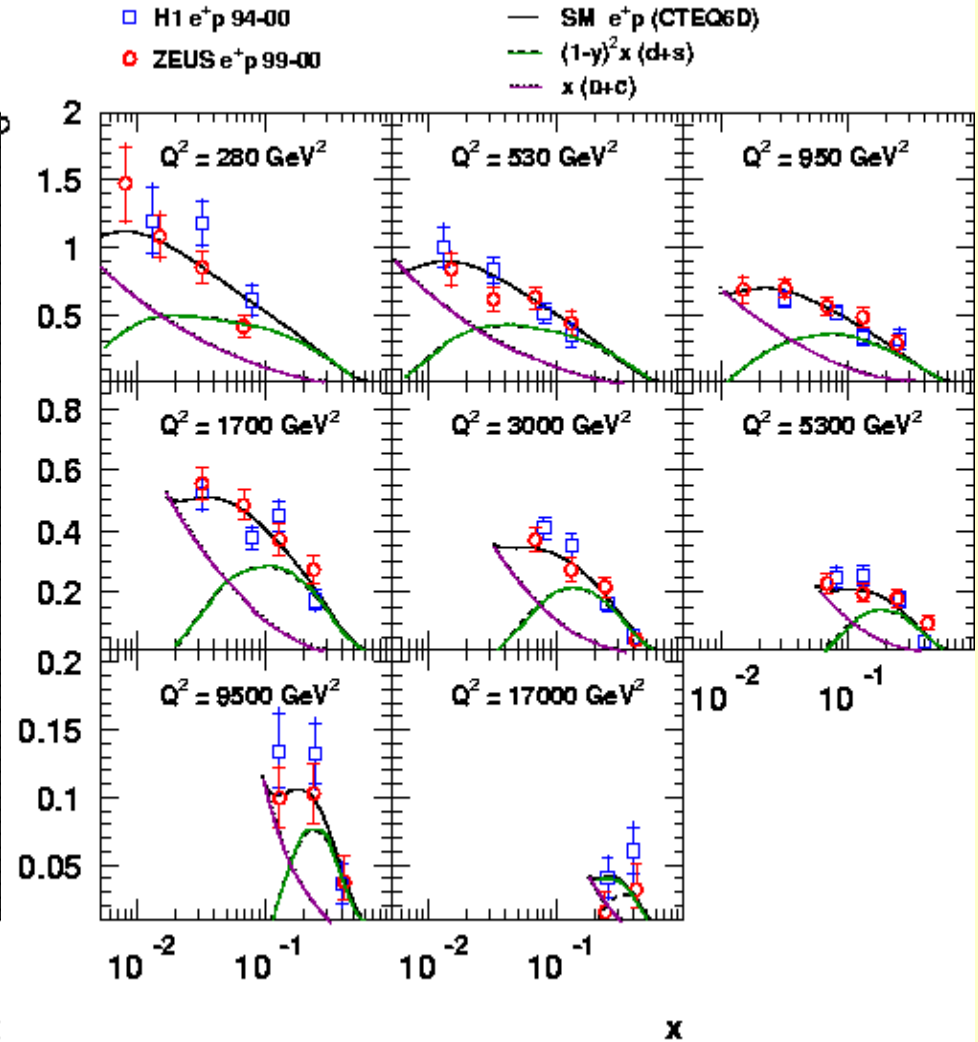


HERA e^-p Charged Current



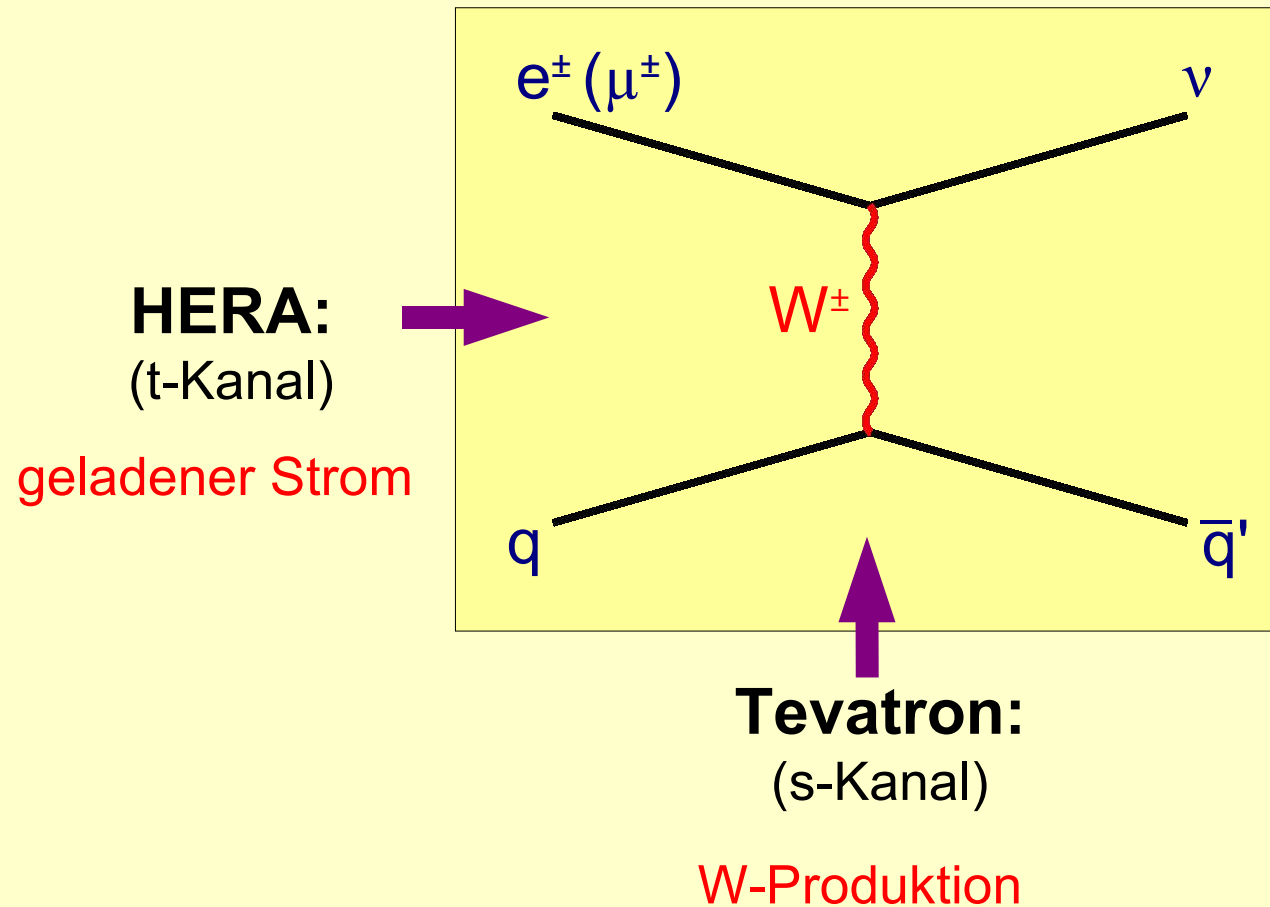
sensitiv auf u-Dichte

HERA e^+p Charged Current

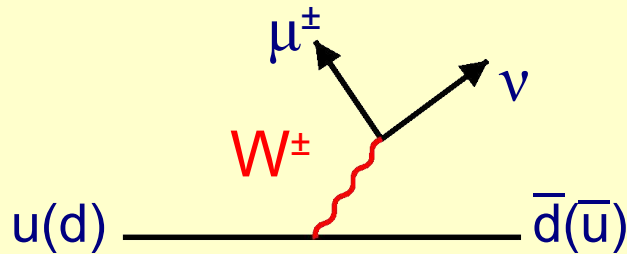


sensitiv auf d-Dichte

Geladener Strom und W-Produktion



W-Ladungsasymmetrie beim Tevatron



Unterschiedliche u,d
Impulsverteilungen:

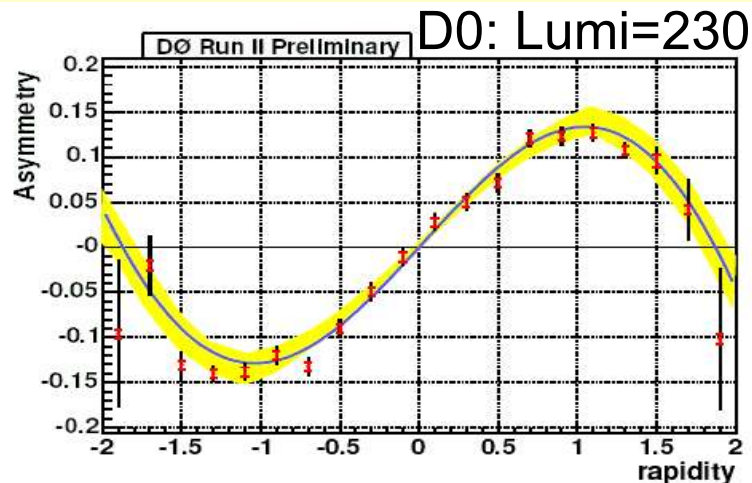
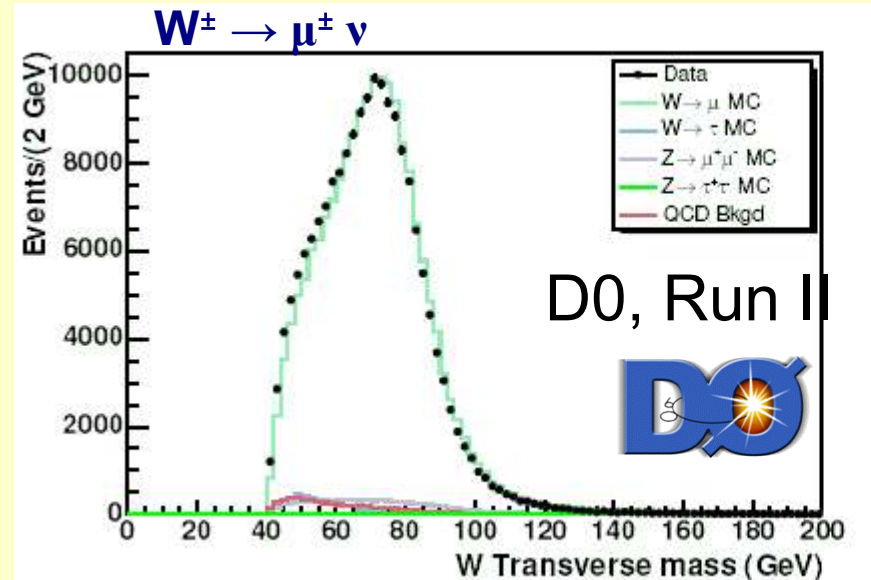
$$\bar{p}(u) > \bar{p}(d)$$

→ Asymmetrie

μ -Winkelverteilung: $W^\pm \rightarrow \mu^\pm \nu$

Rapidität: η

$$\text{Asymmetrie: } A_\mu(\eta) = \frac{d\sigma_{\mu^+}(\eta) - d\sigma_{\mu^-}(\eta)}{d\sigma_{\mu^+}(\eta) + d\sigma_{\mu^-}(\eta)}$$



sensitiv auf d/u Verhältnis
als Funktion der Rapidität

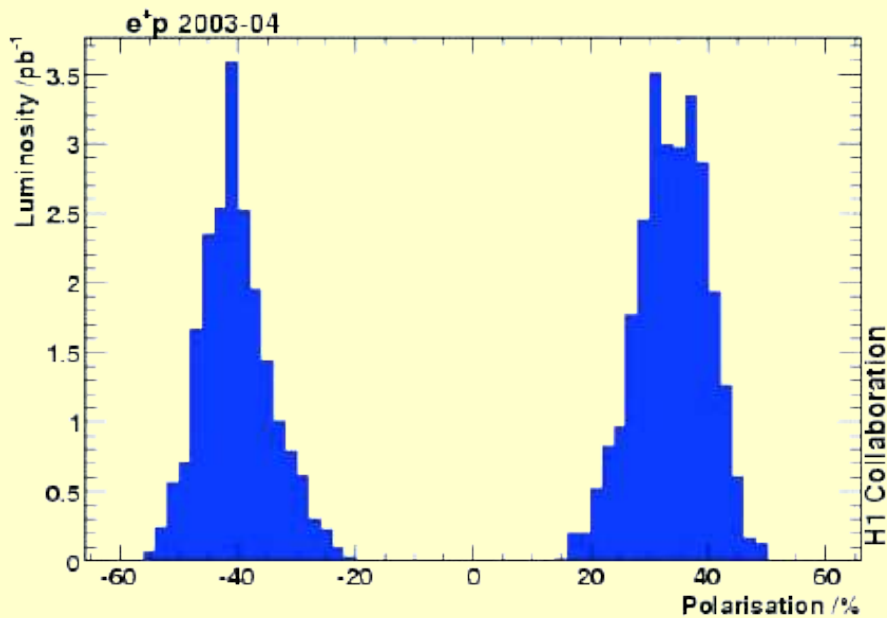
komplementär zu HERA



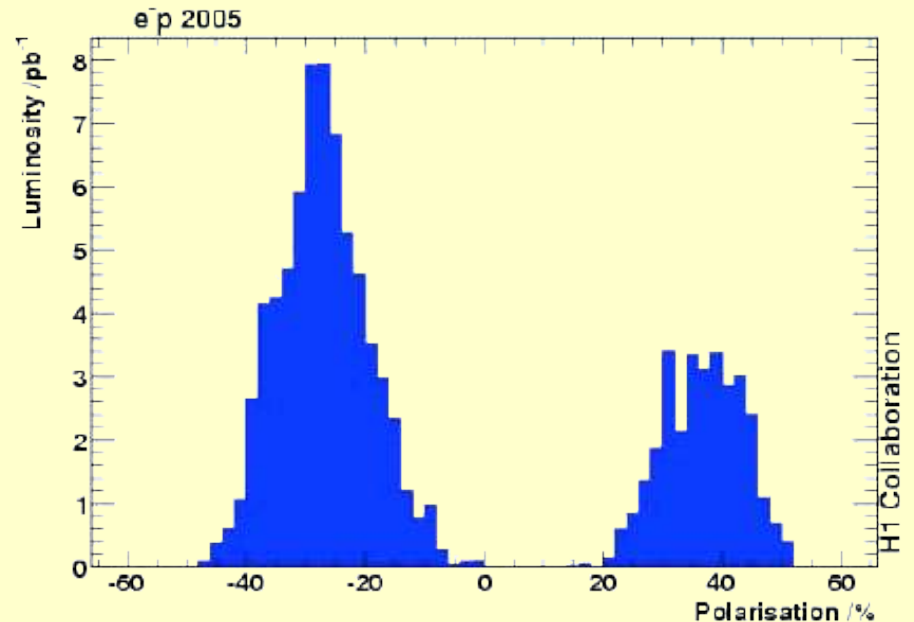
Polarisation HERA II



longitudinal polarisierte e^+



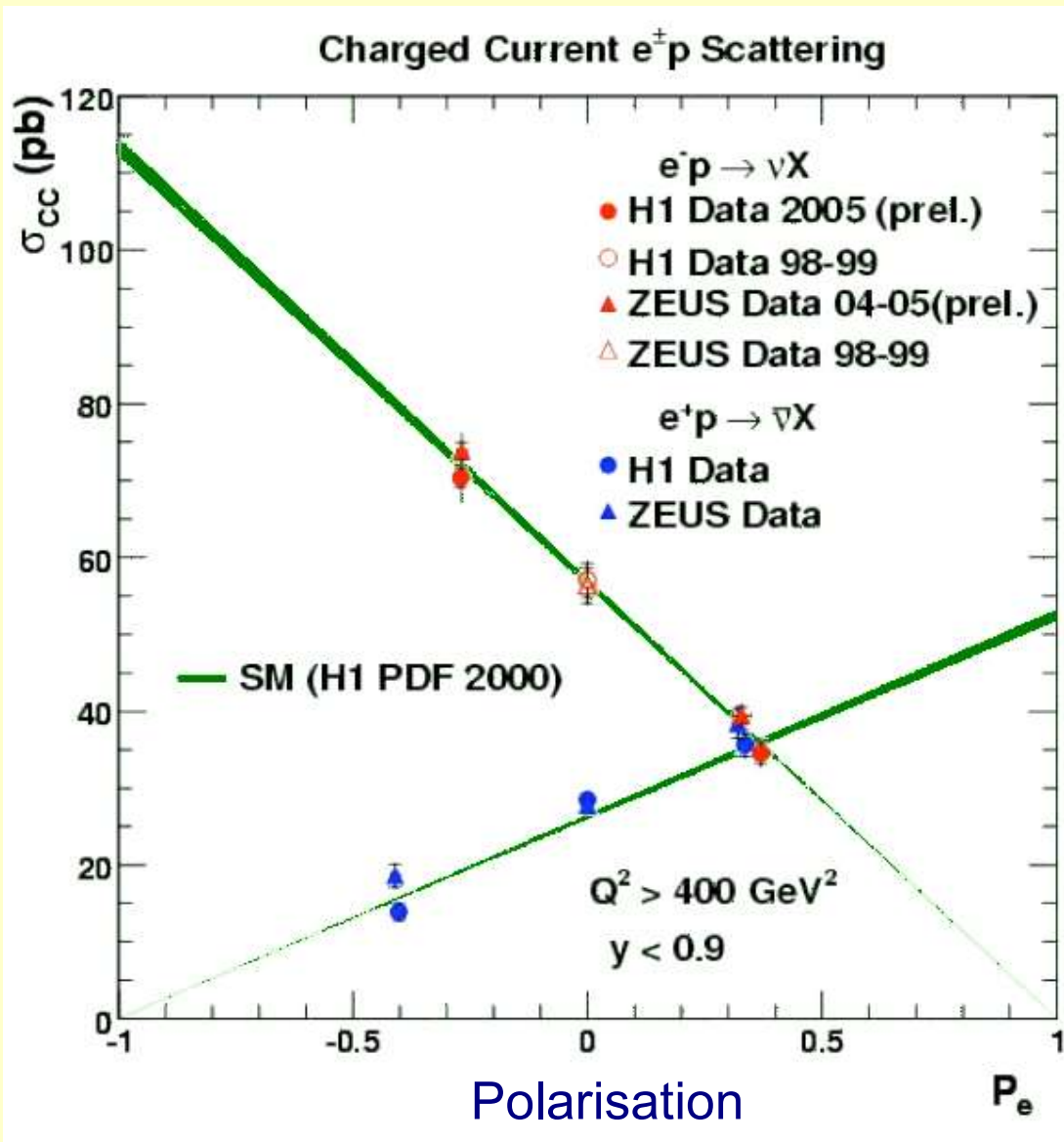
longitudinal polarisierte e^-



- Longitudinale Polarisationen: 20-50%
- Datensätze: links, rechts, e^+ , e^- á 10-80 pb⁻¹ analysiert



Test der V-A Kopplung bei HERA II



CC Wirkungsquerschnitt:

$$\sigma_{CC}^\pm(P_e) = (1 \pm P_e) \cdot \sigma_{CC}^\pm(P_e=0)$$

$P_{\text{Elektron}} = -1$: links pol.

$P_{\text{Elektron}} = +1$: rechts pol.

Ausschlußgrenzen (95%CL)
rechtshändige W_R :

$$M_{WR} > 186 \text{ GeV} \quad (\text{H1 } e^-p)$$

$$M_{WR} > 180 \text{ GeV} \quad (\text{ZEUS } e^-p)$$

$$M_{WR} > 208 \text{ GeV} \quad (\text{H1 } e^+p)$$

Neutraler Strom und Polarisation

$$\frac{d\sigma_{NC}^{\pm}}{dx dQ^2} \approx \frac{e^4}{8\pi x} \left[\frac{1}{Q^2} \right]^2 \left[(Y_+ \tilde{F}_2^0 \mp Y_- x \tilde{F}_3^0) + P_e (Y_+ \tilde{F}_2^P \mp Y_- x \tilde{F}_3^P) \right]$$

↑ Polarisation

$$\tilde{F}_2^0 = \sum x(q_i + \bar{q}_i) \cdot (e_i^2 \underbrace{-2e_i v_i v_e \Pi_Z}_{\gamma/Z} + \underbrace{(v_e^2 + a_e^2)(v_i^2 + a_i^2) \Pi_Z^2}_{Z})$$

$$x \tilde{F}_3^0 = \sum x(q_i - \bar{q}_i) \cdot (\underbrace{-2e_i a_i a_e \Pi_Z}_{\gamma/Z} + \underbrace{4a_i v_i v_e a_e \Pi_Z^2}_{Z})$$

Polarisationsabhängig:

$$\tilde{F}_2^P = \sum x(q_i + \bar{q}_i) \cdot (\underbrace{2e_i v_i a_e \Pi_Z}_{\gamma/Z} - \underbrace{2a_e v_e (v_i^2 + a_i^2) \Pi_Z^2}_{Z})$$

$$x \tilde{F}_3^P = \sum x(q_i - \bar{q}_i) \cdot (\underbrace{2e_i a_i v_e \Pi_Z}_{\gamma/Z} - \underbrace{2a_i v_i (v_e^2 + a_e^2) \Pi_Z^2}_{Z})$$

axial coupling: $a = T^3$

vector coupling: $v = T^3 - 2e \sin^2 \Theta_W$

Analyse verschiedener Datensätze:
e⁺p, e⁻p (polarisiert, unpolarisiert)
 um NC Kopplungen a_u, v_u, a_d, v_d zu bestimmen

Elektroschwache Quarkkopplungen

$$\frac{d\sigma_{NC}^{\pm}}{dx dQ^2} \approx \frac{e^4}{8 \pi x} \left[\frac{1}{Q^2} \right]^2 \left[(Y_+ \tilde{F}_2^0 \mp Y_- x \tilde{F}_3^0) + P_e (Y_+ \tilde{F}_2^P \mp Y_- x \tilde{F}_3^P) \right]$$

↑ Polarisation

$$\begin{aligned} \tilde{F}_2^0 &\propto F_2^{em} + F_2^0(\gamma/Z) + \underline{F_2^0(Z)} \\ x \tilde{F}_3^0 &\propto \underline{x F_3^0(\gamma/Z)} + x F_3^0(Z) \end{aligned}$$

$$\begin{aligned} \tilde{F}_2^P &\propto \underline{F_2^P(\gamma/Z)} + F_2^P(Z) \\ x \tilde{F}_3^P &\propto x F_3^P(\gamma/Z) + \underline{x F_3^P(Z)} \end{aligned}$$

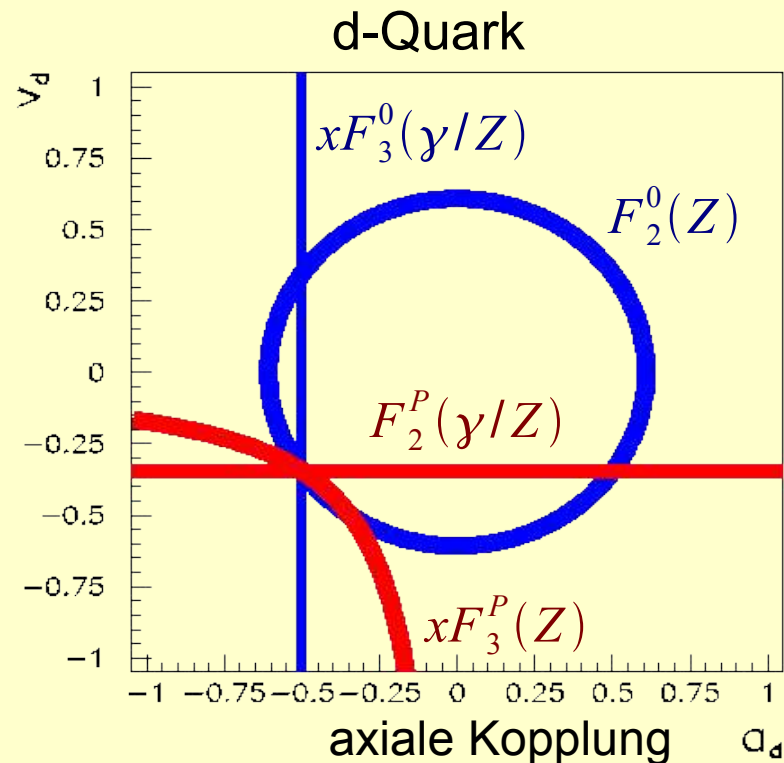
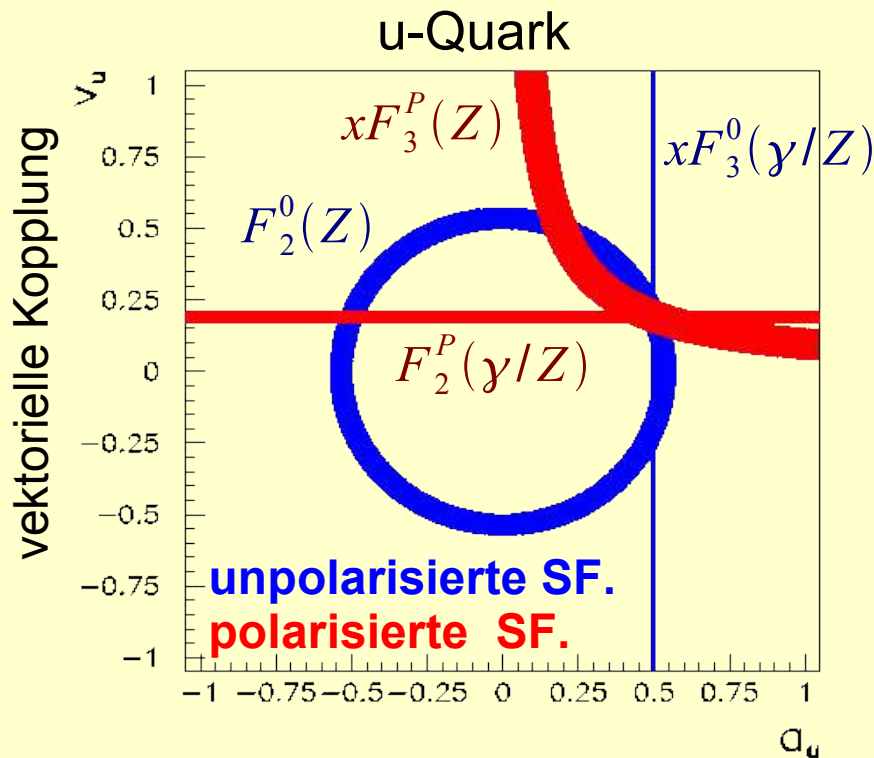
Elektroschwache Quarkkopplungen

$$\frac{d\sigma_{NC}^{\pm}}{dx dQ^2} \approx \frac{e^4}{8 \pi x} \left[\frac{1}{Q^2} \right]^2 \left[(Y_+ \tilde{F}_2^0 \mp Y_- x \tilde{F}_3^0) + P_e (Y_+ \tilde{F}_2^P \mp Y_- x \tilde{F}_3^P) \right]$$

↑ Polarisation

$$\begin{aligned} \tilde{F}_2^0 &\propto F_2^{em} + F_2^0(\gamma/Z) + \underline{F_2^0(Z)} \\ x \tilde{F}_3^0 &\propto \underline{x F_3^0(\gamma/Z)} + x F_3^0(Z) \end{aligned}$$

$$\begin{aligned} \tilde{F}_2^P &\propto \underline{F_2^P(\gamma/Z)} + F_2^P(Z) \\ x \tilde{F}_3^P &\propto x F_3^P(\gamma/Z) + \underline{x F_3^P(Z)} \end{aligned}$$



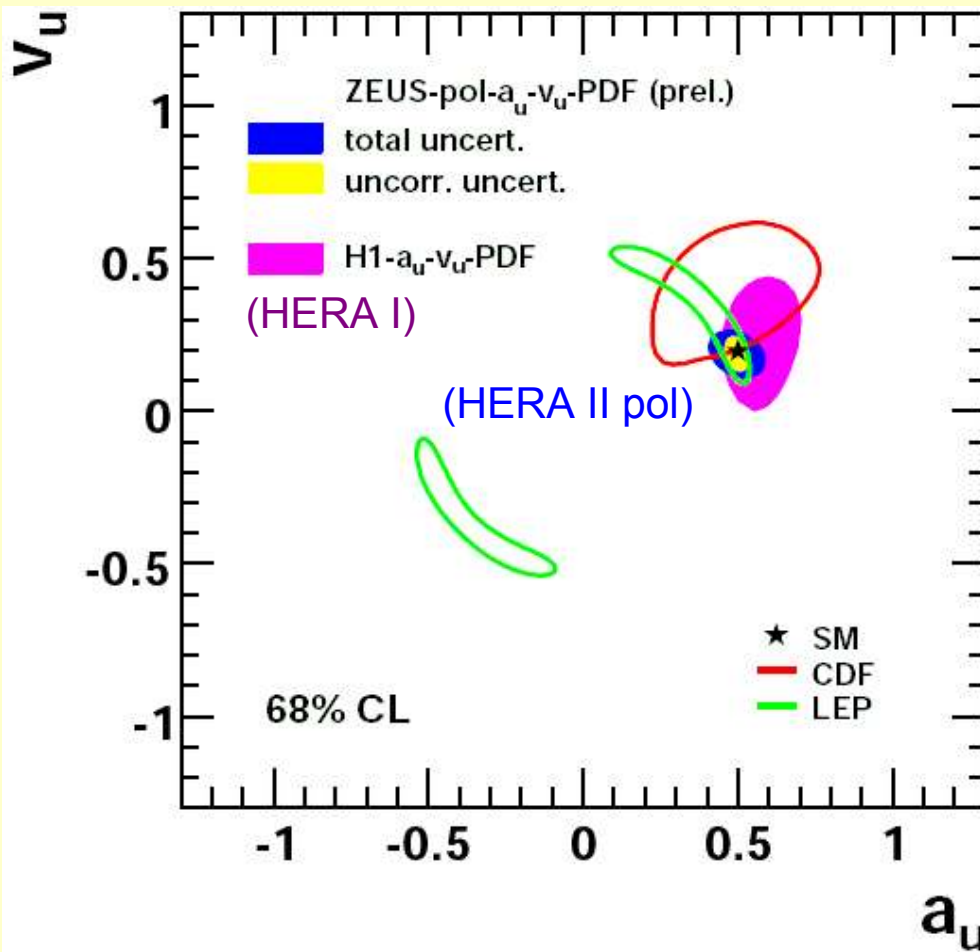


Fit der Quarkkopplungen

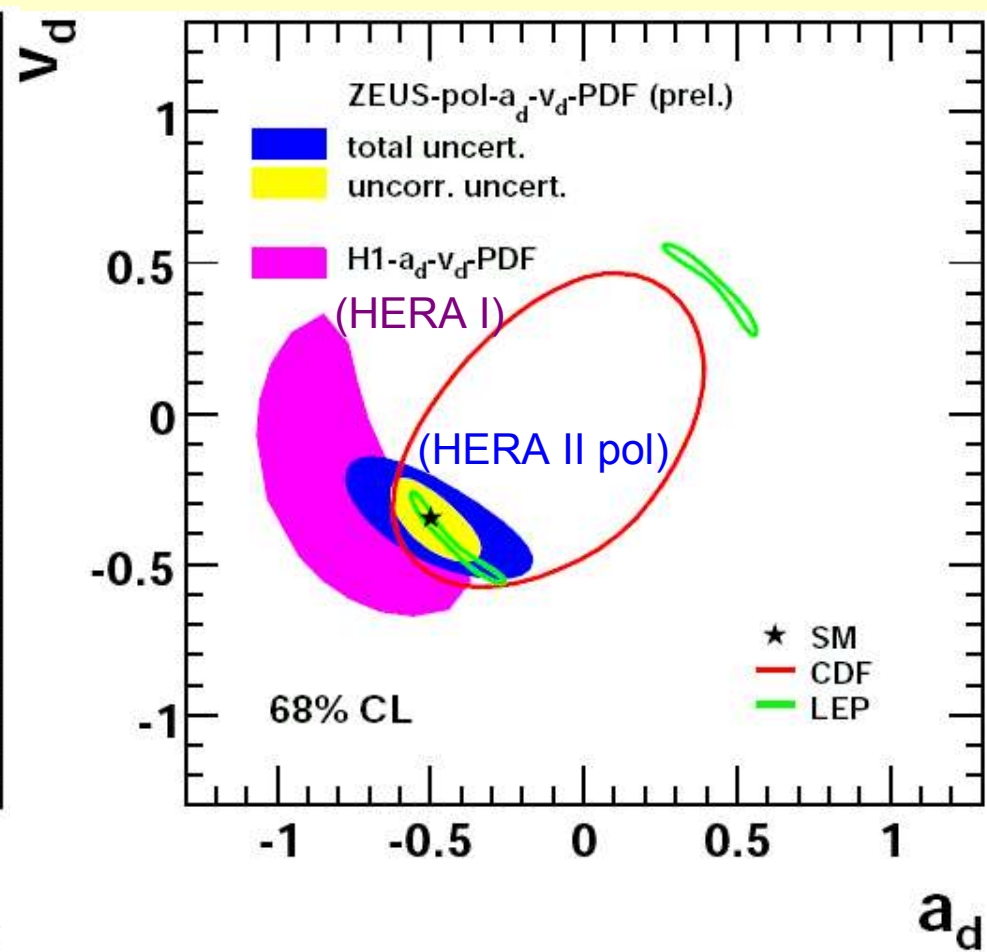


- Kombiniertes Fit von schwachen NC Kopplungen und PDF:

u-Quark



d-Quark

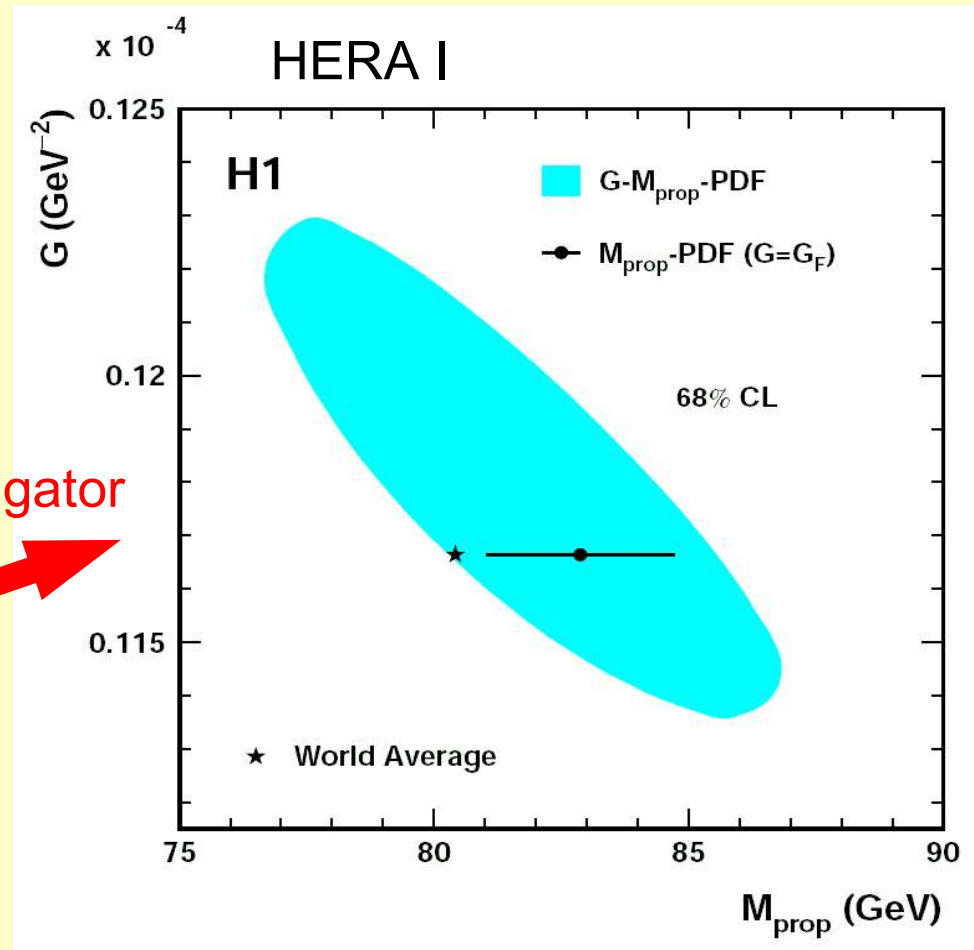
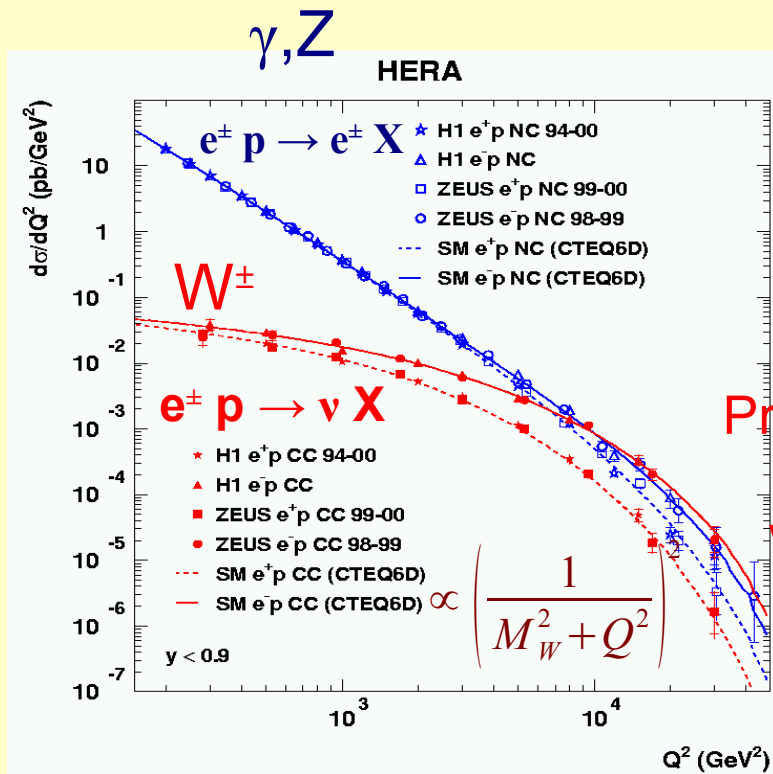


Genaueste Bestimmung der u-Quarkkopplungen bei HERA!



Fit der W-Propagatormasse

- Kombinierter Fit von CC Parametern + Partondichten:



$$M_{prop} = 82.87 \pm 1.82 \pm 0.25 \quad \text{H1 (HERA I)}$$

$$M_{prop} = 79.1 \pm 0.77 \pm 0.99 \quad \text{ZEUS (HERA II)}$$

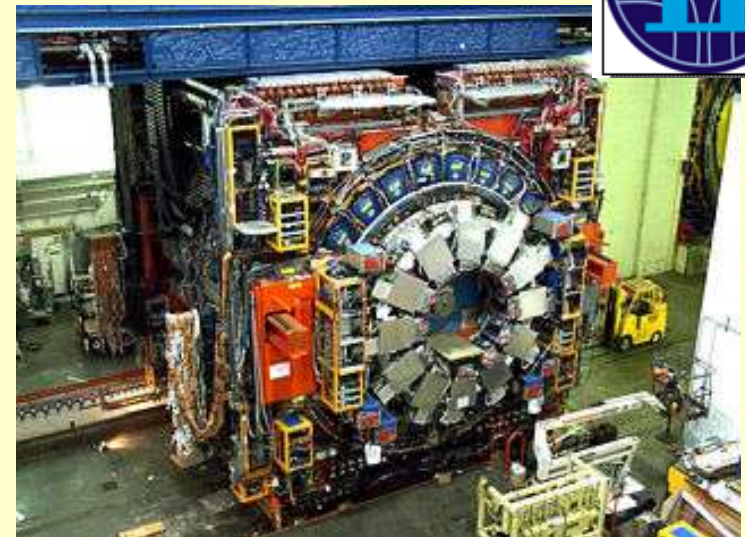
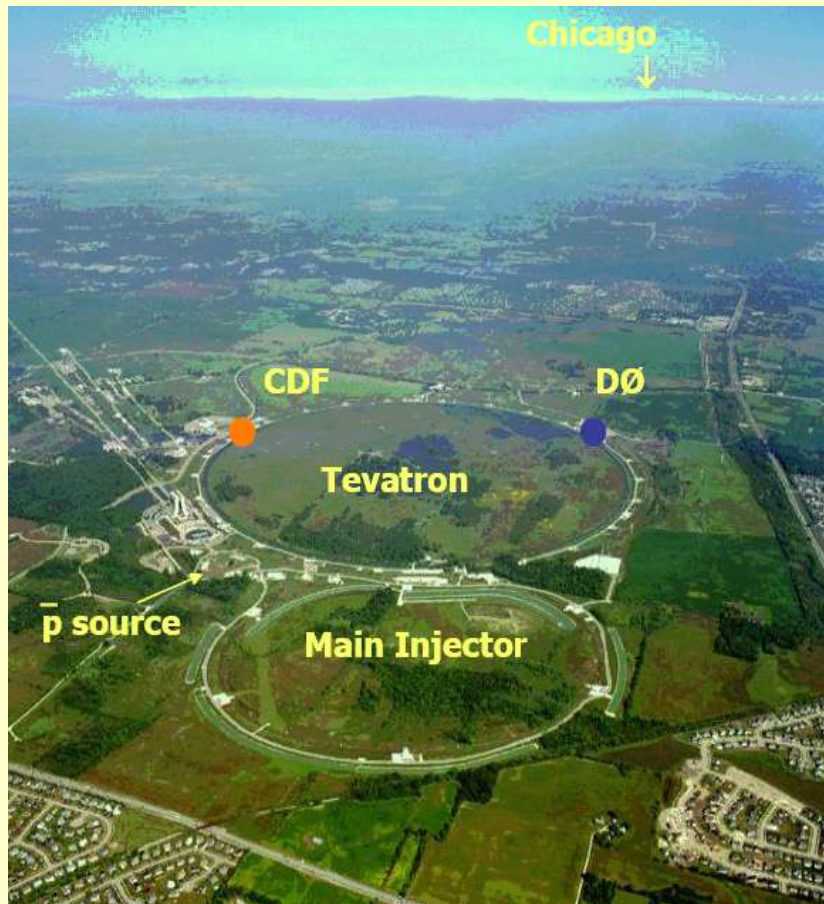
konsistent mit PDG W-Masse!

Proton-Antiproton Collider Tevatron

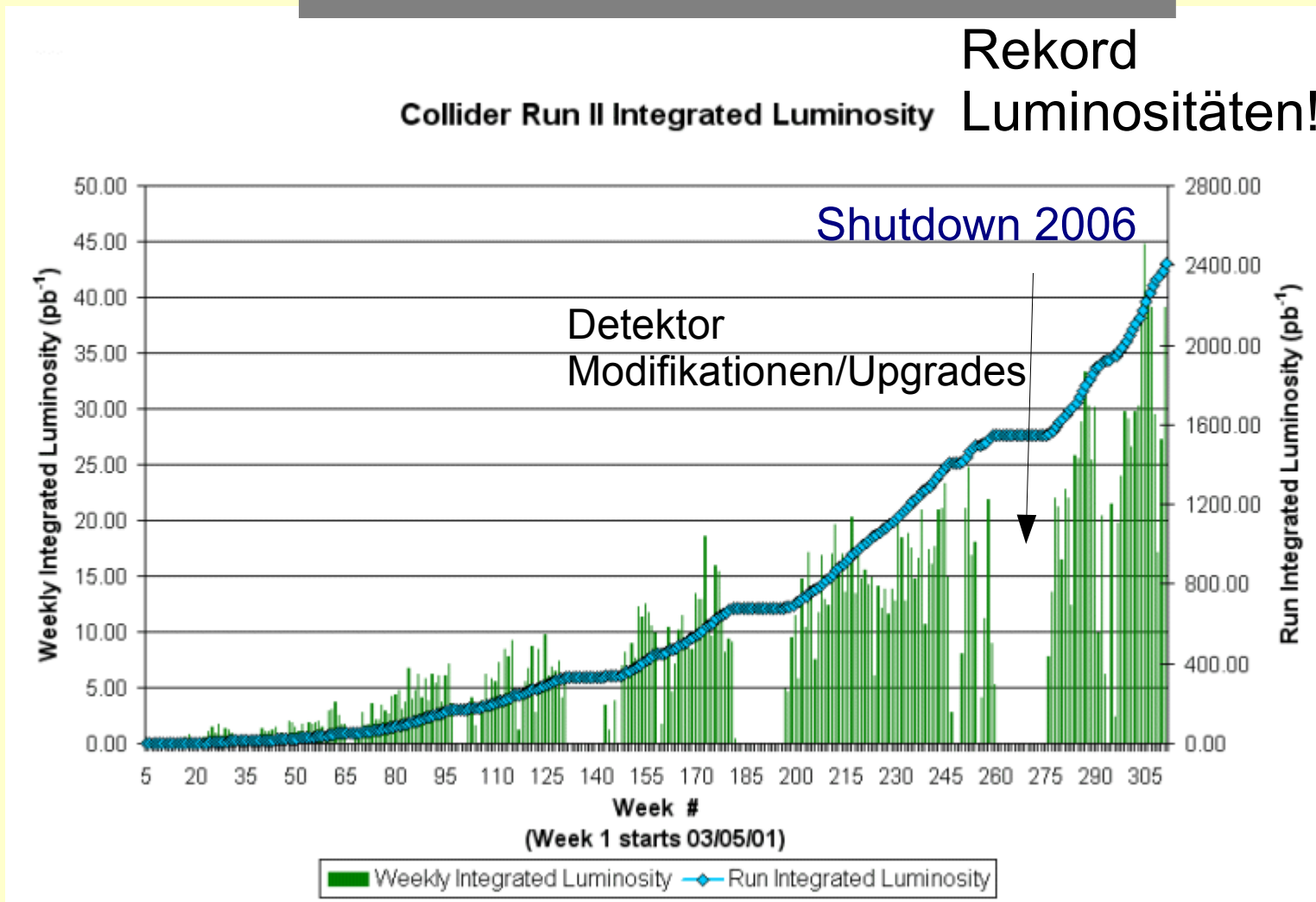
Fermilab:

980 GeV (anti-)protonen

$\sqrt{s}=1.96$ TeV



Tevatron Leistung



- 2 fb^{-1} Run II Daten auf Tape pro Experiment
- Viele neue Ergebnisse mit 1 fb^{-1} Run II Daten

W-Boson Masse



erste Messung der W-Masse bei Run II

CDF Kollaboration

Neue Messung (Lumi=200 pb⁻¹)

$$W \rightarrow e\nu, W \rightarrow \mu\nu$$

CDF II preliminary L = 200 pb⁻¹

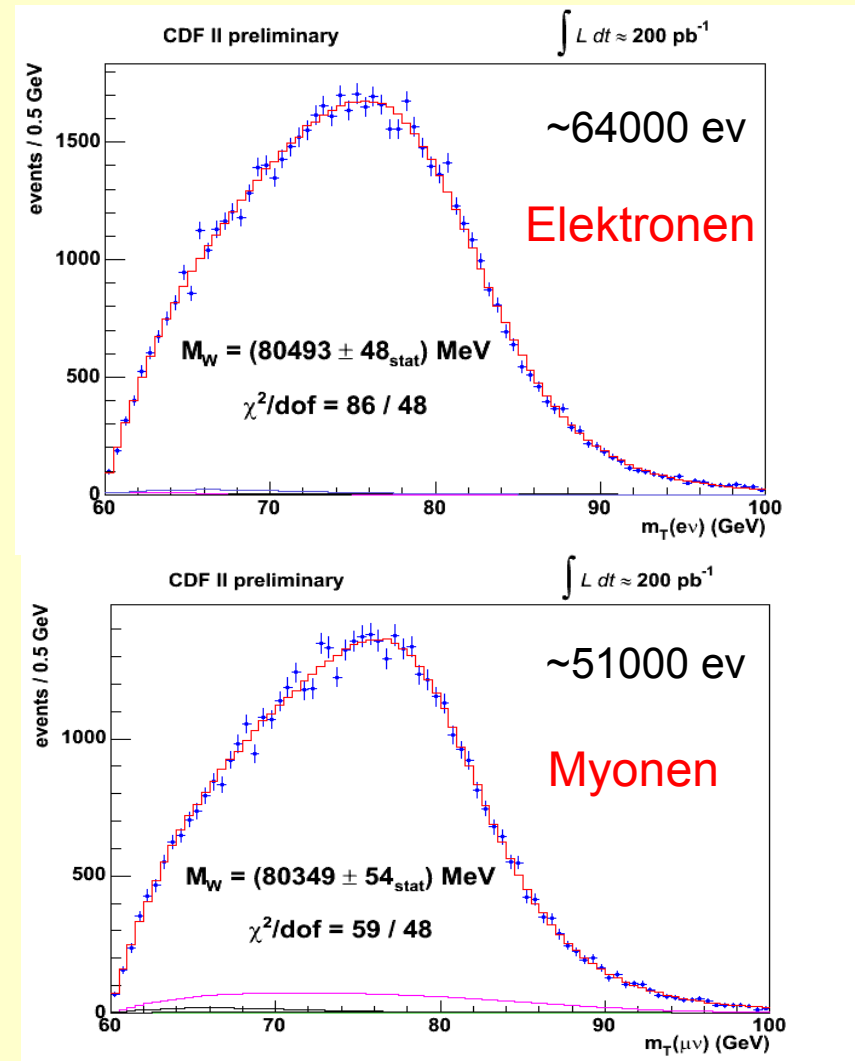
m_T Uncertainty [MeV]	Electrons	Muons	Common
Lepton Scale	30	17	17
Lepton Resolution	9	3	0
Recoil Scale	9	9	9
Recoil Resolution	7	7	7
$u_{ }$ Efficiency	3	1	0
Lepton Removal	8	5	5
Backgrounds	8	9	0
$p_T(W)$	3	3	3
PDF	11	11	11
QED	11	12	11
Total Systematic	39	27	26
Statistical	48	54	0
Total	62	60	26

Elektronen + Myonen kombiniert:

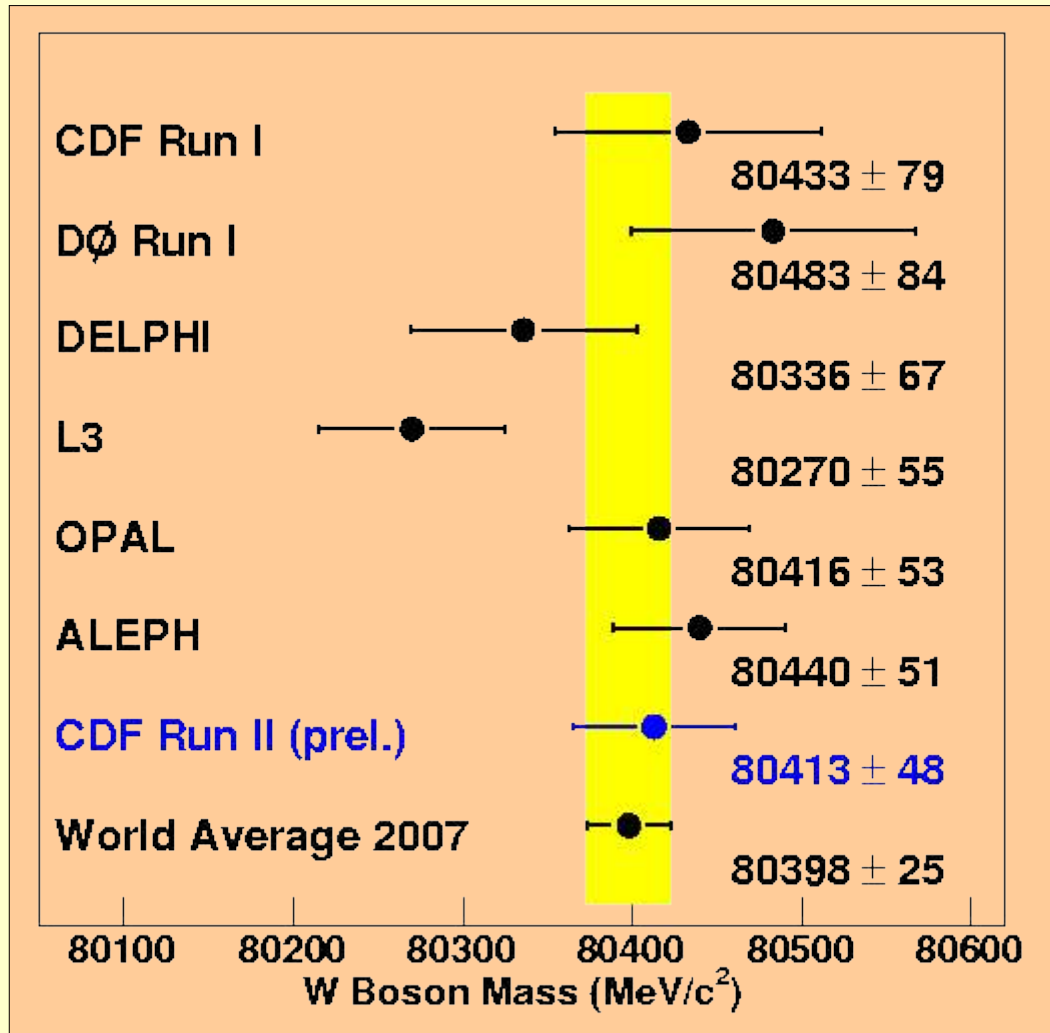
$$M_W = 80413 \pm 34 \pm 34 \text{ MeV}/c^2$$

Transversale Masse (Jakobische-Peaks):

$$m_T = \sqrt{2 p_T^l p_T^\nu (1 - \cos(\Phi_l - \Phi_\nu))}$$



W-Boson Masse



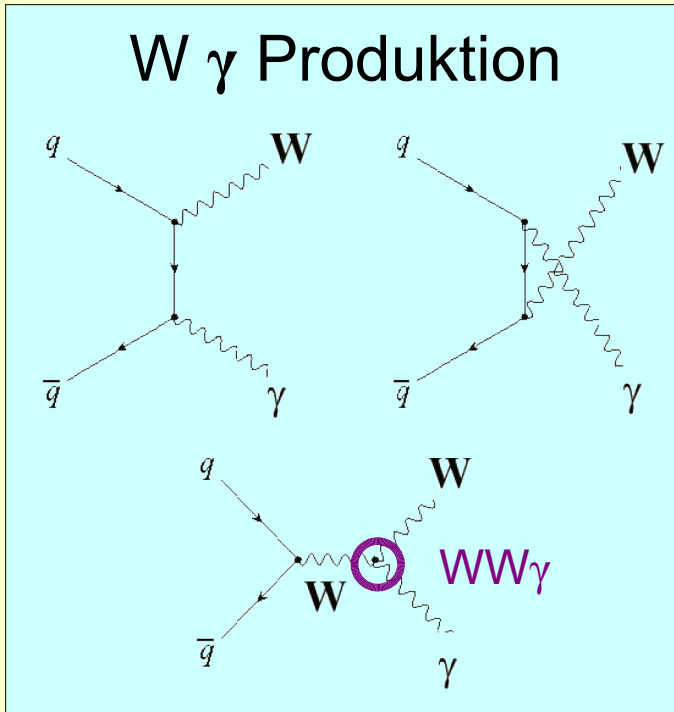
Präziseste
Einzelmessung!

old average: 80392 ± 29 MeV (Sommer `06)

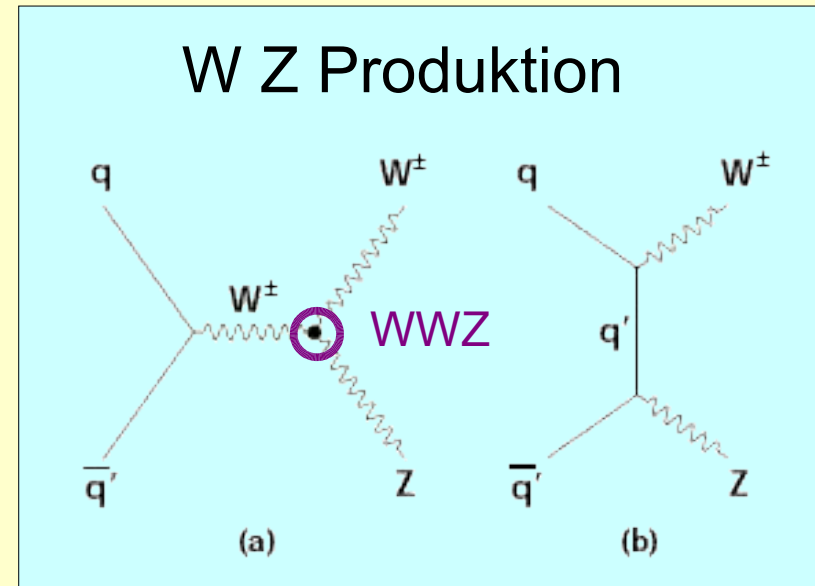
PDG 2006: 80403 ± 29 MeV (Januar `06)

Diboson Produktion am Tevatron

W γ Produktion

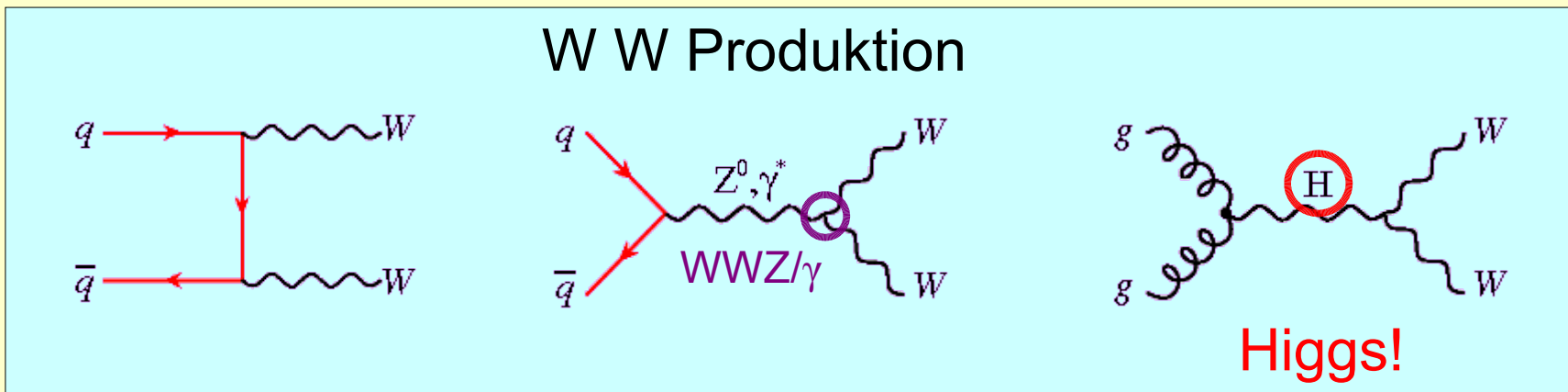


W Z Produktion



Dreiboson-Eichkopplungen

W W Produktion



Higgs!

Erste Messung von WZ Produktion

- CDF Kollaboration (Lumi=1.1 fb⁻¹)

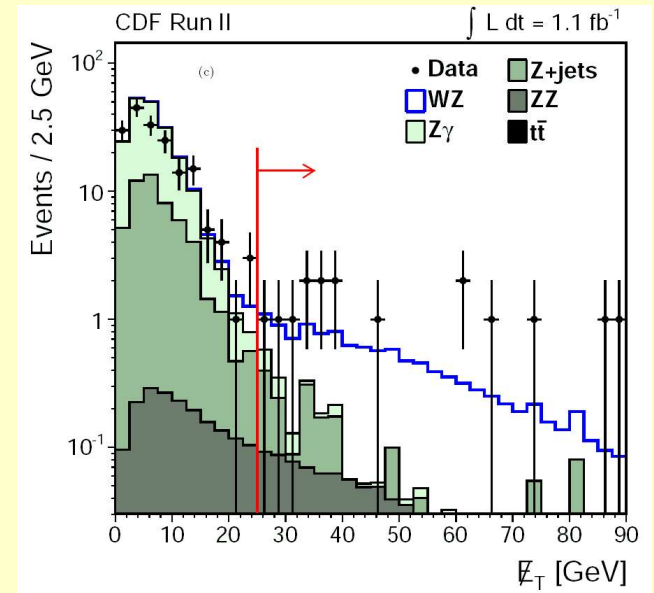


Leptonische Zerfälle: $WZ \rightarrow l' \nu ll$

Beobachtet: 16 (12.4 Signal + 2.7 BG)

$$\sigma(p\bar{p} \rightarrow WZ) = 5.0^{+1.8}_{-1.4} (stat.) \pm 0.4 (syst.) pb$$

$$\sigma_{theor} = 3.7 \pm 0.3 pb$$



Gemeinsame Obergrenze auf WZ+ZZ:

$$\sigma(p\bar{p} \rightarrow WZ + ZZ) < 15.2 pb \quad (95\% CL)$$

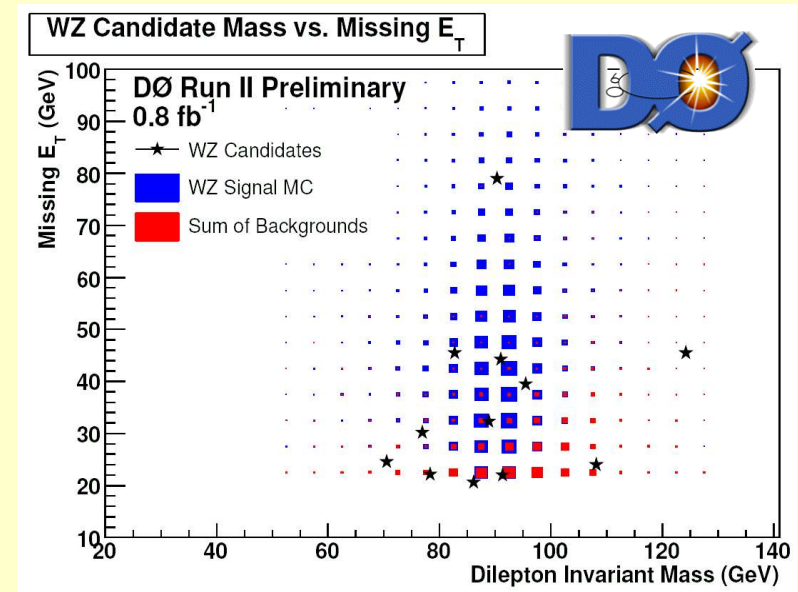
- D0 Kollaboration (Lumi=760-860 pb⁻¹)

Leptonische Zerfälle: $WZ \rightarrow l' \nu ll \quad (l=e, \mu)$

Beobachtet: 12 (7.5 Signal + 3.6 BG)

$$\sigma(p\bar{p} \rightarrow WZ) = 4.0^{+1.9}_{-1.5} pb$$

$$\sigma_{theor} = 3.7 \pm 0.3 pb$$



$W\gamma$ Produktion

- CDF Kollaboration (Lumi=1000 fb⁻¹)

Wirkungsquerschnitt:

$$E_{\text{T}}^{\gamma} > 7 \text{ GeV und } \Delta R(l, \gamma) > 0.7:$$

$$\sigma(p\bar{p} \rightarrow W\gamma \rightarrow l\nu\gamma) = 19.1 \pm 1.0 (\text{stat.}) \pm 2.6 (\text{syst.}) \text{ pb}$$
$$\sigma_{\text{theor}} = 19.3 - 13.4 \text{ pb}$$



- D0 Kollaboration (Lumi= \sim 900 pb⁻¹)

Wirkungsquerschnitt:

$$E_{\text{T}}^{\gamma} > 7 \text{ GeV}, \Delta R(l, \gamma) > 0.7 \text{ und } M_{\text{T}}(l, \gamma; E_{\text{T}}^{\text{miss}}) > 90 \text{ GeV:}$$

$$\sigma(p\bar{p} \rightarrow W\gamma \rightarrow e\nu\gamma) = 3.12 \pm 0.53 \text{ pb}$$
$$\sigma(p\bar{p} \rightarrow W\gamma \rightarrow \mu\nu\gamma) = 3.21 \pm 0.53 \text{ pb}$$



→ sehr gute Übereinstimmungen mit den Vorhersagen!

WW Produktion

- CDF Kollaboration (Lumi=825 fb⁻¹)

Dilepton Zerfall: $WW \rightarrow l' \nu l \nu$ ($l=e, \mu$)

Beobachtet: 95 (52 Signal + 38 BG)

$$\sigma(p \bar{p} \rightarrow WW) = 13.6 \pm 2.3 (stat.) \pm 2.0 (syst.) pb$$

$$\sigma_{theor} = 13.0 - 13.5 pb$$



- D0 Kollaboration (Lumi=252 pb⁻¹)

Dilepton Zerfall: $WW \rightarrow l' \nu l \nu$ ($l=e, \mu$)

Beobachtet: 25 (16.1 Signal + 8.0 BG)

$$\sigma(p \bar{p} \rightarrow WW) = 13.8_{-3.8}^{+4.3} (stat.)_{-1.3}^{+1.5} (syst.) pb$$

$$\sigma_{theor} = 13.0 - 13.5 pb$$



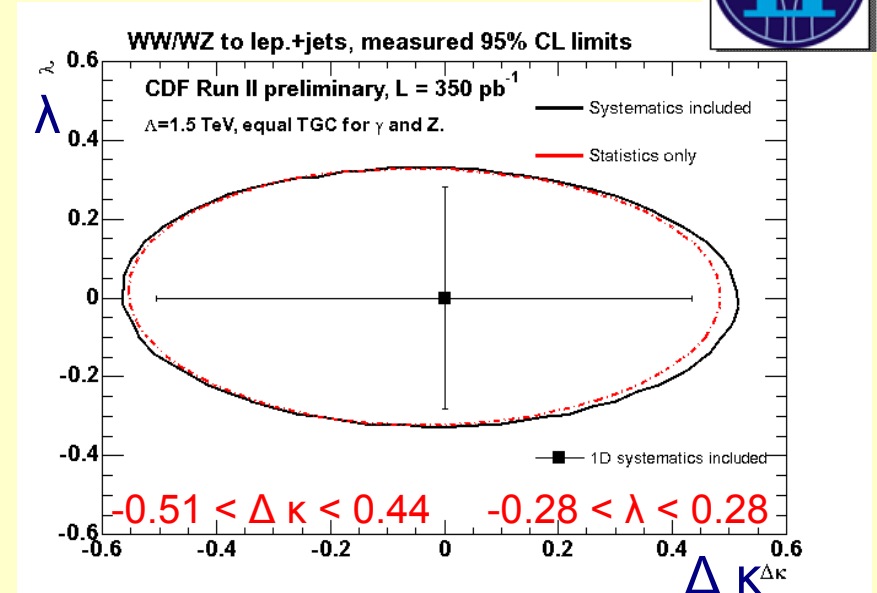
- gute Übereinstimmungen mit den Vorhersagen!
- Grenzen auf anomale Dreibosonkopplungen

Anomale Dreibosonkopplungen



- Analyse von WW(WZ) Produktion:
Dreibosonkopplungen (TGC):

$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = ig_1^V (W_{\mu\nu}^\dagger W^\mu V^\nu - W_\mu^\dagger V_\nu W^{\mu\nu}) + i\kappa_V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{i\lambda_V}{M_W^2} W_{\lambda\mu}^\dagger W^\mu_\nu V^{\nu\lambda}$$



LEP Grenzen (PDG):

$$\Delta\kappa_\gamma = -0.027 \pm 0.045 \quad \lambda_\gamma = -0.028 \pm 0.021$$

$$\Delta\kappa_Z = -0.076 \pm 0.064 \quad \lambda_Z = -0.088 \pm 0.064$$

- LEP Grenzen eine etwa Größenordnung kleiner
- Tevatron testet TGC bei höheren Massen

D0 252 pb⁻¹



Coupling		95% C.L. Limits	Λ (TeV)
WW _γ = WWZ	λ	-0.31, 0.33	1.5
	Δκ	-0.36, 0.47	
WW _γ = WWZ	λ	-0.29, 0.30	2.0
	Δκ	-0.32, 0.45	
HISZ	λ	-0.34, 0.35	1.5
	Δκ _γ	-0.57, 0.75	
SM WW _γ	λ _Z	-0.39, 0.39	2.0
	Δκ _Z	-0.45, 0.55	
SM WWZ	λ _γ	-0.97, 1.04	1.0
	Δκ _γ	-1.05, 1.29	

Statistisch limitiert!



Neue Top Resultate



CDF

D0

Top Mass

- dilepton (ME) 1020 pb⁻¹
- dilepton (ME,btag) 1020 pb⁻¹
- lepton+jets (ME) 940 pb⁻¹
- all hadronic (NN,templ) 1020 pb⁻¹
- all hadronic (templ) 940 pb⁻¹

- e mu (templates) 840 pb⁻¹
- e mu (ME) 840 pb⁻¹
- dilepton (LL,btag) 370 pb⁻¹
- lepton+jets (ideogram) 370 pb⁻¹

Top Paare

- lepton+jets (btag, NN) 700 pb⁻¹
- all hadronic (btag,NN) 1020 pb⁻¹

- dilepton (LL,templates) 900 pb⁻¹
- hadrons (btag) 405 pb⁻¹

Single top

- leptonic (NN) 955 pb⁻¹
- leptonic (LL) 955 pb⁻¹
- leptonic (ME) 955 pb⁻¹

- leptonic (Tree, ME, NN) 900 pb⁻¹

Sonstiges

- top W-helicities 955 pb⁻¹
- resonant ttbar prod. 1000 pb⁻¹
- search for tt → lτννqq 350 pb⁻¹

- top W-helicities 370 pb⁻¹
- top charge 370 pb⁻¹

→ talk by Ch. Schwanenberger T122.1

Selektion von Top Ereignissen

CDF + D0 verwenden alle Zerfallskanäle und unterschiedlichste Analysetechniken

Problem:

- kleines Signal und riesiger Untergrund
- sehr viele Zerfallskanäle

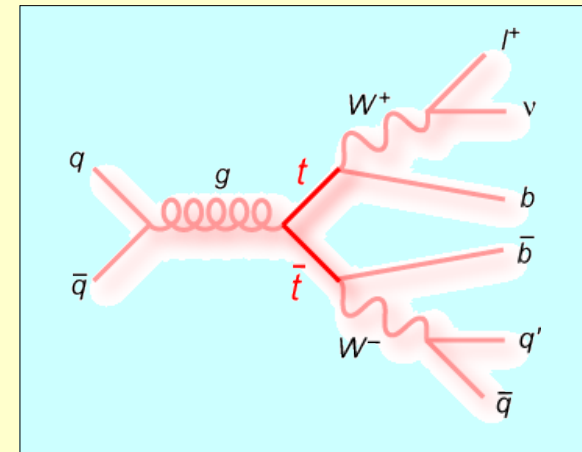
Methoden:

- Neuronale Netze
- Multivariante Likelihoods
- Matrixelementmethoden
- Templates
- Entscheidungsbäume (adaptive)
- Ideogramme

Anwendungen

- kinematische Rekonstruktion
- Selektion
- Signalextraktion

viele – sehr komplizierte Analysen !



Top Pair Decay Channels

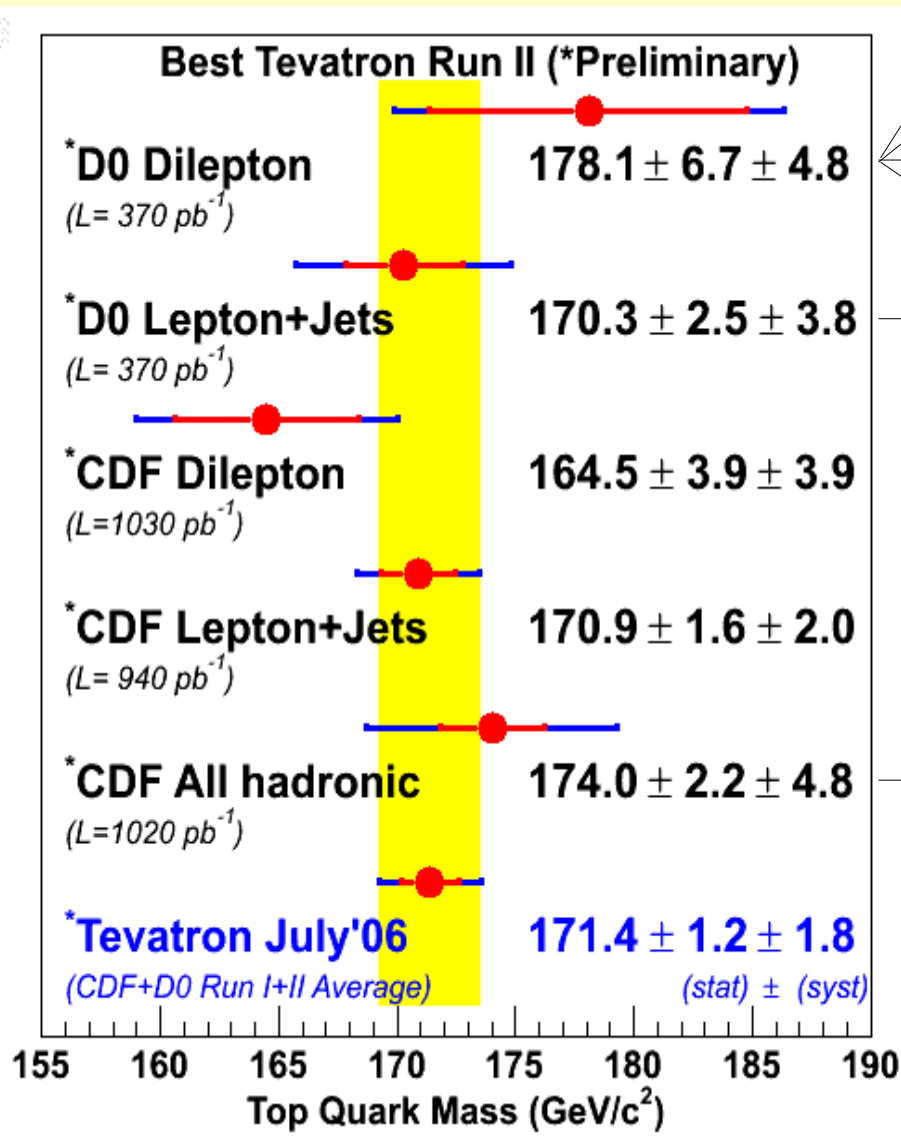
$\bar{c}s$	electron+jets	muon+jets	tau+jets	all-hadronic	
$\bar{u}d$					
τ^-	$e\tau$	$\mu\tau$	$\tau\tau$	tau+jets	
μ^-	$e\mu$	$\mu\mu$	$\mu\tau$	muon+jets	
e^-	$e\tau$	$e\mu$	$e\tau$	electron+jets	
W^- decay	e^+	μ^+	τ^+	$u\bar{d}$	$c\bar{s}$



Messung der Top Masse



Resultate Sommer '06



Neue Resultate

- (L=836 pb⁻¹)
- 177.7 ± 8.8 (stat.)^{+3.7} (syst.) (eμ, Matrix Elem.)
 - 171.6 ± 7.9 (stat.)^{+5.1} (syst.) (eμ, Template I)
 - 173.6 ± 6.7 (stat.)^{+5.1} (syst.) (eμ, Template II)
 - 165.7^{+9.7} (stat.)^{+4.4} (syst.) (eμ, Template III)
 - 173.7 ± 4.4 (stat. + JES)^{+2.1} (syst.) (Ideogram) (L=370 pb⁻¹)

in situ Kalibrationen
(JES=jet energy scale)

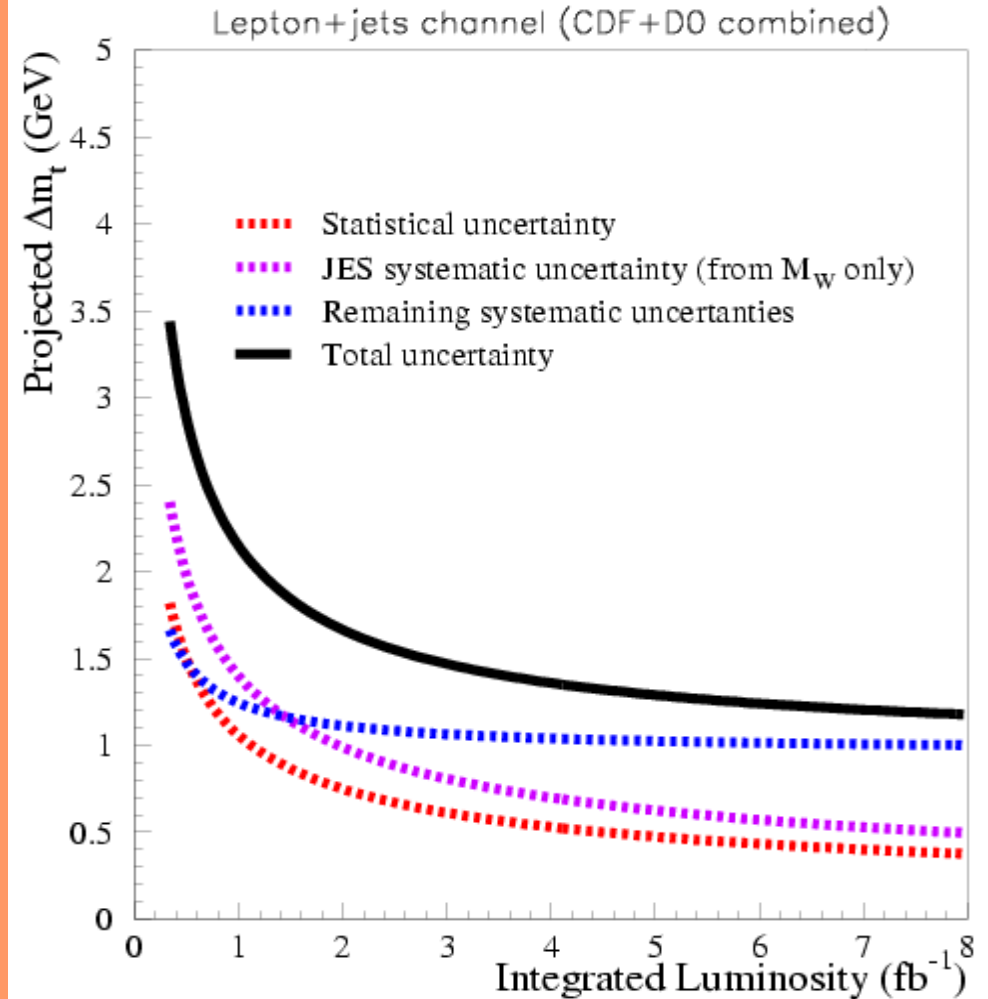
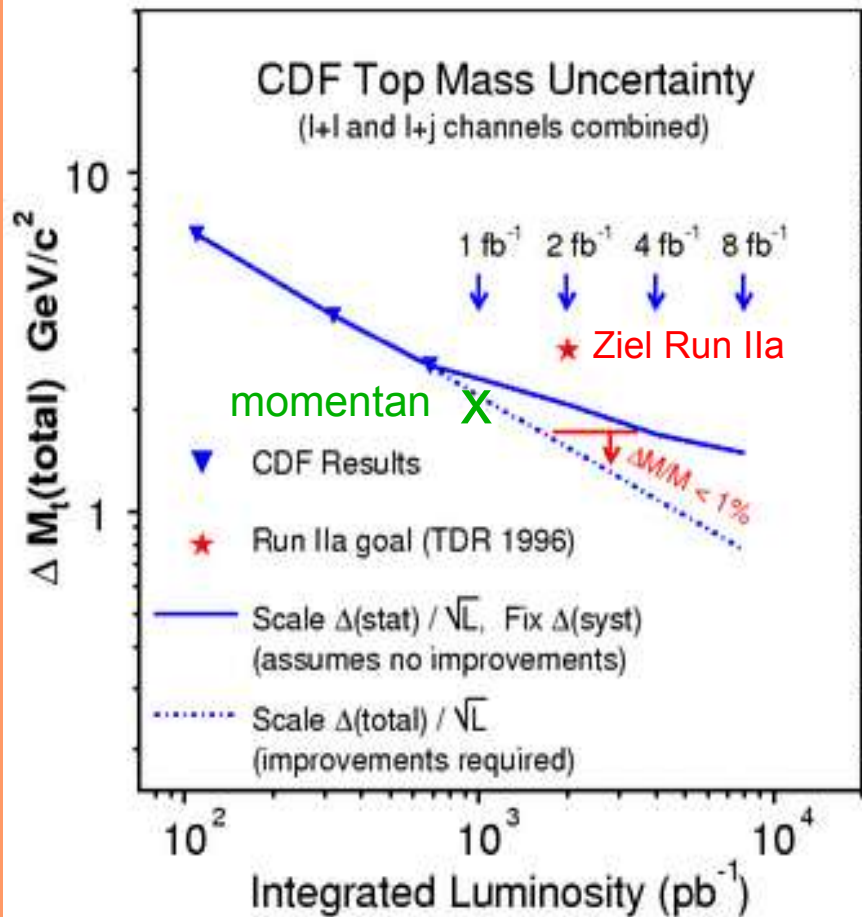
Systematische Fehler reduziert

171.1 ± 3.7 (stat. + JES) ± 2.1 (syst.)

kontinuierliche Fehlerverkleinerung!



Aussichten Top Masse



Δm_t schon genauer als projiziert!

$\Delta m_t \sim 1.2 \text{ GeV}$ ist zu schaffen!

Elektrische Ladung des Top Quarks

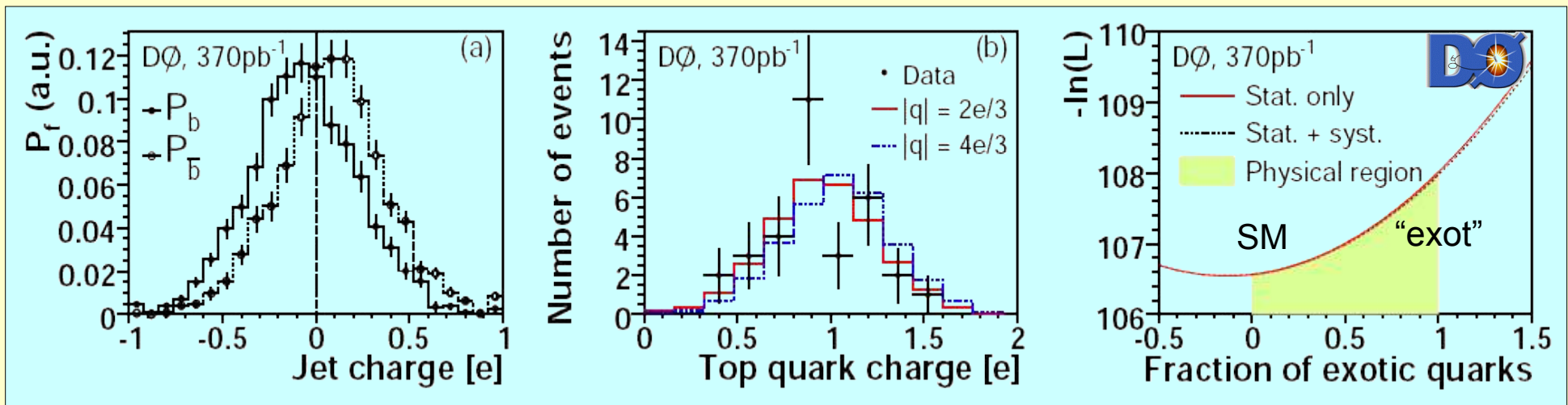
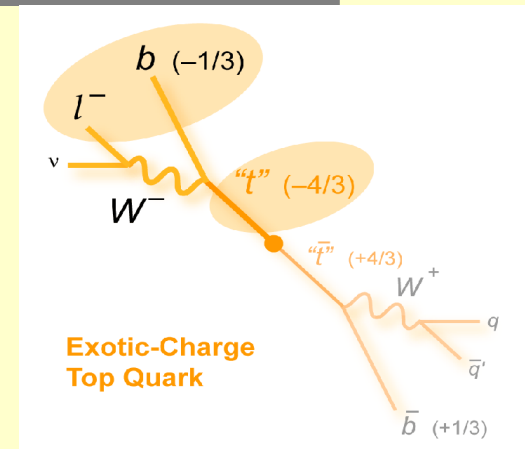
Bekannt:

top zerfällt in b-quarks: $t \rightarrow b W^\pm$

→ mögliche Ladungen: $|Q_{\text{top}}| = 2/3, 4/3$

Messung (D0):

Untersuchung semi-leptonischer top-quark Zerfälle



Ladung b-jet

Ladung Top-quark

Fit "exotisches" Quark

→ $\rho = -0.13 \pm 0.66 \text{ (stat)} \pm 0.11 \text{ (syst.)}$

→ $|Q_{\text{top}}| = 4/3$ ausgeschlossen mit **92% CL**

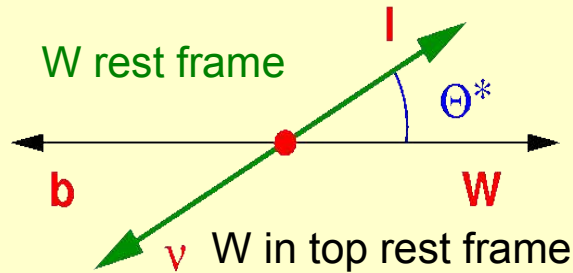
$$\rho = \frac{P_{\text{fit}} - P_{\text{SM}}}{P_{\text{exot}} - P_{\text{SM}}}$$

(CDF: Preliminary → Moriond)

W-Helizität in Top Zerfällen

- Winkelverteilung hat drei Anteile:

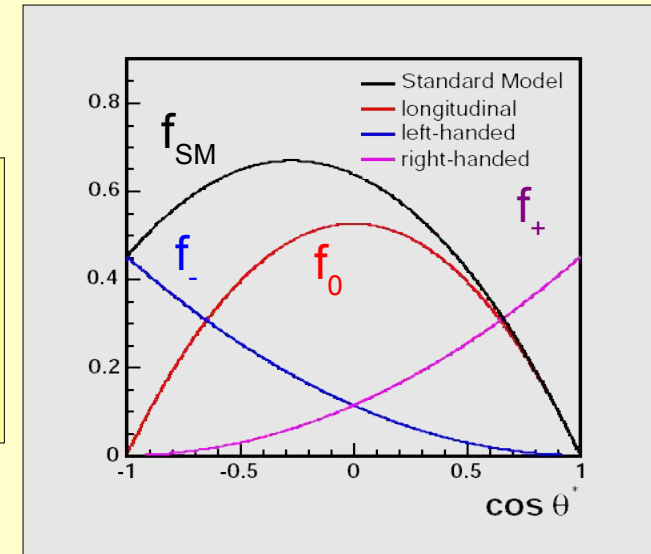
$$w(\Theta^*) = f_0 \cdot w_0(\Theta^*) + f_- \cdot w_-(\Theta^*) + f_+ \cdot w_+(\Theta^*)$$



$$w_0(\Theta^*) = \frac{3}{4}(1 - \cos^2 \Theta^*)$$

$$w_-(\Theta^*) = \frac{3}{8}(1 - \cos \Theta^*)^2$$

$$w_+(\Theta^*) = \frac{3}{8}(1 + \cos \Theta^*)^2$$



- V-A Theorie (SM):

$$f_0 = 0.703 \pm 0.007 \quad (\text{longitudinal})$$

$$f_- = 0.297 \pm 0.007 \quad (\text{linkshändig})$$

$$f_+ = 0 \quad (\text{rechtshändig})$$

$$f_0 = \frac{m_t^2}{2m_W^2 + m_t^2 + m_b^2}$$

- Ergebnisse CDF (955 pb⁻¹):

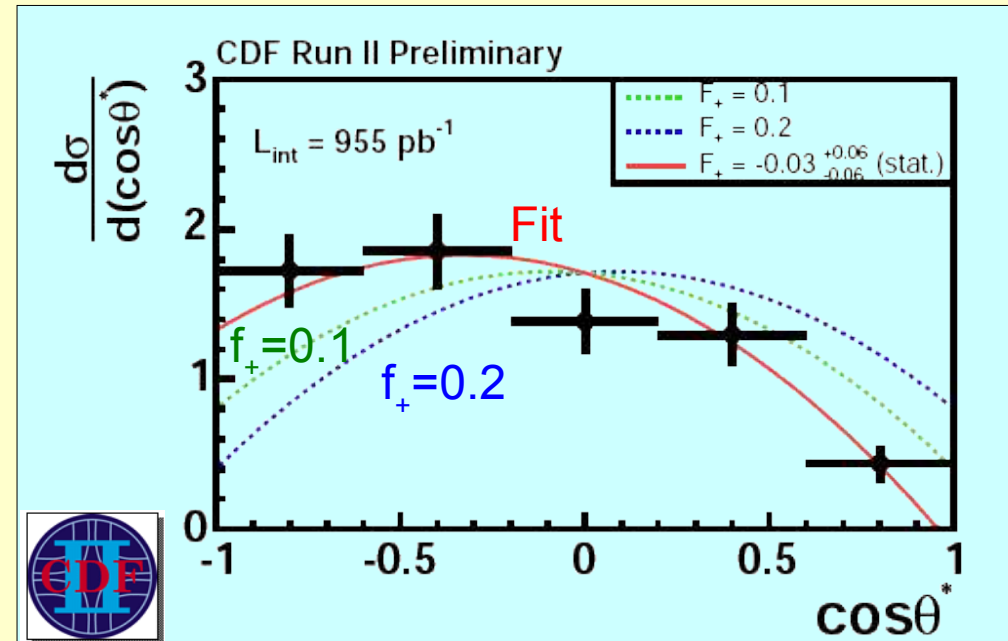
$$f_0 = +0.59 \pm 0.12 (\text{stat.})_{-0.06}^{+0.07} (\text{syst.})$$

$$f_+ = -0.03 \pm 0.06 (\text{stat.})_{-0.03}^{+0.04} (\text{syst.})$$

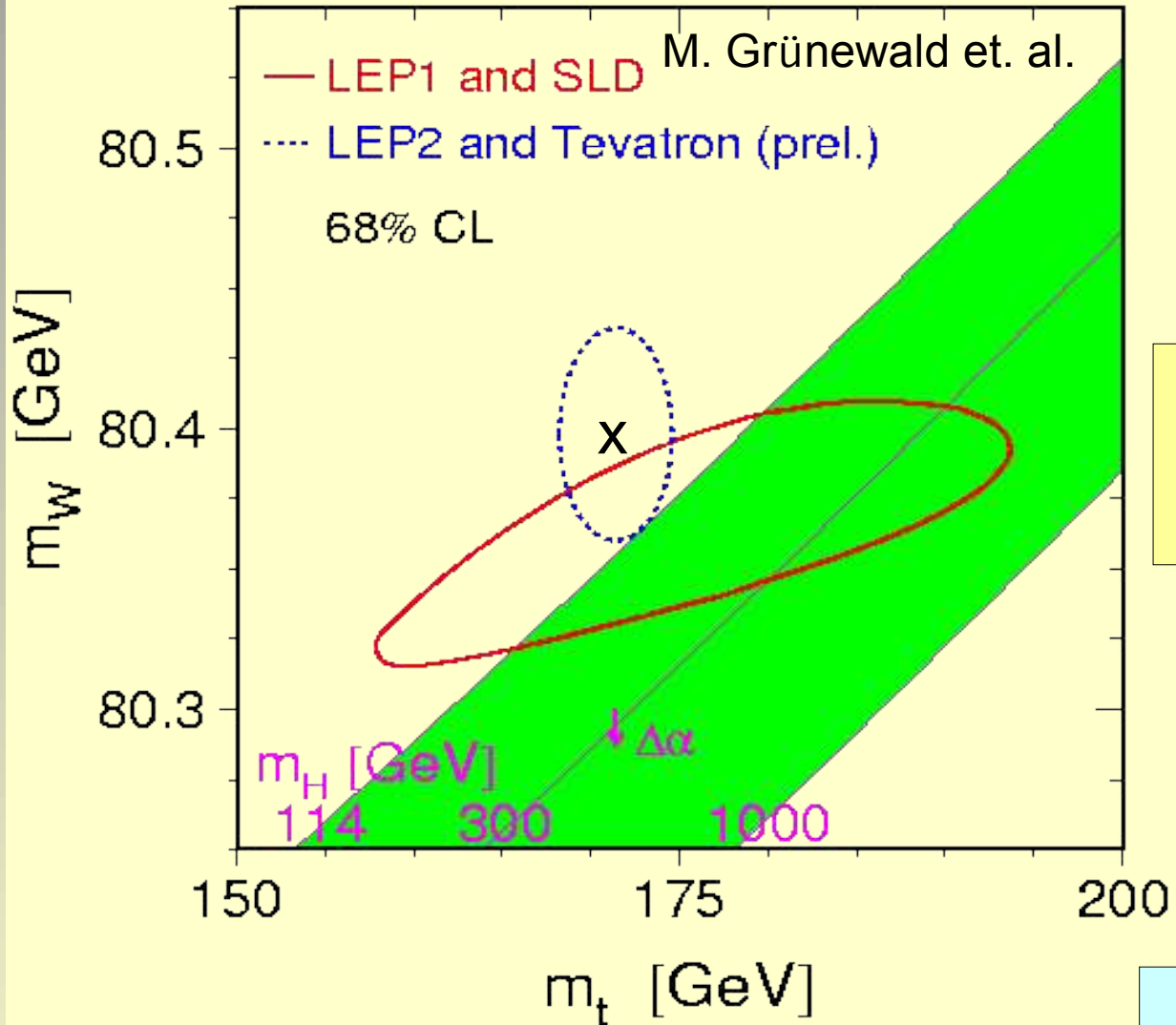
$$f_+ < 0.10 \quad (95\% \text{ CL})$$

- Ergebnisse D0 (370 pb⁻¹):

$$f_+ = -0.056 \pm 0.080 (\text{stat.}) \pm 0.057 (\text{syst.})$$



Vorhersage der Higgsmasse



$$M_W = 80398 \pm 25 \text{ MeV}$$

$$80392 \pm 29 \text{ MeV (Sommer 06)}$$



$$m_{\text{top}} = 171.4 \pm 2.1 \text{ GeV}$$

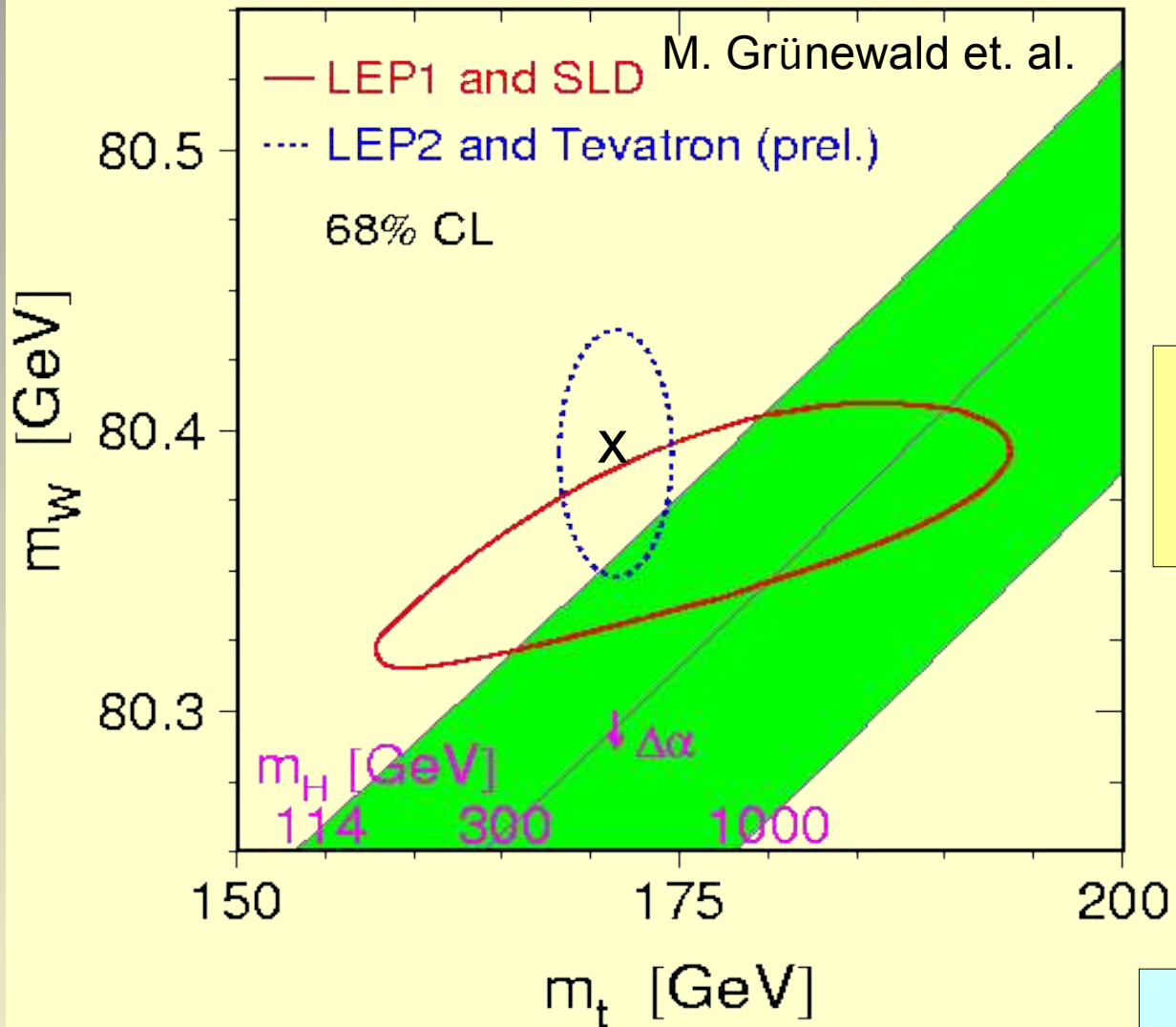
(Status Sommer 06)



$$\rightarrow M_H = 80^{+36}_{-26} \text{ GeV}$$

$$M_H = 85^{+39}_{-28} \text{ GeV (Sommer 06)}$$

Vorhersage der Higgsmasse



$$M_W = 80398 \pm 25 \text{ MeV}$$

$$80392 \pm 29 \text{ MeV (Sommer 06)}$$



$$m_{\text{top}} = 171.4 \pm 2.1 \text{ GeV}$$

(Status Sommer 06)

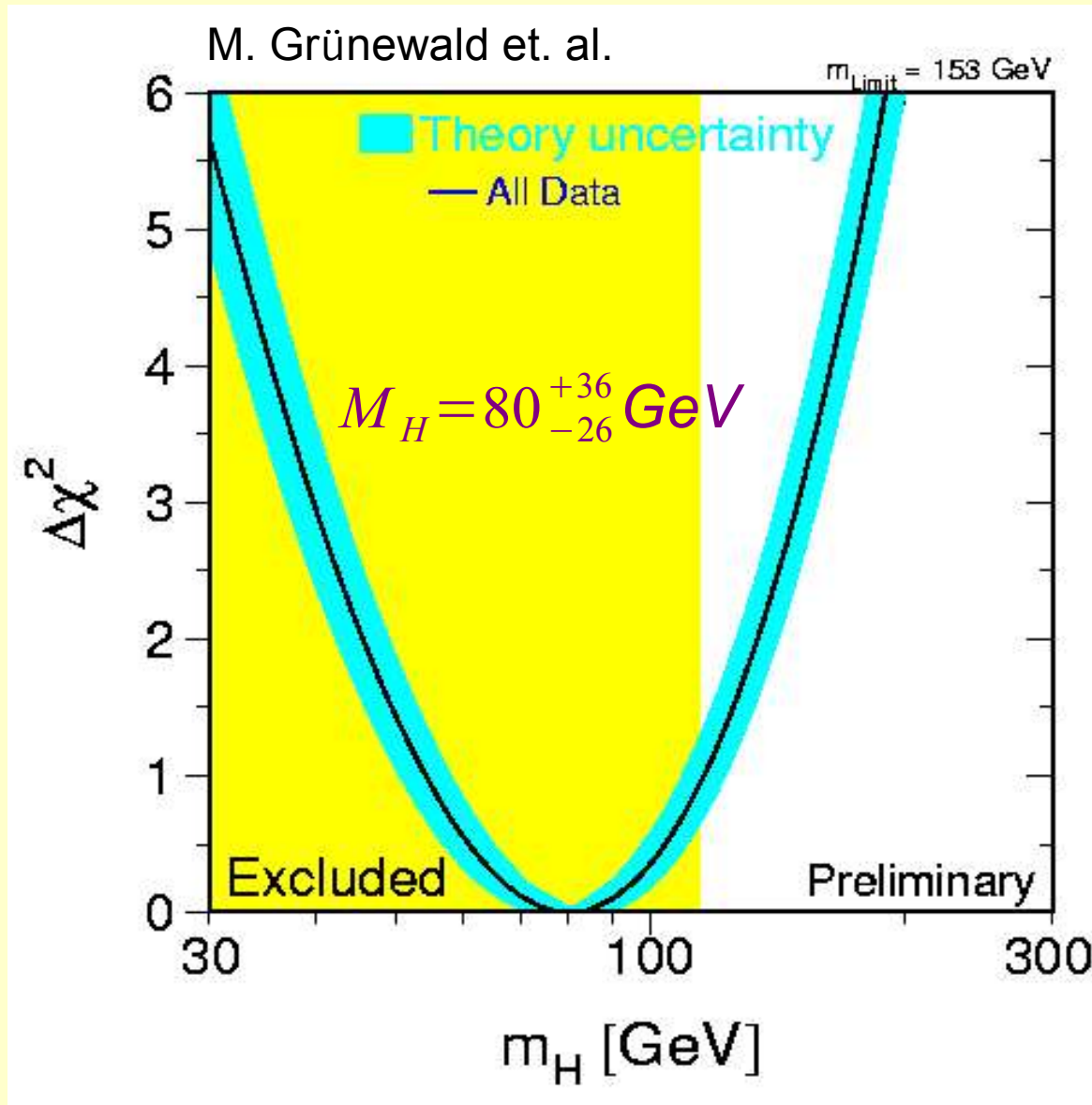


$$\rightarrow M_H = 80^{+36}_{-26} \text{ GeV}$$

$$M_H = 85^{+39}_{-28} \text{ GeV (Sommer 06)}$$

Vorhersage der Higgsmasse

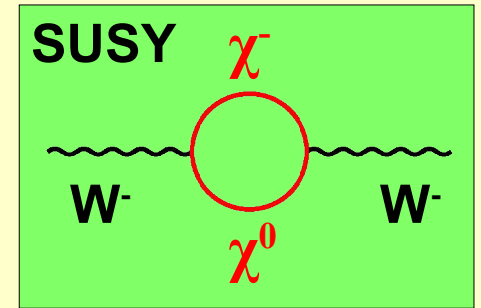
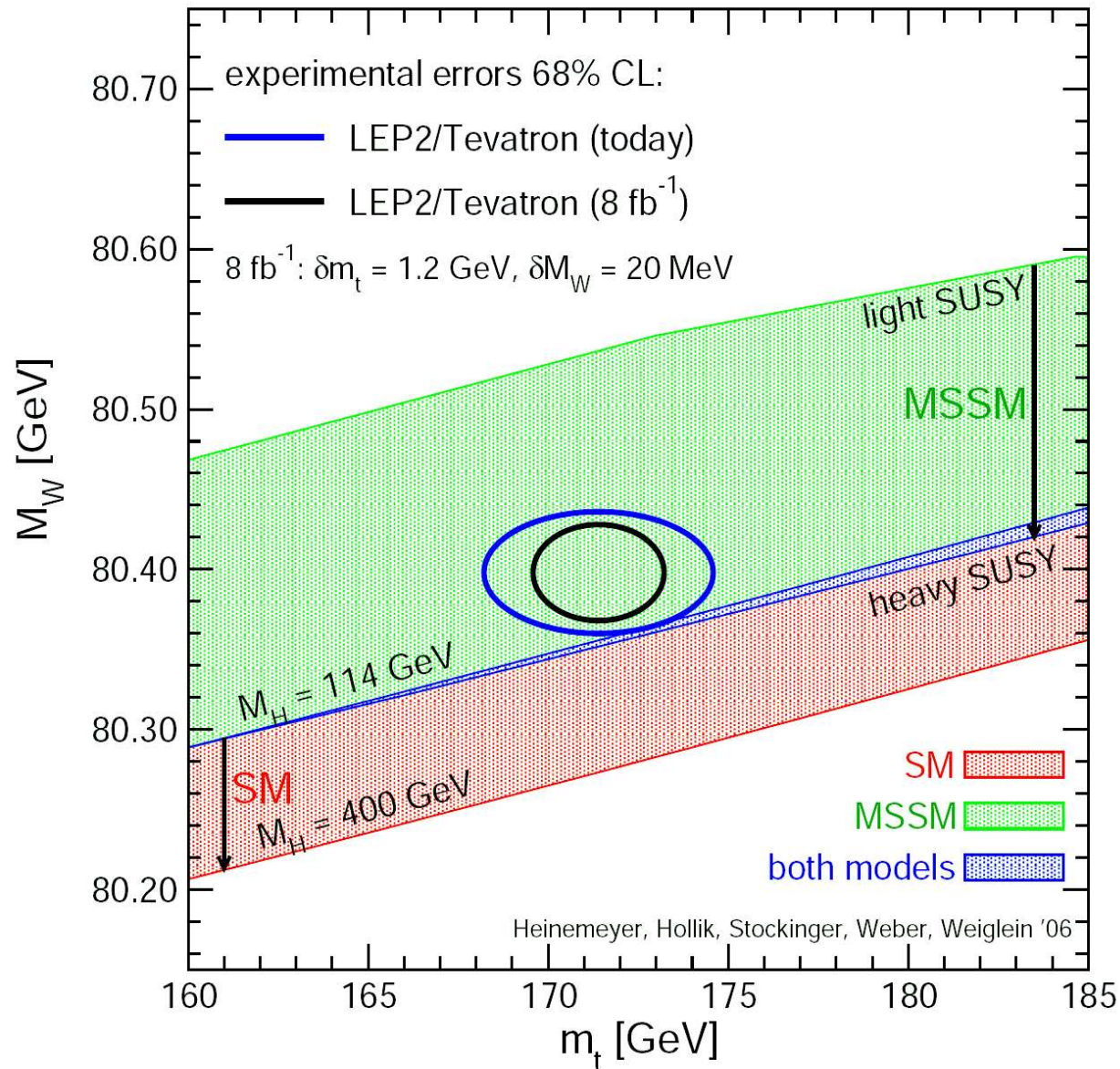
Stand: 2007



$m_H < 153 \text{ GeV}$
(95%CL)

Chance auf
Higgsentdeckung
bei Tevatron

Higgs und Supersymmetrie

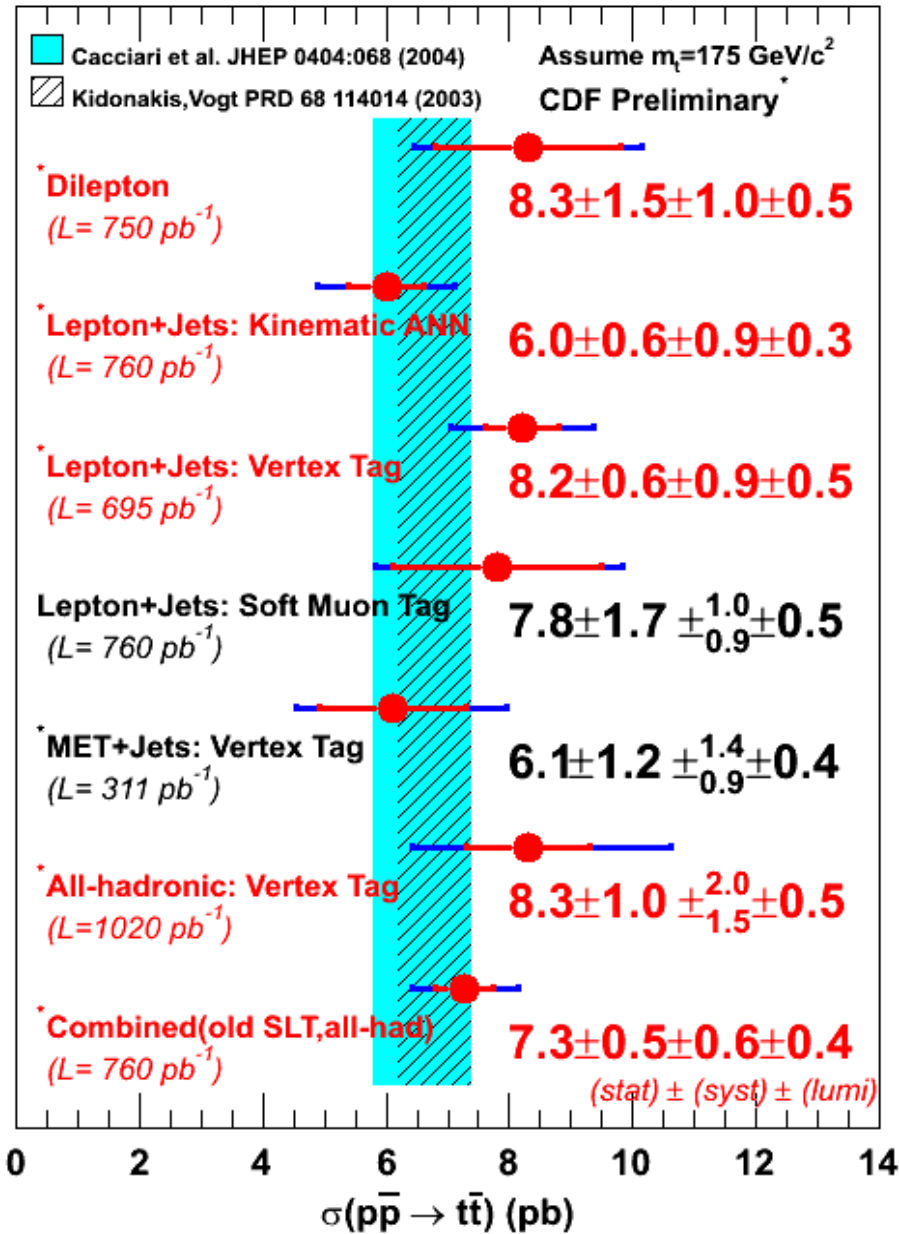




Top Paarproduktion

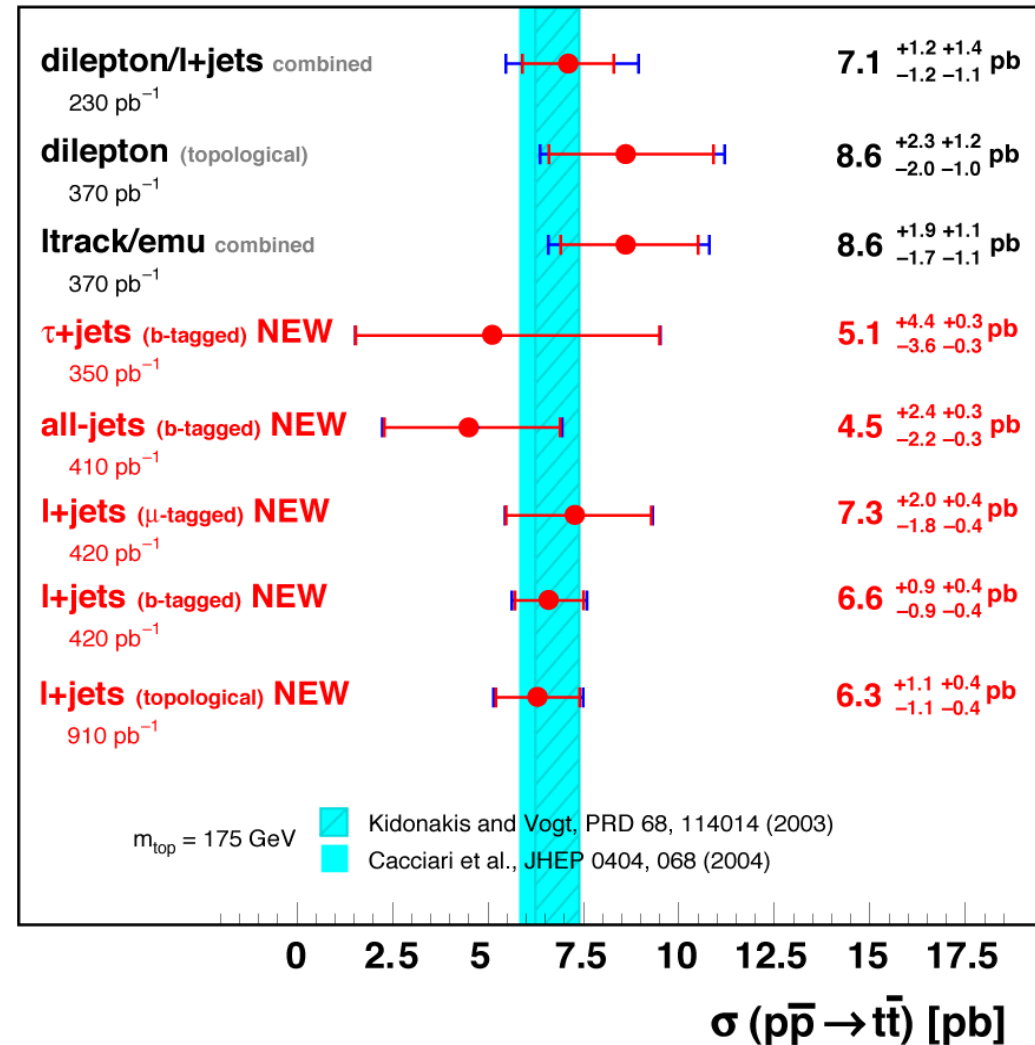


Status Sommer



DØ Run II Preliminary

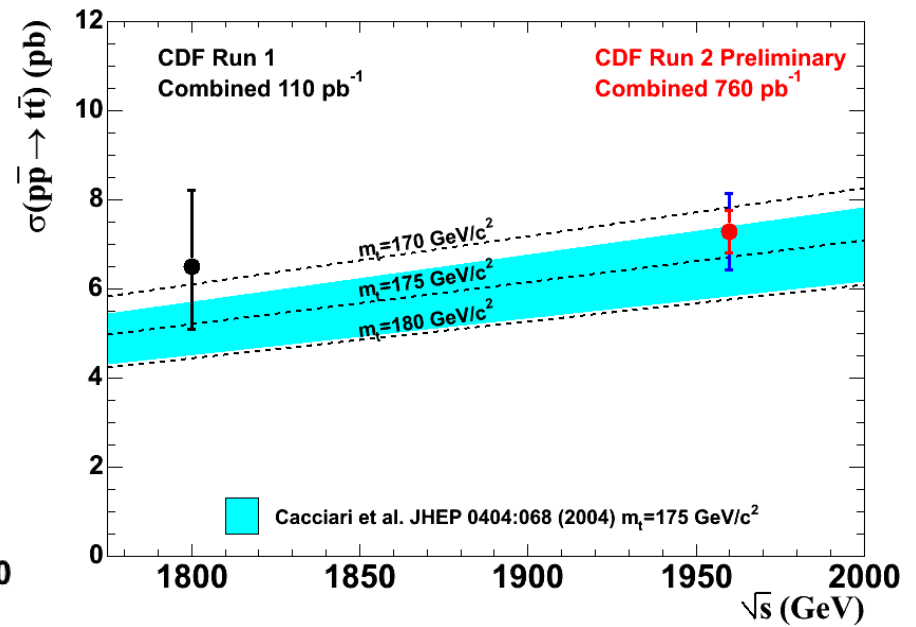
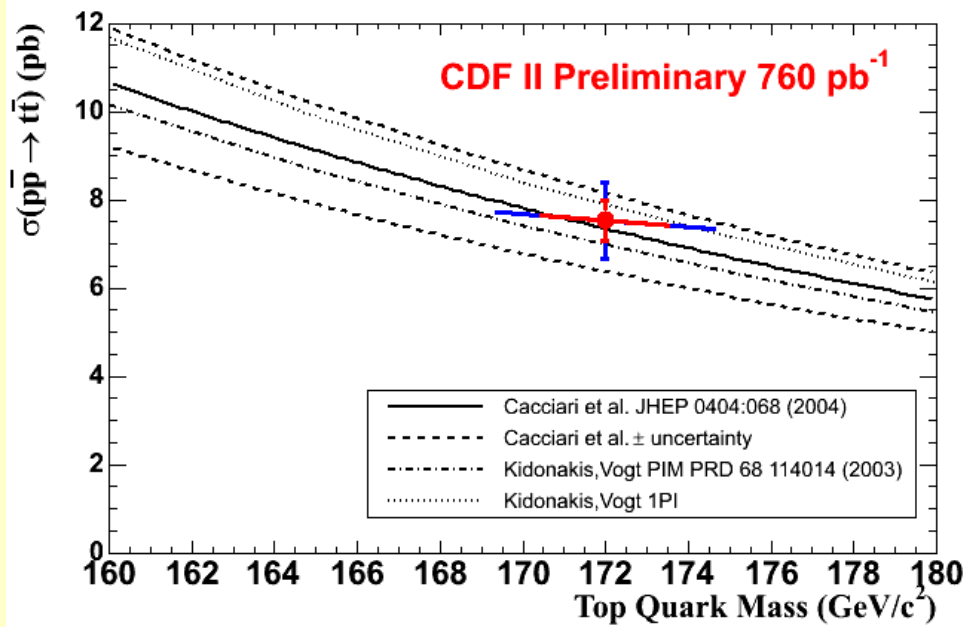
Fall 2006



$$\sigma_{theor} = 6.7_{-0.9}^{+0.7} \text{ pb} \quad (m_{top} = 175 \text{ GeV})$$



Top Paarproduktion



Theoriefehler ~ 15%

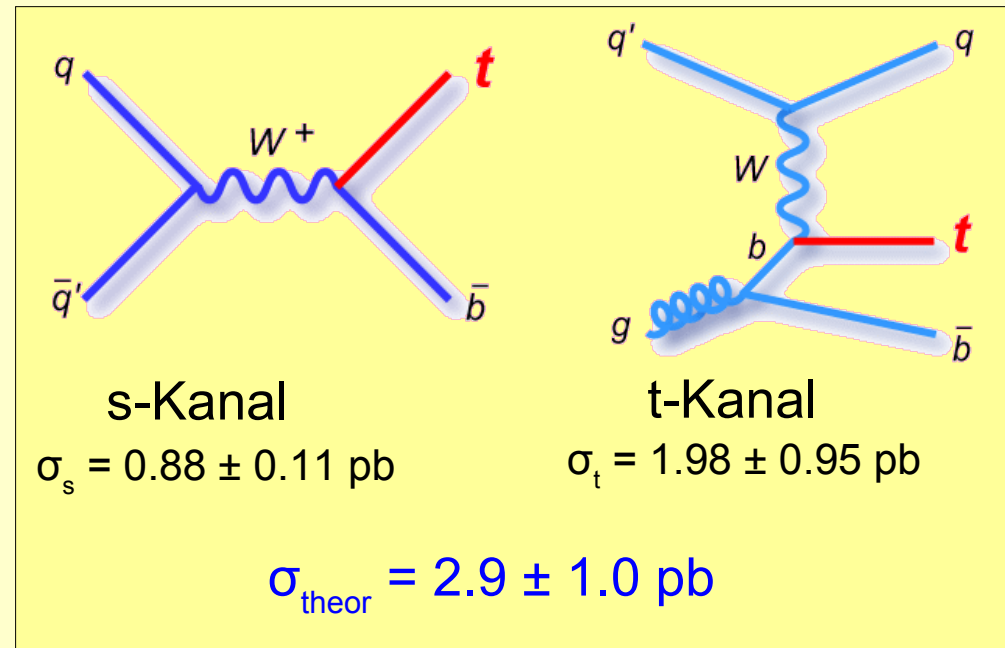
>

Top-Massenunsicherheit!

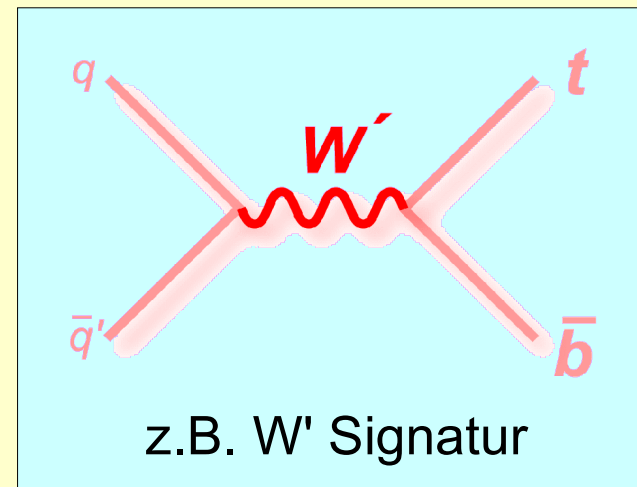
gute Übereinstimmung mit Theorie

Single Top Produktion

- schwacher Prozess
 - Signatur: $W + 2\text{jets}$
 - Untergrund: Wbb
- Messung von $|V_{tb}|$



- sensitiv auf neue Physik:





Single Top Produktion



SM Erwartung: $\sigma_{\text{theor}} = 2.9 \pm 1.0 \text{ pb}$

CDF Resultate: (955pb⁻¹)

NN Methode:

$$\sigma_t = 0.2_{-0.2}^{+1.1} \text{ pb} \quad \sigma_t < 2.6 \text{ pb} \quad (3.8 \text{ erw.}) \quad (95\% \text{CL})$$

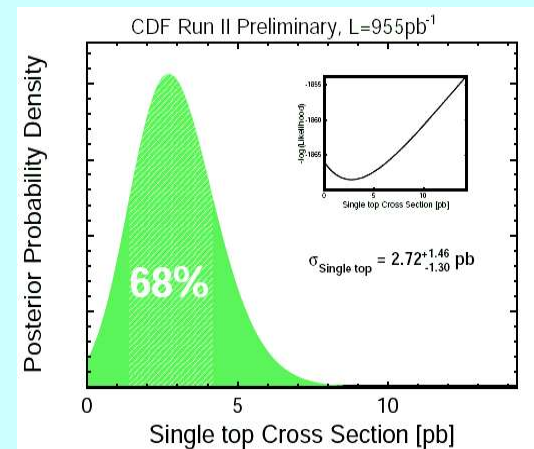
$$\sigma_s = 0.7_{-0.7}^{+1.5} \text{ pb} \quad \sigma_s < 3.7 \text{ pb} \quad (2.9 \text{ erw.}) \quad (95\% \text{CL})$$

$$\text{kombiniert: } \sigma_{s+t} < 2.6 \text{ pb} \quad (5.7 \text{ erw.}) \quad (95\% \text{CL})$$

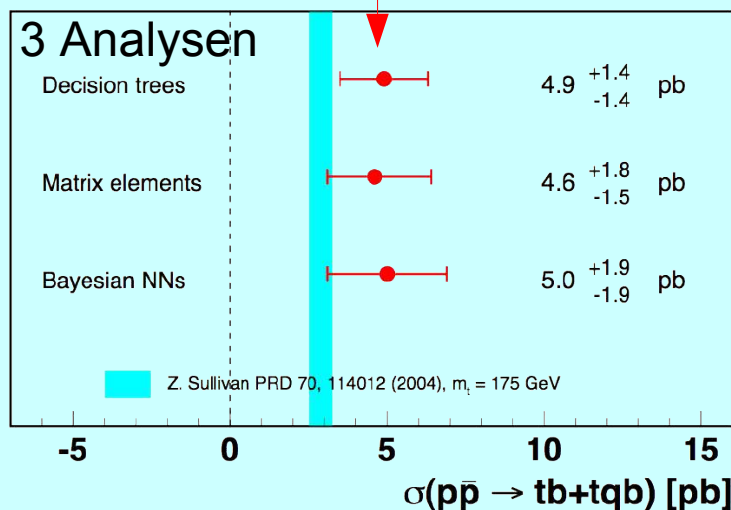
Matrix Element Methode:

$$\sigma_{s+t} = 2.7_{-1.3}^{+1.5} \text{ pb}$$

2.3 σ Messung
(2.5 σ erwartet)



DØ: (900pb⁻¹) **Signifikanz 3.4 sigma !!!**

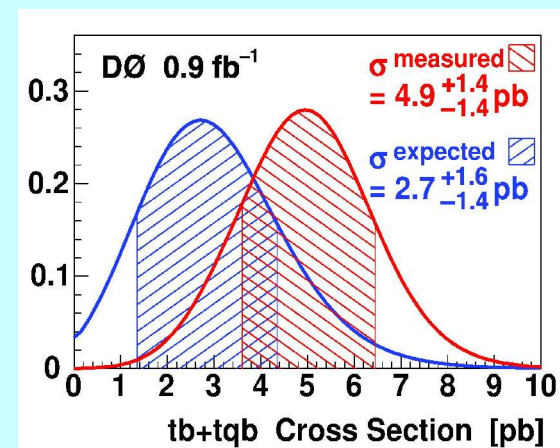


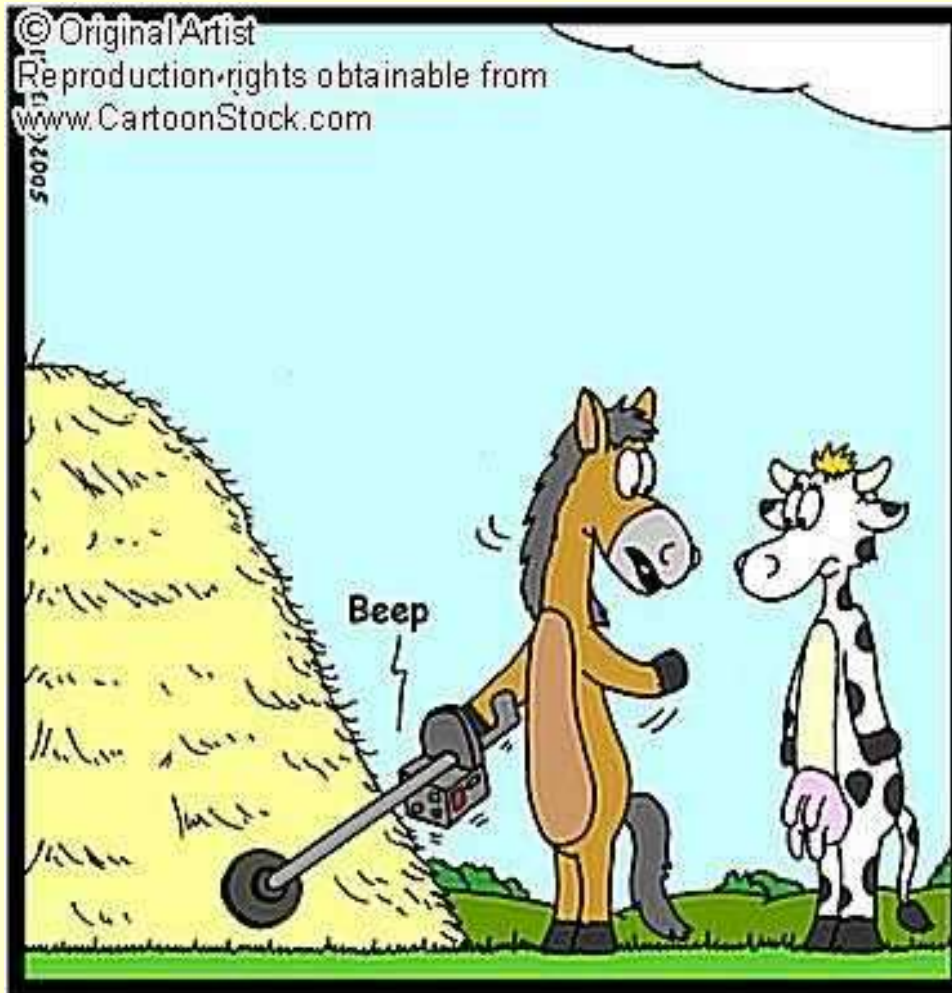
Decision Tree Methode:

$$\sigma_{s+t} = 4.9_{-1.4}^{+1.4} \text{ pb}$$

3.4 σ Messung
(2.1 σ erwartet)

$$0.68 < |V_{tb}| \leq 1 \quad (95\% \text{CL})$$



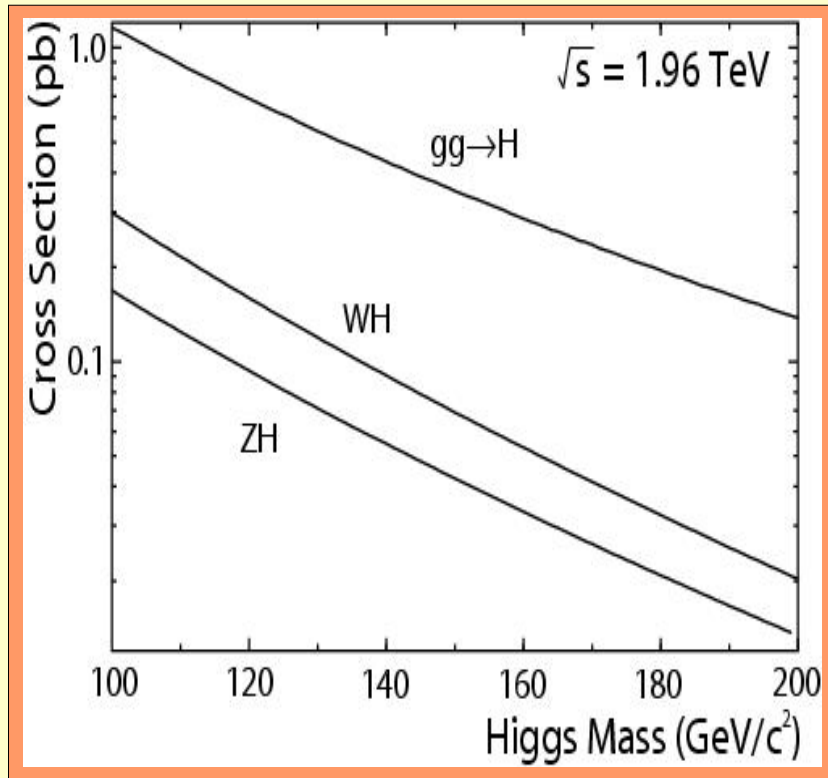


You were right: There's a needle in this haystack...

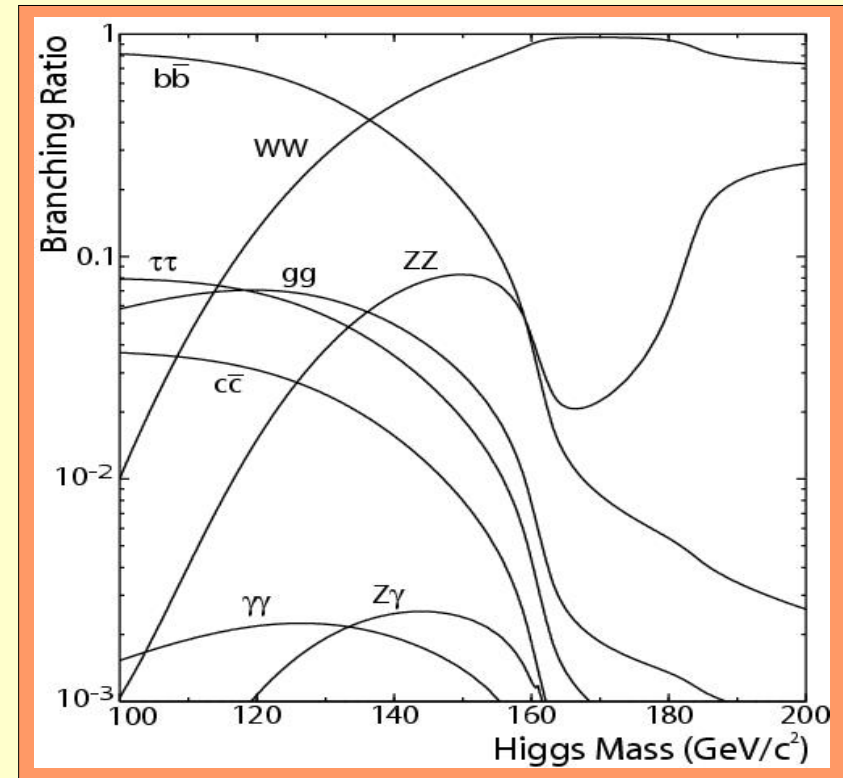
Higgs Produktion und Zerfall am Tevatron

Higgs Suche am Tevatron

Produktion



Zerfall



viele interessante Kanäle...

m_H klein:

WH \rightarrow $l\nu b\bar{b}$
ZH \rightarrow $ll b\bar{b}, \nu\nu b\bar{b}$

m_H gross:

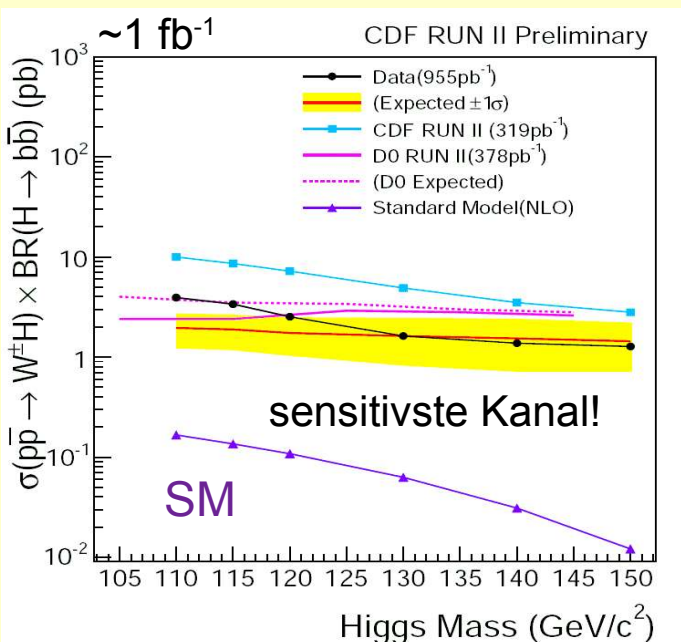
gg \rightarrow H \rightarrow WW



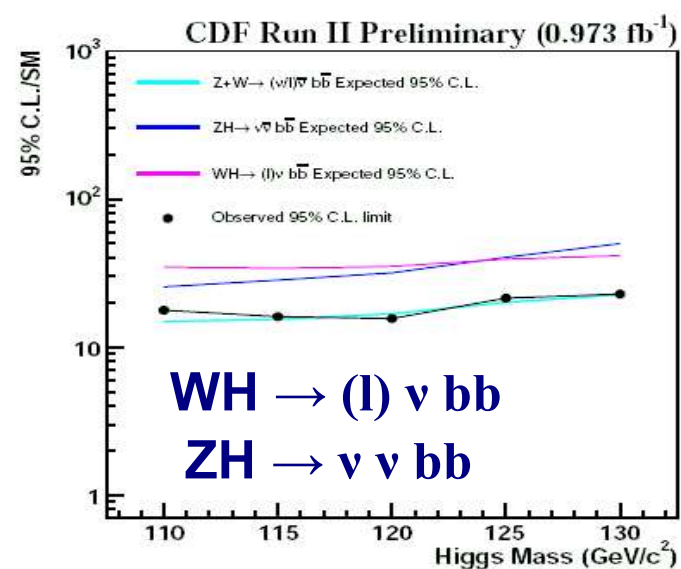
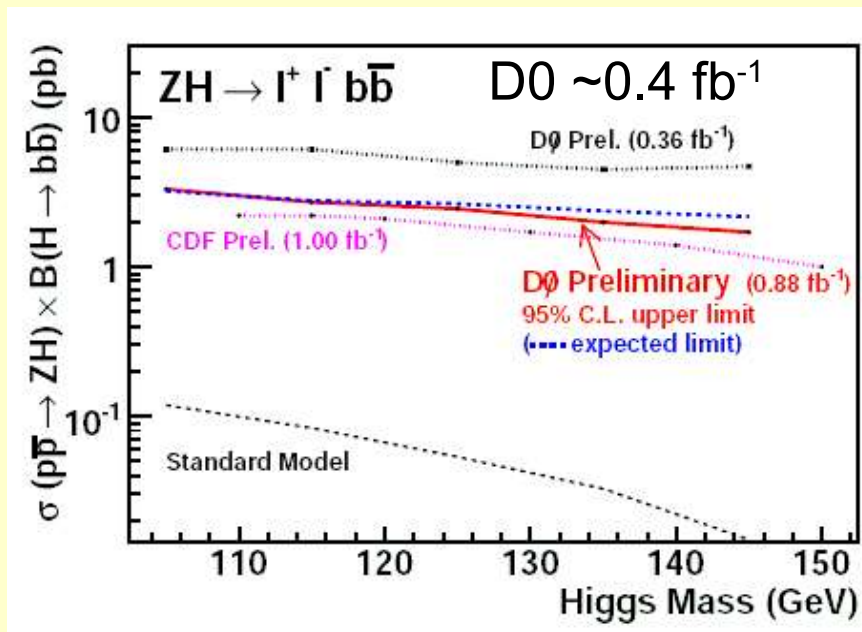
W+Z Higgs Strahlung



WH → l ν bb



ZH → ll bb



- Kanäle sensitiv af kleine Higgs Massen
- Pro Kanal fehlt ein Faktor ~10 um das SM Higgs Boson zu beobachten



Higgs nach WW

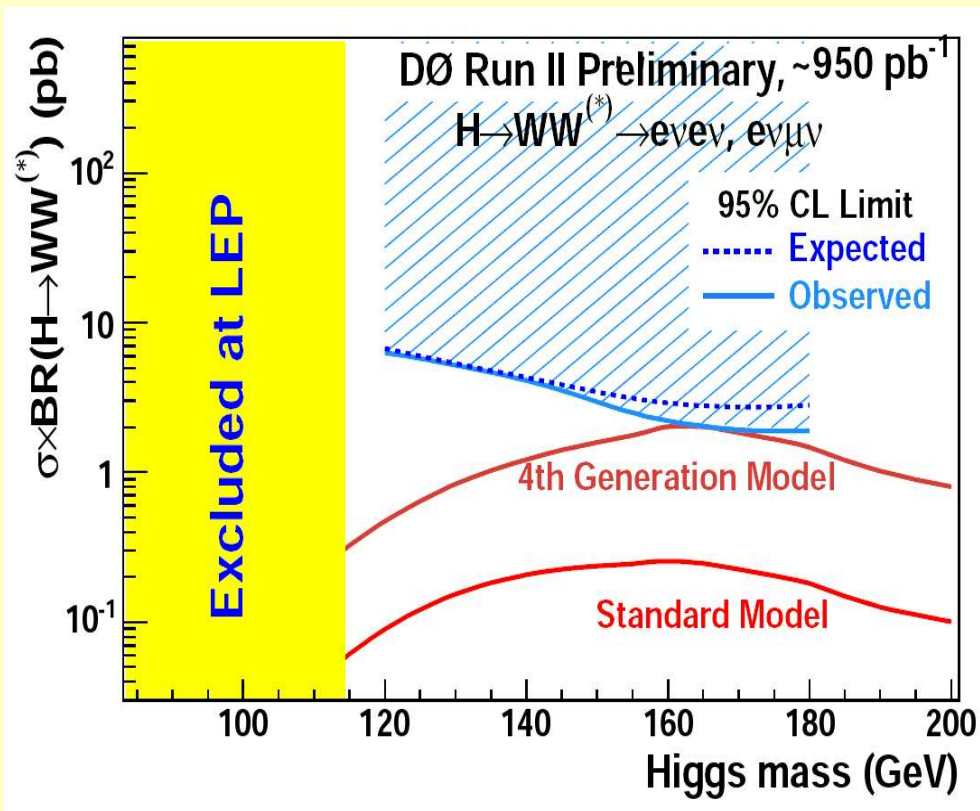
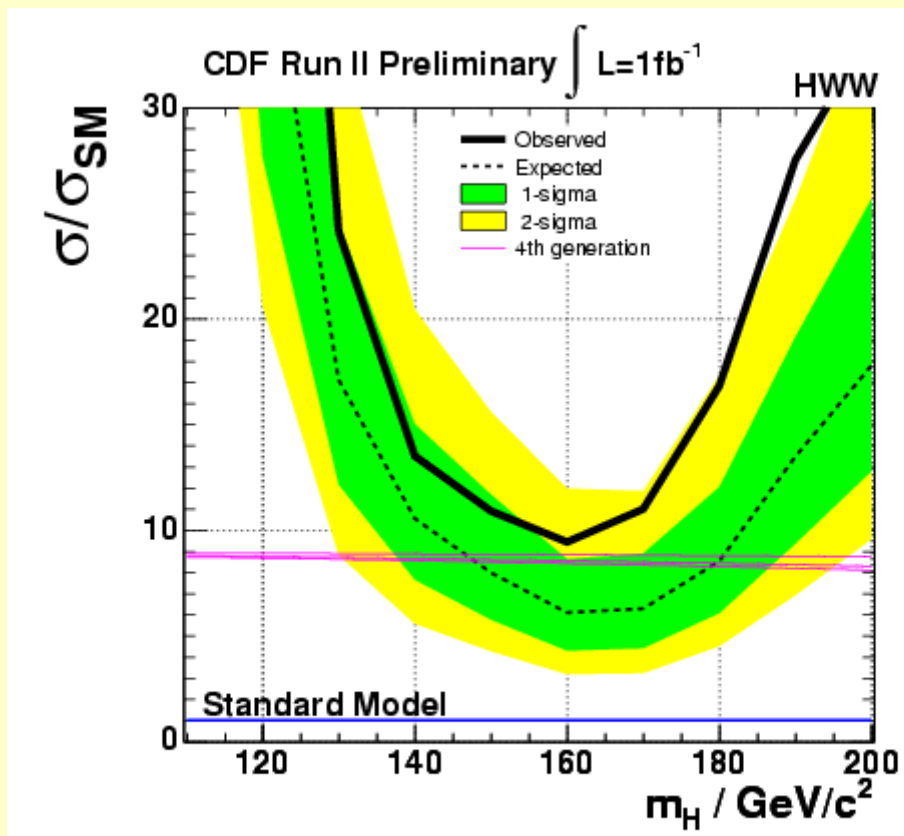


$H \rightarrow W^+W^-$

- BR($H \rightarrow W^+W^-$) gross bei hoher Higgs Masse

CDF 1fb^{-1}

DØ $\sim 1\text{fb}^{-1}$





Kombination von Higgs Kanälen

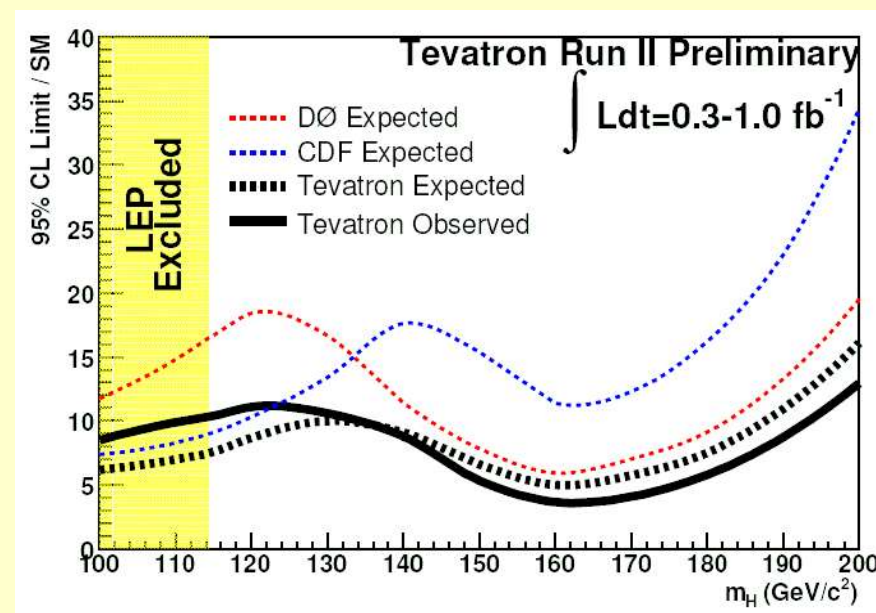
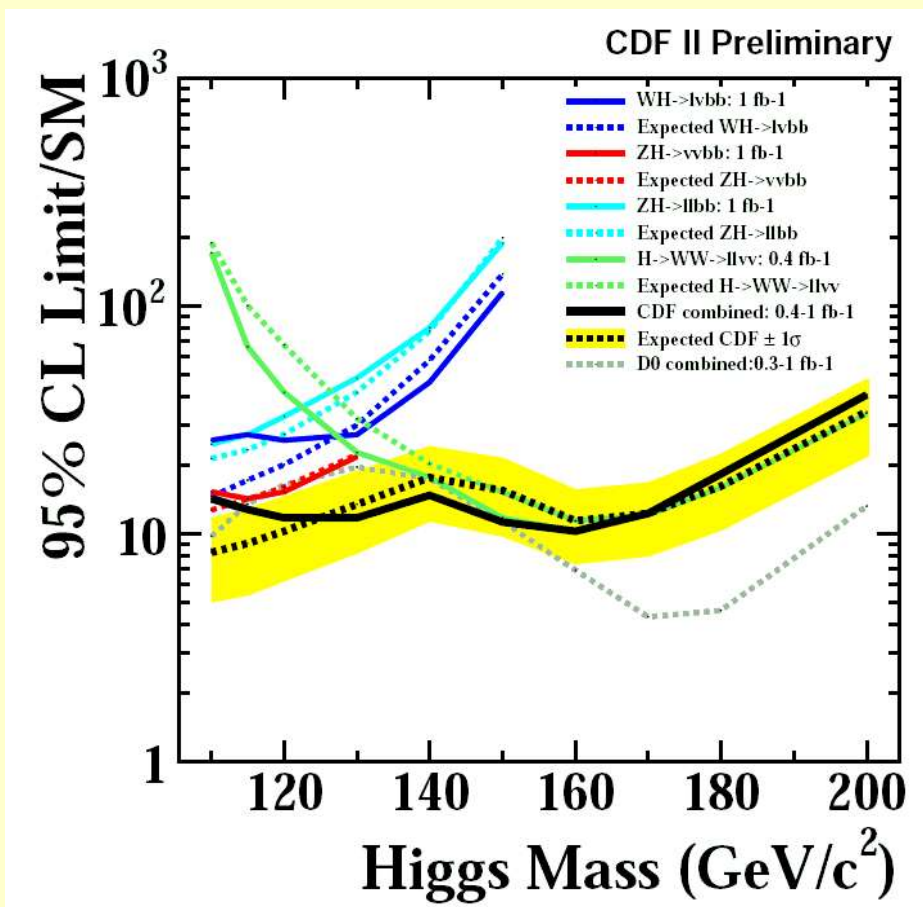


STAND Sommer 2006

CDF Ergebnisse 0.4-1fb⁻¹

CDF/DØ Ergebnisse 0.4-1fb⁻¹

effektiv ~ 1.3fb⁻¹



bei $m_H = 160$ GeV fehlt nur noch ein Faktor 4!

Verbesserung der Sensitivität durch Kombination!



Higgs nach Tau Tau

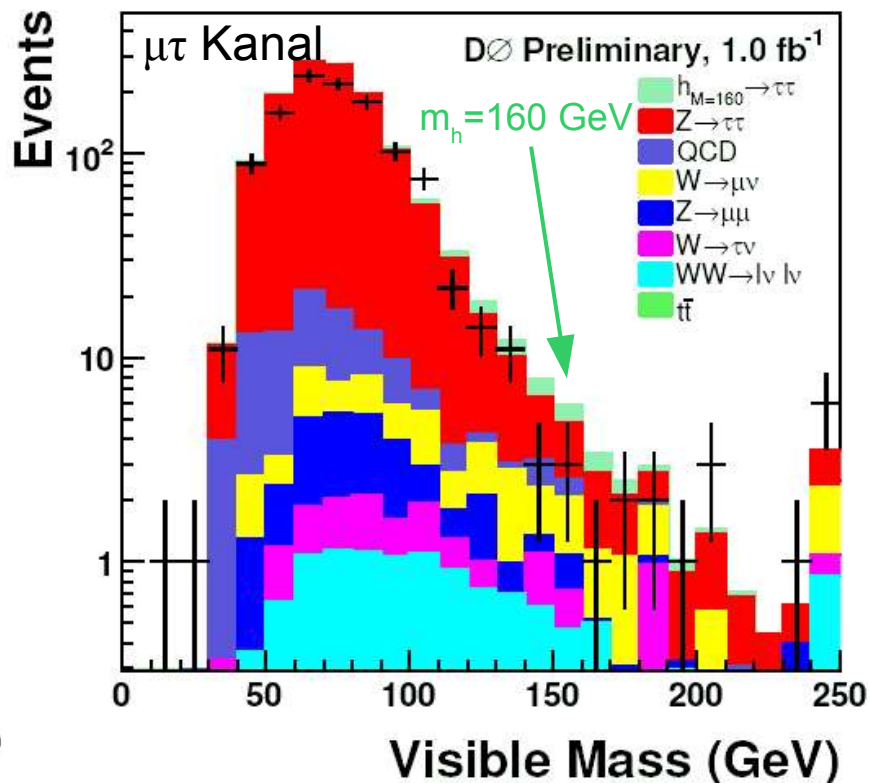
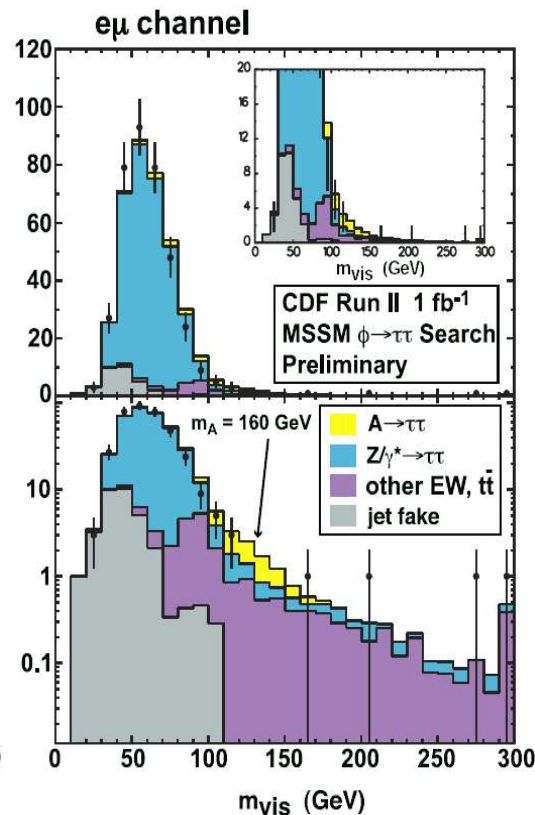
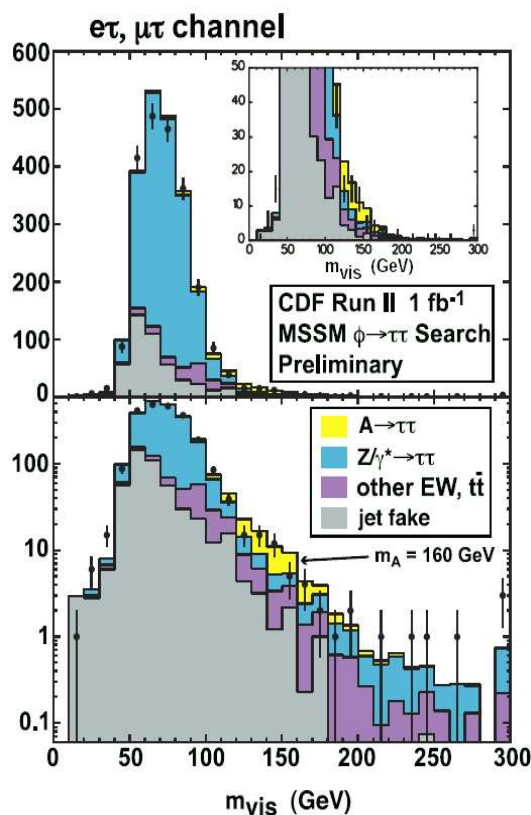


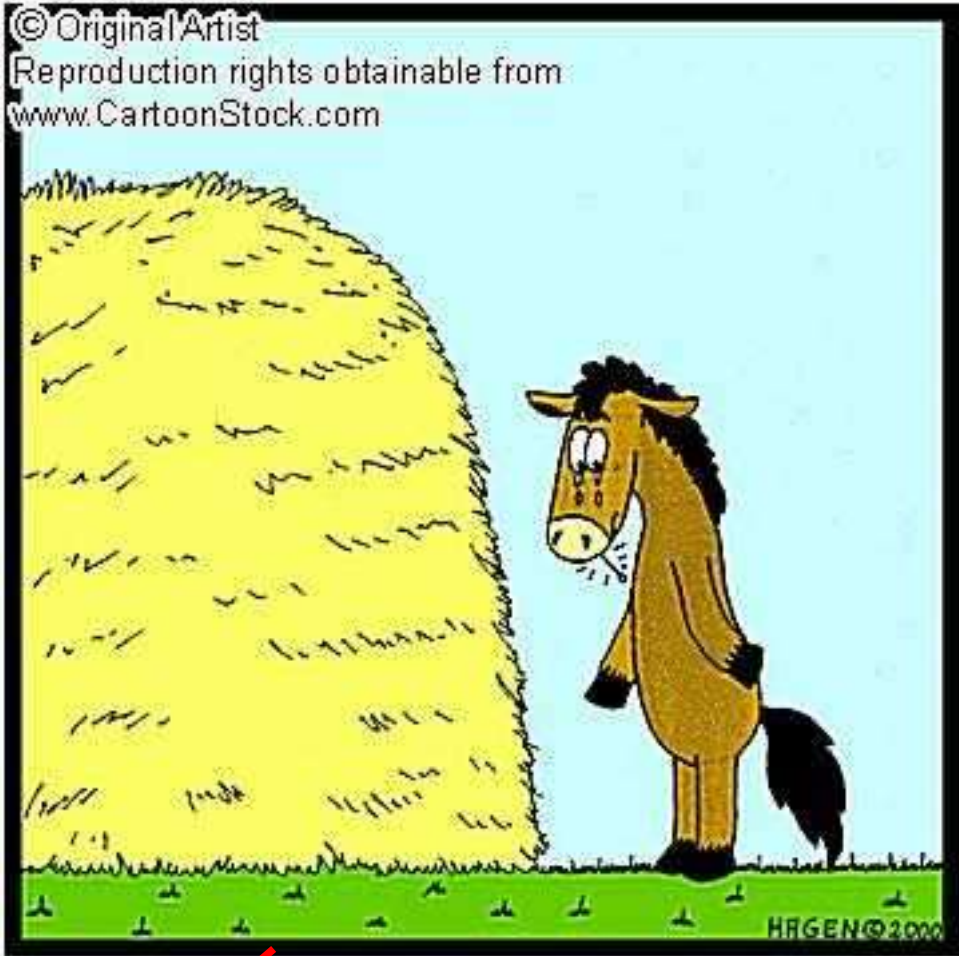
$H \rightarrow \tau^+\tau^-$ (SM), $\Phi \rightarrow \tau^+\tau^-$ (MSSM)

- $BR(\Phi \rightarrow \tau\tau)$ etwa 1/10 $BR(\Phi \rightarrow bb)$
- $BR(\Phi \rightarrow \tau\tau)$ kann gross sein bei hohen Higgs Massen in MSSM (2HDM)
- Masse nur ungenau rekonstruiert (2-4 fehlende Neutrinos)

CDF: $L=1\text{fb}^{-1}$

D0: $L=1\text{fb}^{-1}$





~~CDF~~ Ed was unlucky enough to find
the needle in the haystack!

Zusammenfassung/Ausblick

HERA Hochenergie-Datensatz endet in zwei Wochen

- erst etwa die Hälfte der HERA II Daten analysiert
- Vorhersagen des SM wurden bei HERA bestätigt
- vollständige Analyse aller HERA II Daten wird eine präzise Messung der schwachen NC Kopplungen leichter Quarks erlauben

Tevatron wird vermutlich noch einige Jahre im Betrieb bleiben!

- W, Top neue Präzisionsmessungen vom RunII
- Physik jenseits des SM kann direkt und indirekt getestet werden
- Chance auf Higgsentdeckung bei kleinen Higgsmassen und 8 fb^{-1}

LHC wird in naher Zukunft ultimative Antworten liefern

- Higgs
- Physik jenseits des SM

Danke

- Organisatoren
- O. Behnke
- M.-O. Bönig
- D. Glenzinski
- B. Heinemann
- R. van Kooten
- G. Leibengut
- B. List
- J. Meyer
- B. Naroska

